

# Cambio Climático Global

## Bases Físicas e Impactos en Chile

Aguas Andinas  
Septiembre 2007

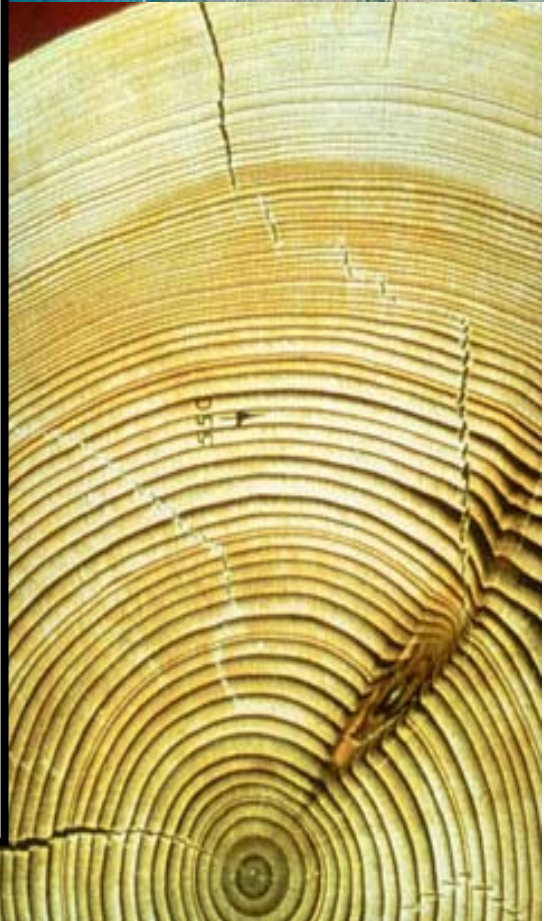
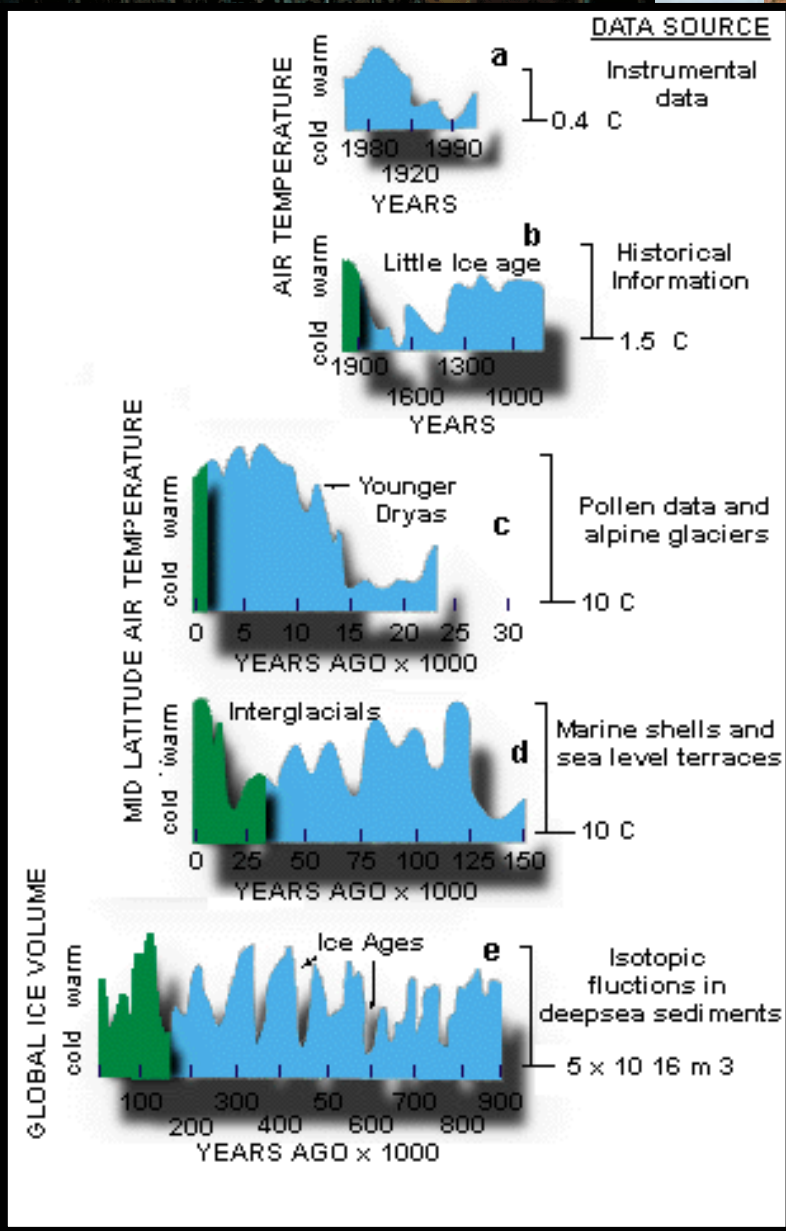
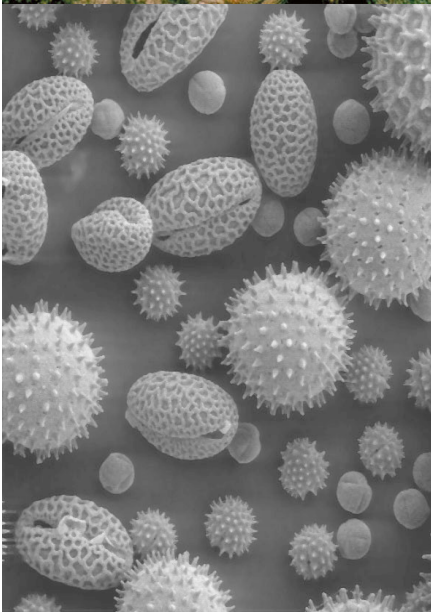
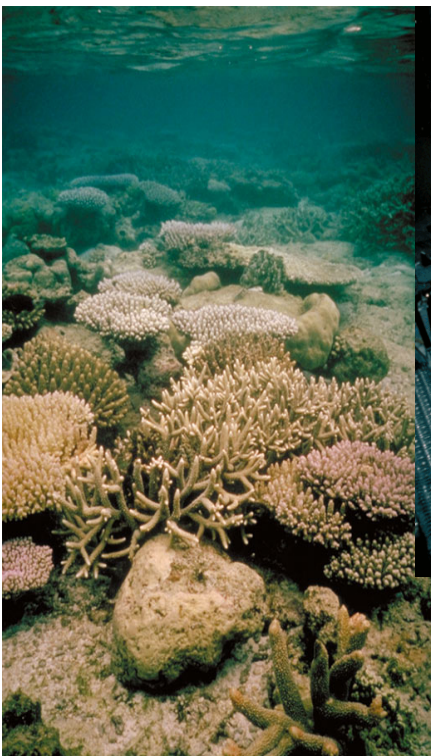
René D. Garreaud y Mark Falvey

*Departamento de Geofísica*  
*Universidad de Chile*

# Temario

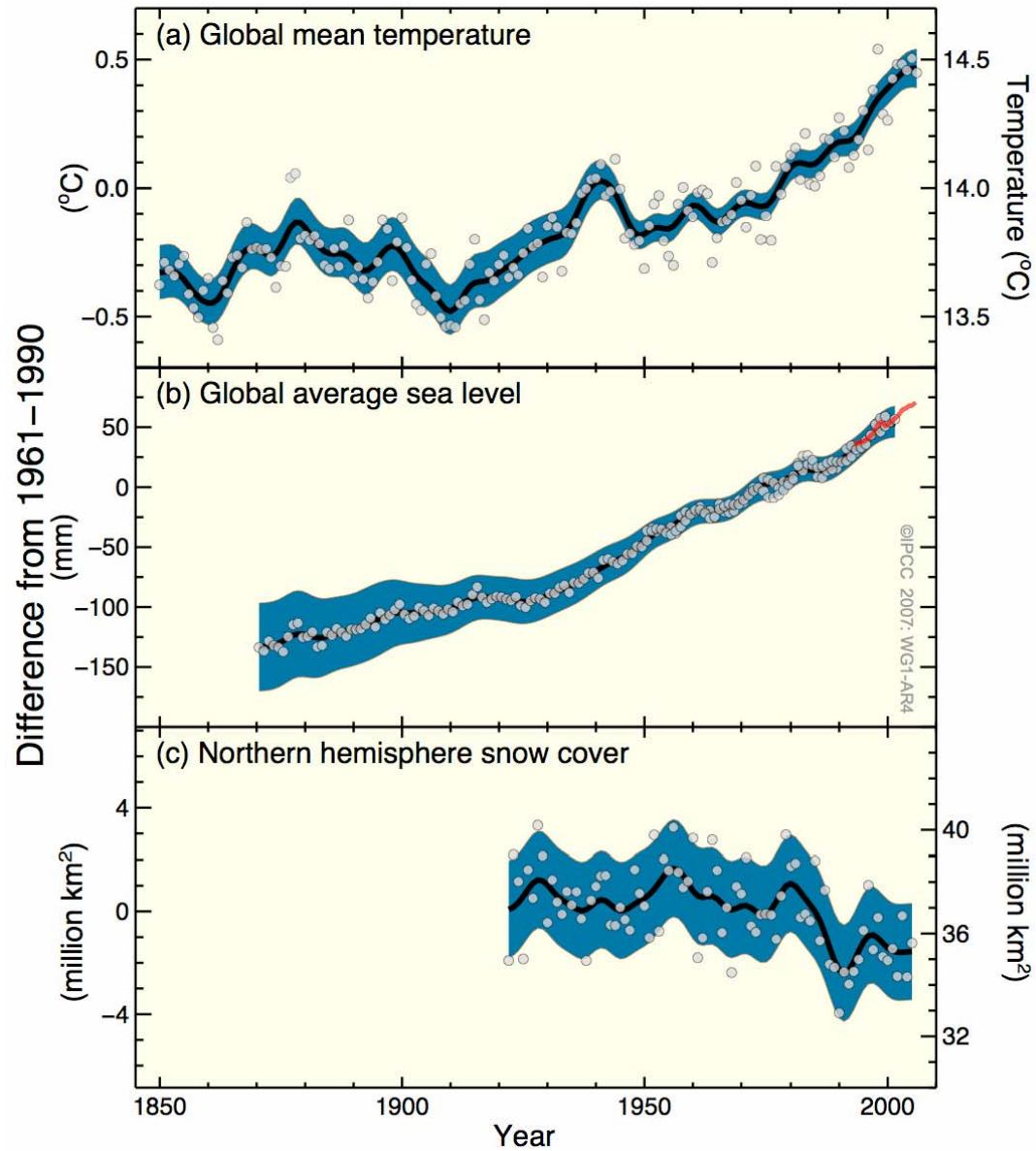
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1. Cambios en el siglo XX: Global /Regional
2. Bases Físicas del Cambio Climático
3. Pronóstico para mañana





# Changes in Temperature , Sea Level and Northern Hemisphere Snow Cover



$$\partial T_{sfc} / \partial t$$

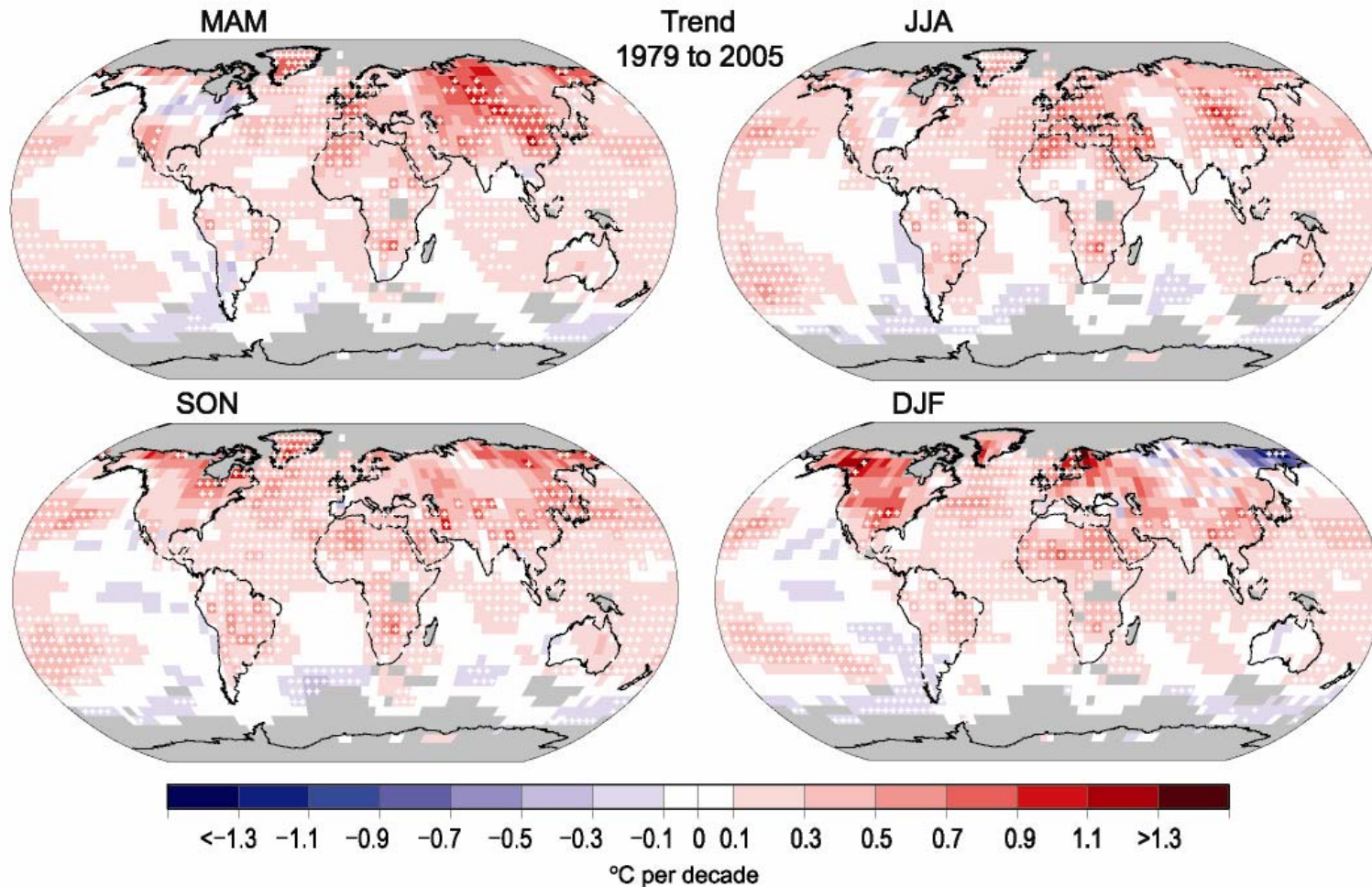
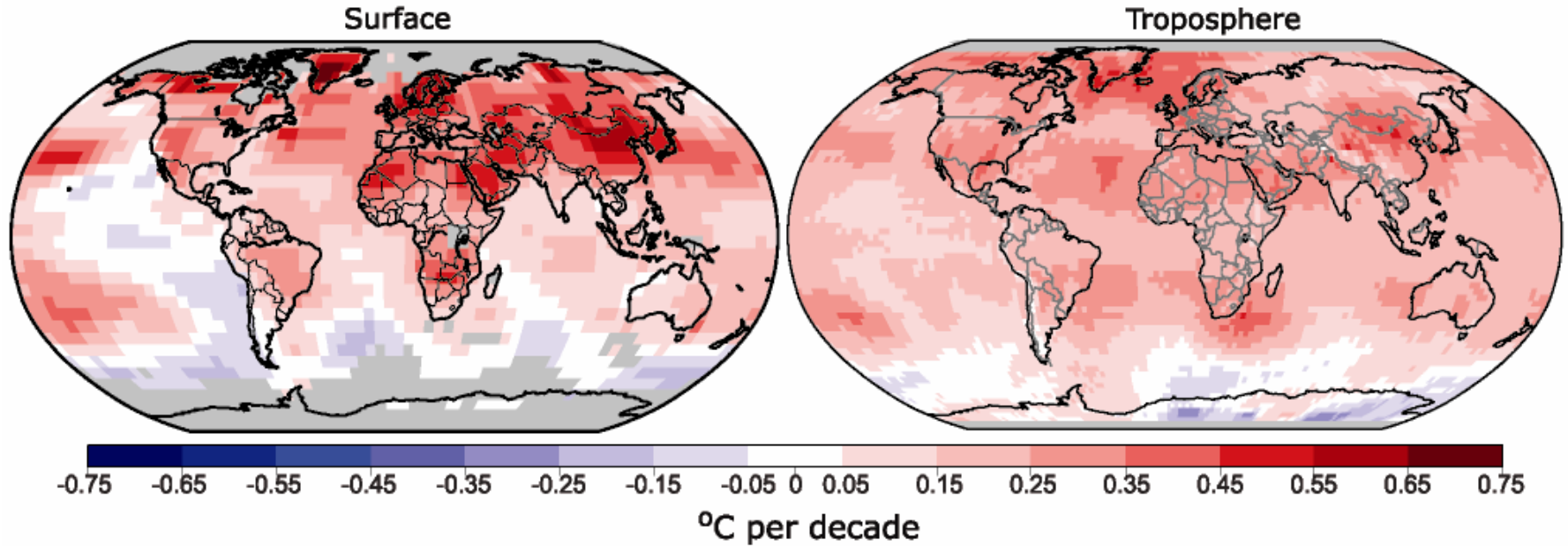


