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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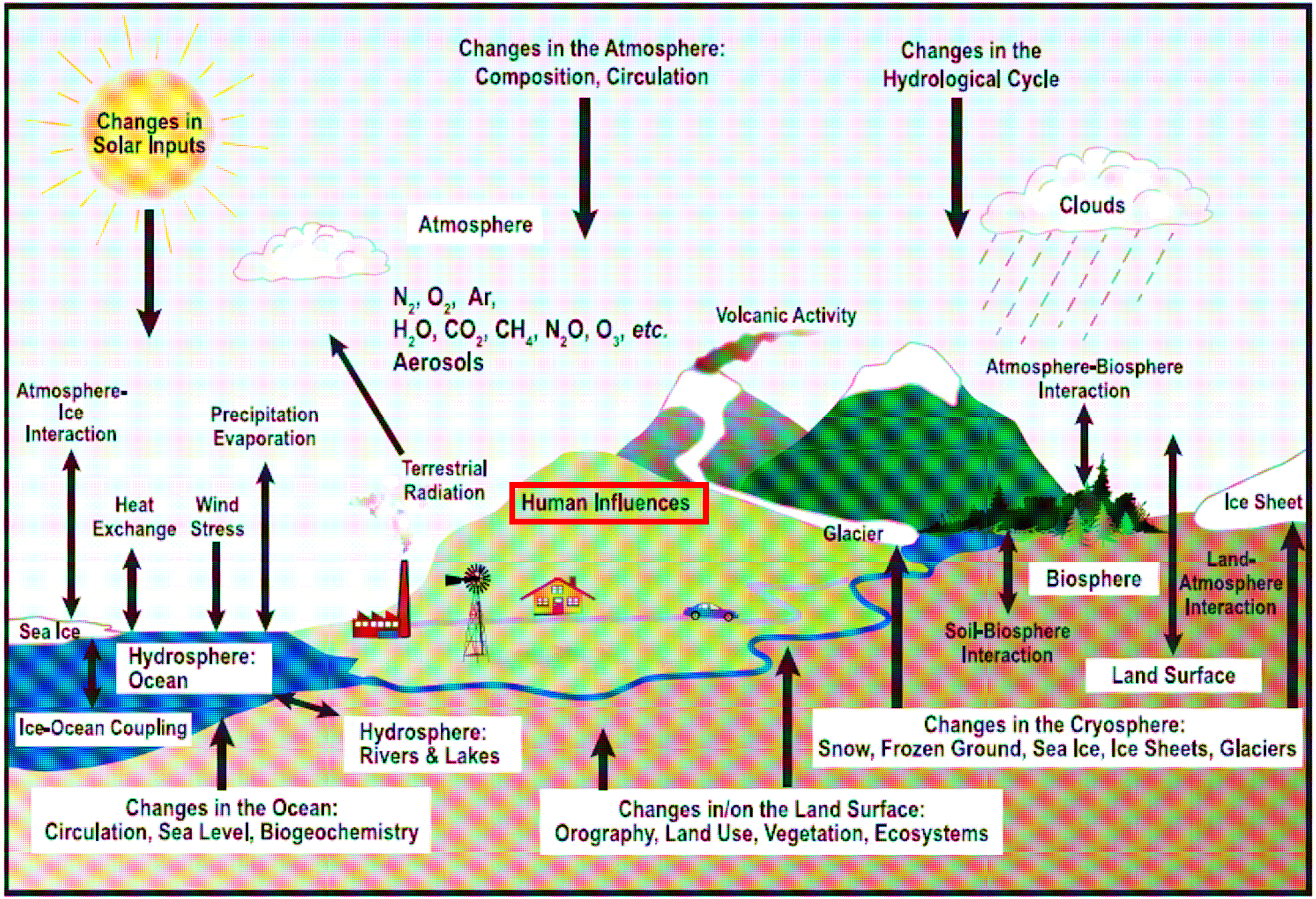
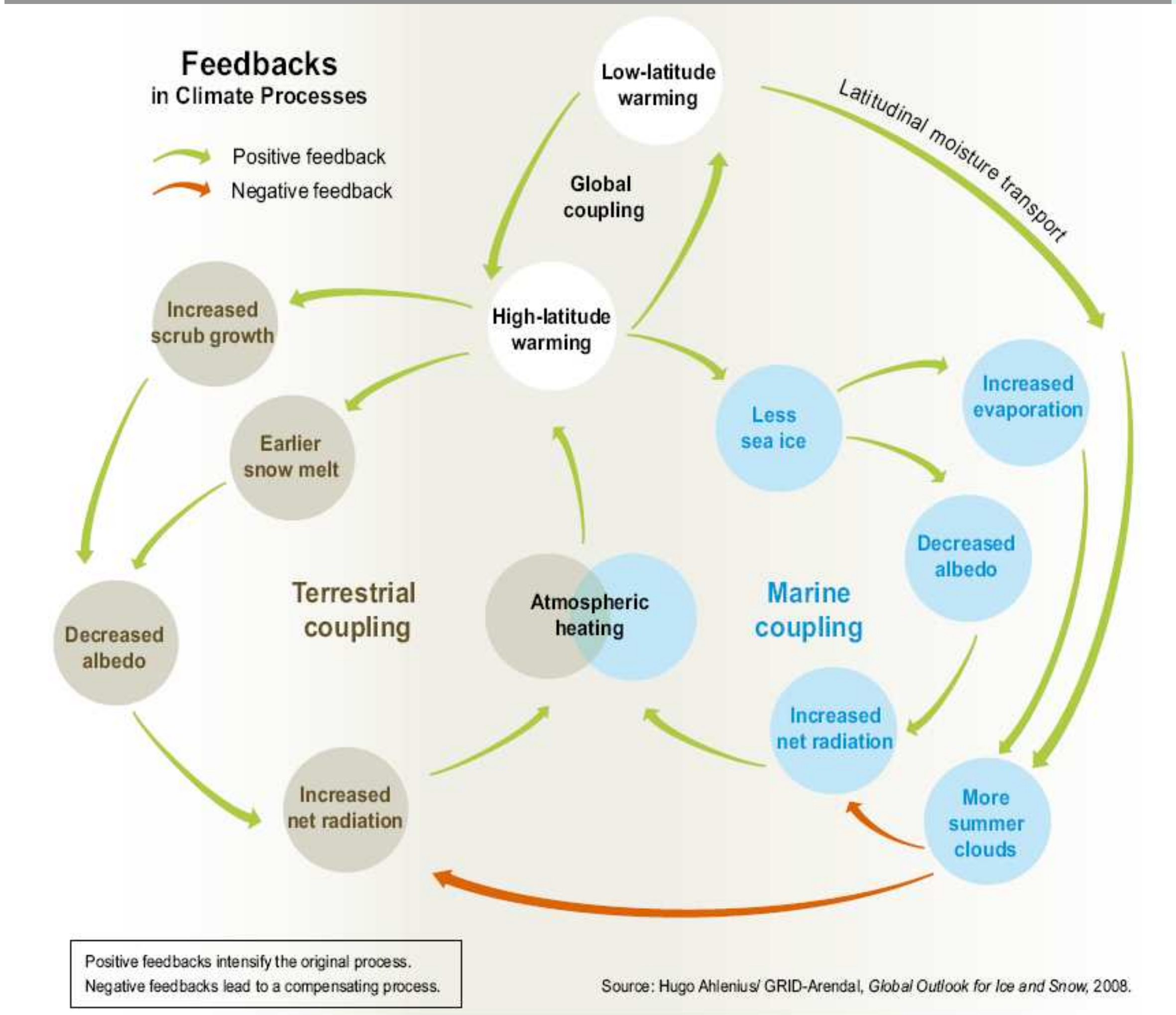
Contenido

- 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

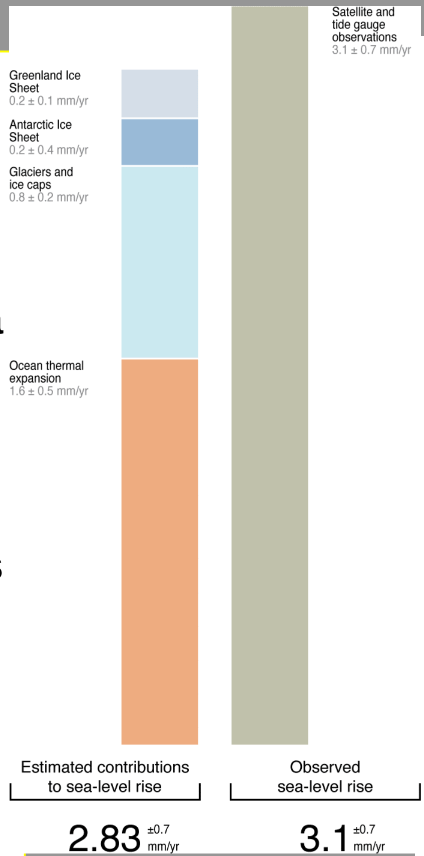
→Models needed!

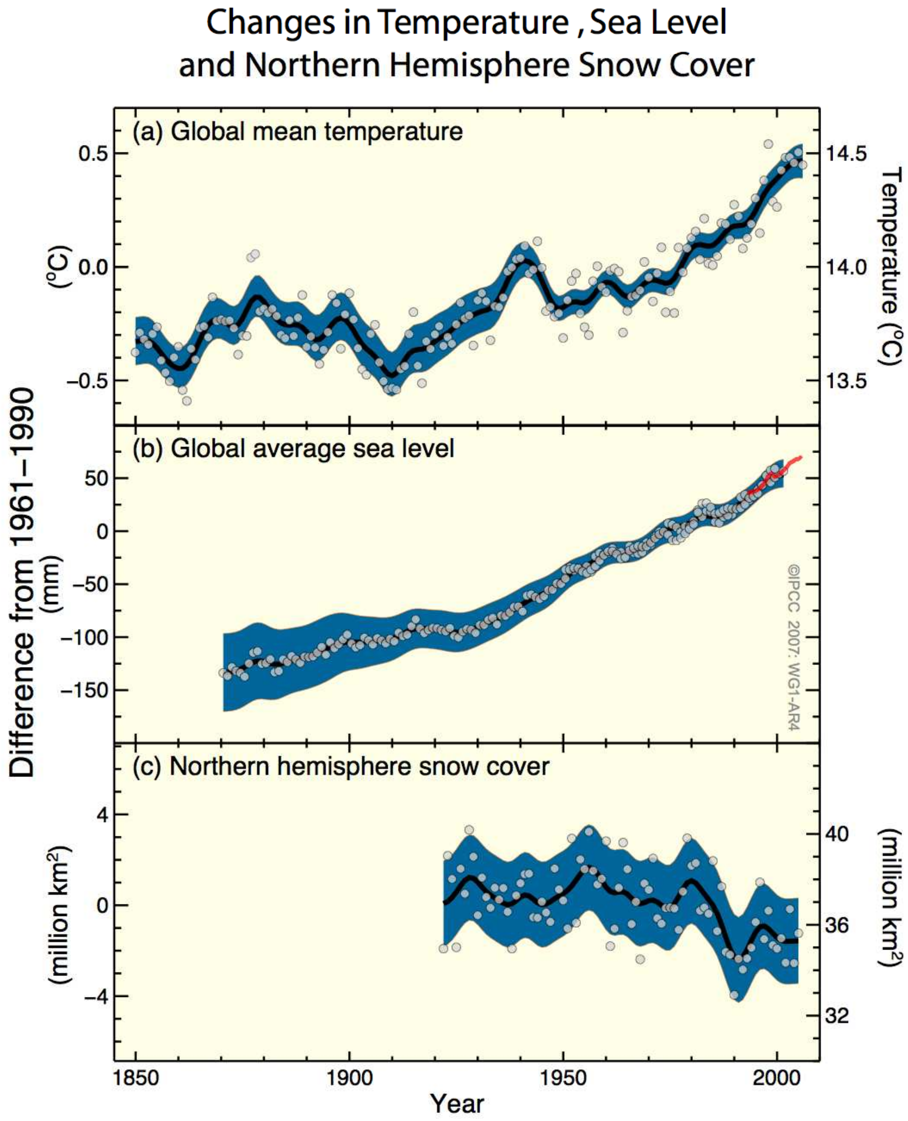
¿Qué CAMBIO CLIMATICO se observa?

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

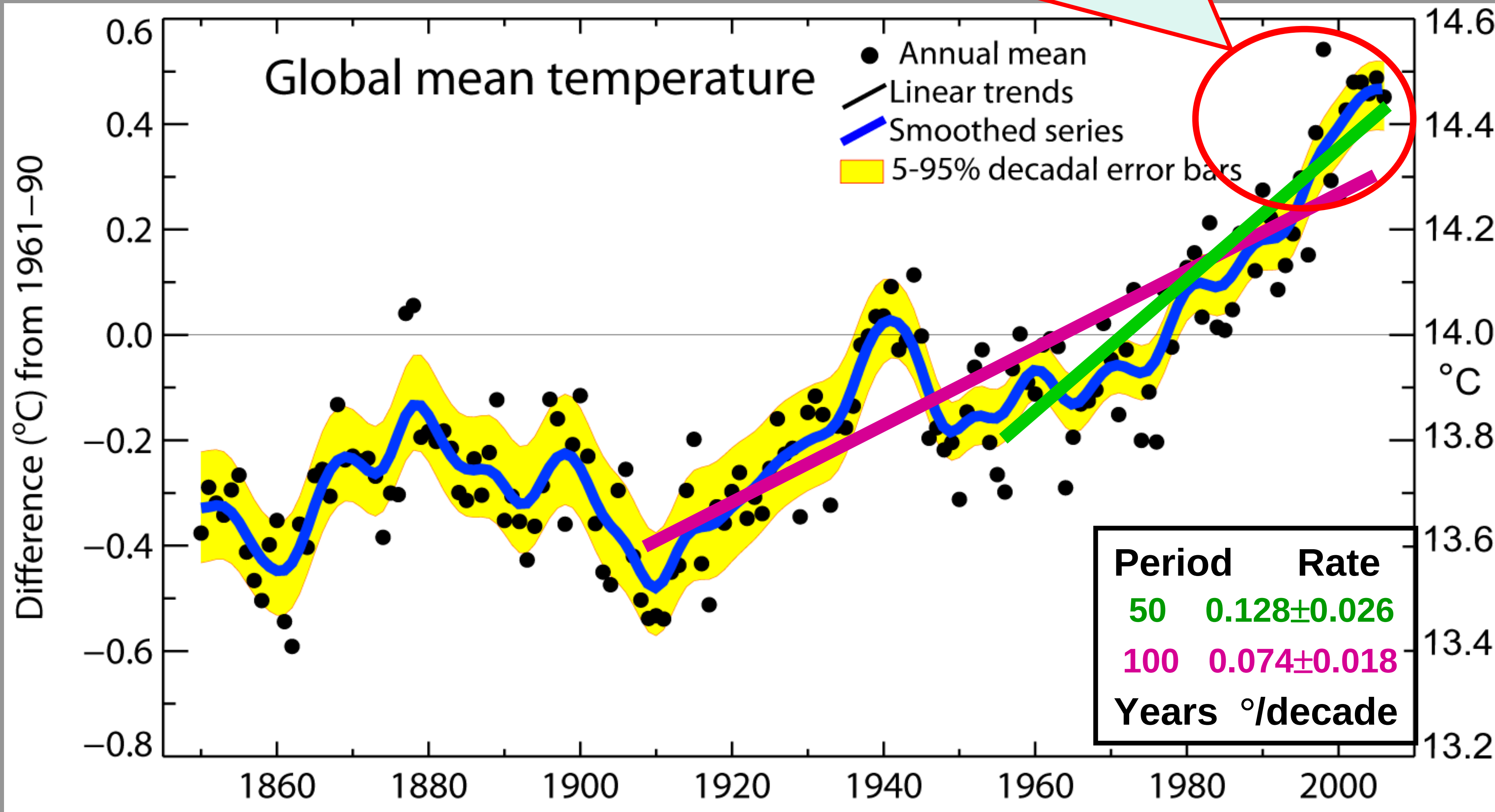
(IPCC-AR4 *dixit*)





