Land-air interaction within the ACCESS climate models

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1) I/We thank our collaborators - both those named here but also the much wider group developing ACCESS (the Australian Community Climate and Earth system simulator) which indirectly includes anyone developing the UM or JULES.
2) The purpose of this presentation is to share some insights emerging from analysis of simulations conducted with ACCESS-CM2 (climate system model – biophysics only) that may be important/of general interest to the JULES community (given our common interests in land surface model performance when coupled to the UM).
3) The title is somewhat misleading – this presentation is really about model sensitivities at multi-annual timescales, not the processes governing how land and atmosphere are coupled at shorter time scales (which is what the term land-air interactions often implies)

What? Why?

CABLE is the land surface model in ACCESS climate models

- ~ big leaf (radiation weighted vertically integrated canopy, multiple pathways for fluxes – sunlit/shaded, wet/dry)
- 10 PFTs, dual source, tiled soil, LAI dependent roughness, roughness sublayer dynamics

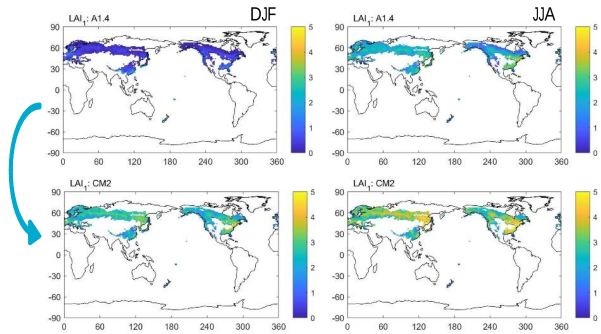
Updates to biophysics in ACCESS-CM2 since ACCESS1.3

- technical interface(s) with the UM/JULES
- internal bug fixes
- new parameter sets
    - Leaf-area index by PFT & ‘optimised’ radiative properties
- new science options
    - Medlyn stomatal function (Kala et al.)
    - soil thermal conductivity (Decker & Verhoef)

DECK-AMIP runs (1980-2009) with ACCESS-AM2 (N96)

- A1.4 – with CABLE configuration as in ACCESS1.3
- A1.4+I – with updated parameters for permanent ice
- A1.4+I+V – with updated parameters for ice and vegetation
- CM2 – with updated parameters and new science configuration

Leaf area for evergreen needleleaf trees



expect changes in 4-band albedo, longwave radiative exchange, roughness, photosynthesis etc. from ΔLAI

Why did this particular work come about?

