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FONDAZIONE
GIUSEPPE OCCHIALINI

06.05 Energia I

problema energetico, struttura atomica, fissione nucleare

06.06 Energia II

fusione nucleare, centrali nucleari, energie rinnovabili

07.06 Clima

sistema climatico, osservazione, modellazione e tendenze

Introduzione al sistema climatico terrestre

FONDAZIONE GIUSEPPE OCCHIALINI

Studio e previsioni dello stato del sistema

Federico Porcù ***(federico.porcu@unibo.it)***
Dipartimento di Fisica e Astronomia
Università di Bologna

definizione del problema;

evidenze della tendenza climatica;

aspetti critici;

sistemi dinamici;

il sistema climatico terrestre;

un approccio osservativo.

CLIMA E TEMPO METEOROLOGICO

diversa scala temporale

diversità di metodo, dati e formulazioni teoriche

tempo meteorologico *stato di un sottosistema (in particolare dell'atmosfera) ad un istante*.

clima *stato medio del sistema e sue variazioni nel tempo*.

INDICATORI

temperatura dell'aria

altezza del mare

precipitazione, vegetazione, insolazione, estensione dei ghiacci, ….

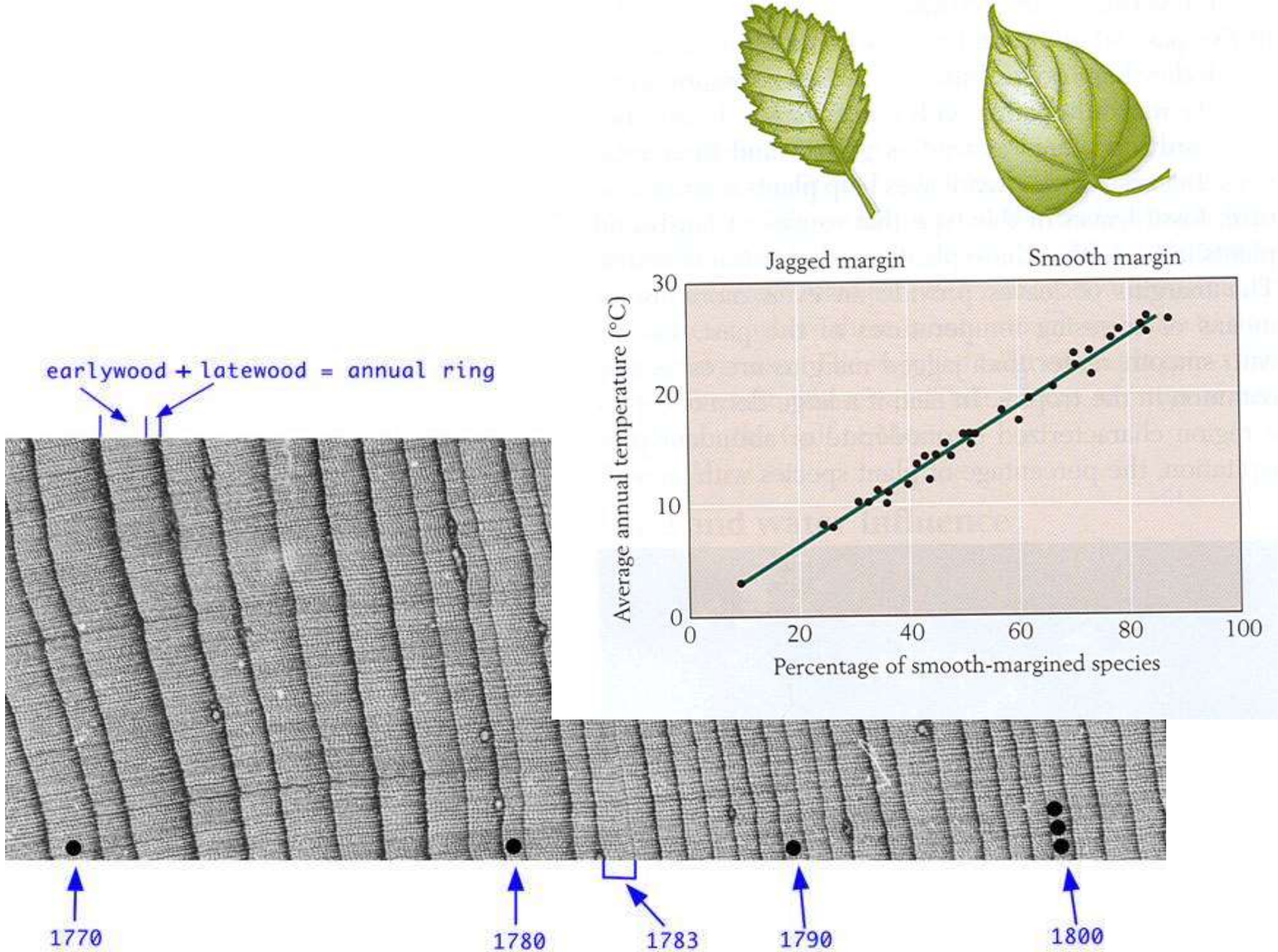
<u>temperatura dell'aria</u> ***(h=2 m)***

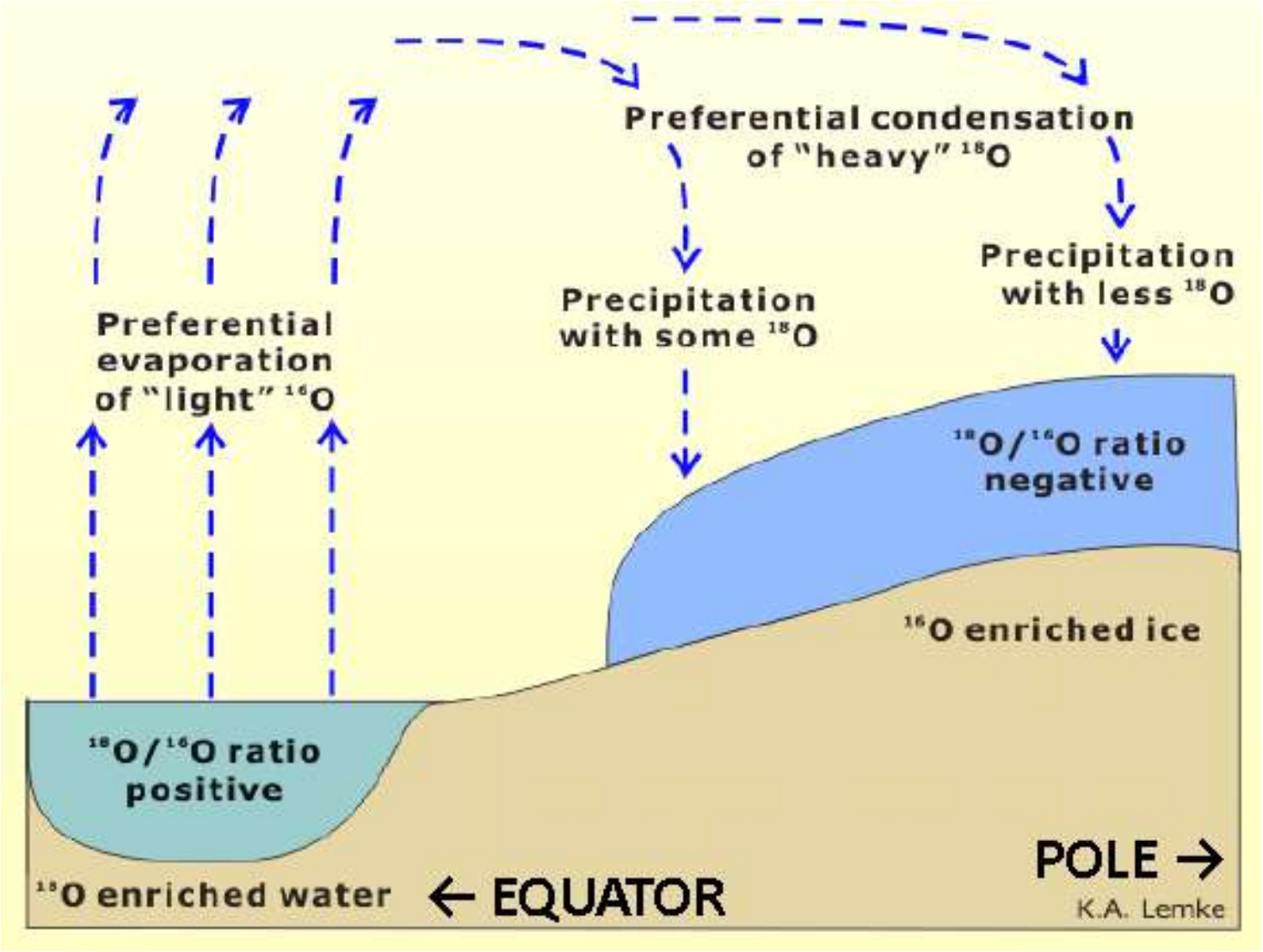
termometri (tempi recenti < 200 anni):

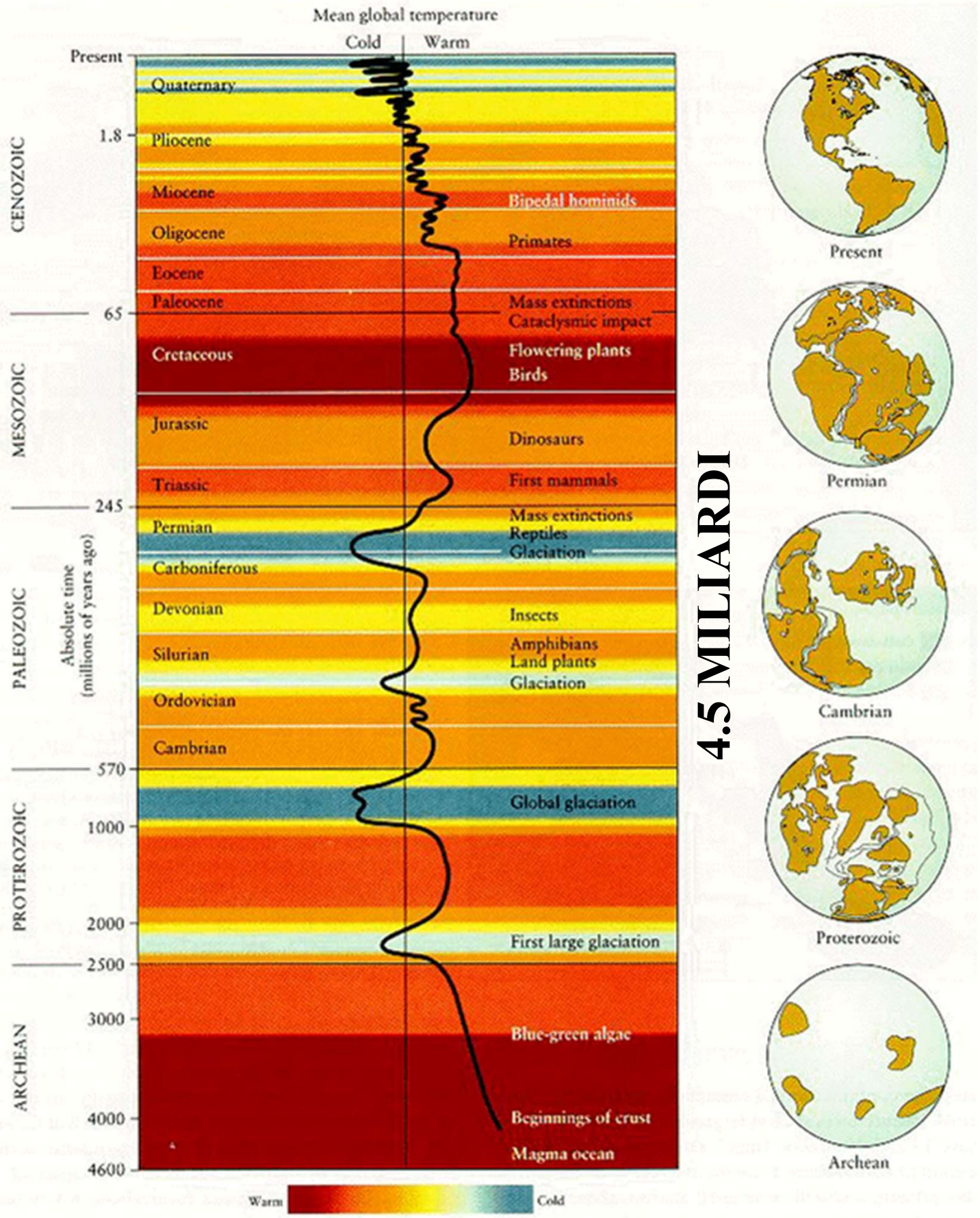
- termometri a mercurio
- termometri a stato solido (termistori)

proxy data (paleoclima):

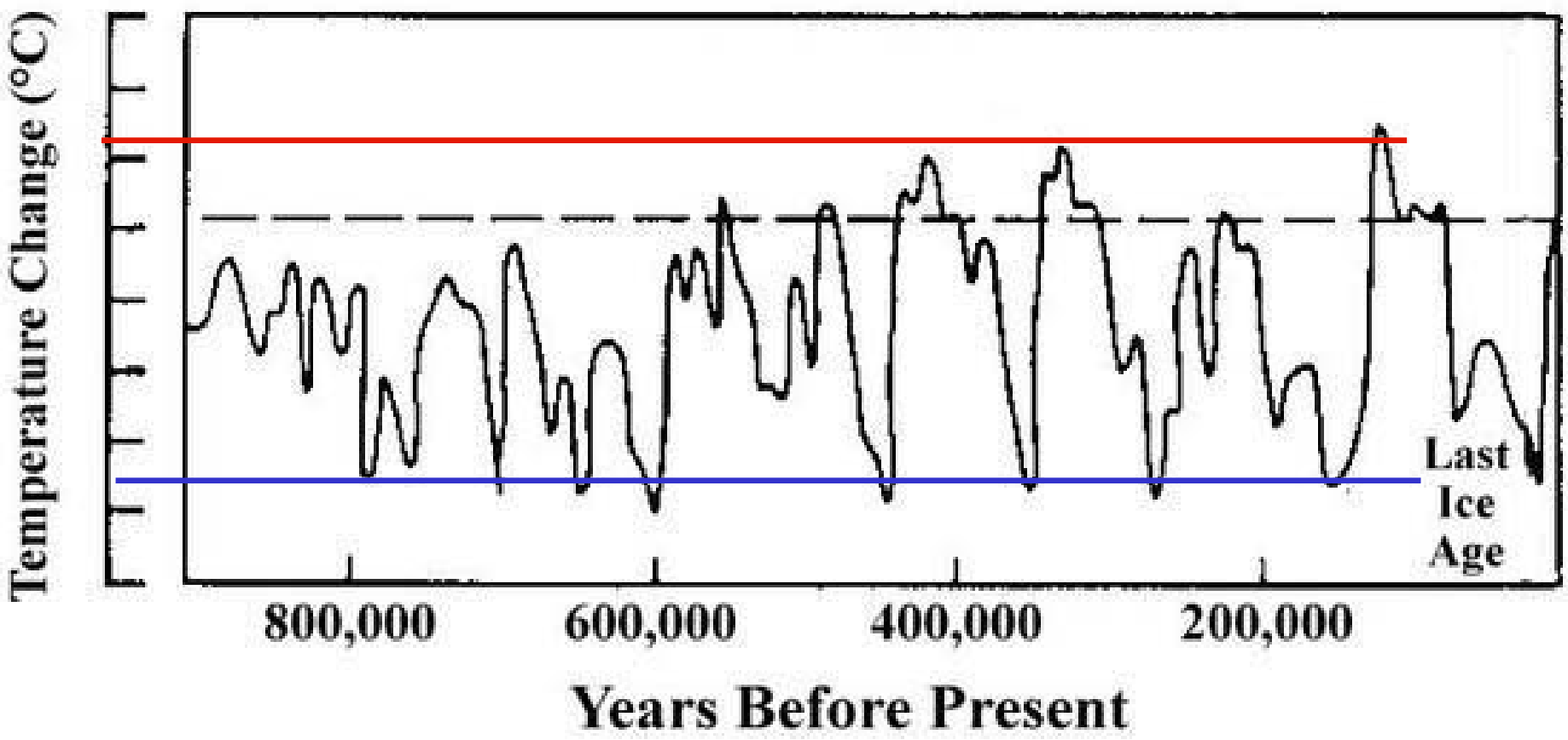
- anelli di accrescimento degli alberi
- forma delle foglie
- O^{16}/O^{18}
- cronache storiche


Jagged margin
Smooth margin
Average annual temperature (°C)
30
20
10
0
0
20
40
60
80
100
Percentage of smooth-margined species
earlywood + latewood = annual ring
1770
1780
1783
1790
1800

