

# *La variazioni climatiche nella realtà storica*

*Maurizio Maugeri*

*Dipartimento di Fisica – Università degli Studi di Milano*



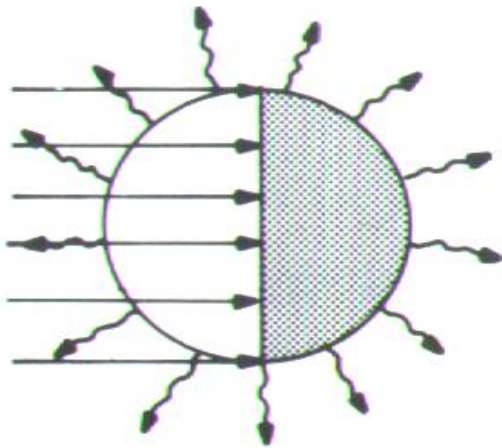
*Formazione ed evoluzione  
dell'ambiente:  
misure e modelli*



*Laboratori Nazionale del Gran Sasso – 27-28 ottobre 2016*

# DA COSA DIPENDE LA TEMPERATURA SUPERFICIALE DI UN PIANETA?

*Un pianeta assume la temperatura che porta all'equilibrio tra la radiazione che esso assorbe e quella che esso emette verso lo spazio esterno.*



*I termini di questo bilancio hanno caratteristiche spettrali molto diverse:*

*Per la terra:*

*Parte entrante: intensità massima nella regione del visibile.*

*Parte uscente: intensità massima nella regione dell'infrarosso.*

*Se il Pianeta può essere trattato come un corpo nero:  $S_0 \pi r_t^2 = 4 \pi r_t^2 \sigma T^4$*

**Fattore chiave n. 1: intensità della radiazione che riceve dalla sua stella**

# DA COSA DIPENDE LA TEMPERATURA SUPERFICIALE DI UN PIANETA?

*Non tutta la radiazione che un Pianeta riceve viene assorbita*



La frazione che non viene assorbita prende il nome di albedo ( $\alpha$ ).

L'albedo può dipendere sia dalla riflessione della radiazione al suolo che da scattering in atmosfera.

Per la terra esso è pari al 30% circa.

Se il Pianeta può comunque essere trattato come un corpo nero nella regione in cui emette:

*Per la Terra:*

$$S_0(1 - \alpha)\pi r_t^2 = 4\pi r_t^2 \sigma T^4 - T_t \approx 255 K$$

**Table 4.1** Flux density of solar radiation  $F_s$ , planetary albedo  $A$ , and equivalent blackbody temperature  $T_E$  of some of the planets based on the assumption that they are in radiative equilibrium. Astronomical units are multiples of Earth-sun distance

Planet	Distance from sun <sup>a</sup>	$F_s$ ( $W m^{-2}$ )	$A$	$T_E$ (K)
Mercury	0.39	8994	0.06	439
Venus	0.72	2639	0.78	225
Earth	1.00	1368	0.30	255
Mars	1.52	592	0.17	216
Jupiter	5.18	51	0.45	105

<sup>a</sup> Astronomical units are multiples of Earth-Sun distance.

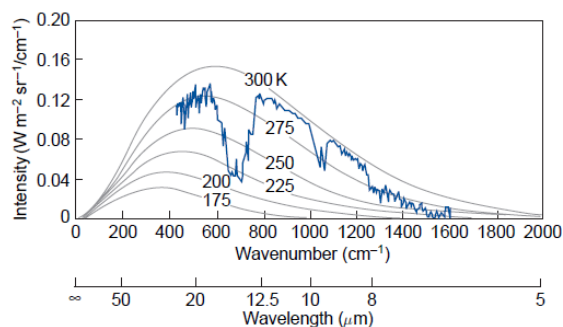
**Fattore chiave n. 2: albedo del Pianeta**



# DA COSA DIPENDE LA TEMPERATURA SUPERFICIALE DI UN PIANETA?

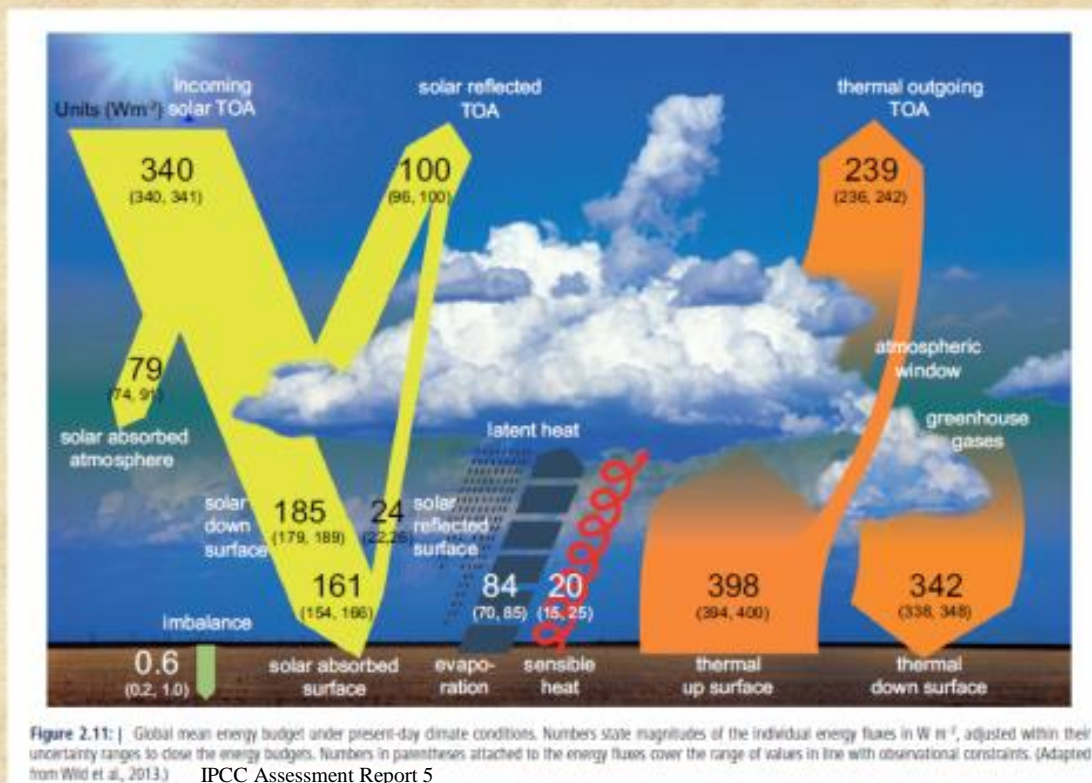
*La superficie è responsabile solo in parte della radiazione emessa*

➔ L'atmosfera gioca un ruolo chiave



**Fig. 4.31** Monochromatic intensity of radiation emitted from a point on the Earth measured by an infrared interferometer spectrometer carried aboard a spacecraft. The gray curves are blackbody spectra computed from Eq. (4.10). The monochromatic intensity of the radiation at any given wavelength is indicative of the temperature of the layer of the atmosphere from which that radiation is emitted (i.e., the level of unit optical depth for that wavelength), which can be inferred from the blackbody spectra. [Adapted from K. N. Liou, *An Introduction to Atmospheric Radiation*, Academic Press, p. 117, Copyright (2002), with permission from Elsevier.]

Wallace JM and Hobbs PV, 2006:  
Atmospheric Science, Academic Press

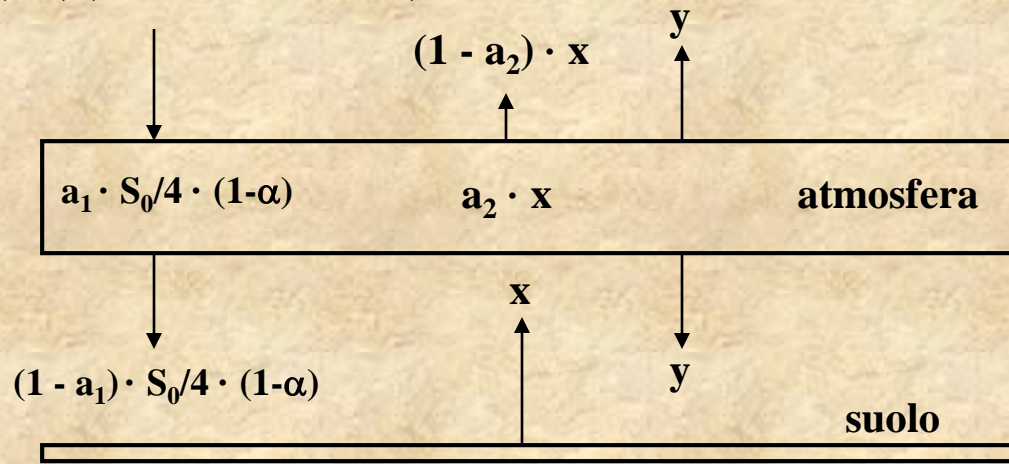


**Figure 2.11:** Global mean energy budget under present-day climate conditions. Numbers state magnitudes of the individual energy fluxes in  $W m^{-2}$ , adjusted within their uncertainty ranges to close the energy budgets. Numbers in parentheses attached to the energy fluxes cover the range of values in line with observational constraints. (Adapted from Wild et al., 2013.) IPCC Assessment Report 5

**Fattore chiave n. 3: trasparenza dell'atmosfera alla radiazione emessa dal suolo**

# Modellizzazione matematica livello scuola secondaria

$S_0/4 \cdot (1-\alpha)$  (cioè circa  $235 \text{ W/m}^2$ )



## Ipotesi di lavoro:

Il suolo è un corpo nero;

L'atmosfera: assorbe una frazione  $a_1$  dell'onda corta e una frazione  $a_2$  dell'onda lunga;

$x$  e  $y$  sono le potenze per unità di superficie emesse dal suolo e dall'atmosfera in condizioni di bilancio radiativo.

## Bilanci

Suolo

In:  $(1 - a_1) \cdot S_0/4 \cdot (1-\alpha) + y$

Out:  $x$

Atmosfera

In:  $a_1 \cdot S_0/4 \cdot (1-\alpha) + a_2 \cdot x$

Out:  $2 \cdot y$

## Con pochi calcoli:

$$x = (2 - a_1) \cdot S_0/4 \cdot (1-\alpha) / (2-a_2)$$

$$y = (a_1 + a_2 - a_1 \cdot a_2) / (2-a_2)$$

## Un esempio (ragionevole) di valori numerici:

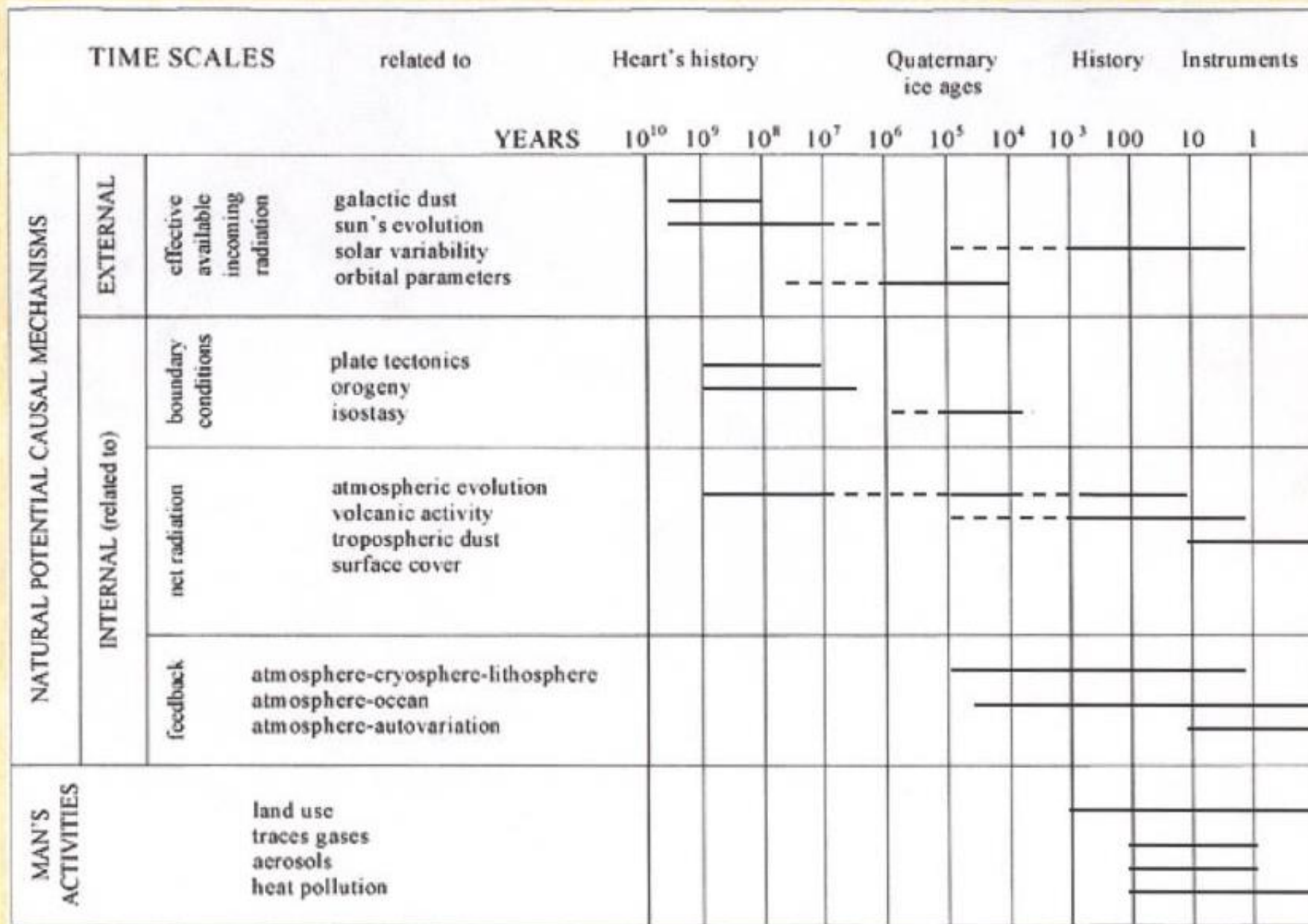
$a_1 = 0.1$  (10%);  $a_2 = 0.8$  (80%);  $S_0/4 \cdot (1-\alpha)$  ( $235 \text{ W/m}^2$ )

