Estimation des incertitudes et construction de la confiance en modélisation du climat

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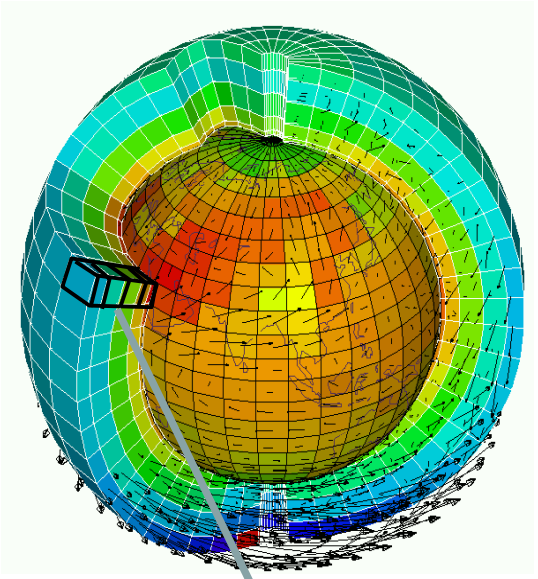
Outlook

I. Climate models

II. Climate change projections

III. Intercomparison of models

General circulation models (GCMs)



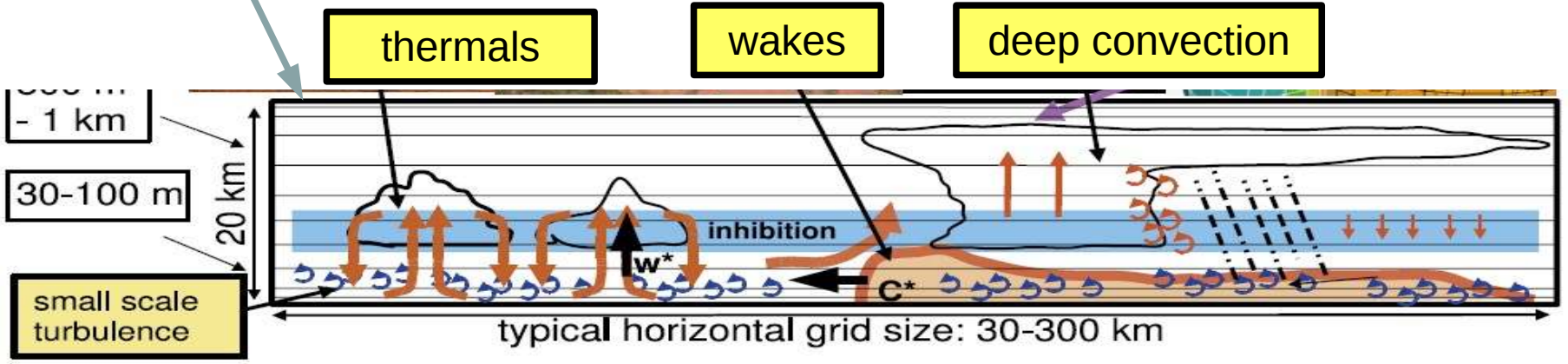
Dynamical core : discretized version of the equations of fluid mechanics

- Mass Conservation: $D\rho/Dt + \rho\, \mathrm{div}\underline{U} = 0$
- Energy Conservation: $D\theta / Dt = Q / Cp \ (p_0/p)^{\kappa}$
- Momentum Conservation

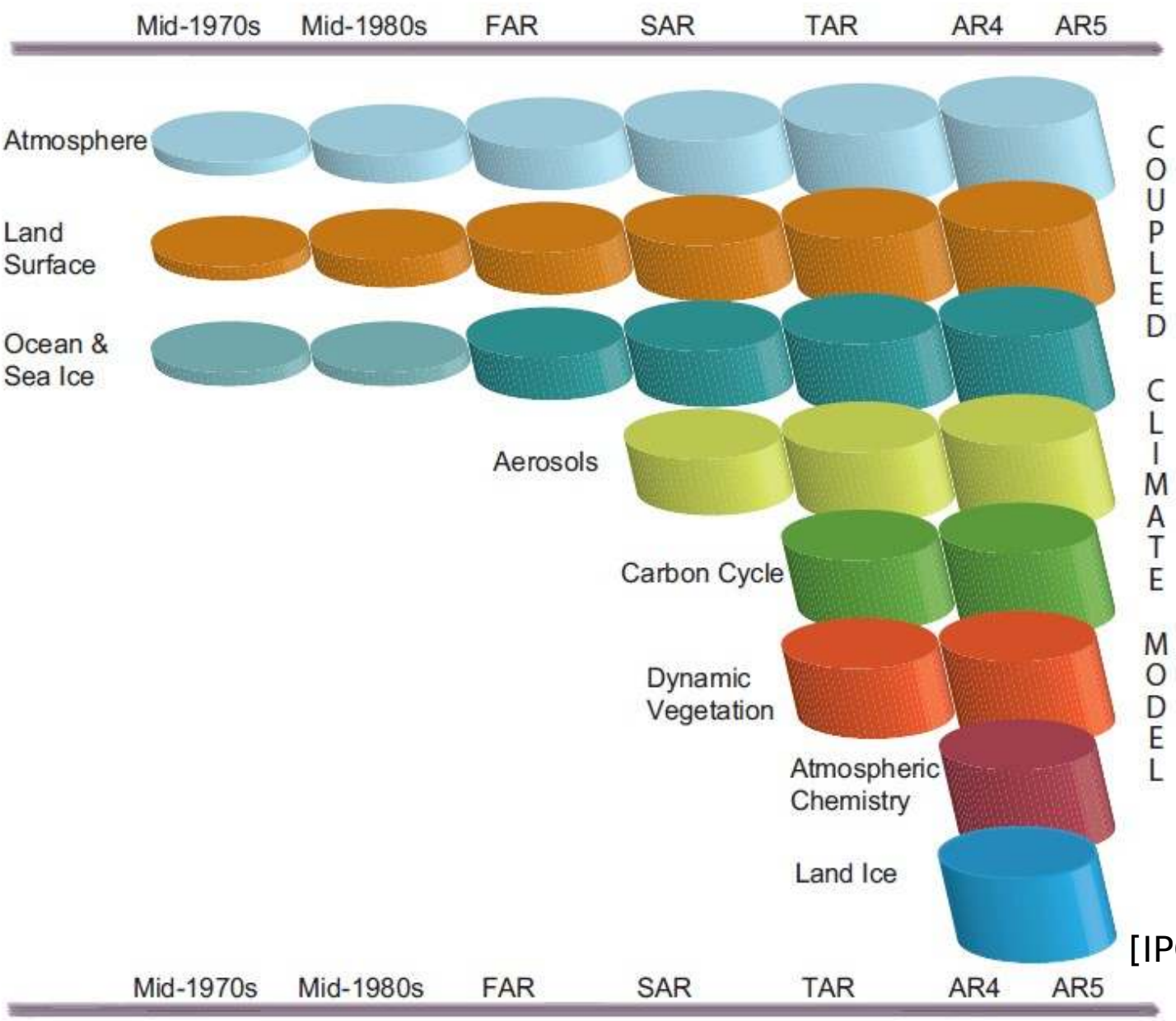
  $D\underline{U}/Dt + (1/\rho)\ \underline{\mathrm{grad}}p - \underline{g} + 2\ \underline{\Omega}\ \hat{}\underline{U} = \underline{F}$
- Conservation of Water (and other species): $Dq/Dt = S_q$

In red, source terms : other than fluid mechanics and unresolved scales

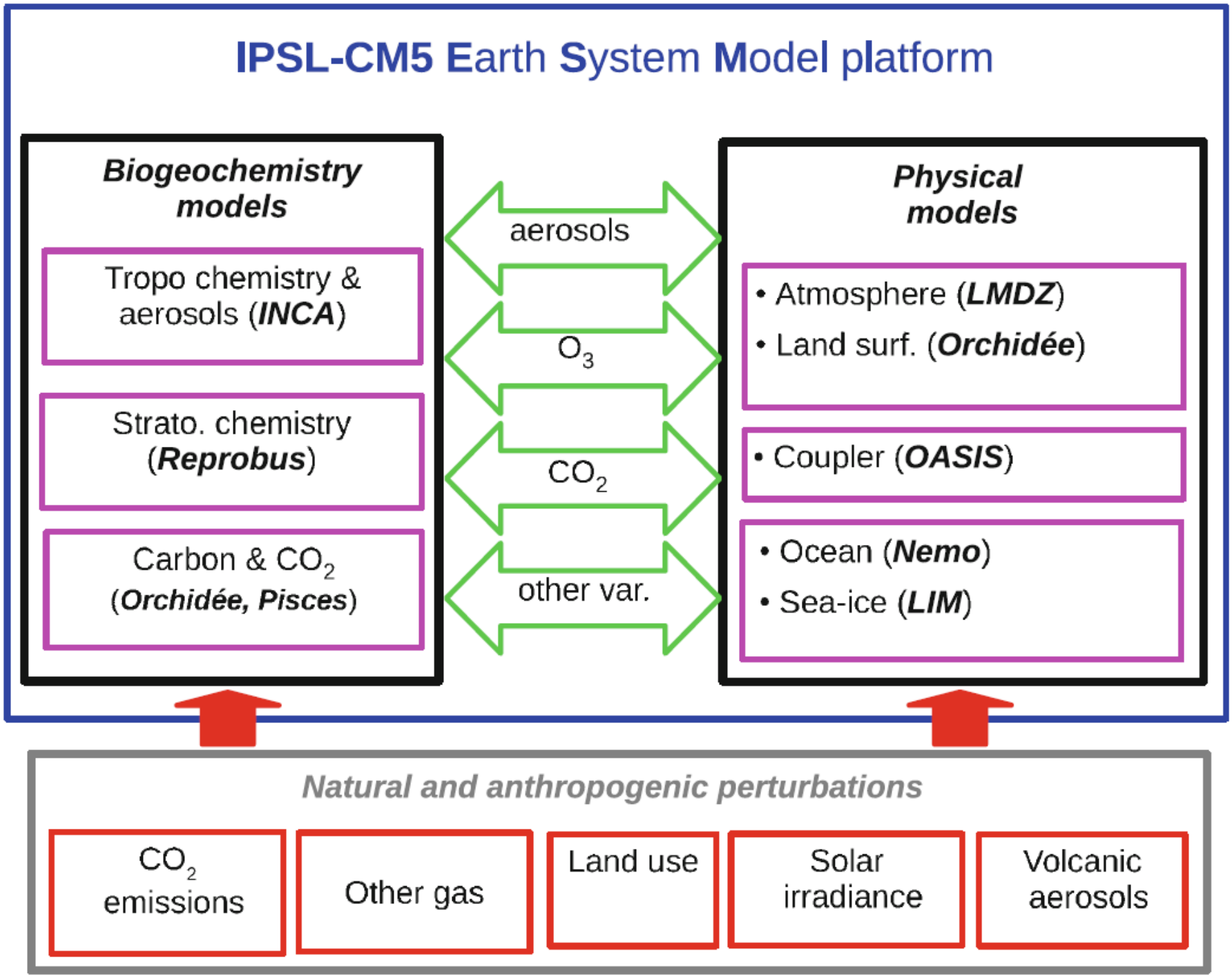
=> sub-grid models (parameterizations)



