

La Ciencia del Cambio Global: Modelos, Millones y Culebras



René D. Garreaud y Roberto Rondanelli

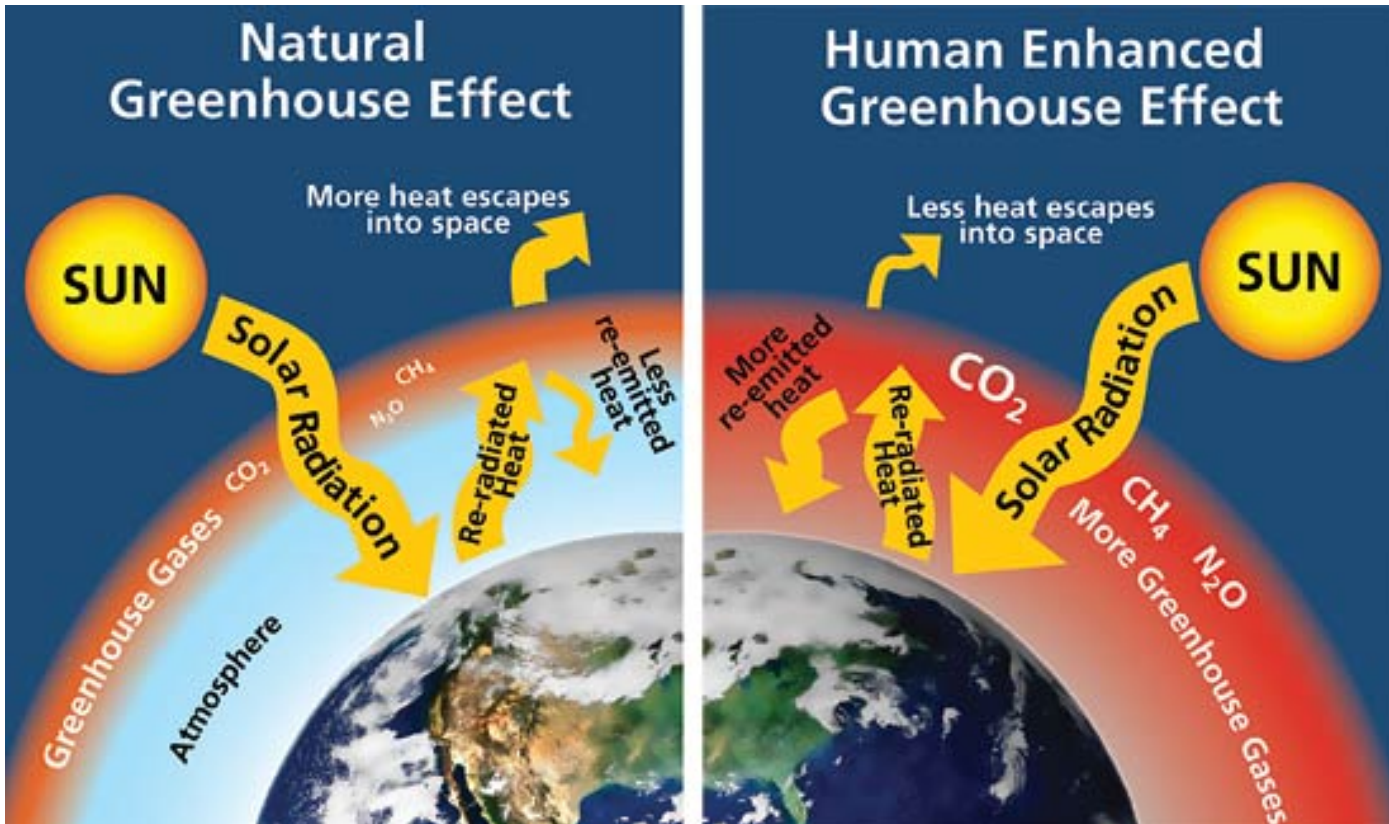
Departamento de Geofísica

Universidad de Chile

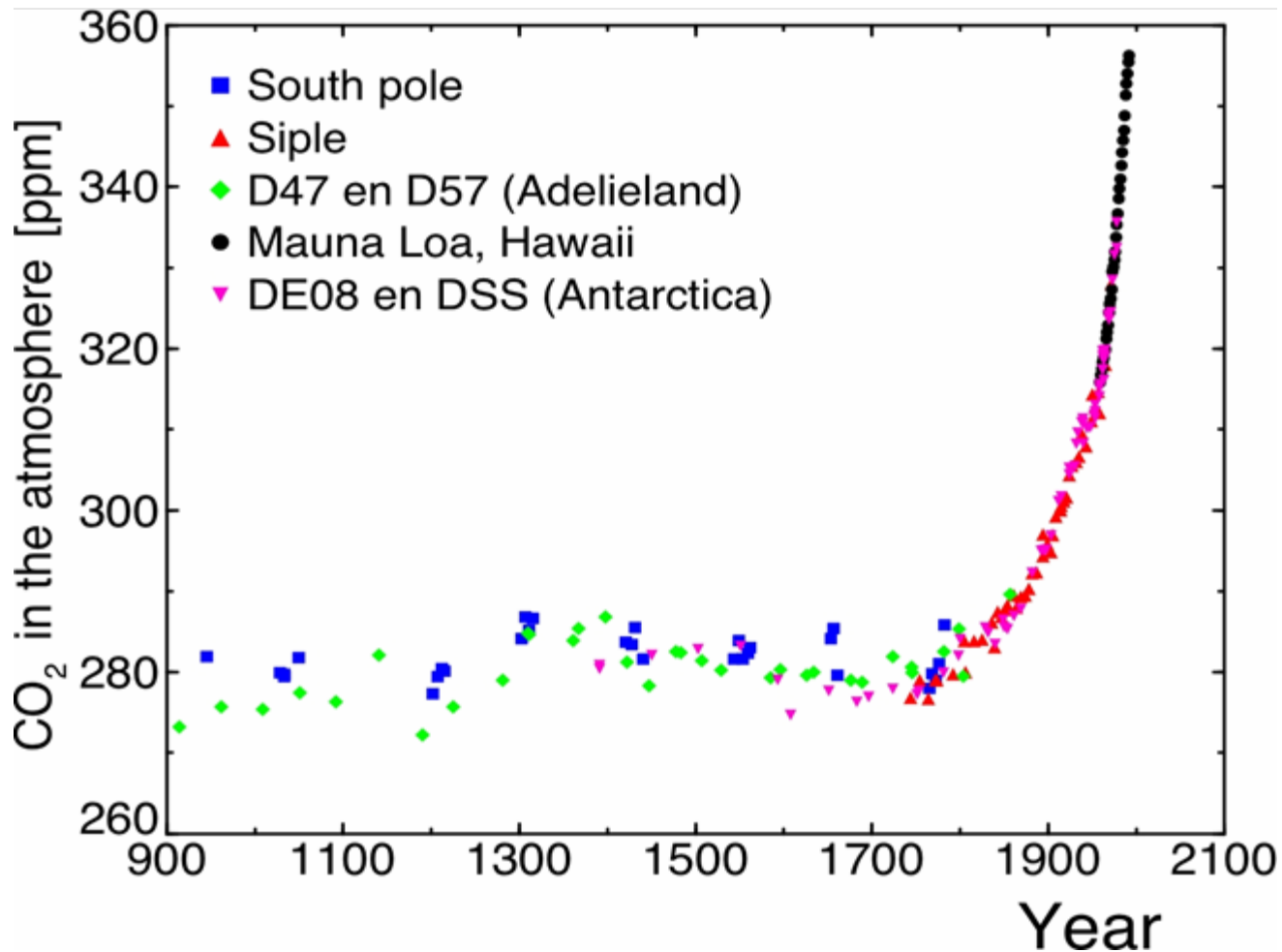
V2: Mayo 2010

Curso muy simple de Clima

Figura popular del efecto invernadero



Cambios observados en CO₂ → Cambios observados en Tsfc



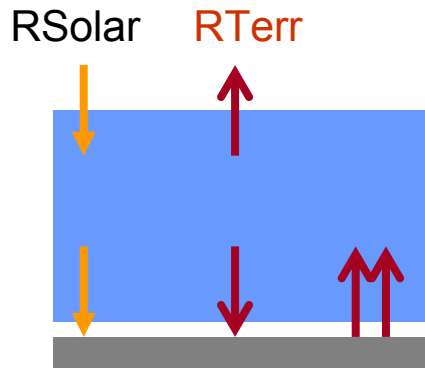
GF45A, Introducción a la Meteorología

Un modelo simple de efecto invernadero

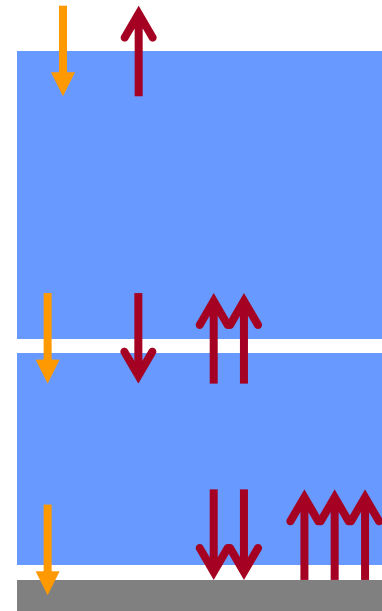
Atmósfera 100% transparente a ROC y 100% opaca a ROL. En estado estacionario hay equilibrio de flujos radiativos en cada interfase y cada capa es isotermal...



