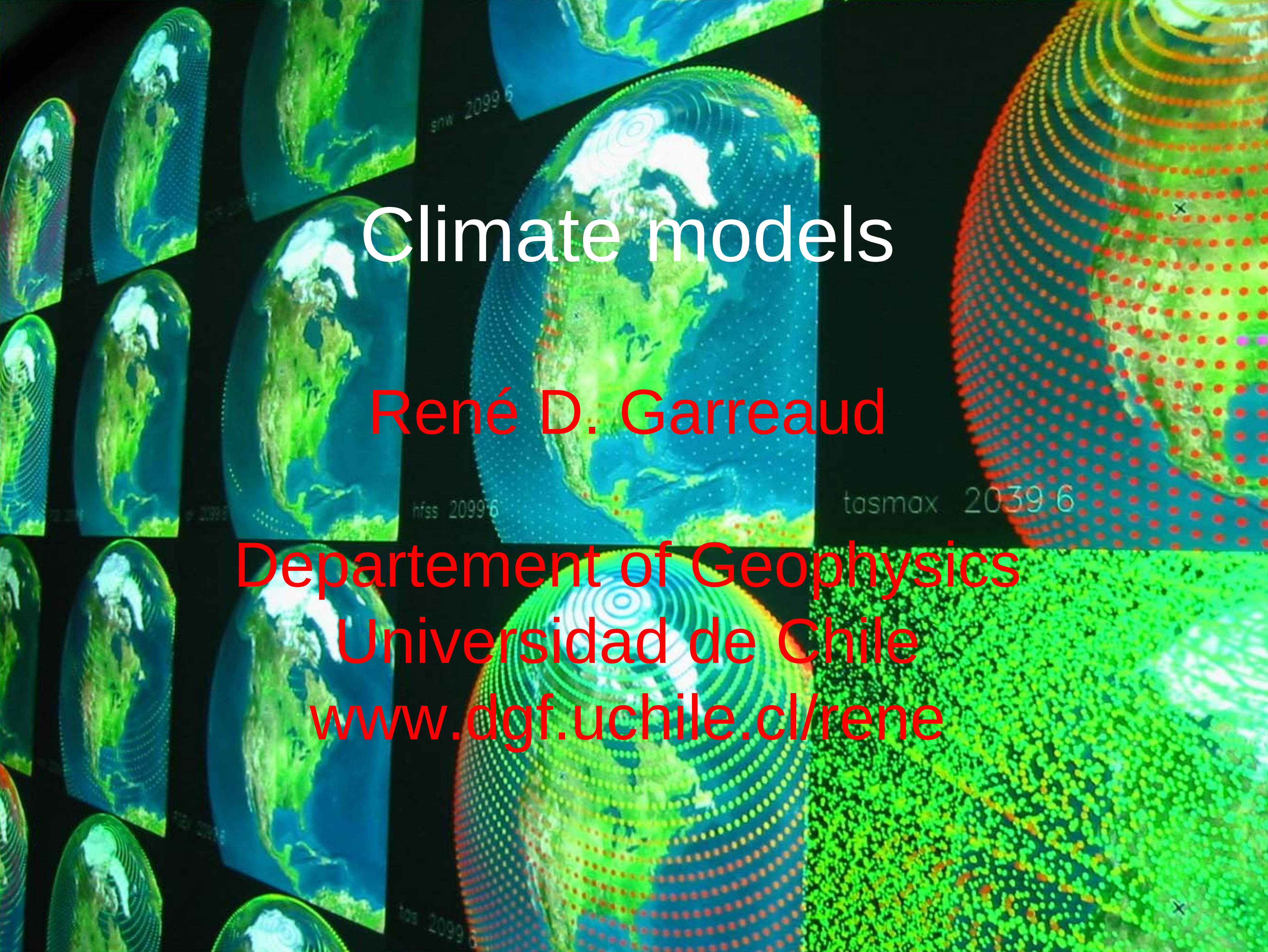

Climate models

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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

