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D.5.16 Assessment of the representation of cloud regimes in the tropical regions

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PU	Public	PU
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D.5.16 Assessment of the representation of cloud regimes in the tropical regions

IPSL (Sandrine Bony, Jean-Louis Dufresne (IPSL/LMD)

Introduction

Cloud feedbacks have long been recognized as a major source of uncertainty for climate change projections, but the identification of the origin of this uncertainty is poor.

In RT4, we have analyzed the climate change cloud feedbacks produced by a large ensemble of general circulation models to better identify the reasons for inter-model differences in cloud feedbacks. The comparison of climate change simulations from coupled ocean-atmosphere GCMs participating in the Fourth Assessment Report of the IPCC, and from two ensembles of GCMs coupled to slab ocean models (simulations CFMIP - Cloud Feedback Intercomparison Project - and QUMP - Quantifying Uncertainty in Model Predictions -) has shown that {\em inter-model differences in climate change cloud feedbacks were mostly attributable to the shortwave cloud feedback component, and more particularly to the response of boundary-layer clouds to global warming} (Bony and Dufresne 2005; Webb et al. 2006). It is thus crucial to evaluate the change in clouds (boundary-layer clouds in particular)that is simulated by climate models in response to a change in environmental conditions.

In RT5, we have used satellite observations and meteorological reanalyses (1) to investigate the sensitivity of the tropical cloud radiative forcing (CRF) to interannual changes in sea surface temperature under different dynamical conditions and (2) to evaluate the ability of climate models to simulate this sensitivity and to point out systematic errors in this sensitivity.

Methodology:

In the tropics, the relative occurrence of the different cloud types
strongly depends on the large-scale atmospheric circulation. By using the monthly-mean mid-tropospheric (500 hPa) vertical pressure velocity \omega as a proxy for large-scale rising (\omega<0) or sinking (\omega>0) motions, we decompose the large-scale tropical circulation as a series of dynamical regimes defined from \omega (bins of 5 hPa/d), and we compute composites of climate variables in these regimes (Bony et al. 2004). To a first approximation, this methodology allows us to segregate regimes of deep convection and upper-level cloud tops from regimes of shallow convection and low-level cloud tops (Figure 1). For each dynamical regime (defined either from ERA-40 or NCEP2 reanalyses), we compute 17-year (1984-2000) time-series of monthly interannual anomalies of CRF and SST derived from ISCCP-FD and Reynolds dataset respectively. Then, the interannual sensitivity of the CRF to SST changes is computed from these timeseries as a linear regression coefficient. A

similar procedure is applied to 20th century simulations of 15 coupled ocean-atmosphere models participating in the AR4 of the IPCC.

Results:

Observations show that the interannual sensitivity of the longwave,
shortwave, and net CRF to SST changes is positive, and that the shortwave component is maximum (about 5 W/m2/K) in regimes of large-scale subsidence covered by low-level clouds (Figure 2). These results are robust to the choice of the meteorological reanalysis dataset used to define the dynamical regimes (ERA40 or NCEP2), and the choice of CRF satellite data (ISCCP-FD or ERBE data).

The same diagnostic applied to coupled model simulations shows that in most circulation regimes, models simulate CRF sensitivities within the observational range of estimates (Figure 3). There is however an important exception. In regimes of large-scale subsidence, which are primarily covered by marine boundary-layer clouds, most models (90%) substantially underestimate the sensitivity of the CRF to SST changes. This quasi-systematic bias reveals serious weaknesses in the representation of boundary-layer cloud processes in models. We also show that it is in these regimes that the interannual CRF sensitivities predicted by low-sensitivity and high-sensitivity models are the most different.

Five ENSEMBLES GCMs participated in this comparison: CNRM-CM3 (Meteo-France),IPSL-CM4 (IPSL), ECHAM5/MPI-OM (Max-Planck), UKMO-HadCM3 and UKMO-HadGEM1 (Hadley Centre). In climate change, these 5 models exhibit a wide range of tropical cloud feedbacks (ranging from 0.4~W/m2/K for UKMO-HadCM3 to +1.0~W/m2/K for the CNRM-CM3 and IPSL CM4 models), albeit smaller than when considering all the AR4 models. Most of them are classified in the "high-sensitivity" group of models.