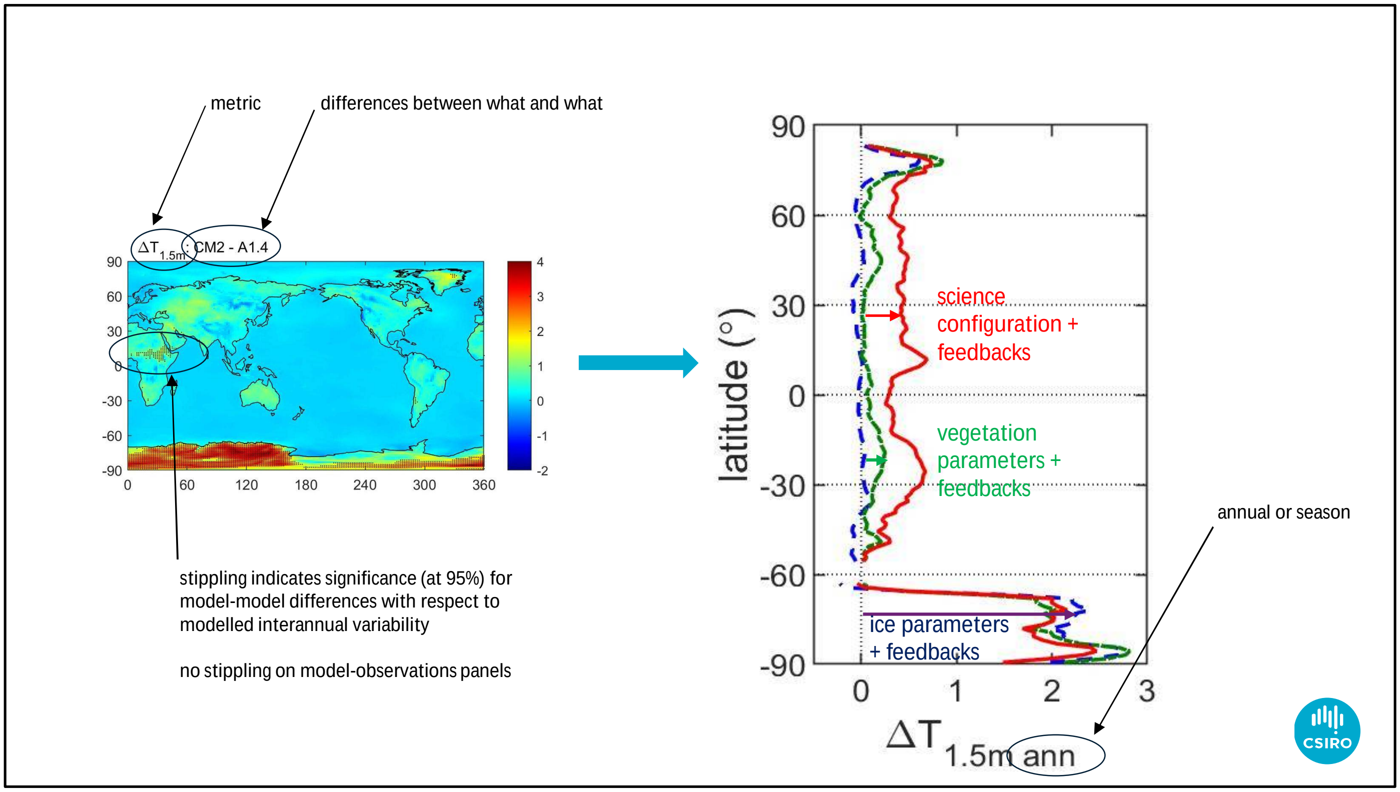
CABLE is the Australian community land surface component of Australia’s main climate model ACCESS. CABLE also operates coupled into WRF and into our own regional climate model CCAM. CABLE includes several unique representations of terrestrial processes – but also has many similarities to JULES.

Within ACCESS CABLE works in partnership with the UM and JULES – it does not completely replace JULES (e.g. sea, sea ice exchange come from JULES – but also some terrestrial processes such as dust emissions). Like JULES, the code base evolves and the configuration of CABLE used differs between the various incarnations (this is more than just whether the biochemistry is turned on/off). Like JULES, some CABLE science is not available in coupled runs. A set of changes to the representation of terrestrial biophysics were included in the latest climate model, ACCESS-CM2. This comprised some updated parameter sets and the leaf area ancillaries, and a small number of science updates. Unfortunately, given the CMIP6 timelines, our choices around configuration were largely driven by need to address obvious issues, and from stand-alone testing; there was insufficient time to conduct coupled testing properly.

So our main question is “what have these changes done to the simulated climate?”

One key area of difference between CM2 and ACCESS1.3 is that the prescribed leaf area ancillaries (by month and by PFT) were changed to better reflect differences between PFTs. Specifically we moved from a MODIS product for LAI to a NCAR-modification of that product that incorporates well established phenology (and tackles acknowledged weaknesses in the MODIS product at high latitudes/low sun angles). For example, the needleleaf evergreen LAI is notable higher (and has a slightly smaller annual cycle) in CM2 than ACCESS1.3. We automatically expect changes in albedo, radiative exchange, aerodynamic roughness – even photosynthesis - because of this change in input.

