The Cloud Feedback Model Intercomparison Project : Summary of Activities and Recommendations for Advancing Assessments of Cloud-Climate Feedbacks

Sandrine Bony, Mark Webb, Bjorn Stevens,
Chris Bretherton, Steve Klein and George Tselioudis

on behalf of the CFMIP coordination committee,
with the endorsement of WGNE and of the GEWEX Scientific Steering Group

Updated March 20th, 2009

Summary

The IPCC AR4 reaffirms the spread in equilibrium climate sensitivity and in transient climate response estimates among current models. Inter-model differences in cloud feedbacks remain the primary source of this spread. The identification of low clouds as the primary (direct) contributor to this spread is one of the signature achievements of the research community as summarized by the AR4. Cloud processes also play a critical role in the large-scale atmospheric circulation and the hydrological cycle. If we are to have confidence in simulations of climate change, particularly at regional scales where cloud biases induce especially strong control on the local energy balance and dynamics, and hence response, developing a better understanding of cloud and moist processes remains imperative.

The main objective of CFMIP-2 is to make, by the time of the AR5, an improved assessment of climate change cloud feedbacks by making progress in the (1) evaluation of clouds simulated by climate models and the (2) understanding of cloud-climate feedback processes. Toward this end CFMIP-2 has been engaged in three types of activities :

1. The development of a CFMIP Observation Simulator Package (COSP). Currently this has modules capable of simulating ISCCP/CloudSat/CALIPSO satellite observations. It is to be distributed to the modelling groups to evaluate model clouds (and thus contribute to the model development process) using satellite observations from the new generation of space-borne sensors.
2. Design and analysis of idealized experiments, requiring simulators and other diagnostics, to better understand the physical mechanisms underlying the different cloud-climate feedbacks in climate models.
3. Collaboration with GEWEX-Cloud Systems Studies (GCSS) to assess the credibility of cloud-climate feedbacks, through the coordinated use of CFMIP-GCSS CRM/LES/SCM[1] case studies focused on the sensitivity of specific cloud types (e.g. low clouds) to changes in climate, and process studies based on the analysis of high-frequency outputs at selected locations.

Experiments, simulators and process diagnostics recommended by CFMIP have now been incorporated into the experimental design for CMIP5, with the support of WGCM. This document is based on the original CFMIP proposal, but is updated to serve as a reference for setting up the CMIP5 experiments and diagnostics recommended by CFMIP.

I. Introduction

Improving climate models to make climate change projections more reliable constitutes a key objective of WGCM. Cloud-climate feedbacks remain one of the largest sources of uncertainty for estimating climate sensitivity and for predicting the global climate state at the end of the 21st century (Randall et al. 2007, Dufresne and Bony 2008). Owing to the strong interaction of clouds with the local energy balance, the atmospheric circulation and the hydrological cycle, biases in the models' representation of clouds and moist processes are also critically problematic for the reliability of climate

[1] CRM: Cloud Resolving Model, LES: Large-Eddy Simulation model, SCM: Single-Column Model.

predictions at regional scales.

To improve this situation, the second phase of the Cloud Feedback Model Inter-comparison Project (CFMIP-2) aims at fostering coordinated research in the area of climate change cloud feedbacks. More specifically CFMIP-2 wishes to make progress by the time of the AR5: (1) in the evaluation of clouds simulated by large-scale models (a "CFMIP simulator" has been developed to facilitate the comparison of model simulations with satellite observations), (2) in the understanding of the physical processes that control cloud-climate feedbacks in the various models, and the understanding of their dependence on cloud modeling assumptions, and (3) in the assessment of the relative credibility of the cloud feedbacks produced by the different models.

For this purpose, CFMIP is developing collaborations between the global climate modeling community and the scientific community involved in high-resolution (LES/CRM) cloud modeling and in the observation of clouds by satellites or ground-based measurements. With this in mind, the CFMIP coordination committee has representatives from the climate model development and evaluation community, the GCSS (GEWEX Cloud System Study) community, the ARM (Atmospheric Radiation Measurement) community and the US-CLIVAR Climate Process Team on subtropical cloud feedbacks (CPT). For the second time since April 2007, the CFMIP and GEWEX/GCSS communities organized a meeting together (PAN-GCSS meeting held on June 2008) and devised collaborative actions to be included in CFMIP-2 plans.

CFMIP, in coordination with WGNE, the GEWEX Modelling and Prediction Panel (GMPP), and the GEWEX Radiation Panel (GRP) made the following recommendations to the September 2008 WGCM meeting :

- To incorporate COSP into a subset of the proposed mandatory CMIP-5 experiments,
- To modestly expand the set of CMIP-5 experiments to include some that will help isolate the role of cloud processes and feedbacks
- To encourage modeling centers to participate in the full suite of CFMIP experiments and diagnostics.

It was argued that so doing would recognize the importance of clouds and moist processes to climate prediction, and would help build a bridge between the scientific communities involved in climate modeling, fine-scale process modeling and observations. Linking CFMIP activities to CMIP5 (use of simulators, idealized experiments) would ensure a large participation of the modeling groups to studies aiming at evaluating cloud processes and their role in climate, at developing thorough climate metrics, and at unraveling and understanding uncertainties associated with climate projections. It was also argued that extensive use of satellite simulators (COSP) is essential to evaluating and improving models, and merits special attention.

At the 2008 WGCM meeting, the main CFMIP requests were granted. It was agreed that:

1. Satellite simulators will be included in the planned activities of WGCM for the next assessment : the use of COSP will be a strong recommendation for CMIP5 simulations, and some COSP outputs will be included into the "core" set of CMIP5 outputs.

2. The idealized experiments proposed by CFMIP-2 will be included into the CMIP5 set of experiments. These experiments will be divided in three categories: a "core" set, a "very high priority" set of experiments, and a "recommended" set of experiments. Two of the idealized experiments proposed by CFMIP2 (patterned SST + aqua-planet experiments) will be added to the "very high priority" set of experiments, and the third one (+/- 2K uniform experiments) to the "recommended" set of experiments.

2. Additional diagnostics requested by CFMIP will also be recommended for the

CMIP5 experiment, subject to the concerns of the CMIP Panel regarding data volumes being addressed.

Since the WGCM meeting the experimental design of the CFMIP experiments (now included in the CMIP5 set) has been revised, and the diagnostic requirements have been refined. This document has now been updated to serve as a source of reference information on CFMIP experimental and diagnostic requirements for CMIP5.

Section II describes the background and rationale for the use of cloud satellite simulators in the CMIP5 experiments. Section III does the same for ther diagnostic output for CMIP5 requested by CFMIP. Section IV describes the rationale for the CFMIP experiments which are now part of CMIP5, as well as the motivation for the CFMIP-GCSS case study. Annex B provides a detailed list of the CFMIP diagnostics requested for CMIP5 and Annex A lists the CMIP5 experiments with additional CFMIP diagnostics, including the periods for which these diagnostics are required.

.

II. COSP, the CFMIP Observation Simulator Package.

Given the importance of the cloud problem to emerging initiatives in regional climate, and given the investment in the current observational system, a special effort to advance our understanding, diagnosis and evaluation of cloud processes in climate models participating in the AR5 is strongly required.

