Jonathon Wright

Where I work:

Department of Earth System Science

Tsinghua University, Beijing, China

My research:

- Coupled water & energy cycles
- Monsoon dynamics
- Atmosphere-ocean interactions
- Stratosphere-troposphere interactions & exchange
- Water isotopes

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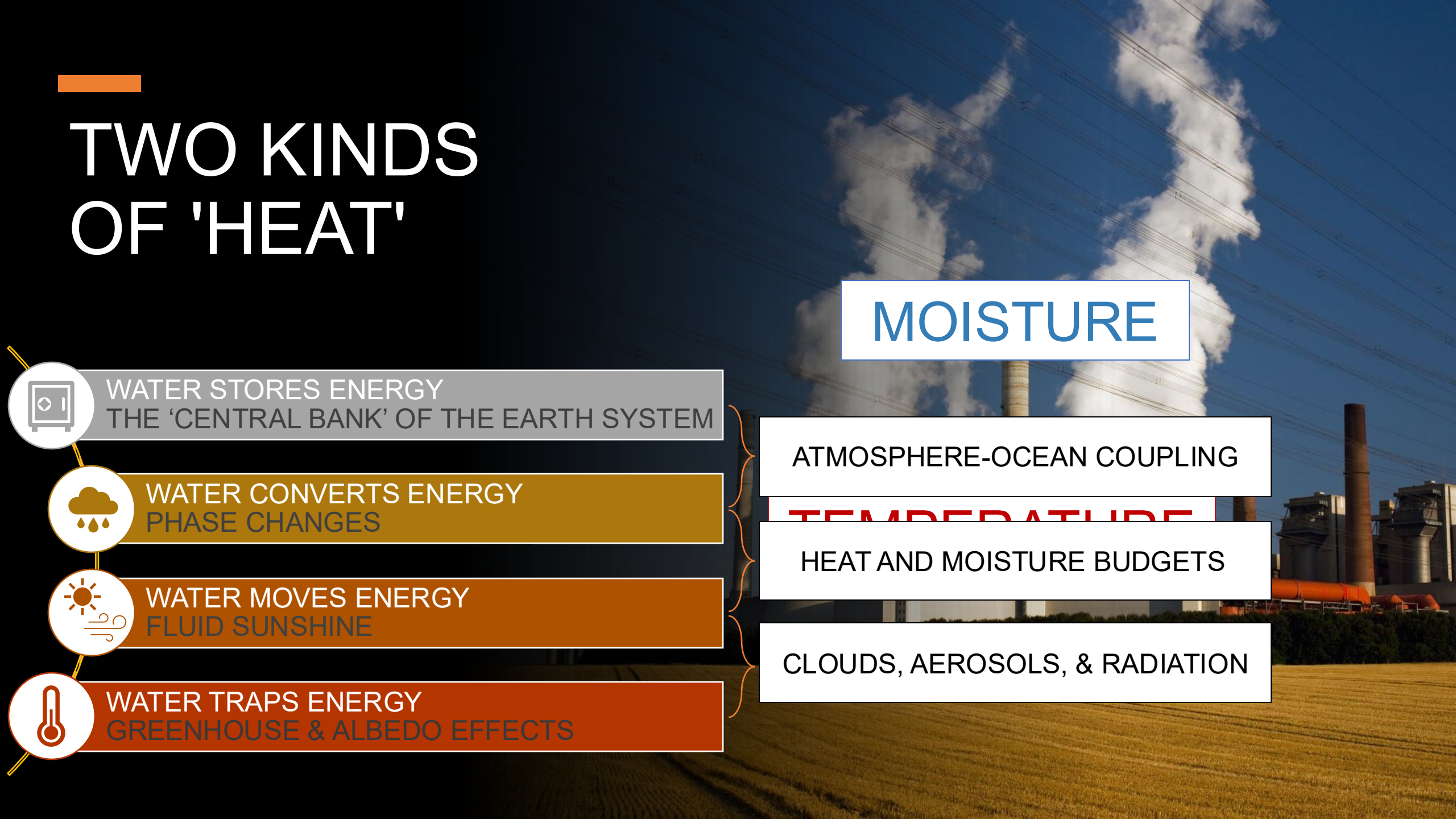
TWO KINDS OF 'HEAT'



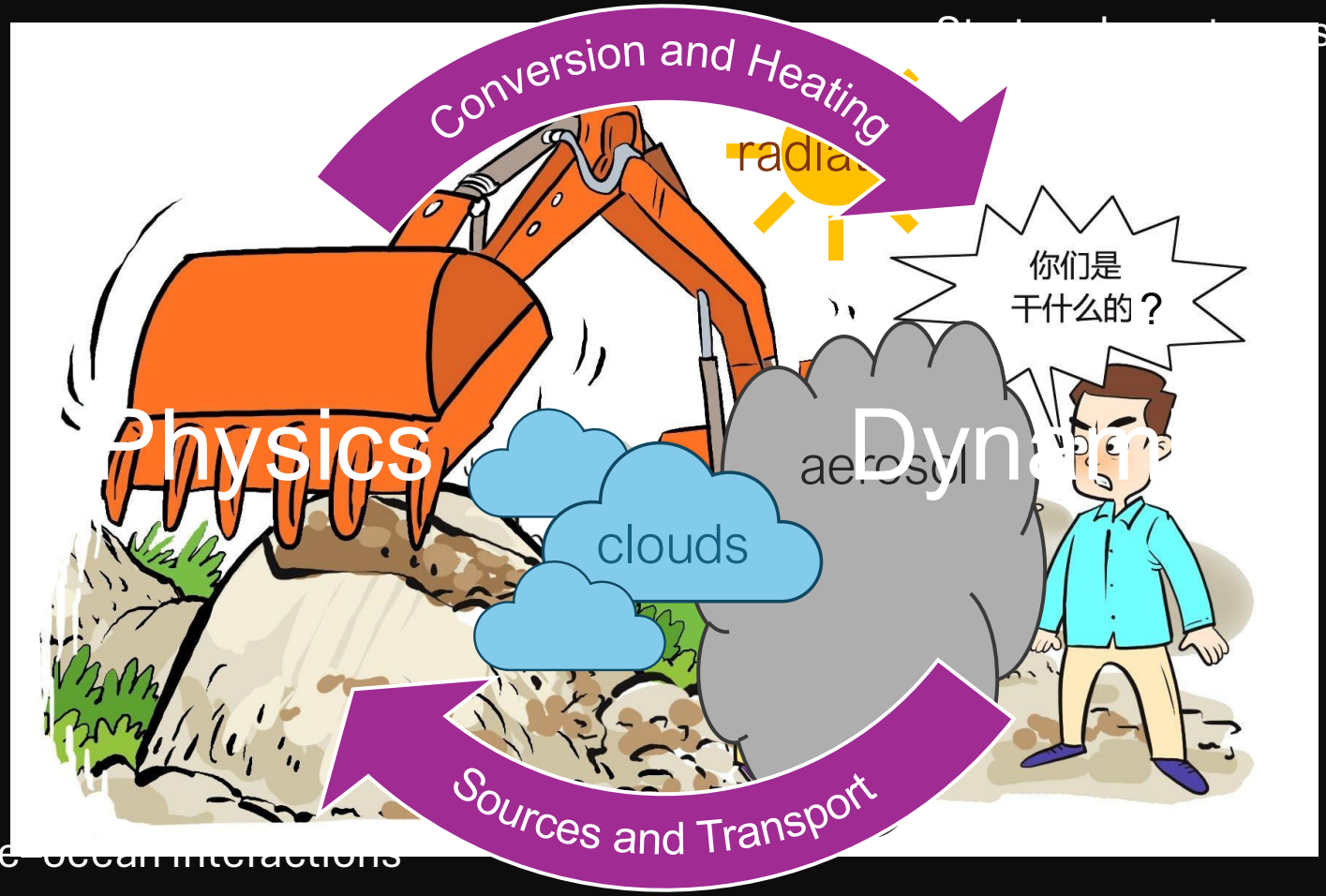
- WATER STORES ENERGY
  THE ‘CENTRAL BANK’ OF THE EARTH SYSTEM
- WATER CONVERTS ENERGY
  PHASE CHANGES
- WATER MOVES ENERGY
  FLUID SUNSHINE
- WATER TRAPS ENERGY
  GREENHOUSE & ALBEDO EFFECTS

MOISTURE

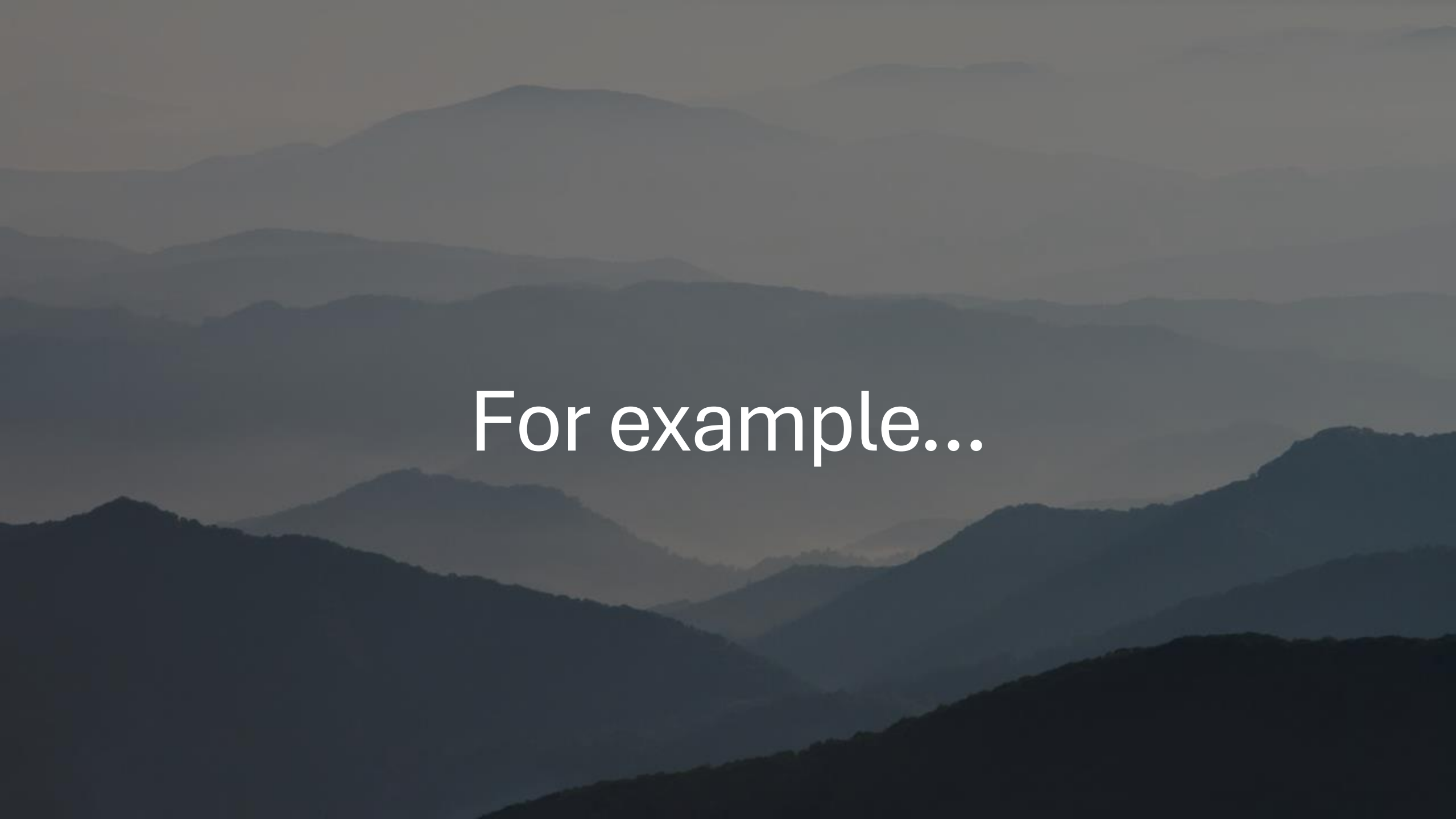
- ATMOSPHERE-OCEAN COUPLING
- TEMPERATURE
- HEAT AND MOISTURE BUDGETS
- CLOUDS, AEROSOLS, & RADIATION

What's Doing the Work?

sphere exchange



Atmosphere-ocean interactions

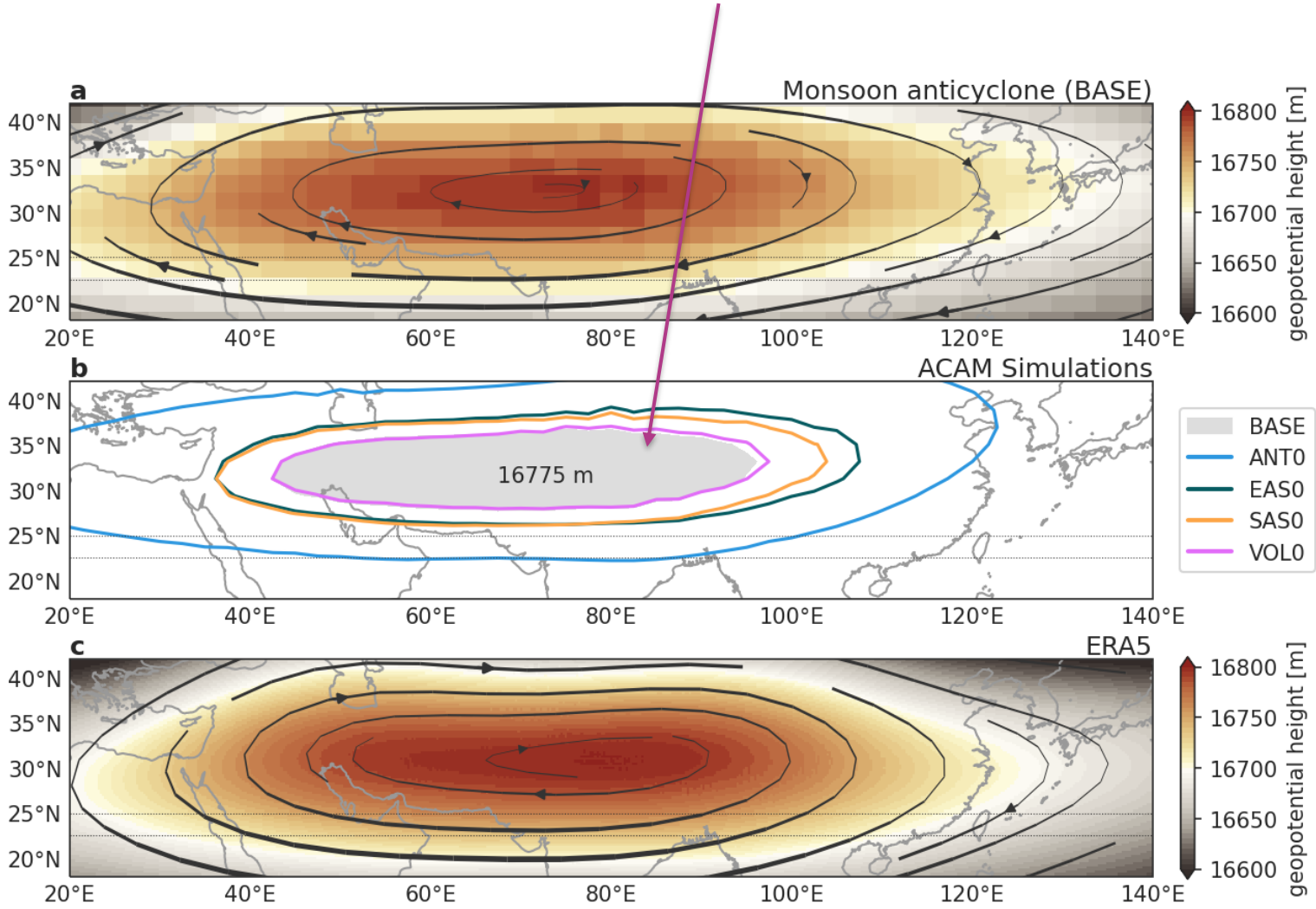

For example...