My first toy model

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

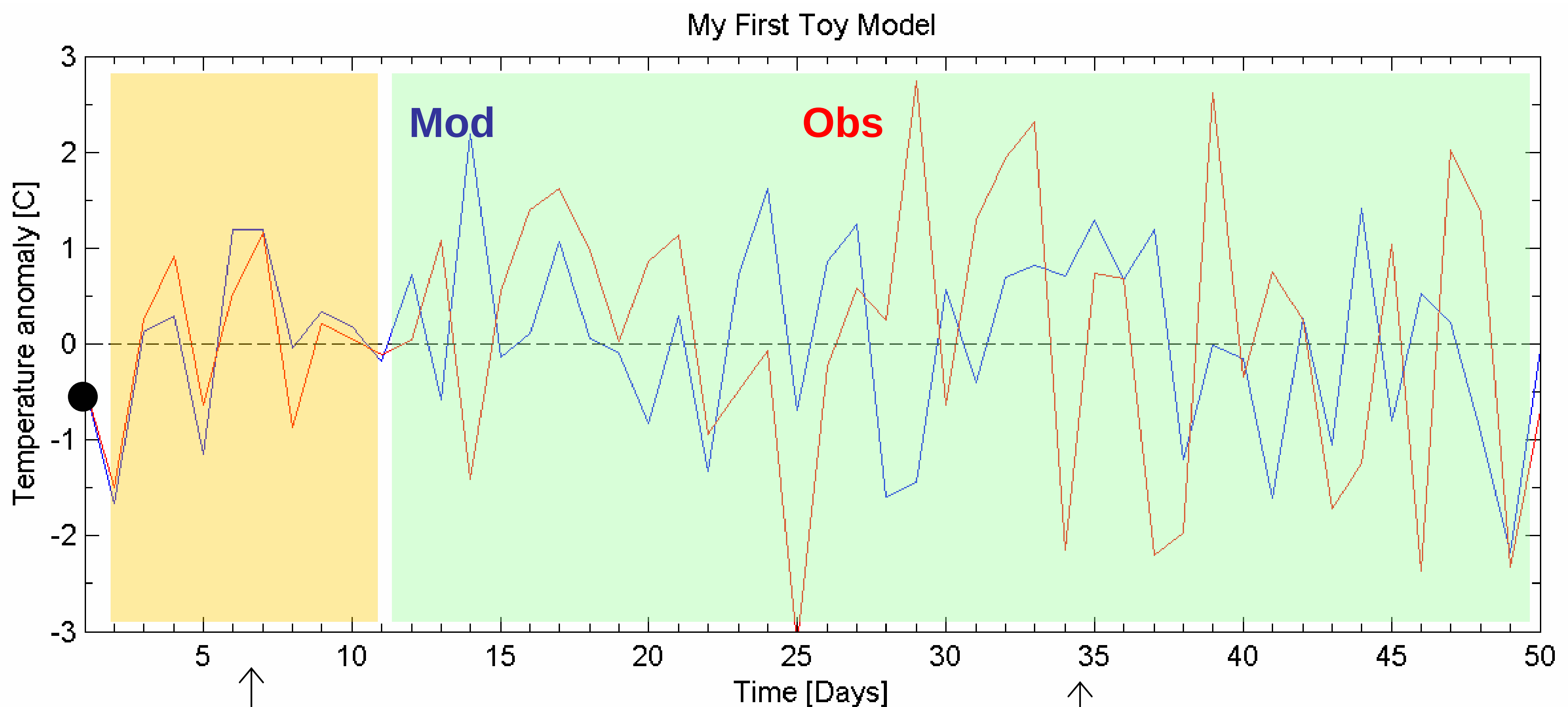
$$Y_{(t)} = C \cdot X_{(t-1)} \cdot Y_{(t-1)} + B \cdot Z_{(t)} + \varepsilon_y$$

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

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

To run the model, we need:

