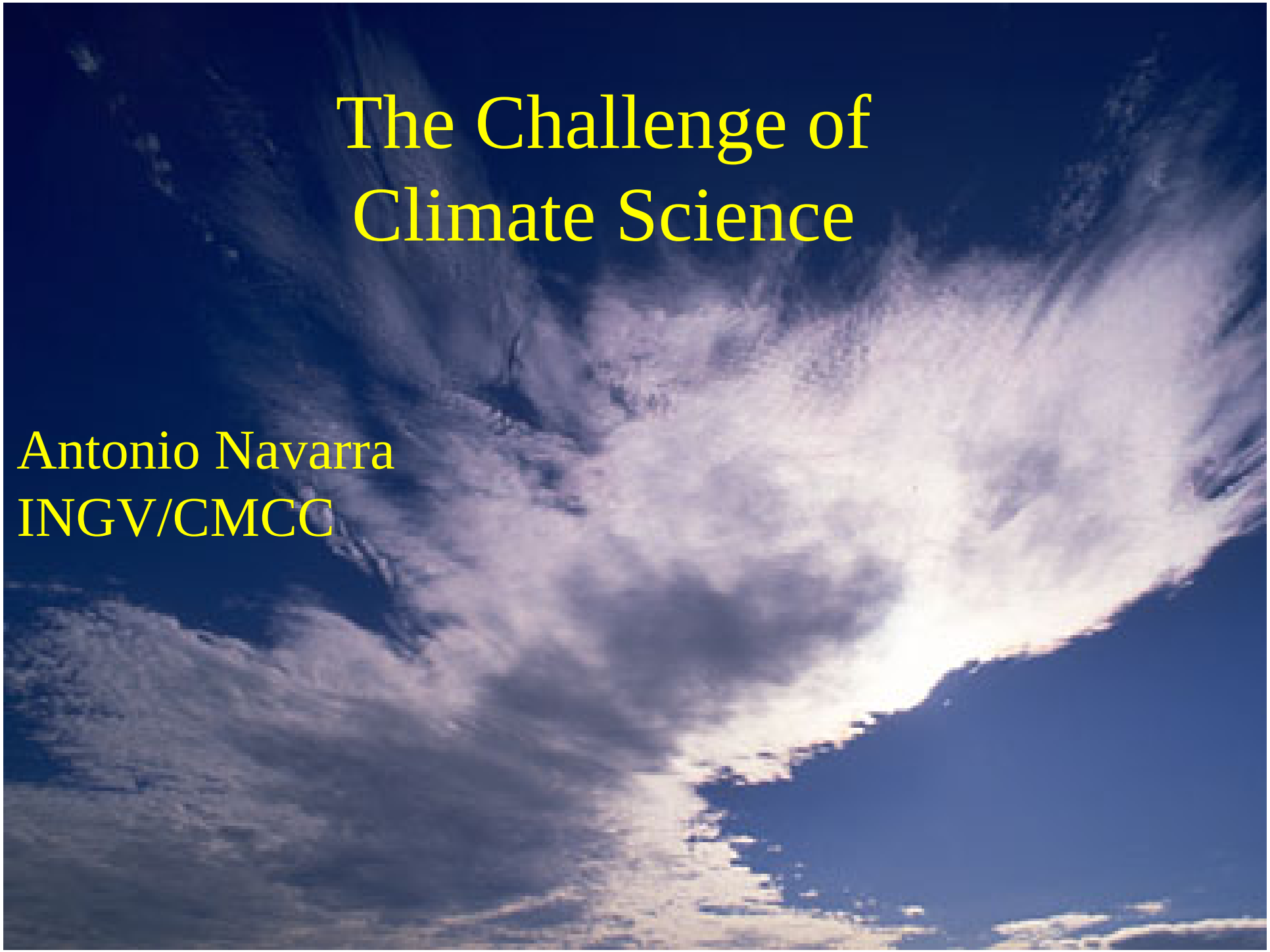


The Challenge of Climate Science

Antonio Navarra
INGV/CMCC

Aristotele

Raffello, la Scuola di Atene

De Meteorologica

However, all the mouths of the Nile, with t at Canopus, are obviously artificial and not natural. And Egypt was nothing m ebes, as Homer, too, shows, modern though he is in relation to such changes.

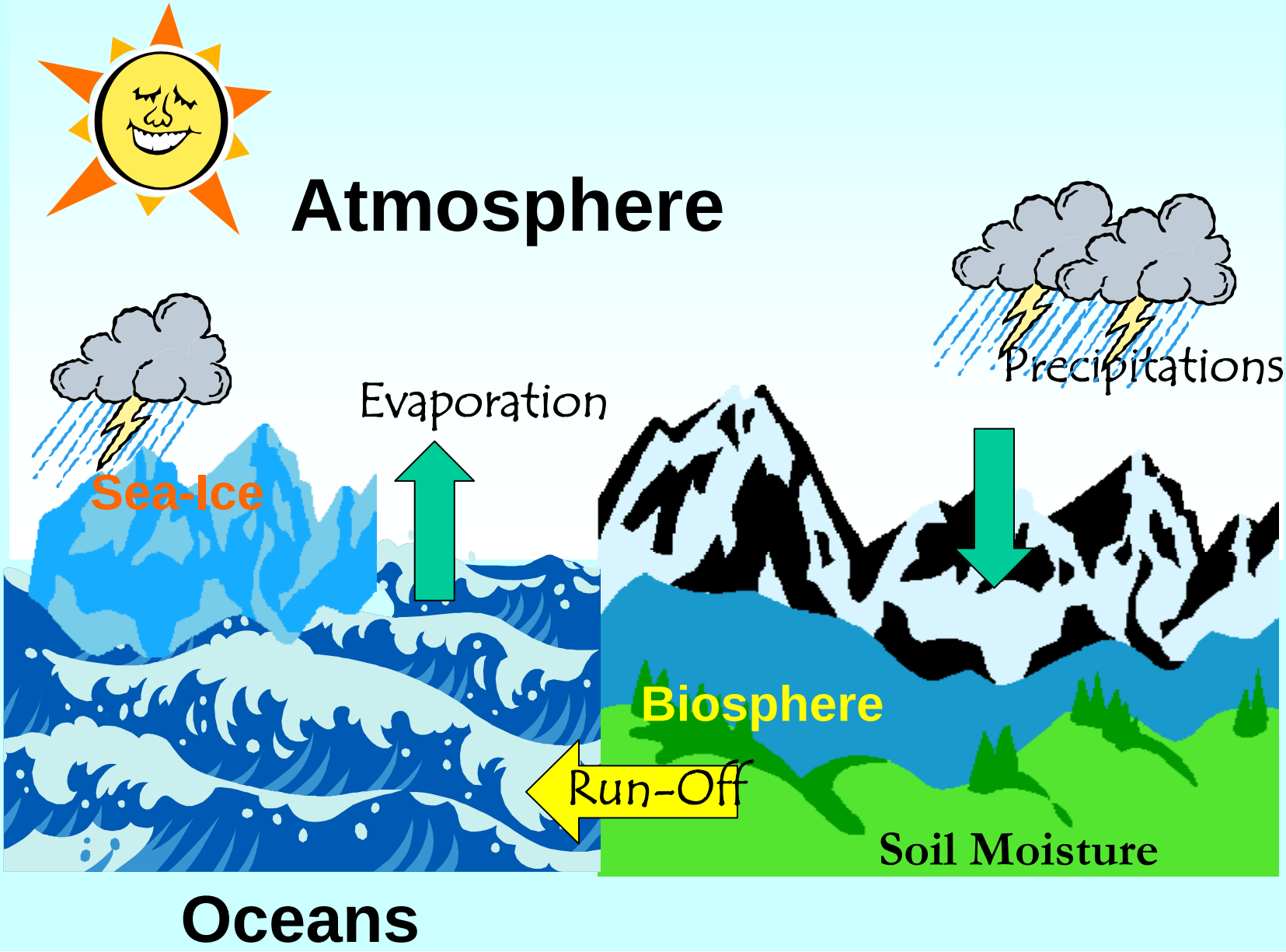
(…)

This happened to the land of Argos and M ime of the Trojan wars the Argive land was marshy and could only support a sma land of Mycenae was in good condition. But now the opposite is the case, for the r the land of Mycenae has become completely dry and barren, while the Argi barren owing to the water has now become fruitful. Now the same process th mall district must be supposed to be going on over whole countries and on a la