$$\rightarrow x = 372 \text{ W/m}^2$$

Se, invece, fosse  $a_2 = 1.0 \rightarrow x = 446 \text{ W/m}^2$

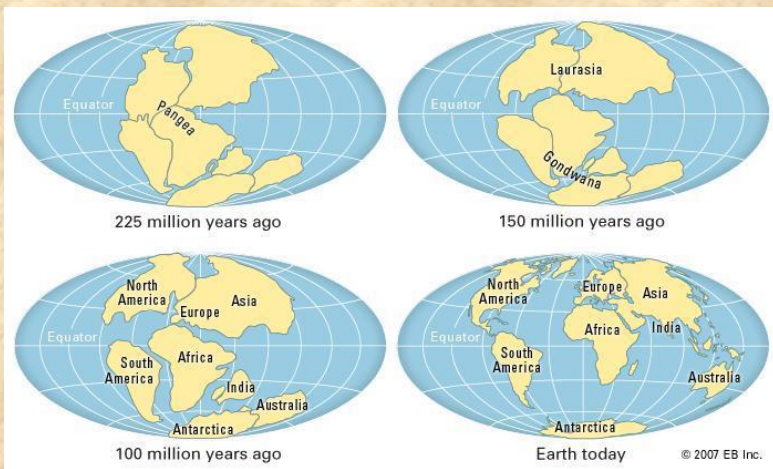
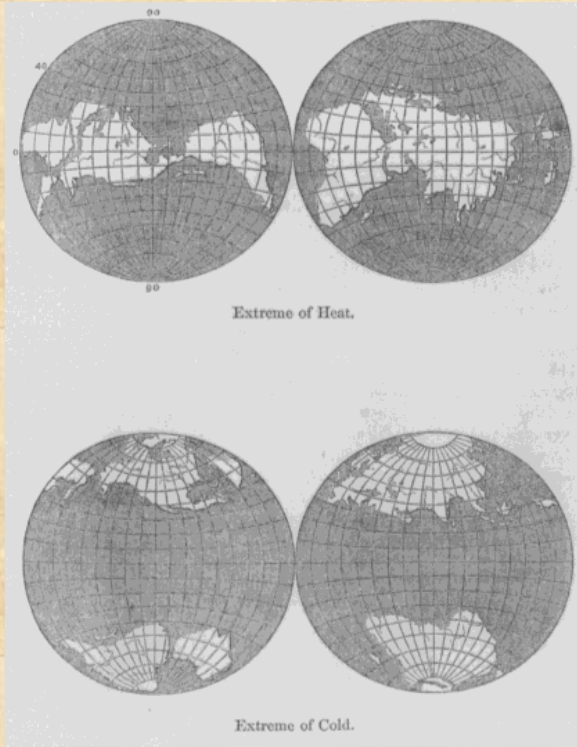
Se, invece, fosse  $a_2 = 0.0 \rightarrow x = 223 \text{ W/m}^2$

... e questi fattori cambiano nel tempo per effetto di numerose cause...

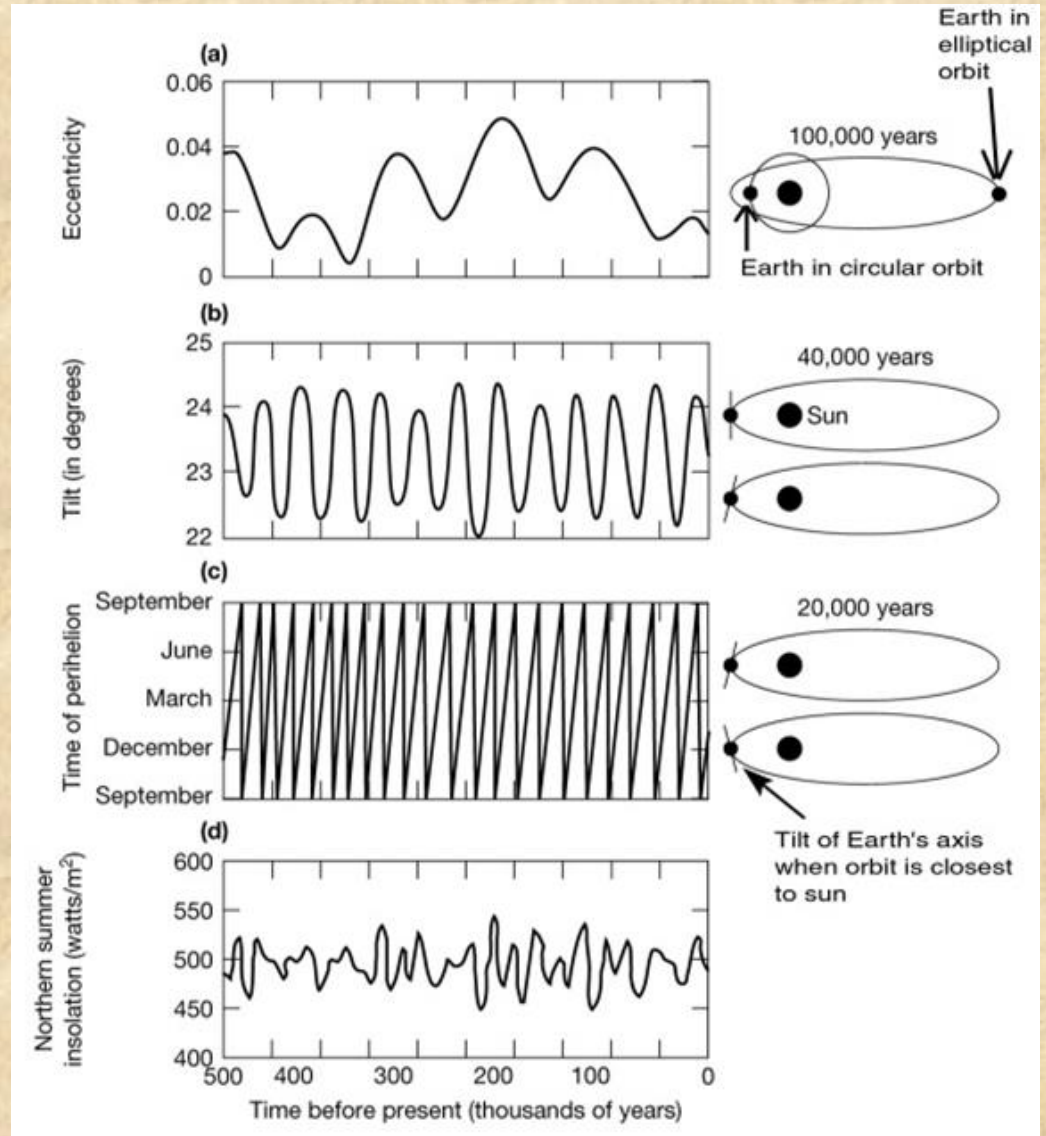




# .... qualche esempio ...

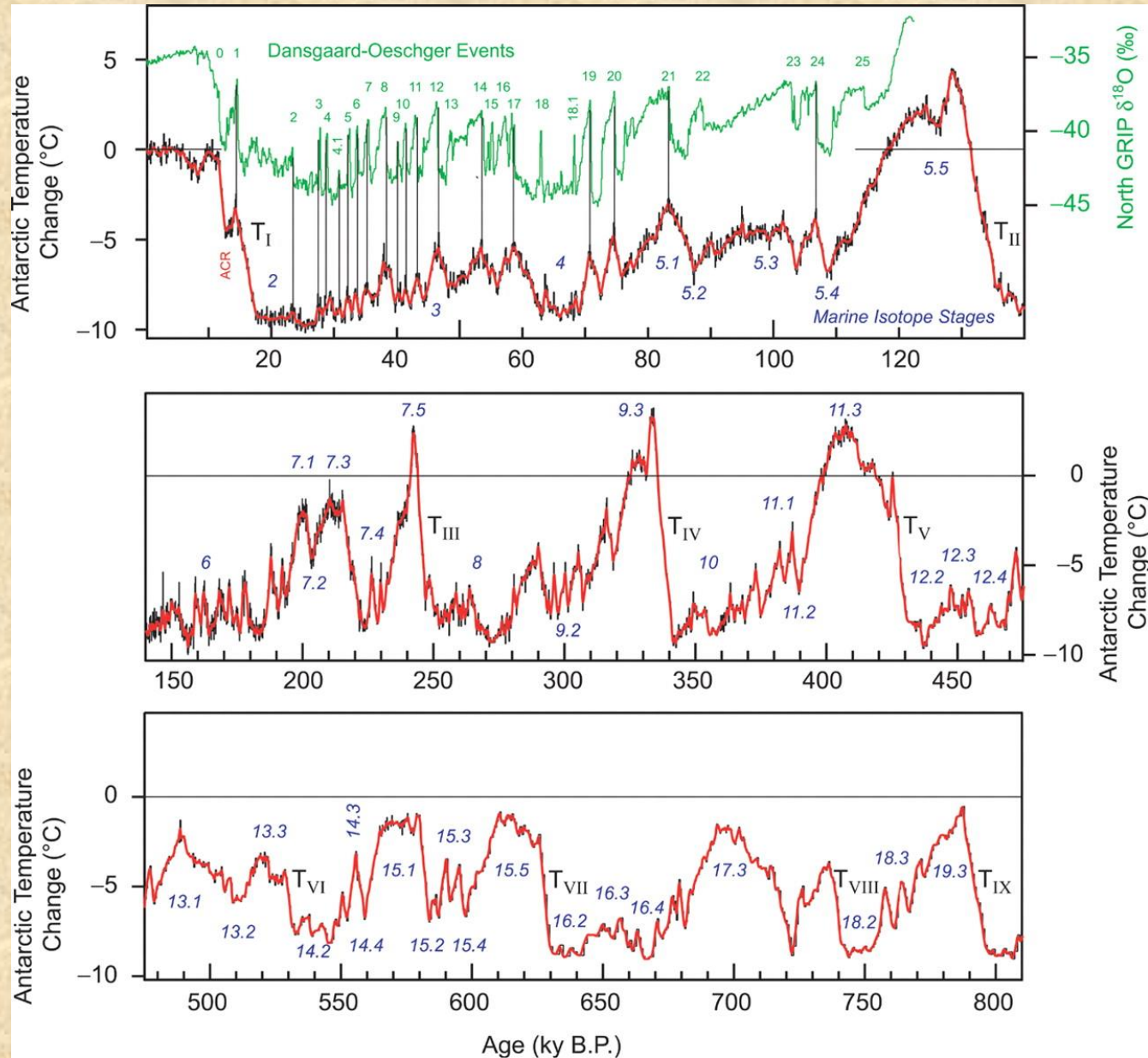


Enciclopedia Britannica



[http://www.soest.hawaii.edu/mguidry/Unnamed\\_Site\\_2/Chapter%202/Chapter2A2.html](http://www.soest.hawaii.edu/mguidry/Unnamed_Site_2/Chapter%202/Chapter2A2.html)

# ... e un esempio dell'effetto che questi cambiamenti possono produrre ...





# Come si studia il clima del passato?

## Archivi naturali PROXY DATA

Adatti per studiare le **variazioni climatiche a lungo periodo** (fino a scale geologiche)



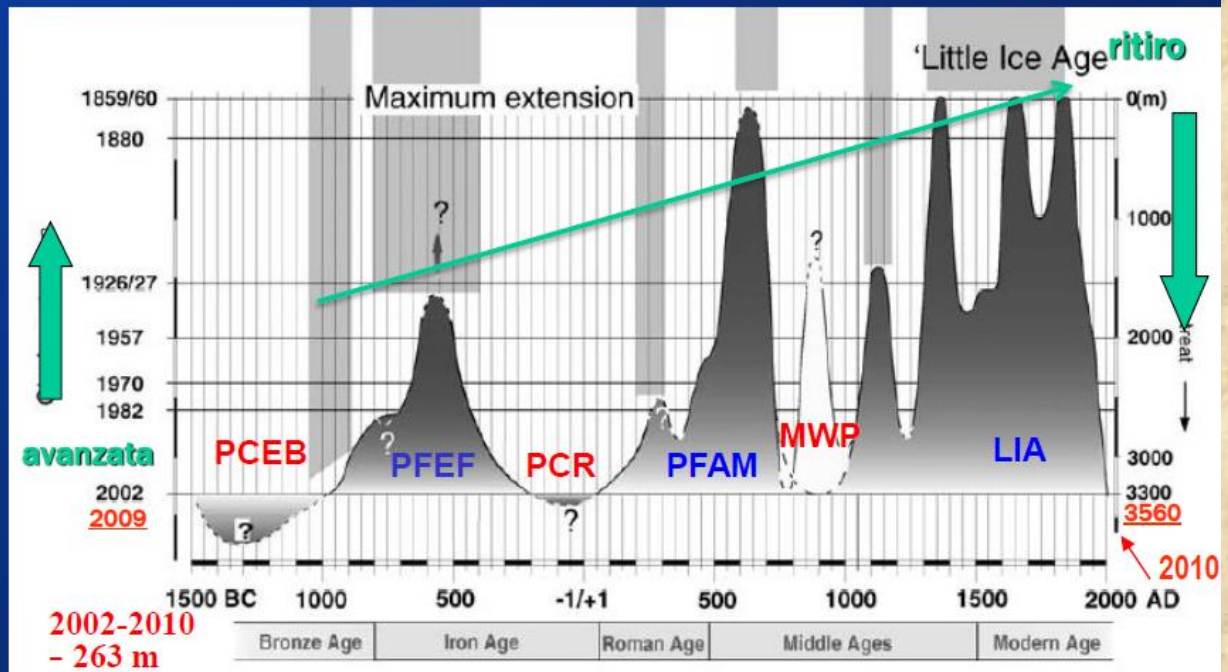


# Come si studia il clima del passato?

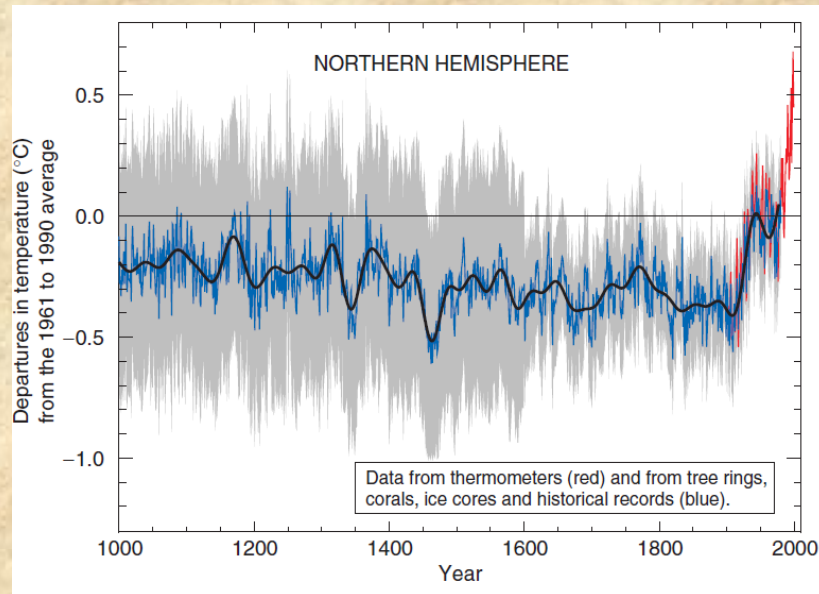
## Gh. Aletsch - fasi di avanzata e ritiro negli ultimi 3000 anni

