Model Information of Potential Use to the IPCC Lead Authors and the AR4.

UKMO-HadGEM1

29 July 2006

I. Model identity:

A. Institution, sponsoring agency, country
Hadley Centre for Climate Prediction and Research
Met Office
United Kingdom

B. Model name (and names of component atmospheric, ocean, sea ice, etc. models)
- Coupled model - Hadley Centre Global Environmental Model, version 1 ("HadGEM1")
- Atmosphere - Atmosphere component of HadGEM1 ("HadGAM1"; includes land and river routing components)
- Ocean - Ocean component of HadGEM1 ("HadGOM1"; includes sea ice component)
- Sea ice - Sea ice component of HadGEM1 ("HadGOM1"; part of)
- Land - Met Office Surface Exchange Scheme, version 2 ("MOSES-2")
- River routing - Total Runoff Integrating Pathways ("TRIP")

C. Vintage (i.e., year that model version was first used in a published application)
2006

D. General published references and web pages

T. C. Johns, C. F. Durman, H. T. Banks, M. J. Roberts, A. J. McLaren, J. K. Ridley, C. A. Senior, K. D. Williams, A. Jones, G. J. Rickard, S. Cusack, W. J. Ingram, M. Crucifix, D. M. H. Sexton, M. M. Joshi, B-W. Dong, H. Spencer, R. S. R. Hill, J. M. Gregory, A.B. Keen, A. K. Pardaens, J. A. Lowe, A. Bodas-Salcedo, S. Stark, and Y. Searl: The new Hadley Centre climate model HadGEM1: Evaluation of coupled simulations, J. Climate, Vol. 19, No. 7, pages 1327-1353, 2006

G.M. Martin, M.A. Ringer, V.D. Pope, A. Jones, C. Dearden and T.J. Hinton: The physical properties of the atmosphere in the new Hadley Centre Global Environmental Model, HadGEM1. Part 1: Model description and global climatology , J. Climate, Vol. 19, No. 7, pages 1274-1301, 2006

M.A. Ringer, G.M. Martin, C.Z. Greeves, T.J. Hinton, P.M. James, V.D. Pope, A.A. Scaife, R.A. Stratton, P.M. Inness, J.M. Slingo, and G.-Y. Yang, 2006: The physical properties of the atmosphere in the new Hadley Centre Global Environmental Model, HadGEM1. Part 2: Aspects of variability and regional climate - J. Climate, Vol. 19, No. 7, pages 1302-1326.

Paper describing transient experiments: Stott, P. A. and G. S. Jones, J. A. Lowe, P. W. Thorne, C. F. Durman, T. C. Johns, J.-C. Thelen, 2006, Transient climate simulations with the HadGEM1 climate model: Causes of past warming and future climate change, J. Climate, Vol. 19, No. 12, pages 2763–2782.

Sea-ice : A. J. McLaren, H. T. Banks, C. F. Durman, J. M. Gregory, T. C. Johns, A. B. Keen, J. K. Ridley, M. J. Roberts, W. H. Lipscomb, W. M. Connolley and S. W. Laxon, 2006: Evaluation of the sea ice simulation in a new coupled atmosphere-ocean climate model, accepted for publication in J. Geoph. Res. Oceans

note : subsequently given references are taken from the above papers. See also:
http://www.metoffice.gov.uk/research/hadleycentre/pubs/HCTN/HCTN_54.pdf
http://www.metoffice.gov.uk/research/hadleycentre/pubs/HCTN/HCTN_55.pdf

E. References that document changes over the last ~5 years (i.e., since the IPCC TAR) in the coupled model or its components. We are specifically looking for references that document changes in some aspect(s) of model performance.