ACAM
ATMOSPHERIC COMPOSITION & THE ASIAN MONSOON

ACAM AeroCom experiments target the effects of Asian aerosols on the monsoon system:

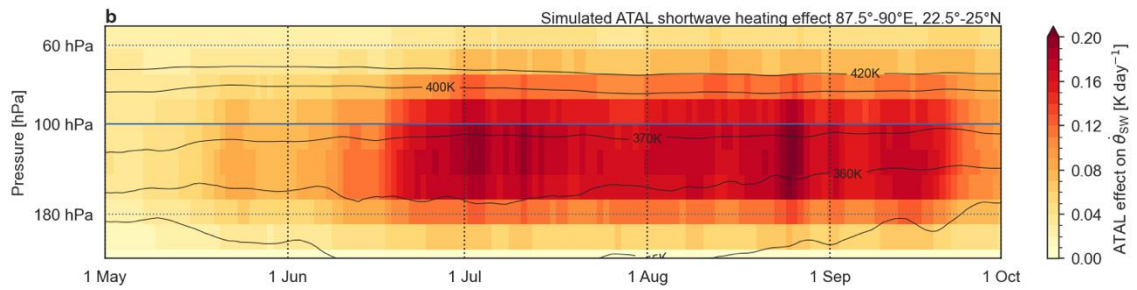
- **BASE:**
  all emissions
- **ANT0:**
  no anthropogenic emissions
- **EAS0:**
  as ANT0 but only over East Asia
- **SAS0:**
  as ANT0 but only over South Asia
- **VOL0:**
  no volcanic emissions

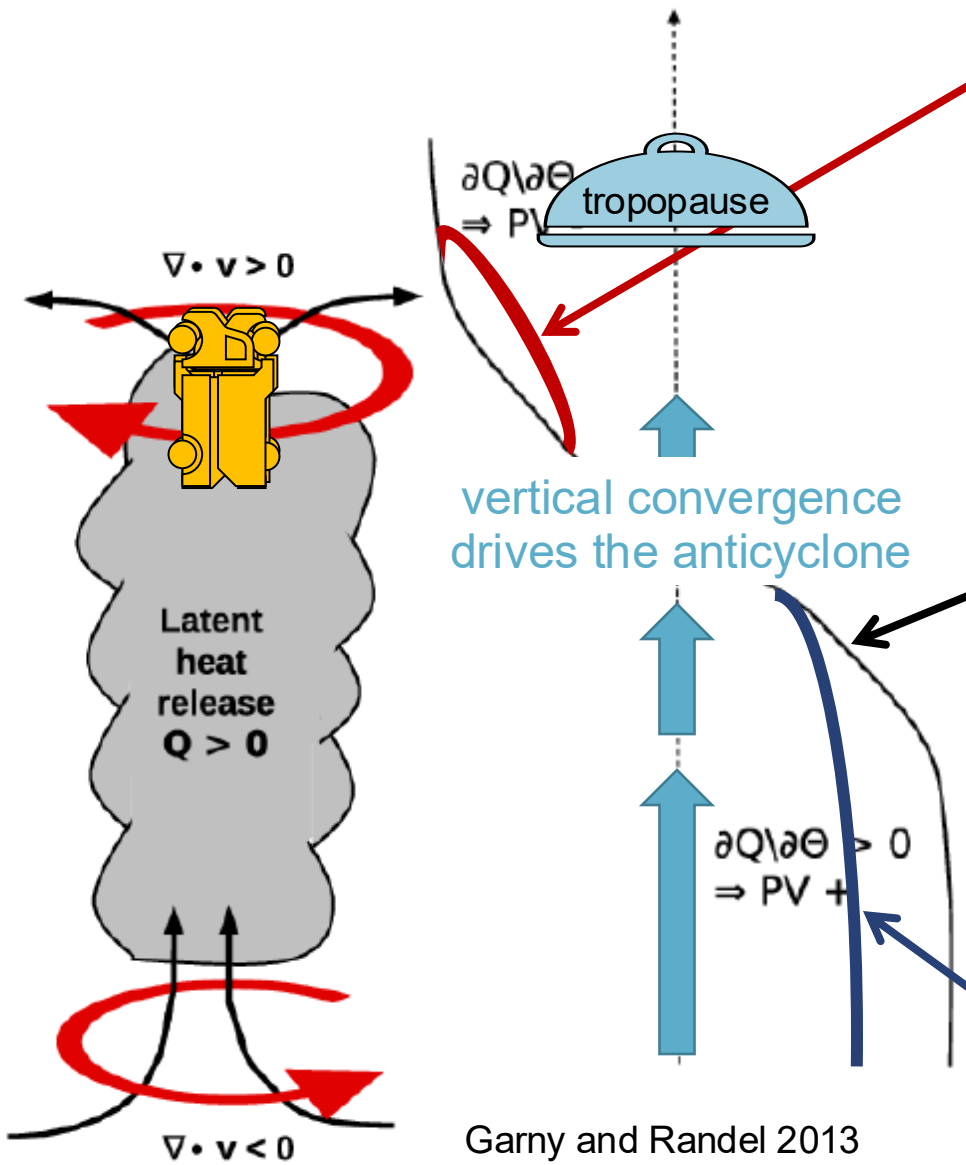
anthropogenic aerosols from all sources weaken the monsoon anticyclone



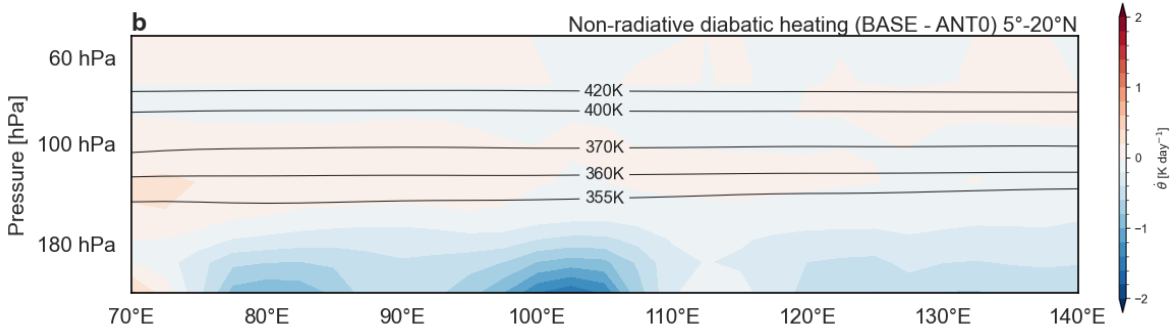
How do aerosols weaken the upper-level anticyclone?

Aerosols absorb sunlight :: longer braking distance





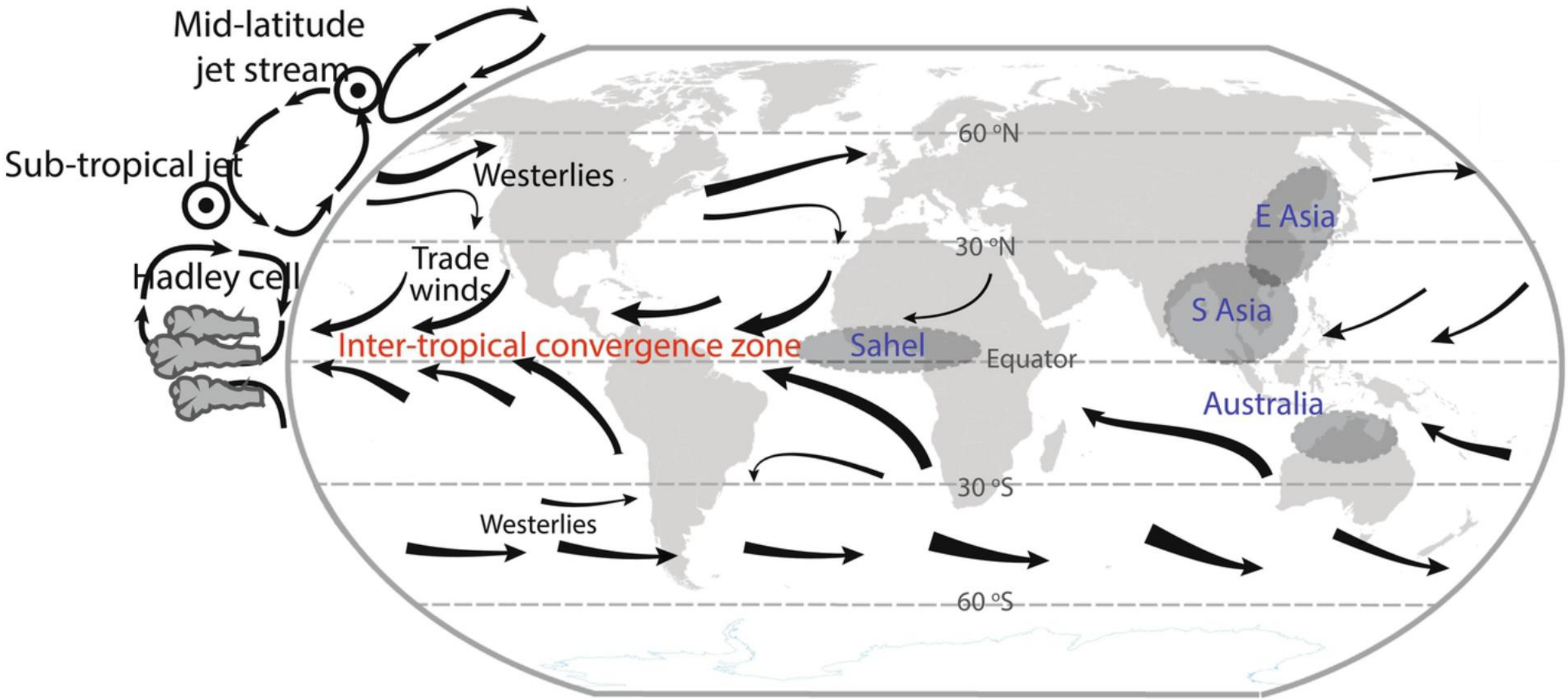
Strength of convergence depends on how sharply the brake is applied



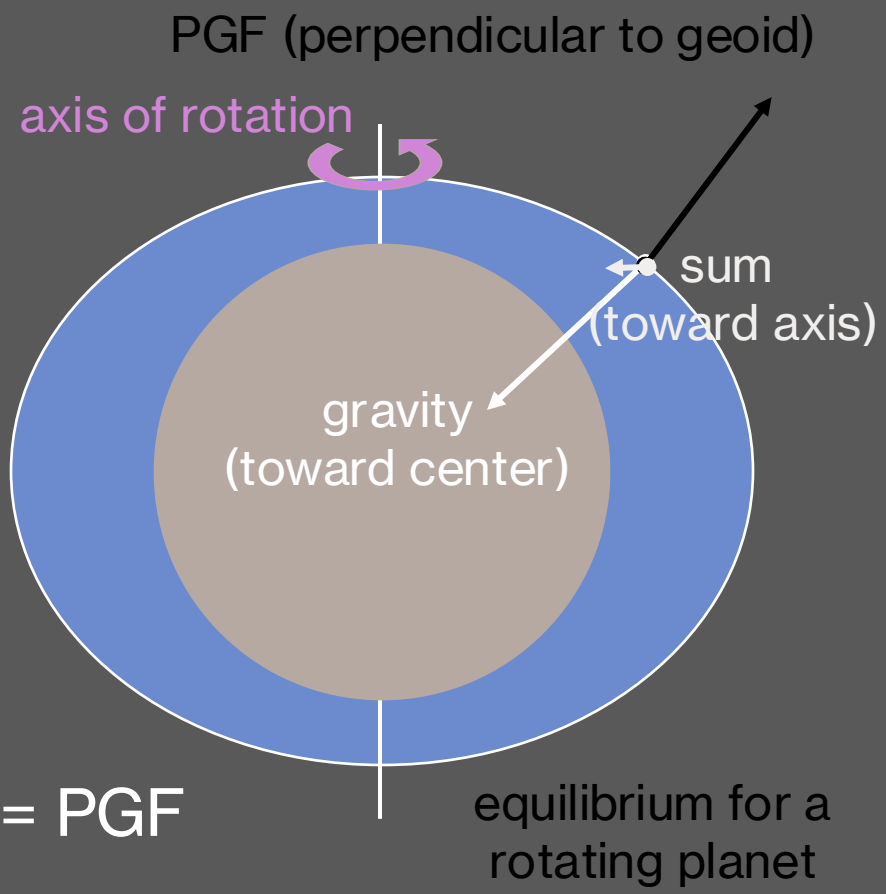
Aerosols suppress storms :: slower starting speed

Garny and Randel 2013

COMPOSITION-CIRCULATION COUPLING IN THE ASIAN MONSOON


Mid-latitude
jet stream
Sub-tropical jet
Hadley cell
Westerlies
Trade
winds
Inter-tropical convergence zone
Sahel
60 °N
30 °N
Equator
30 °S
60 °S
E Asia
S Asia
Australia
Westerlies

Step 1: Rotation



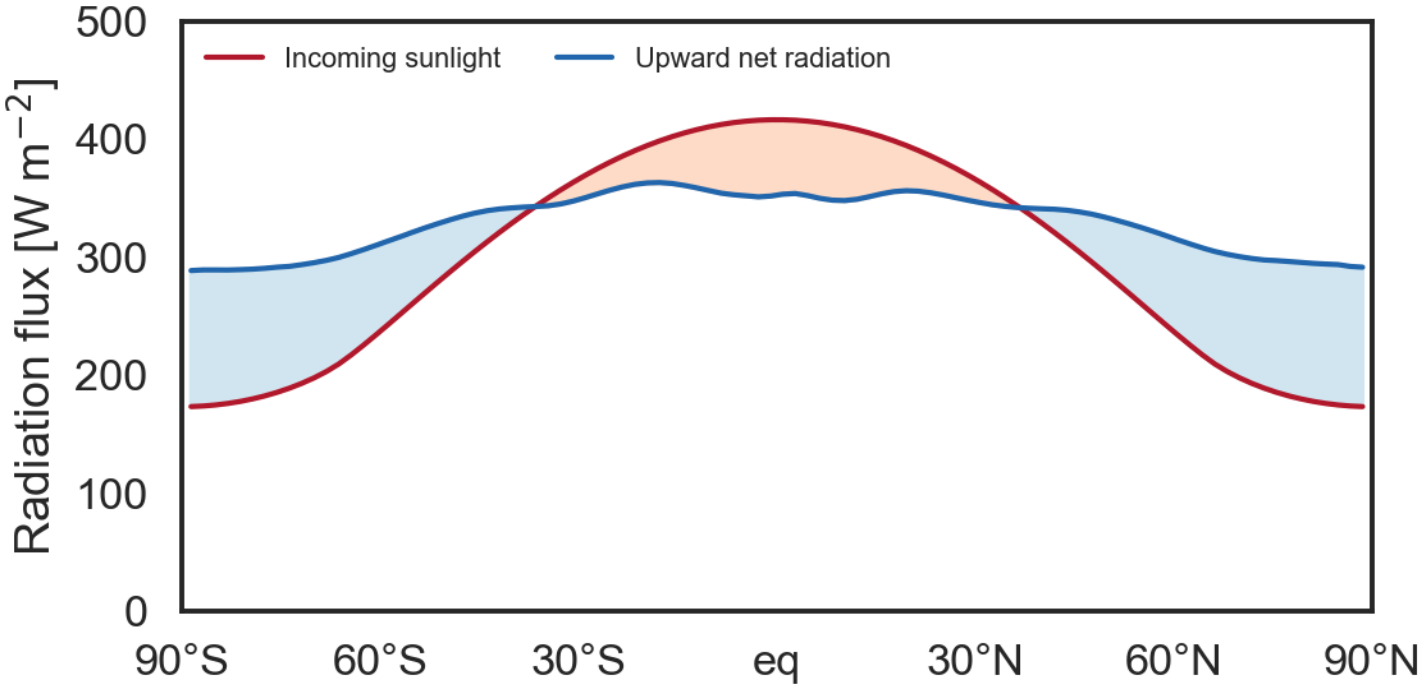
Gravity + circular acceleration = effective gravity = PGF

