Final report for RTD-project

ALP-IMP (EVK-CT-2002-00148)

Multi-centennial climate variability in the Alps based on

Instrumental data, Model simulations and Proxy data

Short version covering sections 1, 5, 6 and annexes 1 and

Period covered by the report: March 1st 2003 to August 31st 2006

Including also a report (sections 0 to 2) for the 4 months extension period May 1st 2006 to August 31st 2006

contents:

project coordination: Reinhard Böhm

(Central Institute for Meteorology and Geodynamics, Vienna, Austria)

project homepage: http://www.zamg.ac.at/ALP-IMP

Fourth periodic report for RTD-project

ALP-IMP

Multi-centennial climate variability in the Alps based on

Instrumental data, Model simulations and Proxy data

EVK-CT-2002-00148

Period covered by the report: May 1st 2006 to August 31st 2006

(4 months extension period)

contents:

project coordination: Reinhard Böhm

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SECTION 1:

MANAGEMENT AND RESOURCE USAGE SUMMARY, RELATED TO THE REPORTING PERIOD (EXTENSION PERIOD)

(MAY 1ST 2006 TO AUGUST 31ST 2006)

1.1. Objectives of the reporting period

- Remaining things for worktask 1 (data WPs), but main concentration on analysis for worktask 3 (three integrative analysis WPs)
- Final project workshop combined with:
- Public science days in Rauris and on the Sonnblick-Observatory

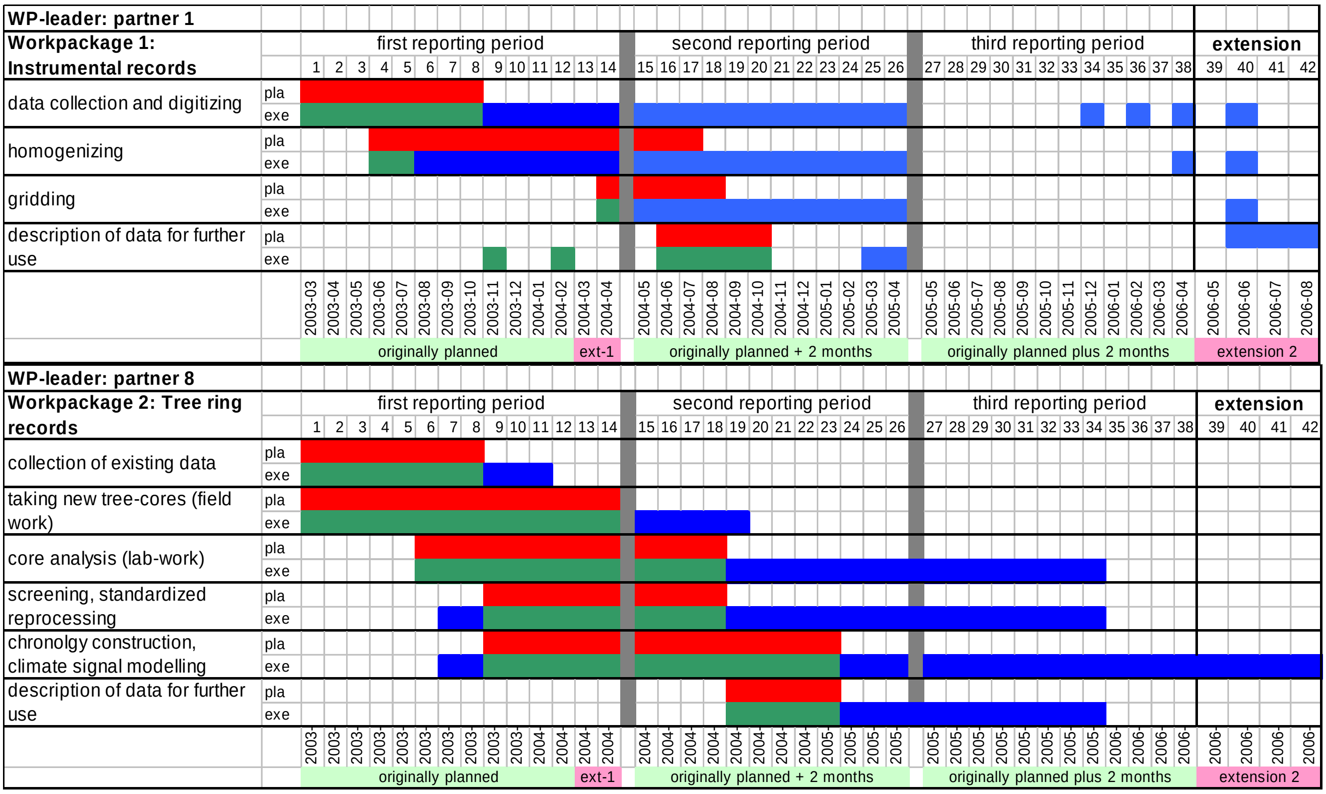
1.2. Scientific/Technical progress made in different work packages according to the planned time schedule:

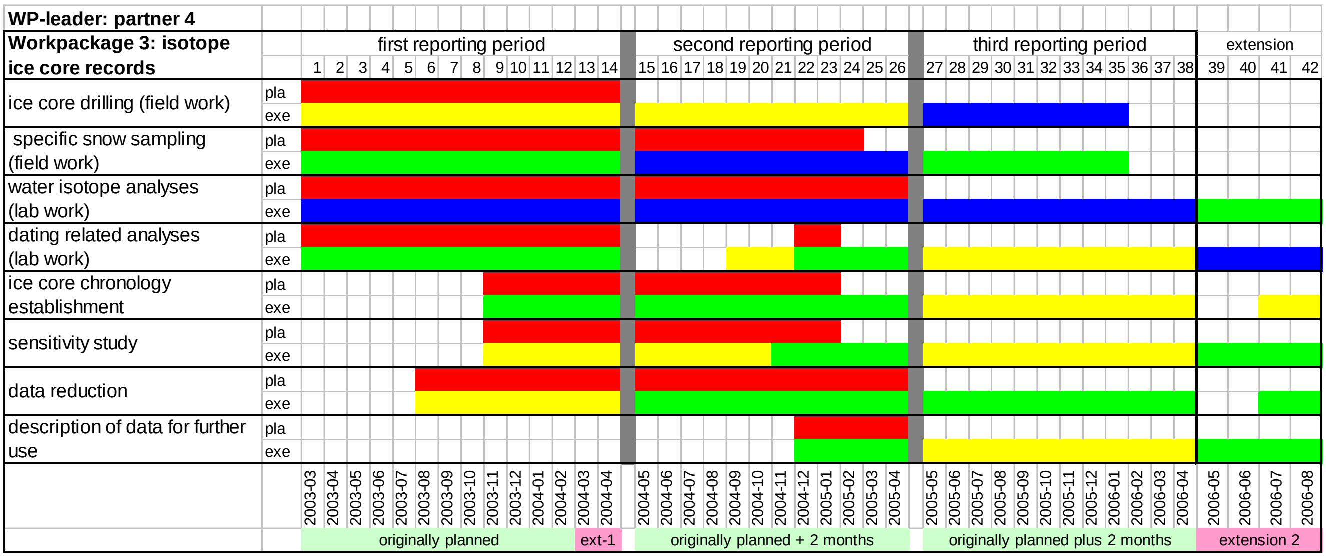
- **Gantt chart update** including the reporting period (months 39 to 42)

pla: working plan
exe: executed during the reporting periods

Colour code:

green: no modifications,
blue: more than planned,
yellow: less than planned

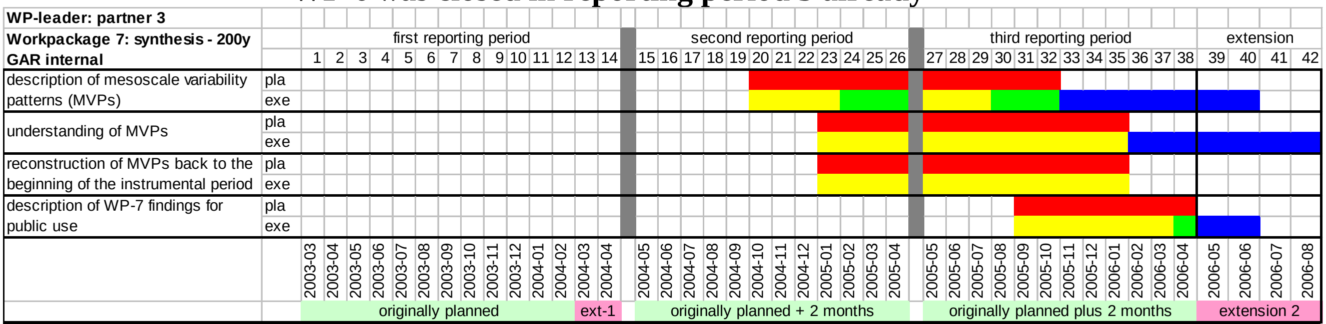


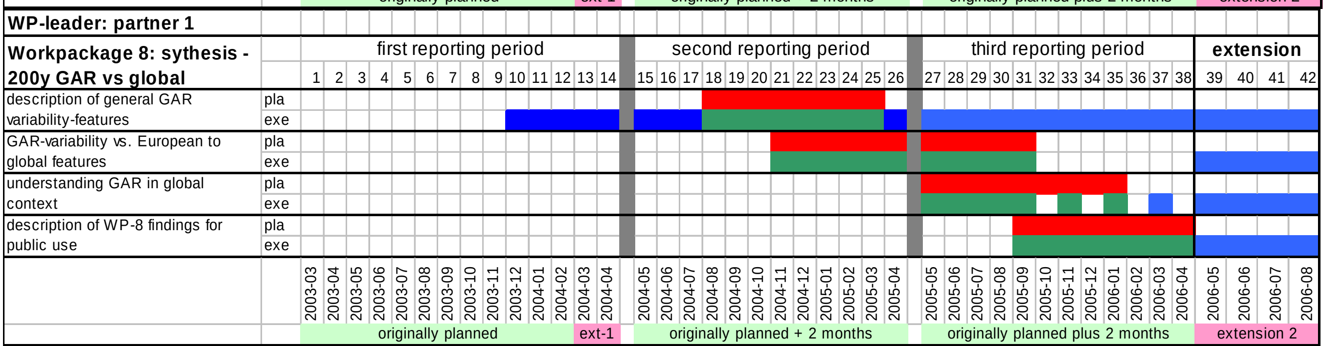


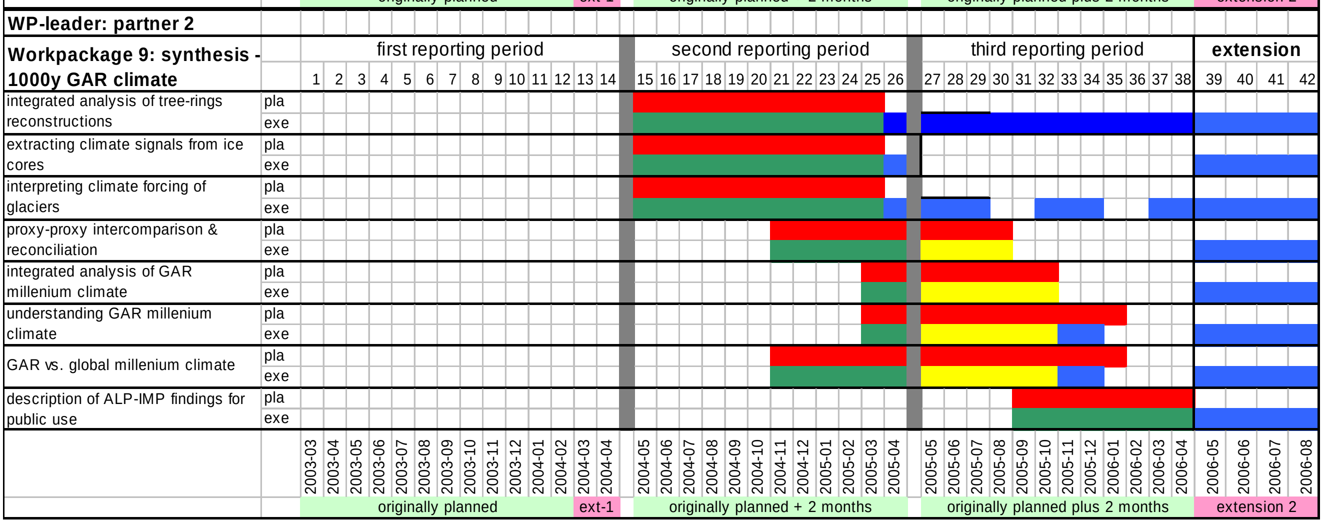
WP-4 was closed in reporting period 2 already

WP-5 was closed in reporting period 2 already

WP-6 was closed in reporting period 3 already







- **Manpower proposed versus executed**

Cumulative manpower usage for Project ALP-IMP (final version, 2006-10)

	WP1						WP2						WP3					
	(pm) prop.	exec. 1	exec. 2	exec. 3	exec. 4	rest	(pm) prop.	exec. 1	exec. 2	exec. 3	exec. 4	rest	(pm) prop.	exec. 1	exec. 2	exec. 3	exec. 4	rest
Partner 1	25.0	17.4	8.0	3.8	1.0	-5.2						0.0	5.0		2.0	1.0	0.5	1.5
Partner 2						0.0	17.3	5.0	11.0	1.3		0.0						0.0
Partner 3						0.0						0.0	1.0	0.5	0.0			0.5
Partner 4						0.0						0.0	60.0	15.2	17.7	21.0	8.2	-2.1
Partner 5	30.0	20.0	8.0	2.0		0.0						0.0						0.0
Partner 6						0.0						0.0	10.0	2.0	7.0		1.0	0.0
Partner 7						0.0						0.0	14.3	7.0	14.0			-6.7
Partner 8						0.0	33.0	22.0	11.0			0.0						0.0
Partner 9						0.0	22.0	11.8	9.2	1.8		-0.8						0.0
Partner 10						0.0	24.0	14.5	7.0	4.0		-1.5						0.0
total	55.0	37.4	16.0	5.8	1.0	-5.2	96.3	53.3	38.2	7.1	0.0	-2.3	90.3	24.7	40.7	22.0	9.7	-6.8

	WP4						WP5						WP6					
	(pm) prop.	exec. 1	exec. 2	exec. 3	exec. 4	rest	(pm) prop.	exec. 1	exec. 2	exec. 3	exec. 4	rest	(pm) prop.	exec. 1	exec. 2	exec. 3	exec. 4	rest
Partner 1	18.0	6.4	9.0	2.0	1.0	-0.4	5.0	1.0	4.0			0.0			3.0	3.0		-6.0
Partner 2						0.0	7.0	1.0	11.0			-5.0						0.0
Partner 3						0.0						0.0	21.0	11.2	9.3	7.0	1.0	-7.5
Partner 4						0.0						0.0	13.0	2.5				10.5
Partner 5						0.0	4.0	2.5	1.5			0.0	6.0		6.0			0.0
Partner 6	38.6	25.0	10.0		3.6	0.0						0.0						0.0
Partner 7						0.0						0.0	5.0	1.4	1.9	0.5		1.2
Partner 8						0.0						0.0						0.0
Partner 9						0.0						0.0						0.0
Partner 10	6.0	1.5	4.5			0.0						0.0						0.0
total	62.6	32.9	23.5	2.0	4.6	-0.4	16.0	4.5	16.5	0.0	0.0	-5.0	45.0	15.1	20.2	10.5	1.0	-1.8

	WP7						WP8						WP9					
	(pm) prop.	exec. 1	exec. 2	exec. 3	exec. 4	rest	(pm) prop.	exec. 1	exec. 2	exec. 3	exec. 4	rest	(pm) prop.	exec. 1	exec. 2	exec. 3	exec. 4	rest
Partner 1					1.0	-1.0	15.0		2.1	6.3	2.0	4.6	10.0		1.0	7.0	4.0	-2.0
Partner 2						0.0	5.0		1.0	4.0		0.0	22.0		2.0	20.0	1.0	-1.0
Partner 3	14.0		0.0	6.0	1.0	7.0						0.0						0.0
Partner 4						0.0						0.0	11.0		2.5		2.0	6.5
Partner 5	14.0		3.0	11.0		0.0						0.0	4.0			1.0	3.0	0.0
Partner 6						0.0						0.0	19.9		8.0	11.5	0.4	0.0
Partner 7						0.0						0.0	3.5			0.5	2.0	1.0
Partner 8						0.0						0.0	9.0			6.0	3.0	0.0
Partner 9						0.0						0.0	6.0		5.0	1.0		0.0
Partner 10						0.0						0.0	12.0		6.0	4.0	2.0	0.0
total	28.0	0.0	3.0	17.0	2.0	6.0	20.0	0.0	3.1	10.3	2.0	4.6	97.4	0.0	24.5	51.0	17.4	4.5

red: reporting period,

green: previous period (already approved),

pink: cumulative for entire project

CO					
(pm)					
prop.	exec. 1	exec. 2	exec. 3	exec. 4	rest
16.0	4.8	4.8	5.0	2.0	-0.6
					0.0
					0.0
					0.0
					0.0
					0.0
					0.0
					0.0
					0.0
					0.0
16.0	4.8	4.8	5.0	2.0	-0.6

TOTAL Balance of PMs			
WP	proposed	executed	prop-exec
1	55.0	60.2	-5.2
2	96.3	96.3	0.0
3	90.3	97.1	-6.8
4	62.6	63.0	-0.4
5	16.0	16.0	0.0
6	45.0	46.8	-1.8
7	28.0	22.0	6.0
8	20.0	15.4	4.6
9	97.4	92.9	4.5
coord	16.0	16.6	-0.6
total	526.6	526.3	0.3

The total of all invested person-months is only 0.3 pms smaller than the proposed. This marginal difference of less than 0.1 permille is more than counterbalanced by the necessary cost increases due to inflation and legally prescribed wage-increases. In terms of working results it will be counterbalanced even more due to the work foreseen by the project partners in the next future to further exploit the project-potential (compare e.g. the publications in preparation in annex 1 of the final report).

Within the total balance there have been systematic shifts from the consistency and abalysis workpackages (6, 7, 8, 9) to the data workpackages (1, 2, 3, 4). This was argued already in the first 3 reports and is due to the message soon to be learnt that an early inclusion of consistency and analysis work into the data-work contributed considerably to a quality increase. Thus there was in fact not less analysis work invested, but parts of it were shifted to the data work packages.

1.3. Milestones and deliverables obtained:

ALP-IMP DELIVERABLES AND MILESTONES - cumulative list, version 2006-06 (for 3rd project report)

Mile stone	Delive rable	planned Date	rev. Date	WP	Description	executed	related papers	reported by partner	
No	No	(month)	due to extension by 2 months			month plus remarks	(ref-IDs of ALP-IMP publication list)		
0				all	Project web-site on line	2 (www.zamg.ac.at/ALP-IMP)		1	first reporting period
1.		1	3	all	Kick-off meeting	3 (see project website)		1	
2.	1/1	2	4	1	Updated temperature and precipitation datasets ready for internal project use	12 (internal part of website)		1	
3.		3	5	4	Existing glaciological data reprocessed	5		6	
4.		4	6	6	Implementation of the water isotope physics into REMO completed	5		7	
5.		5	7	1	Homogenization programs and procedures for instrumental records tested and ready for use	4	rev-1	1	
6.		6	8	2	Existing tree-ring data centralised and reprocessed	6		8	
7.		6	8	3	Analysis of chronology uncertainty and climate sensitivity completed	has been combined with milestone 24		4	
8.		6	8	3	Recovering an ideal ice core at Colle Gnifetti (Monte Rosa) down to bedrock	30 (delay argued in sect. 1.2 of 1st report,		4	
9.		7	9	1	Instrumental metadata collected and reprocessed	5	nrev-13	1	
10.	6/1	8	10	6	Completion of REMO 0.5 degree run	not necessary due to dirct nesting of 1/6-deg-run into ERA-40		3	
11.		8	10	4	Glaciological database extended by additional data	12 (plus option for more data)		6	
12.		10	12	all	First annual meeting. Participants send databases and details of other known sources for the GAR	13		1	
13.	6/4	12	14	6	Evaluation of the REMO “control” run including the water isotopes completed	14	rev-54	3	

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ALP-IMP DELIVERABLES AND MILESTONES - cumulative list, version 2006-06 (for 3rd project report)									
Mile stone No	**Delive rable No**	**planned Date (month)**	**rev. Date** due to extension by 2 months	**WP**	**Description**	**executed** **month plus (ref) plus remarks (if necessary)**	**related papers** (ref-IDs of ALP-IMP publication list)	**reported by partner**	
14.		12	14	all	1st annual report to EC	15 (see project website)		1	Second reporting period
15.		15	17	2	Tree-ring fieldwork to update network	19		8	
16.		15	17	3	Assessment of isotope sensitivity versus seasonal and glacier flow forcing	36 (delay due to already argued field wok delay) reached in terms of experimental base, however additional support by modelling necessary	th-07	4	
17.	6/2	16	18	6	Completion of REMO 1/6 degree run	14 but: During the analysis it became evident that in the simulation, which was completed in May 2004, the solar constant has been reduced drastically by mistake in October 1989, which caused a temperature drop of approximately 10 K. Therefore, the simulation had to be repeated for the period October 1989 to the present and will be completed in the next few weeks. The simulation has thus been compared so far to the observations for the period 1958 to 1988.	nrev-67, nrev-68	3	
18.	4/2	16	18	4	Report on the representativity of glacier variability data within GAR	24	nrev-21, nrev-23, nrev-25, nrev-27	6	
19.	1/2, 1/3, 1/4	18	20	1	Instrumental dataset plus description for external users on project homepage	24 (internal and external parts of the website), compare remarks in section 1.2	rev-3, rev-9, rev-11, rev-12, nrev-1, nrev-1, nrev-19, nrev-22	1	
20.		18	20	2	Laboratory Processing of new tree-ring material completed	21		8	
21.		18	20	2	Site and Regional tree-ring chronology construction completed	21		8	

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22.	4/1, 4/3	18	20	4	Glacier dataset plus description for external users on project homepage. New and improved datasets in the databases of World Glacier Monitoring Service and World Date Center-A for Glaciology	18	rev-8, nrev-26	6	Second reporting period
23.	5/1, 5/2	18	20	5	Completion of between variable comparisons within the GAR	32 plus ongoing work on a number of publications in preparation	rev-20, rev-26, rev-45, rev-46, rev-47, rev-50	2	
24.	3/1, 3/2, 3/3, 3/4, 3/5	20	22	3	Establishment of consistent and appropriate ice core chronologies	36 (due to field-work delay already argued) only partly reachable, since the established chronologies appeared to be not fully consistent in the lower most core sections in terms of aprpriate coherence (more details in section 1.4)	th-08	4	
25.	2/1, 2/2	21	23	2	Analysis of tree-ring chronology uncertainty and climate sensitivity completed	extension of climate reconstruction (precipitation/drought) to low elevation sites; better understanding of the interaction between natural (solar, volcanic, internal oscillations) and anthropogenic recent forcings; interannual to multi-centennial scales;	rev-4, rev-13, rev-14, rev-15, nrev-14, nrev-17	8	
26.	6/3	22	24	6	Assessment of the consistency of the observed and simulated data completed	26 see WP-6 internal progress report	rev-48	3	
27.	6/6	22	24	3, 6	Classification of weather situations in terms of the corresponding isotope pattern	26 (compare respective parts in WP-6 report)	deliverablereport-WP6.pdf	7	
28.	8/1	23	25	8	General 200 years GAR climate variability features detected	25	rev-11, rev-19, nrev-16, nrev-18, nrev-20, nrev-27	1	
29.	9/1	23	25	9, 2	Temperature and Precipitation reconstructions from tree-ring data complete	26	rev-7, rev-10,	2, 8	
30.		23	25	9, 3	Temperature reconstructions from ice cores complete	40 (delayed du to the delayed field work, see WP-3 report in section 3	nrev-28	2, 4	
31.		23	25	all	2nd annual meeting	(http://www.isac.cnr.it/~climstor/alpimp_workshop.html)		1	

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ALP-IMP DELIVERABLES AND MILESTONES - cumulative list, version 2006-06 (for 3rd project report)									
Mile stone No	**Delive rable No**	**planned Date (month)**	**rev. Date** due to extension by 6 months	**WP**	**Description**	**executed** **month plus (ref) plus remarks (if necessary)**	**related papers** (ref-IDs of ALP-IMP publication list)	**reported by partner**	
32.	8/2 ?	24	26		Completion of the comparisons with hemispheric-scale datasets	26	rev-43, rev-12		Third plus fourth reporting period
33.		24	26		2nd report to EC	ready and sent in June 2005			
34.	7/1	25	29		Influence of topography on alpine circulation determined: Catalogue of mesoscale circulation patterns	29: see WP-7 internal progress report	deliverablereport-WP7.pdf	3	
35.	7/2	27	33		Influence of the resolution of topography on circulation patterns determined	33: see WP-7 internal progress report	deliverablereport-WP7.pdf	3	
36.	8/3	29	42		General GAR and European to global features statistically analysed	42	rev-20, rev-43, rev-45, rev-50	2	
37.	9/2	30	32		Glacier model-based simulations complete	32 more than planned	rev-5, rev-17, rev-18, nrev-24		
38.	7/3	32	42		3 dimensional climate reconstruction completed	32 plus ongoing work in the immediate post project time (compare management sections of 2nd and 3rd project reports)		3	
39.	9/1	33	42		Integrated histories of temperature and precipitation based on combined tree-ring and ice-core reconstructions complete	42 plus ongoing work in the immediate post project time	rev-50	2	
40.		33	35		3rd annual meeting	5-9 July 2006, together with 3 open science days in Rauris (this was 1 of the 2 main reasons for the extension by 4 months)	report on the open science days at ZAMG-website plus several reports in the media	1	
41.	7/4	36	42		Determination of the surface temperature and precipitation variability related to mesoscale circulation variability over the GAR	38: see WP-7 internal progress report plus a paper in work doing more than planned (7 climate elements)	deliverablereport-WP7.pdf	3	
42.	8/4	36	42		Explanation of the statistical analysis	42 plus ongoing work in the immediate post project time	rev-50	2	
43.	9/3	36	42		Comparative analyses of GAR Temperature and Precipitation reconstructions against extracted GAR and wider Northern Hemisphere/Global reconstructions based on naturally and anthropogenic forced climate model simulations	42 plus ongoing work in the immediate post project time	rev-50	2	
44.		36	42+2		Final report to EC including TIP	44 organised by ZAMG		1	

1.4. **Deviations from the work plan or /and time schedule and their impact to the project** (if any please explain)

The additional 4 months of the extension period contributed to an adequate exploitation of the much broader than initially planned database of the project. Most of the respective activities have produced more than expected and planned, thus providing a more extensive and higher quality basis for the following consistency and analysis activities. This added value compensated for some delays and the final harvest in terms of scientific analysis was rich – best represented by the project publications (annexes 1 and 2 of final report).

Also the most severe delay (field work to extract a new ice core in the summit region of Monte Rosa, caused by difficulties to receive instrumental support from non project groups and additional weather problems in the short summers at 4500m asl) could be compensated before the end of the project.

The 4 additional project months also allowed for completing the update of the instrumental database which includes now also the complete year 2005.

The 4 months were intensively used to complete the rich palette of project publications. 4 new publications were submitted to peer reviewed journals, 15 new papers were started and are currently in preparation for submission. 10 papers stepped from status “submitted” to “accepted”, “in print”, or “published”.

A significant gain for the final value and the public attention for climate change topics in the Alps, EU’s respective research activities in general and specifically to the project results could be obtained by the “Open Science Days Rauris” in July 2006. The 3 days were organised in connection with the last project meeting and as a joint event with Austrian climate impact project “A Tale of Two Valleys”. More than 100 participants watched the public science lectures of the ALP-IMP community and discussed with them global to local climate change and climate impact topics at day 1. Seventy of them took the opportunity to joined the ALP-IMPs to one of the nearby glaciers and to one of the classical High-Alpine environmental and climate observatories on the summit of Sonnblick (3100m asl). These “science walks” could be organised thanks to the prolongation of the project into the summer 2006 – at a date before the original end of the project, weather and snow conditions would not have allowed the climb for non alpinists. For the contents of the science days compare Annex 4 of the final project report.

The following selection of photos provides impressions of the 3 public science days Rauris 2006. More information on the Science days at the 2-valleys website:

http://www.zamg.ac.at/a-tale-of-two-valleys/

Public Science Day 1, 7 July 2006, Rauris, Heimalm

Science Walks Kolm Saigurn – Goldbergkees – Sonnblick, 8-9 July 2006

1.5. Co-ordination of the information between partners and communication activities (e.g. organised meetings, conference attendance, co-operation with other projects/networks, …)

All existing links to **other research projects** (table 1.5.1.) and programmes were continuously maintained during the excess period. Especially the wide community of "corresponding project partners" could be further maintained. They continue to contribute to the project's database with fresh data. It may be one of the most successful and sustainable remnants of the project for the future to have established a well functioning community of climate and climate related scientists not only within the (funded) project community but also outside. The following tables 1.5.1, 1.5.2 and 1.5.3 resume the links with other projects and the internal and corresponding ALP-IMP project community.

Table 1.5.1. Selection of projects linked with ALP-IMP

CLIVALP (Austrian FWF-Project, P1576-N06: instrumental, partner 1
Italian CNR-special Project 02- 02/05/97- 037681): instrumental, partner 5
Austrian national project EX*PICE* (FWF-P15828-N06): tree-rings, partner 10
WGMS (World Glacier Monitoring Service): glacier variability, partner 6
Interreg IIIb Alpine Space Programme – Project FORALPS instrumental, partner 1
CLIVAR sub-programme MedCLIVAR: all ALP-IMP topics, partner 1
CLIMAGRI - National Project funded by Italian Ministry of Agriculture and Forest: instrumental, partner 5.
Frequency evolution of extreme precipitation events and droughts in Italy in the last 120 years and its impact on bioecosystems, D.M. 1086 24/772002, FIRB- Italian Ministry of Education, University and Research: instrumental, partner 5
"Studies of the impacts of climatic change on the Mediterranean regions of the Northern Hemisphere" in the frame of "US-Italy cooperation on Science and Technology of climatic change", D M 714, funded by Italian Ministry of Environment: instrumental, partner 5
"A Tale of two Valleys" (research programme ProVision of the Austrian Ministry of Education, Research and Culture): all ALP-IMP topics, partner 1

Table 1.5.2. List of ALP-IMP project partners and their responsibilities

Partner code	Short name	Institute	Status	Specific role or major contribution to WP
1	ZAMG	Central Institute for Meteorology and Geodynamics Department of Climatology (Vienna, A)	CO	Coordinator: Worktask-1, Leader: WP1, WP8 Participant: WP3, WP4, WP5, WP9
2	UEA	University of East Anglia, Climatic Research Unit-CRU	CR	Coordinator: Worktask-3, Leader: WP5 and WP9 ,

		(Norwich, UK)		Participant: WP2, WP8
3	GKSS	GKSS Forschungszentrum Institute for Coastal Research (Geesthacht D)	CR	Coordinator: Worktask-2 Leader: WP6, WP7 participant: WP3
4	UHEI-IUP	Universität Heidelberg Institut für Umweltphysik (Heidelberg, D)	CR	Leader: WP3 Participant: WP6, WP9
5	CNR-ISAO	Consiglio Nazionale delle ricerche - Istituto di Scienze dell'Atmosfera e dell'Oceano (Bologna, I)	CR	Participant: WP1, WP5, WP6, WP7, WP9
6	UNIZH	University of Zurich Department of Geography (Zürich, CH)	CR	Leader: WP4 Participant: WP3, WP9
7	LSCE	CNRS Laboratoire des Sciences du Climat et de l'Environment (Saclay, F)	CR	Participant: WP3, WP6, WP9
8	WSL	Swiss Federal Research Institute Department of Dendroclimatology (Birmensdorf, CH)	CR	Leader: WP2, Participant: WP9
9	UAS	University of Agricultural Sciences Institute of Botany (Vienna, A)	CR	Participant: WP2, WP9
10	UIBK	Institute of High Mountain Research University of Innsbruck (Innsbruck, A)	CR	Participant: WP2, WP4, WP9

Table 1.5.3. List of corresponding ALP-IMP project partners and their fields of cooperation

Walter Arnold, University of Veterinary Medicine, Research Institute of Wildlife Ecology, Savoyenstrasse 1, A-1016 Vienna, AUSTRIA (climate impacts research, use of WP-1 data)

Michael Begert, MeteoSchweiz, Klimadienste, Krähbühlstr. 58, CH-8044 Zürich, SWITZERLAND (instrumental data, WP-1)

Franco Biondi, University of Nevada, Dept. of Geography, Mail Stop 144, Reno, Nevada 89557-0048, USA (instrumental data for teaching, WP-1, potential for tree-ring related studies)

Oliver Bochnicek, SHMI (Slovak Hydrometeorological Institute), Jeseniova 17, SK-83315 Bratislava (instrumental data, WP-1), SLOVAKIA (instrumental data, WP-1)

Marco Carrer, Università degli Studi di Padova, Treeline Ecology Research Unit, Dep. Territorio e Sistemi Agro-Forestali, Agripolis, I-35020 Legnaro, ITALY (treering chronologies, WP-2, Italian instrumental datasets, WP-1)

Tanja Cegnar, Environmental Agency, Meteorological Office, Vojkova 1b, SI-1000 Ljubljana, SLOVENIA (instrumental data, WP-1)

Mojca Dolinar, Environmental Agency, Meteorological Office, Vojkova 1b, SI-1000 Ljubljana, SLOVENIA (instrumental data, WP-1)

Ekkehard Dreiseitl, University of Innsbruck, Institute for Meteorology and Geophysics, Innrain 52, A-6020 Innsbruck, AUSTRIA (instrumental data, WP-1)

Olaf Eisen, VAW-ETH Zürich, CH- Zürich, SWITZERLAND (field work and ground penetrating radar, WP 3)

Christoph Frei, MeteoSchweiz, Krähbühlstr. 58, CH-8044 Zürich, SWITZERLAND (instrumental data, WP-1, consistency, WP-6)

Marjana Gajic-Capka, Meteorological and Hydrological Service, Department. for Climatological Research and Applied Climatology, Gric 3, HR-10000, Zagreb, CROATIA (instrumental data, WP-1)

Joseph Kipfstuhl , German Polar Research Institute AWI, Am Handelshafen 12, D-27570 Bremerhaven, GERMANY (special ice core analyses, WP-3)

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SECTION 5:

EXECUTIVE SUMMARY OF ALP-IMP

Multi-centennial climate variability in the Alps based on

Instrumental data, Model simulations and Proxy data

EVK-CT-2002-00148

EXECUTIVE PUBLISHABLE SUMMARY, RELATED TO THE OVERALL PROJECT DURATION

Contract n°	EVK-CT-2002-00148	Project Duration:	March 1st 2003 - August 31st 2006
Title	**ALP-IMP** Multi-centennial climate variability in the **Alp**s based on **I**nstrumental data, **M**odel simulations and **P**roxy data		

OBJECTIVES: The overall goal of ALP-IMP was **to reconstruct climate variability for the "Greater Alpine Region" (GAR) for the past 1000 years**. The target region, the European Alps and their surroundings (4-19 degE, 43–49 degN) have a unique potential to fill existing gaps in our knowledge of the regional features of past climate variability due to a number of climatologically **outstanding features**:
- a unique (in terms of length and spatial density) climate data potential (instrumental and mountain-specific proxies as tree-rings from the tree-line, ice cores from cold glaciers, glacier variations)
- small scale climate variability patterns interesting for statistical and model supported studies
- being a sharp "climate divide" in continental scale in the transitional zone between Atlantic, continental and Mediterranean influences
- having a "vertical potential" with instrumental and proxy data from 0 to 4500m asl. - in many cases from remote places ("climate background sites") – thus covering not only near surface climate but also the lower troposphere
- having a high climate change sensibility (from 1890 to 2000, Alpine $\Delta T \approx 2^* \Delta T_{global}$)
- being sensitive for climate impacts (e.g.: topographically enhanced water cycle plus steep topography resulting in flooding, debris flows, avalanches, or vertical plant migration and also economically as for example winter tourism)
- providing glacier change as a most dynamic and clear demonstration object of climate change impacts.

In spite of the described potential of the project's target region, a number of **research deficits** existed at the time the project was planned:
- the administratively and politically patchy situation of the study region which produces
- a lack of integrative research activities targeting at the region as a whole
- a poor exploitation the given instrumental data potential in terms of adequate spatial density, of the length of time series and of being multiple in terms of using different climate elements
- a lack of the integrated use of different proxy-data for climate reconstruction in the pre-instrumental period

SCIENTIFIC ACHIEVEMENTS: ALP-IMP has significantly reduced these deficits through: Collecting, completing, evaluating, validating and understanding the existing information on millennium scale climate variability in the GAR using instrumental and proxy data and regional climate modelling within the project - and to provide the integrated GAR dataset as well as the project's findings ready for use in the public domain for further climate and climate impact studies.
The project results were obtained through three main activities:
- the creation of climate datasets for the past millennium (**data-worktask**)
- the evaluation of the datasets internally (parameter comparison, spatial correlation, physical consistency with climate modelling results (**consistency worktask**) and externally (vs. external datasets of regional and global extension)
- analysis of the project data as a first round of exploitation of the new project data with the goal to provide a consistent new millennium reconstruction of past climate variability in the GAR (**analysis worktask**)

MAIN DELIVERABLES: Together with and based on a linked national Austrian project (CLIVALP) and on several other national and sub-national projects and efforts, **the instrumental project group** has created the new HISTALP-database. Currently, HISTALP consists of:
- 516 Instrumental stmod datasets of seven climate parameters (pressure, temperature, precipitation, sunshine duration, cloudiness, vapour pressure, relative humidity) as original and as quality enhanced (homogenised, outlier corrected, gap filled) monthly time series 1760-2005
- Instrumental grid-1 datasets for pressure, temperature and precipitation as monthly anomaly fields (relative to 1901-2000) at 1deg lat-long 1760-2005
- 2448 instrumental high-resolution gridded (1/6 deg lat-long) absolute monthly precipitation fields 1800-2003
- 10 "coarse resolution subregional mean" (CRSM) datasets each for up to seven instrumental parameters starting between 1760 (pressure, temperature) and 1880 (sunshine) and updated to 2005

The new instrumental database was used and is currently used by the project community for intensive analysis of climate variability within the GAR and in comparison with continental to global scale climate. A selection of the achieved results:
- uniform long-term trends in all GAR-subregions for temperature (low and high, as well as urban and rural) and air pressure (low) but different seasonal evolutions, significantly different (in some cases even reverse) long-term precipitation, humidity and sunshine/cloudiness trends in "horizontal" sense, respective "vertical" differences for sunshine/ cloudiness, humidity and for air pressure
- an approximately twice as strong 20th-century warming compared to the global one but also the existence of a

rather warm (spring-summer) period near 1800 which is still under critical co-analysis with proxy information
- some physically proof inter-parameter consistencies and co-evolutions with external datasets as well as some closer connections to atmospheric circulation represented by principal MSLP-patterns and by circulation indices for the European-North Atlantic sector but also for rather remote tele-connections as for example ENSO
The treering group created a spatially dense tree ring network based on existing chronologies which were collected, completed, updated. It includes more than 400 ring width and more than 130 density chronologies from 6 main species (*Abies alba ABAL, Larix deciduas LADE, Picea abies PCAB, Pinus cembra PICE, Pinus nigra PINY* and *Pinus sylvestris PISY*). All data sets are centralized, including raw measurements and corresponding metadata, the sites are spread over the entire GAR and consist of living tree samples, such from fossil wood (lakes, glacier moraines, peats…), from historic buildings and from archeologic sites (e.g. salt mines…)
- screened, quality controlled, and reprocessed raw measurement data to form standardized multi-century to millennial site and regional chronologies for different species, using recently developed/improved statistical techniques
- developed +1000 to +1300 years warm season high-elevation temperature reconstructions based on ring-width and on late wood density based on calibrations with the new instrumental HISTALP data
- currently works on respective multi-millennial reconstructions of expectedly 2000years, 3500years and 9000years
- has developed regional multi-centennial growing-season precipitation reconstructions in dry regions of the GAR and in comparative mountainous regions
- has critically co-analysed and compared the Alpine reconstructions with early instrumental data from the GAR and with continental to global scale reconstructions
The isotopic ice-core group achieved two new isotopes records could be achieved from the Mont Blanc area, comprising continuous profiles to bedrock with time resolutions ranging from sub-seasonal to the decadal scale
drilled and analyzed to bedrock a new core at the Monte Rosa drill place
- established an experimental temperature/isotope relationship arising a number of new questions concerning differences to theoretical expectations
- performed several long-term simulations with the isotope module of the meso-scale model REMO
- showing and quantifying correlations/anticorrelations of stable O-isotope ratios with surface temperature/precipitation and no correlations with cloud condensation temperatures
The glacier group has significantly completed, quality enhanced and systematically reprocessed the database of glacier fluctuations (front position, area, volume mass balance) of the World Glacier Monitoring Service (WGMS)
- has assessed climate change impacts on glaciers, including also their use as an integrated proxy for air temperature, radiation, snowcover, atmospheric circulation and its representativity for the GAR
- has used the glacier changes in the Alps as an unequalled demonstration tool for visualizing climate change
The modelling group performed a high-resolution (1/6 deg) simulation of European climate for the period 1958-2001 with the regional climate model REMO
- used the REMO dataset for studies on the consistency of regional modelling with the measured climate of the HISTALP datasets in the "challenging" orography of the Alps
- has provided a 4-simensional model climate of the study region (and beyond) for a better physical understanding of findings of the other project groups (and beyond)
The entire project community is currently working at an integrative co-analysis of the reconstructed climate in the GAR during the past millennium in European and global context.