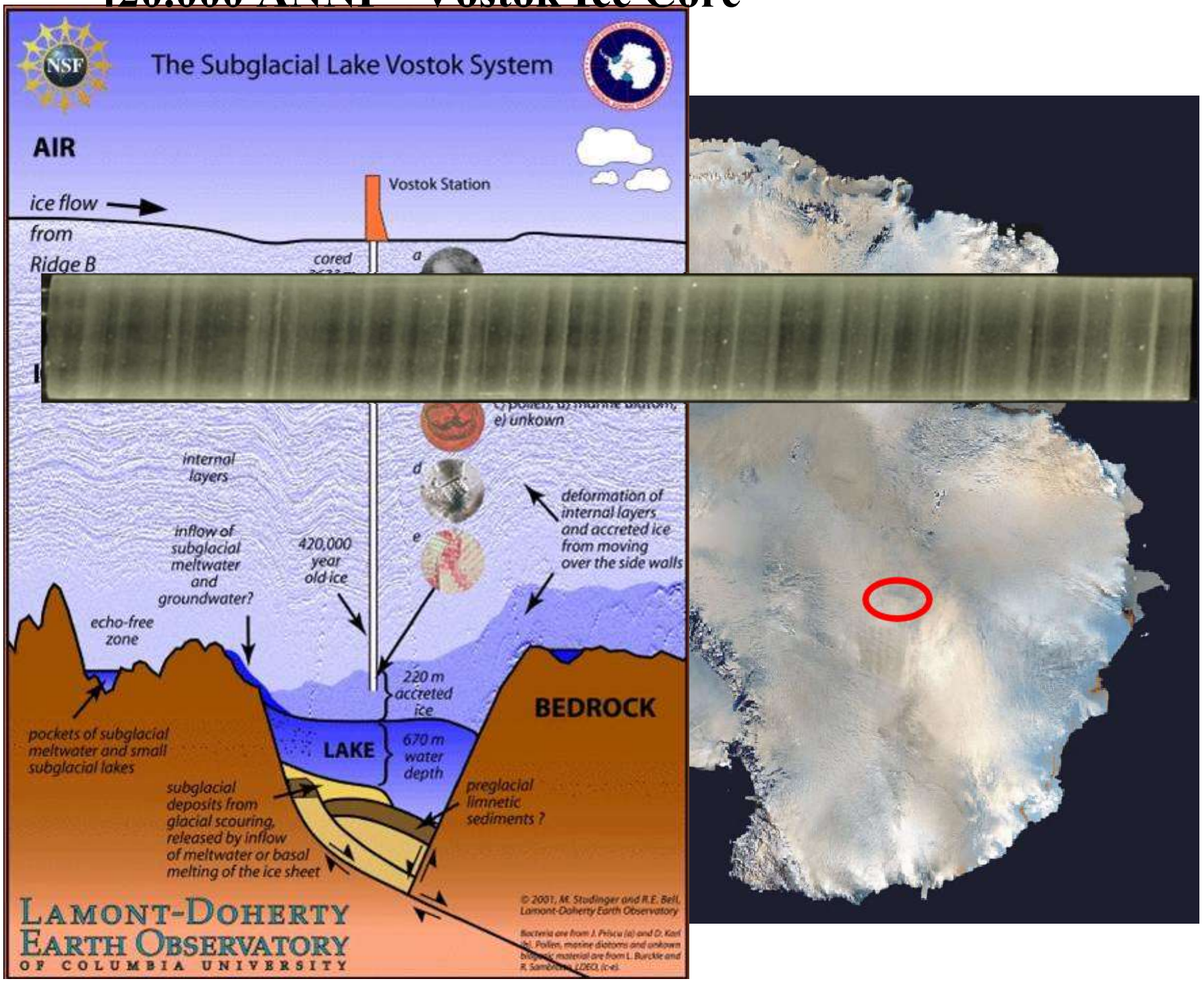

Preferential condensation of "heavy" ^{18}O
Precipitation with less ^{18}O
Precipitation with some ^{18}O
Preferential evaporation of "light" ^{16}O
$^{18}O/^{16}O$ ratio negative
^{16}O enriched ice
$^{18}O/^{16}O$ ratio positive
^{18}O enriched water
← EQUATOR
POLE →
K.A. Lemke


Mean global temperature
Cold
Warm
Present
1.8
65
245
570
1000
2000
2500
3000
4000
4600
CENOZOIC
MESOZOIC
PALEOZOIC
PROTEROZOIC
ARCHEAN
Absolute time (millions of years ago)
Quaternary
Pliocene
Miocene
Oligocene
Eocene
Paleocene
Cretaceous
Jurassic
Triassic
Permian
Carboniferous
Devonian
Silurian
Ordovician
Cambrian
Bipedal hominids
Primates
Mass extinctions
Cataclysmic impact
Flowering plants
Birds
Dinosaurs
First mammals
Mass extinctions
Reptiles
Glaciation
Insects
Amphibians
Land plants
Glaciation
Global glaciation
First large glaciation
Blue-green algae
Beginnings of crust
Magma ocean
Warm
Cold
4.5 MILIARDI
Present
Permian
Cambrian
Proterozoic
Archean

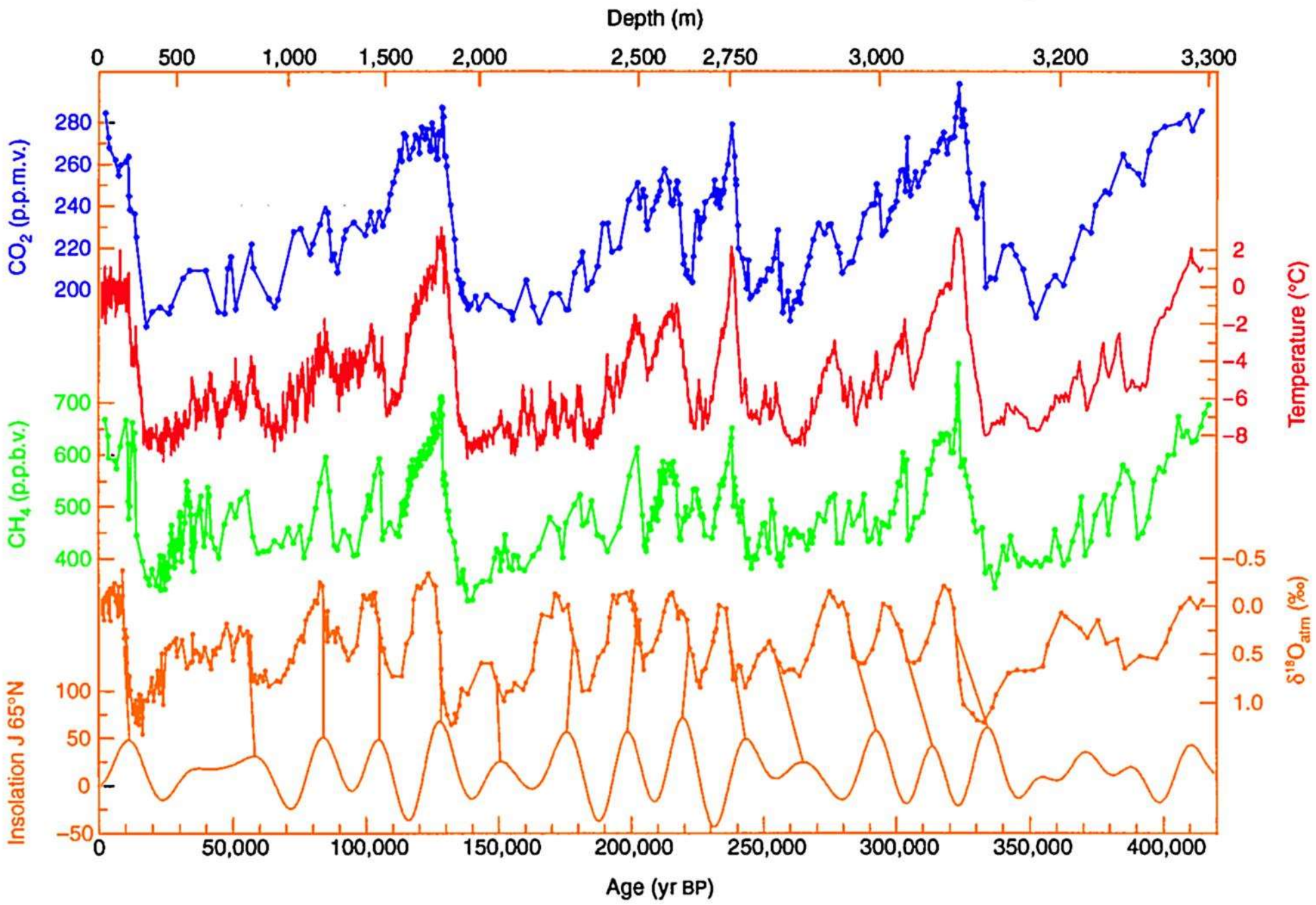
1 MILIONE DI ANNI



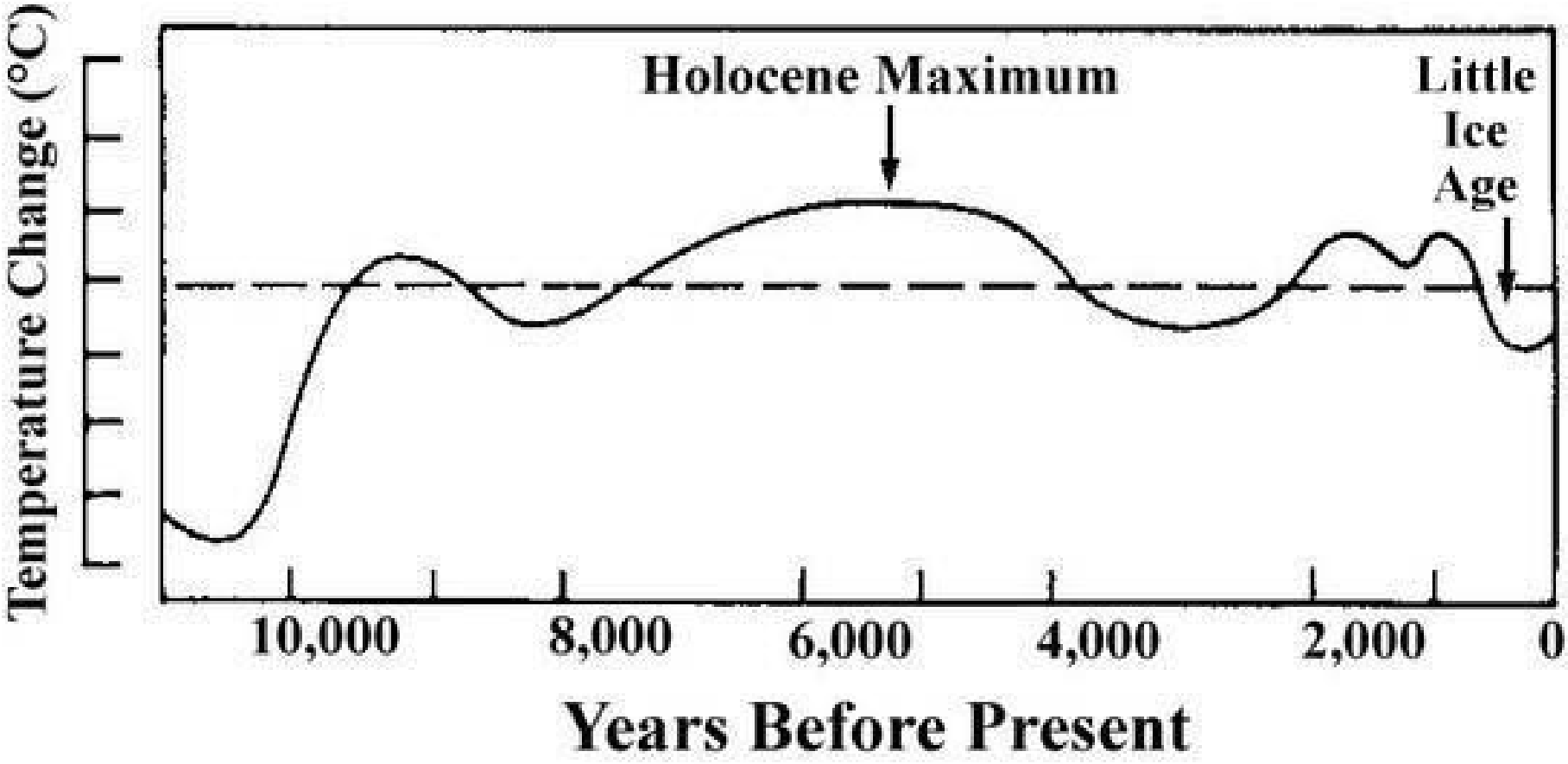
420.000 ANNI – Vostok Ice Core



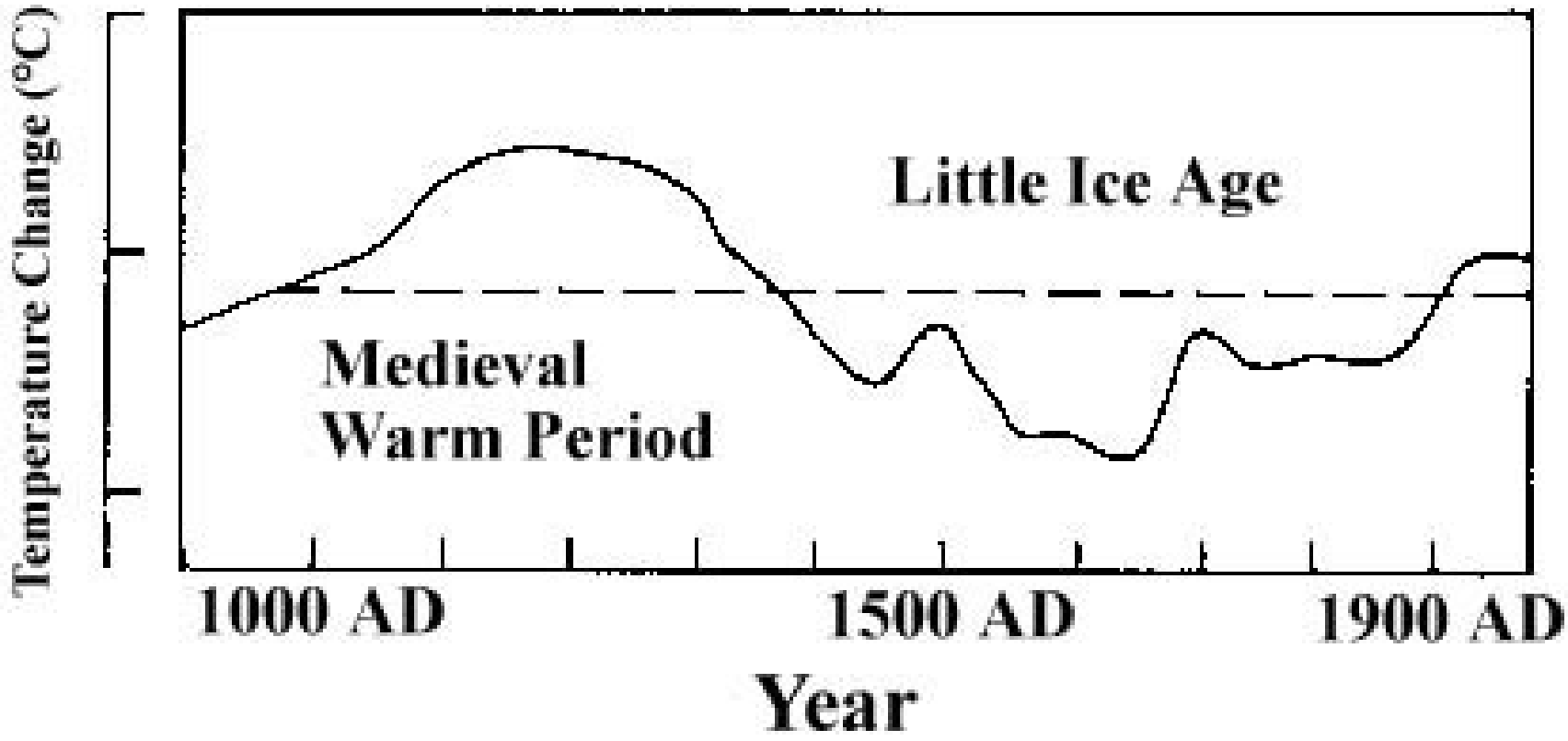
420.000 ANNI – Vostok Ice Core



10.000 ANNI

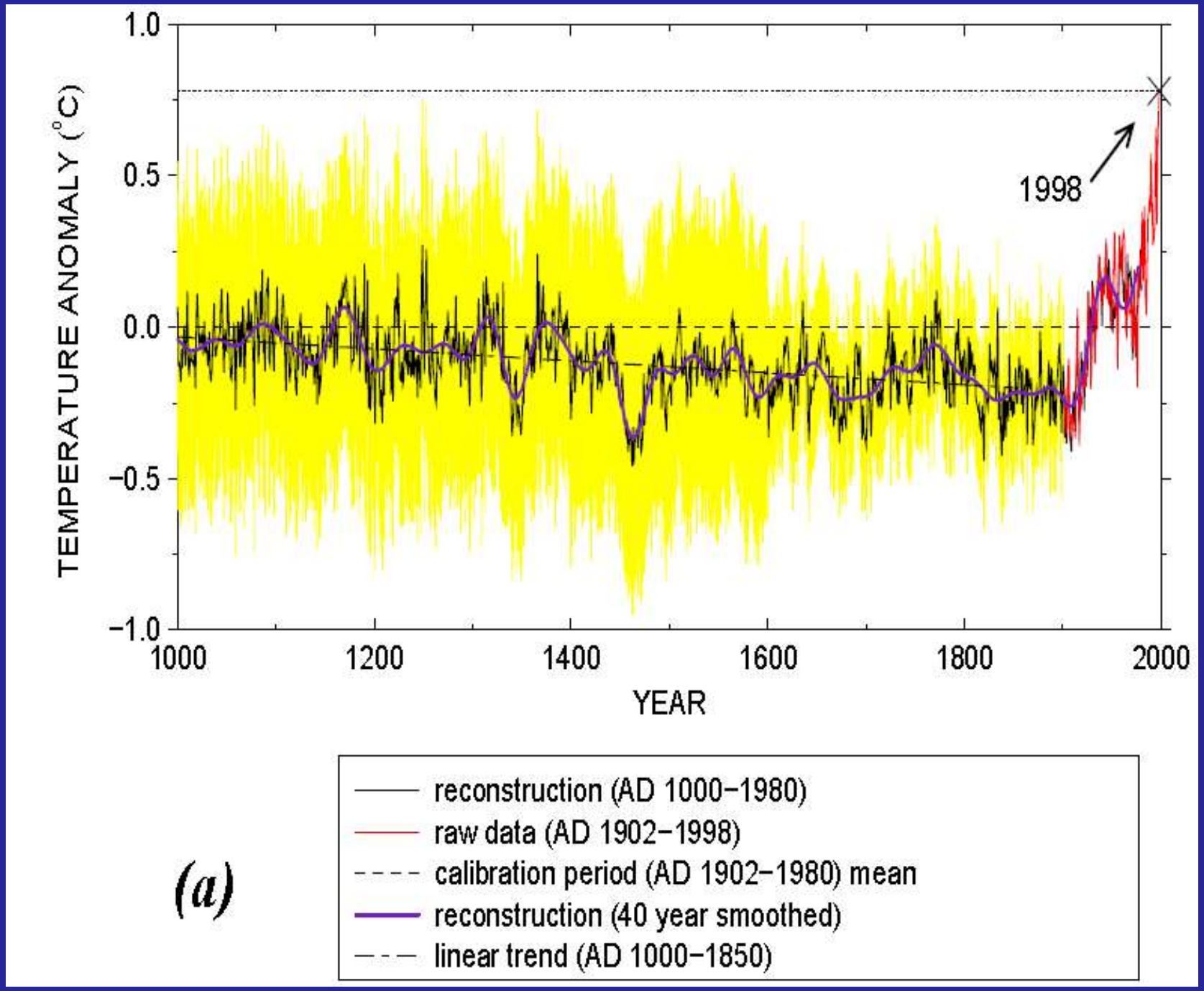

Temperature Change (°C)
Holocene Maximum
Little
Ice
Age
10,000
8,000
6,000
4,000
2,000
0
Years Before Present

