BMRC TECHNICAL REPORT NO. 1

SEPTEMBER 2006

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(December 2, 2005)

Abstract: A single column model (SCM) has been created by incorporating the physics of the Bureau of Meteorology Research Centre (BMRC) Atmospheric Model (BAM), the Bureau's weather prediction and climate simulation model, into the architecture of the National Centre for Atmospheric Research (NCAR) Single-column Community Model (SCCM).

The main purpose of the BAMSCM is for developing, testing and tuning new BAM physics parameterization schemes (vertical diffusion, gravity wave drag, radiation,...) and examining physical processes that are simulated within BAM such as cloud and precipitation formation etc. The effect of these schemes and processes can then be compared to observations and other SCM outputs. The main sources of observations for these comparisons are the Atmospheric Radiation Measurement (ARM) intense observing period (IOP) datasets as well as data from the new Darwin ARM site. This report describes the development of the BAM single column model BAMSCM version 2, hereafter referred to as BAMSCM. Instructions on how to obtain and run the BAMSCM, as well as examples of its use, are included. BAMSCM will be upgraded as new BAM releases are made.

1 Introduction

Physical parameterization schemes are used in large scale atmospheric models to represent non-resolvable physical processes. These parameterization schemes need to be developed, tested and tuned - this can be done in a single column model (SCM), a cloud-resolving model (CRM), as well as in a general circulation model (GCM). The latter is generally the final intended recipient of the scheme. The SCM represents a single grid column within a GCM, while a CRM, which also represents this grid, is designed to capture the cloud-scale processes that are parameterized in the GCM and SCM. Ideally all new parameterization

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schemes would be developed and tested in these three models, which go from the simplest and quickest to the complex and most expensive[2]. The Bureau of Meteorology Research Centre has a GCM, BAM[3], and does not at present have a cloud-resolving model, but its new SCM is discussed here.

While the primary use of an SCM is to develop and test parameterization schemes, other uses are: to study climate sensitivity and feedback mechanisms; to study long-term local climate simulations; as well as to develop portable physics modules which are easily implemented in global models.

When developing and testing a parameterization scheme a SCM has the advantages of being computationally inexpensive and of being able to isolate the effects of a new scheme (Xu and Arakawa 1992 ; Randall *et al.* 1996). While the former is a definite advantage the latter implies that the full model's complex non-linear feedback mechanisms are unable to operate, and so eventual testing and tuning within the parent model is still required. Another difficulty with SCMs is that the horizontal dynamic tendencies for the prognostic variables cannot be resolved explicitly and so must be prescribed. These SCM forcings have to be specified or computed from either archived model output, observations or high-resolution models such as CRMs. Another problem with SCMs testing physical parameterizations is that roundoff, algorithmic changes or small initial condition perturbations can produce significantly different solutions due to the existence of branch points in the physics code. For example, Hack and Pedretti (2000) and Xie and Zhang (2000) had difficulty simulating precipitation, temperature, and moisture fields in SCMs.

In spite of these difficulties, the SCM has been found to be a simple and efficient way of testing parameterization schemes and its use for this purpose is becoming more common (Betts and Miller, 1986; Iacobellis and Somerville, 1991; Randall *et al.*, 1996). The number of SCMs available is rapidly increasing so that intercomparison studies of SCM simulations are also being carried out (Ghan *et al.*, 2000).

A great deal of work has now been done on SCM techniques and the creation of suitable SCM forcing data sets from observational sites (ARM), as well as from field experiments

[2]For the reasoning behind this, see the GEWEX-GCSS and ARM websites *www.msc-smc.ec.gc.ca/GEWEX/GCSS/column_models.html* and *www.arm.gov/docs/research/scm.html*, respectively.

[3]For details, see the BMRC website *gale.ho.bom.gov.au/bm/internal/mdev/model-doc.html*.

(ASTEX, BOMEX, GATE, TOGA-COARE,..). Information on the development of these forcing data sets is in the published literature (Randall *et al.*, 1998), as well as at the Colorado State University and ARM websites[4]. There are several SCMs that are freely available on the web, and we use one of these, the NCAR-SCCM, as a basis for the BAMSCM.

The following sections discuss: the NCAR SCCM and why it was chosen; how the BAM physics is incorporated and how to access and operate the BAMSCM; and finally an example of the BAMSCM in use. All of this work refers to the Unix version of BAMSCM but most is relevant for the Linux version also. The Appendix holds detailed instructions on how to setup the BAMSCM on a Linux workstation.

2 The NCAR SCCM

In order to develop the BAMSCM we have incorporated BAM physics into the NCAR Single-column Community Climate Model (NCAR-SCCM, hereinafter referred to as SCCM). SCCM was chosen because it was well documented, freely available, utilized Network Common Data Format (NetCDF) input and output datasets and came with an excellent graphical user interface making its operation very user friendly.

SCCM is the single grid column model developed from the NCAR global Community Climate Model (CCM). The physical parameterizations in SCCM, such as those of radiation, clouds, deep and shallow convection, large-scale condensation, and boundary layer processes, are the same as those in the CCM. More details about the physical parameterizations of the CCM are given by Kiehl *et al.* (1996). Details on SCCM are given by Hack *et al.* (1999) and are available at the SCCM website[5]. SCCM is freely available and can be run on several Unix platforms including IRIX 6.2 and HP-UX 10.20 as well as Linux platforms running Linux 2.0.

SCCM, as in most SCMs, is a 1-D time-dependent model described by the equations

$$\frac{\delta T}{\delta t} = -\omega(\frac{\delta T}{\delta p} + \frac{RT}{pc_p}) + T_{LS} + T_{physics} \tag{1}$$

$$\frac{\delta q}{\delta t} = -\omega\frac{\delta q}{\delta p} + Q_{LS} + Q_{physics} \tag{2}$$

[4]See websites *www.kiwi.atmos.colostate.edu/scm/* and *www.arm.gov/docs/research/scm.html*, respectively.

[5]See website *www.cgd.ucar.edu/cms/sccm/sccm.html*.

$$\frac{\delta u}{\delta t} = -\omega \frac{\delta u}{\delta p} + U_{LS} + U_{physics} \tag{3}$$

$$\frac{\delta v}{\delta t} = -\omega \frac{\delta v}{\delta p} + V_{LS} + V_{physics} \tag{4}$$

$$(tendency = large\_scale\_vert\_adv + large\_scale\_horiz\_adv + local\_physics)$$

where the local time-rate-of-change of the large-scale state variables (temperature T, moisture q, and horizontal velocities u and v) depend on:

- a specified vertical motion field ω from which the large-scale vertical advection terms $\omega\delta T/\delta p$, $\omega\delta q/\delta p$, $\omega\delta u/\delta p$ and $\omega\delta v/\delta p$ are evaluated for the T, q, u and v fields, respectively;
- specified large-scale horizontal flux divergence forcing terms T_{LS}, Q_{LS}, U_{LS} and V_{LS} for the T, q, u and v fields, respectively; and,
- subgrid-scale sources, sinks and eddy transports $T_{physics}$, $Q_{physics}$, $U_{physics}$ and $V_{physics}$ for the T, q, u and v fields, respectively.

The subgrid-scale contributions are determined by the collection of physical parameterization schemes being evaluated, with the remaining physical parameterizations coming from the standard CCM2 or CCM3 physics packages included in the SCCM[6]. Both Eulerian and semi-Lagrangian advection schemes are included in the SCCM package.

As can be seen in these equations there are no horizontal feedbacks and thus the governing equations are only coupled, incompletely, through the parameterized physics. This implies that the thermodynamic and momentum equations, and their budgets, are generally independent of one another.

These equations show that the SCCM lacks the horizontal feedbacks available in the more complicated three-dimensional CCM3, making it necessary to prescribe the horizontal advective tendencies (T_{LS}, Q_{LS}, U_{LS} and V_{LS}). Hack *et al.* (1999) and Randall and Cripe (1999) detail how the effects of neighbouring columns are specified in the SCCM.

[6]See CCM2 and CCM3 details at the websites *www.cgd.ucar.edu/cms/ccm2/* and *www.cgd.ucar.edu/cms/ccm3/*, respectively.