Temperaturas globales … deprisa

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



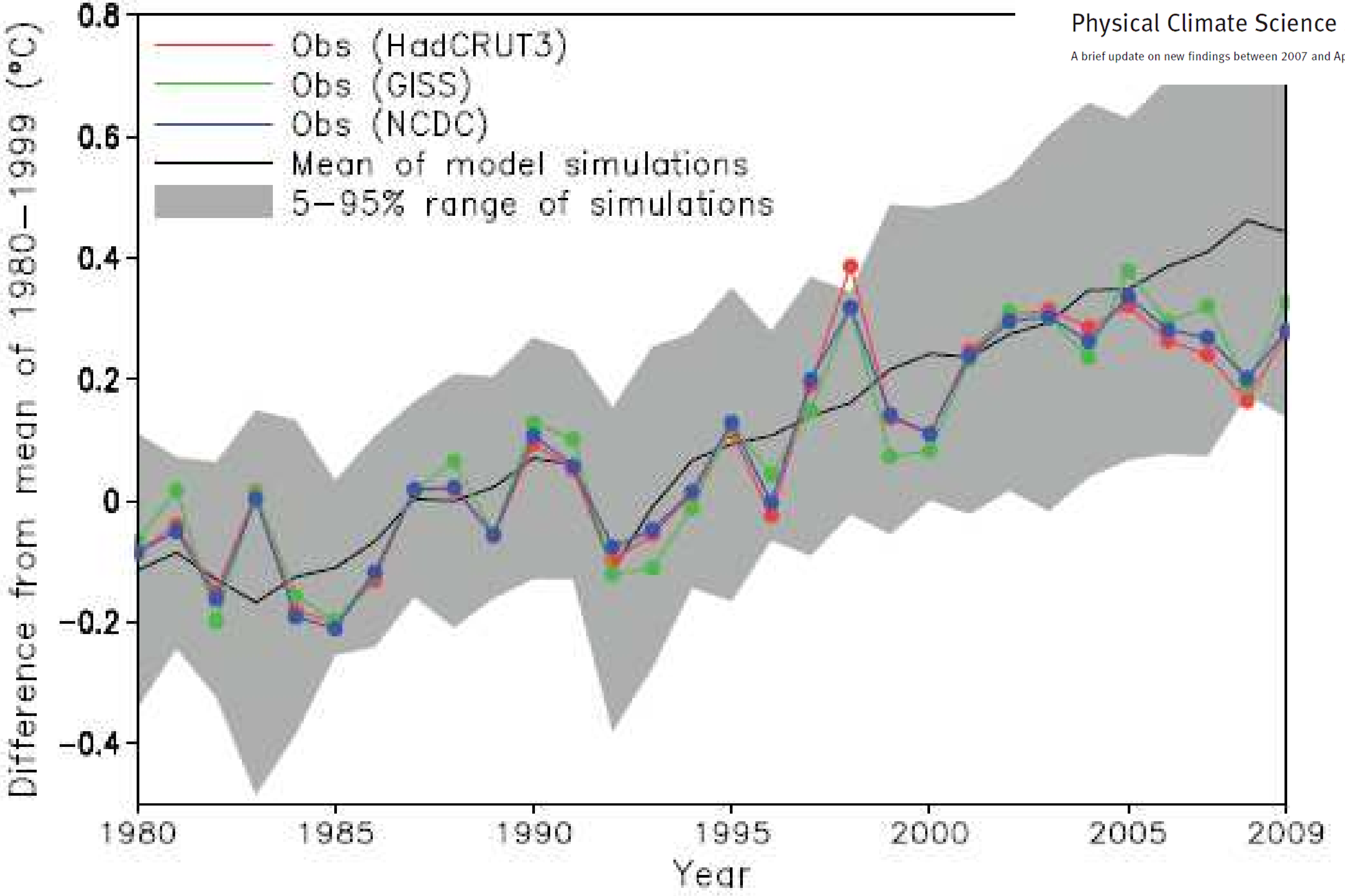
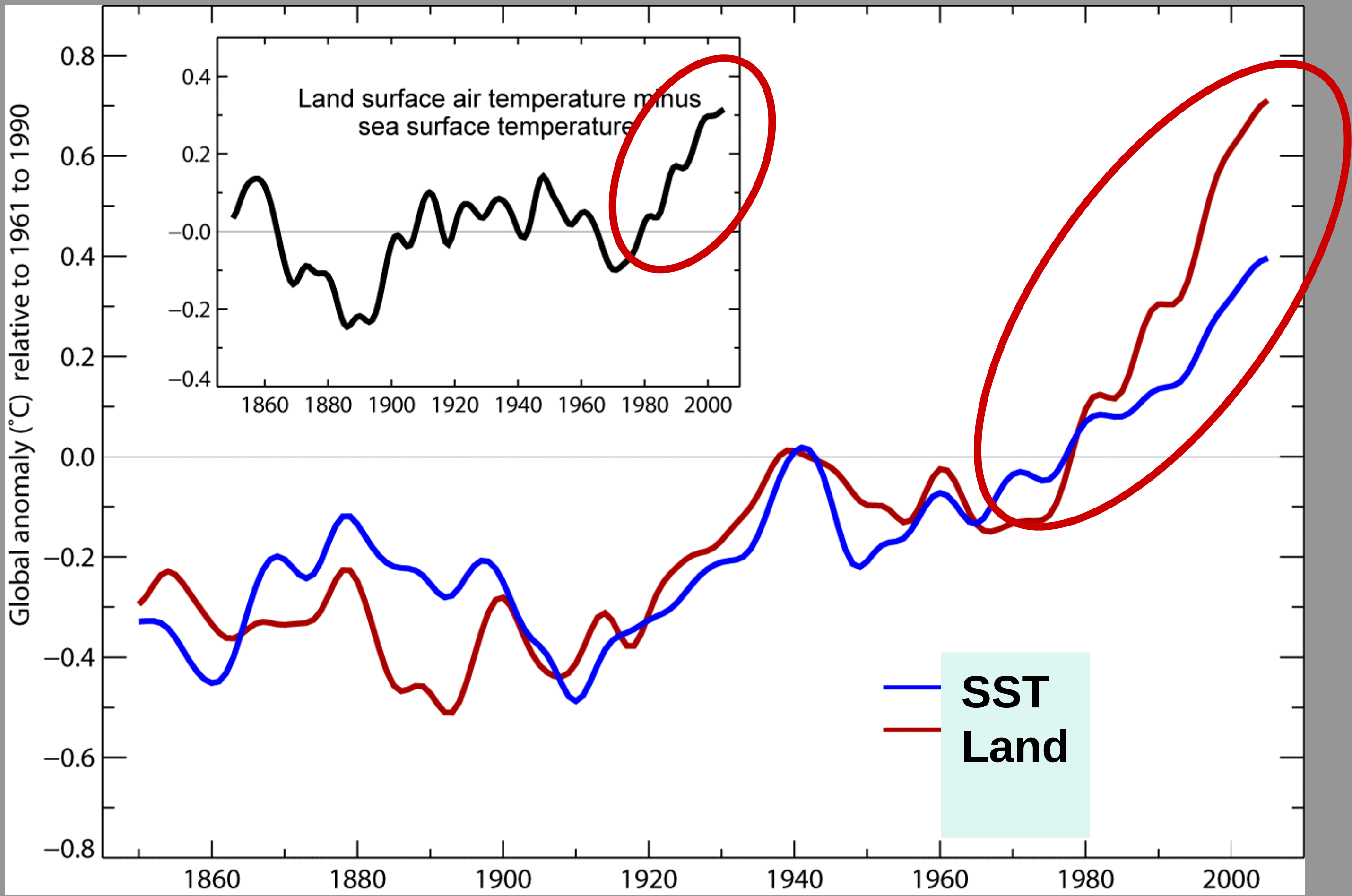
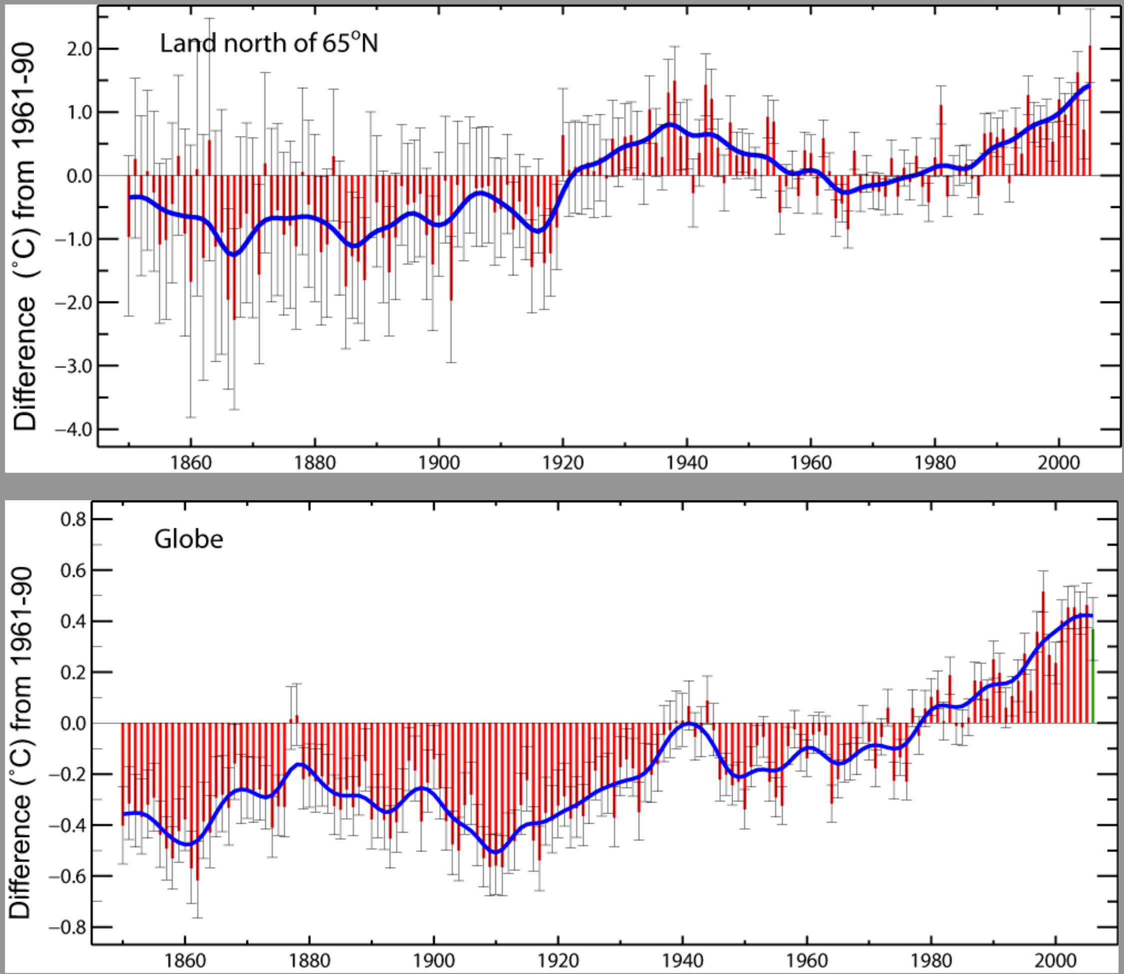


Figure 2. Recent changes in global mean temperature according to three analyses of observations (HadCRUT3, GISS and NCDC) and the 21 climate model simulations without climate policies used in IPCC AR4[19]. The mean of the model results is given by the solid black line. The shading indicates a 5–95% range 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 (℃)

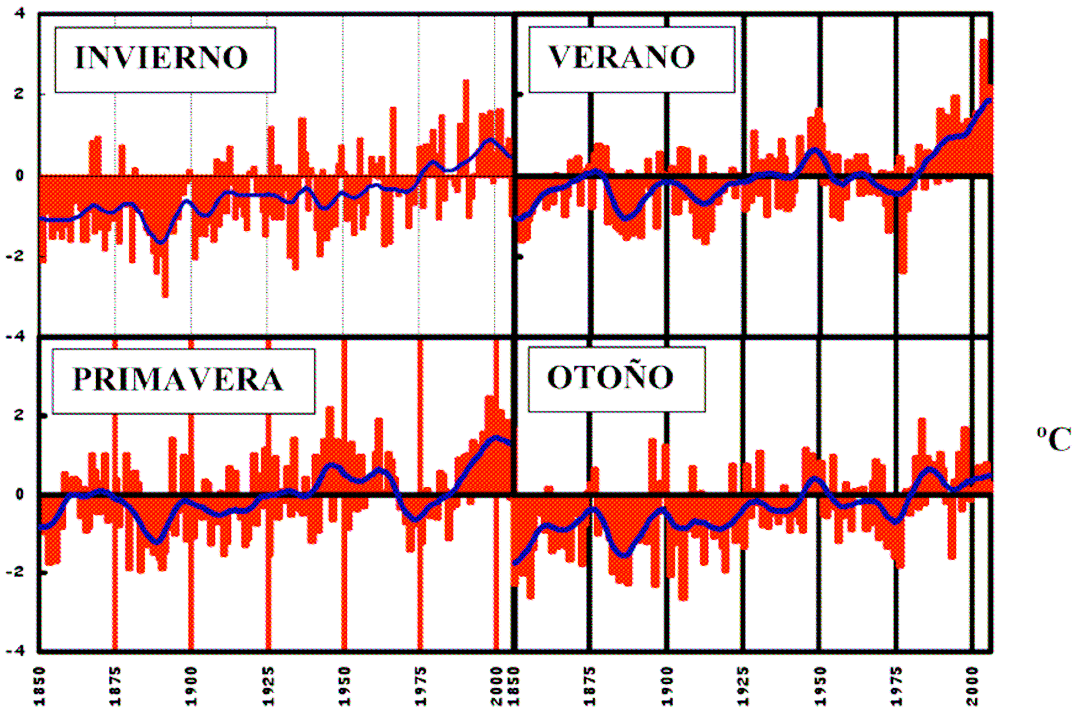


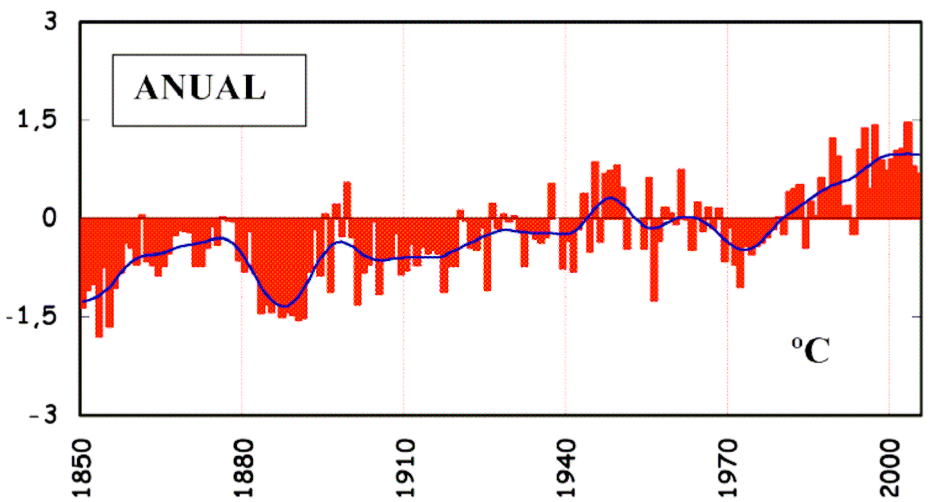
Calentamiento en el Ártico es doble que para el globo desde el s. XIX al XXI y desde los últimos 1960s hasta la actualidad.

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

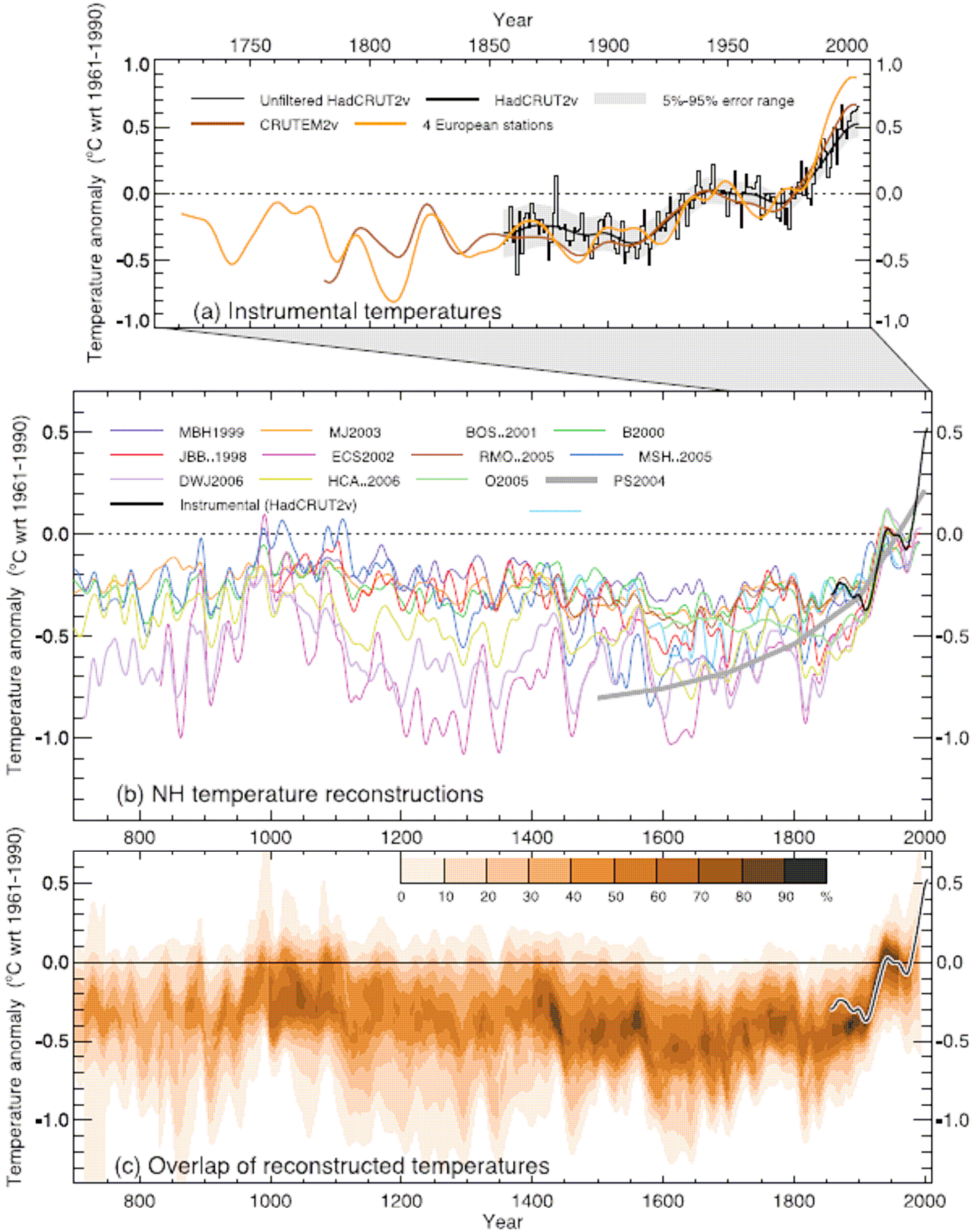
Data sources	Variable measured	Continuity of evidence	Potential geographical coverage	Period open to study (years)	Minimum sampling interval (years)	Usual dating accuracy (years)	Climate-related inferences
Ocean sediments	Isotopic composition of planktonic and benthic fossils Floral and faunal assemblages 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 2–5 >10	Favored areas along continental margins	1 000 000+ 200 000+ 10 000+	1000+ 500+ 50+	±5% ±5% ±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 sedimentological composition	Continuous	All continents	10 000+ (common) 150 000 (rare)	~50	±5%	Temperature, precipitation, soil moisture, air mass frequencies
(varved sediments)			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

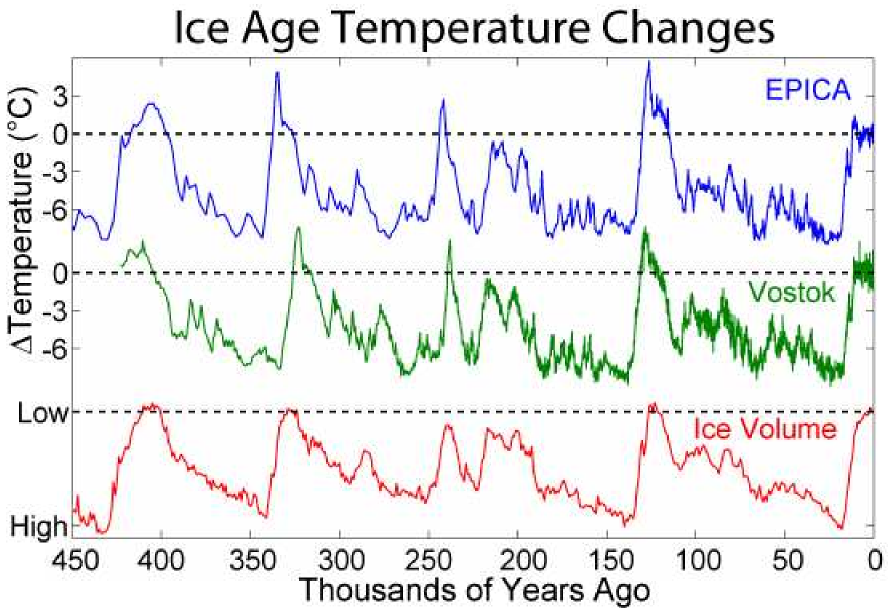
Los últimos 2000 años

(IPCC-AR4, 2007)