1.000 ANNI


Temperature Change (°C)
Little Ice Age
Medieval
Warm Period
1000 AD
1500 AD
1900 AD
Year

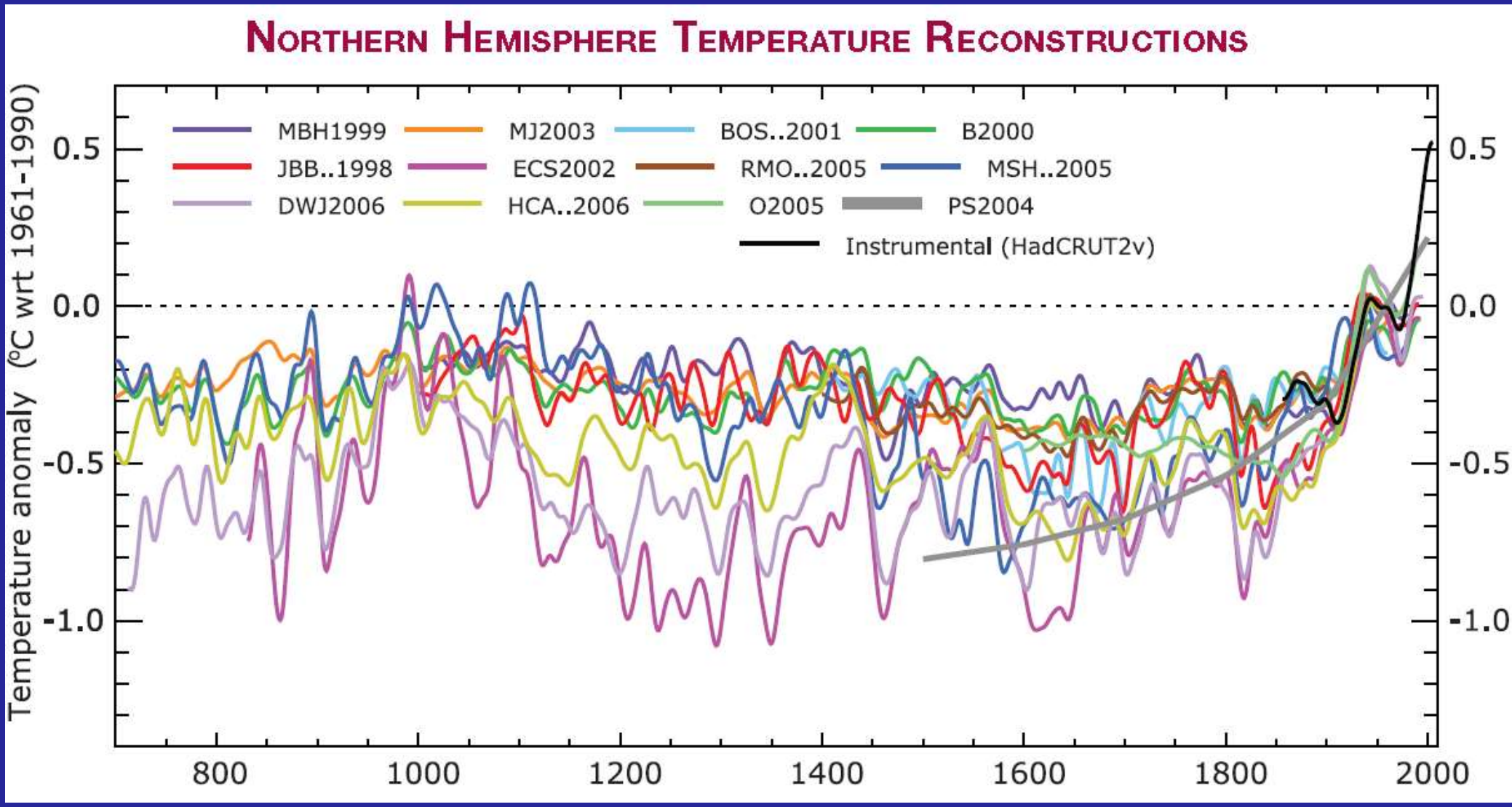
osservazione delle tendenze I

hockey stick (Mann, Bradley, Hughes, JGR, 1999)