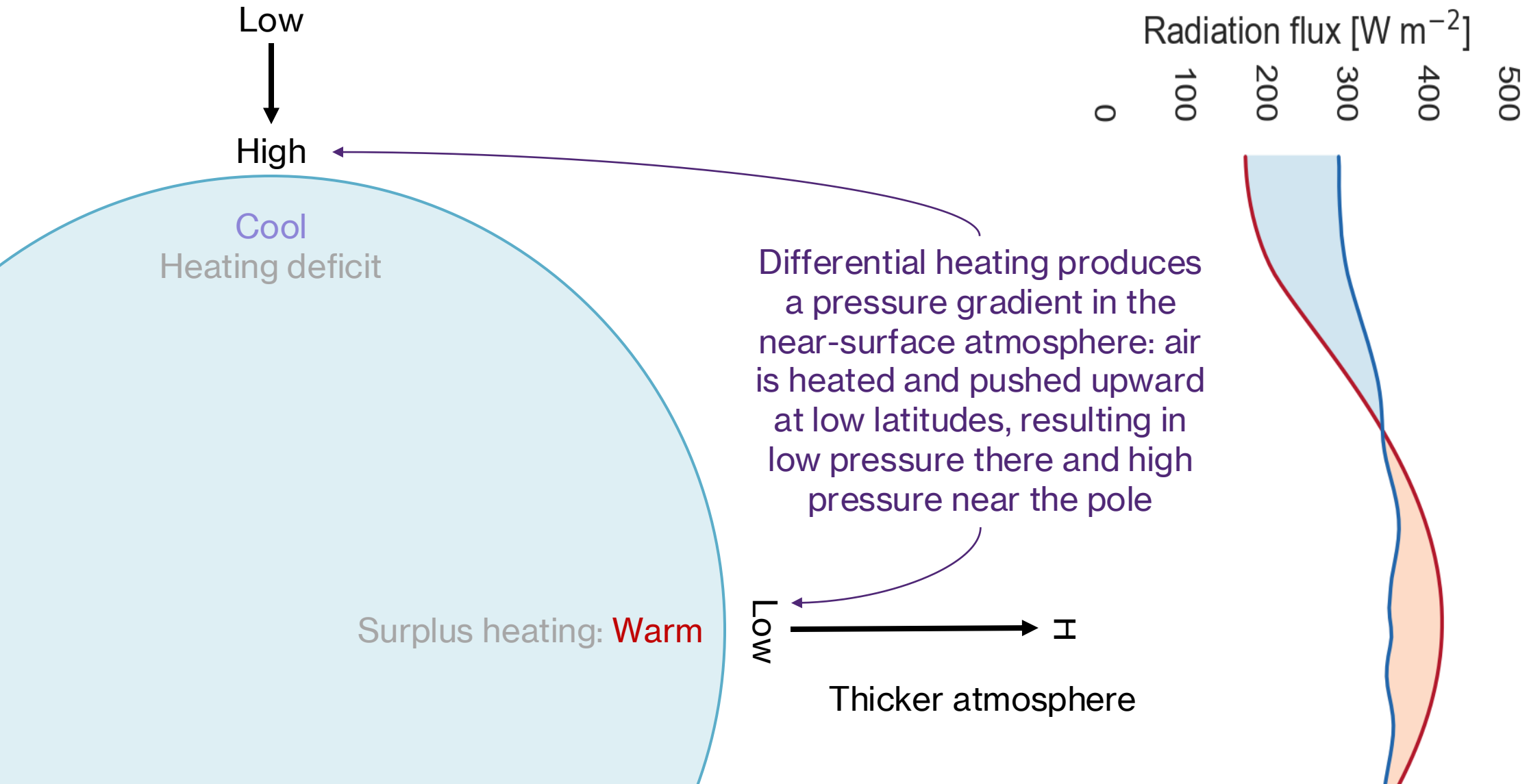
Step 2: Differential Heating

Cool

Heating deficit

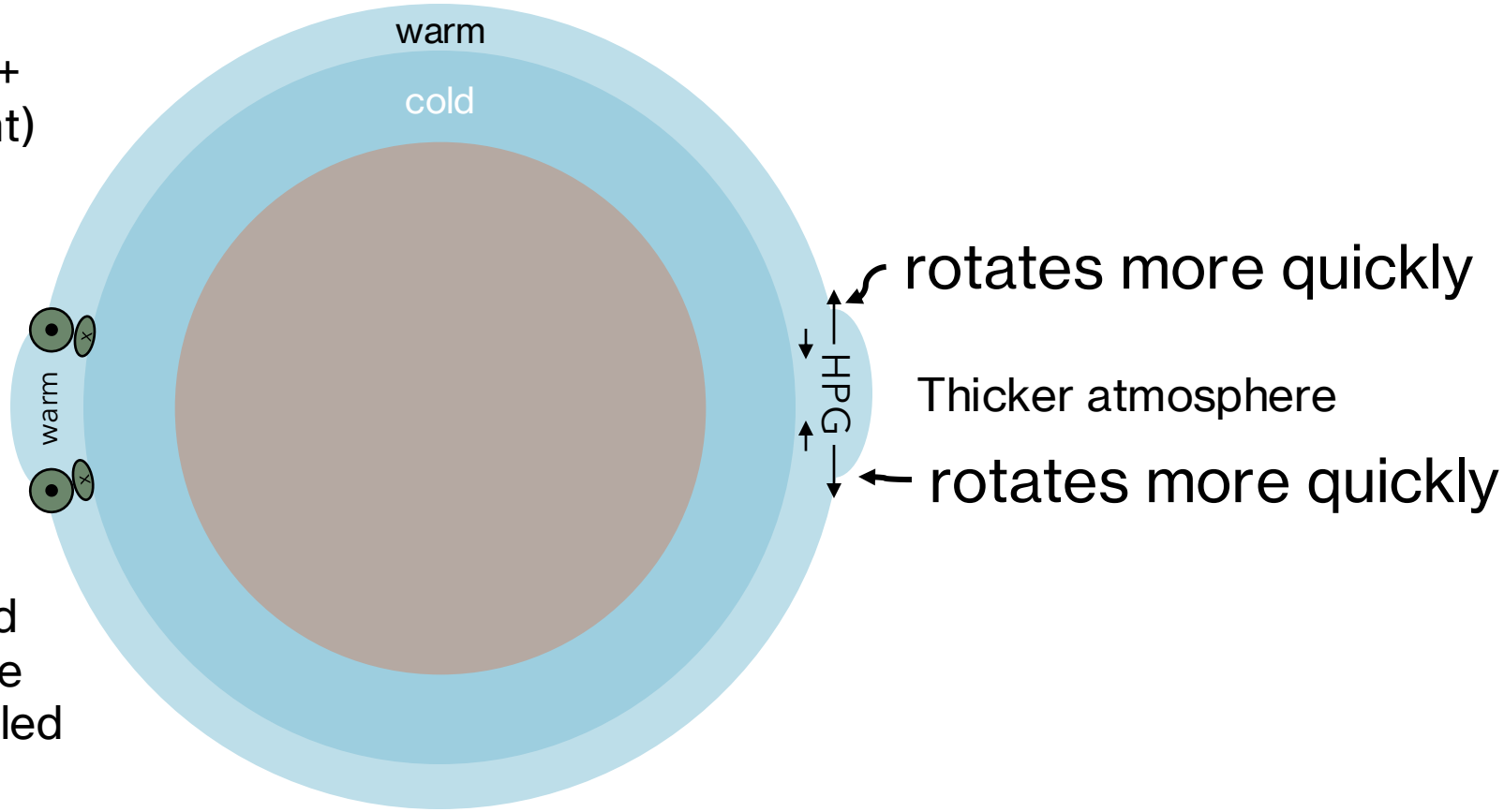
Surplus heating: Warm




Low
High
Cool
Heating deficit
Surplus heating: Warm
Differential heating produces a pressure gradient in the near-surface atmosphere: air is heated and pushed upward at low latitudes, resulting in low pressure there and high pressure near the pole
Low
H
Thicker atmosphere
Radiation flux [W m^{-2}]
0
100
200
300
400
500

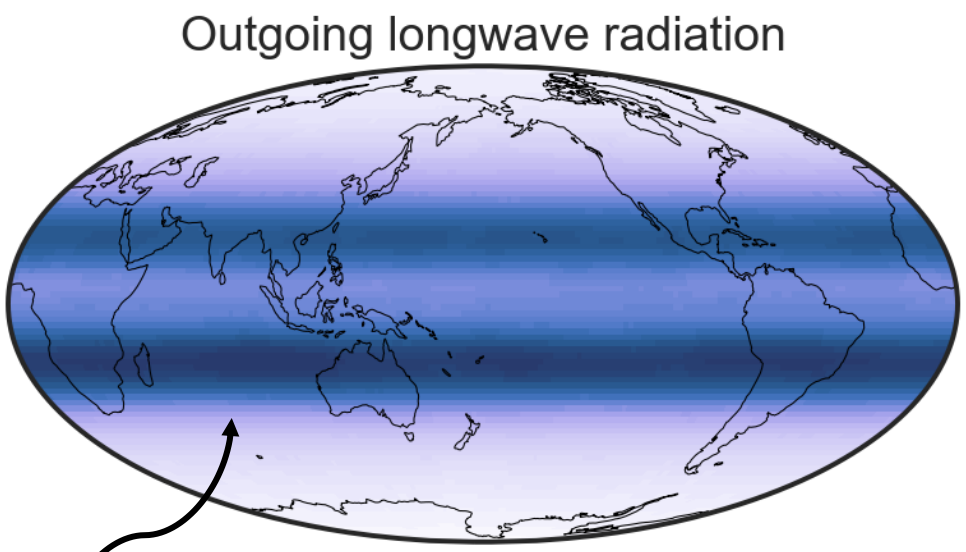
Combine Steps 1 & 2: Thermal Wind Balance

Coriolis (differential rotation) +
T difference (pressure gradient)



The vertical gradient of winds and currents around ‘thicker’ fluid layers like the tropical atmosphere is called the ‘thermal wind’

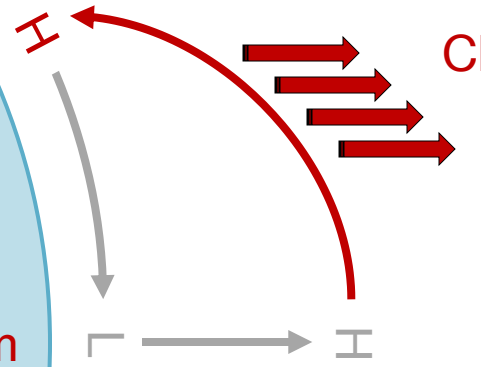
Step 3: Ventilation



“Radiator Fin”:

Sinking air:
Subtropical High

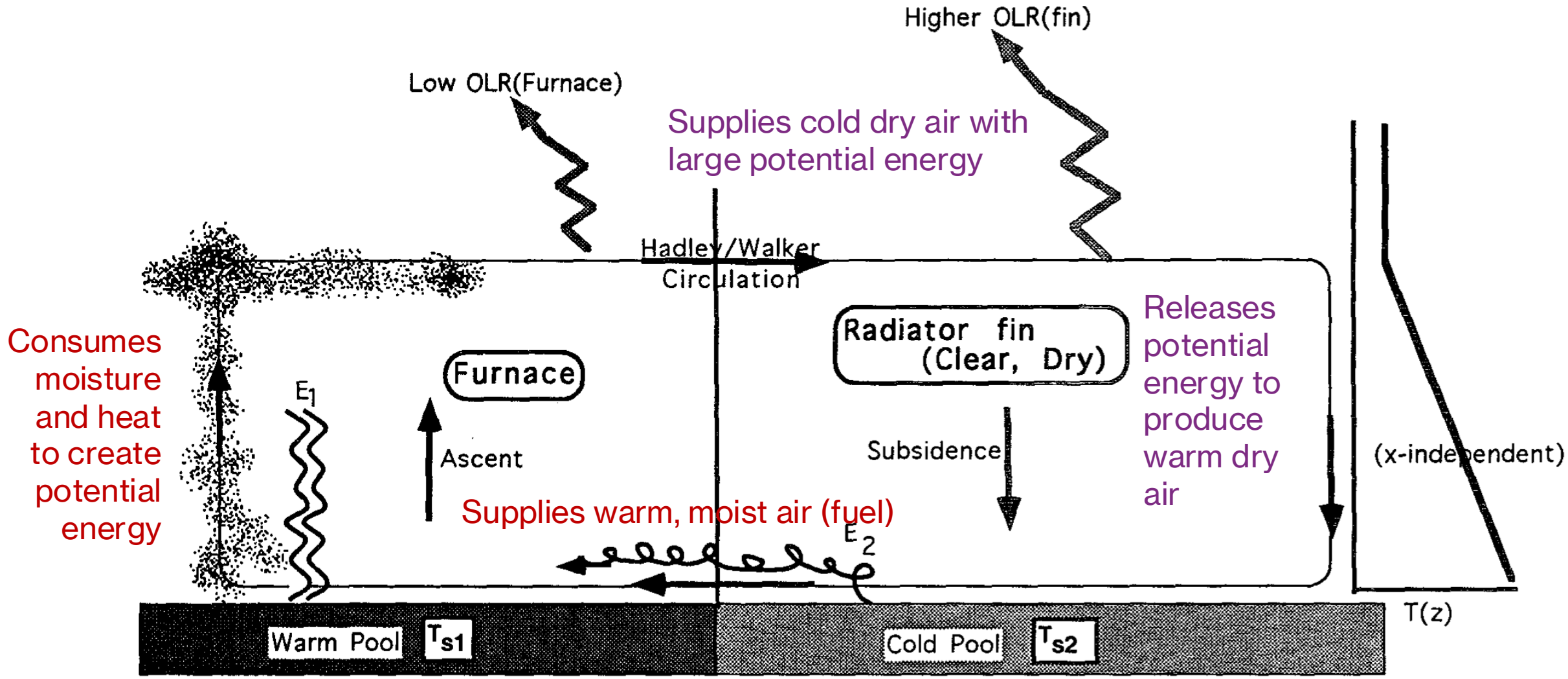
Surplus heating: Warm



Clear-sky energy loss → air sinks

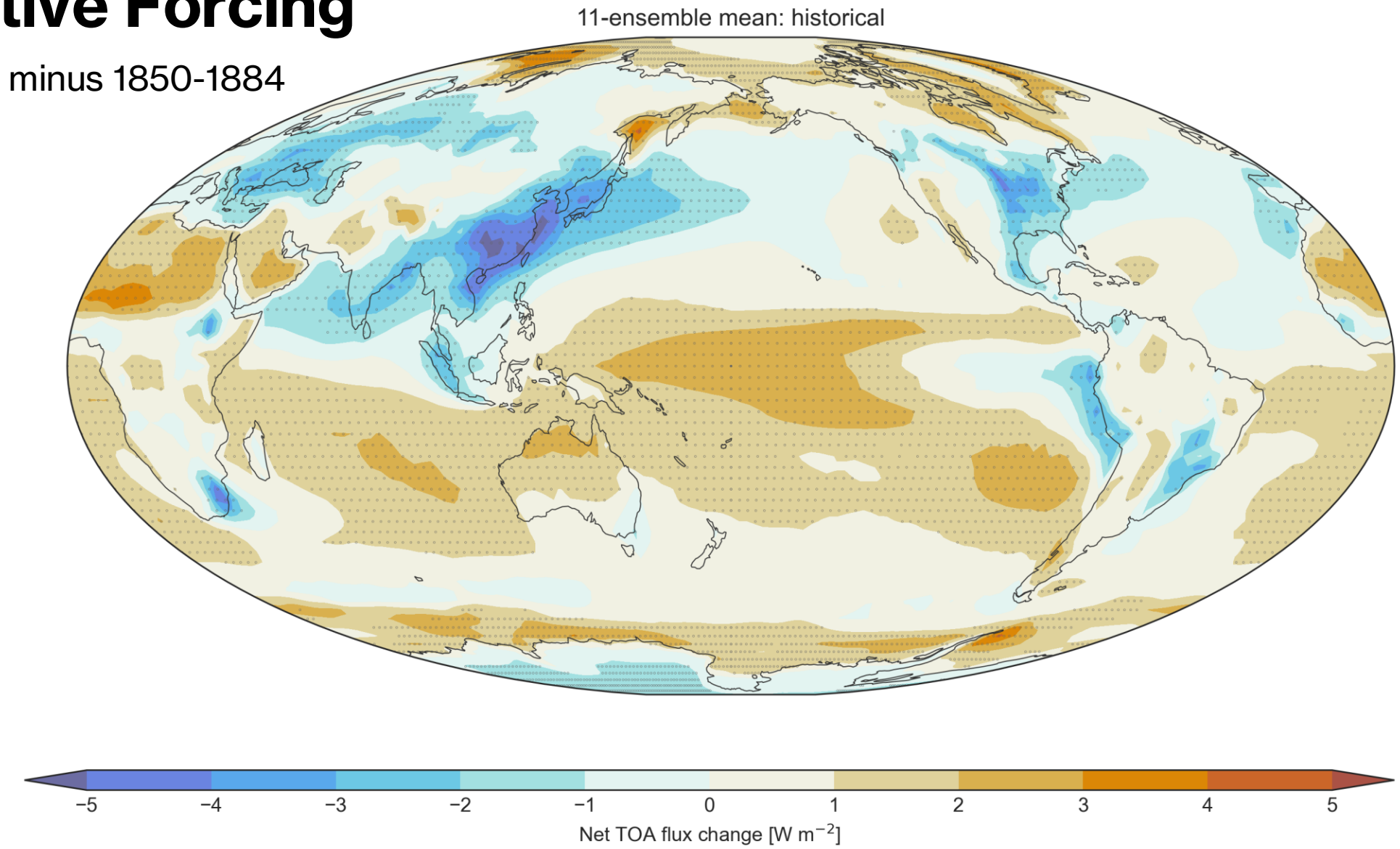
Rising motion: Clouds trap energy

SUBTROPICAL "RADIATOR FINS"