There is no unique definition of clouds or cloud types, neither in models nor in observations. Therefore, to compare models with observations, and even to compare models with each other, it is necessary to use a *consistent* definition of clouds. By using model outputs to diagnose quantities that can be directly observed from satellites (e.g. visible/infrared radiances, radar reflectivities or lidar backscattered signals), "simulators" allow models and observations to speak the same language and be compared quantitatively.

The ISCCP simulator, which is now routinely used by many modeling groups, has been very valuable to compare models with each other and with passive observations, to point out systematic biases of climate models and to analyze cloud feedbacks (e.g. Webb et al. 2001, Zhang et al. 2005, Webb et al. 2006, Williams and Tselioudis 2007, Williams and Webb 2008).

To take advantage of the new generation of active sensors, new simulators are required, that will provide much better diagnostics about the three-dimensional structure of clouds or about statistical relationships between clouds and precipitation. In that way, it will be possible to know the degree to which the accurate simulation of top-of-atmosphere radiative fluxes is due to compensating errors between cloud fraction, optical thickness, and vertical distribution biases. For this purpose, CFMIP has developed COSP, a package that currently consists of three simulators (ISCCP, CloudSat and CALIPSO), as discussed below, and that is expected to include additional simulators in the future. COSP outputs will also be useful in computing cloud-climate metrics.

II.a The ISCCP simulator

The ISCCP simulator allows quantitative evaluation of model clouds using ISCCP and MODIS data, and is required for the calculation cloud climate metrics which penalise compensating errors in models' cloud simulations which are not apparent from standard CMIP3 outputs (Williams and Webb 2008). These errors undermine the credibility of climate models, and the use of simulators as part of the model development process can help to target efforts on the physical schemes responsible.

A new version of the ISCCP simulator (version 4.0) for use in CFMIP2 / CMIP5 is now available from the CFMIP website. Some updates have been made which include a) an improved pseudo-random number generator, b) improvements to the diagnosis of cloud top pressure and c) addition of 'lightweight' diagnostics (grid-box mean cloud occurrence, top pressure and optical depth) to facilitate use of the simulator for longer periods in a wider range of experiments.

The requested ISCCP simulator outputs for CMIP5 are listed in Annex A. Because of the changes to the cloud top diagnosis method, it is essential that ISCCP simulator output submitted to CMIP5 be based on version 4.0. This may be implemented by upgrading from an older version, or, preferably, by installing COSP 1.0, which incorporates version 4.0 of the ISCCP simulator. COSP 1.0 is scheduled for release in April 2009.

II.b CALIPSO/CloudSat simulators

The CloudSat and CALIPSO space-borne cloud profiling radar and lidar instruments in the A-Train constellation of satellites are providing new information on clouds, precipitation and their vertical structures. Although active sensors see more of the 3D structure of clouds than can be seen by passive sensors, the effects of instrument sensitivity and attenuation by clouds and precipitation mean that simulators are still required for quantitative 'like with like' evaluation with models (e.g. Haynes et al 2007, Bodas et al 2008, Chepfer at al, 2008).

CloudSat and CALIPSO simulator modules were released with the first test release of COSP in February 2008 (http://www.cfmip.net). Version 0.3 which contained output diagnostics suitable for use in CMIP5/CFMIP-2 was released in November 2008. The first operational version 1.0 is due for release in April 2009.

These additional packages provide an important complement to the ISCCP simulator as they help rationalize ambiguities associated with cloud overlap, and are thus key components of COSP.

II.c COSP in CMIP5 experiments (Table 1)

In 2007, WGCM recommended that COSP be used in some CMIP5 simulations. A version of COSP including the *updated* ISCCP simulator together with CloudSat and CALIPSO simulators is due in April 2009.

* Long timeseries : At present, only the ISCCP and CALIPSO simulators are ready for in-line, long-term integrations (the codes are vectorized and a lightweight set of diagnostics has been defined)[2]. We recommend with the highest priority that these two simulators (at the very least the upgraded ISCCP simulator) be used in-line in several mandatory CMIP5 experiments (see Table 1 below.)

* Short timeseries : We recommend with the highest priority that COSP (with the ISCCP, Cloudsat and CALIPSO simulators activated together with the A-Train orbital sampling) be used off-line for one year in a subset of the CMIP5 experiments (see also Table 1)

II.d The GCM-Oriented CALIPSO Cloud Product (GOCCP) dataset

The interpretation of the lidar backscatter ratio in terms of cloud products or variables (e.g. cloud fraction) requires to use a set of criteria or parameters that depends on the vertical resolution at which the lidar scattering ratio is measured or computed. To make consistent comparisons between models and CALIPSO data, we have developed, in collaboration with Dave Winker (NASA/Langley), a GCM-Oriented CALIPSO Cloud Product (GOCCP) dataset derived from CALIPSO Level-1 data which is consistent with the CALIPSO simulator outputs (Chepfer et al. 2008). *A priori*, the CALIPSO level 2 dataset developed by NASA will not be as consistent with the simulator outputs as GOCCP, but a comparison is under-way to quantify the difference between both datasets (Chepfer et al., in preparation).

The GOCCP products will be made available on-line from the LMD/IPSL and CFMIP websites. They will include diagnostics of the global 3D monthly mean and seasonal cloud fraction (using the same vertical grid – 40 levels - and the same cloud detection criteria as the CALIPSO simulator) derived from CALIPSO observations, as well as diagnostics of the layered (low-level, middle-level, high-level) cloud fractions, joint height-scattering ratio distribution of the lidar backscatter ratio and of the depolarization ratio. All the diagnostics will be in netcdf format, and any post-processed versions of the ISCCP and CloudSat datasets which are produced during the project will also be made available.

III. GCM outputs requests to CMIP5

Since the last WGCM meeting, CFMIP has reconsidered the list of additional cloud related diagnostics requested from CMIP5 simulations to best serve the needs of climate model development and evaluation community and to support CFMIP-GCSS studies on cloud processes and feedbacks.

Our selection of GCM outputs was guided by the wish that:

1. The value of GCM outputs be as high as possible, by the AR5 and beyond, maximizing the opportunities for people in the model evaluation and process modelling communities to contribute to future improvement of climate models

2. The selection of diagnostics be justified by published studies demonstrating the effective usefulness of the requested outputs.

3. Diagnostics reflect the tremendous advancement (and enormous investment) in satellite remote sensing available to the current epoch of climate simulation.

The list of additional CMIP5 model output requested by CFMIP for model evaluation and for understanding of model systematic biases, cloud processes and feedbacks is summarized in Table 1. Several types of diagnostics are requested.

<u>III.a Type of diagnostics #1 :</u> outputs from simulators

The rationale for these outputs has been discussed in section II.

The set of simulator output variables proposed for long-term integrations includes :
(monthly outputs for all years, daily outputs for a subset of years)

- Ptop-Tau diagnostics from ISCCP (7 vertical levels x 7 optical thickness bins)
- gridbox mean cloud cover, cloud albedo and cloud top pressure from ISCCP simulator
- low-level, mid-level, high-level and total cloud cover from CALIPSO simulator
- vertical profile of cloud fraction from CALIPSO (40 vertical levels)

The set of simulator output variables proposed for one includes:
(monthly outputs for all years, orbital outputs for a subset of years)

- the lightweight set of simulator diagnosics defined above
- joint height-reflectivity distribution of radar outputs, on 40 fixed height levels and in 15 bins of reflectivity, required to repeat and extend the analysis of Zhang et al (2007) or Bodas et al (2008) on CMIP5 outputs.
- joint height-lidar scattering ratio distribution of lidar outputs on 40 fixed height levels and in 15 bins of backscattered scattering ratio, to repeat and extend the analysis of Chepfer et al (2008) on CMIP5 output.

