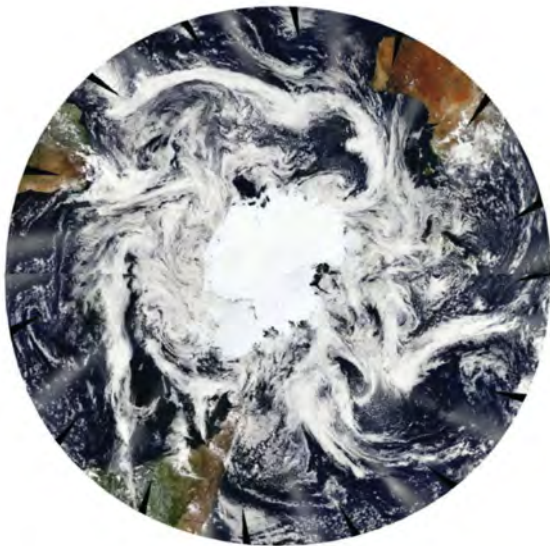# Two way interactions between clouds and large-scale extratropical circulation

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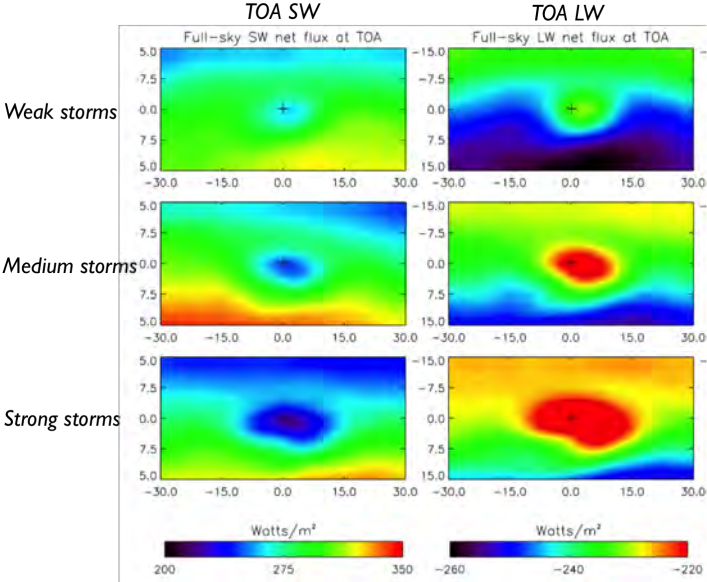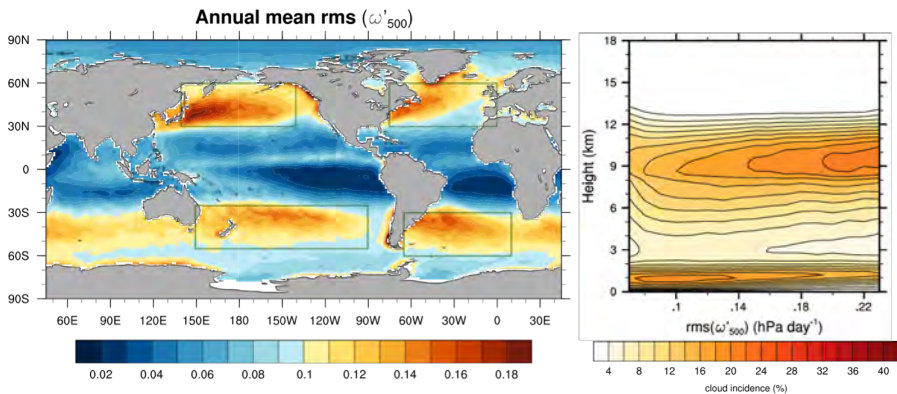
June 6, 2017

Rossow Symposium, 2017

courtesy Rob Wood (derived from Worldview)

More intense storms produce more cloud and larger SW and LW CRE


From *Tselioudis and Rossow, GRL, 2006*

Quantitative estimates of the linkages between cloud incidence and the RMS of vertical motion in the four midlatitude storm track regions from CloudSAT observations

From *Li, Thompson, Stephens and Bony, JGR 2014*

Links between clouds, radiation and large-scale circulation

- cloud responses to poleward jet shifts (Mark Zelinka)
- cloud responses to the extent of Hadley Cell (Bernard Lipat)
- Dynamic and thermodynamics controls on clouds (Kevin Grise)

