GCSS Working Group 4: Case 5 - Transition of Tropical Convection
Work Package 1: Studies with CRMs, SCMs and LAMs

Steve Woolnough[1], Jon Petch[2]

23rd December 2004

1 Introduction

GCSS WG4 Case 5 plans to look at the transition of tropical convection using TOGA–COARE data. This document described the details of work package 1, the intercomparison of SCMs, CRMs and LAMs. There are a number of differences from previous Working Group 4 case studies.

- The companion study involving the use of NWP models forecast models (see WG4 web page for further details) will provide much stronger links with the NWP community. A later stage of this case study will involve forcing CRMs and SCMs with an analysis or forecast dataset to allow for direct comparison with NWP Global and Limited Area Models.
- A new SCM modelling approach has been introduced. In addition to the long integration for direct comparison with the CRM integrations, a series of 48 hour integrations have been requested to assess the impact of drift (accumulated errors) on the simulation of particular periods
- Multiple submissions from one model are actively encouraged. In particular CRM modellers are encouraged to provide output from integrations using their prefered domain, resolution and number of dimensions.
- To extend beyond simple comparisons between models, a new set of diagnostics has been requested to permit a stronger process study component. This case study is focused on the transition from shallow to deep convection, and a set of budget diagnostics has been requested to identify the way in which convection modifies its environment during this transition period.

2 Motivation

The transition from suppressed to deep convection presents a particular challenge for NWP and climate models, particularly for their convective parametrizations. Johnson et al. (1999) described the role that cumulus congestus clouds play in preconditioning the lower troposphere during periods of suppressed convection and the importance of this for the subsequent deepening of the convection. A good representation of this is likely to be important if we hope to model the transition from the break phase to the active phase of the MJO.

[1]NCAS Centre for Global Atmospheric Modelling, University of Reading, UK
[2]Met Office, UK

Inness et al. (2001) showed in simulations of the Met Office climate model (HadAM3) that by improving the vertical resolution in the mid-troposphere they were able to improve the models simulation of the Madden-Julian Oscillation. They attributed this improvement to an increase in the frequency of the models ”congestus” type clouds through improvements in resolution of the freezing level. Redelsperger et al. (2002) by analysing the moisture and temperature budgets, showed the important role shallow and mid-level clouds play in moistening the atmosphere following the arrival of a dry intrusion, and preconditioning the atmosphere for deep convection. This study will use the same approach to investigate the degree to which these processes are important in the transition from periods of suppressed convection to periods of deep convection, associated with the transition from the suppressed to active phase of the Madden-Julian Oscillation during TOGA–COARE.

The aims of this study are:

- to determine the processes that are important for the transition from suppressed to deep convection
- to determine the role that shallow and mid-level convection play in this transition
- to see how various parametrization schemes currently cope with this transition

3 Methodology

As for past GCSS WG4 case studies, the intercomparison between CRMs, SCMs and observations will play a major part of the study. The initial stages of this work package will follow a similar approach to previous case studies; CRMs and SCMs will be forced with large-scale forcing from an ”observed” dataset and the simulations will be compared with each other and the observations. A subsequent phase will make use of some of the results from WP2 to extend the experiment to use forcing data generated from NWP models themselves, to allow comparisons between the NWP models and the CRMs, and SCMs as well as providing a forcing dataset for Limited Area NWP Models (LAMs).

Stage 1

CRMs and SCMs to provide 10 day simulations of three sub-periods in TOGA-COARE using forcing data derived from observations. The periods that have been chosen are dominated by suppressed convection. The initial dates have been chosen to include the end of a previous period of deep convection to allow the CRMs to evolve a convectively generated moisture field prior to the suppressed period. The length of the integrations have been chosen to include the start of a subsequent period of deep convection.

In addition to the standard integration described above, SCMs should perform a series of further 2 day integrations initialised on each day of the integration period. The purpose of these further SCM integrations is to investigate the role of the accumulated errors from previous days in the SCM integrations compared to errors in the SCM’s response to the forcing and environmental profiles. This method will be consistent with the NWP runs from WP2, which will look at 24-48 hour forecasts during the period.

Stage 2

This stage will re-run the experiments from stage 1 but with the forcing provide by an analysis dataset, to enable the SCMs and CRMs to experience forcing more consistent with the NWP models in WP2. Also, this will allow LAMs to run with non-cyclic boundary conditions and over a domain size similar to the OSA of the TOGA-COARE region. The CRM and SCM integrations for this stage provide a consistent dataset with which to make comparisons with the NWP runs and any LAM results. The LAM integrations allow a larger domain size than is possible with the CRM integrations and will enable the role of organization, and feedbacks from the mesoscale circulation on the simulations to be investigated. The experimental method for this stage will be prescribed at a later date, following the completion of the initial stages of WP2.

4 Numerical Experiment Protocol

This section describes the standard domain and resolution requirements for the CRM integrations and the forcing method for both the SCM and CRM integrations for stage 1 of the experiment and details of the integrations to be performed. The SCM integrations should use the operational configuration of their model as the standard integration. Results from additional CRM and SCM integrations with different domain and resolution specifications may be submitted, where possible we encourage groups to provide a 3D CRM simulation.

4.1 Experiments

A0 CRMs and SCMs. A 12 day integration beginning at 00UTC on 28th of November and ending at 00UTC on 10th December

A1,A2,...,A13 SCMs only. A series of 13, 48 hour integrations, the first beginning at 00UTC on 27th November, with each subsequent integration beginning 24 hours later, the last beginning at 00UTC on 9th December

B0 CRMs and SCMs. A 12 day integration beginning at 00UTC on 9th of January and ending at 00UTC 21st January

B1,B2,...,B13 SCMs only. A series of 13, 48 hour, integrations, the first beginning at 00UTC on 8th January, with each subsequent integration beginning 24 hours later, the last beginning at 00UTC on 20th January

C0 CRMs and SCMs. An 8 day integration beginning at 00UTC on 21st of January and ending at 00UTC on 29th January

C1,C2,...,C9 SCMs only. A series of 9, 48 hour, integrations, the first beginning at 00UTC on 20th January, with each subsequent integration beginning 24 hours later, the last beginning at 00UTC on 28th January

Integrations B13 and C1 are identical, but please submit the results twice, once for each experiment, it will make reading the files simpler.

