# What can we learn from the spectral longwave feedback analysis?

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# Outlines

- Spectral longwave radiative feedbacks
  - Definitions and motivations
  - Spectral radiative kernel: derive spectral long-wave feedbacks from the CMIP3/5 archives
- Case study 1: LW water-vapor feedbacks
- Case study 2: "Engineering climate sensitivity" (ongoing)
- Conclusions and discussions
- Other updates

# Spectral LW radiative feedbacks: defintion

Averages of net TOA **broadband** flux R(x,y;t)

$$\lambda_X = -\frac{\delta_X \overline{R}}{\delta X}\frac{\delta X}{\delta T_s}$$

$Wm^{-2}\,K^{-1}$

Change of global-mean surface temperature

X : [Temp, WV, cloud, albedo]

(Soden et al., 2008)

$\overline{R}$ has another dimension, the frequency $v$

Spectral radiative feedbacks

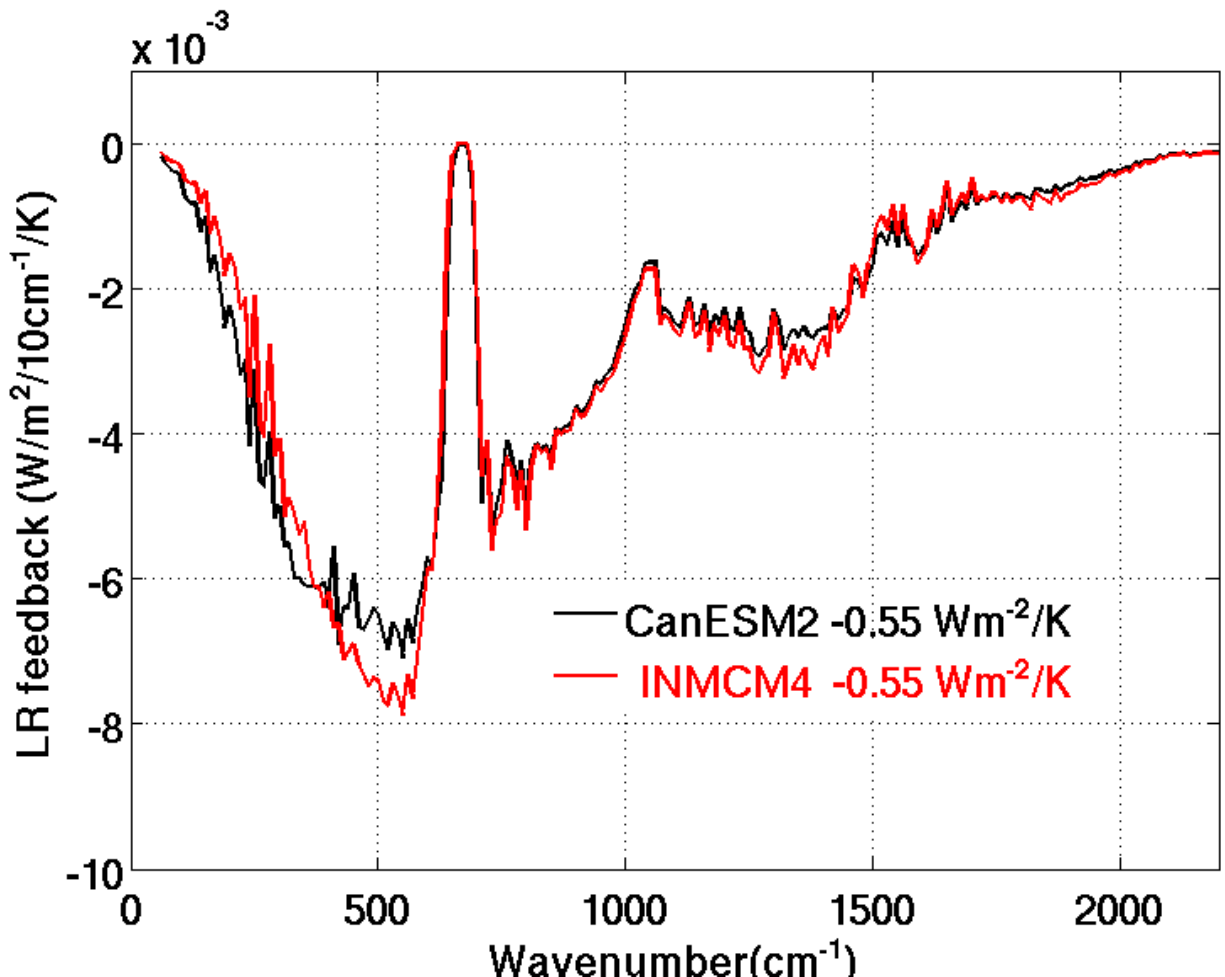
$$\lambda_{x_v} = -\frac{\delta_x \overline{R_v}}{\delta X}\frac{\delta X}{\delta T_s}$$

$Wm^{-2}\,cm^{-1}\,K^{-1}$

# What spectral dimension can offer?

*Reveal compensating differences that cannot be revealed in broadband diagnostics alone.*

# Example: Spectral decomposition of broadband lapse-rate feedback

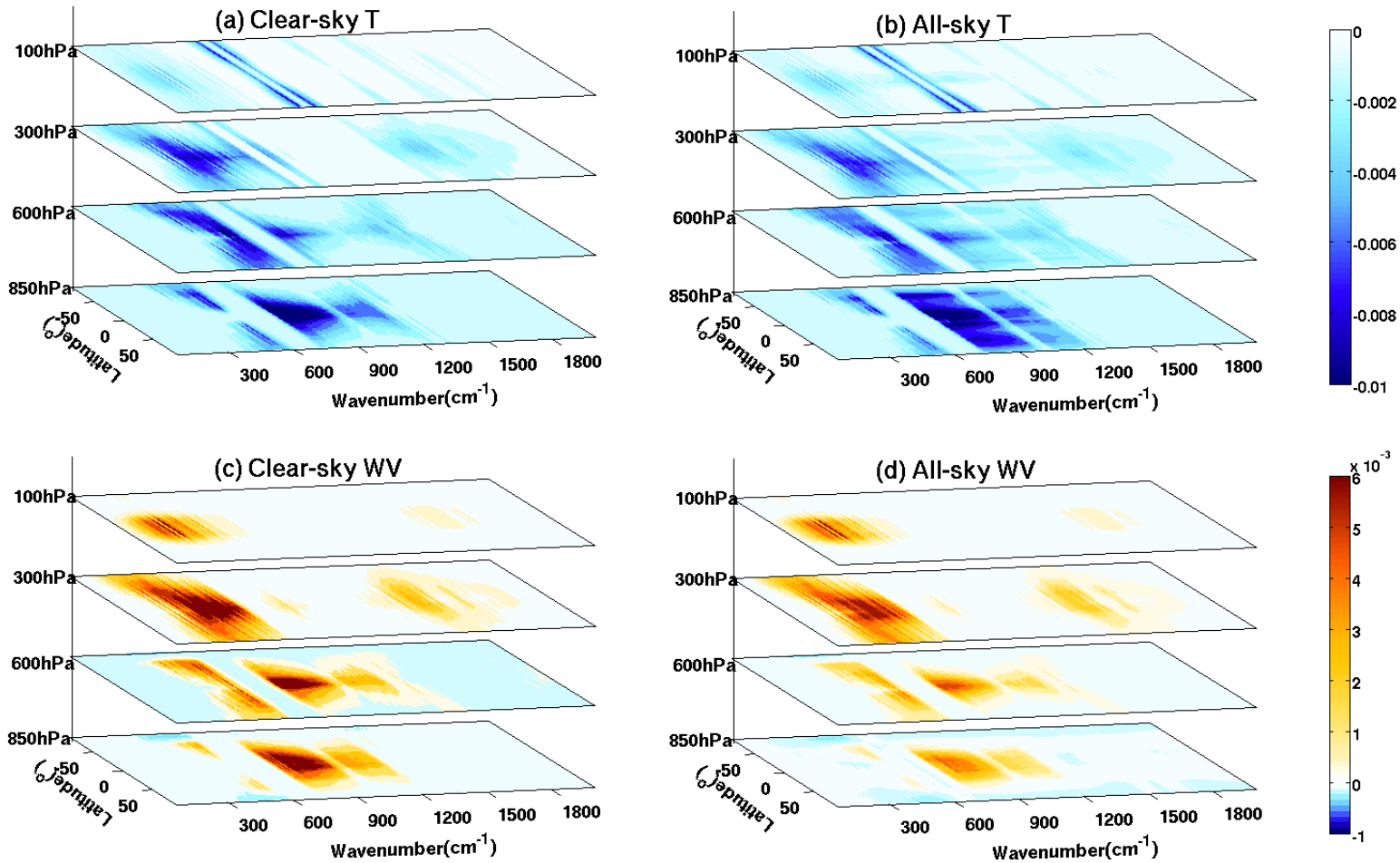



**Contribution to ΔTs @2x$CO_2$**

| | 0-400 LR |
|---|---|
| CanESM2 | -0.08K |
| INMCM4 | -0.04K |

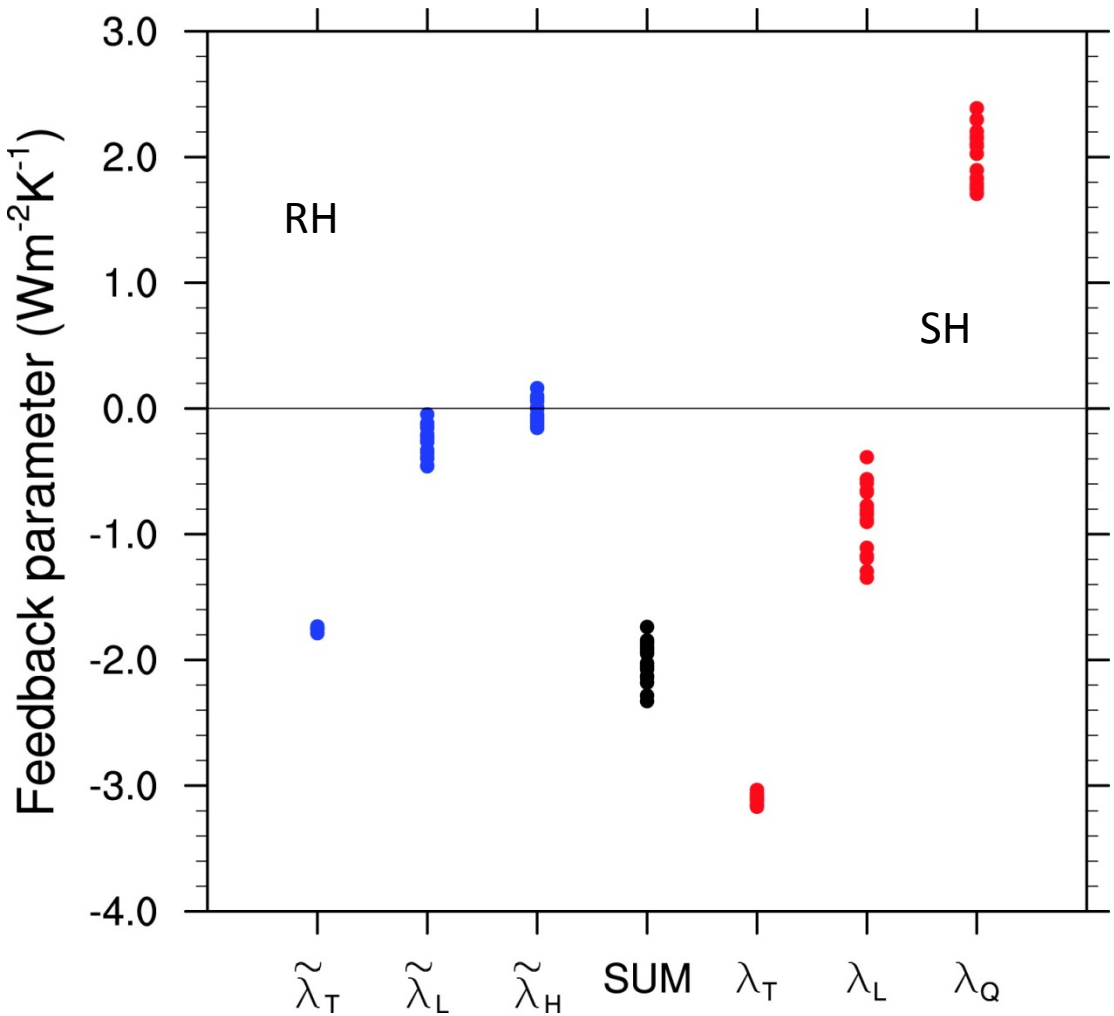
# How to obtain them?

- Huang et al. (2014, GRL) developed and validated spectral radiative kernel techniques to compute spectral LW feedbacks from the CMIP3/5 monthly-mean archives.



- Spectral information, though useful, could be also overwhelming.
- How to make best use of it in model diagnostics and data-model evaluation?