Note that COSP simulator outputs will also be useful in computing cloud-climate metrics.

<u>III.b Type of diagnostics #2 :</u> 3-hourly global instantaneous outputs for a short period

These diagnostics will be requested for the year 2007 of an AMIP experiment.They will serve three main objectives. First, they will allow the GCSS community to examine the representation of cloud processes by GCMs in the current climate in any climate regime or meteorological situations without imposing *a priori* geographical constraints (this is particularly necessary for climate models because the large-scale dynamical structures simulated are often shifted in space compared to observations). Second, these high-frequency outputs will enable us to analyze in detail the diurnal cycle of clouds and convection simulated by climate models, which is known to be a long-standing weakness of NWP and climate models. Third, these data will support the development of future CFMIP simulator modules (e.g. Combined CloudSat/CALIPSO, TRMM, MLS, RTTOVS...)

This unique global dataset is likely to be used by the scientific community for a long time, well beyond the AR5.

III.c Type of diagnostics #3 : half-hourly/timestep output at selected locations for several years

These diagnostics will be requested for AMIP experiments and other climate experiments which use the AMIP experiment as their control. They will be requested along a few transects (e.g. WGNE-GPCI, VOCALS) and locations for which a large number of observations will be available (satellite data for GPCI, field campaign for VOCALS, long-time series of ground-based observations for ARM instrumented sites). These data will attract the focus of a large community of researchers (within the GCSS and ARM communities in particular) encouraging evaluation with a wealth of in-situ measurements which have not until now been possible. One example application of such data is the EUROCS/GCSS Pacific Cross Section inter-comparison (Siebesma et al 2004), which compared clouds and circulation in climate and forecast models along a vertical section cutting through the Hadley circulation. Another is a comparison of the space-time organization of tropical deep oceanic cumulus convection in three climate models (Mapes et al. 2008). These data will also inform the design of idealized SCM/CRM/LES case studies.

III.d Additional diagnostics to aid understanding of cloud processes and cloud feedbacks in models.

A number of additional diagnostics are proposed by CFMIP for a subset of the CMIP5 experiments. The lightweight nature of the atmospheric experiments (max 30 years in length) means that data volumes are small compared to CMIP, allowing a more extensive diagnostic list.

Cloud condensate tendency diagnostics (CCTD) will be used to gain insight into the physical mechanisms responsible for cloud feedbacks in the CFMIP-2 experiments. (Ogura et al, 2008a, 2008b). We also plan to save temperature and humidity tendency terms (including 3D radiative fluxes) to assess (for example) the impact of changes in convection and boundary layer mixing on the atmospheric structure, hydrological cycle, and clouds in the warmer climate. (See Zhang and Bretherton 2008 for an example of this analysis in an SCM.)

IV. CMIP5 experiments proposed by CFMIP

Climate models still exhibit large inter-model differences in the response of clouds to climate change, and many factors or processes potentially contribute to these differences. Experience shows that it is generally extremely difficult to determine the reasons why complex models behave the way they do, and why complex models differ from each other. As discussed by Held (2005), this leads to a widening “gap between simulation and understanding in climate modeling”.

Isolating the cloud response simulated by climate models in simplified or idealized context is necessary if we are to narrow this gap and thereby provide credible guidance to policy makers and stakeholders in the coming decades.

Toward this end CFMIP proposed a hierarchy of experiments which are now included in CMIP5 (see Taylor et al, 2008) This suite of experiments will help to isolate and to understand the effects of the warming and resultant circulation changes on clouds and precipitation, and will help to build a bridge between fully coupled simulations (from Earth System Models or ocean-atmosphere coupled GCMs), very fine-scale simulations (from LES models, cloud resolving models, and large-scale models using super-parameterizations), and conceptual representations of the climate system. These are described below, and are referred to according to the numbering system of Taylor et al, 2008.

IV.a Ocean-atmosphere coupled experiments.

Here CFMIP does not propose additional simulations but proposes to diagnostically augment existing CMIP-5 AOGCM experiments. (See Table 1).

IV.b Atmosphere-only experiments with 'realistic' control simulations.

Gregory and Webb (2008) have shown that a significant fraction of inter-model spread in cloud 'feedback' in slab models occurs shortly after CO2 doubling. It is not in fact related to the global mean surface temperature response, but results from the rapid cloud response to changes in atmospheric structure that are induced by the CO2 increase. To allow these two aspects of cloud 'feedback' to be separately quantified, we have proposed a combination of prescribed SST and CO2 forced experiments. These experiments use the AMIP experiment (3.3) as their control.

1/ Experiment 6.6: A patterned SST-perturbed climate change experiment. and will be run for 30 years with an SST perturbation pattern based on a composite of coupled model SST responses taken from 1% coupled model CMIP3 experiments at time of CO_2 quadrupling (to be provided.). Although these experiments are not expected to reproduce exactly the global mean cloud feedbacks as in a coupled experiment or slab experiments, they are expected to explore the same range of cloud feedback processes (Wyant et al 2006, Ringer et al 2006).

2/ Experiment 6.8: A uniform SST-perturbed climate change experiment. This complements 1/ above, and in combination will allow the effects of local and remote changes in SST on cloud feedbacks to be assessed (e.g. as discussed by Caldwell and Bretherton, 2008).

3/ Experiment 6.5: A 4CO2 ‘Hansen’ experiment. In this experiment, the AMIP experiment is repeated with the same SSTs, but radiation sees $4CO_2$. (Note that only radiation must see the CO2 perturbation; any non radiative effects of CO2 – e.g. on vegetation should continue to see the AMIP CO2 value.)

Slab model experiments are no longer part of the coordinated experiments of CMIP, mainly because the increasing complexity of sea-ice schemes in coupled models makes it increasingly difficult to have a consistent representation of sea ice in slab and coupled model versions. Moreover, recent comparisons of the CMIP3 slab and AOGCMs show that quantitative predictions from slab models are only a limited guide to the long term sensitivities of AOGCMS models and that some (possibly most) of the differences in the feedbacks between coupled GCMs for 21st century climate change are due to differences in model feedbacks on decadal timescales which are different in slab and coupled models (Williams et al, 2008). It is proposed that these effects be studied via CMIP5 AOGCM experiments where CO_2 is instantaneously quadrupled (experiments 6.3, 6.3-E) (Gregory et al 2004, Williams et al, 2008.) These experiments will also allow the separation of rapid cloud adjustments in direct response to CO_2 forcing from of temperature dependent cloud feedbacks in the AOGCMs (Gregory and Webb, 2008).

IV.c Aqua-planet experiments

Aqua-planets are examples of simplified models. By using the idealized boundary conditions proposed by the WGNE Aqua-Planet Experiment Project (APE, Neale and Hoskins 2001) and by adding a uniform perturbation of the sea surface temperature, one may investigate the cloud response to global warming in a simplified, idealized framework where complexities associated with land-surface processes, monsoons, or the Walker atmospheric circulation, do not come into play.

