Modeling the land surface processes: a summary of different applications with UTOPIA

Claudio Cassardo

Department of Physics

UNIVERSITÀ DEGLI STUDI DI TORINO

Department of Environmental Science and Engineering

claudio.cassardo@unito.it

Outline - 개요

- The UTOPIA (model)
  - Structure and input/output data
  - General outline: main processes studied
- Applications
  - Energy and hydrological budget of Alpine area in future climate
  - Korean monsoon
  - The case of the 2003 summer
  - Sensitivity analysis on vegetation parameters
  - Snow: Siberia, Piemonte, Antarctica

 Prof. Claudio Cassardo

The UTOPIA

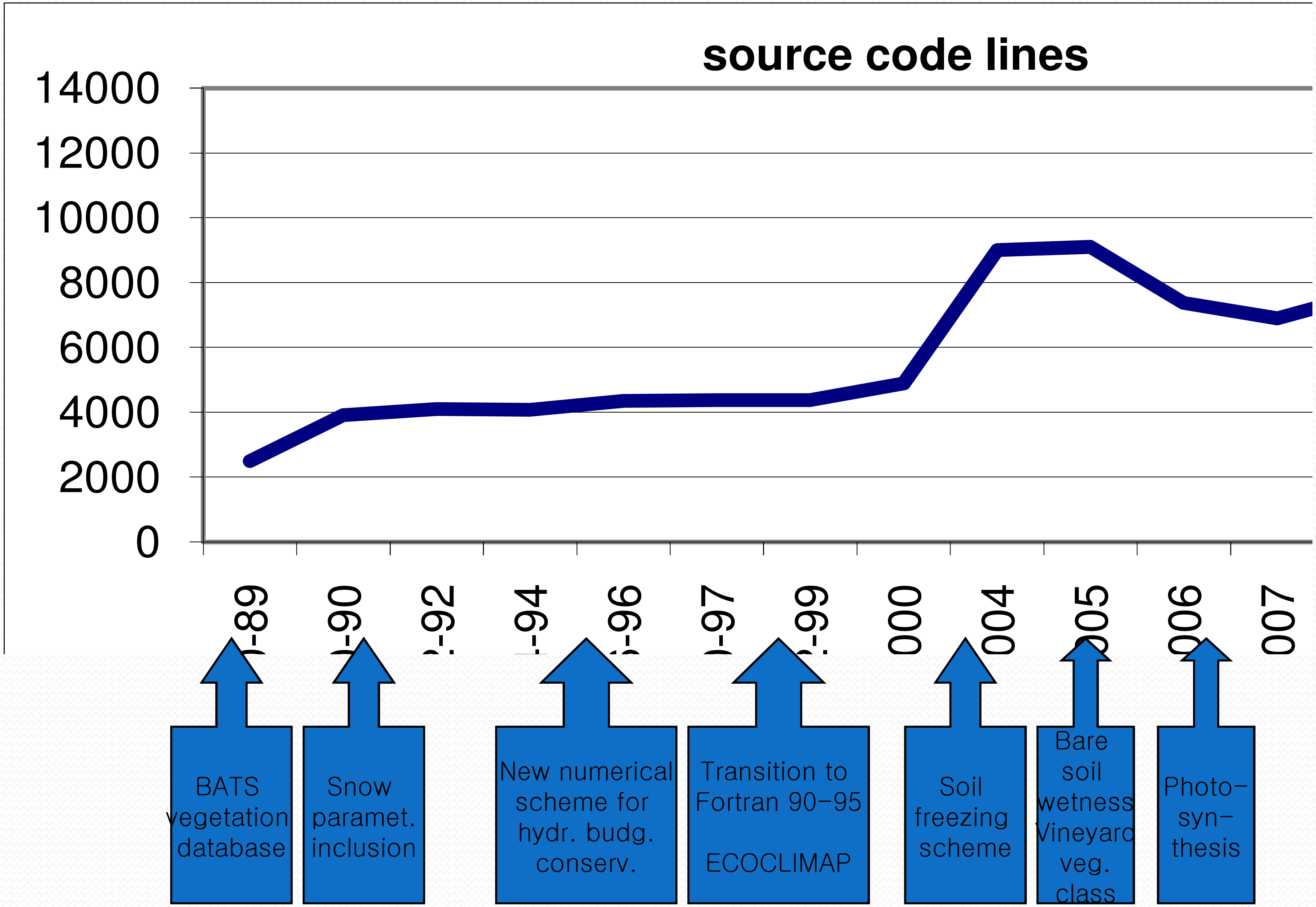
The origin of the name

- The model celebrates 23 years in 2014
- Created in 1991 by myself, A. Longhetto and J.J. Ji
- For 18 years it has been called LSPM (Land Surface Process Model)
- In 2009 it has been renamed UTOPIA, acronym of:

University of TOrino land surface Process model for

Interaction in the Atmosphere

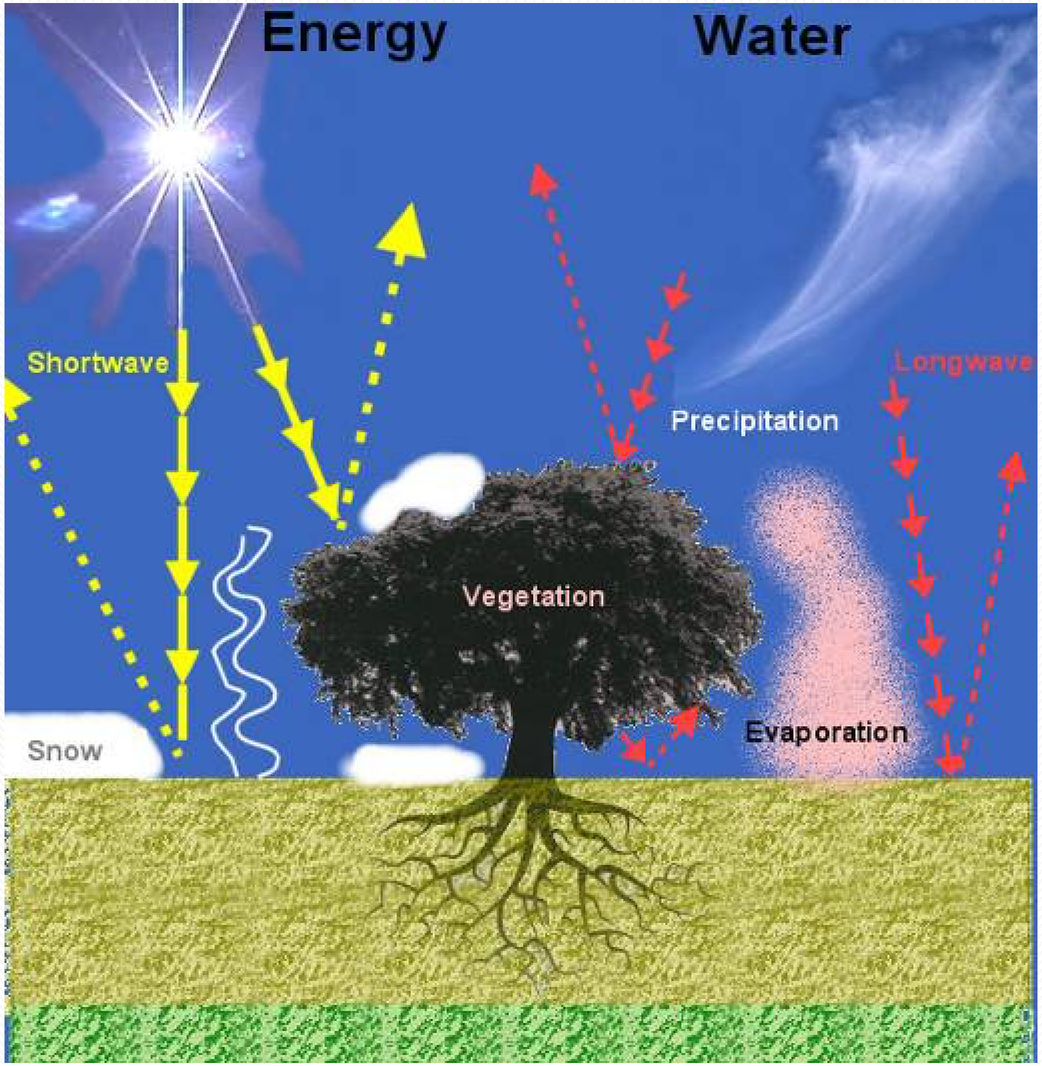
The evolution of LSPM-UTOPIA



The UTOPIA

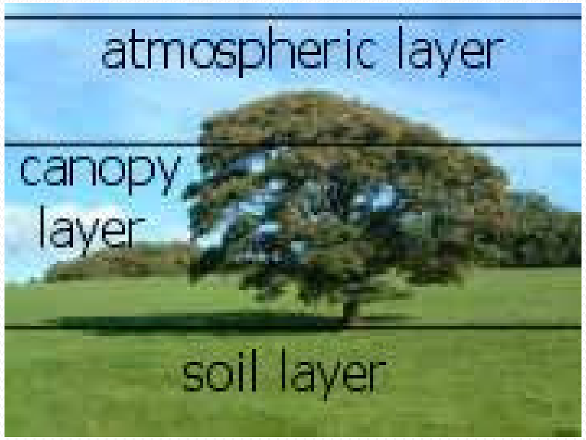
(University of TOrino land surface Process model for Interaction in the Atmosphere)

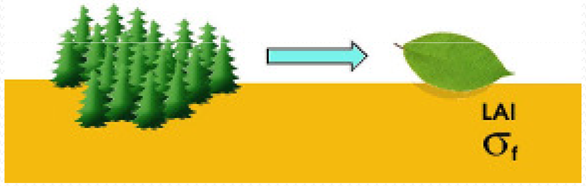
UTOPIA is a **bigleaf** 1D model which calculates the exchanges of mass, momentum and water vapor between the atmosphere and the surface (bio-geo-hydrosphere)

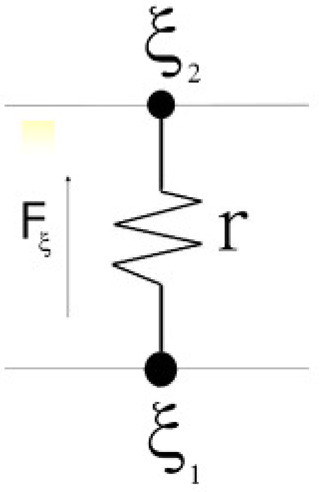


The UTOPIA structure

- 3 zones: atmosphere, vegetation, soil
- Vegetation → uniform layer (big-leaf approximation)
- Variables → weighted averages between atmospheric, canopy and snow components
- Canopy → vegetation cover, height, leaf area index (LAI), albedo, minimum stomatal resistance, leaf dimension, emissivity and root depth
- Soil → thermal conductivity, hydraulic conductivity, soil porosity, permanent wilting point, dry volumetric heat capacity, soil surface albedo and emissivity
- Soil variables → multi-layer schemes (N layers)
- Turbulent fluxes → electric analogue scheme
- Photosynthesis evaluation







Input/output data

Boundary conditions

- Air temperature (°C or K)
- Atmospheric pressure (hPa)
- Relative (%) or specific (g(Kg) humidity
- (Total and low) cloudiness
  - or solar radiation (Wm-2)
- Wind speed (m/s)
- Precipitation (mm/Δt)

Initial conditions

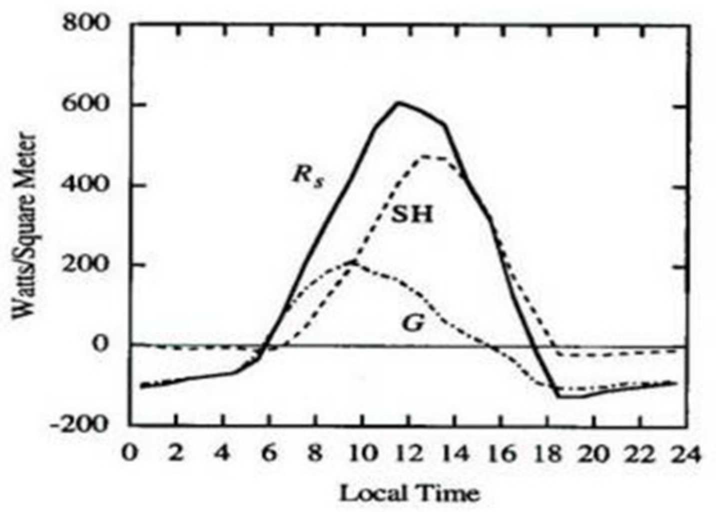
- Coordinates (Lat, Lon, Quote)
- Height of observations
- Azimuth and slope of site
- Sky turbidity (needed for radiation)
- Time step of observations
- Initial date and time
- Soil temperature
- Soil moisture
- Initial snow height

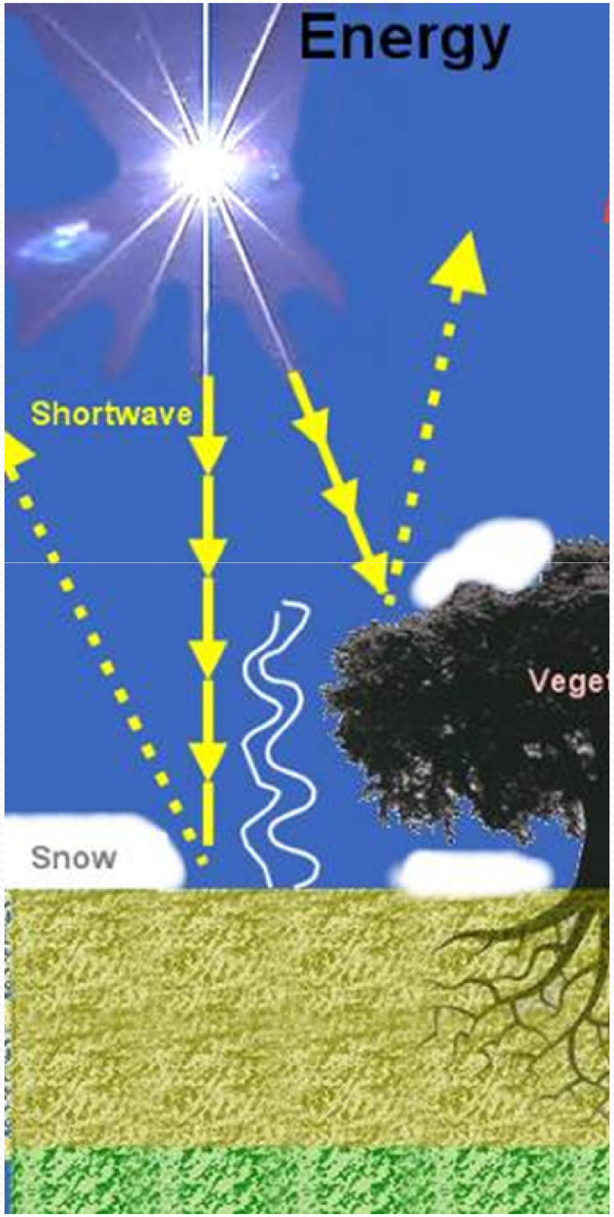
Output

- Vegetation + multi-layer soil temperature
- Vegetation and multi-layer soil moisture
- Energy Balance (Radiative, Turbulent and Conductive heat fluxes)
- Hydrologic Balance (Rain – Snow - Water evaporation drainage runoff)
- Other soil-vegetation parameters

The physical processes

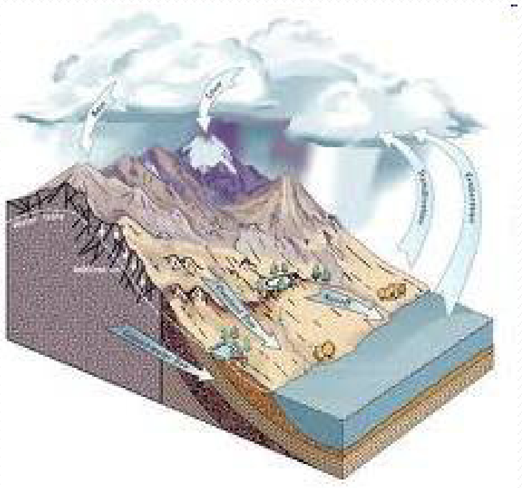
- Radiative fluxes
- Momentum flux
- Sensible heat flux
- Latent heat flux
- Partitioning of latent heat flux into canopy evaporation, soil evaporation and transpiration
- Heat transfer in a multi-layer soil or lake