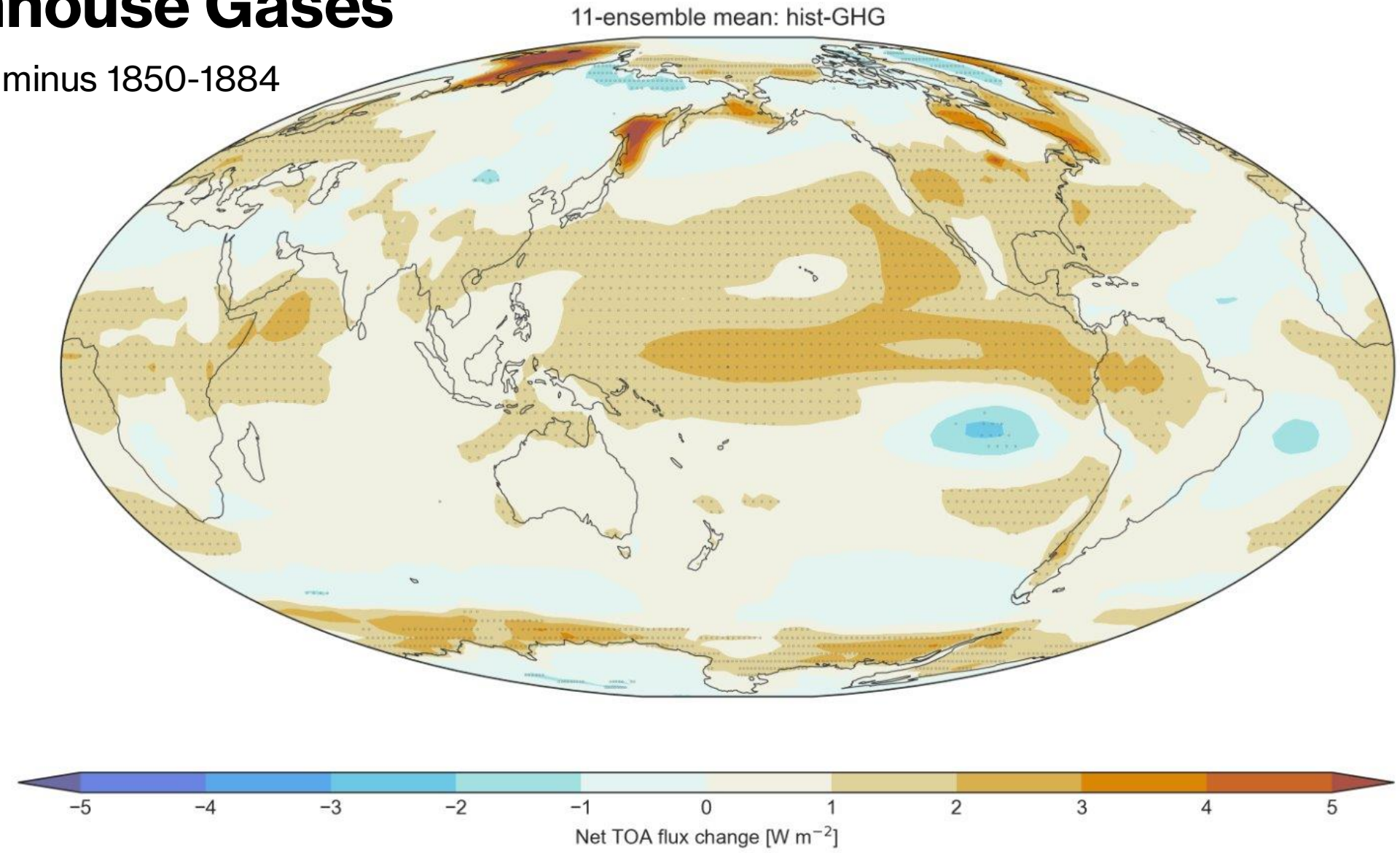
Radiative Forcing

1980-2014 minus 1850-1884



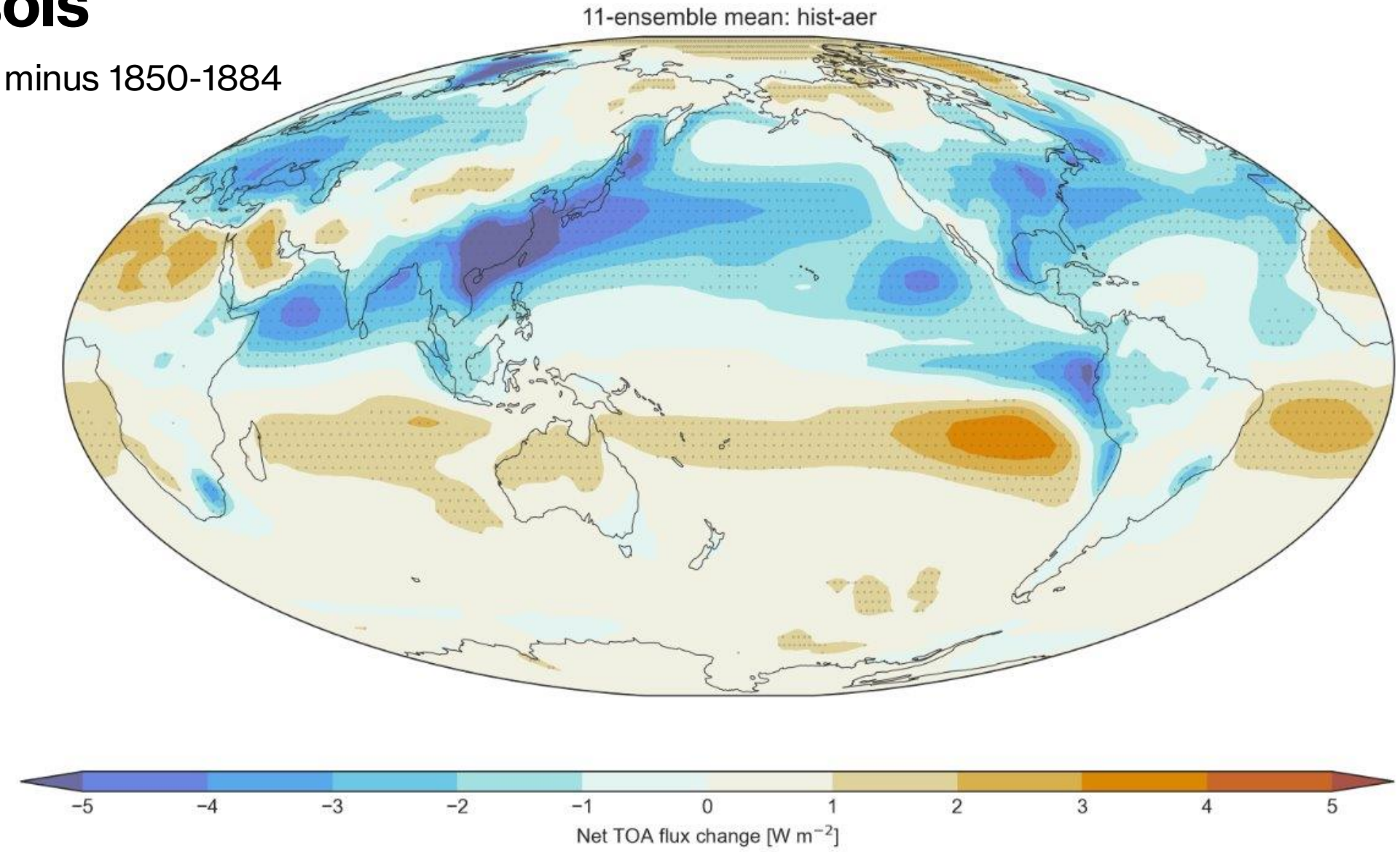
Greenhouse Gases

1980-2014 minus 1850-1884

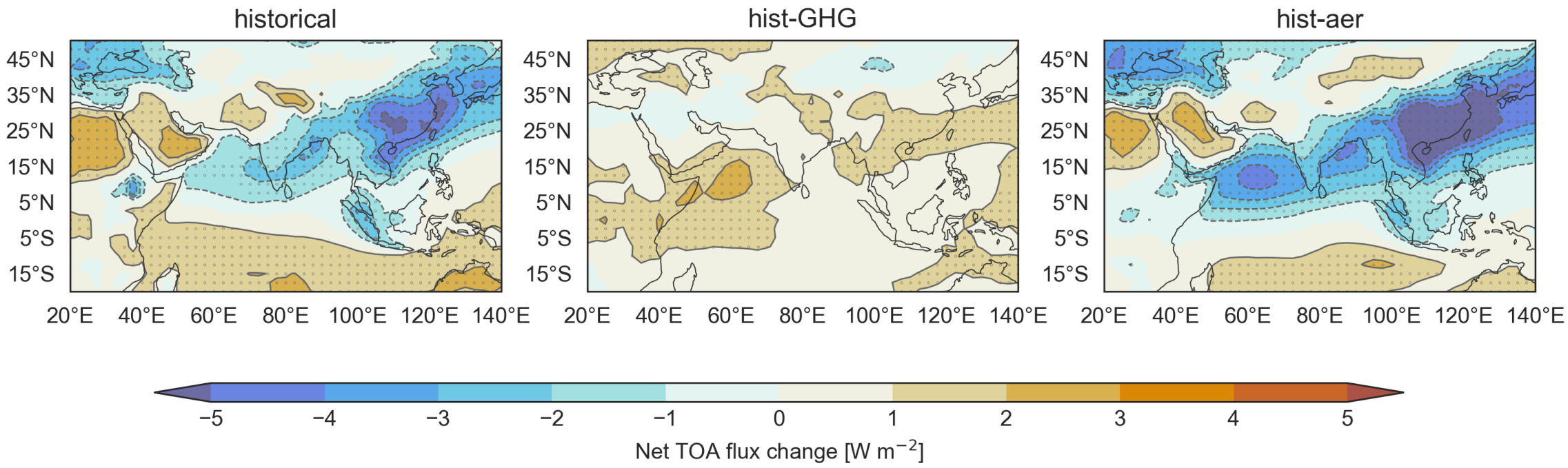


Aerosols

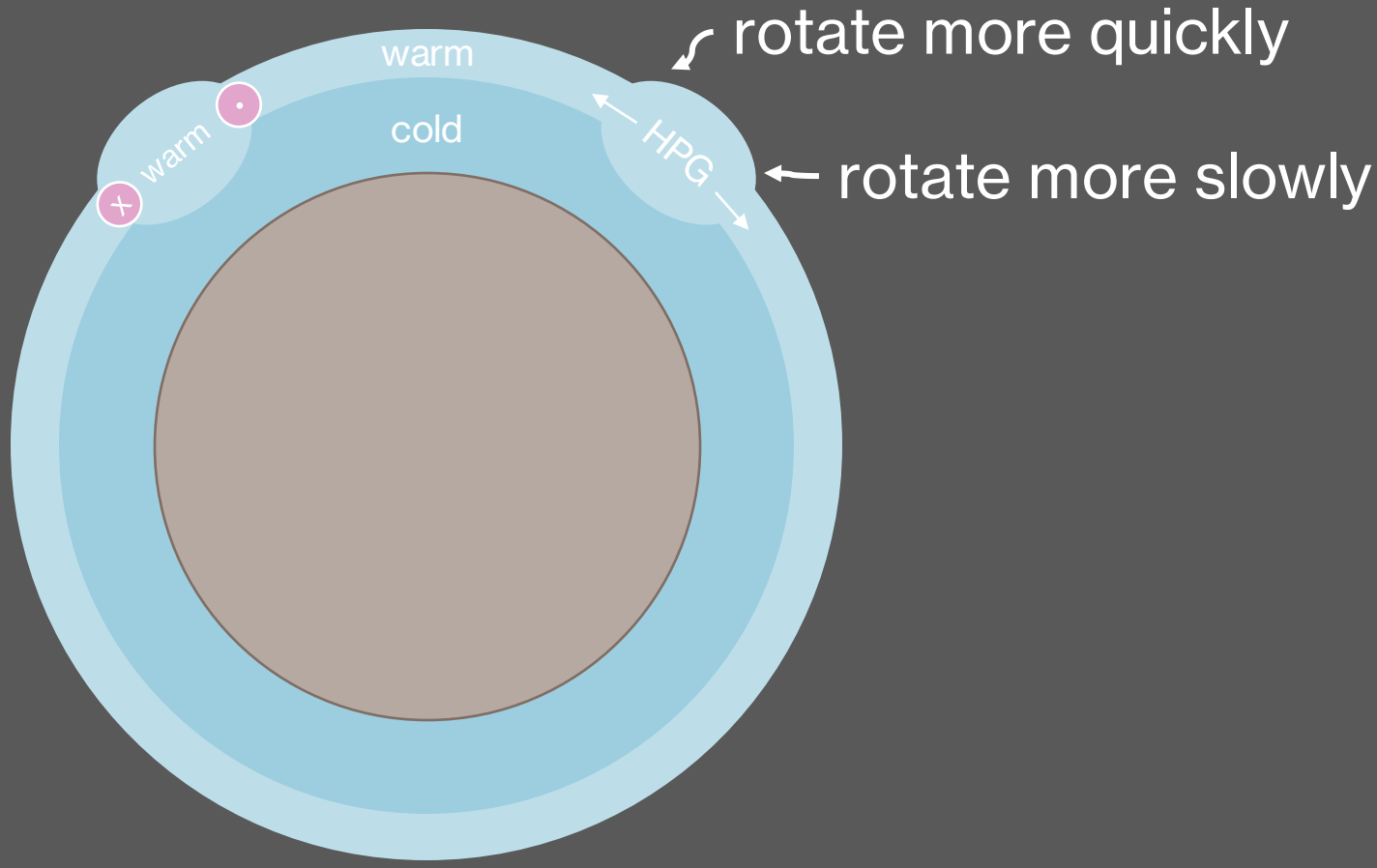
1980-2014 minus 1850-1884



Forcing in the monsoon domain

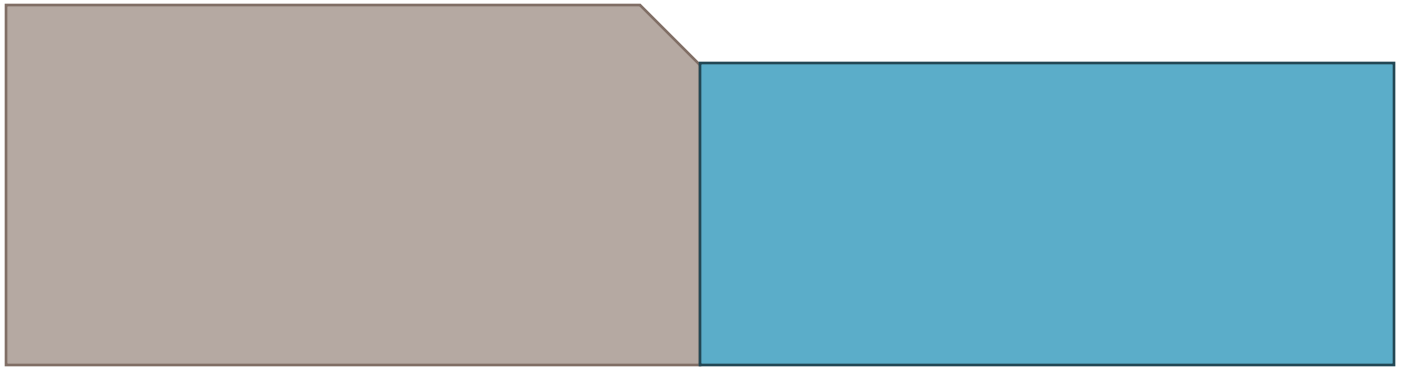


Toward the monsoon: Heating off the equator



The Simplest Model

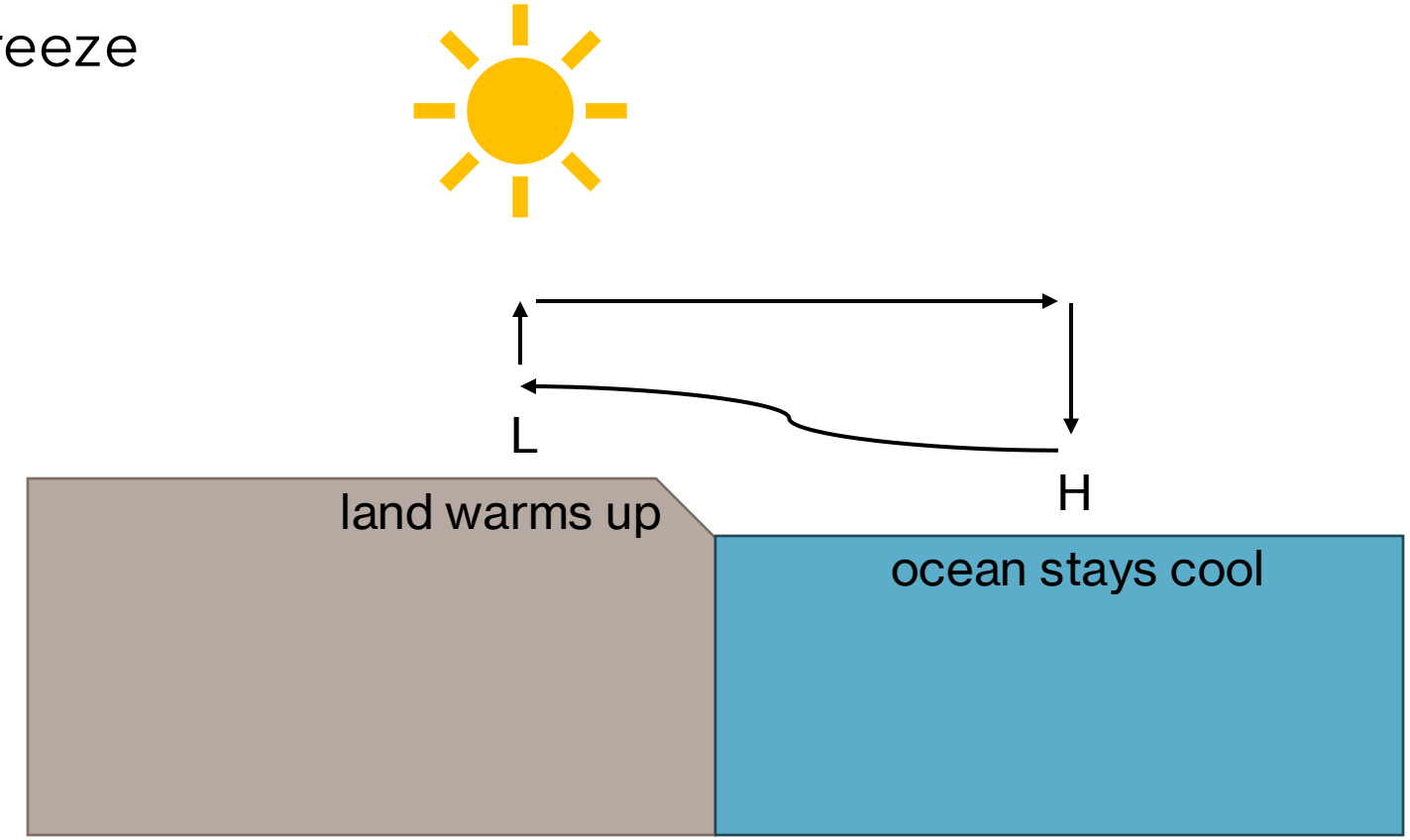
Land-sea breeze



The Simplest Model

Land-sea breeze

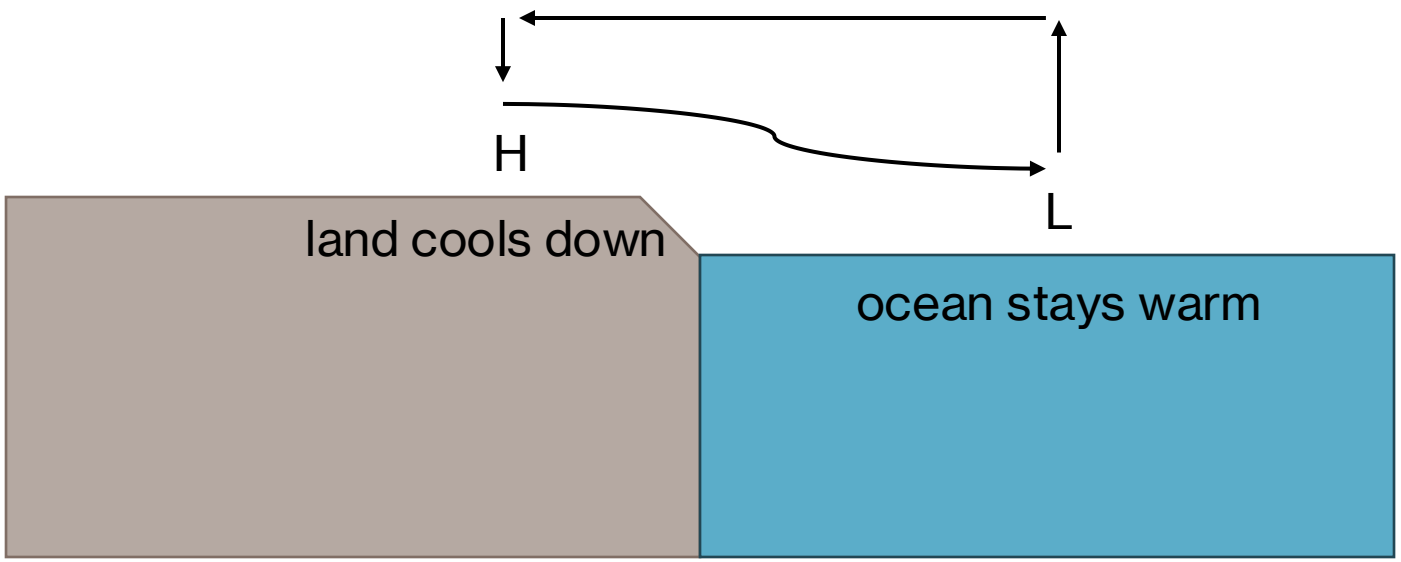
Daytime



The Simplest Model

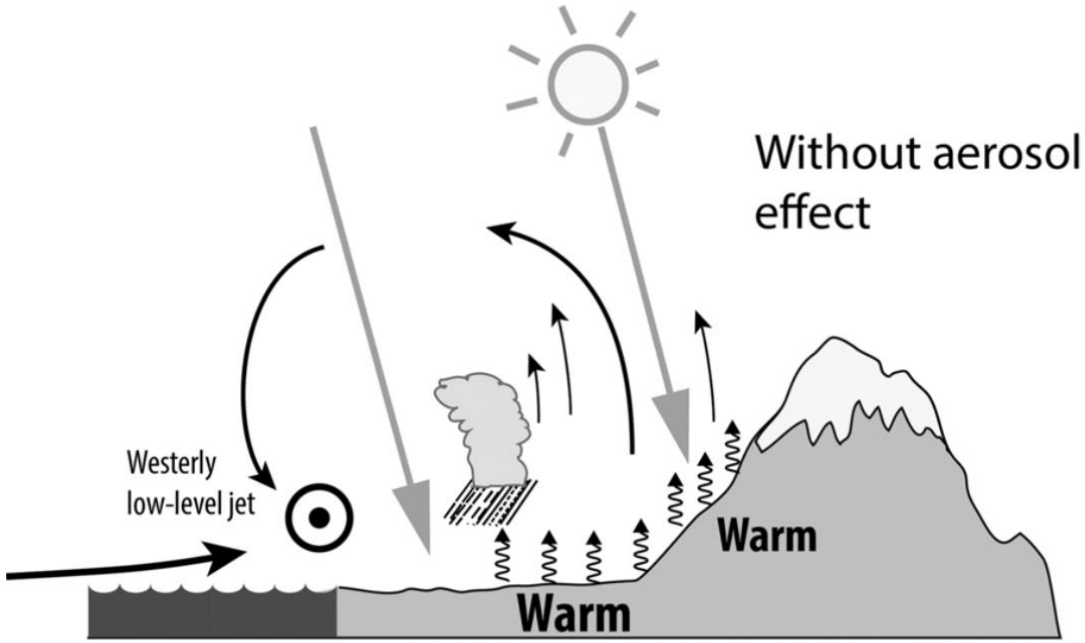
Land-sea breeze

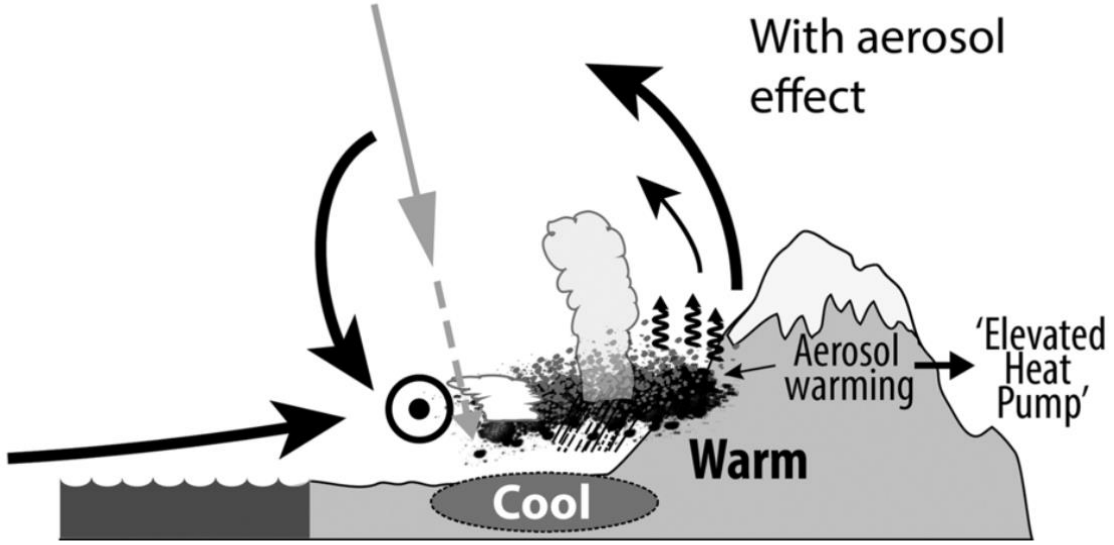
Nighttime / winter



"Elevated heat pump"

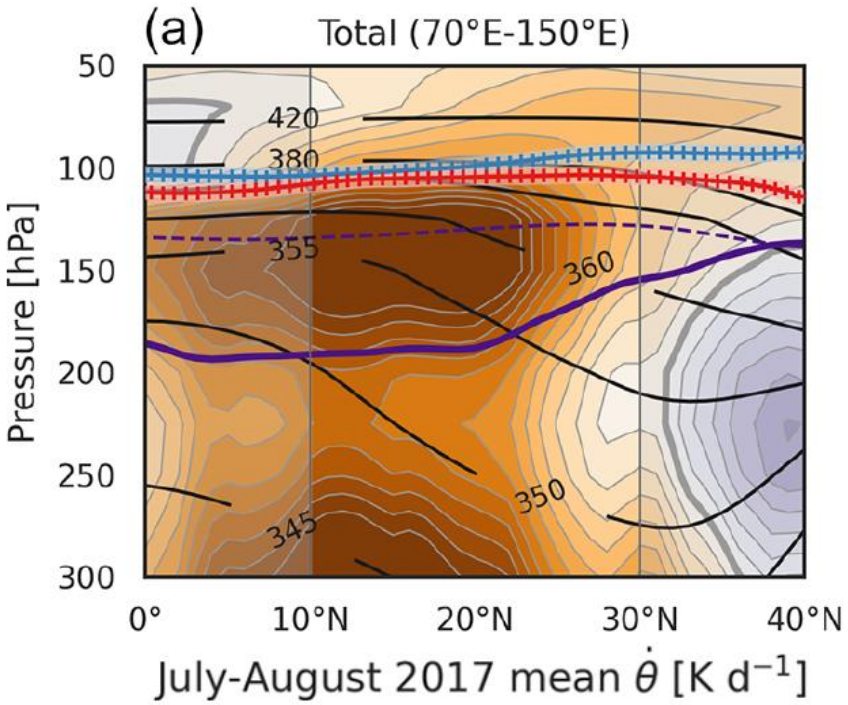
- Aerosols increase heating in the atmosphere
- Pumps more moisture from surrounding oceans
- This effect seems to be most important in the pre-monsoon and in La Nina years
- In the time mean, aerosols weaken the monsoon – why?