With the aim of interpreting differences between the cloud feedbacks produced by the NCAR and GFDL GCMs, Medeiros et al. (2008) showed that the climate sensitivity of aqua-planets was similar to that of the realistic configurations of those models, and that robust aspects of the cloud response were present both in aqua-planet and realistic configurations. Their analysis suggested that the representation of shallow cumulus convection was playing a key role in climate sensitivity differences between the two models. The extent to which these results may be generalized to a larger ensemble of models remains to be investigated.

Short aqua-planet experiments (CTRL, +4K and 4CO2 are now included in the CMIP5 experimental design (6.7a-c). The protocol to be followed will be largely similar to that proposed by APE : a “control climate” simulation of four years (6 months of spin-up + 3.5 years of simulation) will be first performed using a zonal distribution of SST derived from observations and no sea-ice at high latitudes; then +4K and 4CO2 experiments of the same length will be performed All other boundary conditions will remain unchanged.

An important feature to be noted is that since SSTs are prescribed in these experiments, high-resolution models such as the super-parameterized CAM (SP-CAM, Khairoutdinov et al. 2005; Wyant et al. 2006b) or the global CRM NICAM (e. g. Miura et al. 2005) will be able to participate in this aqua-planet inter-comparison, even though ocean-atmosphere coupled versions of these models have not been developed yet.

Several components of the climate response to global warming noted in climate change experiments carried out by CMIP3/AR4 ocean-atmosphere models may be investigated in more detail using these simulations: One may cite for instance : the response of the different tropical clouds to dynamical and thermodynamical changes in climate (Bony and Dufresne 2005, Williams et al. 2006, Wyant et al. 2006, Medeiros et al. 2008), the poleward shift and the change in the strength and the frequency of mid-latitude storms (Yin et al. 2005, Tselioudis and Rossow 2006), the relationship between cloud phase changes and climate sensitivity (Tsushima et al. 2006), the connection between tropical and extra-tropical cloud changes (Volodin et al., communication at the PAN-GCSS meeting, June 2008), as well as the connection between the atmospheric moistening by convection and the response of low-level clouds (Sherwood et al., in preparation).

IV.e Sensitivity experiments to assess impact of modelling assumptions on cloud feedbacks

The lightweight nature of the CFMIP-recommended atmospheric CMIP5 experiments (modified SST pattern, uniform +4K, aqua-planet, etc) makes the prospect of running sensitivity tests (where various aspects of model physics are changed) more attractive. Modelling groups participating in CFMIP-2 will be encouraged to use the CFMIP-2 experiments as a base for physical sensitivity tests to clarify the dependence of the cloud feedbacks on any aspects of their model formulation that they consider relevant.

For example, a pilot study with the Hadley Centre model (based on the CFMIP-2 experiments with realistic control simulations) suppressed the two main source terms producing shallow clouds in the subtropics. This showed that the positive shallow cloud feedback in the subtropics in this model is mainly due to reduced detrainment of condensate from shallow convection in stratocumulus/trade cumulus transition region in a warmer climate, although reductions in condensation driven by LW cooling at cloud top also plays a role closer to the coast. (Mark Webb, Adrian Lock and Tomoo Ogura.). Alternatively, modelling groups may choose to assess the impact of increasing boundary layer resolution on the cloud feedbacks in their models.

As the sensitivity experiments will vary from model to model, (and may be made in realistic, aquaplanet or SCM configuration), this is not proposed as a coordinated inter-comparison activity, but more as a 'spinoff' activity to support improved understanding of cloud feedback mechanisms in individual models.

IV.d SCM/LES cloud feedback experiments

Aqua-planets already represent a simplification of climate models but are still too complex to investigate the dependence of the cloud response on modeling assumptions at the level of the numerical representation of sub-grid scale processes. Uni-dimensional simulations are better suited for this purpose as they are cheap enough to run to repeat and analyze the same experiment with many different representations of convective, cloud or micro-physical processes. Uni-dimensional simulations are also the framework commonly used by climate modelers to develop and test parameterizations within GEWEX/GCSS.

At the time of the AR4, the response of low-level clouds was the largest contributor to for inter-model differences in global cloud feedbacks (Bony and Dufresne 2005, Webb et al. 2006, Wyant et al. 2006, Randall et al. 2007). In subsidence regions of the tropics, for instance, some models (e.g. NCAR CAM3, INM) predict an increase in marine boundary-layer clouds while other models predict the opposite (e.g. MIROC, GFDL or IPSL). To better understand the reasons for these differences, Zhang and Bretherton (2008) proposed an idealized set-up of climate change experiments that simplifies the large-scale dynamics and mimics the behavior of the subsidence regimes of the subtropical eastern oceans where boundary-layer clouds (stratus, stratocumulus or shallow-cumulus) predominate. In brief, this set-up takes advantage of the moist-adiabatic temperature structure of convective regimes and of the weak horizontal temperature gradient of the tropical free troposphere to diagnose the effect, on the subsidence rate of non-convective regions, of a global warming of the tropical ocean.

When applied to the single-column version of the NCAR model, this idealized framework allowed Zhang and Bretherton (2008) to reproduce the negative feedback of low-level clouds produced by the NCAR coupled ocean-atmosphere model in climate change experiments. Recently, Minghua Zhang et al. applied the same framework to different climate models (NCAM CAM3, GFDL AM2, HadGEM2) and to different large-eddy simulation (LES) models (SAM, UCLA) and found more consistent responses among LES models than among climate models (Zhang et al., communication at the PAN-GCSS meeting, June 2008). Chris Bretherton's group has found that at least for one climate model (SP-CAM), it even appears possible to *quantitatively* reproduce the subtropical boundary layer cloud feedbacks of the global model within a column modeling framework (Bretherton et al., communication at the PAN-GCSS meeting, June 2008). Therefore, this idealized set-up is promising to examine the physical processes underlying the low-level cloud feedbacks of GCMs in climate change, to investigate their dependence on model parameterizations, and to assess their credibility by comparison with LES or cloud-resolving models (CRMs). Modeling centers should be strongly encouraged to participate in this CFMIP-2 SCM/LES cloud feedback experiment.

As part of a collaboration between the GCSS Boundary Layer Cloud Working Group and CFMIP, Minghua Zhang and Chris Bretherton will coordinate such idealized experiments across climate models and LES/CRM models. The goal will be both to understand and to assess the credibility of cloud-climate responses produced by climate models using SCM/LES models. The focus will be put first on trade cumulus and on stratocumulus-to-cumulus transition regimes, which are thought to be the cloud regimes primarily responsible for inter-model differences in climate change cloud feedbacks (Williams and Webb 2008, Medeiros et al. 2008). Two main hypotheses will be tested: (1) that single-column model case studies can capture the different GCM cloud-climate responses (positive/negative) in these regimes, and (2) that inter-model differences among LES models will be smaller than among GCM models and therefore that LES results expose SCM flaws as well as offer guidances on model improvements . The extent to which SCMs with idealized forcings reproduce the physical feedback mechanisms operating in the full GCMs will be assessed by comparing SCM outputs with the high frequency outputs from the CFMIP-2 GCMs at selected locations. The GCM outputs described in Section III will be used to examine and improve the representativeness of (1) the cloud changes at the selected locations to the area averages in the GCMs, and the (2) idealized forcing to the dynamical conditions at these locations in the GCMs.