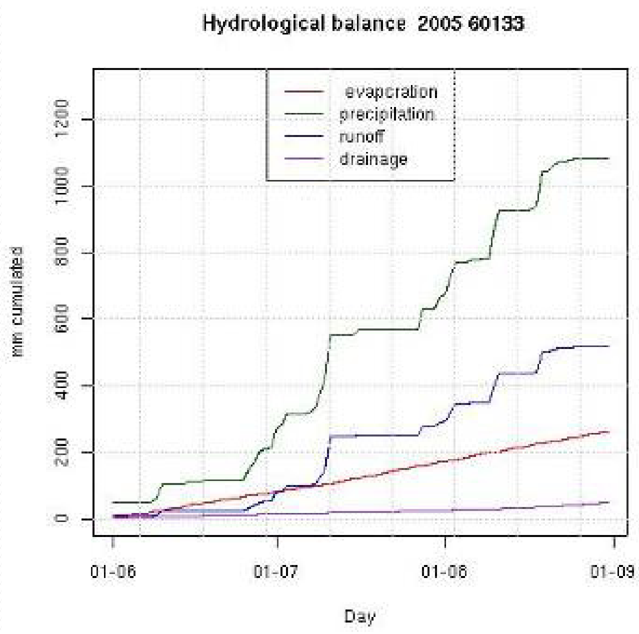


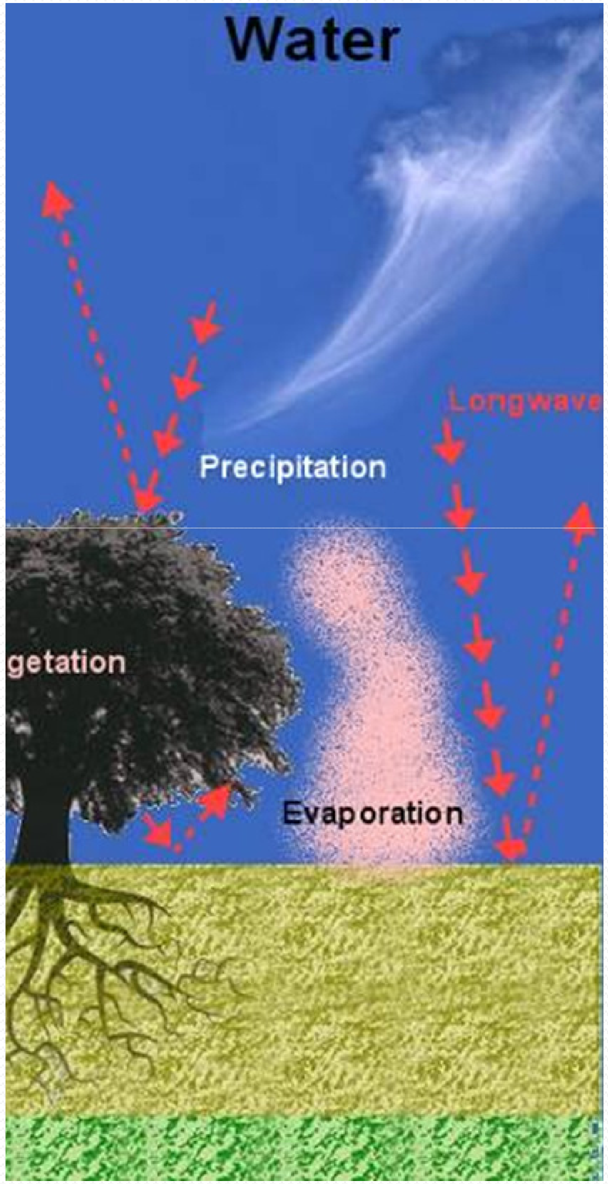


Hydrological processes

- Snow accumulation and melt
- Rainfall, interception, infiltration and runoff
- Soil hydrology, including water transfer in a multi-layer soil

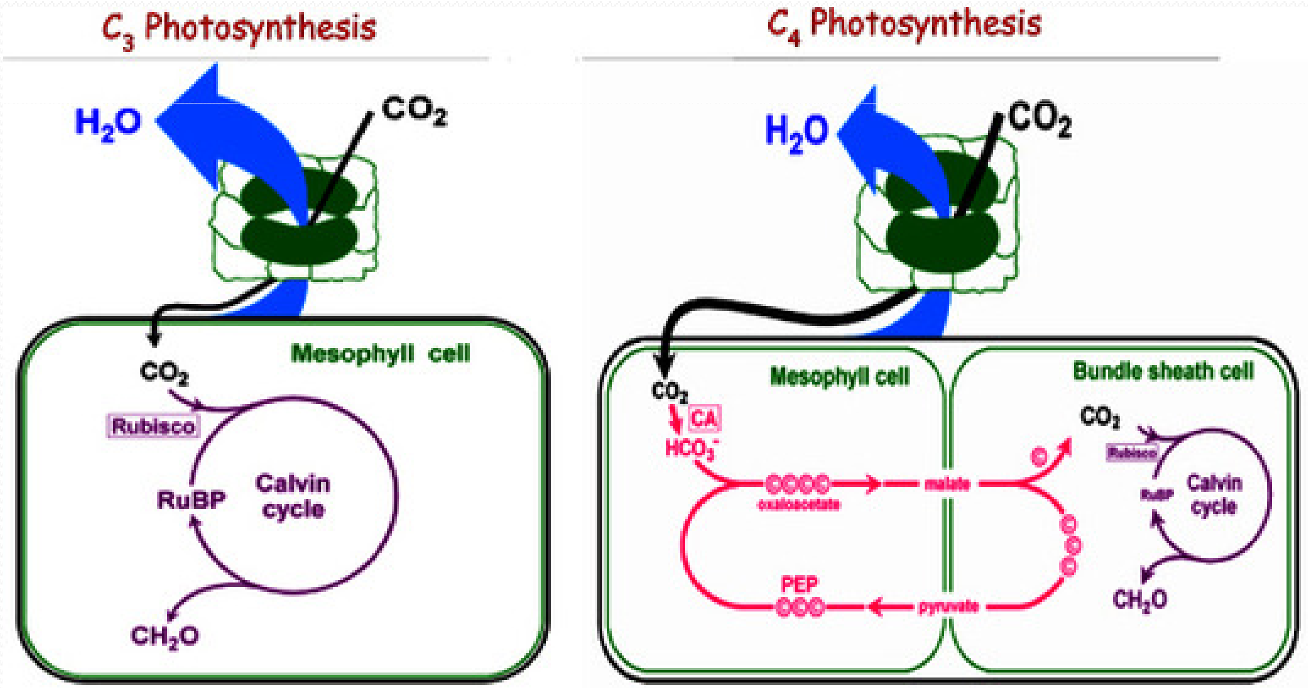






Photosynthesis

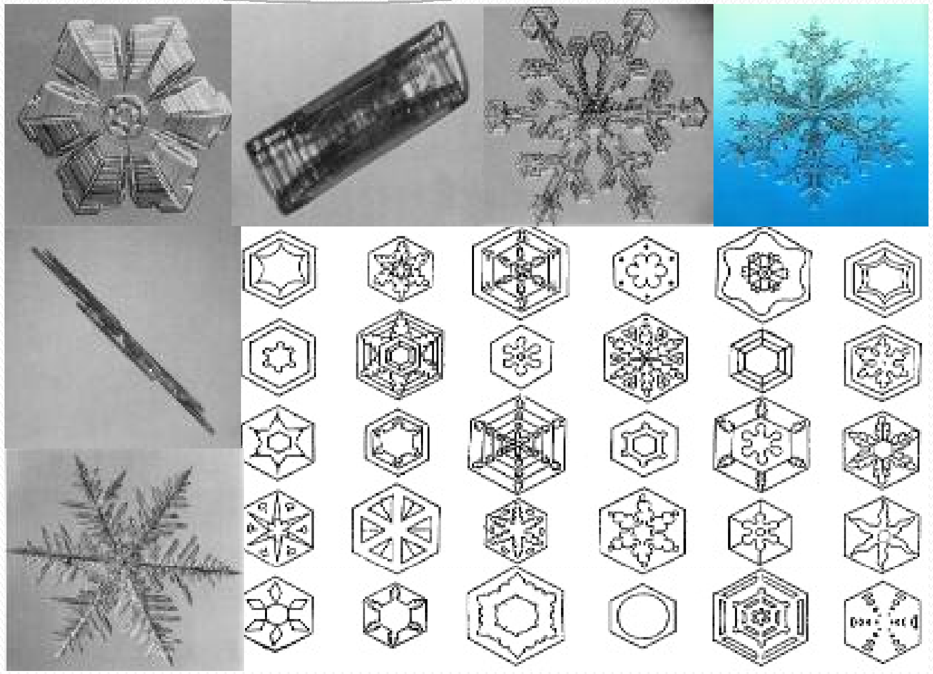
- Evaluation of NPP and GPP
- Quantification of photosynthesis (C3 and C4)
- Detailed evaluation of canopy resistance



Source: Chuanli et al., 2012

The snow

- Snow → single homogeneous layer lying upon land surface
- Frost = snow
- Metamorphism for calculating density
- Albedo
- Snowpack considered as a single homogeneous layer lying upon land surface

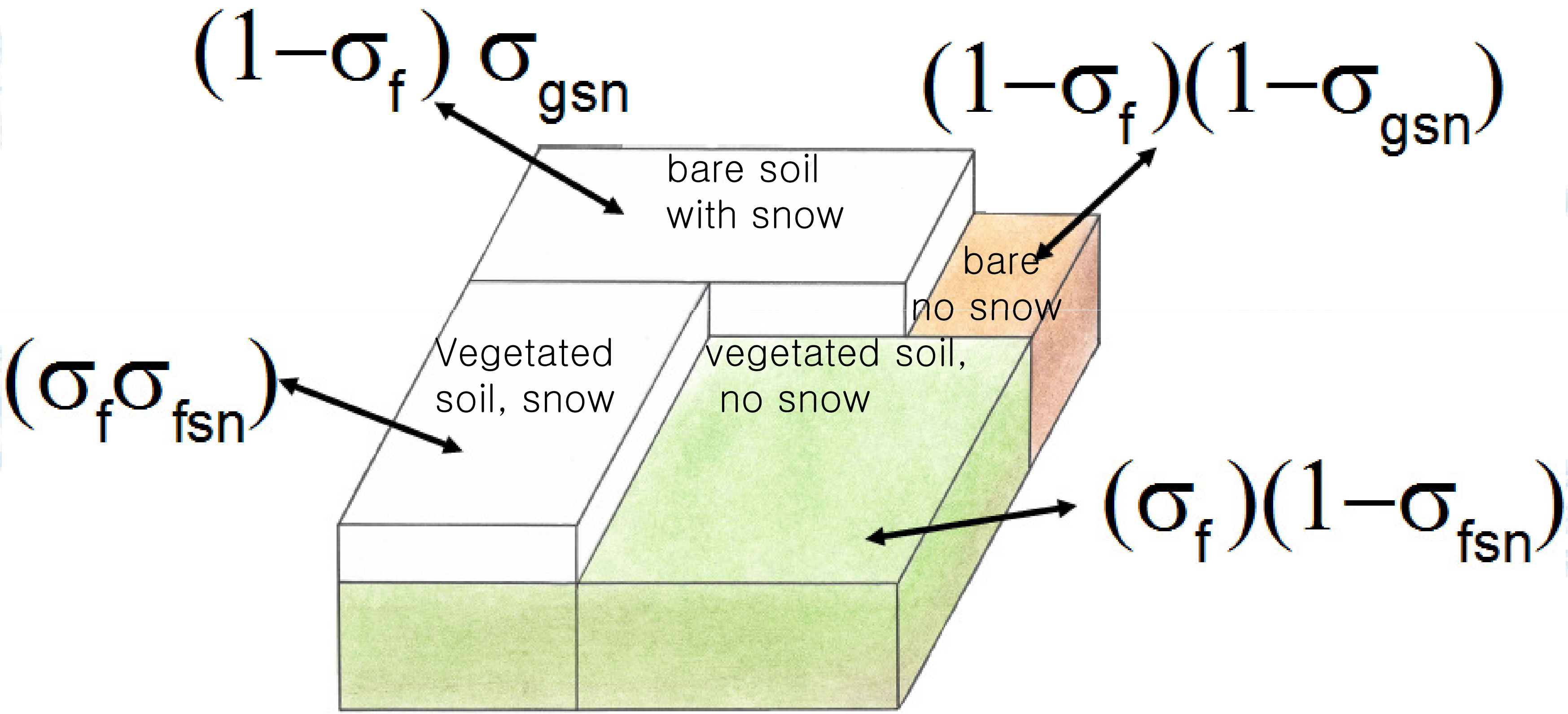


- Snow mass, thermal and hydrological balances are considered, to evaluate water equivalent and liquid water content
- Each component of energy and hydrologic budgets has been modified taking into account the new partition of soil coverage fractions (snow covered/free bare & vegetated soil)

Snow cover

Partition among soil, vegetation and snow fractions

$$\sigma_{sn} = \sigma_f \, \sigma_{fsn} + \left(1 - \sigma_f\right)\sigma_{gsn}$$



$$\sigma_{sn} = \sigma_f \sigma_{fsn} + (1 - \sigma_f)\,\sigma_{gsn}$$

UTOPIA Applications

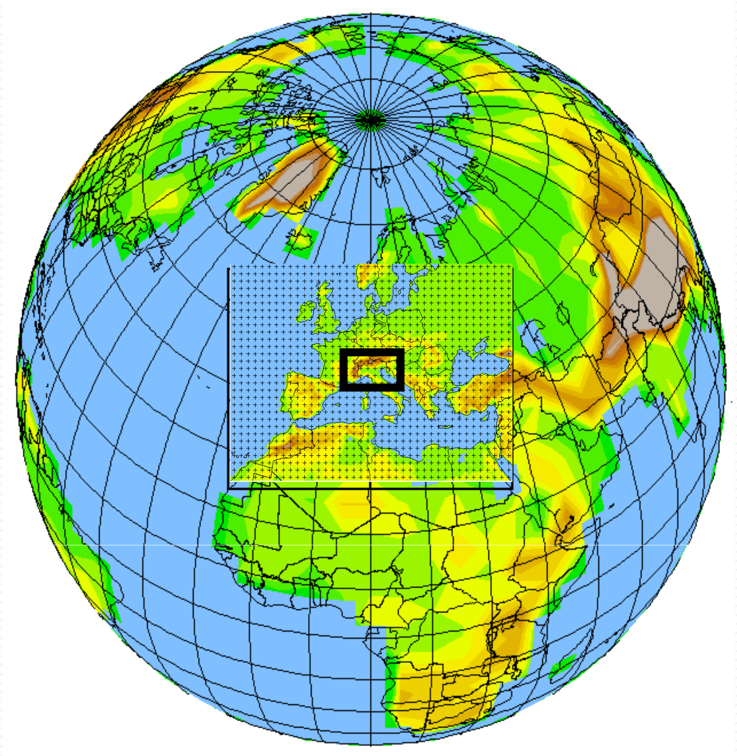
Energy and hydrological budget of Alpine area in future climate

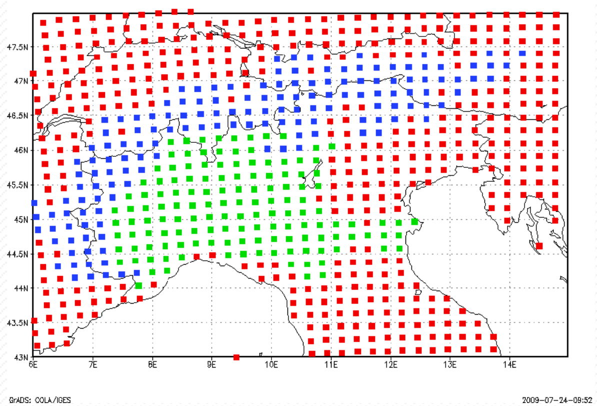
The experimental setup

- **Evaluation of surface layer parameters (energy and hydrological budget, soil temperature and humidity)**

- Method: run of UTOPIA driven by a regional climate model (RegCM3) in turn driven by a global model (HadAMH)

- Selected simulations: present (1961-90) and future (2071-2100, A2 and B2 scenarios) climate

