

# Introduzione al sistema climatico terrestre



# Studio e previsioni dello stato del sistema

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**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, ....**

## temperatura dell'aria ( $h=2\text{ m}$ )

termometri (tempi recenti < 200 anni):

- termometri a mercurio

- termometri a stato solido (termistori)

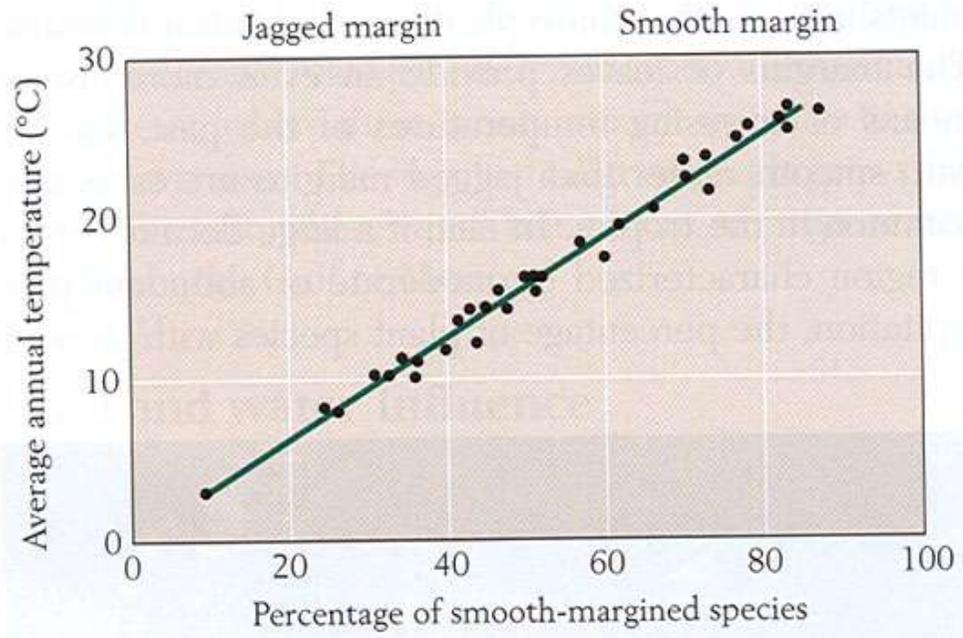
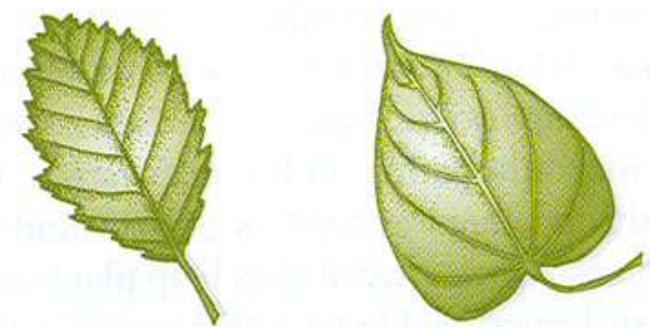
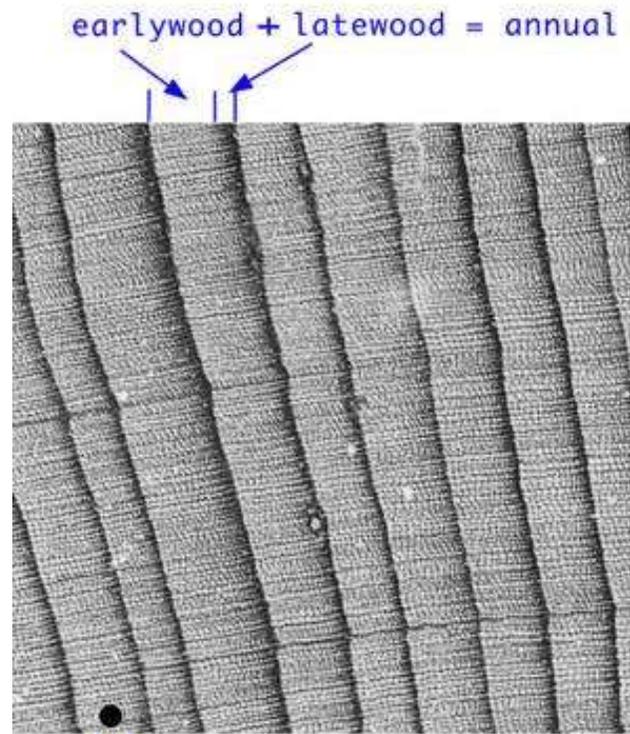
proxy data (paleoclima):