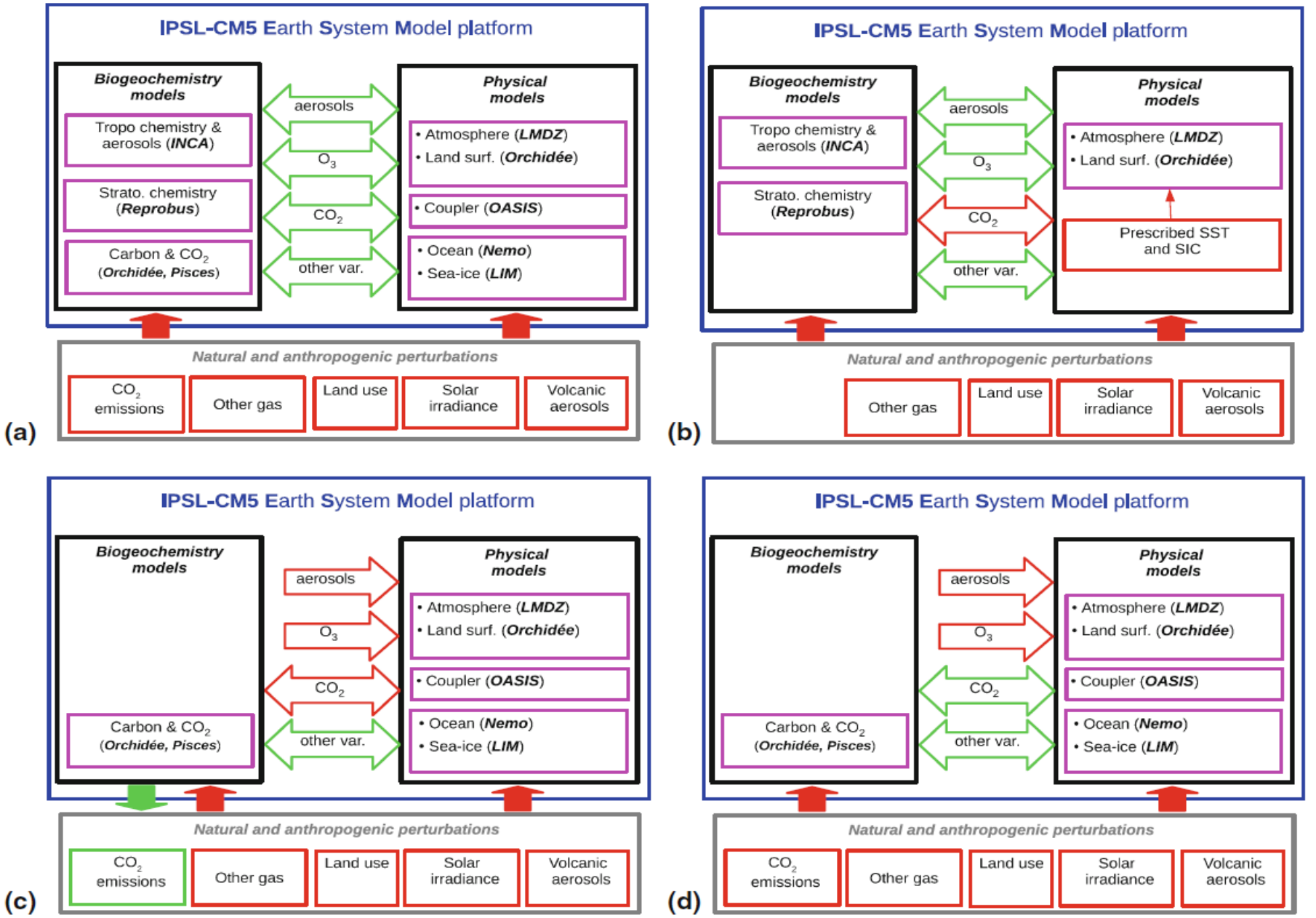
Evolution of climate models



[IPCC, AR5]


IPSL-CM5 Earth System Model platform
Biogeochemistry models
Tropo chemistry & aerosols (INCA)
Strato. chemistry (Reprobus)
Carbon & CO2 (Orchidée, Pisces)
aerosols
O3
CO2
other var.
Physical models
• Atmosphere (LMDZ)
• Land surf. (Orchidée)
• Coupler (OASIS)
• Ocean (Nemo)
• Sea-ice (LIM)
Natural and anthropogenic perturbations
CO2 emissions
Other gas
Land use
Solar irradiance
Volcanic aerosols

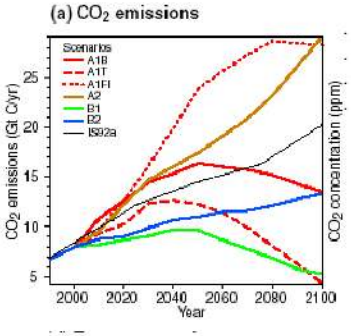
More than a model, a model family

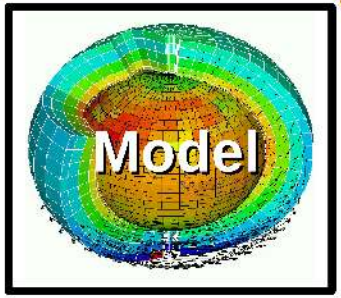


Climate simulations

Initial conditions
Temperature
water vapour
salinity
all over the globe

Boundary conditions (forcings)
Ex: insolation
Greenhouse gases

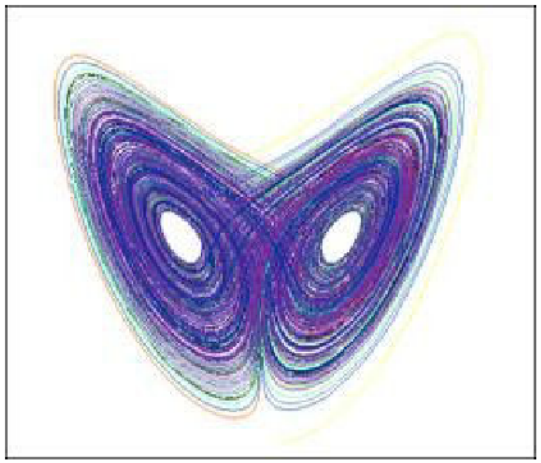


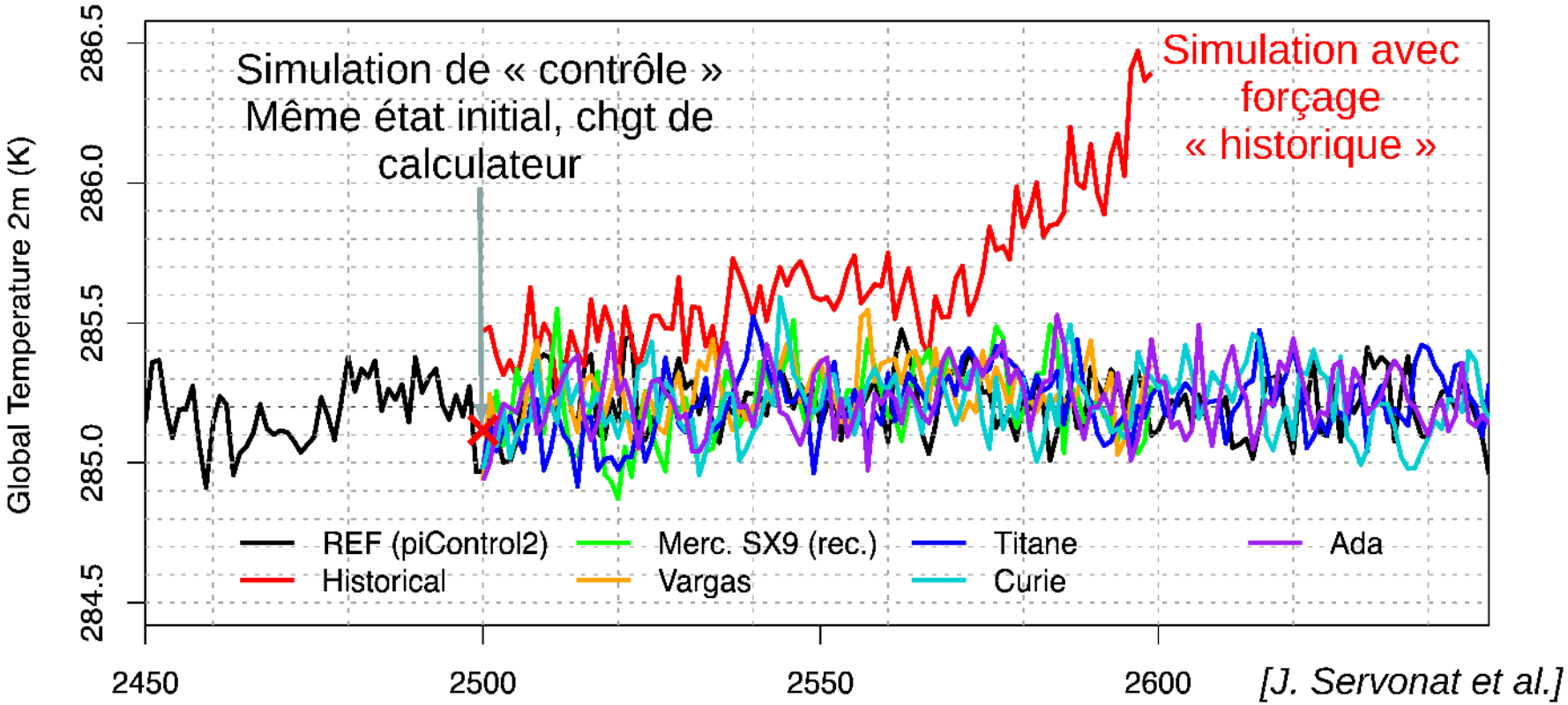


Results
Temperature
water vapour
salinity

Statistical analysis

Sensibilité à l'état initial... ou au calculateur.



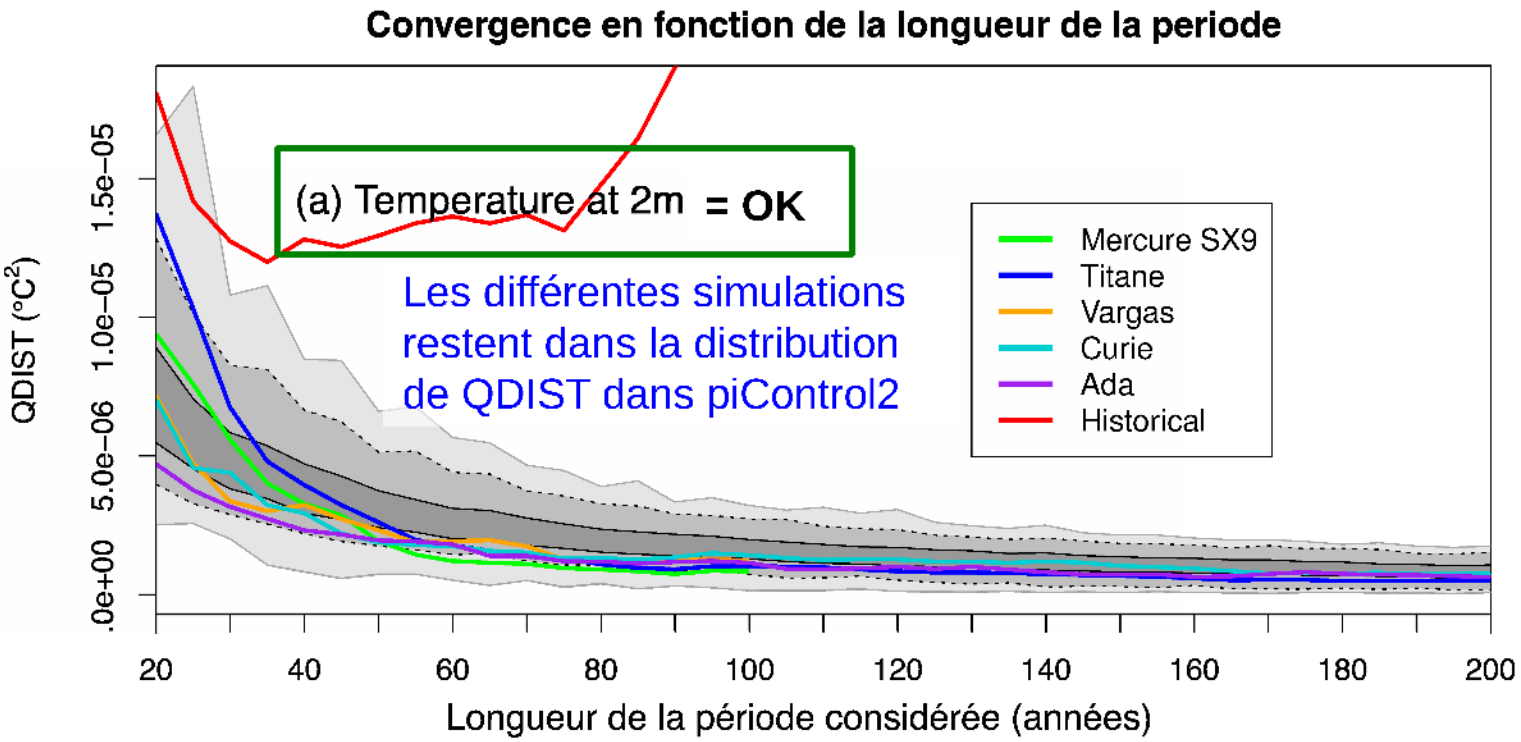


[J. Servonat et al.]

Les climats sont-ils identiques? Convergences des valeures moyennes?