CLOUDS & PRECIPITATION

CIRCULATION

ENERGY radiative & latent heating
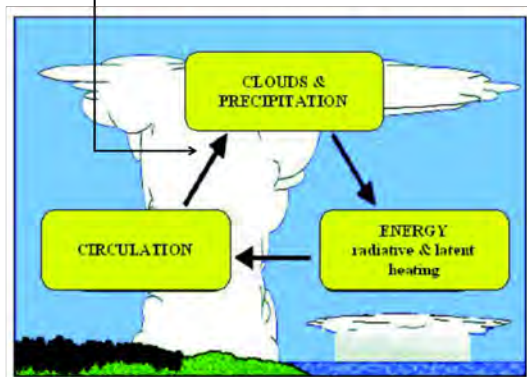
From *Stephens, JCLI 2005*

Changes in radiative flux at TOA, surface, and atmosphere when a cloud layer is inserted in the atmosphere
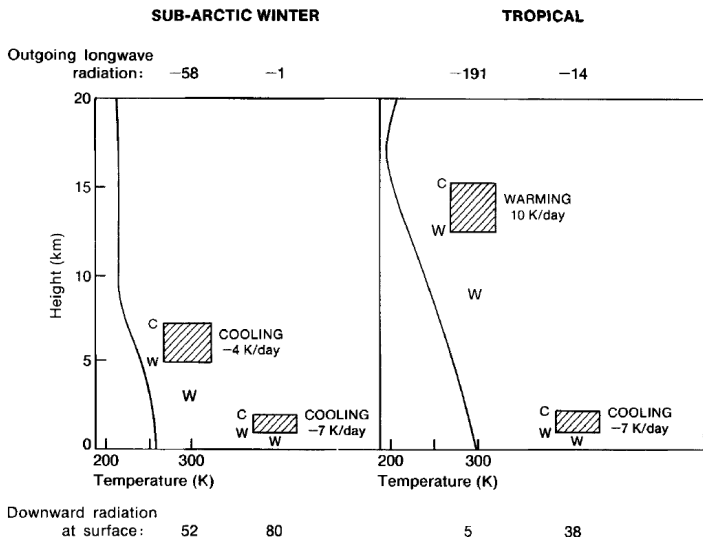
From *Slingo and Slingo, QJRMS 1988*

Quantitative estimates of the cloud-induced radiative heating rate for specific cloud layers from CloudSAT observations

Cloud LW forcing   *Cloud*

Li and Thompson, in preparation
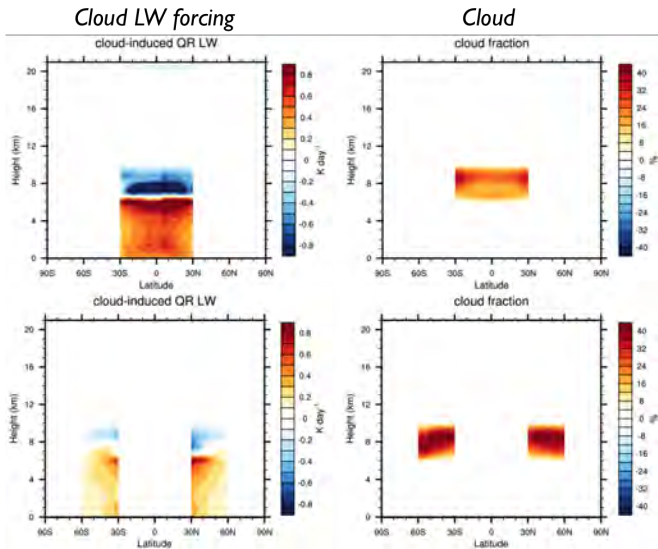
- What kind of influence do clouds have on long-term mean atmospheric circulation?

- What kind of influence do clouds have on the variability of the atmospheric circulation?

Two primary approaches of assessing the influence of CREs on the atmospheric circulation

COOKIE (Clouds On-Off Klimate Intercomparison Experiments) method

to turn off cloud radiative effects at every call in the radiation code

(e.g., Slingo and Slingo 1988; Randall et al. 1989; Slingo and Slingo 1991; Stevens et al. 2012; Fermepin and Bony 2014; Crueger and Stevens 2015; Li et al. 2015; Merlis 2015; Harrop and Hartmann 2016)

"cloud locking" method

to lock/prescribe radiative properties of clouds to those in the control values at every call in the radiation code

Clouds On-Off Klimate Intercomparison Experiments (COOKIE)

- Two AMIP-type experiments from IPSL (Institue Pierre Simon Laplace) AGCM (IPSL-CM5A-LR)

  30-yr control "clouds-on" experiments
  > include full suite of model atmospheric cloud radiative effects (ACREs)

  30-yr "clouds-off" experiments
  > model ACREs are *turned off* in the radiative computation

- Forced by the same observed monthly-mean SSTs and SICs over the period 1979–2008.