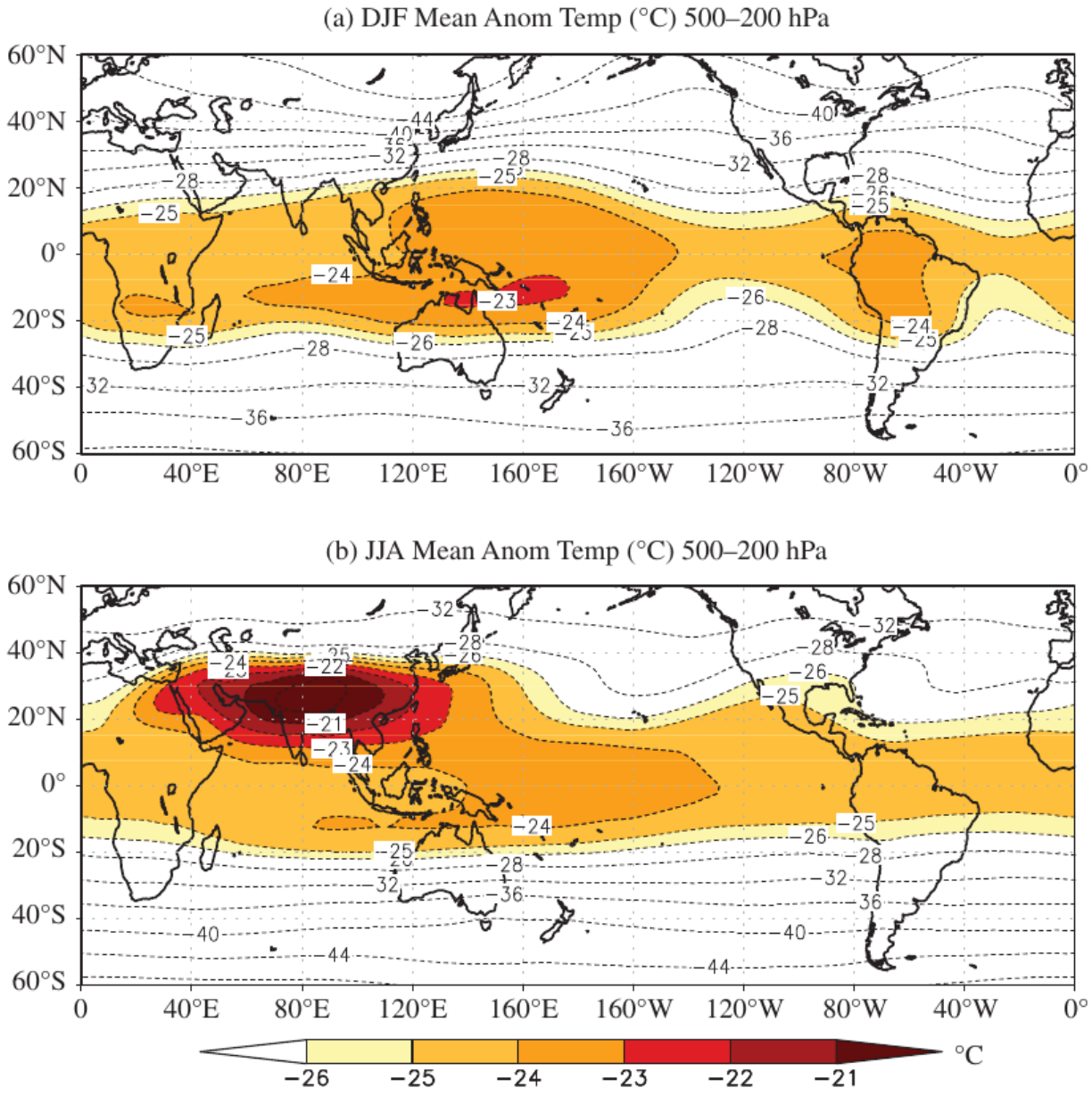




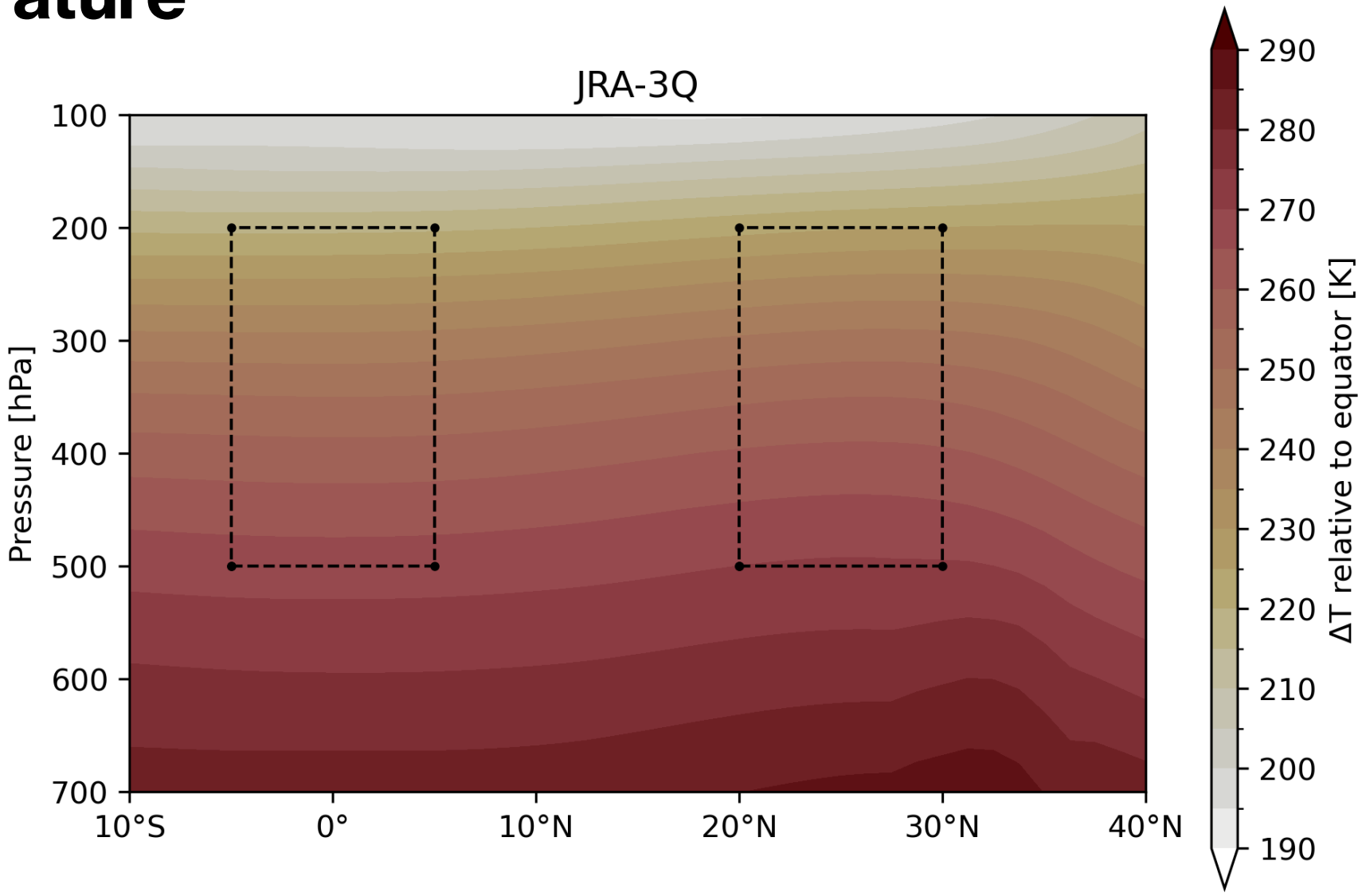
Temperature

In fact, the atmospheric temperature reversal matters more

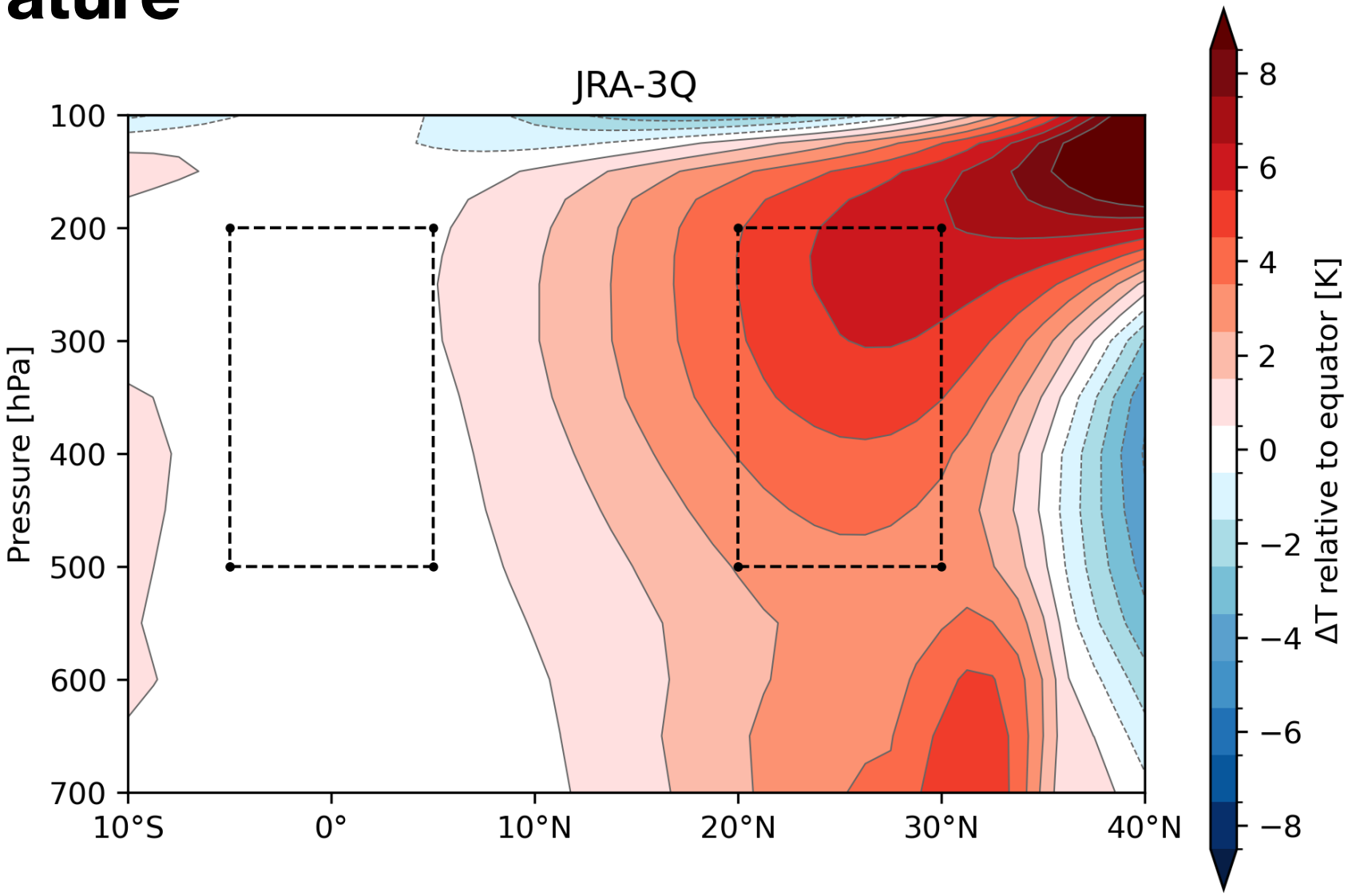




Temperature

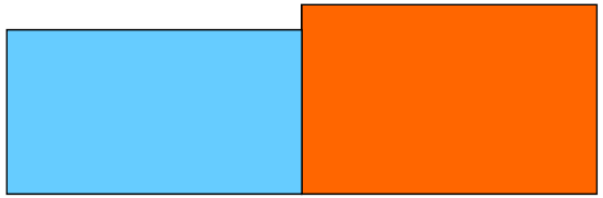


Temperature

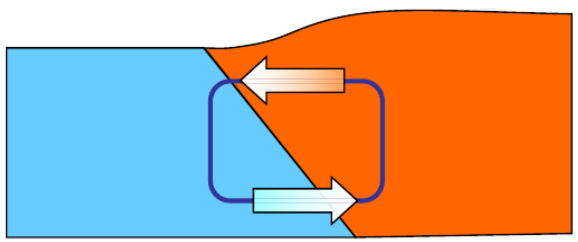


Temperature

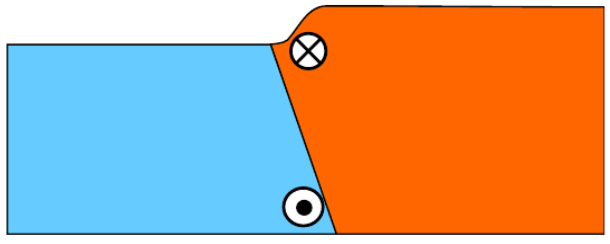
Two possible responses to a poleward gradient of upper-level temperature