Periodo Caldo Età del Bronzo  
Periodo Freddo Età del Ferro  
Periodo Caldo Romano  
Periodo Freddo Alto Medioevo  
Periodo Caldo Medioevale  
Piccola Età Glaciale:  
3 max: 1360-90  
1600-50  
1820-60

Holzhauser, Magny  
& Zumbuhl, 2005



# I proxy data non sono facili da leggere

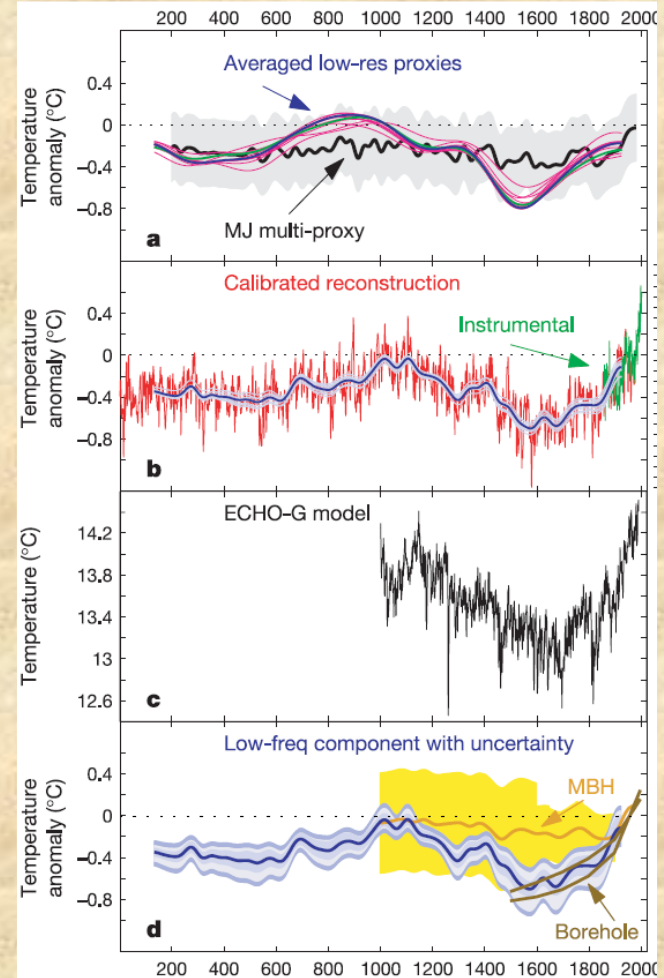


## Hockey stick curve – IPCC TAR - Mann-Bradley-Hughes

### Highly variable Northern Hemisphere temperatures reconstructed from low- and high-resolution proxy data

Anders Moberg<sup>1</sup>, Dmitry M. Sonechkin<sup>2</sup>, Karin Holmgren<sup>3</sup>,  
Nina M. Datsenko<sup>2</sup> & Wibjörn Karlén<sup>3</sup>

**Figure 2** Estimations of Northern Hemisphere mean temperature variations. **a**, Previous multi-proxy reconstruction (MJ: from Mann and Jones<sup>7</sup>, black line) with  $\pm 2$  s.d. uncertainty (grey shading), and various averages (blue, green, magenta; see Methods) of smoothed low-resolution temperature indicators (nos 2–10 in Table 1). **b**, Our multi-proxy reconstruction AD 1–1979 (red) with its  $>80$ -yr component AD 133–1925 (blue) and its jack-knifed estimates (light blue), and the instrumental record<sup>19</sup> (green). **c**, Forced ECHO-G model<sup>13,14,26</sup>. **d**, Low-frequency component of multi-proxy reconstruction in **b** (blue curve) with confidence intervals for three separate uncertainties. The innermost medium-blue band shows the uncertainty due to variance among the low-resolution proxy



series. The two outer bands show the uncertainty in the variance scaling factor (light blue) and the constant adjustment (outermost blue band) separately. Each uncertainty is illustrated with an approximate 95% confidence interval (see Supplementary Information). Also shown are ground surface temperatures estimated from boreholes<sup>12</sup> with their uncertainty interval (brown; see Methods), and the  $>80$ -yr component of a previous multi-proxy reconstruction (MBH: from Mann *et al.*<sup>1,2</sup>, orange) with  $\pm 2$  s.d. uncertainty (yellow). **e, f**, Wavelet transform (see Methods) of the series in **b** and **c** where warm/cold anomalies are red/blue. Temperature anomalies in **a, b** and **d** are with respect to the 1961–90 average.



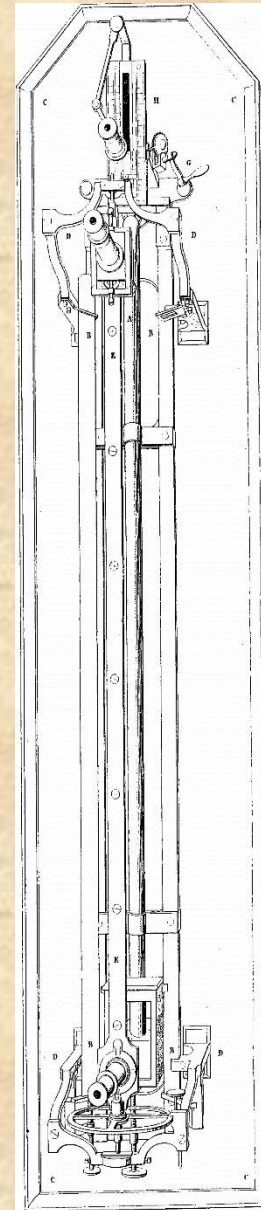


OSSERVAZIONI METEOROLOGICHE FATTE ALL'ALTO-CARRETO DI FINCA DEL LICO DI MANTOVA nel mese di *Settembre*

Giorni	Oriz.	Temperatura Barometrica	Risultato	Spazio in m.	Altezza del bar.	Vento	Altre osservazioni	ATTI E NOTE
1	10	14.5	10.5	10.5	10.5	10.5	10.5	10.5
2	11	15.0	11.0	11.0	11.0	11.0	11.0	11.0
3	12	15.5	11.5	11.5	11.5	11.5	11.5	11.5
4	13	16.0	12.0	12.0	12.0	12.0	12.0	12.0
5	14	16.5	12.5	12.5	12.5	12.5	12.5	12.5
6	15	17.0	13.0	13.0	13.0	13.0	13.0	13.0
7	16	17.5	13.5	13.5	13.5	13.5	13.5	13.5
8	17	18.0	14.0	14.0	14.0	14.0	14.0	14.0
9	18	18.5	14.5	14.5	14.5	14.5	14.5	14.5
10	19	19.0	15.0	15.0	15.0	15.0	15.0	15.0
11	20	19.5	15.5	15.5	15.5	15.5	15.5	15.5
12	21	20.0	16.0	16.0	16.0	16.0	16.0	16.0
13	22	20.5	16.5	16.5	16.5	16.5	16.5	16.5
14	23	21.0	17.0	17.0	17.0	17.0	17.0	17.0
15	24	21.5	17.5	17.5	17.5	17.5	17.5	17.5
16	25	22.0	18.0	18.0	18.0	18.0	18.0	18.0
17	26	22.5	18.5	18.5	18.5	18.5	18.5	18.5
18	27	23.0	19.0	19.0	19.0	19.0	19.0	19.0
19	28	23.5	19.5	19.5	19.5	19.5	19.5	19.5
20	29	24.0	20.0	20.0	20.0	20.0	20.0	20.0
21	30	24.5	20.5	20.5	20.5	20.5	20.5	20.5
22	31	25.0	21.0	21.0	21.0	21.0	21.0	21.0

# Dati strumentali

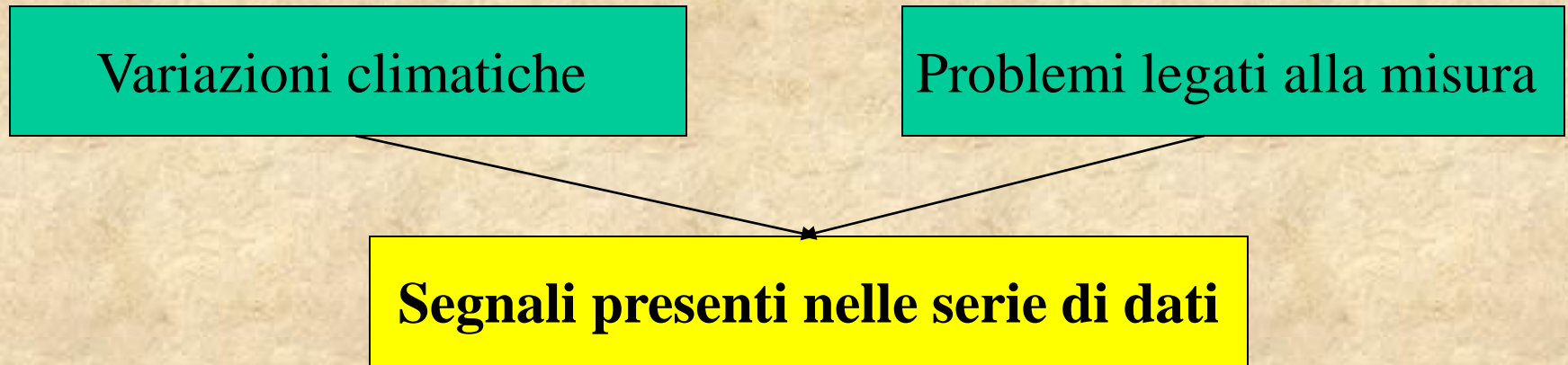
TAVOLA I  
 MINISTERO D'AGRICOLTURA INDUSTRIA E COMMERCIO  
 1866  
 Direzione di Statistica  
 METEOROLOGIA ITALIANA  
 1868



MINISTERO DELL'AGRICOLTURA E DELLE FORESTE  
 UFFICIO CENTRALE DI METEOROLOGIA E CLIMATOLOGIA  
 OSSERVATORIO METEOROLOGICO DI *Castellina*  
 10 GEN 1868  
 Mese di *Gennaio*  
 Decade



# Ma anche i dati strumentali hanno i loro problemi



## Problemi legati alla misura

Rilocalizzazioni

Errori strumentali (cambiamenti o ricalibrazioni degli strumenti)

Metodologie di osservazione

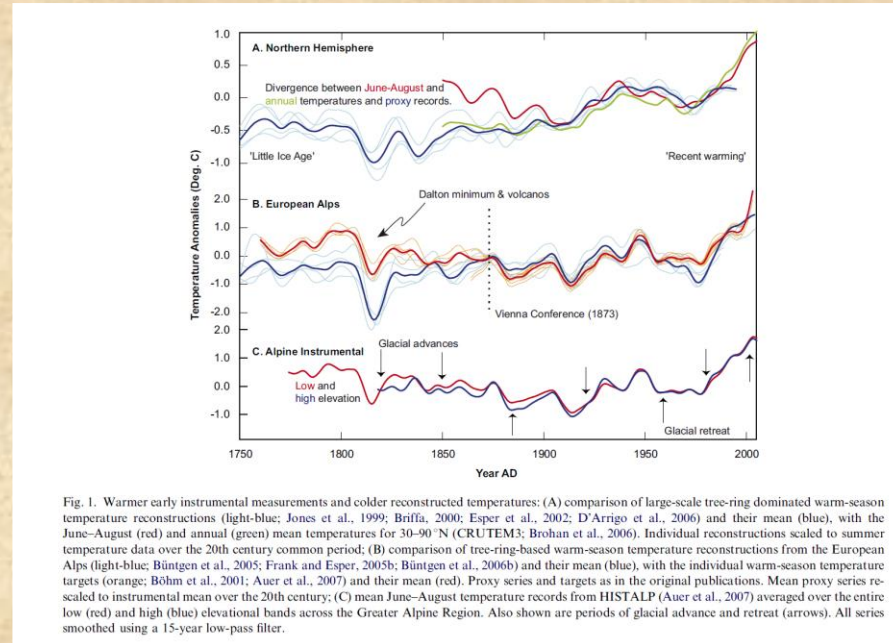
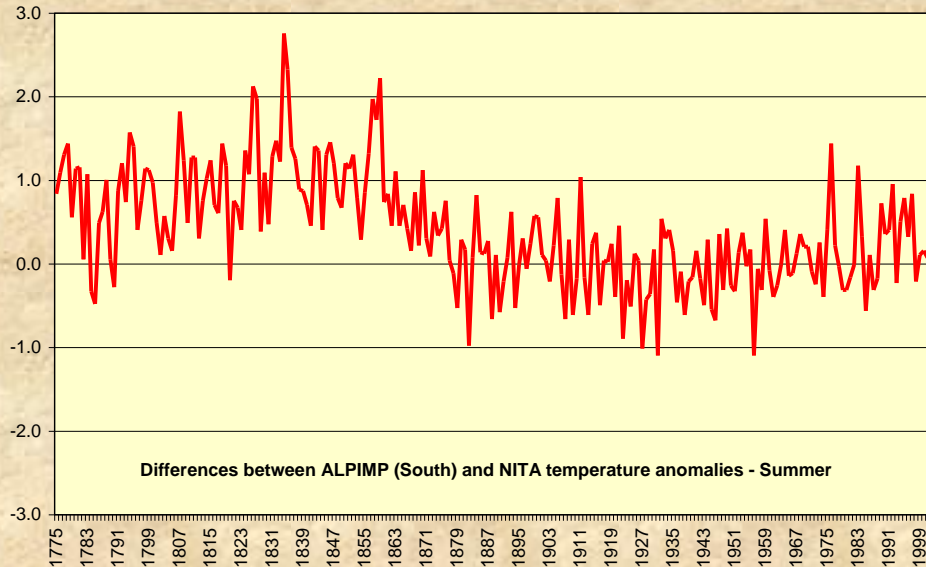
Caratteristiche delle schermature