- anelli di accrescimento degli alberi

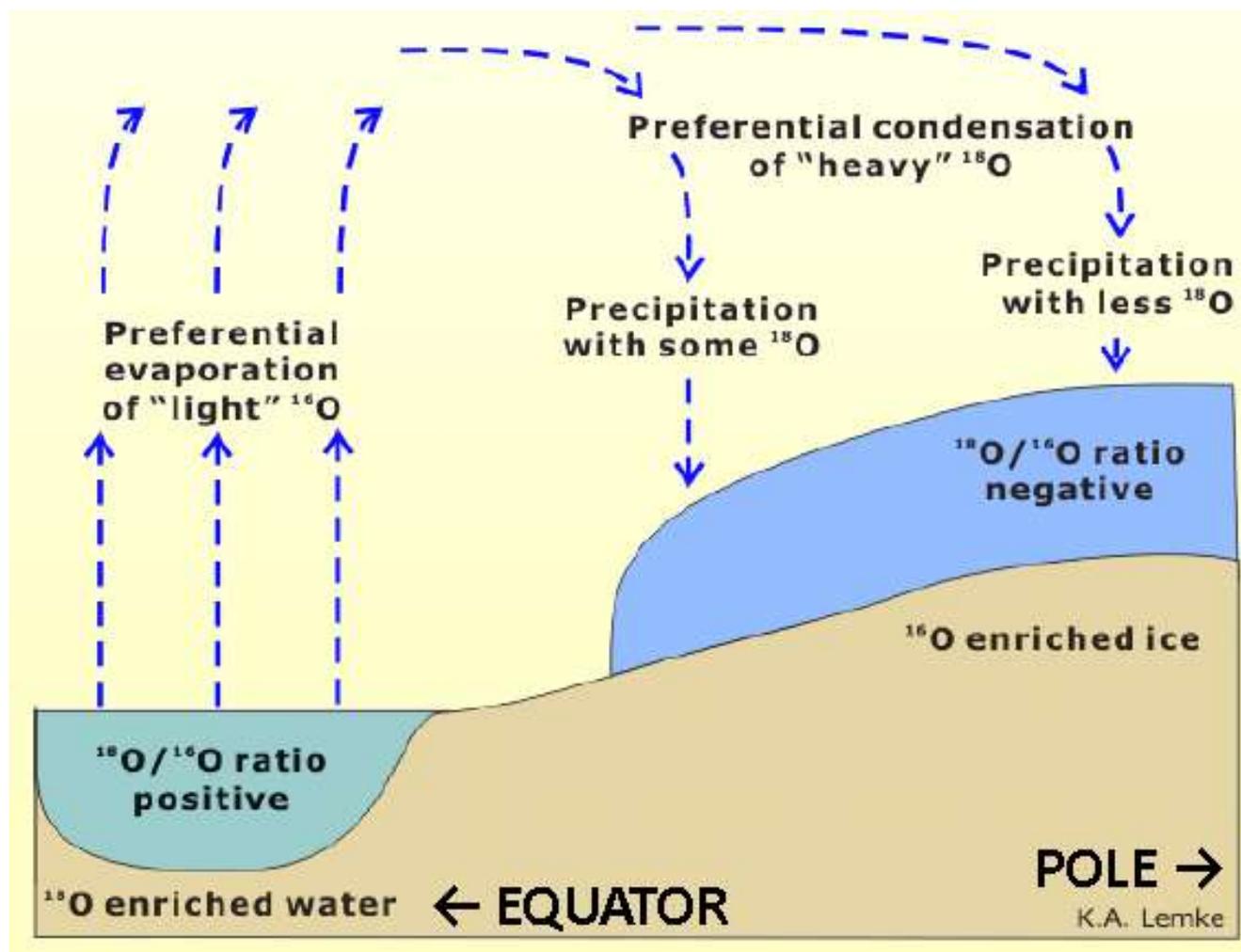
- forma delle foglie

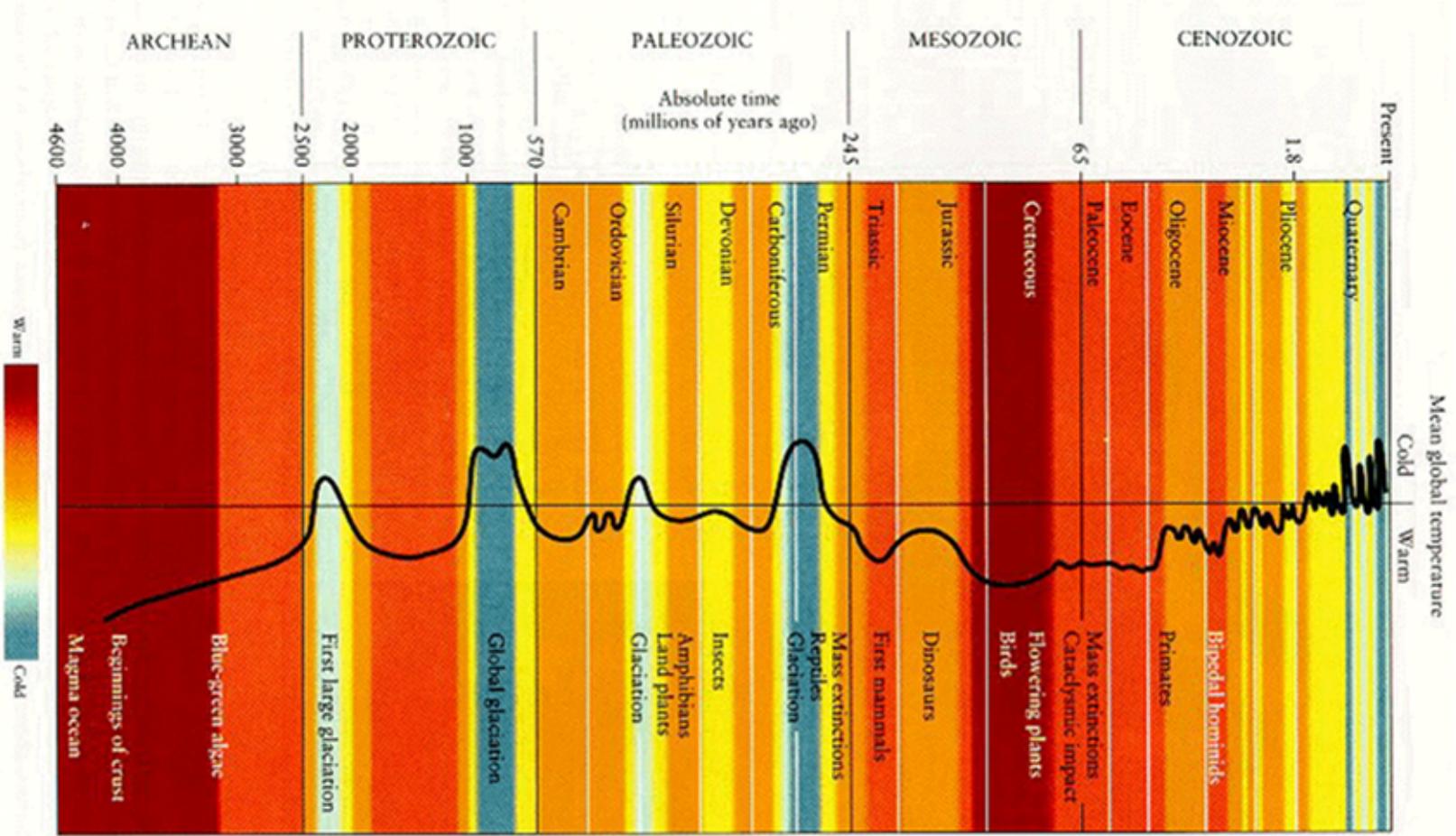
- $O^{16}/O^{18}$

- cronache storiche



1770      1780      1783      1790      1800

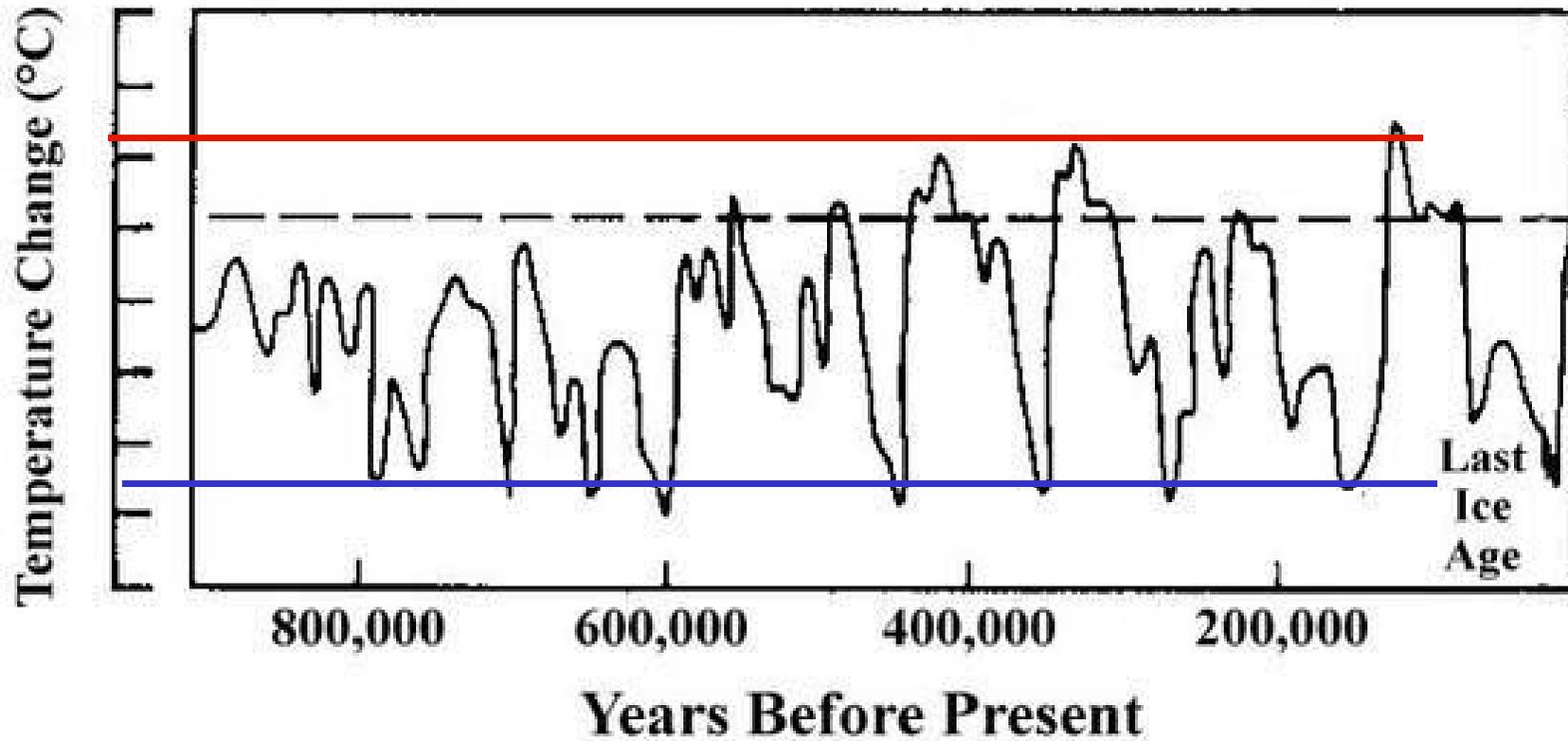




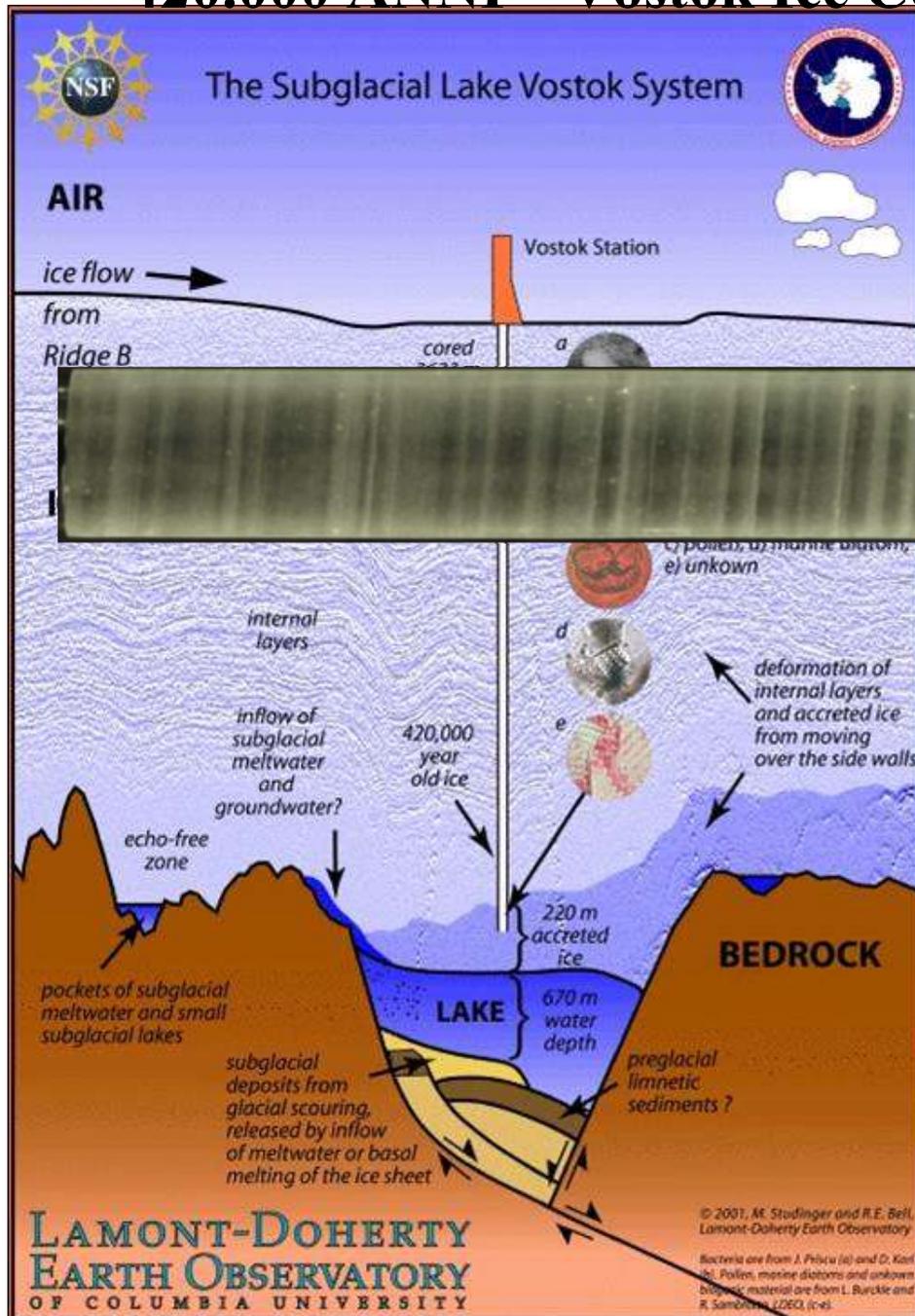
## 4.5 MILIARDI



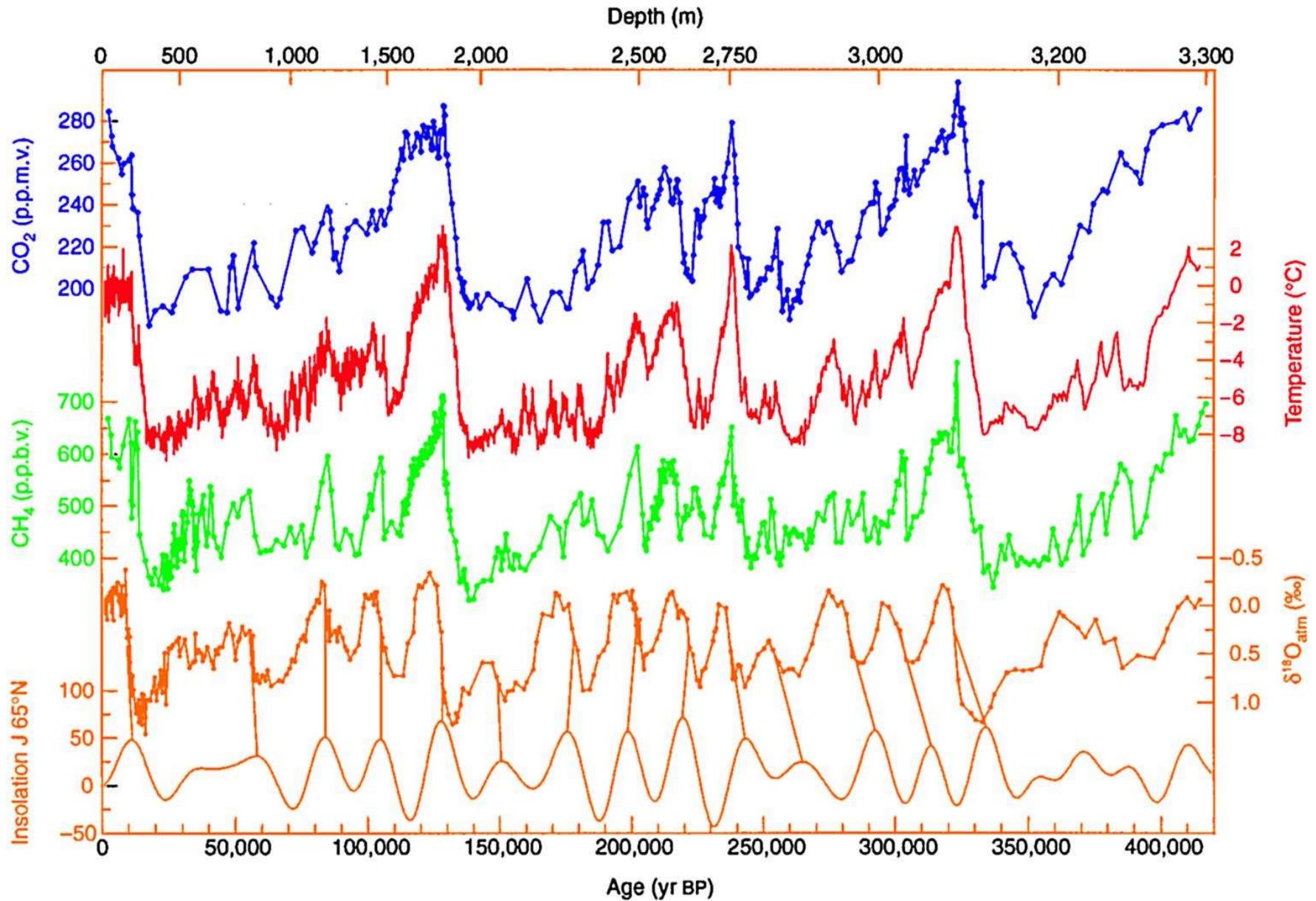
# 1 MILIONE DI ANNI



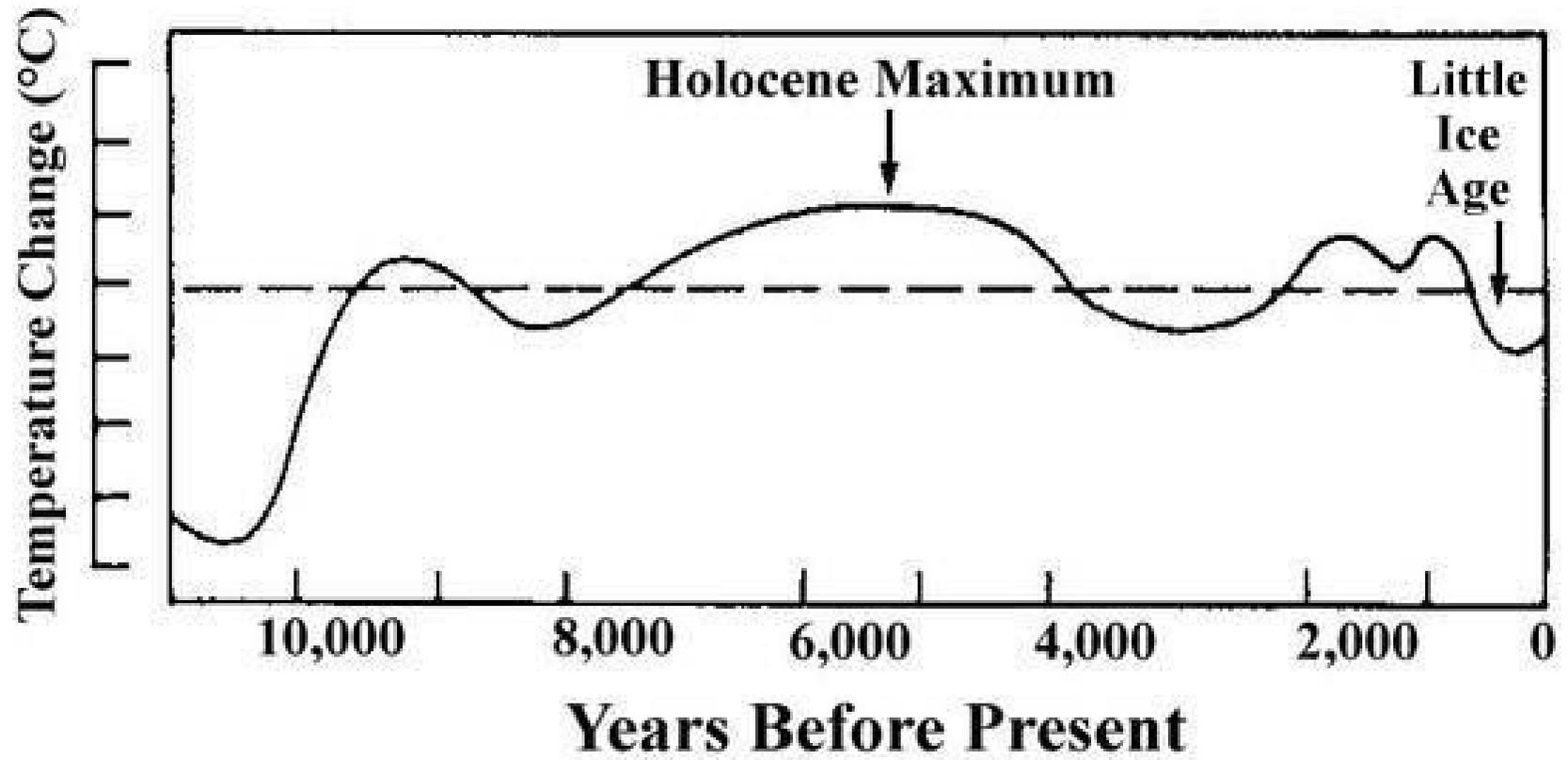
# 420,000 ANNI – Vostok Ice Core



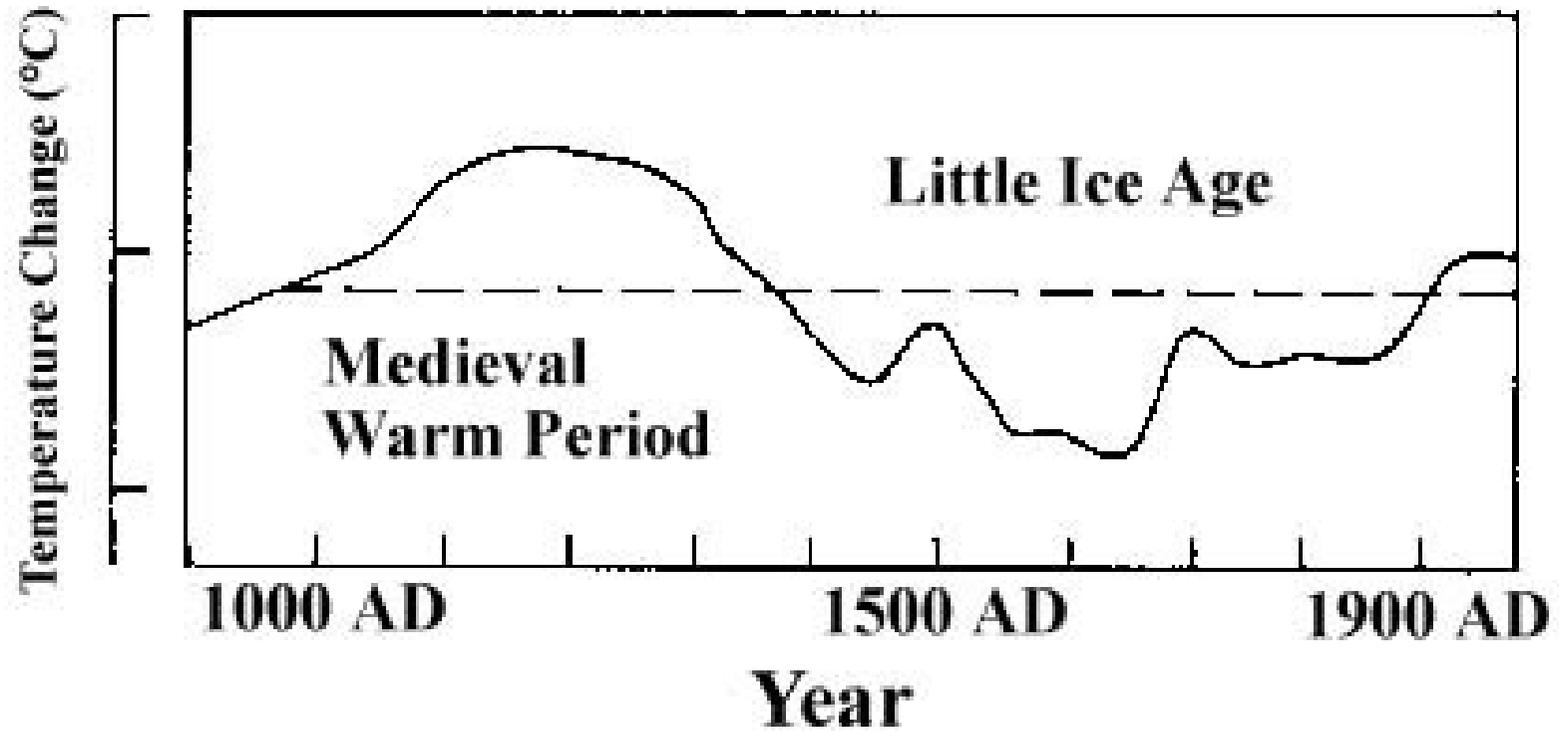
