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To what extent are tropical cloud feedbacks circulation-driven?

Emily Van de Koot[1], Michael Byrne[2] & Tim Woollings[1]
[1] University of Oxford, UK
[2] University of St Andrews, UK

Emily.Vandekoot@physics.ox.ac.uk
@EmilyVanDeKoot_

To what extent are observed tropical cloud feedbacks circulation-driven?

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UNIVERSITY OF OXFORD

This work aims to contribute to our understanding of tropical cloud feedbacks by

- Using a longer-duration satellite dataset to study linear multi-decadal trends in cloud radiative effects
- Decomposing feedbacks into dynamic and thermodynamic components as in Bony et al. (2004) to gain new insight into the mechanisms driving the cloud response to warming

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Key details:

Period: 1985 – 2020, monthly means
Region: 30°N-30°S, 1° resolution
All-sky radiative fluxes: DEEP-C v5 (Liu and Allan, 2022), ERA5 (Hersbach et al., 2020)
Clear-sky radiative fluxes: ERA5
Vertical velocity at 500hPa, ω_{500}: ERA5
Tropical mean surface temperature, T: ERA5
Radiative kernels: CloudSat/CALIPSO (Kramer et al., 2019)

DEEP-C: Satellite observations from the period 1985-2000 have been reconstructed and combined with CERES EBAF. The reconstruction uses ERBS WFOV satellite observations (10° resolution) combined with ERA-Interim reanalysis. AMIP simulations and other high-resolution atmospheric model simulations were used to manage gaps in the data.

CloudSat/CALIPSO radiative kernels: Cloud and water vapour data from CloudSat and CALISPO, temperature and humidity data from ECMWF reanalysis, and surface albedo from the International Geosphere Biosphere Programme global land surface classification project were used to generate the kernels. The use of observational data means the kernels are free of bias associated with using a model-derived base state.

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Method:

- Vertical velocity at 500hPa, ω_{500}, is used as a proxy for the large-scale circulation
- ω_{500} is discretised into dynamical regimes
- Circulation is characterized by a PDF, $P(\omega_{500})$, which describes the statistical weight of each regime
- Finding the mean cloud radiative effect for each dynamical regime allows a representation of the relationship between CRE and ω_{500}, $CRE(\omega_{500})$
- The tropical mean CRE, CRE, is then

$$CRE = \int P(\omega_{500}) CRE(\omega_{500}) d\omega_{500}$$

Calculated using the linear trend in $CRE(\omega_{500})$ divided by the linear trend in T

- And the tropical mean cloud feedback, $dCRE/dT$, can be written as

$$\frac{dCRE}{dT} = \int \frac{dP(\omega_{500})}{dT} CRE(\omega_{500}) d\omega_{500} + \int P(\omega_{500}) \frac{dCRE(\omega_{500})}{dT} d\omega_{500} + \int \frac{dP(\omega_{500})}{dT} \frac{dCRE(\omega_{500})}{dT} d\omega_{500}$$

Dynamic | Thermodynamic | Nonlinear

Bony et al. (2004)