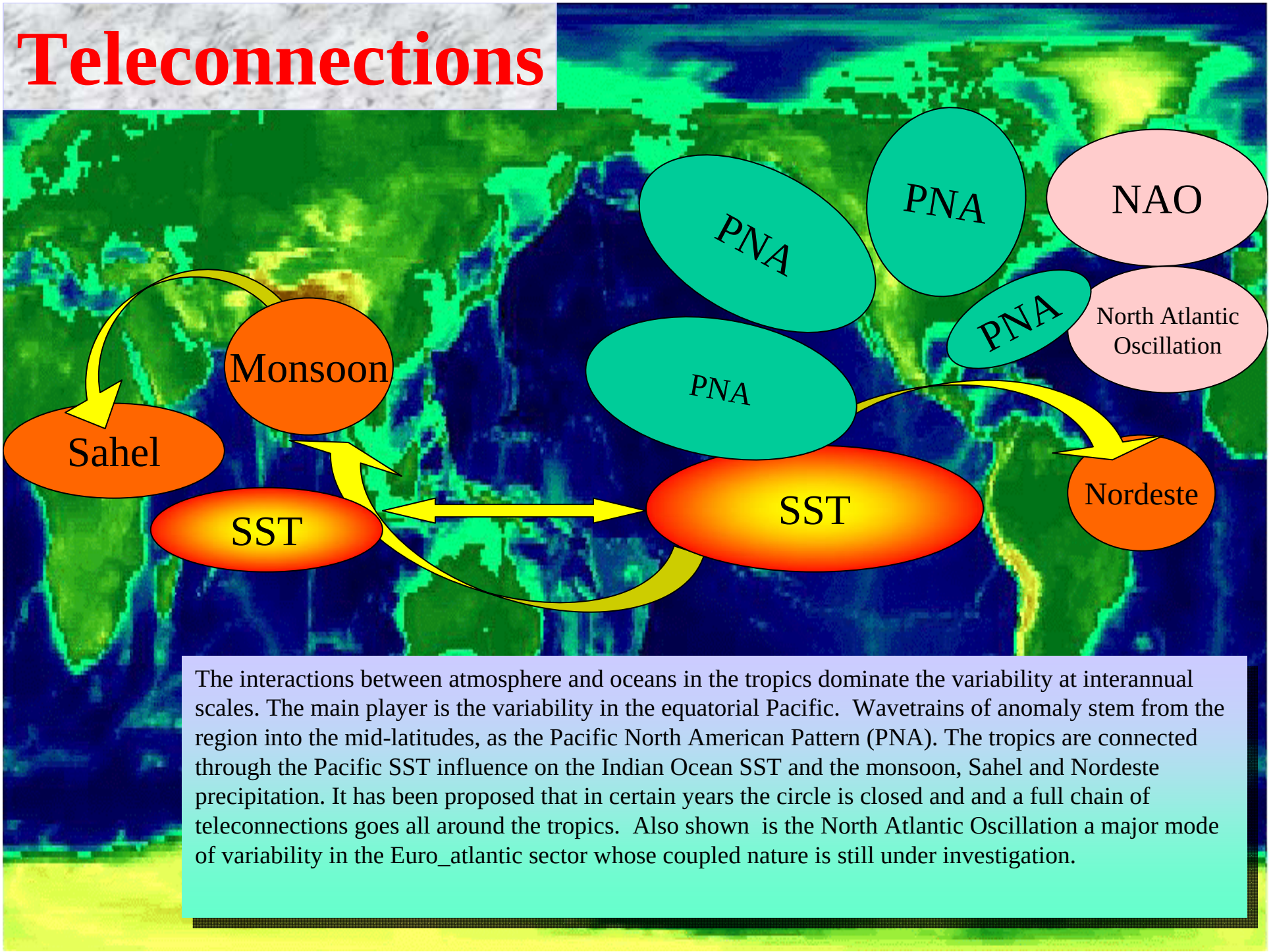
(…)

So it is clear, since there will be no end to nal, that neither the Tanais nor the Nile has always been flowing, but that the regi once dry: for their effect may be fulfilled, but time cannot. And this will be equally true of all other rivers. But if rivers come into existence and perish and the same parts of the earth were not always moist, the sea must needs change correspondingly. And if the sea is always advancing in one place and receding in another it is clear that the same parts of the whole earth are not always either sea or land, but that all this changes in course of time.

The Climate System



Teleconnections

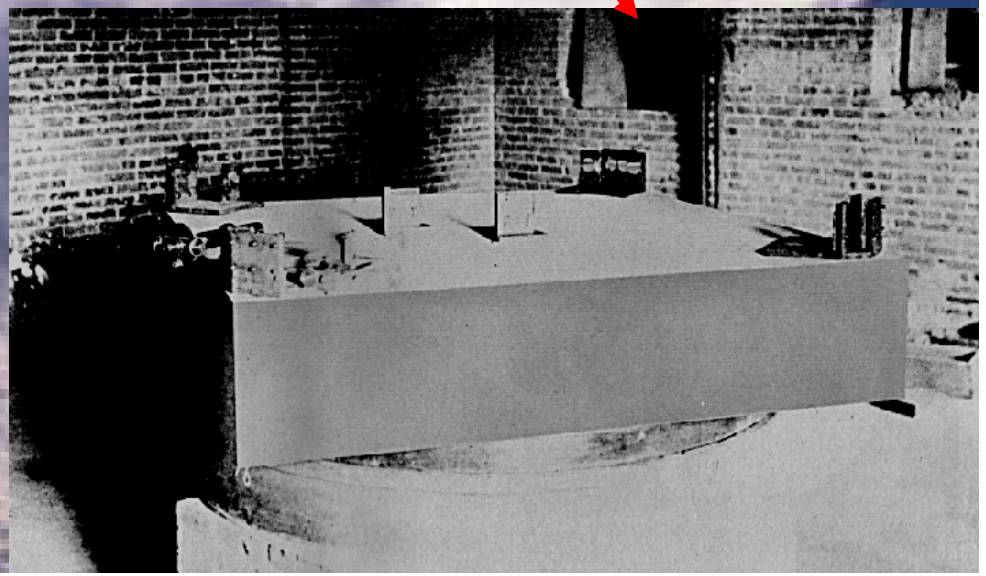


The interactions between atmosphere and oceans in the tropics dominate the variability at interannual scales. The main player is the variability in the equatorial Pacific. Wavetrains of anomaly stem from the region into the mid-latitudes, as the Pacific North American Pattern (PNA). The tropics are connected through the Pacific SST influence on the Indian Ocean SST and the monsoon, Sahel and Nordeste precipitation. It has been proposed that in certain years the circle is closed and and a full chain of teleconnections goes all around the tropics. Also shown is the North Atlantic Oscillation a major mode of variability in the Euro_atlantic sector whose coupled nature is still under investigation.

A scientific consideration of climate (I)

Crucial experiments like the famous experiment of Michelson e Morley are not possible in climate science

How is it possible a scientific investigation of climate ?