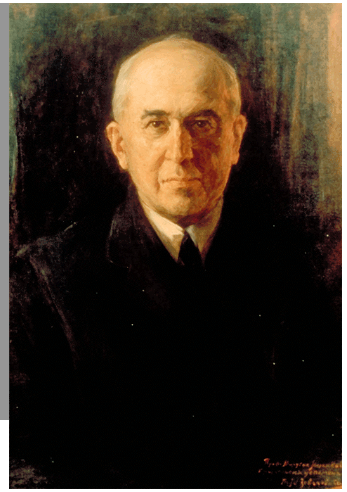


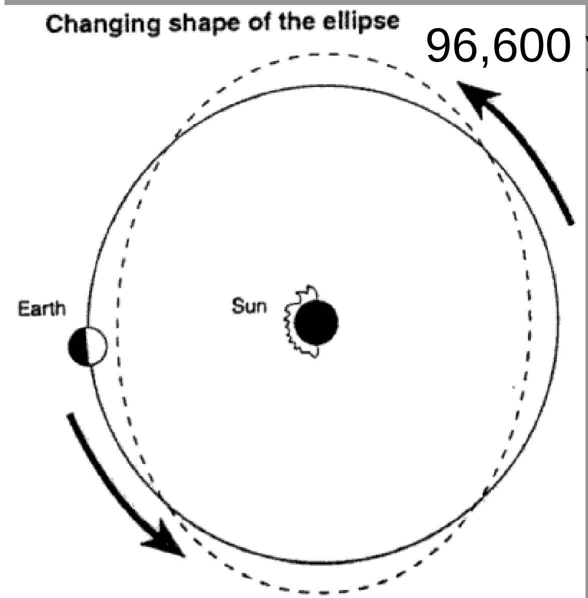
Louis Agassiz (1837)

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

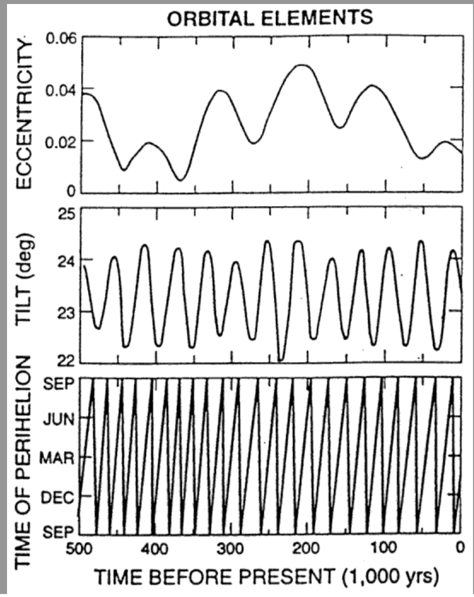


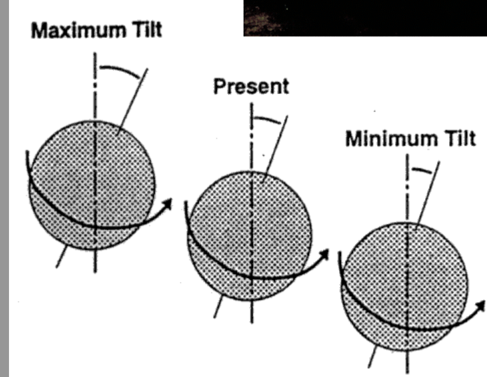
FORZAMIENTO NATURAL DEL SISTEMA CLIMATICO: ciclos de Milankovitch





96,600 years

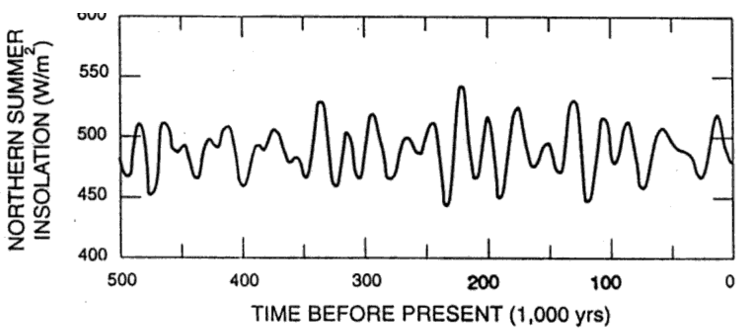


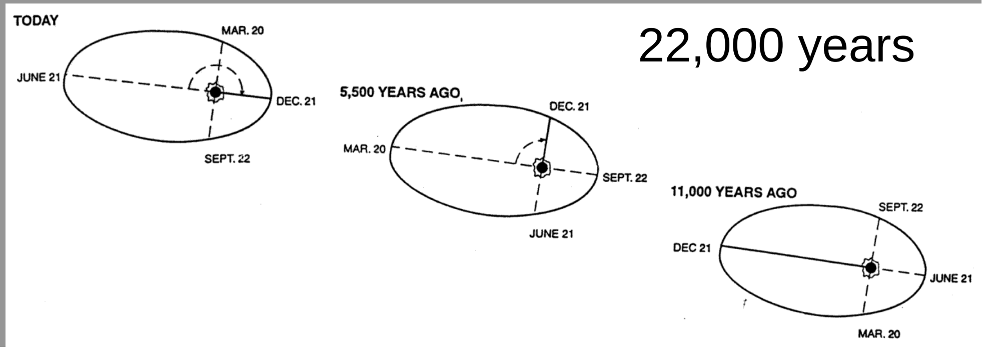


22° to 24.5°, over 41,000 years

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

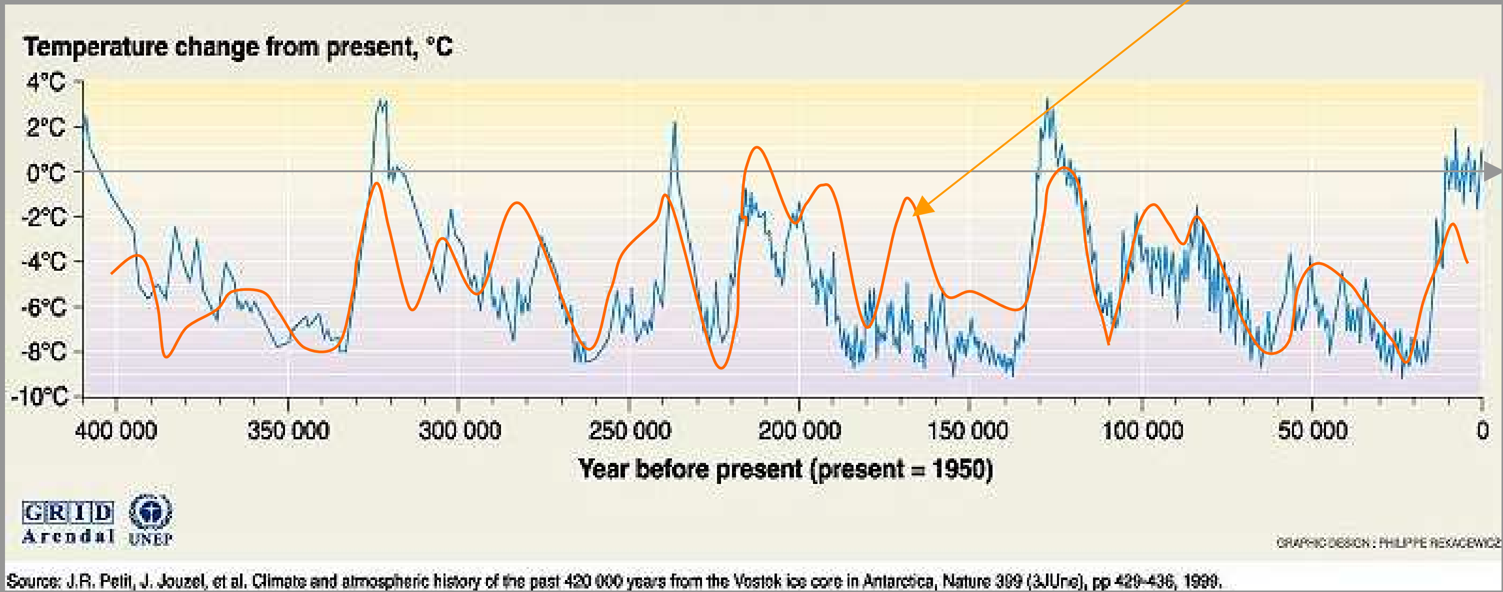
Variations in insolation (in watts per square meter) determined from the variation in Earth's orbital elements (Barron, 1994, figure 13).

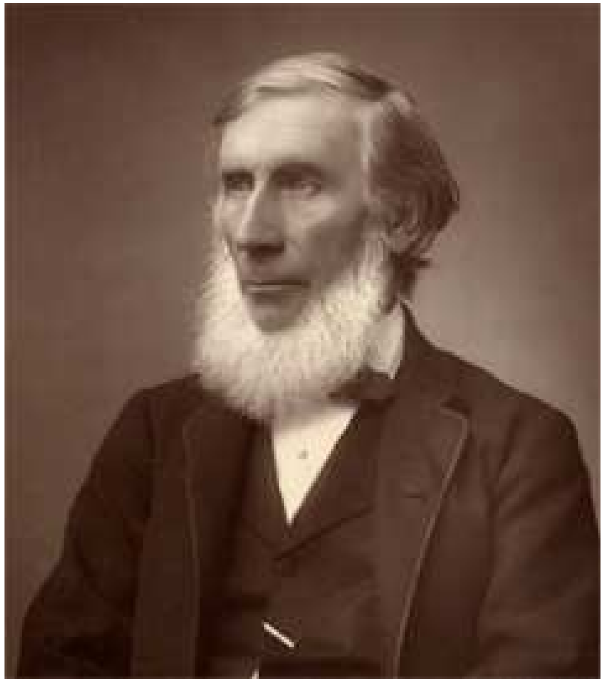




22,000 years

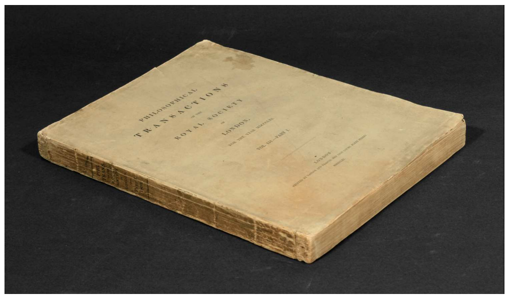
Insolation according to Milankovitch parameters

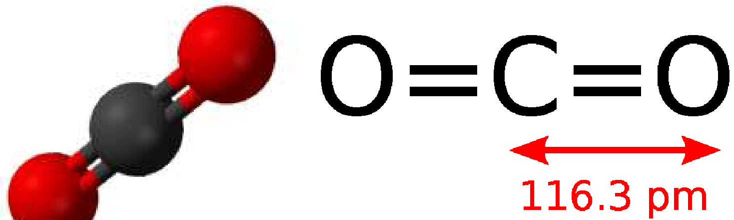




- He established for the first time that molecules of WV, CO2, N2O, CH4 y O3 exhibit different absorption properties when IR radiation travels through them
- Changes in the amount of any of the radiatively active constituents of the atmosphere "could have produced all the mutations of climate which the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

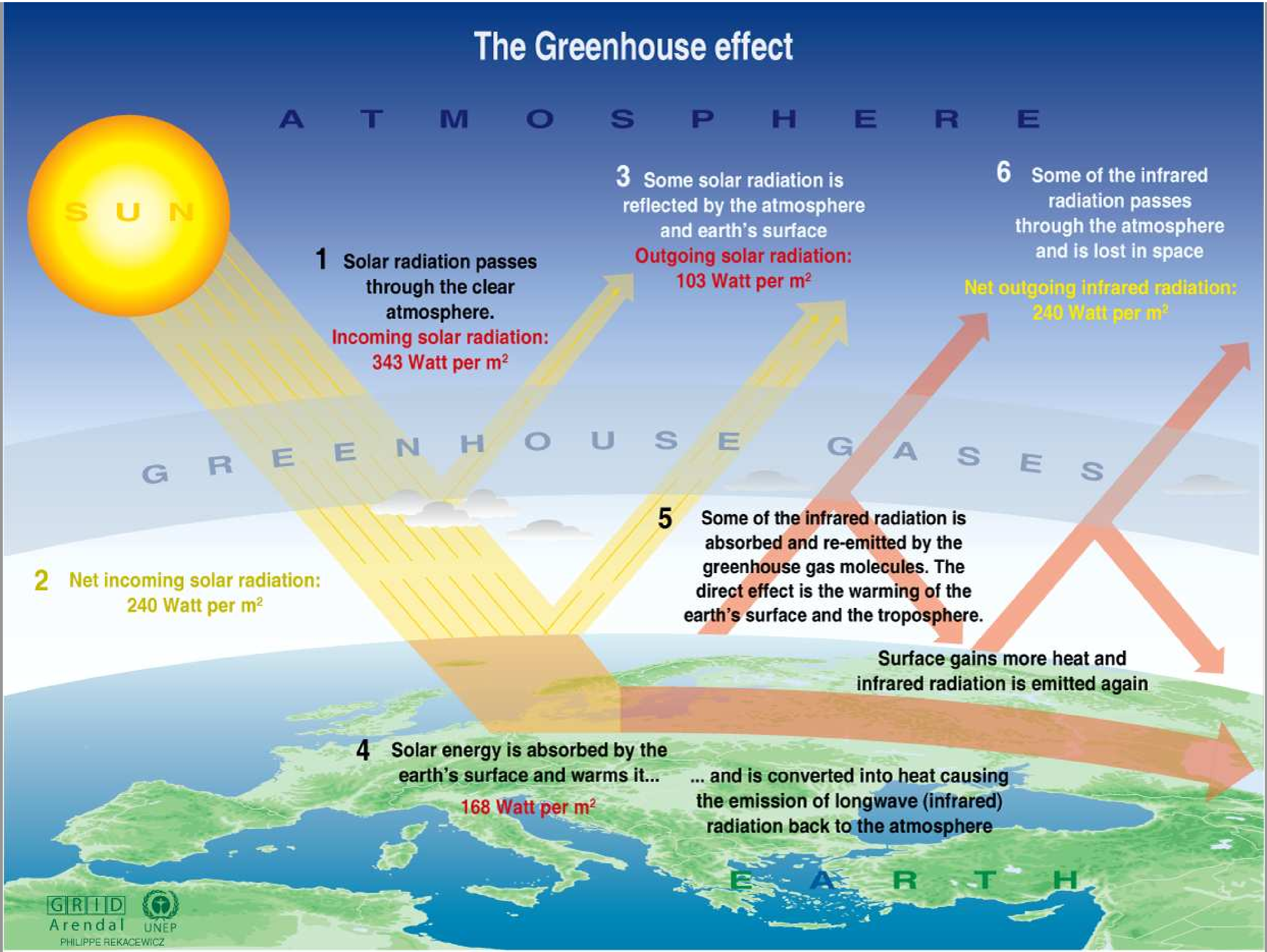
John Tyndall (1859)



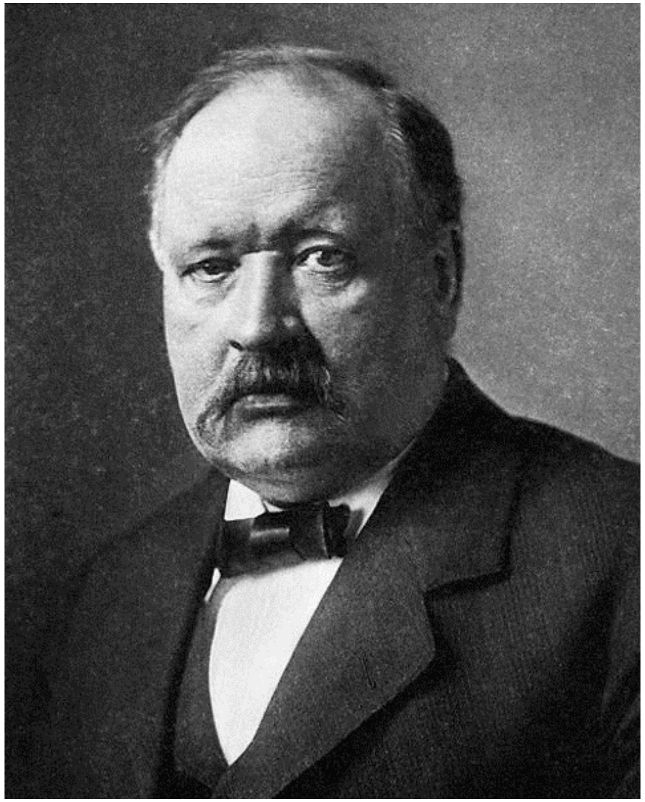


(pm=10^{-12} m)

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.