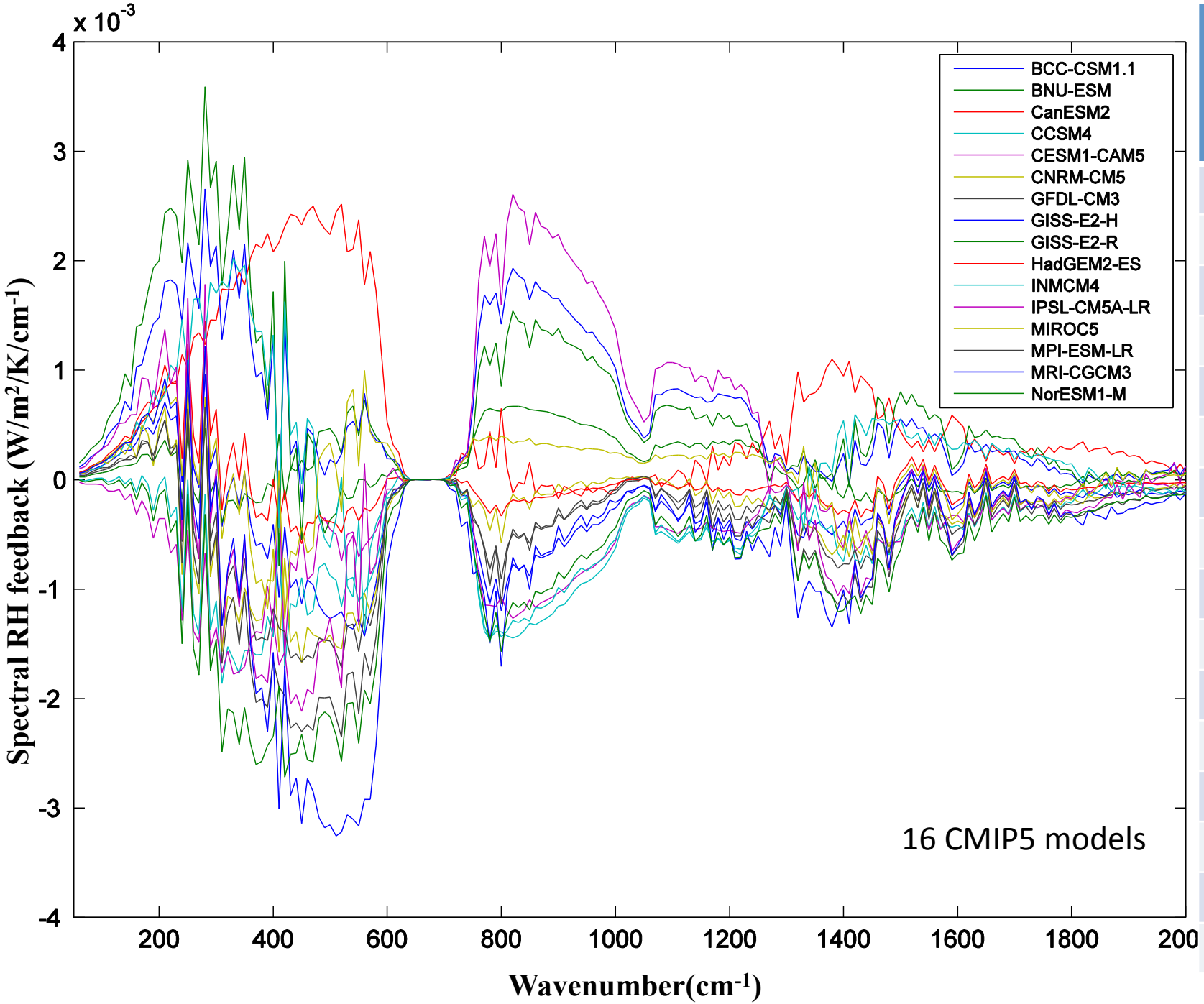
# Case1: Water-vapor feedback using RH as state variable



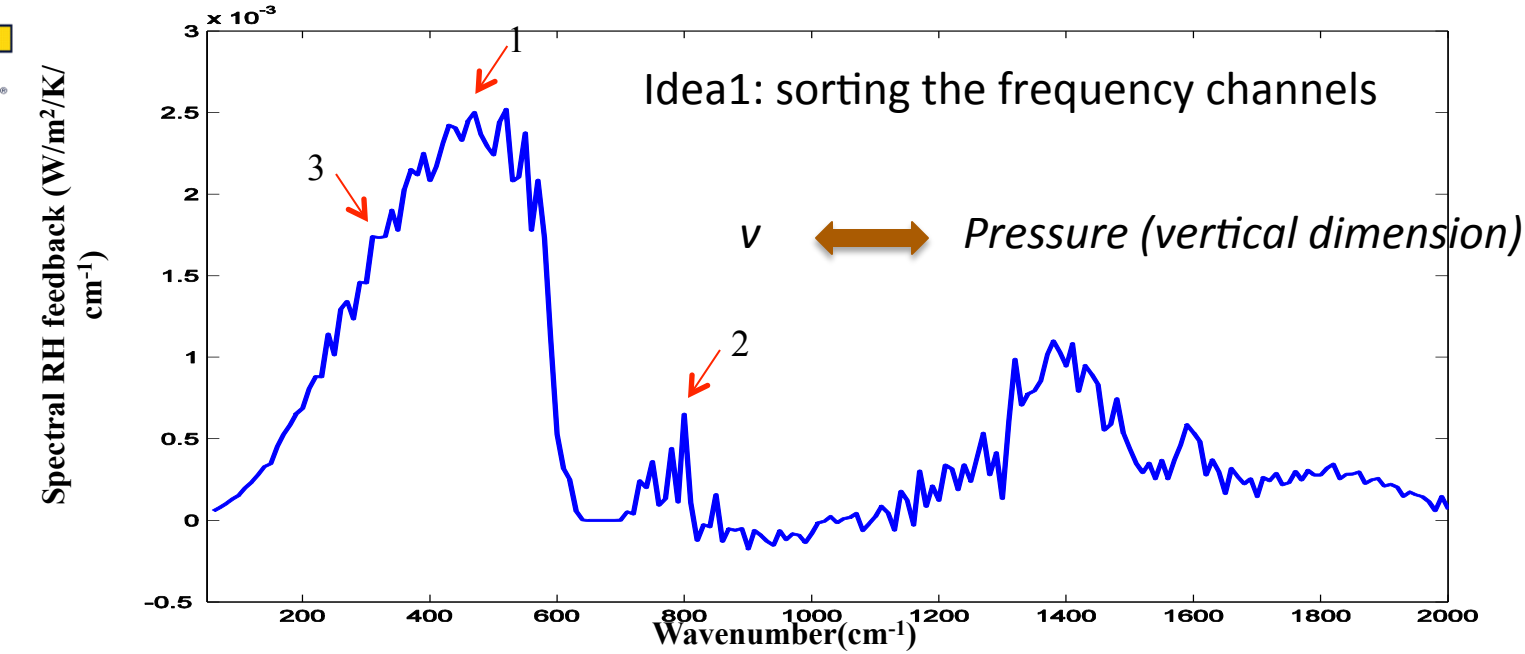

CMIP3 models

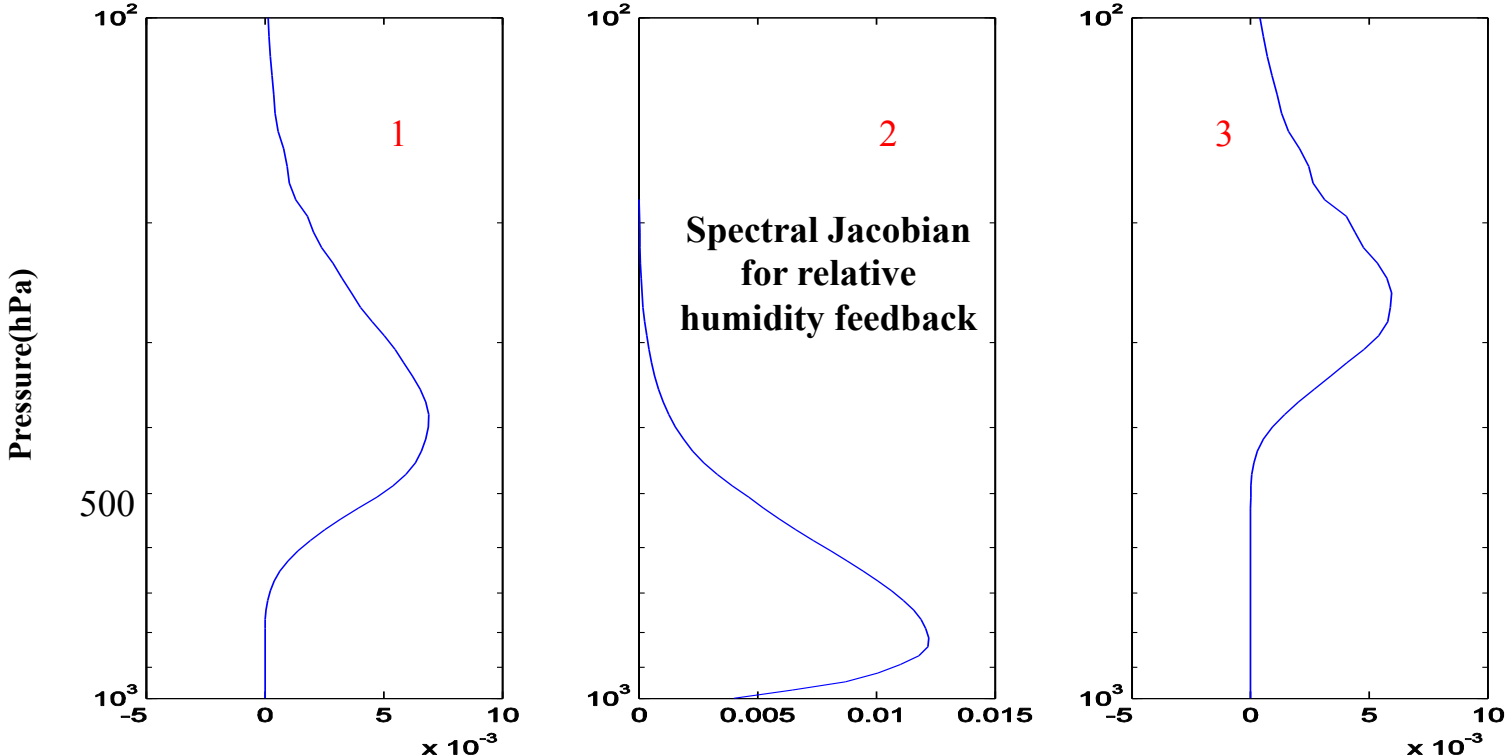
(Held and Shell, 2012)

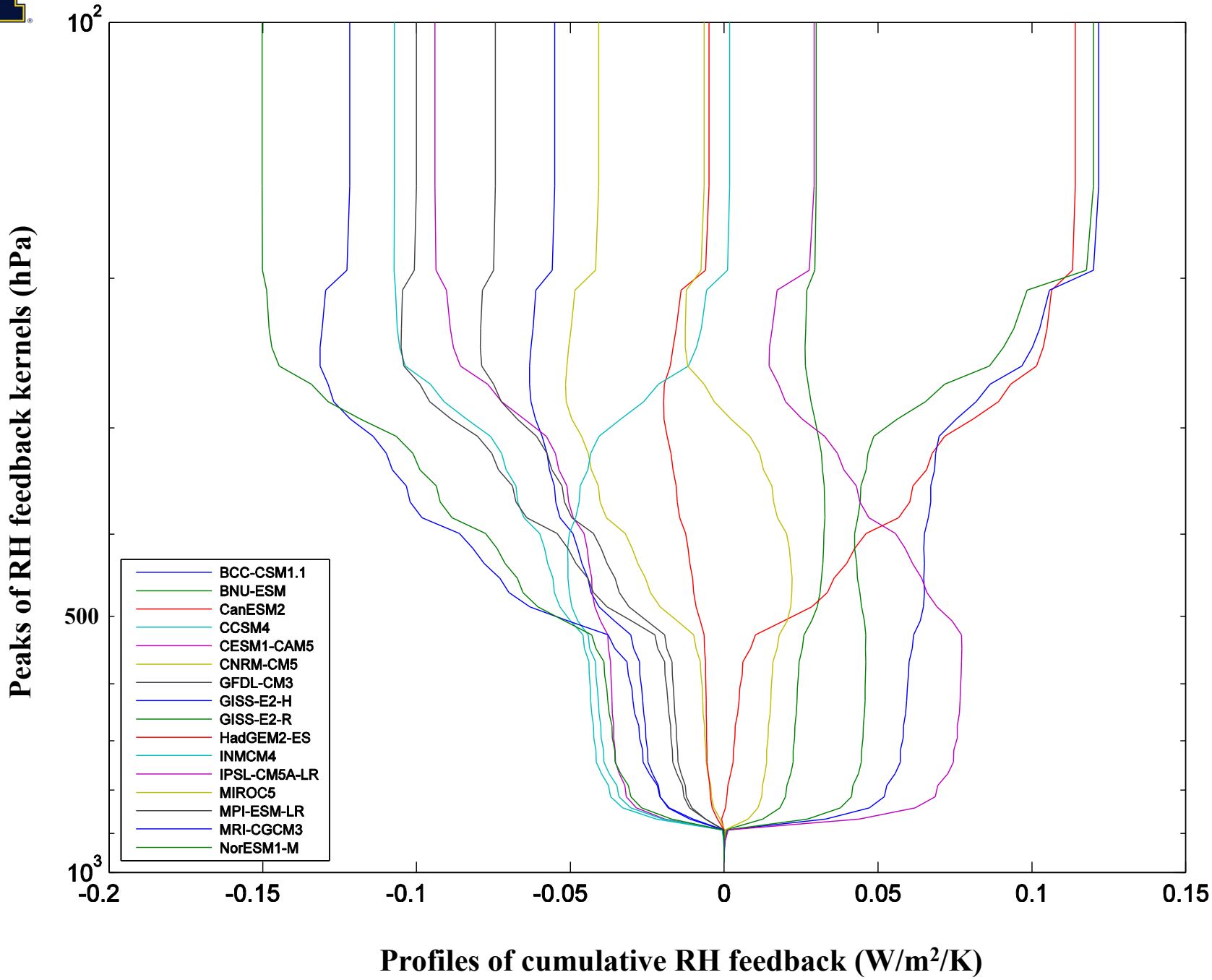
**The puzzle of "constant relative humidity"**