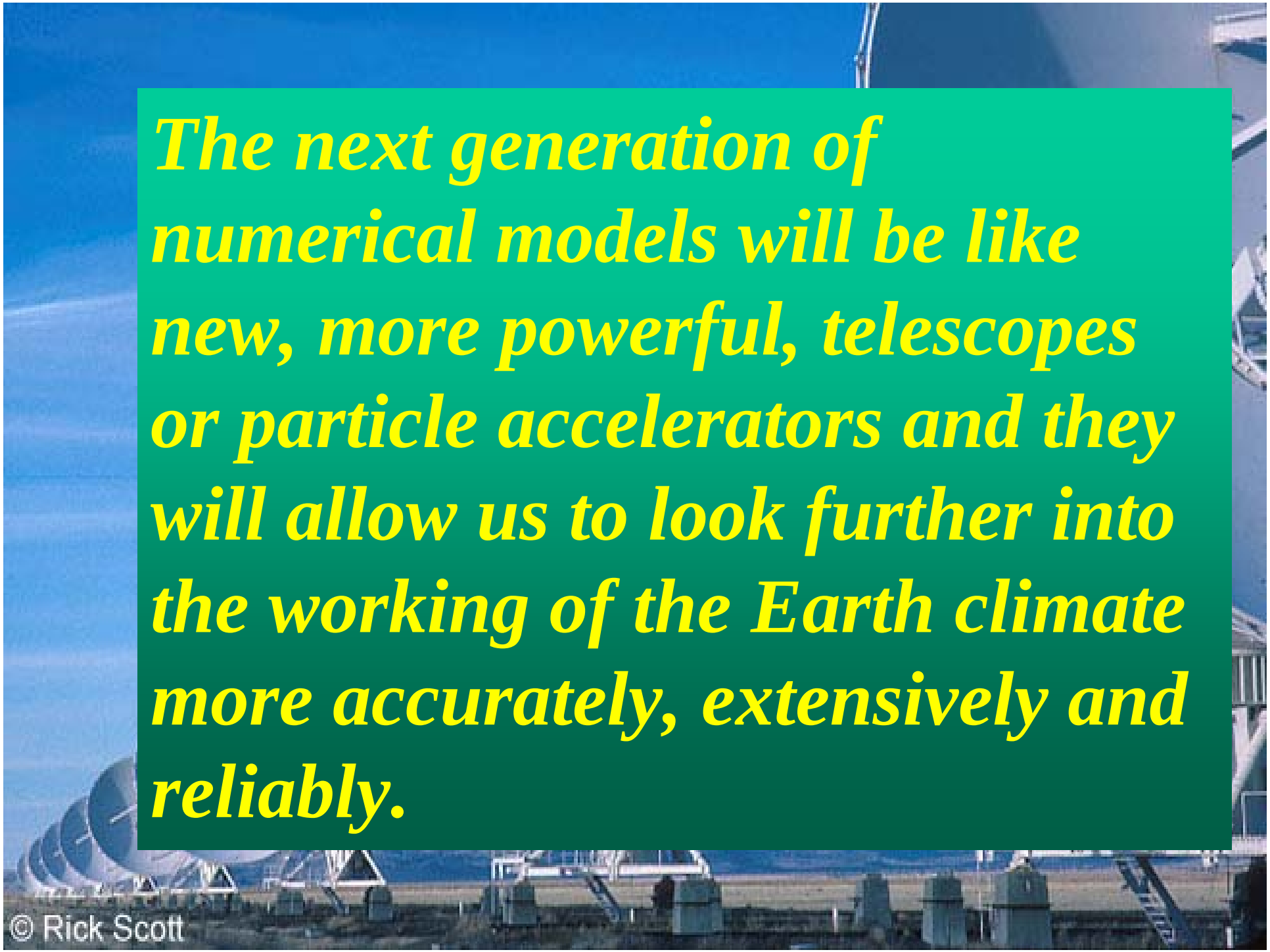


A scientific consideration of climate (II)

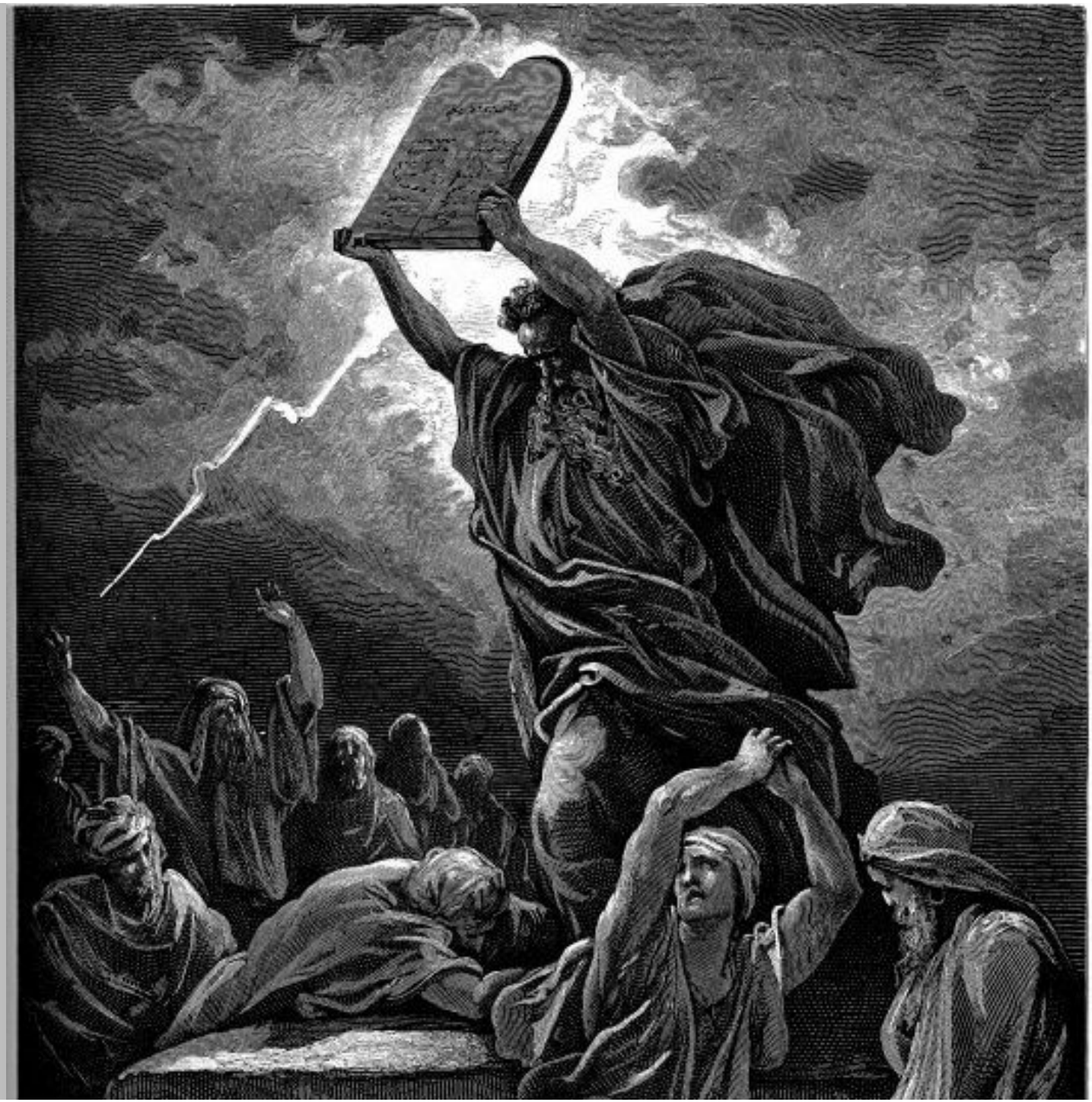
We can make experiments if we represent the climate system via a set of mathematical relations: the equation of climate.

The equation of climate are very difficult, but they can be solved by numerical methods.

We can then treat very complex mathematical equations, paying the price of a enormous number of elementary operations.



The next generation of numerical models will be like new, more powerful, telescopes or particle accelerators and they will allow us to look further into the working of the Earth climate more accurately, extensively and reliably.



Le Equazioni di Navier-Stokes

$$\frac{\partial u}{\partial t}+\vec{v}\cdot\nabla u-2\Omega\sin\theta v-\frac{uv\tan\theta}{a}+\frac{uw}{a}=-\frac{1}{\rho a\cos\theta}\frac{\partial p}{\partial\lambda}+F_{\lambda}$$

$$\frac{\partial v}{\partial t}+\vec{v}\cdot\nabla v+2\Omega\sin\theta u-\frac{u^2\tan\theta}{a}+\frac{vw}{a}=-\frac{1}{\rho a}\frac{\partial p}{\partial\theta}+F_{\theta}$$

$$\frac{\partial w}{\partial t}+\vec{v}\cdot\nabla w-\frac{u^2+v^2}{a}=-\frac{1}{\rho}\frac{\partial p}{\partial z}-g+F_z$$

$$\frac{\partial T}{\partial t}+\vec{v}\cdot\nabla T=\frac{1}{C_p\rho}\frac{dp}{dt}-Q$$

$$\frac{\partial\rho}{\partial t}+\vec{v}\cdot\nabla\rho+\frac{\rho}{a\cos\theta}\left[\frac{\partial u}{\partial\lambda}+\frac{\partial}{\partial\theta}\left(v\cos\theta\right)\right]=-\rho\frac{\partial w}{\partial z}$$

$$p=\rho Rt$$

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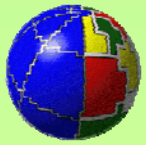


