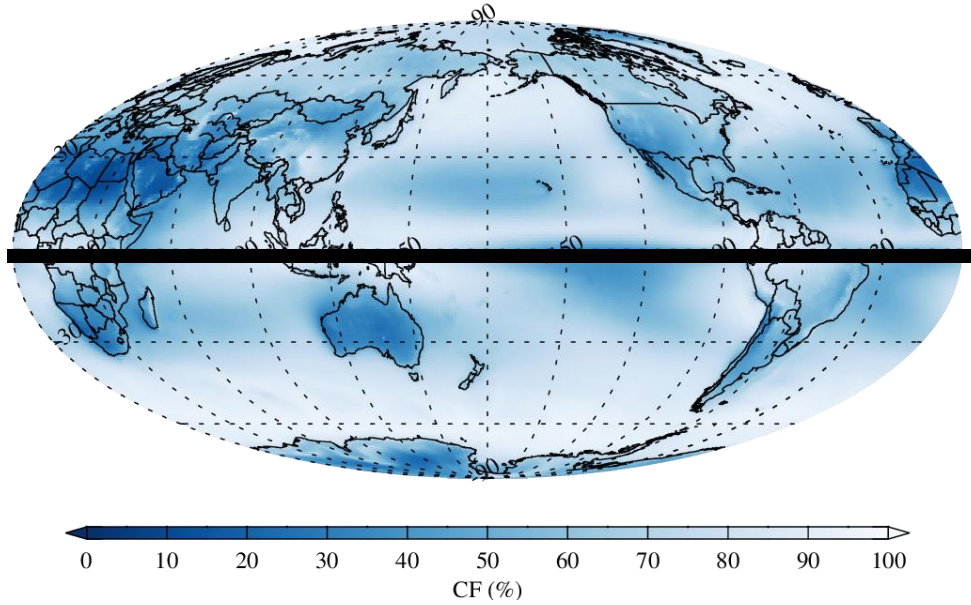
A different perspective on the role of clouds in the symmetry of hemispheric reflected solar radiation

Nayeong Cho(NASA-GSFC and UMBC)
Lazaros Oreopoulos (NASA-GSFC) and
Dongmin Lee (NASA-GSFC and MSU)



Different circumstances

NH
- more land, more aerosol loading

SH
- more ocean

Reflected solar radiation

98.75 Wm^{-2}

$\approx$

98.83 Wm^{-2}

Clouds as a Key Driver of Albedo Symmetry

This work: Role of Clouds modulating the mean state and variability of symmetry

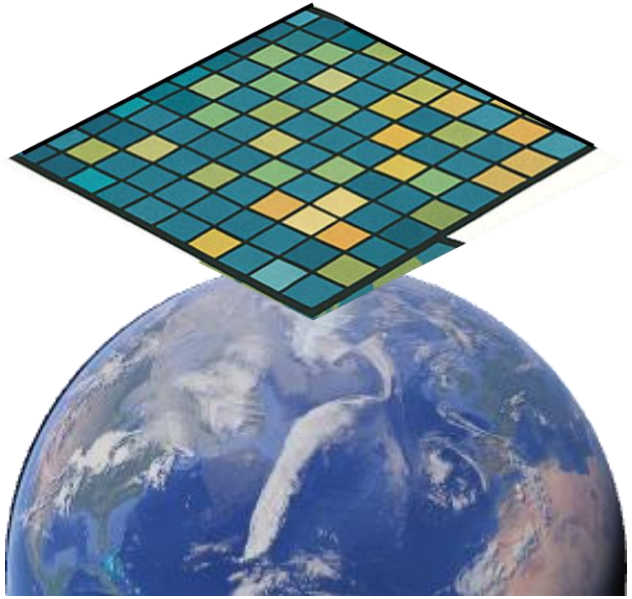
- ✓ CERES EBAF Ed4.2.1 & MODIS Terra and Aqua C6.1 (2003 – 2024, 22 years)
- ✓ **RSR** : Reflected solar radiation

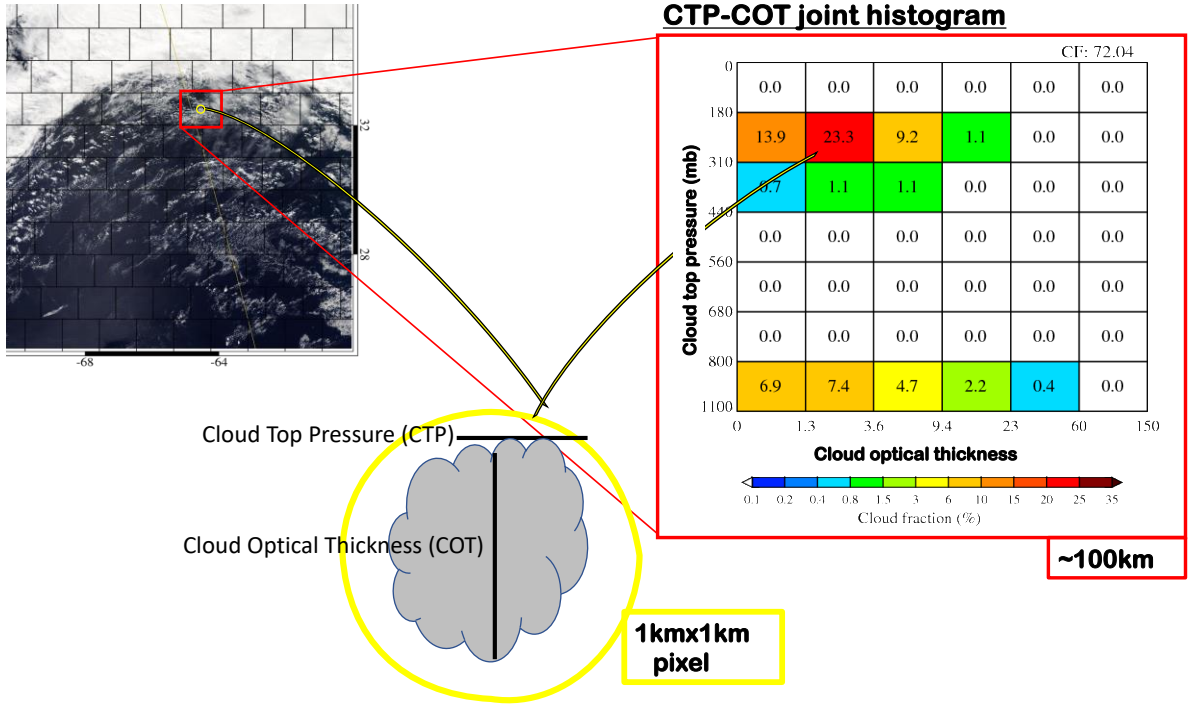
$$RSR(year, month, lat, lon) = \frac{RSI(year, month, lon, lat)}{ISI(year, month, lon, lat)} \times \overline{ISI(month, lat, lon)}$$

  - Weighted average accounting for varying number of days per month
  - Latitude-dependent geodetic weights

How do we define the cloud systems?

Pixel level cloud information –
COT, CTP, CF from MODIS Terra & Aqua C6.1



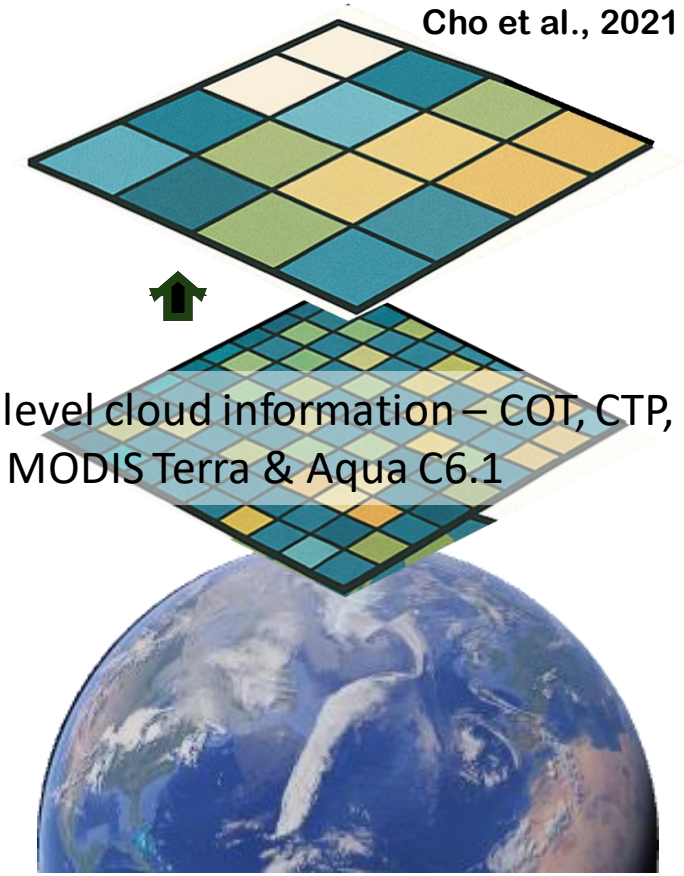


- Each pixel's CTP-COT values from MODIS within a 1deg grid cell is assigned to one of 42 bins defined by predetermined CTP-COT pairs

