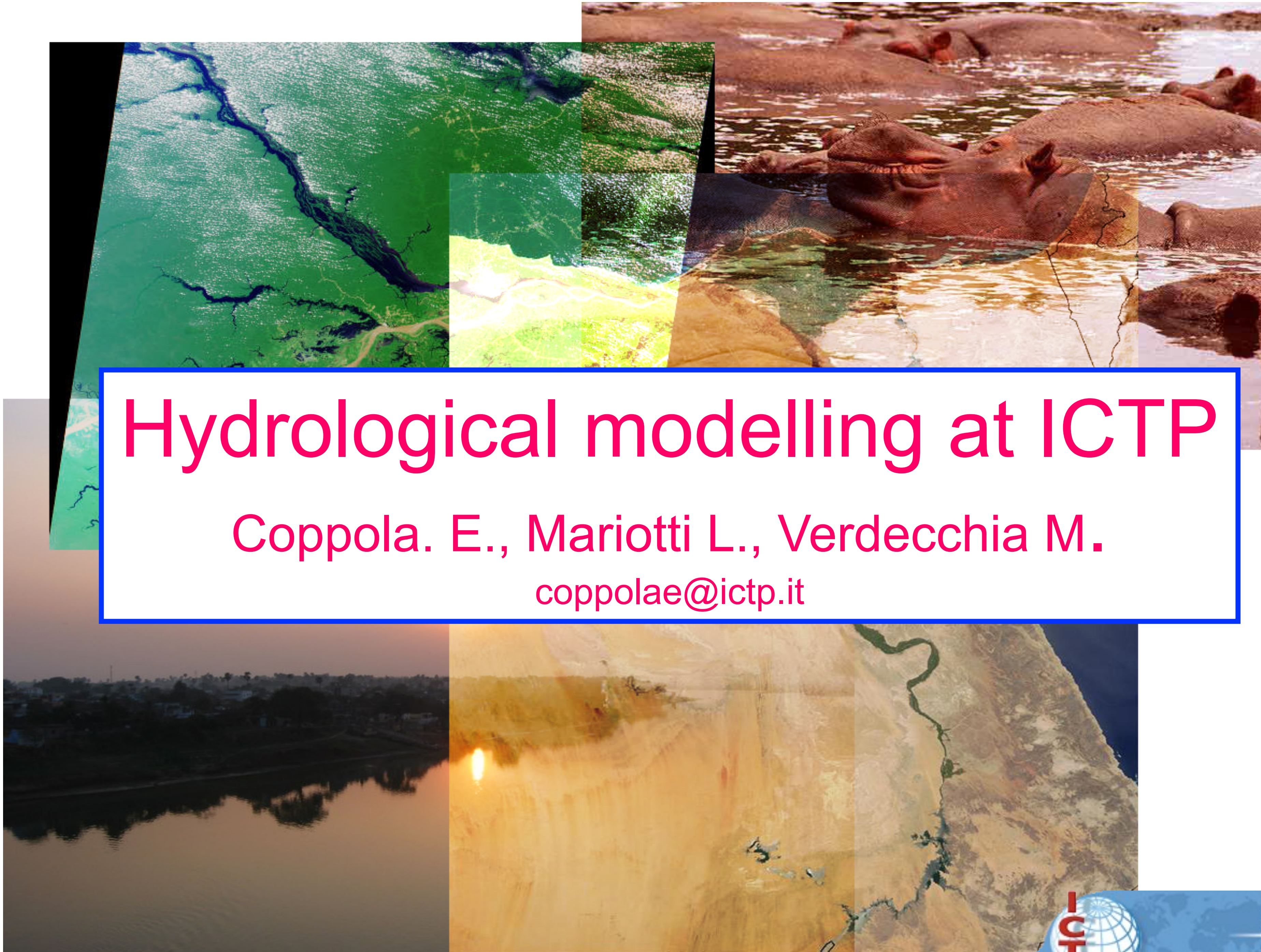
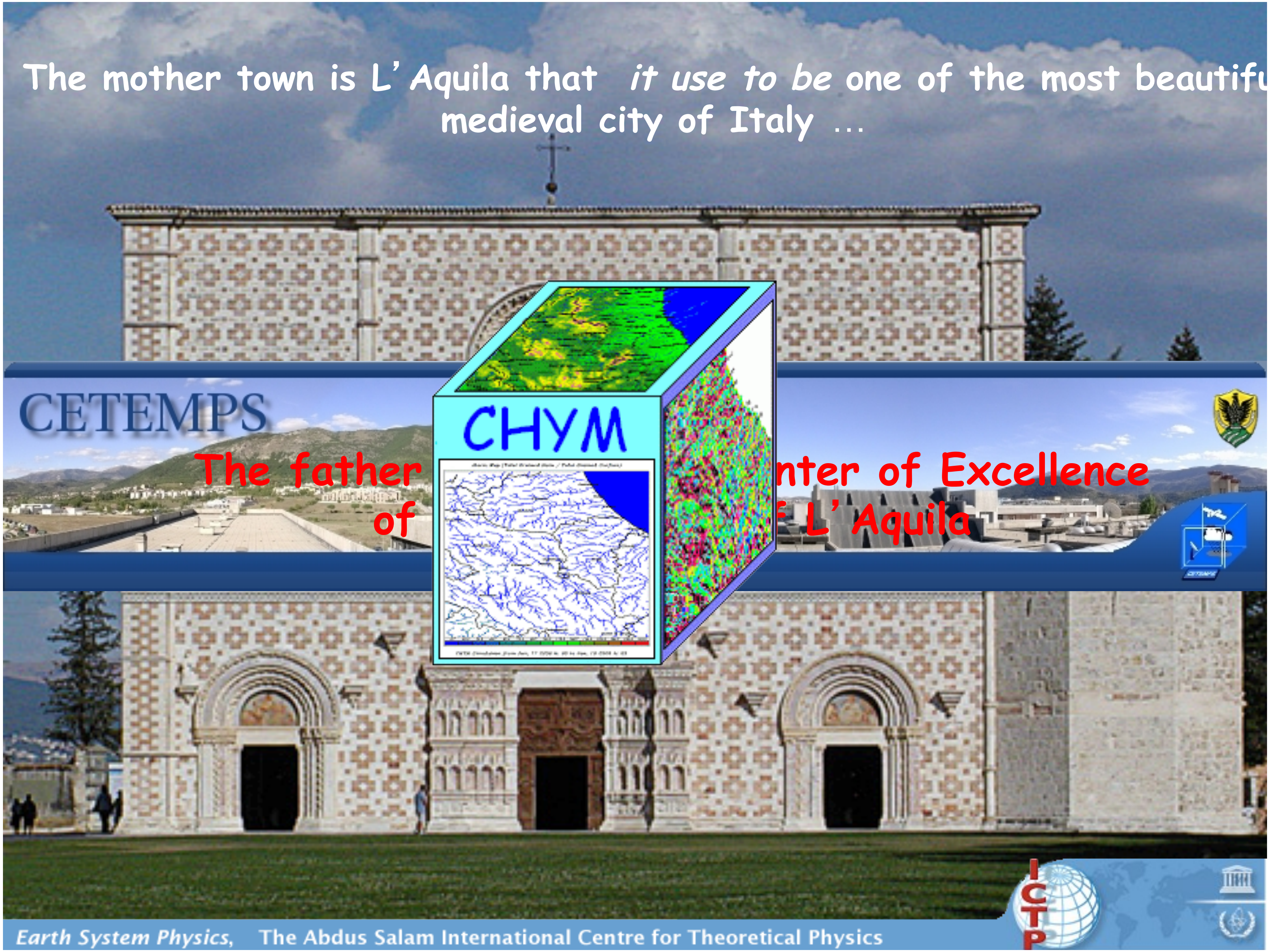


Hydrological modelling at ICTP

Coppola. E., Mariotti L., Verdecchia M.

coppolae@ictp.it


28 November 2002:
CHyM has been presented for the first time…
It was more a battle than a presentation but
we all survived
Earth System Physics, The Abdus Salam International Centre for Theoretical Physics
ICTP


The mother town is L'Aquila that *it use to be* one of the most beautifu
medieval city of Italy …
CETEMPS
The father
of
CHYM
nter of Excellence
f L'Aquila
ICTP
Earth System Physics, The Abdus Salam International Centre for Theoretical Physics


http://cetemps.aquila.infn.it/allissaos/issaos_2005/index2.html
ISSAOS 2005
ISSAOS 2005
Hydrological modelling and water cycle.
Coupling of the atmospheric and hydrological models.

September 2006

CLIMATE
Erika Coppola
ICTP

Real Time flood forecast
Marco Verdecchia and team
University of L'Aquila

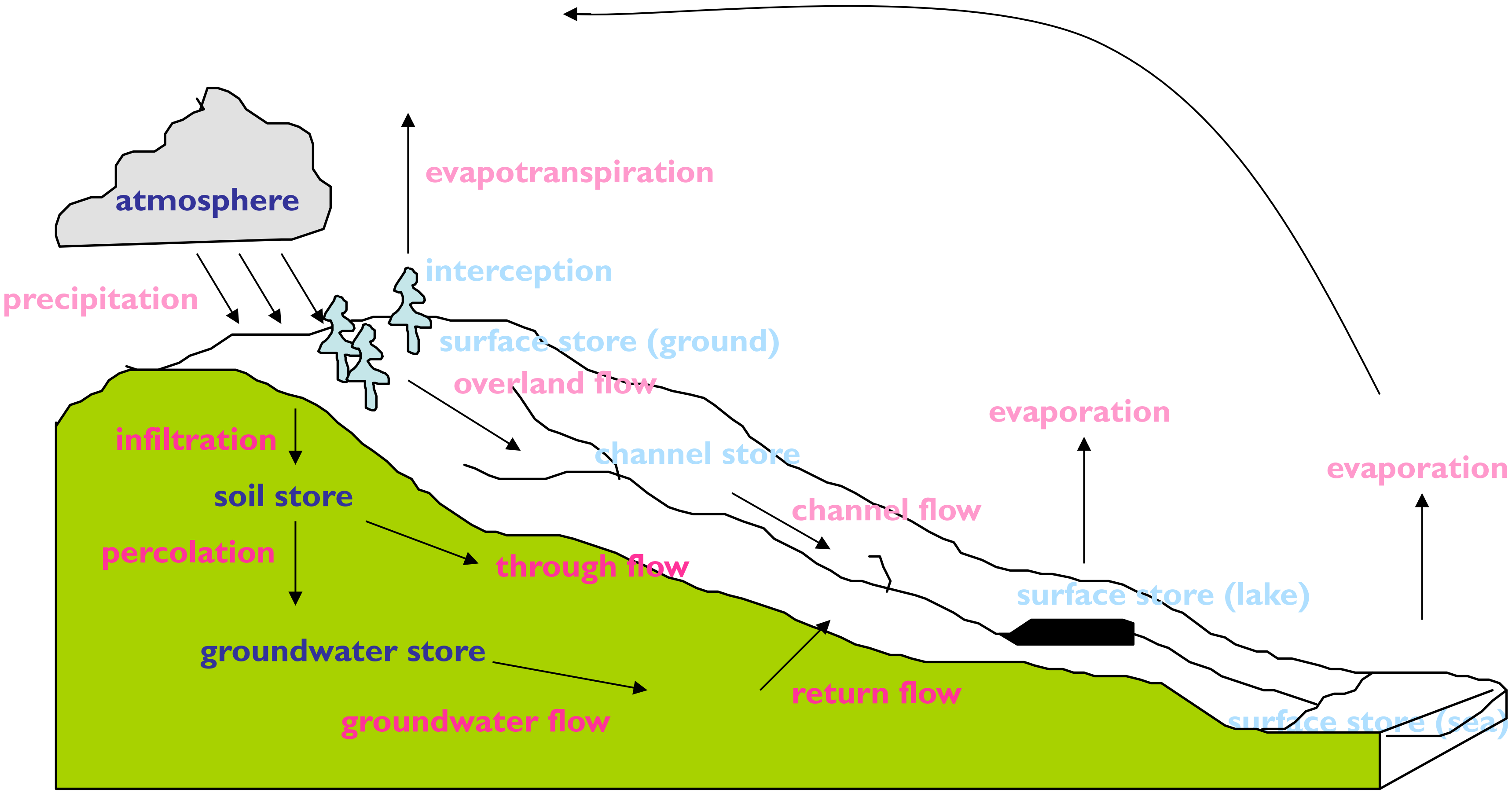
•E. Coppola, B. Tomassetti, L. Mariotti, M. Verdecchia and G. Visconti, Cellular automata algorithms for drainage network extraction and rainfall data assimilation, Hydrological Science Journal, 52(3), 2007

•Hydrological Modelling and the Water Cycle Coupling the Atmospheric and Hydrological Models Series: Water Science and Technology Library , Vol. 63 Sorooshian, S.; Hsu, K.-I.; Coppola, E.; Tomassetti, B.; Verdecchia, M.; Visconti, G. (Eds.) 2008, XI, 291 p. 138 illus., 66 in color., Hardcover ISBN: 978-3-540-77842-4

•Singh, V. P., and D. K. Frevert, Mathematical Models of Small Watershed Hydrology and Application,Water Resource Publications, LLC, Highlands Ranch, Colorado, USA, 2002.

•Singh, V. P., and D. K. Frevert, Mathematical Models of Large Watershed Hydrology, Water Resource Publications, LLC, Highlands Ranch, Colorado, USA, 2002.

The hydrological cycle



From School of Geography, University of Leeds Course material

For each cell the simulated processes are:

- Rainfall
- Runoff
- Evapotraspiration
- Infiltration
- Melting

CHym: Runoff

Continuity equation

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q_c$$

A= cross sectional area of the river
Q= flow rate of water discharge
q_c= rain for length unit

Momentum equation

$$Q = \frac{S^{1/2} R^{2/3}}{n} A$$

S= slope

1/R= wetter perimeter

n= Manning 's roughness coefficient

$R = \beta + \gamma D \delta$ R is the hydraulic radius that can be written as a linear function of the drained area D as:
$R = \beta + \gamma D^{\delta}$

B, γ and δ are empirical constants to be calibrated

CHym: Infiltration

The infiltration term is given by:

$$I\,(t) = I_s\,(t) - P_s\,(lu)$$

where **Is(*t*)** and **Ps(*lu*)** are respectively the **infiltration** and the **percolation** rate at the ground surface.

Ps(lu) is only dependent from the kind of **landuse (lu)** of the considered cell and its value is established during the calibration of the model.

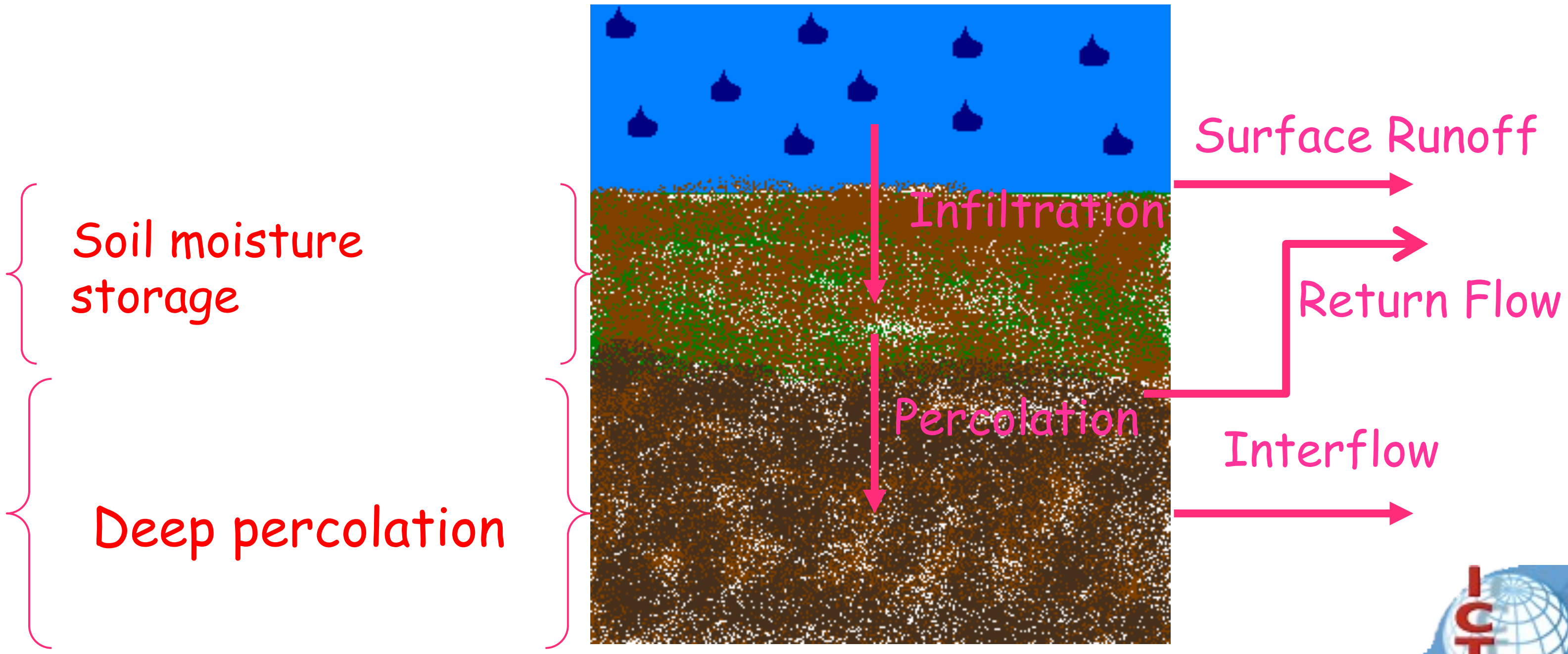
Infiltration

The infiltration process is modelled using a conceptual model similar to those proposed by several authors as Overton (1964), Singh and Yu (1990).

The water available for surface runoff decreases with a rate:

$$\frac{\partial \Re}{\partial t} = \frac{1}{1 - e^{\left(\frac{Rh - a}{b}\right)}} \Re$$

Being R_h the relative humidity of upper soil layer.



