Alpine Spring Festival

Bolzano

4th- 8th March 2013

The impacts of climate change on hydrological cycle

Bruno Majone & Alberto Bellin

University of Trento

Some Questions

- What do we understand by climate change?
- What are the impacts of climate change on water resources and the water sector?
- How do we adapt to climate change?

Open Problems

- To identify present trends in the system:
  - External forcing: separation between natural and anthropogenic components;
  - River basin status: identification of changes associated to anthropogenic effects (forestation or de-forestation, land use changes, etc.).
- Scenarios and projections
  - High uncertainty associated to projections;
  - IPCC scenarios are usually adopted;
  - Complex and non-linear interaction between different spatial scales (global and local);
  - Infrastructures will be able to cope with projected changes?

Factors affecting the Climate

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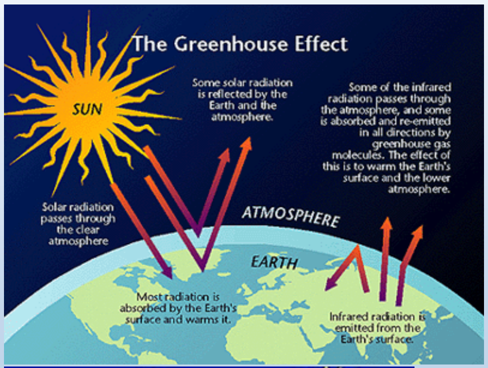
HUMAN FACTORS

Greenhouse gasses

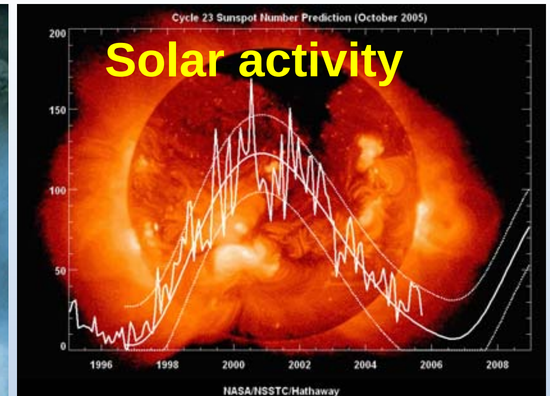


Atmospheric Aerosol

Soil use

NATURAL FACTORS

Volcanic activity



Solar activity

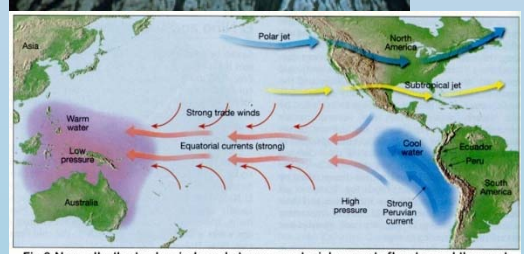
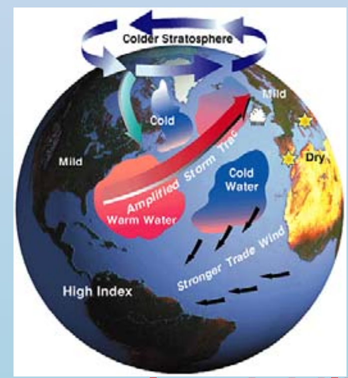


Fig.6 Normally, the trade winds and strong equatorial currents flow toward the west. At the same time, an intense Peruvian current causes upwelling of cold water along the west coast of South America.



Natural variability

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Concentrations of greenhouse gasses

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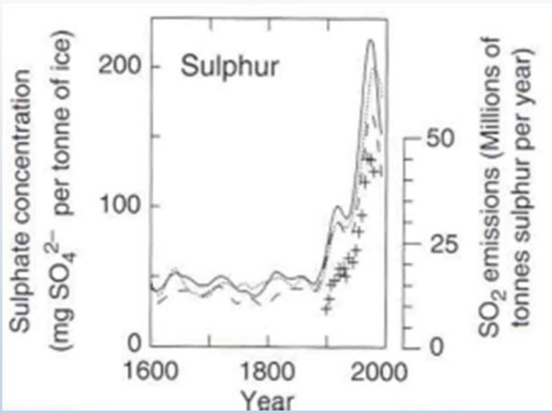
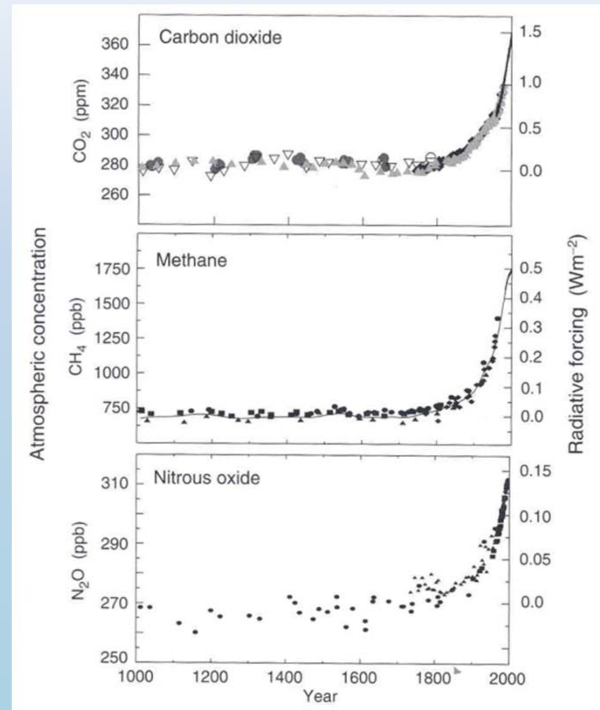


Sulphate aerosols deposited in Greenland ice

Global atmospheric concentrations of three well mixed greenhouse gases



The concentration of greenhouse gasses is today the largest observed in the last 65000 years and shows a clear increasing trend.

