Mechanisms of the non-constancy of radiative feedbacks

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Discrepancies in ECS estimates due to the pattern effect

CMIP5+6 abrupt4xCO2
150yr-regression

CMIP5+6 ECS (150yr): Zelinka et al. 2020
Discrepancies in ECS estimates due to the pattern effect

CMIP5+6 abrupt4xCO2
150yr-regression

CMIP5+6 abrupt4xCO2
last130yr regression

CMIP5+6 ECS (130yr): Dong et al. 2020
CMIP5+6 ECS (150yr): Zelinka et al. 2020
Discrepancies in ECS estimates due to the pattern effect

- CMIP5+6 abrupt4xCO2 150yr-regression
- AGCM forced observed SST/SIC (amip-piForcing)

CMIP5+6 ECS (amipPF): Andrews et al. 2018; Dong et al. 2021
CMIP5+6 ECS (130yr): Dong et al. 2020
CMIP5+6 ECS (150yr): Zelinka et al. 2020
Discrepancies in ECS estimates due to the pattern effect

CMIP5+6 abrupt4xCO2
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AGCM forced observed SST/SIC
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CMIP5 4xCO2 SST trend (150yr)
CMIP5 4xCO2 OHU trend (150yr)
Outline

Non-constant $\lambda$

$\lambda$ dependence on **surface heat flux** patterns

$\lambda$ dependence on **surface temperature** patterns

Reconcile the two perspectives

Summary and Open questions
Outline

\( \lambda \) dependence on surface heat flux patterns

Non-constant \( \lambda \)

Reconcile the two perspectives

\( \lambda \) dependence on surface temperature patterns

Summary and Open questions
The OHU pattern effect: tropics vs. extratropics

Fully-coupled CESM1 abrupt4xCO2
(Rugenstein et al. 2016)

Transition of OHU from a tropics-centered pattern to an extratropics-centered pattern
The OHU pattern effect: tropics vs. extratropics

Various slab-ocean simulations with distinct zonal bands of qflux forcing

Rose et al. 2014 (GRL)

With the same global mean OHU, more cooling in response to extratropical OHU than to tropical OHU

- Extratropical OHU: less-stabilizing $\lambda$
- Tropical OHU: more-stabilizing $\lambda$
- Mostly from SW cloud $\lambda$

Also see: Winton et al. 2010; Kang and Xie 2014; Rose and Rayborn 2016
The OHU pattern effect: tropics vs. extratropics

Rugenstein et al. 2016 (GRL)

Slab-ocean runs with full patterns of OHU derived from the fully-coupled model under 4xCO2

- As OHU evolves towards a “polar-amplified” pattern, $\lambda$ becomes less negative
- Mostly due to enhanced positive SW cloud $\lambda$

Also see: Winton et al. 2010; Kang and Xie 2014; Rose and Rayborn 2016
The OHU pattern effect: tropics vs. extratropics

Tropical OHU is mostly balanced by local TOA fluxes due to unstable atmosphere.

Extratropical OHU is not balanced locally due to atmospheric stability, thus requires large heat transport into extratropic.

Rugenstein et al. 2016 (GRL)

Also see: Rose et al. 2014; Kang and Xie 2014
Outline

Non-constant $\lambda$

- $\lambda$ dependence on **surface heat flux** patterns
  - Differences in temperature and cloud response to tropical/extratropical OHU

- $\lambda$ dependence on **surface temperature** patterns

Reconcile the two perspectives

Open questions and future work
*Non-constant $\lambda$*

- $\lambda$ dependence on surface heat flux patterns
- Differences in temperature and cloud response to tropical/extratropical OHU

*Reconcile the two perspectives*

$\lambda$ dependence on surface temperature patterns

*Open questions and future work*
Projected changes in $\lambda$ and tropical SST pattern

Andrews et al. 2015 (J. Climate)

Change in net Cloud feedback

Net $\lambda$ (yr1 – 20)

Net $\lambda$ (yr21 – 150)

Net $\Delta\lambda$ (late - early)
Projected changes in $\lambda$ and tropical SST pattern

Dominant role of tropical cloud $\Delta\lambda$ associated with changes in tropical SSTs