CHym: Evapotraspiration

Thornthwaite Formula (Thornthwaite and Mather, 1957)

$$ET_p = k_c \cdot ET_0$$

where k_c is the crop factor that is a function of land use. For details about the computation of the reference evapotranspiration refer to Todini (1996) and Thornthwaite and Mather (1957)

Melting rate

Melting rate (mm/h) is the sum of a temperature term and a solar radiation term

$$M = T_F T + S_{RF}(1-\alpha)G_{\downarrow}$$

The incoming solar radiation $G_{\downarrow}$ is computed as:

$$G_{\downarrow} = C_s A_{tr} \sin(\Psi)$$

With C_s solar constant. The net sky trasmissivity A_{tr} can be approximate by (Stull, 1999)

$$A_{tr} = \left[0.6 + 0.2\sin(\Psi)\right](1.0 - 0.4\sigma_H)(1.0 - 0.7\sigma_M)(1.0 - 0.4\sigma_L)$$

The sinusoidal function of solar elevation angle depends on the latitude and longitude

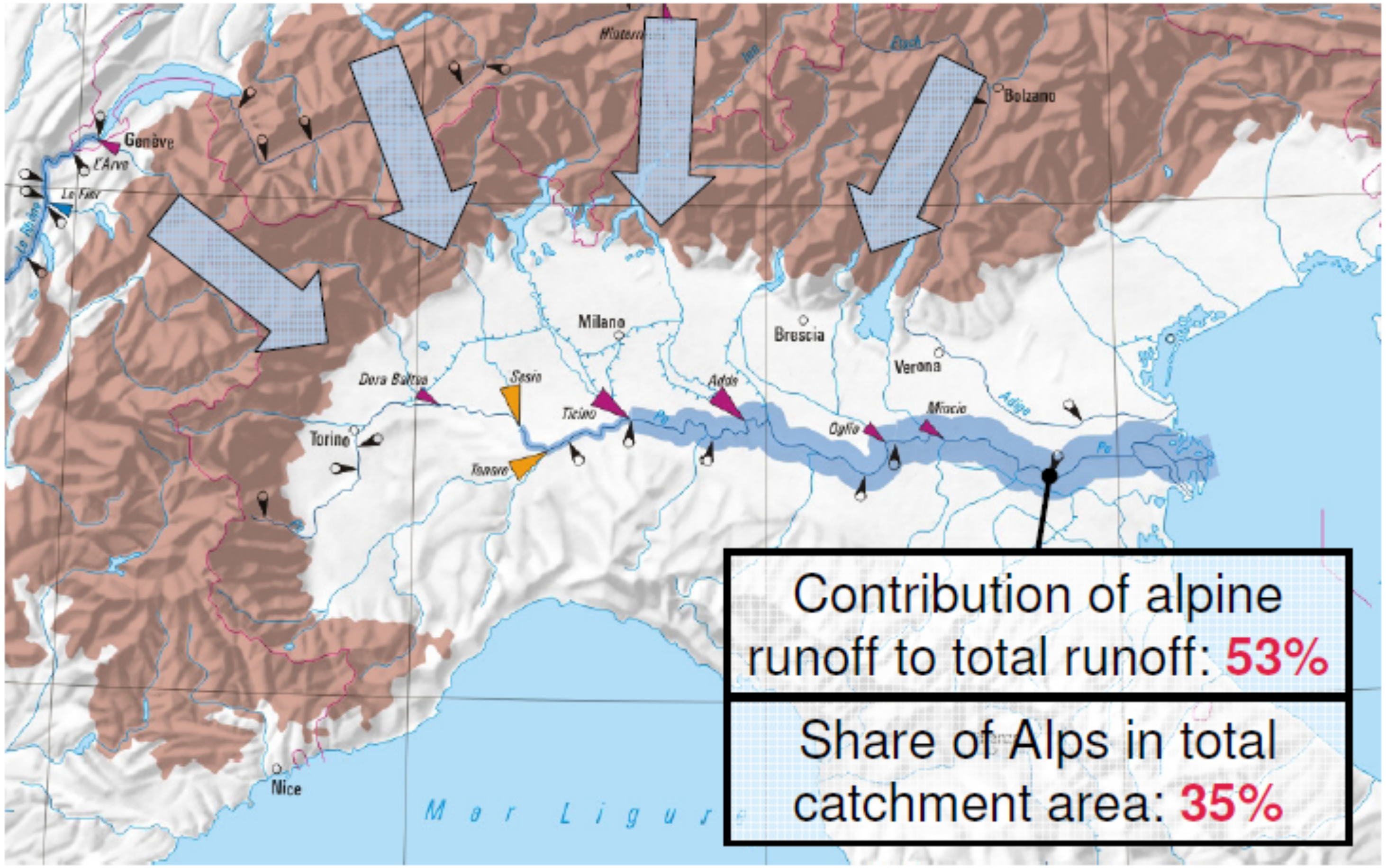
$$\sin(\Psi) = \sin(\phi)\sin(\delta_s) - \cos(\phi)\cos(\delta_s)\cos\left(\frac{2\pi t_{utc}}{t_d} - \lambda\right)$$

The solar declination angle , defined as the angle between the ecliptic and the plane of earth's equator, for the Julian day d , it is given by

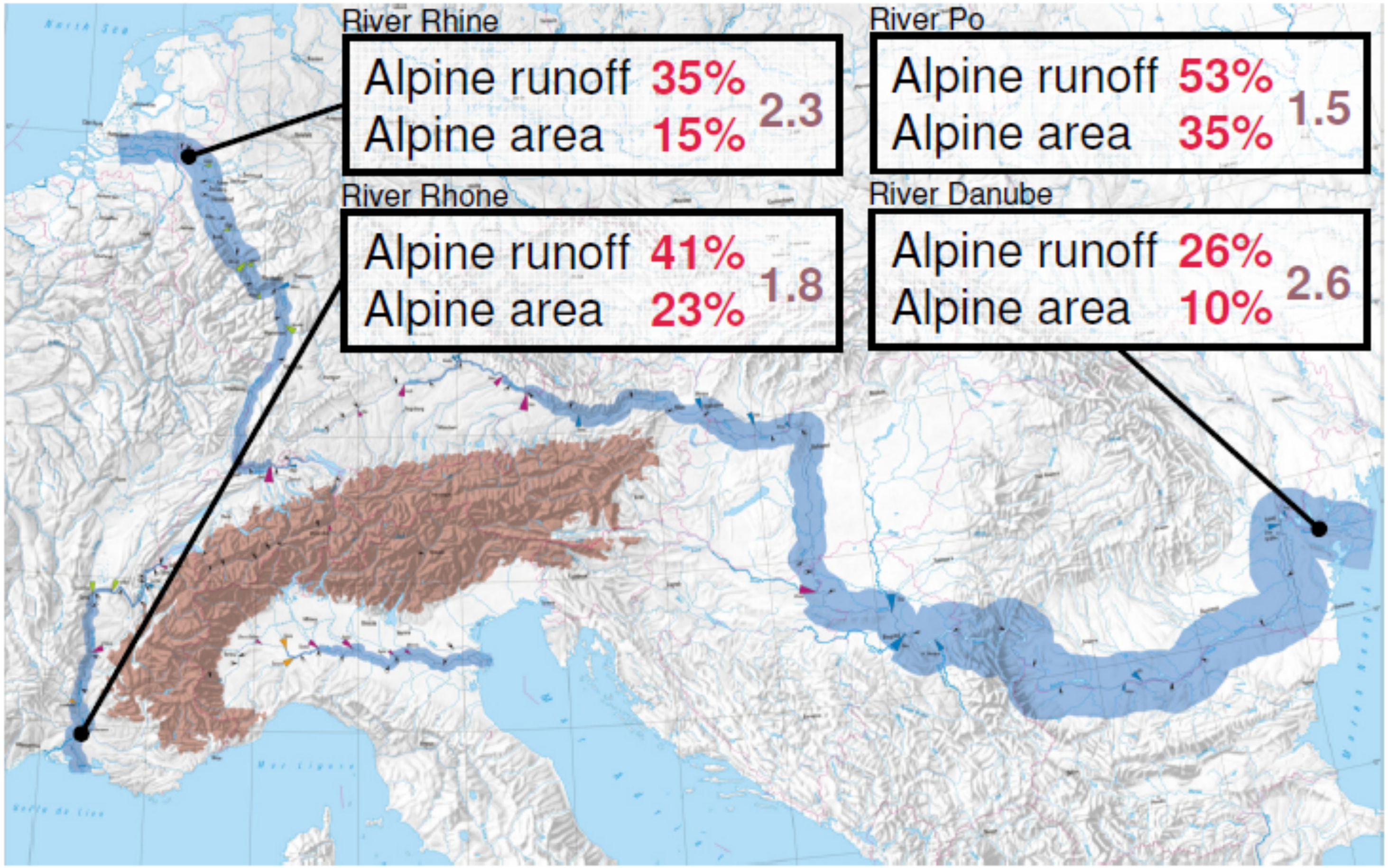
$$\delta_s = \Phi_r \cos\left[\frac{2\pi(d-d_r)}{d_y}\right]$$

1)Why do we want to use hydrological model for climate simulation

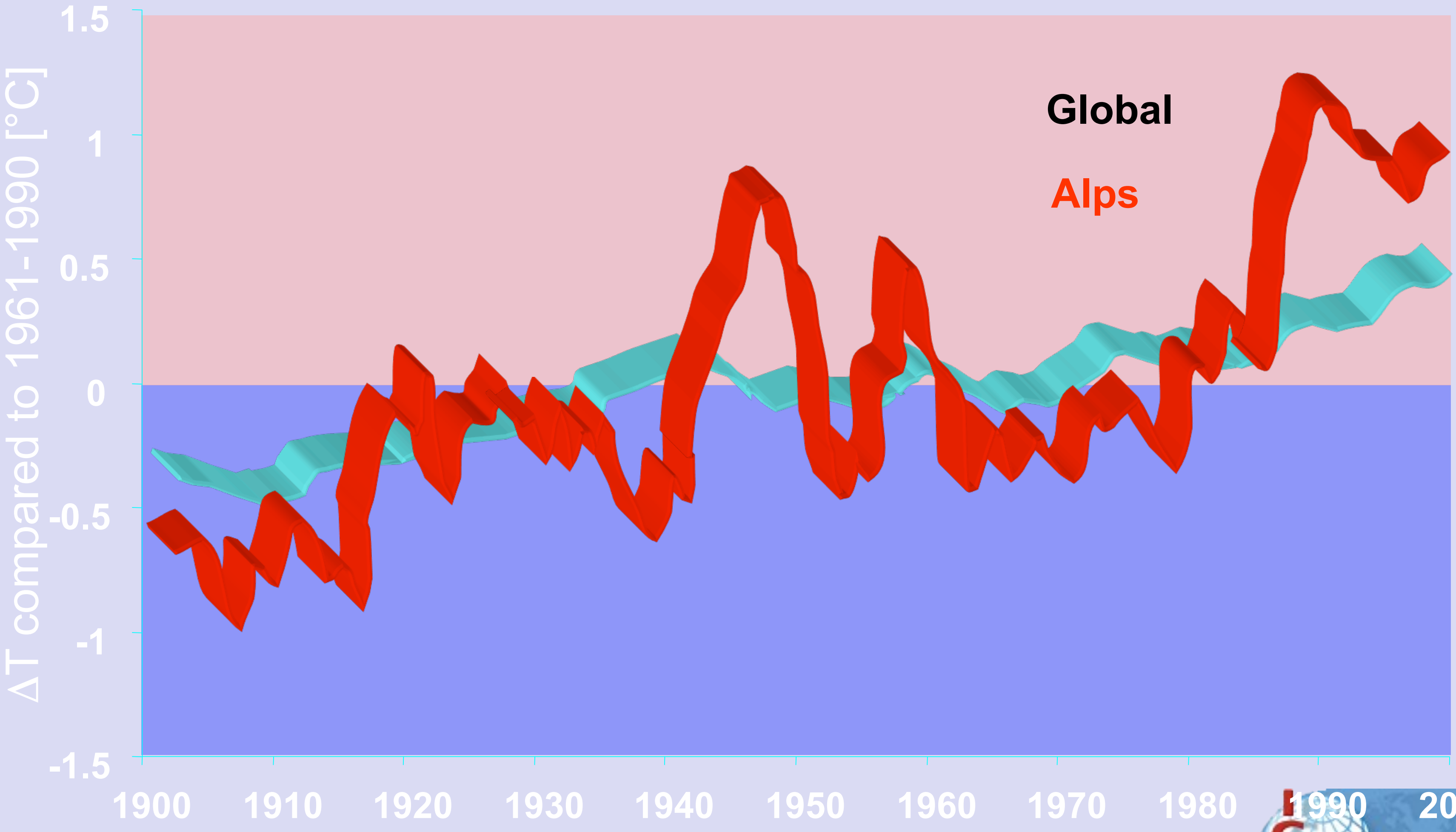
The Alps water tower of Europe
the river Po



The Alps water tower of Europe: the 4 major rivers

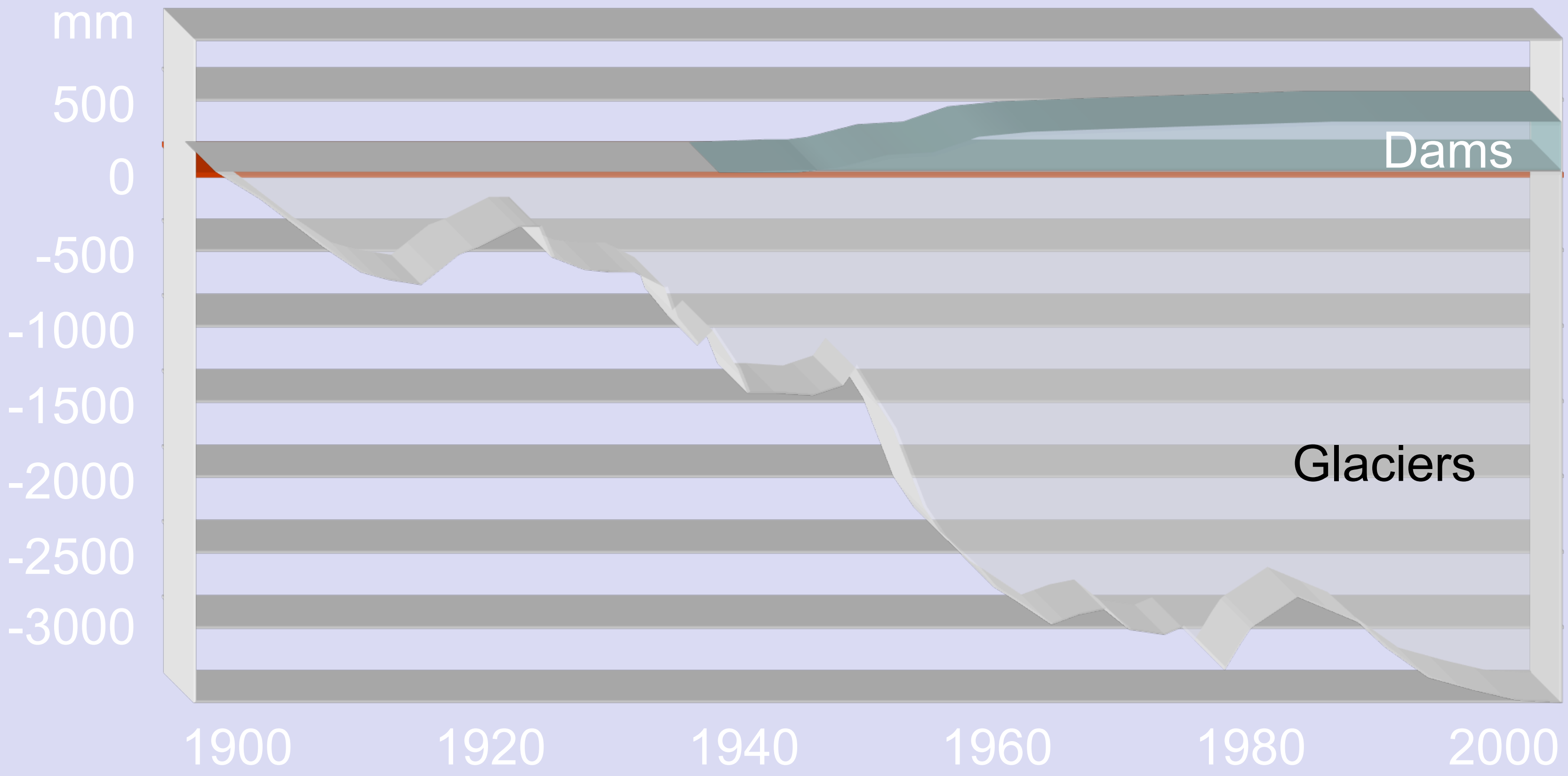


Evolution of global and alpine temperatures, 1901-2000

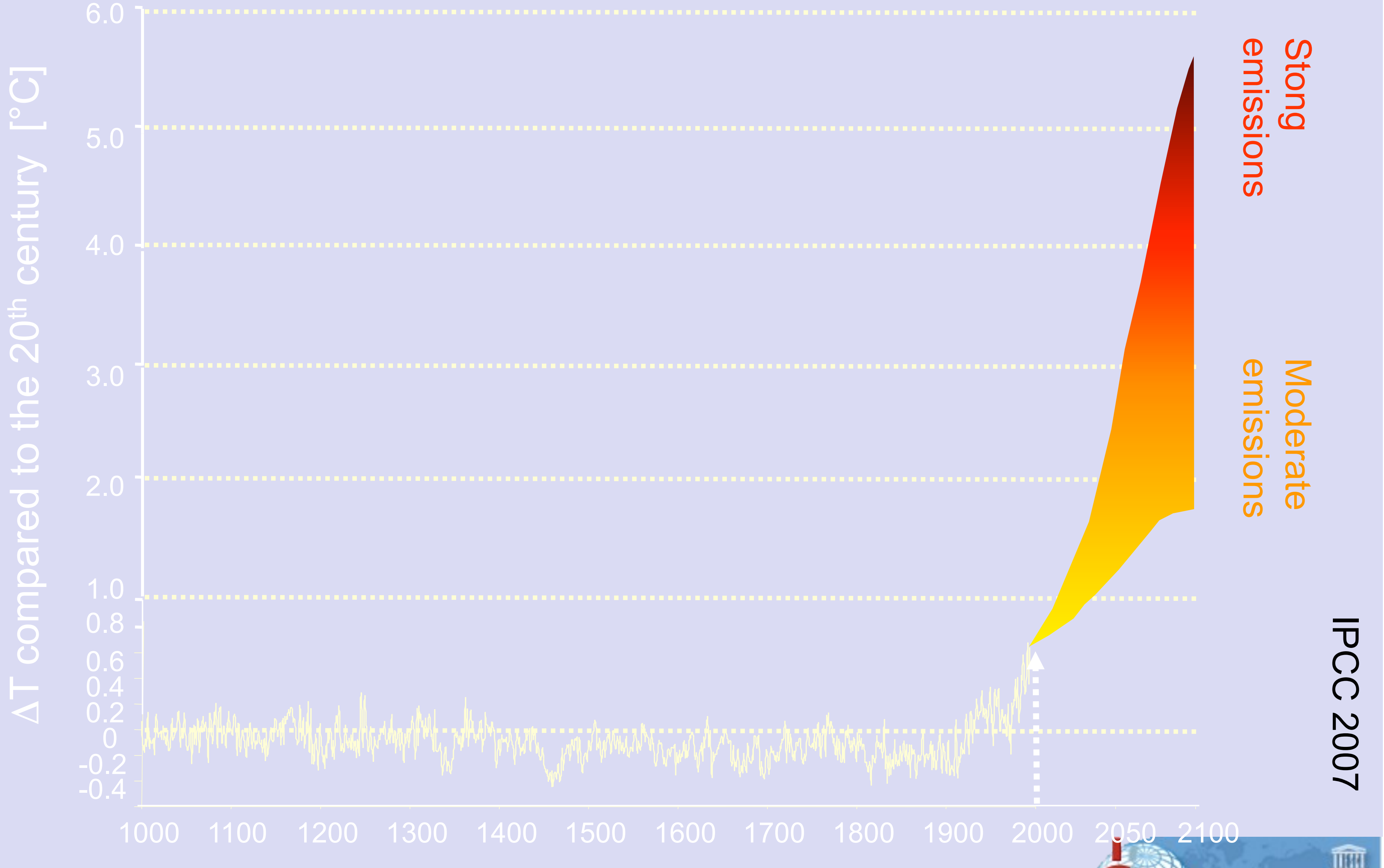


Beniston, 2000: Environmental Change in Mountains, Arnold, London

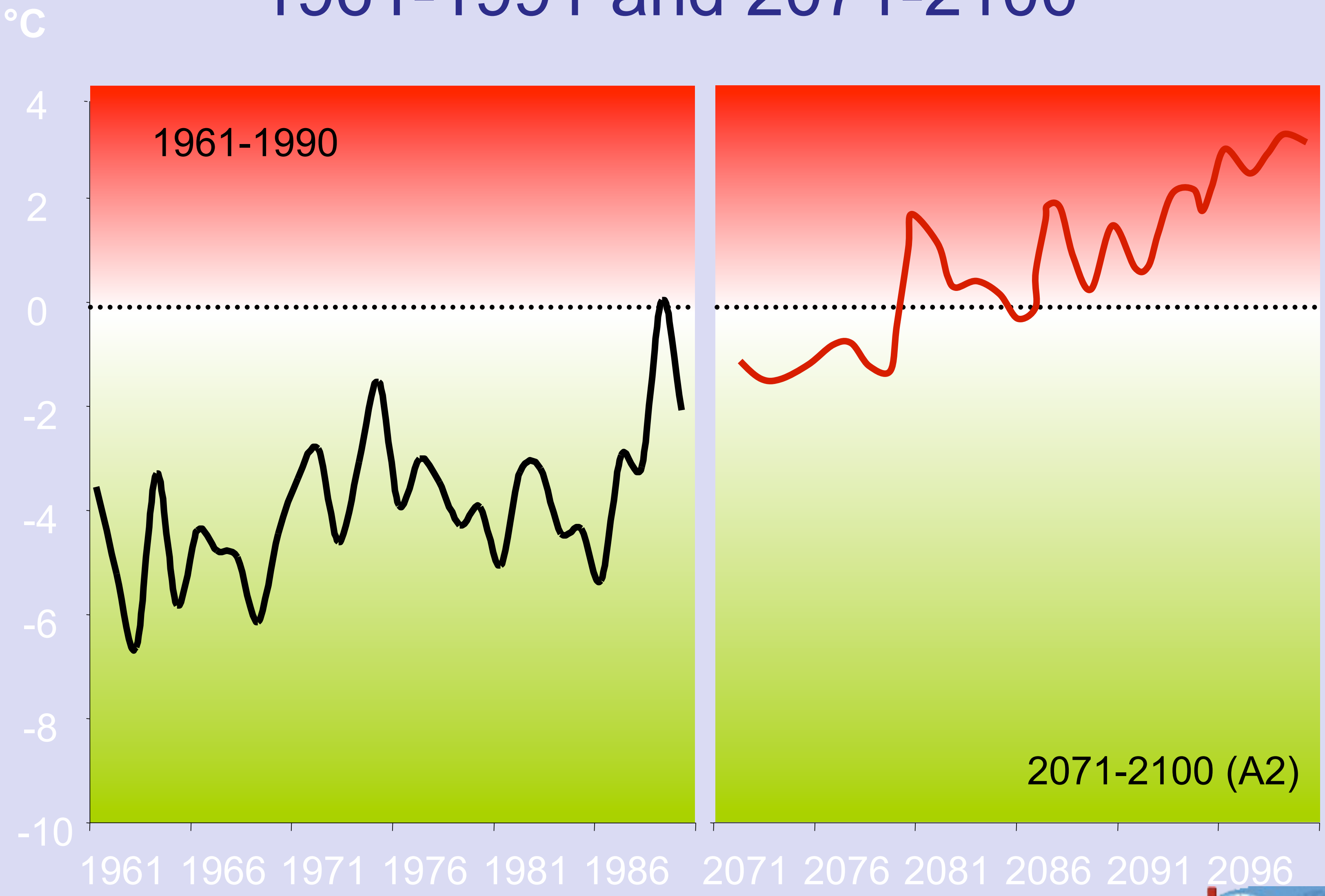
Changes in water availability for the Rhône River