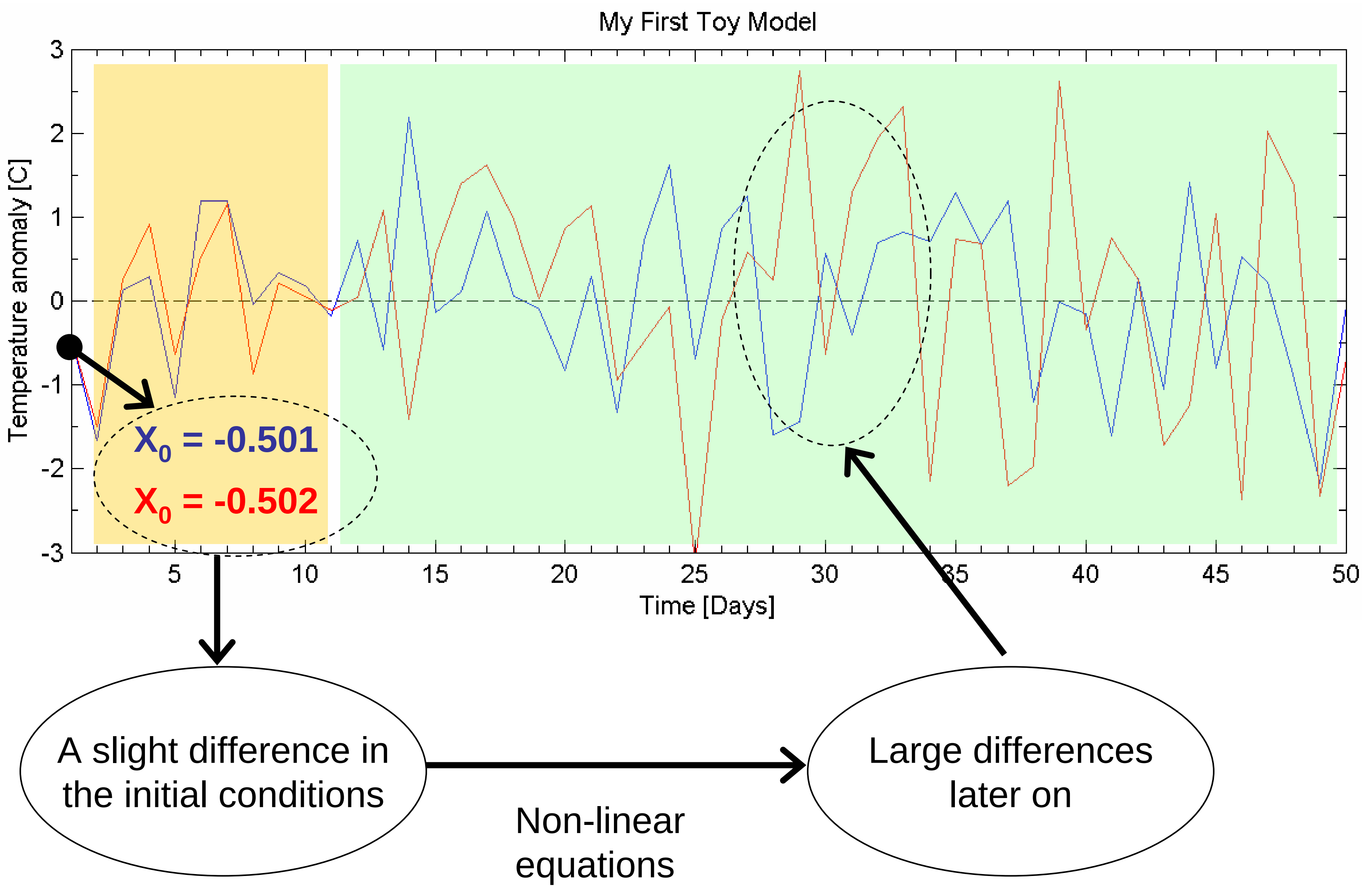
- Initial conditions: X_0, Y_0, Z_0
- The values of the External Parameters … <u>they can vary on time</u>
- A numerical algorithm to solve the equations
- A computer big enough



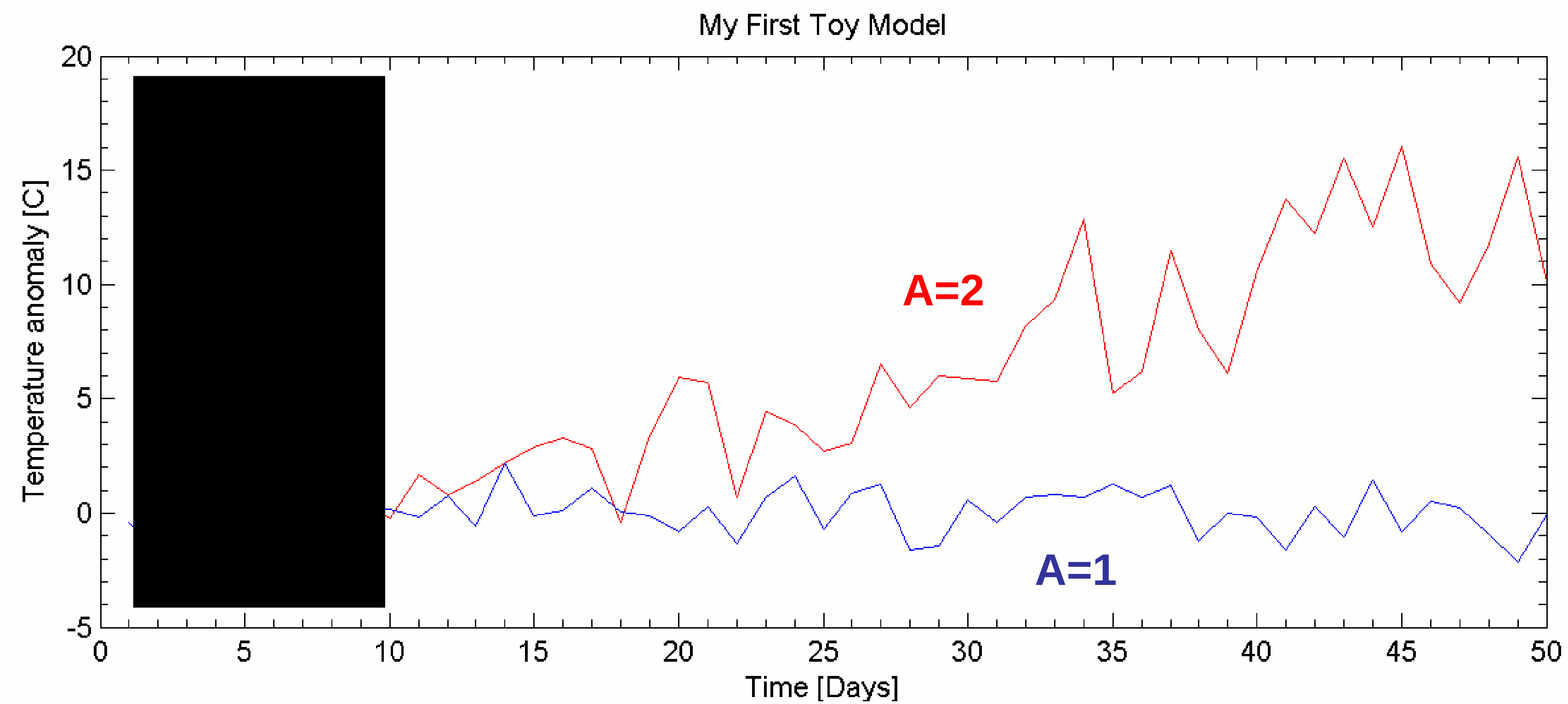
Weather forecast
Model predicts daily values

