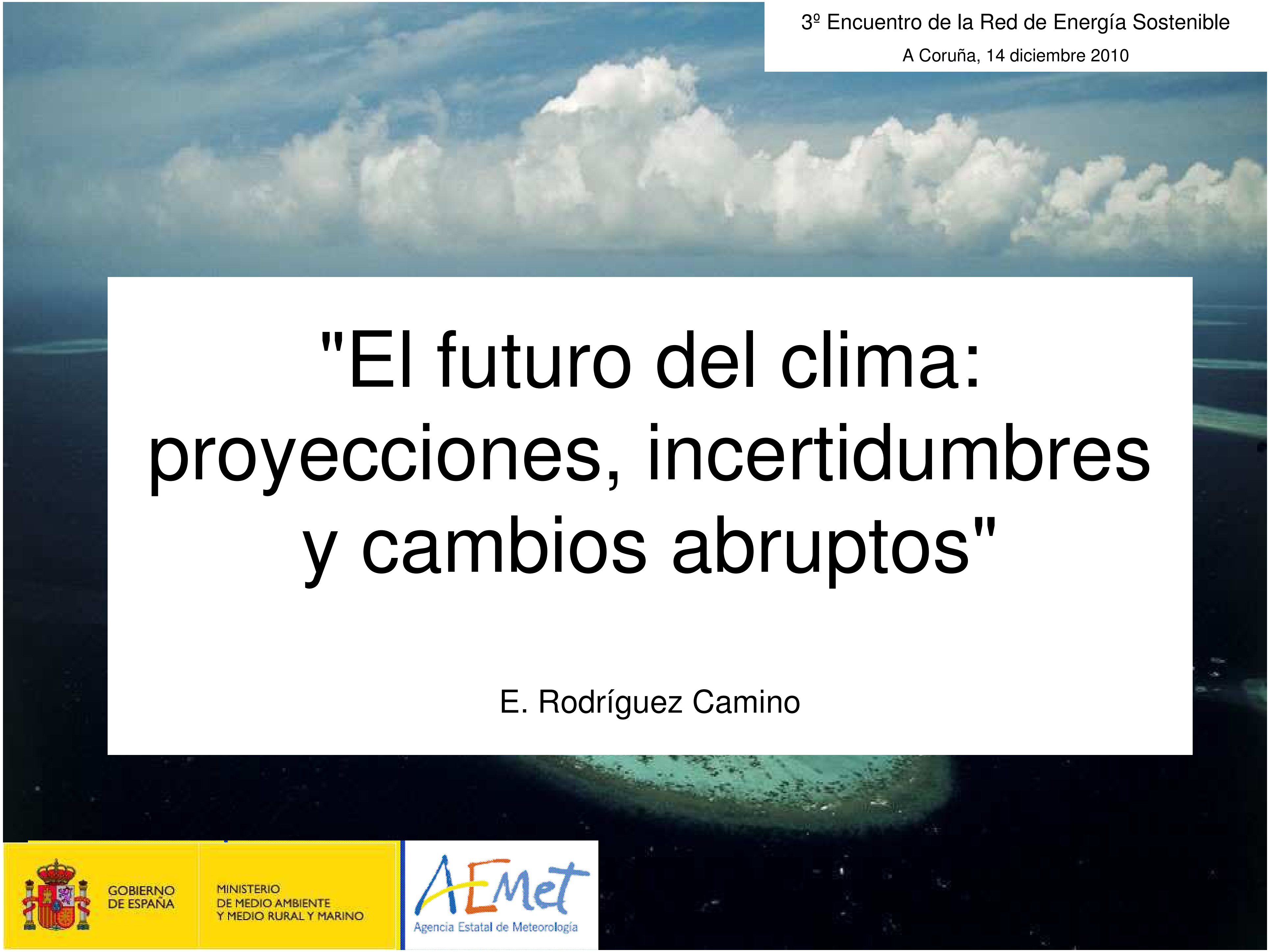
3º Encuentro de la Red de Energía Sostenible
A Coruña, 14 diciembre 2010



"El futuro del clima: proyecciones, incertidumbres y cambios abruptos"

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GOBIERNO DE ESPAÑA

MINISTERIO DE MEDIO AMBIENTE Y MEDIO RURAL Y MARINO

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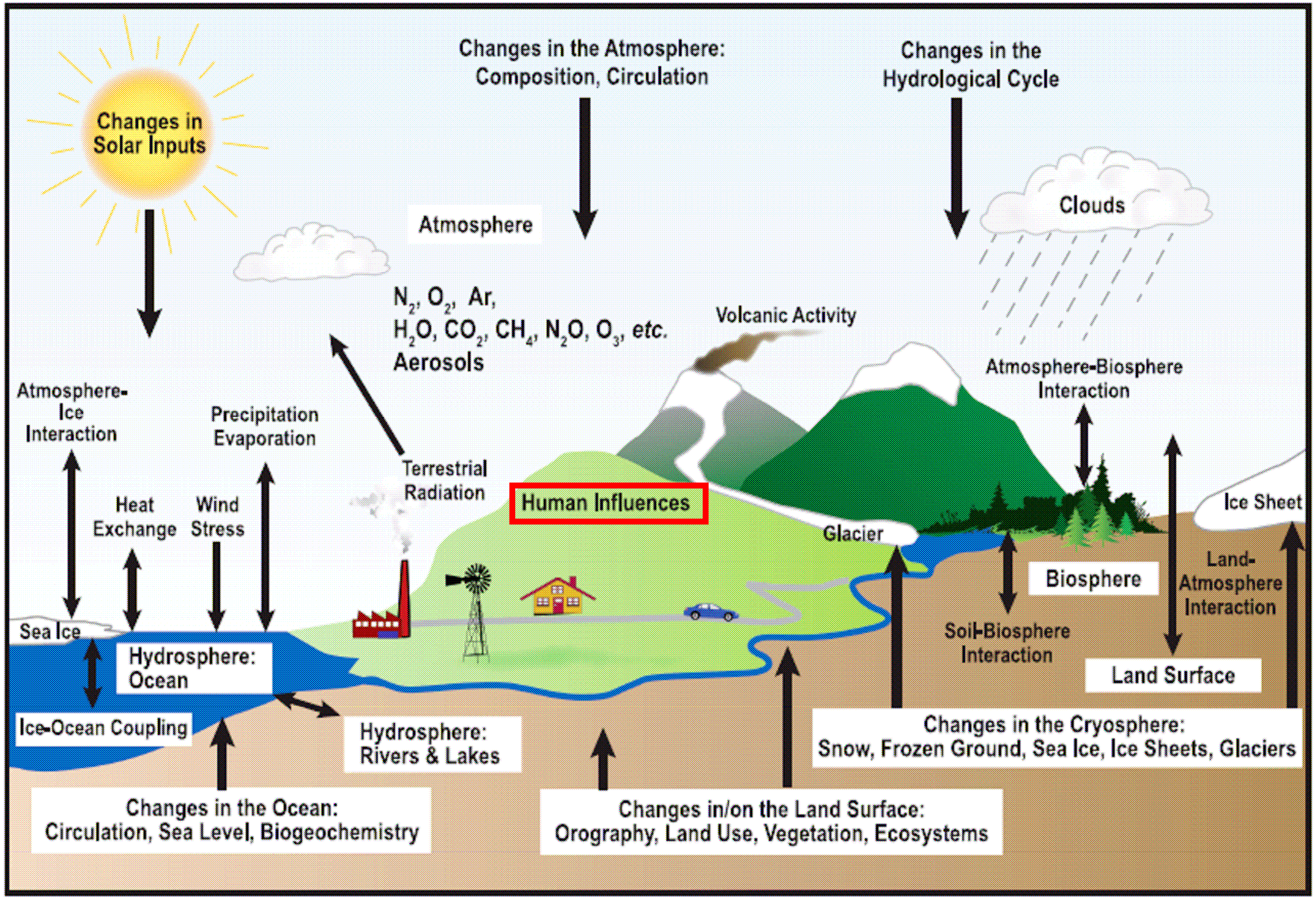
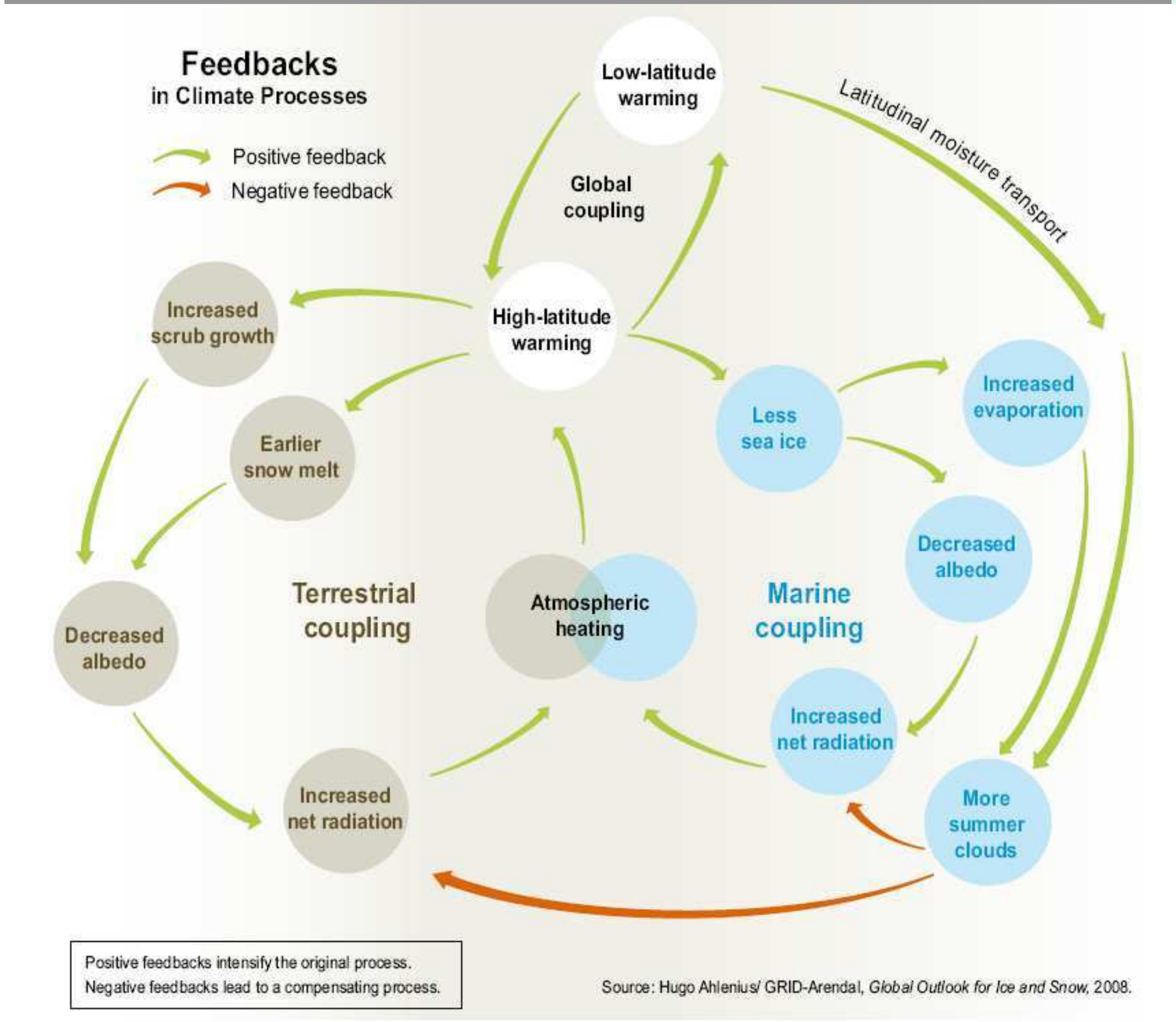
Contenido