Modificazioni ambientali (microscala – intera città)



# Ma anche i dati strumentali hanno i loro problemi

Differenze nell'evoluzione della temperatura estiva nel periodo 1775-2003 nella Grande Regione Alpina (sud) secondo Auer et al. (2007) e Brunetti et al. (2006)



Climatic Change (2010) 101:41-67  
DOI 10.1007/s10584-009-9649-4

## The early instrumental warm-bias: a solution for long central European temperature series 1760-2007

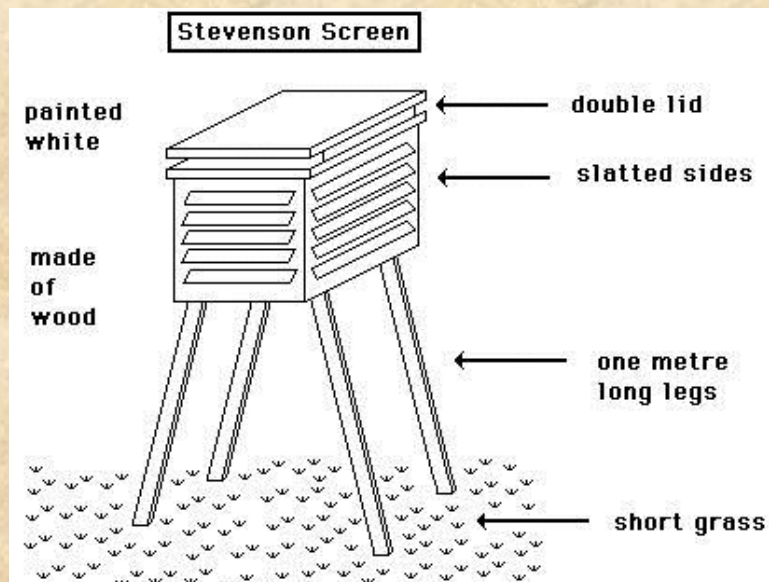
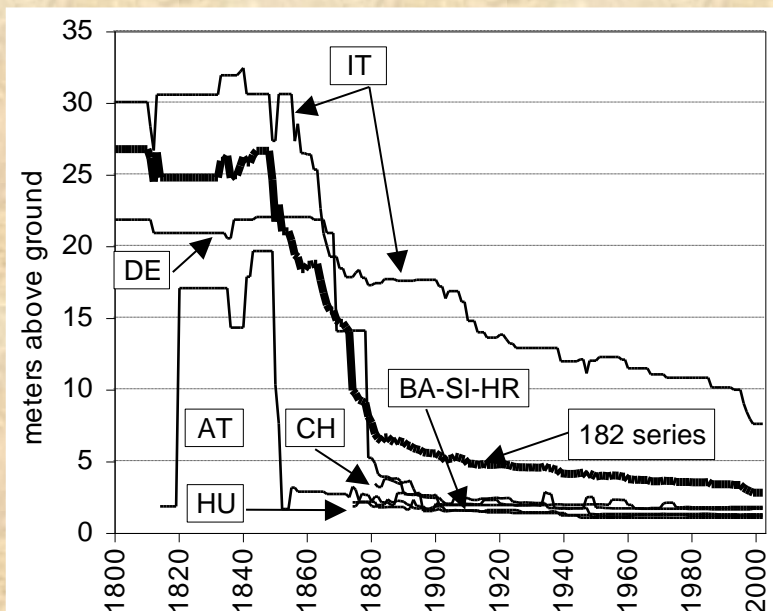
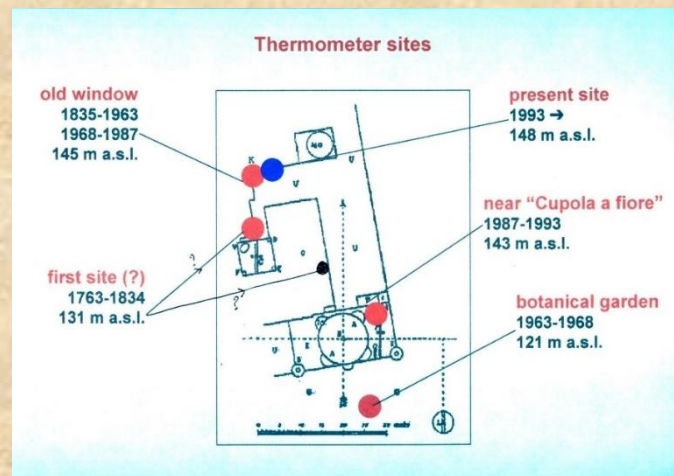
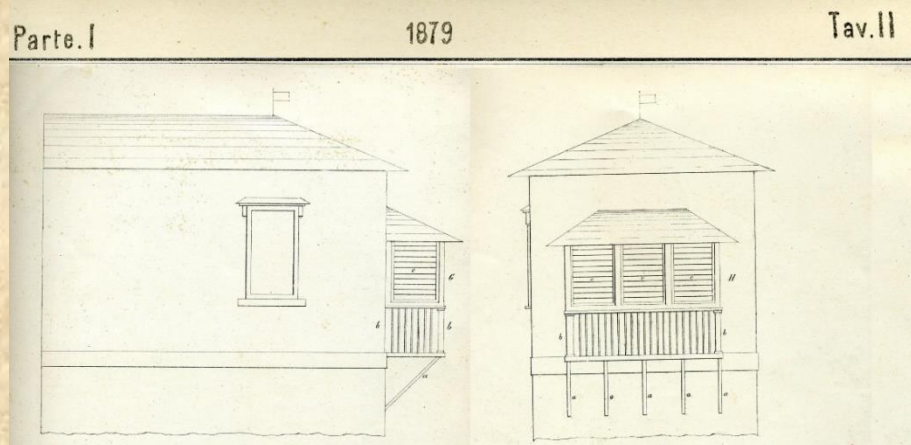
Reinhard Böhm · Philip D. Jones · Johann Hiebl · David Frank · Michele Brunetti · Maurizio Maugeri

Frank, D., Büntgen, U., Böhm, R., Maugeri, M., Esper, J., 2007: Warmer early instrumental measurements versus colder reconstructed temperatures: shooting at a moving target, Quaternary Science Reviews, 26, 3298-3310



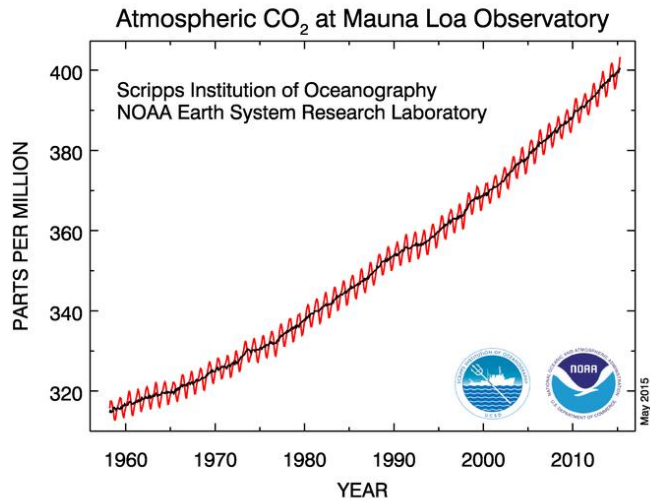
I problemi maggiori riguardano naturalmente le serie più antiche. Ma anche per periodi più recenti la questione va affrontata con grande attenzione.

→ L'omogeneizzazione dei dati è una fase chiave nell'analisi dei dati strumentali



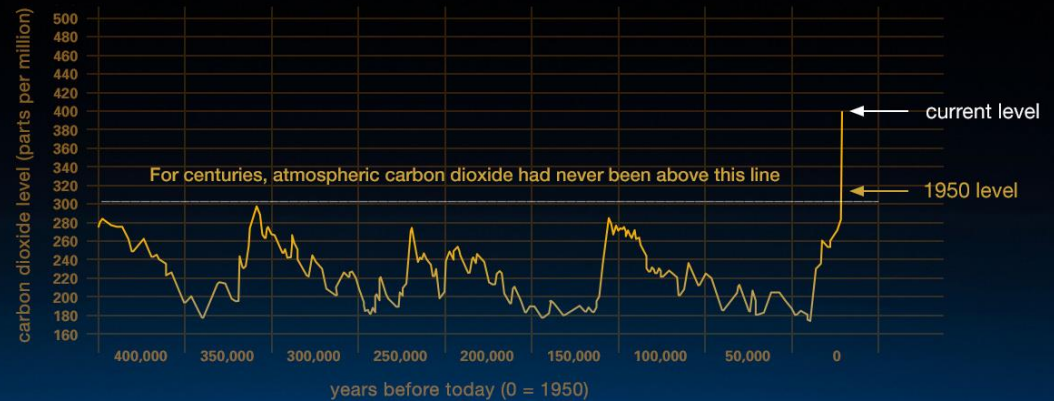
*La piena consapevolezza del ruolo cruciale dei metodi di omogeneizzazione costituisce uno dei principali risultati a cui la comunità scientifica del settore è arrivata nel corso degli ultimi 20 anni circa*

# Cosa ci preoccupa oggi: CO<sub>2</sub> e gas serra



... e le concentrazioni sono molto lontane dall'essere in equilibrio con le emissioni ...

carbon dioxide atmospheric concentration from Mauna Loa (19°32'N, 155°34'W) since 1958.  
Fonte: US National Oceanic and Atmospheric Administration (NOAA)