CONCLUSIONS: In general, **ALP-IMP has confirmed** the coarse subdivision of the last millennium into an initial "medieval warm period" (MWP), a following "little ice age" (LIA) and a "modern warming" (MW) in the 20th century, **has significantly refined** it by new decadal- and centennial scale regional and subregional features, by a **higher quantitative, temporal and spatial precision** and by a **deeper understanding of the physical background** of the internal and external driving forces of climate and climate change in the wider region of the European Alps.
DISSEMINATION OF RESULTS: The project results have been published in **139 publications**, 63 of them in peer reviewed journals, 10 in non reviewed journals, 2 larger stand-alone publications, 31 extended and 27 short abstracts in conference proceedings, 6 PhD-theses and 2 diploma theses.
The project papers are visible at the public part of the **project website** as abstracts http://www.zamg.ac.at/ALP-IMP, the full publications can be downloaded on demand as "author's copies" from the password secured area of the website.
Project datasets are available via the project website - most of the instrumental data non restricted, the proxy-datasets on demand from the providers.

Keywords: past climate variability, climate reconstruction, climate modelling, European Alps

SECTION 6:

DETAILED REPORT

RELATED TO OVERALL PROJECT DURATION

Multi-centennial climate variability in the Alps based on

Instrumental data, Model simulations and Proxy data

EVK-CT-2002-00148

6.1. BACKGROUND

The European Alps and their surroundings, the target region of the project (GAR – "Greater Alpine Region") have a unique potential to fill existing gaps in our knowledge of the regional features of past climate variability due to a number of climatologically outstanding features:

The study region stands out through:

- unique (in terms of length and spatial density) but not yet adequately and systematically exploited climate data potential (instrumental and proxy)
- proxies that are typical for mountain-regions (tree-rings from the tree-line, ice cores from cold glaciers, glacier variations)
- small scale climate variability patterns interesting for statistical and model supported studies
- being a sharp "climate divide" in continental scale in the transitional zone between Atlantic, continental and Mediterranean influences
- having "vertical potential" with instrumental and proxy data from 0 to 4500m asl. - in many cases from remote places ("climate background sites") – thus covering not only near surface climate but also the lower troposphere
- having a high climate change sensibility (Alpine $\Delta T_{1890\text{-}2000} = 2$ times ΔT_{global})
- being highly sensitive for climate impacts (e.g.: topographically enhanced water cycle plus steep topography resulting in flooding, debris flows, avalanches, or vertical plant migration and others)
- glacier change as a most dynamic and clear demonstration object of climate change defects in the European Alps

In spite of the potential of the project's target region, in terms its data-richness, its highly interesting climatic situation and its vulnerability to climate impacts, a number of research deficits existed at the time the project was planned.

In general the **pre-project deficits** arose from:

- the administratively and politically patchy situation of the study region which produces
- a lack of integrative research activities targeting at the region as a whole
- a poor exploitation the given instrumental data potential in terms of adequate spatial density, of the length of time series and of being multiple in terms of using different climate elements
- using different proxy-data for climate reconstruction in the pre-instrumental period in rare cases only
- including regional climate modelling to evaluate the findings of the data-based reconstructions and to deepen the physical understanding of climate variability in the region

6.2. SCIENTIFIC/TECHNOLOGICAL AND SOCIO-ECONOMIC OBJECTIVES

6.2.1. SCIENTIFIC TECHNOLOGICAL:

ALP-IMP planned to use the described research potential of the greater Alpine region to reduce the still existing data-, research and knowledge deficits by:

- Collecting,
- completing,
- evaluating,
- validating

and

- understanding

the existing information on millennium scale climate variability in the "Greater Alpine Region" within the project and to provide the integrated GAR dataset as well as the project's findings ready for use in the public domain for further climate and climate impact studies.

This general task was headed for by the following **specific objectives of the project:**

- to extend the instrumental climate database in the greater Alpine region to high spatial density, to the maximum possible length and to add additional important climate parameters to the main elements (temperature and precipitation) – thus creating a multiple instrumental dataset adequate to cope with the needs of understanding the climate system.
- to remove non climatic inhomogeneities from the instrumental series using a state of the art approach based on statistical testing and intensive use of metadata from station history.
- to extend the database by several additional centuries through the integration of typical Alpine proxy data sources (tree rings, stable water isotopes from Alpine ice cores, glacier variability) to a homogeneous and consistent data archive describing climate variability, outstanding periods, abrupt climate changes in the Alpine realm – covering also the two controversial periods of a *Medieval Climate Optimum* and the flickering climate of the *Little Ice Age* – which define the baseline for studying potential anthropogenic changes.
- to test the consistency of the GAR dataset with existing other (continental to global scale) datasets and versus backward model simulations for the Alps in high spatial resolution (both in horizontal and in vertical aspect)
- to analyze the dataset for regional climate variability patterns within the topographically complicated study region and set them into the context of continental to hemispheric patterns.
- to use sophisticated statistical methods and high resolution mesoscale regional climate modeling to understand the observed climate variability in the study region under the aspect of natural and/or anthropogenic forcing
- to study climate impact on the cryosphere in the Alps (having an important influence on winter-tourism which is among the leading economic factors in the region)

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6.2.2. SOCIO-ECONOMIC:

The mentioned complicated political and administrative structure of the study region has so far severely hampered climate research there. Today, ten different national meteorological services and some 20 other subnational organizations are maintaining the instrumental database in the greater Alpine region. Going back in time, the situation becomes even more complicated. The unstable history of Central Europe, during the last two and a half centuries – being the instrumental period here – full of political breaks, warfare, revolutions and changing national borders (Figure 6.1 shows two examples, more details are provided by section 2 of Auer et al., 2005 – project-paper-rev-3) has spread historic climate data into a multitude of archives at very different levels of structure and quality. This is one of the typical disadvantages European researchers have to face compared to e.g. Americans. The single state of Colorado for example is of similar size and shape as the study region of the European Alps. Also the existing routine exchange of climate data organized by WMO does not match the needs defined by the complicated orography of the region. As climate "knows no borders", one of the most intriguing challenges of the project was to overcome those obstacles by establishing and maintaining a climate data exchange in the region which did not exist before, a before unknown sample of climate information was collected, quality tested and studied - for instrumental as well as for treering and for glacier data. The initiated underlying international and interdisciplinary cooperation in the region may be regarded as the most remarkable socio-economic progress in terms of strengthening the European position in the field of research and for a further political integration of Europe. It has to be shortly remarked here once more (details in the respective 1.5-sections of the 3 annual reports) that this goal could only be reached through an extensive expansion of the project-community by greater number of external partner institutes which contributed data and knowledge at an informal basis.

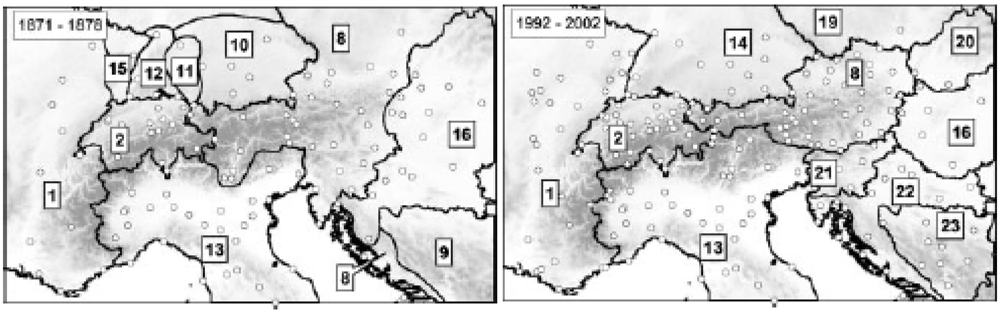


Figure 6.1. The administrative-political structure of the GAR in the 1870s (left) and in recent years (right). Dots: instrumental network in the two periods. (1) France, (2) Switzerland, (8) left map: Cisleithanian part of Austro-Hungarian Monarchy, (8) right map: Austria, (9) Ottoman Empire, (10) Bavaria, (11) Württemberg, (12) Baden, (13) Italy, (14) Germany, (15) Alsace-Lorraine, (16) left map: Transleithanian part of Austro-Hungarian Monarchy, (16) right map: Hungary, (19) Czech Republic, (20) Slovakia, (21) Slovenia, (22) Croatia, (23) Bosnia and Herzegovina

6.3. APPLIED METHODOLOGY, SCIENTIFIC ACHIEVEMENTS AND MAIN DELIVERABLES

6.3.1. OUTLINE OF THE INNOVATIVE SCIENTIFIC STRENGTHS OF THE PROJECT

There have been very few studies for any region where different paleoclimatologists have joined with instrumental climatologists to bring together all the records from this diverse array of indicators of the past. None has undertaken such a comprehensive exercise with the additional assistance of climate modellers. The greater Alpine region (GAR) is a significant fraction of the European area and it is also unique in being able to provide evidence about the past not only from a variety of proxy and instrumental sources but also from a transect of elevations within the region. The first innovative aspect of ALP-IMP has been the bringing together of a diverse group of scientists to develop the **definitive climatic history of the GAR for the last millennium**. The project has also provided the most detailed information about the range of natural climatic variability available for any region of the world.

The potential of **instrumental records** (project paper rev-3, rev-12, rev-20, nrev-3, nrev-5, nrev-13, nrev-15, nrev-22) for the GAR extends back to the mid-18th century and could be significantly enhanced through the project. This has – for the three leading climate elements air pressure, air temperature and precipitation - provided the region with the most detailed evidence with which to consider the changes of the last 200-250 years and to assess the causes and the reasons for what has happened (project papers rev-2, rev-9, rev-11, rev-19, rev-21, rev-26, rev-43, rev-46, nrev-2, nrev-16, nrev-31).

The additional inclusion of a number of other climate elements during the project (sunshine/cloudiness, relative humidity, vapour pressure, snow) has for the first time established a real "climate" data base covering the whole region in adequate spatial resolution – describing climate in a multiple sense.

The main innovative attempt of the project concerning the instrumental database has been the clear and strict definition of quality in terms of homogeneity. The method for homogenizing used (project papers rev-1, rev-3 and rev-20) was based on statistical testing and on intensive use of meta-data from station history. Testing and adjusting relied on a system of relative homogeneity testing in sub-periods and in smaller sub-regions under the assumption of the non existence of *a priori* homogeneous reference series - thus avoiding the well known dangers of trend export (inadmissible fitting to a small number of "reference series"). Homogenizing of pressure, temperature and precipitation was accompanied by an intensive detection and elimination procedure of non climatic outliers in the series based on an interactive GIS-supported procedure (section 3.2 of project paper rev-20,

An Alpine-specific innovative aspect has used the "vertical potential" of the study region from sea-level up to 3500m asl. and has produced (section 6 of project paper rev20) and is going to produce (post-project papers rev-45 and rev-47 in preparation) new insight also in the vertical structure of climate variability of the first 3.5 kms of the atmosphere.

Detection and Attribution (D&A) studies have all focused on changes in hemispheric- and global-scale temperature patterns, and detection claims have been made in the last two IPCC reports (in 1995 and 2001). For these studies to be given more credence by politicians and the public it is important that evidence be **sought at the regional level** and for variables that can be shown to have a clear societal and economic impact. Several of the project papers have been used for the respective parts IPCC's 4th Assessment Report to be published in 2007.

The **tree-ring** component of this project has several important areas of innovation, namely: the application of new chronology construction techniques, never applied in this region, that has captured long (century plus) as well as short time-scale variability; the combined use of densitometric as well as ring-width parameters, at different elevations, to enable the parallel reconstruction of both temperature and precipitation-related histories over hundreds to thousands of years in the same region; and the separate use of different tree species data (with their different climate sensitivities) to deduce more information about intra-seasonal changes than can be inferred from the use of aggregate chronology data. The availability of such comprehensive and long instrumental records has also stimulated (and will continuously do so in the future) an unprecedented detailed investigation of time-dependent changes in climate influences on tree growth and a very rigorous approach to the calibration and verification of statistical reconstruction models.

It has been specifically the treering component that has pointed to an interesting mismatch of this proxy with the instrumental evidence in the area's early instrumental period (project papers rev-7, rev-10, rev-33, rev-44). For the time being no solution of the "early instrumental paradox" (of warmer low-elevation instrumental versus colder high elevation treering evidence in the early 19th and late 18th century) has been found. The well described inconsistency is one of the prominent and relevant "negative project findings" to be further studied in the post project time – successfully probably under inclusion of additional independent proxies as lake sediments, speleothems and combined studies also with documentary evidence as well as a second closer look at the homogeneity problem and at glacier evidence.

The ALP-IMP attempts to extract paleo-climate information inherent to **water isotope records from Alpine ice cores** are unique through dedicated deploying closely related instrumental climate records. This aspect clearly stands out compared to polar or (sub)-tropical ice core sites, where such an attempt can be realized in a very restricted way only. Including in this context, regional scale isotope modeling, eventually aimed at disentangling temperature and circulation driven components of the observed isotope variability constitutes a highly innovative approach. To reduce the relatively strong meteorological and glaciological noise, specifically carried by Alpine isotope records, a multi-core approach, covering both of the highest summit range was applied. This attempt included the selection of sites, particularly allowing to retrieve multi-centennial isotope-temperature records and lead to a more clear assessment of the restriction and climate significance of the isotope variability stored in these archives Apart from deployments towards regional scale isotope models, specific technical innovation aspects comprised modern stratigraphical dating methods to meet the necessary depth resolution as well as back up dating attempts based on cosmogenic radionuclides .

The innovative aspect concerning **glacier variability** has not so much been due to the use of new techniques but mainly to the systematic application of such state of the art techniques for the whole study region (GAR) using the whole potential of the new instrumental and proxy data which was made available for the first time for glacier variability analysis at a comparable quality level. This new potential is given not only by the quality of the comparative data, but also by their temporal and their spatial coverage.

The regionally now much better resolved picture of Alpine glacier variability (project papers rev-16, rev-28) and its better understanding (project papers rev-5, rev-8, rev-17, rev-18, rev-27, rev-29, rev-30, rev-31, rev-51) based on the information from the other ALP-IMP project's findings has contributed to a better understanding and a better description of *the* leading symbol for climate change – the glaciers which have a high public awareness to be used to demonstrate the practical implications of climate impacts – especially in a sensitive region like the Alps. Substantial progress could also be made with repect to the modelling of the impact of future climate change on glacier cange (project papers rev-27, rev-29, nref-45), clearly demonstrating that dramatic changes of the Alpine landscape, including a complete deglacierization of entire mountain ranges must be taken into account (project papers rev-30, rev-31)

In terms of the **climate modelling** part of the project a statistical 4-d reconstruction of the Alpine climate for the instrumental period based on mesoscale variability patterns that are obtained from the high-resolution regional model simulation was planned. The simulation has a resolution of 1/6 deg and was forced by the ERA40 reanalysis which has a resolution of 1.125 deg. To achieve this high resolution for a 41 years regional climate simulation of the whole of Europe, the project exploited a major technical innovation at one of the leading European climate computing centres (DKRZ – Deutsches Klimarechenzentrum), where a new supercomputer has been installed in 2002. The simulation took more than nine months. The analysis revealed unexpected problems of the simulation concerning the quality and added value compared to the driving reanalysis with a much coarser resolution. This led to a more detailed and time consuming validation showing that other recent studies also came across the absence of a clear added value of a high-resolution simulation compared to the driving simulation with a coarser resolution. This topic is of huge interest for the development of regional climate models and needs more analysis. Therefore, the modelling part of the project took an unexpected turn but produced very important results written up in a paper (project paper rev-48). The detailed validation needed extra time leading to the delay of the reconstruction. As the analysis did not show a clear added value for the temperature but indicates an added value for circulation, the reconstruction will be performed solely for circulation on different levels during the next year. This reconstruction will have a very high resolution with fields reaching the lower stratosphere, which goes beyond surface pressure and 4d-reconstructions existing before the project, which focused on larger scales and could not use high-resolution anomaly patterns for the free troposphere.

The European (and particularly the GAR) region is **unique, within a global context**, incorporating a variety of long proxy climatic information and instrumental records going back to the late-18th century. Work within ALP-IMP has attempted to resolve the early instrumental paradox, where the warm summers before about 1820 may be slightly too warm, possibly because of exposure problems. Work in Fennoscandia has suggested a similar problem. The tree-ring reconstructions suggest that the summers were not as warm as recorded instrumentally (project papers rev-07, rev-10, rev33, rev44), but this finding is not conclusive, only suggestive. Instrumental records from NW Europe appear to confirm the early alpine instrumental records. ALP-IMP has given much new evidence to the debate, which also relates to the common misconception that as climate warms or cools all seasons act in a similar way. Resolution will come through a comprehensive study of all the instrumental data (particularly pressure and circulation, project paper rev-45).

The development of the high-resolution precipitation database will be particularly useful to all the proxy climate groups (not just within ALP-IMP), providing a comprehensive picture of precipitation change for the GAR for over 200 years (project papers rev-14).

ALP-IMP had developed a number of **millennial length reconstructions** of summer climate variability across the GAR. Together with already available information, these will be summarized in project paper rev-50. In summary, they show that summers were warm in the first two centuries of the millennia, but cooler than the average of the last 20 years. The summer of 2003 was clearly the warmest in the past 1000 years. Despite the general pattern of warmth between 900 and 1200, then cooler conditions from 1350 to 1820 and gradual warming to the current record levels, there are a number of decades (e.g. the very cold 1040s to 1060s and the warm decades around 1500 and 1800) which run counter to the prevailing centennial levels indicating that European climate history is a lot more complex than generally understood.

6.3.2.: PRINCIPAL FINDINGS IN DETAIL – STRUCTURED IN WORKTASKS AND WORKPACKAGES

The project's activities were broadly divided into **three worktasks (WTs)** which reflect the main temporal and also the methodological structure of the project:

WT-1, the "Data Worktask"

developed the necessary GAR-database, including a first description of +200 (instrumental) to +1000 years (proxy) of climate variability in the "Greater Alpine Region and meets the demands of the first three of the main objectives of the project.

WT-2, the "Consistency Worktask"

is a necessary link between WT-1 and the synthesis WT-3. It tested the internal intervariable consistency of the WT-1 results as well as the consistency with other existing (continental to global scale) datasets including regional scale model simulations of the past climate variability.

WT-3, the "Synthesis Worktask")

provided a 4-dimensional climate variability analysis within the GAR and of the GAR in the greater context of continental to hemispheric scale reaching back some 200 years (for instrumental) and to 1000 years and more for proxy datasets.

WORKTASK 1 included **four workpackages (WPs)** focusing on data collection, new data analyses, quality control, presenting and processing for further analysis in the other two worktasks. WP-1 is established in the instrumental domain, WP-2, WP-3 and WP-4 in the proxy-domain:

- **WP-1, "Instrumental records"** collected as long as possible (100 to +240 years) instrumental climatological time series of a number of climate elements from internal and external sources, tested them for homogeneity, processed them for further use in the three other proxy-data WPs and put them in the public domain for research and practical application also outside the project

- **WP-2, “Tree-ring records”** collected climate relevant tree-ring data (for the past 1000 years and beyond) from internal and external sources, focusing on the specific potential of the GAR in respect to temperature sensitivity of tree-rings with increasing altitude and precipitation sensitivity in dry regions.
- **WP-3, “Isotope ice core records”** dealt with stable water isotopes from ice cores from high elevated Alpine glaciers focusing on their temperature sensitivity. The time scale was also 500 to 1000 years and more.
- **WP-4, “Glacier records”** collected glacier variability data (successfully for length, area, volume and mass-balance less successful for geomorphological evidence which resulted to be poorer then expected) from existing international databanks and from additional national and sub-national sources focusing on their proxy-potential for temperature and precipitation but mainly on their nature as typical Alpine climate impact objects well usable for the demonstration of climate change. The typical time-scales are 50 years (mass balance), 100 to 150 years (length, areas, volume) and 1000 years (historical and geomorphological evidence of outstanding periods).

WORKTASK 2 served as an additional quality assessment to **test the consistency** of the data deliverables of worktask 1 with other datasets and modeling results.
It was broken down into two workpackages:

- **WP-5, “Consistency observed vs. observed data”** tested the **internal** consistency of the different instrumental variables of the WP-1 data and assessed their **external** consistency with the respective GAR-grid-boxes of large scale datasets

- **WP-6, “Consistency observed vs. simulated data”** tested the consistency of the observed WP-1 data including ice core isotopes with GAR-climate variability patterns simulated by high resolution **regional modeling.** A module of modeling-based ice core data evaluation worked within the workpackage.

In both workpackages of WT-2 the validation process was not a one way procedure - WP-1 data from the GAR were in some aspects tested against the background of the larger datasets, but the higher spatial resolution of the GAR data and their higher potential in terms of homogenizing allowed them to serve as well as reference for the ability of large scale datasets to resolve small scale climate variability patterns. The situation was similar in terms of comparing data-based variability with the patterns from regional models.

WORKTASK-3 was the **synthesis worktask. It** used all final data sources from worktask 1 which had been additionally quality assessed and validated in worktask 2. The first leading goal of worktask-3 was **to produce integrated analyses of climate variability in the greater Alpine region.** For the 19^{th} and 20^{th} century the analysis could rely on a high spatial resolution covering the entire study region, for the earlier centuries the analysis has to concentrate on the typical source regions of the three available proxies. The representativity of those regions is given by the spatial variability patterns derived for the 19^{th} and 20^{th} century.

- **Workpackage 7 – Internal climate variability in the greater Alpine region (200 years GAR internal):**
  In addition to a descriptive part focusing on **climate variability patterns** in the complex terrain of the greater Alpine region (GAR), special attention was paid to the analysis of the **physical properties of the climate variability system** in order to better understand the internal patterns within the GAR. This was achieved by intensive use of sophisticated statistical methods combined with the results of regional model simulations with runs of a regional model (REMO) at high spatial resolutions.

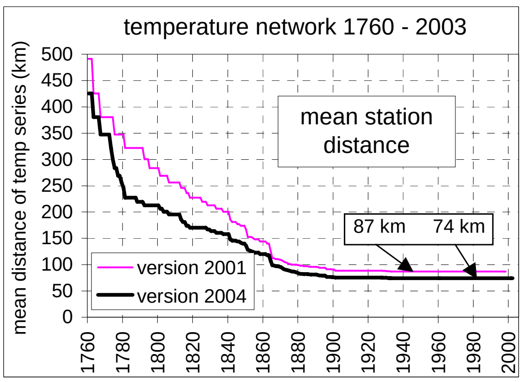
- **Workpackage 8 - GAR in the greater context of large scale variability and forcing (200 years GAR versus global):**
  The focal point of WP-8 was the analysis of the **climate variability in the GAR in the greater context of large scale** (continental to global) **climate variability and large scale forcing factors** with the option to distinguish between natural and anthropogenic forcing factors. Special attention was paid to the situation of GAR-climate in the deviation zone between three leading geographical influences (Atlantic, Mediterranean, continental) given by large scale circulation, the role of the Alps as a steep divide of European climate systems as well as the Alpine climate under natural versus anthropogenic forcing.

- **Workpackage 9 - The proxy period (1000+ years GAR climate and beyond):**
  In contrast to WP-7 and WP-8 (which concentrate mainly on the 100 to +200 years of the instrumental period) **WP-9 focused on the description and analysis of the proxy period – extending the observational period back to +1000 years B.P** based on the findings of the workpackages 2, 3, 4 together with 5 and 6. The focus of the WP-2 and 3 data (tree-rings and ice cores) was on their application as proxies for climate variability. The glacier changes data of WP-4 were also used as proxies but mainly as the typical Alpine climate impact item: glacier variability as the leading visualization tools to demonstrate the consequences of climate change.

6.3.2.1. WORKPACKAGE 1: INSTRUMENTAL RECORDS

The first objective of the workpackage was **"to collect all available monthly long-term instrumental climate data from the GAR"**. This could be realized to a large extent. The instrumental climate database which existed before the start of the project could be considerably improved. The improvement was possible only through the already described establishment of an informal cooperation with the more than 20 data providers of the administratively and politically complicated study region. This cooperation worked nearly frictionless but was nevertheless extremely time consuming. Thus, it exceeded considerably what was funded by the project and could be realized only thanks to existing personal and institutional contacts and through the cooperation with some parallel national projects.

The first improvement concerned the **multiple approach** of ALP-IMP – seven climate elements are now available as monthly time series. Remarkable progress could be obtained in terms of including new series and/or extending series into the **early instrumental period** (mid 18th to mid 19th century, project-paper nrev-05). Figure 6.2. shows two examples.



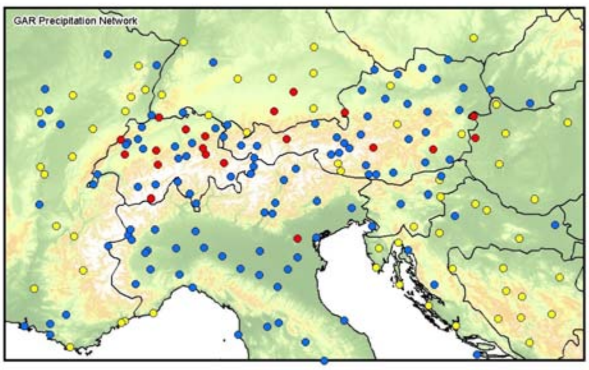


Figure 6.2. Two examples for the extension of the instrumental database in the GAR. Left: Evolution of the temperature network density 1760-2003 before (pink) and after ALP-IMP (black). Right: Map of the GAR precipitation network. Blue dots: sites before ALP-IMP, red dots: additional early data, yellow dots: new series

The second objective was a reanalysis **in terms of general quality and homogeneity.** This objective afforded the greatest part of the invested manpower. A critical analysis of the state of the collected instrumental data and a comparison of the experience within the WP-1 group led to the decision to completely re-analyze the quality of the database. On the one hand the additional data allowed a better testing and adjusting of already pre-homogenised series (from pre-project activities) simply due to the obtained higher network density. On the other hand some more sophisticated techniques had emerged or could be developed within the project (exemplarily described for precipitation in project paper rev-03, more generally in rev-20, regarding specific items in nrev-05, nrev-13, nrev-15, nrev-19, nrev-31). Thirdly it became clear soon that adjusting homogeneity breaks was not sufficient but had to be accompanied by a systematic detection and elimination of incorrect outliers. Hundreds of inhomogeneities and thousands of outliers were detected and were subsequently eliminated. The elimination of inhomogeneities made the dataset fit for analysis of climate trends, the correction of outliers now allows for a correct analysis of climate extremes. Table 6.1. outlines the necessary corrections, adjustments and filed gaps. The station list of annex 1 to this report contains detailed information on each instrumental site. It can be stated that the project's instrumental database now has the highest quality obtainable at regional scale and for a time resolution of one month at the given state of the art in the field.

Table 6.1. Outline statistics of available data and detected breaks, outliers and gaps for the five leading climate elements of the project's instrumental database

	Air pressure	Temperature	Precipitation	Sunshine	Cloudiness	All	
No. of series	72	131	192	55	66	516	Series
Available data	10 215	19 312	26 063	7886	7669	71 145	Years
Mean length of the series	141,9	147,4	135,7	88,8	119,5	137,9	Years
Detected breaks	256	711	966	366	234	2533	Breaks
Mean homogeneous subinterval	31,1	22,9	22,7	11,6	26,3	23,4	Years
Detected real outliers	638	4175	529	–	–	–	Outliers
Filled gaps	4217	12 392	14 927	2011	3513	37 060	Months
Mean gap rate	3,4	5,3	4,8	2,1	3,8	4,3	%

The third objective of the instrumental data workpackage was a **"standardized re-procession of the data and description for further internal and external use"**. This requirement was met by the system of the newly generated "HISTALP" database, a common product of Austrian project CLIVALP and ALP-IMP. An extensive paper published in 2006 (project paper rev-20) describes the creation of the dataset and serves as the main reference for the use of the instrumental database.

Data are stored in HISTALP in different modes:

station-mode original (stmod-ori): the single station series before quality enhancement

station-mode homogenized (stmod-hom): the single station series after quality enhancement

Coarse resolution subregional means (CRSM-mode): Mean anomaly series averaged over 5 principal subregions of the GAR (relative to 1901-2000 average)

grid-1-mode: gridded anomaly series at 1 deg lat-long (relative to 1901-2000 average)

grid-2-mode: gridded absolute series at 1/6 deg lat-long

Within the project-community, all data are freely available (for regular as well as for corresponding project partners) via the password secured internal opart of the project website. The station-mode data are available outside the project community at request. They are sent under the condition of the approval of the original data provider. All gridded products are publicly available without restrictions.

Stmod-data exist for 7 climate elements for 242 sites (details in annex 1). The longest series extend back to 1760. Figure 6.3. illustrates the development with the clearly distinguishable three main sections: An early period from approximately 1760 to 1850 with a limited number of series, a fully developed network in the 20th century and a transition period in the second part of the 19th century. In spite of the reduced network density in the early period, HISTALP represents nevertheless the highest spatial density of early instrumental climate information anywhere in the world. The differences between the bold and the thin lines in the figure reflect the gaps that had to be filled.

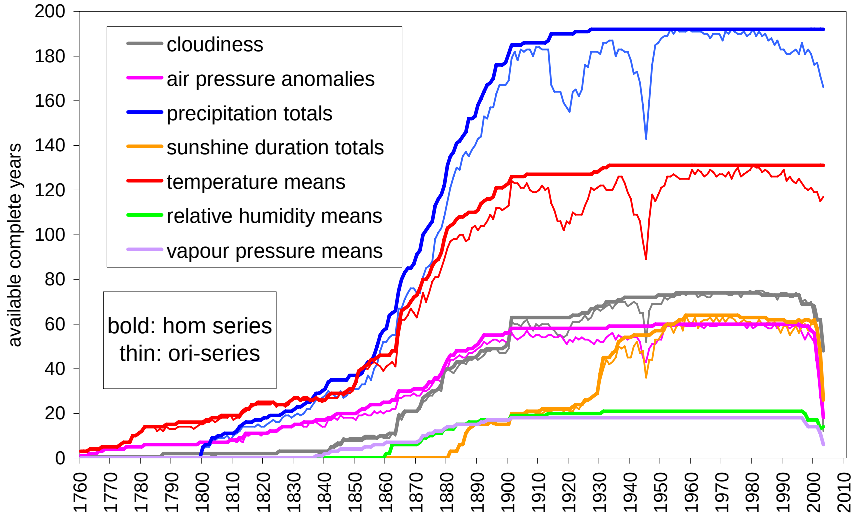


Figure 6.3. Development of the HISTALP station-mode-ori and station-mode-hom networks for the five leading climate elements

CRSM-data were calculated for all seven climate elements of HISTALP. The map of Figure 6.4. below shows the four low elevation "coarse resolution subregions" of the GAR - a fifth represents the high elevation parts of the Alps and corresponds to the areas shaded in dark grey.

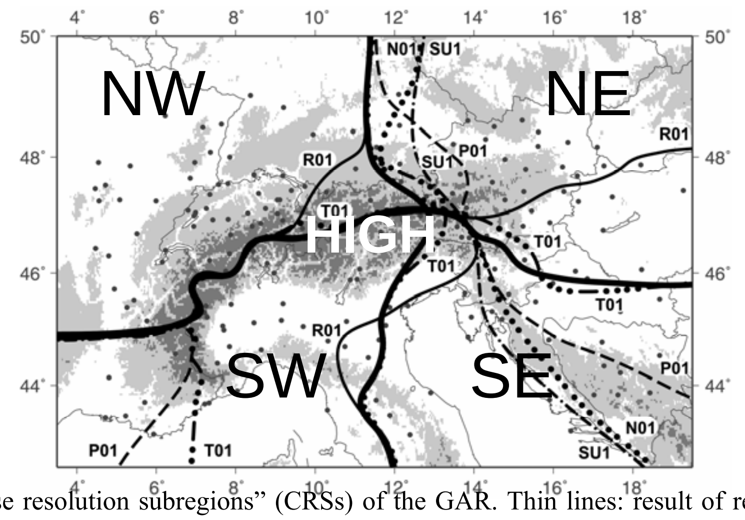


Figure 6.4. The "coarse resolution subregions" (CRSs) of the GAR. Thin lines: result of regionalization of the single climate elements, bold lines: The low-elevation CRS-compromise common for all elements, dark-grey areas: CRS-HIGH, dots: HISTALP sites

The basic idea behind the coarse resolution means (which were not planned initially but emerged during the course of the project) is based on an objective PCA regionalization for each climate element and for each season separately. As the results were similar, it was feasible to calculate the mean series for identical subregions for all climate elements. The advantage of allowing intercomparisons between the elements was more important than following the PCA regionalization too literally. Within the CRSs inter-station correlation is high for all climate elements and decadal scale trends and variability highly similar. Only for studies of climate extremes station-mode data should be preferred in order not to loose small scale events.

Grid-1 mode data were interpolated for the three leading climate elements air pressure, air temperature and precipitation. “Grid-1” stands for monthly anomaly series (relative to 20th century means) interpolated on a regular grid at 1 deg lat-long. Interpolation was performed using an inverse distance algorithm with some additional conditions regarding some special features of the region (project papers rev-3, rev-20 and nrev22). For air temperature the grids are provided for two altitude-bands: HIGH (>1500m) and LOW (<1500m) elevation. Figure 6.5. illustrates grid-1 for temperature. For precipitation and air pressure only one layer (low) is provided.

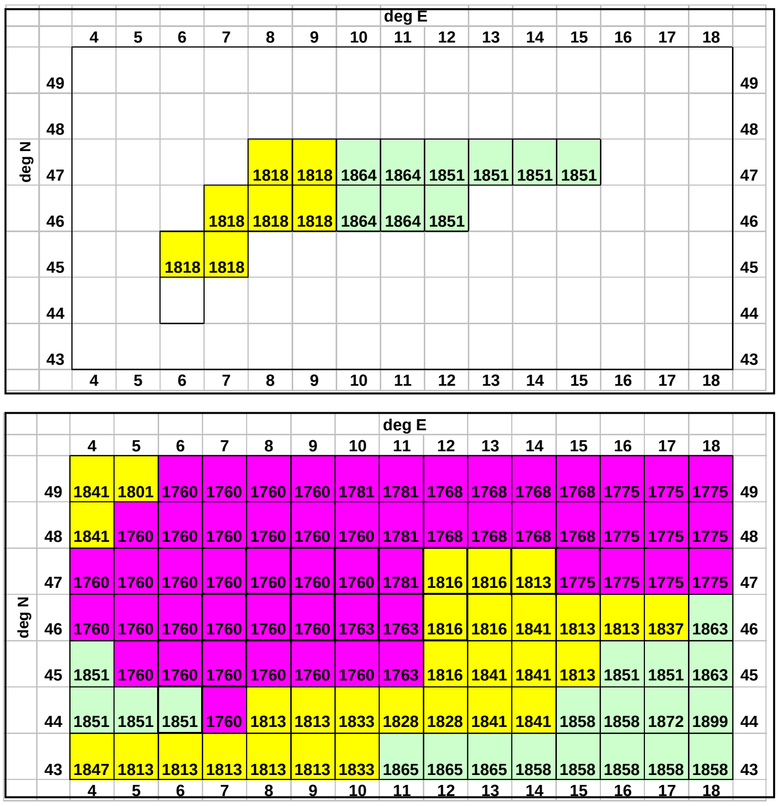


Figure 6.5.

The 2 layer grid-1 for temperature: Shown are starting years of the single grid-series.
The two layers refer to above (top) and below (bottom) altitudes of 1500m asl.

Grid-2 mode data are the ultimate goal of HISTALP products. They consist of gridded series in absolute values at the highest feasible spatial resolution. This concept could be realized within the project for **precipitation** (project paper rev-12, nrev-33). Figure 6.6. shows two examples of the 2460 highly resolved monthly precipitation fields. Both indicate cases of extreme regional precipitation, one (August 2002) caused widespread flooding in Northern Austria, Czechia and Eastern Germany. The other is typical for the even more intensive precipitation in the Mediterranean part of the GAR, and particularly for the two orographically driven “wet spots” in NE-Italy (shown) and NW-Italy (not shown). Note that the second case is one from the early instrumental period (November 1826) for which an analysis like this was unthinkable before ALP-IMP.

For **temperature** the necessary preconditions (high resolution monthly climatologies of the GAR) were not fulfilled and therefore only a respective unplanned additional activity was started (GAR-HR-climatology) and the final goal will be reached in the post project time in the frame of an ECSN-project (ECSN/HRT-GAR, project paper nrev-34) started with a workshop in Vienna in February 2006. For **air pressure** a higher resolution than 1 deg lat-long is neither necessary nor possible at the given network density, for **sunshine, cloudiness, relative humidity and vapour pressure** grid-1 and grid-2 datasets for the cannot be realistically expected in the near future – for these elements analysis will have to remain on stmod- or CRSM-data.

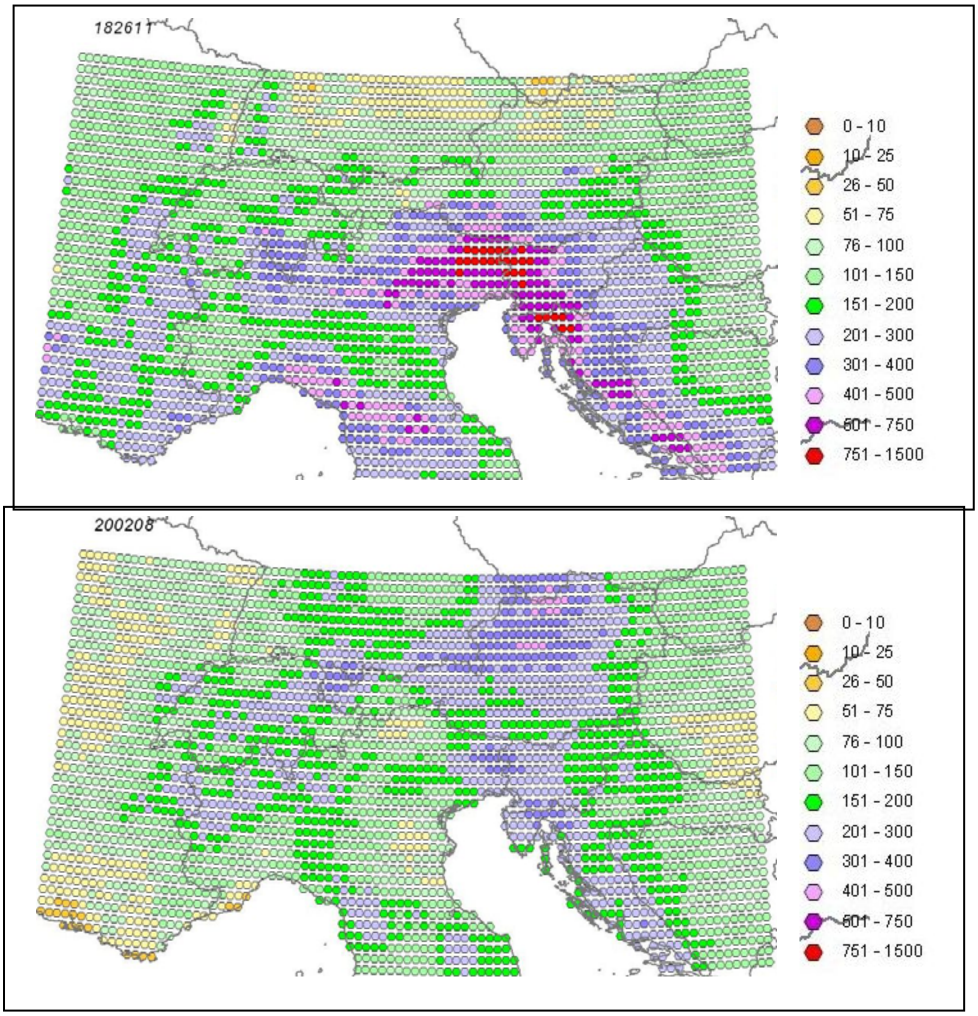


Figure 6.6. Two examples of grid-2 precipitation fields at 1/6 deg lat-long resolution for two exceptional months in the early instrumental period (top) and in recent time (bottom) -values in mm/month.

For an eighth climate element – snow – the instrumental project group had to perform first steps into the domain of daily data. Unlike for the other 7 climate elements treated in WP-1, there was no reliable basis of uniformly processed monthly snow statistics neither in yearbooks nor in other archives of the data providers in the GAR. Nevertheless we regarded snow as a climate element of great interest especially in the GAR. Therefore an initial activity tested the existing data potential and the feasibility in regard to longterm daily snow data. A semi-automatic procedure (project paper nref-36) allowed to electronically digitize, quality check, correct and complete a large subset (1895/96-1916/17) of more than 200 daily snow-depth series from the former Austrian-administrated part of the Austro-Hungarian monarchy (recent Austria, Czech Republic, Slovenia and parts of Italy). The snow-activity showed the feasibility of rescuing and processing large data quantities if the source is well printed sheets or books. For hand written sources automatic scanning is not possible and the rescue of such data therefore extremely painstaking.

Concluding and resuming the activities in the instrumental data activities, WP-1 can generally be described as successful. The overwhelming part of the planned deliverables were more than fulfilled, some unforeseen difficulties could be balanced by much more than planned results in other parts of the workpackage. Especially the close cooperation with a greater number of external project partners guaranteed the success of the instrumental data activity of ALP-IMP which would not have been affordable at the given financial frame of the project. The HISTALP database, to which ALP-IMP contributed substancially, distinguishes the GAR from most of the other regions in terms of having fully exploited the existing historic instrumental climate data potential, having done what is possible to obtain highest quality and having put them to the disposal of already performed or initiated internal project studies compare working task 3) as well as for oncoming external studies and applications in the post project time (details in the TIP).