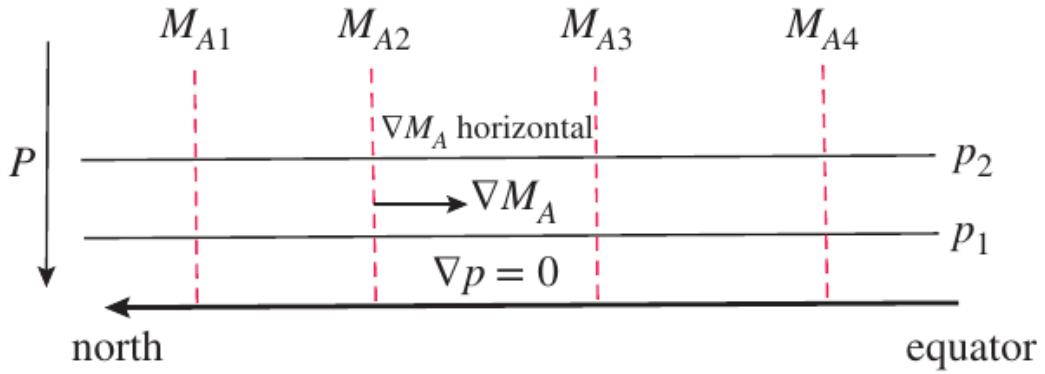
A t = 0



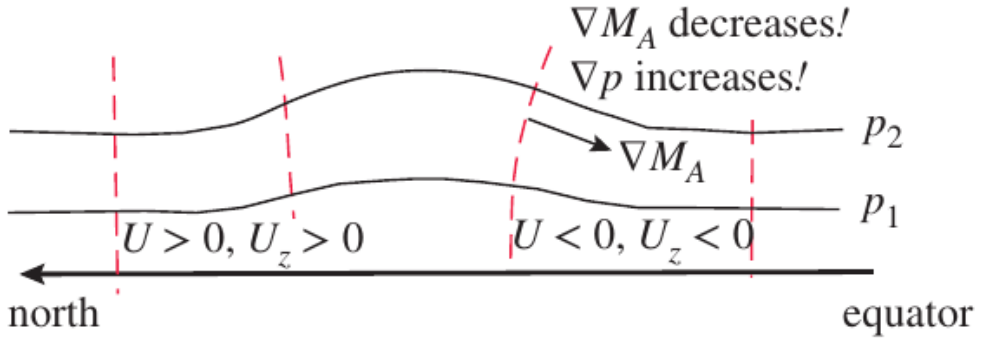
B f = 0 Overturning



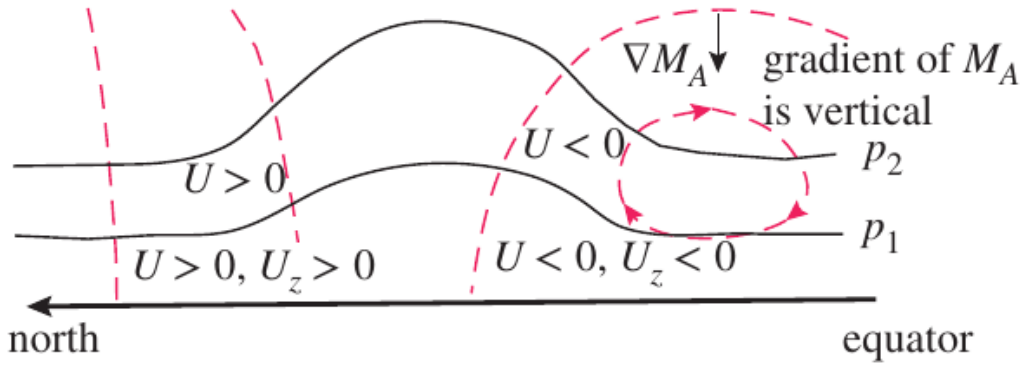
C f > 0 Thermal wind balance N



(a) No heat source

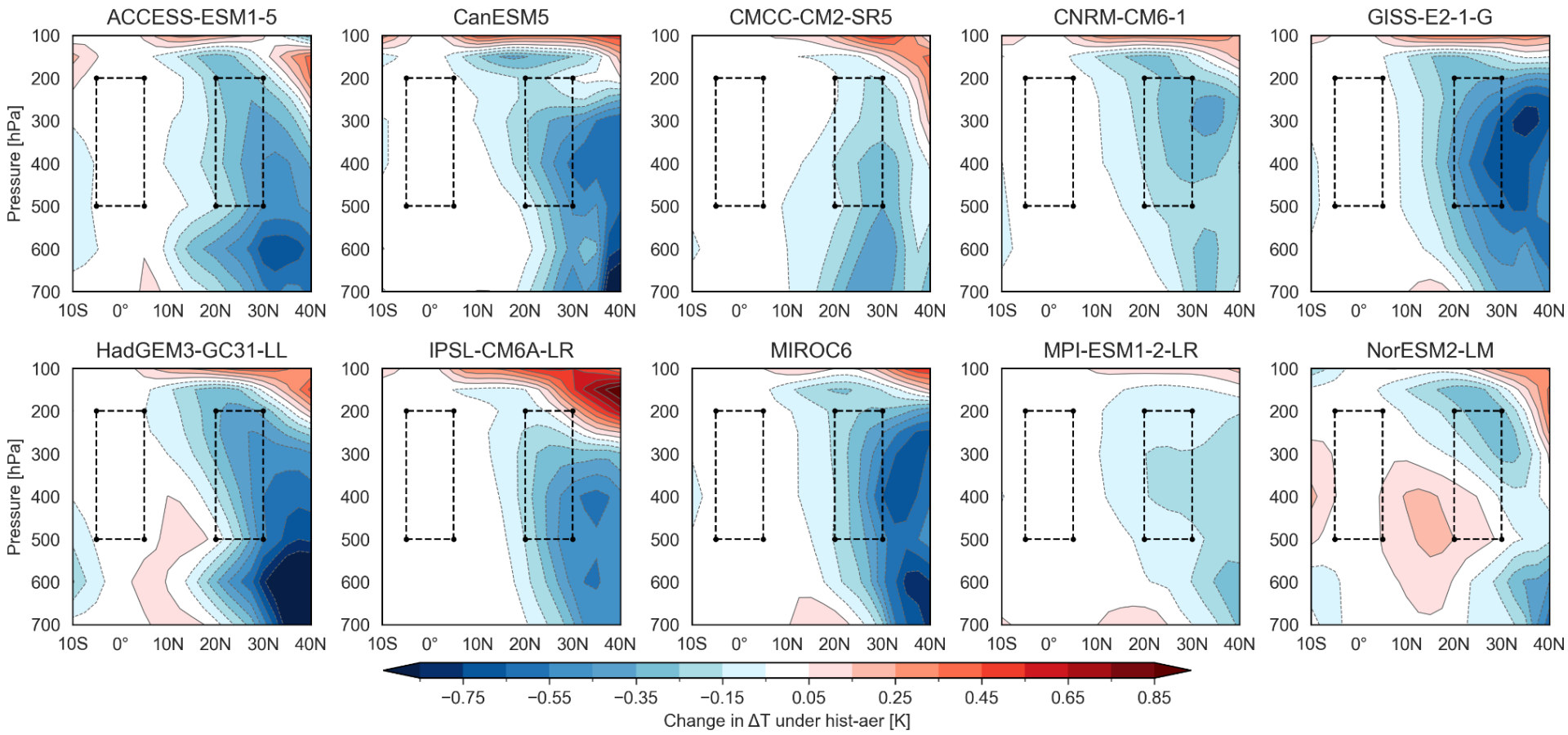


(b) Weak axisymmetric heat source

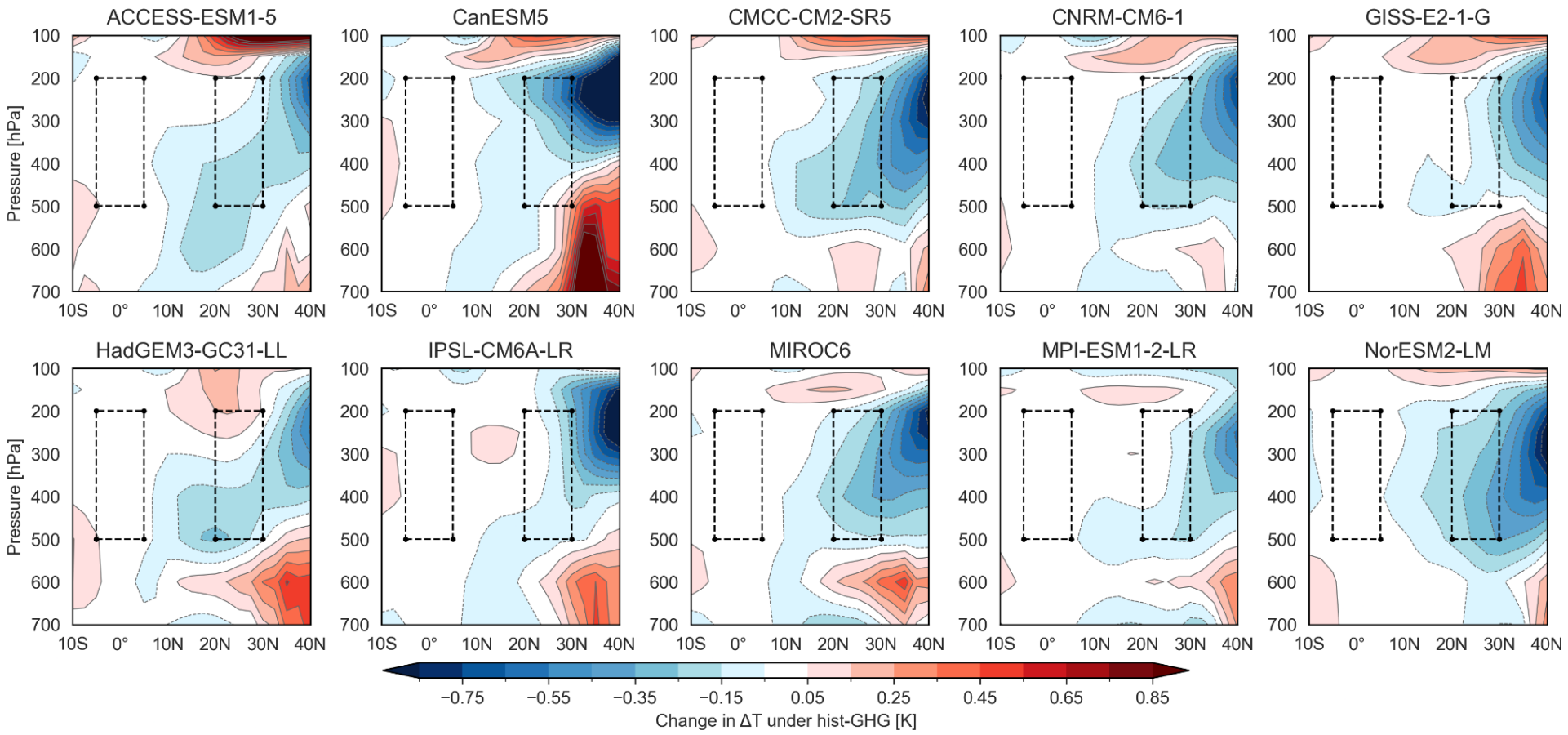


(c) Strong axisymmetric heat source

Aerosol response

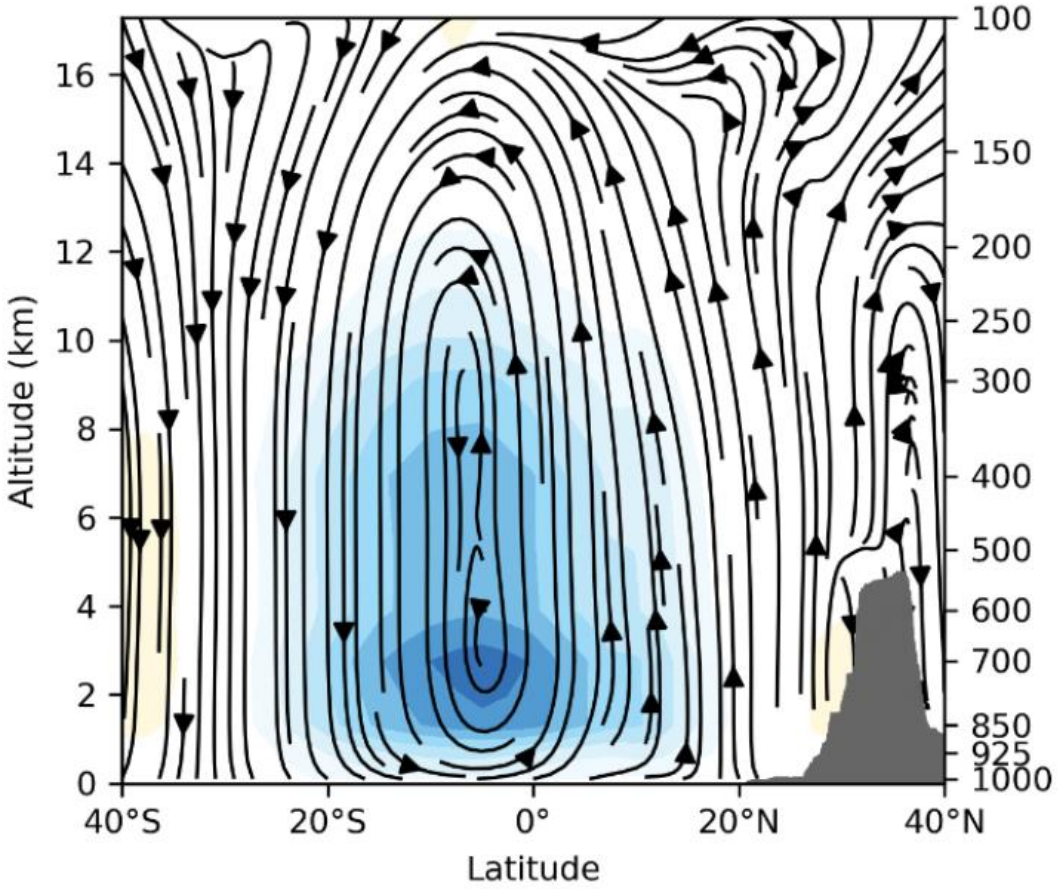


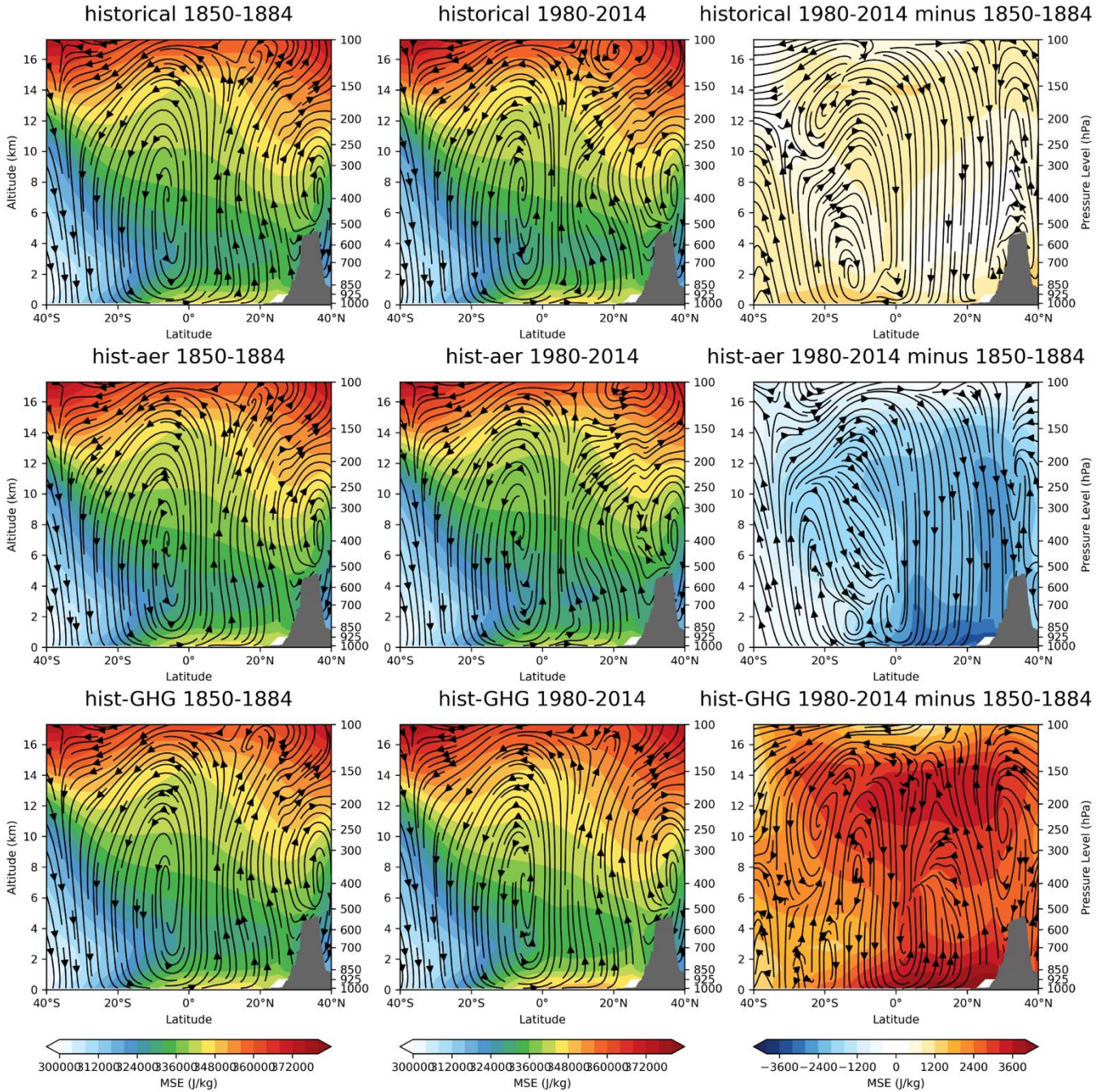
Greenhouse gas response



Monsoon Overturning

Moist static energy explains forced changes well





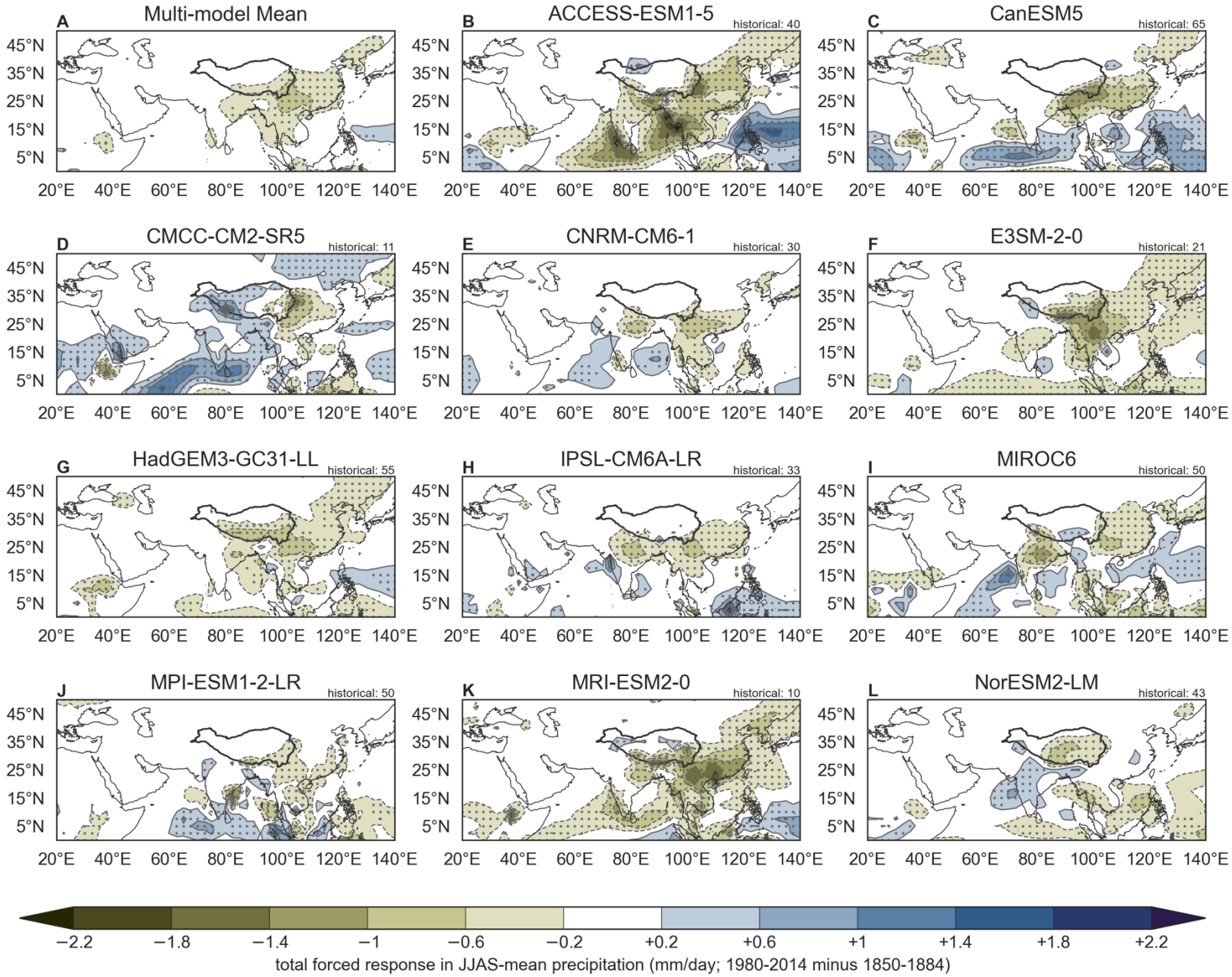
Precipitation

A. Multi-model mean: average the ensemble means

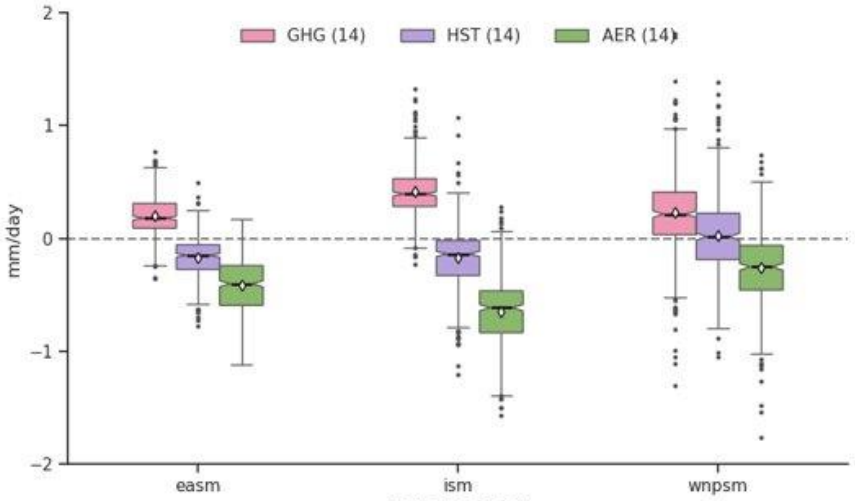
- Stippling: >80% of model ensemble means agree on the sign

