A hierarchical approach to climate sensitivity

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Based on joint work with: T. Becker, S. Bony, D. Coppin, C. Hohenegger, B. Medeiros, D. Fläschner, K. Reed
as part of the WCRP Grand Science Challenge on Clouds Circulation and Climate Sensitivity.
"If you have a problem that you do not know how to solve, then there exists a simpler problem that you do not know how to solve, and your first job is to find it."
... and was very much part of Charney’s mental make up.
“We believe, therefore, that the equilibrium surface global warming due to doubled CO$_2$ will be in the range 1.5°C to 4.5°C, with the most probable value near 3°C.” Charney et al., 1979

Charney et al. ‘79

- Reasoning from Radiative Convective Equilibrium, (RCE) corroborated by global computations with then emerging general-circulation models

- Most early RCE calculations neglected weaker bands of CO$_2$, including these increased the forcing and hence the ECS, Charney et al., actually corrected liberally for this. Early RCE estimates of FAT varied between 0.75 Wm$^{-2}$ and 1.0 Wm$^{-2}$.

- Lapse-rate feedbacks were not included, but about 0.3 Wm$^{-2}$ was added to account for surface albedo feedbacks.

- Uncertainty was inflated
The field moved on to study more complex problems

Charney et al. ‘79

Cess et al. ‘89

Schlesinger and Mitchell documented the diversity of ECS estimates, in their summary water vapor and lapse rate feedbacks give $dT = 2.85$ K, Clouds contributed about 1 K, and overall ECS was 4.2 K

In a systematic intercomparision Cess et al showed that differences in how clouds responded to warming explained most of the change.
... a form of stasis

... modern models scatter as much as they did 25 years ago.
... which tends to mask great progress (and an expanded model hierarchy)

... we now have a better idea of which clouds, and the mechanisms involved. A key one is how cloudiness at the base of convective layers responds to the intensity of mixing.

This is leading us to data (field experiments) and simpler modelling frameworks.
Aqua Planets

the spread is not reduced, but ECS tends to be smaller …
These basic interactions between deep and shallow convection should be apparent in RCE

The simulations hint that basic elements of the thermal structure of the atmosphere are more dependent on the representation of deep convection than they are on continents, the carbon cycle, and so on …
These basic interactions between deep and shallow convection should be apparent in RCE

RCE estimates of ECS using comprehensive models is similar to the range of early estimates, with fixed cloud amount.

This finding opens the door to other, more fundamental approaches.

Changes in the convection influence large-scale organization


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... and this has a much bigger influence on estimates of ECS

Changes in ECS are not stable at different temperatures, and this reflects changes in organization.
... instability of the sensitivity parameter is also evident in other models

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1. Even for a very simple problem the uncertain representation of clouds and convection leads to a very large range in the radiative response to forcing.
2. The instability in the sensitivity parameter appears related to the emergence of organization.

But the real advantage of RCE is that it is amenable to more fundamental approaches.
... little evidence of a structural dependence on domain size

Even for a relatively stable mean climate, still considerable spread in estimates of ECS

ICON based RCE on different sized domain, with a fixed grid spacing.
First estimates of ECS using a convection resolving model in RCE
Aggregation is essential to stabilize the climate in the UCLA-LES

Aggregation leads to much drier areas in simulations with resolved deep convection.
But strong SW (low?) cloud feedbacks give a much larger (3.8) ECS

CRM simulations have twice the climate sensitivity, and the difference is in the cloud response.

unfortunately the simulations still aren’t able to resolve shallow convection … but if they did they might not aggregate …
... there is a case to be made that realism is a distraction.
ECS estimates in RCE still encompass a tremendous range.

Large-Scale convective aggregation plays an important role, also in stabilizing the climate.

We’ve settled on a simpler problem that we can solve, and perhaps an even simpler one (fixed cloud RCE) that we must solve.

…the hierarchy of problems we solve is as important as the hierarchy of models we employ.