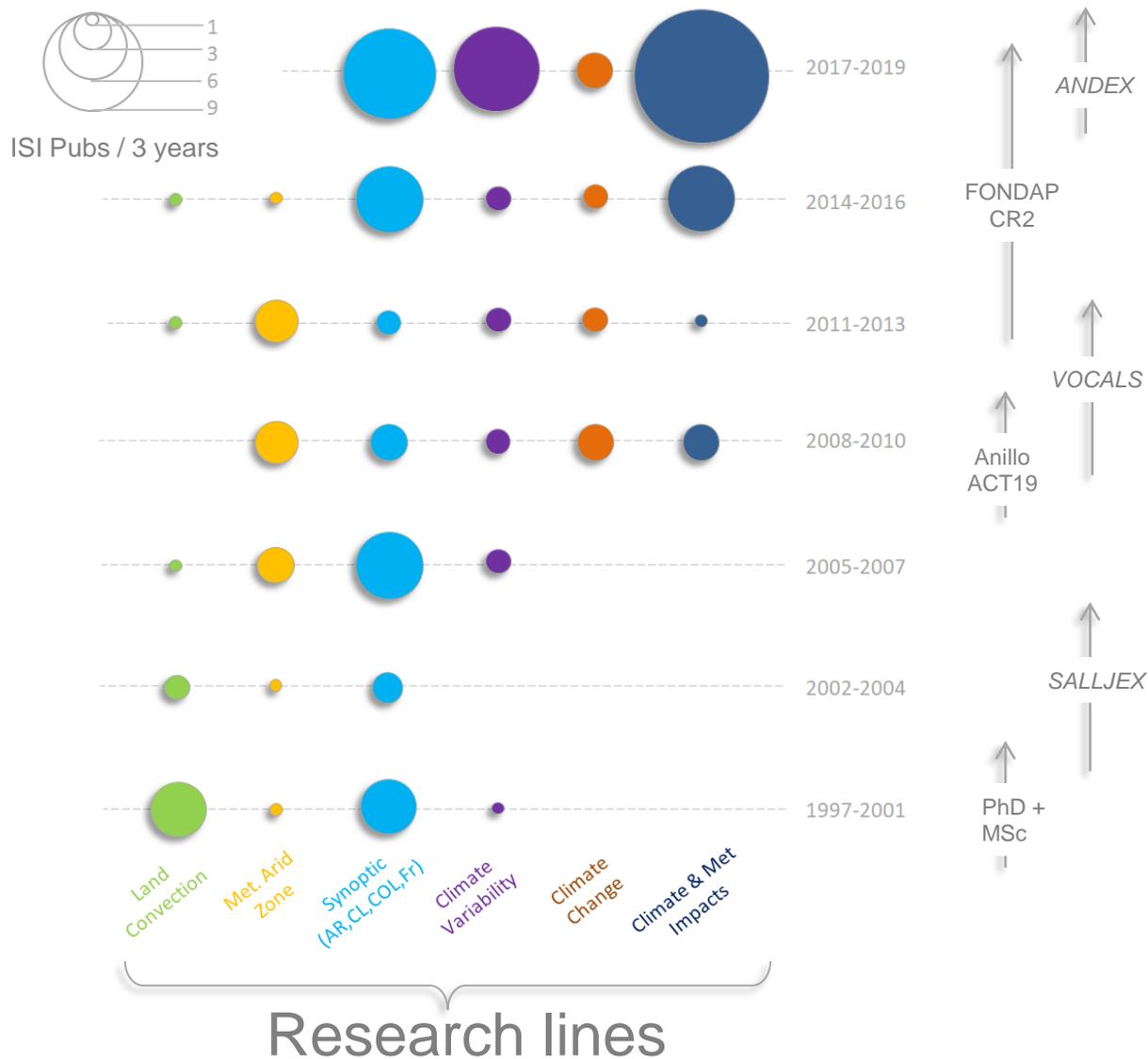


¿Qué hace?

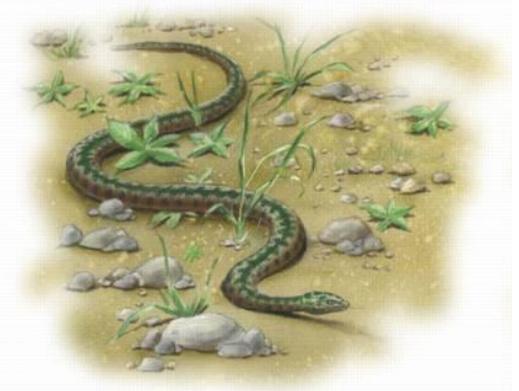
Temas y áreas de trabajo



“Las preguntas científicas del cambio
climático están resueltas....
ahora es solo un problema técnico-
económico”

(ca 2012, algún ministro o subsecretario)

La Ciencia del Cambio Climático: Modelos, Millones y Culebras



René D. Garreaud

Departamento de Geofísica / Centro del Clima y Resiliencia CR2
Universidad de Chile

Modelos, Millones y Culebras

- No todo es Cambio Climático
- Ha cambiado el clima? Largo y corto plazo
- Factores del cambio (CO₂ y mas...)
- Pronóstico para mañana?
- Podemos salvar al oso polar?
- Sensibilidad climática y la Sra. Juanita
- Conclusiones

Encuesta flash sobre Cambio Climático (CC)....

- El CC es **uno** de los mayores problemas de la humanidad en el siglo XXI

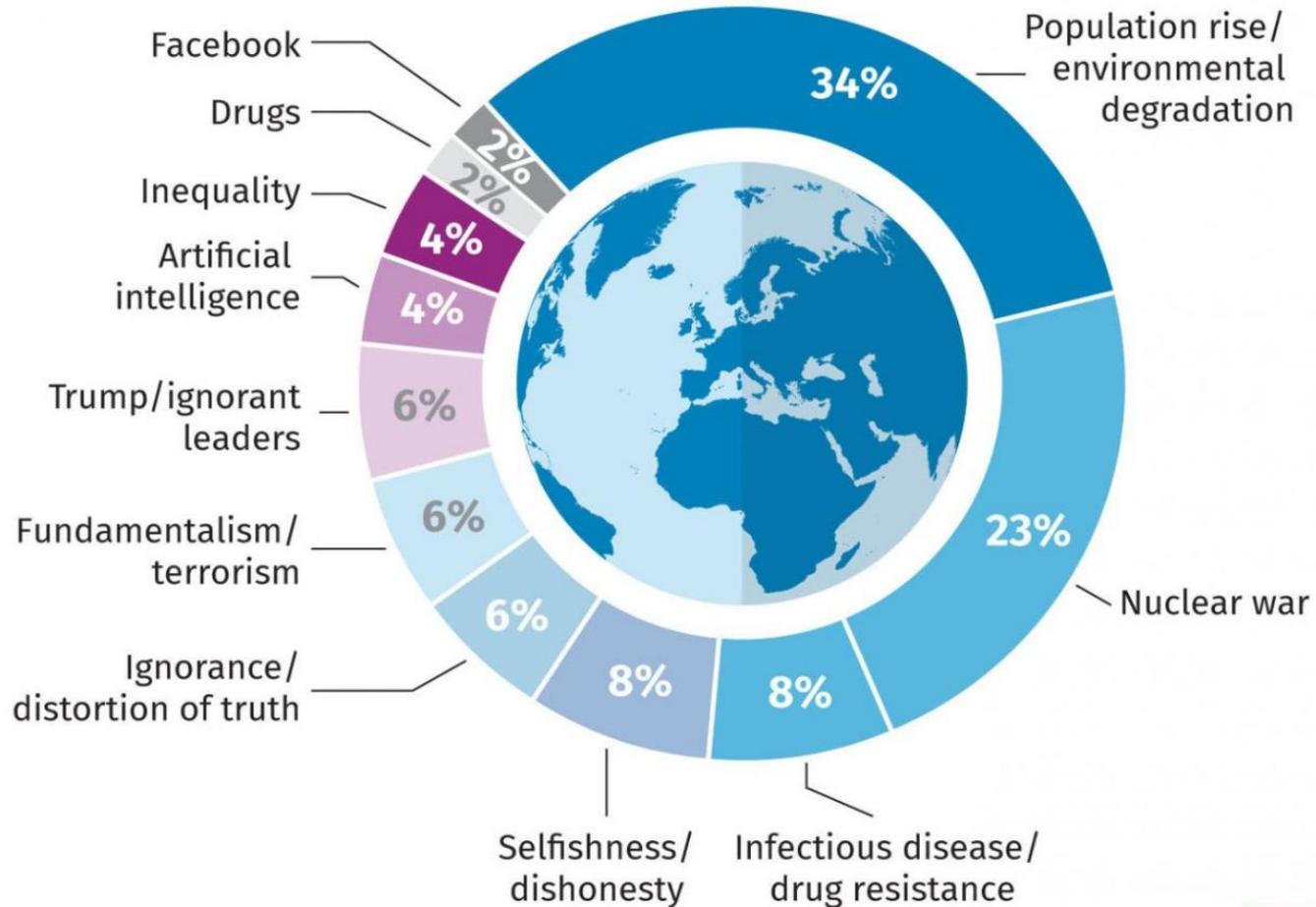
Encuesta flash sobre Cambio Climático (CC)....

- El CC es uno de los mayores problemas de la humanidad en el siglo XXI
- El CC es **el** mayor problema de la humanidad al 2050

Encuesta flash sobre Cambio Climático (CC)....

- El CC es uno de los mayores problemas de la humanidad en el siglo XXI
- El CC es el mayor problema de la humanidad al 2050
- El CC es **el** mayor problema de Chile en esta década

Biggest threats to humanity according to Nobel Prize winners



Source: Times Higher Education and Lindau Nobel Laureate Meetings



La Megasequía 2010-2015 Una lección para el futuro

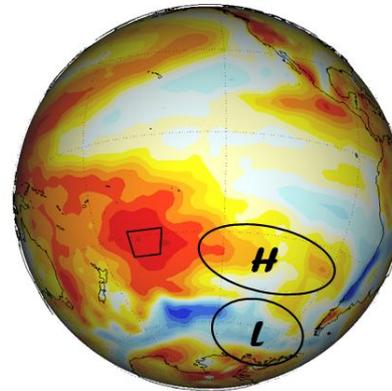
<http://www.cr2.cl/megasequia/>



(CR)²
Center for Climate
and Resilience Research
www.cr2.cl

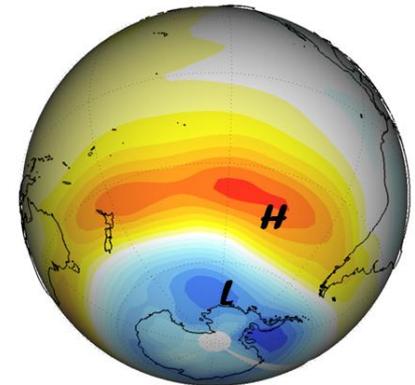


Observed SAT Anomalies (°C)
Natural (+ Trend?)



2/3

SLP Anomalies (hPa)
Antropogenic



1/4



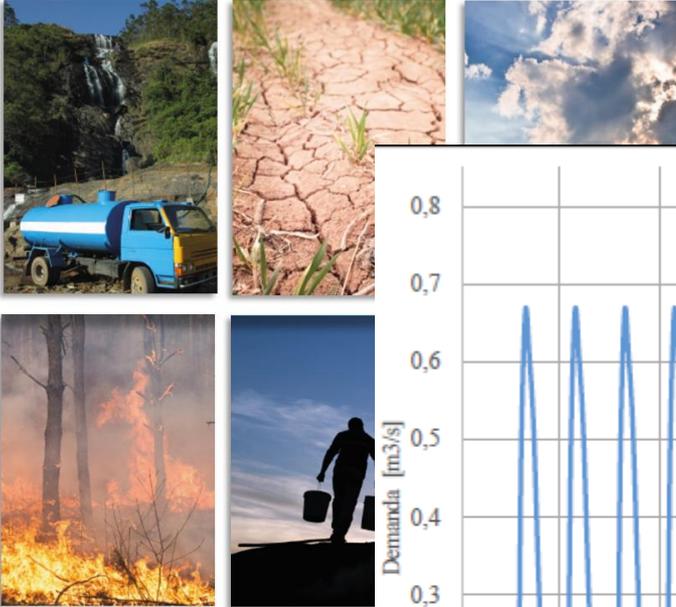
2010-2018 Central Chile MD

Imágenes LANDSAT – USGS. © RGS @ DGF-UCh + CR2



La Megasequía 2010-2015 Una lección para el futuro

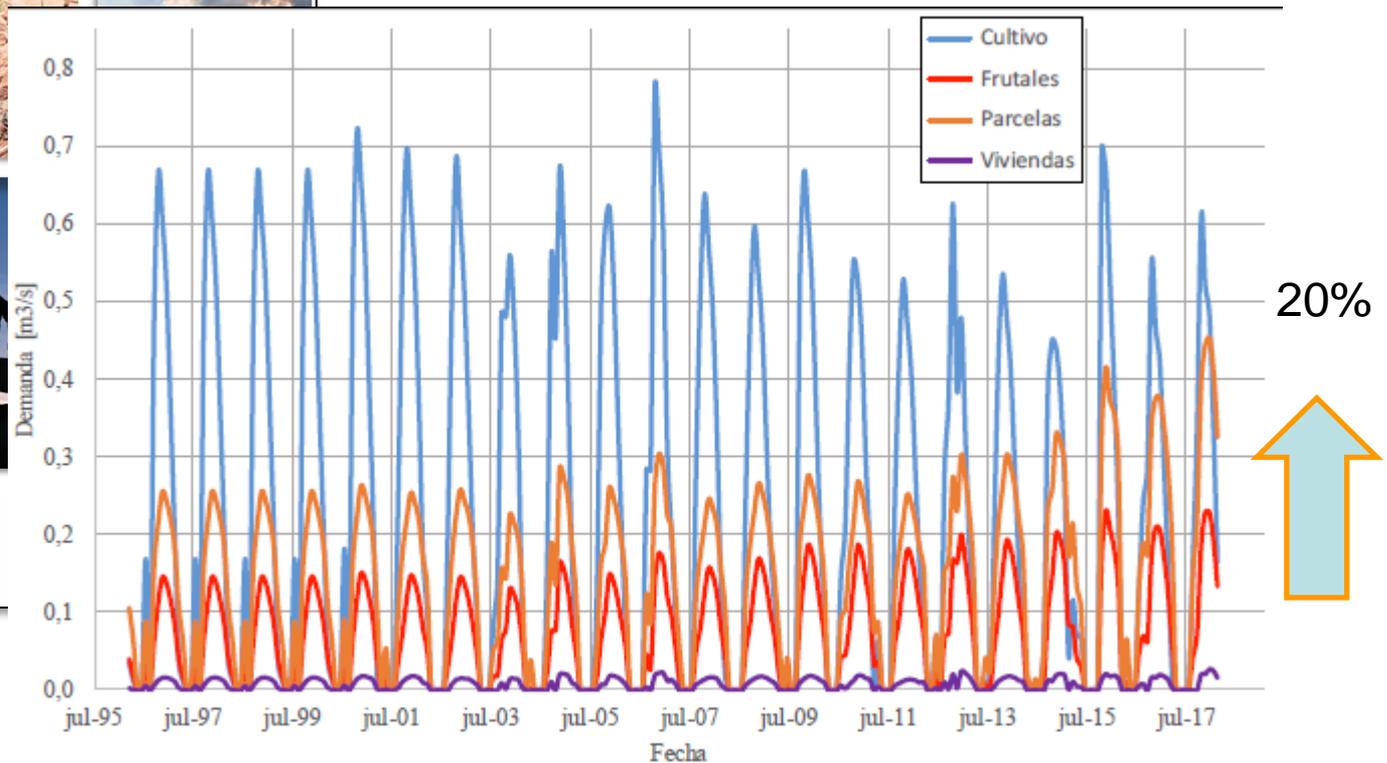
<http://www.cr2.cl/megasequia/>



(CR)²
Center for Climate
and Resilience Research
www.cr2.cl

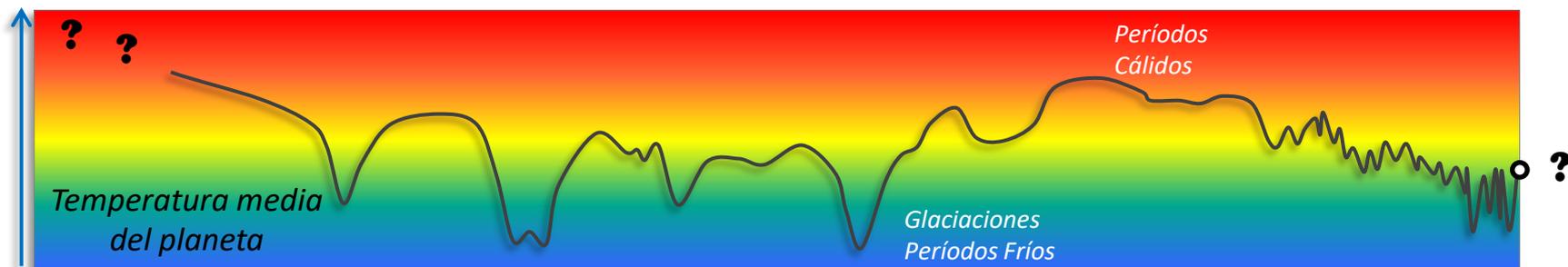


Demanda agrícola según uso de suelo



Proyecto FIC-R 2017 código BIP 40002646-0
Caracterización del consumo hídrico y del sistema hidrogeológico en la
cuenca de Aculeo, determinación de posibles soluciones y campaña de
educación ambiental

El clima siempre cambia....



