A hybrid-resolution climate model

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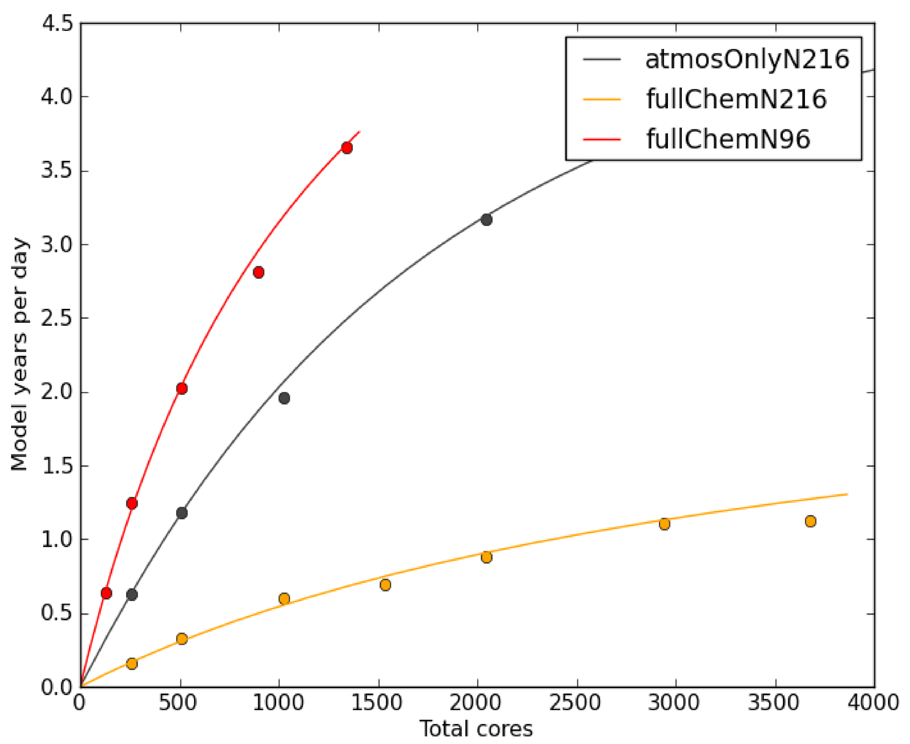
Background

The UK Earth System Model (UKESM) consists of the HadGEM3 coupled physical climate model plus earth system components including a terrestrial carbon cycle, an ocean biogeochemical model, an advanced representation of atmospheric chemistry and aerosols, and an interactive ice-sheet model.

Adding these components results in a significant increase in model computational cost and reduction in throughput which make it difficult to use the planned high-resolution version of UKESM for centennial timescale simulations such as those required in CMIP6.

The leading computational overhead for UKESM comes from the chemistry and aerosol scheme, as implemented by the UKCA component of the atmosphere executable. Turning on UKCA makes the high-resolution version of the model run about ***three times more slowly*** (see right), and about ***six times more slowly*** than the low-resolution version with UKCA.



Model performance as a function of number of compute cores, for the high-resolution (N216) and low-resolution (N96) version of the model, and for the atmosphere-only (i.e. no UKCA) model at high resolution.