Effects of emissions in the climate

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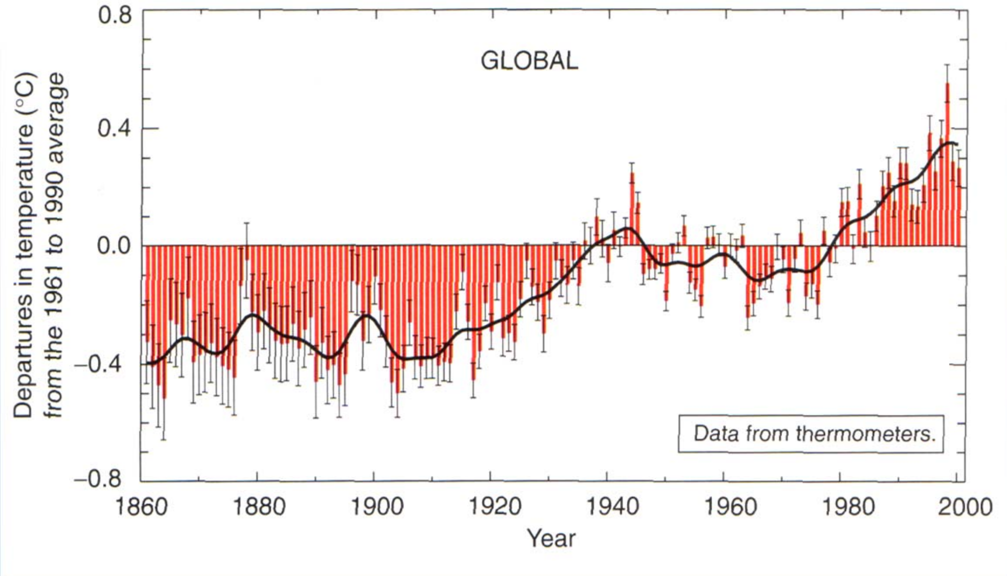
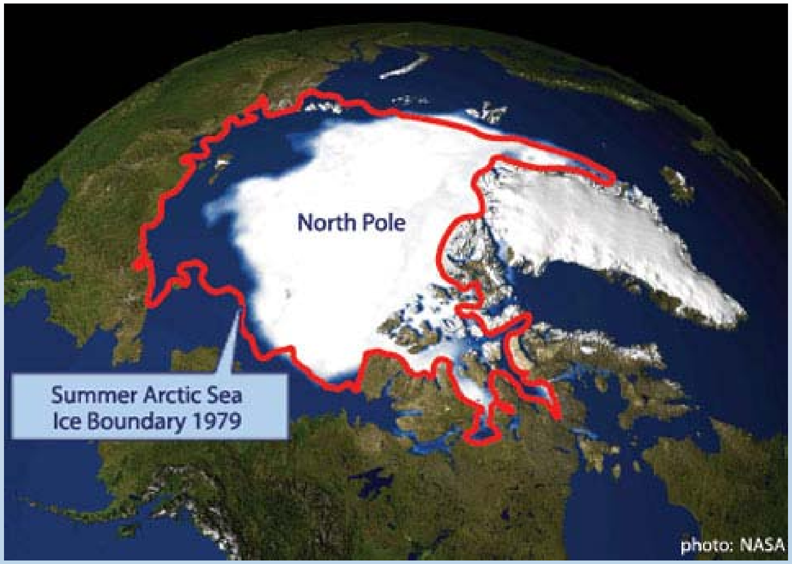
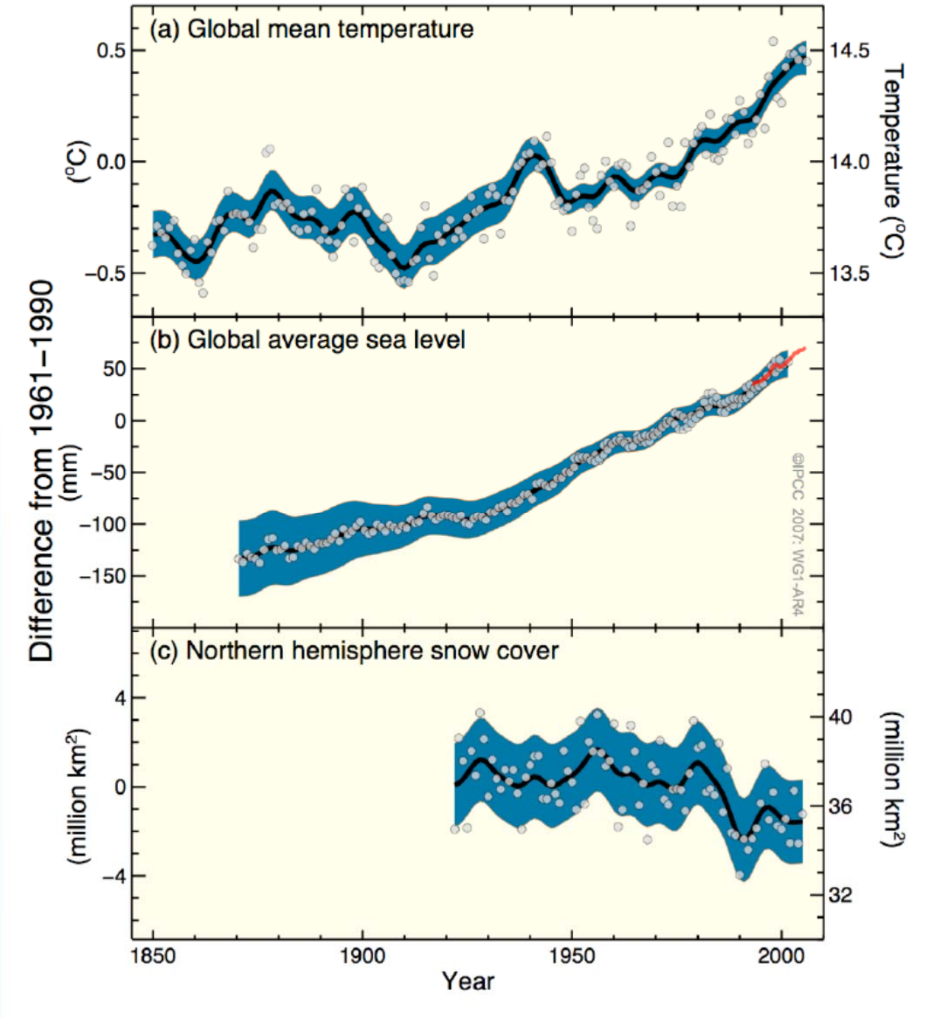




Combined annual land-surface air and sea surface temperature anomalies (C˚) 1861 to 2000 relative to 1961 and 1990. Two standard error uncertainties are shown as bars on the annual number.