F. IPCC model version's global climate sensitivity ($KW^{-1}m^2$) to increase in CO_2 and how it was determined (slab ocean expt., transient expt--Gregory method, ±2K Cess expt., etc.)
4.4 K / (3.83 W/m2) = 1.15 KW-1m2, from a slab ocean experiment ("HadGSM1")
2.8 K / (3.83 W/m2) = 0.73 KW-2m2, effective climate sensitivity from transient 1%-per-annum HadGEM1 CMIP experiment at CO2 doubling (20 year mean)

G. Contacts (name and email addresses), as appropriate, for:
   1. coupled model tim.johns@metoffice.gov.uk
   2. atmosphere gill.martin@metoffice.gov.uk
   3. ocean helene.banks@metoffice.gov.uk
   4. sea ice helene.banks@metoffice.gov.uk
   5. land surface richard.betts@metoffice.gov.uk
   6. vegetation richard.betts@metoffice.gov.uk
   7. scenarios jason.lowe@metoffice.gov.uk, peter.stott@metoffice.gov.uk ; gareth.jones@metoffice.gov.uk

II. Besides atmosphere, ocean, sea ice, and prescription of land/vegetated surface, what can be included (interactively) and was it active in the model version that produced output stored in the PCMDI database?

A. atmospheric chemistry?
YES (production of sulfate aerosols on the basis of SO_2 and DMS emissions; oxidants concentrations provided by running the STOCHEM model offline)

B. interactive biogeochemistry? NO

C. what aerosols and are indirect effects modeled? sulphate (Aitken, accumulation and dissolved modes) with wet and dry removal processes, sea salt, black carbon and biomass-burning aerosol schemes. Roberts and Jones, 2004; Woodage et al., 2003). All aerosols species have direct and "semi-direct" radiative effects. All aerosols species but black carbon contribute to the first and second indirect effects on clouds (modifying cloud albedo and precipitation efficiency, respectively). Cf. Jones et al., 2001.

D. dynamic vegetation? NO

E. ice-sheets? NO (ice sheets and glaciers are specified, but there are no dynamic ice sheets)

III. List the community based projects (e.g., AMIP, C4MIP, PMIP, PILPS, etc.) that your modeling group has participated in and indicate if your model results from each project should carry over to the current (IPCC) version of your model in the PCMDI database.

AMIP2: yes, compatible HadGAM1 run(s) submitted to PCMDI

CMIP2: yes, compatible HadGEM1 run(s) submitted to PCMDI
CFMIP: yes
THCMIP: yes (ongoing project)

IV. Component model characteristics (of current IPCC model version):

A. Atmosphere

1. resolution
   N96L38 : 1.25° latitude by 1.875° longitude with 38 layers in the vertical extending to over 39 km
2. numerical scheme/grid (advective and time-stepping schemes; model top; vertical coordinate and number of layers above 200 hPa and below 850 hPa)
   - non-hydrostatic, fully compressible
   - Numerical scheme - semi-Lagrangian transport of all prognostic variables except density
   - Grid - Arakawa C-grid horizontally, Charney-Phillips grid vertically
   - Time stepping - Predictor-corrector implementation of two time-level, semi-implicit integration scheme
   - Model top - 39254.8 m (3.1 hPa)
   - Vertical coordinate - generalized terrain-following height-based hybrid coordinate, 38 levels
   - Number of layers above 200 hPa - 14
   - Number of layers below 850 hPa - 8

3. list of prognostic variables (be sure to include, as appropriate, liquid water, chemical species, ice, etc.). Model output variable names are not needed, just a generic descriptive name (e.g., temperature, northward and eastward wind components, etc.)
   potential temperature, U-V-W velocity, surface pressure, dry density, specific humidity, liquid water content, liquid water potential temperature, convective cloud fraction and liquid water path, cloud liquid and frozen water, plus chemical tracers and aerosols (SO_2, DMS, SO_4 : Aitken, accumulation and dissolved models). Non-comprehensive list
4. Include, as appropriate, descriptions of name, terse descriptions, and references (journal articles, web pages) for all major parameterizations.
   (cf the Martin et al., 2006 paper for full references)
   a. clouds
      Diagnostic scheme with triangular probability function Smith (1990). Parameterized RH-crit, assuming a width of PDF dependent on local variability of temperature and moisture (Cusack et al., 1996, 1999b). Vertical gradient cloud scheme (Smith et al., 1999). Microphysics : mixed phase scheme including prognostic ice content; solves physical equations for microphysical processes using particle size information (Wilson and Ballard 1999)
   b. convection
      - Mass flux scheme based originally on Gregory and Rowntree (1990), but with major modifications including convective momentum transport based on flux-gradient relationship, separate deep and shallow schemes, and inclusion of a simple radiative representation of anvils:

- Deep convection
  Explicitly coupled to boundary layer
  CAPE closure based on Fritsch and Chappell (1980a,b)
- Shallow convection:
  Closure based on Grant (2001)
  Entrainment/detrainment rates as in Grant and Brown (1999)
- Convective anvils:
  Radiative effect represented via a vertically varying convective amount,
Gregory (1999)

c. boundary layer
   Lock et al. 2000
d. SW, LW radiation
   Edwards and Slingo (1996). Six spectral band in the shortwave and eight in the longwave. Cusack et al. (1999a) for gaseous absorption.
e. any special handling of wind and temperature at top of model

B. Ocean
   references are taken from the Johns et al., 2006 paper
   1. resolution
      1^o in longitude. 1^o in latitude between the poles and 30^o latitude, from which it increases smoothly to $1/3^o$ at the equator, giving 360 x 216 grid points in total. 40 levels in the vertical
   2. numerical scheme/grid, including advection scheme, time-stepping scheme, vertical coordinate, free surface or rigid lid, virtual salt flux or freshwater flux
      Brian-Cox code (Bryan 1969; Cox 1984) similar to the HadCM3 ocean (Gordon et al., 2000) but with free linaer surface and forth-order advection scheme (Paconowski and Griffies, 1998) with upwind at the bottom.
   3. list of prognostic variables and tracers
      Temperature, Salinity, U and V velocity, mixed-layer depth, turbulent kinetic energy,
   4. name, terse descriptions, and references (journal articles, web pages) for all parameterizations. Include, as appropriate, descriptions of:
      a. eddy parameterization
         Isopycnal diffusivity with constant value of 500 m^2s^{-1} using the Griffies et al., 1998 scheme. Adiabatic mixing scheme in skew flux form (Gent and McWilliams 1990, Griffies 1998) with spatially and temporally varying coefficient (Visbeck et al., 1997 ; Roberts 2004).
      b. bottom boundary layer treatment and/or sill overflow treatment
         semi-implicit representation of linear bottom friction.
      c. mixed-layer treatment
         Kraus-Turner 1967, and K-theory scheme (Pacanowski and Philander 1981) for momentum
      d. sunlight penetration
         two-band scheme (one more penetrative) assuming pure water type 1B (Paulson and Simpson, Journ. Phys. Ocean., 7, p. 952 (1977), with coefficients adjusted.
      e. tidal mixing
         no
      f. river mouth mixing

no: runoff added to P-E flux in the into top ocean layer.

g. mixing isolated seas with the ocean
Mediterranean water is partially mixed with Atlantic water across the Strait of Gibraltar (constant flux of 0.4 Sv over the top 80 m and out at 600m). The Red Sea has 0.2 Sv fluxed in over the top 20 m and out at 40-60m. The Persian Gulf has 0.1 Sv fluxed in over the top 20 m and out at 40-60 m.

h. treatment of North Pole "singularity" (filtering, pole rotation, artificial island?)
Polar island, and Fourier filtering North of 74.5^{o}N.

