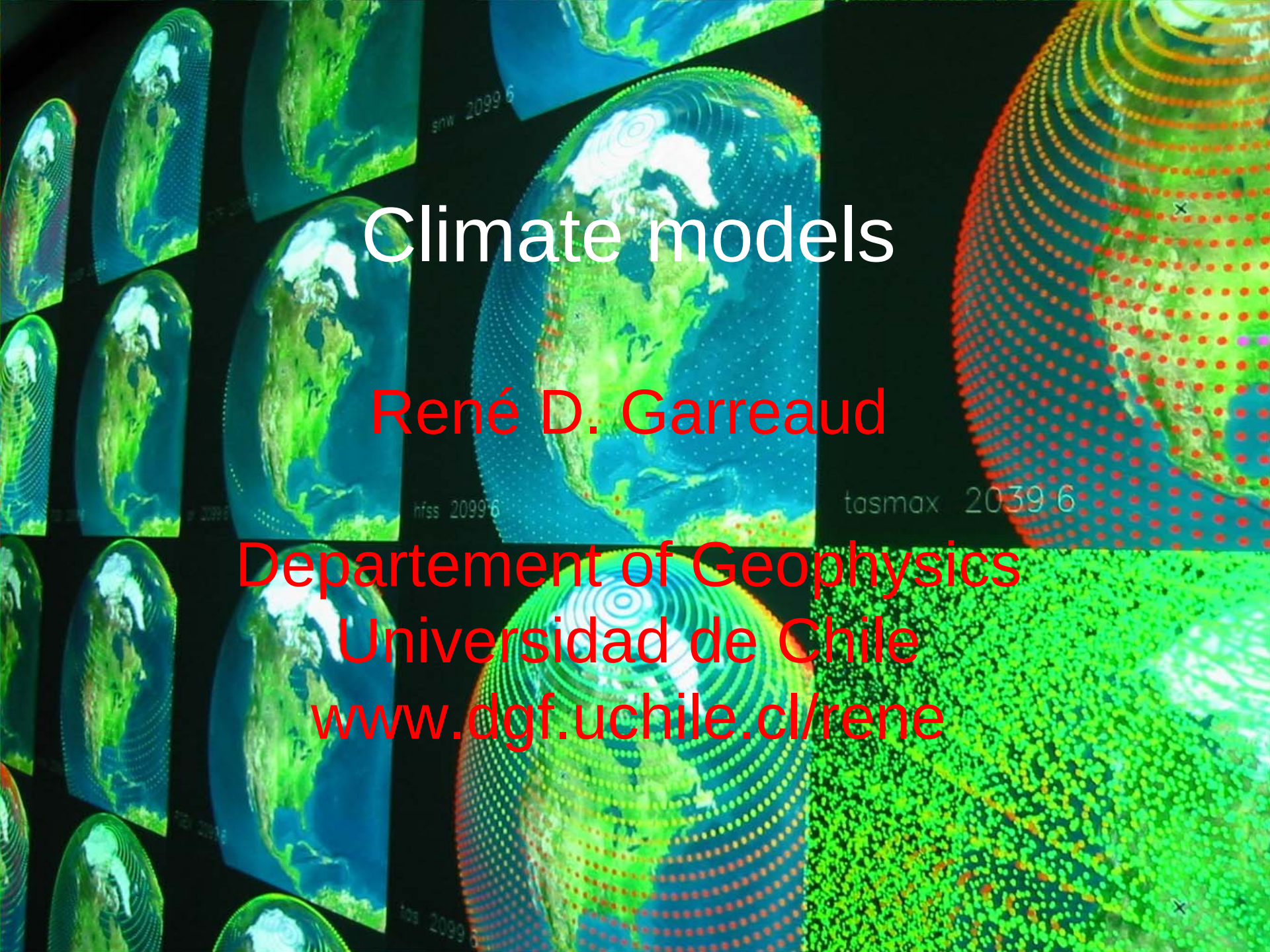

Climate models

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Temario

1. Modelos Climáticos (general)

2. Cambios en el siglo XX: Global /Regional

3. Pronóstico para mañana: GCMs / RCMs

¿Porque empleamos modelos climáticos?

- Suplemento de observaciones climáticas (interpolación física)
- Experimentos de gran escala (cambio en forzantes) y análisis de sensibilidad.
- Generación de escenarios climáticos pasados y futuros.
- Dynamical downscaling (escalamiento hacia abajo basado) de climas pasados y futuros.

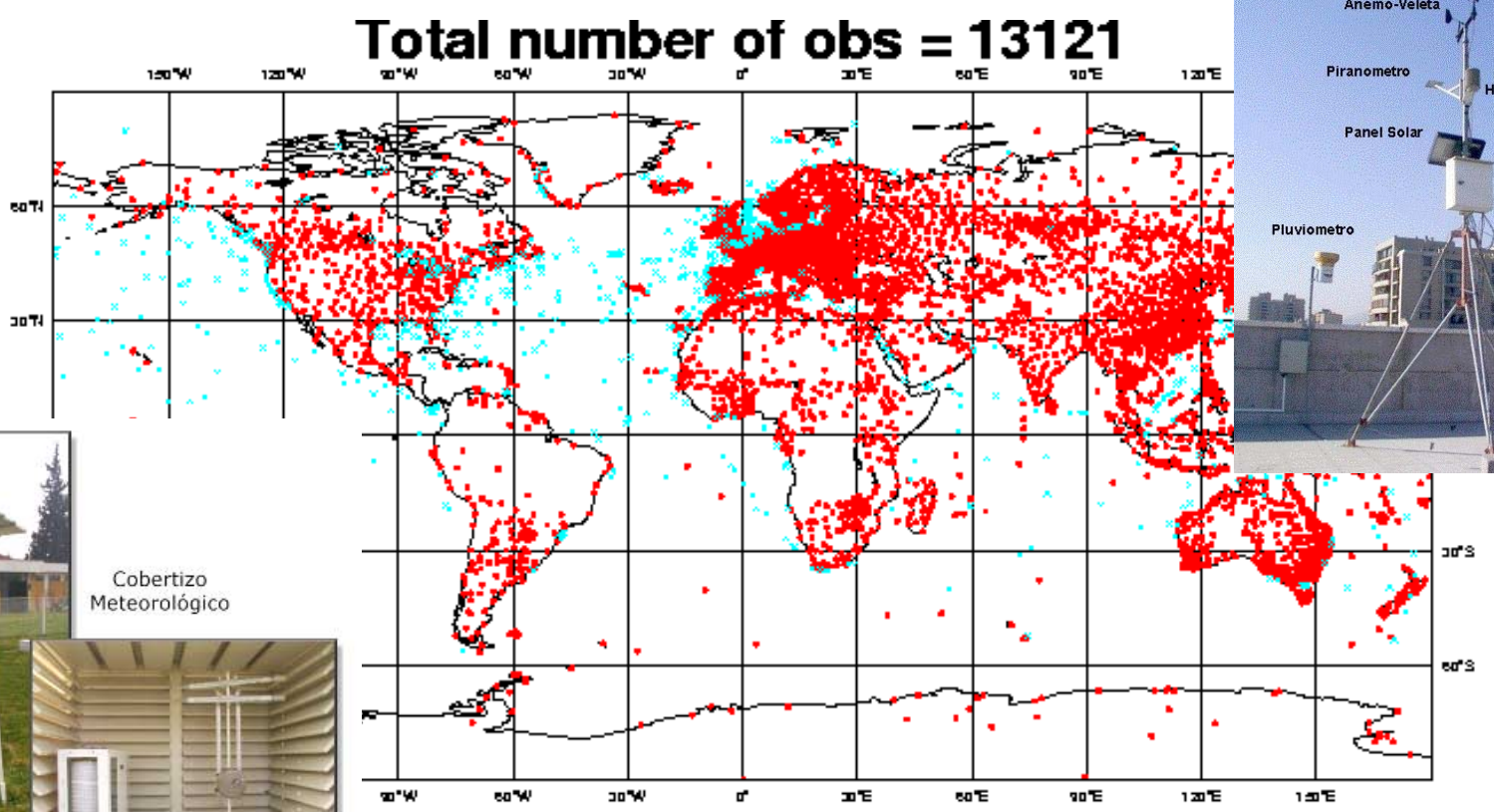
¿Porque me gustan tanto las modelos?

- Aunque son una representación incompleta del mundo real, un buen modelo captura gran parte de la dinámica del sistema climático terrestre.
- Método alternativo (modelos conceptuales cualitativos) aguanta cualquier cosa…
- Los números que entrega un modelo pueden no ser “exactos” pero dan un rango plausible de cambio climático pasados o futuros.

From where do we get climate data? Almost all climate data is initially meteorological data, acquired to assist weather nowcast and forecast (especially for aviation)

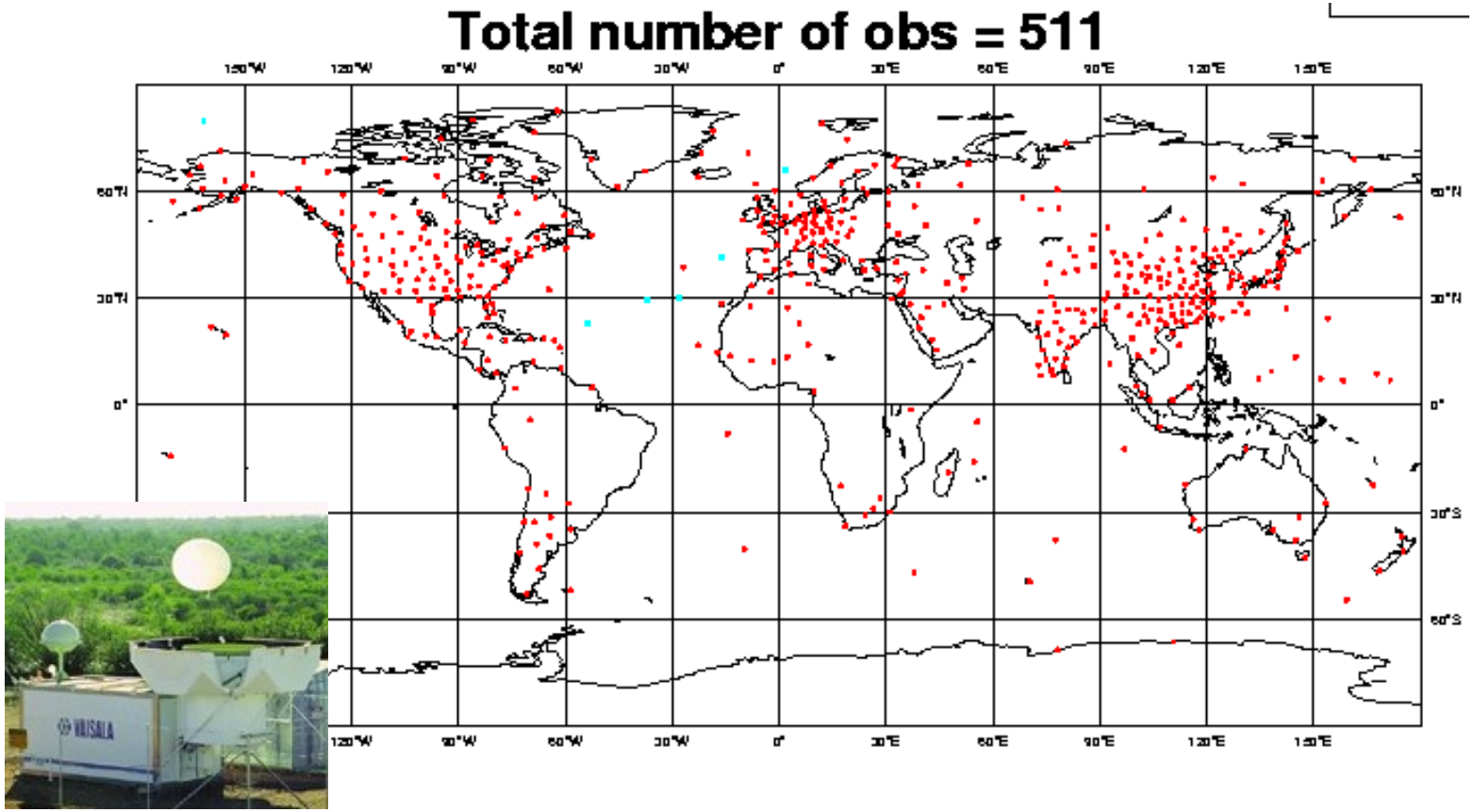
Surface (land/ocean) Synoptic Stations

Met. Observations (T,Td,P,V,…) @ 0, 6, 12, 18 UTC are transmitted in real-time to WMO and Analysis Centers



Red de Radiosondas (OMM, GTS)