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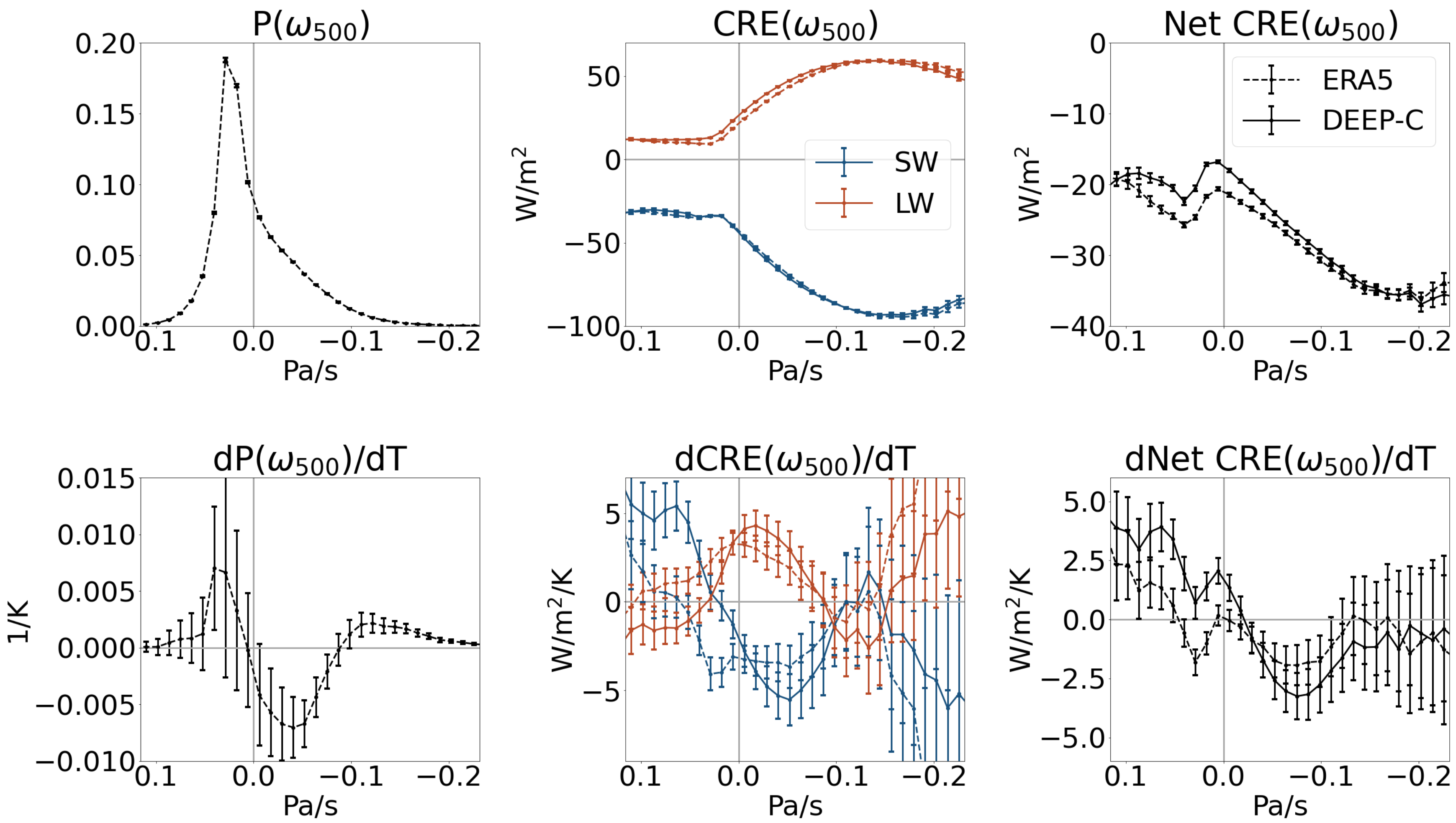
Time-mean:

Feedback:



Errors are 2 * standard error

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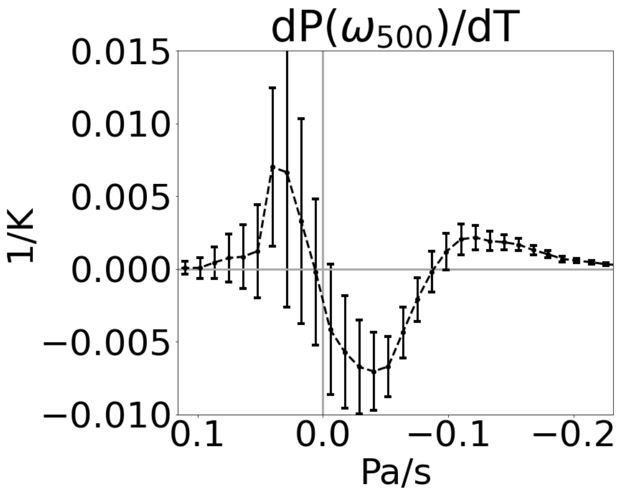
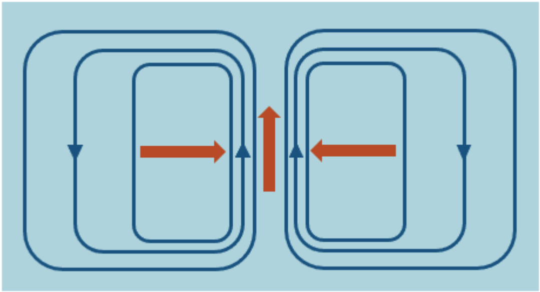
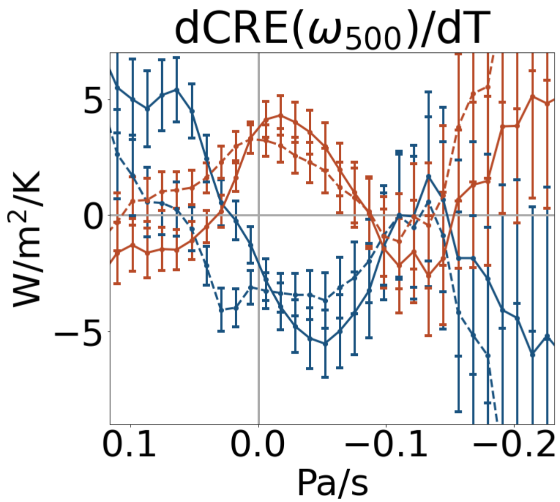




Reduction in weak ascent (ω_{500}>-0.1Pa/s) is balanced by an increase in strong ascent and in descent. This likely corresponds to a narrowing and strengthening of ascending regions.

This qualitatively agrees with trends in other reanalysis datasets (Su et al., 2020) and with GCM simulations (Byrne et al., 2020).



The clearest result is a strengthening of both the SWCRE and LWCRE in weakly ascending regions, with larger changes in the SWCRE.

The agreement between ERA5 and DEEP-C is less good in descending regions where they disagree on the magnitude, and sometimes the sign, of the SW and LW feedbacks.