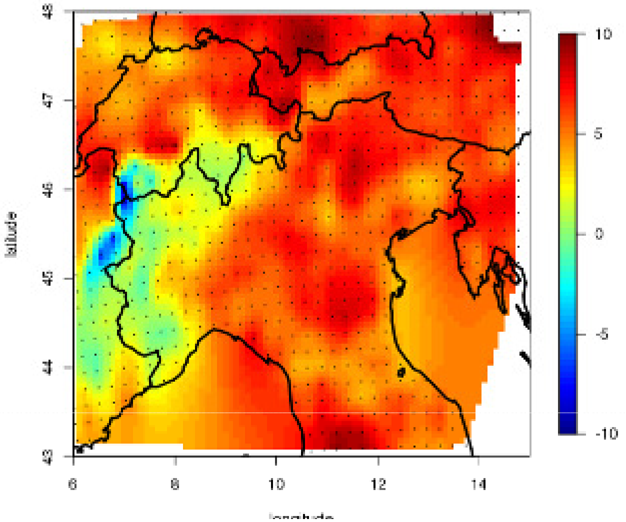




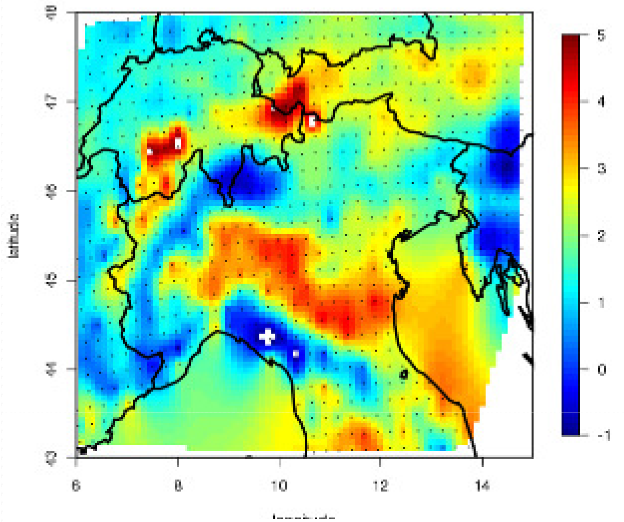
Hydrological components

20th decade, Future (A2) minus present climate

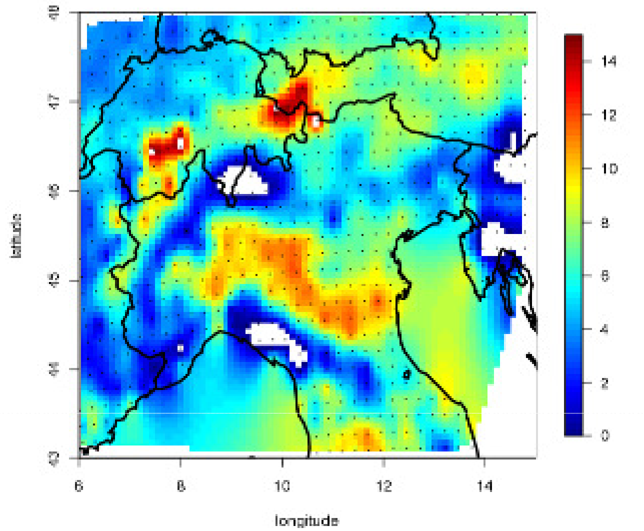
Net Radiation



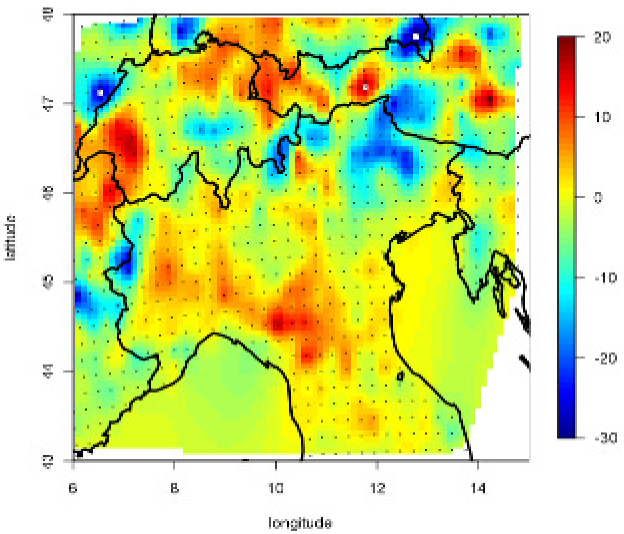
Evaporation



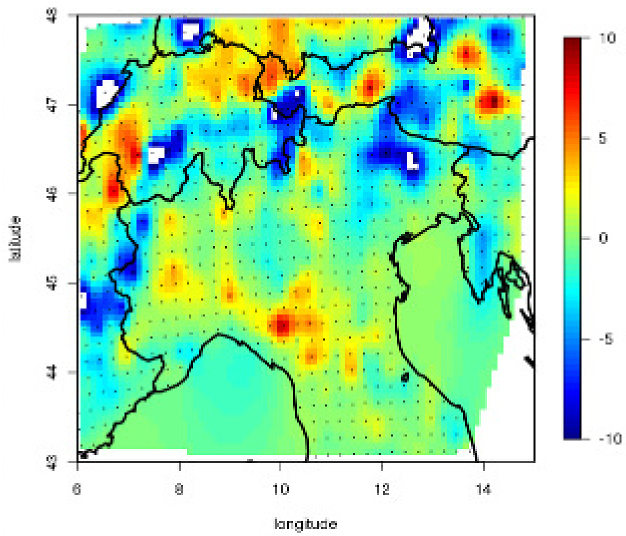
Latent Heat



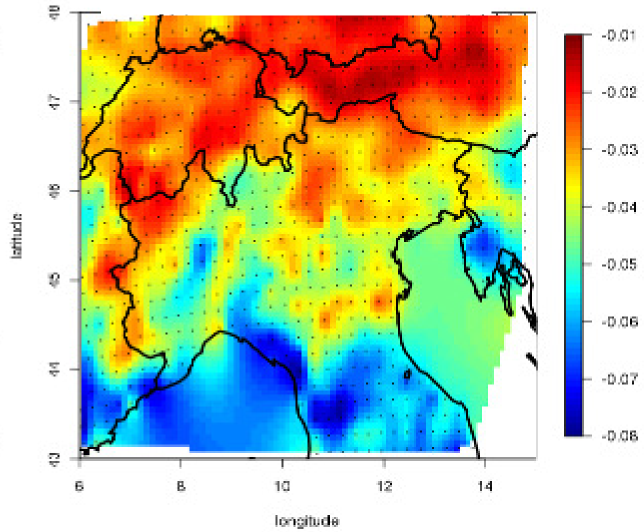
Precipitation



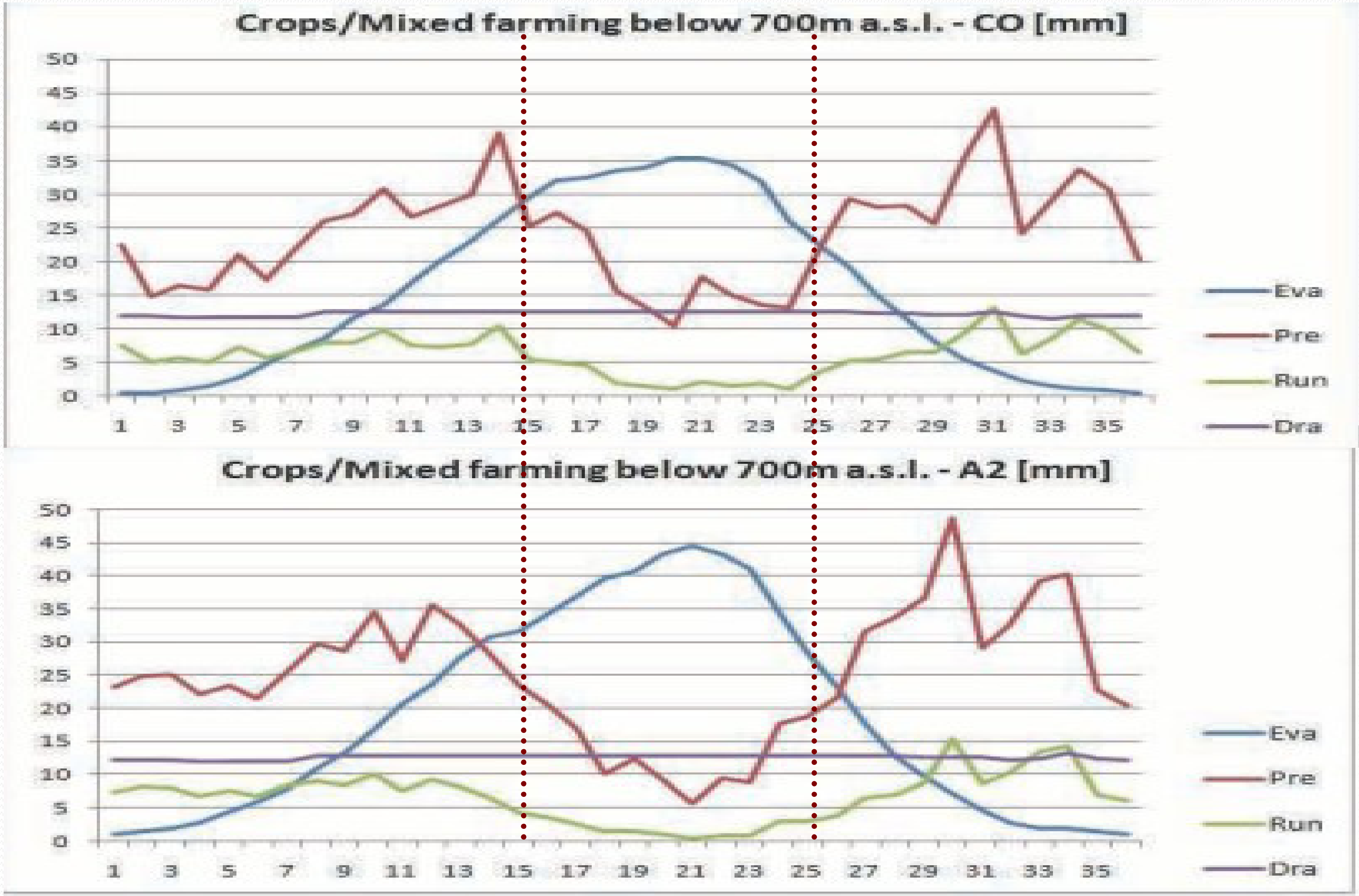
Runoff



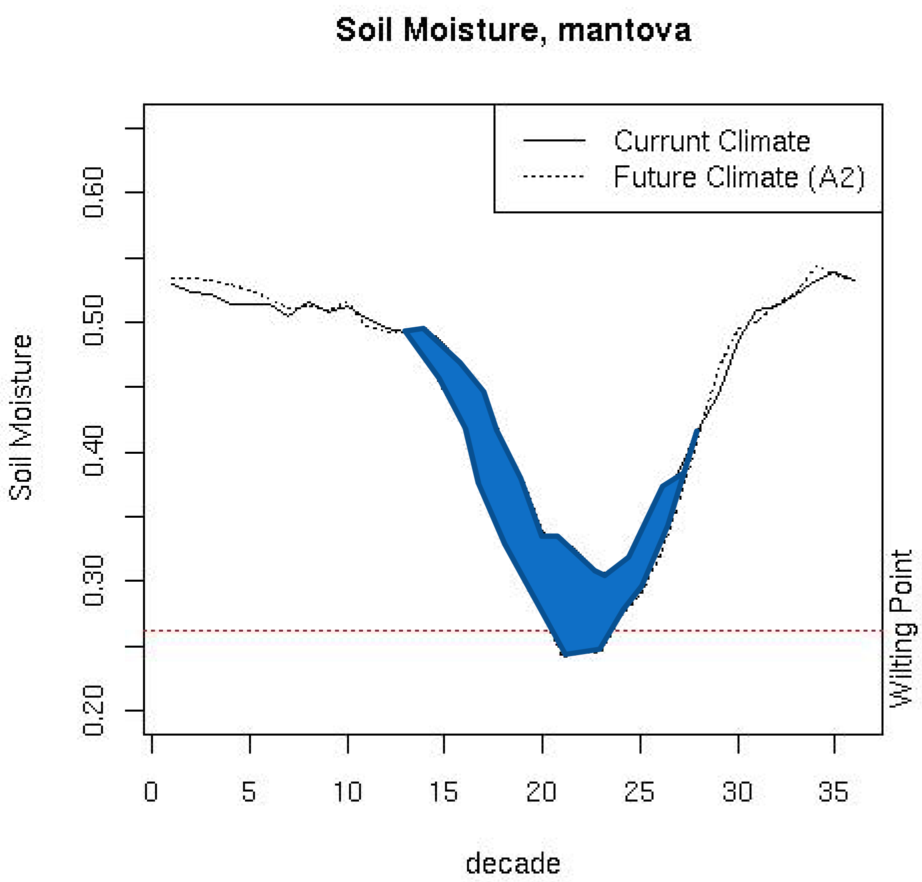
Soil Moisture

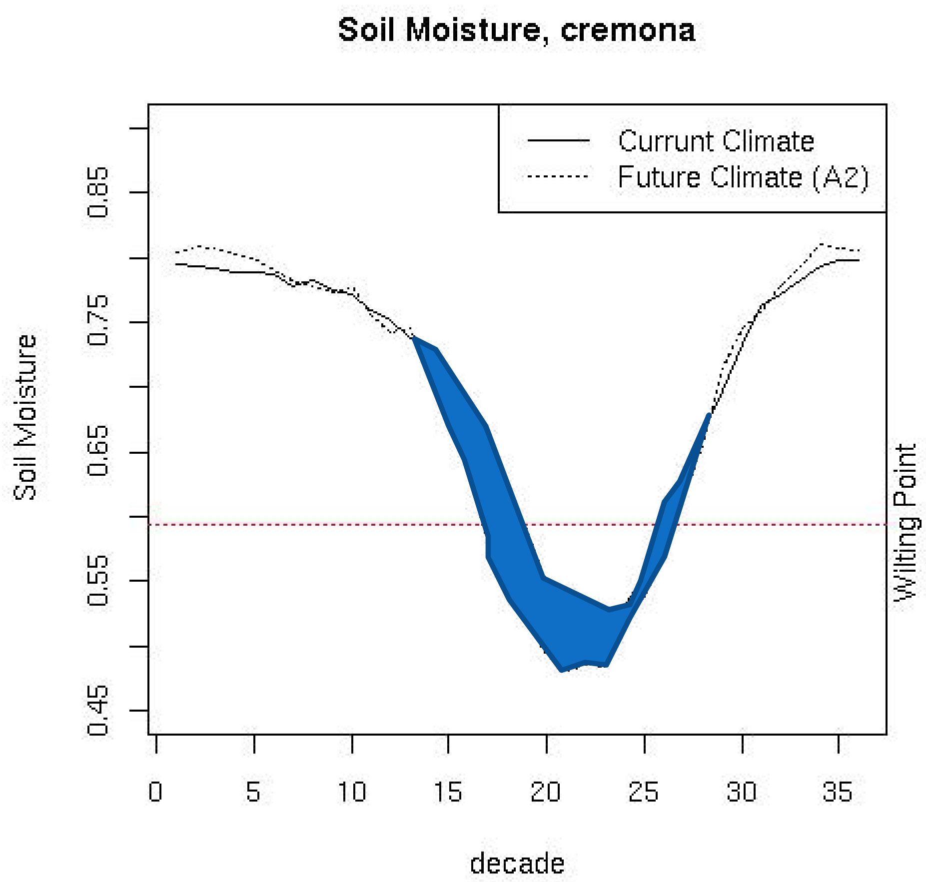


Hydrological budget: cultivated soils (Po valley)



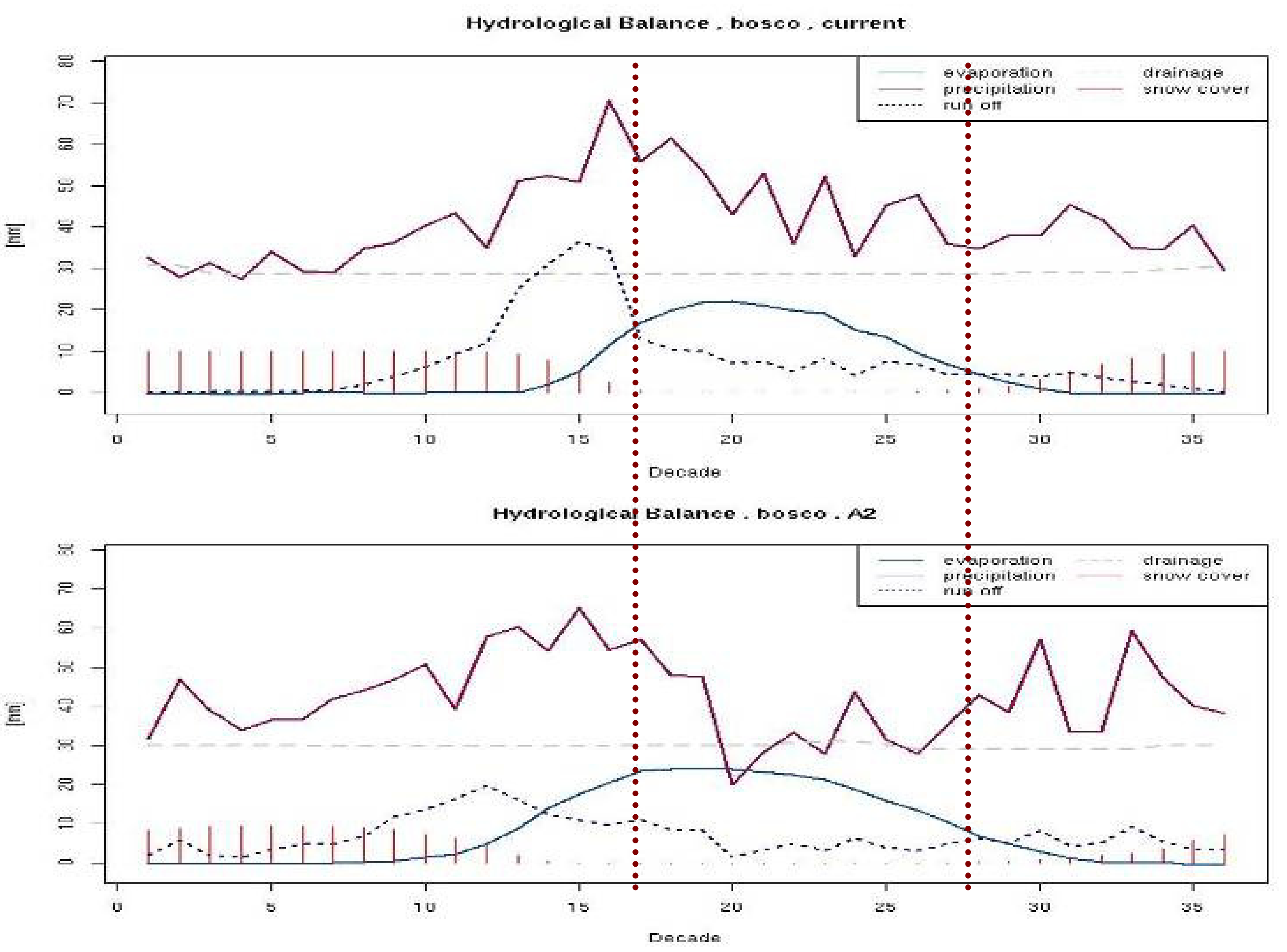
Effects on soil moisture (Po valley)