To solve these equations in the SCCM the initial conditions and horizontal forcing terms (T_{LS}, Q_{LS}, U_{LS} and V_{LS}) need to be specified and this can be accomplished in three ways:

- The first is to select a column from anywhere on the globe and use initial conditions (surface properties, optical path lengths etc) from monthly averaged climatological European Centre for Medium-Range Forecasting (ECMWF) analyses or CCM3 model-generated results. In this case the horizontal forcing tendencies are assumed to be zero.

- The second is to use Intensive Observing Period (IOP) data that specifies the initial conditions as well as the transient forcing terms. At present the SCCM has access to IOP data from GATE, ARM and TOGA COARE field experiments[7]. Any quantity not specified by an IOP dataset will automatically come from the global ECMWF or CCM3 datasets for a column nearest the IOP site.

- It is also possible to setup a synthetic dataset that can be used to illustrate aspects of a parameterization scheme. This is handled in a similar manner to the IOP datasets mentioned above.

SCCM comes as a zipped tar file with the source code, datasets and a graphical user interface (gui) executable (but not the gui source code). When unpacking the code ($\approx 100MB$) an INSTALL file is created which describes how to setup the SCCM and it automatically creates the *data* and *sccm-1.2* directories, storing data in the first and the model in the second.

The *data* directory has subdirectories: *boundary*; *global*; and *iop*. These contain the: surface, pressure level and ozone datasets; global analysis and model datasets; and the IOP datasets, respectively.

The *sccm-1.2* directory has the files: GNUmakefile which controls the making of the SCCM; INSTALL which documents the installation of the SCCM; configure a script to setup the parameters for the SCCM operation (Fortran compiler, C compiler, system type, CCM2 or CCM3 build, number of vertical levels, number of advected constituents, path to

[7] Details of these datasets can be found at the websites: *www.kiwi.atmos.colostate.edu/scm/gate.html*, *www.arm.gov/*, and *www.ncdc.noaa.gov/coare/*, respectively.

search for alternate source files, NetCDF library location); and, sccmgui the pre-compiled gui executable.

The *sccm-1.2* directory has subdirectories: *ccm2, ccm3.2, ccm3.6* which hold the NCAR CCM2, CCM3.2 and CCM3.6 source code, respectively; *html* which holds html files describing the SCCM, its Userguide and Index; *init* contains the initialization routines for the SCCM; *lib* which holds ncar graphics routines; *obj* which holds all the compiled files; and, *userdata* which is where all user NetCDF output from the SCCM are saved. Each of these physics packages has a different structure so BAM was linked only to the latest available package, CCM3.6.

3 BAMSCM (BAMSCM v2)

In order to develop BAMSCM v2 we have incorporated the BAM v4.0 physics into the SCCM[8]. Note that BAMSCM versions 1 and 2 have been created and are available for use and these use the BAM version 3.1 and 4.0 physics packages, respectively. The release version of BAM v4.0, which is the operational version of the code at this time, uses the development BAM v4.0.08 code and is the SX6 realised version of the SX5 BAM v4.0.

Figure 1 is a flowchart which shows the linkage from the SCCM to the BAM v4.0 physics. The linkage is basically from the CCM3.6 time-stepping routine stepon.F through a linking routine c2b2_loop.F and then into the main BAM v4.0 physics driving routine phy_latg.F.

The CCM3.6 routine stepon.F has been edited so that if the user parameter "switch 1" is set to 0, the default, then the standard CCM3.6 physics is run or if set to 1 then the BAM v4.0 physics will run by calling the newly created linking routine c2b2_loop.F. The SCCM NetCDF outputting routine outfld.F is also used here to output some BAM fields.

The linking routine c2b2_loop.F is the link between the SCCM and the BAM physics and as such it:

- does the SCCM pre-physics operations as in CCM3.6 routine stepon.F
- copies and converts SCCM parameters and arrays into forms suitable for the BAM physics; *e.g.*, creates the BAM sigma levels from the SCCM hybrid levels etc.

[8] Details of BAM v4.0 can be found at the website *gale.ho.bom.gov.au/bm/internal/mdev/model-doc.html*.

- initializes the BAM physics by calling BAM routines: phyinit_reg.F, eclssin.F, inital_bam.F, inihdf.F, ecmwfin.F and gridin.F

- for later timesteps it follows the procedure in BAM routine phys2_reg.F and calls the extra routines: zerobfgh.F, zero_qcloud.F, zerorad.F, zerocfgh.F, zero_stresses_prec.F, physingh.F, inradg.F, coning.F, flxing.F, phy_latg.F, gridot.F

- does the SCCM post-physics operations as in CCM3.6 routine stepon.F

- uses the SCCM NetCDF outputting routine outfld.F to output some BAM fields.

The BAM v4.0 physics driving routine phy_latg.F has also been edited to output some BAM fields using outfld.F.

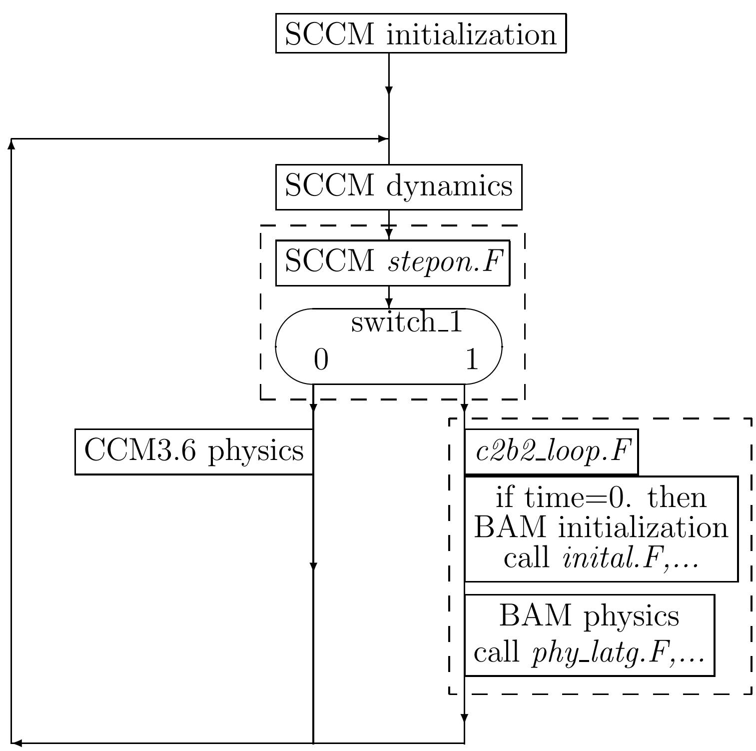

Figure 1: BAMSCM flowchart showing linkage between NCAR SCCM and BAM physics. See text for details.

3.1 Obtaining and setting up the BAMSCM Single Column Model

This section details how to obtain and set up the BAMSCM v2 on the BMRC HP workstation Gale.

In order to get a version of the BAMSCM which will setup the model files in the correct subdirectories and create the directory where the model will be run from (*sccm-1.2*), the following steps need to be taken:

- move to the directory where you want to place the model *e.g.*

  `cd /bm/gkeep/glr/bamscm`

- retrieve the BAMSCM compressed/tar files from sam

  `rcp sam1-hippi:/samcrc/gen/glr/SCM/tar/05july_bamscm_v2_bam4.0.tar.Z .`

- uncompress and untar the tar file to create the BAMSCM and its directories

  `uncompress 05july_bamscm4.0.tar.Z`

  `tar -xvf 05july_bamscm4.0.tar`

The BAMSCM directory tree is seen in (Figure 2). The *data* directory holds the boundary, global and iop datasets, in their respective directories *boundary*, *global* and *iop*, that are included in the SCCM and are used to run the model. The *boundary* directory also holds the file press18.nc, which contains the parameters which define the vertical levels the BAMSCM will run on, in hybrid vertical co-ordinates. The rest of the BAMSCM is held in the *sccm-1.2* directory.