Climate futures

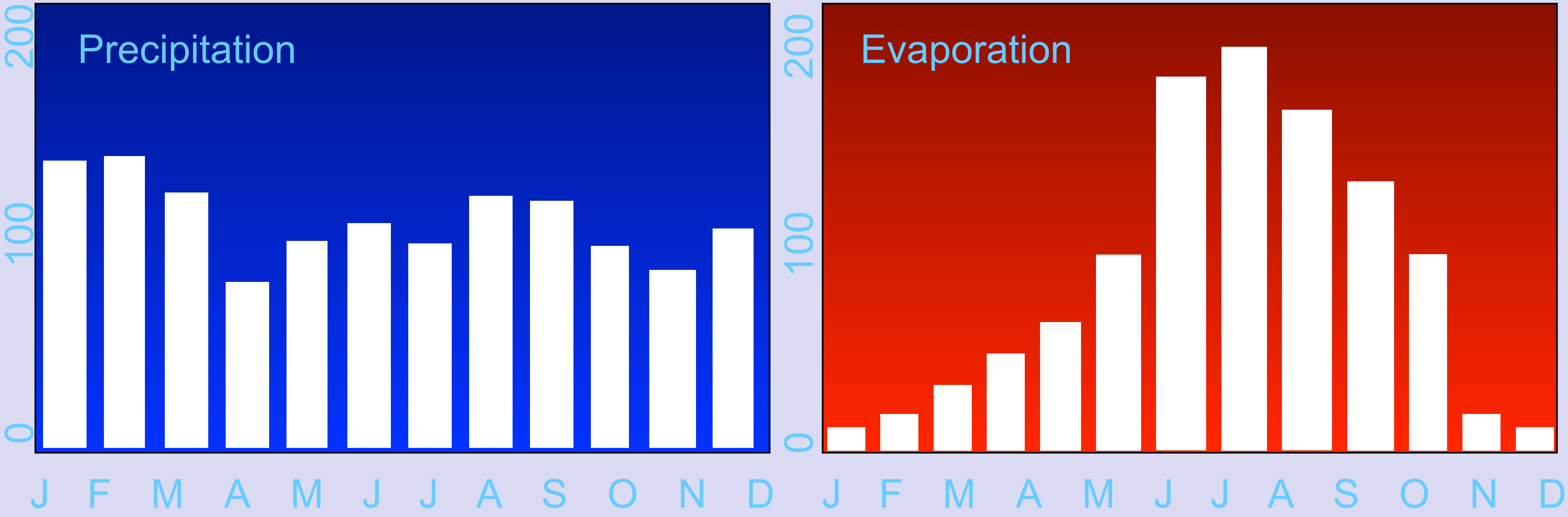


Winter temperatures at Säntis (2,500 m): 1961-1991 and 2071-2100



Beniston, 2004: Climatic Change and Impacts, Springer Publishers

Components of the hydrological cycle by 2100 (mm, Rhone)

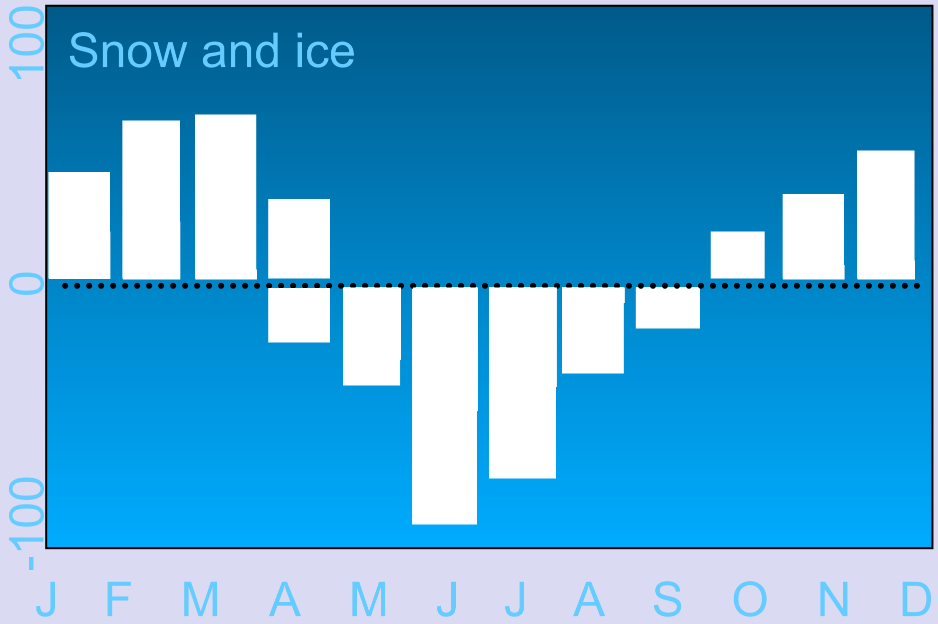


Glacier retreat: Italian Alps

Glacier retreat: Tschierva Glacier, Engadine

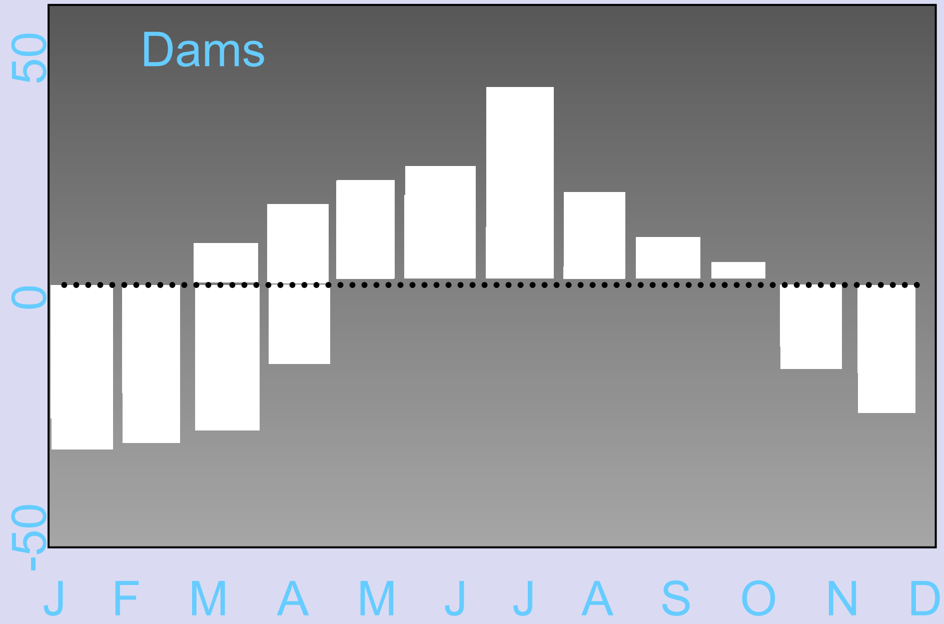
Courtesy: Max Maisch
University of Zurich, Switzerland

Components of the hydrological cycle by 2100 (mm, Rhone)



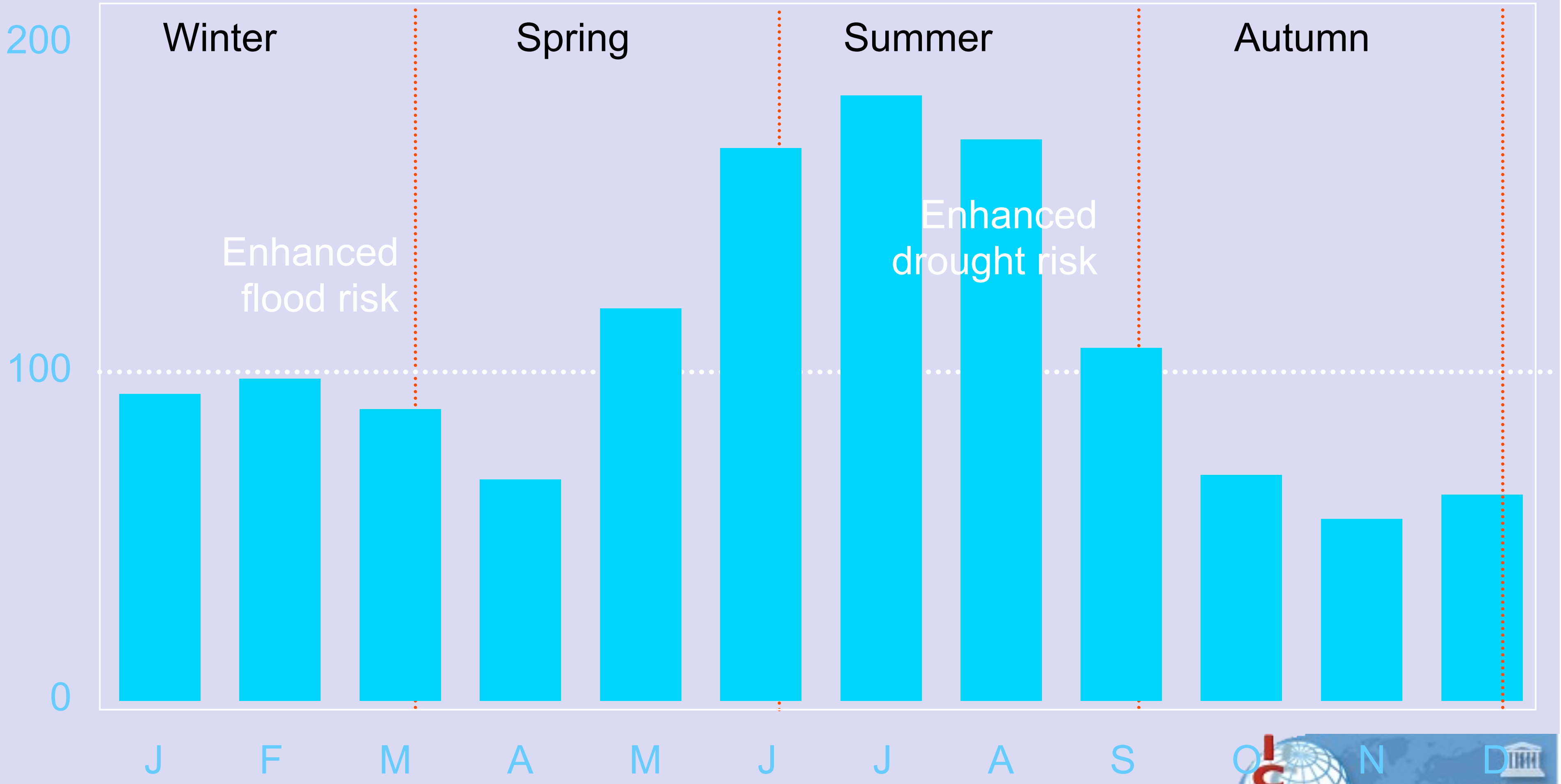
Grande Dixence, Switzerland

Components of the hydrological cycle by 2100 (mm, Rhone)



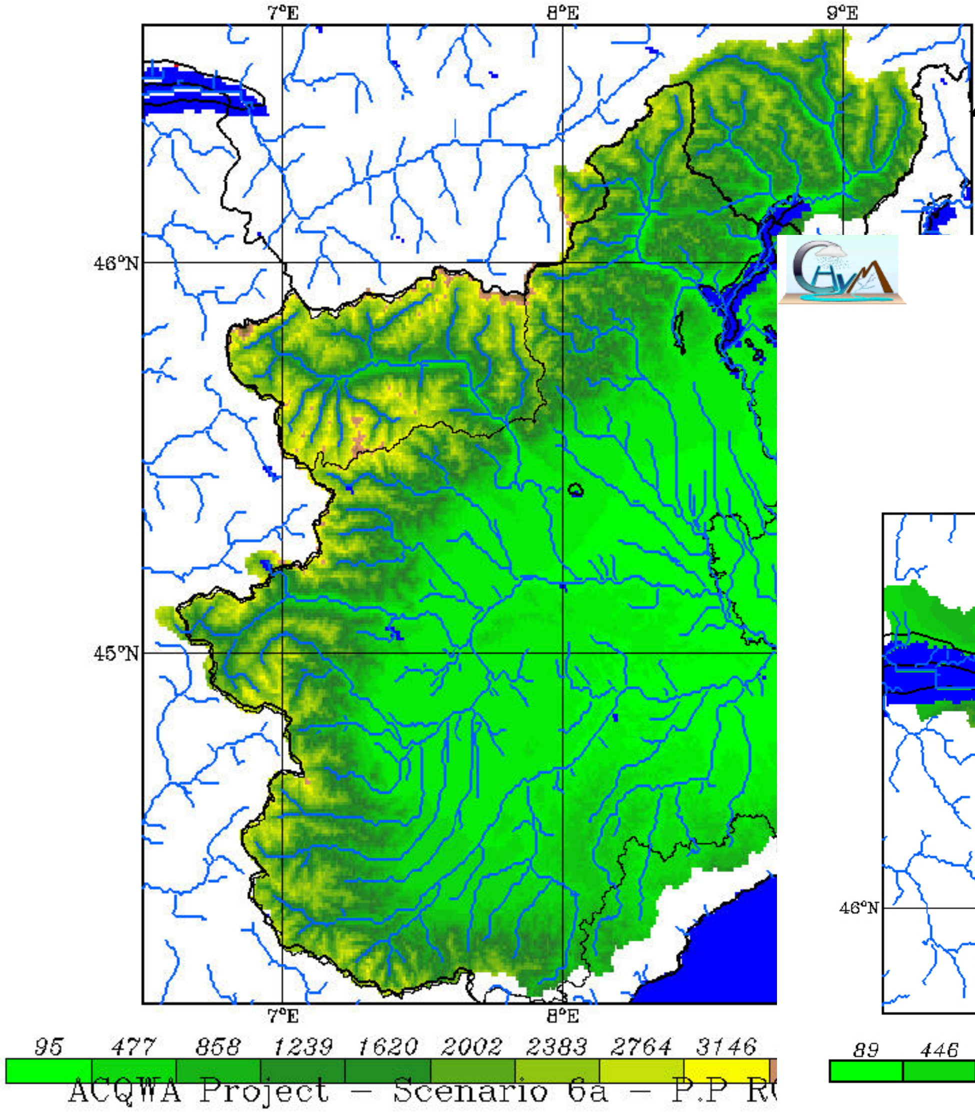
Average discharge by 2100 (mm, Rhone)

Beniston, 2004:
Climatic Change and Impacts,
Springer Publishers



2)How can we use hydrological model for climate simulation

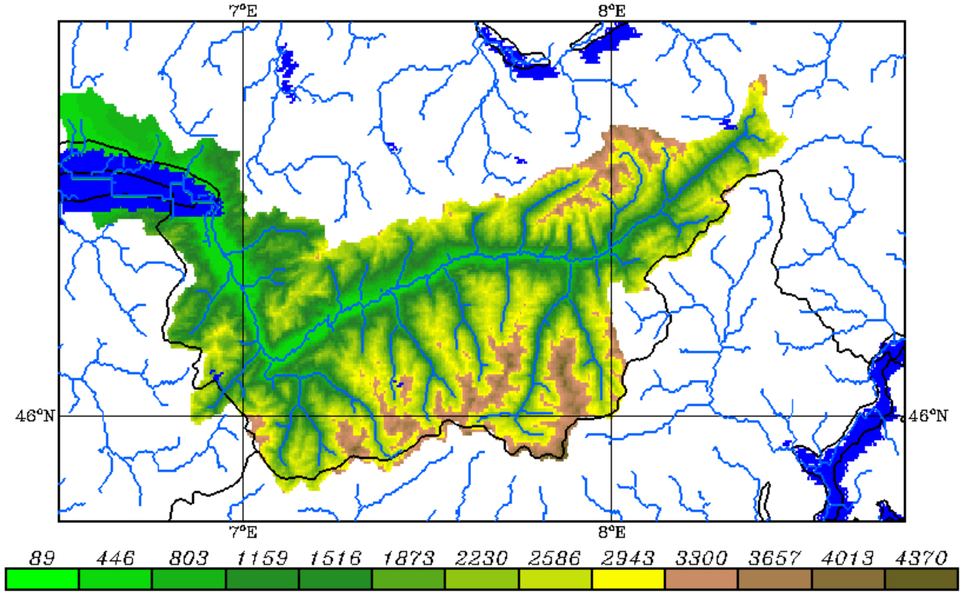
Po River Basin



330 lon x 280 lat
44.10°N-46.61°N 6.50°E-9.46°E
Res.: 990 m

Rhone River Basin

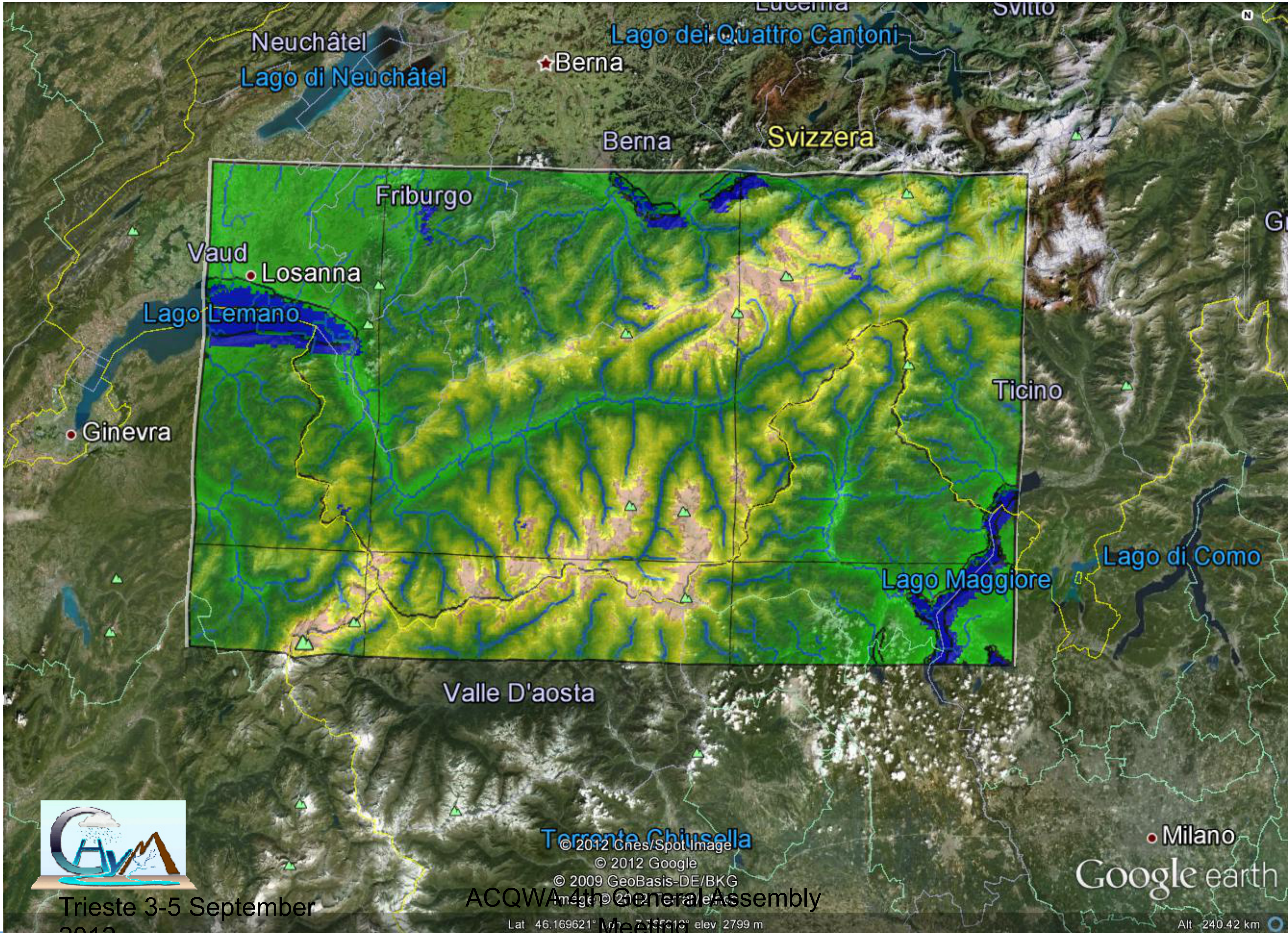
460 lon x 190 lat
45.80°N-46.75°N 6.50°E-8.79°E
Res.: 550 m



