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Implementation, testing and sensitivity experiments with a high resolution sub-grid land surface module over the Alpine region.

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Implementation, testing , and sensitivity experiments with a high resolution sub-grid land surface module over the Alpine region

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Background I

Mountain Climate Change

❖ Mountainous regions are likely to be among the most affected by global warming due to specific environmental conditions (IPCC 2007).

❖ The changes in vertical lapse rate on a mountain slope and local snow-albedo feedback at high elevation region give rise to much more complexity and nonlinearity of climate system in response to the global warming compared to the flatland area.

❖ Any changes in mountain climate will have a major influence that may reach for far beyond the mountain regions, in particular hydrological regimes.

Background II

Why SUB-BATS parameterization?

❖ For dealing with climatic change issue over high mountainous regions, explicitly representing the interactions between surface variables and the underlying topography is key process, in particular hydrological cycle, because of vertical gradient of changes in the altitude of the freezing level.

❖ Complex topographical features and land surface characteristics can locally modulate the climate change signal by regulating the land-atmosphere exchanges of heat, water and momentum, modifying the structure of traveling synoptic systems and triggering convection .

❖ Due to huge computational demand, regional climate models (RCMs) also allow a limited increase in resolution for long-term climate simulation.

❖ To bridge the scale gap between climate information and local application without use of a full dynamical model, a mosaic-type parameterization of subgrid-scale topography and land use (SUB-BATS) is implemented within the RegCM3 modeling system.

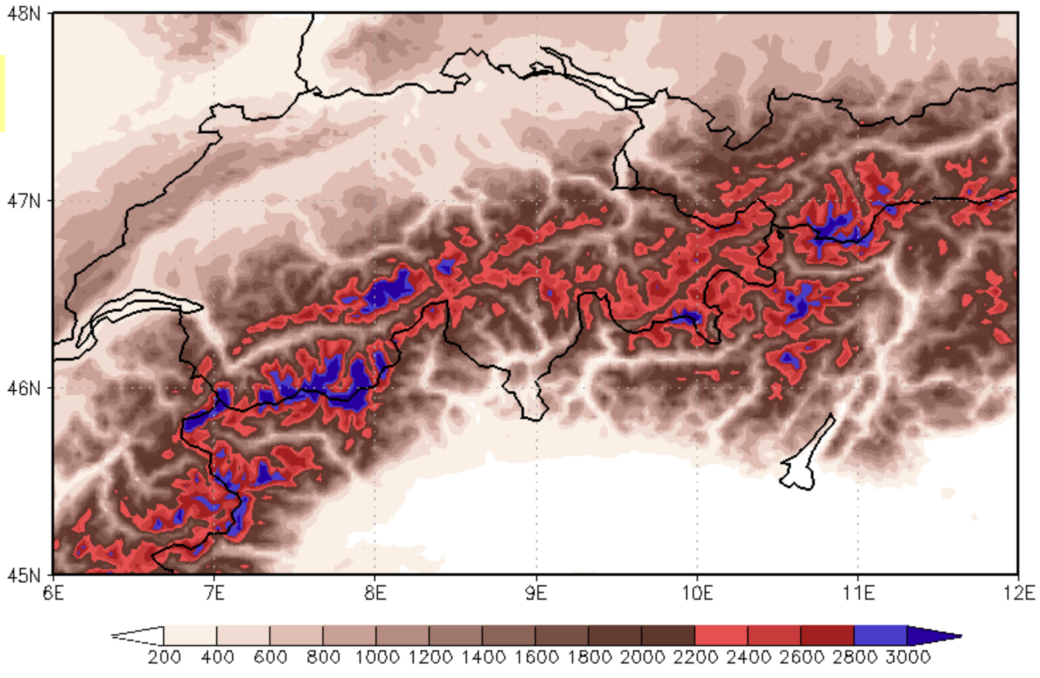
Background III

Why the Alpine region ??

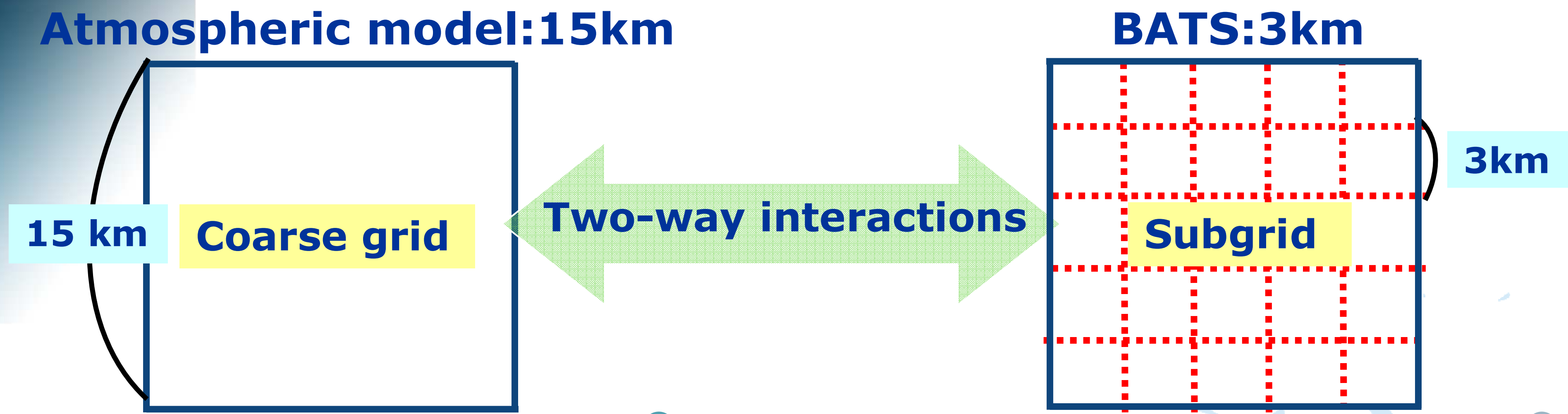
❖ The Alps have often been referred to as the “water tower” of Europe because many of Europe’s major rivers originate there, and thus provide a natural starting point for examining the effects of climate change on vulnerable mountain regions.

❖ The Alpine region is indeed maximized by physiographical complexity with a wide range of altitude. This characteristic lead to great subgrid-scale heterogeneity, making it difficult for climate models to accurately reproduce the observed climatology, and high resolution is thus required to capture such system with sufficient accuracy.

GTOPO 2min



SUB-BATS Methodology I



Solar and infrared downward radiative fluxes, precipitation, near-surface air temperature, water vapor, wind speed, pressure, and density

Albedo, upward infrared flux, momentum flux (wind stress), sensible heat flux, and latent heat flux (evaporation)

❖ The meteorological variables from original coarse grid are directly disaggregated to subgrid for calculation of land surface fluxes.

❖ Surface fluxes calculated from subgrid are reaggregated onto the coarse grid for input to the atmospheric model.

SUB-BATS Methodology II

Disaggregation Procedure

❖ Disaggregate climatic fields from the coarse grid to the fine grid are based on the elevation differences between coarse grid and fine grid.

$$T_{i,j}^{sg} = \overline{T} + \Gamma_T \left(\overline{h} - h_{i,j}^{sg} \right)$$

$$\overline{h} = \frac{1}{N} \sum_{i,j} h_{i,j(sg)}$$

Fundamental assumption

$$\overline{T} = \frac{1}{N} \sum_{i,j} T_{i,j(sg)}$$

- **Giorgi, F.**, et al., 2003: Effects of a subgrid-scale topography and land use scheme on the simulation of surface climate and hydrology. Part1: Effects of temperature and water vapor disaggregation. ***J. Hydrometeor.*** 4, 317-333.
- **Im, E.-S.**, et al., 2010: Validation of a high resolution regional climate model for the Alpine region and effects of a subgrid-scale topography and land-use representation. ***J. Climate***. 23, 1854-1873.

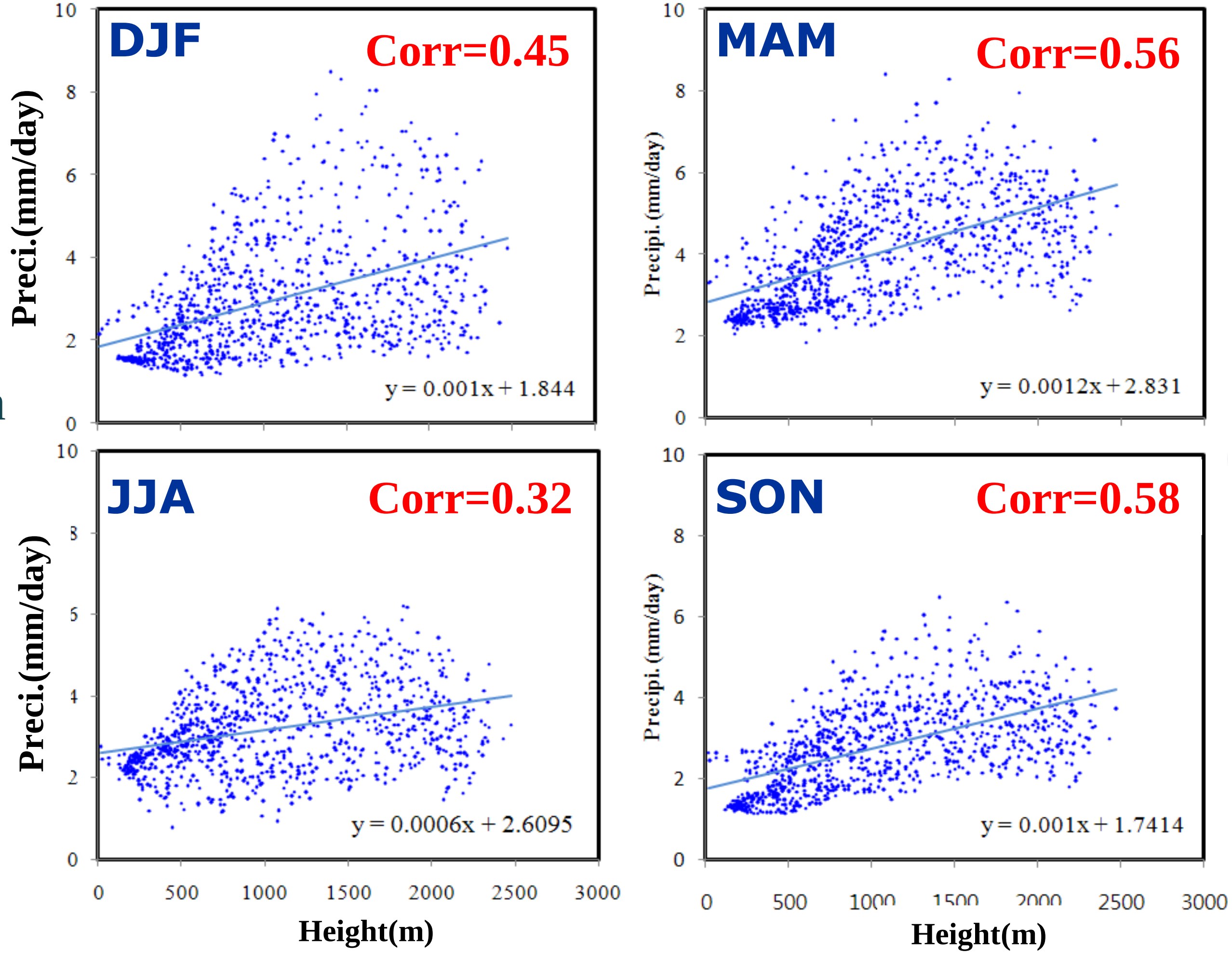
Sensitivity EXP. of Precip. Disaggregation

Empirical relationship between preci. & elevation

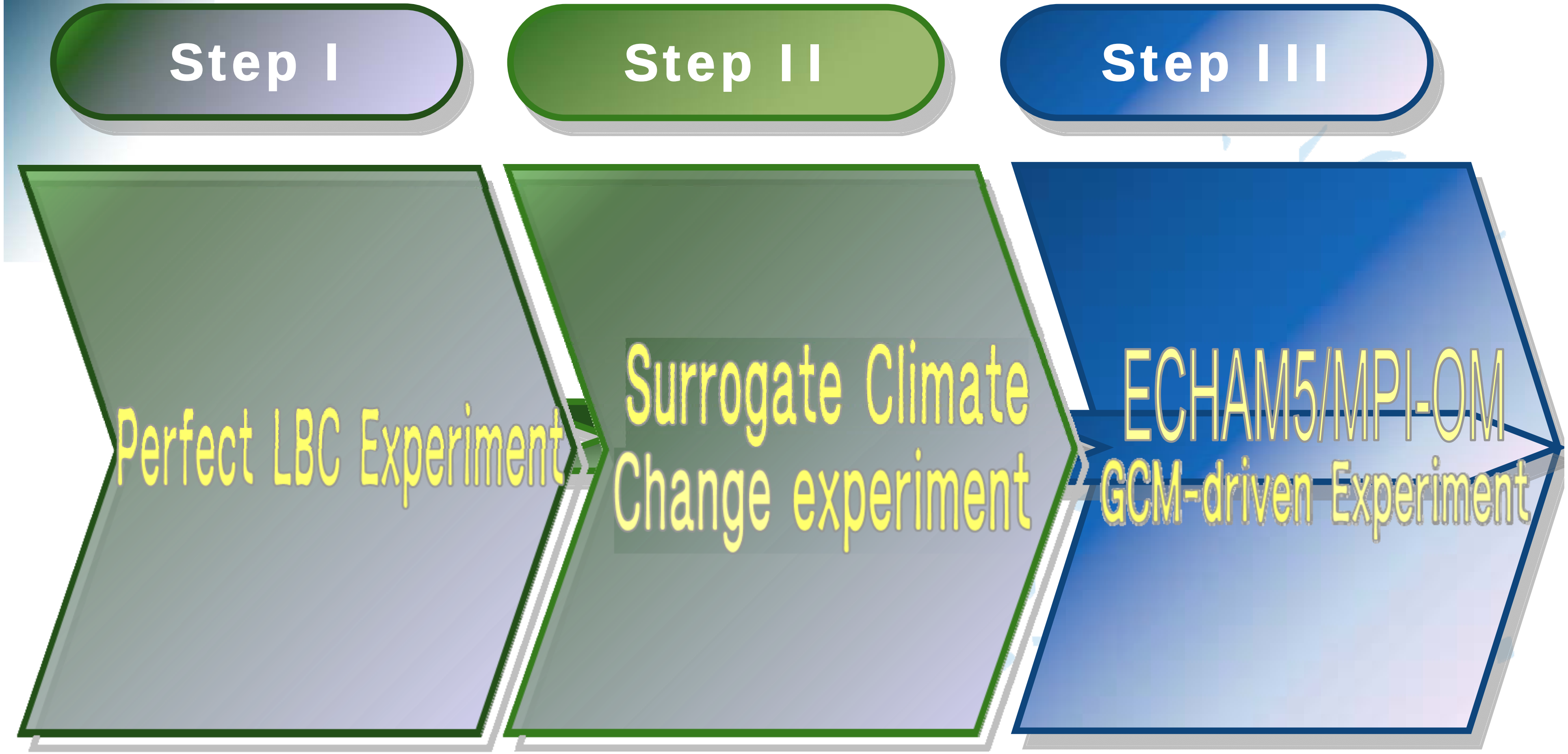
- The precipitation at sub-grid cell is disaggregated based on the empirical linear regression

$$P_s = \overline{P} + [a(h_s - \overline{h})]$$

a: slope coefficient
P_s: subgrid precipitation
$\overline{p}$: coarse-grid precipitation
h_s: subgrid height
$\overline{h}$: coarse-grid height



Research Strategy



Research Strategy

Step I

- IC and LBC from analyses of observation : NCEP/NCAR Reanalysis
  - 1983-1992 (10-year): Validation of the model against observation

Step II

- Sensitivity experiments with an imposed 3K warming on the large-scale forcing (IC & BC)
- To assess how internal thermodynamical and hydrological processes respond to the impose warming

Step III

- Dynamical downscaling of 25km A1B scenario simulation produced by ENSEMBLES Project (1961-2010: 140yr)
- Comparison of "future" and "present day" climate statistics in order to identify the change signal

Experiment Design

CONT	15km	1983-1992(10yr)	Without SUB-BATS
SUB	3km	1983-1992(10yr)	SUB-BATS, NCEP/NCAR BC
SCC	3km	1983-1992(10yr)	SUB-BATS, T+3K/RH const

CONT vs. SUB

- For model validation and for the evaluation of the effects of subgrid scale heterogeneity, the CONT and SUB simulations are compared against various observation dataset.