Signos Globales durante el antropoceno

Temperatura media del Planeta [°C]



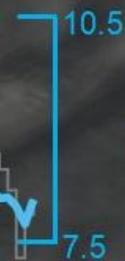
Nivel medio del mar [mm]



pH del Océano

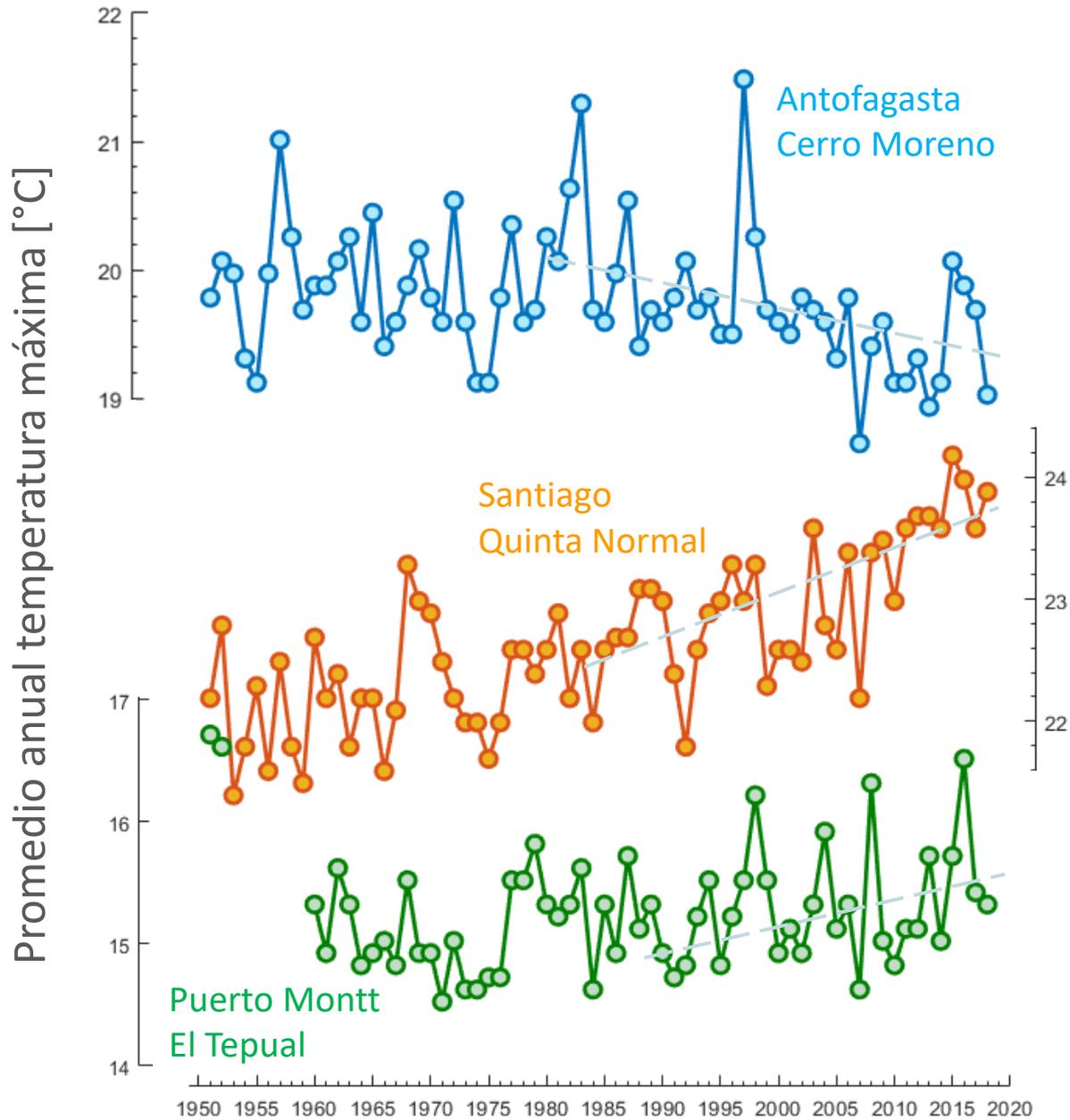


Hielo Marino Océano Ártico (Mill Km²)

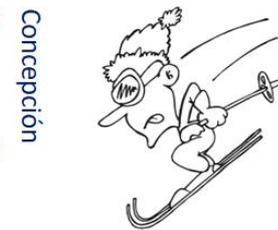
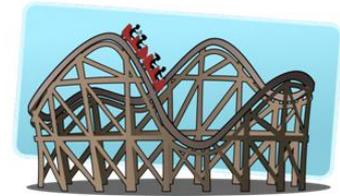
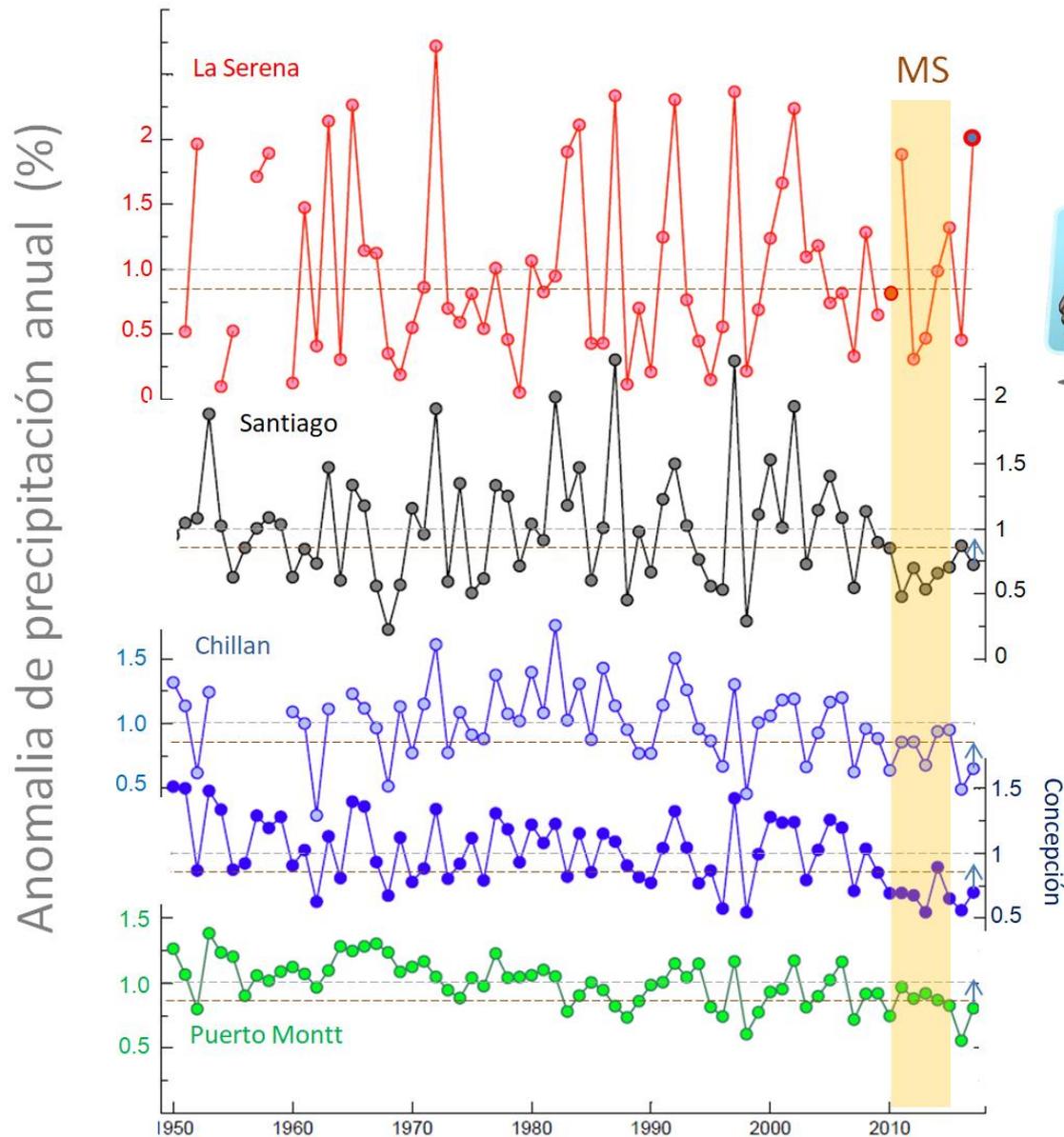


1900 1920 1940 1960 1980 2000 2020

Calentamiento en Chile?



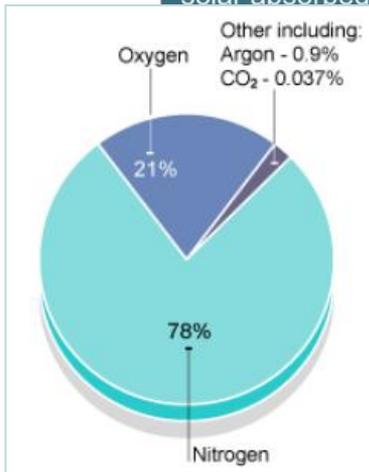
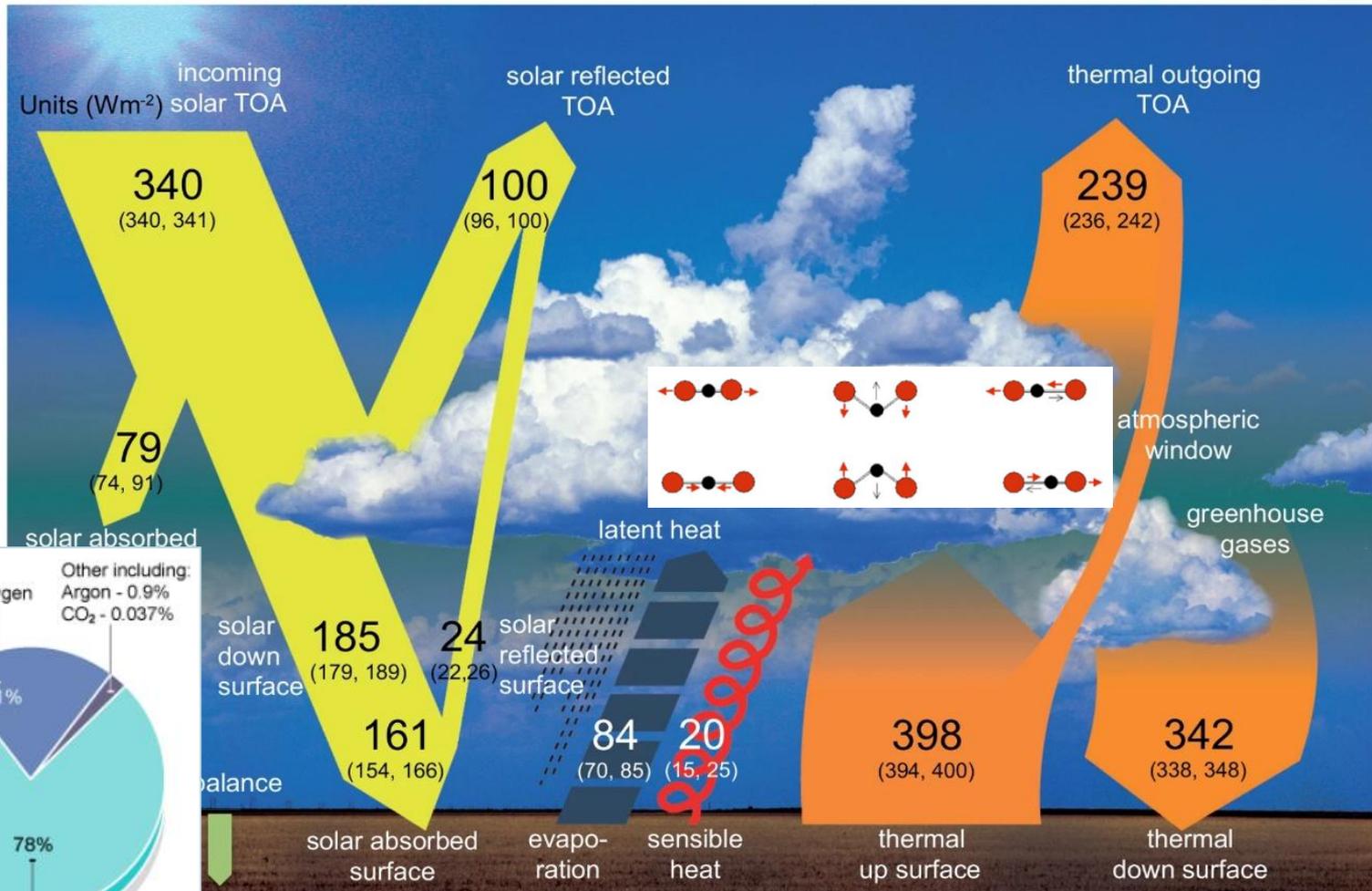
Y que pasa con la precipitación?



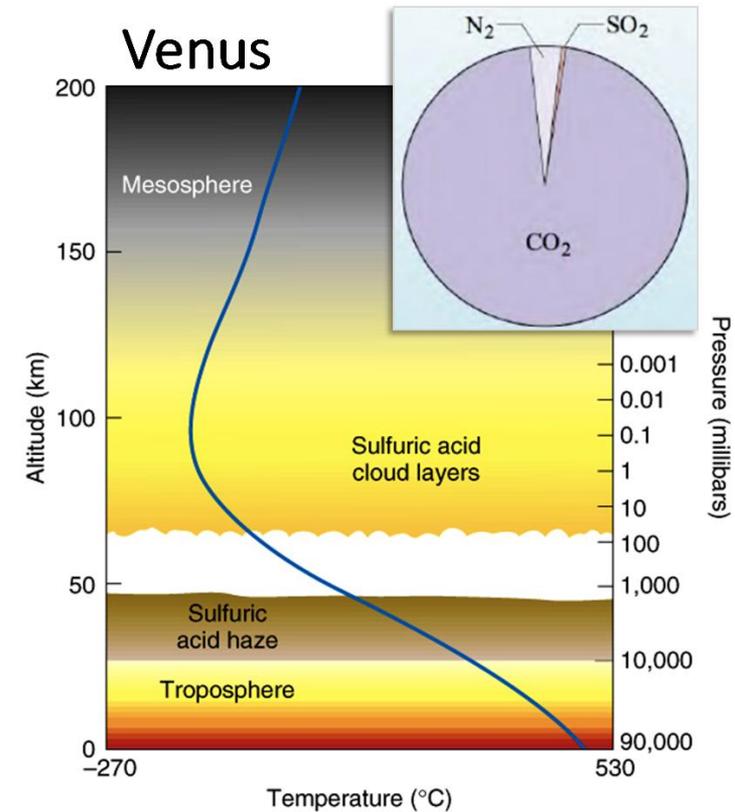
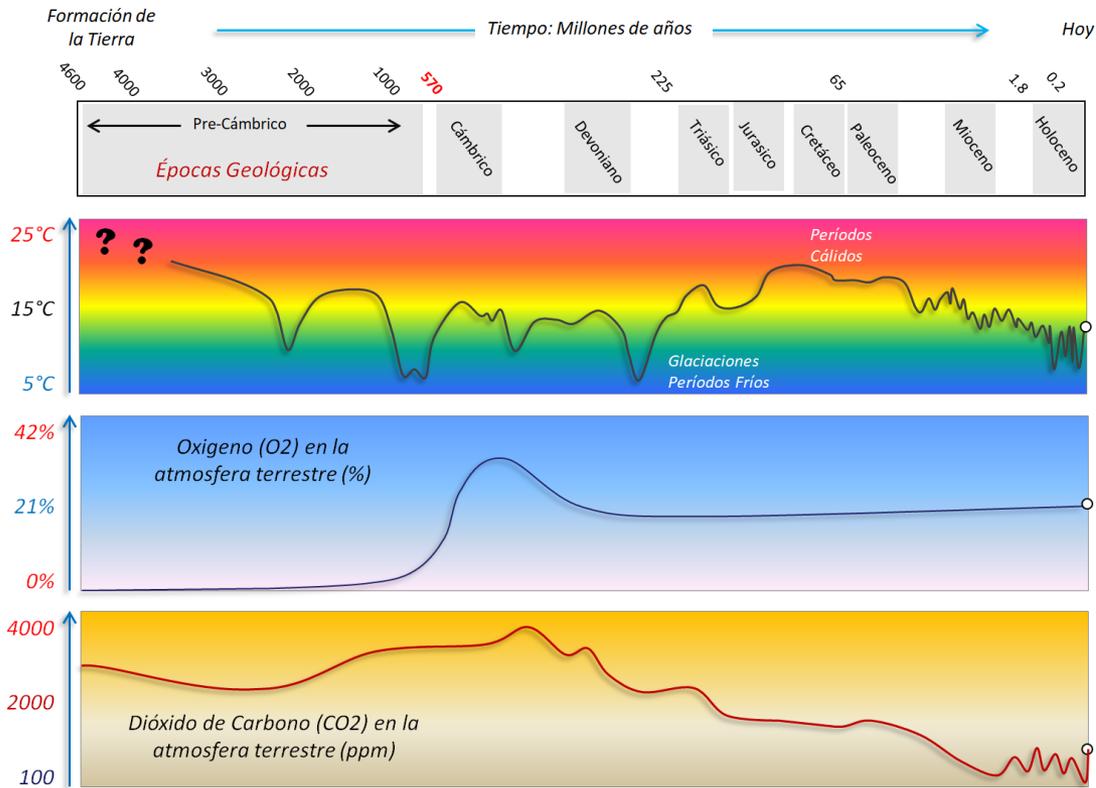
Efecto invernadero y cambio climático

Algo pequeño tiene un efecto grande....

CO₂, CH₄, H₂O and other gasses absorb longwave radiation emitted by the surface....



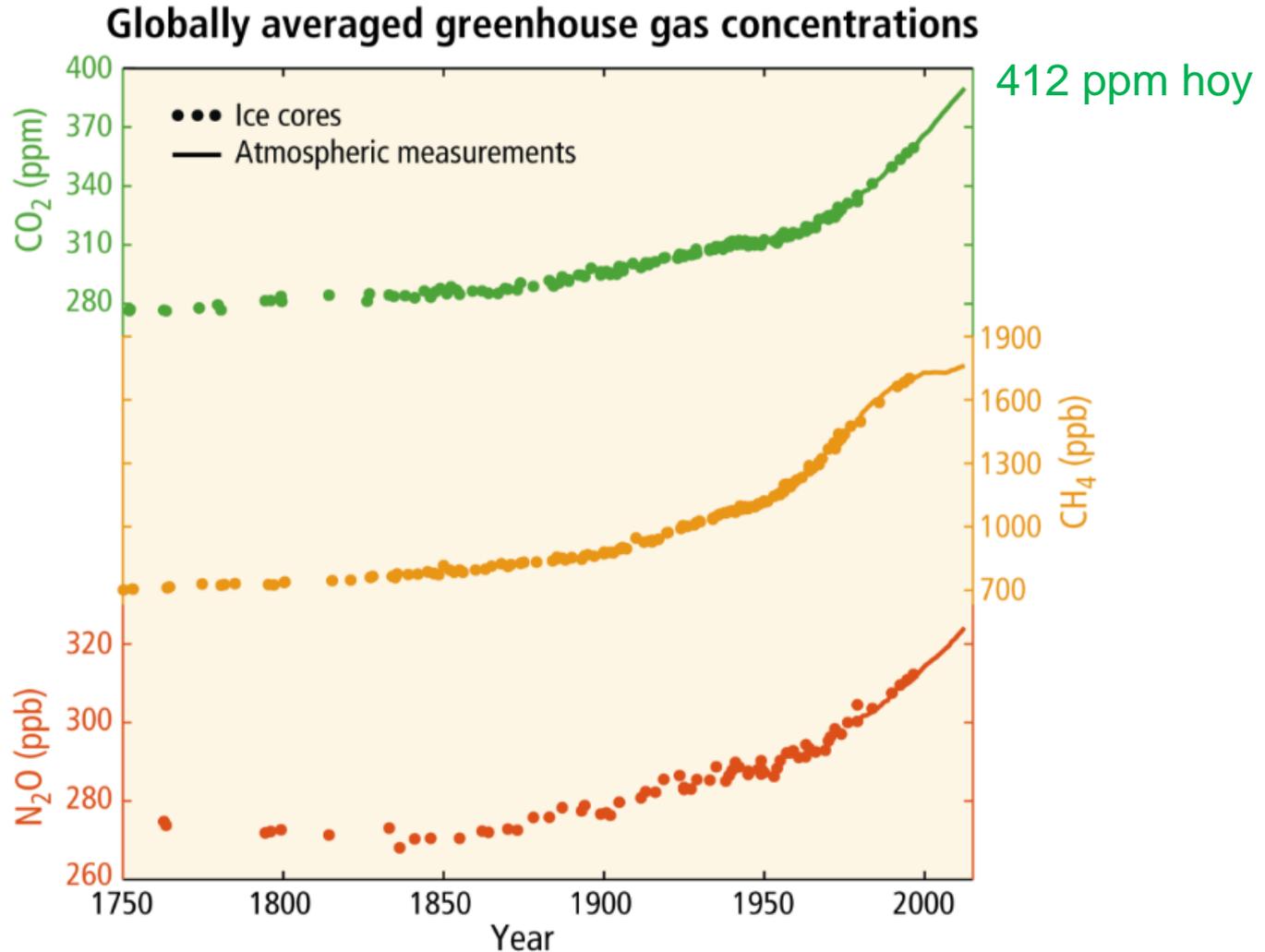
Evidencia paleo-climática y extraterrestre del control del CO2 en el Clima