4.2 CRM Domain and Resolution

The standard CRM integration will be a 2D simulation with a horizontal resolution of 500m and a domain size of 256km, orientated in the east-west direction. The vertical domain should be at least 20km, with a vertical resolution of not less than 250m above the boundary layer and below the tropopause. The following grid structure is recommended for CRMs and gives a vertical grid size near the surface of 50m.

For the model levels, z_k where vertical velocity is defined

$$
\begin{aligned}
z_k &= (a_1 + b_1\, z'_k)\, z'_k && k = 0, 20 \quad z'_k = k\Delta z_1 \\
z_k &= 3000. + (k - 20)\Delta z && k = 21, 64 \quad \Delta z = 250\text{m} \\
z_k &= 14000. + (a_2 + b_2\, z'_k)\, z'_k && k = 65, 80 \quad z'_k = (k - 64)\Delta z_2
\end{aligned}
$$

and for the model levels z_n where the horizontal velocities and pressure are defined.

$$
\begin{aligned}
z_n &= (a_1 + b_1\, z'_n)\, z'_n && n = 1, 20 \quad z'_n = (n - 0.5)\Delta z_1 \\
z_n &= 3000. + (n - 20.5)\Delta z && n = 21, 64 \quad \Delta z = 250\text{m} \\
z_n &= 14000. + (a_2 + b_2\, z'_n)\, z'_n && n = 65, 80 \quad z'_n = (n - 64.5)\Delta z_2
\end{aligned}
$$

where $a_1 = 17/57$, $b_1 = 1/4275$, $\Delta z_1 = 150$m and $a_2 = 29/45$, $b_2 = 1/16875$, $\Delta z_2 = 375$m.

In addition to the standard integration, we would like modelling groups to provide additional integrations with what they consider to be their prefered model configuration(s) for this problem.

4.3 Obtaining and reading the data files

Profiles of the large-scale temperature, mixing ratio and velocity components, the SST and surface pressure, and profiles of the large-scale advective tendencies of temperature and mixing ratio can found on the Case 5 web page at
`http://www.met.reading.ac.uk/~swrwoono/WG4_CASE5/index.html`
The files for experiments A0,B0,C0 can be found in {`a,b,c`}`0_CRM_data.tar`, the files for 48 hour SCM experiments can be found in {`a,b,c`}`_SCM_data.tar`. Each experiment has an initial condition file and a forcing file, *`experiment`*`_init.dat`, *`experiment`*`_force.dat`. Descriptions of the files along with sample fortran code `read_init.f`, `read_force.f` to read the files can also be found on the web-page. Because of some problems with the forcing data above 15km, the large-scale forcing of temperature and humidity have been set to zero above 150hPa.

4.4 Initial Conditions

The model integrations should be initialised with the temperature, moisture and large-scale velocity profiles, SST and surface pressure for the start time of the integrations, taken from the data files described above. The file *`experiment`*`_init.dat` contains the initial temperature and humidity profiles along with the surface temperature and pressure. Values should be interpolated onto the model grid. The first line of each file contains the time (0.0), SST (K), year, month and day. The second line contains values at the surface of: pressure(mb), T(K), q(g kg^{-1}) u,v (m s^{-1}). Subsequent lines contain the data for 1000mb to 25mb at 25mb intervals

4.5 Large-scale forcing

The files *`experiment`*`_force.dat` contain the large-scale forcing for each experiment. The large-scale forcing should be interpolated to the models vertical grid and in time to obtain values at each timestep. The first line of data in each file contains the time since the start of the integration (hr), SST(K), year, month and day. The next 41 lines contain values of pressure(mb), large-scale advective tendency of potential temperature ($\mathrm{K\,day^{-1}}$), large-scale advective tendency of water vapour mixing ratio ($\mathrm{g\,kg^{-1}\,day^{-1}}$), u,v ($\mathrm{m\,s^{-1}}$) and vertical pressure velocity ($\mathrm{Pa\,s^{-1}}$). The vertical velocity is supplied for SCMs which use vertical velocity to trigger or close their convection scheme, and should not be used to calculate the advective tendencies. The large-scale forcing terms given for potential temperature and water vapour are tendencies and can be applied directly. For the horizontal wind components the large-scale forcing tendencies should be calculated from by relaxing the model winds to the given observed profiles with a timescale, τ of 2 hours, e.g.

$$\left.\frac{\partial u}{\partial t}\right|_{LS} = -\frac{u - u_{obs}}{\tau}$$

The next 42 lines contain the record for the next time-level, etc.

4.6 Lower Boundary Conditions

The lower boundary condition is an ocean surface, with the SST and surface pressure specified from the files `experiment_force.dat`, the SST and surface pressure should be updated at each timestep, by interpolating from the 6 hourly data. The surface fluxes of heat, momentum and moisture should be calculated interactively from the ocean using the models own surface transfer scheme, using values appropriate for the open ocean.

4.7 Radiation

Experiments should include interactive radiation calculations, with the diurnal cycle included. The centre of the IFA was located at 2°S, 156°E. For the ocean surface use an albedo of 0.05.

5 Results to submit

In keeping with previous studies the majority of the results to be submitted will consist of domain averaged and time averaged profiles and some timeseries. As this case study is concerned with the transition from suppressed to deep convection the time averaging period will be 1 hour for CRMs with a sampling frequency of not more than 10 minutes and preferably 5 minutes or better, to give good time resolution of the evolution. For SCMs timestep diagnostics should be submitted. To examine how the convection modifies the profiles during the transition from the suppressed to deep convection, in response to the change in forcing, a number of additional diagnostics have been requested in a new budget section to decompose the temperature and moisture tendencies of the convection. With your results please submit a file *modeller*.desc.*run*, which descibes the model. A template file (`template.desc`) can be found on the Case 5 webpage.