A hybrid-resolution model

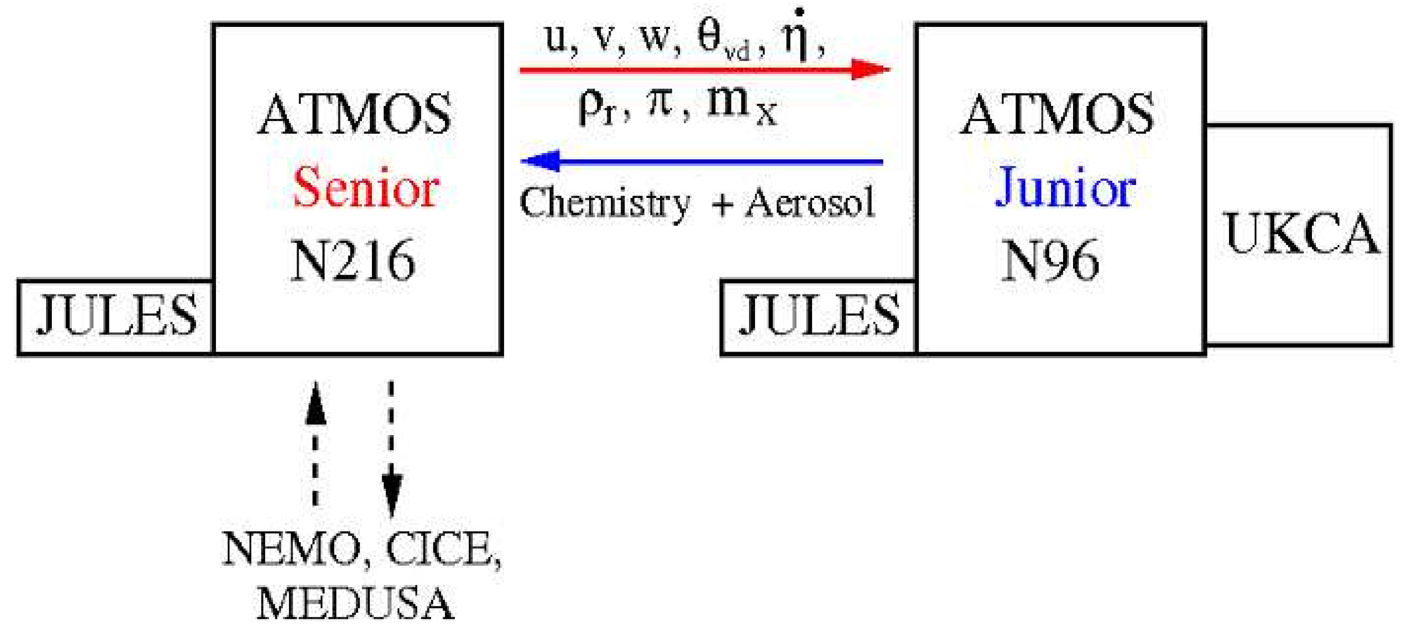
We are developing a hybrid-resolution version of UKESM to retain high model resolution where it is most needed (e.g. in physical atmospheric and oceanic processes) while retaining process complexity as required (e.g. for atmospheric chemistry and aerosol) and keeping the model computationally viable. We run the atmospheric physics and dynamics at one resolution (labelled here N216, corresponding to an equatorial grid spacing of around 60km) and the aerosols, chemistry and tracer advection at a lower resolution (N96, or about 140km).

The implementation requires frequent two-way exchange of 3D fields – e.g.

- the chemistry requires prognostic and physical parameterization fields from the atmosphere, and
- the atmosphere needs trace gas and aerosol fields from the chemistry.

We use the OASIS3-MCT coupler for the exchange of the fields, and for interpolating them onto the different grids. The same vertical grid is used in both parts of the model.

Model architecture



The hybrid-resolution version (see above) consists of a high-resolution (called Senior) and a low-resolution (Junior) copy of the original model, run concurrently.

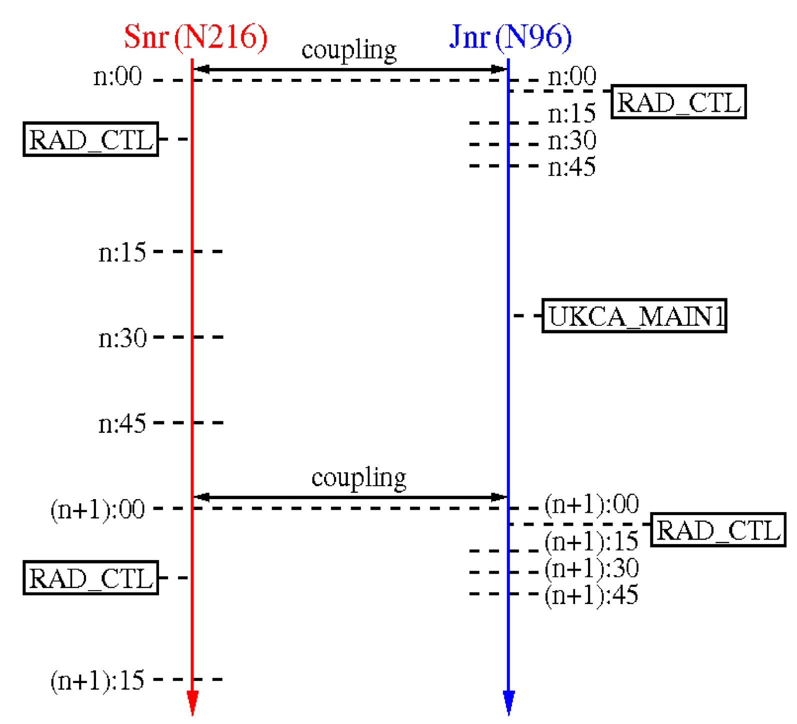
- Senior contains the atmosphere, but has the UKCA component turned off
- Junior contains both the atmosphere and UKCA (including tracer advection)