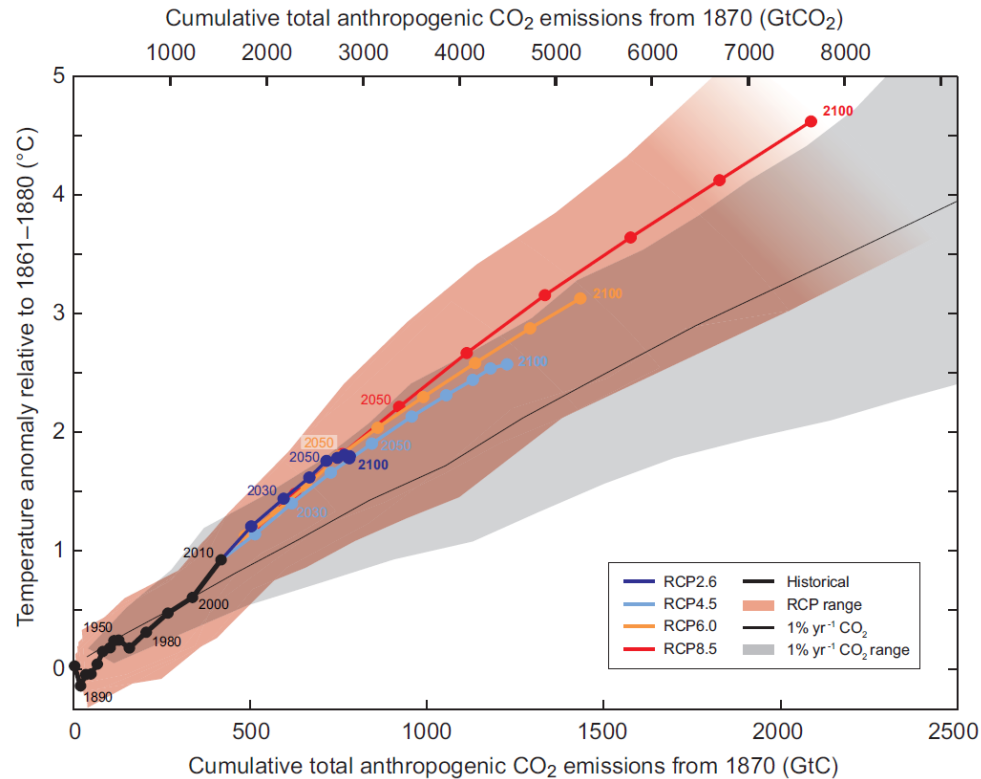


<http://climate.nasa.gov/evidence/>



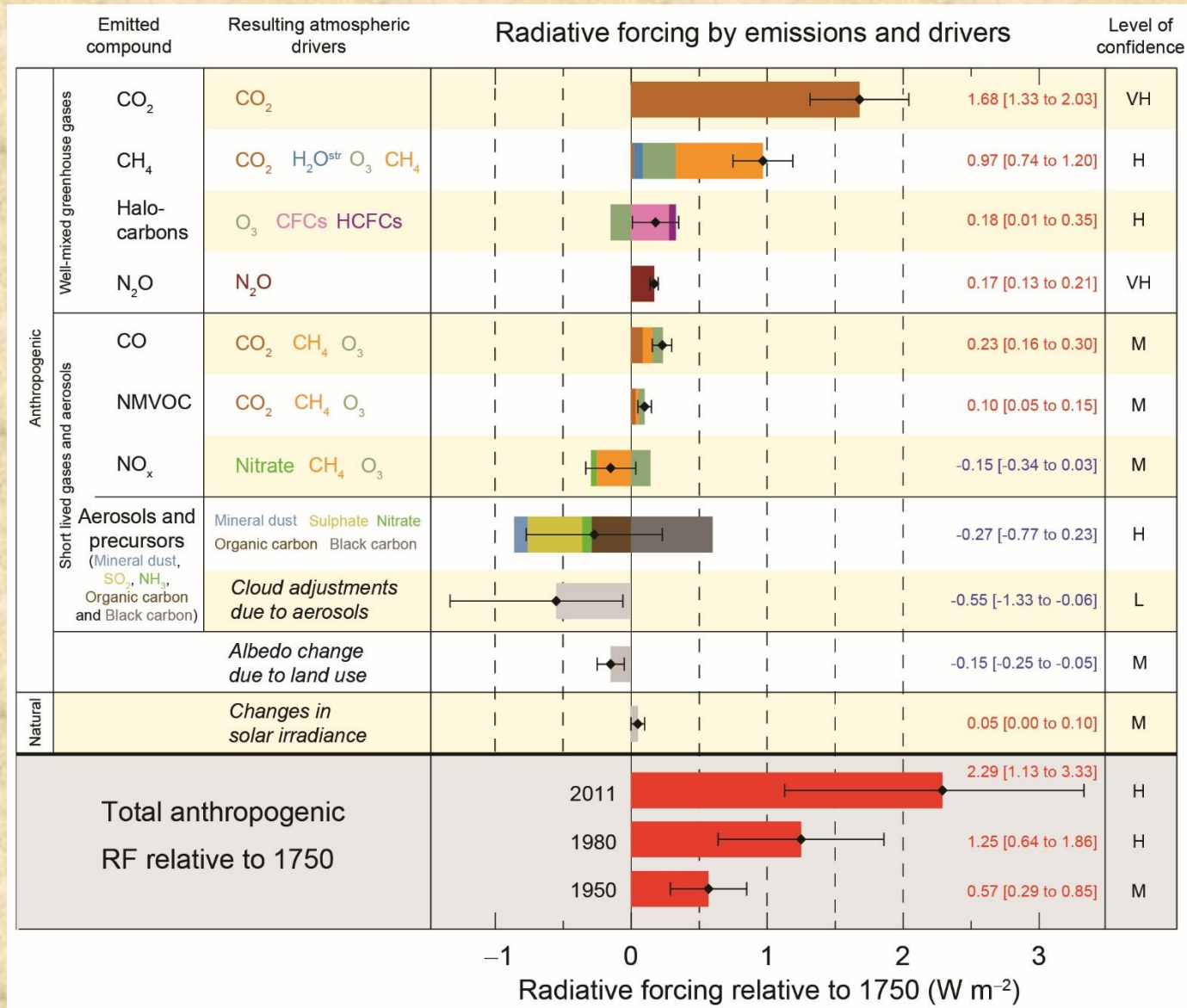
# Cosa ci preoccupa oggi: tempo di vita dei gas serra in atmosfera.

## Una parte della CO<sub>2</sub> in eccesso ha una vita così lunga che ... alla fine ciò che conta è solo l'integrale delle emissioni nel tempo ...

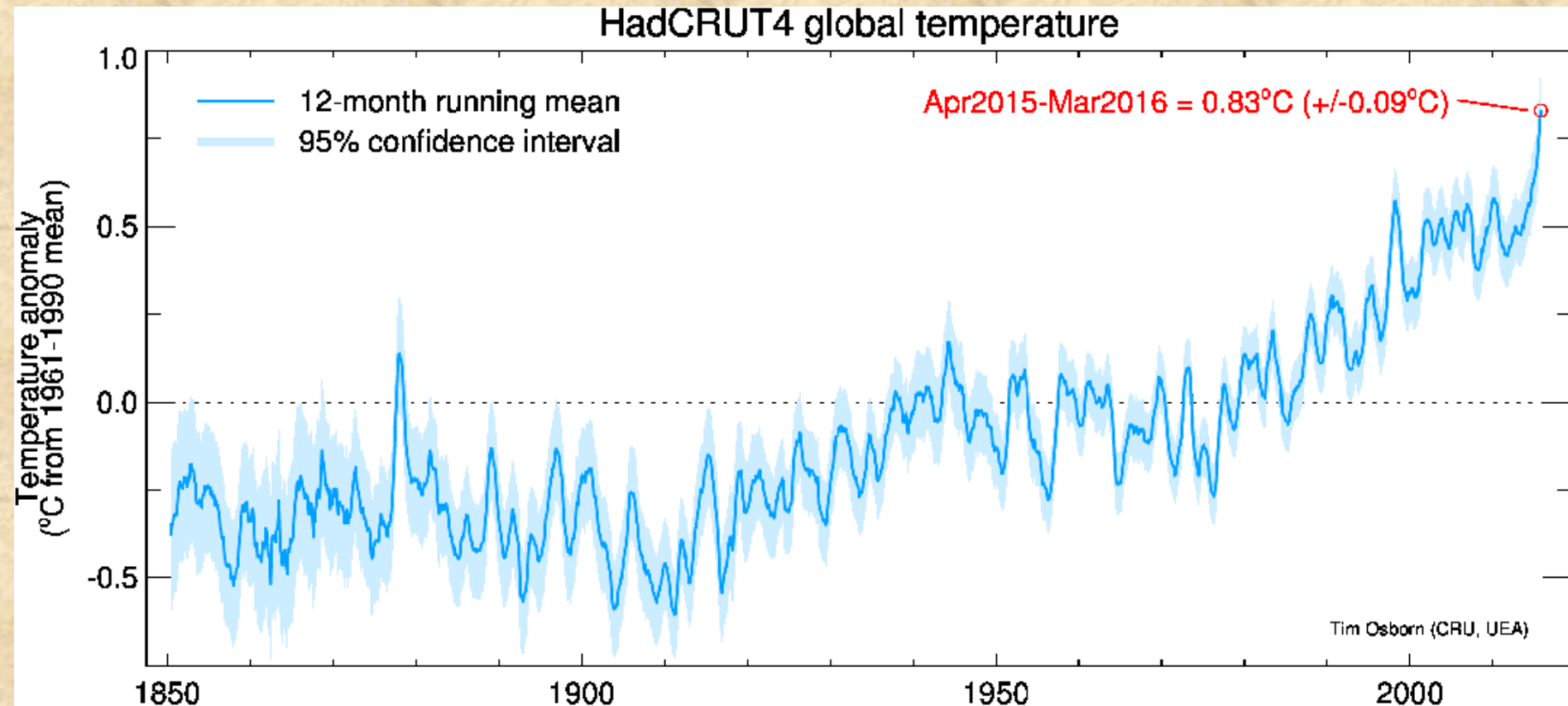


**Figure SPM.10 |** Global mean surface temperature increase as a function of cumulative total global CO<sub>2</sub> emissions from various lines of evidence. Multi-model results from a hierarchy of climate-carbon cycle models for each RCP until 2100 are shown with coloured lines and decadal means (dots). Some decadal means are labeled for clarity (e.g., 2050 indicating the decade 2040–2049). Model results over the historical period (1860 to 2010) are indicated in black. The coloured plume illustrates the multi-model spread over the four RCP scenarios and fades with the decreasing number of available models in RCP8.5. The multi-model mean and range simulated by CMIP5 models, forced by a CO<sub>2</sub> increase of 1% per year (1% yr<sup>-1</sup> CO<sub>2</sub> simulations), is given by the thin black line and grey area. For a specific amount of cumulative CO<sub>2</sub> emissions, the 1% per year CO<sub>2</sub> simulations exhibit lower warming than those driven by RCPs, which include additional non-CO<sub>2</sub> forcings. Temperature values are given relative to the 1861–1880 base period, emissions relative to 1870. Decadal averages are connected by straight lines. For further technical details see the Technical Summary Supplementary Material. {Figure 12.45; TS TFE.8, Figure 1}

# Cosa ci preoccupa oggi: gas serra e forcing radiativo



# Cosa dicono le osservazioni: scala Planetaria

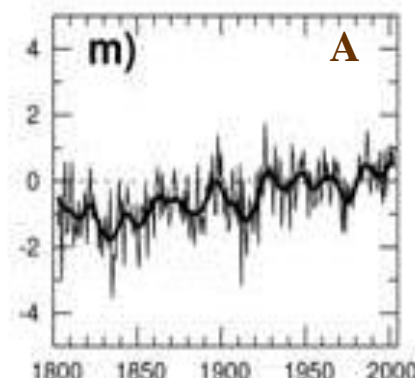
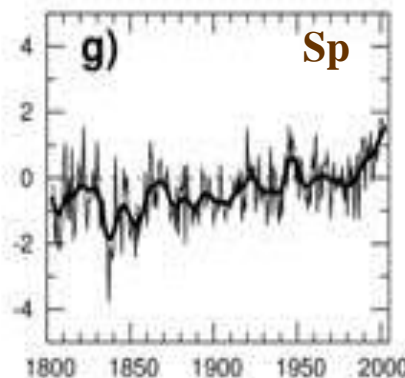
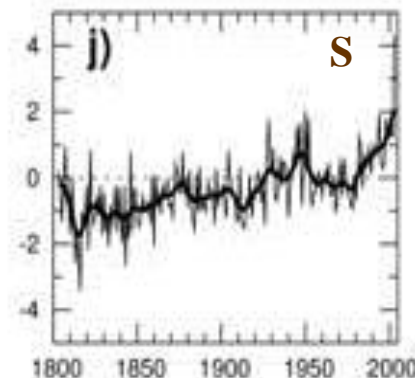
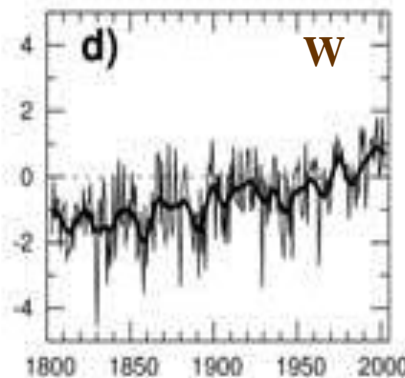
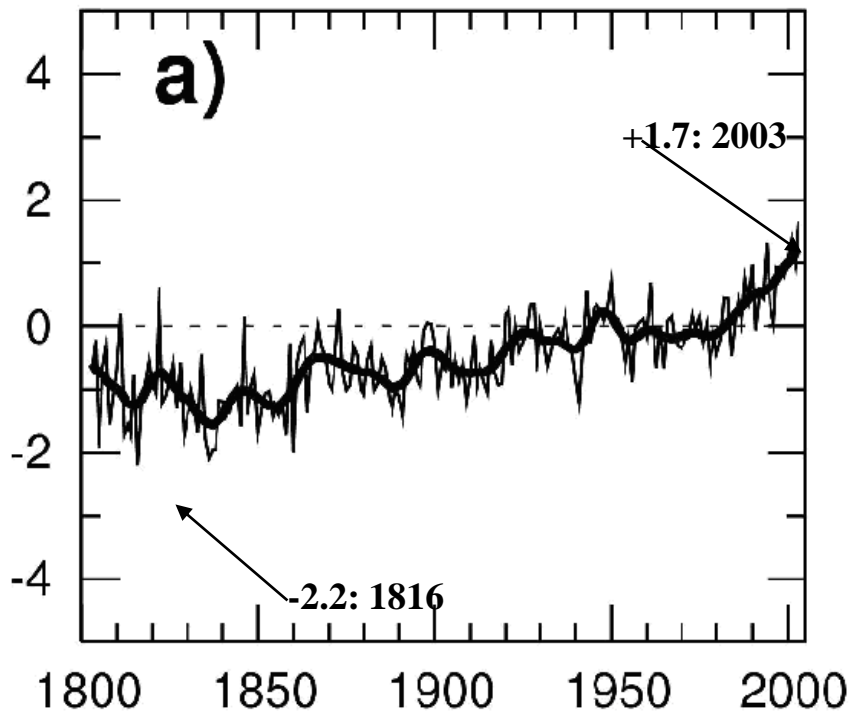