Figure 4 compares with observations the CRF sensitivity to interannual SST changes that is simulated in the current climate by each of these models (first column). Like most AR4 models, the five europeean models reproduce reasonably well the observed CRF sensitivity in regimes of deep convection and of moderate subsidence. However, the IPSL-CM4 model overestimates the LW and SW components of the sensitivity in deep convective regimes(the NET component is correct due a compensation between the two components), which suggests that the model simulates clouds that are too optically thick in these regimes. On the other hand, the HadGEM1 model overestimates the SW CRF sensitivity in regimes of moderate subsidence (which have the largest frequency in the tropics), which might reveal some problem in the simulation of the transition from shallow to deep convective clouds. In regimes of strong subsidence, all the European models underestimate the SW CRF sensitivity compared to observations. With that respect,the european models do not differ much from the other AR4 models. Nevertheless, the five european models appear to give better results than most of the other AR4 models.

Conclusion:

From these results we conclude that the simulation by climate models of the response of boundary-layer clouds to a change in environmental conditions is associated with substantial systematic biases. This applies in particular to the five european models considered in this study. Given the prominent role of these clouds in driving inter-model differences in climate change cloud feedbacks (cf RT4), these errors constitute a serious concern for the credibility of model estimates of climate sensitivity. These results have been published in Bony and Dufresne (2005) and in Bony et al. (2006).

Further observational analyses and model evaluation tests are now required to better interpret the origin of this systematic bias. In particular,comparisons between model cloud outputs and new satellite data (radar data from CloudSat and lidar data from CALIPSO) will allow to better assess the 3D distribution and properties of clouds. Part of our ongoing work is thus to develop new methodologies of model-data comparison allowing us to take benefit of these new data(an ENSEMBLES/CFMIP workshop - CFMIP standing for WCRP Cloud Feedback Model Intercomparison Project - on these aspects will be organized in April 2007 in Paris). These new observational tests will be applied first to european models.

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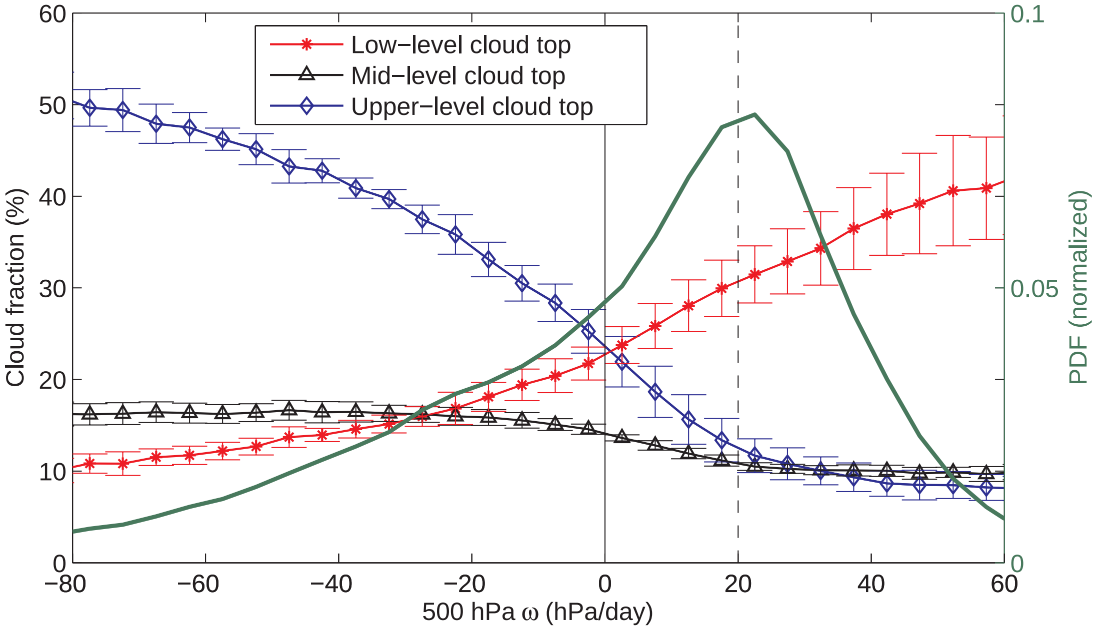