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

The Lorenz's (butterfly) chaos effect



Nevertheless, simulations after two-weeks are still "correct" in a climatic perspective and highly dependent upon external parameters $\rightarrow$ 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**

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.

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.

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

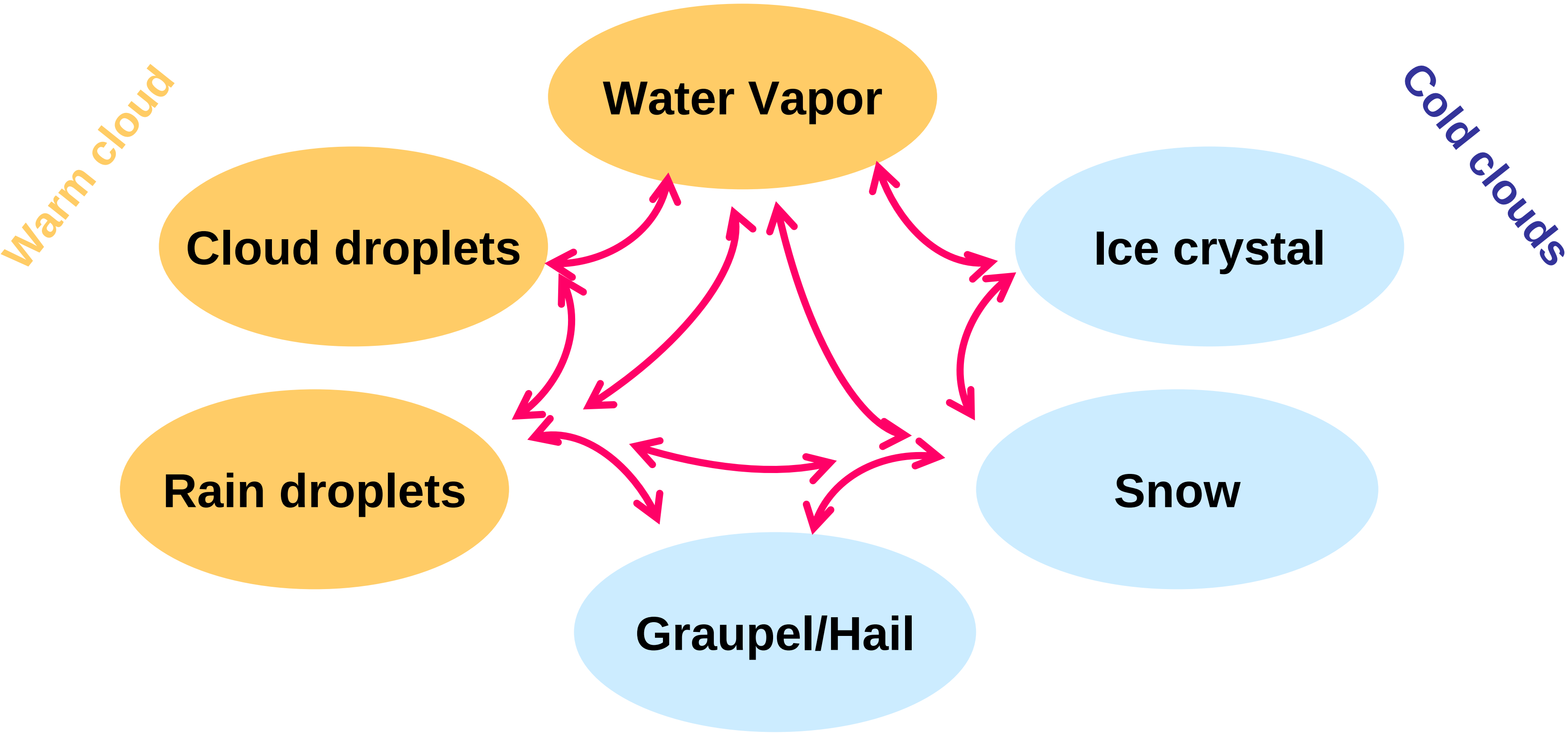
Idea gas law

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

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

Water substance eqns.

¿¿¿Where is precipitation???



$$\frac{dq_v}{dt} = -C + E_c + E_r$$

$$\frac{dq_c}{dt} = +C - E_c - A_c - K_c$$

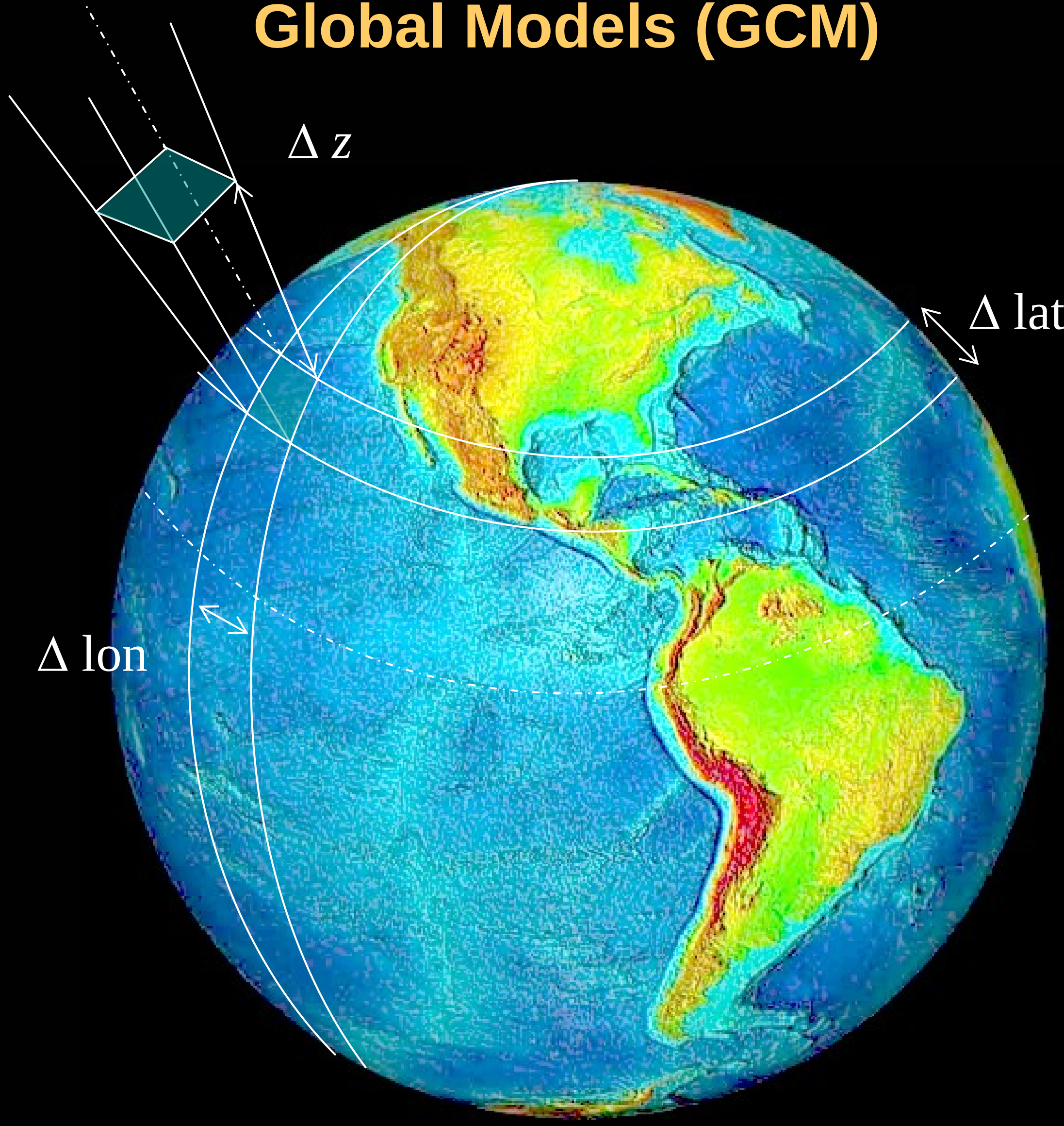
$$\frac{dq_r}{dt} = A_c + K_c - E_r - F_r \quad \rightarrow PP_s \propto F_r$$

