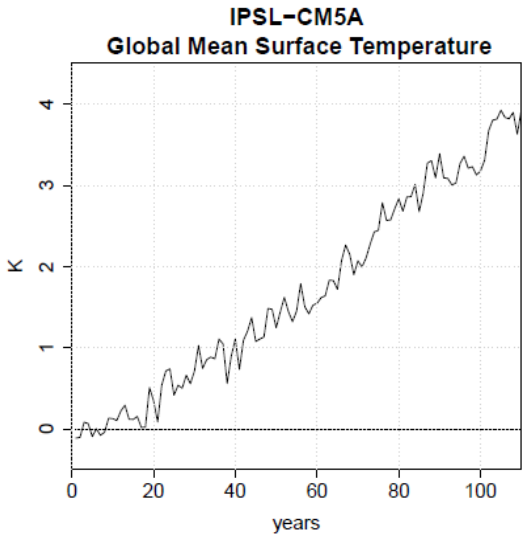
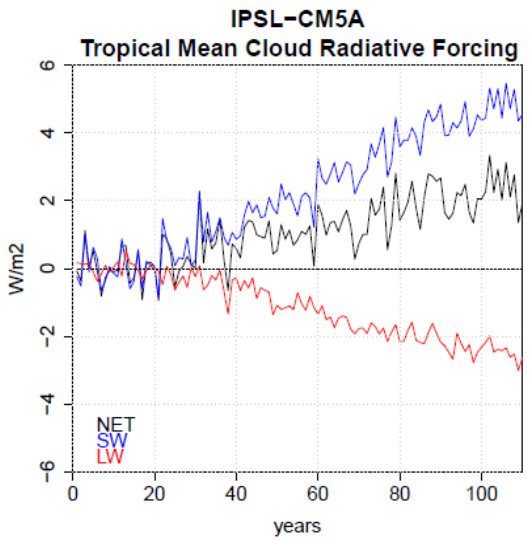
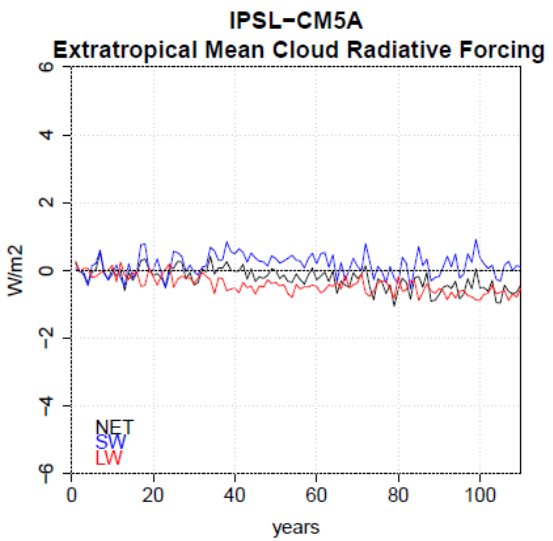
Understanding tropical cloud feedback mechanisms in the IPSL GCM through a hierarchy of models

Florent Brient, Sandrine Bony & Jean-Louis Dufresne
LMD/IPSL, CNRS, Paris, France

IPSL-CM5A Ocean-Atmosphere Coupled GCM
CO2 increase by 1%/year







- In this model: global cloud feedback dominated by the tropical cloud response

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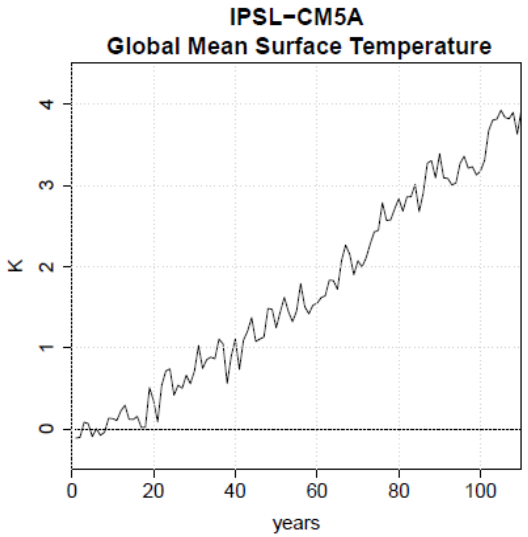

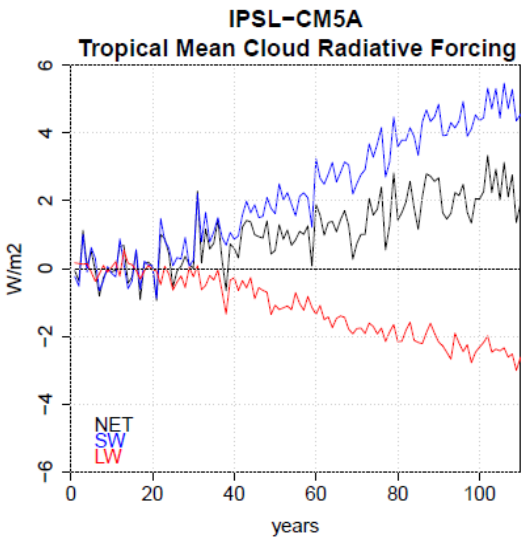

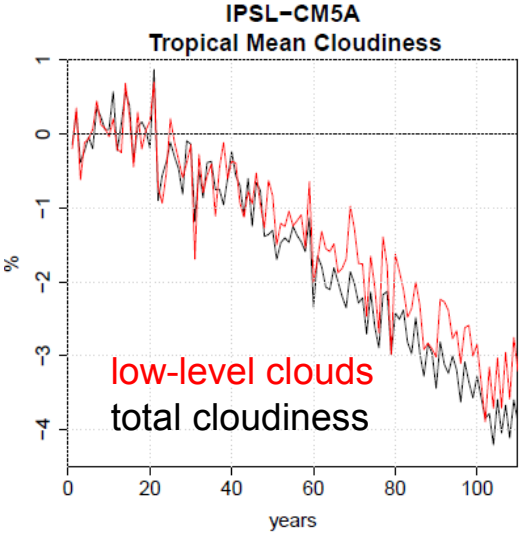

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- Tropical cloud response associated with a strong decrease of low-level clouds