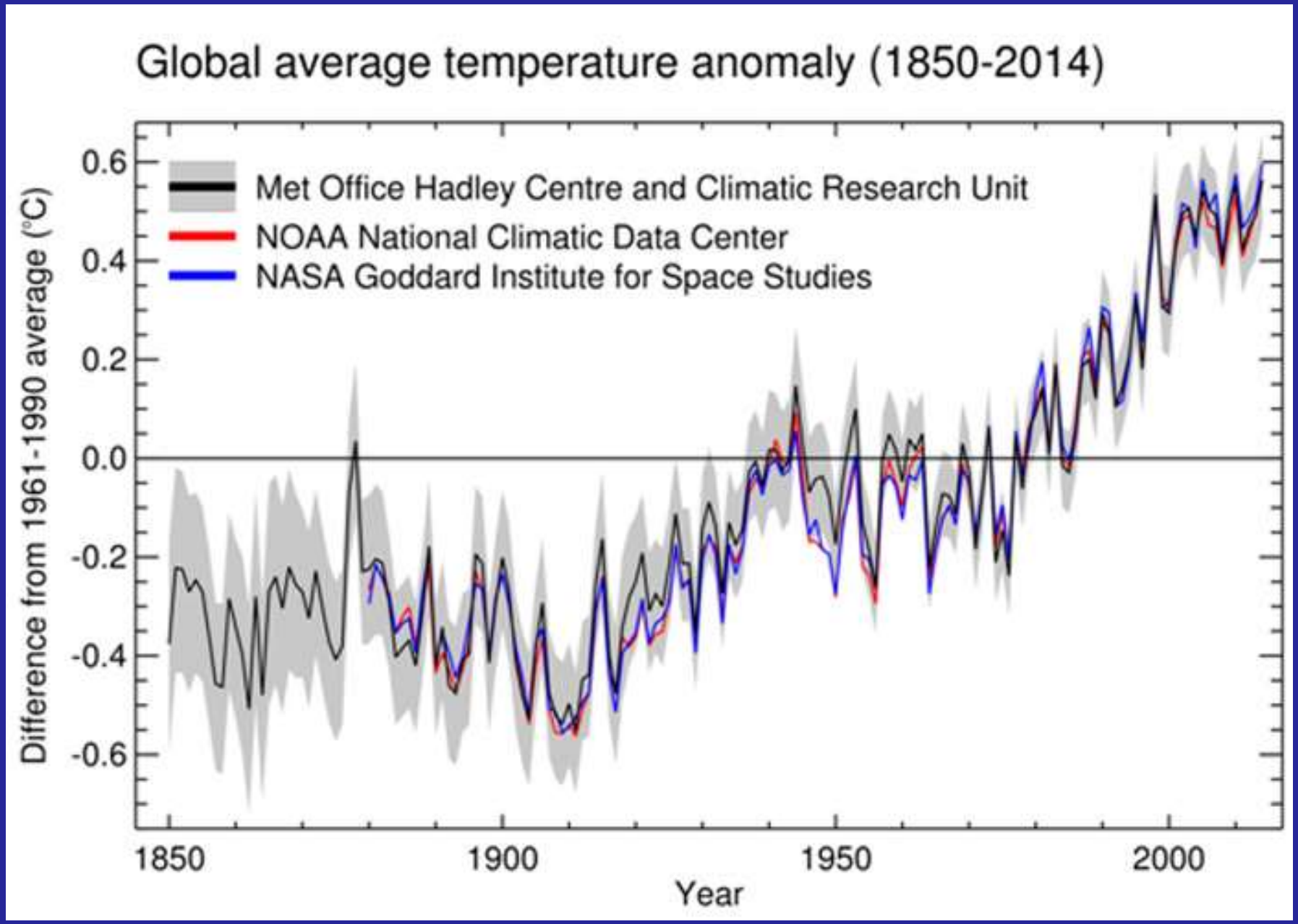
osservazione delle tendenze II

stime della temperatura media dell'emisfero nord



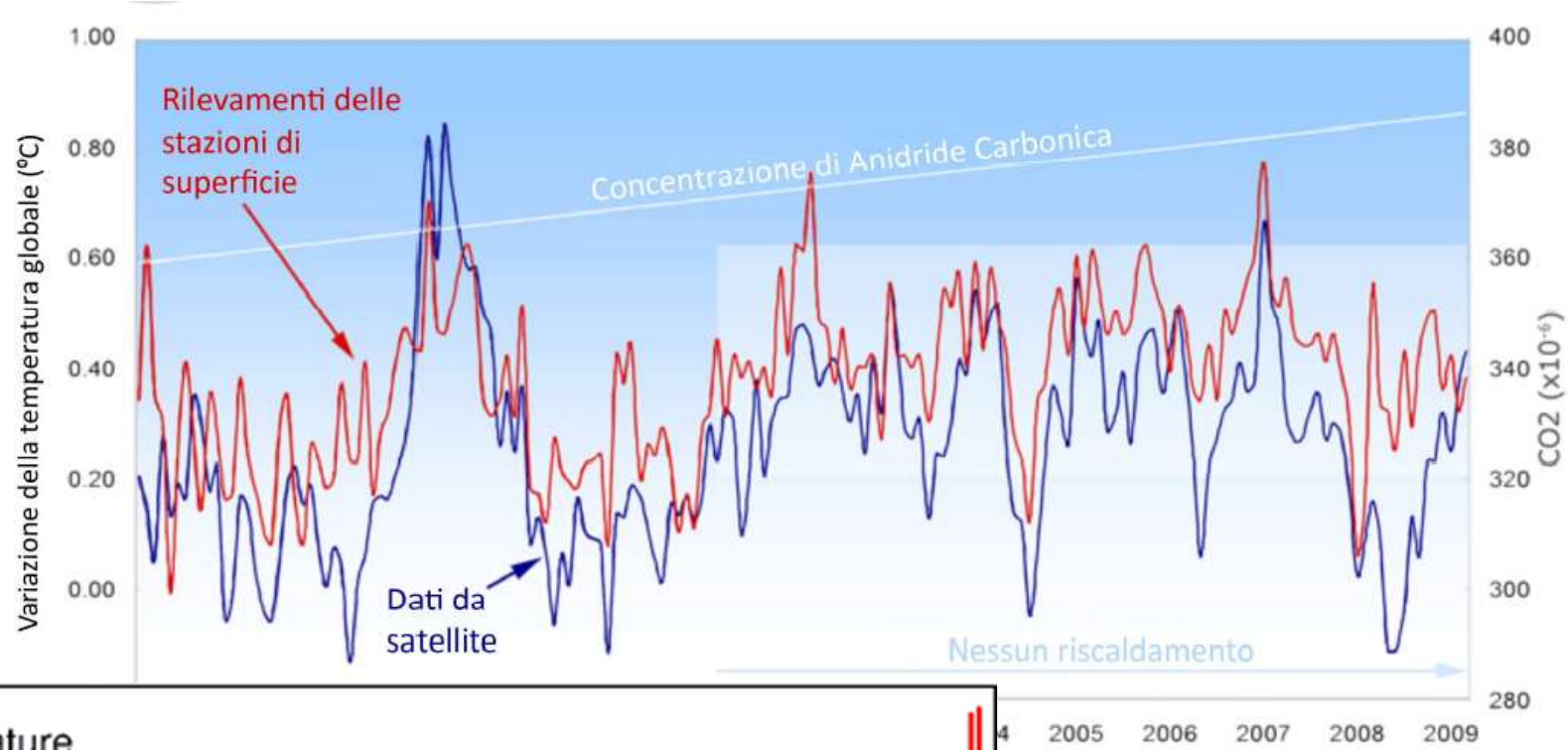
osservazione delle tendenze III

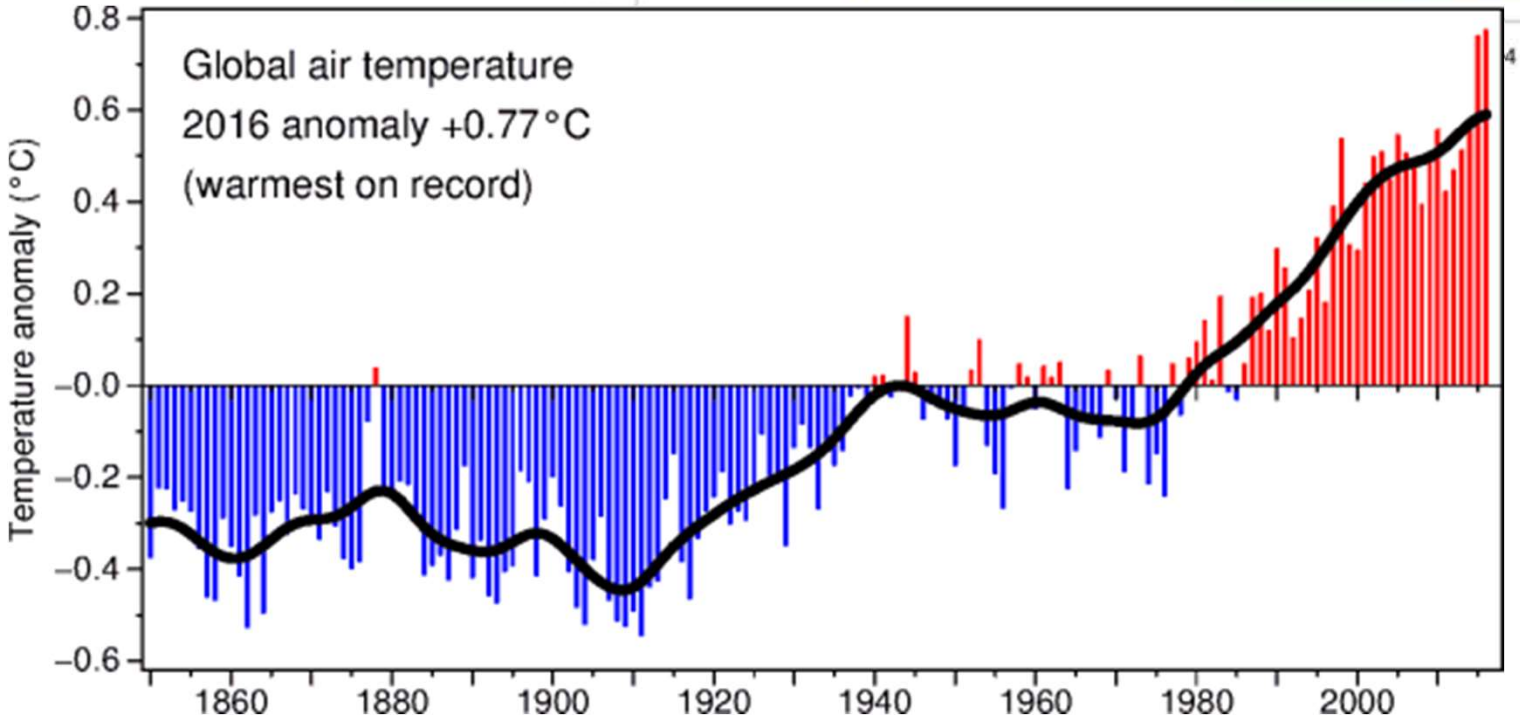
ultimi anni



osservazione delle tendenze III

GW hiatus

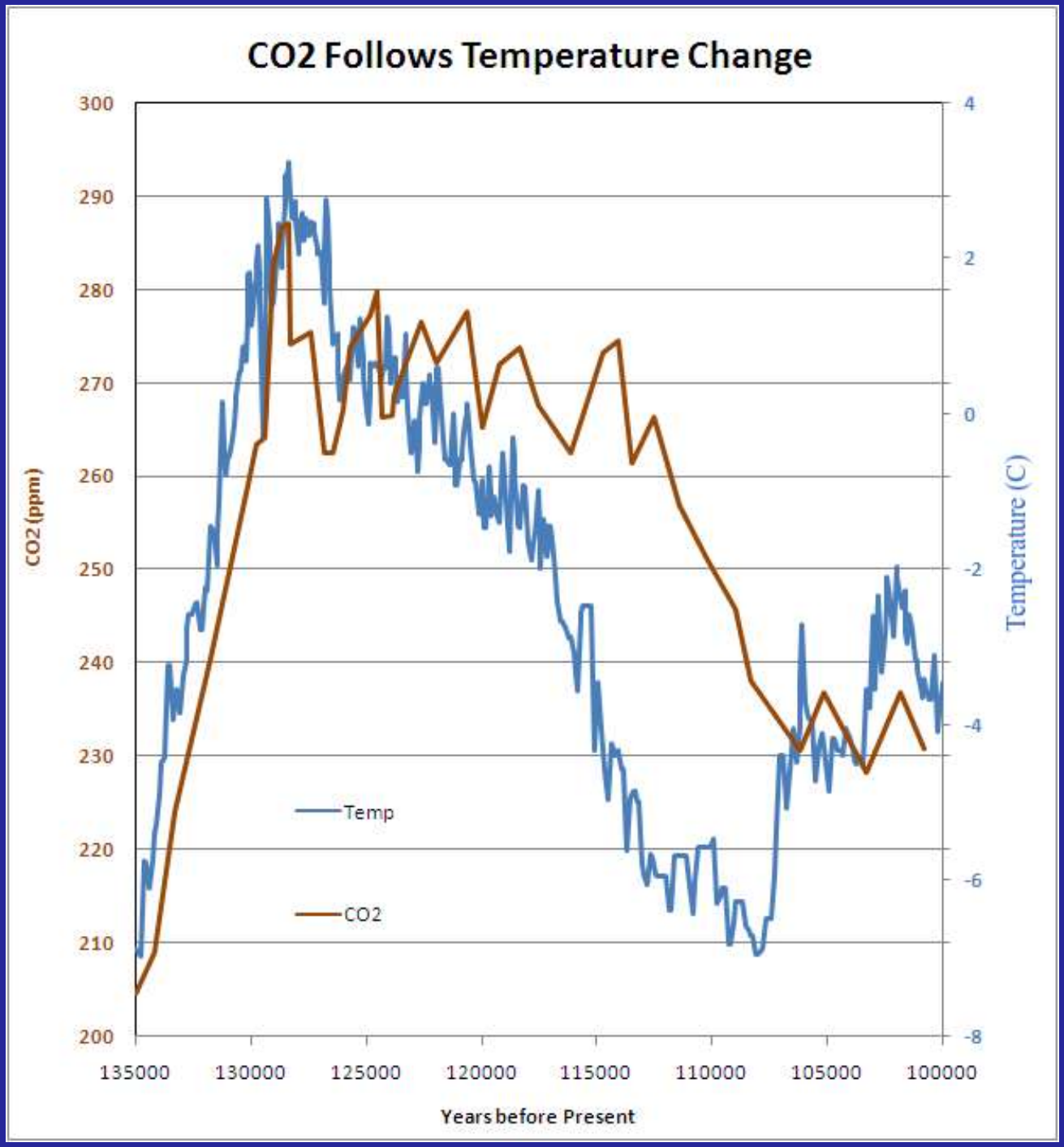




osservazione delle tendenze IV

relazione GHG/ΔT

le variazioni di contenuto di CO_2 seguono di circa 800 anni le variazioni della temperatura

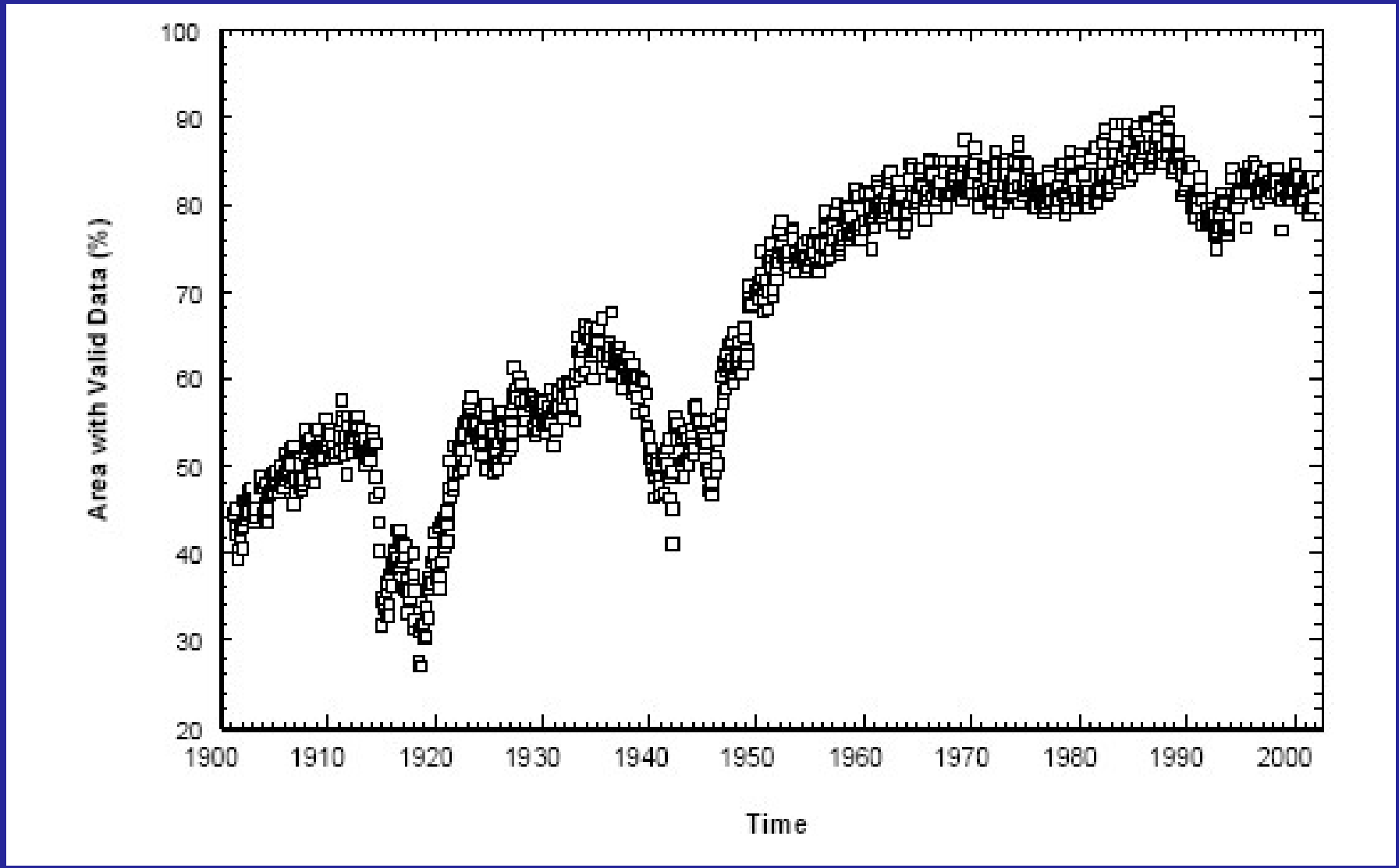


Mudelsee, 2001

osservazione delle tendenze V

copertura globale dei sensori

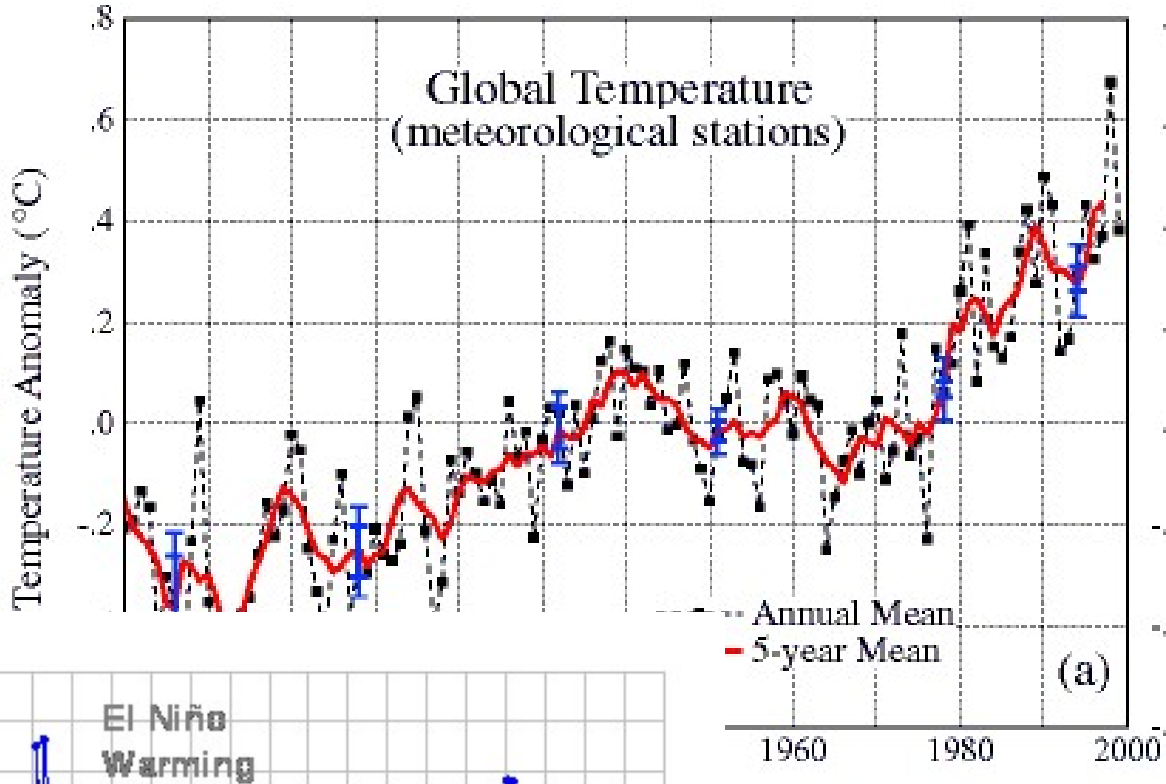
la frazione di superficie globale monitorata varia
5°×5° ~ 550×400 km²