One other issue relevant to this activity is the extent to which changes in large-scale environment for boundary layer clouds associated with a climate change are consistent between models. Climate responses of temperature, relative humidity and subsidence rate in the CFMIP slab models will be composited by lower tropospheric lapse rate to examine this question. If they are similar across the models then this will indicate that the different low cloud changes in climate models are mainly due to differences in boundary layer moist physics rather than large scale forcings. These results composites will also serve to inform the design of future idealised SCM/LES forcing cases.

The CFMIP-GCSS case study was released in February 2009. See:
http://atmgcm.msrc.sunysb.edu/cfmip_figs/Case_specification.html

for details.

V. Acknowledgements

We would like to acknowledge the following people for their help in the CFMIP-2 planning process: Alejandro Bodas-Salcedo, Helene Chepfer, Rob Colman, Jean-Louis Dufresne, Christian Jakob, Adrian Lock, Brian Mapes, Brian Medeiros, Roger Marchand, Tomoo Ogura, Robert Pincus, Johannes Quaas, Mark Ringer, Cath Senior, Steve Sherwood, Pier Siebesma, Brian Soden, Karl Taylor, Joao Teixeira, Keith Williams, Rob Wood, Minghua Zhang and Yuying Zhang.

VI. References Cited:

Bodas-Salcedo A., M. J. Webb, M. E. Brooks, M. A. Ringer, S. F. Milton, and D. R. Wilson, 2008: Evaluation of cloud systems in the Met Office global forecast model using CloudSat data. *J. Geophys. Res.*, in revision.

Bony S., Dufresne J.-L., 2005: Marine boundary layer clouds at the heart of cloud feedback uncertainties in climate models. *Geophys Res Lett,* 32(20):Vol. 32, No. 20, L20806.

Caldwell, P. and C. S. Bretherton, 2008 : Response of a subtropical stratocumulus-capped mixed layer to climate and aerosol changes. *J. Climate*, in press.

Chepfer H, Bony S, Winker D, Chiriaco M, Dufresne JL and Seze G, 2008: Use of CALIPSO lidar observations to evaluate the cloudiness simulated by a climate model. *Geophys. Res. Lett.*, in press.

Dufresne J.-L. and S. Bony, 2008: An assessment of the primary sources of spread of global warming estimates from coupled ocean-atmosphere models. *J. Climate,* in press.

Gregory, J. M., W. J. Ingram, M. A. Palmer, G. S. Jones, P. A. Stott, R. B. Thorpe, J. A. Lowe, T. C. Johns, and K. D. Williams, 2004 : A new method for diagnosing radiative forcing and climate sensitivity. Geophys. Res. Lett., 31, L03205.

Gregory, J. and M. J. Webb, 2008: Tropospheric adjustment induces a cloud component in CO2 forcing. *J. Climate*, in press.

Haynes J. M., R. T. Marchand, Z. Luo, A. Bodas-Salcedo, G. L. Stephens, 2007: A multi-purpose radar simulation package: Quickbeam. *Bull. Am. Meteorol. Soc.*, Nov, 1723-1727, DOI:10.1175/BAMS-88-11-1723.

Held, I. M., 2005: The gap between simulation and understanding in climate modeling. *Bull. Am. Meteorol. Met. Soc.*, Nov, 1609-1614.

Khairoutdinov, M. F., C. DeMott, and D. A. Randall, 2005: Simulation of the atmospheric general circulation using a cloud-resolving model as a super-parameterization of physical processes. *J. Atmos. Sci.*, **62**, 2136-2154.

Mapes, B., J. Bacmeister, M. Khairoutdinov, C. Hannay, and M. Zhao, 2008: Virtual field campaigns on deep tropical convection in climate models. *J. Climate*, in press.

Medeiros B, Stevens B, Held IM, Zhao M, Williamson DL, Olson JG, Bretherton CS, 2008: Aquaplanets, climate sensitivity, and low clouds. *J. Climate*, doi: 10.1175/2008JCLI1995.1

Miura, H., H. Tomita, T. Nasuno, S.-I. Iga, M. Satoh,T. Matsuno, 2005: A climate sensitivity test using a global cloud resolving model under an aqua-planet condition. Geophys. Res. Lett., 32, L19717, doi:10.1029/2005GL023672.

Neale R. B., and B. J. Hoskins, 2001: A standard test for AGCMs including their physical parameterizations. I. The proposal. *Atmos. Sci. Lett.*, 1, doi:10.1006/asle.2000.0019

Ogura T., M. J. Webb, A. Bodas-Salcedo, K. D. Williams, T. Yokohata and D. R. Wilson, 2008a: Comparison of mixed phase cloud response to CO2 doubling in two GCMs. *SOLA*, in press.

Ogura T., S. Emori, M. J. Webb, Y. Tsushima, T. Yokohata, A. Abe-Ouchi, and M. Kimoto, 2008b: Towards understanding cloud response in atmospheric GCMs: the use of tendency diagnostics. *J. Meteor. Soc. Japan*, in press.

Randall DA, Wood RA, Bony S, Colman R, Fichefet T, Fyfe J, Kattsov V, Pitman A, Shukla J, Srinivasan J, Stouffer RJ, Sumi A, Taylor KE, 2007 : Climate models and their evaluation. *In Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. C. Marquis, K. B. Averyt, M. Tignor and H. L. Miller (eds.)].

Ringer MA, McAvaney B, Andronova N, Buja L, Esch M, Ingram W, Li B, Quaas J, Roeckner E, Senior C, Soden B, Volodin E, Webb M, Williams K, 2006: Global mean cloud feedbacks in idealized climate change experiments. *Geophys Res Lett,* 33:L07718 doi:10.1029/2005GL025370.

Siebesma, A. P., and coauthors, 2004: Cloud representation in general circulation models over the northern Pacific Ocean: a EUROCS intercomparison study. *Quart. J. Roy. Meteor. Soc.*, **130**, 3245-326.

Taylor, K.E., R. J. Stouffer, G. A. Meehl, 2008: A summary of the CMIP5 experimental design. http://www.clivar.org/organization/wgcm/references/Taylor_CMIP5_dec31.pdf

Tselioudis G. and W. B. Rossow, 2006: Climate feedback implied by observed radiation and precipitation changes with midlatitude storm strength and frequency. *Geophys. Res. Lett.,* 33, L02704, doi:10.1029/2005GL024513.

Tsushima, Y. et al., 2006: Importance of the mixed-phase cloud distribution in the control climate for assessing the response of clouds to carbon dioxide increase: a multi-model study. *Climate Dyn.*, 27, 113-126, doi:10.1007/s00382-006-0127-7.

Webb M., C. Senior, S. Bony, and J.-J. Morcrette, 2001: Combining ERBE and ISCCP data to assess clouds in the Hadley Centre, ECMWF and LMD atmospheric climate models. *Climate Dyn*, 17:905–922.

Webb M.J., C.A. Senior, D.M.H. Sexton, W.J. Ingram, K.D. Williams, M.A. Ringer, B.J. McAvaney, R. Colman, B.J. Soden, R. Gudgel, T. Knutson, S. Emori, T. Ogura, Y Tsushima, N.G. Andronova, B. Li, I. Musat, S. Bony, K.E. Taylor, 2006: On the contribution of local feedback mechanisms to the range of climate sensitivity in two GCM ensembles. *Climate Dyn*, 27(1):17–38, doi:10.1007/s00382-006-0111-2.

