Cloud - Radiation Interactions

Sandrine Bony
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Outline :

Why are these interactions so critical for climate modelling ?

- Impact on the global energy balance
- Interactions with atmospheric dynamics

Their evaluation in GCMs and promising approaches to study these interactions.

ECMWF Seminar, 1-4 September 2008

Advertisement !

Cloud Radiative Interactions and their uncertainty in climate models

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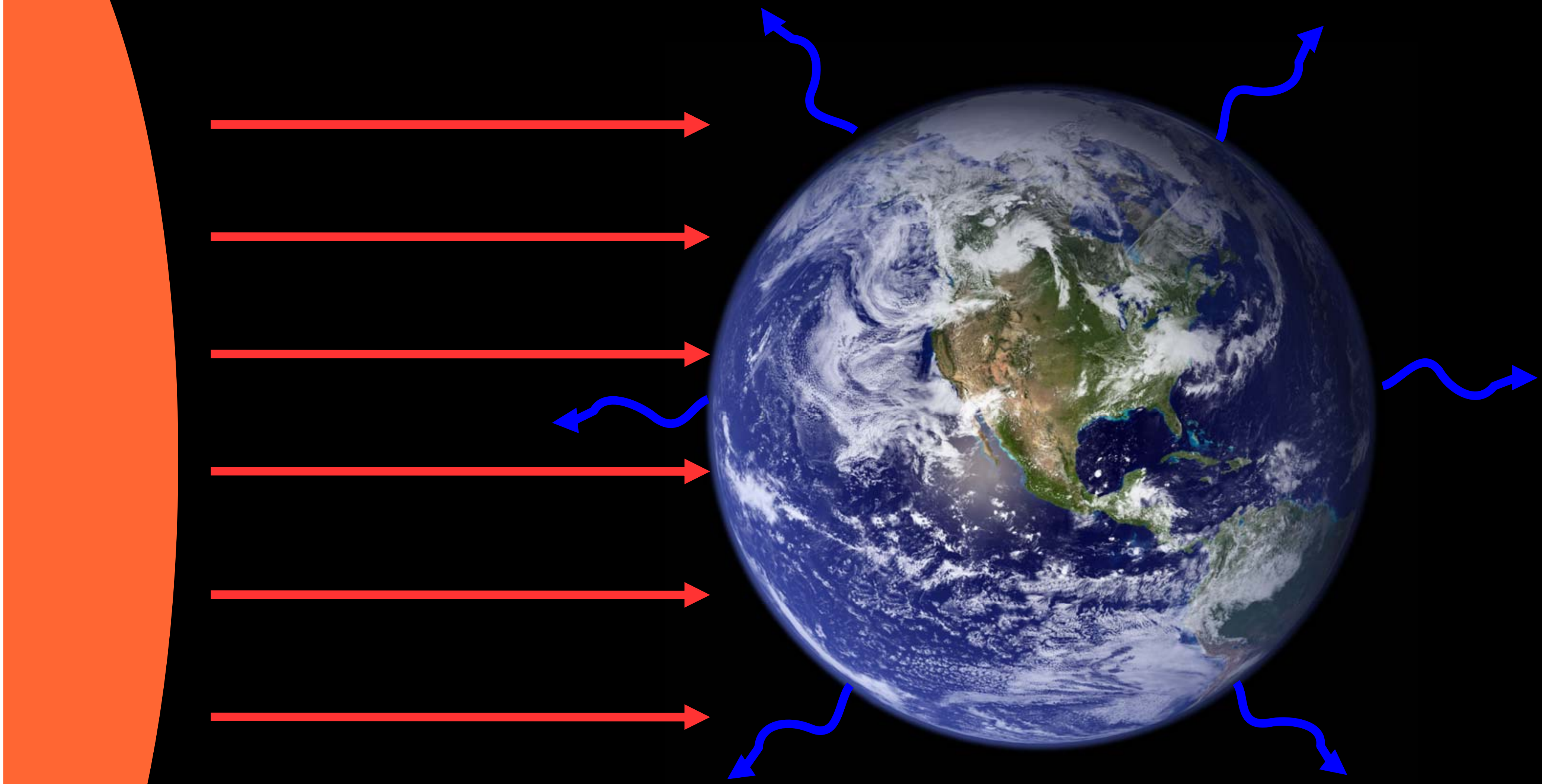
Book chapter to be published soon ...

Earth's Radiation Budget

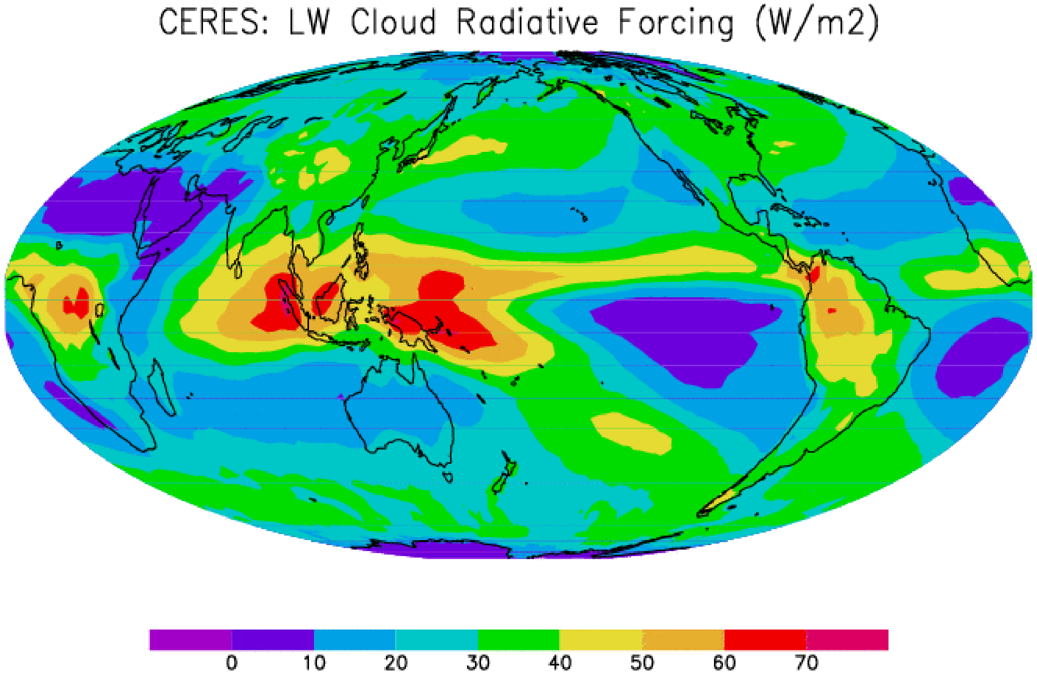


$$R = SW - LW = \frac{S_o}{4}(1-\alpha) - \sigma T^4$$

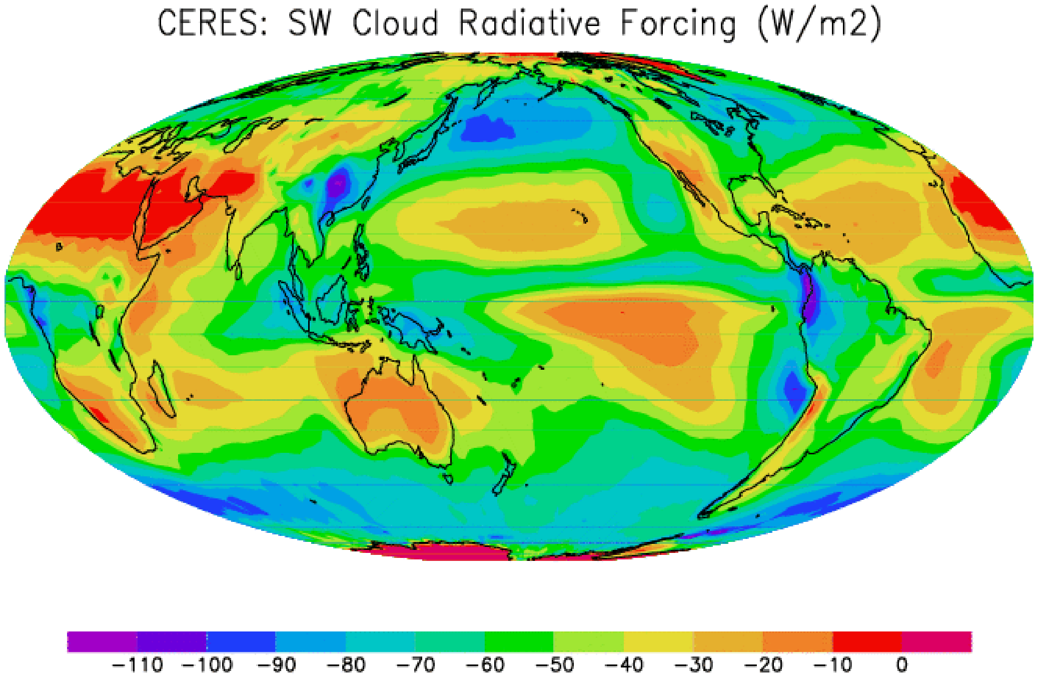
Impact of clouds on the Earth Radiation Budget :

Cloud Radiative Forcing or CRF

$$CRF = R - R_{clr} = (SW-SW_{clr}) + (LW_{clr}-LW)$$

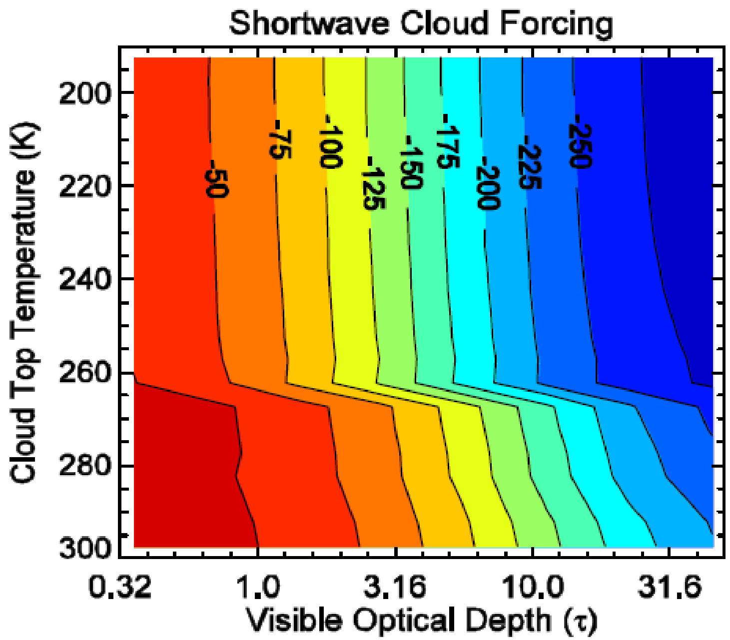


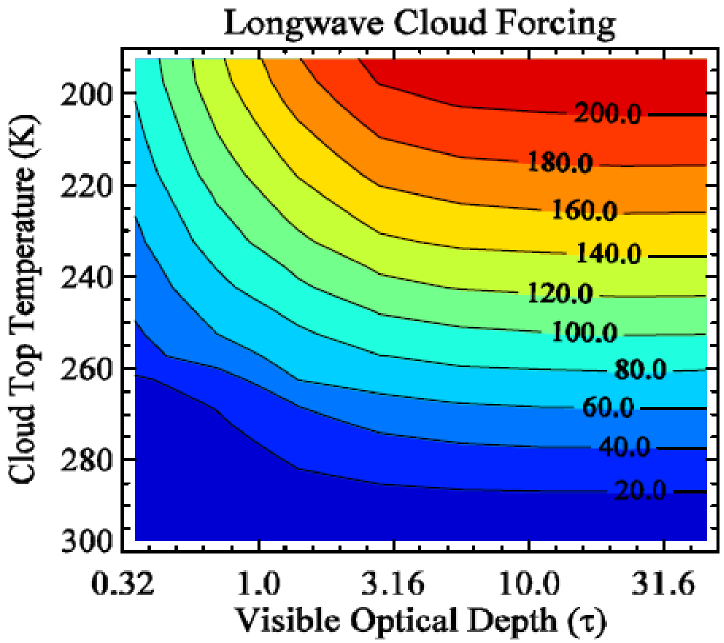
Infrared radiation :
Contribution to
the Earth greenhouse effect
(LW CRF > 0)

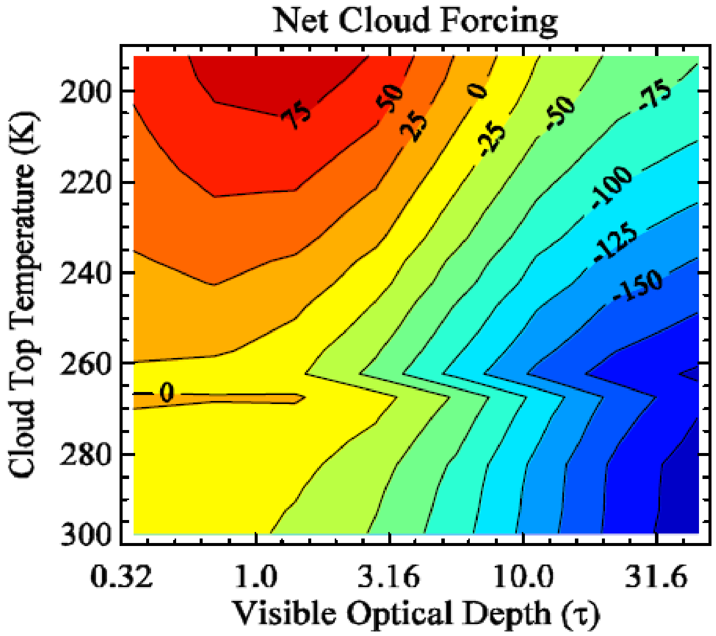


Solar radiation :
Contribution to
the Earth planetary albedo
(SW CRF < 0)

Dependence of the cloud radiative forcing on visible optical depth and cloud top temperature :



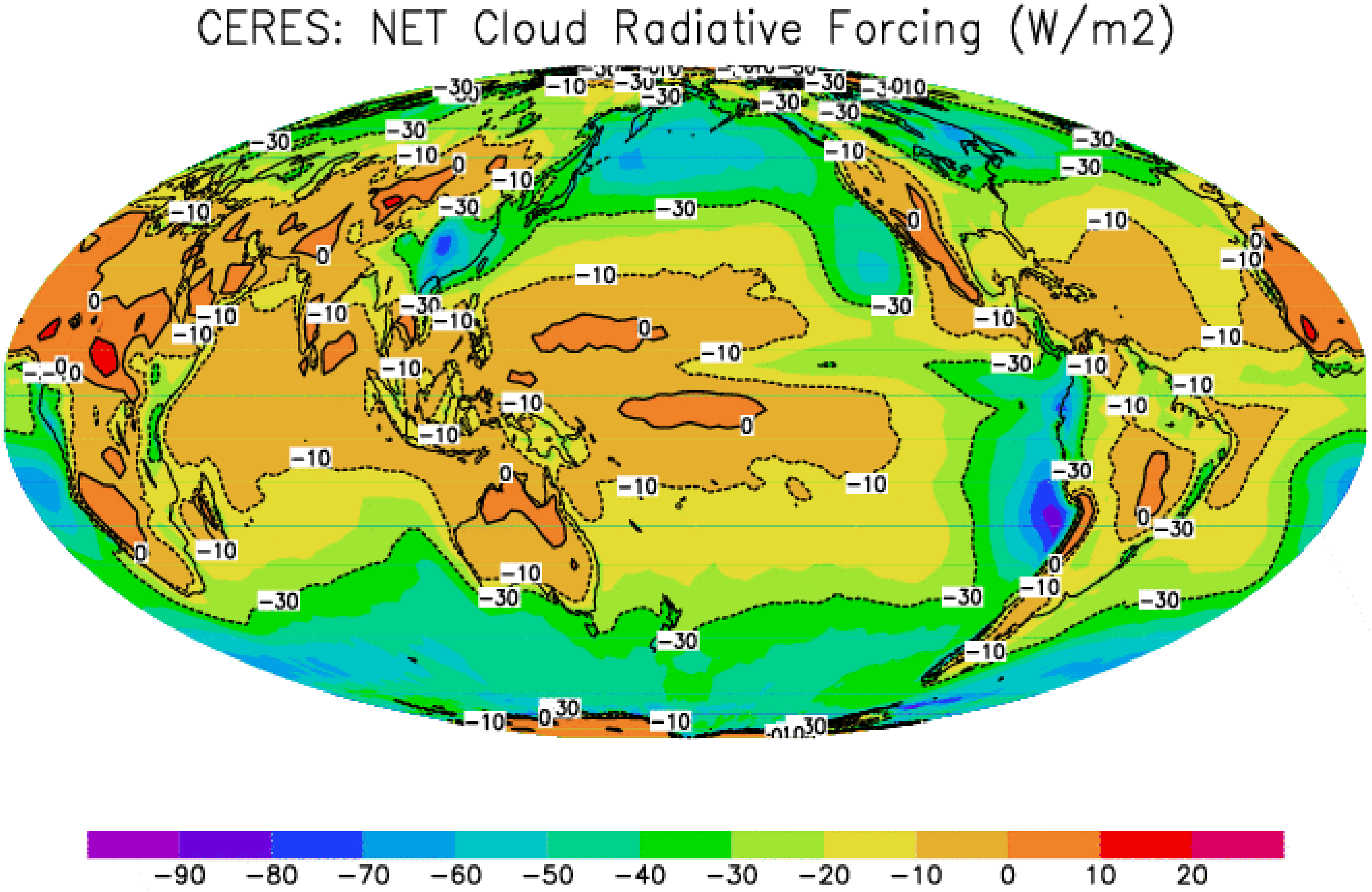




Radiative calculations for West Pacific assuming 100% cloud cover, and prescribed effective radius and climatological cloud thickness

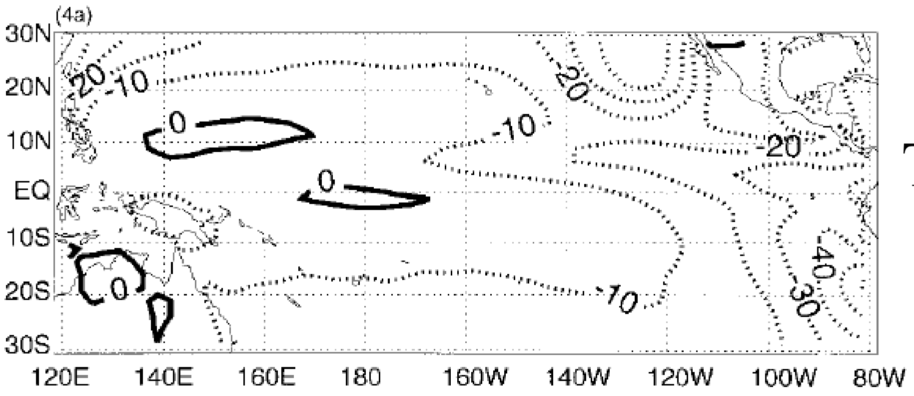
(Kubar et al., J. Climate, 2007)

Impact of clouds on the Earth's Radiation Budget



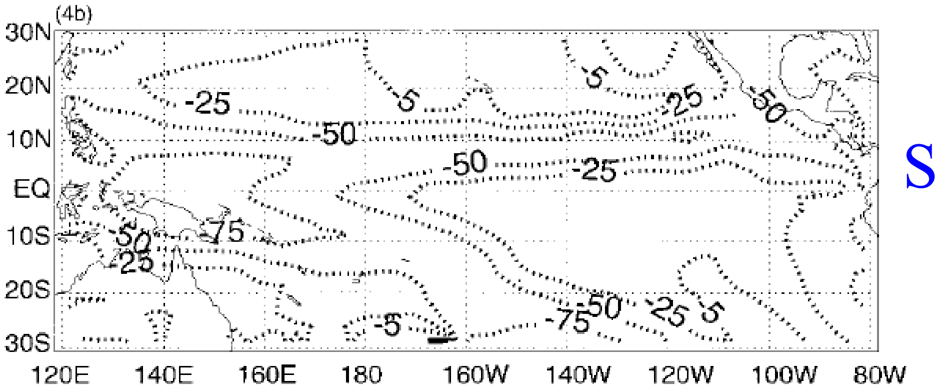
Impact of clouds on the Earth's Radiation Budget (cont'd)

Deep convective clouds
have a weak impact on
NET radiation TOA, but ...



TOA CRF
(W/m2)

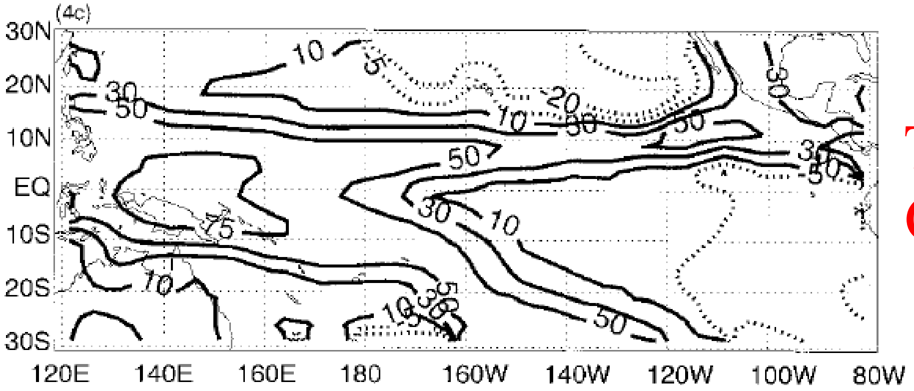
cool the surface
(by increasing the albedo)



Surface CRF
(W/m2)

and

warm the troposphere
(by reducing the radiative cooling)



Tropospheric
CRF (W/m2)

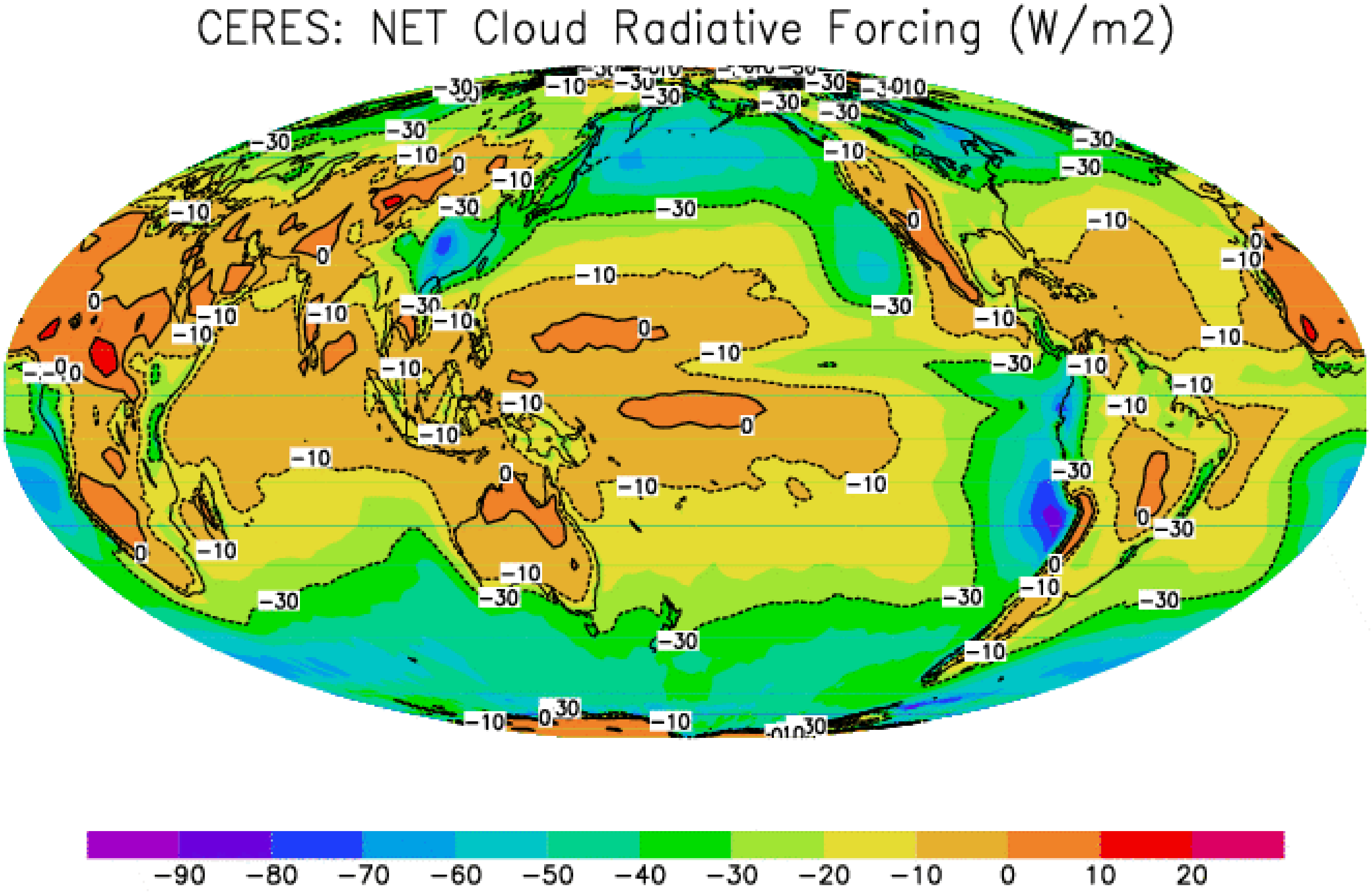
(Tian and Ramanathan, J. Climate, 2002)

Owing to their modulation of the Earth's radiation budget, of the surface energy balance and of the tropospheric diabatic heating, cloud radiative effects have the potential to affect many aspects of climate.

This has been recognized for a long time by climate modelers,
... for better or for worse !

1. Cloud-radiation interactions and climate sensitivity

Impact of clouds on the Earth's Radiation Budget

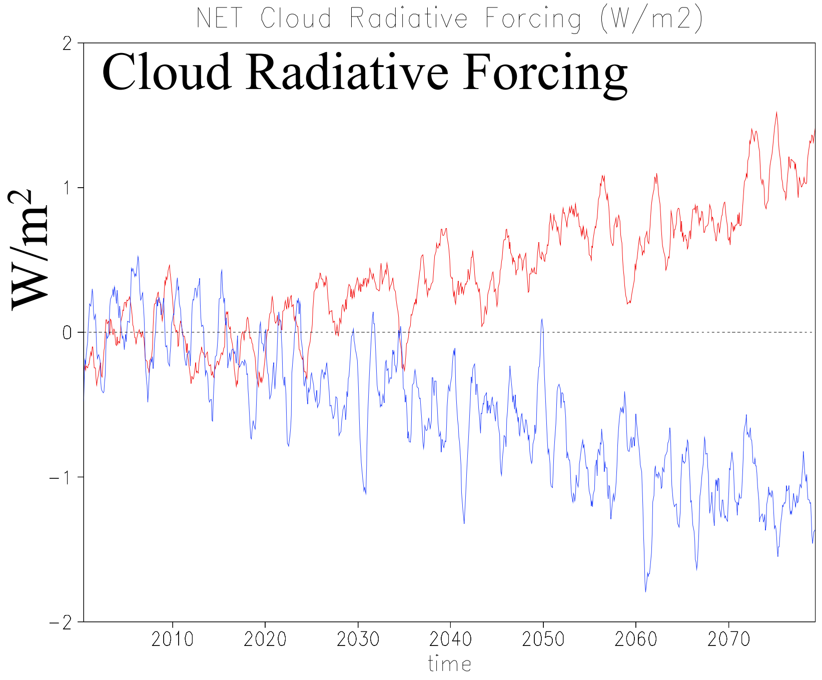


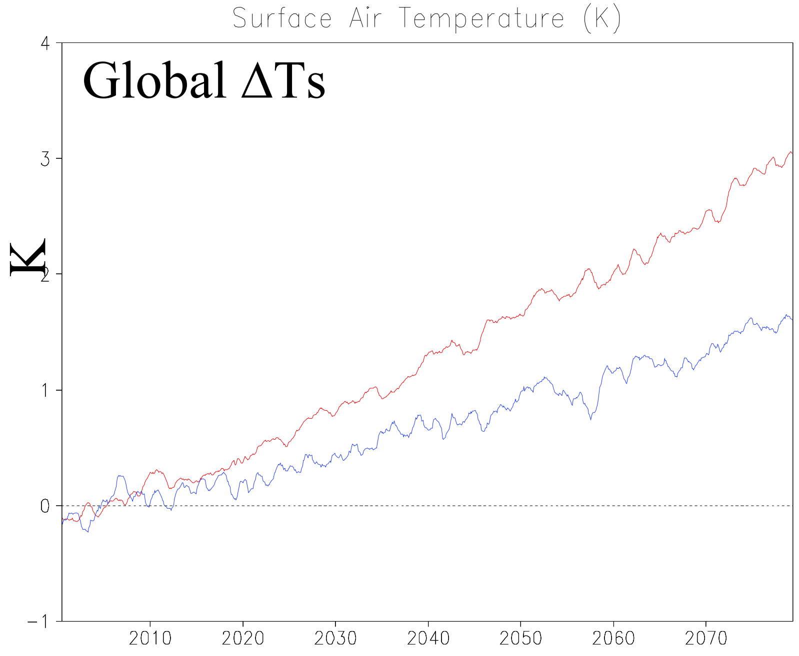
Global mean : -20 W/m^2 in the current climate

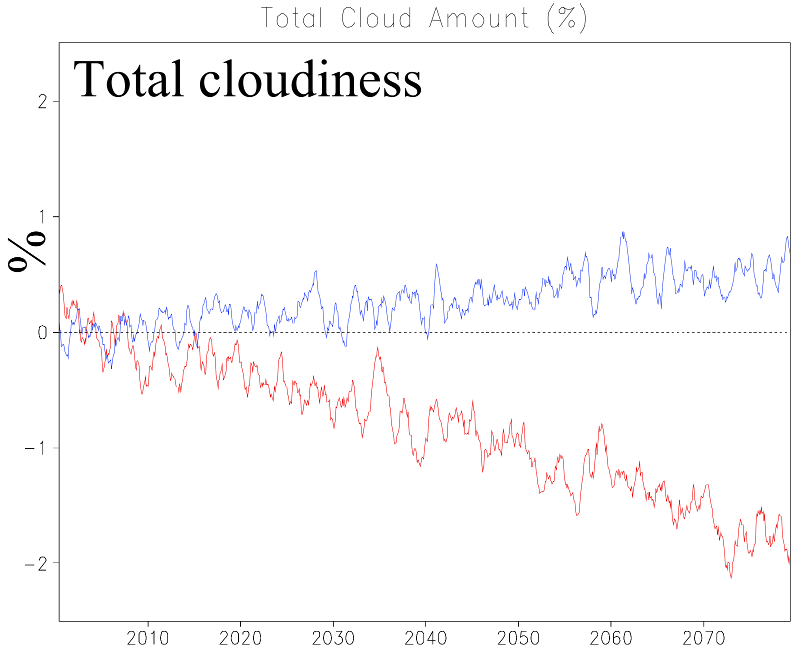
Clouds & climate sensitivity

AR4 OAGCMs :

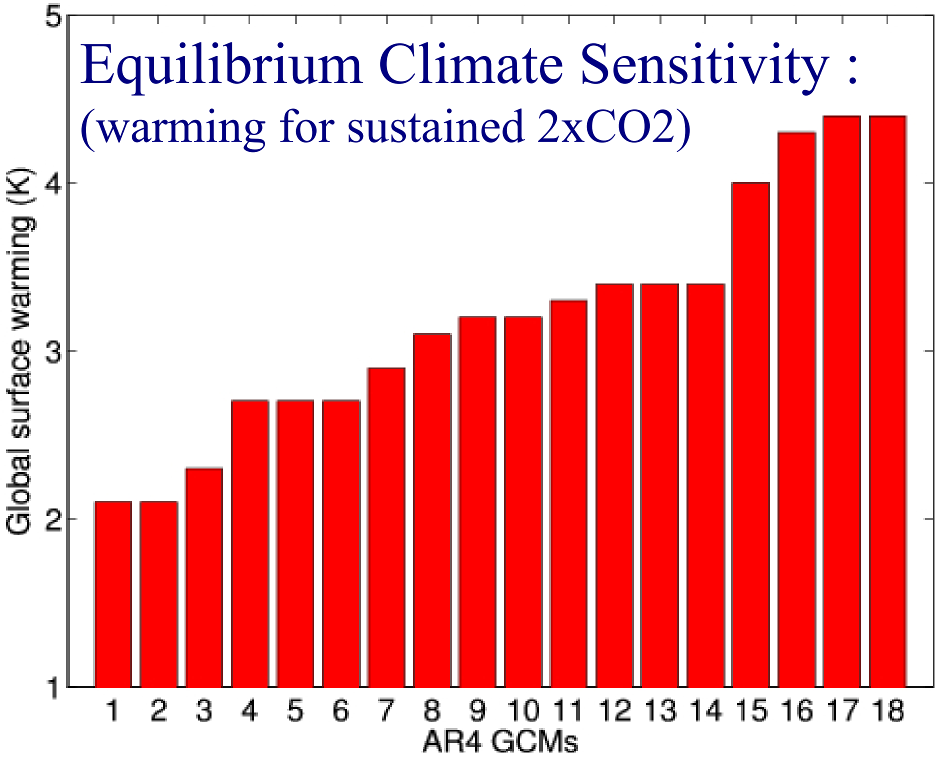
MIROC-HIRES vs NCAR CCSM3
global warming experiments
(+1% CO_2/yr)

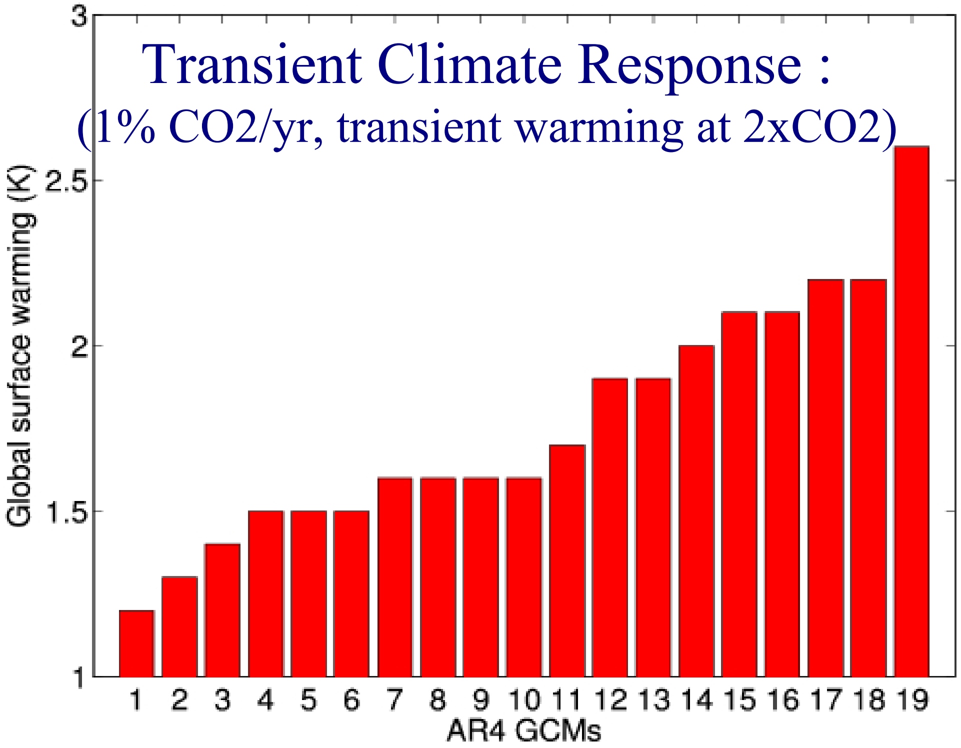






Climate sensitivity estimates from CMIP3 GCMs participating in the IPCC AR4 :





[IPCC AR4, Randall et al. 2007]

<u>Spread in climate sensitivity and TCR</u> : a concern for many aspects of climate change research (assessment of climate extremes and impacts, the design of mitigation scenarios, etc)

<u>Origin of the spread</u> : radiative forcing ? climate feedbacks ? ocean heat uptake ?