On entering the main model directory *sccm1.2* it is found to contain the subdirectories: *GSTORE* holding the standard BAM and CCM configuration files; *ccm3.6* holding the CCM3.6 physics source code; *html* holding the SCCM userguide; *init* holding routines required to initialize the SCCM; *lib* holding ncarg routines used for displaying the data via the gui; *myanal* holding IDL routines to plot BAMSCM output; *obj* which holds all the object files when the executable file *sccm* is created; *userdata* which holds output from the single column model; and, *mymods* which is the directory where all the BAM modified routines are placed. Note that some variables in the SCCM code needed to be re-named to avoid conflict with BAM variables. Thus in *ccm3.6* there are several edited files along with the original files *e.g.* lsmini.F and lsmini.F_orig etc.

The *mymods* directory contains scripts to create the BAMSCM (see below) as well as four directories: *BAMW4* contains the files needed from BAM v4.0 to run the BAM physics;

MERGE contains files from BAM v4.0 which need to be changed (see the run_bam_scm.csh script below for details), as well as files needed to merge the BAM physics into the SCCM; *namelists* contains same namelist files for the BAM physics; and, *MTEST* which is the directory where new files are placed which are to be compiled and placed into the BAMSCM.

Note that as this version of the SCCM only comes with an executable sccmgui then there are three files we need to be careful with press18.nc, bldfld.F and intht.F. If we want to run the BAMSCM on different hybrid vertical levels then the file must be held in the *data/boundary* directory and named press18.nc. The file bldfld.F held in the directory *init* lists all the output fields which are allowed to be outputted to the NetCDF files in the *userdata* directory. If more fields are added to this file, then the sccmgui will not recognize them and will not output them unless an outfld call for them is also added to the intht.F file, also in the directory *init*. Thus it will not be possible to create these new outputs interactively. However, a successful run can be made in background mode without the gui (see below), and then the output can be viewed with the gui. The original SCCM bldfld.F and my modified file are listed as bldfld.F_orig1 and bldfld.F_extras, respectively, and need to be copied to bldfld.F if they are to be changed. Note: if you change either of these files press18.nc or bldfld.F then you will need to re-create the sccm executable using the scripts below.

The following files are also created: GNUmakefile and configure which are used to create the SCM; some sample quick-start files (*.scm) for running the model in background mode; a sample namelist file nl.all and a sample climdata.nc file needed for the BAM physics; and, a sccmgui executable file which runs the SCCM gui.

In order to personalize the BAMSCM, the directory (*/bm/gkeep/glr/bamscm*), which is where the model is placed, must be replaced with your directory in the two *GSTORE* directory files:

config.out_SCM_64bit_ccm3.6_debug_L30 and config.out_BAM_64bit_ccm3.6_debug_L30

and in the five *mymods* directory files:

ncar_sccm3.6.csh, bam4.0scm.csh and run_bam_scm.csh, run0.csh, and run1.csh.

We will retain */bm/gkeep/glr/bamscm* as the BAMSCM root directory for this paper.

The SCCM, to which we add the BAM v4.0 physics to create the BAMSCM, must

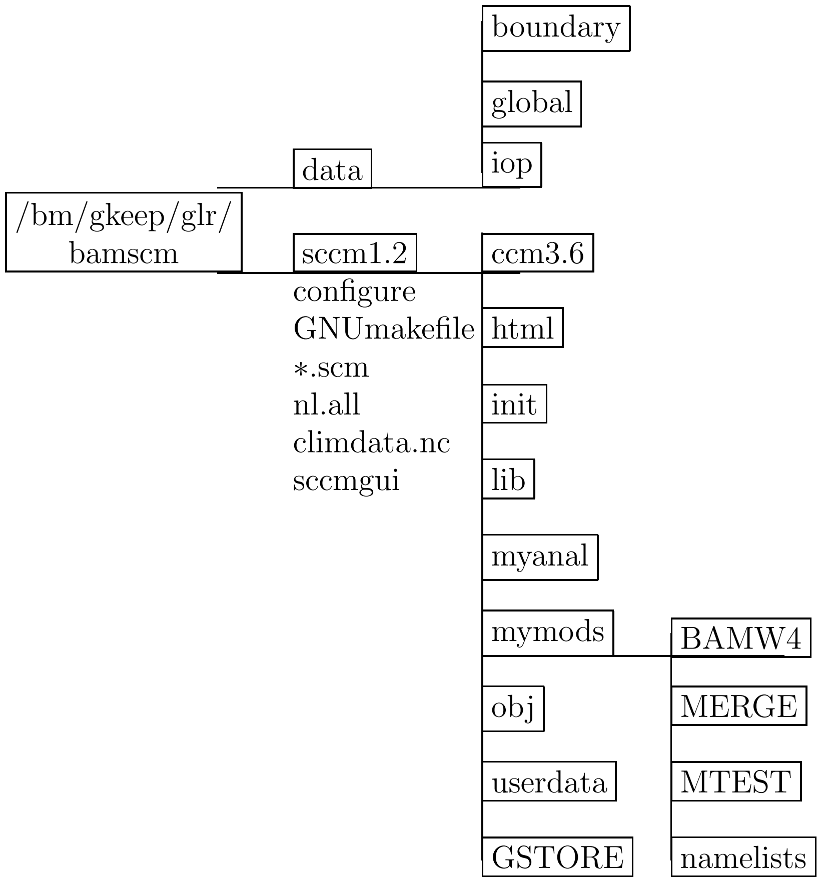

Figure 2: BAMSCM directory tree structure. See text for details.

be created first. Do this by running the *mymods* script ncar_sccm3.6.csh which creates the executable sccm in the main directory and the SCCM, using ccm3.6 physics, can now be run via the command `sccm`. This will open a gui whose operation is described in the SCCM userguide, found in the *html* directory[9].

The BAMSCM can now be created by adding the BAM v4.0 physics to this SCM by running the script bam4.0scm.csh in directory *mymods* which also sets some environmental variables to point at the necessary datasets for BAM physics to run. This replaces the previous sccm executable and enables it to run using the CCM3.6 physics, the default, or if "switch 1" in the **options/switches** settings in the gui is changed from 0 (the default) to 1, then BAM v4.0 physics is run.

The BAMSCM can now be run interactively using the gui by the typing `sccm` or run

[9] as well as on the web at *www.cgd.ucar.edu/cms/sccm/userguide.html*

in the background via a command such as:

`sccm -ng -o out.hist -t 120 arm07953h_bam.scm` where:

- `-ng`: "no gui", implies not to use the gui interface;
- `-o out.hist`: gives the name of the output history file which will be saved in the *userdata* directory;
- `-t 120`: run for 120 timesteps; and,
- `arm07953h_bam.scm`: names the quick-start file in the *sccm-1.2* directory that contains the rest of the parameters.

Examples of these run procedures and further discussion can be found in the run_bam_scm.csh, run0.csh and run1.csh scripts in the *mymods* directory. Some sample quick-start files are included in this package and more information on how to make them is in the SCCM User-guide.

Just as BAM requires a list of parameter settings to run, the "keyword file" but commonly called the "namelist", so to does the BAMSCM, when running BAM physics, and its BAM namelist parameters are set in the nl.all file held in the *sccm-1.2* directory. Changing the namelist file nl.all enables different physics parameterization schemes to run with different control settings.

When new code is being tested it needs to be placed in the *mymods/MTEST* directory and then `gmake` needs to be run in the *sccm-1.2* directory to compile this code and create a new sccm executable. SCCM parameters are adjusted by editing quick-start files or using the gui *e.g.* see the run∗.csh script in the *mymods* directory. All output is NetCDF, saved to the *userdata* directory. NetCDF file names are selected via the gui or by the background run job *e.g.* see the run∗.csh scripts in the *mymods* directory.

The BAMSCM now provides a simple method to isolate and study BAM physical parameterization schemes within the framework of the well developed SCCM. The BAMSCM:

- can complete a 20 day run with a 1200 second timestep in 40 seconds on a typical modern workstation (so is fast and cost effective)

- has been organized so it can run with CCM3.6 or BAM v4.0 physics packages and compare the results with observations (where available)

- is able to show field development graphically as it runs

- enables the experimenter to use "point-and-click" methods to change initial conditions.