# 420.000 ANNI – Vostok Ice Core



# 10.000 ANNI

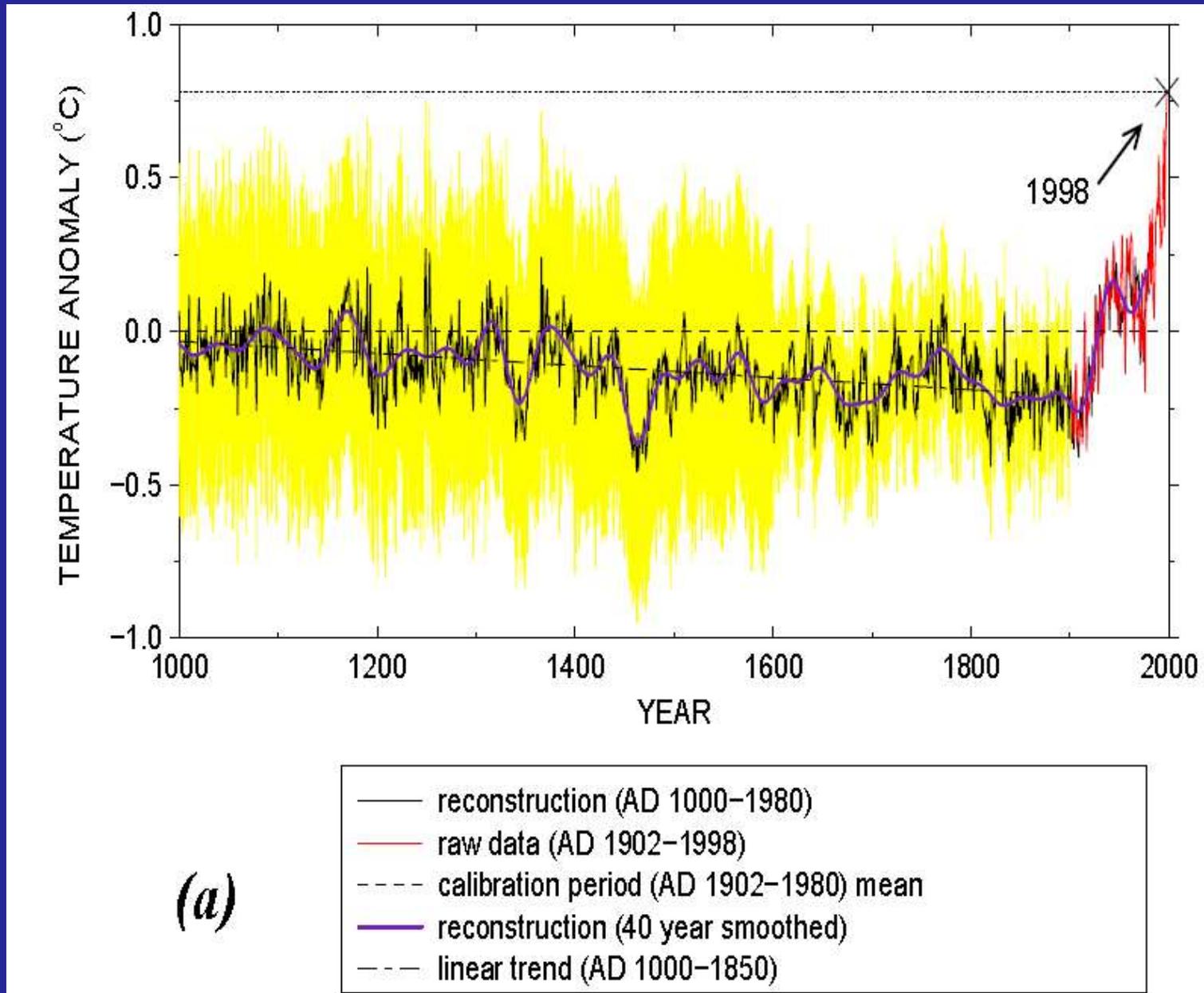


# 1.000 ANNI



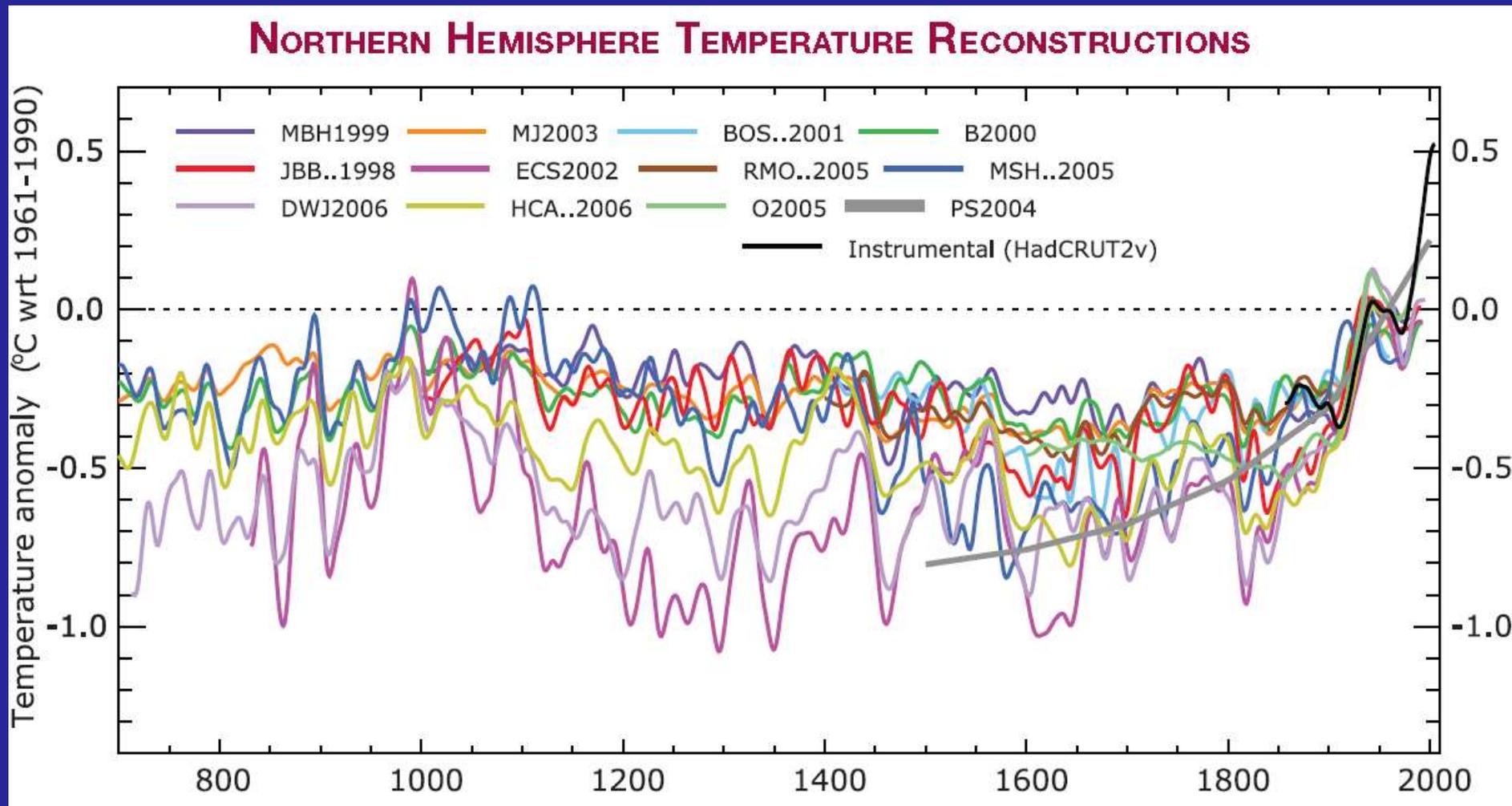
# osservazione delle tendenze I

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



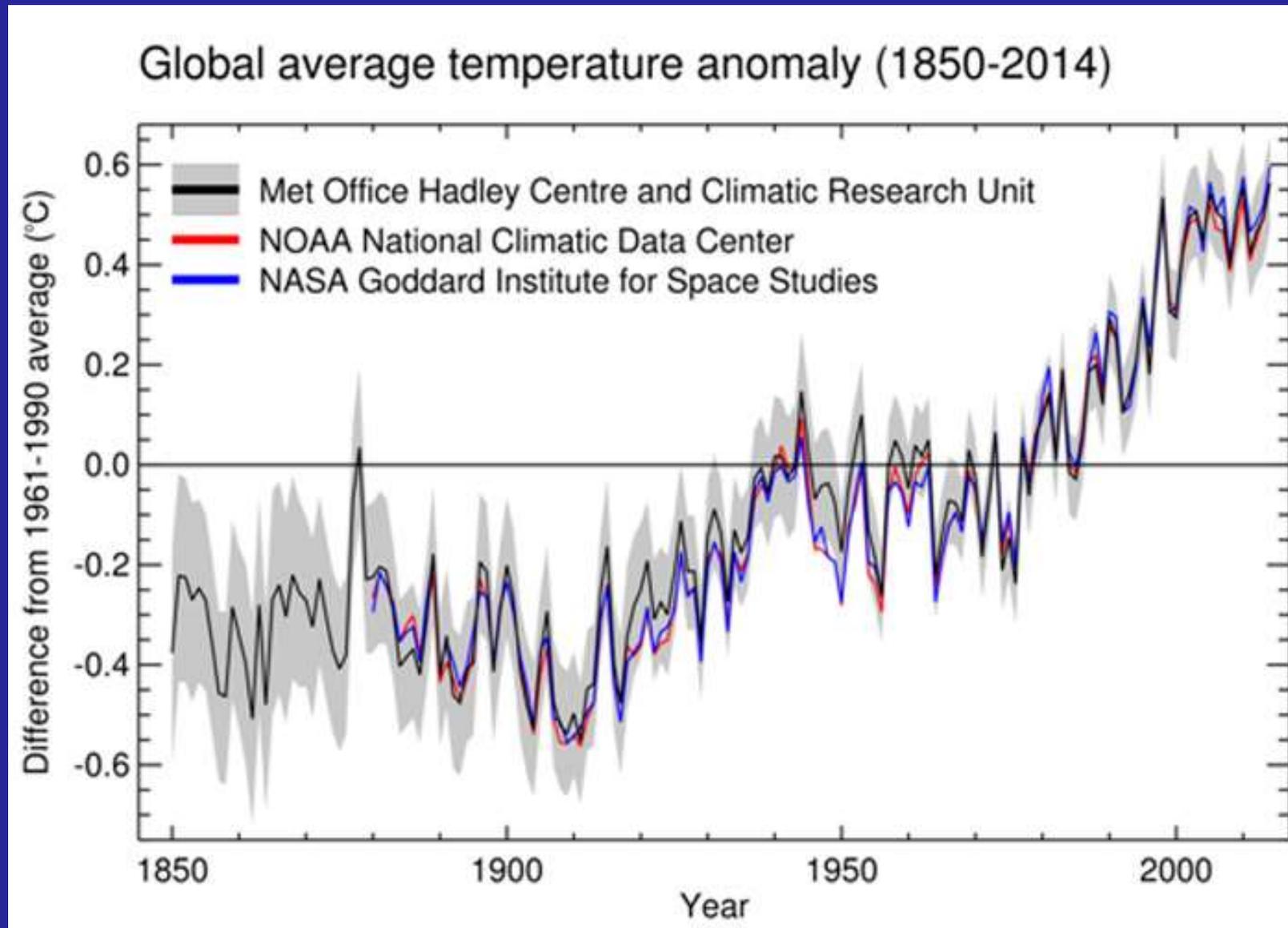
## osservazione delle tendenze II

*stime della temperatura media dell'emisfero nord*



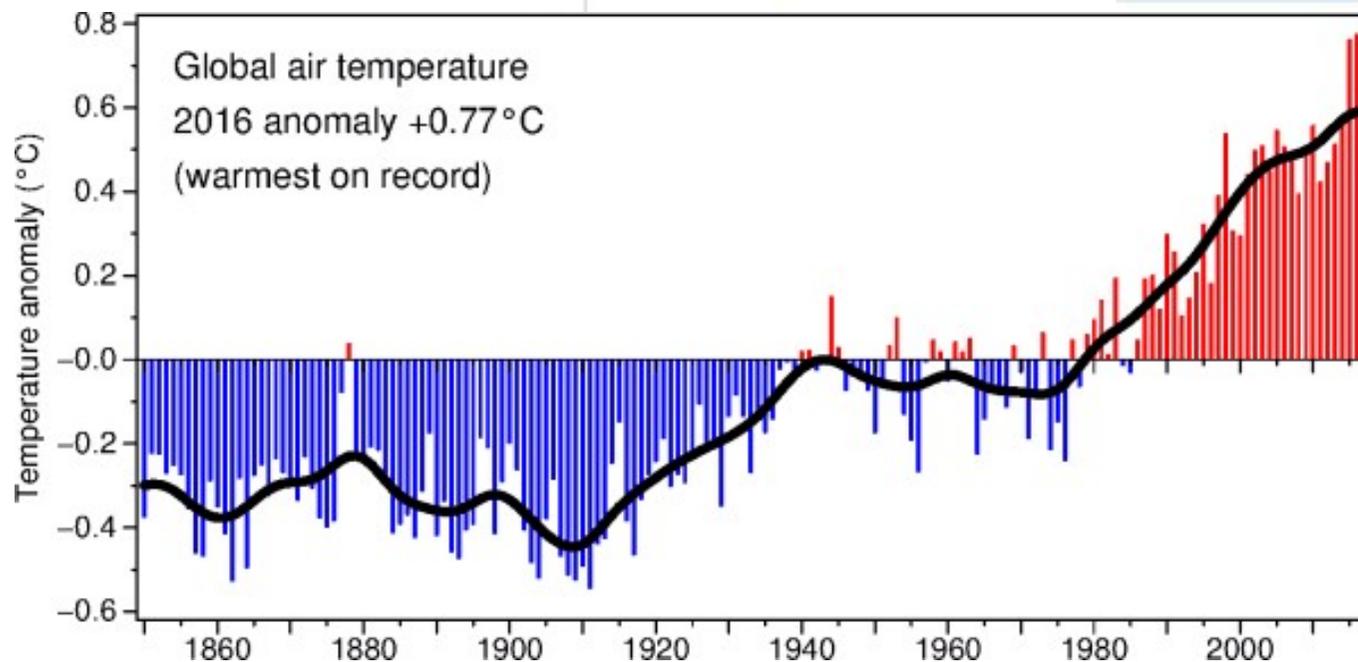
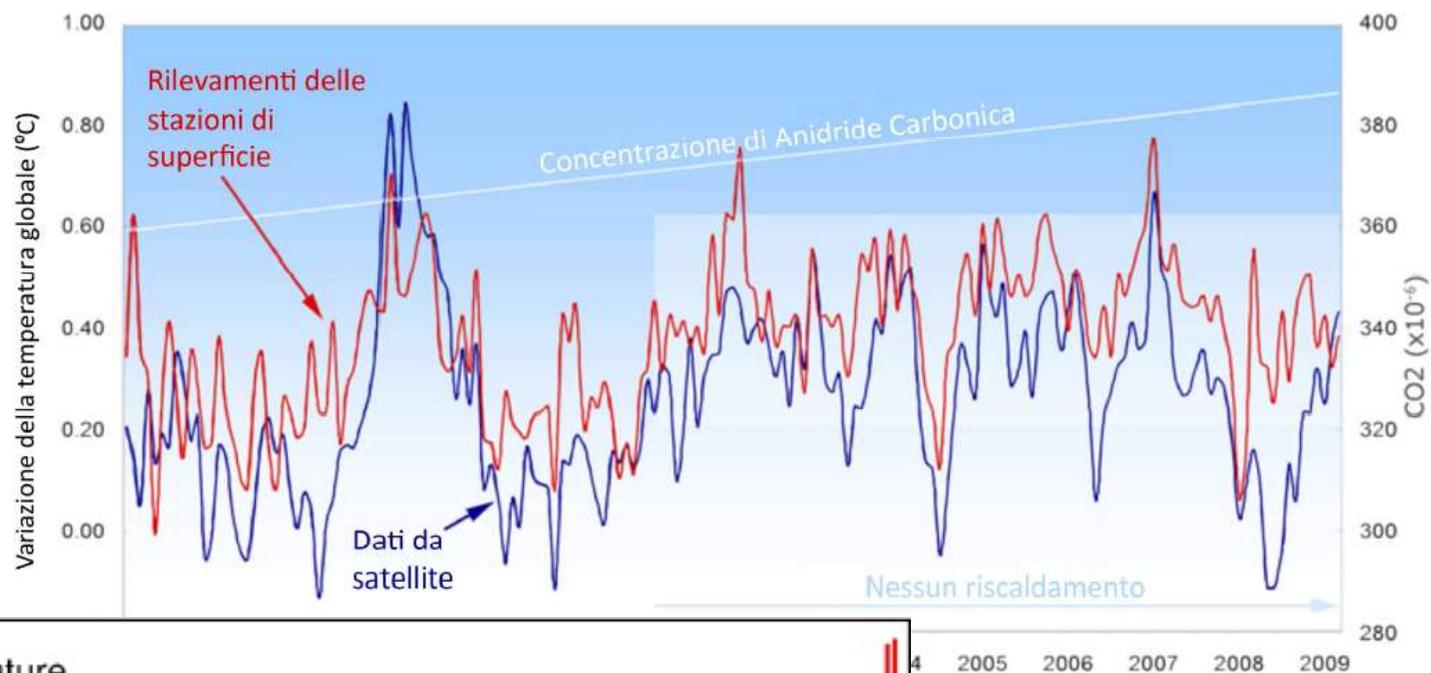