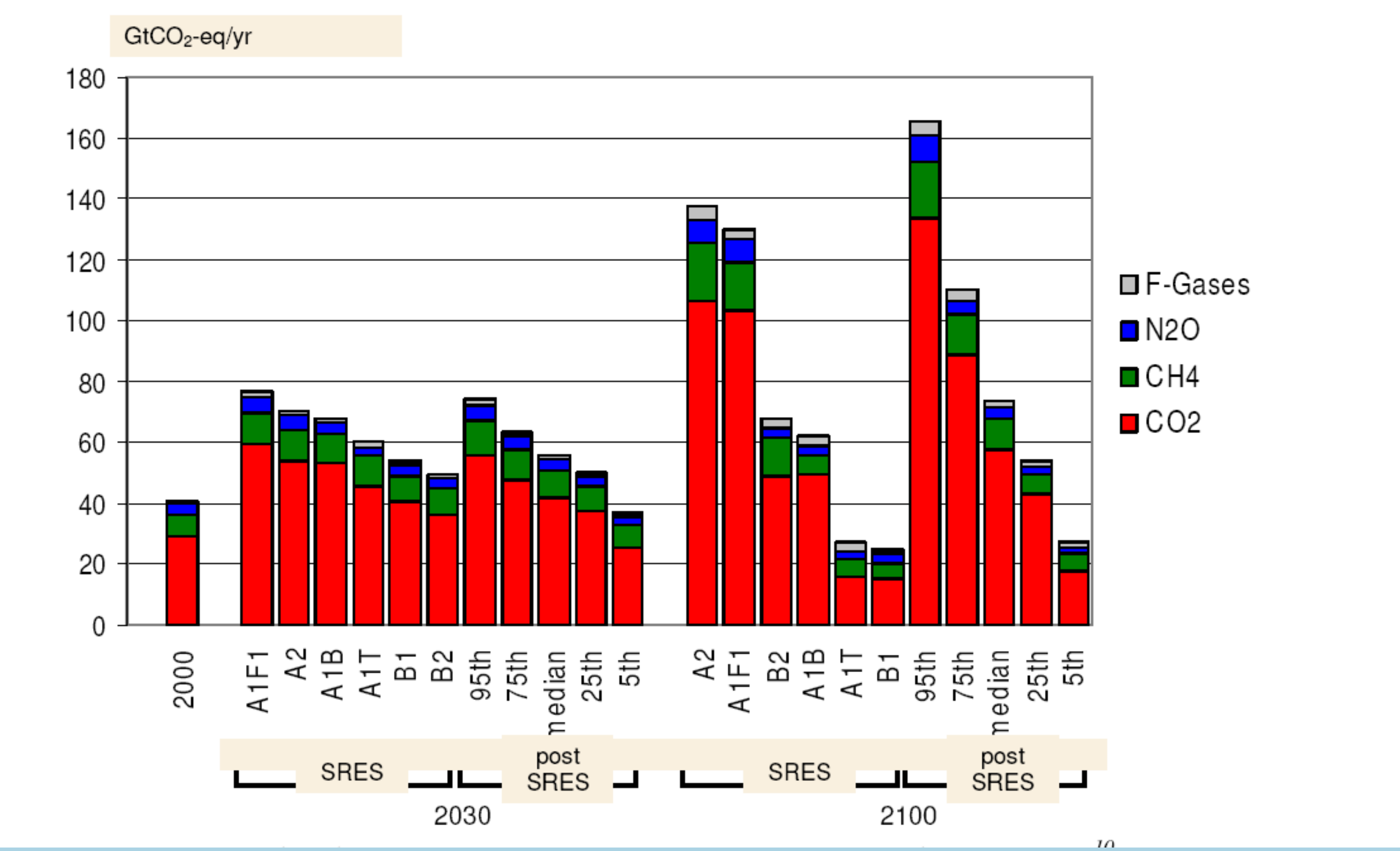
IPCC-2007
Global warming cannot be neglected, as shown by the increase of temperature of the atmosphere and the oceans, ice melting and increase of the see levels.