As the analysis of these integrations progresses it may be that additional diagnostics are requested, so if possible, please retain grid-point fields of the three wind components, temperature or potential temperature, water substance mixing ratios, pressure and upwelling and downwelling radiative fluxes at sufficient temporal resolution to allow computation of additional diagnostics. Or, alternatively, retain files to allow you to rerun the integrations.

Section 5.1 describes the results to submit for CRM integrations and the section 5.2 describes the results to submit for SCM integrations. Many of the diagnostics appear in both sections but some are specific to CRMs and SCMs. Most of the diagnostics are similar to those requested for previous case studies, although there are some differences. In particular the definition of cloud and the numbering has changed since cases 2&3 (Krueger et al. 1996; Krueger et al. 1999))

Instructions of how to submit the data files will be described on the Case 5 web page
`http://www.met.reading.ac.uk/~swrwoono/WG4_CASE5/index.html`

5.1 Description of quantities for CRMs

5.1.1 Profiles

Submit the results for each quantity listed below as a separate ASCII file in the file format described in appendix A. Include the height z (km, F7.3) of the model level or half level as appropriate, and the mid-point of the time interval $\bar{t}$ (hours, F6.1) from the start of the integration x,y coordinates respectively. Name each file as *experiment*.cp*item*.*modeller*(*.run*) where *experiment* is the experiment number given in section 4.1, *item* is the number of the diagnostic from the list below and *modeller* is the name of the modeller. *.run* is an extra 6 (exactly) character file extension to identify data from additional integrations with the non-standard setup.

Hourly averages of domain mean profiles of

1 Pressure, $\overline{p}$ (Pa), (F8.2)

2 Temperature, $\overline{T}$ (K), (F7.2)

3 Potential Temperature, $\overline{\theta}$ (K), (F7.2)

4 Density, $\overline{\rho}$ ($\mathrm{kg\,m^{-3}}$), (F7.4)

5 Water Vapour Mixing Ratio, $\overline{q}$ ($\mathrm{g\,kg^{-1}}$), (F7.3)

6 Relative Humidity, R (unitless), (F6.3): R = $\overline{q}/q^*(\overline{T},\overline{p})$, where $q^*(T,p)$ is the saturation mixing ratio over water.

7 Cloud water (suspended liquid water), $\overline{q_c}$ ($\mathrm{g\,kg^{-1}}$), (F7.4)

8 Cloud ice (suspended ice), $\overline{q_i}$ ($\mathrm{g\,kg^{-1}}$), (F7.4)

9 Rain (falling liquid water), $\overline{q_r}$ ($\mathrm{g\,kg^{-1}}$), (F7.4)

10 Snow (slow falling ice), $\overline{q_s}$ ($\mathrm{g\,kg^{-1}}$), (F7.4)

11 Graupel (fast falling ice, including hail if you have any), $\overline{q_g}$ ($\mathrm{g\,kg^{-1}}$), (F7.4)

12 Cloud fraction, $\overline{\sigma}$ (unitless), (F6.3): At each gridpoint, $\sigma = 1$ if $q_c + q_i > 0.01\mathrm{g\,kg^{-1}}$; otherwise, $\sigma = 0$

13 Total hydrometeor fraction, $\overline{\sigma_{HM}}$ (unitless), (F6.3): At each gridpoint, $\sigma_{HM} = 1$ if $q_c + q_i + q_r + q_g + q_s > 0.01\mathrm{g\,kg^{-1}}$; otherwise, $\sigma_{HM} = 0$

14 Horizontal wind velocity in the x-direction, $\overline{u}$ ($\mathrm{m\,s^{-1}}$), (F7.2)

15 Horizontal wind velocity in the y-direction, $\overline{v}$ ($\mathrm{m\,s^{-1}}$), (F7.2)

16 Apparent heat source, $\overline{Q}_1$ (K day^{-1}), (F7.2):

$$\overline{Q}_1 = \left(\frac{\overline{p}}{p_0}\right)^{R/c_p} \left[\frac{\partial\overline{\theta}}{\partial t} - \left.\frac{\partial\overline{\theta}}{\partial t}\right|_{LS}\right] - \overline{Q}_R,$$

where $\left.\frac{\partial\overline{\theta}}{\partial t}\right|_{LS}$ is the large-scale forcing term which is specified from the observations

17 Apparent moisture source, $\overline{Q}_2$ (g kg^{-1} day^{-1}), (F7.2):

$$\overline{Q}_2 = \left[\frac{\partial\overline{q}}{\partial t} - \left.\frac{\partial\overline{q}}{\partial t}\right|_{LS}\right],$$

where $\left.\frac{\partial\overline{q}}{\partial t}\right|_{LS}$ is the large-scale forcing term which is specified from the observations.

18 Shortwave Radiative heating rate, $\overline{Q}_R^{SW}$ (K day^{-1}), (F7.2)

19 Longwave Radiative heating rate, $\overline{Q}_R^{LW}$ (K day^{-1}), (F7.2)

20 Large scale temperature forcing, $\left.\frac{\partial\theta}{\partial t}\right|_{LS}$ (K day^{-1}) (F7.2): On model grid

21 Large scale humidity forcing, $\left.\frac{\partial q}{\partial t}\right|_{LS}$ (g kg^{-1} day^{-1}) (F7.2): On model grid

22 Fractional area of cloudy updrafts, $\overline{\sigma}_{cu}$ (unitless) (F7.4):

$$\overline{\sigma}_{cu} = \frac{\Sigma_j \sigma_{cu}}{\Sigma_j},$$

where $\sigma_{cu} = 1$ if $\sigma = 1$ and $w > 0$, otherwise $\sigma_{cu} = 0$

23 Cloudy updraft mass flux, $\overline{M}_{cu}$ (kg m^{-2} s^{-1}) (F7.4):

$$\overline{M}_{cu} = \frac{\overline{\rho}\Sigma_j \sigma_{cu} w}{\Sigma_j},$$

where σ_{cu} is the cloud updraft fraction defined above.