C. sea ice
main reference : A. McLaren et al.: Evaluation of the sea ice simulation in a new coupled atmosphere-ocean climate model (HadGEM1) – accepted for publication in J. Geoph. Res (Oceans)

1. horizontal resolution, number of layers, number of thickness categories
horizontal grid same as ocean component (nominally 1 degree, see ocean resolution). 1 layer in ice + 1 snow layer. 5 categories + open water (Bitz et al., 2001; Lipscomb 2001).
2. numerical scheme/grid, including advection scheme, time-stepping scheme,
   - Incremental remapping (Lipscomb and Hunke, Mon Wea. Rev, 132, 1341-1354, 2004)
   - ITD solved using linear remapping (Lipscomb, 2001)
   - Vertical heat equation solved using an implicit backwards-Euler space-centered scheme?
3. list of prognostic variables
   - For each gridcell : sea ice velocity; stress tensor components (not resolved across the thickness distribution)
   - For each gridcell and each ice category: sea ice concentration, sea ice volume, snow volume, surface temperature
   - For each ice category and each ice level: sea ice internal energy?
4. completeness (dynamics? rheology? leads? snow treatment on sea ice)
elastic-viscous-plastic (EVP) ice dynamics (Hunke and Dukowicz, 1997) with the CICE model ice ridging scheme (Hunke and Lipscomb 2004)
5. treatment of salinity in ice
Assume a constant salinity of 0.6 per mil.
6. brine rejection treatment
Sublimation increases ocean salinity, as the salt is assumed to blow into leads, and white ice formation reduces it to account for the salt added in converting snow to ice.
7. treatment of the North Pole "singularity" (filtering, pole rotation, artificial island?)
artificial polar island + Fourier filtering North of 74.5^{o}N

D. land / ice sheets (some of the following may be omitted if information is clearly included in cited references.
MOSES II land surface scheme see Cox et al., 1999 and Essery et al., 2003, given in the Johns et al. 2006 reference. Same resolution as atmospheric model.
resolution (tiling?), number of layers for heat and water
Up to nine tiles, representing different vegetation types + urban, water, snow and bare soil. 4 layers for heat and water

1. treatment of frozen soil and permafrost

Diagnostic treatment of frozen water fraction (subsurface temperature updated using a discretised from of the heat diffusion equation)

2. treatment of surface runoff and river routing scheme

Explicit, time-dependent river routing scheme based on TRIP (Oki and Sud 1998) including river transport dynamics operating on a 1^o x 1^o grid. Snow accumulation over glaciers and routing to inland lakes is lost to the system (see point E.4 below). Glaciers and inland lakes are assumed to be constant in time.

3. treatment of snow cover on land

Each of the eight non-ice tiles comprised in each grid box can be snow-covered, with its own snow amount. Tile-dependent parameterizations apply for albedo and roughness length. Snow surface albedo is assumed to vary from its snow-free value to its deep-snow (temperature dependent) value at large snow depth (the spectral-dependent albedo described in Essery 2003 is not enabled).

4. description of water storage model and drainage

   Water fluxes determined by Darcy law closed by Clapp and Hornberger relations. Excess water is drained (Cox et al., 1999)

5. surface albedo scheme

   all-band surface albedo. Prescribed snow-free albedo for each tile. Sea-surface albedo based on the functional form of Barker and Li (1995) (modified on the basis of aircraft data provided by J. Haywood)

6. vegetation treatment (canopy?)

   canopy conductance calculated for each tile on the basis of an diagnostic treatment of net primary productivity. Represents the bulk effect of stomatal openings on plan leaves and the gain of carbon dioxide through photosynthesis.

7. list of prognostic variables

   canopy water (on tiles), lying snow, total soil moisture and temperature on 4 layers

8. ice sheet characteristics (How are snow cover, ice melting, ice accumulation, ice dynamics handled? How are the heat and water fluxes handled when the ice sheet is melting?)

E. coupling details

1. frequency of coupling

   1-day

2. Are heat and water conserved by coupling scheme?

   Yes, using a coastal tiling scheme (an atmospheric grid point may encompass a land and an ocean fraction), but note bug in HadGEM1 (loss of some river outflow) cf. Johns et al., 2006,p. 1332, 1st column.