Williams K.D., Ringer M.A., Senior C.A., Webb M.J., McAvaney B.J., Andronova N., Bony S., Dufresne J.L., Emori S., Gudgel R., Knutson T., Li B., Lo K., Musat I., Wegner J., Slingo A., Mitchell J.F.B., 2006: Evaluation of a component of the cloud response to climate change in an intercomparison of climate models. *Climate Dyn*, 26:145–165 doi:10.1007/s00382-005-0067-7.

Williams K.D., G. Tselioudis, 2007: GCM intercomparison of global cloud regimes: Present-day evaluation and climate change response. *Climate Dyn*, doi:10.1007/s00382-007-0232-2.

Williams K. D. and M. J. Webb, 2008: A quantitative climate performance assessment of cloud regimes in GCMs. *Climate Dyn.*, in press.

Williams K.D., W.J. Ingram and J.M. Gregory, 2008. Time variation of effective climate sensitivity in GCMs. *J. Climate*, doi:10.1175/2008JCLI2371.1, in press.

Wyant MC, Bretherton CS, Bacmeister JT, Kiehl JT, Held IM, Zhao M, Klein SA, Soden BJ, 2006a : A comparison of low-latitude cloud properties and their response to climate change in three AGCMs sorted into regimes using mid-tropospheric vertical velocity. *Climate Dyn,* 27(2-3), 261– 279, doi:10.1007/s00382-006-0138-4.

Wyant, M. C., M. Khairoutdinov, and C. S. Bretherton, 2006b: Climate sensitivity and cloud response of a GCM with a superparameterization, *Geophys. Res. Lett.*, **33**, L06714, doi:10.1029/2005GL025464.

Yin H., 2005: A consistent poleward shift of the storm tracks in simulations of 21st century climate. Geophys. Res. Lett., 32, L18701, doi: 10.1029/2005GL023684.

Zhang M, Bretherton CS, 2008: Mechanisms of low cloud climate feedback in idealized single column simulations with the Community Atmospheric Model (CAM3). *J. Climate*, in press.

Zhang MH, Lin WY, Klein SA, Bacmeister JT, Bony S, Cederwall RT, Del Genio AD, Hack JJ, Loeb NG, Lohmann U, Minnis P, Musat I, Pincus R, Stier P, Suarez MJ, Webb MJ, Wu JB, 2005: Comparing clouds and their seasonal variations in 10 atmospheric general circulation models with satellite measurements. *J Geophys Res* 110(D15).

Zhang Y., S. Klein, G. G. Mace, J. Boyle, 2007: Cluster analysis of tropical clouds using CloudSat data. *Geophys Res Lett,* 34:L12813 doi:10.1029/2007GL029336.

Annex A: List of CMIP5 experiments with additional CFMIP diagnostics, including the periods for which these diagnostics are required. See Annex B for contents of tables A1a, A1c, etc...

	AMIP 30 years	CFMIP-2 expts	Preindustrial AOGCM control and 1%	Instantaneous 4CO2 AOGCM	ESM 1% loop cuts	Ensemble of 5 year 4CO2 expts	Preindistrial SST forced runs	Historical AOGCM
	3.3 AMIP	6.5 4CO2 79-08 6.6 Pat SST 79-08 6.7a Aqua ctrl 5 6.7b Aqua 4CO2l 5 6.7c Aqua +4K 5 6.8 +4K 79-08	3.1 preind ctrl 6.1 1%	6.3 AOGCM instataneous 4CO2	5.4 5.5	6.3E	6.2a control 6.2b 4co2 6.4 sulphate	3.2
	30 (All years)	105 (All years)	640 (All=500+140)	150 (All=150)	280 (All years 2*140)	55 (All years = 5*11)	90 3*30 years	156 (All years)
	1 (2007 only)	1 (2007 only)	40 2xlast 20 years	40 (first/last 20 years)	40 Last 20 years of 2 expts			27 (79-05)
		3 (2007 in 6.5,6.6,6.8)	10 2*last 5 years	10 (first/last 5 years)				
		90 (only in 6.5,6.6,6.8)						
A1a (monthly 2D) 6	30	105	640	150	280	55	90	156
A1c (monthly on model levels)	30	105	40	150	40	55	90	27
A1c_cfmip (monthly model levels)	30	105						
A1d (monthly 2D ISCCP simulator variables)	30	105	40	40	40	55	90	27
A1d (monthly 4D ISCCP 7x7 levels)	30	105	40	40	40	55	90	27
A1e (monthly COSP offline data on 40 levels)	1	3						
A1e (monthly COSP offline data 40x15 bins)	1	3						
A1e (monthly COSP offline CALIPSO 1x5 bins)	1	3						
A1e (monthly COSP offline CALIPSO/PARASOL 2D)	1	3						
A1f (monthly inline CALIPSO 2D)	30	105	40	40	40	55	90	27
A1f (monthly inline CALIPSO/PARASOL 1x5 bins)	30	105	40	40	40	55	90	27
A1g (monthly inline CALIPSO 40 COSP levels)	30	105	40	40	40	55	90	27
A2a (daily 2D)	30	105	40	40	40	55	90	27
A2b (daily 3D on model levels)	30	105	10	10				
A2c (daily 2D ISCCP simulator variables)	30	105	10	10	40	55	90	27
A2d (daily ISCCP 7x7 levels)	30	105	10	10				
A2e COSP curtain output (40 COSP levels)	1	3						
A2e COSP curtain output (40x15 bins)	1	3						
A2e COSP curtain output (1x5 bins)	1	3						
A2e COSP curtain output (CALIPSO/PARASOL 2D)	1	3						
A2f (daily long term inline CALIPSO 2D)	30	105	40	40	40	55	90	27
A2f (daily long term inline CALIPSO/PARASOL 1x5 bins)	30	105	40	40	40	55	90	27
A2g (daily long term inline CALIPSO 40 COSP levels)	30	105	10	10				
A3a (half hourly timeseries 2D) = 44 CMIP3 + 6 CFMIP	30	105						
A3b (half hourly tseries 3D on m. levels)	30	105						
A4a (3 hrly global 2D)	1							
A4b (3 hrly global 3D)	1							

Annex B: Additional CMIP5 outputs requested by CFMIP

These are additions to the tables for CMIP3 which are available at
http://www-pcmdi.llnl.gov/ipcc/standard_output.html

Note that most of the additional diagnostics can be found in the CFMIP tables:
http://cfmip.metoffice.com/CFMIP_standard_output.html

This list is based on initial work by Keith Williams and Karl Taylor.

NOTE many of the variable names listed here are yet to be agreed under the CF convection and so are subject to change. This version is provided mainly to help modeling groups to make plans for providing the output.