24 Fractional Area of updraft cores, $\overline{\sigma}_{wu}$ (unitless) (F7.4):

$$\overline{\sigma}_{wu} = \frac{\Sigma_j \sigma_{wu}}{\Sigma_j},$$

where $\sigma_{wu} = 1$ if $w > 5\text{m s}^{-1}$; otherwise $\sigma_{wu} = 0$

25 Updraft core mass flux, $\overline{M}_{wu}$ (kg m^{-2} s^{-1}) (F7.4):

$$\overline{M}_{wu} = \frac{\overline{\rho}\Sigma_j \sigma_{wu} w}{\Sigma_j},$$

where σ_{wu} is the updraft core fraction defined above.

26 Fractional area of buoyant cloudy updrafts, $\overline{\sigma}_{bcu}$ (unitless) (F7.4):

$$\overline{\sigma}_{bcu} = \frac{\Sigma_j \sigma_{bcu}}{\Sigma_j},$$

where $\sigma_{bcu} = 1$ if $\sigma = 1$ and $w > 0$ and $\theta_v' > 0$, otherwise $\sigma_{bcu} = 0$

27 Buoyant cloudy updraft mass flux, $\overline{M}_{wu}$ (kg m^{-2} s^{-1}) (F7.4):

$$\overline{M}_{wu} = \frac{\overline{\rho}\Sigma_j \sigma_{bcu} w}{\Sigma_j},$$

where σ_{bcu} is the buoyant cloudy updraft fraction defined above.

5.1.2 Budget terms

The diagnostics in this section contain terms which will allow the contributions to the models Q_1 and Q_2 to be diagnosed. Analysis of these terms will form a major part of the case study as they indicate how the convection modifies its environment following a period of suppressed convection and will give information on the non-equilibrium nature of convection during these transition periods. Redelsperger et al. (2002) made extensive use of these diagnostics in their analysis of recovery following a dry intrusion over TOGA-COARE. The diagnostics should be calculated in the same way as the profile diagnostics. For the tendencies due to the vertical transports terms (items 5–8) please use the model difference formulation to evaluate these terms. Name each file as *experiment*.cb*item*.*modeller*(*.run*) where *experiment* is the experiment number given in section 4.1, *item* is the number of the diagnostic from the list below and *modeller* is the name of the modeller. *.run* is an extra 6 (exactly) character file extension to identify data from additional integrations with the non-standard setup.

Hourly domain averaged profiles of

1 Vertical flux of potential temperature $\overline{w\theta}$ (K m s^{-1}), due to resolved motions, (E10.3)

2 Vertical flux of water vapour $\overline{wq}$ (g kg^{-1} m s^{-1}), due to resolved motions, (E10.3)

3 Vertical flux of potential temperature $\overline{w\theta}^{SG}$ (K m s^{-1}), due to the subgrid and surface schemes (E10.3)

4 Vertical flux of water vapour $\overline{wq}^{SG}$ (g kg^{-1} m s^{-1}), due to subgrid and surface schemes, (E10.3)

5 Rate of change of potential temperature due to resolved vertical transports, $\overline{D\theta}^{adv}$ (K day^{-1}) (F7.2):

$$\overline{D\theta}^{adv} = \frac{\Sigma_j - \frac{\partial w\theta}{\partial z}}{\Sigma_j}$$

6 Rate of change of water vapour due to resolved vertical transports, $\overline{Dq}^{adv}$ (g kg^{-1} day^{-1}) (F7.2):

$$\overline{Dq}^{adv} = \frac{\Sigma_j - \frac{\partial wq}{\partial z}}{\Sigma_j}$$

7 Rate of change of potential temperature due to subgrid (and surface) vertical transports, $\overline{D\theta}^{SG}$ (K day^{-1}) (F7.2):

$$\overline{D\theta}^{SG} = \frac{\Sigma_j - \frac{\partial (w''\theta'')}{\partial z}}{\Sigma_j}$$

where $w''\theta''$ is the subgrid vertical flux of potential temperature including the surface flux.

8 Rate of change of water vapour due to subgrid (and surface) vertical transports, $\overline{Dq}^{SG}$ (g kg^{-1} day^{-1}) (F7.2):

$$\overline{Dq}^{SG} = \frac{\Sigma_j - \frac{\partial (w''q'')}{\partial t}}{\Sigma_j}$$

9 Rate of change of potential temperature due to microphysical processes, $\overline{D\theta}^{\mu}$ (K day^{-1}) (F7.2):

$$\overline{D\theta}^{\mu} = \frac{\Sigma_j \left[L_v \left. \frac{\partial (q_c + q_r)}{\partial t} \right|_{\mu-phys} + (L_v + L_s) \left. \frac{\partial (q_i + q_s + q_g)}{\partial t} \right|_{\mu-phys} \right]}{\Sigma_j}$$

10 Rate of change of water vapour due to microphysical processes, $\overline{Dq}^{\mu}$ (g kg^{-1} day^{-1}) (F7.2):

$$\overline{Dq}^{\mu} = \frac{\Sigma_j \left. \frac{\partial q}{\partial t} \right|_{\mu-phys}}{\Sigma_j}$$

5.1.3 Timeseries

Submit results for each of the groups in separate files. Name each file *experiment*.ct*group*.*modeller*.*run*, following the convention for the profile diagnostics. Start each file with the two comment lines described in the special file format in appendix A, with the group number for *item* and omitting *variable_name*. Please write the data as: all the variables for each time level 1 on one line, all the variables at time level 2 on the next line, ..., all the variables at the last time level on the last line. Using the formats specified below, with no spaces between the variables, will ensure all the data fits on one line of 80 characters. Please use a time resolution of 10 minutes or better from timeseries diagnostics.