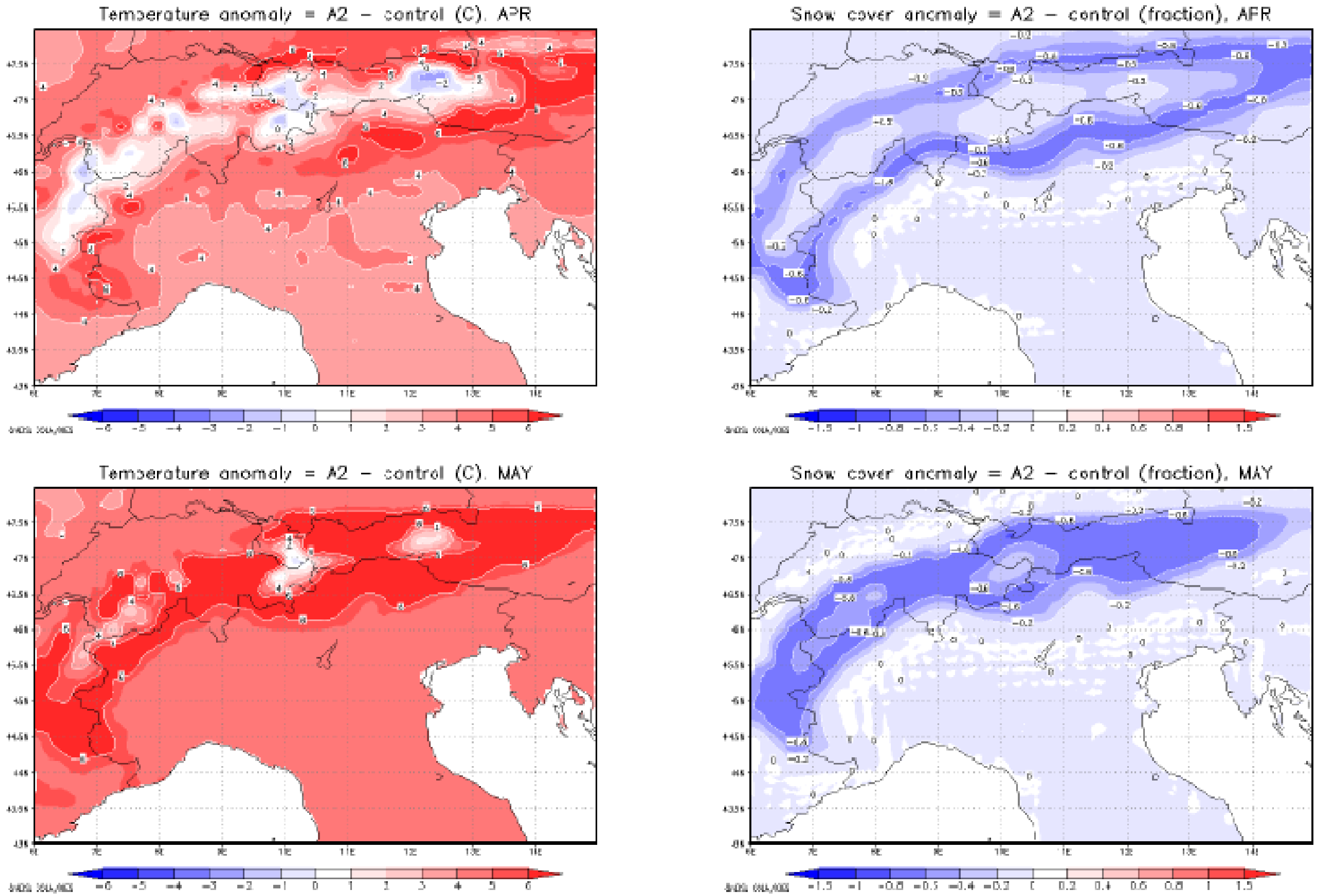


- In summer, soil moisture decreases below wilting point, or remains below wilting point for a longer time

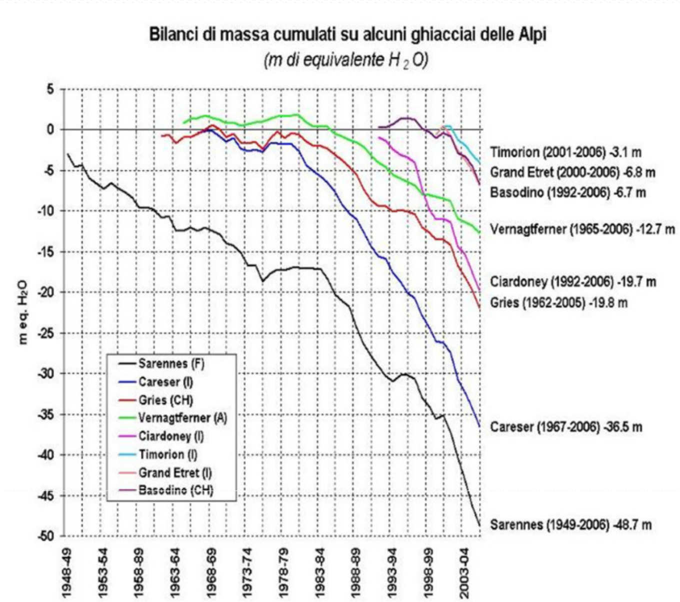
Hydrological balance: Faido

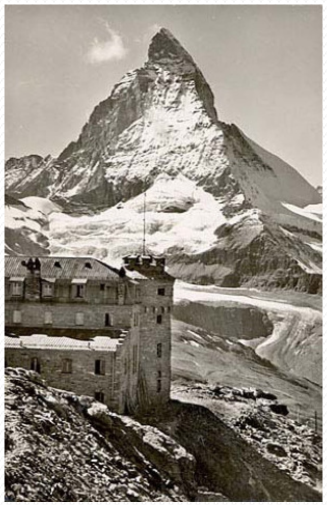


Temperatures - snow melting

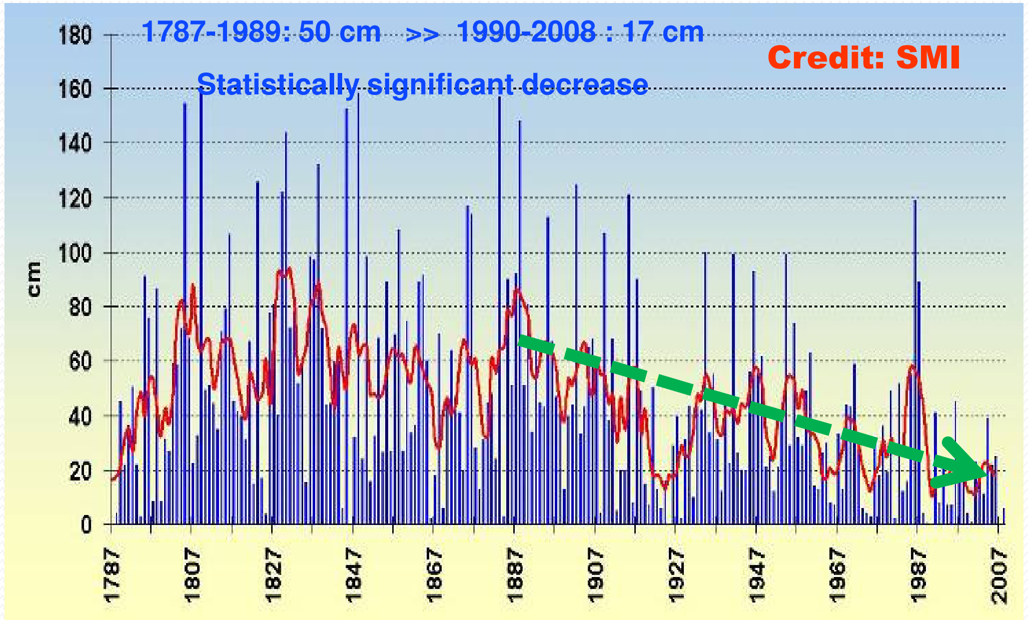


Future climate confirms a tendency already occurring



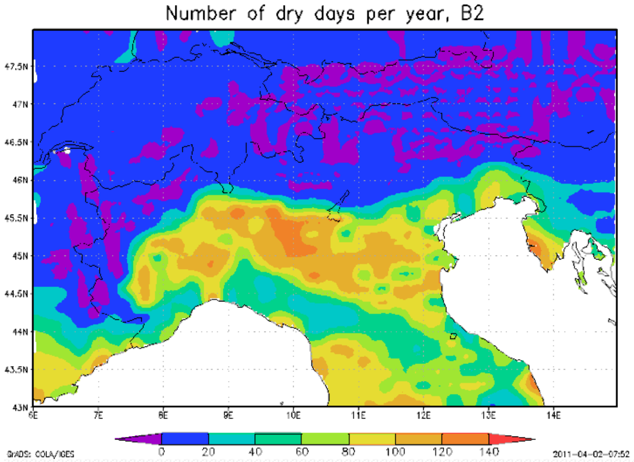


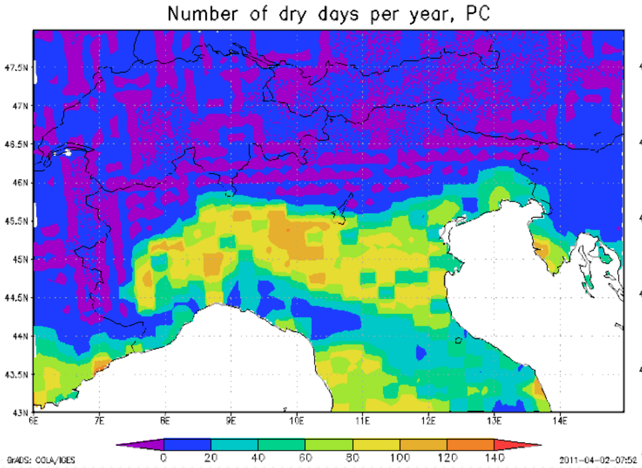
The snow series of Torino

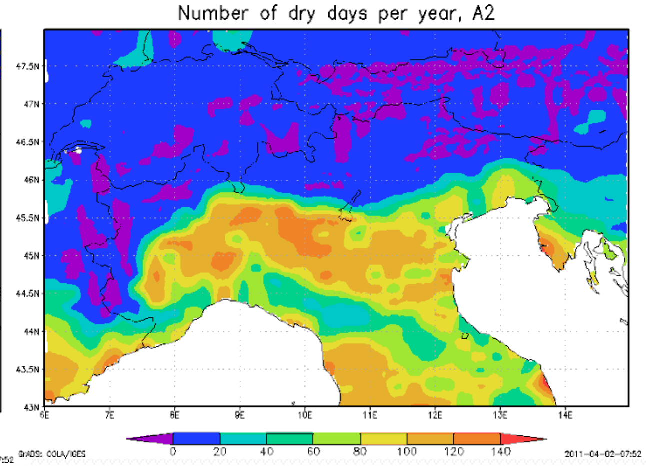


Several locations in the Alps will see just occasional snowfalls by 2050, and ice will disappear from all but few glaciers