Andrews et al. 2015 (J. Climate)
**Historical changes in \( \lambda \) and tropical SST pattern**

\( \Delta \lambda \) over historical period in CMIP5 amip-piForcing runs (w/ observed SST)

Also see:
- **For CMIP6 models**
  - Dong et al. 2021
- **For other individual models**
  - Gregory and Andrews 2016
  - Silvers et al. 2018
  - Gregory et al. 2020
Historical changes in $\lambda$ and tropical SST pattern

$\Delta\lambda$ over historical period in CMIP5 amip-piForcing runs (w/ observed SST)

Zhou et al. 2016 (Nat. Geo.)

$\Delta\lambda_{\text{cloud}}$ arises due to changes in SST patterns

AMIP TS trend (1980-2005)
Historical changes in $\lambda$ and tropical SST pattern

$\Delta \lambda$ over historical period in CMIP5 amip-piForcing runs (w/ observed SST)

$\Delta \lambda_{\text{cloud}}$ arises due to changes in SST patterns mostly associated with tropical marine low clouds that are sensitive to lower tropospheric stability

Andrews & Webb 2017 *(J. Climate)* and lapse-rate feedback!
Tropical mean circulation

Low clouds $\propto$ Inversion Strength (Wood and Bretherton, 2006)

Tropospheric temperature set by SSTs in deep convective regions

Climatology
More-negative $\lambda$ response to enhanced tropical SST W-E SST gradient

Recent observed SST trend pattern (enhanced west-east gradient)

Tropospheric warming

Ascent

Descent

Inversion increase

More negative LR $\lambda$
Negative cloud $\lambda$

Zhou et al. 2016; Andrews and Webb 2017
Less-negative $\lambda$ response to decreased tropical SST W-E SST gradient

Projected equilibrium SST pattern (decreased west-east gradient)

Zhou et al. 2016; Andrews and Webb 2017
Less-negative $\lambda$ response to decreased tropical SST W-E SST gradient

Projected equilibrium SST pattern (decreased west-east gradient)

Zhou et al. 2016; Andrews and Webb 2017
Radiative feedback Green’s functions

Green’s function approach
• A suite of prescribed SST simulations within an AGCM
• Each simulation is forced by a localized patch of SST anomalies

- Useful to quantify local and remote impacts of regional SST changes on TOA radiation/clouds/precipitation/circulation/etc.
- Assuming climate responses remain linear

Zhou et al. 2017 (JAMES) CAM5

Dong et al. 2019 (J. Climate) CAM4
Radiative feedback Green’s functions

Imposed SST anomaly

Surface air-temperature response ($\Delta T$)

Net TOA downward radiation response ($\Delta R$)

Zonal-mean temperature response ($\Delta T$)

(+): down to surface (positive feedback)

(-): Out to space (negative feedback)

Dong et al. 2019 (J. Climate)
Radiative feedback Green’s functions

Global $\lambda$ response to local $\Delta$SST

$\frac{\partial \lambda}{\partial SST}$

CAM5

Zhou et al. 2017

CAM4

Dong et al. 2019

Changes in $\lambda$ primarily determined by relative warming in the west Pacific Warm Pool region with respect to global mean (or tropical mean) warming
GFMIP: inter-model comparison of Green’s functions

Stay tuned for the GFMIP discussion on Friday and individual GF posters on Wednesday!
The tropical SST pattern effect in observations

Low-cloud cover trend (1983-2005) in a satellite product (ISCCP)

Zhou et al. 2016 (Nat. Geo.)

CERES SW CRE times series

Fueglistaler. 2019 (GRL)

Observed SW cloud feedback tracks the ratio between tropical-mean warming and warming over the warmest 30% convective regions
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Non-constant $\lambda$

$\lambda$ dependence on **surface heat flux** patterns

Differences in temperature and cloud response to tropical/extratropical OHU

$\lambda$ dependence on **surface temperature** patterns

Tropical low-cloud feedback and lapse-rate feedback sensitive to the tropical Pacific zonal SST gradient

Reconcile the two perspectives

Summary and Open questions
Is $\lambda$ more sensitive to OHU pattern or SST pattern?