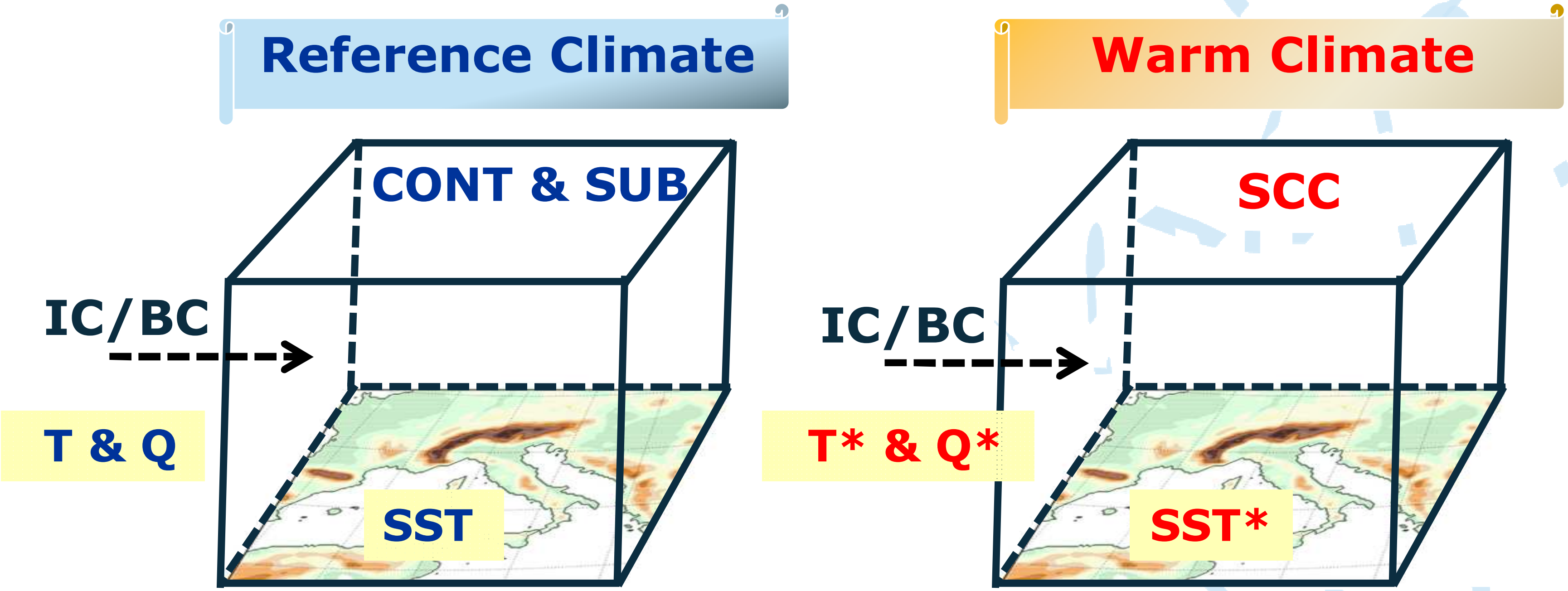
SUB vs. SCC

- To assess how internal thermodynamical and hydrological process respond to the imposed warming

Surrogate Climate Change

Objective & Method (Schar et al. 1996)

- To assess how internal thermodynamical and hydrological process (especially the surface ones) respond to the imposed warming
- Sensitivity experiments are driven by modified initial and boundary fields
- **T*= T+3K, SST*=SST+3K, RH*=RH** ⇒ **Warmer and wetter climate**



Surrogate Climate Change

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Advantage vs. Limitation

- It allows to investigate isolated thermodynamical and hydrological process associated with global warming.
- It is not dependent on a driving GCM
- However, it does not account for potential changes in the large-scale circulation patterns.

Experiment Design

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CONT vs. SUB

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SUB vs. SCC

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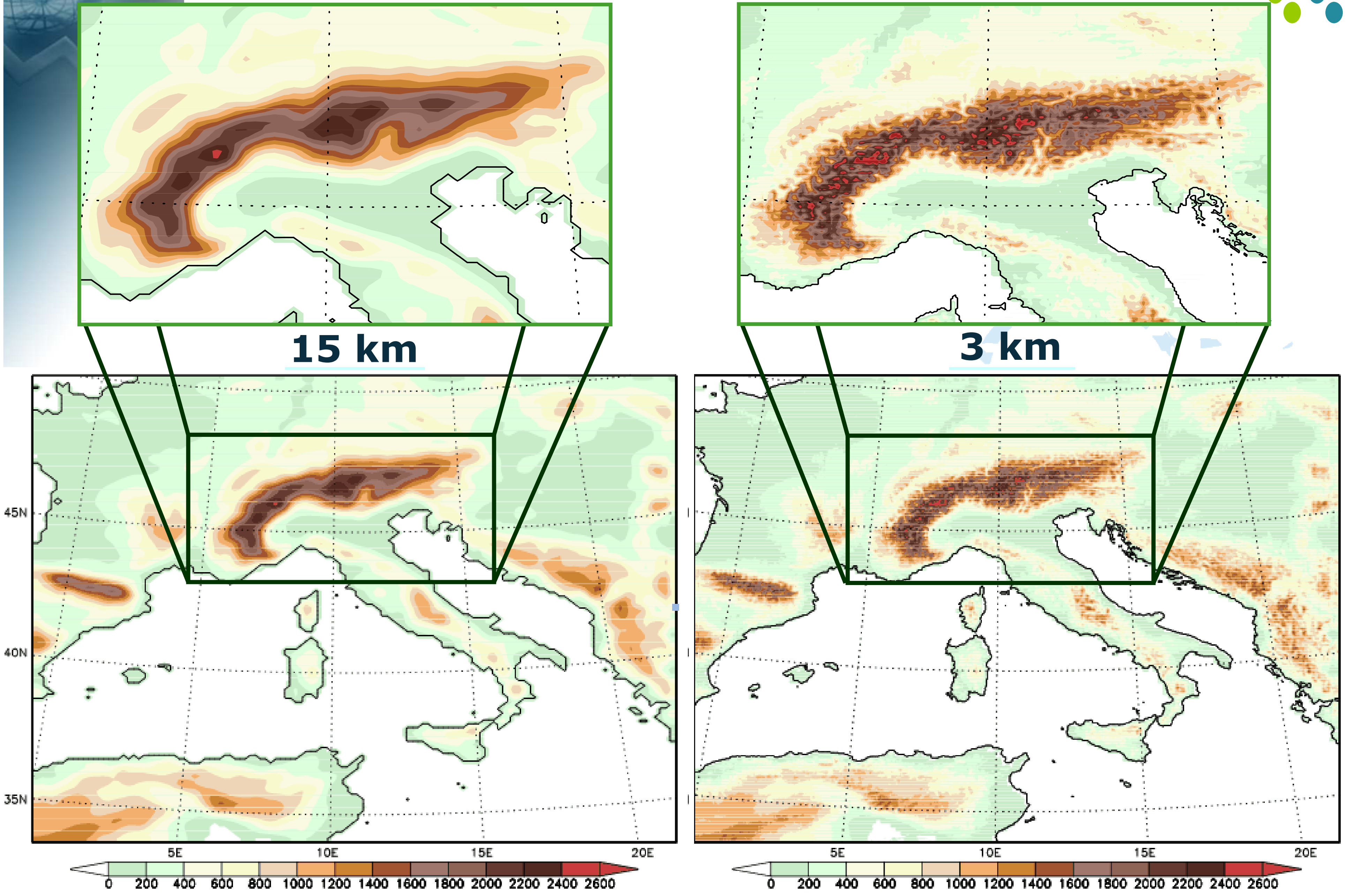
RegCM3 SUB-BATS System

Model Configuration

- ICTP RegCM3 (Regional Climate Model Ver.3)
- Resolution: Coarse grid-15km, Subgrid-3km
- Initial & Boundary condition: NCEP-DOE Reanalysis II
- Integration period: 1982.9.1 – 1992.12.31 (10yr + 4 month spin-up)
- Analysis period: 1983.1.1-1992.12.31 (10yr)
- Physical parameterization
  - Convection: Grell with Arakawa and Schubert closure
  - PBL: Nonlocal vertical diffusion scheme
  - Radiation: CCM3
  - Land surface scheme: BATS

Topography


15 km
3 km
45N
40N
35N
5E
10E
15E
20E
0 200 400 600 800 1000 1200 1400 1600 1800 2000 2200 2400 2600

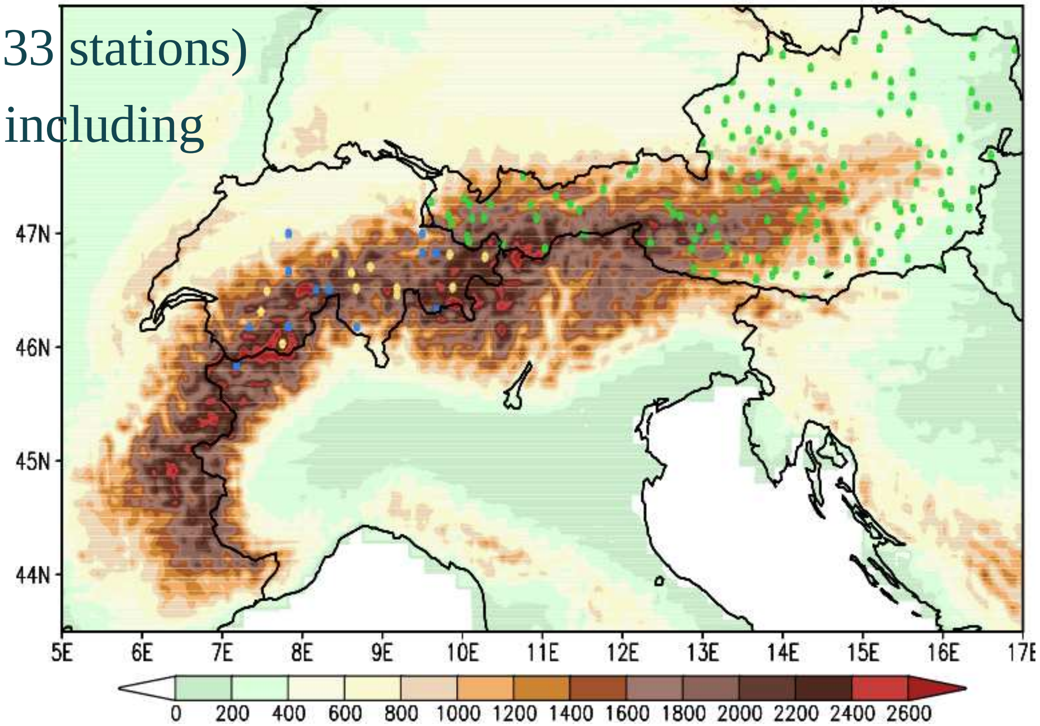
Observation dataset

Over whole domain (25km grid)

- European land-only dataset of daily temperature and precipitation on a 25km grid (Haylock et al. 2008)

Over the Alpine region (158 stations)

- Station dataset for Austria (133 stations) and Switzerland (25stations) including precipitation and snow