6.3.2.2. **TREE-RING RECORDS**

The first objective of the tree-ring work-package was to **assemble the best possible 'optimum' set of existing and new tree-ring data for the Greater Alpine Region (GAR) with a focus on identified key regions and tree-growth variables**. This duty was reached through a extended compilation of existing data. Key sites with outmost rings in the 1970's were updated to include rings covering the warmest recent decades, and new sites were sampled. These efforts led to the development of a spatially dense GAR tree ring network including more than 400 ring width (TRW) and more than 130 density chronologies from 6 main species (*Abies alba ABAL, Larix deciduas LADE, Picea abies PCAB, Pinus cembra PICE, Pinus nigra PINY* and *Pinus sylvestris PISY*) (Figure 6.7). All data sets are centralized, including raw measurements and corresponding metadata, at the institute of partner 8 on a newly created ALPIMP tree ring data bank. These data are currently available via the WSL server. Based on former investigations and ALPIMP related network analyses it was evident, that tree growth in the Greater Alpine Region is mainly determined by altitude and less by species differences. At high altitudes summer temperatures are largely independent from species control tree-ring formation (rev-4, rev-10, rev-14, rev-25). At intermediate altitudes climate-growth relationships are less distinct, representing a mixture of temperature and precipitation signals. At the lowest altitudes growth is favoured by warm late winters and cool and moist springs and summers and a precipitation signal is maximised at dry low elevation sites (rev-24, rev-25,). Therefore, with these geographical and ecological considerations, the following sub-regions of the GAR network have been defined for different aspects of climate reconstruction: Valais and Engadin in the Central Swiss Alps, Tyrolean Central Alps, Dachstein, Northern Limestone Alps, Vienna basin (all Austria).

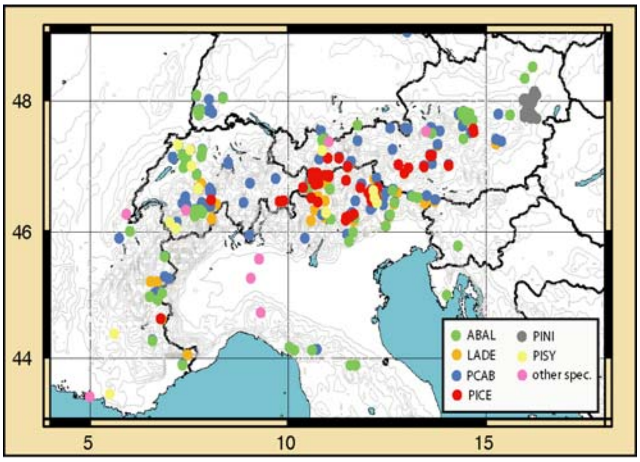


Figure 6.7. The GAR tree ring network, grouped after species (abbreviations see text)

The second objective was **screen, quality control, and reprocess raw measurement data to form standardized multi-century to millennial site and regional chronologies for different species, using recently developed/improved statistical techniques**. This objective afforded a great part of the invested manpower and was met by numerous standardisation tests applied and adapted to each specific data set used for climate calibration and reconstruction. Those tests finally determined that adjusting the variance of the single series with so-called power transformation (dendro program ARSTAN) followed by calculating the residuals from 300-year splines is a suitable method to handle particularly ring-width data reaching 300-500 years back. With this detrending, most (but not all) of the low frequency variation is preserved whilst biological induced age trends are eliminated. In contrast density records are of a more homoscedastic nature and hence possess more linear age trends. Raw density measurements could be standardised by calculating residuals from linear fittings (rev-4, rev-10). With adequate sample depth and ecological considerations, size and structure of millennium-long composite data sets (i.e. combining living and historical or relict material) tree-ring records also provide the potential for novel age-related standardisation methods to be applied. In addition to their appeal of greater length, the age-related detrending that can be applied to such composite chronologies allows for greater preservation of low-frequency climate variation. Therefore, our efforts have focused on the development and analyses of millennial length chronologies, with sufficient sample replication for the application of such novel techniques. The development of composite chronologies was only possible in close cooperation between workpackage partners and with the help of independent archaeological labs providing valuable data of archaeological wood. We found the described methods to be the only way to retain climatic related variation from inter-annual to multi-centennial scales, and avoid the "segment length curse" inherent to conventional tree-ring data. In particular we have been using a newly developed method known as "Regional Curve Standardisation" (RCS) to produce chronologies. By splitting the data sets in several sub-groups based on criteria such as living vs. relict material, geographic region, species, age-class, or based on pith-offset information, the robustness of common signals within these data could be proved (Figure 6.8) (rev-7, rev-32, rev-33, rev-38, rev-39, nrev-14).

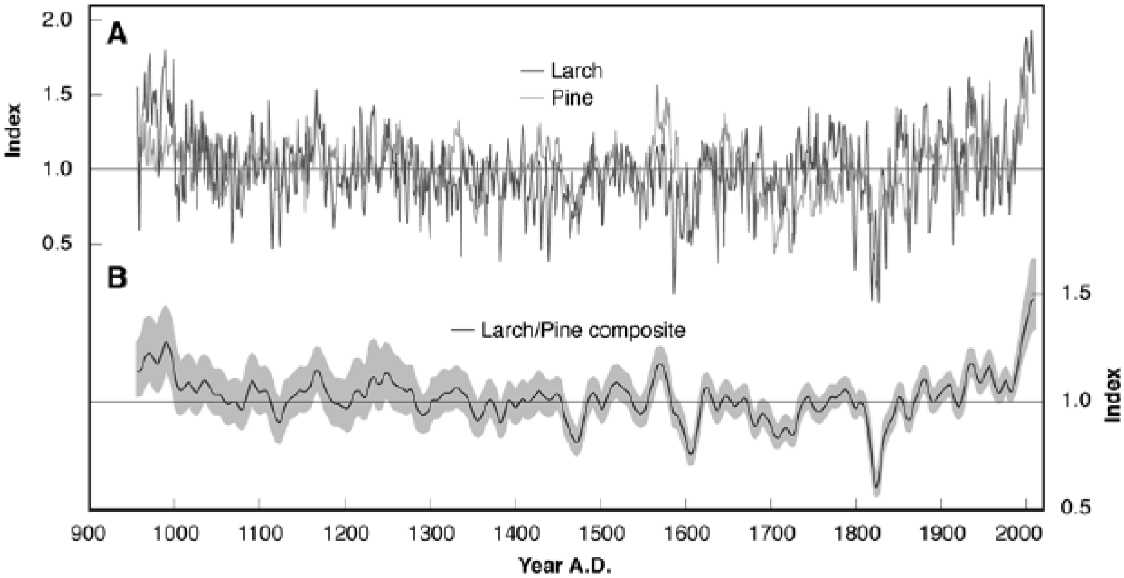


Figure 6.8. Comparison of two RCS records from the GAR network: one from Switzerland (composed of four Larch chronologies) and one from Austria (Pine). Both chronologies show strong similarities from interannual to multi-decadal and centennial variations. These independent records display the Medieval Warm Period (MWP), Little Ice Age and recent warmth that seems to exceed that during the MWP (rev-33).

Objective 3 was to **undertake systematic detailed identification of climate signals in the chronology data, with emphasis on quantifying time-dependent changes.** The availability of excellent, homogenized instrumental climate data provided by WP-1 allowed very rigorous climate calibration on different temporal and spatial scales, and enabled time-dependent changes in response to be quantified (rev-32). For calibration/verification statistics, various regression models are applied including different periods, seasonalities, and wavelengths. To understand climatic extremes and their temporal distribution, a larger Alpine network of high elevation temperature sensitive tree sites was analyzed (rev-4, rev-10), preserving the relative frequency and magnitude of extreme events. In so doing, temporal changes in year-to-year tree-ring width variability were found. Decadal length periods of increased or decreased likelihood of extremes coincide with variability measures from a long instrumental summer temperature record, representative for high elevation conditions in the Alps reported by WP-1. The study demonstrates that growth rings of trees can be utilized to quantify past frequency and amplitude changes in extreme variability. The approach addresses the role of external forcing, ocean-atmosphere interactions, or synoptic scale changes in determining patterns of observed extremes prior to the instrumental period.

As already highlighted at objective two, a central aspect of the WP-2 work was the development of well-replicated, millennial-long tree-ring chronologies basically from the key regions mentioned above. Ring width and maximum density measurements from living trees (mainly larch and pine) and relict wood (own samplings from the Swiss and western Austrian sites, and existing recent and historical ring width data from archeologists, namely M. Schmidthalter and M. Seifert) covering the full past millennium (AD 744-2004) have been performed. Correlations with high elevation meteorological station data provided by WP-1 since 1864 (rev-20) indicate an optimal response of the RCS ring-width chronologies to June-August mean temperatures (rev-7), but an even higher and seasonally extended (June-September) temperature response of the maximum density chronology, derived from 180 (vs. 1110) individual series (rev-33). After correction for larch bud moth induced negative outliers using also the ring-width data set mentioned above (rev-35), the MXD-RCS preserves high to low frequency information and explains 60% of Alpine temperature variations back to 1818, however, with a clear weighting towards high frequency variation.

Both proxies reveal warm conditions from before AD 1000 into the 13th century, followed by a prolonged cool period, reaching minimum values in the 1820s, and a warming trend into the 20th century. The high temperatures in the 10th and 13th century, comparable to those of the last decade, confirm the putative Medieval Warm Period. The cooling from ~1300–1820, relative to the 20th century, reflects to the so-called Little Ice Age. With 2003 being the warmest summer over the past 1250 years, the proxies capture the full range of the instrumental measurements, and especially the MXD chronology provides an annual (decadal) temperature amplitude of 6.4 (3.1)°C.

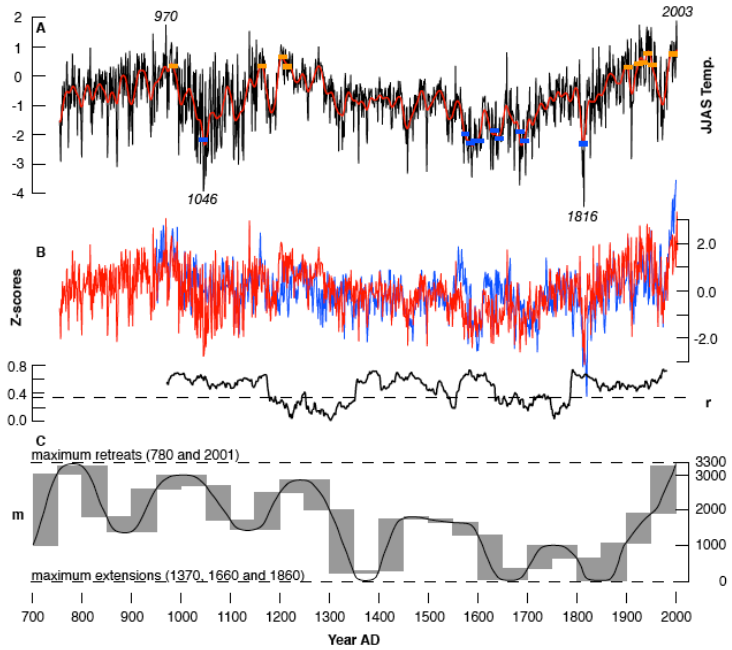


Figure 6.9 A: Alpine summer temperature reconstruction with orange and blue boxes denoting the 10 warmest and coldest decades, and the smoothed red line being a 20-yr low-pass filter. Temperatures are expressed as anomalies wrt. 1901-2000.
Figure 6.9 B: High frequency comparison between the MXD (red) and ring width (blue) RCS chronologies. Records were normalized over the common AD 951-2002 period. 51-yr moving correlations indicate their temporal relationship, with the horizontal line denoting the 95% significance level, corrected for lag-1 autocorrelation.
Figure 6.9 C: Length fluctuation and 50-yr average mass balance (grey) of the Grest Aletsch Glacier (Haeberli & Holzhauser 2003) (rev-33).

Moreover, the MXD-RCS reconstruction is compared with radiative forcing series derived for volcanic eruptions and solar activity, and the North Atlantic Oscillation. Warmest summer temperatures coincide with periods of high solar and low volcanic activity, and coldest temperatures vice versa. However, no relationship with the NAO is found. As this study and other regional- and large-scale temperature reconstructions share common variability (rev-33), evidence of the timing of the MWP, LIA and recent warming is provided, however the amplitude of temperature variations is still not fully understood. Nevertheless, the new GAR reconstructions and particularly the MXD chronology suggest that summer temperatures during the last decade are unprecedented over the past millennium and as a longer-term goal, spatial differentiation of subtle climatic variations over the alpine arc.

These alpine reconstructions are already of unique sample replication and rather high quality in terms of the captured climate signals. Nevertheless, further efforts are under progress e.g. including the newly developed composite maximum latewood density chronology of high-elevation *Picea abies* samples from the Tyrol region (Austria) (AD 1028-2003) (nrev-70) and multi-millennial tree-ring series from central Austria (Dachstein, Hallstatt) (rev-22, rev-38). As expected from instrumental data analyses, which report strong homogeneity in temperature variations over broad Alpine ranges (rev-6, rev-20, nrev-63), first comparisons using again RCS show temperature-growth relationships very similar to the reported high elevation sites. We expect, however, a well-replicated independent verification and more detailed information about the realistic temperature amplitude over the past millennium.

A detailed comparison of tree-ring based warm-season temperature reconstructions and their targets was performed for the European Alps and the Northern Hemisphere. Since the longest and highest quality instrumental measurements worldwide can be found in Central Europe, with many stations extending to the mid 18th century (rev- rev-6, rev-20, nrev-63), these data can be calibrated over exceptionally long periods and their temporal stability can be tested (rev-15, rev-44). A compilation of tree-ring temperature reconstructions and those targets, however, revealed substantial divergence between (warmer) early instrumental measurements and (colder) proxy estimates (Figure 6.10), which currently cannot be explained. The homogenization applied to the instrumental data was discussed, and attention drawn to the misfit's relevance for understanding recent anthropogenic and past natural forced climate systems.

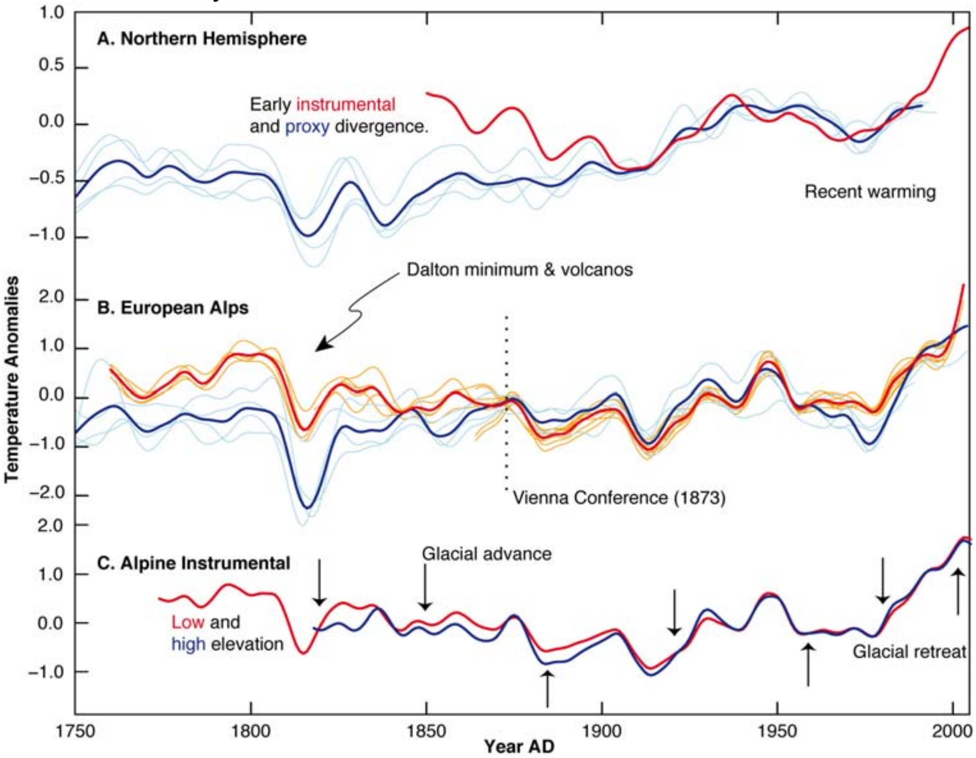


Figure 6.10 A Comparison of large-scale tree-ring dominated warm-season temperature reconstructions (light-blue; Briffa, 2000; Esper et al., 2002; Jones et al., 1999; D'Arrigo et al., 2006) and their mean (blue), with the June-August temperature mean (red) of 30-90°N (CRUTEM3; Brohan et al., 2006).
Figure 6.10 B Comparison of tree-ring based warm-season temperature reconstructions from the European Alps (light-blue; rev-7, rev-10, rev-33) and their mean (blue), with the individual warm-season temperature targets (orange; rev-20) and their mean (red). Mean proxy series are scaled against the instrumental target means over the 20th century common period, and all series smoothed using a 15-year low-pass filter.
Figure 6.9 C Mean June-August temperature records from HISTALP (rev-20) averaged over the entire low (red) and high (blue) elevational bands across the Greater Alpine Region. Also shown are periods of glacial advance and retreat (arrows). Rev-44.

All above described WP-2 results suggest a clear focus on temperature. **Investigations on precipitation changes,** however, are much more challenging because of the more spatially heterogeneous nature of precipitation itself and the less uniform signal in low elevation tree-ring samples. Nevertheless, first analyses from Austrian dry sites prove the potential for precipitation/drought reconstruction at least on a local to regional basis (rev-24, rev-25). A large sample set of *Pinus nigra* Arn. tree-ring series collected within the Vienna basin, from trees growing near the ecological species limits was used. Ring-widths showed a strong and positive spring-summer precipitation signal, indicating a growth dependence on water availability during the growing season. During the late 20th century, tree-rings grew wider than expected by the model, calibrated in the early 20th century. During the last quarter of the century the sensitivity of ring growth to spring summer precipitation disappeared and was replaced by a strong and positive correlation with summer temperature, which had previously been negatively correlated with growth. This change in sensitivity indicates that tree growth was not longer dependent on water availability. We hypothesise, that there was an improvement in water-use-efficiency in consequence of raising atmospheric CO_2 concentrations, enhanced by a relatively high input of nitrogen due to the proximity of N emission sources. We interpret the recent correlation of growth with temperature as a result of an increase in the temperature optimum for photosynthesis under elevated atmospheric CO_2 concentrations (rev-24).

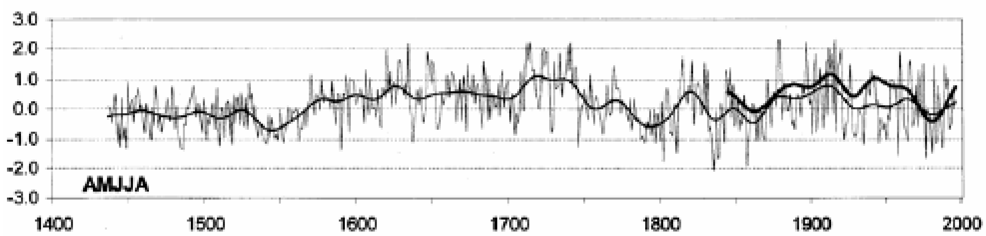


Figure 6.11. 550-years reconstruction of AMJJA-precipitation totals for the Vienna region from *pinus nigra* tree rings. Thin line: reconstruction (annual), medium line: reconstruction 20-years lowpass , bold line: measured precipitation 20-years lowpass (Vienna, HISTALP-series no. 152). Shown are deviations from the 1961-90 average

A 600-year reconstruction of summer precipitation and drought periods is going to be developed for eastern Austria (south of Vienna) and will be combined with data from samples recently taken from black pine trees in the driest region of Austria, the Weinviertel (north-east of Vienna). Figure 6.11 shows an example for the Vienna region. In Switzerland, a combined data set (recent and historical wood) for nearly 1000 low elevation samples has been provided (Schmidthalter). Recent efforts are exploring the possibility of reconstructing precipitation and drought metrics, such as the Palmer Drought Severity Index (rev-26), and ultimately to search for teleconnections with Austrian results.

In addition to the above activities that met the deliverables and objectives of the ALP-IMP project, we conducted additional research that goes far beyond what was initially proposed. Based on the internal ALP-IMP tree-ring databank installed at the WSL, a re-assessment of growth trends, climate response and insect defoliation of the European larch (*Larix decidua* Mill.) was launched. We compiled a network of 70 larch site chronologies and 73 spruce reference chronologies from the European Alps and western Carpathian arc. For the detection of cyclic insect population dynamics and their spatio-temporal patterns throughout the Alpine arc, we used ‘non-host’ evidence from the 73 spruce reference chronologies and the multi-proxy Alpine summer-temperature reconstruction by Casty et al. (rev-6). By focusing on analysis of millennial-length larch chronology the noise introduced by periodic larch bud moth defoliation cycles could be detected a history of the frequency and magnitude of bud moth population dynamics over the past millennium was provided (rev-34, rev-35). With over 1,000 generations represented, this is the longest annually resolved record of herbivore population dynamics, and our analysis demonstrates that remarkably regular LBM fluctuations persisted over the past 1173 years with population peaks every 8.9 years. These regular abundance oscillations recurred until 1981, with the absence of peak events during recent decades. The late 20th century absence of LBM mass-outbreaks corresponds to a period of regional warmth that is exceptional with respect to the last 1000+ years, suggesting vulnerability of an otherwise stable ecological system in a warming environment.

Moreover, we developed a multi-species tree-ring width and density network in the western Carpathian arc and analyzed the growth/climate response of 24 tree-ring width and four maximum latewood density chronologies from the greater Tatra region in Poland and Slovakia (rev-34). The novel network comprises 1,183 ring-width and 153 density measurement series from four conifer species (*Picea abies* [L.] Karst., *Larix decidua* Mill., *Abies alba* [L.] Karst., and *Pinus mugo* L.) between 800-1,550 m asl. The network was analyzed to assess growth/climate response as a function of species, elevation, parameter, frequency, and site ecology. Principal component analyses elucidate, that ring width chronologies significantly correlate ($p< 0.05$) with June-July temperatures, while the density chronologies reveal strongest response to the wider April-September season. Climatic effects of the previous year summer were generally not found to significantly influence ring formation, while site elevation and wavelength of growth variations (i.e., inter-annual and decadal) were found to be significant variables in explaining growth/climate response. Increasing precipitation response with decreasing elevation is observed. Correlations between summer temperatures and annual growth rates of Larix decidua are lower than for Picea abies. Comparison with reconstructions from the Alps and Central Europe support the dominant influence of warm season temperatures on high-elevation forest growth. This analysis enabled us to spatially extend our Alpine results towards surrounding mountain systems. In this regard, we are currently developing a similar data compilation of living and historic high-elevation wood in the southern European Pyrenees.

Finally, although not directly related to the GAR region, a millennium long oxygen isotope record from tree rings in northern Pakistan proves this novel tree ring parameter to be a promising tool for precipitation reconstruction at sites, where ring widths and densities are currently used for temperature reconstruction (rev-36). The study suggests an intensification of the global hydrological cycle due to global warming, a finding which needs to be empirically verified by the development of more long-term precipitation reconstructions e.g. from alpine areas.

The existing GAR tree-ring records and their explained local and regional climatic sensitivity provide detailed insight in climate variability before, at the transition to, and during unprecedently intense anthropogenic activity. Our millennium long temperature reconstructions point to the summer AD 2003 being the warmest over the whole period, but closely followed by the pre-industrial, medieval summer AD 970. Although, reconstructed temperature variations mimic natural forcings (volcanic and radiative activity) reasonably well, anthropogenic impact during the industrial period cannot be excluded. Moreover, the obtained Alpine temperature history shows significant similarities with reconstructed NH decadal scale variations and longer-term trends. These findings suggest that Alpine climate is of larger-scale importance. In future, ALPIMP data provided by the tree-ring workpackage will be useful to quantify natural (e.g., solar and volcanic) vs. anthropogenic (e.g., CO_2 and manmade aerosols) forcings in the highly sensitive Greater Alpine Region in a long-term context. Moreover, the data sets will help enable quantifying long-term spatial and temporal changes of GAR biomass. This will yield information to aid in future valuation of forest resources, and can provide data to help shape, and/or assess compliance with policies seeking regulate the flux and sequestration of carbon.

In concluding and summarizing the tree-ring data activities, WP-2 can be described as very successful. The overwhelming parts of the planned deliverables were more than fulfilled. The close cooperation with a greater number of external project partners played a big role in the success of the tree-ring data activity of ALP-IMP which would not have been affordable at the given financial frame of the project. The sample replication, quality and length of the tree-ring data base developed in ALPIMP distinguishes the GAR from most of the other regions and has contributed significantly to our understanding of past climatic fluctuations in the GAR. Project outcome included the development of several high quality reconstructions, many of which are already used by the international community. Additional ALP-IMP results will be published in the near future (details in the TIP). Work package results show the need and feasibility for additional well replicated reconstructions during and prior to the Medieval Warm Period in the GAR and also highlight the need to better understand the critical transition between our understanding of climate based on recent instrumental measurements and that reconstructed in the previous centuries to millennia. The spatial extension of proxy reconstructions outside of the GAR will also contribute to a furthered understanding of regional to hemispheric climatic variation.

6.3.2.3. **ISOTOPE ICE CORE RECORDS**

The isotope ratios (δ18 O or δ D) of ice recovered from non-temperate glaciers are well recognized proxies, which may eventually reflect the local temperature variability. While polar ice core studies have extensively deployed this isotope- thermometer back into the past glacial(s), much less studies focused on the near past (e.g. last millenium) and on mid-latitude glaciers. The latter ice bodies are however subject to a series of shortcomings (as fragmentary snow deposition, ice flow effects and highly non-linear depth/age relationships), which still deserves basic investigation to reliably explore these climate archives.

Selected target regions for the ALP-IMP ice core studies have been the Monte Rosa and Mt. Blanc summit ranges, which offer the most suitable Alpine drill sites for recovering long term and high resolution isotope records, respectively. To enhance and to confirm the climate significance of Alpine isotope records, their spatial and temporal coverage needed to be substantially improved.

To deal with the difficulties arising when stable isotopes in the complicated terrain of the European Alps shall be studied and understood with the final goal to contribute to climate reconstruction the physical-experimental orientated part of the workpackage 3 of ALP-IMP (6.3.2.3.1.) was accompanied by a more mathematical-model orientated part (6.3.2.3.2) performed in cooperation with the regional climate modeling attempts of the project (WP-6)

6.3.2.3.1. Experimental-physical work on stable isotopes in Alpine ice cores

Major objectives of this workpage comprised the following, strongly interlinked tasks:

- to retrieve first isotope records from the Mt. Blanc area, which exceed the 100y time scale and thus supplement the existing Monte Rosa ice core records
- to extend the usable time scale of the Monte Rosa isotope records beyond some 100y through recovering and analysing a dedicated long term ice core
- to provide appropriate ice core chronologies, relating the records of the different drilling areas
- to identify periods of abrupt changes and long-term trends in isotope summer precipitation signature, representative for high elevation Alpine areas, and
- to provide recent and long term isotope records, assessed for their climate significance, as to be used, in related paleo- climate research

From the Mt. Blanc area, two new isotopes records could be achieved, comprising continuous profiles to bedrock with time resolutions ranging from sub-seasonal to the decadal scale. While the flank core at Col du Dome is characterized by similar glaciological conditions as the Monte Rosa core, the Dome de Gouter one, stands out by its ice divide position. The latter core is thus the only one obtained so far from the Alps, which is virtually not influenced by horizontal glacier flow. Detailed stratigraphical evaluations associated with the establishments of respective core chronologies revealed unexpected, strong changes of the net accumulation, experienced by the flank core through irregular up-stream glacier flow. This finding renders the usable time scale of this core at approximatly 200 years, during which abrupt changes in the isotope levels have to be attributed to glaciological, rather than to atmospheric signals. The Mt. Blanc flank core was found, therefore to be less suited for isotope-temperature reconstraction compared to its Mont Rosa counterparts of the Colle Gnifetti flank area. In contrast, no seasonal stratigraphy could be identified in the Mt. Blanc dome core, which was found to preserve only about 5 % of the total precipitation, and which show the least short term coherence with the recent isotope (air temperatur) changes, but a rather smooth long term isotope record on the centennial time scale.

At the Monte Rosa drill place a new core had been drilled and analyzed to bedrock, which was shown to actually offer the optimal glaciological characteristics to infer long term isotope records beyond 1000 years, approximately. This is due to the low surface accumulation rate of less than 15 cm water per year in conjunction with an inverse upstream effect, partly compensating for the annual layer thinning.

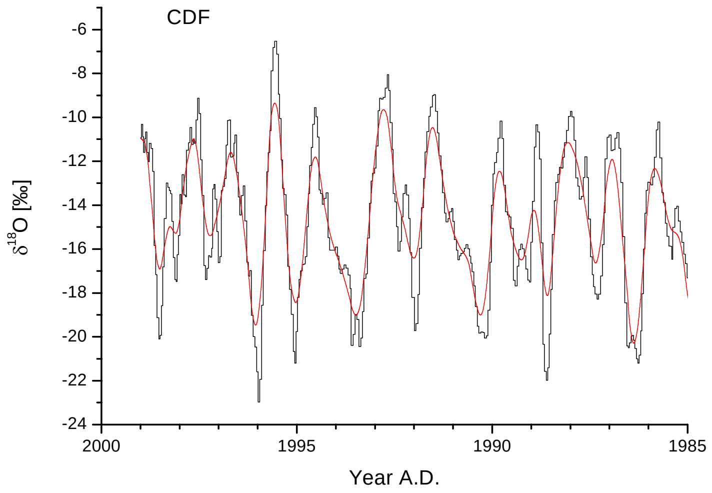


Figure 6.12.

Upper section of Mt.Blanc flank core showing regular seasonal cycles, with a substantial part of winter precipitation preserved. This feature is changed further downcore to variable winter snow amounts leading to correspondingly changing isotope levels

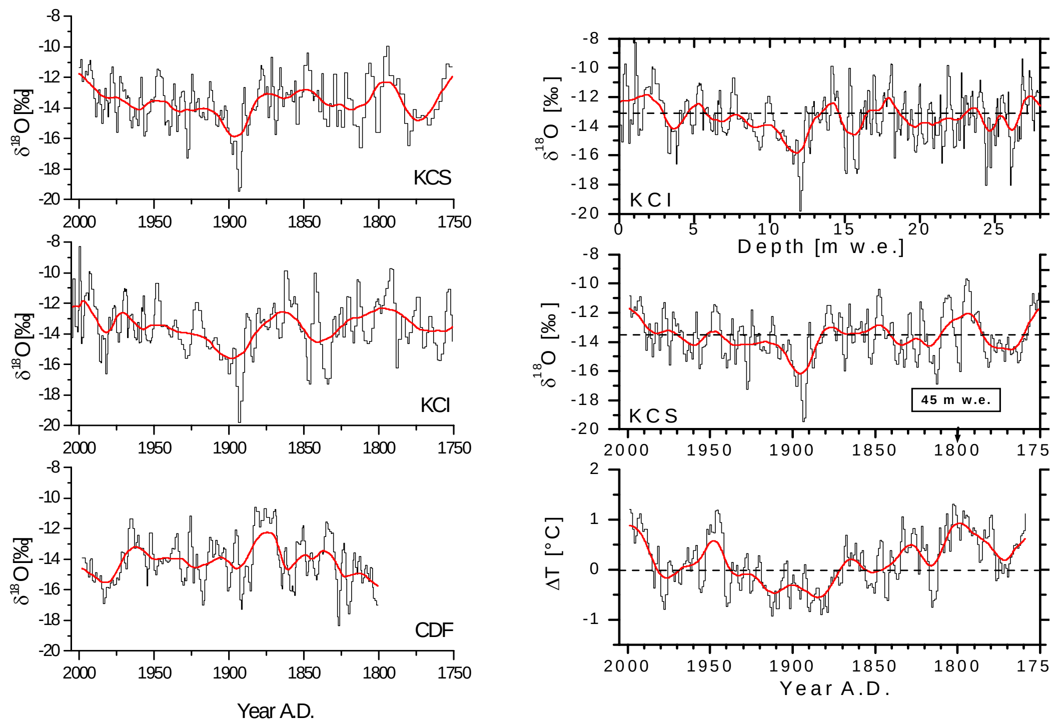
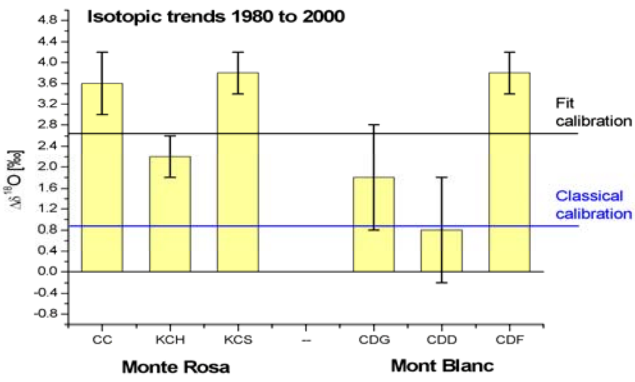


Figure 6.13. Comparison of flank cores from Monte Rosa (KCS&KCI) and Mt.Blanc (CDF) over the instrumental period(left). Note the reasonable good intra-site and temperature coherence of the Monte Rosa cores in contrast to the CDF core(right).

The climate significance of the entire set of ice core records appeared to be strongly influenced by glacier flow and (associated) depositional noise, which leads to the poor intersite coherences of relatively short temperature excursions. However, as exemplary illustrated in Fig. 6.14, it could be shown, that the very recent, strong warming trend is seen in all cores(i.e. independent of flow regime and seasonal fraction), but at different isotope sensitivities.

Figure 6.14. Isotope trends over the last 20 years seen in different ice cores. Horizontal lines indicate the isotope shifts, corresponding to the observed mean temperarure trend as based on the expected and on the specific ALP-IMP calibration, respectively



Based on the reasonably good correspondence between the Monte Rosa isotope records and the instrumental temperature time series (combined core high/low level restricted to growing season and weighted with precipitation) a experimental temperature/ isotope relationship could be established. Unexpectedly, this "calibration" differ by a factor of 2-3 from theoretical values or those established within WP3 for seasonal isotope/temperater changes (see Figure 6.15).

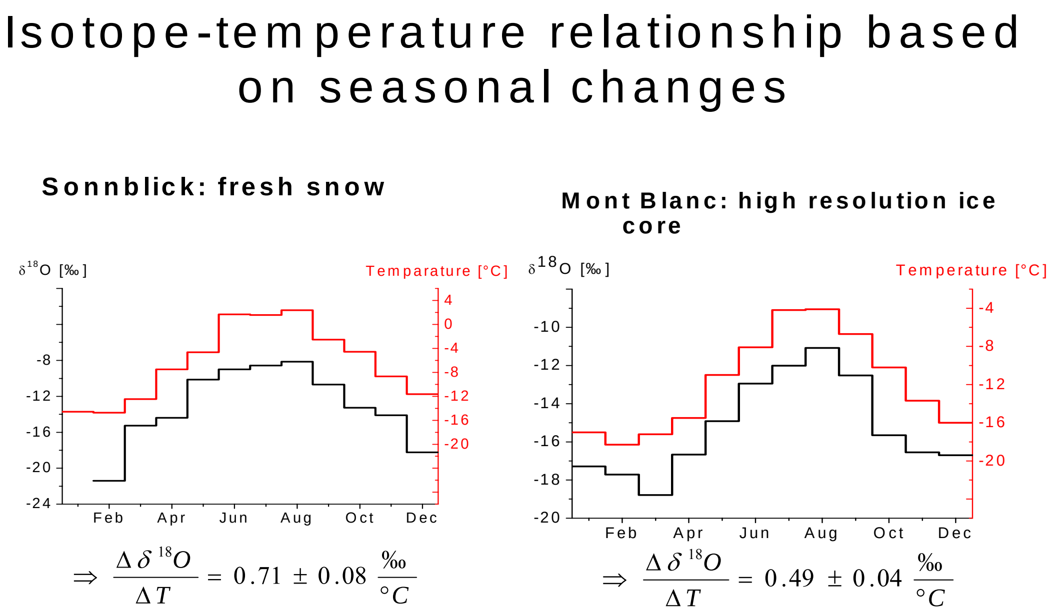


Figure 6.15. Composite values of monthly adjusted isotope values from new snow (left) and from a high resolution core from Mont Blanc area compared to respective mean seasonal temperature cycle. The derived isotope relationships lie clearly in the expected range.

According to extremely high isotope values seen in convective precipitation at the drill sites, the findings of higher isotope sensitivity in low accumulation cores appeared to be due to the preferential preservation of summer snow.

Overall comparisons of the instrumental era with respective isotope findings are thus not immediately possible in terms of absolute temperature deviations. This aspect needs still the incorporation of dedicated isotope circulation modelling (see following section 6.3.2.3.2). Nevertheless, the general trends and main feature of the instrumental temperature series are essentially reflected in the ice core records as well. This holds especially true for the general warming trend from the late 19th century to the beginning of the instrumental series in the mid 18th century. However, the isotope trend points to a less strong warming than that suggest by the temperature series.

For studying **long term trends** substantially extending the instrumental period one core at the Mt. Blanc and four cores at the Monte Rosa area are now available. In terms of the general isotope trends associated with the expected warm medieval times conflicting results are obtained, showing a slight warming trend only at the Mt. Blanc dome core. For details see outline in the WP 9 section. Because, such weak long term temperature changes are found to be easily counterbalanced or even reversed by systematic glacier flow effects, no immediate inter-site correspondence may be expected for cores drilled in different flow regimes.

Despite these clear glaciological constraints in interpreting the long term isotopic trends, a strong shift of isotope levels was found at all ALP-IMP cores in the near bedrock section. This feature is expected to correspond to a mean temperature decrease larger than 6 degree C, which would point to a remnant of ice of the last glacial stage. It is, however, not clear yet, if a continuous stratigraphical sequence is preserved throughout the complete Holocene.

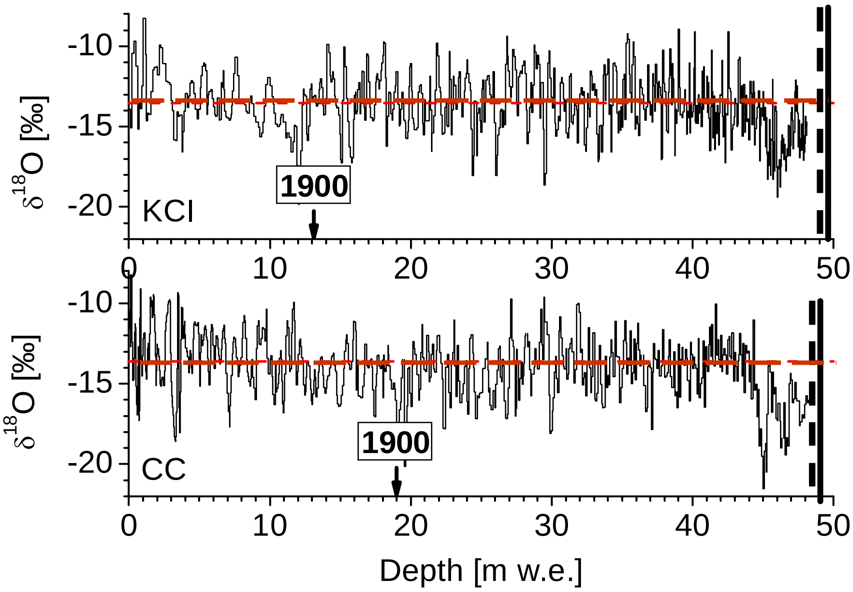


Figure 6.16. Isotope depth (in water equivalent) profiles down to bedrock of two Monte Rosa flank cores, with KCI denoting the newly drilled core, providing the relatively highest time resolution in the lower third section. Note the abrupt isotope decrease basically seen in all other cores as well.

6.3.2.3.2. Mesoscale modelling with an isotopic module in REMO

The LSCE, partner 7, performed several long-term simulations with the isotope module of the meso-scale model REMO. (IREMO in the following). As described in the 2005 ALP-IMP interim report, during our work with IREMO, we realized the need to realistically prescribe not only the meteorological boundary conditions for the time period simulated, i.e. the second half of the XXth century, but to formulate isotopic boundary conditions in a similarly realistic way. We found out that for a consistent high-resolution simulation with IREMO a two-step global and regional simulation is needed. First, the global IGCM (general circulation model fitted with water isotope diagnostics) ECHAM4 is run forced by ERA40 data in a nudged mode over the full period 1958-1998. Second, ECHAM4 output including the isotope fields were numerically processed to serve as boundary condition for the subsequent IREMO simulation over the same time span. We were obliged to apply this intricate procedure since all other techniques didn't guarantee consistency between isotope and meteorological fields. As we could show in the 2005 report and now squarely confirm, the chosen procedure successfully allows realistic IREMO simulations. Figure 6.17 illustrates this by comparing results from a single nudged simulation (IREMO directly forced by ERA40 meteorological fields and water isotopes boundary conditions estimated by an empirical relationship) with the double nudged approach described above.