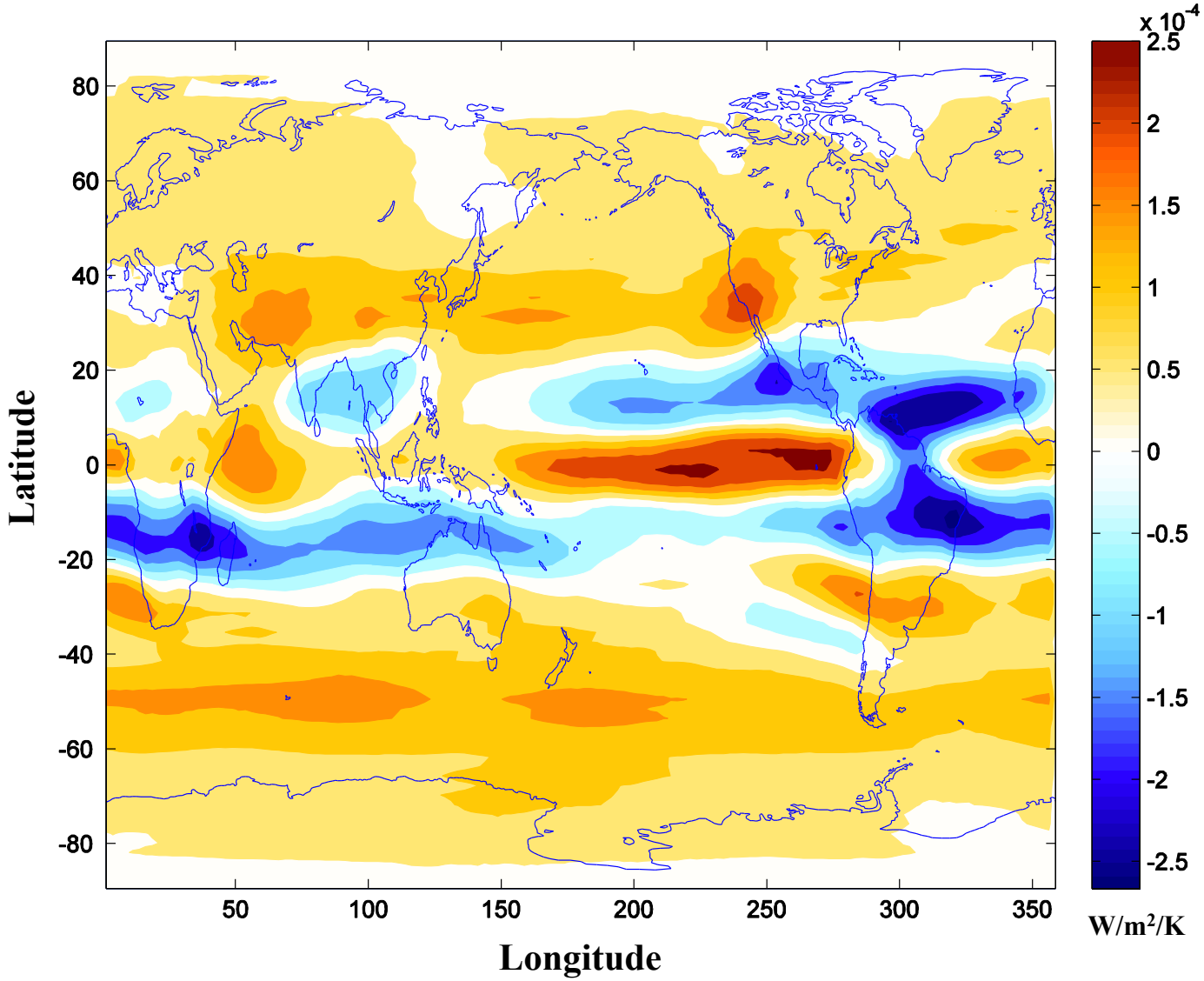

| Broadband RH feedback ($W/m^2/K$) |
|---|
| -0.055 |
| 0.030 |
| 0.114 |
| -0.107 |
| -0.094 |
| -0.041 |
| -0.074 |
| 0.122 |
| 0.120 |
| -0.005 |
| 0.002 |
| 0.029 |
| -0.007 |
| -0.100 |
| -0.122 |
| -0.150 |


Idea1: sorting the frequency channels
v
Pressure (vertical dimension)
Spectral RH feedback (W/m²/K/cm⁻¹)
Wavenumber(cm⁻¹)
x 10⁻³
1
2
3

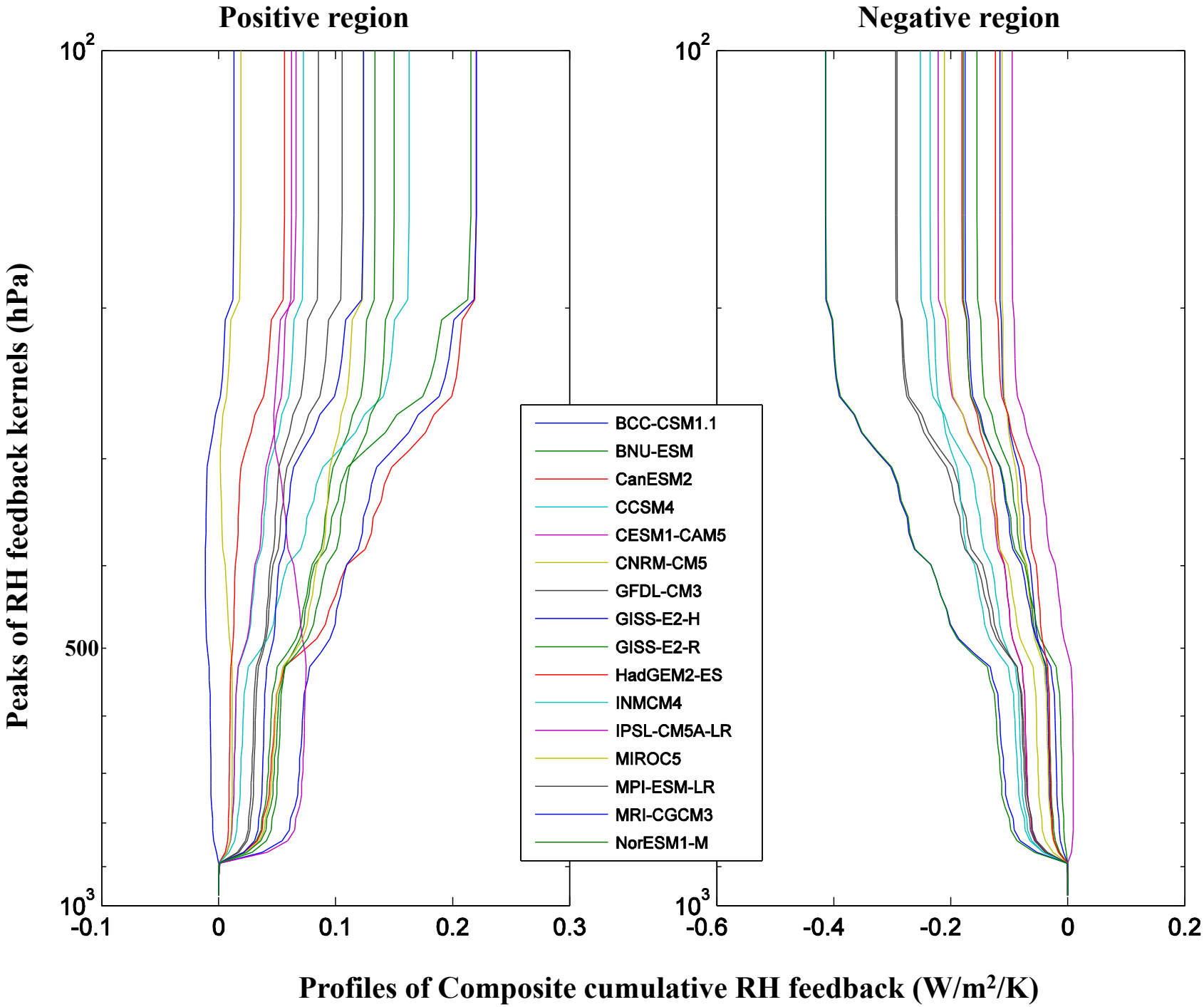

Spectral Jacobian for relative humidity feedback
Pressure(hPa)
500
1
2
3
x 10⁻³

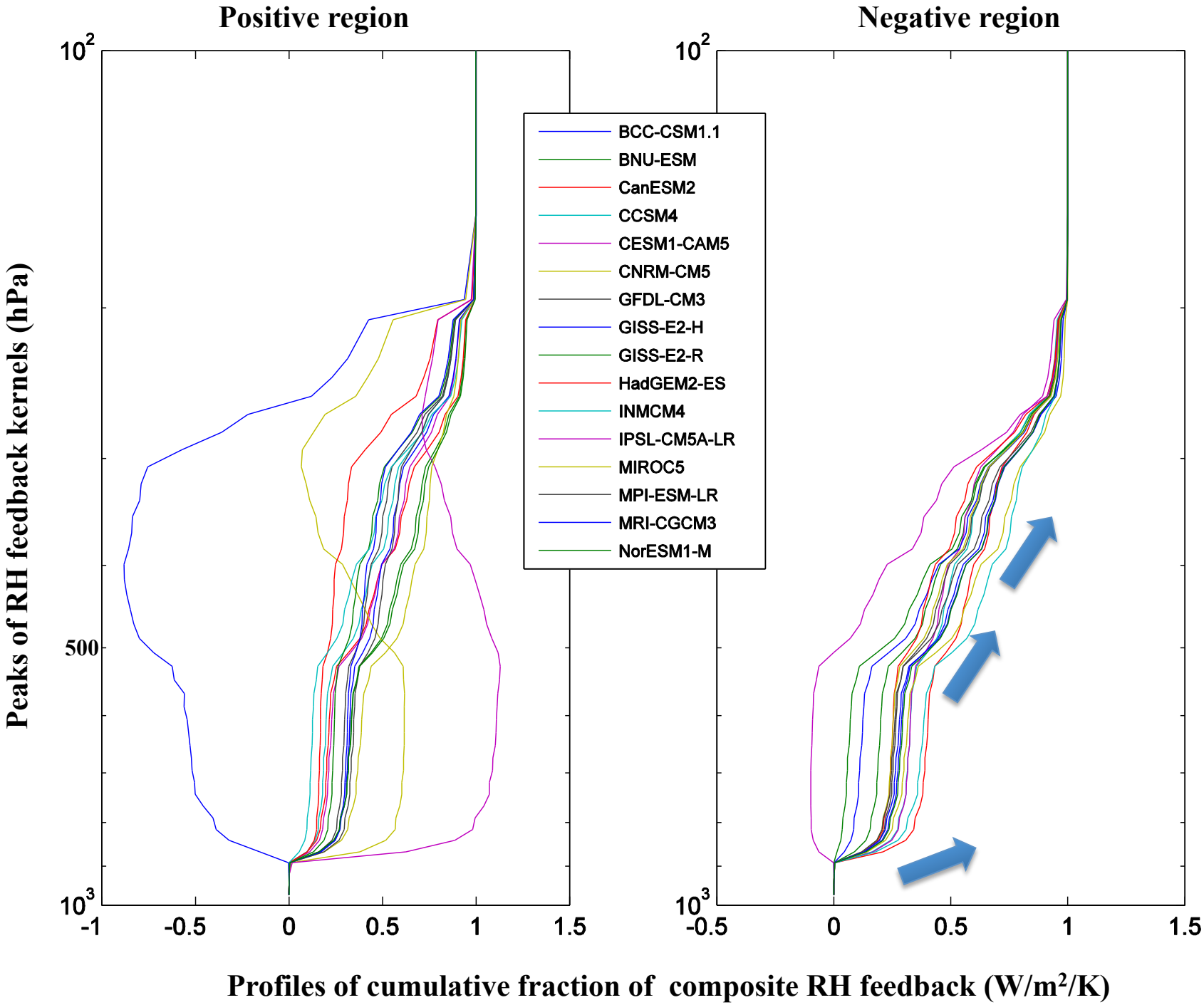

Peaks of RH feedback kernels (hPa)
Profiles of cumulative RH feedback (W/m2/K)
10^2
500
10^3
-0.2
-0.15
-0.1
-0.05
0
0.05
0.1
0.15
BCC-CSM1.1
BNU-ESM
CanESM2
CCSM4
CESM1-CAM5
CNRM-CM5
GFDL-CM3
GISS-E2-H
GISS-E2-R
HadGEM2-ES
INMCM4
IPSL-CM5A-LR
MIROC5
MPI-ESM-LR
MRI-CGCM3
NorESM1-M

