UK/Korea modelling for CMIP6

Catherine Senior

WGCM-20, October 10th 2017
# HadGEM3 & UKESM1

<table>
<thead>
<tr>
<th></th>
<th>Physical climate model</th>
<th>Earth system model</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CMIP5</strong></td>
<td>HadGEM2-AO</td>
<td>HadGEM2-ES</td>
</tr>
<tr>
<td></td>
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<tr>
<td><strong>CMIP6</strong></td>
<td>HadGEM3-GC31-LL</td>
<td>UKESM1-0-LL</td>
</tr>
<tr>
<td></td>
<td>HadGEM3-GC31-MM</td>
<td>Jointly developed by UK Met Office &amp; UK universities</td>
</tr>
<tr>
<td>Developed by UK Met Office (with input from UM partners &amp; UK universities)</td>
<td></td>
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</tr>
</tbody>
</table>

Developed by UK Met Office (with input from UM partners & UK universities)
Physical Model development: HadGEM3-GC3.1

Global Atmosphere and Land (GA-7.1/GL-7)
- GA6 (Walters, 2016 - ENDGame dynamical core)
- Convection
  - improved numerics & vertical velocity dependent CAPE closure
- Radiation, Cloud, & Microphysics
  - improved treatment of gaseous absorption
  - McICA upgrades
  - convective cores seen by radiation
  - warm rain microphysics
  - forced" shallow cumulus
  - new ice optical properties and realistic ice PSD
  - turbulent production of liquid water
  - revised cloud top entrainment
  - new variable RHcrit for cloud formation
- New unified stochastic physics scheme
- UKCA-MODE aerosol scheme with offline oxidants
- Multi-layer snow scheme into JULES

These changes all relative to HadGEM3-GC2 (Williams et. al. (2015); Senior et. al. (2016)).

Completely new relative to HadGEM2 used for CMIP5 (new dynamical core for the atmosphere, new NEMO ocean, new CICE sea-ice model, and new land surface model JULES)

Global Ocean (GO-6)
- non-linear free surface,
- Lagrangian icebergs
- extended grid around Antarctica
- ice shelf scheme
- revised ocean mixing

Global Sea-Ice (GSI8)
- multi-layer thermodynamic sea-ice
- Improved representation of melt-ponds,
Earth System Model Development
UKESM1 (compared to HadGEM2-ES)

• Terrestrial carbon-nitrogen cycle
  – TRIFFID vegetation dynamics (9 plant functional types), RothC soil carbon, simple N-limitation scheme (Wiltshire, in prep.)

• Ocean BGC
  – MEDUSA2 intermediate complexity plankton ecosystem model, inc. prognostic diatoms/non-diatoms with variable C:N (Yool 2013)

• Aerosols
  – UKCA-GLOMAP-mode, 2-moment, 5-mode aerosol scheme (Mann 2014)

• Chemistry
  – UKCA stratospheric-tropospheric chem w/ isoprene chemistry (Morgenstern 2009, O’Connor 2014)

• Ice sheets
  – BISICLES land ice model (Cornforth 2013) over Antarctica and Greenland (active in ISMIP only)
Model Configurations for CMIP6

- **Physical model configurations:**
  HadGEM3-GC3.1=GC3.0(GA7+GL7+GO6+GSI8) + …
  - HadGEM3-GC3.1-N96ORCA1 (HadGEM3-GC31-LL)
  - HadGEM3-GC3.1-N216ORCA025 (HadGEM3-GC31-MM)

- **ESM configurations:**
  UKESM1=HadGEM3-GC3.1 + UKCA, GLOMAP-mode, JULES-CN, TRIFFID, MEDUSA2, BISCICLES
  - UKESM1.0-N96ORCA1 (UKESM-1-0-LL)
  - UKESM1.0-N216ORCA025hybrid atmospheric chemistry, ocean BGC at degraded resolution
    - under development
CMIP6 forcing data

- **Input4MIPs**
  - a standardised approach to version control is a good thing
  - cf. previous distributed approach from independent suppliers
- **Delays**
  - make it harder to plan experiments & plan effort for processing and testing
  - very little communication on slipping timeline
- **Quality control**
  - many forcing datasets released before papers published
    - Seems risky
    - Should CMIP forcings be “cutting-edge”?
- **Volcanic bug fix (v6.2.0)**
  - impact on PI is not quite as small as promised
    - (we are still exploring this)
- **Replication**
  - 29 files don’t get replicated to UK ESGF node
    - Incompatibility between file contents and ESGF/synda?
PI Spinup (black) and Control (red)