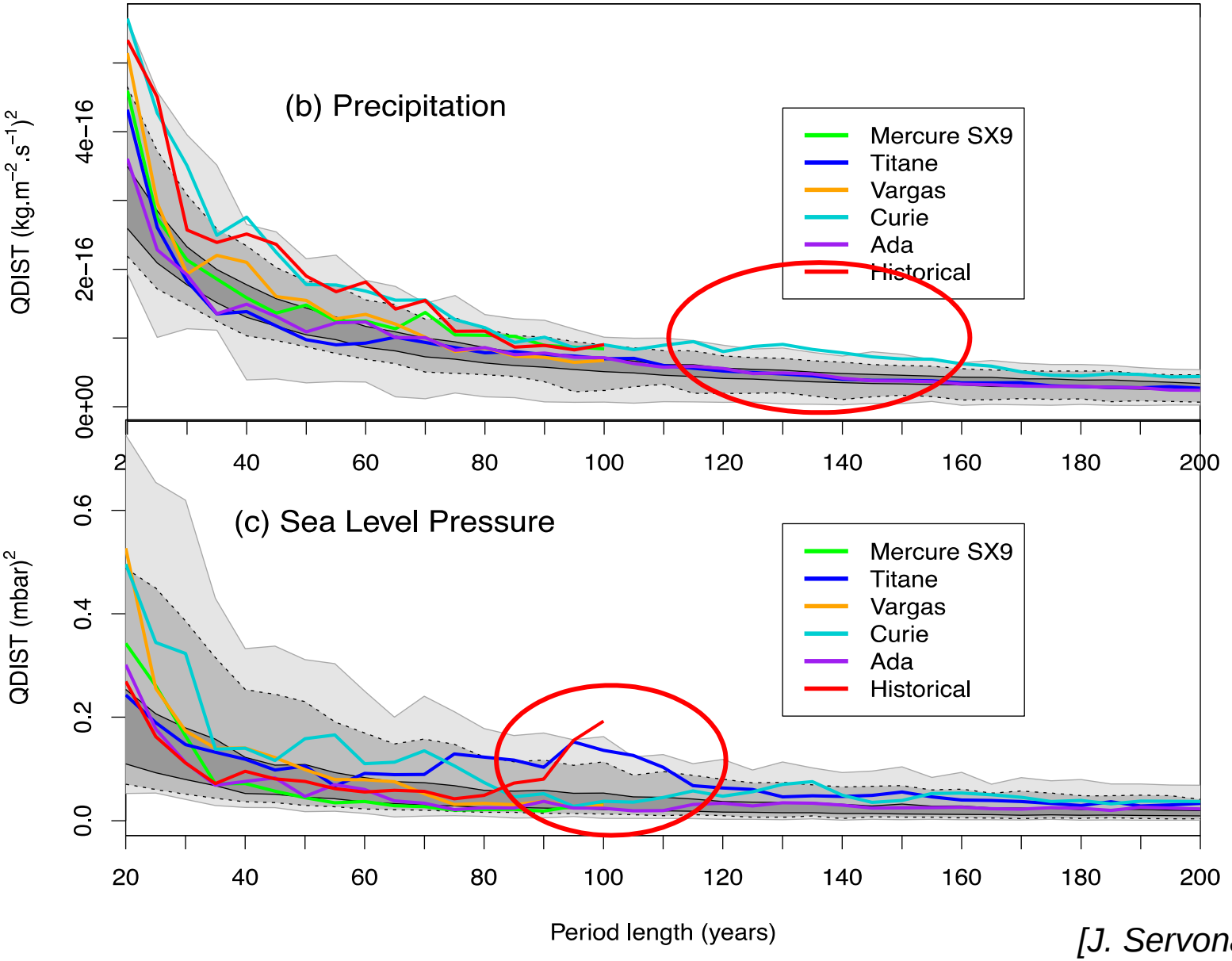
$$QDIST(T, calc) = \sum_{i}^{N} \left(w_i \times \left[X_{T,calc}(i) - X_{T,piControl2}(i) \right]^2 \right)$$

période



[J. Servonat et al.]

Convergences des valeures moyennes?



[J. Servonat et al.]

Ajustement des paramètres

Modélisation des phénomènes sous-maille :

•Comporte des paramètres « agrégés » ou empiriques

•Certains ont un effet global important

Modèles climatiques :

•Aucun rappel aux observations

•Bilan d'énergie doit être nul pour un climat « préindustriel »

Il y a une phase d'ajustement des paramètres (« tuning »)

• Jusqu'à présent essentiellement empiriques

• Minimisation de critères ? (risques de sur-ajustement)

• Suppression des valeurs conduisant à des comportement « non phyisque », recherche de paramètres acceptable « history matching » (Williamson et al., 2013, 2015)

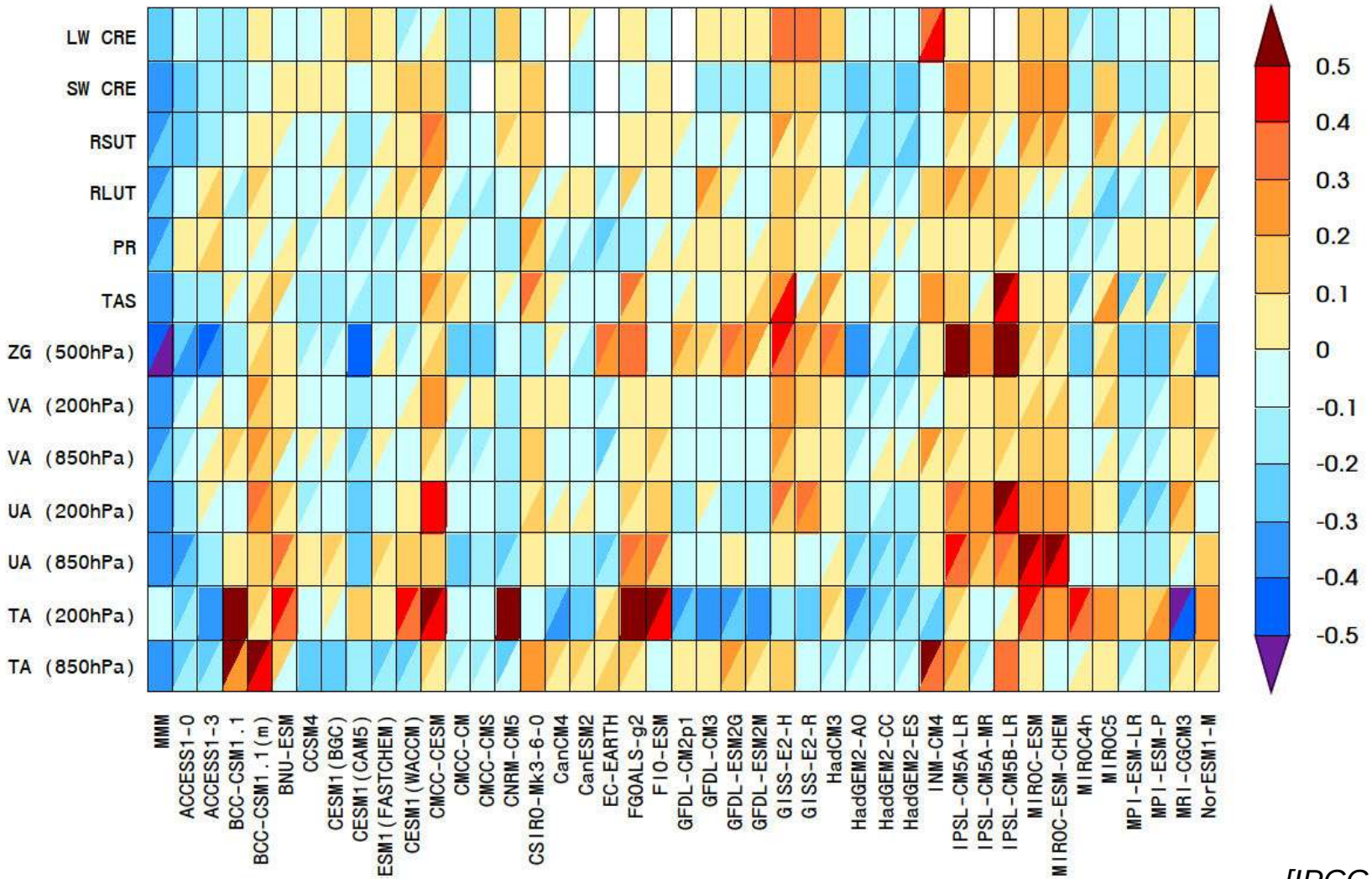
Quelle information utiliser lors de cet ajustement ?

• Réchauffement observé au 20^{e} siècle ?

•Sensibilité climatique ?

Ajustement des paramètres

Emergence et importance croissante des « metriques »



[IPCC, AR5]

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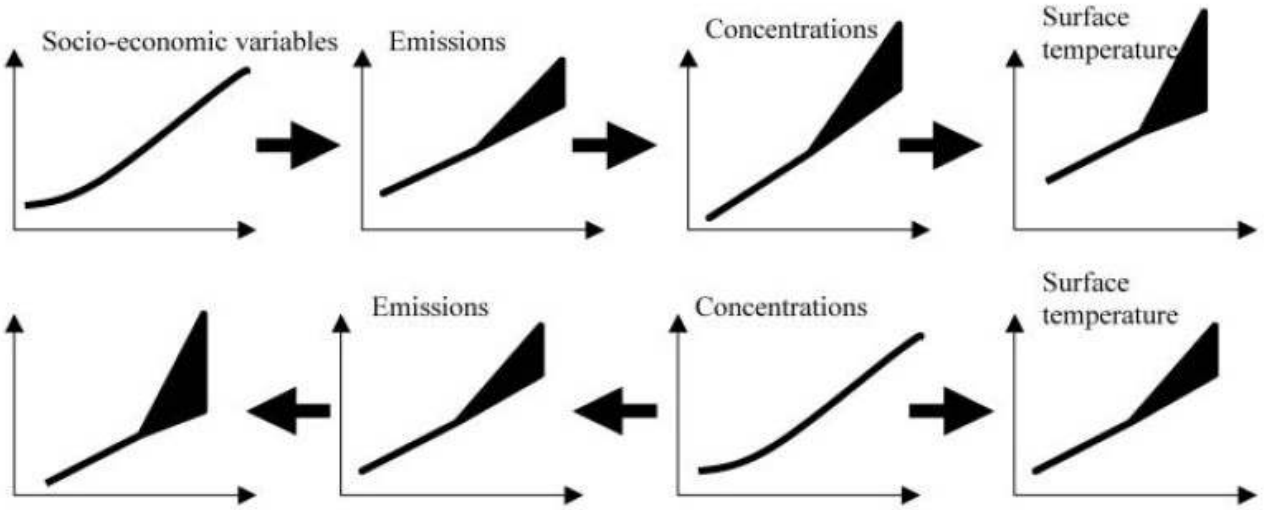
Scenario for future climate change projections

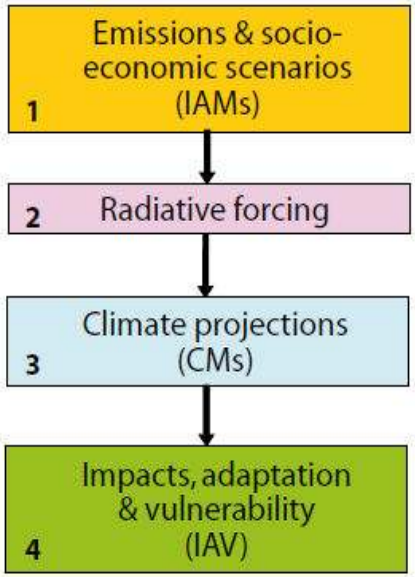
SRES

RCP

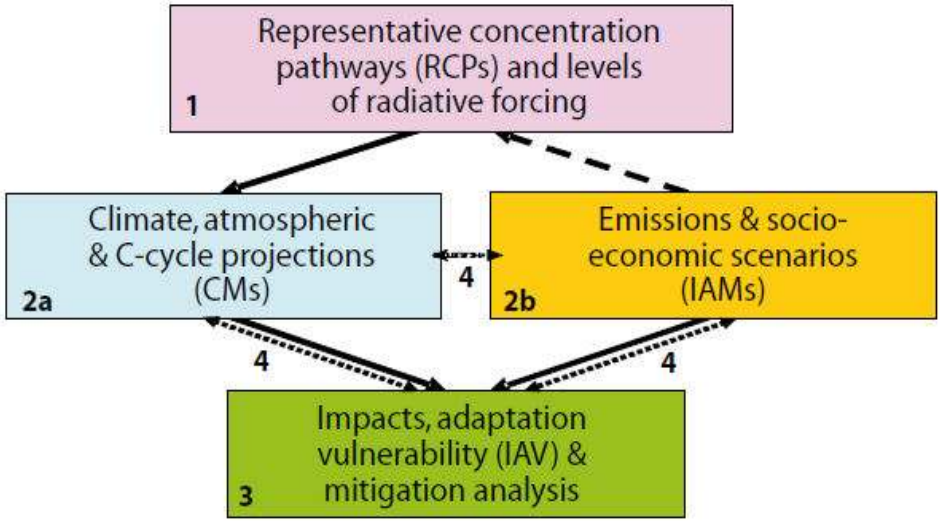


[Hibbard et al., EOS, 2007]