Perfiles verticales (20 km) de T, HR, viento, presión, cada 12 / 24 hr

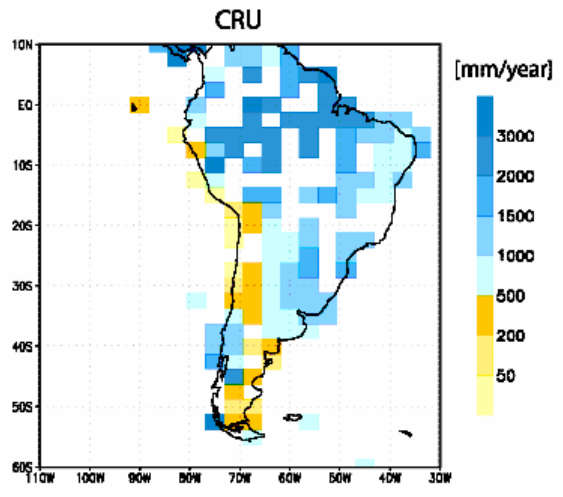


DATA SOURCES AND PRODUCTS

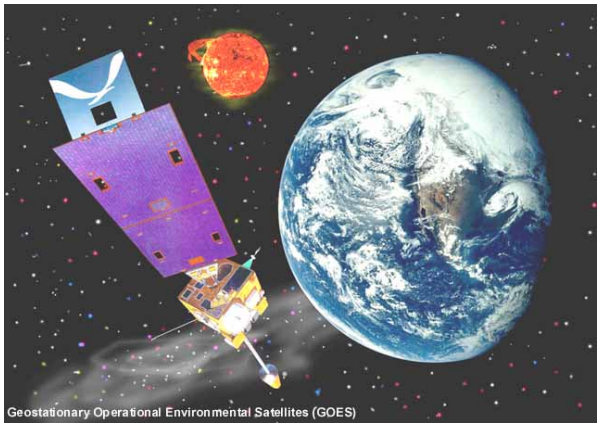
Surface and Upper Air Observations

Gridding method

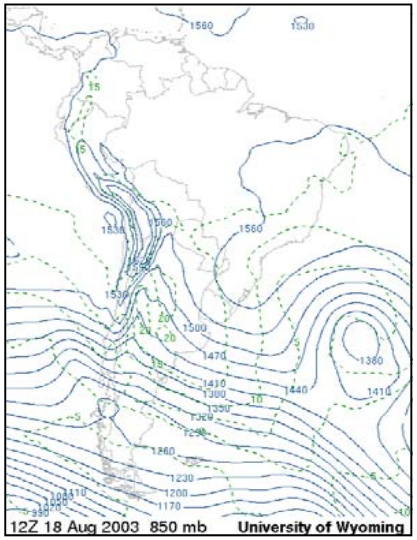
Gridded Analysis



Satellite Products

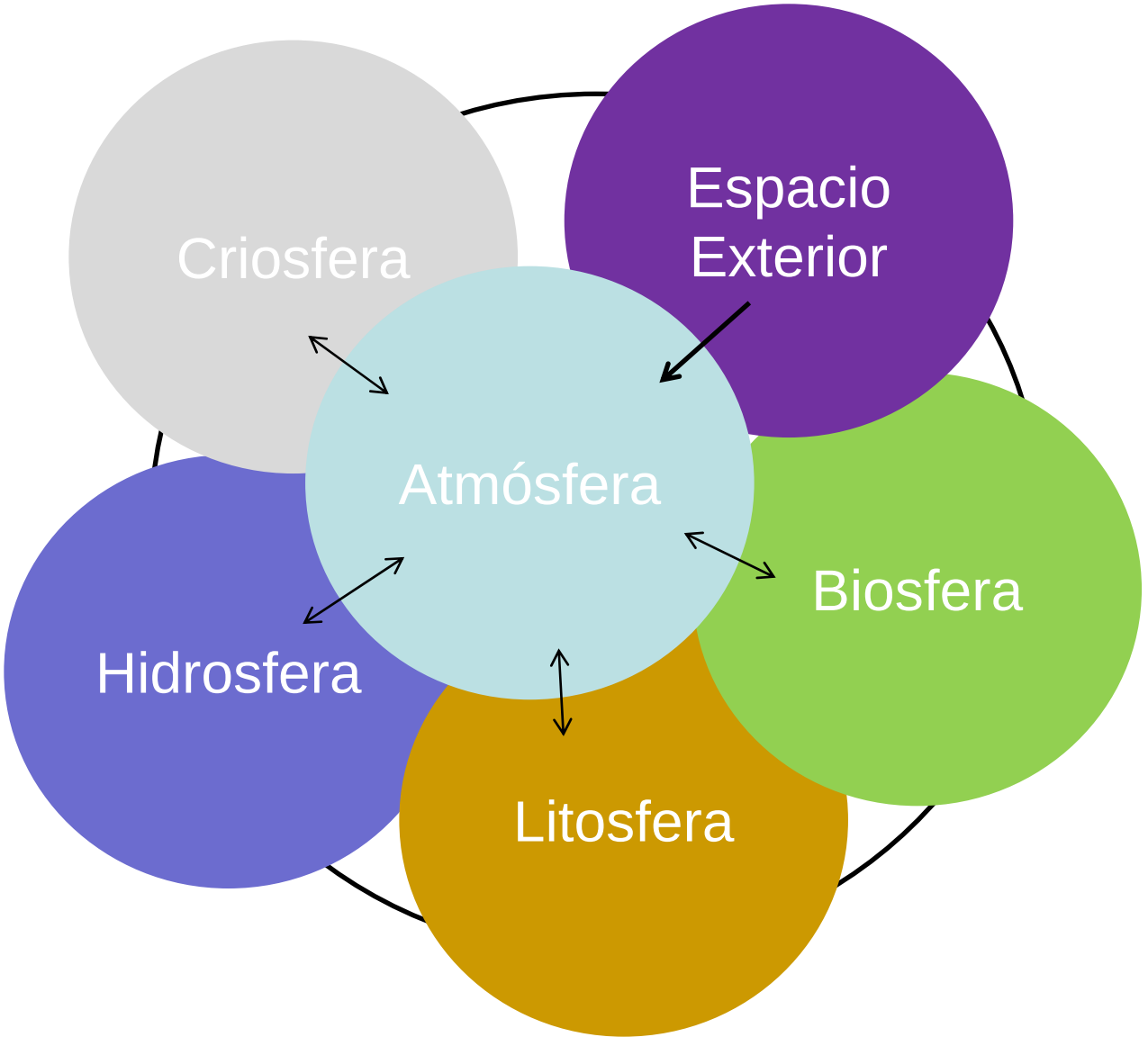


Assimilation System Model



Sistema Terrestre

Todos juntos y al mismo tiempo

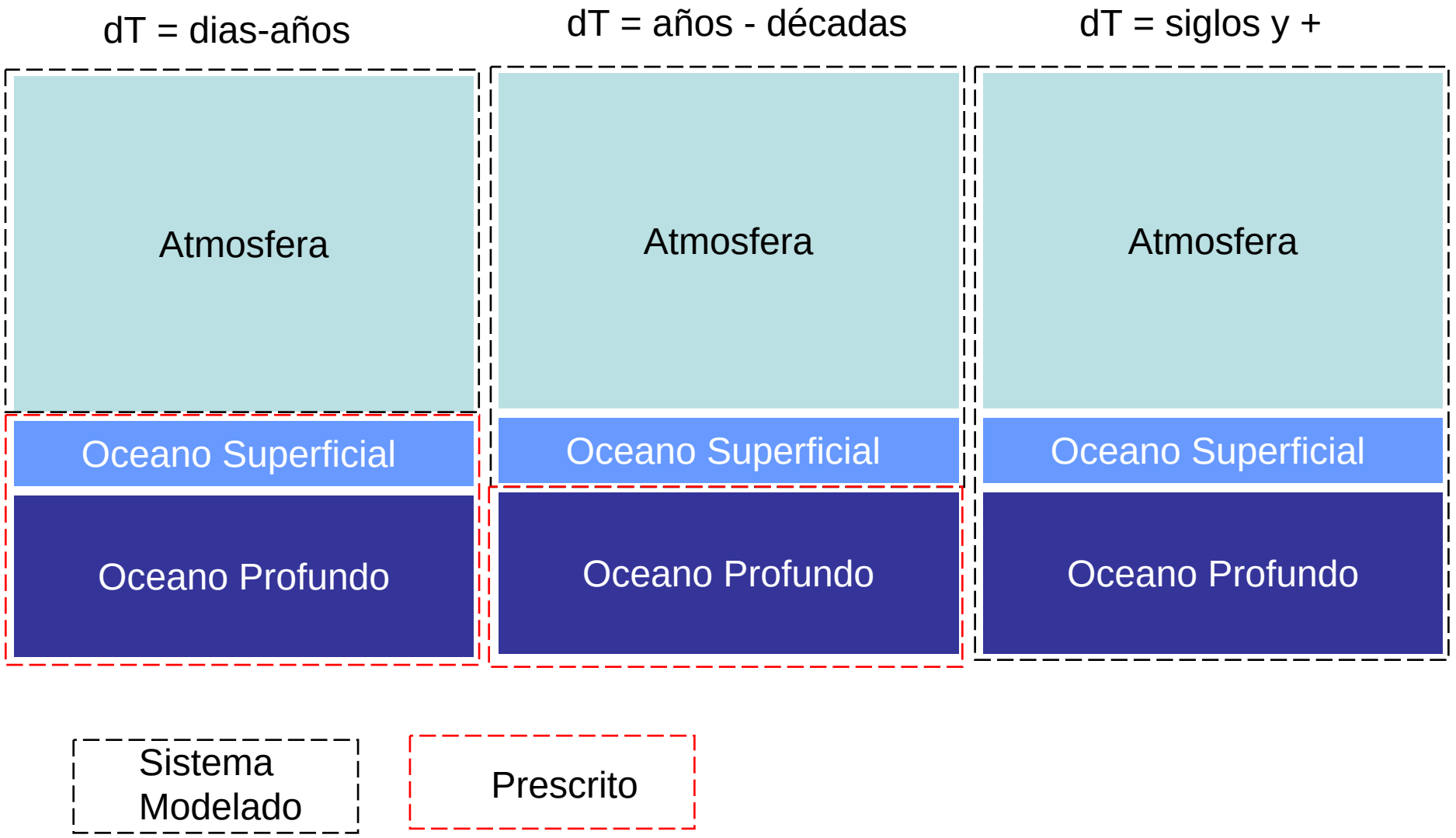


Sistema Terrestre

Tiempo de respuesta de distintos componentes del Sistema terrestre a un forzante externo de gran escala (por ejemplo, cambios en forzante solar)

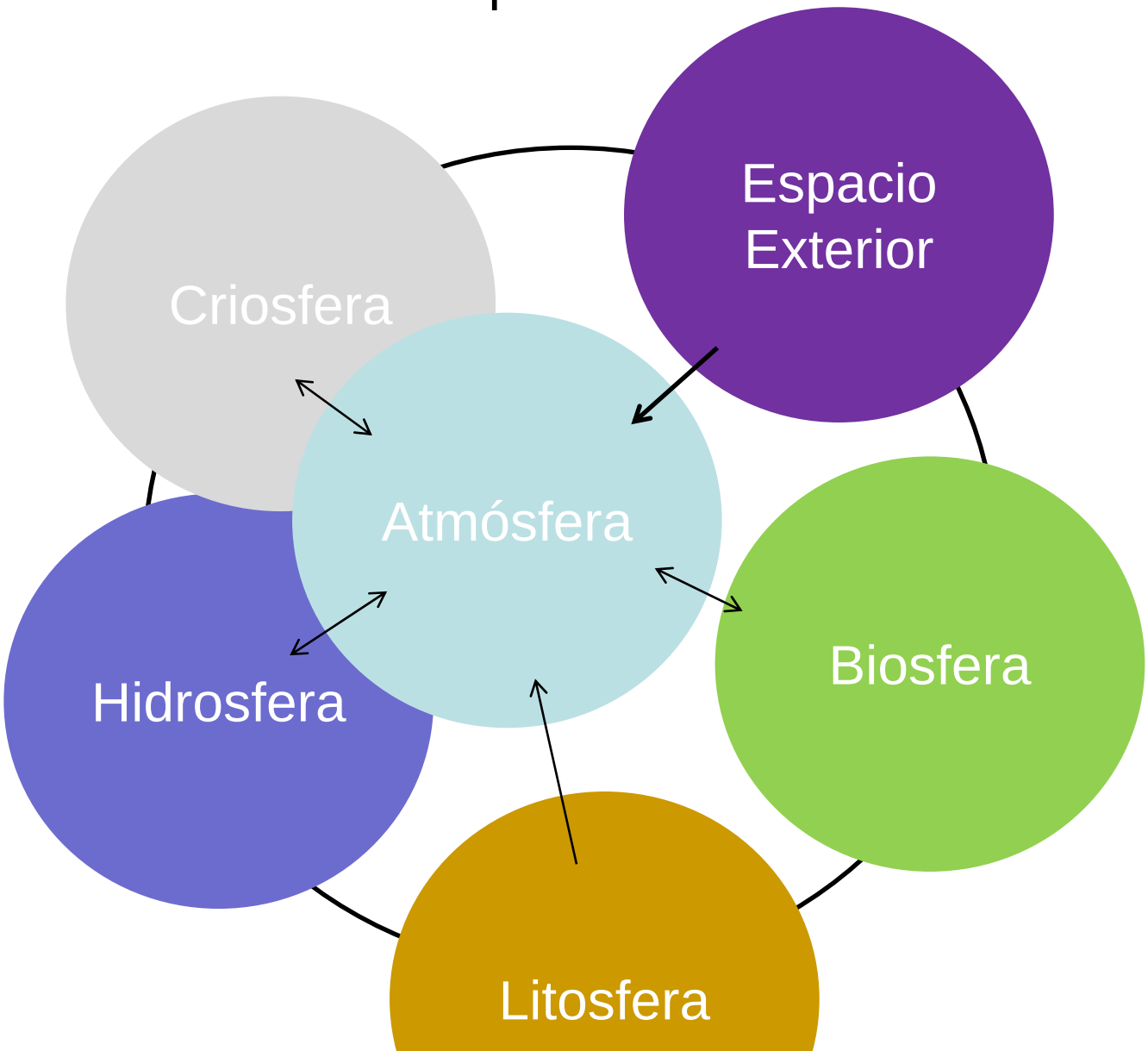
Subsistema	Tiempo de ajuste a cambio climático de escala global
Atmósfera	Dias - Meses
Océano superficial	Meses - Años
Océano Profundo	Años - Décadas
Campos de Hielo	Años - Décadas
Biosfera continental	Años - Décadas
Litosfera	> Miles de años

Mayor largo de simulacion requiere incorporar mas subsistemas terrestres a la simulacion (variables vs parámetros) hasta llegar a modelos del sistema terrestre completo (atmos-ocean-crio-bio-lito)

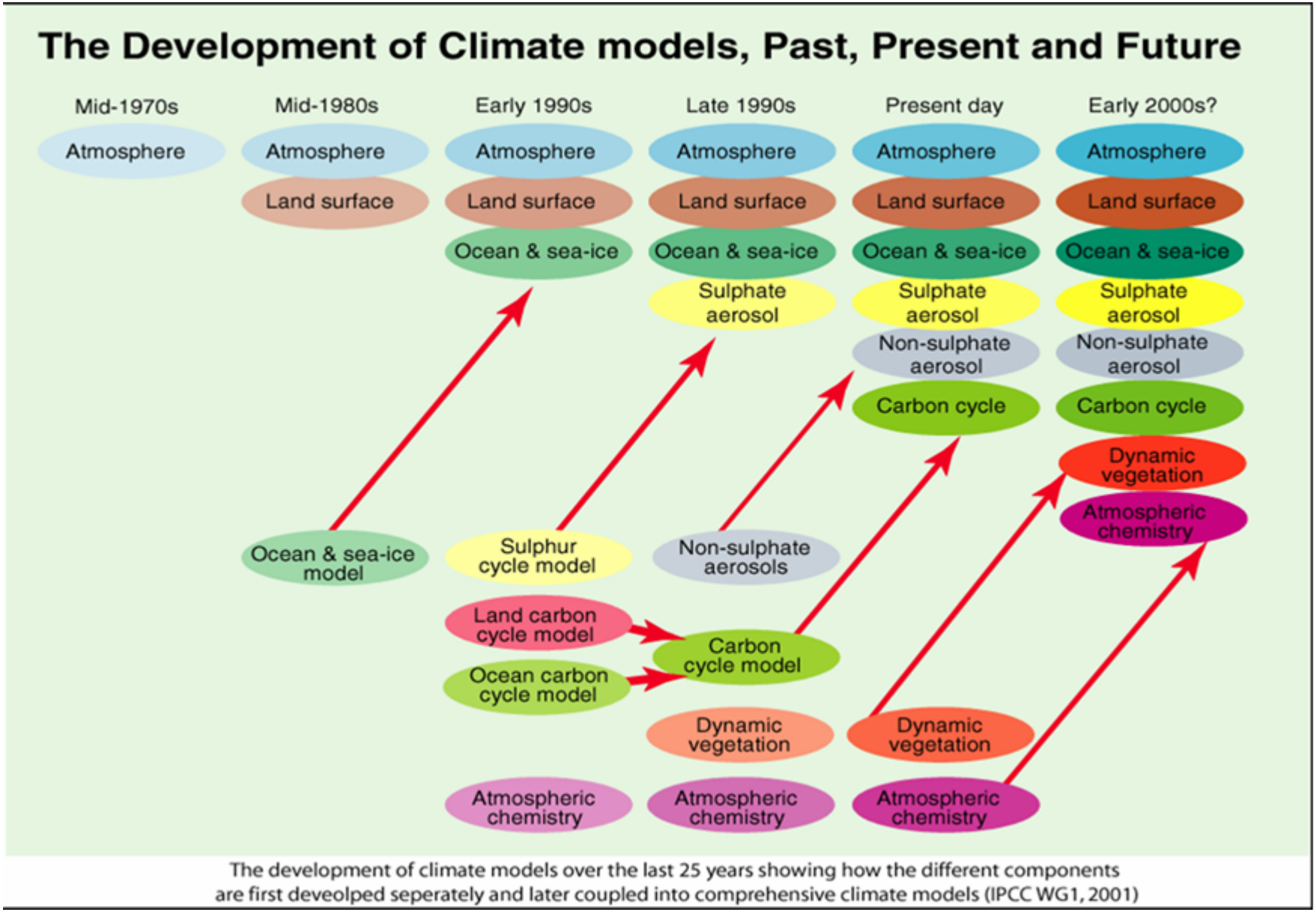


Sistema Terrestre

Dividir para modelar



Global Models (GCM)



The development of climate models over the last 25 years showing how the different components are first deveolped seperately and later coupled into comprehensive climate models (IPCC WG1, 2001)

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,….

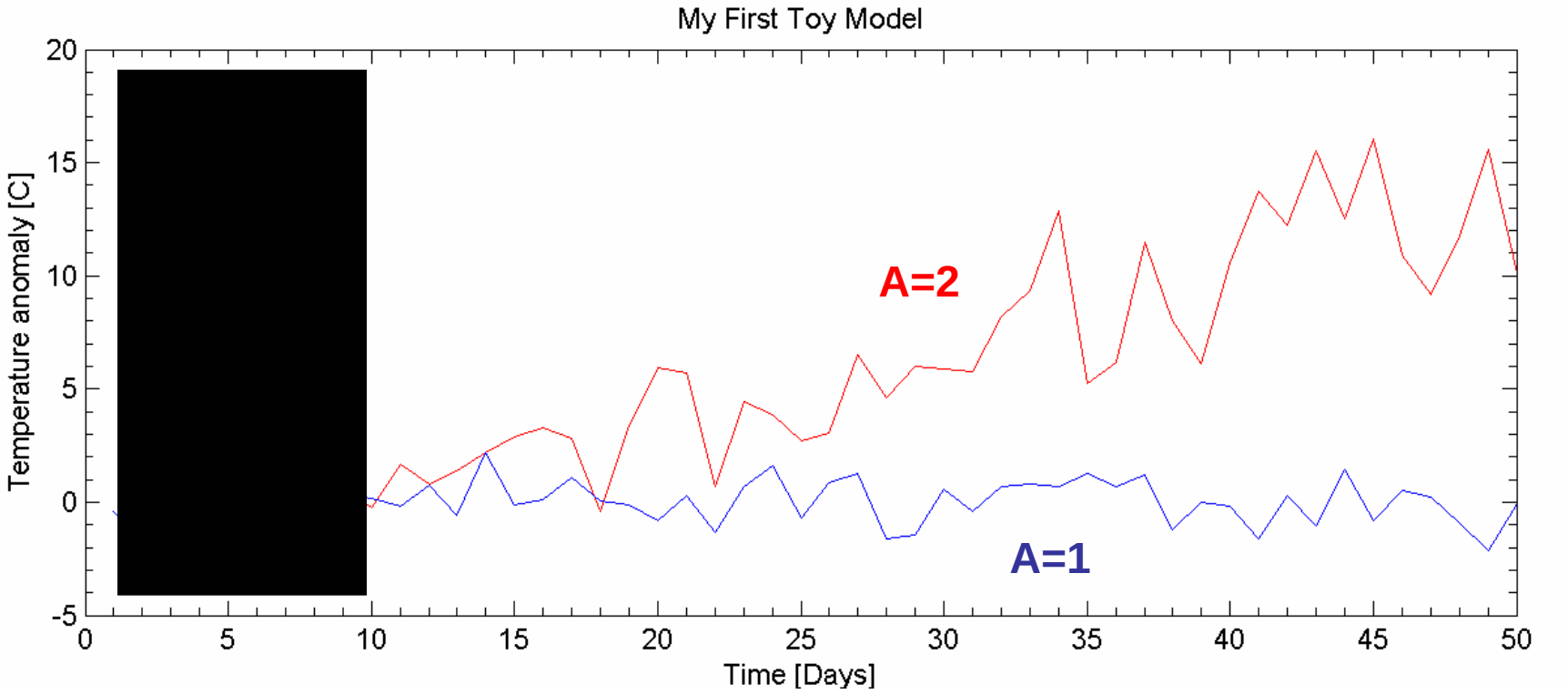
A, B, C, D: External parameter

Orbital parameters, CO_2 Concentration, SST (AGCM), Land cover

ε_x ε_y ε_z **Randoms error**

Set to zero → Deterministic model

Nevertheless, simulations after two-weeks are still “correct” in a climatic perspective and highly dependent upon external parameters → models can be used to see how the climate changes as external parameters vary.