GC3.1 N216/ORCA026

- Spinup from 1970s ocean state
- Model error corrected at year 2019
Data submission/ ES-Doc

- We don’t deliver our data directly
  - but pass it to CEDA for publication on ESGF
- Monthly & daily data from DECK+hist
  - ready by Nov 2018, published to ESGF by Jan 2019
  - Sub-daily data due to follow 3 months later
- Data from earlier runs could be ready earlier
- Data from MIP experiments
  - second half of 2018?
- Questionnaire not released yet (scheduled for end 2017?)
- We’re generating the ES-DOC directly from our metadata system
- Verified our process by documenting NEMO
  - using draft specifications
  - was more efficient than for CMIP5
- Documenting other components to start soon
  - still using draft specifications
  - followed by update once they’re finalized
MIP Experiments

• HadGEM3-GC3.1-N96ORCA1
  • CFMIP, FAFMIP, RFMIP, DAMIP

• HadGEM3-GC3.1-N216ORCA025:
  • DCPP, GMMIP, HighResMIP, OMIP (physics runs only)

• UKESM1.0-N96ORCA1:
  • AerChemMIP*, C4MIP, GeoMIP, ISMIP6, LUMIP, ScenarioMIP, VolMIP, OMIP (physics + biogeochemistry)

• UKESM1.0-N216ORCA025hybrid:
  • repeat experiments for a number of selected MIPs

* Jointly with KMA and NIWA runs
Timeline 1: spinup & DECK

- Pre-industrial control
  - AMIP, 4xCO2, 1%CO2, historical
    - AMIP, 4xCO2, 1%CO2, pre-industrial control, historical
      - UKESM1.0-N96ORCA1
      - HadGEM3-GC3.1-N96ORCA1
      - HadGEM3-GC3.1-N216ORCA025

2017 - 2018

13 June, 2017
Timeline 2: MIPs

ScenarioMIP, C4MIP, AerChemMIP, GeoMIP, LUMIP

Repeat of some simulations with UKESM1-N216ORCA025hybrid

CFMIP, DAMIP, RFMIP, DCPP

LUMIP Tier2, GeoMIP Tier2

50% of RFMIP Tier2

50% of DCPP
# KMA’s CMIP6 Participation (I)

## Global model

<table>
<thead>
<tr>
<th>Model</th>
<th>K-ACE</th>
<th>UKESM (KMA run under collaboration with UKMO)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brief Description</td>
<td>K-ACE for CMIP6 = GA7.1 + GL7 + MOM4-SiS + OASIS-MCT compared to UKESM</td>
<td>UKESM for CMIP6 = GA7.1 + GL7 + GO6-GSI7 + OASIS-MCT + ES modules</td>
</tr>
<tr>
<td></td>
<td>* Used HadGEM2-AO in CMIP5</td>
<td>* Same configuration as UKMO</td>
</tr>
<tr>
<td>Simulations (MIPs)</td>
<td>DECK, HIST, ScenarioMIP</td>
<td>HIST, ScenarioMIP, AerChemMIP, C4MIP</td>
</tr>
<tr>
<td>Current Progress</td>
<td>Freezing K-ACE and testing DECK run (pi-Control &amp; AMIP with CMIP6 forcing)</td>
<td>Implementation of UKESM newest version and consistency check to UKMO results</td>
</tr>
<tr>
<td></td>
<td>DECK results from K-ACE are expected to be submitted in early next year</td>
<td></td>
</tr>
<tr>
<td>Plan of Data Submission</td>
<td>DECK &amp; HIST : ~2018 Other MIPs : ~2019</td>
<td>HIST : ~2018 Other MIPs : 2019</td>
</tr>
<tr>
<td>ES-Doc</td>
<td>Preparing</td>
<td>Preparing</td>
</tr>
</tbody>
</table>
## KMA’s CMIP6 Participation (II)