Group 1:

1 Time at midpoint of averaging interval, $\overline{t}$ (h), (F7.2)

2 Sea Surface Temperature, SST (K), (F7.2)

3 Near surface dry static energy, $\overline{s}_0$, (kJ kg^{-1}), (F7.2): $s = c_p T + gz$. "Near-surface" is the first model-level.

4 Near surface water vapour mixing ratio, $\overline{q}_0$, (g kg^{-1}), (F6.2)

5 Near surface moist static energy, $\overline{h}_0$: , (kJ kg^{-1}), (F7.2): $h = s + L_v q$.

6 Near surface horizontal wind velocity in the x-direction, $\overline{u}_0$ (m s^{-1}), (F7.2)

7 Near surface horizontal wind velocity in the y-direction, $\overline{v}_0$ (m s^{-1}), (F7.2)

8 Surface turbulent flux of sensible heat $\overline{F_{s0}}$ (W m^{-2}), (F6.1): $F_s = \overline{\rho} c_p \left(\frac{\overline{p}}{p_0} \right)^{R/c_p} < w''\theta'' >$.

9 Surface turbulent flux of latent heat $L_v \overline{F_{q0}}$ (W m^{-2}), (F6.1): $F_q =< w''q'' >$.

10 Surface turbulent flux of horizontal momentum in the x-direction $\overline{F_{u0}}$ (N m^{-2}), (F8.4): $F_u = \overline{\rho} < w''u'' >$.

11 Surface turbulent flux of horizontal momentum in the y-direction $\overline{F_{v0}}$ (N m^{-2}), (F8.4): $F_v = \overline{\rho} < w''v'' >$.

Group 2:

1 Time at midpoint of averaging interval, $\overline{t}$ (h), (F7.2)

2 Surface downwelling solar radiative flux, $\overline{F_{SW0}^{-}}$ (W m^{-2}), (F7.1)

3 Surface downwelling infrared radiative flux, $\overline{F_{LW0}^{-}}$ (W m^{-2}), (F6.1)

4 Surface upwelling solar radiative flux, $\overline{F_{SW0}^{+}}$ (W m^{-2}), (F6.1)

5 Surface upwelling infrared radiative flux, $\overline{F_{LW0}^{+}}$ (W m^{-2}), (F6.1)

6 TOA (top of atmosphere) downwelling solar radiative flux, $\overline{F_{SWT}^{-}}$ (W m^{-2}), (F7.1)

7 TOA upwelling solar radiative flux, $\overline{F_{SWT}^{+}}$ (W m^{-2}), (F7.1)

8 TOA upwelling infrared radiative flux, OLR (W m^{-2}), (F7.1)

9 Cloud amount, $\overline{A_{cld}}$ (unitless), (F6.3)

Group 3:

1 Time at midpoint of averaging interval, $\overline{t}$ (h), (F7.2)

2 Surface rainfall rate, $\overline{\mathrm{PPT}}$ (mm day^{-1}), (F7.2): Calculate from the surface rain accumulated over every timestep

3 Precipitable water, $\overline{\mathrm{PW}}$ (kg m^{-2}), (F6.2): $\mathrm{PW} = \int_0^{z_t} \overline{\rho} q \, dz$, where z_T is the model top height.

4 Cloud liquid water path, $\overline{\mathrm{LWP}}$ (kg m^{-2}), (E10.3): $\mathrm{LWP} = \int_0^{z_t} \overline{\rho} q_c \, dz$,.

5 Cloud ice path, $\overline{\mathrm{IWP}}$ (kg m^{-2}), (E10.3): $\mathrm{IWP} = \int_0^{z_t} \overline{\rho} q_i \, dz$,.

6 Vertical integrated rain, $\overline{\mathrm{RP}}$ (kg m^{-2}), (E10.3): $\mathrm{RP} = \int_0^{z_t} \overline{\rho} q_r \, dz$,.

7 Vertical integrated snow, $\overline{\mathrm{SP}}$ (kg m^{-2}), (E10.3): $\mathrm{SP} = \int_0^{z_t} \overline{\rho} q_s \, dz$,.

8 Vertical integrated graupel, $\overline{\mathrm{GP}}$ (kg m^{-2}), (E10.3): $\mathrm{GP} = \int_0^{z_t} \overline{\rho} q_g \, dz$,.

Group 4:

1 Time at midpoint of averaging interval, $\overline{t}$ (h), (F7.2)

2 Fraction of warm clouds, $\overline{A_{cld}^{warm}}$ (unitless), (F6.3): Fraction of columns which are cloudy and the cloud top temperature is greater than 273.15K

3 Fraction of ice-free clouds, $\overline{A_{cld}^{liq}}$ (unitless), (F6.3): Fraction of columns which are cloudy and have $\mathrm{IWP} + \mathrm{GP} + \mathrm{SP} < 0.02$kg m^{-2}

4 Fraction of deep/high clouds, $\overline{A_{cld}^{high}}$ (unitless), (F6.3): Fraction of columns which have a cloud top above 9km

5 Fraction of mid-level clouds, $\overline{A_{cld}^{mid}}$ (unitless), (F6.3): Fraction of columns which have a cloud top between 4km and 9km

6 Fraction of shallow clouds, $\overline{A_{cld}^{low}}$ (unitless), (F6.3): Fraction of columns which are cloudy and have a cloud top below 4km

7 Surface rainfall rate from warm clouds $\overline{\mathrm{PPT}}^{warm}$ (mm day^{-1}), (F7.2): Surface rainfall rates in columns diagnosed as containing warm clouds

8 Surface rainfall rate from ice free clouds $\overline{\mathrm{PPT}}^{liq}$ (mm day^{-1}), (F7.2): Surface rainfall rate in columns diagnosed as containing ice free clouds

