Tropical cloud feedbacks estimated from observed multi-decadal trends

Motivation

It is unclear whether climate models accurately represent cloud feedbacks because

1. small-scale processes are parameterised,
2. they can't reproduce recent trends in Pacific sea surface temperature (SST) pattern, so their projected Pacific SSTs (and thus large scale tropical circulation) may be biased.

Previous observational studies estimated cloud feedbacks from co-variability in cloud radiative effect (CRE) and surface temperature but CO_2-forced and natural variability-induced cloud changes may not be the same.

For the first time, we estimate tropical cloud feedbacks based on observed multi-decadal trends in CRE and tropical-mean surface temperature (T_S).

Data

- DEEP-C all-sky radiative fluxes (Liu and Allan, 2022) [combines CERES and ERBS]
- Other variables from ERA5 (Hersbach et al., 2020)
- CloudSat/CALIPSO radiative kernels (Kramer et al., 2019)
- 1985-2020, monthly means, 1° resolution, 30°N-30°S

Decomposition by circulation regime

We calculate feedbacks as a function of vertical velocity at 500hPa, ω_{500}, which characterises the large-scale tropical circulation.

This tells us:

- how circulation changes drive feedbacks
- how this differs for multidecadal trends versus variability.

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

$$\frac{dCRE}{dT_s} = \int \frac{dPDF(\omega_{500})}{dT_s} CRE(\omega_{500}) d\omega_{500}$$

dynamic component

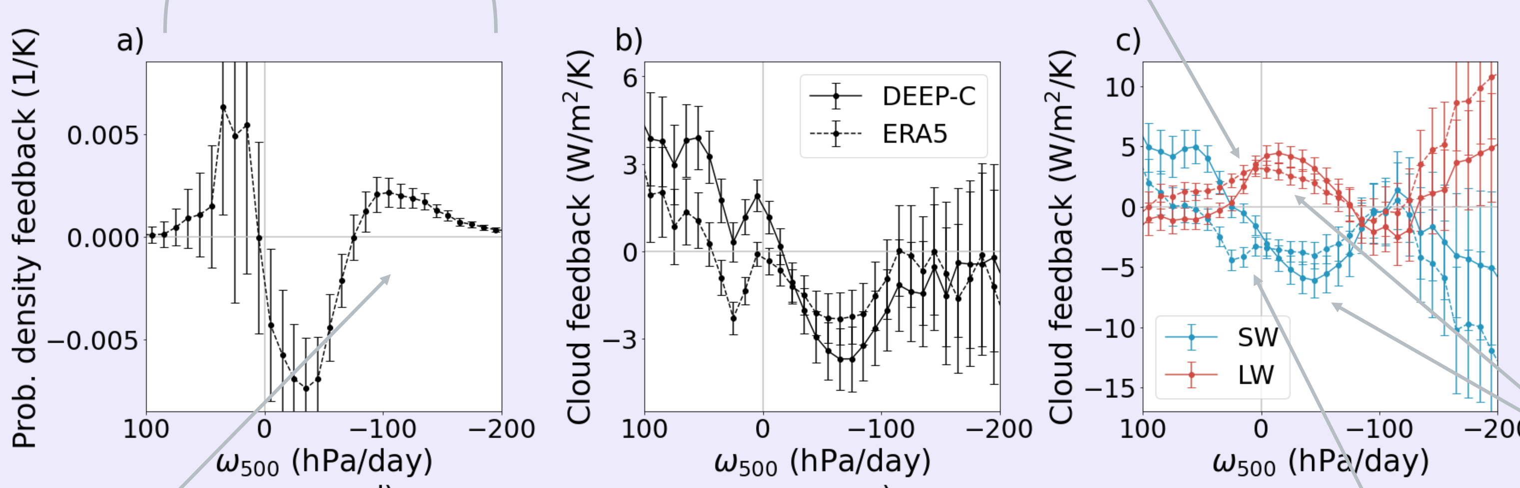
$$+ \int PDF(\omega_{500}) \frac{dCRE(\omega_{500})}{dT_s} d\omega_{500}$$