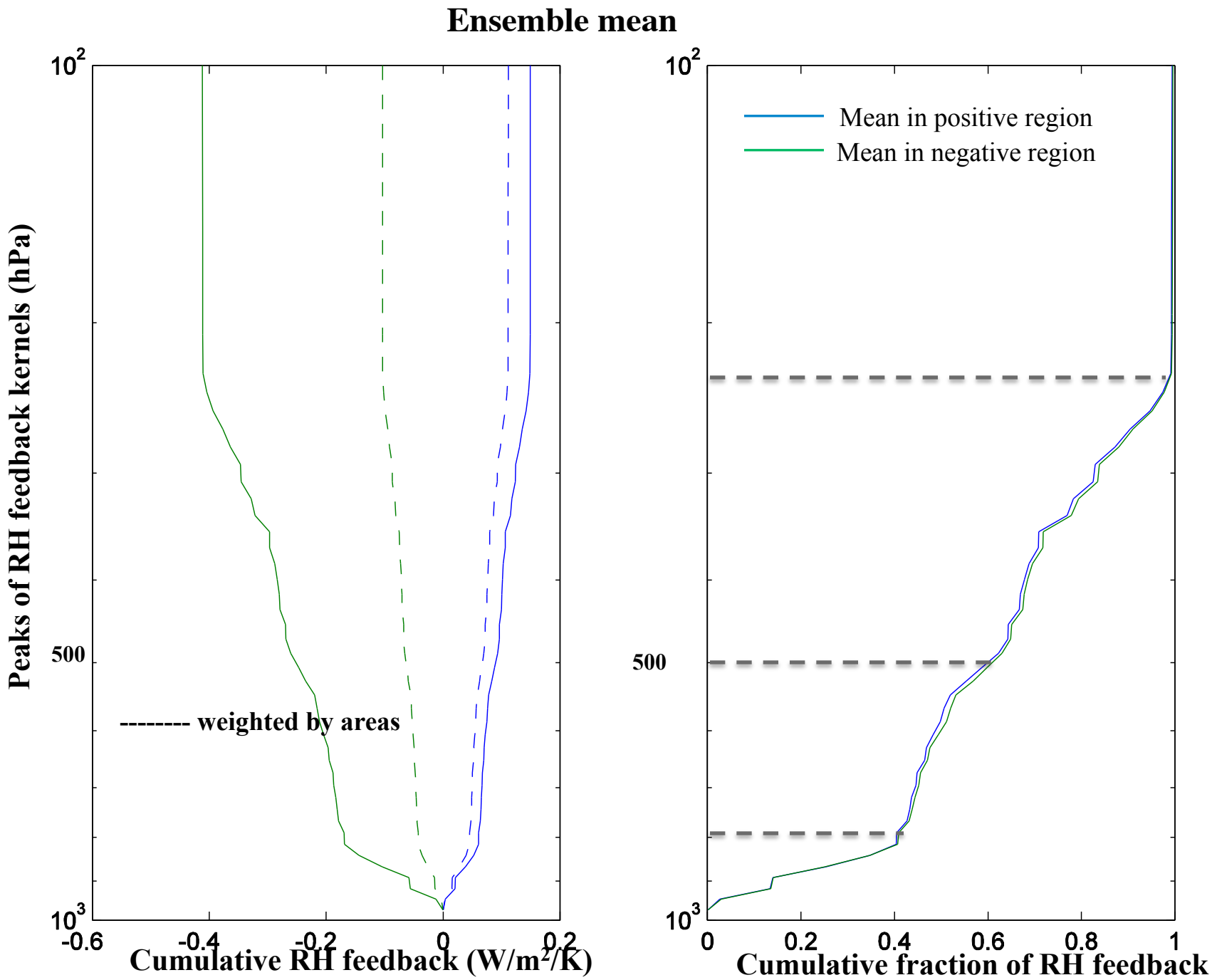
# Spatial distribution of broadband RH feedback: ensemble mean of the CMIP5 models




**Further composite with respect to the positive and negative RH-feedback regions**


Positive region
Negative region
Peaks of RH feedback kernels (hPa)
Profiles of Composite cumulative RH feedback (W/m²/K)
10²
500
10³
-0.1
0
0.1
0.2
0.3
-0.6
-0.4
-0.2
0
0.2
BCC-CSM1.1
BNU-ESM
CanESM2
CCSM4
CESM1-CAM5
CNRM-CM5
GFDL-CM3
GISS-E2-H
GISS-E2-R
HadGEM2-ES
INMCM4
IPSL-CM5A-LR
MIROC5
MPI-ESM-LR
MRI-CGCM3
NorESM1-M


Positive region
Negative region
Peaks of RH feedback kernels (hPa)
Profiles of cumulative fraction of composite RH feedback (W/m²/K)
10²
500
10³
-1
-0.5
0
0.5
1
1.5
BCC-CSM1.1
BNU-ESM
CanESM2
CCSM4
CESM1-CAM5
CNRM-CM5
GFDL-CM3
GISS-E2-H
GISS-E2-R
HadGEM2-ES
INMCM4
IPSL-CM5A-LR
MIROC5
MPI-ESM-LR
MRI-CGCM3
NorESM1-M


Ensemble mean
Peaks of RH feedback kernels (hPa)
$10^2$
500
$10^3$
-0.6
-0.4
-0.2
0
0.2
Cumulative RH feedback (W/m²/K)
-------- weighted by areas
Mean in positive region
Mean in negative region
0
0.2
0.4
0.6
0.8
1
Cumulative fraction of RH feedback

# Case2



## Uncertainty in Model Climate Sensitivity T
## of Cumulus Precipitation Mi

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L. J. DONNER, AND D. PAY

*NOAA/Geophysical Fluid Dynamics Laboratory,*

H. GUO

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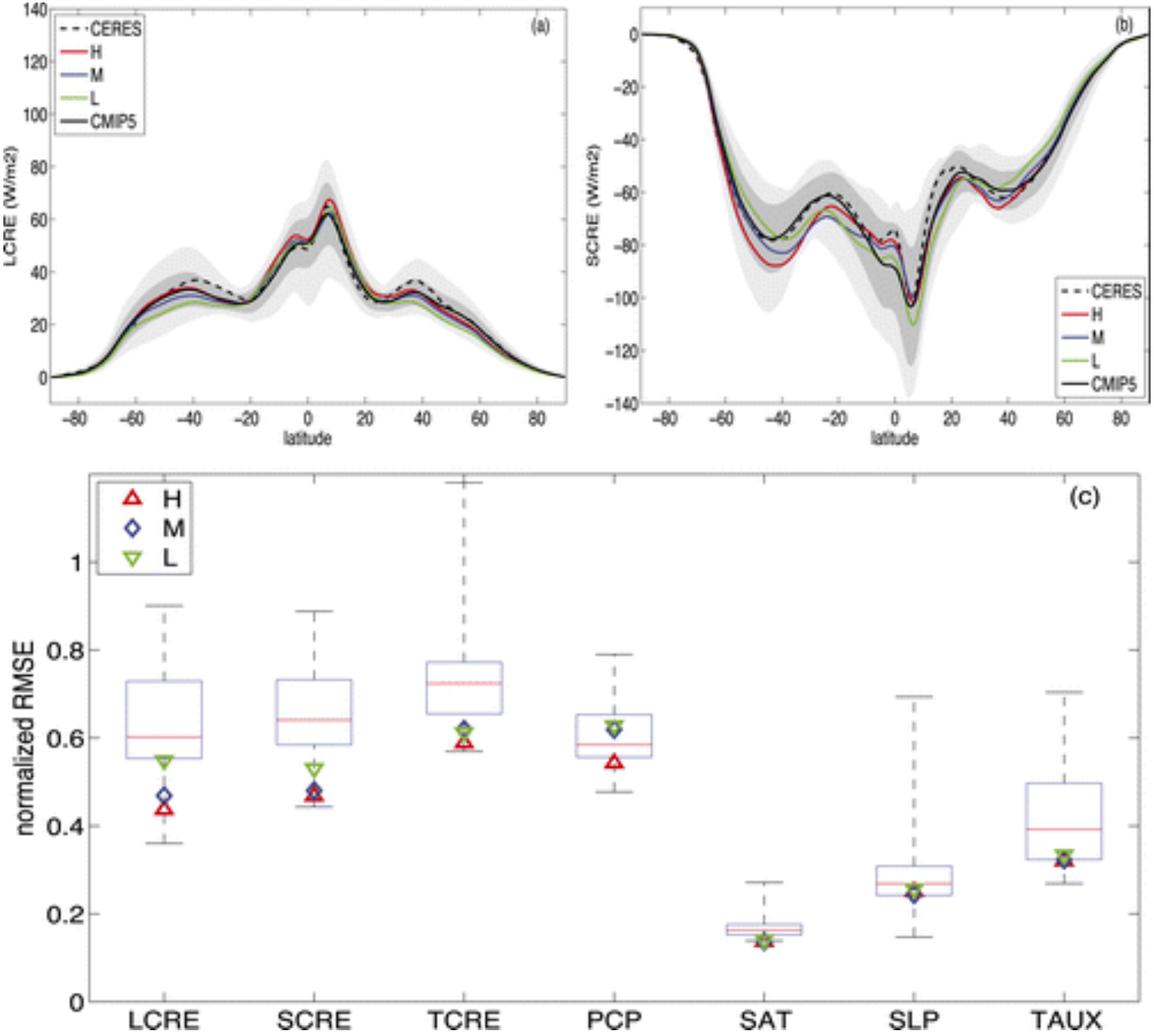
*University Corporation for Atmospheric Researc*

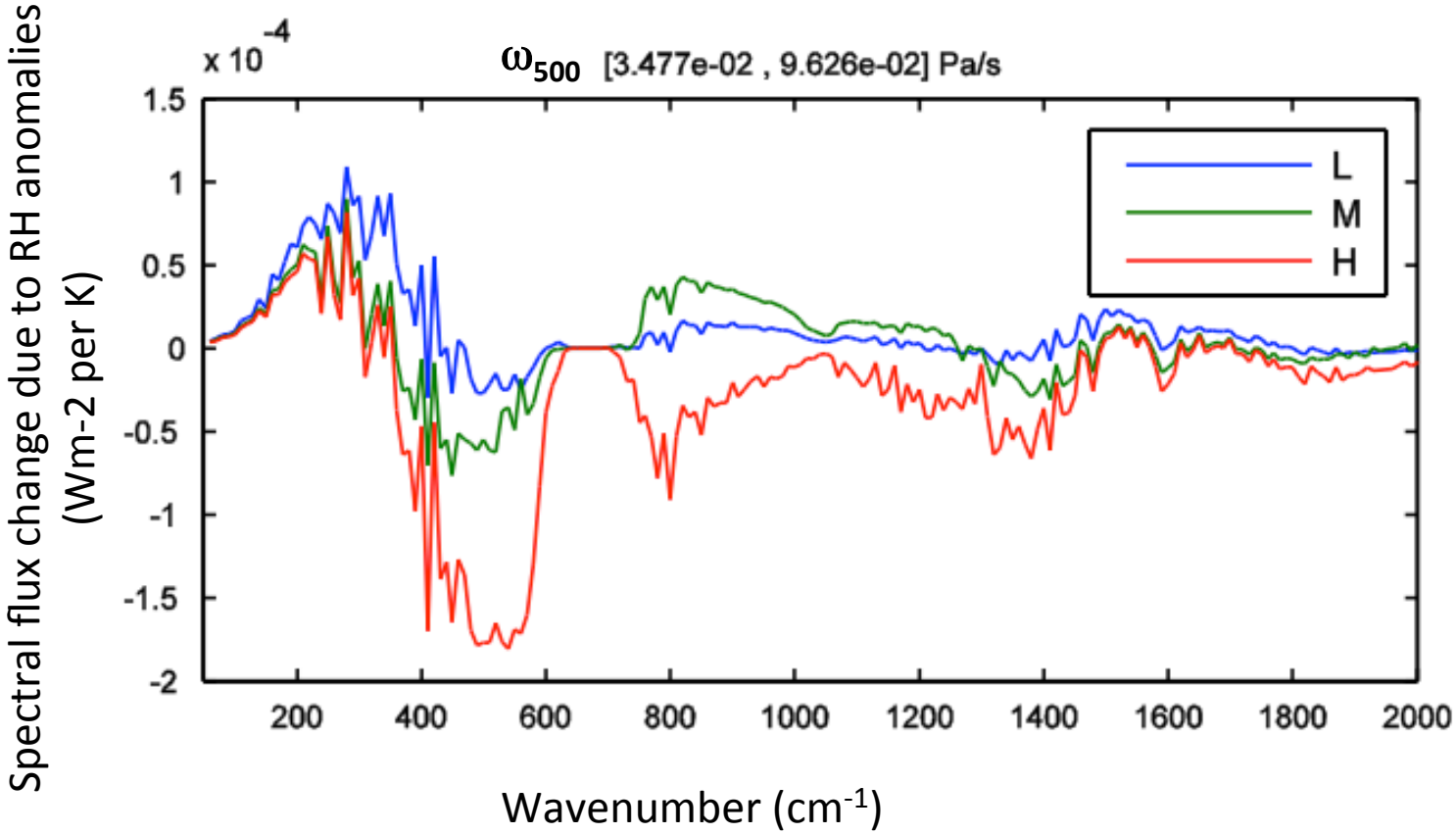
TABLE 1. A list of the parameters used in the convective precipitation schemes in H, M, and L models and some of their simulated global quantities. See text for the definition of the parameters. The global quantities include the Cess climate sensitivity parameter, TOA total CRE and its LW and SW component, the low, middle, and high cloud amount, the cloud liquid and ice water path, and the precipitation.

| Parameters used | H | M | L |
|---|---|---|---|
| $q_0$ (g kg$^{-1}$) | 1.5 | 0.8 | 0.8 |
| $T_{crit}$ (°C) | −90 | — | — |
| $\beta_l$ (Pa$^{-1}$) | — | $1.5 \times 10^{-5}$ | $4.0 \times 10^{-5}$ |
| $\beta_i$ (Pa$^{-1}$) | — | $3.0 \times 10^{-5}$ | $8.5 \times 10^{-5}$ |
| $\alpha$ | — | 4 | 1 |
| Model-simulated global quantities | | | |
| Cess climate sensitivity (K W$^{-1}$ m$^2$) | 0.82 | 0.53 | 0.48 |
| TOA TCRE (W m$^{-2}$) | −24.2 | −24.7 | −24.8 |
| TOA LCRE (W m$^{-2}$) | 25.9 | 24.7 | 23.8 |
| TOA SCRE (W m$^{-2}$) | −50.1 | −49.4 | −48.6 |
| Low cloud amount (%) | 37.0 | 36.3 | 34.7 |
| Middle cloud amount (%) | 17.5 | 17.9 | 17.8 |
| High cloud amount (%) | 37.7 | 36.4 | 36.1 |
| Liquid water path (g m$^{-2}$) | 47.1 | 47.9 | 47.3 |
| Ice water path (g m$^{-2}$) | 50.0 | 43.4 | 47.0 |
| Precipitation (mm day$^{-1}$) | 3.00 | 3.00 | 3.01 |




(Zhao et al., 2016)