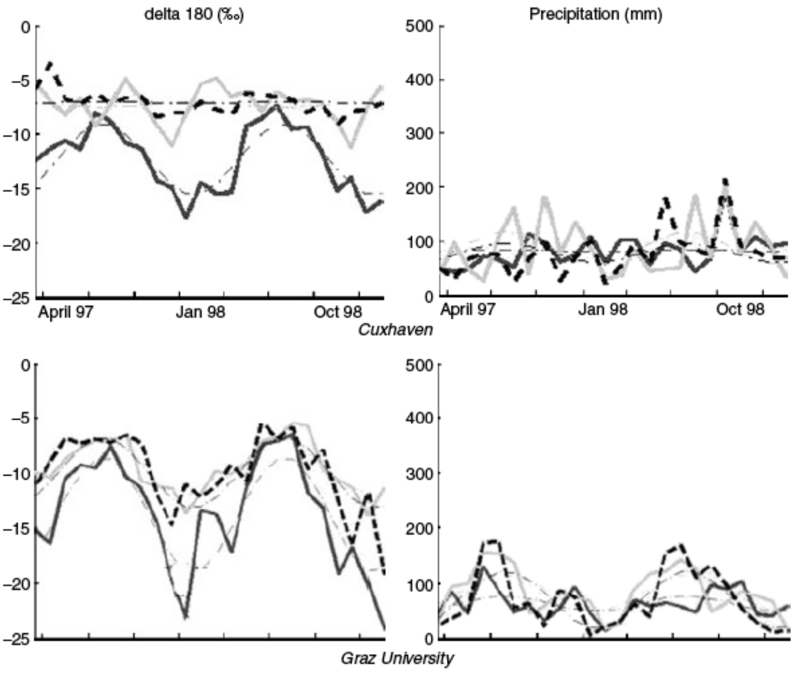


Figure 6.17: Comparison between observations at two stations (Cuxhaven, Germany, and Graz University, Austria) and IREMO results. IREMO is run once in a single nudged (dark grey line) and once in a double nudged mode (light grey). Observations are precipitation and water isotope concentrations (thick dashed line and dotted for a sinusoidal fit through the observations). Figure taken from project paper rev-54]

Due to these difficulties, the full IREMO simulation (deliverable 6/2) will be finished a couple of weeks after the project end and some of the presented following analysis are certainly preliminary based on a simulation from 1957-1987 in 0.5° resolution.

Figure 6.18 shows the annual and seasonal distribution of the simulated water isotope fields (for a complete analysis of the climatology of basically the same simulation with REMO see the report of partner 6, GKSS). Obviously IREMO captures quite precisely the impact of air mass lifting, forced condensation, cooling and isotopic depletion at orographic obstacles. A full analysis of the isotope climatology of a simulation run under climatological conditions can be found in [*Sturm, et al.*, 2005].

To investigate further the question how to interpret quantitatively interannual (or even long-term) variations of water isotopes as monitored in many different paleo archives, such as high Alpine ice cores analysed within the ALP-IMP project (Partner 3), we introduced a specific diagnostics into the IREMO model. The objective of this analysis was to separate local influences on the water isotopes from remote ones.

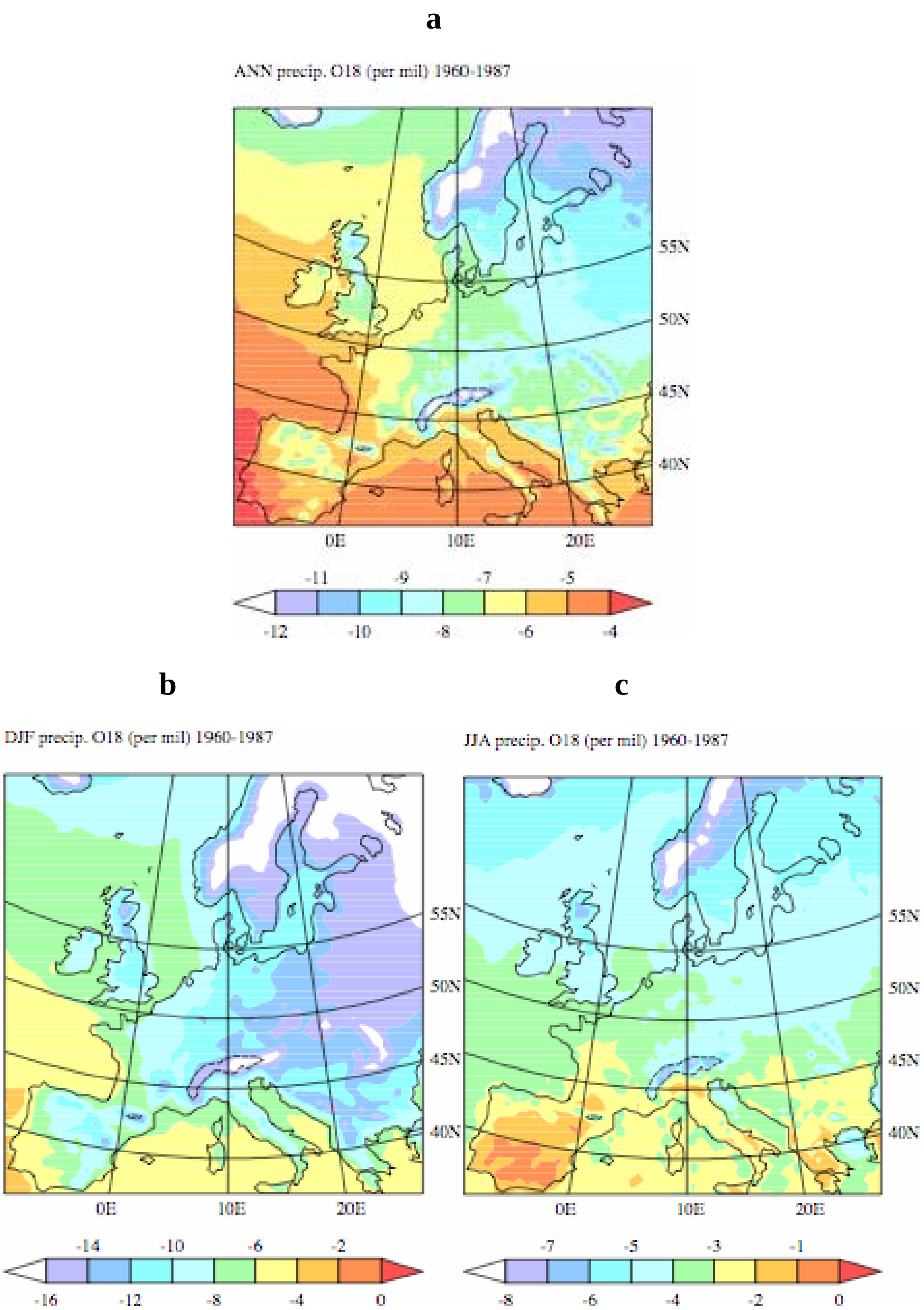


Figure 6.18. a-c Water isotopic composition of annual mean (a), DJF (b) and JJA (c) seasons for the period 1960-1987

Figure 6.19 shows IREMO results for two of the ALP-IMP drilling sites, Monte Rosa and Mont Blanc. Surprisingly both grid points (MR grid point has an altitude of 2160m and MB of 2050m) show quite different isotope-climate relationships. Among each other these two points show some similar interannual temperature variations ($TSURF_{MB}$ and $TSURF_{MR}$) with a correlation of r=0.88. However, the modelled isotope variations were marked by a high noise level (a strong resemblance between grid point series would indicate a well-defined regional isotope signal, i.e. a low noise level) and the correlation between the two isotope series decreases to r=0.55. Only at the Mont Blanc site local temperature explain some fraction of the corresponding isotope signal (r=0.28, whereas on the Monte Rosa correlation is near zero, r = 0.08).

These results are of course disappointing since the model even at a 0.5° resolution does not deliver en easy interpretation for the estimated empirical isotope/temperature relationships (see the report of Partner 3).

Two points seem important to us. For both sites, MB and MR, correlation to cloud temperatures is higher (MB/MR = 0.68/0.3 with slopes of 0.81/0.23‰/K, the lower slope at MR mainly due to the low correlation) and there are good reasons to speculate that on longer time scales (multi-decadal to centennial) surface and cloud temperatures are more tightly linked.

The second point has to do with the seasonality of our isotopic signal and the seasonally varying regimes in the Alps. Isotope/climate relationships have a strong seasonal component. We therefore introduced a specific diagnostic to compute the effective cloud condensation temperature. This diagnostic helps to test the hypothesis of comparably homogeneous vertical temperature variations which is often implied when relating isotope variations to surface temperatures.

The actual control on condensation processes and on the intensity of isotopic rainout is of course executed by cloud temperatures. For the winter period (DJF), in fact cloud condensation temperatures explain much better than any other quantity the simulated isotope variations (MB: r=0.91) which confirms the idea that the formation of winter time precipitation can be considered largely as a Rayleigh condensation process. Correlation of the isotopes with surface temperature is remarkably lower (MB: r=0.28) and points to a rather perturbing influence of boundary layer physics.

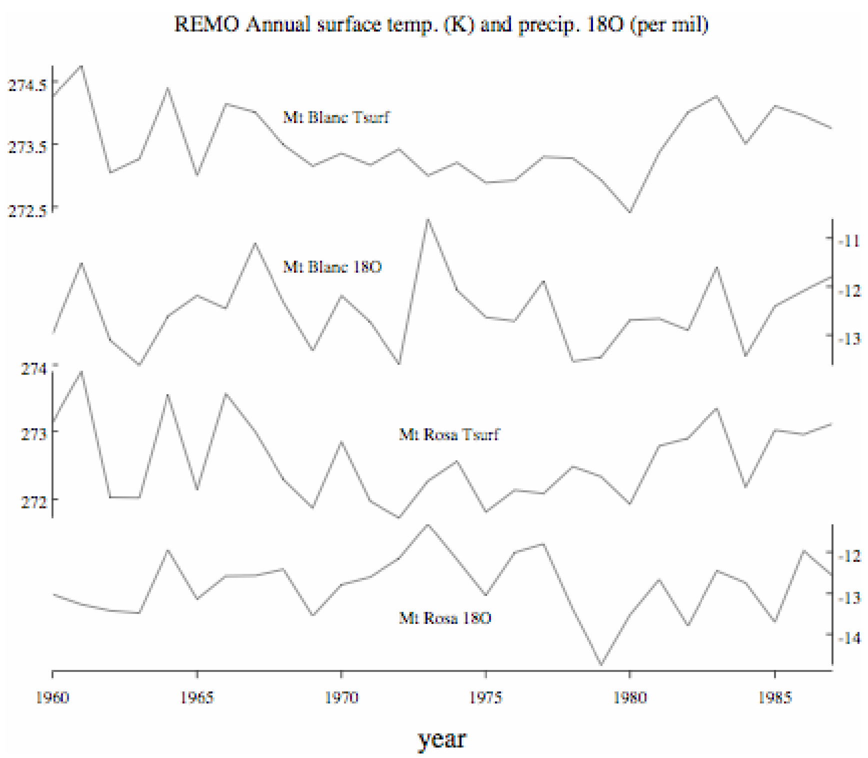


Figure 6.19. Results for T and $\delta^{18}O$ for the Mont Blanc and Monte Rosa gridpoint in the 1960-1987 IREMO simulation.

During summer time we are situated however in a regime dominated by convective activity (principally triggered by the orographic obstacle of the Alps). For the isotopes this regime is “amount effect” dominated which means that higher rainfall is associated with more depleted isotope values. In the original work of W. Dansgaard [*Dansgaard*, 1964] the explanation of the amount effect evokes the intensity of the vertical water vapour transport in convective systems responsible for the strength of rainout and of the isotopic depletion of the rising vapour mass. In tropical land regions, this amount effect is accompanied by an "artificial" anti-correlation between temperature and the water isotopes (temperature and precipitation are closely correlated since warmer conditions often are triggering the convective rainfall). However, in our case in the Alps, the cooling effect of rainfall seems to be dominating and, therefore, we find significant anti-correlation between surface temperature and precipitation. Consequently there is significant correlation between surface temperature and the water isotopes (cooling effect in an "amount effect" dominated regime) whereas there is no relation with the actual cloud condensation temperatures.

Table 6.2 summarizes the discussed relationships.

Table 6.2. Summer and winter time correlations between the water isotopic signal and different climate parameters in the 1957-1987 simulation of IREMO

Mont Blanc JJA			
	Surface T	Cloud Condensation T	Precipitation
$\delta^{18}O_{Precip}$	R=0.72 Slope=1.17‰/K	R=-0.08	R=-0.73 Slope=-1.91‰/(mm/d)
Mont Blanc DJF			
$\delta^{18}O_{Precip}$	R=0.28 Slope=0.34‰/K	R=0.92 Slope=0.68‰/K	R=0.41

.

What limits our analysis here? First, even in 0.5° resolution IREMO has certainly still a very limited resolution of the Alps. Better resoved orography and therefore higher condensation levels will most probably a) strengthen the influence of condensation temperatures on the isotopes and b) augment the fraction of precipitation as snow. The latter is less influenced by potential post-formation processes such as evaporation below the cloud base and fractionating evaporation from the soil. However, a trial of a 1/6° simulation was stopped and not further analysed due to intricate numerical problems.

6.3.2.4. **GLACIER RECORDS**

Apart from the accomplishment of all originally envisaged deliverables and aims of WP4, several additional studies could be performed. Some of them are still ongoing and the results will be published after the end of ALP-IMP. The first objective of WP4 was to create a "**dense and long term set of glacier variability data within the Greater Alpine Region (GAR)**". This objective was related to the deliverable of *a quality checked dataset of glacier variability within the GAR, including measurements of mass balance, front position, area and volume with associated changes, as well as historical / geomorphological evidences*. Before the project and with respect to the GAR, the database at the World Glacier Monitoring Service (WGMS) was neither complete, nor up-to-date nor able to store meta-information. Thanks to the close cooperation of the project partners within ALP-IMP, it was possible to fill most of the missing datasets on glacier fluctuation records within the GAR (Figure 6.20).

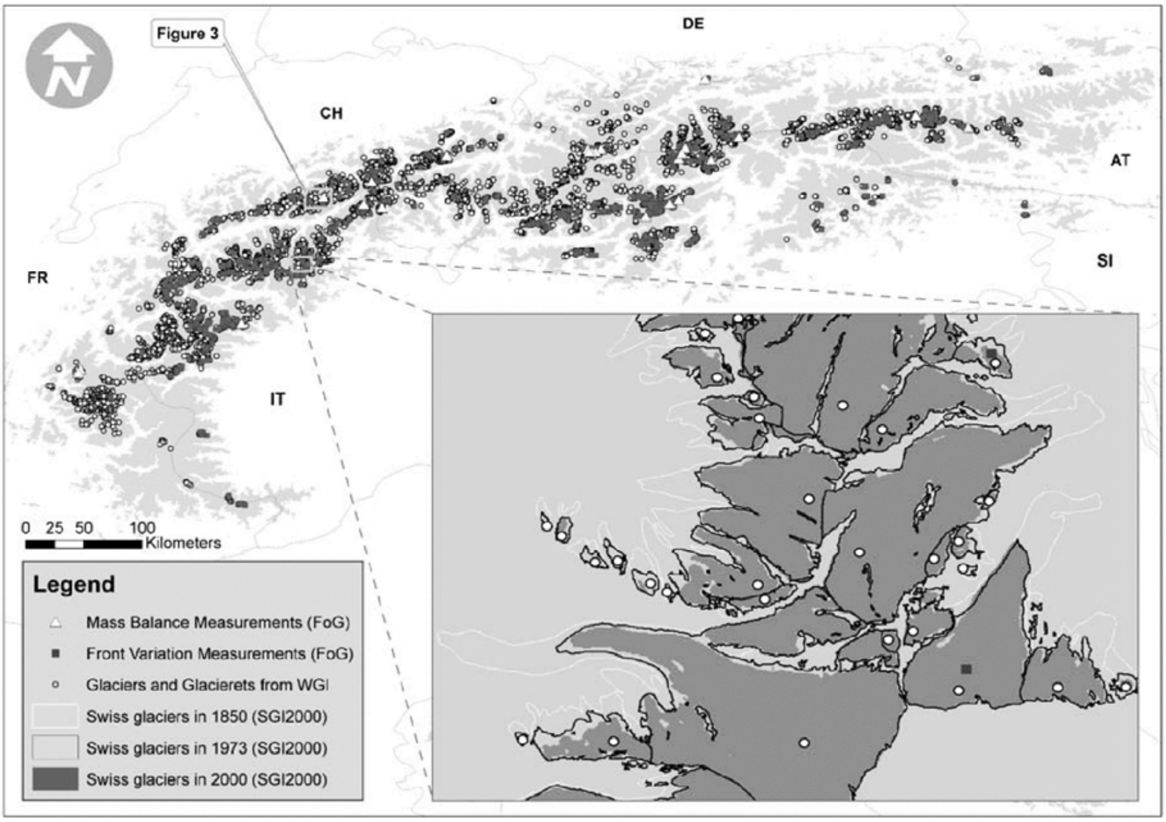


Figure 6.20. Geographical distribution of available glacier information in the Alps

Moreover, the database was completely revised and expanded, not only to allow storage of meta-information and reconstructed glacier fluctuation data but also to facilitate common GIS applications. Now a web-browser for information on available data sets has been installed at http://www.zamg.ac.at/ALP-IMP/member/alpimp_glacierdata.htm (Figure 6.21). Several in-situ measurements could be corrected, partly by a comparison with long-term (1973-1998/99) satellite-derived measurements (Kappeler, 2006). Overall, we achieved a "**uniform structure in terms of data quality**" which was another aim of WP4. The complete GAR glacier dataset plus description is now ready for use on the project home page and has been transferred to the existing dataset of WGMS and the World Data Center-A for Glaciology at NSIDC.

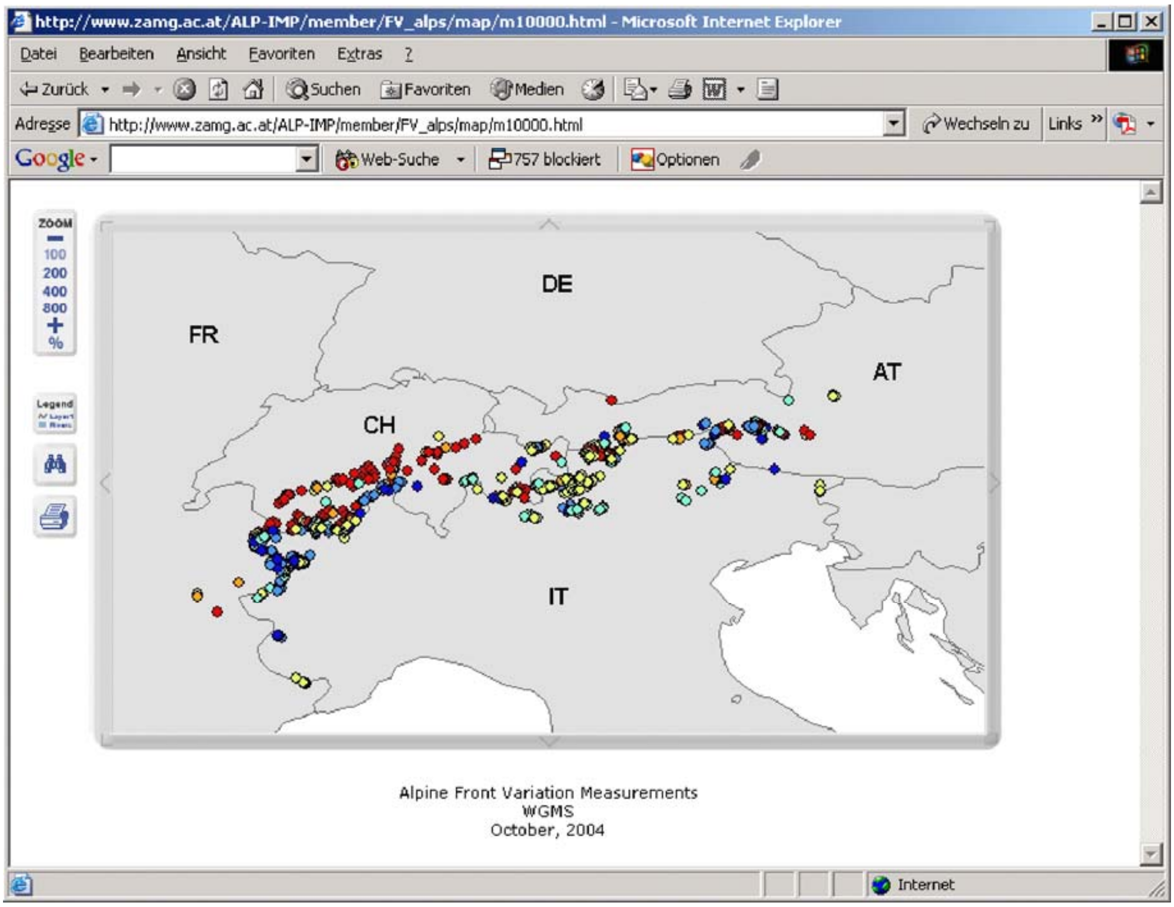


Figure 6.21. Online glacier meta-information browser

The 1D information on glacier fluctuations was supplemented by glacier outlines (2D inventory data) from 1850, 1973 (digitized maps) and 1998/99 (classified satellite imagery). While the latter data set is available through the GLIMS database at NSIDC, the two former are available through the new digital Atlas of Switzerland (http://www.atlasderschweiz.ch/). A regionally differentiated analysis of glacier changes between 1850 and 2000 have been published by Maisch et al. (2004) and a publication of individual glacier data and their changes with time for the same period is in preparation (to be published after the end of the project). All 2D data sets have already been used in several publications (e.g. Haeberli and Zumbühl, 2003; project paper nrev-65; Paul and Maisch, 2006) to visualize past and ongoing glacier changes (Figure 6.22), as well as for numerical modelling of climate change effects on current and future glacier mass balance and extent (project paper rev-31).

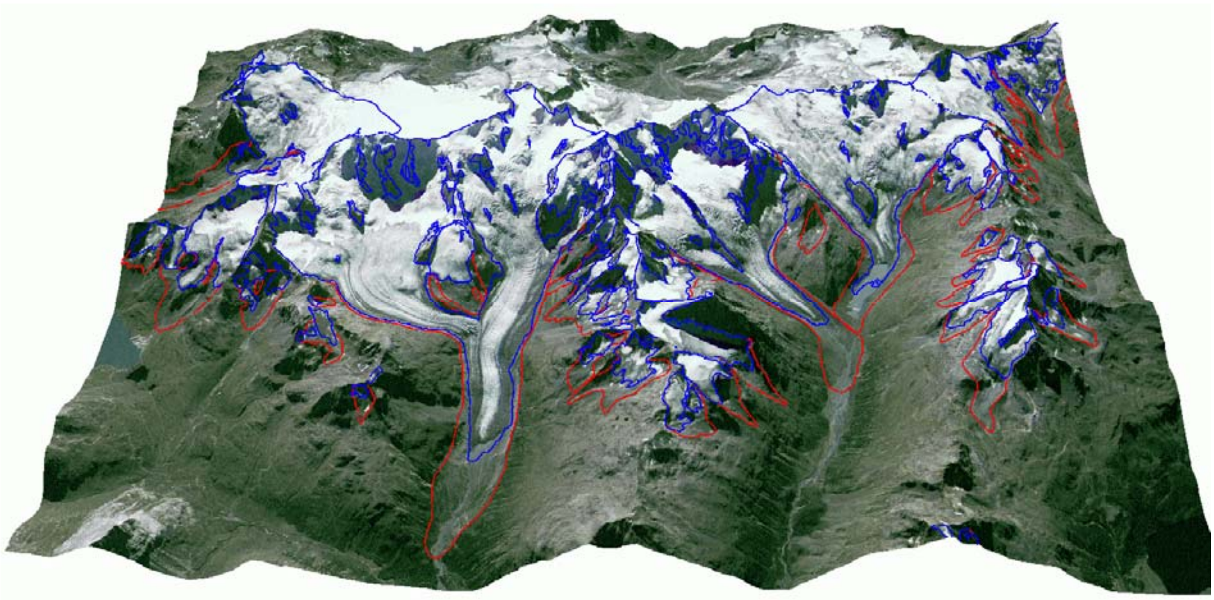


Figure 6.22. Synthetic oblique perspective view of the Bernina region with a satellite image from 1999 and glacier outlines from 1850 and 1973 draped over a DEM.

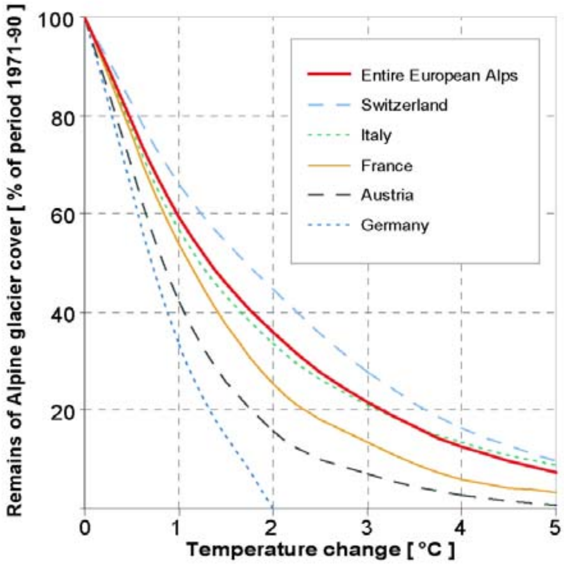
A second deliverable was the assessment of the "**representativity of glacier variability data within the GAR**". We performed this evaluation by incorporating all so far compiled data sets about glacier extent and change through time to obtain a GAR wide coherent data set of glacierisation in 1850, c. 1975 and 2000 (Table 6.3). This data set has then been used to determine the representativity of the fluctuation measurements (project papers th-01; rev-28).

Table 6.3. Outline statistics on glacier extent in Switzerland and in the Alps 1850 – 1970s - 2000

class	Switzerland (SGI2000)								Alps			
	1850		1973		2000		1850–1973*	1973–2000*	1970's		1850§	2000§
[km^2]	num.	area [km^2]	num.	area [km^2]	num.	area [km^2]	area change [%]	area change [%]	num.	area [km^2]	area [km^2]	area [km^2]
< 0.1	297	17.3	1022	40.1	164	3.6	-55.4	-64.6	1953	100.7	225.5	35.6
0.1–.5	715	181.3	673	153.9	448	60.3	-52.9	-45.6	2254	497.0	1055.0	270.4
0.5–1	249	172.5	151	104.1	131	63.5	-44.3	-29.1	430	299.8	538.0	212.6
1–5	253	524.4	157	296.0	141	217.1	-33.2	-17.9	425	862.3	1291.1	707.9
5–10	26	195.5	35	249.4	36	232.6	-19.7	-10.8	66	461.7	574.8	412.1
10–20	18	259.9	14	216.3	13	192.8	-14.8	-8.2	27	387.9	455.1	356.1
> 20	9	270.5	5	225.9	5	213.0	-12.3	-5.7	7	293.6	334.8	276.9
Total	1567	1621.4	2057	1285.7	938	982.9	-27.1	-16.1	5162	2902.9	4474.3	2271.6

A second objective was to perform "**climate impact study on glaciers (use of glaciers as key indicator of climate change)**". For this purpose we developed a suite of models with varying complexity, from simple statistical-empirical relations to fully distributed energy balance models (project papers rev-17, rev-27, rev-28, rev-29, rev-30). A strong focus was on the development of simple but robust models, that can be widely applied (i.e. for the entire GAR) and make efficient use of the climatic time series compiled within ALP-IMP. All models help to better quantify the expected changes with respect to the past and extend the available measurements in space and time. First studies have been performed on the impact of current climatic conditions on overall glacier change (project papers rev-08, rev-18) as well as an on the extrapolation of possible future glacier development according to various climate change scenarios (project papers rev-30, rev-31). Thereby, we were able to quantify that current rates of glacier wastage by far exceed the historical changes and that deglaciation of entire mountain ranges within the coming decades must be taken into account (Figures 6.23 and 6.24). Several further studies that utilize the data sets compiled by ALP-IMP and within WP4 are ongoing or in preparation (project papers rev-59, nrev-11).

a)



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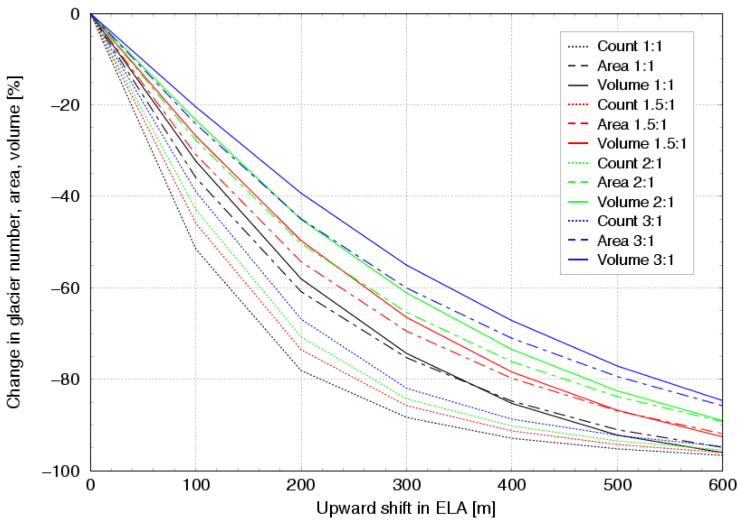

Figure 6.23 a) Modeled remains of Alpine glacierization as a consequence of a 1-5 °C warming of the 6-month summer temperature.
b) Modelled relative changes in glacier number, area and volume for six shifts of the ELA_0 and four different AAR_0 values.

A third aim of WP4 was to use "**glaciers as an integrated proxy for air temperature, precipitation, radiation, snow cover, atmospheric circulation and its representativity for GAR**". Apart from the use of the temperature and precipitation at the glacier equilibrium line in one of the models presented above (Figure 6.23a), we got an ongoing PhD project funded by the SNF. This project will investigate the usability of glaciers as a proxy for high-mountain precipitation from glacier specific tuning of a distributed mass balance model (project paper nrev-11). As detailed investigations of glacier specific accumulation have shown (Machguth et al., 2006), the amount of precipitation in high-mountain regions might have little correlation with elevation. The model will make efficient use of the compiled glacier fluctuation data in combination with remote sensing derived products (e.g. glacier albedo and outlines), thereby facilitating the strategy of the global terrestrial network for glaciers (GTN-G) within GCOS/ GTOS (Haeberli, 2006) for spatio-temporal extrapolation of observations made at Tier 2, 3 and 4 sites (mass balance, length change) with Tier 5 data (glacier inventories).

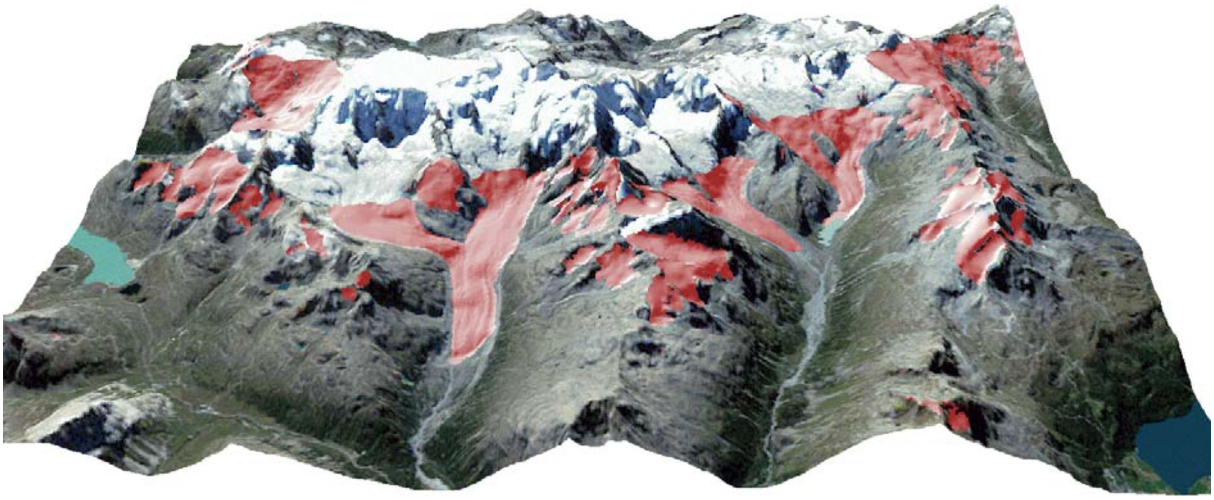

Figure 6.24. Visualisation of the modelled new glacier sizes in the Bernina group for an upward shift of the ELA_0 of 300 m. See Fig. 3 for comparison with the 1850-2000 glacier fluctuation.

In a joint study with COST action 719 and the MPI for Meteorology we developed a strategy to force distributed mass balance models with gridded meteorological data sets (project paper rev-17) as well as with output from regional climate models (project paper nrev-50). In an ongoing diploma thesis we reconstructed little ice age (about 1850) glacier surfaces and investigated the influence of a changing surface elevation on mass balance. Both studies will later be combined to force the mass balance model with the little ice age glacier geometry and the data sets compiled by ALP-IMP.

The results of WP4 have been communicated to the public at several workshops, meetings, national and international conferences as well as in several scientific journals (both refereed and non-refereed) and other media. Up to now, we presented the results of WP4 in more than 15 conference contributions (oral and poster) and published more than ten articles in refereed and non-refereed journals. Several more are in preparation and will follow after the end of the project.

6.3.2.5. **CONSISTENCY: OBSERVED VERSUS OBSERVED DATA**

The basic idea of WP-5 was to verify the instrumental climate database of the project in two ways. The first used the potential of having seven different climate parameters with long-term series in HISTALP allowing for inter-parameter comparisons in respect to their physical correctness. The second verified the leading three HISTALP parameters (temperature, pressure and precipitation), for which continental to global scale equivalent datasets exist, against those. In both cases, no a-priori "truth" was taken for granted; therefore the term "consistency" was preferred instead of "verification".

6.3.2.5.1. Internal consistency

Inter parameter comparisons for internal consistency testing were performed for the studies already published in project paper rev-20 and are currently in preparation more extensively for rev-45 and rev-47. The following few examples shall illustrate what we understand under internal consistency and for which parameters of the project's instrumental database and to what extent it is fulfilled.

For **air pressure**, different longterm evolutions could be detected for high-elevations versus low-elevations whereas the low elevation evolution has been highly uniform in the entire GAR. The similarities of the high-low pressure series and the respective temperature series hints at the potential of the GAR-pressure data to derive "thermometer-independent" temperature series for the lower 3.5 km of the atmosphere in the European Alps. A respective study (project paper rev-47) is in preparation. The results so far obtained (an example is shown in Figure 6.25) are going to fully confirm the directly measured temperature series in the region. This is a perfect example of physically consistent relations between two climate parameters. On the other hand it has a greater relevance than simply consistency testing – the derived "non thermometric" GAR-temperature series disprove an often heard argument claiming that global warming is merely an artefact of urban effects and other inhomogeneities in temperature series.

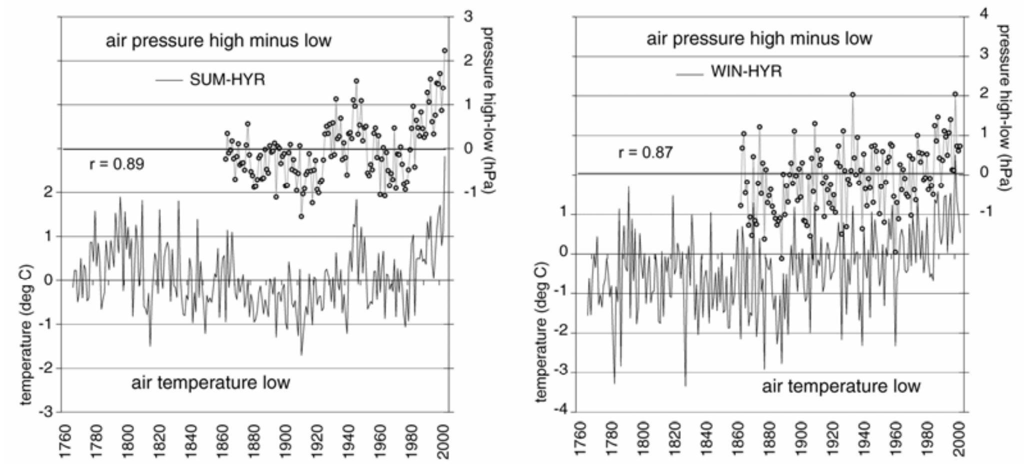

Figure 6.25. Difference series HIGH minus LOW of GAR air pressure for AMJJAS(top-left) and for ONDJFM (top-right) together with the respective low elevation mean air temperature (bottom)

Another example for internal consistency concerns a combination of three climate parameters: temperature, pressure and sunshine duration.

The example for subregion NW shown in the six graphs of Figure 6.26 stands for similar features in the other GAR-subregions. In the warm season temperature is obviously influence by sunshine duration (at high elevations) which seems to be forced by air pressure to a certain extent. In the cold season the similarity of the evolution of the three parameters is obvious as well. The mechanism behind has much to do with in situ forcing within the GAR together with large scale circulation changes (studied in WP-8). Some open questions remain, for example why the temperature-sunshine coupling is stronger for high elevation sunshine in the warm season and for low elevation sunshine in winter. Highly interesting is the decoupling of warm-season-temperature from air pressure in recent decades. This may be explained as a "detection signal" of anthropogenic forcing. On the other hand the ongoing similarity in the cold season tells another story.

The third example of internal consistency refers to the newly discovered and described (project papers nrev-2, rev-5, rev-20, rev-21) bipolarity of long-term precipitation NW versus NE of the Alpine chain. Figure 6.27 confirms the centennial wetting/drying trends by respective evolutions of the cloudiness series.

The shown examples are a selection from many, which generally attest to the inter-parameter and inter-regional consistency of the HISTALP series. Two respective more extensive studies on the consistency topic are currently going on and soon to be published (rev-46, rev-47).

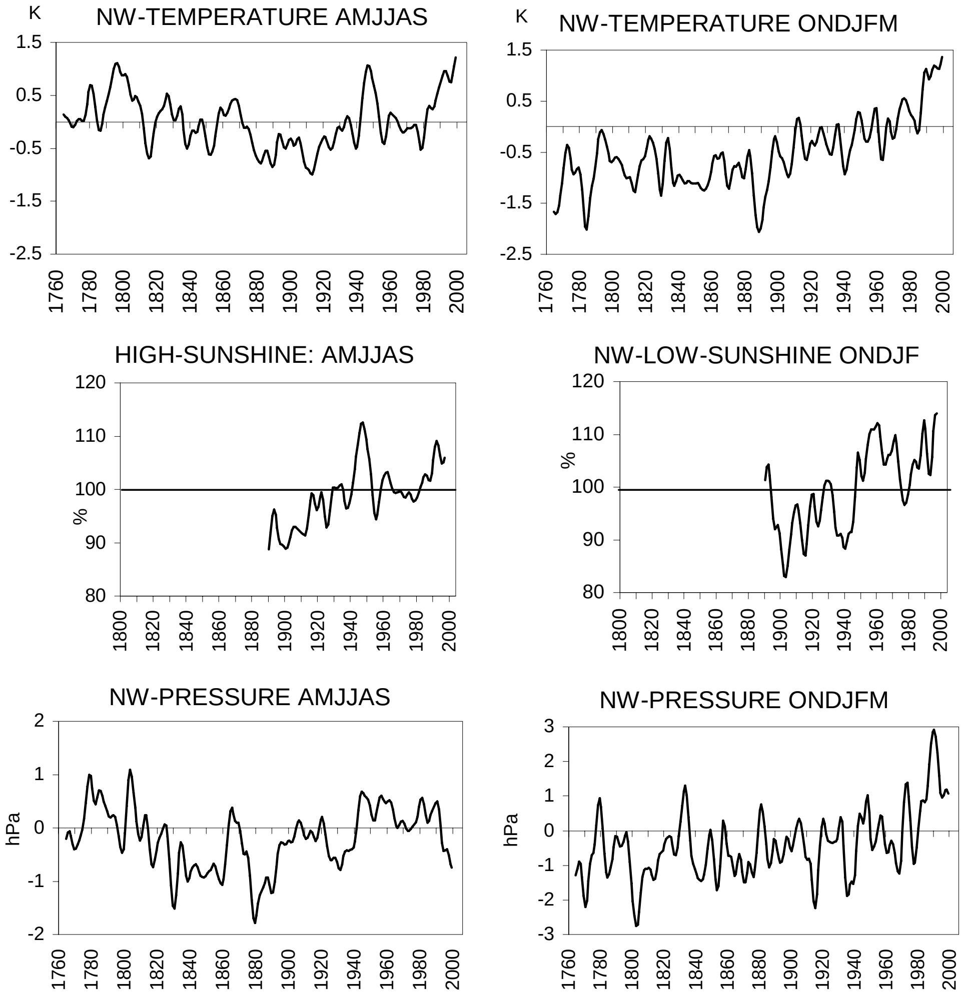

Figure 6.26. Longterm 10-years low pass filtered temperature, sunshine and pressure series for the summer- (left) and the winter-half-years (right) of GAR-subregion NW. All series are for low elevations, only the sunshine-AMJJAS-curve is for high elevations

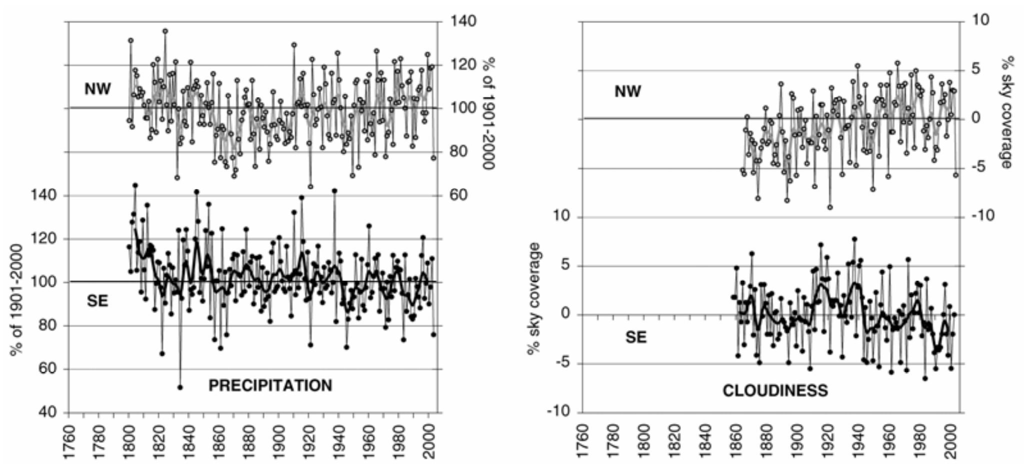

Figure 6.27. Left graph: annual precipitation series, right graph: annual cloudiness series GAR subregion NW (top) vs. SE (bottom. All values relative to the 1901-2000 averages

6.3.2.5.2. External consistency

The key project activities dealing with the intentions to study the consistency of GAR's instrumental series with large scale datasets are described in section 4 of project paper rev-43. Some 6.3.2.5.2 topics have been touched also by rev-20, rev-45 and nrev-16.

