Do climate models over-estimate cloud feedbacks?

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Cloud feedbacks
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Strength of the Mixing Induced Low Cloud (MILC) feedback?
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Iris effect?
Do models over-estimate their (positive) low-cloud feedback? Miss a negative cloud feedback?
A negative high-cloud feedback associated with an Iris effect?

- Iris effect: expanding dry, clear areas in a warming climate.
- Negative LW feedback
- A strong Iris effect would reconcile models with observations in a number of aspects (low ECS, strong SW cloud feedback, strong HS, etc).
Is a negative cloud feedback associated with an Iris effect supported by cloud observations?
Zelinka and Hartmann (2011) show that when the tropical-mean SST rises during ENSO:

- high cloud fraction decreases (Iris-like effect)
- robust physical mechanism
- SW effects oppose LW effects, resulting in a statistically insignificant net high cloud feedback

Observational evidence for an Iris effect...

*but not for a strong negative feedback associated with it*
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Observational evidence for an Iris effect... but not for a strong negative feedback associated with it

Does it translate to climate change? Could other mechanisms lead to a stronger Iris effect? e.g. What if convective aggregation increases with temperature? as proposed by CRMs
Observational investigation of the radiative impact of changes in convective aggregation

For given large-scale forcings (including SST):

- The atmosphere is drier, clearer (RH, AIRS data)
- More efficient at radiating heat to space (OLR, CERES data)

Enhanced convective aggregation = Iris-like effect

Tobin, Bony & Roca, J. Climate 2012
Tobin et al., JAMES, 2013
Observational investigation of the radiative impact of changes in convective aggregation

For given large-scale forcings (including SST):

- The atmosphere is drier, clearer (RH, AIRS data)
- Less efficient at reflecting solar radiation (SW, CERES data)

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Tobin et al., JAMES, 2013
Observational investigation of the radiative impact of changes in convective aggregation

For given large-scale forcings (including SST):

- the atmosphere is drier, clearer (RH, AIRS data)
- LW and SW changes compensate each other (NET, CERES data)

For a given SST: net TOA radiation seems insensitive to aggregation

Tobin, Bony & Roca, J. Climate 2012
Tobin et al., JAMES, 2013
Is a negative cloud feedback associated with an Iris effect supported by cloud observations?

There is evidence for an Iris effect

...but not for a negative cloud feedback associated with it (so far)

Could a change in convective organization with temperature affect this feedback? Remains to be investigated...
Is a negative cloud feedback associated with an Iris effect supported by cloud observations?

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Would GCMs be missing the effects of convective organization and its dependence on temperature?
GCMs run in Radiative-Convective Equilibrium

3D RCE:
- aqua-planet
- no rotation
- uniform insolation
- fixed, uniform SST

Like Cloud-Resolving Models:
- GCMs produce spontaneously a convective organization ("self-aggregation")
GCMs run in Radiative-Convective Equilibrium

3D RCE:
- aqua-planet
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Like Cloud-Resolving Models:
- GCMs produce spontaneously a convective organization ("self-aggregation")
- GCMs exhibit an enhanced aggregation of convection at high temperatures
Effect of rising surface temperatures

- Iris effect-like
- High Hydrological Sensitivity (4 %/K or more)
- Nearly neutral LW cloud feedback
  + Strong positive SW cloud feedback
  = *high Climate Sensitivity despite the Iris effect*

→ GCMs can produce an Iris-like effect due to changes in convective aggregation with $T$

→ But SW cloud feedbacks, especially those from low-level clouds, can easily oppose the LW negative feedback associated with the Iris effect
Low-cloud feedback

Controlled by two competing processes:
- moistening by surface turbulent fluxes
- drying by low-tropospheric mixing (shallow convection + shallow circulation)

Inter-model differences in the strength of low-tropospheric mixing explains about half of the variance in climate sensitivity (Sherwood et al. 2014).
Observational constraints on low-tropospheric (LT) mixing

Reanalyses suggest that LT mixing by the large-scale circulation is unrealistically weak in low-sensitivity models.

Observational constraints suggest a LT convective mixing near the middle of the GCM range.
Additional constraints on convective mixing?
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In present-day climate:
- Models predict contrasted vertical distributions of low-level clouds in shallow cumulus regimes

Nam, Bony, Dufresne and Chepfer, GRL, 2012
Additional constraints on convective mixing?

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$\gamma$: shallowness index

Brient, Schneider, Tan and Bony, submitted

Nam, Bony, Dufresne and Chepfer, GRL, 2012
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Consistent with the constraint on convective mixing of Sherwood et al. (2014)
Conclusion

- No strong evidence (so far) that GCMs miss a negative cloud feedback associated with the Iris effect

- Process-oriented observational constraints suggest that lowest-sensitivity models under-estimate the positive low-cloud feedback

- Suggests that models with ECS lower than 3K are unlikely to be realistic

But the investigation should continue...
Thank You