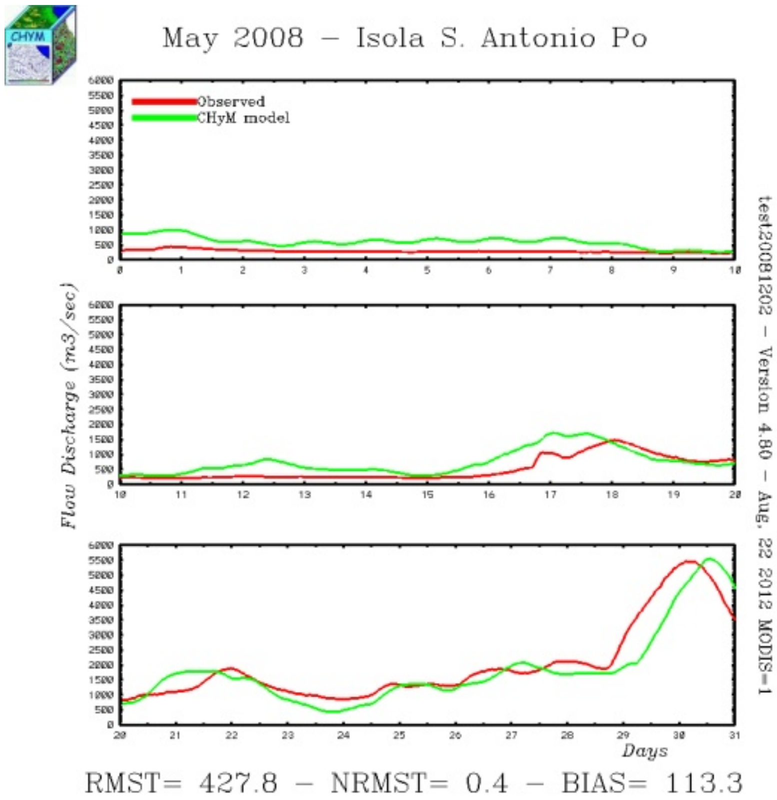
CHyM Rhone Basin Simulation – ACQWA Project

3)What we need to start our exercise?

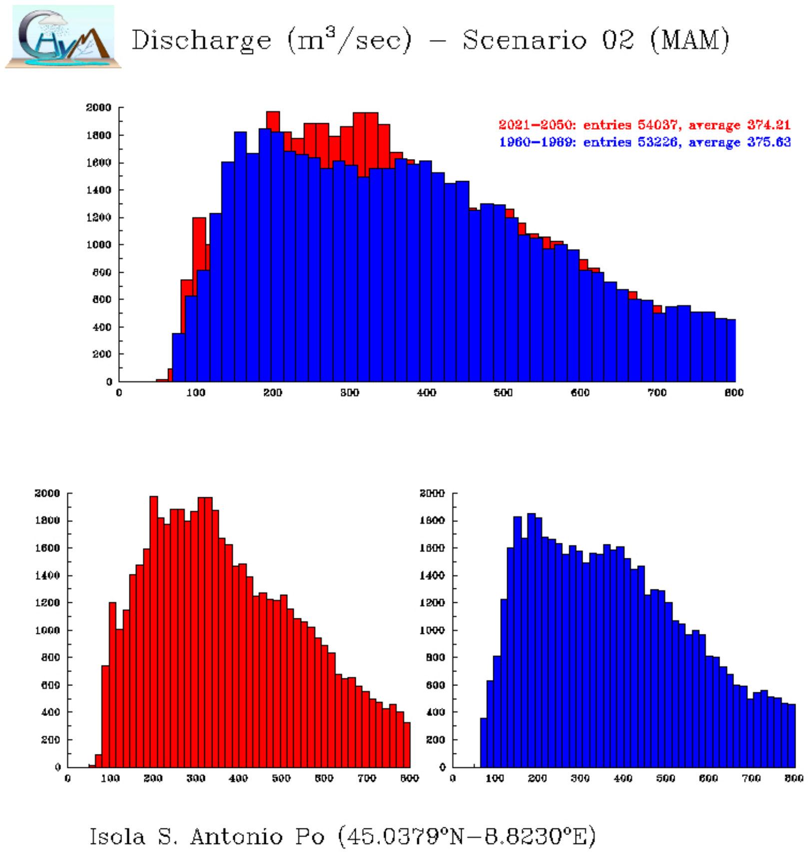
Model calibration


Lucerna
Svitto
Neuchâtel
Lago di Neuchâtel
Lago dei Quattro Cantoni
Berna
Berna
Svizzera
Friburgo
Vaud
Losanna
Lago Lemano
Ginevra
Ticino
Lago di Como
Lago Maggiore
Valle D'aosta
Torrente Chiusella
Milano
© 2012 Cnes/Spot Image
© 2012 Google
© 2009 GeoBasis-DE/BKG
Google earth
Lat 46.169621°
elev 2799 m
Alt 240.42 km