For the leading climate elements temperature and precipitation, correlation fields of the GAR coarse resolution subregional mean series with the CRU 0.5deg-lat-long gridded datasets (Mitchell and Jones, 2005: CRU TS 2.1 – temperature and CRU TS 2.1 – precipitation) have been calculated for all months, seasons and the year. Some of those spatial correlation patterns are shown by the seasonal maps in Figures 6.28 and 6.29 for winter and summer temperature and for precipitation.

GAR-low-elevation temperature (Figure 6.28.) correlates well with broader European temperatures throughout the year. Nevertheless there are some differences between the seasons – winter coherence has a prominent zonal character, which is not observed in summer. GAR high elevation temperature behaves slightly different – it is weaker correlated with the nearer surroundings of the Alps, whereas higher correlations exist with temperature fields in remote regions like Scandinavia and the Middle East. In general, GAR temperatures are quite strongly correlated with wide regions of Europe, more in winter, less in summer.

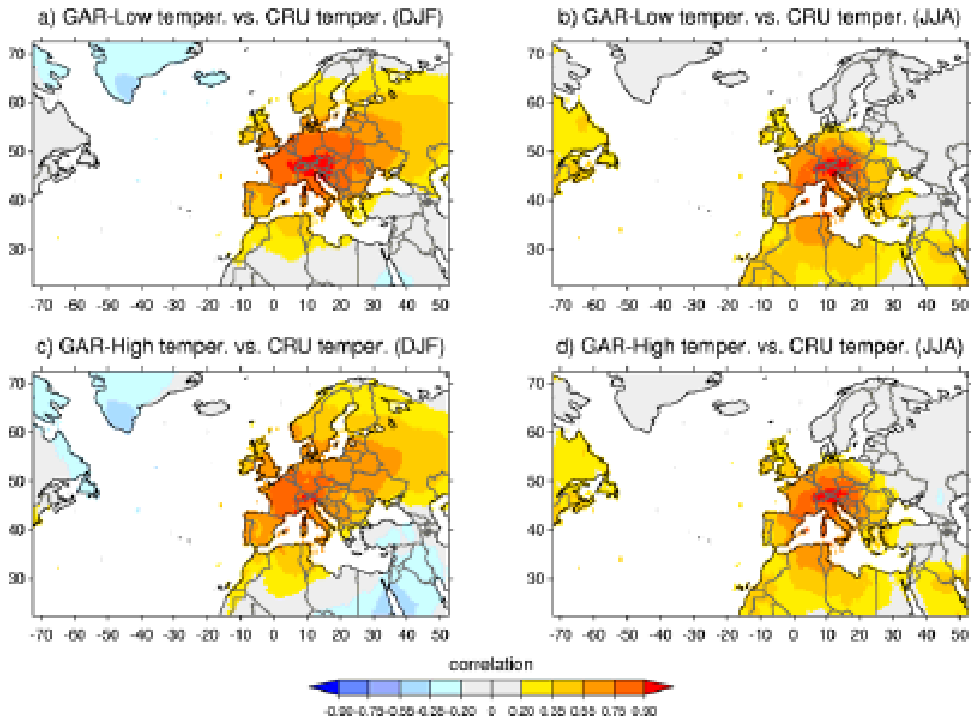

Figure 6.28. Correlation of the GAR temperature interannual variability with the wider European–North Atlantic land temperature (CRU TS 2.1 - temperature). Left: winter, right: summer, top: GAR-low-elevation, bottom: GAR high elevation

The correlation with of the GAR- and wider European precipitation fields (Figure 6.29.) is less strong than for temperature, though there are some associations that extend across Europe, especially in winter. As to be expected from the GAR-internal regionalization (WP-1), the four GAR subregions are linked to different parts of Europe. The sharp divide of the Alpine chain which exists in the GAR is part of a larger scale European border between Mediterranean and Atlantic influences. But also the meridional climate divide in the GAR near 13deg E continues to the north and to the south into larger parts of Europe. In general, winter precipitation is correlated with larger regions of Europe than the more convective and local summer precipitation. The broadest area related to GAR-precipitation exists for GAR-NW. These are related with the precipitation in a broad area of northern continental Europe from France to Poland.

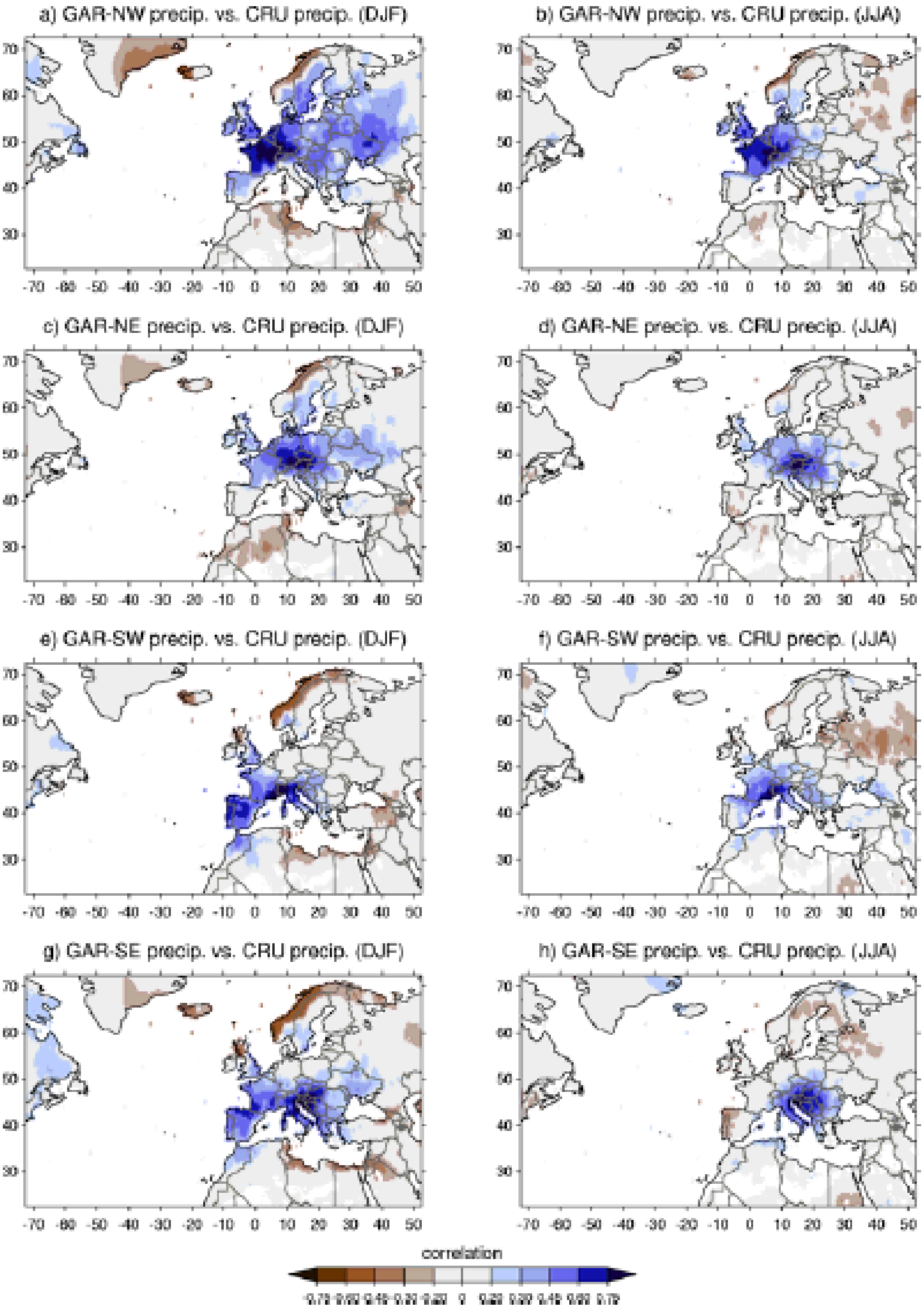

Figure 6.29. Correlation of the GAR subregional precipitation interannual variability with the wider European–North Atlantic land precipitation (CRU TS 2.1-precipitation). Left: winter, right: summer, top: GAR-low-elevation, bottom: GAR high elevation

The highest correlation of any GAR-climate parameter exists for air pressure. Spatial decorrelation is extremely flat – correlation of two pressure series at a distance of 1000 km typically is higher than 0.8. The GAR low-elevation pressure fields are also in very good accordance to the existing European scale monthly MSLP-fields of project EMULATE (Ansell et al., 2006). These EMSLP 1850-2003 fields were intensively used for WP-8 to study the influence of atmospheric circulation on climate variability in the GAR.

The GAR high-elevation pressure subset (consisting of the mountain observatories above 2000m asl) shows a particularly different behaviour. High-elevation pressure increased significantly stronger during the past 120 years than low elevation GAR as well as EMULATE pressure. This is currently used by a WP-8 study in preparation to be published soon as project paper rev-47 to calculate “non thermometric temperature series” for Alpine air columns between high elevation observatories and their low elevation base-stations.

For the other climate parameters of HISTALP, sunshine duration, cloudiness, vapour pressure and relative humidity, no equivalent long-term large scale datasets exist currently. Therefore the external consistency of the respective GAR series could not be verified and studied. Figure 6.30 (project paper rev-20) shows spatial decorrelation of these parameters at the example of GAR subregion NE. Decorrelation varies quite differently from parameter to parameter and from season to season. For sunshine and relative humidity it is stronger in winter than in summer, for cloudiness there is no significant seasonal cycle and vapour pressure de-correlates more quickly in summer than in winter. The fact, that some of the climate fields show significant de-correlation already within a relatively small GAR-subregion underlines the importance of the currently existing deficit of not having dense and long-term gridded fields for the actinic and the moisture components of the climate system at continental or global scales. HISTALP could serve as an example respective data rescuing activities to fill that gap of the current state of the art.

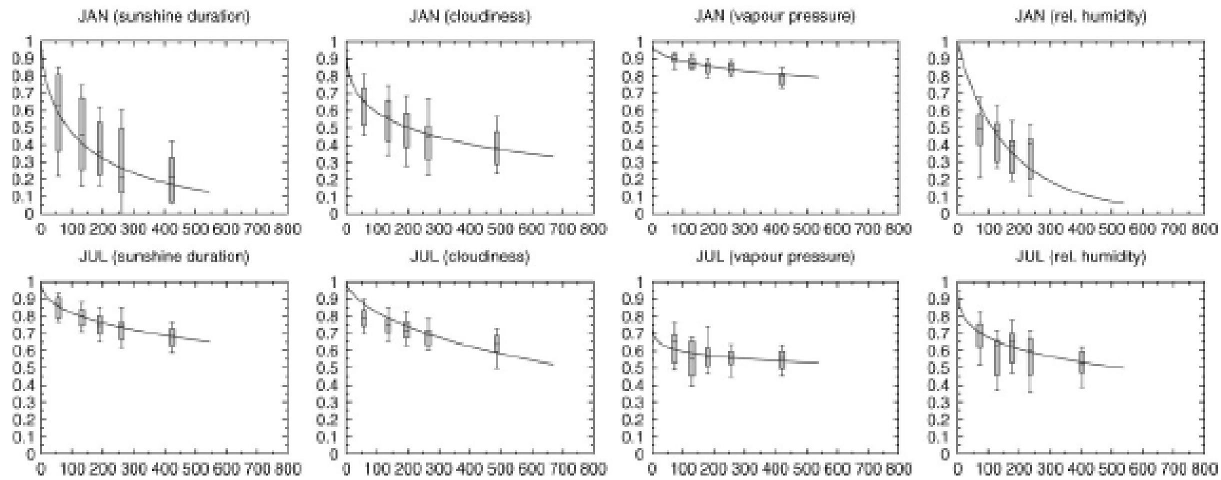

Figure 6.30. Spatial inter-station de-correlation in January and July within GAR-CRS-NE for the four climate parameters having no systematic continental or global scale lon-gterm comparative fields. Vertical axis: Spearman’s correlation coefficient, horizontal axis: interstation distance in km, boxes: 25, 50 and 75% quantiles, lines: exponential decorrelation fits

6.3.2.6. **CONSISTENCY OBSERVED VERSUS SIMULATED DATA**

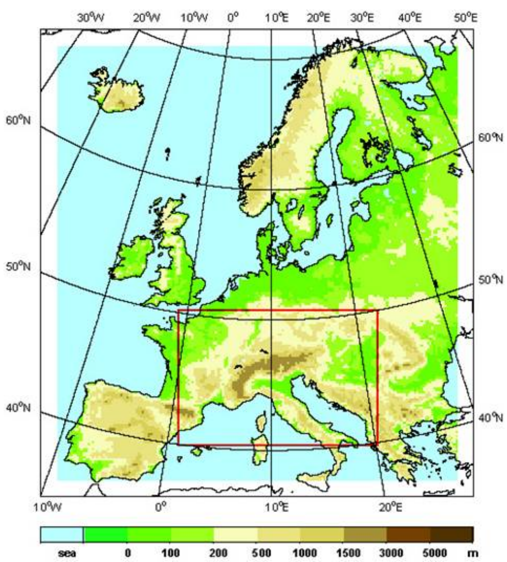

Figure 6.31. The model domain of the REMO simulation and topography of REMO with a resolution of 1/6 deg. Area analysed in this study in red rectangle.

At the GKSS (partner 3) a high-resolution regional simulation has been performed with the regional model REMO (Jacob and Podzun 1997) over the whole of Europe for the period 1958 to 1998 (Fig. 1). The simulation with a resolution of 1/6 deg (about 17 km) on 20 vertical levels is driven by the 1.125 deg resolution ERA40 reanalysis. The extension of the existing 0.5 deg REMO simulation driven by the NCEP/NCAR reanalysis (deliverable 6/1) was not necessary as the ERA40 reanalysis became available, which has a resolution twice as fine as NCEP/NCAR. Therefore, the double nesting with the 0.5 deg simulation was not required. After the completion of the 1/6 deg simulation (deliverable 6/2) in May 2004 it became evident that the solar constant in the simulation was reduced by mistake in October 1989 causing a drastic temperature drop. Therefore, the period 1989 to 1998 of the simulation was repeated and completed in May 2005.

To assess the consistency of simulated and observed data (deliverable 6/3) the REMO simulation was compared to different observational datasets for the two metre (2m) temperature and the precipitation over the Greater Alpine Region (GAR). For 2m temperature the question of whether REMO adds value to the coarser resolution driving ERA40 reanalysis was also addressed to assess the profit of a potential reconstruction of 2m temperature using REMO instead of ERA (deliverable 7/3). Therefore, ERA temperature was also validated.

The validation of 2m temperature performed at the GKSS for the period 1958 to 1998 is based dominantly on the HISTALP monthly mean temperature dataset (project paper rev-20), which consists of a station dataset containing 131 stations and two gridded anomaly datasets of 1 deg resolution, one derived from low- and one from high-elevation stations.

In the first step, we used the HISTALP gridded anomaly datasets, together with the gridded temperature dataset CRU TS 2.0 (Mitchell and Jones, 2005) of the Climatic Research Unit (CRU) with a resolution of 0.5 deg. Correlation and bias between both REMO and ERA and the observed datasets were calculated for each month and grid box separately. A regridding of simulations and observations to resolutions of 1/6, 1/2, 1, 2 and 3 deg allows for a scale-dependent analysis which shows that for both REMO and ERA the correlations with the datasets averaged over the whole Alpine area increase with spatial scale.

As the HISTALP gridded temperature dataset consists of anomalies in contrast to the station dataset consisting of absolute values and as the mixture of gridded and station data makes an overall conclusion difficult, as it is difficult to separate out whether differences are due to different regions, or to the interpolation of the gridded datasets. Therefore, we focused the further analysis on station datasets. In addition to the HISTALP station dataset we used for the comparison another station dataset consisting of 59 Austrian and Swiss stations with daily data (ZMdaily and ZMmonthly). The stations were compared to the corresponding grid box of REMO and ERA, respectively.

The results of the comparison were averaged over the subregions West, East, South, Po Plain, Central Alpine Low Level and High Level (Figure 6.32) defined by Böhm et al. (2001). The temporal variability, as quantified by correlation, is well represented by both ERA and REMO. However, both models show problems with the bias and are too warm during the whole year except in high elevations. In REMO the bias is largest in summer and reaches 3 K in subregions Po Plain and East, which are known to experience a problem with summer drying in a number of regional models (e.g. Hagemann et al. 2002; Christensen et al. 1997; Noguer et al. 1998; Vidale et al. 2003). Initial analysis suggests that this may be due to an underestimation of cloud cover in REMO. In winter the REMO bias is negligible except for the high-elevation stations, where it is highly negative (-3.5 K) and is probably caused by elevation differences resulting from the comparison of grid box data with station data. The large winter bias for high-elevation stations was also found for ERA.

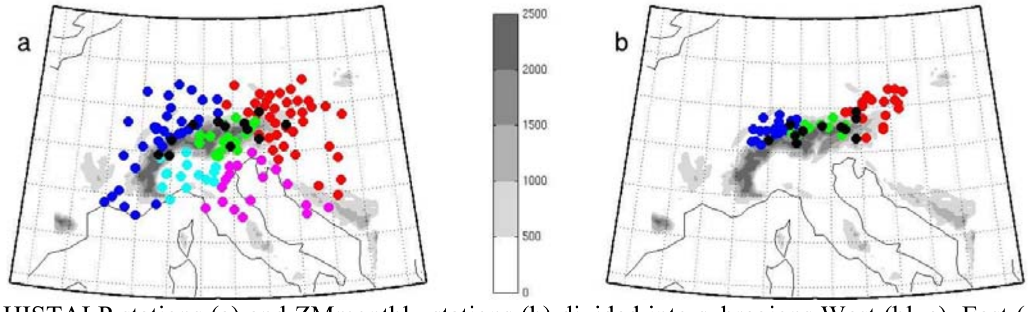

Figure 6.32. HISTALP stations (a) and ZMmonthly stations (b) divided into subregions West (blue), East (red), South (magenta), Po Plain (cyan), Central Alpine Low Level (green) and High Level (black), underlying orography in meter above mean sea level.

To answer the question of whether the high-resolution REMO simulation shows added value compared to the ERA40 reanalysis, the reduction of error was calculated (Figure 6.33). Negative values indicate that REMO is worse than ERA, zero denotes the same performance and positive values indicate the magnitude of improvement of REMO. The results based on the two different datasets vary between the regions and seasons and show a dependence on the selection of validation stations. Also the comparison of REMO and ERA with the daily dataset ZMdaily does not show an added value of REMO, even though one may expect more added value in the performance of the high-resolution regional model compared to a coarser resolution on a daily timescale because spatially small-scale phenomena, which take place on small temporal scales, are simulated better with a higher resolution. Therefore, our analysis shows that despite the very high resolution it is difficult for REMO to represent Alpine temperature better than the ERA40 reanalysis for which temperature is one of the input variables. The absence of a clear added value of a high-resolution simulation compared to a simulation with coarser resolution is supported by emerging studies in other regions (Roads et al. 2003; Duffy et al. 2006; Seth et al. 2006).

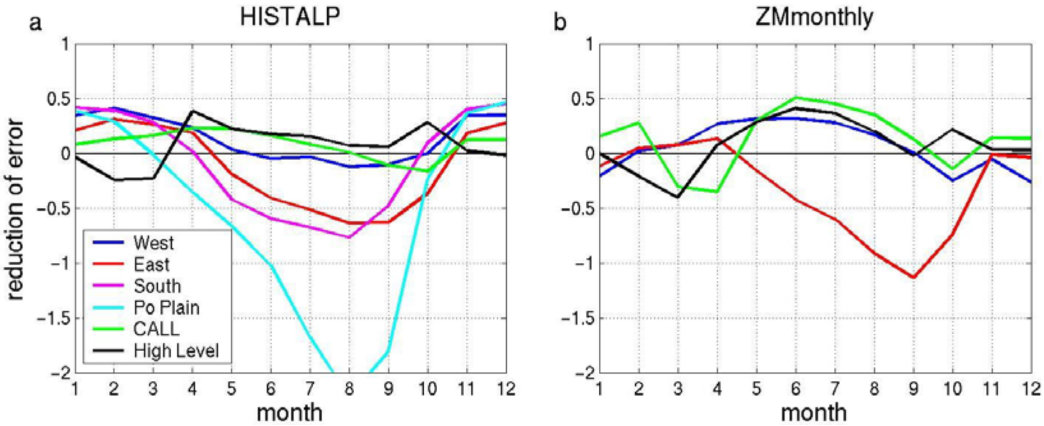

Figure 6.33. Annual cycles of the reduction of error of temperature for HISTALP (a) and ZMmonthly (b) averaged over the subregions.

An added value of regional model simulations is expected on smaller spatial scales (Feser 2006). Therefore, three different approaches of scale separation were applied, namely a kriging filter, an EOF decomposition and a two-dimensional spectral filter (Feser and von Storch, 2005). However, none of these methods was able to successfully separate the spatial scales, so the added value on small spatial scales could not be assessed.

The evaluation of monthly precipitation sums over the GAR simulated by REMO has been undertaken at ZAMG (partner 1). The evaluation resides essentially on a gridded analysis of the ETHZ (Eidgenössische Technische Hochschule Zürich, Frei et al. 1998) high resolution rain gauge data interpolated to the REMO grid and to some extent also on the HISTALP precipitation data set with a monthly resolution. The hourly REMO and daily ETHZ precipitation sums were added up to monthly sums. The time period considered begins with January 1971 and ends with November 1999.

The general spatial distribution of long term mean yearly precipitation sums is simulated with moderate success including features of up- and downwind effects of the topography on the precipitation distribution. The common spatial variance of the long term mean yearly precipitation sums between ETHZ and REMO is 25% (Figure 6.34). At the level of individual grid points REMO is not well able to reproduce long term yearly and monthly precipitation sums. A few specific areas can be identified, where the model is unable to come reasonably close to the observed absolute precipitation sums. The topographical effects on the precipitation sums are exaggerated, which means that the precipitation of upwind areas is overestimated and of downwind areas is underestimated. The temporal succession of the seasonal spatial precipitation patterns are largely reproduced by the model.

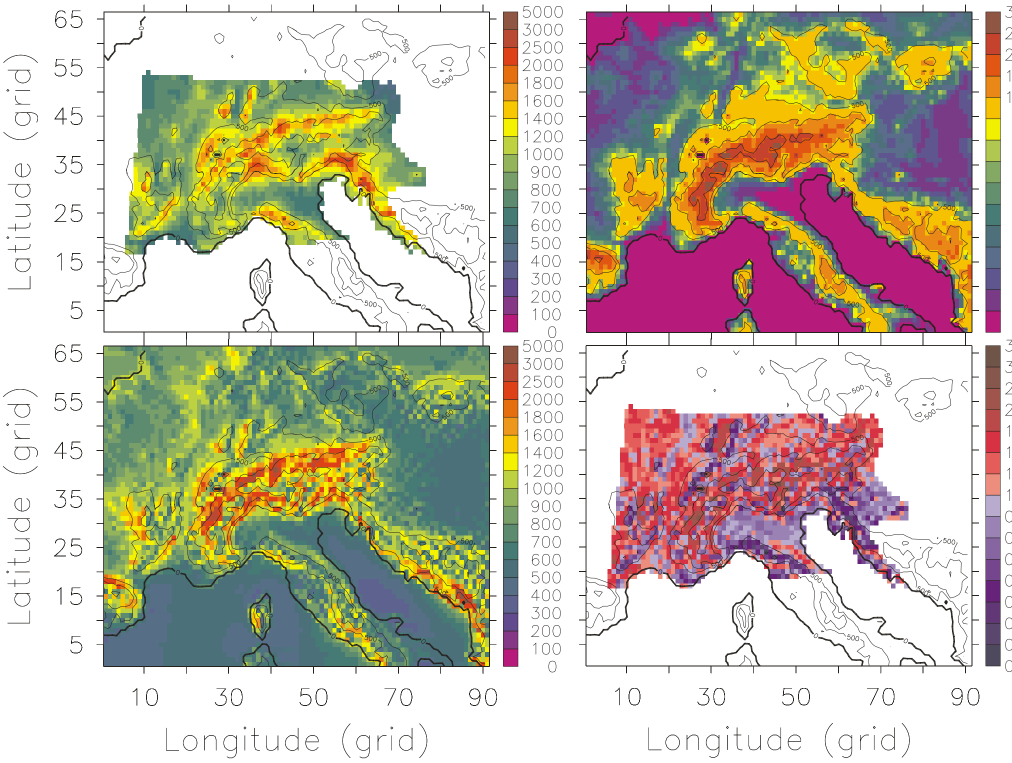

Figure 6.34. Distribution of the ETHZ mean yearly precipitation (mm/year, upper left), REMO mean yearly precipitation (mm/year, lower left), the model topography (geopotential in m, upper right) and the ratio REMO/ETHZ (lower right). Time ranges from 1971 to 1999.

There is a general desiccation of the model atmosphere to be observed over the simulation period from 1971 – 1999. This general trend towards lower precipitation sums produces a bias on most of the precipitation trends. Apart from this long term bias the spatial distribution of linear trends of the mean yearly precipitation sums is fairly well described by the model. The spatial distribution of the cold season linear trends is also captured by the model to large extent. The spatial distribution of the warm season linear trends is captured by the model only to a minor extent. The same is valid for the extreme precipitation sums in the 10% and 90% percentile ranges. The model reproduces general time - space variance, as summarised by the EOFs, quite well.

The results of this study are evidence that for a number of above mentioned features of the precipitation fields REMO can serve as a physically consistent link between the large scale forcing and the local scale precipitation variability.

6.3.2.7. INTERNAL CLIMATE VARIABILITY IN THE GAR

6.3.2.7.1 Descriptive part focusing on climate variability patterns in the complex terrain of the greater Alpine region.

The climate variability patterns in the complex terrain of the GAR have been intensively analyzed already and described in the project papers rev-2, rev-9, rev-11, rev-19, section 6 of rev-20, rev-21, rev-26, nrev-2, nrev-3, nrev-16, nrev-31, nrev-32, nrev-35, nrev-62, nrev-63 and by three project papers currently in work (rev-45, rev-46, rev-47). The principal internal pattern of high-frequency climate variability is expressed by the five subregions described in 6.3.2.1 (compare the map there) as “coarse resolution subregions” (CRSs). The respective regionalization is based on rotated PCAs and focuses more on interannual/seasonal/monthly variability and less on decadal scale and longer features.

In regard to low frequency variability, decadal scale evolutions resulted to be rather similar for the entire GAR for **temperature** (Figure 6.35). It should be stressed that this has not been a matter of fact before the first project results emerged. Especially the non existing difference between high and low elevations is of special interest as well as the identical trends between rural and urban sites. The former deviates to what is expected by some regional scale model runs to the end of 21st century (showing a stronger warming), the latter tells that correct homogenization allows for eliminating the urban bias from temperature time series (which sometimes is used as an argument against the reality of global warming).

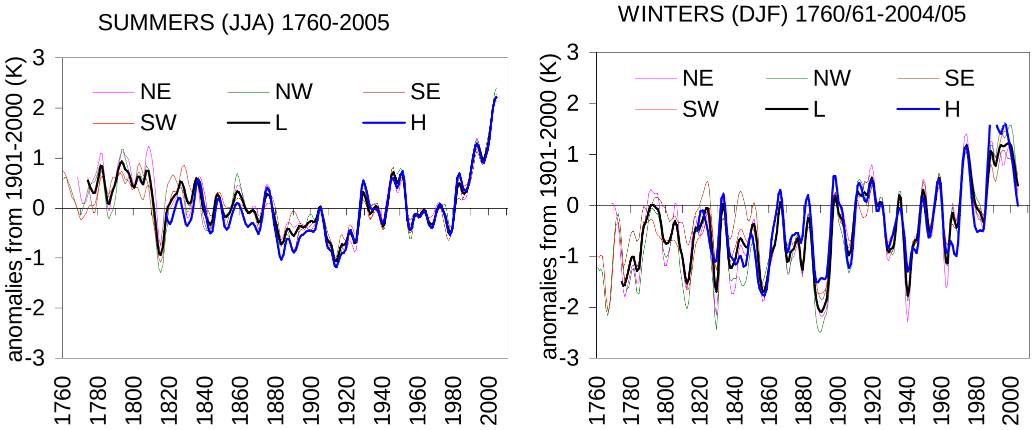

Figure 6.35. Decadal scale variability of summer (left) and winter air temperature (right) in the coarse resolution subregions. Shown are 10-years lowpass filtered curves

GAR's **air pressure** series are characterized by a high degree of similarity among the low elevation subregions and a striking difference between low- and high elevations. This has been discussed already in section 6.3.2.5.1. Figure 6.36 shows the effect through a comparison of the annual mean over all low-elevation series and the mean of the high elevation observatories above 2000m.

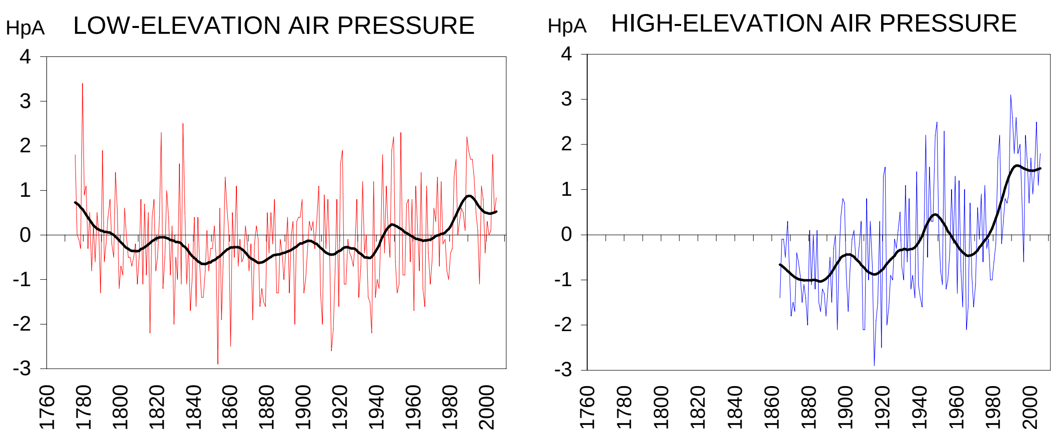

Figure 6.36. GAR annual mean air pressure series, averaged over all low elevation (left, 1775-2005) and all high elevation sites (1864-2005). Single years and 30-years lowpass, anomalies to 20th century average

Precipitation shows the most outstanding regional trend differences of all climate elements at decadal to centennial scale. Particularly between the NW versus the SE subgroup – obviously caused by the obstacle of alpine chain – the trends of the last 150 years even show opposite sign with a 10% increase in the NW and a 10% decrease in the SE of the GAR. The annual "Alpine precipitation dipole" has been discussed and shown already (section 6.3.2.5.1), the two graphs in Figure 6.37 display the most antagonistic pair of seasonal precipitation – NW-winter vs. SE-autumn. Both show very long-term stable wetting/drying trends over 120/180 years, but also both long-term trends have abruptly changed into their opposite in recent times. Winter precipitation is decreasing again since 1980, autumn precipitation increasing in the SE since 1990.

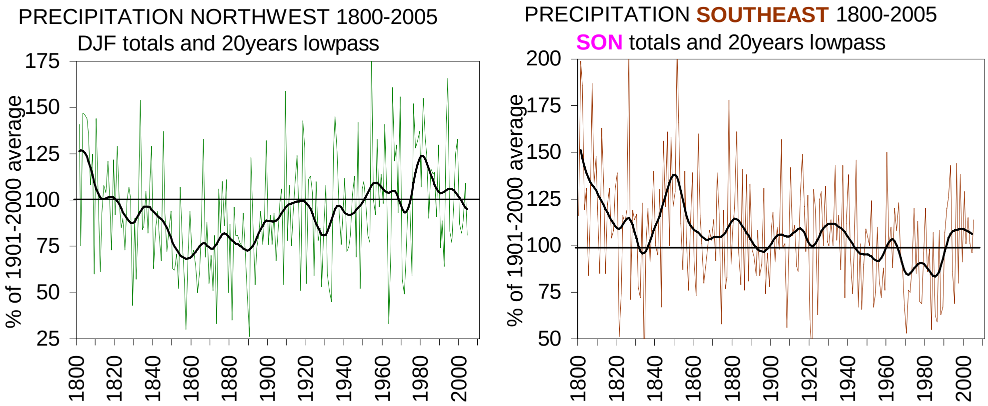

Figure 6.37. Seasonal precipitation evolution 1800 to 2005 in NW-winters (left) and SE-autumns (right) of the GAR

From the **actinic component** the most interesting findings are the different 20th century evolutions of high versus low elevation annual **sunshine totals** (Table 6.4, Figure 6.38). There was a clear trend of significant "brightening" at high elevations (2000-3500m altitude) in both sections of the 20th century whereas the low elevations (below 1000m asl.) show weaker to not significant sunshine trends. **Cloudiness** trends confirm the decadal scale sunshine features, at centennial scale there are some yet not well understood misfits or perhaps some remaining homogeneity problems – most possibly assignable rather to the (subjectively estimated) element cloudiness than to the (measured) sunshine series.

Table 6.4. 50-years linear trends (in % per decade) of annual sunshine duration in the coarse resolution subregions of the GAR. Significant trends (90% Mann-Kendall) in bold, left: 1901-1950, right: 1951-2000, centre: geographical scheme of the tables

1901-1950						1951-2000		
1.3	0.3	**3.1**	NW	NE	HIGH	-0.6	0.3	**1.2**
1.6	0.8	1.0	SW	SE	LOW	-0.6	0.4	-0.1

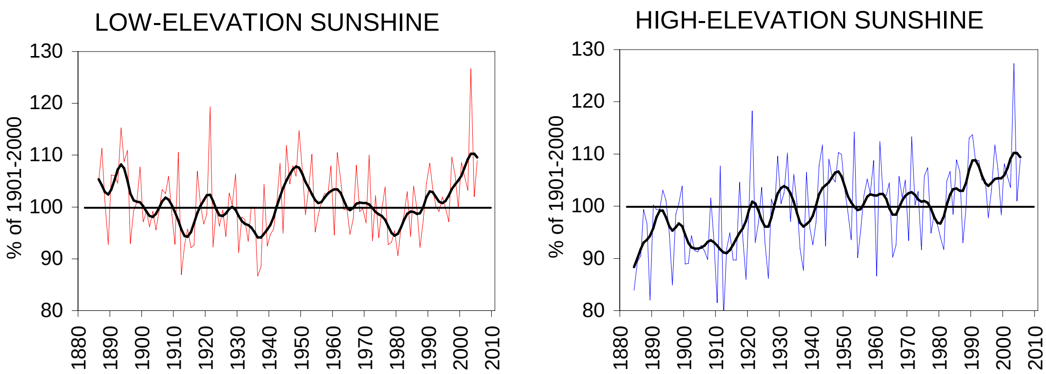

Figure 6.38. GAR annual mean sunshine totals 1880s-2005, averaged over all low elevation (left) and all high elevation sites (right). Single years and 10-years lowpass, anomalies to 20th century average

In spite of its great practical importance, **air-humidity** has been among the strongly under-represented elements in climate variability research so far. ALP-IMP has reduced this deficit for four of the five subregions of the GAR with independently homogenized CRSM-series of relative humidity and of vapour pressure for the NW, the NE, the SE and the high elevation parts of the alpine realm. The interesting first findings confirm the advantage of including humidity into the ensemble of climate elements for variability studies. Vapour pressure, a measure for the absolute humidity content of the air, follows closely the general increase of air temperature and also some of the decadal scale peculiarities at low as well as for high altitudes. Relative humidity, on the other hand has reacted differently on the warming of the past 120 years. At low elevations decadal scale temperature is inversely mimicked by relative humidity resulting in a long-term 7%-drying from 1880 to 2005. At the elevation of the Alpine summit observatories, on the other hand, moisture transport from the source regions (Atlantic and Mediterranean) could feed more effectively the increased moisture demand of the warmer air. Therefore the long-term drying trend has been considerably less in the high Alps (above the stagnating low level air masses especially in the cold season) due to their closer coupling to the maritime source regions.

The graphs in Figure 6.39 show this in a more conventional way by smoothed time series, those of Figure 6.40 use the innovative method "running trend analysis" described in project papers rev-21 and rev-45.

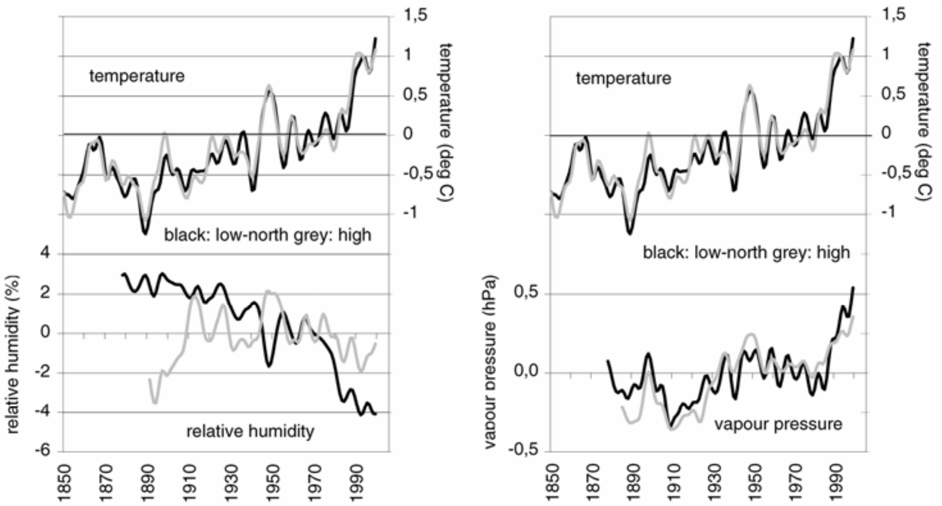

Figure 6.39. Annual relative humidity (bottom, left) and vapour pressure series (bottom, right) compared to temperature (upper graphs, left and right respectively). Black: low-elevation mean NORTH (NW+NE); grey: high elevation mean. All values are 10-years low-pass filtered anomalies to the 1901-2000 averages

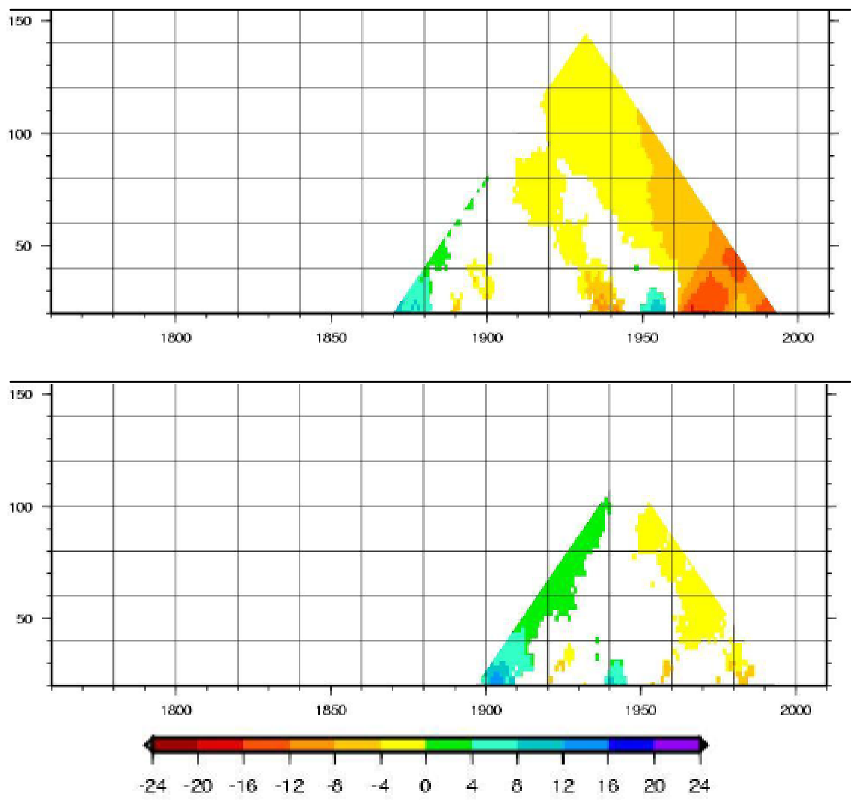

Figure 6.40. Running trend analysis (RTA) for relative humidity in CRS-SE (top) and HIGH (bottom). The RTA graphs display all linear trends in windows of variable width between 20 years and the total length of the series (vertical axis) moved along the time axis (horizontal axis shows the central years of the windows). Only trends of a significance >90% are shown in a colour code from 4 to 4 %/50 years

An example for the potential of the HISTALP database to be used for combined analysis of different climate parameters has been given by a study (project paper rev-26) using HISTALP monthly temperature and precipitation for deriving +200 years long soil moisture series. The method applied was an Alpine version (including a simple snow melt model) of the "scPDSI" (self calibrating Palmer drought severity index, developed by *van der Schrier et al, 2006*).