<http://www.cru.uea.ac.uk/>



# Scala nazionale: temperature

## Anno e stagioni



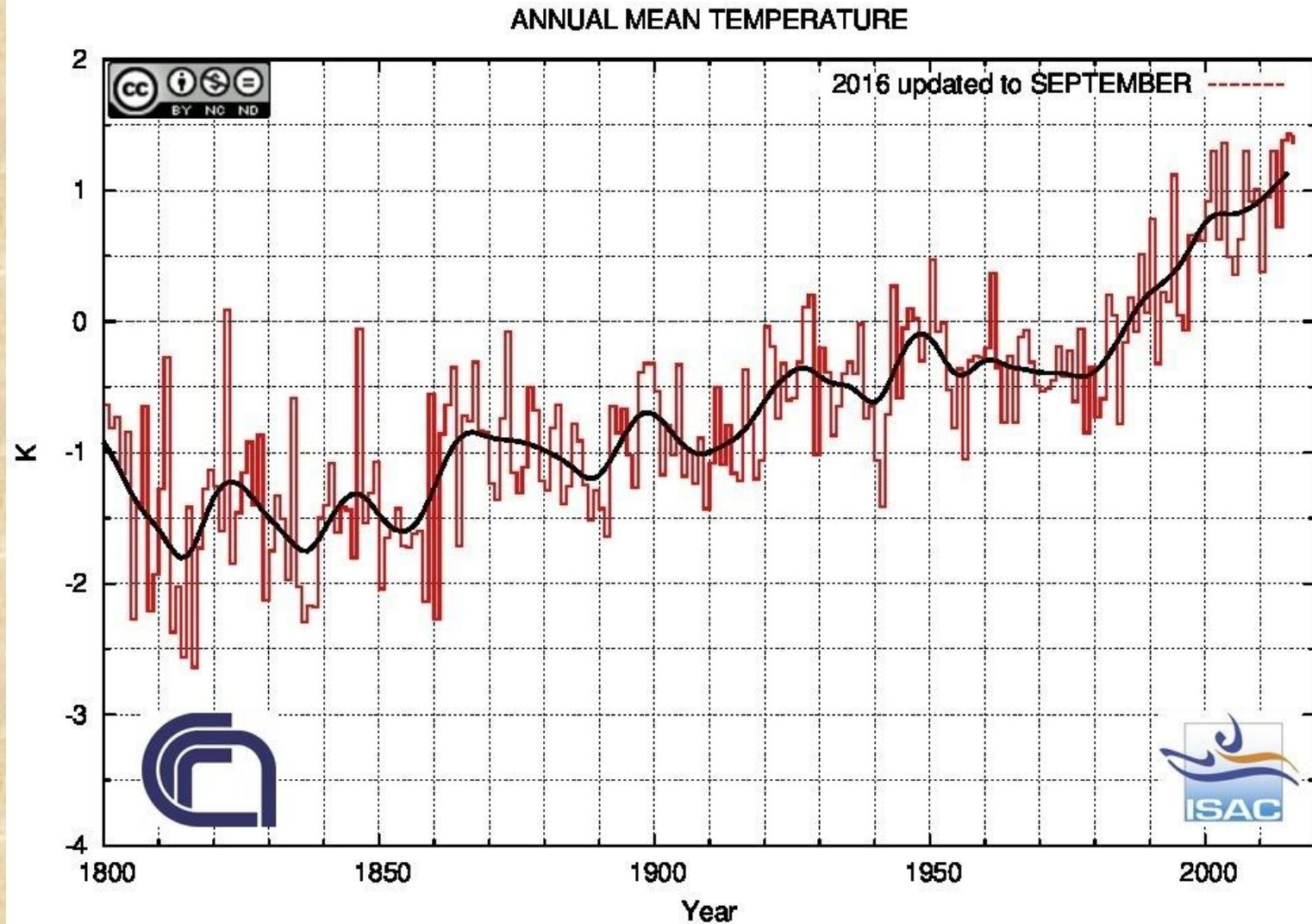
*Int. J. Climatol.* **26**: 345–381 (2006)

TEMPERATURE AND PRECIPITATION VARIABILITY IN ITALY IN THE LAST TWO CENTURIES FROM HOMOGENISED INSTRUMENTAL TIME SERIES

M. BRUNETTI, M. MAUGERI, F. MONTI and T. NANNI

	Tmed				Tmax				Tmin			
	AL	PP	PI	ITA	AL	PP	PI	ITA	AL	PP	PI	ITA
Y	1.0±0.1	1.0±0.1	1.0±0.1	1.0±0.1	0.8±0.1	1.1±0.1	0.7±0.1	0.9±0.1	1.2±0.1	0.9±0.1	1.3±0.1	1.1±0.1
W	1.2±0.2	1.0±0.3	1.0±0.2	1.1±0.2	1.2±0.2	1.2±0.3	0.8±0.2	1.0±0.2	1.4±0.2	1.1±0.3	1.2±0.2	1.2±0.2
Sp	1.0±0.2	1.0±0.2	1.0±0.2	1.0±0.2	0.9±0.2	1.2±0.2	0.7±0.2	0.9±0.2	1.2±0.1	0.9±0.2	1.2±0.1	1.0±0.1
S	1.0±0.2	1.1±0.2	1.2±0.2	1.1±0.2	0.4±0.2	1.1±0.2	0.7±0.2	0.9±0.2	1.2±0.2	0.9±0.2	1.6±0.2	1.2±0.2
A	0.8±0.2	0.8±0.2	0.9±0.2	0.8±0.2	0.6±0.2	0.9±0.2	0.6±0.2	0.8±0.2	1.0±0.2	0.8±0.2	1.1±0.2	0.9±0.2

# La serie viene aggiornata ogni mese



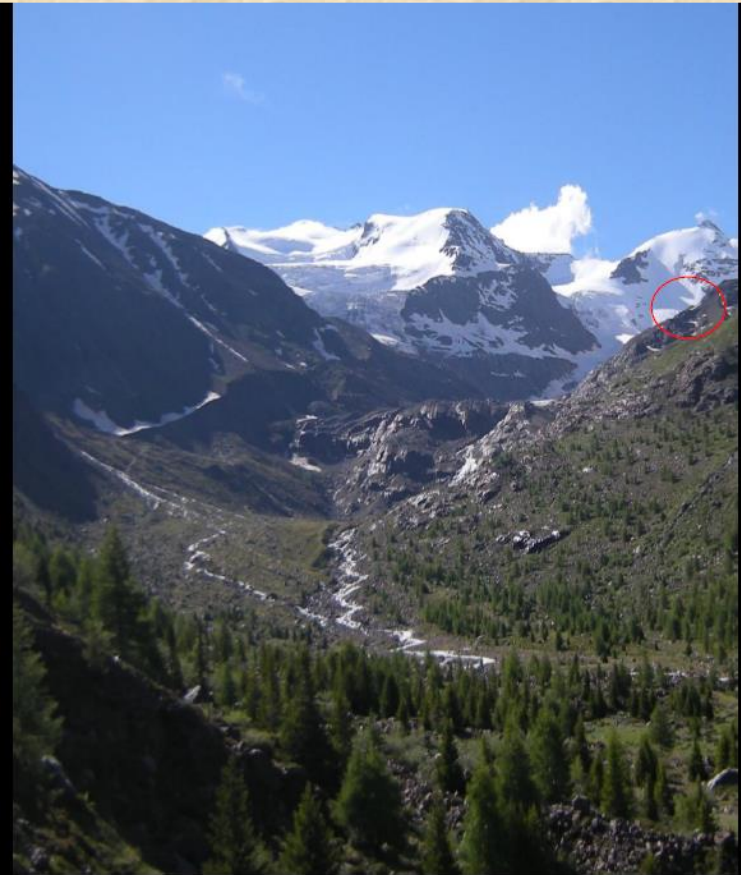
[http://www.isac.cnr.it/climstor/climate\\_news.html](http://www.isac.cnr.it/climstor/climate_news.html) - Anomalies dalle normali 1971-2000 – Anno meteorologico (Dec – Nov)

Brunetti M, Maugeri M, Monti F, Nanni T. 2006. *Temperature and precipitation variability in Italy in the last two centuries from homogenised instrumental time series. Int. J. Climatol.* 26, 345-381

**... le immagini sono spesso più efficaci a livello comunicativo dei numeri...**



Foto A. Desio 1947



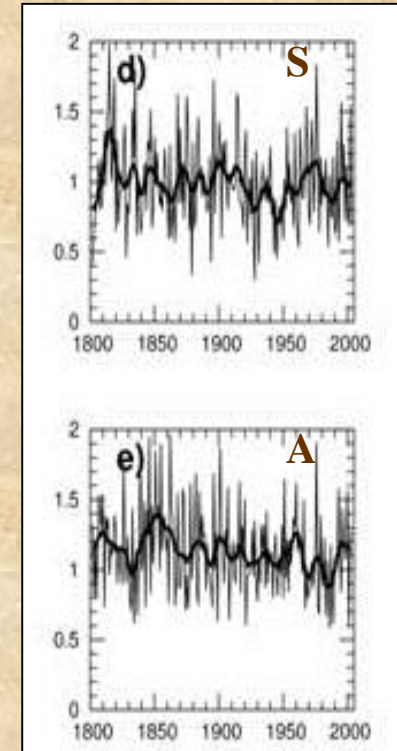
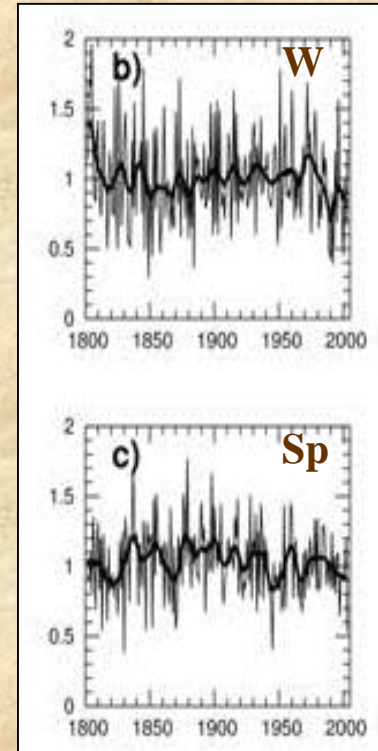
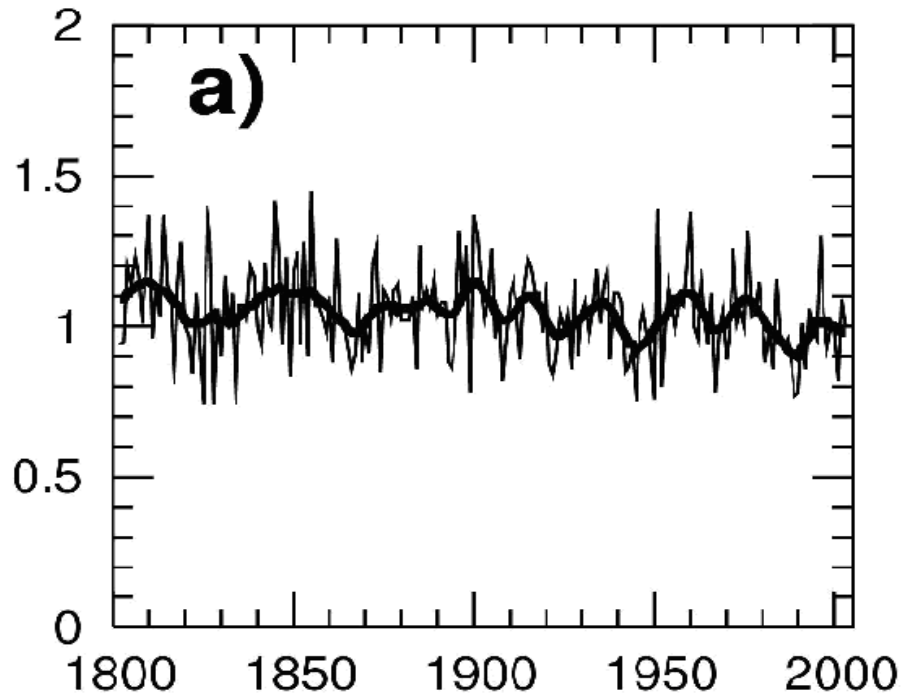
2015

Il ghiacciaio dei Forni: il più grande ghiacciaio della Lombardia. Fonte: Claudio Smiraglia



# Scala nazionale: precipitazioni (trends in %/100y)

## Anno e stagioni



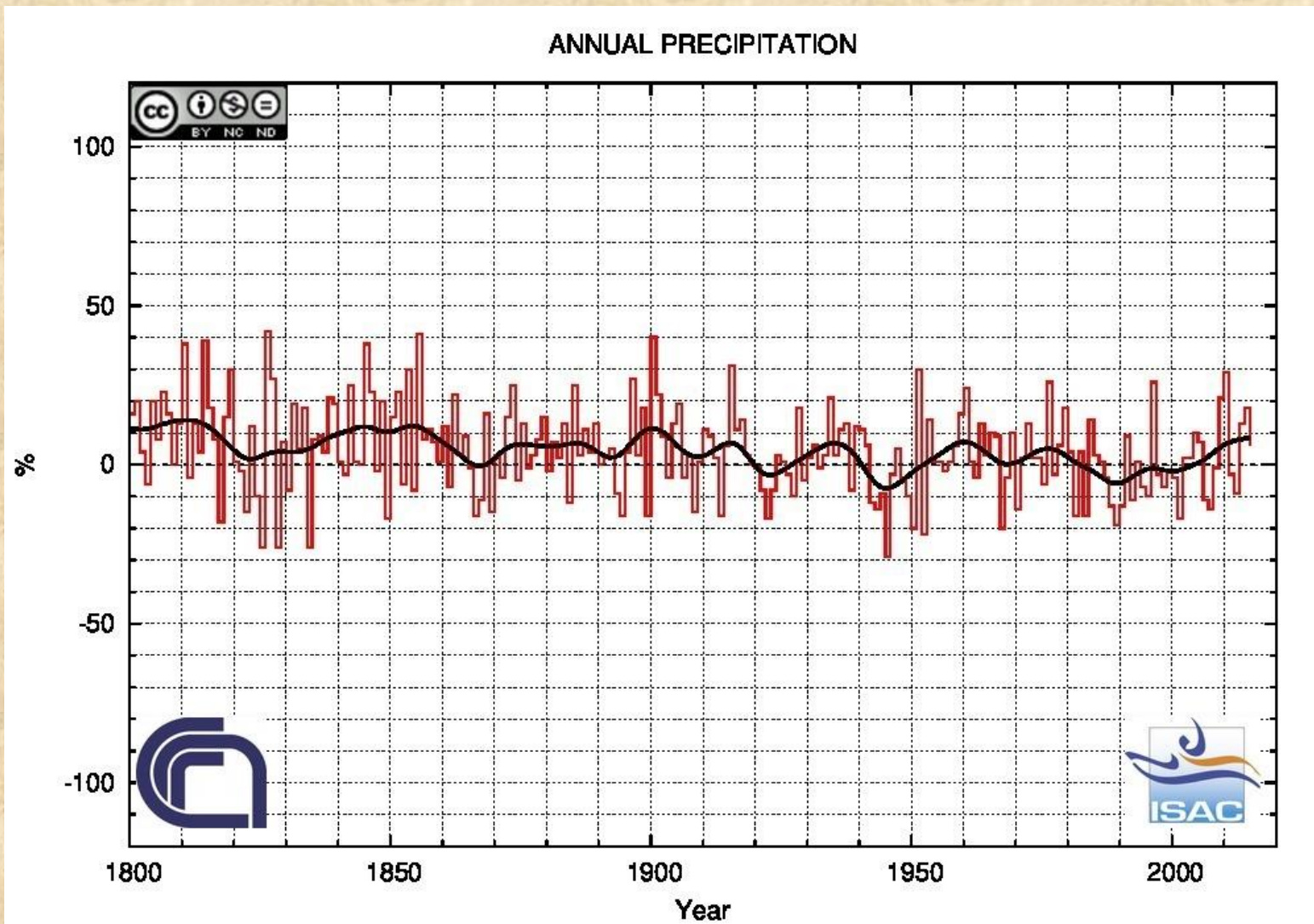
*Int. J. Climatol.* **26**: 345–381 (2006)