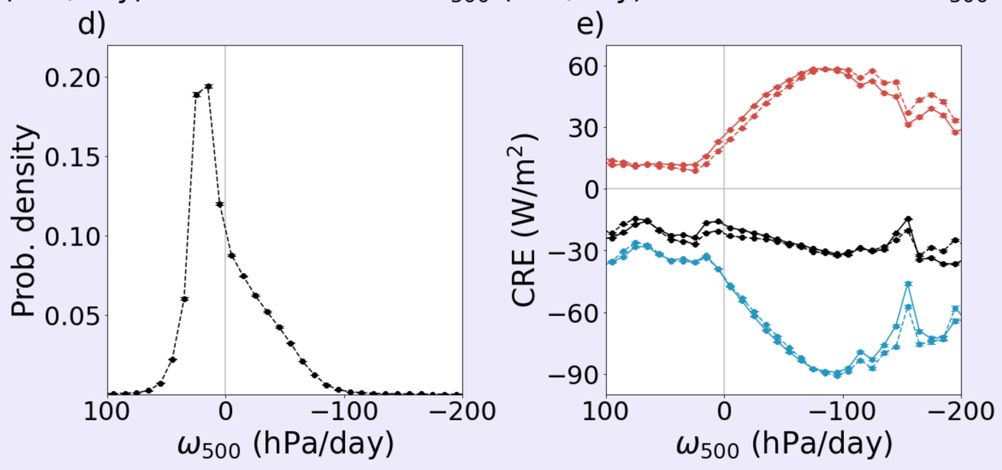
non-dynamic component

A neutral tropical-mean net cloud feedback results from positive feedbacks in regions of descent and weak ascent combined with a negative feedback in regions of strong ascent

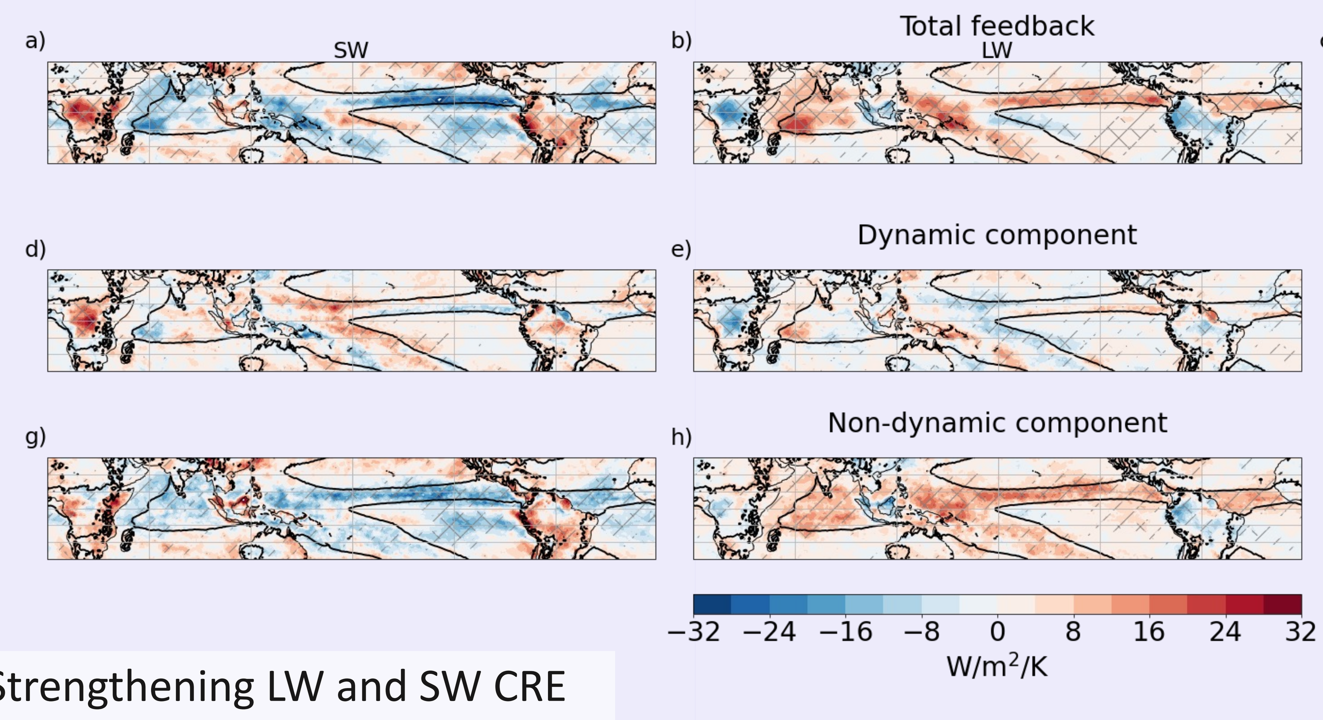
Narrowing and strengthening of ascending regions

LW feedbacks in regions of climatological descent hypothesised to be due to changes in the high clouds associated with brief updrafts





Dynamic feedbacks dominate in regions of strongest ascent



Contour: $\omega_{500} = 0$
Hatch: trend > error
Crosshatch: trend > 2∗error

Strengthening LW and SW CRE in ascending regions due to combination of changes in cloud altitude, amount and albedo