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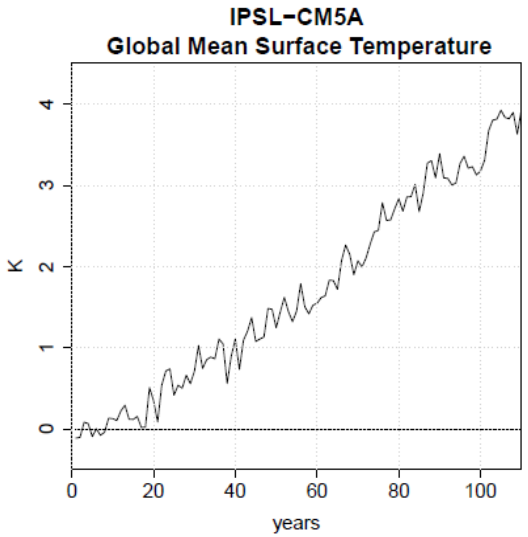

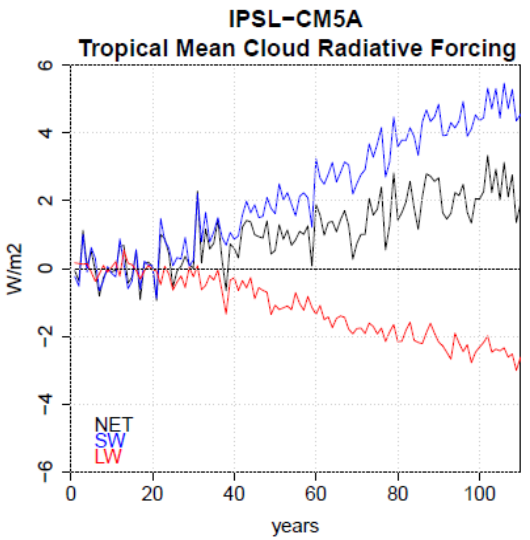

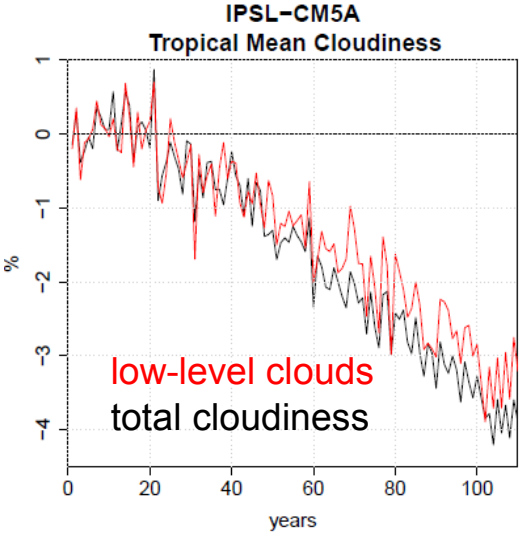

- In this model: global cloud feedback dominated by the tropical cloud response
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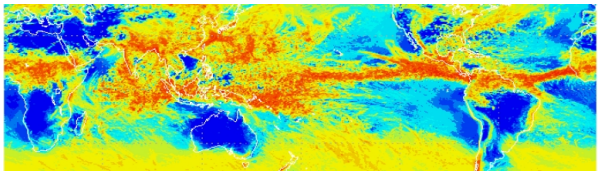
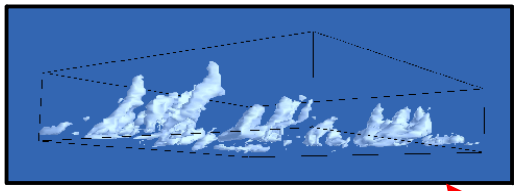
How credible is this projection ?

How to gain confidence in GCMs projections ?

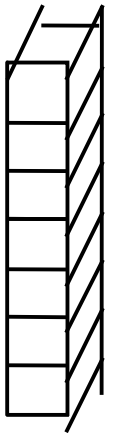
(1) Bottom-Up approach : evaluate and improve the physical basis of climate models through large-scale and process-scale evaluations (WP3)



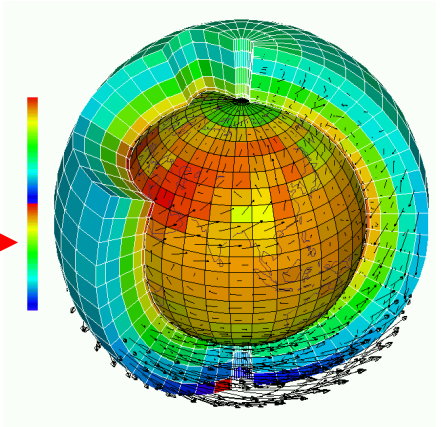
High resolution global models (global CRM, MMF)



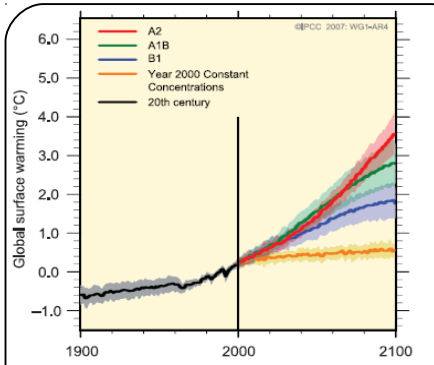
LES models Cloud Resolving Models



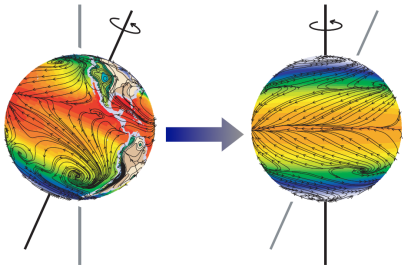
Single Column Models



3D-Climate Models NWP Models

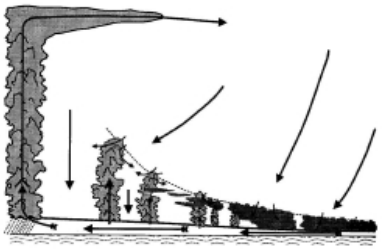


Model projections



Field campaigns & instrumented sites

Global observational datasets

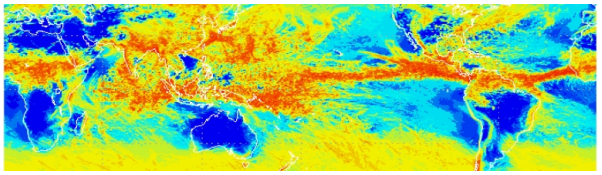


Analysis & Understanding climate change

How to gain confidence in GCMs projections ?