Figure 1: Satellite-derived fractional area covered by low-level, mid-level and upper-level clouds (as classified by the International Satellite Cloud Climatology Project ISCCP) binned by ERA40 monthly-mean mid-tropospheric vertical velocity ω over tropical oceans for 1984-2000. Also reported (thick solid line) is the mean probability distribution function(P_ω) of the different dynamical regimes (bins of ω of 5~hPa/d). The cumulated frequency of occurrence of all regimes $\omega > 20~hPa/d$ is about 30\%.

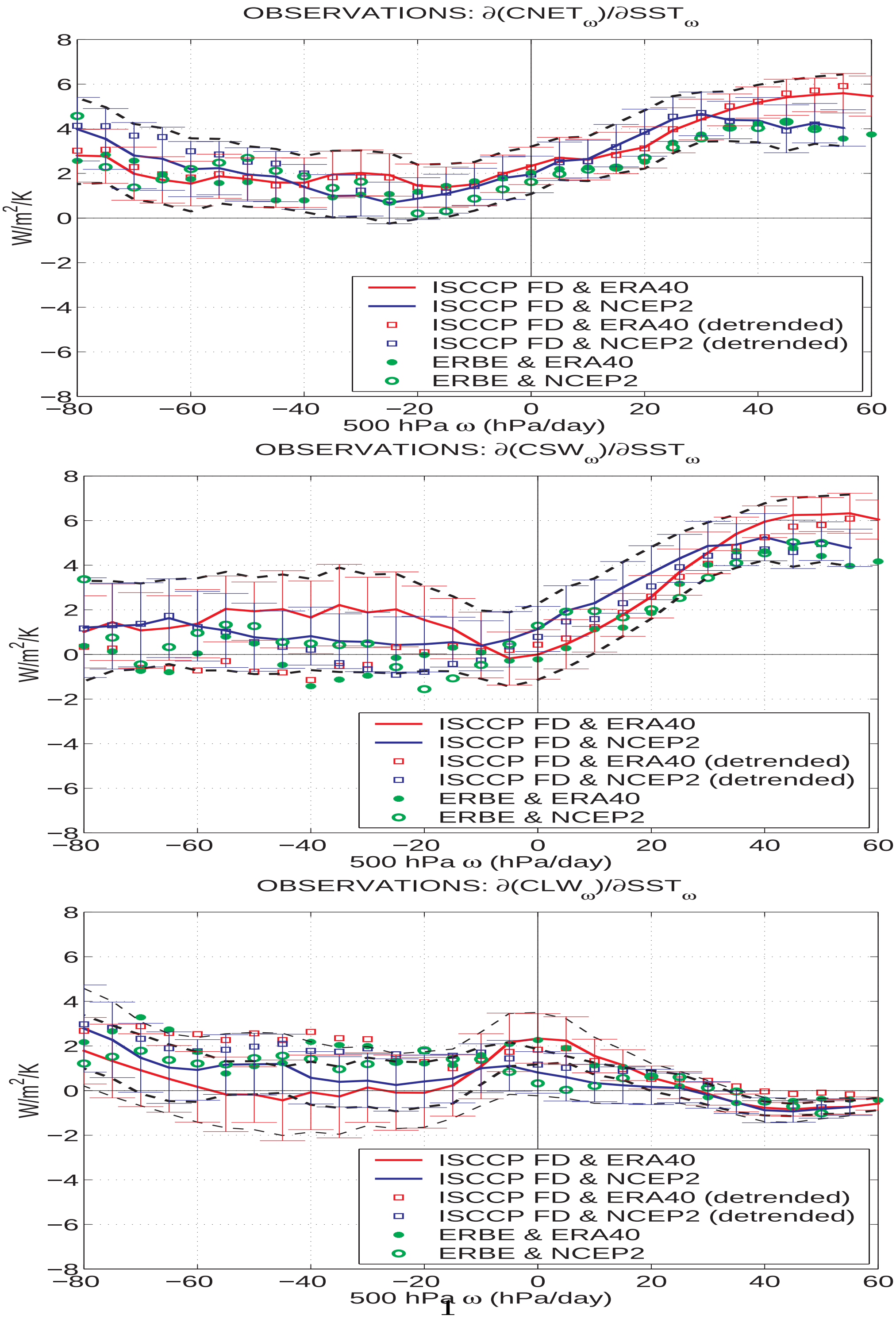

Figure 2: Observational estimates of the interannual sensitivity of the (top) NET, (middle) SW and(bottom) LW components of the CRF to SST: estimates are computed by using ISCCP-FD CRF data and meteorological reanalyses (either ERA40 or NCEP2)over the period 1984-2000. The sensitivity computed within each dynamical regime is associated with a 5%-95% confidence interval. The envelope of the ISCCP-FD/ERA40 and ISCCP-FD/NCEP2 confidence intervals defines the observational range of estimates used in our study. Also reported are the mean sensitivities computed