Results from the BAMSCM can also be compared to outputs from the ECMWF SCM, which uses the ECMWF physics and dynamics packages (this model has been provided by Christian Jakob and can be run in-house at BMRC). The ECMWF SCM is the single column version of the model used for the ERA-40 reanalysis (Uppala, 2002). Results can also be compared to (limited) output from the Commonwealth Science and Industrial Research Organization (CSIRO) Division of Atmospheric Research (DAR) SCM, which uses the DAR physics and dynamics packages (McGregor *et al.*, 1993).

The gui enables plotting, using NCAR graphics, of this output. Comparison of the NetCDF output from different runs and CCM/ECMWF/DAR or observations, when available, can be made by your favourite plotting suite or by using some IDL routines using the g_scm_diff_all.csh script held in directory *myanal* (see the g_scm_diff_all_ctl.csh script in directory *myanal* for some examples).

For those wishing to run on a Linux platform, all of the above is still relevant except for the original setup for the model. The BAMSCM Linux setup process is detailed in the Appendix.

4 BAMSCM Experiment: Comparison of BAM cloud schemes

Several experiments which have been made with the BAMSCM can be seen on the BMRC web pages[10]. In the following section we discuss one of these which was run using ARM Southern Great Planes (SGP) IOP data from July 18 to August 4, 1995 and was a comparison of the BAM cloud schemes ie the prognostic cloud scheme *qcloudn* is compared with the diagnostic cloud schemes *cld98* and *cld93*, all of which are available in BAM.

Here we compare BAMSCM v2, which uses BAM v4.0 physics, running in standard AGCM mode and compare the effect of implementing the various cloud scheme options in

[10] *gale.ho.bom.gov.au/bm/internal/regn/staf/glr/stuf/scm/glr.html*

the namelist. The cloud scheme used is controlled by the namelist parameter "cldscheme", and the available options are cld93, cld98 and qcloudn[11]:

cldscheme = 'cld93'.

Here stratiform cloud formation is based on the relative humidity diagnostic form of Slingo (1987). Clouds are of 3 height classes: high (sigma levels 0.189-0.336), middle (sigma levels 0.500-0.664), and low (sigma levels 0.811-0.926). The fractional amount of each type of cloud is determined by a threshold relative humidity that varies with sigma level. In addition the amount of low cloud increases with the strength of the inversion, if one is present (Rikus, 1991).

Deep convection is simulated by a variation of the method of Kuo (1974) that includes modifications of Anthes (1977). Penetrative convection is assumed to occur only in the presence of conditionally unstable layers in the vertical and large-scale net moisture convergence. The convective cloud base is assumed to be at the first level (maximum sigma = 0.926) above the planetary boundary layer (PBL) which is conditionally unstable. The convective cloud is assumed to dissolve instantaneously through lateral mixing, thereby imparting heat and moisture to the environment.

The simulation of shallow convection is parameterized as part of the model's vertical diffusion scheme, following the method of Tiedtke (1983, 1988).

cld93 requires namelist settings: `cldscheme = 'cld93'`, `swscheme = 'shortv12'`, `clstype = 'lsadj'`. Here swscheme and clstype are the namelist parameters for the shortwave parameterization scheme and the stratiform/large scale precipitation, respectively. These two settings force the use of the Lacis and Hansen (1974) short wave scheme and large scale adjustment for stratiform/large scale precipitation.

cldscheme = 'cld98'.

Shallow convection is parameterized as in cld93, but the Kuo penetrative convection in cld93 is replaced by the mass-flux scheme of Tiedtke (1989), but without inclusion of momentum effects (Colman and McAvaney, 1995 and McAvaney *et al.*, 1995). The scheme accounts for mid-level and penetrative convection, and also includes effects of cumulus-scale downdrafts. The closure assumption for mid-level/penetrative convection is that large-scale

[11] For more details see the BMRC website *gale.ho.bom.gov.au/bm/internal/mdev/model-doc.html*.

moisture convergence determines the bulk cloud mass flux. Entrainment and detrainment of mass in convective plumes occurs through both turbulent exchange and organized inflow and outflow.

Unlike cld93, convective cloud amount is diagnosed following Hack *et al.* (1993). In each vertical column, the total fractional cloud amount is a logarithmic function of the convective precipitation rate, but is constrained to values between 0.2 and 0.8. Changes in cloud fraction are allocated equally to vertical layers between the bottom and top of the convective tower.

Stratiform cloud formation is based on the relative humidity diagnostic of Slingo (1987) as in cld93, but with further modifications adopted by Hack *et al.* (1993). The criteria for the height classes and relative humidity thresholds for cloud formation are also different.

Inversion cloud also forms at low levels following the diagnostics of Rikus (1991), as in cld93; however, the cloud fraction is reduced as the height of the maximum inversion strength increases, following Hack *et al.* (1993).

cld98 requires namelist settings: `cldscheme = 'cld98', swscheme = 'swr89dar', clstype = 'lsadj'`. These two settings force the use of a CSIRO-modified version of Lacis and Hansen (1974) short wave scheme and large scale adjustment for stratiform/large scale precipitation.

cldscheme = 'qcloudn'.

Unlike the above which are diagnostic cloud schemes this namelist setting implements the Rotstayn (1997) prognostic cloud scheme which includes two prognostic variables (cloud liquid water and ice) with physically based treatment of associated cloud microphysical processes. Cloud formation is based on the statistical condensation scheme of Smith (1990) and clouds are permitted on all model levels except the lowest. An additional diagnostic treatment of convective clouds is included, with the fraction of cloud based on the convective rainfall rate, and only vertical advection of cloud variables by model dynamics is available.

qcloudn requires namelist settings: `cldscheme = 'qcloudn', swscheme = 'swr89dar', clstype = 'rotstayn'`. These two settings force the use of a CSIRO-modified version of Lacis and Hansen (1974) short wave scheme and Rotstayn (1997) for stratiform/large scale precipitation.

These schemes are compared via the following steps:

- `cd /bm/gkeep/glr/bamscm/sccm-1.2` : go to BAMSCM directory
- `cp /bm/gkeep/glr/bamscm/sccm-1.2/mymods/namelists/nl_agcm_ec nl.all` : get the namelist nl.all, which uses mainly defaults for the AGCM mode
- edit the namelist nl.all to run diagnostic cloud scheme cld93 *ie* set: `cldscheme = 'cld93', swscheme = 'shortv12', clstype = 'lsadj'`. Then run the BAMSCM: `sccm -ng -o userdata/arm07953h_agcm_cld93.nc arm07953h_bam.scm > out`
- edit the namelist nl.all to run diagnostic cloud scheme cld98 *ie* set: `cldscheme = 'cld98', swscheme = 'swr89dar', clstype = 'lsadj'`. Then run the BAMSCM: `sccm -ng -o userdata/arm07953h_agcm_cld98.nc arm07953h_bam.scm > out`
- edit the namelist nl.all to run prognostic cloud scheme qcloudn *ie* set: `cldscheme = 'qcloudn', swscheme = 'swr89dar', clstype = 'rotstayn'`. Then run the BAMSCM:

  `sccm -ng -o userdata/arm07953h_agcm_qcloudn.nc arm07953h_bam.scm > out`
- run the BAMSCM with the ccm3.6 physics:

  `sccm -ng -o userdata/arm07953h_ccm3_std.nc arm07953h_ccm.scm > out`
- plot fields from these runs. Use your favourite NetCDF plotting package or a supplied Interactive Data Language (IDL) script g_scm_diff_all.csh in the *myanal* directory which can create time-height contour plots and single level time series line plots. Figures 3-5 are examples of contour plots of the cloud fraction (CLOUD), cloud liquid water mixing ratio (CLWMR), and cloud ice water mixing ratio (CLWMR), created using this script for these runs via the following commands:
  - `cd /bm/gkeep/glr/bamscm/sccm-1.2/myanal`
  - `g_scm_diff_all.csh arm07953h CLOUD agcm_std agcm_cld98 agcm_cld93`
  - `g_scm_diff_all.csh arm07953h CLWMR agcm_qcloudn agcm_cld98 agcm_cld93`
  - `g_scm_diff_all.csh arm07953h CIWMR agcm_std agcm_cld98 agcm_cld93`

This script can also produce output from the ECMWF SCM and CSIRO DAR SCM if they are available. The plots created by these commands are discussed below. These two dimensional plots are time (hours) against pressure (hPa); the mean (mn), standard deviation (sd), minimum (min), maximum (max), and contour interval (ci) of the plotted field are listed below each plot; the number of model levels and their locations are indicated on the right side of each plot; the title contains the userdata file, field name and units; the bottom label contains the latitude and longitude of the site and the field name from the BAMSCM.