- Difference between "cloud-on" and "clouds-off" reveals the impact of ACRE on the model climate given identical surface boundary conditions.

Atmospheric cloud radiative effect (ACRE) in "clouds-on" experiments

From *Li, Thompson and Bony, JCLI 2015*

Total ACREs are dominated by the LW component
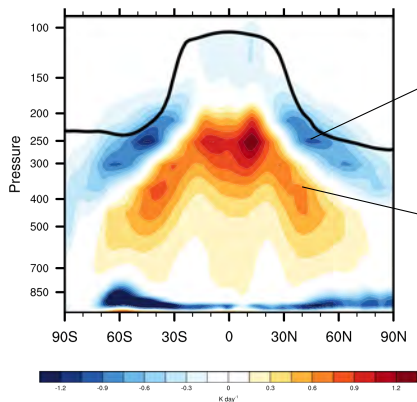
cooling
(longwave emission by cloud tops exceeds that incident from above)
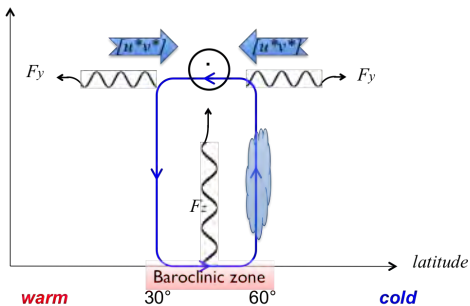
warming
(Trapping of OLR by middle and upper-level clouds)

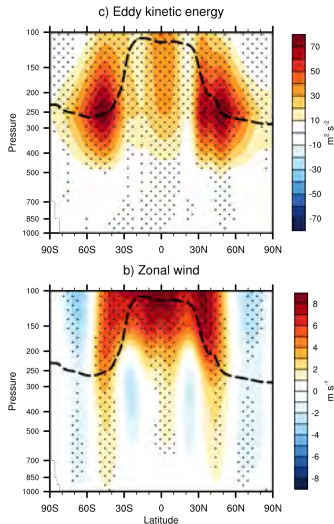increases in upper tropospheric baroclinicity in the midlatitudes

Inclusion of ACRE leads to 1) increases in extratropical EKE, and 2) strengthening of midlatitude jet

Wave activity flux vector:

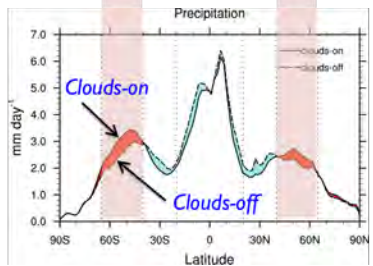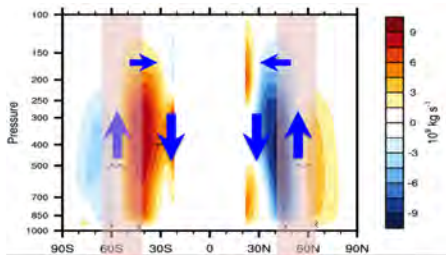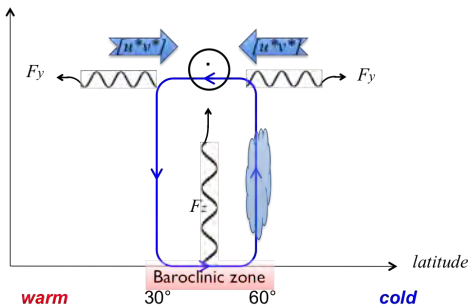$$F_y \propto -[u^*v^*]$$
$$F_z \propto [v^*T^*]$$



From Li, Thompson and Bony, JCLI 2015

Inclusion of ACRE leads to increases in precipitation at middle latitudes but decreases at subtropical latitudes


Eulerian vertical motion follows directly from changes in the momentum flux

From *Li, Thompson and Bony, JCLI 2015*

Inclusion of ACRE leads to 1) strengthening of the Brewer-Dobson circulation, 2) a cooling of the tropical lower stratosphere, and 3) a weakening and warming of the polar vortex