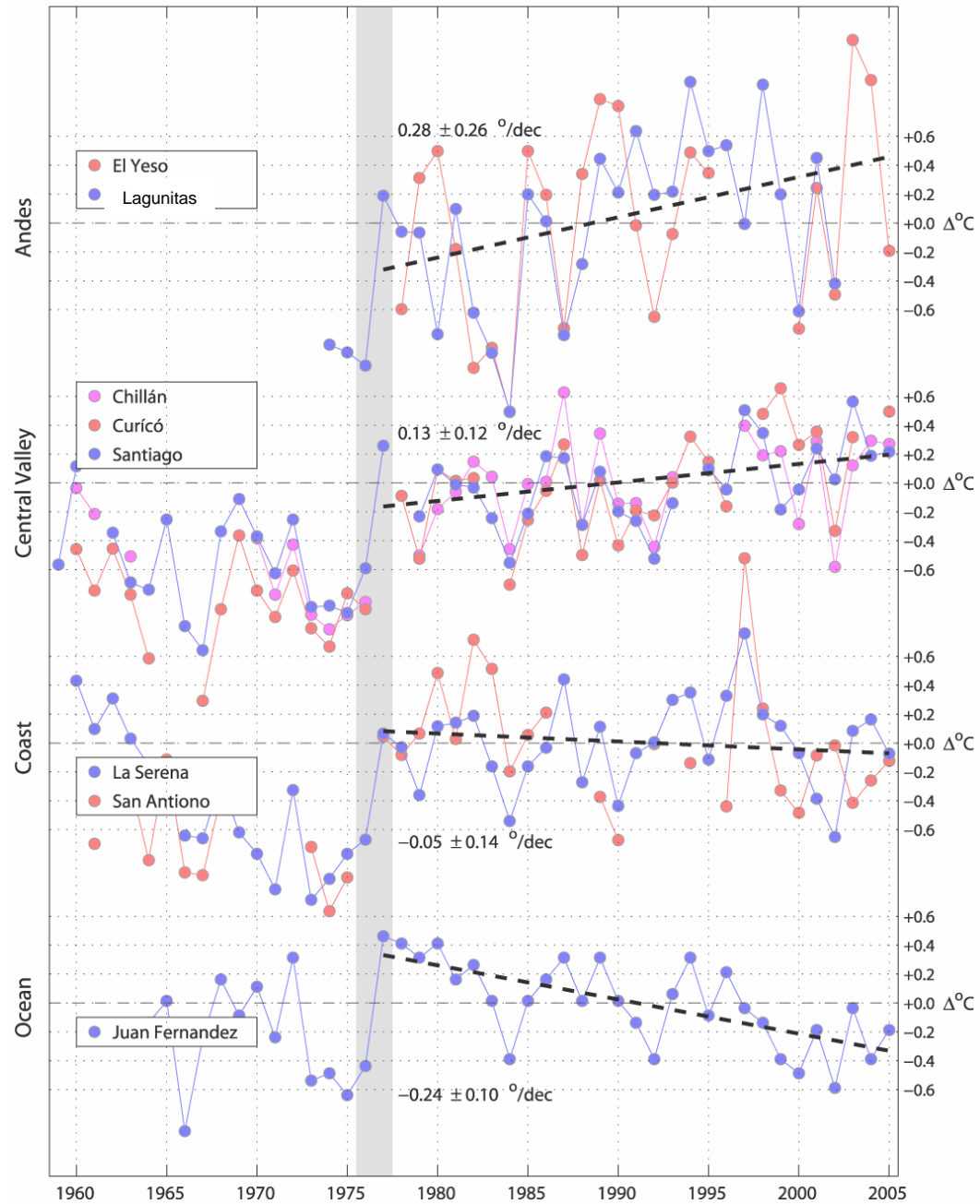
Figure 3.10. Linear trend of seasonal MAM, SON and DJF temperature for 1979 to 2005 (°C per decade). Areas in grey have insufficient data to produce reliable trends. The minimum number of years required to calculate a trend value is 18. A seasonal value is available if there are two valid monthly temperature anomaly values. The data used was produced by NCDC from Smith and Reynolds (2005). Trends significant at the 5% level are indicated by white + marks.

$$\partial T / \partial t \quad 1979-2005$$



Patterns of linear global temperature trends from 1979-2005 estimated at the surface (left) and for the troposphere (right) from surface to about 10 km altitude, from satellite records.

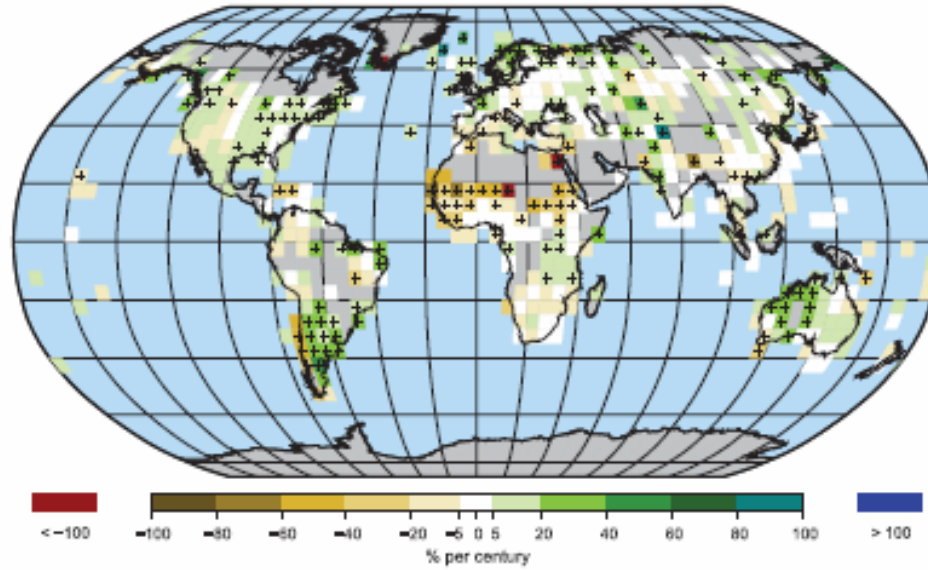
# Central Chile Temperatures



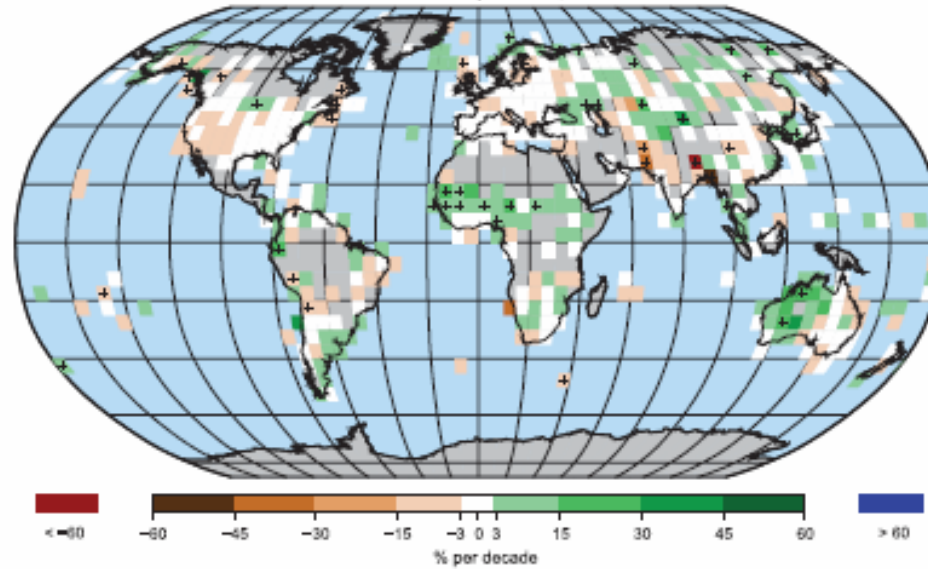


$$\partial R / \partial t$$

Trend in Annual Precipitation, 1901 to 2005

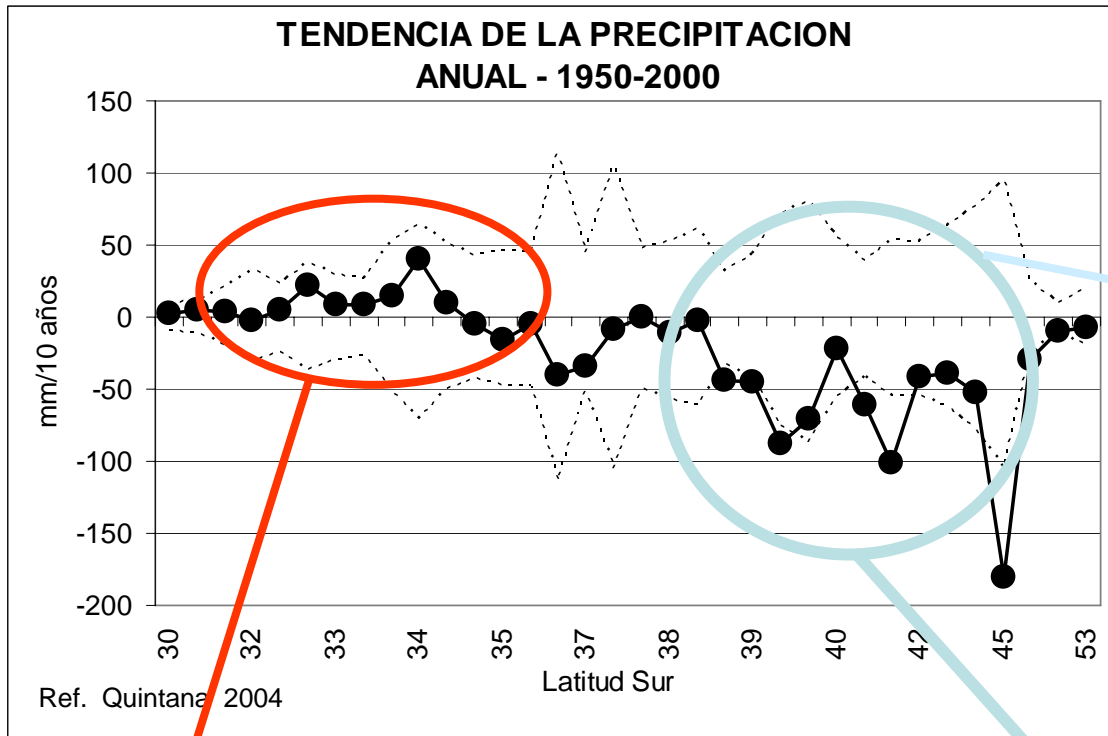


Trend in Annual Precipitation, 1979 to 2005



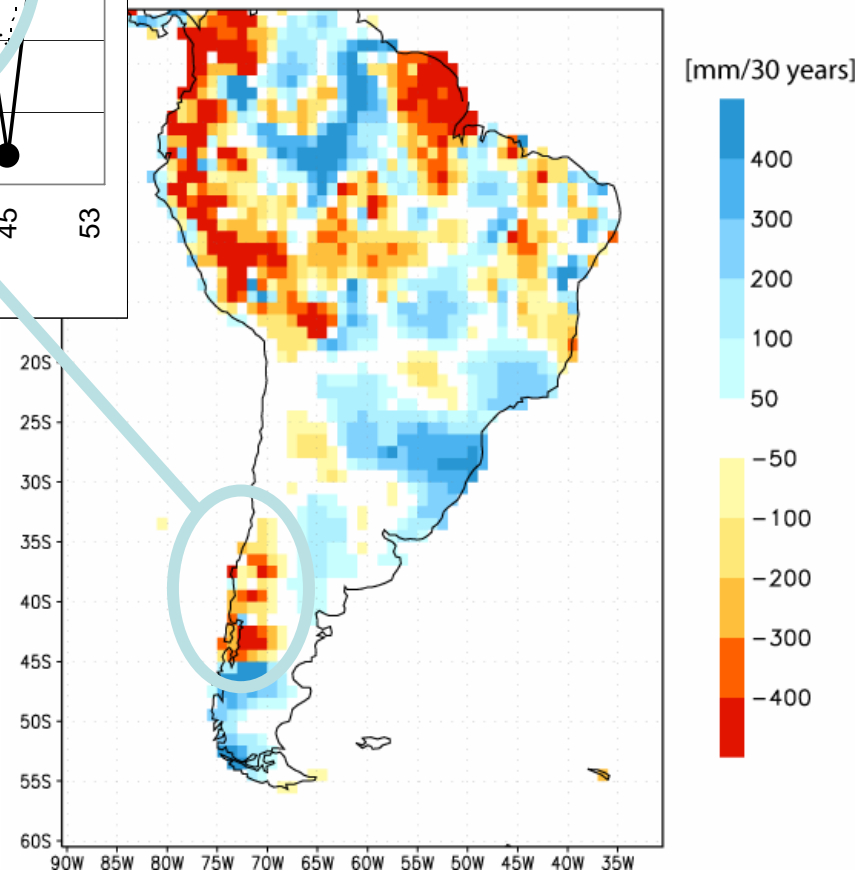


# Cambios absolutos en precipitación



- Rainy climate
- MAP ~ 1000-3000 mm
- $\sigma(IA)/MAP \sim 0.1$
- Weak ENSO Impact
- Significant drying trend