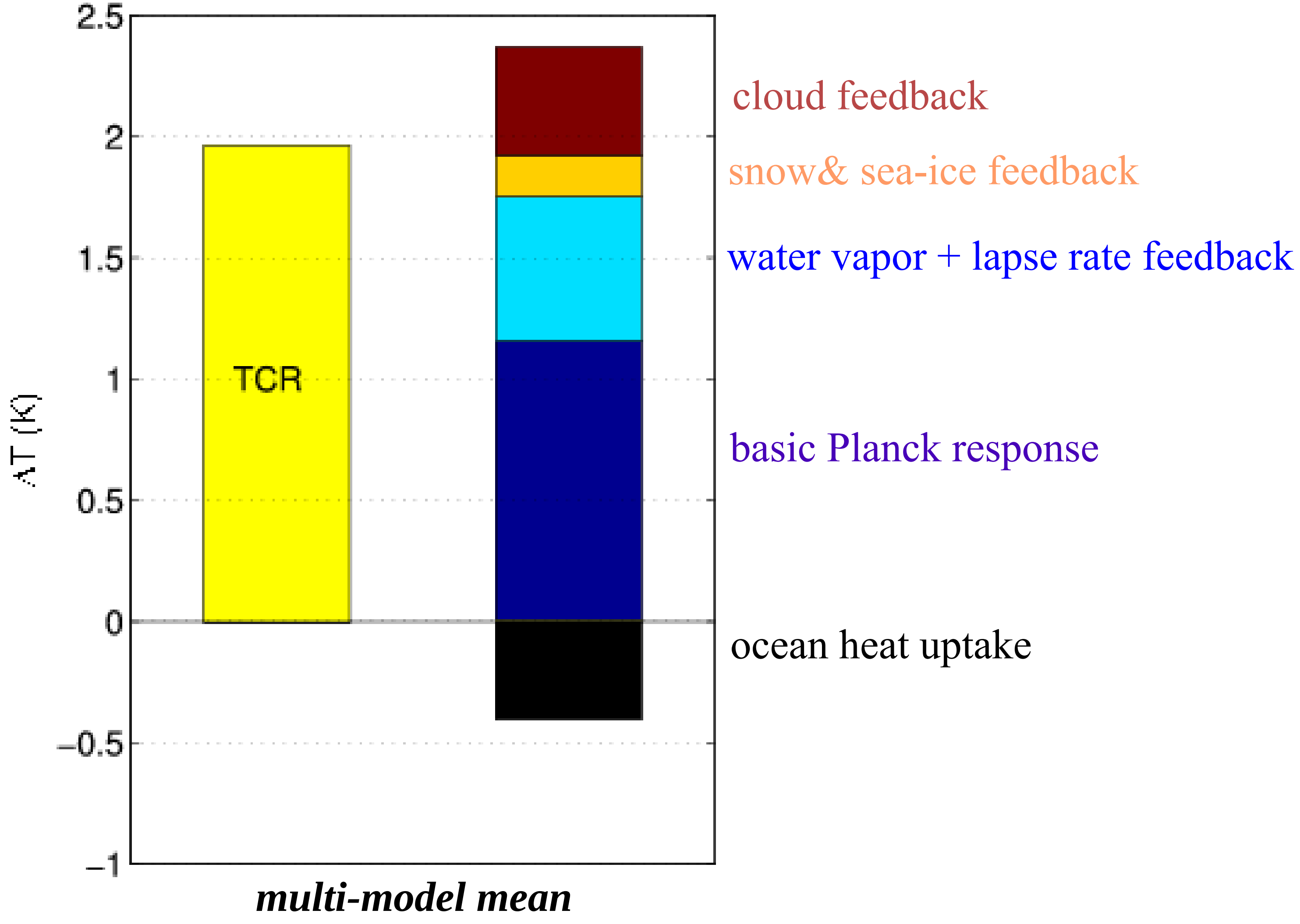
Decomposition of the Transient Climate Response (TCR) simulated by CMIP3/AR4 OAGCMs :

$$\Delta T_s = \Delta T_{s,P} + \sum_{x \neq P} \Delta T_{s,x} + \Delta T_{s,\kappa}$$

Planck response

Feedback contributions

Ocean heat uptake contribution



(Dufresne & Bony, J. Climate, 2008)

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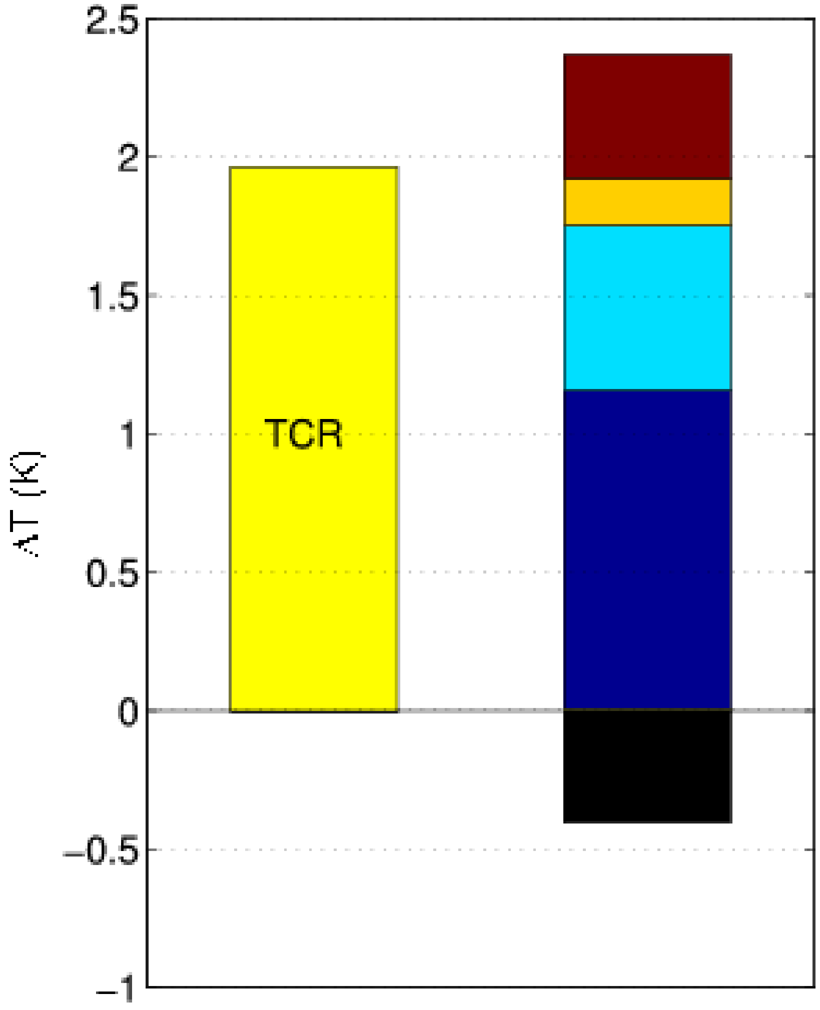
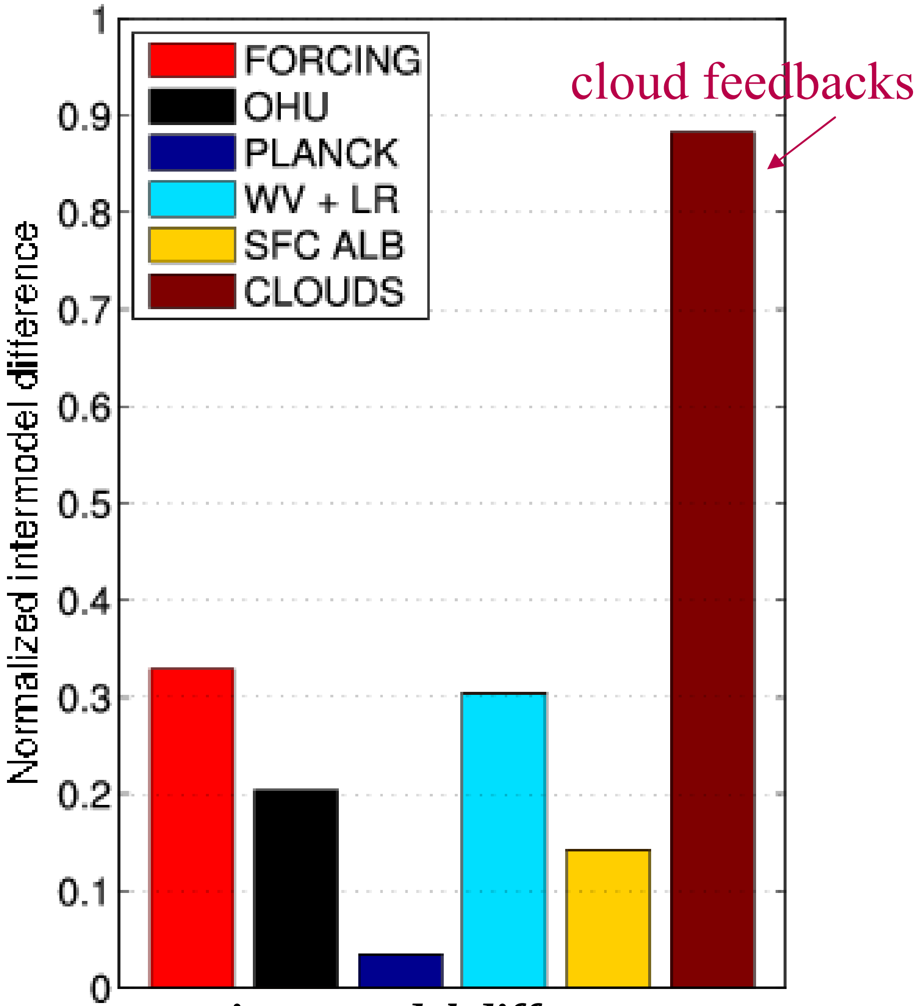


multi-model mean



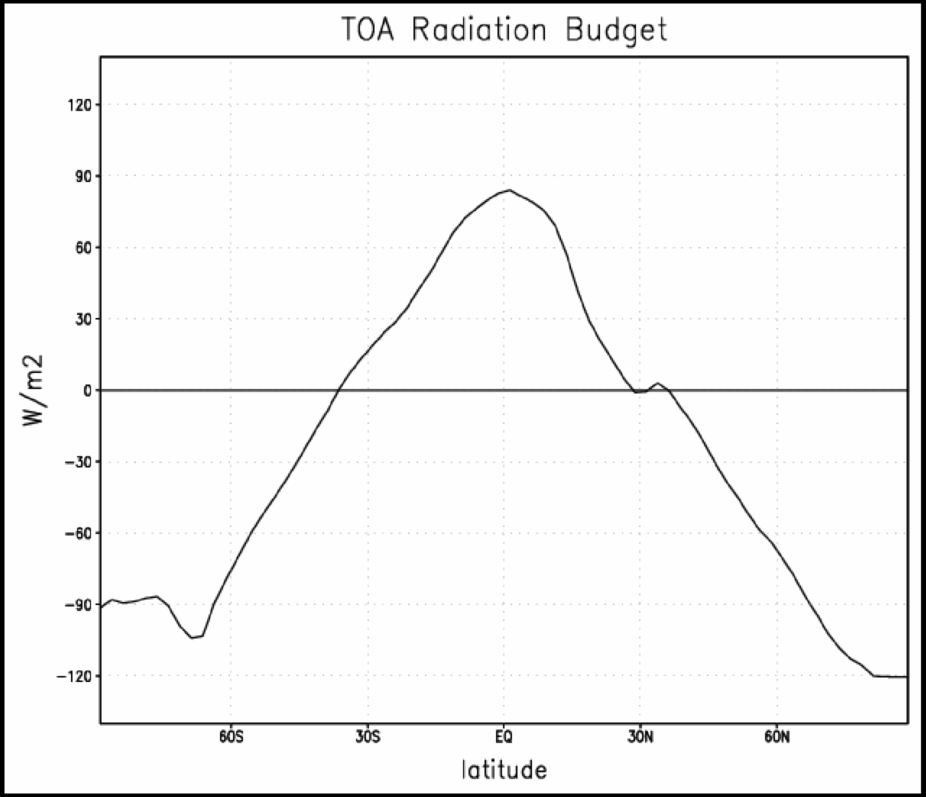
inter-model differences

(Dufresne & Bony, J. Climate, 2008)

“Cloud feedbacks remain the largest source of uncertainty in model based estimates of climate sensitivity”

IPCC AR4, 2007

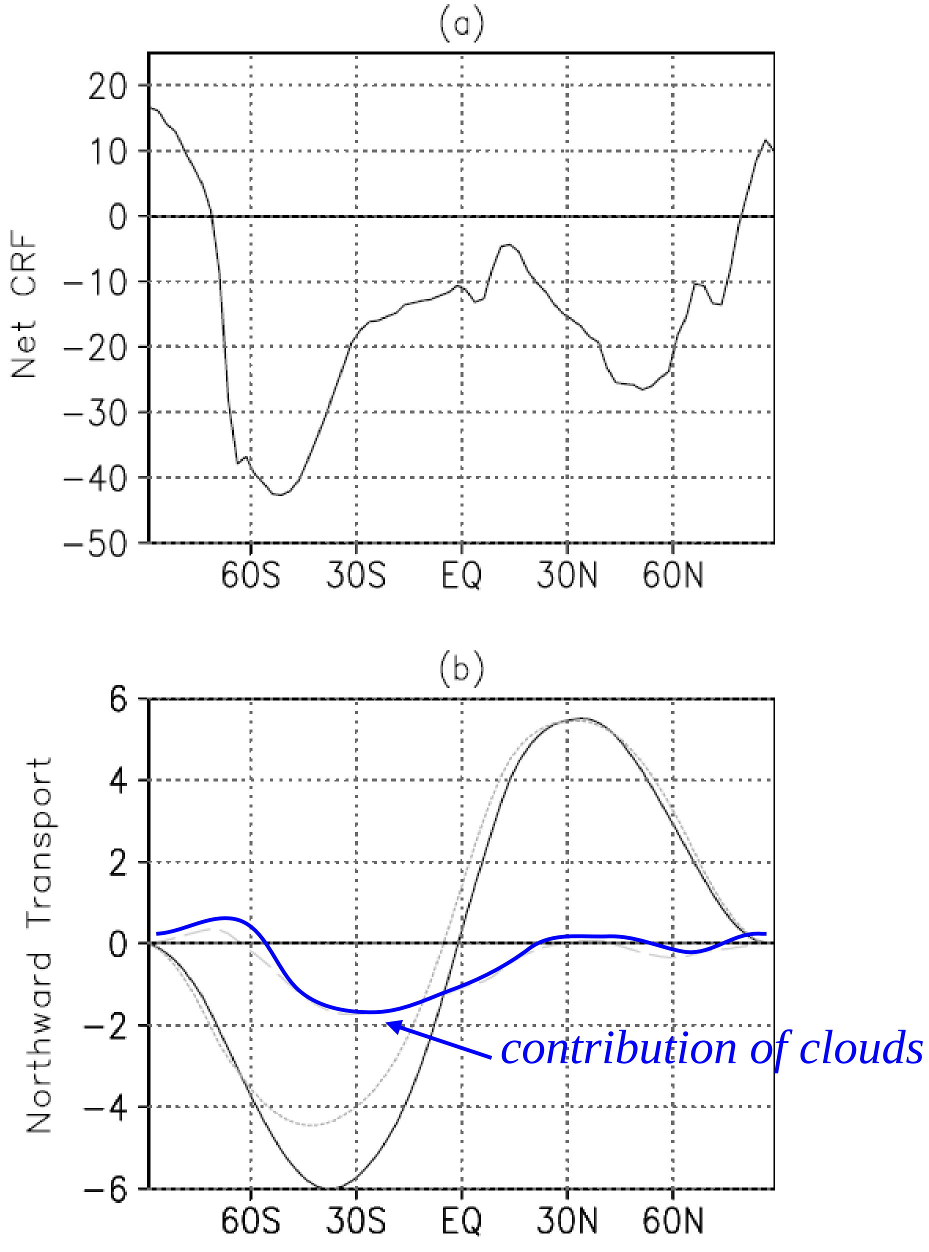
2. Cloud-radiation interactions and hemispheric energy transports



Cloud-radiative effects and poleward heat transports

Clouds enhance the meridional gradient of the TOA radiation budget, and thus the poleward heat transport by the ocean-atmosphere system.

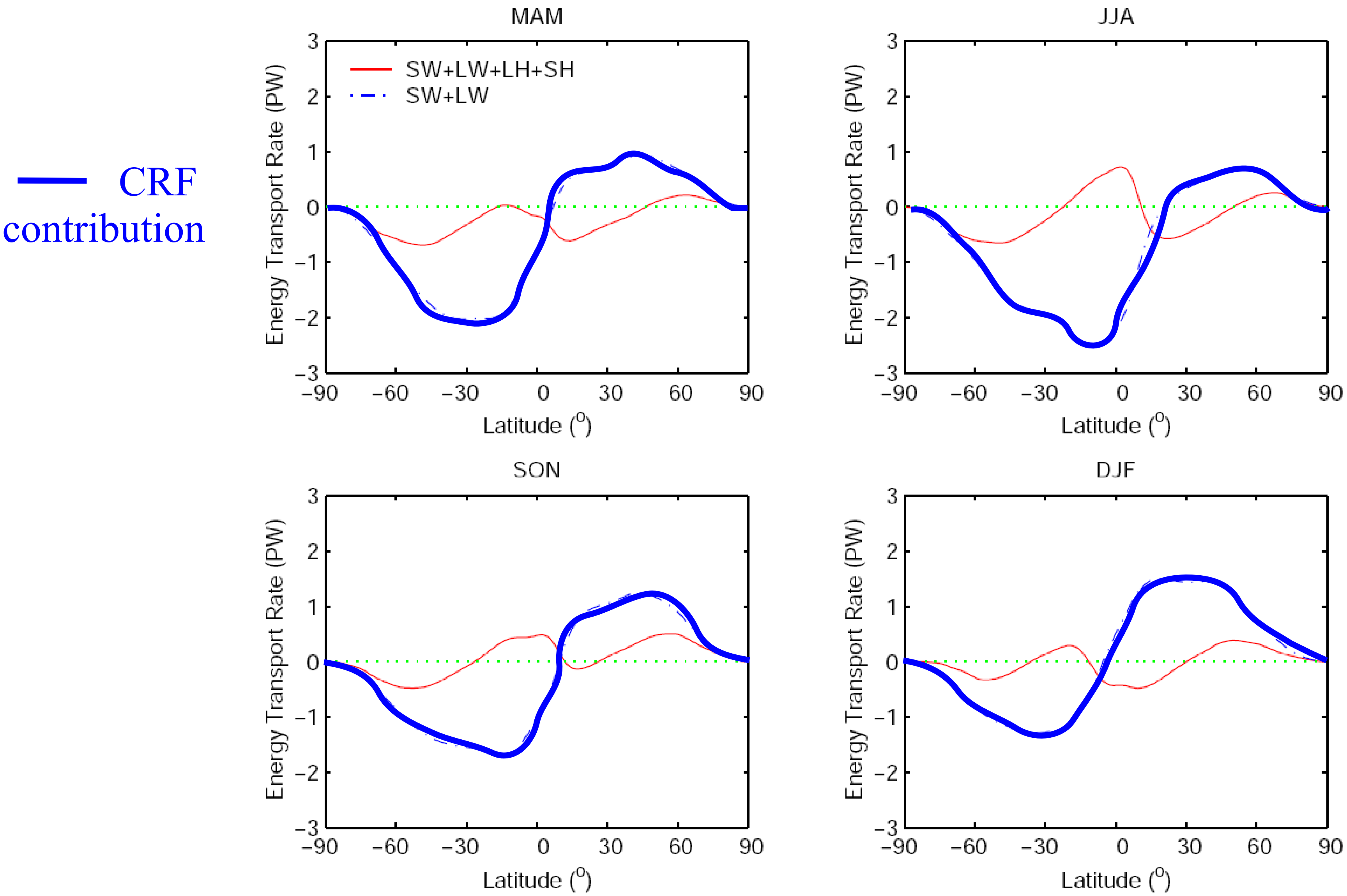
The heat transport attributable to cloud-radiative effects represents a significant part of the total *(Zhang & Rossow 1997, Weaver 2003)*



(Weaver, GRL, 2003)

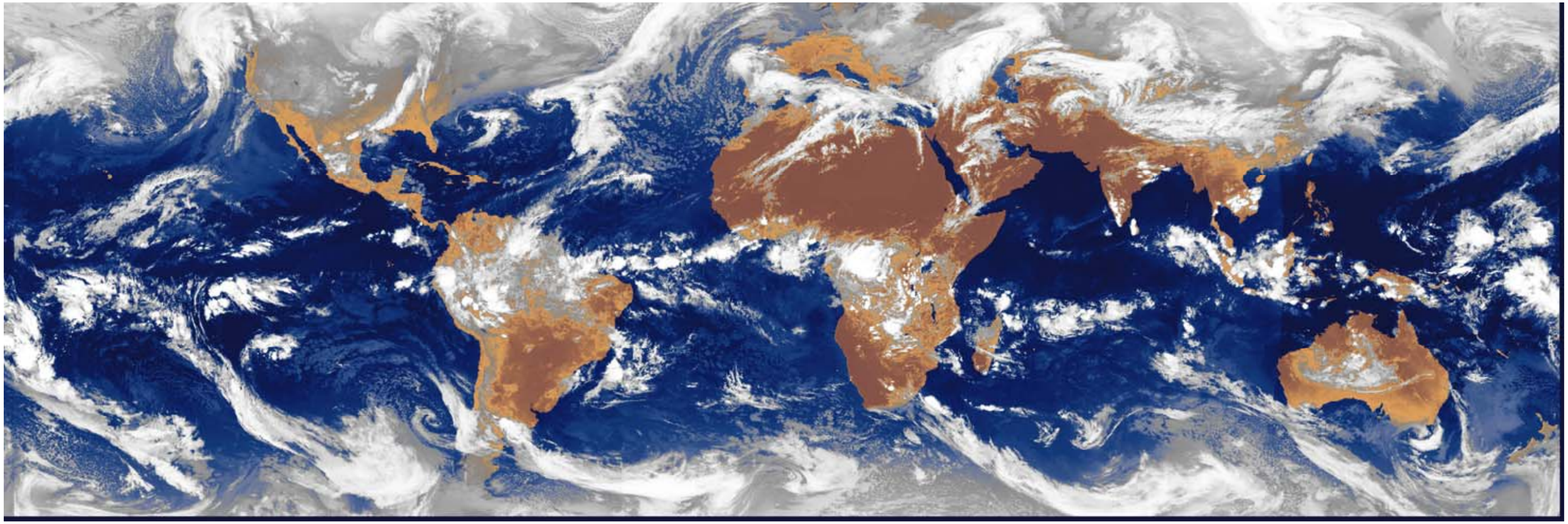
Cloud-radiative effects and poleward heat transports

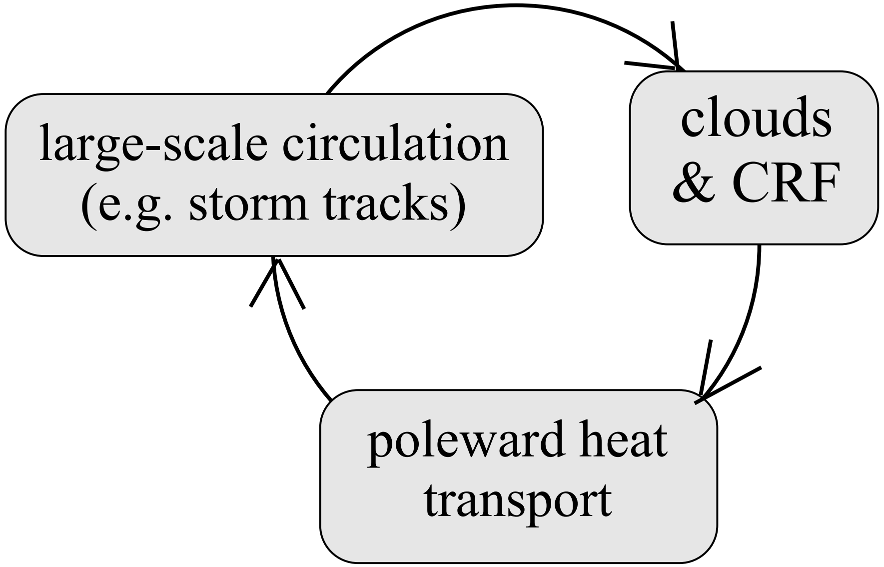
Recent observational estimates (using CERES) suggest that cloud-radiative effects enhance the equator-to-pole transport of energy ***by the atmosphere***



(Kato et al., J. Climate, 2008)

Cloud-radiative effects and poleward heat transports





large-scale circulation
(e.g. storm tracks)

clouds
& CRF

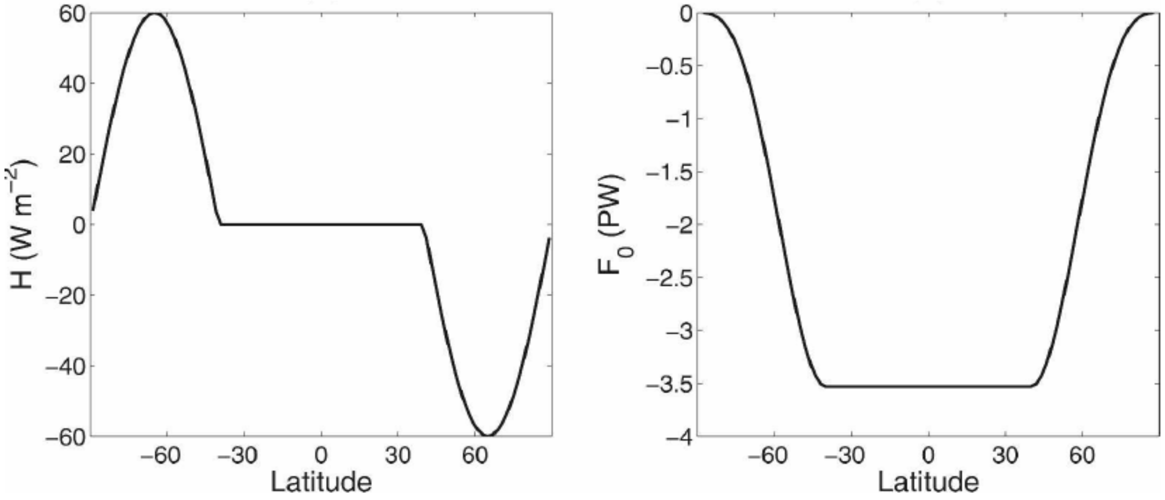
poleward heat
transport

Feedback
between clouds, radiation
and atmospheric dynamics

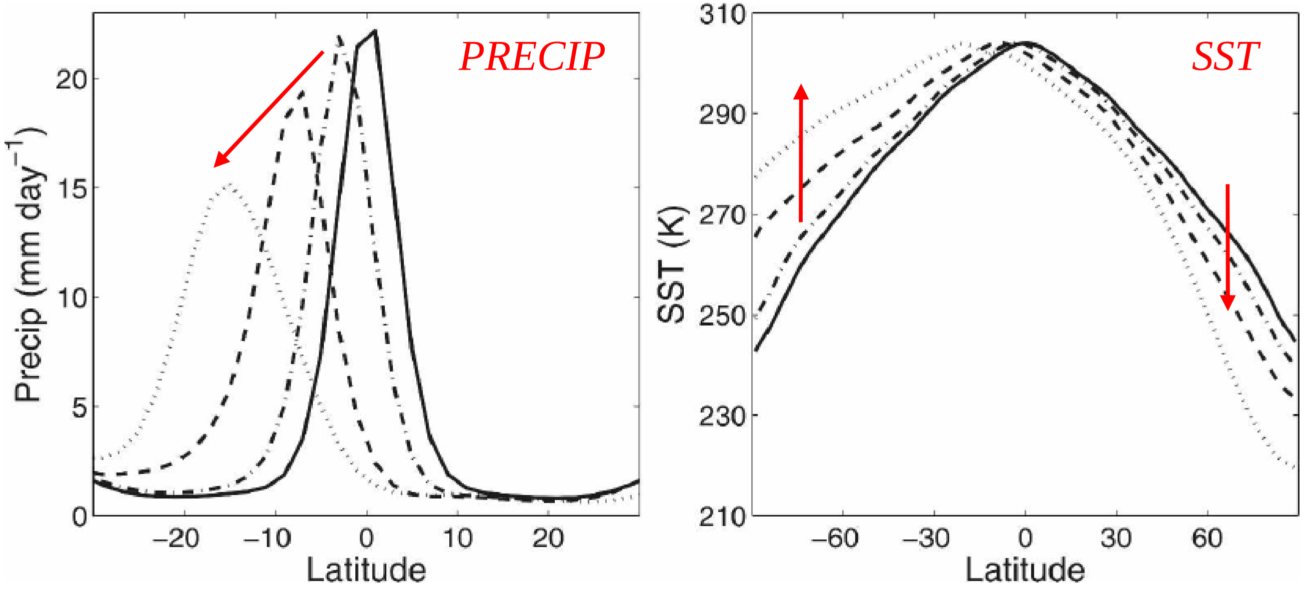
Key component of the
current general circulation
.... and potentially critical for
its sensitivity to external forcings

Response of the ITCZ to an imposed extratropical forcing in an aqua-planet GCM coupled to a slab ocean

(Kang et al., J. Climate, 2008)



An extratropical thermal forcing is imposed beneath the ocean mixed layer (equivalent to an imposed NH-to-SH cross-equatorial ocean heat transport)



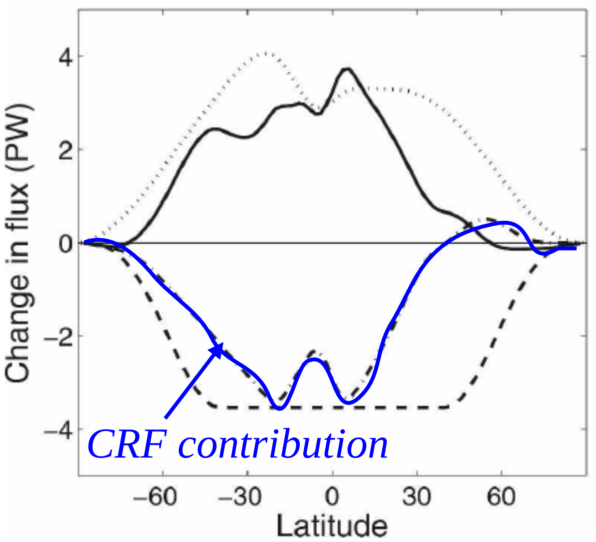
Response (plotted here for different strengths of the forcing) :

- warmer SH, cooler NH
- shift of the ITCZ toward the warmed hemisphere

Response of the ITCZ to an imposed extratropical forcing in an aqua-planet GCM coupled to a slab ocean

(Kang et al., J. Climate, 2008)

The impact of SW CRF changes on energy transports *amplifies* the effect of the extratropical forcing (less low clouds in the warmer hemisphere, more in the cooler hemisphere).



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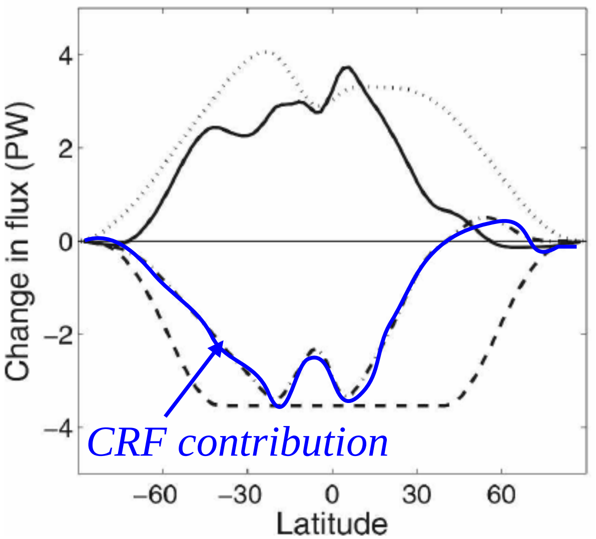
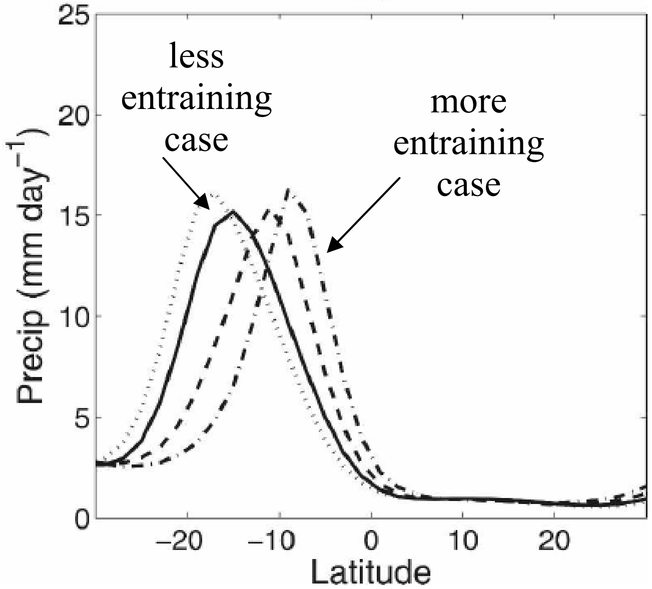


The magnitude of the ITCZ displacement turns out to be very sensitive to the model's convection scheme.