Both copies contain the JULES land surface component, whilst Senior will need to communicate with other UKESM components (including the NEMO ocean component, the CICE sea-ice component and the MEDUSA ocean biogeochemistry component) – see **Conclusions & further work**, below.

We want Junior to be driven by Senior's dynamic meteorological trajectory, and to use the results of Junior's chemical and aerosol calculations in the evolution of the Senior atmosphere.

Coupling within the model

- Once an hour (every fourth timestep), Senior passes to Junior dynamical core fields and other prognostics which are interpolated onto the Junior grid, and overwrite Junior's fields. This has the effect of locking the temporal evolution of Junior's physical climate to that of Senior's.
- Chemistry and aerosol calculations are then performed in Junior.
- Lastly, Junior's trace gas and aerosol fields are passed to Senior, where they are interpolated onto the Senior grid and used in the parameterization schemes for cloud microphysics, precipitation and radiation.



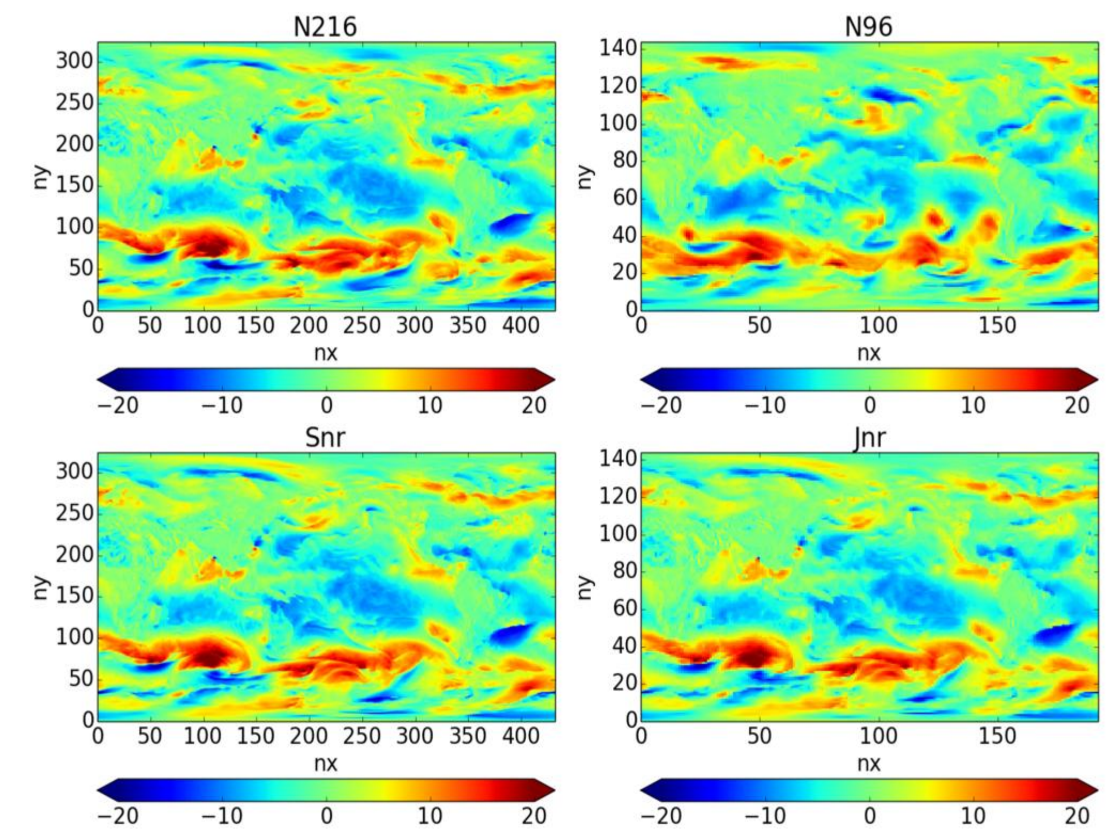
Coupling between Senior and Junior. Junior runs faster, but calculates chemistry (in the UKCA_MAIN1 routine), which is part of the input to Senior's radiation calculation (in RAD_CTL). Both parts use a 15 minute timestep.