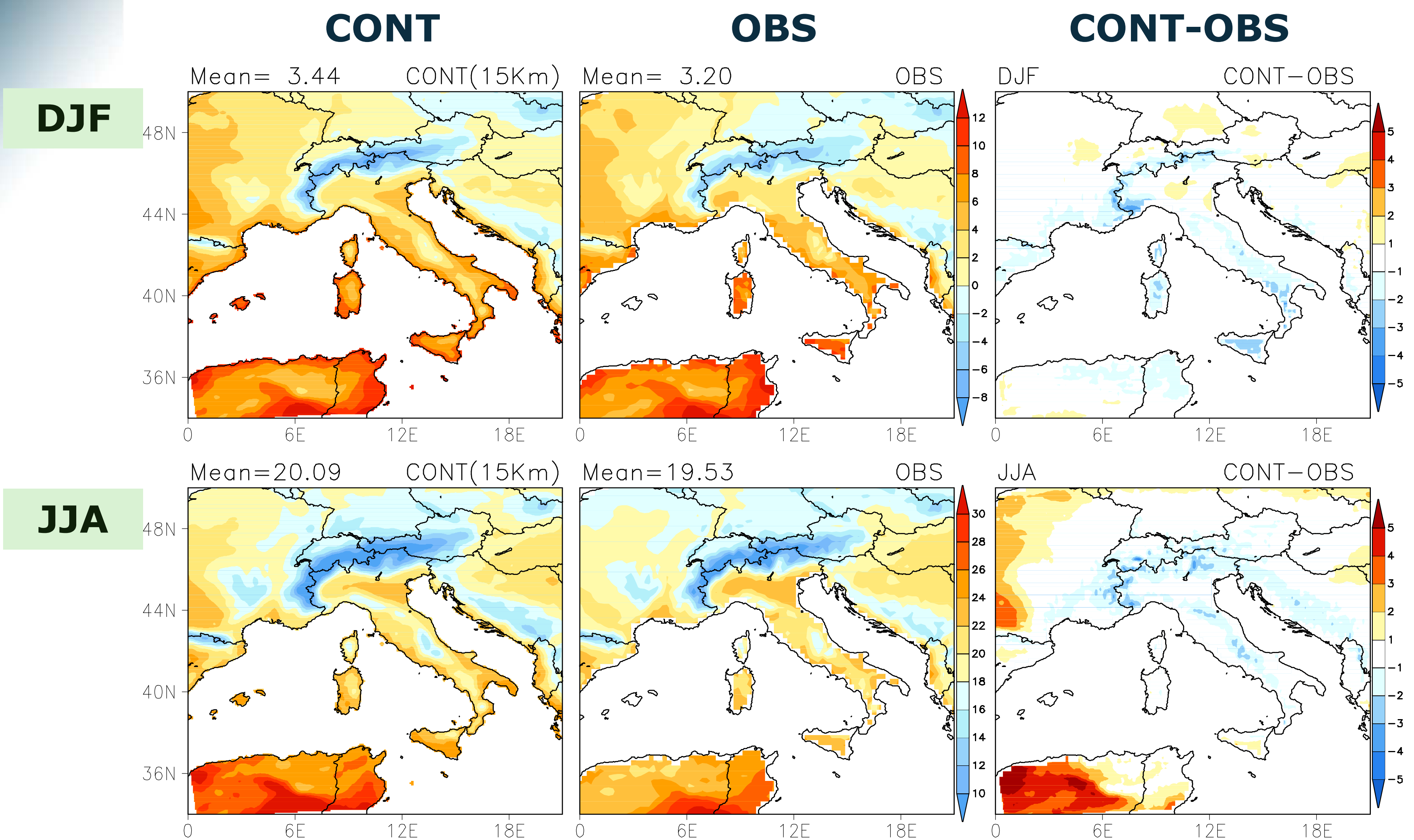


Evaluation of the SUB-BATS Simulation

CONT vs. SUB

Validation of CONT

Seasonal Mean Temperature



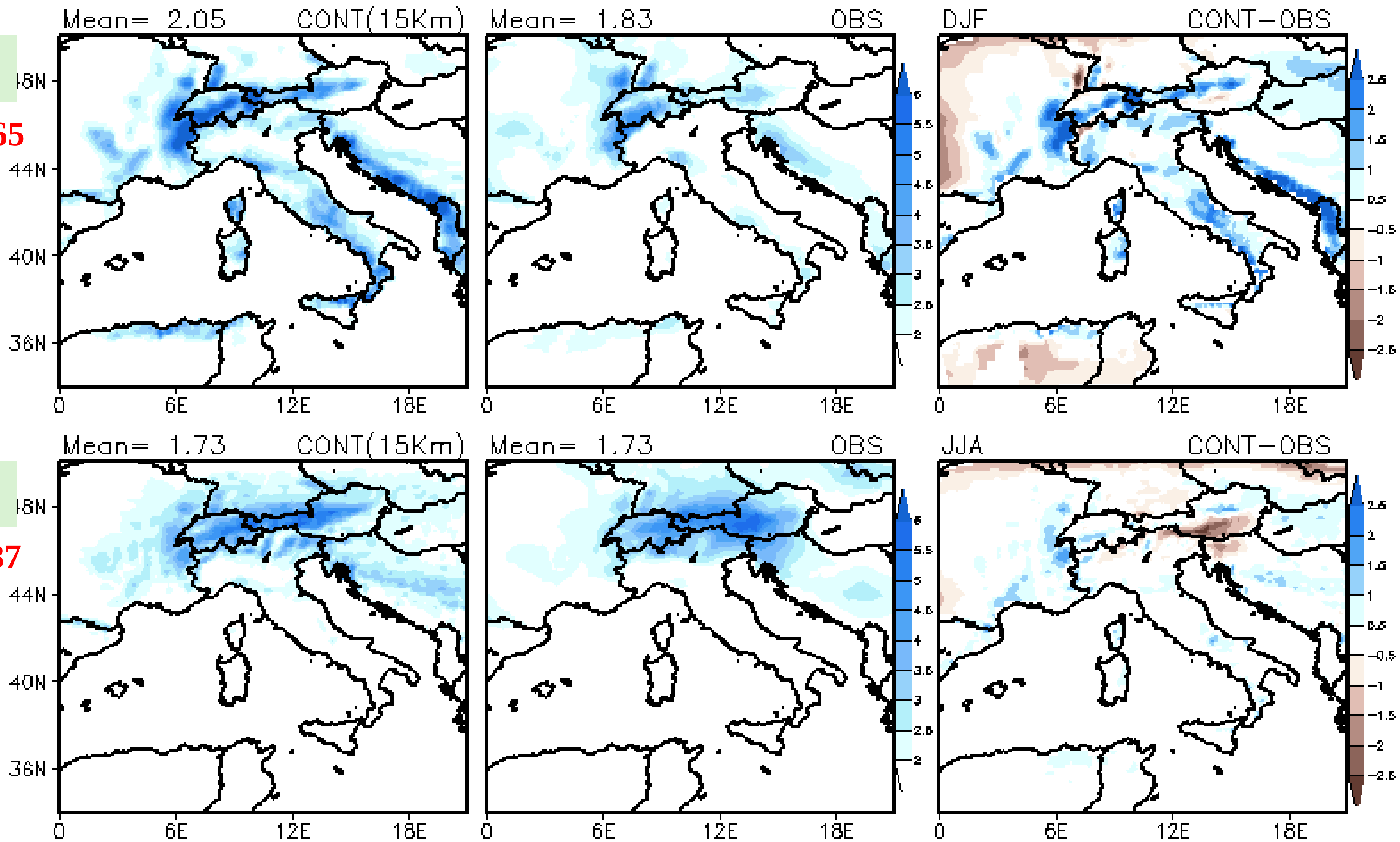
Validation of CONT

Seasonal Mean Precipitation

CONT **OBS** **CONT-OBS**

DJF
Corr=0.65

JJA
Corr=0.87



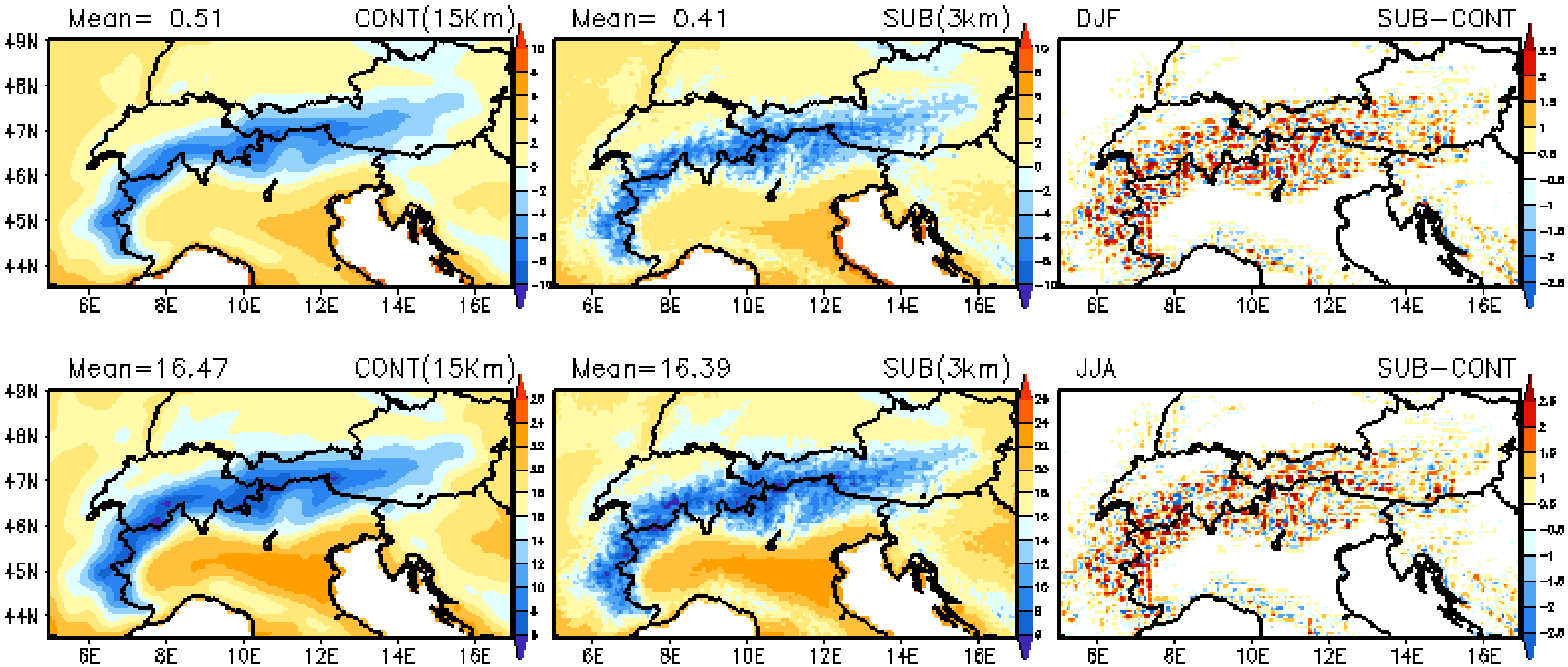
SUB-BATS Effects

Seasonal Mean Temperature

CONT | **SUB** | **SUB-CONT**

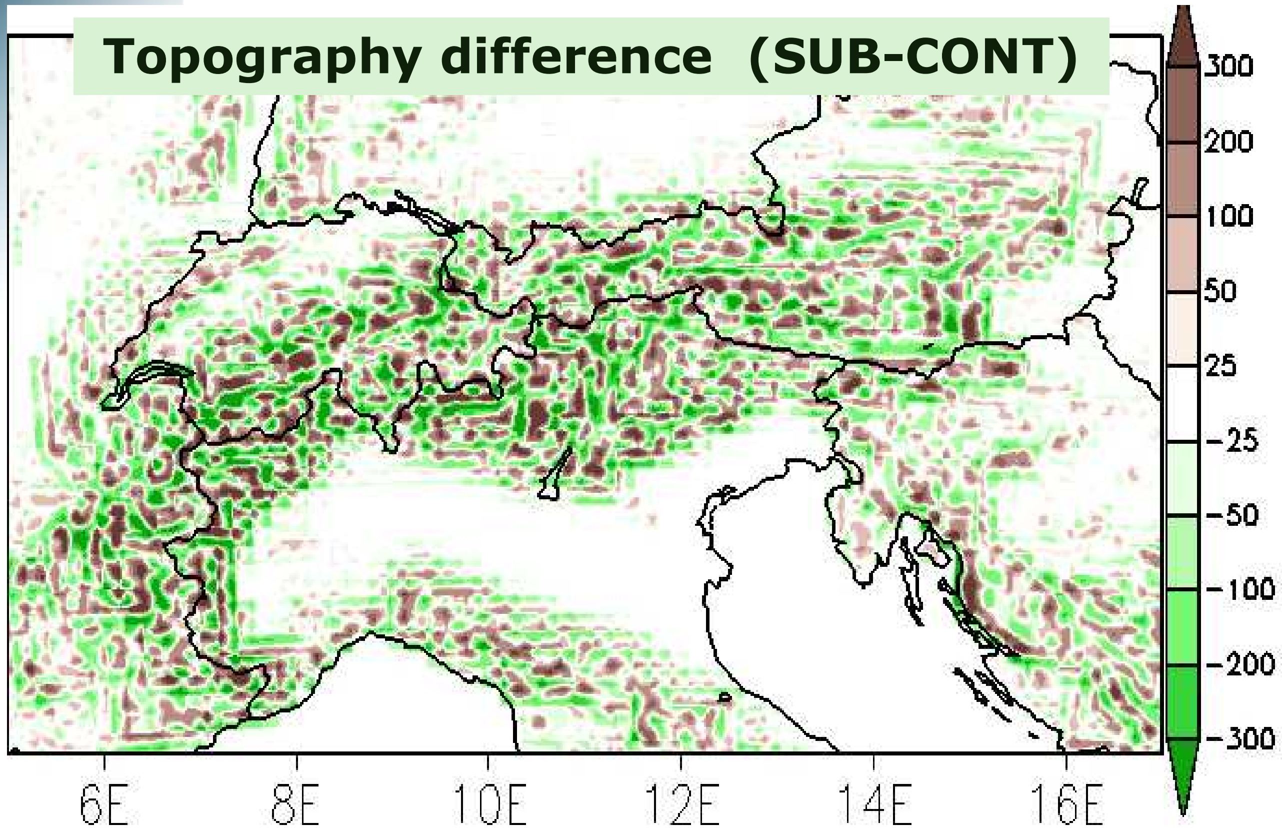
