MODELOS CLIMÁTICOS

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Area de Evaluación y Modelización del Clima

Laguna Palcacocha, situada en los Andes. Peligro con el derretimiento del glaciar

Los peligros del cambio climático azotan con más fuerza a los más vulnerables. Siempre igual …. : (

¿Te vas a creer lo que diga tu líder político/ideológico? ¿O vas a pensar por tí mismo y vas buscar la verdad?

Modelos Climáticos

- El clima condiciona la vida en la Tierra y modela la naturaleza
- Necesitamos conocer el clima futuro
- Para conocerlo tenemos que entender todos los procesos interconectados que configuran el clima
- Los modelos climáticos recogen todos estos procesos y son la mejor herramienta de que disponemos para estudiar y predecir el clima del planeta

Modelos Climáticos

- **Tyndall** (1861) : Las moléculas de vapor de agua, CO_2, CH_4, N_2O, O_3, presentes en la atmósfera presentas propiedades diferentes a la absorción de radiación solar de onda corta y de radiación infrarroja. Los cambios en el clima que los geólogos encontraron se podrían haber producido por cambios en la cantidad de cualquiera de estos elementos.

- **Arrhenius** (1896) : Si la concentración de CO_2 se duplicase, se produciría una aumento en la temperatura media global en superficie de entre 4 y 5 ºC.

- **Callendar** (1938) : Señaló las emisiones antropogénicas de combustibles fósiles como las responsables de los cambios observados en el clima.

Modelos Climáticos

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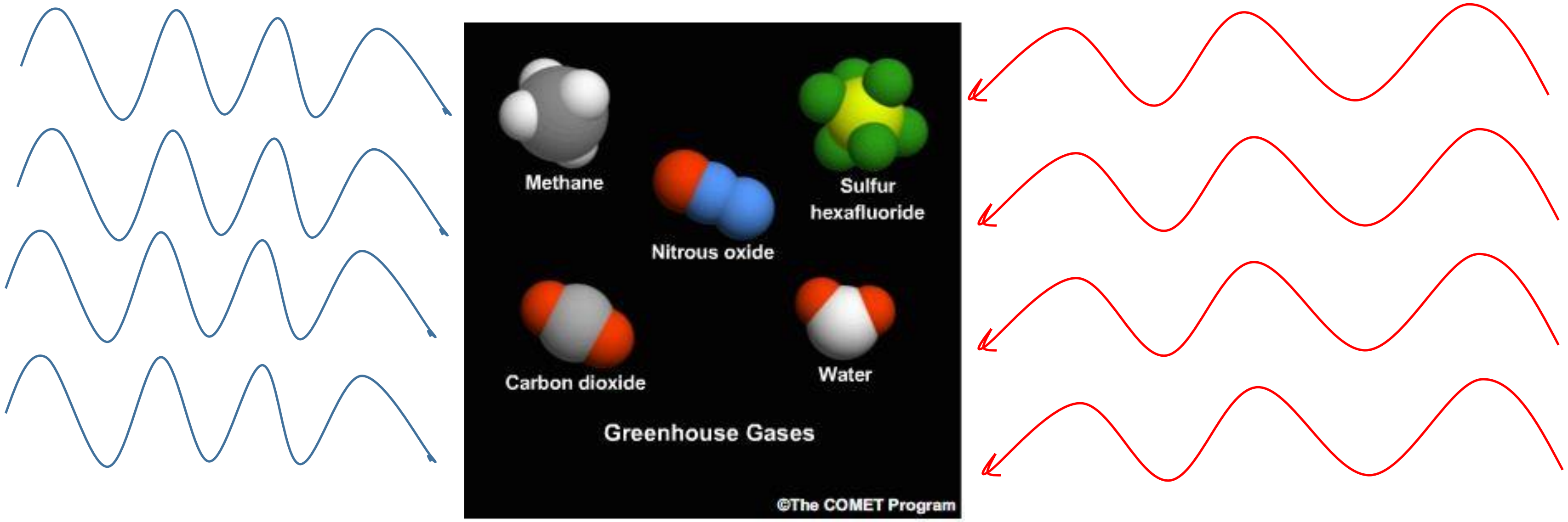
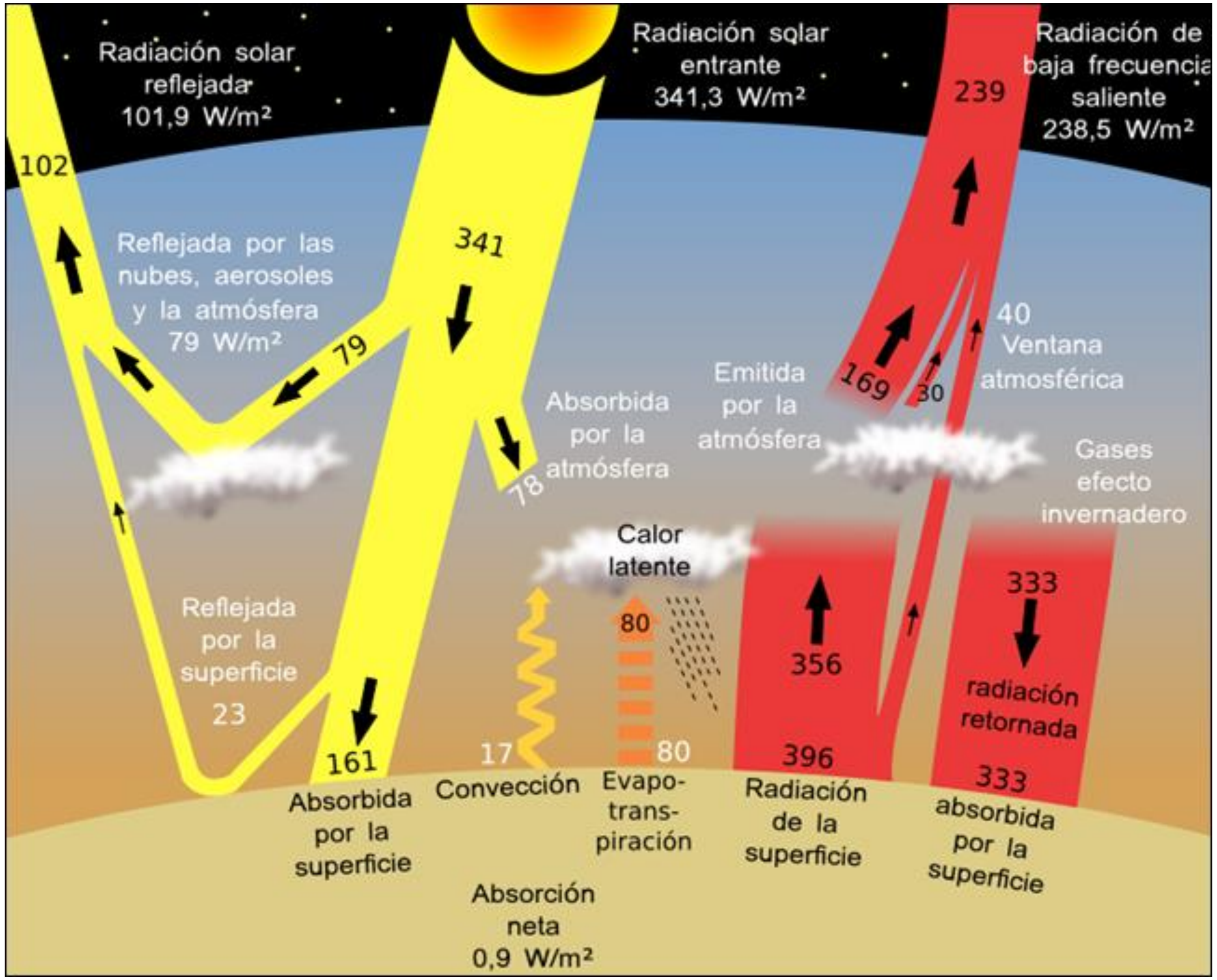


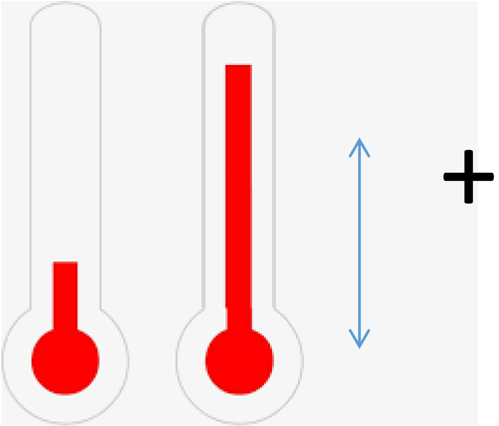


Radiación solar reflejada 101,9 W/m²
Radiación solar entrante 341,3 W/m²
Radiación de baja frecuencia saliente 238,5 W/m²
102
341
239
Reflejada por las nubes, aerosoles y la atmósfera 79 W/m²
79
40
Ventana atmosférica
169
30
Emitida por la atmósfera
Absorbida por la atmósfera
78
Gases efecto invernadero
Calor latente
80
Reflejada por la superficie 23
333
356
radiación retornada
161
17
80
396
333
Absorbida por la superficie
Convección
Evapo-trans-piración
Radiación de la superficie
absorbida por la superficie
Absorción neta 0,9 W/m²

Modelos Climáticos

- **Arrhenius** (1896) : Si la concentración de CO2 se duplicase, se produciría una aumento en la temperatura media global en superficie de entre 4 y 5 ºC.

X 2



+ 4 K

¿Primer modelo climático?

Modelos Climáticos

- **Callendar** (1938) : Señalo las emisiones antropogénicas de combustibles fósiles como las responsables de los cambios observados en el clima.

Modelos Climáticos

- Video interesante sobre el cambio climático:

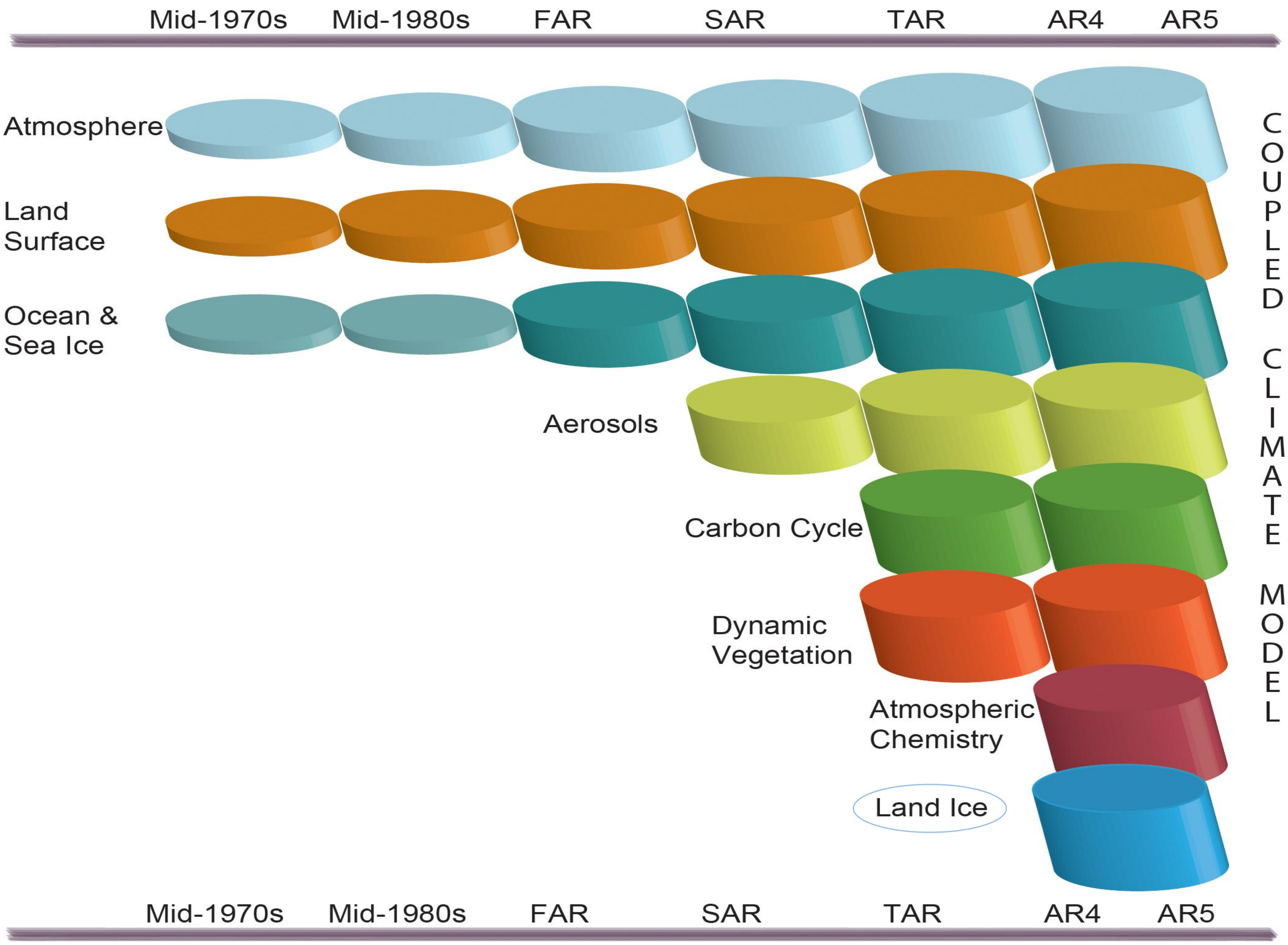
- https://www.youtube.com/watch?v=3X-Z0kMfh4M

Modelos Climáticos

- **What is a Global Climate Model?**

A global climate model (GCM) is a complex mathematical representation of the major climate system components (atmosphere, hydrosphere, land surface, cryosphere, biosphere), and their interactions. The main climate system components treated in a climate model are:

- The atmospheric component, which simulates clouds and aerosols, and plays a large role in transport of heat and water around the globe.
- The land surface component, which simulates surface characteristics such as vegetation, snow cover, soil water, rivers, and carbon storing.
- The ocean component, which simulates current movement and mixing, and biogeochemistry, since the ocean is the dominant reservoir of heat and carbon in the climate system
- The sea ice component, which modulates solar radiation absorption and air-sea heat and water exchanges



Mid-1970s
Mid-1980s
FAR
SAR
TAR
AR4
AR5
Atmosphere
Land Surface
Ocean & Sea Ice
Aerosols
Carbon Cycle
Dynamic Vegetation
Atmospheric Chemistry
Land Ice
COUPLED CLIMATE MODEL
Mid-1970s
Mid-1980s
FAR
SAR
TAR
AR4
AR5