9 Surface rainfall rate from deep/high clouds $\overline{\mathrm{PPT}}^{deep}$ (mm day^{-1}), (F7.2): Surface rainfall rates in columns diagnosed as containing deep clouds

10 Surface rainfall rate from mid-level clouds $\overline{\mathrm{PPT}}^{mid}$ (mm day^{-1}), (F7.2): Surface rainfall rates in columns diagnosed as containing mid-level clouds

11 Surface rainfall rate from shallow clouds $\overline{\mathrm{PPT}}^{low}$ (mm day^{-1}), (F7.2): Surface rainfall rates in columns diagnosed as containing shallow clouds

5.1.4 Hovmüller diagrams

In addition to the profile and timeseries diagnostics, a small number of x-t cross-sections (at 15 or 20 minute intervals) are requested to allow the development of cloud field to be monitored (for CRMs only). The diagnostics requested will also be used to produce frequency diagrams of in particular cloud heights, to enable comparisons with e.g. Johnson et al. (1999). Files should use the special file format with horizontal distance, x (km), (F7.2) across the domain as the x-coordinate and time, t (h), (F7.2) as the y-coordinate. File names should be of the form *experiment.*x*item.modeller.run*

1 Surface rainfall rate, P (mm hr^{-1}), (F7.2)

2 Cloud top height z_c (km), (F6.2)

3 Cloud top temperature T_B (K), (F7.2)

4 Echo top height, z_e (km), (F6.2)

The cloud top height follows the definition used in CASE 3 of WG4 (Krueger et al. 1999) and the echo top height is taken from CASE 2 Krueger et al. (1996)

- The cloud top height is defined as the height at which the top-downward integrated cloud water path exceeds 0.01kg m^{-2}. I.e., z_c satisfies

$$\int_{z_c}^{z_T} \overline{\rho}(q_c + q_i)dz = 0.01$$

- The echo top height is defined as the maximum height where $q_r + q_g + q_s > 10^{-3}$ g kg^{-1}

5.2 Description of quantities for SCM integrations

For SCMs please submit timestep dianostics.

5.2.1 Profiles

Submit the results for each quantity listed below as a separate ASCII file in the file format described in appendix A. Include the height z (km, F7.3) of the model level or half level as appropriate, and the mid-point of the time interval $\bar{t}$ (hours, F6.1) from the start of the integration x,y coordinates respectively. Name each file as *experiment*.sp*item*.*modeller*(*.run*) where *experiment* is the experiment number given in section 4.1, *item* is the number of the diagnostic from the list below and *modeller* is the name of the modeller. *.run* is an extra 6 (exactly) character file extension to identify data from additional integrations with the non-standard setup.

Timestep profiles of

1 Pressure, $\overline{p}$ (Pa), (F8.2)

2 Temperature, $\overline{T}$ (K), (F7.2)

3 Potential Temperature, $\overline{\theta}$ (K), (F7.2)

4 Density, $\overline{\rho}$ (kg m^{-3}), (F7.4)

5 Water Vapour Mixing Ratio, $\overline{q}$ (g kg^{-1}), (F7.3)

6 Relative Humidity, R (unitless), (F6.3): R = $\overline{q}/q^*(\overline{T},\overline{p})$, where $q^*(T,p)$ is the saturation mixing ratio over water.

7 Cloud water (suspended liquid water), $\overline{q_c}$ (g kg^{-1}), (F7.4)

8 Cloud ice (suspended ice), $\overline{q_i}$ (g kg^{-1}), (F7.4)

9 Rain (falling liquid water), $\overline{q_r}$ (g kg^{-1}), (F7.4)

10 Snow (slow falling ice), $\overline{q_s}$ (g kg^{-1}), (F7.4)

11 Graupel (fast falling ice, including hail if you have any), $\overline{q_g}$ (g kg^{-1}), (F7.4)

12 Cloud fraction, $\overline{\sigma}$ (unitless), (F6.3):

13 Total hydrometeor fraction, if appropriate $\overline{\sigma_{HM}}$ (unitless), (F6.3):

14 Horizontal wind velocity in the x-direction, $\overline{u}$ (m s^{-1}), (F7.2)

15 Horizontal wind velocity in the y-direction, $\overline{v}$ (m s^{-1}), (F7.2)

16 Apparent heat source, $\overline{Q}_1$ (K day^{-1}), (F7.2):

$$\overline{Q}_1 = \left(\frac{\overline{p}}{p_0}\right)^{R/c_p}\left[\frac{\partial\overline{\theta}}{\partial t} - \left.\frac{\partial\overline{\theta}}{\partial t}\right|_{LS}\right] - \overline{Q}_R,$$

where $\left.\frac{\partial\overline{\theta}}{\partial t}\right|_{LS}$ is the large-scale forcing term which is specified from the observations

17 Apparent moisture source, $\overline{Q}_2$ (g kg^{-1} day^{-1}), (F7.2):

$$\overline{Q}_2 = \left[\frac{\partial\overline{q}}{\partial t} - \left.\frac{\partial\overline{q}}{\partial t}\right|_{LS}\right],$$

where $\left.\frac{\partial\overline{q}}{\partial t}\right|_{LS}$ is the large-scale forcing term which is specified from the observations.