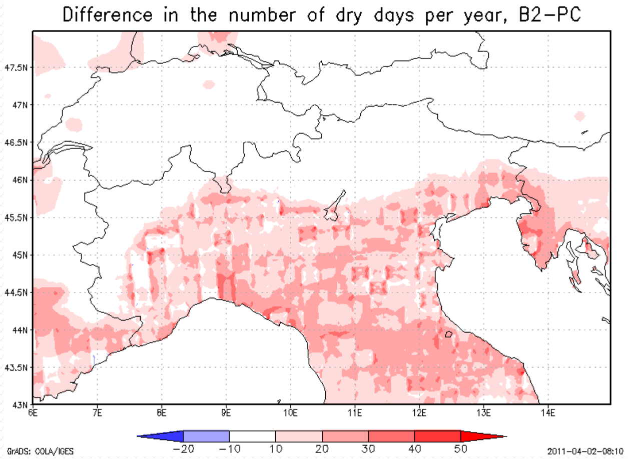
The number of dry days

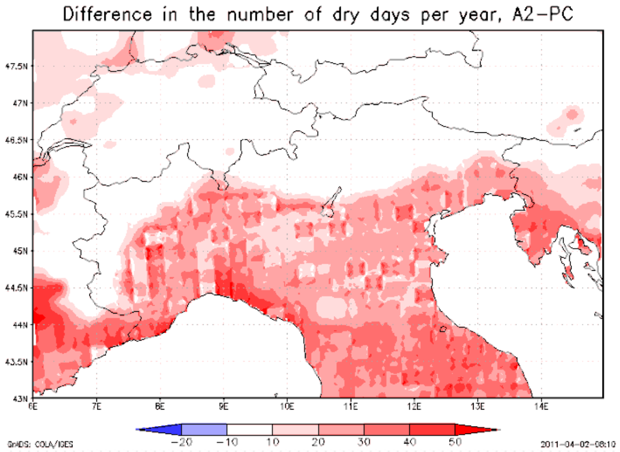






Increase in the plains

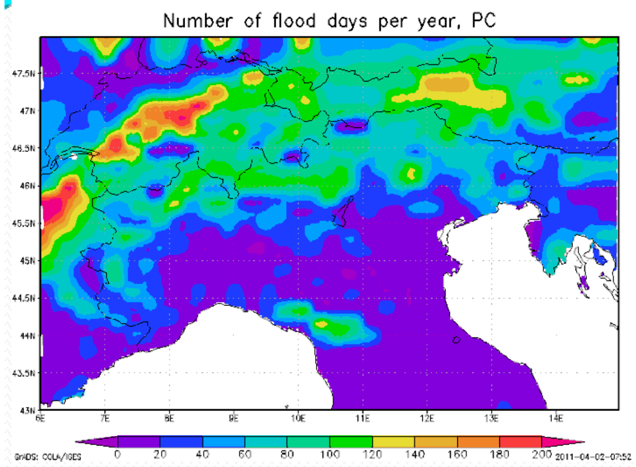


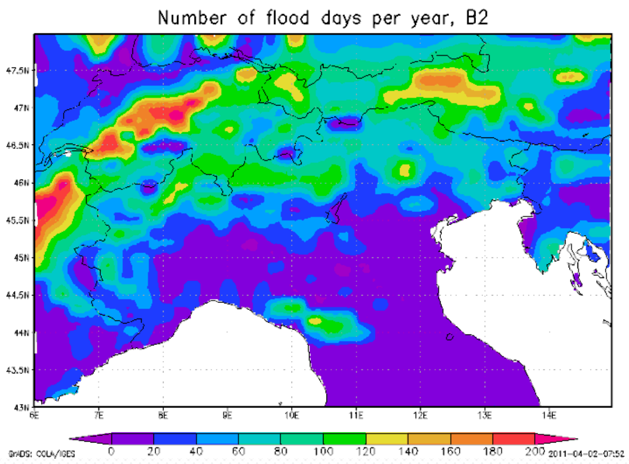


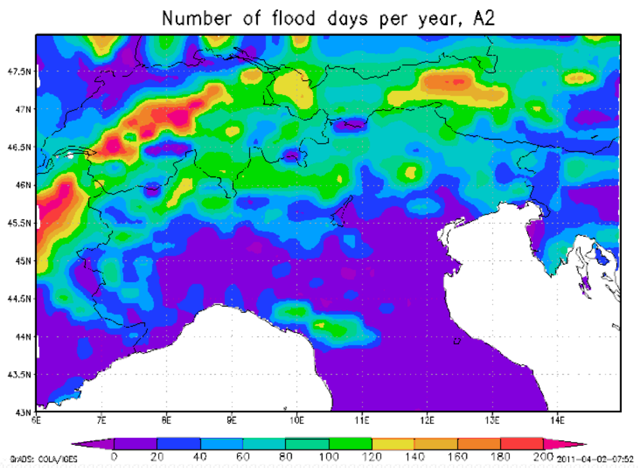
Dry days: when $Q_I<0$

$$Q_I = \frac{q_1 - q_{WI}}{q_{FC} - q_{WI}}$$

The number of wet days

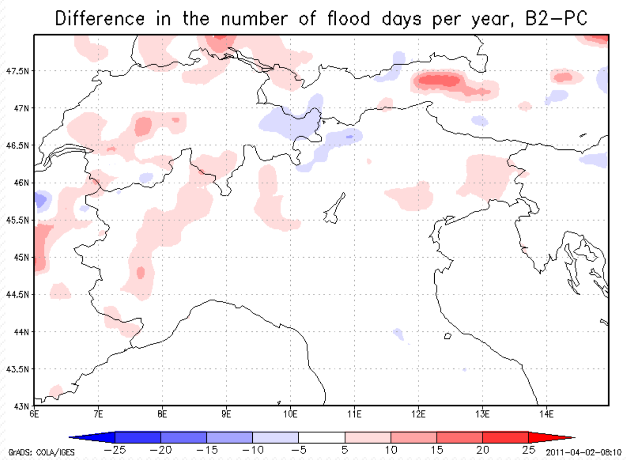


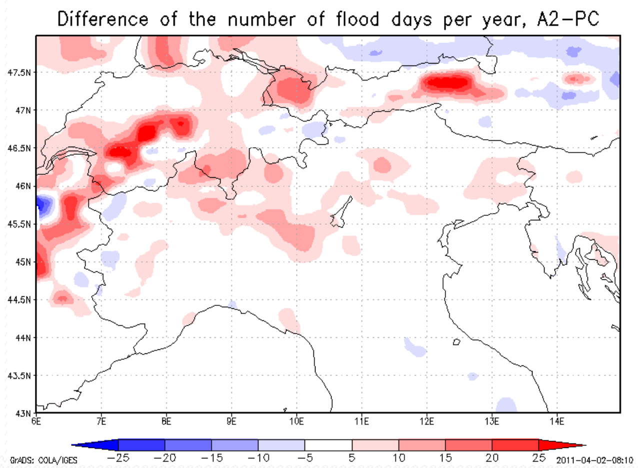




Increase near Alps

Decrease elsewhere

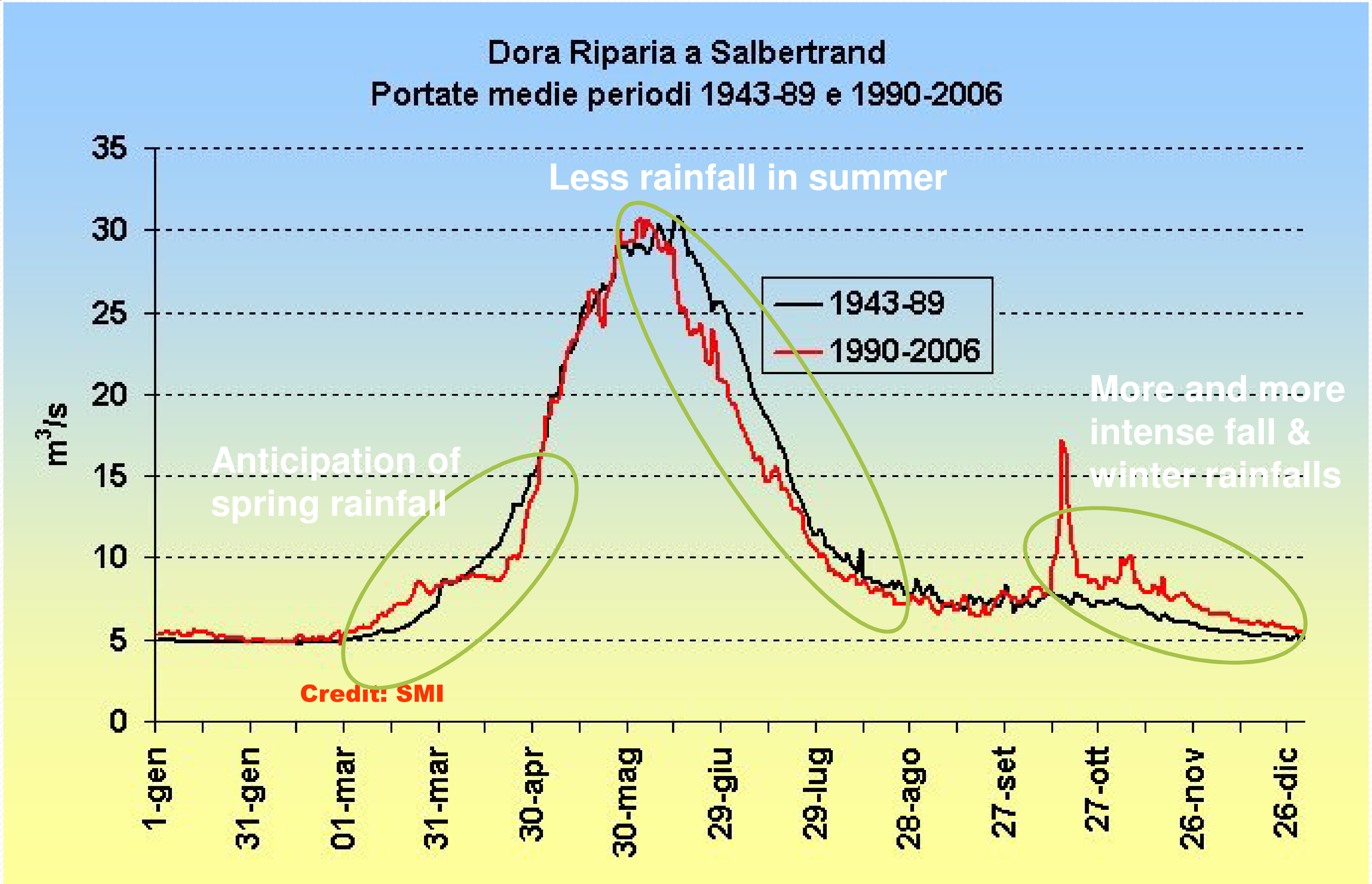




Wet days: when $Q_I > 0.8$

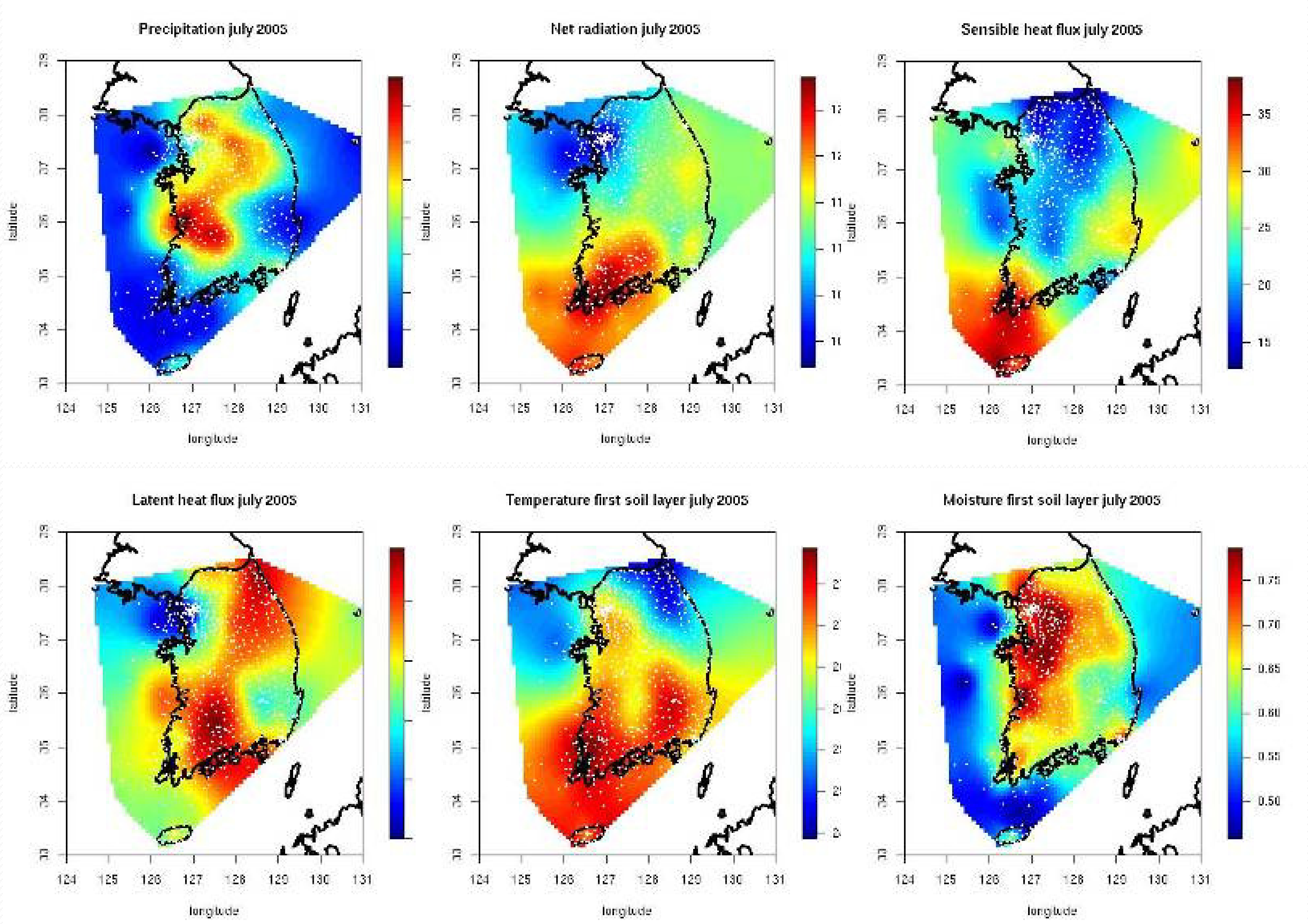
$$Q_I = \frac{q_1 - q_{WI}}{q_{FC} - q_{WI}}$$

Dora Riparia river



The Korean monsoon

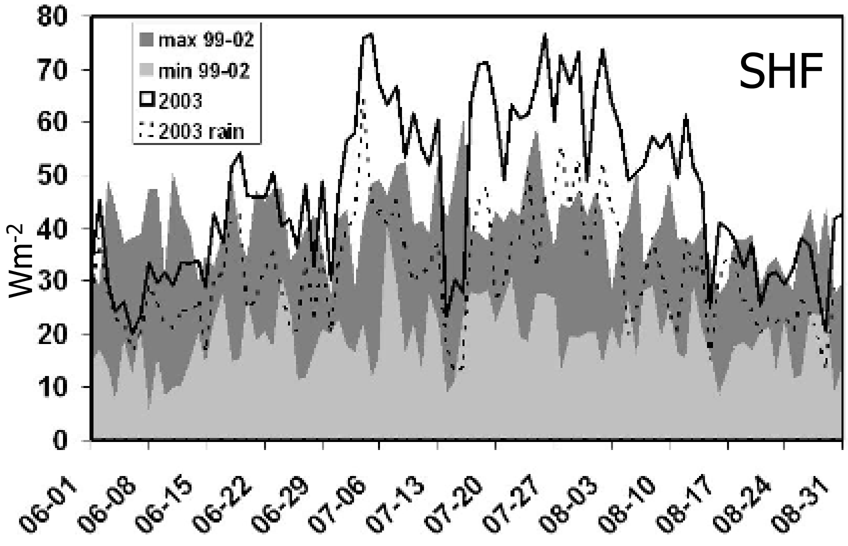
UTOPIA result - 2005 Korean Monsoon

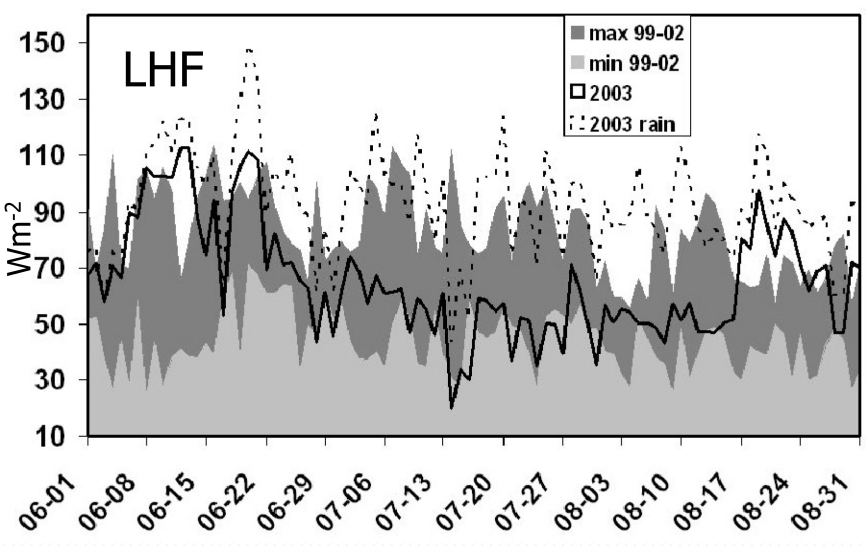


The case of 2003 summer

The heat fluxes

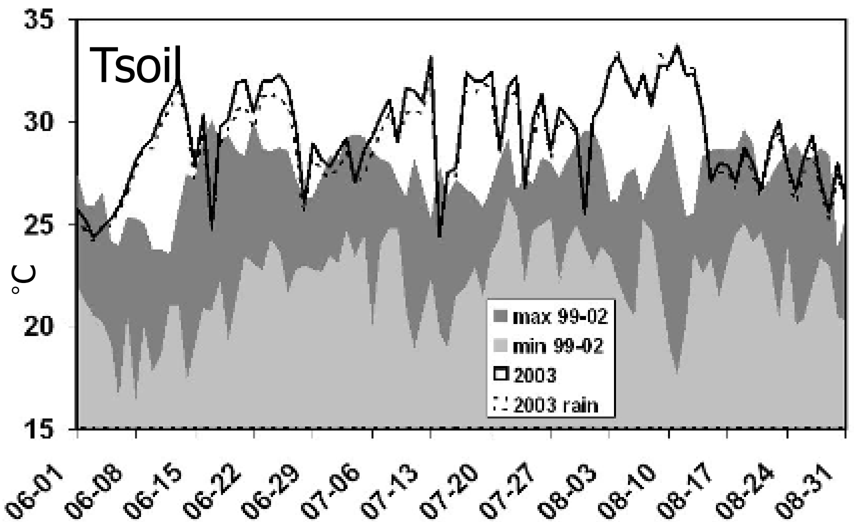
- SHF is very large since July, when LHF becomes minimum
- In the wet simulation, LHF increases and SHF becomes «normal»
  - Soil dryness has favored the evapotranspiration decrease

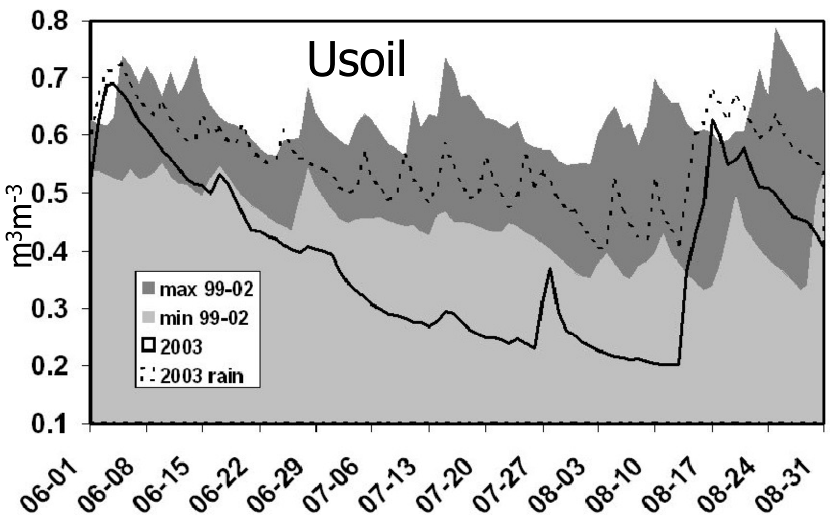




Soil variables

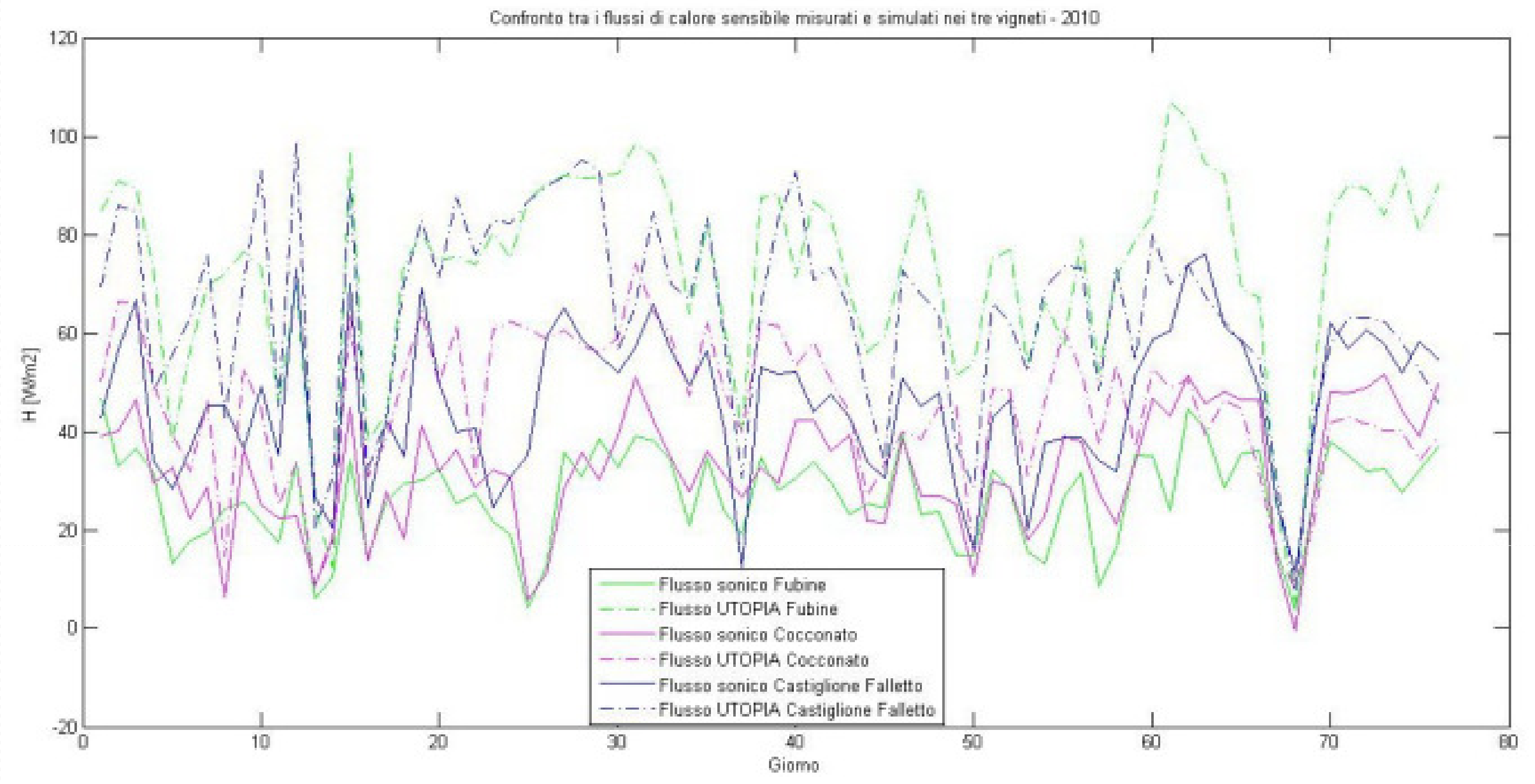
- The soil was warmer and drier than normal
- In 44 days (on 92: 48%) the first 5 cm of soil were drier than wilting point
  - (normally: 3±7 days)
- Soil moisture in the ***wet run*** becomes normal, but not temperature