$$T_e = T_0 \approx -18^\circ\text{C}$$



$$T_e = (2)^{1/4} T_0 \approx 15^\circ\text{C}$$

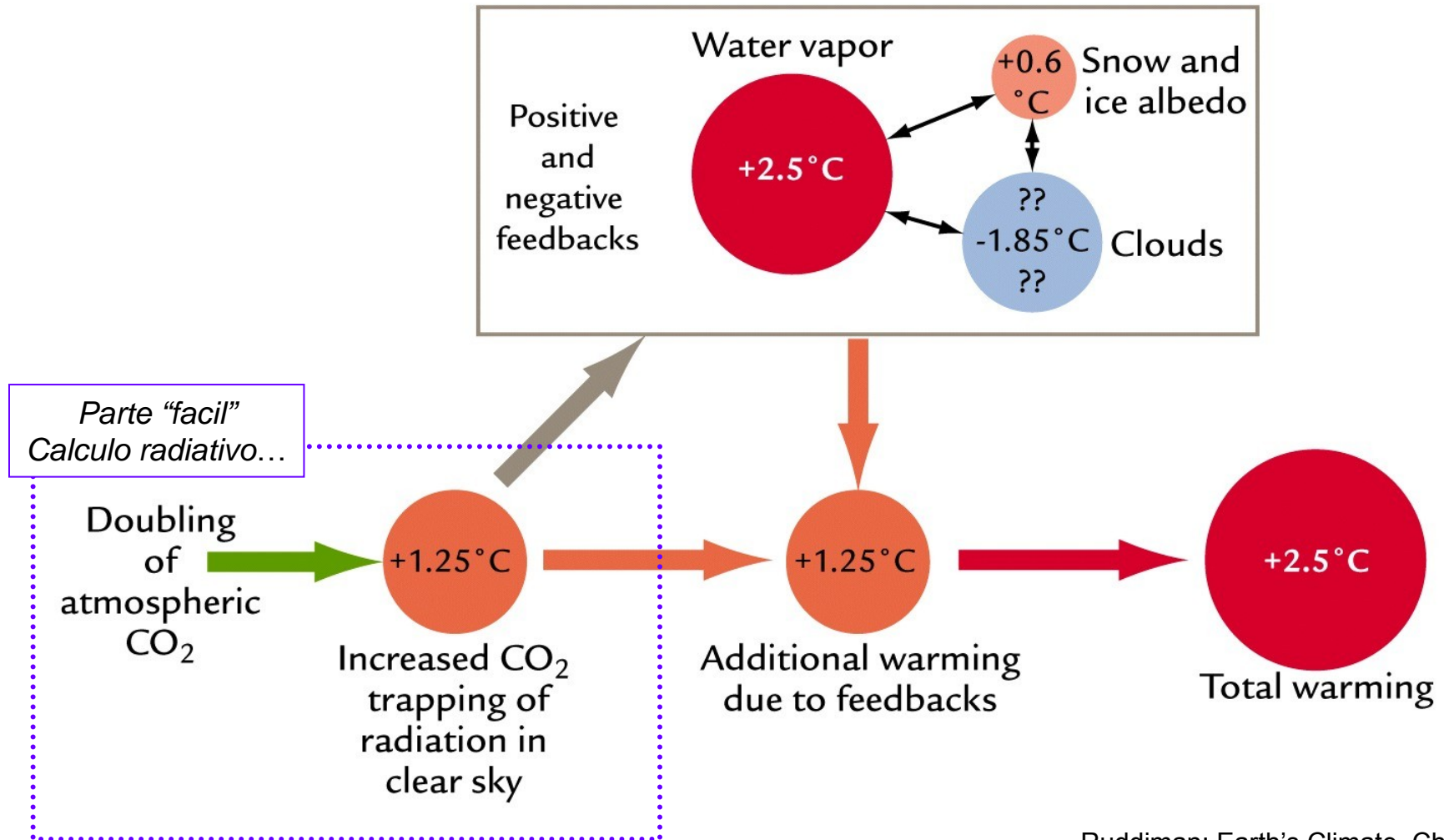


$$T_e = (3)^{1/4} T_0 \approx 30^\circ\text{C}$$

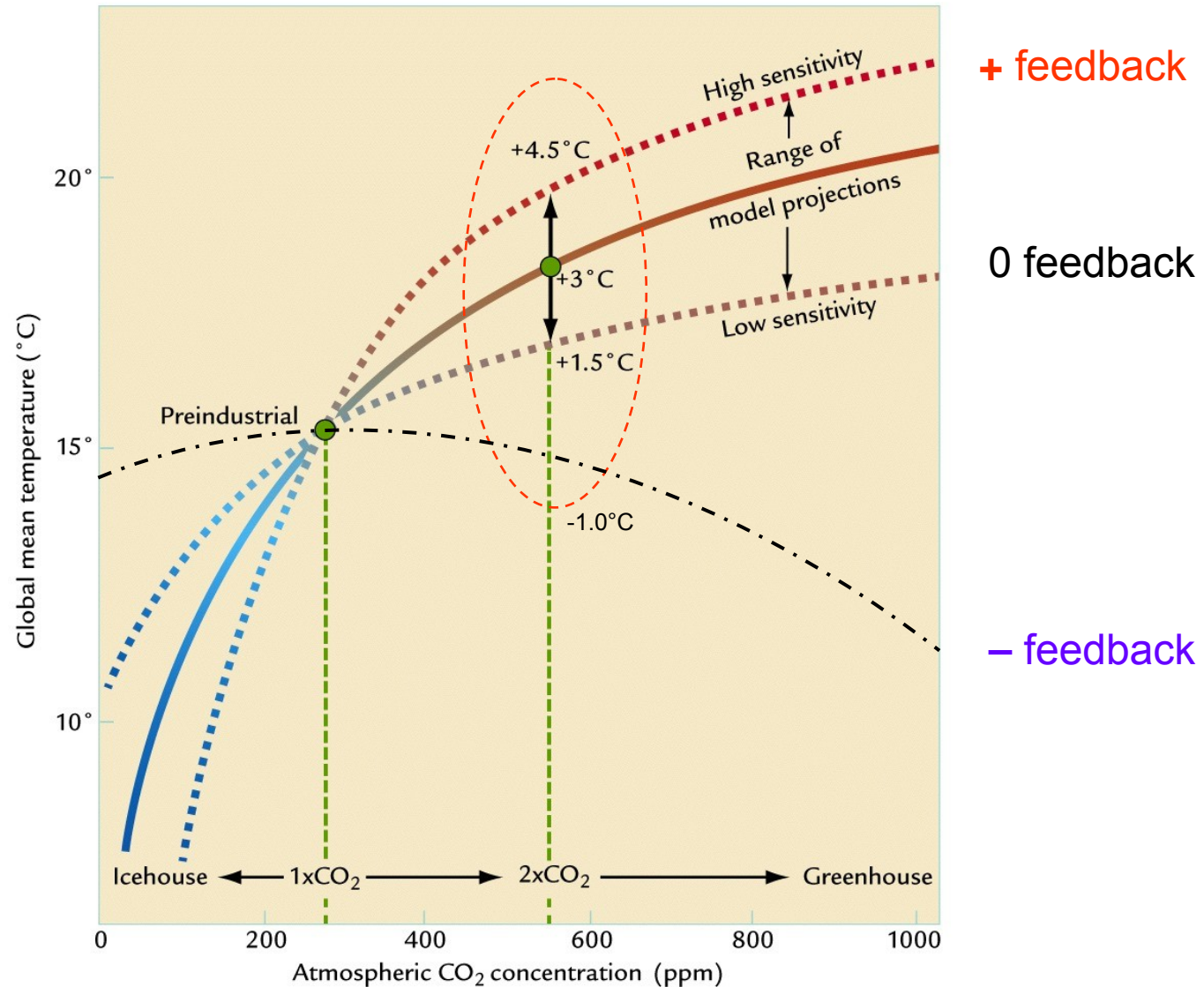
...

$$T_e = (n+1)^{1/4} T_0$$

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

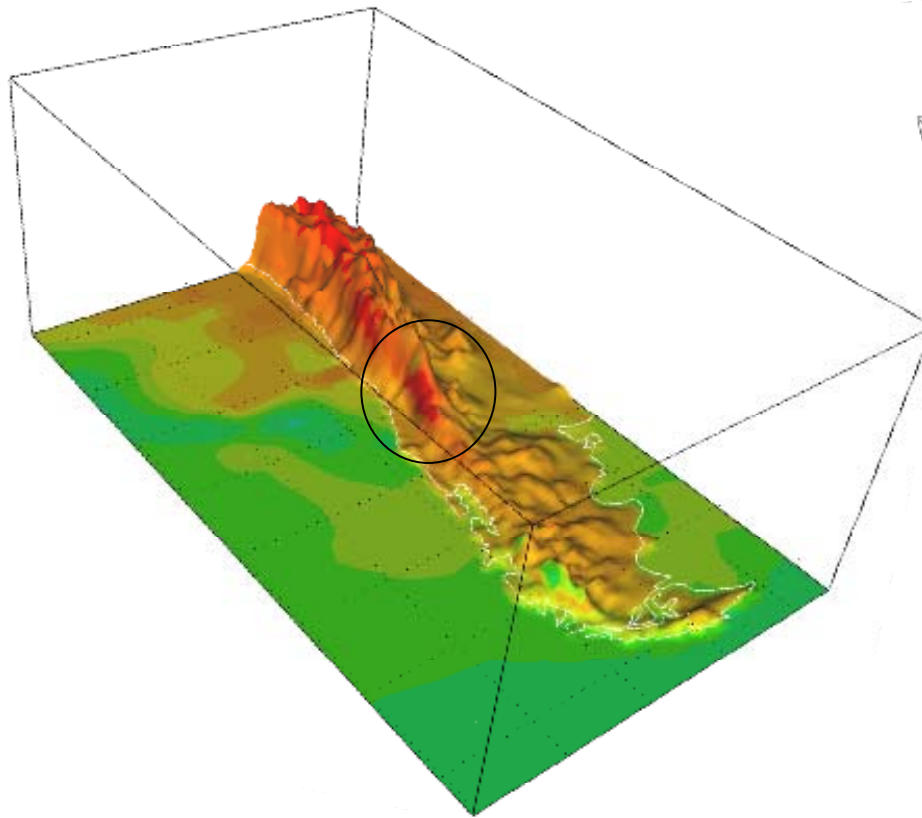


Sensibilidad climática se cuantifica con $\Delta T(2\times\text{CO}_2)$ y depende de la retroalimentación del sistema

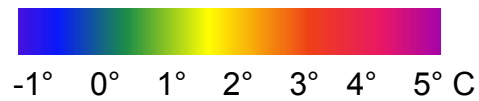
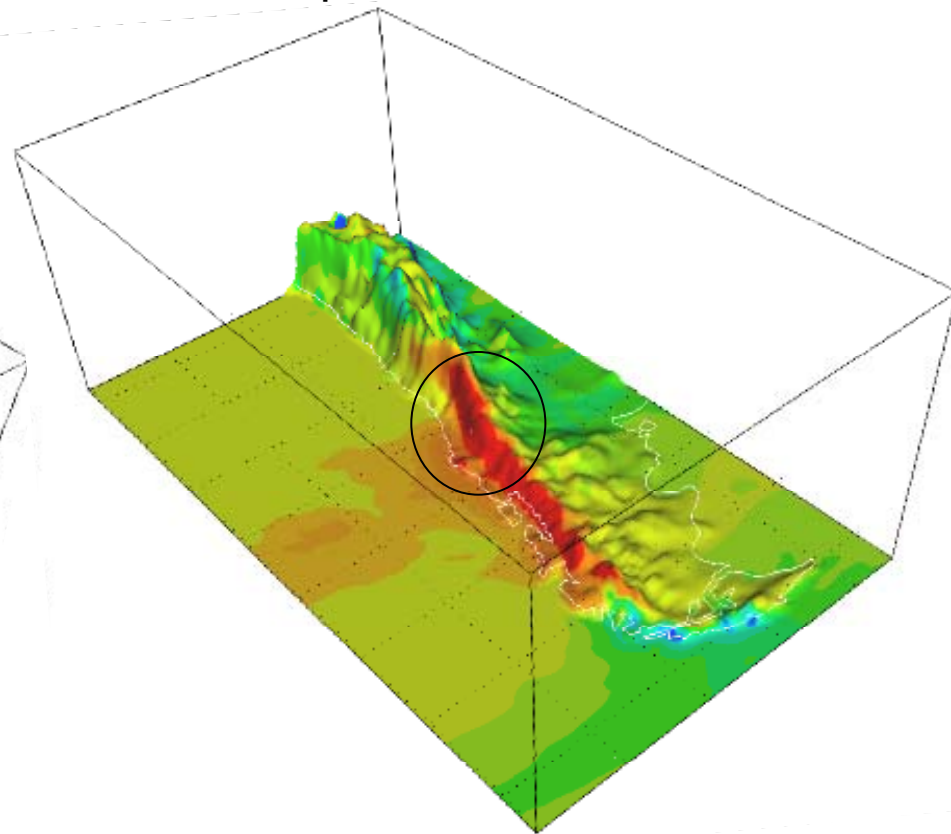


Diferencias A2(2100-2070) – BL(1960-1990)

Temperatura Superficial



Precipitación



PRECIS-DGF-UCH



Modelación de sistemas físicos: Situación ideal

- Formulación del modelo: ecuaciones, **variables**, **forzantes** y **parámetros**
- Determinación física de los parámetros
- Integrar modelo con forzante conocido
- Contrastar resultado del modelo con la realidad
- Aumentar complejidad del modelo

Ejemplo: Modelación Hidrológica

- $Q(t) = A * (1-\Lambda) * P(t) + Q(t-1)$
- **Área** de un mapa y Λ usando pruebas de infiltración
- Emplear Precipitación medida
- $Q_{sim} \approx Q_{obs} \text{ ???}$
- $Q(t) = A * (1-inf) * P(t) + Q(t-1) - ET$

Atmospheric circulation is governed by fluid dynamics equation + ideal gas thermodynamics

Momentum eqn.

$$\frac{d\vec{V}}{dt} + f\hat{k} \times \vec{V} = -\frac{1}{\rho} \nabla p - \vec{F}_R + \vec{g}$$

Energy eqn.

$$\left(\frac{\partial}{\partial t} + \vec{V} \cdot \nabla\right)T - S_p \omega = Q_{RAD} + Q_{Conv} + Q_{Sfc}$$

Mass eqn.

$$\nabla \cdot \vec{V} + \frac{\partial \omega}{\partial p} = 0$$

Idea gas law

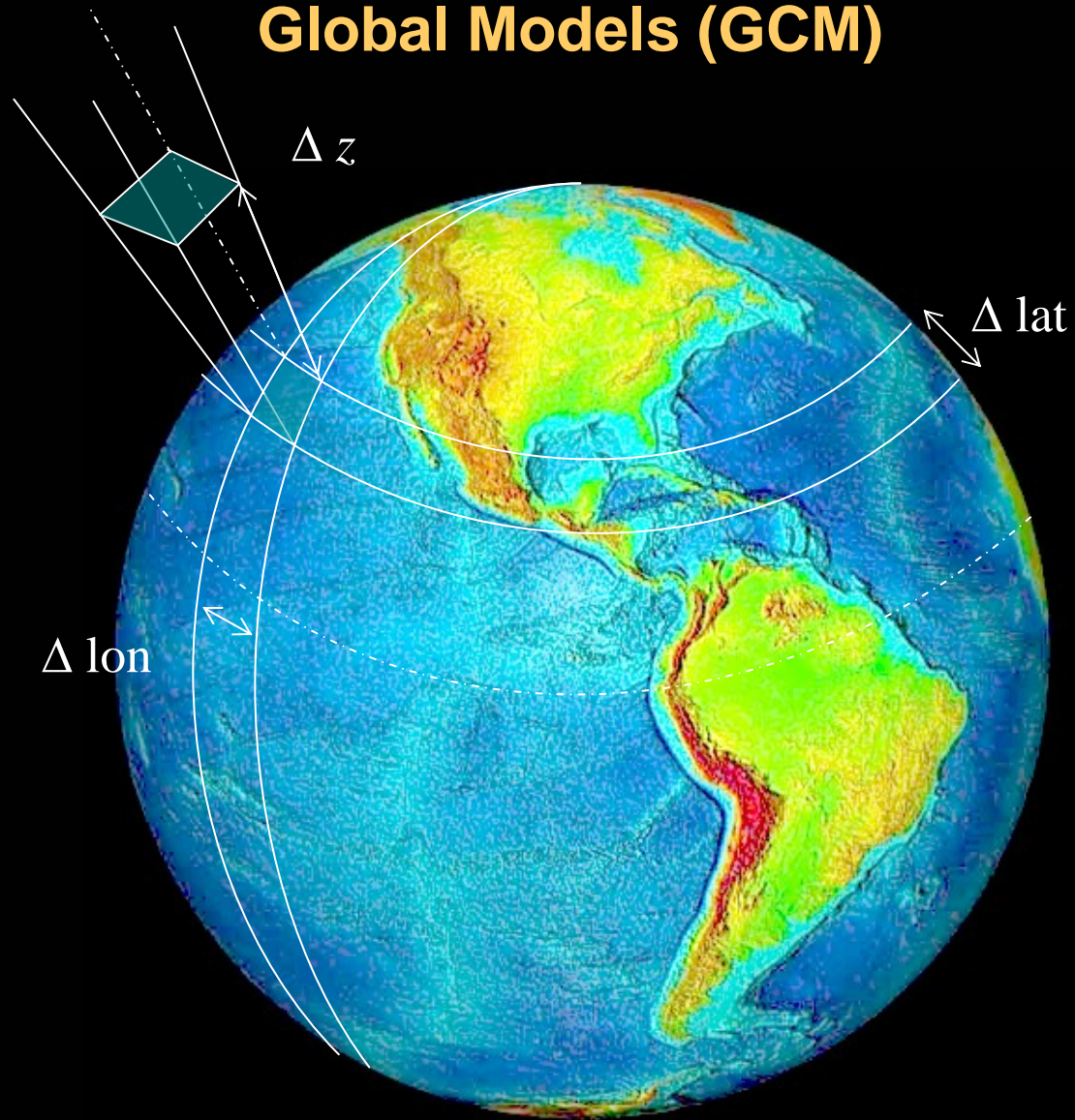
$$\frac{\partial(gz)}{\partial p} = -\frac{RT}{p}$$

Water substance eqns.

$$\frac{dq_v}{dt} = -C + E$$
$$\frac{dq_r}{dt} = +C - E + S_r$$

Sub-grid Processes
Highly parameterized

Global Models (GCM)