18 Shortwave Radiative heating rate, $\overline{Q}_R^{SW}$ (K day^{-1}), (F7.2)

19 Longwave Radiative heating rate, $\overline{Q}_R^{LW}$ (K day^{-1}), (F7.2)

20 Large scale temperature forcing, $\frac{\partial \theta}{\partial t}\Big|_{LS}$ (K day^{-1}) (F7.2): On model grid

21 Large scale humidity forcing, $\frac{\partial q}{\partial t}\Big|_{LS}$ (g kg^{-1} day^{-1}) (F7.2): On model grid

22 Convective Cloud fraction σ^{conv}, (F6.3)

23 Convective Updraft Mass Flux (if appropriate), $M_c u$, (kg m^{-2} s^{-1}), (F7.4)

24 Convective Downdraft Mass Flux (if appropriate), $M_c d$, (kg m^{-2} s^{-1}), (F7.4)

25 Convective cloud water, q_l^{conv} (g kg^{-1}), (F7.4)

26 Convective cloud ice q_i^{conv} (g kg^{-1}), (F7.4)

27 Large-scale Cloud fraction σ^{LS}, (F6.3)

28 Large-scale cloud water q_l^{LS} (g kg^{-1}), (F7.4)

29 Large-scale cloud ice q_i^{LS} (g kg^{-1}), (F7.4)

30 Clear Sky Shortwave Radiative heating rate, $\overline{Q}_R^{SW}$ (K day^{-1}), (F7.2)

31 Clear Sky Longwave Radiative heating rate, $\overline{Q}_R^{LW}$ (K day^{-1}), (F7.2)

5.2.2 Budget terms

The diagnostics in this section contain terms which will allow the contributions to the models Q_1 and Q_2 to be diagnosed. These terms will be compared with the more detailed breakdown provided by CRM simulations. The analysis of these terms from the CRM integration will form a major part of the case study as they indicate how the convection modifies its environment following a period of suppressed convection and will give information on the non-equilibrium nature of convection during these transition periods. Redelsperger et al. (2002) made extensive use of these diagnostics in their analysis of recovery following a dry intrusion over TOGA-COARE. Comparisons between the CRM budgets and SCM budgets will provide useful information on which components of the convection are currently poorly represented by parametrization schemes. All modellers should provide items 1-6 listed below which provide a breakdown of the contribution from separate physics packages to Q_1 and Q_2. If you have additional physics packages not mentioned below which contribute to Q_1 and Q_2, please supply these terms.

Where possible any additional breakdown of the physics package including any diagnosis of boundary layer type, shallow or deep convection etc would be helpful, for single level fields please use a file format similar to the timeseries diagnostics listed below. If you are easily able to provide a more detailed breakdown of contributions within a particular physics package, (particularly the convection scheme, e.g. contributions to Q_1, Q_2 from updraughts and downdrafts for a mass flux scheme, or even further to e.g. subsidence and detrainment terms) please do.

Name each file as *experiment*.sb*item*.*modeller*(*.run*) where *experiment* is the experiment number given in section 4.1, *item* is the number of the diagnostic from the list below and *modeller* is the name of the modeller. *.run* is an extra 6 (exactly) character file extension to identify data from additional integrations with the non-standard setup. For any additional terms (other packages or details of a particular package) please provide a description of each term in a file bdesc.*modeller*, including the format used to write it with your submitted results.

Timestep profiles of

1 Rate of change of potential temperature due to convection, $\overline{D\theta}^{conv}$ (K day^{-1}) (F7.2):

2 Rate of change of water vapour due to convection, $\overline{Dq}^{conv}$ (g kg^{-1} day^{-1}) (F7.2):

3 Rate of change of potential temperature due to boundary layer and vertical diffusion, $\overline{D\theta}^{BL}$ ($\mathrm{K\,day^{-1}}$) (F7.2):

4 Rate of change of water vapour due to boundary layer and vertical diffusion, $\overline{Dq}^{BL}$ ($\mathrm{g\,kg^{-1}\,day^{-1}}$) (F7.2):

5 Rate of change of potential temperature due to large-scale clouds and precipitation, $\overline{D\theta}^{CLD}$ ($\mathrm{K\,day^{-1}}$) (F7.2):

6 Rate of change of water vapour due to large-scale clouds and precipitation, $\overline{Dq}^{CLD}$ ($\mathrm{g\,kg^{-1}\,day^{-1}}$) (F7.2):

5.2.3 Timeseries

Submit results for each of the groups in separate files. Name each file *experiment*.st*group*.*modeller*.*run*, following the convention for the profile diagnostics. Start each file with the two comment lines described in the special file format in appendix A, with the group number for *item* and omitting *variable_name*. Please write the data as: all the variables for each time level 1 on one line, all the variables at time level 2 on the next line, ..., all the variables at the last time level on the last line. Using the formats specified below, with no spaces between the variables, will ensure all the data fits on one line of 80 characters. Please output data for each model timestep

Group 1:

1 Time at midpoint of averaging interval, $\overline{t}$ (h), (F7.2)

2 Sea Surface Temperature, SST (K), (F7.2)

3 Near surface dry static energy, $\overline{s}_0$, ($\mathrm{kJ\,kg^{-1}}$), (F7.2): $s = c_pT + gz$. "Near-surface" is the first model-level.

4 Near surface water vapour mixing ratio, $\overline{q}_0$, ($\mathrm{g\,kg^{-1}}$), (F6.2)

5 Near surface moist static energy, $\overline{h}_0$: , ($\mathrm{kJ\,kg^{-1}}$), (F7.2): $h = s + L_vq$.

6 Near surface horizontal wind velocity in the x-direction, $\overline{u}_0$ ($\mathrm{m\,s^{-1}}$), (F7.2)

7 Near surface horizontal wind velocity in the y-direction, $\overline{v}_0$ ($\mathrm{m\,s^{-1}}$), (F7.2)

8 Surface turbulent flux of sensible heat $\overline{F_{s0}}$ ($\mathrm{W\,m^{-2}}$), (F6.1):
$F_s = \overline{\rho}c_p\left(\frac{\overline{p}}{p_0}\right)^{R/c_p} < w''\theta'' >$.

9 Surface turbulent flux of latent heat $L_v\overline{F_{q0}}$ ($\mathrm{W\,m^{-2}}$), (F6.1): $F_q =< w''q'' >$.

10 Surface turbulent flux of horizontal momentum in the x-direction $\overline{F_{u0}}$ ($\mathrm{N\,m^{-2}}$), (F8.4): $F_u = \overline{\rho} < w''u'' >$.