Previous system is highly non-linear,
with no simple analytic solution

?!

…. We solve the system using numerical methods
applied upon a three-dimensional grid

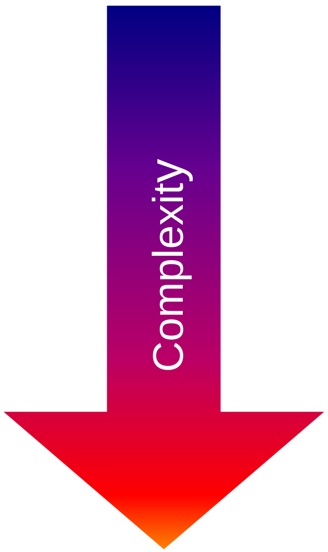
Global Models (GCM)



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

Top of atmosphere: 15-50 km

Global Models (GCM)

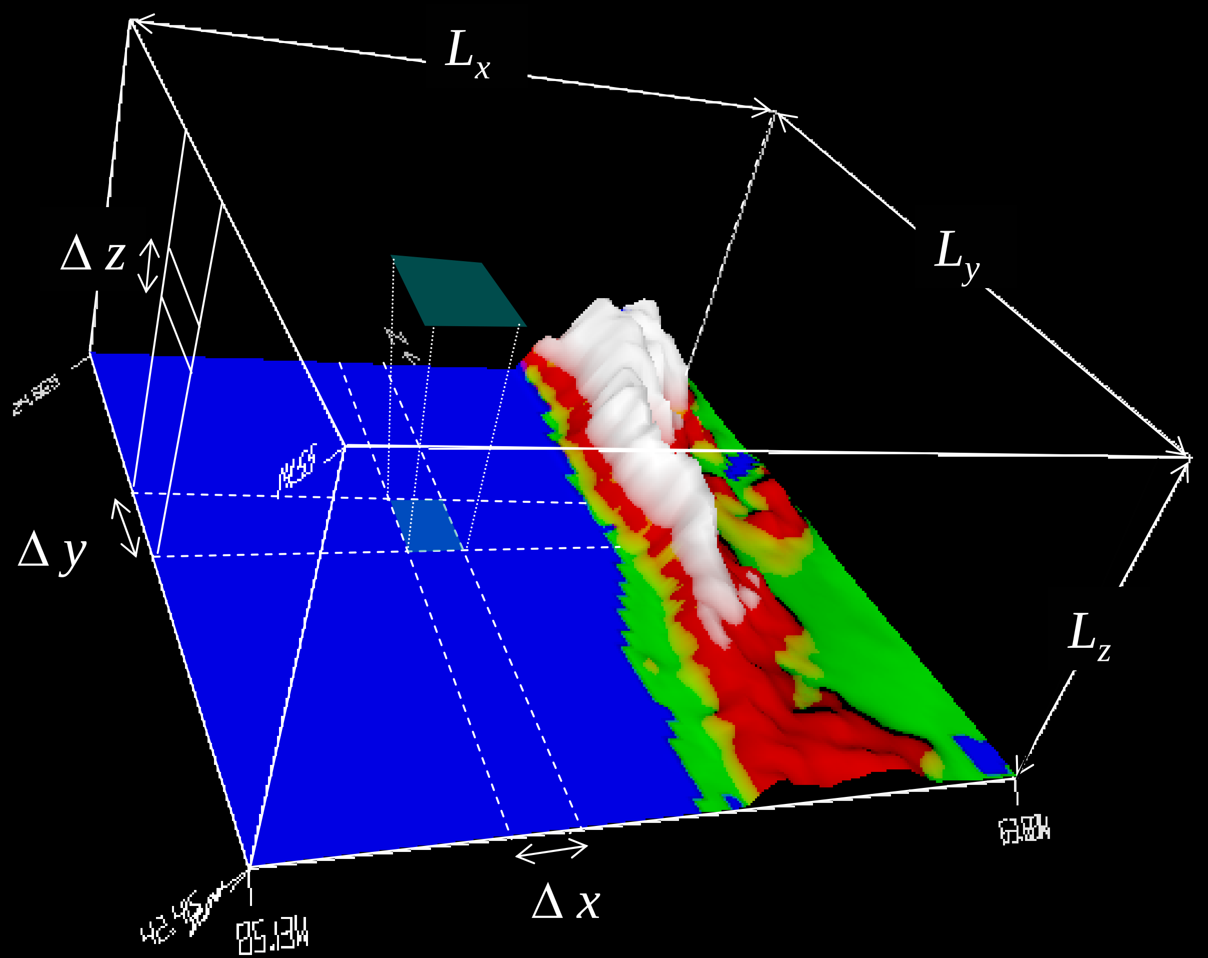