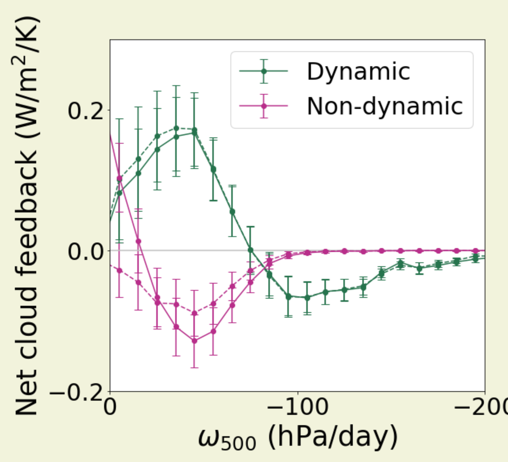
Strengthening SWCRE in descending regions likely due to increased inversion strength causing increased cloudiness

Circulation changes have negligible impact on the tropics-wide net cloud feedback

Because (1) climatological net CRE varies linearly with ω_{500} and (2) changes in upward motion balance changes in downward motion in the tropics (i.e. $\int \omega_{500}(dPDF(\omega_{500})/dT_s)d\omega_{500} \approx 0$), the tropical-mean dynamic component is constrained to be small.

…but play a key role in determining local feedbacks…

In ascending regions, the negative non-dynamic feedback is balanced by a positive dynamic feedback and a weak negative dynamic feedback resulting from the narrowing and strengthening of ascending regions.

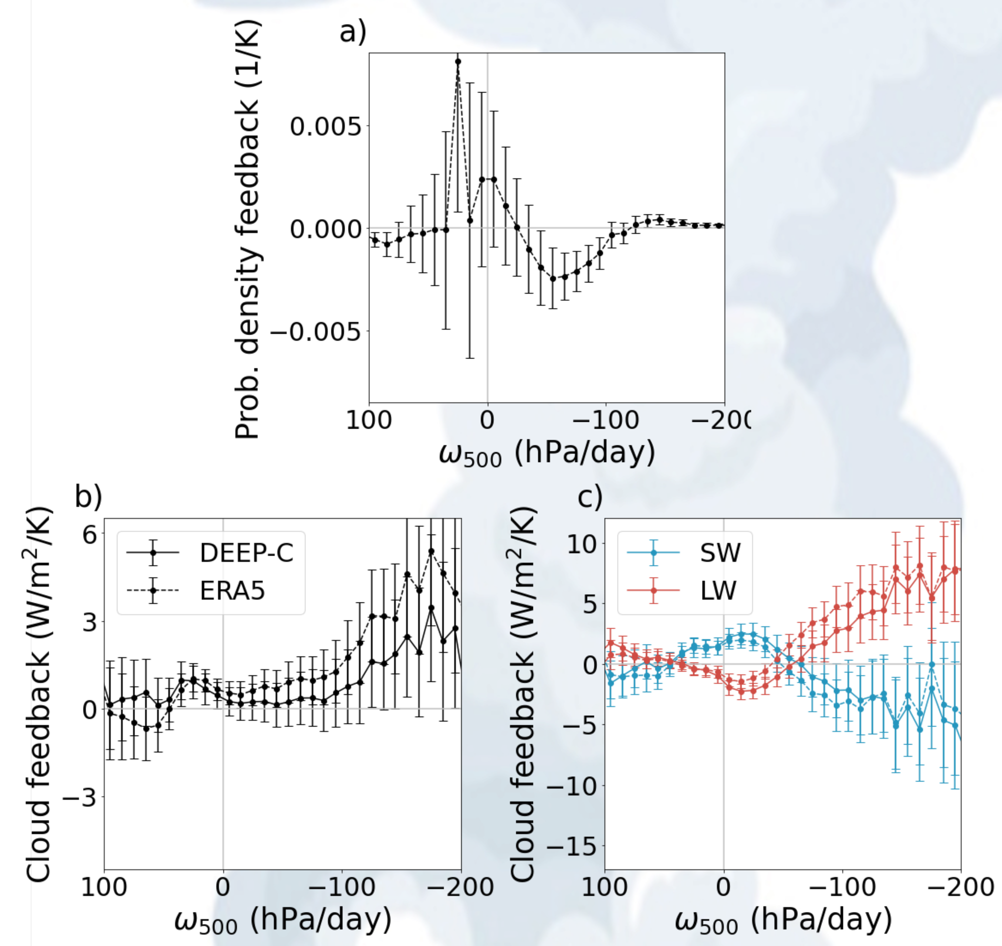


…and may also have important non-local effects

The positive SW feedback in regions of strong descent likely results from increasing West Pacific convection increasing the inversion strength over the East Pacific. Because the cloud changes are driven by non-local circulation changes, they are 'non-dynamic' in this framework.

Cloud feedbacks estimated from trends differ from those estimated from monthly variability

Feedbacks estimated from variability:



Anvil area + albedo feedback calculated following Sherwood et al. (2020) method:

	Feedback (W/m²/K)
From trend	$-0.29 \pm 0.09\ (1\sigma)$
From variability	$-0.13 \pm 0.06\ (1\sigma)$

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