Priorities are marked H/M/L High, Medium and Low

To be added to the existing table A1a (monthly 2D) (6 variables):

water_evaporation_flux	evspsbl	kg m-2 s-1	H
air_pressure_at_convective_cloud_base	ccb	Pa	H
air_pressure_at_convective_cloud_top	cct	Pa	H
convection_indicator	ci	dimensionless	H
shallow_convection_indicator	sci	dimensionless	M
deep_convection_indicator	dci	dimensionless	M

To be added to the existing table A1c (monthly 3D on model levels): 3 variables

mass_fraction_of_cloud_liquid_water_in_air	clw	dimensionless	H
mass_fraction_of_cloud_ice_in_air	cli	dimensionless	H
convective_mass_flux	mc	$kgm^{-2}s^{-1}$	H

New Table A1c_cfmip for CFMIP-2 experiments only: 63 variables
(all on model levels or half levels for fluxes)

upwelling_longwave_flux_in_air	TBD	W m-2	H
upwelling_shortwave_flux_in_air	TBD	W m-2	H
downwelling_longwave_flux_in_air	TBD	W m-2	H
downwelling_shortwave_flux_in_air	TBD	W m-2	H
upwelling_longwave_flux_in_air_assuming_clear_sky	TBD	W m-2	H
upwelling_shortwave_flux_in_air_assuming_clear_sky	TBD	W m-2	H
downwelling_longwave_flux_in_air_assuming_clear_sky	TBD	W m-2	H
downwelling_shortwave_flux_in_air_assuming_clear_sky	TBD	W m-2	H

(8)

tendency_of_air_temperature	TBD	K s-1	H
tendency_of_air_temperature_due_to_advection	TBD	K s-1	H
tendency_of_air_temperature_due_to_diabatic_processes	TBD	K s-1	H
tendency_of_air_temperature_due_to_stratiform_cloud_condensation_and_evaporation	TBD	K s-1	H
tendency_of_air_temperature_due_to_radiative_heating	TBD	K s-1	H
tendency_of_air_temperature_due_to_moist_convection	TBD	K s-1	H

(6)

tendency_of_specific_humidity	TBD	s-1	H
tendency_of_specific_humidity_due_to_advection	TBD	s-1	H
tendency_of_specific_humidity_due_to_convection	TBD	s-1	H
tendency_of_specific_humidity_due_to_diffusion	TBD	s-1	H

tendency_of_specific_humidity_due_to_stratiform_cloud_condensation_and_evaporation
TBD s-1 H
tendency_of_specific_humidity_due_to_model_physics TBD s-1 H
(6)

eddy_viscosity_coefficients_for momentum_variables evu m^2s^{-1} H
eddy-diffusivity_coefficients_for_temperature_variable edt m^2s^{-1} H
eddy-diffusivity_coefficients_for_water_variables edw m^2s^{-1} H
(3)

convective_cloud_area_fraction_in_atmosphere_layer clc % M
mass_fraction_of_convective_cloud_liquid_water_in_air clwc dimensionless M
mass_fraction_of_convective_cloud_ice_in_air clic dimensionless M
stratiform_cloud_area_fraction_in_atmosphere_layer cls % M
mass_fraction_of_stratiform_cloud_liquid_water_in_airclws dimensionless M
mass_fraction_of_stratiform_cloud_ice_in_air clis dimensionless M
(7)

updraught_convective_mass_flux mcu $kgm^{-2}s^{-1}$ M
downdraught_convective_mass_flux mcd $kgm^{-2}s^{-1}$ M
shallow_convective_mass_flux smc $kgm^{-2}s^{-1}$ M
deep_convective_mass_flux dmc $kgm^{-2}s^{-1}$ M
(4)

tendency_of_mass_fraction_of_stratiform_cloud_liquid_water_in_air_due_to_condensation_
and_evaporation TBD s-1 M
tendency_of_mass_fraction_of_stratiform_cloud_liquid_water_in_air_due_convective_detrai
nment TBD s-1 M
tendency_of_mass_fraction_of_stratiform_cloud_liquid_water_in_air_due_to_homogeneous_
nucleation TBD s-1 M
tendency_of_mass_fraction_of_stratiform_cloud_liquid_water_in_air_due_to_heterogeneous
_nucleation TBD s-1 M
tendency_of_mass_fraction_of_stratiform_cloud_liquid_water_in_air_due_to_riming
TBD s-1 M
tendency_of_mass_fraction_of_stratiform_cloud_liquid_water_in_air_due_to_accretion_to_r
ain TBD s-1 M
tendency_of_mass_fraction_of_stratiform_cloud_liquid_water_in_air_due_to_accretion_to_s
now TBD s-1 M
tendency_of_mass_fraction_of_stratiform_cloud_liquid_water_in_air_due_to_melting_from_
cloud_ice TBD s-1 M
tendency_of_mass_fraction_of_stratiform_cloud_liquid_water_in_air_due_to_autoconversio
n TBD s-1 M
tendency_of_mass_fraction_of_stratiform_cloud_liquid_water_in_air_due_to_advection
TBD s-1 M
(10)

tendency_of_mass_fraction_of_stratiform_cloud_ice_in_air_due_convective_detrainment
TBD s-1 M
tendency_of_mass_fraction_of_stratiform_cloud_ice_in_air_due_to_homogeneous_nucleatio
n TBD s-1 M
tendency_of_mass_fraction_of_stratiform_cloud_ice_in_air_due_to_heterogeneous_nucleatio
n_from_cloud_liquid TBD s-1 M
tendency_of_mass_fraction_of_stratiform_cloud_ice_in_air_due_to_heterogeneous_nucleatio
n_from_water_vapor TBD s-1 M
tendency_of_mass_fraction_of_stratiform_cloud_ice_in_air_due_to_riming_from_cloud_liqu
id TBD s-1 M
tendency_of_mass_fraction_of_stratiform_cloud_ice_in_air_due_to_riming_from_rain

TBD s-1 M
tendency_of_mass_fraction_of_stratiform_cloud_ice_in_air_due_to_deposition_and_sublimation TBD s-1 M
tendency_of_mass_fraction_of_stratiform_cloud_ice_in_air_due_to_aggregation TBD s-1 M
tendency_of_mass_fraction_of_stratiform_cloud_ice_in_air_due_to_accretion_to_snow TBD s-1 M
tendency_of_mass_fraction_of_stratiform_cloud_ice_in_air_due_to_evaporation_of_melting_ice TBD s-1 M
tendency_of_mass_fraction_of_stratiform_cloud_ice_in_air_due_to_melting_to_rain TBD s-1 M
tendency_of_mass_fraction_of_stratiform_cloud_ice_in_air_due_to_melting_to_cloud_liquid TBD s-1 M
tendency_of_mass_fraction_of_stratiform_cloud_ice_in_air_due_to_icefall TBD s-1 M
tendency_of_mass_fraction_of_stratiform_cloud_ice_in_air_due_to_advection TBD s-1 M
(14)

tendency_of_mass_fraction_of_stratiform_cloud_condensed_water_in_air_due_to_condensation_and_evaporation TBD s-1 M
tendency_of_mass_fraction_of_stratiform_cloud_condensed_water_in_air_due_to_autoconversion_to_rain TBD s-1 M
tendency_of_mass_fraction_of_stratiform_cloud_condensed_water_in_air_due_to_autoconversion_to_snow TBD s-1 M
tendency_of_mass_fraction_of_stratiform_cloud_condensed_water_in_air_due_to_icefall TBD s-1 M
tendency_of_mass_fraction_of_stratiform_cloud_condensed_water_in_air_due_to_advection TBD s-1 M
(5)

Table A1d (monthly ISCCP simulator output)

isccp_total _cloud_area_fraction	tclisccp	dimensionless	H
isccp_mean_cloud_albedo	albisccp	dimensionless	H
isccp_mean_cloud_top_pressure	ctpisccp	Pa	H
isccp_cloud_area_fraction (7 levels x 7 tau)	clisccp	dimensionless	H

New Table A1e CFMIP CloudSat/CALIPSO simulator (monthly gridded output based on orbitally sampled simulator output)[3].