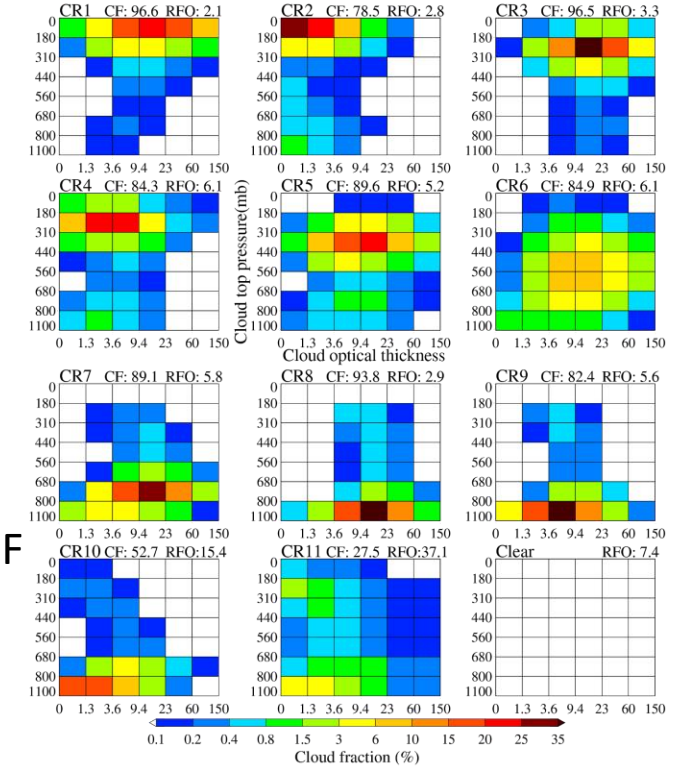
How do we define the cloud systems?

Daily Cloud regimes (CR)

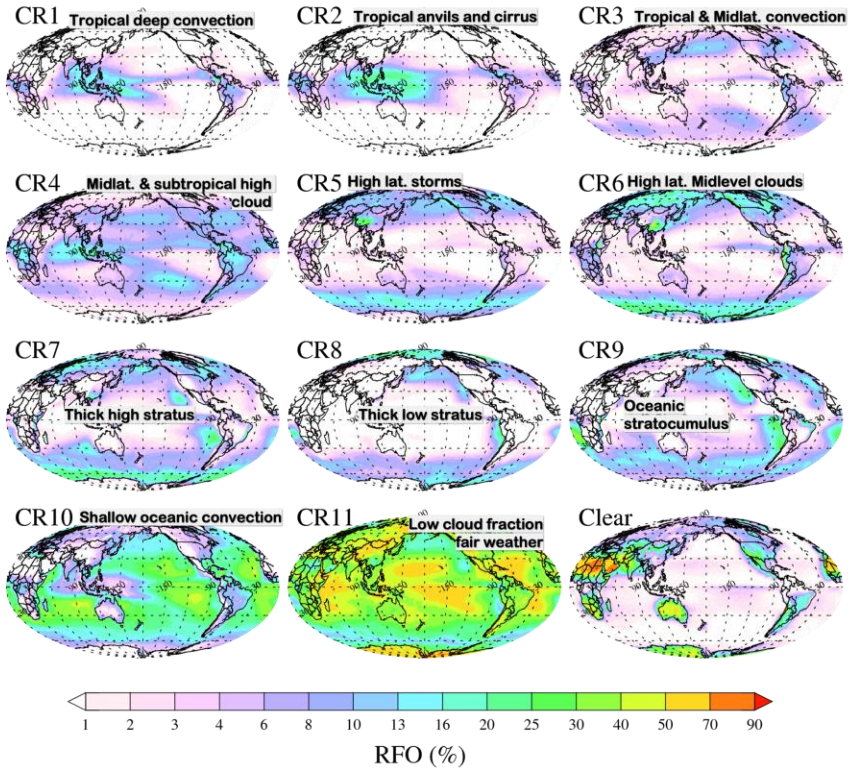
Cho et al., 2021



Pixel level cloud information – COT, CTP, CF from MODIS Terra & Aqua C6.1



Global means (centroids) of joint-histograms assigned to the11 MODIS Cloud Regimes (CRs)

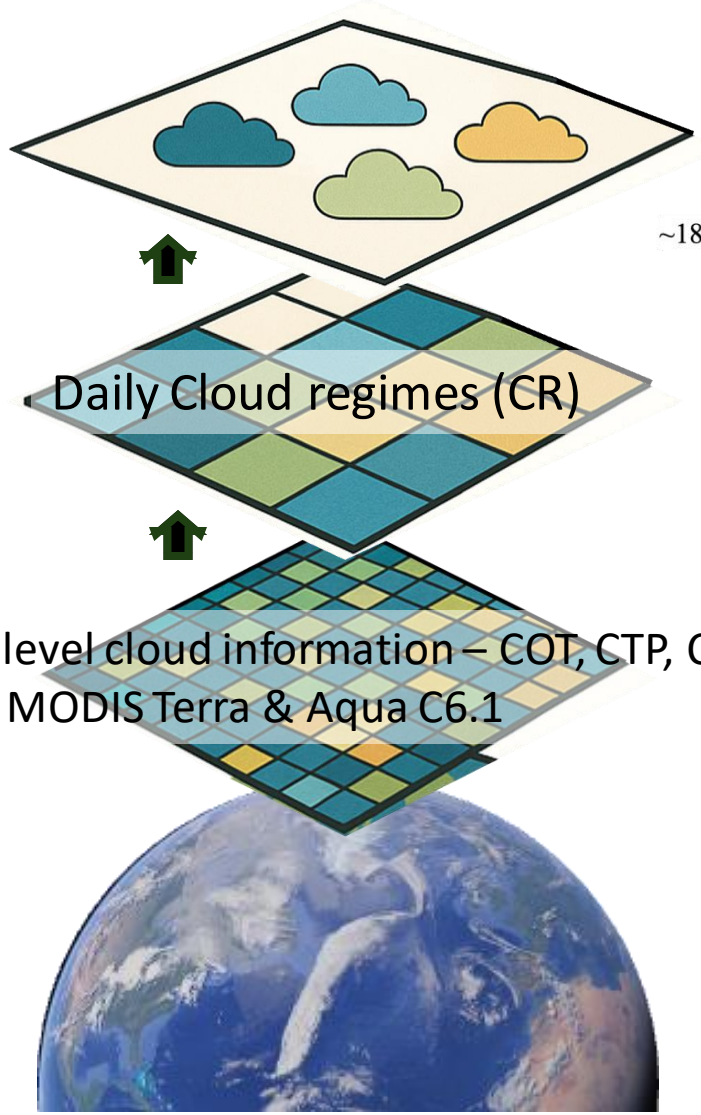


Maps of the multi-annual relative frequency of occurrence of MODIS CRs

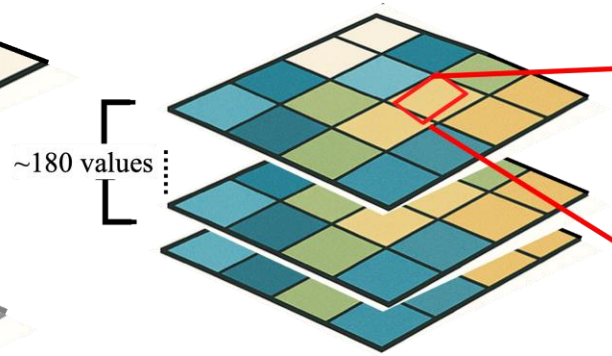
How do we define the cloud systems?