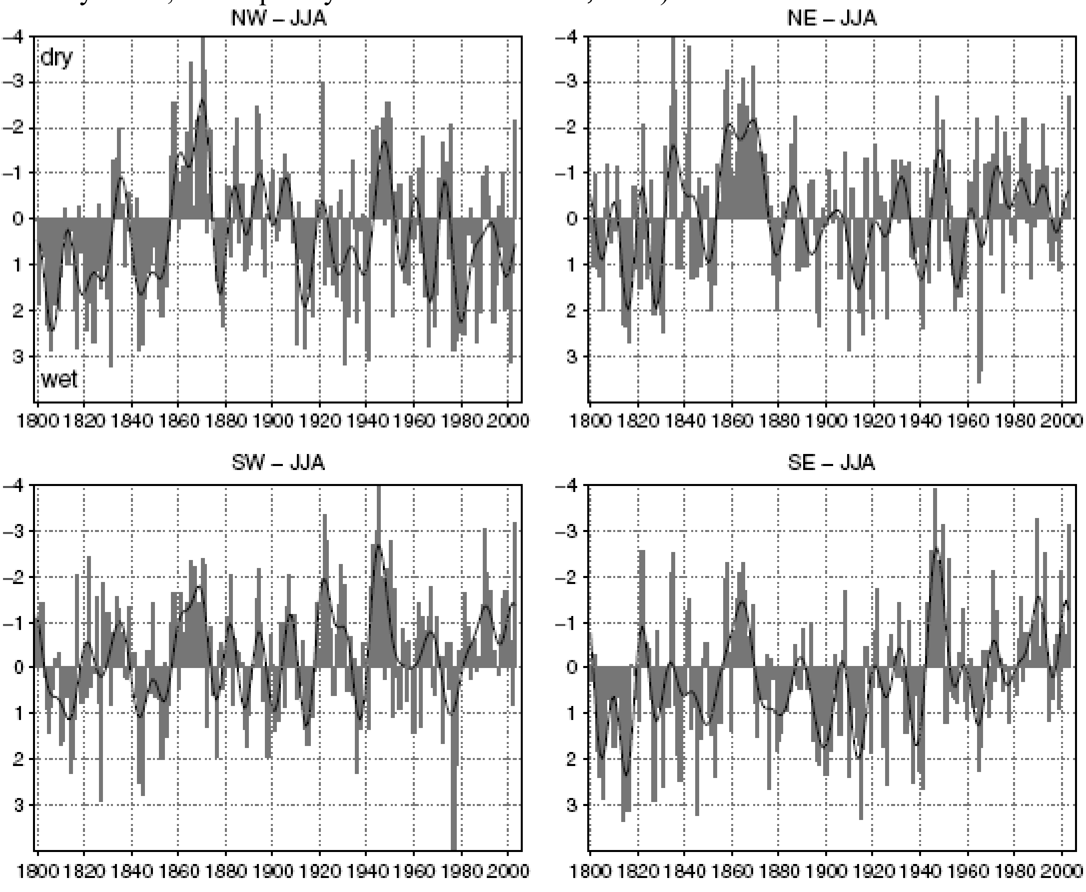

Figure 6.41. scPDSI values averaged over the four GAR subregions for summer (JJA). The solid line shows the 10-year lowpass filtered values. Note the inverted vertical scale with upward bars indicating drier conditions

The PDSI-curves better rely to problems in agriculture through drying than precipitation alone, although the subregional differences are caused by precipitation and not by temperature. Clear to see in Figure 6.41 is the dominant feature of the dry 1860s in the northern subregions, whereas this period is less important in the southern parts of he GAR which are dominated by two more recent dry periods near 1950 and in the 1980s and 90s. The least dryness-affected GAR subregion in recent decades is the northwest, where increasing precipitation still balances increasing temperatures The study could explain that soil moisture deficits in the 19th century were typically caused by such of precipitation, whereas in the 20th century temperature is increasingly taking the lead.

The PDSI-study may serve as an example for innovative ways of using the new potential given by the HISTALP series for future studies of practical importance for the sensitive study region.

6.3.2.7.2. **Analysis of the physical properties of the climate variability system in order to better understand the internal patterns within the GAR.**

The objectives of 6.3.2.7.2 were achieved by intensive use of sophisticated statistical methods combined with the results of regional model simulations with runs of a regional model (REMO) at high spatial resolutions).

The high-resolution REMO simulation performed and described in workpackage 6 has been used in workpackage 7 by GKSS (partner 3) to investigate the internal climate variability of the GAR. To determine the mesoscale variability patterns in the GAR (deliverable 7/2) and the influence of the resolution of topography on circulation patterns (deliverable 7/1), an EOF analysis (von Storch and

Zwiers 1999) was applied to sea level pressure (SLP) of both the REMO simulation (1/6 deg resolution) and the driving ERA40 reanalysis (1.125 deg resolution) for each season over the GAR. The first three EOFs (those for DJF are shown in Figure 6.42) explain more than 97% (REMO) and 94% (ERA), respectively, of the field. The fourth EOF explains only around 1% and is probably where the noise starts.

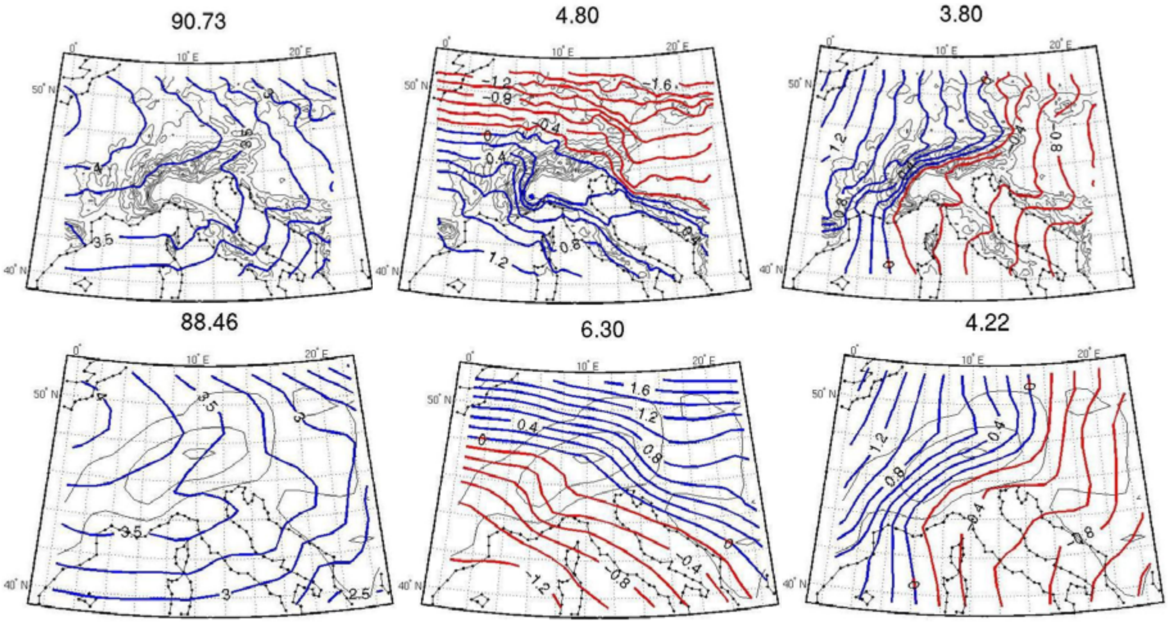

Figure 6.42. The first three winter (DJF) EOFs of mean sea level pressure of REMO (upper row) and ERA40 (lower row) with explained variance in percent and model topography in the background (contour levels every 400 m). Units of the EOFs are hPa change for 1 standard deviation of the principal component.

The first EOF has a monopole pattern in all seasons describing the mean pressure anomaly. It is very similar for ERA and REMO due to the assimilation of observations in ERA and the spectral nudging applied in the REMO simulation. Small differences are located over the Alps, which may be partly due to the different resolution. The explained variance is very high for both REMO and ERA, which reflects the fact that the domain is small compared to the distances over which SLP varies strongly, and is slightly higher for REMO. This indicates a less complex SLP field in REMO despite the higher resolution, which could be related to the assimilation of observations in ERA. To aid interpretation of the EOFs, the principal components (PCs) of all EOFs were correlated with the Arctic Oscillation (AO) Index (AOI) (Thompson and Wallace 2000), and show significant values mainly for PC1. The largest value is found in winter indicating a close link between EOF1 and the Arctic Oscillation in winter.

The second and third EOFs have dipole structures describing a north-south or east-west pressure gradient (the order differs between seasons) and have for both REMO and ERA very similar general structures. The north-south pressure gradient is associated with a westerly or less frequent easterly flow and shows noticeable differences between REMO and ERA in all seasons in north-western Italy. The decreased pressure in the Piemont region in REMO relative to ERA shows that REMO simulates small-scale lee effects not included in ERA. Associated with a northerly or southerly flow is the east-west pressure gradient which shows small differences between REMO and ERA over northern Italy, where the REMO EOFs are slightly more complex.

As a next step the relationship between the REMO mesoscale circulation variability and 2m temperature and precipitation (deliverable 7/4) was investigated by correlating REMO temperature and precipitation with the first four REMO SLP PCs for all gridpoints and seasons. Due to space limitations we describe here the results for winter (Figure 6.43). Results for all four seasons are described in the deliverable report for Workpackage 7.

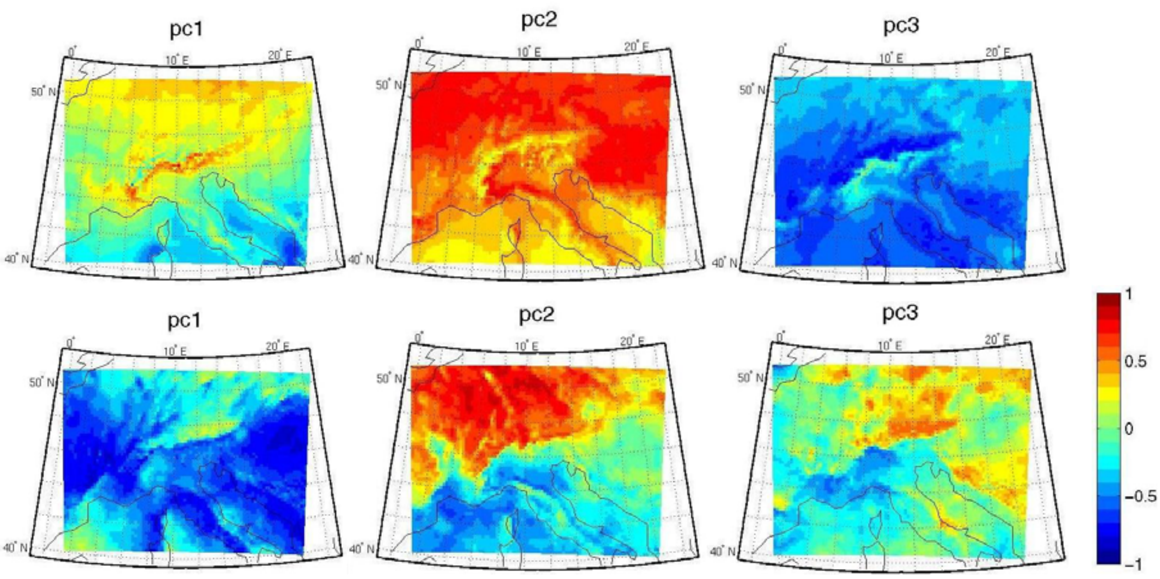

Figure 6.43. Correlations between the first three REMO winter PCs and REMO winter temperature (upper row) and winter precipitation (lower row) for the period 1958 to 1998.

Reduced winter precipitation (negative correlations in Figure 6.43) in the positive phase of EOF1 is caused by higher pressure described by the monopole pattern of this EOF. This is in agreement with Quadrelli et al. (2001). The correlation pattern between winter temperature and PC1 will be discussed later. The second EOF is associated in the positive phase with an advection of maritime air leading to increased temperature in winter (high positive correlations in Fig. 2) and wetter conditions north of the Alps and due to the blocking effect drier conditions south of the Alps. The decreased temperature over the whole domain in the positive phase described by the negative correlation in Figure 6.43 is related to the advection of cold air from the north, which brings precipitation to the northern side of the Alps and a rain-shadow effect to the south. The correlations for the other seasons also reflect the influence of advection of warmer or cooler and wetter or drier air and the blocking effect of the Alps.

As the first REMO winter SLP PC is highly correlated (0.85) with the AOI, the correlation map can be interpreted in terms of the AO. The positive values in the north and more negative values to the south show the standard AO-temperature signal. The interesting feature is the separated area of high positive correlations south of the Alpine main ridge, which is typically not seen in correlation maps with coarser resolution. To analyse whether this feature is solely caused by the model, REMO temperature was also correlated with the AOI and the similar North Atlantic Oscillation Index (NAOI) (Hurrell 1995). Additionally, the winter temperature from the HISTALP stations was correlated with the REMO winter SLP PC1, the AOI and the NAOI.

The high correlations of REMO winter temperature south of the main ridge are also visible for the AOI and NAOI (not shown). The correlation between HISTALP winter temperature and both REMO winter SLP PC1 and the AOI shows highest values for high elevation stations and low elevation stations located in the Dolomites south of the main Alpine ridge. Therefore, the high correlations are found in the same regions for REMO and HISTALP. However, the prominent high correlations in high elevation stations and the Dolomites are absent in the correlation pattern between HISTALP winter temperature and the NAOI, which needs further analysis and comparison with existing studies.

The Alpine climate of the last 250 years has recently been investigated using the global coupled atmospheric ocean general circulation model ECHO-G with a resolution of 3.75 deg by Matulla et al. (project paper nrev-16). They investigated the relationship between large-scale circulation and regional-scale temperature for significantly warm or cold periods. By comparing the results of differently forced simulations they could additionally analyse the impacts of the external forcing, like volcanic and solar forcing on the regional climate.

The reconstruction of Alpine climate of the last 200 years throughout the troposphere using the 1/6 deg REMO simulation and the long HISTALP station records (deliverable 7/3) is delayed but will start during the next months. The results of WP6 do not show a clear added value of REMO temperature compared to the ERA40 reanalysis temperature, but we expect more added value for circulation supported by the results of WP7. Therefore, the reconstruction will be performed for geopotential height on different levels.

6.3.2.8. **200 YEARS GAR VERSUS GLOBAL**

The leading climate element in the scientific as well as in the public discussion on climate warming is temperature. The annual mean temperature evolution in the GAR (Figure 6.44) in the instrumental period can be characterized by two main sections. A 100-years period from 1790 to 1890 with a cooling of -0.97K was followed by a 116 years warming by +1.48K. Compared to the global trend from 1890 to 2005 of +0.74K (global land at 0.5 deg grid - CRU TS 2.1), the GAR has warmed nearly twice as much. The first cooling in the early instrumental period cannot be compared due to the lack of a global climate observing system earlier than the 1850s.

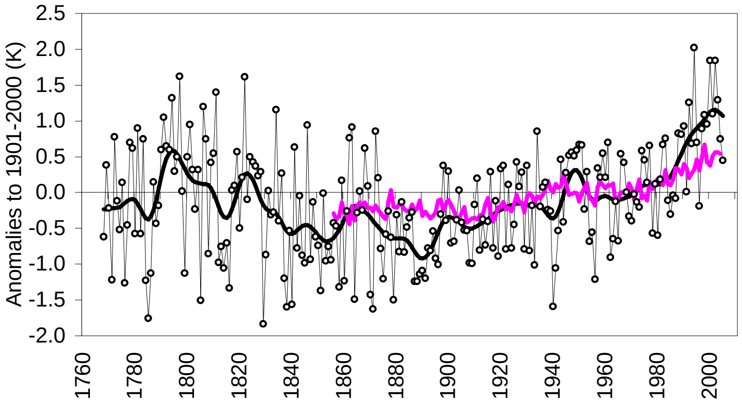

Figure 6.44. Annual mean temperature series for the low-elevation GAR-mean (black, single years 1768-2005 and 20-years lowpass) and for the global land mean (pink 1858-2005, CRU TS 2.1-temperature, Mitchell and Jones, 2005). Both series are anomalies to 20th century mean

This project finding has quickly developed to one of the most cited in the public change debate in the region – arguing the Alps to be particularly sensitive to climate change. To avoid a fluent misunderstanding we underline here what has been shown already (WP-7), that it is neither the mountains, nor the Alps alone which show this stronger warming, but the entire "greater" Alpine region. A closer look at the figure above indicates that most of the stronger GAR-warming has been caused by two outstanding periods mainly: in the 1890s (significantly colder in the GAR) and in the recent 20 years (much warmer). From 1900 to the late 1980s the GAR behaved rather similar to the global evolution. Another outstanding feature of the GAR-temperature curve is the warmth of the two decades from 1790 to 1910, followed by the sharp cooling of the 1810s. As the latter is in accordance with our physical understanding of these years as to be strongly influenced by volcanic activity together with a solar minimum (Dalton), the preceding two warm (low elevation,) decades show a positive bias versus the (high elevation) tree-ring based reconstructions in the region. This "early instrumental paradox" sets a question mark behind the reliability of pre-1850 spring and summer temperatures in the region. The topic was intensively studied in the multi-proxy-workpackage-9.

The described annual temperature evolution at regional and global scale is only one example of many, typical for the intentions and themes of workpackage 8 – to analyze climate variability in the GAR in the greater context of and compared to large scale (continental to global) climate variability and under the influence of atmospheric circulation. This objective was pursued in several project papers as rev-09, section 6 of rev-20, rev-21, rev-26, rev-45. The main paper dedicated to WP-8 is rev-43 - *Influence of large-scale atmospheric circulation on climate variability in the Greater Alpine Region of Europe*.

The influence of large-scale atmospheric circulation on GAR temperature and precipitation was studied using some continental to global scale leading MSLP-patterns derived from the

EMULATE monthly gridded sea level pressure dataset (EMSLP, 1850-2003), the monthly North Atlantic oscillation index (NAO, 1821-2004, Gibraltar-Iceland, CRU, Jones et al., 1997), the Arctic Oscillation (AO) index 1899-2002 (Thompson and Wallace, 1998, 2000), the Southern Oscillation Index (SOI, ENSO, Tahiti-Darwin, 1850-2004 and a treering based reconstruction 1706-1977 (van Loon and Madden, 1981) and the Nino3 Index 1408-1978 (Stahle et al., 1998). The following selection of results of rev-43 shall provide an impression of some of the results of the extensive main WP-8 study.

The MSLP-patterns in the wider Euro-Atlantic region play a significant role in the GAR in winter, much less in summer. High elevation temperatures are markedly linked with the Northern Hemisphere zonal circulation as expressed by the NH annular mode (NAM), whereas the low elevation temperature field is associated more with the circulation over the NE-Atlantic. North of the Alps (GAR-NW and NE), a British Isles-centred pressure pattern plays the principal influence on winter precipitation, whereas the Mediterranean subregions are dominated by NAO (in particular its Mediterranean component). The impact of the ENSO phenomenon on GAR climate is weak, although it is intermittently manifested in subperiods of some decades. In these "ENSO-sensitive decades" late autumn-winter temperature and winter-spring precipitation exhibit significant correlation with the ENSO-state of the preceding autumn and late summer. Some signs of ENSO-impact on GAR-summer temperatures are also apparent, increasingly in the last 2 to 3 decades.

Table 6.5. The percentage of temperature and precipitation variance explained by selected EMSLP EOFs and the NAO and AO indices, for 20th century winters (DJF)

No	Region	Temperature						Precipitation					
		NAO EOF#1	Greenl. REOF	Medit. REOF	Br. Isl. REOF	NAO index	AO index	NAO EOF#1	Greenl. REOF	Medit. REOF	Br. Isl. REOF	NAO index	AO index
1	GAR	30	15	31	**51**	28	22	33	25	38	**50**	17	**36**
2	GAR-NW	27	17	28	**57**	30	19	12	9	22	**50**	3	15
3	GAR-NE	31	14	28	**43**	33	21	2	2	11	15	2	4
4	GAR-SW	33	17	33	39	27	28	24	12	17	38	22	25
5	GAR-SE	14	7	15	**54**	16	7	**57**	**41**	**60**	27	**44**	**59**
6	GAR-Low	25	12	26	**53**	26	17						
7	GAR-High	**42**	26	**53**	36	31	39						

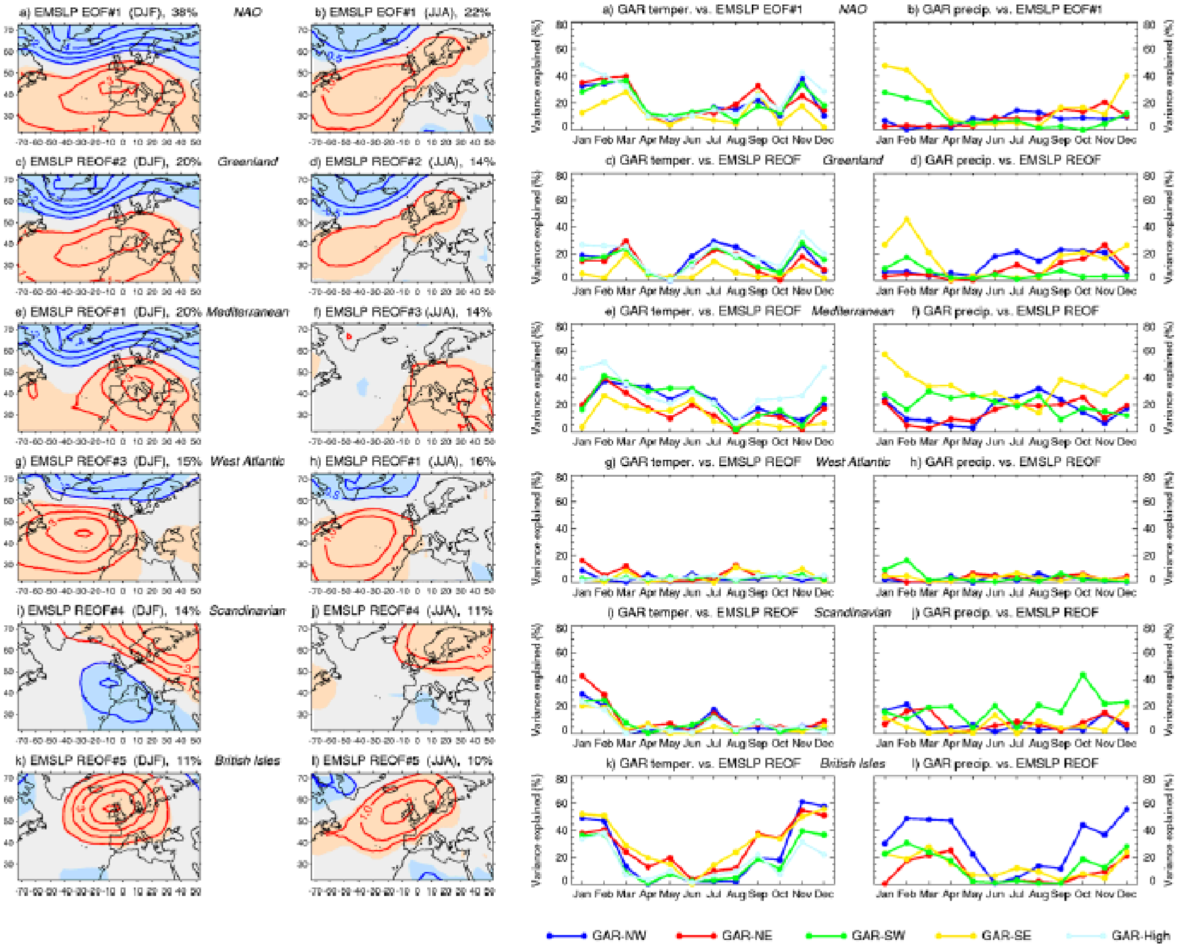

Figure 6.45. Variance explained by the EMSLP EOF/REOFs shown in the left maps for the individual climatic subregions of the GAR for each calendar month over the 1850-2003 period

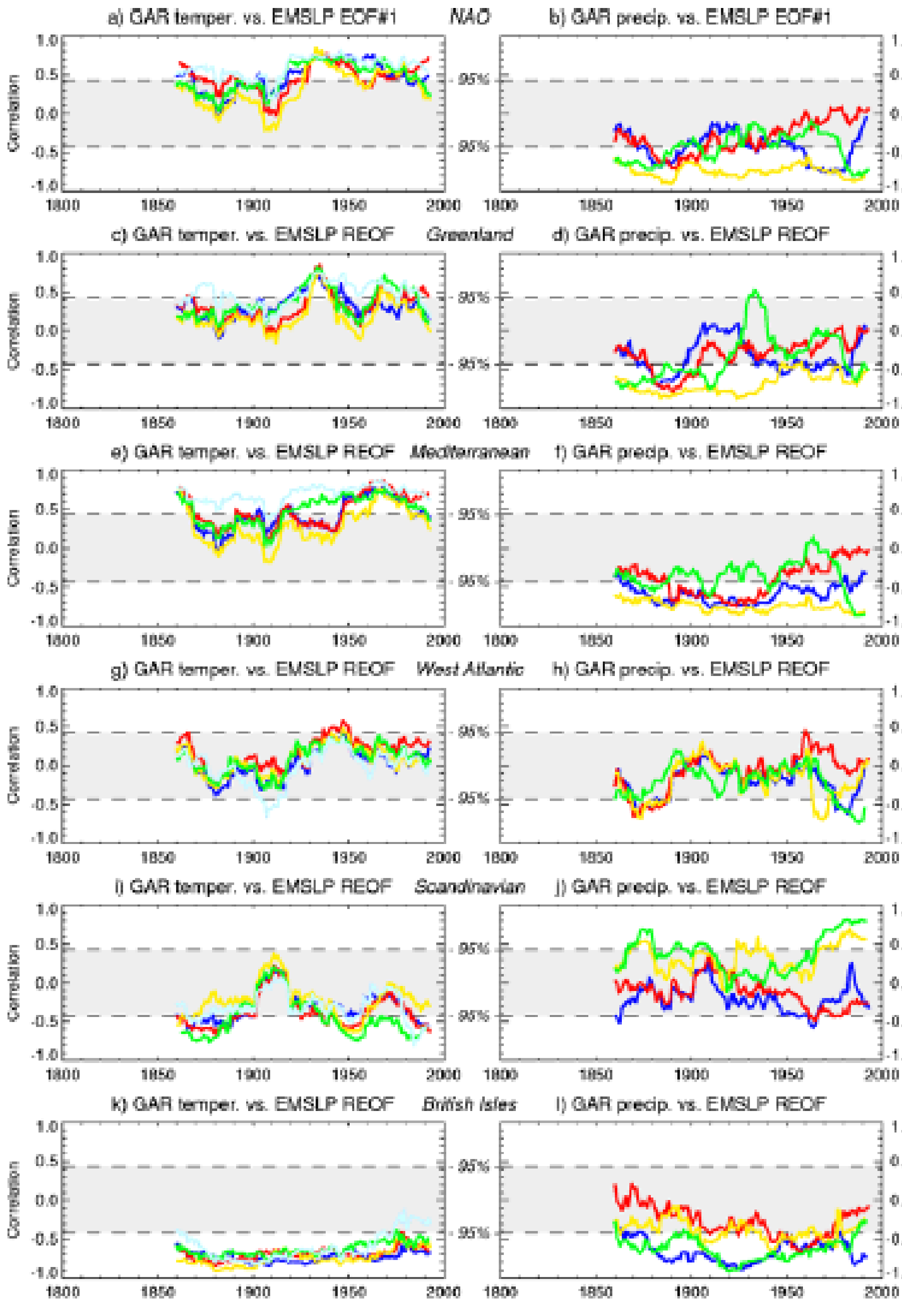

Figure 6.46. Running correlation (21-year window) between subregional climatic fields in winter (DJF) for the 1850-2003 period. Correlation range below the 95% confidence level is shaded

6.3.2.9. **1000 YEARS GAR VERSUS GLOBAL**

The purpose of WP-9 is to extend the synthesis activities of WP-1 and WP-5, which considered the instrumental period within the GAR, to encompass evidence of GAR climate variability throughout the whole of the last millennium. In addition, WP-8 synthesises the evidence for last 200 years of instrumental records. WP-9, therefore, is a synthesis of all the proxy climate reconstructions developed within WPs 2-4, with an emphasis on the pre-1800 period, although it also expands on the ‘early instrumental paradox’ alluded to in the WP-8 part of this report. All technical details about the reconstructions from the three domains are discussed within the separate WP 2-4 reports. The character of the reconstructions in these three WPs differs, principally with respect to timescale. Tree-ring reconstructions (WP-2) are annually resolved and dating is assured through comprehensive cross-dating of the developed chronologies. Ice-core-based reconstructions (WP-3) using isotope measurements also have potential annual resolution, but dating is more problematic and cannot be considered exact. Glacier-based reconstructions (WP-4), using the dating of terminal moraines are less temporally resolved, so they provide information on past temperatures at decadal-to-century timescales at best.

Emphasis here is, therefore, initially placed on the tree-ring results, with confirmation of longer-timescale changes sought through graphical comparisons. Finally, a number of earlier reconstructions (from non-ALP-IMP work), principally from documentary-based reconstructions since about 1200, are included to help understand the reconstructions for the GAR and provide some thoughts on the early instrumental paradox. This synthesis report is based on several plots of the reconstructions, which will serve to highlight the principal findings of the project.

6.3.2.9.1. Early Instrumental Paradox

The early instrumental temperature series for the GAR (see Figure in WP-8) showed a marked warm period during the 1790s and 1800s (comparable to the mean warmth of the 1980s, but below that for the years 1990-2005). Following the 1800s, temperatures cooled markedly in the 1810s, were warm again in the 1820s and then cooled to their lowest levels from the 1830s right through to the early-20th century. Instrumental records in other parts of Europe [England and Scandinavia (Manley, 1974 and Moberg *et al*., 2003, respectively)] give some support for the warmth of the 1790s and 1800s, but for all sites there are issues of exposure of the early instruments that do not allow us to conclude with certainty that the warmth was real. For example, all the sites in the GAR for this period are at low elevation, the higher-elevation site records not starting until some decades later.

In WP2, and also in rev-33, it was shown that tree-ring density data more closely resemble the high-elevation summer (JJAS) temperature for the GAR, as opposed to the low-elevation station average. When compared to the earlier instrumental data from the low-elevation sites for the period before about 1820, there is an apparent offset between temperature and tree-ring indices (see Figure 6.47). The instrumental data are warmer than the tree-ring density record would imply. The difference is of the order of 0.5°C, suggestive of residual homogeneity problems in the early instrumental records. The agreement between 1760 and 1820 is as good at high-frequency (i.e. interannual timescales) as for the period from 1820 onwards. Over the period 1760 to 2003, the tree-ring density data indicate that the warmest summer occurred in 2003 (in agreement with the instrumental data). However, the coolest summer as indicated by the trees was in 1816. This is not consistent with the instrumental record, where the summer of 1816 is only one among the coldest three summers that occurred during the 1760-2003 period.

A number of the studies within ALP-IMP (rev-33, rev-44) have attempted to resolve the decadal-scale differences between the warmer early-instrumental series for the GAR and the cooler inferred summer temperatures from the tree-ring reconstructions. The issue of early summers being too warm is also a problem in Sweden (Moberg *et al.*, 2003), so we cannot look at the GAR in isolation. Whilst we cannot consider the Luterbacher *et al*. (2004) series in this discussion (as they will have used the HISTALP data series), the longer instrumental records from Central England and the Netherlands both indicate a number of warm decadal-length periods during the 18th century (see also the discussion of the 1730s and 1740s in Jones and Briffa, 2006). These two series track the summer HISTALP/GAR low-elevation series very well for almost all the last 200 years. The GAR is more continental than the more maritime NW European locations, so slightly greater variability in the GAR is to be expected. The GAR also shows much greater recent warming since about 1990. So, attempts to resolve the paradox must be mindful of other early instrumental series, as well as the statistical uncertainty associated with the expression of temperature based on tree-ring series and that of the early alpine instrumental data. The marked cooling of summer temperatures during the 1810s is clear in all the tree-ring reconstructions. Although undoubtedly cool in the instrumental series, it is not as anomalous. We will extend this analysis and discussion in rev-52, particularly the period from 1790 to 1830.

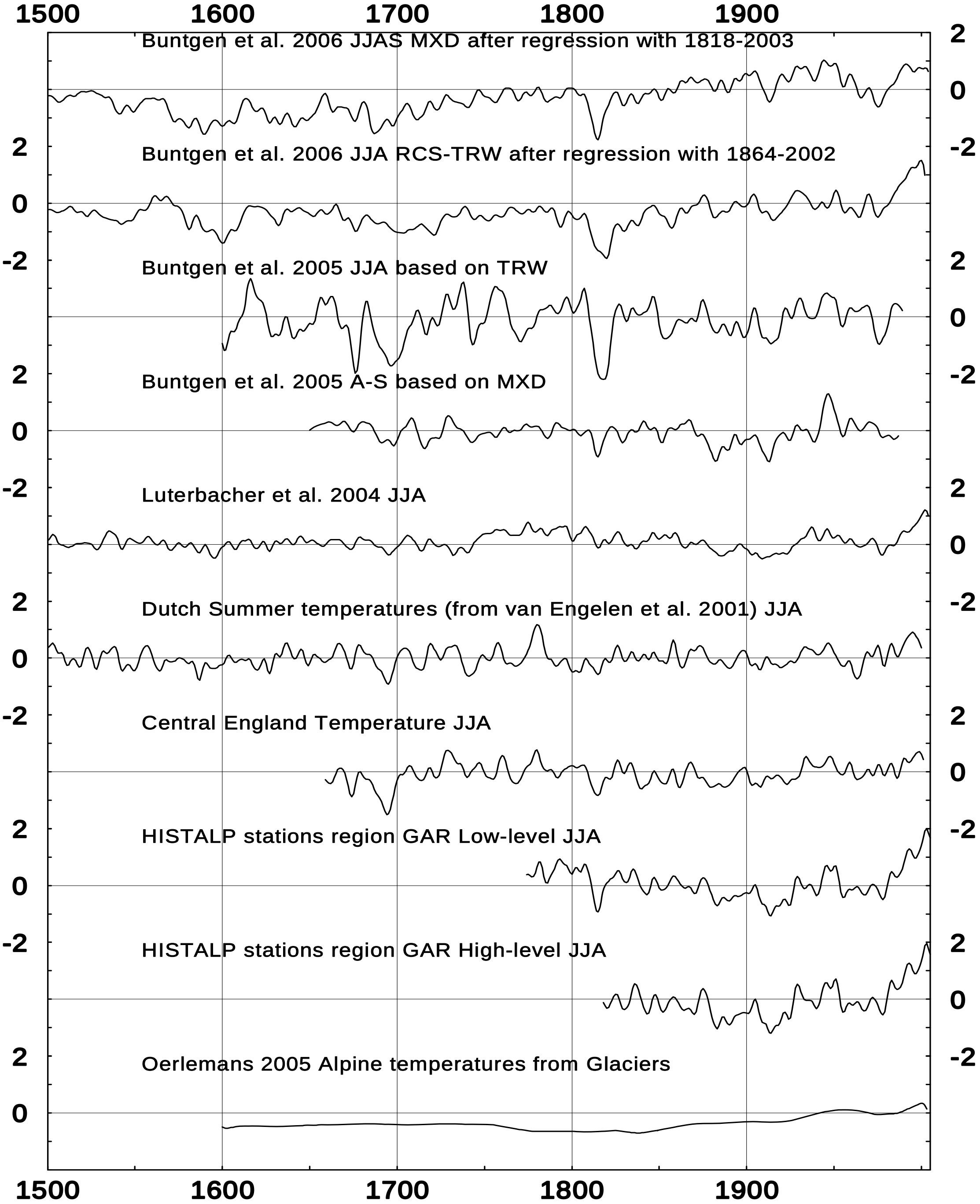

Figure 6.47. Instrumental and tree-ring based reconstructions of 'summer' temperatures for the period from the 16th century. The top 4 plots are reconstructions discussed in the WP-2 report (from rev-33 and rev-7). The next three curves are the European summer (JJA) temperature reconstructed by Luterbacher *et al*. (2004), for the Low-Countries (principally the Netherlands, from van Engelen *et al*., 2001) and the Central England temperature record (Manley, 1974, updated by Parker *et al*., 1992). The final three curves are the low- and high-elevation temperature averages from WP-8 (so rev-20) and the Alpine-glacier inferred temperature record from Oerlemans (2005). All series smoothed with a 10-year Gaussian filter. Not all series extend to the present (the last years range from 1989 to 2005).

6.3.2.9.2. The long millennial temperature record

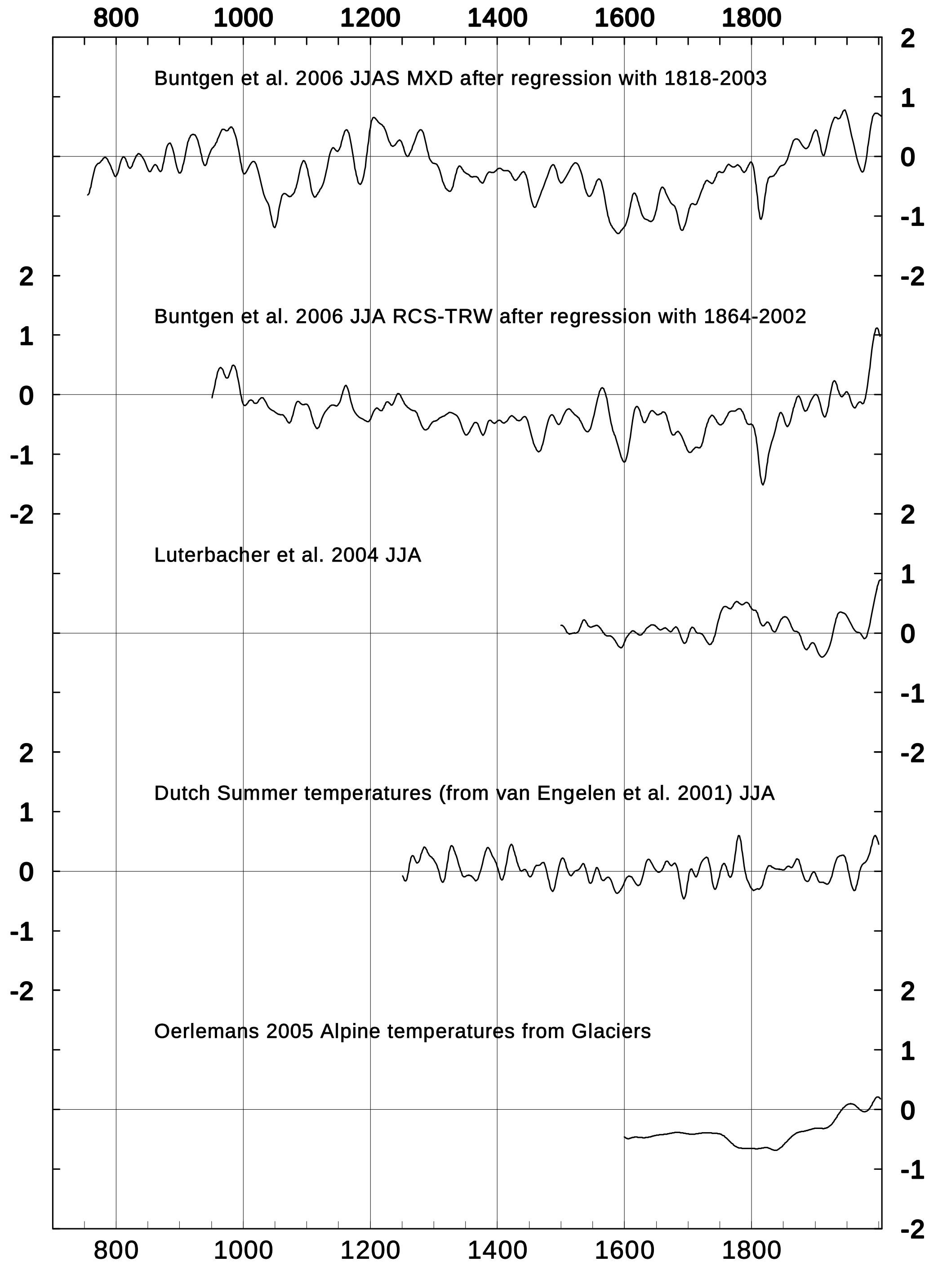

Figure 6.48. The two tree-ring based reconstructions from Figure 1 (from rev-33), together with the full records from Luterbacher *et al.* (2004), van Engelen *et al.* (2001) and Oerlemans (2005). All series are smoothed with a 30-year Gaussian filter.

Figure 6.48 shows two of the long tree-ring reconstructions compared to several other reconstructions that span a part of the millennium. As with Figure 1, we have chosen series that are within about 1000km from the GAR, and so can be expected to show reasonable correlation, given our knowledge of summer correlation-decay lengths (Briffa *et al.*, 1993). The long tree-ring density reconstruction since 755 shows warmer summers in the Medieval period, with cooler summers between about 1350 and 1820 and the warmest of all in the last 20 years. Particularly warm decades were recorded by the trees during the 960s to 980s, the 1200s to 1220s and the recent 25 years. Of particular note are the cooler summers during the 1040s to 1060s. Cool temperatures were also recorded, particularly during the period from 1400 to 1710 and during the 1810s (discussed earlier). Warm summers during this period were evident around 1500 and 1800. These are partly confirmed by the ring-width-based reconstruction, but the two reconstructions are markedly at odds with each other during the first two centuries of the millennium, particularly with respect to the trend over that period. Both reconstructions show markedly more low-frequency variability during the summers than is seen, for example, in the Dutch summer temperatures compiled by van Engelen *et al*. (2001). On century timescales there is some agreement with the temperature reconstruction from alpine glaciers advances/retreats developed by Oerlemans (2005). This analysis of the longer millennial period will also be extended in rev-52, incorporating glacier evidence (from WP-4) and from speleothem records (e.g. Mangini *et al*., 2005).