# What "current-climate observations" can differentiate the H/M/L models?



# Conclusions and discussions

- Spectral information is under-utilized in current climate studies, yet it can be of help in many constraints and diagnostics.
- The “constant relative humidity” is largely due to a cancellation across the globe. The cancellation exists for every pressure level.
- Contributions: Lower troposphere vs. upper troposphere
- Different ways of utilizing the spectral info

# Other updates

- We have processed spectral flux from 2002 to 2015 using collocated AIRS v6 and CERES (Ed2, Ed3, Ed4)
  - Footprint-level and monthly gridded spectral flux
  - http://www-personal.umich.edu/~xianglei/datasets.html
- We have developed a global surface spectral emissivity data set (including far-IR), which is anchored on MODIS retrievals and validated against IASI retrievals.
  - Incorporate this into the CESM
  - Correct bias in simulated upward LW flux at surface
  - Impact on simulated climate

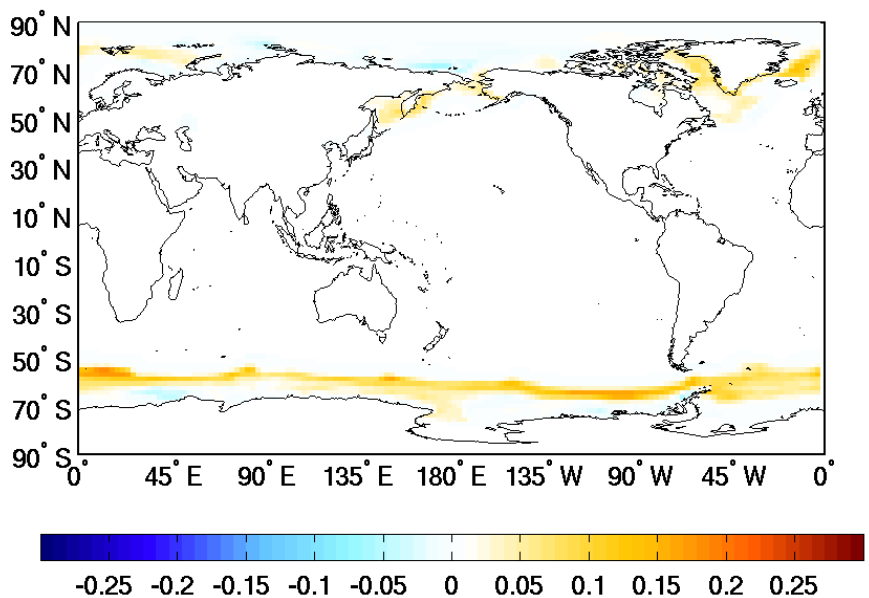
# Impact of the radiation budget and column radiative cooling

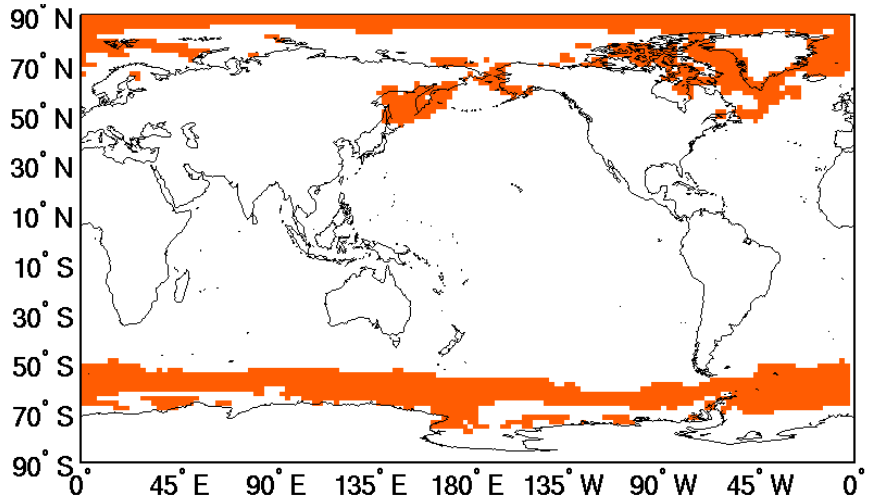
| Control runs at 2000s forcing | CESM Slab Ocean (15-year avg ) | | Fully Coupled CESM (18-year avg) | |
|---|---|---|---|---|
| | Standard | Modified – Standard **diff** | Standard | Modified-Standard **diff** |
| **Surface (all in $Wm^{-2}$)** | | | | |
| LW flux↑ | 401.0 | -5.7 | 400.7 | -4.0 |
| LW flux↓ | 344.3 | -4.5 | 343.8 | -2.6 |
| SW flux↑ | 22.9 | 0.5 | 22.7 | 0.3 |
| SW flux↓ | 181.5 | 0.5 | 181.5 | 0.2 |
| Latent heat flux | 83.3 | -1.3 | 83.7 | -0.5 |
| Sensible heat flux | 18.0 | 0.5 | 18.0 | 0.5 |
| **TOA (all in $Wm^{-2}$)** | | | | |
| LW flux↑ | 233.7 | -2.3 | 233.7 | -1.8 |
| SW flux↑ | 106.7 | 0.5 | 106.6 | 0.3 |
| | | | | |
| **Col. Rad. Cooling ($Wm^{-2}$)** | 101.9 | -0.6 | 101.7 | -0.1 |
| **Precip Rate (mm/ day)** | 2.88 | -0.04 | 2.87 | -0.02 |
| **Ts** | 288.65 | -0.20 | 288.61 | 0.13 |

- Modified untuned version
- If model is tuned to TOA balance first, surface flux difference is even larger

**Slab ocean run, 20-year average**

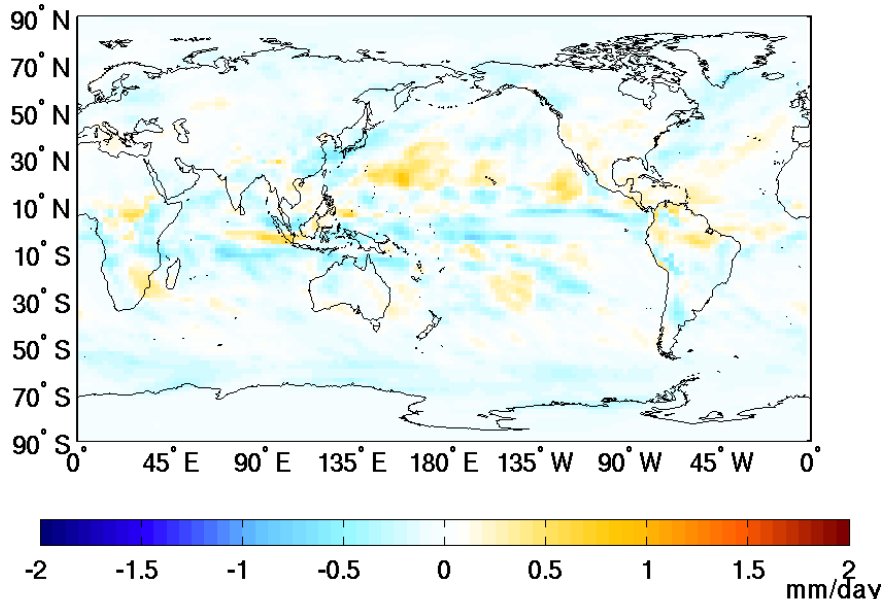
## (Modified – Standard) Sea Ice Fraction