From *Li, Thompson and Huang, JCLI, in press*
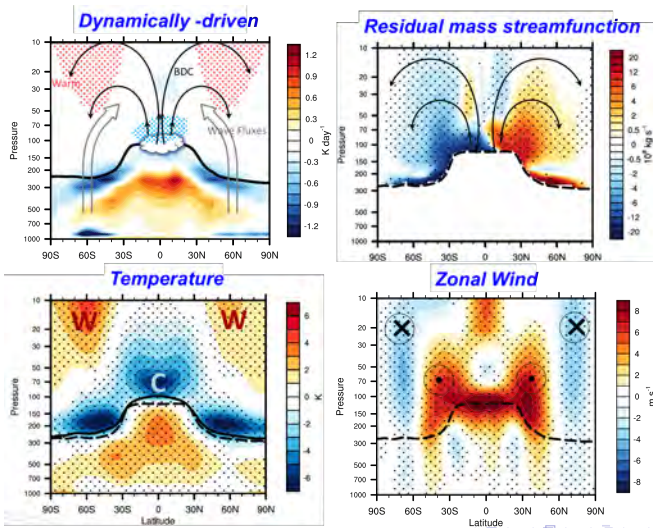
Inclusion of ACRE leads to 1) cooling of the extratropical lower stratosphere, 2) changes in the static stability and 3) increases in cloud fraction near the extratropical tropopause

From *Li, Thompson and Huang, JCLI, in press*
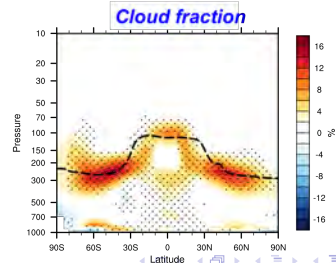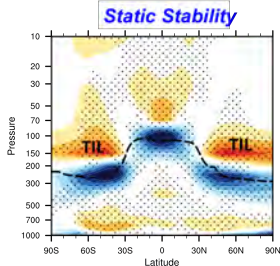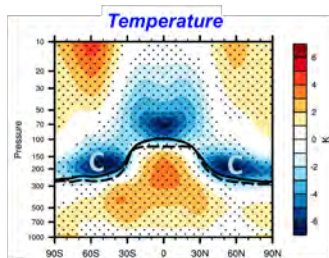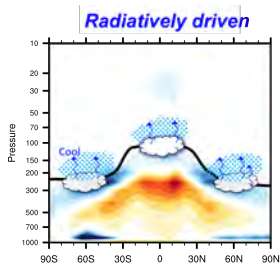
Inclusion of ACRE leads to shortening of the time scale of extratropical stratospheric variability
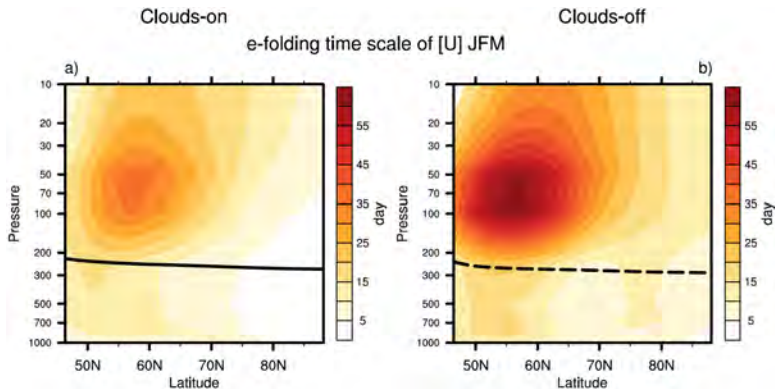
From *Li, Thompson and Huang, JCLI in press*

The shorter time scale of the extratropical stratospheric circulation in the clouds-on experiment are consistent with both the dynamic and radiative components of the responses
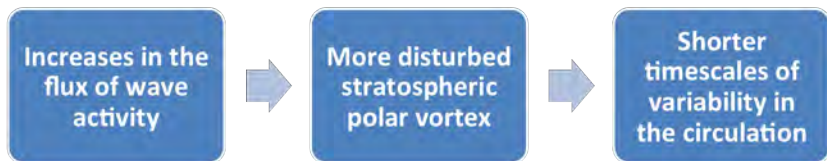
Dynamically -driven

| Increases in the flux of wave activity | → | More disturbed stratospheric polar vortex | → | Shorter timescales of variability in the circulation |

Radiatively -driven

| Negative ACRE imposed in the extratropical upper troposphere | → | Enhanced the amplitude of the local clear-sky radiative cooling rates | → | Shorter local radiative damping timescales | → | Less persistence of the stratospheric flow |

Key results, so far ...