(1) Bottom-Up approach : evaluate and improve the physical basis of climate models through large-scale and process-scale evaluations (WP3)

(2) Top-Down approach : understand the models' results & identify critical processes to provide guidance for specific observational tests/process studies and model improvements (WP2)



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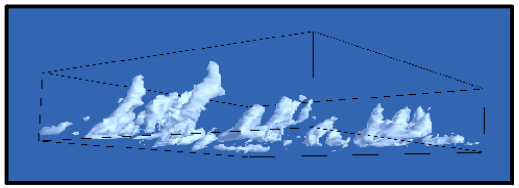

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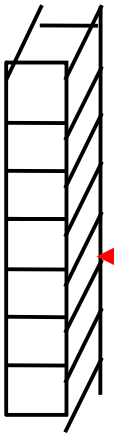
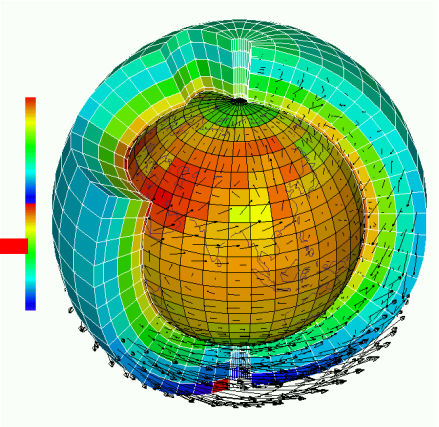


Single Column Models



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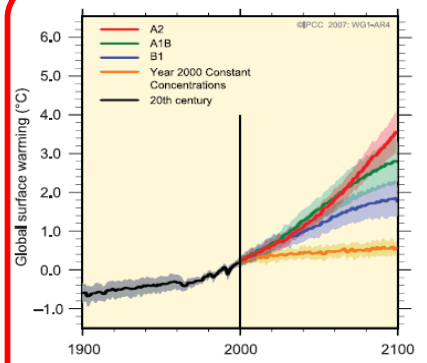

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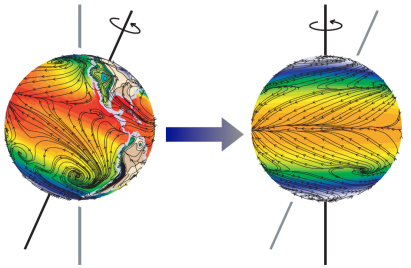

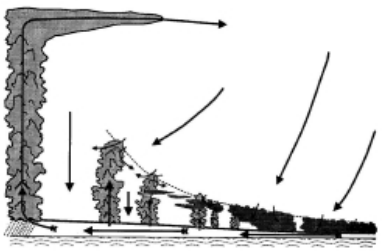

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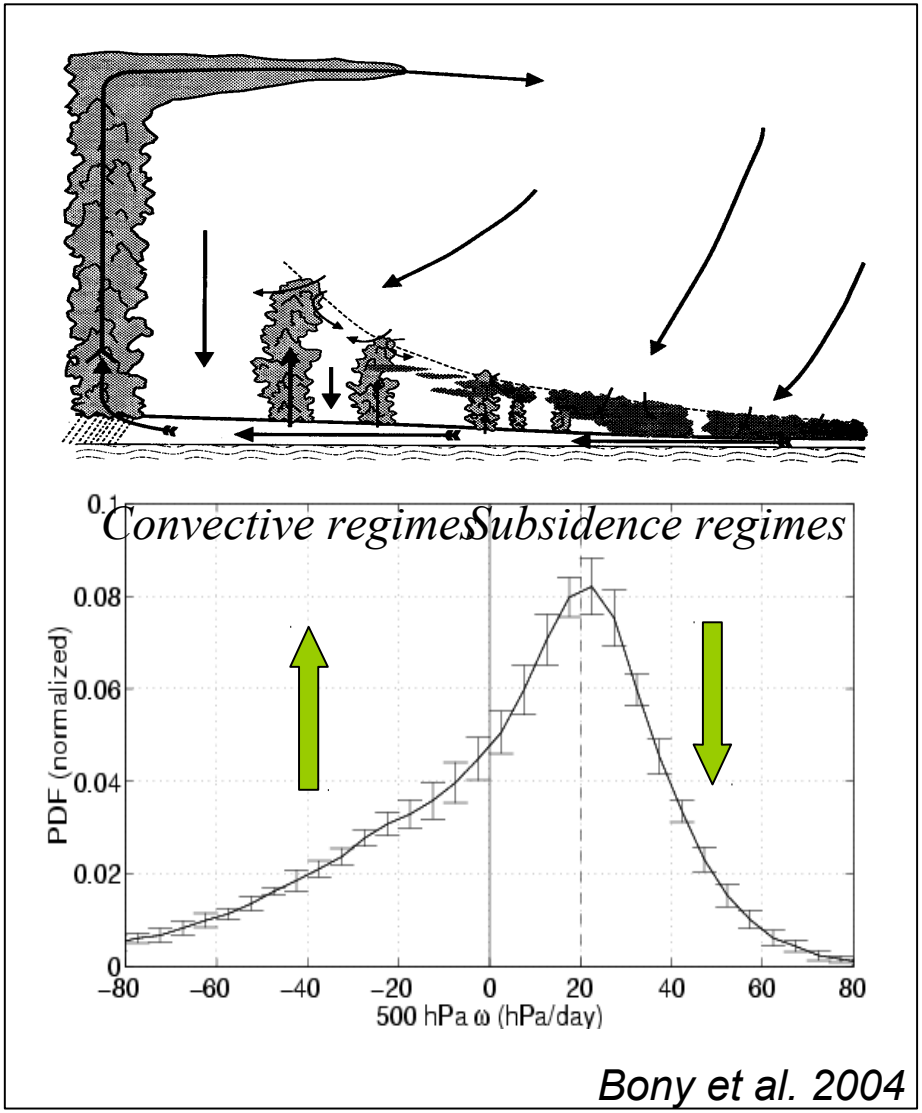
Analysis of the tropical mean cloud response