- Introducción
- Observación del cambio climático
- Proyecciones climáticas
- Causas
- Incertidumbres
- Cambios abruptos
- Futuro

Sistema climático





- Climate system is highly nonlinear
- Strong coupling among subsystems with different time scales

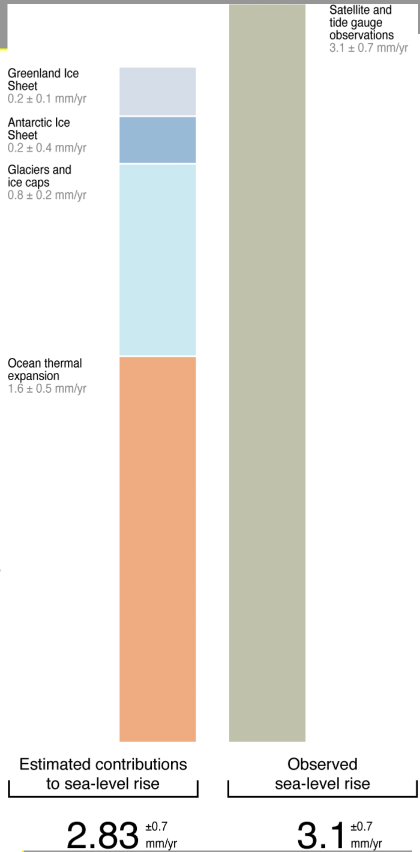
Models needed!

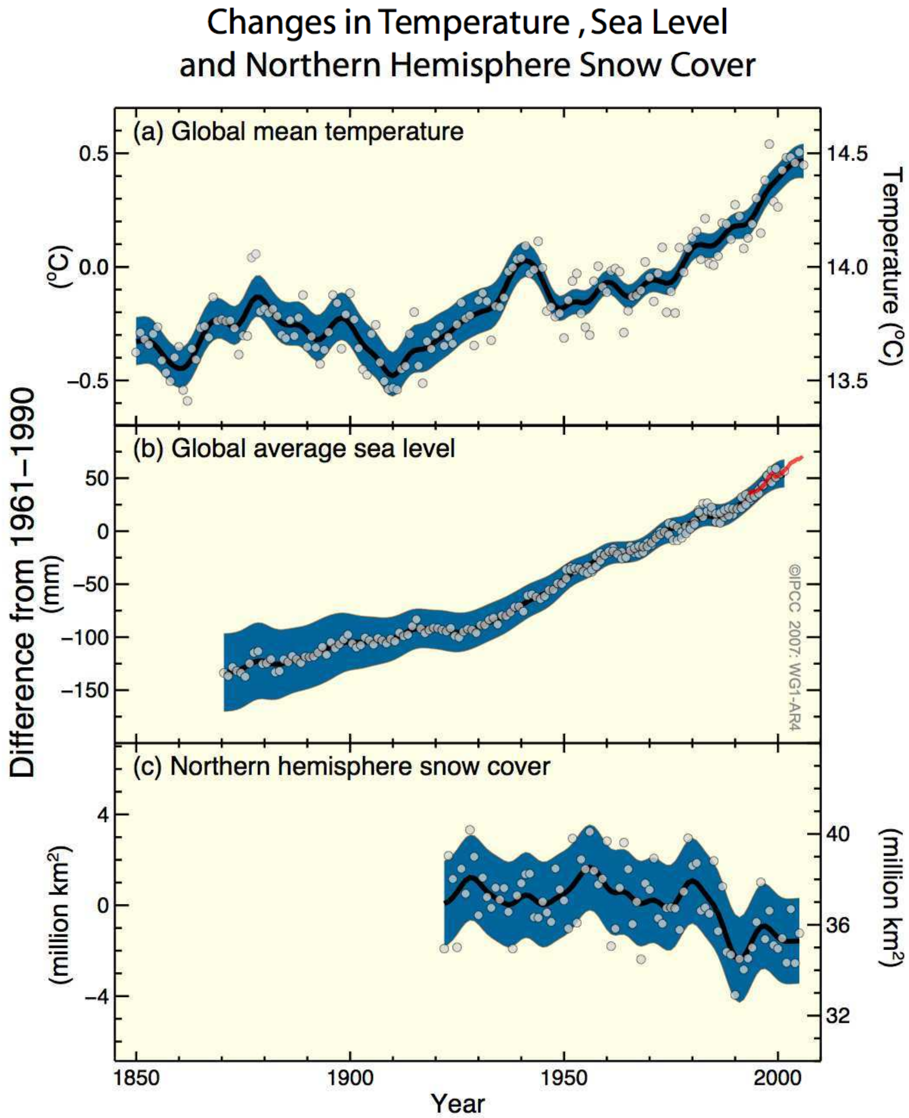
¿Qué CAMBIO CLIMATICO se observa?

El calentamiento del sistema climático es inequívoco,

tal y como se evidencia de las observaciones del incremento de las temperaturas globales medias del aire y del océano, de la fusión de las nieves y hielos y de la elevación global del nivel medio del mar

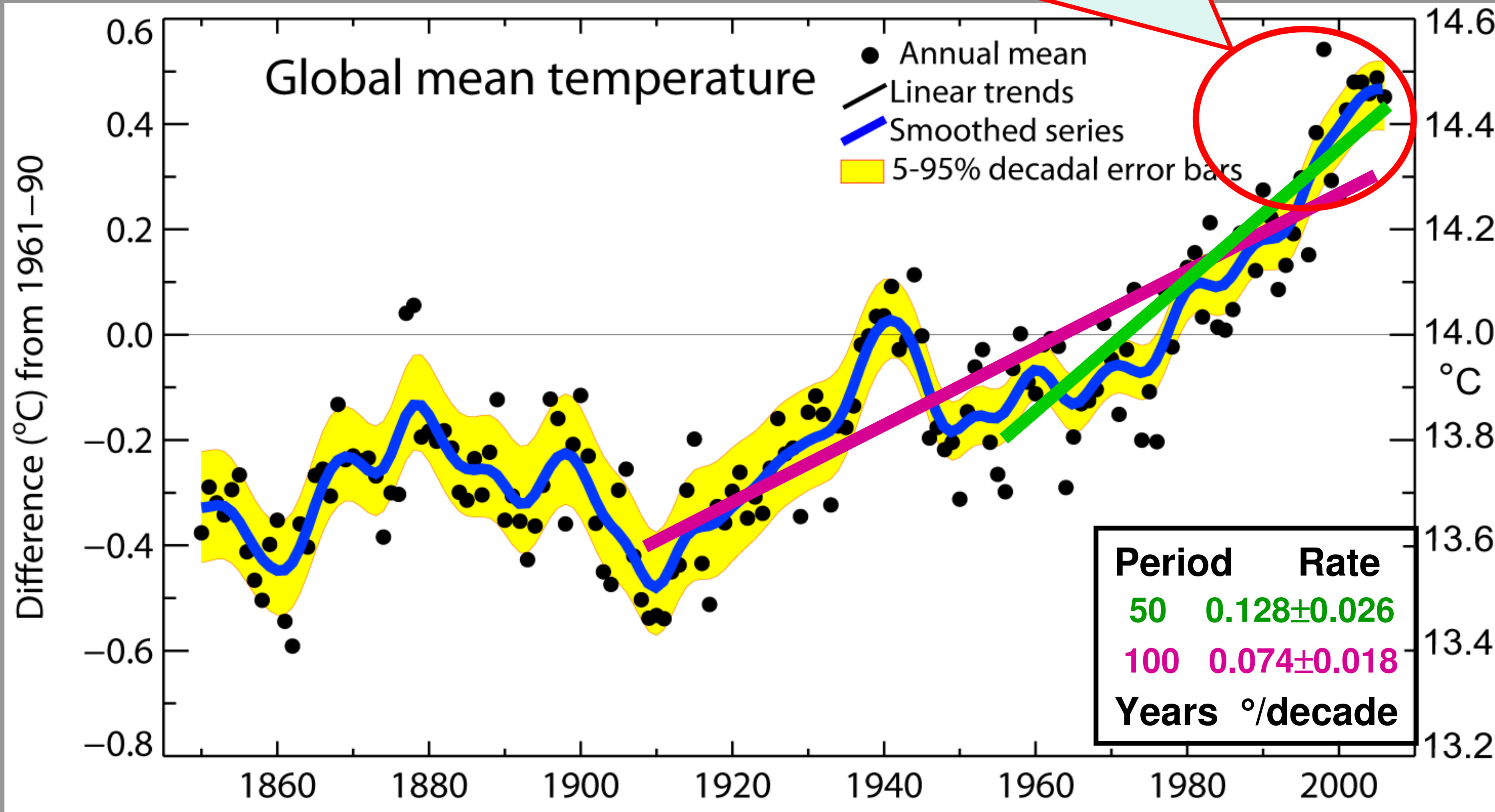
(IPCC-AR4 *dixit*)





Temperaturas globales ... deprisa

Los 12 años más cálidos:
1998,2005,2003,2002,2004,2006,
2001,1997,1995,1999,1990,2000