SRES **a) Sequential approach**



RCP **b) Parallel approach**

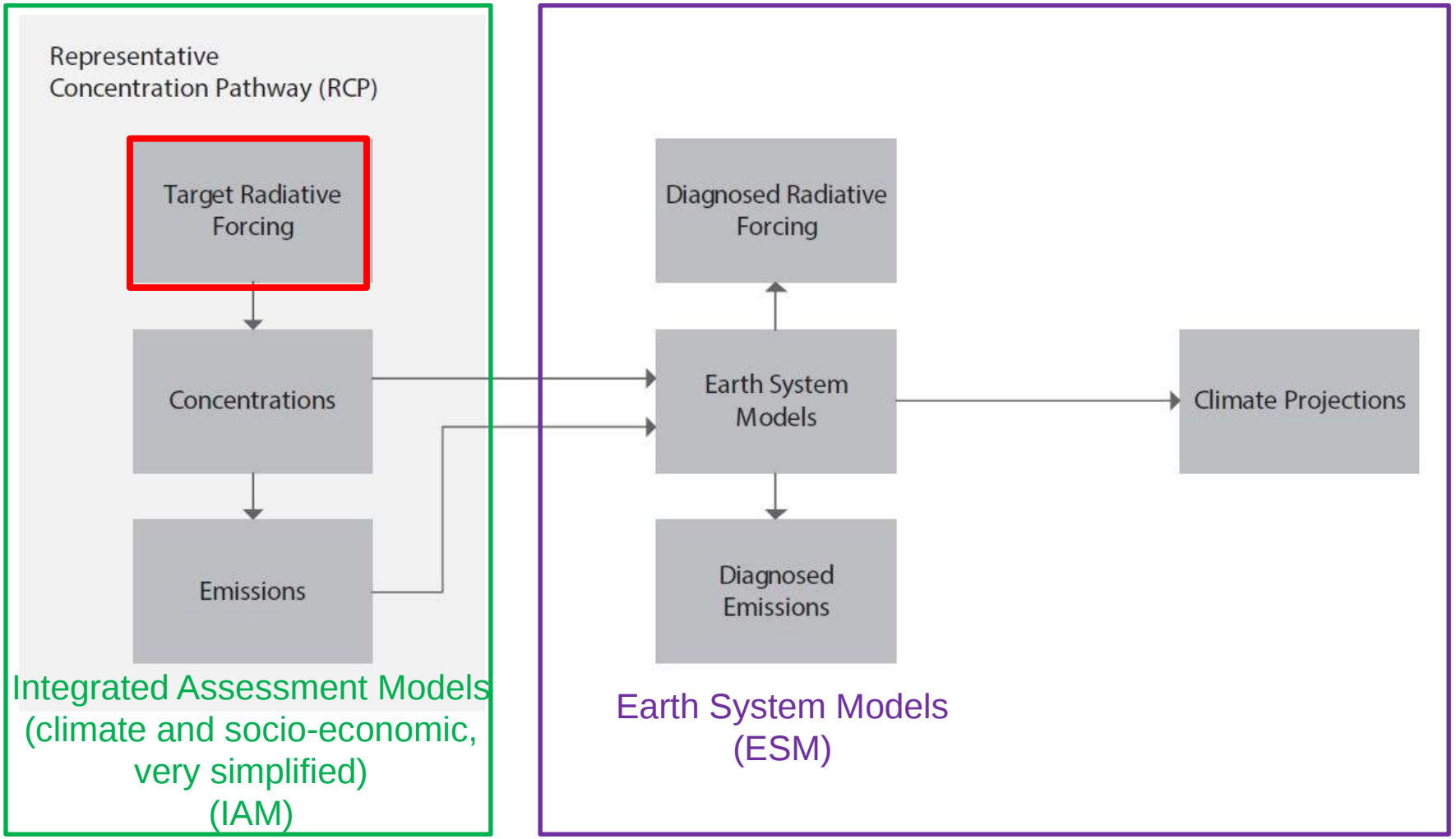


[Moss et al., IPCC, 2008]

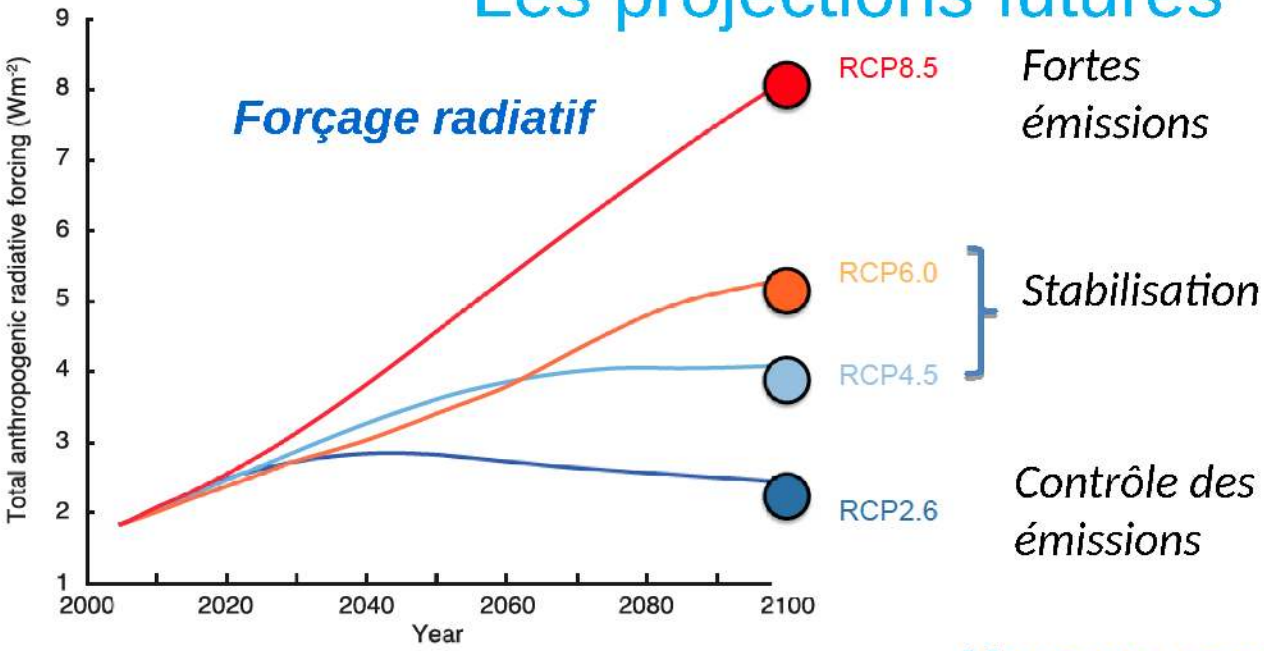
Scenarios for future projections

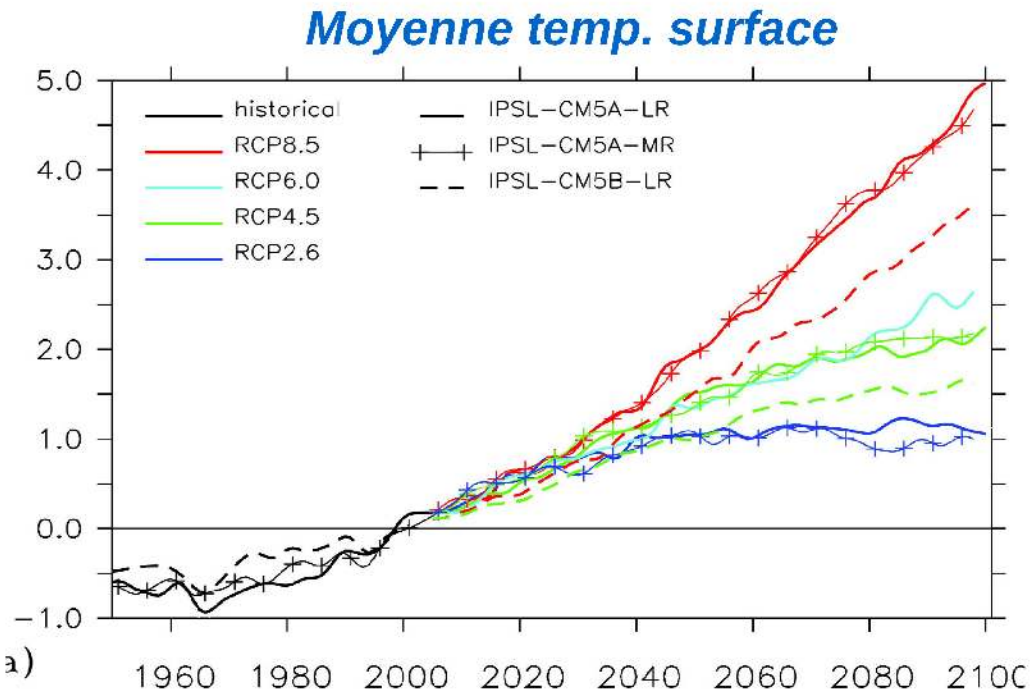
Scenarios are defined with a target value of the ***radiative forcing (W.m^{-2})***

RCP : « Representative concentration pathways »



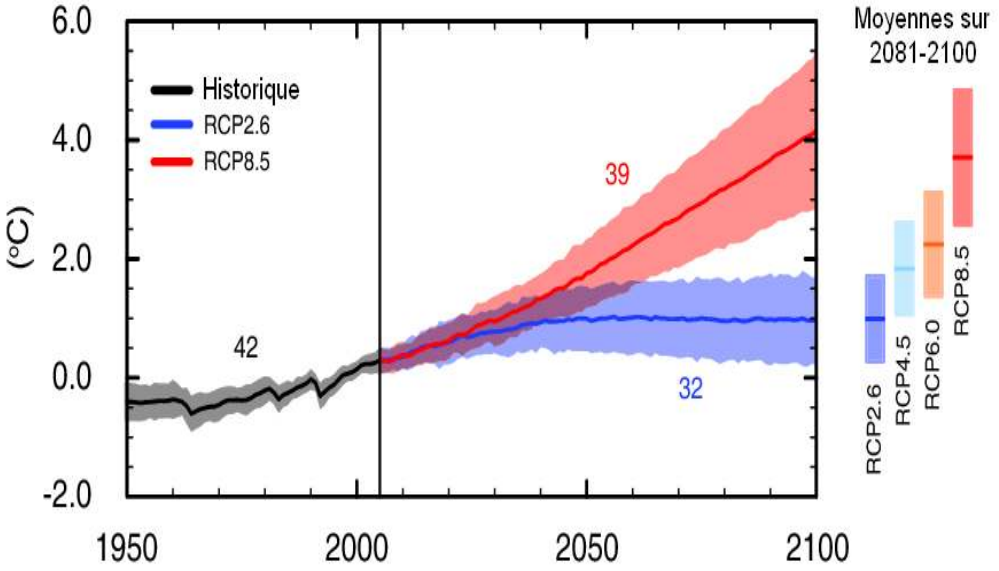
Les projections futures



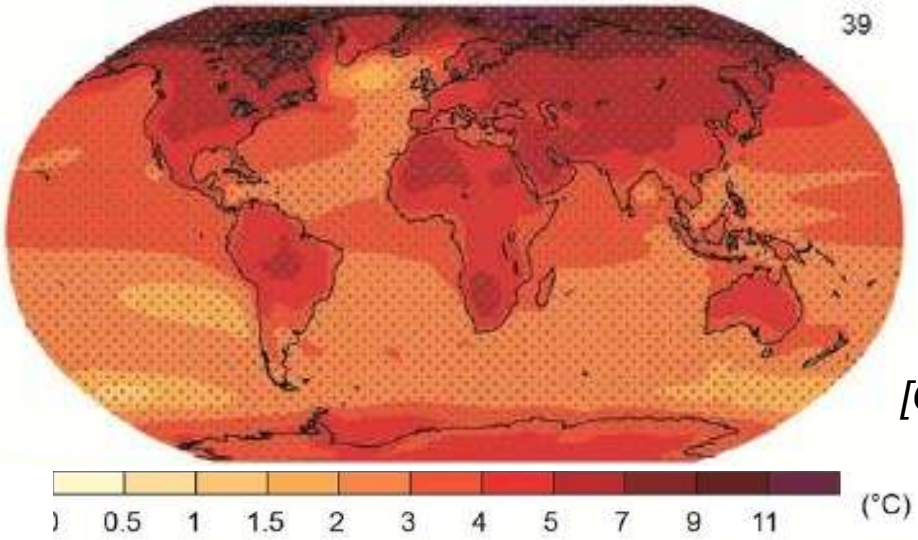


Température de surface

Moyenne globale
1950 à 2100
(40 modèles CMIP5)



En 2100,
scénario RCP8.5
(39 modèles CMIP5)



[GIEC, 2013]

Variability and response to forcings.