- Proxy ω for large-scale motions: ω_{500hPa}.
- Decomposition of the tropical circulation into dynamical regimes: $\int_{-\infty}^{+\infty} P_\omega \, d\omega = 1$
- Composite of cloud or radiative variables in each dynamical regime: C_ω
- Tropical average: $\overline{C} = \int_{-\infty}^{+\infty} P_\omega \, C_\omega \, d\omega$



Bony et al. 2004

$$\overline{\delta C} = \underbrace{\int_{-\infty}^{+\infty} C_\omega \, \delta P_\omega \, d\omega}_{\text{dynamic component}} + \underbrace{\int_{-\infty}^{+\infty} P_\omega \, \delta C_\omega \, d\omega}_{\text{thermodynamic component}} + \underbrace{\int_{-\infty}^{+\infty} \delta P_\omega \, \delta C_\omega \, d\omega}_{\text{co-variation}}$$

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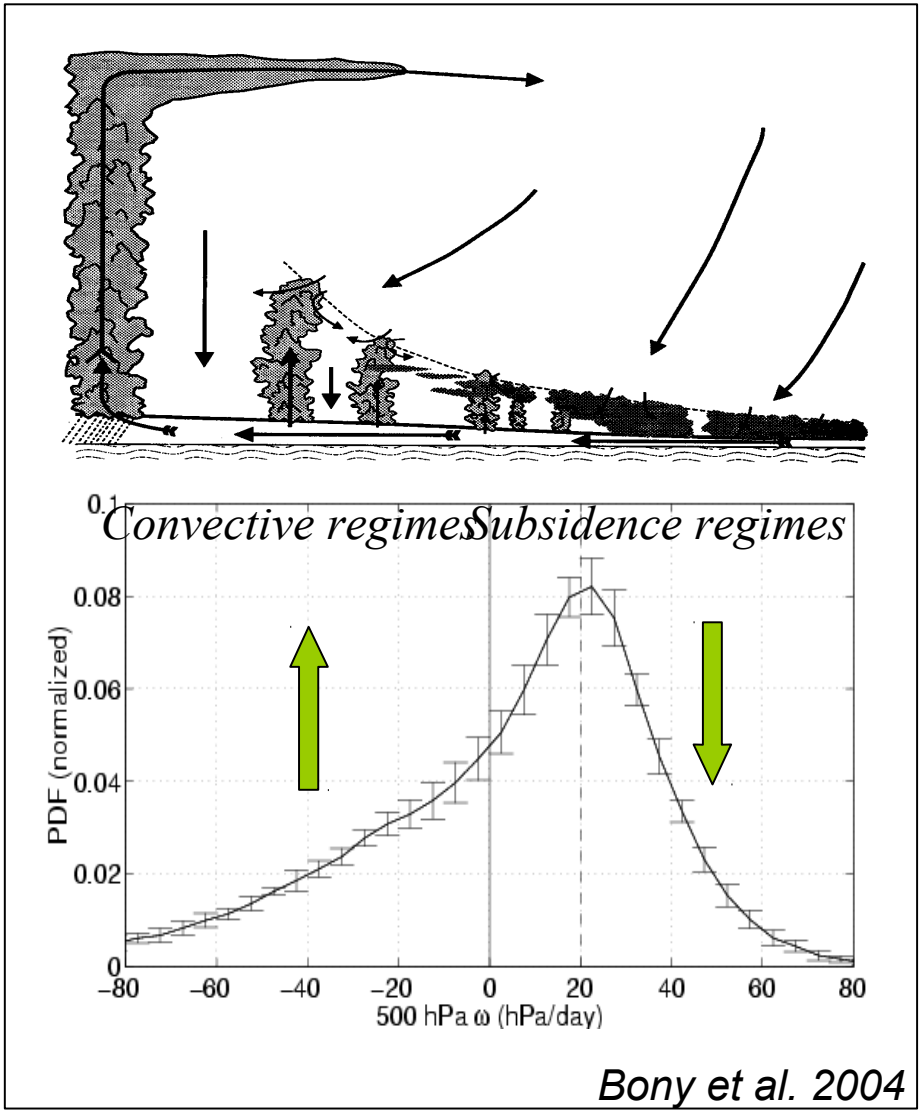
→ In the OAGCM: tropical mean CRF response dominated by the "thermodynamical" component



Bony et al. 2004

1.17 W/m2

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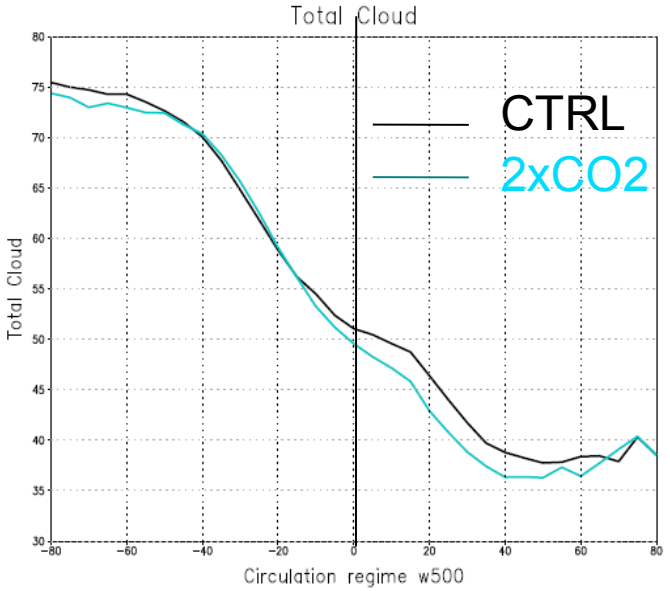
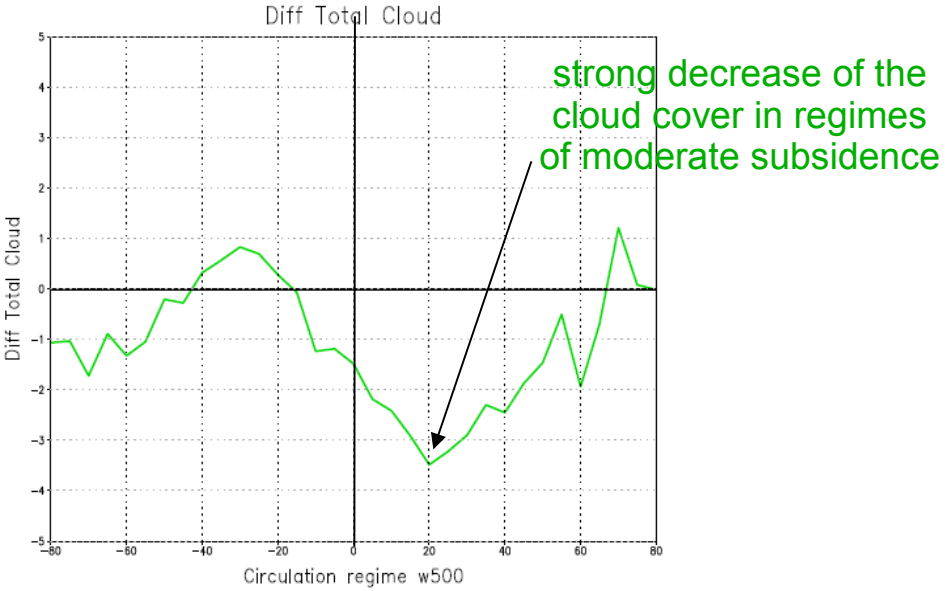
0.06 W/m2 | 1.09 W/m2 | 0.03 W/m2