$\Delta \text{lat} \sim \Delta \text{lon} \sim 1^\circ - 3^\circ$

$\Delta z \sim 1 \text{ km}$

$\Delta t \sim \text{minutes-hours}$

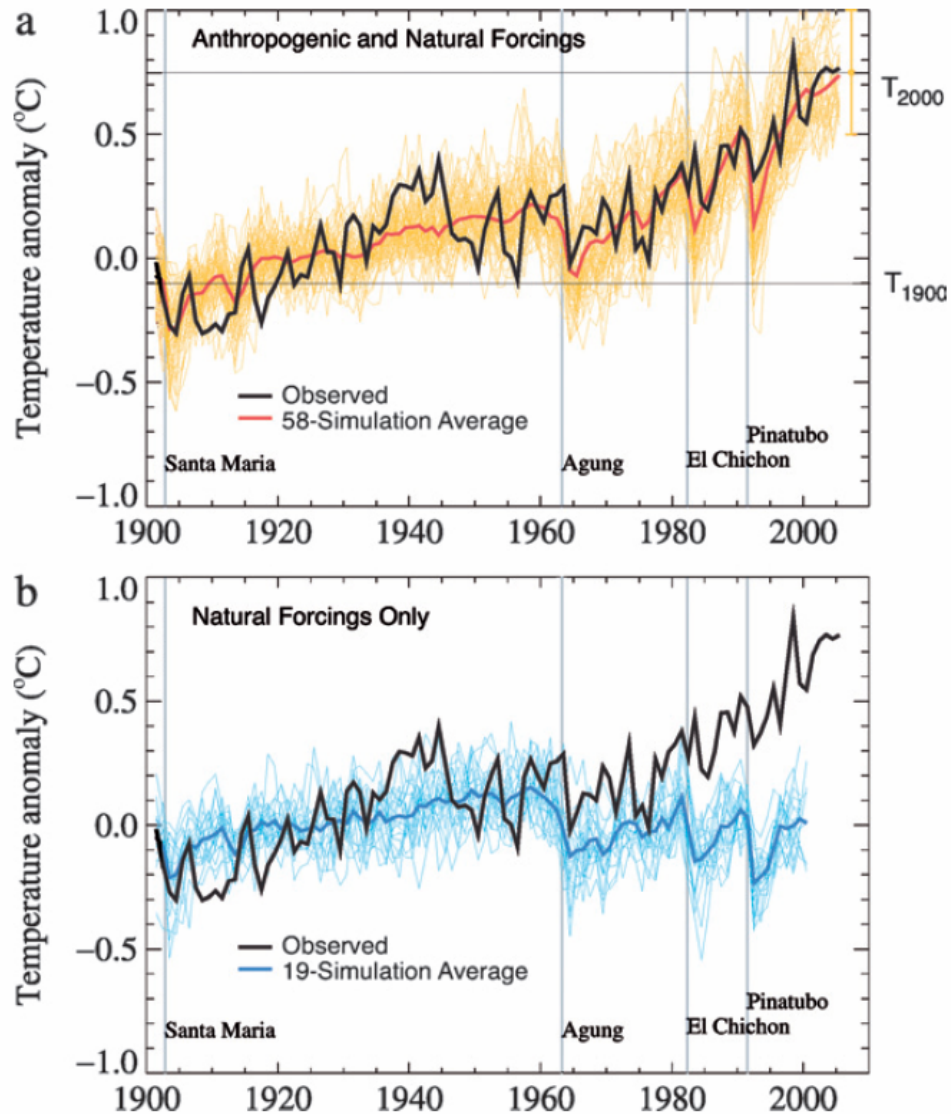
Top of atmosphere: 15-50 km

Modelación de sistemas físicos: GCMs

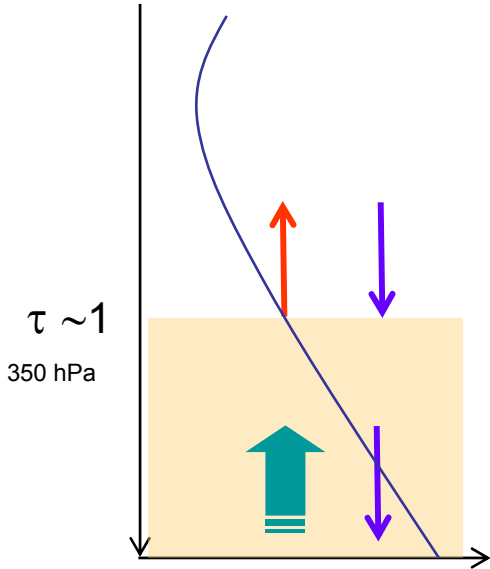
- GCMs: ecuaciones, 20 variables, forzantes y 100 parámetros
- ~ 10 parámetros débilmente acotados
- Forzante GEI siglo XX conocido
- Forzante Aerosoles siglo XX menos conocido
- Contrastar modelo con realidad: Promedio global T_{sfc}
- Modificar parámetros hasta obtener un buen ajuste...

No muy elegante, pero “es lo que hay”....

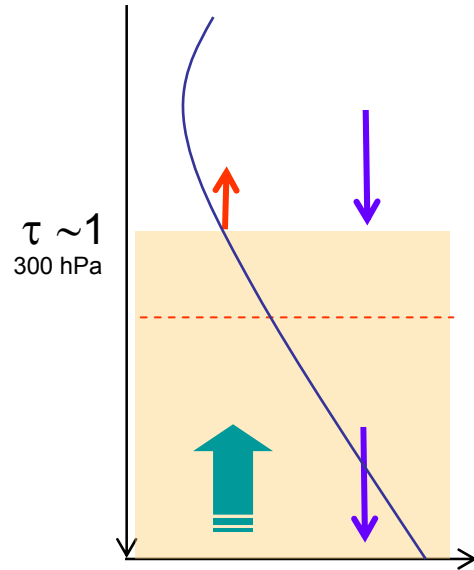
Cambios observados y simulados en T_{sf}c



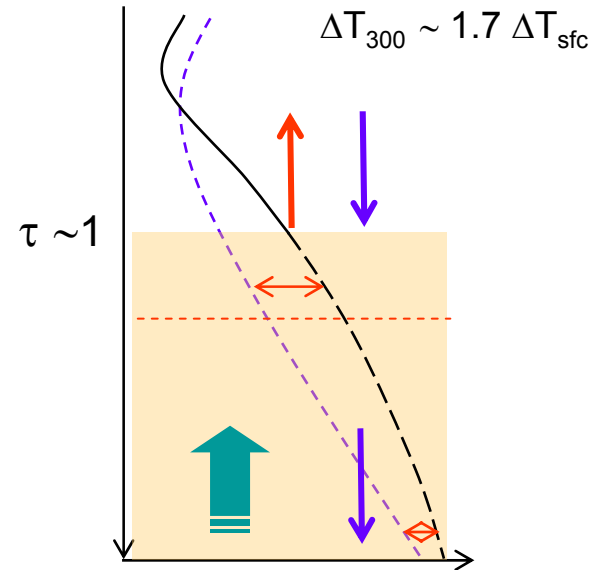
Efecto invernadero, versión 2 (Lindzen 1999, 2007)



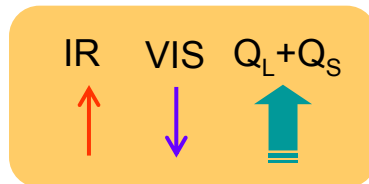
CO₂: 280 ppm
Equil. actual



CO₂: 540 ppm
Transiente

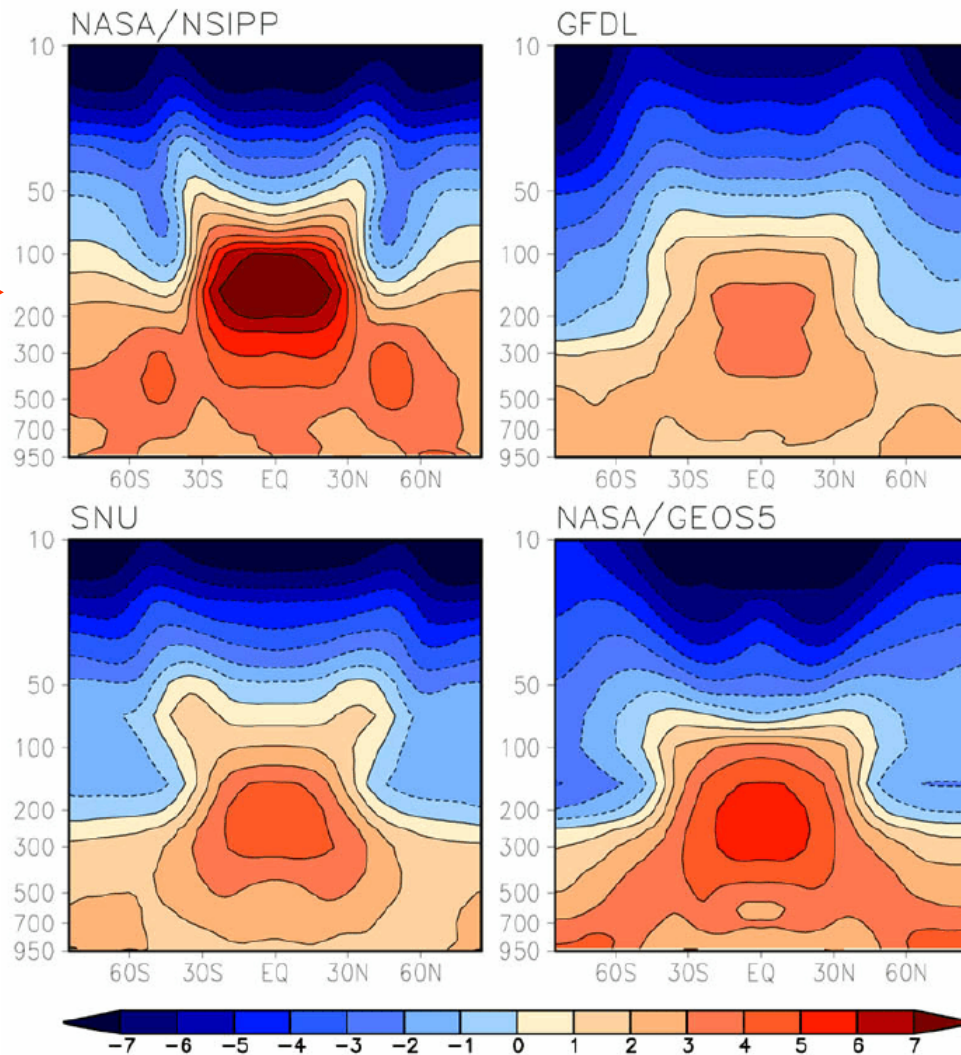


CO₂: 540 ppm
Equil. Futuro
No feedback



Efecto invernadero, versión 2

Promedio zonal cambio temperatura $2 \times \text{CO}_2$ -CTR



Modelos y argumentos físicos simples predicen máximo calentamiento en troposfera alta

Zonal mean distributions of temperature change ($2 \times \text{CO}_2$ -Control). Units are Kelvin.

Cambios observados y simulados en T(z)