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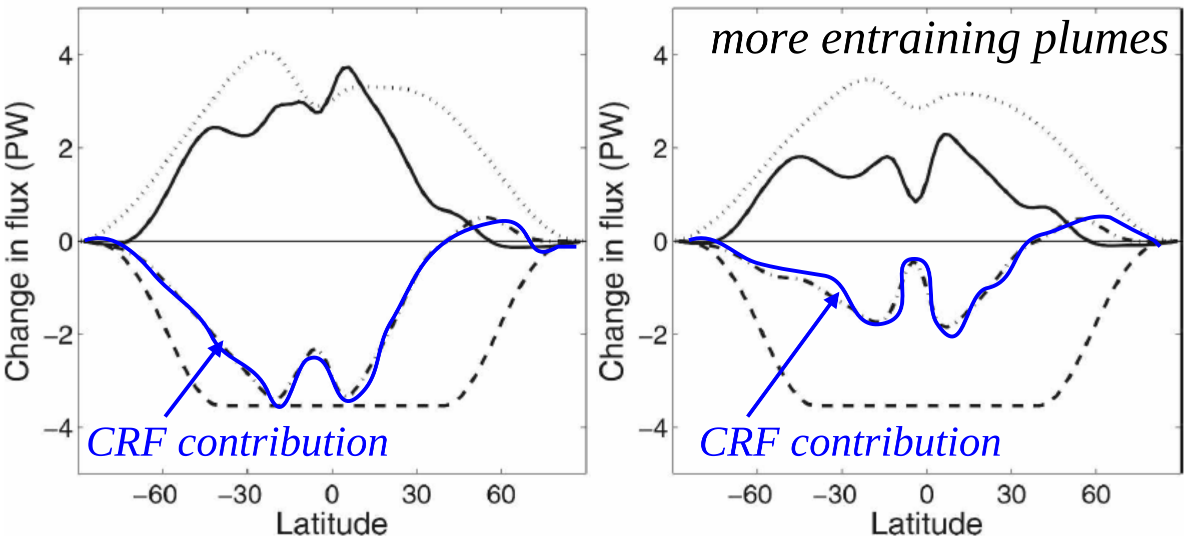
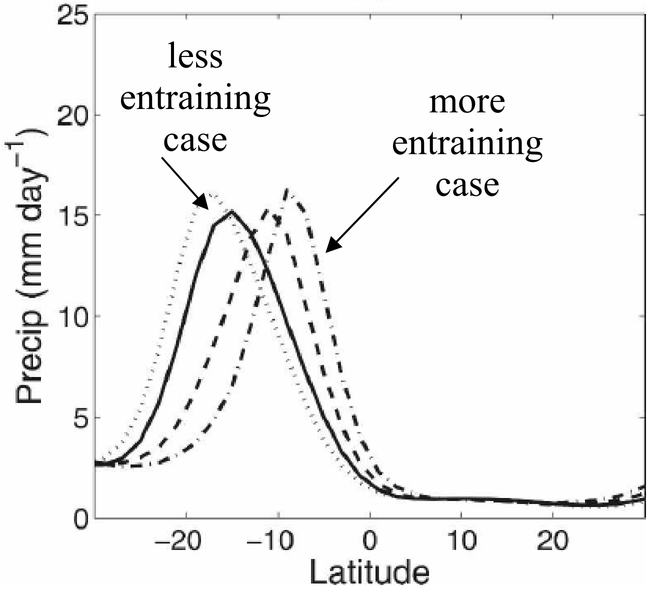


Convective entrainement affects the response of (low-level) clouds and CRF, and thereby the contribution of CRF changes to energy transports.

The magnitude of the ITCZ displacement turns out to be very sensitive to the model's convection scheme.



Response of the ITCZ to an imposed extratropical forcing in an aqua-planet GCM coupled to a slab ocean

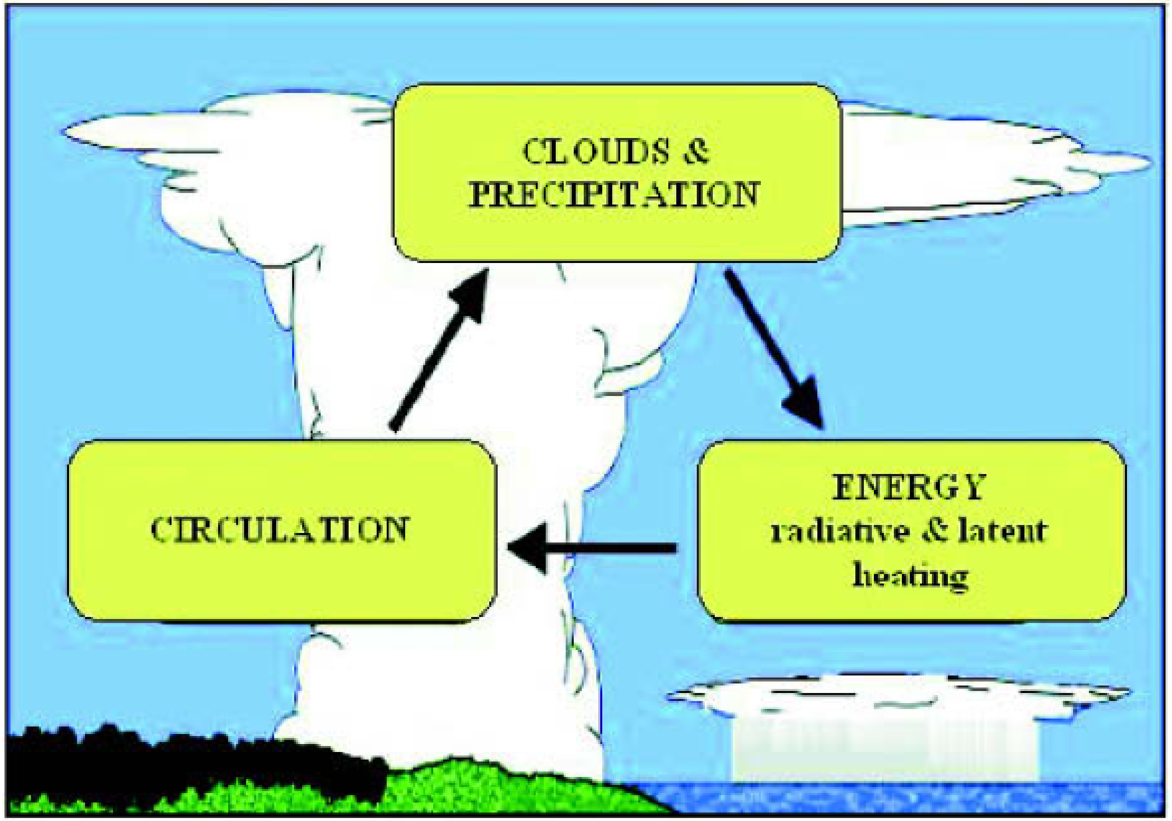
(Kang et al., J. Climate, 2008)

- Illustration of the effect of multiple interactions between processes in a GCM :

convection / clouds / radiation / energy transports / ITCZ

- Cloud-radiative feedbacks do not matter only for the global energy balance and climate sensitivity, but also for *tropical/extratropical interactions* (e.g. paleo changes, inter-hemispheric gradients in aerosols, changes in the thermohaline circulation..), and for *the regional climate response* (e.g. ITCZ shift) to an external forcing.

Interactions between clouds, radiation, atmospheric dynamics and climate :



CLOUDS & PRECIPITATION

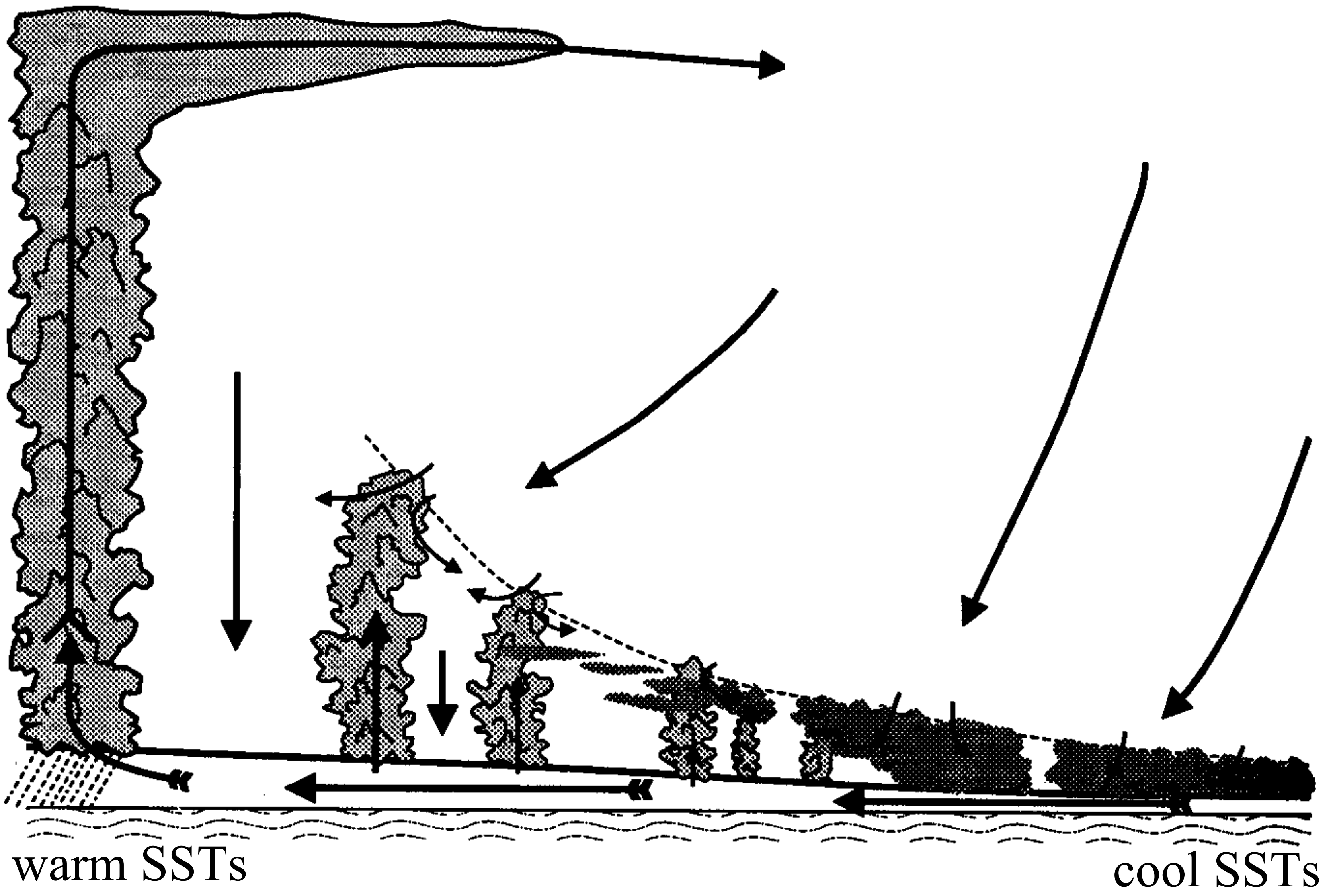
ENERGY
radiative & latent
heating

CIRCULATION

(Stephens, J. Climate, 2005)

3. Cloud-radiation interactions and the Hadley-Walker circulation

- Dynamical control on clouds and radiation

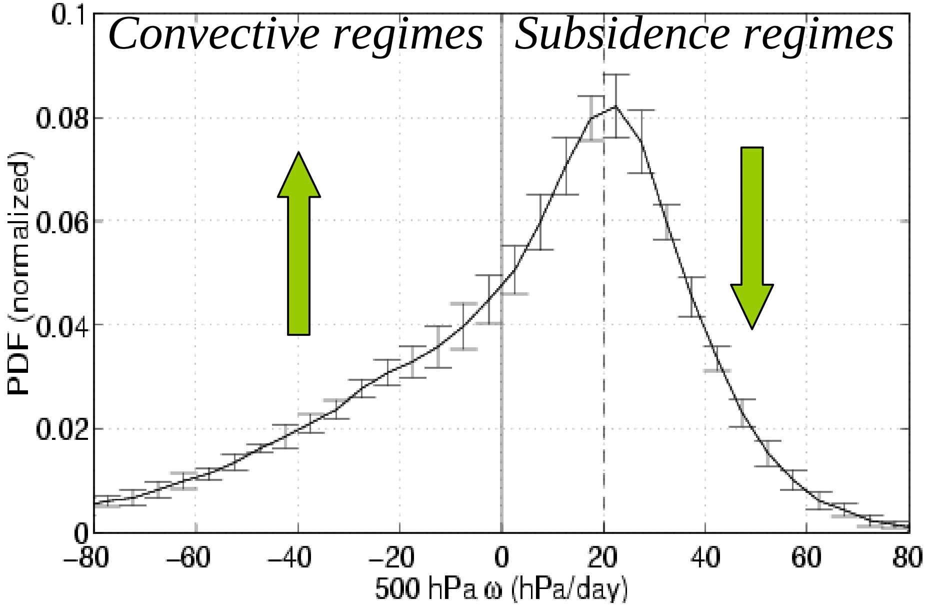


(Emanuel, 1994)

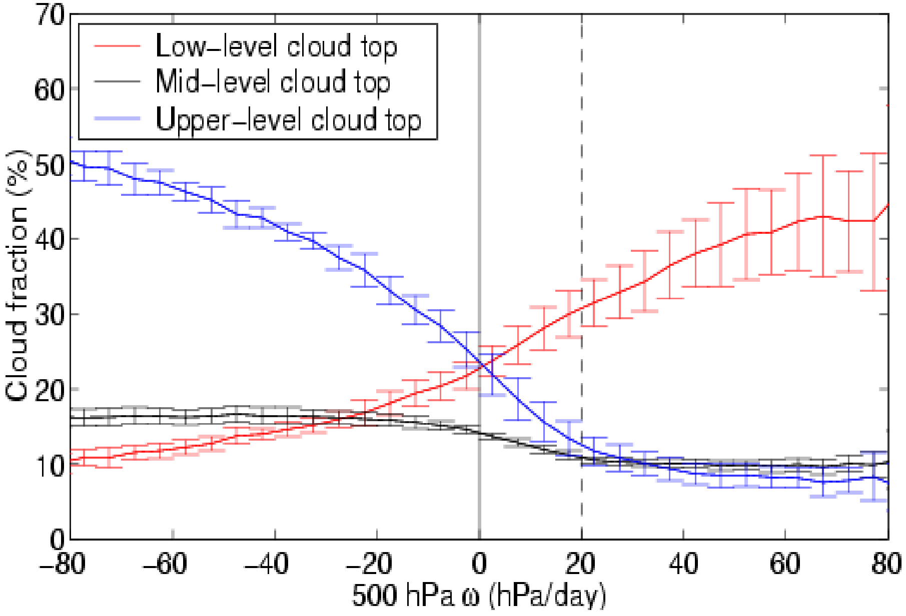
Analysis Method

- 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: $\overline{C} = \int_{-\infty}^{+\infty} P_\omega \, C_\omega \, d\omega$

Hadley-Walker circulation as a PDF of 500 hPa ω :

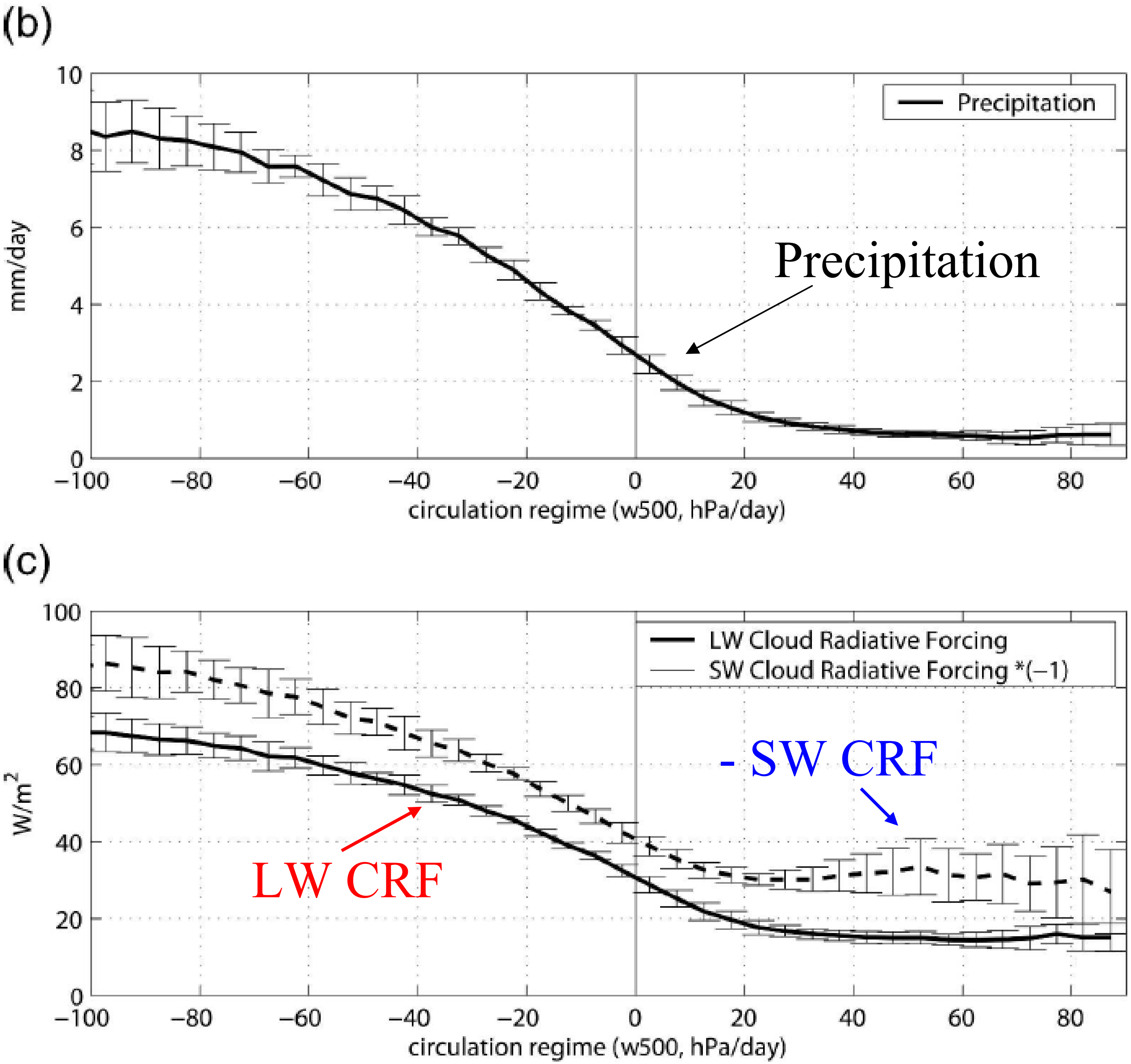


ISCCP Cloud Types sorted by dynamical regimes



(Bony et al., 2004, Bony and Dufresne, 2005)

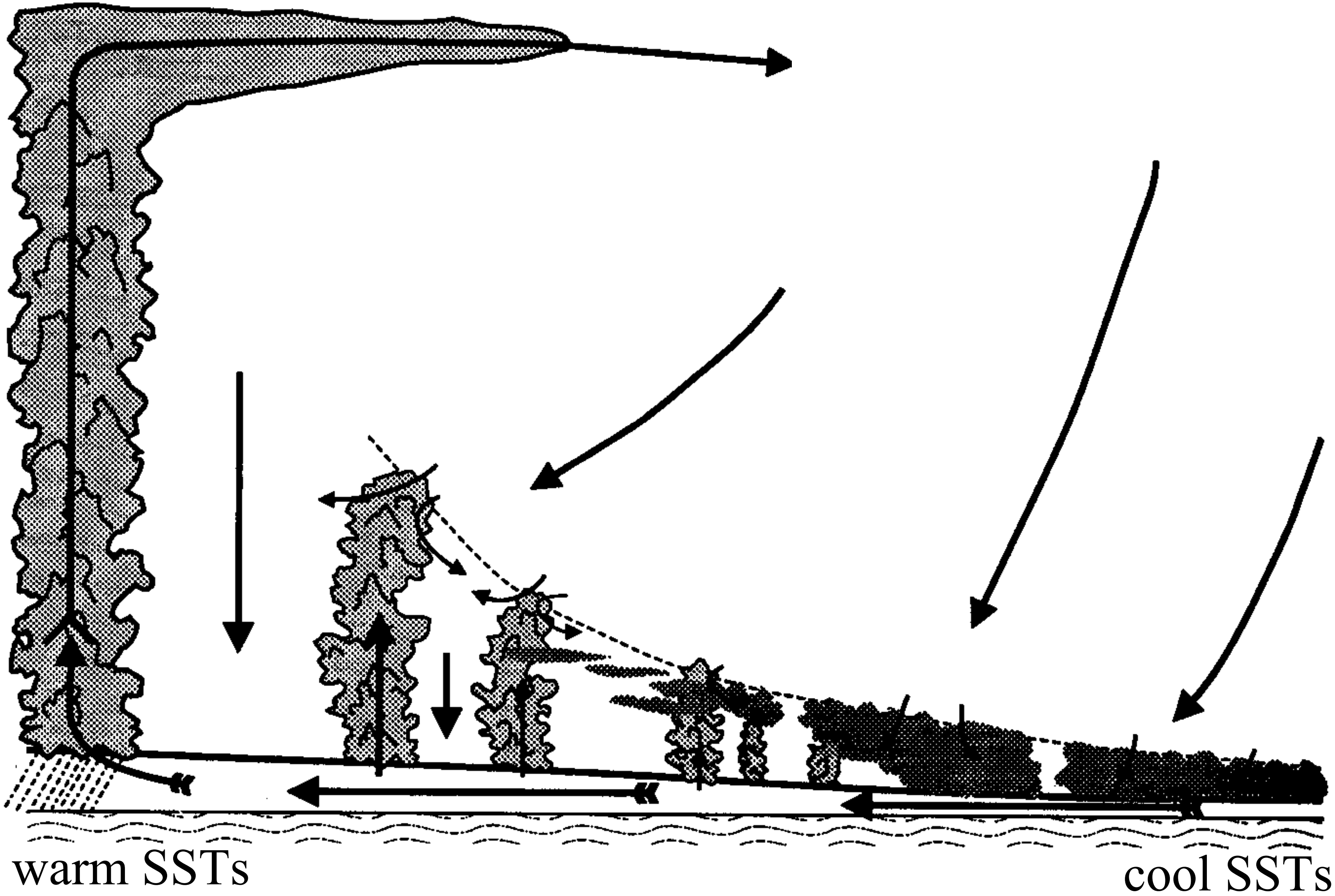
Relationship between large-scale atmospheric circulation, precipitation and cloud-radiative effects in the tropics



(Bony et al., J. Climate, 2006)

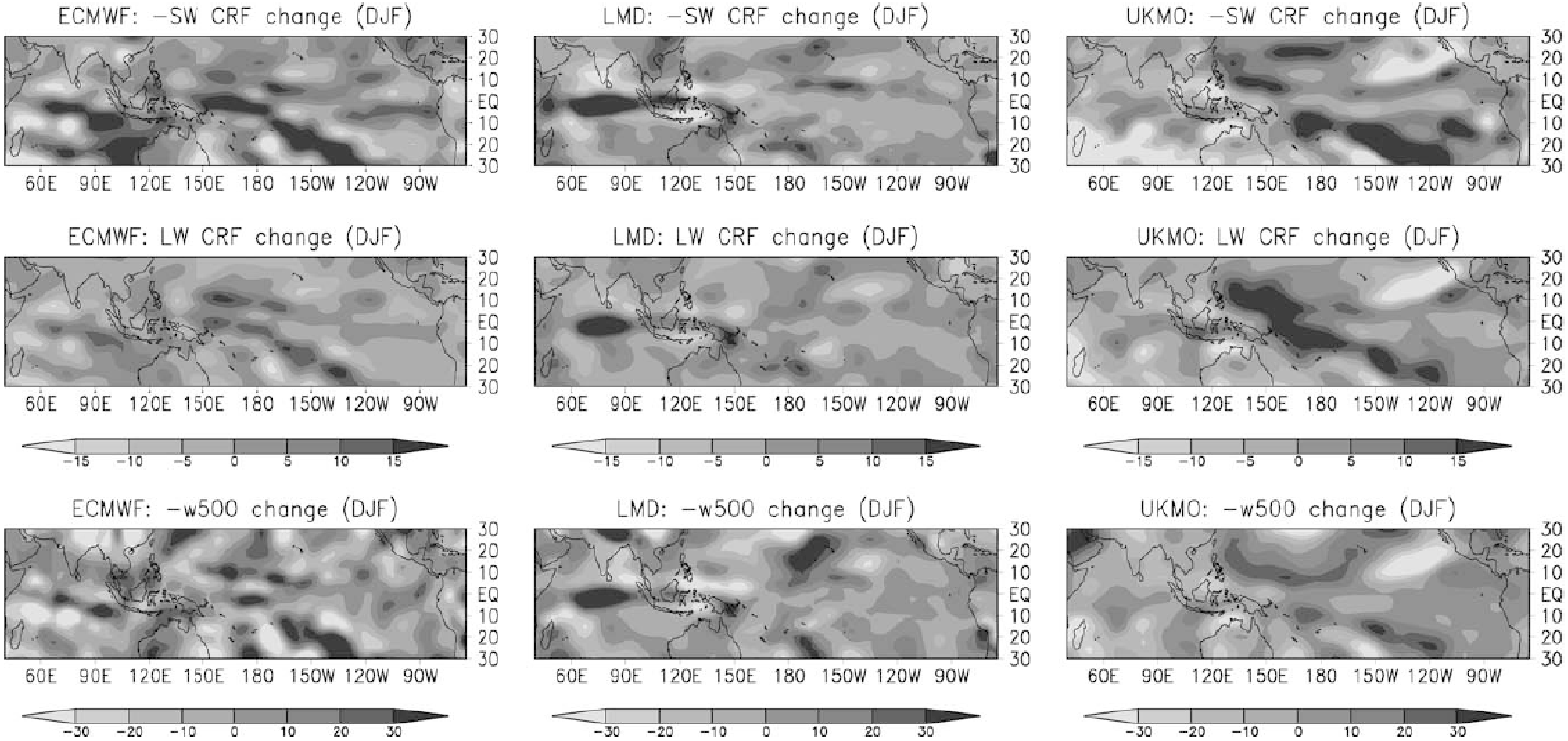
- Dynamical control on clouds and radiation

→ How does a change in the circulation affect the CRF ?



(Emanuel, 1994)

Regional changes in the large-scale atmospheric circulation and CRF in GCM experiments (uniform +2K)



(Bony et al., Clim. Dyn., 2004)

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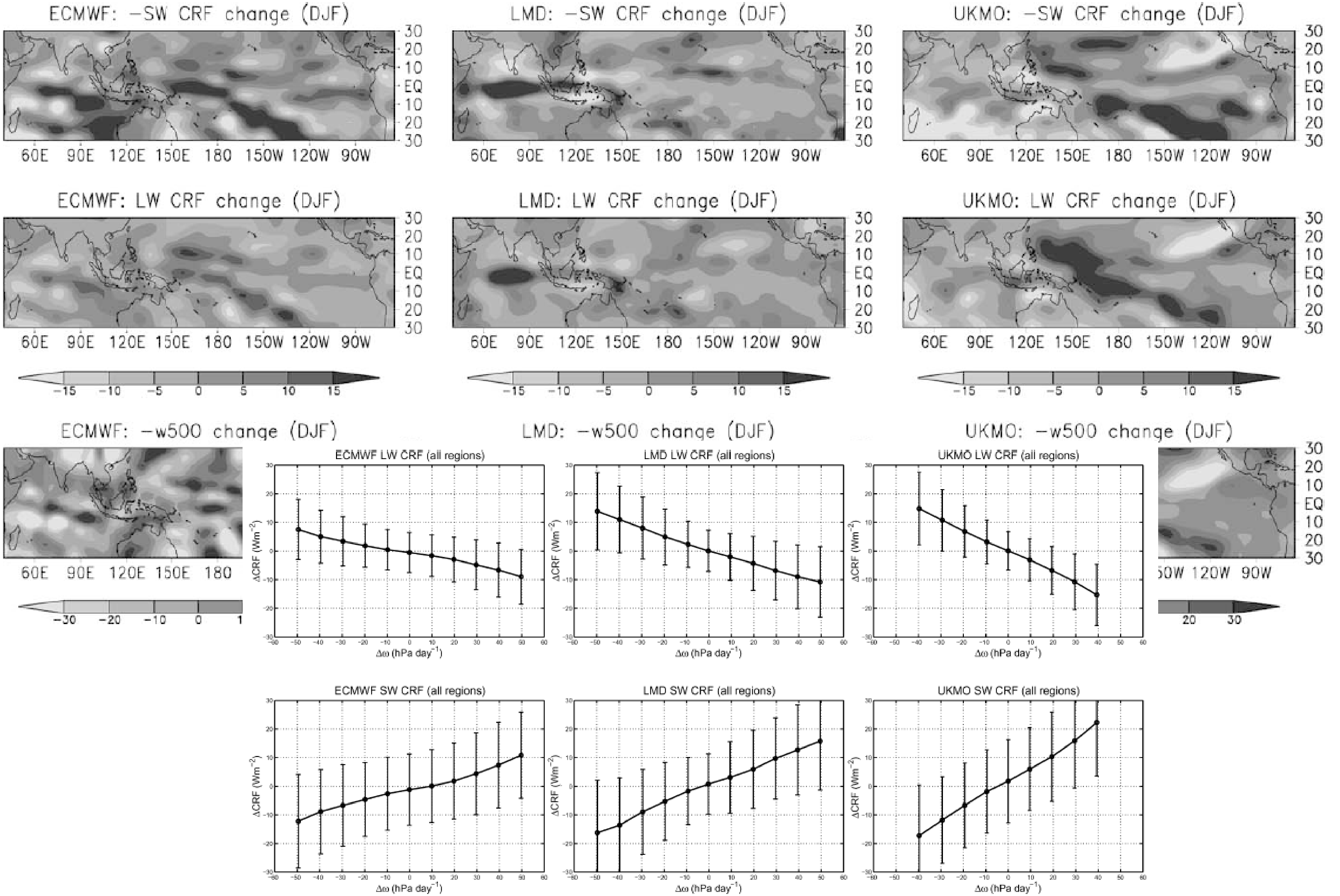
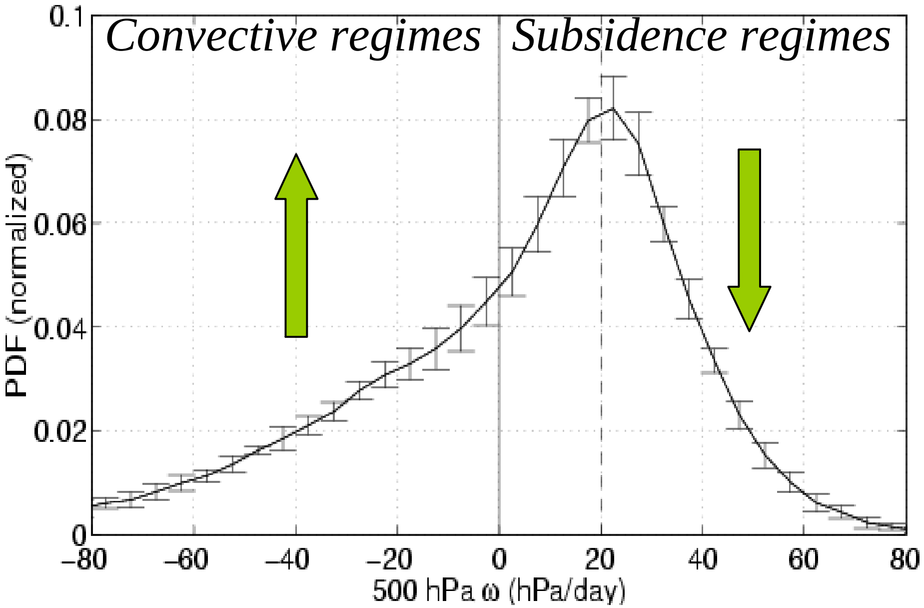


Impact at the tropics-wide scale ? *(Bony et al., Clim. Dyn., 2004)*

Analysis Method

Hadley-Walker circulation as a PDF of 500 hPa ω :



- Proxy ω for large-scale motions: ω_{500hPa}.