DJF

JJA

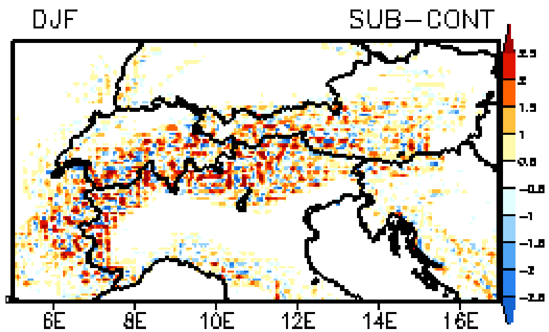


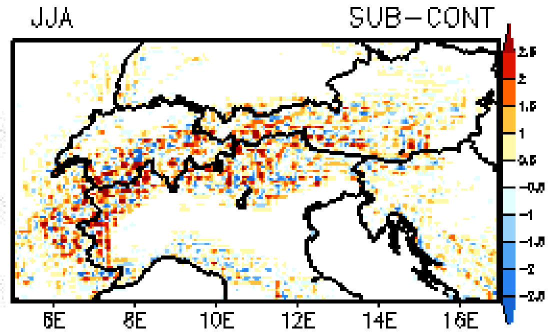
SUB-BATS Effects

Seasonal Mean Temperature



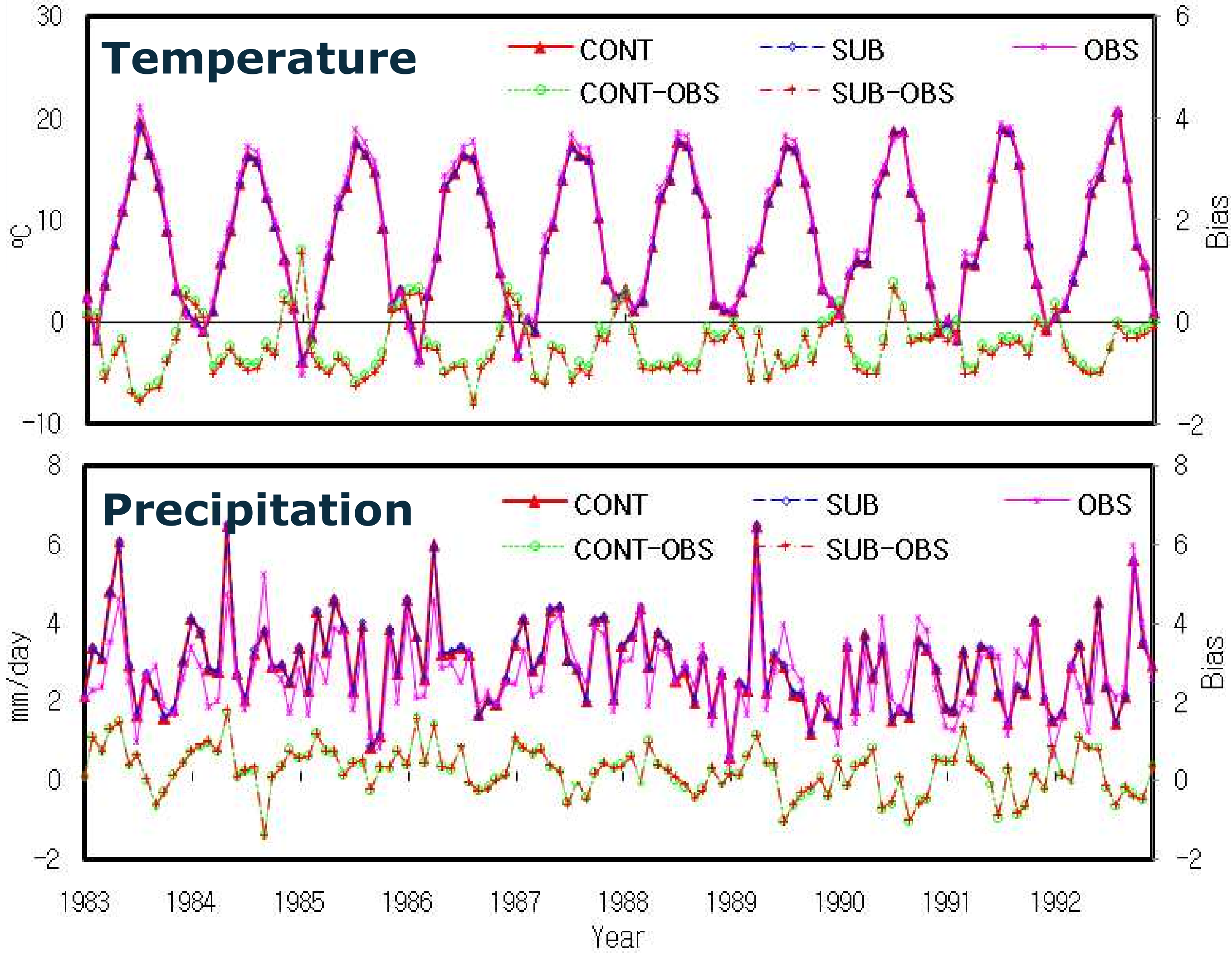
SUB-CONT

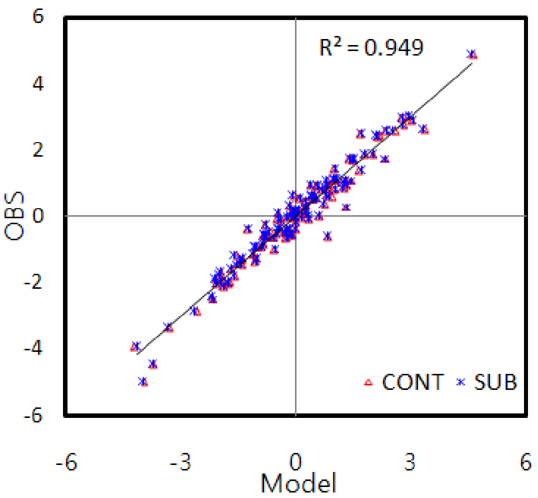


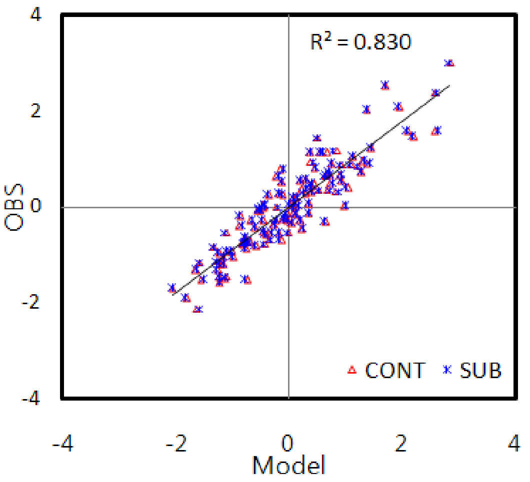


SUB-BATS Effects

Temporal evolution of Temp. & Precip.

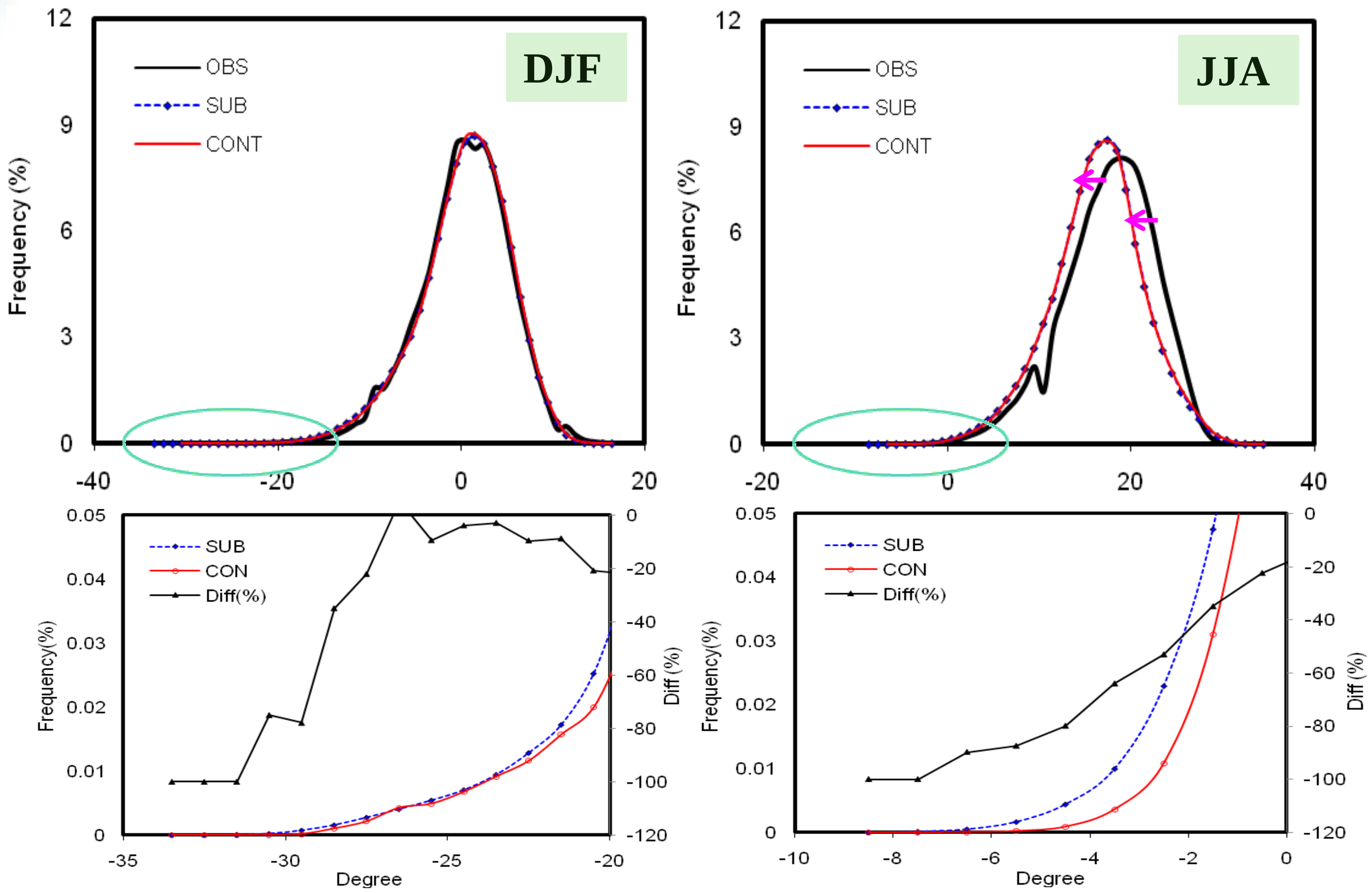






SUB-BATS Effect

Frequency distribution of daily Temp.