Predicción numérica del tiempo: atmósfera, superficie terrestre, hielos marinos

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

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

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

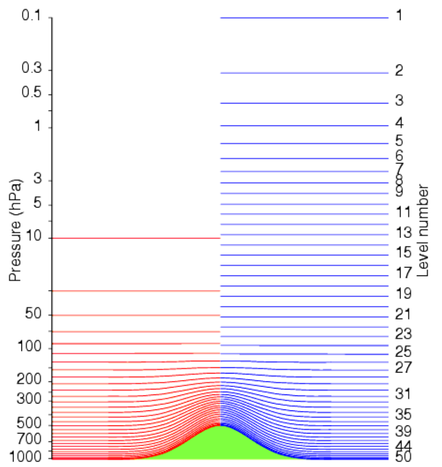
$$\frac{\partial\rho}{\partial t} = -\nabla\cdot\rho\mathbf{V}$$

$$p = R\rho T$$

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

Ecuaciones primitivas

u, v, w, p, ρ, T

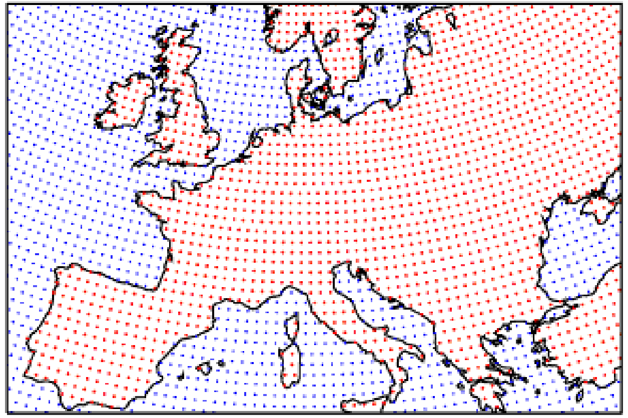


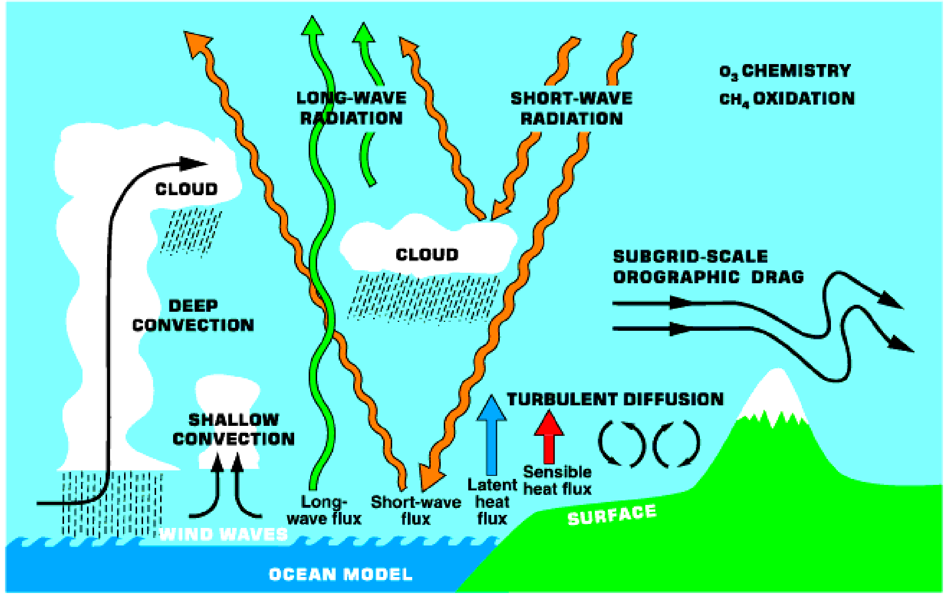
(19)

(10)

(7)

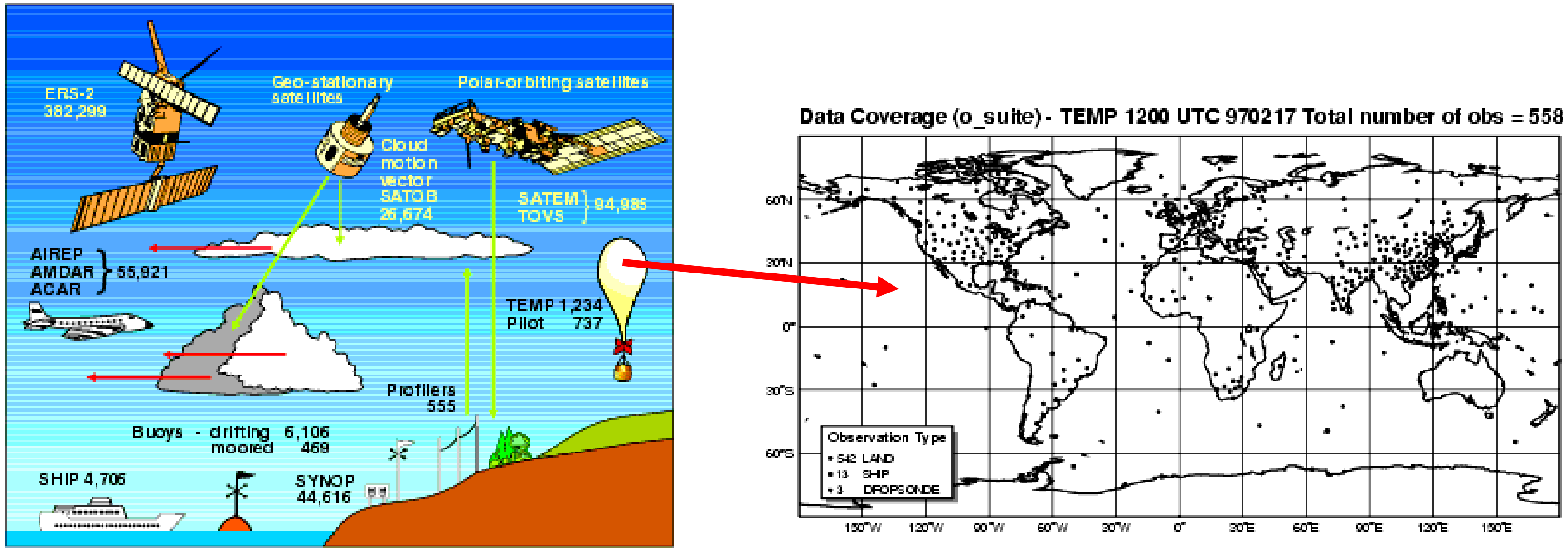
Discretización





Parametrizaciones

Predicción numérica del tiempo: condiciones iniciales

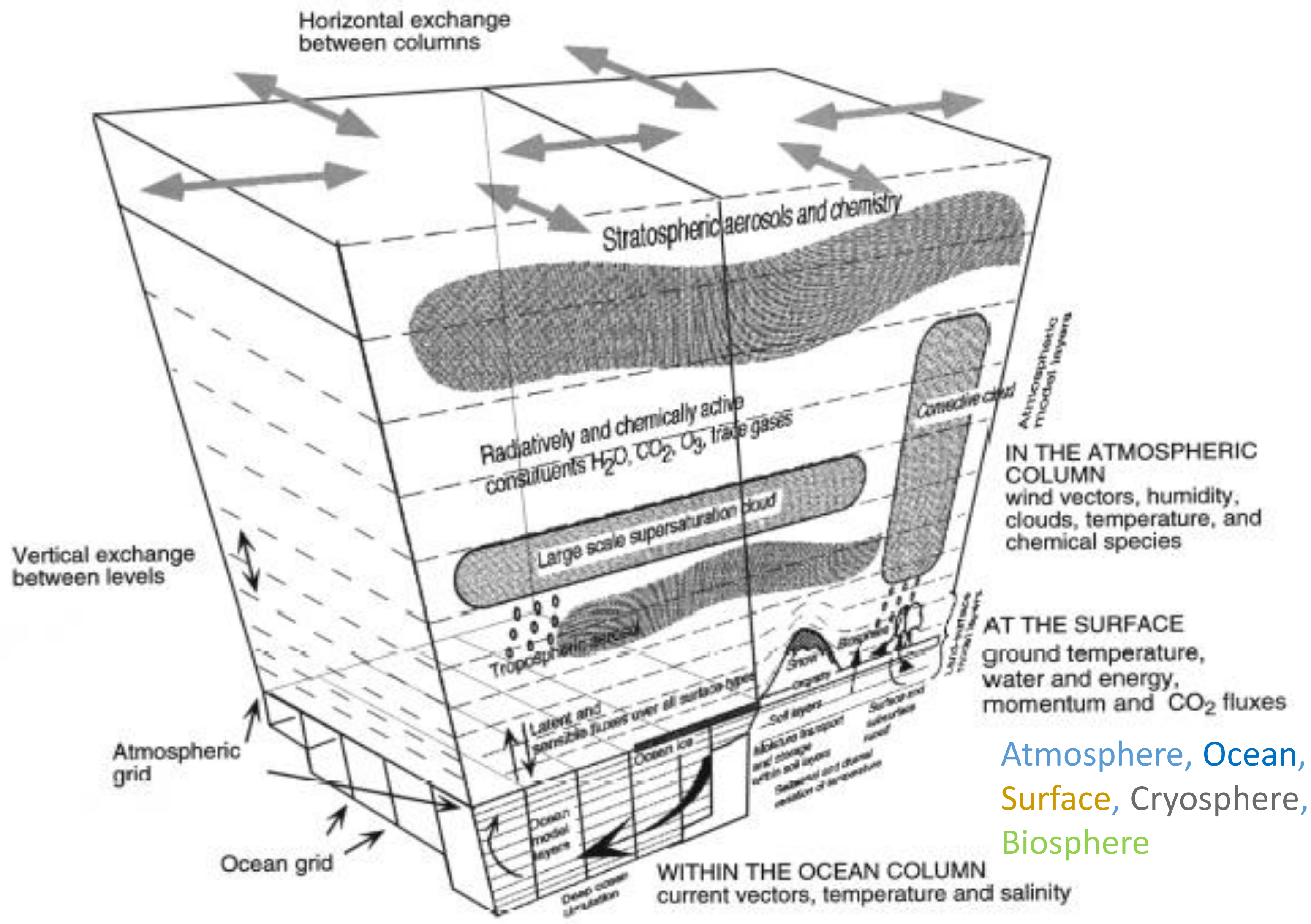


+ Algoritmo de asimilación (variables del modelo, interpolación, filtrado de escalas)

Climate models divide the globe into a three-dimensional grid of cells representing specific geographic locations and elevations.

Each of the components (atmosphere, land surface, ocean, and sea ice) has equations calculated on the global grid for a set of climate variables such as temperature.

In addition to model components computing how they are changing over time, the different parts exchange fluxes of heat, water, and momentum. They interact with one another as a coupled system



Atmosphere, Ocean, Land Surface, Cryosphere, Biosphere

Figure 8. Illustration of the basic characteristics and processes within a GCM, showing the manner in which the atmosphere and ocean are split into columns. Both atmosphere and ocean are modelled as a set of interacting columns distributed across the Earth's surface. The resolutions of the atmosphere and ocean models are often different because the processes differ and have different time-scales and equilibration times. Typically, many types of cloud and land surface are treated. In this example, soil moisture is modelled in a number of layers and tropospheric and stratospheric aerosols are included (redrawn from *A Climate Modelling Primer*, by K McGuffie and A Henderson-Sellers, 1997, reproduced by permission of John Wiley & Sons, Ltd)

Modelos Climáticos. Resolution

- In 2001, the resolution of the atmospheric part of a typical model was about 250 km in the horizontal and about 1 km in the vertical above the boundary layer. The resolution of a typical ocean model was about 200 to 400 m in the vertical, with a horizontal resolution of about 125 to 250 km.
- In 2020, the resolution of a global climate model can be 25 Km aprox.
- The regional climate models (RCM) nested in global climate models (GCM) run up to 2.5 Km in non-hydrostatic mode!!! This allows to study the extreme precipitation associated to convective storms. These phenomena influences the local climate.