## osservazione delle tendenze III

*ultimi anni*



# osservazione delle tendenze III

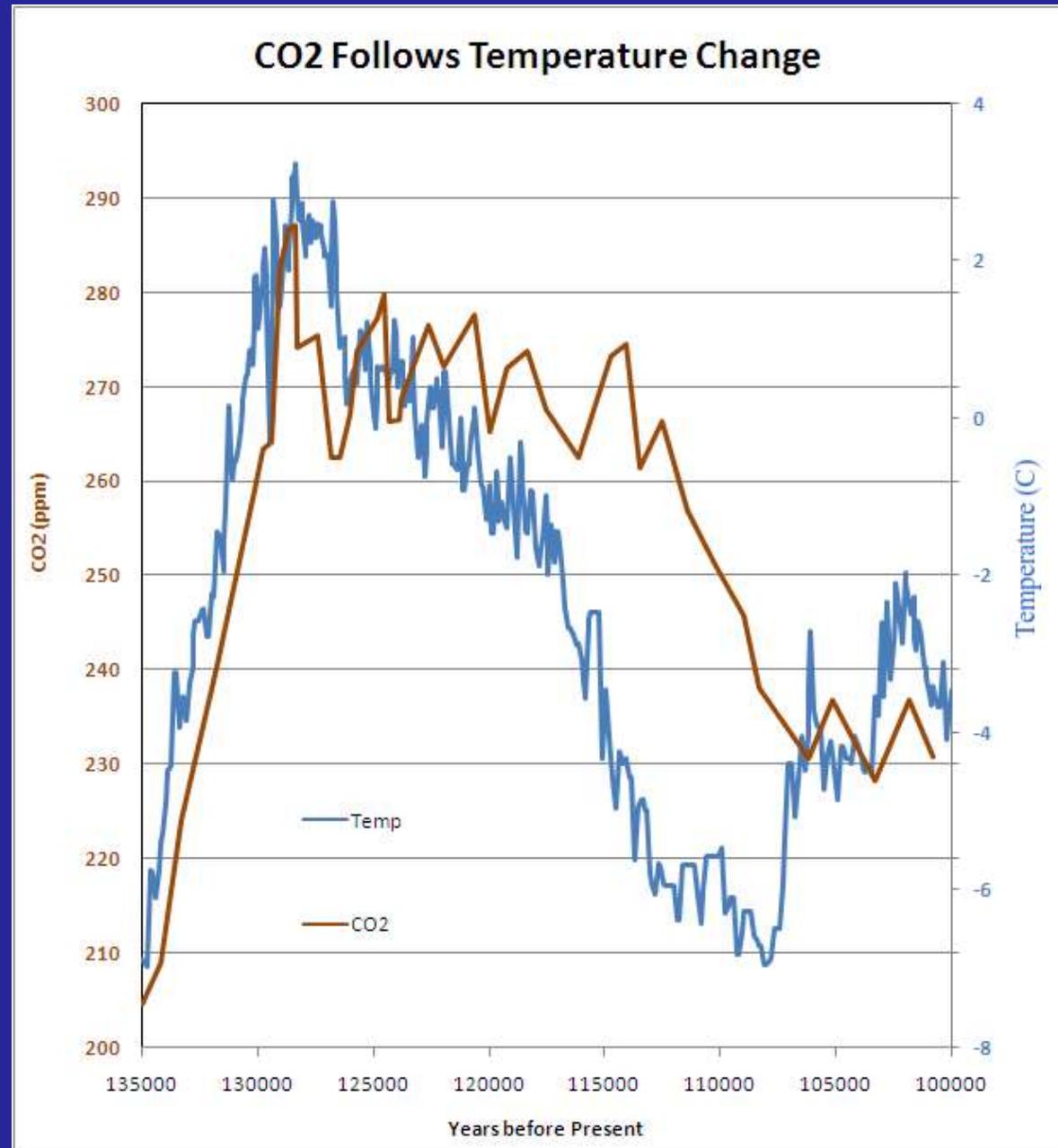
## *GW hiatus*



## osservazione delle tendenze IV

*relazione GHG/ $\Delta T$*

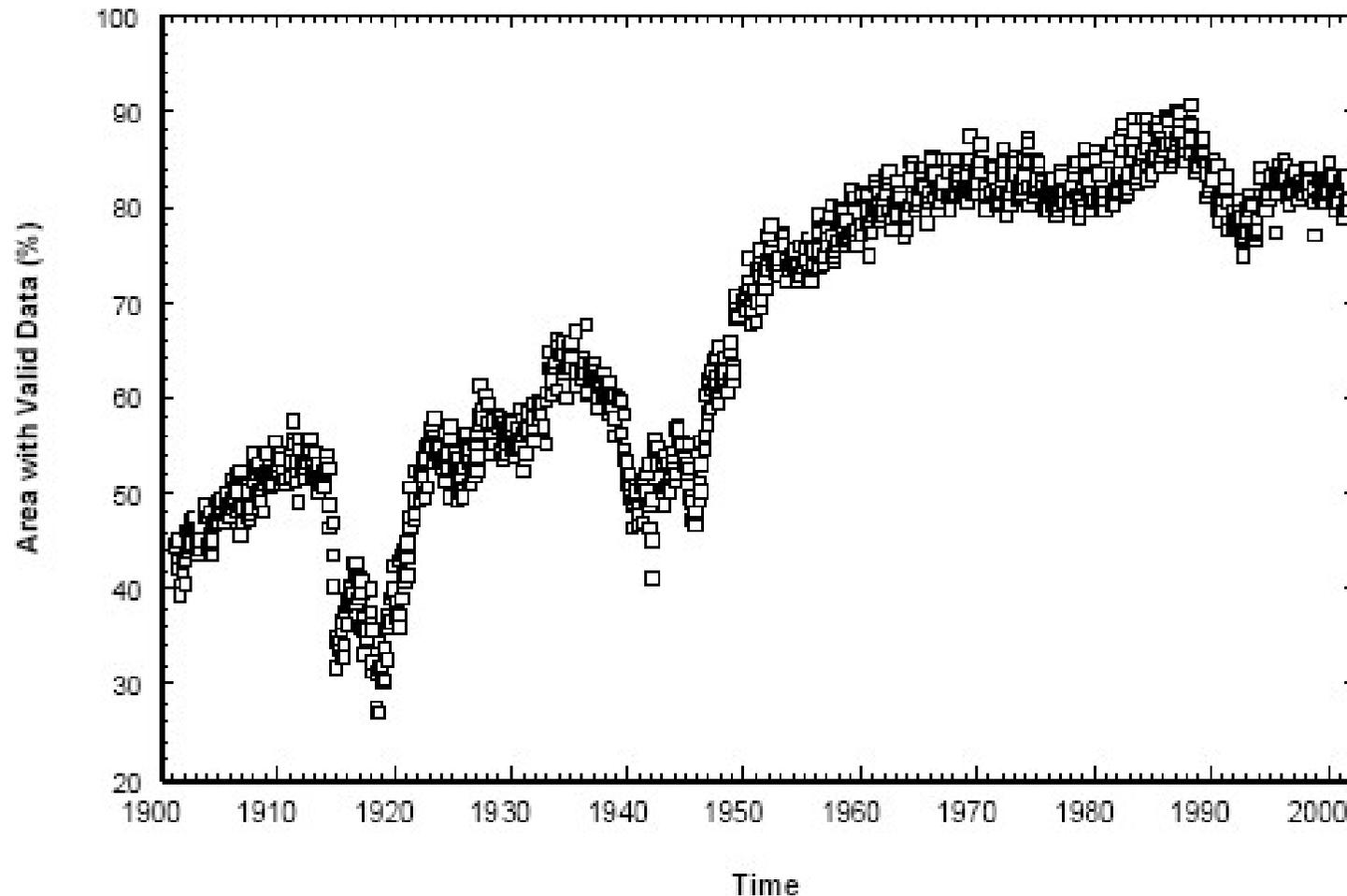
*le variazioni di contenuto di  $CO_2$  seguono di circa 800 anni le variazioni della temperatura*



*Mudelsee, 2001*

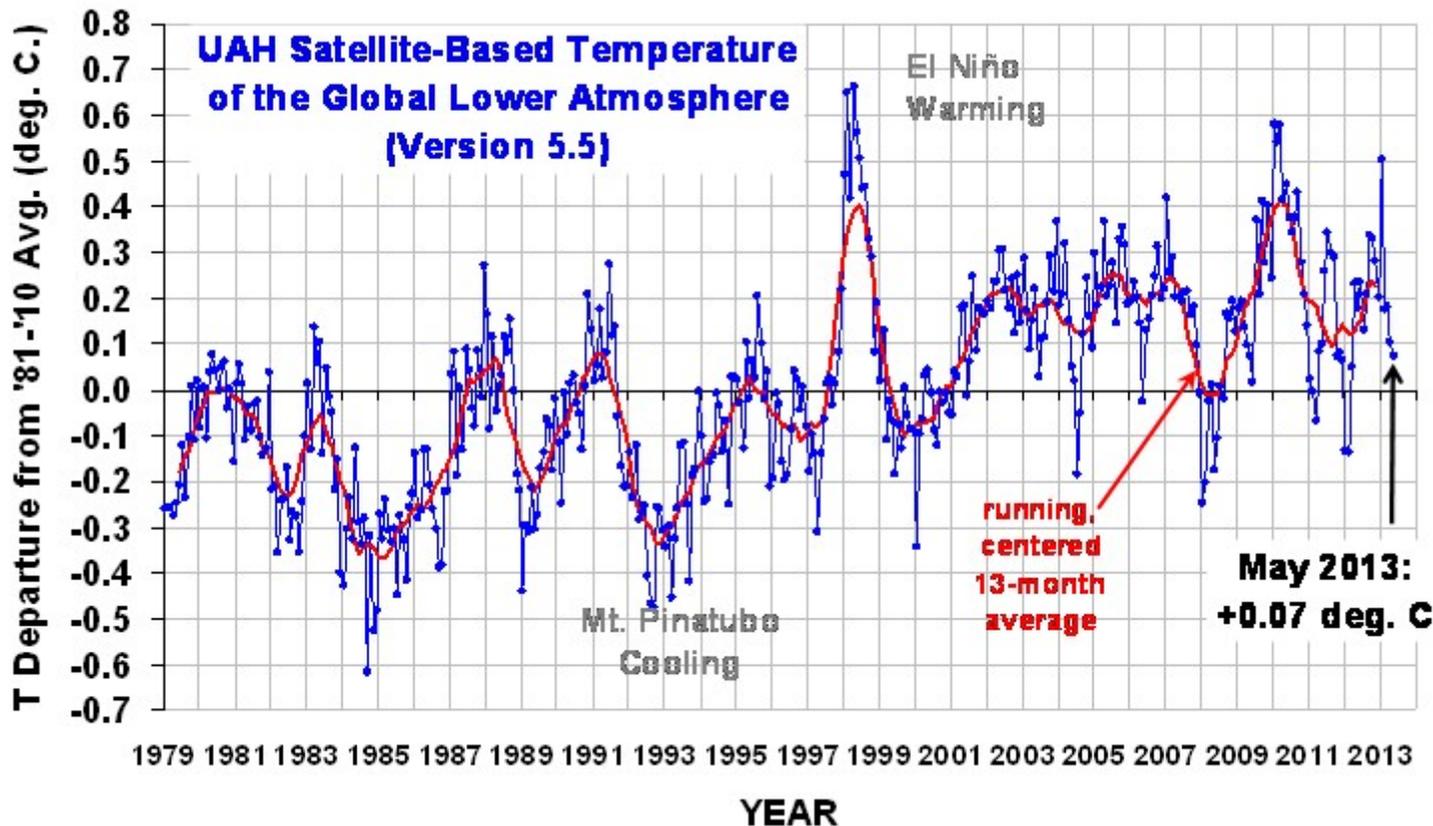
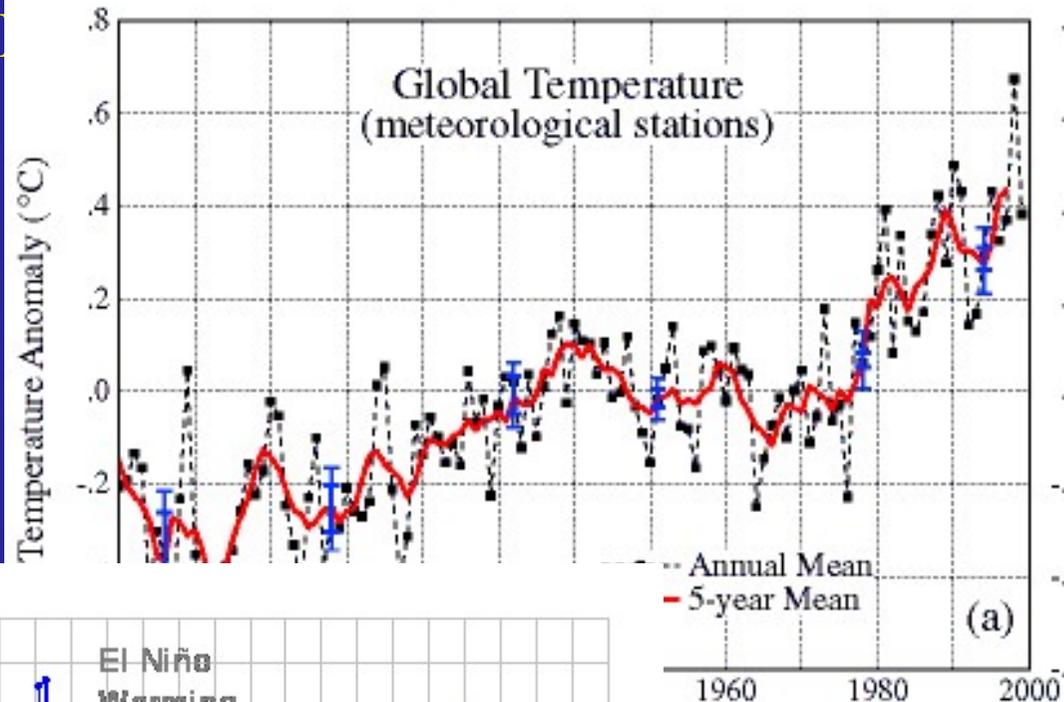
**osservazione delle tendenze V**  
*copertura globale dei sensori*