Haugstad et al. 2017 (GRL)

- one slab-ocean run: forced by 2xCO2 and qflux climatology
- one AGCM prescribed-SST run: SST anomaly taken from the coupled slab ocean
- The two have the same SSTs but different surface heat fluxes

Same feedbacks arise from a given SST pattern, regardless the SST pattern is generated by coupled models or prescribed
Is $\lambda$ more sensitive to OHU pattern or SST pattern?

Mitevski et al. *in prep (poster!)*

1. Fully-coupled CESM1 runs: forced by 4xCO$_2$ (2x, 3x,… 8x CO$_2$), run for 150yrs
2. CAM5 runs: prescribe SSTs generated from CESM1

Same feedbacks arise from a given SST pattern, regardless the SST pattern is generated by coupled models or prescribed.
Southern Ocean OHU mostly responsible for changes in $\lambda_{\text{cloud}}$

Lin et al. 2021 (GRL)

CESM abrupt4xCO2 reconstruction using Qflux Green’s function

$\lambda_{\text{cloud}}$ vs. $\lambda_{\text{cloud}}$ (OHU 30S–90S)
Tropical-extratropical OHU vs. tropical West-east SST

Lin et al. 2021 (GRL)

CESM abrupt4xCO2 reconstruction using Qflux Green’s function

$\lambda$ is governed by tropical SST pattern, which itself can be influenced by extratropical OHU

Southern Ocean OHU mostly responsible for changes in $\lambda_{\text{cloud}}$ through changing tropical SSTs via teleconnections
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Non-constant $\lambda$

$\lambda$ dependence on surface heat flux patterns

- Differences in temperature and cloud response to tropical/extratropical OHU

$\lambda$ dependence on surface temperature patterns

- Tropical low-cloud feedback and lapse-rate feedback sensitive to the tropical Pacific zonal SST gradient

Reconcile the two perspectives

$\lambda$ more sensitive to the pattern of SST, though it can be modulated by OHU

Summary and Open questions
Summary and outlook

**Attribution**: What regions/feedbacks are most responsible for the pattern effect?

- The relative role of different regions (aside from the tropical Pacific)?
  - Other tropical basins (Silvers et al. 2018)
  - Southern Ocean (Senior & Mitchell 2011; Armour et al. 2013)
  - North Atlantic (Trossman et al. 2016; Lin et al. 2019; Mitevski et al. in prep)
Summary and outlook

**Attribution**: What regions/feedbacks are most responsible for the pattern effect?

- The relative role of different regions (aside from the tropical Pacific)?
- The relative role of **different feedbacks** (aside from the tropical low-cloud feedback)?
  - Lapse-rate feedback (Andrews and Webb 2017; Ceppi and Gregory 2017)
  - Extratropical cloud feedbacks (Zelinka et al. 2020)
- Do the findings from CMIP5 hold in CMIP6?

Correlation between $\Delta \lambda$ and local $\Delta$SST across **CMIP5** models

Correlation between $\Delta \lambda$ and local $\Delta$SST across **CMIP6** models

Dong et al. 2020 ([J. Climate](https://doi.org/10.1175/JCLI-D-19-0749.1))
Summary and outlook

Methodology: How useful are the Green’s functions for understanding the pattern effect?

• To what extent the key feedback processes are linear/nonlinear w/t to local or global warming?
  o Nonlinearity of feedbacks (Bloch-Johnson 2015; 2021; Meraner et al. 2013)

Cloud Optical depth feedback in CESM2 abrupt4xCO2

Nonlinear state-dependence of Southern Ocean mixed-phase clouds in a CMIP6 model

Bjordal et al. 2021 (Nat. Geo.)
Non-constant $\lambda$

$\lambda$ dependence on surface heat flux patterns
Differences in temperature and cloud response to tropical/extratropical OHU

$\lambda$ dependence on surface temperature patterns
Tropical low-cloud feedback and lapse-rate feedback sensitive to the tropical Pacific zonal SST gradient

Reconcile the two perspectives
The OHU pattern effect comes about through changing SST pattern

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