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.

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

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.

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

Variables (se calculan internamente):

Temperatura (T), viento (u,v,w), presión (p), densidad (ro), humedad (q, RH), precipitación (Pr).

Parametros (se prescriben):

Forzante solar
Composición atmosférica (segun modelo)
Condición de borde superficial (segun modelo)

Examples of External Parameters that can be modified:

1. The relatively long memory of tropical SST can be used to obtain an idea of the SST field in the next few months (e.g., El Niño conditions). Using this predicted SST field to force an AGCM, allows us climate outlooks one season ahead.

2. Changes in solar forcing (due to changes in sun-earth geometry) are very well known for the past and future (For instance, NH seasonality was more intense in the Holocene than today). Modification of this parameter allow us paleo-climate reconstructions (still need to prescribe other parameters in a consistent way: Ice cover, SST, etc.…hard!)

3. Changes in greenhouse gases concentration in the next decades gases give us some future climate scenarios.

Once selected the domain and grid, the numerical integration uses finite differences in time and space

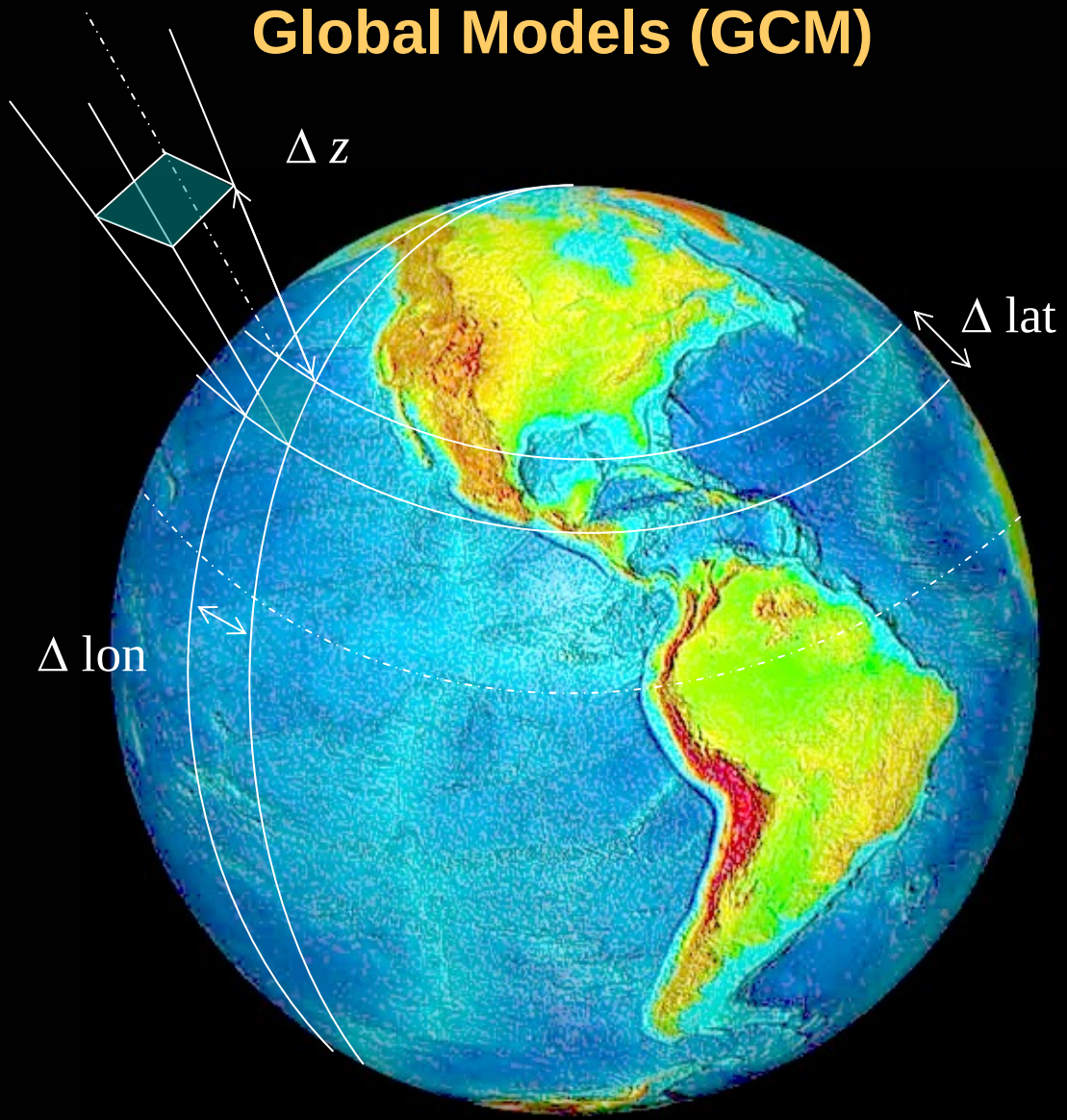
$$\frac{\partial T}{\partial t} + u\frac{\partial T}{\partial x} = Q_{diab}$$

Numerial method (stable & efficient)

$$\frac{T_{t+1}^{i} - T_{t-1}^{i}}{\Delta t} + u_{t-1}^{i}\frac{T_{t}^{i+1} - T_{t}^{i-1}}{\Delta x} = Q_{diab}$$

Sub-grid processes must be parameterized, that is specified in term of large-scale variables

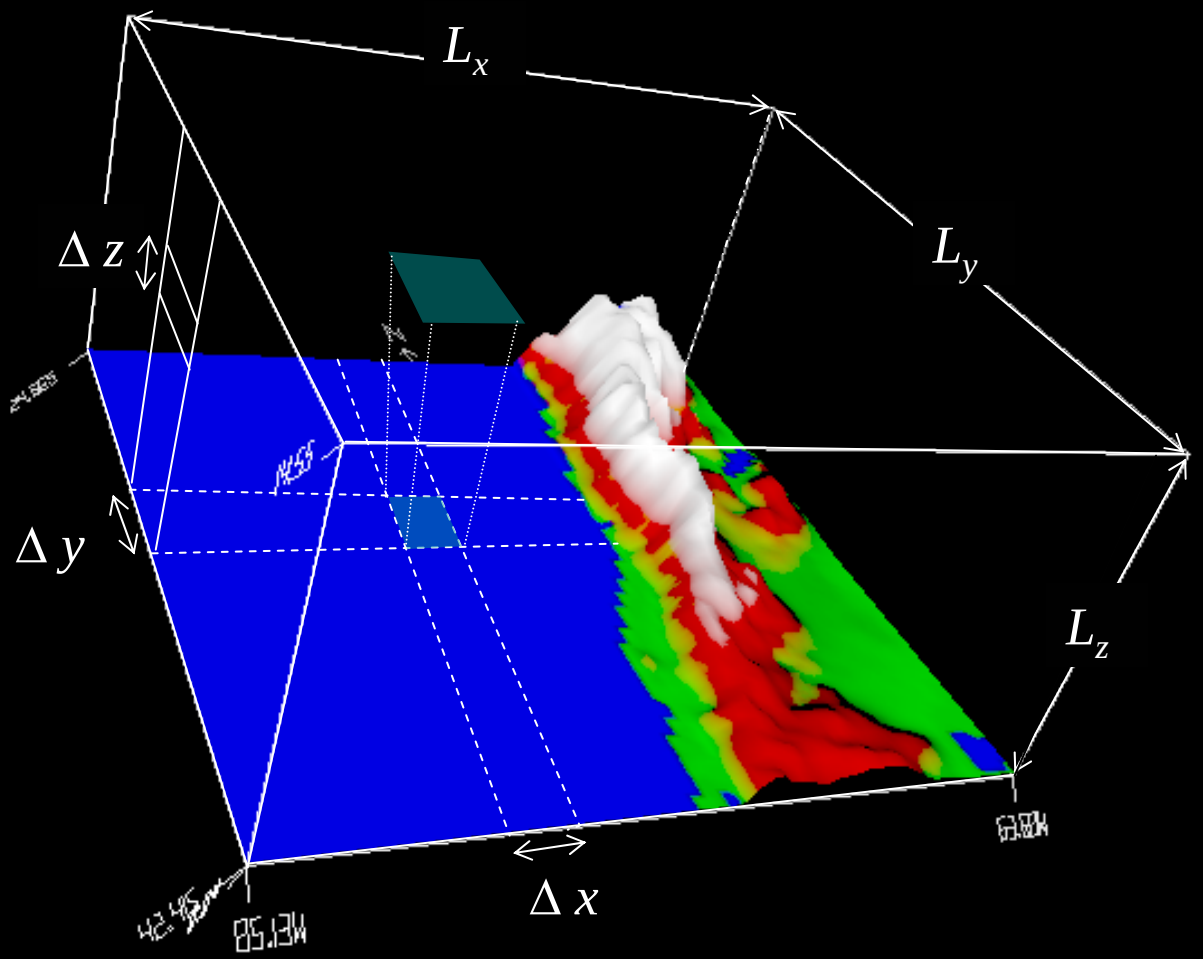
Global Models (GCM)



Δlat ~ Δ lon ~ 1° - 3° Δ*z* ~ 1 km Δ*t* ~ minutes-hours

Top of atmosphere: 15-50 km

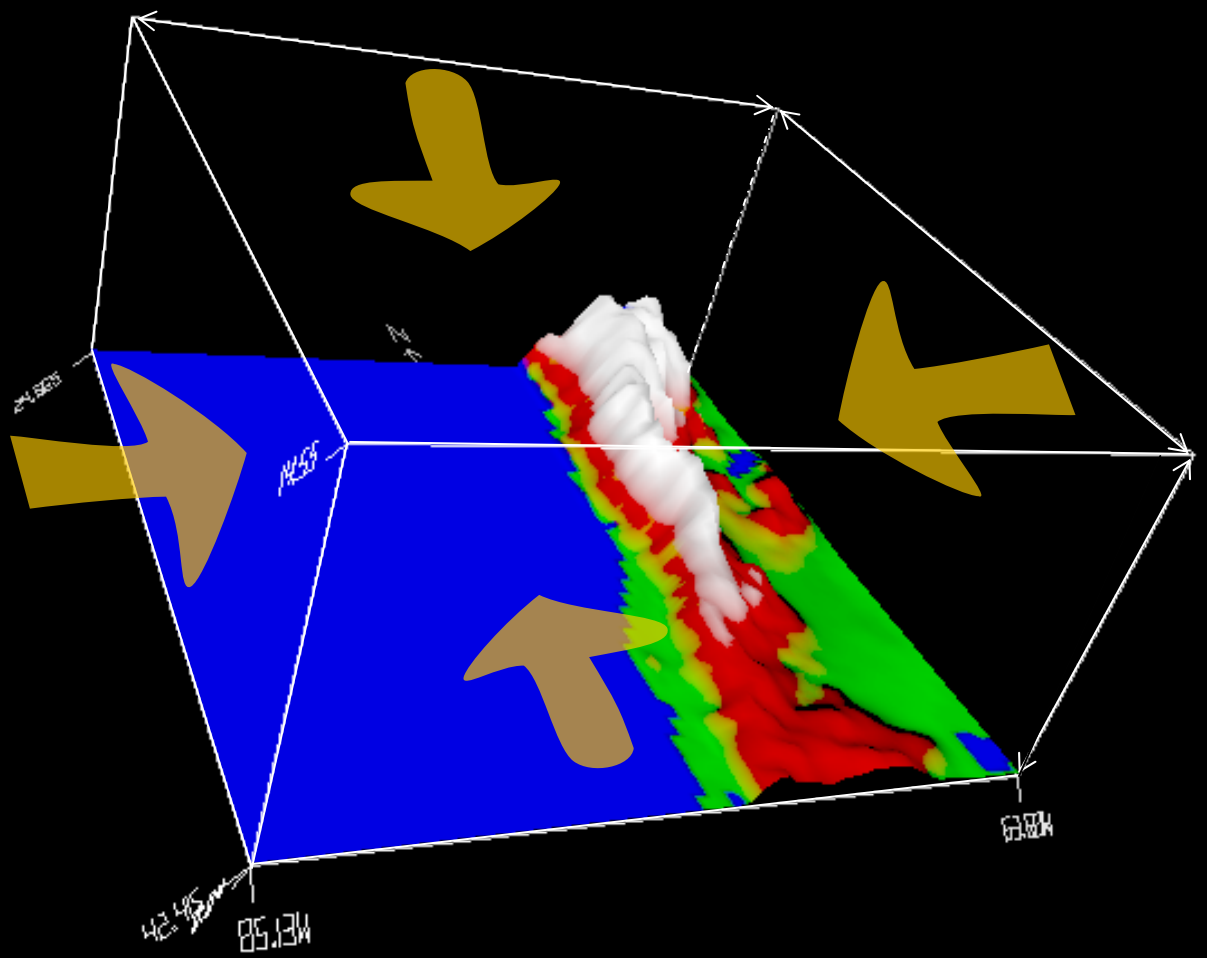
Regional Models (LAM, MM)



$\Delta x \sim \Delta y \sim$ 1-50 km $\Delta z \sim$ 50-200 m $\Delta t \sim$ seconds

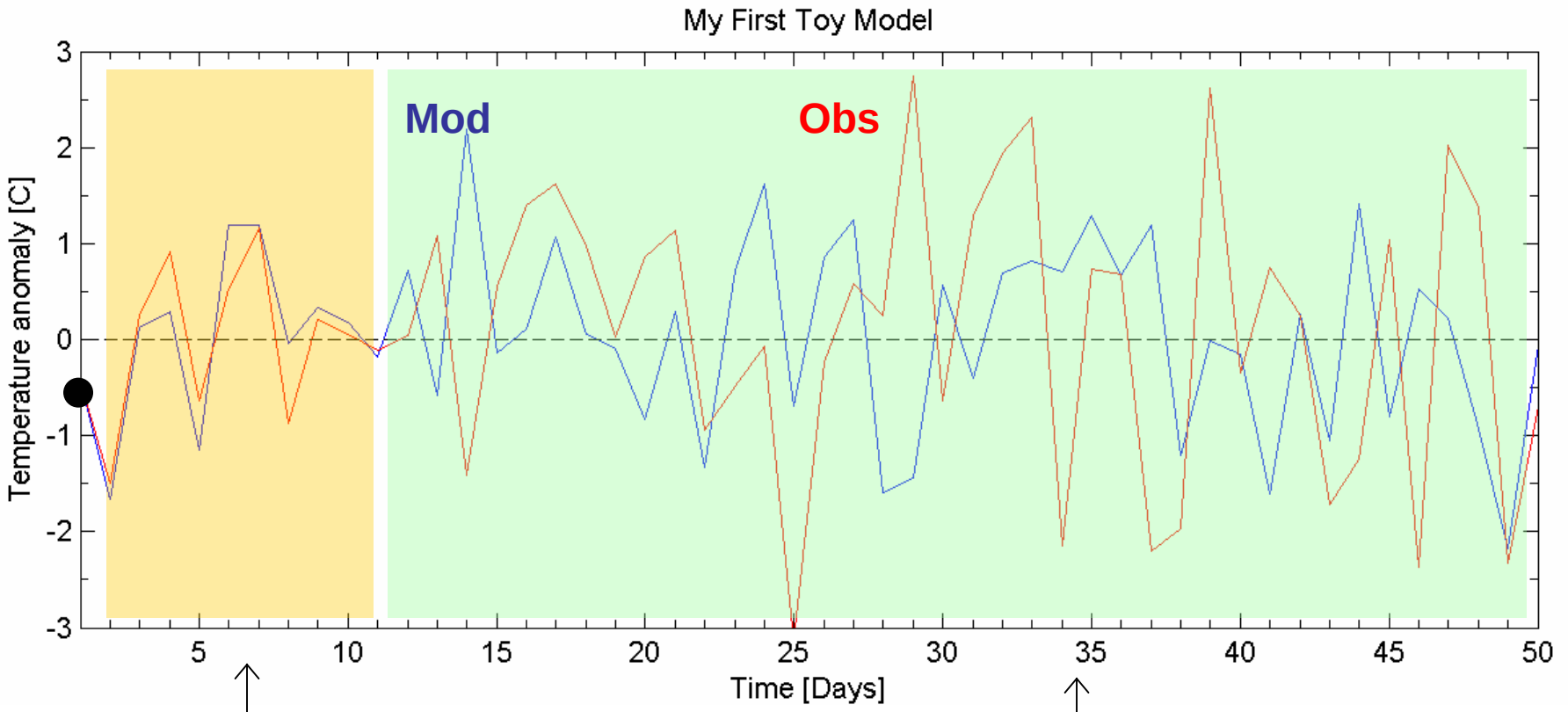
$L_x \sim L_y \sim$ 100-5000 km $L_z \sim$ 15 km

Regional Models (LAM, MM)



Regional models gives us a lot more detail (including topographic effects) but they need to be “feeded” at their lateral boundaries by results from a GCM.