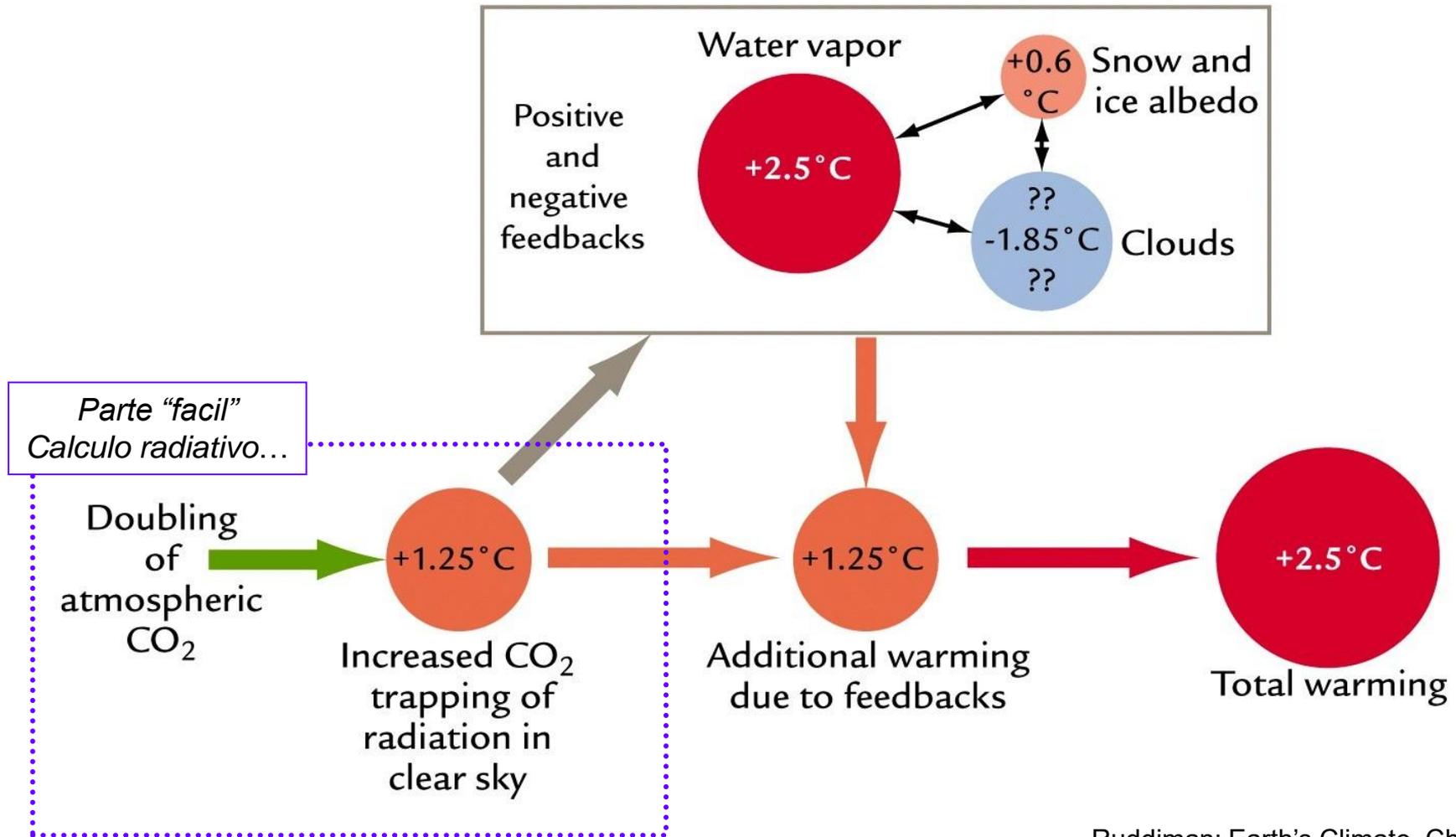
Efecto invernadero y cambio climático

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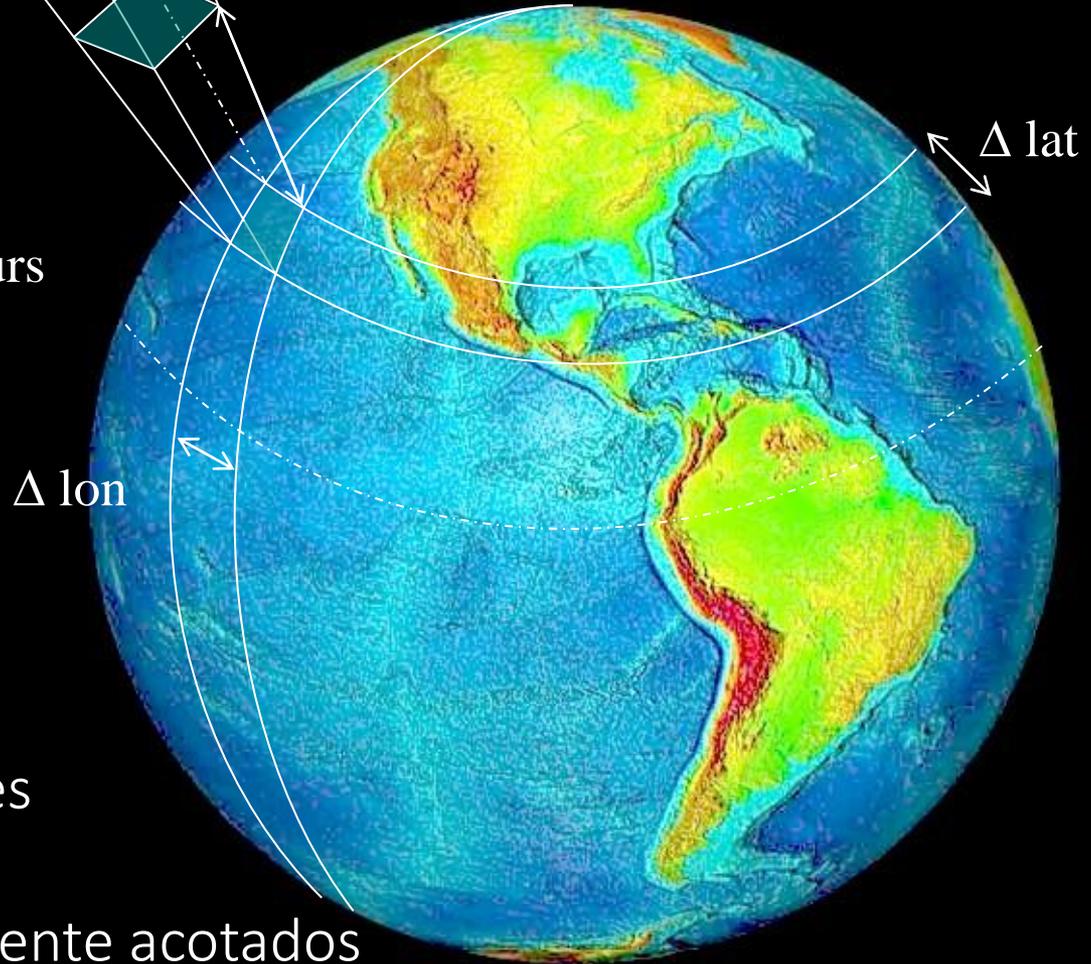


Retro-alimentación del sistema climático cambian la respuesta al incremento del CO₂



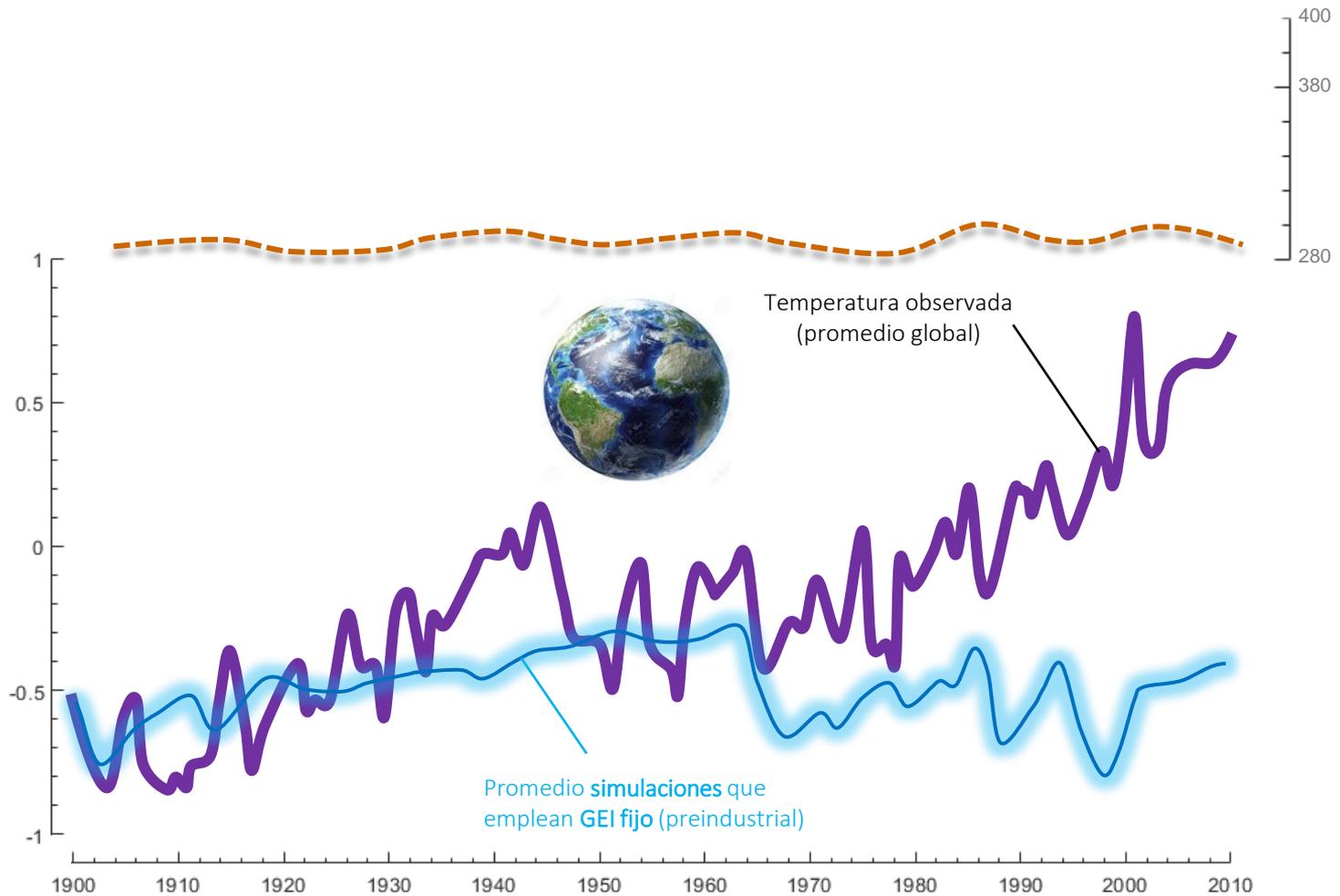
Global Circulation Models (GCM)

$\Delta \text{lat} \sim \Delta \text{lon} \sim 1^\circ - 3^\circ$
 $\Delta z \sim 1 \text{ km}$ $\Delta t \sim \text{minutes-hours}$

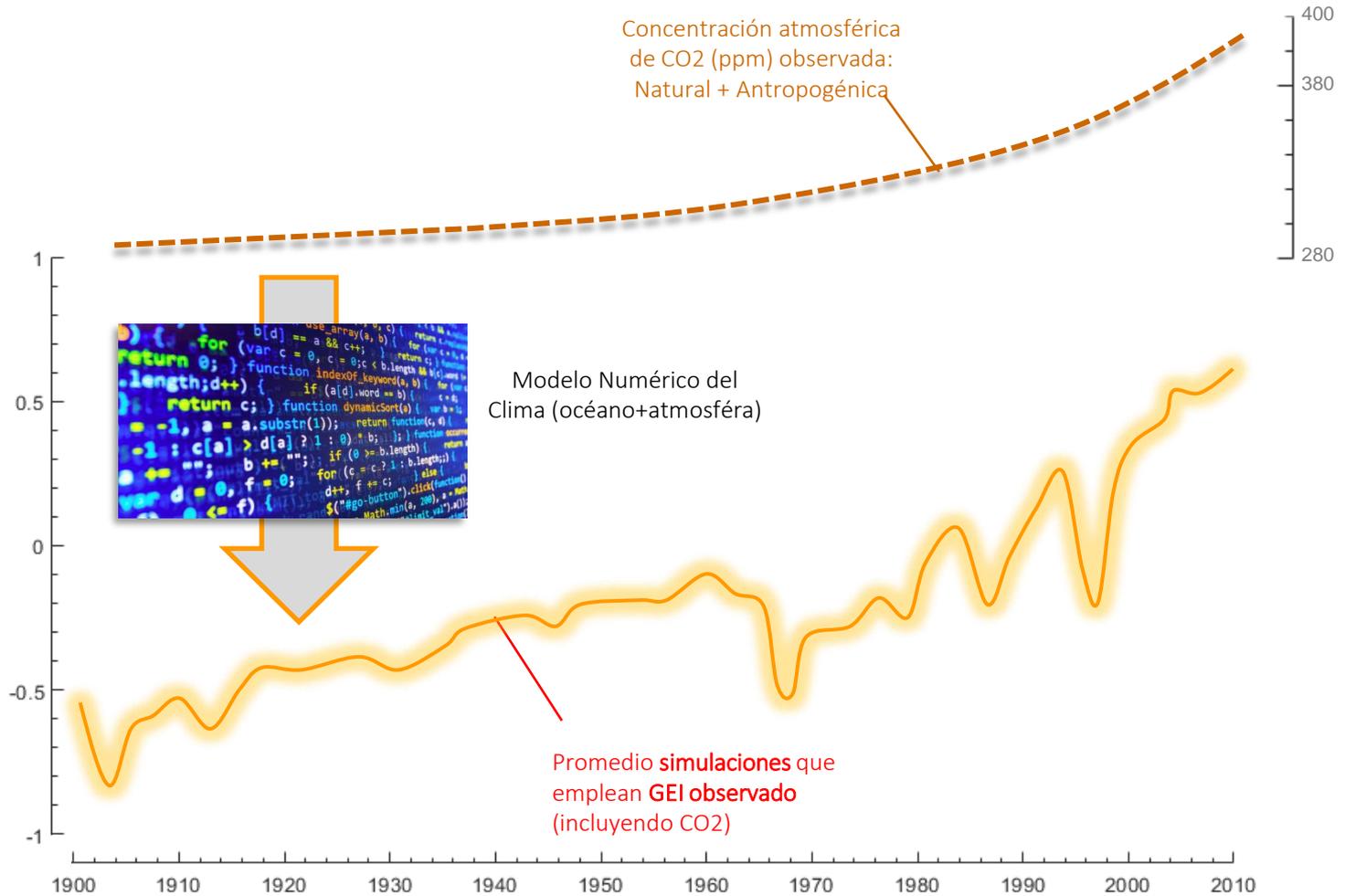


- ~ 10 ecuaciones/variables
- ~ 100 parámetros
- ~ 10 parámetros débilmente acotados
- Forzante GEI siglo XX conocido
- Forzante Aerosoles siglo XX menos conocido

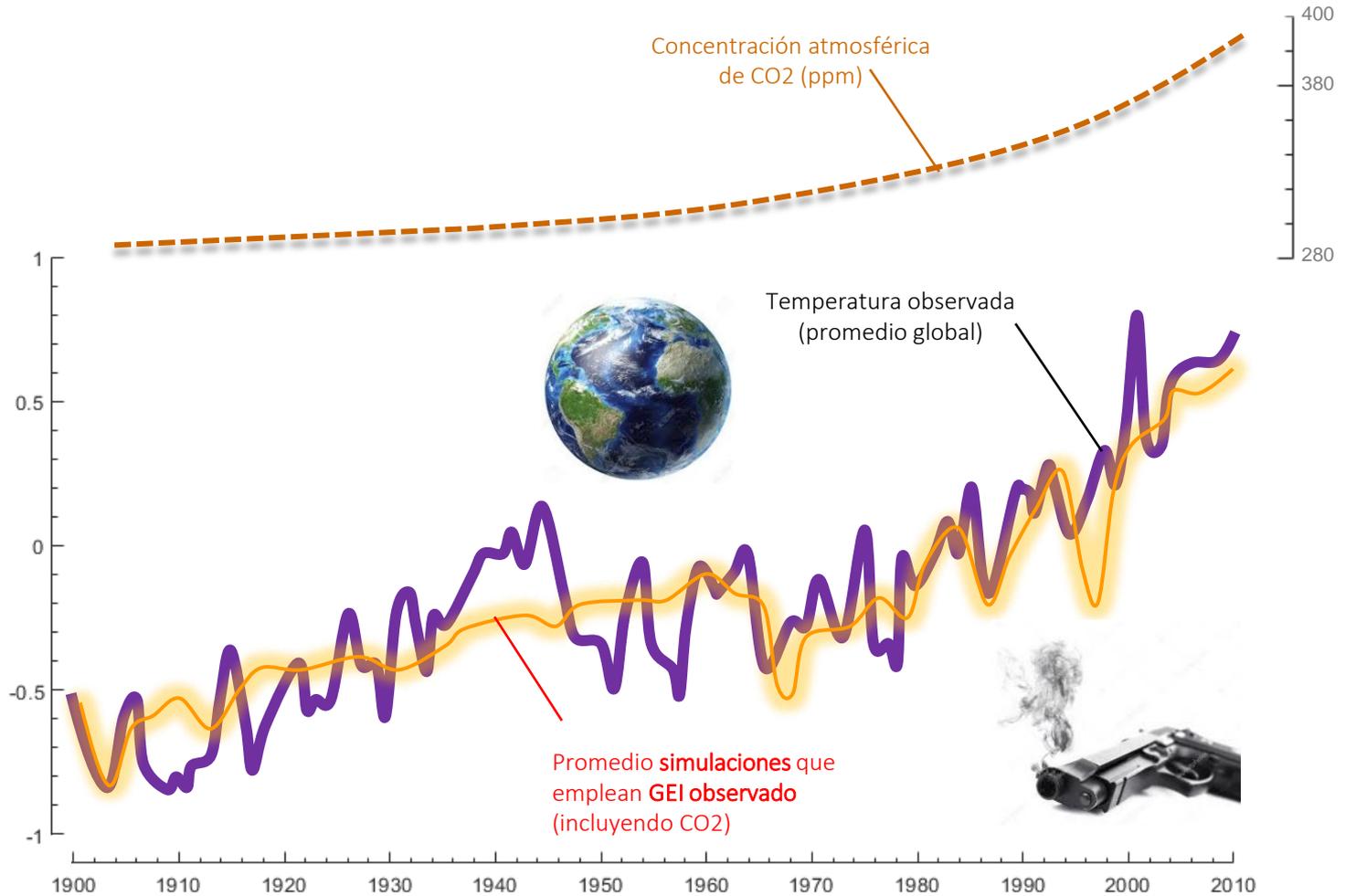
Cambios observados y simulados de Temperatura