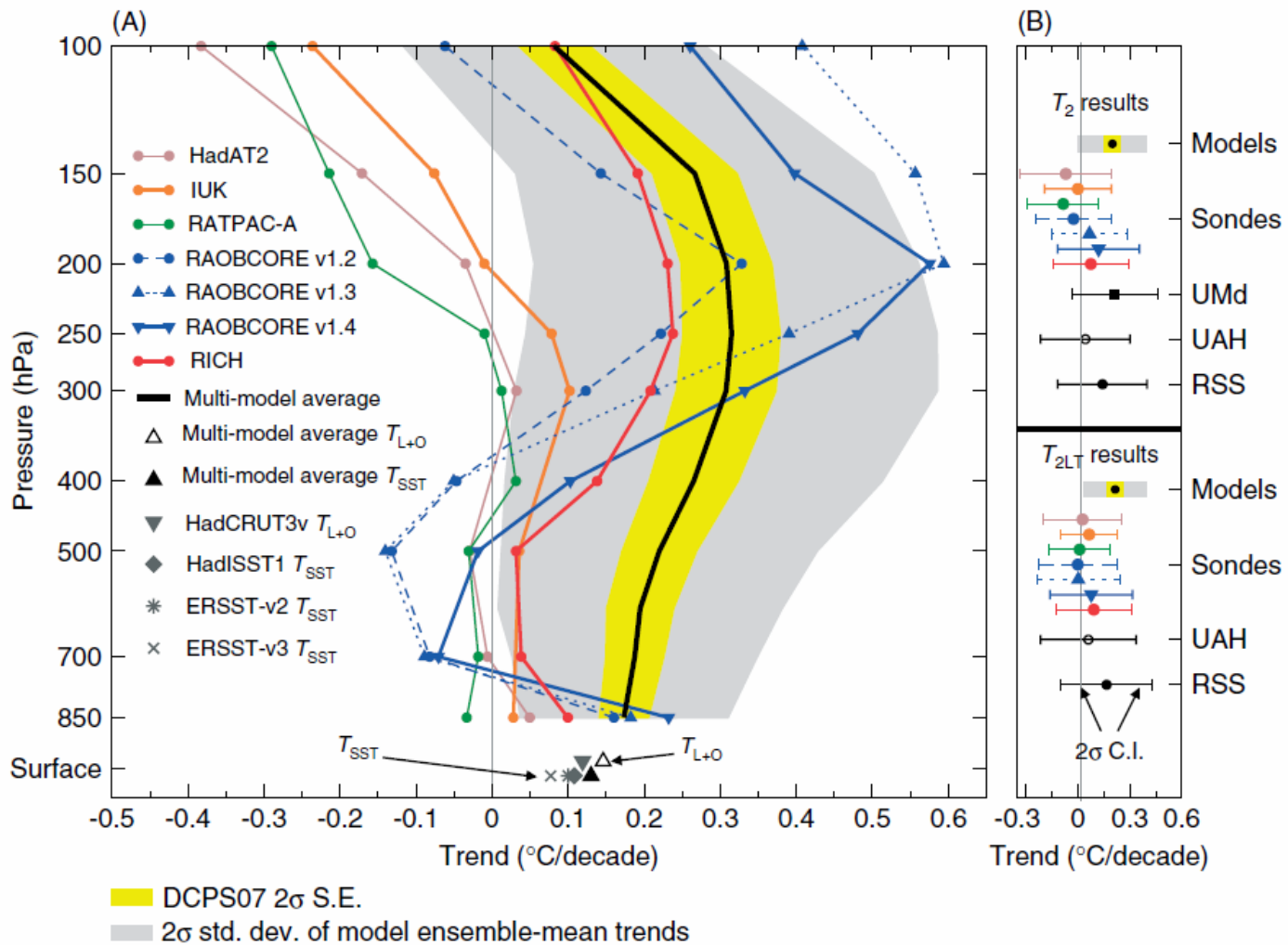
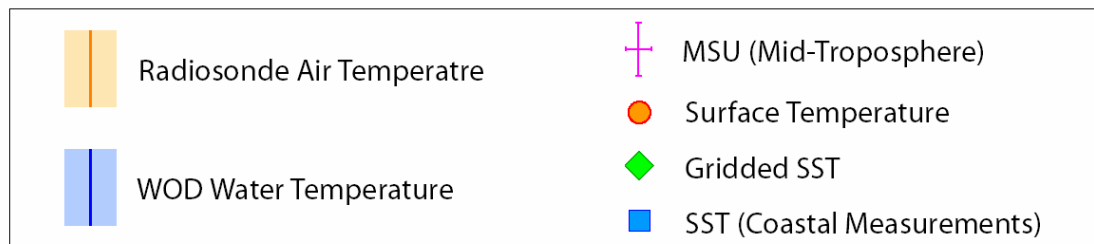
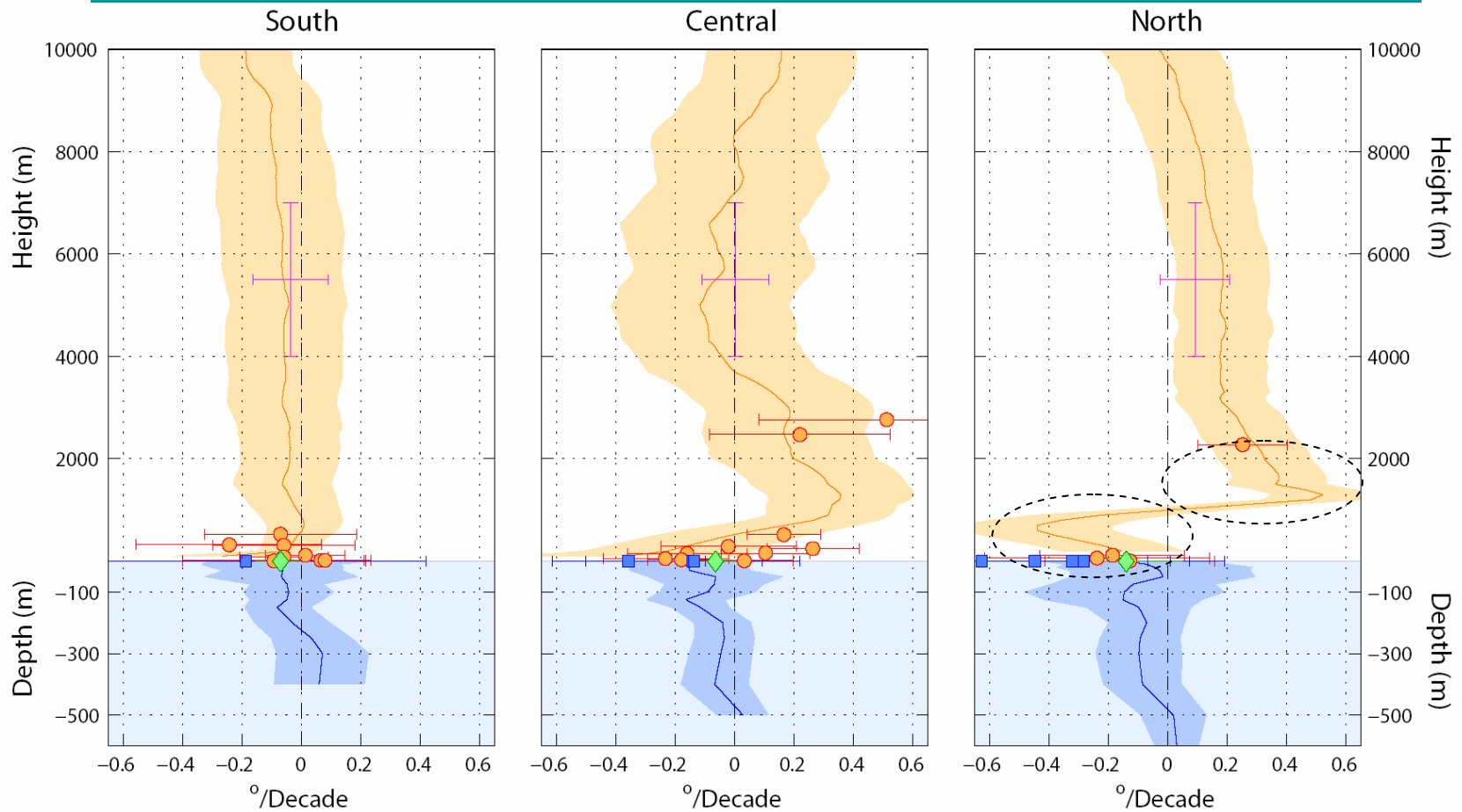
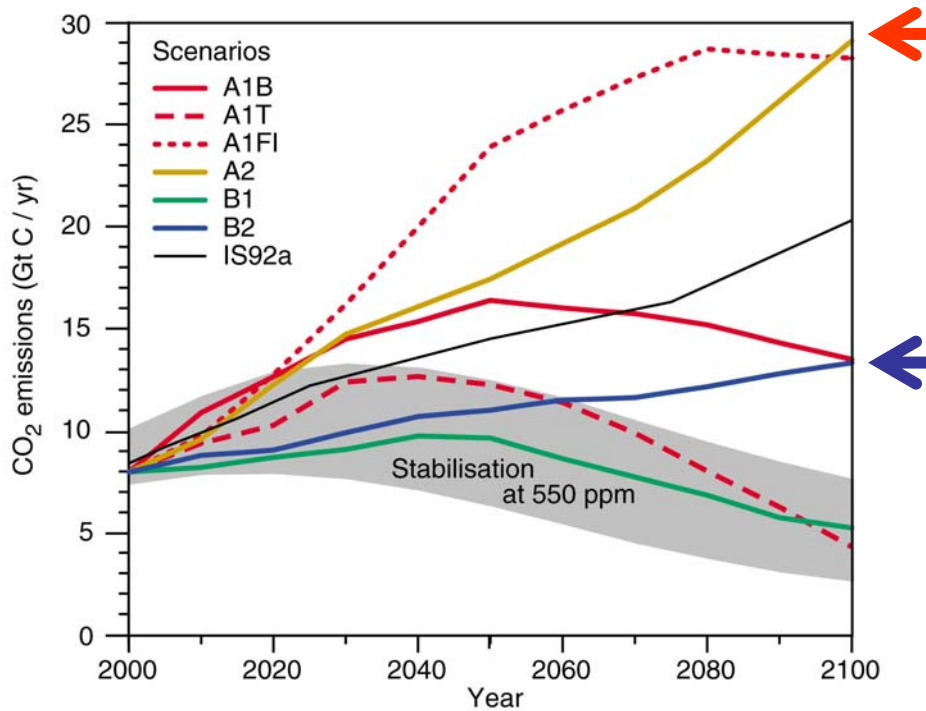


Figure 6. Vertical profiles of trends in atmospheric temperature (panel A) and in actual and synthetic MSU temperatures (panel B).

Cooling MBL / warming lower free troposphere → increased lower tropospheric stability ... Sc?