Climate variations have different origins:

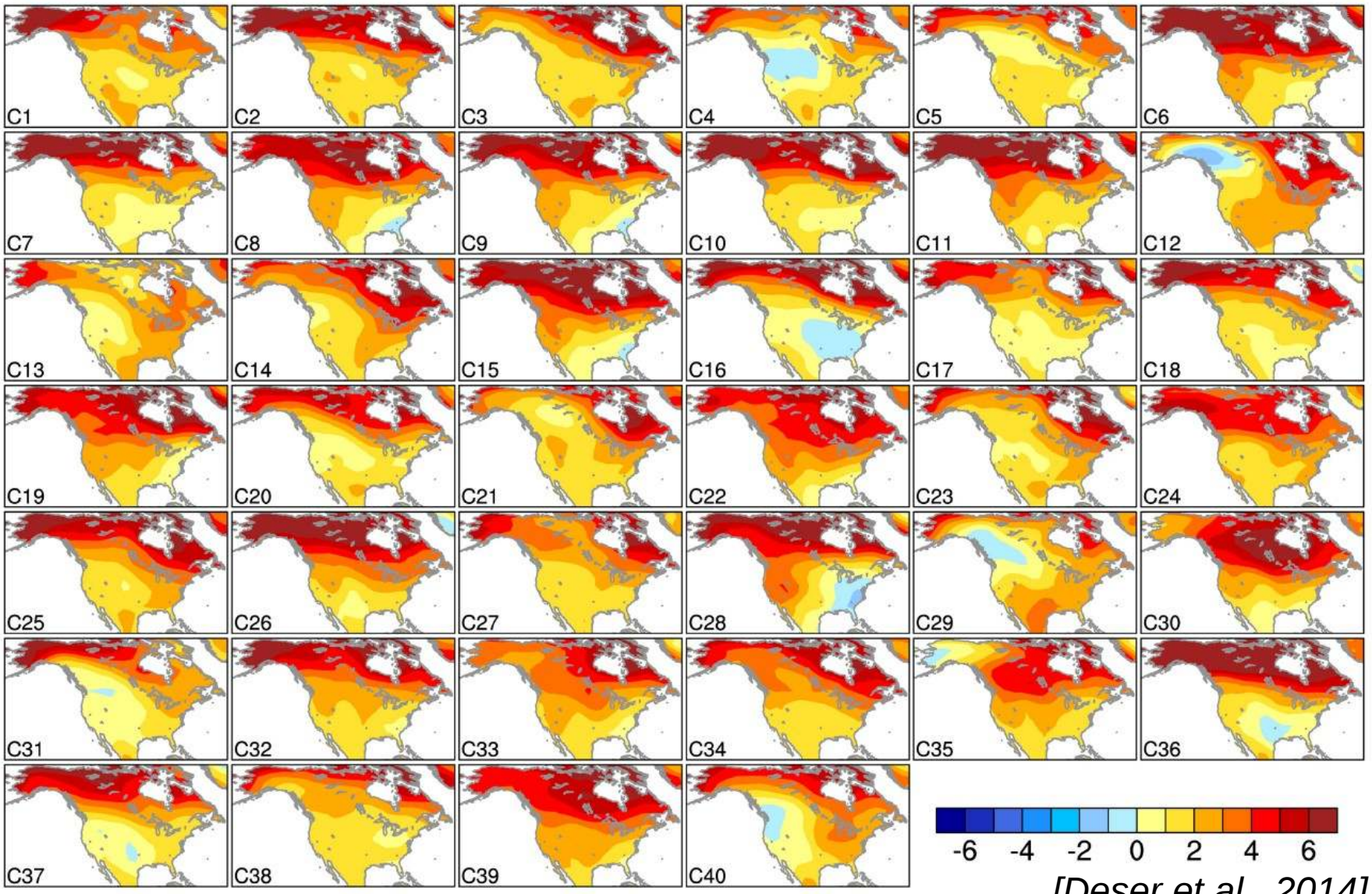
$$\underbrace{\Delta T}_{\text{variation}} \approx \underbrace{\Delta T_{int}}_{\text{internal variability}} + \underbrace{\frac{\partial T}{\partial Q}\Delta Q_{nat}}_{\text{response to natural forcings}} + \underbrace{\frac{\partial T}{\partial Q}\Delta Q_{ant}}_{\text{response to anthropogenic forcings}}$$

$$\underbrace{\qquad\qquad\qquad\qquad}_{\text{natural variability}}$$

- Difference between simulations includes all these terms
- Their relative difference depends on time average and on the amplitude of the forcings
- All these terms may differ among models

Changement climatique et variabilité naturelle

Tendance sur 50 ans de la température hivernale (°C/50 ans)



[Deser et al., 2014]

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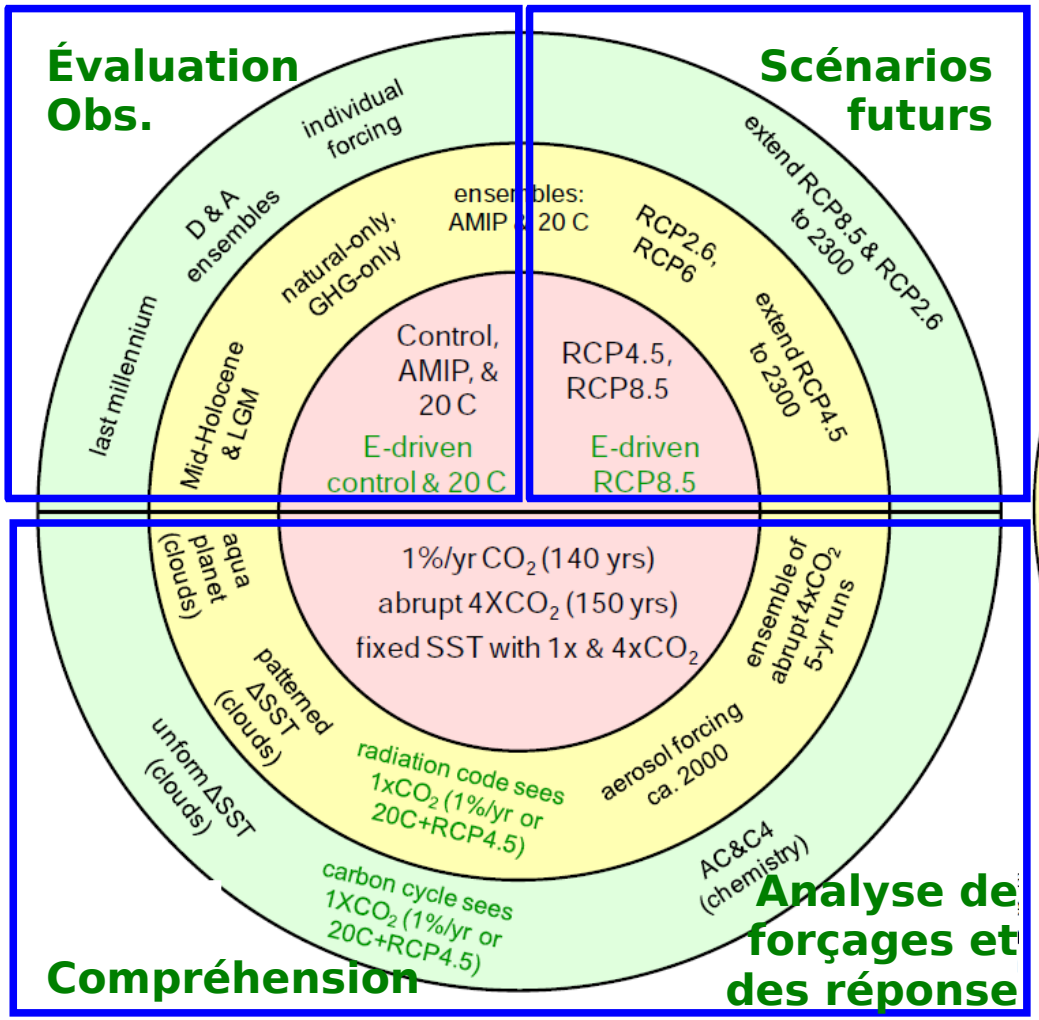
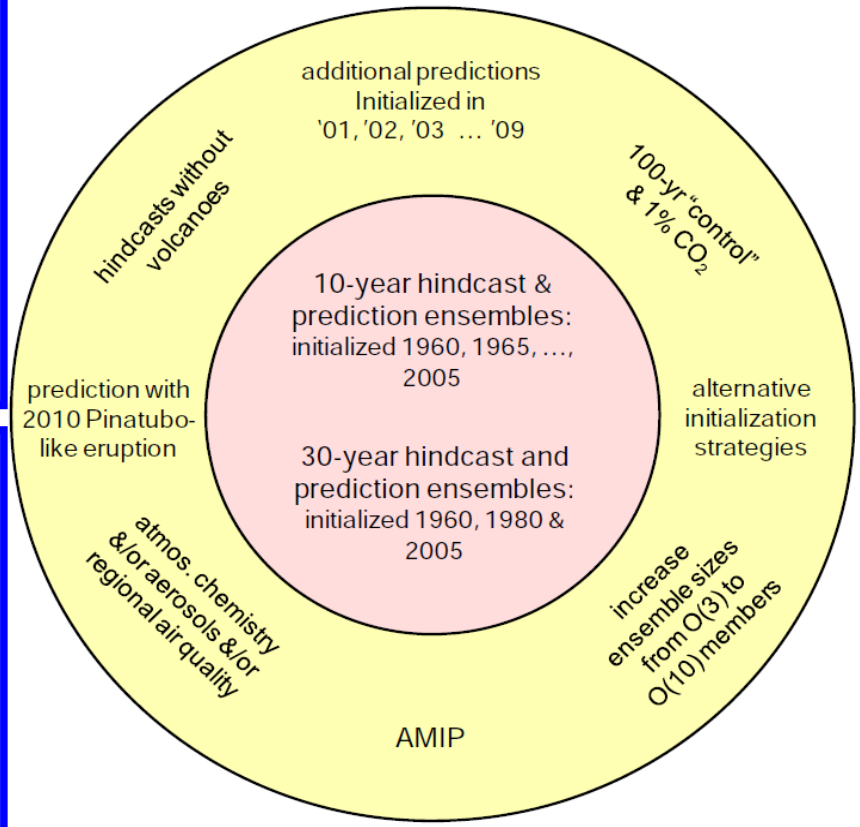
Simulations proposées par CMIP-5

Long terme (centennal)



Court terme (décennal)

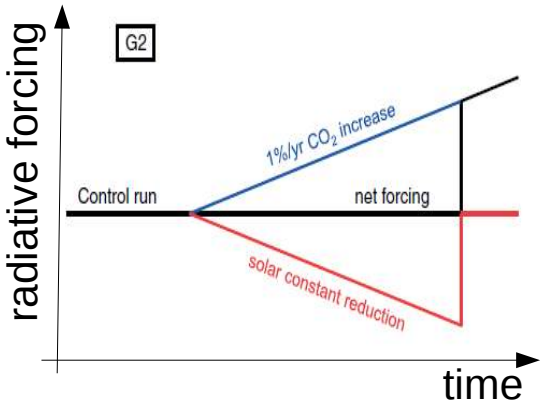


[Taylor et al., 2012]

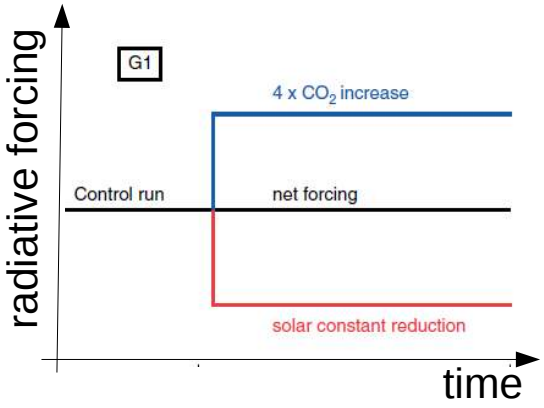
Future projections

Idealized experiments:

- Understanding climate response
- Quantified climate sensitivity
- Idealized tests



•CO2 concentration increase 1%/year
•Instantaneous quadrupling of CO2 concentration
•Idealized geoengineering: decrease solar constant
•Ocean surface temperature increase by +4°C



Scenarios. Their roles:

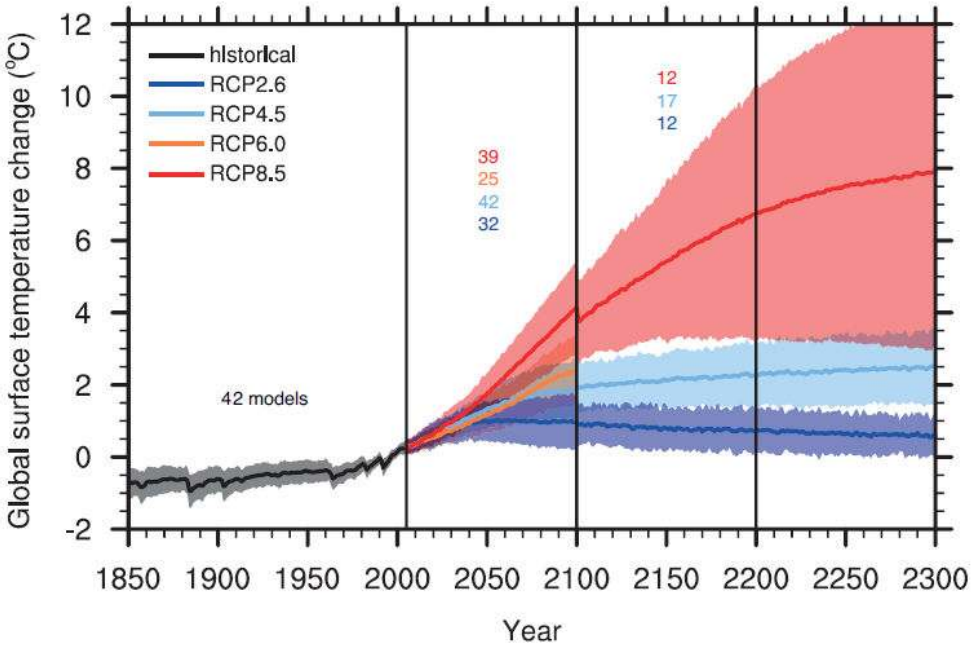
- Represent realistic possible futures?
- Explore contrasted hypothesis of possible futures?
- Train simplified models (climate emulators)?
- Understanding climate responses?

Currently, it is mainly the two first points that are addressed

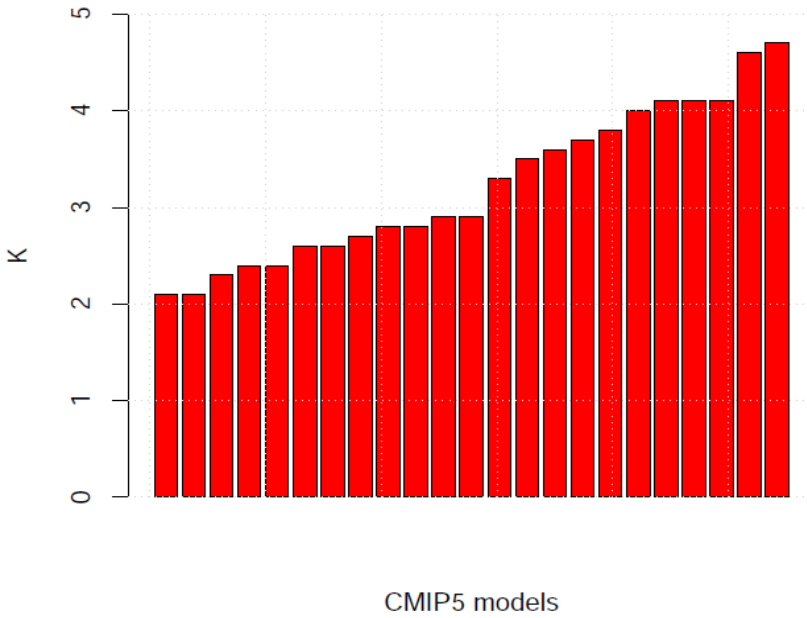
Amplitude du réchauffement
Sensibilité climatique

Accroissement de la moyenne des températures de surface

Pour des scénarios « réalistes »



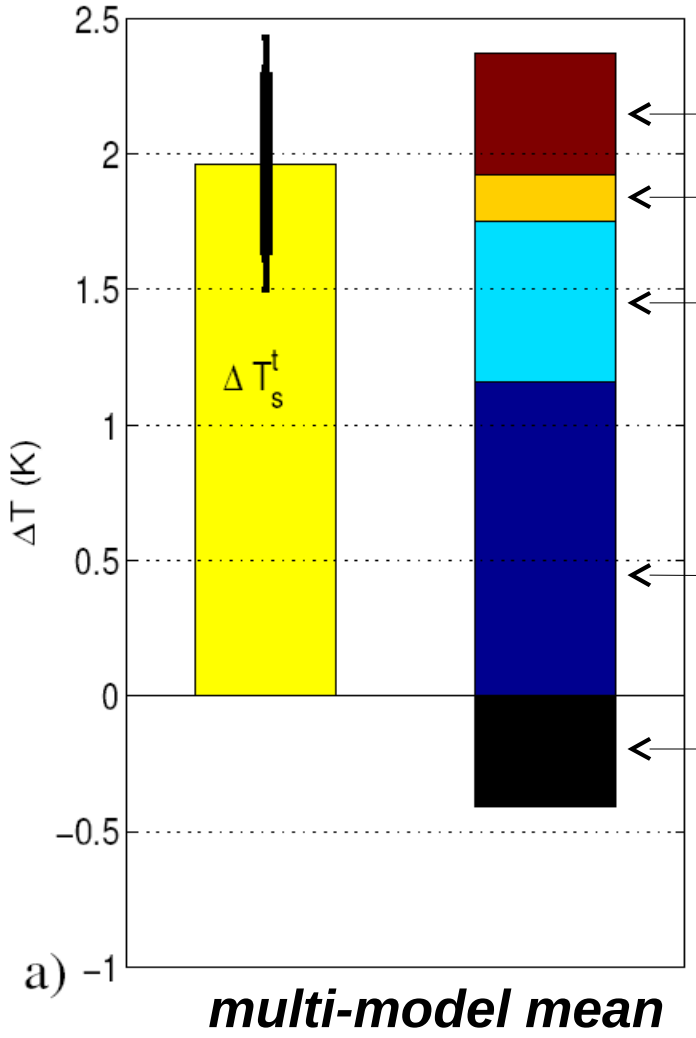
Pour un doublement de CO_2



[GIEC, 2013]

Transient temperature response to a CO_2 doubling

(CO_2 increase 1%/year, 70 years)