SUB-BATS Effects

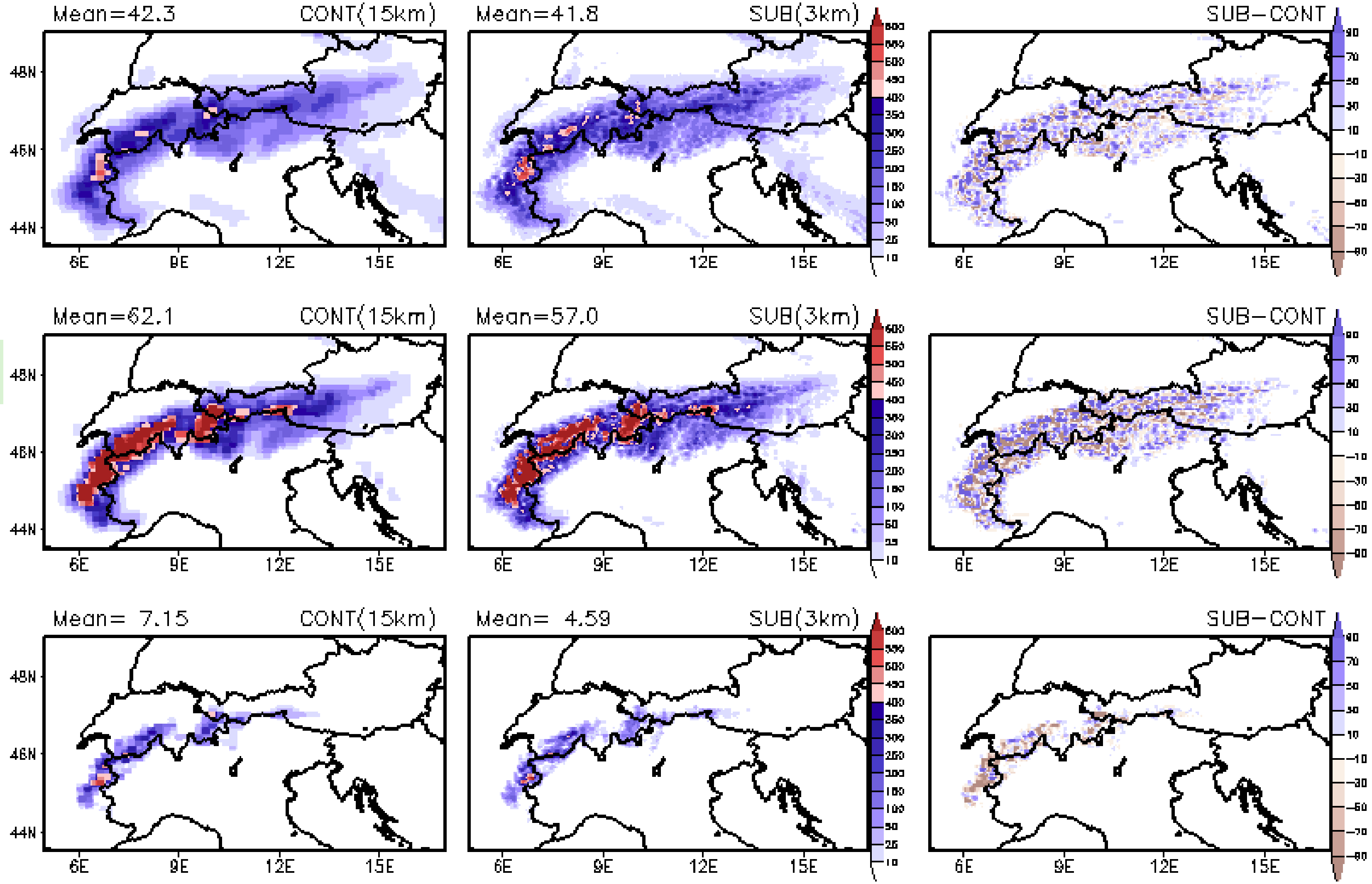
Seasonal Mean Snow Depth

CONT **SUB** **SUB-CONT**

DJF

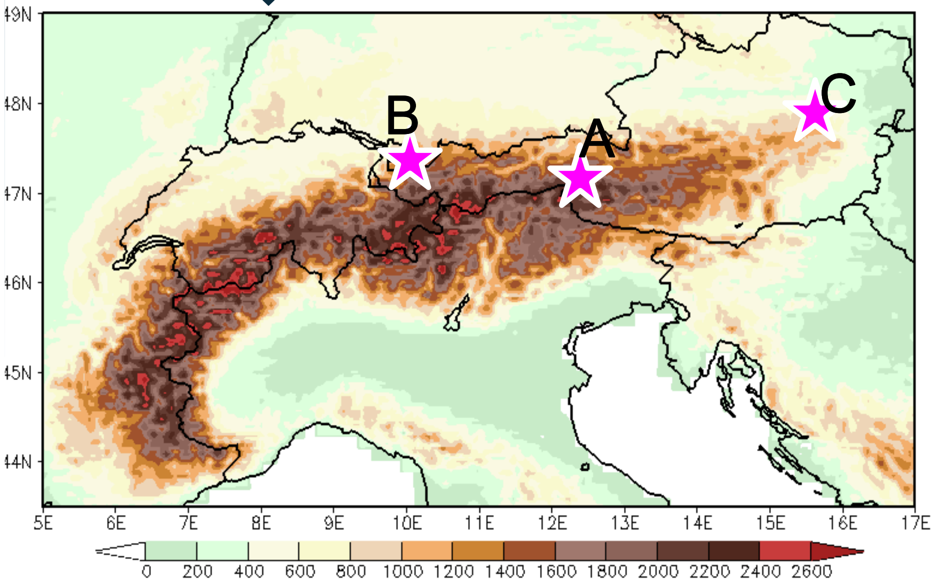
MAM

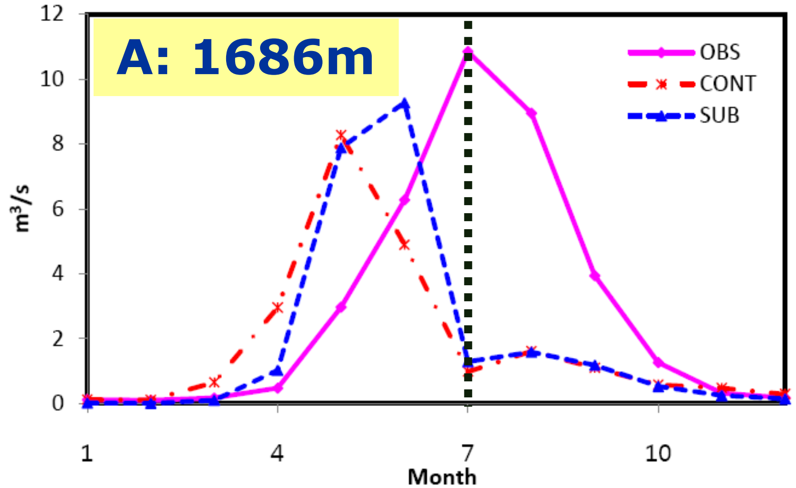
JJA

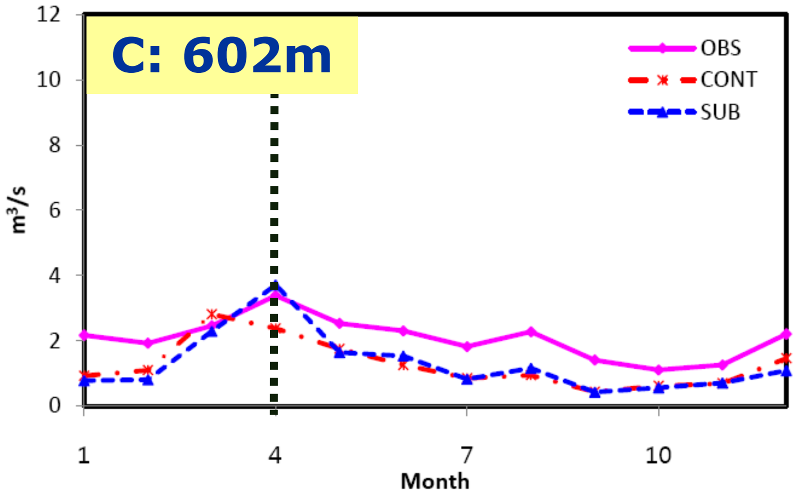


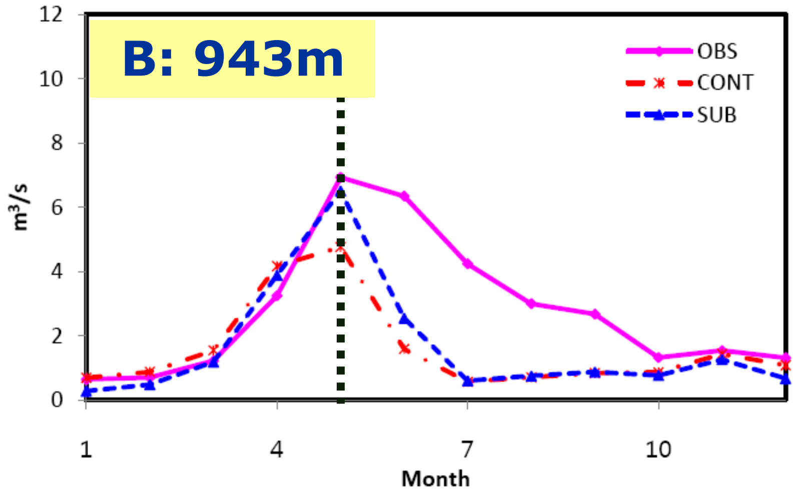
SUB-BATS Effect

Monthly variation of runoff







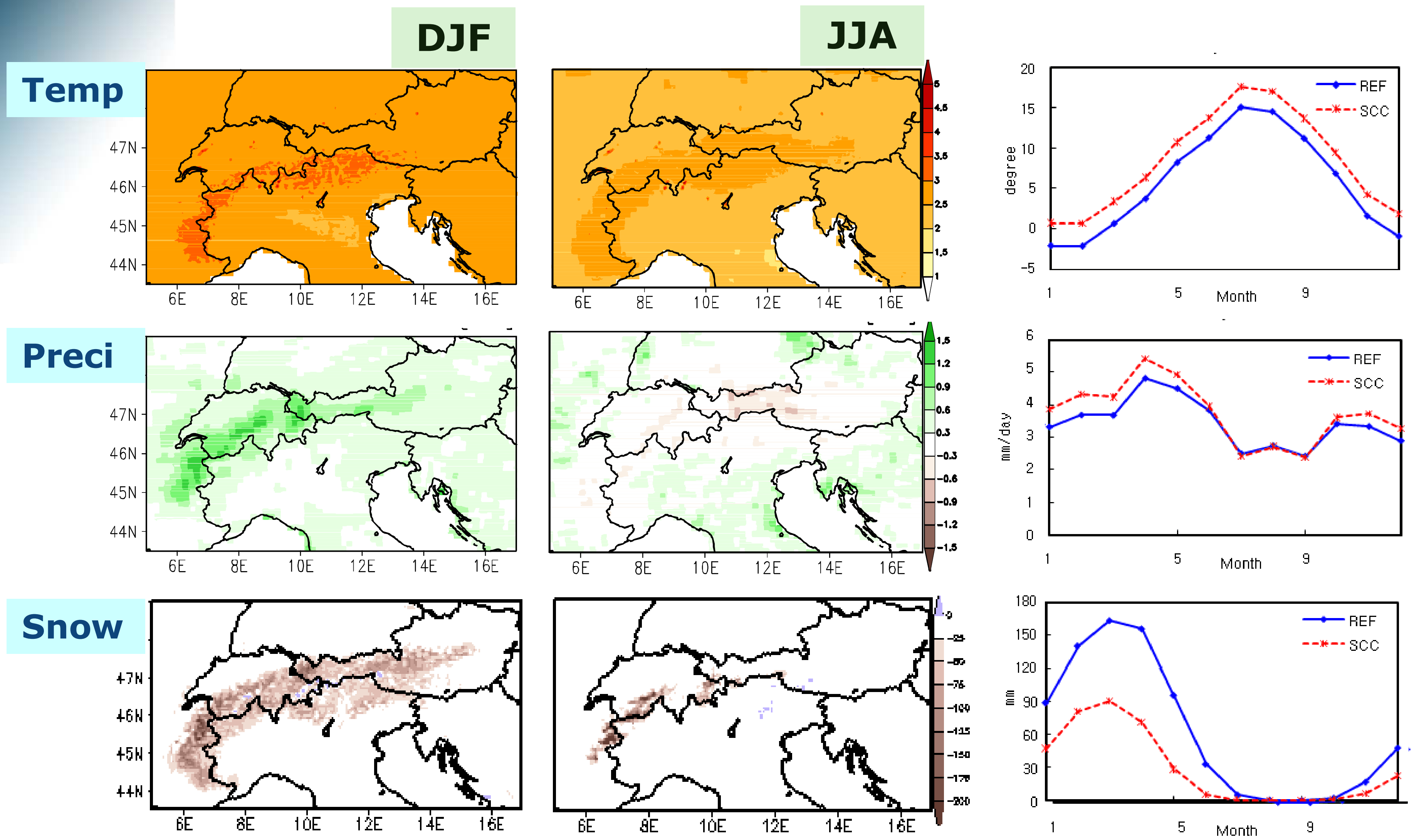


Assessment of Surrogate Climate Change

SUB vs. SCC

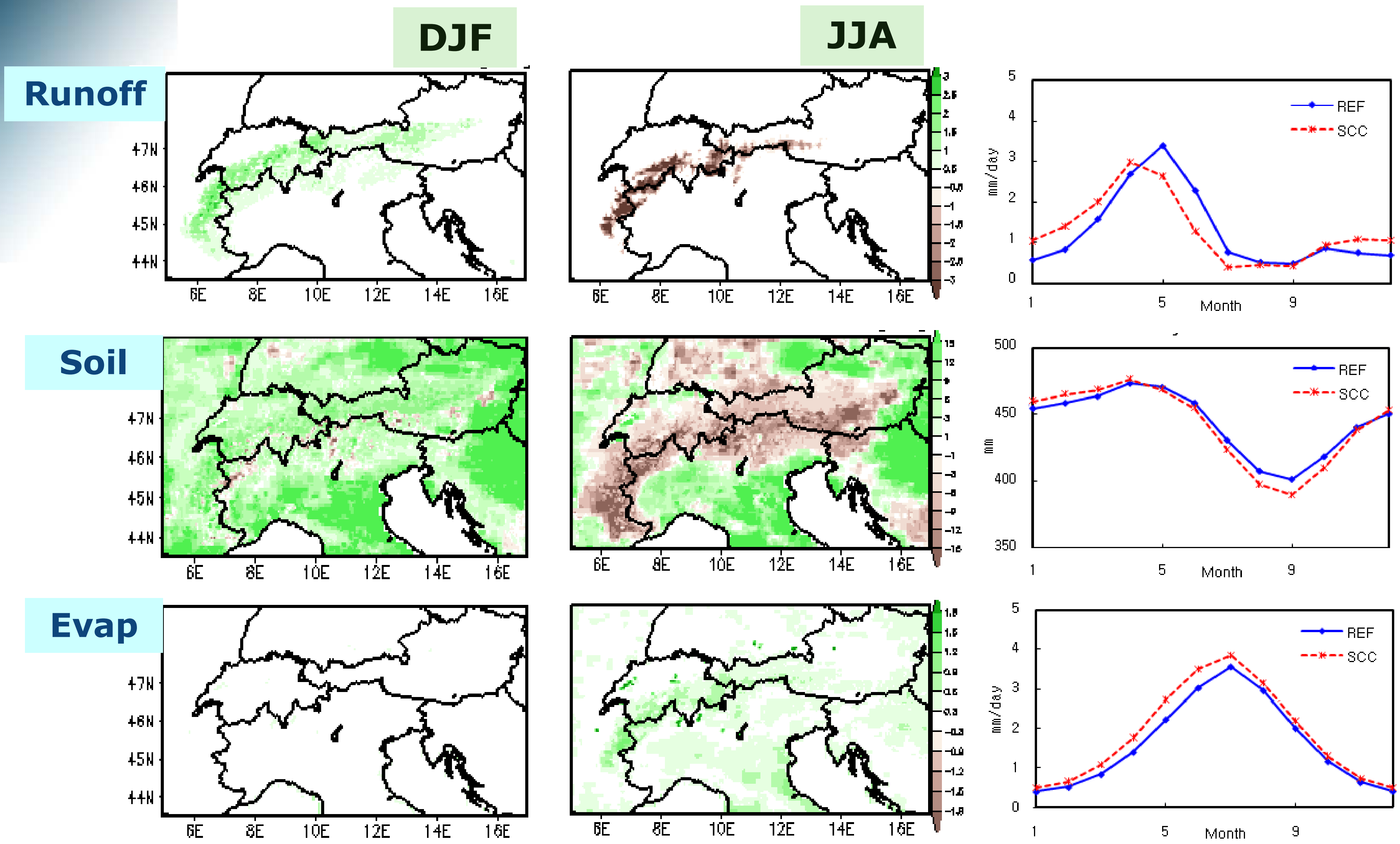
SCC Effects

Spatial distribution of Diff. (SCC-SUB)

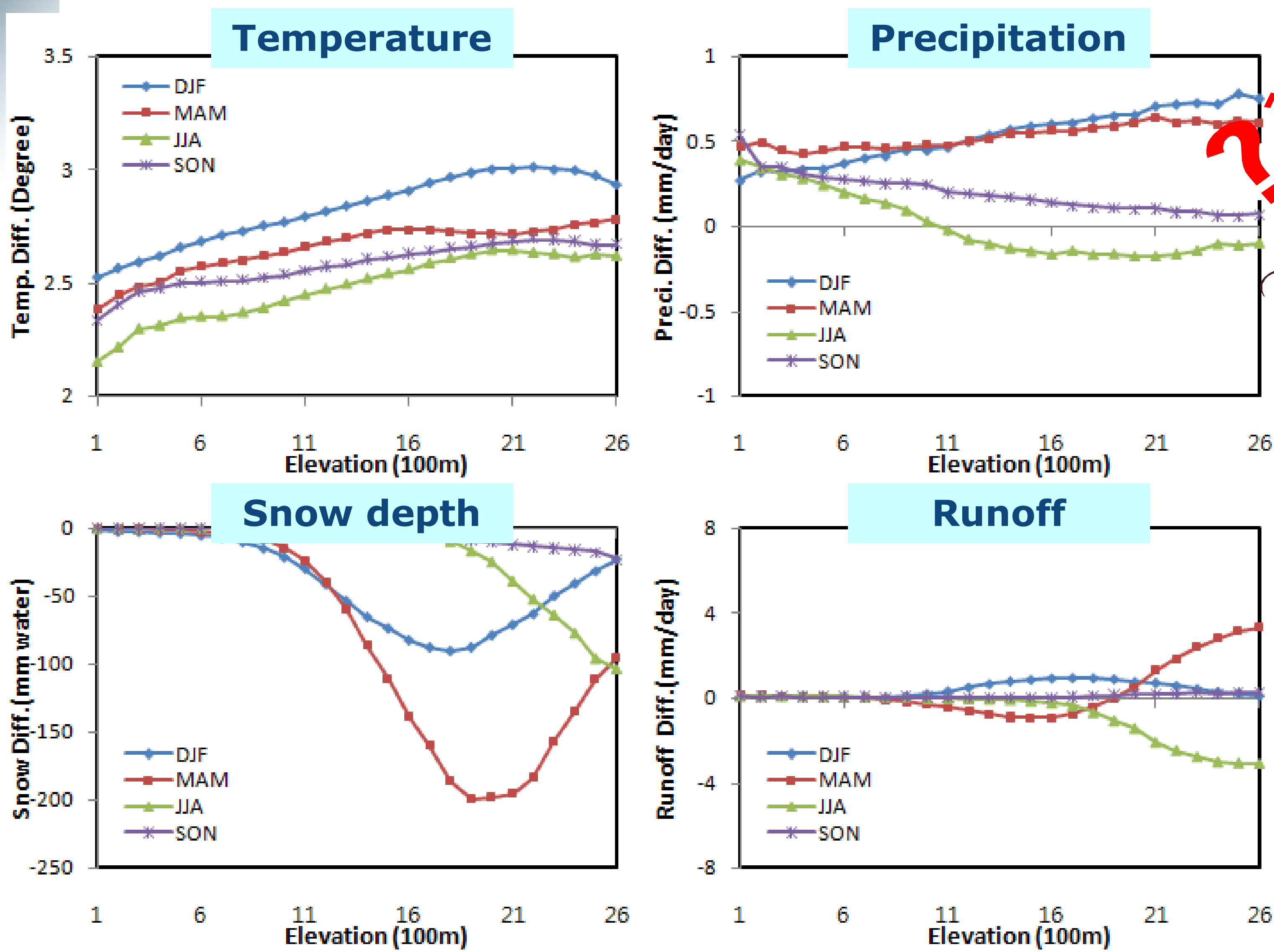


SCC Effects

Spatial distribution of Diff. (SCC-SUB)