Numerical Methods

Discretize the atmosphere

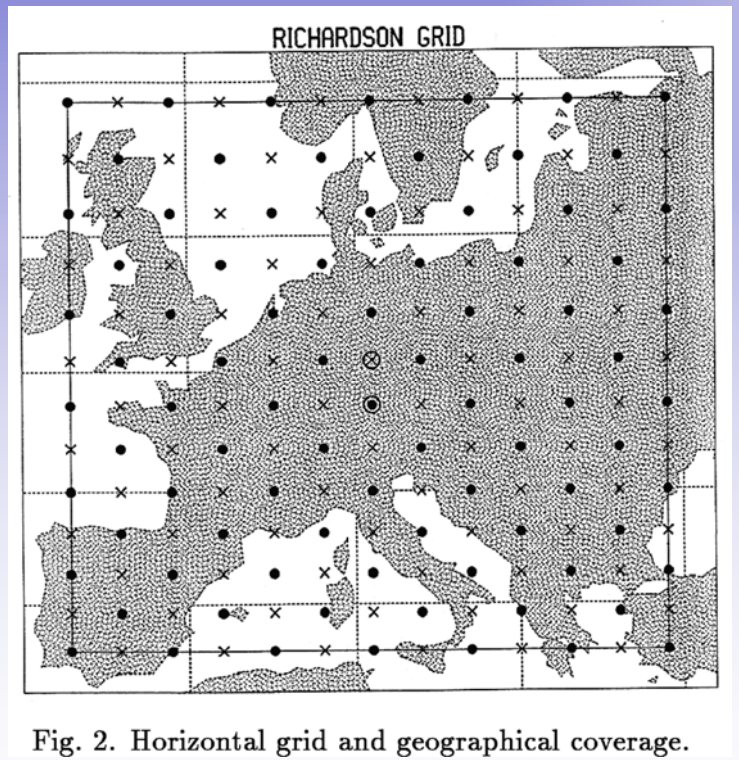
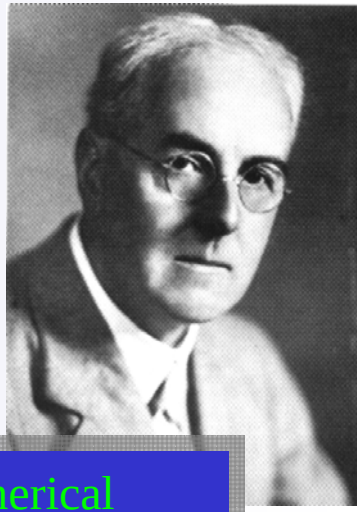
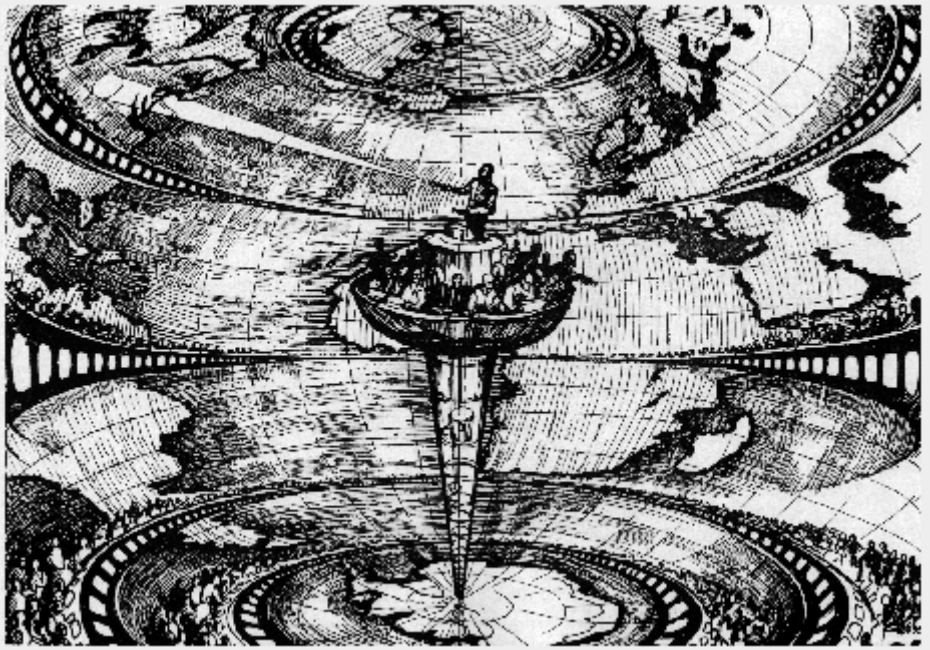


Fig. 2. Horizontal grid and geographical coverage.



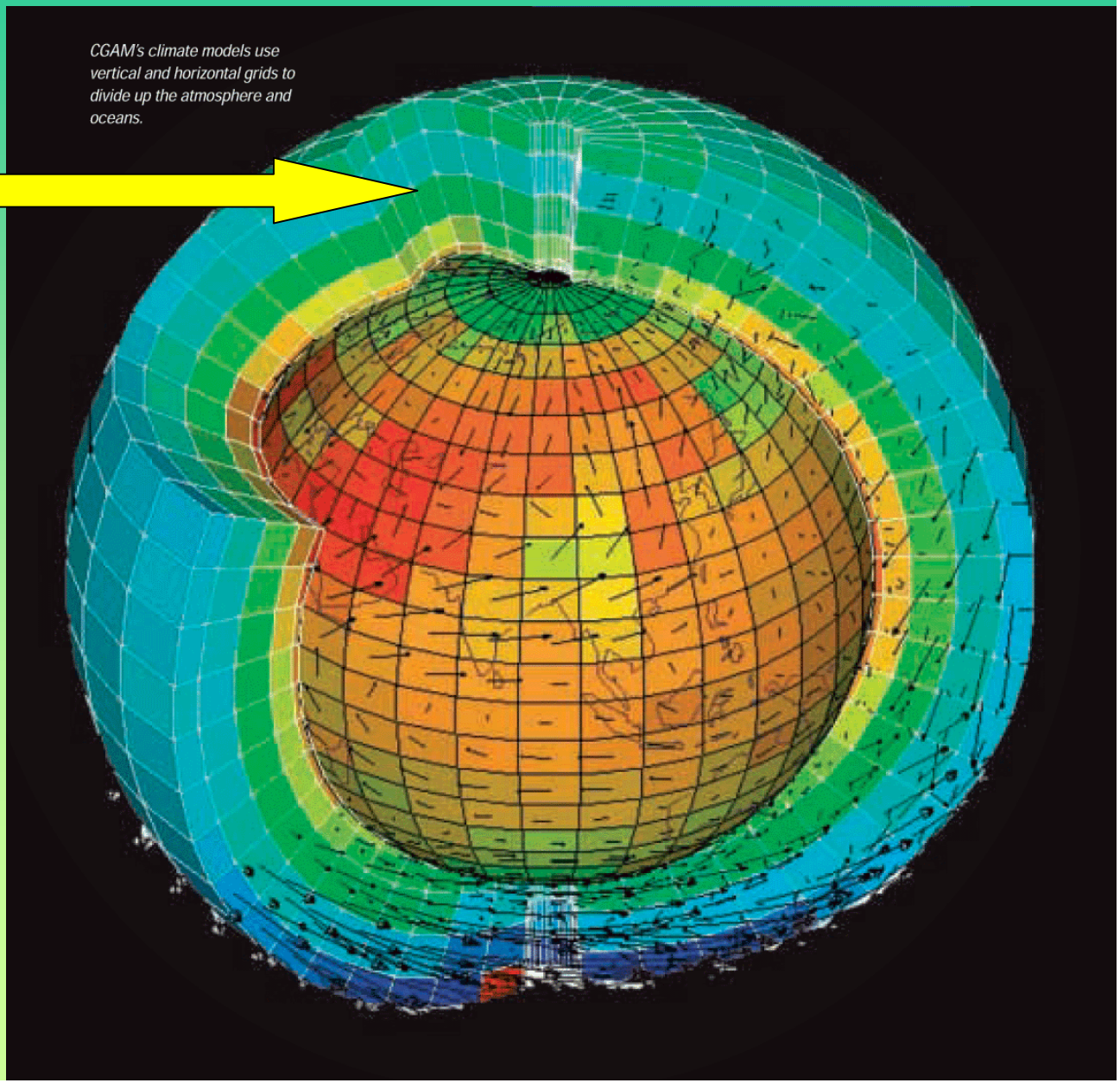
L.F. Richardson, Numerical Weather Forecasts