The experiment in the vineyards and the UTOPIA sensitivity analysis

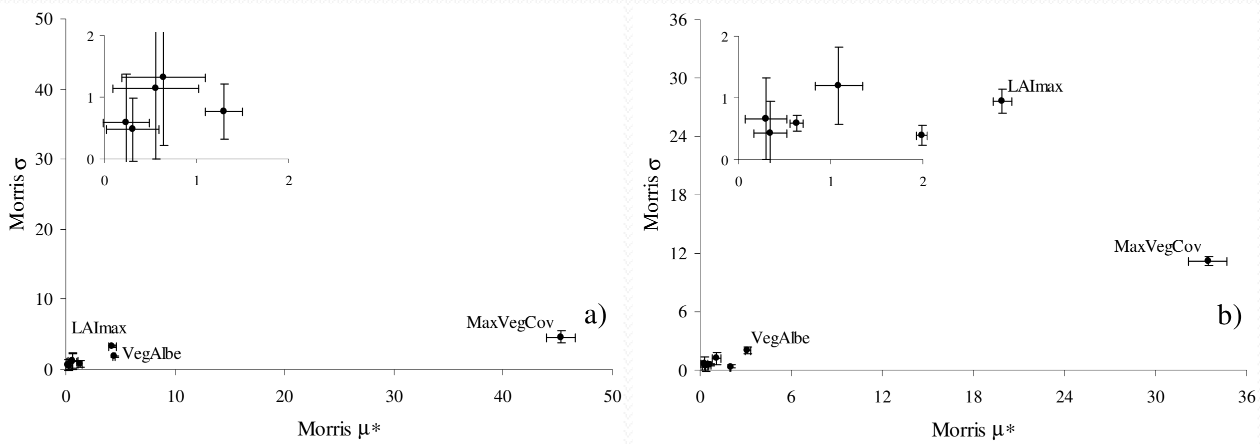
Sensible heat flux

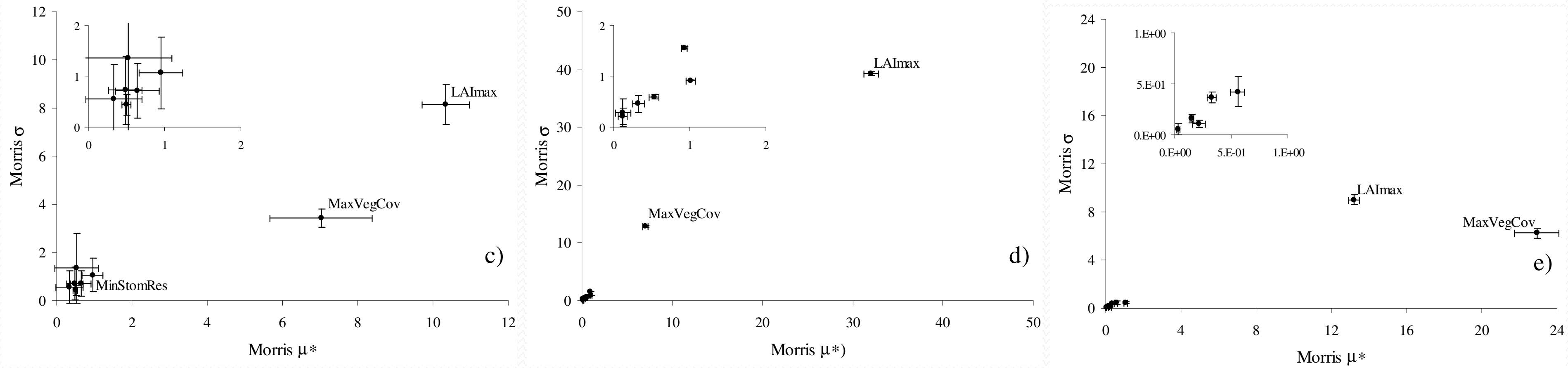


Sensitivity analysys on parameters used by UTOPIA for describing vegetation processes

Morris method (Morris, 1991) adapted by Campolongo et al. (2007)
8 vegetation parameters, 11 soil types → 990 run

a) Net Radiation (W m^{-2})
b) Sensible Heat Flux (Wm^{-2})
c) Latent Heat Flux (W m^{-2})
d) Soil-Veg Heat Flux (W m^{-2})
e) Transpiration (W m^{-2})





Francone et. al, Sensitivity analysis based investigation of the behaviour of the UTOPIA land surface process model. A case study for vineyards in northern Italy. Boundary layer meteorology, 2013.

Snow: Siberia

Siberian stations

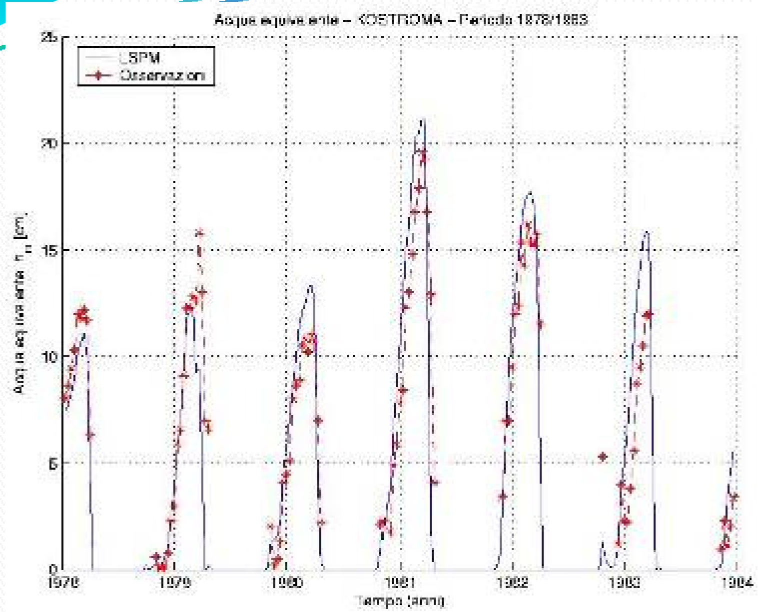
PRO's

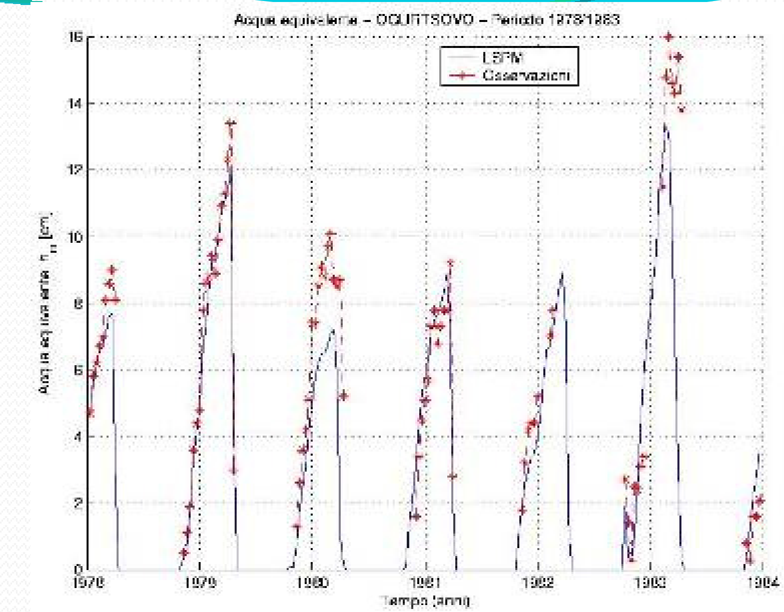
1) Good quality measurements
2) Long duration
3) Distributed over the territory
4) During winter, always snow
5) Data well known in literature

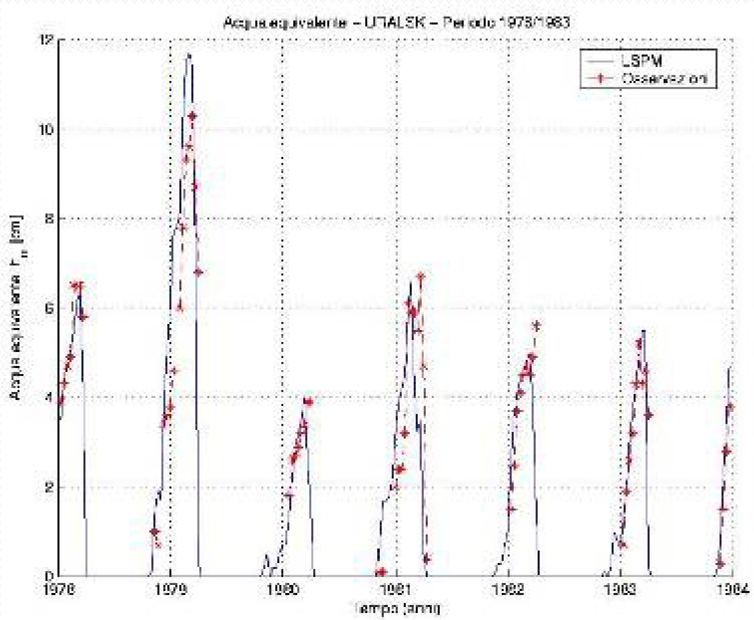
CON's

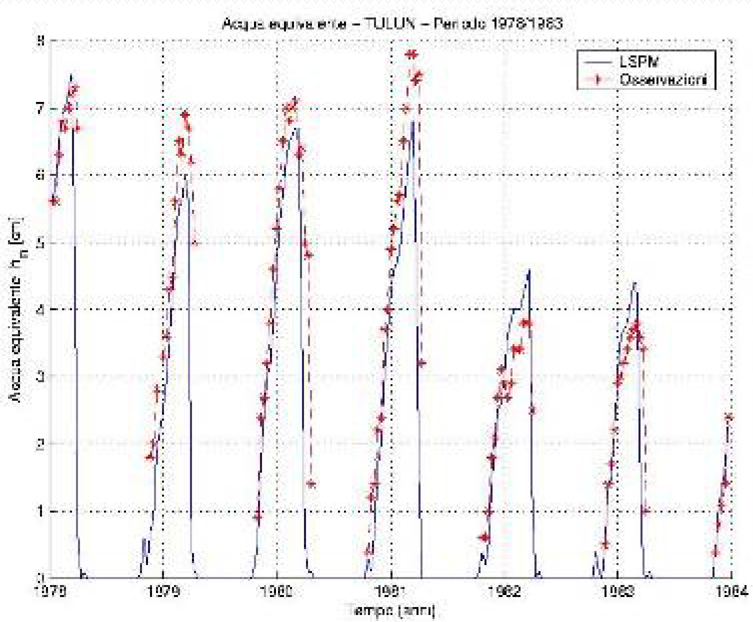
1) Monotonic behaviour
2) Missing daily detail
3) Unknown summer surface
4) Old data

The equivalent water

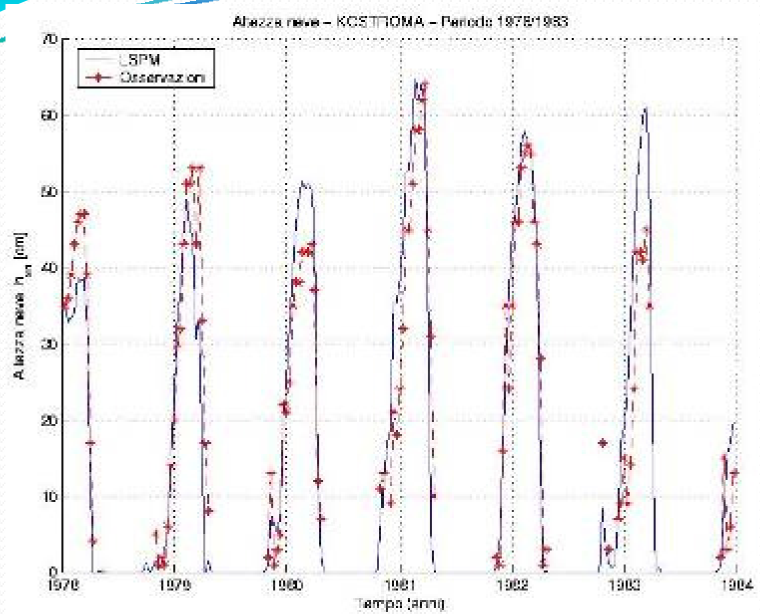


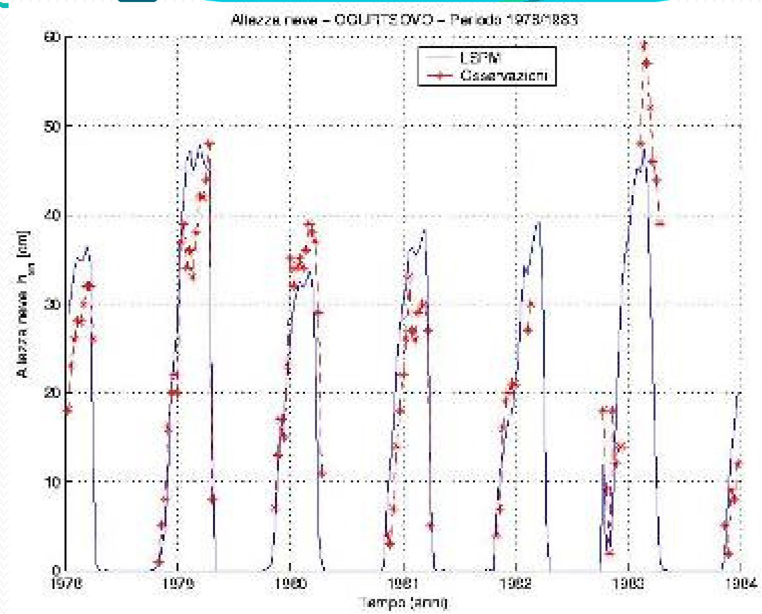


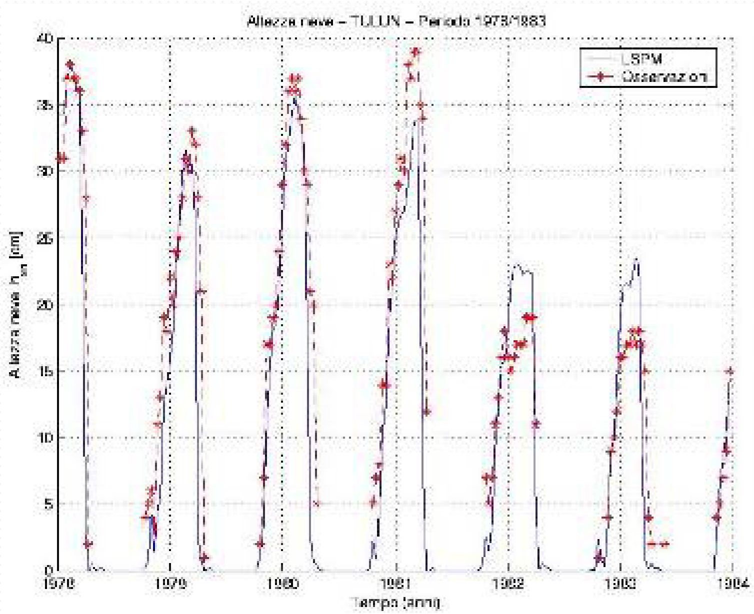


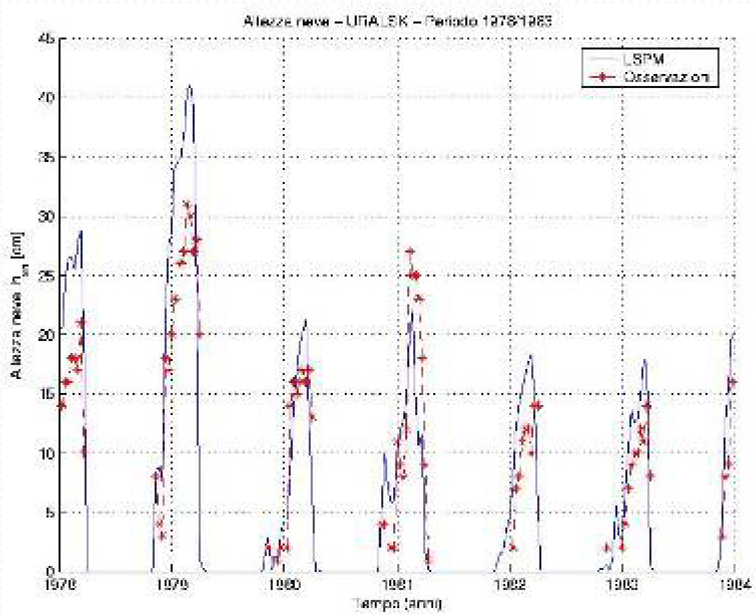


Snow height

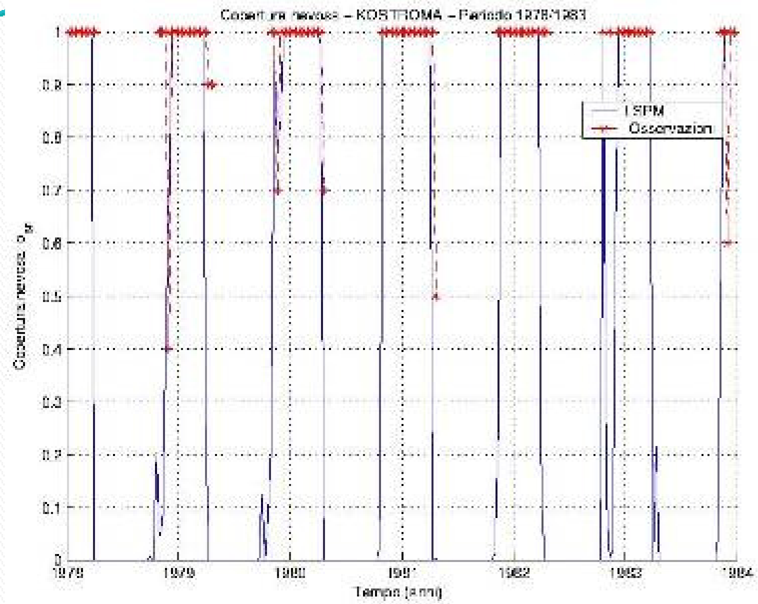

Altezza neve – KOSTROMA – Periodo 1978/1983
LSPM
Osservazioni
Altezza neve h_sn [cm]
Tempo (anni)