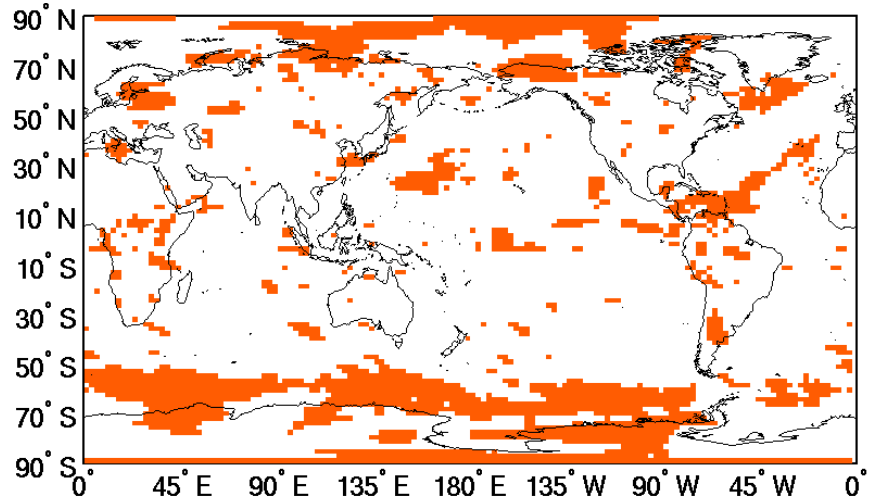



Colored cells are significant at the 0.05 level

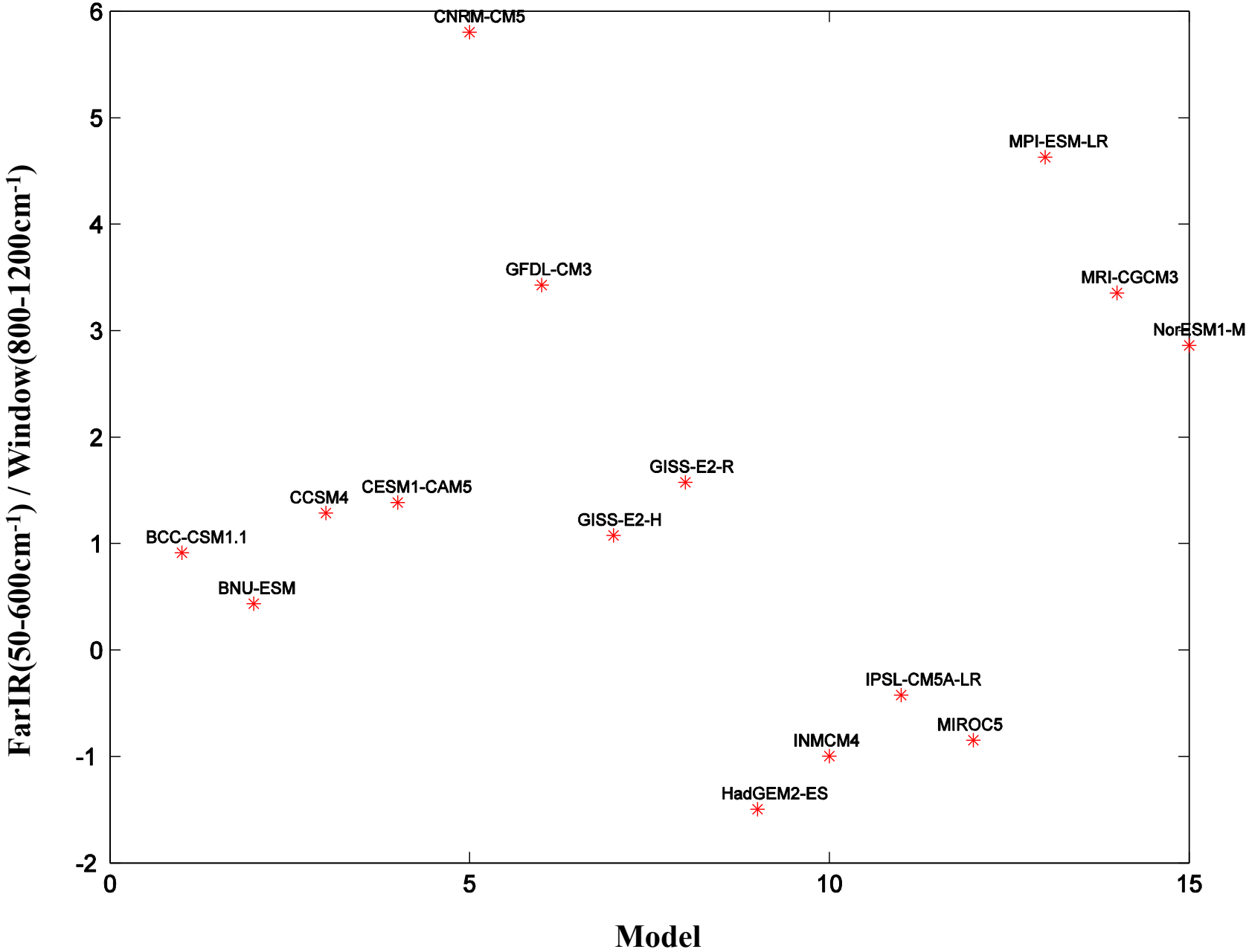
## (Modified – Standard) Precip Rate



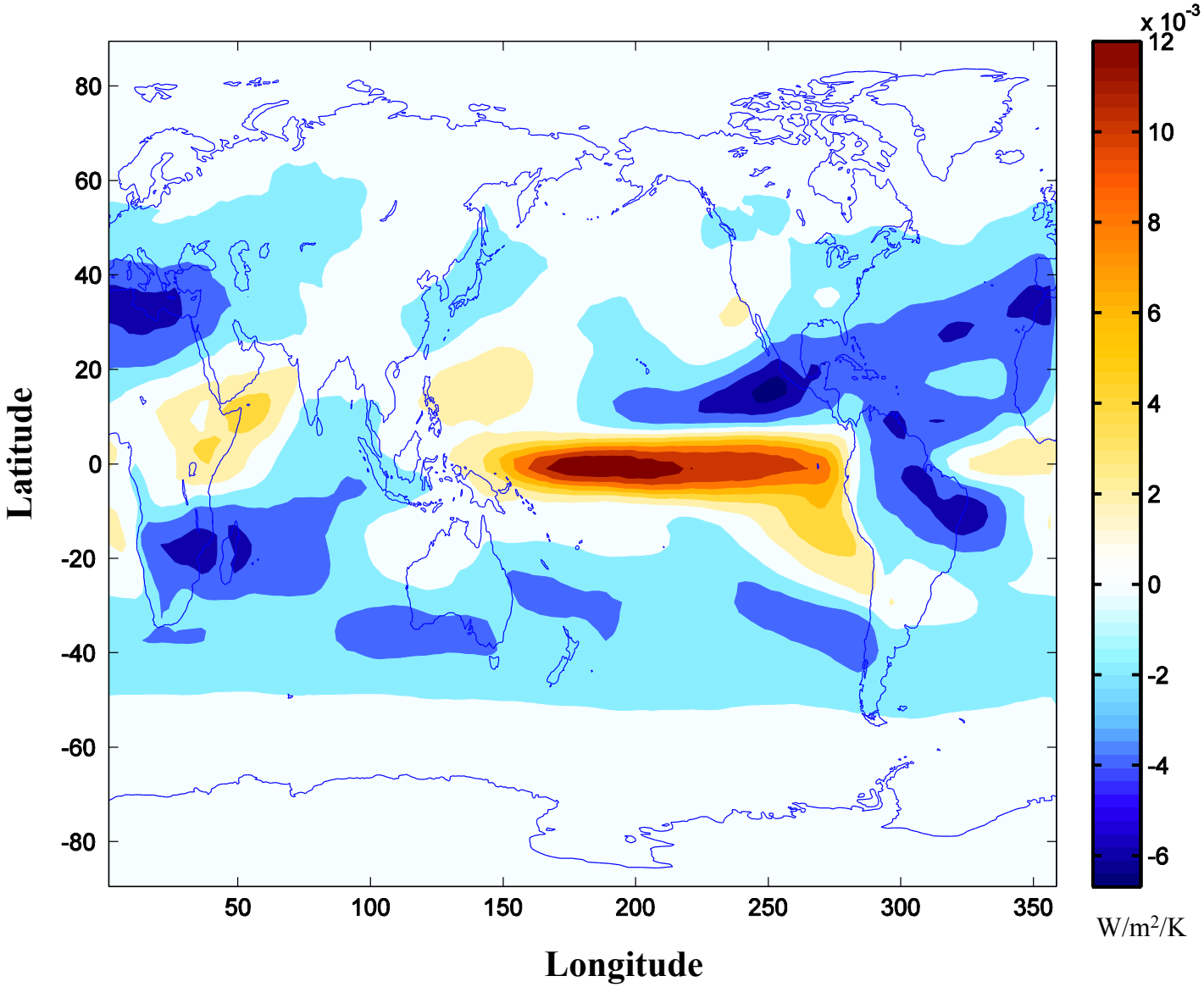




Colored cells are significant at the 0.05 level

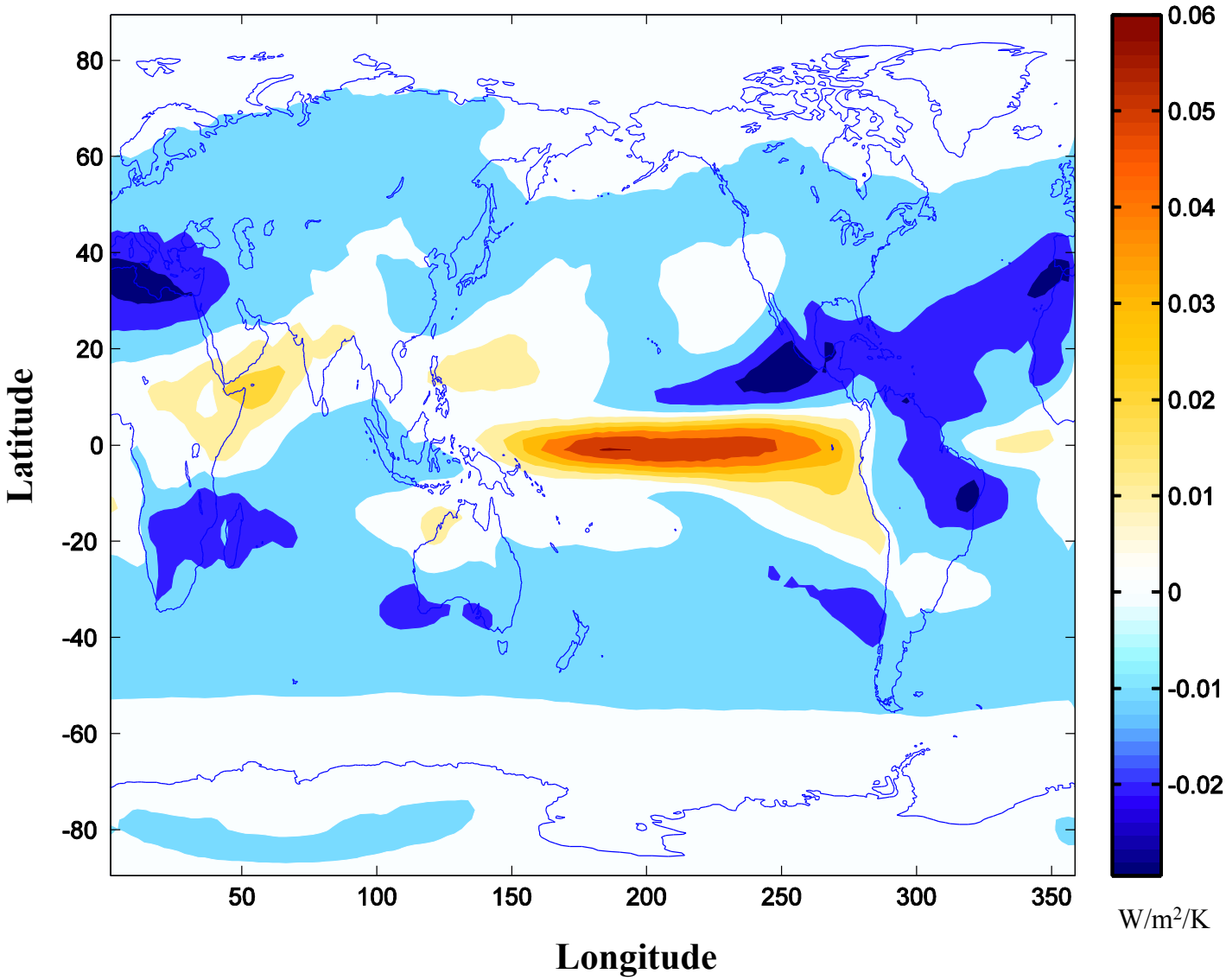
# Thank You!


CNRM-CM5
MPI-ESM-LR
GFDL-CM3
MRI-CGCM3
NorESM1-M
GISS-E2-R
CESM1-CAM5
CCSM4
GISS-E2-H
BCC-CSM1.1
BNU-ESM
IPSL-CM5A-LR
MIROC5
INMCM4
HadGEM2-ES
6
5
4
3
2
1
0
-1
-2
0
5
10
15
FarIR(50-600cm-1) / Window(800-1200cm-1)
Model

# Mean broadband far-IR RH feedback across CMIP5 models



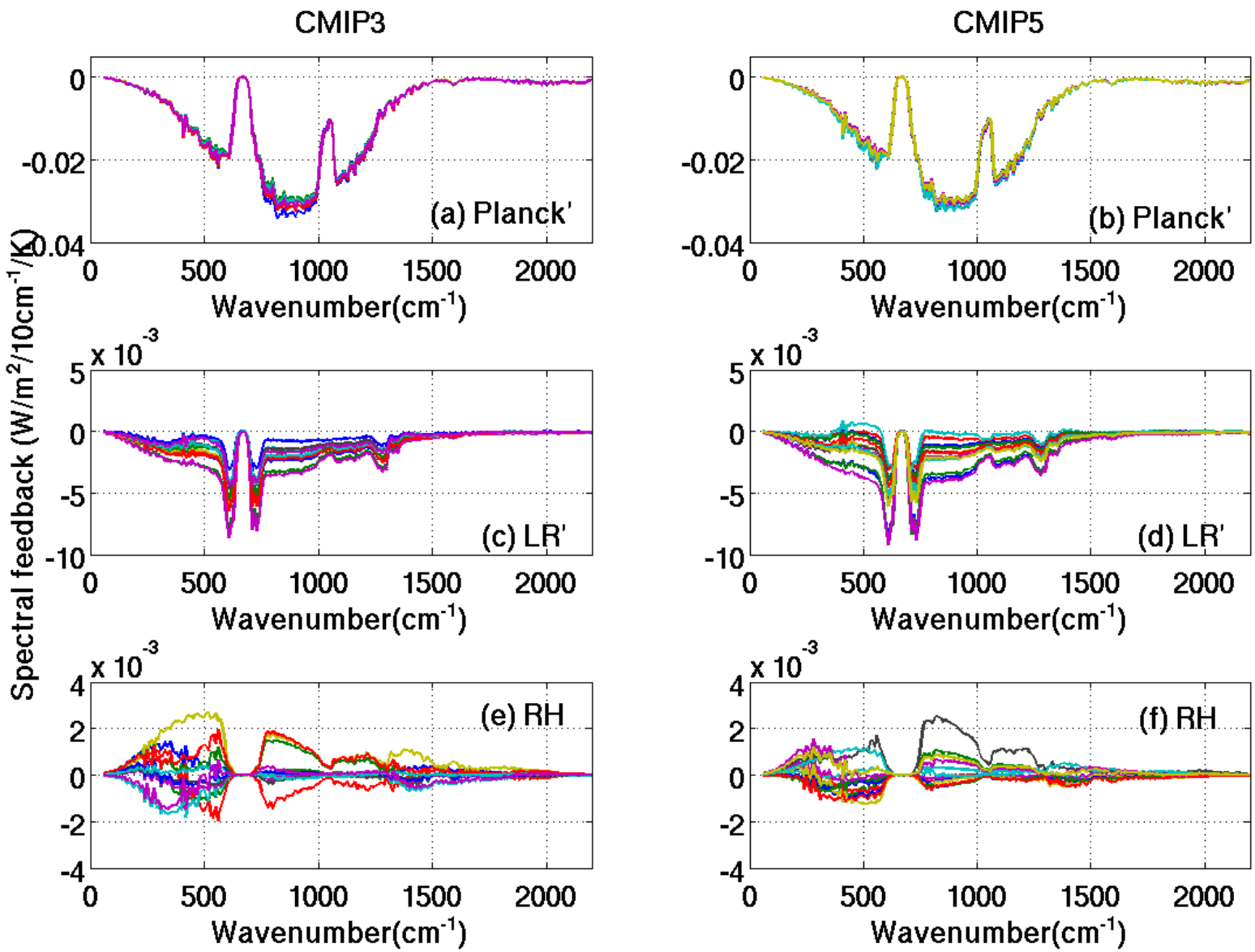
# Mean broadband RH feedback of IR window region across CMIP5 models



# Using RH as a state variable

| | Planck' | LR' | RH |
|---|---|---|---|
| gfdl cm2.0 | -1.95 | -0.26 | 0.05 |
| giss er | -1.95 | -0.36 | -0.02 |
| inmcm 3.0 | -2.07 | -0.25 | -0.04 |
| miroc3-2-medres | -2.02 | -0.16 | -0.07 |
| mpi-echam5 | -2.07 | -0.38 | -0.02 |
| m-cgcm2-3-2a | -1.99 | -0.25 | 0.17 |
| ncar-ccsm3 | -2.01 | -0.18 | -0.02 |
| MPI-ESM-LR | -2.05 | -0.40 | -0.04 |
| IPSL-CM5A-LR | -1.97 | -0.39 | 0.01 |
| CNRM-CM5 | -2.05 | -0.09 | -0.02 |
| BNU-ESM | -2.08 | -0.05 | 0.01 |
| HadGEM2-ES | -2.01 | -0.23 | -0.00 |
| MRI-CGCM3 | -1.96 | -0.20 | -0.05 |
| FGOALS-s2 | -2.06 | -0.22 | 0.13 |