- Semiarid climate
- MAP ~ 30-500 mm
- $\sigma(IA)/MAP \sim 0.3 - 0.5$
- Strong ENSO Impact
- No significant trend



## Cambios relativos en precipitación

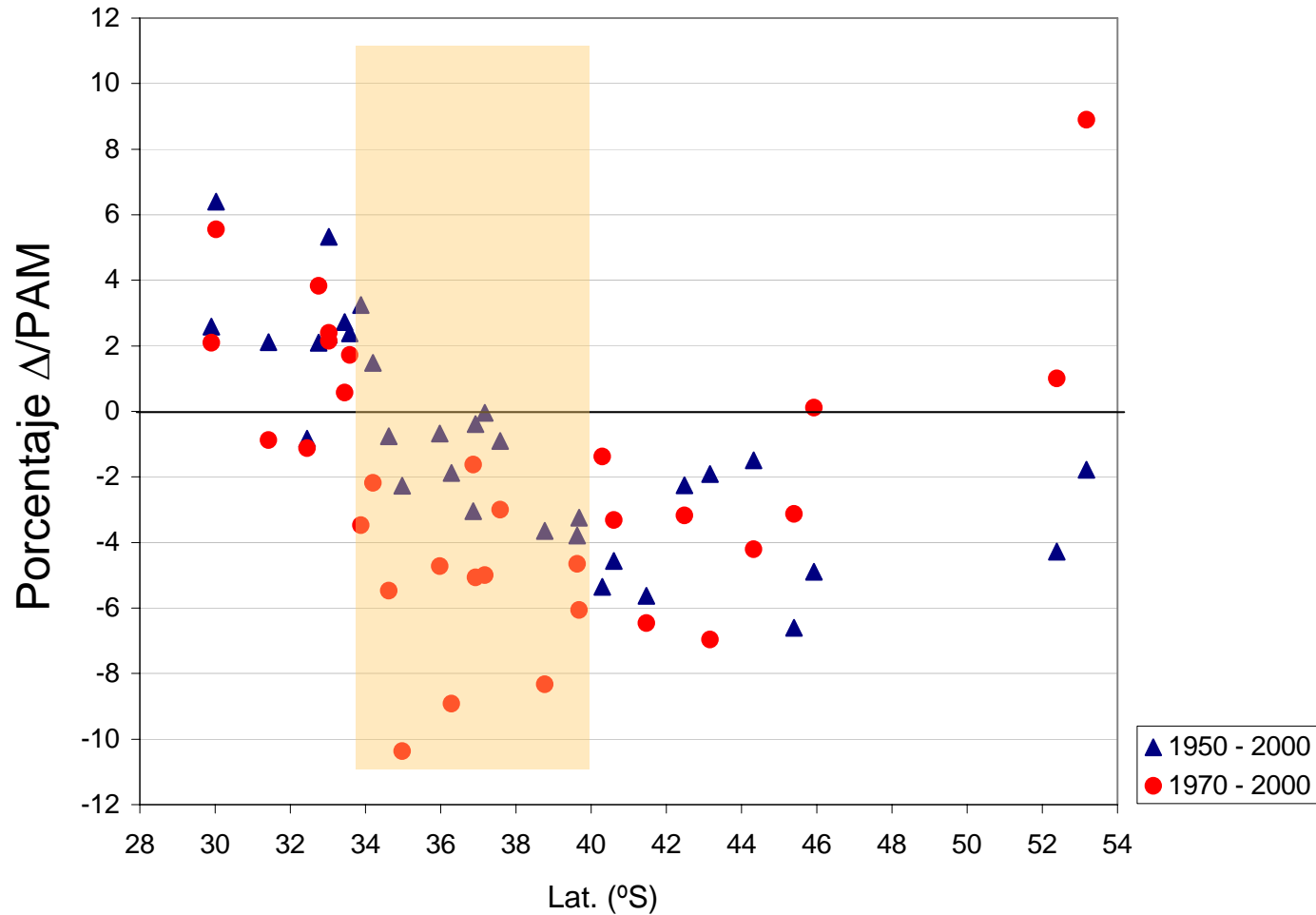


Figura 2. Tendencia de la precipitación anual expresada como el cambio porcentual por década (el porcentaje se evalúa con respecto al promedio de precipitación durante el periodo respectivo).

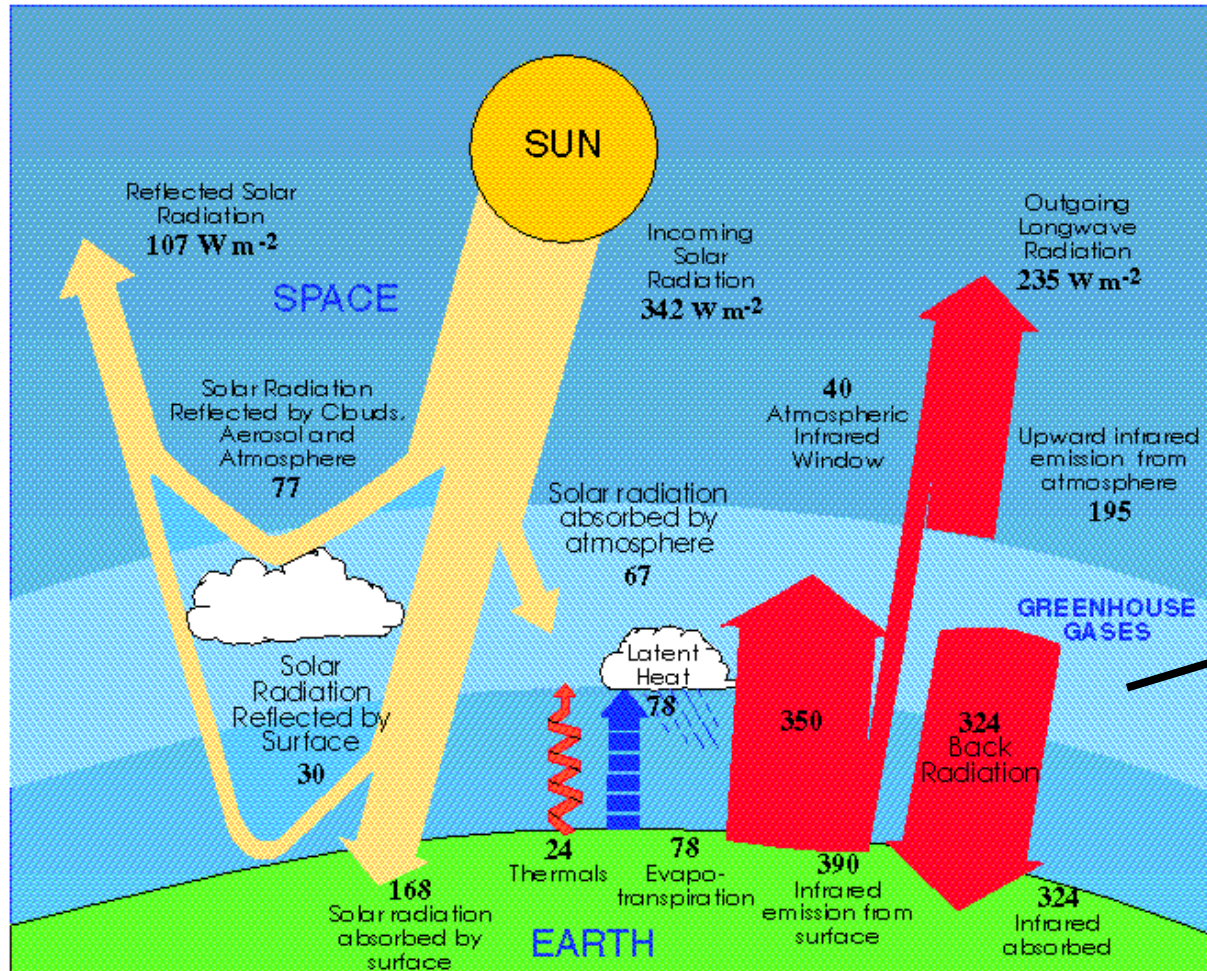
# Factores de cambio climático

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- Factores internos: tectónica, volcanismo,...
- Factores externos: actividad solar, meteoros,.....
- Factores antropogénicos: Cambios en la composición de la atmósfera terrestre, uso de suelo, etc.



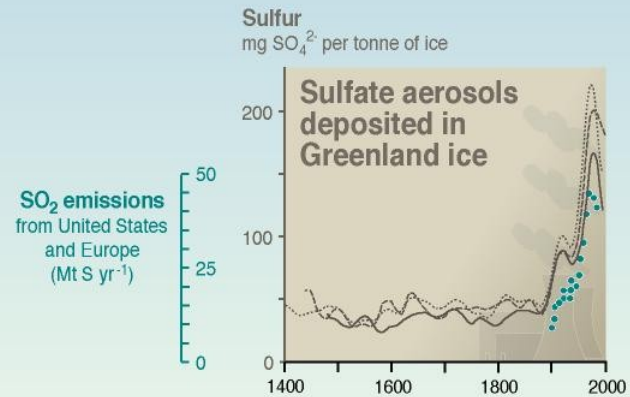
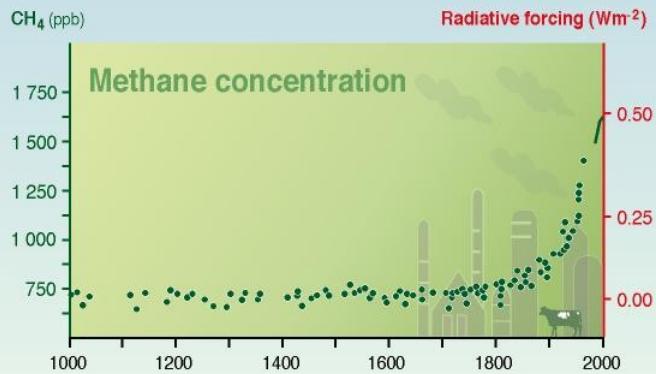
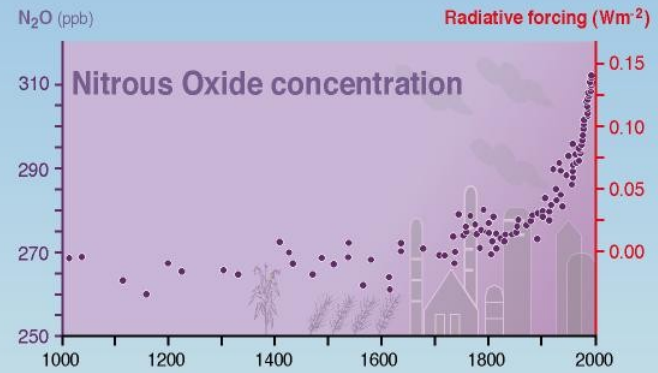
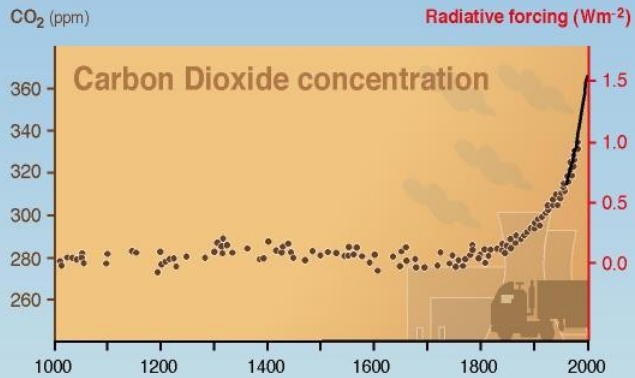
# Balance Global de Energía del Planeta Tierra (promedio en latitud y longitud)



Gases Invernadero  
 $\text{H}_2\text{O}$ ,  $\text{CO}_2$ ,  $\text{CH}_4$ ,  $\text{N}_2\text{O}$