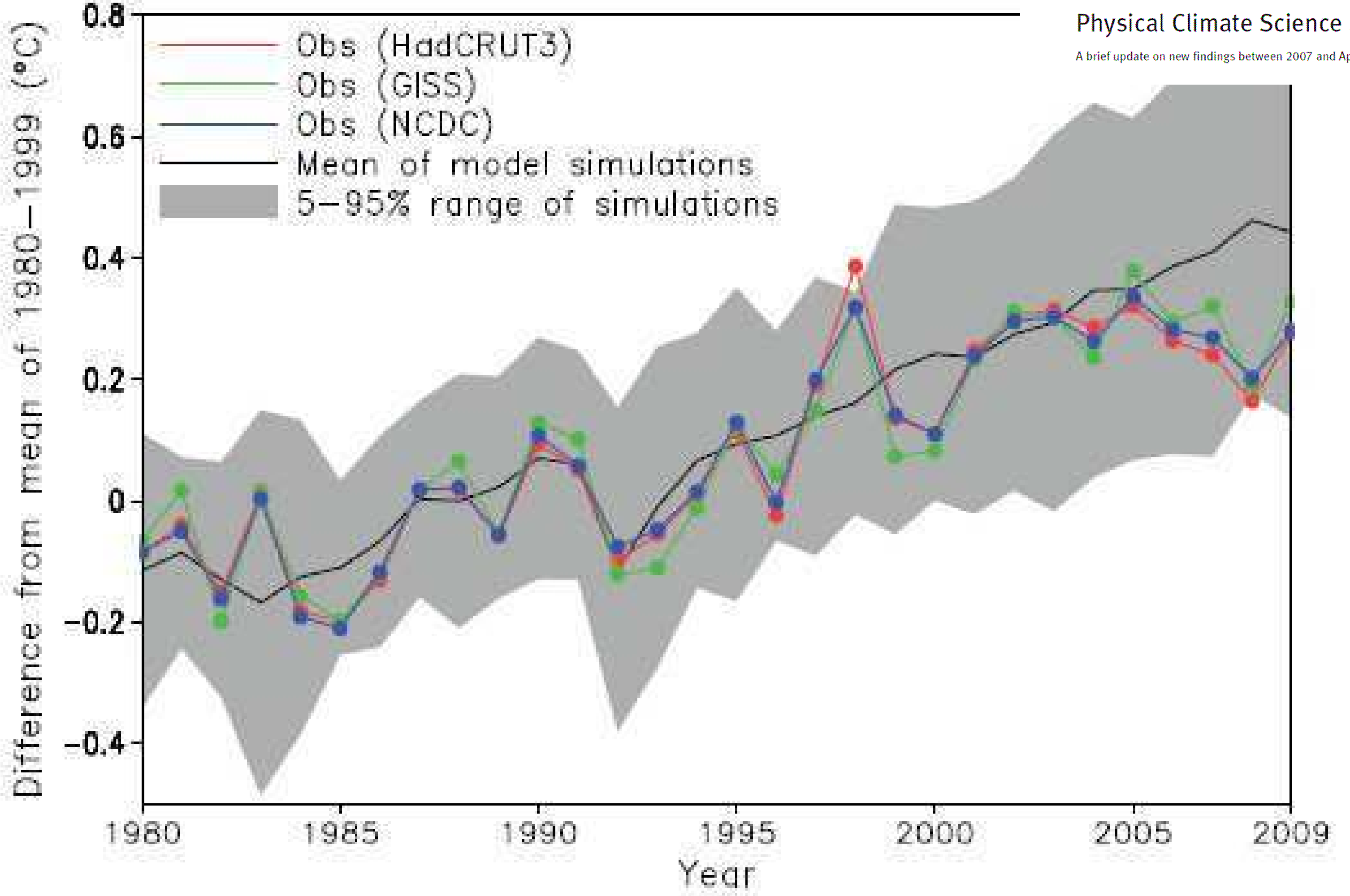
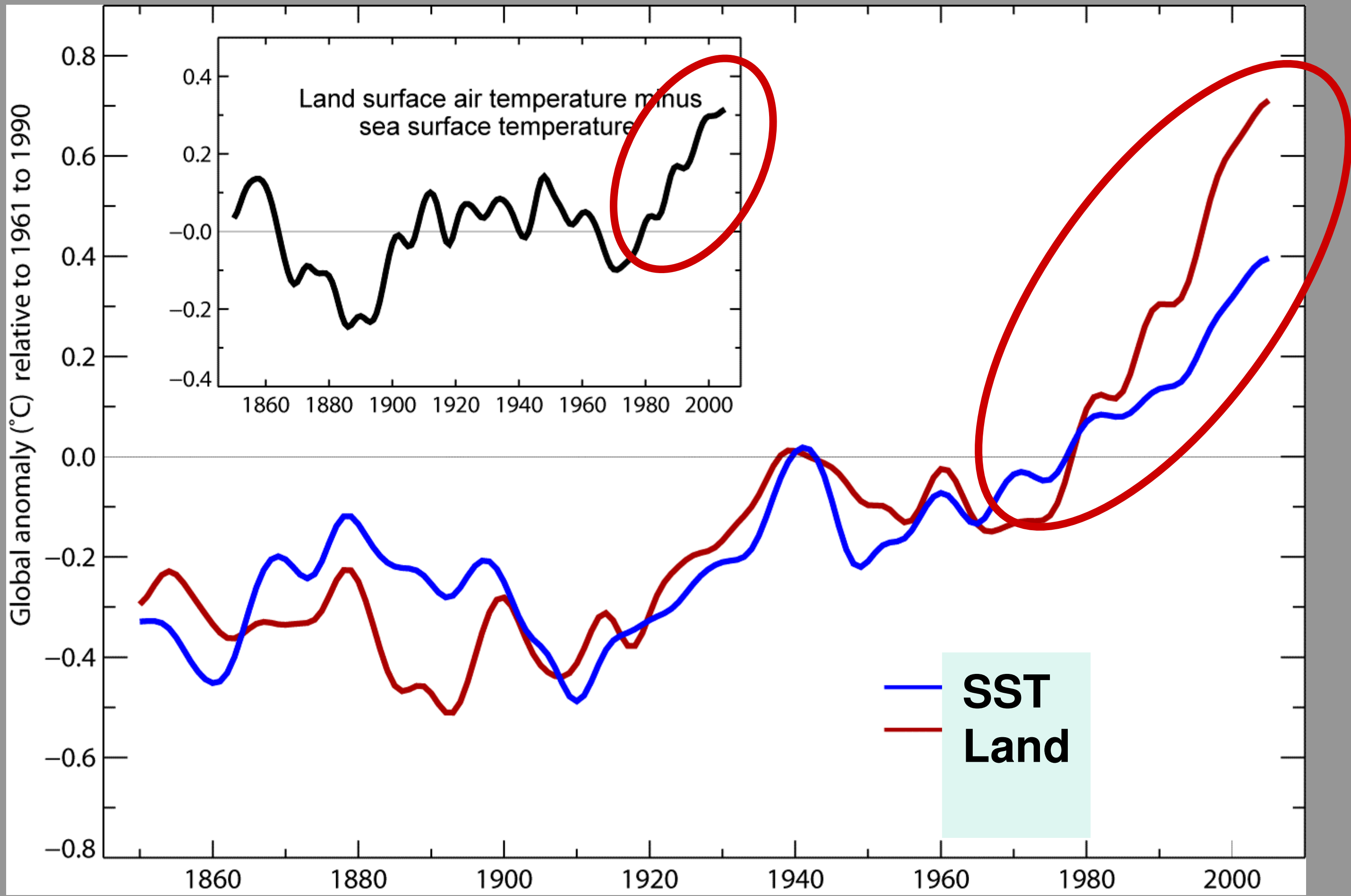
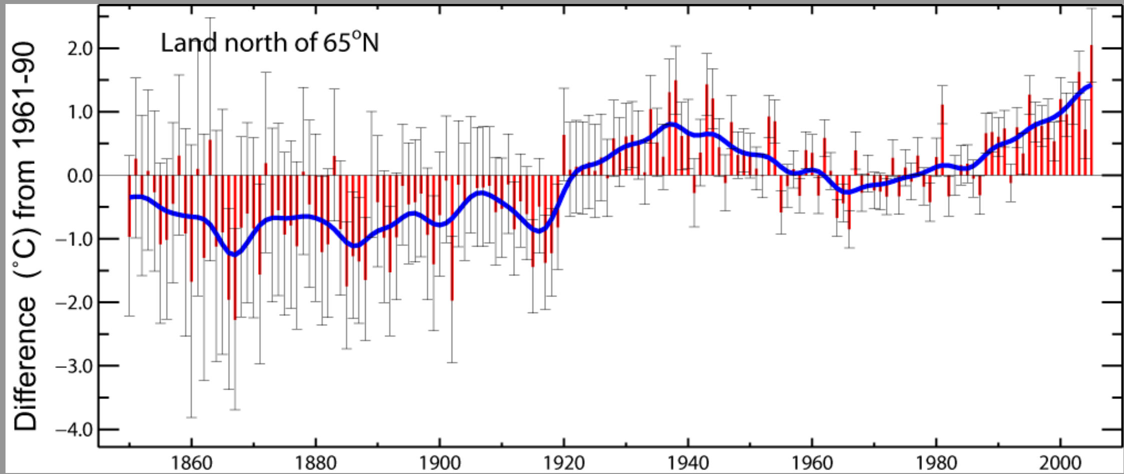


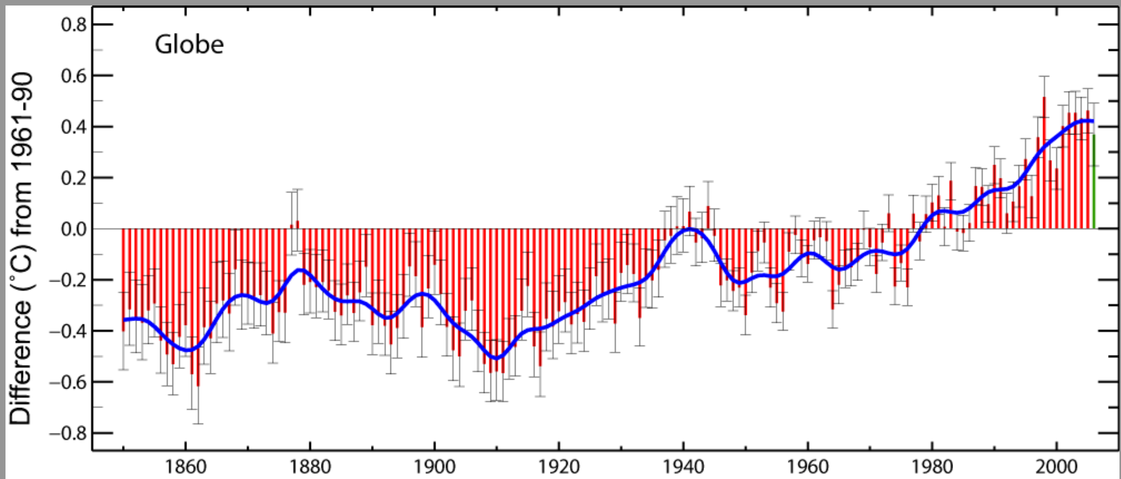
Figure 2. Recent changes in global mean temperature according to three analyses of observations (HadCRUT3, GISS and NCDC) and the 21 climate model simulations without climate policies used in IPCC AR4[19]. The mean of the model results is given by the solid black line. The shading indicates a 5–95% range of variability according to the same model simulations. The temperatures are given as deviations from the mean value over the period 1980–1999.