Figure 3 shows the cloud fraction ($fraction$) for ARM SGP IOP from July 18 to August 4 1995 for: (a) BAMSCM using BAM physics with the ECMWF land-surface scheme and the prognostic cloud scheme 'qcloudn', the diagnostic cloud scheme 'cld98' and the diagnostic cloud scheme 'cld93', respectively; (b) BAMSCM using CCM3 physics and ECMWF SCM. In the discussion below these last two are referred to as CCM and ECMWF, respectively.

All of these five outputs show patchy cloud formation up to $\approx$ hour 230 then a relatively cloud free period up to $\approx$ hour 250. A period of increasing cloud fraction and deeper penetrative clouds, with reducing cloud bottoms, then continues until $\approx$ hour 380, then the cloud bottom heights increase with time.

All the BAM cloud scheme BAMSCM runs tend to form clouds during the same periods of this IOP and have similar maximum and minimum cloud heights, but the **cld93** run shows the least natural cloud formation. This is because it tends to form cloud layers at the top and bottom of deep clouds that are seen in the other runs. These are never 'filled', so no deep cloud ever forms, and once created they tend to remain with little vertical variation until they evaporate. This cloud scheme tends to produce these empty clouds because it only allows three cloud layers and each only two levels deep. Thus you can see the low, middle and high cloud, such as near $\approx$ hour 360, but no deep clouds throughout the depth of the atmosphere. Note that cld93 is the cloud scheme used in the BAM physics for the operational Global ASsimilation and Prediction (GASP) system at the time of this Report.

The **cld98** run is an improvement on cld93 in that there are still low, middle and high cloud but now they vary vertically with time, and deep clouds are also forming. This scheme allows cloud to occur between the bottom and top of the convective tower. It can now be seen how cld93 created cloud at the top and bottom of the deep cloud, but never managed to create any deep cloud. One problem with cld98 is that once deep cloud forms, the middle of the cloud has a cloud fraction that is almost always 1.0, as was also found in cld93.

The **qcloudn** run is an improvement over cld98 in that the cloud fraction inside the penetrative clouds is not automatically set to 1, there is a gradual increase and then decrease in this parameter. It also differs from both cld93 and cld98 in having a lot less lower cloud.

The output from CCM shows a lot more low cloud and high cloud but very little middle cloud, while ECMWF shows more penetrative clouds which start at lower levels.

Figures 4 and 5 show similar plots but for the cloud liquid water mixing ratio ($g\,kg^{-1}$) and cloud ice water mixing ratio ($g\,kg^{-1}$), respectively. Note: these also have output from the CSIRO DAR SCM (referred to as DAR in the discussion below).

Figure 4 shows that the cloud liquid water mixing ratio (CLWMR) have similar differences between the runs as in the cloud fraction plots. Thus, cld93 is restricted in the vertical, has no penetrative regions and little vertical change in cloud structure. The low cloud always has high CLWMR, and a sudden jump to/from large CLWMR values at its bottom and top, while the middle cloud varies a great deal. The penetrative cloud in cld98 always has high cloud liquid water mixing ratios except for the cloud top and the bottom of the middle level cloud. qcloudn has much more penetrative cloud and less of a step-function change at the cloud base. These step-function changes are far less dramatic in the output from BAMSCM using CCM3 physics, ECMWF SCM and the CSIRO DAR SCM runs. The maximum height for the CLWMR is ≈400 hPa for the cld93, cld98 and DAR runs but this is raised to ≈300 hPa for the qcloudn, CCM and ECMWF cases.

Figure 5 shows that the cloud ice water mixing ratio (CIWMR) all form below ≈100 hPa and above ≈600 hPa, except CCM which forms above ≈400 hPa. The maximum CIWMR is centred near ≈450 hPa for the cld93 and cld98 cases but extends much higher in qcloudn, ECMWF and DAR cases, while CCM is much weaker and centred on ≈300 hPa. The step-function changes in the vertical seen in the CLWMR are not present for the CIWMR field.

This experiment demonstrates how the various cloud schemes can be compared within the BAMSCM and how very different the resulting clouds appear.

5 Conclusions

The BAM single column model BAMSCM has been created by incorporating the physics from the three-dimensional BAM model into the NCAR Single-column Community Model. The BAMSCM can be used in developing, testing and tuning new BAM physics parameterization schemes and examining physical processes that are simulated within BAM. These experiments can be completed much more quickly and using fewer resources than in the full three-dimensional model, and can be run on both Unix and Linux platforms.

The development of the BAMSCM and details of its structure have been described in this paper while instructions on how to obtain and operate the model have also been provided. The BAMSCM has also been demonstrated here by examining the various cloud schemes available in BAM and showing that the most realistic of these is the **qcloudn** prognostic cloud scheme.

As new BAM physics packages are developed, corresponding BAMSCM versions will also be released which incorporate these upgrades.

Appendix: BAMSCM Linux setup

All of the details of the BAMSCM model in this report are still relevant for the Linux version except for the original obtaining and setting-up of the model. The steps to obtain, setup and run the linux version of BAMSCM v2 are listed below.

```
-get bamscm tar files and extract files from them:
 cd /home/glr/linux_test == your bamscm directory
 rcp sam1:/samcrc/gen/glr/SCM/tar/05apr04_bam4.0scm_linux.tar .
 tar -xvf 05apr04_bam4.0scm_linux.tar
 \rm 05apr04_bam4.0scm_linux.tar
 mkdir data
 cd /home/glr/linux_test/data
 rcp sam1:/samcrc/gen/glr/SCM/tar/05apr04_bam4.0scm_linux_data.tar .
 tar -xvf  05apr04_bam4.0scm_linux_data.tar
 \rm 05apr04_bam4.0scm_linux_data.tar
-change home dir to your own in sccm-1.2/mymods files:
 replace dir '/home/glr/scmdir2' with your dir eg '/home/glr/linux_test'
```

```
  in files

  ncar_linuxL30_oldf90.csh   obj_config.outL30_oldf90

  bam4.0scm_linuxL30.csh     obj_config.outL30_bamf90

  via:


    cd /home/glr/linux_test/sccm-1.2/mymods

sed s?/home/glr/scmdir2?/home/glr/linux_test?g obj_config.outL30_oldf90 >a

mv a obj_config.outL30_oldf90

sed s?/home/glr/scmdir2?/home/glr/linux_test?g obj_config.outL30_bamf90 >a

mv a obj_config.outL30_bamf90

sed s?/home/glr/scmdir2?/home/glr/linux_test?g ncar_linuxL30_oldf90.csh >a

mv a ncar_linuxL30_oldf90.csh

sed s?/home/glr/scmdir2?/home/glr/linux_test?g bam4.0scm_linuxL30.csh >a

mv a bam4.0scm_linuxL30.csh


  and get data in right spot:


sed s?/home/glr/data?/home/glr/linux_test/data?g ncar_linuxL30_oldf90.csh >a

mv a ncar_linuxL30_oldf90.csh

sed s?/home/glr/data?/home/glr/linux_test/data?g bam4.0scm_linuxL30.csh >a

mv a bam4.0scm_linuxL30.csh


  note: the *config* files are where the f90 type, netcdf root, number of

  vertical levels etc are set.


 -now, create the bamscm executable:

  chmod a+rwx ncar_linuxL30_oldf90.csh bam4.0scm_linuxL30.csh

  ncar_linuxL30_oldf90.csh

  bam4.0scm_linuxL30.csh
```

```
-now run bamscm v2
  cd /home/glr/linux_test/sccm-1.2
  sccm
```

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Acknowledgements

I would like to thank the members of the BMRC Model Development and Data Assimilation Groups, in particular Ilia Bermous and Mike Naughton, for their help in pointing me in the right direction when this project hit some difficult programming obstacles. I would also like to thank: NCAR for providing the SCCM; Christian Jakob and Leon Rotstayn for providing the ECMWF SCM and DAR SCM output, respectively; Kamal Puri and Lawrie Rikus for their encouragement in developing BAMSCM; and Lilia Deschamps, Tim Hume and Mike Naughton for their input to improving this paper.