### Regional model

<table>
<thead>
<tr>
<th>Model</th>
<th>HadGEM3-RA</th>
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<tr>
<td>Brief Description</td>
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<tr>
<td>Simulations (MIPs)</td>
<td>CORDEX (East Asia domain)</td>
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<tr>
<td>Current Progress</td>
<td>According to CORDEX-II CORE project proposal, done with ERA-Interim forcing doing CMIP5-GCM forcing runs</td>
</tr>
<tr>
<td>Plan of Data Submis sion</td>
<td>2018~2019 (ESGF node for CORDEX-EA will be constructed from next year including improvement of web page of CORDEX-EA Data Center)</td>
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Regional model

- **Model**: HadGEM3-RA
- **Brief Description**: Same model as UKMO
- **Simulations (MIPs)**: CORDEX (East Asia domain)
- **Current Progress**: According to CORDEX-II CORE project proposal, done with ERA-Interim forcing doing CMIP5-GCM forcing runs
- **Plan of Data Submission**: 2018~2019 (ESGF node for CORDEX-EA will be constructed from next year including improvement of web page of CORDEX-EA Data Center)
**Overview**

- **SAM0-UNICON** is a CAM5/CESM1-based GCM with a new convection scheme (UNICON, Park 2014a,b) and the revised treatment of convective detrainment process (Park et al. 2017).
- **UNICON** (Unified Convection Scheme) replaces the CAM5’s deep and shallow convection schemes.
- Compared to CAM5, SAM0 substantially improved the simulations of MJO, diurnal cycle of precipitation and tropical cyclones with reasonable climatologies and ENSO.

**CMIP6 forcings**:

- SAM0 uses CMIP6-specified GHGs, solar irradiance, aerosol emission, volcanic aerosols, land state, ozone concentration and nitrogen deposition forcings and also SST and sea ice fraction for AMIP simulation.
- SAM0 ran successfully with the CMIP6 forcings. A test simulation in a pre-industrial configuration with CMIP6 forcings produced little cooler Earth (-0.3K for SST) than that with CMIP5 forcings.
- Production simulations will use the most recently released v6.2.0 CMIP6 forcing data set.

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<table>
<thead>
<tr>
<th></th>
<th>SAM0-UNICON</th>
<th>CAM5-CESM1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boundary Layer Turbulence</td>
<td>Bretherton-Park (09) UW Moist Turbulence</td>
<td>Same</td>
</tr>
<tr>
<td>Shallow Convection</td>
<td>Park (14) UNICON (A Unified Convection Scheme)</td>
<td>Park-Bretherton (09) UW Shallow Convection</td>
</tr>
<tr>
<td>Deep Convection</td>
<td>Park et al. (17)</td>
<td>Zhang-McFarlane Neale et al.(08)</td>
</tr>
<tr>
<td></td>
<td>Park-Bretherton-Rasch (14) Revised Cloud Macrophysics</td>
<td>Richter-Rasch (08)</td>
</tr>
<tr>
<td>Cloud Macrophysics</td>
<td>Morrison and Gettelman (08) Double Moment</td>
<td>Same</td>
</tr>
<tr>
<td>Stratiform Microphysics</td>
<td>RRTMG Iacono et.(08) / Mitchell (08)</td>
<td>Same</td>
</tr>
<tr>
<td>Aerosols</td>
<td>Modal Aerosol Model Liu &amp; Ghan (2009)</td>
<td>Same</td>
</tr>
</tbody>
</table>
**Progress**

- We are testing/tuning the pre-industrial coupled simulation with CMIP6 forcings to obtain reasonable global energy balance at the top of the atmosphere.
- We will start DECK simulations in early October 2017.
- Post processing for submission will be done simultaneously with the production simulation.

**ESGF submission**

- We will start to submit the output of DECK simulations to the ESGF in December 2017.
- We will start to submit the output of historical simulations to the ESGF in December 2017.
- We are also planning to participate in the Scenario-MIP. Submission will be made in early 2018.