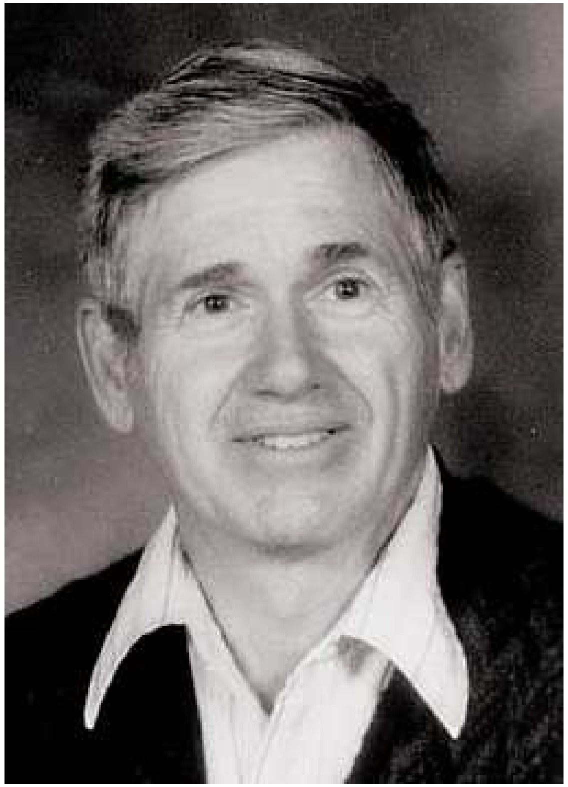


Svante Arrhenius (1896)

- He showed that doubling the concentration of CO_2 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 CO_2 over the course of the years

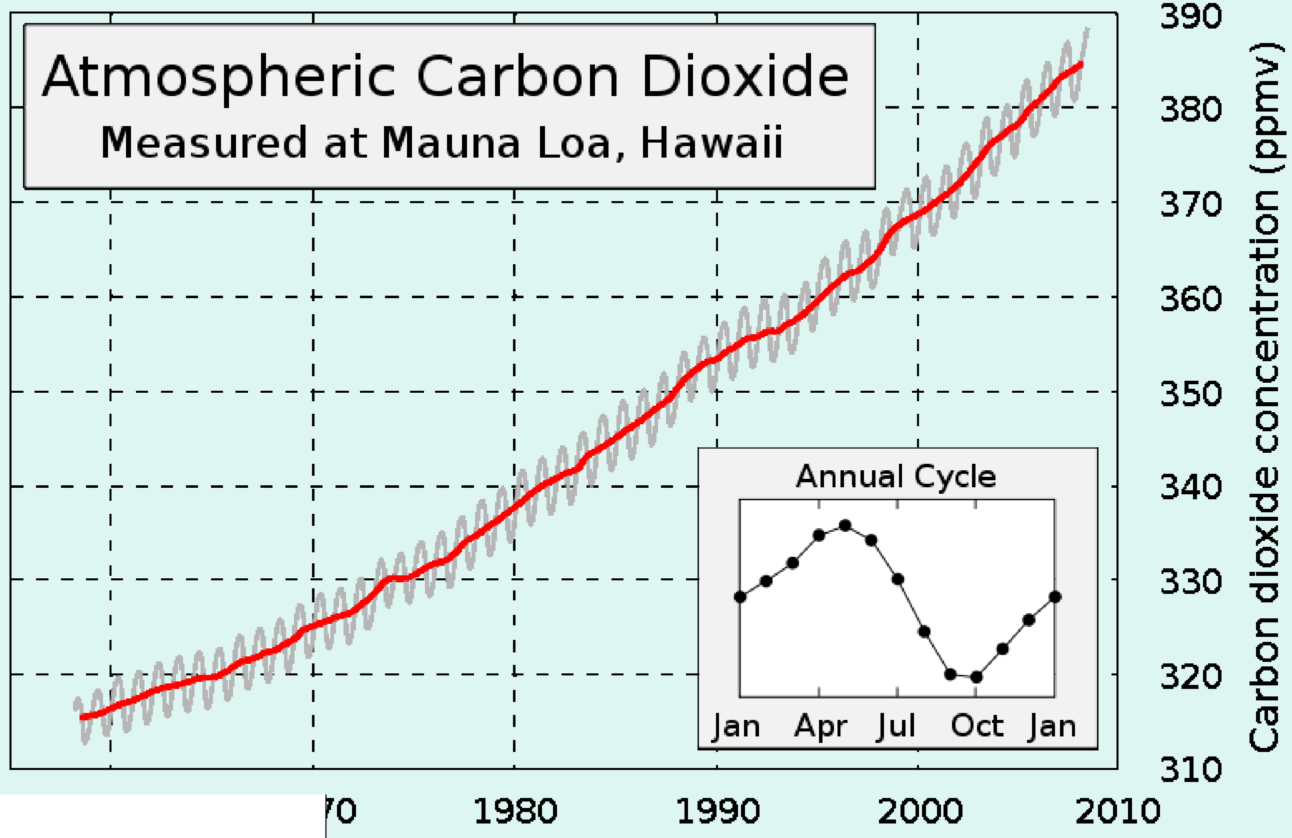
Guy S. Callendar (1938)

- "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

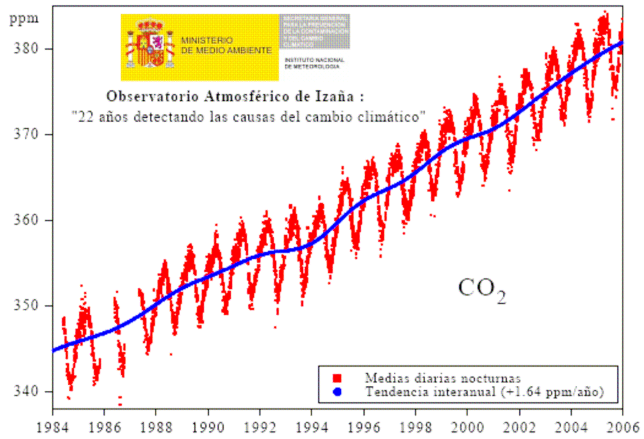


Charles D. Keeling (1957)

- 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



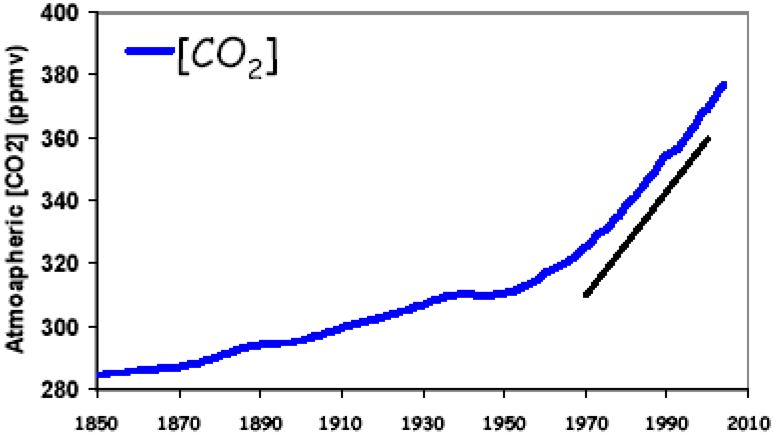
Atmospheric Carbon Dioxide
Measured at Mauna Loa, Hawaii
Annual Cycle
Jan Apr Jul Oct Jan
390
380
370
360
350
340
330
320
310
Carbon dioxide concentration (ppmv)
70 1980 1990 2000 2010



ppm
MINISTERIO DE MEDIO AMBIENTE
INSTITUTO NACIONAL DE METEOROLOGIA
Observatorio Atmosférico de Izaña :
"22 años detectando las causas del cambio climático"
CO2
Medias diarias nocturnas
Tendencia interanual (+1.64 ppm/año)
380
370
360
350
340
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

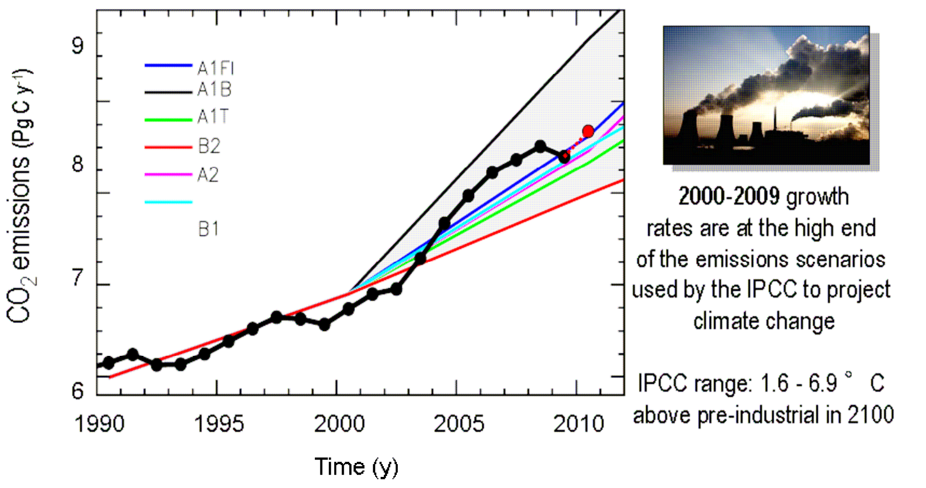


1970 – 1979: 1.3 ppm y^{-1}
1980 – 1989: 1.6 ppm y^{1}
1990 – 1999: 1.5 ppm y^{-1}

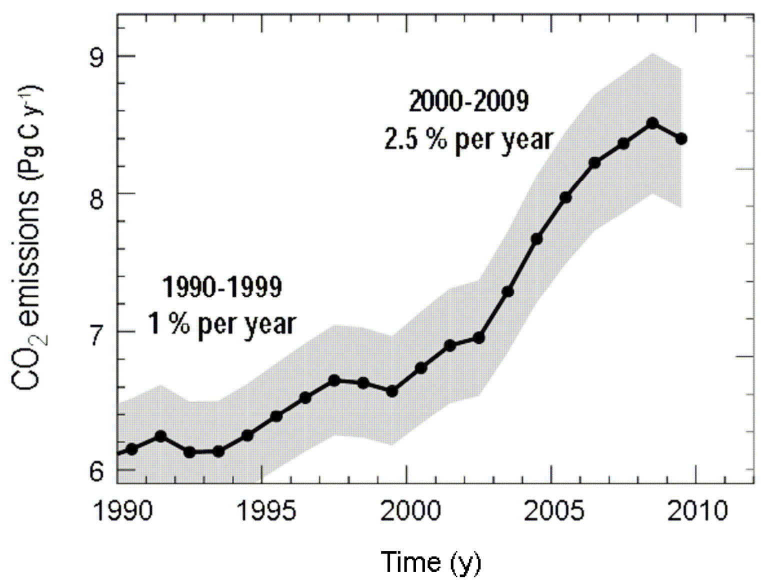
2000 - 2006: 1.9 ppm y^{-1}

Emisiones CO2

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



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

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

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

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

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

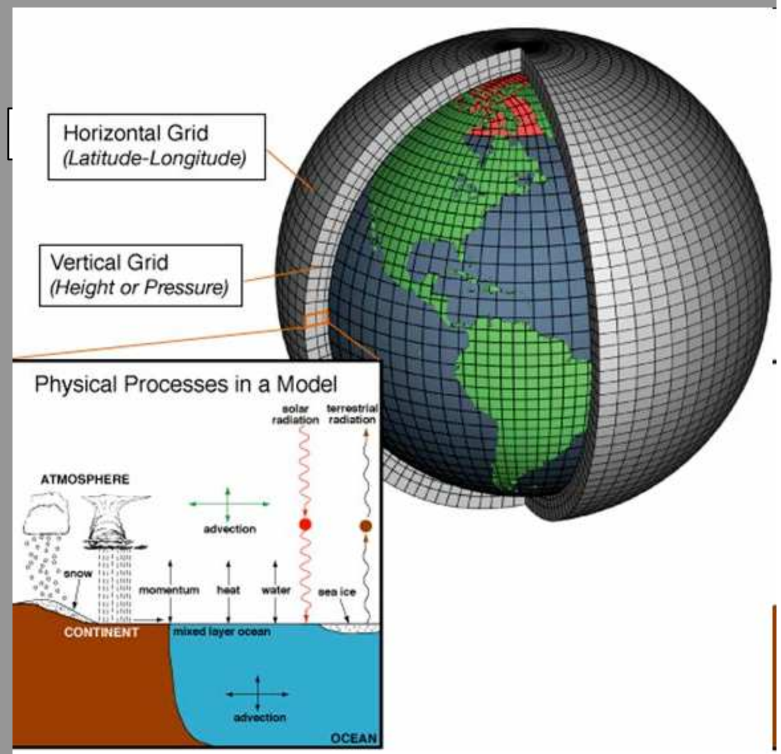
$$C_p\frac{d\Theta}{dt} = \frac{\Theta}{T}Q$$