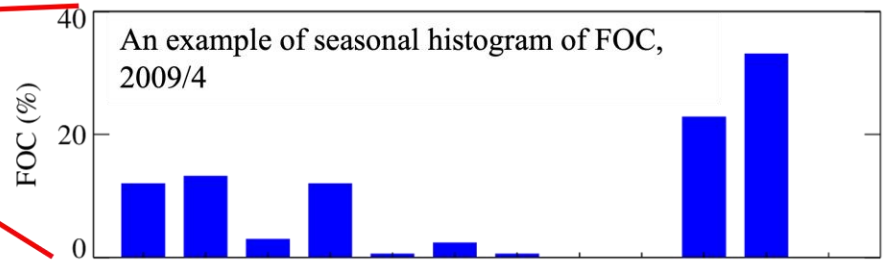
Monthly cloud systems : Regimes Of Regimes (ROR)

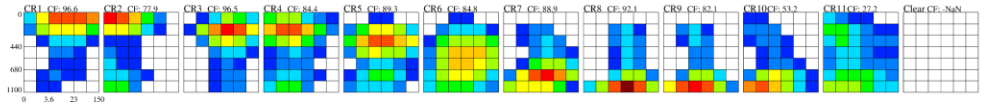
Cho et al., J. Climate, 2025



Pixel level cloud information – COT, CTP, CF from MODIS Terra & Aqua C6.1





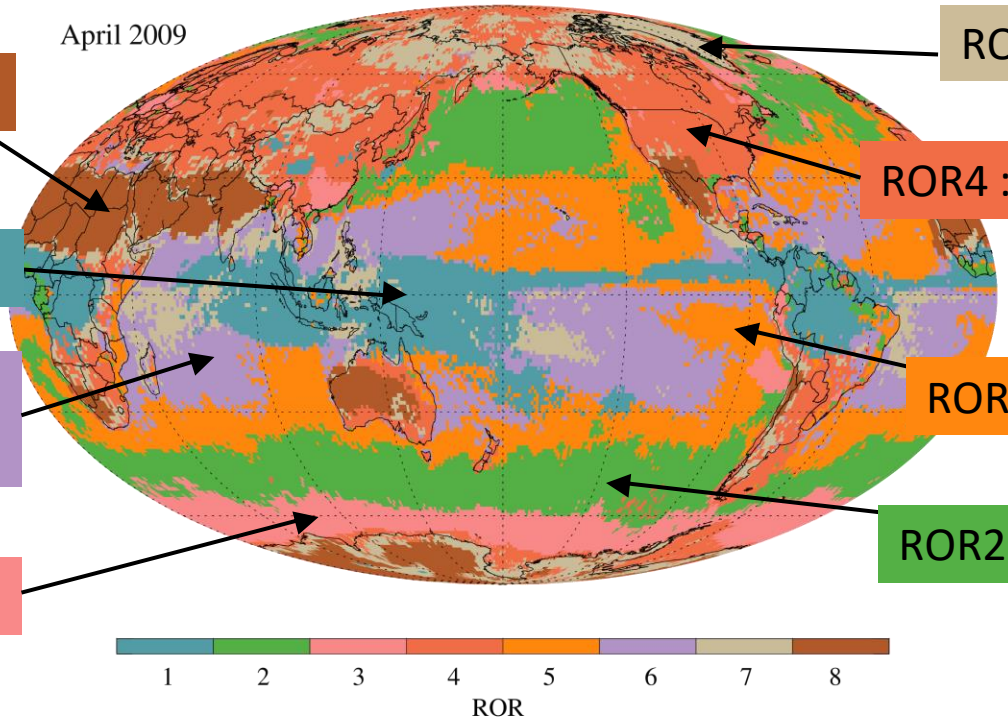


		CR1	CR2	CR3	CR4	CR5	CR6	CR7	CR8	CR9	CR10	CR11	CR12	CF
Convective lifting	ROR 1	11.8	13.8	4.4	13.3	2.4	3.3	0.8	0.1	1.1	7.8	39.7	1.6	59.1
Middle latitude oceanic storms	ROR 2	0.5	0.3	5.5	5.3	9.6	7.1	9.2	10.9	15.6	15.9	18.9	1.2	69.7
High latitude midlevel clouds	ROR 3	0.5	0.1	3.2	2.1	12.0	20.8	20.2	6.7	7.0	8.5	17.4	1.3	73.0
Continental high latitude and polar environment	ROR 4	0.4	0.2	2.9	4.1	8.2	12.9	6.8	5.3	4.8	5.0	42.0	7.4	54.1
Low marine cloud environment	ROR 5	0.9	1.7	3.1	6.4	3.5	3.0	6.7	1.8	7.8	31.0	32.2	2.1	55.4
Subtropical convection and low cloud environment	ROR 6	1.3	3.3	1.7	5.6	1.8	1.9	2.2	0.4	2.2	23.8	52.8	3.1	44.5
Suppressed fair-weather	ROR 7	0.5	0.9	0.7	2.4	3.1	6.5	1.5	1.8	1.1	2.3	66.0	13.3	35.2
Arid environment	ROR 8	0.1	0.6	0.6	2.3	1.7	2.7	0.7	0.2	0.4	1.4	35.1	54.1	18.4

How do we define the cloud systems?

Monthly cloud systems : Regimes Of Regimes (ROR)

Seasonal geographical distribution of RORs



ROR8 : arid almost clear

ROR1 : tropical convective

ROR6 : subtropical shallow convection

ROR3: high-lat thick stratus

ROR7 : suppressed low CF

ROR4 : mid-lat continental mid-level

ROR5 : subtropical shallow marine

ROR2 : mid-lat oceanic storm track

15 FEBRUARY 2025 CHO ET AL.

Describing Seasonal Mixtures of Cloud Regimes via "Regimes of Regimes"

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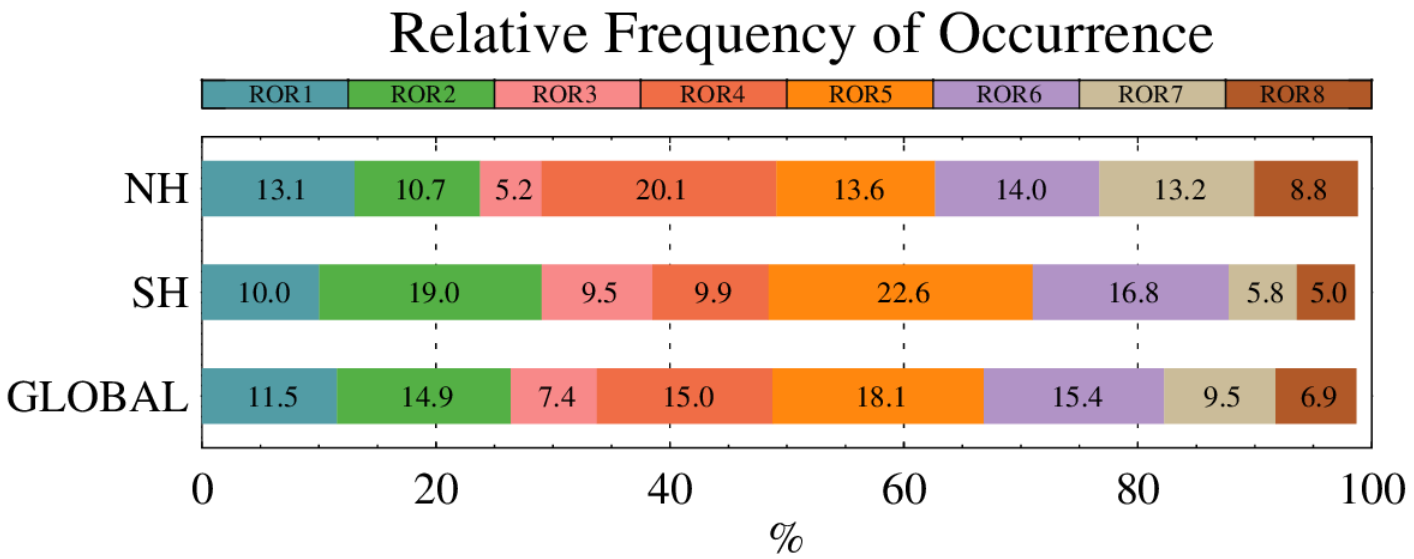
[c] *Morgan State University, Baltimore, Maryland*

(Manuscript received 17 May 2024, in final form 25 November 2024, accepted 13 December 2024)

