GCM simulations with 10-m vertical resolution in the boundary layer

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Low-latitude boundary-layer cloud makes a major contribution to uncertainty in climate sensitivity, and lack of vertical resolution in GCMs may be the main reason.

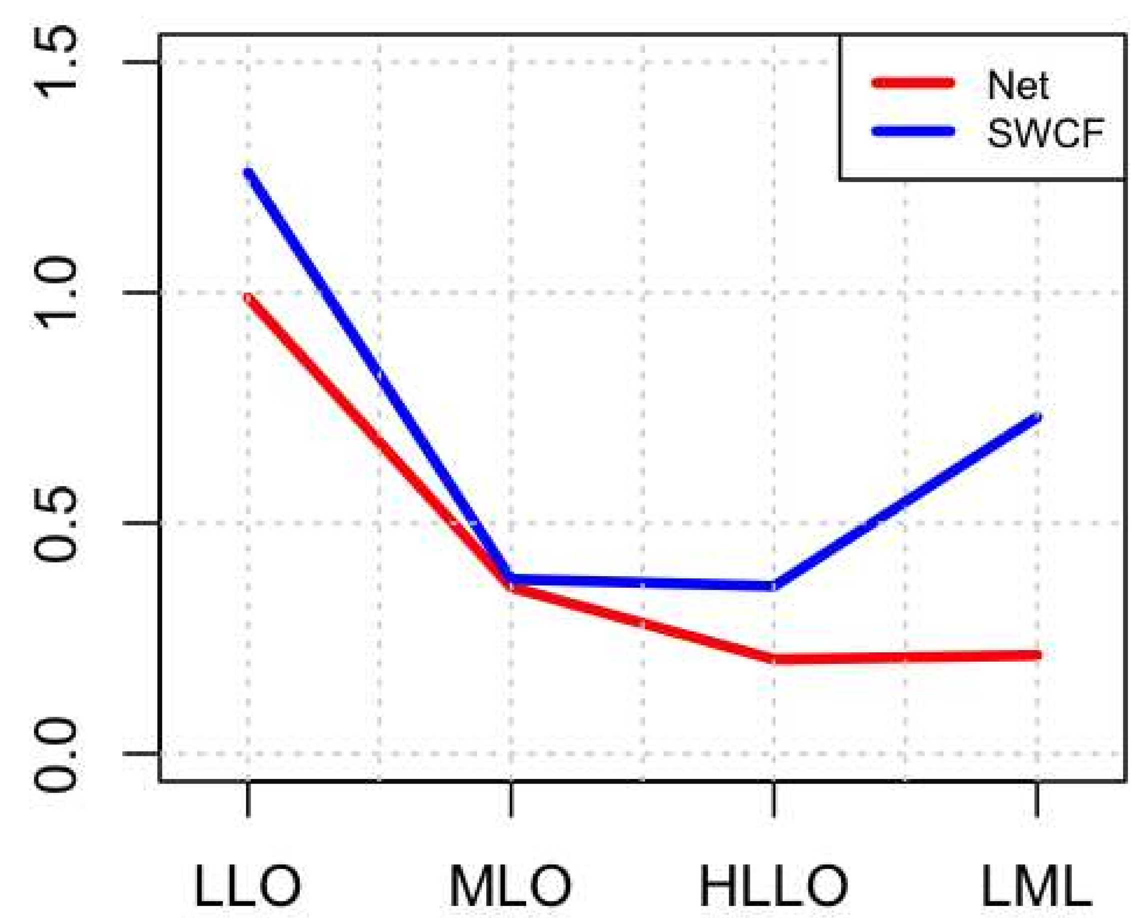
WHY? Condensate is the difference between 2 nearly-equal quantities (total and saturation humidity), and so can be expected to be numerically non-robust.

This doesn't matter very much for deep convective cloud, whose SWCF (solar effects) and LWCF (thermal ones) cancel. Nor for clouds created by baroclinic instability - their fractional cover is largely determined by a physically and numerically robust feature of the general circulation, and they are largely optically thick.

But boundary-layer cloud

1. Has little LWCF, but at low latitudes can have high SWCF
2. Is not strongly coupled to the general circulation
3. Can maintain itself by cloud-top LW radiative cooling and by cutting off the solar heating via the surface - strong positive feedbacks, tending to bistability and hysteresis
4. Is often thinner than GCM levels.