Analysis of the tropical mean cloud response

Coupled ocean-atmosphere GCM :

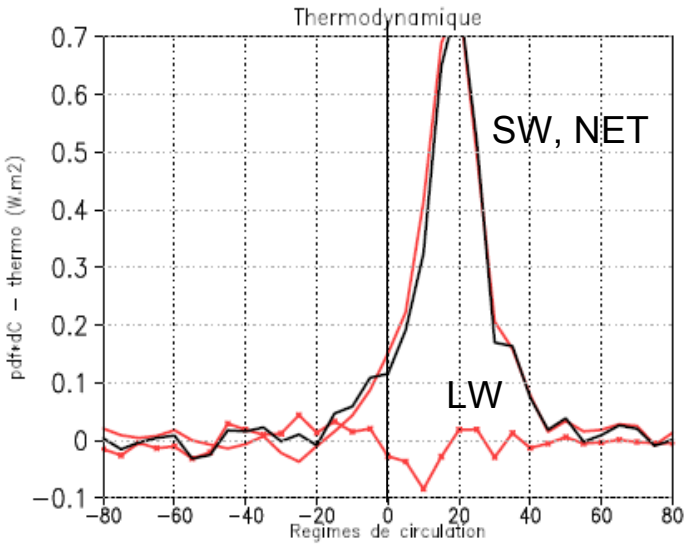




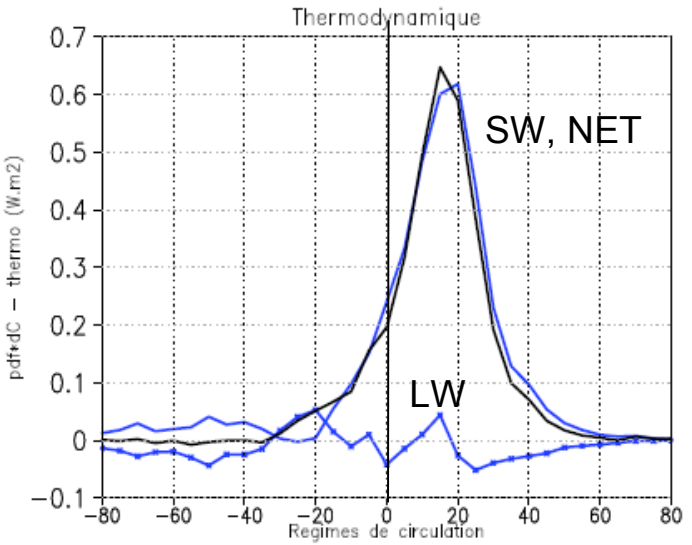
In the OAGCM: Tropical mean CRF response associated with large CRF and cloud changes in regimes of moderate subsidence

Analysis of the tropical mean cloud response to a prescribed uniform warming (+2K) in idealized atmospheric simulations (AMIP, aqua-planet)