- ✓ CloudSat/CALIPSO Cloud type
- ✓ Cloud vertical structure
- ✓ Cloud precipitation radar Reflectivities
- ✓ Cloud radiative effect (CRE), CRE trends, CRE feedback

Result

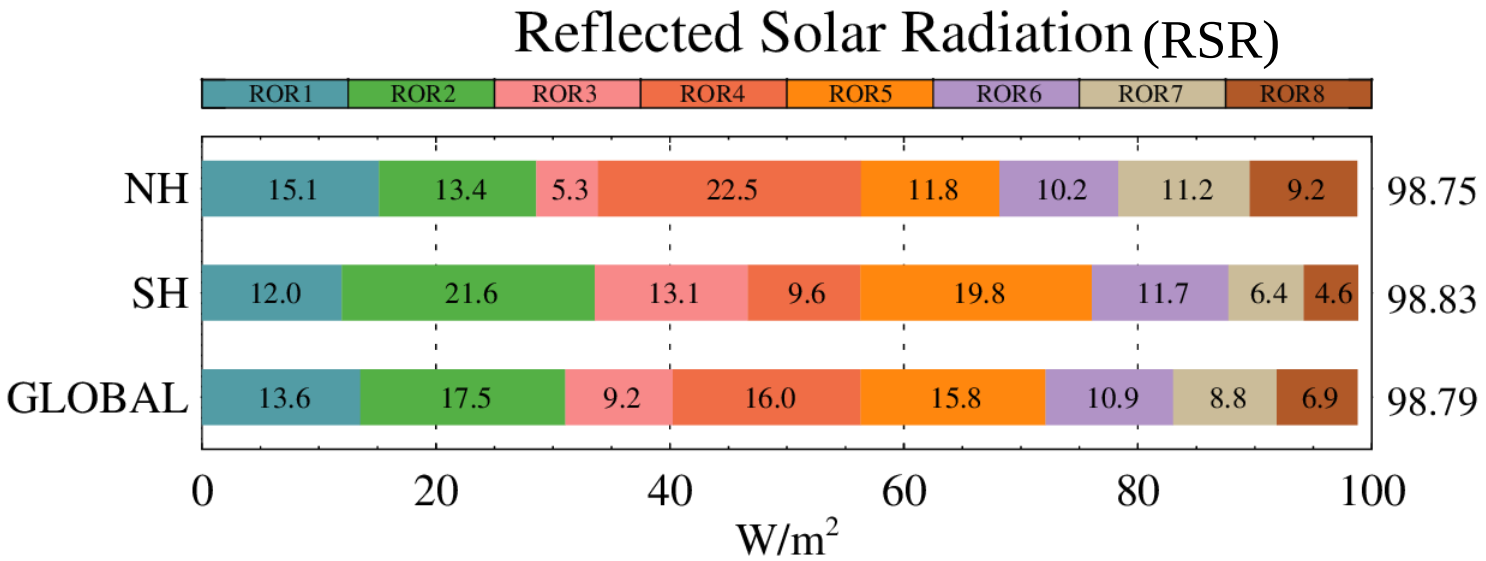
ROR populations and contributions to SW reflected