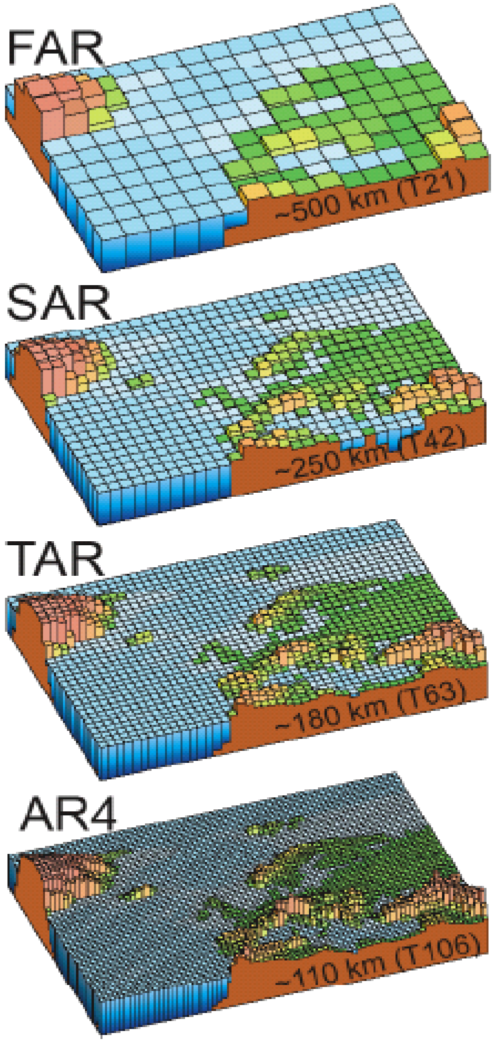
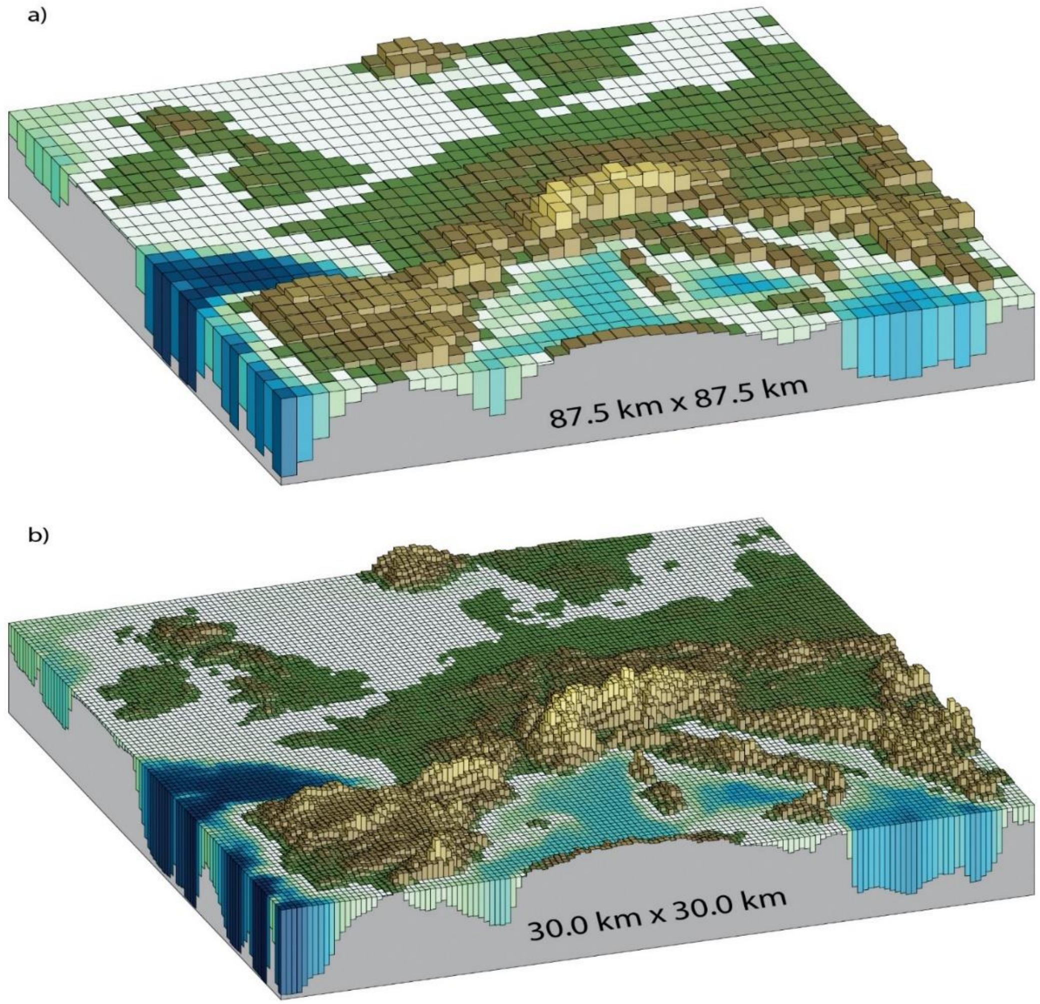
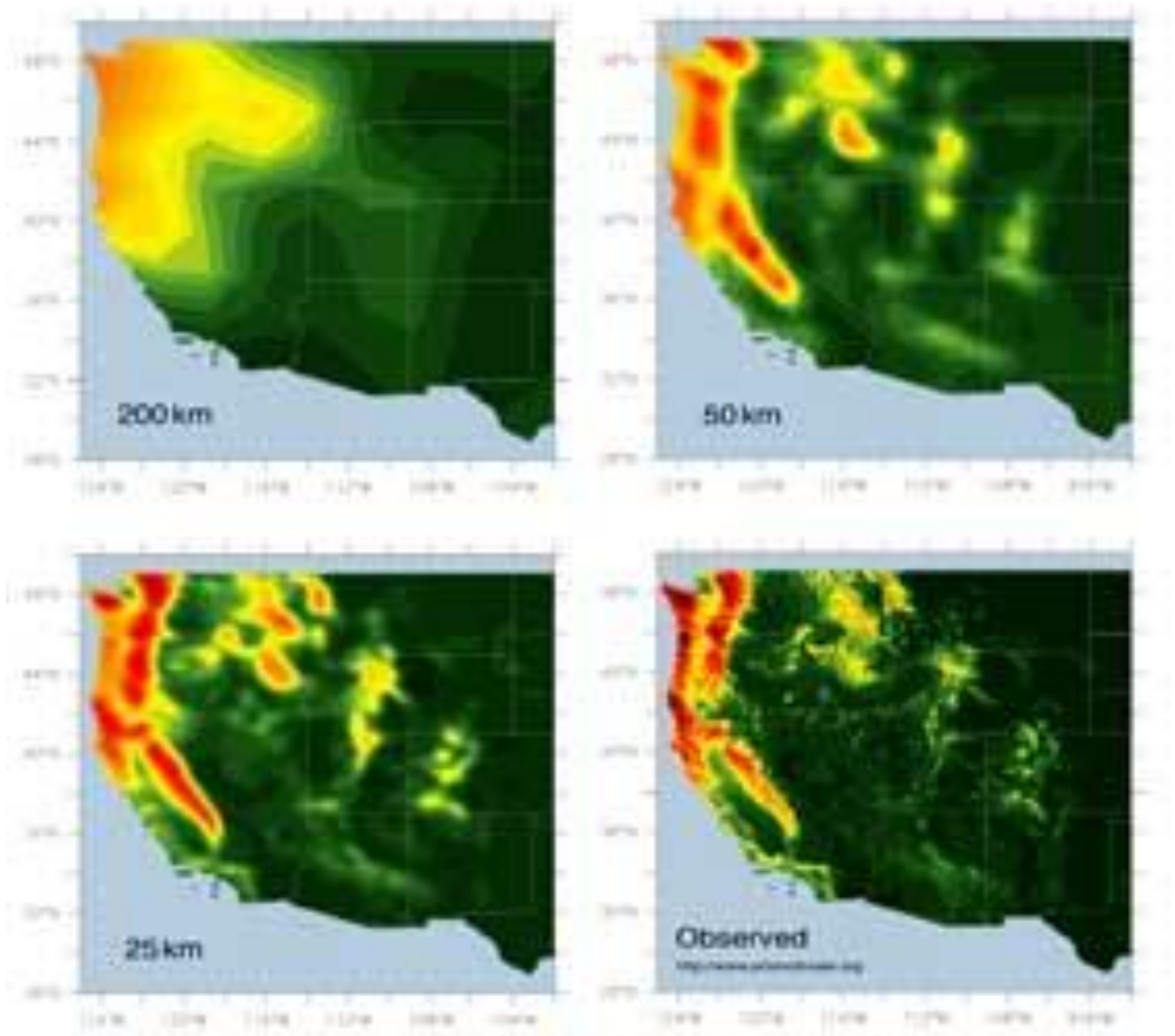


Figure 1.4. Geographic resolution characteristic of the generations of climate models used in the IPCC Assessment Reports: FAR (1990), SAR (1996), TAR (2001), and AR4 (2007). The figures above show how successive generations of these global models increasingly resolved northern Europe. These illustrations are representative of the most detailed horizontal resolution used for short-term climate simulations. The century-long simulations cited in IPCC Assessment Reports after the FAR were typically run with the previous generation's resolution. Vertical resolution in both atmosphere and ocean models is not shown, but it has increased comparably with the horizontal resolution, beginning typically with a single-layer slab ocean and ten atmospheric layers in the FAR and progressing to about thirty levels in both atmosphere and ocean.





Current model resolution (200 km) compared to high-resolution models (50 km and 25 km) and observed data

Figure 1.14 | Horizontal resolutions considered in today's higher resolution models and in the very high resolution models now being tested: (a) Illustration of the European topography at a resolution of 87.5 × 87.5 km; (b) same as (a) but for a resolution of 30.0 × 30.0 km.

Modelos Climáticos

- Types of Models

The simplest EBMs (Energy Balance Model) represent the flux of energy in and out of the climate system as a whole but do not represent components of the climate system or Earth's geography.

Radiative-convective models have into account the radiative properties of the atmosphere and simulate the vertical profile of T under the assumption of radiative-convective equilibrium

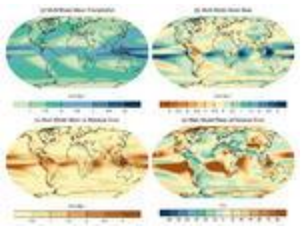
EMICs (Earth Model of Intermediate Complexity) do represent climate system components as well as Earth's geography, but often in a relatively coarse and simplified way.

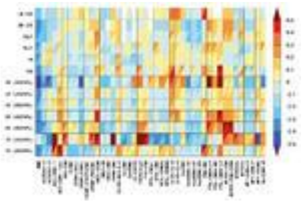
GCMs (AGCMs, AOGCMs) are characterized by their higher resolution and by their explicit representation of a wide range of atmospheric and oceanic processes.

The latest generation of complex climate models, Earth system models (ESMs), are akin to GCMs but also represent biogeochemical processes that are relevant to climate change.

Another important kind of climate model is the regional climate model (RCM). RCMs have a higher resolution than the typical 100 km resolution of GCMs and ESMs, but the domains of RCMs cover only portions of the globe.

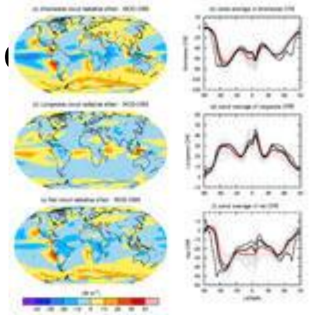
Modelos Climáticos



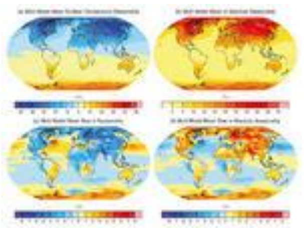


- **What Are Their Uses?**

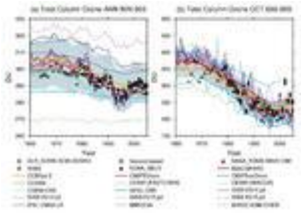
GCMs are important tools that enable us to improve the understanding and prediction
atmosphere, ocean, and climate behavior



- Models allow us to determine the distinct influence of different climate features by providing a way of exploring climate sensitivities with experiments that cannot be performed on the actual Earth.
- Changes can be made to one feature in a climate model, such as warming or cooling ocean surface temperatures, to discern the impact those changes have on the climate.
- The uses for climate modeling also include diagnosis and prognosis. An example of a diagnostic use is detection and attribution. Detection and attribution require first demonstrating that a detected change is statistically significant, and then attributing this change to unnatural causes such as the role of anthropogenic forcing in 20th century climate change.

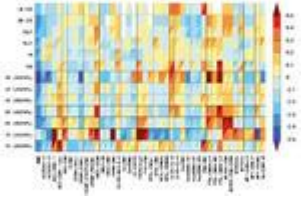


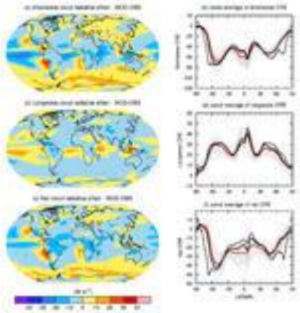
- Prognostic climate modeling predicts future climate, such as global warming trends, using current or historic data (ocean structure, radiative forcing, etc) as a basis. Timescales for projection include seasonal/interannual variability, decadal prediction, and 21st century scenarios.



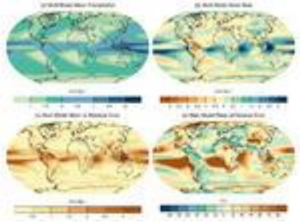
Note: Global climate is highly variable, which implies that there is much more to understand than just climate change!

Modelos Climáticos

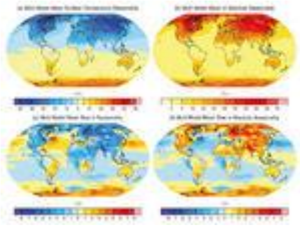




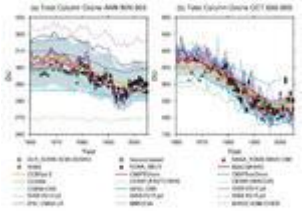
- **What Are Their Uses?**
- **Short-Term Predictions Using Climate Models**



- **Weather prediction**: Since the TAR (Third Assesment Report), it has been shown that climate models can be integrated as weather prediction models if they are initialised appropriately, due to improvements in the forecast model analyses and increases in the climate model spatial resolution.



- Some of the sub-grid scale physical processes that are parametrized in models (e.g., cloud formation, convection) can be evaluated on time scales characteristic of those processes, without the complication of feedbacks from these processes altering the underlying state of the atmosphere. Some of the biases found in climate simulations are also evident in the analysis of their weather forecasts. Improvements in weather forecast models may lead also to better climate predictions
- **Seasonal prediction:** provides a direct test of a model's ability to represent the physical and dynamical processes controlling (unforced) fluctuations in the climate system.



- Satisfactory prediction of variations in key climate signals such as ENSO and its global teleconnections provides evidence that such features are realistically represented in long term forced climate simulations.

Modelos Climáticos. How to use them

- **What Are Their Uses?**
- **Long-Term Predictions Using Climate Models**
- **Climate Change Projections**: A strategy has been designed for carrying out climate experiments that removes much of the effects of some model errors on results. What is often done is that first a "control" climate simulation is run with the model. Then, the climate change experiment simulation is run, for example, with increased CO_2 in the model atmosphere. Finally, the difference is taken to provide an estimate of the change in climate due to the perturbation. The differencing technique removes most of the effects of any artificial adjustments in the model, as well as systematic errors that are common to both runs. However, a comparison of different model results makes it apparent that the nature of some errors still influences the outcome.
- **Ensembles**: Many aspects of the Earth's climate system are chaotic. Its evolution is sensitive to small perturbations in initial conditions. This sensitivity limits predictability of the detailed evolution of weather to about two weeks. However, predictability of climate is not so limited because of the systematic influences on the atmosphere of the more slowly varying components of the climate system (Annual cycle, radiative forcings). Nevertheless, to be able to make reliable forecasts in the presence of both initial condition and model uncertainty, it is desirable to repeat the prediction many times from different perturbed initial states and using different global models. These ensembles are the basis of probability forecasts of the climate state

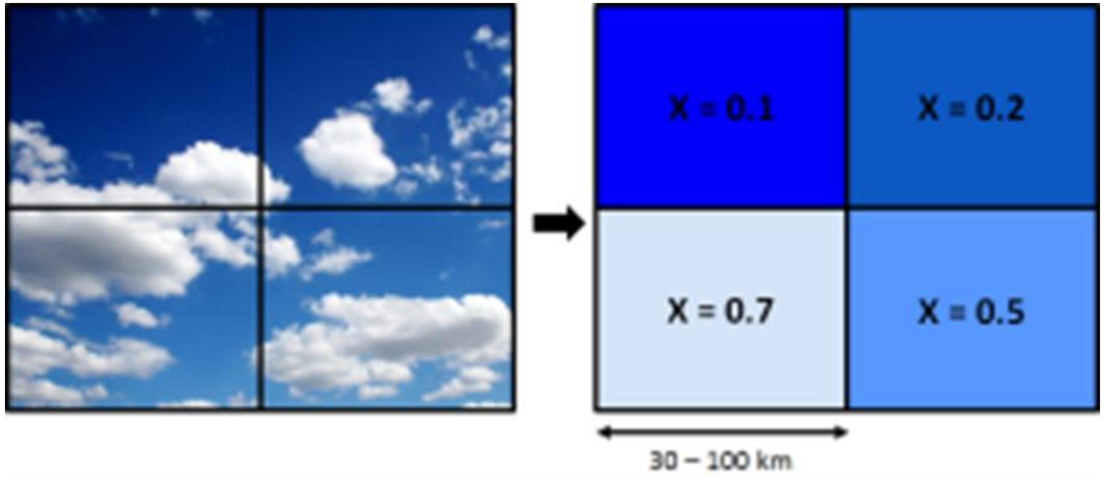
Modelos Climáticos

- **Simulated/Parameterized Processes:**

There are two types of processes within climate models that are used today: simulated and parameterized.

Simulated processes are larger than grid-scale and based on bedrock scientific principles (conservation of energy, mass, and momentum). An example of a simulated process is one that represents tropical cyclones and storm activity.

Parameterized processes represent more complex processes that are smaller than grid scale (so, cannot be physically represented) using simpler processes. Their formulations are guided by fundamental physical principles, but also make use of observational data. An example of a parameterized process is one that represents cloud and aerosol composition.



Representación de las nubes como una fracción de cada celda

Modelos Climáticos

TUNING

- The parametrizations also involve numerical parameters that must be specified as input. Some of these parameters can be measured, at least in principle, while others cannot. It is therefore common to adjust parameter values (possibly chosen from some prior distribution) in order to optimise model simulation of particular variables or to improve global heat balance. This process is often known as 'tuning'.