Some preliminary results

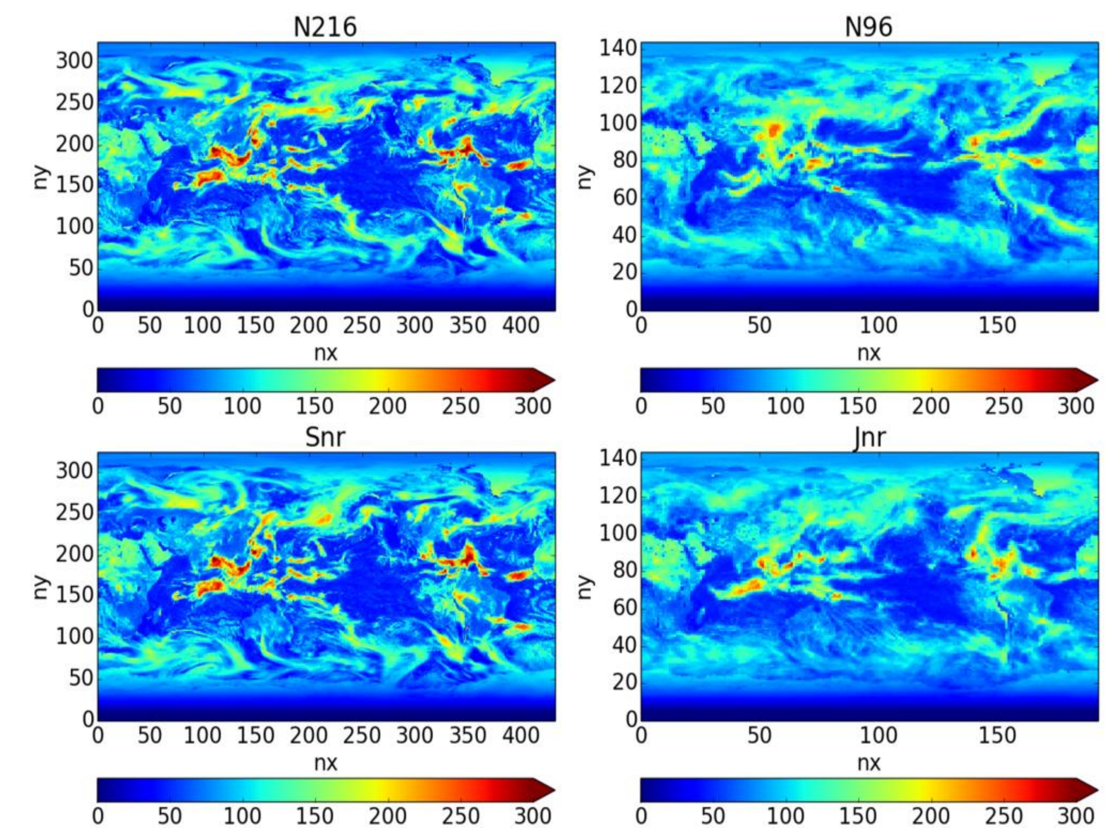
For a given starting configuration, we compare results from the (Senior and Junior parts of the) hybrid-resolution version to those from corresponding runs using the original high- and low-resolution versions.

We see good agreement between the fields of the full high-resolution version (in which the atmosphere, chemistry, aerosols and tracer advection are all run at N216), and those of the Senior part of the hybrid-resolution version. This includes properties that are derived from several core fields, such as the outgoing shortwave radiation flux at top of atmosphere (see right).

As regards performance, the hybrid is currently running ***around three times faster*** than the full high-resolution version.



U-velocity at lowest level after ten days.



Outgoing SW radiation flux at TOA averaged over one day, after ten days.

Conclusions & further work

The results of the initial comparison between the output from the hybrid-resolution version and that of the high-resolution version, and the speedup shown by the hybrid, are promising. We are still exploring the greater flexibility in load balancing provided by the use of two executables in the hybrid version.

The results presented here come from atmosphere-only runs, and a major aspect of our current work is focussed on coupling the hybrid to the other components in UKESM – in particular, the ocean, sea-ice and ocean biogeochemistry components, as noted in **Model architecture**, above.

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