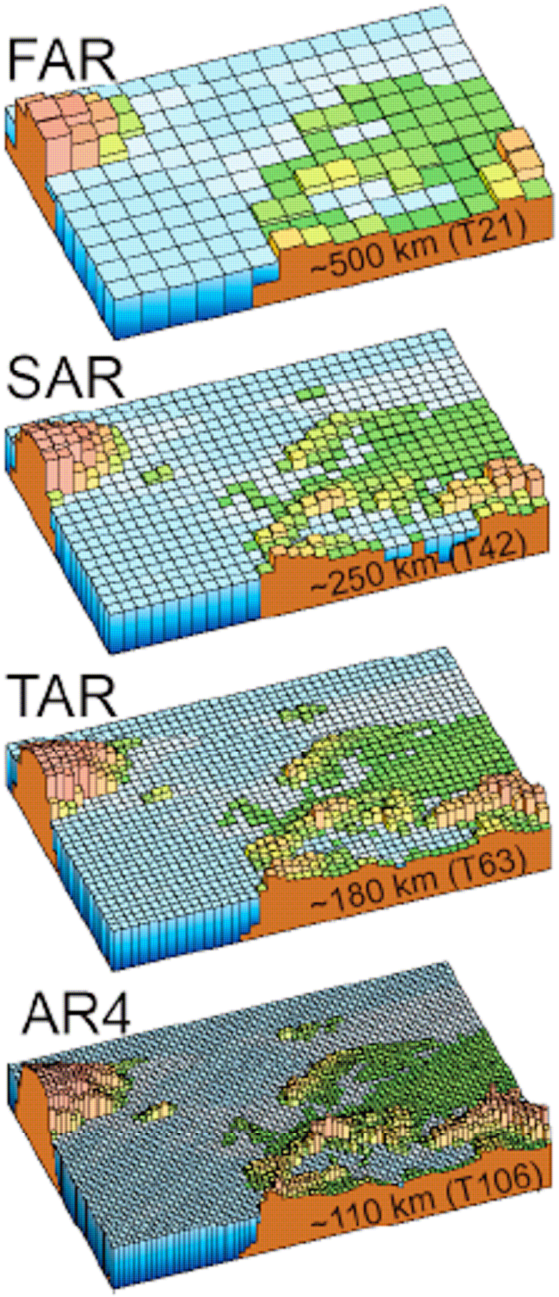
$$p = R\rho T$$

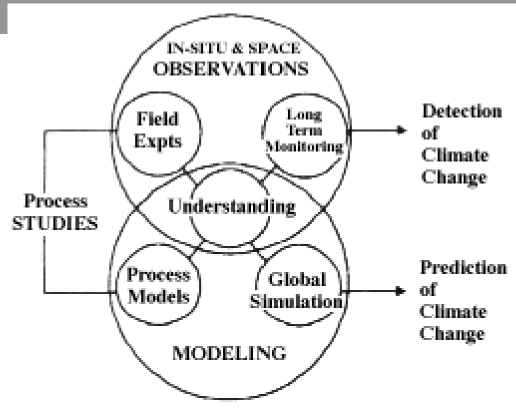
Ecuaciones atmósfera

$\Rightarrow$ 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, …



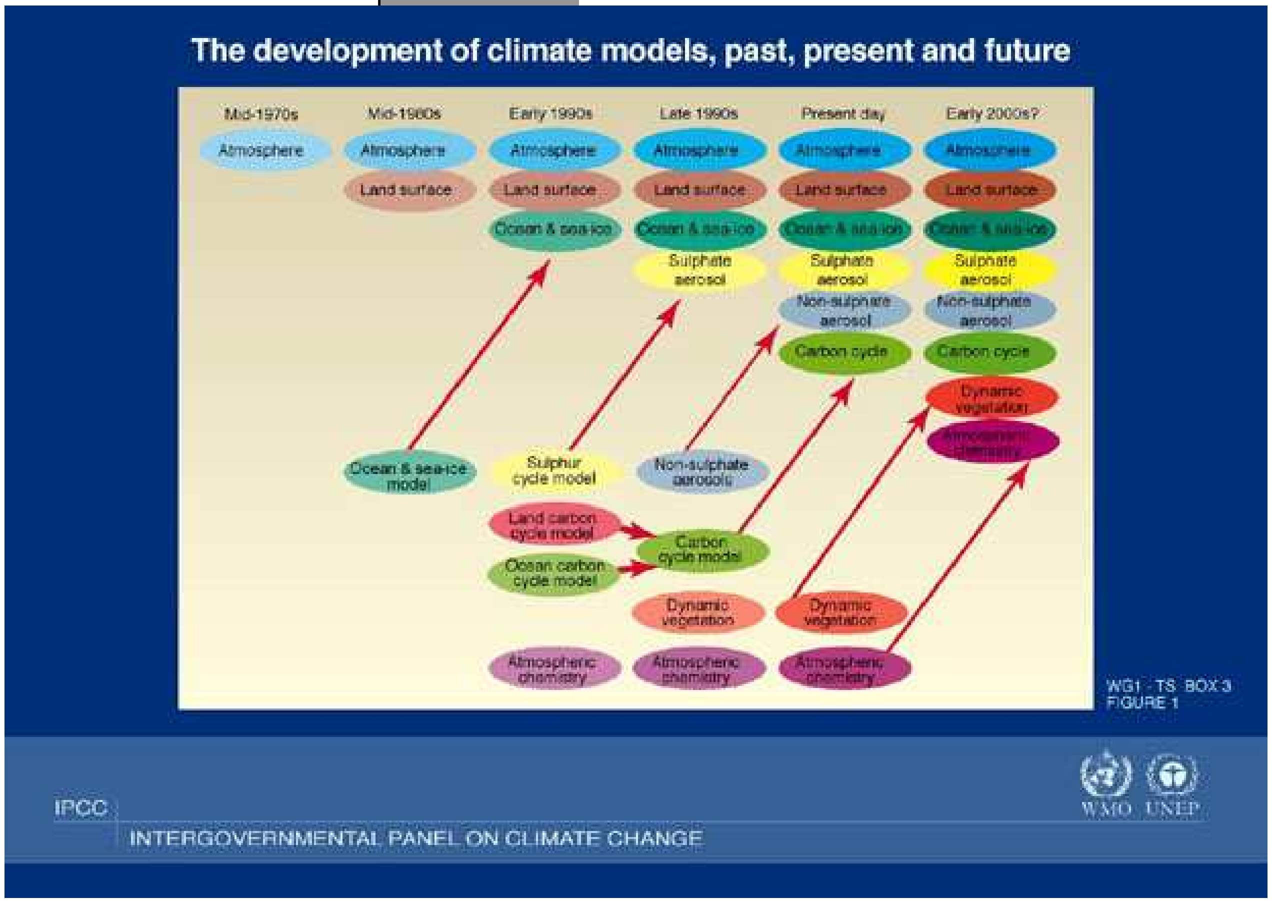




NUMERICAL CLIMATE MODELLING: A REVIEW

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

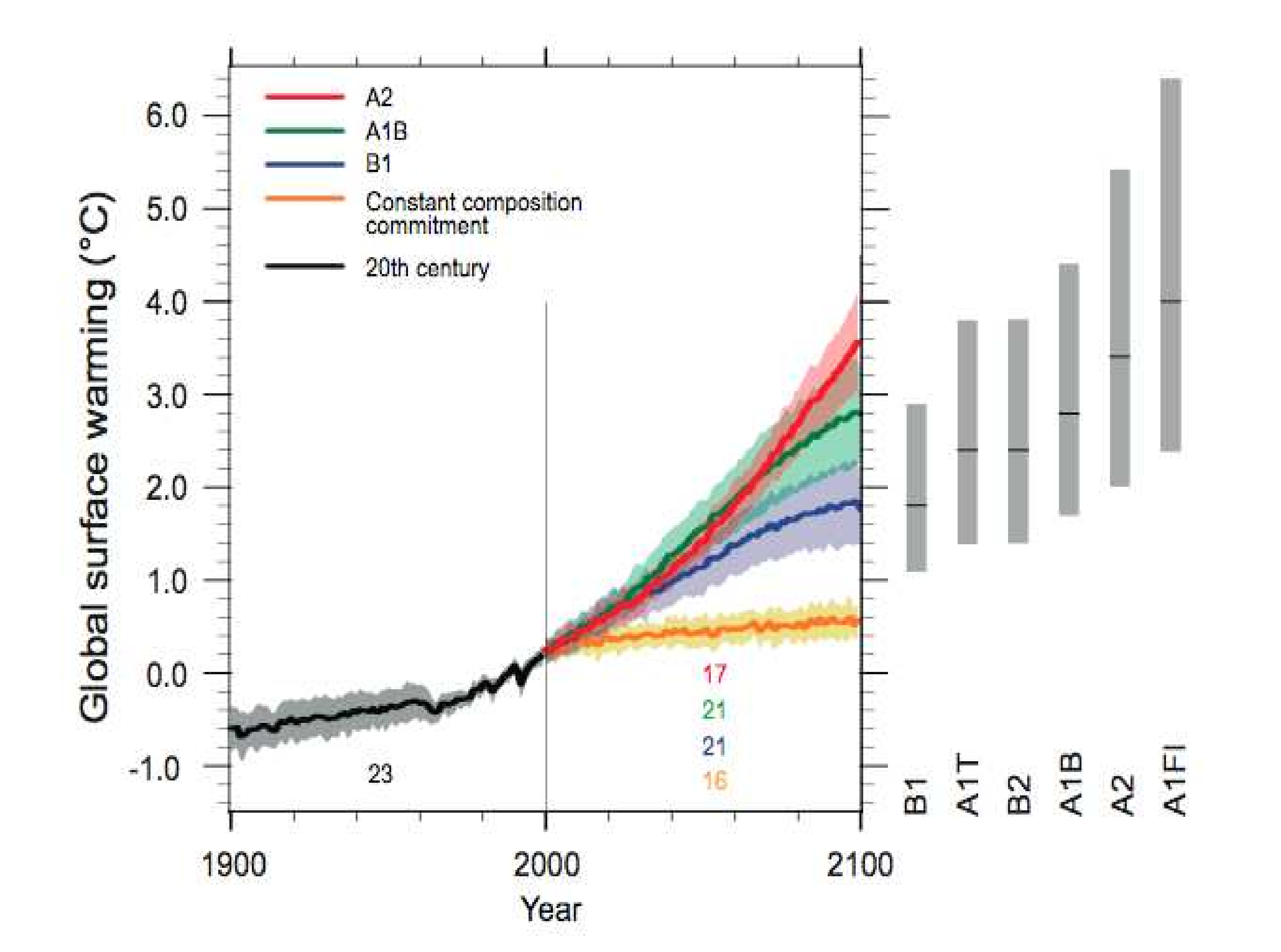


Proyecciones de cambios futuros en el clima
(escenarios sin compromisos políticos!!!)

* 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



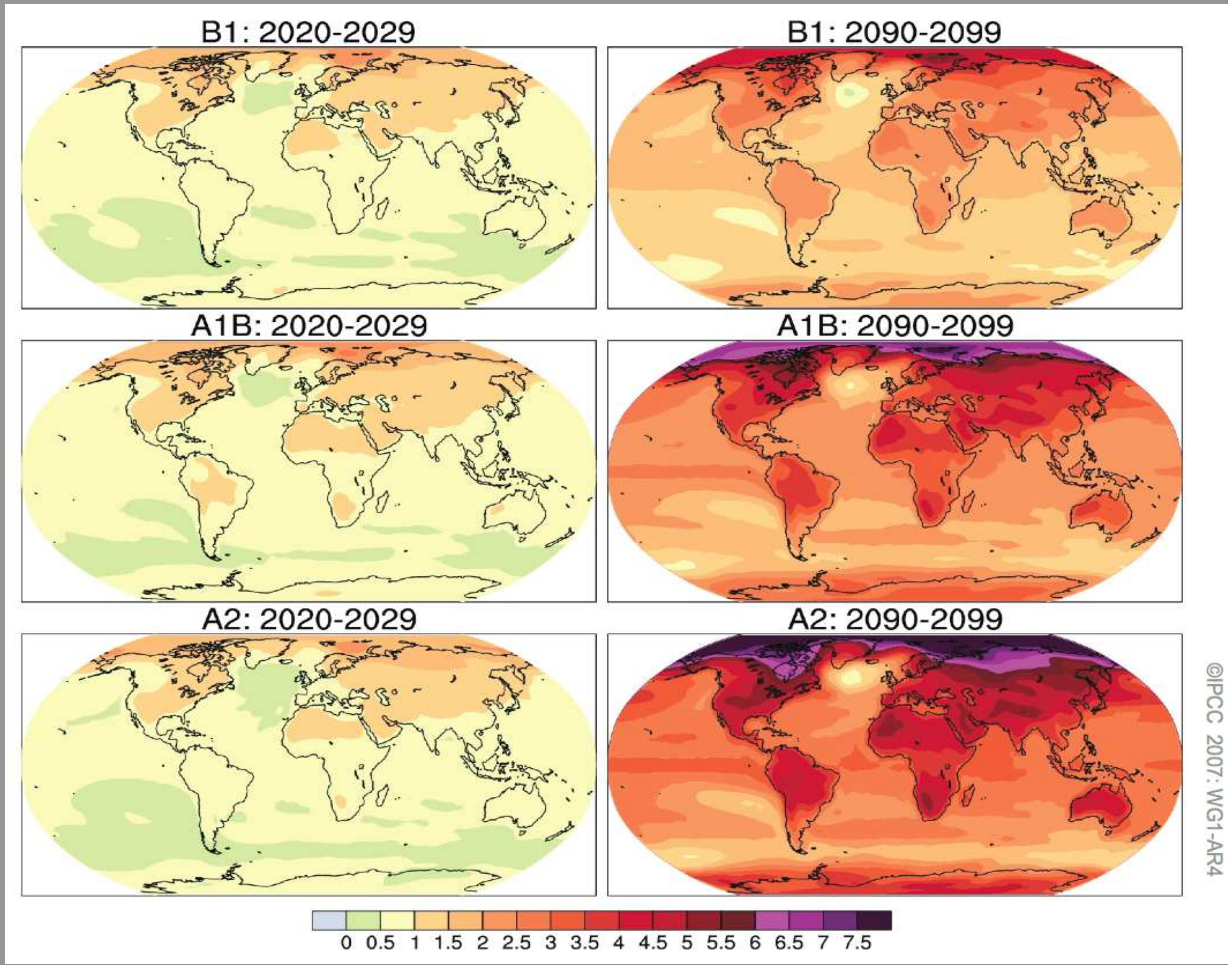
(AR4, 2007)

Proyecciones de cambios futuros en el clima

Mayor sobre tierra y en latitudes altas

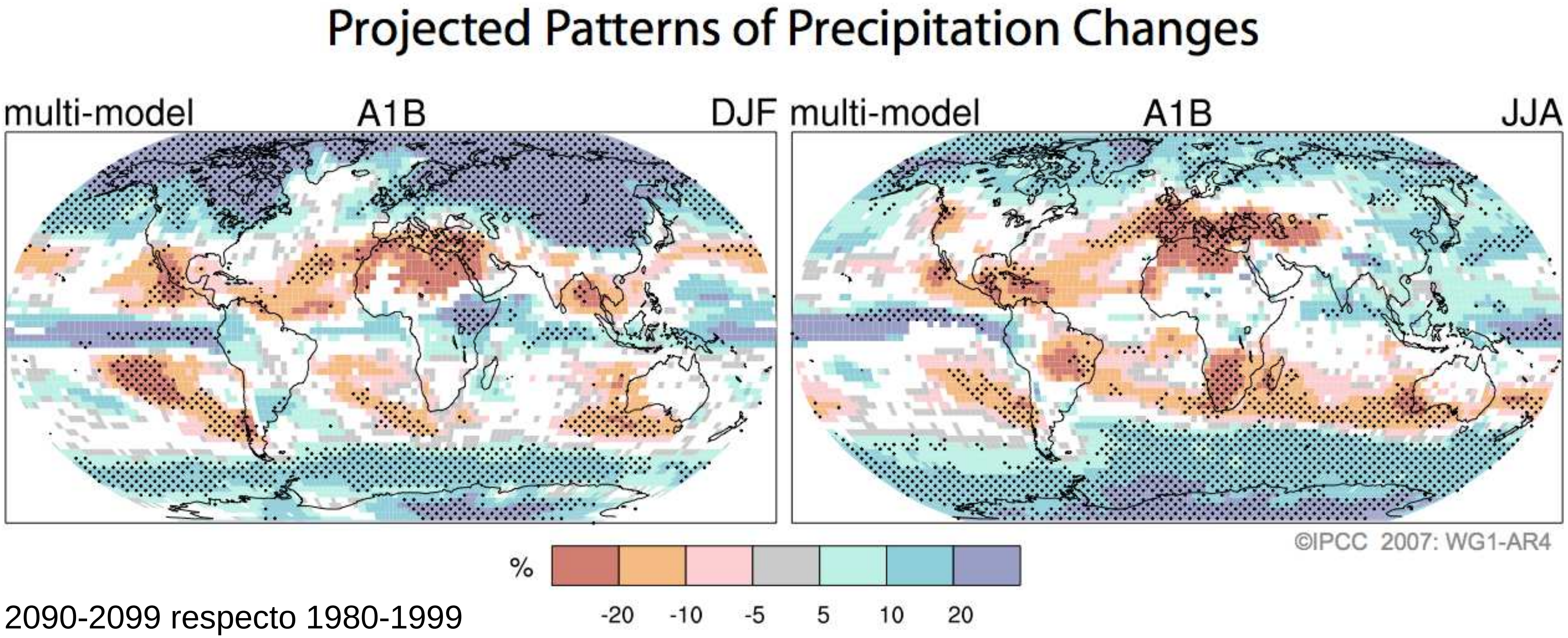
Proyecciones para las próximas décadas son insensibles a la elección del escenario

Proyecciones a largo plazo dependen del escenario y de la sensibilidad de los modelos climáticos



(AR4, 2007)

Proyecciones de cambios futuros en el clima



2090-2099 respecto 1980-1999

(AR4, 2007)

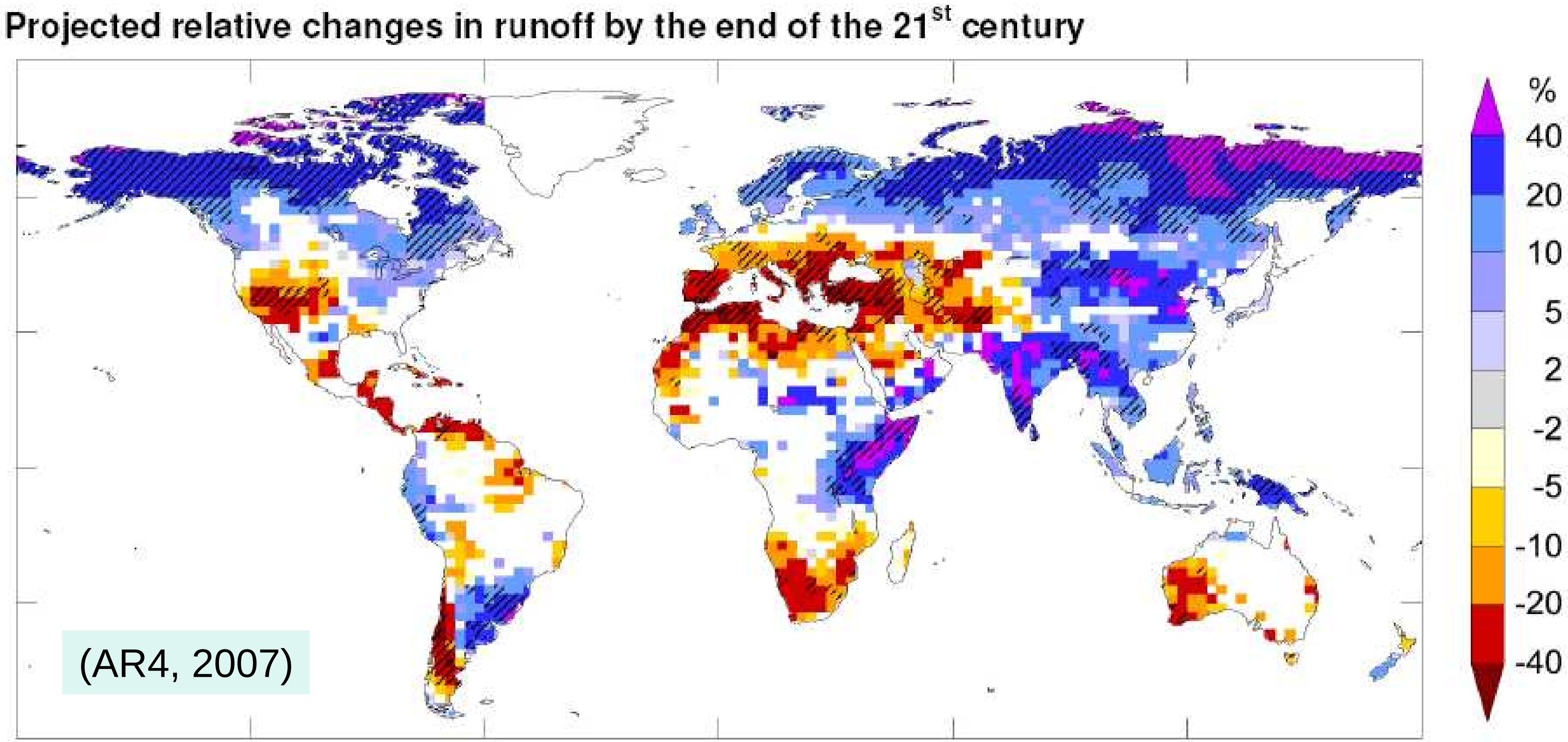
Precipitación aumenta muy probablemente in latitudes altas

Decrece probablemente en la mayoría de las regiones terrestres subtropicales

Cambio (%) en escorrentía

[2090-2099 respecto a 1980-1999]

Ensemble basado en escenario SRES A1B



La región Mediterránea parece mostrar una gran respuesta al cc

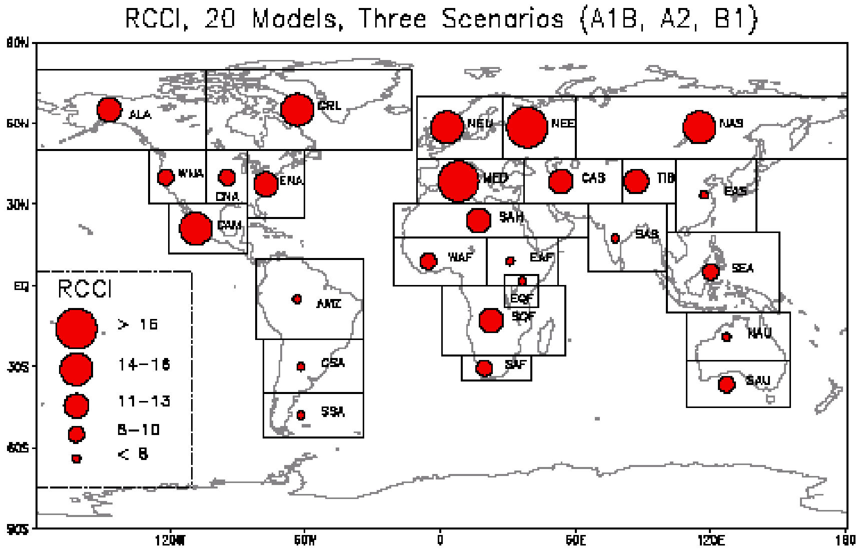


Figure 1. Regional Climate Change Index (RCCI) over 26 land regions of the World calculated from 20 coupled AOGCMs and 3 IPCC emission scenarios (A1B, A2, B1). The models used are BCCR-BCM2-0, CCMA-3-T47, CNRM-CM3, CSIRO-MK3, GFDL-CM2-0, GFDL-CM2-1, GISS-AOM, GISS-EH, GISS-ER, IAP-FGOALS, INMCM3, IPSL-CM4, MIROC3-2H, MIROC3-2M, MIUB-ECHO-G, MPI-ECHAM5, MRI-CGCM2, NCAR-CCSM3, NCAR-PCM1, UKMO-HADCM3. See also Table 1 of GB05a and http://www-pcmdi.llnl.gov.

- RCCI basado en cambio de T, RR y su cambio en variabilidad interanual

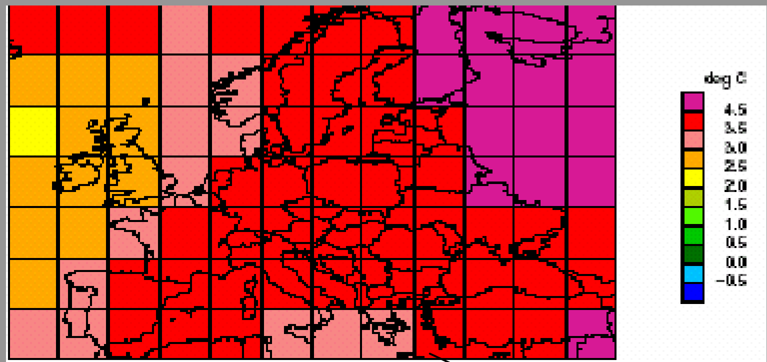
(Giorgi, 2006)

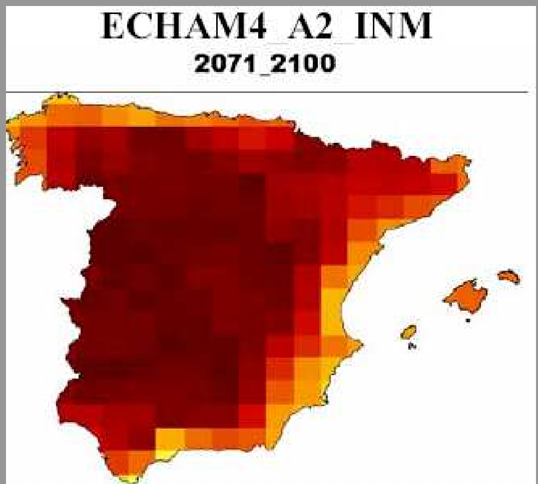
Muir Glacier, Alaska, August 13, 1941, photo by W.O. Field http://nsidc.org (National Snow and Ice Data Center)

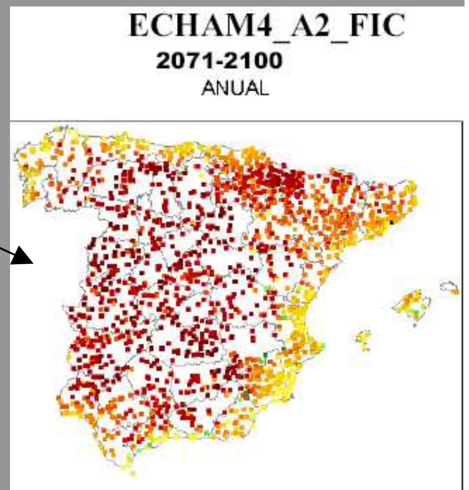
Europe


Climate change hotspot
Amsterdam
Rotterdam
Rhine delta
London
Hamburg
Alps
Venice
Istanbul
Mediterranean basin
More precipitation
Less precipitation
Sea-level rise concerns and affected major cities
Malaria:
Possible extension by 2050
Permafrost:
Present permafrost
Permafrost in 2050
Negative agricultural changes
Changes in ecosystems
Forest fires
Impact on fisheries
Impact on mountain regions
Melting of glaciers
Source: IPCC, 2007; Klein et. al., 2002.