- If the model has been tuned to give a good representation of a particular observed quantity, then agreement with that observation cannot be used to build confidence in that model.

- Computationally cheaper models such as EMICs allow a more thorough exploration of parameter space, and are simpler to analyse to gain understanding of particular model responses

- Tuning is justifiable to the extent that two conditions are met:
  - Observationally based constraints on parameter ranges are not exceeded. Note that in some cases this may not provide a tight constraint on parameter values.
  - The number of degrees of freedom in the tuneable parameters is less than the number of degrees of freedom in the observational constraints used in model evaluation.

Modelos Climáticos

- Preparing the simulations ….

GCMs

1) External forcings : Radiation flux income (solar rad.), volcanoes, aerosols, GHG evolution.
2) Initial conditions of atmospheric fields (P,T,q,u,v, [gases, aerosols]) and surface fields (T,w,SST).
3) Physiography fields (orography, vegetation covers, soil types, lakes, rivers,…).
3) Parameters (tuning) and constants (k,g,…).

ESMs Also include initial fields related with biogeoquimical processes (carbon, nitrogen, others gases, dynamical vegetation,…).

RCMs

1) Atmospherics forcings (Boundary Conditions, BC): P,T,q,u,v, [gases, aerosols] in vertical levels.
2) Initial conditions for atmosphere and surface in more detail.
3) Physiography.

Can include more fields as water table depth, … other initial data of variables related to processes included in the RCMs and not included in GCMs.

3) Parameters and Constants.

Modelos Climáticos

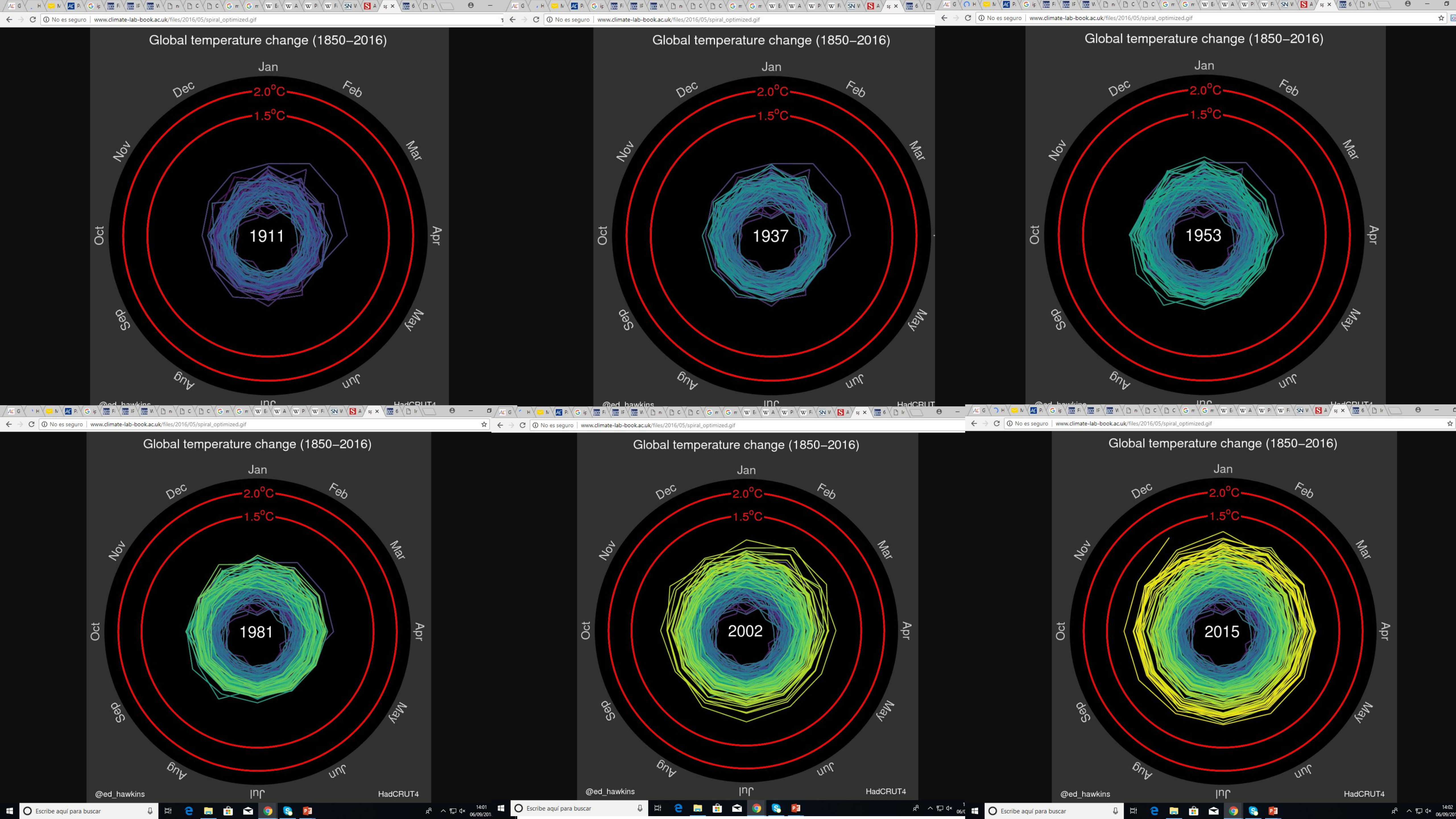
- ¿Está cambiando el clima?
- ¿Qué dicen los modelos climáticos?

Gráficos cambio climático:

http://www.climate-lab-book.ac.uk/files/2016/05/spiral_optimized.gif

http://www.bloomberg.com/graphics/2015-whats-warming-the-world/

http://ctxt.es/es/20170816/Politica/14463/cambio-climatico-temperatura-extrema-calentamiento-global.htm



www.climate-lab-book.ac.uk/files/2016/05/spiral_optimized.gif
Global temperature change (1850–2016)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2.0°C
1.5°C
1911
1937
1953
1981
2002
2015
@ed_hawkins
HadCRUT4


Bloomberg LP [US] | https://www.bloomberg.com/graphics/2015-whats-warming-the-world/
Bloomberg the Company & Its Products | Bloomberg Anywhere Remote Login | Bloomberg Terminal Demo Request
Menu
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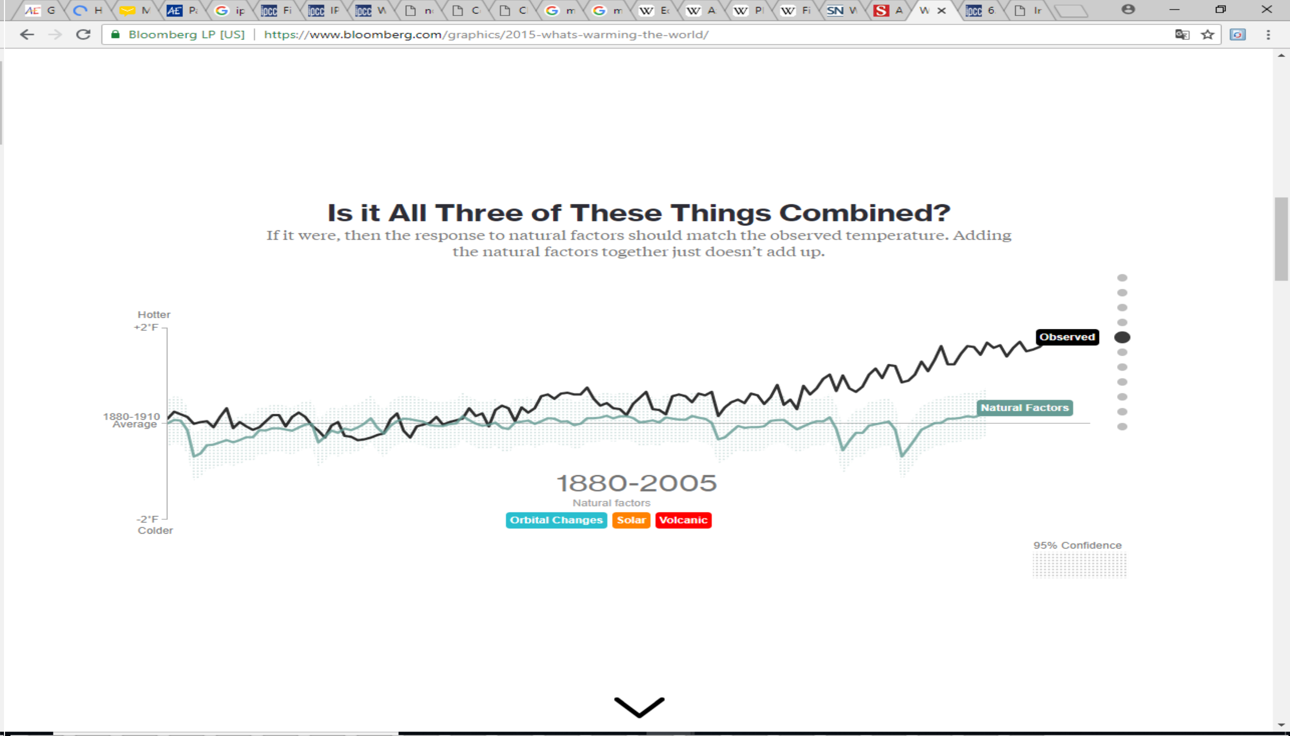
What's Really Warming the World?
By Eric Roston and Blacki Migliozzi | June 24, 2015
Skeptics of manmade climate change offer various natural causes to explain why the Earth has warmed 1.4 degrees Fahrenheit since 1880. But can these account for the planet's rising temperature? Scroll down to see how much different factors, both natural and industrial, contribute to global warming, based on findings from NASA's Goddard Institute for Space Studies.
Hotter
+2°F
1880-1910 Average
-2°F
Colder
Observed
This line shows the measured, or "observed," land-ocean temperature
1880-2015


Bloomberg LP [US] | https://www.bloomberg.com/graphics/2015-whats-warming-the-world/
Is it All Three of These Things Combined?
If it were, then the response to natural factors should match the observed temperature. Adding the natural factors together just doesn't add up.
Hotter
+2°F
1880-1910 Average
-2°F
Colder
Observed
Natural Factors
1880-2005
Natural factors
Orbital Changes
Solar
Volcanic
95% Confidence

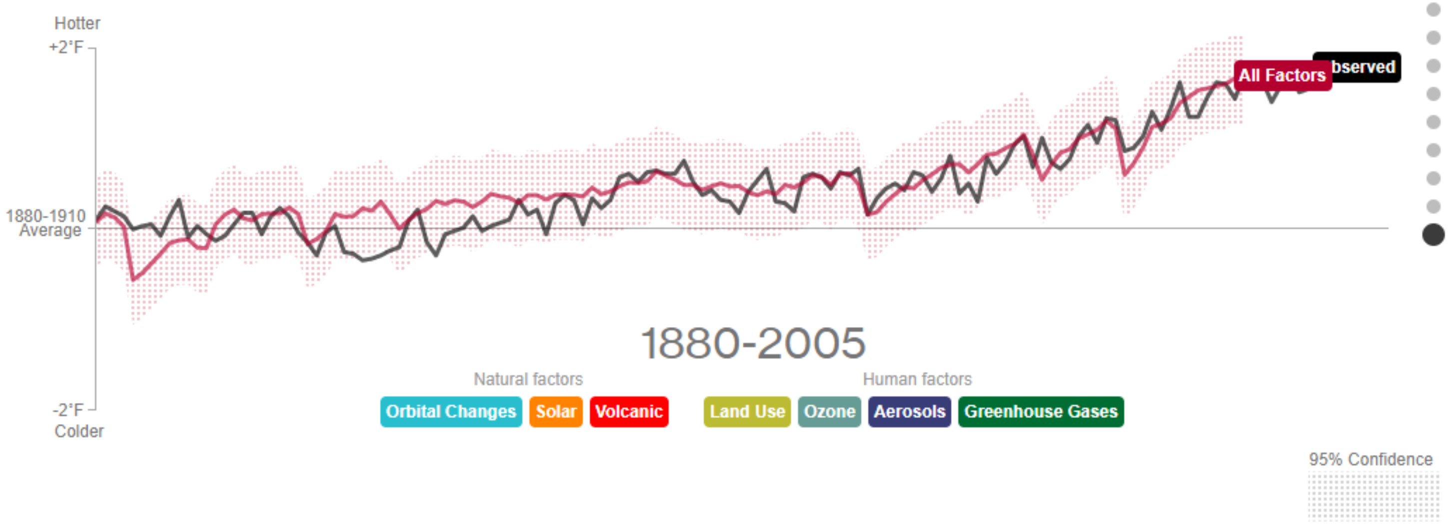

Bloomberg LP [US] | https://www.bloomberg.com/graphics/2015-whats-warming-the-world/
No, It Really Is Greenhouse Gases.
Atmospheric CO2 levels are 40 percent higher than they were in 1750. The green line shows the influence of greenhouse gas emissions. It's no contest.
Hotter
+2°F
1880-1910 Average
-2°F
Colder
Greenhouse Gases
Observed
1880-2005
95% Confidence
Escribe aquí para buscar
14:05
06/09/2018


Bloomberg LP [US] | https://www.bloomberg.com/graphics/2015-whats-warming-the-world/
See for Yourself
Greenhouse gases warm the atmosphere. Aerosols cool it a little bit. Ozone and land-use changes add and subtract a little. Together they match the observed temperature, particularly since 1950.
Hotter
+2°F
1880-1910 Average
-2°F
Colder
Observed
Human Factors
1880-2005
Human factors
Land Use
Ozone
Aerosols
Greenhouse Gases
95% Confidence
Escribe aquí para buscar
14:06
06/09/2018