Effects of emissions in the climate

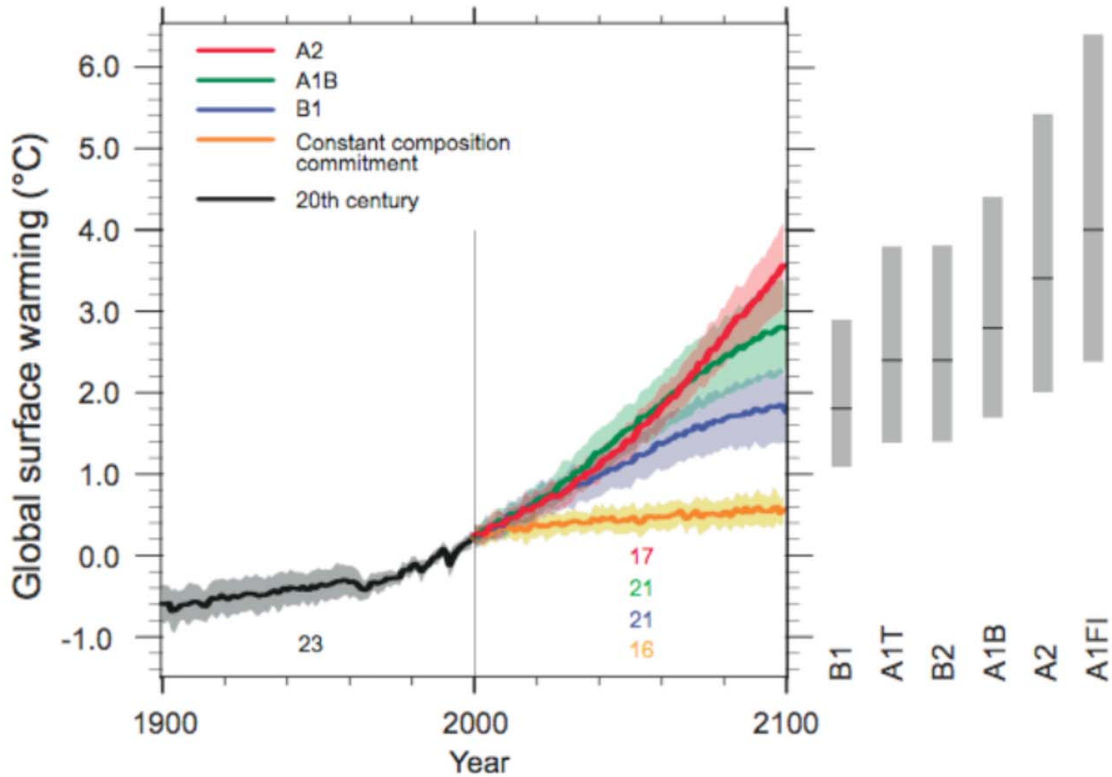


But what is happening and most likely will happen at the catchment scale?

Possible scenarios



Scenarios


A2
A1B
B1
Constant composition commitment
20th century
Global surface warming (°C)
6.0
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
23
17
21
21
16
1900
2000
2100
Year
B1
A1T
B2
A1B
A2
A1FI

Needs for Forecasting

- Risk is part of the human live, the sophistication of the impacts and interrelation of the modern society shows that the risk is increasing and the perception and knowledge of the integrated impacts are small.
- There is a need to increase information for population in dealing with uncertainties and risks.
- Managing uncertainties and risks requires the development of forecast tools and scenarios.
- Forecasting is an important tool to support water resource management in reducing its vulnerability.

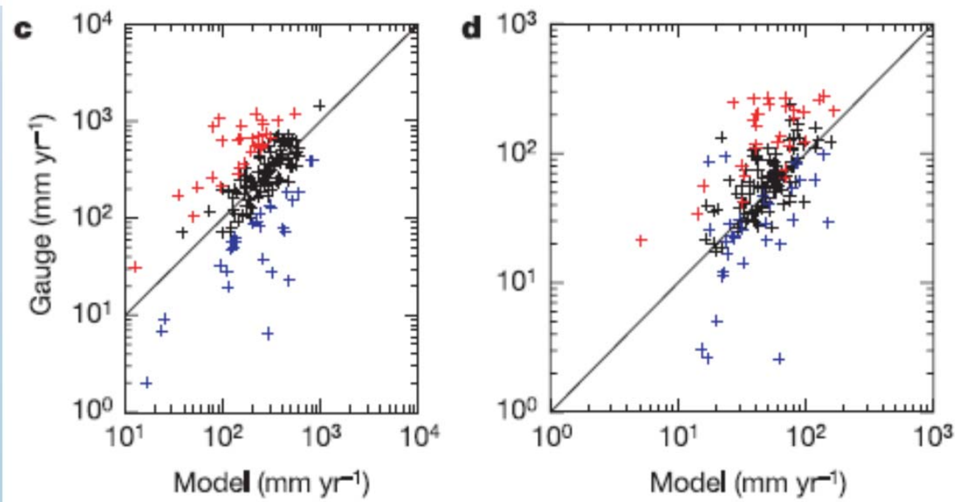
Models and measurements

Vol 438|17 November 2005|doi:10.1038/nature04312 nature

LETTERS

Global pattern of trends in streamflow and water availability in a changing climate

P. C. D. Milly[1], K. A. Dunne[1] & A. V. Vecchia[2]



Mean

Standard Deviation

12 GCMs
Scenario A1B

Streamflow measured in 165 river basins with surface larger than 50.000 km^2 (only gauges with at least 28 years are considered) during the period 1900-1998.

Ebro river basin: 100000 km^2

Large prediction errors
Simulated streamflow mean and standard deviation are in the range between ½ to 2 times the observed values.

Models and measurements

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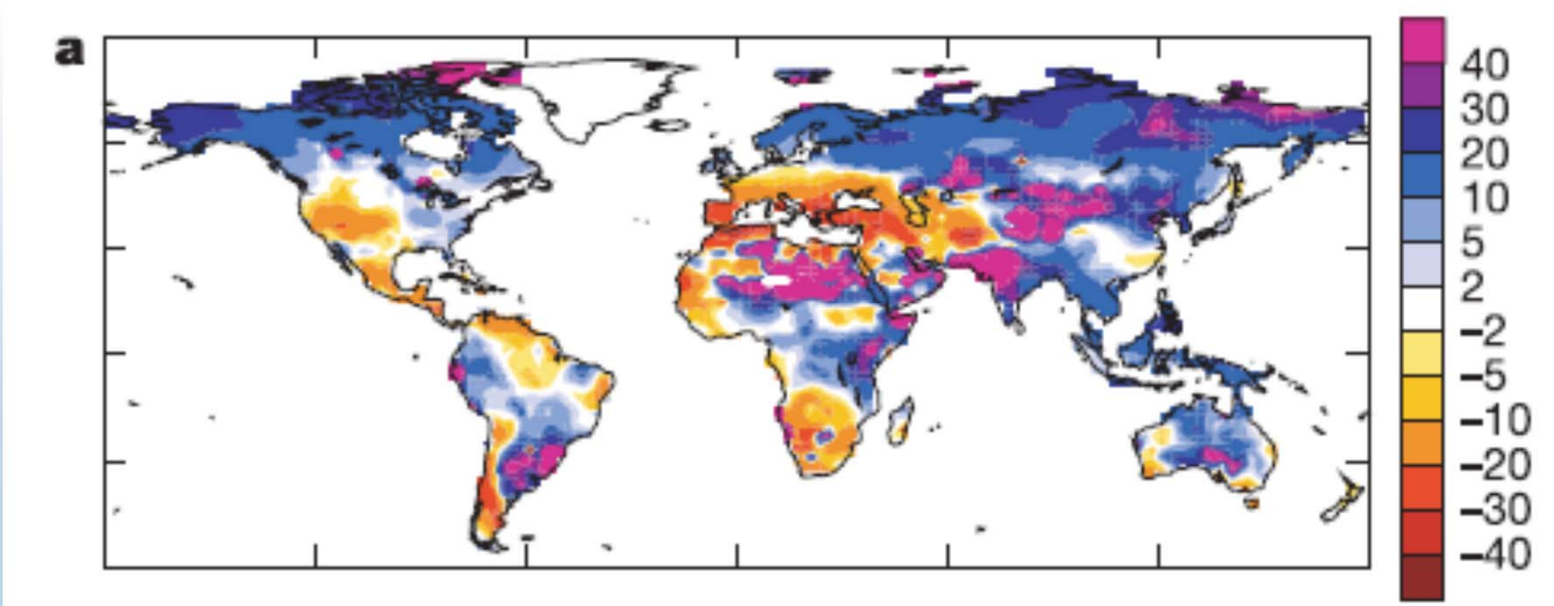