Temperatura superficie terrestre suben más deprisa que SST



Anomalías de temperatura anual Ártica vs Global (°C)



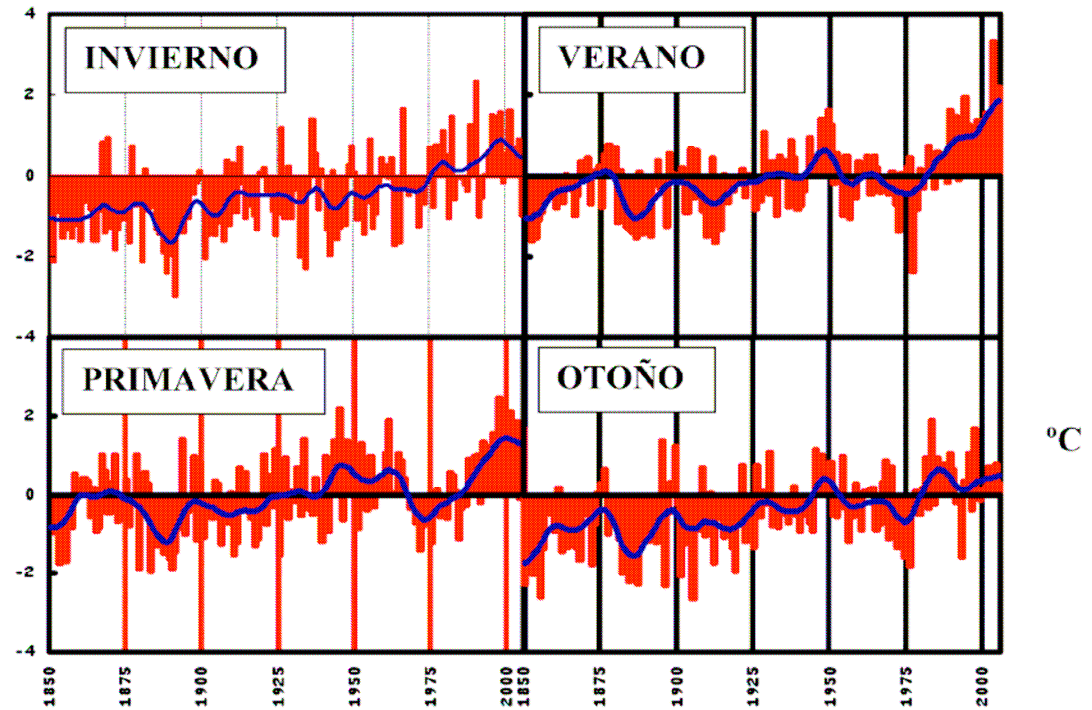


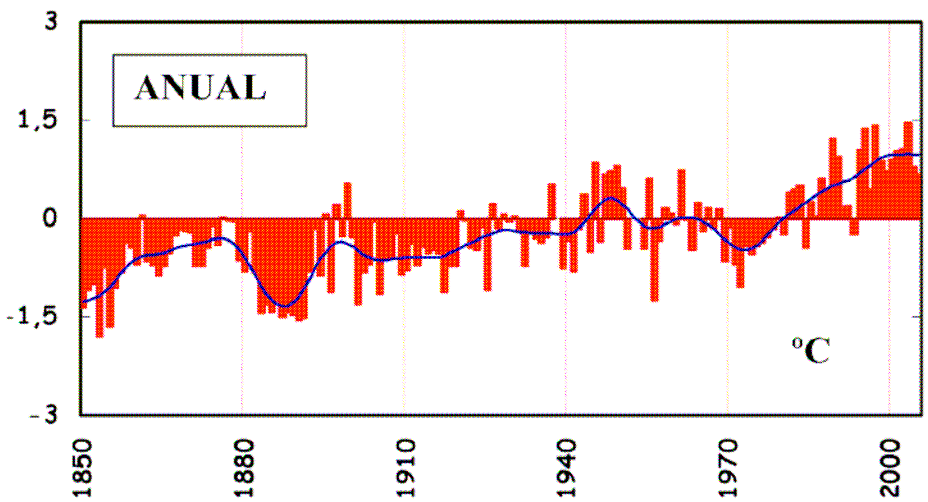
Calentamiento en el Ártico es doble que para el globo desde el s. XIX al XXI y desde los últimos 1960s hasta la actualidad.

Calentamiento entre 1925 y 1950 in el Ártico no fue tan generalizado como el reciente calentamiento global.

Escalas diferentes!

Cambio de temperaturas en España (I)





	1901-2005	1973-2005
Anual	0.13	0.48
Invierno	0.14	0.27
Primavera	0.12	0.77
Verano	0.13	0.67
Otoño	0.12	0.29

Brunet et al. 2006

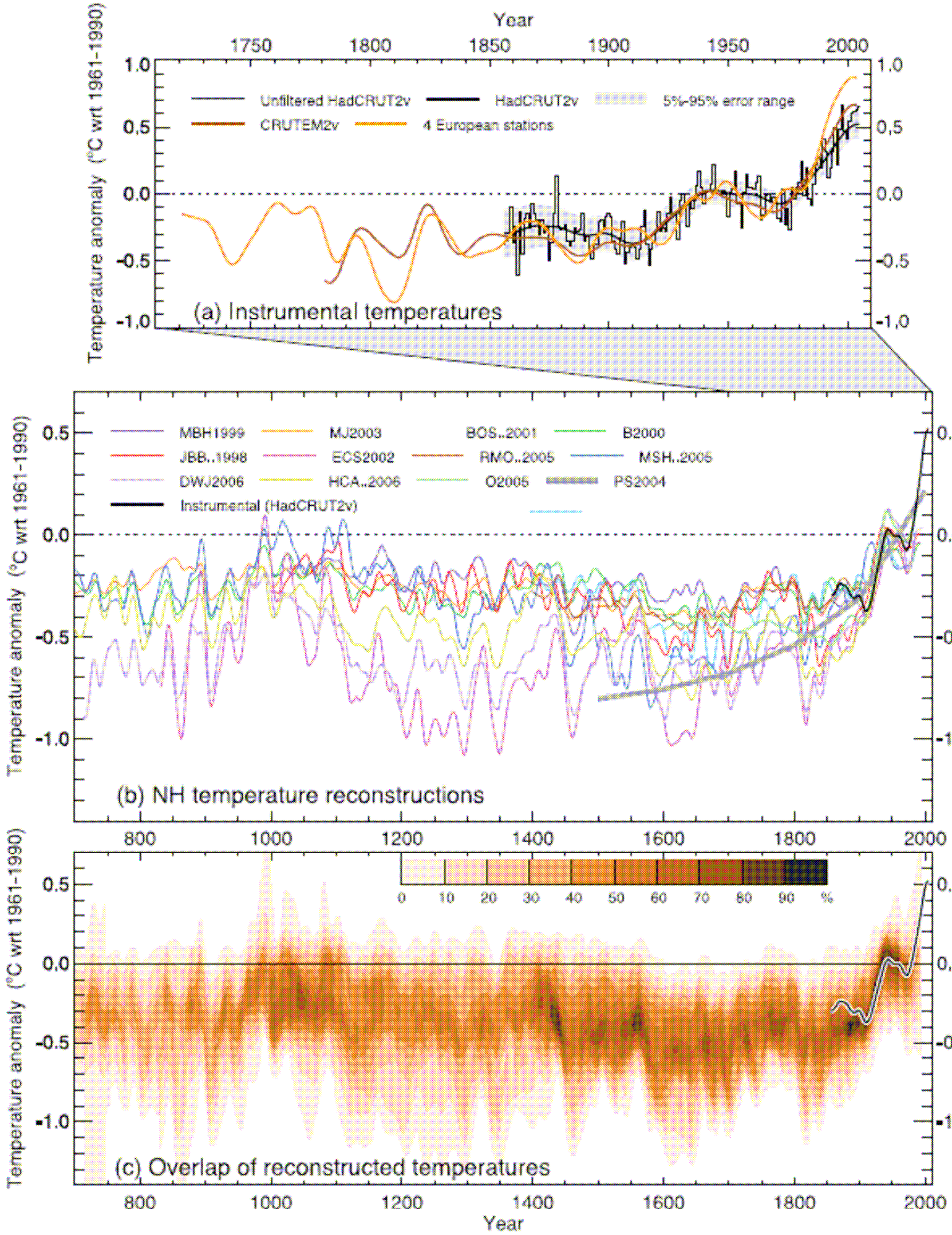
OBSERVACION DEL CLIMA (II)

TABLE 2. Major Paleoclimatic Data Sources

Data sources	Variable measured	Continuity of evidence	Potential geographical coverage	Period open to study (years)	Minimum sampling interval (years)	Usual dating accuracy (years)	Climate-related inferences
Ocean sediments	Isotopic composition of planktonic and benthic fossils Floral and faunal assemblages Morphological characteristics of fossils Mineralogical composition and abundance	Continuous	Global ocean, except (for carbonate fossils) deepest zones (below $CaCO_3$ compensation depths)				Global ice volume; surface temperature and salinity; bottom temperature and bottom water flux; aridity of adjacent land areas; prevailing wind direction and strength
		Sedimentation rates (cm per 1000 years)					
		<2	Favored areas	1 000 000+	1000+	±5%	
		2–5	along continental	200 000+	500+	±5%	
		>10	margins	10 000+	50+	±5%	
Ice cores	Oxygen isotope composition Trace chemistry and electrolytic conductivity Fabric	Continuous	Glaciated regions in polar and alpine areas (optimally in dry snow zones)	100 000+	Variable, but optimally 1–10 years for last 10^4 years	Variable, but optimally 0.05% for last 10^3 years	Temperature, accumulation rates atmospheric composition and turbidity, ice thick (height), solar outp variations
Mountain glaciers	Terminal positions Glaciation levels and equilibrium line altitudes	Episodic	45°S to 70°N	50 000	—	±5–10%	Temperature, precipitation (net accumulation)
Closed basin lakes	Lake level	Episodic	Low to mid latitudes (arid and semi-arid environments)	50 000		±5%	Moisture availabili ("effective precipitation")
Bog or lake sediments	Insect assemblage composition Pollen type concentration, geochemical and	Continuous	All continents	10 000+ (common) 150 000 (rare)	~50	±5%	Temperature, precipitation, soil moisture, air mass frequencies
(varved sediments)	sedimentological composition		Mid to high latitudes	10 000+	1–10	+1–10	
Tree rings	Ring width anomaly, density, isotopic composition	Continuous	Mid- and high-latitude continents	1000 (common) 8000 (rare)	1	1	Temperat precipitat moisture, (circulatio
Written records	Phenology, weather logs, sailing logs, etc.	Episodic or continuous	Global	1000+	1	1	Varied

http://www.ucm.es/info/reclido/

http://www.worldviewofglobalwarming.org/index.html



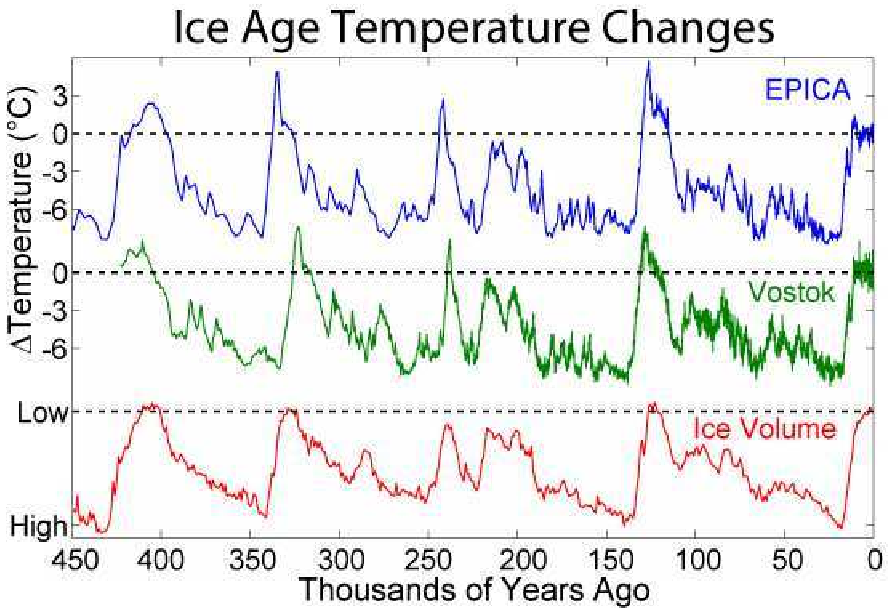
Los últimos 2000 años

(IPCC-AR4, 2007)

