Atmospheric feedbacks in HadGEM3

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Jane Mulcahy, Tim Andrews, Keith Williams, Mark Ringer, Paul Field, and Gregory Elsaesser
EffCS, estimated using a Gregory plot and abrupt-4xCO2 experiments.

<table>
<thead>
<tr>
<th>Model</th>
<th>EffCS (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HadGEM2</td>
<td>4.4</td>
</tr>
<tr>
<td>HadGEM3-GC2.0</td>
<td>3.2</td>
</tr>
<tr>
<td>HadGEM3-GC3.1</td>
<td>5.5</td>
</tr>
</tbody>
</table>

Large fraction of EffCS increase between GC2.0 and GC3.1 driven by atmospheric feedbacks.

(Andrews et al, submitted)
Experimental design
Model changes between GA6 and GA7

- Implement new ice PSD
- Revised cloud top entrainment
- McICA upgrades
- Improved treatment of gaseous absorption
- New ice optical properties
- Convective cores
- Implement new warm rain microphysics scheme
- PC2 / Convection Coupling
- UKCA-MODE aerosols with offline oxidants
- Improved updraft numerics in the 6a convection scheme
- Include forced convective clouds
- CAPE closure for deep & mid-level convection dependent on large-scale vertical velocity
- Implement heating due to gravity-wave dissipation
- Replace fixed RH crit profile with a variable one
- Improvements to PC2 for high ice clouds (cirrus)
- Introduce standard GA stochastic physics settings
- Turbulent production of liquid water in mixed phase clouds
- New ancillary for topographic index data
- Retuning of low cloud
- Moisture advection: Hermite Cubic Vertical Interpolation and Priestley Conservation
- Minor bug-fix to methane oxidation scheme.
- Fix Raymond filtering in ENDGame global orography ancillaries.
- Retune the adaptive detrainment parameter (RDet) in response to the 6a convection scheme
- Priestley conservation of mass weighted potential temperature
- Switch on temporary logics not used in pre-GA7 science configurations.
- Reduce atmospheric solver tolerance.
- Generate Kettle (1999) DMS datasets through general regridding.
- Generate Reynolds SST ancils via general regridding.
- New land fraction files for coupled models for use with the GO6.0 grid.
- Fix bit-comparison issue with TRIP river routing in UM/JULES.
- Set reference height used in the ENDGame w-damping code to 85km rather than 80km in L85 runs.
- Retune cloud threshold for shear dominated BL in GA7.
- Non-orographic (USSP) GWD scheme launch factor tuning in response to GA7.0 changes
Package: collection of changes that are logically related.

Experiments:
• amip and amip-p4K
• 1979/01 – 1989/12 (11 yr) and 1979/01 – 2014/12 (36 yr)
• N96L85
• 30+ experiments
• 1000+ years of simulations

<table>
<thead>
<tr>
<th>Packages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Convection</td>
</tr>
<tr>
<td>Radiation</td>
</tr>
<tr>
<td>Microphysics and L-S precipitation</td>
</tr>
<tr>
<td>Cloud</td>
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<tr>
<td>Boundary layer</td>
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<tr>
<td>Dynamics</td>
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<tr>
<td>Gravity wave drag</td>
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<tr>
<td>Stochastic physics</td>
</tr>
<tr>
<td>Aerosols</td>
</tr>
<tr>
<td>Effective Radiative Forcing</td>
</tr>
<tr>
<td>Land surface</td>
</tr>
</tbody>
</table>
Package testing
Microphysics
  • New mixed-phase cloud scheme
  • Changes to warm rain microphysics
  • Upgrades to McICA