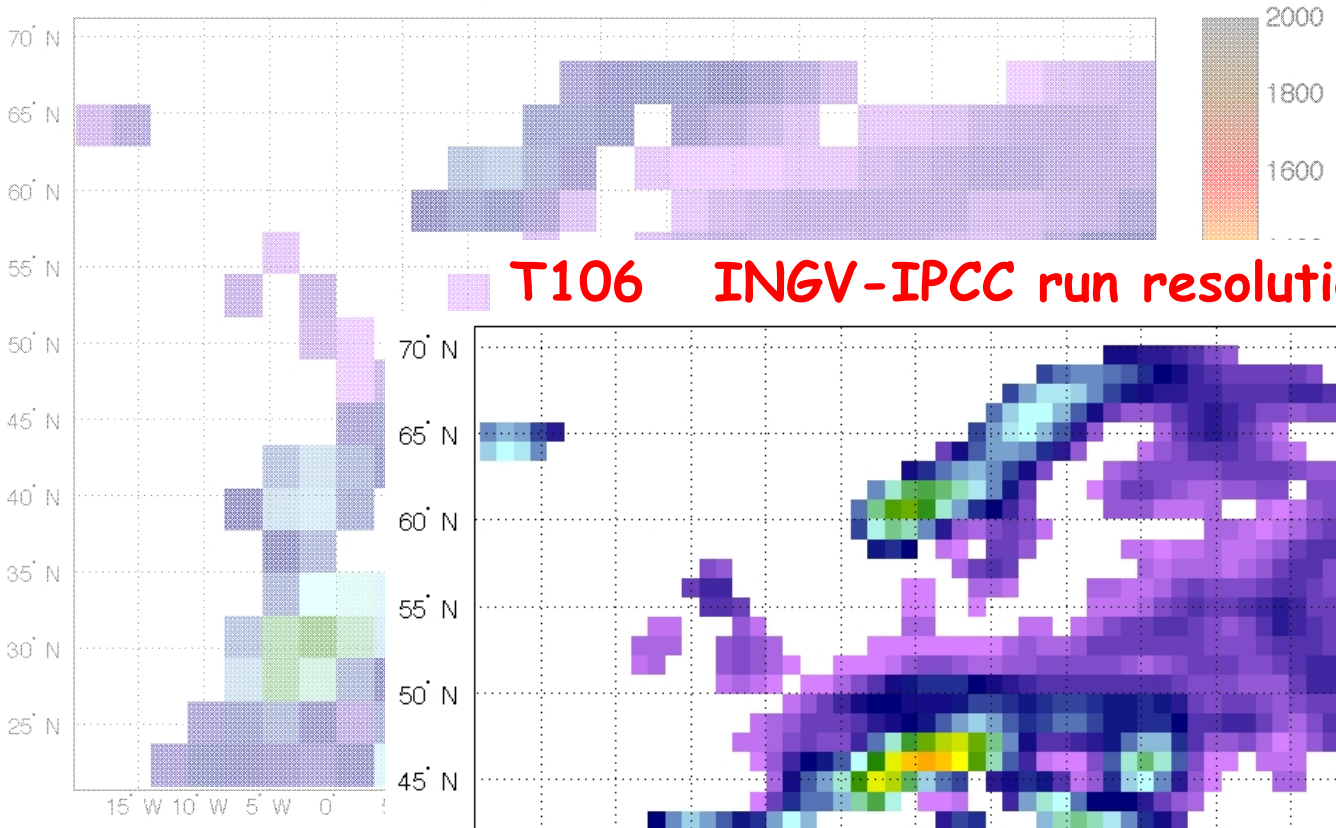
Meteorologists in front of the Electronic Computer Project at the Institute for Advanced Study (Princeton)

Grids for Earth

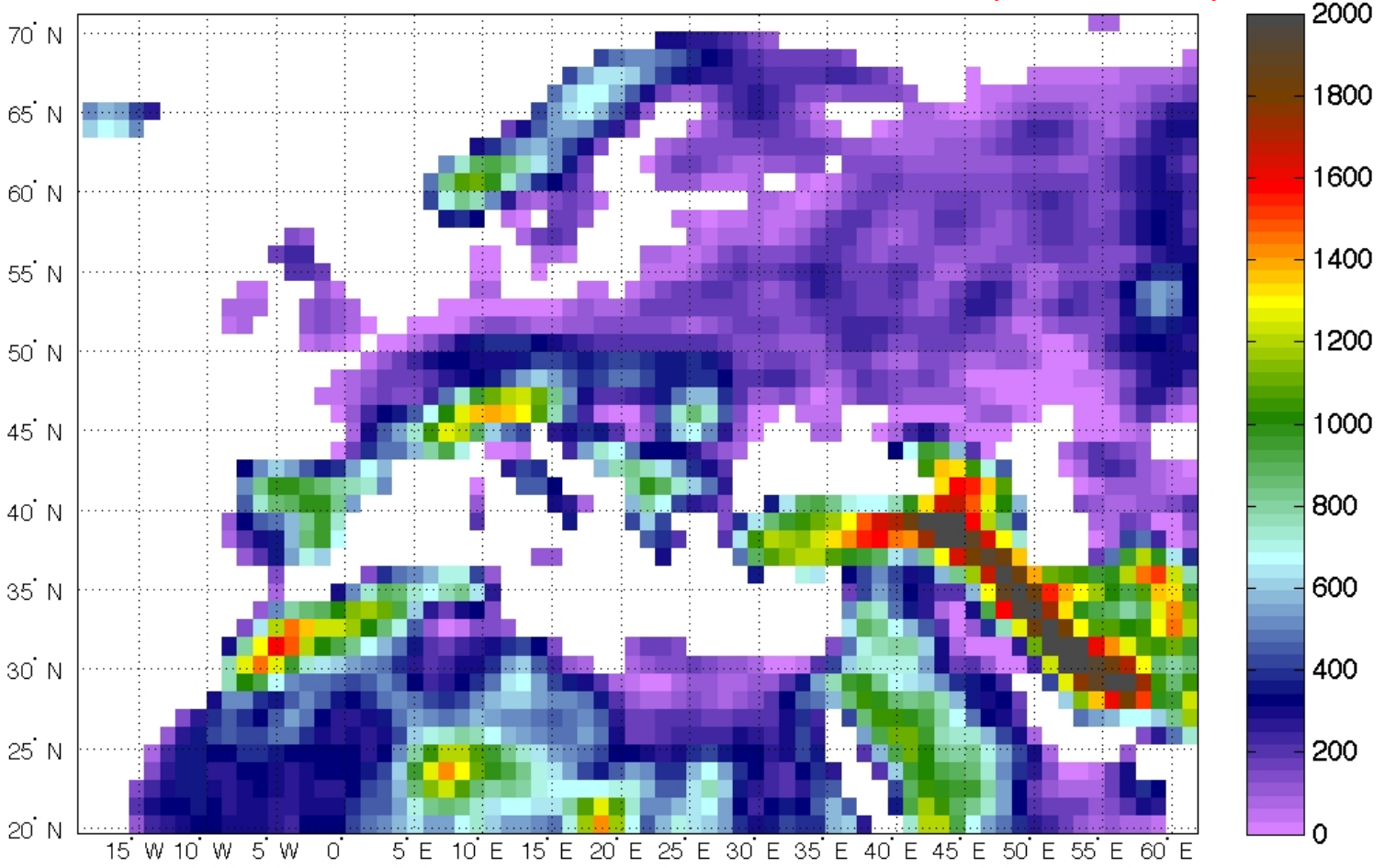
Sort of crowded at the pole



T42 IPCC standard resolution (~ 300Km)