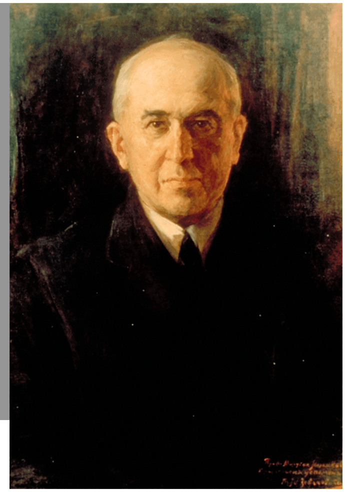
Louis Agassiz

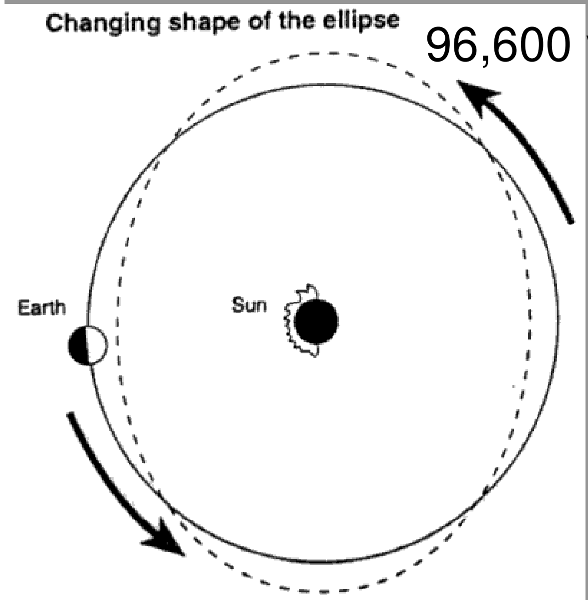
(1837)

- He was the first to scientifically propose that the Earth had been subject to a past ice age.

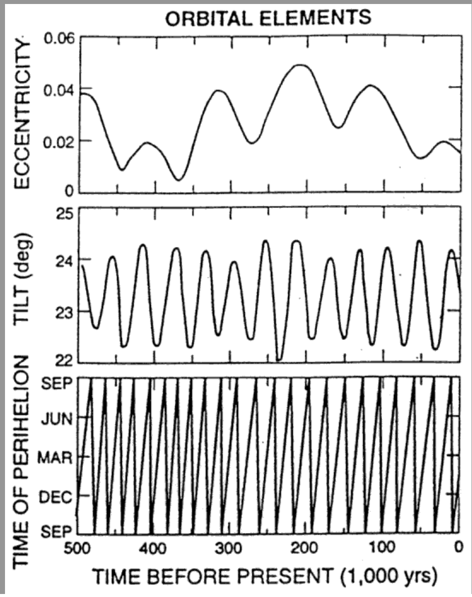


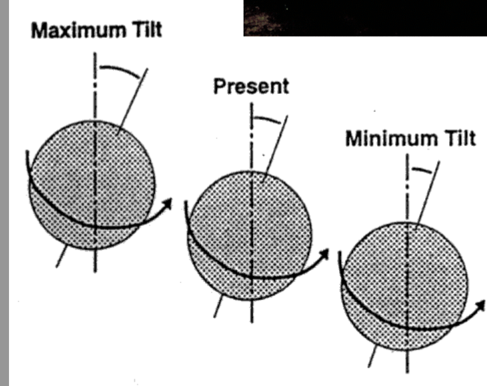
FORZAMIENTO NATURAL DEL SISTEMA CLIMATICO: ciclos de Milankovitch





96,600 years

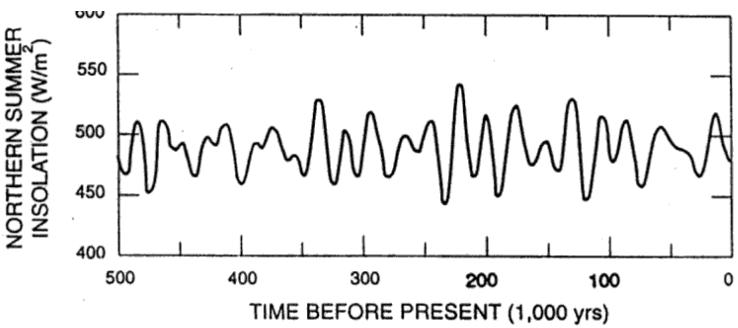


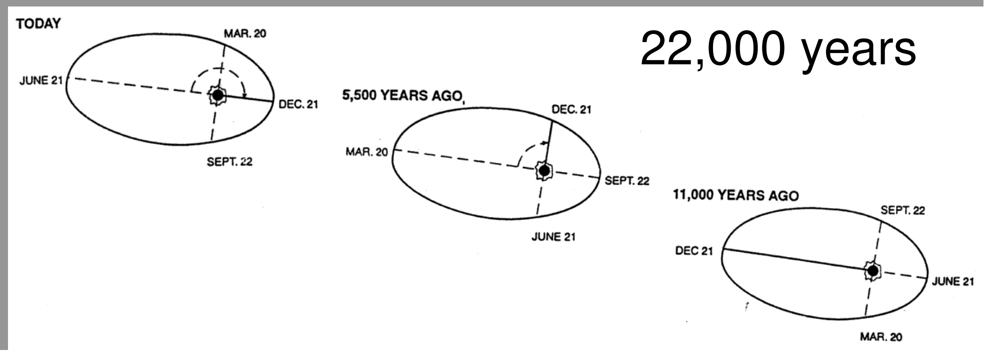


22° to 24.5°, over 41,000 years

Variations in Earth's orbital elements, eccentricity, tilt (obliquity), and time of perihelion (precession of the equinoxes) computed for the last 500,000 years with a computer program written by Tamara Ledley and Starley Thompson (Barron, 1994, figure 12).

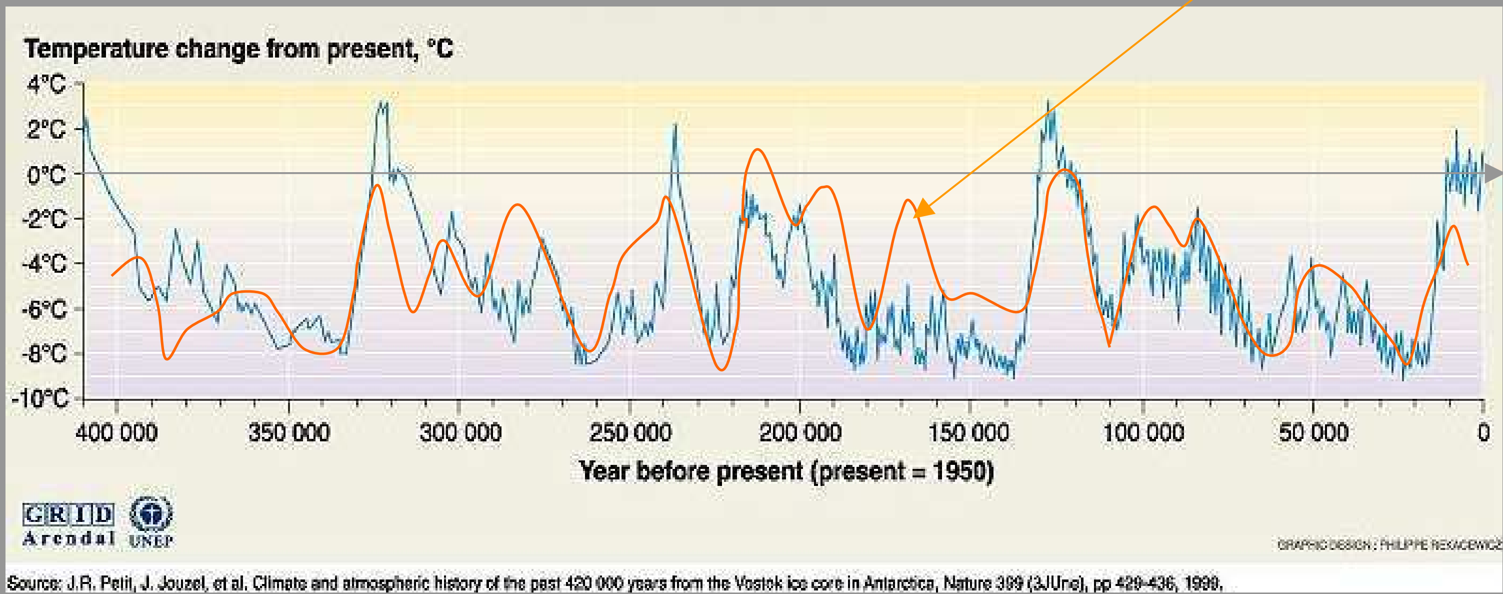
Variations in insolation (in watts per square meter) determined from the variation in Earth's orbital elements (Barron, 1994, figure 13).

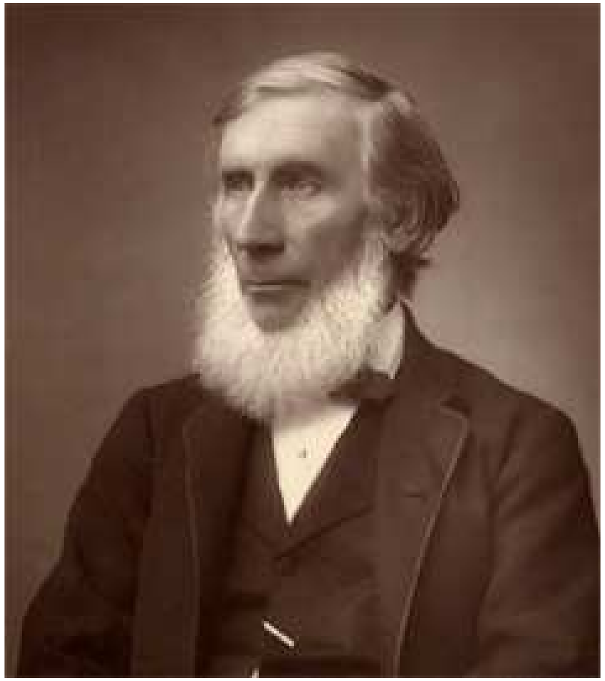




22,000 years

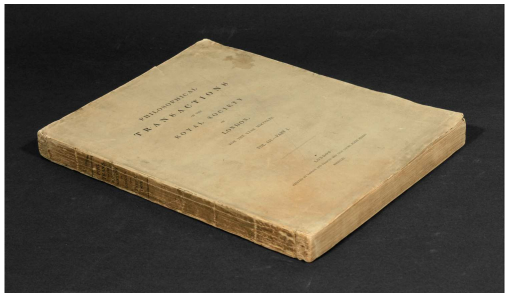
Insolation according to Milankovitch parameters

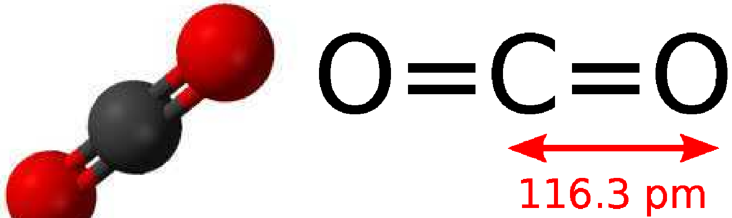




- He established for the first time that molecules of WV, CO2, N2O, CH4 y O3 exhibit different absorption properties when IR radiation travels through them
- Changes in the amount of any of the radiatively active constituents of the atmosphere “could have produced all the mutations of climate which the researches of geologists reveal” (1861)