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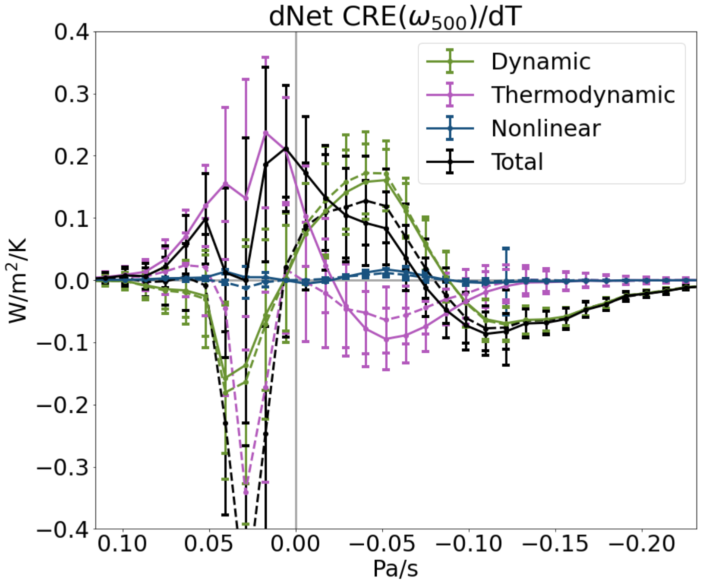
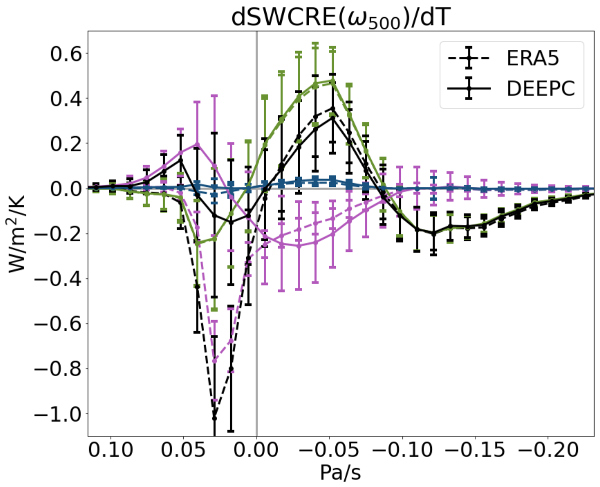
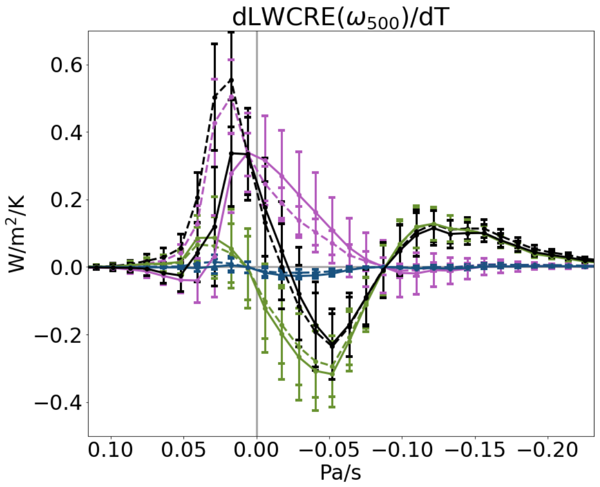
Dynamic/thermodynamic decomposition:







The tropics-wide dynamical feedback is relatively small (-0.14$\pm$0.17 W/m^2/K for DEEP-C and -0.14$\pm$0.20 W/m^2/K for ERA5) but circulation changes play a significant role locally.

- In ascending regions, cancellation between the dynamic and thermodynamic terms leads to an overall feedback of -0.06$\pm$0.10 W/m^2/K for DEEP-C and 0.03$\pm$0.11 W/m^2/K for ERA5.
- In strongly ascending regions, the feedback is almost entirely dynamically driven.

This emphasises that, to understand future cloud feedbacks, it is essential to understand future changes to the large-scale tropical circulation.

Differences in descending regions mean ERA5 and DEEP-C do not agree on the sign of the tropics-wide thermodynamic feedback. In weakly ascending regions, the thermodynamically-driven strengthening of the SWCRE produces a negative feedback.

Broadly speaking, the LW and SW cloud feedbacks act in opposite directions, with the net feedback reflecting the greater magnitude of the SW feedback.

Next steps

How are results impacted by experimental design choices?

- Method: short-term variability/trends
- Region: entire tropics/tropical land/tropical ocean
- Time period
- Surface temperature and TOA radiative flux dataset choice

Should the local influence of the dynamic component affect our choice of methodology for calculating global mean cloud feedbacks? The mapping between circulation changes and cloud type distribution may mean that we can't assume all clouds of a given type will respond to warming in a similar way. Additionally, atmospheric mass conservation requires that, in the global mean, circulation changes average to zero. Although this doesn't necessarily imply that the associated cloud feedbacks will average to zero, it may be useful to study cloud feedbacks within a certain large-scale circulation system (e.g. the Hadley cells) in parallel.

How does the dynamic/thermodynamic decomposition of feedbacks in tropical ascending regions relate to the anvil area/altitude decomposition? Can observational evidence of the dynamic/thermodynamic responses help with our mechanistic understanding of the feedbacks?