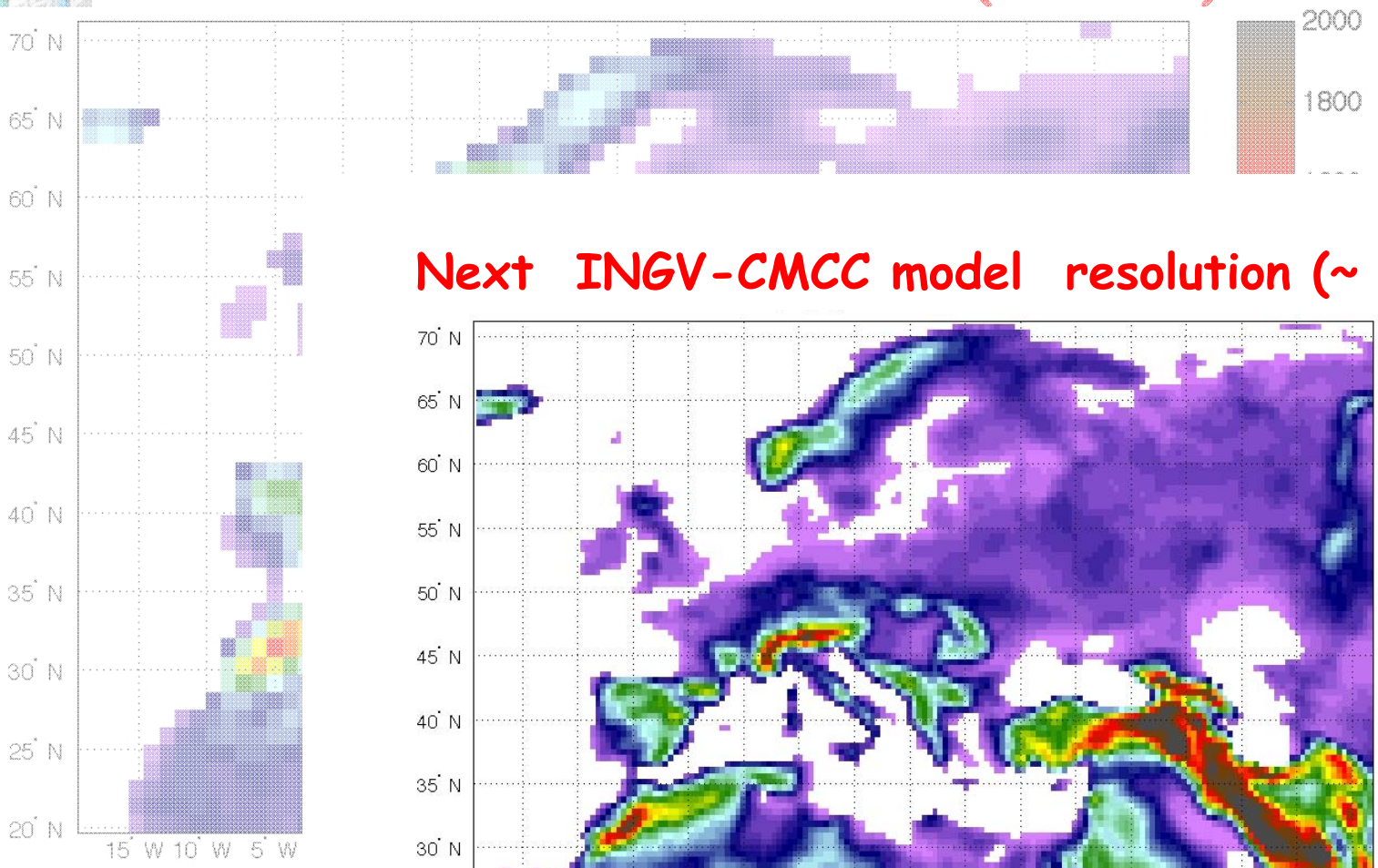


T106 INGV-IPCC run resolution (~ 120Km)



INGV - Istituto Na

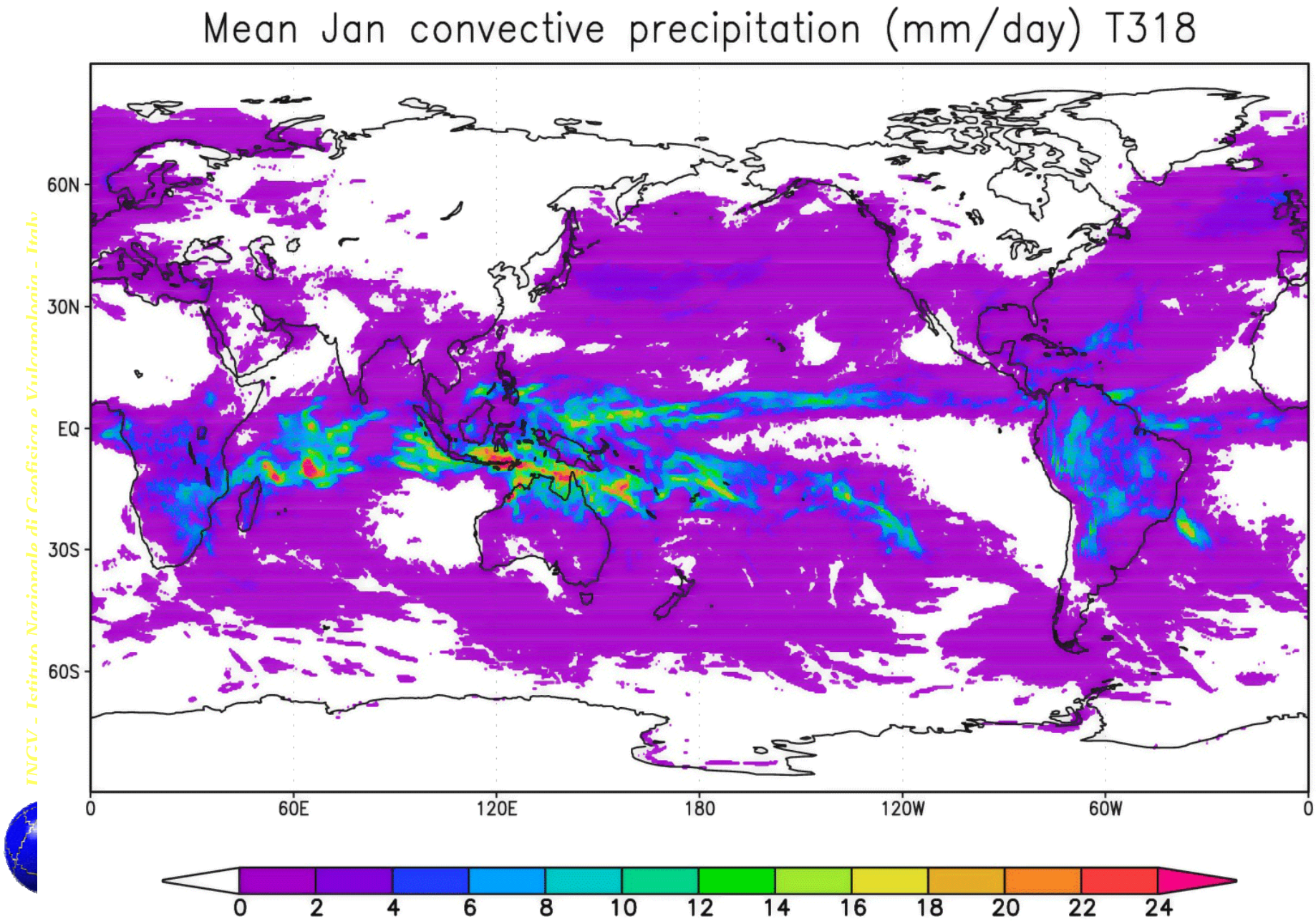
T106 INGV-IPCC run resolution (~ 120Km)



Next INGV-CMCC model resolution (~ 60Km)

INGV - Is

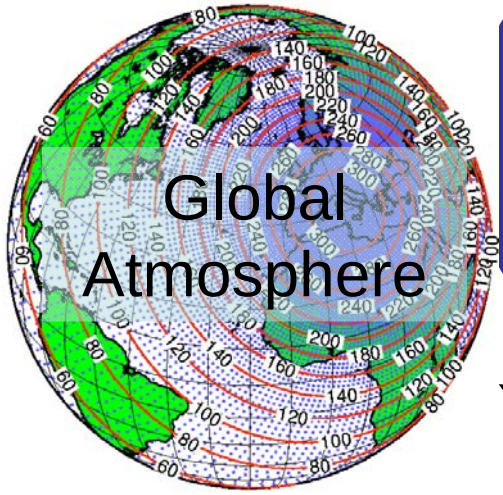
Mean JAN Precipitation Global 30km Resolution