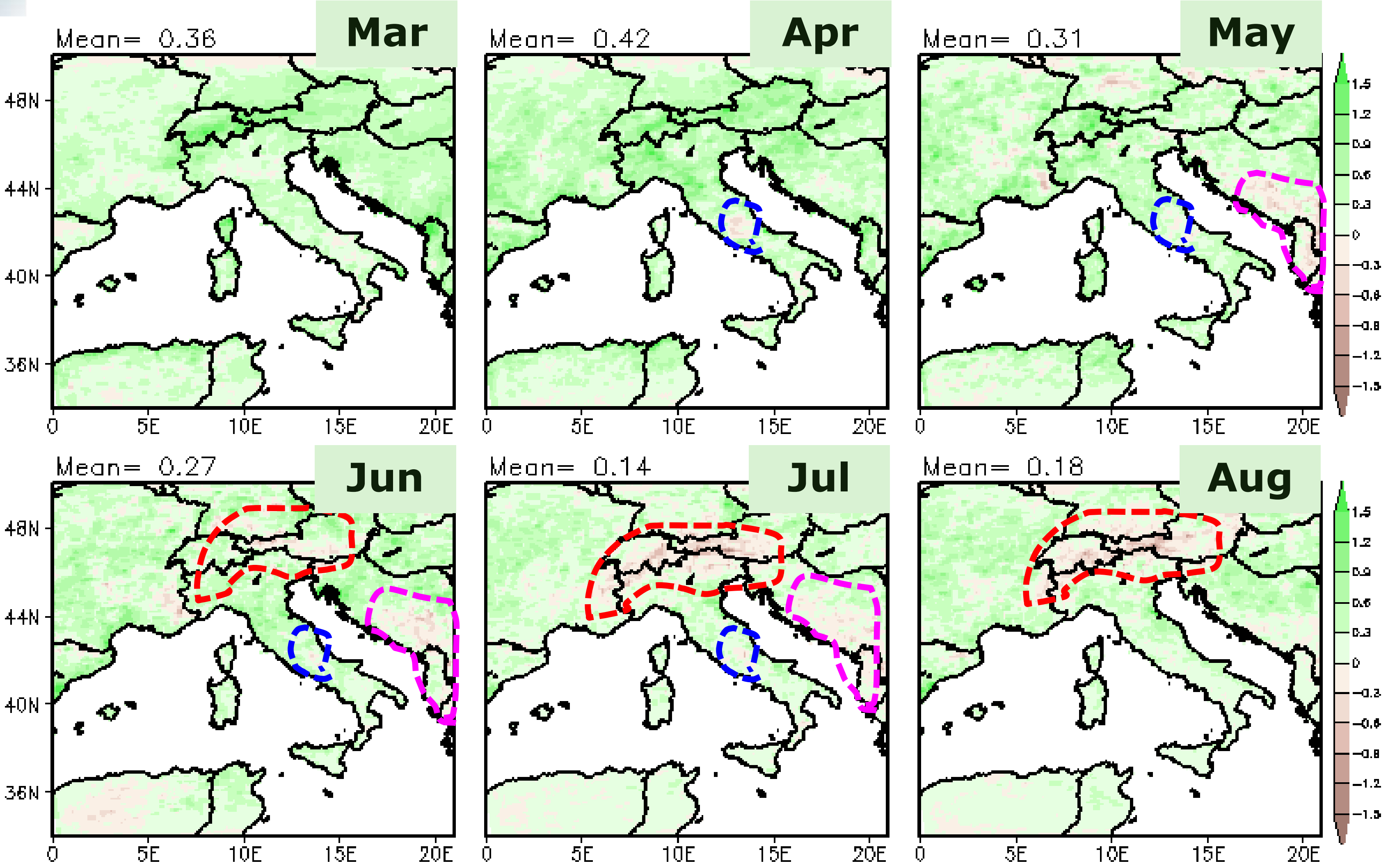


Elevation dependency

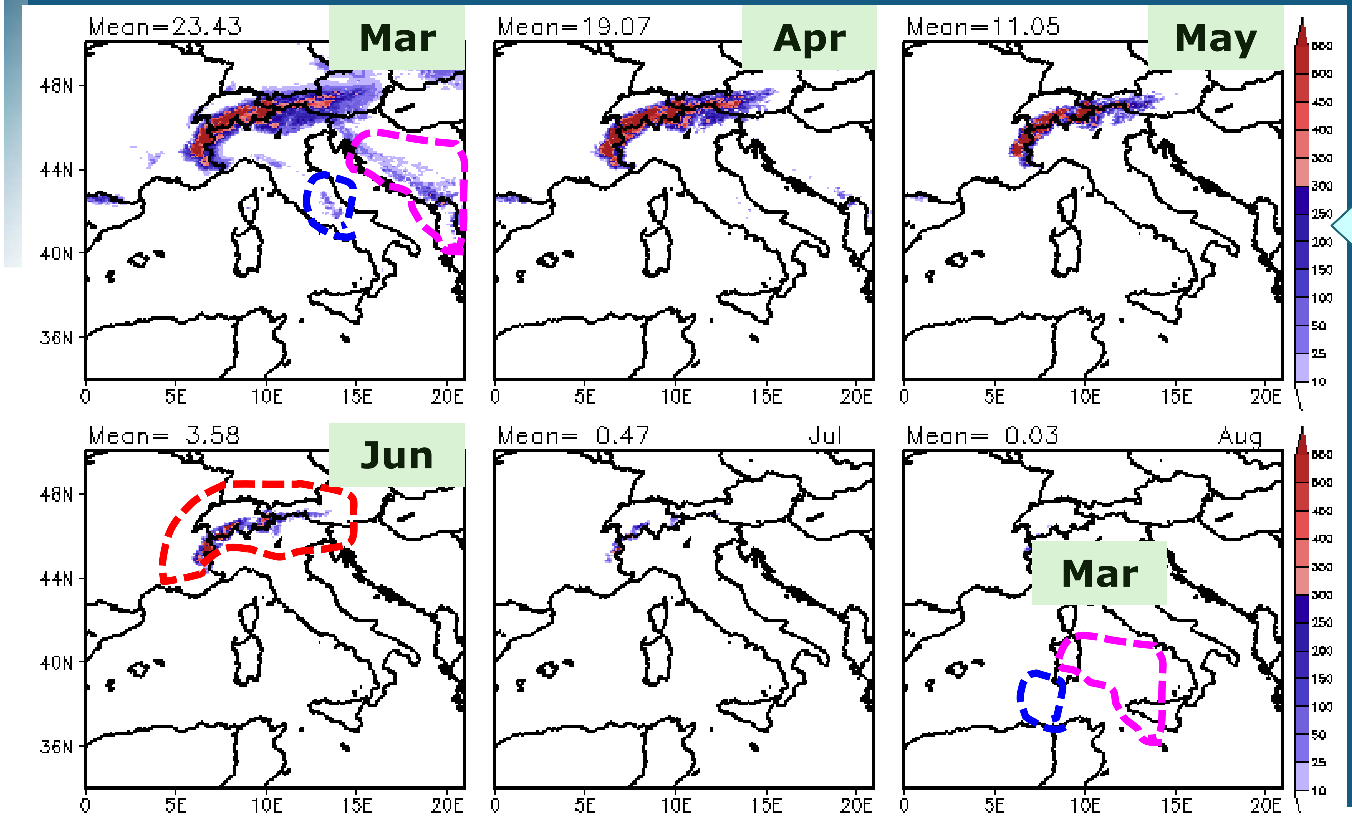


Precipitation Change

Summer precipitation decrease



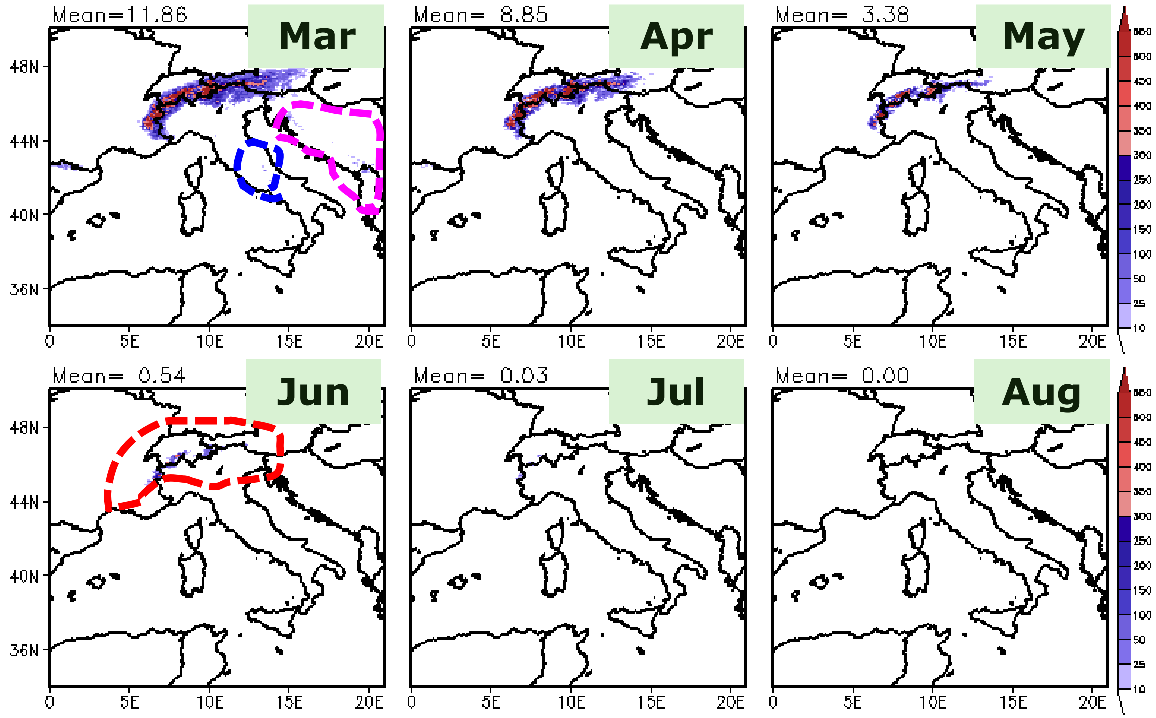
Snow Depth Change



SUB
Reference Climate

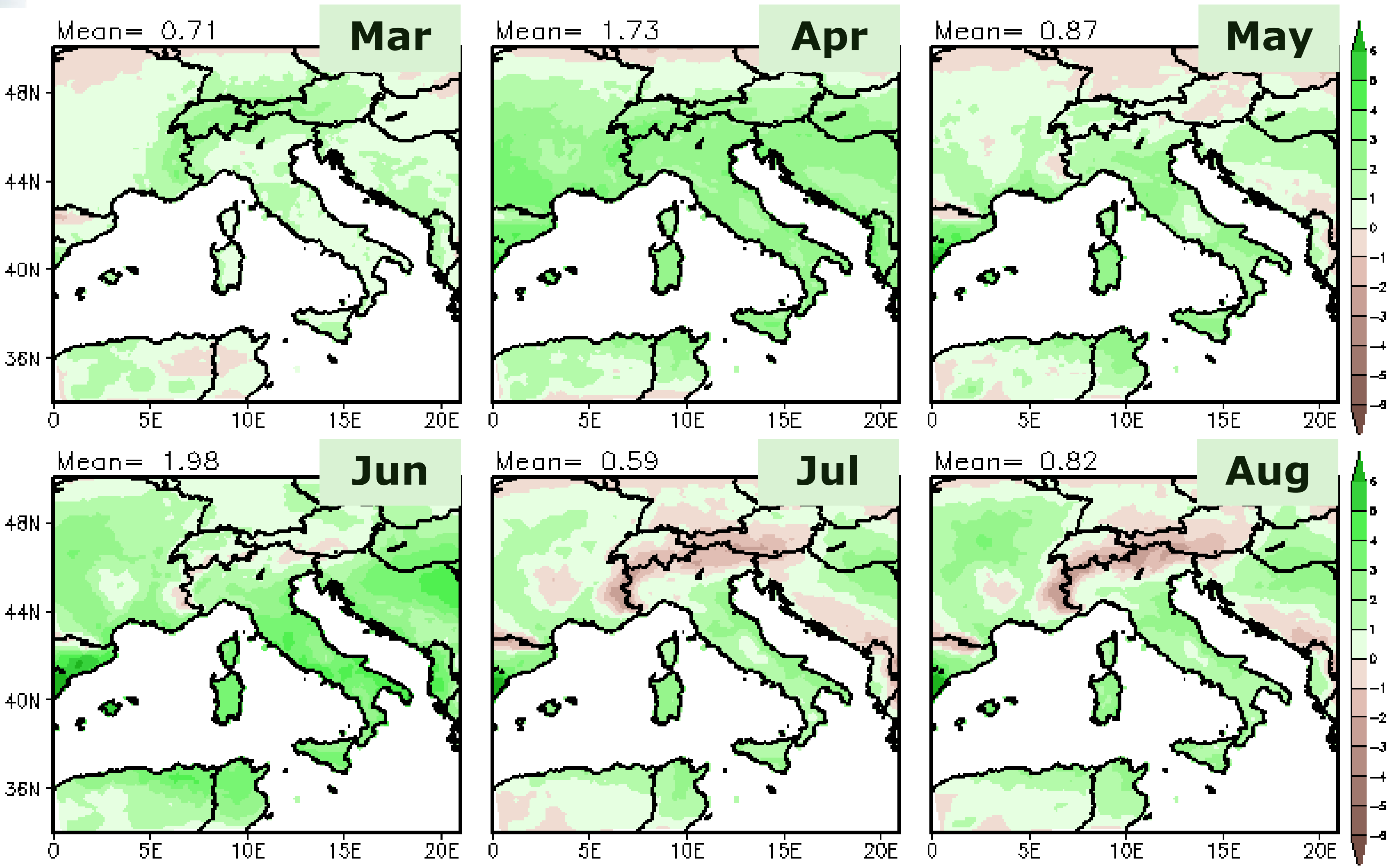
Snow Depth Change

SCC
Warm Climate

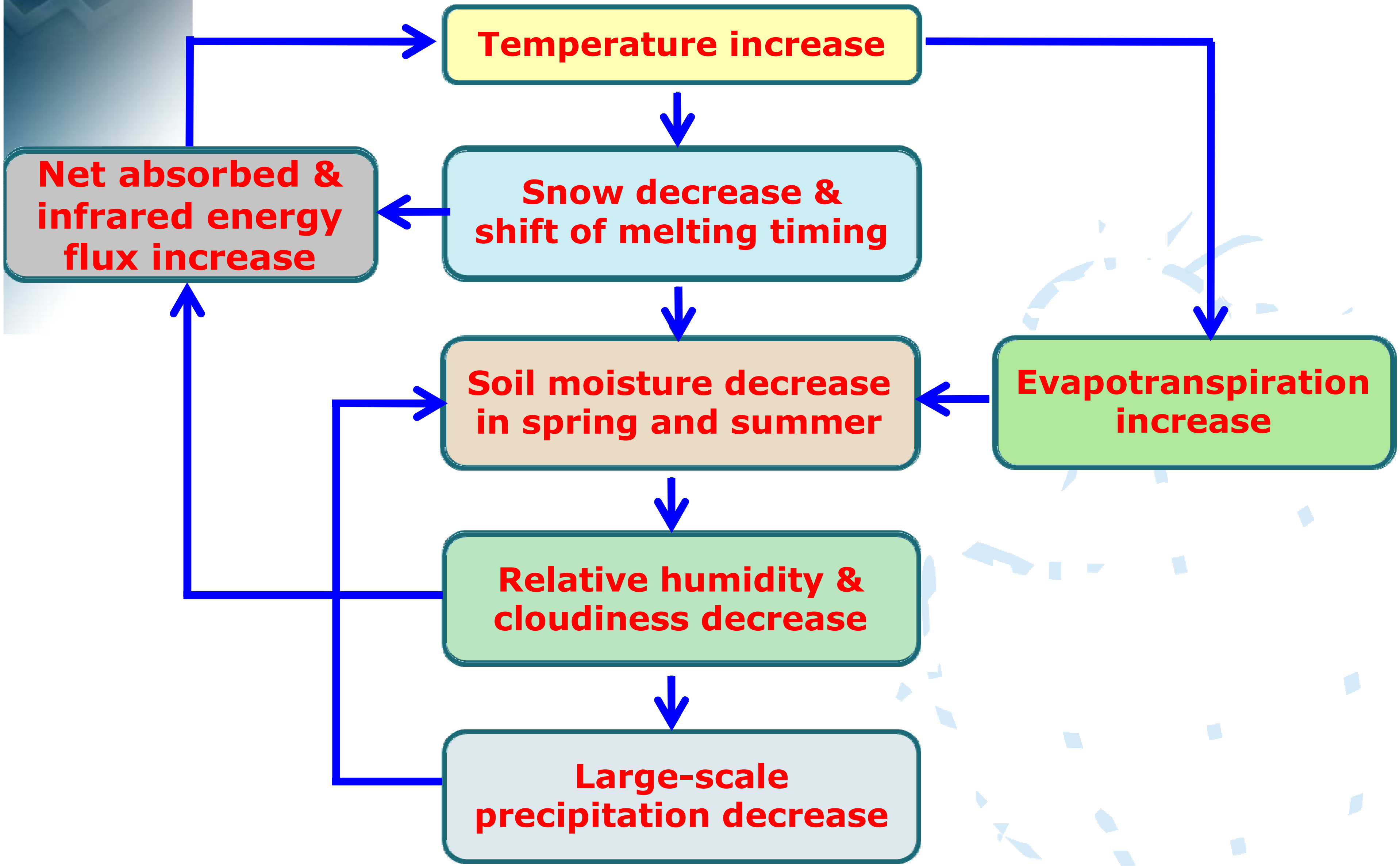


Relative Humidity Change

Relative Humidity (925hPa)



Local Feedback

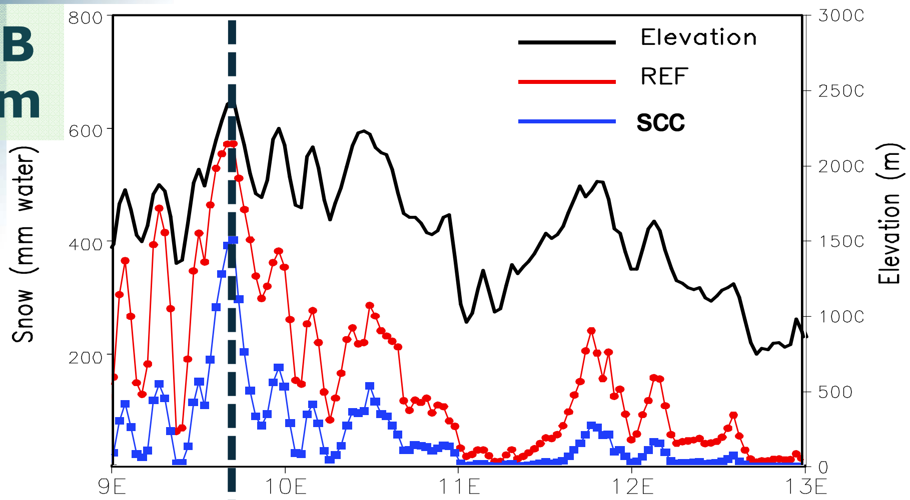


Topography Effect