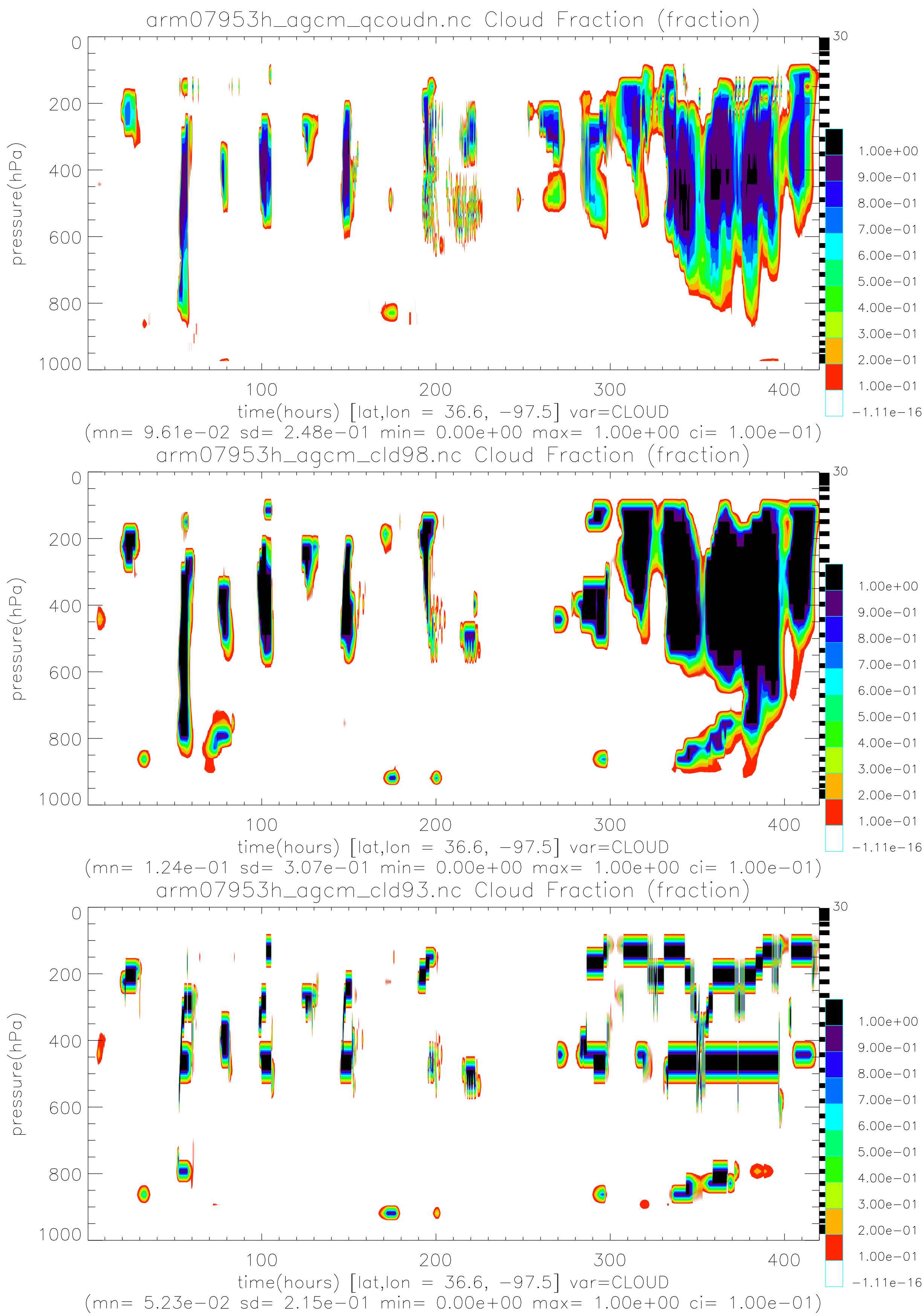

Figure 3: (a) BAMSCM cloud fraction for ARM SGP IOP from July 18 to August 4 1995 for BAM physics using ECMWF land surface scheme with the cloud schemes: (top) qcloudn; (middle) cld98; and, (bottom) cld93. See the text for the plot description.

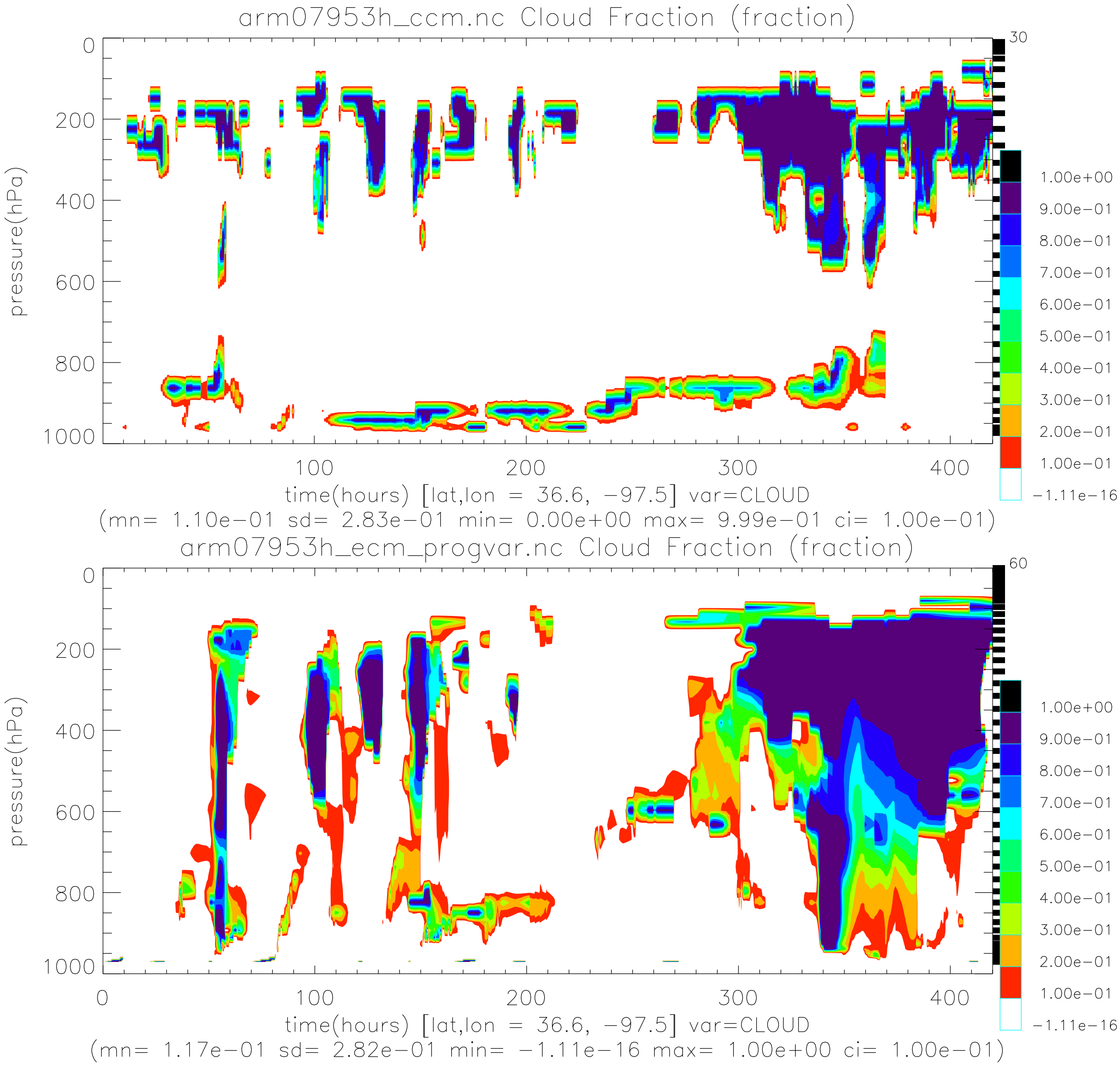

Figure 3: (b) As in (a) but for output from: (top) the BAMSCM using CCM3 physics and (bottom) the ECMWF SCM.