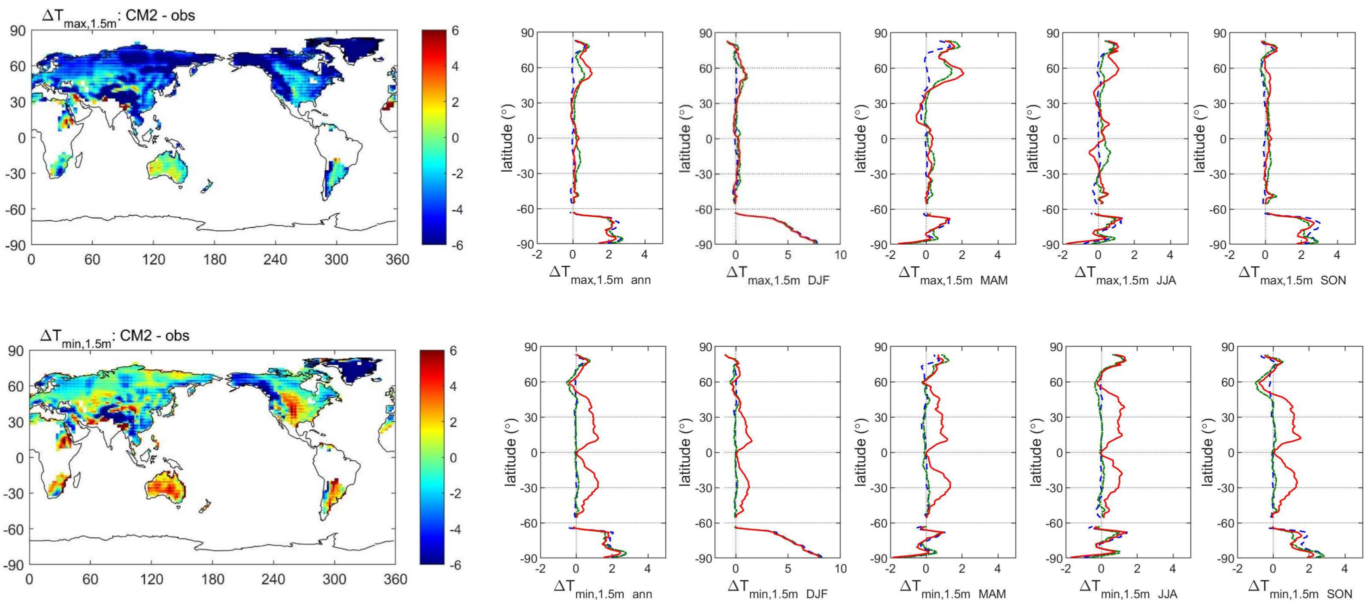
In order to quantitative assess the impact of these changes – we've completed 4, single realisation, 30 year AMIP simulations (so prescribed SST's) using the ACCESS-CM2 model. These simulations operate under the same atmospheric model (GA7.1) and with same, constant land cover – so cleanly quantify the impact of land initiated changes in the modelled climate.



We are going to show several of these types of figure: Left panel – conventional lat-lon plots of either model-model differences or model-observation differences. All at the grid cell (not by tile).

Right panels – longitudinal averages over land fraction, of the difference from the A1.4 simulation. These figures are always model-model differences:
- Difference between Black-Blue lines illustrates impact of changing ice parameters
- Difference between Blue-Green lines illustrates impact of changing vegetation parameters, including leaf area ancillary.
- Difference between Green-Red lines illustrates impact of changing the science configuration.

diurnal temperature extremes vs HadGHCND (30y)