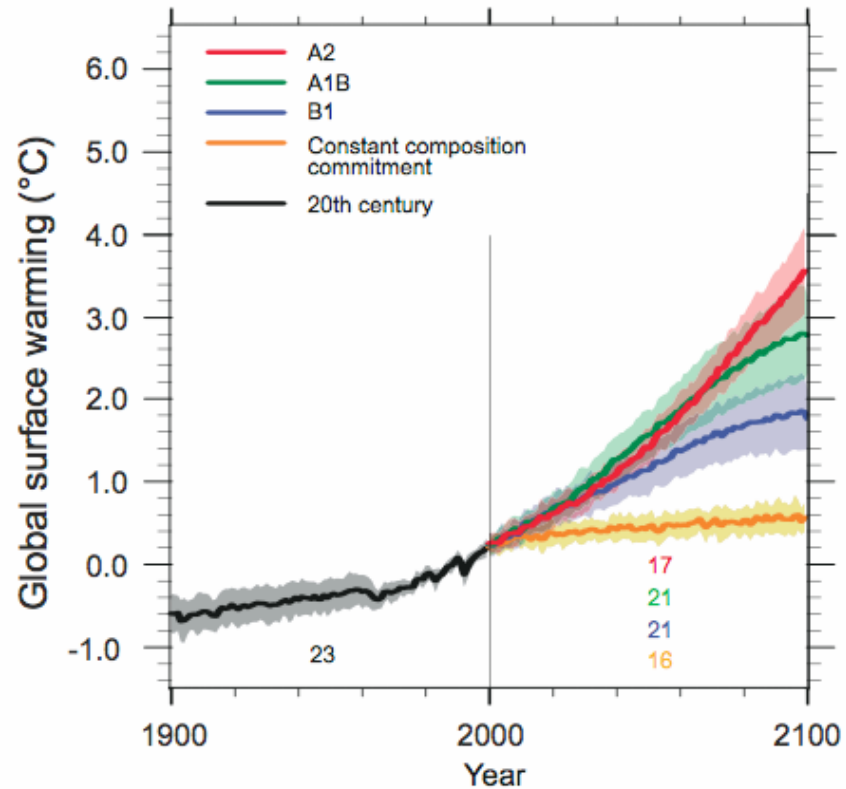


Falvey &
Garreaud 2009

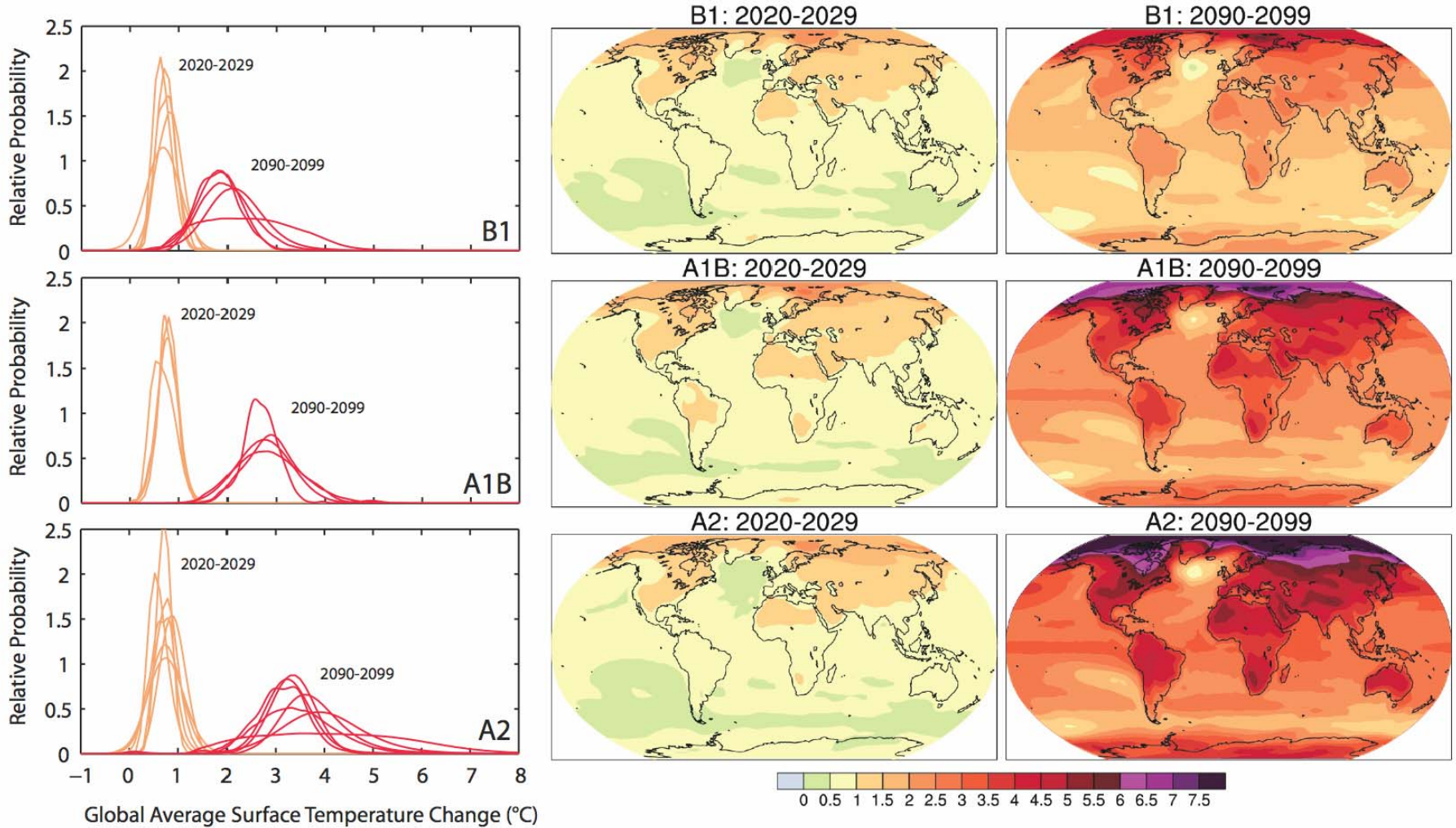


Escenarios Desarrollo Económico-Social

GCMs

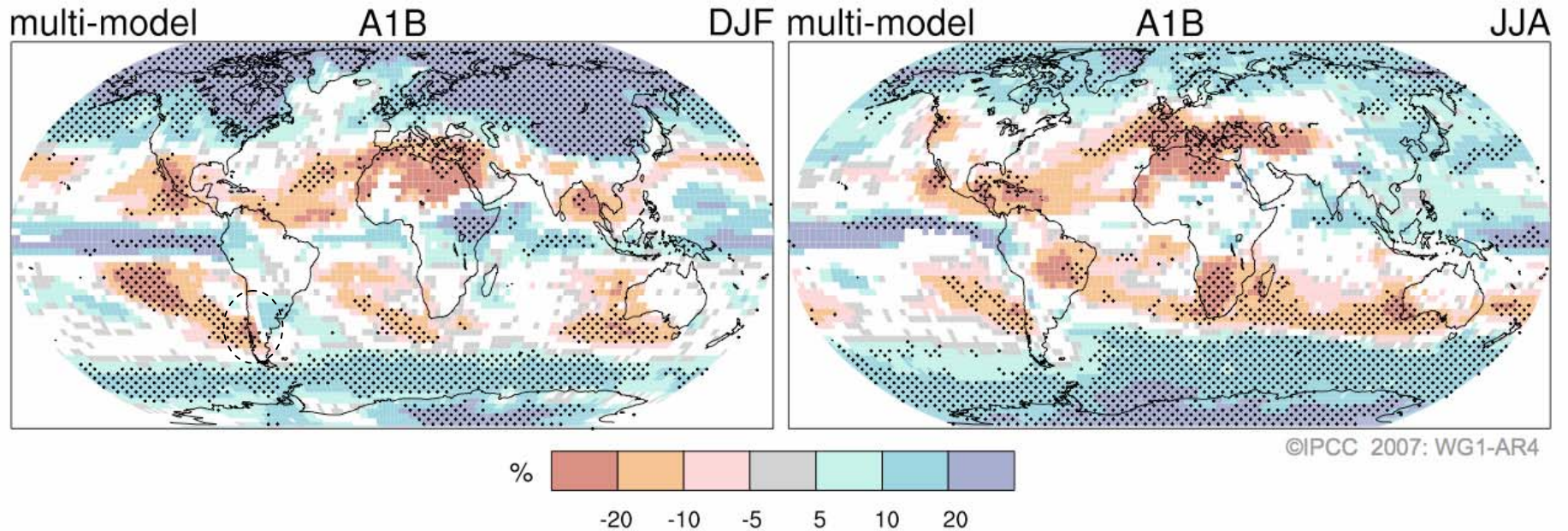


AOGCM Projections of Surface Temperatures

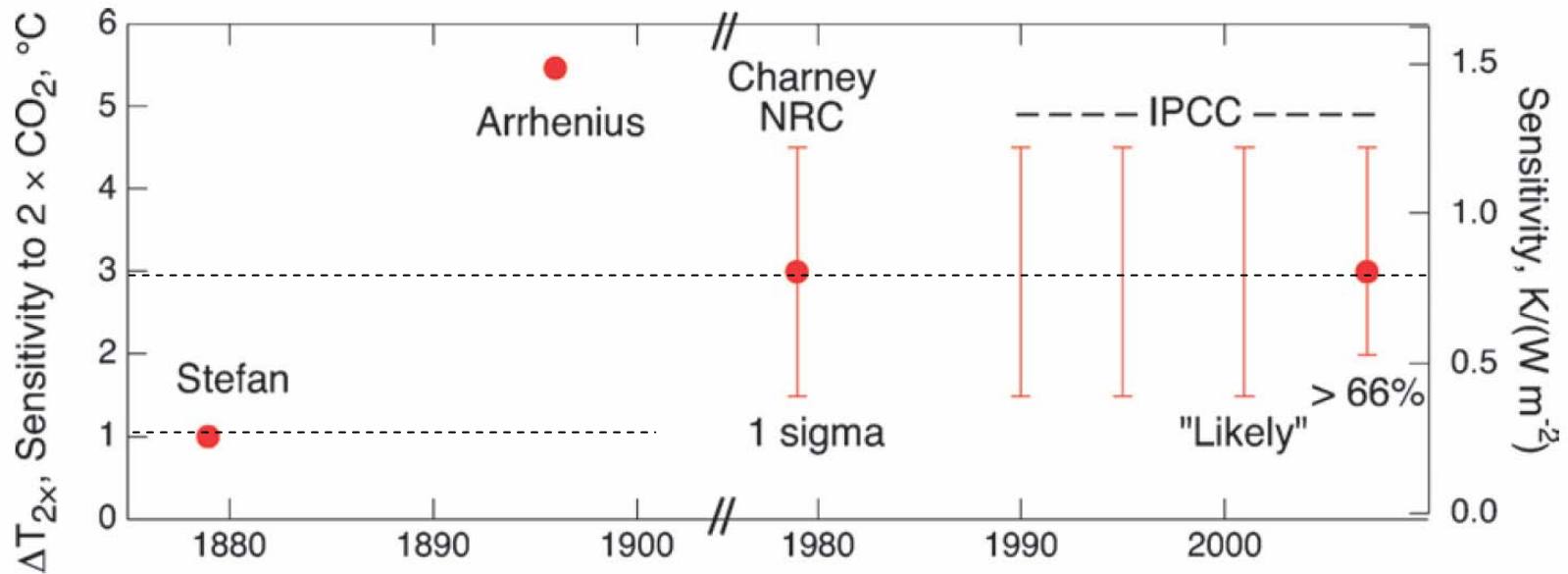


© IPCC 2007: WG1-AR4

Projected Patterns of Precipitation Changes



Sensibilidad climática: $\Delta T(2\times\text{CO}_2)$ Fácil de calcular en los modelos GCMs



Sensibilidad climática ($2\times\text{CO}_2$) SIN retroalimentación $\sim 1.2^{\circ}\text{C}$

Modelos logran ajuste a Tsfc con bastante esfuerzo

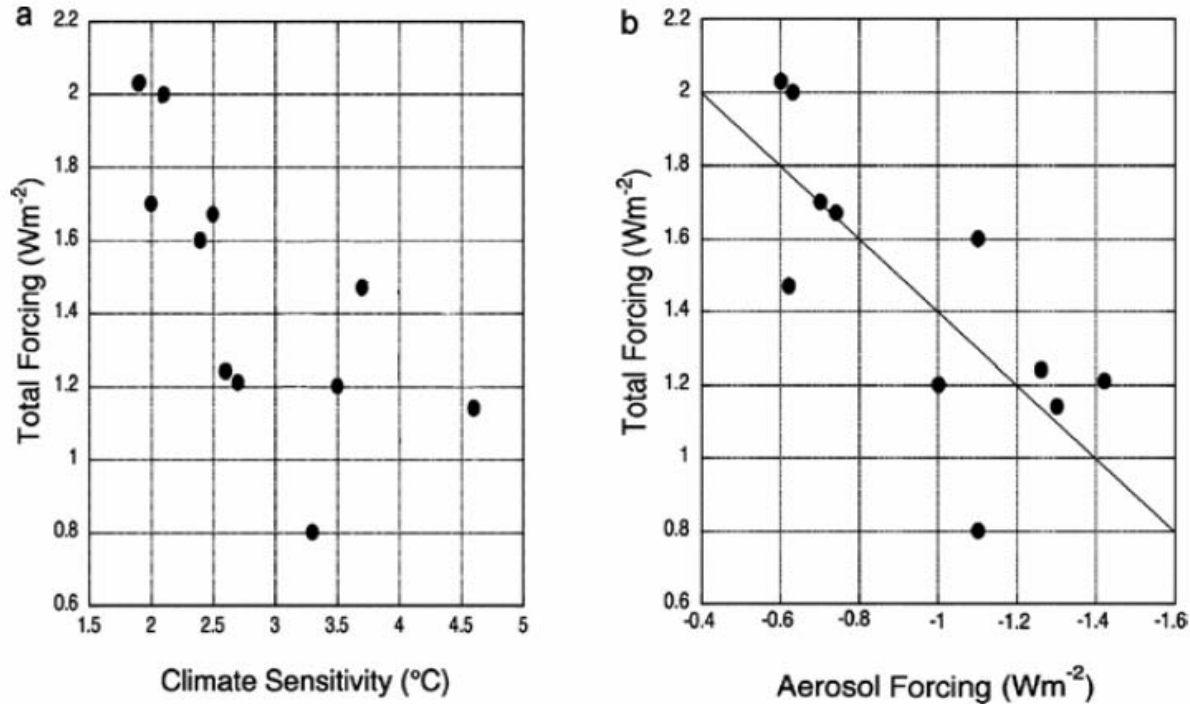
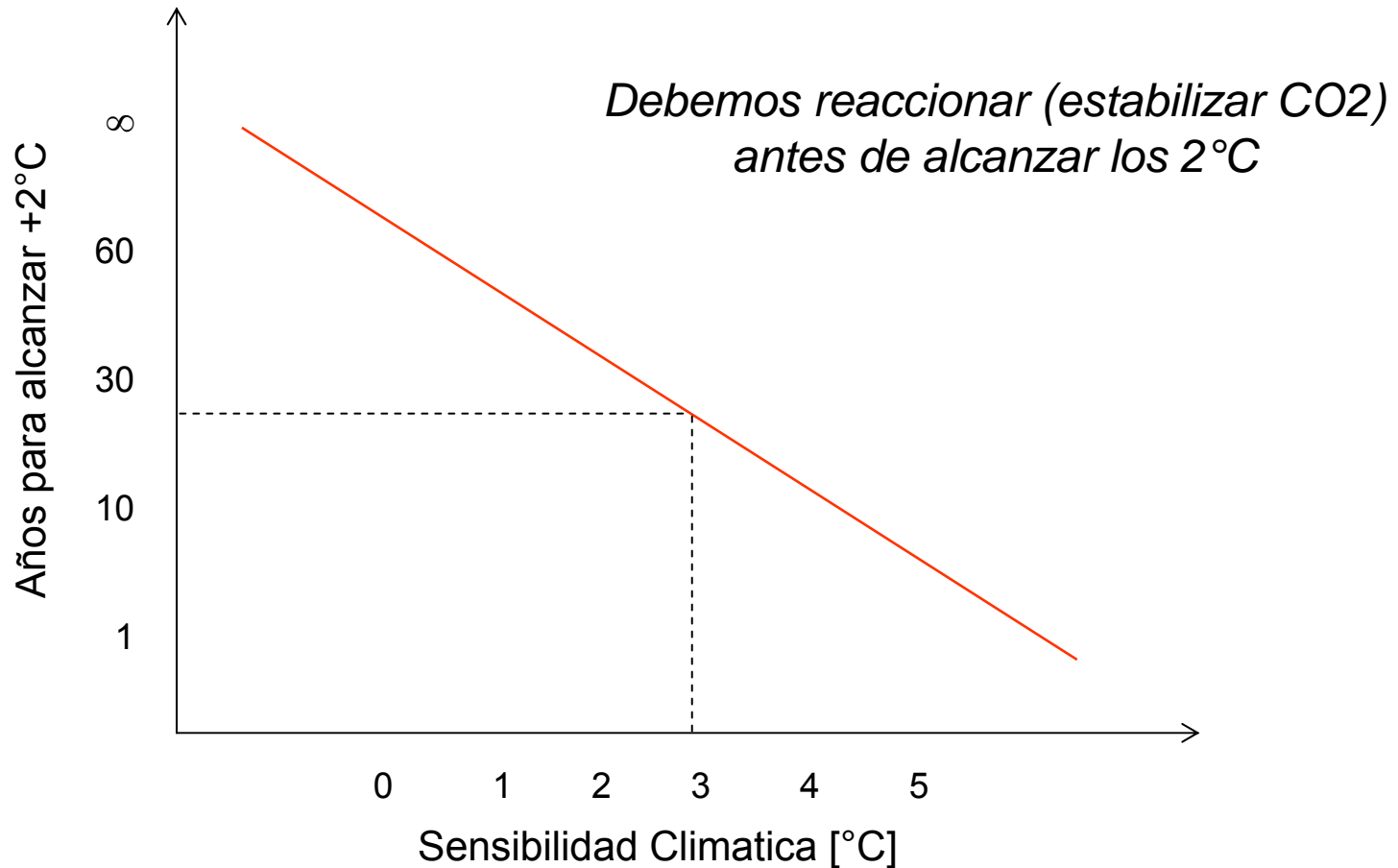


Fig. 9 (a) Total anthropogenic forcing *versus* equilibrium climate sensitivity $\Delta T_{2\times}$ from nine coupled climate models and two energy balance models that were used to simulate the climate of the 20th century. (b) Total anthropogenic forcing *versus* aerosol forcing; note reverse sense of the abscissa scale; slope of diagonal corresponds to $\Delta(\text{total forcing})/\Delta(\text{aerosol forcing})$ equal to unity. Modified from ref. 43.

¿Que debemos hacer para evitar los +2°C?

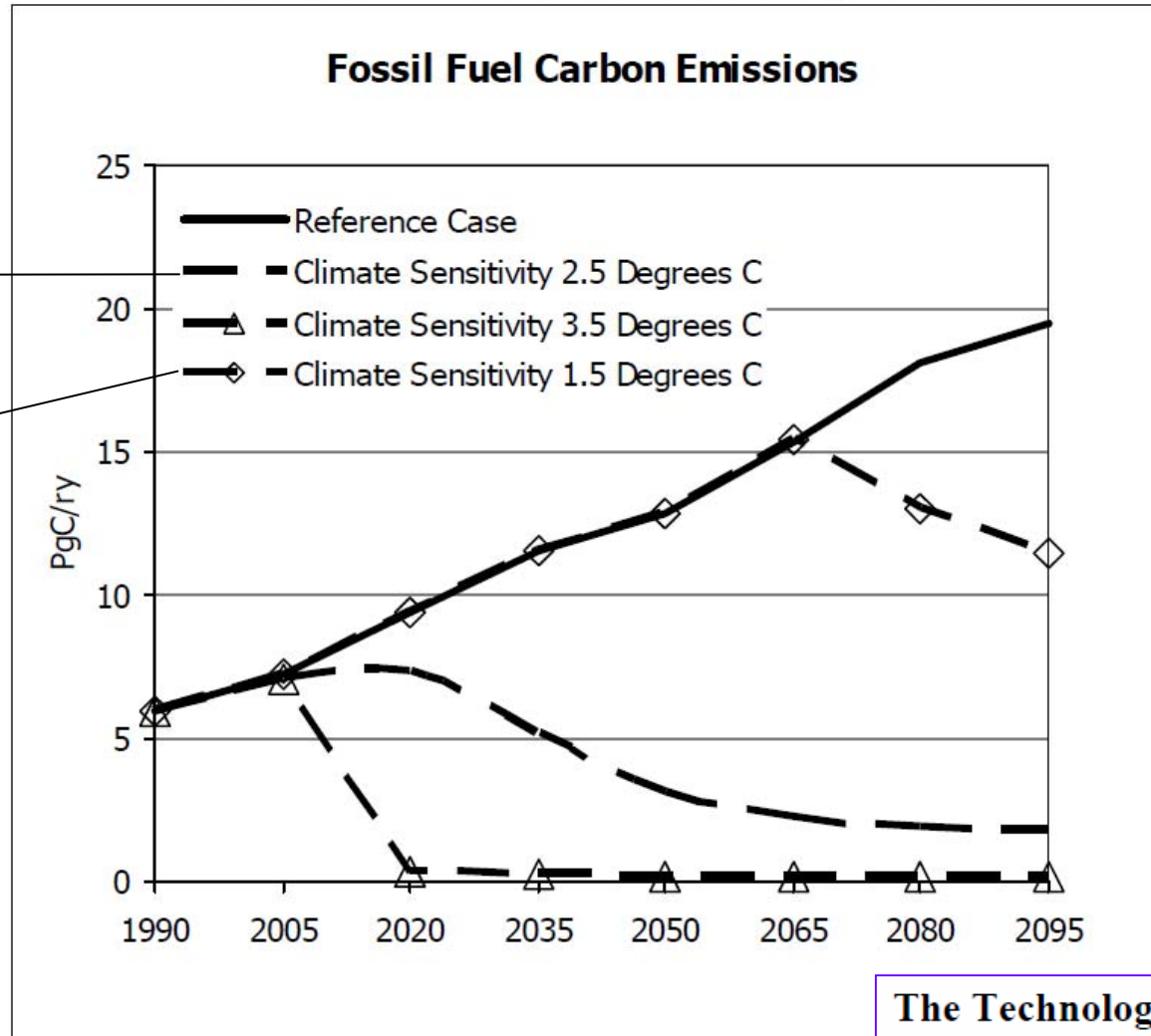


The Technology of Two Degrees

Jae Edmonds and Steven J. Smith

¿Que debemos hacer para evitar los +2°C?