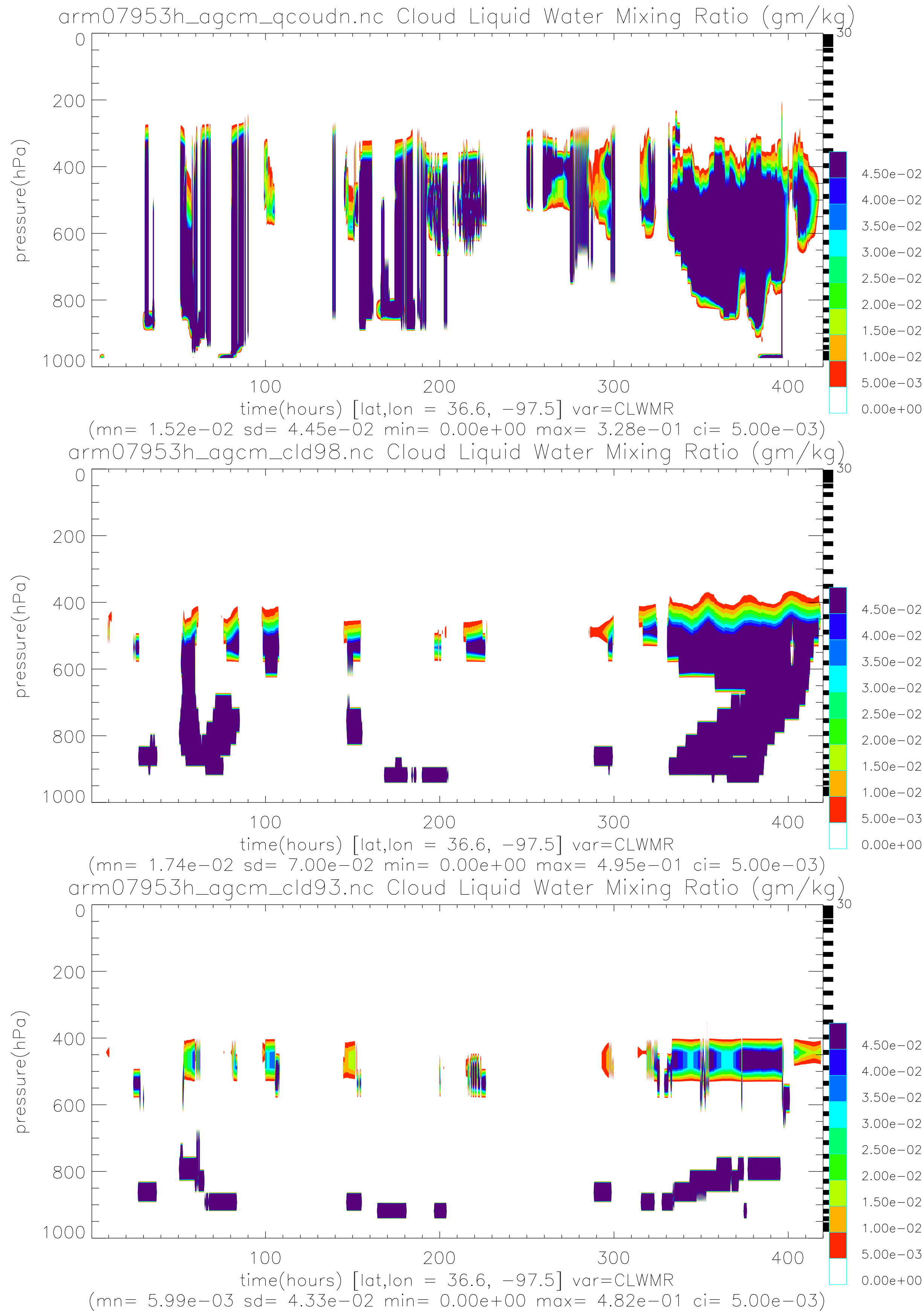

Figure 4: (a) As in Figure 3(a) but for the cloud liquid water mixing ratio ($g\,kg^{-1}$).

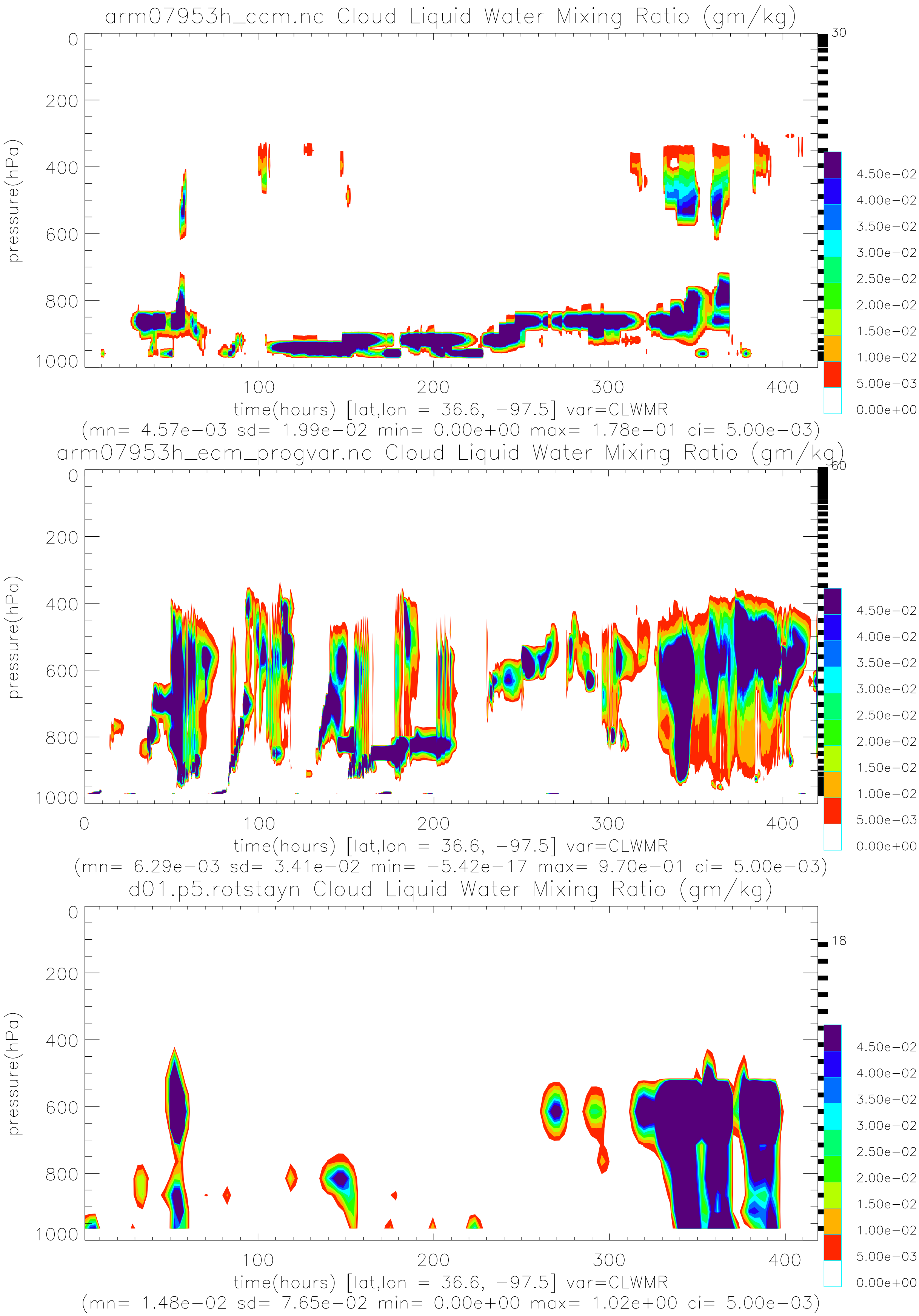

Figure 4: (b) As in (a) but for output from: (top) the BAMSCM using CCM3 physics; (middle) the ECMWF SCM; and, (bottom) the CSIRO DAR SCM.