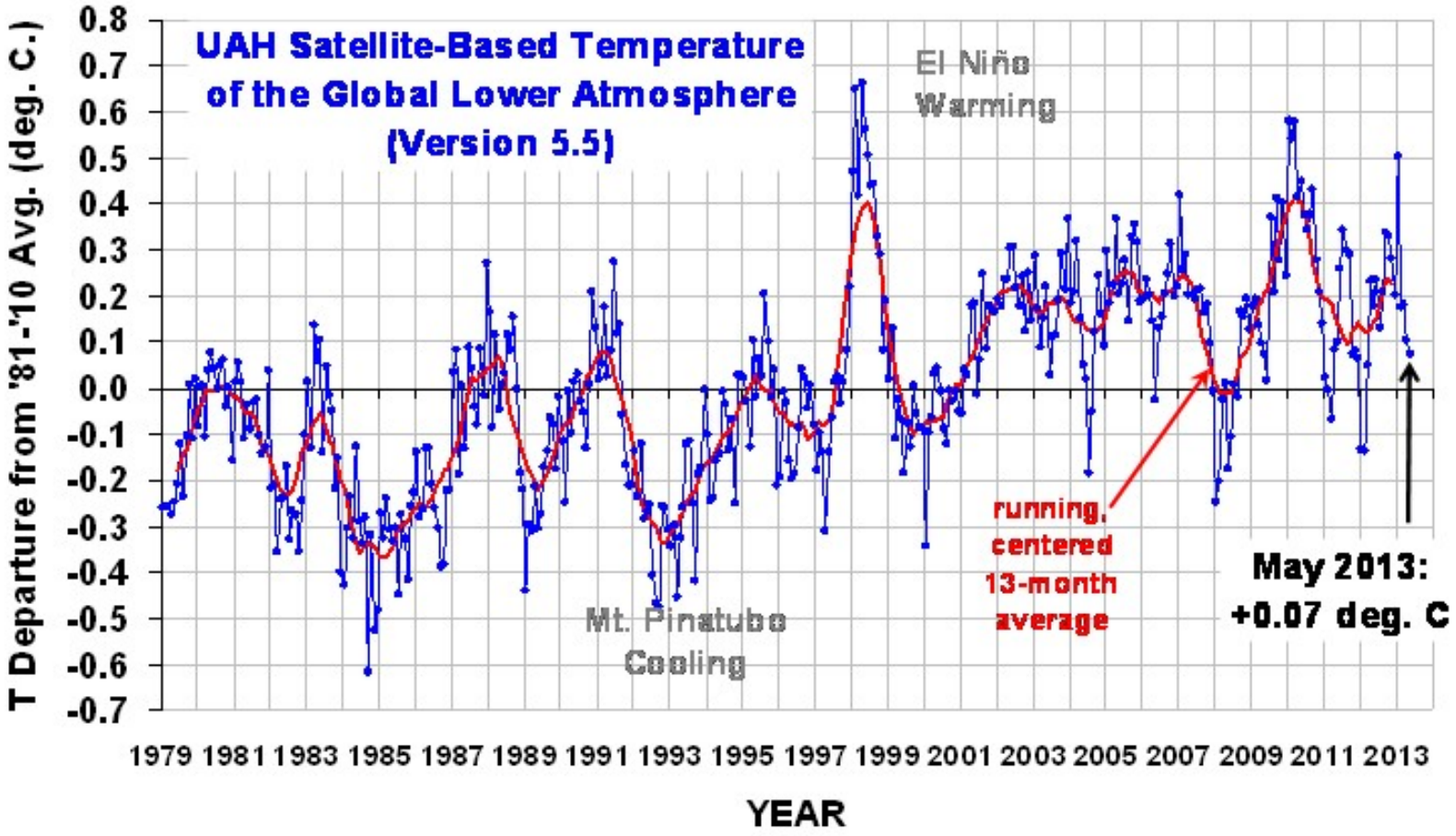


osservazione delle tendenze VI

osservazioni dallo spazio

0,2 K/decade

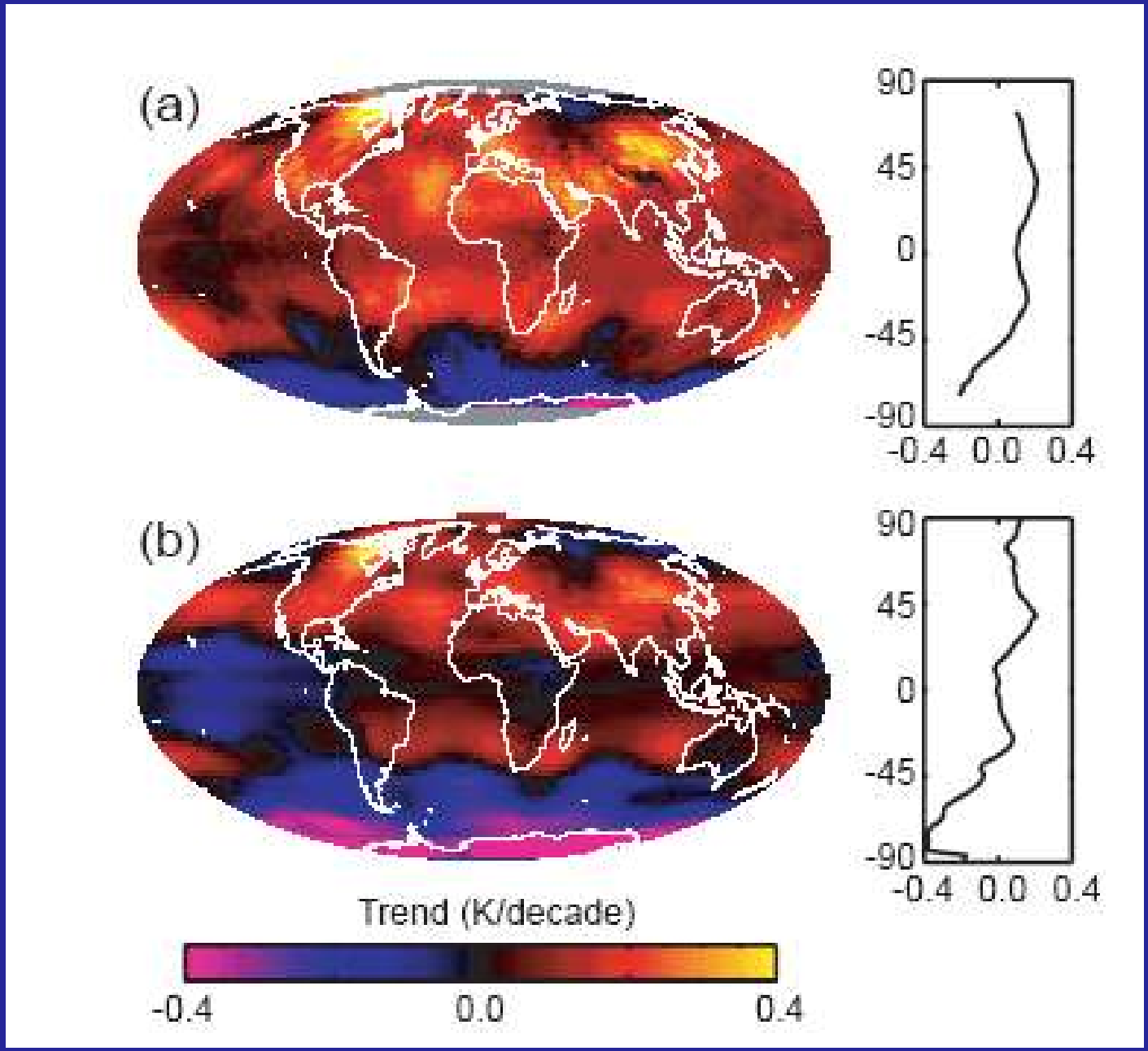




0,09 K/decade

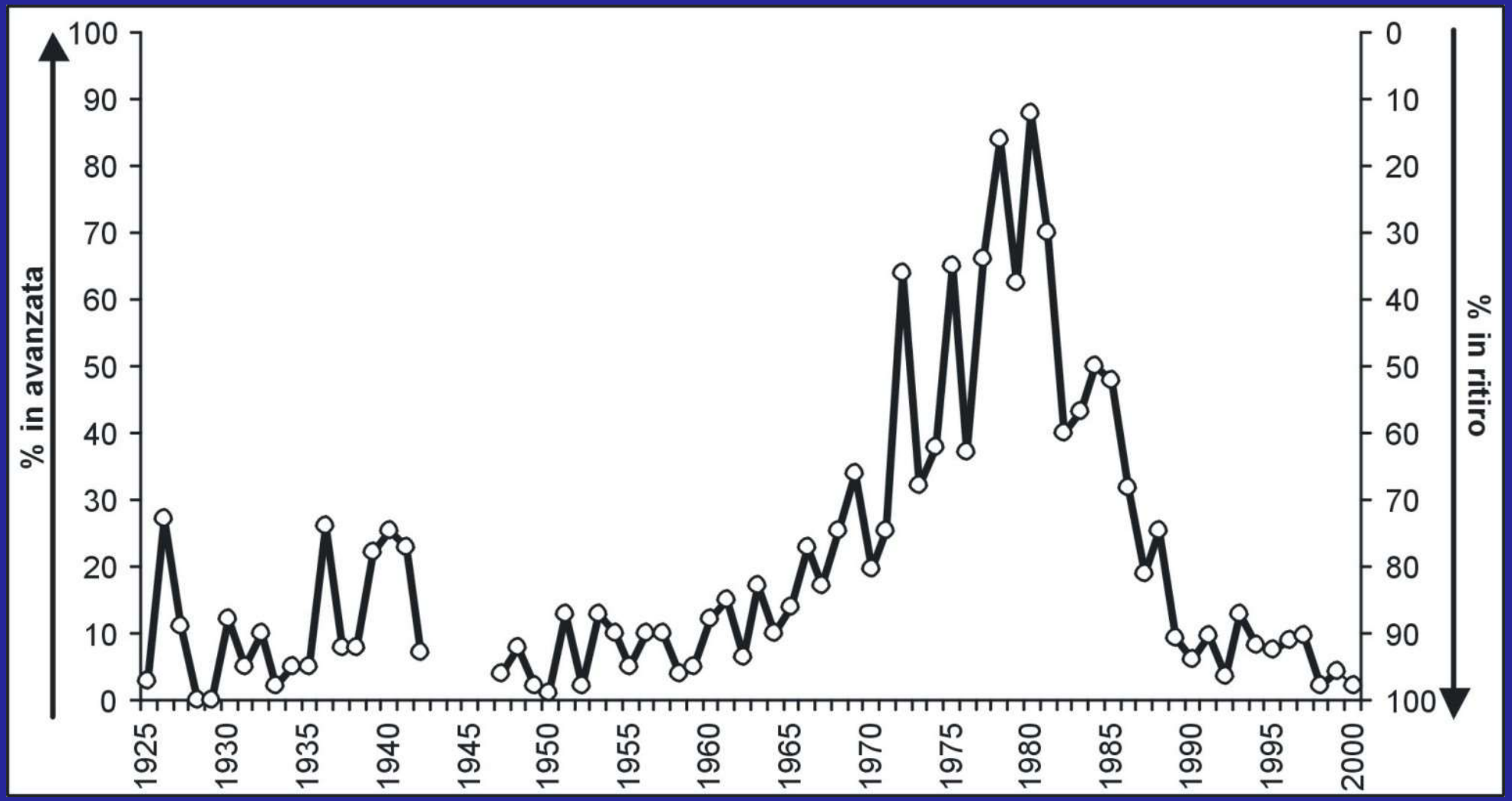
osservazione delle tendenze VIII

Microwave Sounding Unit (MSU)