Main problem: Garbage in – Garbage out



Weather forecast
Model predicts daily values

Climate Prediction
Model does NOT predict daily values
but still gives reasonable climate state
(mean, variance, spectra, etc…)

Temario

1. Modelos Climáticos (general)

2. Cambios en el siglo XX: Global /Regional

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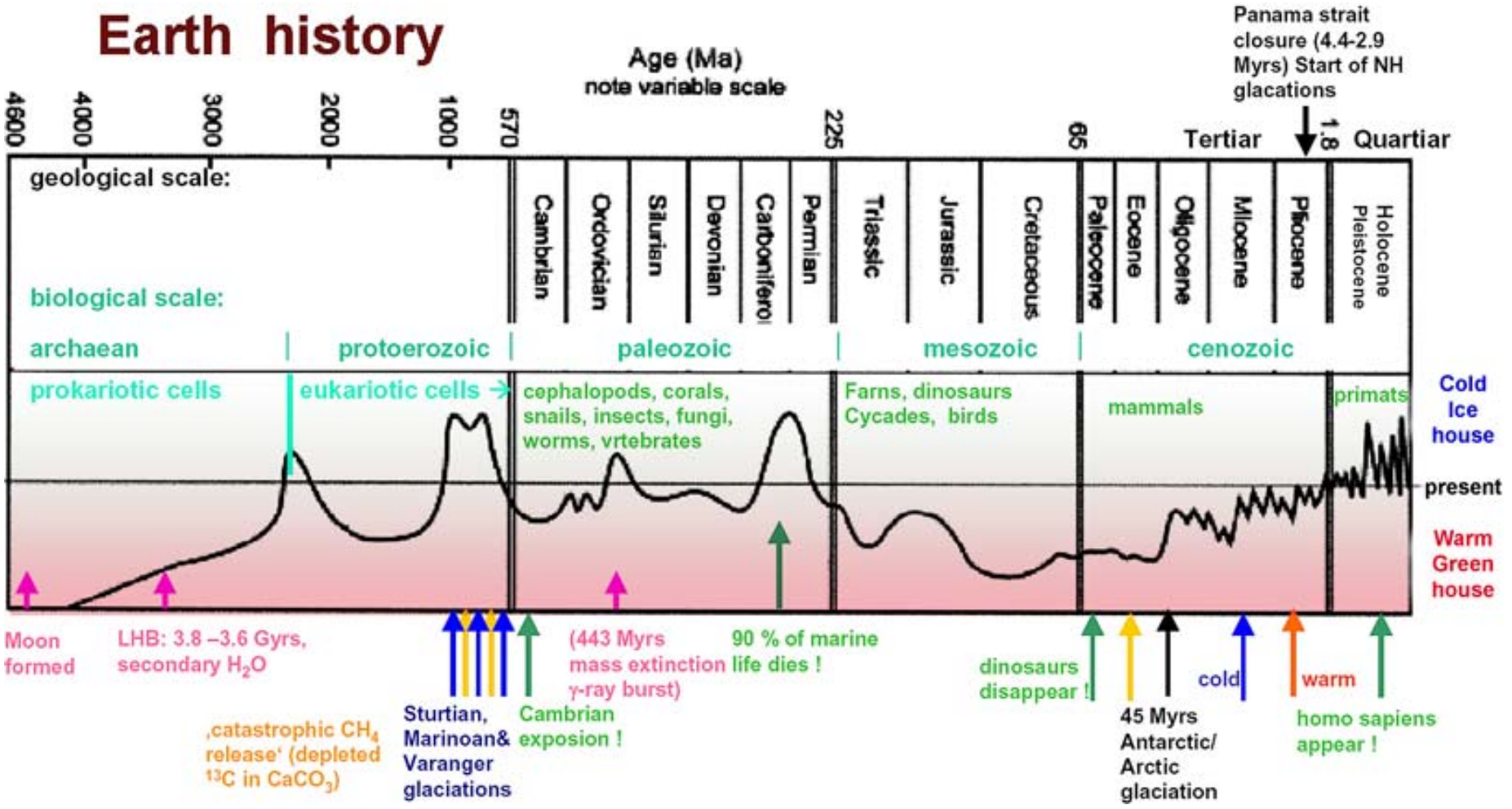
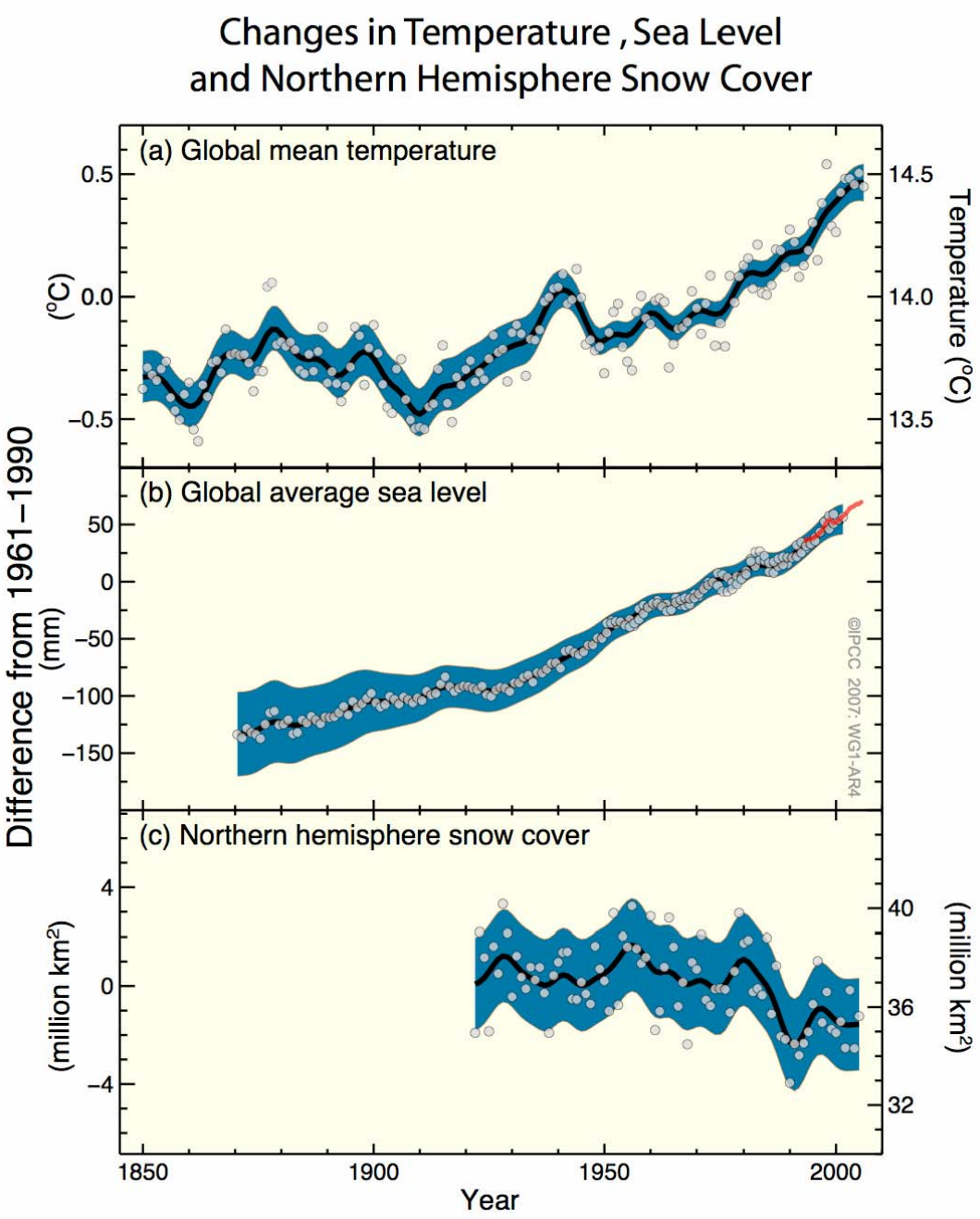
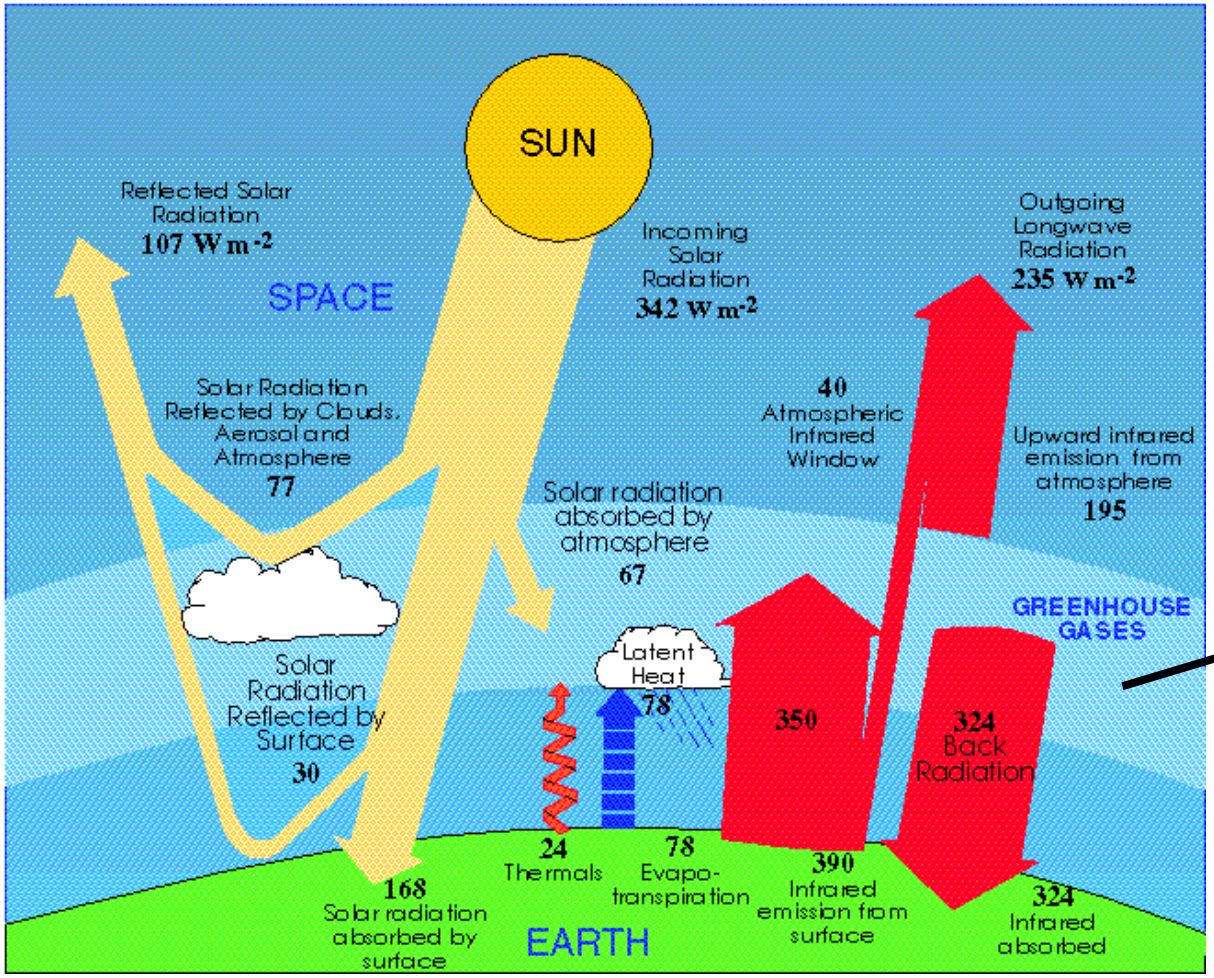
Historia climática del Planeta: Usualmente más calido que las condiciones actuales y en permanente cambio



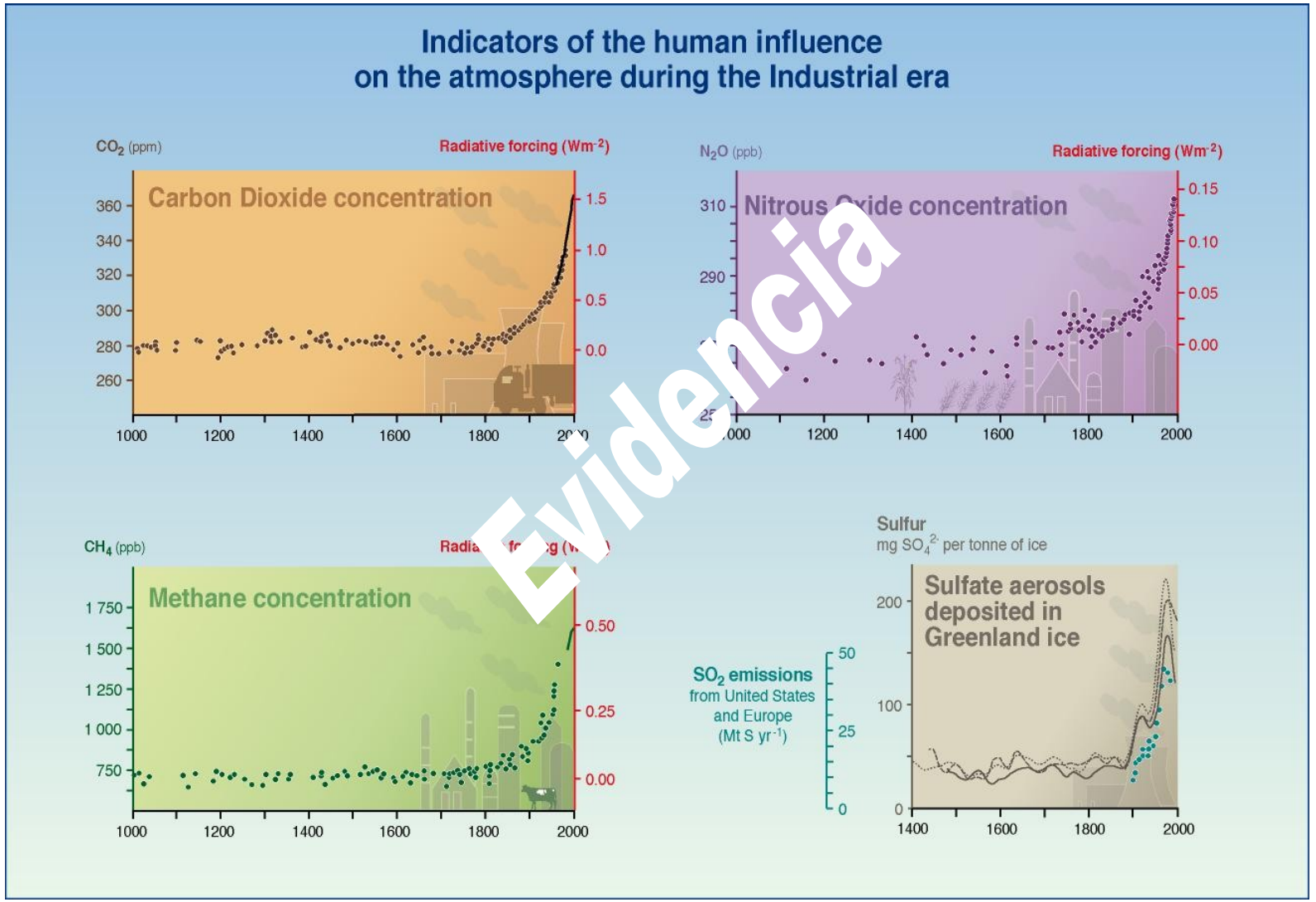


Balance Global de Energía del Planeta Tierra (promedio en latitud y longitud)