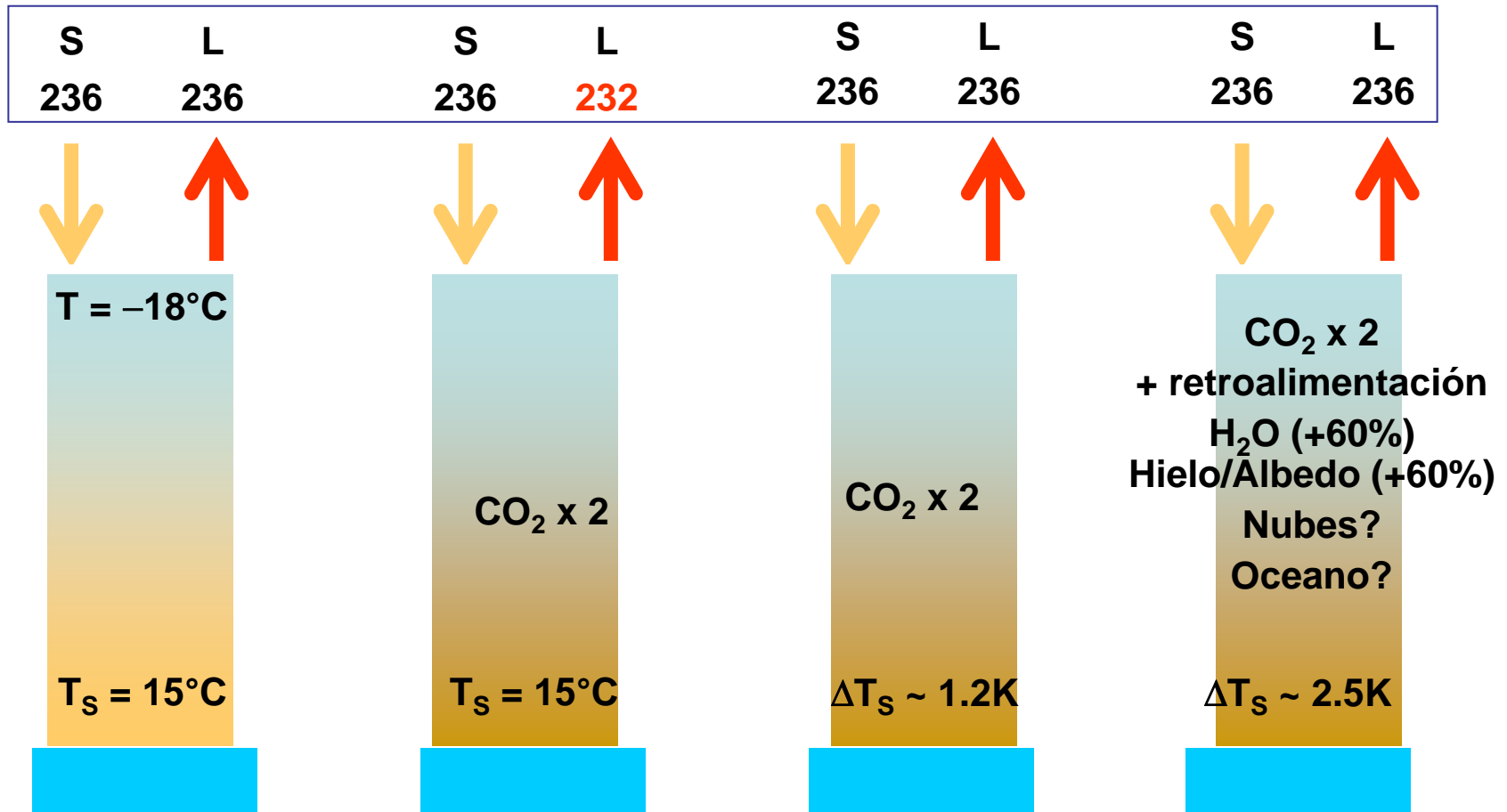


## Indicators of the human influence on the atmosphere during the Industrial era

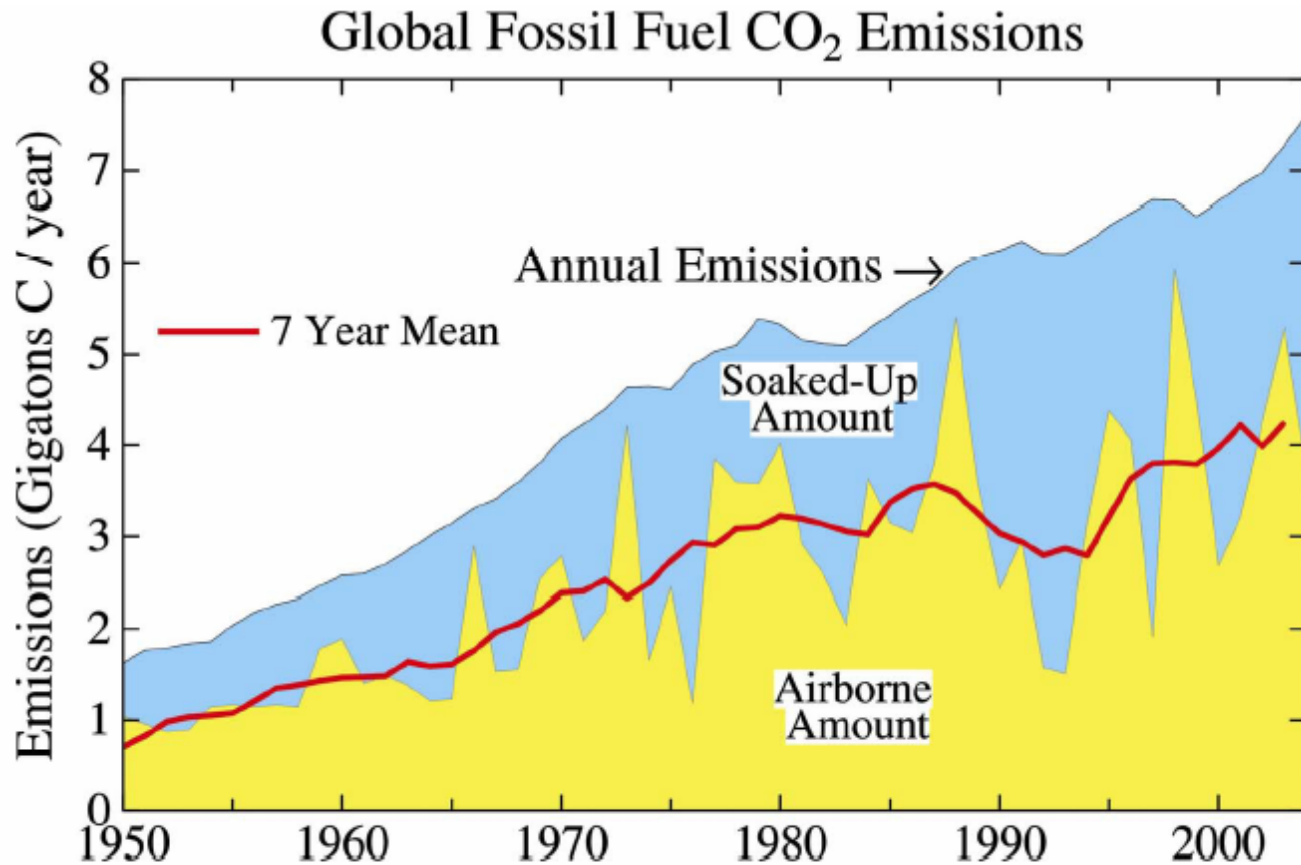


# Efecto invernadero antrópico

Sistema terrestre tiende al equilibrio



Durante el siglo XX el océano/biosfera ha capturado cerca del 40% del CO<sub>2</sub> emitido...captura puede variar ( $\pm$  ?) con incremento de T



Global fossil fuel CO<sub>2</sub> emissions with division into portions that remain airborne or are soaked up by the ocean and land.

Source: Hansen and Sato, *PNAS*, 101, 16109, 2004.

# Proyecciones Climáticas para el siglo XXI

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- i. Modelos atmosféricos
- ii. Resultados Globales
- iii. Resultados Regionales



# My first toy model

A system of coupled, non-linear algebraic equations

$$X_{(t)} = A \cdot X_{(t-1)} \cdot Y_{(t)} + B \cdot Z_{(t-1)} + \varepsilon_x$$

$$Y_{(t)} = C \cdot X_{(t-1)} \cdot Y_{(t-1)} + B \cdot Z_{(t)} + \varepsilon_y$$

$$Z_{(t)} = D \cdot Z_{(t-1)} \cdot Y_{(t)} + E \cdot X_{(t-1)} + \varepsilon_z$$

$$\varepsilon_x = \varepsilon_y = \varepsilon_z = 0$$

**X, Y, Z: Time-dependent variables**

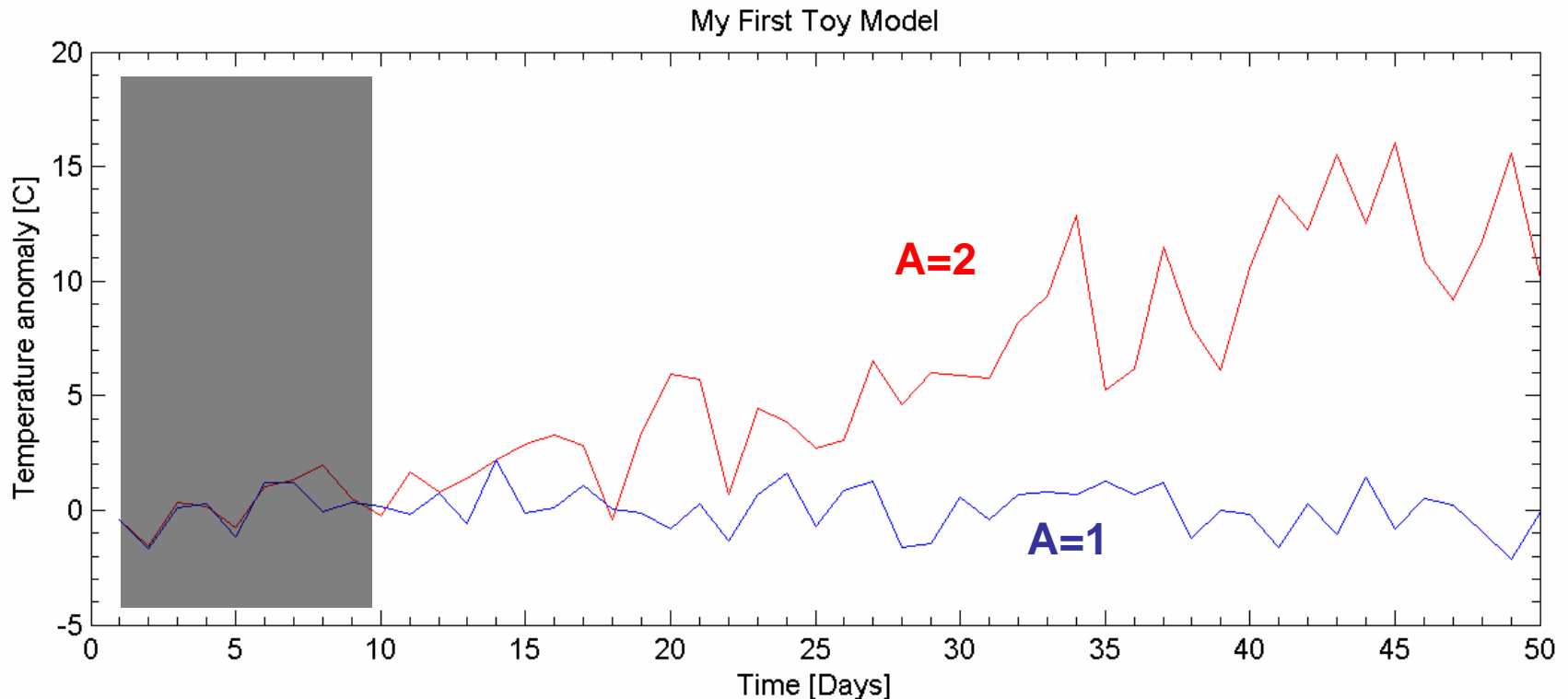
Pressure, winds, temperature, moisture,....

**A, B, C, D: External parameters**

Orbital parameters, CO<sub>2</sub> Concentration, SST (AGCM), Land cover

$\varepsilon_x$   $\varepsilon_y$   $\varepsilon_z$  **Random errors**

Model results departs from reality after two-weeks because of “butterfly effect” (uncertainty in initial conditions) but they are still useful in a climatic perspective and highly dependent upon external parameters



Two runs of the model, everything equal but parameter  $A$   
Note the “Climate Change” related to change in  $A$

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

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

**Momentum eqn.**

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

**Energy eqn.**

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

**Mass eqn.**

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

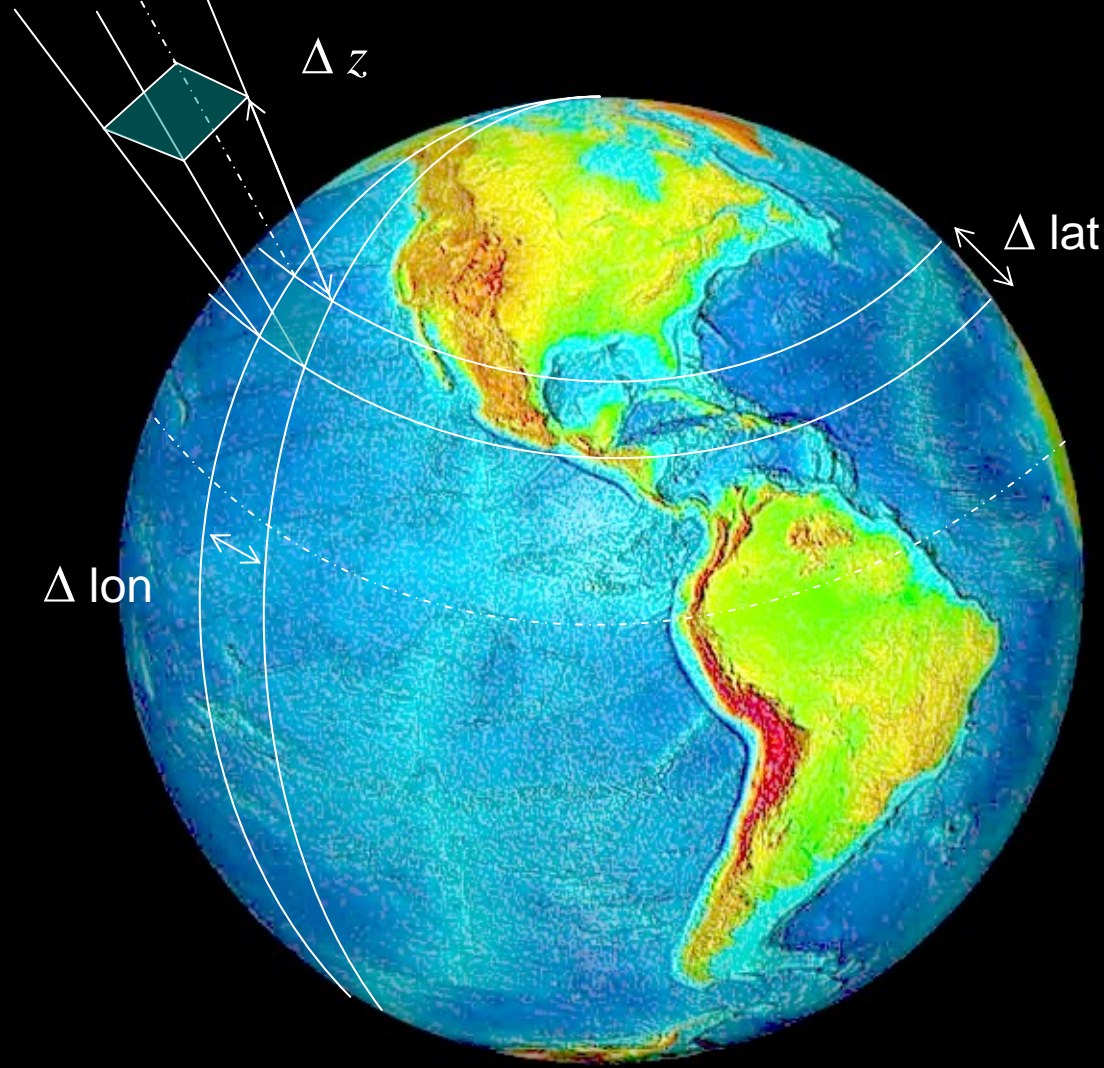
**Idea gas law**

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

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

**Water substance eqns.**

# Global Models (GCM)



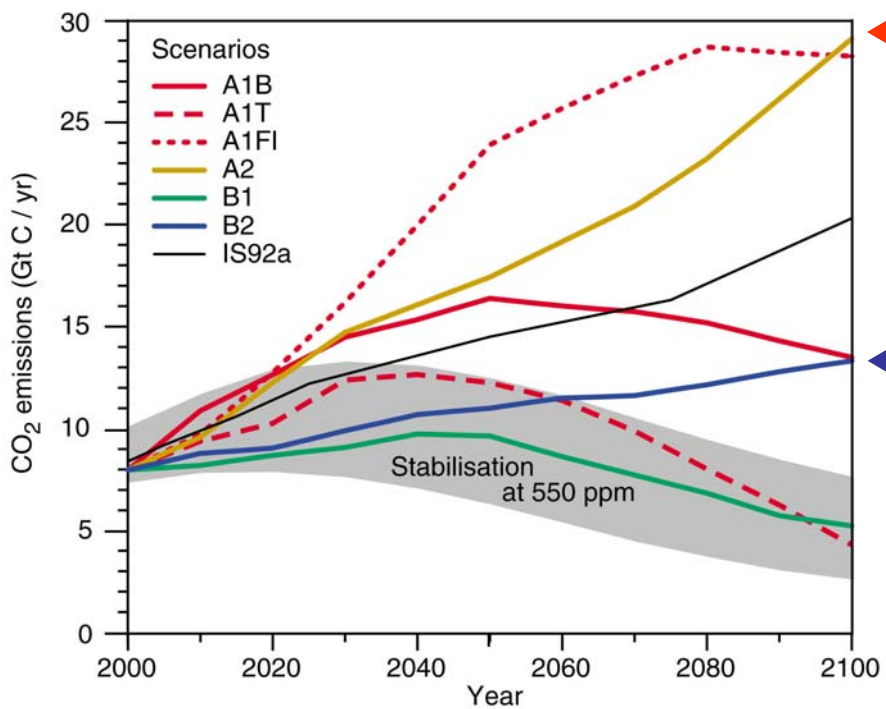
$\Delta \text{lat} \sim \Delta \text{lon} \sim 1^\circ - 3^\circ$