TEMPERATURE AND PRECIPITATION VARIABILITY IN ITALY IN THE LAST TWO CENTURIES FROM HOMOGENISED INSTRUMENTAL TIME SERIES

M. BRUNETTI, M. MAUGERI, F. MONTI and T. NANNI

	<b>NW</b>	<b>NEN</b>	<b>PP</b>	<b>CE</b>	<b>SE</b>	<b>SO</b>	<b>ITA</b>
<b>Y</b>	-	-	-	<b>-(10±3)</b>	<b>-(8±5)</b>	+	<b>-(5±3)</b>
<b>W</b>	-	+	+	-	-	+	-
<b>Sp</b>	-	-	-	<b>-(20±5)</b>	-	-	<b>-(9±5)</b>
<b>S</b>	-	-	+	<b>-(13±8)</b>	-	-	-
<b>A</b>	-	-	-	-	-	+	-

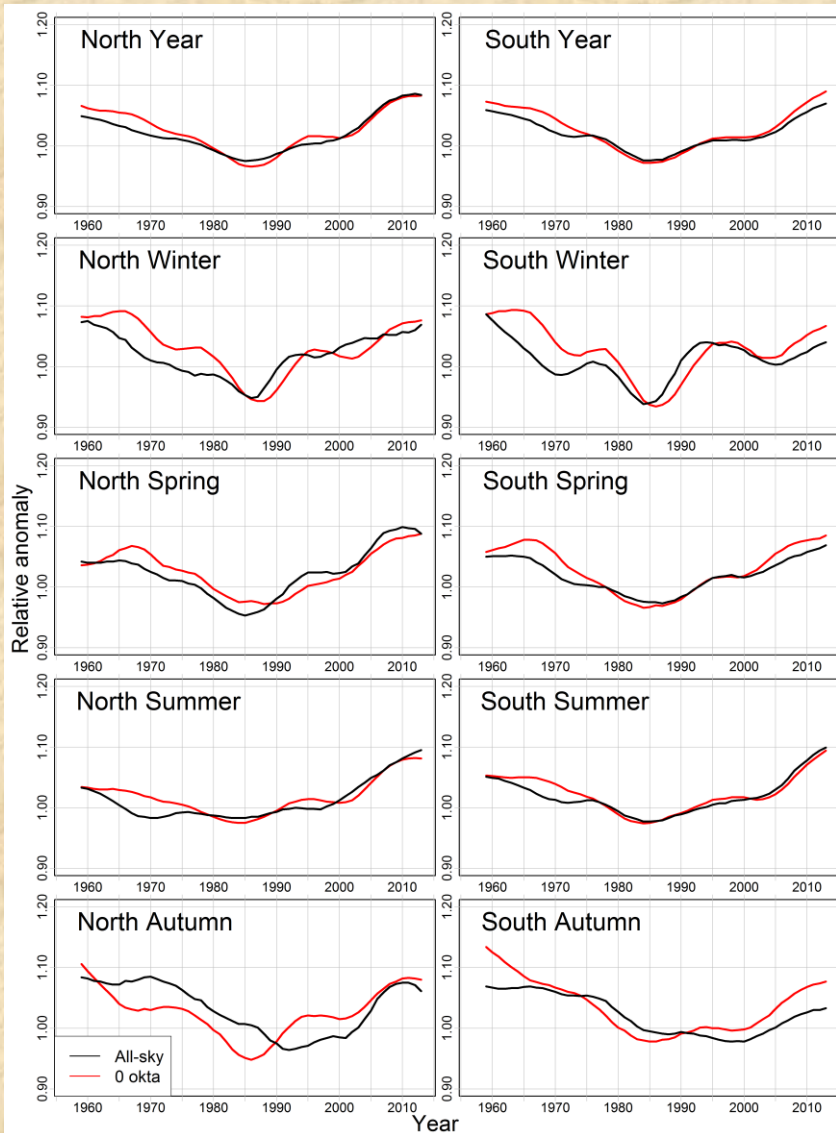
# La serie viene aggiornata ogni anno



[http://www.isac.cnr.it/climstor/climate\\_news.html](http://www.isac.cnr.it/climstor/climate_news.html) - Anomalies dalle normali 1971-2000 – Anno meteorologico (Dec – Nov)

Brunetti M, Maugeri M, Monti F, Nanni T. 2006. *Temperature and precipitation variability in Italy in the last two centuries from homogenised instrumental time series. Int. J. Climatol.* 26, 345-381

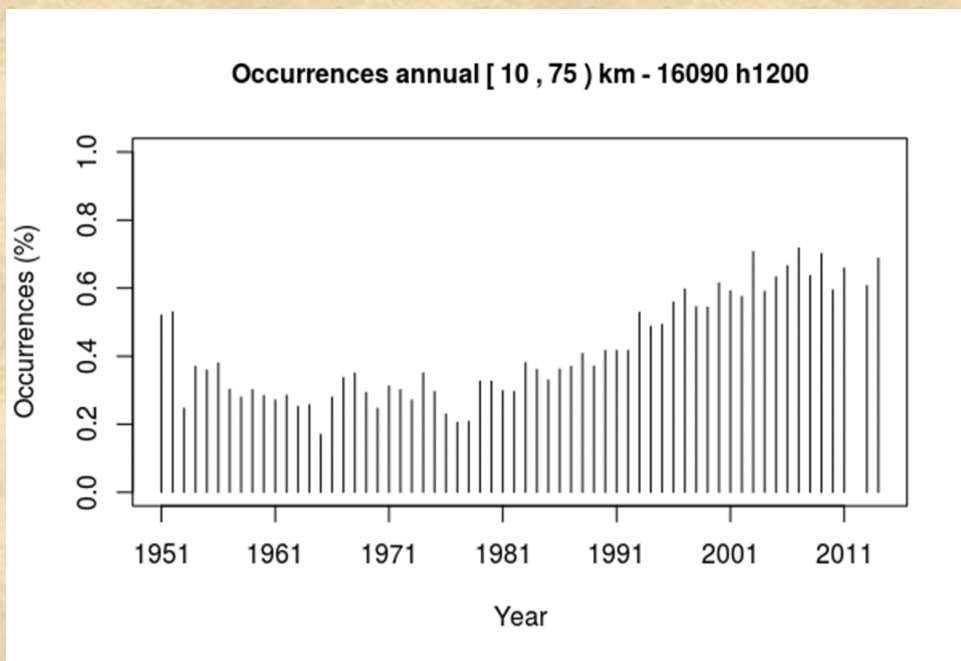
# ... non solo temperature e precipitazioni ...



**Detection of dimming/brightening in Italy from homogenized all sky and clear-sky surface solar radiation records and underlying causes (1959-2013)**

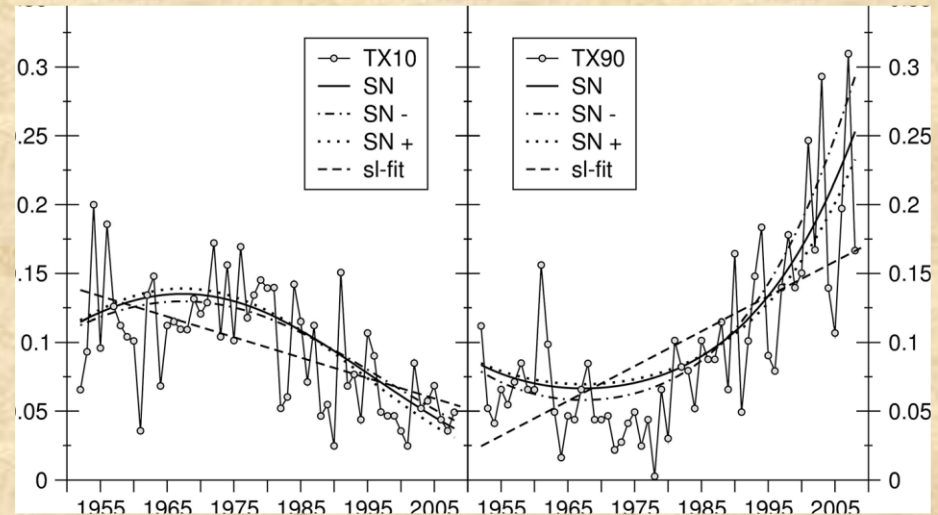
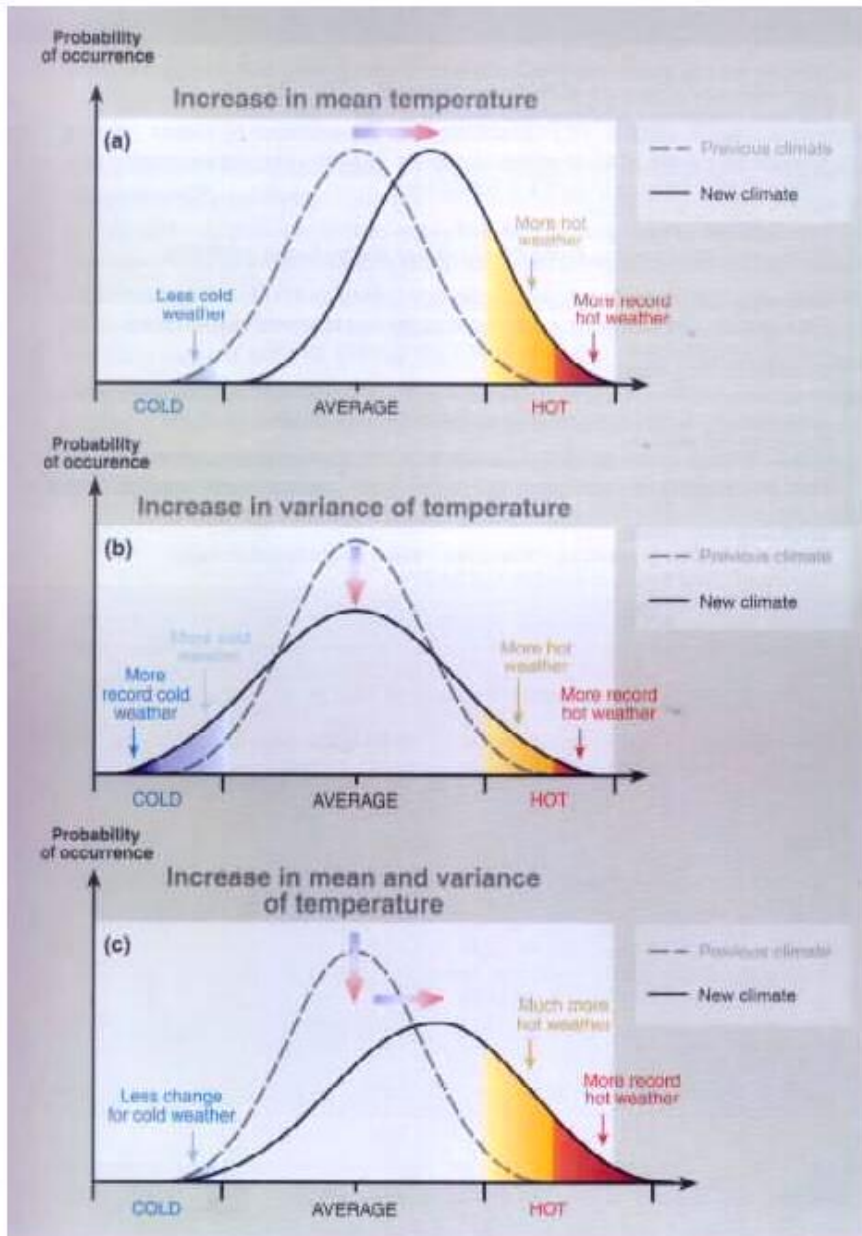
V. Manara, M. Brunetti, A. Celozzi, M. Maugeri, A. Sanchez-Lorenzo, M. Wild

*Paper recente anche su eliofania  
Molti aspetti da approfondire  
(per esempio visibilità)*





# Temperature: cambiano gli estremi? E perché?



Simolo, C., Brunetti, M., Maugeri, M., Nanni, T., Speranza, A., 2010: Understanding climate change-induced variations in daily temperature distributions over Italy. *J. Geophys. Res.*, **115**, D22110.