Reproduced from Milly et al., 2005

"Ensemble (arithmetic) mean of relative change (percentage) in runoff for the period 2041–60, computed as 100 times the difference between 2041–60 runoff in the SRESA1B experiments and 1900–70 runoff in the 20C3M experiments, divided by 1900–70 runoff."

Extreme Events more frequent?

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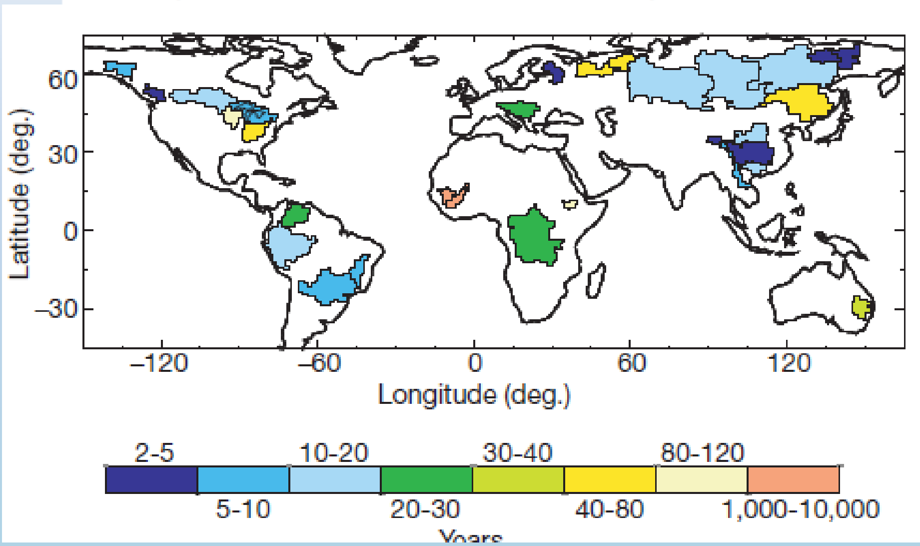
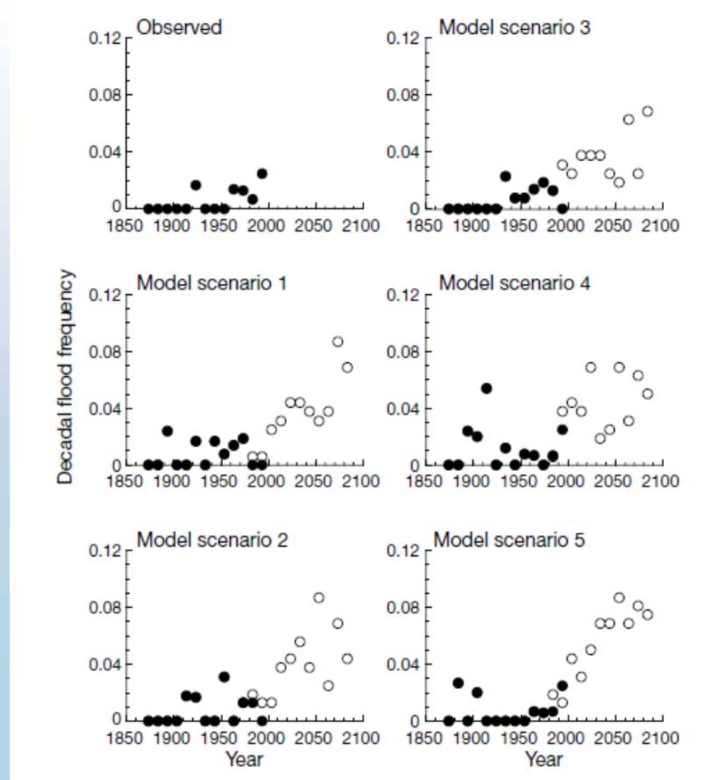
NATURE | VOL 415 | 31 JANUARY 2002 | www.nature.com

Increasing risk of great floods in a changing climate

P. C. D. Milly*, R. T. Wetherald†, K. A. Dunne* & T. L. Delworth†

** US Geological Survey, GFDL/NOAA; and † Geophysical Fluid Dynamics Laboratory/NOAA, P.O. Box 308, Princeton, New Jersey 08542, USA*





29 river basins with area larger than 200.000 km^2 and at least 30 yr of data

5 scenarios with same radiative forcing but different initial conditions

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Effects on Water Resources stationarity hypothesis?

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WATER RESOURCES RESEARCH, VOL. 44, W03201, doi:10.1029/2007WR006704, 2008

When will Lake Mead go dry?

Tim P. Barnett[1] and David W. Pierce[1]

SCIENCE VOL 319 1 FEBRUARY 2008

CLIMATE CHANGE

Stationarity Is Dead: Whither Water Management?