osservazione delle tendenze IX

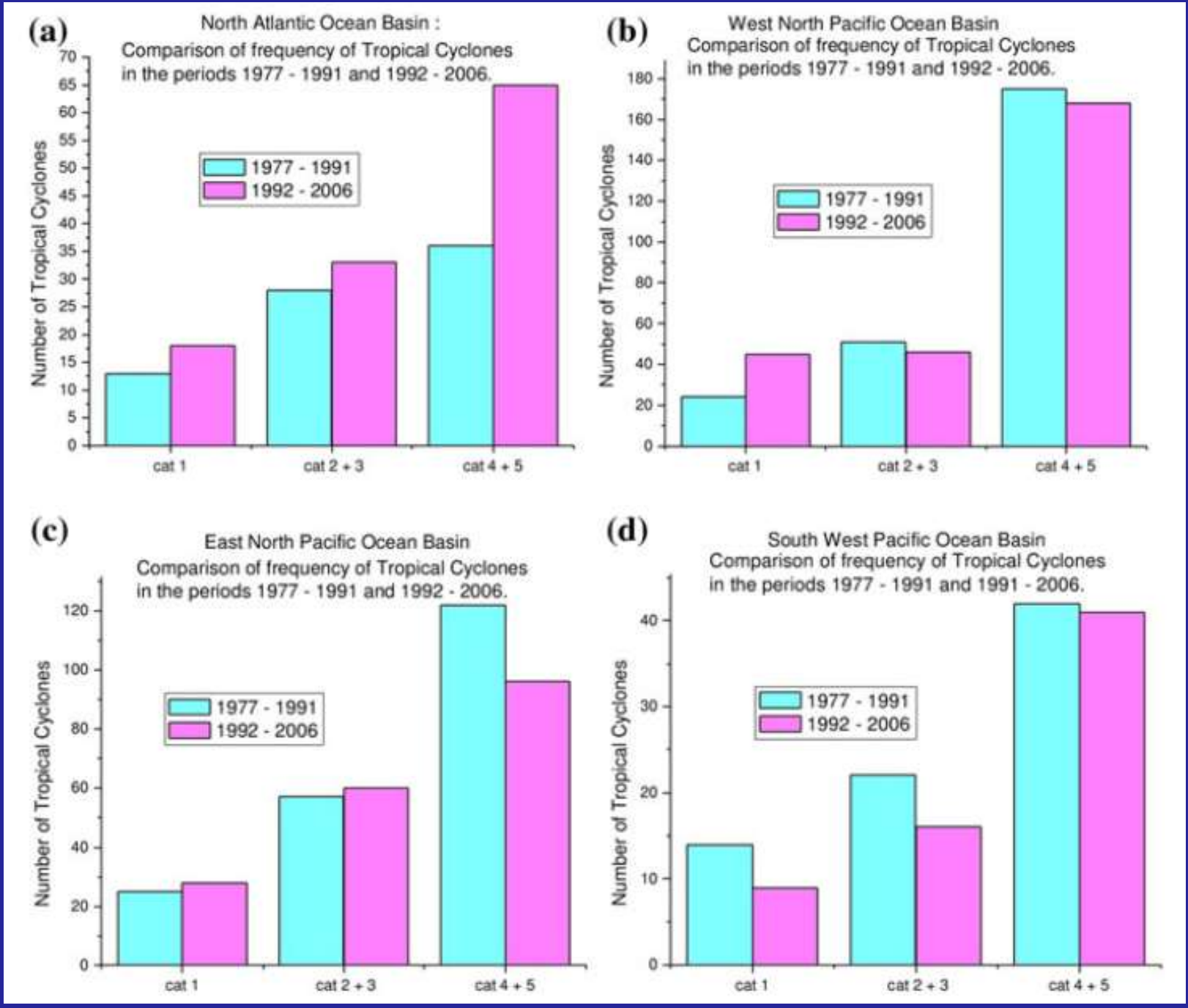
ritiro dei ghiacciai



osservazione delle tendenze X

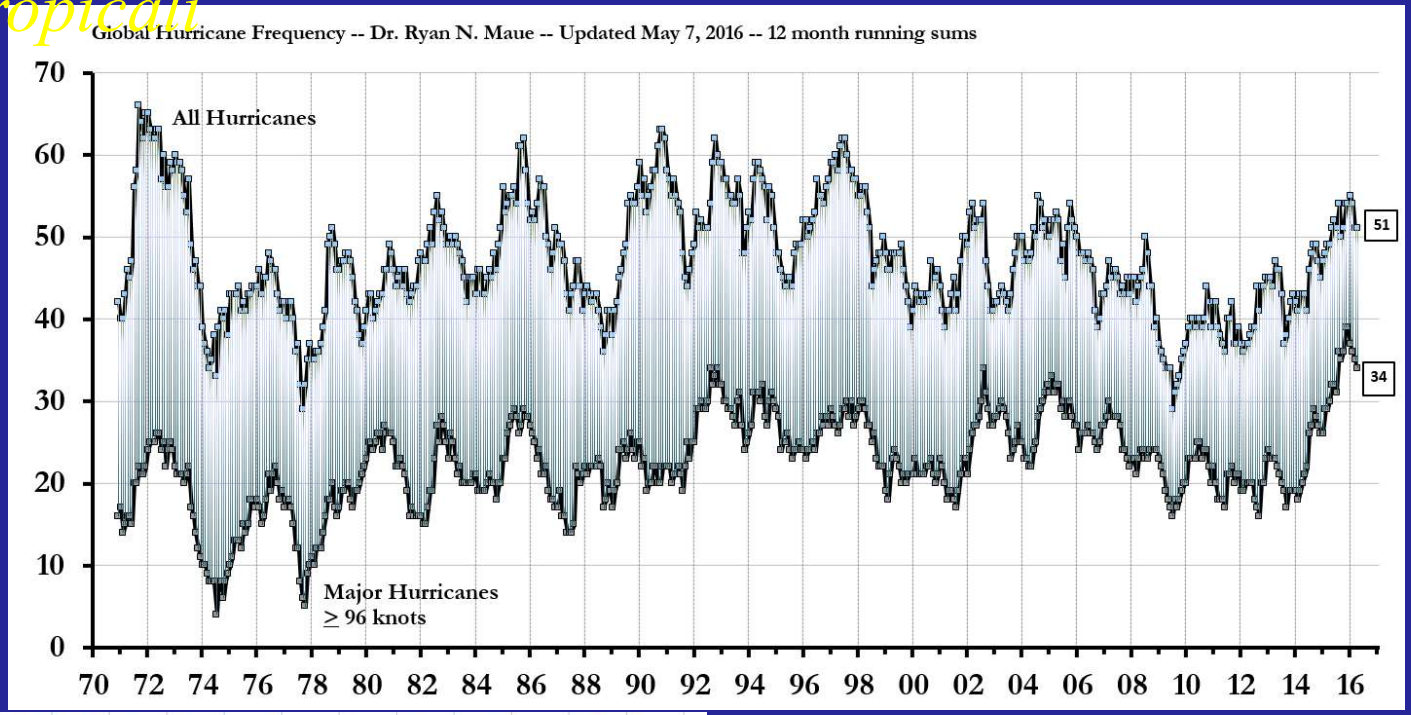
eventi estremi: cicloni tropicali

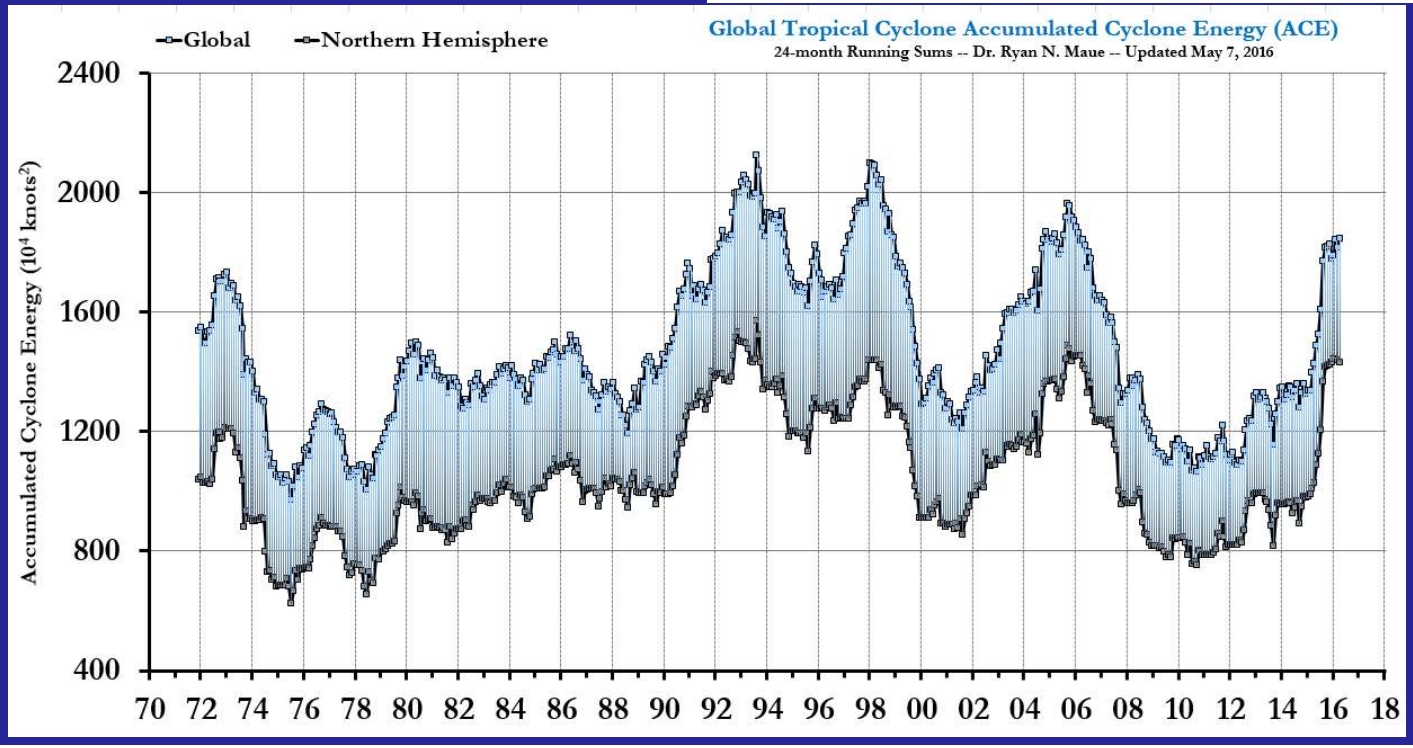
Deo et al., 2011



osservazione delle tendenze X

eventi estremi: cicloni tropicali

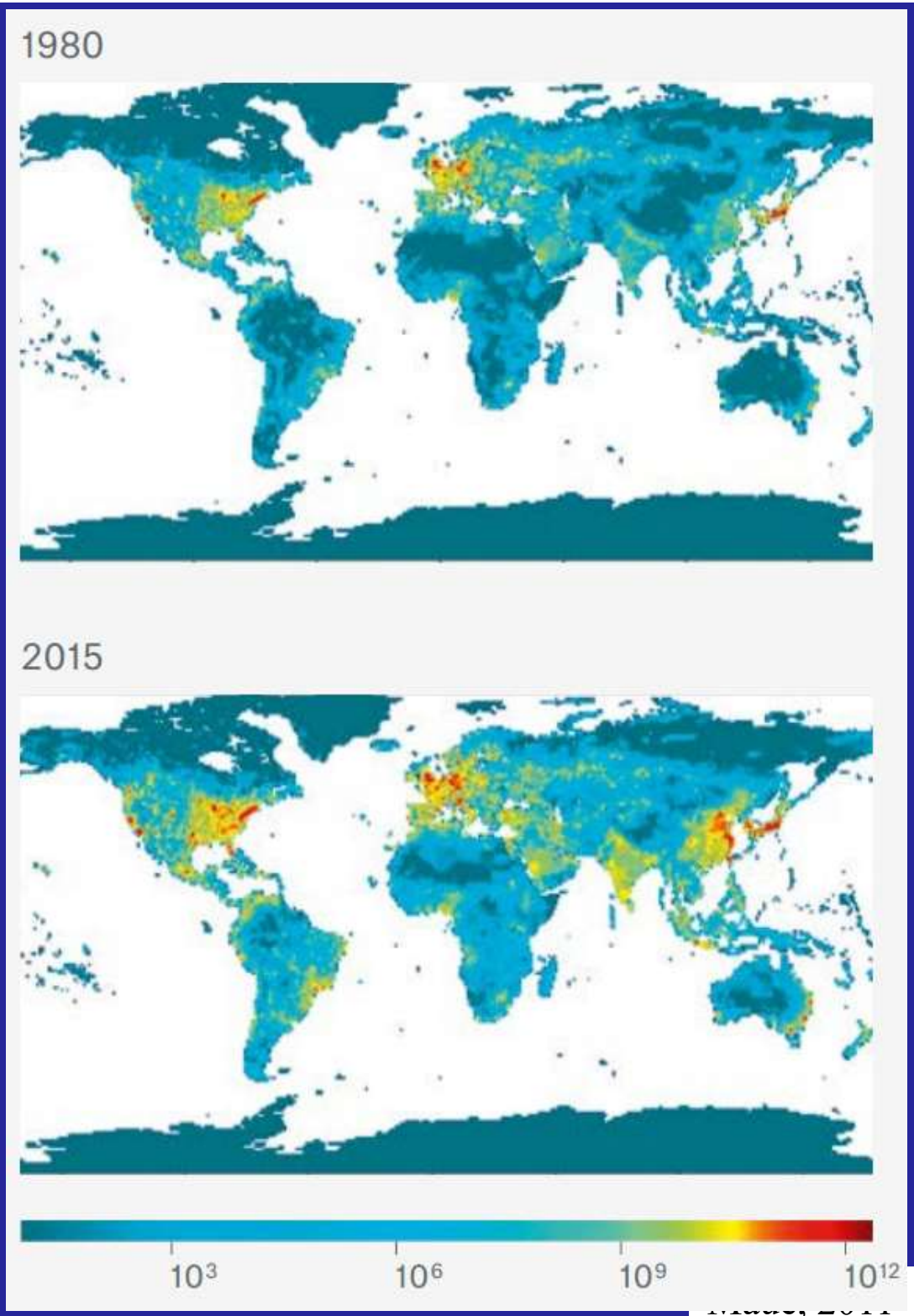




Maue, 2011

osservazione delle tendenze

eventi estremi: PIL

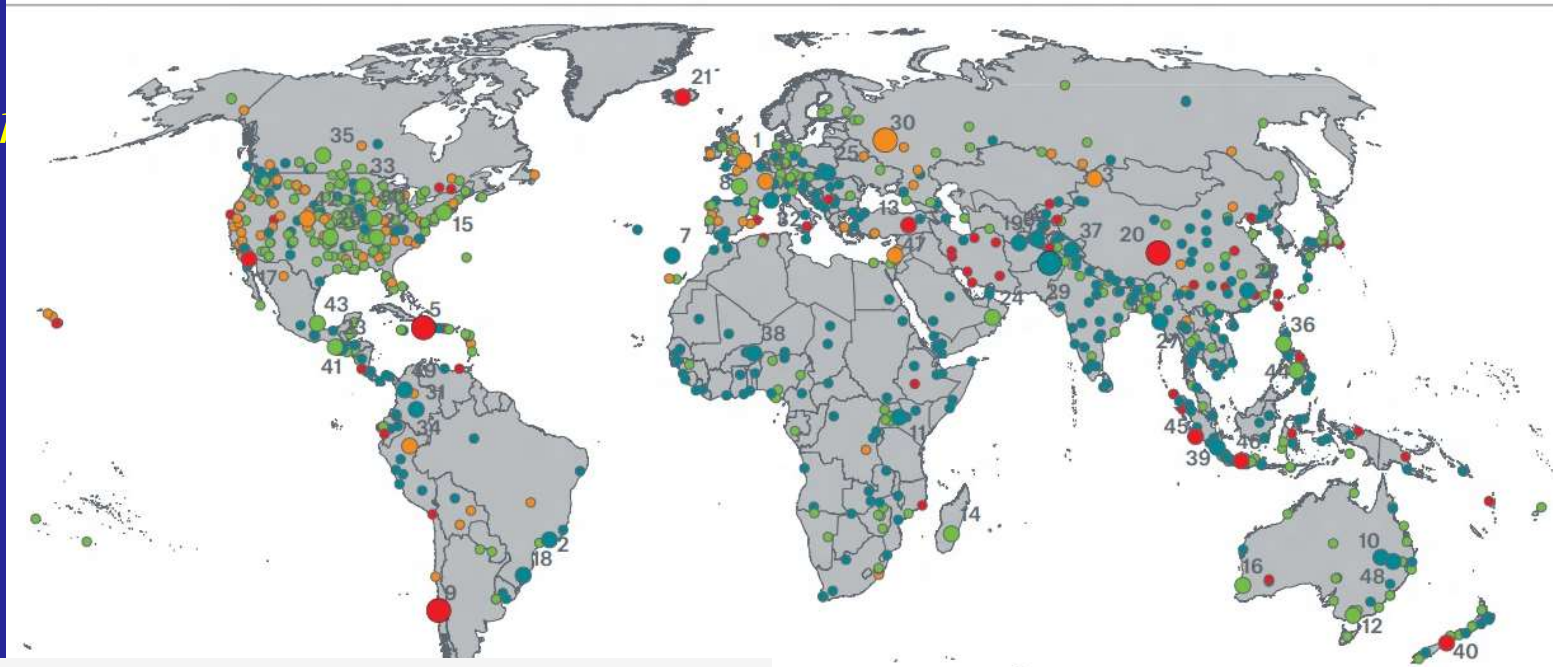


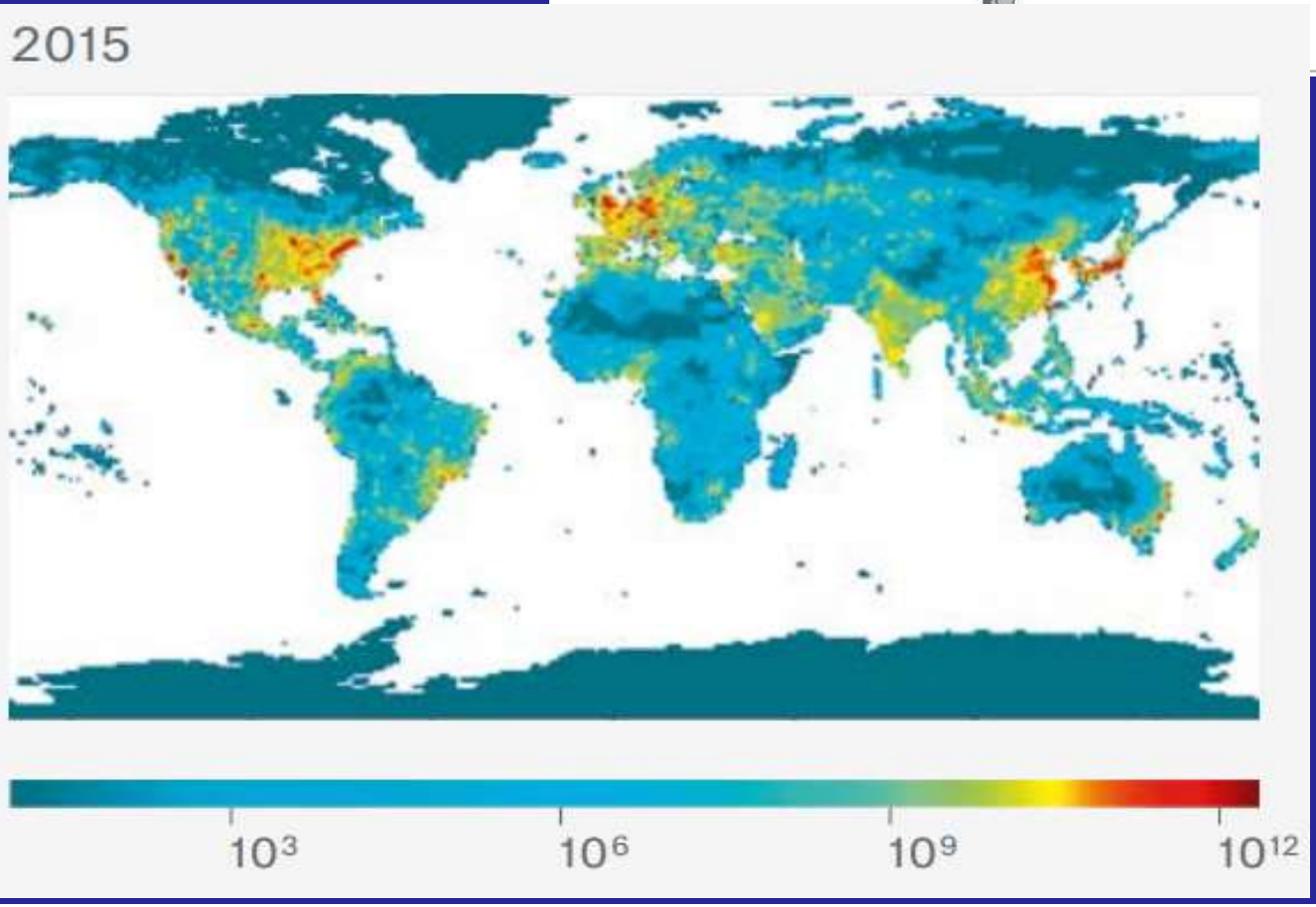
Munich RE

osservazione delle

eventi estremi: dan

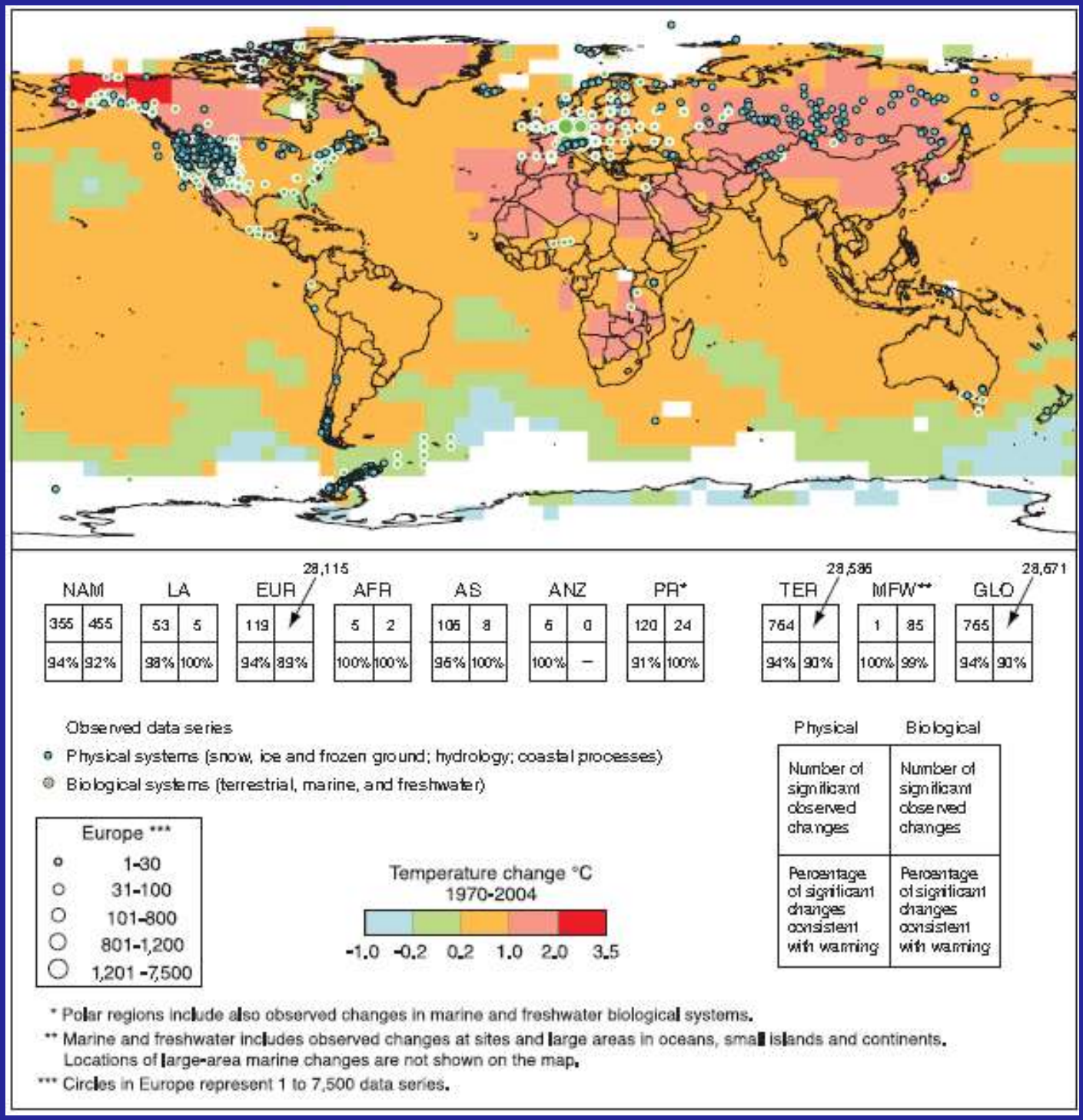
Munich RE





osservazione delle tendenze XI

impatto sui sistemi fisici e biologici



La scienza è fatta di dati come una casa di pietre.
Ma un ammasso di dati non è scienza più di quanto un mucchio di pietre sia una casa.

-Henri Poincaré-

sistemi dinamici, non linearità, caos;

componenti e caratteristiche del sistema climatico terrestre;

un approccio osservativo.

Il sistema climatico è un sistema complesso;

non esiste una definizione univoca e generale di sistema complesso;

definiamo allora un sistema non complesso:

sistema semplice o lineare o riducibile.

sistema: insieme di elementi che interagiscono tra loro con un obiettivo seguendo proprie regole

linearità: l'effetto è proporzionale alla causa

riduzionismo: il sistema può essere compreso studiando separatamente le parti di cui è composto

caratteristiche di un sistema lineare:

- i componenti interagiscono tra loro in modo lineare;

- è riducibile;

- è predicibile;

- è descritto da un numero finito di parametri.

caratteristiche di un sistema non lineare:

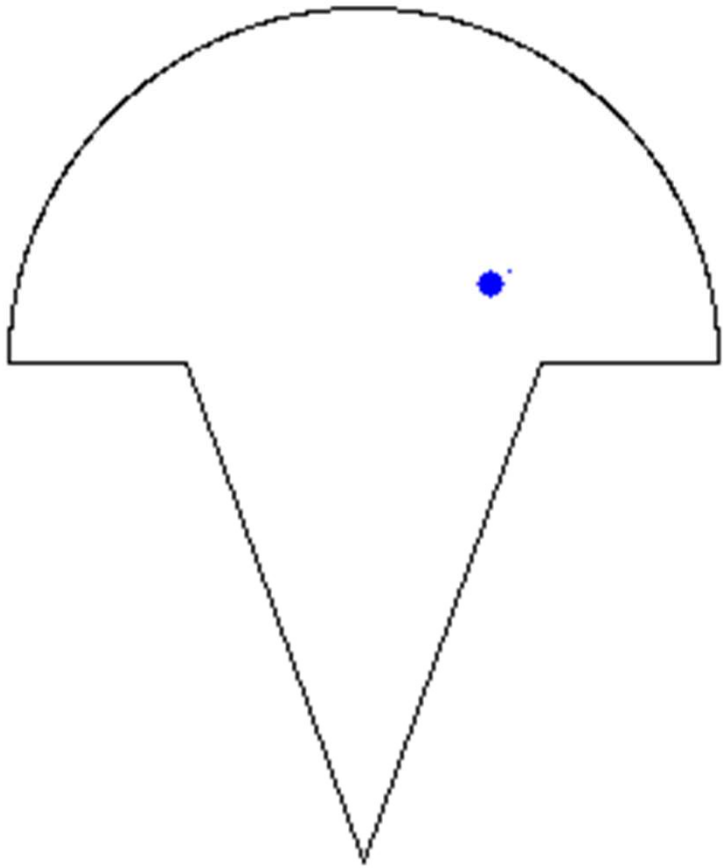
-non è possibile riconoscere il ruolo di ogni singolo elemento in un processo (meccanismi di retroazione);

- è non predicibile (caos, sensibilità alle condizioni iniziali);

- piccole perturbazioni possono dare grandi risposte e viceversa;

- fenomeni di auto-organizzazione (vortici, convezione).