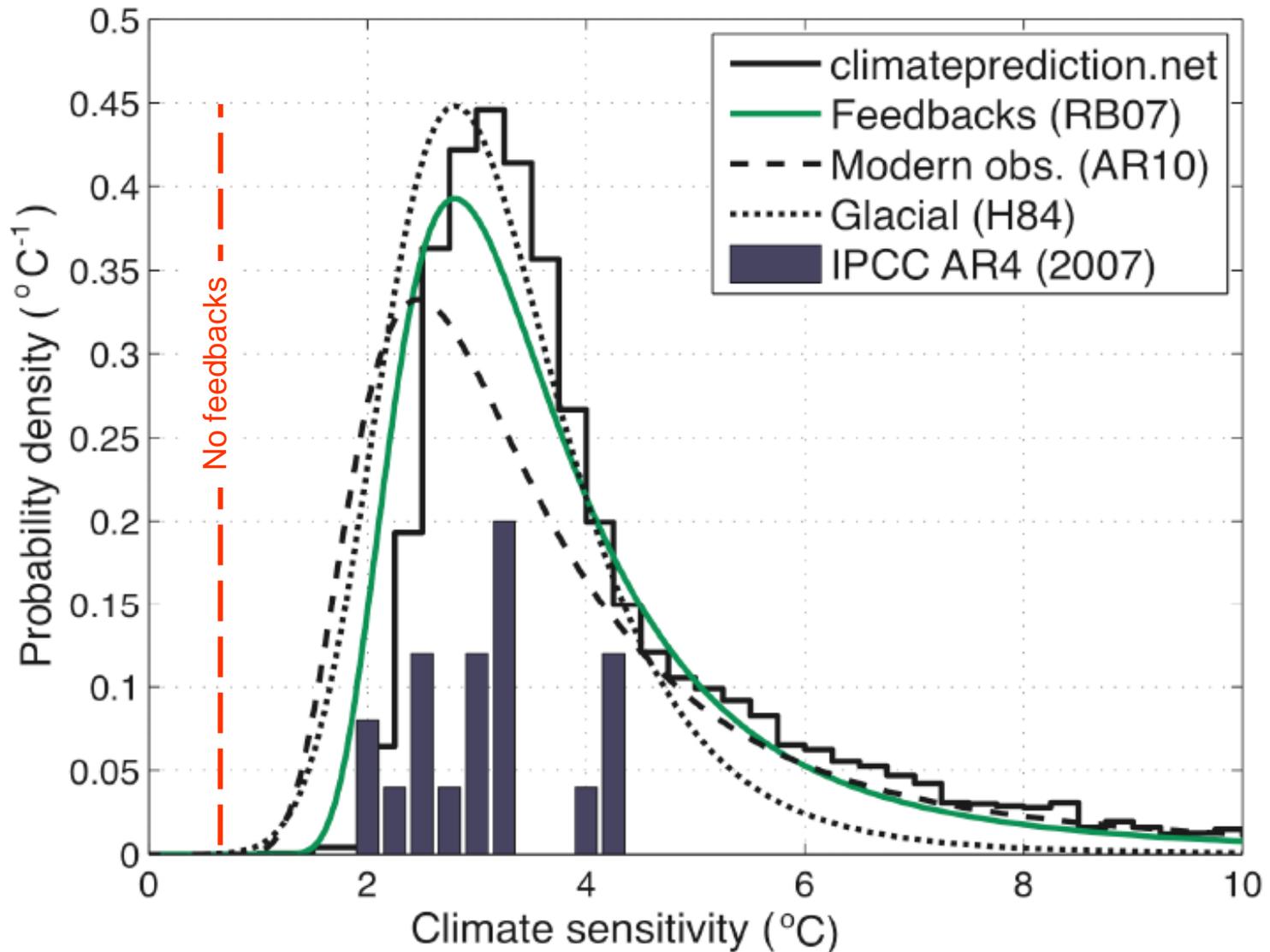
Cambios observados y simulados de Temperatura



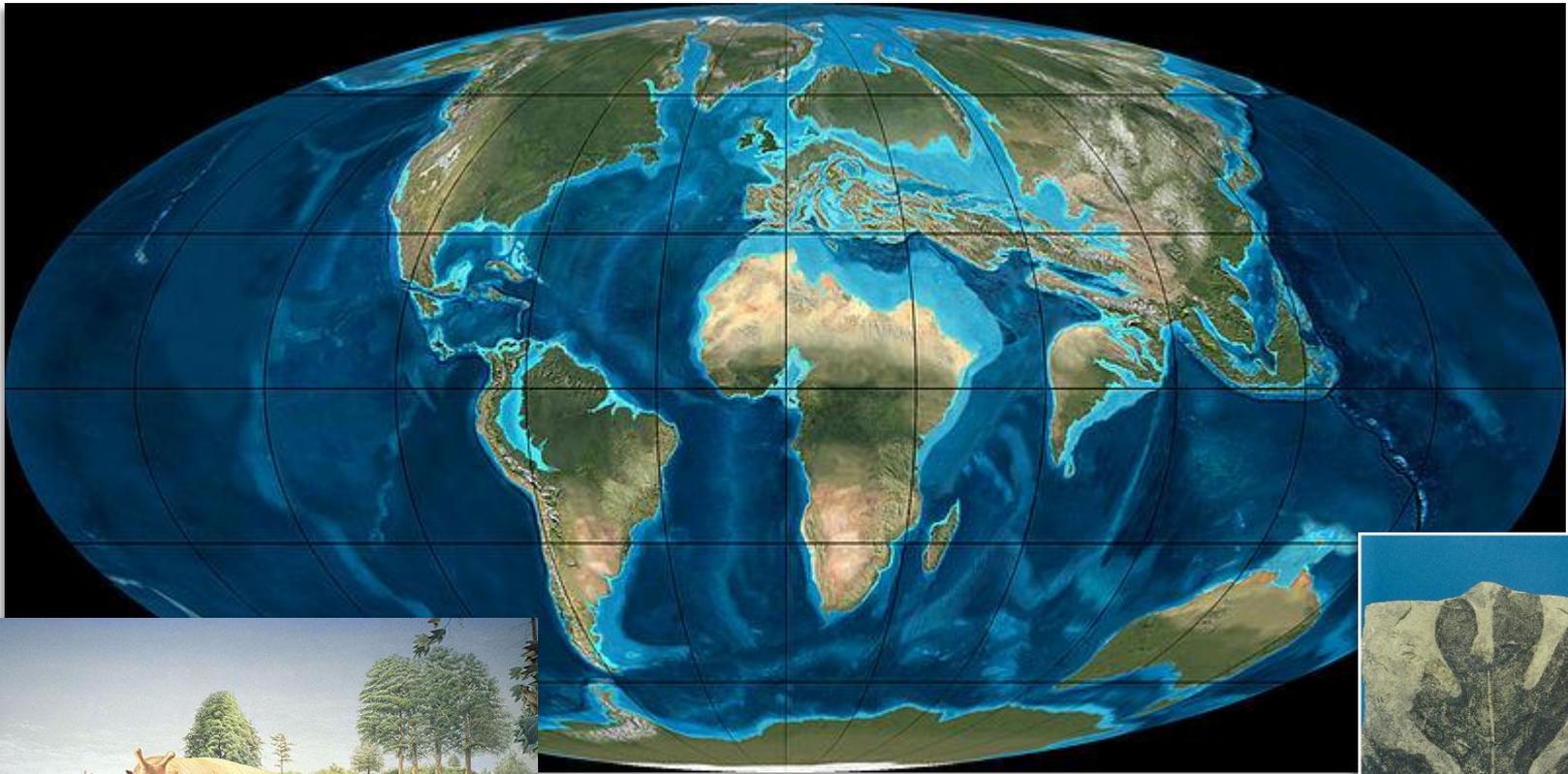
Cambios observados y simulados de Temperatura



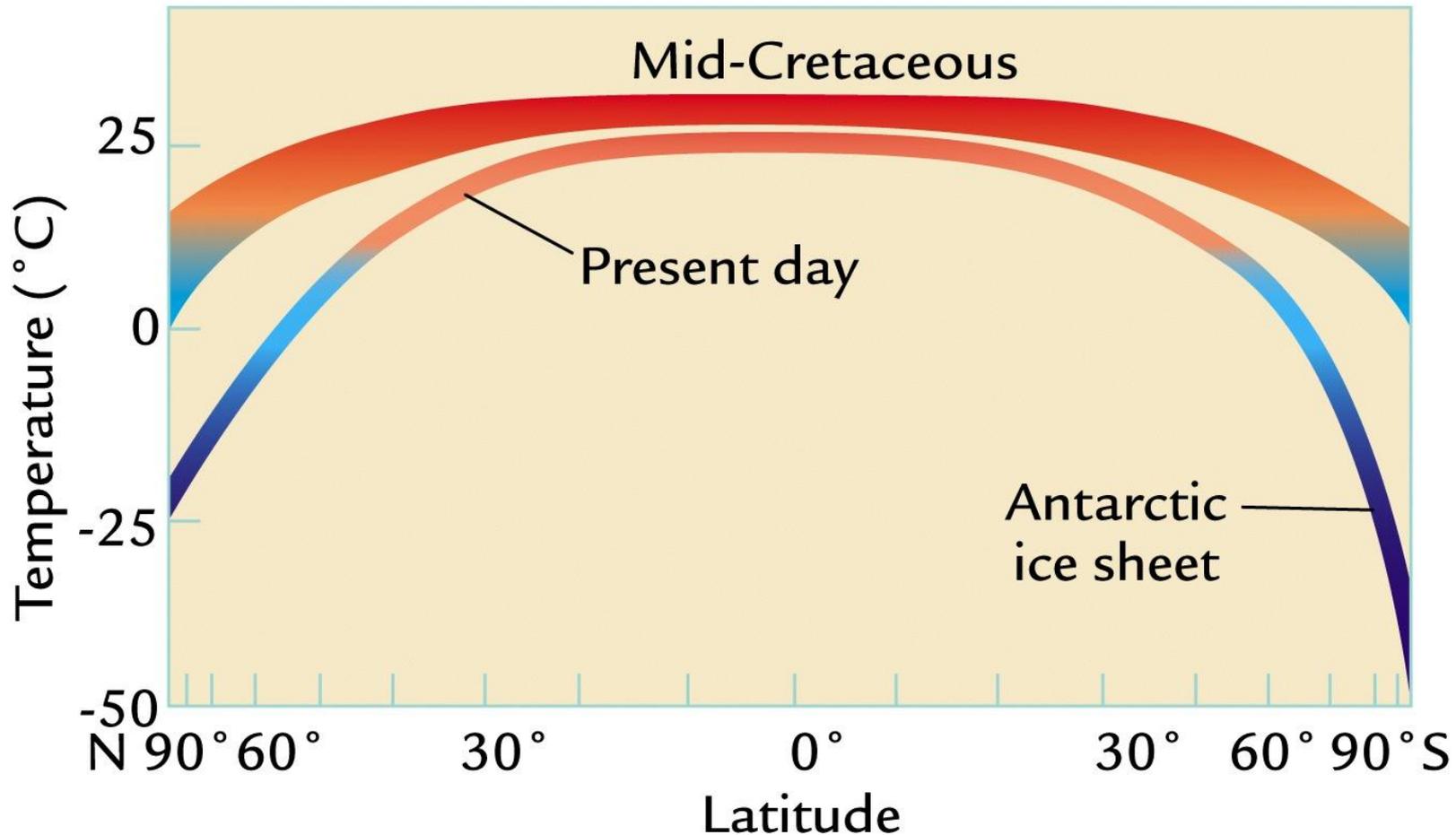
Sensibilidad climática: $\Delta T(2\times\text{CO}_2)$



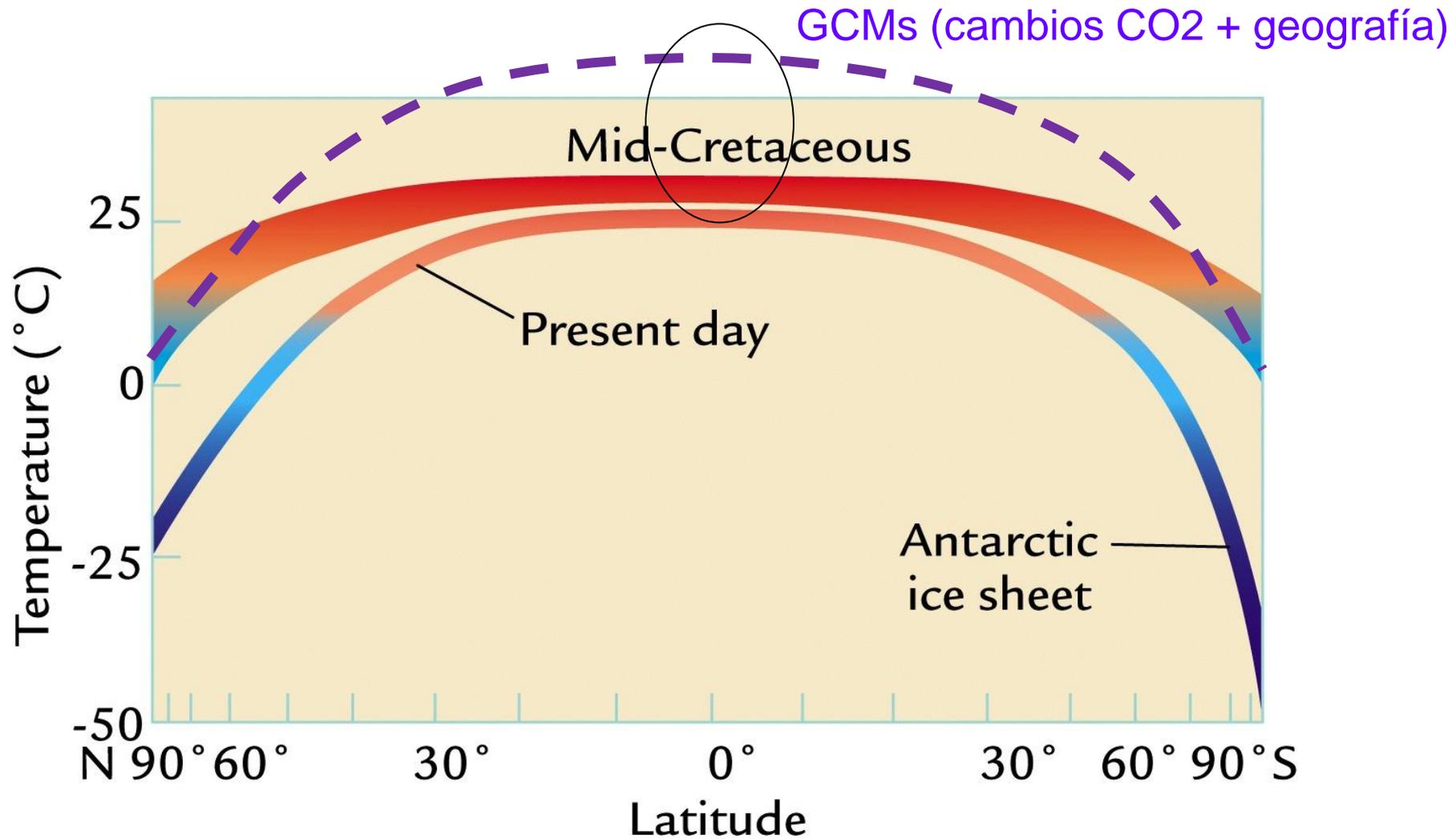
The long summer of the Eocene world (50-60 Myrs ago)



Modelos además presentan problemas en climas pasados
Termostato tropical? Múltiples equilibrios?



Modelos además presentan problemas en climas pasados
Termostato tropical? Múltiples equilibrios?



La aparente existencia de un termostato tropical y su falta de representación en GCMs es un problema... Sin embargo una buena culebra ayuda

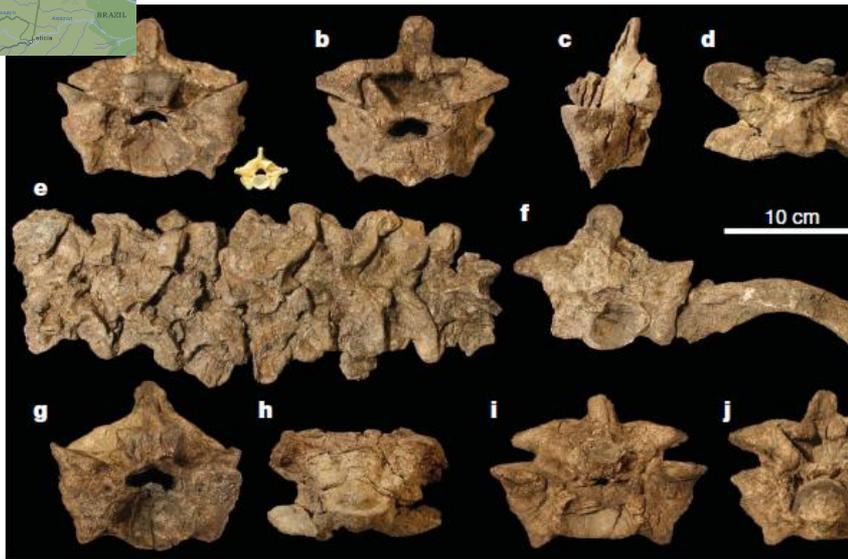


Figure 1 | *Titanoboa cerrejonensis* preloacal vertebrae. a, Type specimen (UF/IGM 1) in anterior view compared to scale with a preloacal vertebra from approximately 65% along the preloacal column of a 3.4 m *Boa constrictor*. Type specimen (UF/IGM 1) shown in posterior view (b), left lateral view (c) and dorsal view (d). Seven articulated preloacal vertebrae (e-j).