¿Qué necesita la comunidad de impactos al cambio climático?

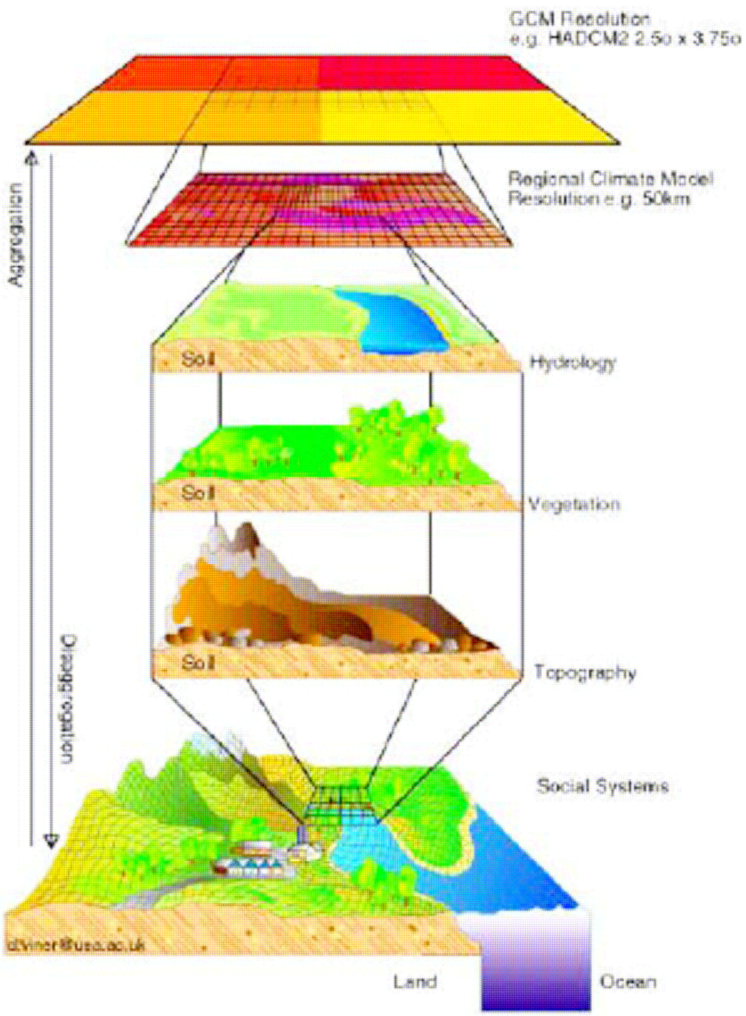






Proyecciones regionalizadas ajustadas a las necesidades específicas de cada sector (variables, resolución espacial/temporal, alcance, etc) con estimación de incertidumbres

¿Qué es la regionalización? (Top-down approach)



*** Las proyecciones directas de las variables superficiales a partir de los GCMs es difícil a escala subcontinental y a altas resoluciones temporales.**

*** Las técnicas de regionalización combinan salidas de GCMs con datos observacionales para mejorar la escala temporal y espacial de las proyecciones de cambio climático.**

*** Las técnicas de regionalización se conocen y se han aplicado desde los 70s y 80s en PNT:**

(i) LAMs

(ii) Técnicas de adaptación estadística basadas en regresiones lineales, p.e., MOS, Perfect Prog.

¿Por qué es necesaria la regionalización?

- **Variables de sup. adaptadas a características locales.**
- **Estimar extremos: AOGCMs "suavizan"**
- **Adaptar res. esp/temp a los modelos de impactos**

T max. (ºC) (2071-2100) SRES A2, HadAM3, INM

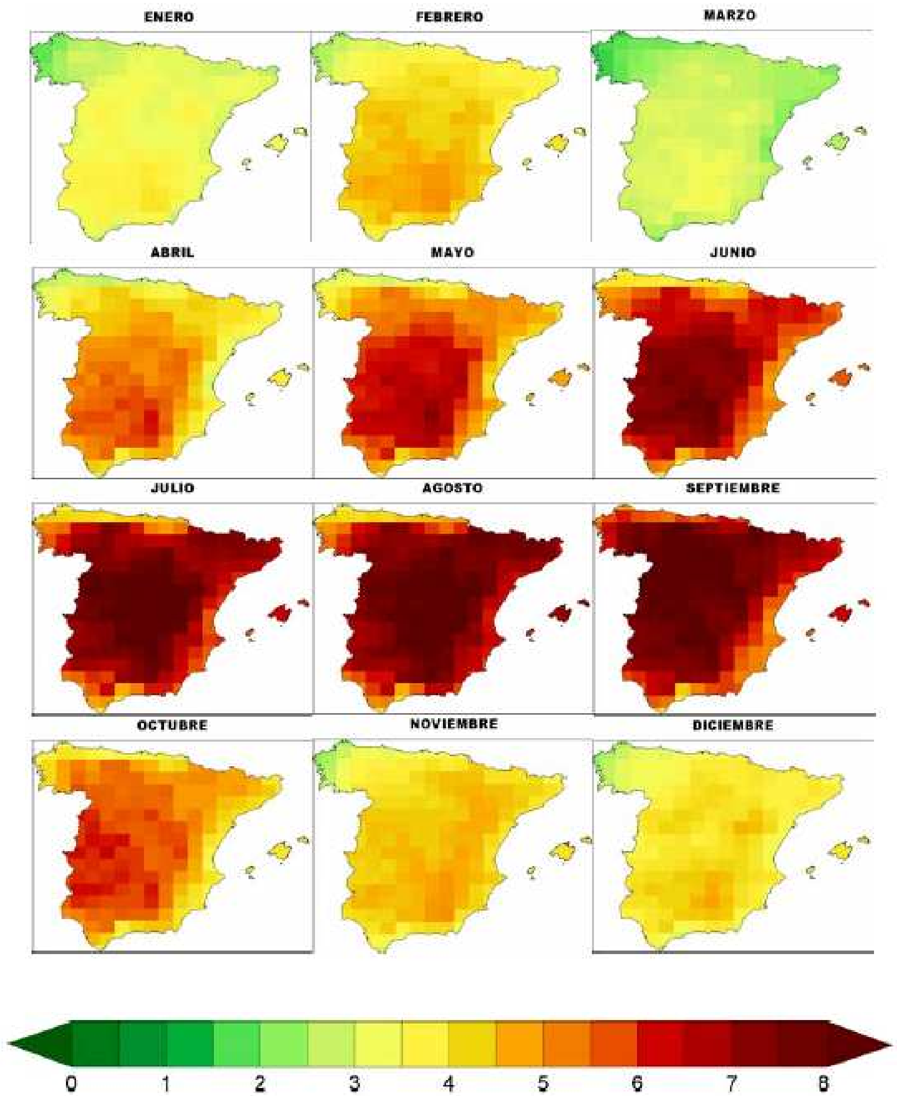
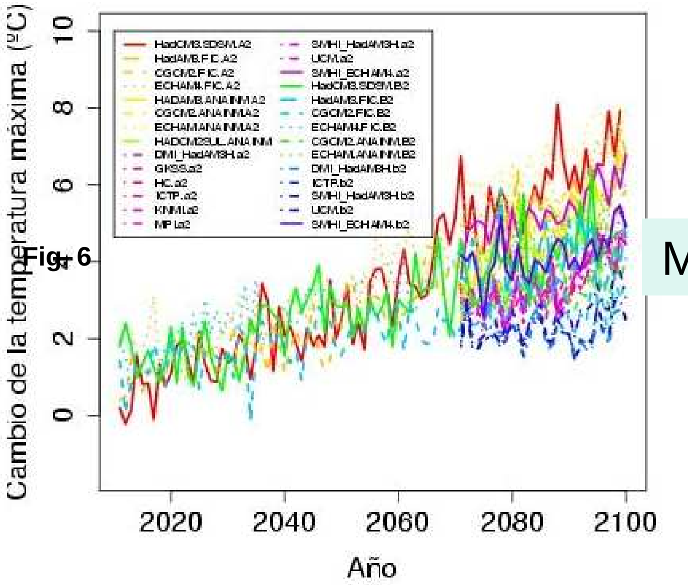


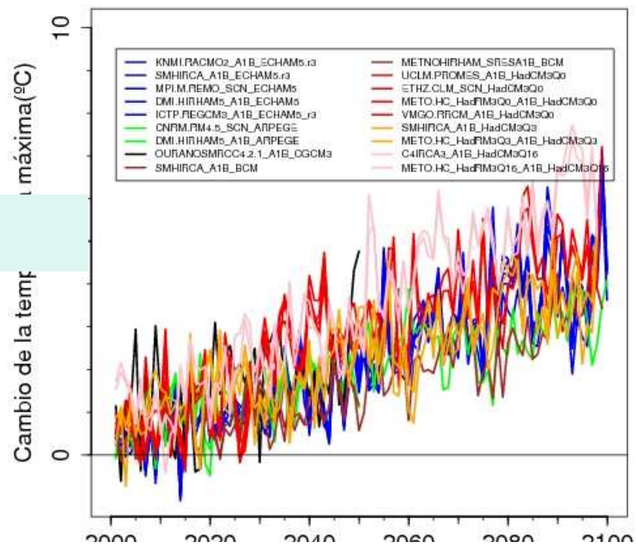
Figura 7.6.- Cambio medio mensual de temperatura máxima proyectado para el periodo (2071-2100) respecto al clima actual (1961-1990) por el modelo global HadAM3H y regionalizado con el método de análogos (INM) para el escenario de emisión A2.

(INM, 2007)

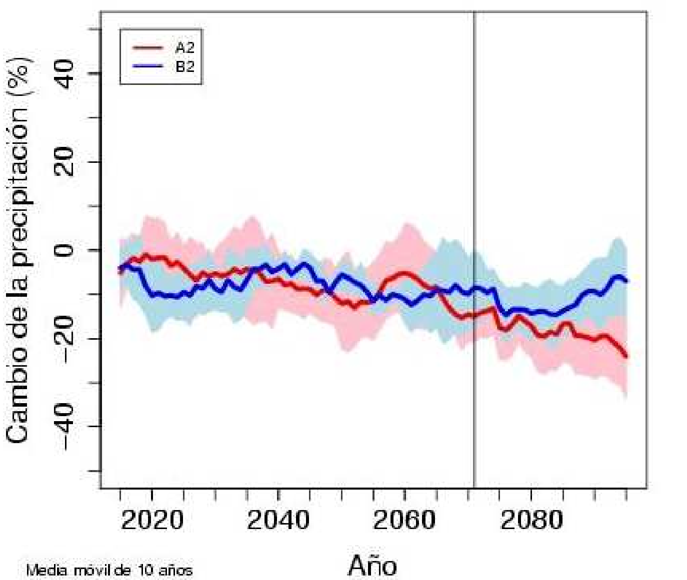
AEMET, Escenarios A2 y B2

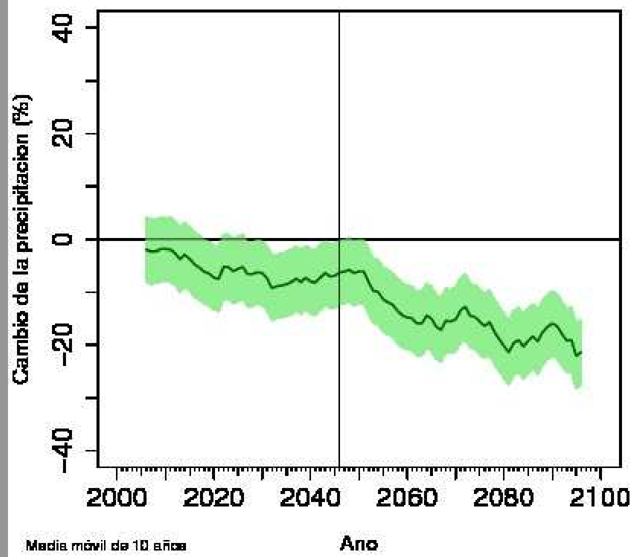
ENSEMBLES, Escenario A1B



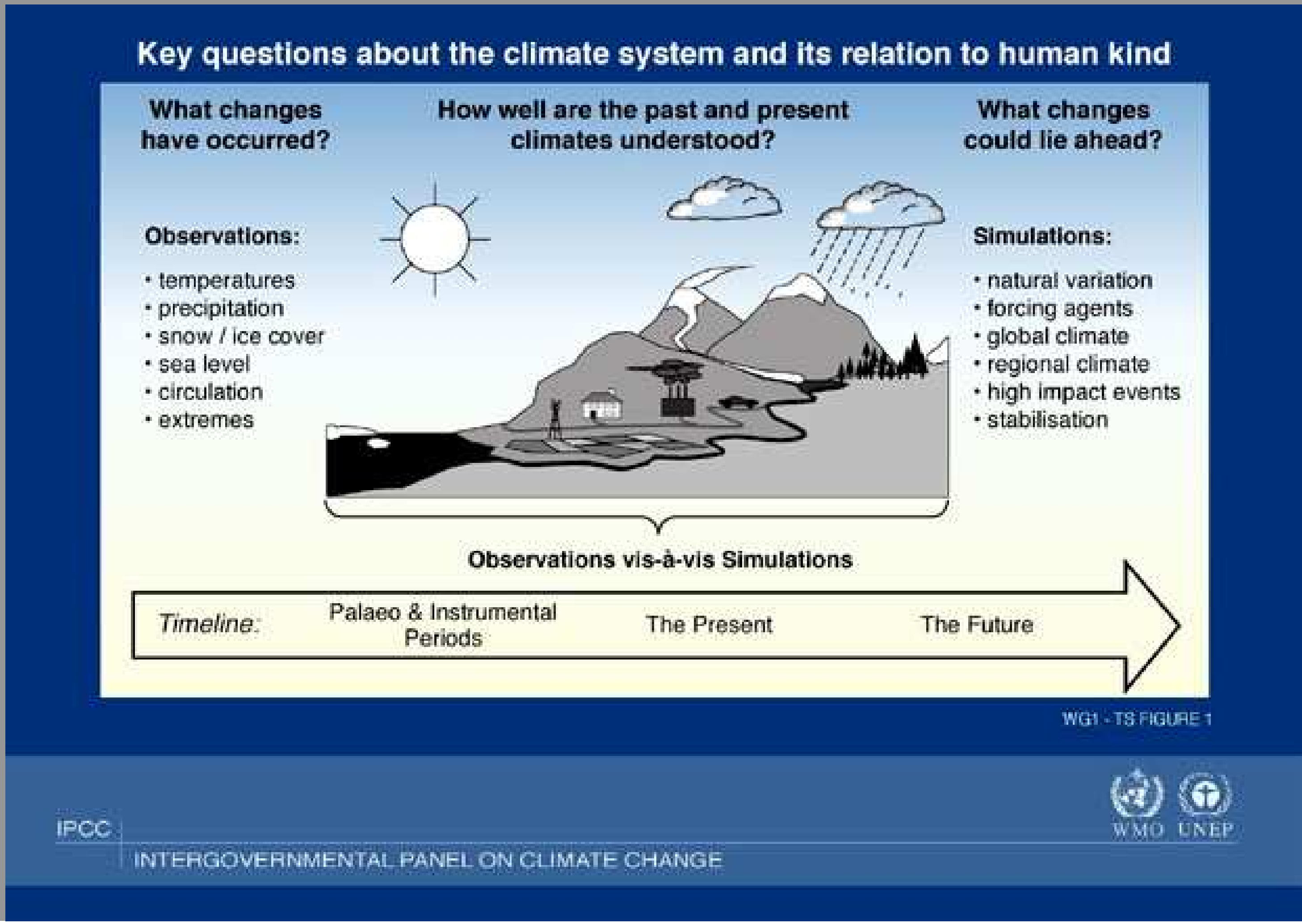


Más en http://www.aemet.es





What if? → Simulations



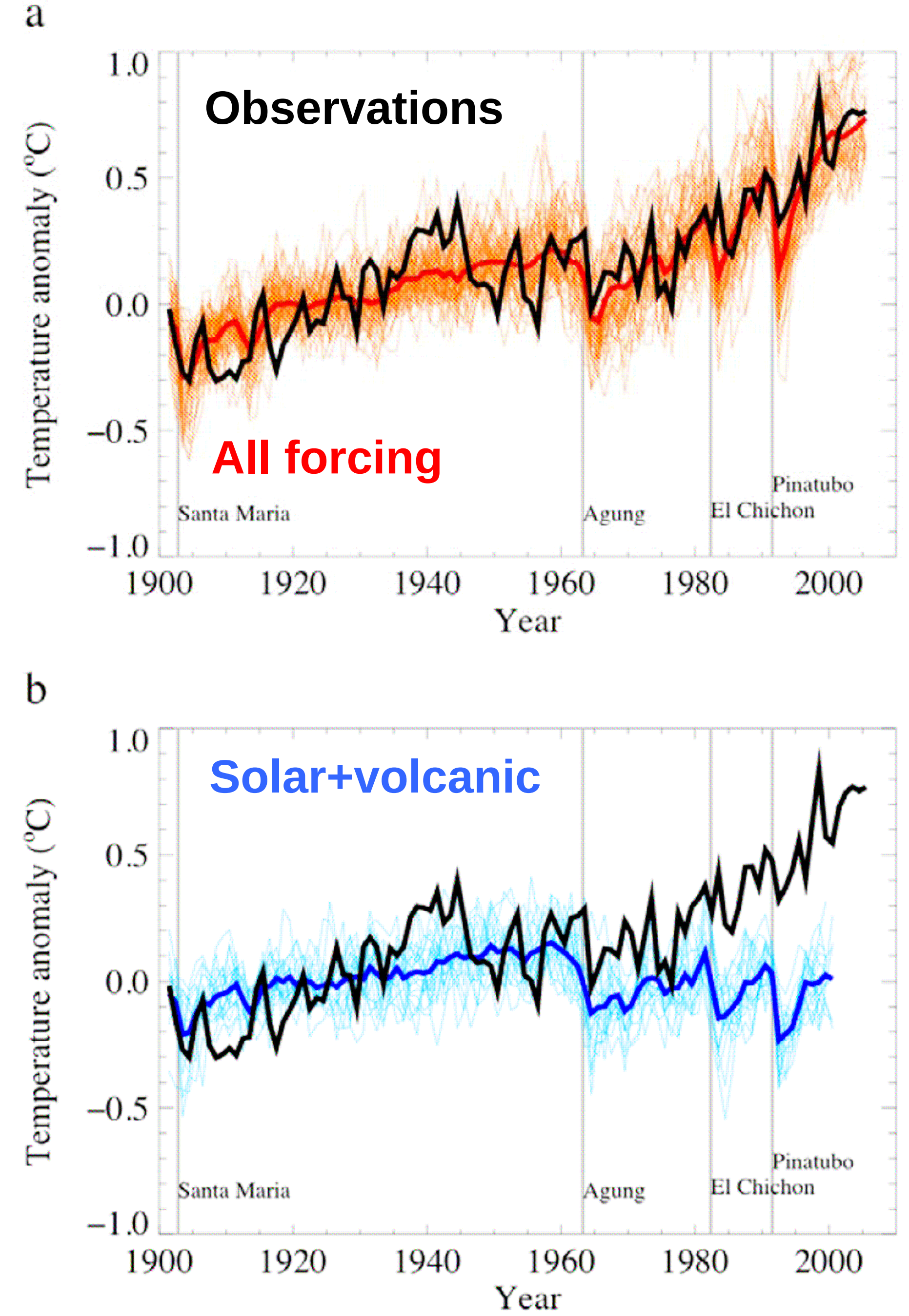
Attribution: cause(s) of global warming

How reliable are the models?