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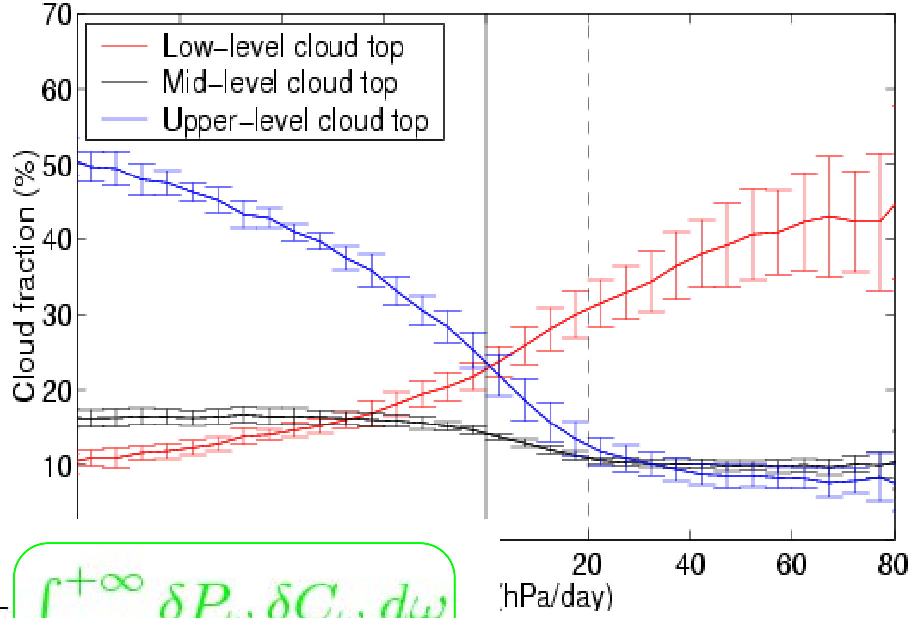
ISCCP Cloud Types sorted by dynamical regimes



$$\overline{\delta C} = \boxed{\int_{-\infty}^{+\infty} C_\omega \, \delta P_\omega \, d\omega} + \boxed{\int_{-\infty}^{+\infty} P_\omega \, \delta C_\omega \, d\omega} + \boxed{\int_{-\infty}^{+\infty} \delta P_\omega \, \delta C_\omega \, d\omega}$$

dynamic component **thermodynamic component** **co-variation**

How do changes in the statistical weight of the different circulation regimes (P_ω) affects the *tropical-mean* radiation budget ?

$$\overline{\delta C} = \boxed{\int_{-\infty}^{+\infty} C_\omega \, \delta P_\omega \, d\omega} + \boxed{\int_{-\infty}^{+\infty} P_\omega \, \delta C_\omega \, d\omega} + \boxed{\int_{-\infty}^{+\infty} \delta P_\omega \, \delta C_\omega \, d\omega}$$

dynamic component **thermodynamic component** **co-variation**

For observed seasonal, interannual (ENSO), decadal variations, as well as for GCM climate change experiments :

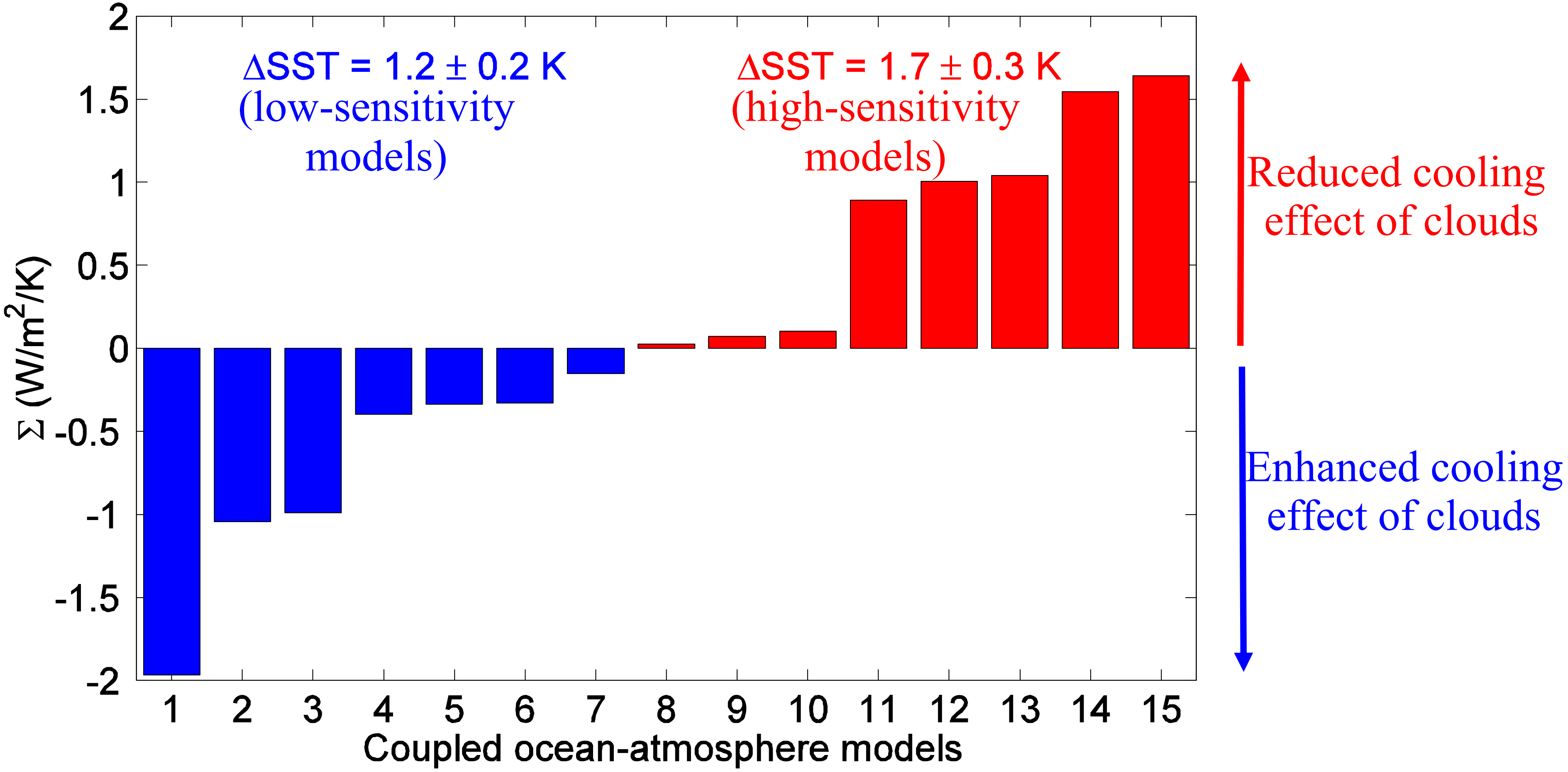
dynamic component << thermodynamic component

Bony et al., Clim. Dyn., 2004
Bony and Dufresne, GRL, 2005
Clement and Soden, J. Climate, 2005
Wyant et al., Clim. Dyn., 2006
Yuan et al., J. Climate, 2008

Therefore, although regional changes in the CRF are primarily controlled by dynamical changes, changes in the tropically-averaged radiation budget may be interpreted at first order by examining how clouds and radiation change within specified dynamical regimes (sensitivity to surface conditions, atmospheric stratification, etc).

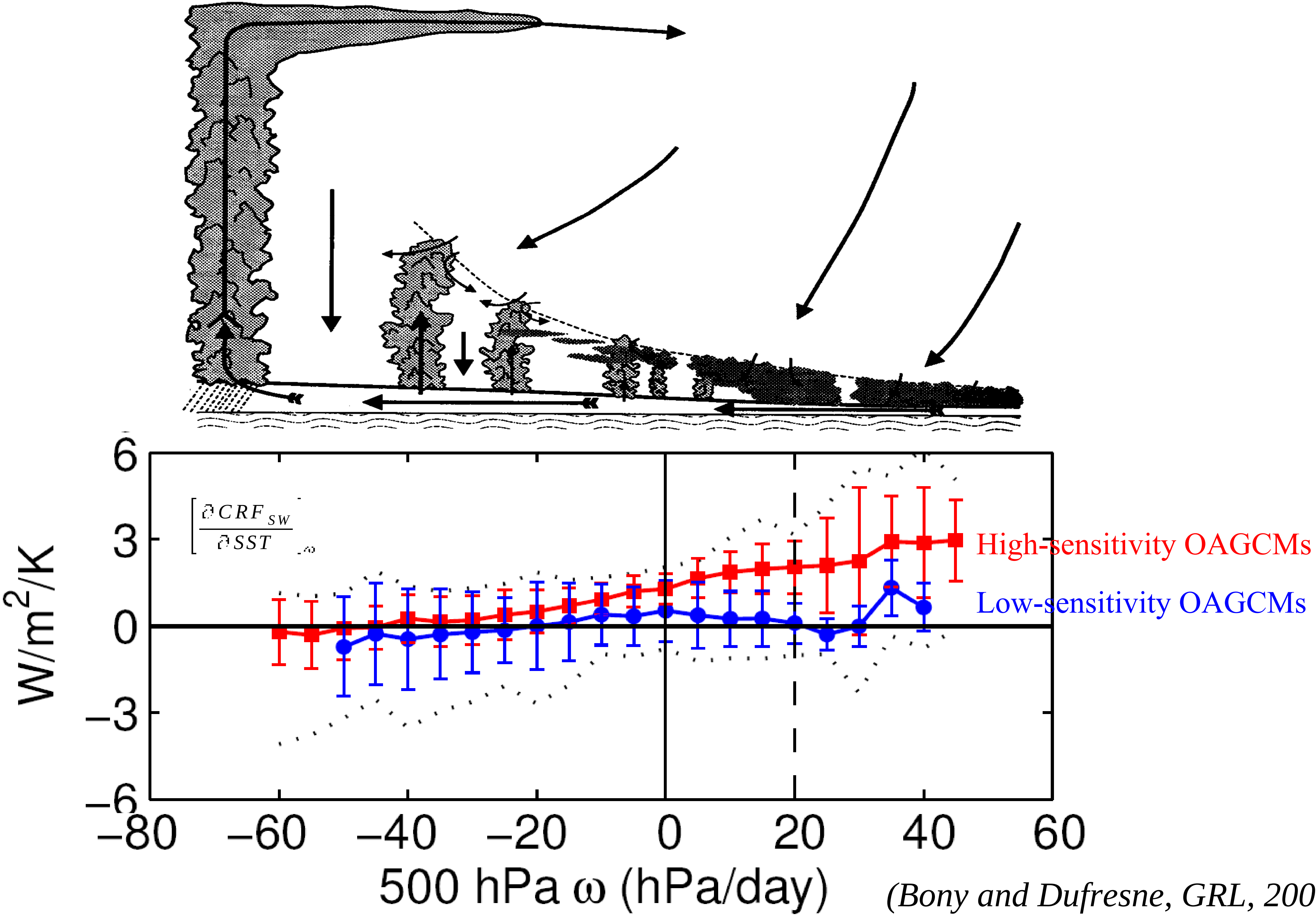
15 CMIP3/AR4 Coupled Ocean-Atmosphere GCMs
(+1% CO2/year experiments)

Sensitivity of the tropical NET CRF to global warming (W/m^2/K)



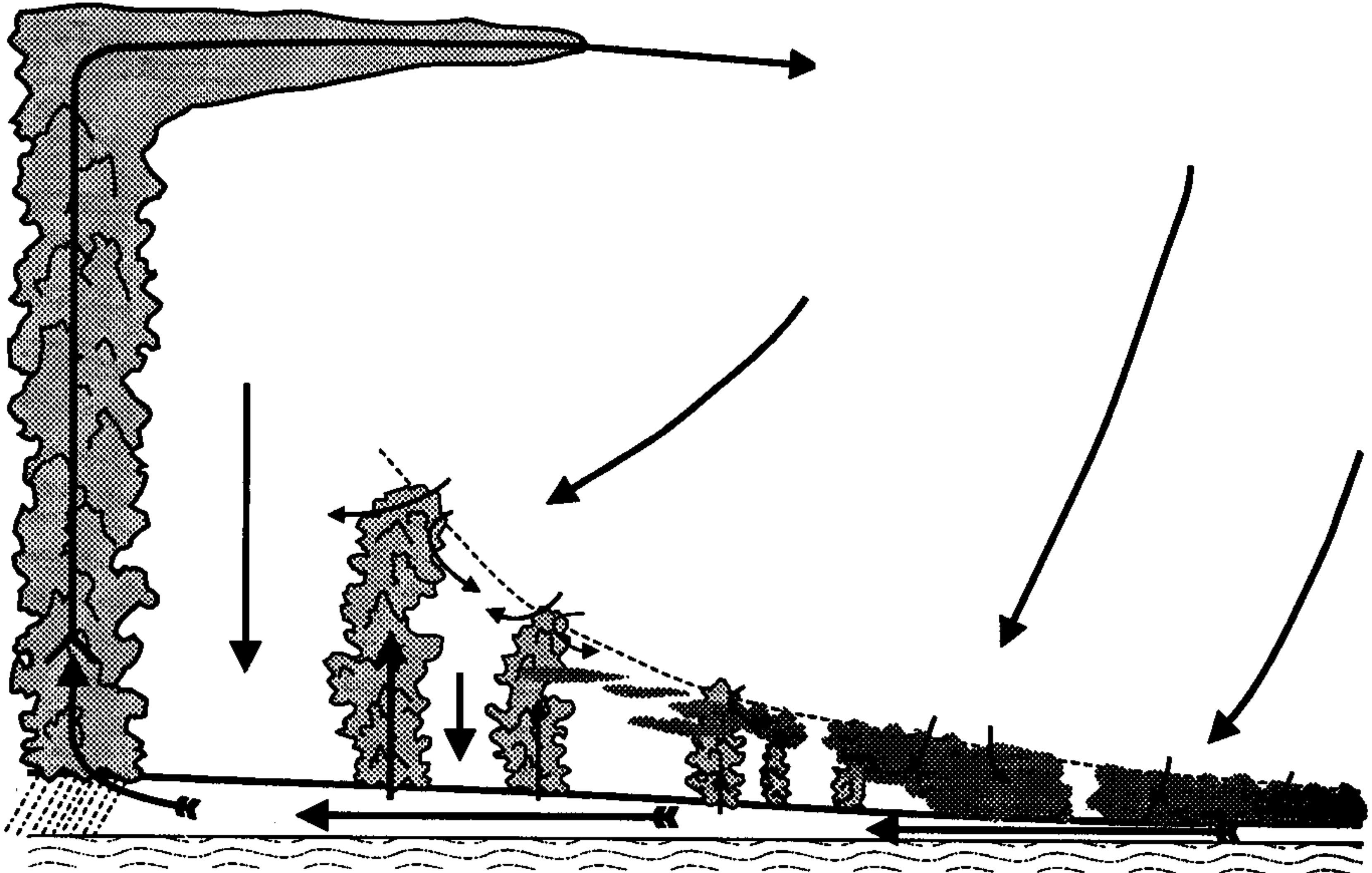
(Bony and Dufresne, GRL, 2005)

Sensitivity of the Tropical Cloud Radiative Forcing to Global Warming



(Bony and Dufresne, GRL, 2005)

- Dynamical control on clouds and radiation
- How do cloud-radiation interactions affect the Hadley-Walker circulation ?



warm SSTs

cool SSTs

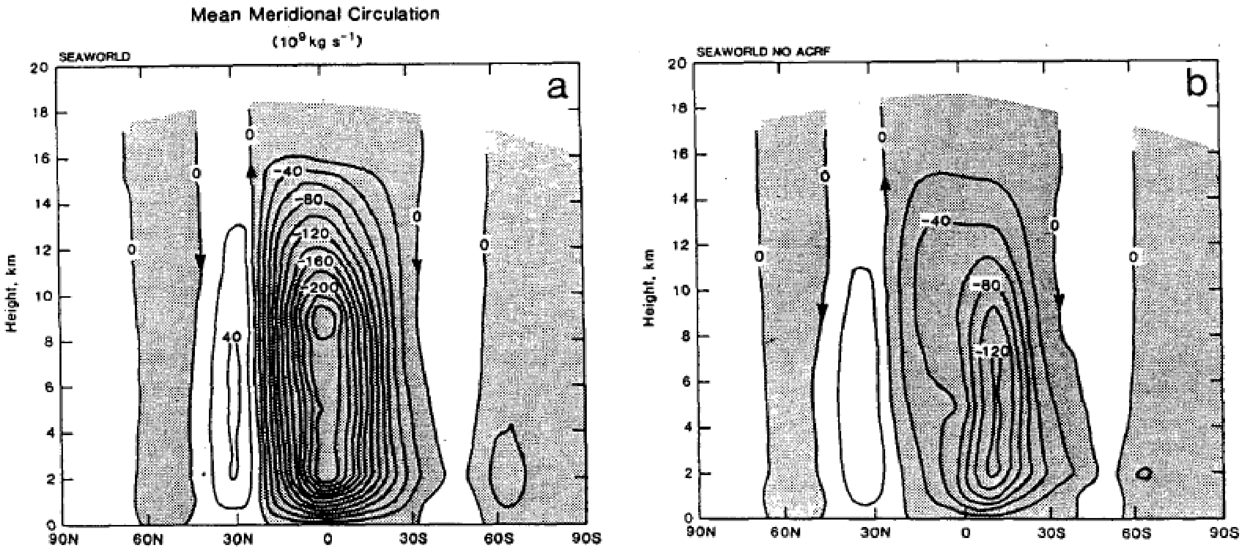
(Emanuel, 1994)

Impact of the tropospheric cloud radiative forcing on the Hadley-Walker circulation

Not a new question ...

e.g. Slingo and Slingo (1988), Randall et al. (1989), Sherwood et al (1994)...

with ACRF

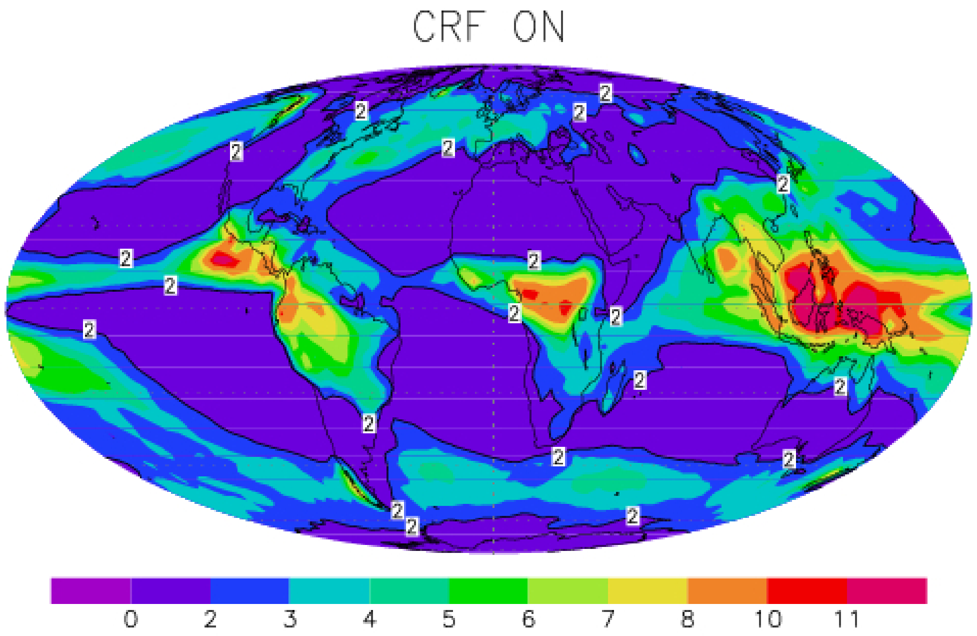


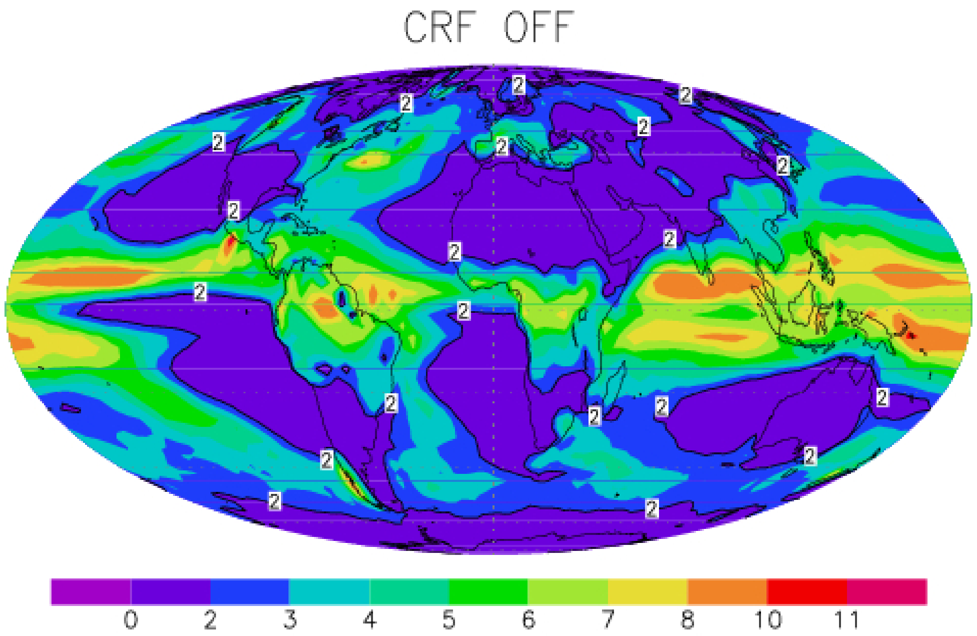
without ACRF

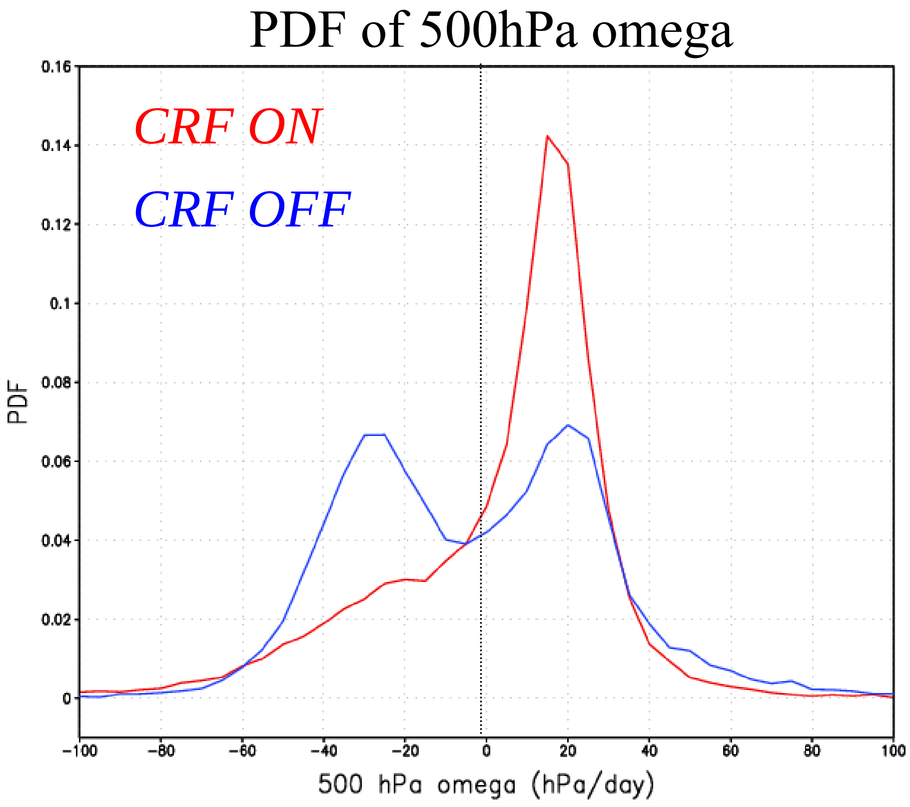
"The atmospheric CRF enhances deep convection and precipitation while supressing shallow convection, [...] and warms and moistens the tropical troposphere". In aqua-planet experiments where atmospheric cloud radiative effects are omitted, *"there is a double tropical rain band in the cloud-free run, and a single, more intense tropical rain band in the cloudy run. The cloud-free run produces relatively weak but frequent cumulus convection, while the cloudy run produces relatively intense but infrequent convection. The mean meridional circulation transports nearly twice as much mass in the cloudy run."*

(Randall et al., JAS, 1989)

Impact of the atmospheric cloud radiative forcing on GCM-simulated tropical climate



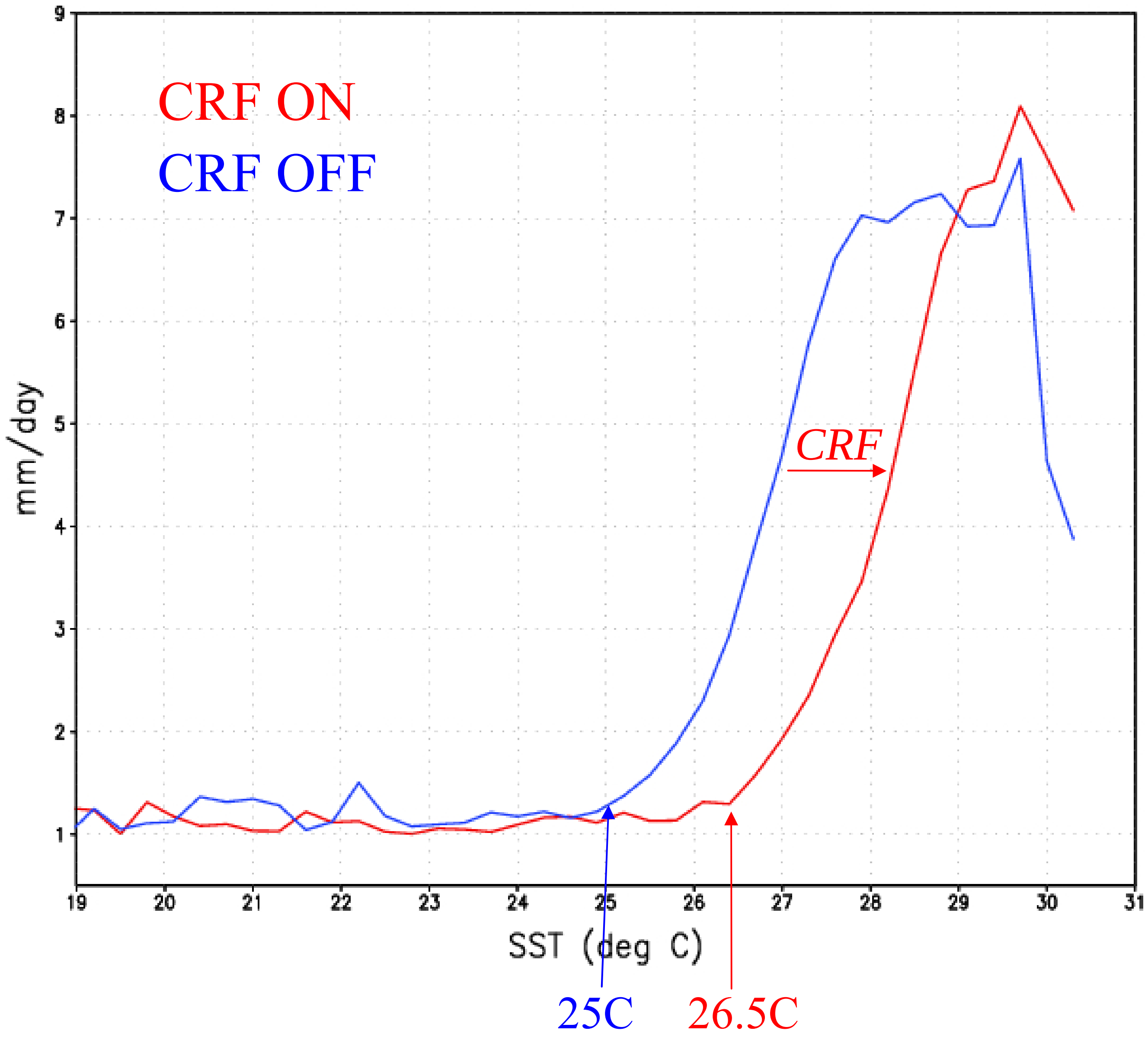




Aconv ≈ 0.3; Aconv ≈ 0.5

Cloud-radiative effects strengthen the Hadley-Walker circulation and make the ITCZ more narrow

Precipitation – SST relationship :

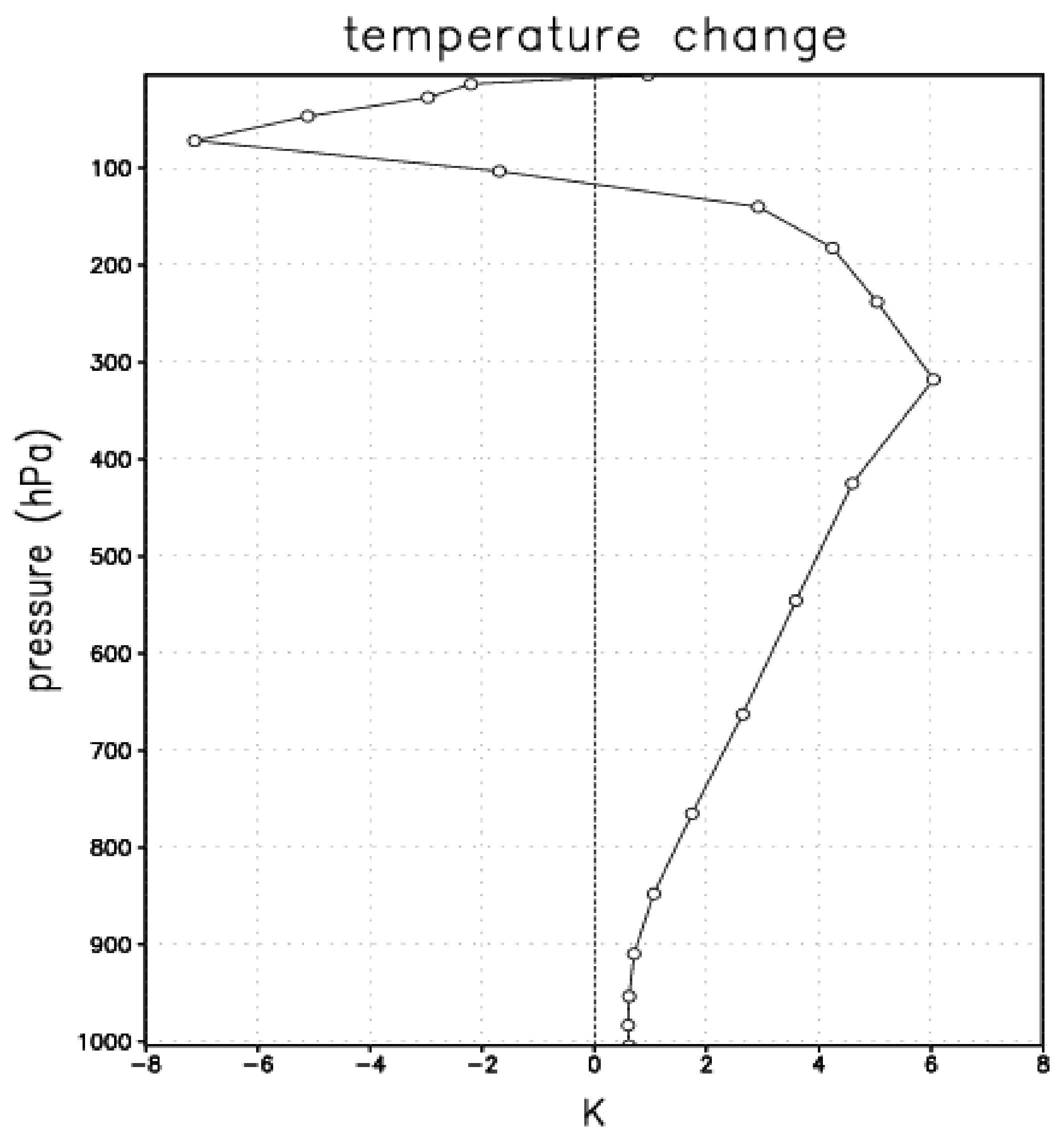


When ACRF ON :

Convection and precipitation occur over warmer SSTs

➔ Consequence of the warmer free troposphere (up to 6K at altitude) cf WTG and QE

Impact of the atmospheric cloud radiative forcing on GCM-simulated tropical climate



An approach to investigate feedbacks between parameterized atmospheric physics and large-scale dynamics *using a single-column version* of a GCM :

The Weak Temperature Gradient (WTG) approximation

(Sobel & Bretherton, J. Climate, 2000).