3. list of variables passed between components:

   a. atmosphere – ocean

      - wind stress, zonal and meridional components -> O
      - penetrative solar radiation -> O
      - non-penetrative net heat into the ocean -> O
      - precipitation minus evaporation -> O
      - snowfall -> O
      - sea ice sublimation -> O
      - sea ice (per category) top melting flux -> O
      - sea ice (per category) basal heat flux -> O
      - sea surface current, zonal and meridional components -> A

- sea surface temperature -> A

b. atmosphere – land : fluxes (heat, moisture, momentum), surface and air temperature, humidity, snow fraction

c. land – ocean : river discharge (daily average)

d. sea ice – ocean : heat flux, temperature, bottom and top melt, snow depth on ice, sea-ice concentration and depth (by ice category)

e. sea ice – atmosphere

- sea ice (per category) concentration -> A
- sea ice (per category) depth -> A
- snow depth on sea ice (per category) -> A

4. Flux adjustment? (heat?, water?, momentum?, annual?, monthly?). NO, but freshwater imbalance due to snow accumulating over ice sheets and routing to inland lakes are returned to ocean by an appropriate water flux over the areas of the adjacent oceans where icebergs occur. The largest local value of the iceberg term are about 0.15 mm.day-1, i.e., 5 % of the P-E term in the North Atlantic, and up to 20 % near the coast around Antarctica.

V. Simulation Details (report separately for each IPCC simulation contributed to database at PCMDI):

note : full references available in Stott et al., J. Clim. 2006.

A. IPCC "experiment" name
PIcntrl

B. Describe method used to obtain initial conditions for each component model

1. If initialized from a control run, which month/year.
2. For control runs, describe spin-up procedure.
Initialised directly from the Levitus observed ocean state (Levitus 1998) and sea-ice initialized from analyzed state corresponding to 1 September 1978.
and then 85 years of coupled spinup. First year uploaded to the database is "Dec. 1859".

C. For pre-industrial and present-day control runs, describe radiative forcing agents (e.g., non-anthropogenic aerosols, solar variability) present. Provide references or web pages containing further information as to the distribution and temporal changes in these agents.
forcings representative of year 1860 for GHG, aerosol precursor emissions (SO_2, DMS sea-salt and soot), ozone and land-surface. See Stott et al., 2006 for full references.
TSI : 1365 W/m2 (constant)
CO_2 : 286.2 ppmv; CH_4 = 805.5 ppbv ; N_2O = 286.2 ppbv, CFCs = 0.

D. For perturbation runs, describe radiative forcing agents (e.g., which greenhouse gases, which aerosols, ozone, land surface changes, etc.) present. Provide references or web pages containing further information as to the distribution and temporal changes in these agents.

A. IPCC "experiment" name
1%to2x

B. Describe method used to obtain initial conditions for each component model
   Run 1 : Initial conditions as is PInctrl
   Run 2 : branches on run 70 of Run 1
C. For pre-industrial and present-day control runs, describe radiative forcing agents (e.g., non-anthropogenic aerosols, solar variability) present. Provide references or web pages containing further information as to the distribution and temporal changes in these agents.
D. For perturbation runs, describe radiative forcing agents (e.g., which greenhouse gases, which aerosols, ozone, land surface changes, etc.) present. Provide references or web pages containing further information as to the distribution and temporal changes in these agents
   Run 1 : CO2 increased by 1% compound during 80 years. All others as in PInctrl.
   Run 2 : Branches on year 70 of run 1 and keeps the forcing constant.