The CMCC-MED climate scenario simulations:

climate simulations and projections with interactive Mediterranean Sea

The model: CMCC-MED



ATMOSPHERE ***(dynamics, physics, prescribed gases and aerosols)***

ECHAM5 T159 (T255)

~ 80 Km (60 Km)

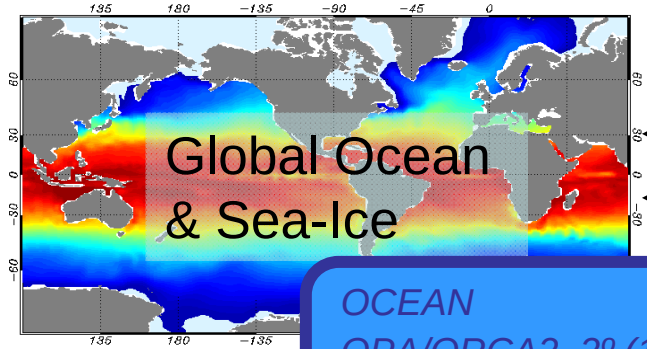
Heat Flux
Water Flux
Momentum

SST
Sea-ice

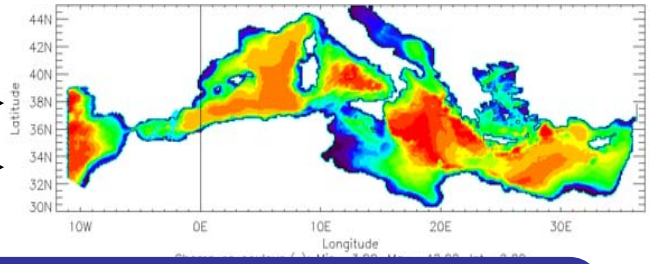
COUPLER Oasis 3

Heat Flux
Water Flux
Momentum

SST



T, S,
u, v, η



OCEAN
OPA/ORCA2 2º (1/4 °)

SEA-ICE: LIM

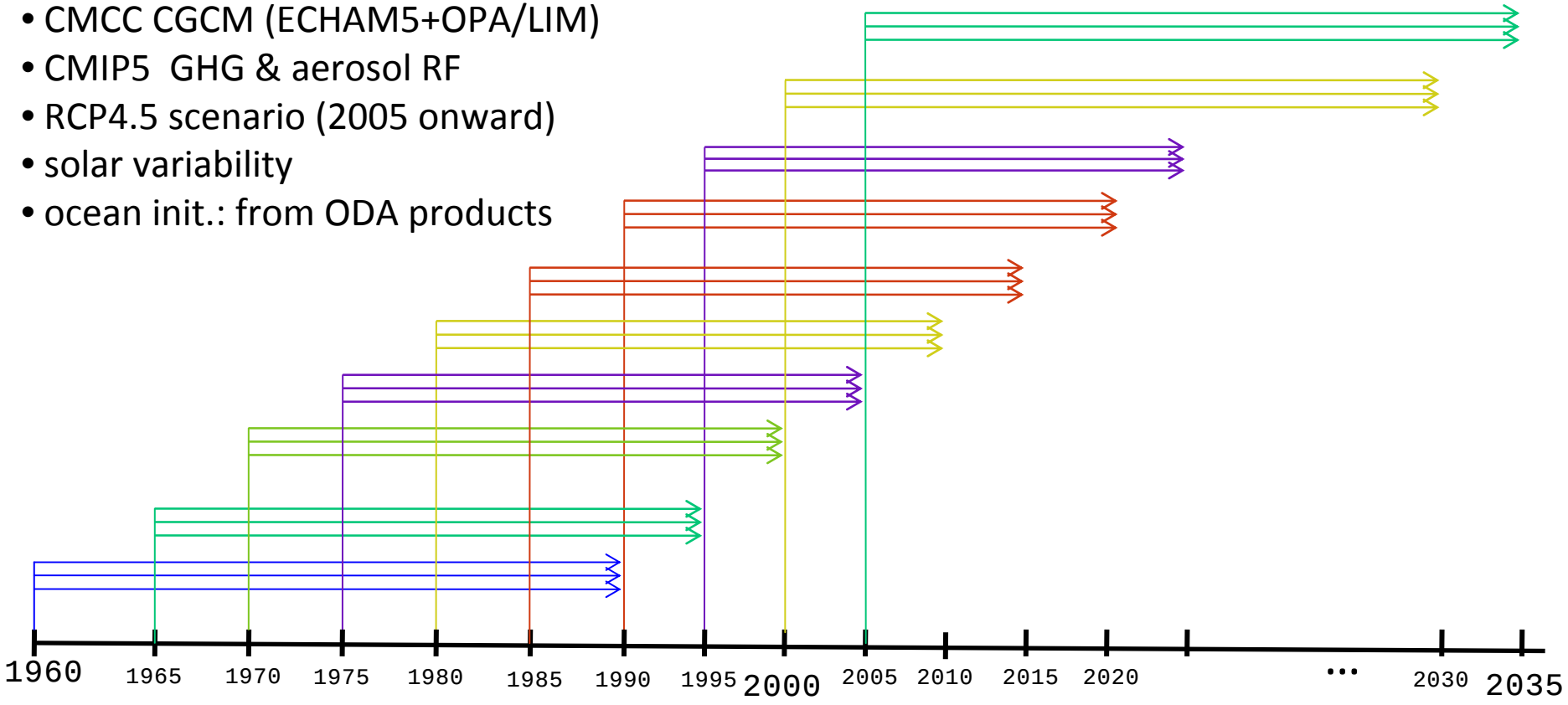
OCEAN Mediterranean
NEMO/MFS 1/16° , 71 vert. levs

Oddo et al. (2009)

Decadal Predictions: experiment setup

◆ 30-year hindcast/forecast simulations grouped into 3-members ensembles, for different start dates.

- CMCC CGCM (ECHAM5+OPA/LIM)
- CMIP5 GHG & aerosol RF
- RCP4.5 scenario (2005 onward)
- solar variability
- ocean init.: from ODA products