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

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

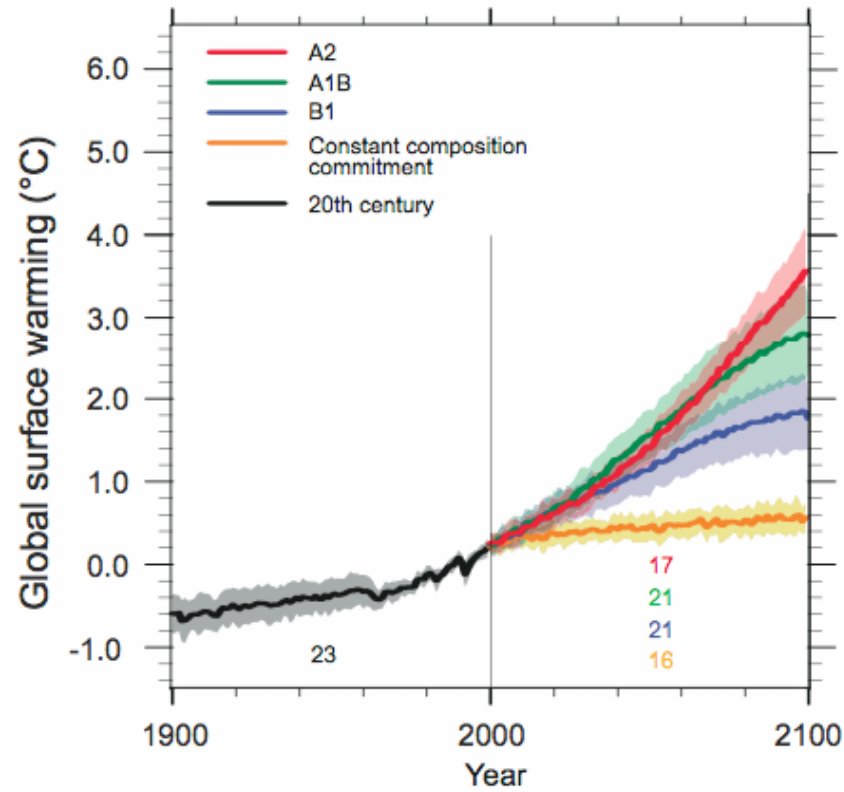
Top of atmosphere: 15-50 km



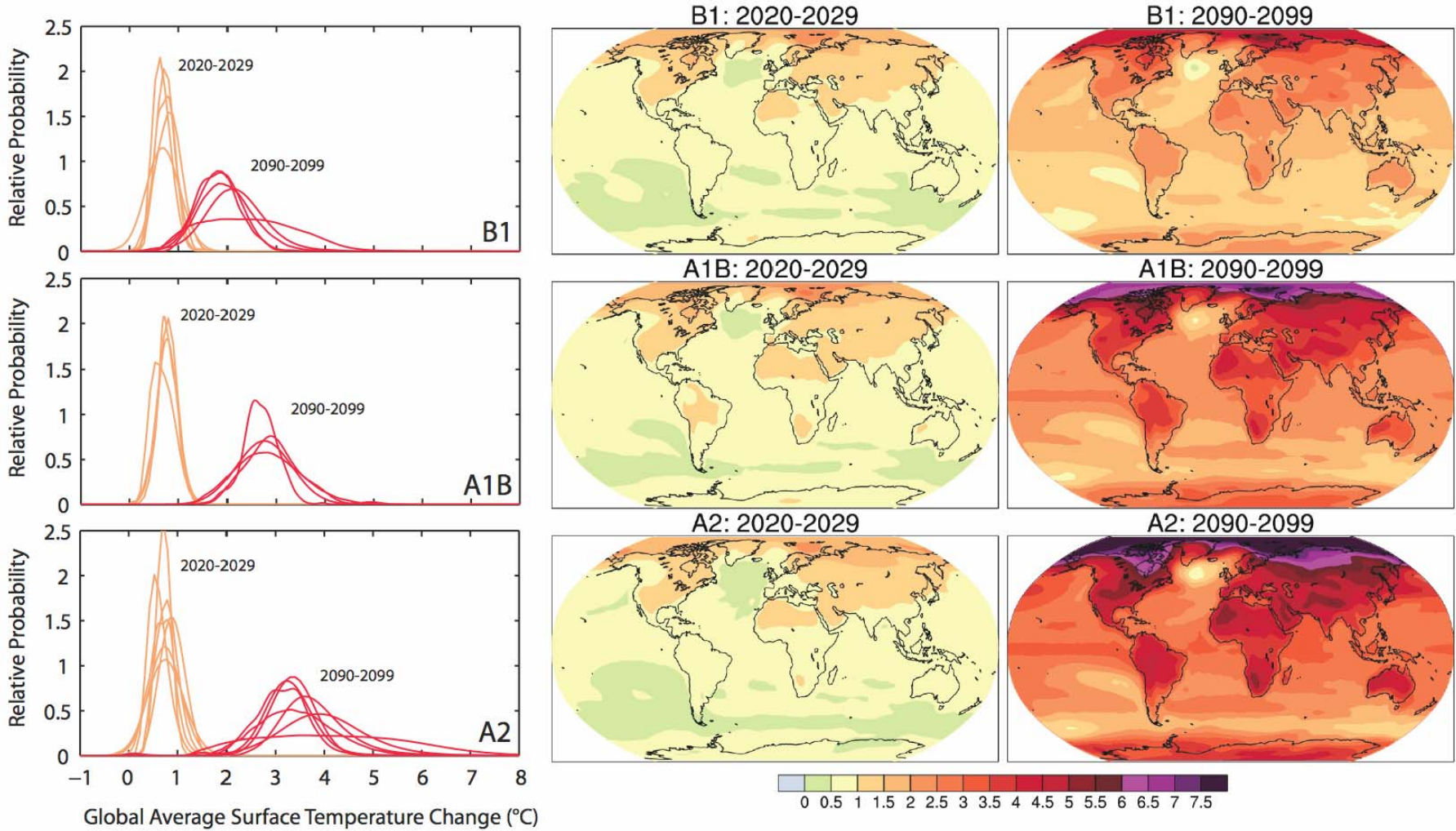


Escenarios Desarrollo  
Economico-Social

GCMs

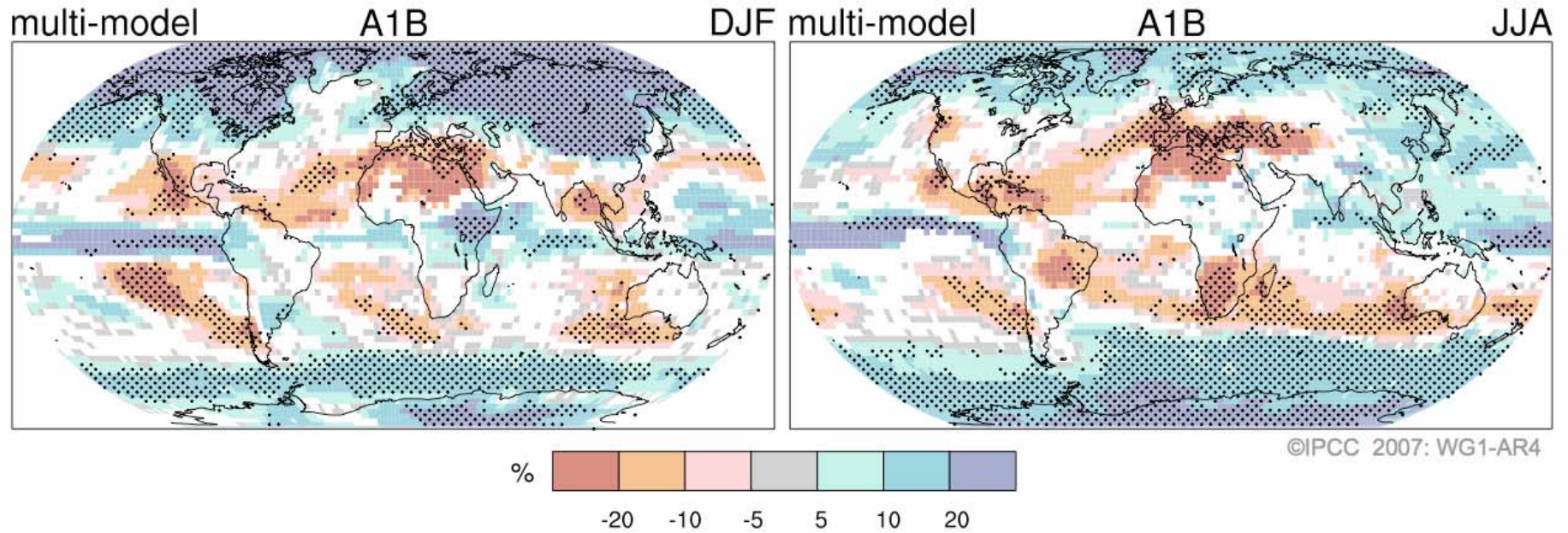


# AOGCM Projections of Surface Temperatures



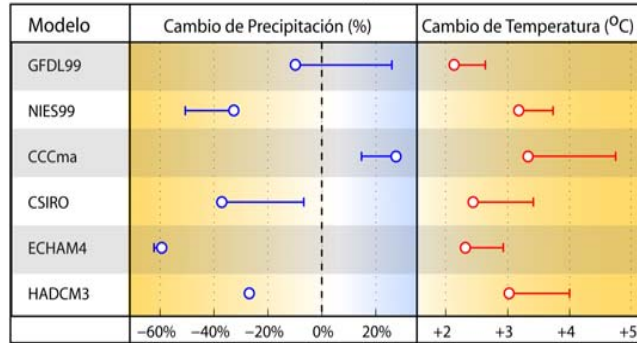
© IPCC 2007: WG1-AR4

# Projected Patterns of Precipitation Changes

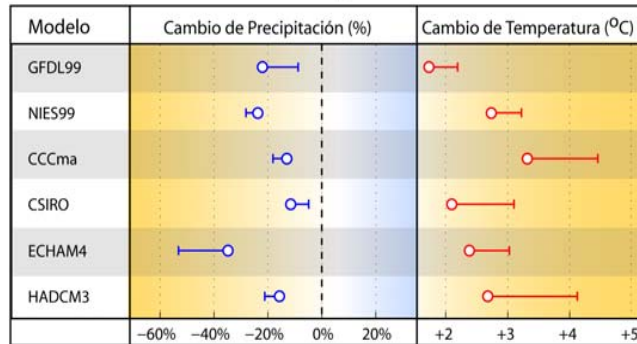




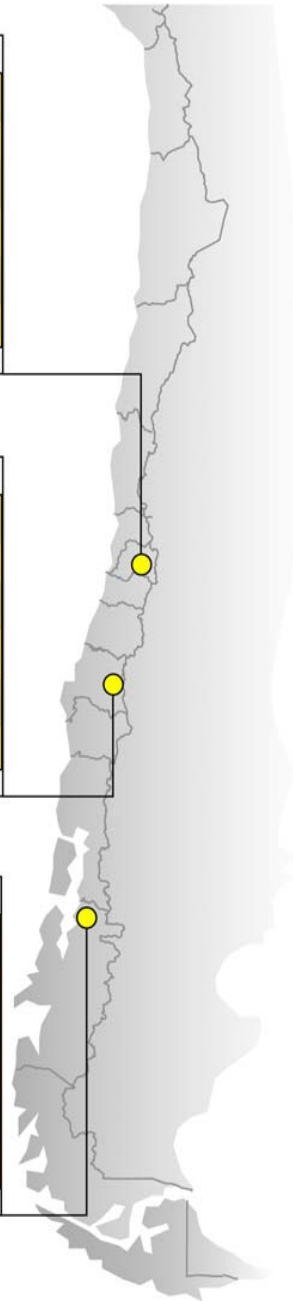
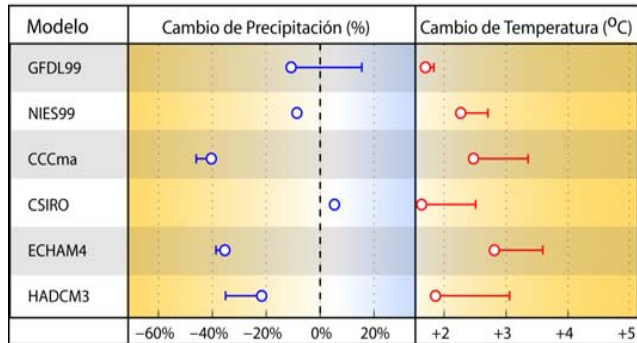
## Santiago