P. C. D. Milly,[1*] Julio Betancourt,[2] Malin Falkenmark,[3] Robert M. Hirsch,[4] Zbigniew W. Kundzewicz,[5] Dennis P. Lettenmaier,[6] Ronald J. Stouffer[7]

Climate change undermines a basic assumption that historically has facilitated management of water supplies, demands, and risks.

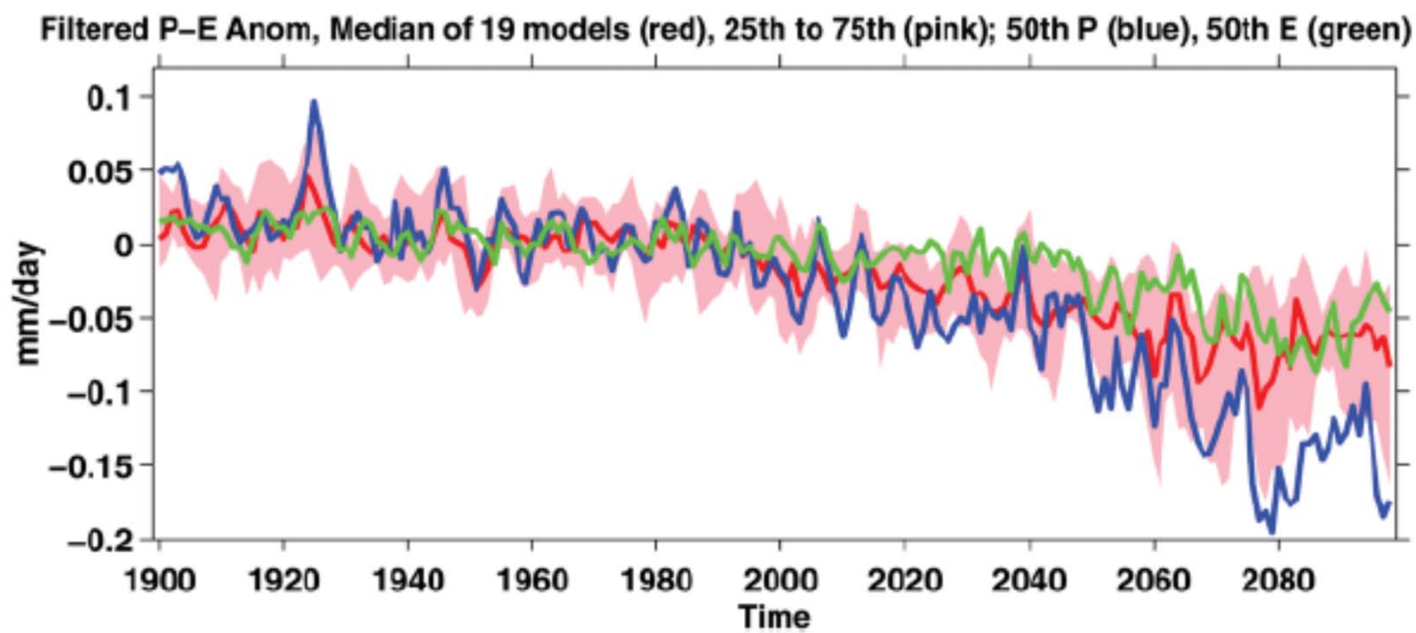
Need for Regional Studies

SCIENCE VOL 316 25 MAY 2007

Model Projections of an Imminent Transition to a More Arid Climate in Southwestern North America

Richard Seager,[1*] Mingfang Ting,[1] Isaac Held,[2,3] Yochanan Kushnir,[1] Jian Lu,[4]
Gabriel Vecchi,[2] Huei-Ping Huang,[1] Nili Harnik,[5] Ants Leetmaa,[2] Ngar-Cheung Lau,[2,3]
Cuihua Li,[1] Jennifer Velez,[1] Naomi Naik[1]

19 RCMs



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Multidisciplinary approach: Model coupling

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WATER RESOURCES RESEARCH, VOL. 48, W01512, doi:10.1029/2011WR010985, 2012

Modeling the impacts of future climate change on water resources for the Gállego river basin (Spain)

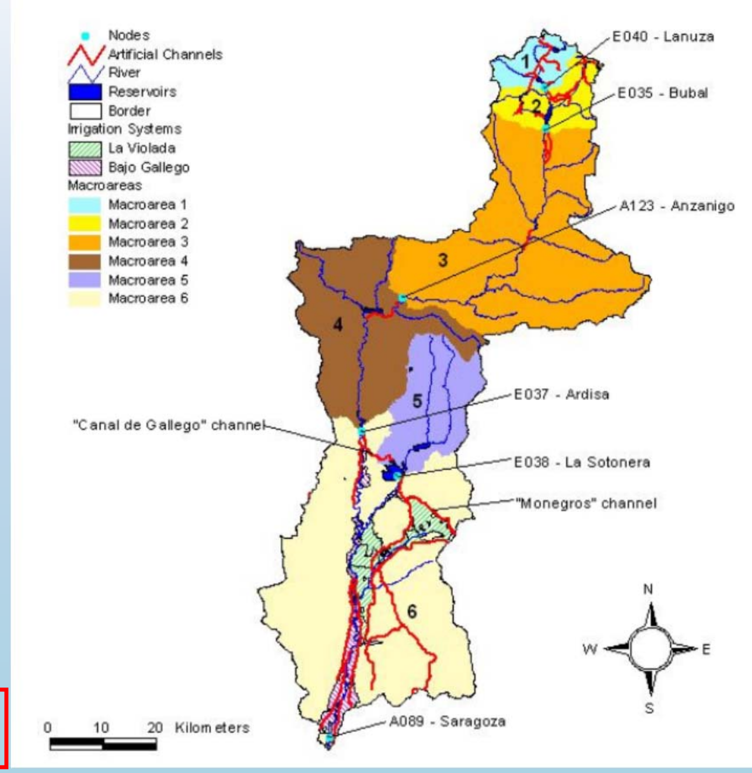
B. Majone,[1] C. I. Bovolo,[2] A. Bellin,[1] S. Blenkinsop,[2] and H. J. Fowler[2]

Received 1 June 2011; revised 11 November 2011; accepted 22 November 2011; published 14 January 2012.