Biliardo
sensibilità alle condizioni iniziali ($\Delta\phi$ = 0.5%)



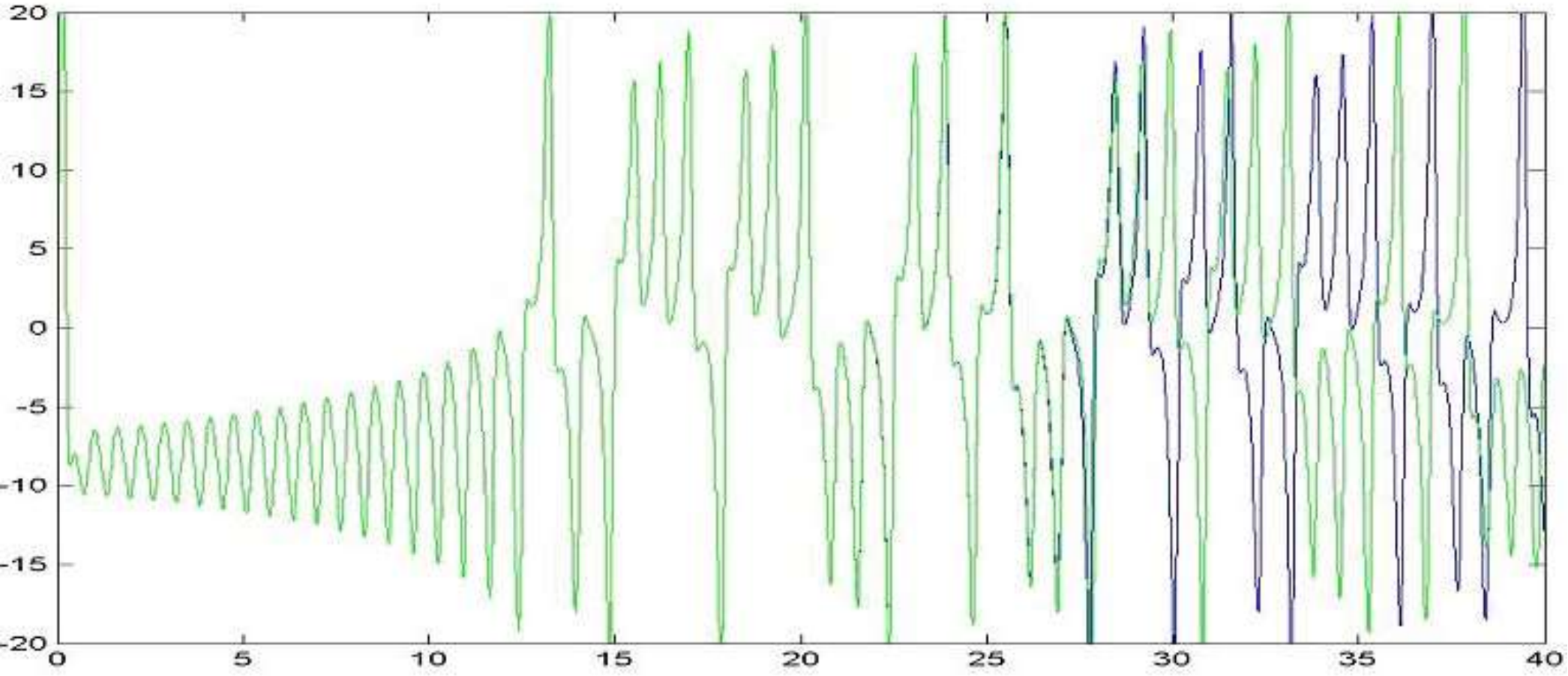
http://www.mpipks-dresden.mpg.de/mpi-doc/kantzgruppe/wiki/Visual.html