- CloudSAT observations provide unprecedented insight into the influence of large-scale extratropical climate variability on clouds.

- Cloud radiative effects play a central role in determining the structure, amplitude and timescale of the extratropical circulation in climate models.

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Future work

What kind of influence do clouds have on the variability of the atmospheric circulation?

Assessing the influence of CREs on the variability of atmospheric circulation

"cloud locking" method

radiative properties of clouds are locked/prescribed to those in the control simulation in model's radiative transfer scheme at every call of the radiation code

- to quantify various radiative feedbacks (e.g., Wetherald and Manabe 1980, 1988; Hall and Manabe 1999; Schneider et al. 1999; Mauritsen et al. 2013),
- to isolate the atmospheric circulation response to cloud radiative effects from the direct radiative forcing of 4xCO2 (Ceppi and Hartmann 2016; Voigt and Shaw 2016)
- to explore the climate response to the suppression of cloud/circulation interactions (Rädel et al. 2016).

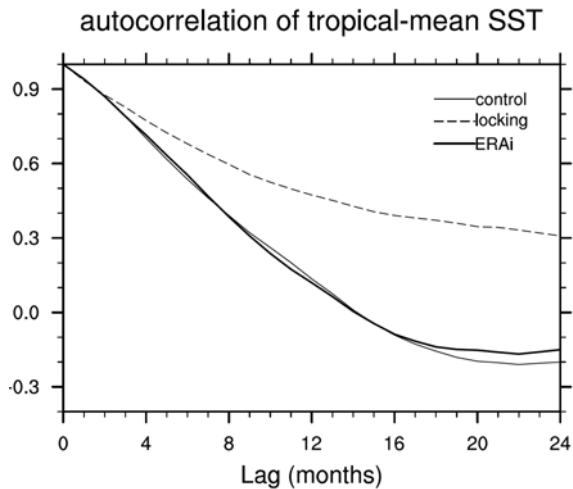Cloud feedbacks have a profound influence not only on the interannual variability in T_s,

Ratio of variance (control/locking)
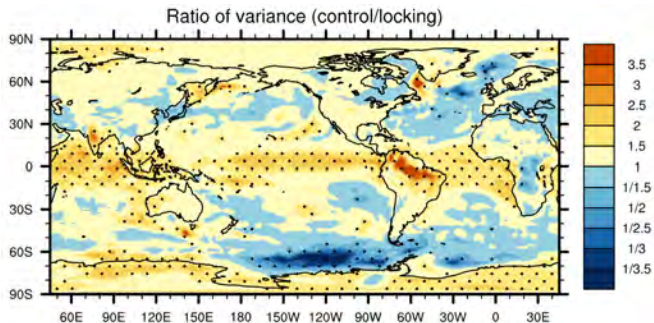
From *Li and Thompson, in preparation*

but also on large scale temperature and wind fields at various levels.

a) ratio (control/locking) temperature

b) ratio (control/locking) zonal wind
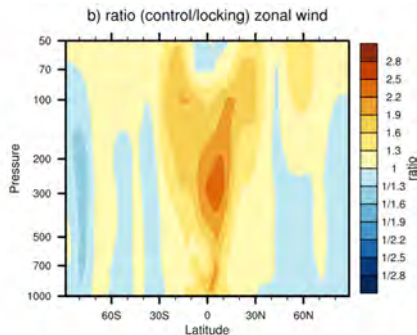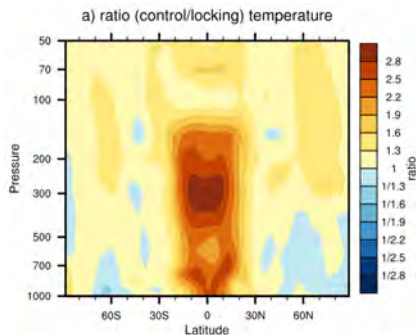
From *Li and Thompson, in preparation*

Cloud feedbacks on the persistence of SST anomalies

autocorrelation of tropical-mean SST

From *Li and Thompson, in preparation*