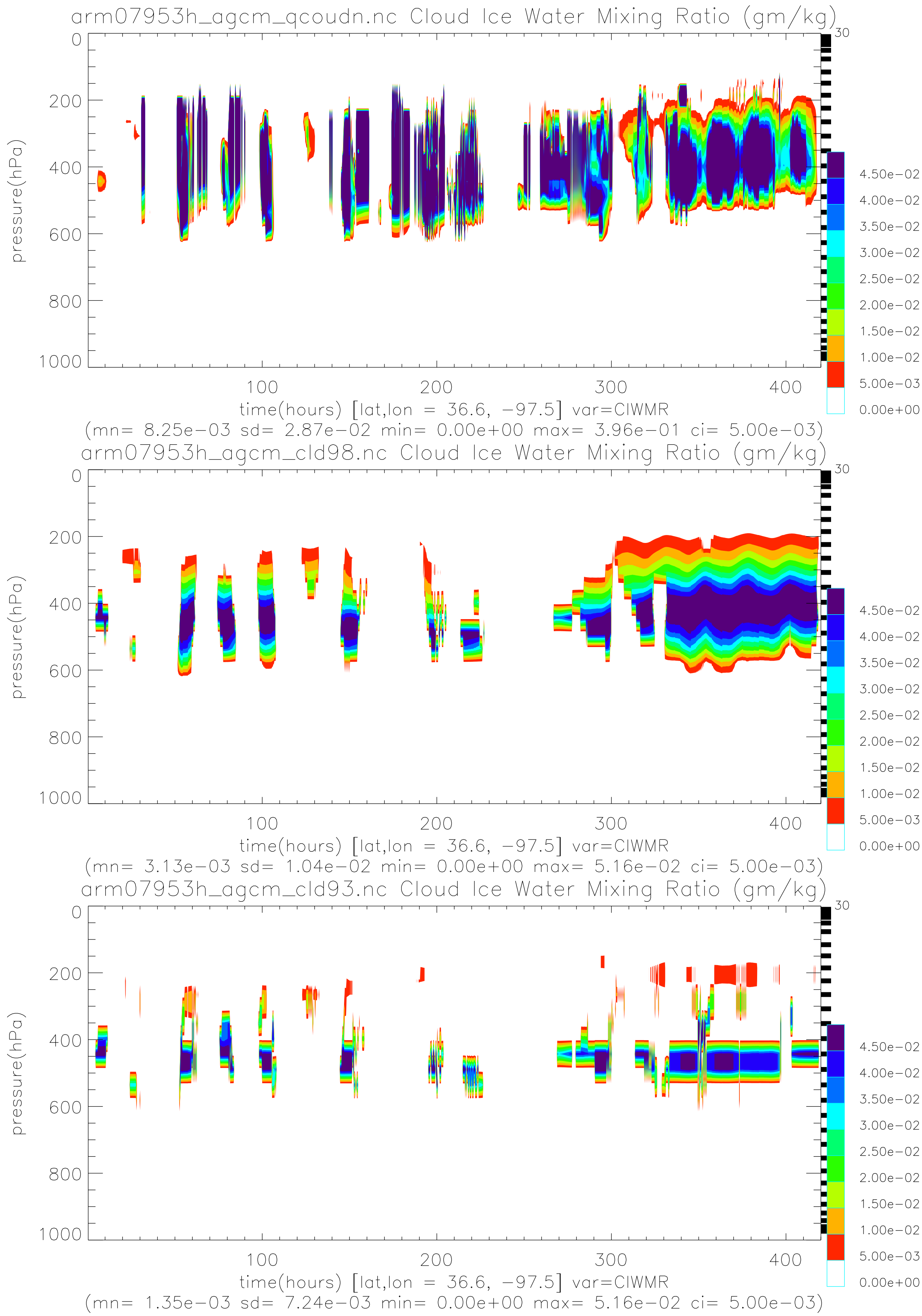

Figure 5: (a) As in Figure 3(a) but for the cloud liquid water mixing ratio ($g\,kg^{-1}$).

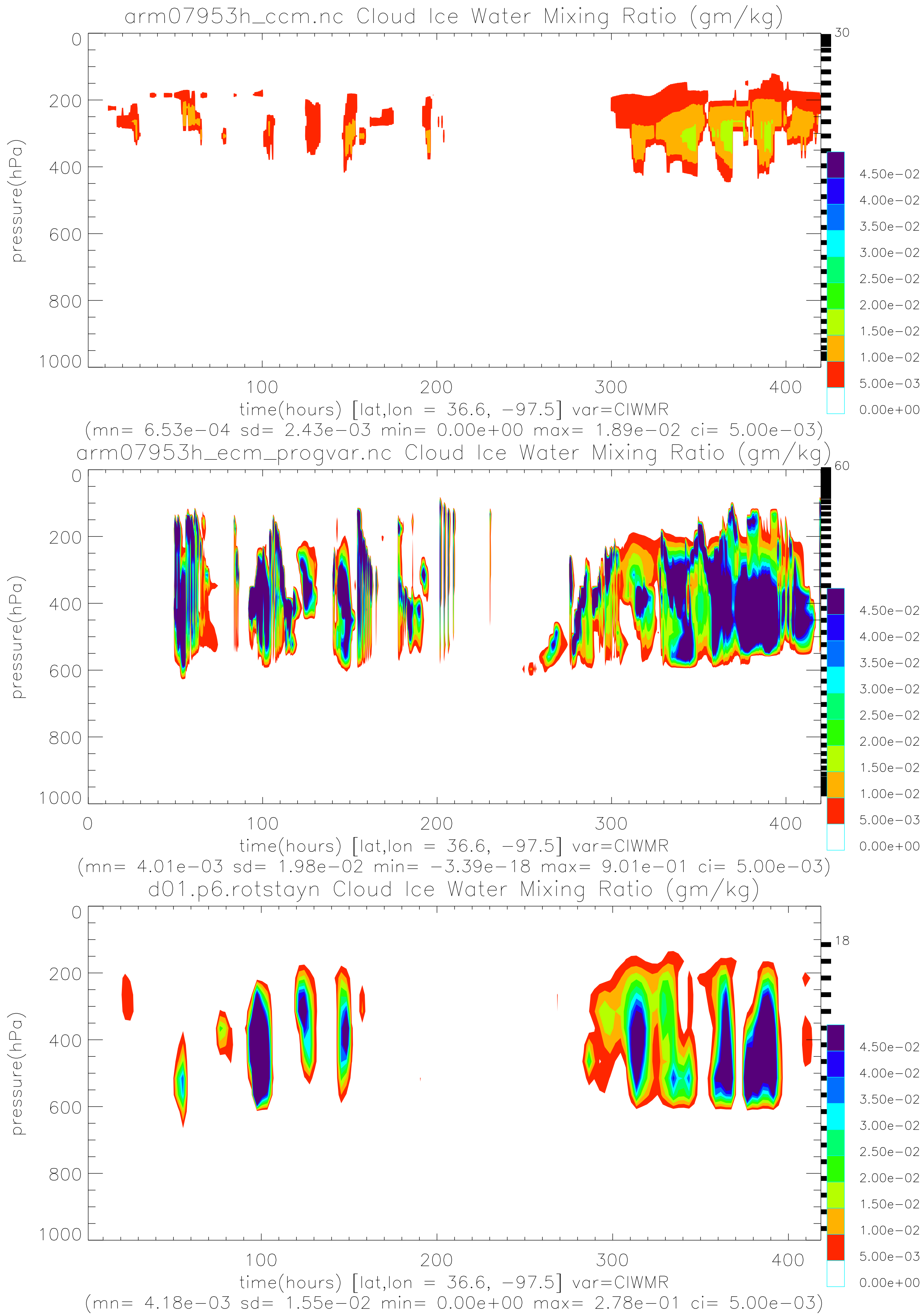

Figure 5: (b) As in (a) but for output from: (top) the BAMSCM using CCM3 physics; (middle) the ECMWF SCM; and, (bottom) the CSIRO DAR SCM.