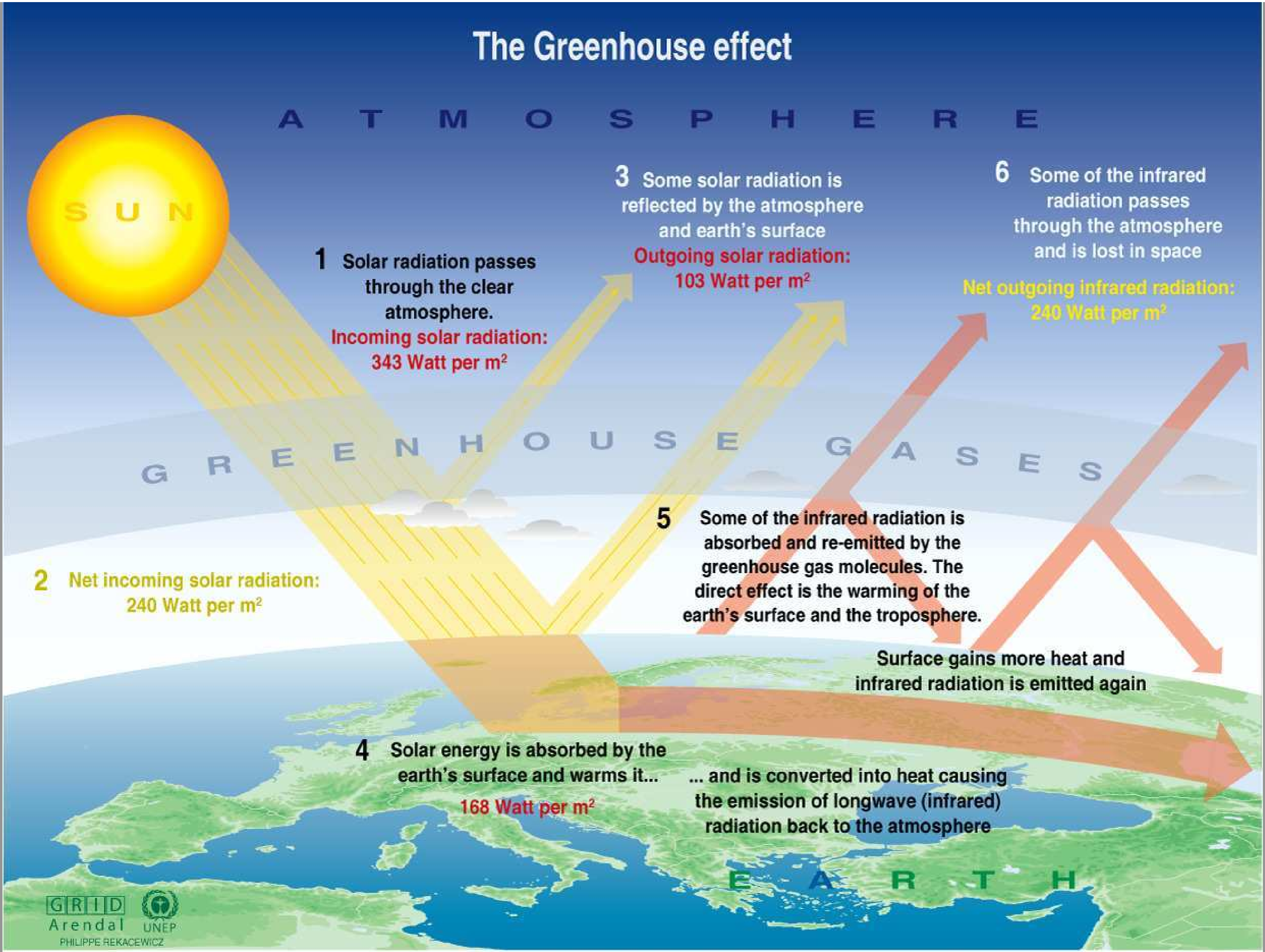
John Tyndall (1859)



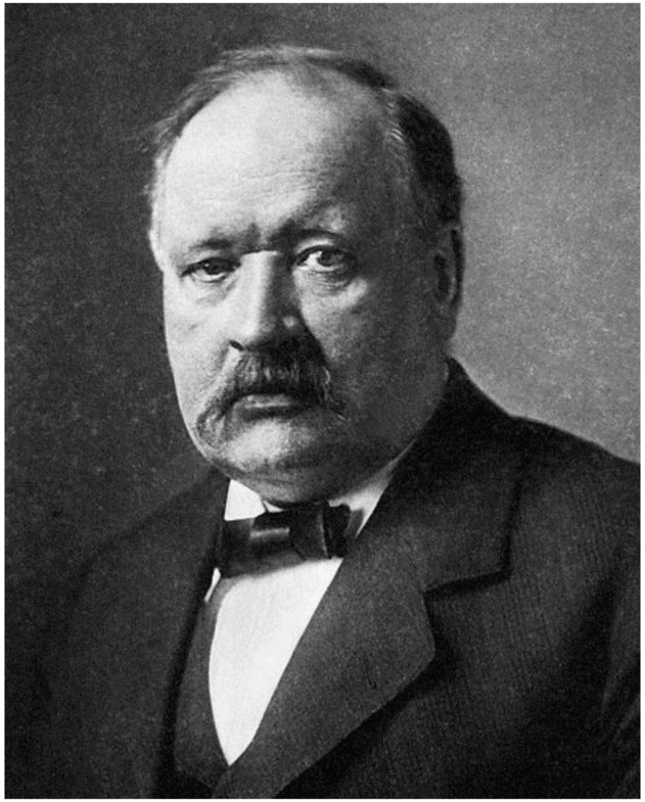


(pm=10^{-12} m)

Tyndall, J. (1861): On the Absorption and Radiation of Heat by Gases and Vapours, Philosophical Magazine (Ser.4) 22, pp 276-277



Sources: Okanagan university college in Canada, Department of geography, University of Oxford, school of geography; United States Environmental Protection Agency (EPA), Washington; Climate change 1995, The science of climate change, contribution of working group 1 to the second assessment report of the intergovernmental panel on climate change, UNEP and WMO, Cambridge university press, 1996.

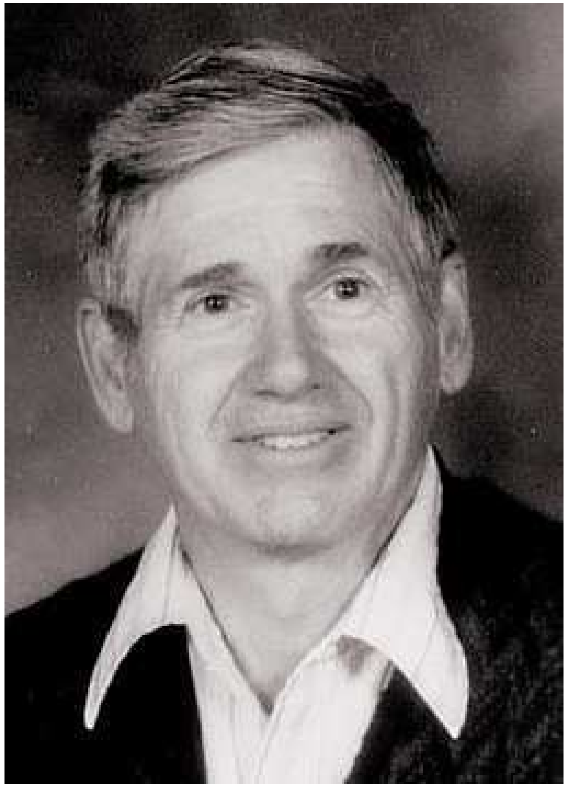


Svante Arrhenius (1896)

- He showed that doubling the concentration of CO2 in the global atmosphere would lead to changes in average surface air temperature of between about 4º-5ºC (2º-4.5º, IPCC 2007!!)
- Combustion of coal might induce “a noticeable increase” in atmospheric CO2 over the course of the years

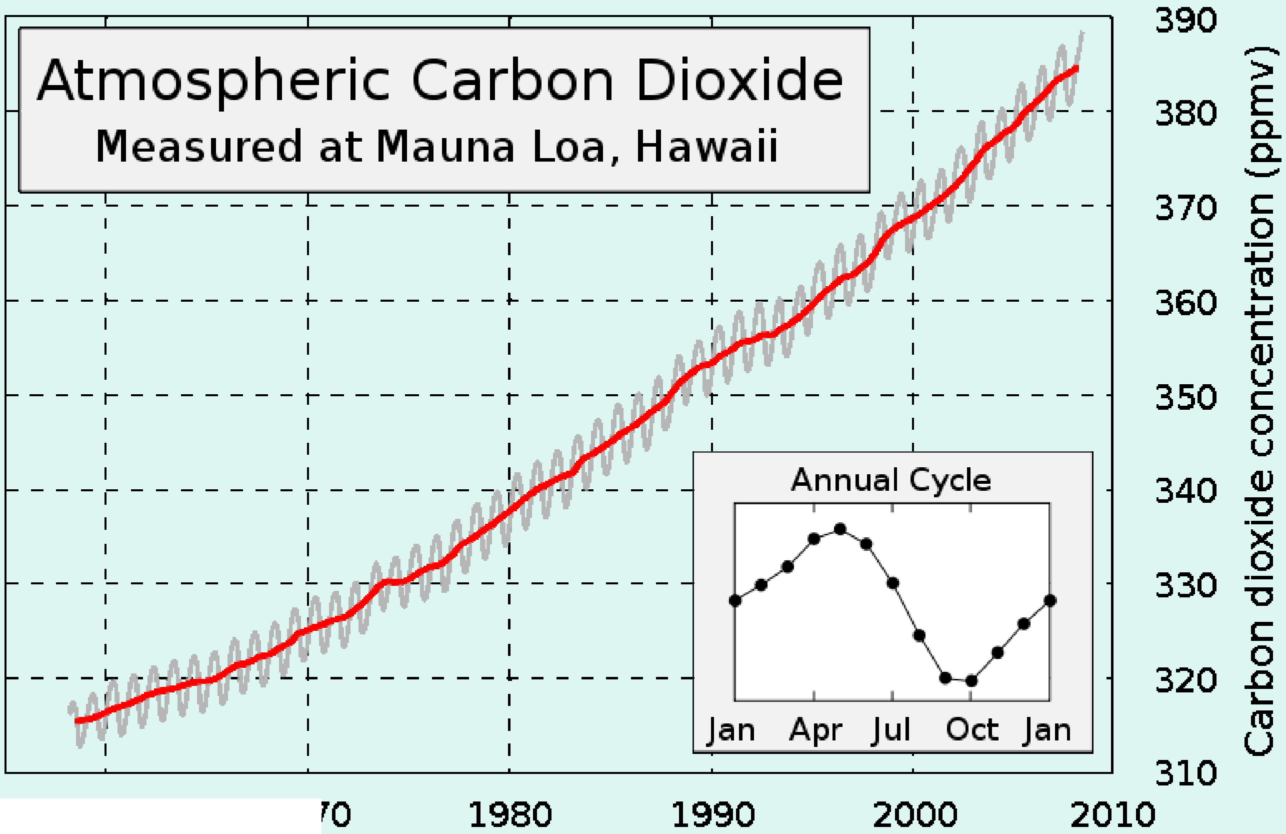
Guy S. Callendar (1938)