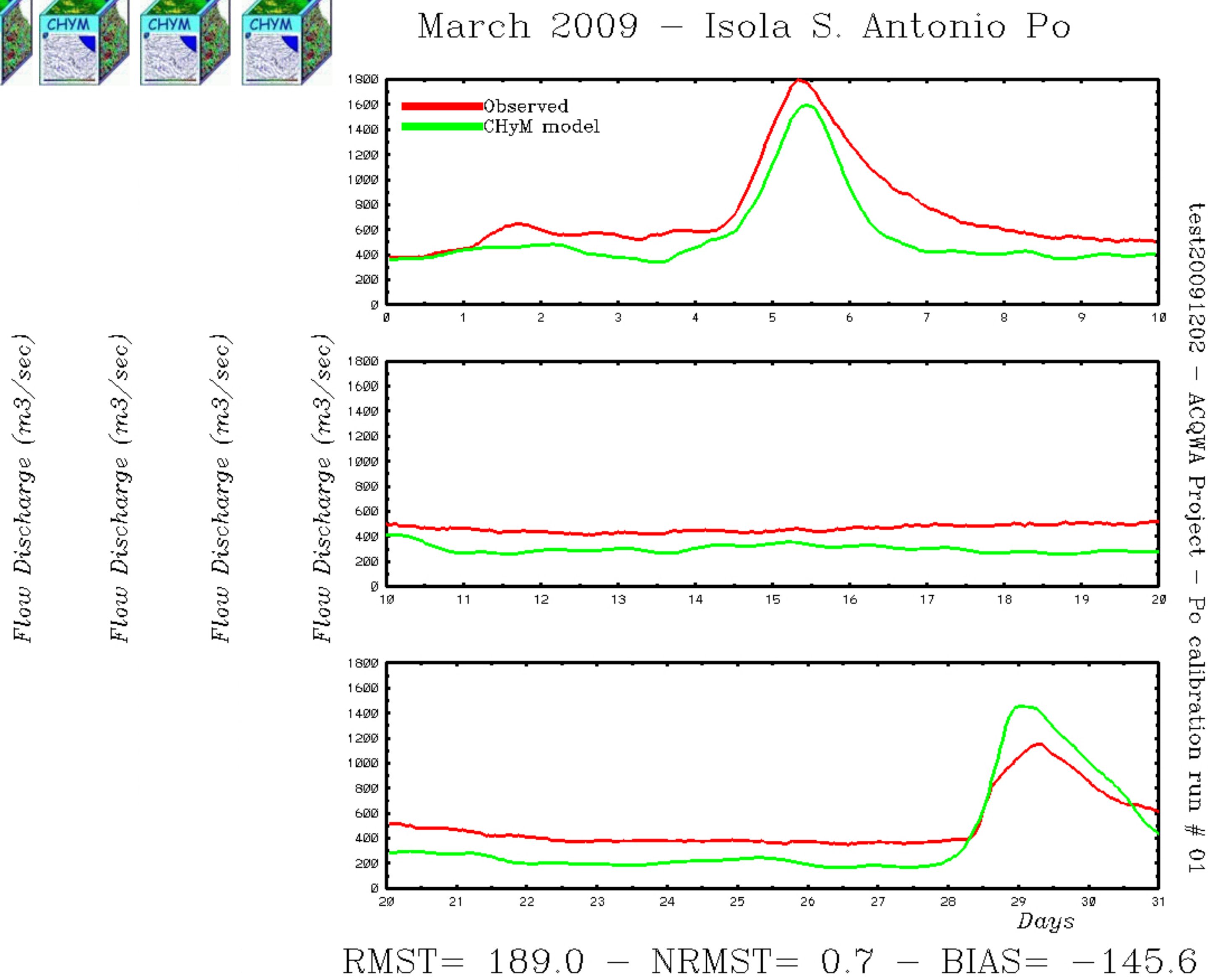
Calibration



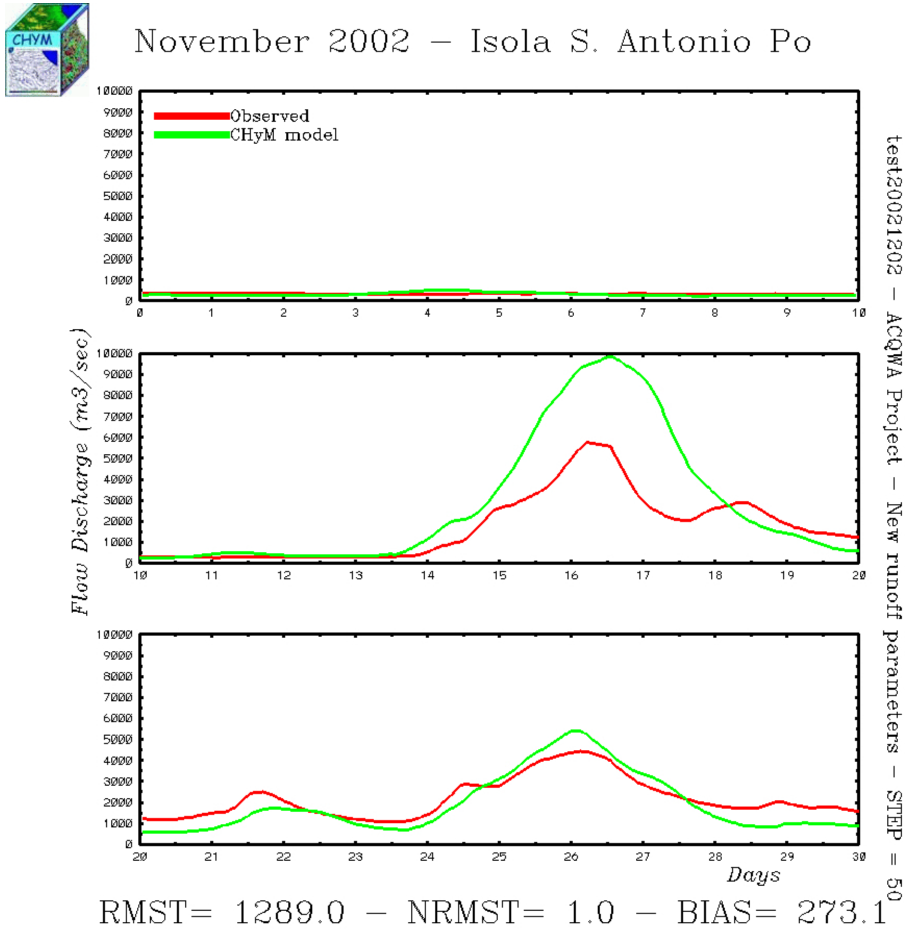
Simulations

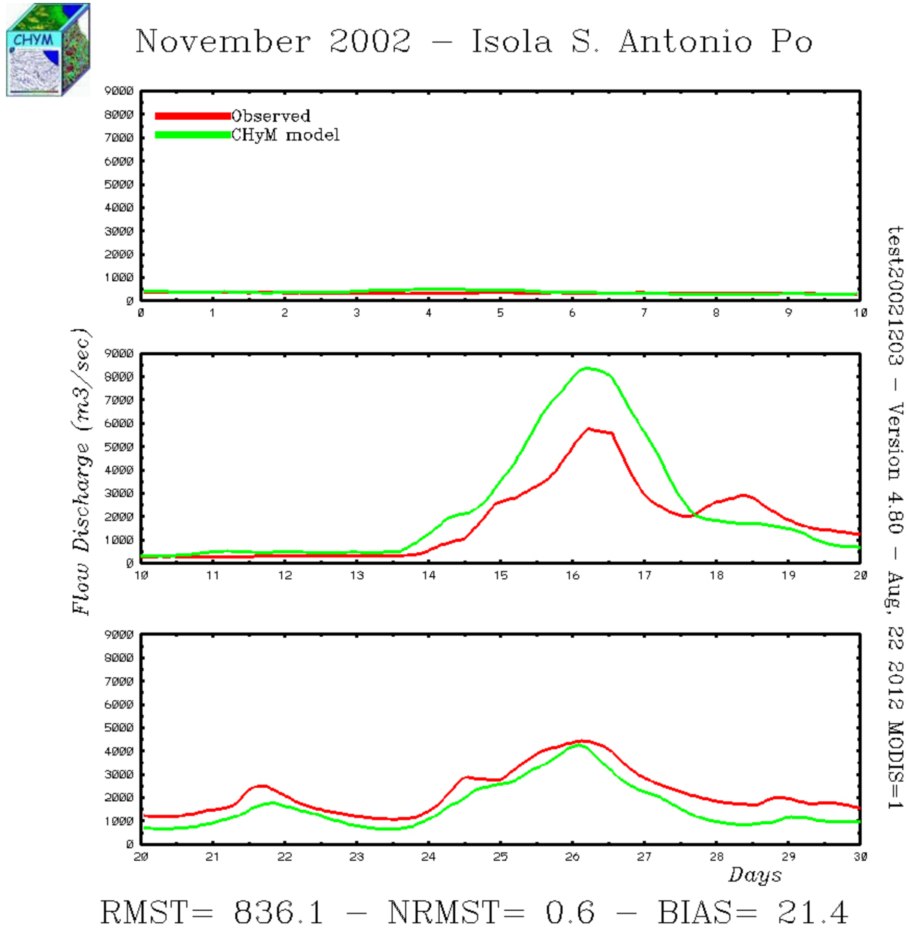


CHyM model calibration

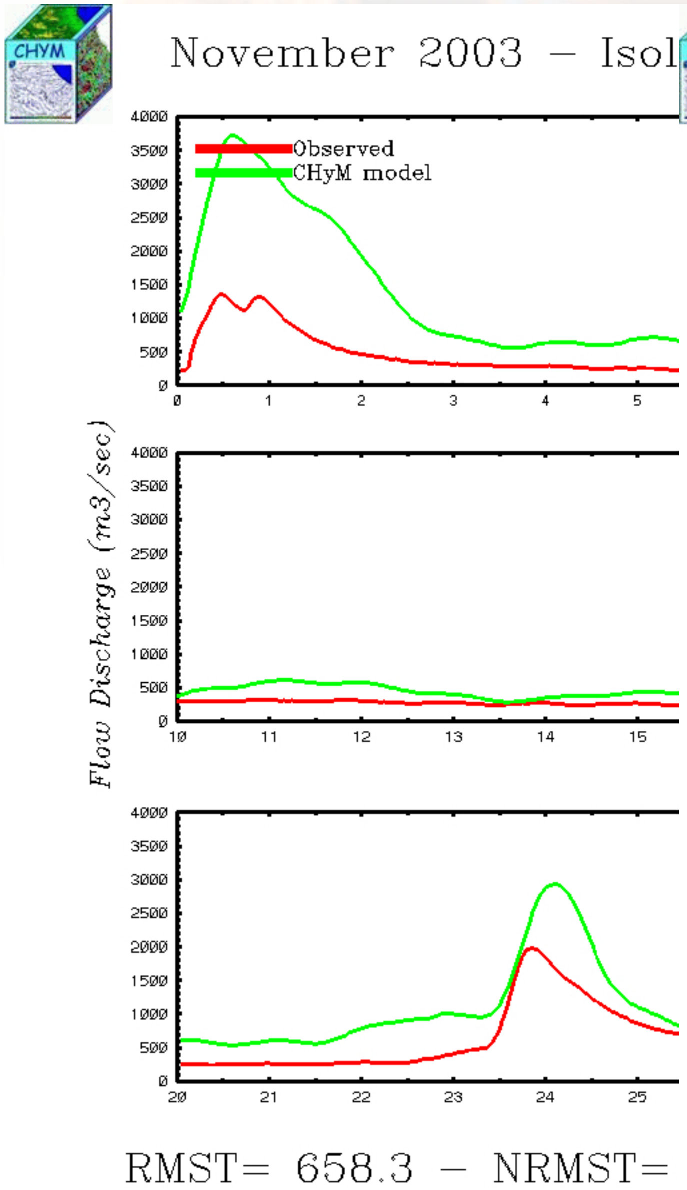


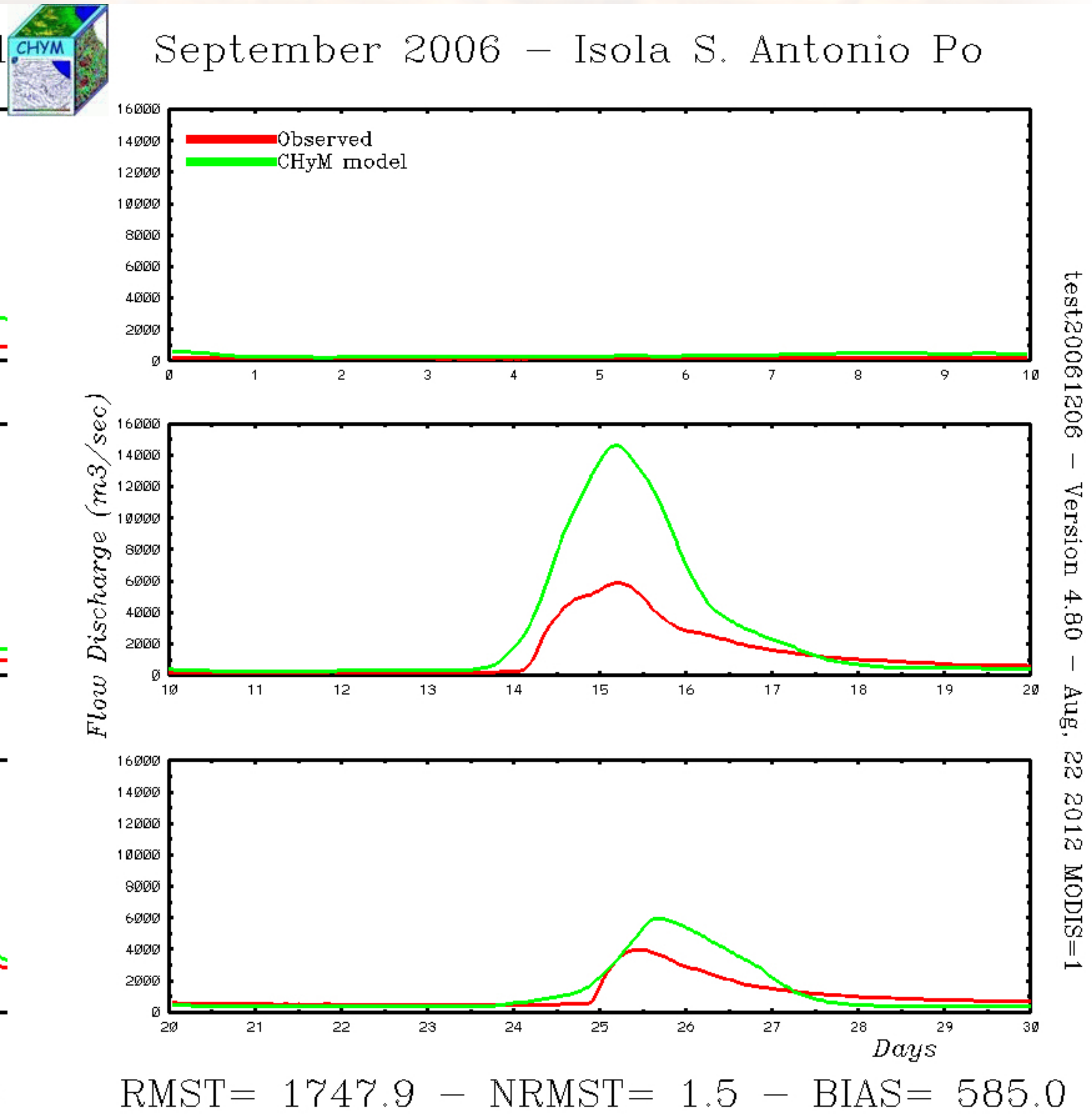
CHyM model calibration



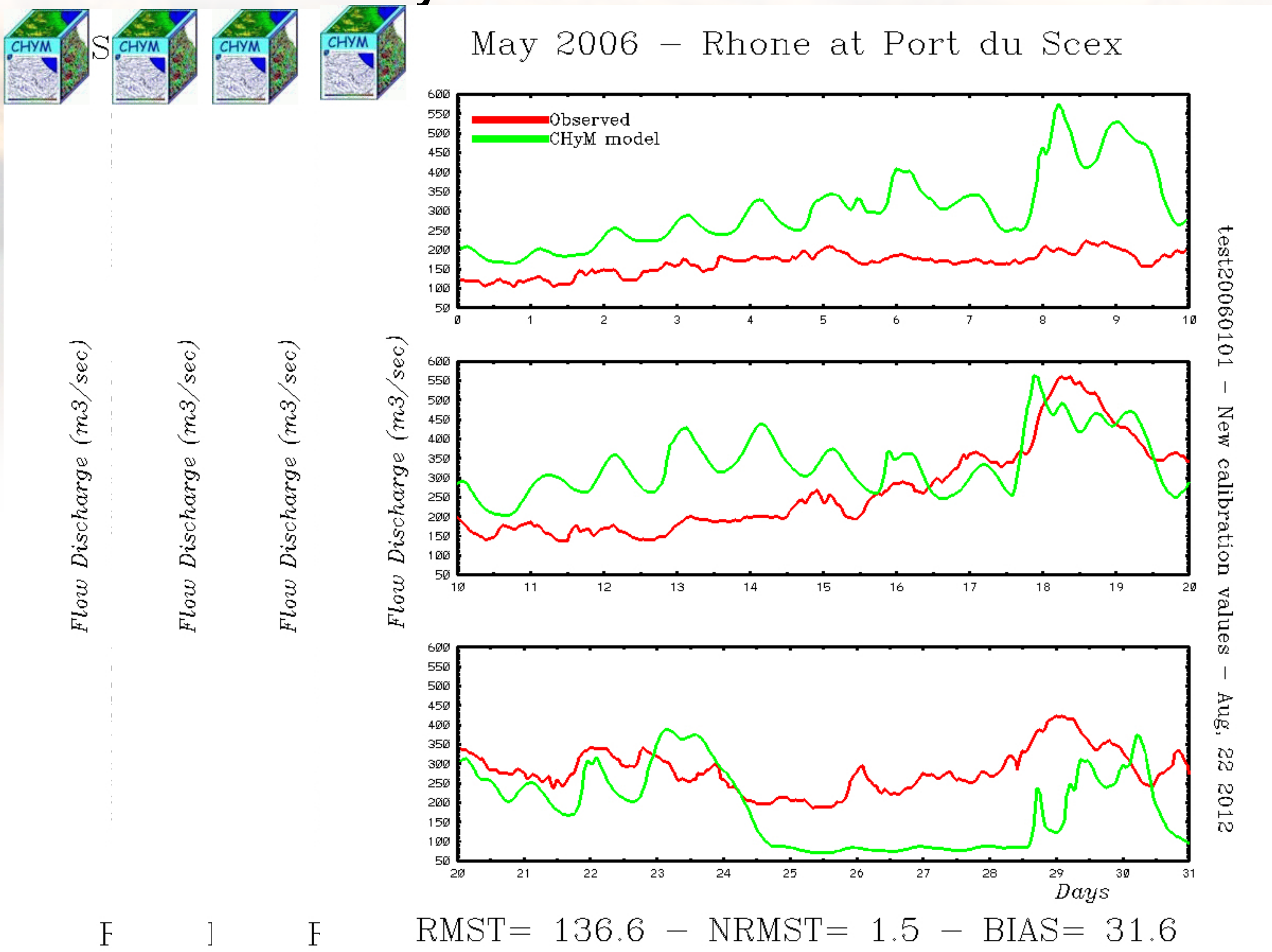


CHyM model calibration



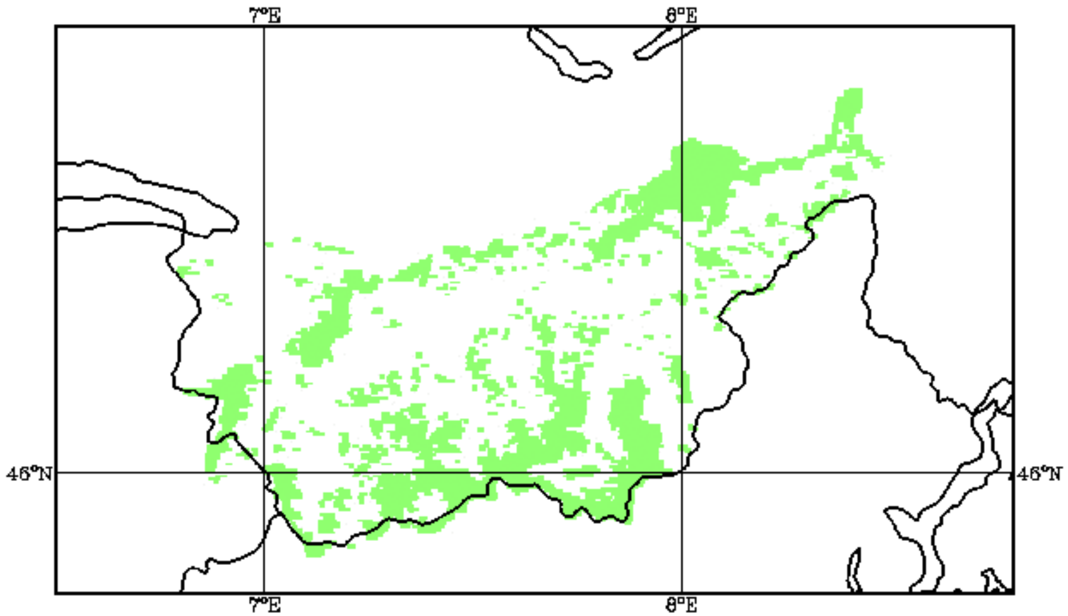


CHyM model calibration



CHyM model calibration

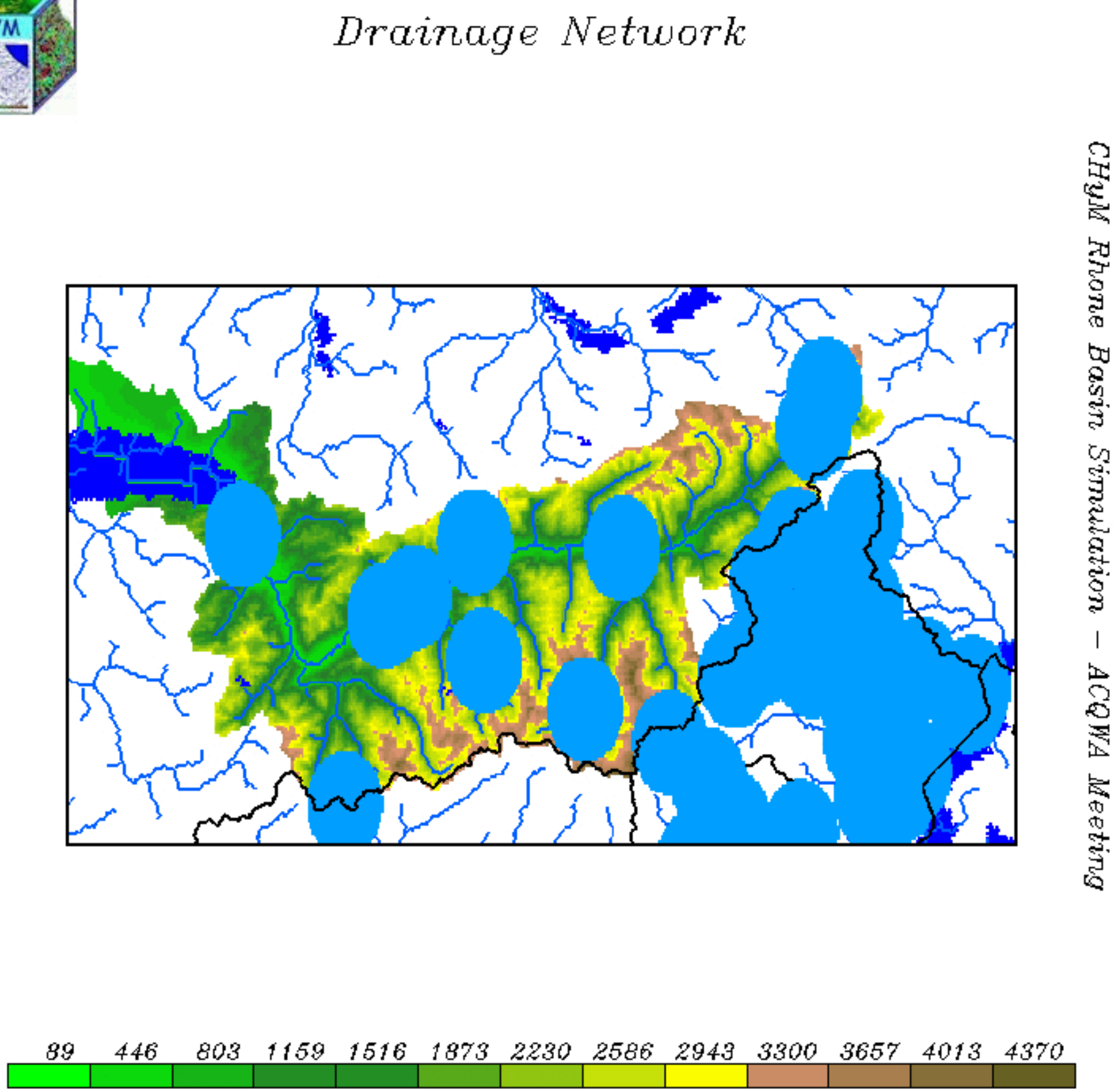
September 8, 2001



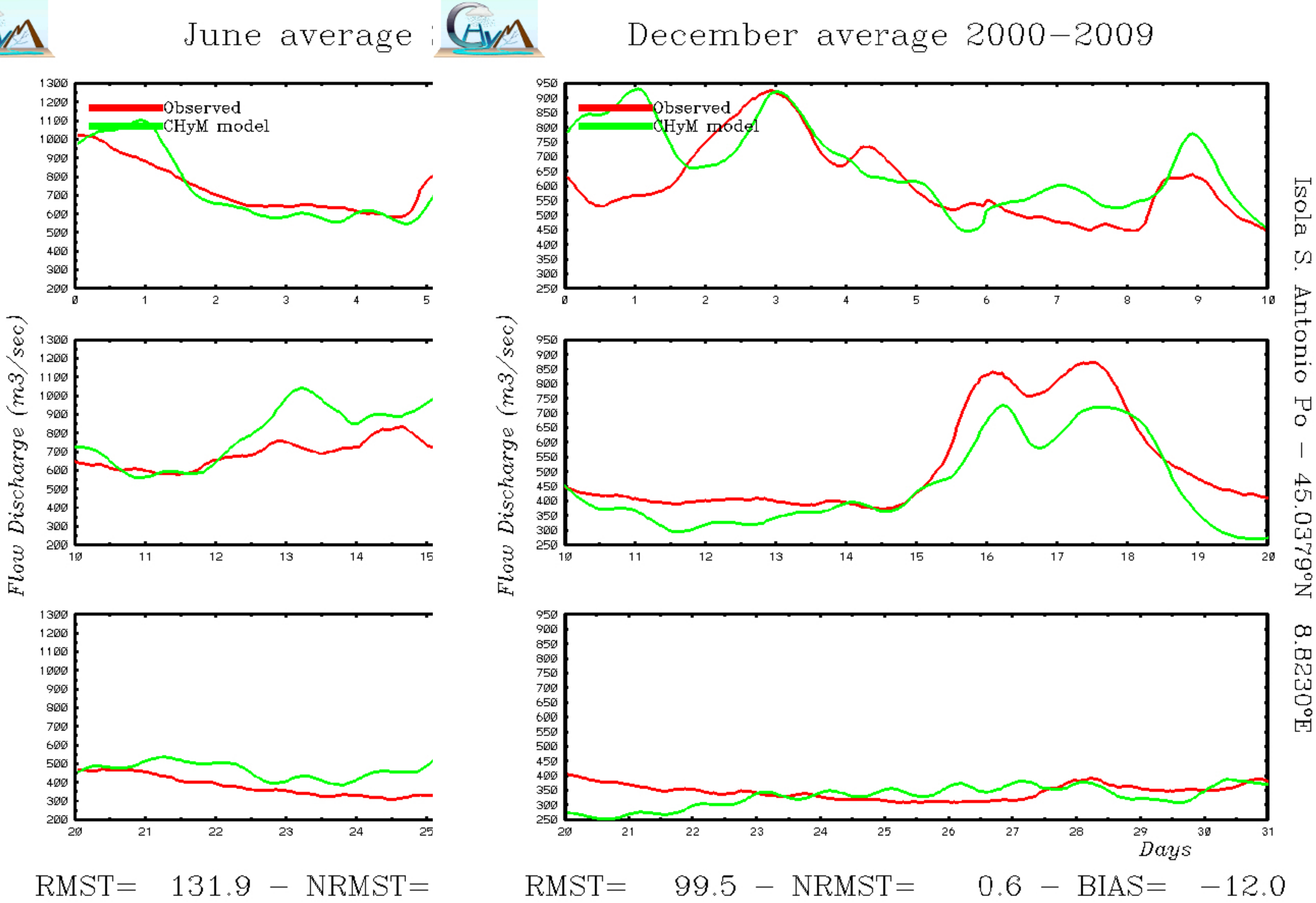
Snow cover – MODIS data corrected by J. P. Didier

4)What does it mean to calibrate the model?