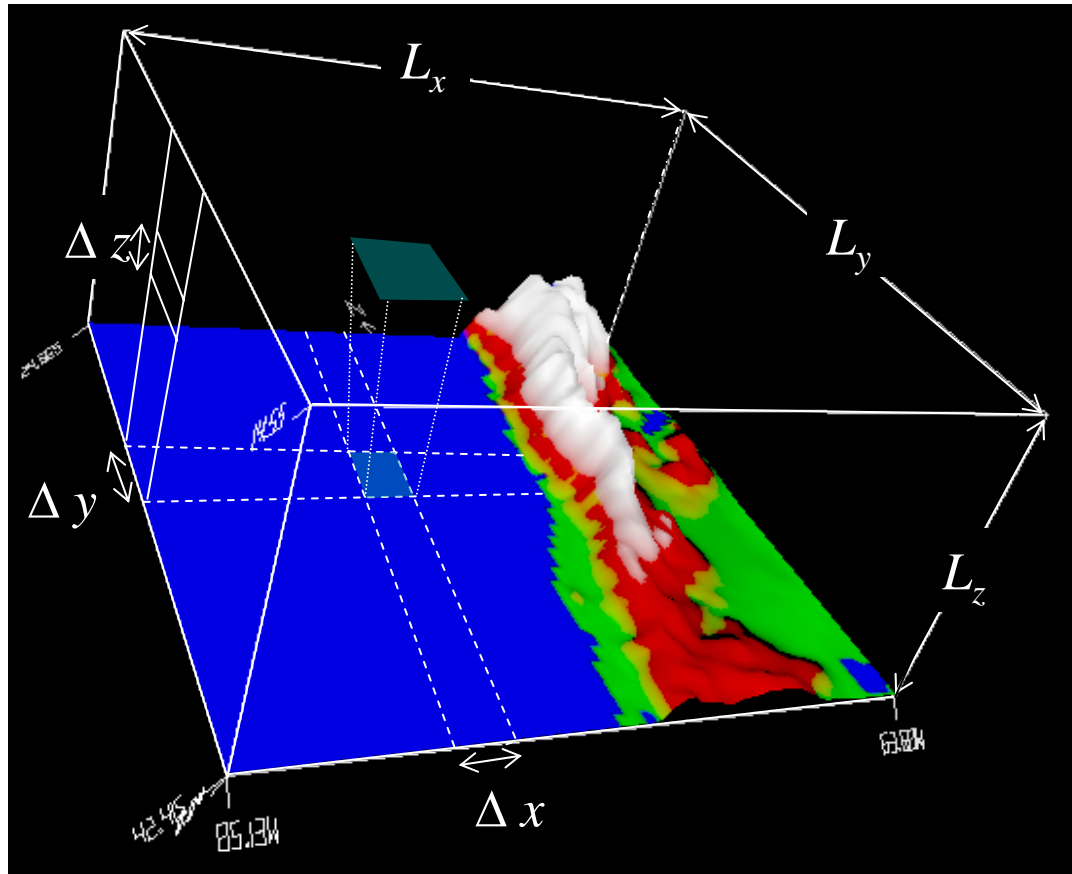
## Concepción



## Aysén



# Regional Models (LAM, Mesoscale Models)



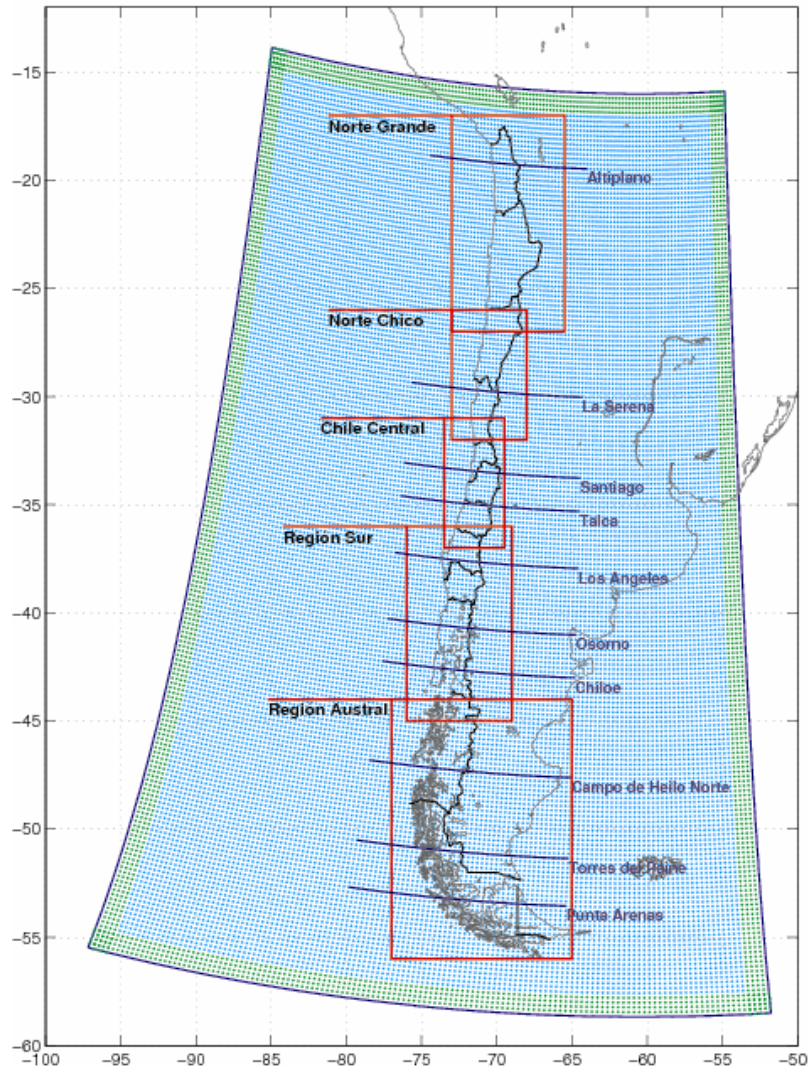
$\Delta x \sim \Delta y \sim 1-50 \text{ km}$      $\Delta z \sim 50-200 \text{ m}$      $\Delta t \sim \text{seconds}$   
 $L_x \sim L_y \sim 100-5000 \text{ km}$      $L_z \sim 15 \text{ km}$     LBC from GCMs

Main Problem: Garbage in – Garbage out



# Proyecto CONAMA – DGF/UCH

<http://www.dgf.uchile.cl/PRECIS>



## Model:

- PRECIS – UK

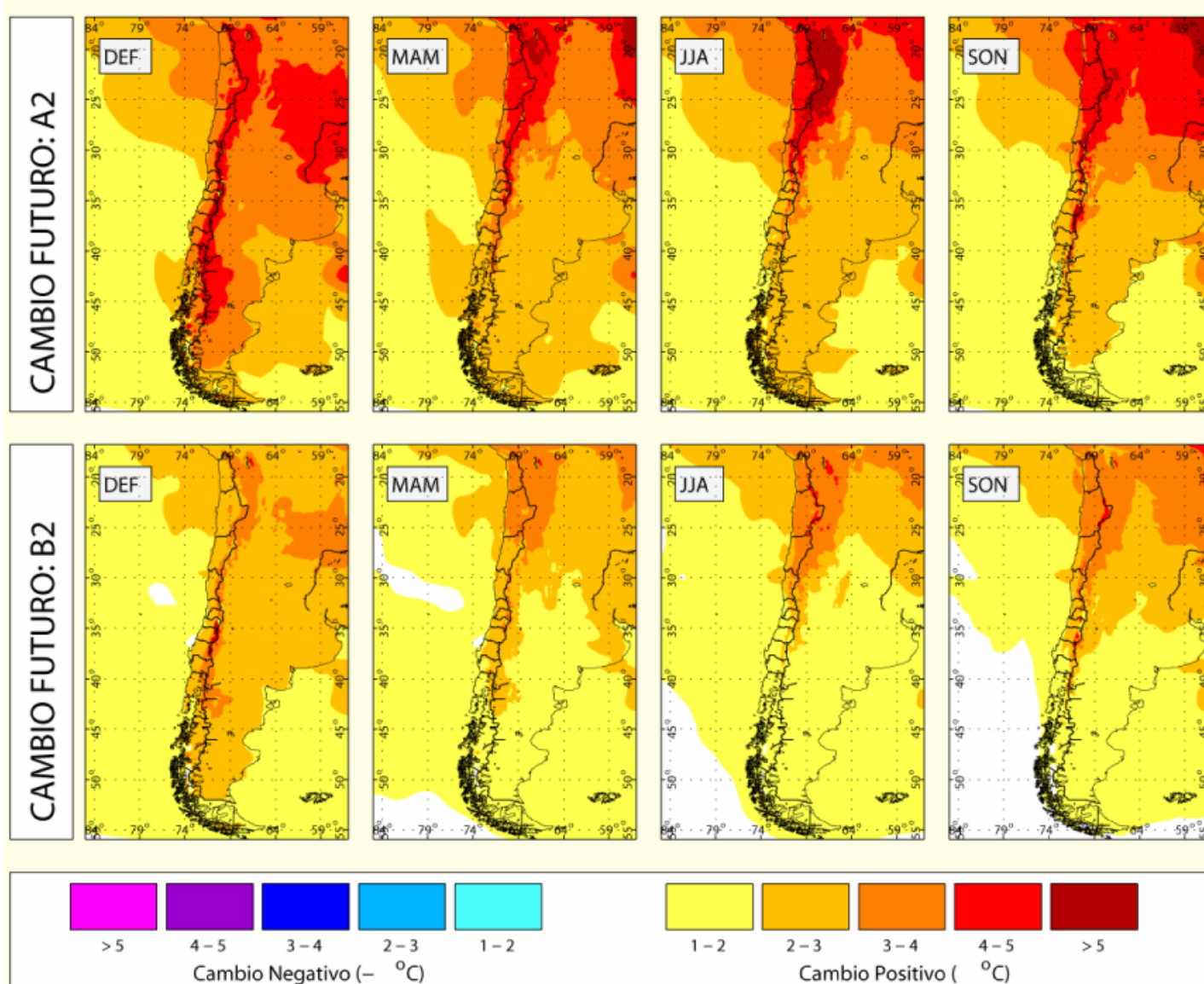
## Single domain

- Horiz. grid spacing. 25 km
- 19 vertical levels
- Lateral BC: HadAM every 6h
- Sfc. BC: HadISST1 + Linear trend

## Simulations

- **1961-1990 Baseline**
- **2071-2100 SRES A2 y B2**
- 30 years @ 3 min → 4 months per simulation in fast PC

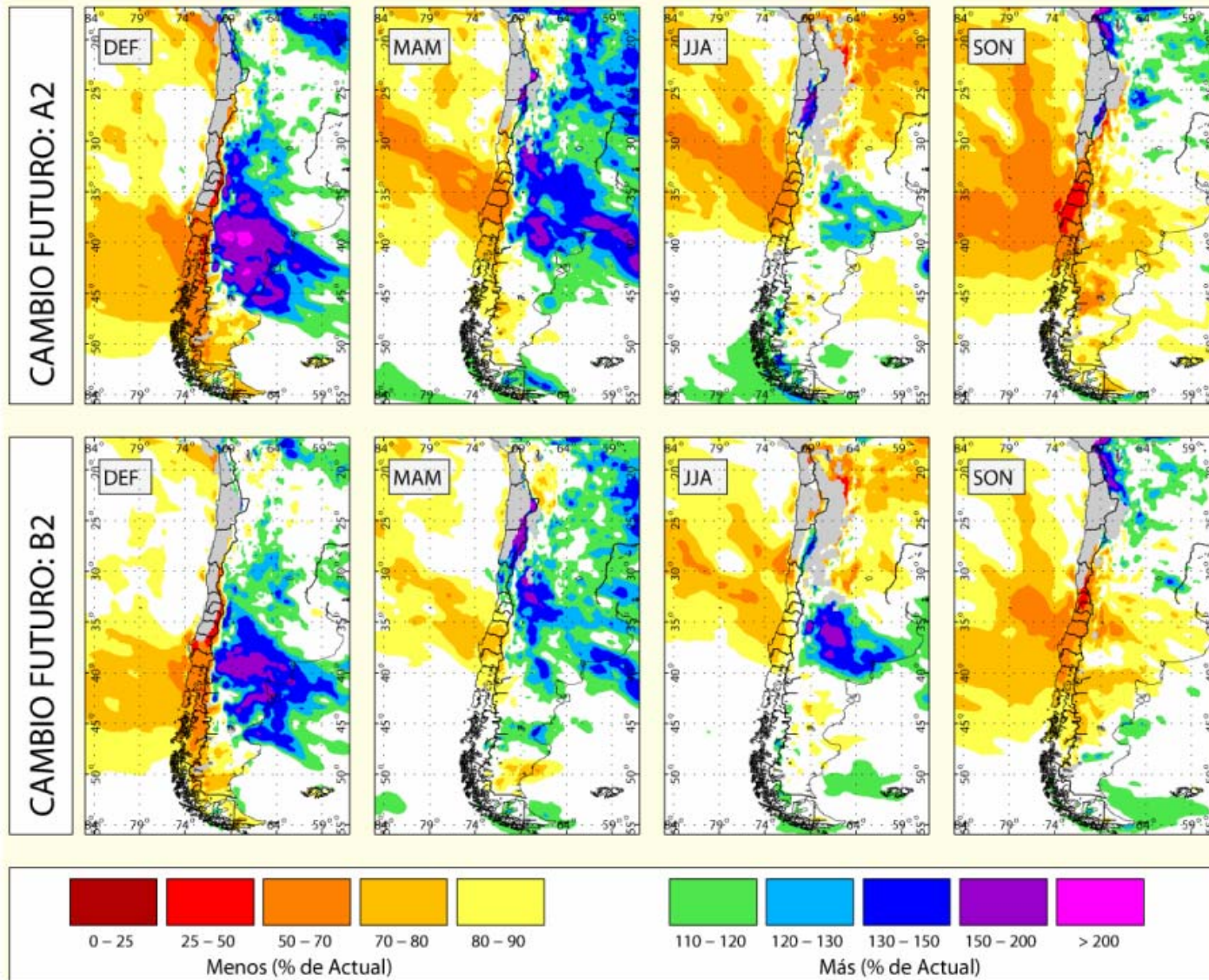
# PRECIS-DGF $T_{\text{futuro}} - T_{\text{presente}}$