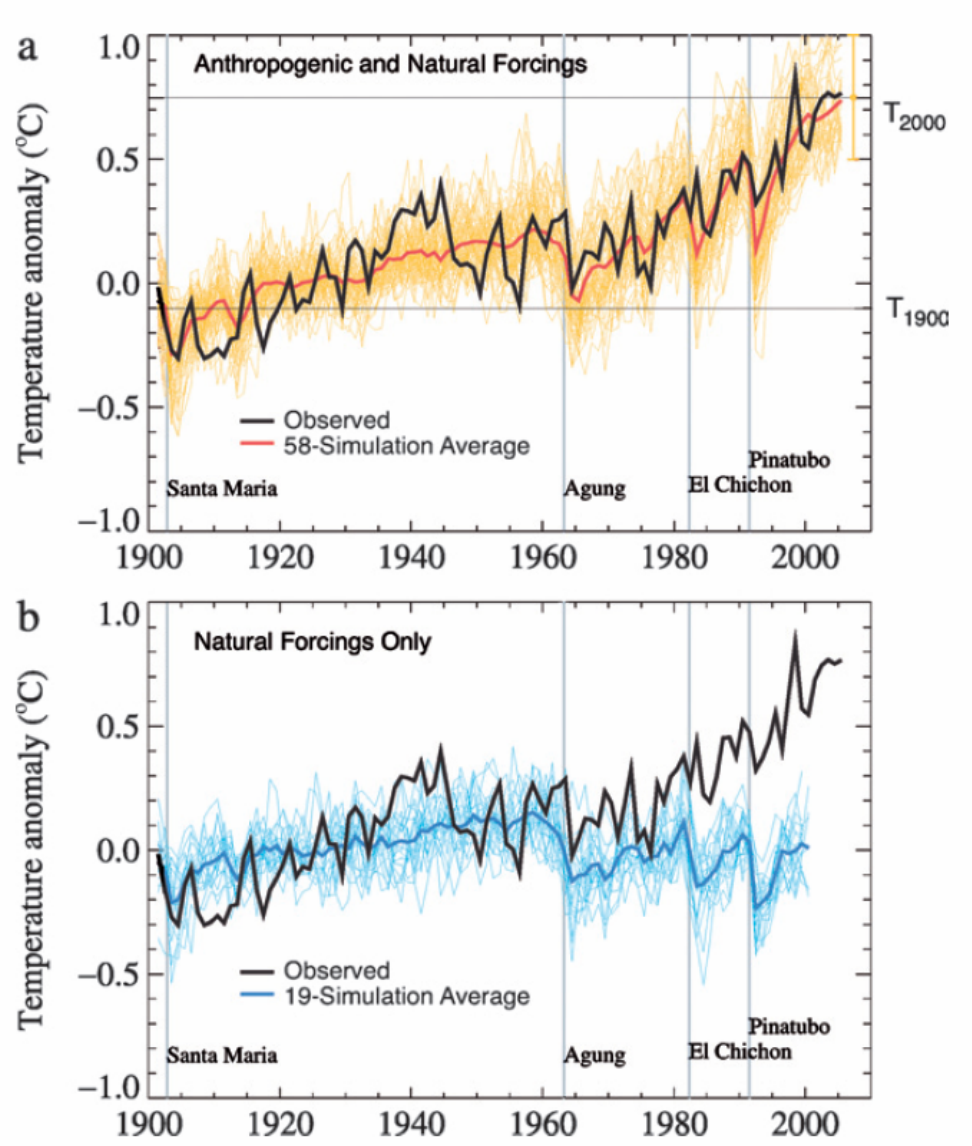


Gases Invernadero

H_2O, CO_2, CH_4, N_20



Cambios observados y simulados en Tsfc



Evidencia

Cambios observados en Temp. Superficial

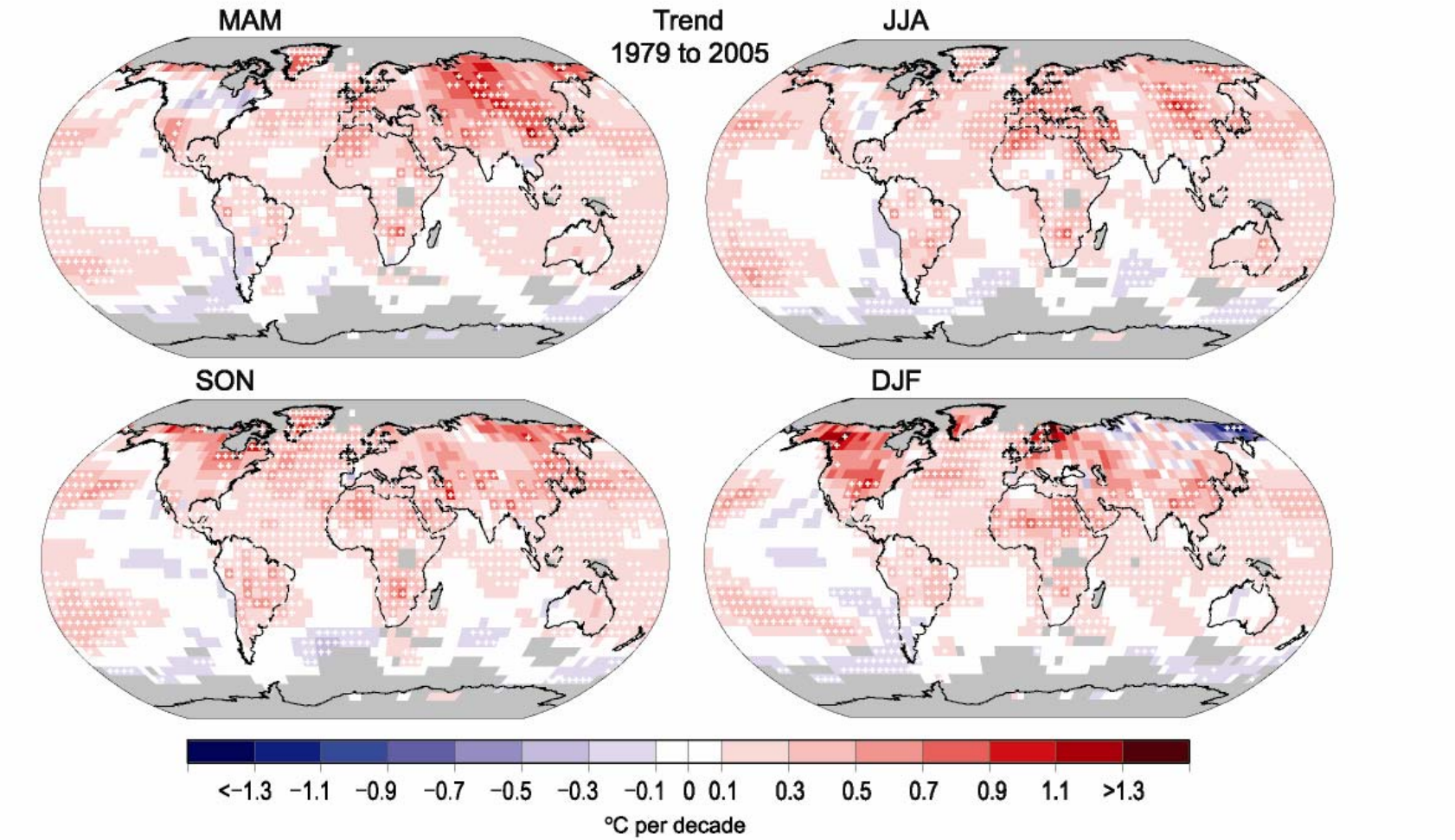
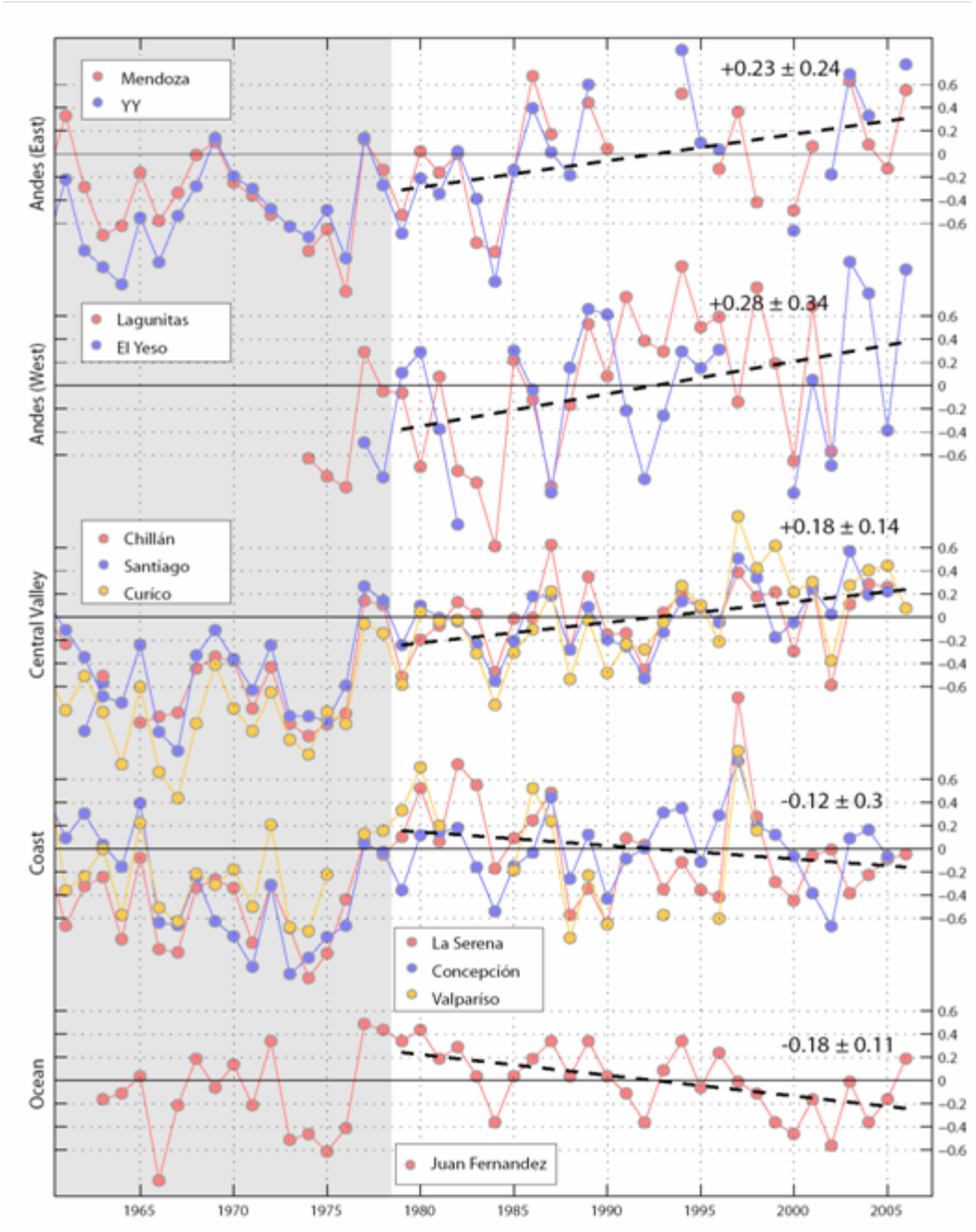


Figure 3.10. Linear trend of seasonal MAM, SON and DF temperature for 1979 to 2005 (°C per decade). Areas in grey have insufficient data to produce reliable trends. The minimum number of years required to calculate a trend value is 18. A seasonal value is available if there are two valid monthly temperature 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.

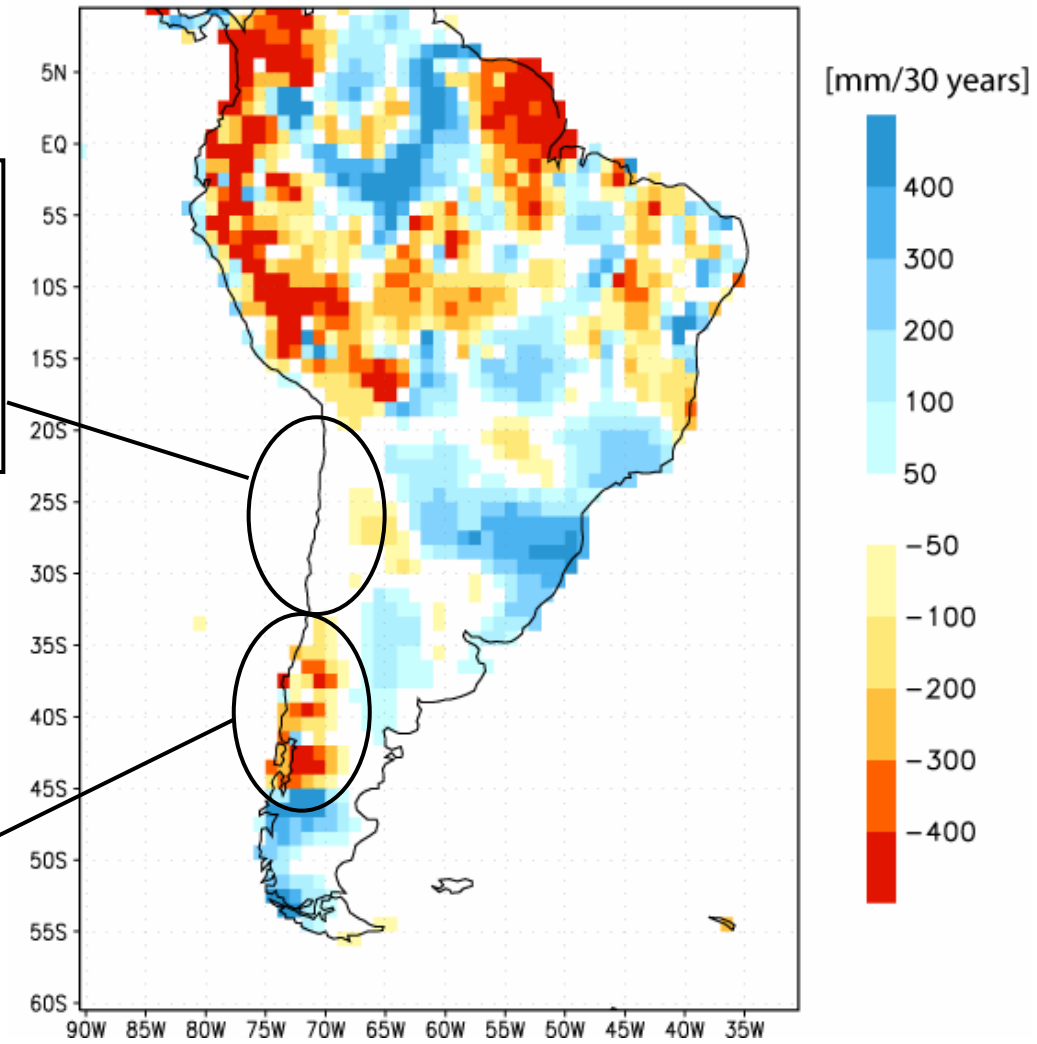
Cambios de Temperatura en Chile



Cambios observados de Precipitación (1960-2000)

- Semiarid climate
- MAP ~ 30-500 mm
- σ(IA)/MAP ~ 0.3 – 0.5
- Strong ENSO Impact
- No significant trend

- Rainy climate
- MAP ~ 1000-3000 mm
- σ(IA)/MAP ~ 0.1
- Weak ENSO Impact
- Significant drying trend