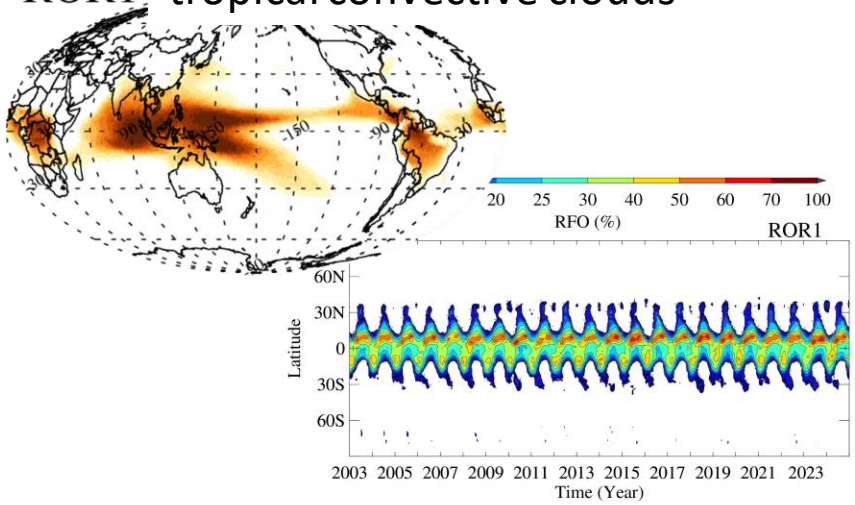
$$RSR = f\overline{RSR}$$

ROR global (hemispheric) RFO

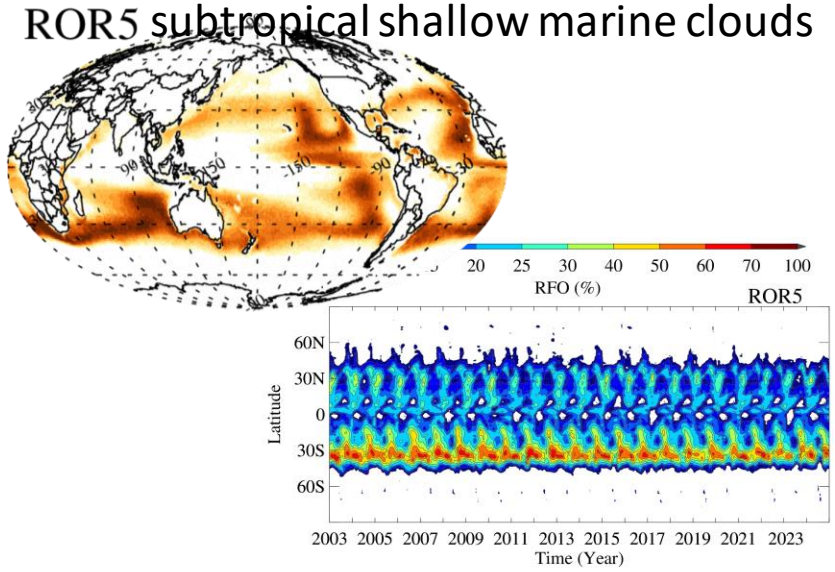
ROR-specific inherent RSR



ROR1 tropical convective clouds

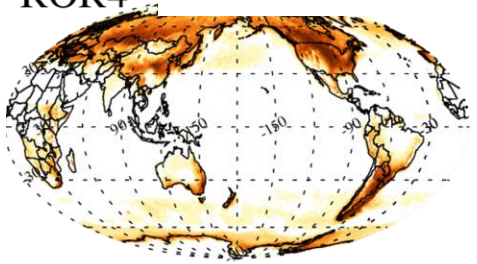


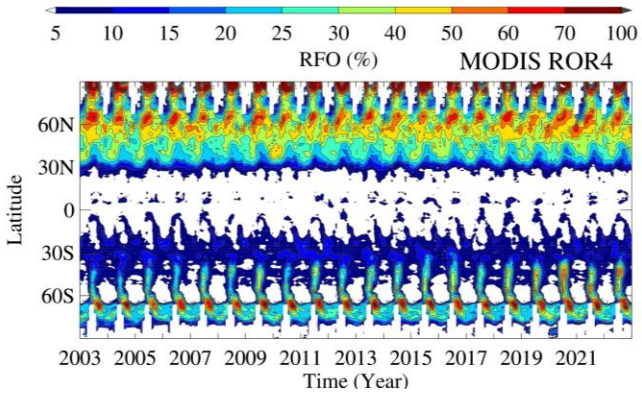
ROR5 subtropical shallow marine clouds



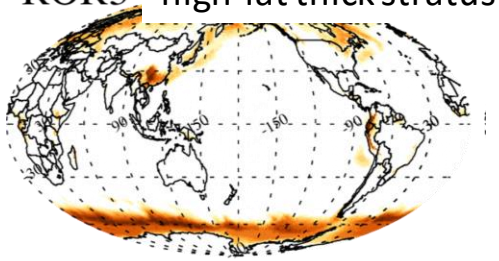
NH - SH RSR decomposition by ROR

ROR4 mid-lat continental mid-level

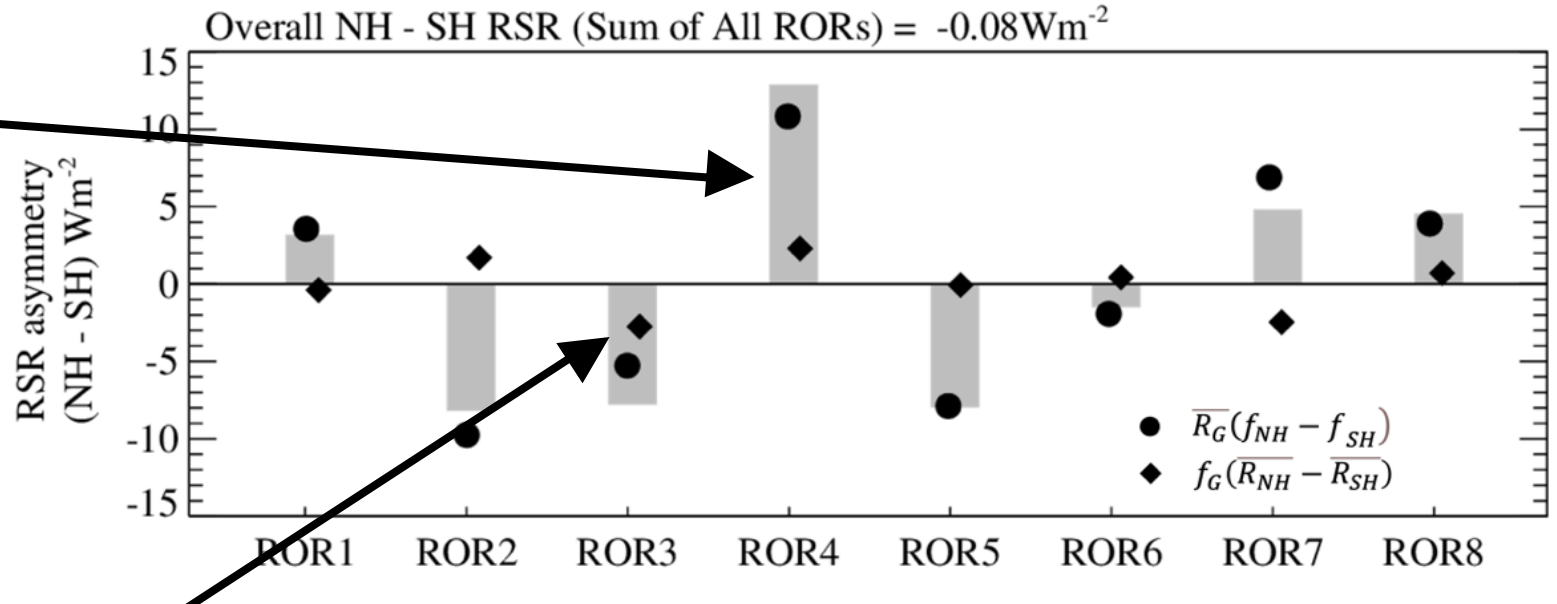




ROR3 high-lat thick stratus



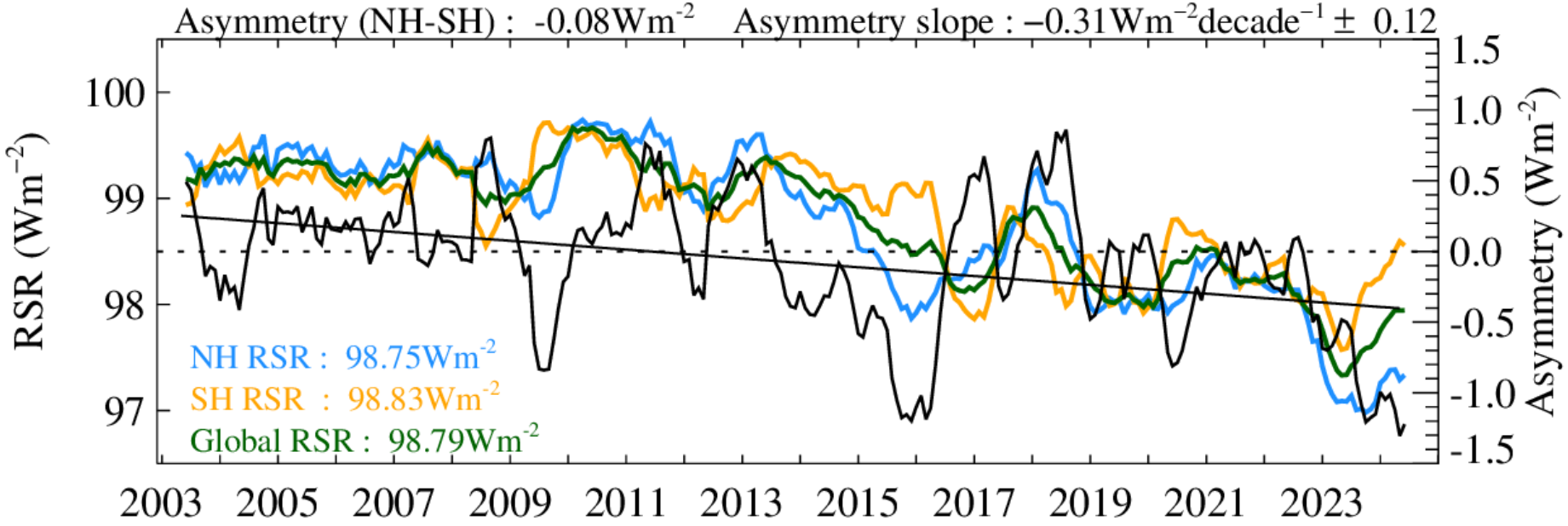
$\overline{R_{NH}}$	$\overline{R_{SH}}$
100.88	138.22



Differences in RSR contributions between NH and SH, shown as grey bars, based on the values from the previous slide. *Circles* represent the contributions of ROR RFO differences, while *diamonds* show the contributions of inherent ROR RSR differences.

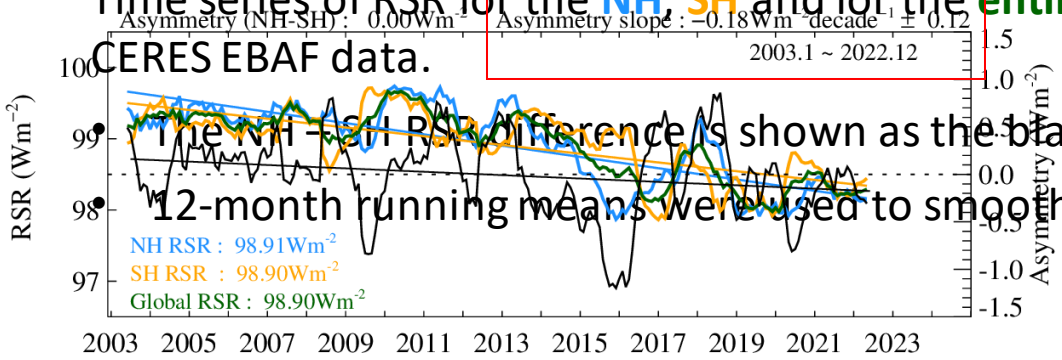
Result

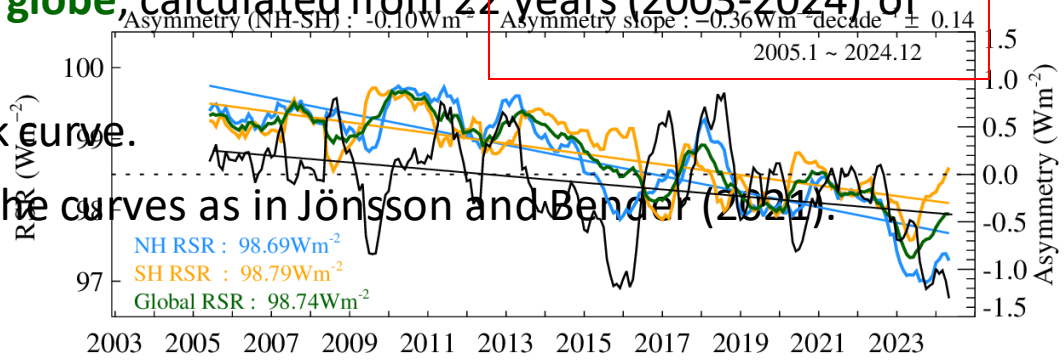
RSR trend



Time series of RSR for the **NH**, **SH** and for the **entire globe**, calculated from 22 years (2003-2024) of CERES EBAF data.