Single-column simulations in WTG mode

(Sobel & Bretherton, J. Climate, 2000)

Consider the primitive temperature and moisture equations in pressure coordinates: [with $S = (T/\theta)(\partial\theta/\partial p)$]

$$\frac{\partial T}{\partial t} + \mathbf{u}_h \cdot \nabla T + \omega S = Q_c + Q_R + Q^T_{\mathrm{diff}} \qquad (1)$$

$$\frac{\partial q}{\partial t} + \mathbf{u}_h \cdot \nabla q + \omega \frac{\partial q}{\partial p} = Q_q + Q^q_{\mathrm{diff}}, \qquad (2)$$

Assuming horizontal temperature advection is negligible, in steady state (1) reduces to

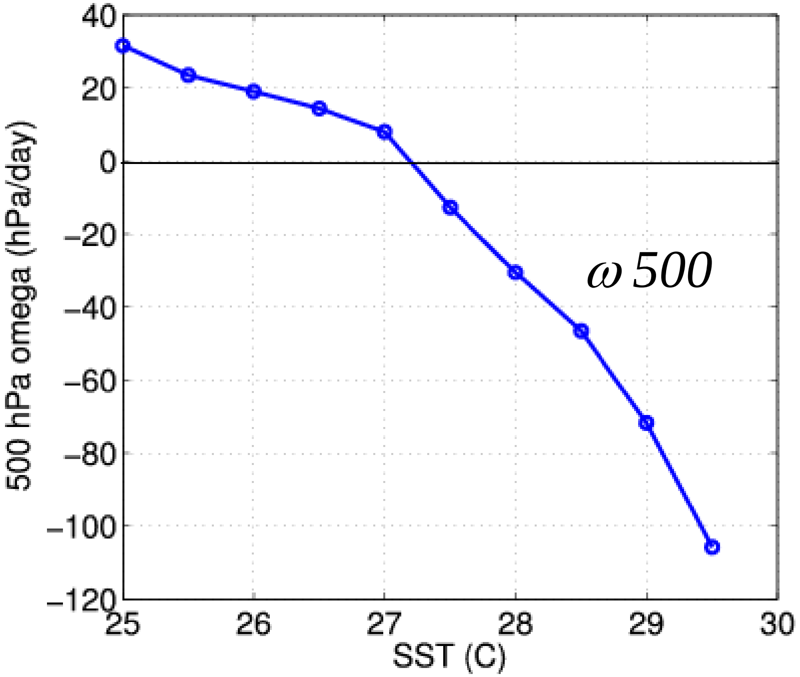
$$\omega S = Q_c + Q_R + Q^T_{\mathrm{diff}} \qquad (3)$$

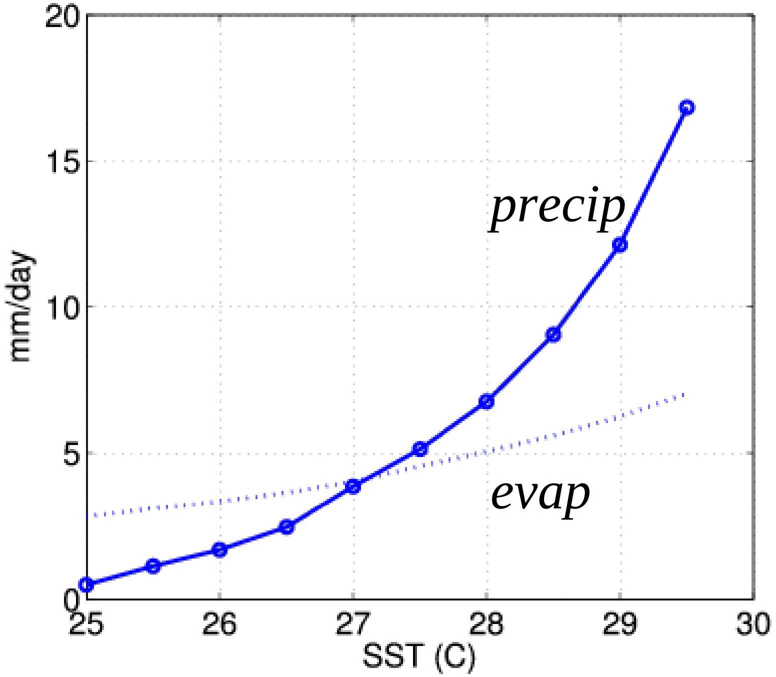
↓

if the temperature profile in the free troposphere is externally prescribed, then the vertical velocity can be diagnosed as a function of diabatic processes

Single-column simulations in WTG mode

In the absence of cloud-radiation interactions :

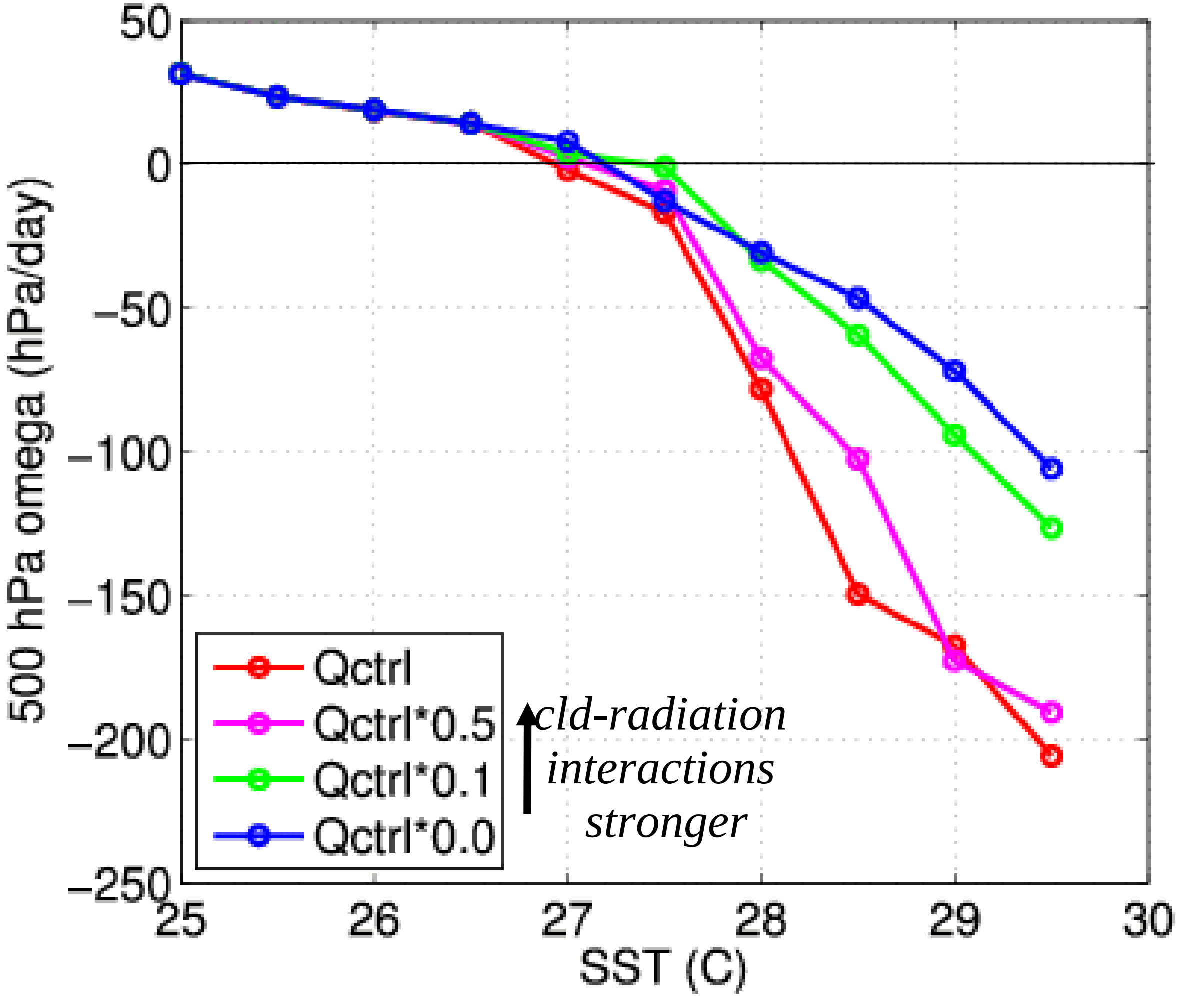




(NB: in these calculations, we have not used the same physics as in the GCM so results are not directly comparable to GCM results)

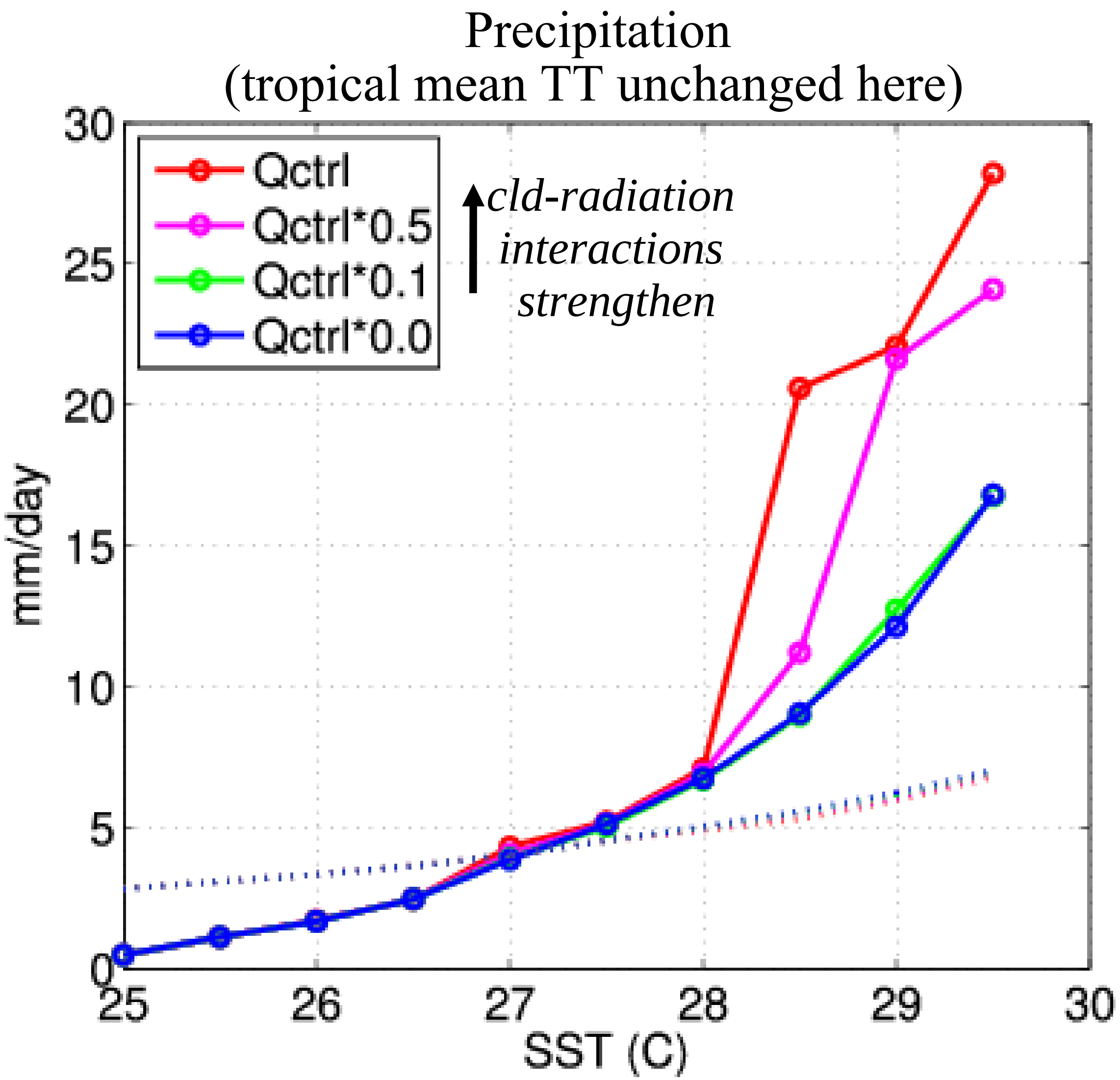
Single-column simulations in WTG mode

Large-scale vertical velocity in mid-troposphere diagnosed
(tropical mean TT unchanged here)



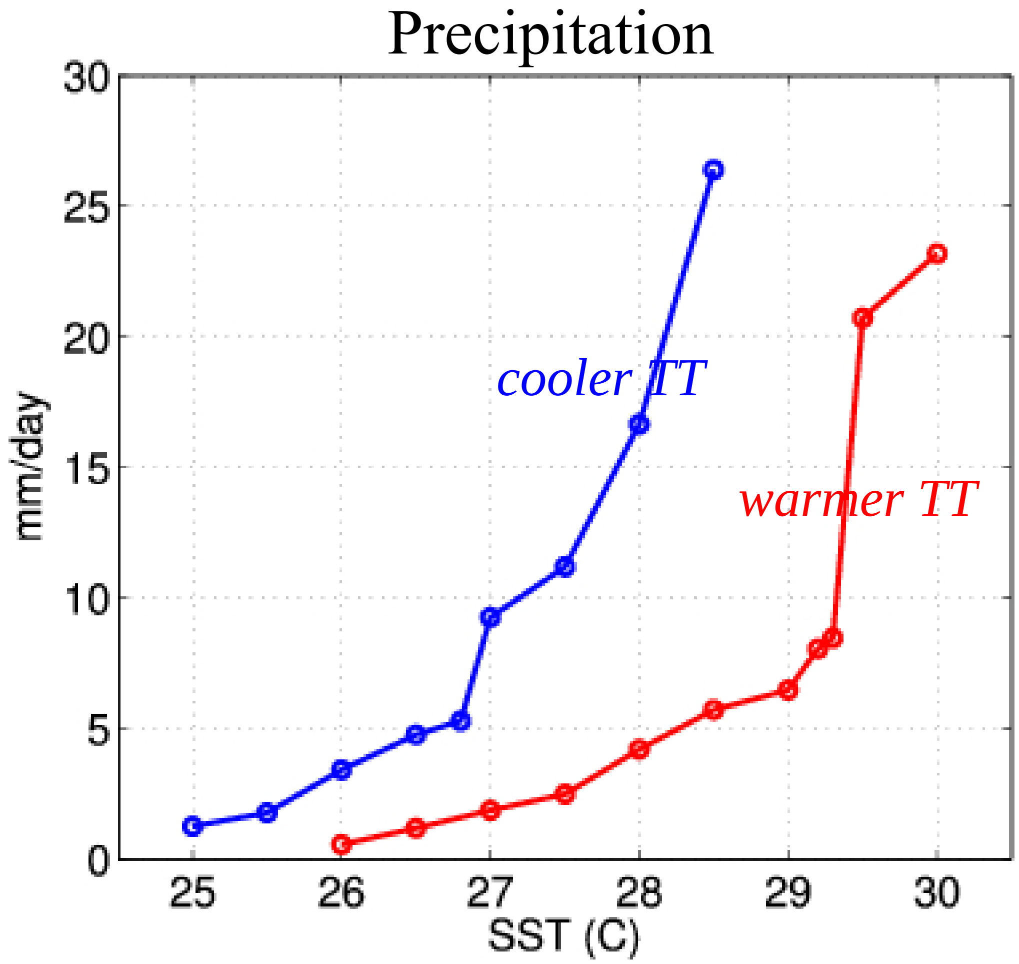
Strengthening the interaction between clouds and radiation results in stronger deep convection over warm SSTs

Single-column simulations in WTG mode



Strengthening the interaction between clouds and radiation results in stronger deep convection over warm SSTs

Single-column simulations in WTG mode



Warming the free troposphere results in a shift of the SST-precipitation relationship

(NB: calculations not done with the same physics package nor the same TT profile as the GCM)

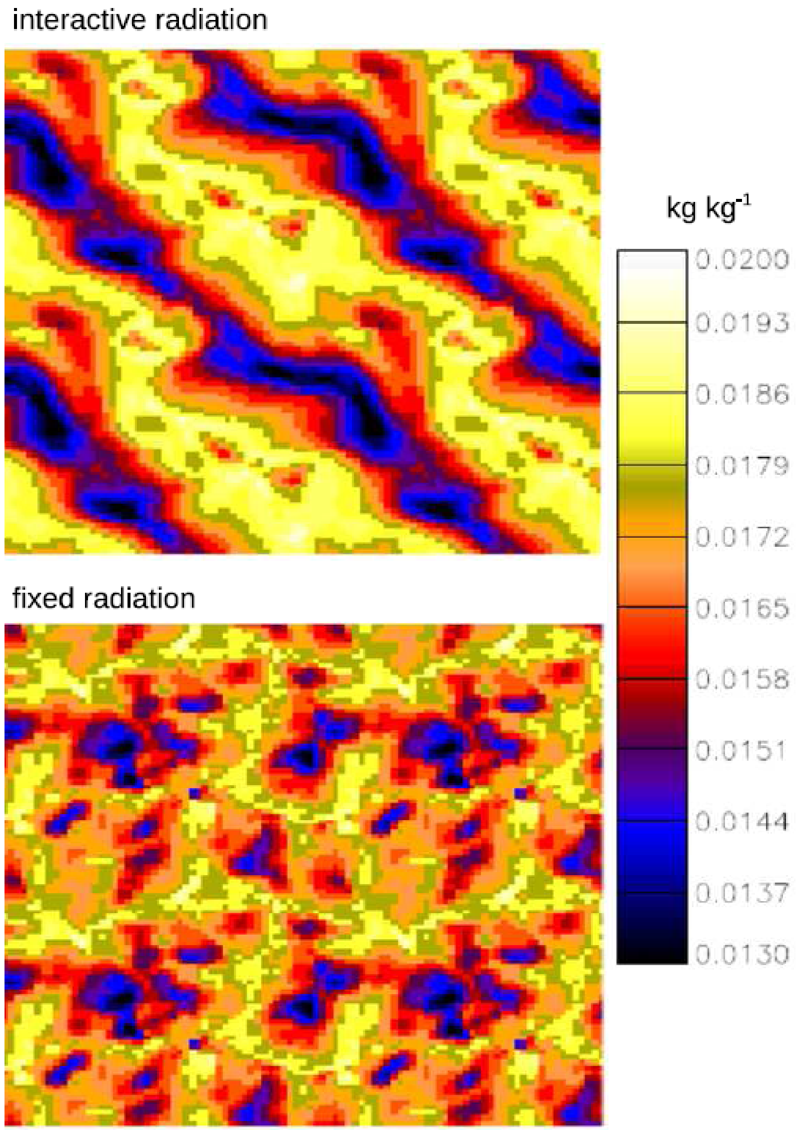
- It has to be investigated how far such 1D calculations can reproduce, at least qualitatively, the GCM behaviour (when using the same physics package and same TT profiles)

- Might be useful to test the sensitivity of physics-dynamics interactions to parameterizations (microphysics, etc).

4. Cloud-radiation interactions, the organization of the tropical atmosphere and intra-seasonal variability

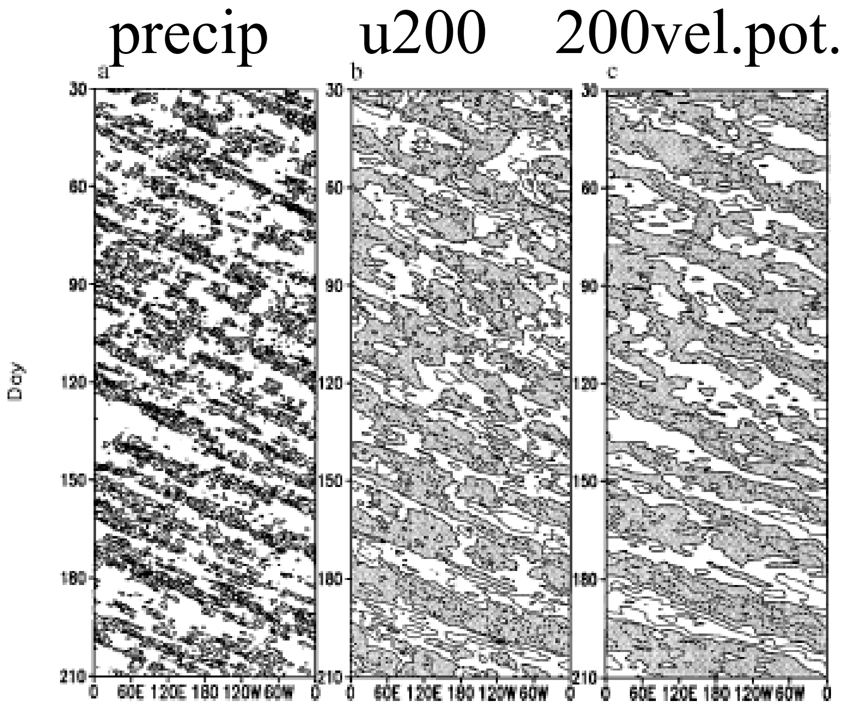
3D radiative-convective simulations using a CRM

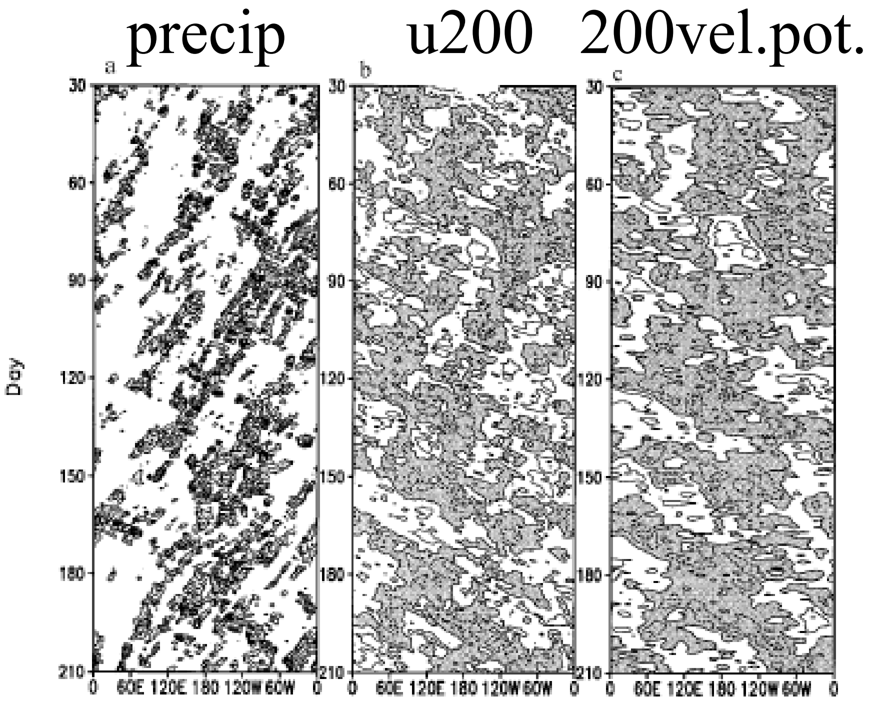
(domain size 100 km x 100 km)



(after Tompkins and Craig, 1998)

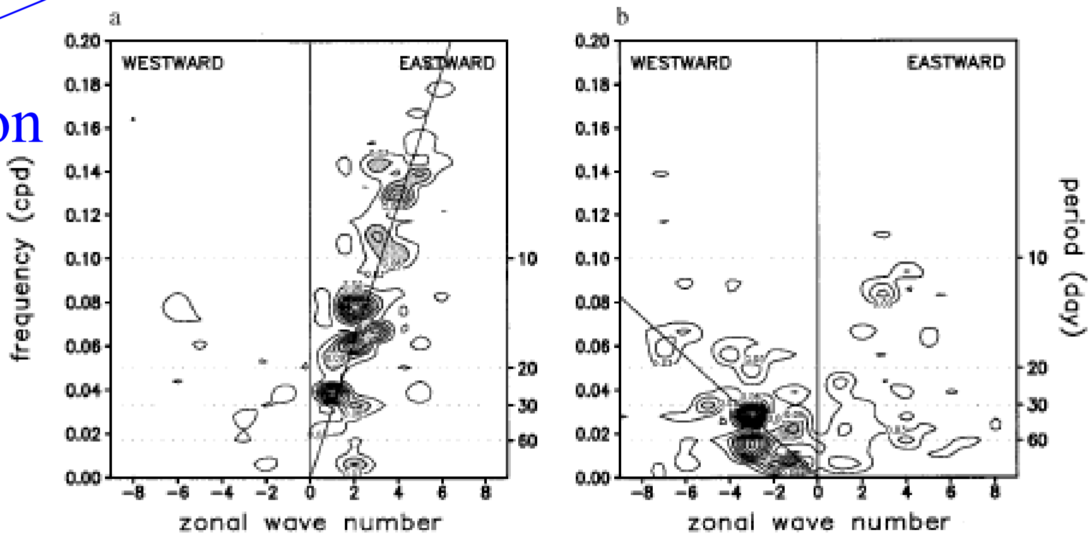
Influence of cloud-radiation interactions on simulating tropical intraseasonal oscillation with a GCM (Lee et al. 2001)





Fixed Cloud-radiation

Interactive Cloud-radiation

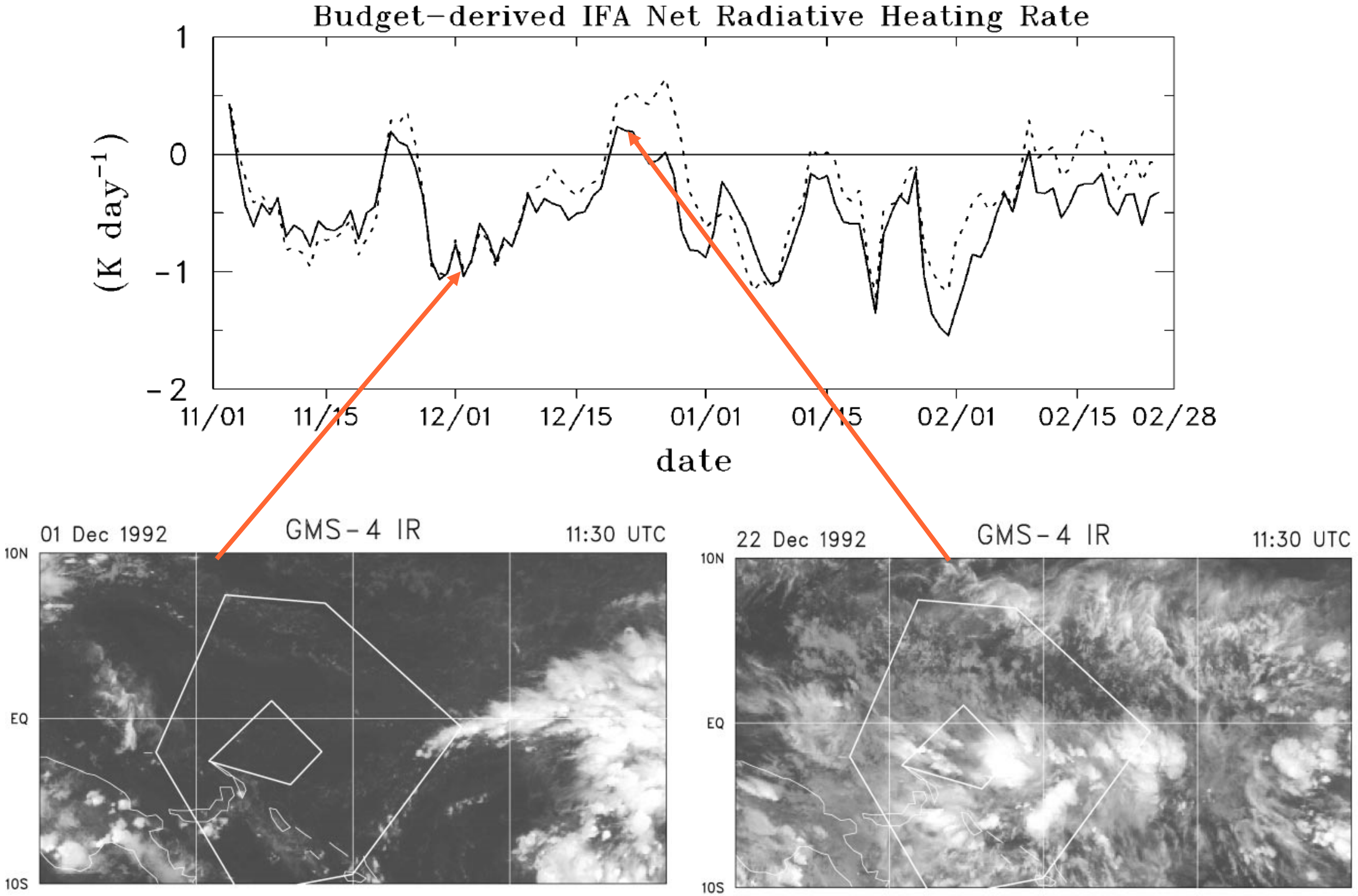


- Contamination of the eastward propagation of the ISO by small-scale disturbances moving westward with the easterly basic winds
- Sensitive to microphysical processes!

TOGA COARE :

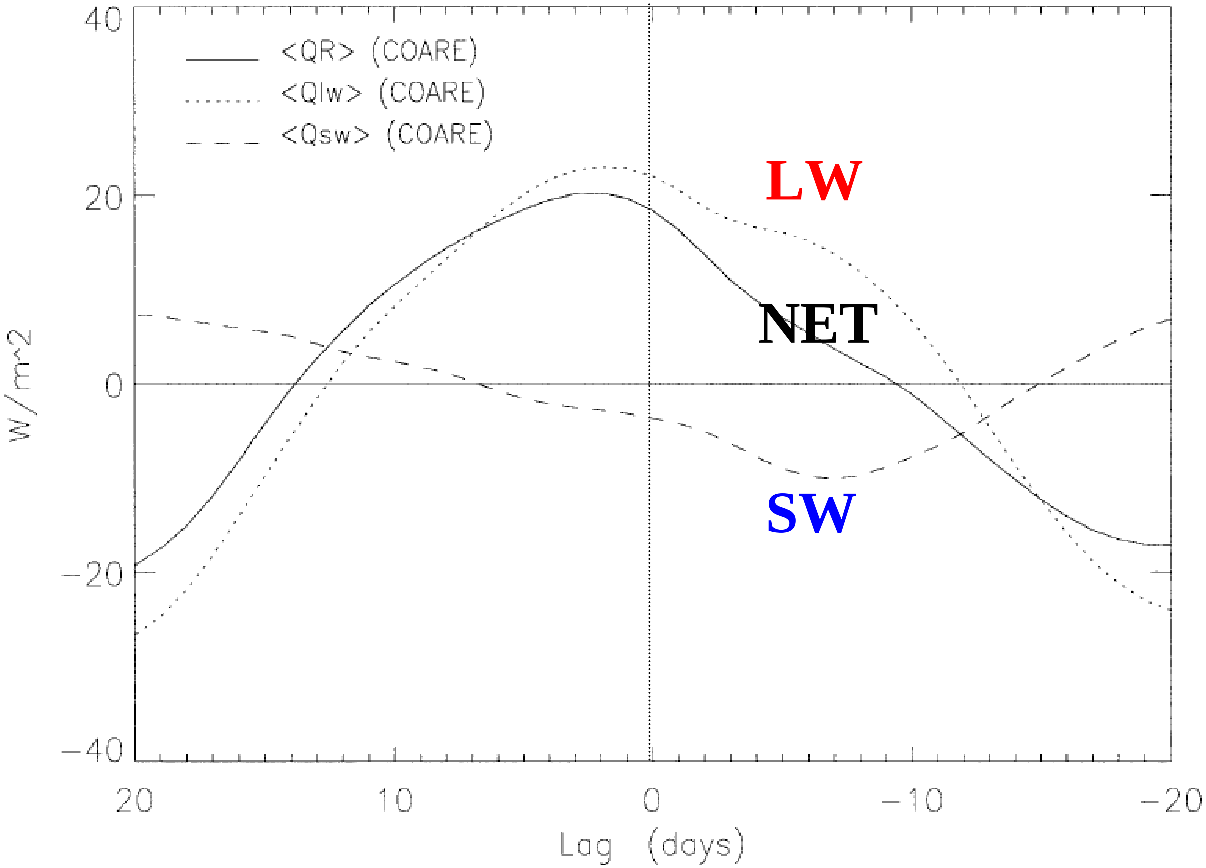
Tropospheric Radiative Heating Rate

(Johnson and Ciesielski, JAS, 2000 ; Ciesielski et al., JAS, 2003)



TOGA COARE
Composite of the Dec 1992 ISO event

(Lin and Mapes, JAS, 2004)



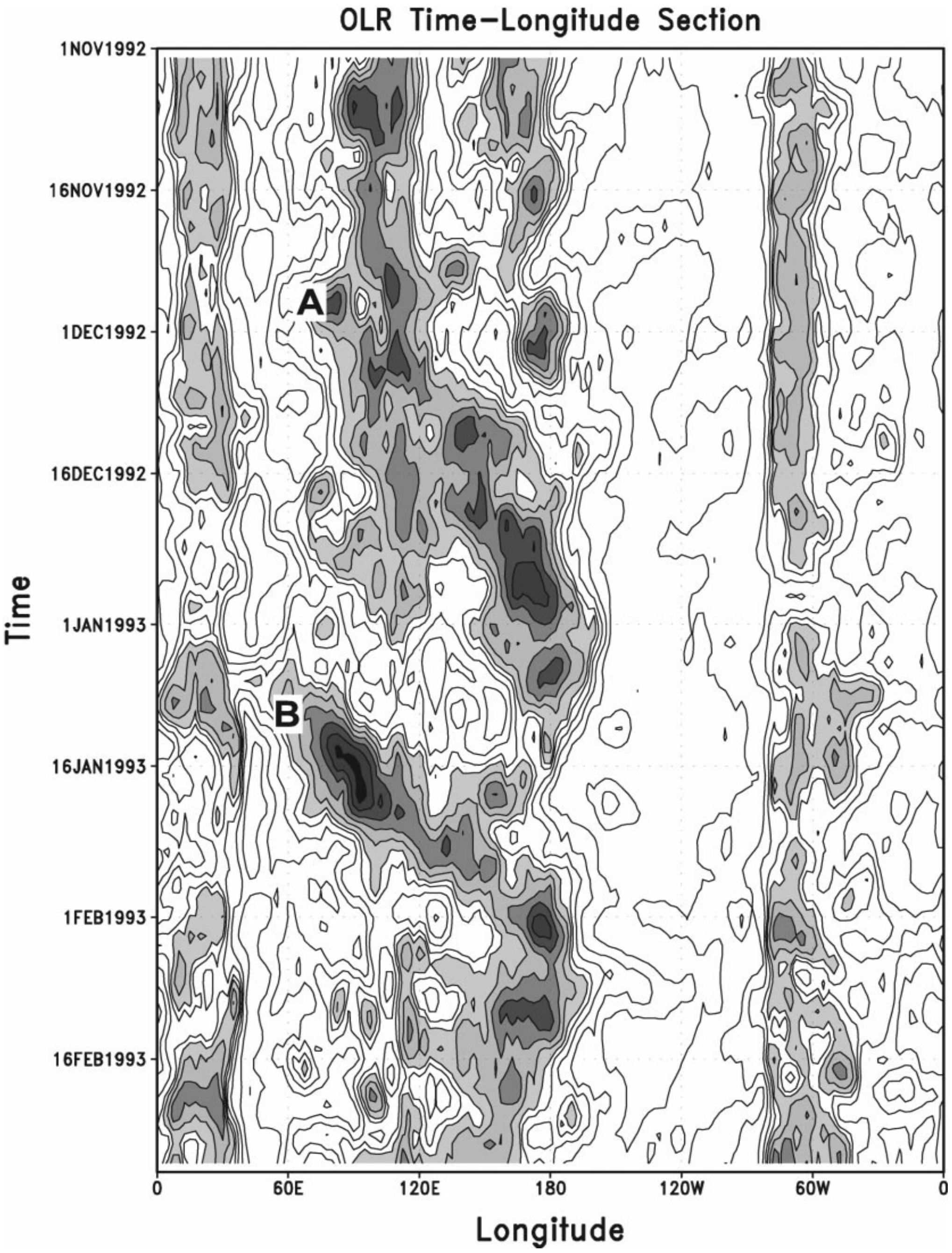
The troposphere-integrated radiative heating :

- is dominated by the *reduction of LW emission by clouds*
- is *partially* in phase with the precipitation anomaly
- *lags* the column-integrated convective heating by a few days

TOGA COARE

Fluctuations of tropical clouds and OLR have long been considered as manifestations of tropical variability...