Alternative Climate Sensitivity Values



~10¹⁰ US\$

~0 US\$

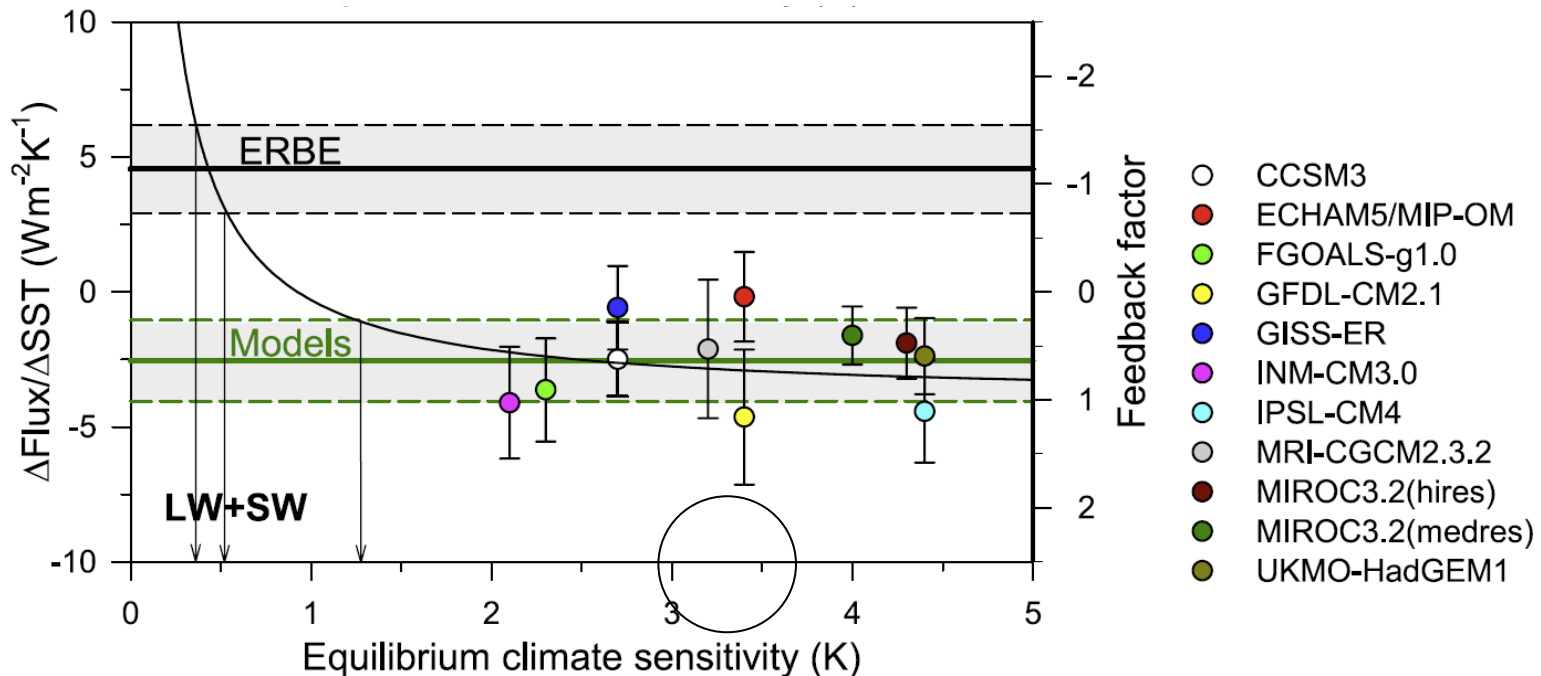
The Technology of Two Degrees

Jae Edmonds and Steven J. Smith

Sensibilidad climática $\Delta T(2\times\text{CO}_2)$ empleando observaciones de TSM / Radiación emergente

Fuertemente atacado por main-stream

$\Delta T(2\times\text{CO}_2) \sim 0.6^\circ < 1.2^\circ\text{C} \rightarrow$ Feedback negativos (Cuales?)



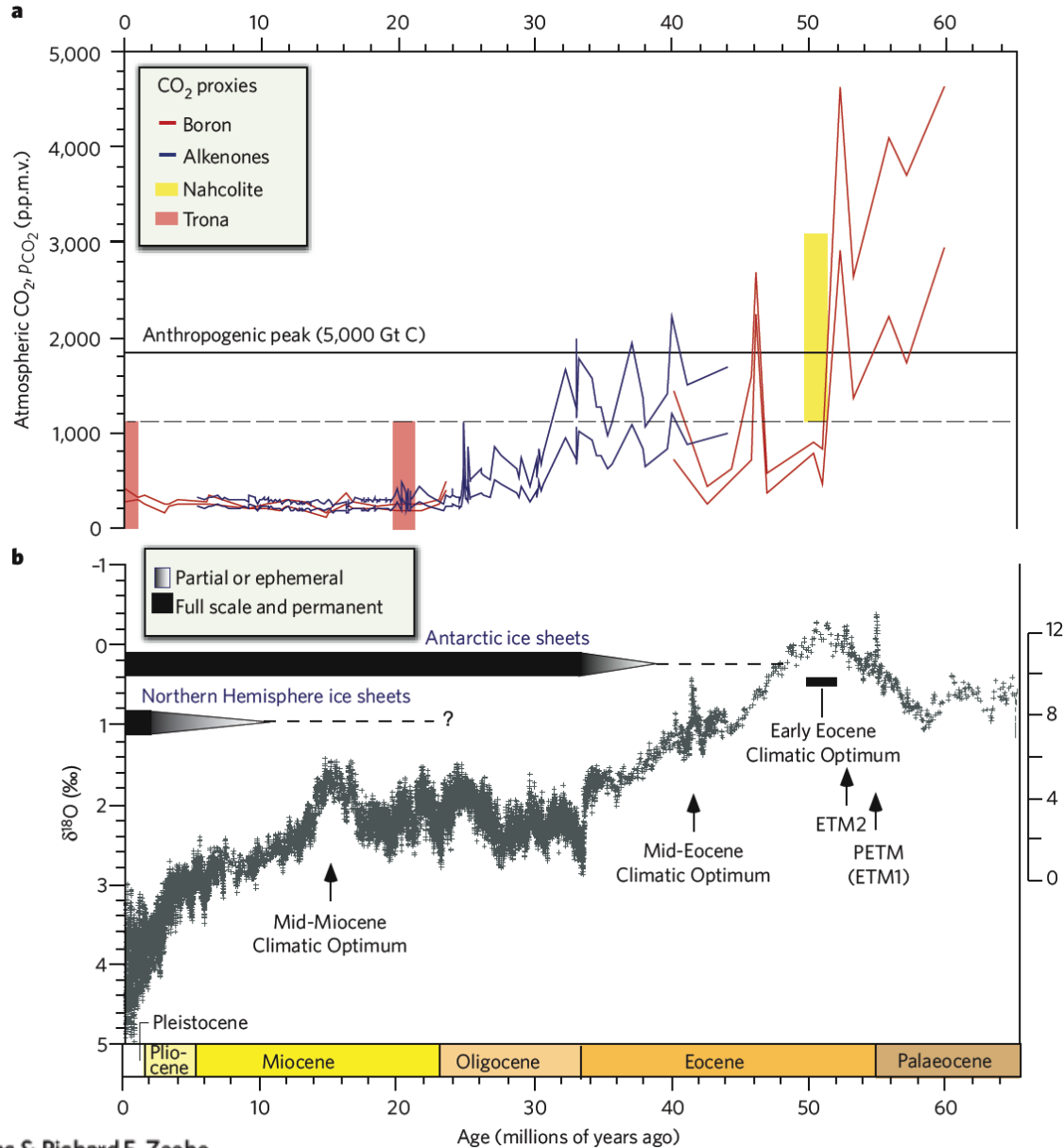
On the determination of climate feedbacks from ERBE data

Richard S. Lindzen¹ and Yong-Sang Choi¹

GRL

Received 16 June 2009; revised 14 July 2009; accepted 20 July 2009; published 26 August 2009.

Paleos al rescate?