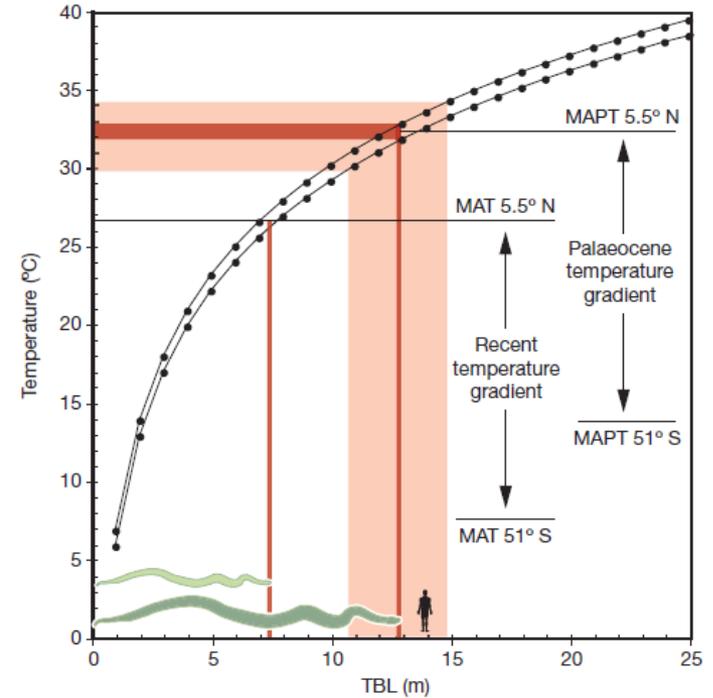
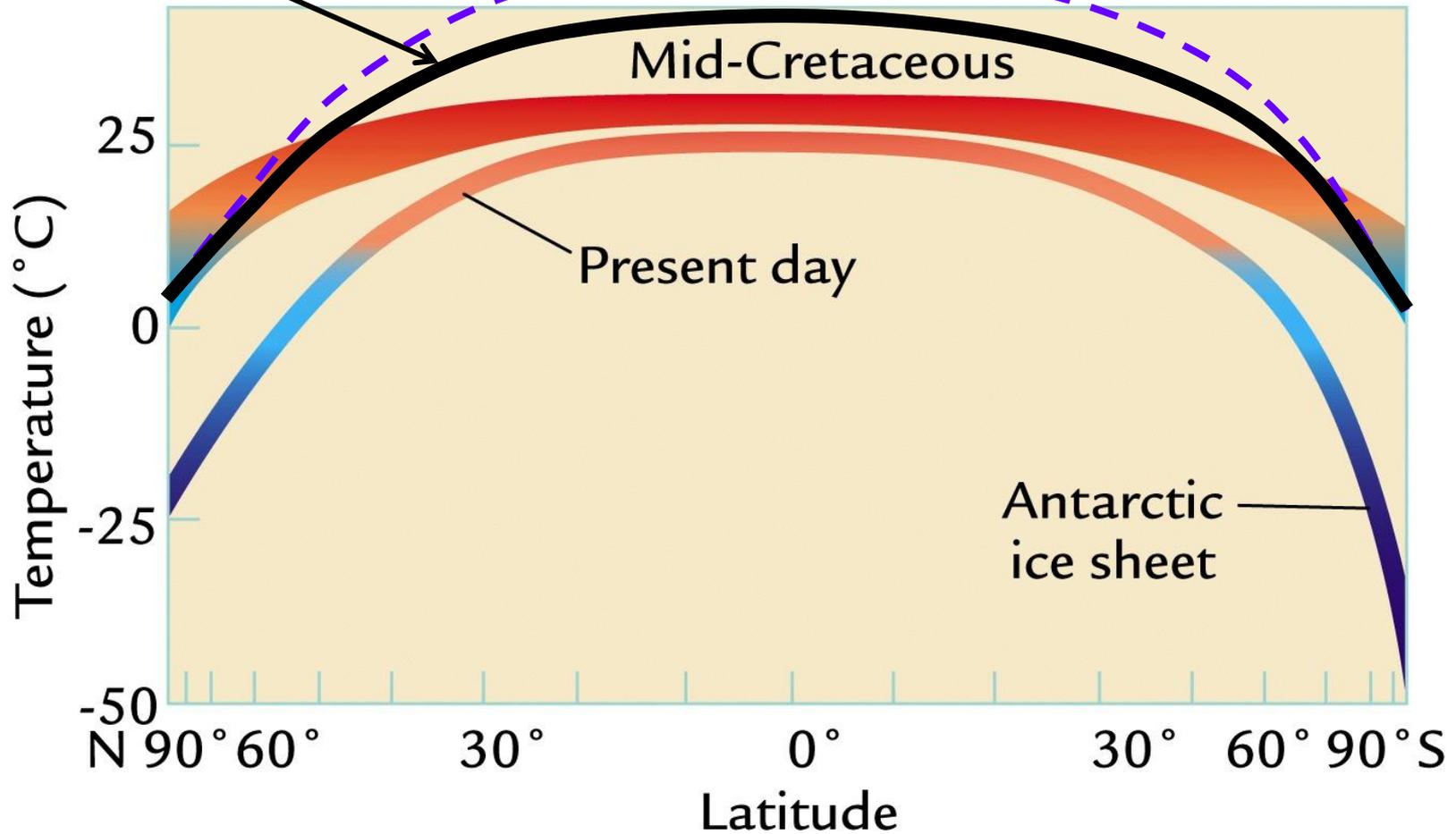


Figure 3 | Mean annual palaeotemperature and Palaeocene latitudinal temperature gradients derived from body size of the green anaconda *Euneectes murinus* (light green) and body size estimates of *Titanoboa cerrejonensis* (dark green). Curves represent model body size increases with

Reconstrucción incluyendo *Titanoboa* otorga más credibilidad a GCMs

Reconstrucción
con culebra

GCMs (cambios CO₂ + geografía)



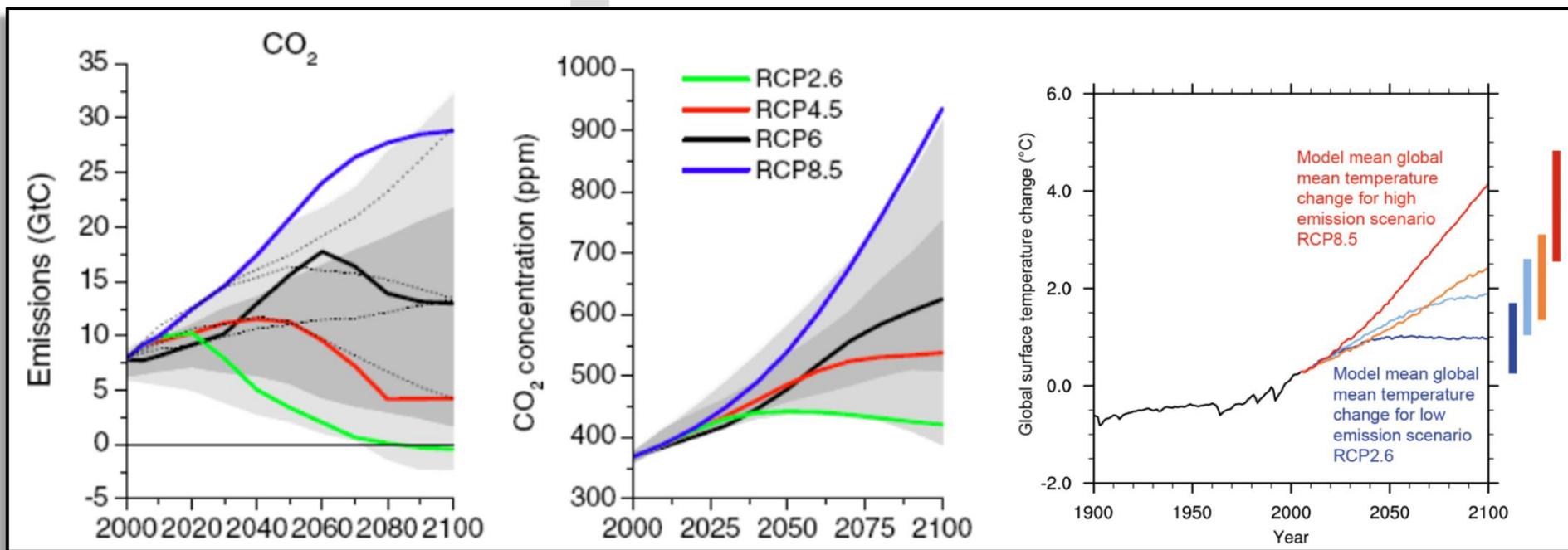


Però come viene la mano?

La gran incertidumbre: cuanto CO2 habrá en el futuro?

Socio-economic development
pathways

Climate Scenarios



Balance
De Masa

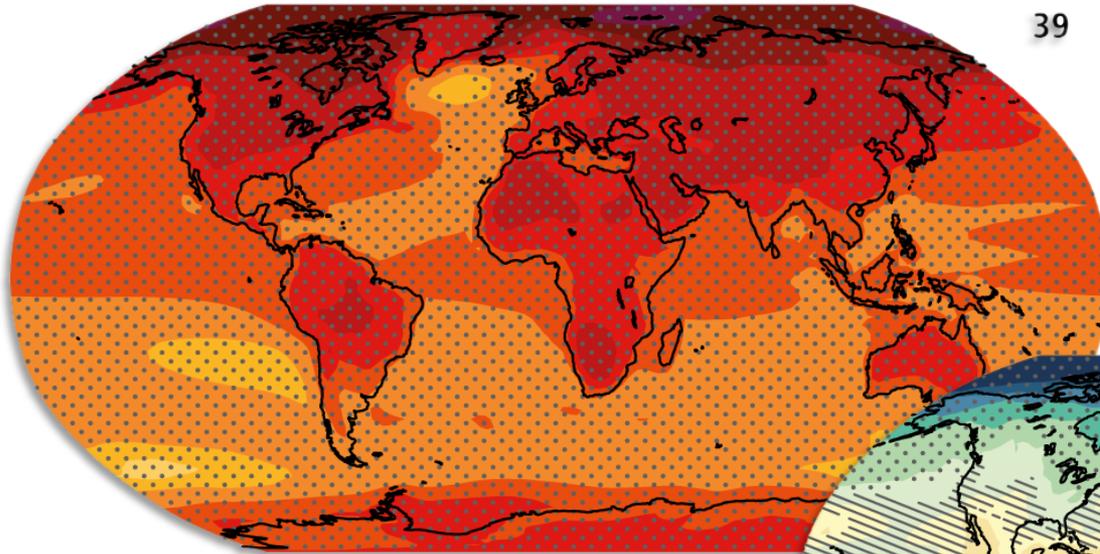
GCMs (more than 40)

Proyecciones Climáticas Globales

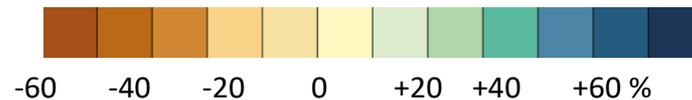
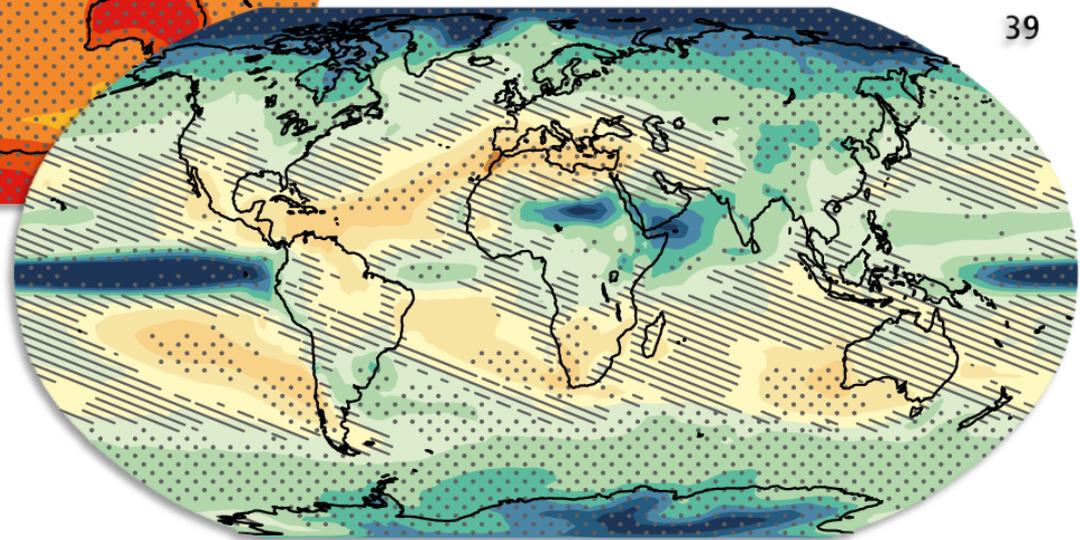
para fines del siglo XXI bajo escenario RCP8.5
(1000 ppm CO₂ a fines de siglo)

Promedio 39 GCM

Temperatura



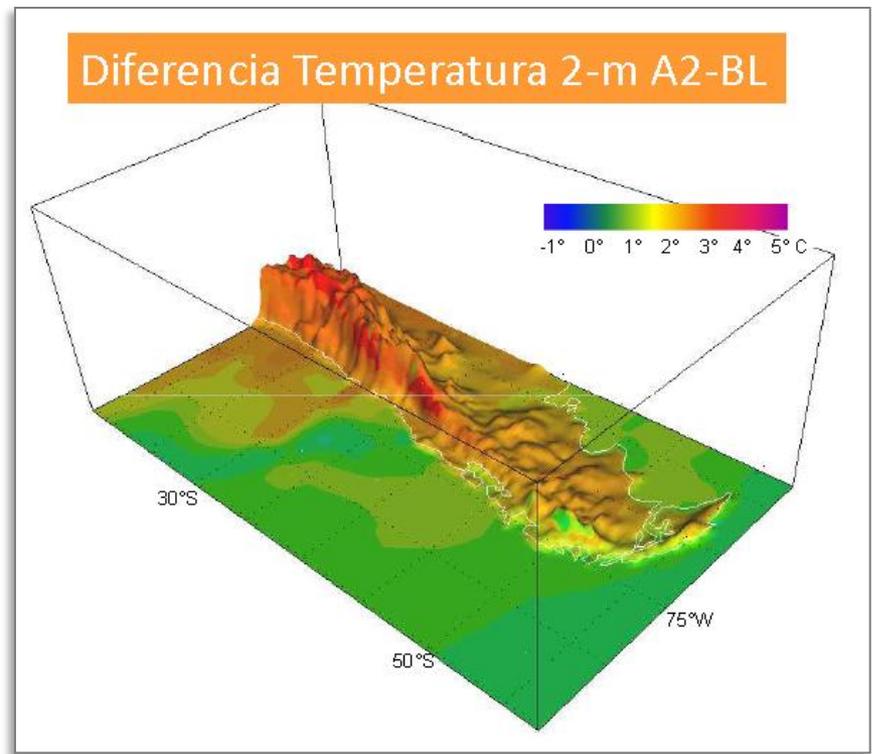
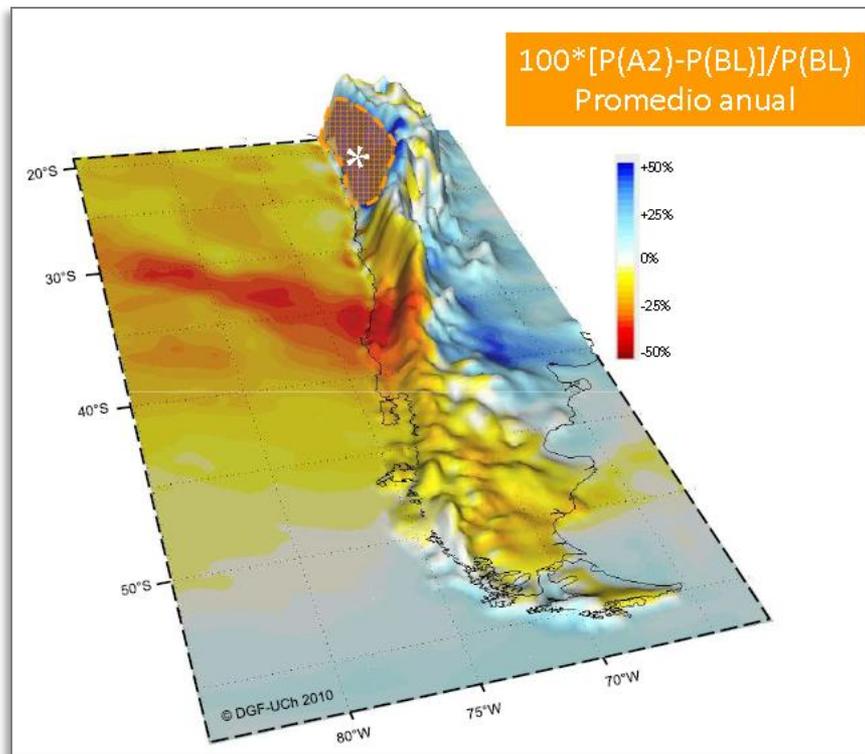
Precipitación



Impactos Regionales del Cambio Climático

- Aumento de temperatura 2.5-3.5°C (*)
- Disminución de precipitación 25-35% (*)

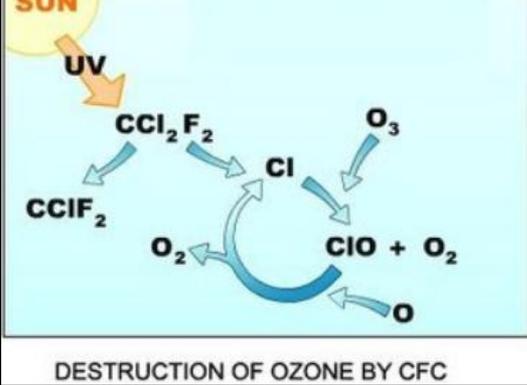
(*) **Proyección a fin de siglo bajo escenario A2**



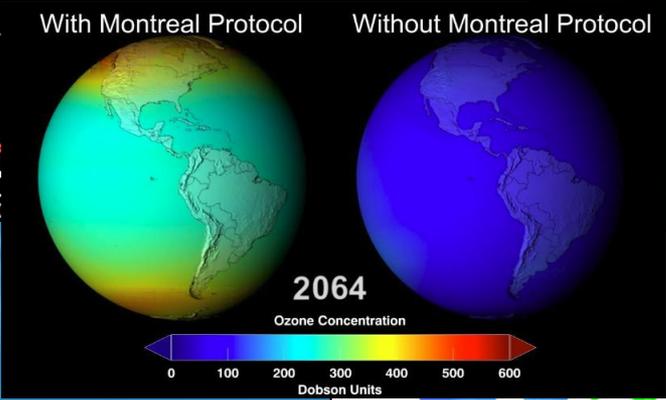
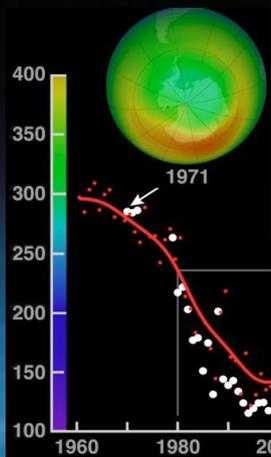


Podremos salvar al
Oso polar?

Se acuerdan del
agujero de la
capa de Ozono?



Se acuerdan del agujero de la capa de Ozono?