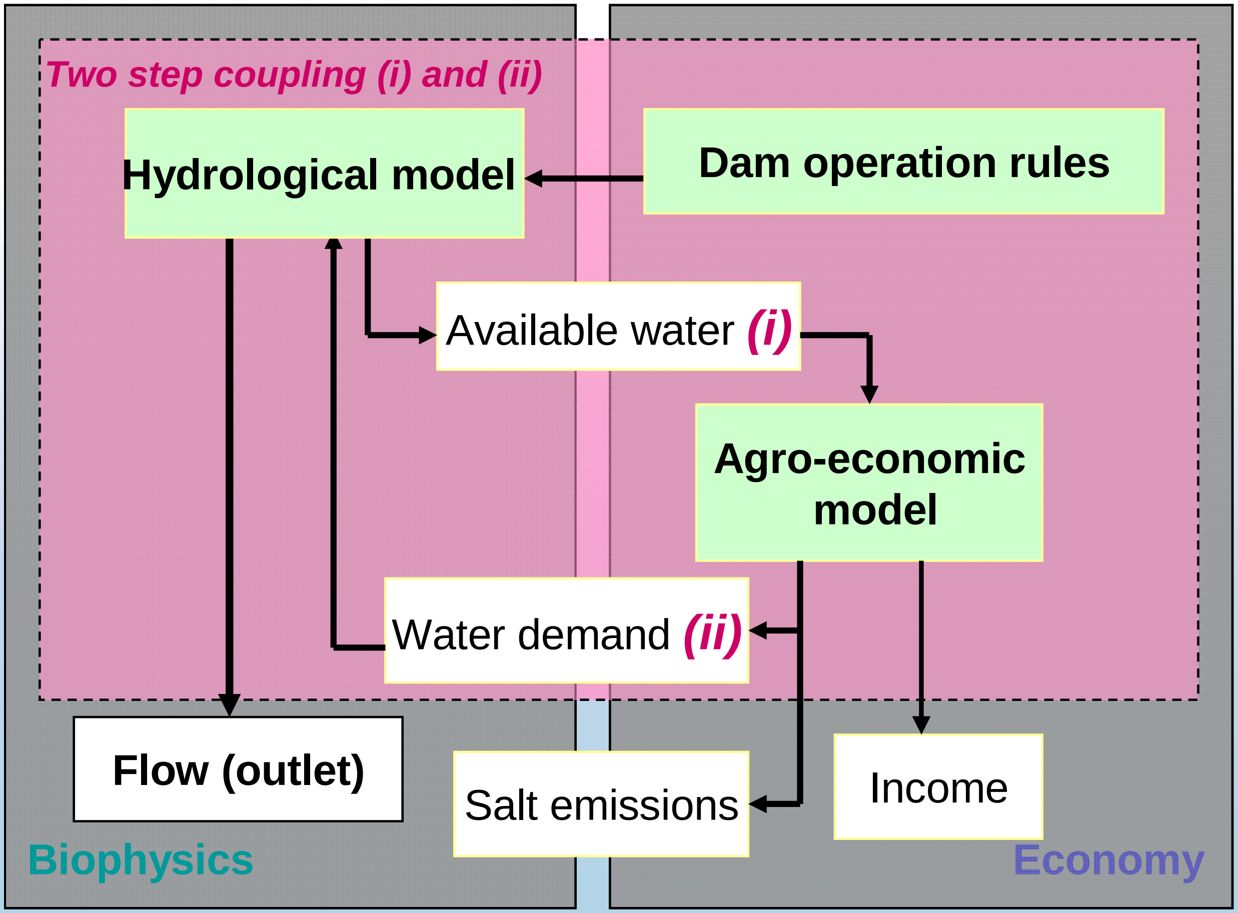
Objective:
develop **an integrated model** that integrates:
- **bio-physical processes** *(hydrology)*
- **decision making and socio-economic processes** (*how water is allocated and used*)

6 RCMs → Hydrological Model ← Agro-economic Model

Gallego river basin (Spain)



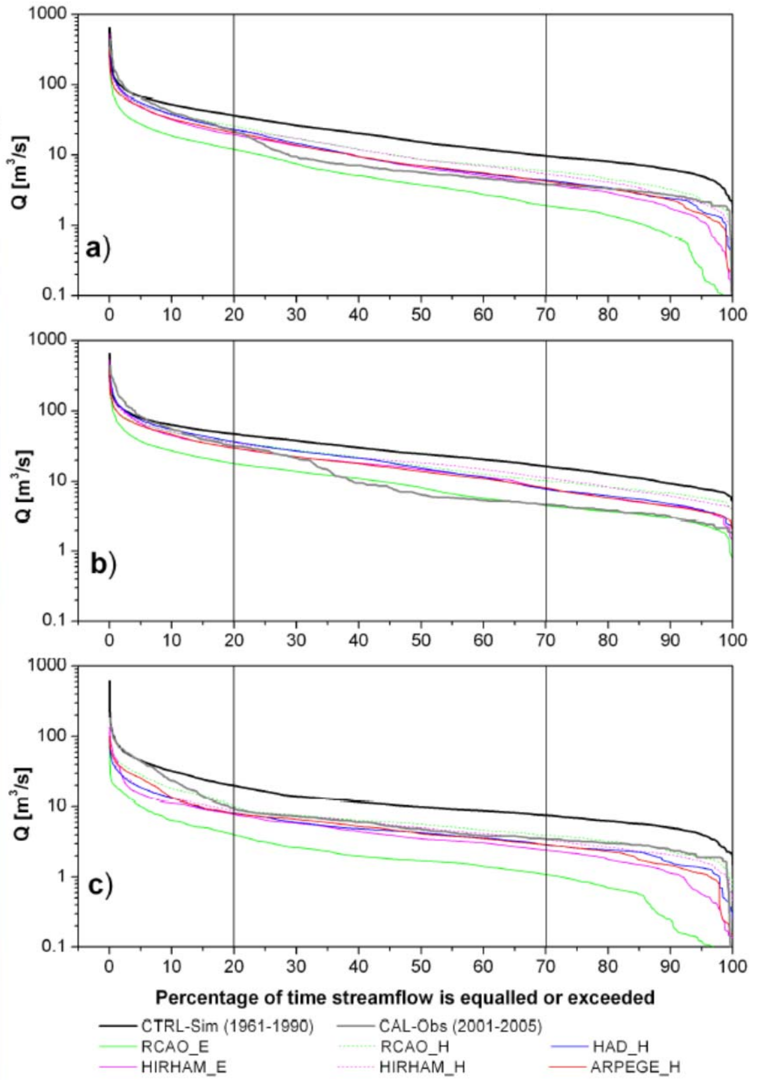
Integrated hydro-economic modeling



Graveline et al., 2013, *Reg. Env. Ch.* (under review)

Compartment approach: separate models for the different compartments which allow the output of one model to be used as input in the others.