A. IPCC "experiment" name
   1%to4x
B. Describe method used to obtain initial conditions for each component model
   Run 1 : Initial conditions as is PInctrl
C. For pre-industrial and present-day control runs, describe radiative forcing agents (e.g., non-anthropogenic aerosols, solar variability) present. Provide references or web pages containing further information as to the distribution and temporal changes in these agents.
D. For perturbation runs, describe radiative forcing agents (e.g., which greenhouse gases, which aerosols, ozone, land surface changes, etc.) present. Provide references or web pages containing further information as to the distribution and temporal changes in these agents
   Run 1 : CO2 increased by 1% compound during 140 years and then kept constant. All others as in PIcntrl.

A. IPCC "experiment" name
   20C3M
B. Describe method used to obtain initial conditions for each component model
   Initial conditions as in PIcntrl.

C. For pre-industrial and present-day control runs, describe radiative forcing agents (e.g., non-anthropogenic aerosols, solar variability) present. Provide references or web pages containing further information as to the distribution and temporal changes in these agents.

D. For perturbation runs, describe radiative forcing agents (e.g., which greenhouse gases, which aerosols, ozone, land surface changes, etc.) present. Provide references or web pages containing further information as to the distribution and temporal changes in these agents.
   run1 : anthropogenic forcing. Greenhouse gases : historic reconstructions followed by concentrations as tabulated on the ENSEMBLES RT2A website : http://www.cnrm.meteo.fr/ensembles; Ozone : SPARC dataset (Randel and Wu (1999), Randel et al (2003); Kiehl et al (1999) . Natural emissions form DMS (time independent) [Kettle et al. 1999], Jones and Roberts (2004), Andres and Kasgnoc (1998). Anthropogenic emissions by Smith, Pacific Northwestern National Laboratory, USA (pers. comm.). Fossil fuel black carbon and biomass smoke : provided by T. Nozawa,

National Institute for Environmental Studies, Japan (pers. comm..). Land use changes following Goldewijk (2001).
run2 : as run 1 + natural forcings : SO2 emissions by volcanoes (following a recently updated version of Sota et al. 1993, from http://www.giss.nasa.gov/data/strataer/). Solar variations following Solanki and Krivova (2003).

A. IPCC "experiment" name
   SRESA1B
B. Describe method used to obtain initial conditions for each component model
   Branches on year Dec1999 of 20C3M, run 1
C. For pre-industrial and present-day control runs, describe radiative forcing agents (e.g., non-anthropogenic aerosols, solar variability) present. Provide references or web pages containing further information as to the distribution and temporal changes in these agents.

D. For perturbation runs, describe radiative forcing agents (e.g., which greenhouse gases, which aerosols, ozone, land surface changes, etc.) present. Provide references or web pages containing further information as to the distribution and temporal changes in these agents

   emissions and concentrations following the SRES A1B scenario (Nakicenovic and Swart, 2000). The SRES A1B simulation was extended beyond 2100 by fixing the annual concentration of long lived greenhouse gases and the emissions of short lived aerosols species, although the seasonally varying quantities had their seasonal cycles preserved. Ozone trends derived from calculations of the off-line STOCHEM chemistry transport model (Collins et al., 1997)

E. IPCC "experiment" name
   SRESA2
F. Describe method used to obtain initial conditions for each component model
   Branches on year Dec1999 of 20C3M, run 1
G. For pre-industrial and present-day control runs, describe radiative forcing agents (e.g., non-anthropogenic aerosols, solar variability) present. Provide references or web pages containing further information as to the distribution and temporal changes in these agents.

H. For perturbation runs, describe radiative forcing agents (e.g., which greenhouse gases, which aerosols, ozone, land surface changes, etc.) present. Provide references or web pages containing further information as to the distribution and temporal changes in these agents

   emissions and concentrations following the SRES A2 scenario (Nakicenovic and Swart, 2000). The SRES A2 simulation was extended beyond 2100 by fixing the annual concentration of long lived greenhouse gases and the emissions of short lived aerosols species, although the seasonally varying quantities had their seasonal cycles preserved. Ozone trends derived from calculations of the off-line STOCHEM chemistry transport model (Collins et al., 1997)