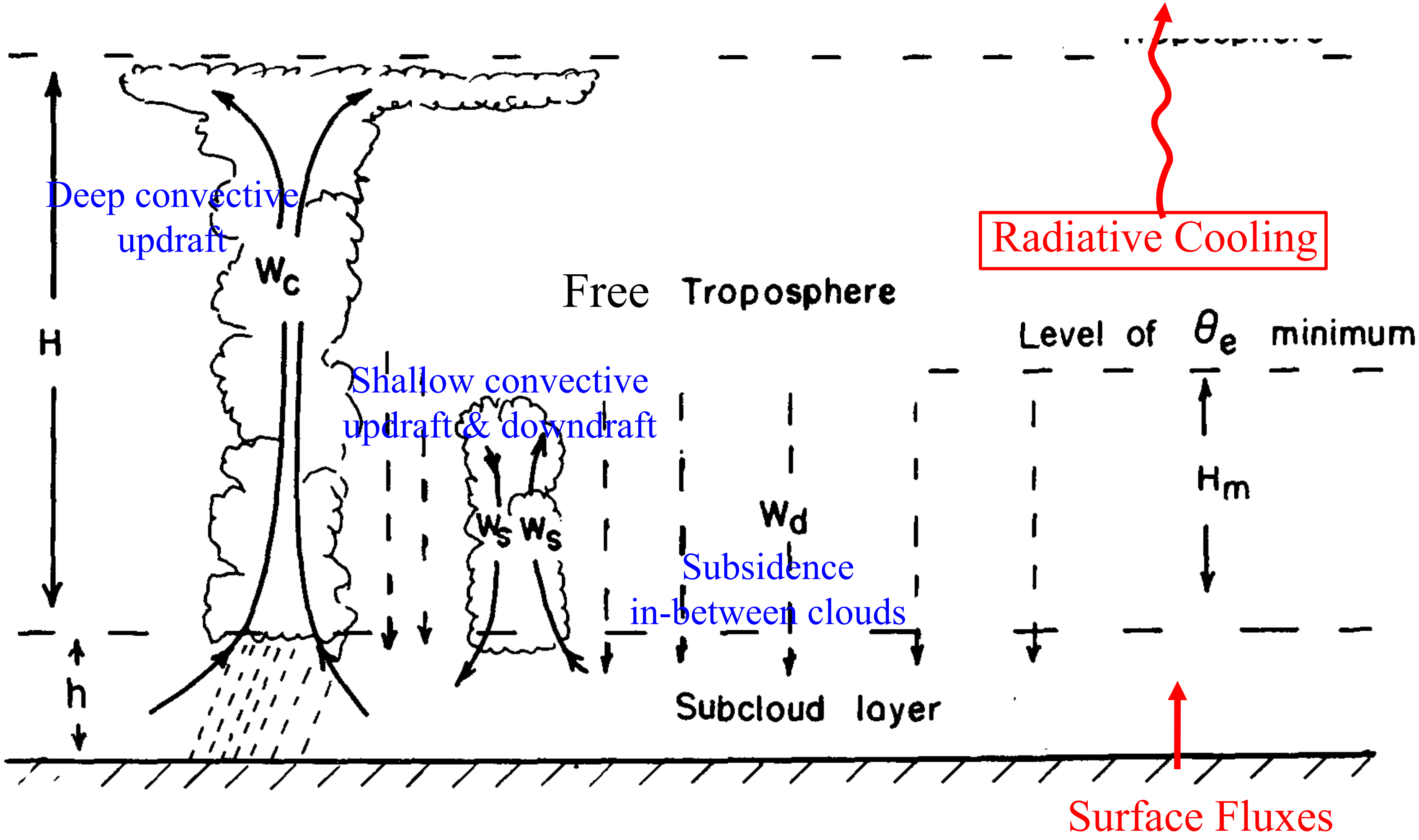
May cloud-radiation interactions also play an active role in the variability of the tropical atmosphere ?



(Yanai et al. 2000)

Simple Linear Model of the Equatorial Atmosphere

(Yano & Emanuel, JAS, 1991 ; Bony & Emanuel, JAS, 2005)



- thin subcloud layer + deep free troposphere
- moist adiabatic temperature lapse rate
- shallow updraft and downdraft of equal mass flux
- precipitation efficiency : $\varepsilon_p = M_c/(M_c + M_s)$
- subcloud-layer quasi-equilibrium
- radiative cooling rate dependent on the degree of saturation of the atmosphere

Simple linear model :

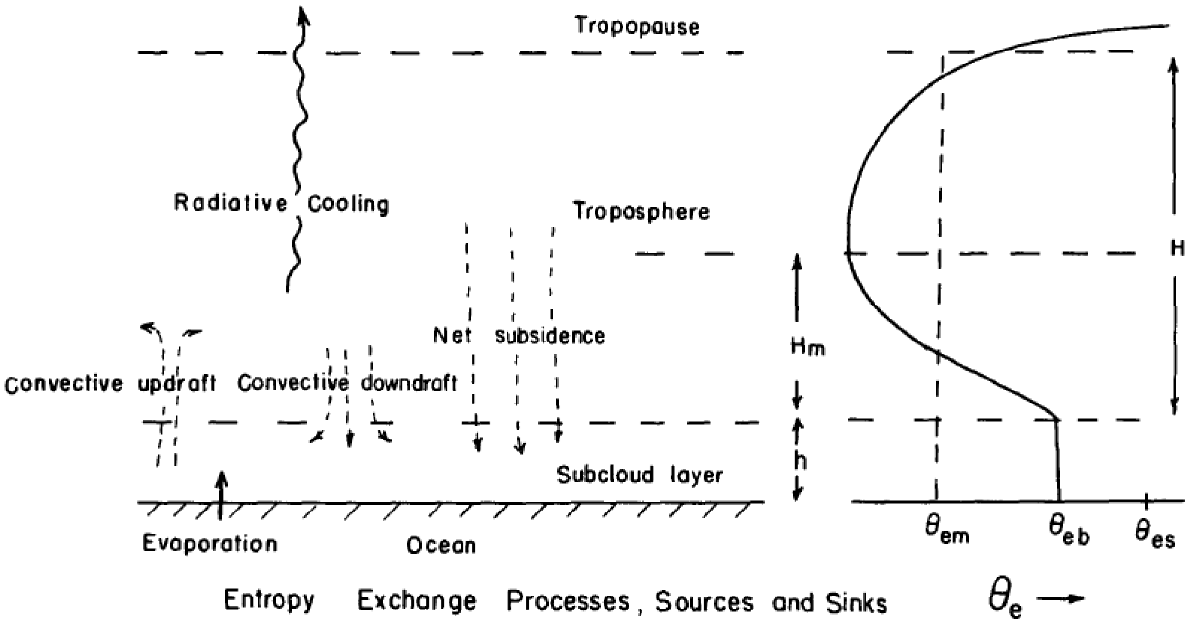
$$\frac{\partial u_b}{\partial x} + \frac{w}{H_m} = 0$$

$$\left(\frac{\partial}{\partial t} + u_b\frac{\partial}{\partial x}\right)u_b = -\frac{\partial \Phi_b}{\partial x} - \frac{C_d}{h}|\mathbf{V}_b|u_b$$

$$g\left(\frac{\partial}{\partial t} + u_b\frac{\partial}{\partial x}\right)\ln\theta = N^2(-w + \sigma w_c) - g\dot{R}$$

$$h\left(\frac{\partial}{\partial t} + u_b\frac{\partial}{\partial x}\right)\ln\theta_{\mathrm{eb}} = C_k|\mathbf{V}_b|(\ln\theta_{\mathrm{es}} - \ln\theta_{\mathrm{eb}}) + \left(w - \frac{\sigma w_c}{\varepsilon_p}\right)(\ln\theta_{\mathrm{eb}} - \ln\theta_{\mathrm{em}})$$

$$H_f\left(\frac{\partial}{\partial t} + u_b\frac{\partial}{\partial x}\right)\ln\theta_{\mathrm{em}} = -H_f\dot{R} - \left(w - \frac{\sigma w_c}{\varepsilon_p}\right)(\ln\theta_{\mathrm{eb}} - ln\theta_{\mathrm{em}})$$

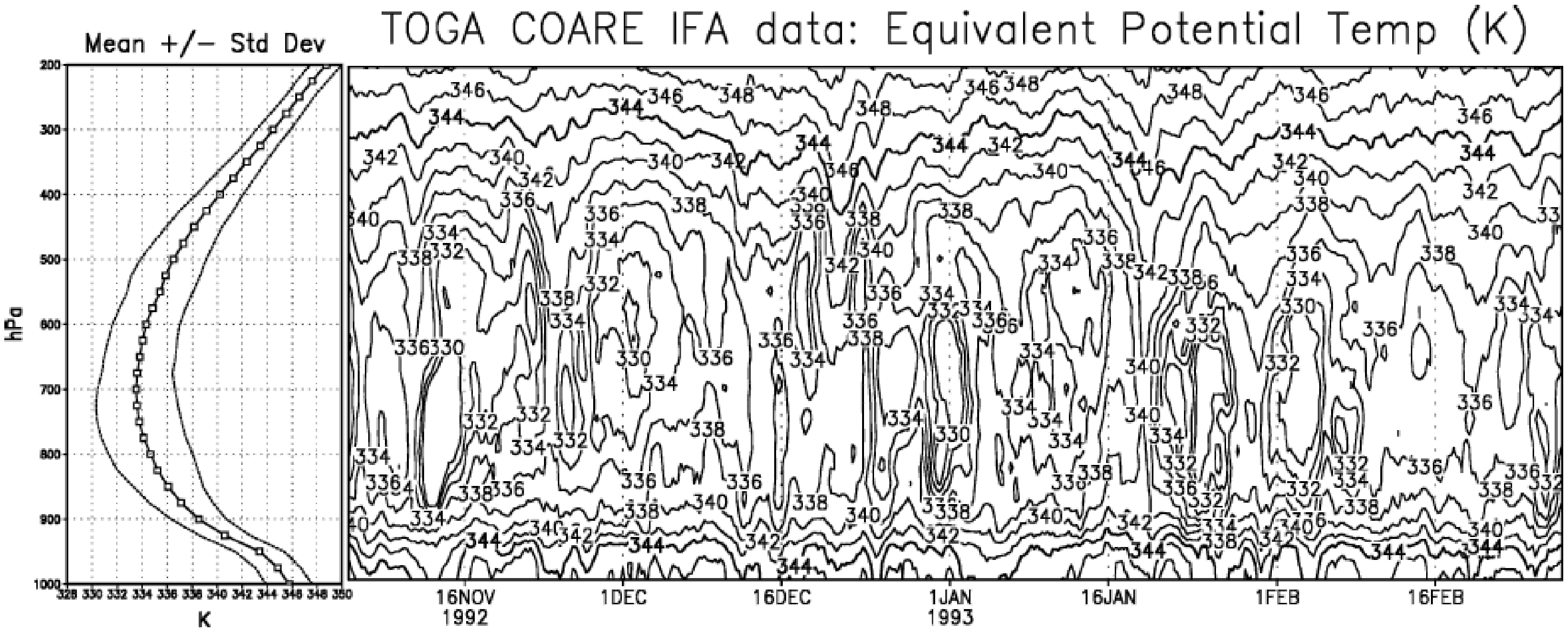


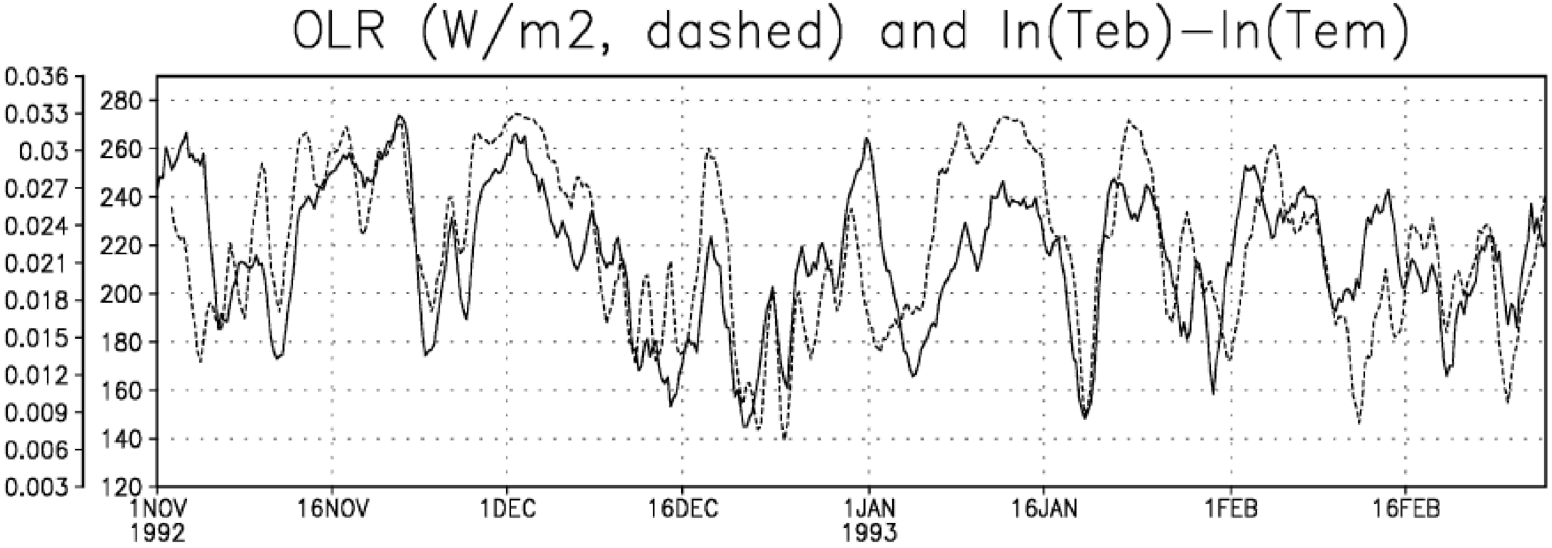
The tropospheric radiative cooling is parameterized as a function of the moist entropy deficit (proxy for clouds and moisture):

$$\dot{R} = \dot{R}_0\left\{1 + \alpha\frac{\delta(\ln\theta_{\mathrm{eb}} - \ln\theta_{\mathrm{em}})}{[\ln\theta_{\mathrm{eb}} - \ln\theta_{\mathrm{em}}]}\right\}$$

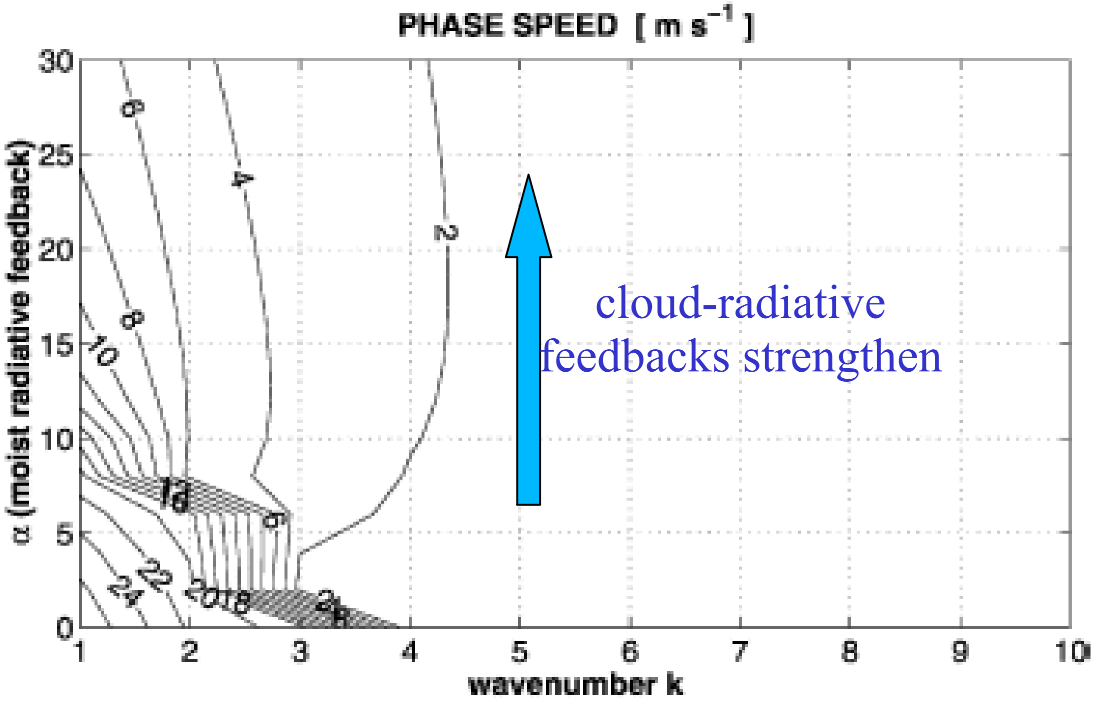
positive parameter
whose value is specified

TOGA COARE :
Relationship between tropospheric moist entropy deficit and OLR :



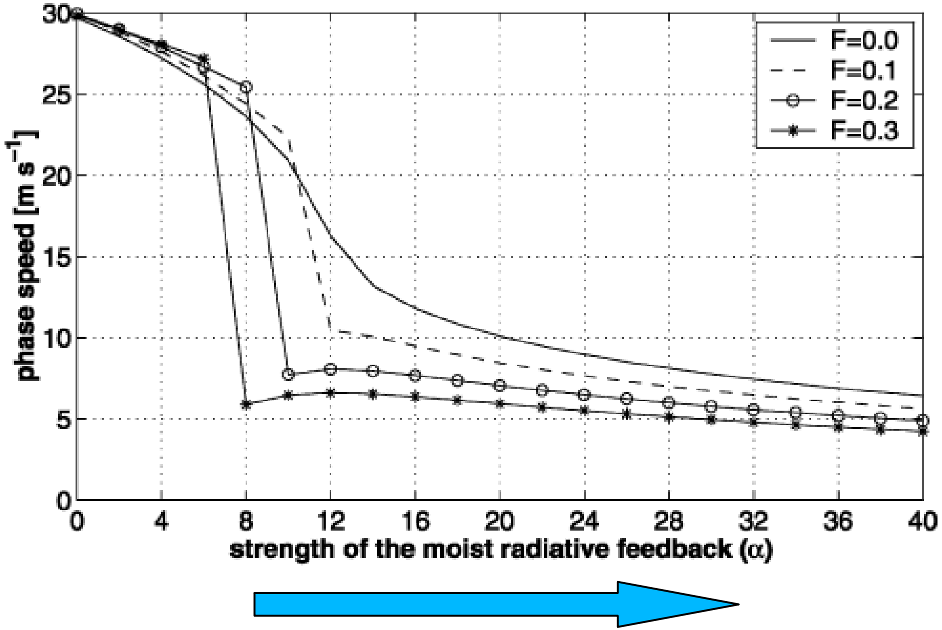


(1) Cloud-radiative feedbacks reduce the phase speed of large-scale tropical disturbances



cloud-radiative feedbacks strengthen

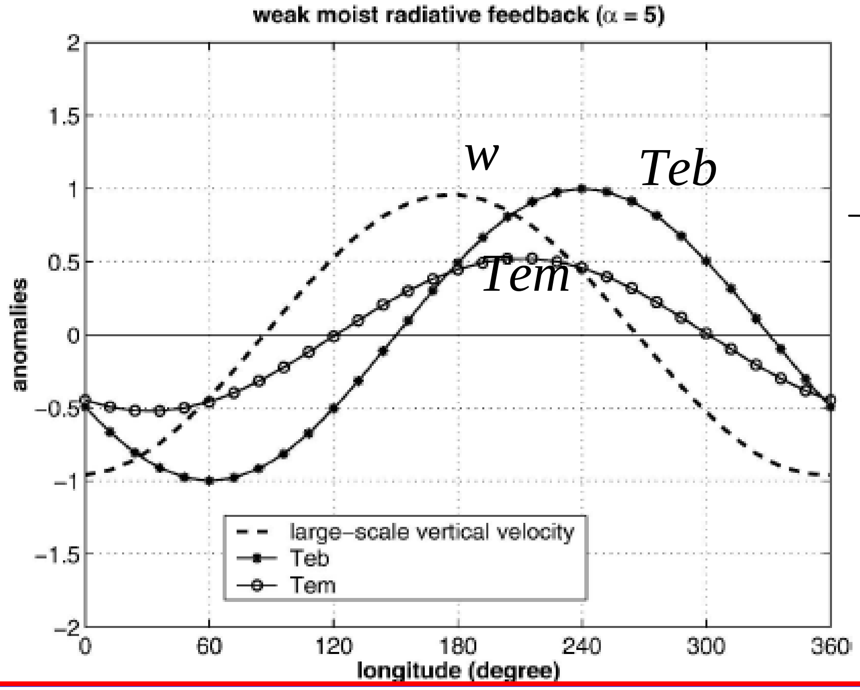
effect particularly strong at planetary scales:

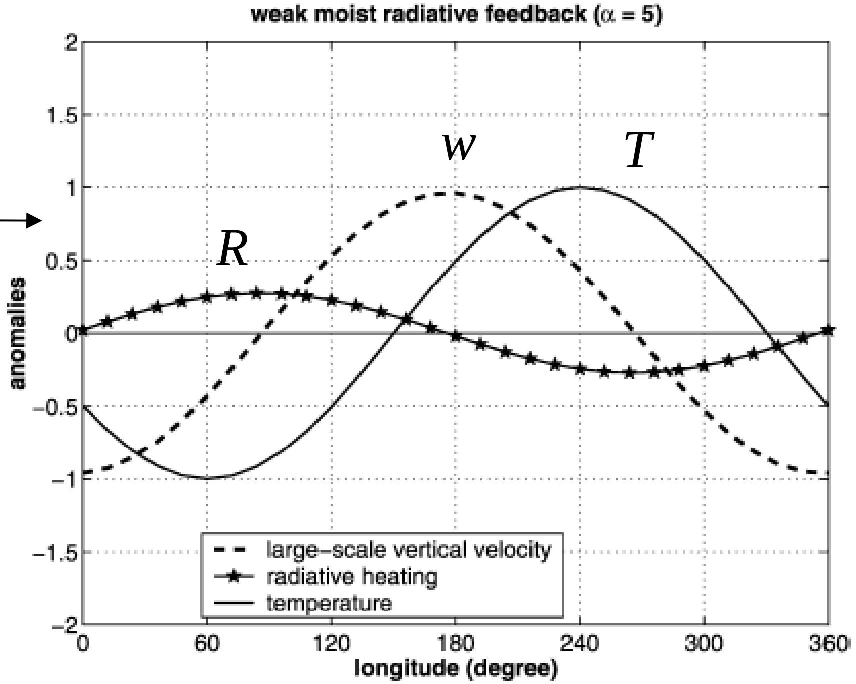


cloud-radiative feedbacks strengthen

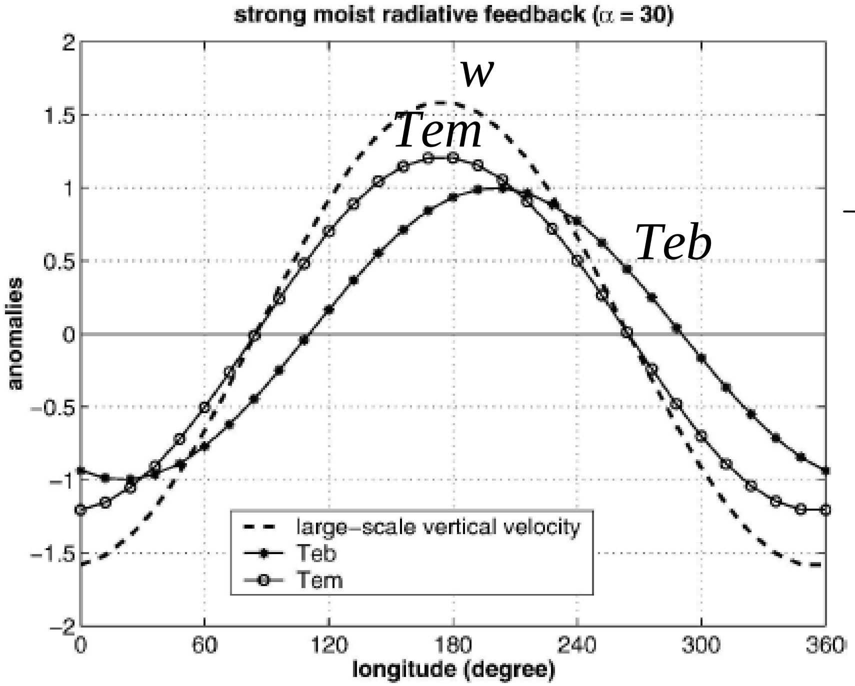
k = 1 composites

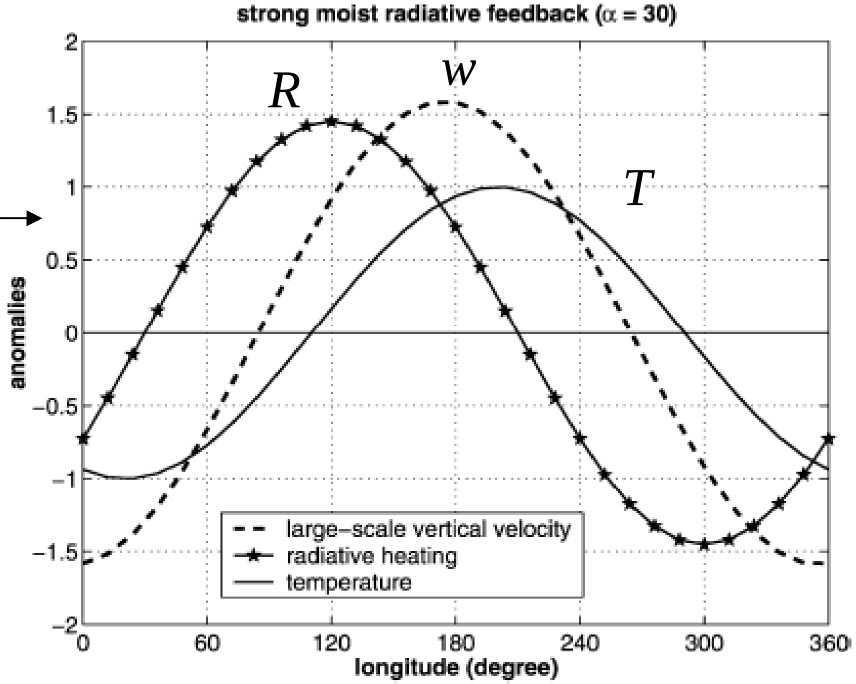
weak radiative feedback





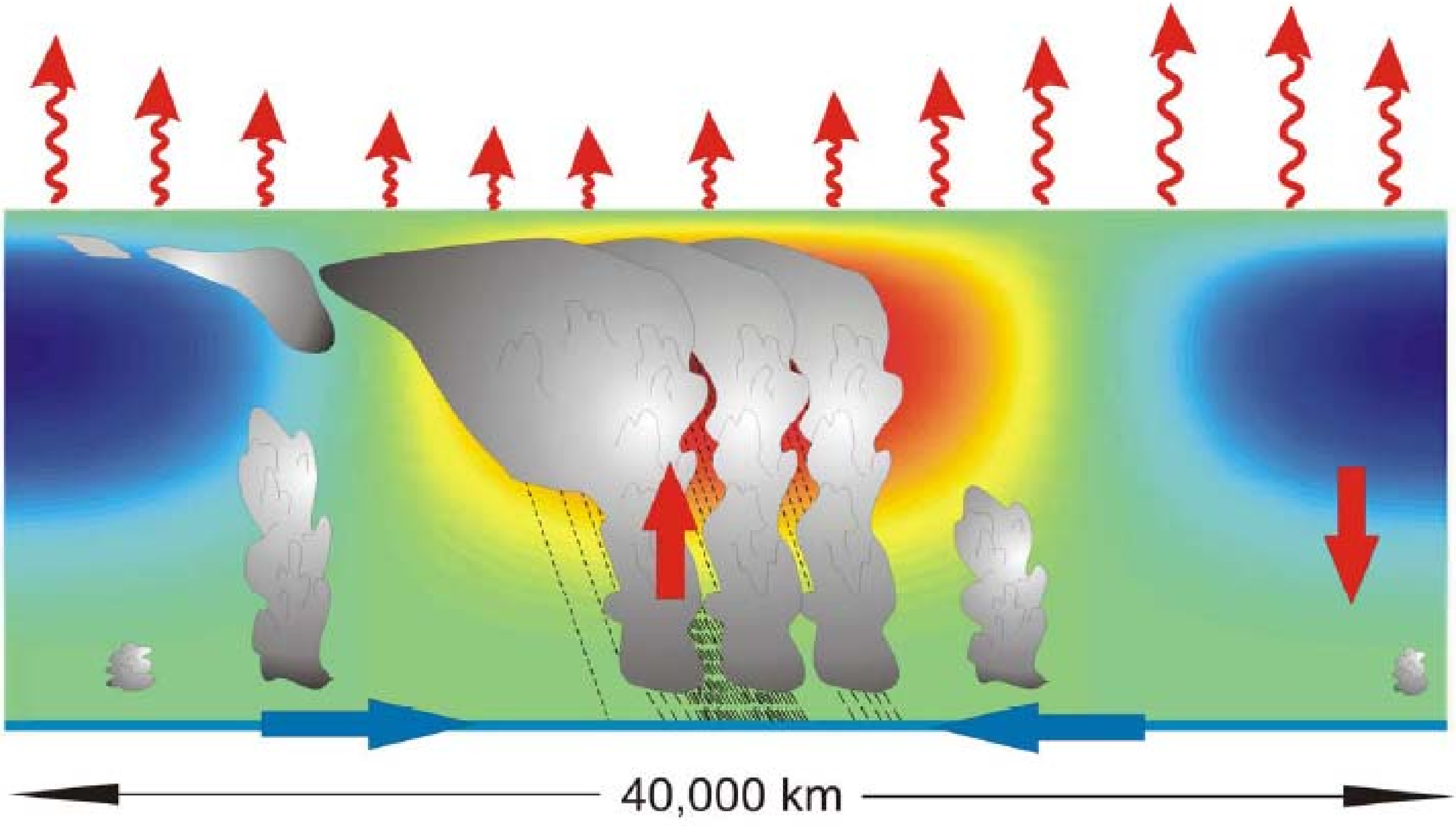
strong radiative feedback





Slowing down of large-scale tropical disturbances by cloud radiative feedback :

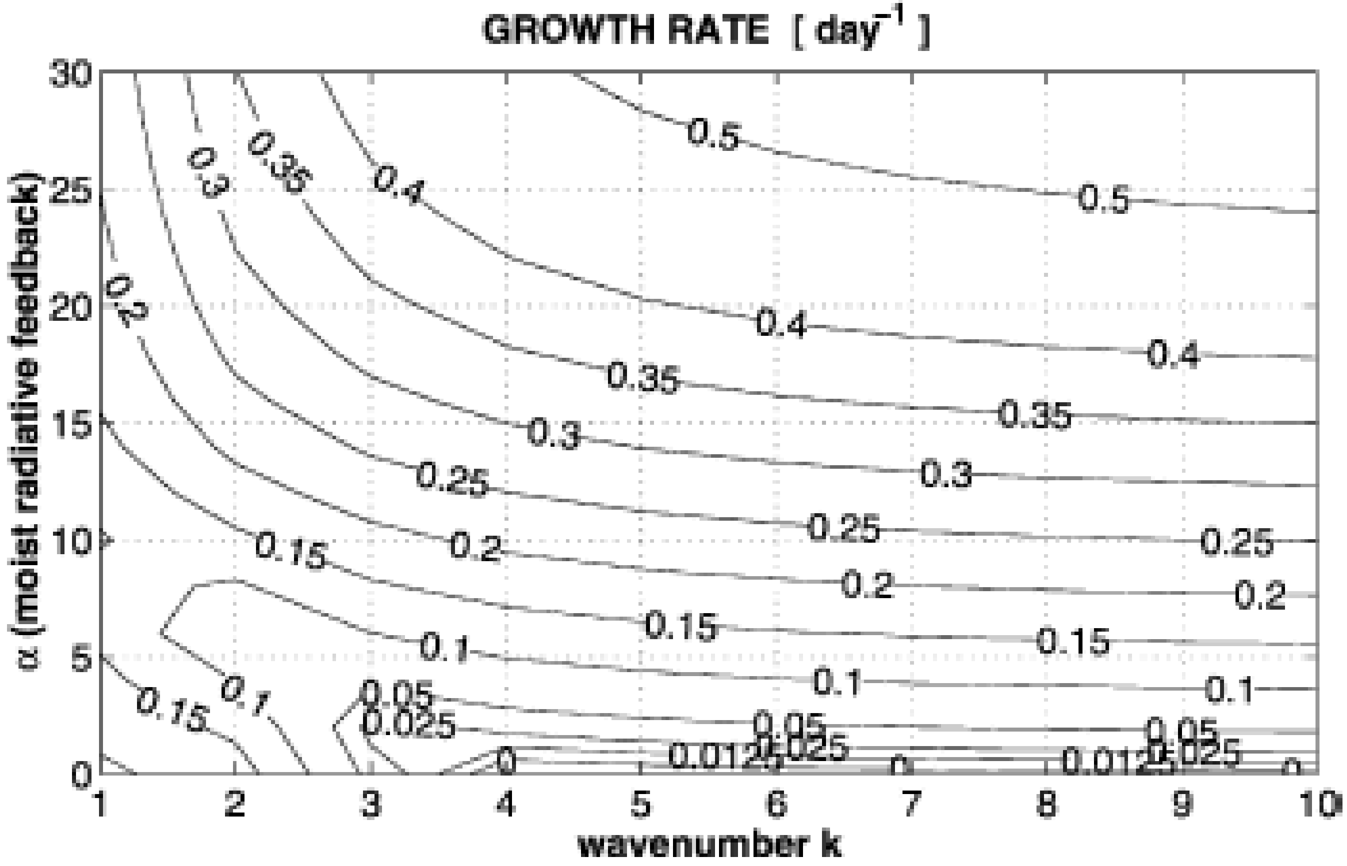
By reducing the radiative cooling of the troposphere in the rising phase of the oscillations, cloud-radiation interactions partly oppose the thermodynamical effect of adiabatic motions. This reduces the effective stratification felt by propagating waves and slows down their propagation.



(2) Cloud-radiative feedbacks affect the growth rate of unstable modes of the tropical atmosphere.

Strong cloud-radiative feedbacks excite small-scale advective disturbances traveling with the mean flow.

The prominent modes of variability of the equatorial atmosphere thus depend on the intensity of cloud-radiative feedbacks (and or moisture-convection feedbacks, not shown).