Type	SST	Sea Ice	Land Ice	Biosphere	Land use	
AGCM	P	P	P	P	P	1980-
CGCM	C	C	P/C	P/C	P	1990-
OGCM	C	C	P	P	P	
ESM	C	C	C	C	C	2005-

A: Atmospheric Only; C: Coupled; O: Ocean; ESM: Earth-system models

External parameters: GHG, O3, aerosols concentration; solar forcing

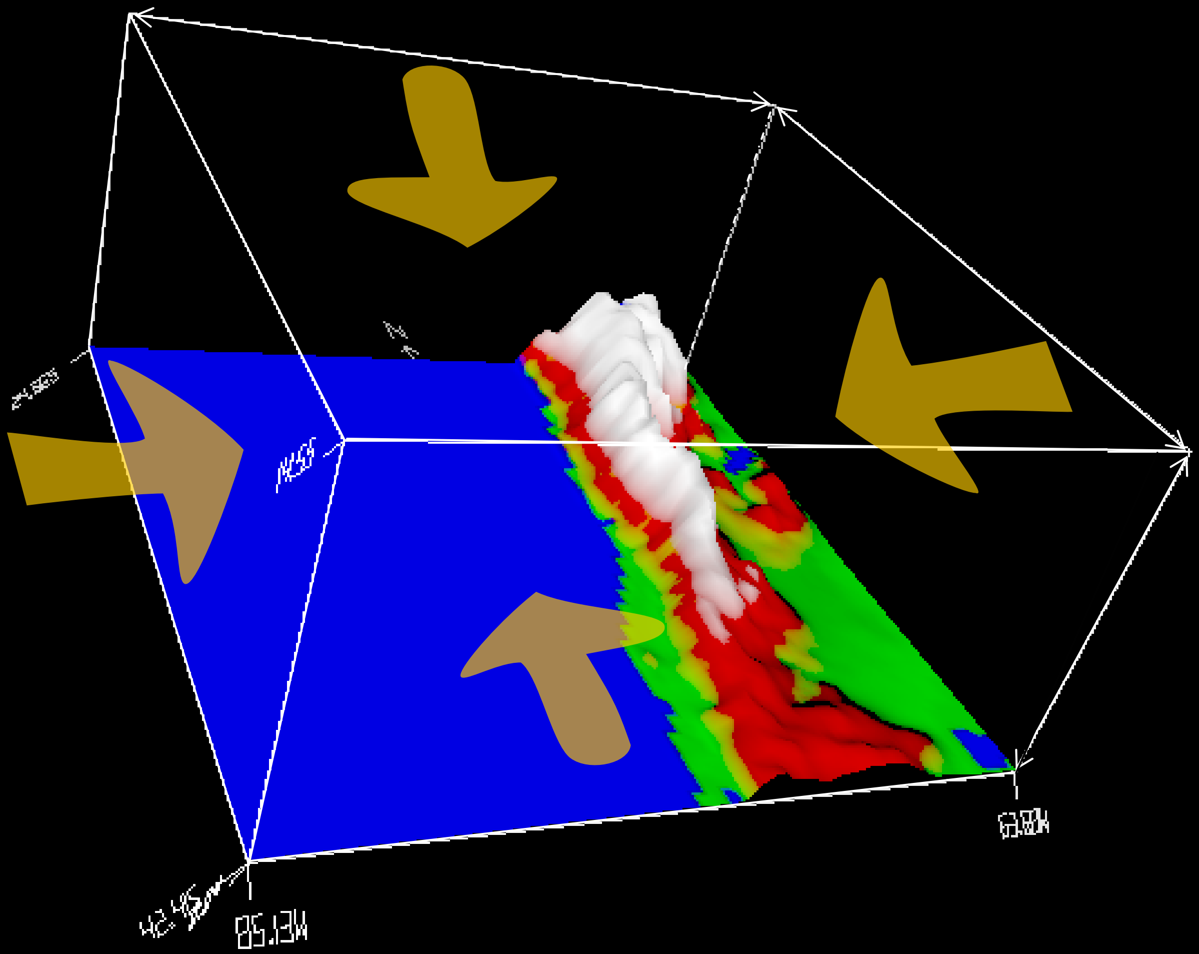
Regional Models (LAM, MM)