- are observed changes consistent with

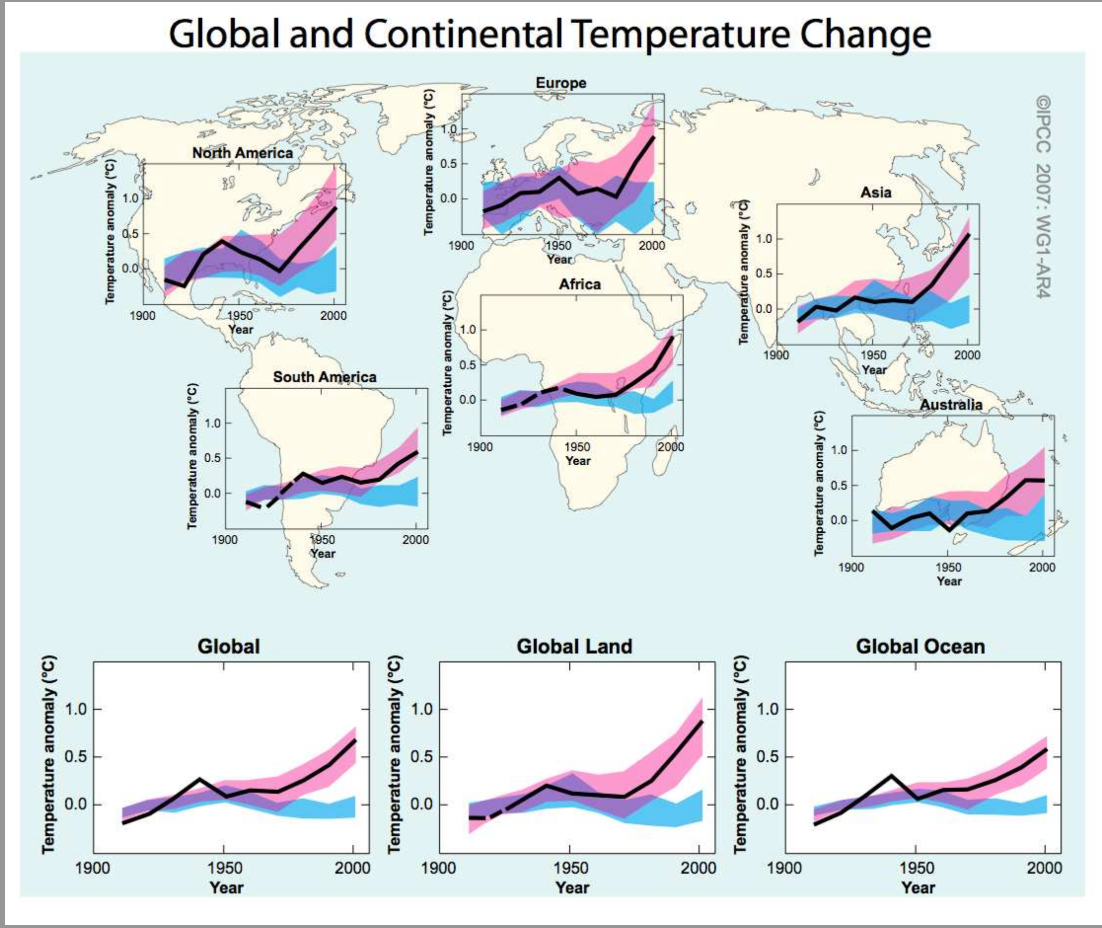
☑ expected responses to forcings

☒ inconsistent with alternative explanations

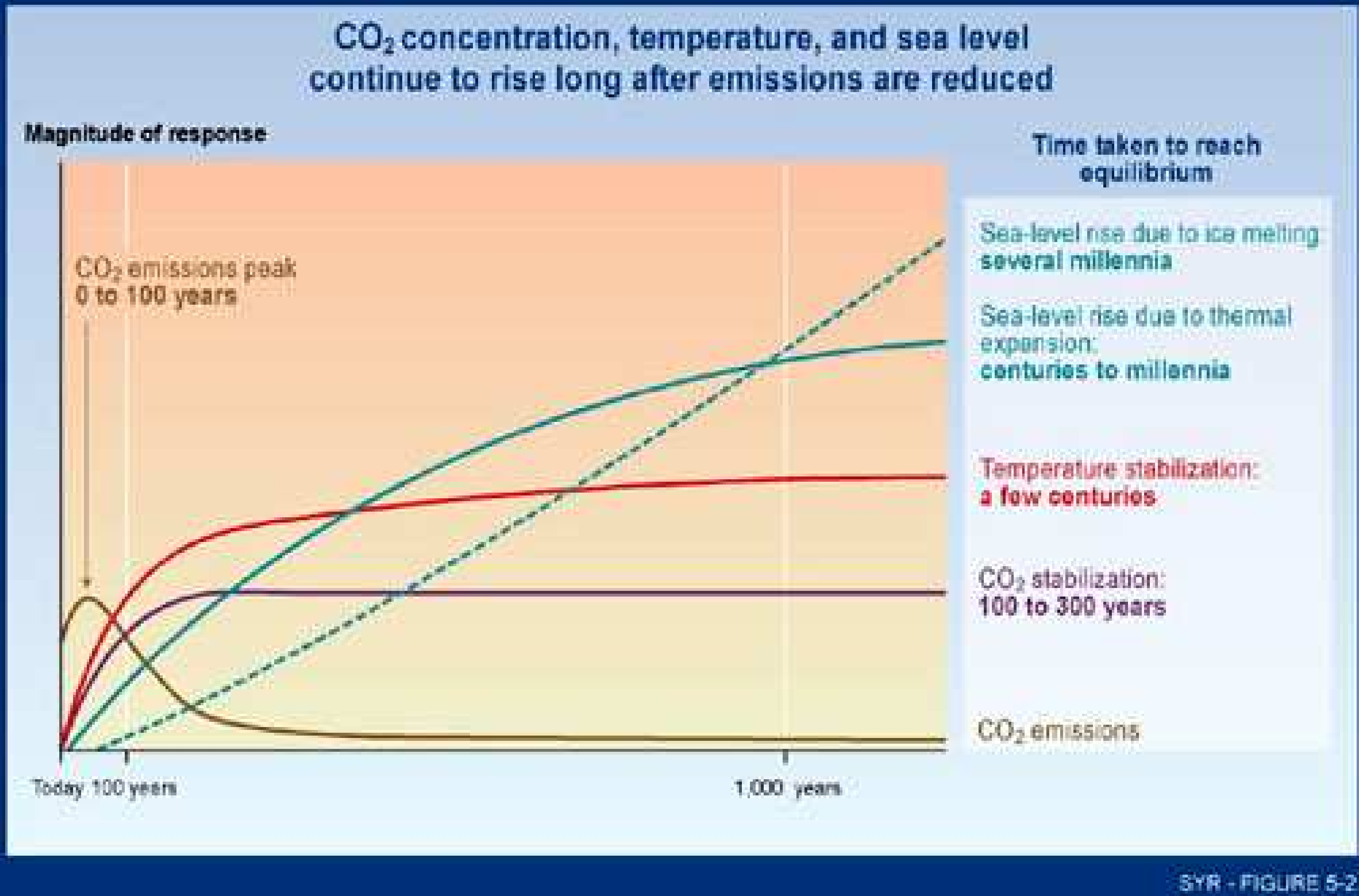


Understanding and Attributing Climate Change

Warming very probably (90%) of anthropogenic origin



Inercia del sistema climático

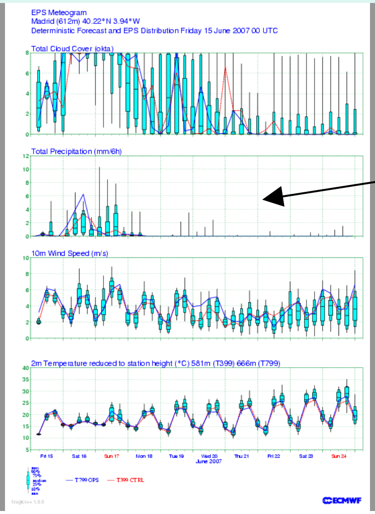


Necesidad de estrategias de adaptación!!

Uncertainties in climate change projections

- Natural forcing (sun, volcanoes)
- GHG emissions ⇦
- GHG concentrations
- AOGCM differences ⇦
- Internal variability (IC dependency)
- Downscaling techniques ⇦
- Tipping points

UNCERTAINTY DOESN'T MEAN TOTAL LACK OF KNOWLEDGE!!



- The uncertainty studies are something relatively new in atmospheric sciences. Only recently uncertainty (probabilistic approach) was introduced in our forecasts/projections
- Dealing with lack of knowledge and uncertainties → a task for risk management

Cascade of uncertainties

Timothy D. Mitchell and Mike Hulme

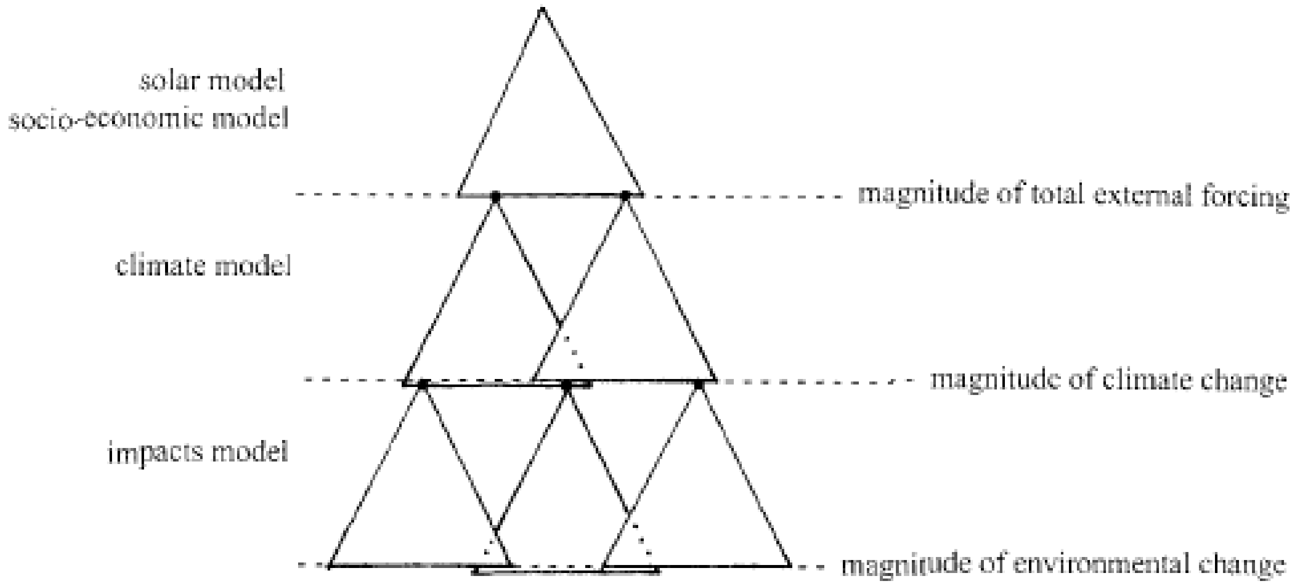
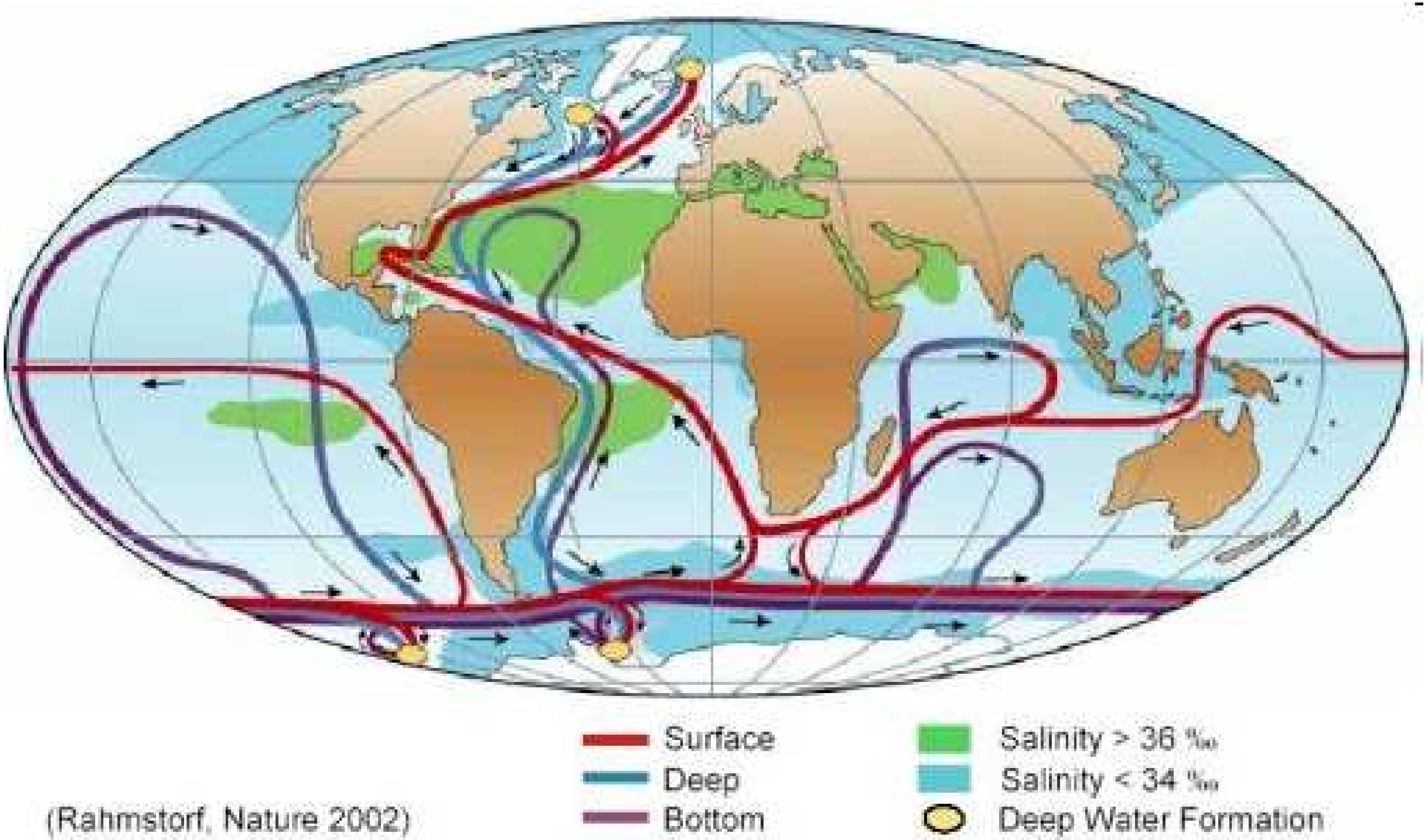


Figure 4 The magnitude of external radiative forcing is uncertain and so is presented as a range of possibilities in the top triangle. Two of these possibilities are selected as the starting points from which is presented the uncertainty concerning the magnitude of the climatic response. Thus we find that the cascade of uncertainties ultimately presents us with a wide variety of possible environmental futures at the base of the lowest triangles