from ERBE CRF data over a much shorter period (1985-89). ISCCP-FD radiation fluxes and ERA40 vertical velocities exhibit some decadal "trends" over the period 1984-2000. As shown by these figures, the sensitivities estimated from detrended data do not differ significantly from those estimated from raw data (particularly in subsidence regimes).

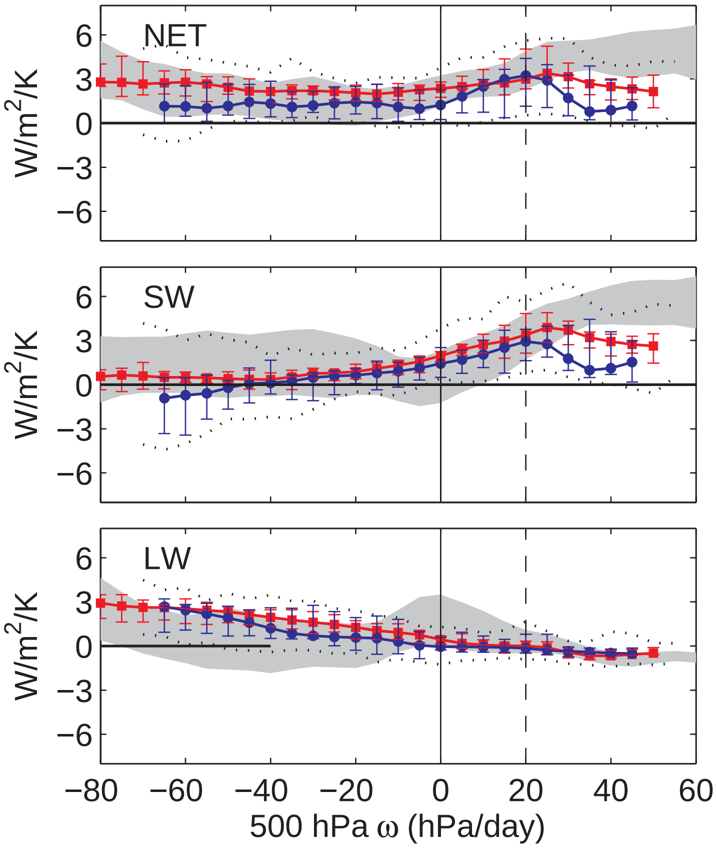

Figure 3: Sensitivity of the NET, SW and LW CRF to SST changes within dynamical regimes derived from observations and from 20th century simulations. The shaded area shows the 5\%-95\% confidence interval of observational estimates derived from satellite data and reanalyses. Dotted lines show the minimum and maximum values the sensitivity predicted by the 15 OAGCMs. Lines with red squares show the median, 25th and 75th percentiles of the sensitivity predicted by the 8 high-sensitivity models that predict a positive anomaly of the tropical-mean CRF in climate change. Lines with blue circles show the same for the 7 low-sensitivity models that predict a negative anomaly of the tropical-mean CRF in climate change.