# Using RH as a state variable

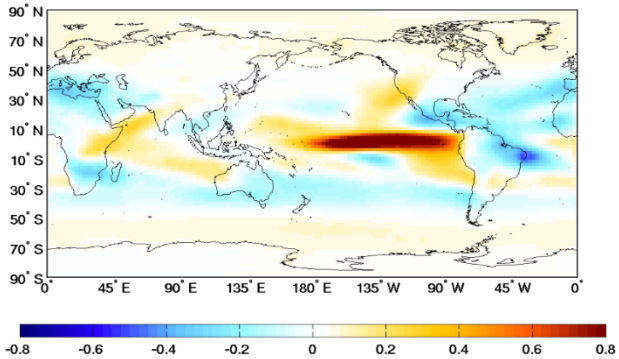


Ensemble-mean in CMIP3

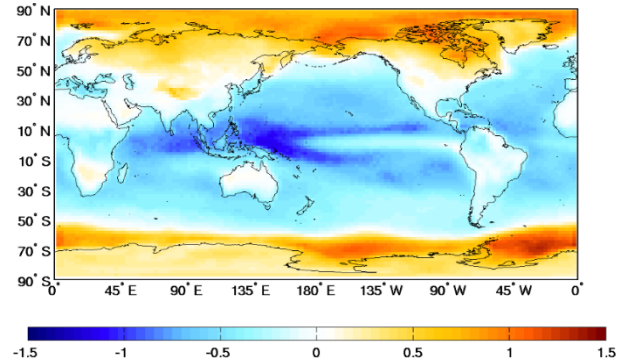
RH feedback

LR2 feedback

Broadband

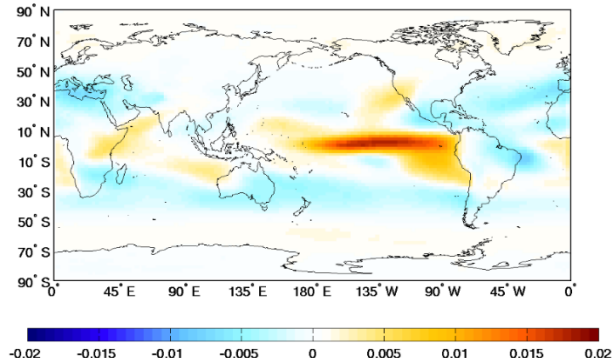



$Wm^{-2}K^{-1}$

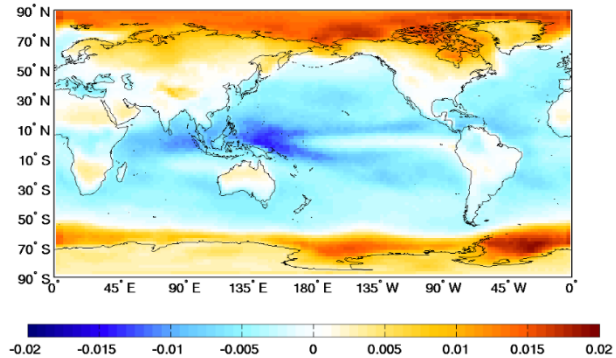



$Wm^{-2}K^{-1}$

550-560cm$^{-1}$

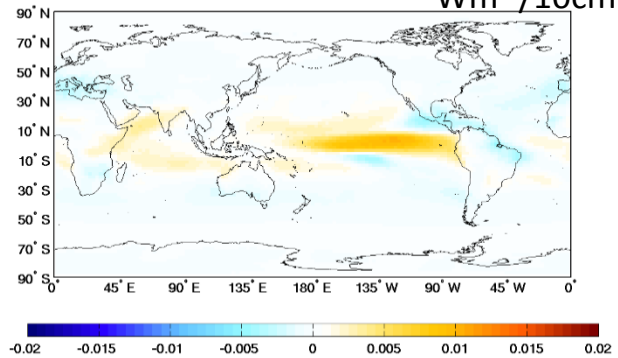



$Wm^{-2}/10cm^{-1}K^{-1}$

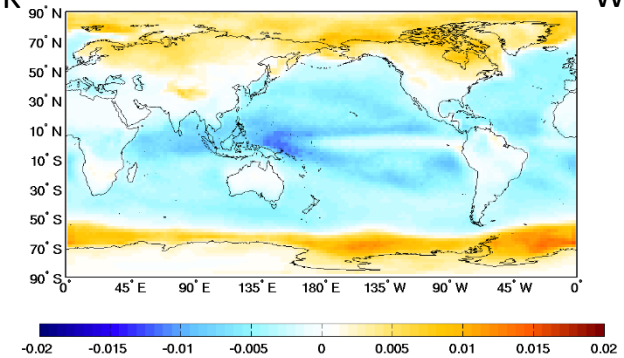



$Wm^{-2}/10cm^{-1}K^{-1}$

900-910cm$^{-1}$




$Wm^{-2}/10cm^{-1}K^{-1}$



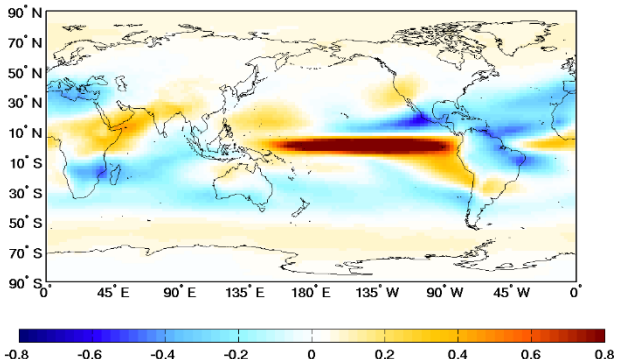

$Wm^{-2}/10cm^{-1}K^{-1}$

Ensemble-mean in CMIP5

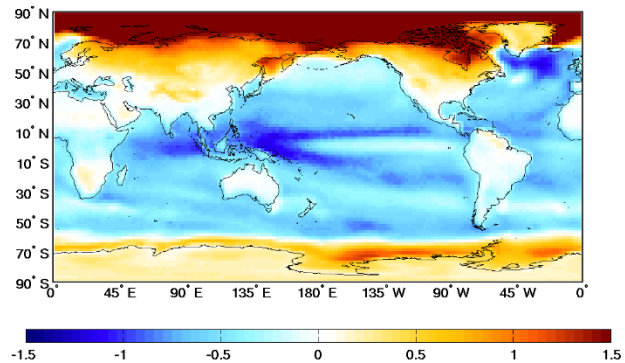
RH feedback

LR2 feedback

Broadband

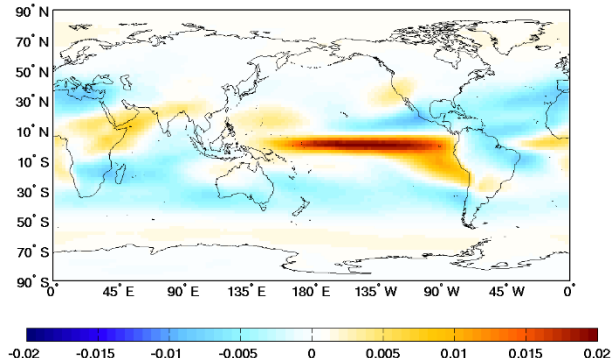



$Wm^{-2}K^{-1}$

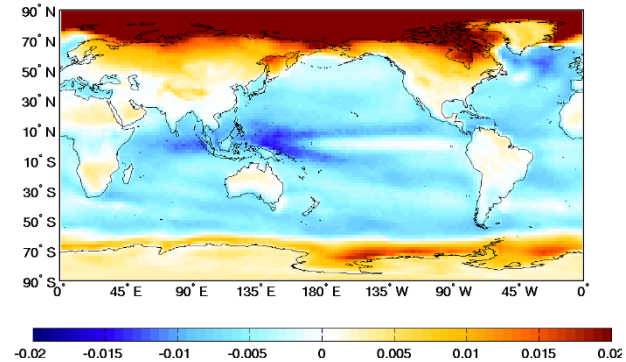



$Wm^{-2}K^{-1}$

550-560cm$^{-1}$

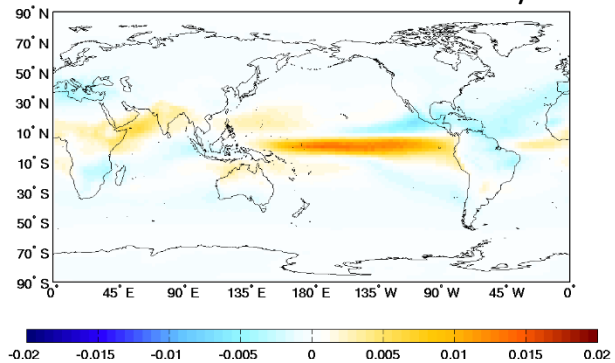



$Wm^{-2}/10cm^{-1}K^{-1}$

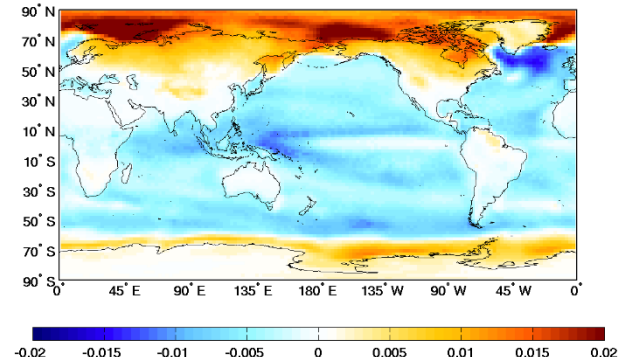



$Wm^{-2}/10cm^{-1}K^{-1}$

900-910cm$^{-1}$




$Wm^{-2}/10cm^{-1}K^{-1}$




$Wm^{-2}/10cm^{-1}K^{-1}$

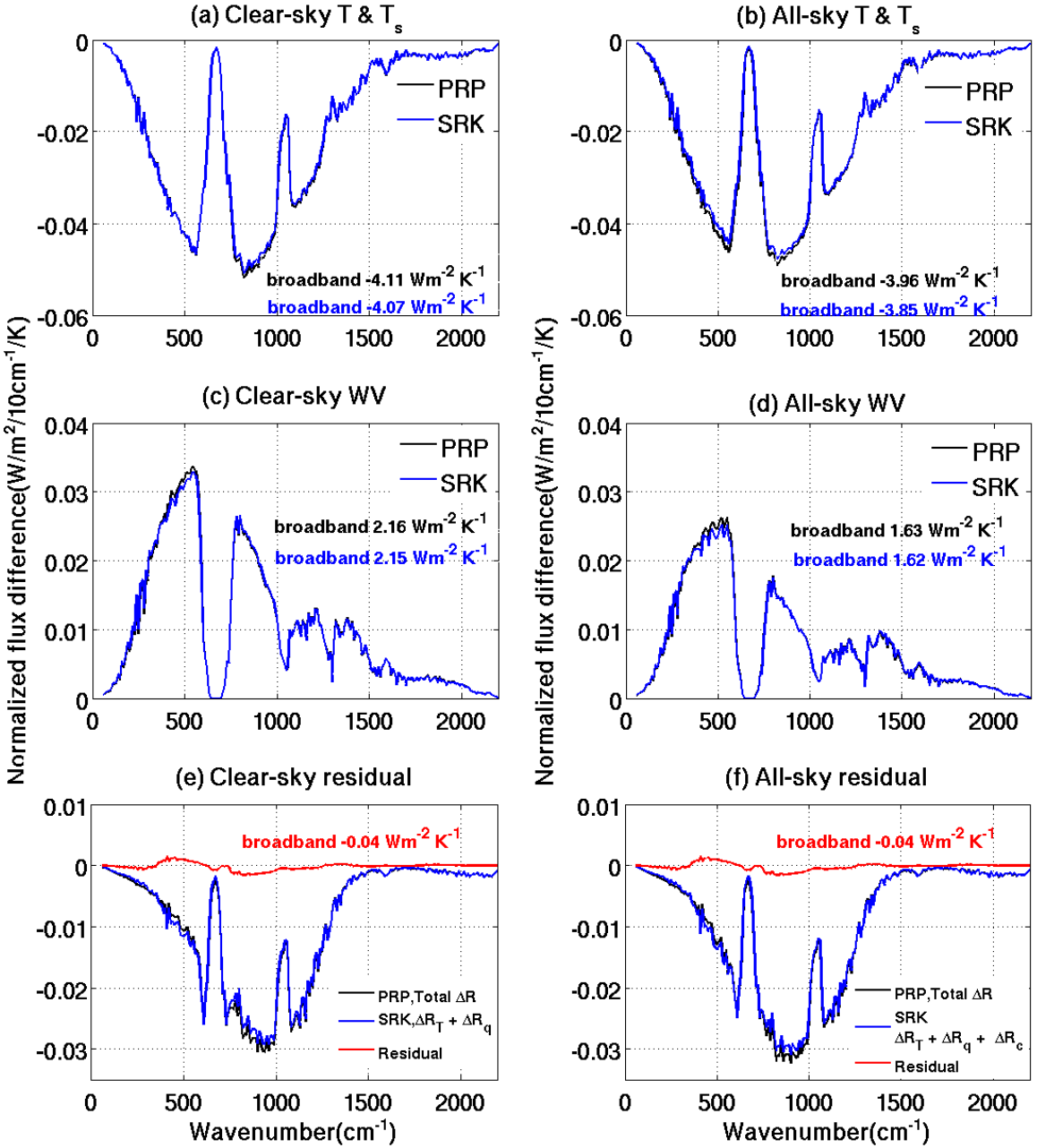
# Questions to be addressed

- Can we derive spectral feedbacks from CMIP3 and CMIP5 **monthly-mean** archives?
- If so, what new insights spectral feedbacks can bring?

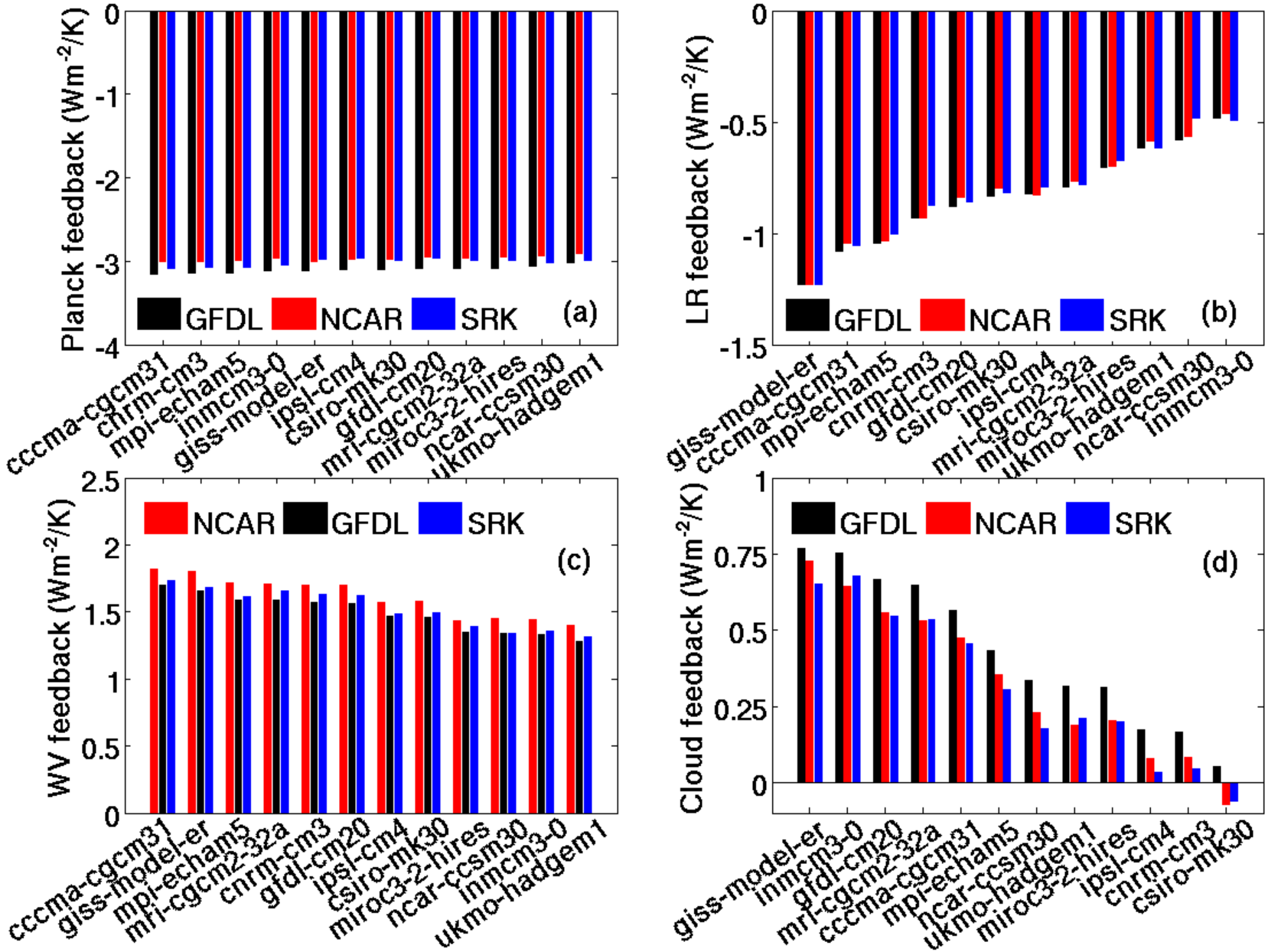
# Construction of Spectral Radiative Kernel (SRK)