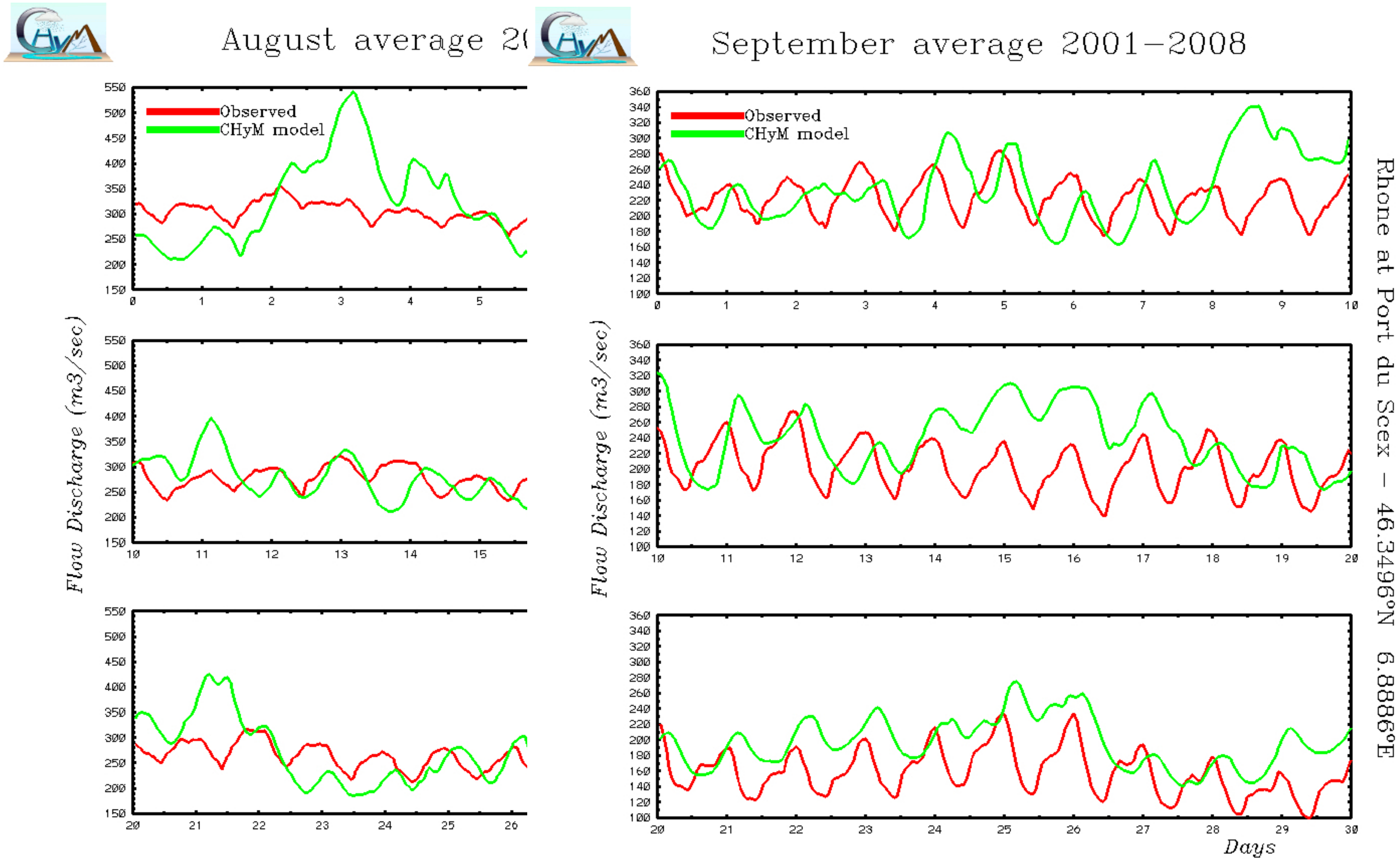
CHyM model calibration



CHyM model calibration



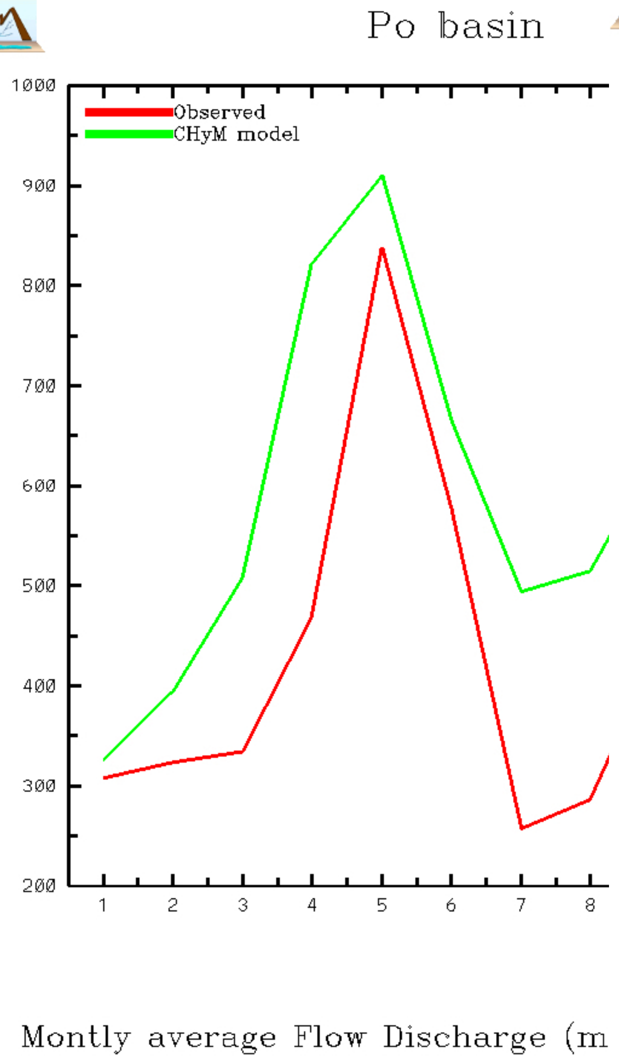
CHyM model calibration

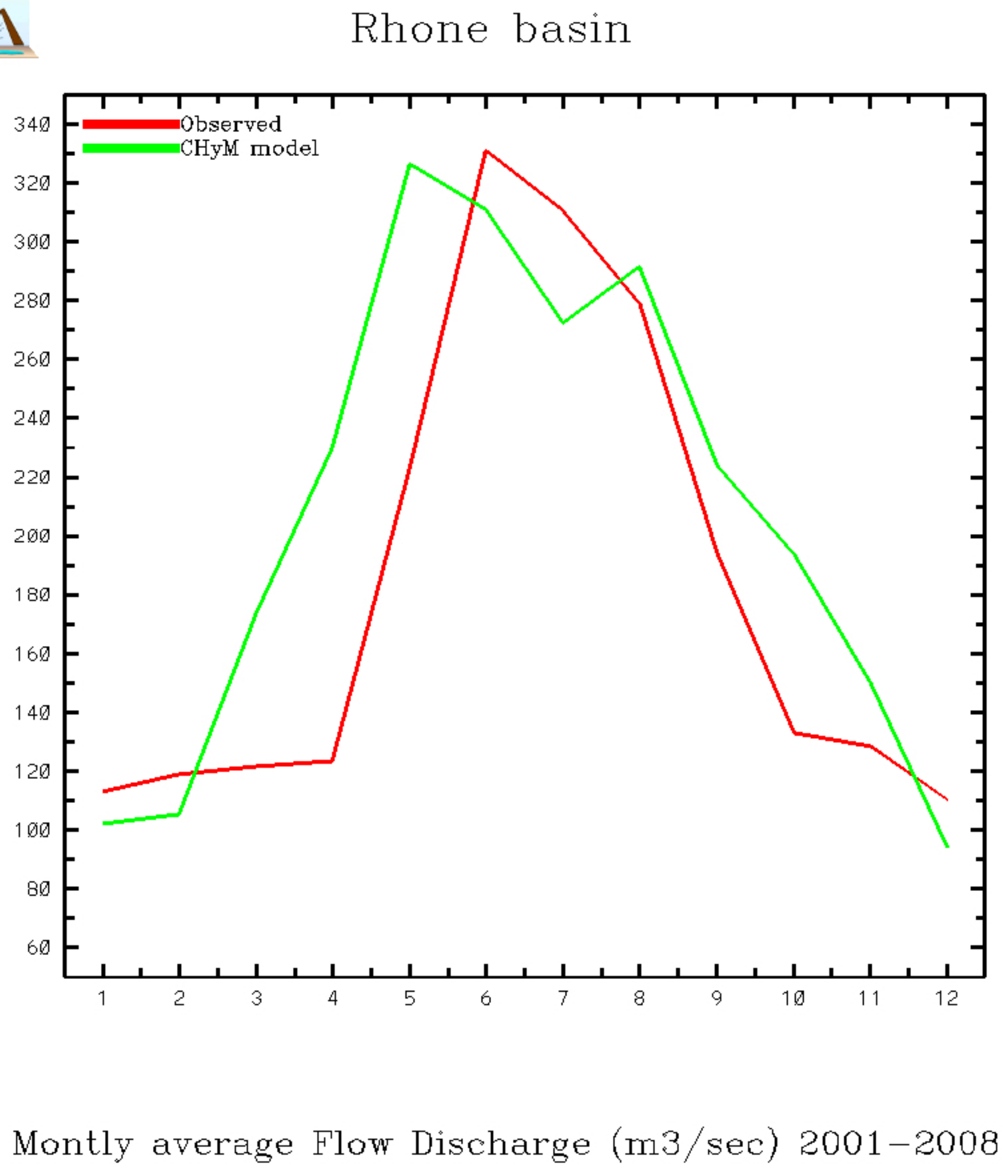


RMST= 63.3 – NRMST=

RMST= 55.2 – NRMST= 1.4 – BIAS= 30.0

CHyM model calibration





what can we learn from this exercise

✓Good performances of CHyM in reproducing observed discharge time series, the timing of major peaks are (almost) always well captured
✓Overestimation of major peaks after dry period especially for Po basin (hydropower)
✓Difficulties in reproducing daily cycle on Rhone basin (snow cover map)
✓Year cycle is well reproduced for both basins (overestimation during summer for Po basin)

what are the problems

✓A parameterization of hydropower is needed
✓Refine the parameterization of melting, basic flow and evapotranspiration
✓Use MODIS snow deep estimation instead of snow cover map only

5)How do I run a hydro-climate simulation?

I want to complete a scenario simulation with CHyM of 140 years, what do I need?

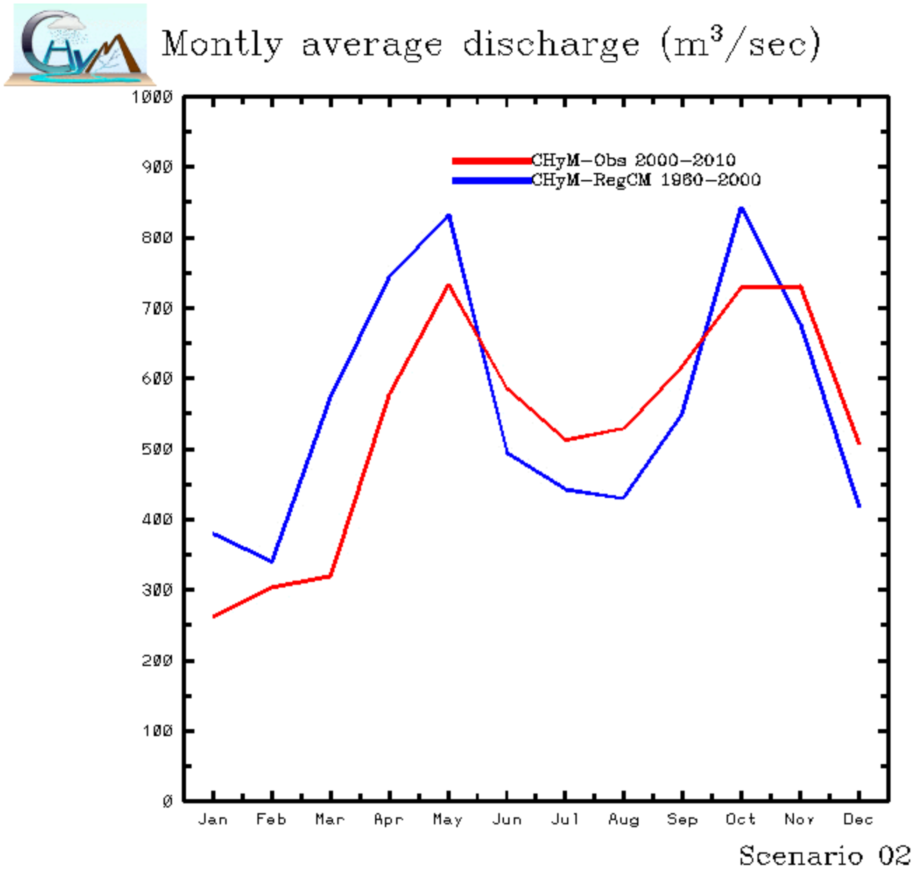
1) **storage space for the climate model input data**
2) **for each field of the hydro simulationand for each basin for each scenario**

330x280x24x365x90 ≈ 18 bilions of data ≈ 72 Gbyte

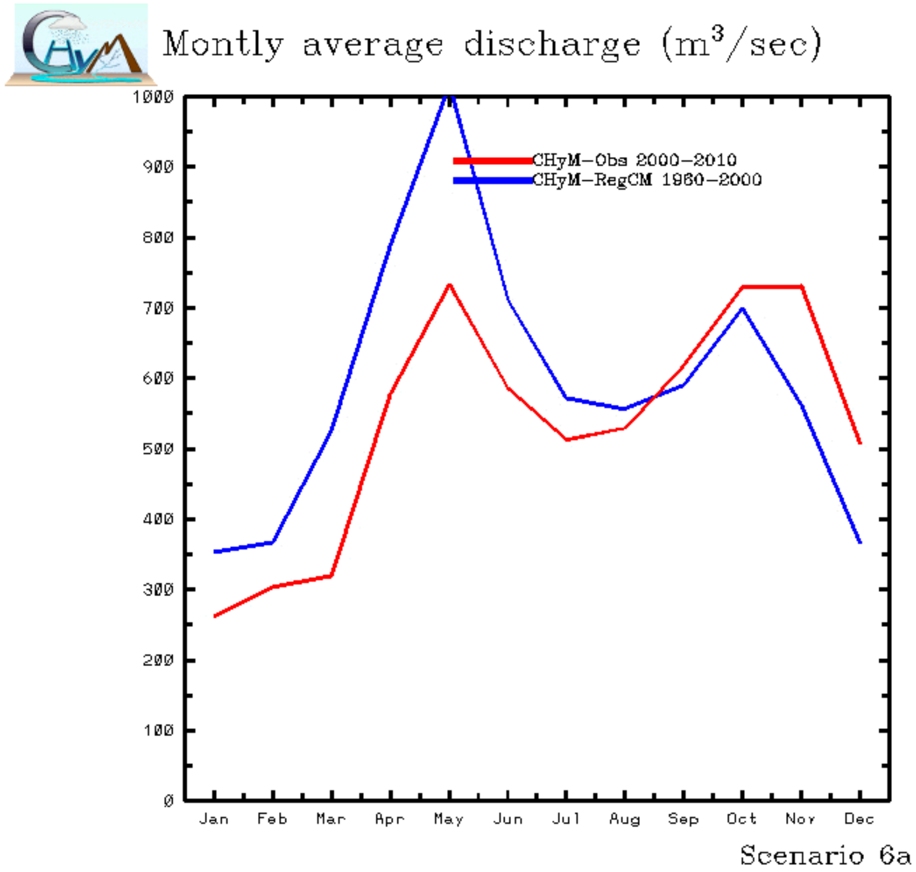
3) capability of analyzing the big amount of data

4) method to estimate the uncertancy

CHyM - Simulation of climatic scenarios – Po river-Validation

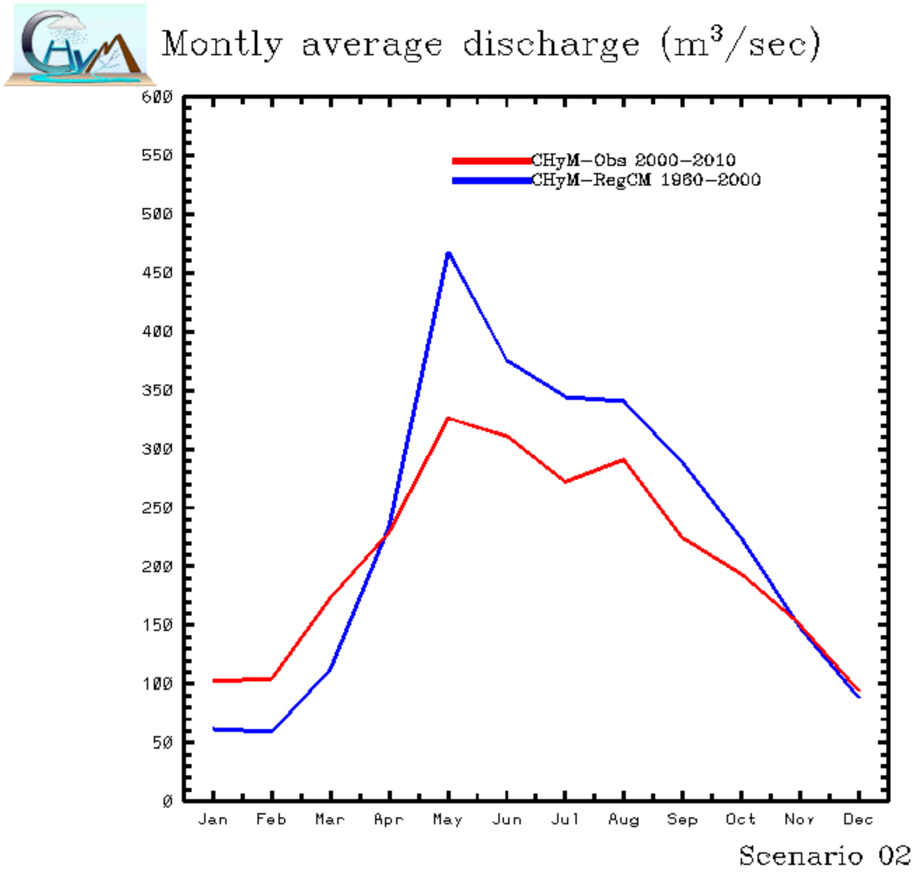


Isola S. Antonio Po (45.0379°N–8.8230°E)

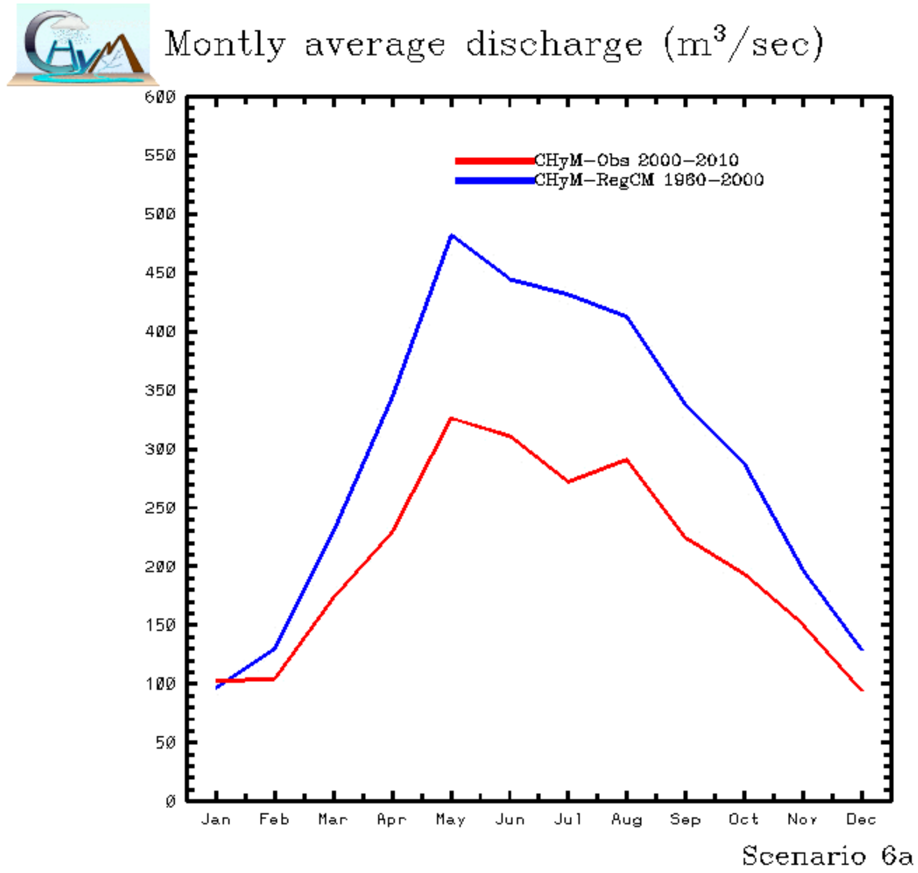


Isola S. Antonio Po (45.0379°N–8.8230°E)

CHyM - Simulation of climatic scenarios-Rhone river-Validation

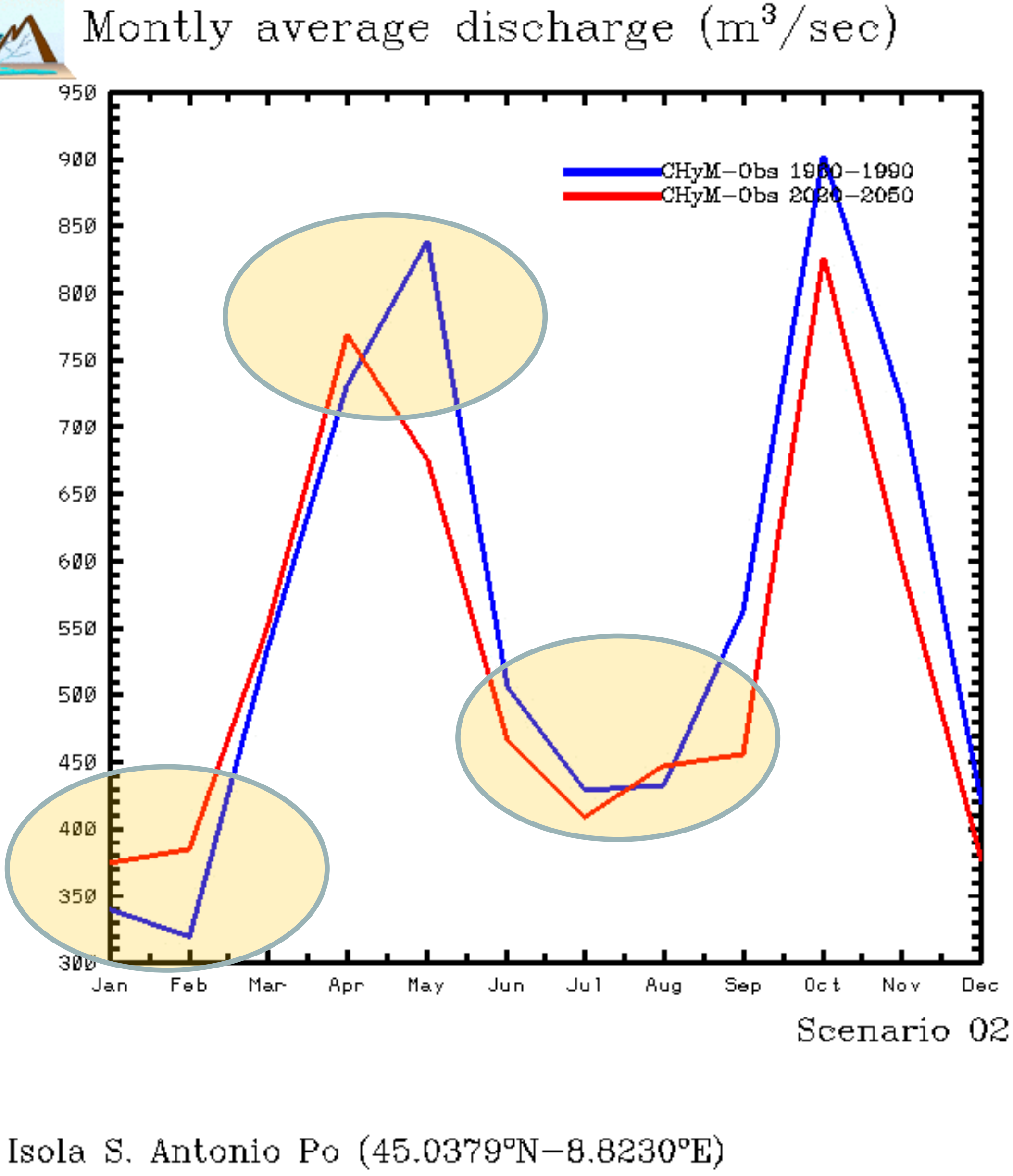


Rhone at Port du Scex (46.3496°N–6.8886°E)