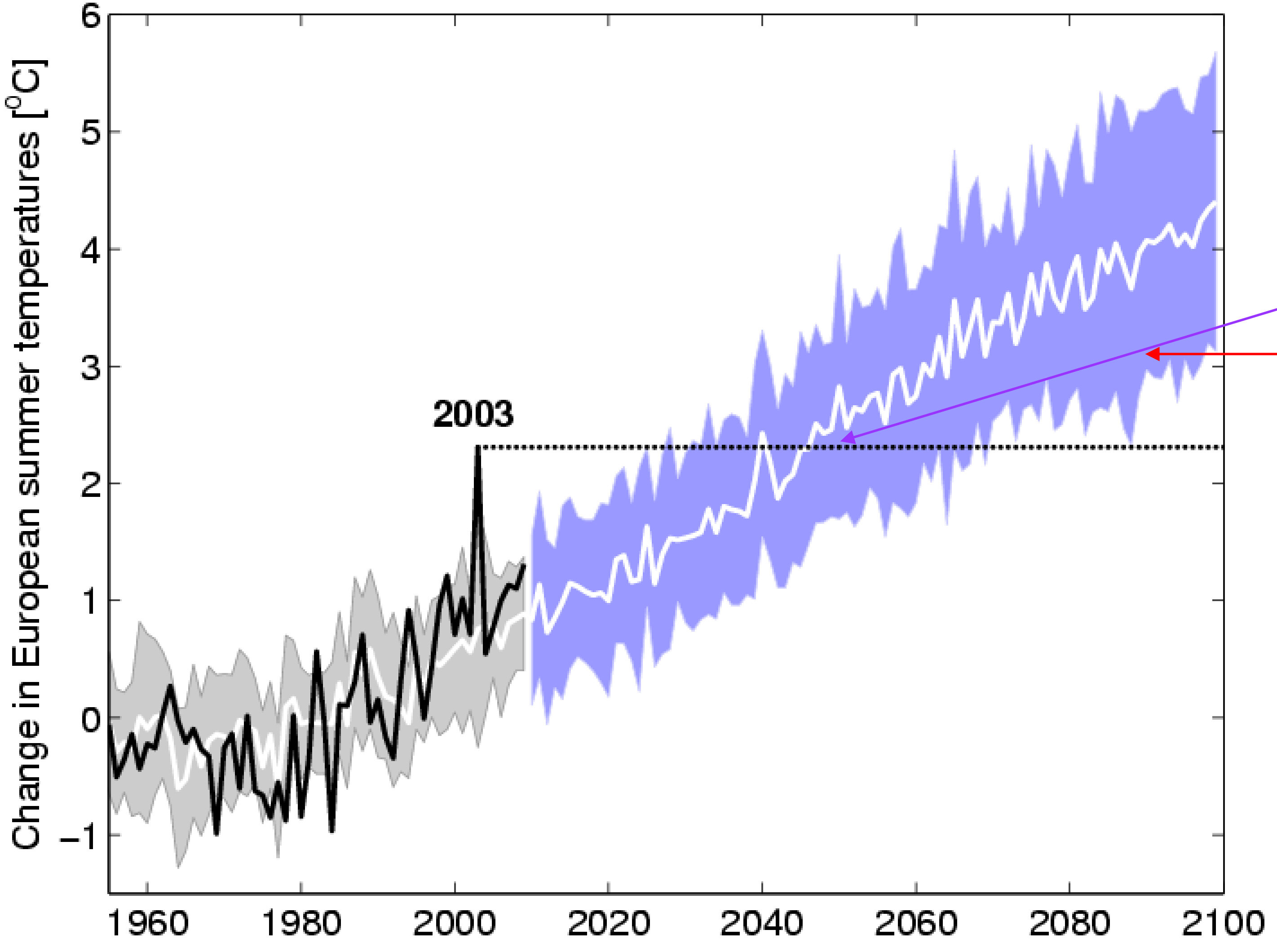
https://www.bloomberg.com/graphics/2015-whats-warming-the-world/

Compare and Contrast

Putting the possible natural and human causes of climate change alongside one another makes the dominant role of greenhouse gases even more plainly visible. The only real question is: What are we going to do about it?



Modelos Climáticos. Qué nos dicen



The extreme summer temperatures in 2003 are evident in the observations (Fig. 3, black line).

Projections of summer EU temperatures (for `medium' future emissions) indicate that the type of summer experienced in 2003 will become normal (i.e. 1-in-every-2 years) by around 2050, and that Europe would rarely experience a summer as cold as 2003 by the end of the 21st century (Fig. 3, blue shading).

Fig. 3: Observed EU summer temperatures (black; derived from Brohan et al., 2006), and IPCC AR4 projections of future summer temperatures using the 'medium' future emission scenario (SRES A1B, blue shading). The grey shading shows the spread in IPCC AR4 climate models when using historical external forcings. The dashed black line indicates the level of the 2003 summer. A similar figure using a single climate model was shown in Stott et al. (2004).

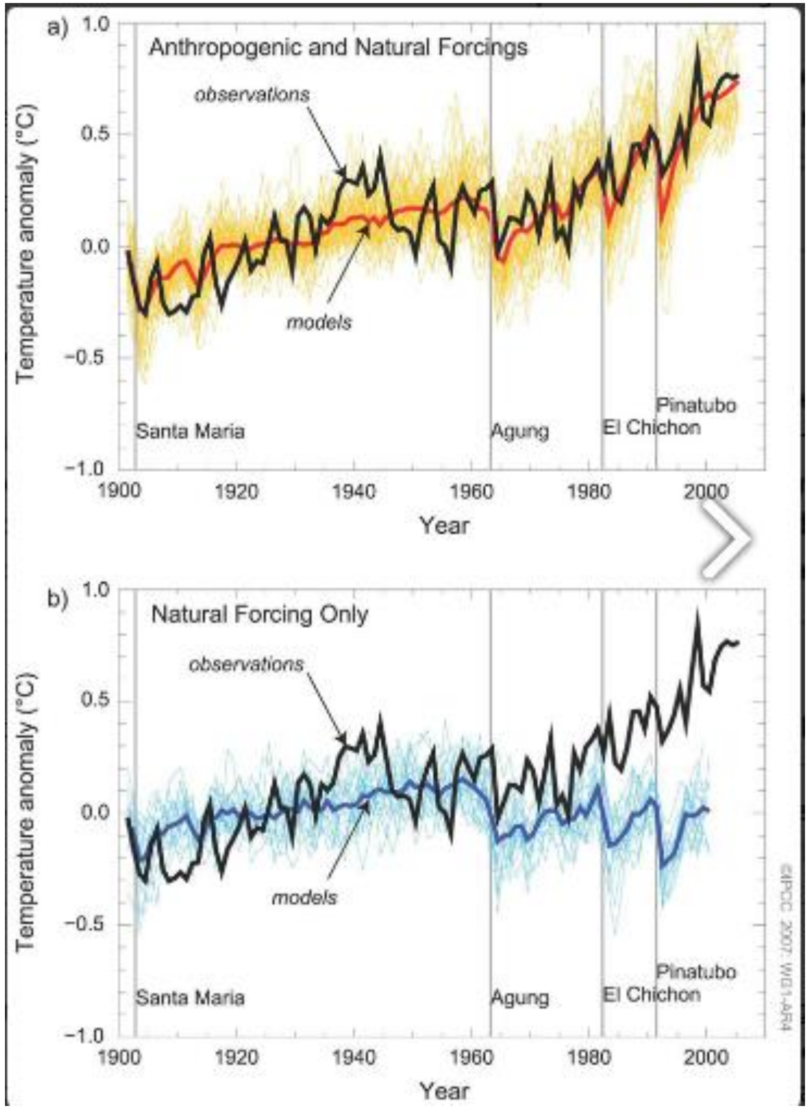
Modelos Climáticos

- **Why Do We Believe Them?**

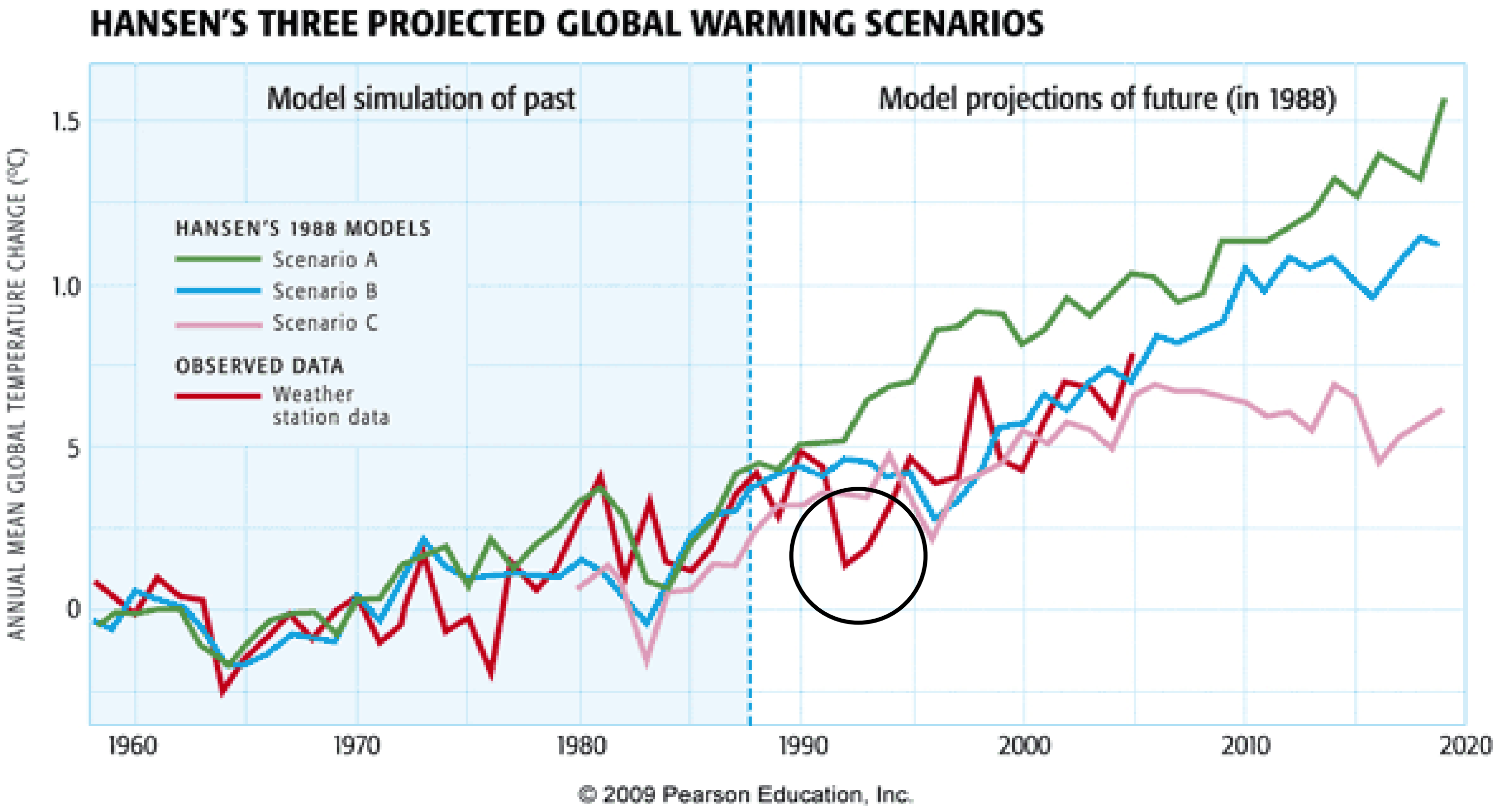
Although there is some level of disagreement among climate models, these models are based on well-founded physical principles either directly for simulated processes or indirectly for parameterized processes.

The results of one experiment are extensively checked by a large community of modelers and researchers around the world (for example, as part of the IPCC), which reduces uncertainty. Generally, models produce simulations of current and past large-scale climates that agree with observations.

Climate models have also produced an accurate hindcast of 20th century climate change, including increased warming partly due to CO_2 emissions. This gives us confidence in using these models to project future climate change



Modelos Climáticos



Hansen's 1988 simulations, can be viewed as one of the great validation experiments in climate modeling history. In these experiments, Hansen included a high, medium, and low fossil fuel future emissions scenario, corresponding to the green, blue, and purple curves respectively. As it turns out, our actual fossil fuel emissions scenario during the two decades subsequent to Hansen's 1988 projections, has corresponded most closely to his middle scenario, the blue curve. And as you can see from the subsequent observations (the red curve), his prediction for that scenario quite closely matched the observed warming

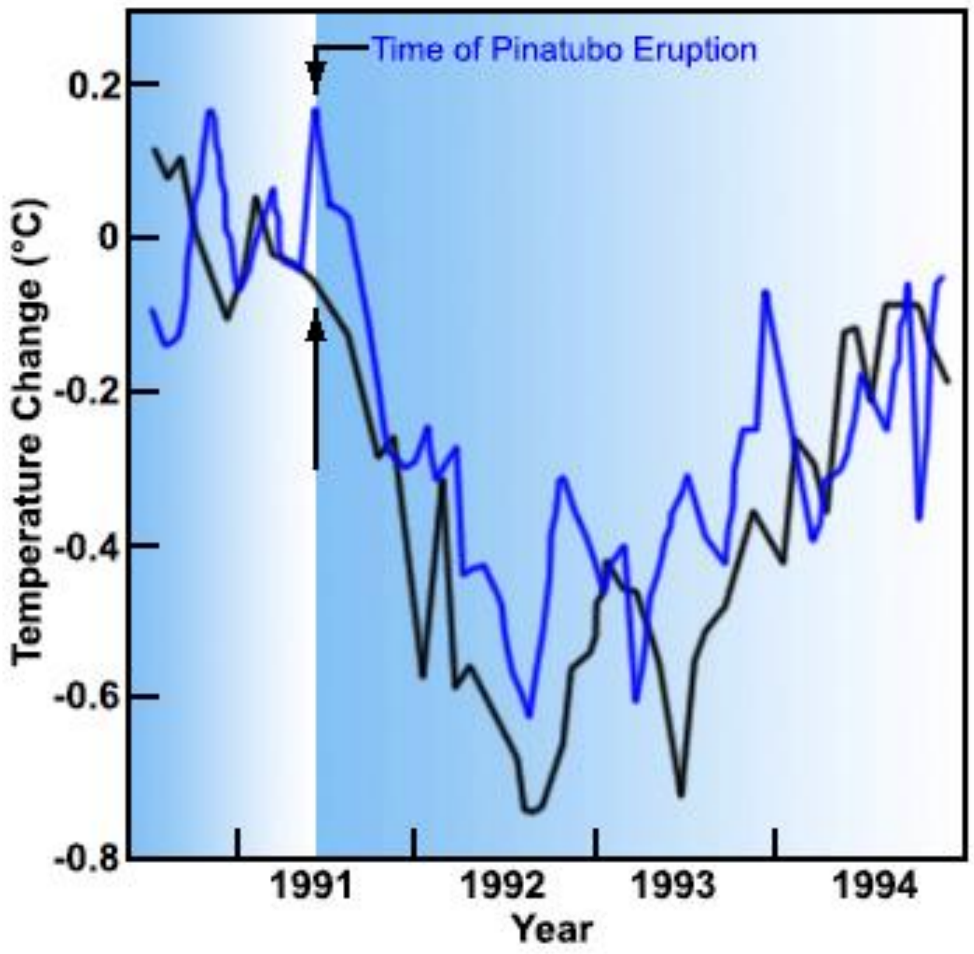
Modelos Climáticos

There is no way that anyone could have predicted the eruption of Mt. Pinatubo.

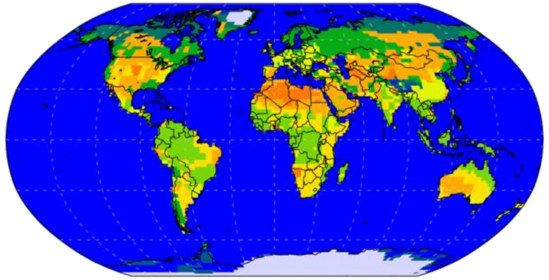
And rather than proving a fault with the model, the Pinatubo eruption actually provided Hansen with another key test of the climate models. It takes about 6 months for the volcanic aerosol to spread out around the globe and begin to have a global cooling impact. This gave Hansen about six months to run his model and make a prediction, at the instant Pinatubo erupted.

As you can see, he was able to predict quite accurately the short-term cooling of the globe by a bit less than 1°C that would result from this eruption.