Centro Euro-Mediterraneo per i Cambiamenti Climatici

Carbon dioxide

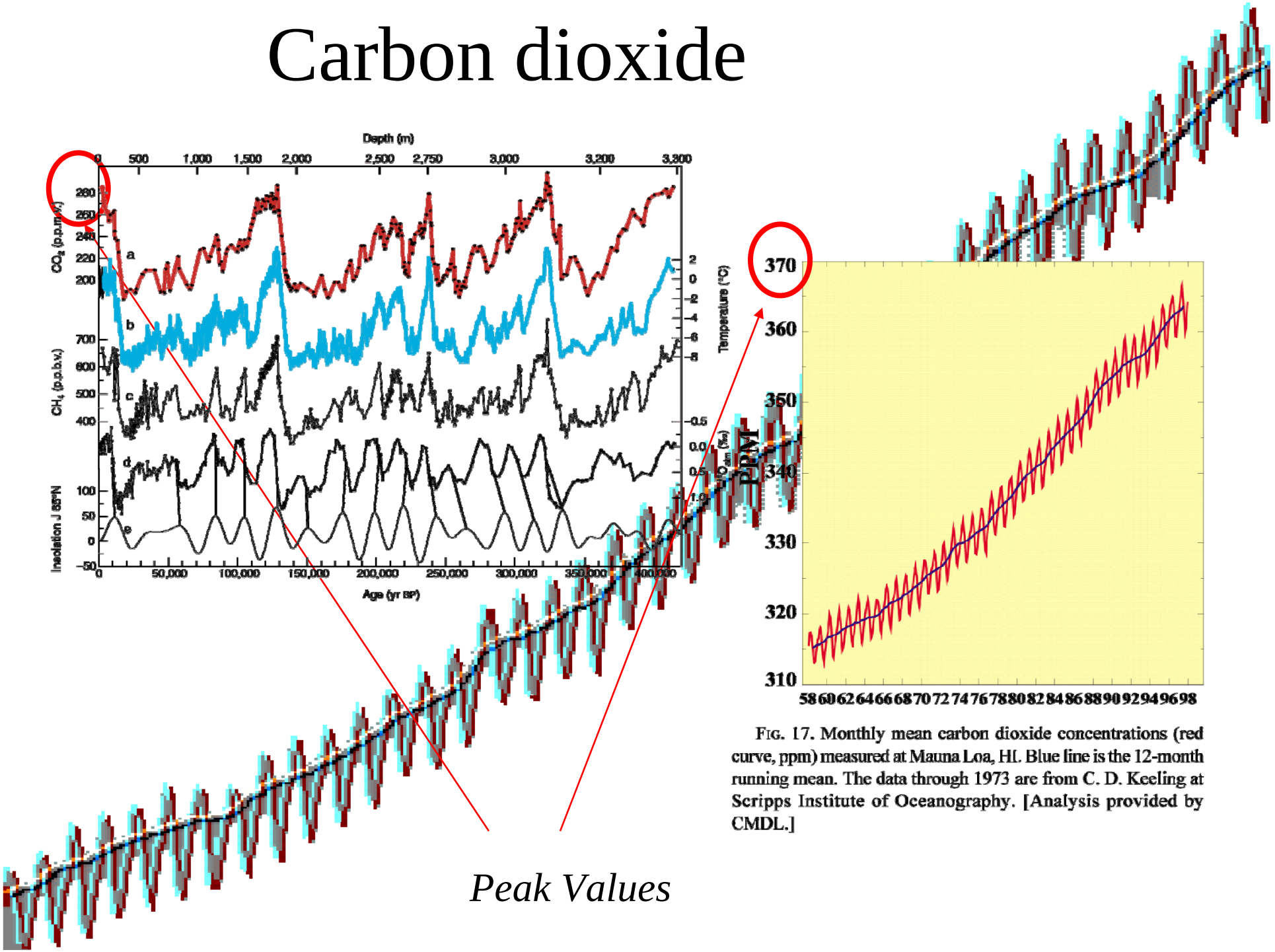


FIG. 17. Monthly mean carbon dioxide concentrations (red curve, ppm) measured at Mauna Loa, HI. Blue line is the 12-month running mean. The data through 1973 are from C. D. Keeling at Scripps Institute of Oceanography. [Analysis provided by CMDL.]

Peak Values

The dilemma of climate change

Strongly science-based problem.

A special responsibility for scientists to provide honest, accurate, sound science

Global scope and complex interactions

Euro Mediterranean Center for Climate Change

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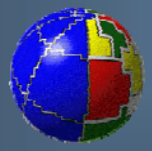


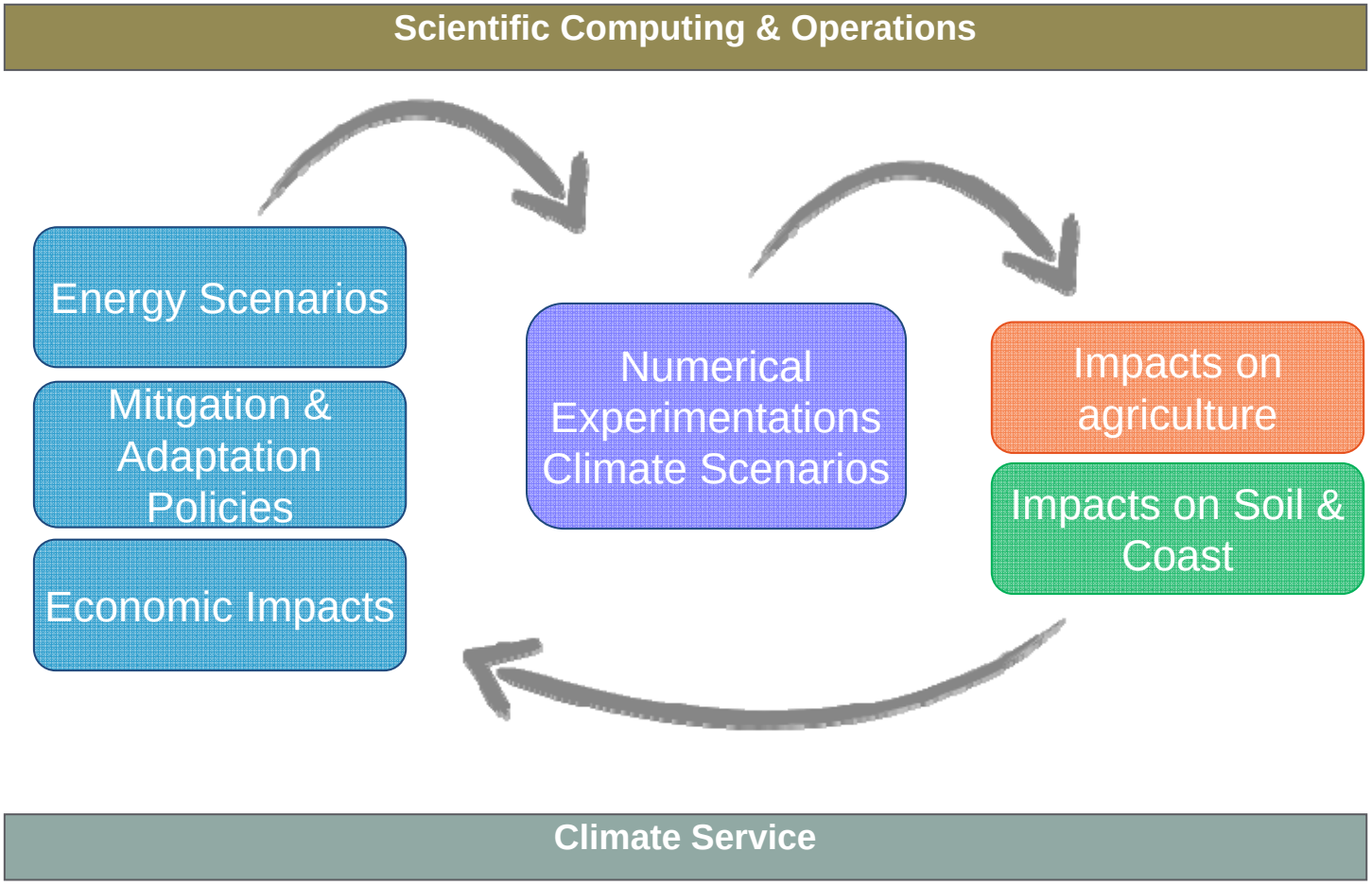
Centro Euromediterraneo per i Cambiamenti Climatici

- **CMCC was established in 2005 by a group of Italian Research Institutions that now includes**(Istituto Nazionale di Geofisica e Vulcanologia, Fondazione Eni Enrico Mattei, Università degli Studi del Salento, Centro Italiano Ricerche Aerospaziali, Universita' di Venezia, Università degli Studi del Sannio)

- **CMCC is the Italian Research Centre on Climate Science and Policy**. Supported by the Italian Ministry for the Environment Land and Sea, the Ministry for Education, University and Research and the Ministry for Economy

- **CMCC hosts the IPCC Italian Focal Point**

Six Integrated Divisions



The Dimension of the Climate Problem

Resolution. What is the size of equivalent grid spacing that is eeded to open up new physics and solve present problems ?

Complexity. Is the present set of systems included in climate models complete ? What are the next priorities ?

Length. What is the required length to obtain robust estimates of the probability distribution of cliate variables ?

Ensemble size. Estimation of uncertainties will require a Montecarlo approach, how to constuct the ensembles, what are the dimension of the problem ?

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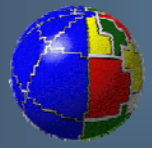
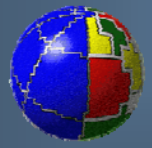


The dawn of a new era

Sustained performances > 1 Pflops will be needed, prompting a major reorganization of the research, i.e. the era of

Industrial Computing

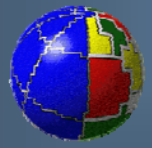


Issues

- The power on the desktop for scientists is growing slower than the backend machines.
- The data processing capability at the desktop is growing even slower
- Increasing separation between computer science and application

  User-driven development
- Insufficient talent pool for application

(who remembers FORTRAN ?)



Sustaining and directing the research effort

Funding for Earth Systems research is stationary or decreasing.

University programs, with their reliance on individually funded research, are too small to engage in a global programmatic approach.

Research spending from those institutions that do have scale – e.g. defense budgets and private sector entities – is significantly lower than it used to be.

We are not increasing our investments in research right at the time when we need to generate new intellectual capital that can help us manage both the planet and our economic activities in the 21st Century.

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