Thermodynamic component in AMIP simulation



Thermodynamic component in Aqua-Planet simulation

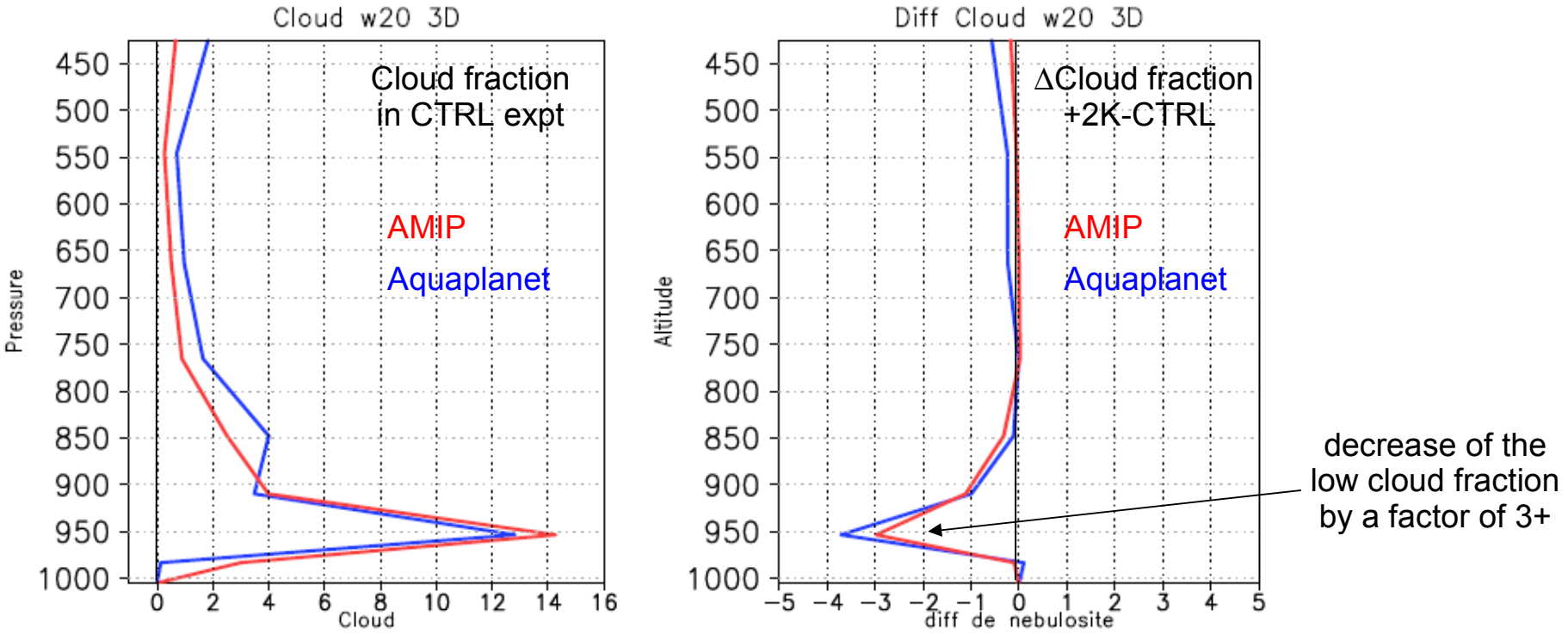


- Tropical mean CRF response also dominated by the (SW) “thermodynamical” component

- This component is dominated by the cloud response in regimes of moderate subsidence

Analysis of the tropical mean cloud response to a prescribed uniform warming (+2K) in idealized atmospheric simulations (AMIP, aqua-planet)

Regimes of moderate subsidence :



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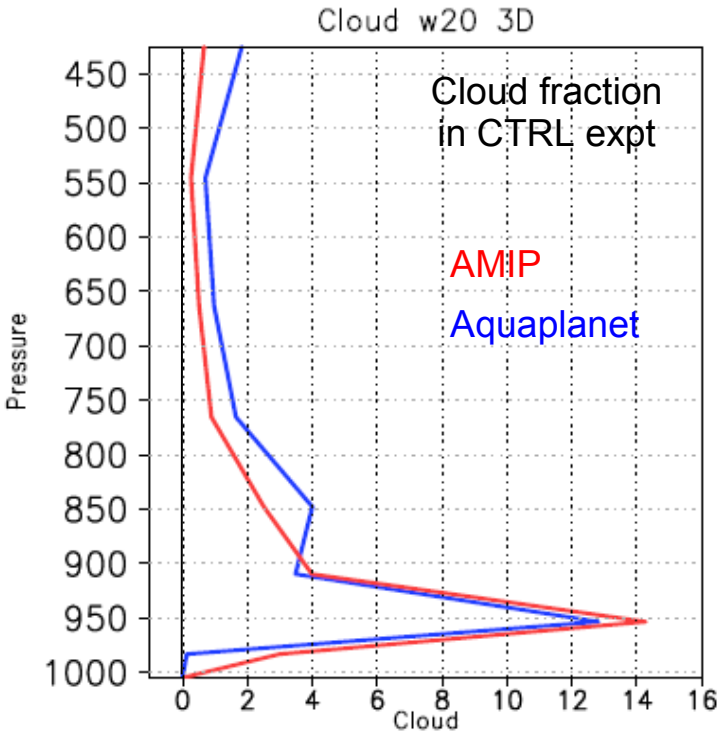
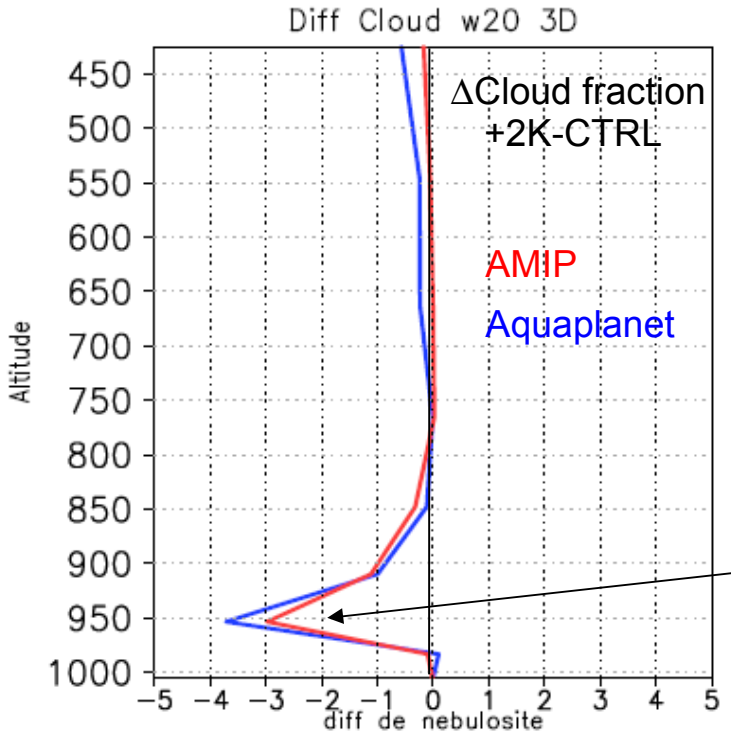




decrease of the low cloud fraction by a factor of 3-4

- Tropical mean CRF response also dominated by the (SW) “thermodynamical” component