Streamflow Flow Duration Curves



Entire Year

6 RCMs

Storing period

GEOTRANSF model
Calibration 2000-2005
Validation 1961-1990

Irrigation Period

SCENARIOS
2071-2100

Reproduced from Majone et al., 2012. *WRR*

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Water delivered to agricultural systems

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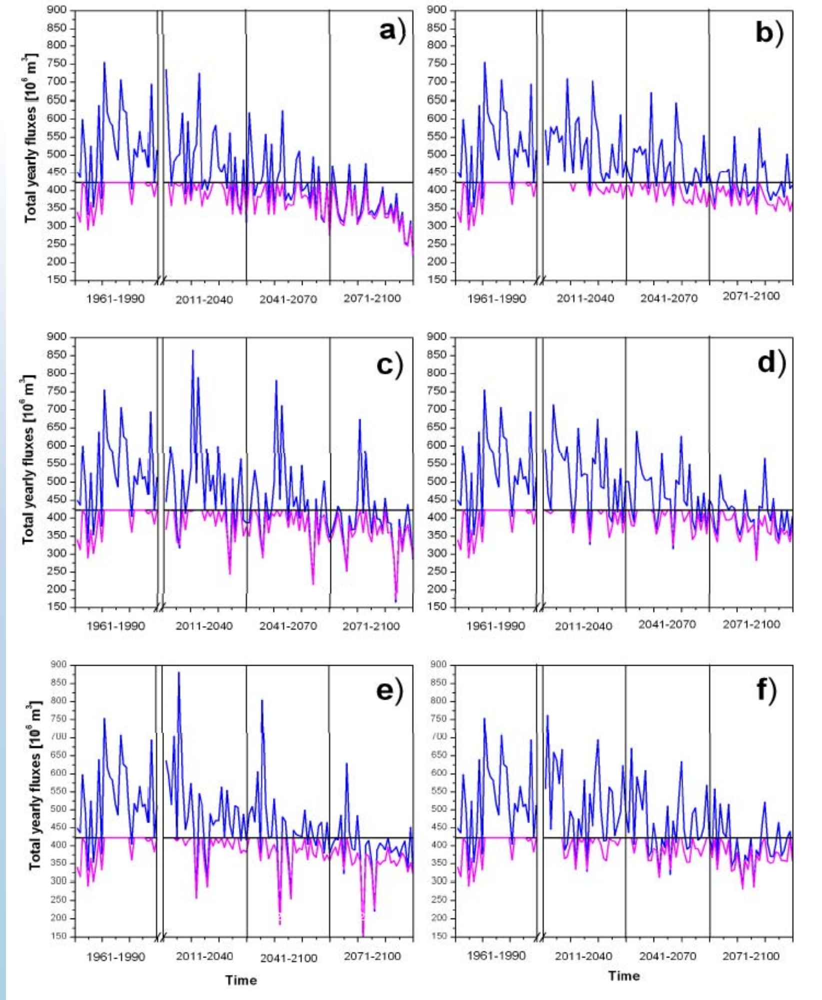

Reproduced from Majone et al., 2012. *WRR*

Results overview

Scenarios of change impacts on main indicators.

Mean values	Reference period	Climatic Change scenario	Dam extension scenario	Modernisation scenario	Global Change scenario
Irrigated area (ha)	15550	-3%	+5%	+4%	+20%
Total water delivery (hm^3/year)	415	-4%	+6%	-2%	+16%
Average regional agricultural income ($10^{\wedge 6}$ €)	9.4	-8%	+9%	+27%	+48%
Salt emissions (tonnes/year)	248	-4%	+7%	+7%	+23%

- The combined effects of an increase in storage capacity and modernization mitigate the effect of reduced water availability due to climate change and they lead to an increase of the agricultural regional income of 48% compared with the reference scenario.
- Modernization of irrigation technology has also a very positive outcome on agricultural income, but at the cost of increased pressure on the environment through increased salinity.

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CLIMB project

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CLIMATE INDUCED CHANGES OF HYDROLOGY IN THE MEDITERRANEAN BASINS

CLIMB
Climate Induced Changes on the Hydrology of Mediterranean Basins

http://www.climb-fp7.eu/home/home.php

SEVENTH FRAMEWORK PROGRAMME

Conclusions

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- Impact studies at the river basin scale require a coupling between climate models (global and regional) and hydrological models, and also a detailed definition of the scenarios for emissions and water resources management;
- Preparation of more reliable projections for water resources calls for additional research effort in order to improve coupling between climate and hydrlogical models.
- Assessment of uncertainty originating from different sources should complement Integrated Water Resources Management to explore alternative adaptation measures to climate change.
- Multidisciplinary approach allows to combine and test different factors of change order to simulate possible future outlooks. Such outlooks can assist decision makers in river basin planning by providing them a view of the basin with ongoing climate change effects as well as policies to adapt to these effects.

Acknowledgements

MeteoTrentino, Incarico Speciale Sicurezza Idraulica della Provincia Autonoma di Trento, Autorità di Bacino dell'Adige, Ufficio Idrografico della Provincia Autonoma di Bolzano

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Fabrizio Zanotti   and many others……

Hydrologis
Smart Hydrogeological Solutions

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Thank you for your attention