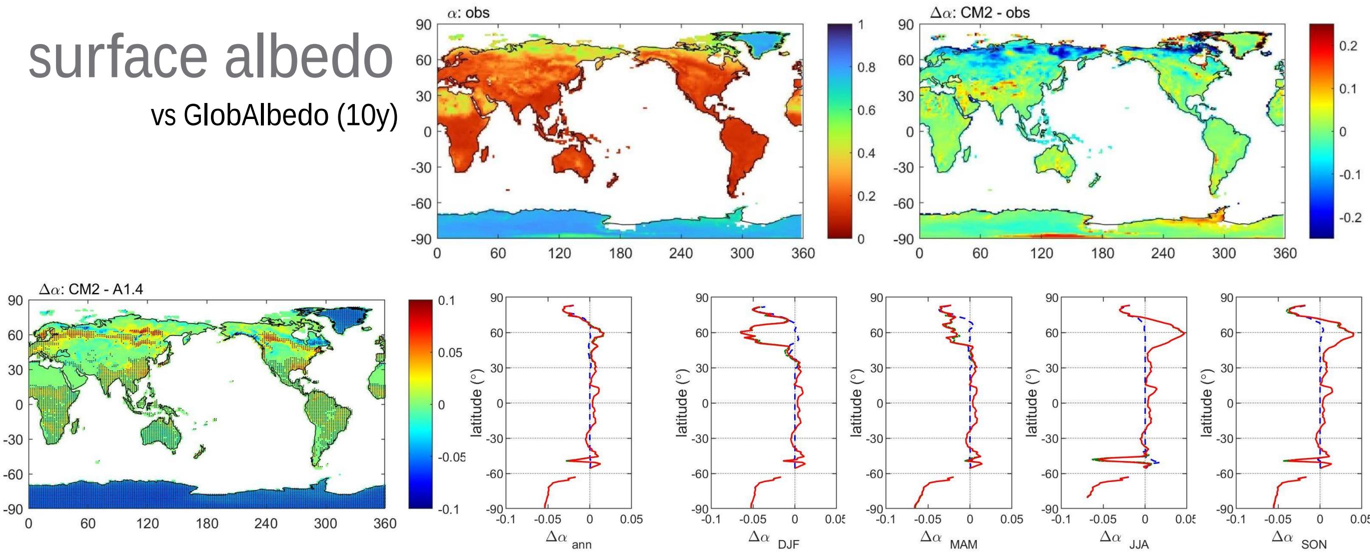
We start with surface air temperature. Left panels show the bias of AM2 (in the CM2 configuration) versus HadGHCND data for annually averaged, daily maximum/minimum screen temperature. Right panels: break down by season of changes from the A1.4 configuration.

There is lots of detail here – so from now on we focus on what's happening in the boreal forests (50-70N). We see a modest increase in annual Tmax and small decrease in annual Tmin compared to the A14 configuration – elsewhere diurnal T range is decreased. This is unfortunate as we would have liked the diurnal temperature range to increase more generally.

This raises a question as I/we expected that the increases in LAI would act to decrease the average diurnal temperature range in these regions as a result of roughness effects.

surface albedo

vs GlobAlbedo (10y)



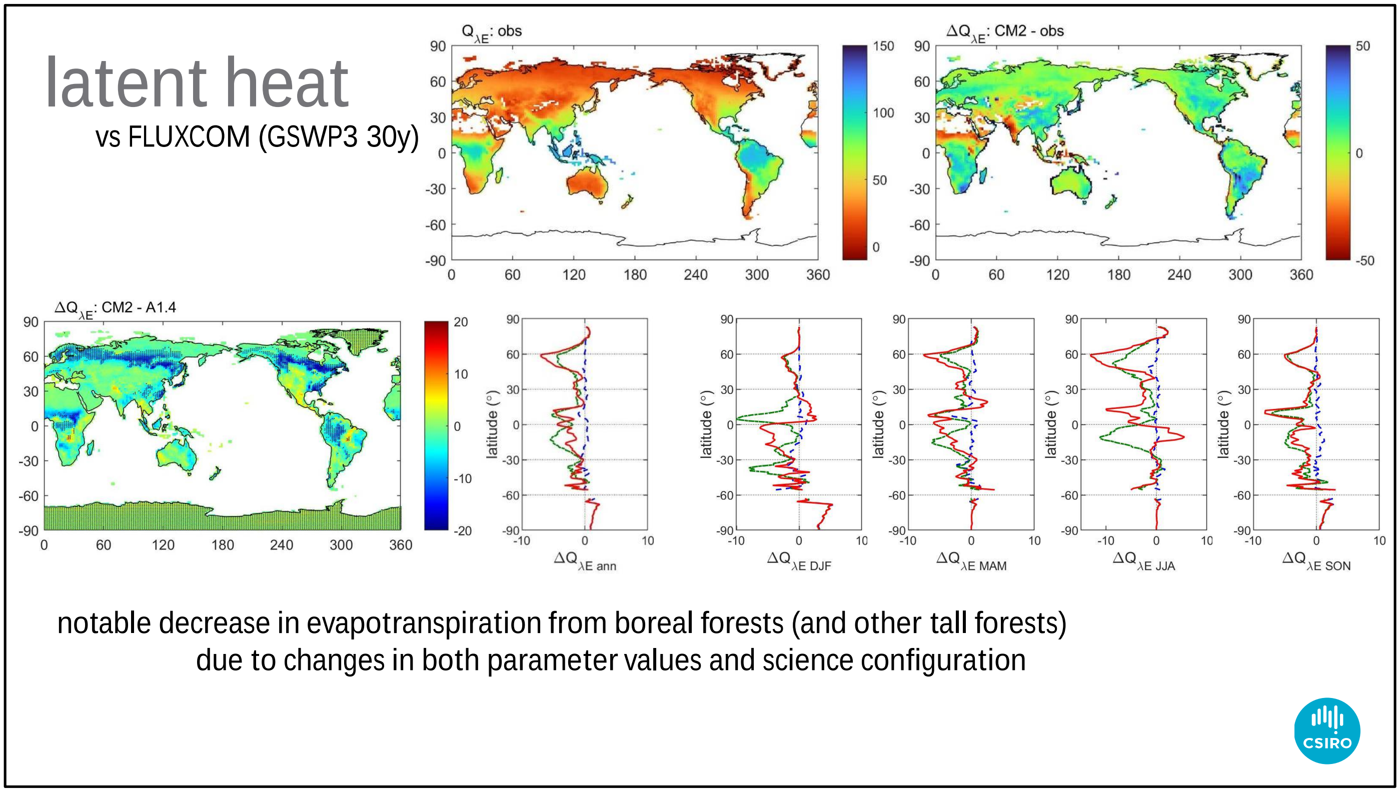
general increase in albedo over boreal forests (with little change in snow cover)
due to changes in parameters only