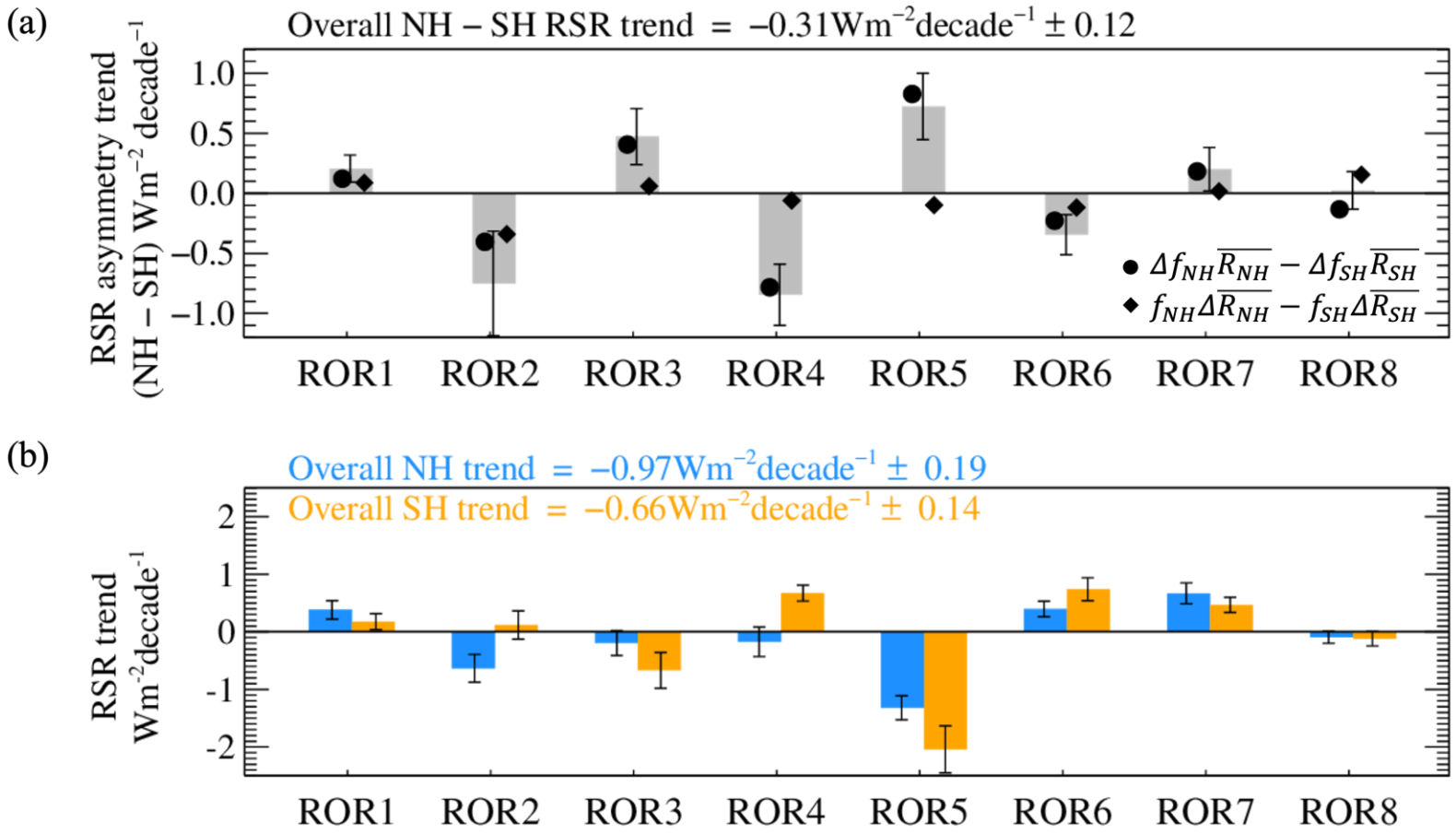
- The NH – SH RSR difference is shown as the black curve.
- 12-month running means were used to smooth the curves as in Jönsson and Bender (2021).





Result

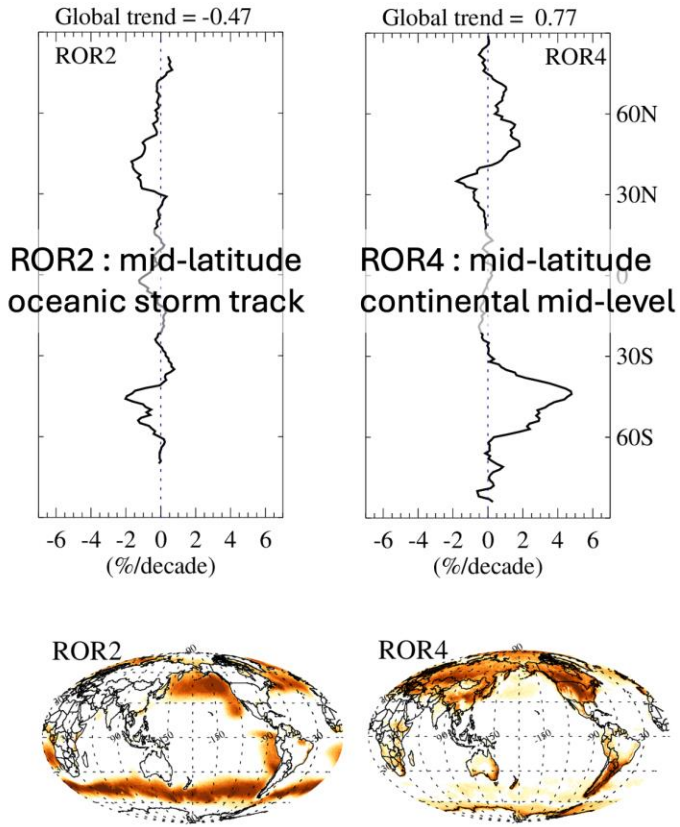
NH - SH RSR trends decomposition by ROR



(a) The **NH minus SH difference** in RSR trends. *Solid circles* indicating the contributions of frequency trends, and *diamonds* indicating the contributions of inherent RSR trends.

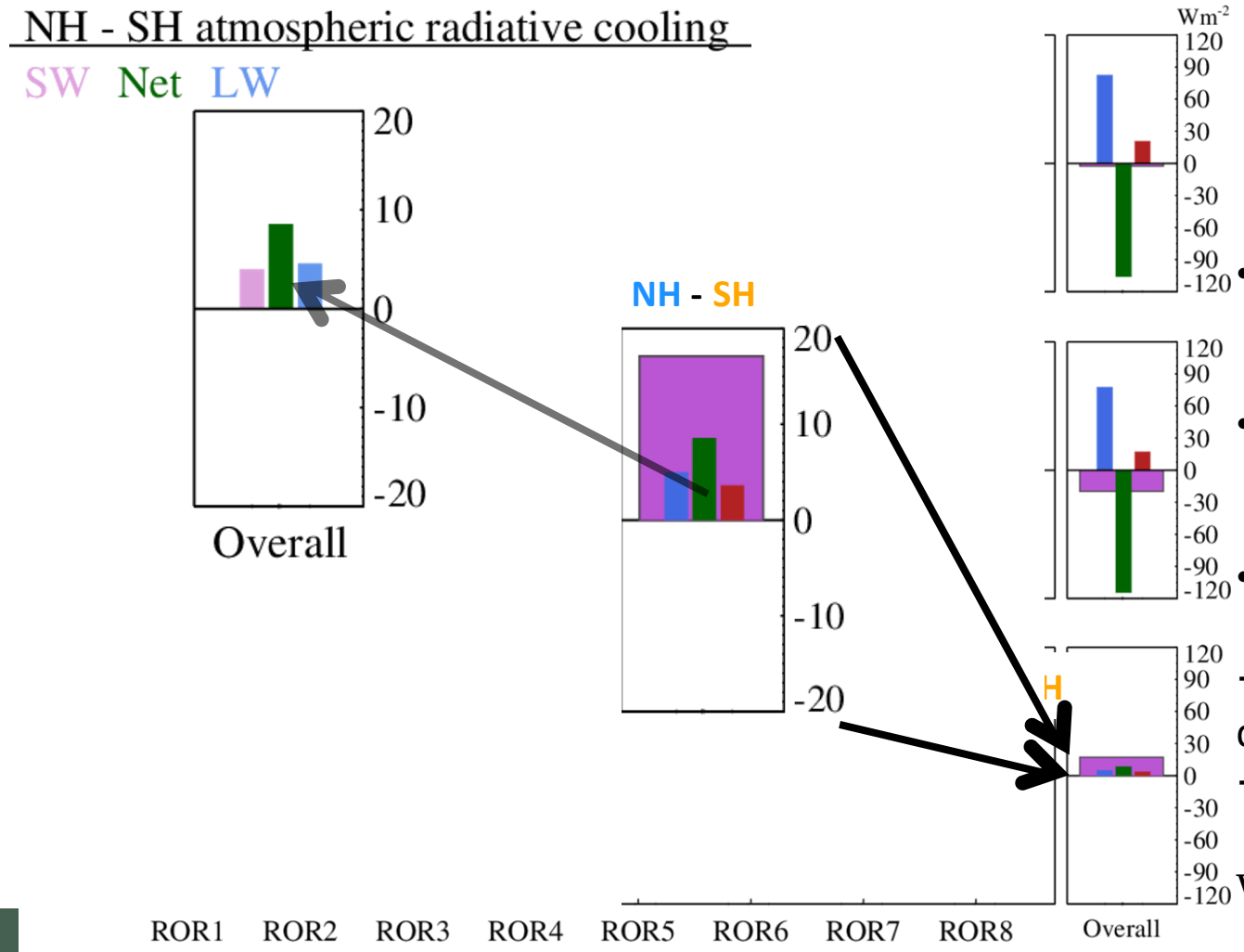
(b) **NH** and **SH** RSR trends by ROR for the 22-year period.