Simolo, C., Brunetti, M., Maugeri, M., Nanni, T., 2011: Evolution of extreme temperatures in a warming climate. *Geophysical Research Letters*, **38**, L16701

Reg Environ Change (2014) 14:1825–1832  
DOI 10.1007/s10113-012-0373-7

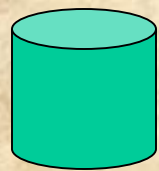
ORIGINAL ARTICLE

**Increasingly warm summers in the Euro-Mediterranean zone: mean temperatures and extremes**

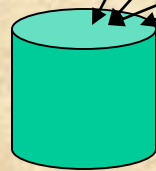
Claudia Simolo · Michele Brunetti ·  
Maurizio Maugeri · Teresa Nanni

# Precipitazioni: cambiano le distribuzioni?

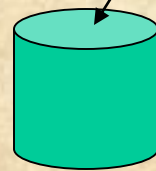
	1	2	3	4	5	6	7	8	9	10
Bo	0.0	0.0	0.0	34.1	5.4	37.5	41.3	7.0	0.0	0.0
Fe	0.0	0.0	15.1	5.1	9.8	7.6	0.0	4.5	0.0	0.0
Ge	0.0	0.0	0.0	4.3	11.1	35.4	13.5	55.6	9.7	7.5
Mn	0.0	0.0	0.0	40.3	11.3	6.4	3.4	38.8	0.7	0.5
Mi	0.0	0.0	0.5	15.4	30.7	22.2	1.8	42.4	0.0	0.0



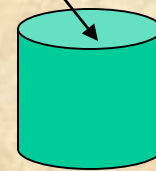
0.0 – 2.5



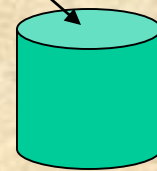
2.5-12.5



12.5-25.0



25.0-50.0



>50.0

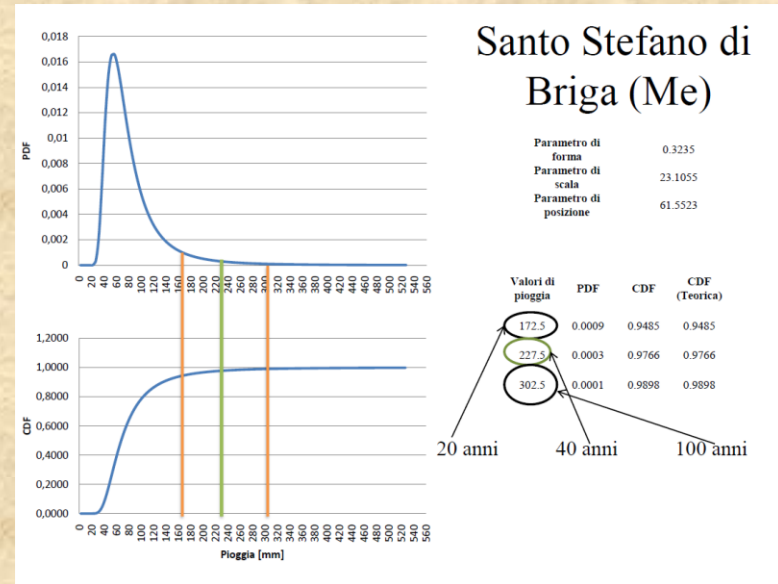
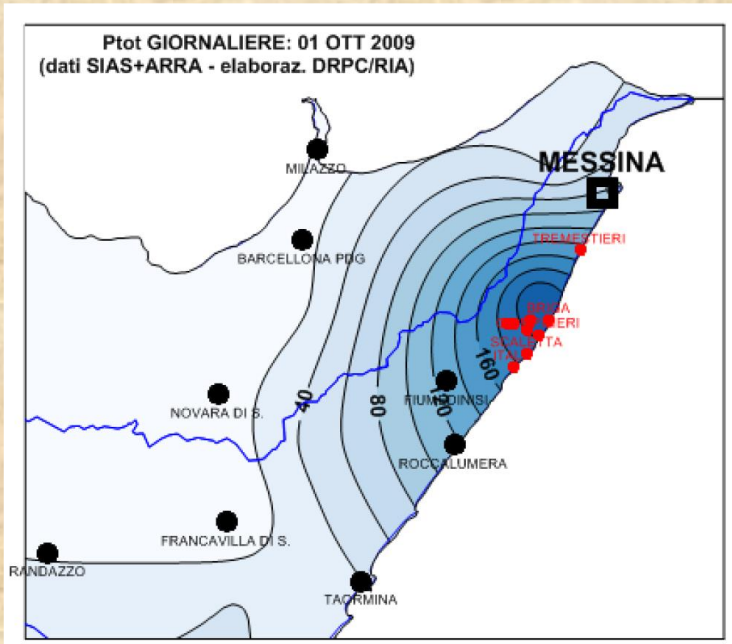
**Serie da analizzare: rapporti tra precipitazioni  
nelle varie classi e precipitazioni totali  
Anno/stagioni/mesi**

$$\frac{\sum_i P_{ij}}{\sum_i P_i}$$

**Scelta classi: esistono molte opzioni**



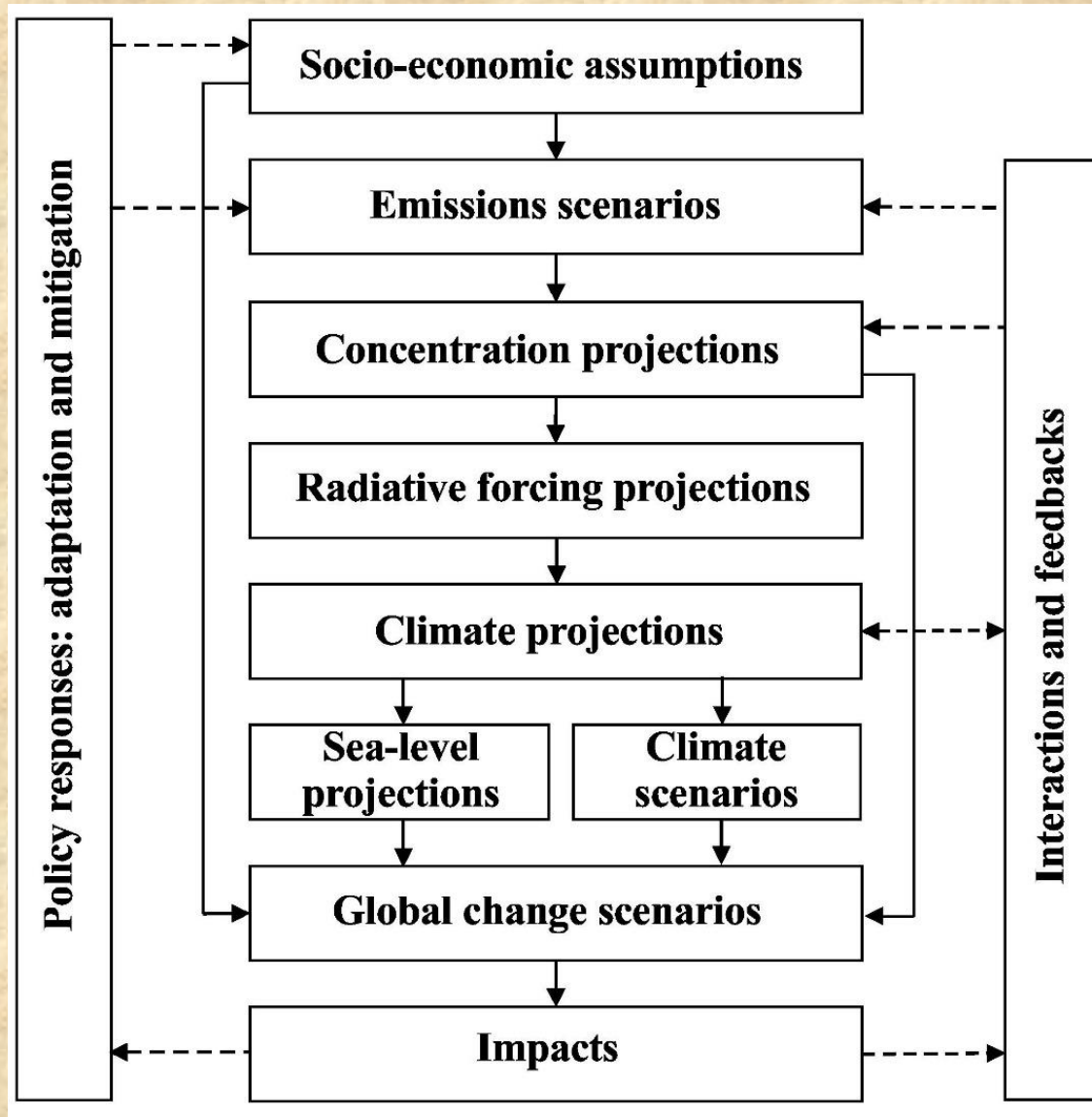
# Precipitazioni: cambiano gli estremi? E perché?

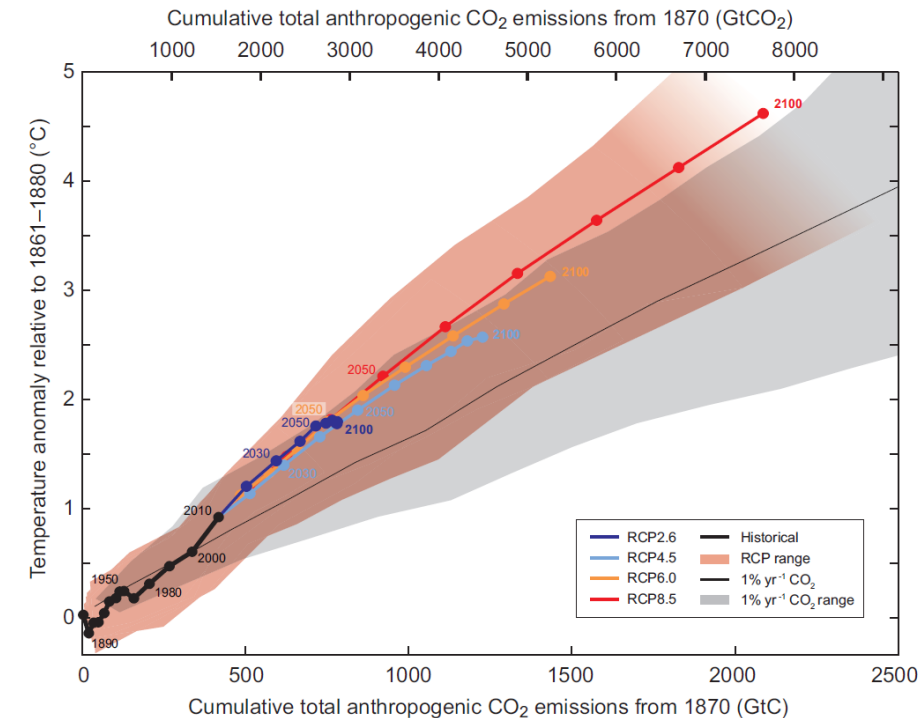
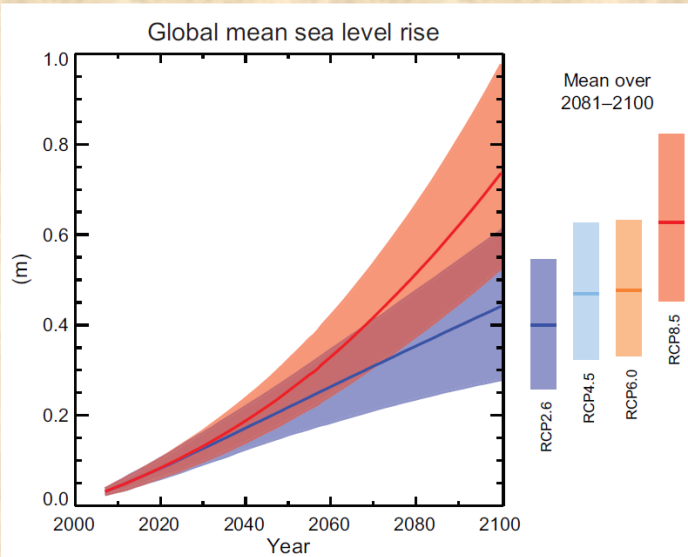
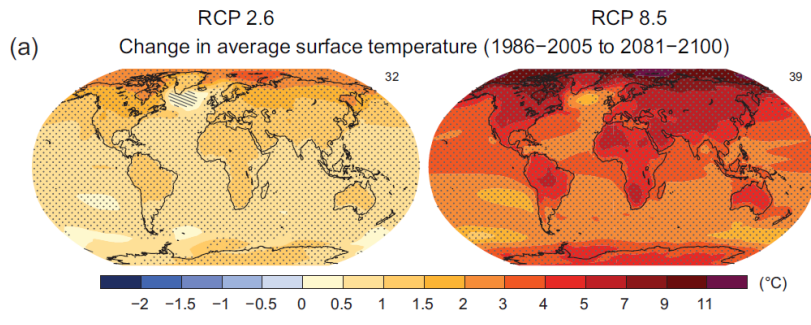
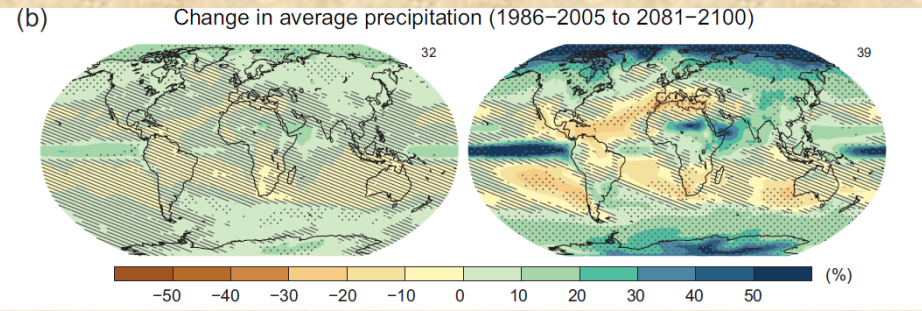
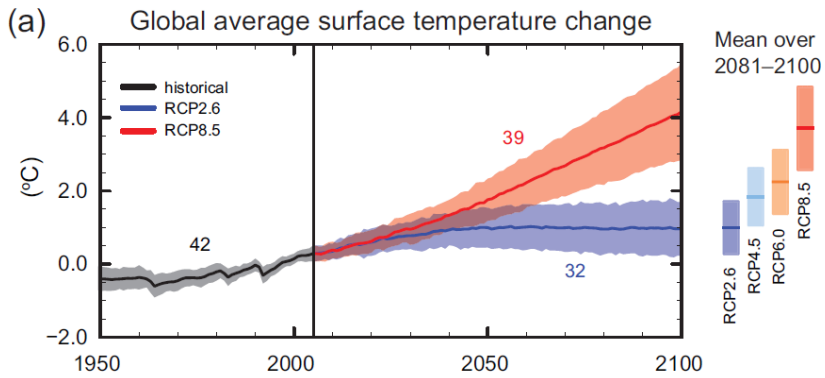


1st October 2009



# ... e come si studia cosa accadrà in futuro...?





Fonte: IPCC AR5 - SPM