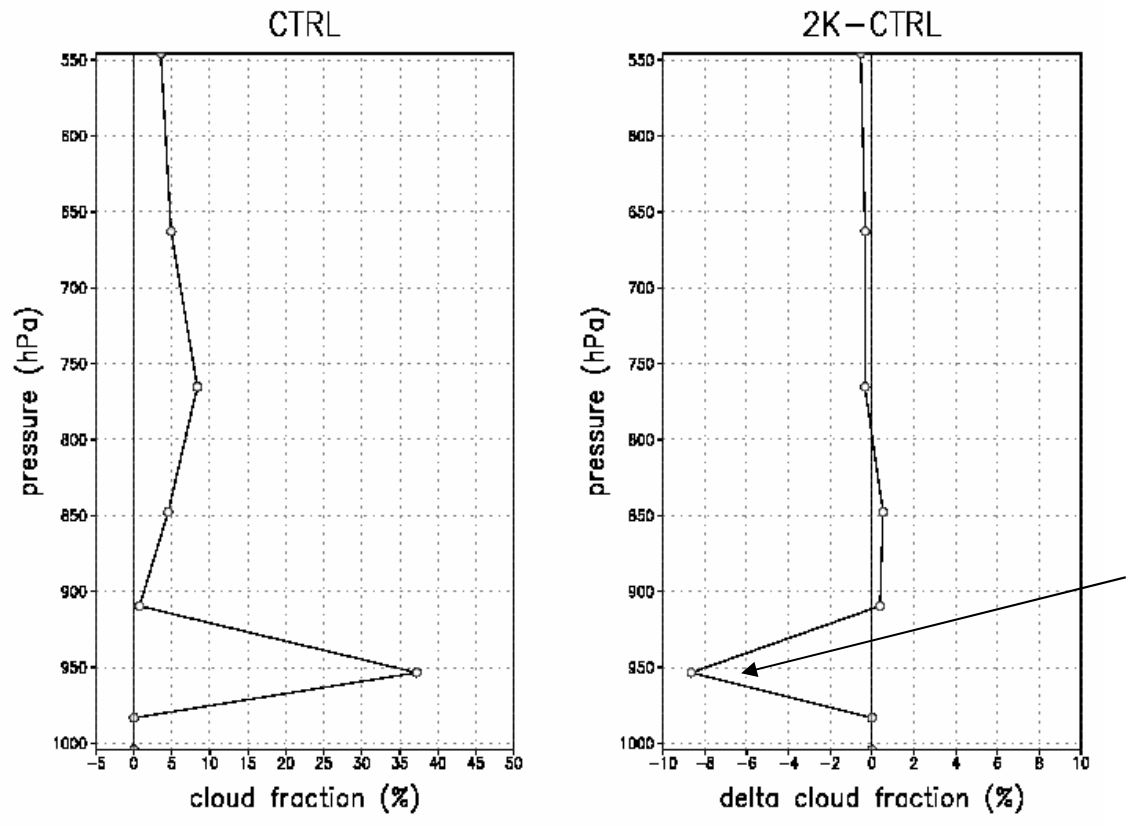
- This component is dominated by the cloud response in regimes of moderate subsidence

- May this behaviour be reproduced with a Single Column Model (SCM) ?

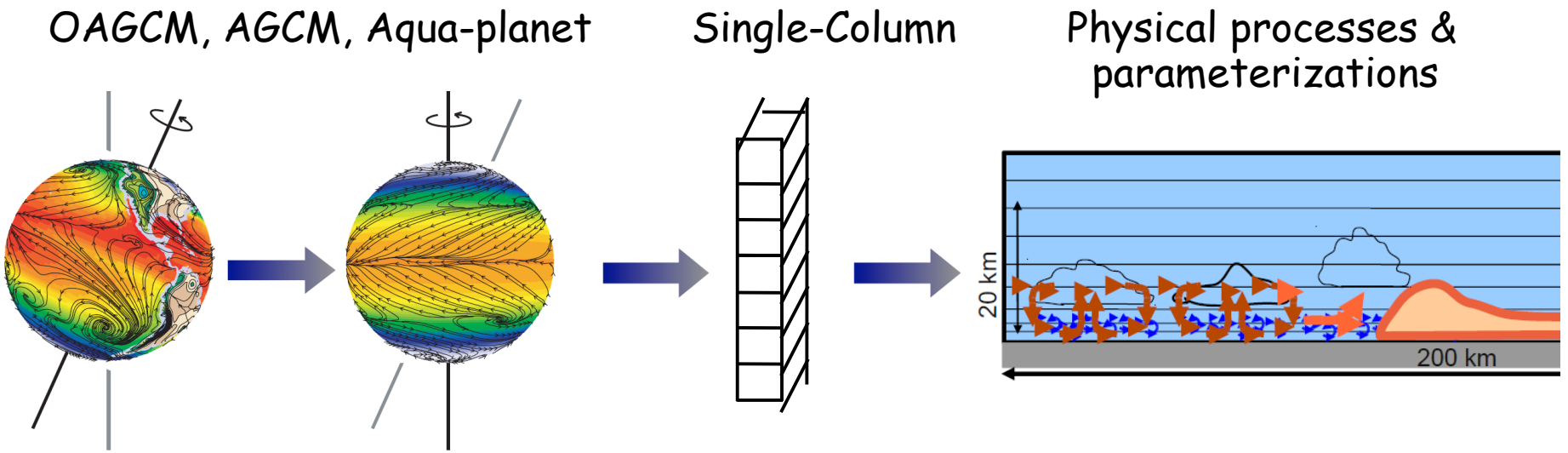
Analysis of the tropical mean cloud response to a prescribed uniform warming (+2K) in Single Column Model simulations

Regimes of moderate subsidence:

Large-scale forcing from aquaplanet simulations
+ stochastic forcing added on large-scale omega
cf Florent Brient's talk on Wed



Analysis of the tropical mean cloud response to a prescribed uniform warming (+2K) through a hierarchy of models



- Physical interpretation of the decrease of low-level clouds ?

  → increase of the (clear-sky) radiative cooling aloft
  → enhanced shallow convection
  → RH decrease at low levels