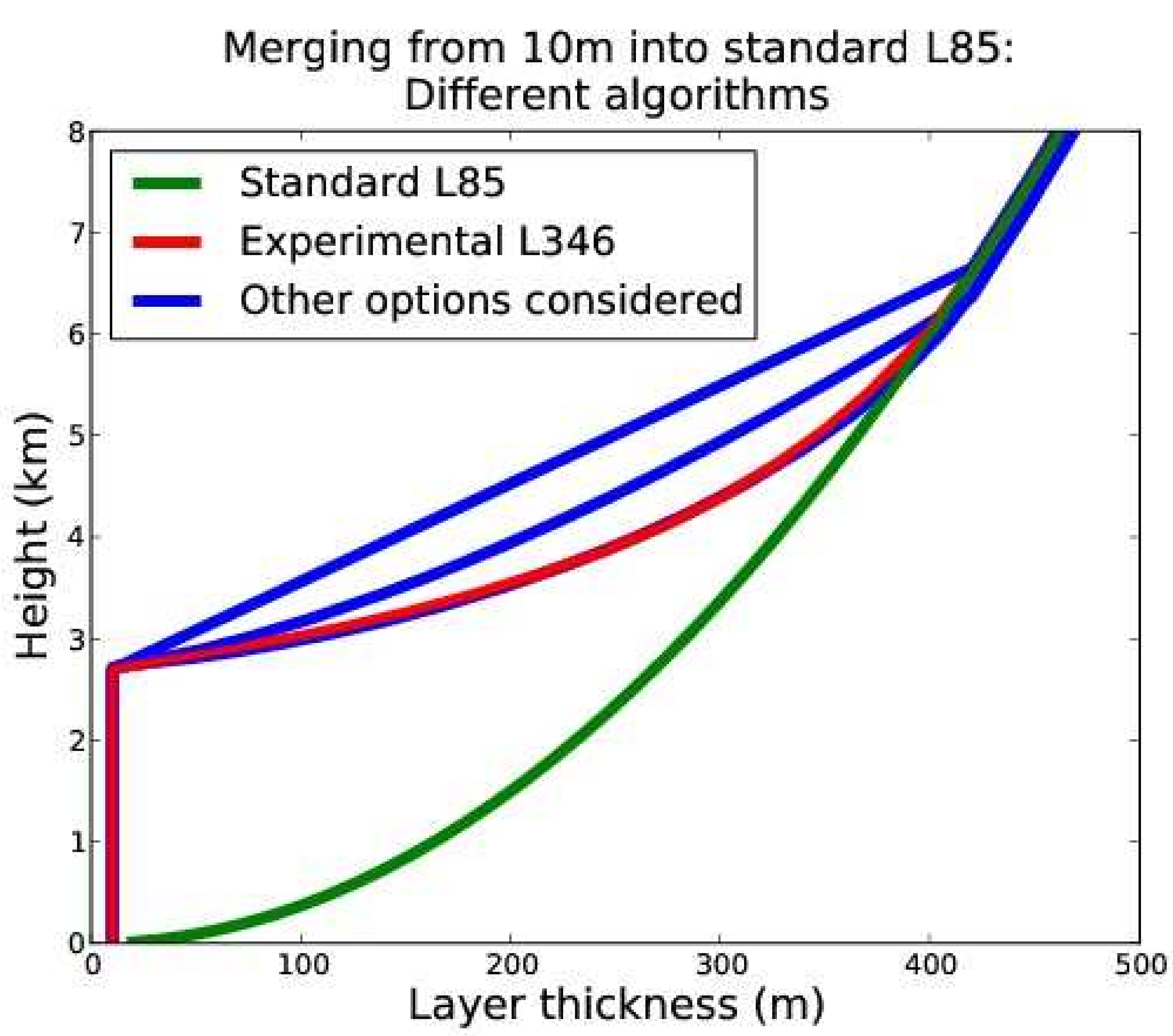
SO? Much higher resolution models (LESs and CRMs) get round **4**, but need the large-scale forcing prescribed. With inadequacy of GCM resolution most obvious in the vertical, running a GCM with LES resolution in the vertical yet all the interactions with the general circulation explicitly simulated may usefully complement LES simulations with prescribed large-scale forcing.



Much of the "uncertainty" (variation between GCMs) in climate feedback is from Low Latitude Oceans, and most of this is from SWCF. (Plot courtesy of Richard Millar.)

The plan:

- Use the Met Office Hadley Centre's benchmark GCM, HadGEM3.
- Choose a set of levels with 10-m (later if possible also 5-m and 20-m) resolution below 2.7 km, merging "smoothly" into its standard L85 set above 5.5 km (on the grounds that boundary-layer-top inversions are below 2.3 km in the present day, and that if the model physics will converge in the boundary layer, it must have by 10m, while we could never run a state-of-the-art GCM with 10-m resolution all the way, so the simplest comparison is with no change aloft).
- Initially, prescribed-SST simulations (high statistical significance affordable even with this many levels), hopefully present-day Earth but Earthlike aquaplanet if need be.
- Compare to a uniform +4K, and perhaps other patterns of warming, and ideally a "slab-like" ocean to capture the basics of the SST/cloud feedback.
- Hopefully also some physics perturbations.



So far:

- I have created levels sets that aim to fulfil the plan, though nobody seems certain just what "smooth" means - limiting the 2nd derivative of layer thickness? The 2nd difference? One of these normalized by layer thickness? Or by 1st derivative, or by difference? The plot left shows some options.
- I have set up simulations and tried to run them.
- With everything except the levels matching the standard version, e.g. the main timestep still 20 minutes, numerical instability develops very fast.
- With the timestep TS, and the dynamics solver tolerance TOL, reduced it runs longer but I do not yet have a stable configuration - see table right.

TS (min)	TOL	Time till failure
20	10^{-4}	1 hour
5	10^{-4}	21 hours
2.5	10^{-4}	9 days
2.5	10^{-5}	11 days
2.5	10^{-5}	13 days
2.5	10^{-6}	83 days

So I am still totally able to take account of any comments or suggestions.

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