His **model** simulation (the **black** curve below) actually predicted a bit too much cooling (**observations** shown by the **blue** curve below). But that, too, wasn't his fault. El Niño events occur randomly in time, and there was no way to know that an extended El Niño event would occur in 1991-1993, offsetting some of the volcanic cooling: El Niño events warm the globe by about 0.1-0.2°C.



Modelos Climáticos. Paleoclima



IPCC AR5

With medium confidence, global mean surface temperature was significantly above pre-industrial levels during several past periods characterised by high atmospheric CO2 concentrations

Mid-Pliocene (3.3 to 3.0 million years ago), CO2 between 350 ppm and 450 ppm, global mean surface temperatures were 1.9°C to 3.6°C (medium confidence) higher than for pre-industrial climate. Both terrestrial and marine paleoclimate proxies show that high latitudes were significantly warmer, but that tropical SSTs and surface air temperatures were little different from the present (less latitudinal gradient).

Atmospheric GCM simulations driven by reconstructed SSTs from the Pliocene produced winter surface air temperature warming of 10°C to 20°C at high northern latitudes, whereas there was essentially no tropical surface air temperature change. In contrast, a coupled atmosphere-ocean experiment with an atmospheric CO_2 concentration of 400 ppm produced warming relative to pre-industrial times of 3°C to 5°C in the northern North Atlantic, and 1°C to 3°C in the tropics, generally similar to the response to higher CO_2.

Conclusions:

The high-latitude response may indicate that high latitudes are more sensitive to increased CO_2 than model simulations suggest for the 21st century.

Alternatively, it could has been the result of increased ocean heat transports due to either an enhanced thermohaline circulation or increased flow of surface ocean currents due to greater wind stresses, or associated with the reduced extent of land and sea ice.

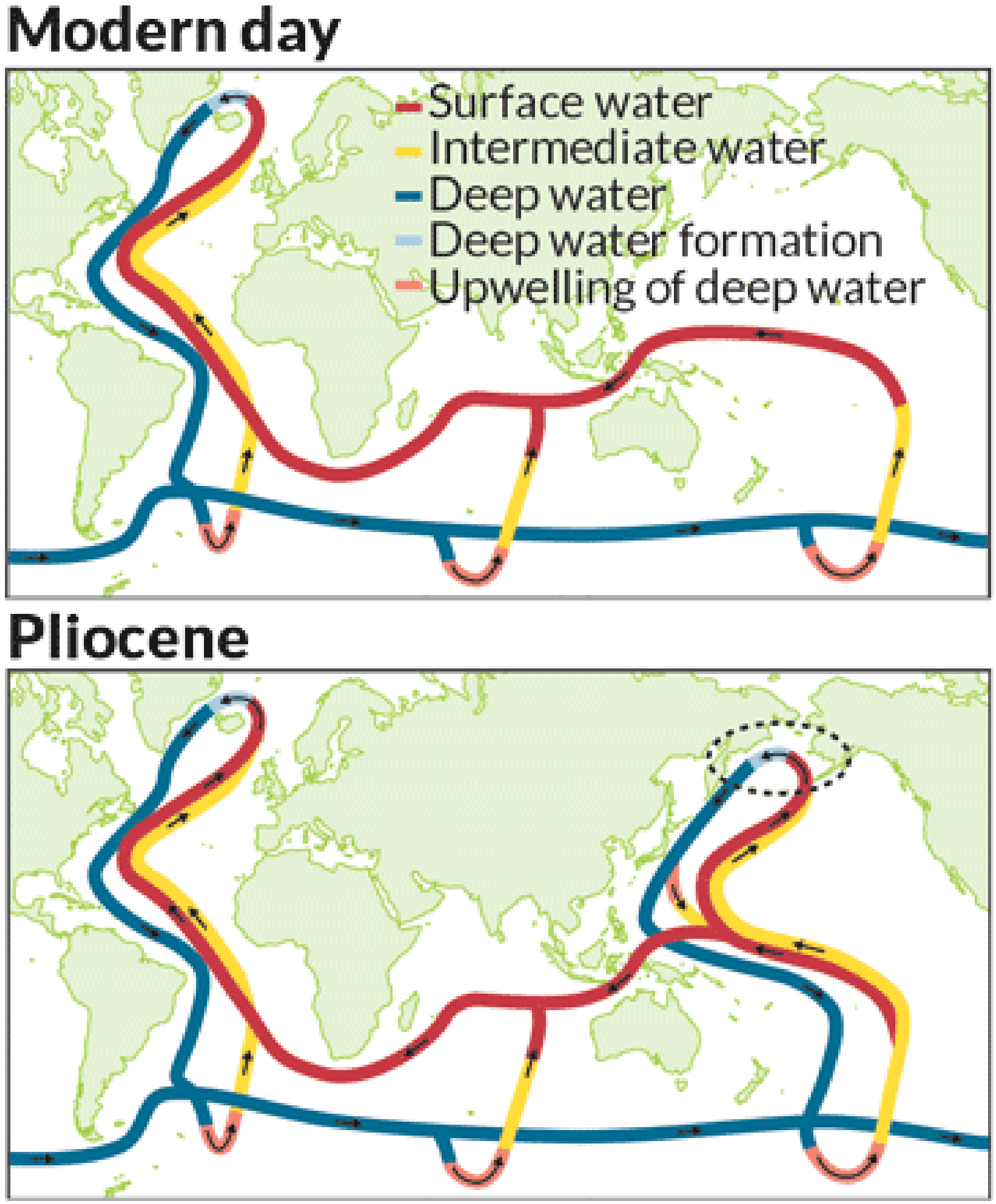
Currently available proxy data are equivocal concerning a possible increase in the intensity of the meridional overturning cell for either transient or equilibrium climate states during the Pliocene, although an increase would contrast with the North Atlantic transient deep-water production decreases that are found in most coupled model simulations for the 21st century. The transient response is likely to be different from an equilibrium response as climate warms. Understanding the climate distribution and forcing for the Pliocene period may help improve predictions of the likely response to increased CO_2 in the future, including the ultimate role of the ocean circulation in a globally warmer world

https://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch6s6-3-2.html https://www.sciencenews.org/article/what-pliocene-epoch-can-teach-us-about-future-warming-earth

Modelos Climáticos. Paleoclima

Ocean circulation today is driven in part by a deep circulation pattern in the North Atlantic (top). Currents there flow north and then become cooler and saltier, causing the water to sink and return southward in a conveyor belt–like circulation.

In the warm Pliocene, some 3 million years ago, a similar conveyor belt may have set up in the Pacific (bottom) thanks to reduced rainfall in the North Pacific (dotted circle).

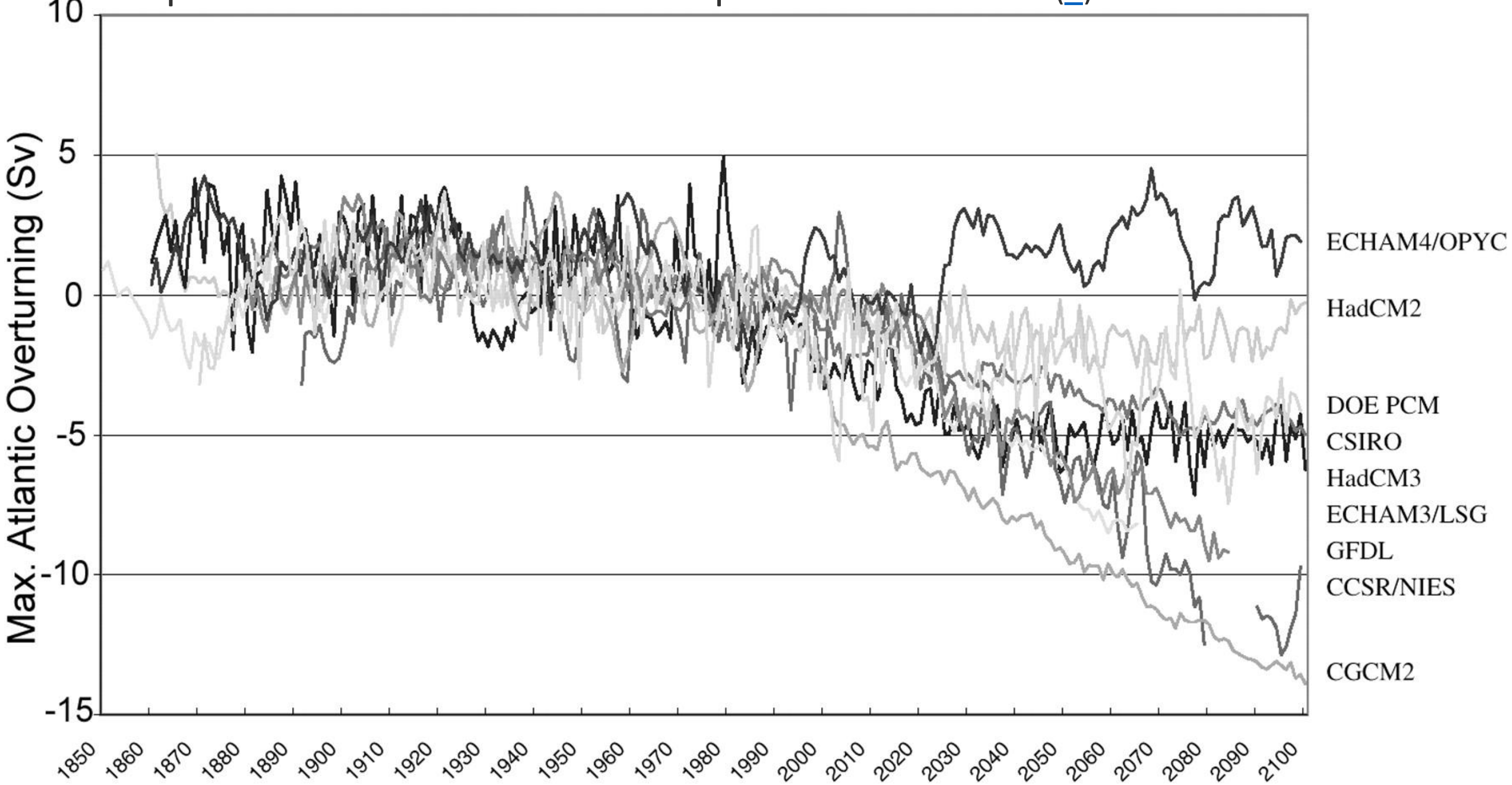


Active Pacific meridional overturning circulation (PMOC) during the warm Pliocene

Natalie J. Burls[1], Alexey V. Fedorov[2], Daniel M. Sigman[3], Samuel L. Jaccard[4], Ralf Tiedemann[5] and Gerald H. Haug[6],

Change in ocean circulation strength (1 Sv = 106 m3·s−1).

Most models predict an increase in precipitation in high latitudes and a decrease in the strength of the deep-water formation (Fig. 1) due to increased atmospheric greenhouse gases. The considerable differences in model simulations can be attributed to uncertainties in the parameterization of subgrid-scale processes such as vertical mixing and the representation of clouds and oceanic overflow (7), and a possible interaction between the El Niño/Southern Oscillation phenomenon and Atlantic deep-water formation (8).



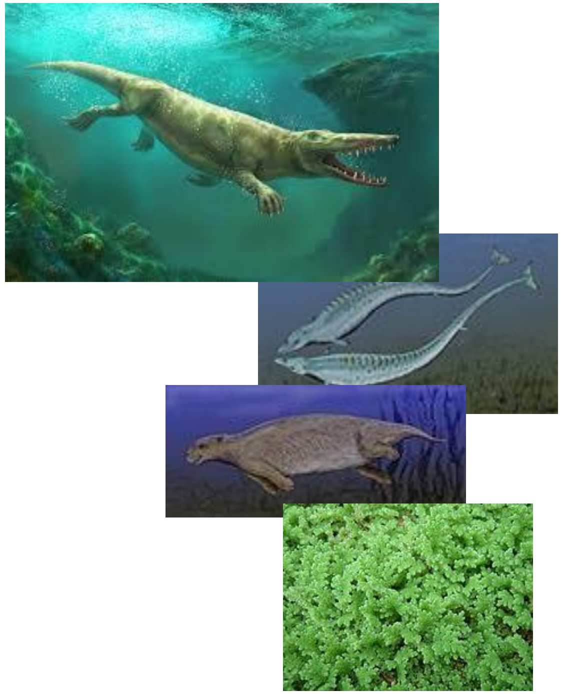
Martin Stute et al. PNAS 2001;98:10529-10530

Paleoclimatic evidence suggests that some past climate shifts such as the glacial-interglacial cycles were associated with changes in North Atlantic deep-water formation. This circulation imposes strong northward heat transport, making the northern North Atlantic about 4°C warmer than corresponding latitudes in the Pacific. Variations in ocean circulation therefore have the potential to cause significant large-scale climate change

Modelos Climáticos. Paleoclilma

IPCC AR5

With medium confidence, global mean surface temperature was significantly above pre-industrial levels during several past periods characterised by high atmospheric CO_2 concentrations.



During the Early Eocene (52 to 48 million years ago), atmospheric CO_2 concentrations exceeded ~1000 ppm (medium confidence) when global mean surface temperatures were 9°C to 14°C (medium confidence) higher than for pre-industrial conditions.

Model simulations of peak carbon addition to the ocean–atmosphere system during the PETM (Paleocene-Eocene Thermal Maximum) give a probable range of 0.3–1.7 Pg C yr^{-1}, which is much slower than the currently observed rate of carbon emissions: 10 Pg C/yr (8.7 from fossil fuel combustion and industries, the rest from land change use) aprox. in 2008

https://es.wikipedia.org/wiki/M%C3%A1ximo_t%C3%A9rmico_del_Paleoceno-Eoceno

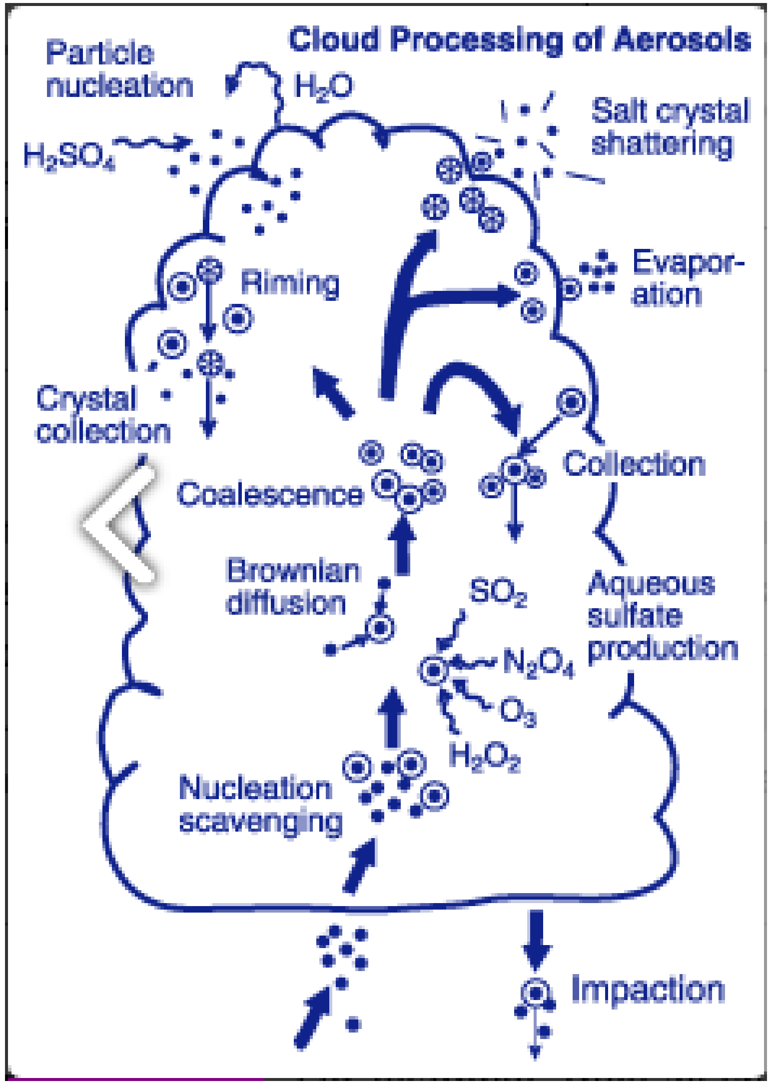
Modelos Climáticos. Certezas

What Do They Agree On?