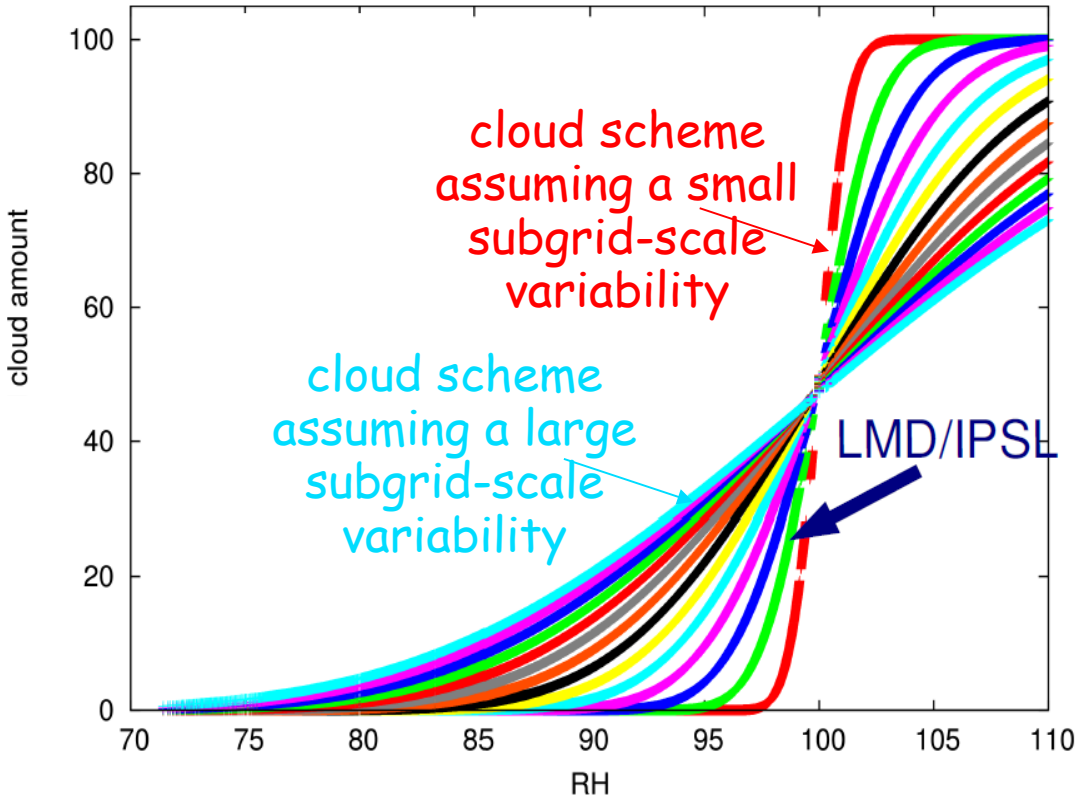
- Relationship between RH and cloud fraction ?

  → statistical cloud parameterization

Influence of the model formulation on the magnitude of PBL cloud feedback in climate change (1) 1D simulations

PBL cloud amount predicted by a statistical cloud scheme

@ 950 hPa



f depends on RH and on the assumed subgrid-scale variability (ssv)
However, ssv also affects RH (e.g. through the occurrence of precipitation)

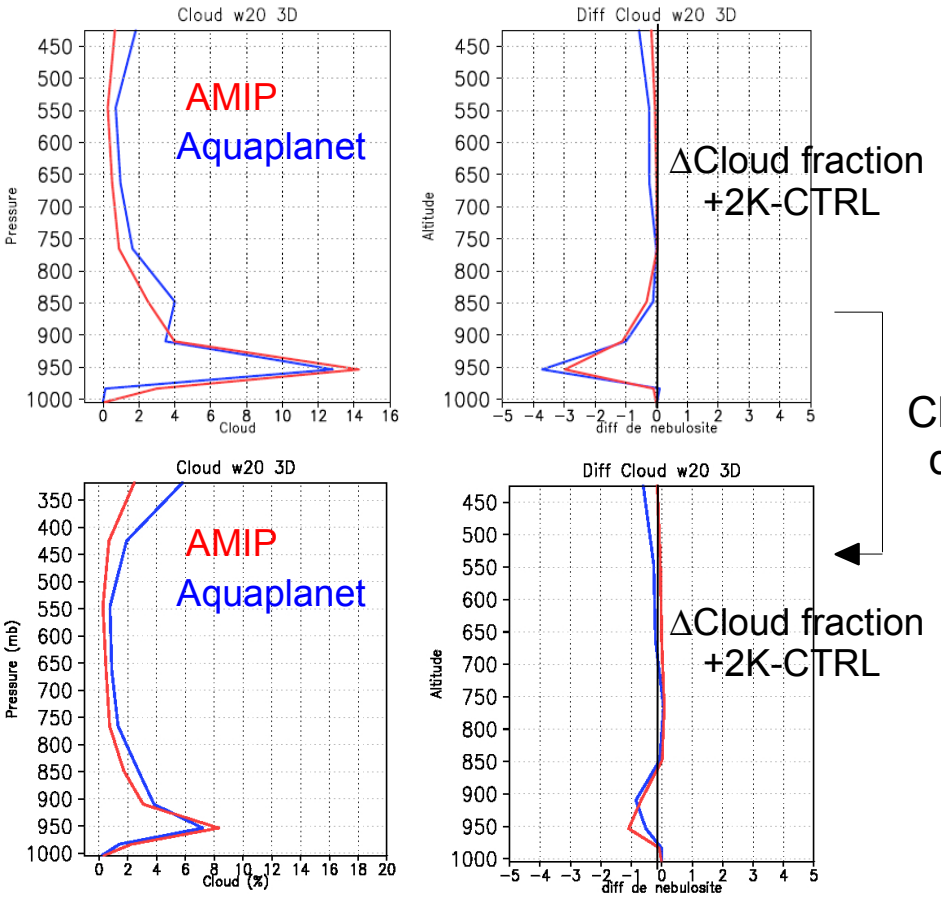
If our SCM, increasing the ssv makes the PBL drier, less cloudy & less sensitive

What about 3D simulations ?

Influence of the model formulation on the magnitude of PBL cloud feedback in climate change (2) 3D simulations (AMIP, aquaplanet)

Usual ssv

Increased ssv



Mean cloudiness decreased by a factor of 2

Cloud response decreased by a factor of 3

As in the SCM, increasing the ssv makes the PBL drier, less cloudy & less sensitive

Similar results for other perturbations (e.g. removing cloud-radiative effects)

CONCLUSION

- Analysing the cloud response to global warming in a hierarchy of IPSL-CM5A model configurations (OAGCM, AGCM, Aqua-planet, SCM) can help to:

  - extract robust responses
  - understand physical processes
  - understand the dependence of cloud feedbacks on model formulation

- Such analyses will be possible for EUCLIPSE GCMs thanks to :

  - CMIP5/CFMIP experiments
  - CGILS experiments (CFMIP-GCSS Intercomparison of LES and SCMs)

- On-going work:

  - explore ways to reproduce the 3D cloud behaviour with a 1D model
  - refine the physical interpretation of the cloud response
  - look at the model version with new physics

- Model evaluations against satellite / in-situ observations, as well as NWP evaluations can then help to put constraints on processes that have been pointed out as most critical, and thereby help assess the credibility of the model cloud feedbacks.