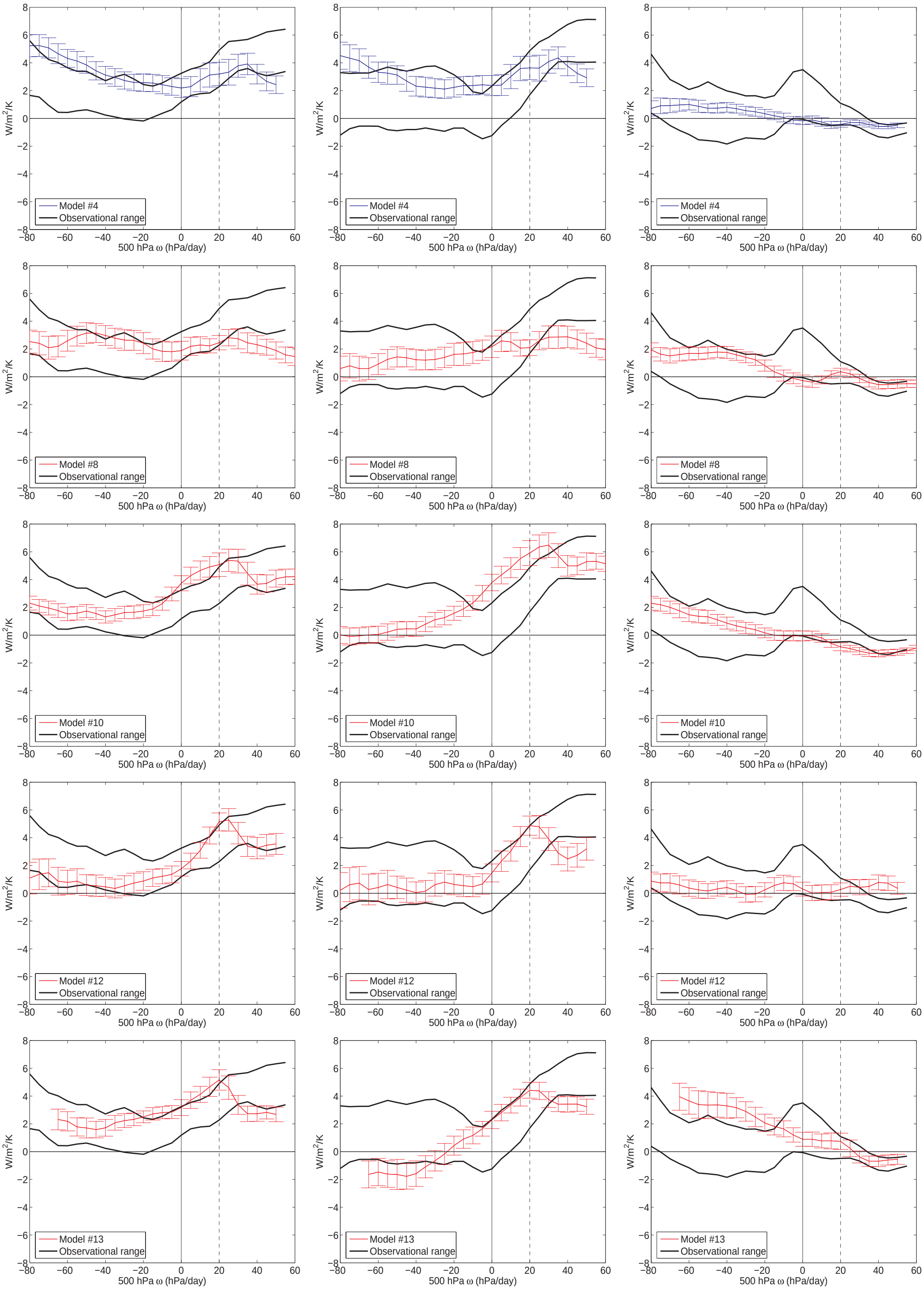

Figure 4: Sensitivity of the CRF to SST changes within dynamical regimes derived from observations and from 20th century simulations produced by the different ENSEMBLES GCMs (model 4, 8, 10, 12 and 13 are the UKMO-HadCM3, ECHAM5/MPI-OM, UKMO-HadGEM1, CNRM-CM3 and IPSL_CM4 GCMs, respectively). From left to right, the first, second and third columns show results for the NET, SW and LW components of the CRF.