Futuro: 2071-2100 / Presente: 2071-2100

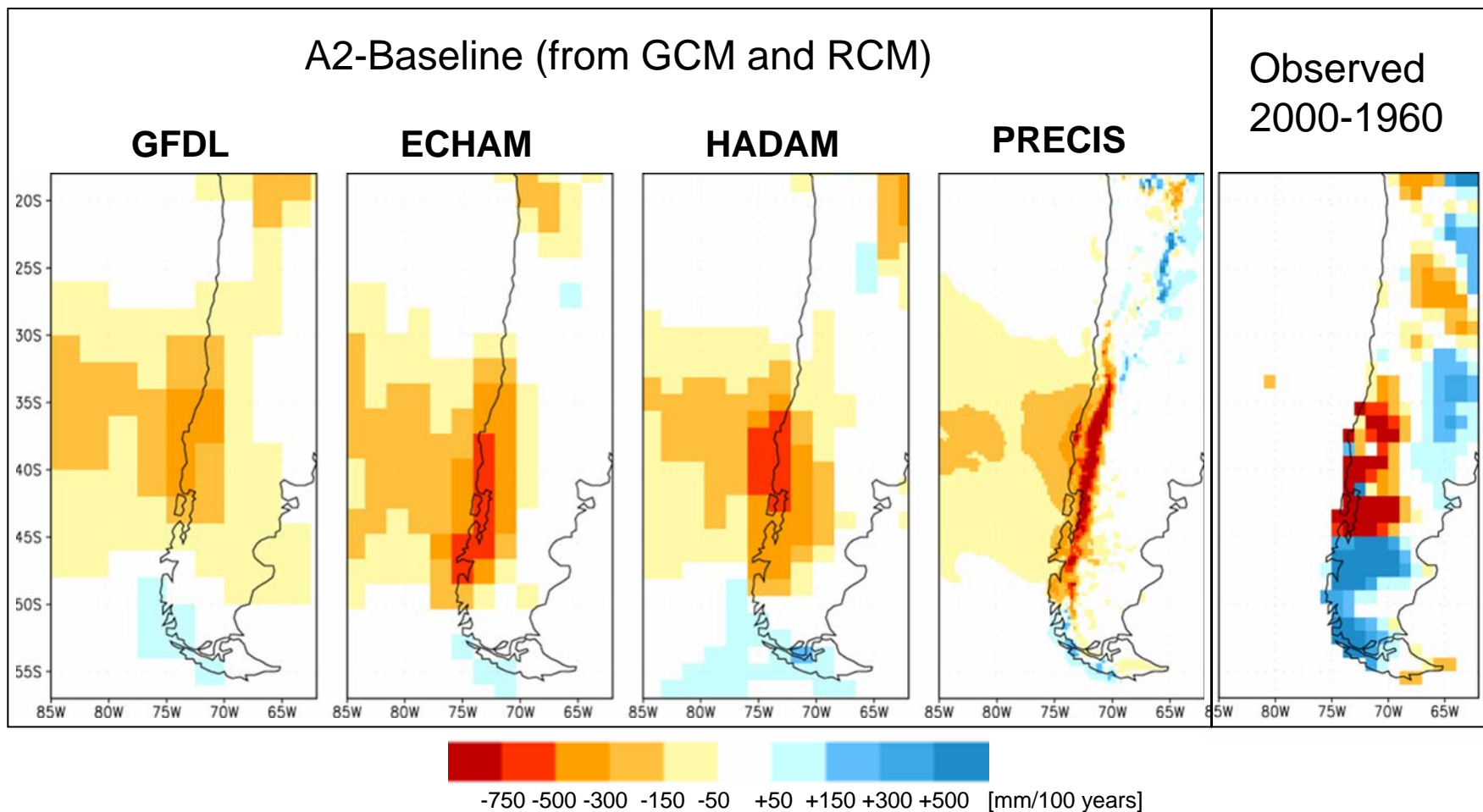


# PRECIS-DGF $R_{\text{futuro}} / R_{\text{presente}}$

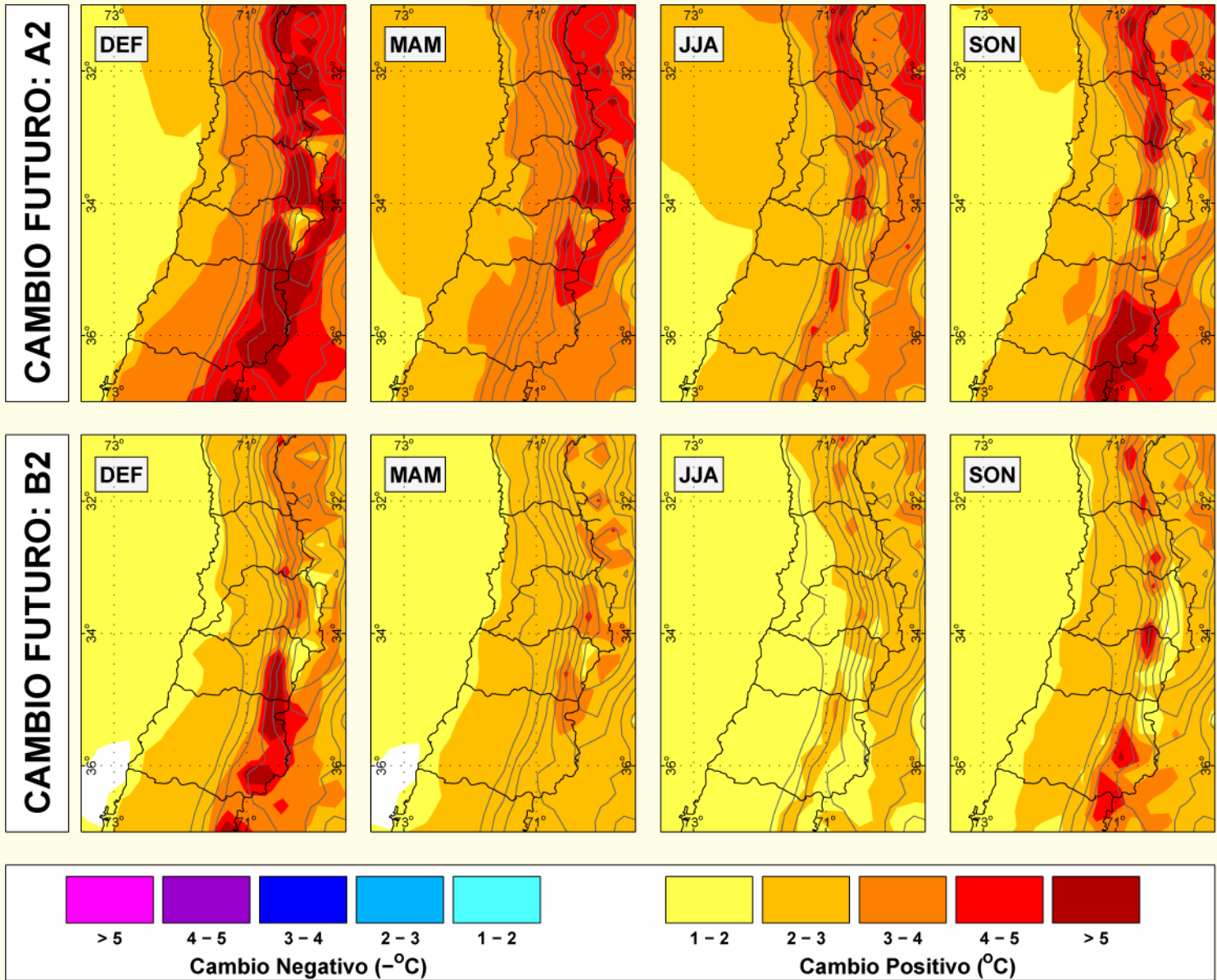


Futuro: 2071-2100 / Presente: 2071-2100

# Cambios previstos en $R$ ya parecen estar manifestandose



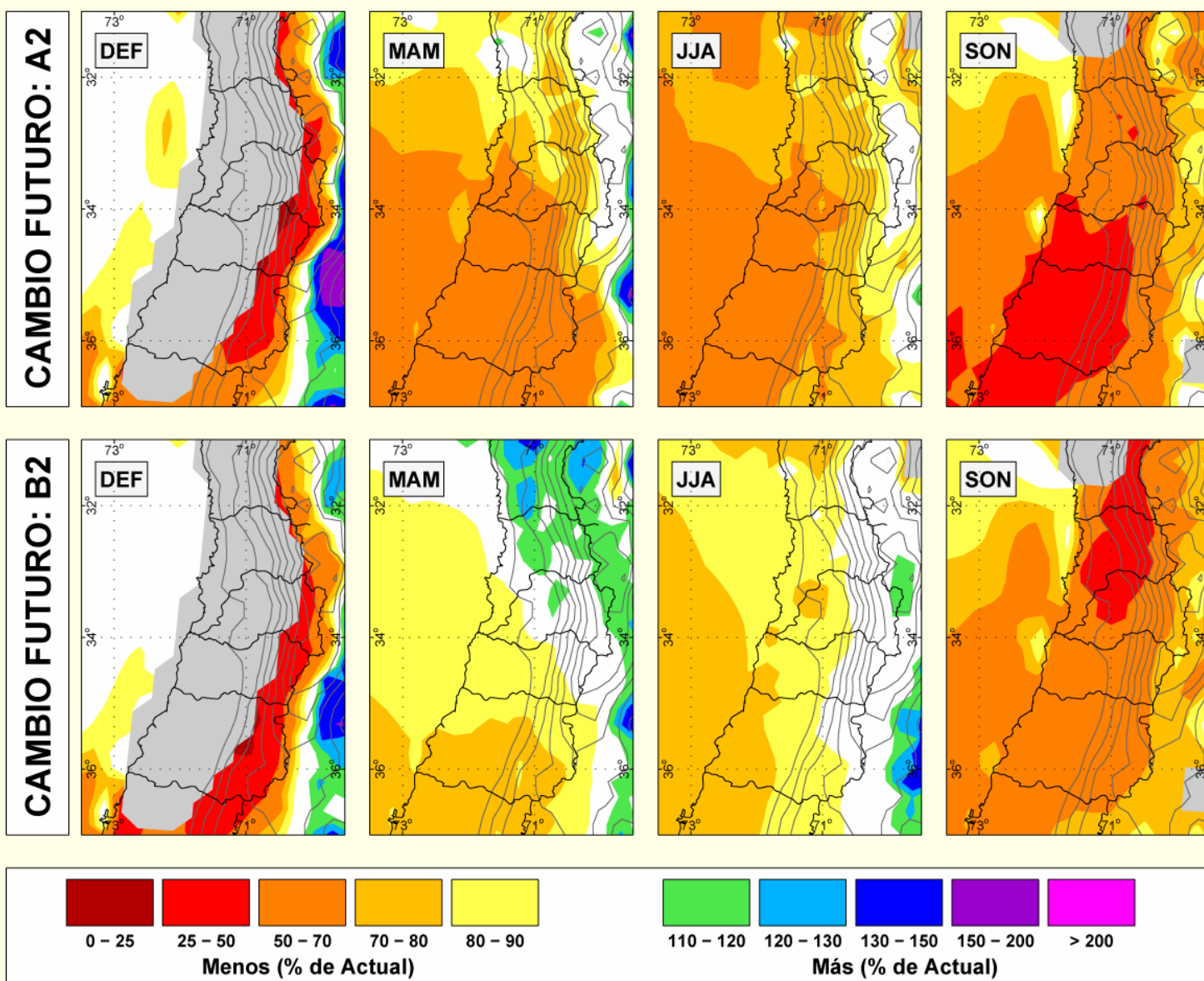
# PRECIS-DGF $T_{\text{futuro}} - T_{\text{presente}}$



Futuro: 2071-2100 / Presente: 2071-2100



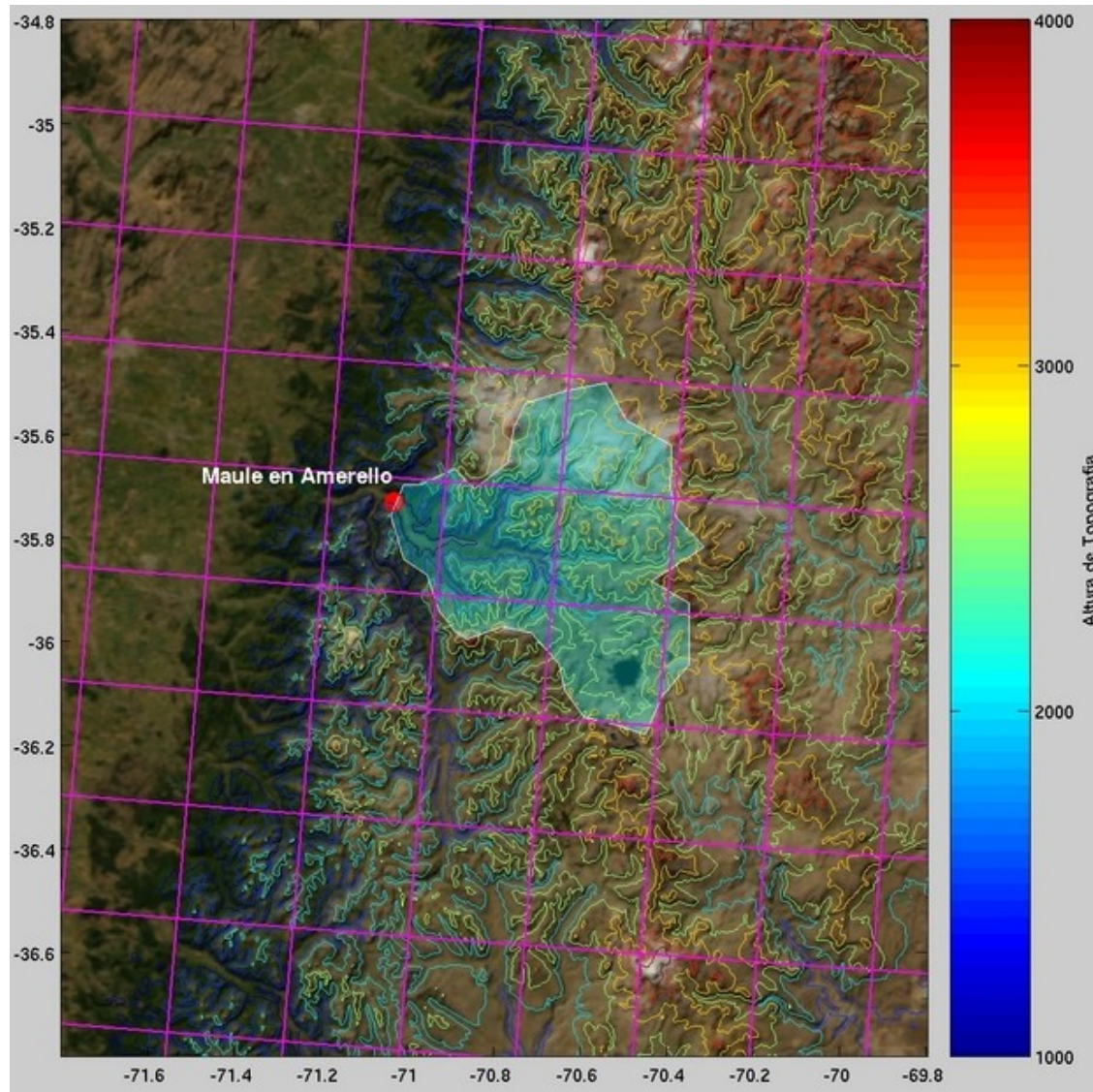
# PRECIS-DGF $R_{\text{futuro}} / R_{\text{presente}}$