Altezza neve – OGURTSOVO – Periodo 1978/1983
LSPM
Osservazioni
Altezza neve h_sn [cm]
Tempo (anni)

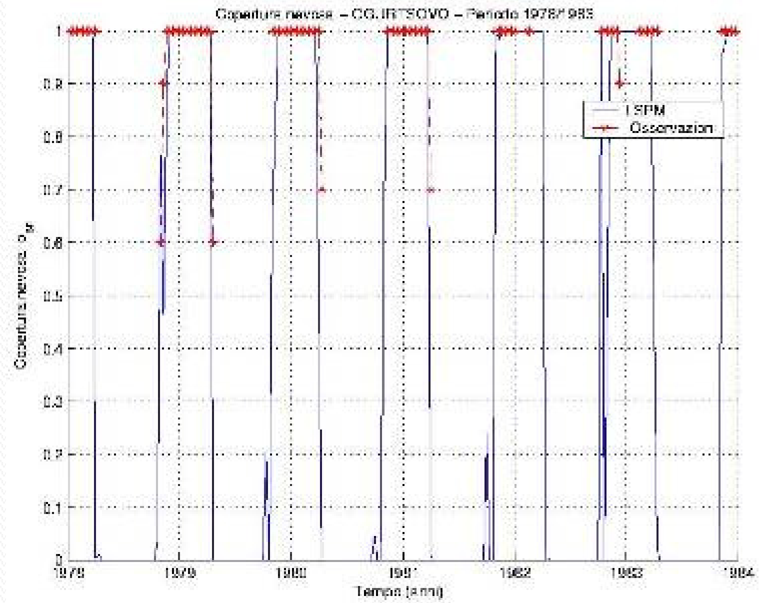

Altezza neve – TULUN – Periodo 1978/1983
LSPM
Osservazioni
Altezza neve h_sn [cm]
Tempo (anni)


Altezza neve – URALSK – Periodo 1978/1983
LSPM
Osservazioni
Altezza neve h_sn [cm]
Tempo (anni)

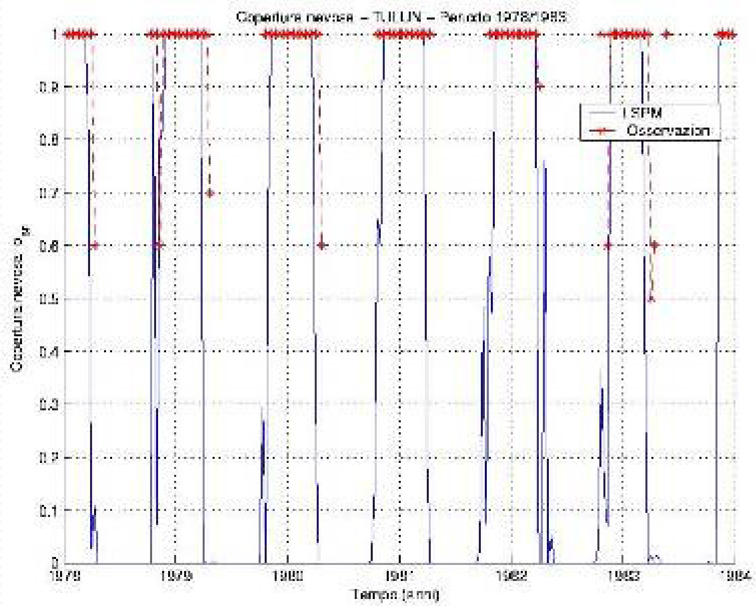
Snow cover



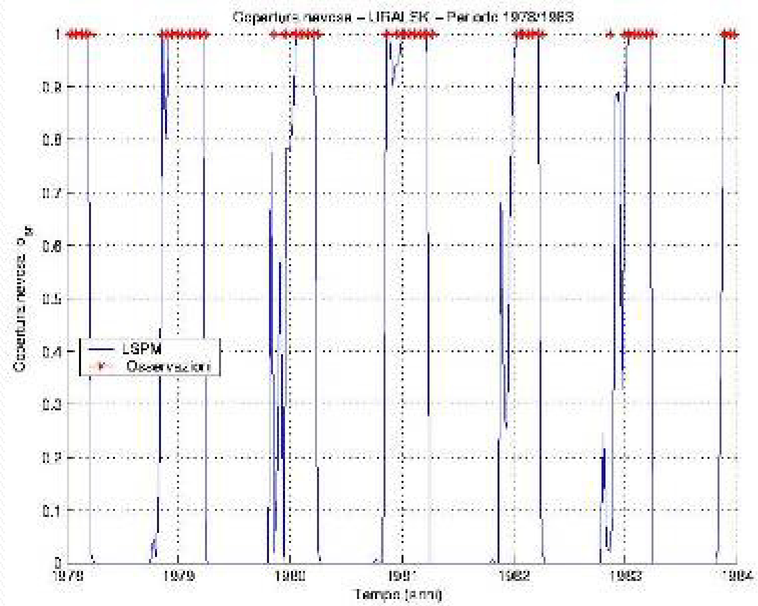
Copertura nevosa – KOSTROMA – Periodo 1978/1983
LSPM
Osservazioni
Tempo (anni)



LSPM
Osservazioni
Tempo (anni)



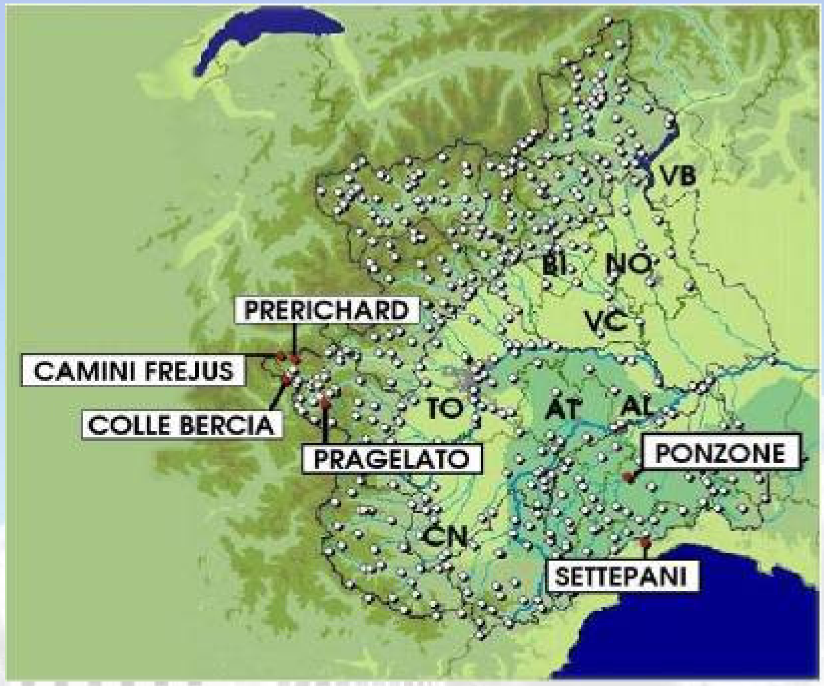
Copertura nevosa – TULUN – Periodo 1978/1983
LSPM
Osservazioni
Tempo (anni)



LSPM
Osservazioni
Tempo (anni)

Snow: Piemonte, the Alps

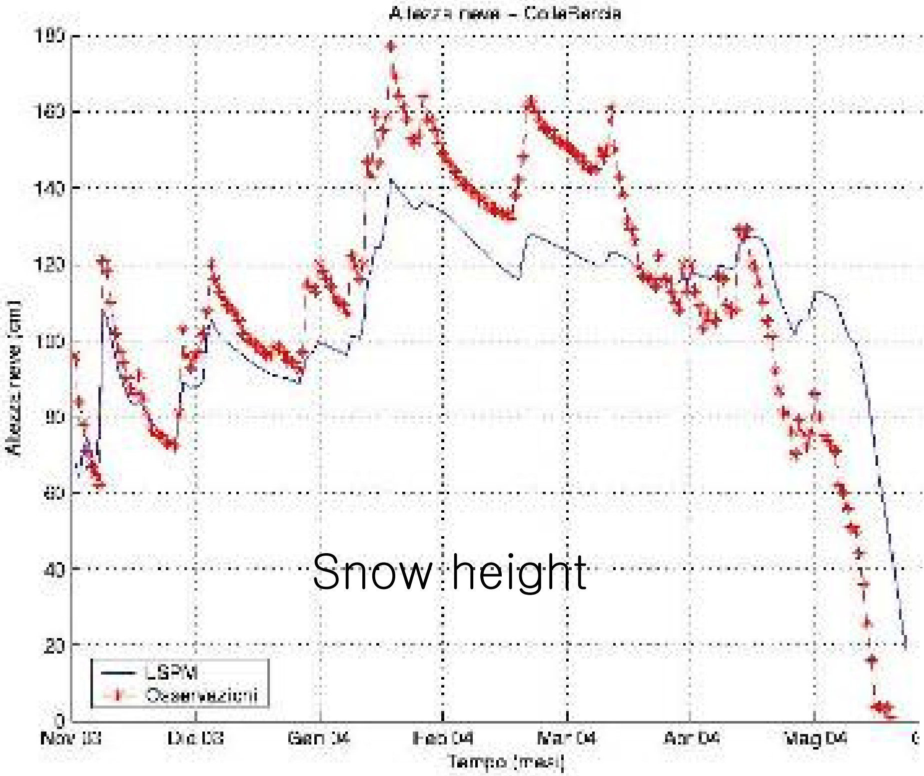
The Alpine stations in Piemonte

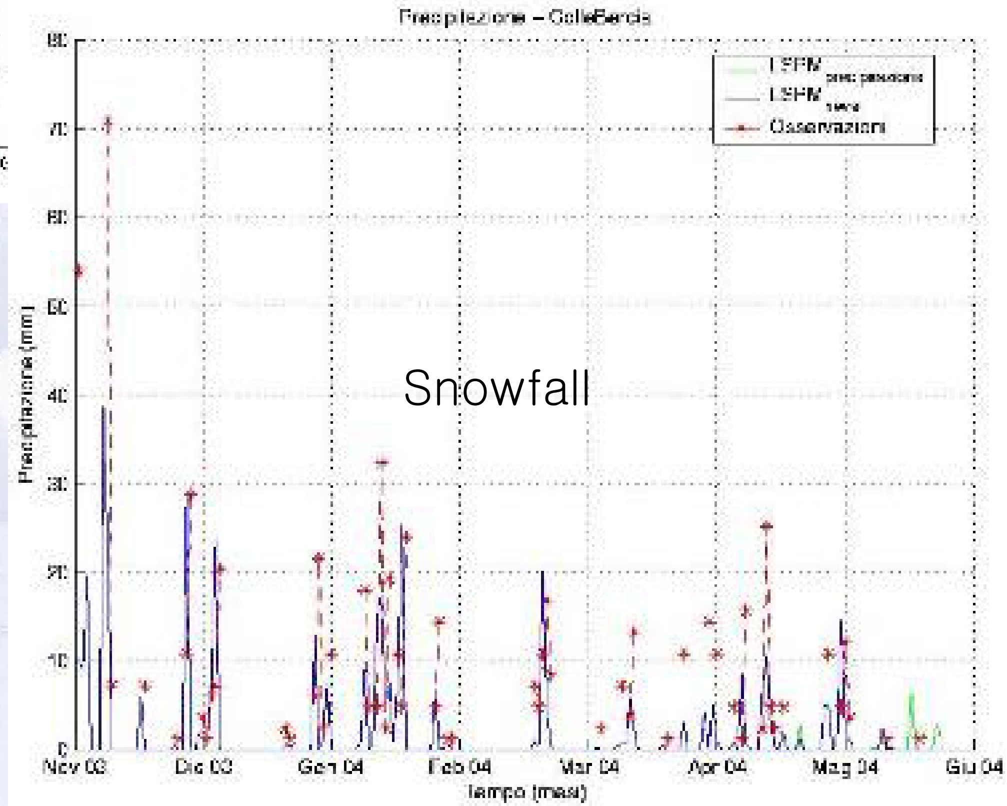


Characteristics:

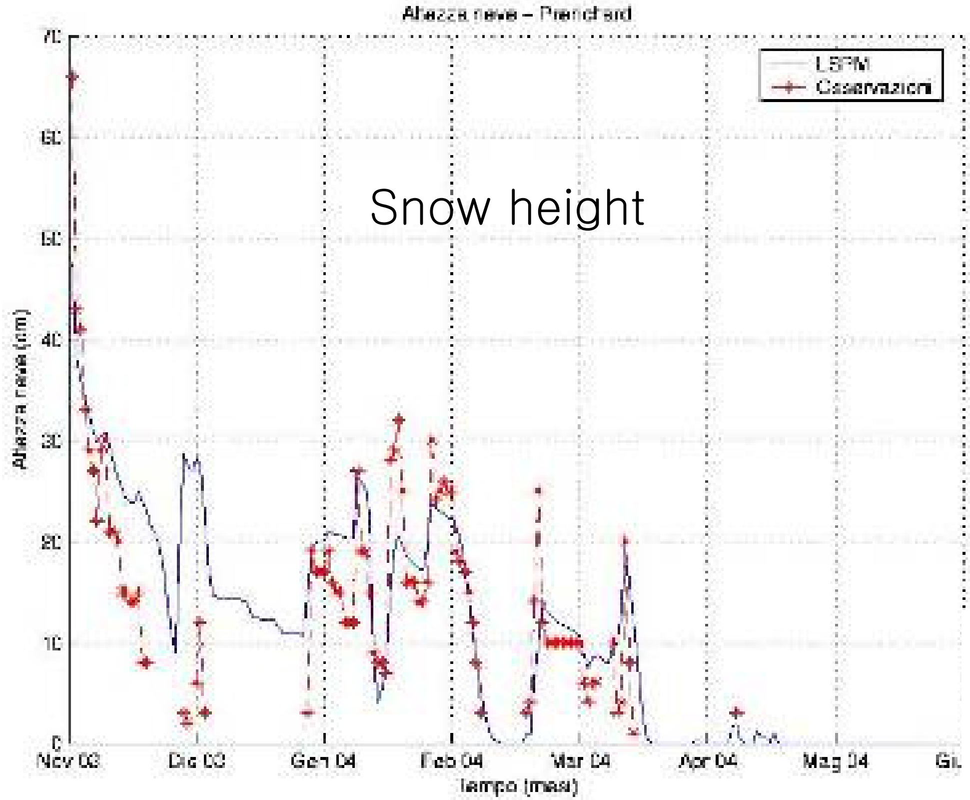
1. More dynamic evolution (T not always <0 °C even in winter)
2. Presence of rain and snow in winter together
3. More complicated soil morphology

Colle Bercia

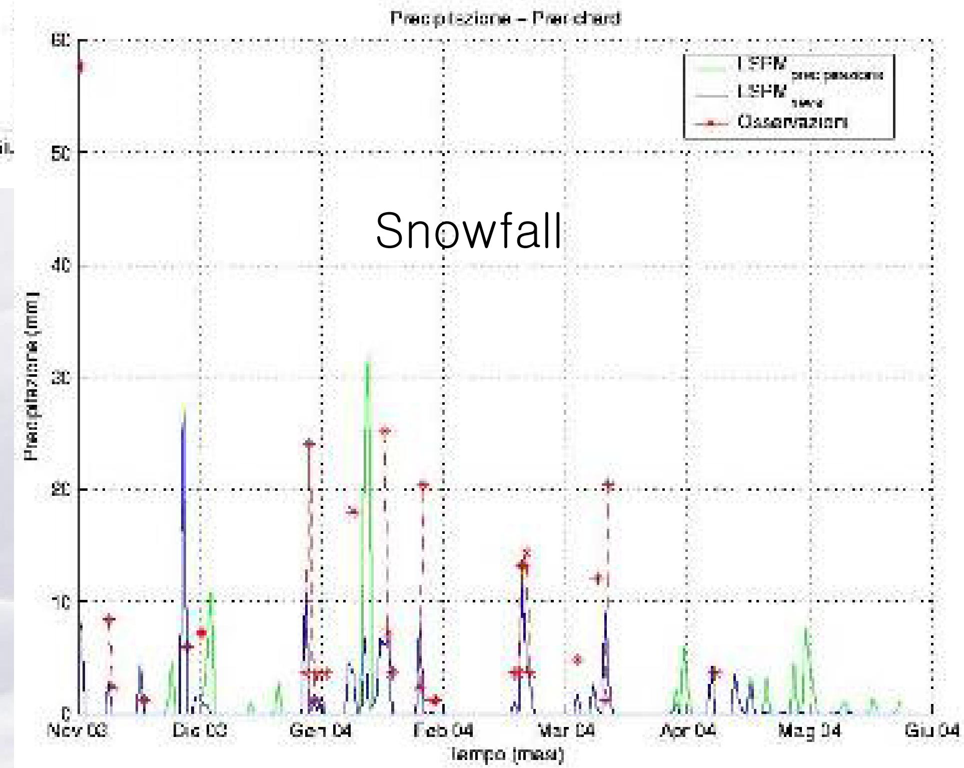




Prerichard

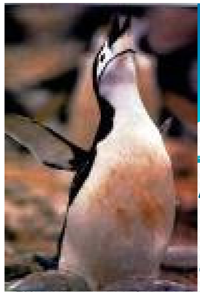


Altezza neve – Prerichard
Snow height
LSPM
Osservazioni
Altezza neve (cm)
70
60
50
40
30
20
10
0
Nov 03
Dic 03
Gen 04
Feb 04
Mar 04
Apr 04
Mag 04
Tempo (mesi)