6.3.2.9.3. Long term climate records from Alpine ice cores

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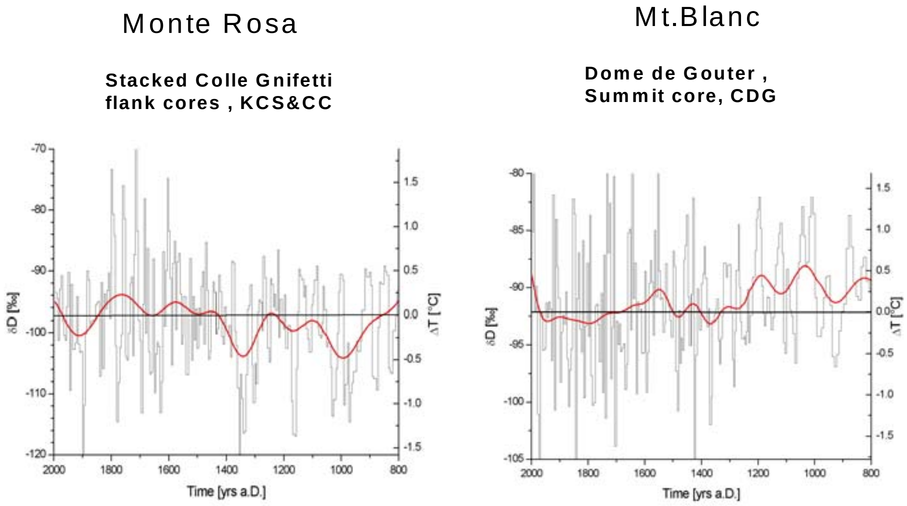

Figure 6.49. δD records over the last 1200 years from low accumulation areas in the Monte Rosa and Mont Blanc summit ranges. Note, that the lower time resolution in the older sections, arise from rapid annual layer thinning. Note also that time in this figure runs from right to left.

Stable isotope ($\delta^{18}O$ or δD) records from ice cores are likely to reflect local temperature changes, though meteorological noise and systematic depositional effects challenge the extraction of (the relatively weak) signal over the last 1200 years. Alpine ice cores, which cover the last 1200 years with a usable depth resolution are confined to extremely low accumulation (wind exposed) drill sites, thus mostly reflecting isotope changes of the summer half years. This season is comparable to the information that can be gleaned from tree-ring- and glacier-based reconstructions (compare Figures 2 and 3). For the evaluation of a millennial record, we specifically selected cores from the Monte Rosa and Mt. Blanc drill sites, which were obtained on low-accumulation flank and ice-dome positions, respectively. The initial results show that while all Monte Rosa isotope records drilled at flank positions show broad agreement with the long-term temperature change of the instrumental period (as used for calibration of the temperature scale), but with an apparent cooling trend observed during Medieval times. At least, partly, this strange feature is due to an overestimation of the upstream effect, which may especially affect the older section. In contrast, a weak Medieval warming trend is observed in the Mt. Blanc summit core, where ice flow is not significant. Apart from this advantage of the summit site at Mont Blanc in relation to the older part of the core, the highly irregular snow deposition at this dome site led to a poor correspondence with recent instrumental records and a more uncertain time scale. Apart from the conflicting long-term trend feature, a cold excursion around 1350 is seen in all long-term records.

Based on the existing isotope records it remains difficult to quantify long-term changes over the last 1000 years, especially regarding the extent of a possible Medieval warming in relation to recent times. However, the newly drilled Monte Rosa core, being less influenced by ice-flow effects and offering a much better temporal resolution beyond 1000 years is expected to reconcile the area-specific ice-core findings. The ice-core evidence will be integrated into the planned review paper (rev-50).

6.3.2.10. Cited non-project references (for project literature see 6.5.)

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6.4. Conclusions including socio-economic relevance, strategic aspects and policy implications

ALP-IMP has exemplarily shown how existing deficits in climate variability research can be overcome by

- concentrating on a region of manageable size, allowing for being in direct contact with all data providers – thus having direct access to data and metadata
- concentrating on a clearly defined study period – the last millennium
- trying to better exploit the existing data-potential in terms of spatial density, length and through the integrative and interdisciplinary co-analysis of instrumental and proxy data supported by high resolution regional modelling
- strictly obeying to the scientific needs in terms of quality of data and methods
- understanding climate in a multiple sense by including more than just one or two climate parameters

The project may thus serve as an example for other regions of the earth of similar size and with other interesting climate features. Adding more and more well understood regional spots on the map of global datasets will overcome the still existing white spots necessarily left by the global climate studies with their regional deficits.

ALP-IMP could show that even in a well developed region like Central Europe, the existing climate data potential is not at all fully exploited – but that the job can be done. Even digitising of historic data sources has been necessary and could significantly reduce respective pre-project data deficits.

ALP-IMP could show that the interdisciplinary cooperation may have its difficulties, but that the added value exceeds by far the difficulties. A good example among several is the detected "early instrumental paradox". The fact that it was not solved during the project, but clearly defined and described, hints at a respective research topic for the future.

ALP-IMP has produced datasets and scientific findings about the climate past well usable for

- continuous climate research in the interesting study region at the crossing of three main European scale climate regimes, accentuated here through the existence of the mountain chain of the Alps
- application in climate related research in fields like biology, history and many others dealing with climate sensitive processes
- application in climate impact research dealing with the future of the region which can be regarded in many aspects as climate-sensitive – a well understood past climate and it's impacts on nature and society is the necessary pre-condition to derive scenarios for the future

ALP-IMP has reached it's goals not at last due to a widespread network of informally incorporated "corresponding project partners" which could be built up during the initial phase and successfully maintained until the end. Together with the core project community, those external partners contributed considerably to the success of the project with data, instruments, equipment for field activities and scientific know-how. Although the management problems arising from the enlargement of the project community were not marginal and caused some delays and much additional work, the results were positive and the extension has – a posteriori - to be declared necessary. The sometimes painstaking and time consuming management activities to maintain the "GAR-network of data and human resources" points at some crucial messages to be learnt for the future. One of the most striking refers to the level of administrative and political structures:

Although programs like ALP-IMP are already now possible through the research policy of the European Union, they are still severely hampered by the still existing lacks of integration of the Union. The instrumental data activities of our project provide a good example: Although data exchange was performed in a friendly atmosphere, it strongly relied on personal acquaintance and was only poorly supported through official international structures. The clear message for the future should be a development towards an easy to handle and legally well defined Europe-wide climate database. ECSN can only be a first step, attempts from single projects like ours may be too costly to be alienated to Europe as a whole – so the final solution should be a real "European Weather Service". Only such an organisation would be able to play an equal counterpart to the American NOAA and provide climate research in the European Union with a well developed climate data base – thus contribute to better exploit the existing human resources in European climate research. Nature itself is the example: Climate knows no borders, let us try to cope that by overcoming the still existing political-administrative obstacles to study it.

6.5. Dissemination and exploitation of the results

The typical exploitation of a research project dealing with the basic understanding of environmental physical processes is executed through the dissemination via publications in scientific journals. ALP-IMP has done so extensively and the results have been introduced to the climatic and also to related scientific communities also at a greater number of scientific conferences (details in the 3 annual project reports).

Project data are to public and to restricted disposal via the project website http://www.zamg.ac.at/ALP-IMP. All gridded datasets are available without restrictions, only some of the instrumental stmod-data and of the proxies (compare 6.3.2.1.) had to be placed at a password secured area of the website according to respective legal obligations of the data providers.

In addition to that, some projects were initiated in the realm of ALP-IMP (described in the 3 annual project reports) and are going to sustainably continue and broaden some detected problems, described but not completely solved during the ALP-IMP years. Many of the project results – scientific findings as well as datasets – also have a potential for practical application and are therefore of direct public interest. A typical example for the latter is an Austrian funded project ("A tale of two valleys" – http://www.zamg.ac.at/a-tale-of-two-valleys/ trying to include and further apply ALP-IMP data and findings in a blow-up study focusing on past climate and life in two neighbouring Alpine valleys. The project seeks the direct contact with the local population to raise awareness on climate change and extreme climate events and to learn from their management of changing surroundings and natural hazards to adapt to the future challenges. ALP-IMP's concluding workshop was held in the study region of the two-valleys project and the scientific ALP-IMP community took the opportunity to contribute to a "public science day" with lectures, discussions and with the active participation at two "science-walks" through the remnants of past 150-years' climate change in the glaciated central Alpine study region (details in section 1 of this report and on the Two-valleys-website).

The pure scientific dissemination of the project findings is shown in the following section 6.6.

6.6. Main literature produced

ALP-IMP has produced a total of 139 publications.

63 of them as articles in **peer reviewed scientific journals**. 30 of those are already printed or online publications, 5 are accepted for publication, 11 are in review and 17 are in preparation and to be submitted in the immediate post project time. Several other planned publications are still under discussion among the project community but have not yet started. They are not included in the publication statistics.

10 articles in non reviewed journals and 2 larger stand-alone publications were published.

Project findings were introduced and described as **58 oral or poster** presentations at scientific conferences so far. 31 have been included in conference proceedings as **extended abstracts** or invited contributions, for 27 **short abstracts** are available.

The project literature is rounded up by **6 PhD-theses** and **2 diploma theses**.

All details are included in ANNEX 1 of this report – the project's publication list

ANNEX 2 of this report is a collection of all abstracts of the peer reviewed project papers and of a selection of abstracts of the non reviewed papers

The project papers are visible at the public part of the project website as abstracts http://www.zamg.ac.at/ALP-IMP, the full publications can be downloaded on demand at ZAMG as "author's copies" from the password secured area of the website.

ANNEX 1

To final report of

RTD-project ALP-IMP

ALP-IMP PUBLICATION LIST

Part 1:

peer reviewed articles

Status: 31 October 2006

ALP-IMP PUBLICATION LIST version 2006-10			PEER REVIEWED ARTICLES		
Authors	**Date**	**Title**	**Journal**	**Reference**	**ALP-IMP ref-ID**
Aguilar E, Auer I, Brunet M, Peterson TC, Wieringa J	2003	Guidlines on Climate Metadata and Homogenization	*WMO-TD* **1186** *WCDMP* **53**	53 pages	ALP-IMP-rev-1
Maugeri M, Brunetti M, Monti F, Nanni T	2004	Sea-level pressure variability in the Po-plain (1765-2000) from homogenized daily secular records	*International Journal of Climatology* **24**	437-455	ALP-IMP-rev-2
Auer I, Böhm R, Jurkovic A, Orlik A, Potzmann R, Schöner W, Ungersböck M, Brunetti M, Nanni T, Maugeri M, Briffa K, Jones P, Efthymiadis D, Mestre O, Moisselin JM, Begert M, Brazdil R, Bochnicek O, Cegnar T, Gajic-Capka M, Zaninovic K, Majstorovic Z, Szalai S, Szentimrey T	2005	A new instrumental precipitation dataset in the greater alpine region for the period 1800-2002	*International Journal of Climatology* **25/2**	139-166	ALP-IMP-rev-3
Frank D, Esper J	2005	Characterization and climate response patterns of a high elevation, multi species tree-ring network for the European Alps.	*Dendrochronologia* **22**	107-121	ALP-IMP-rev-4
Zemp M, Kääb A, Hoelzle M, Haeberli W	2005	GIS-based modelling of glacial sediment balance.	*Zeitschrift für Geomorphologie N.F.*, Suppl.-Vol. **138**.	113-129	ALP-IMP-rev-5
Casty C, Wanner H, Luterbacher J, Esper J, Böhm R	2005	Temperature and precipitation variability in the European Alps since 1500	*International Journal of Climatology* **25**	1855-1880	ALP-IMP-rev-6
Büntgen U, Esper J, Frank DC, Nicolussi K, Schmidhalter M	2005	A 1052-year tree-ring proxy of Alpine summer temperatures.	*Climate Dynamics* **25,** DOI 10.1007/s00382-005-0028-1, 2005	141-153	ALP-IMP-rev-7
Zemp M, Frauenfelder R, Haeberli W and Hoelzle M	2005	Worldwide glacier mass balance measurements: general trends and first results of the extraordinary year 2003 in Central Europe.	*Data of Glaciological Studies [Materialy glyatsiologicheskih issledovanii]*, **99**, Moscow	3-12	ALP-IMP-rev-8
Böhm R	2006	Reconstructing the Climate of the 250 Years of Instrumental Records at the Northern Border of the Mediterranean (The Alps)	*Il Nuovo Cimento* **29 C** N 1 DOI 10.1393/ncc/i2005-10216-0, 2006	13-19	ALP-IMP-rev-9
Frank D, Esper J	2005	Temperature reconstructions and comparisons with instrumental data from a tree-ring network for the European Alps	*International Journal of Climatology* **25**	1437-1454	ALP-IMP-rev-10
Brunetti M, Maugeri M, Monti F, Nanni T	2006	Temperature and Precipitation Variability in Italy in the Last Two Centuries from Homogenized Instrumental Time Series	*International Journal of Climatology* **26-3,** DOI: 10.1002/joc.1216, 2006	345-381	ALP-IMP-rev-11
Efthymiadis D, Jones PD, Briffa K, Auer I, Böhm R, Schöner W, Frei C, Schmidli J	2006	Construction of a 10-min.gridded precipitation dataset for the Greater Alpine Region 1800-2003	*Journal of Geophysical Research - Atmospheres* **111**, D01 105, doi: 10.1029/2005JD006120, 2006		ALP-IMP-rev-12
Büntgen U, Bellwald I, Kalbermatten H, Frank DC, Freund H, Schmidhalter M, Bellwald W, Neuwirth B, Esper J	2006	700-years of settlement and building history in the Lötschental/Vallis.	*Erdkunde,* **2/60**	96-112	ALP-IMP-rev-13
Carrer M, Urbinati C	2006	Long-term change in the sensitivity of tree-ring growth to climate forcing of *Larix decidua* (L.)	*New Phytologist* **2006**, doi: 10.1111/j.1469-8137.2006.01703.x		ALP-IMP-rev-14
Frank D, Wilson R, Esper J	2005	Synchronous variability changes in Alpine temperature and tree-ring data over the last two centuries	*Boreas* **34** 2005 DOI: 10.1080/03009480500231443 # 2005	498-505	ALP-IMP-rev-15
Zemp, M., Paul, F., Hoelzle, M. and Haeberli	2006: in press	Glacier fluctuations in the European Alps 1850-2000: an overview and spatio-temporal analysis of available data.	In: Orlove, B., Wiegandt, E. and B. Luckman (eds.): The darkening peaks: Glacial retreat in scientific and social context. University of California Press.		ALP-IMP-rev-16
Paul, F., Machguth, H., Hoelzle, M., Salzmann, N. and Haeberli, W.	2006: in press	Alpine-wide distributed glacier mass balance modelling: a tool for assessing future glacier change?	In: Orlove, B., Wiegandt, E. and B. Luckman (eds.): The darkening peaks: Glacial retreat in scientific and social context. University of California Press.		ALP-IMP-rev-17
Paul, F., Machguth, H. and Kääb, A.	2005	On the impact of glacier albedo under conditions of extreme glacier melt: the summer of 2003 in the Alps.	EARSeL Workshop on Remote Sensing of Land Ice and Snow, Bern, 21.-23.2. 2005. *EARSeL eProceedings* **4**, *2/2005 CD-ROM.*	139-149	ALP-IMP-rev-18
Brunetti M, Maugeri M, Monti F, Nanni T	2006	The Variability and Change of Italian climate in the last 160 years	*Il Nuovo Cimento* **29 C** N 1, 3-12 DOI 10.1393/ncc/i2005-10215-1, 2006	3-12	ALP-IMP-rev-19
Auer I, Böhm R, Jurkovic A, Lipa W, Orlik A, Potzmann R, Schöner W, Ungersböck M, Matulla C, Brunetti M, Nanni T, Maugeri M, Mercalli L, Briffa K, Jones P, Efthymiadis D, Mestre O, Moisselin JM, Begert M, Müller-Westermeier G, Kveton V, Bochnicek O, Stastny P, Lapin M, Nieplova E, Cegnar T, Dolinar M, Gajic-Capka M, Zaninovic K, Majstorovic Z, Szalai S,	2006	HISTALP - Historical instrumental climatological surface time series of the Greater Alpine Region 1760-2003	*International Journal of Climatology,* in press, published online: DOI: 10.1002/joc.1377		ALP-IMP-rev-20

ALP-IMP PUBLICATION LIST continued			PEER REVIEWED ARTICLES		
Authors	**Date**	**Title**	**Journal**	**Reference**	**ALP-IMP ref-ID**
Brunetti M, Maugeri M, Nanni T, Auer I, Böhm R, Schöner W	2006	Precipitation variability and changes in the greater Alpine region over the 1800-2003 period	Journal of Geophsical Research **111** D11, D11107		ALP-IMP-rev-21
Grabner, M., Klein, A., Geihofer, D., Reschreiter, H., Barth, F.E., Sormaz, T., Wimmer, R.	2006	Bronze Age dating of timber from the salt-mine at Hallstatt, Austria.	accepted for: *Dendrochronologia*		ALP-IMP-rev-22
Leal, S., Melvin, T.M., Grabner, M., Wimmer, R., Briffa, K.R.	2006	Extreme growth years in relation to climate in precipitation sensitive Pinus nigra Arn. Trees growing in Austria	in preparation for: *New Phytologist*		ALP-IMP-rev-23
Leal, S., Eamus, D., Grabner, M., Wimmer, R., Cherubini, P.	2006	Tree rings of *Pinus nigra* Arn. from the Vienna basin region (Austria) show evidence of CO_2-induced change in sensitivity to water availability and temperature	submitted to: *Global Change Biology*		ALP-IMP-rev-24
Leal, S., Melvin, T.M., Grabner, M., Wimmer, R., Briffa, K.R.	2006	Tree ring-growth variability in the Austrian Alps: the influence of site altitude, tree species and climate	submitted to: *Boreas*		ALP-IMP-rev-25
van der Schrier G, Efthimiadis D, Briffa K, Jones P	2006	European Alpine moisture variability for 1800-2003	*International Journal of Climatology,* in press, published online: (www.interscience.wiley.com) DOI: 10.1002/joc.1411		ALP-IMP-rev-26
Schöner W and Böhm R	2006	A statistical mass balance model for reconstruction of LIA ice mass of glaciers of the European Alps	submitted to: *Annals of Glaciology* (IGS-Cambridge)		ALP-IMP-rev-27
Hoelzle M, Chinn T, Stumm, Paul F, Zemp M, Haeberli W	2006	The applicaton of glacier inventory data for estimating past climate-change effects on muntain glaciers: a comparison between the European Alps and the Southern Alps of New Zealand	in press (published online: www.sciencedirect.com) *Global and Planetary Change,* special issue on climate change impacts on glaciers and permafrost.		ALP-IMP-rev-28
Zemp M, Hoelzle M. and Haeberli W	2006	Distributed modelling of the regional climatic equilibrium line altitude of glaciers in the European Alps.	*in press:* (published online: www.sciencedirect.com) *Global and Planetary Change, special issue on climate change impacts on glaciers and permafrost.*		ALP-IMP-rev-29
Zemp, M., Haeberli, W., Hoelzle, M. and Paul, F.	2006	Alpine glaciers to disappear within decades?	*Geophysical Research Letters* **33** in press, published online doi:10.1029/2006GL026319, 2006		ALP-IMP-rev-30
Paul, F. Maisch, M., Rothenbühler, C., Hoelzle, M. and Haeberli, W.	2006	Calculation of future glacier extent in the Swiss Alps by means of hypsographic modelling.	*Global and Planetary Change.* In press		ALP-IMP-rev-31
Büntgen U, Frank DC, Schmidhalter M, Neuwirth B, Seifert M, Esper J	2006	Growth/climate response shift in a long subalpine spruce chronology	*Trees - Structure and Function* **20**	99-110	ALP-IMP-rev-32
Büntgen U, Frank DC, Nievergelt D, Esper J	2006	Summer temperature variations in the European Alps: AD 755-2004	*Journal of Climate,* accepted		ALP-IMP-rev-33
Büntgen U, Frank DC, Kaczka RJ, Verstege A, Zwijacz-Kozica T, Esper J	2006	Growth/climate response of a multi-species tree-ring network in the Western Carpahian Tatra Mountains, Poland and Slovakia	*Tree Physiology* **27**, accepted		ALP-IMP-rev-34
Esper j, Büntgen U, Frank DC, Nievergelt D, Liebhold A	2006	Insect outbreak clockwork stops after 1200 years	submitted to: *Proceedings of the Royal Society: B,* in review		ALP-IMP-rev-35
Treydte K, Schleser GH, Helle G, Frank DC, Winiger M, Haug G, Esper J	2006	The twentieth century was the wettest period in northern Pakistan over the past millennium	*Nature* **44**	1179-1182	ALP-IMP-rev-36
Wilson RJS, Frank DC, Topham J, Nicolussi K, Esper J	2005	Problems and opportunities for the spatial reconstruction of summer temperatures in central Europe	*Boreas* **34**	490-497	ALP-IMP-rev-37
Nicolussi K , Kaufmann M, Patzelt G, van der Plicht J, Thurner A	2006	Holocene tree-line variability in the Kauner Valley, Central Eastern Alps, indicated by dendrochronological analysis of living trees and subfossil	*Vegetation History and Archaeobotany* **14**	221-234.	ALP-IMP-rev-38
Melvin T., Brifffa K., Nicolussi K., Grabner M.	2006	Time-varying response smoothing	accepted for*: Dendrochronologia*		ALP-IMP-rev-39
Nicolussi K., Pichler T., Kaufmann M., Thurner A		Years of extreme tree-ring growth during the last millennium in the European Alps	in preparation for: *Dendrochronologia*		ALP-IMP-rev-40
Nicolussi K., Böhm R., Briffa K.R., Melvin T., Thurner A		A summer temperature reconstruction for the last 2000 years	in preparation for: *The Holocene*		ALP-IMP-rev-41
Nicolussi K., Kaufmann M.		Evolution of the tree line in the central European Alps during the last 2000 years	in preparation for: *Arctic, Antarctic and Alpine Research*		ALP-IMP-rev-42
Efthymiadis D, Jones PD, Briffa K, Böhm R, Maugeri M	2006	Influence of large-scale atmospheric circulation on climate variability in the Greater Alpine Region of Europe	submitted to: *Journal of Geophysical Research*		ALP-IMP-rev-43
Frank D, Büntgen U, Böhm R, Maugeri M, Esper J	2006	Warmer early instrumental measurements versus colder reconstructed temperatures: hemispheric to regional evidence	submitted to: *Quaternary Science Reviews (Rapid Communication)*		ALP-IMP-rev-44

ALP-IMP PUBLICATION LIST continued			PEER REVIEWED ARTICLES		
Authors	**Date**	**Title**	**Journal**	**Reference**	**ALP-IMP ref-ID**
Brunetti M, Lentini GL, Maugeri M, Nanni T, Auer I, Böhm R, Schöner W	post project	Climate variability and change in the Greater Alpine Region over the last two centuries based on multiple variable analysis	in preparation for a peer reviewed journal		ALP-IMP-rev-45
Böhm R, Brunetti M and co-authors	post project	Trends of climate variability in the European Alps in the past 2 centuries	in preparation for a peer reviewed journal		ALP-IMP-rev-46
Böhm R, Brunetti M, Jones P, Maugeri M, Ungersböck M	post project	An independent confirmation of past decadal-scale temperature increase by high- and low elevation air pressure series from the European Alps	in preparation for a peer reviewed journal		ALP-IMP-rev-47
Prömmel K, Geyer B, Jones JM, Widmann M	2006	Evaluation of the skill and added value of a reanalysis-driven regional simulation for Alpine temperature	submitted to: *Climate Dynamics*		ALP-IMP-rev-48
Scheifinger H, Böhm R, Widmann M, Frei Ch	post project	Climatological evaluation of the REMO (REgional MOdel) precipitation simulation over the Greater Alpine Region 1971 – 1999.	in preparation for a peer reviewed journal		ALP-IMP-rev-49
Jones PD, Briffa K, Melvin T, Böhm R, Schöner W, Büntgen U, Esper J, Frank D, Grabner M, Nicolusi K, Hoelzle M, Zemp M, Haeberli W + co-authors still to be decided	post project	Climate variability in the alpine region over the last millennium in a European context	in preparation for: *Geophysical Research Letters* or *Journal of Geophysical Research*		ALP-IMP-rev-50
Schöner W, Auer I and Böhm R	2007	Long term trend of snow depth at Sonnblick (Austrian Alps) and its relation to climate change	*submitted to: Hydrological Processes,* special issue: Hydrometeorology and Snow Seasonality in Mountains		ALP-IMP-rev-51
Grabner M plus author-consortium from partners 9, 2, 10	post project	Temperature reconstruction at the mountain Dachstein, Austria	in preparation for a peer reviewed journal		ALP-IMP-rev-52
Grabner M plus author-consortium from	post project	Reconstructing early summer precipitation at Eastern Austria with the help of tree-rings	in preparation for a peer reviewed journal		ALP-IMP-rev-53
Sturm K, Hoffmann G, Langmann B, Stichler W	2005	Simulations of $d^{18}O$ in precipitation by the regional circulation model $REMO_{iso}$.	*Hydrological Processes* **19**	3425-3444	ALP-IMP-rev-54
Sturm K, Hoffmann G, Langmann B	2006	Simulation of the stable water isotopes in precipitation over South America: comparing regional to global circulation models	under revision at: *Journal of Climate*		ALP-IMP-rev-55
Frank D, Büntgen U, Esper J, Pichler T, Nicolussi K	post project	Temperature variability in the Alps: extension and update of the Tyrol dataset	in preparation for a peer reviewed journal		ALP-IMP-rev-56
author consortium of partners7 and 4	post-project	High-Resolution Modelling of Water Isotopes in Western Europe and the Greater Alpine Region: From day-to-day variability to climatological isotope/temperature relationships.	in preparation for a peer reviewed journal		ALP-IMP-rev-57
author consortium of partners 7 and 4	post-project	Using high resolution modelling to construct an archive transfer function for high Alpine water isotope records	in preparation for a peer reviewed journal		ALP-IMP-rev-58
Haeberli W, Hoelzle M, Paul F, Zemp M	2006	Integrated monitoring of mountain glaciers as key indicators of global climate change: the European Alps	acceoted for: *Annals of Glaciology*		ALP-IMP-rev-59
Paul F, Wipf A, Maisch M, Hoelzle M, Haeberli W	2006	Long-term changes in alpine glaciervolume obtained by six independent approaches	*Annals of Glaciology* in review		ALP-IMP-rev-60
Nicolussi K, Briffa K., Melvin T, Thurner A	post project	Reconstruction of the temperature variability of the last 2000 years, based on dendroclimatological analysis of Pinus cembra tree-ring data from the central eastern Alps and by using the new Alpine temperature data set	The paper extends already established summer temperature reconstructions to the Roman Period. It's based on measurements of total tree-ring of high elevated samples from living trees and subfossil material from the central Eastern Alps.		ALP-IMP-rev-61
Thurner A, Pichler T, Kaufmann M, Nicolussi K	post project	Analysis of a multi-species tree-ring width data set, mainly historical samples from the eastern Alps, establishment of a record of synchronous extreme growth events, analysis of climatic forcing	The paper establishes a record of "event years" of three different Alpine tree-species (Larix decidua, Picea abies, Pinus cembra). The analyses are mainly based on the historical tree-ring data set (some 2400 samples) of the western part of the Eastern Alps		ALP-IMP-rev-62
Nicolussi K, Pichler T	post project	title yet to bed decided	The paper presents the dendrochronological results of the investigation of one of the oldest Alpine farmhouses		ALP-IMP-rev-63

ALP-IMP PUBLICATION LIST

Part 2:

other publications

status: 31 October 2006

ALP-IMP PUBLICATION LIST version 2006-10			OTHER PUBLICATIONS			
(conference papers, non reviewed journals, stand alone publications, PhD and Diploma theses, popular science articles,…)						
Authors/Editors	**Date**	**Title**	**Event**	**Reference**	**Type***	**ALP-IMP ID**
Böhm R, Auer I, Ungersböck M, Schöner W, Huhle C, Nanni T, Brunetti M, Maugeri M, Mercalli L, Gajic-Capka M et	May 2003	Mesoscale patterns of long-term precipitation variability in the greater alpine region	ICAM-03: International Conference on Alpine Meteorology	Binder P, Richner H, Schär Ch (eds): ICAM-03 Extended Abstracts, *Publications of MeteoSwiss* **66** 555	abstract (of an oral presentation)	ALP-IMP nrev-1
Böhm R.,Auer I, Schöner W, Ungersböck M, Huhle C, Nanni T, Brunetti M, Maugeri M, Mercalli L, Gajic-Capka M, Zaninovic K, Szalai S, Szentimrey T, Cegnar T, Bochnicek O, Begert M, Mestre O, Moisselin JM, Müller-Westermeier G, Majstorovic Z	Sep. 2003	Der Alpine Niederschlagsdipol – ein dominierendes Schwankungsmuster der Klimavariabilität in den Scales 100 km – 100 Jahre *(The alpine precipitation dipole - a dominant climate variability pattern at the scales of 100 km - 100 years)*	6. Deutsche Klimatagung - Klimavariabilität, 22.9. - 25.9.2003, Potsdam (DE) *(6th German climate conference - climate variability)*	Negendank FW, Ristedt H (eds), 2003: *Terra Nostra* **2003/6**, 61-65	extended abstract (of an oral presentation)	ALP-IMP nrev-2
Scheifinger H, Böhm R, Auer I	Sep. 2003	Räumliche Dekorrelation von Klimazeitreihen unterschiedlicher zeitlicher Auflösung und ihre Bedeutung für ihre Homogenisierbarkeit und die Repräsentativität von Ergebnissen *(Spatial de-correlation of climate time series of different time-resolution and it's relevance for homogenization and spatial representation of results)*	6. Deutsche Klimatagung - Klimavariabilität, 22.9. - 25.9.2003, Potsdam (DE) *(6th German climate conference - climate variability)*	Negendank FW, Ristedt H (eds), 2003: *Terra Nostra* **2003/6**, 375-379	extended abstract (of an poster)	ALP-IMP nrev-3
Roswitha Drosg, Walter Kutschera, Martin Schock, Peter Steier, Dietmar Wagenbach, Eva Maria Wild	Sep. 2003	Radiocarbon determination of particulate organic carbon in glacier ice	18th International Radiocarbon Conference in Wellington, New Zealand, 1-5 September 2003	Proceedings of the 18th International Radiocarbon Conference (in Press)	abstract (of an oral presentation)	ALP-IMP nrev-4
Böhm R	Apr. 2004	Systematische Rekonstruktion von zweieinhalb Jahrhunderten instrumentellem Klima in der größeren Alpenregion – ein Statusbericht (*Systematic reconstruction of two and a half centuries of instrumental climate in the greater alpine region - a status report*)	54. Deutscher Geographentag, Bern (CH) 28.9.2003 bis 4.10.2003 *(54th German Geographer's Day)*	Gamerith, W., Messerli, P., Meusburger, P., Wanner, H. (Hrsg.) (2004): Alpenwelt – Gebirgswelten. Inseln, Brücken, Grenzen. Tagungsbericht und wissenschaftliche Abhandlungen, 121-131	invited contribution (of an oral presentation)	ALP-IMP nrev-5
Böhm R, Auer I, Jurkovic A, Orlik A, Potzmann R, Schöner W, Ungersböck M, Brunetti M, Maugeri M, Nanni T, Jones P, Briffe K, Efthimiadis D	Apr. 2004	Die neuen ALP-IMP - CLIVALP Klimadatensätze - Neuerungen, Datenqualität unsd erste Ergebnisse *(The new ALP-IMP - CLIVALP datasets - news, data quality and first results)*	8. Österreichischer Klimatag, 19. und 20.Apr. 2004, Wien (AT) (8th Austrian Climate Day)	http://oegm.boku.ac.at/Veranstaltungen/klimatag08.html	ppt-file of poral presentation	ALP-IMP nrev-6
Paul, F., Kääb, A., Maisch, M., Kellenberger, T. W. and Haeberli, W.	2003	Das neue Schweizer Gletscherinventar: Anwendungen in der Gebirgskartographie. (*The new Swiss glacier inventory: Applications in mountain catography*)		*Kartographische Nachrichten* **5** 212-217.	atricle in a non reviewed journal	ALP-IMP nrev-7

ALP-IMP PUBLICATION LIST continued			OTHER PUBLICATIONS			
Authors/Editors	**Date**	**Title**	**Event**	**Reference**	**Type***	**ALP-IMP ID**
Haeberli, W., Paul, F., Gruber, S., Hoelzle, M., Kääb, A., Machguth, H., Noetzli, J., Rothenbühler, C.	2004	Effects of the extreme summer 2003 onglaciers and permafrost in the Alps - first impressions and estimations.	EGU 1st General Assembly, Nice, 25-30 April 2004	*Geophysical Research Abstracts* , **6,** 2004, CD-ROM (ISSN: 1029-7006)	abstract (of an oral presentation)	ALP-IMP nrev-8
Hoelzle, M., Zemp, M., Frauenfelder, R. and Haeberli, W.	2004	Integration of alpine glacier monitoring into the GTN-G network of the global climate observing system (GCOS) by applying the global hierarchical observing strategy (GHOST). A discussion report.	EGU 1st General Assembly, Nice, 25-30 April 2004	*Geophysical Research Abstracts* , **6,** 2004, CD-ROM (ISSN: 1029-7006)	abstract (of an oral presentation)	ALP-IMP nrev-9
Zemp, M. and Hoelzle, M.	2004	Revision and expansion of World Glacier Monitoring Service's database	EGU 1st General Assembly, Nice, 25-30 April 2004	*Geophysical Research Abstracts* , **6,** 2004, CD-ROM (ISSN: 1029-7006)	abstract (of an oral presentation)	ALP-IMP nrev-10
Machguth, H.; Paul, F.;Hoelzle, M. and Haeberli, W.	2004	Calculating distributed glacier mass balance over entire mountain groups.	EGU 1st General Assembly, Nice, 25-30 April 2004	*Geophysical Research Abstracts* , **6,** 2004, CD-ROM (ISSN: 1029-7006)	abstract (of an oral presentation)	ALP-IMP nrev-11
Paul, F.; Machguth, H.; Hoelzle, M.; Salzmann, N. and Haeberli, W.	2004	Application of a distributed glacier mass balance model to the western part of the Swiss Alps	EGU 1st General Assembly, Nice, 25-30 April 2004	*Geophysical Research Abstracts* , **6,** 2004, CD-ROM (ISSN: 1029-7006)	abstract (of an oral presentation)	ALP-IMP nrev-12
Auer I, Böhm R, Scheifinger H, Ungersböck M, Orlik A, Jurkovic A	Sep. 2004	Metadata and their role in homogenising	Fourth Seminar for Homogenization and Quality Control in Climatological Databases, 6.-10.10.2003, Budapest	Szalai S, Szentimrey T (eds.), 2004: Proceedings of the 4th Seminar for... *WMO-WCDMP* **56**, *WMO-TD* **1236** 17-23	extended abstract (of an oral presentation)	ALP-IMP nrev-13
Büntgen U, Esper J, Frank DC, Nicolussi K, Schmidhalter M, Seifert M	2005	The effect of power transformation on RCS – case study from 3 millennial-length alpine chronologies	TRACE Dendrosymposium 2004 April 22nd-24th, Birmensdorf, Switzerland	*TRACE* **3** 141-149	invited contribution (of an oral presentation)	ALP-IMP nrev-14
Scheifinger H, Böhm R	2004	Räumliche Dekorrelation und Homogenisierbarkeit von Klimazeitreihen	DACH-2004 Meteorologen-Tagung, 7.-10.9.2004, Karlsruhe	Extended Abstracts CD, P12.21	extended abstract (of a poster presentation)	ALP-IMP nrev-15
Matulla C, Auer I, Böhm R, Ungersböck M, Schöner W, Wagner S, Zorita E	Apr.05	Outstanding past decadal-scale climate events in the Greater Alpine Region analysed by 250 years data and model runs		*GKSS-Report* **2005-04**, 1-115	extended stand-alone publication in a non reviewed institute series	ALP-IMP nrev-16
Leal, S., Melvin T.M., Grabner, M., Wimmer, R., Briffa, K.R.	Sep.04	Tree-ring width variability in the Austrian Alps and its relation with climate	Eurodendro 2004, September 15.-19., 2004, Rendsburg, Germany	Proceedings of the EuroDendro 2004, September 15.-19., 2004, Rendsburg, Germany: 29-30	abstract of a poster	ALP-IMP nrev-17
Auer I, Böhm R, Matulla C, Ungersböck M, Nanni T, Maugeri M, Pastorelli R	Sep.04	Frost occurrence in the European Alps - A view into the future and into the past	4th Annual Meeting of the European Meteorological Society, 26-30 Sept. 2004, Nice	EMS Annual Meeting Abstracts CD Vol.1, 00167, 2004	abstract proceedings	ALP-IMP nrev-18
Böhm R, Auer I, Potzmann R, Schöner W, Ungersböck M, Brunetti M, Nanni T, Maugeri M	Sep.04	Homogenising 192 precipitation time series in the greater alpine region (GAR) - A field report on theoretical and practical problems and solutions	4th Annual Meeting of the European Meteorological Society, 26-30 Sept. 2004, Nice	EMS Annual Meeting Abstracts CD Vol.1, 00168, 2004	abstract proceedings	ALP-IMP nrev-19
Böhm R, Auer I, Schöner W, Brunetti M, Nanni T, Maugeri M, Jones PD, Briffa K, Efthymiadis D	Sep.04	4-dimensional precipitation patterns in the greater alpine region - re-analysed with the new HISTALP dataset	4th Annual Meeting of the European Meteorological Society, 26-30 Sept. 2004, Nice	EMS Annual Meeting Abstracts CD Vol.1, 00169, 2004	abstract proceedings	ALP-IMP nrev-20

ALP-IMP PUBLICATION LIST continued			**OTHER PUBLICATIONS**			
Authors/Editors	**Date**	**Title**	**Event**	**Reference**	**Type***	**ALP-IMP ID**
Zemp, M., Paul, F., Hoelzle, M., Haeberli, W. and Frauenfelder, R.	Oct.04	Spatio-temporal analysis of 150 years of Alpine glacier fluctuations.	International and Interdisciplinary Workshop on Mountain Glaciers and Society, Wengen, October 6 - 9, 2004.	Proceedings volume not yet available	pdf of poster	ALP-IMP nrev-21
Schöner W, Auer I, Böhm R, Briffa K, Efthymiadis D, Jones PD, Widmann M, Brunetti M, Nanni T, Maugeri M	Oct.04	Long-term gridded air temperature and precipitation for the Greater Alpine Region	Conference on Spatial Interpolation Techniques in Climatology and Meteorology, 25. to 29. October 2004, Budapest	Proceedings volume not yet available	extended abstract (of an oral presentation)	ALP-IMP nrev-22
Zemp, M., Paul, F., Hoelzle, M., Haeberli, W. and Frauenfelder, R.	Feb.05	Spatio-temporal analysis of 150 years of Alpine glacier fluctuations.	9th Alpine Glaciology Meeting, Milano, February 24 - 25, 2005.	http://users.unimi.it/glaciol/9agm/zemp.pdf	abstract (of an oral presentation)	ALP-IMP nrev-23
Zemp, M., Hoelzle, M., Paul, F. and Haeberli, W.	Apr.05	Distributed Modelling of Regional Equilibrium Line Altitude in the European Alps: First Results and Discussion Report.	EGU 2nd General Assembly, Vienna, 25-29 April 2005.	*Geophysical Research Abstracts* , 7, 2005, CD-ROM (ISSN: 1029-7006)	abstract (of an oral presentation)	ALP-IMP nrev-24
Zemp, M., Paul, F., Hoelzle, M., Frauenfelder, R. and Haeberli, W.	Apr.05	Spatio-temporal Analysis of 150 Years of Alpine Glacier Fluctuations.	EGU 2nd General Assembly, Vienna, 25-29 April 2005.	*Geophysical Research Abstracts* , 7, 2005, CD-ROM (ISSN: 1029-7006)	abstract (of a poster)	ALP-IMP nrev-25
Hoelzle, M., Chinn, T., Stumm, D., Paul, F., Zemp, M. and Haeberli, W.	Apr.05	Application of inventory data for estimating characteristics of and regional climate-change effects on mountain glaciers: a comparison between the European Alps and the New Zealand Alps.	EGU 2nd General Assembly, Vienna, 25-29 April 2005.	*Geophysical Research Abstracts* , 7, 2005, CD-ROM (ISSN: 1029-7006)	abstract (of a poster)	ALP-IMP nrev-26
Böhm R, Auer I, Jurkovic A, Orlik A, Potzmann R, Schöner W, Ungersböck M	Apr.05	Climate variability changes in the greater alpine region in the past two centuries	EGU General Assembly 2005, 24-29 April 2005, Vienna, Austria	*Geophysical Research Abstracts* **7** 06634 2005 Sref-ID: 1607-7962/gra/EGU05-A-06634	abstract	ALP-IMP nrev-27
Pettinger M, Keck L, Fischer H, Wagenbach D, Preunkert S, Böhm R, Hoelzle M, Leuenberger M Hoffmann G	Apr.05	Centennial scale isotope thermomentry from Alpine ice core records: shortcomings and challenges	EGU General Assembly 2005, 24-29 April 2005, Vienna, Austria	*Geophysical Research Abstracts* **7** 07941 2005 Sref-ID: 1607-7962/gra/EGU05-A-07941	abstract	ALP-IMP nrev-28
Arnold W	Jan-2005	Schwarzwild: Hintergründe einer Explosion (Wild boars: background of an explosion)		*Waidwerk* **1/2005** 8-11	atricle in a non reviewed journal	ALP-IMP nrev-29
Böhm R	2004-09	Daten von Gestern für Lösungen von Morgen (Yesterday's data for tomorrow's solutions)		*Innovativ* **2004/05** 22-25	article in a popular science journal	ALP-IMP nrev-30
Böhm R	2004-10	Systematische Rekonstruktion von zweieinhalb Jahrhunderten instrumentellem Klima in der größeren Alpenregion – ein Statusbericht.		*In: Gamerith, W., Messerli, P., Meusburger, P., Wanner, H. (Hrsg.) (2004): Alpenwelt – Gebirgswelten. Inseln, Brücken, Grenzen. Tagungsbericht und wissenschaftliche Abhandlungen. 54. Deutscher Geographentag, Bern 2003. 28.9. bis 4.10.2003. – Heidelberg, Bern.*	invited article in the proceedings of the 54th German Geographer's Day 2004, Berne, Switzerland, 121-131	ALP-IMP nrev-31
Böhm R, Auer I, Schöner W	May.05	Exploring past climate variability in the greater alpine region	28th International Conference on Alpine Meteorology, Zadar, 23-27 May 2005	*Croatian Meteorological Journal* **40** 106-110	extended abstract (of an oral presentation)	ALP-IMP nrev-32