- Climate models agree on certain basic aspects of future climate change.
- For example, they all show rising global temperatures with amplified warming in the Arctic, enhancement of the hydrologic cycle (dry places becoming dryer and wet places becoming wetter), and rising sea level. Many of these factors affect each other and could be drastically altered in an already changing climate.
- Climate models reduce the uncertainty of climate change impacts, which aids in adaptation.
- Generally, more confidence is placed in simulations that are at larger scales because of the agreement in global averages and patterns

Modelos Climáticos. Fuentes de incertidumbre

- **Why Do They Disagree?**
- Climate models can disagree on many results and projections due to natural variability, differences in forcing, and differences in feedbacks.
- Natural climate variability can be reduced by using an ensemble of simulations with slight changes in each, which produces an average result and reveals the response to forcing.
- However, forcings vary greatly among climate models. Forcings are the prime movers of climate change.
- The turbulent behaviour of the near-surface atmosphere, the effects of ocean eddies and the microphysics of clouds and aerosols need to be better incorporated into climate models so that the uncertainty due to these imperfections is reduced



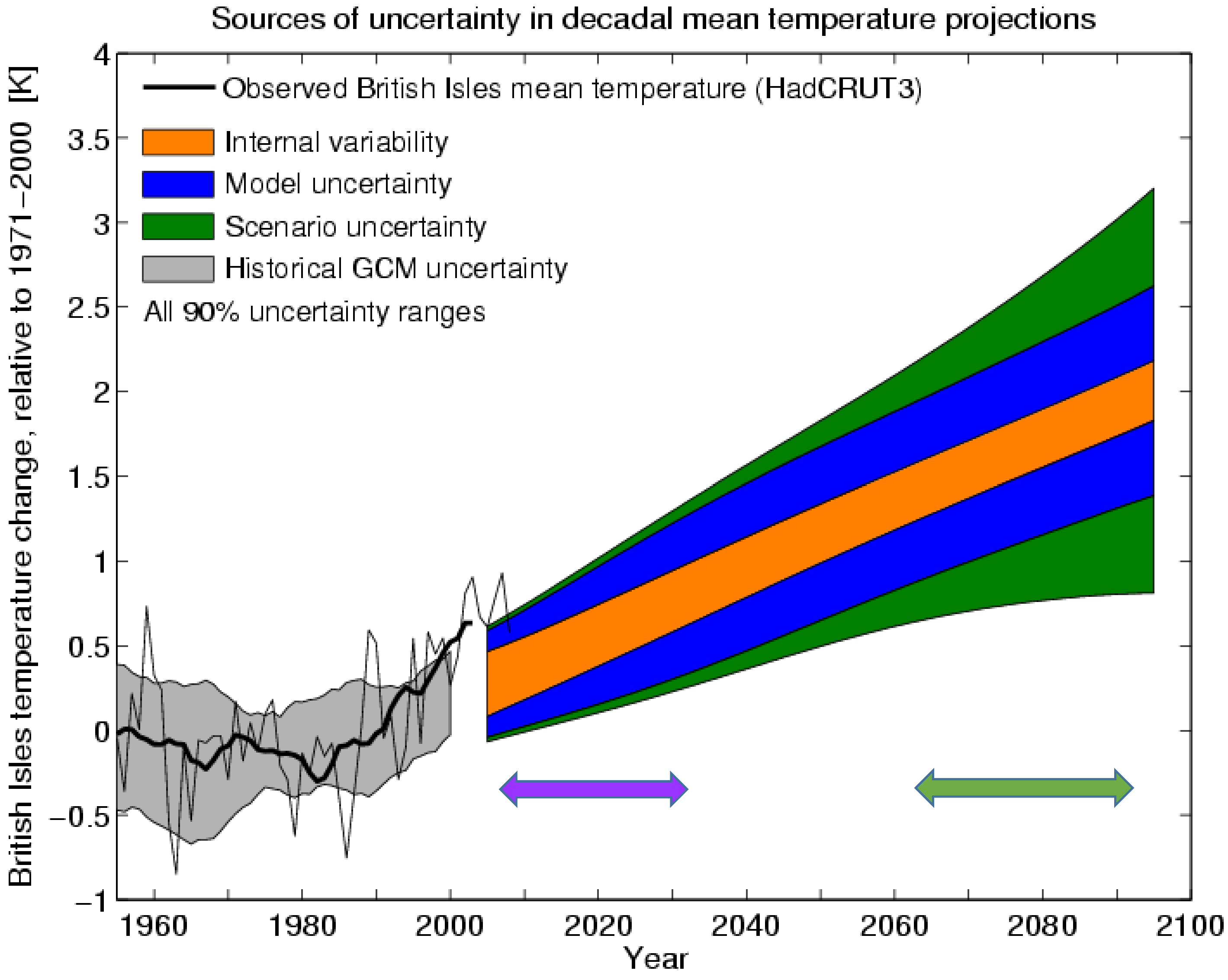


Fig. 4: The relative importance of three sources of uncertainty in future UK temperature projections as coloured. The black lines show observed temperatures (thin - annual averages, thick - decadal averages; derived from Brohan et al., 2006). After Hawkins and Sutton (2009).

The natural, internal variability component (orange) is the largest source of uncertainty for the next couple of decades, and the choice of emissions scenario (green) is relatively unimportant for the near-term.

This may be surprising, but it takes around 30 years for any changes in emissions to have an appreciable effect on the climate (so called `climate inertia').

The climate is already compromised for the next few decades and we may have to adapt. Towards the end of the century, the particular levels of greenhouse gas emissions have a larger impact on temperatures. Thus, we are committed to further increases in temperature, and any actions taken now to change our emissions will only have an influence later in the century. However, waiting to reduce emissions will further delay the climate response and lead to a larger increase in temperatures.

The remaining uncertainty is due to our choice of climate model (blue). Reducing this uncertainty by improving our climate models is possible, but challenging, and is the only way to narrow uncertainty in long term projections.

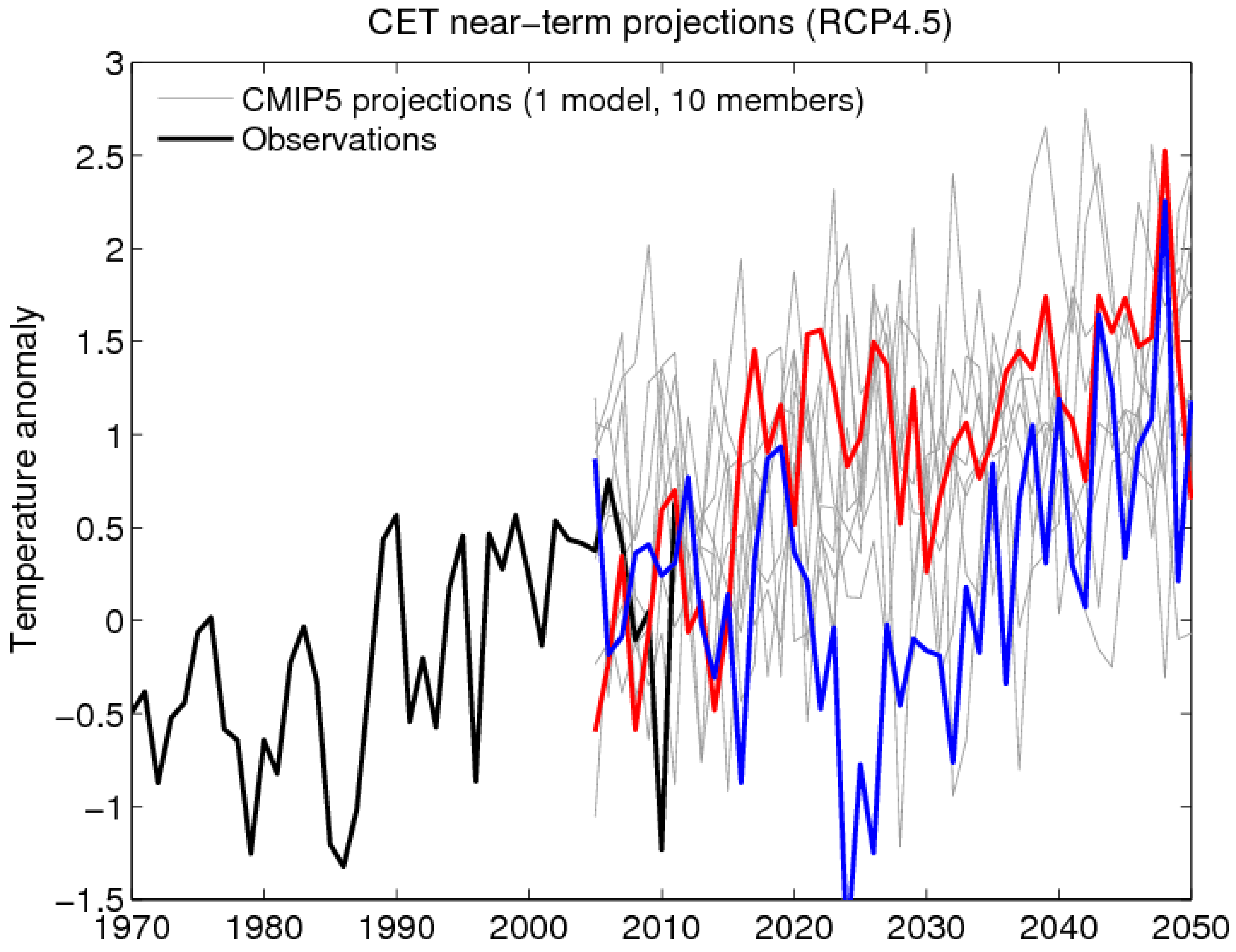
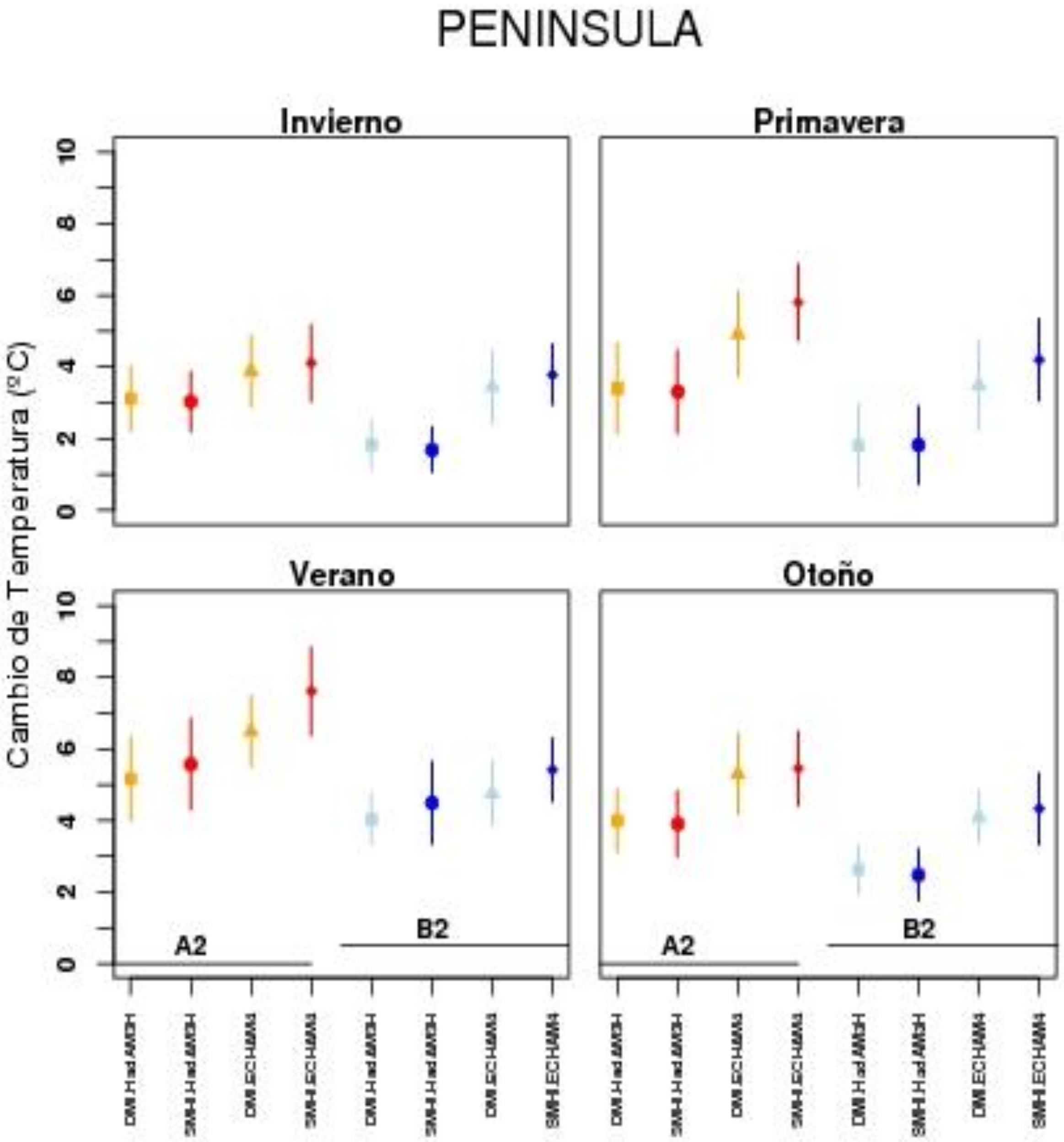


Fig. 2: Projections of Central England Temperature (CET) from a single model (CSIRO 3.6) and identical radiative forcings. The only difference is the initial conditions

Our climate is evolving. Although global and regional temperatures generally have a long-term upwards trend, the presence of natural variability means that each year, or decade, is not necessarily warmer than the last. Communication of the impact of natural fluctuations is vital for decision makers and for a skeptical public. Progress in understanding and predicting the natural fluctuations in climate offers the potential to test and improve climate models, narrow the uncertainty in climate predictions and aid adaptation to our evolving climate. Meeting these substantial scientific challenges requires continued investment in global observations, more advanced climate models and better ways of testing climate models against observations