Sistema di Lorenz

$$\dot{x} = \sigma(y - x)$$
$$\dot{y} = rx - y - xz$$
$$\dot{z} = xy - bz$$

$x_{(t=0)} = 8$
$y_{(t=0)} = 1$
$z_{(t=0)} = 1$

$x_{(t=0)} = 8$
$y_{(t=0)} = 1.0000001$
$z_{(t=0)} = 1$



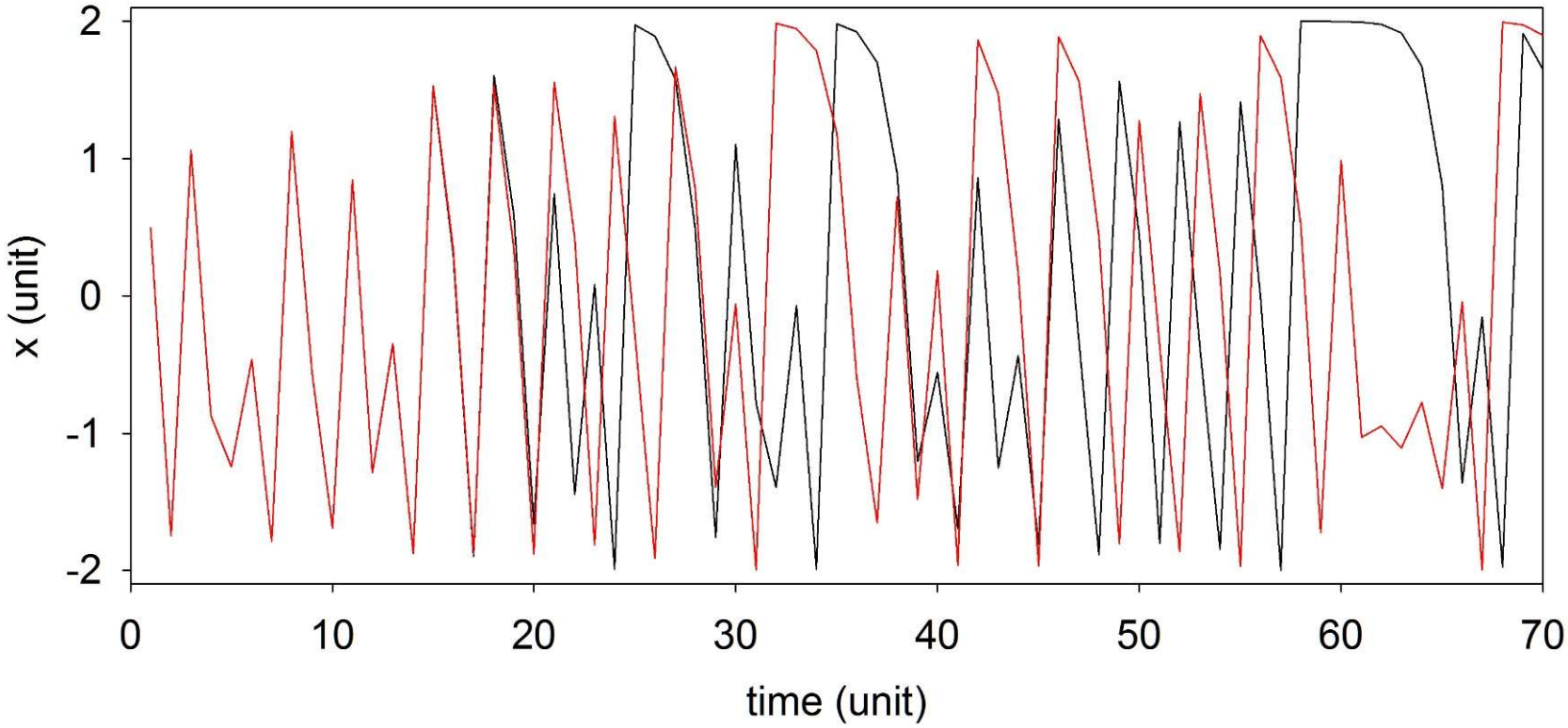
tempo

http://www.ace.gatech.edu/experiments2/2413/lorenz/fall02/

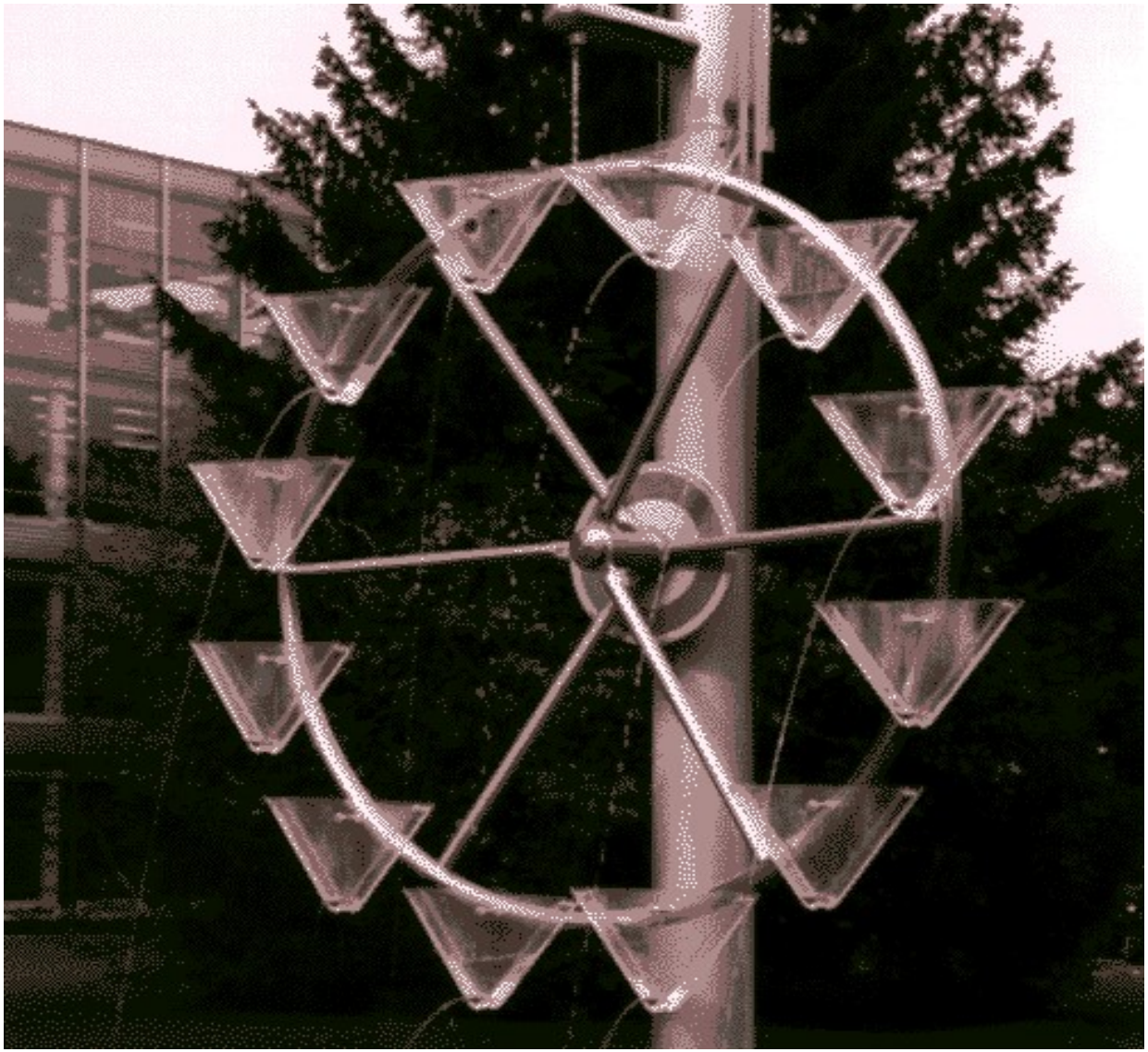
$$x_t = x_{t-1}^2 - 2$$

$x_o = 0.500000$

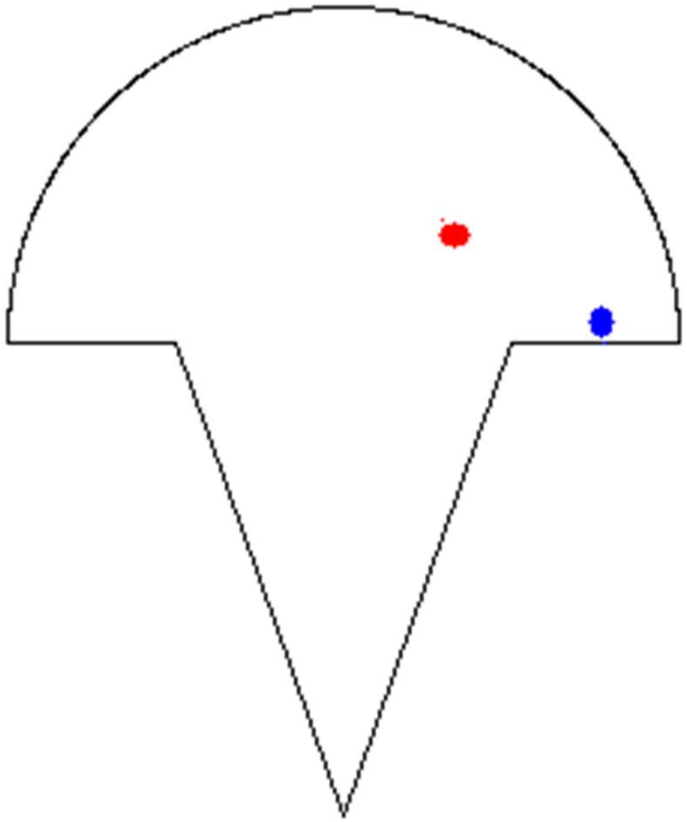
$x'_o = 0.500001$



ruota ad acqua di Lorenz

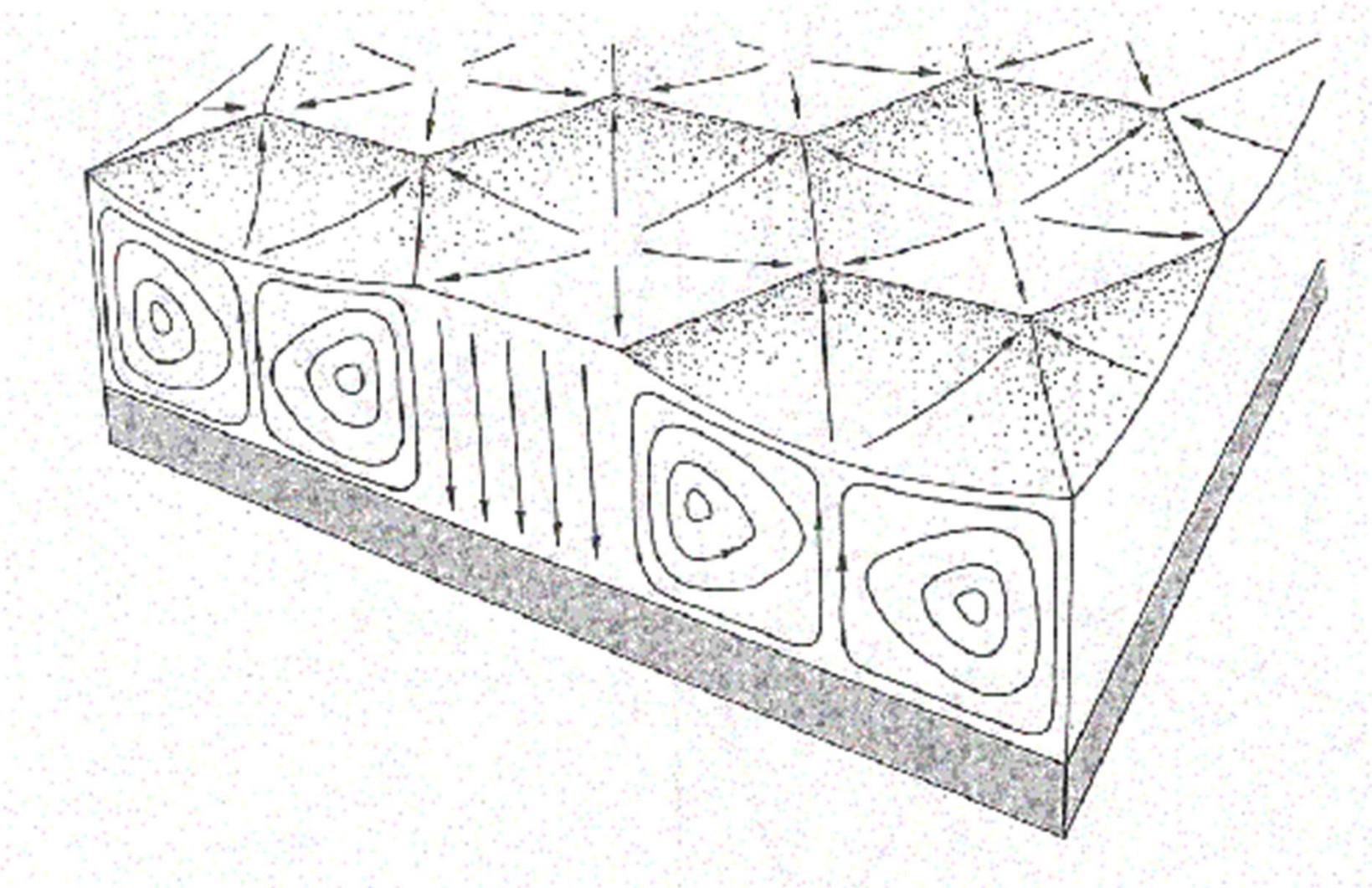


Biliardo
ordine

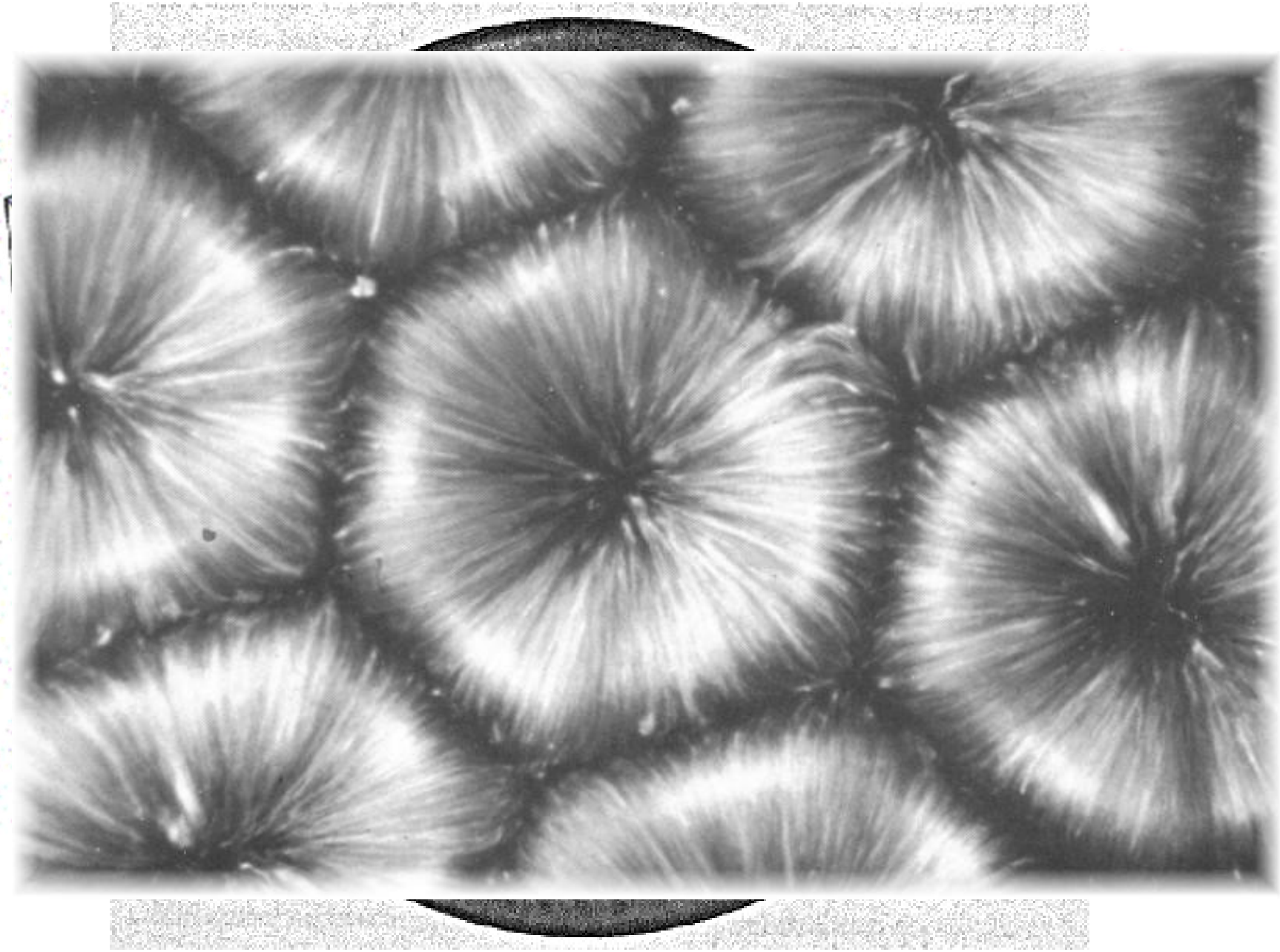


http://www.mpipks-dresden.mpg.de/mpi-doc/kantzgruppe/wiki/Visual.html

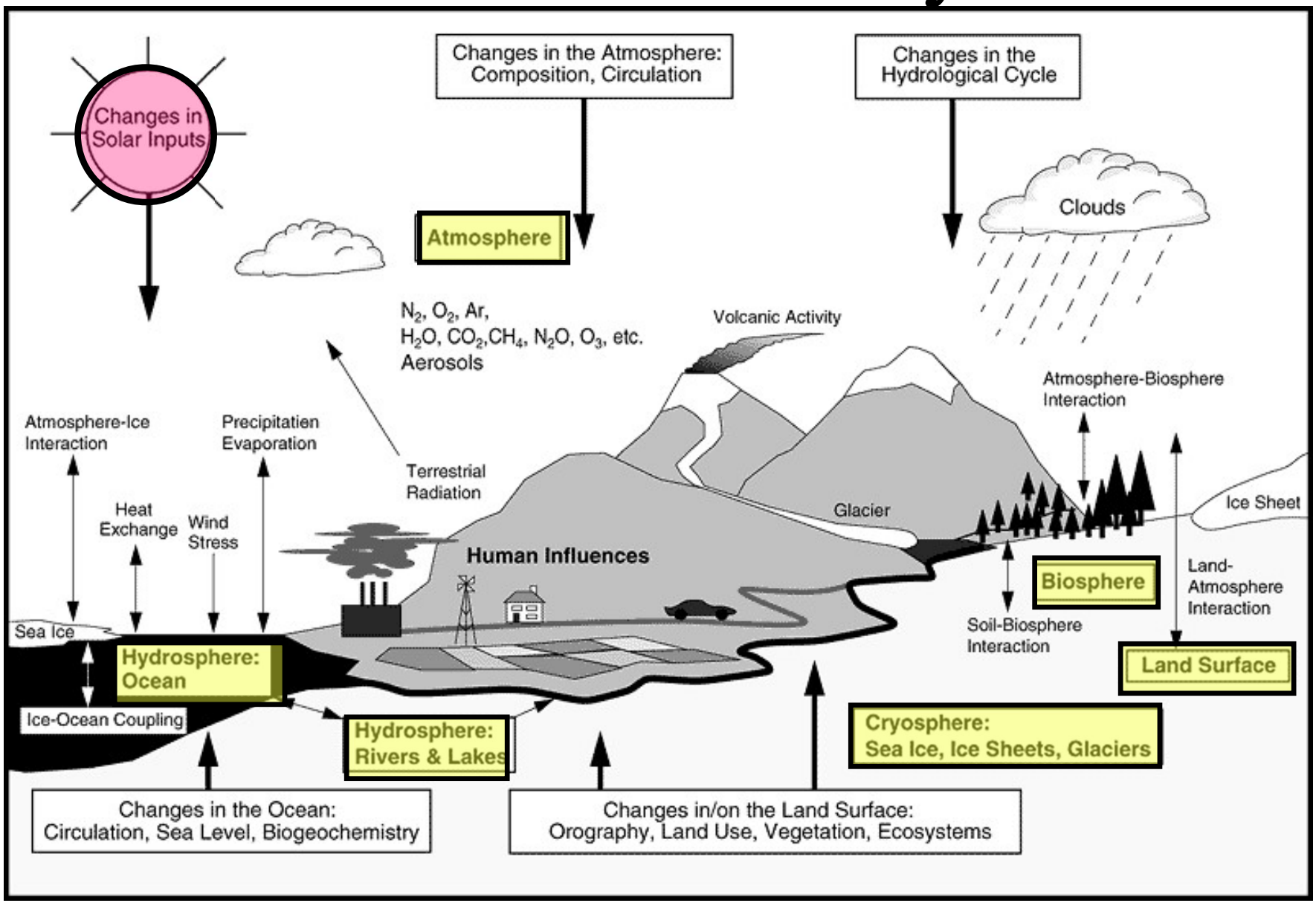
Convezione (Benard)



Convezione (Benard)



The Global Climate System



caratteristiche del sistema climatico:

1) diversi sottosistemi con:
   diversi scale spazio-temporali,
   diverse metodologie di studio,
   diversi livelli di conoscenza;

2) interazioni tra sottosistemi:
   difficilmente osservabili,
   poco studiate,

3) necessità di tempi “sperimentali” lunghi;

4) sistema caotico.

Pubblicità

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

SECOND CYCLE DEGREE/TWO YEAR MASTER IN
SCIENCE OF CLIMATE

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

LAUREA MAGISTRALE IN
FISICA DEL SISTEMA TERRA

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

PHD PROGRAMME
FUTURE EARTH, CLIMATE CHANGE AND SOCIETAL CHALLENGES

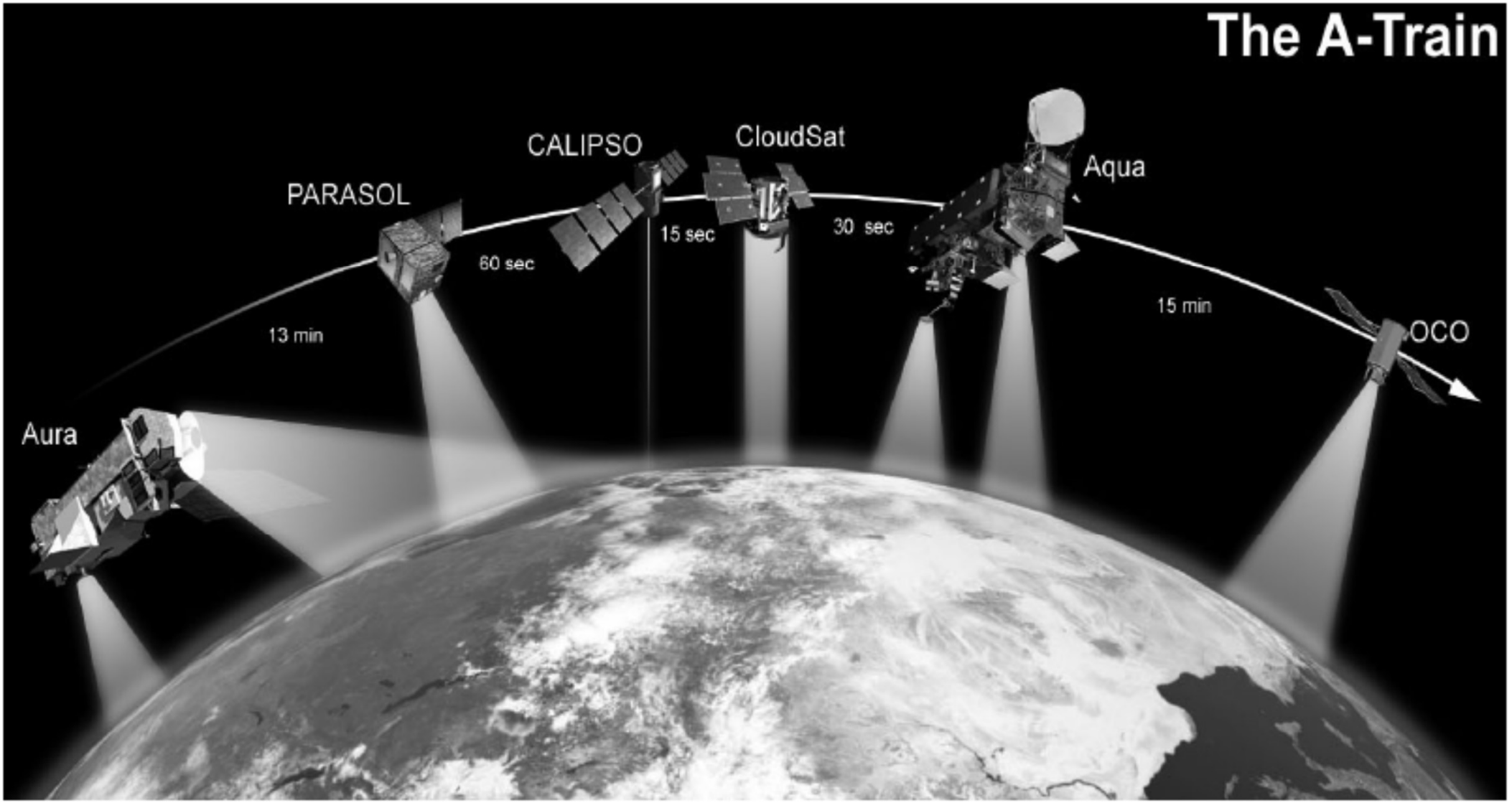
IT EN

*The key to gaining a better understanding of the **global environment** is exploring how the Earth's systems of air, land, water, and life interact with each other, **blending together** fields like meteorology, oceanography, biology, and atmospheric sciences*

1991: Earth Science Enterprise

1999: Earth Observing System

*EOS will observe the key physical variables needed to advance understanding of the entire Earth system and develop a **deeper comprehension** of the **components** of that system and the **interactions** among the components*


The A-Train
PARASOL
CALIPSO
CloudSat
Aqua
OCO
Aura
60 sec
15 sec
30 sec
13 min
15 min

24 EOS Measurements

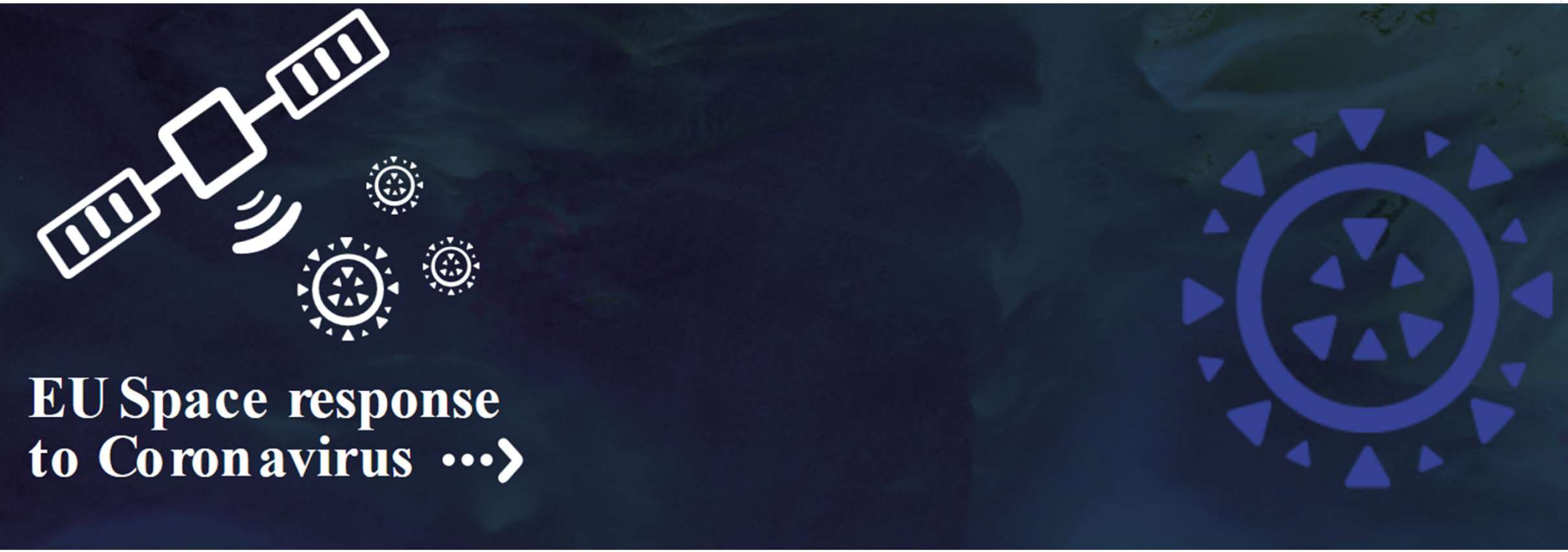
ATMOSPHERE	**Cloud Properties** ***(amount, optical properties, height)***	**MODIS, GLAS, AMSR-E, *MISR*, *AIRS*, *ASTER*,** SAGE III
	Radiative Energy Fluxes ***(top of atmosphere, surface)***	**CERES, ACRIM III, MODIS, AMSR-E, *GLAS*, *MISR*, *AIRS*,** ASTER, SAGE III
	Precipitation	**AMSR-E**
	Tropospheric Chemistry ***(ozone, precursor gases)***	**TES, MOPITT,** SAGE III, MLS, HIRDLS, LIS
	Stratospheric Chemistry ***(ozone, ClO, BrO, OH, trace gases)***	**MLS, HIRDLS, SAGE III, OMI, *TES***
	Aerosol Properties ***(stratospheric, tropospheric)***	**SAGE III, *HIRDLS*** **MODIS, MISR, *OMI*, *GLAS***
	Atmospheric Temperature	**AIRS/AMSU-A, MLS, *HIRDLS*,** TES, MODIS
	Atmospheric Humidity	**AIRS/AMSU-A/HSB, *MLS*, *SAGE III*, *HIRDLS*,** Poseidon 2/JMR/DORIS, MODIS, TES
	Lightning ***(events, area, flash structure)***	**LIS**
SOLAR RADIATION	**Total Solar Irradiance**	**ACRIM III, TIM**
	Solar Spectral Irradiance	**SIM, SOLSTICE**

24 EOS Measurements

LAND	**Land Cover & Land Use Change**	**ETM+, MODIS, *ASTER*, *MISR***
	Vegetation Dynamics	**MODIS, MISR, ETM+, *ASTER***
	Surface Temperature	**ASTER, MODIS, *AIRS*, *AMSR-E*, ETM+**
	Fire Occurrence *(extent, thermal anomalies)*	**MODIS, ASTER, *ETM+***
	Volcanic Effects *(frequency of occurrence, thermal anomalies, impact)*	**MODIS, ASTER, ETM+, *MISR***
	Surface Wetness	**AMSR-E**
OCEAN	**Surface Temperature**	**MODIS, AIRS, *AMSR-E***
	Phytoplankton & Dissolved Organic Matter	**MODIS**
	Surface Wind Fields	**SeaWinds, *AMSR-E*, Poseidon 2/JMR/DORIS**
	Ocean Surface Topography *(height, waves, sea level)*	**Poseidon 2/JMR/DORIS**

24 EOS Measurements

CRYOSPHERE	**Land Ice** ***(ice sheet topography, ice sheet volume change, glacier change)***	**GLAS, ASTER, ETM+**
	Sea Ice ***(extent, concentration, motion, temperature)***	**AMSR-E, *Poseidon 2/JMR/DORIS*,** MODIS, ETM+, ASTER
	Snow Cover ***(extent, water equivalent)***	**MODIS, AMSR-E, *ASTER, ETM+***



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