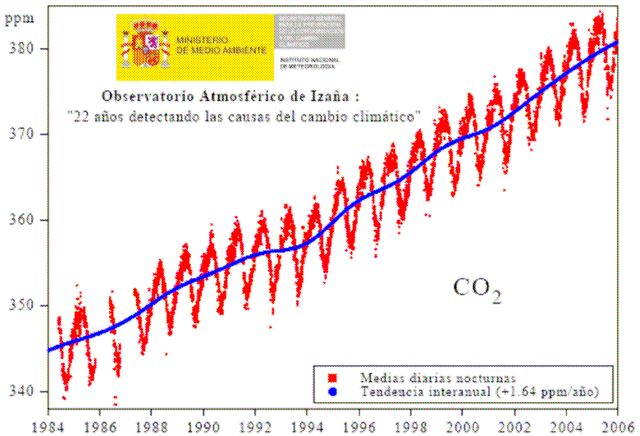
- “As man is now changing the composition of the atmosphere at a rate which must be very exceptional on the geological time-scale, it is natural to seek for the probable effects of such a change”.
- First attempt at detecting and attributing large-scale climate change to human-induced emissions of GHGs
- He linked together the 3 pillars of the idea of anthopogenic climate change: (i) CO2 as GHG; (ii) rising concentration of CO2; (iii) increase in world temperature



Charles D. Keeling (1957)

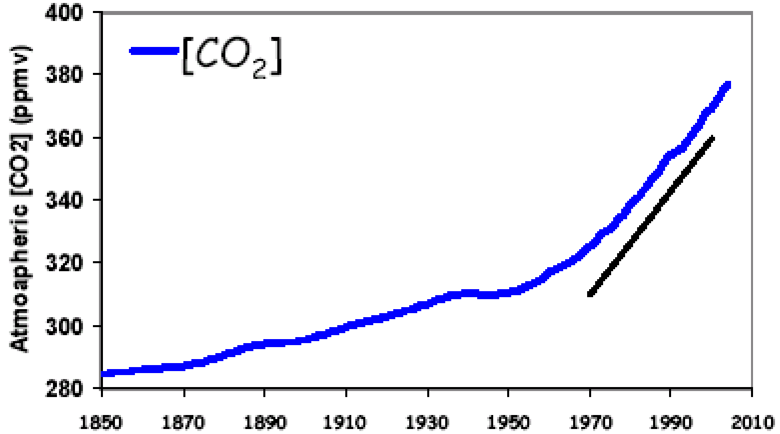
- Which is the fate of the CO_2 molecules emitted into the atmosphere?
- First incontrovertible evidence for the contemporary increase of CO_2 concentration in the atmosphere


Atmospheric Carbon Dioxide
Measured at Mauna Loa, Hawaii
Annual Cycle
Jan
Apr
Jul
Oct
Jan
390
380
370
360
350
340
330
320
310
Carbon dioxide concentration (ppmv)
70
1980
1990
2000
2010


ppm
380
370
360
350
340
MINISTERIO
DE MEDIO AMBIENTE
Observatorio Atmosférico de Izaña :
"22 años detectando las causas del cambio climático"
CO2
Medias diarias nocturnas
Tendencia interanual (+1.64 ppm/año)
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006

Concentración de CO2 en la atmósfera

Year 2007
Atmospheric CO_2
concentration:
382.6 ppm
35% above pre-industrial

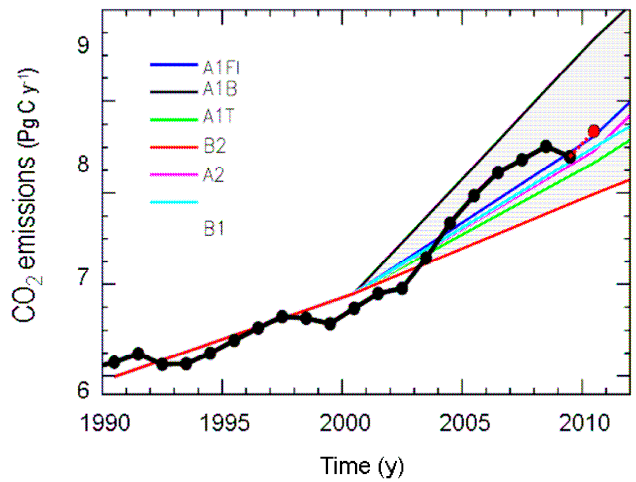


1970 - 1979: 1.3 ppm y^{-1}
1980 - 1989: 1.6 ppm y^{1}
1990 - 1999: 1.5 ppm y^{-1}

2000 - 2006: 1.9 ppm y^{-1}

Emisiones CO2

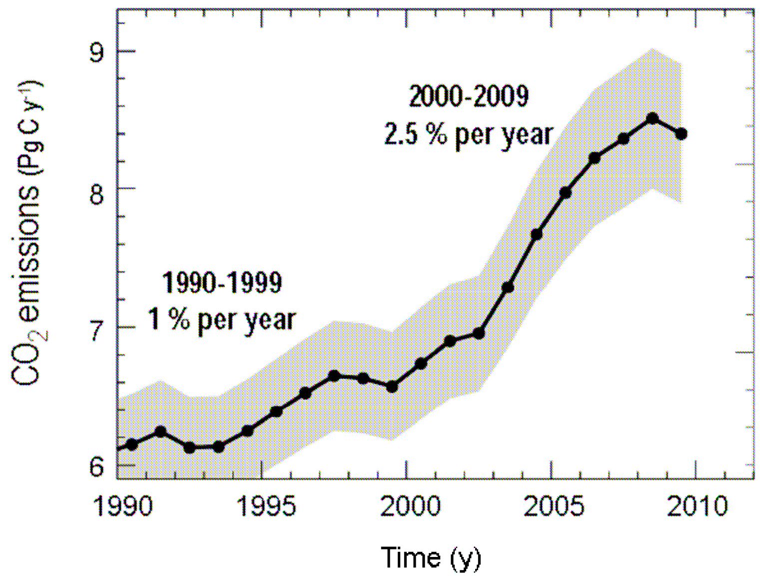
Fossil Fuel CO_2 Emissions compared to
IPCC Marker scenarios used for climate projections



2000-2009 growth rates are at the high end of the emissions scenarios used by the IPCC to project climate change

IPCC range: 1.6 - 6.9 ° C above pre-industrial in 2100

Updated from Le Quéré et al (2009) Nature Geoscience, using Marker scenarios modified from Raupach et al. PNAS (2007)



2009:
Emissions: 8.4 PgC
(30.5 Gt CO_2)
Growth rate: -1.3%

CDIAC; Friedlingstein et al. 2010, Nature Geoscience

Fate of anthropogenic CO_2 emissions
(2000-2008)

+

45%

29%

26%

Le Quéré et al. 2009, Nature geoscience; Canadell et al. 2007, PNAS, updated

Syukuro Manabe (1975)

- First model experiment which explicitly simulated the three-dimensional response of global climate to a doubling of atmospheric CO_2 concentration (2.9ºC)

Modelos climáticos

$$\frac{du}{dt} = -\frac{1}{\rho a\cos\varphi}\frac{\partial p}{\partial\lambda} + fv + uv\frac{\tan\varphi}{a} + F_\lambda$$

$$\frac{dv}{dt} - \frac{1}{\rho a}\frac{\partial p}{\partial\varphi} - fu - u^2\frac{\tan\varphi}{a} + F_\varphi$$

$$\frac{\partial p}{\partial z} = -\rho g$$

$$\frac{\partial\rho}{\partial t} = -\nabla\cdot\rho\mathbf{V}$$

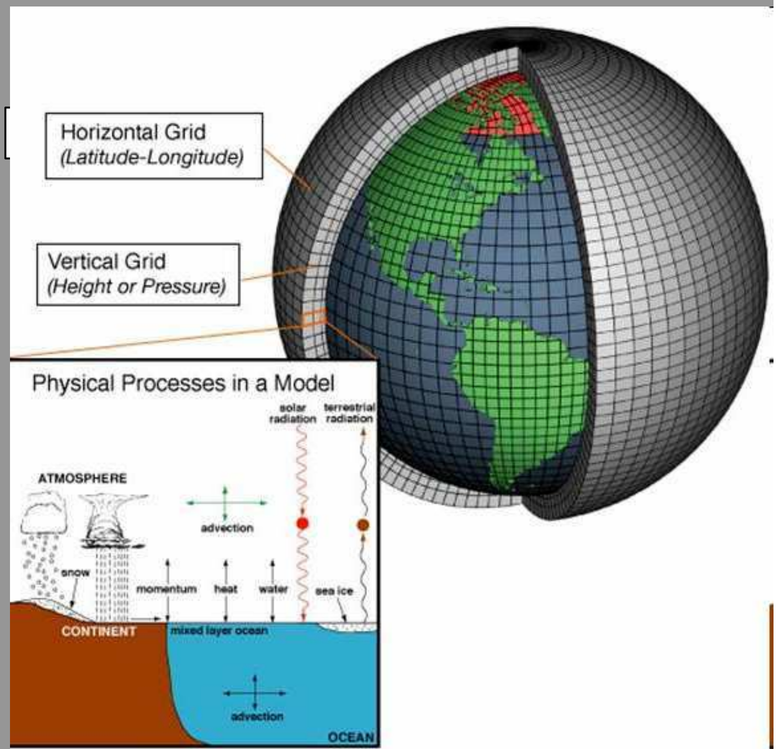
$$C_p\frac{d\Theta}{dt} = \frac{\Theta}{T}Q$$

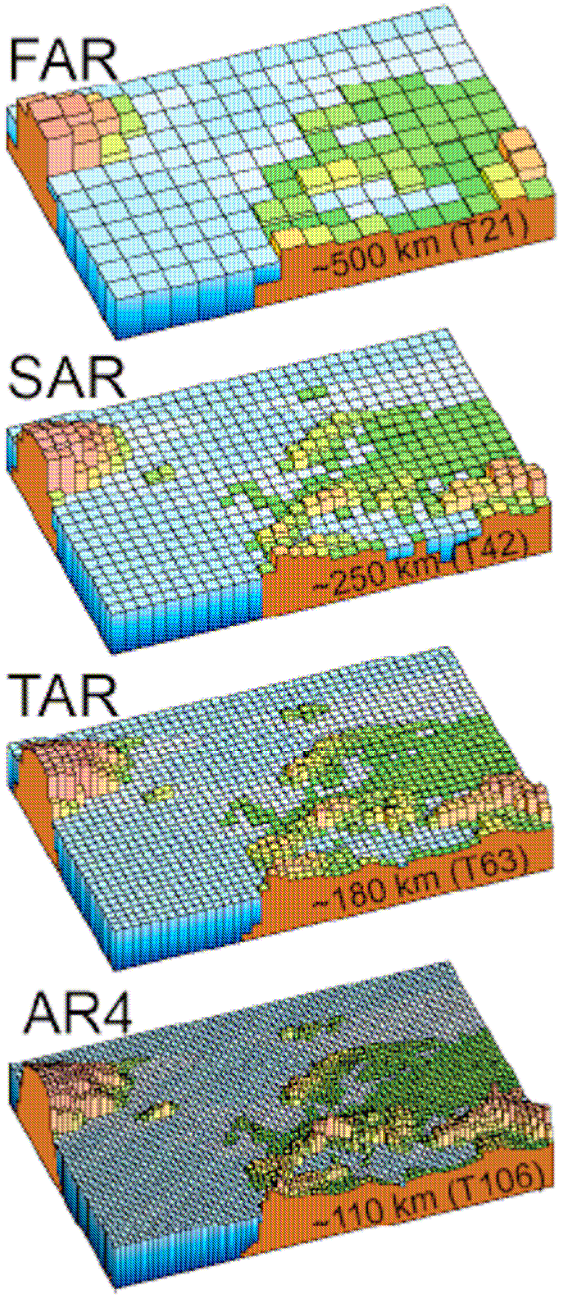
$$p = R\rho T$$

Ecuaciones atmósfera

$\Rightarrow$ u, v, w, p, ρ, T

Los modelos climáticos son programas informáticos basados en las ecuaciones que describen la evolución de los distintos componentes del sistema climático: atmósfera, océano, hielos, biosfera, …