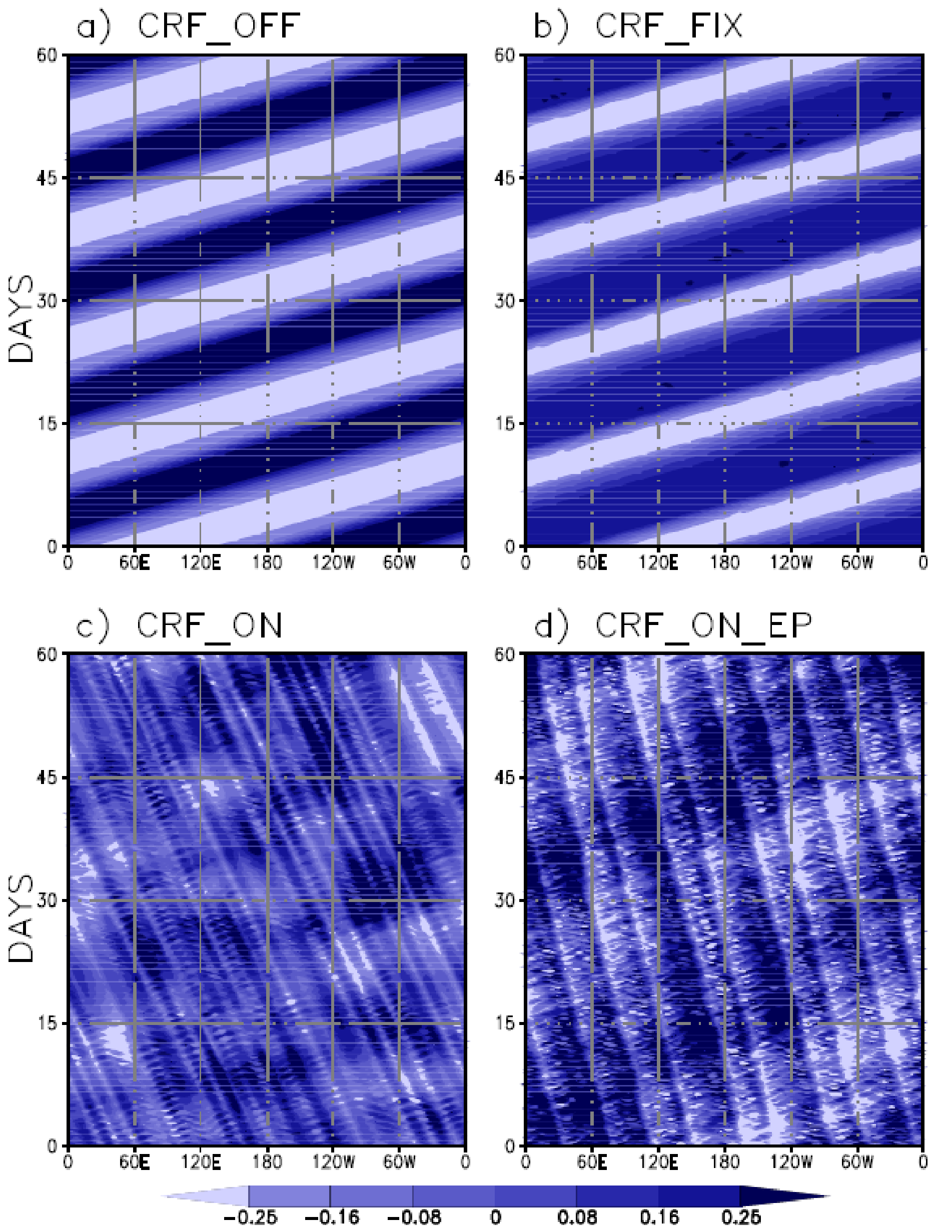


cloud-radiative feedbacks strengthen

Numerical simulations using an equatorial (aquaplanet) GCM

- 2D model (equatorial plane, 1.5 deg, 40 levels), fixed SSTs (300 K), uniform background flow.

- Parameterizations :
  - Radiation (Morcrette-Fouquart 1991)
  - Convection (Emanuel and Zivkovic-Rothman 1999)
  - Clouds (Bony and Emanuel 2001)



As in the simple linear model and in the GCM results from Lee et al. (2001), cloud-radiative feedbacks affect:

- the phase speed of planetary-scale disturbances

- the relative prominence of small-scale vs planetary-scale modes of variability of the equatorial atmosphere

The simulation of cloud-radiative processes matters for the simulation of tropical variability by large-scale models!

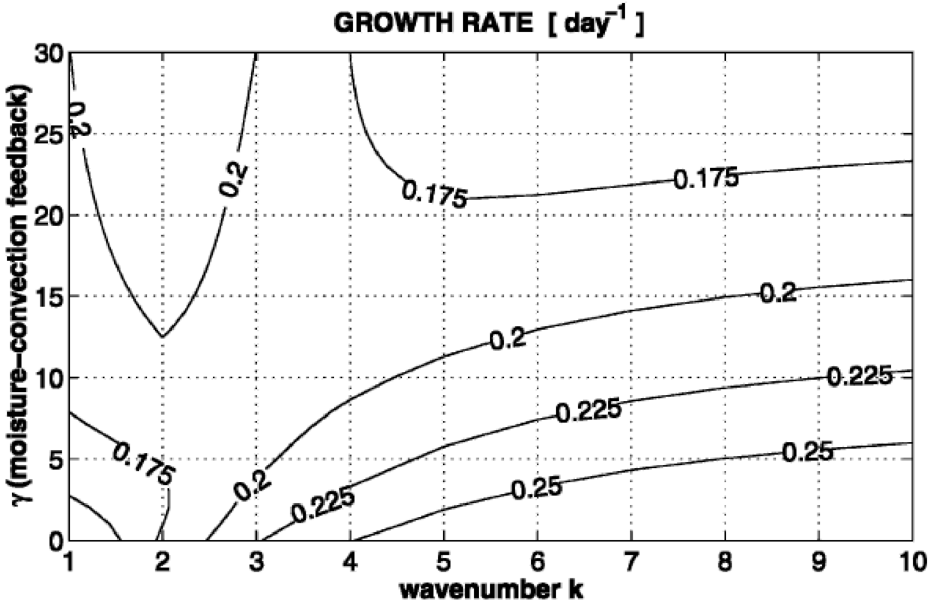
(Zurovac-Jevtic, Bony & Emanuel, JAS, 2006)

Investigation of the role of moisture - convection interactions with the simple linear model

Let's increase of the precipitation efficiency
as the atmosphere gets moister :
(i.e. larger proportion of deep convective
updrafts, less reevaporation of rain)

$$\tilde{\varepsilon}_p = \frac{\varepsilon_p}{1 + \gamma \dfrac{\delta(\ln\theta_{\mathrm{eb}} - \ln\theta_{\mathrm{em}})}{[\ln\theta_{\mathrm{eb}} - \ln\theta_{\mathrm{em}}]}}$$

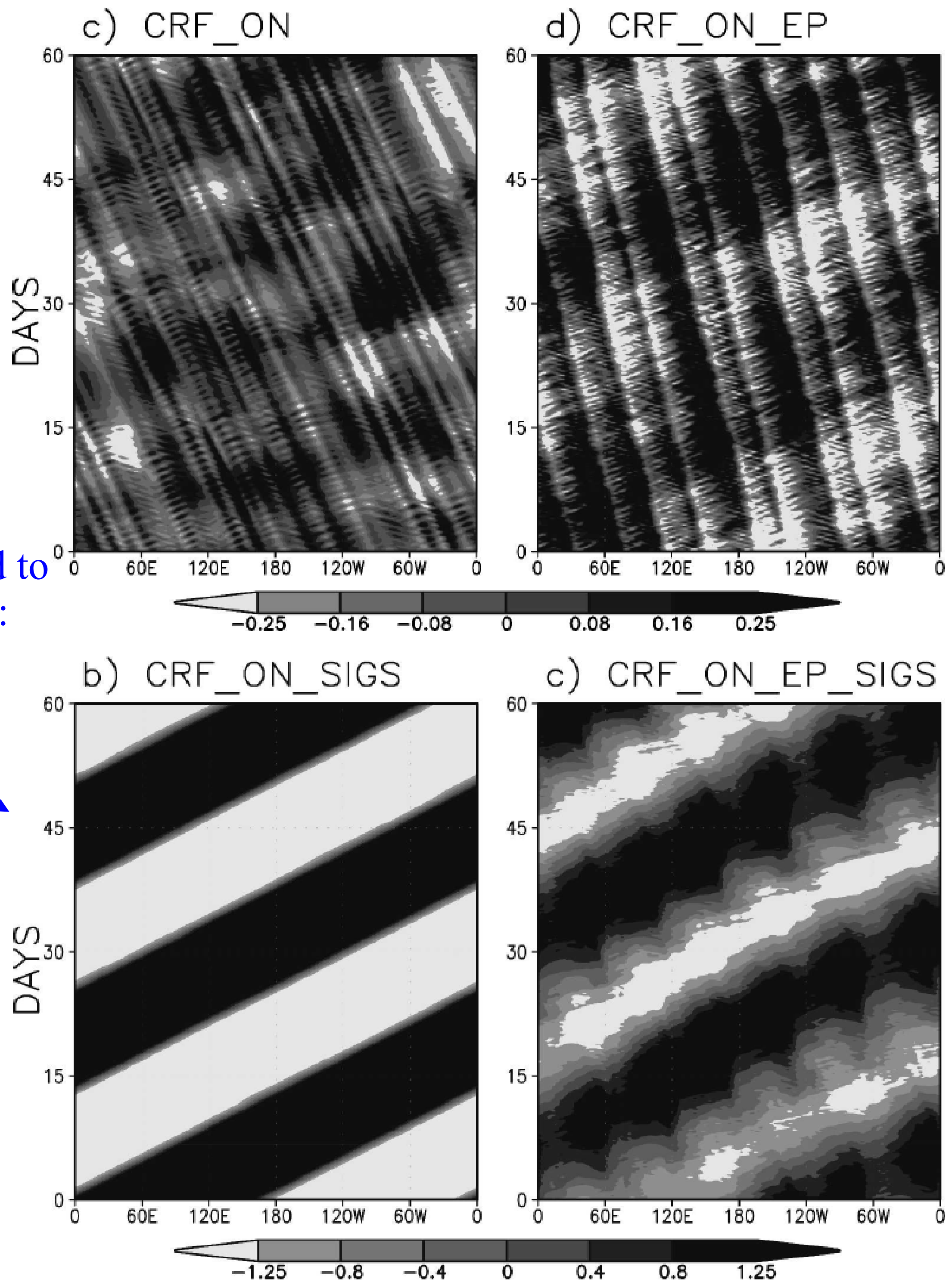
The moisture-convection feedback favors the prominence of planetary-scale propagating modes at the expense of small-scale advective disturbances.



(Bony & Emanuel, JAS, 2005)

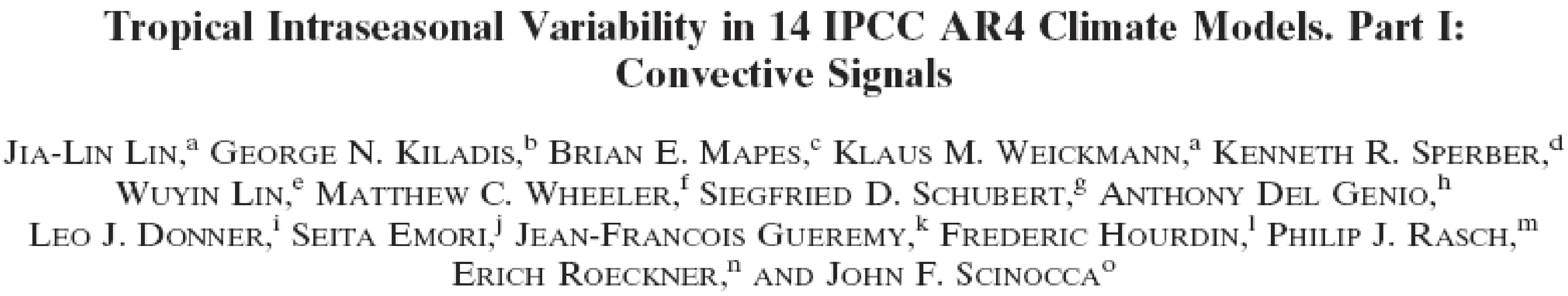
Impact of an enhanced sensitivity of convection to tropospheric moisture (equatorial aquaplanet GCM)

Increase of the fraction of precipitation that falls outside the cloud (more exposed to evaporation in the unsaturated downdraf): "SIGS" experiment
(cf Grabowski & Moncrieff 2004)



As in the simple linear model, an enhanced moisture-convection feedback favors the prominence of planetary-scale propagating modes at the expense of small-scale advective disturbances.

(Zurovac-Jevtic, Bony & Emanuel, JAS, 2006)



Tropical Intraseasonal Variability in 14 IPCC AR4 Climate Models. Part I: Convective Signals

JIA-LIN LIN,[a] GEORGE N. KILADIS,[b] BRIAN E. MAPES,[c] KLAUS M. WEICKMANN,[a] KENNETH R. SPERBER,[d]
WUYIN LIN,[e] MATTHEW C. WHEELER,[f] SIEGFRIED D. SCHUBERT,[g] ANTHONY DEL GENIO,[h]
LEO J. DONNER,[i] SEITA EMORI,[j] JEAN-FRANCOIS GUEREMY,[k] FREDERIC HOURDIN,[l] PHILIP J. RASCH,[m]
ERICH ROECKNER,[n] AND JOHN F. SCINOCCA[o]

Journal of Climate (2006)

- Current state-of-the art GCMs still have significant problems and display a wide range of skill in simulating the tropical intraseasonal variability.

- Lack of highly coherent eastward propagation of the MJO in many models.

- The phase speeds of convectively coupled equatorial waves are generally too fast, suggesting that these models may not have a large enough reduction in their “effective static stability” by diabatic heating.

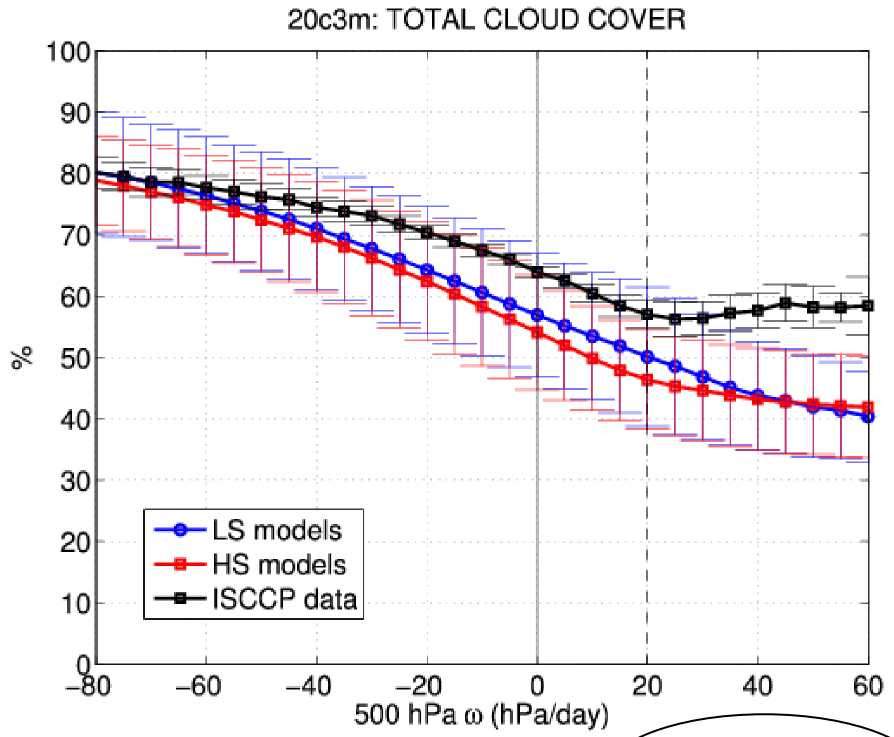
The simulation of cloud radiative processes and feedbacks
→ *(as well as an under-estimated sensitivity of convection*
to tropospheric humidity) may explain part of these problems

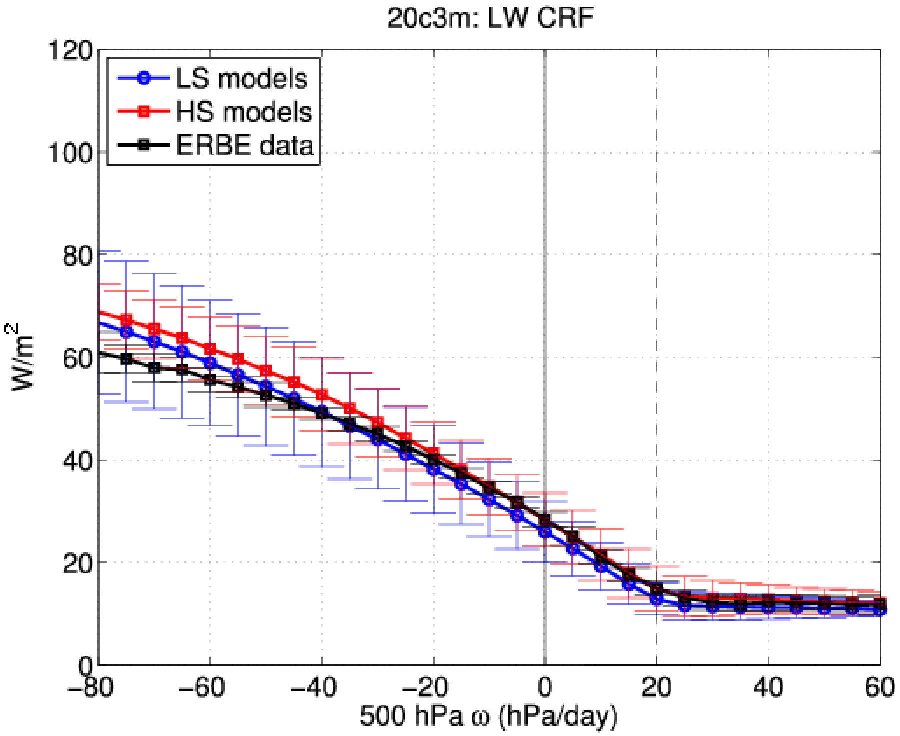
Cloud-radiation interactions thus matter for many aspects of climate ...

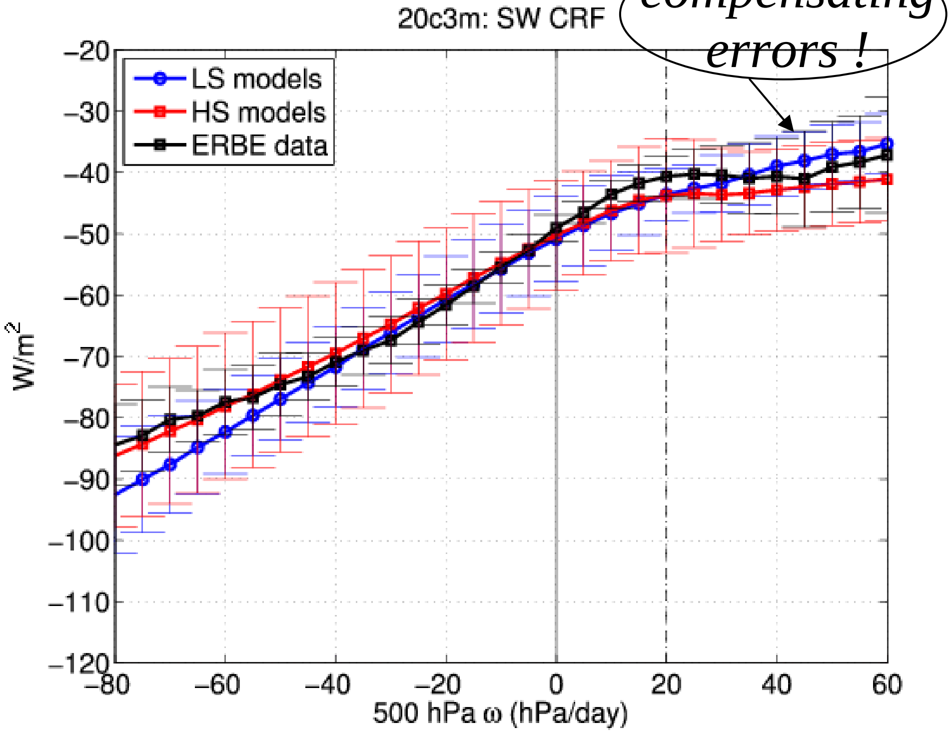
How well do GCMs simulate these interactions ?

Mean CRF and total cloud cover simulated by AR4 GCMs in the current climate (20th century run)

- High-sensitivity GCMs (8 OAGCMs)
- Low-sensitivity GCMs (7 OAGCMs)
- Observations



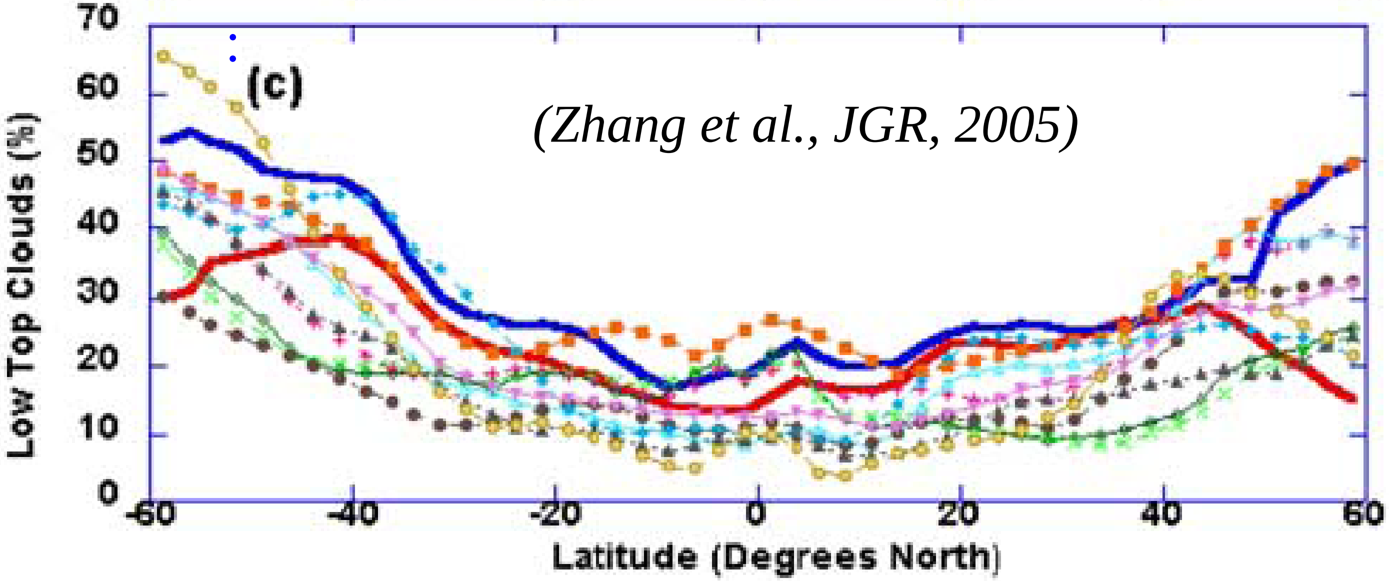




compensating errors !

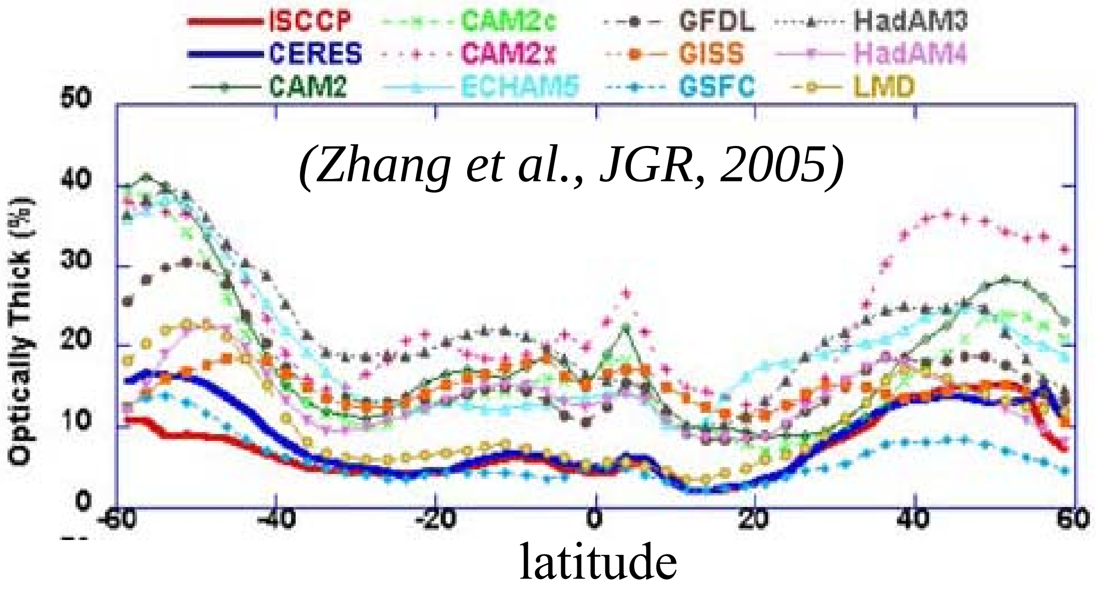
Not a new story ....

Most GCMs underestimate low-level clouds
:



(Zhang et al., JGR, 2005)

- The majority of the models simulate too many optically thick clouds and not enough optically thin and intermediate clouds :



(Zhang et al., JGR, 2005)

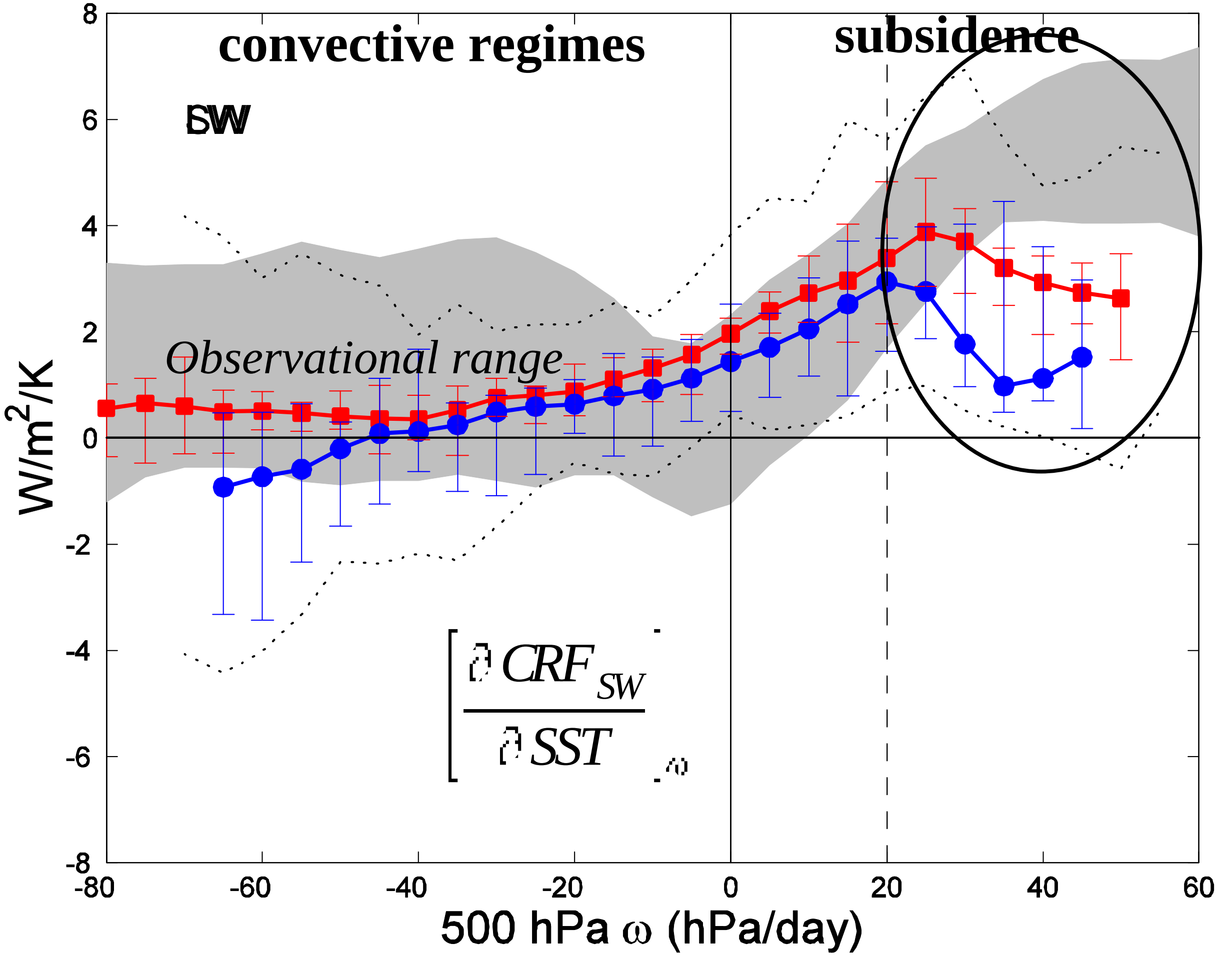
Possible causes :
subgrid-scale cloud scheme,
overlap of cloud layers, inability
to simulate tilted circulations, etc.

Therefore a good agreement between observed and simulated CRF presumably results from compensating errors.

- Note that the *cloud albedo is not linearily related to cloud optical depth.* This implies that if the mean cloud optical depth is wrong, the impact of a given change in cloud water on SW radiation is *also* wrong.

Sensitivity of the SW CRF to interannual SST changes
(an example, not an analogue of climate change)

15 AR4 OAGCMs (20th Century simulations)
vs Observations

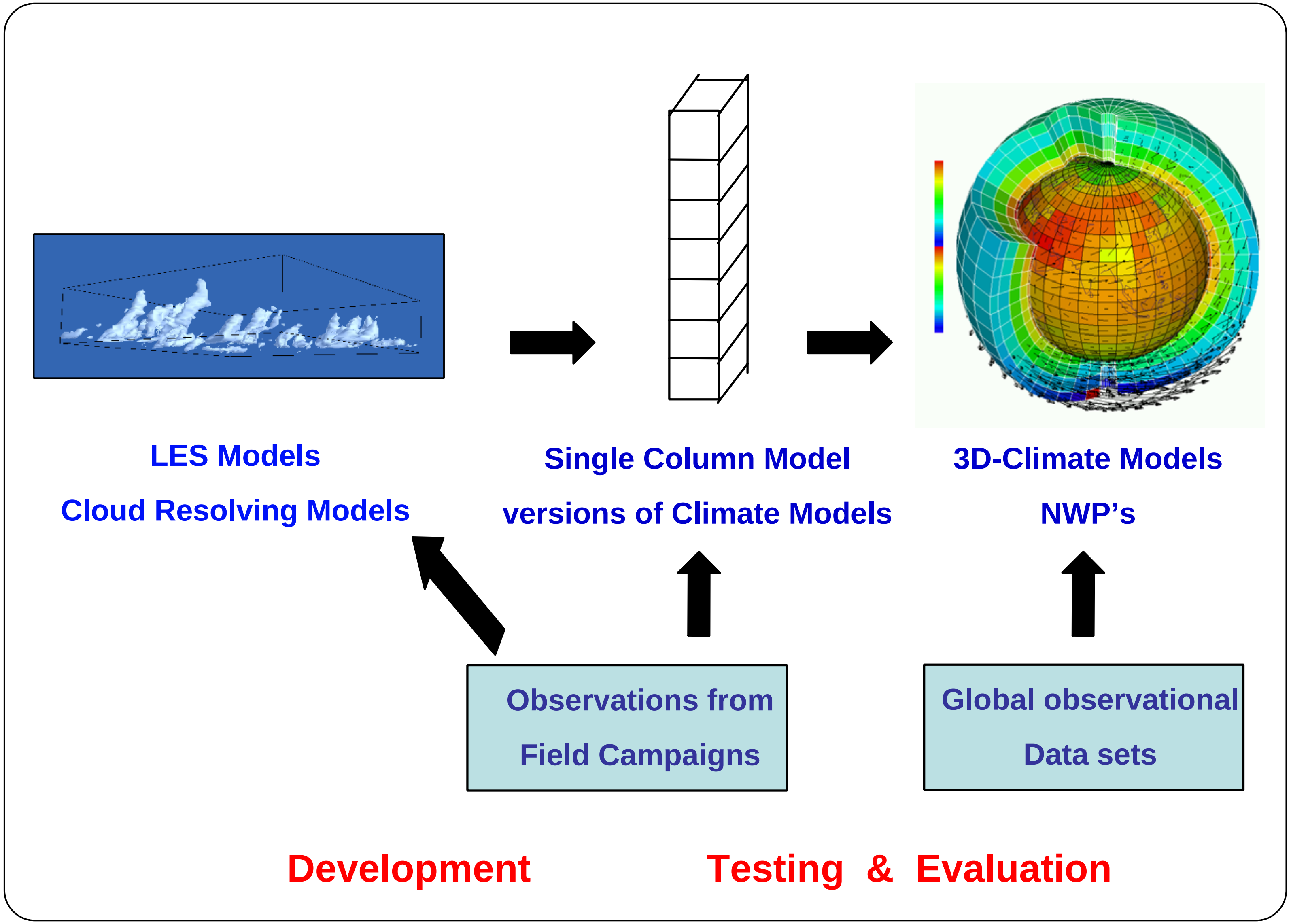


1984-2000 monthly data :

- ISCCP-FD / ERBE rad fluxes
- Reynolds SST
- ERA40 / NCEP2 reanalyses

(Bony and Dufresne, GRL, 2005)

(Simplified) Working strategy for development and evaluation



LES Models

Cloud Resolving Models

Single Column Model

versions of Climate Models

3D-Climate Models

NWP’s

Observations from

Field Campaigns

Global observational

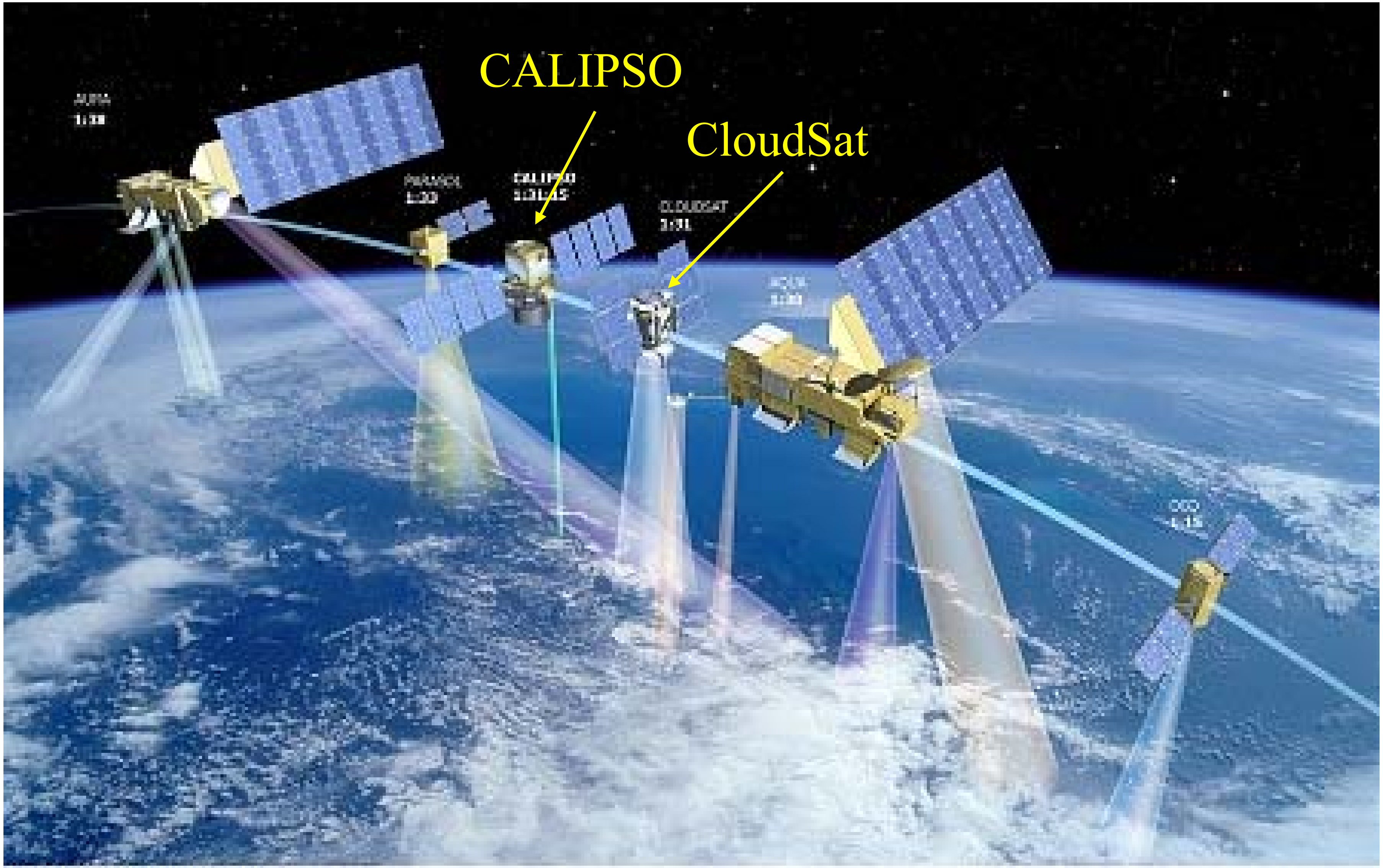
Data sets

Development

Testing & Evaluation

Courtesy of Pier Siebesma

Aqua-Train constellation of satellites



© cnes

Cloud properties (e.g. cloud fraction) and radiative properties can now be assessed separately (allows to point out compensating errors)

But :

The cloud cover derived from satellites is not directly comparable to model outputs
(vertical overlap, sensitivity of measurements, attenuation...)