A deeper look: First consider the surface albedo – we see that the CM2 configuration gives a small increase albedo annually in the boreal forest zone. This is an improvement as the A1.4 configuration is too low here (but there are larger biases in other regions, especially for tundra).

The annual increase is also hiding larger differences in the seasonal variation – with a large decrease in albedo in winter (as expected from the increased LAI) but increases in the other seasons.

Also weirdly – note that albedo is increased in JJA but maxT also increased.

This change is due to vegetation parameter changes only (green and red lines overlay) not the new science parameterisations.



The combination of changes in the parameters/science configuration is also beneficial to the simulated latent heat flux/evapotranspiration in boreal regions. CM2 configuration has lower ET and is therefore much closer to observations than the A1.4 configuration – the wet bias is decreased. This is quite a substantive change – almost 30% annually – and it's due to both parameters and science.

Changes outside the boreal zone are generally not significant (i.e. a smaller fractional effect and highly variable). However, note that the combined changes have also reduced ET over tall forest regions in tropical areas.

conundrum (boreal regions)

- expected changes in LAI expected to lead to increased roughness and a decreased albedo
- ➢ therefore increased T_{min}, a competition on T_{max} and small increase in ET

- found a generally improved agreement against observations
- see little change in large scale climate – surface pressure, wind, friction velocity, precipitation, snow cover/depth – or net radiation
- see decreased T_{min}, increased T_{max}, increased albedo and a notable decrease in ET

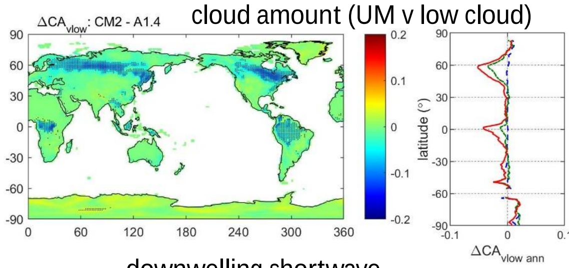
What's the missing ingredient?

So we have a bit of a conundrum: From our understanding of the science in CABLE and earlier stand-alone runs we expected certain changes in the simulated climate of boreal regions in the CM2 and A1.4 configurations – specifically an increased Tmin, a small increase in ET and possibly a small decrease in Tmax. (On the basis that these regions are characterised by energy limitation).

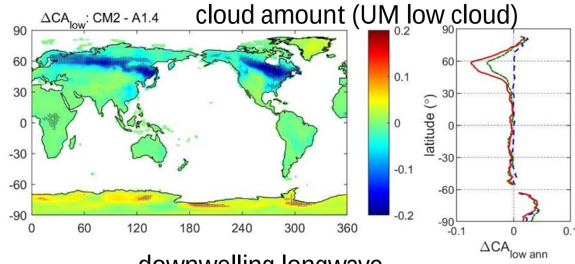
However, this is a) not what we see and b) the combined effect is difficult to explain from a land modelling perspective.