Trends in zonal RFO for RORs



Result

NH - SH RSR trends decomposition by ROR



NH and **SH** multi-annual (2003-2023) mean values of **atmospheric diabatic heating** and its three components (**latent heating**, **sensible heating** and **radiative cooling**)

How RORs affect the energy budget

- ROR1 (tropical convective clouds) :
  LH larger in NH → strong diabatic heating in NH than SH
- All other RORs contribute negative diabatic heating for both NH and SH
- Negative diabatic heating for both hemispheres :
  This is not physically possible.

→ Reflects uncertainties and biases in constituent datasets. (since global mean shows $-11.2\ Wm^{-2}$)

→ Assumes the bias is the same for both hemispheres.

NH : $-2.7\ Wm^{-2} + 11.2\ Wm^{-2} = +8.5\ Wm^{-2}$

SH : $-19.7\ Wm^{-2} + 11.2\ Wm^{-2} = -8.5\ Wm^{-2}$

→ Implies net energy transport from NH to SH

Conclusions

- Despite distinct seasonal cloud distributions between hemispheres, hemispheric symmetry in reflected solar radiation (RSR) is preserved within ~0.1% over two decades, though interannual variability and trends suggest a global dimming—faster in the NH.

- Using the "Regimes of Regimes" (RORs) framework, we find that population differences among cloud regimes—rather than inherent radiative properties—mainly drive hemispheric RSR symmetry and its variability.

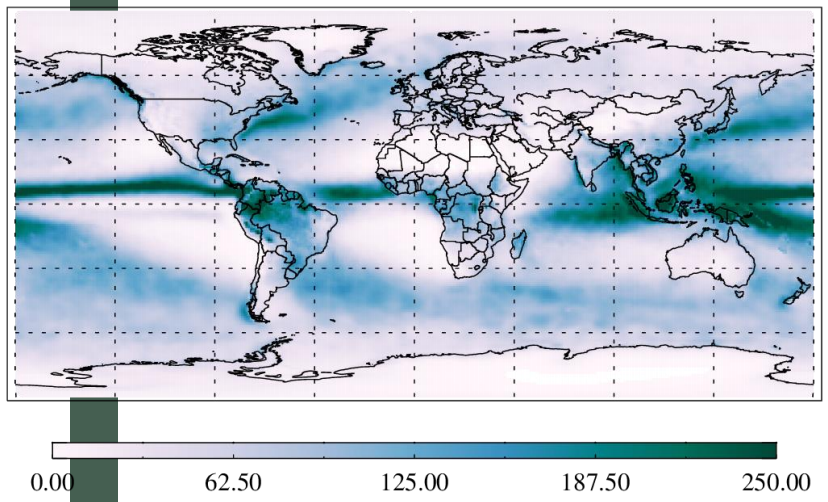
- The albedo symmetry results in the NH atmosphere absorbing more solar radiation which when combined with its weaker radiative cooling strengthens even more the contrast between positive DH in the NH and negative DH in the SH, i.e., the NH to SH energy transport.

- RORs offer a powerful framework for interpreting the mean state and variability of albedo symmetry and its implications for the Earth's energy budget.

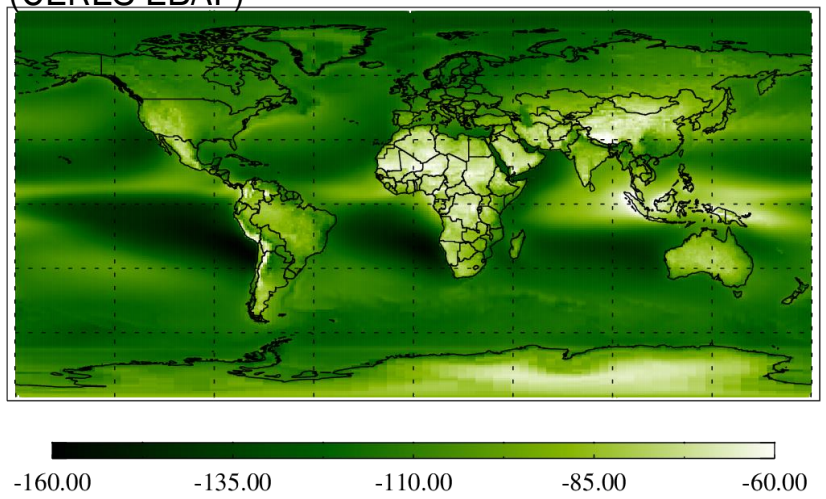
- Submitted to *J.Climate* : "The role of Earth's major cloud systems in the hemispheric albedo symmetry"

BACKUP SLIDES

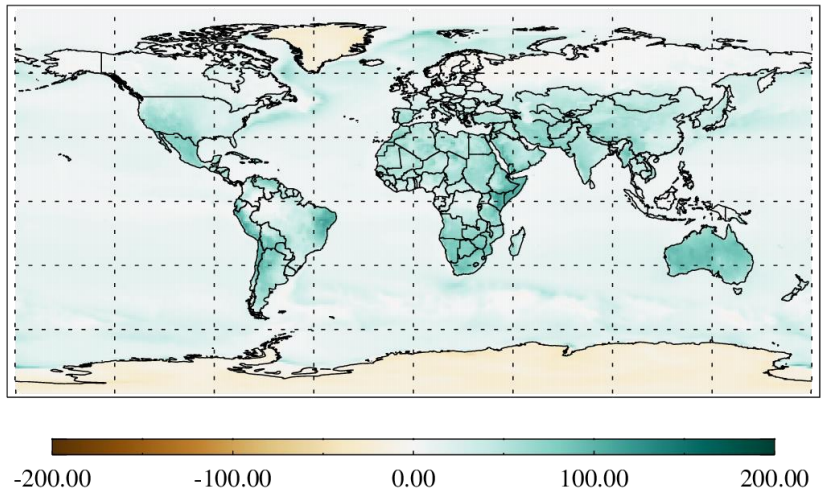
Latent heat (LH) =
GPCP V3.2 × 2.4665e6/86400 = W/m^2



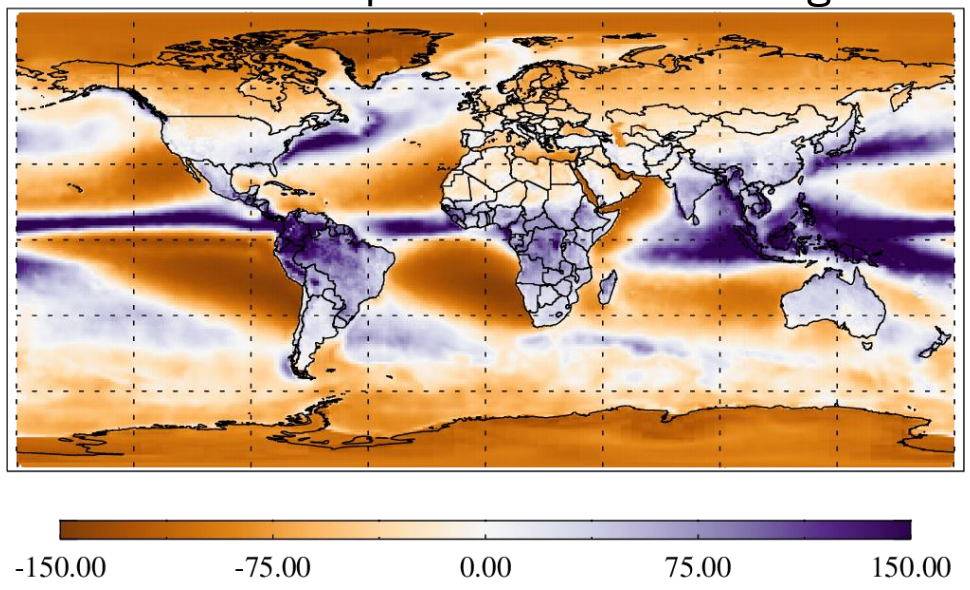
Atmospheric radiative flux divergence (Qr) = toa-net_all_mon - sfc_net_tot_all_mon (CERES EBAF)