ALP-IMP PUBLICATION LIST continued			**OTHER PUBLICATIONS**			
Authors/Editors	**Date**	**Title**	**Event**	**Reference**	**Type***	**ALP-IMP ID**
Efthymiadis D, Jones PD, Briffa K, Auer I, Böhm R, Schöner W, Frei C, Schmidli J	May.05	A new high-resolution bi-centenial (1800-2003) precipitation dataset for the greater alpine region	28th International Conference on Alpine Meteorology, Zadar, 23-27 May 2005	*Croatian Meteorological Journal* **40** 111-113	extended abstract (of an oral presentation)	ALP-IMP nrev-33
Auer I, Böhm R, Potzmann R, Schöner W, Müller-Westermeier G, Kveton V, Cegnar T, Dolinar M, Gajic-Capka M, Zaninovic K, Maugeri M, Brunetti M, Nanni T, Carrer M, Mercalli L, Majstorovic Z, Begert M, Moisselin J-M, Ceron J-P, Bochnicek O, Zitari B, Nola P	May.05	A high resolution temperature climatology for the Greater Alpine Region (GAR)	28th International Conference on Alpine Meteorology, Zadar, 23-27 May 2005	*Croatian Meteorological Journal* **40** 593-596	ppt-file of poster	ALP-IMP nrev-34
Brunetti M, Nanni T, Maugeri M, Auer I, Böhm R, Schöner W, Briffa K, Efthymiadis D, Jones PD	May.05	Patterns of precipitation variability in the greater alpine region	28th International Conference on Alpine Meteorology, Zadar, 23-27 May 2005	*Croatian Meteorological Journal* **40** 597-600	extended abstract (of a poster)	ALP-IMP nrev-35
Jurkovic A, Auer I, Böhm R, Debit S, Orlik A, Schöner W	May.05	The new centennial snow initiative for the greater alpine region (GAR). Status report and first results	28th International Conference on Alpine Meteorology, Zadar, 23-27 May 2005	*Croatian Meteorological Journal* **40** 601-603	extended abstract (of a poster)	ALP-IMP nrev-36
Proemmel, K., B. Mueller, M. Widmann, and J. M. Jones	May.05	Comparison of a high-resolution regional simulation and the ERA40 reanalysis over the Alpine region	28th International Conference on Alpine Meteorology, Zadar, 23-27 May 2005	*Croatian Meteorological Journal* **40** 369-372	extended abstract (of a poster)	ALP-IMP nrev-37
Schöner W, Böhm R, Zemp M	May.05	First climate related analyses of a recovered Alpine long-term glacier variability dataset	28th International Conference on Alpine Meteorology, Zadar, 23-27 May 2006	*Croatian Meteorological Journal* **40** 584	extended abstract (of an oral presentation)	ALP-IMP nrev-38
Grabner, M., Wimmer, R.	March 06	Dendroklimatologie - Klimainformationen in der Holzstruktur	9. Österreichischer Klimatag, Vienna	http://www.austroclim.at/index.php?id=39	extended abstract (of a poster)	ALP-IMP nrev-39
Geihofer, D., Grabner, M., Gelhart, J., Wimmer, R., Fuchsberger, H.	October 05	New master chronologies from historical and archaeological timber in Eastern Austria	Eurodendro 2005, 29 Sep - 1 Oct. 2005, Viterbo	Proceedings of the EuroDendro 2005 50-51	pdf of an oral presentation	ALP-IMP nrev-40
Grabner, M., Klein, A., Geihofer, D., Reschreiter, H., Barth, F.E., Sormaz, T.,	October 05	First dendrochronological results from the Bronze Age salt mine at Hallstatt, Austria	Eurodendro 2005, 29 Sep - 1 Oct. 2005, Viterbo	Proceedings of the EuroDendro 2005 20	pdf of an oral presentation	ALP-IMP nrev-41
Böhm R.	March 06	Hat die Klimavariabilität im Alpenraum zugenommen? Eine Flash-Studie mit ~200-jährigen HISTALP Daten (Did climate variability change in the Alpine realm? A flash-study based on ~200 years of HISTALP data)	9. Österreichischer Klimatag, Vienna	http://www.austroclim.at/index.php?id=39	pdf of an oral presentation	ALP-IMP nrev-42
Ingeborg Auer, Reinhard Böhm, Anita Jurkovic, Alexander Orlik, Wolfgang Schöner, Markus Ungersböck	March 06	HISTALP – 250 Jahre instrumentelle Klimareihen im Großraum Alpen – Status und erste Analysen (HISTALP - 250 years of instrumental climate series in the greater Alpine region - status and first results)	9. Österreichischer Klimatag, Vienna	http://www.austroclim.at/index.php?id=40	English-ppt-version of a poster	ALP-IMP nrev-43

ALP-IMP PUBLICATION LIST continued			OTHER PUBLICATIONS			
Authors/Editors	**Date**	**Title**	**Event**	**Reference**	**Type***	**ALP-IMP ID**
Prömmel,K., M. Widmann, J.M. Jones, and B Geyer	Mar.06	High-resolution simulation for the Alpine climate since 1958 - validation on mothly and daily timescales	Annual WGNE-meeting 2006	WGNE Blue Series, Reprt on WGNE-meeting 2006, Section 5, 46-47	report	ALP-IMP nrev-44
Zemp, M., Hoelzle, M., Paul, F. and Haeberli, W.	2005	Glaciers and climate change – past and present spatial glacier variability within the European Alps.	4th International NCCR Climate Summer School, Grindelwald.		abstract (of a poster)	ALP-IMP nrev-45
Zemp, M., Hoelzle, M. and Haeberli, W.	2005	Glaciers and climate change – Distributed modelling of the regional climatic equilibrium line altitude of glaciers in the European Alps.	3rd Swiss Geoscience Meeting, Zurich.		abstract (of an oral presentation)	ALP-IMP nrev-46
Zemp, M., Paul, F., Hoelzle, M. and Haeberli,	2005	Glaciers and climate change – Spatio-temporal analysis of 150 years of glacier fluctuations in the European Alps.	3rd Swiss Geoscience Meeting, Zurich.		abstract (of an oral presentation)	ALP-IMP nrev-47
Zemp, M., Paul, F., Hoelzle, M. and Haeberli, W.	2006	Past, present and future glacierisation in the European Alps.	EGU General Assembly, Vienna.	Geophysical Research Abstracts, Vol. 8, 06556, 2006; SRef-ID: 1607-7962/gra/EGU06-A-06556	abstract (of an oral presentation)	ALP-IMP nrev-48
Zemp, M., Haeberli, W., Hoelzle, M. and Paul, F.	2006	Potential sea level rise estimates from the glacierisation of an entire mountain range as exemplified with observations from the European Alps	WCRP Workshop on Understanding Sea-level Rise and Variability		abstract (of a poster)	ALP-IMP nrev-49
F. Paul, F., Kotlarski, S. and Hoelzle, M.	2006	Coupling of a distributed glacier mass balance model to the regional climate model REMO: Down-scaling strategy and first results	EGU General Assembly, Vienna.	Geophysical Research Abstracts, Vol. 8, 09019, 2006	abstract (of a poster)	ALP-IMP nrev-50
Paul, F., Rothenbühler, C., Maisch, M., Hoelzle, M. and Haeberli, W.	2006	Assessment of future glacier extent by means of hypsographic and GIS-based modelling	EGU General Assembly, Vienna.	Geophysical Research Abstracts, Vol. 8, 09199, 2006	abstract (of a poster)	ALP-IMP nrev-51
Zemp M, Frauenfelder R, Haeberli W, Hoelzle M	2006	Worldwide glacier mass balance measurements: general trens and first results of the extraordinary year 2003 in Central Europe	DGS St. Petersburg, May 2004	Conference proceedings, full articles	pdf of an oral presentation	ALP-IMP nrev-52
Schöner W	2006	Chapters 2 (Klimaänderung in den Alpen-Climate change in the Alps), Chapter 3 (Gletscheränderung in den Alpen - glacier change in the Alps), Chapter 6 (Auswirkungen der Klimaänderung auf den Apinismus - Impacts of climate change on alpinism) of: Auswirkungen der Klima- und Gletscheränderung auf den Alpinismus (Inpacts of climate- and glacier change on alpinism),		text.um 1/06, Umwelt-Dachverband, Vienna, 2006, 96 pages	4 pdfs: a: contents, b: chapter 1, c: chapter 2, d: chapter 6 of a popular science book on climate impacts on Alpinism)	ALP-IMP nrev-53
Büntgen U, Frank Böhm R, Esper J	2006	Effect of uncertainty in instrumental data on reconstructed temperature amplitude in the European Alps	In: Heinrich I (ed) *TRACE* **4**	38-45	extended abstract	ALP-IMP nrev-54
Nicolussi K., Kaiser K.F., Patzelt G., Schießling P	2005	Precisely dated glacier Glacier advances and retreat periods during the 1st millennium AD in the eastern European Alps	International Glaciological Society – International Symposium on High-Elevation Glaciers and Climate Records. Lanzhou, China, 5.–9. September 2005	Conference proceedings	Abstract	ALP-IMP nrev-55

ALP-IMP PUBLICATION LIST continued			OTHER PUBLICATIONS			
Authors/Editors	**Date**	**Title**	**Event**	**Reference**	**Type***	**ALP-IMP ID**
Nicolussi K., Kaufmann M., Patzelt G., Plicht van der J., Thurner A	2005	A Holocene tree-line record from the Central Eastern Alps, based on the dendrochronological analysis of living trees and subfossil logs	EuroDendro 2005, 28.September – 2. Oktober 2005, Viterbo	Proceedings of the EuroDendro 2005 60-61	Abstract	ALP-IMP nrev-56
Nicolussi K	2006	Gletscher der Alpen – vom Anwachsen und Abschmelzen	In: Slupetzky H. (Hrsg.): Bedrohte Alpengletscher. *Alpine Raumordnung*	**27**: 47-49	atricle in a non reviewed journal	ALP-IMP nrev-57
Nicolussi K., Patzelt G.	2006	Klimawandel und Veränderungen an der alpinen Waldgrenze – aktuelle Entwicklungen im Vergleich zur Nacheiszeit	*BFW-Praxisinformation*	**2006/10**, 3-5.	atricle in a non reviewed journal	ALP-IMP nrev-58
Böhm R	2006	Klimawandel oder Klimavariation?	*BFW-Praxisinformation*	**2006/10**, 6-8.	atricle in a non reviewed journal	ALP-IMP nrev-59
Pichler T., Nicolussi K	2006	Zur Bauentwicklung der Obermairalm am Fuchsberg – Ergebnisse dendrochronologischer Analysen	*Der Schlern*	**80/4**, 4-11	atricle in a non reviewed journal	ALP-IMP nrev-60
Nicolussi K., Stötter H	2006	Zur Geschichte der Gletscher der nördlichen Ortlergruppe im 19. und 20. Jh.	*Der Schlern*	**80**, in print	atricle in a non reviewed journal	ALP-IMP nrev-61
Auer I, Böhm R, Jurkovic A, Orlik A, Schöner W, Ungersböck M	2006	HISTALP – 250 years of instrumental climate in the alpine realm – status and first results	EMS-ECAC 2006, 4.-7.Sep. 2006, Ljubljana	*EMS Annual Meeting Abstracts* **3 2006** CD ISSN 1812-7053	ppt of poster	ALP-IMP nrev-62
Böhm R	2006	Trends of climate variability in Central Europe in the past 200 years – derived from early-instrumental monthly time series	EMS-ECAC 2006, 4.-7.Sep. 2006, Ljubljana	*EMS Annual Meeting Abstracts* **3 2006** CD ISSN 1812-7054	ppt of oral presentation	ALP-IMP nrev-63
Paul F, Maisch M, Rothenbühler Ch, Hoelzle M, Haeberli W	2006	Hypsographic modelling as a tool for assessment of future glacier extent in the Swiss Alps	4th Swiss Geoscience Meeting, Bern 2006	Proceedings of 4th SGM 2006	extended abstract	ALP-IMP nrev-64
Paul F	2006	Gletscherschwund in den Alpen: Beobachtungen und Konsequenzen (Vanishing of glaciers in the Alps: Observations and consequences)	Hutter CP und Link FG (Eds): Warnsignal Klimawandel: Wird Wasser knapper?. *Beiträge der Akademie für Natur- und Umweltschutz Baden-Württemberg* Wissenschaftliche Verlagsgesellschaft mbH, Stuttgart	**42**, 49-60	atricle in a non reviewed journal	ALP-IMP nrev-65
Scheifinger, H, Böhm R, Widmann H and Frei Ch	2006	Climatological evaluation of the REMO (REgional MOdel) precipitation simulation over the Alps 1971 – 1999.	EGU, 2006; ECAC, 2006	Scheifinger, H., R. Böhm, M. Widmann and C. Frei (2006): Climatological evaluation of the REMO (REgional MOdel) precipitation simulation over the Alps 1971 – 1999. Geophysical Research Abstract, Vol. 8, 03583, 2006.	abstract of a poster	ALP-IMP nrev-66

ALP-IMP PUBLICATION LIST continued			OTHER PUBLICATIONS			
Authors/Editors	**Date**	**Title**	**Event**	**Reference**	**Type***	**ALP-IMP ID**
Prömmel K, Geyer B, Widmann M, Jones J	2005	High-resolution simulation for the Alpine climate since 1958 - validation and potential applications for climate reconstruction	4th International NCCR Climate Summer School, Grindelwald.		pdf (of a poster)	ALP-IMP nrev-67
Prömmel K, Widmann M, Jones J, Geyer B	2006	High-resolution simulation for the Alpine climate since 1958 - validation on mothly and daily timescales	3rd ICTP Workshop "Theory and Use of Regional Climate Models", Trieste		pdf (of an oral presentation)	ALP-IMP nrev-68
Nicolussi K, Jörin U, Kaiser KF, Patzelt G, Thurner A	2006	Precisely dated glacier fluctuations in the Alps over the last four millenia	Open science conference on global change in mountain regions, Perth, UK, 2-6 Oct.2005	In: Price MF (ed): Global Change in Mountain Regions. Sapiens Publishing, UK, 59-60	pdf (of an oral presentation)	ALP-IMP nrev-69
Esper J, Büntgen U, Frank D, Pichler T, Nicolussi K	2006	Updating the Tyrol tree-ring dataset	In: Heinrich I (ed) *TRACE* **4**		extended abstract	ALP-IMP nrev-70
ALP-IMP PUBLICATION LIST continued			**PhD and Diploma theses**			
Zemp M.	2006	Glaciers and climate change – Spatio-temporal analysis of glacier fluctuations in the European Alps after 1850.	PhD thesis, University of Zurich	*Schriftenreihe Physische Geographie Glaziologie und Geomorphodynamik* **49** 201 pages	PhD thesis	ALP-IMP th-01
Hiebl J.	2006	The early instrumental climate period (1760-1869) in Europe - Evidence from the Alpine region and Southern Scandinavia	Diploma thesis, Universities of Vienna (Institute of Geography and Regional Studies) and Stockholm (Department of Physical Geography and Quaternary Geology)		Diploma thesis (to be submitted in 2006, draft for internal use on demand of the author)	ALP-IMP th-02
Leal, S.	Post project	Climate variability in Eastern Austria reconstructed by the help of tree-rings	PhD thesis, University of Natural Resources and Applied Life Sciences Vienna		PhD thesis in preparation	ALP-IMP th-03
Frank DC	2005	Temperature Reconstructions from Alpine Tree-Rings.	PhD thesis, University of Bern	107 pages	PhD thesis	ALP-IMP th-04
Büntgen U.	2006	Long-term European climate reconstructions from high-elevation tree-rings	PhD thesis, University of Bern		PhD thesis	ALP-IMP th-05
Brunetti M.	2005	Ricostruzione ed analisi delle variazioni climatiche in Italia negli ultimi due secoli	Dottorato di Ricerca, XVII Ciclo, Università degli Studi di Bologna	157 pages	PhD thesis	ALP-IMP th-06
Jahn F.	2006	Einsatz der Continous Flow Analysis zur vorläufigen Datierung eines alpinen Eiskerns	Diploma thesis, Universiy Heidelberg (Institut für Umweltphysik)	68 pages	Diploma thesis	ALP-IMP th-07
Pettinger M.	Post project	Climate significance of Alpine ice cores	PhD thesis, University Heidelberg	in preparation	PhD thesis	ALP-IMP th-08

ANNEX 3

To final report of
RTD-project ALP-IMP

ALP-IMP STATION LIST

of instrumental sites

of the

HISTALP database

Status: 31 October 2006

HISTALP-monthly - STATIONLIST (stations with homogensised monthly series) Version 2006

station identification				coordinates				starting years of series								
ID	full name	acr.	nat	lon	lat	alt	CRS	N11	P01	P02	P99	R01	SU1	T01	H01	H11
HISTALP ID-number		HISTALP acronym	recent nationality of data provider	deg E	deg N	am above sealevel	coarse resolution subregion	cloudiness	air pressure means (stat. level)	air pressure means (sea level)	air pressure anomalies (both)	precipitation totals	sunshine duration totals	temperature means	relative humidity means	vapour pressure means
1	Admont	ADM	AT	14.45	47.57	646	1	1853				1854		1884		
2	Aix-En-Provence	AIX	FR	5.37	43.50	106	4					1892				
3	Alessàndria	ALS	IT	8.63	44.92	98	4							1865		
4	Altdorf	ALT	CH	8.63	46.87	449	2	1864				1864	1956	1864		
5	Aosta-Airport	AOS	IT	7.30	45.73	544	4							1841		
6	Arezzo	ARE	IT	11.88	43.45	274	3					1876		1879		
256	Arezzo AF	ARZ	IT	11.85	43.47	249	3	1879								
7	Arles - Salins de Giraud	ARL	FR	4.72	43.41	1	4					1882				
8	Arosa	ARO	CH	9.68	46.78	1847	2					1890				
159	Augsburg	AUG	DE	10.93	48.42	463	1	1901	1812		1812	1812	1947	1813		
9	Bad Bleiberg	BBL	AT	13.66	46.62	907	3					1874				
11	Bad Gleichenberg	BGL	AT	15.90	46.87	280	1	1879				1879	1930	1880	1878	1878
12	Bad Ischl	BIL	AT	13.63	47.72	512	1	1864	1855		1855	1858	1880	1855	1860	1860
10	Badgastein-Böckstein	BGA	AT	13.12	47.09	1100	1	1864				1858		1854	1913	
13	Balme	BAL	IT	7.21	45.31	1432	4					1914				
164	Banja Luka	BLU	BA	17.22	44.78	153	3					1881				
14	Bardonecchia	BAR	IT	6.70	45.08	1340	4					1914				
15	Basel - Binningen	BAS	CH	7.60	47.60	316	2	1864	1760		1760	1861	1886	1760		
161	Belfort	BFT	FR	6.85	47.64	422	2					1895				
16	Belluno	BEL	IT	12.22	46.14	404	4					1875		1873		
17	Bern-Liebefeld	BER	CH	7.42	46.93	565	2	1901				1856	1886	1777		
214	Bernstein	BST	AT	16.26	47.35	600	1					1859				
160	Besancon	BES	FR	5.99	47.25	307	2		1890		1890	1885	1894			
18	Biel/Bienne	BIE	CH	7.26	47.12	434	2					1883				
162	Bihac	BIH	BA	15.88	44.82	246	3					1888				
163	Bjelovar	BJE	HR	16.85	45.90	141	1					1872				
254	Bologna Borgo Panigale AF	BOP	IT	11.30	44.53	42	4	1879								
19	Bologna-SI	BOL	IT	11.34	44.50	60	4			1814	1814	1813		1814		
20	Bozen/Bolzano	BOZ	IT	11.33	46.50	272	4			1878	1878	1856		1850		
21	Bra	BRA	IT	7.84	44.70	290	4					1863				
22	Bratislava	BRL	SK	17.10	48.17	280	1	1872	1852		1852	1857	1934	1850	1871	1871
23	Bregenz	BRE	AT	9.73	47.50	424	2	1872	1874		1874	1874		1869	1873	1873
24	Brixen/Bressanone	BRX	IT	11.65	46.72	569	4					1878		1865		
165	Brno-Turany	BRN	CZ	16.70	49.16	241	1	1871	1851		1851	1805		1848		
25	Bruck/Mur	BMU	AT	15.26	47.41	482	1	1875				1876				
215	Budapest - Lörinc Airport	BUL	HU	19.22	47.45	130	1					1841		1780		
207	Budapest Meteorologia	BUD	HU	19.03	47.52	118	1		1809		1809					
26	Casale Monferrato	CAS	IT	8.46	45.13	113	4					1870				
27	Celje	CEL	SI	15.27	46.23	234	3	1932				1853	1950	1851		
28	Ceresole Reale	CER	IT	7.25	45.43	1579	4					1927				
29	Chanceaux	CHA	FR	4.72	47.52	462	2					1880				
30	Changins	CHG	CH	6.23	46.40	430	2					1901				
226	Chateau d'Oex	CHO	CH	7.14	46.48	985	2	1901						1879		
31	Chaumont	CHT	CH	6.99	47.05	1073	2					1864		1864		
166	Cluny	CLU	FR	4.67	46.43	240	2					1879				
167	Colmar	COL	FR	7.36	48.08	190	2					1891				
250	Cortina d'Ampezzo	COR	IT	12.15	46.55	1270	4							1878		
243	Courcy	CUR	FR	4.03	49.30	91	2						1931			
32	Crikvenica	CRK	HR	14.70	45.19	10	3	1891				1891		1891		
33	Cùneo	CUN	IT	7.54	44.40	536	4					1877		1877		
34	Davos-Dorf	DAV	CH	9.84	46.81	1590	2	1901	1901		1901		1886	1866		
35	Delémont	DEL	CH	7.35	47.36	415	2					1901				
36	Deutschlandsberg	DLB	AT	15.22	46.83	354	1					1894				
37	Dijon-Longvic airport	DIJ	FR	5.08	47.27	227	2					1831		1883		
38	Ebnat-Kappel	EBN	CH	9.12	47.27	623	2					1880				
39	Einsiedeln	EIN	CH	8.76	47.13	910	2					1864				
216	Eisenkappel	EIS	AT	14.59	46.49	623	3					1886				
40	Elm	ELM	CH	9.17	46.92	965	2					1878				
170	Embrun-Gap	GAP	FR	6.48	44.57	750	4					1866				
41	Engelberg	ENG	CH	8.41	46.82	1035	2					1864		1864		
42	Feldkirch	FEL	AT	9.62	47.27	440	2	1878				1876	1936	1875		

HISTALP-monthly - STATIONLIST continued

station identification				coordinates				starting years of series									
ID	full name	acr.	nat	lon	lat	alt	CRS	N11	P01	P02	P99	R01	SU1	T01	H01	H11
HISTALP ID-number		HISTALP acronym	recent nationality of data provider	deg E	deg N	am above sealevel	coarse resolution subregion	cloudiness	air pressure means (stat. level)	air pressure means (sea level)	air pressure anomalies (both)	precipitation totals	sunshine duration totals	temperature means	relative humidity means	vapour pressure means
43	Ferrara	FER	IT	11.61	44.82	15	4					1865		1879		
44	Feuerkogel	FEU	AT	13.72	47.82	1618	5	1930					1930	1930	1931	1931
45	Firenze-Ximeniano	FIR	IT	11.25	43.78	75	4		1814		1814	1860		1878		
46	Formazza Ponte	FOR	IT	8.44	46.38	1300	4					1901				
169	Freiburg/Breisgau	FBG	DE	7.83	48.00	300	2					1868		1869		
47	Freistadt	FRE	AT	14.50	48.52	549	1	1877				1878		1876		
244	Frejus-airport	FRJ	FR	6.74	43.43	2	4						1931			
225	Freudenstadt-Kurgarten	FRU	DE	8.42	48.47	736	2	1949					1951			
208	Garmisch-Partenkirchen	GAR	DE	11.07	47.48	719	2	1936	1889		1889		1936			
48	Genève-Cointrin	GNV	CH	6.15	46.19	380	2	1846	1768		1768	1826	1901	1760		
49	Genova-University	GOV	IT	8.93	44.42	53	4			1833	1833	1833		1833		
50	Glarus	GLA	CH	9.07	47.04	515	2	1901				1872		1864		
51	Gospic	GOS	HR	15.38	44.53	573	3	1872	1872		1872	1873	1957	1872		
52	Gr. St. Bernhard	GSB	CH	7.18	45.87	2472	5	1846	1864		1864			1818		
171	Grandfontaine	GFO	FR	7.12	48.52	515	2					1890				
53	Graz - Universität	GRA	AT	15.45	47.08	377	1	1864	1837		1837	1837	1922	1837	1862	1856
258	Gressoney-Ejola	GRE	IT	7.85	45.85	1850	4	1927								
54	Hallau	HAL	CH	8.46	47.70	432	2	1901				1864	1887			
55	Heiligenblut	HEI	AT	12.85	47.03	1315	3					1896				
56	Hohenpeißenberg	HOP	DE	11.02	47.80	986	1	1879	1781		1781	1800	1937	1781	1879	1880
57	Hurbanovo	HUR	SK	18.20	47.87	124	1	1872	1874		1874	1871	1934	1872	1872	1872
58	Hvar	HVR	HR	16.43	43.17	20	3	1858	1858		1858	1858	1952	1858		
158	Imperia	IMP	IT	8.04	43.90	54	4					1876		1875		
59	Innsbruck-Universität	INN	AT	11.38	47.27	609	2	1866	1830		1830	1858	1906	1777	1883	1893
60	Interlaken	ITL	CH	7.87	46.67	580	2					1890		1864		
61	Ivrea	IVR	IT	7.88	45.46	267	4					1837				
172	Jajce	JAJ	BA	17.27	44.35	431	3					1892		1892		
62	Jungfraujoch	JFJ	CH	7.98	46.55	3580	5	1938	1933		1933		1931	1933		
63	Kals	KAL	AT	12.63	47.00	1338	4					1896				
177	Karlovac	KVA	HR	15.55	45.50	112	3					1872				
173	Karlsruhe	KAR	DE	8.35	49.03	112	2	1880	1868		1868	1801	1936	1779		
176	Keszthely	KSZ	HU	17.25	46.75	115	1					1861				
227	Kirchbichl	KIR	AT	12.09	47.52	498	1	1893								
64	Klagenfurt-Flughafen	KLA	AT	14.33	46.65	459	3	1844	1844		1844	1813	1884	1813	1860	1845
217	Kocevje	KOC	SI	14.87	45.63	461	3					1872		1872		
65	Kollerschlag	KOL	AT	13.84	48.61	725	1					1887		1886		
174	Konstanz-Meersburg-Friedrichshafen	KMF	DE	9.18	47.67	443	2					1827				
218	Kornat	KOR	AT	12.89	46.69	1047	3					1871				
66	Krems	KRM	AT	15.60	48.40	204	1	1874				1867				
67	Kremsmünster	KRE	AT	14.13	48.05	389	1	1842	1822		1822	1820	1884	1767	1862	1840
175	Krizevci	KRI	HR	16.55	46.03	155	1					1873				
68	Kufstein	KUF	AT	12.17	47.58	493	1	1924				1901		1906		
69	La Chaux-de-Fonds	CDF	CH	6.80	47.09	1018	2	1901				1900	1901	1900		
178	La Cote St. André	LCA	FR	5.26	45.36	340	2					1893				
245	Laas	LAS	AT	13.00	46.68	800	3						1924			
70	Lago Gabiet	LGA	IT	7.85	45.84	2340	5							1928		
71	Landeck	LAD	AT	10.57	47.13	798	2					1881				
180	Landshut	LHU	DE	12.10	48.53	393	1					1879				
72	Langen	LAG	AT	10.12	47.13	1270	2					1881				
73	Langnau i.E.	LIE	CH	7.79	46.94	755	2					1901				
179	Langres	LGR	FR	5.34	47.85	467	2					1877				
74	Lemie - C.le.	LEM	IT	7.28	45.23	940	4					1923				
219	Lienz	LIZ	AT	12.81	46.83	659	4					1854		1853		
75	Linz-Stadt	LIN	AT	14.28	48.30	263	1					1852		1816		
181	Livno	LVO	BA	17.02	43.83	724	3					1886				
76	Livorno	LIV	IT	10.31	43.55	3	4			1879	1879	1857		1865		
77	Ljubljana	LJU	SI	14.52	46.07	316	3	1891	1854		1854	1853	1948	1851		
78	Locarno-Monti	LOC	CH	8.79	46.17	366	4					1876	1931			
80	Lugano	LUG	CH	8.97	46.00	273	4	1864	1864		1864	1861	1886	1864		
81	Luzern	LUZ	CH	8.30	47.04	456	2	1901				1861	1911			
82	Lyon-Bron airport	LYO	FR	4.94	45.72	198	2		1881		1881	1841	1881	1851		

HISTALP-monthly - STATIONLIST continued																
station identification				coordinates				starting years of series								
ID	full name	acr.	nat	lon	lat	alt	CRS	N11	P01	P02	P99	R01	SU1	T01	H01	H11
HISTALP ID-number		HISTALP acronym	recent nationality of data provider	deg E	deg N	am above sealevel	coarse resolution subregion	cloudiness	air pressure means (stat. level)	air pressure means (sea level)	air pressure anomalies (both)	precipitation totals	sunshine duration totals	temperature means	relative humidity means	vapour pressure means
182	Macon	MAC	FR	4.80	46.30	216	2					1887				
183	Mali Losinj	MLO	HR	14.47	44.53	53	3					1881				
83	Mantova	MAN	IT	10.79	45.15	20	4					1840		1828		
228	Mariapfarr	MPF	AT	13.75	47.15	1153	1						1929			
84	Maribor	MAB	SI	15.65	46.57	270	1		1948		1948	1876				
85	Marienberg/Montemaria	MAI	IT	10.49	46.74	1323	4					1858		1857		
86	Marigny-Le-Cahouet	MLC	FR	4.46	47.46	310	2					1880				
87	Marseille - Marignagne airport	MAR	FR	5.23	43.44	5	4		1883		1883	1800	1930	1847		
204	Metz - Augny	MEZ	FR	6.12	49.08	190	2		1892		1892					
253	Milano Linate AF	MLL	IT	9.28	45.43	122	4	1763								
88	Milano-Brera	MIL	IT	9.19	45.47	103	4			1763	1763	1800		1763		
89	Millstatt	MST	AT	13.58	46.80	719	3					1896				
203	Montelimar-Aerodrome	MON	FR	4.74	44.58	73	4		1881		1881		1930			
184	Montmorod	MMO	FR	5.51	46.69	280	2					1866				
90	Montpellier	MOP	FR	3.96	43.58	3	4							1874		
91	Mosonmagyarovar	MOS	HU	17.27	47.88	121	1					1859		1871		
185	Mostar	MTR	BA	17.80	43.35	99	3					1880		1880		
92	München-Stadt	MUN	DE	11.55	48.18	525	1	1825	1825		1825	1848	1936	1781		1842
93	Nancy-Essey-Tomblaine airport	NAN	FR	6.22	48.68	217	2					1811	1930	1879		
94	Nauders	NAU	AT	10.50	46.90	1360	2					1896				
95	Neuchatel	NCH	CH	6.95	47.00	485	2	1901	1864		1864	1856	1901	1864		
96	Nice - Aeroport	NIC	FR	7.20	43.65	4	4					1870		1806		
220	Nice - Cap Ferrat	NIF	FR	7.30	43.68	138	4					1900				
97	Nimes airport	NIM	FR	4.41	43.86	59	4		1891		1891		1930	1851		
209	Nürnberg-Kraftshof airport	NUR	DE	11.05	49.50	314	1	1955	1879		1879		1955			
186	Oberstdorf	OBS	DE	10.27	47.38	810	2					1886				
229	Oberwoelz	OBW	AT	14.28	47.20	810	1	1927					1927			
187	Oderen	ODE	FR	6.98	47.92	450	2					1890				
188	Orange	ORA	FR	4.85	44.14	53	4					1817		1881		
98	Osijek	OSK	HR	18.67	45.55	91	1	1899	1899		1899	1899	1957	1899		
99	Ovada	OVA	IT	8.64	44.64	187	4					1914				
100	Padova	PAD	IT	11.88	45.40	14	3			1766	1766	1800		1774		
189	Papa-Pannonhalma	PAP	HU	17.48	47.32	147	1					1857				
101	Parma	PAR	IT	10.32	44.80	57	4					1833		1866		
249	Passo Rolle	ROL	IT	11.78	46.30	2000	5							1895		
223	Patscherkofel	PAK	AT	11.46	47.21	2247	5	1932					1935	1931		
102	Pavia	PAV	IT	9.15	45.17	75	4					1812				
103	Payerne	PAY	CH	6.94	46.82	490	2					1901				
190	Pazin	PAZ	HR	13.93	45.23	291	3					1885				
104	Pécs	PEC	HU	18.17	46.06	150	1					1854		1871		
105	Perugia	PRG	IT	12.39	43.10	520	3					1836		1865		
106	Pèsaro	PES	IT	12.91	43.87	11	3			1879	1879	1866		1871		
107	Piacenza	PIA	IT	9.70	45.06	50	4					1872		1865		
252	Piacenza AF	PIC	IT	9.72	45.90	38	4			1876	1876					
255	Pisa AF	PIS	IT	10.38	43.68	1	4	1879								
108	Pouilly-En-Auxois	POU	FR	4.56	47.25	408	2					1880				
191	Pozega	POZ	HR	17.68	45.33	152	3					1883				
248	Predazzo	PRE	IT	11.62	46.31	1020	4							1896		
192	Prozor	PRZ	BA	17.62	43.83	800	3					1892				
109	Pula	PUL	HR	13.85	44.87	30	3					1865		1864		
110	Radenthein	RDT	AT	13.70	46.78	688	3							1891		
111	Radstadt	RAD	AT	13.45	47.38	858	1					1896		1901		
112	Rauris	RAU	AT	12.99	47.22	941	1					1876				
193	Regensburg	RBG	DE	12.10	49.03	366	1					1800		1773		
113	Reggio Emilia	REM	IT	10.75	44.70	62	4					1867		1876		
114	Reichenau/Rax	REI	AT	15.84	47.70	486	1							1865		
115	Retz	RET	AT	15.95	48.77	256	1					1895		1896		
116	Rheinfelden	RHE	CH	7.81	47.57	300	2					1883				
117	Ried	RIE	AT	13.48	48.22	431	1					1872		1872		

HISTALP-monthly - STATIONLIST continued

station identification				coordinates				starting years of series								
ID	full name	acr.	nat	lon	lat	alt	CRS	N11	P01	P02	P99	R01	SU1	T01	H01	H11
HISTALP ID-number		HISTALP acronym	recent nationality of data provider	deg E	deg N	am above sealevel	coarse resolution subregion	cloudiness	air pressure means (stat. level)	air pressure means (sea level)	air pressure anomalies (both)	precipitation totals	sunshine duration totals	temperature means	relative humidity means	vapour pressure means
194	Rijeka - Kozala	RIJ	HR	14.45	45.33	104	3					1869				
210	Rimini	RIM	IT	12.62	44.02	13	3	1879								
195	Rosenheim	ROS	DE	12.12	47.87	444	1					1879				
119	Rovereto	ROV	IT	11.05	45.89	206	4					1864		1862		
120	Rovigo	RVG	IT	11.78	45.08	9	3					1878		1879		
198	Saint Martin d'Herés-Grenoble	SMH	FR	5.76	45.20	212	2					1893		1878		
121	Saint-Paul-Les-Durance	SPA	FR	5.76	43.71	296	4					1882				
122	Salzburg-Flughafen	SAL	AT	13.00	47.80	430	1	1842	1842		1842	1839		1842	1862	1853
123	Samedan airport	SAM	CH	9.88	46.53	1705	4					1861				
124	Säntis	SNT	CH	9.35	47.25	2490	5	1882	1883		1883		1888	1864		1901
196	Sarajewo	SAR	BA	18.43	43.87	630	3		1880		1880	1880		1880		
213	Schmittenhöhe	SCH	AT	12.73	47.33	1973	5						1929	1880		
224	Schöckl	SCK	AT	15.47	47.20	1445	5	1929					1929	1901		
125	Seckau	SEK	AT	14.78	47.28	855	1	1890				1891		1890	1890	1890
247	Segl Maria	SEG	CH	9.77	46.43	1802	4							1864		
197	Sibenik	SIB	HR	15.92	43.73	77	3					1890				
126	Sion	SIO	CH	7.37	46.23	482	2	1864				1861	1941	1864		
127	Sonnblick	SON	AT	12.95	47.05	3105	5	1887	1887		1887		1887	1886	1887	1886
128	Sopron	SOP	HU	16.60	47.68	234	1	1871				1865	1929	1871	1872	1872
129	Split	SPL	HR	16.43	43.52	128	3							1896		
130	St. Andrä im Lavanttal	SAN	AT	14.83	46.77	402	1							1852		
131	St. Gallen	STG	CH	9.40	47.43	779	2					1864				
230	St. Moritz	SMO	CH	9.83	46.50	1800	4	1901					1901			
221	St. Pölten	SPO	AT	15.61	48.18	285	1					1894		1893		
132	St. Sebastian	SSB	AT	15.31	47.79	872	1	1883				1884	1927			
133	Sta. Maria/Müstair	STM	CH	10.43	46.60	1390	4					1901				
134	Stift Zwettl	ZWE	AT	15.20	48.62	505	1	1883				1883	1930	1883	1883	1883
231	Stolzalpe	STO	AT	14.19	47.12	1215	1	1921					1920			
135	Strasbourg - Entzheim airport	STR	FR	7.64	48.55	150	2		1892		1892	1803		1801		
136	Stuttgart-Schnarrenberg	STU	DE	9.20	48.83	311	2	1900	1826		1826	1807	1925	1792		
137	Szombathely	SZO	HU	16.63	47.27	221	1	1873				1865	1929	1874	1876	1876
211	Tabor	TAB	CZ	14.66	49.44	461	1	1886	1876		1876					
138	Tamsweg	TAM	AT	13.80	47.13	1025	1	1866				1880				
118	Torbole-Riva	RIV	IT	10.88	45.88	73	4					1870		1869		
139	Torino	TOR	IT	7.67	45.07	275	4					1803		1760		
212	Torino Caselle airport	TOC	IT	7.65	45.22	301	4	1787		1799	1799					
140	Torino Moncalieri	TOM	IT	7.70	45.00	267	4					1864		1864		
199	Toulon	TOU	FR	5.93	43.11	24	4		1891		1891	1870		1891		
200	Travnik	TRA	BA	17.68	44.23	581	3					1881				
141	Trento	TRT	IT	11.12	46.07	199	4					1864		1816		
142	Trieste	TRI	IT	13.77	45.65	67	3			1841	1841	1841		1841		
206	Troyes-Aerodrome	TRO	FR	4.02	48.33	112	2		1878		1878					
201	Tuzla	TUZ	BA	18.70	44.55	305	3					1880		1880		
143	Udine	UDI	IT	13.24	46.06	51	3					1803		1803		
222	Ulm - Giengen	ULM	DE	9.95	48.38	567	2					1822		1868		
144	Vallombrosa	VAL	IT	11.53	43.73	955	4					1872				
145	Venezia-Cavanis	VEN	IT	12.33	45.43	18	3	1900				1836		1868		
251	Verona-Villafranca airport	VER	IT	10.87	45.38	67	4			1880	1880			1788		
146	Villach	VIL	AT	13.87	46.62	493	3					1888				
147	Villacher Alpe	VIA	AT	13.67	46.60	2160	5	1878	1880		1880		1884	1851		1880
148	Visp	VIS	CH	7.84	46.30	640	2					1901				
149	Vix	VIX	FR	4.54	47.91	205	2					1880				
150	Waidhofen/Ybbs	WAI	AT	14.76	47.95	360	1					1896		1896		
151	Wiener Neustadt airport	WRN	AT	16.23	47.83	285	1					1857				
152	Wien-Hohe Warte	WIE	AT	16.35	48.22	209	1	1842	1775		1775	1841	1881	1775	1862	1837
202	Zadar	ZAD	HR	15.22	44.13	5	3					1865				
153	Zagreb-Gric	ZAG	HR	15.98	45.82	162	3	1861	1862		1862	1862	1889	1861		
154	Zell am See	ZEL	AT	12.78	47.32	766	1					1875	1937	1875		
155	Zermatt	ZER	CH	7.75	46.03	1638	2					1892				
156	Zugspitze	ZUG	DE	10.98	47.42	2962	5	1901	1900		1900		1900	1901	1900	1901
157	Zürich Meteo Schweiz	ZUR	CH	8.57	47.38	556	2	1864	1864		1864	1830	1886	1830	1901	1901