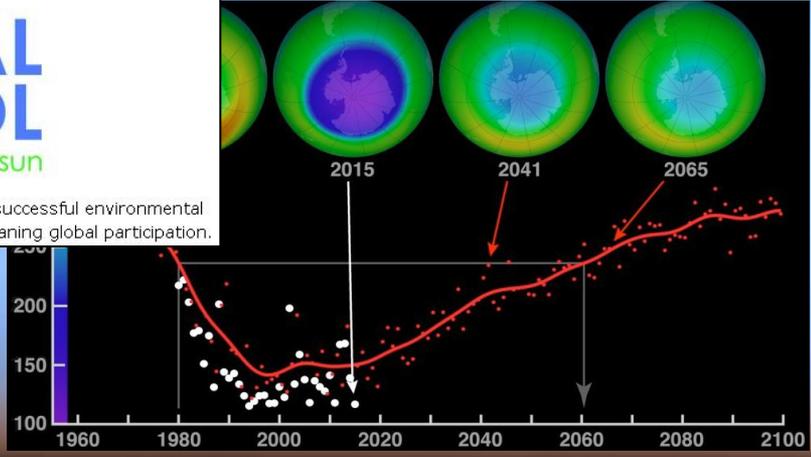


50

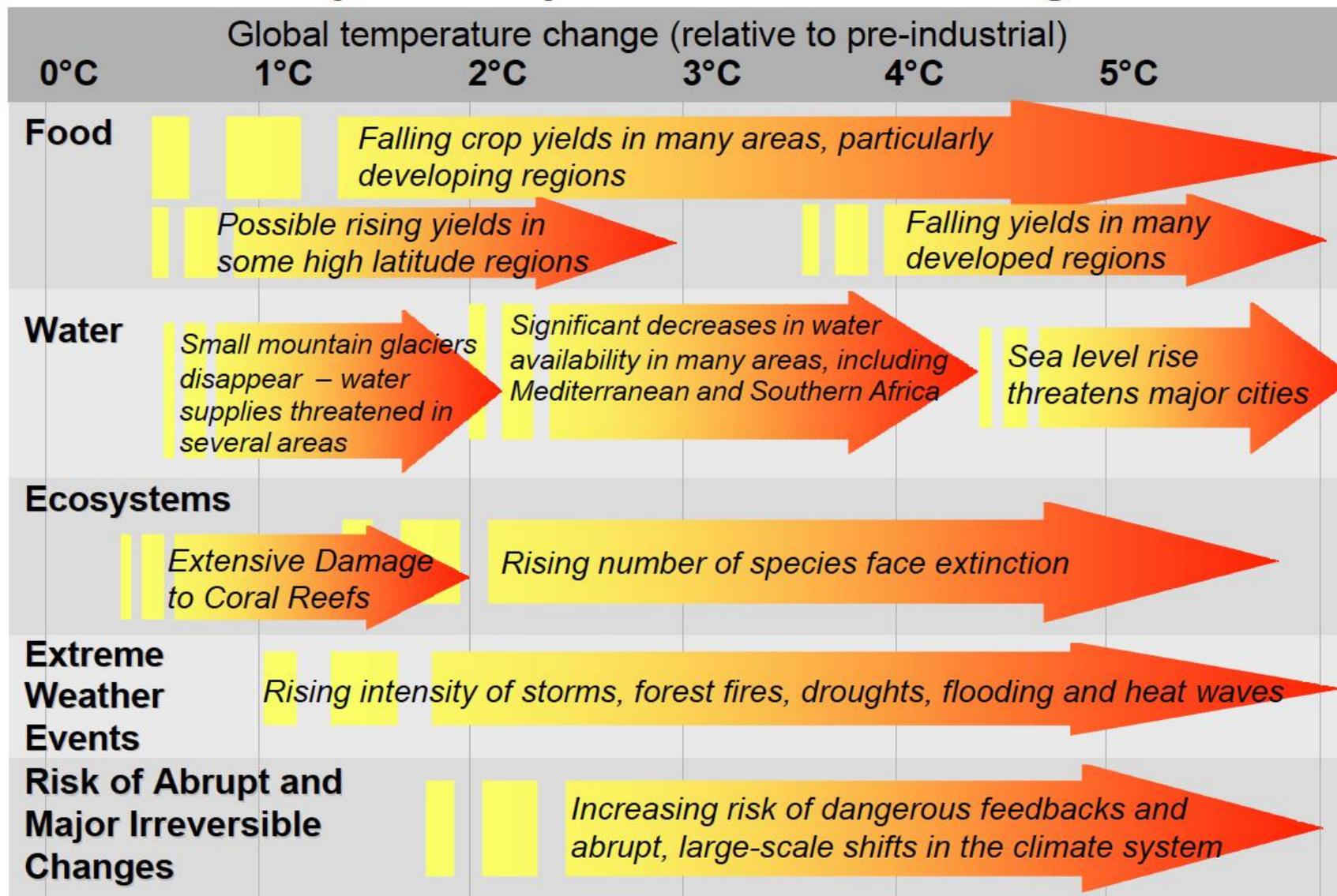
MONTREAL PROTOCOL

caring for all life under the sun

The Montreal Protocol is the world's most successful environmental treaty. It now has universal ratification, meaning global participation.



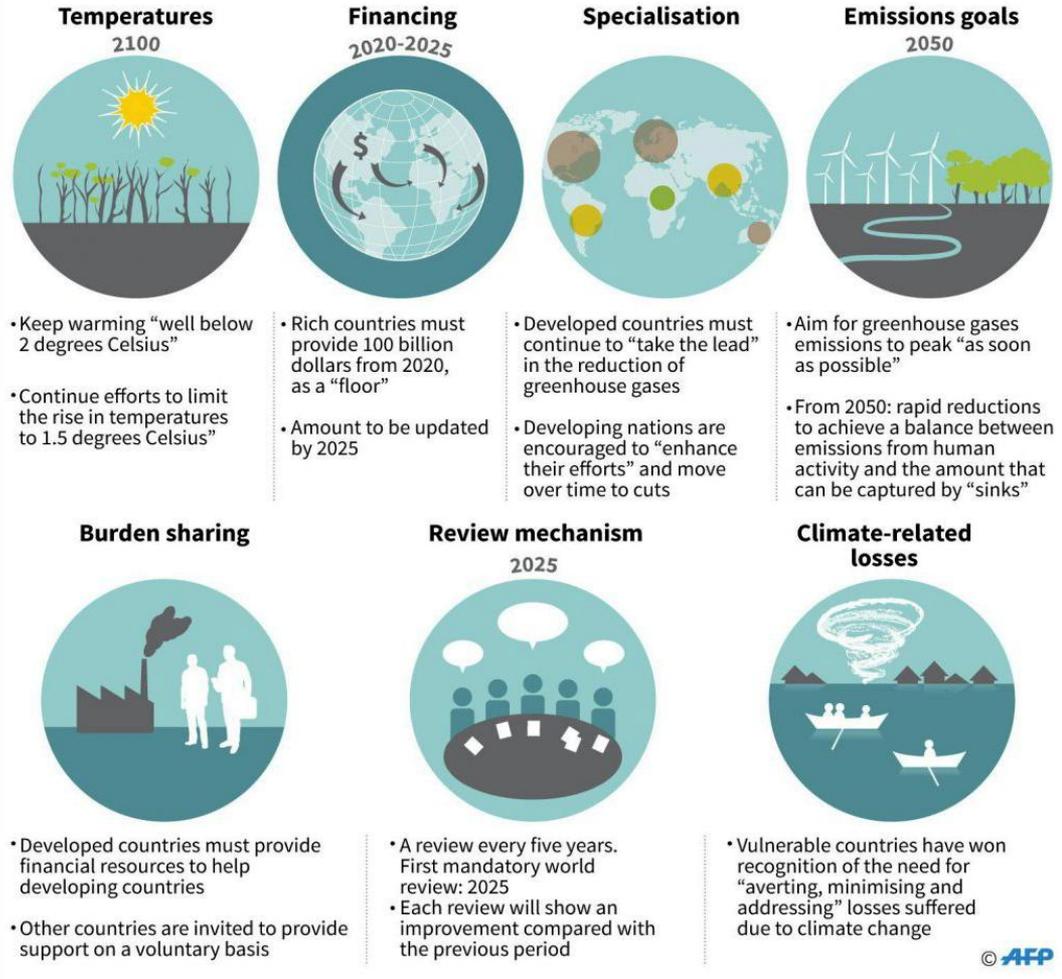
Projected Impacts of Climate Change



Las Buenas Noticias Acordamos <2°C, <1.5°C



The Paris climate agreement: key points

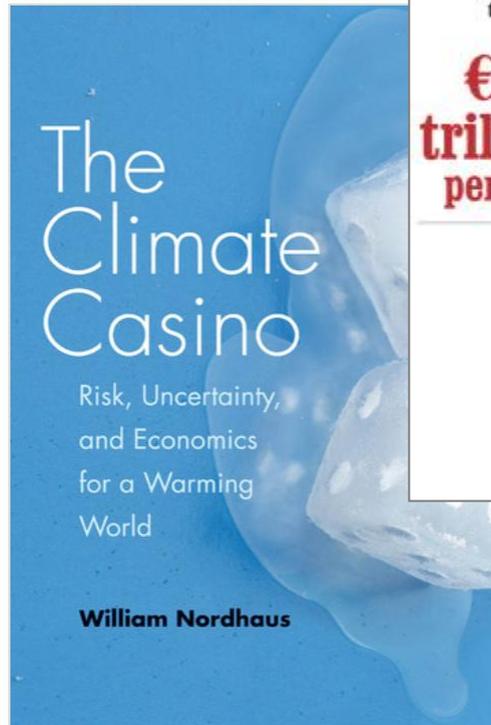


The Economic Impacts of Climate Change

Richard S. J. Tol*

Introduction

For such a fractious discipline, there has been remarkable agreement among economists concerning the first-best climate policy. Ever since the writings of Nordhaus (1977), d'Arge (1979), and Schelling (1992), it has been widely recognized that climate change is a negative externality and that greenhouse gas emissions should preferably be taxed. Although there continues to be a vigorous debate about the long-term (Stern et al. 2006; Nordhaus 2013), most economists agree that climate change is a significant risk to the world economy.

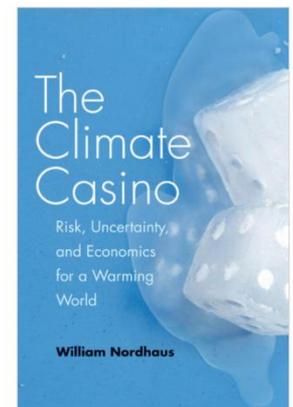
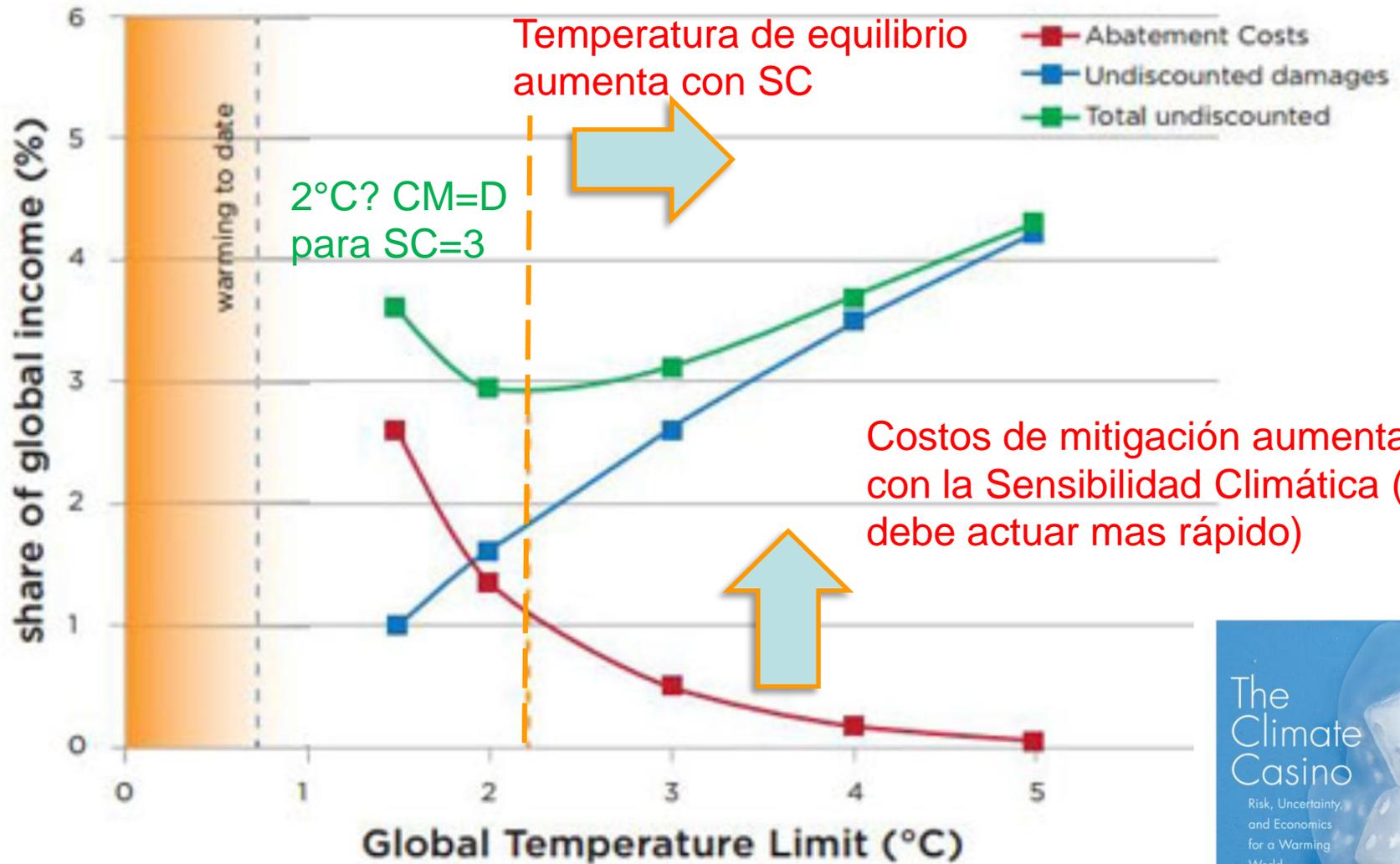


Climate change could cost the world at least **€ 2.6 trillion per year**



Reducing emissions would cost around **€ 0.5 trillion per year**





CAT, Nov 2016



Las Noticias
 Compromiso
 nacionales e
 en meta glob
 COP21 (2016)
**MITIGAR
 NO ES GRA**

Chile – Progress on coal-phase out but still more work to do – CAT, May 2018

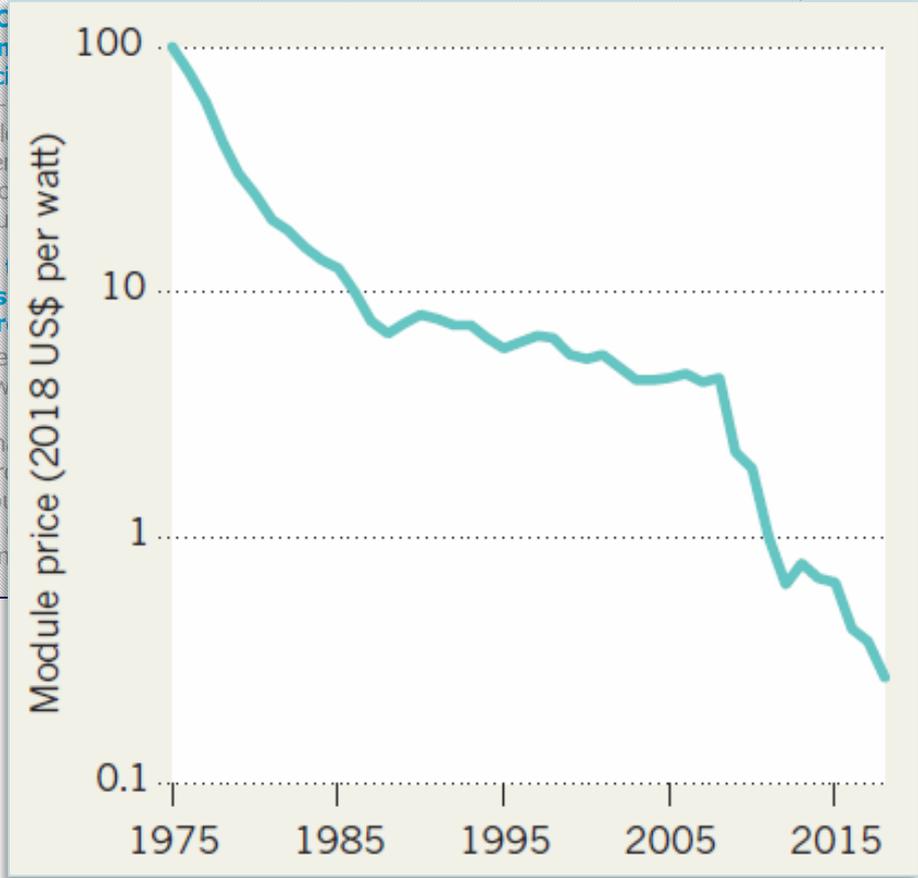
Pero las cosas cambian rápidamente...

In early 2018, Chile's coal power plants are expected to account for 44% of electricity generation. Chile, where coal-fired power plants are still to comparatively large extent, published in December 2017 plans to add new plants beyond those expected to account for 44% of electricity generation.

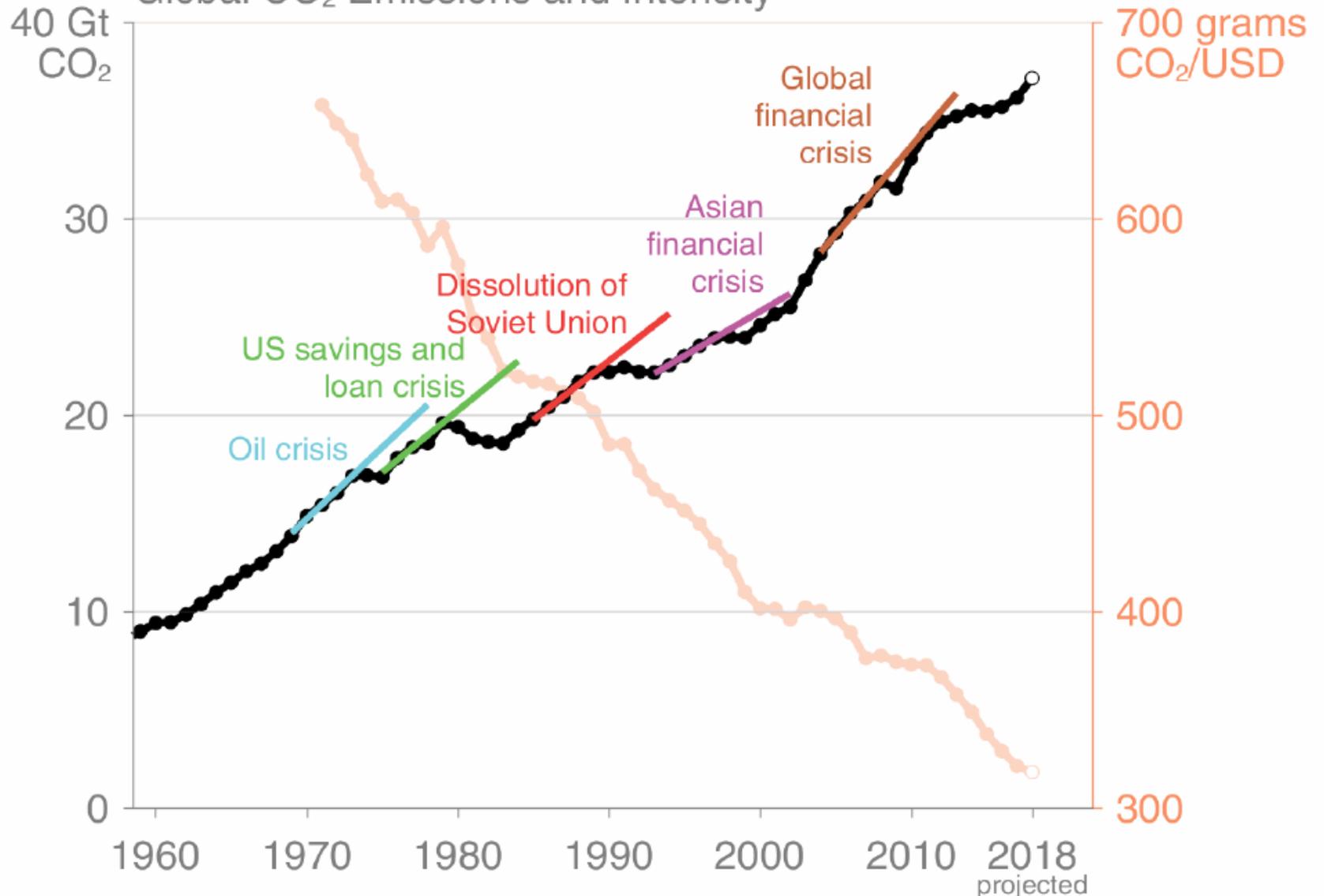
The changes in Chile's renewable energy capacity in 2017 are as low as in previous assessments. (Ministerio de Energía y Minería de Chile)