Sensible heat (SH) =
sensible_heat_flux (MERRA2)



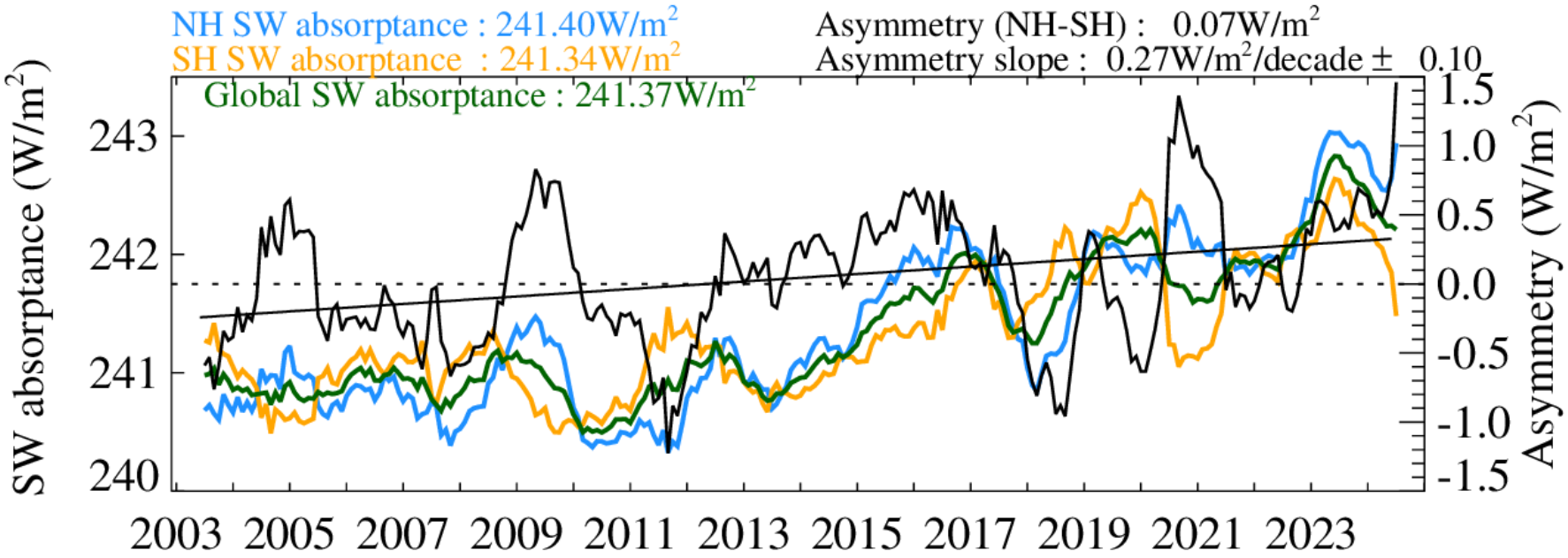
Total atmospheric diabatic heating



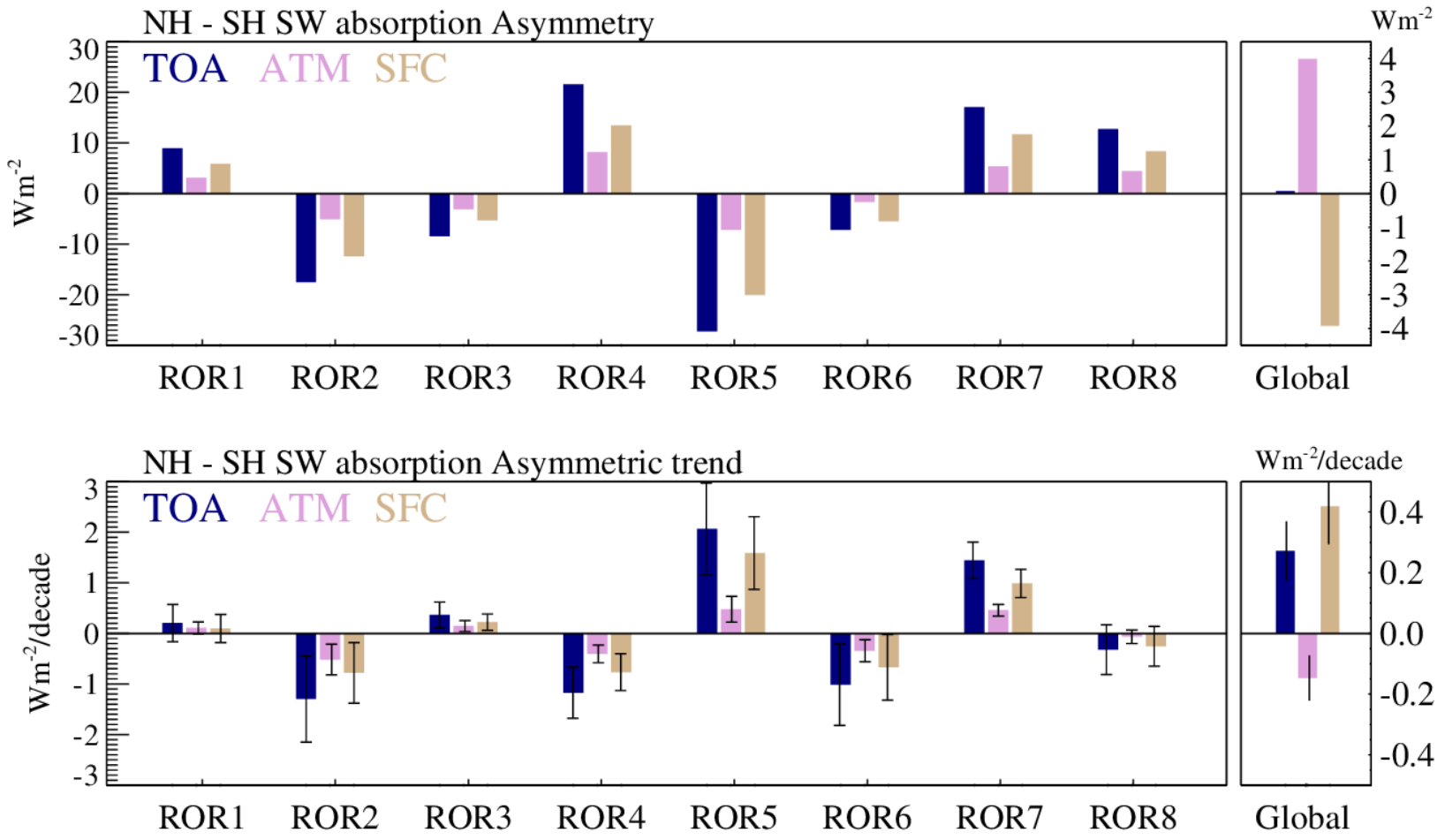
Period : 2003-2023 (21 years)

Result

ASR trend



ASR


NH - SH SW absorption Asymmetry
TOA ATM SFC
Wm-2
30
20
10
0
-10
-20
-30
4
3
2
1
0
-1
-2
-3
-4
ROR1 ROR2 ROR3 ROR4 ROR5 ROR6 ROR7 ROR8 Global
NH - SH SW absorption Asymmetric trend
TOA ATM SFC
Wm-2/decade
Wm-2/decade
3
2
1
0
-1
-2
-3
0.4
0.2
0.0
-0.2
-0.4
ROR1 ROR2 ROR3 ROR4 ROR5 ROR6 ROR7 ROR8 Global