**la frazione di superficie globale monitorata varia**  
 **$5^\circ \times 5^\circ \sim 550 \times 400 \text{ km}^2$**



**osservazione delle tendenze VI**  
*osservazioni dallo spazio*

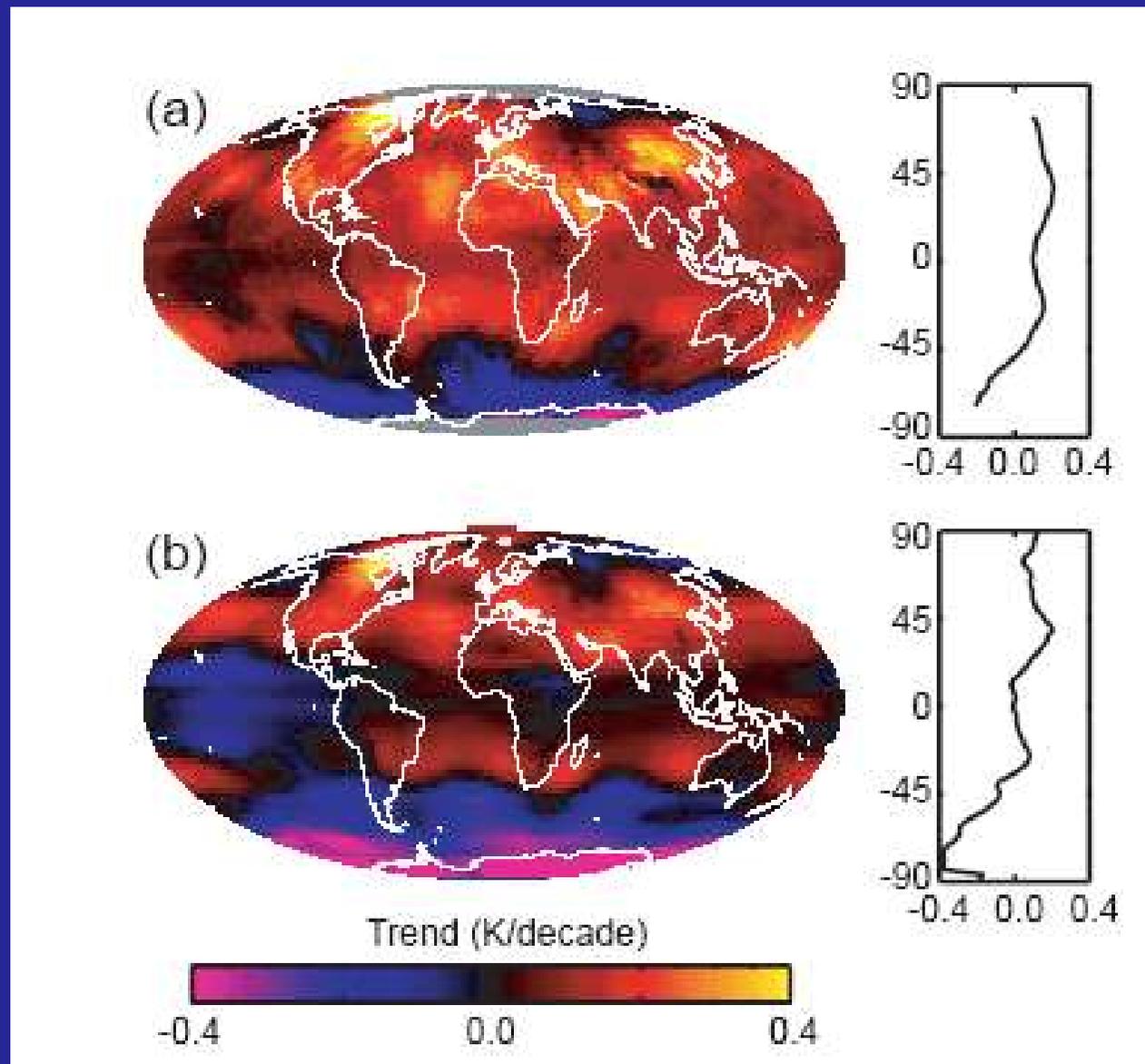
**0,2 K/decade** ←



**0,09 K/decade** ←

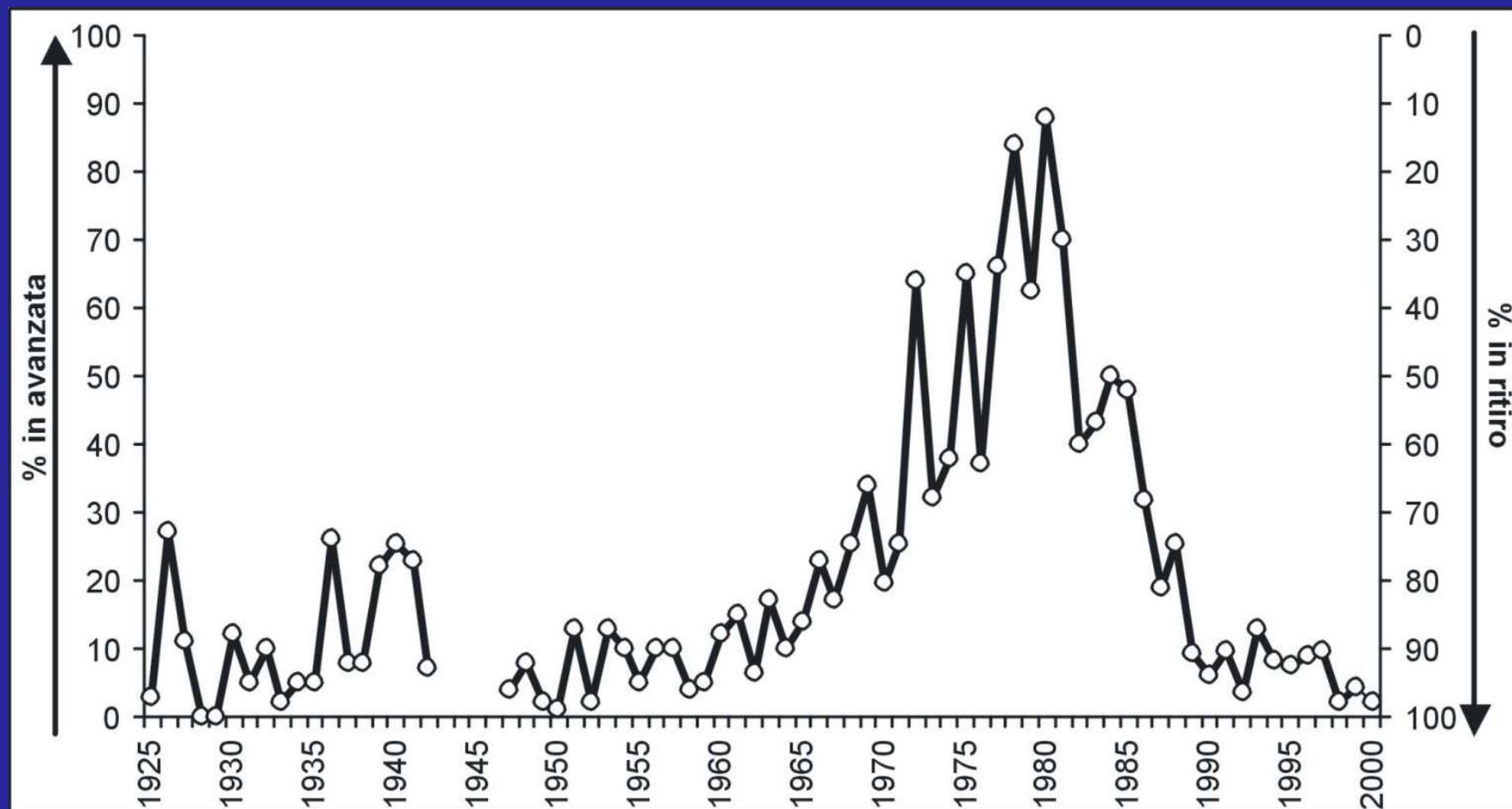
# osservazione delle tendenze VIII

## *Microwave Sounding Unit (MSU)*



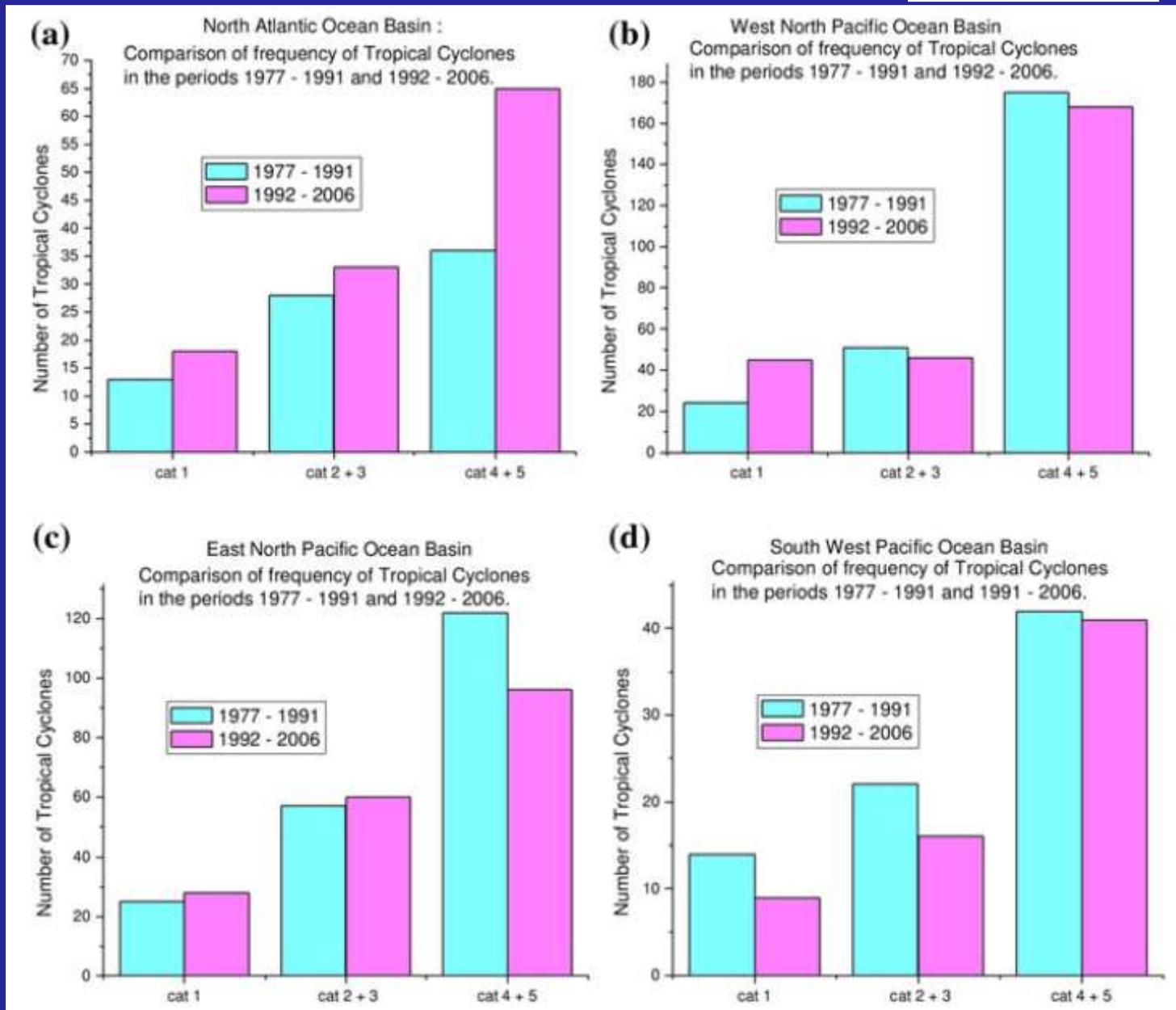
# osservazione delle tendenze IX

*ritiro dei ghiacciai*

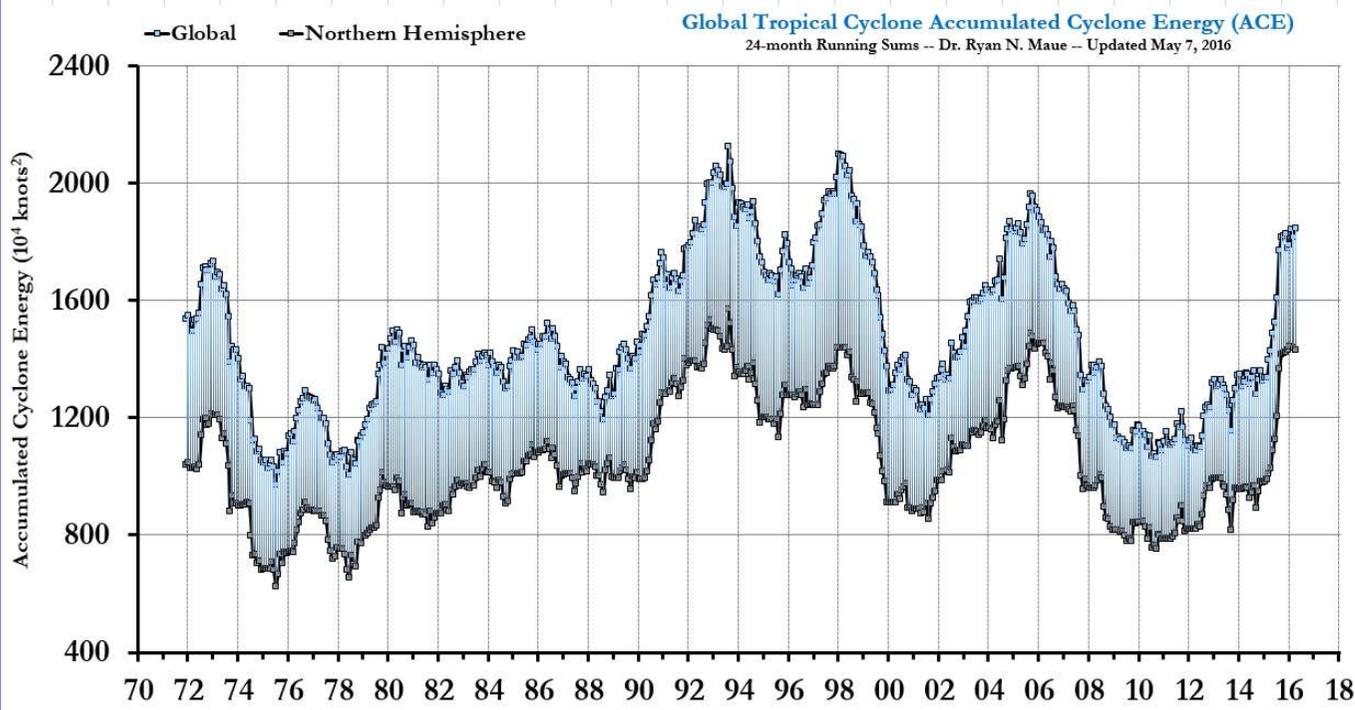
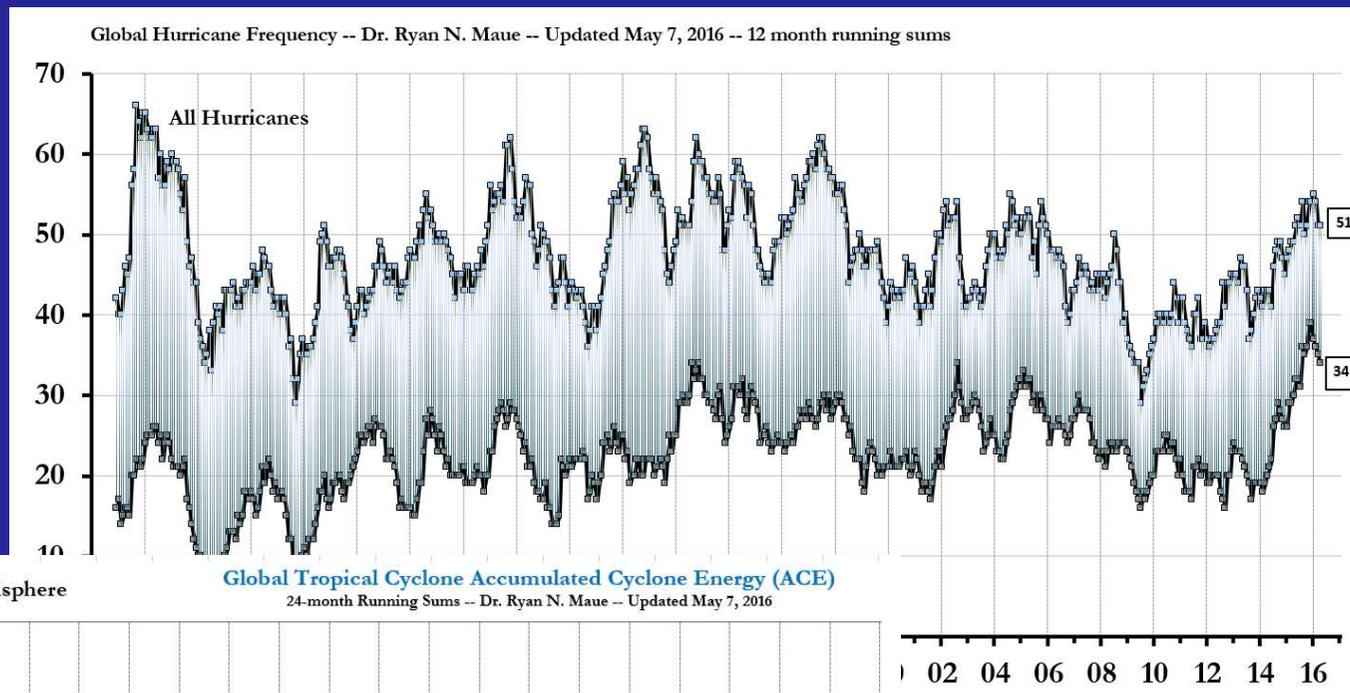


# osservazione delle tendenze X eventi estremi: cicloni tropicali

Deo et al., 2011

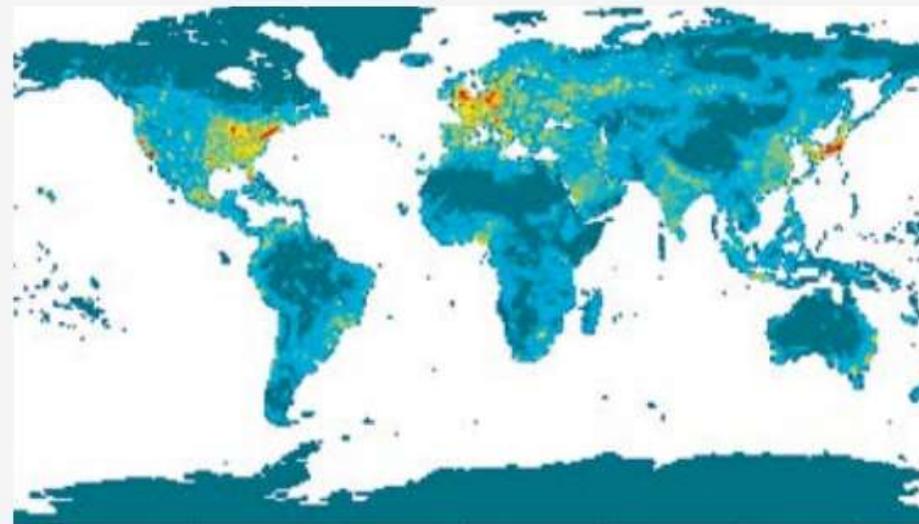