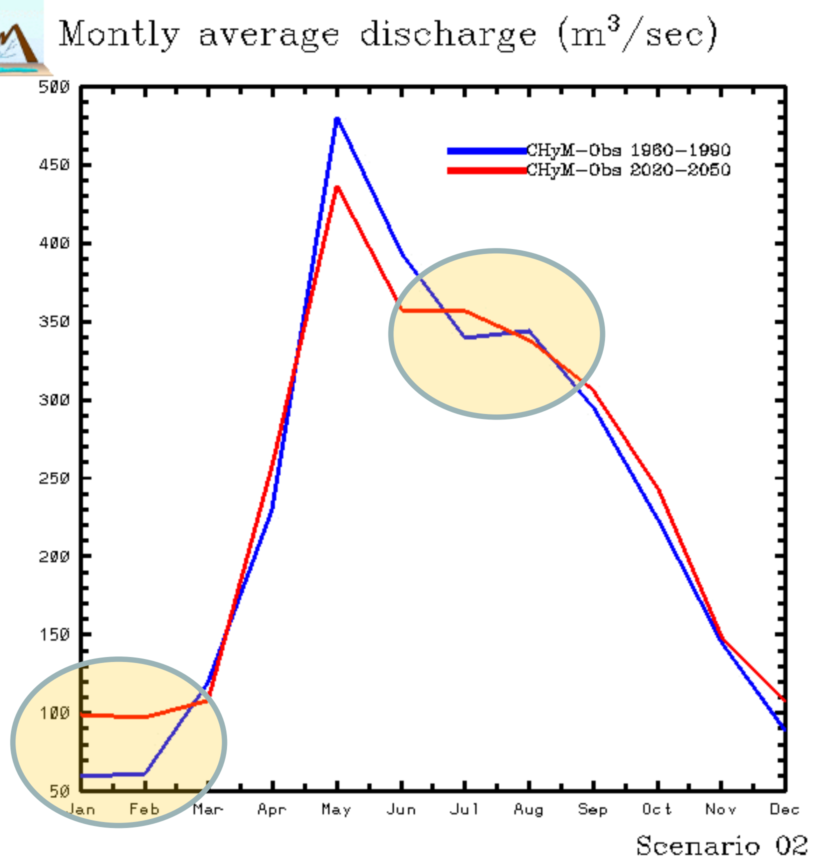


Rhone at Port du Scex (46.3496°N–6.8886°E)

CHyM - Simulation of climatic scenarios – Po river Change



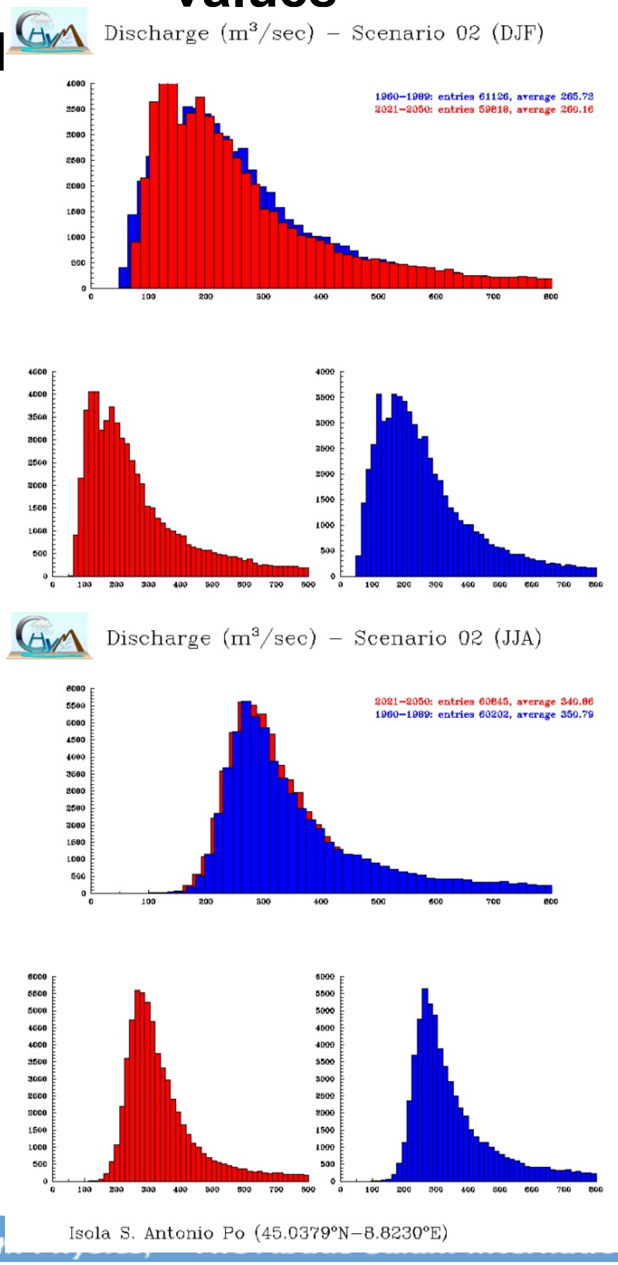
CHyM - Simulation of climatic scenarios- Rhone river- Change



Rhone at Port du Scex (46.3496°N–6.8886°E)

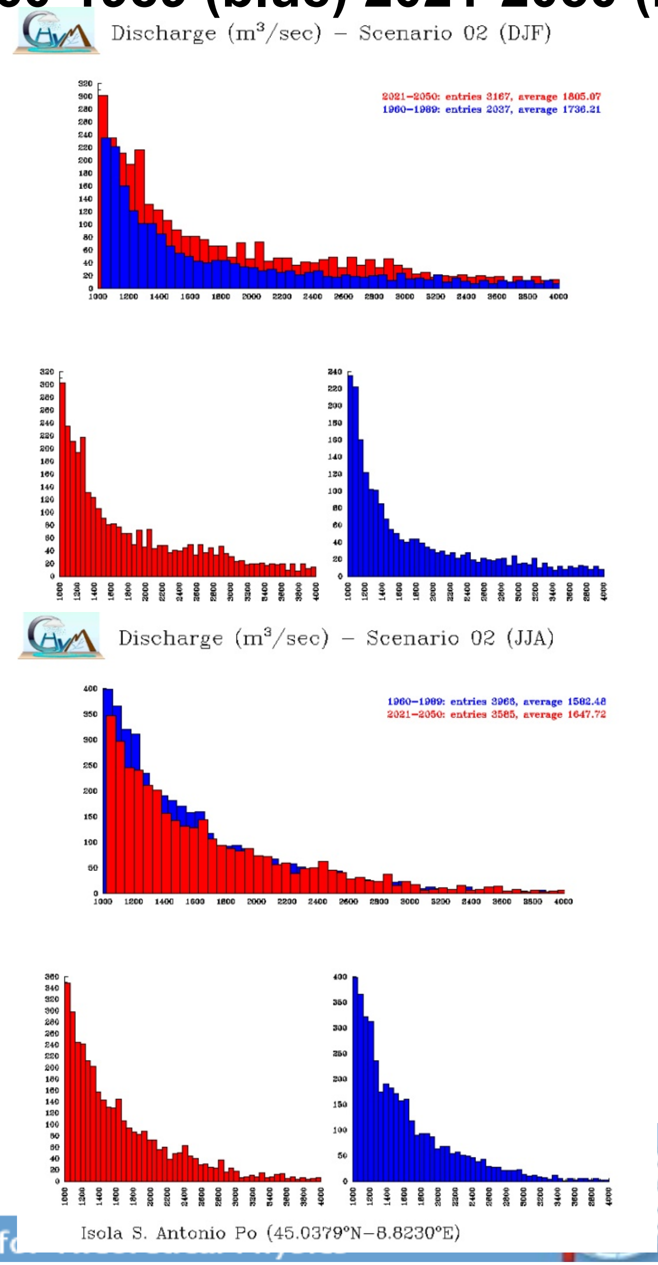
CHyM - Scenarios 02 – Po basin - Distribution of low discharge values

1960-1)

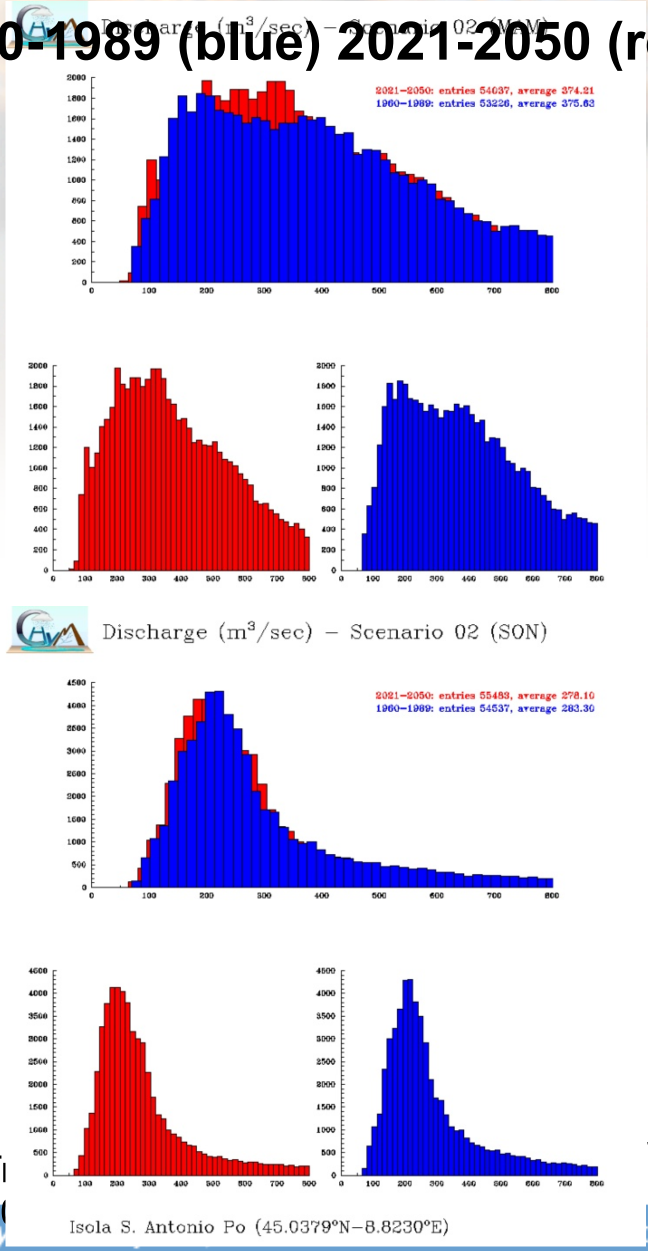


CHyM - Scenarios 02 – Po basin - Distribution of high discharge values

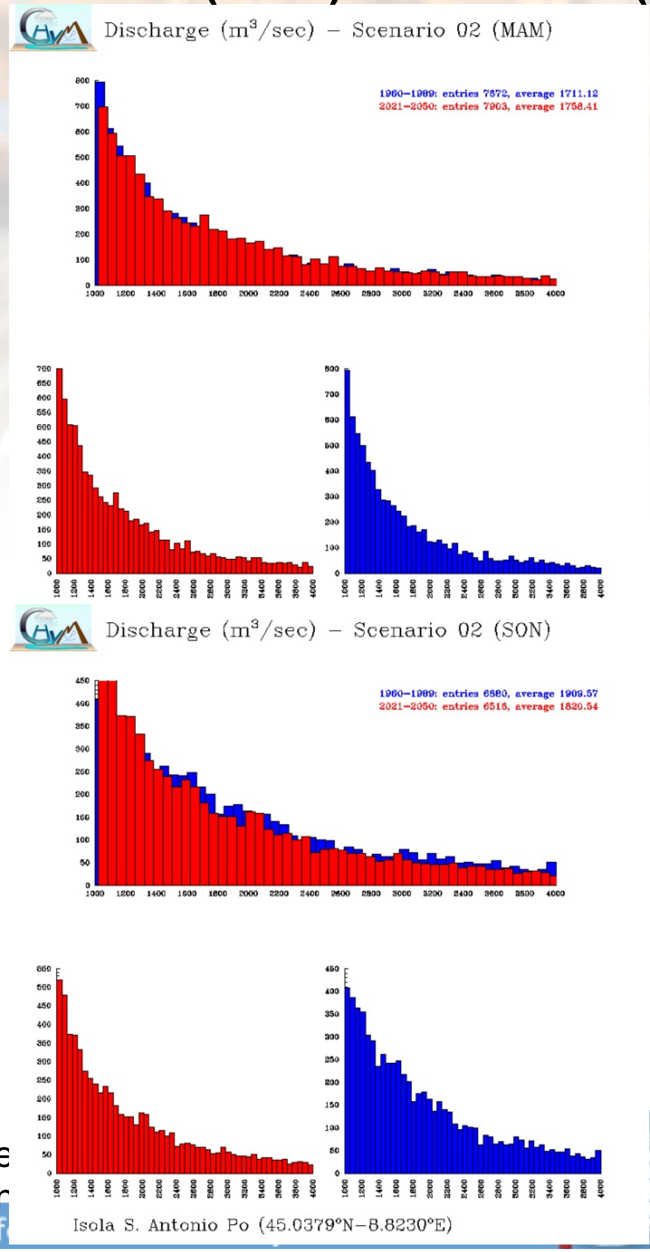
1960-1989 (blue) 2021-2050 (red)



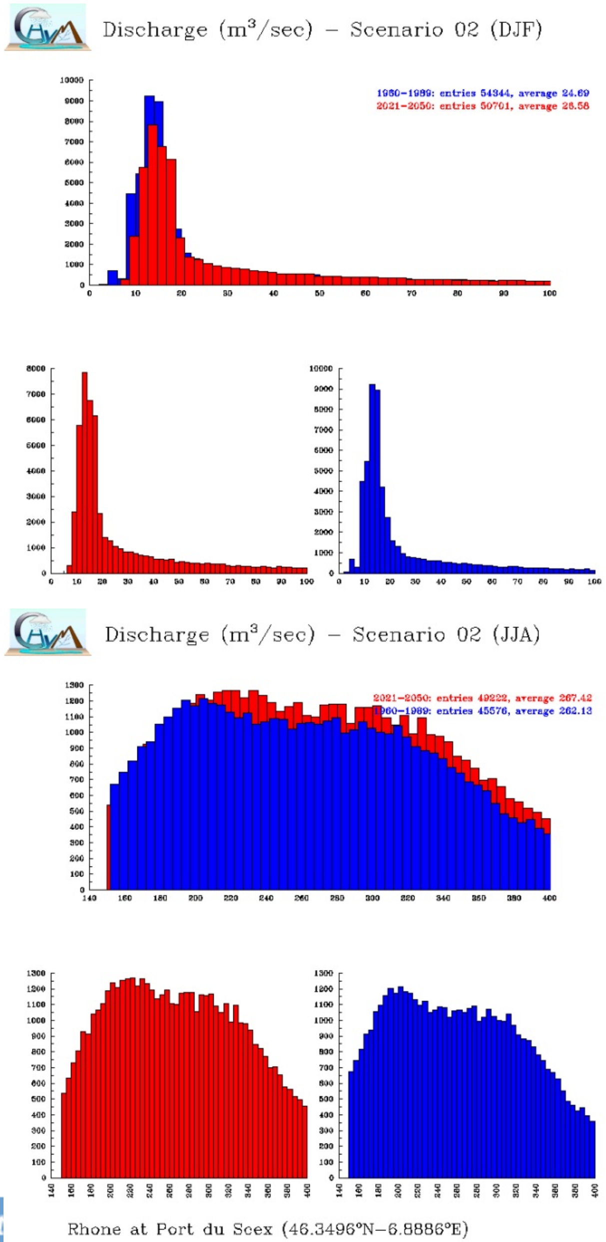
CHyM - Scenarios 02 – Po basin - Distribution of low discharge values 1960-1989 (blue) 2021-2050 (red)



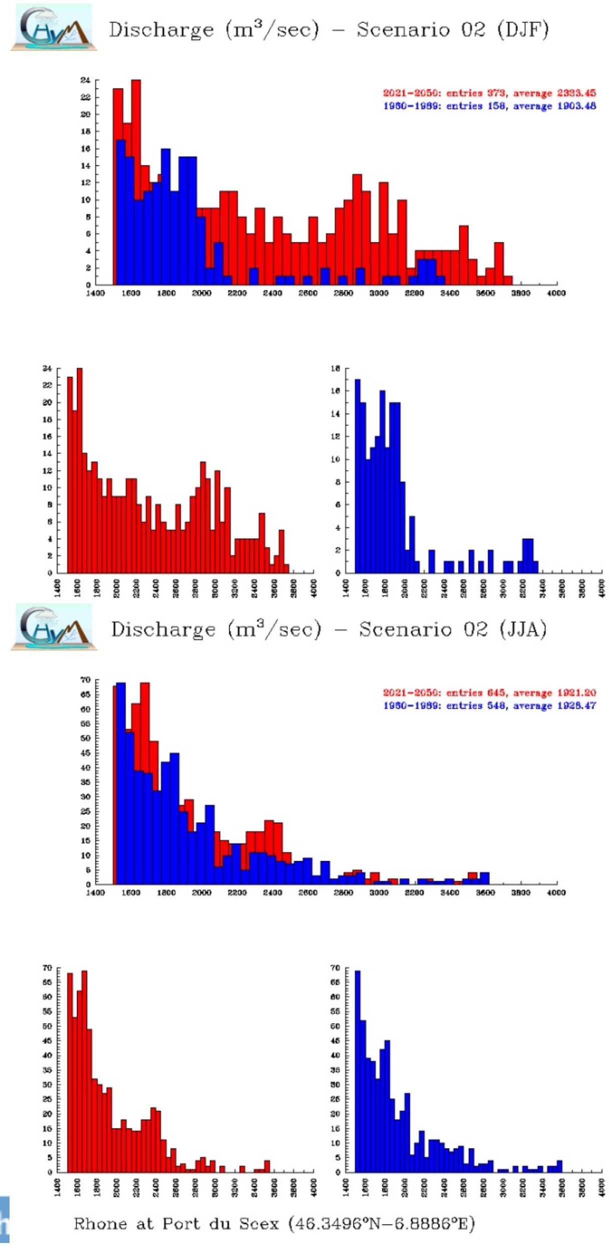
CHyM - Scenarios 02 – Po basin - Distribution of high discharge values 1960-1989 (blue) 2021-2050 (red)



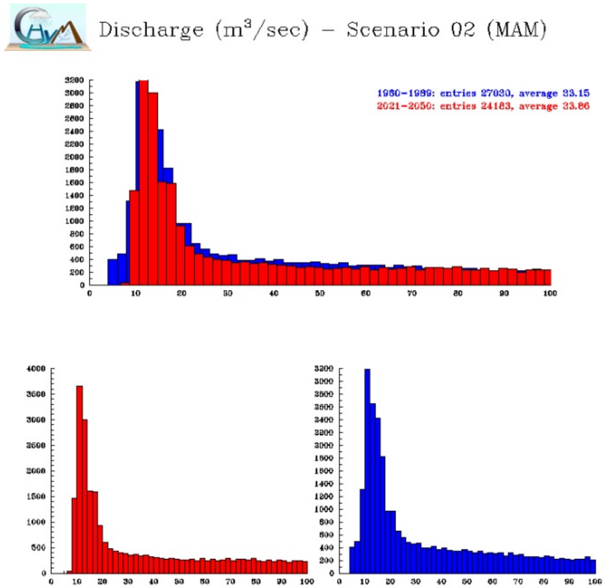
CHyM - Scenarios 02 – Rhone basin - Distribution of low discharge values 1960-1989 (blue) 2021-2050 (red)