11 Surface turbulent flux of horizontal momentum in the y-direction $\overline{F_{v0}}$ ($\mathrm{N\,m^{-2}}$), (F8.4): $F_v = \overline{\rho} < w''v'' >$.

Group 2:

1 Time at midpoint of averaging interval, $\overline{t}$ (h), (F7.2)

2 Surface downwelling solar radiative flux, $\overline{F^-_{SW0}}$ ($\mathrm{W\,m^{-2}}$), (F7.1)

3 Surface downwelling infrared radiative flux, $\overline{F^-_{LW0}}$ ($\mathrm{W\,m^{-2}}$), (F6.1)

4 Surface upwelling solar radiative flux, $\overline{F^+_{SW0}}$ ($\mathrm{W\,m^{-2}}$), (F6.1)

5 Surface upwelling infrared radiative flux, $\overline{F^+_{LW0}}$ ($\mathrm{W\,m^{-2}}$), (F6.1)

6 TOA (top of atmosphere) downwelling solar radiative flux, $\overline{F^-_{SWT}}$ ($\mathrm{W\,m^{-2}}$), (F7.1)

7 TOA upwelling solar radiative flux, $\overline{F^+_{SWT}}$ ($\mathrm{W\,m^{-2}}$), (F7.1)

8 TOA upwelling infrared radiative flux, OLR ($\mathrm{W\,m^{-2}}$), (F7.1)

9 Cloud amount, $\overline{A_{cld}}$ (unitless), (F6.3): Cloud shadow as seen by radiation.

Group 2a:

1 Time at midpoint of averaging interval, $\bar{t}$ (h), (F7.2)

2 Clear Sky Surface downwelling solar radiative flux, $\overline{F^-_{SW0}}$ ($\mathrm{W\,m^{-2}}$), (F7.1)

3 Clear Sky Surface downwelling infrared radiative flux, $\overline{F^-_{LW0}}$ ($\mathrm{W\,m^{-2}}$), (F6.1)

4 Clear Sky Surface upwelling solar radiative flux, $\overline{F^+_{SW0}}$ ($\mathrm{W\,m^{-2}}$), (F6.1)

5 Clear Sky Surface upwelling infrared radiative flux, $\overline{F^+_{LW0}}$ ($\mathrm{W\,m^{-2}}$), (F6.1)

6 Clear Sky TOA upwelling solar radiative flux, $\overline{F^+_{SWT}}$ ($\mathrm{W\,m^{-2}}$), (F7.1)

7 Clear Sky TOA upwelling infrared radiative flux, OLR ($\mathrm{W\,m^{-2}}$), (F7.1)

Group 3:

1 Time at midpoint of averaging interval, $\bar{t}$ (h), (F7.2)

2 Surface rainfall rate, $\overline{\mathrm{PPT}}$ ($\mathrm{mm\,day^{-1}}$), (F7.2):

3 Precipitable water, $\overline{\mathrm{PW}}$ ($\mathrm{kg\,m^{-2}}$), (F6.2): $\mathrm{PW} = \int_0^{z_t} \overline{\rho} q \, dz$, where z_T is the model top height.

4 Cloud liquid water path, $\overline{\mathrm{LWP}}$ ($\mathrm{kg\,m^{-2}}$), (E10.3): $\mathrm{LWP} = \int_0^{z_t} \overline{\rho} q_c \, dz$,.

5 Cloud ice path, $\overline{\mathrm{IWP}}$ ($\mathrm{kg\,m^{-2}}$), (E10.3): $\mathrm{IWP} = \int_0^{z_t} \overline{\rho} q_i \, dz$,.

6 Convective precipitation $\overline{\mathrm{PPT}_{\mathrm{CV}}}$ ($\mathrm{mm\,day^{-1}}$), (F7.2):

7 Large-scale precipitation $\overline{\mathrm{PPT}_{\mathrm{LS}}}$ ($\mathrm{mm\,day^{-1}}$), (F7.2):

A Special File Format

Please use this format for submitting 2D arrays $f(x, y)$ with x,y coordinates.

```
# experiment modeller p/b/x/t item run variable_name
# comments
nx ny
x(1) x(2) ...x(nx)
y(1) y(2) ...y(ny)
f(x1,y1) f(x2,y1) ...f(xnx,y1) f(x1,y2) ...
f(x1,yny) f(x2,yny) ...f(xnx,yny)
```

Where `experiment, modeller, p/b/x/t, item, run` are the identifiers used in the filename and described in section 5. For the control integration please use `xxxxxx` as the run identifier in the file (but not in the file name). Please supply a short variable name as a double check. Include in the comments line, the sampling frequency used. If you have no data to submit for a particular variable please submit a file containing the first two lines with `NO_DATA` as the first comment.

References

Inness, P. M., Slingo, J. M., Woolnough, S. J., Neale, R. B., and Pope, V. D. (2001). Organisation of tropical convection in a GCM with varting vertical resolution; Implications for the simulation of the Madden-Julian Oscillation. *Climate Dyn.*, **17**, 777–793.

Johnson, R. H., Rickenbach, T. M., Rutledge, S. A., Ciesielski, P. E., and Schubert, W. H. (1999). Trimodal characteristics of tropical convection. *J. Climate*, **12**, 2397–2418.

Krueger, S., Gregory, D., Moncrieff, M., Redelsperger, J.-L., and Tao, W.-K. (1996). GEWEX Cloud Systems Study Working Group 4: First Cloud-Resolving Model Intercomparison Project CASE 2. Technical report.

Krueger, S., Cederwall, R., Xie, S., and Yio, J. (1999). GCSS Working Group 4 Model Intercomparison Procedures for Case 3: Summer 1997 ARM SCM IOP. Technical report.

Redelsperger, J.-L., Parsons, D. B., and Guichard, F. (2002). Recovery processes and factors limiting cloud top height following the arrival of a dry intrusion observed during toga-coare. *J. Atmos. Sci*, **59**, 2438–2457.