calipso_cloud_fraction (40 height levels)	clcalipso	dimensionless	H
calipsonocloudsat_cloud_fraction (40 height levels)	clcalipso2	dimensionless	H
cloudsat_radar_reflectivity_cfad[4] (40 levelsx15 bins)	cloudsatcfad	dimensionless	H
calipso_scattering_ratio_cfad (40 levelsx15)	calipsosrcfad	dimensionless	H
parasol_reflectance (1 levels x 5 bins of solar zenith angle)	TBD	dimensionless	H
calipso_total_cloud_fraction	cltcalipso	dimensionless	H
calipso_low_level_cloud_fraction	cllcalipso	dimensionless	H
calipso_mid_level_cloud_fraction	clmcalipso	dimensionless	H
calipso_high_level_cloud_fraction	clhcalipso	dimensionless	H

New Table A1f 2D CFMIP CALIPSO/Parasol simulator output (monthly inline)[5]

[3] This output is to be produced by taking the orbital curtain outputs from Table A2e (below) and averaging them into monthly means on the original model grid.
[4] CFADs (Cloud Frequency Altitude Diagrams) are joint height - radar reflectivity (or lidar scattering ratio) distributions.

calipso_total_cloud_fraction	cltcalipso	dimensionless	H
calipso_low_level_cloud_fraction	cllcalipso	dimensionless	H
calipso_mid_level_cloud_fraction	clmcalipso	dimensionless	H
calipso_high_level_cloud_fraction	clhcalipso	dimensionless	H
parasol_reflectance (1 levels x 5 bins of solar zenith angle)	TBD	dimensionless	H

New Table A1g 3D CFMIP CALIPSO/Parasol simulator output (monthly inline)

calipso_cloud_fraction	(40 height levels)	clcalipso	dimensionless	H

To be added to the existing table A2a (daily 2D): (19 variables)

surface_temperature	ts	K	H
surface_air_pressure	ps	Pa	H
specific_humidity	huss	dimensionless	H
toa_incoming_shortwave_flux	rsdt	Wm-2	H
toa_outgoing_shortwave_flux	rsut	Wm-2	H
net_downward_radiative_flux_at_top_of_atmosphere_model	rtmt	Wm-2	H
surface_downwelling_shortwave_flux_in_ir_assuming_clear_sky	rsdscs	Wm-2	H
surface_upwelling_shortwave_flux_in_air_assuming_clear_sky	rsuscs	Wm-2	H
surface_downwelling_longwave_flux_in_air_assuming_clear_sky	rldscs	Wm-2	H
toa_outgoing_longwave_flux_assuming_clear_sky	rlutcs	Wm-2	H
toa_outgoing_shortwave_flux_assuming_clear_sky	rsutcs	Wm-2	H
cloud_area_fraction	clt	%	H
atmosphere_cloud_condensed_water_content	clwvi	kg m-	H
atmosphere_cloud_ice_content	clivi	kgm-2	H
lagrangian_tendency_of_air_pressure_at_500hPa	wap500	Pa s-	H
air_temperature_at_700hPa	ta700	K	H
air_pressure_at_convective_cloud_base	ccb	Pa	H
air_pressure_at_convective_cloud_top	cct	Pa	H
convective_precipitation_flux	prc	kg m-2 s-1	H

The existing table A2b (daily 3D) to all be changed to all be on model levels and the following added: (7 variables)

Lagrangian_tendency_of_air_pressure	wap	Pa s-1	H
geopotential_height	zg	m	H
relative_humidity	hur	%	H
cloud_area_fraction_in_atmosphere_layer	cl	%	H
mass_fraction_of_cloud_liquid_water_in_air	clw	dimensionless	H
mass_fraction_of_cloud_ice_in_air	cli	dimensionless	H
convective_mass_flux	mc	ms-1	H

New table A2c Daily 2D ISCCP simulator (3 variables)

isccp_total _cloud_area_fraction	tclisccp	dimensionless	H
isccp_mean_cloud_albedo	albisccp	dimensionless	H
isccp_mean_cloud_top_pressure	ctpisccp	Pa	H

New table A2d Daily 4D ISCCP simulator output (1 variable)

isccp_cloud_area_fraction	(7 levels x 7 tau)	clisccp	dimensionless	H

New table A2e CloudSat/CALIPSO simulator output in orbital curtain format. To include all variables in Table A1e, as well as longitude and latitude.)[6]

---

[5] Tables A1f and A1g contain CALIPSO/PARASOL simulator outputs run inline, sampled at all locations for all timesteps (or all radiation timesteps).

[6] Variables in A2e will in most cases be produced by extracting simulator input variables from the models along A-train orbits, and running COSP on these in 'offline' mode. Separate latitude and

New table A2f Daily 2D CALIPSO/PARASOL simulator output same as A1f but requested daily (4 2D + 5 2D)

New table A2g Daily 40L CALIPSO simulator output same as A1g but requested daily (1 variable)

New table A3a 2D half-hourly (or nearest timestep multiple) time series of *instantaneous* values at specified points (about 115 stations – see http://cfmip.metoffice.com/cfmip2/pointlocations**) To include:**
CMIP3 diagnostics in table A1a (44 variables)
CFMIP diagnostics for A1a listed above (6 variables)

New table A3b 3D time series (sampled as A3a) to include:
CMIP3 diagnostics in monthly table A1c but all on model levels (10 variables)
CFMIP diagnostics in monthly table A1c but all on model levels (3 variables)
CFMIP diagnostics marked (H) in monthly table A1c_cfmip above (23 variables)

New table A4a to be the same 2D diagnostics as in A1a but global 3 hourly *instantaneous* values. Also to include:

surface_emissivity [1]		M
sunlit_binary_mask [1]		M

New table A4b global 3 hourly *instantaneous* values on model levels.

height_of_full_levels_above_reference_ellipsoid [m]	I	M
height_of_half_levels_above_reference_ellipsoid [m]	I	M
air_pressure_at_full_levels [Pa]		M
air_pressure_at_half_levels [Pa]		M
temperature_in_air		M
specific_humidity		M
mass_fraction_of_stratiform_cloud_liquid_water_in_air		M
mass_fraction_of_stratiform_cloud_ice_in_air		M
mass_fraction_of_convective_cloud_liquid_water_in_air		M
mass_fraction_of_convective_cloud_ice_in_air		M
hydrometeor_effective_radius_of_stratiform_cloud_liquid_water_in_air		M
hydrometeor_effective_radius_of_stratiform_cloud_ice_in_air		M
hydrometeor_effective_radius_of_convective_cloud_liquid_water_in_air		M
hydrometeor_effective_radius_of _convective_cloud_ice_in_air		M
stratiform_graupel_flux		M
convective_rainfall_flux		M
stratiform_rainfall_flux		M
convective_snowfall_flux		M
stratiform_snowfall_flux		M
hydrometeor_effective_radius_of_stratiform_graupel		M
hydrometeor_effective_radius_of_convective_rainfall		M
hydrometeor_effective_radius_of_stratiform_rainfall		M

---

longitude variables may be required because, although CMO2 supports fixed 'station data' timeseries, it is not currently clear whether it supports variables with time varying lat/lon.

hydrometeor_effective_radius_of_convective_snowfall	M
hydrometeor_effective_radius_of_stratiform_snowfall	M
stratiform_cloud_optical_depth [1]	M
convective_cloud_optical_depth [1]	M
stratiform_cloud_emissivity [1]	M
convective_cloud_emissivity [1]	M