Temario

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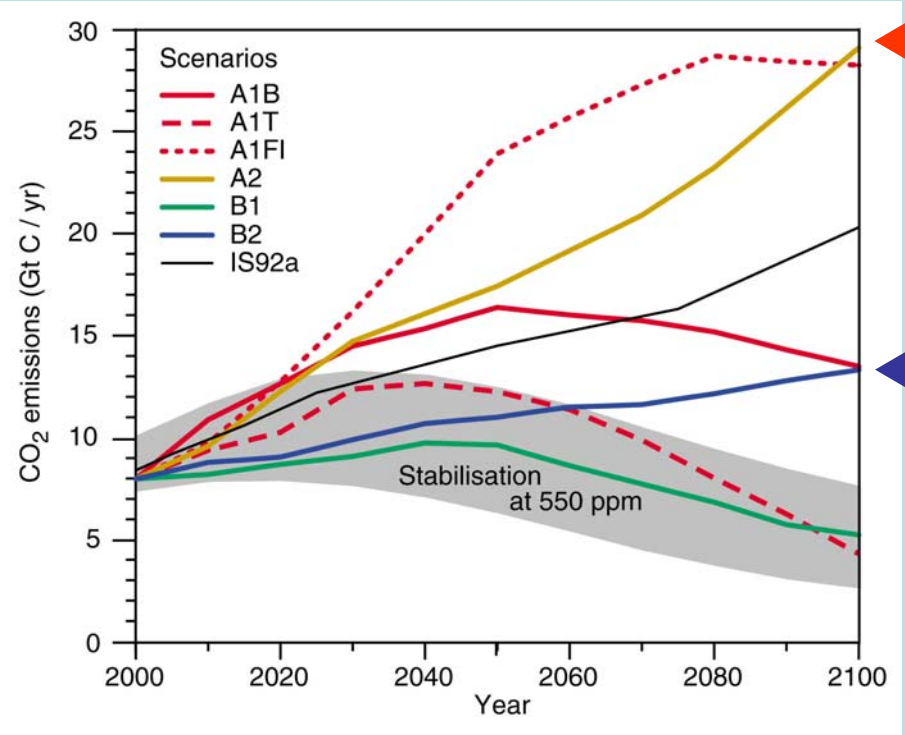
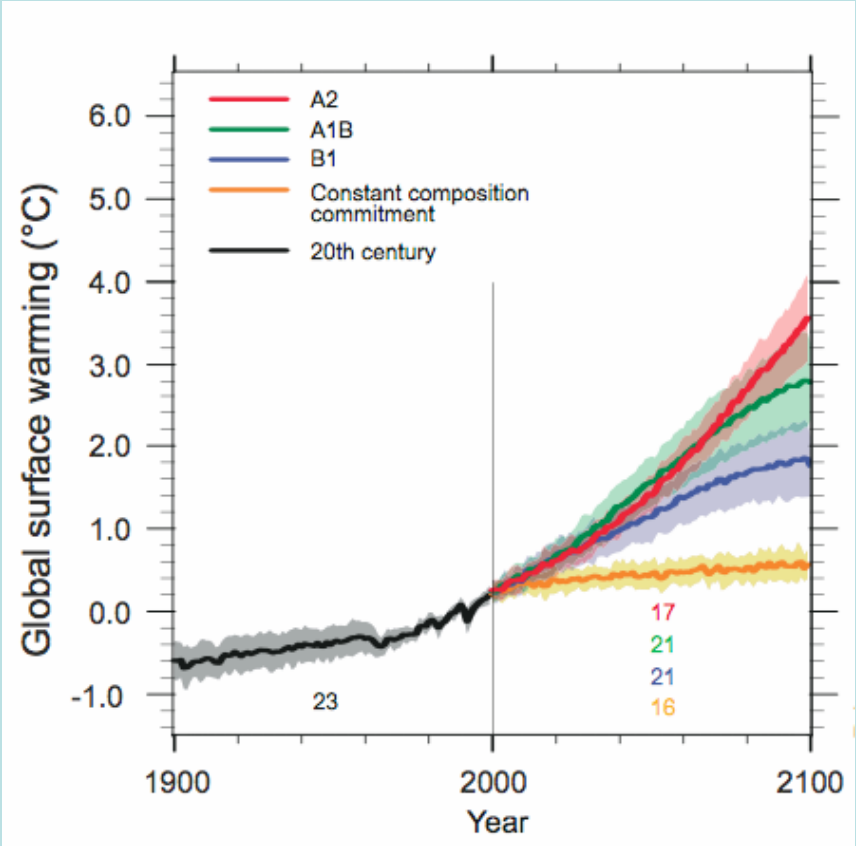
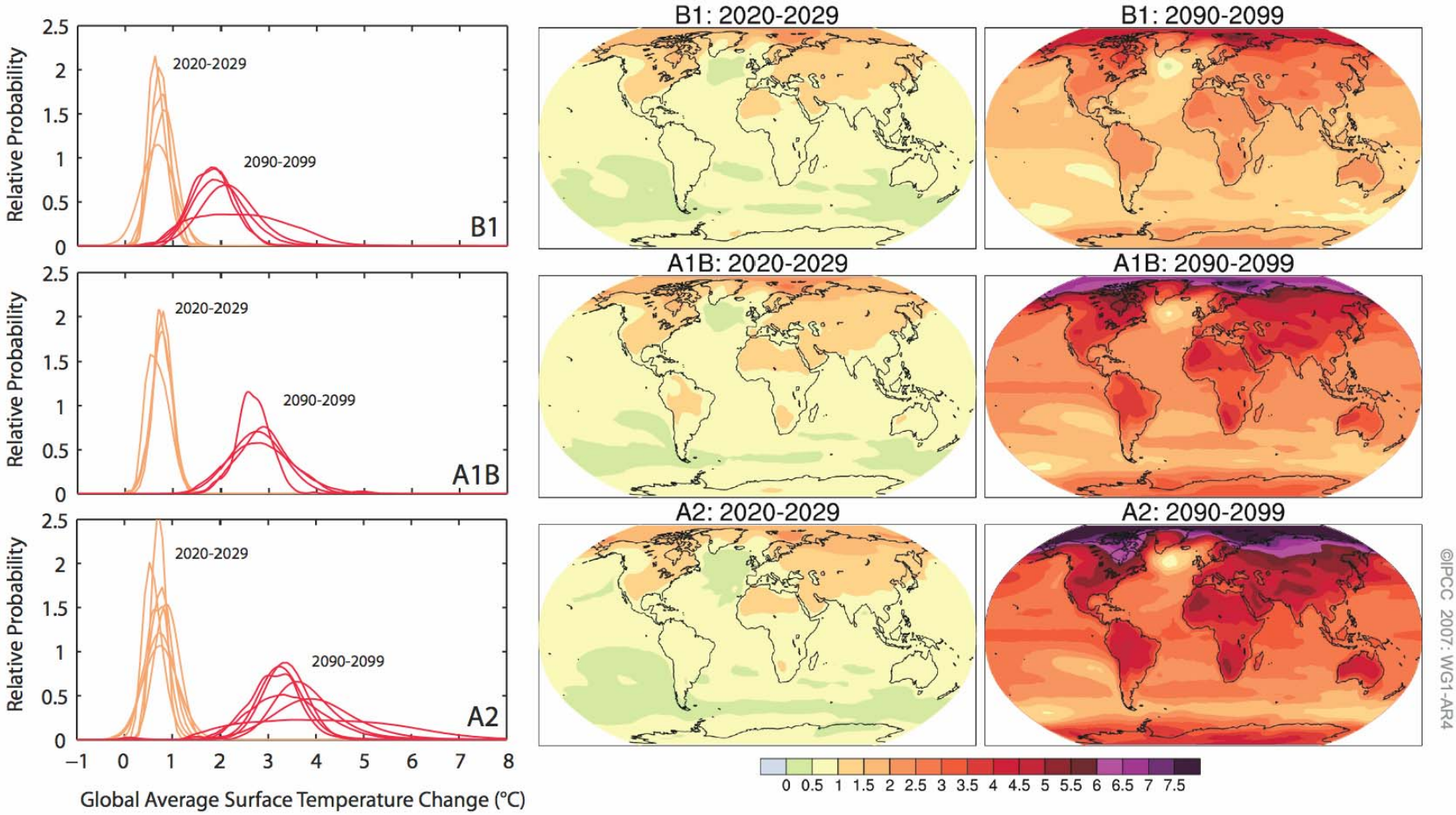


Escenarios Desarrollo Economico-Social

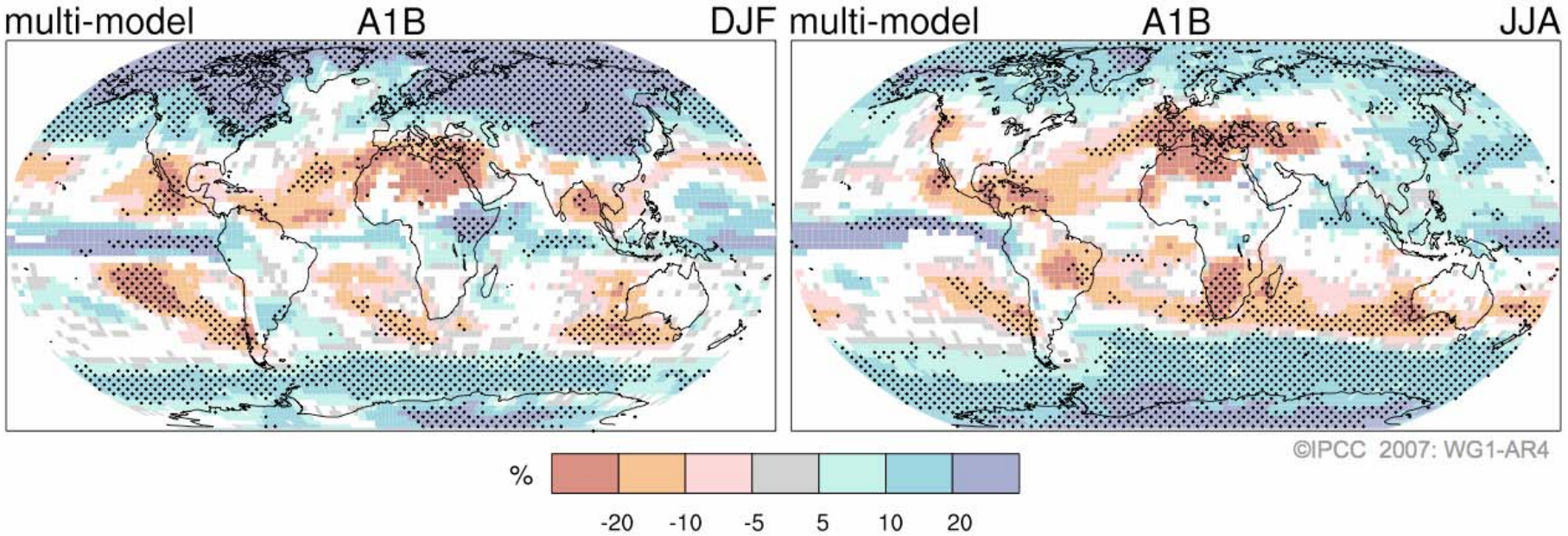
GCMs



AOGCM Projections of Surface Temperatures



Projected Patterns of Precipitation Changes



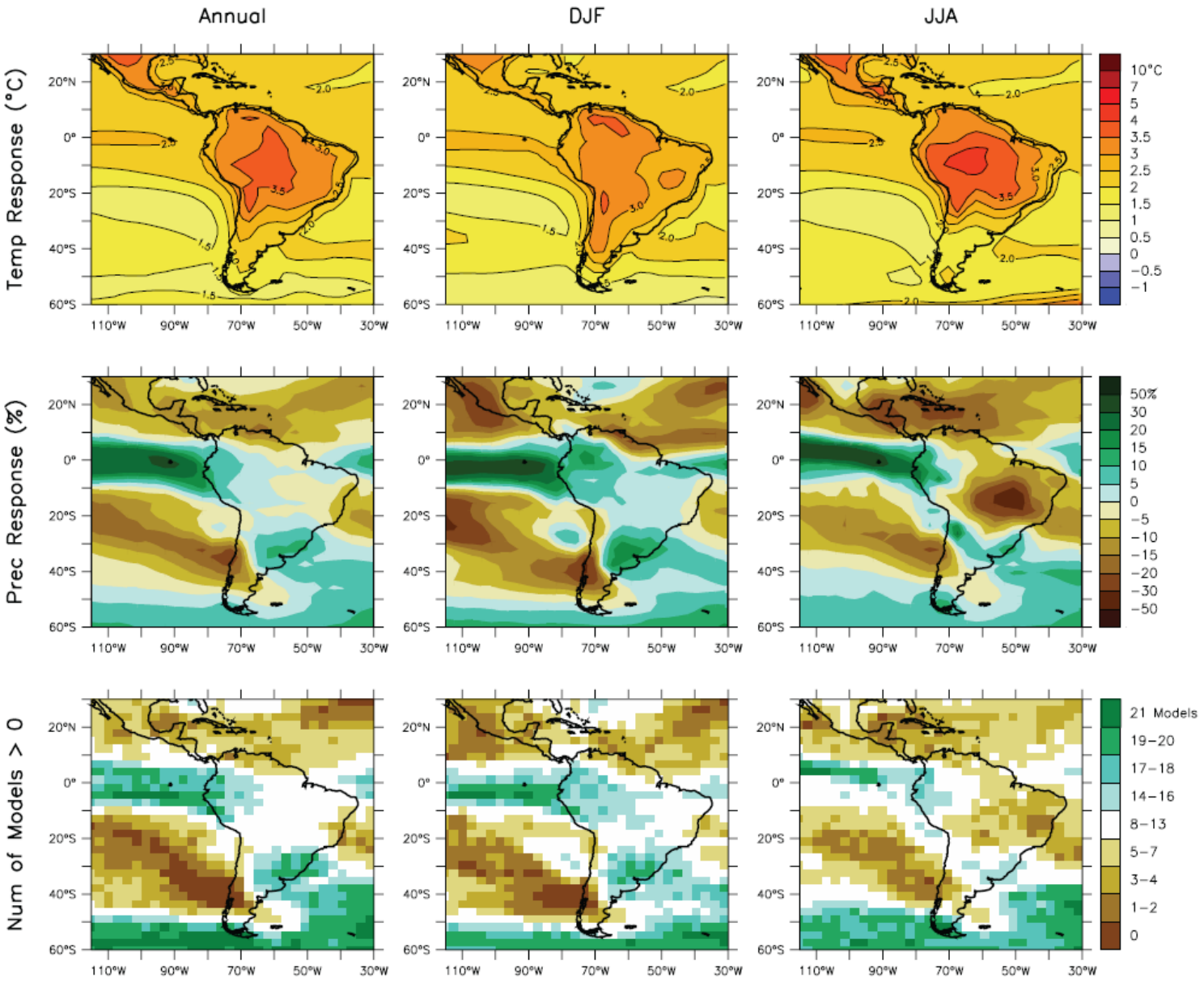
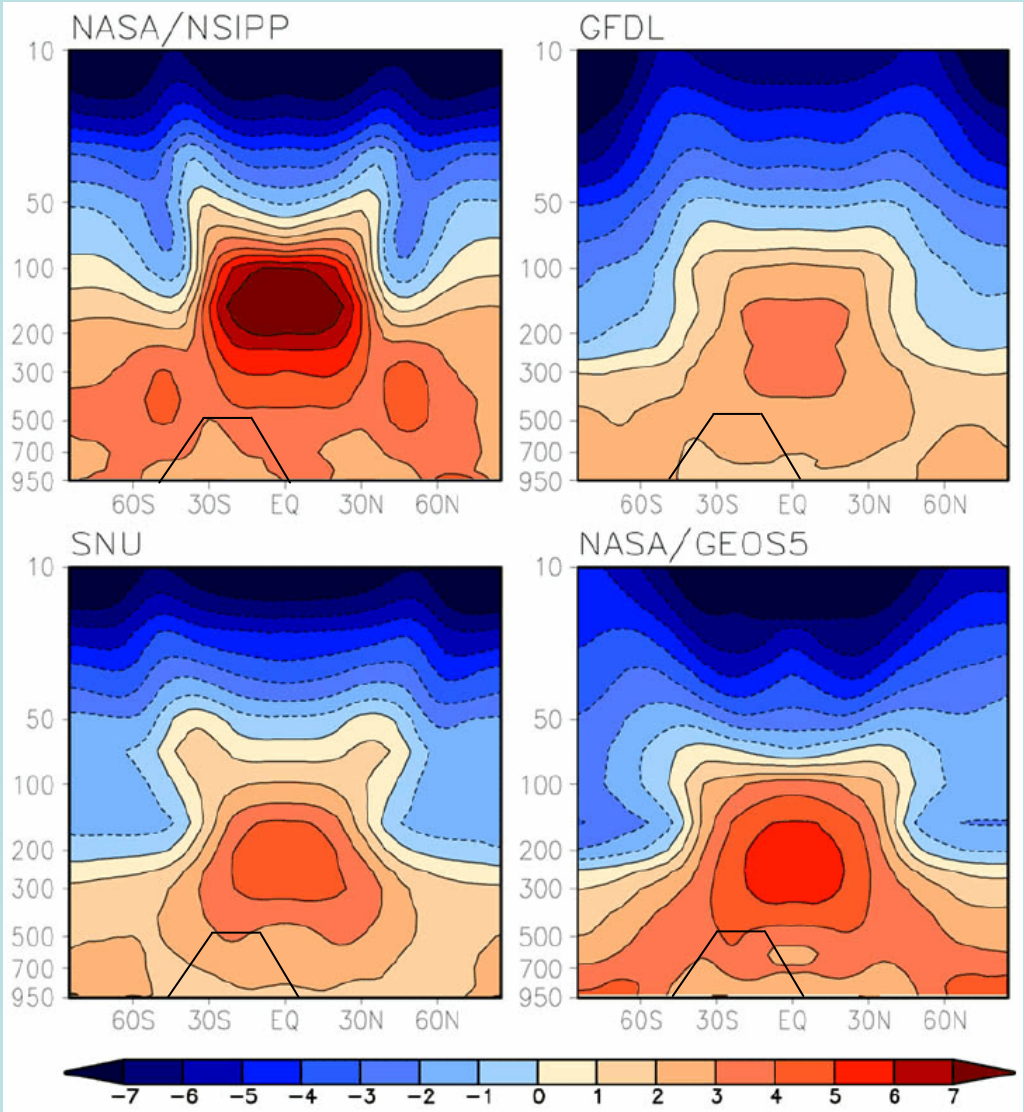


Figure 11.15. *Temperature and precipitation changes over Central and South America from the MMD-A1B simulations. Top row: Annual mean, DJF and JJA temperature change between 1980 to 1999 and 2080 to 2099, averaged over 21 models. Middle row: same as top, but for fractional change in precipitation. Bottom row: number of models out of 21 that project increases in precipitation.*

Zonal mean distribution of temperature change (2xC02-Ctr)

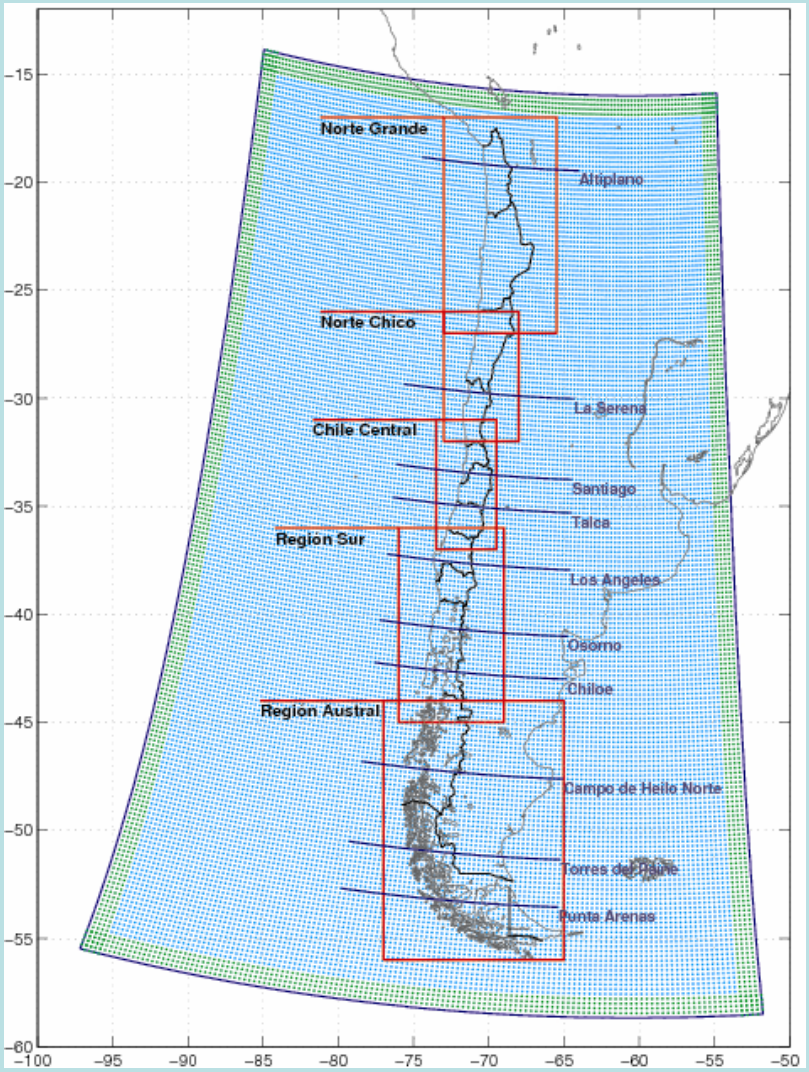


Zonal mean distributions of temperature change (2×CO2–Control). Units are Kelvin.

averaged, equilibrated temperature change associated with doubling of latitude and pressure for four different GCMs. From Lee et al, 2007.