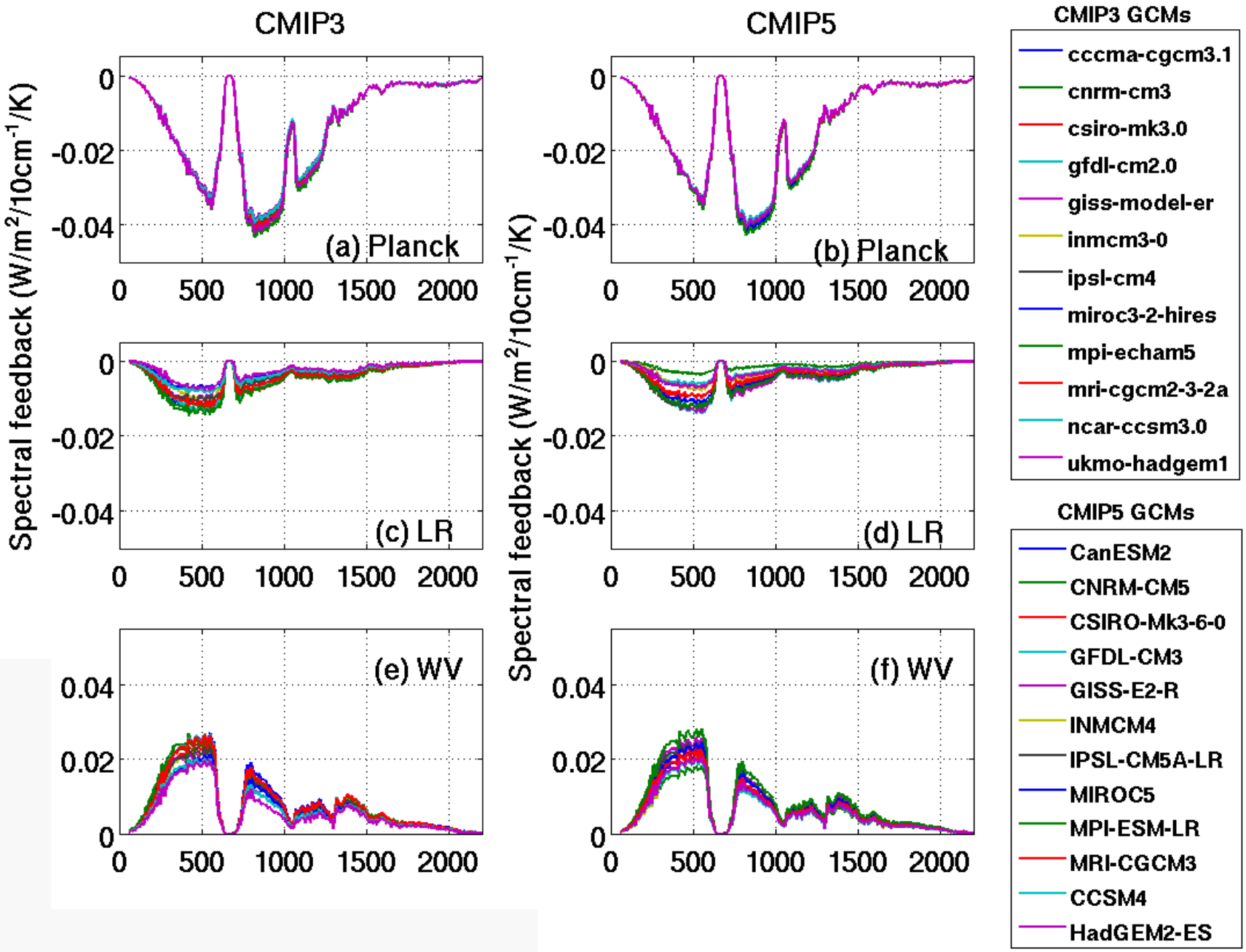
- Forward model: Liu et al. (2006, Appl. Optics) and Chen et al. (2013, JGR)
  - PCRTM (Liu et al., 2006): a fast radiative transfer model with enough accuracy
  - Chen et al. (2013) takes cloud sub-grid variability into account as done in the ISCCP simulator
- Use the same data sets as in Soden et al. (2008) to develop and validate the spectral radiative kernel.
- SRK is computed at 0.5cm$^{-1}$spectral interval (shown here at 10cm$^{-1}$ interval)
- Currently LW only

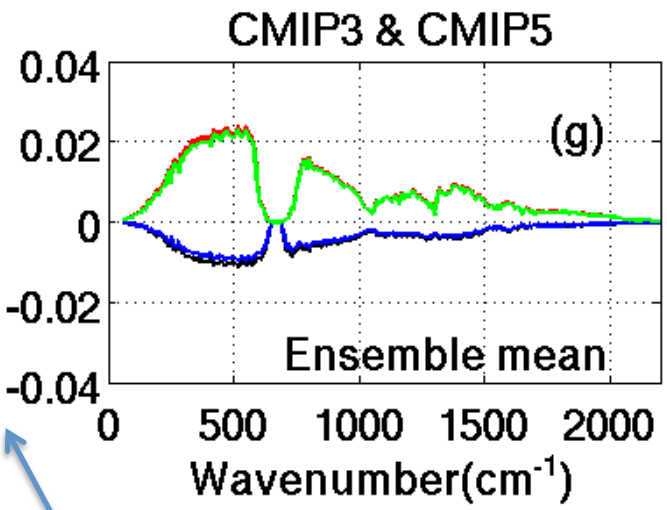
# Validation: comparisons with the PRP results

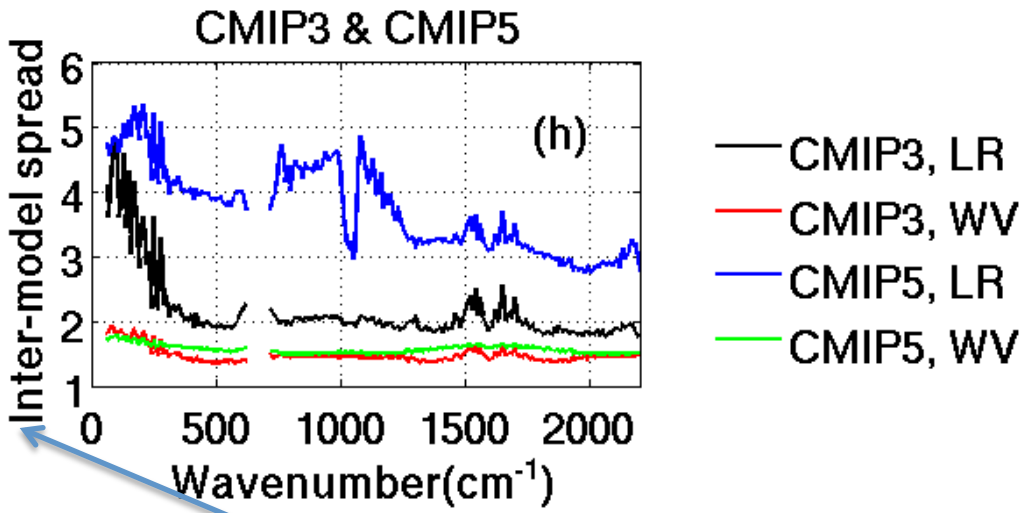


# Validation: comparisons with the PRP results




CMIP3
CMIP5
Spectral feedback (W/m$^2$/10cm$^{-1}$/K)
(a) Planck
(b) Planck
(c) LR
(d) LR
(e) WV
(f) WV
0
-0.02
-0.04
0.04
0.02
0
500
1000
1500
2000
CMIP3 GCMs
cccma-cgcm3.1
cnrm-cm3
csiro-mk3.0
gfdl-cm2.0
giss-model-er
inmcm3-0
ipsl-cm4
miroc3-2-hires
mpi-echam5
mri-cgcm2-3-2a
ncar-ccsm3.0
ukmo-hadgem1
CMIP5 GCMs
CanESM2
CNRM-CM5
CSIRO-Mk3-6-0
GFDL-CM3
GISS-E2-R
INMCM4
IPSL-CM5A-LR
MIROC5
MPI-ESM-LR
MRI-CGCM3
CCSM4
HadGEM2-ES

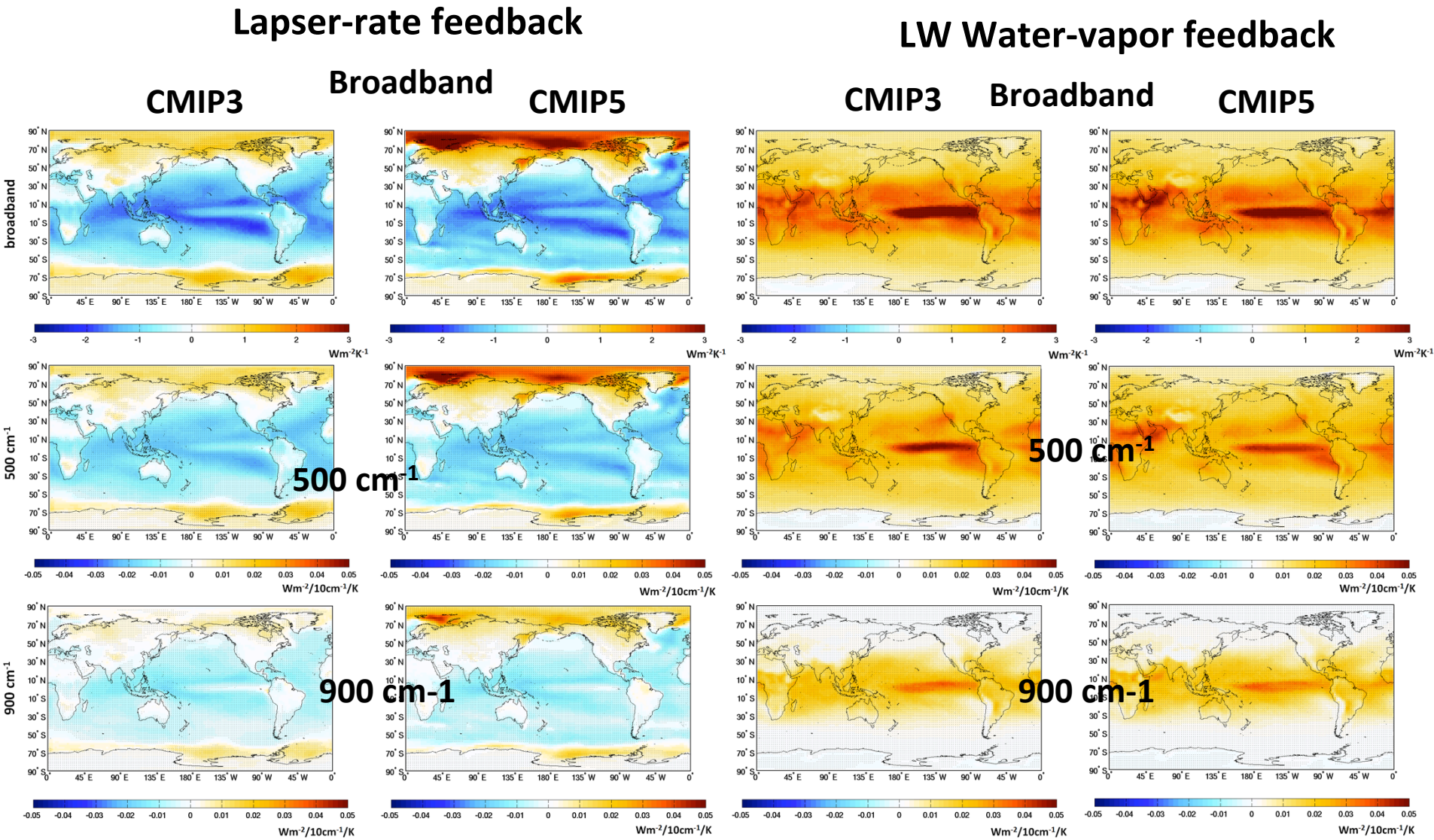



Spectral Radiative Feedback
($Wm^{-2}$ per $10cm^{-1}$ per K)

Intermodel Spectral = Max/Min

# Spatial distribution of the all-sky spectral feedback: deciphering the broadband feedback




Maps of clear-sky feedbacks are similar