$\Delta x \sim \Delta y \sim$ 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

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

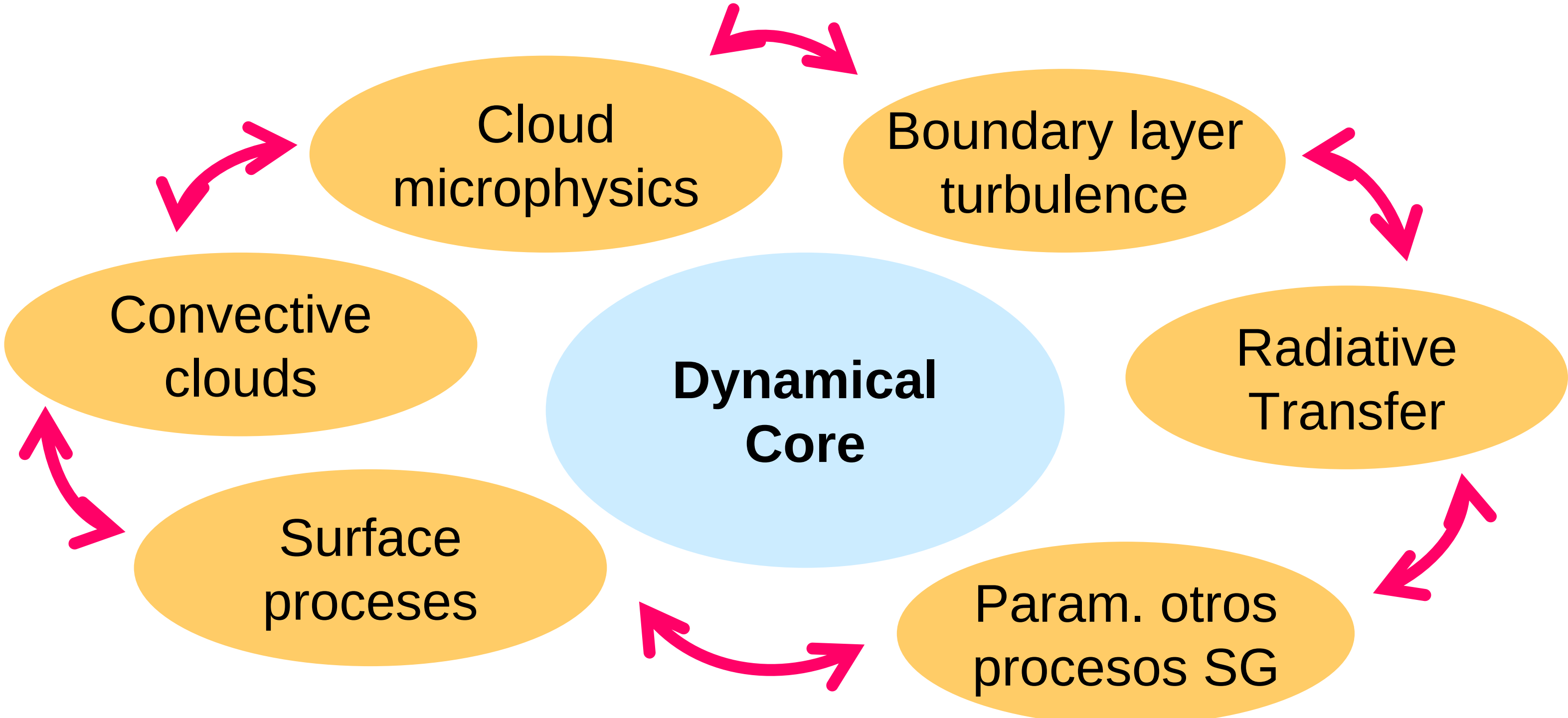
$$\frac{\partial T}{\partial t} + u\frac{\partial T}{\partial x} = Q_{diab}$$

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

Thus, a real atmospheric model has



For instance, MM5 (LAM) has 220 programs, 50 directories and 55.000 code lines F77...Ufff!