Proyecto CONAMA – DGF/UCH

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



Model:

- PRECIS – UK

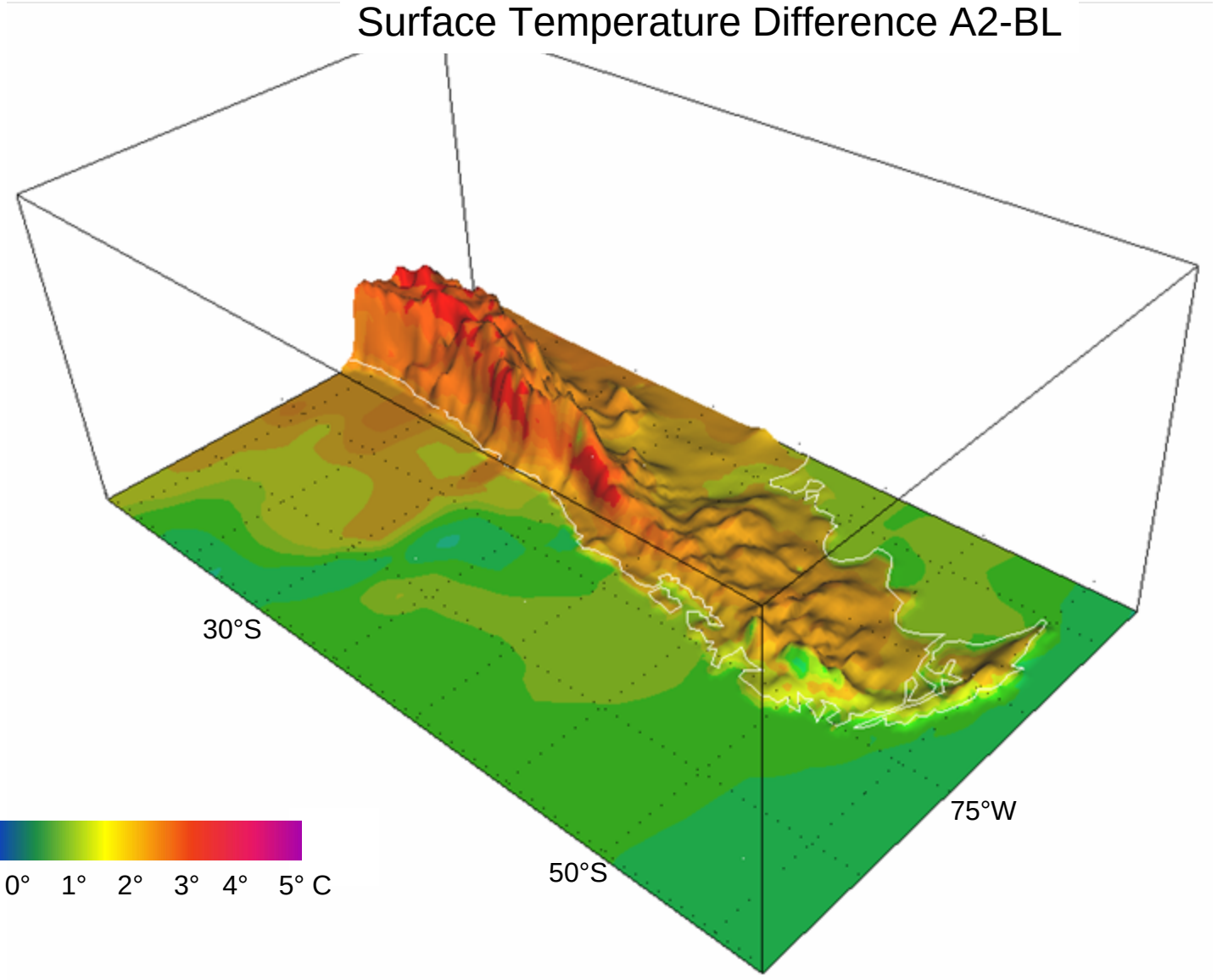
Single domain

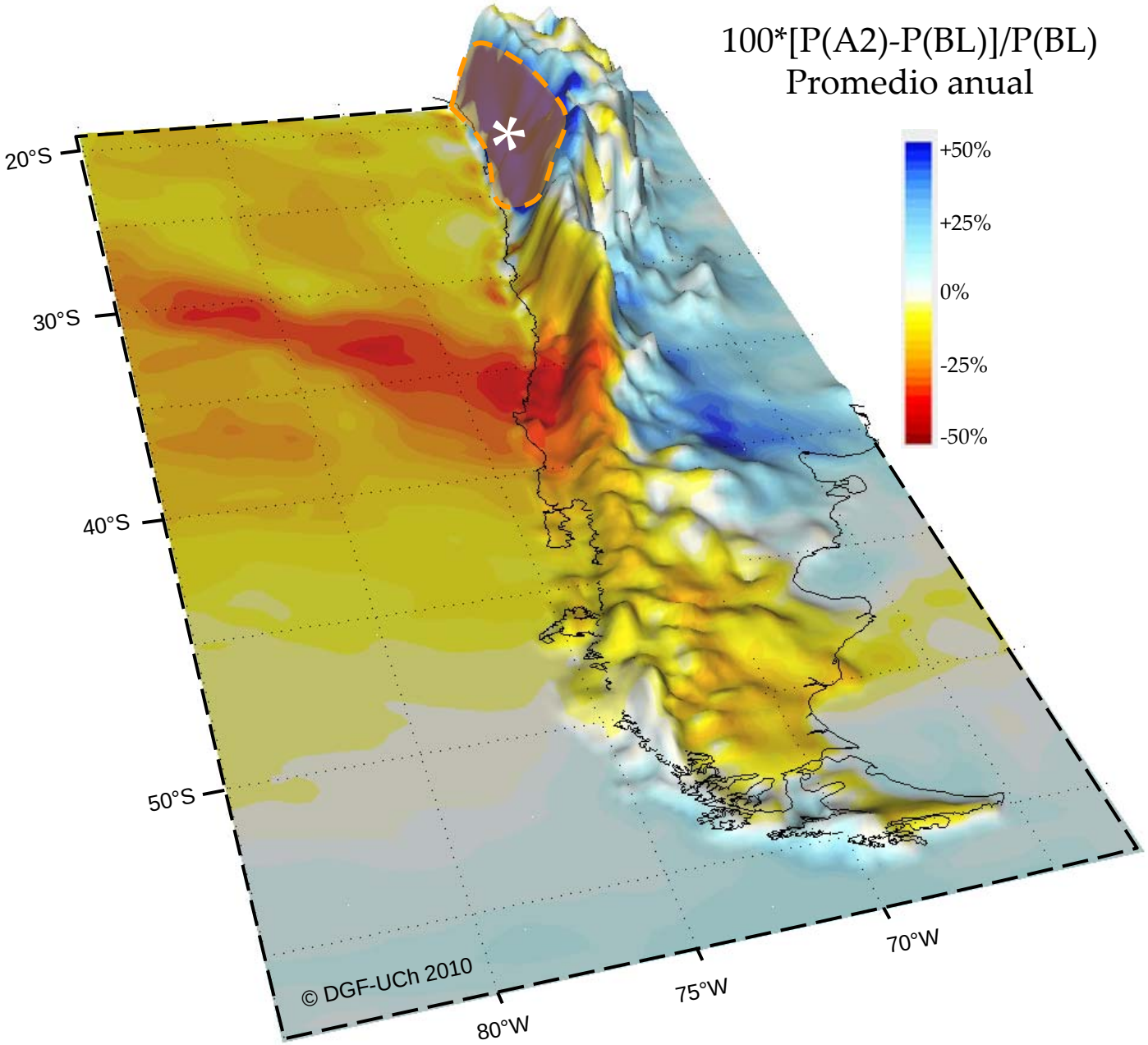
- Horiz. grid spacing. 25 km
- 19 vertical levels
- Lateral BC: HadAM every 6h
- Sfc. BC: HadISST1 + Linear trend

Simulations

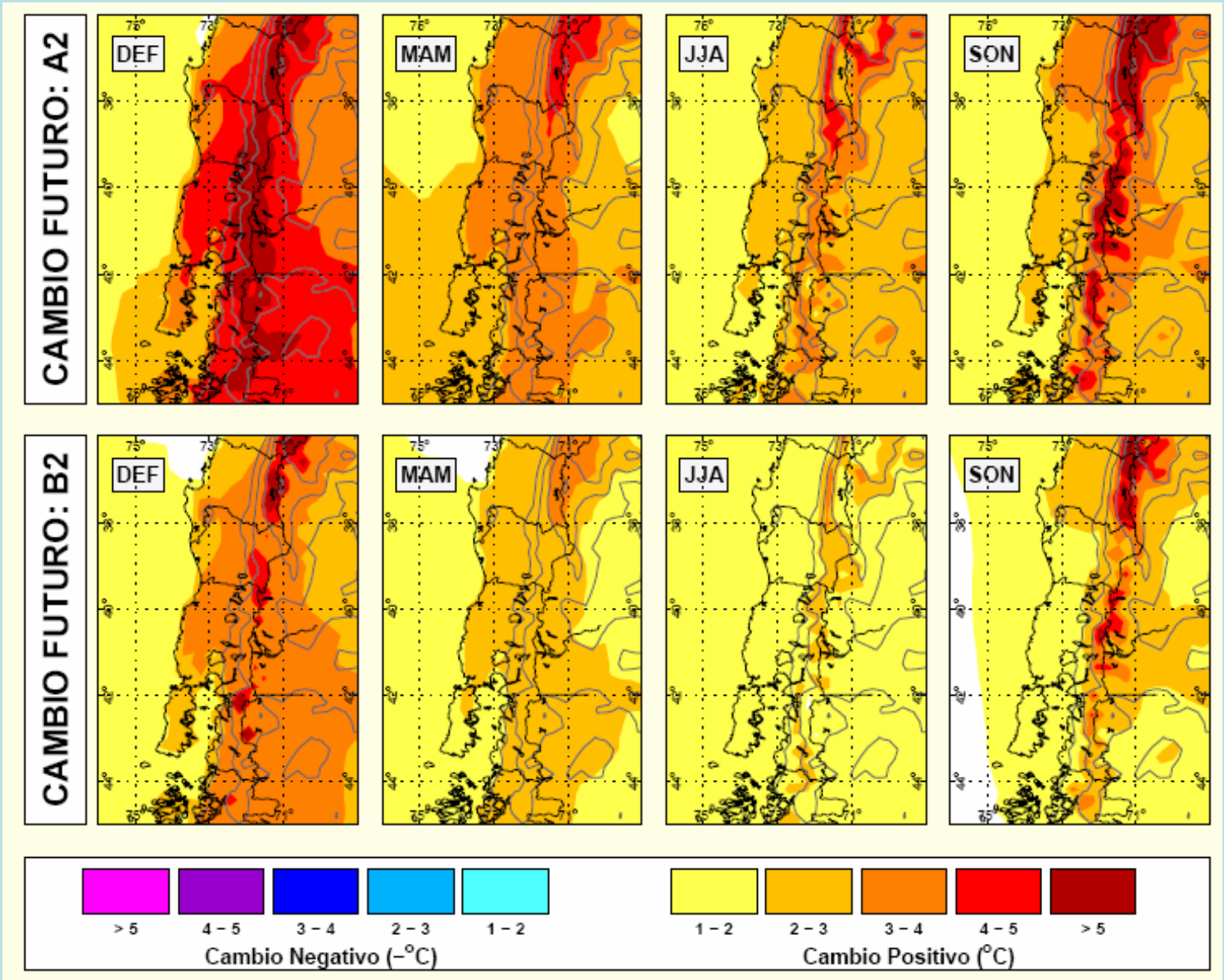
- **1961-1990 Baseline**
- **2071-2100 SRES A2 y B2**
- 30 years @ 3 min → 4 months per simulation in fast PC

Surface Temperature Difference A2-BL



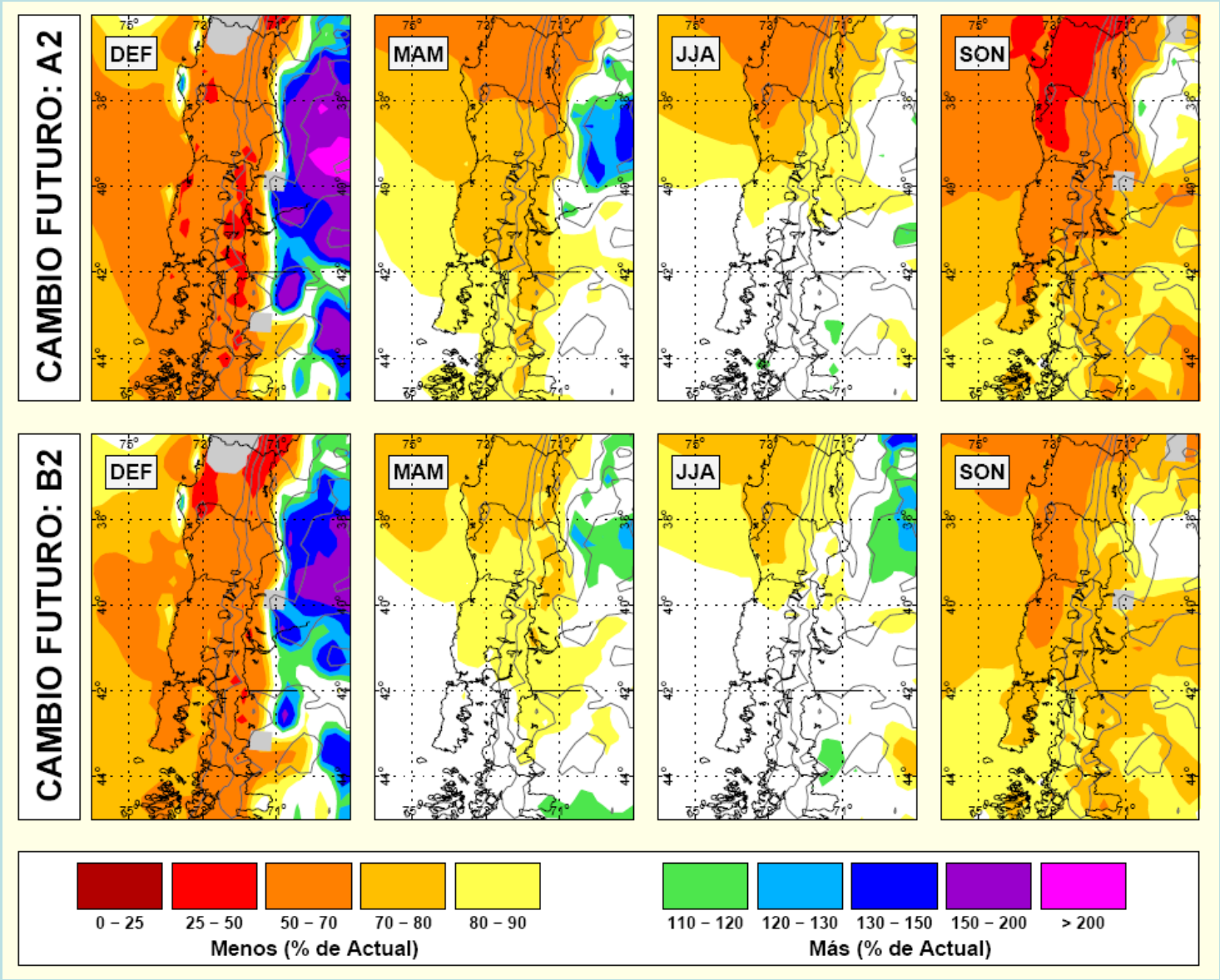

100*[P(A2)-P(BL)]/P(BL)
Promedio anual
+50%
+25%
0%
-25%
-50%
20°S
30°S
40°S
50°S
80°W
75°W
70°W
© DGF-UCh 2010