# osservazione delle tendenze X eventi estremi: cicloni tropicali

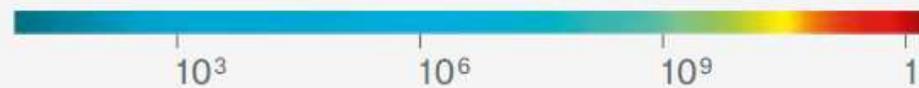
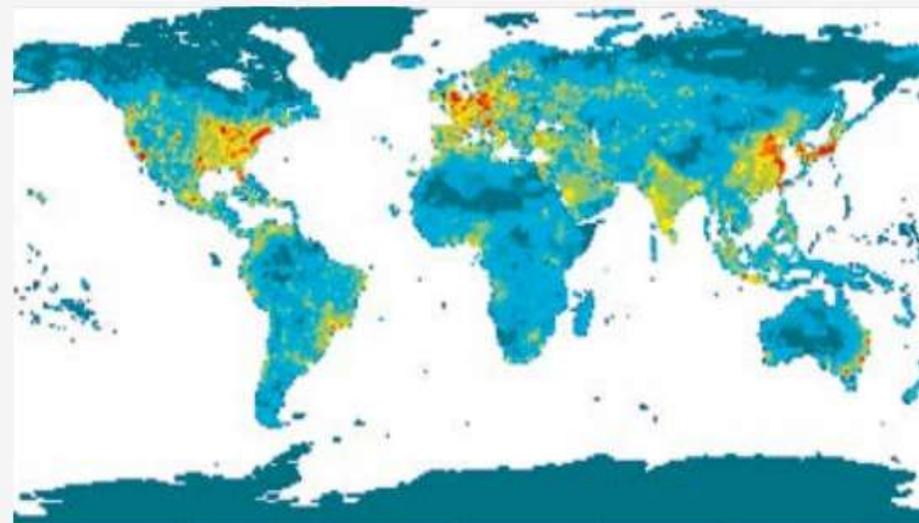


**osservazione delle tendenze**  
*eventi estremi: PIL*

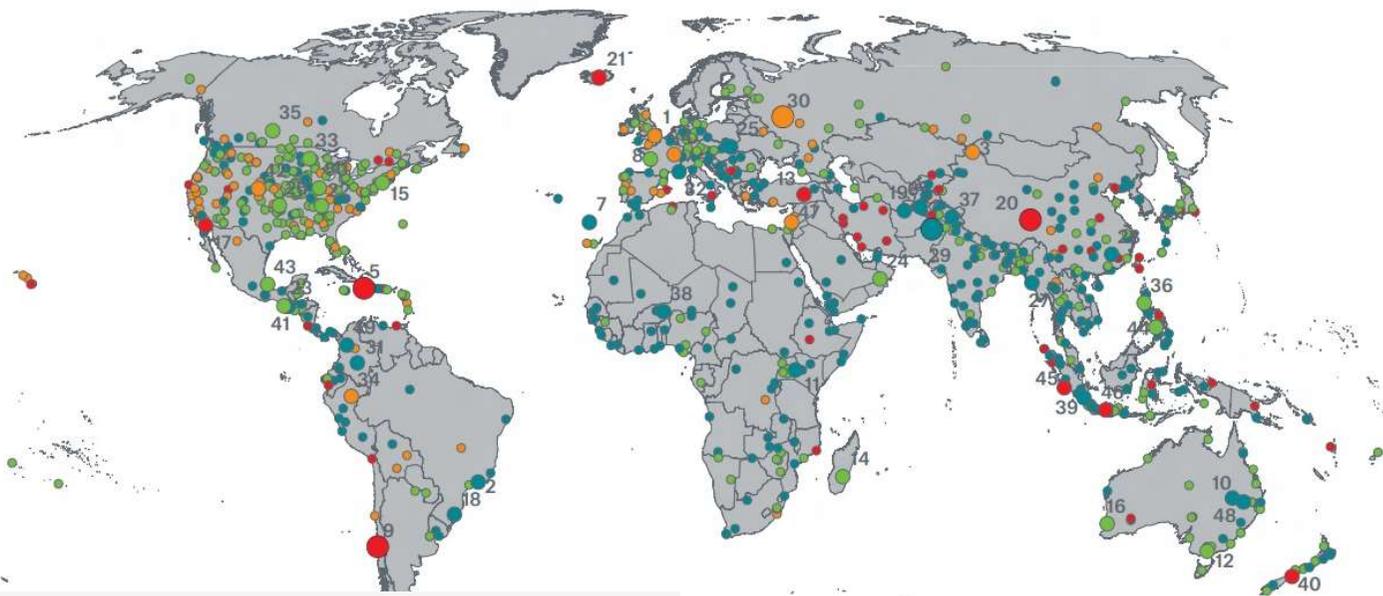
1980



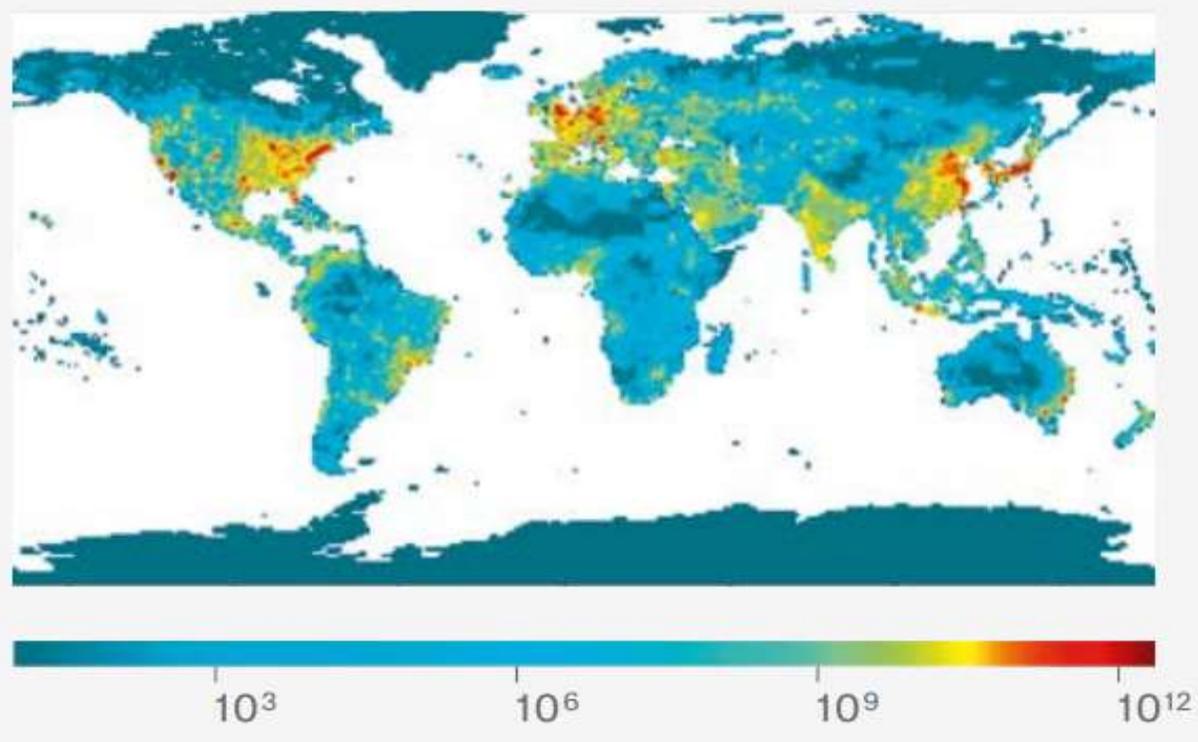
2015



# osservazione delle eventi estremi: dan

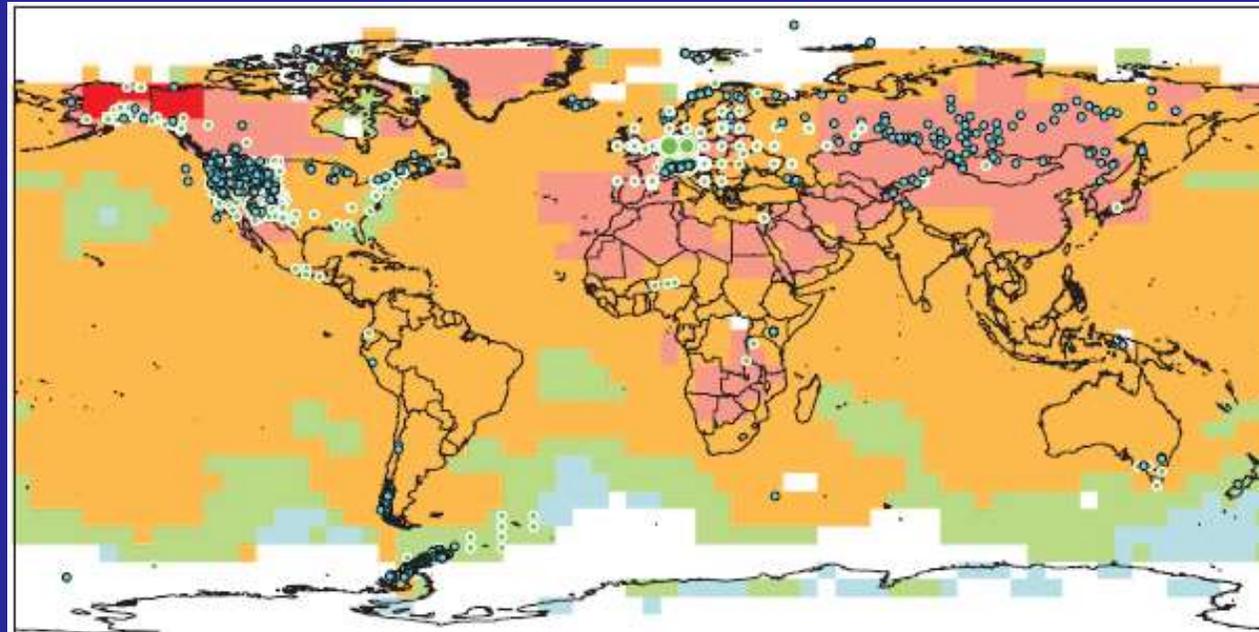


2015



# osservazione delle tendenze XI

*impatto sui  
sistemi fisici e  
biologici*

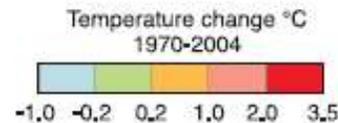


NAM		LA		EUR		AFR		AS		ANZ		PR*		TER		MFW**		GLO	
355	455	53	5	119	28,115	5	2	106	8	6	0	120	24	764	28,586	1	85	765	28,671
94%	92%	98%	100%	94%	89%	100%	100%	95%	100%	100%	—	91%	100%	94%	90%	100%	99%	94%	90%