multi-model mean

Climate feedbacks: Indirect response to the forcing

- clouds
- snow and ice (surface albedo)
- water vapor

Direct response to the forcing

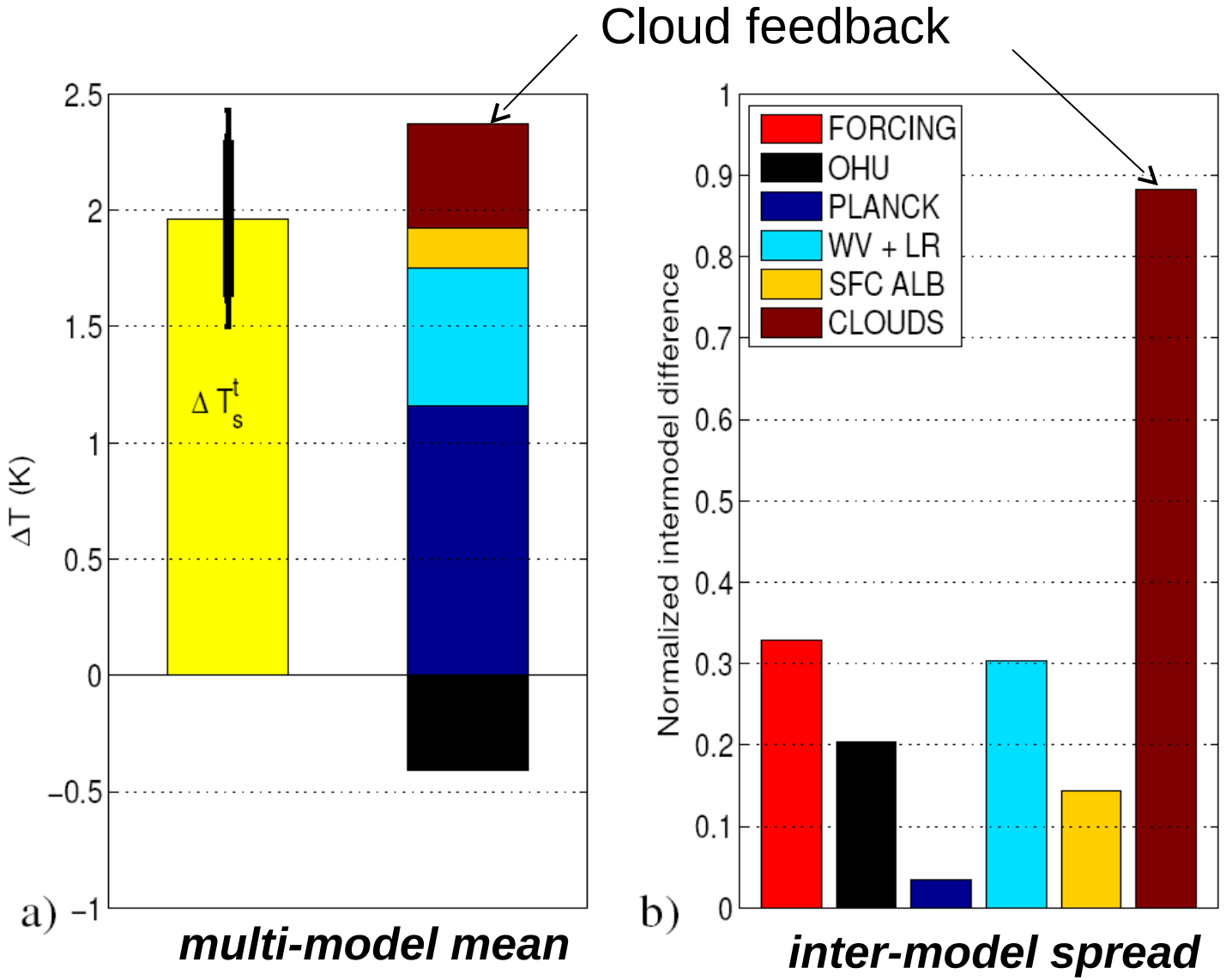
- Planck response

- ocean heat uptake

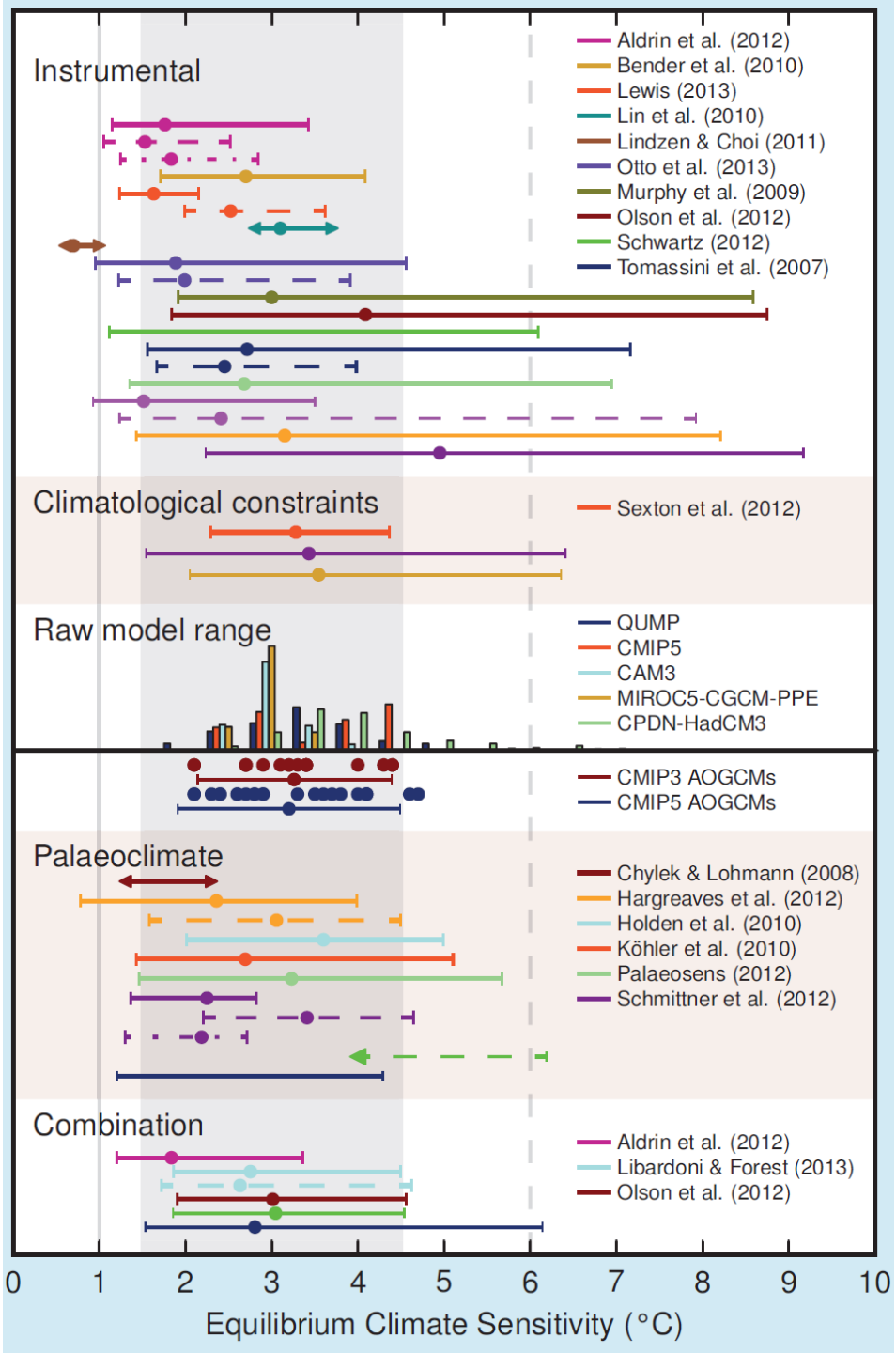
(Dufresne & Bony, 2008)

Transient temperature response to a CO_2 doubling

(CO_2 increase 1%/year, 70 years)



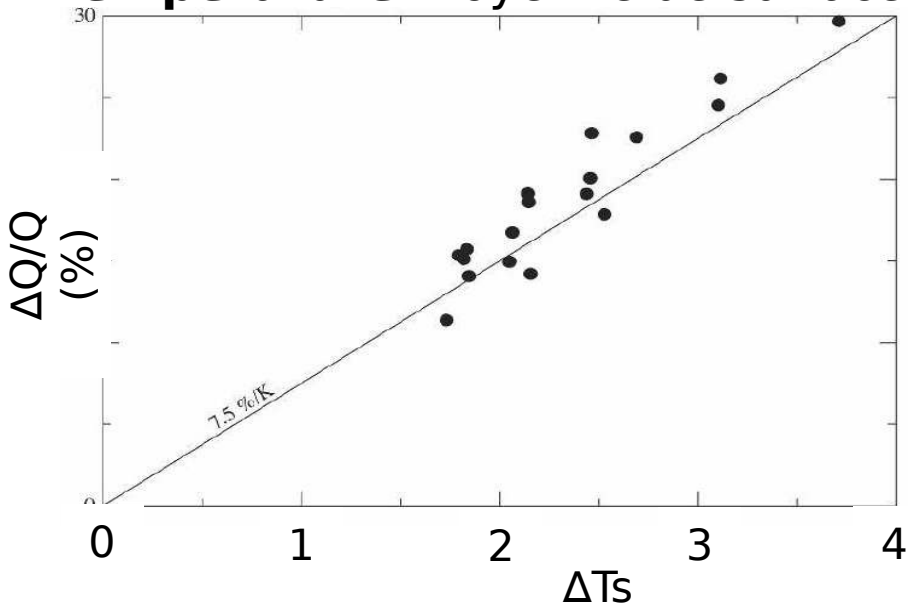
(Dufresne & Bony, 2008)


Instrumental
Aldrin et al. (2012)
Bender et al. (2010)
Lewis (2013)
Lin et al. (2010)
Lindzen & Choi (2011)
Otto et al. (2013)
Murphy et al. (2009)
Olson et al. (2012)
Schwartz (2012)
Tomassini et al. (2007)
Climatological constraints
Sexton et al. (2012)
Raw model range
QUMP
CMIP5
CAM3
MIROC5-CGCM-PPE
CPDN-HadCM3
CMIP3 AOGCMs
CMIP5 AOGCMs
Palaeoclimate
Chylek & Lohmann (2008)
Hargreaves et al. (2012)
Holden et al. (2010)
Köhler et al. (2010)
Palaeosens (2012)
Schmittner et al. (2012)
Combination
Aldrin et al. (2012)
Libardoni & Forest (2013)
Olson et al. (2012)
0
1
2
3
4
5
6
7
8
9
10
Equilibrium Climate Sensitivity (°C)

[IPCC, 2015]

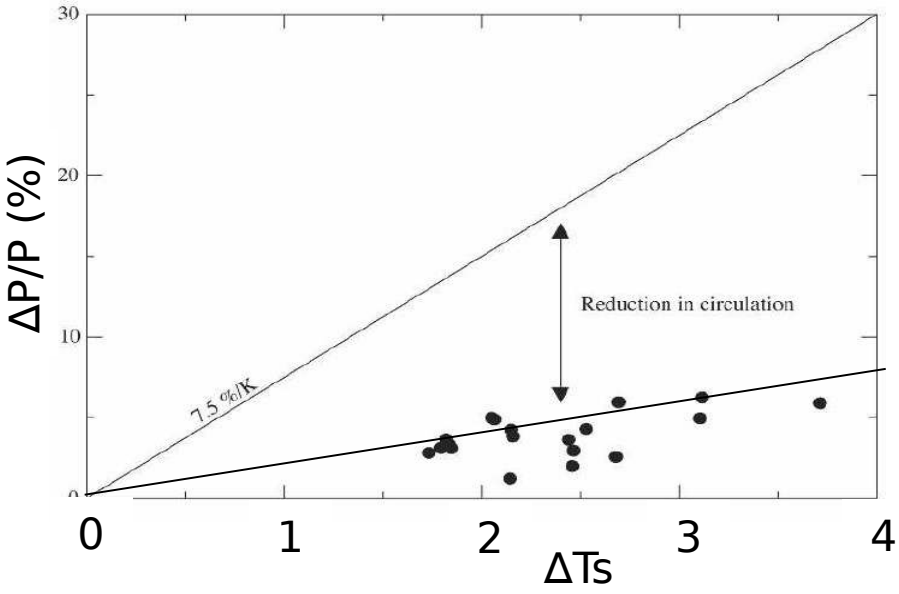
Changement de la moyenne des précipitations

Changement de la **quantité de H_2O** vs changement de la **température** moyenne de surface



$\Delta Q/Q\ (\%) \approx 7.5\ \Delta Ts$

Changement **précipitations** vs changement de la **température** moyenne de surface



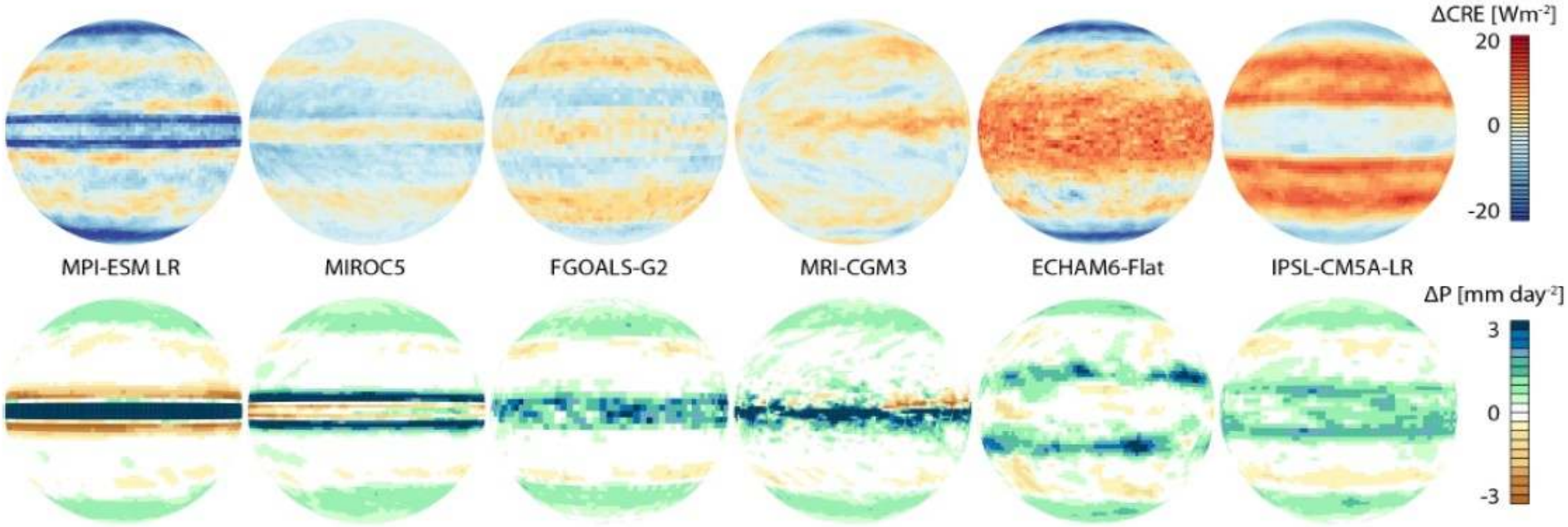
$\Delta P/P\ (\%) \approx 1.5\ \Delta Ts$

- Changement moyen de précipitation n'est pas directement relié au changement moyen de vapeur d'eau
- Contrainte énergétique

(Vecchi & Soden, 2007)

Idealized experiments: simplify to understand

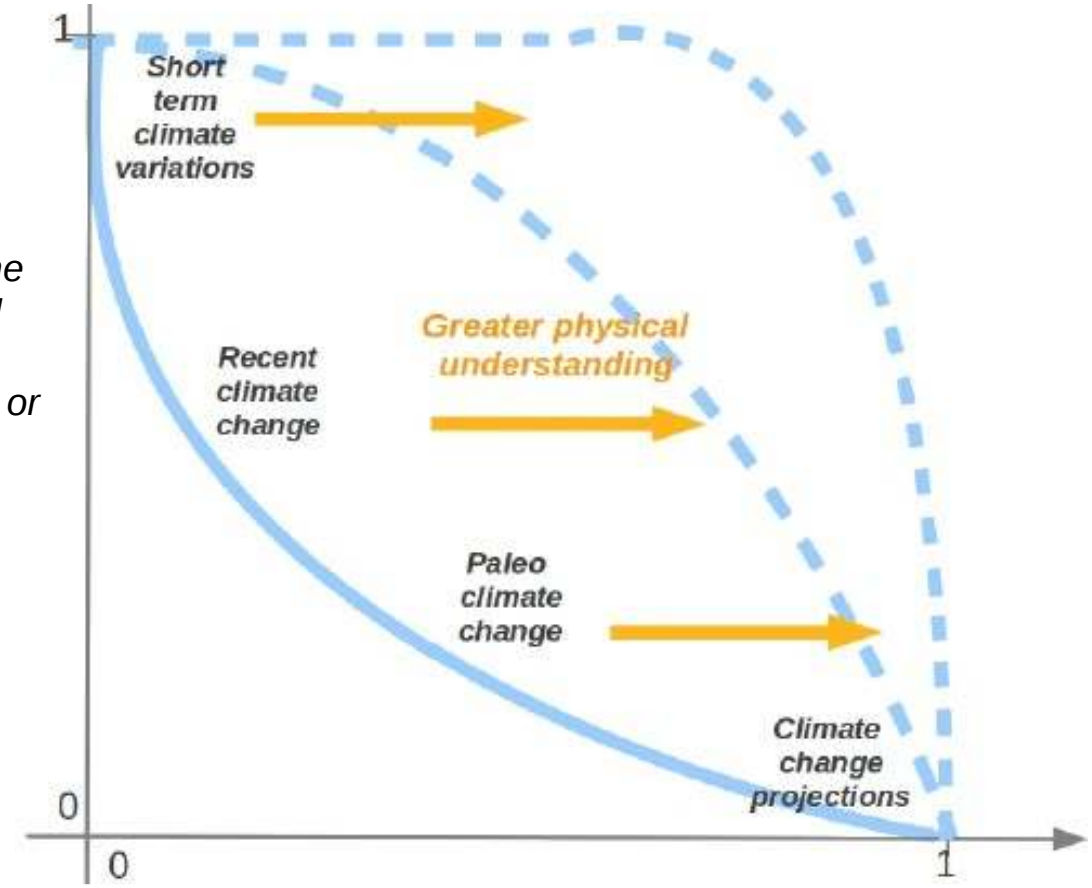
Clouds and precipitation changes for an aquaplanet+4K experiment



[Stevens & Bony, 2013]

Uncertainty and confidence primary depend on our understanding

- Unlike in weather prediction, the reliability of model predictive capabilities for long-term climate change can not be established in a straightforward way... but *only through indirect routes*.