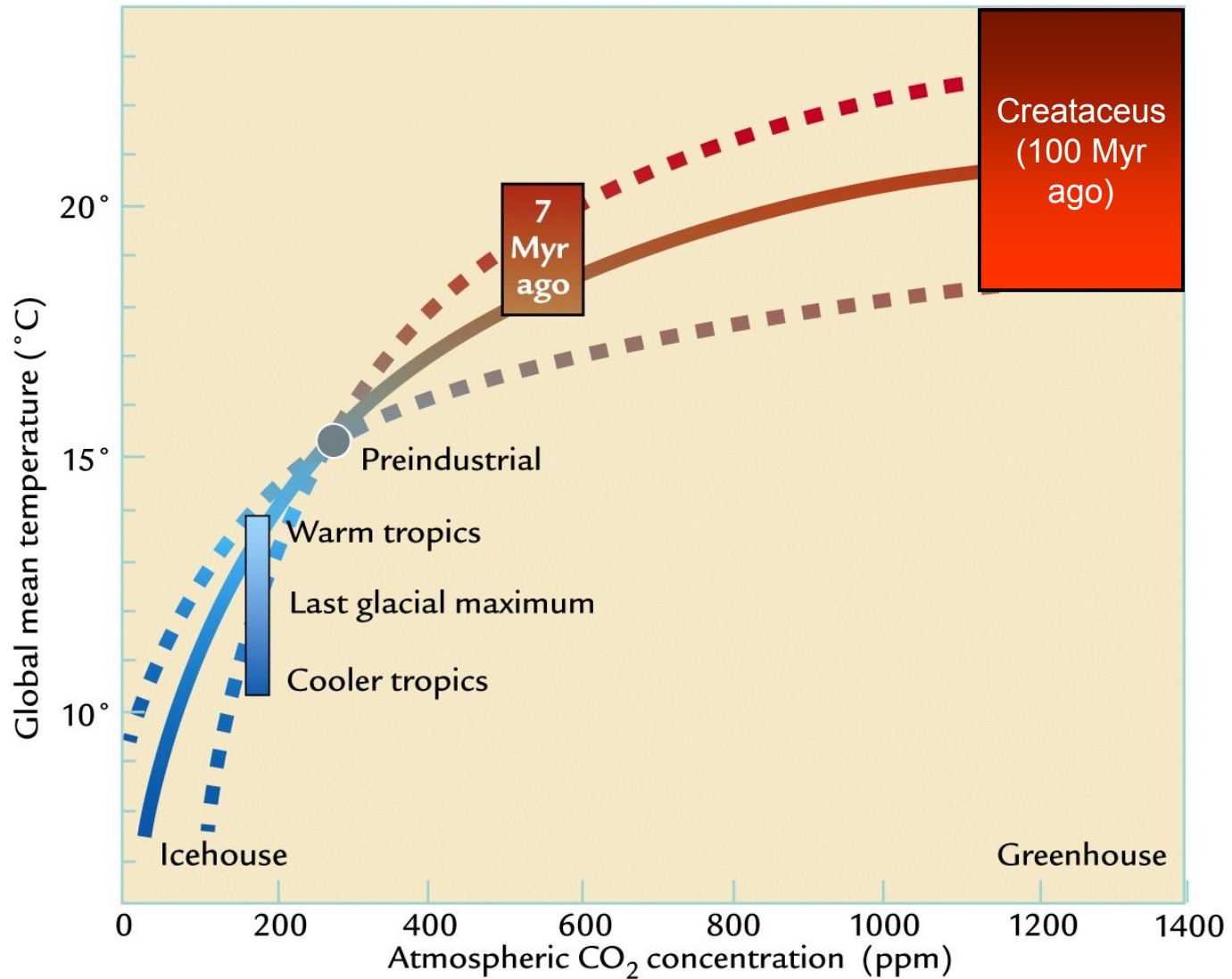


James C. Zachos, Gerald R. Dickens & Richard E. Zeebe

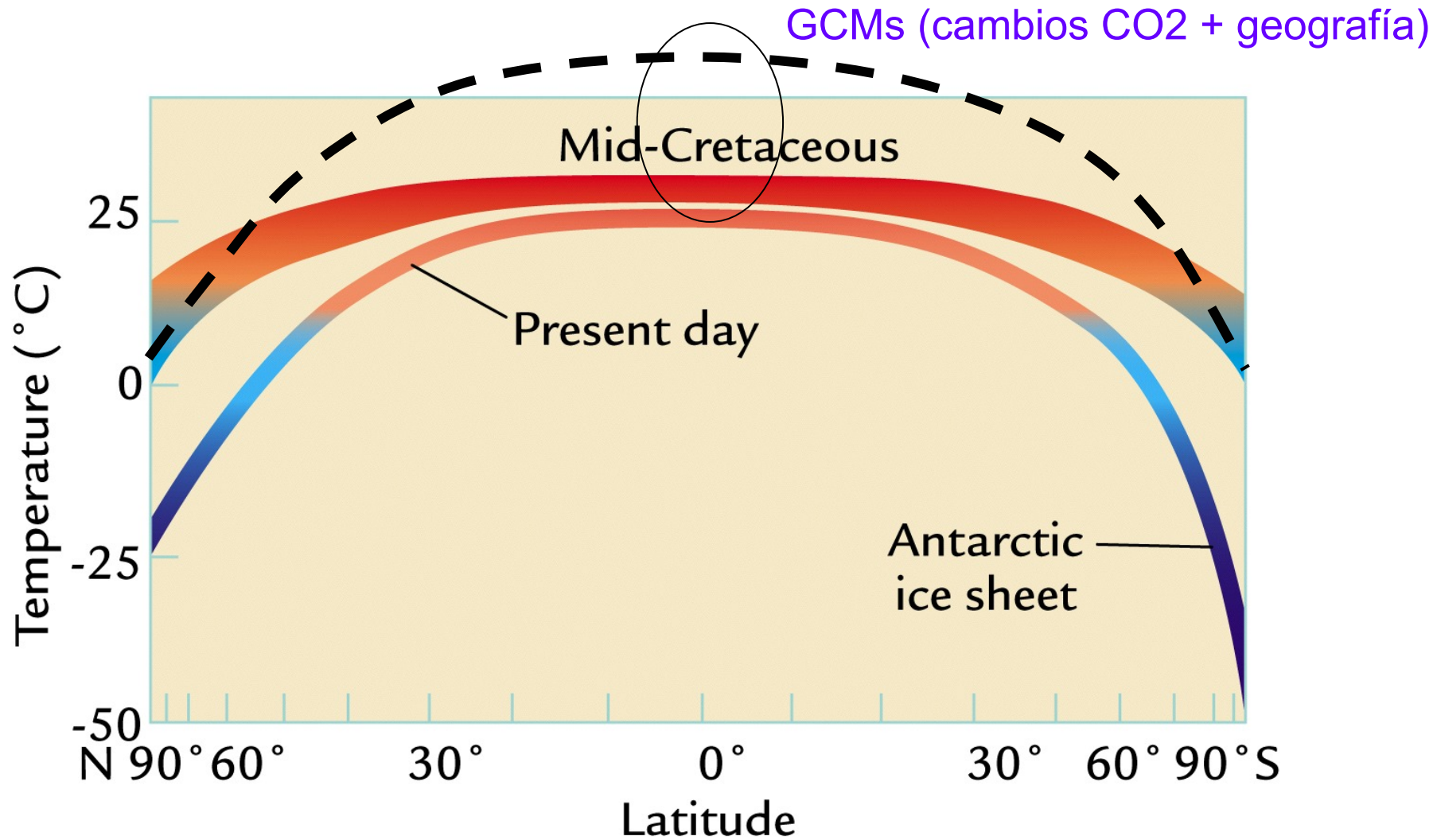
NATURE | Vol 451 | 17 January 2008 | doi:10.1038/nature06588

Sensibilidad climática

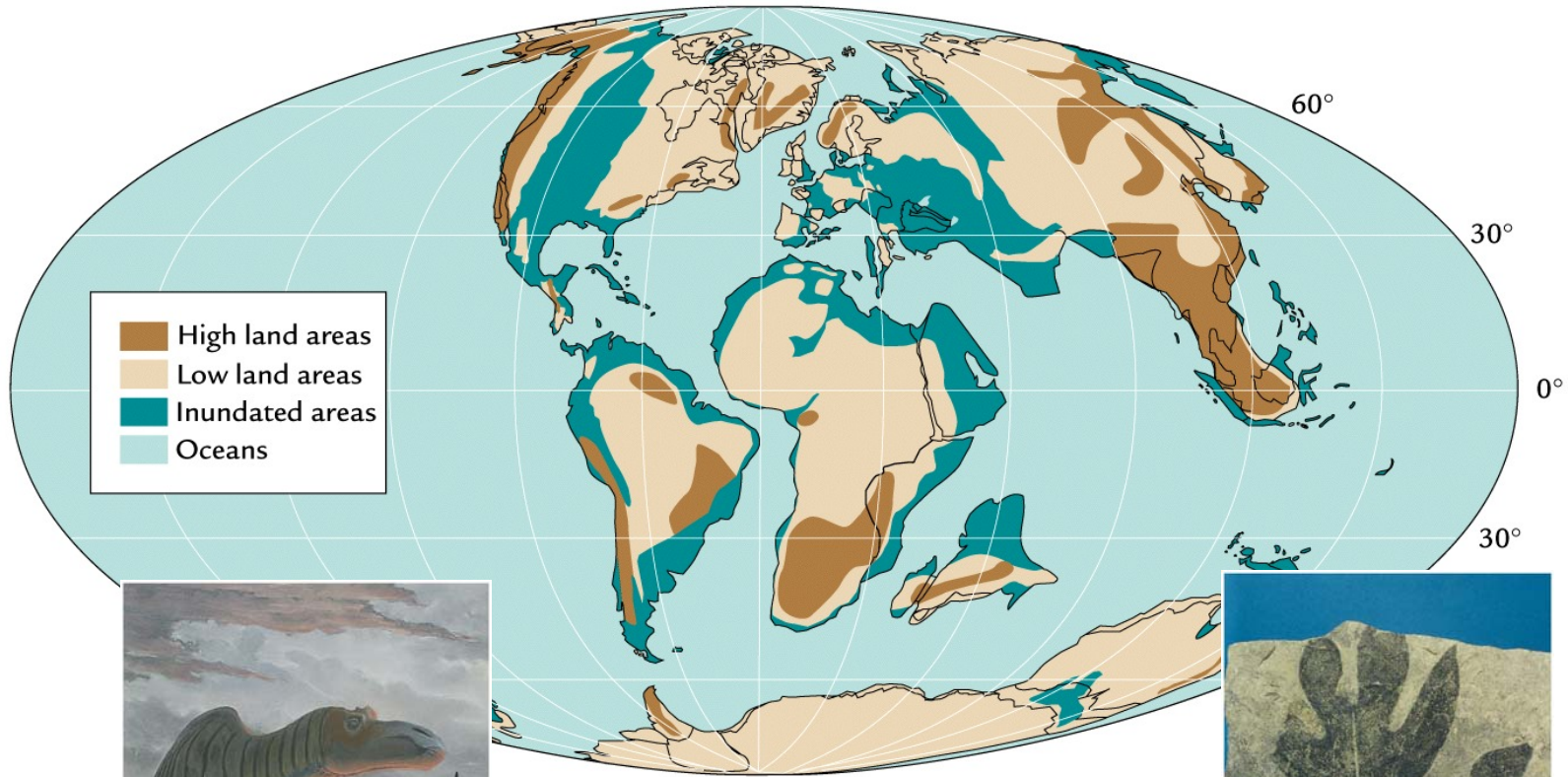
Difícil de estimar en registros Paleo



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



Early Cretaceous world



La aparente existencia de un termostato tropical y su no representación en GCMs es un problema...
Sin embargo una buena culebra ayuda

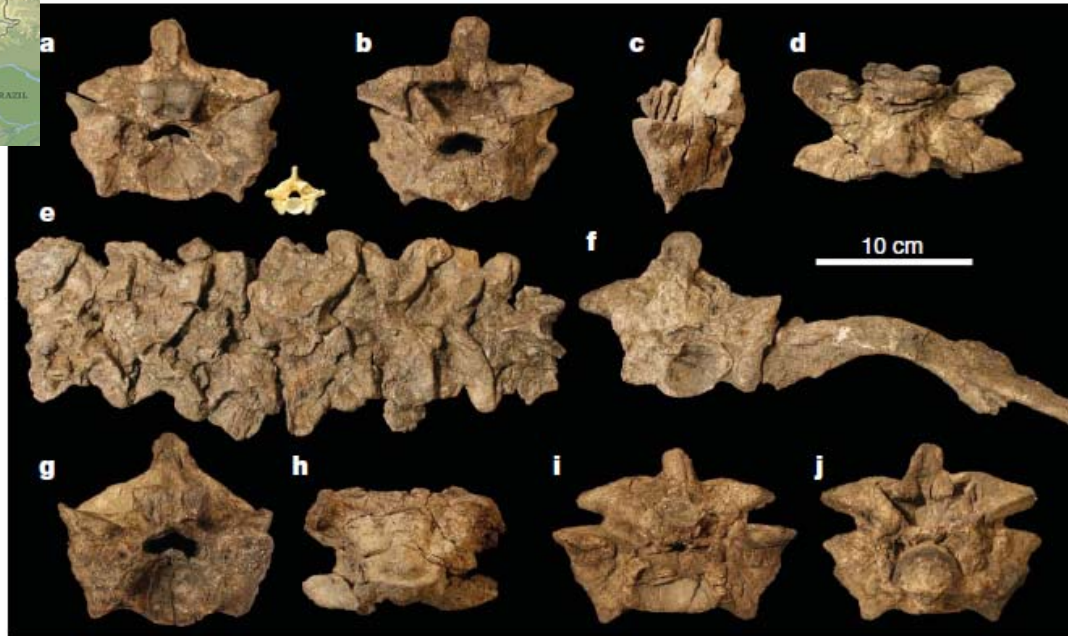


Figure 1 | *Titanoboa cerrejonensis* preloacal vertebrae. a, Type specimen (UF/IGM 1) in anterior view compared to scale with a preloacal vertebra from approximately 65% along the preloacal column of a 3.4 m *Boa constrictor*. Type specimen (UF/IGM 1) shown in posterior view (b), left lateral view (c)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

(UF/IGM 3) in dorsal view (e). Articulated preloacal vertebra and rib (UF/IGM 4) in anterior view (f). Preloacal vertebra (paratype specimen UF/IGM 2) in anterior view (g) and ventral view (h). Preloacal vertebra (UF/IGM 5) in anterior view (i) and posterior view (j). All specimens are to scale.

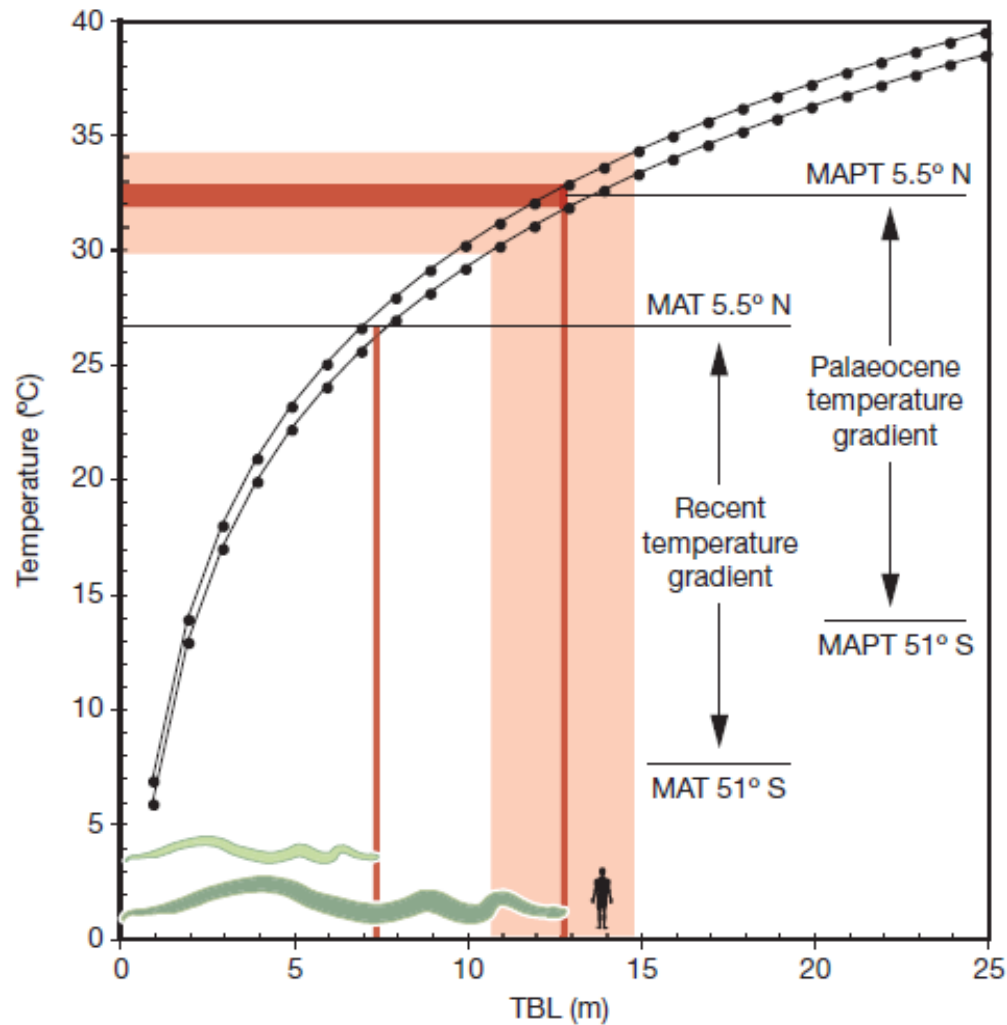


Figure 3 | Mean annual palaeotemperature and Palaeocene latitudinal temperature gradients derived from body size of the green anaconda *Euneptes murinus* (light green) and body size estimates of *Titanoboa correjonensis* (dark green). Curves represent model body size increases with