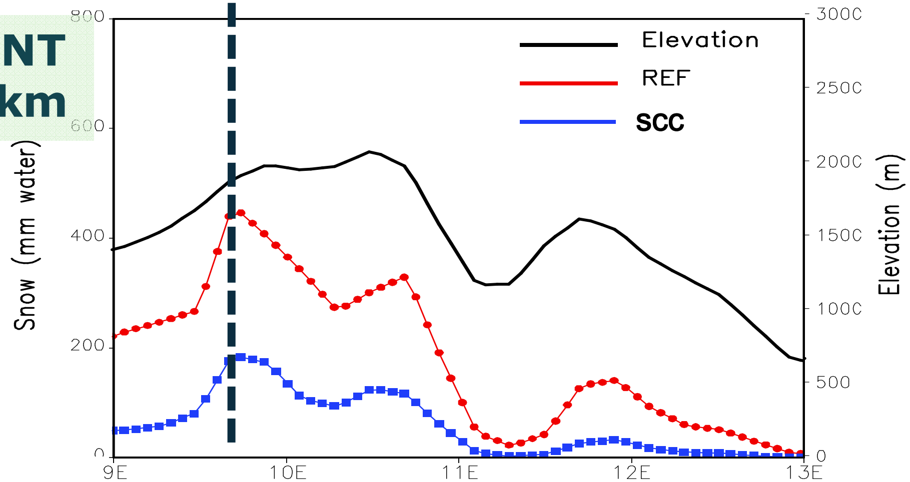
Eastwest transects (Lat: 46.3N)

Snow Depth [MAM]

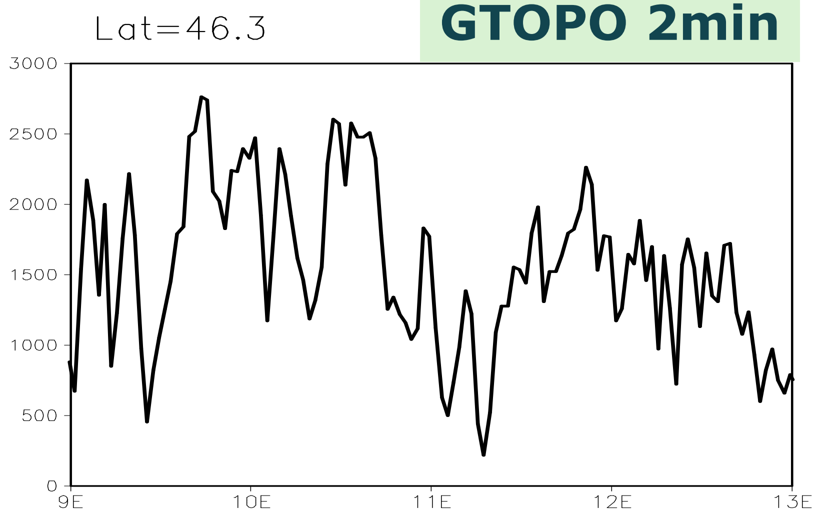
SUB 3km



CONT 15km



GTOPO 2min



Topography Effect

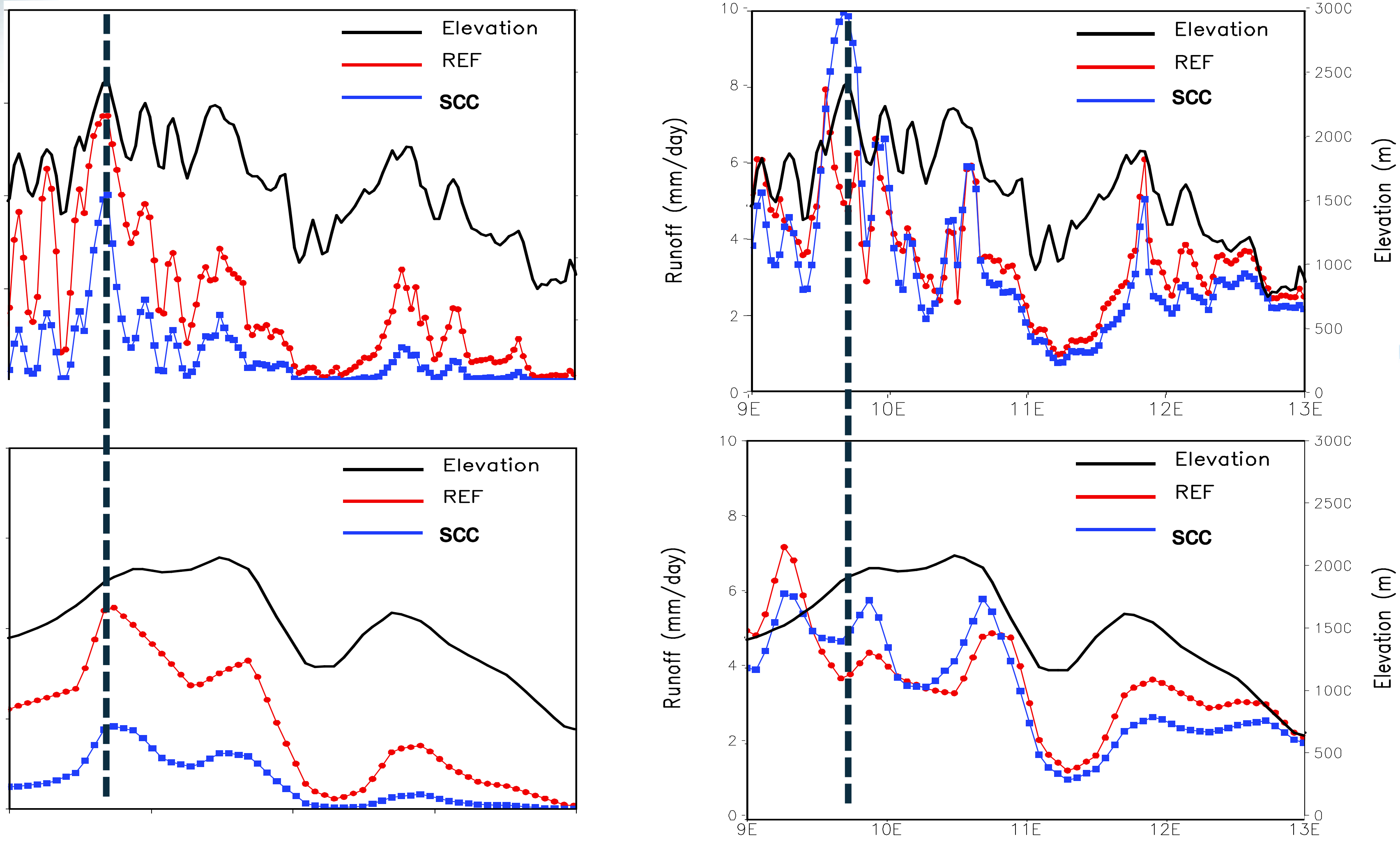
Eastwest transects (Lat: 46.3N)

Snow Depth [MAM]

Runoff [MAM]

SUB 3km

CONT 15km



Summary

❖ Subgrid-scale heterogeneity in topography and land use conditions are profoundly affect climate and the surface energy and water budgets, in particular at the regional and local scale.