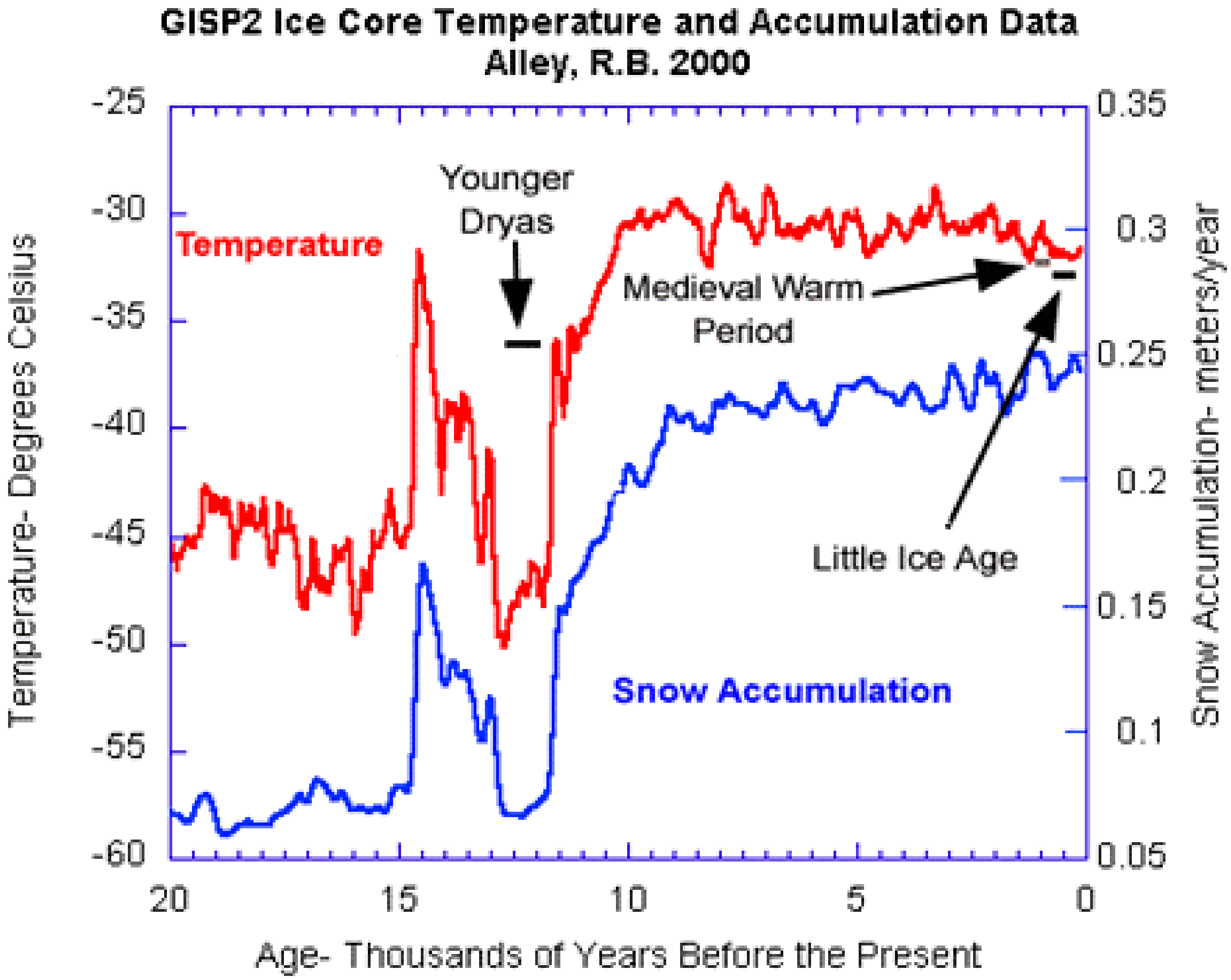
Wallace S. Broecker (1987)

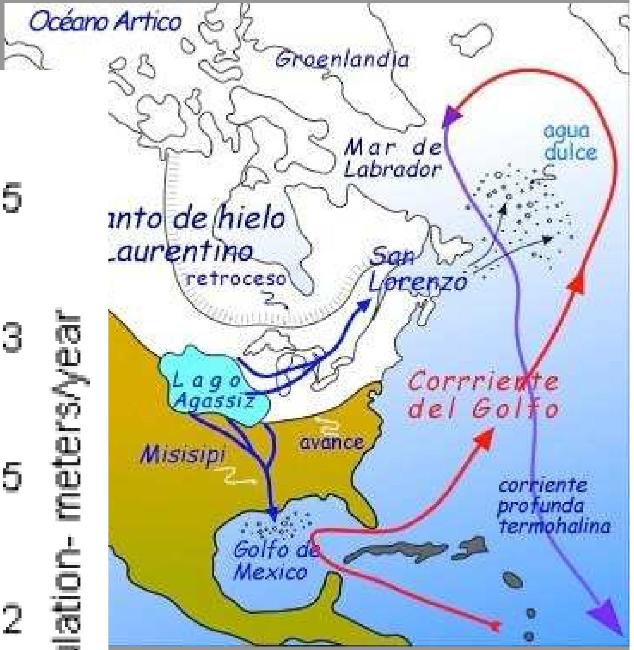
- He connected the evidence of relatively rapid changes in climate in the past to the possibility that anthropogenic climate change in the future might also trigger abrupt changes in aspects of the Earth’s climate
- Ice cores records indicate that the Earth’s climate responds in sharp jumps



(Rahmstorf, Nature 2002)

Younger dryas (12 900-11 500 BP)

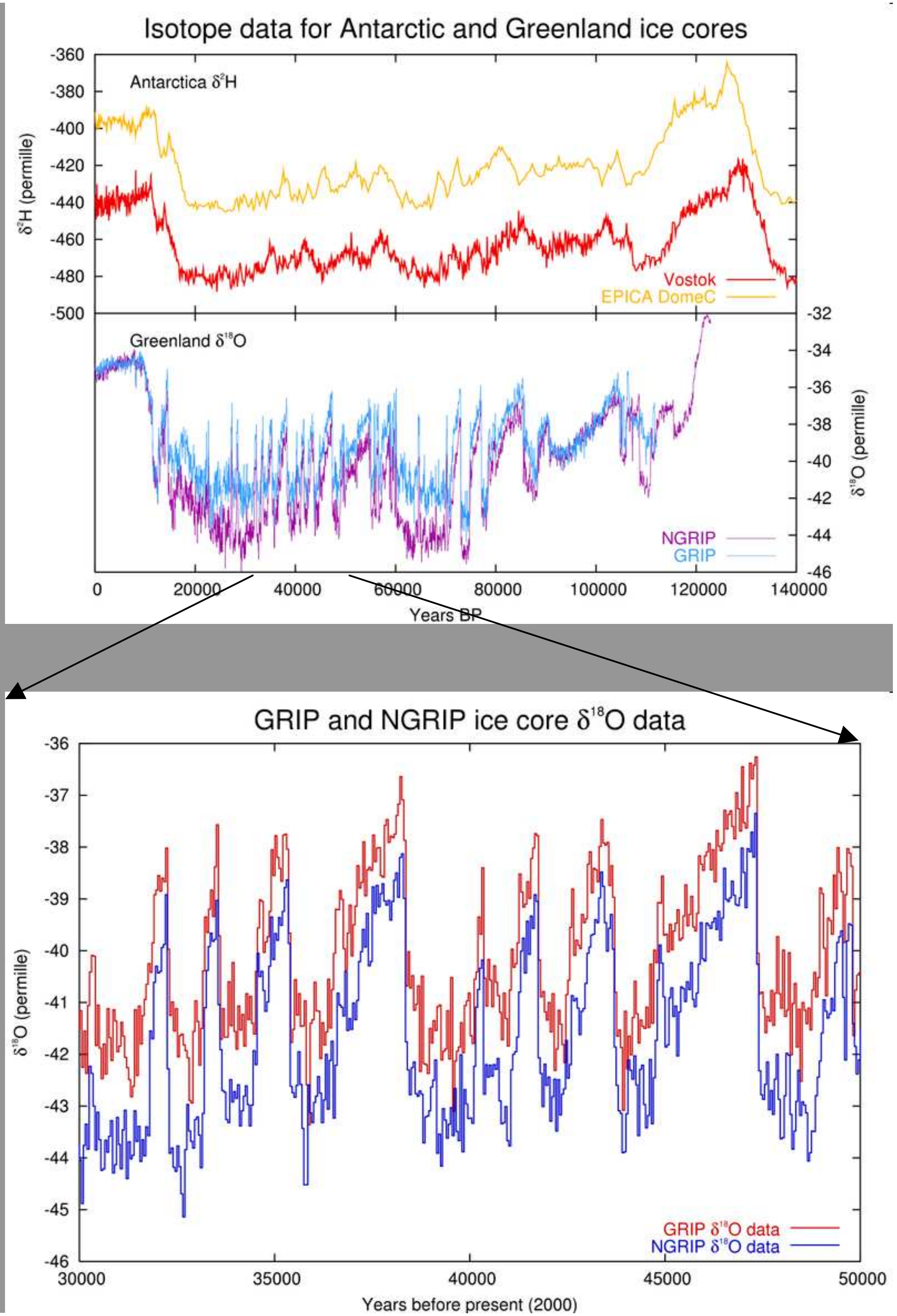


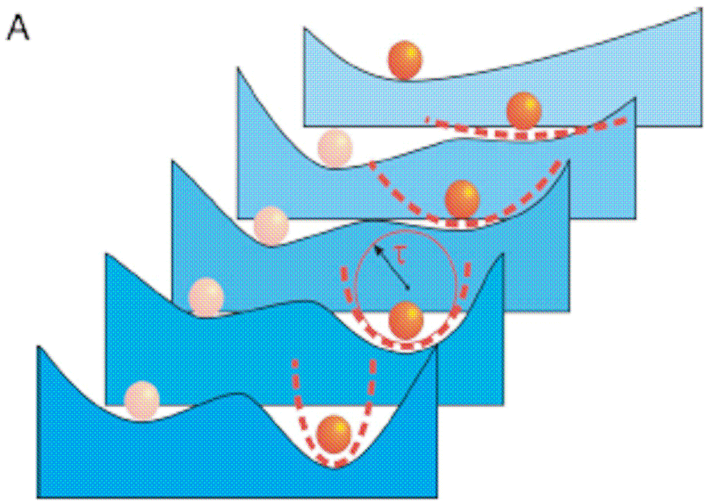


Dryas octopetala

Dansgaard-Oeschger events

- 25 times during the last glacial period
- Events occur quasi-periodically with a recurrence time being a multiple of 1,470 years
- The best evidence remains in the Greenland ice cores.
- The events appear to reflect changes in the North Atlantic ocean circulation, perhaps triggered by an influx of fresh water



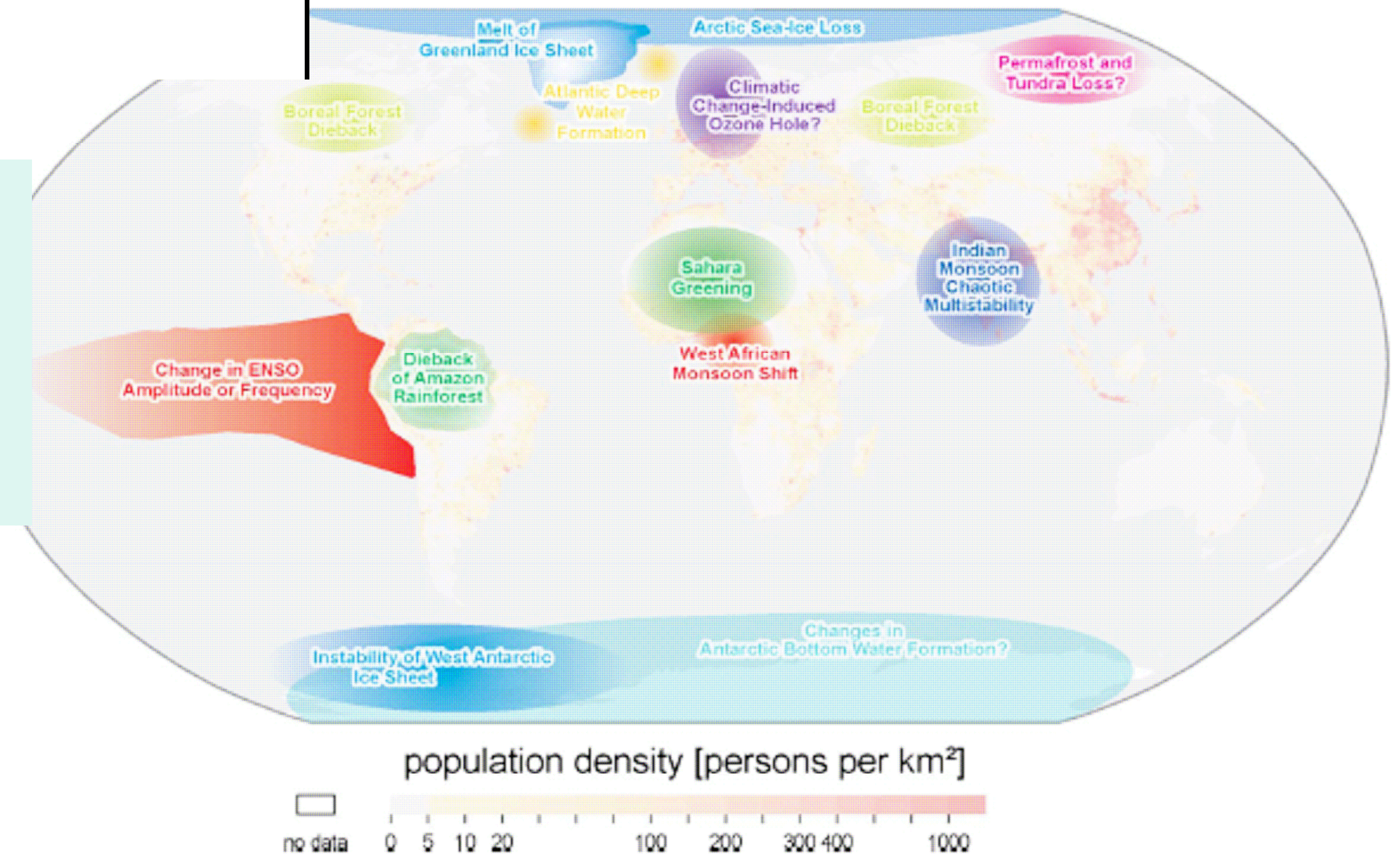


"Tipping points"

sobrepasables este siglo

Small changes can produce big long term effects

Ex.: forced convection!!



(Lenton et al., 2008)

Tipping points (II)

Tipping element	Feature of system, F (direction of change)	Control parameter(s), ρ	Critical value(s),[†] ρ_{crit}	Global warming[†‡]	Transition timescale,[†] T	Key impacts
Arctic summer sea-ice	Areal extent (−)	Local ΔT_{air}, ocean heat transport	Unidentified[§]	+0.5–2°C	~10 yr (rapid)	Amplified warming, ecosystem change
Greenland ice sheet (GIS)	Ice volume (−)	Local ΔT_{air}	+~3°C	+1–2°C	>300 yr (slow)	Sea level +2–7 m
West Antarctic ice sheet (WAIS)	Ice volume (−)	Local ΔT_{air}, or less ΔT_{ocean}	+~5–8°C	+3–5°C	>300 yr (slow)	Sea level +5 m
Atlantic thermohaline circulation (THC)	Overturning (−)	Freshwater input to N Atlantic	+0.1–0.5 Sv	+3–5°C	~100 yr (gradual)	Regional cooling, sea level, ITCZ shift
El Niño–Southern Oscillation (ENSO)	Amplitude (+)	Thermocline depth, sharpness in EEP	Unidentified[§]	+3–6°C	~100 yr (gradual)	Drought in SE Asia and elsewhere
Indian summer monsoon (ISM)	Rainfall (−)	Planetary albedo over India	0.5	N/A	~1 yr (rapid)	Drought, decreased carrying capacity
Sahara/Sahel and West African monsoon (WAM)	Vegetation fraction (+)	Precipitation	100 mm/yr	+3–5°C	~10 yr (rapid)	Increased carrying capacity
Amazon rainforest	Tree fraction (−)	Precipitation, dry season length	1,100 mm/yr	+3–4°C	~50 yr (gradual)	Biodiversity loss, decreased rainfall
Boreal forest	Tree fraction (−)	Local ΔT_{air}	+~7°C	+3–5°C	~50 yr (gradual)	Biome switch
Antarctic Bottom Water (AABW)*	Formation (−)	Precipitation–Evaporation	+100 mm/yr	Unclear[¶]	~100 yr (gradual)	Ocean circulation, carbon storage
Tundra*	Tree fraction (+)	Growing degree days above zero	Missing[‖]	—	~100 yr (gradual)	Amplified warming, biome switch
Permafrost*	Volume (−)	$\Delta T_{permafrost}$	Missing[‖]	—	<100 yr (gradual)	CH_4 and CO_2 release
Marine methane hydrates*	Hydrate volume (−)	$\Delta T_{sediment}$	Unidentified[§]	Unclear[¶]	10^3 to 10^5 yr (>T_E)	Amplified global warming
Ocean anoxia*	Ocean anoxia (+)	Phosphorus input to ocean	+~20%	Unclear[¶]	~10^4 yr (>T_E)	Marine mass extinction
Arctic ozone*	Column depth (−)	Polar stratospheric cloud formation	195 K	Unclear[¶]	<1 yr (rapid)	Increased UV at surface

(Lenton et al., 2008)

Tipping element	Feature of system, F (direction of change)	Control parameter(s), ρ	Critical value(s),† ρ_{crit}	Global warming†‡	Transition timescale,† T	Key impacts
Amazon rainforest	Tree fraction (−)	Precipitation, dry season length	1,100 mm/yr	+3–4°C	≈50 yr (gradual)	Biodiversity loss, decrease rainfall

Effects of thermokarst on a railway track.
Photo: US Geological Survey

Tipping element	Feature of system, F (direction of change)	Control parameter(s), ρ	Critical value(s),† ρ_{crit}	Global warming†‡	Transition timescale,† T	Key impacts
Permafrost*	Volume (−)	$\Delta T_{permafrost}$	Missing‖	—	<100 yr (gradual)	CH_4 and CO_2 release

No todos los “tipping points” muestran la misma sensibilidad e incertidumbre

Sensibilidad alta e incertidumbre pequeña

- Hielo marino ártico
- Hielo en Groenlandia

Sensibilidad baja e incertidumbre intermedia

- Circulación termohalina

Sensibilidad intermedia y alta incertidumbre → sorpresas

- Hielo en Antártida Occ.
- Colapso bosques boreales
- Colapso selva amazónica
- ENSO
- Monzón África Occ.

¿Qué podemos hacer? (I)

- Inercia del sistema climático → algunos cambios son inevitables → **actuación sobre los efectos → ADAPTACION**
- El calentamiento se produce por emisiones GEI → a más emisiones, mayor calentamiento → **actuación sobre las causas → MITIGACION** (cambio modelo energético, usos de suelo (deforestación), demografía, desarrollo sostenible, …)
- Mejorar el conocimiento del sistema climático: **INVESTIGACION**

¿Qué podemos hacer? (II)

- **Actuación a diferentes niveles**: gobiernos, ciudades, individuos
- Aumentar el nivel de **concienciación del problema** → Influencia en la acción de individuos, ciudades, gobiernos.
- El problema del cambio climático está íntimamente **ligado a otros problemas** de la humanidad en su conjunto:
  - pobreza (demografía),
  - desarrollo sostenible,
  - modelo energético,
  - patrones de producción y consumo,
  - comercio
  - etc

Conclusiones

- Sistema climático es complejo y altamente no lineal → modelos
- Inequívoco calentamiento global
- Proyecciones probabilísticas climáticas globales → ensemble multi-modelo
- Causas: Emisiones por quema de combustibles fósiles + deforestación → Uso de modelos
- Incertidumbres → En cascada
- Posibles cambios abruptos → monitorizar

Bibliografía básica

http://www.aemet.es

¡Gracias por su atención!

http://www.ipcc.ch

http://www.marm.es