Clouds

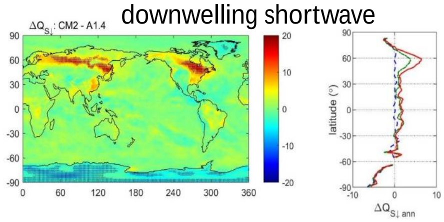
cloud amount (UM v low cloud)



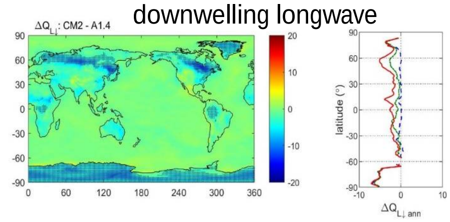
cloud amount (UM low cloud)



downwelling shortwave



downwelling longwave



CABLE's biophysics (canopy radiative exchange, conductances & photosynthesis → stomatal function) depends on LAI *and* the split between direct and diffuse shortwave

less ET → less clouds → more direct beam → feedbacks (higher albedo, higher T_{leaf}, even less ET)

There would appear to be 2 missing ingredients in our (naïve) surface-centric perspective (we can't say for definite yet): The first ingredient is clouds. The decrease in ET is accompanied by a significant change the amount of low/boundary layer clouds in the simulations over the boreal region. Left panel is cloud amount in lowest model level (ie. fog), right panel is cloud amount in the boundary-layer (<2km). Note that there is little/no change in cloudiness above 2km. This has an immediate response of increasing the downwelling shortwave and decreasing the downwelling longwave at the surface – the net radiation stays the same. This change helps explain the increased Tmax, and the decreased Tmin.

Note that the process is not restricted to boreal regions – again the smaller decrease in ET over tropical tall forests is accompanied by similar decreases in low and very low level cloudiness.

The second ingredient(s) are the feedbacks between the land and atmosphere. We suspect that the selection involved is strongly dependent on the parameterisations of canopy radiation physics in CABLE and how they link into the surface energy balance – in particular links between the sunlit/shaded leaves and leaf level conductances. While complicated to disentangle, the net effect depends on both the LAI and on the split between direct and diffuse shortwave radiation (and between visible and near-infrared). Direct beam radiation generally has a higher albedo than diffuse, and the sunlit leaf has differing formulations for leaf level aerodynamic conductance.

The picture that emerges is that the modest change in surface energy balance due directly to different LAI + other parameters + science has been sufficient to decrease ET, which in turn has impacted the cloudiness. The changed cloudiness then triggers a positive feedback in the coupled model via the direct/diffuse partitioning.

We can't (typically) assess the potential of this feedback in stand-alone sensitivity tests since the partitioning of the shortwave is rarely available within prescribed meteorology.

Take home messages

- Surface climatology in coupled modelling is the net result of complex interactions between atmospheric and terrestrial processes – results in stand-alone mode don't necessarily carry over into coupled modelling
- Differences in local climate between CABLE configurations > historical trends due to GHG
- Surface-atmosphere interactions over tall canopies, especially in boreal regions, seem particularly sensitive (at least in CABLE-UM model runs - likely due to albedo/canopy radiation parameterisations)
- (multi-)Annual climatologies are hiding important variation by season, correlation with modes of climate variability, and differences in response between vegetation types
- Plenty of challenges remain – in understanding and model representation

Key points are given on the slide: The first, fourth and last points are included really to emphasise the obvious (but are worth repeating).

On the CABLE configurations vs historical trends – this is both good and bad news. Good because there's enough signal when we change parameters/science configurations that we can take objective decisions. Bad because this likely implies that need to test CABLE coupled to the UM more than we routinely do, and so CABLE risks becoming overly tied to the UM, and because it raises the importance of the problem of land cover change.

With respect to surface-atmosphere interactions - this seems to be somewhat unusual with respect to other studies (where semi-arid and convective permitting regions are usually identified as exhibiting strong interaction between land-air in the modelled climatology). This is perhaps down to unique attributes in both CABLE and the UM. At the moment this is a model result with no implication as to whether it is realistic.

Thank you

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