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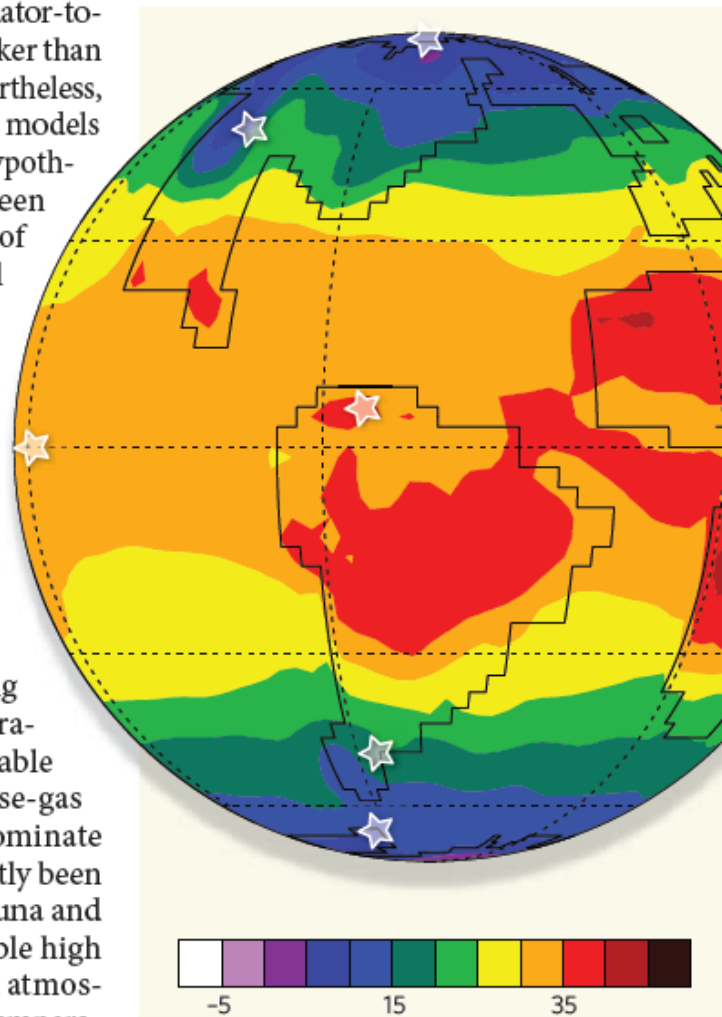


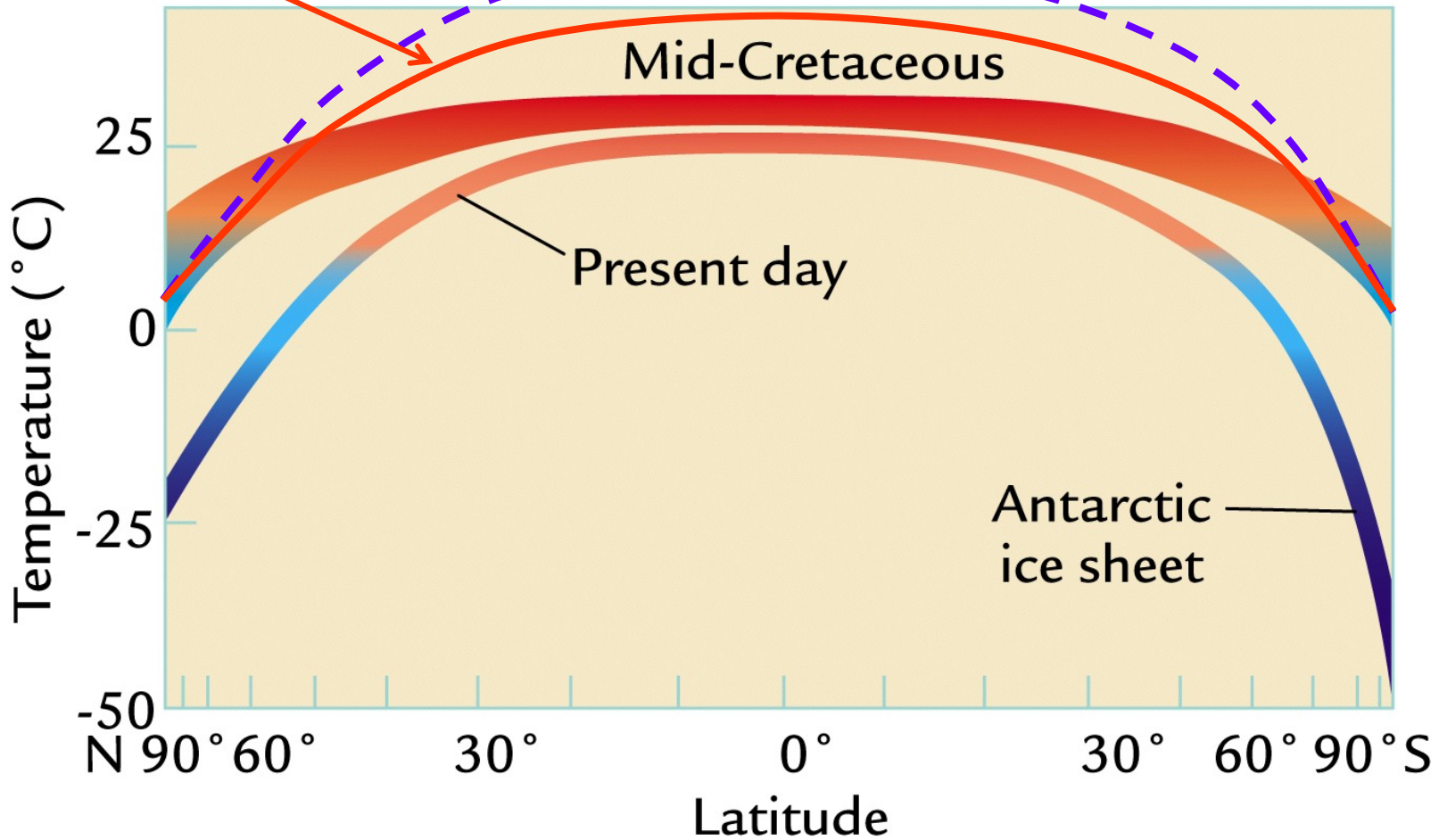
Figure 1 | Simulation of annual average surface temperatures about 58 million years ago. Stars

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Reconstrucción incluyendo *Titanoboa* otorga más credibilidad a GCMs

Reconstrucción c/culebra

GCMs (cambios CO₂ + geografía)



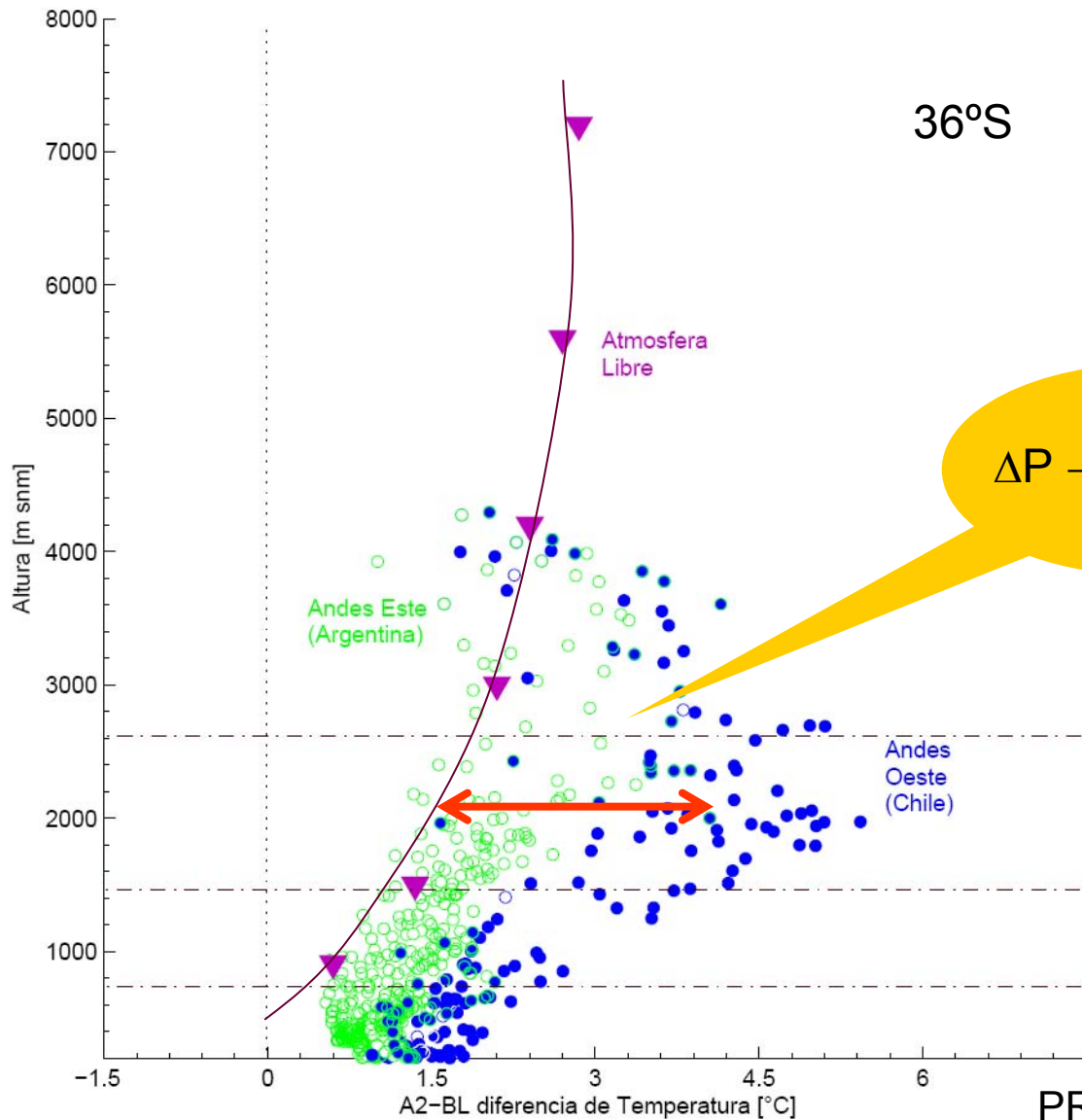
Conclusiones

- No hay duda del incremento del CO₂. Calentamiento de la troposfera media es relativamente modesto. Calentamiento superficial es mas fuerte, debido a superposición de variabilidad natural y/o retro-alimentaciones

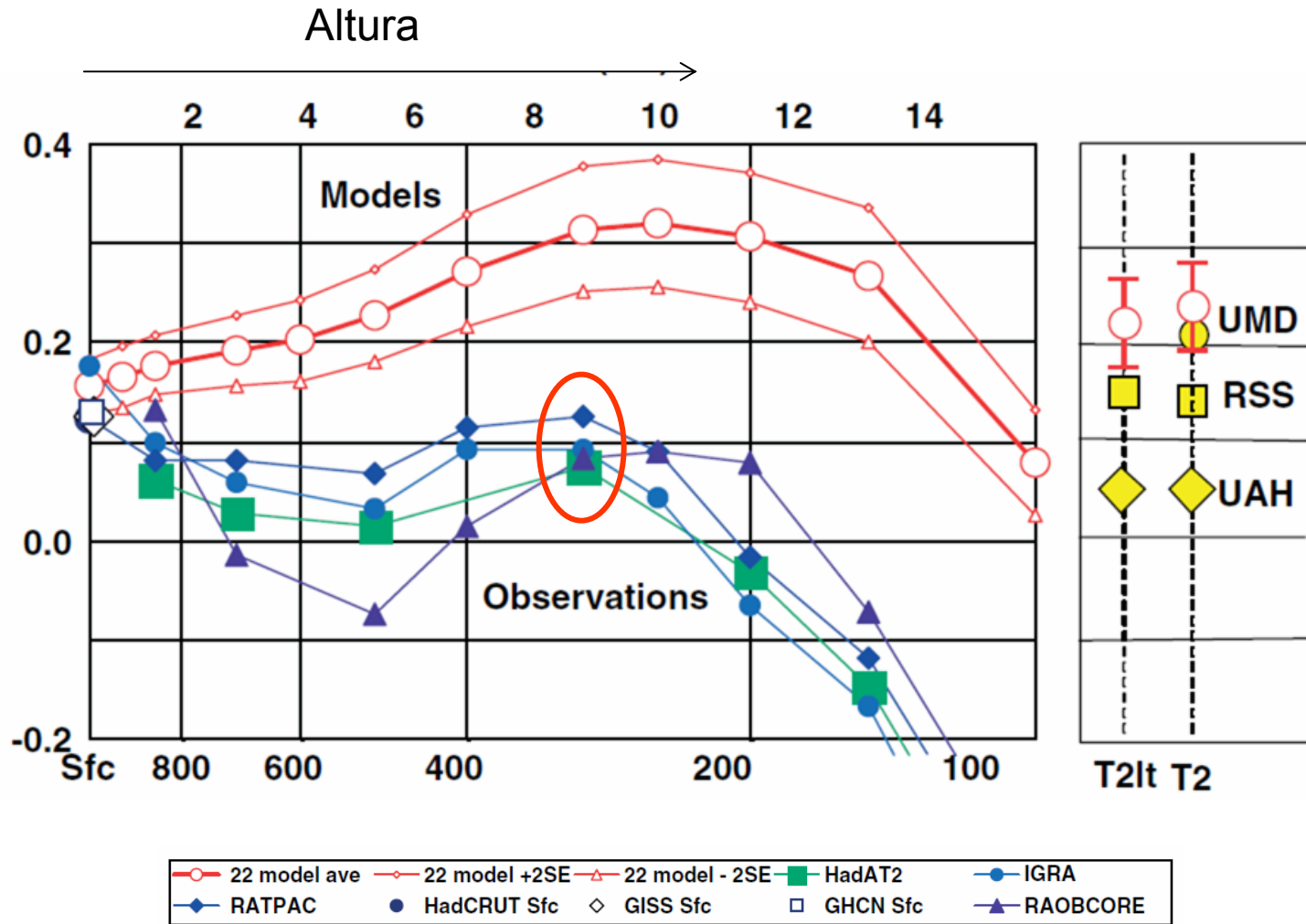
- Incremento del CO₂ durante siglo XXI provocará un aumento en la Temp. media y cambios en los regimenes de viento/precipitación.
- Cuanto y cuando son las preguntas correctas.
- Los GCMs / RCMs son la unica herramienta para mirar al futuro
- Es bueno mantener un ojo critico en los modelos y continuar su mejoramiento...problema lejos de estar resuelto.
- Incertidumbre en modelos tiene tremendas consecuencias en la toma de decisiones para la mitigación y adaptación al CCA

- Para avanzar en ciencia hay que simplificar, pero no sobre-simplificar
- Una buena culebra siempre ayuda

ΔT (A2-BL) versus Height



Cambios observados y simulados en $T(z)$



Efecto invernadero, versión 2 (Lindzen 1999, 2007)