Strength of the observational constraint [availability and / or quality of observations]

Relevance for constraining long-term climate projections

- Few observational tests are fully discriminating of long-term projections.
- Do we apply relevant observational tests ?
- Confidence in climate projections thus remains disproportionately dependent on the development of understanding

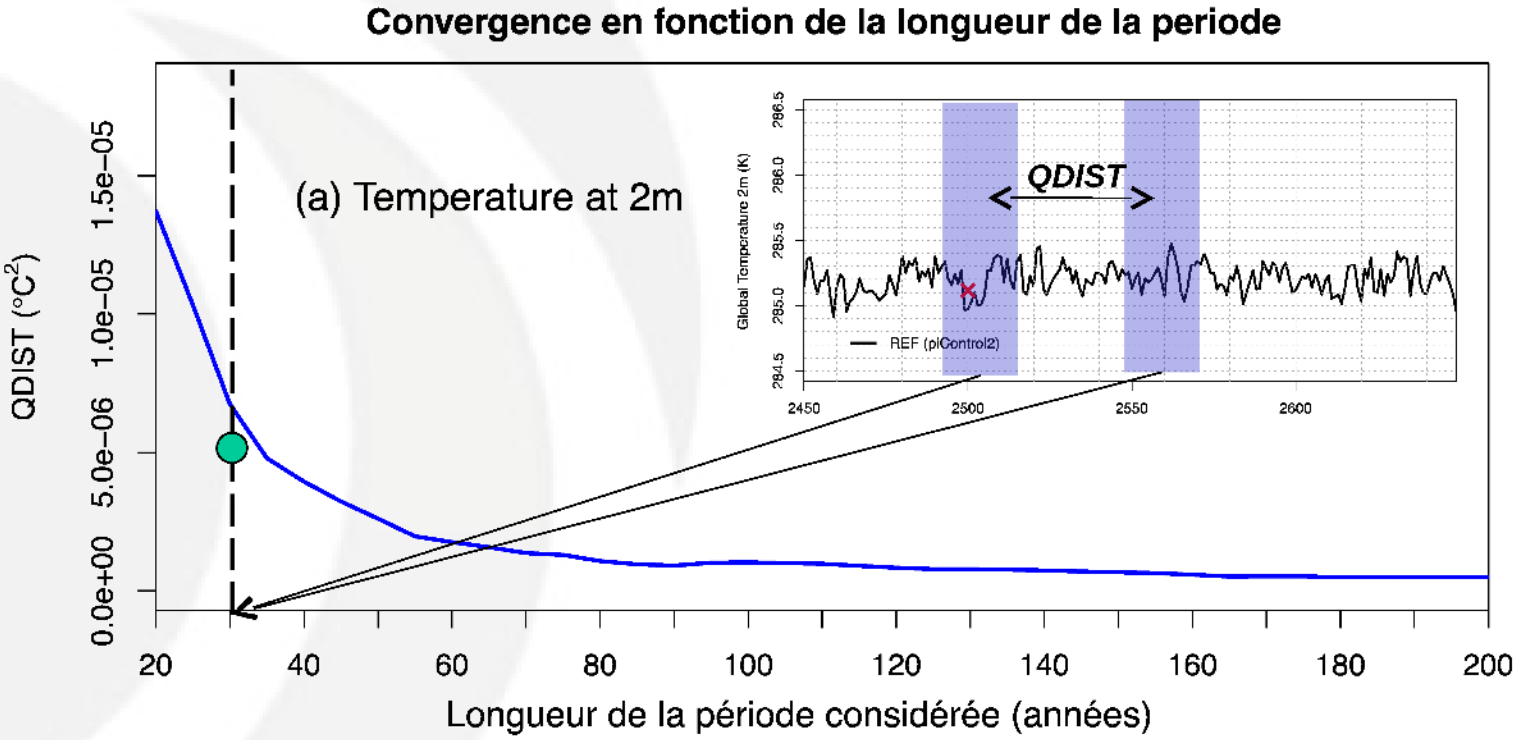
[Bony et al, 2013]


Merci de votre attention

Comment sait-on si le climat est différent?

Estimation de la distribution de QDIST dans piControl2

$$QDIST(T, calc) = \sum_{i}^{N} \left(w_i \times \left[X_{T,calc}(i) - X_{T,piControl2}(i) \right]^2 \right)$$



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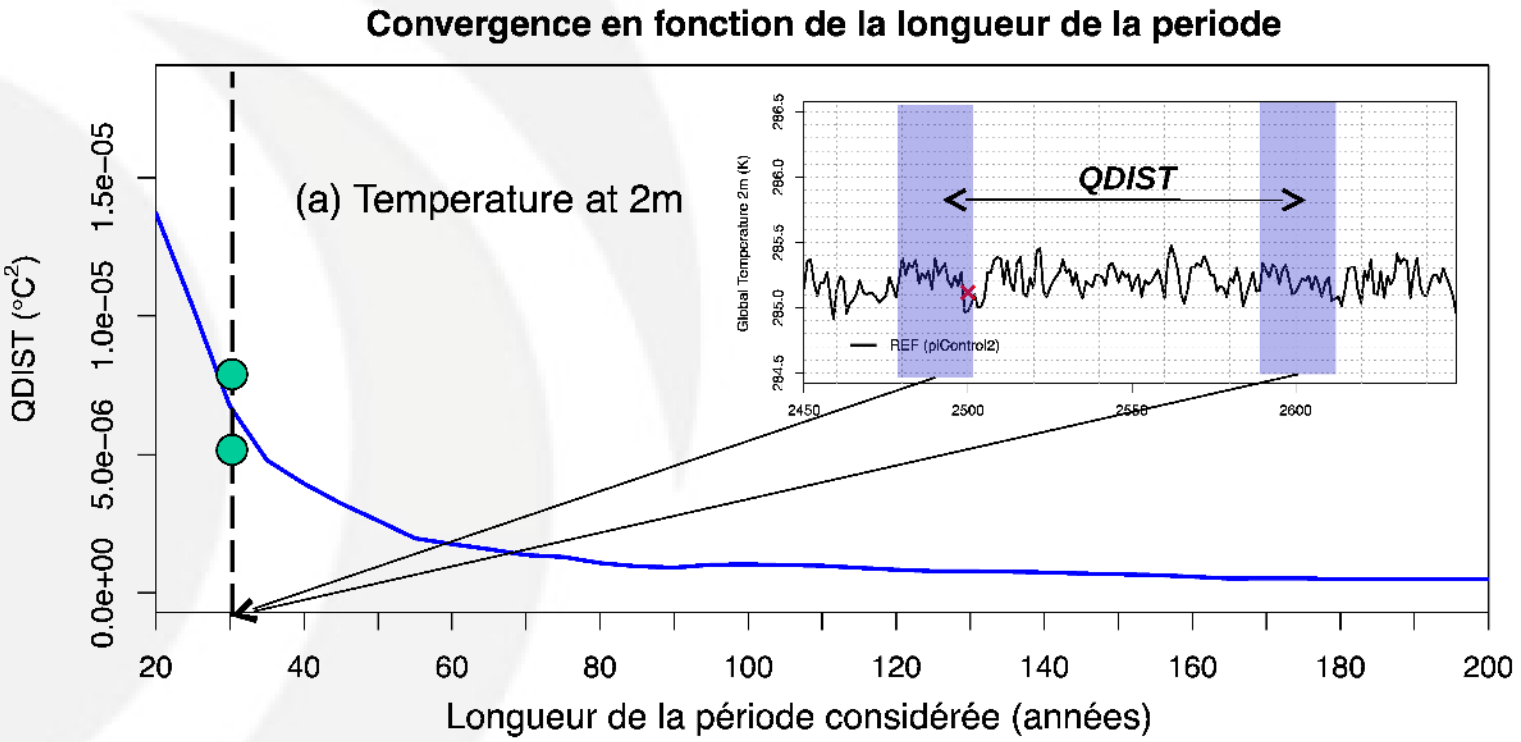

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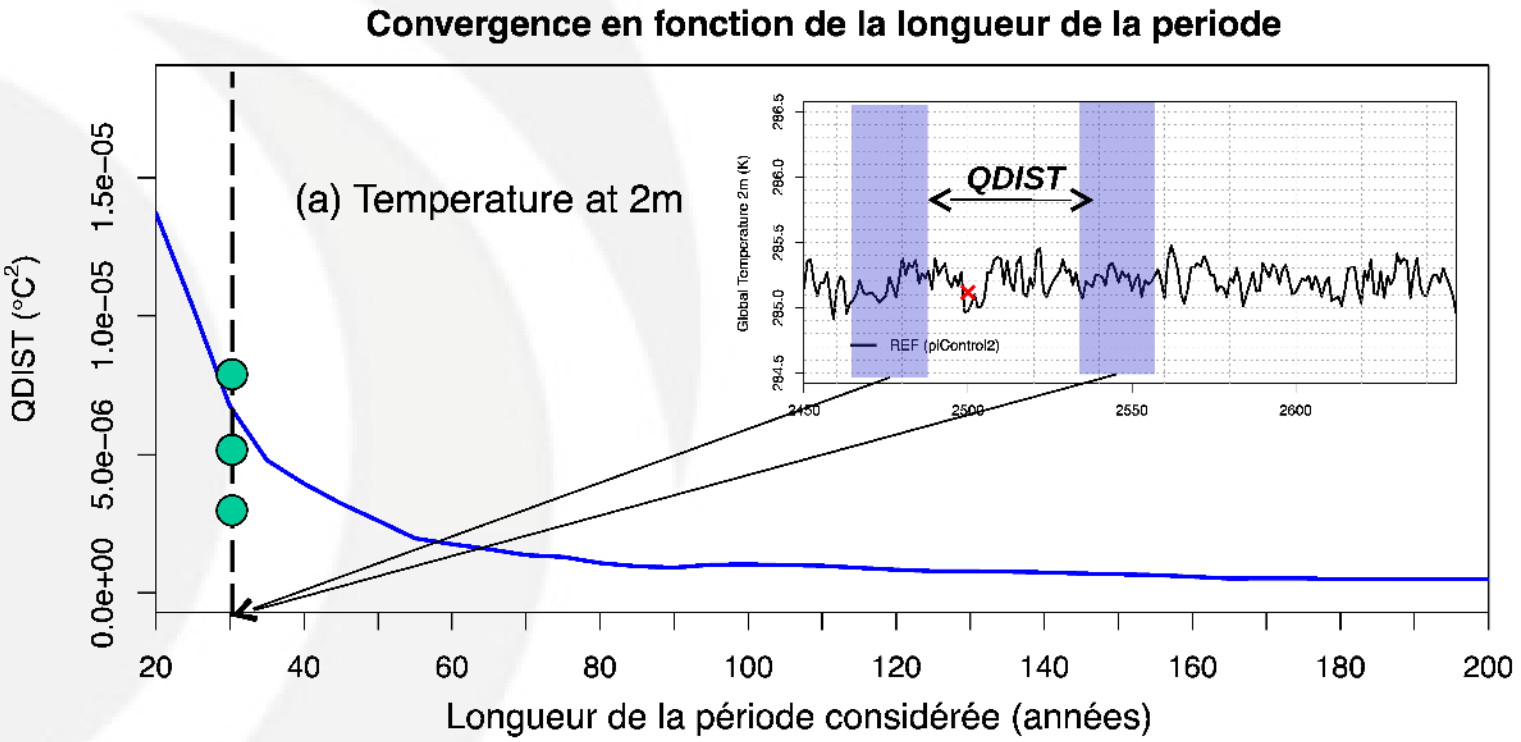

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