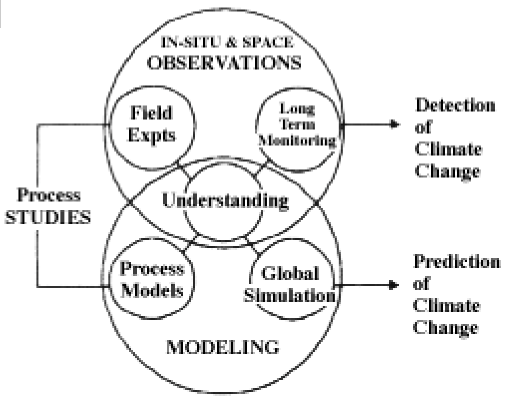
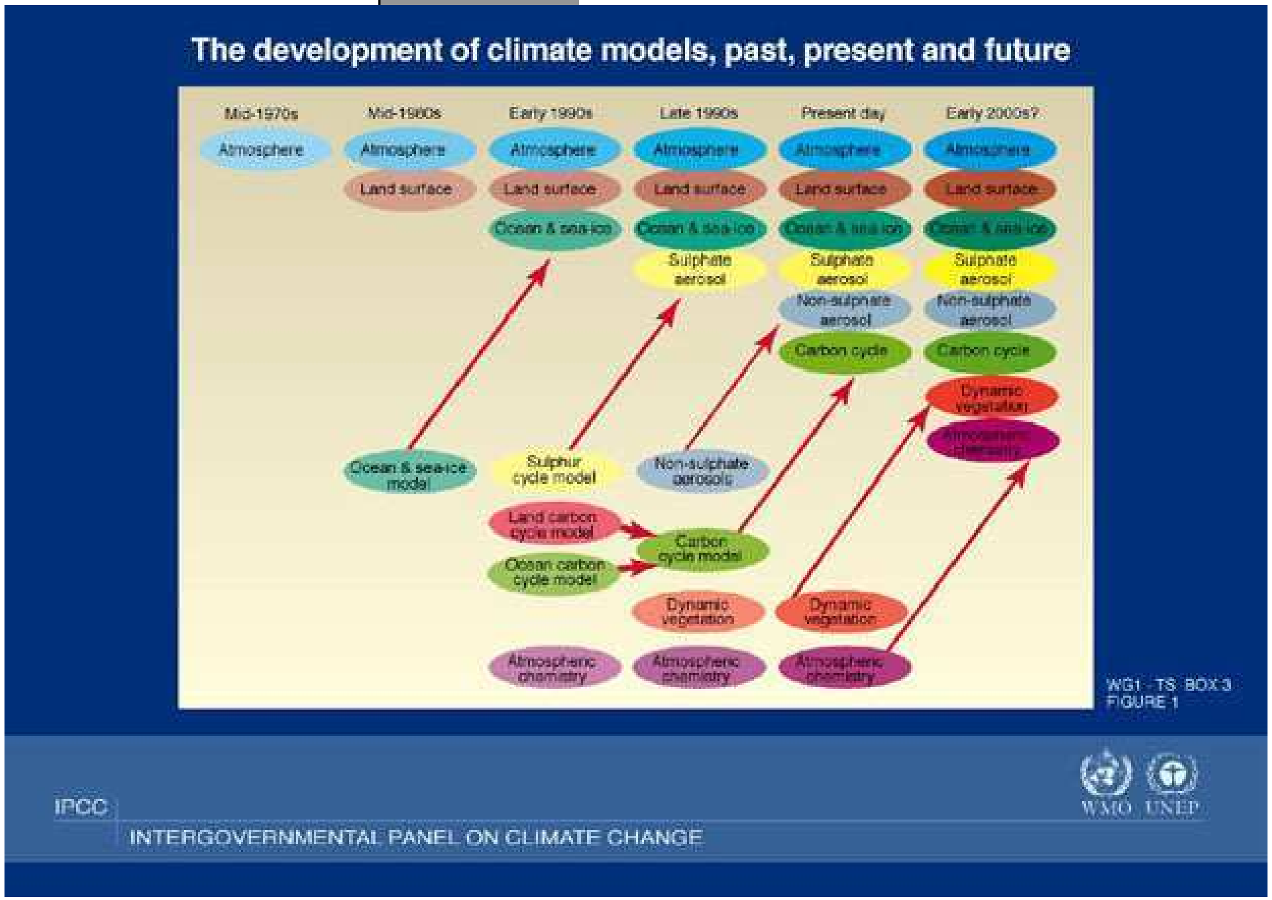


Table II. Historical evolution of climate models

Decade and landmark papers	Climate model status
≤1969	
Manabe and Möller (1961)	Numerical weather forecasts extended
Manabe and Strickler (1964)	RC models developed
Sellers (1969)	Dynamics and radiation virtually separate
Budyko (1969)	EBMs newly described
1969–1981	
Manabe and Bryan (1969)	Multi-layer oceans added to GCMs
Green (1970), Stone (1973)	SD models developed
Manabe and Wetherald (1975)	Greenhouse modelling with GCMs
CLIMAP (1981)	Palaeo datasets first employed for 'validation'
1981–1989	
Hansen *et al.* (1981)	GCMs becoming predominant model type
Sellers *et al.* (1986)	Surge in computational power and capacity
Oort and Peixoto (1983)	Satellites generate global observations
Luther *et al.* (1988)	Model intercomparisons suggested
1989–1999	
Houghton *et al.* (1990)	Simpler models required by IPCC
Semtner and Chervin (1992)	OAGCMs established but need flux correction
Flato and Hibler (1992)	Sea-ice and land-surface components evolving
Cubasch *et al.* (1994)	First ocean–atmosphere coupled ensemble
Santer *et al.* (1996)	Validation and attribution first described
2000s	
? ? ?	EMICs as important as GCMs
	Past climate simulations re-emerging for testing
	Observational need driven by evaluation demand
	Policy needs a major driver of numerical models



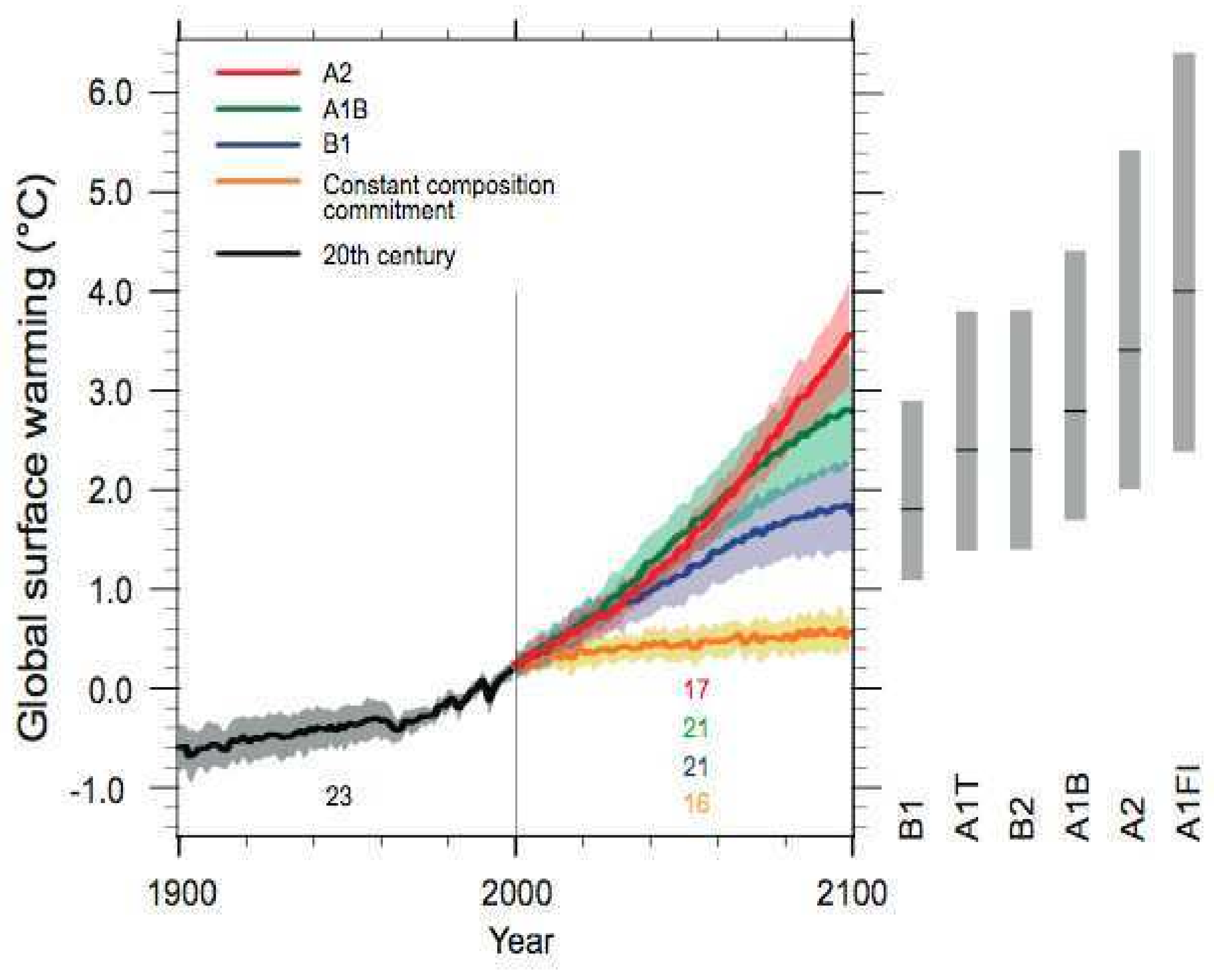
Proyecciones de cambios futuros en el clima

(escenarios sin compromisos políticos!!!)

* Mejor estimación para escenario bajo (B1) es 1.8℃ (rango probable 1.1-2.9℃), y para escenario alto (A1FI) es 4.0℃ (*rango probable* 2.4-6.4℃).

* Generalmente consistente con el rango citado para SRES en TAR pero no directamente comparable

* Dos próximas décadas aprox. 0.2º/decada para muchos de los SRES



(AR4, 2007)