**References**

- Impact of detrained cumulus on climate simulated by the Community Atmosphere Model Version 5 with a unified convection scheme. Sungsu Park et al.
UKESM1 components

Physical Model: HadGEM3-GC3

New ocean and sea-ice models (NEMO, CICE, Hewitt et al, 2011)
Enhanced vertical resolution: L85
ENDGame dynamical core (Wood et al 2014)
PC2 cloud scheme (Wilson et al, 2008)

Chemistry/Aerosols
UKCA full stratosphere–troposphere chemistry + GLOMAP-mode aerosols
* Simplified version of UKCA chemistry also available employing offline oxidants and full tropospheric sulfur cycle (full UKCA ~4.5 times UM cost, simplified scheme ~1.7 times UM)

Soil-Vegetation coupled Carbon-Nitrogen cycle
JULES+TRIFFID (dynamic vegetation) + soil/veg carbon-nitrogen + wetlands + diagnostic wildfires + some permafrost improvements

Ocean Biogeochemistry
MEDUSA2 within NEMO ocean model.

Interactive Land Ice sheets (Greenland and Antarctic)
BISICLES and ice shelf basal and cavity melt within NEMO-ORCA.

Coupler
OASIS3-MCT
Bias in cloud cover (against CALIPSO)

GA7p1-AMIP
Low-top cloud bias

GA7p1-AMIP
Mid-top cloud bias

GA7p1-AMIP
High-top cloud bias

HadGEM2-AMIP
Low-top cloud bias

HadGEM2-AMIP
Mid-top cloud bias

HadGEM2-AMIP
High-top cloud bias
Cloud simulation: comparison against satellite data over the tropics

ISCCP

CloudSat

CALIPSO

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# ENSO simulation

<table>
<thead>
<tr>
<th></th>
<th>Obs</th>
<th>HadGEM2</th>
<th>N96 ORCA025 100 yr</th>
<th>N216 ORCA025 100 yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nino3 standard deviation SST</td>
<td>0.79</td>
<td>0.86</td>
<td>0.71</td>
<td>0.82</td>
</tr>
<tr>
<td>Nino4 standard deviation SST</td>
<td>0.54</td>
<td>0.47</td>
<td>0.43</td>
<td>0.45</td>
</tr>
<tr>
<td>Nino3 SST power spectrum timescale (yrs)</td>
<td>3.5, 5.3</td>
<td>3.4, 6-8</td>
<td>3.4, 4.2, 6.2</td>
<td>2.7, 4.2</td>
</tr>
<tr>
<td>Ann. Mean Nino3 SST</td>
<td>25.9</td>
<td>25.2</td>
<td>26.5</td>
<td>26.4</td>
</tr>
<tr>
<td>Ann. Mean Nino4 TAUX</td>
<td>-0.029</td>
<td>-0.047</td>
<td>-0.037</td>
<td>-0.034</td>
</tr>
<tr>
<td>Nino4 standard deviation PPTN</td>
<td>2.7</td>
<td>1.9</td>
<td>2.1</td>
<td>2.4</td>
</tr>
</tbody>
</table>

![ENSO simulation maps](image1.png)

![ENSO simulation maps](image2.png)

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GA7 ERFs

<table>
<thead>
<tr>
<th>ERF (1850-2000)</th>
<th>HadGEM2-A</th>
<th>GA7 (GC3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerosols</td>
<td>-1.4 Wm$^{-2}$</td>
<td>-2.3 Wm$^{-2}$</td>
</tr>
<tr>
<td>Direct effect</td>
<td>-0.2 Wm$^{-2}$</td>
<td>-0.5 Wm$^{-2}$</td>
</tr>
<tr>
<td>Indirect effect</td>
<td>-1.3 Wm$^{-2}$</td>
<td>-1.8 Wm$^{-2}$</td>
</tr>
<tr>
<td>Total anthropogenic ERF</td>
<td>1.1 Wm$^{-2}$</td>
<td>0 Wm$^{-2}$</td>
</tr>
<tr>
<td>(aerosols, GHGs, ozone, land use*)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
HadGEM2-ES Historic runs

![Graph showing temperature trends over time](image)

- HadCRUT4
- Historical ensemble (CMIP5)
- Historical mean (CMIP5)
- Historical (HadGEM2-ES)
- Historical mean (HadGEM2-ES)

Tim Andrews
GC3.1 Model improvements

- Increase to black carbon refractive index (absorption component) from $1.75 - 0.044i$ to $1.85 - 0.71i$ in light of recent evidence (Bond and Bergstrom 2006; Bond et al., 2013).
- RADAER look-up-tables which store aerosol optical properties have been improved to better resolve absorption of solar absorption
- Correct an error in SO$_2$ emissions from continuously erupting volcanoes
- Increase marine emissions of DMS (x1.7) as a proxy for missing emissions of primary marine organic aerosol
Liu Spectral Dispersion