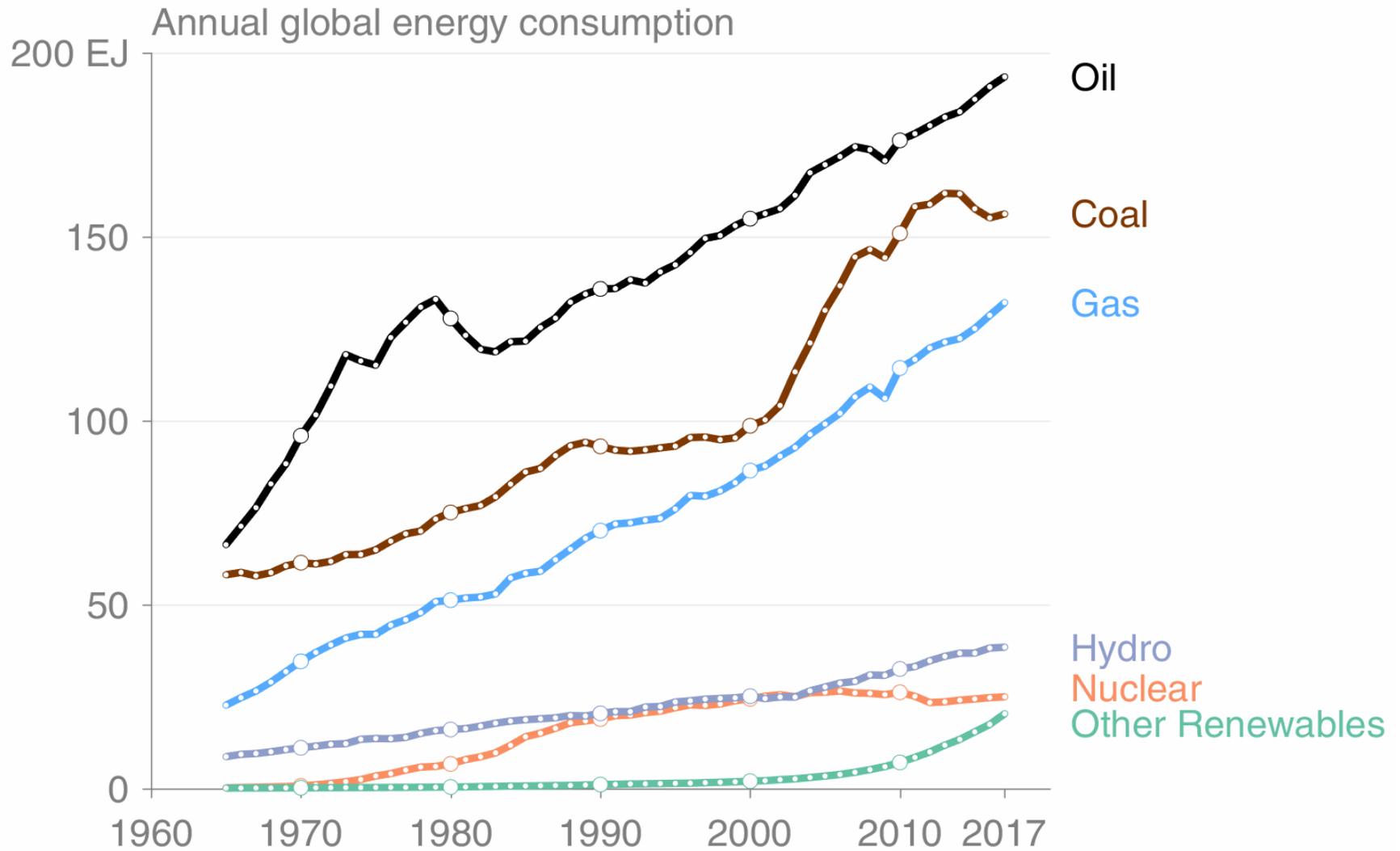
The updated scenario shows a downward shift from 2017, with emissions lower than previous assessments. The updated scenario is "Highly Insufficient".



Global CO₂ Emissions and Intensity



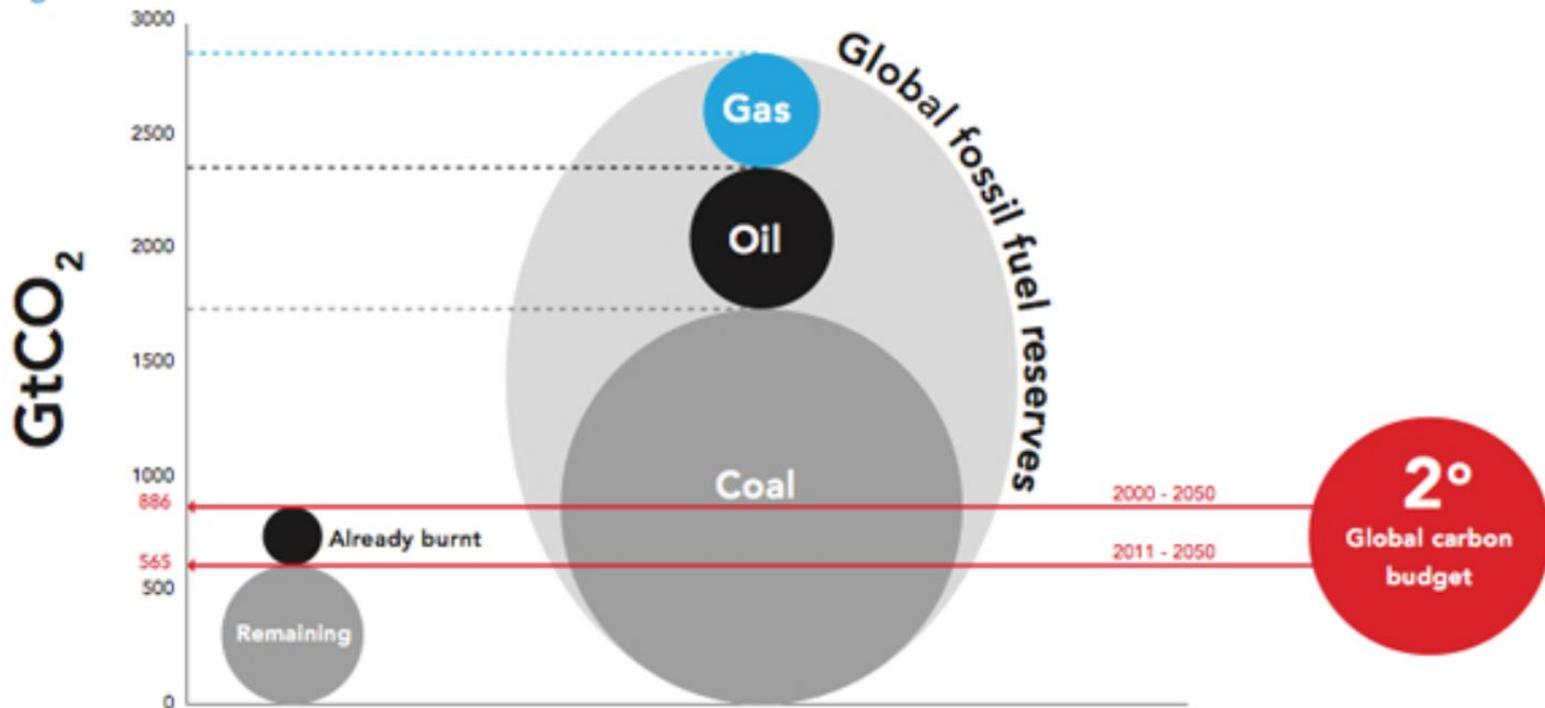
El vaso medio vacío



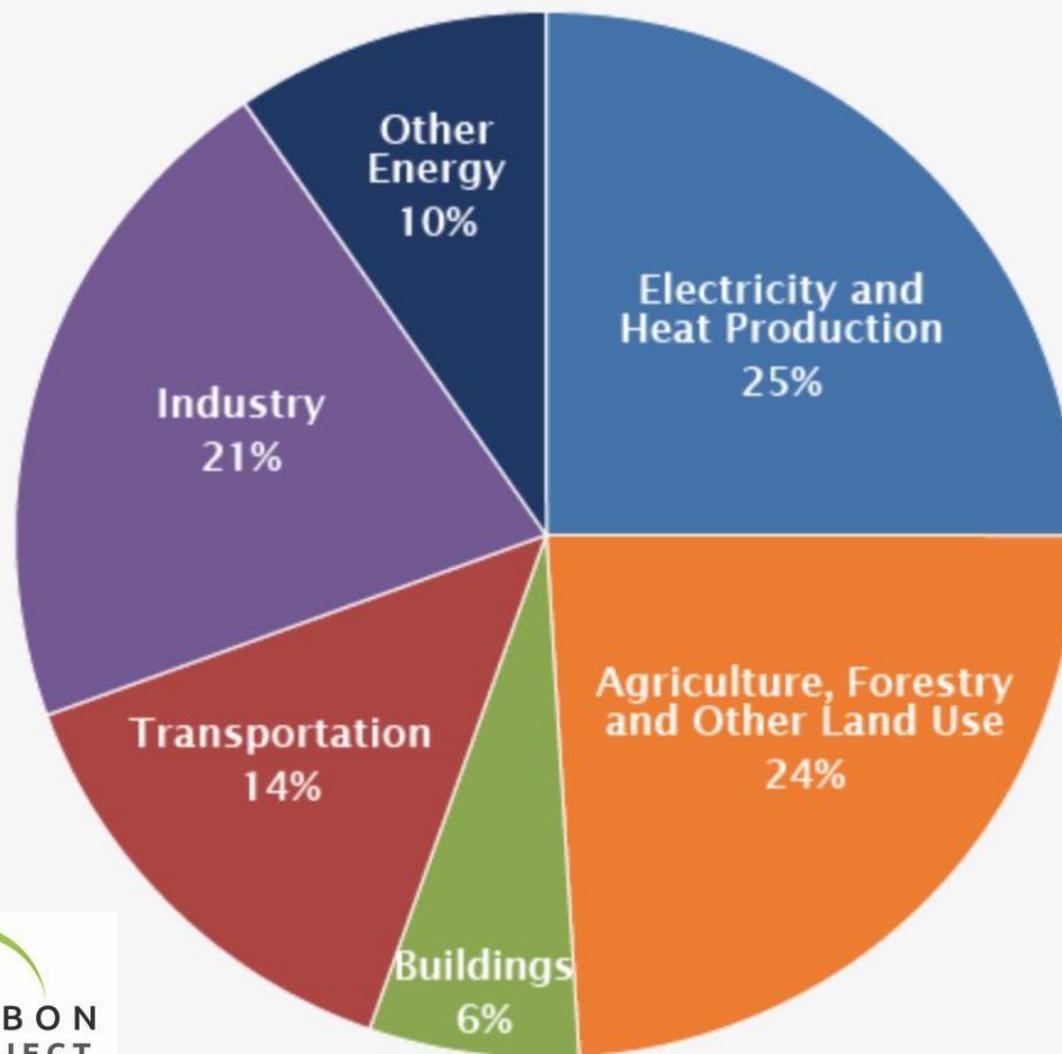
El vaso medio vacio

Comparison of the global 2°C carbon budget with fossil fuel reserves CO₂ emissions potential

Fig.1

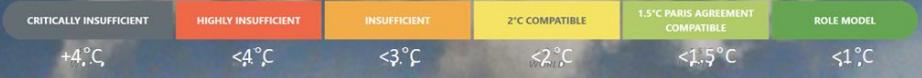


Global Greenhouse Gas Emissions by Economic Sector



CAT, Nov 2016

Las Noticias:
Compromisos nacionales e Impacto en meta global de COP21 (2016)
MITIGAR NO ES GRATIS!



CAT, Nov 2016



Las Noticias
Compromiso
nacionales e
en meta glob
COP21 (2016)
**MITIGAR
NO ES GRA**

Pero las
cosas cambian
rápidamente...

Chile – Progress on coal-phase out but still more work to do – CAT, May 2018

In early 2018, Chile announced that it will not build any new coal-fired power plants and will phase out the existing plant stock—which makes up 44% of electricity generation—by 2050. This is in line with current trends in Chile, where coal-fired power plant permitting has stalled in recent years in response to comparatively low costs of renewable energy. Chile’s revised energy sector planning, published in December 2017, already reflects this change, with no additional coal plants added beyond those under construction today. Renewables, in contrast, are expected to account for 56% of electricity generation in 2030.

The changes in the energy supply sector are substantial compared to previous assessments, and are linked to the increasingly lower costs for renewable energy in Chile, particularly solar, in comparison to coal

(Ministerio de Energía 2017b; IRENA 2015). Current solar PV and onshore wind costs in Chile are as low as USD 0.03/kWh to USD 0.04/kWh (IRENA 2018).

The updated scenario under implemented policies also represents a significant downward shift from earlier estimates, projected emissions in 2030 are now 28% lower than previously projected. If Chile follows this scenario, it will achieve its 2020 pledge and come close to meeting its unconditional NDC target, which is in itself “Highly Insufficient” and instead consistent with warming between 3°C and 4°C.

 ClimateActionTracker

Paris Tango. Climate action so far in 2018: Individual countries step forward, others backward, rising stranded coal assets
Summary of latest country assessments
3 May 2018

Que hace especial el “problema” del Cambio Climático

- Origen global pero diferenciado
 - Impacto global y diferenciado
 - La historia cuenta: acumulación de GEI desde 1850...
 - La historia cuenta: Acciones de hoy definen impactos durante el resto del siglo XXI
 - Científicamente tratable
 - Impactos cuantificables
 - Agendas socio-político-económicas
- } *Desacoplados*

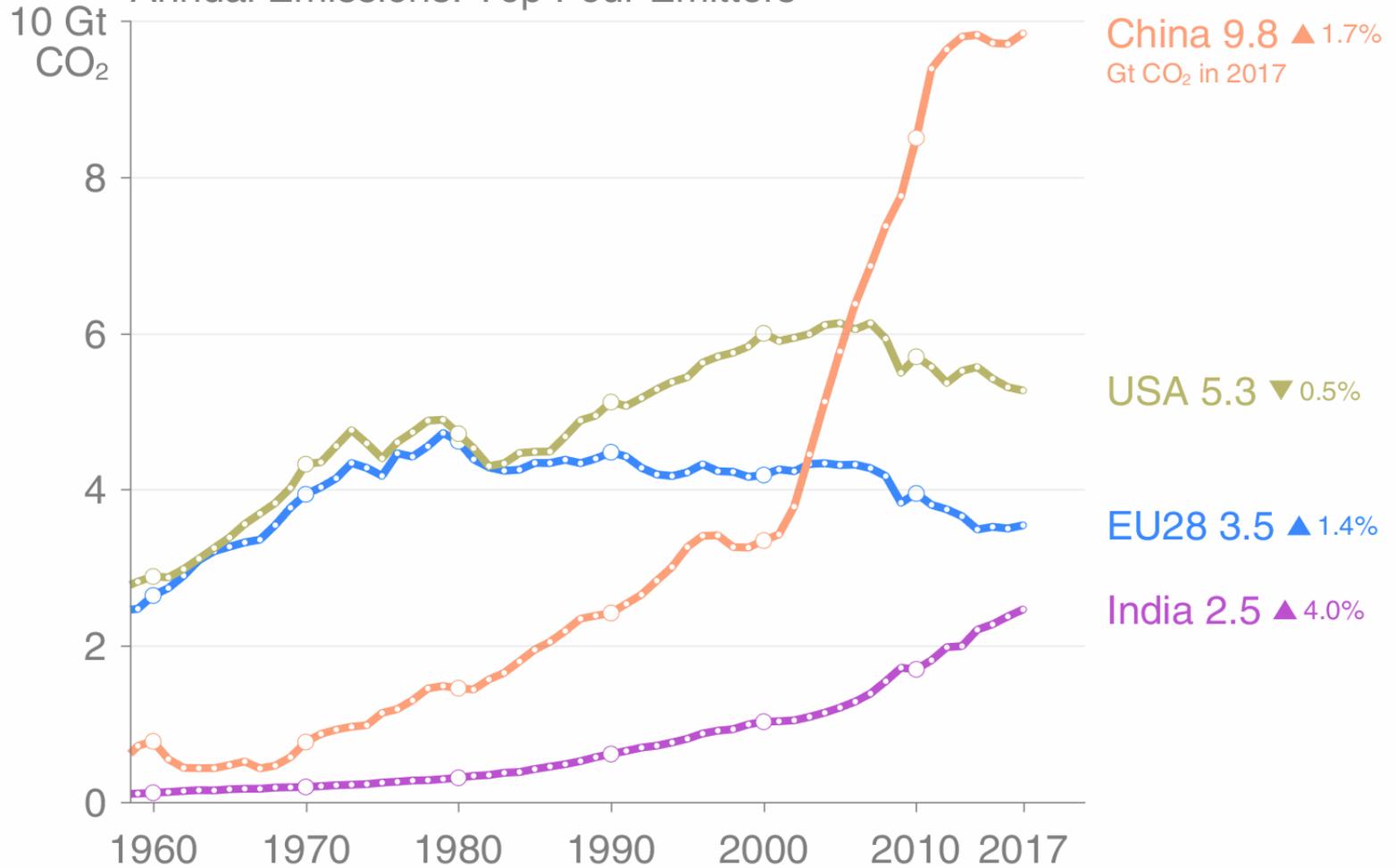
“Las preguntas científicas del cambio
climático están resueltas....
ahora es solo un problema técnico-
económico”

(ca 2012, algún ministro o subsecretario)

“La ciencia del cambio climático ha avanzado pero no está completa. El cambio climático representa un complejo problema social de escala y multi-generacional”

(ca 2019, René Garreaud @ DGF-UCh + CR2)

Annual Emissions: Top Four Emitters



© Global Carbon Project • Data: CDIAC/UNFCCC/BP/USGS

Las Noticias

CLIMATE ACTION TRACKER

[Home](#) > Countries

 244

In each category, countries are listed in alphabetical order, with no ranking.

- Morocco
- The Gambia
- Bhutan
- Costa Rica
- Ethiopia
- India
- Philippines
- Australia
- Brazil
- EU
- Indonesia
- Kazakhstan
- Mexico
- New Zealand
- Norway
- Peru
- Switzerland
- UAE
- Argentina
- Canada
- Chile
- China

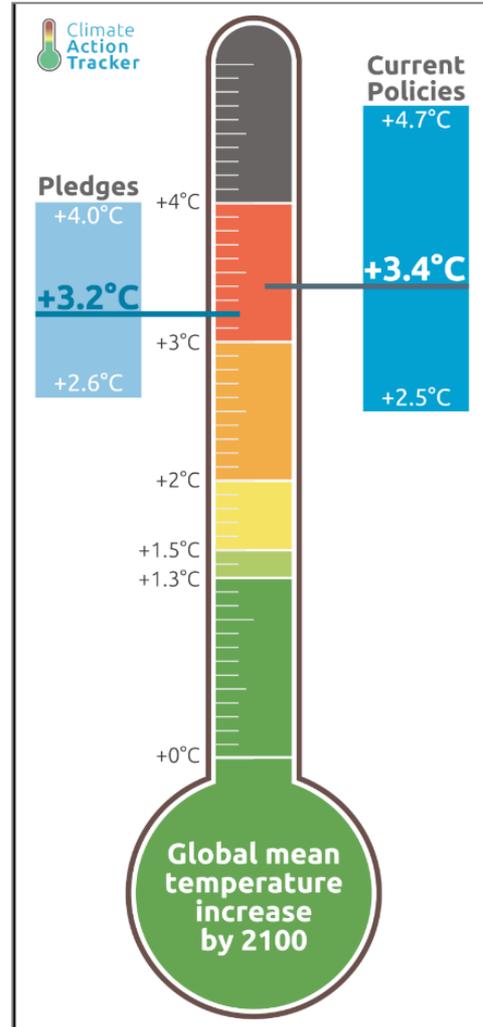
Rating countries

With the adoption of the Paris Agreement, governments have agreed to hold warming well below 2°C, and pursue efforts to limit warming to 1.5°C above preindustrial levels. They have put forward their proposed contributions to a "fair sharing" of effort to move global emissions downward in the period 2020-2025-2030 in their (Intended) Nationally Determined Contributions.