Therefore :

To make models and satellites speak the same language, we use “simulators”
i.e. we diagnose from model outputs the quantities that would be observed by satellites
(e.g. radar reflectivities for CloudSat, lidar backscattered signals for CALIPSO)
if the satellites were flying above an atmosphere similar to that predicted by the model.

ISCCP (International Satellite Cloud Climatology Project) :

- data *widely and regularly* used for the evaluation of GCMs since the distribution of the ISCCP simulator (almost 15 years after the start of the program)

A-Train observations :

CFMIP is developing an ISCCP-CloudSat-CALIPSO simulator (named CICCS)

- that will be distributed freely to climate & NWP modeling groups
- that will be used in some IPCC AR5 simulations (WGCM recommendation)
- ongoing work, version 1 distributed in Feb 2008

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- data *widely and regularly* used for the evaluation of GCMs since the distribution of the ISCCP simulator (almost 15 years after the start of the program)

A-Train observations :

CFMIP is developing an ISCCP-CloudSat-CALIPSO simulator (named CICCS)

- that will be distributed freely to climate & NWP modeling groups
- that will be used in some IPCC AR5 simulations (WGCM recommendation)
- ongoing work, version 1 distributed in Feb 2008

But :

The cloud cover derived from satellites is not directly comparable to model outputs
(vertical overlap, sensitivity of measurements, attenuation...)

Therefore :

To make models and satellites speak the same language, we use "simulators"
i.e. we diagnose from model outputs the quantities that would be observed by satellites
(e.g. radar reflectivities for CloudSat, lidar backscattered signals for CALIPSO)
if the satellites were flying above an atmosphere similar to that predicted by the model.

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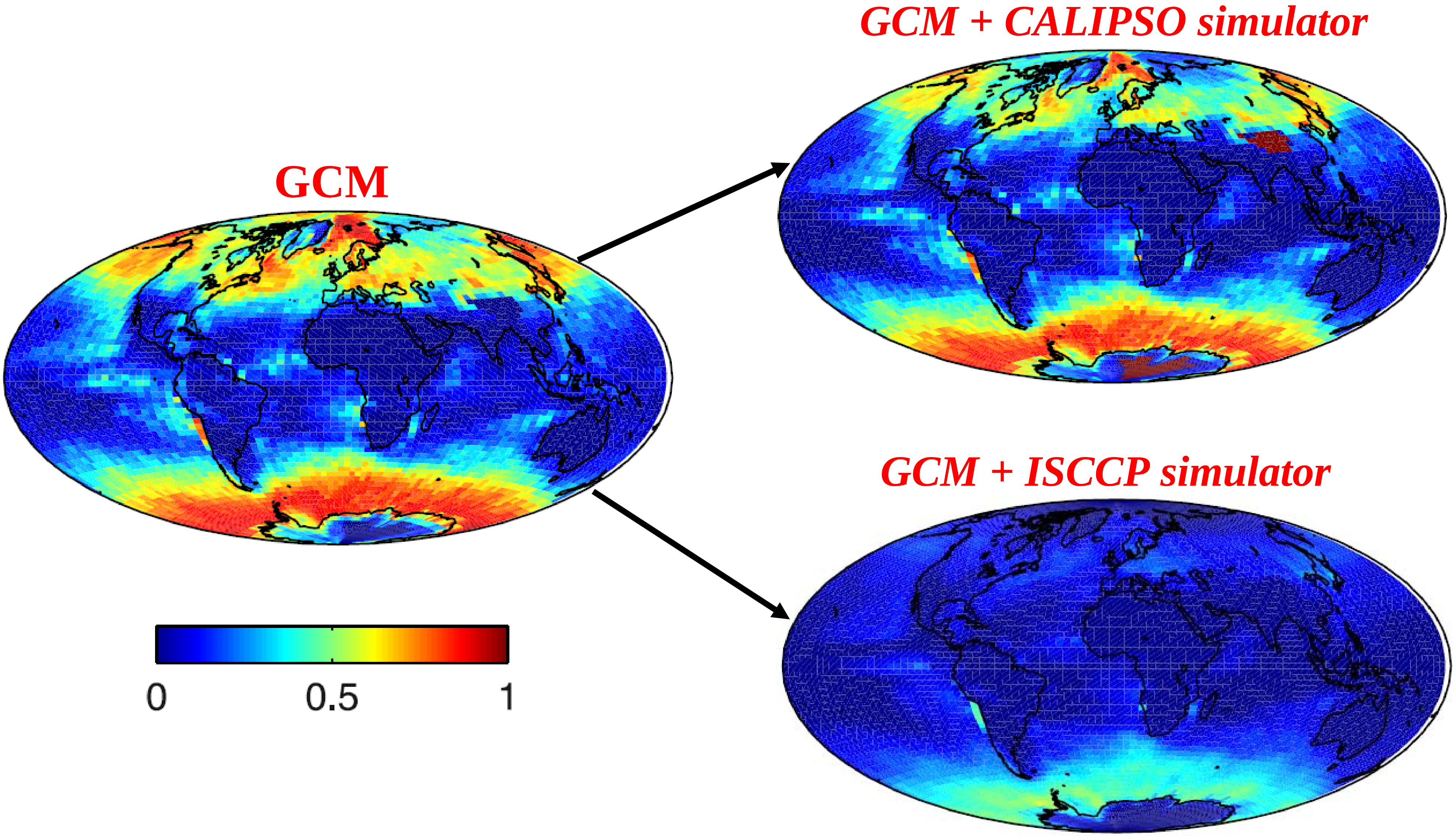
Low Level cloud fraction (Ptop > 680hPa) Jan-Feb-Mar



GCM

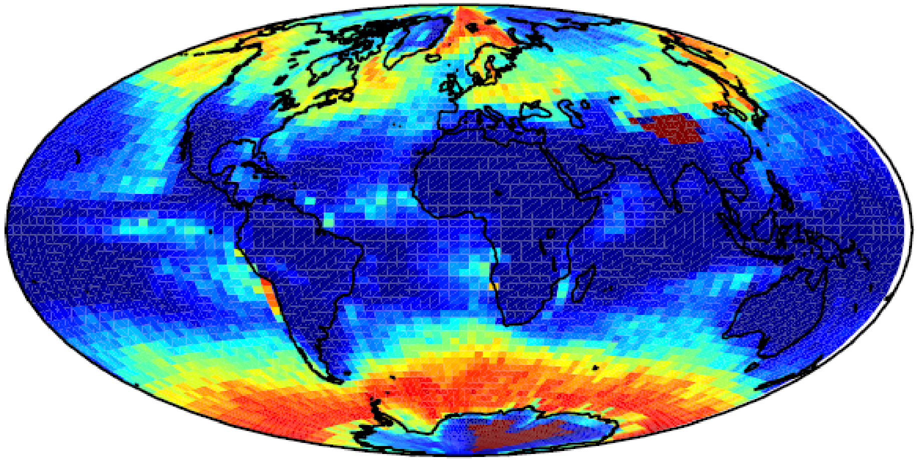
GCM + CALIPSO simulator

GCM + ISCCP simulator

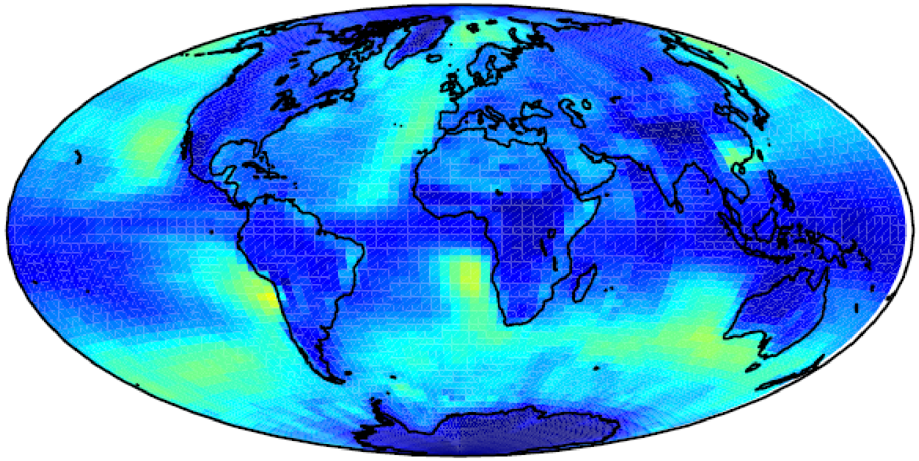
(Chepfer, Bony, Winker, Chiriaco, Dufresne & Seze, GRL, 2008)

Low Level cloud fraction (Ptop > 680hPa) Jan-Feb-Mar

GCM + CALIPSO simulator



ISCCP data



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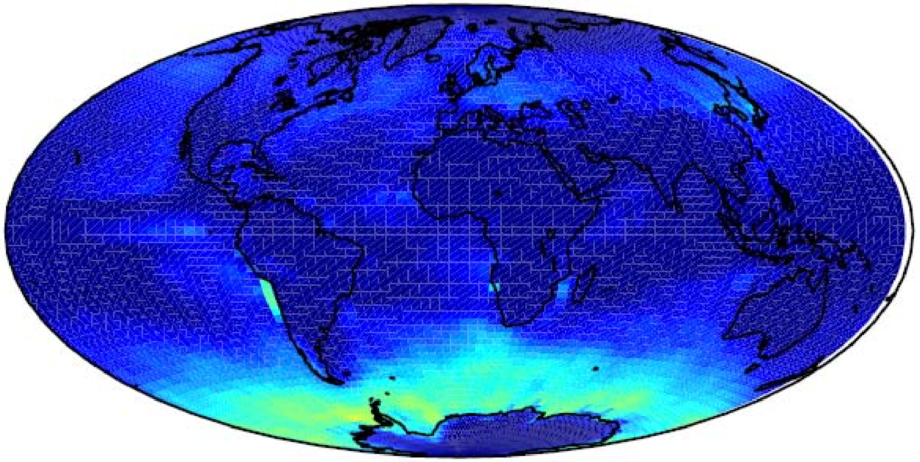
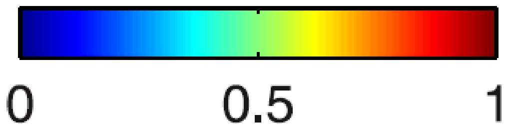
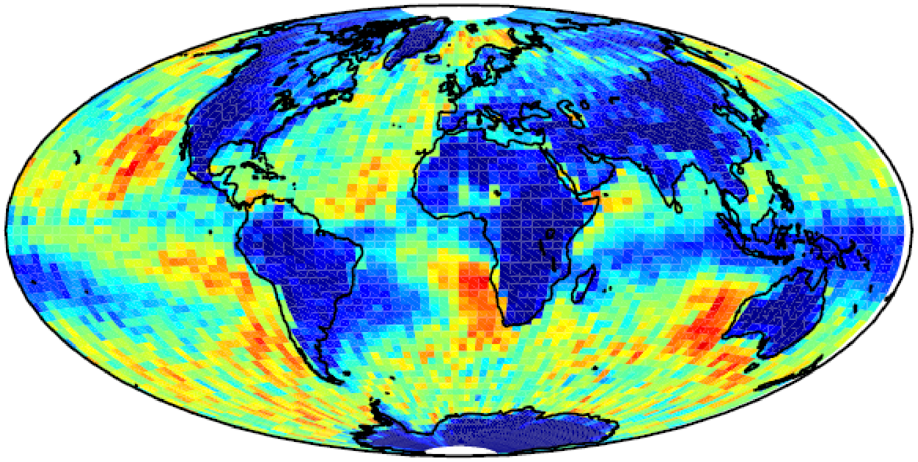


(Chepfer, Bony, Winker, Chiriaco, Dufresne & Seze, GRL, 2008)

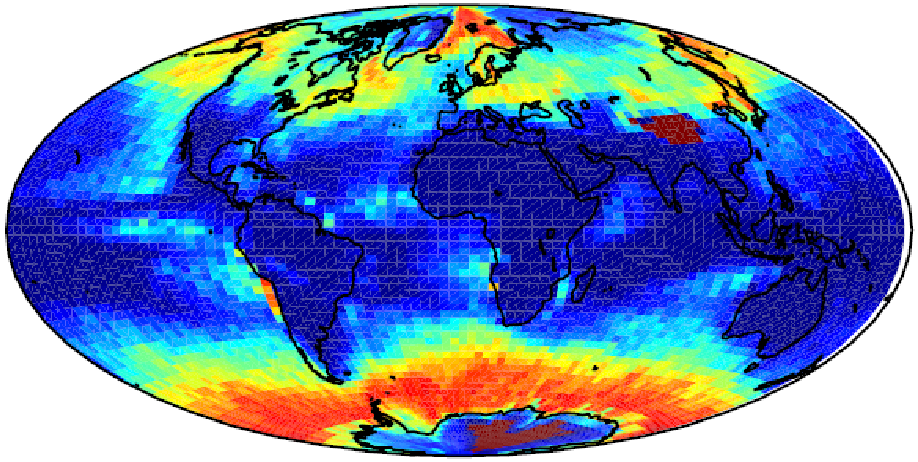


Low Level cloud fraction (Ptop > 680hPa) Jan-Feb-Mar

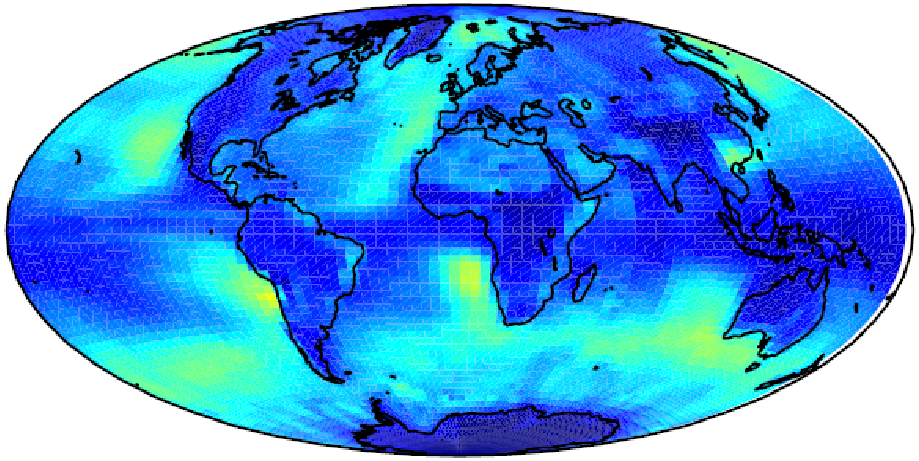
CALIPSO data



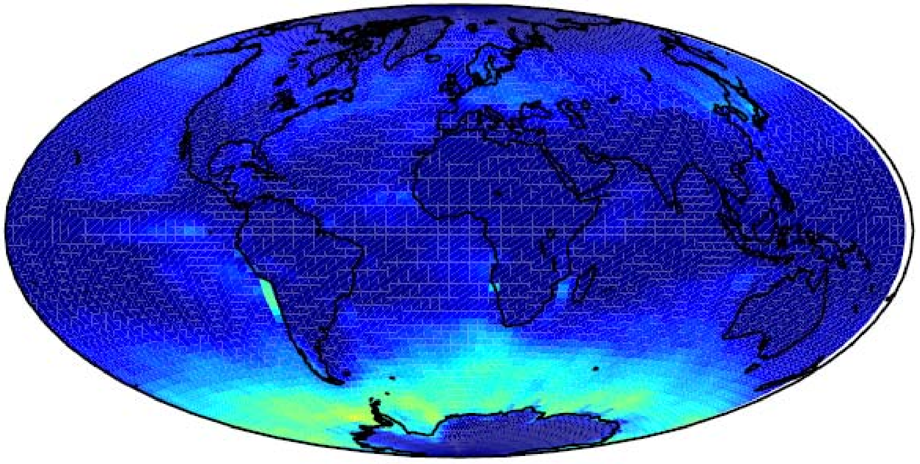
GCM + CALIPSO simulator

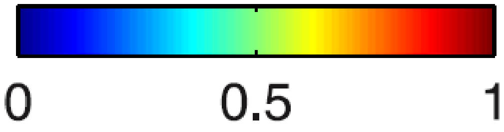


ISCCP data



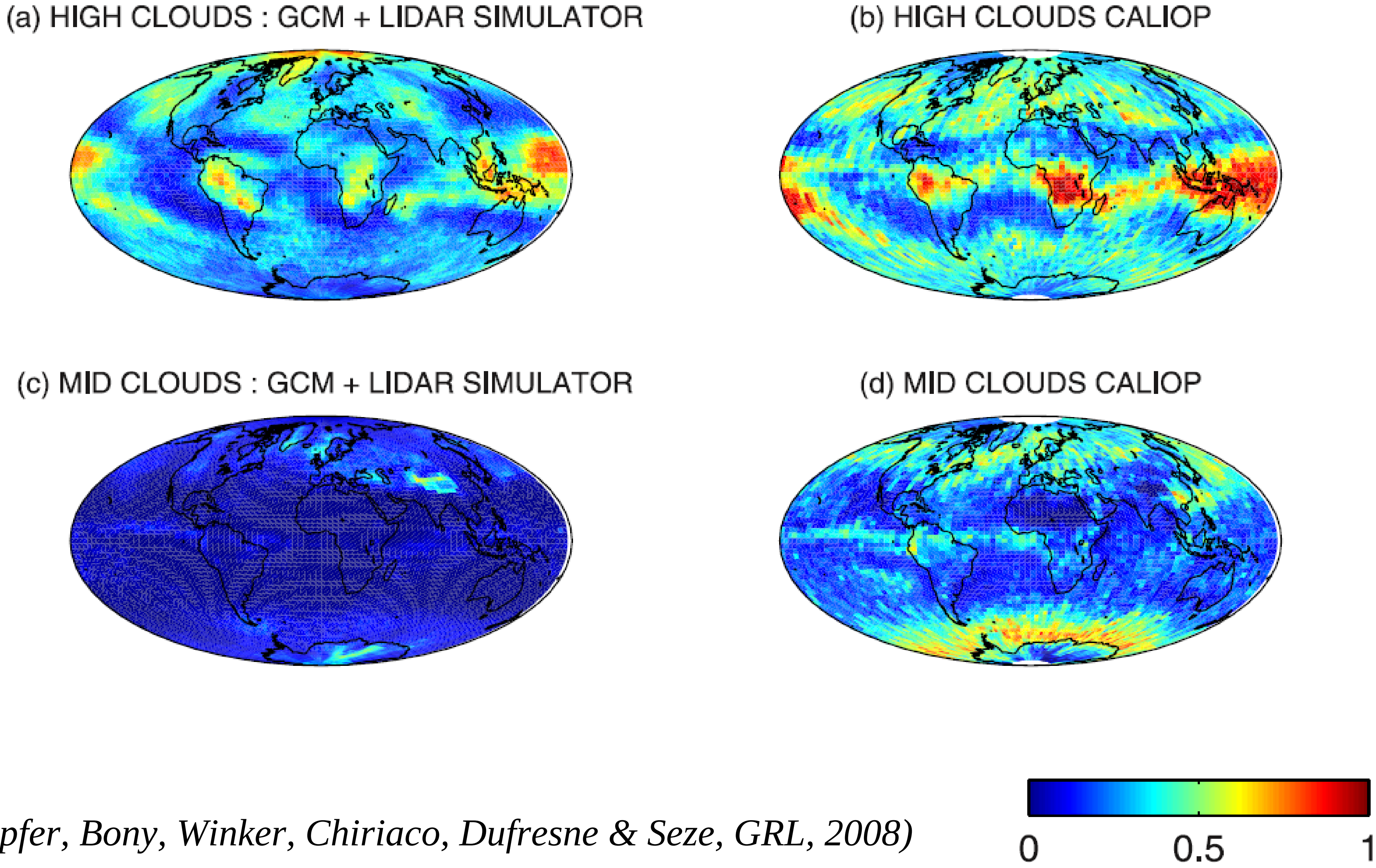
GCM + ISCCP simulator





(Chepfer, Bony, Winker, Chiriaco, Dufresne & Seze, GRL, 2008)

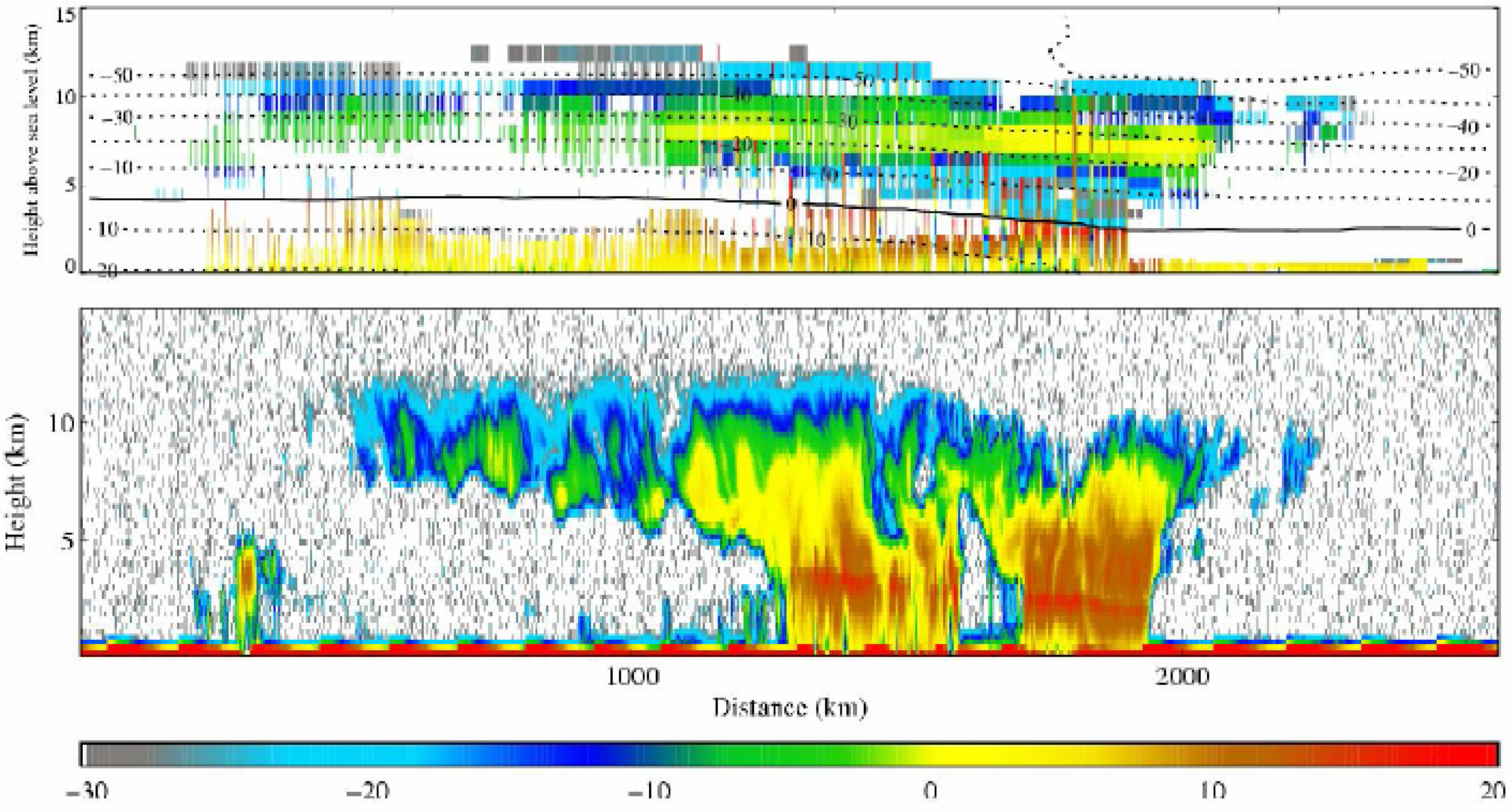
Mid-level and High-level cloud fractions (Jan-Feb-Mar)



(Chepfer, Bony, Winker, Chiriaco, Dufresne & Seze, GRL, 2008)

GCM / CloudSat comparison of radar reflectivities

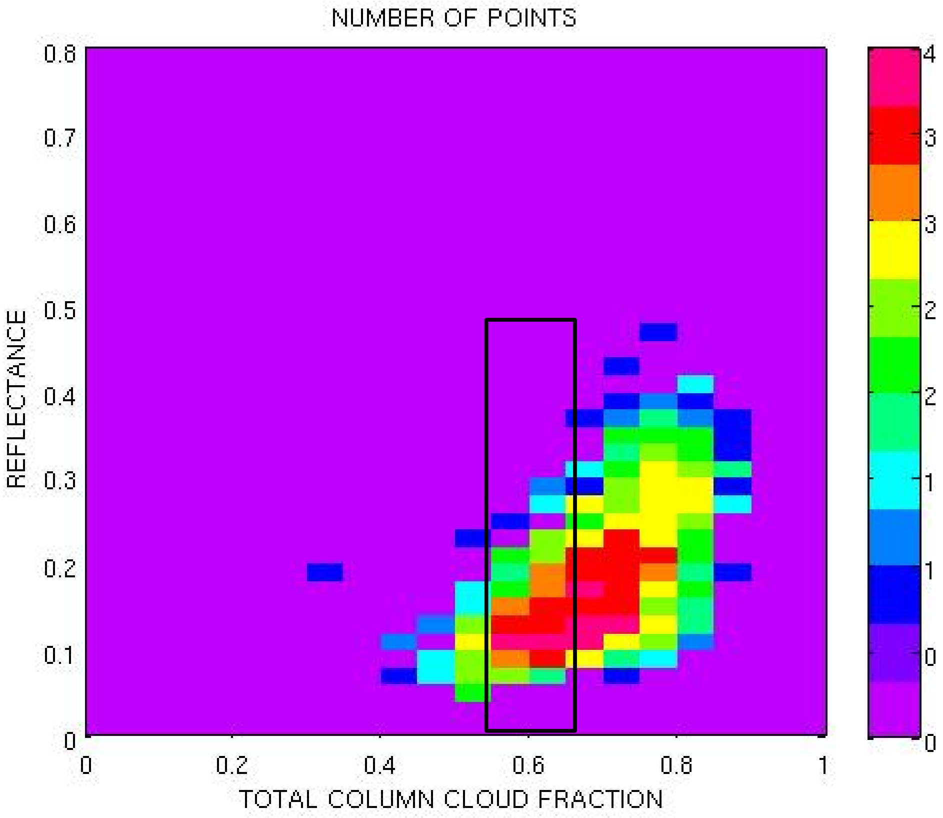
Mid-latitude system in the North Atlantic (UK Met Office global forecast model, Jul 7th 2006)



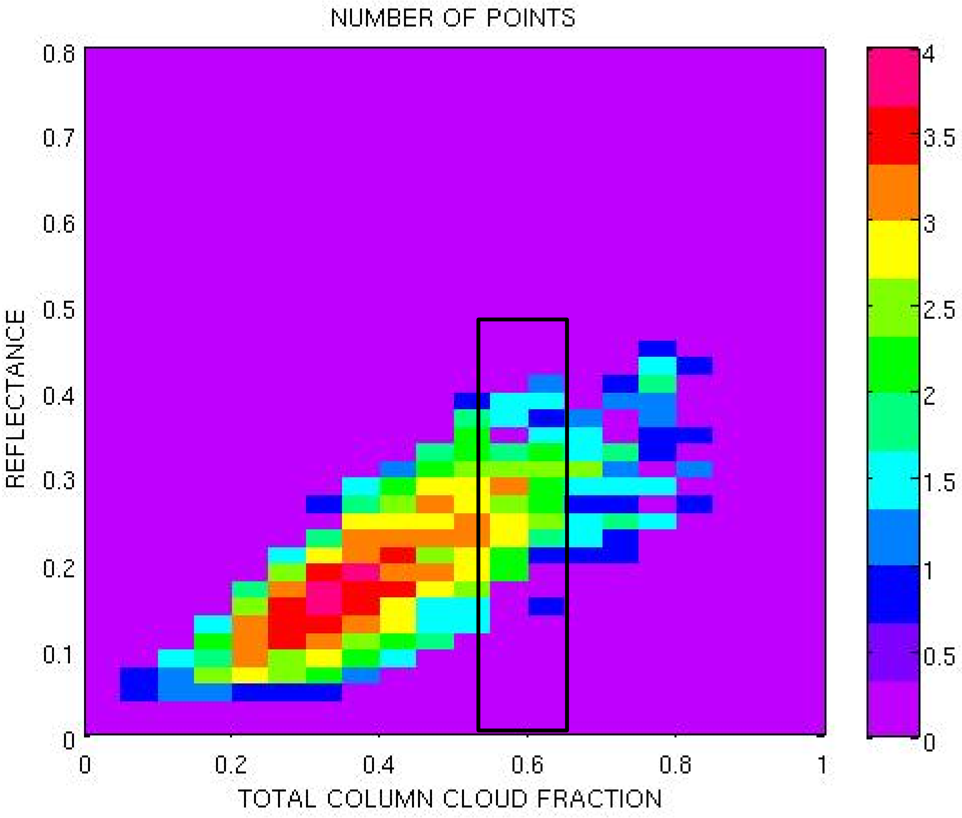
Alejandro Bodas-Salcedo (Hadley Centre)

PARASOL mono-directional reflectance vs CALIPSO cloud fraction

Observations



GCM + simulators



- too little cloud cover over tropical oceans
- overestimate of the reflectance associated with a given cloud fraction : vertical distribution of cloud layers ? bias of the optical depth ?

Courtesy of Helene Chepfer

Conclusion

- TOA and surface cloud-radiative effects have long been recognized as critical for climate sensitivity and ocean-atmosphere coupling.

- Tropospheric cloud-radiative effects, through their interaction with atmospheric dynamics, also strongly matter for the simulation of many aspects of climate :

  e.g.:
    - ➡tropical/extratropical interactions
    - ➡Hadley-Walker circulation
    - ➡large-scale organization of the equatorial atmosphere
    - ➡intraseasonal variability
    - ➡many others (e.g. cloud scale processes)

- Therefore the parameterization of of cloud-radiative effects matters a lot, for both NWP and climate models

    - ➡still a challenging issue for GCMs ! (e.g. compensating errors between cloud fraction and optical thickness)

Concluding remarks

Future improvements in the representation of cloud-radiative interactions possible with :

➨ improved parameterizations of cloud, radiation, microphysics, convection, PBL (cf other talks)

➨ better evaluation of cloud and radiative properties through multiple instruments (CALIPSO, CloudSat, PARASOL, MODIS...) that will provide guidance for model developments.

➨ increased horizontal & vertical resolutions of models

Promising approaches to better understand the role of cloud-radiative feedbacks (and of many other interactions) in GCMs :

➨aquaplanets

➨single-column calculations using WTG

... such approaches would also help build a bridge between GCMs, simple climate models, and high-resolution models (e.g. MMF or global CRM)

and thus foster improvements both in the GCMs' representation of physical processes and in our physical understanding of how the climate system works.


Thank you