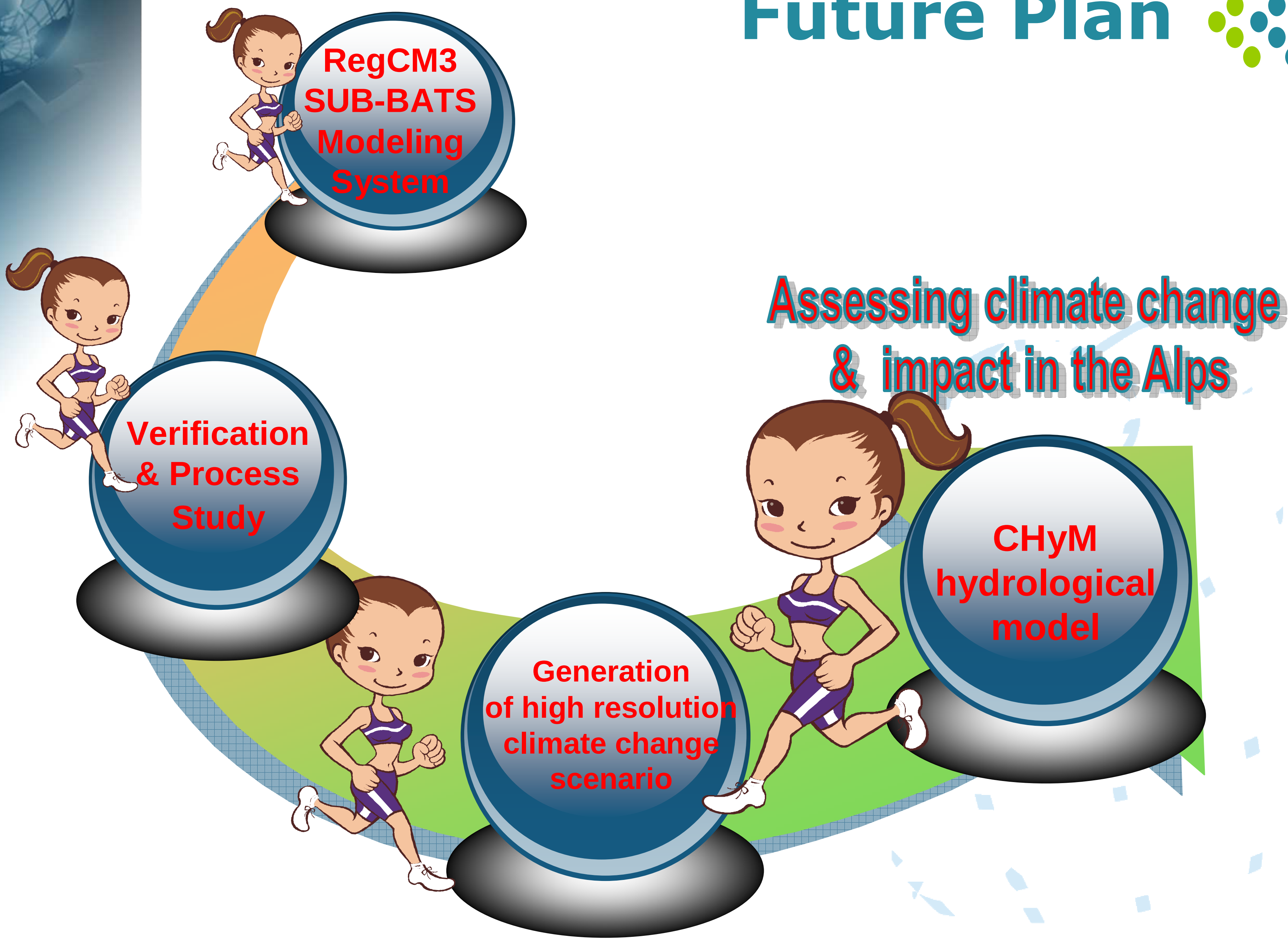
❖ Validation against various observations shows that the SUB simulation improves the model simulation of the surface hydrological cycle, in particular snow and runoff, especially at high elevation sites.

❖ The results from the surrogate climate change indicate that during summer local feedbacks associated with the surface hydrologic budget might be more important than large scale forcings in determining the local response to global warming over mountainous region.

❖ Considering the computational efficiency and improvement of spatial heterogeneity, the RegCM3 SUB-BATS system could be a useful tool to produce fine-scale long-term climate information.

❖ A very high resolution climate change information generated by the RegCM3 SUB-BATS system will link to hydrological impact studies for the Alps climatic change.

Future Plan


RegCM3 SUB-BATS Modeling System
Verification & Process Study
Generation of high resolution climate change scenario
CHyM hydrological model
Assessing climate change & impact in the Alps

Key References

❖ **Giorgi, F.**, et al., 2003: Effect of a subgrid-scale topography and land use scheme on the simulation of surface climate and hydrology. Part I: Effects of temperature and water vapor disaggregation. ***J. Hydrometol.***, 4, 317-333.

❖ **Im, E.-S.**, et al., 2010: Validation of a high resolution regional climate model for the Alpine region and effects of a subgrid-scale topography and land-use representation. ***J. Climate.***, 23, 1854-1873.

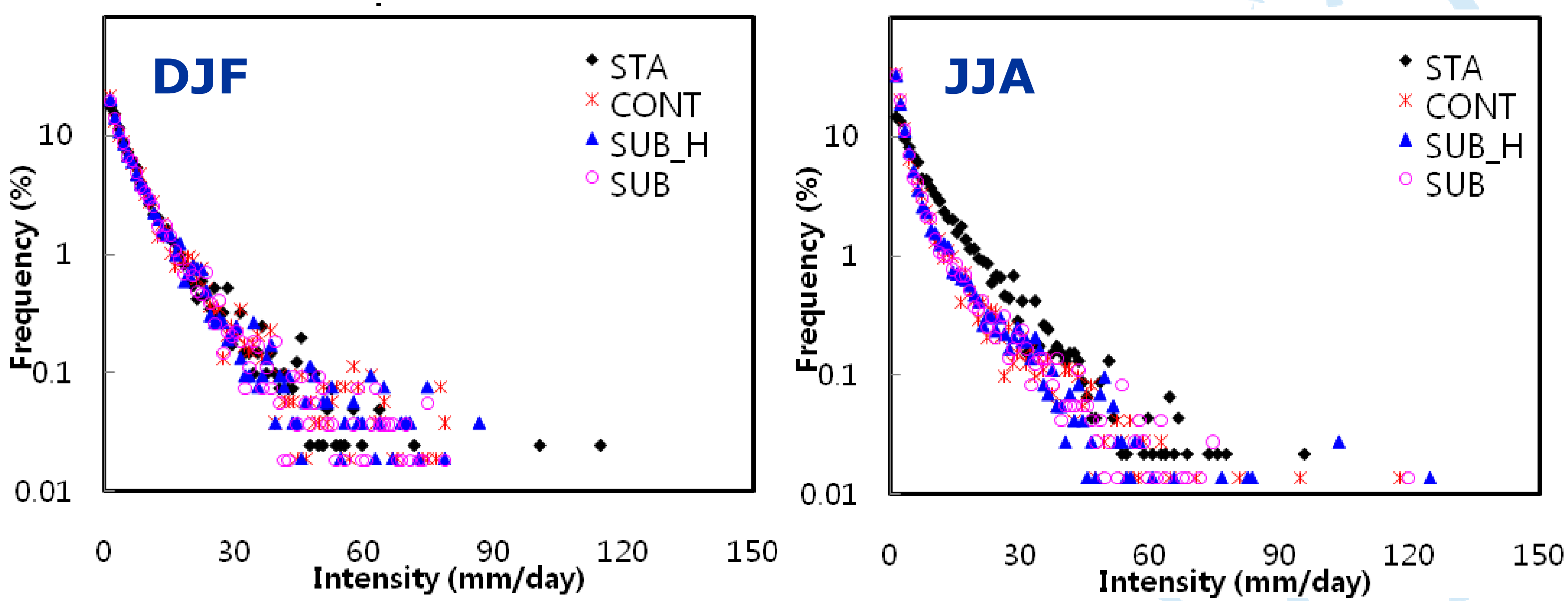
❖ **Im, E.-S.**, et al., 2010: Local effects of climate change over the Alpine region: A study with a high resolution regional climate model with a surrogate climate change scenario. ***Geophy. Res. Lett.***, 37, L05704, doi:10.1029/2009GL041801

Grazie!!

Sensitivity EXP. of Precip. Disaggregation

Verification of basic performance

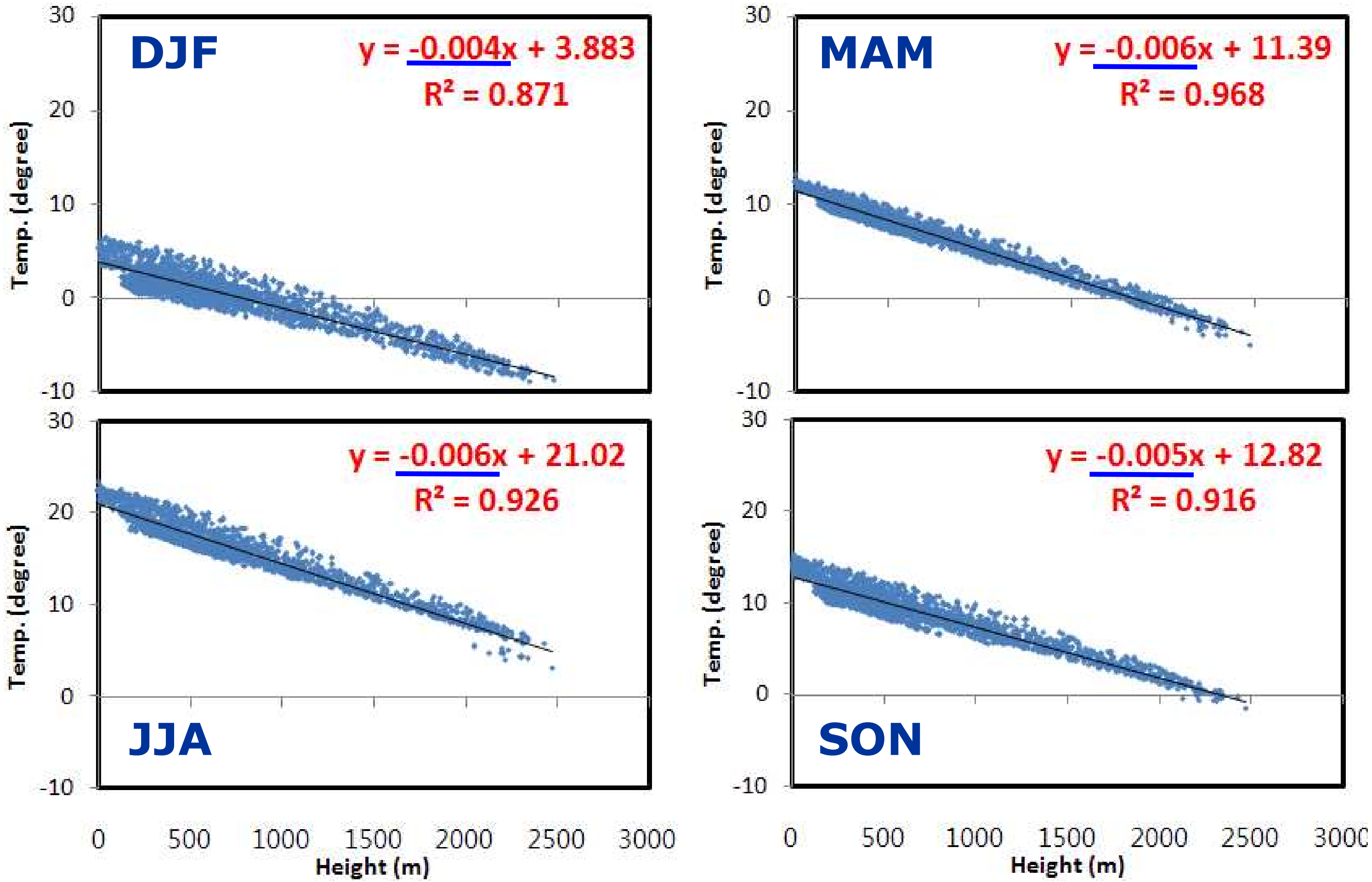
- The main effect in the precipitation disaggregation is the occurrence of few intense precipitation events in the tail of the distribution in closer agreement with observation in the winter season.
- For root-mean-square error and spatial correlation, the first-order precipitation disaggregation scheme appears to slightly improve the simulation



Sensitivity of SUB-BATS I

Relationship between Temp. & Height

- Linear relationship empirically derived from the CONT simulation



Future change of ENS Run

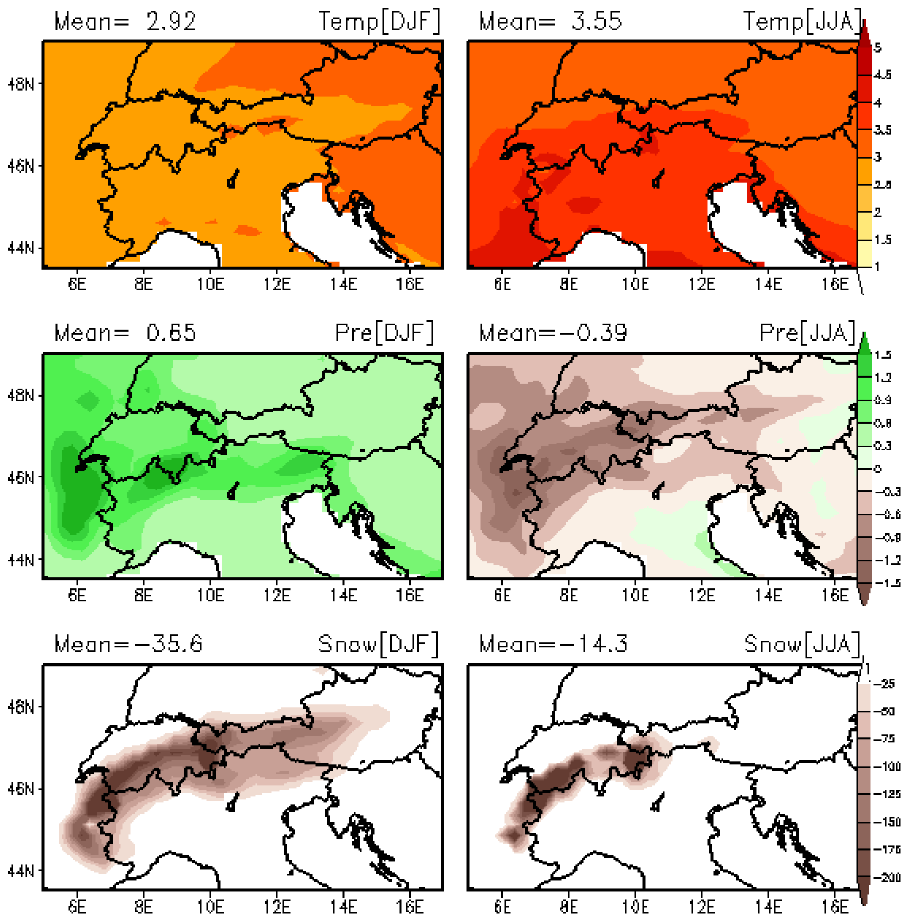
RegCM3 (25km) driven by ECHAM5-MPI/OM

- Decrease in summer precipitation over the Alpine region consistent with the SCC results. This decrease, however, is also due to changes in large scale circulations.

Temperature

Precipitation

Soil moisture



SCC Energy Budget

Difference in surface radiative term for summer

Net absorbed solar energy flux & net infrared energy flux