Los modelos son sensibles a las condiciones iniciales (variabilidad natural), a los distintos forzamientos (escenarios de emission) -> Ensembles (mejor multi-modelo)

Modelos Climáticos. Incertidumbre



Sensibilidad frente a SRES, AOGCM, RCM

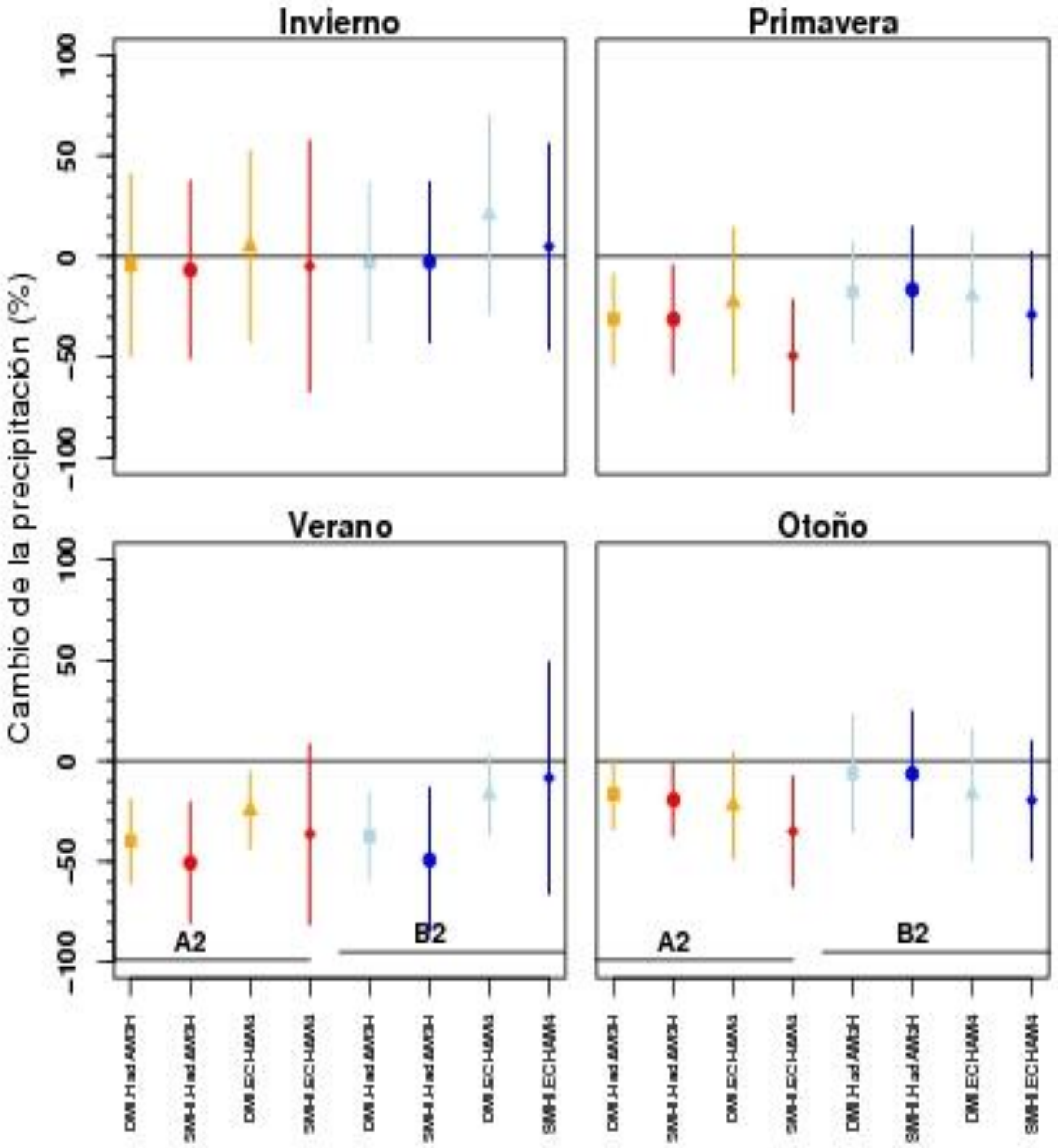
Valor medio de la diferencia de temperatura del periodo 2071-2100 respecto al periodo 1961-1990 para la España peninsular.

Se ha estimado a partir de dos **modelos regionales** (DMI en amarillo y celeste y SMHI en rojo y azul), dos modelos globales (HadAM3H y ECHAM4/OPYC) y dos escenarios de emisión (A2 y B2).

(cada barra indica la separación en +/-1 desviación estándar respecto de la media)

- El escenario de emisiones produce la mayor incertidumbre, seguido del modelo global usado.
- El modelo ECHAM predice mayor calentamiento que el Hadley

PENINSULA



Invierno
Primavera
Verano
Otoño
Cambio de la precipitación (%)
100
50
0
−50
−100
100
50
0
−50
−100
A2
B2
A2
B2
DMI.HadAM3H
SMHI.HadAM3H
DMI.ECHAM4
SMHI.ECHAM4
DMI.HadAM3H
SMHI.HadAM3H
DMI.ECHAM4
SMHI.ECHAM4
DMI.HadAM3H
SMHI.HadAM3H
DMI.ECHAM4
SMHI.ECHAM4
DMI.HadAM3H
SMHI.HadAM3H
DMI.ECHAM4
SMHI.ECHAM4

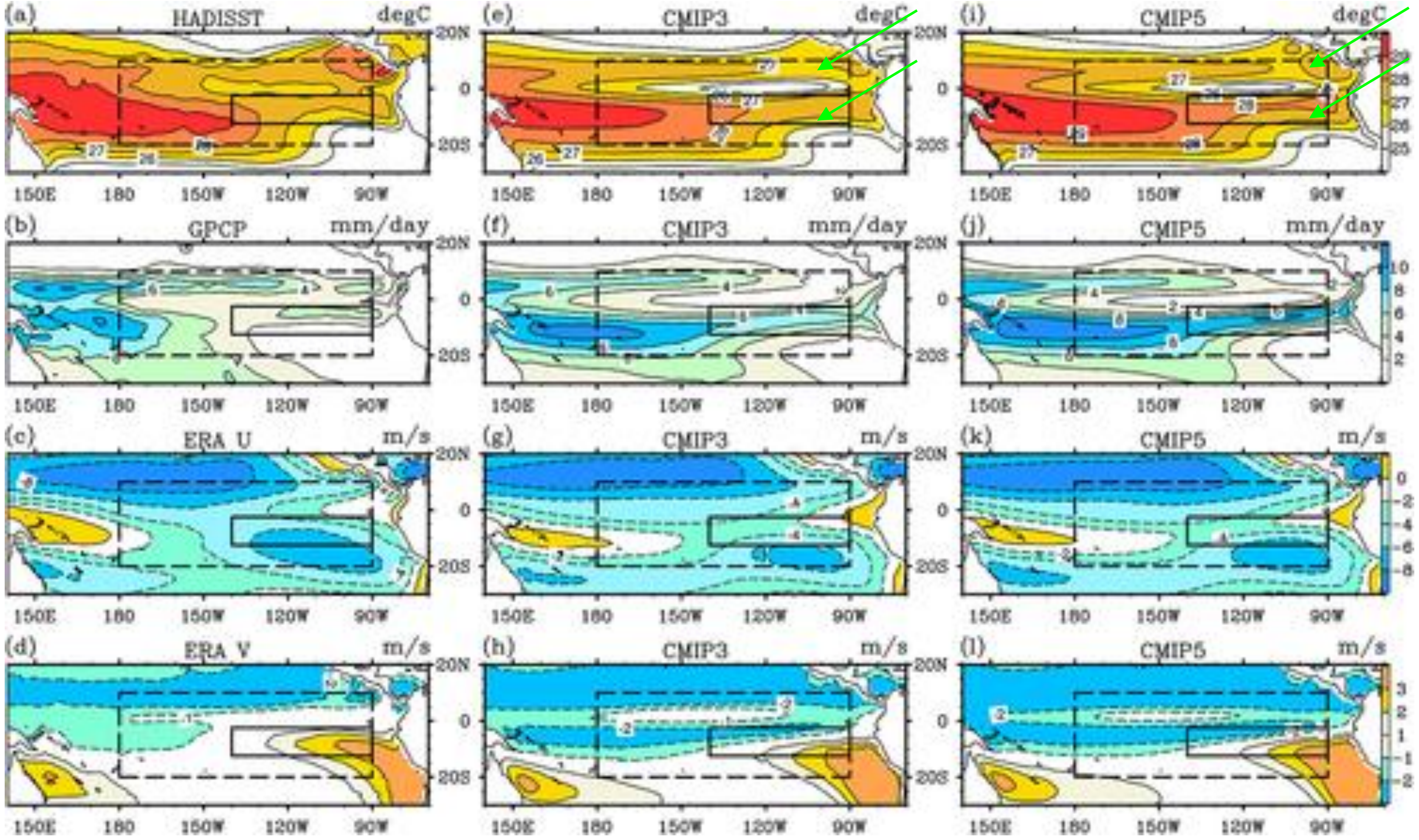
Modelos Climáticos. Sesgos

These include biases in:

- The cold tongue and intertropical convergence zone regions (e.g., Li and Xie 2014; Grose et al. 2014),
- The structure of El Niño–Southern Oscillation (ENSO) sea surface temperature (SST) and precipitation anomalies (e.g., Bellenger et al. 2014; Grose et al. 2014),
- Simulation of the Madden–Julian oscillation (MJO; Kim et al. 2014a; Hung et al. 2013; Jiang et al. 2015; Ahn et al. 2017),
- Tropical monsoon precipitation and Indian Ocean processes (e.g., Sperber et al. 2013; Annamalai et al. 2017),
- The strength of the Atlantic meridional overturning circulation (AMOC; e.g., Wang et al. 2014),
- Extratropical cyclone tracks (Zappa et al. 2013),
- Tropical–extratropical teleconnections (e.g., Sheffield et al. 2013a,b; Henderson et al. 2017),
- General interactions of clouds with the large-scale circulation (Stevens and Bony 2013), among others

Some aspects of simulations can often be improved, but seemingly for the wrong reasons. For example, improving biases in model tropical intraseasonal variability often systematically degrades other aspects of the simulation like the mean state (Kim et al. 2011; Mapes and Neale 2011; Hannah and Maloney 2014). Model biases are rooted in imperfect parameterizations of unresolved processes.

Modelos Climáticos. Sesgos



Los modelos tienen que mejorar algunos aspectos

- The lack of progress in reducing the double ITCZ bias from CMIP3 to CMIP5 is likely due to several known model biases that have persisted through generations of coupled models. These include the inadequate simulations of stratocumulus clouds in the southeastern Pacific and the stratocumulus to cumulus transition away from the coast, the triggering and entrainment parameterizations of deep convection, insufficient resolution of the models in resolving mesoscale eddy transport in the ocean, and the upwelling along the coast

Modelos Climáticos. Evaluación

EVALUATION

- For any given metric, it is important to assess how good a test it is of model results for making projections of future climate change. This cannot be tested directly, since there are no observed periods with forcing changes exactly analogous to those expected over the 21st century.
- ‘Present climate simulations’: Since forcing changes are not perfectly known over 20th century, simulated climate over that period do not fully constrain future response to forcing changes
- Study observed climate sensitivity vs model climate sensitivity.
- Simulations of climate states from the more distant past allow models to be evaluated in regimes that are significantly different from the present. The limitations of paleoclimate tests are that uncertainties in both forcing and actual climate variables (usually derived from proxies) tend to be greater than in the instrumental period, and that the number of climate variables for which there are good paleo-proxies is limited.
- Further, climate states may have been so different (e.g., ice sheets at last glacial maximum) that processes determining quantities such as climate sensitivity were different from those likely to operate in the 21st century
- Climate simulations of recent past allows to evaluate the model behavior. It is usual to force the model with boundary conditions from a reanalysis (era5, era-interim, …), hindcast, and compare the outputs with observations. This gives confidence in the model ability to predict climate.

Modelos Climáticos. Process-Oriented validation

Process Oriented Diagnostics (PODs) examples :

- Cloud microphysical processes
- Tropical and extratropical cyclones
- ENSO teleconnections and atmospheric dynamics
- Land–atmosphere interactions
- MJO moisture, convection, and radiative processes
- Precipitation diurnal cycle
- AMOC
- Arctic sea ice
- Lake-effect processes
- Monsoon
- Radiative forcing and cloud–circulation feedbacks
- Temperature and precipitation extremes….

All they impact climate and climate variability.

- Traditionally, diagnostics for climate models are based on monthly mean statistics and climatologies. Increasingly, models are being analyzed in more detail against observations of specific processes.
- The closer to a model process the observations and evaluation are, the better the ability to constrain the process and hence provide a guide to parameterization improvement.
- For a simple example: cloud radiative effects at the top of the atmosphere are a non unique function of cloud microphysical properties (drop number and liquid water path). Thus, constraining radiative effects of clouds is better done in conjunction with detailed observations of cloud microphysics than with just radiative fluxes.
- Focus on model improvement rather than general model evaluation

Climate Change , space-time patterns. Studying climate change

Climate Dynamics (2003) 20: 491–502 DOI 10.1007/s00382-002-0286-0
K. Braganza Æ D.J. Karoly Æ A.C. Hirst Æ M.E. Mann P. Stott Æ R.J. Stouffer Æ S.F.B. Tett
Simple indices of global climate variability and change: Part I – variability and correlation structure

The indices are surface temperature based and include the global-mean, the land–ocean contrast, the meridional gradient, the interhemispheric contrast, and the magnitude of the annual cycle. These indices contain information independent of the variations of the global-mean temperature for unforced climate variations. They also represent the main features of the modelled surface temperature response to increasing greenhouse gases in the atmosphere. Hence, they should have a coherent response for greenhouse climate change
There are other simple indices of climate variability and change that may have similar properties to those used here. These include the temperature contrast between the troposphere and lower stratosphere (Karoly 1989; Karoly et al. 1994; Santer et al. 1996a) and the diurnal temperature range (Folland et al. 2001; Risbey et al. 2000)

The indices represent physical phenomena:

Global-mean: Radiative balance at large scale, GHG
Land-ocean contrast: Different calorific capacity, breeze
Meridional gradient: General atmospheric circulation, meridional eddy heat transport
Interhemispheric contrast: Different land-sea distribution, differences in ice sheets
Annual cycle: Radiative forcing
Diurnal T range: Radiative balance, GHG
T contrast between troposphere and stratosphere: Radiative balance, GHG, General circulation, vertical eddy heat transport.

Resumen
Modelos Climáticos: para qué se usan

- Para **conocer el clima** futuro.
- Para **estudiar procesos físicos** (atmosféricos, oceánicos, …) importantes o poco conocidos
- Para **estudiar la sensibilidad y la estabilidad del clima** y los mecanismos que pueden producir los **cambios climáticos**.
- Para saber las **zonas más críticas**, más sensibles, más afectadas.
- Para estudiar los **climas del pasado** (paleoclimatología)
- Para mostrar la **influencia de los humanos en el clima** …
- En último extremo: ¡para obtener información que nos permita **salvar vidas**!