Futuro: 2071-2100 / Presente: 2071-2100

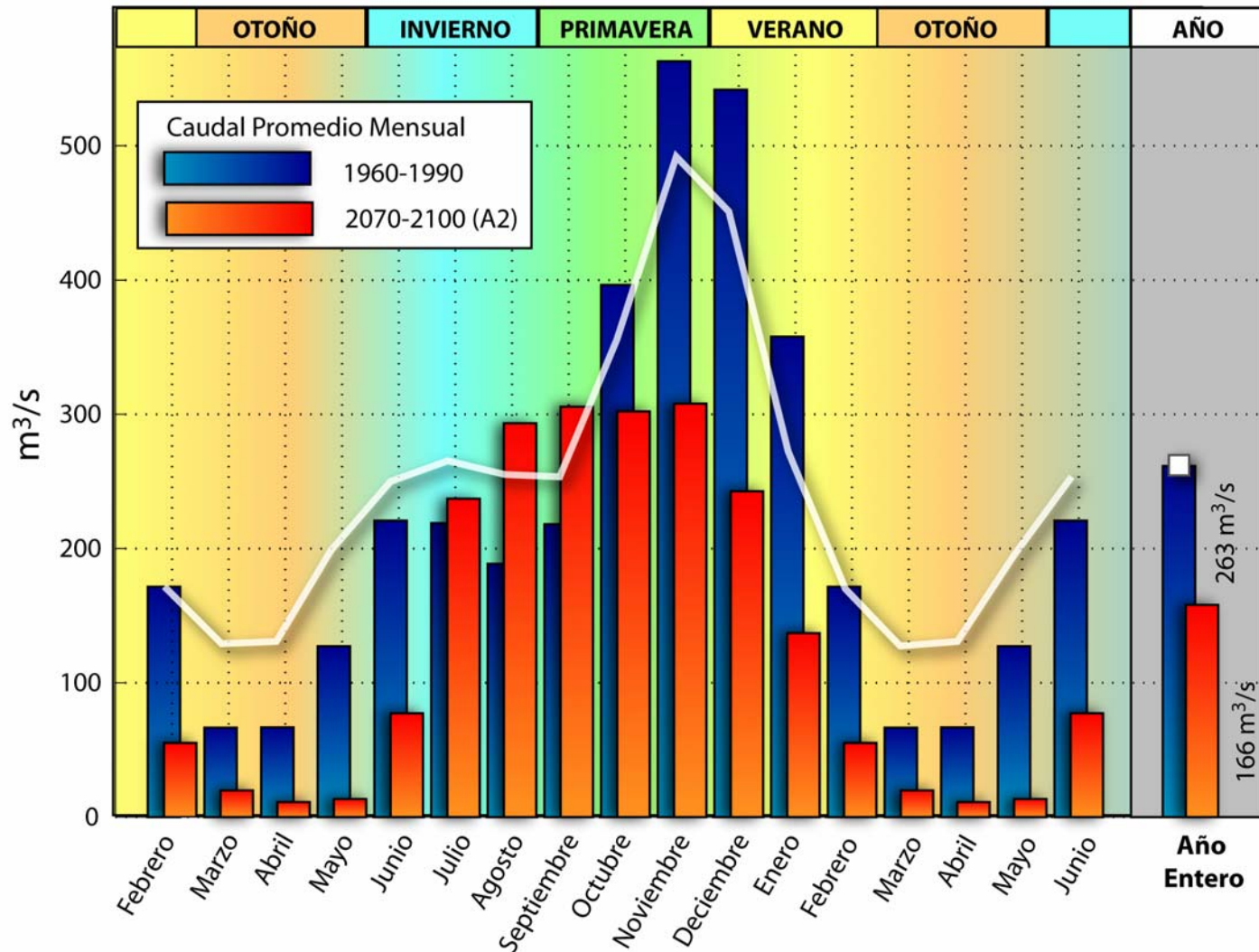
# PRECIS-DGF

Acomplamiento con modelos hidrológicos.



# PRECIS-DGF Acomplamiento con modelos hidrológicos.

## CAUDAL SIMULADO DEL RIO MAULE\* - PRESENTE y FUTURO (A2)



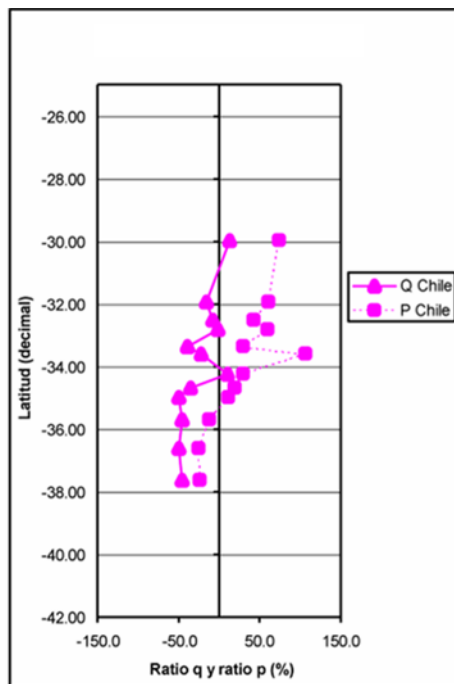
\* Rio Maule en Armerillo - Pre-Cordillera

# PRECIS-DGF - Promedios Estacionales

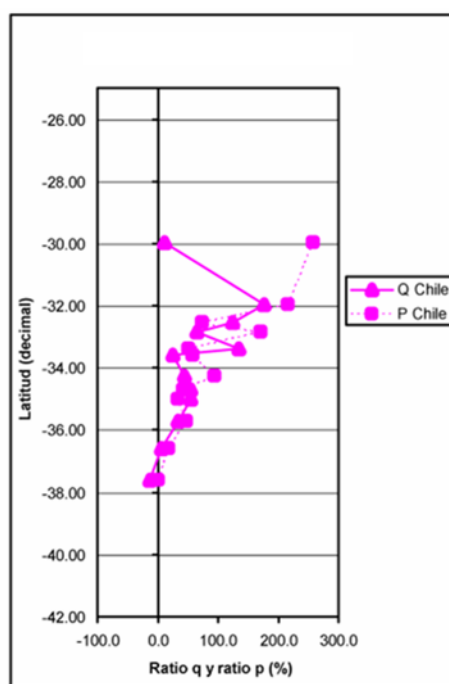
Modelo hidrológico simple indica disminución de caudal promedio anual, pero aumento en invierno y fuerte disminución en verano-otoño sobre Chile central y centro norte.

$$\Delta Q/Q \text{ y } \Delta P/P$$

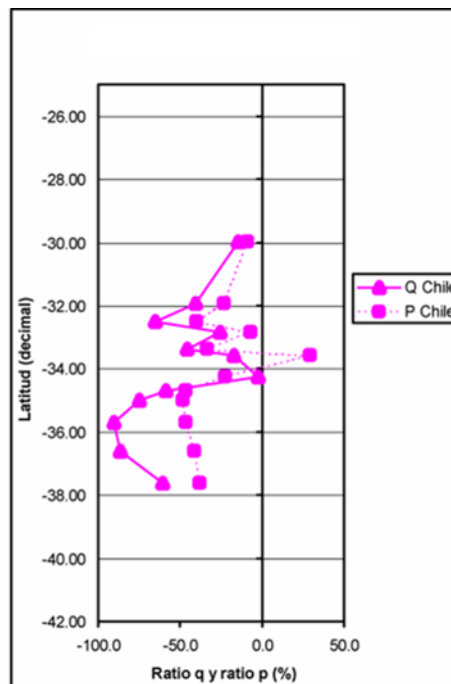
MAM



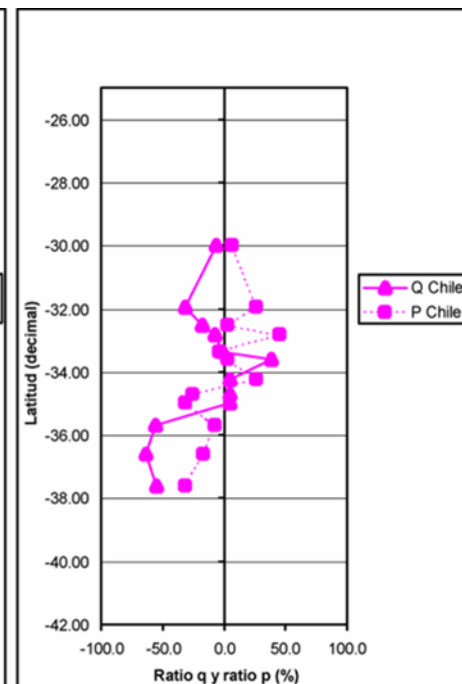
JJA



SON



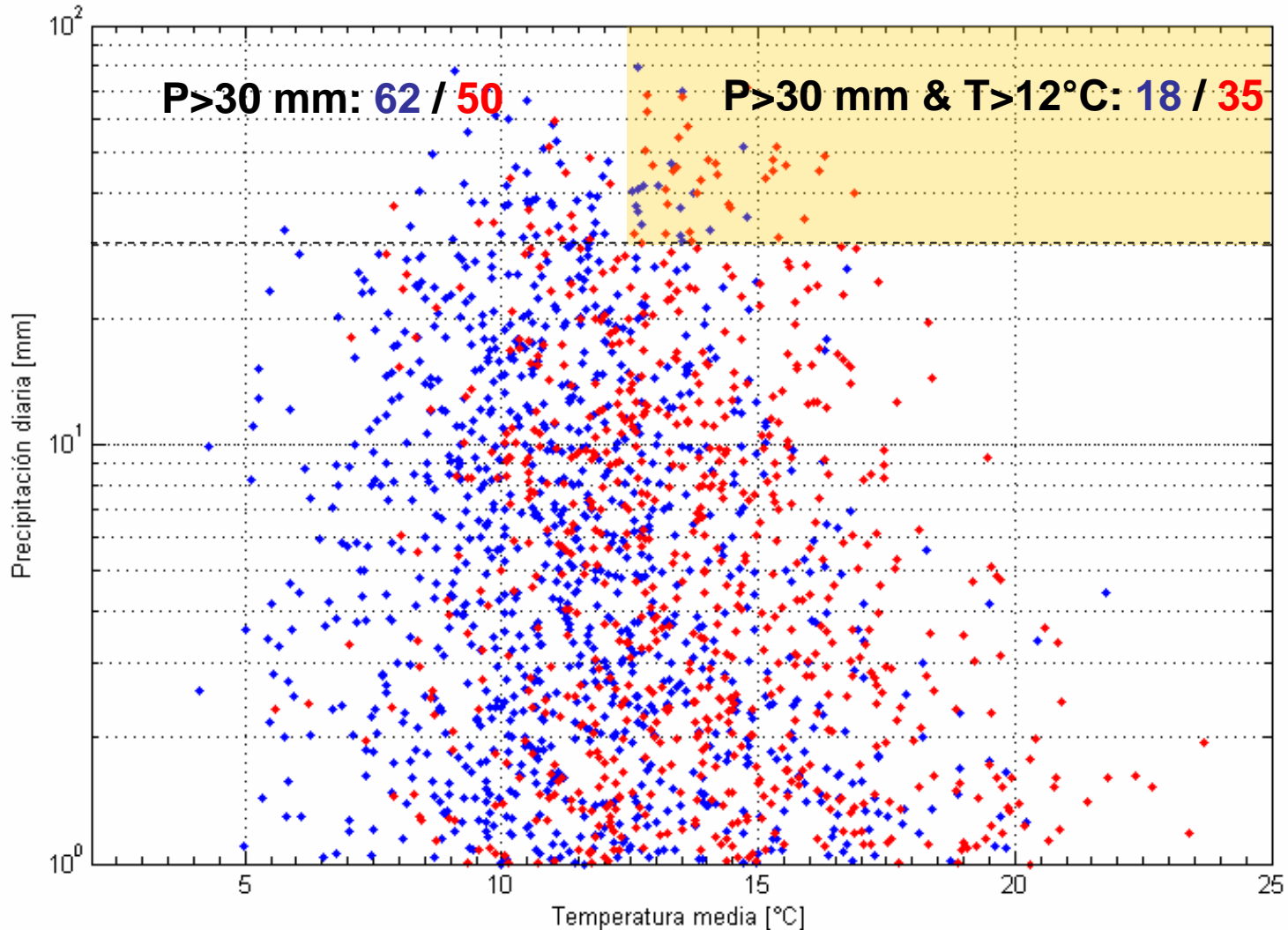
DEF





# PRECIS-DGF – Eventos Extremos

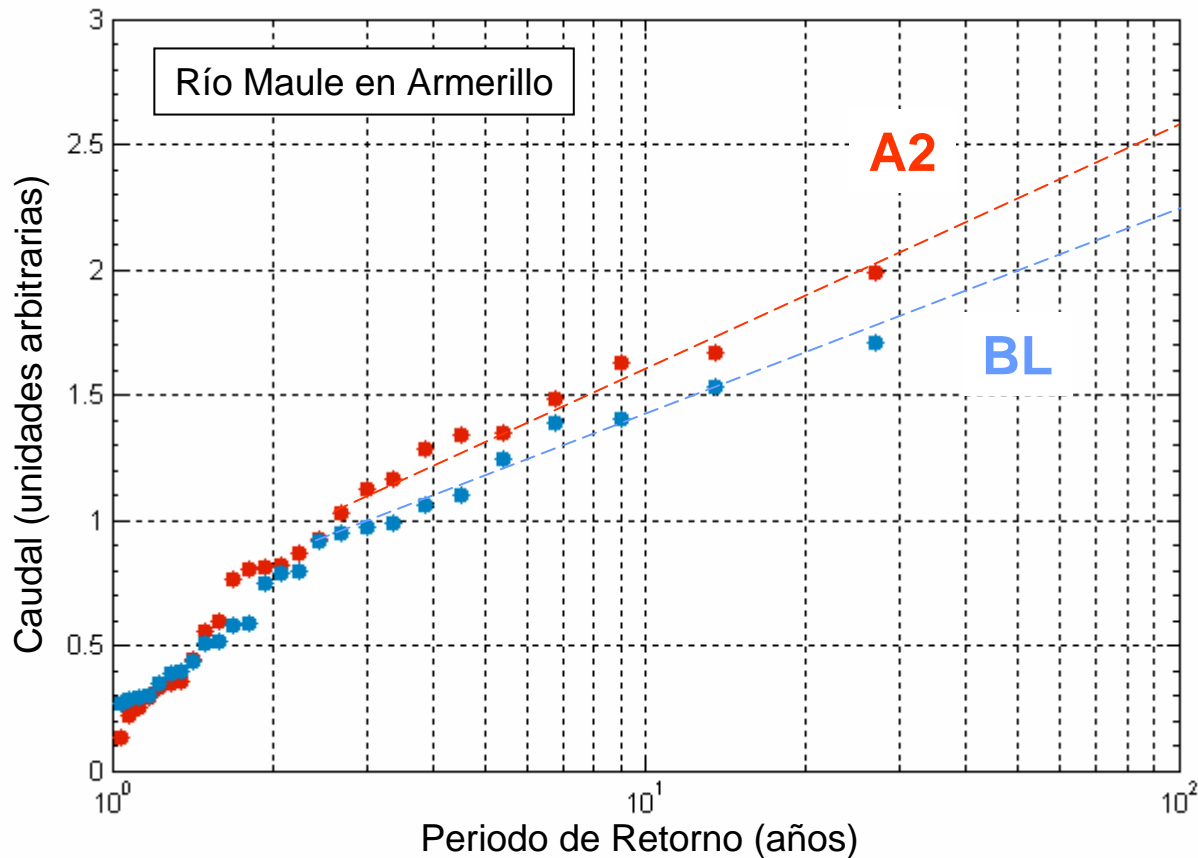
Sobre Chile central disminuye precipitación media annual, pero **tormentas cálidas** aumentan al doble.





# PRECIS-DGF - Eventos Extremos

Modelo hidrológico simple indica cierta disminución de **caudales extremos diarios** con bajo periodo de retorno pero un aumento de caudales extremos diarios con alto periodo de retorno



# Conclusiones

Existen manifestaciones del cambio climático asociado a los GI en las últimas décadas a lo largo del país.

Cambios proyectados son en algunos casos similares en magnitud y signo a los observados en las últimas décadas.

Recursos hídricos superficiales se verán afectados por disminución de precipitación y aumento de temperatura, tanto en su promedio anual, estacionalidad y eventos extremos.

PRECIS-DGF es una buena base de datos para análisis sectoriales, pero solo un comienzo....