Observed data series

- Physical systems (snow, ice and frozen ground; hydrology; coastal processes)
- Biological systems (terrestrial, marine, and freshwater)

Europe ***	
•	1-30
○	31-100
○	101-800
○	801-1,200
○	1,201-7,500



Physical      Biological

Number of significant observed changes	Number of significant observed changes
Percentage of significant changes consistent with warming	Percentage of significant changes consistent with warming

\* Polar regions include also observed changes in marine and freshwater biological systems.

\*\* Marine and freshwater includes observed changes at sites and large areas in oceans, small islands and continents. Locations of large-area marine changes are not shown on the map.

\*\*\* Circles in Europe represent 1 to 7,500 data series.

**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);

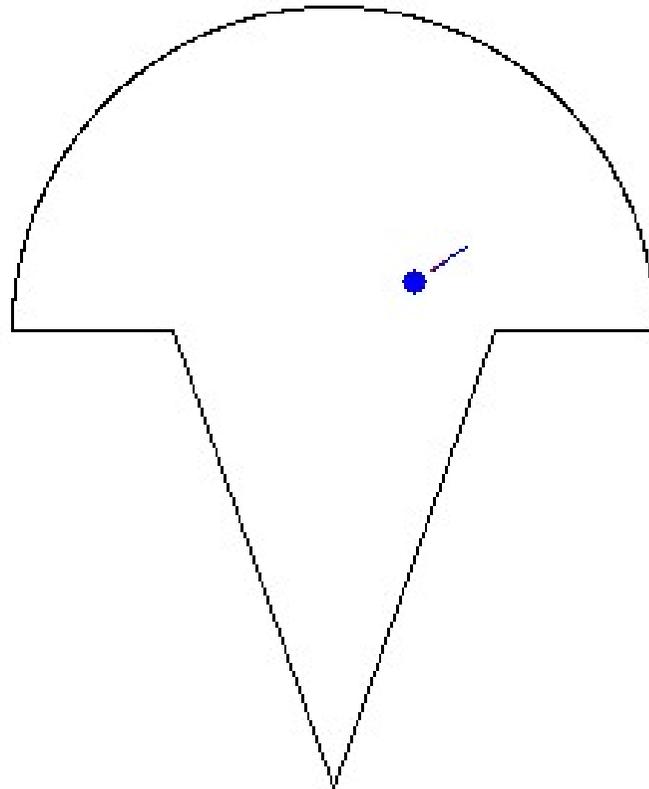
- è non predicibile (caos, sensibilità alle condizioni iniziali);

- piccole perturbazioni possono dare grandi risposte e viceversa;

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

# Biliardo

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



# Sistema di Lorenz

$$\dot{x} = \sigma(y - x)$$

$$\dot{y} = rx - y - xz$$

$$\dot{z} = xy - bz$$

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$$x_{(t=0)} = 8$$

$$y_{(t=0)} = 1$$

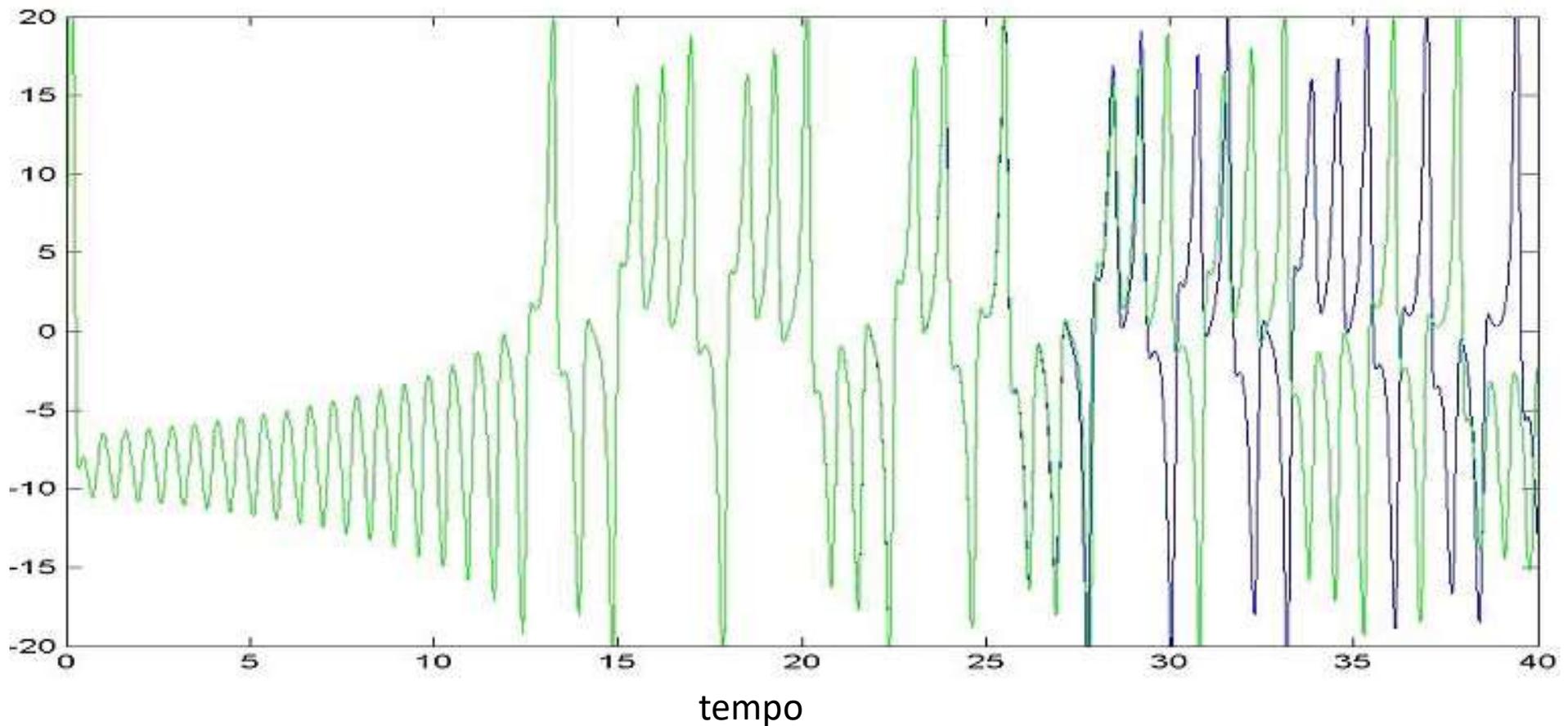
$$z_{(t=0)} = 1$$

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$$x_{(t=0)} = 8$$

$$y_{(t=0)} = 1.0000001$$

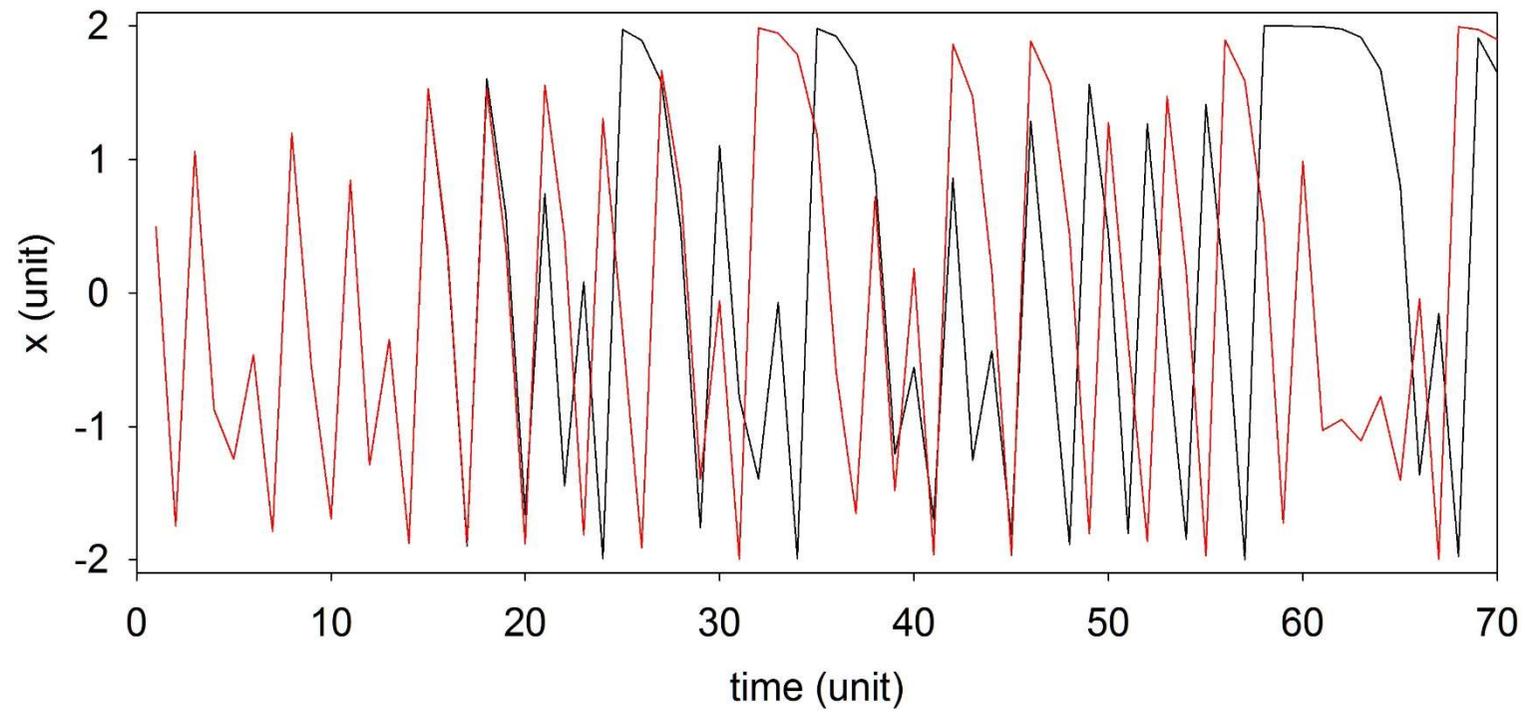
$$z_{(t=0)} = 1$$



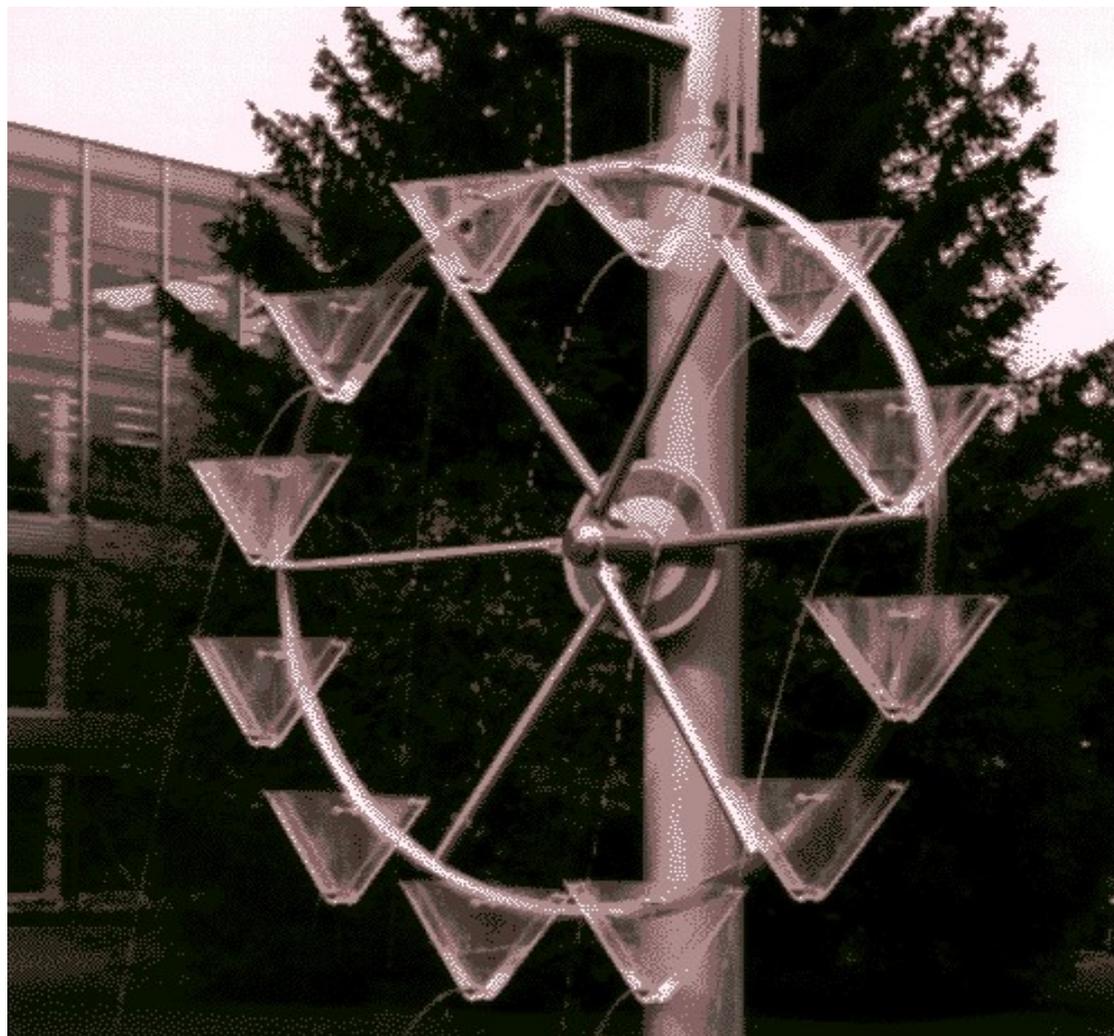
$$\mathbf{x}_t = \mathbf{x}_{t-1}^2 - 2$$