Parameterization of cloud droplet spectral dispersion:

\[ r_e = \sqrt[3]{\frac{3q_c\rho_a}{4\pi\rho_w kN_d}} \]

Currently \( k = 0.67 \) (land) and \( k = 0.80 \) (ocean) (following Martin et al. 1994)

Liu et al. (2008): \( \beta = 0.07 \cdot \left( \frac{L}{N_d} \right)^{-0.14} \) \( \beta = \text{Spectral shape parameter} \) and \( k = \beta^{-3} \)

Jane Mulcahy
## ERFs

<table>
<thead>
<tr>
<th>ERF (1850-2000)</th>
<th>HadGEM2-A</th>
<th>GA7.0</th>
<th>GA7.1</th>
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<tr>
<td>Aerosols</td>
<td>-1.4 Wm⁻²</td>
<td>-2.3 Wm⁻²</td>
<td>-1.4 Wm⁻²</td>
</tr>
<tr>
<td>of which: <strong>direct</strong> effect</td>
<td>-0.2 Wm⁻²</td>
<td>-0.5 Wm⁻²</td>
<td>-0.4 Wm⁻²</td>
</tr>
<tr>
<td><strong>indirect</strong> effect</td>
<td>-1.3 Wm⁻²</td>
<td>-1.8 Wm⁻²</td>
<td>-1.0 Wm⁻²</td>
</tr>
<tr>
<td><strong>Total anthropogenic ERF</strong></td>
<td>1.1 Wm⁻²</td>
<td>~0 Wm⁻²</td>
<td>~0.9 Wm⁻²</td>
</tr>
<tr>
<td>(aerosols, GHGs, ozone, land use*)</td>
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</tbody>
</table>

### Aerosol ERF:

**GA7**

![Image of aerosol ERF for GA7](image1)

**GA7.1**

![Image of aerosol ERF for GA7.1](image2)
GC3.1 Model improvements

- Increase to black carbon refractive index (absorption component) from 1.75 – 044i to 1.85 – 0.71i in light of recent evidence (Bond and Bergstrom 2006; Bond et al., 2013).
- RADAER look-up-tables which store aerosol optical properties have been improved to better resolve absorption of solar absorption
- Correct an error in SO\(_2\) emissions from continuously erupting volcanoes
- Increase marine emissions of DMS (x1.7) as a proxy for missing emissions of primary marine organic aerosol
- Thermal conductivity of snow on sea-ice reduced from 0.5 to 0.255 Wm\(^{-1}\)K\(^{-1}\)
- Ice-ocean drag co-efficient increased from 0.00536 to 0.01
Arctic Sea-ice thickness

Arctic ice volume

GC3.0: March

GC3.1: March

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Ann Keen
SSTs

HadGEM3-GC3 – ESA CCI SSTs

HadGEM3-GC3.1 – ESA CCI SSTs
HadGEM3-GC3.1-N96ORCA1

HadGEM3-GC3-N96O1 – ESA CCI SSTs

HadGEM3-GC3.1-N216O0.25 – ESA CCI SSTs

Timeseries of maximum Atlantic MOC (0-3000m)

ACC transport for years 1991-2045
UK-CMIP6 status

• Model details
  • changes since UK-CMIP5
• Forcing data experience
• First results
• Timetables for data submission
• ES-DOC questionnaire
HadGEM3

• New versions of components
  – ocean (NEMO), sea-ice (CICE), land surface (JULES)

• Prognostic cloud, condensate and rain

• New dynamical core (ENDGAME)

• Modal aerosol scheme (UKCA-GLOMAP-mode)

• Improved cloud & radiation performance

• Resolutions
  – 130 km atmos + 1 degree ocean (N96ORCA1)
  – 65 km atmos + 0.25 degree ocean (N216ORCA025)
First results

- HadGEM3-GC3.1 N216 piControl
  - started Sep 2017
  - completion in Jul 2018
- Other HadGEM3-GC3.1 runs to start soon once e.g. historical forcings are available
- HadGEM3-GC3.1 N96 piControl about to start after 490 years of CMIP6 spin-up and 750 years of CMIP5 spin-up
- UKESM1 carbon cycle uncoupled spin-up of ~5000 years