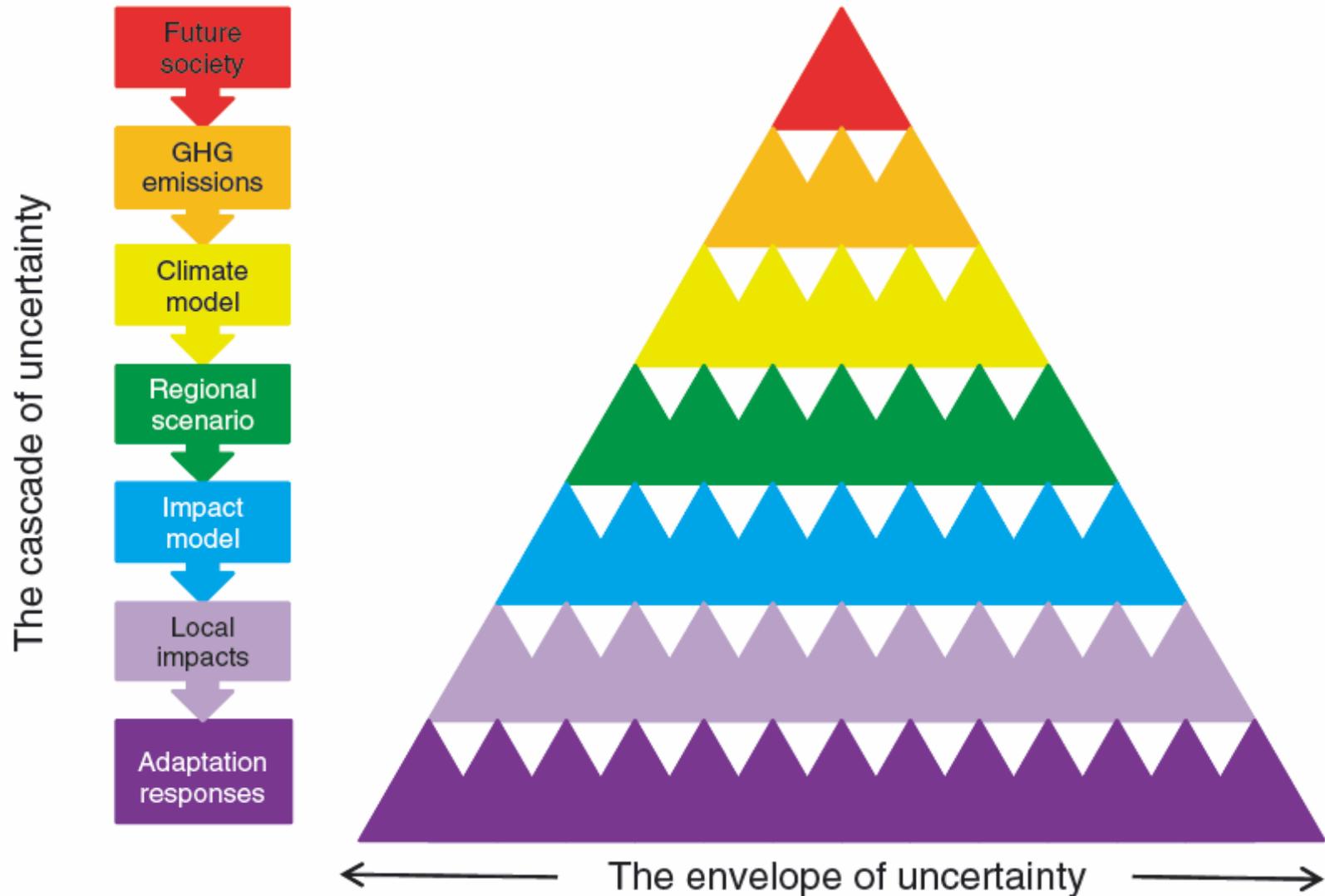
The Climate Action Tracker rates (I)NDCs, 2020 pledges, long-term targets and current policies against whether they are consistent with a country's fair share effort to [the Paris Agreement 1.5°C temperature goal](#).

The [CAT "Effort Sharing" assessment methodology](#) applies state-of-the-art scientific literature on how to compare the fairness of government efforts and (I)NDC proposals against the level and timing of emission reductions consistent with the Paris Agreement. The focus of the assessment is on the period 2020, 2025 and 2030.

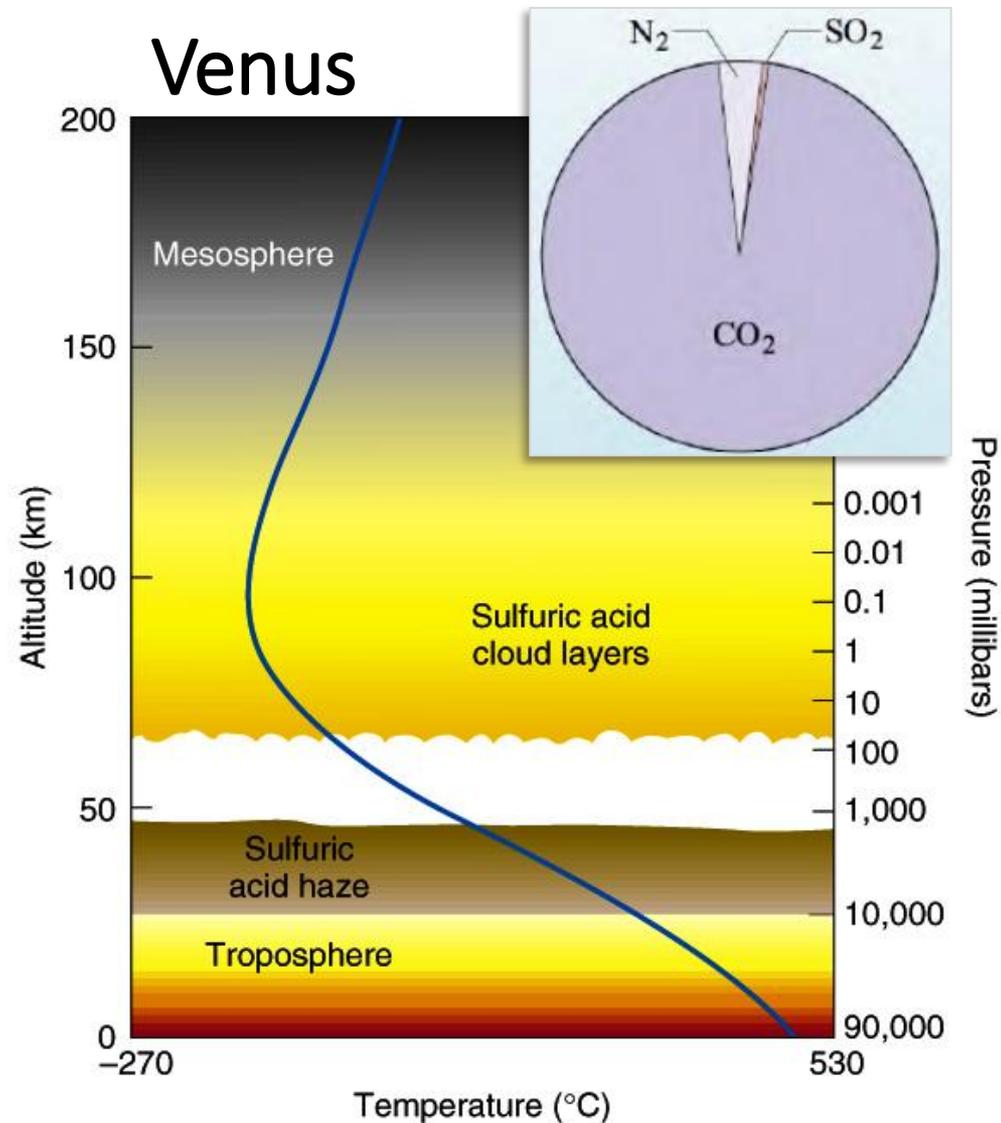
Ratings



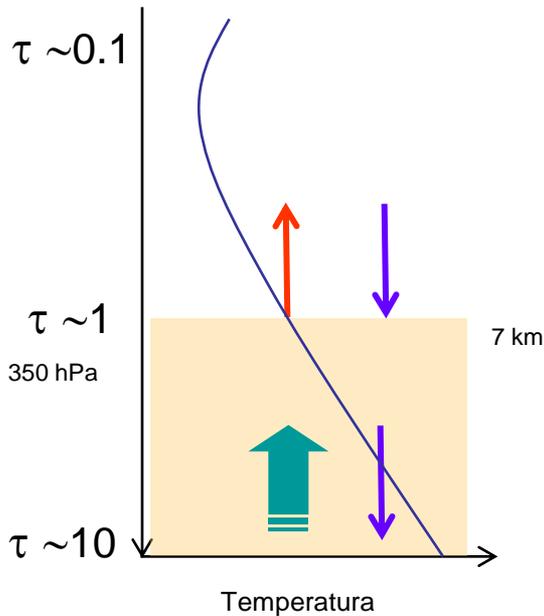
La pirámide de incertidumbre



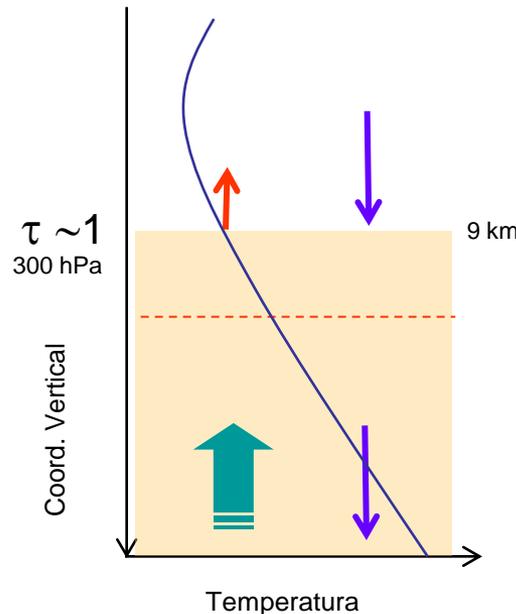
Venus está más cerca del sol que la tierra, pero su persistente y extensa cubierta de nubes hace que la radiación solar incidente en superficie sea menor que lo que recibe la superficie de la tierra. **Aun la temperatura superficial de Venus es 530°C!**



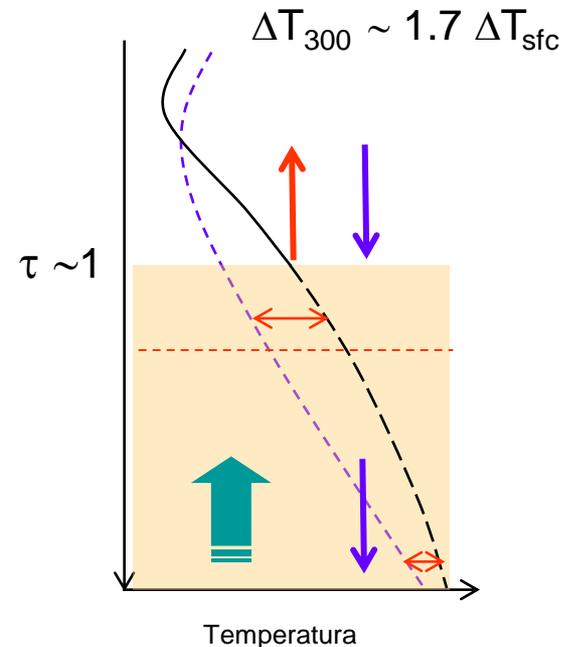
Efecto invernadero, versión 2 (Lindzen 1999, 2007)



CO₂: 280 ppm
Equil. actual



CO₂: 540 ppm
Transiente



CO₂: 540 ppm
Equil. Futuro
No feedback

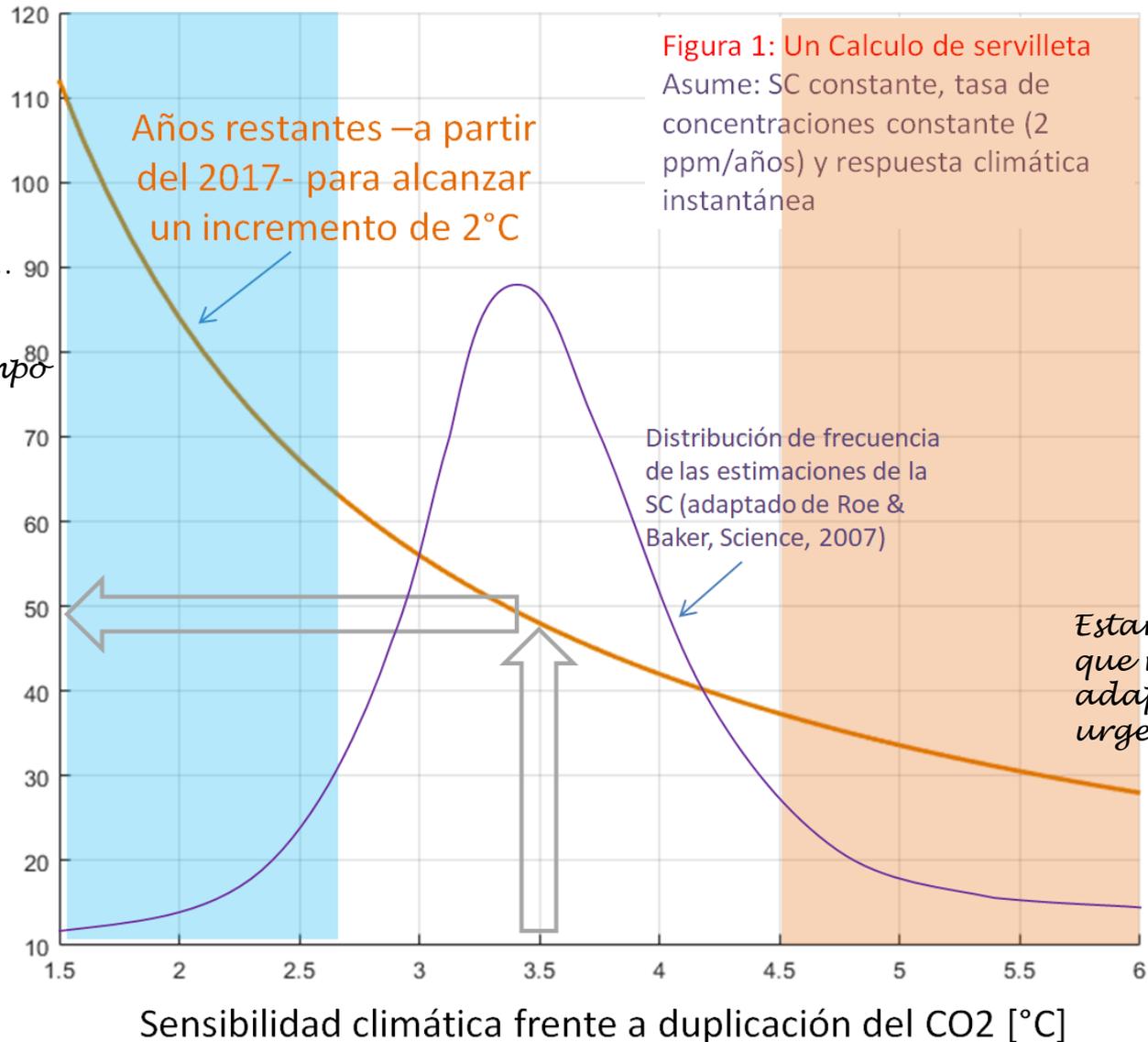


$$(L_{\lambda} - L^*) = (L_{\lambda 0} - L^*) \exp(-\tau_{\lambda})$$

$$\tau_{\lambda} = \int_z^{\infty} k_{\lambda} \rho \cdot dz$$

Sensibilidad climática y la Señora Juanita

Si aumentamos el CO2 el planeta se calienta....pero cuanto?



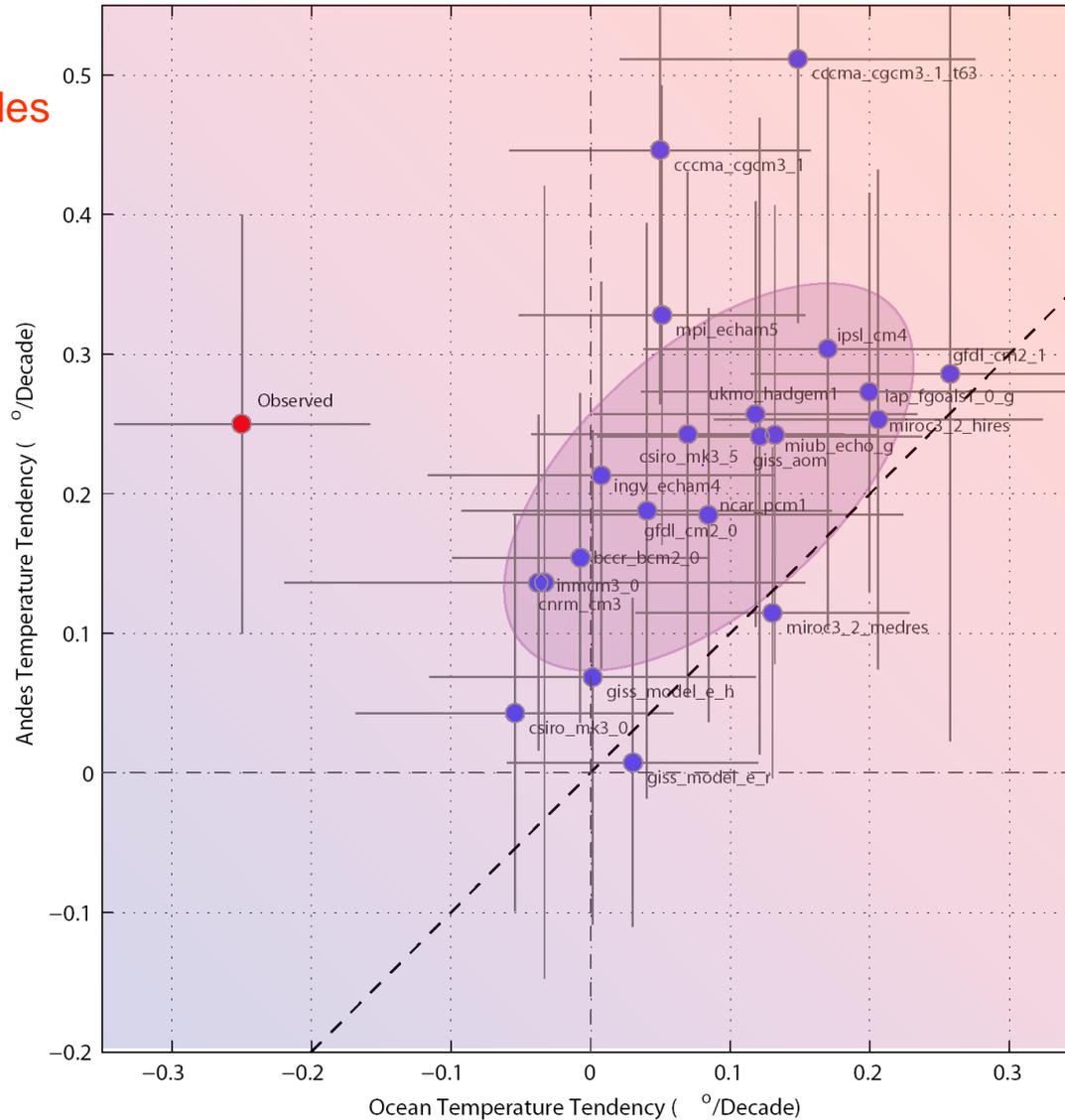
*Tranquilo papa...
Podemos adaptarnos y mitigar con tiempo*

Estamos fritos...hay que mitigar y adaptarnos con urgencia

Como andan los modelos en Chile?



$\partial T/\partial t$
central Andes



$\partial T/\partial t$
off Central Chile