Aerosol + Erf
  • UKCA-MODE: new aerosol scheme
  • Scaling of DMS to account for marine organic
  • Cloud droplet spectral dispersion
  • Tuning of mixed-phase scheme
Controls of feedback differences
<table>
<thead>
<tr>
<th></th>
<th>clear scat</th>
<th>cloud</th>
<th>cloud amt</th>
<th>cloud scat</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>70°S - 30°S</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GA6.0</td>
<td>-0.14</td>
<td><strong>0.01</strong></td>
<td>0.68</td>
<td>-0.61</td>
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<tr>
<td>GA7.1</td>
<td>0.07</td>
<td>0.86</td>
<td><strong>0.24</strong></td>
<td>0.62</td>
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<tr>
<td>AerMic_On</td>
<td>0.08</td>
<td>0.73</td>
<td>0.15</td>
<td>0.60</td>
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<tr>
<td>Aer_On</td>
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<td>0.06</td>
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<tr>
<td>Mic_On</td>
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<td>0.11</td>
<td>0.22</td>
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<tr>
<td><strong>50°S - 30°S</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GA6.0</td>
<td>-0.07</td>
<td><strong>0.68</strong></td>
<td>0.97</td>
<td>-0.22</td>
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<tr>
<td>GA7.1</td>
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<td><strong>0.96</strong></td>
<td><strong>0.32</strong></td>
<td><strong>0.63</strong></td>
</tr>
<tr>
<td>AerMic_On</td>
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<td>0.89</td>
<td>0.22</td>
<td>0.69</td>
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<tr>
<td>Aer_On</td>
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<td>0.53</td>
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<td>0.46</td>
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<tr>
<td>Mic_On</td>
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<td>0.42</td>
<td>0.18</td>
<td><strong>0.25</strong></td>
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<tr>
<td><strong>70°S - 50°S</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GA6.0</td>
<td>-0.26</td>
<td><strong>-1.07</strong></td>
<td>0.23</td>
<td>-1.24</td>
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<tr>
<td>GA7.1</td>
<td>0.17</td>
<td><strong>0.79</strong></td>
<td><strong>0.13</strong></td>
<td><strong>0.66</strong></td>
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<tr>
<td>AerMic_On</td>
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<td>0.54</td>
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<tr>
<td>Aer_On</td>
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<td>0.31</td>
<td>0.02</td>
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<tr>
<td>Mic_On</td>
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<td>0.21</td>
<td>0.01</td>
<td><strong>0.21</strong></td>
</tr>
</tbody>
</table>

**APRP method**
*(Taylor et al., J Clim, 2007)*

- Contributions from amount and optical depth (1:2).
- Larger contribution from 30°S-50°S.
- CF feedback change much weaker in 50°S-70°S.
- Optical depth feedback changes partition quite similar in both regions. Mic_On slightly stronger in 50°S-70°S.
Separating $\Delta$LWP & $\Delta$Reff contributions

(b) 50°S - 70°S

Cloud albedo

-0.05  0.00  0.05  0.10

GA6.0 (0.426)  GA7.1 (0.518)  Mic_On (0.453)  Aer_On (0.475)  AerMic_On (0.496)  AerMicErf_On (0.537)
Aer_On suppresses $r_{eff}$ feedback

From reduction to increase in $r_{eff}$ with warming

Smaller climatological $r_{eff}$ in GA7.1
Aerosol-cloud interaction

![Images of plots showing aerosol-cloud interaction](image-url)
Summary

• Changes in midlatitude cloud feedbacks explain the differences between GA6.0 and GA7.1.
• The new aerosol and mixed-phase schemes are responsible for most of the feedback differences.
• Aerosol acts through \( r_{\text{eff}} \), and mixed-phase through LWP. Both the climatology and the response matter.

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Special Section:
The UK Earth System Models for CMIP6

Key Points:

Strong Dependence of Atmospheric Feedbacks on Mixed-Phase Microphysics and Aerosol-Cloud Interactions in HadGEM3

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Future work

More work needed to assess the realism of midlatitude feedbacks using observational sensitivities, i.e. response to cloud-controlling factors (Myers and Norris, 2016).

• Strong CF feedback in lower midlatitudes, is it realistic?
• Phase-change feedback in higher midlatitudes
• Aerosol-cloud interactions

Improved observations of (climatology and variability):

• Supercooled liquid clouds
• $\tau$: LWP, CDNC and effective radius