PRECIS-DGF TX_{futuro} - $TX_{presente}$



Futuro: 2071-2100 / Presente: 1961-1990

PRECIS-DGF R_{futuro} / $R_{presente}$



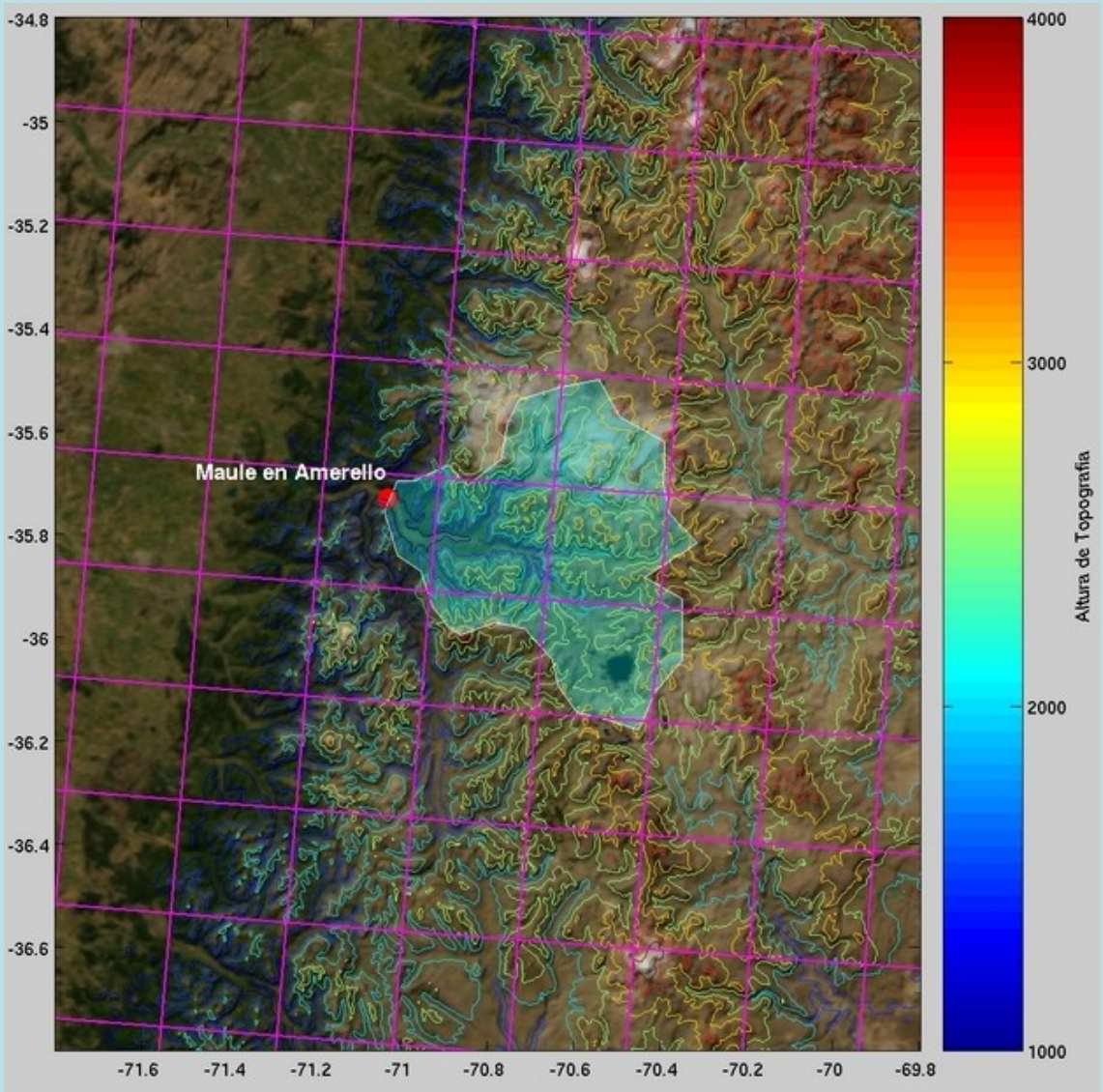
Futuro: 2071-2100 / Presente: 1961-1990

Aplicaciones en Sectores Dependientes del Recurso Hídrico

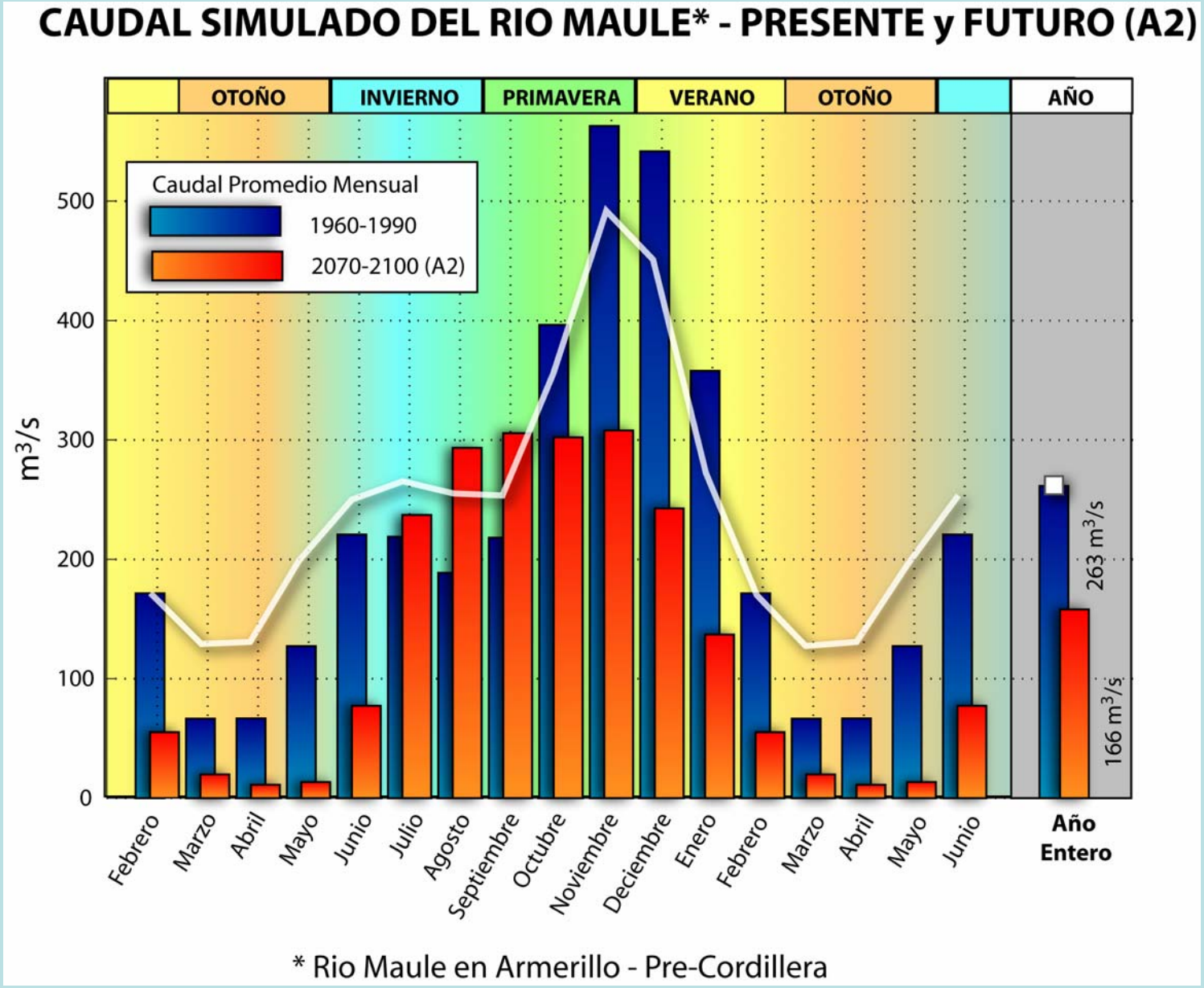
- Cambios en régimen de precipitación (más o menos agua?)
- Cambios en la estacionalidad de los caudales (cuando hay agua?)
- Cambios en eventos extremos (crecidas y aluviones)

PRECIS-DGF

Acomplamiento con modelos hidrológicos.



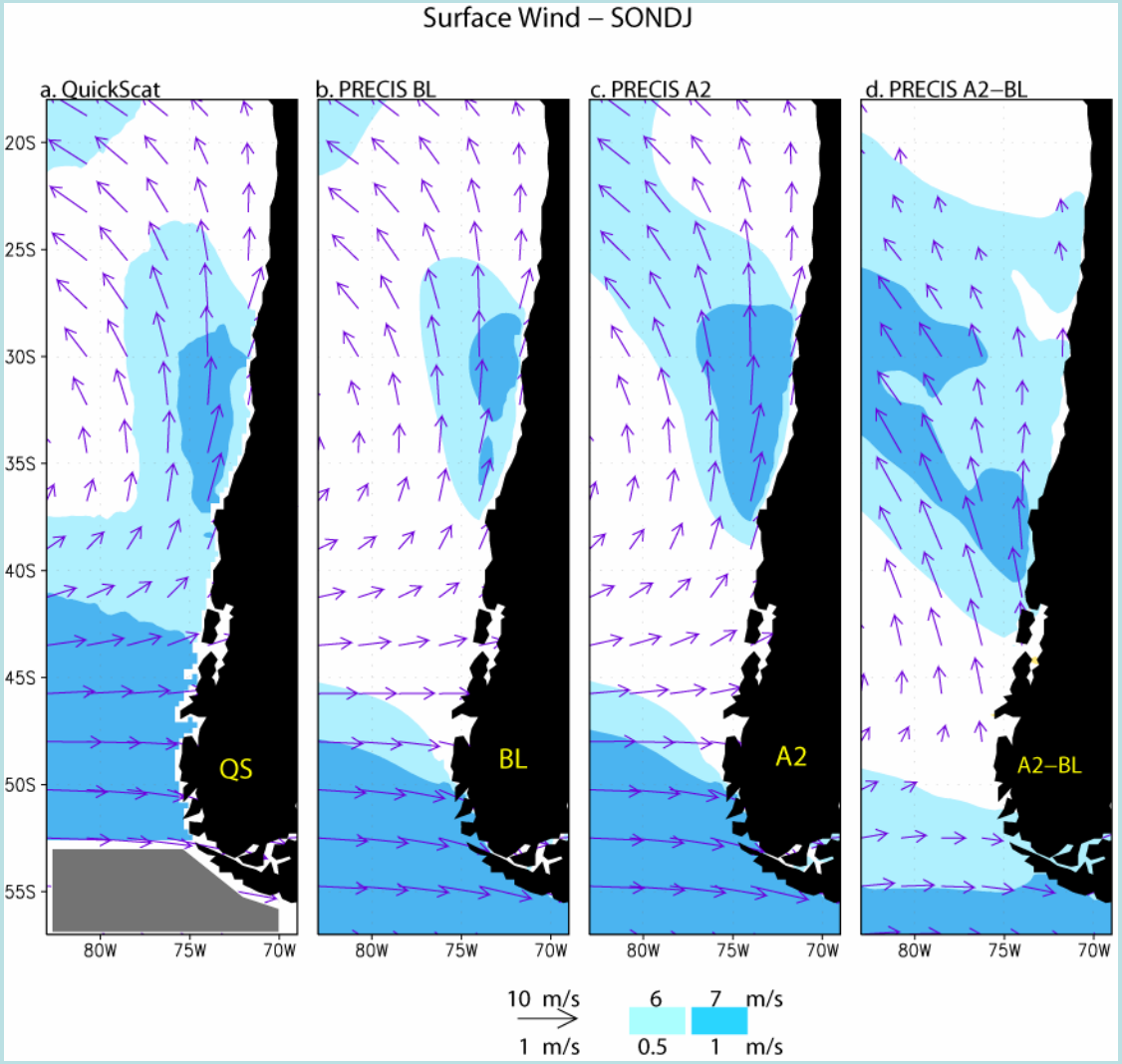
PRECIS-DGF Acomplamiento con modelos hidrológicos.



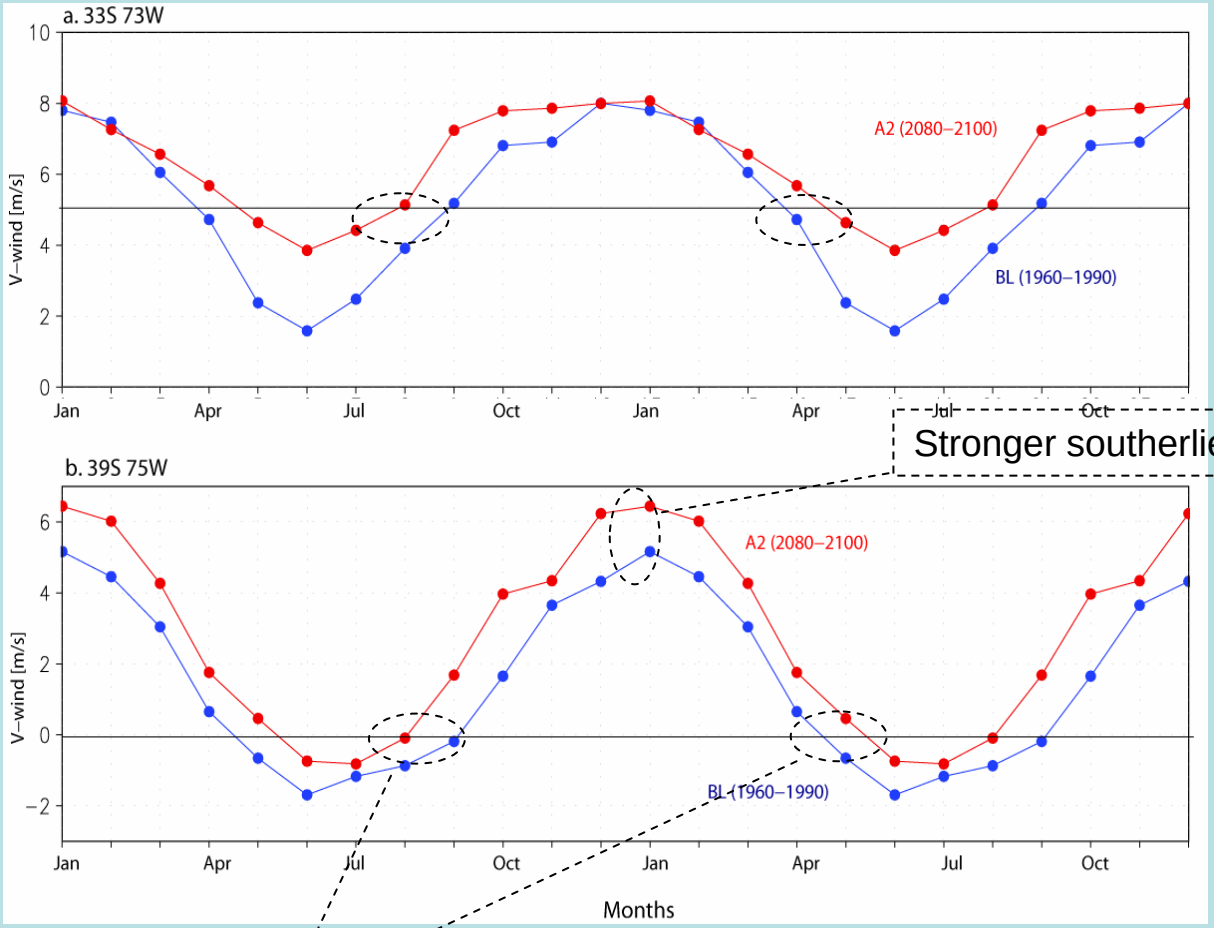
Aplicaciones en el Sector Pesquero

- Cambios en la intensidad y estacionalida del viento costero
- Cambios en Temperatura Superficial del Mar
- Cambios en episodios de surgencia costera

PRECIS Results



PRECIS Results



Stronger southerlies

2 month extended upwelling season
(earlier onset, later demise)