$$\mathbf{x}_o = 0.500000$$

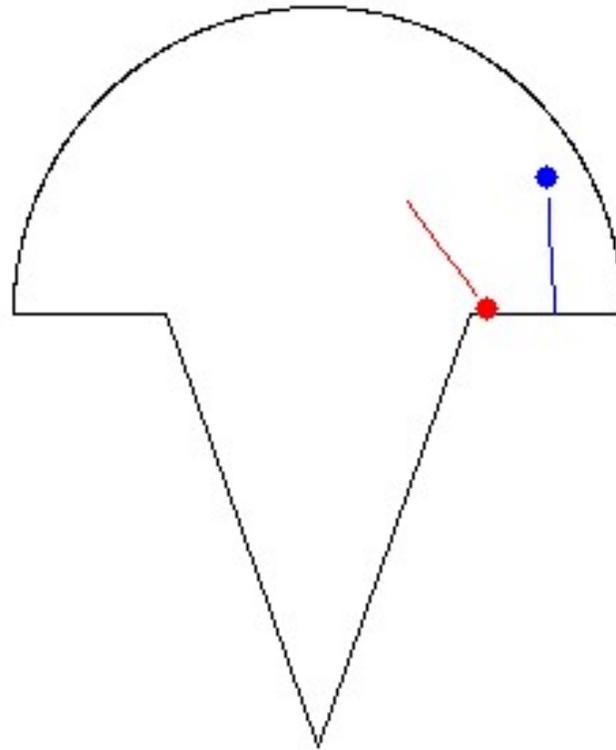
$$\mathbf{x}'_o = 0.500001$$



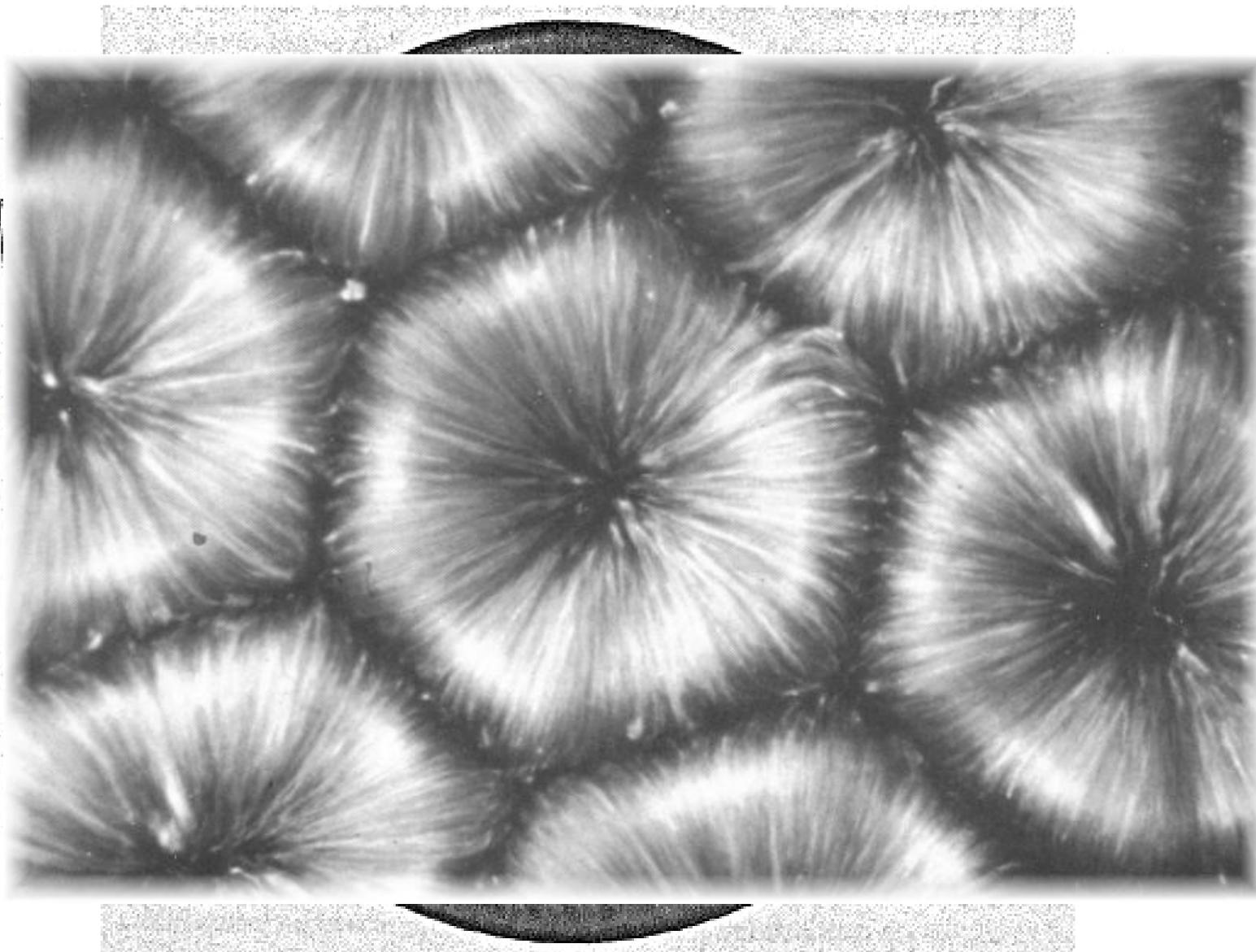
# ruota ad acqua di Lorenz



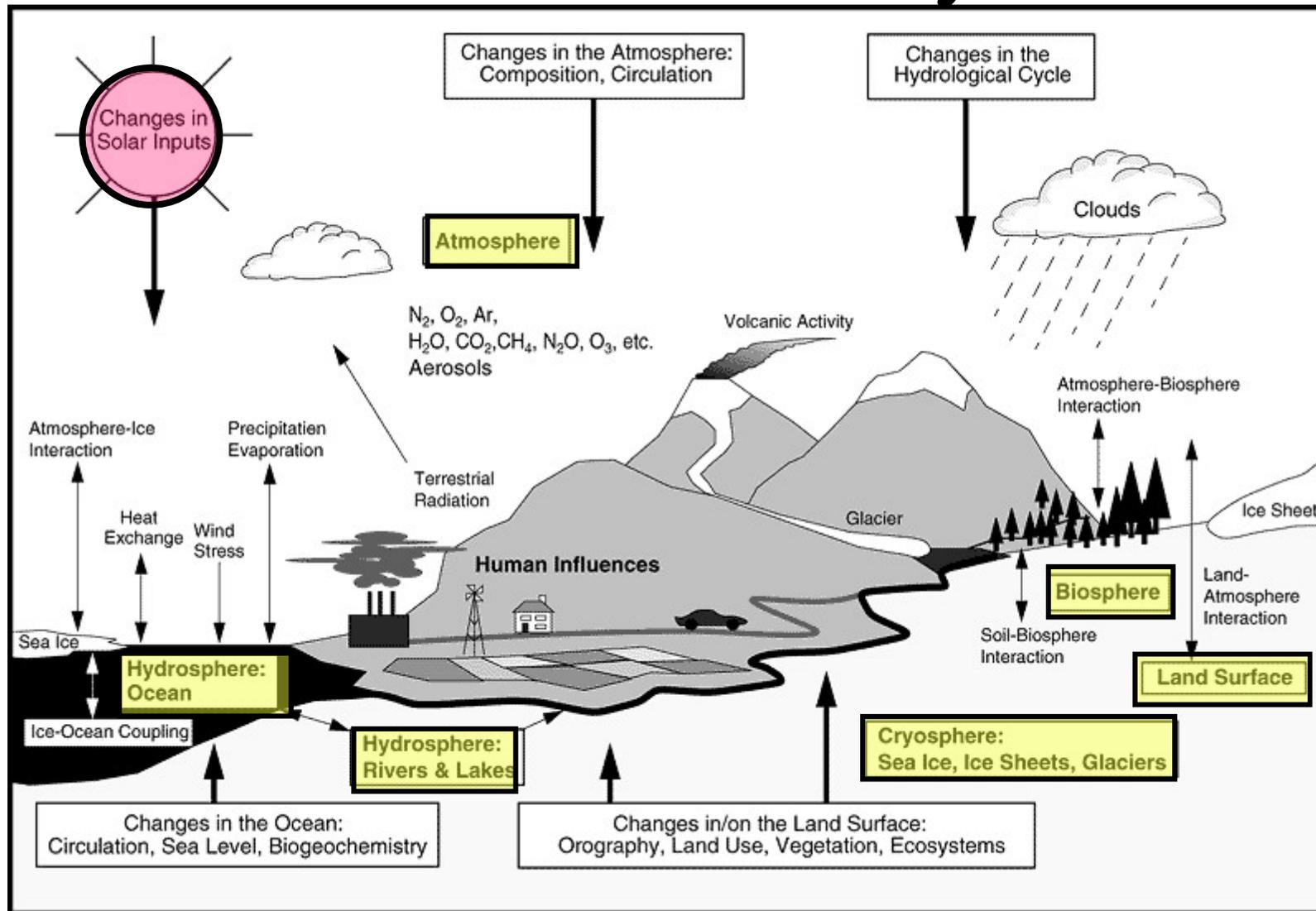
# Biliardo ordine



# Convezione (Benard)



# The Global Climate System



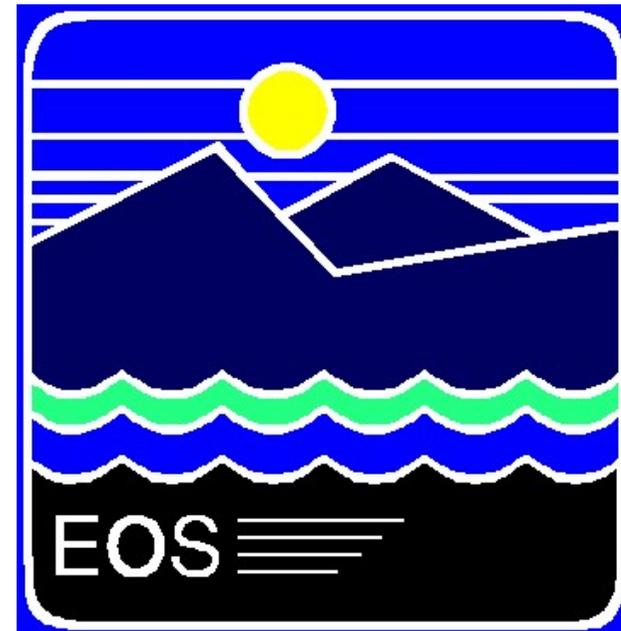
## caratteristiche del sistema climatico:

- 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.

*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*

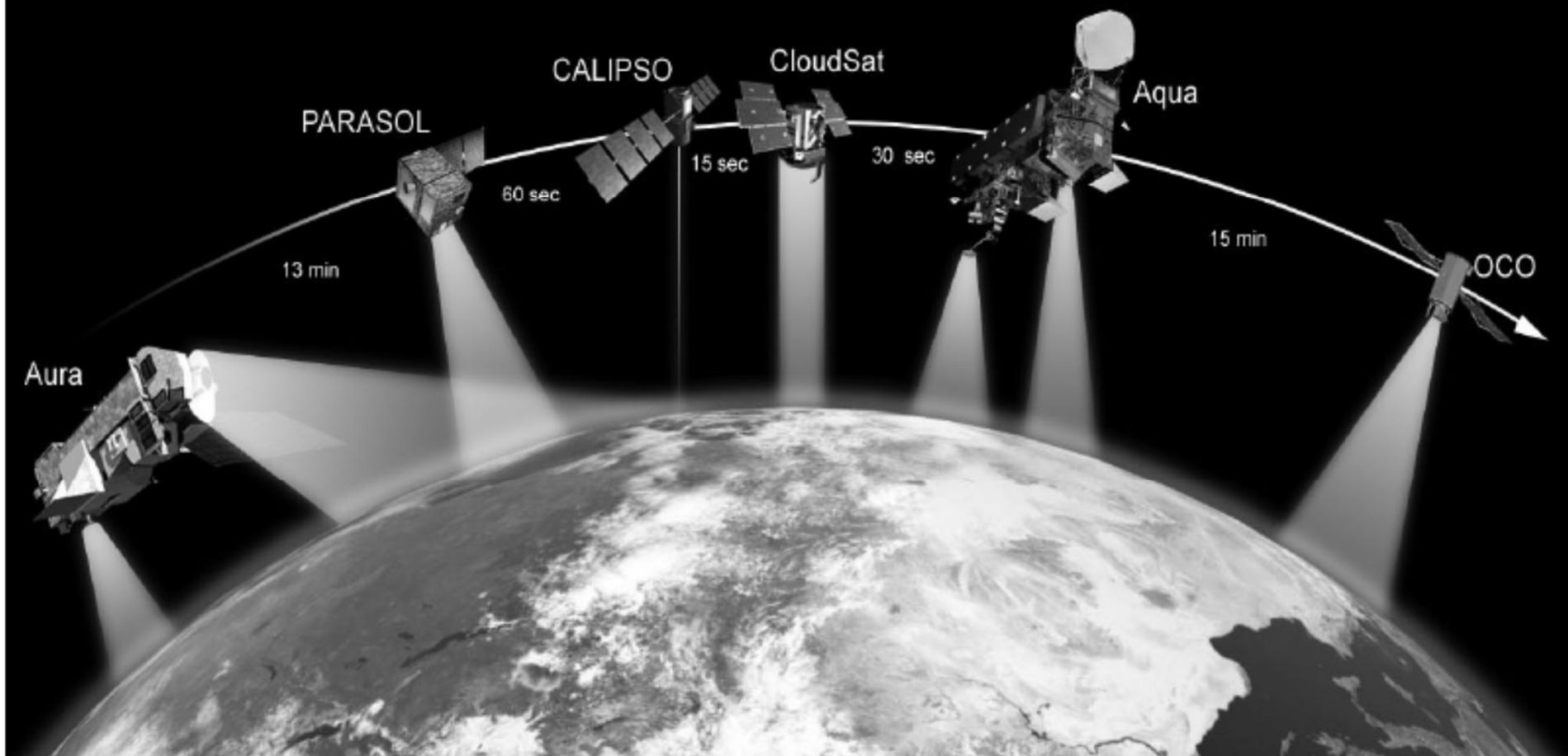
1991: Earth Science Enterprise

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



# 24 EOS Measurements



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

# 24 EOS Measurements



<b>LAND</b>	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
<b>OCEAN</b>	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+**