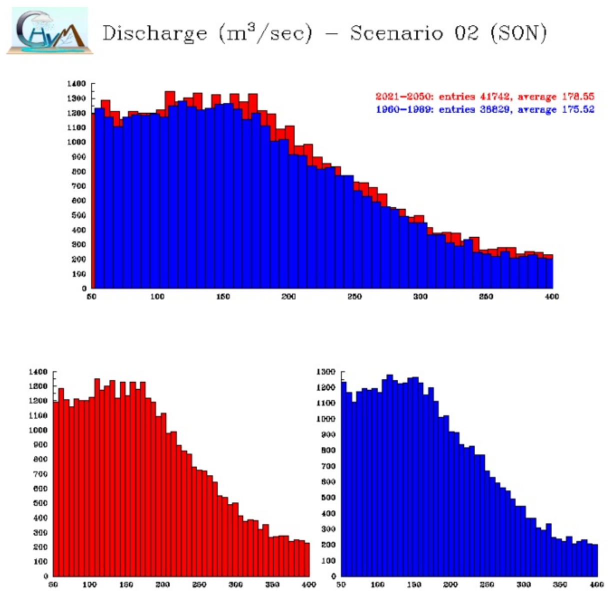


CHyM - Scenarios 02 – Rhone basin - Distribution of high discharge values 1960-1989 (blue) 2021-2050 (red)



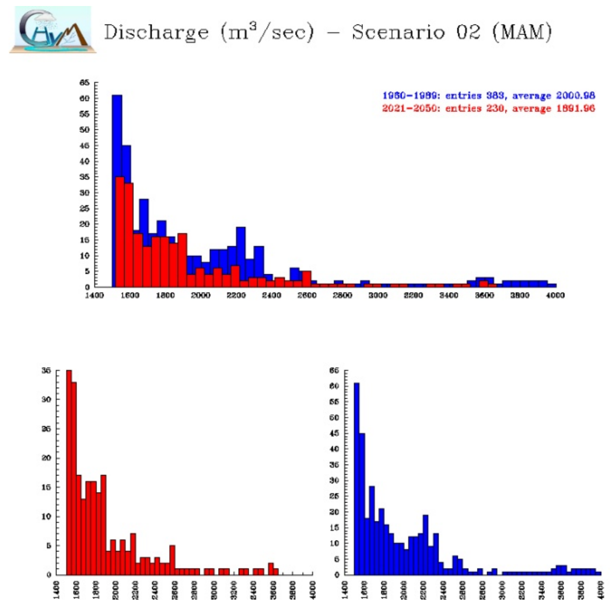
CHyM - Scenarios 02 – Rhone basin - Distribution of low discharge values 1960-1989 (blue) 2021-2050 (red)

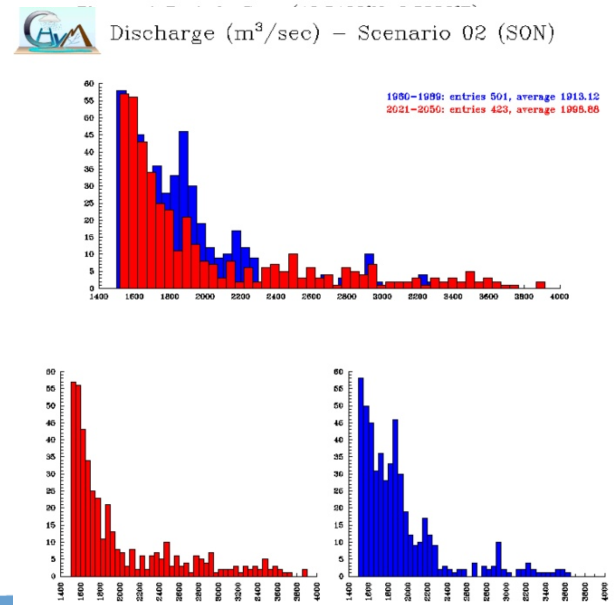




Rhone at Port du Scex (46.3496°N–6.8886°E)

CHyM - Scenarios 02 – Rhone basin - Distribution of high discharge values 1960-1989 (blue) 2021-2050 (red)





Rhone at Port du Scex (46.3496°N–6.8886°E)

6) What if I have an ensemble of simulation?

MPI and ICTP scenarios

01 RCM-REMO (25x25 km; daily) available (3hours ?)

02 RCM-RegCM3 (25x25 km; 3 hours)

03 RCM REMO Hi (10x10 km, 3hours)

04 RCM RegCM3 Hi (3x3 km, 3hours)

UNIGRAZ post-processed-bias-corrected RCMs scenarios

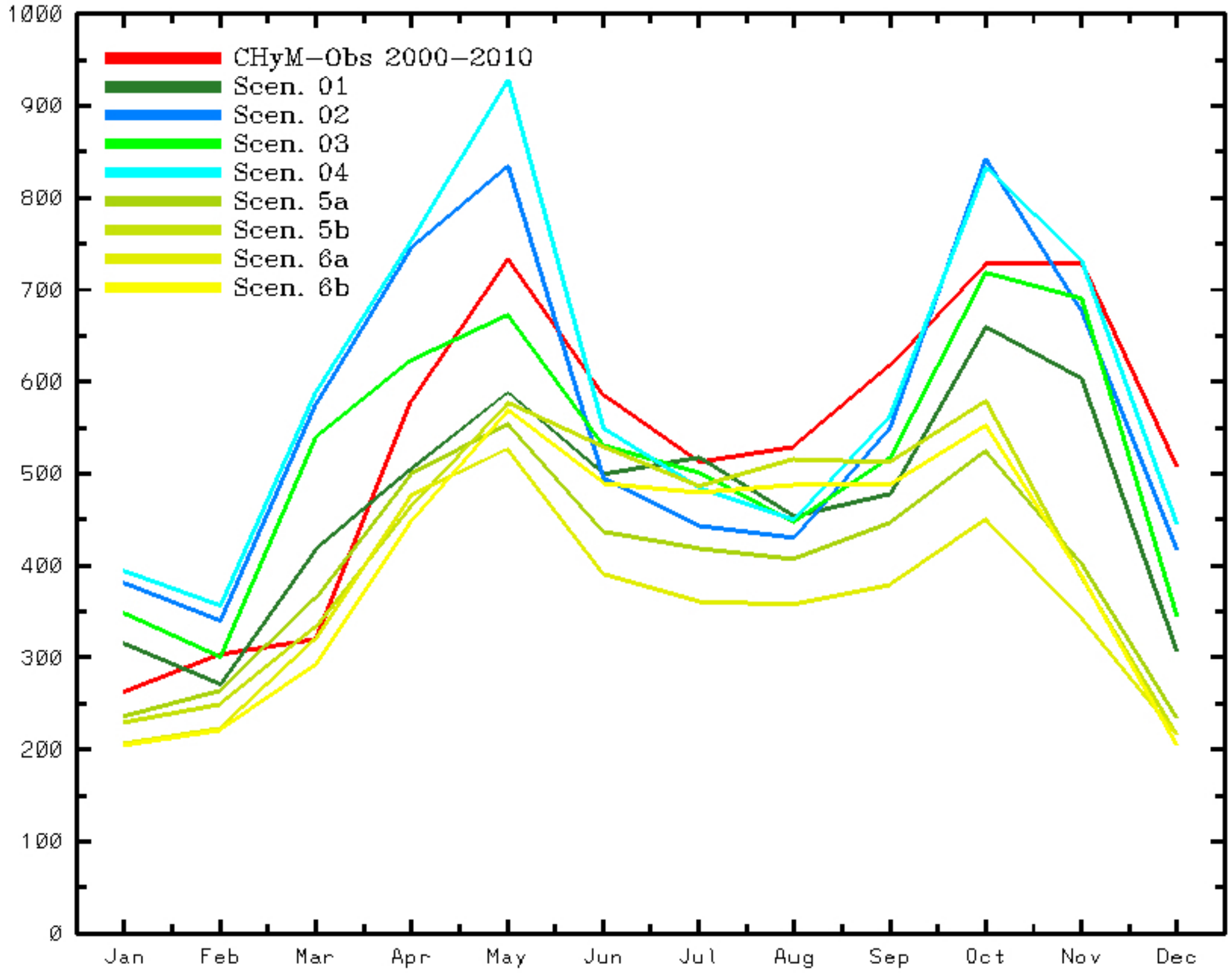
5a Post processed RCM-REMO (25x25 km; 3hr)

5b Post processed RCM-REMO (1x1 km; daily, 3hr)

6a Post processed RCM-RegCM3 (25x25 km; daily, 3hr)

6b Post processed RCM-RegCM3 (1x1 km; daily, 3hr)

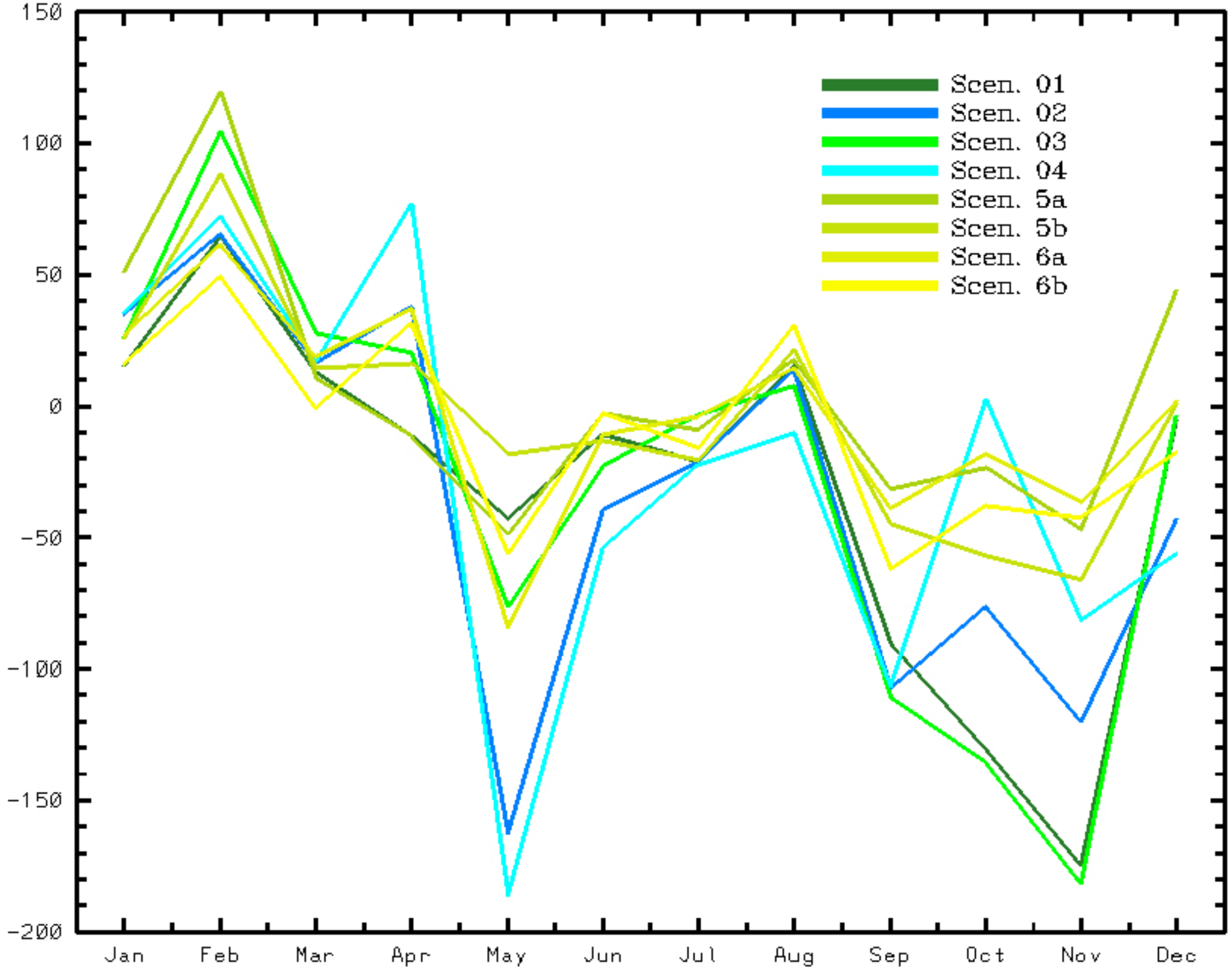
Monthly average discharge (m^3/sec) 1960–2000



Isola S. Antonio Po (45.0379°N–8.8230°E)

Earth System

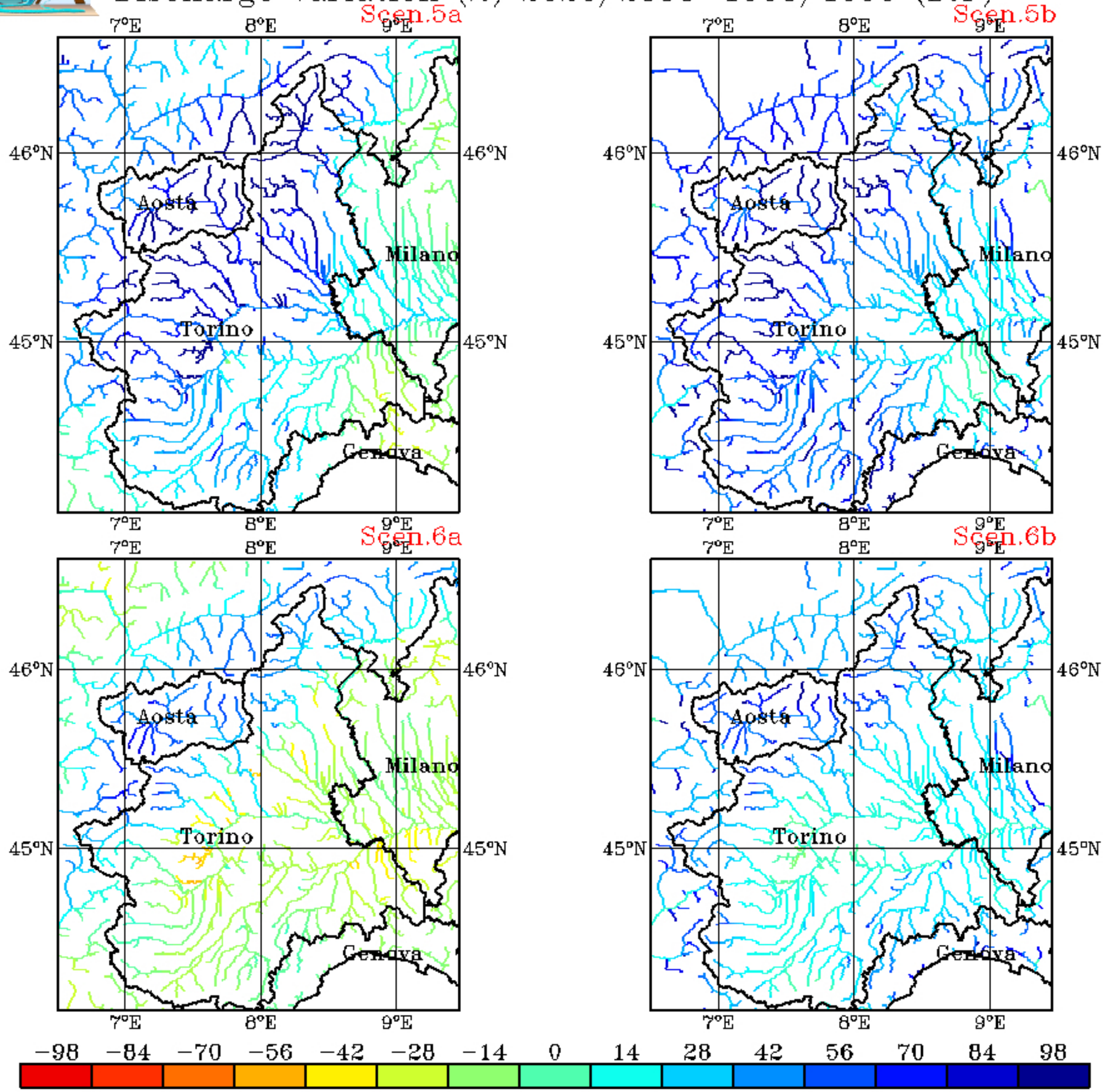
Average discharge diffrences (m^3/sec) 2020/2050-1960/1990



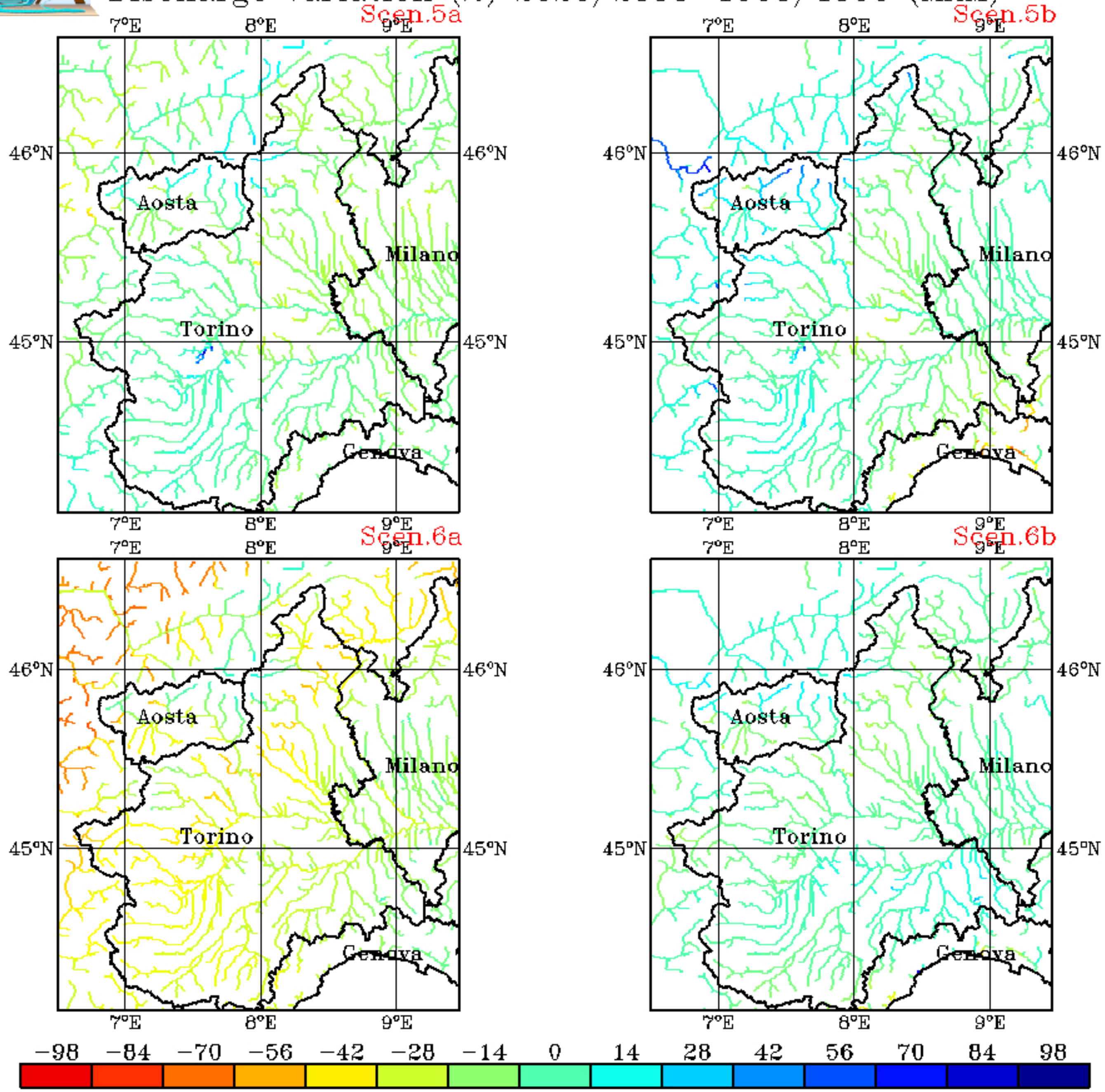
Isola S. Antonio Po (45.0379°N-8.8230°E)

Earth System

Discharge variation (%) 2020/2050–1960/1990 (DJF)



Discharge variation (%) 2020/2050–1960/1990 (MAM)



What did I learn?

- The source of uncertancy in hydro-climate simulations are many
- different model input data can lead to different hydrological results
- resolution of input data can impact the hydrological results
- bias correction of input data not necessarily improve the hydrological simulation in the validation period

Can I use these results to give a message to the non scientific community?

- Yes I can, but I have to be good in communicating them the grade of uncertancy that is associated to the hydro-climate signal
- How can I do that? by using the probabilistic approach
- What can I say? I can say something like the probability of reduce discharge in the summer time will be of N% and the uncertancy associated with it is of M%