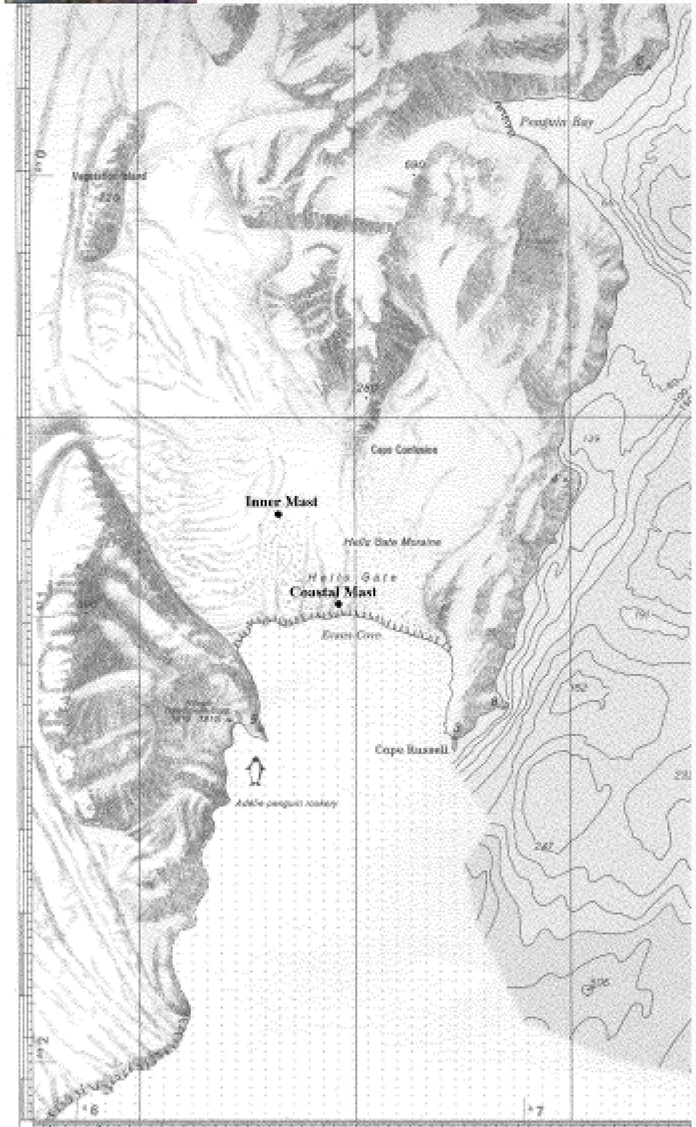


Precipitazione – Prerichard
Snowfall
LSPM
LSPM
Osservazioni
Precipitazione (mm)
60
50
40
30
20
10
0
Nov 03
Dic 03
Gen 04
Feb 04
Mar 04
Apr 04
Mag 04
Giu 04
Tempo (mesi)

Antarctic ice shelf

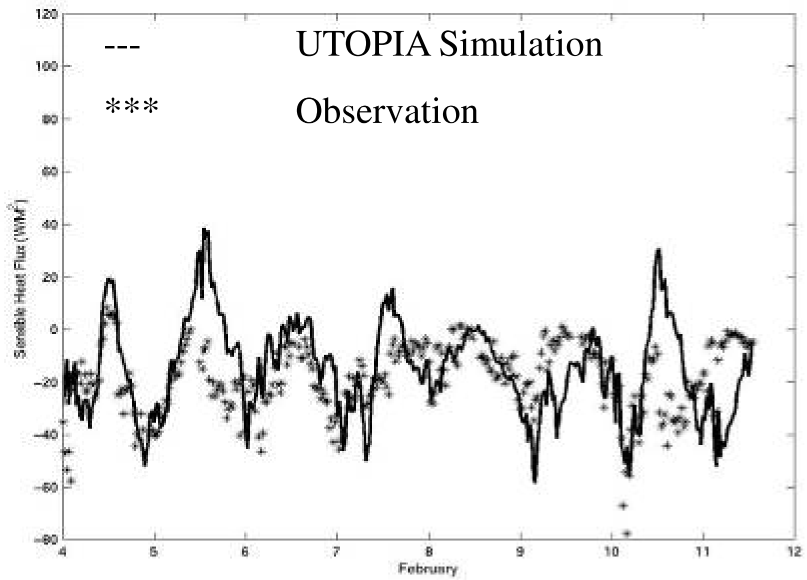


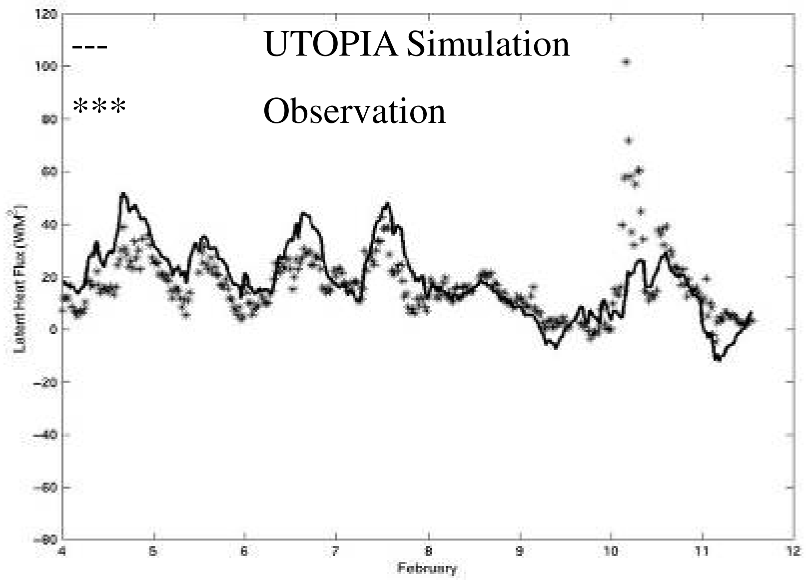
APPLICATION OF A LAND SURFACE MODEL (LSPM) ON ICE SHELF OF ANTARCTICA



- The site: Hells Gate ice shelf.
- The XIII Southern-Summer Antarctic Expedition at Terra Nova Bay (1996-97) was performed in this site, during the warm period (1997-1998)
- The data were collected at two locations, 2.6 km apart from each other, of the Hells Gate ice shelf
- The experiment in Antarctica started on 28th January and ended on 18th February 1998. It lasted 22 days
- The model simulation covered only the period from the 3rd to the 11th February 1998 for the reason of continuous data availability

The turbulent heat fluxes

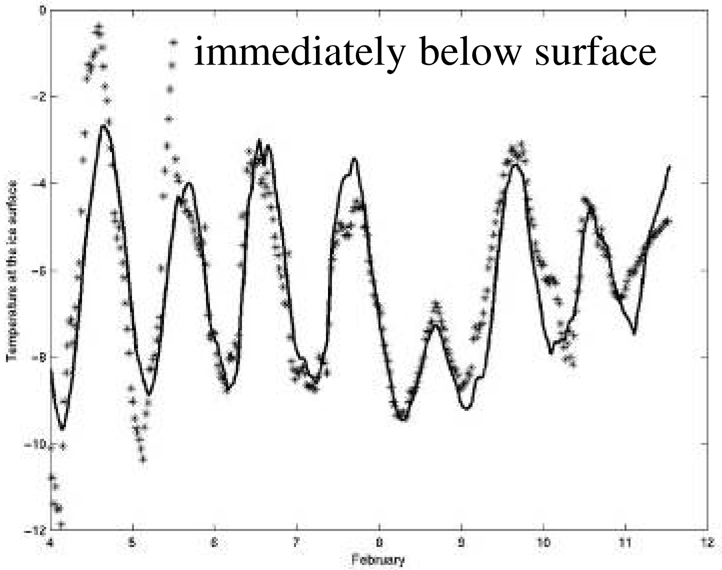


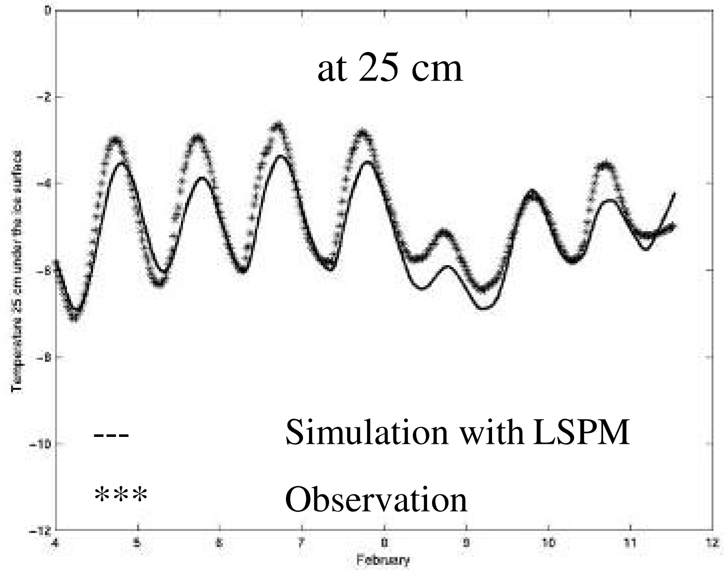


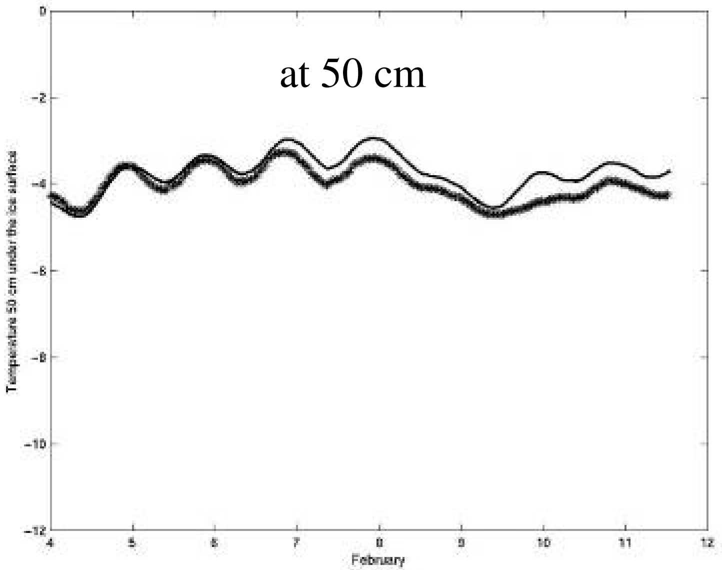
- ➢During most of the time, SHF was negative (air T > ice T) → surface layer stable
- ➢|SHF| is maximum during nighttime → ice T is minimum; SHF ≈ 0 during daytime because ice T is maximum
- ➢Some overestimations during daytime 5th and 10th February (errors in soil albedo?)

- ➢ Good simulation when wind is weak
- ➢ Some small disagreements during strong katabatic wind episodes (10th February)
- ➢ There could be some **unclear physical processes** under these extreme katabatic wind conditions: for instance, the surface resistance for the evaporation (or sublimation), supposed to be constant in present simulation, might be related to the weather conditions.

The ice temperatures







- The errors of the ice temperature simulations were within 1.0 °C, excepting for the surface temperatures in the first two days of the simulations, in which the large daily excursions were underestimated by UTOPIA
- The simulated ice temperature and the observed one were in good phase.
- These results demonstrate that the energy transfer in the ice was well simulate by UTOPIA

Some suggested references for UTOPIA

- C. Francone, C. Cassardo, R. Richiardone, R. Confalonieri "Sensitivity analysis based investigation of the behaviour of the UTOPIA land surface process model. A case study for vineyards in northern Italy", Boundary Layer Meteor.
- M. Galli, S. Oh, C. Cassardo, S. K. Park (2010) "The Occurrence of Cold Spells in the Alps Related to Climate Change", Water, 2, doi:10.3390/w2030363, pp. 363-380.
- C. Cassardo, S. K. Park, B. Malla Thakuri, D. Priolo, Y. Zhang (2009) "Soil Surface Energy and Water Budgets during a Monsoon Season in Korea", Journal of Hydrometeorology, in press.
- C. Cassardo, L. Mercalli and D. Cat Berro (2007) "Characteristics of the Summer 2003 Heat Wave in Piedmont, Italy, and its Effects on Water Resources" Journal Of The Korean Meteorological Society, 43, 3, pp. 195-221
- C. Cassardo, N. Loglisci, G. Paesano, D. Rabuffetti and M.W. Qian (2006) "The hydrological balance of the october 2006 flood in Piedmont, Italy: quantitative analysis and simulation" Physical Geography, 27, 2, pp. 1-24
- C. Cassardo, S. Ferrarese, A. Longhetto, M.G. Morselli and G. Brusasca (2006) "A reanalysis of the atmospheric boundary layer field experiment (SPCFLUX93) at San Pietro Capofiume (Italy)" Il Nuovo Cimento C - Editrice Compositori - Bologna, 29C(5), pp. 565-597
- C. Cassardo, N. Loglisci and M. Romani (2005) "Preliminary results of an attempt to provide soil moisture datasets in order to verify numerical weather prediction models" Il Nuovo Cimento C - Editrice Compositori - Bologna, DOI 10.1393/ncc/i2005-10180-7, 28C, pp. 159-171
- C. Cassardo, N. Loglisci, D. Gandini, M. W. Qian, G. Y. Niu, P. Ramieri, R. Pelosini and A. Longhetto (2002) "The flood of November 1994 in Piedmont, Italy: a quantitative analysis and simulation" Hydrol. Process., 16, pp. 1275–1299
- C. Cassardo, G. P. Balsamo, C. Cacciamani, D. Cesari, T. Paccagnella and R. Pelosini (2002) "Impact of soil surface moisture initialization on rainfall in a limited area model: a case study of the 1995 South Ticino flash flood" Hydrol. Process., 16, pp. 1301–1317
- M. W. Qian, N. Loglisci, C. Cassardo, A. Longhetto and C. Giraud (2001) "Energy and water balance at soil-interface in a Sahelian region" Advances in Atmospheric Sciences, 18 (5), pp. 897-909
- C. Cassardo, E. Carena and A. Longhetto (1998) "Validation and sensitivity tests on improved parametrizations of a land surface process model (LSPM) in the Po Valley" Il Nuovo Cimento, Editrice Compositori - Bologna, 21C (2), pp. 189–213
- P. M. Ruti, C. Cassardo, C. Cacciamani, T. Paccagnella, A. Longhetto and A. Bargagli (1997) " Intercomparison between BATS and LSPM surface schemes, using point micrometeorological data set" Beiträge zur Physic der Atmosphäre (Contributions to Atmospheric Physics, Germany), 70 (3), pp. 201-220, ISSN 0005-8173/98/03
- J.C. Feng, X.M. Liu, C. Cassardo and A. Longhetto (1997) " A model of plant transpiration and stomatal regulation under the condition of waterstress" Journal of Desert Research, Science Press, Lanzhou, China, 17 (3), pp. 59-66, ISSN 1000-694-X
- C. Cassardo, J. J. Ji and A. Longhetto (1995) " A study of the performances of a land surface process model (LSPM)" Boundary Layer Meteorology, Dordrecht (Olanda), 72, pp. 87-121

PDFs available on: http://personalpages.to.infn.it/~cassardo/curri/pubb.html

Conclusions

- Land surface processes are crucial in improving both short term forecasts and climatic projections
- UTOPIA has been created with the aim to improve weather forecasts relative to extreme events (floods, heat waves, snow)
  - It has been verified in several climatic zones in the world, and its performances have been compared with those of other models (BATS, NOAH, H-Tessel)
- In the time, it has been applied also for determining soil and vegetation parameters in cultivated areas
- Recently, it has been decided to use UTOPIA also in climatic studies, for determining future energy and hydrological budget components
  - Presently we have used UTOPIA in offline simulations, driven by simulations with regional climate models
  - To perform more detailed simulations, we are currently transforming this model in a 3rd generation model

One reason for which we have named the model UTOPIA is that …

… to pretend that a numerical model is able to represent realistically all land surface processes is an utopia …

Similarly as we pretend that cows will adapt to a world in which sea level will be 100 m higher in such way …

However we are doing our best to make the model good

질문 받습니다.