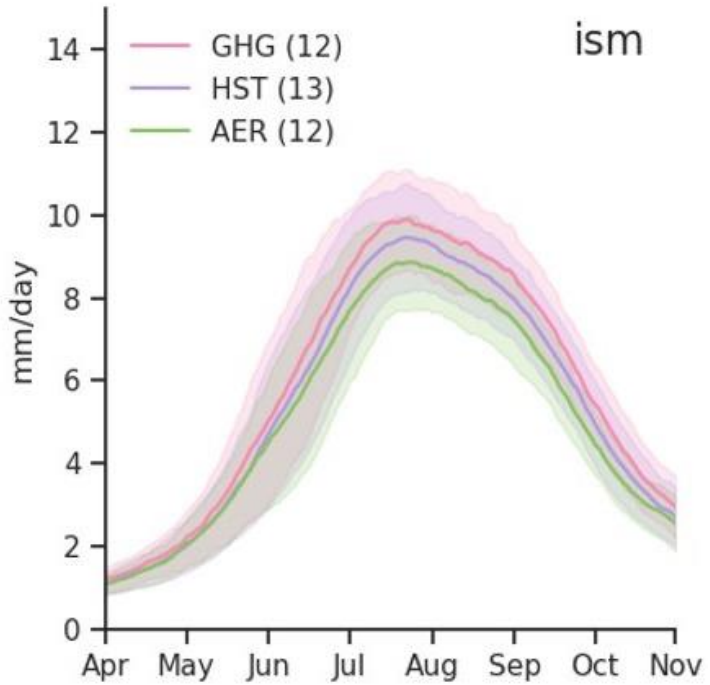
B-L. Individual models

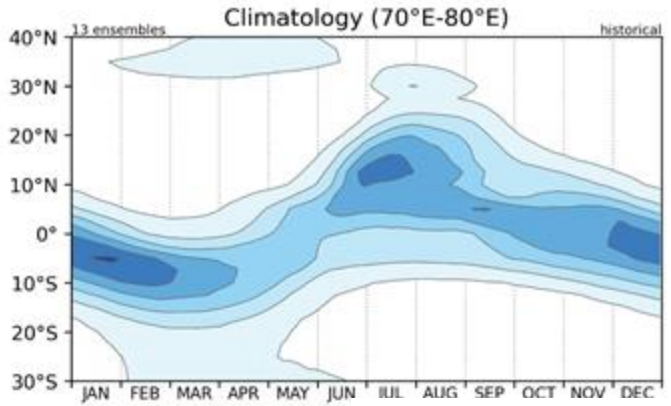
- Stippling: >90% of runs agree on the sign
- Change PI – PD
- PI period: 1850-1884
- PD period: 1980-2014
- PI includes all experiments (hist, GHG, aer, totalO3)
- PD includes only noted experiments (upper right)

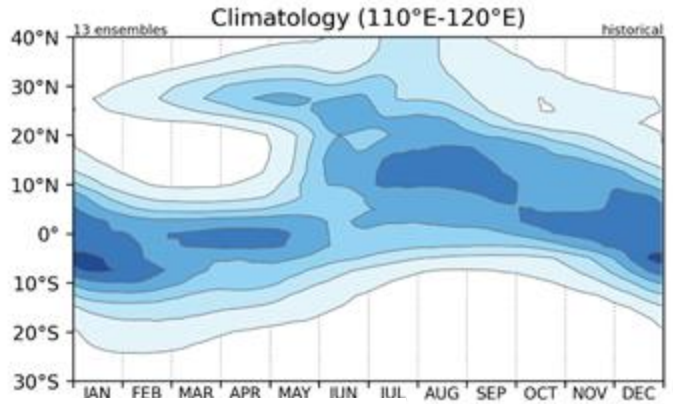


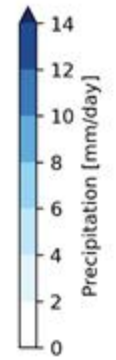
Precipitation



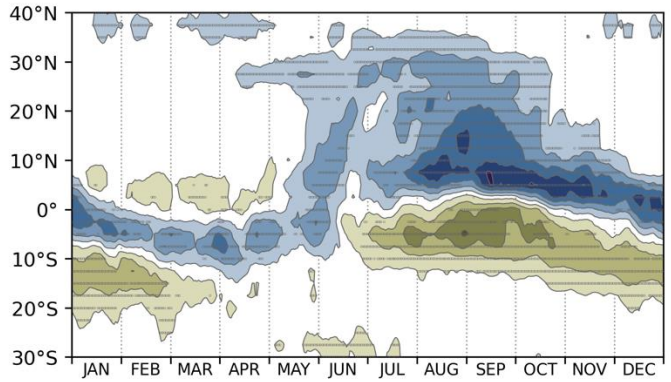


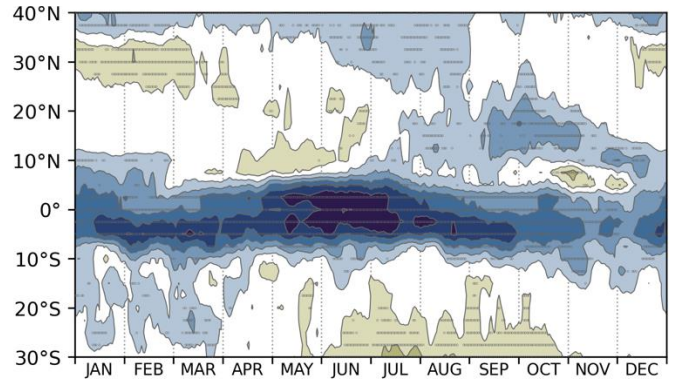


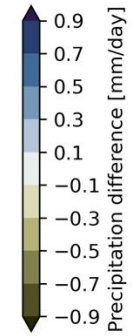




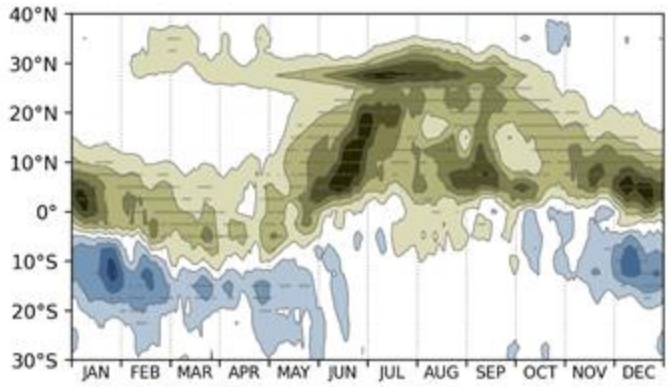
Multi-ensemble mean GHGs response

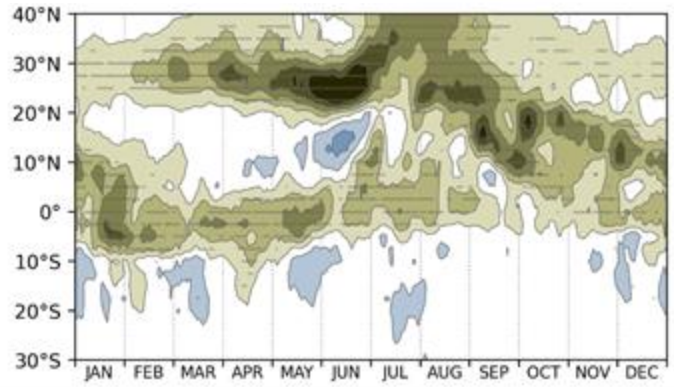


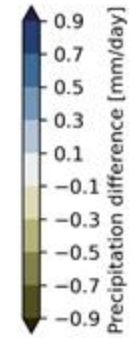




Multi-ensemble mean aerosol response

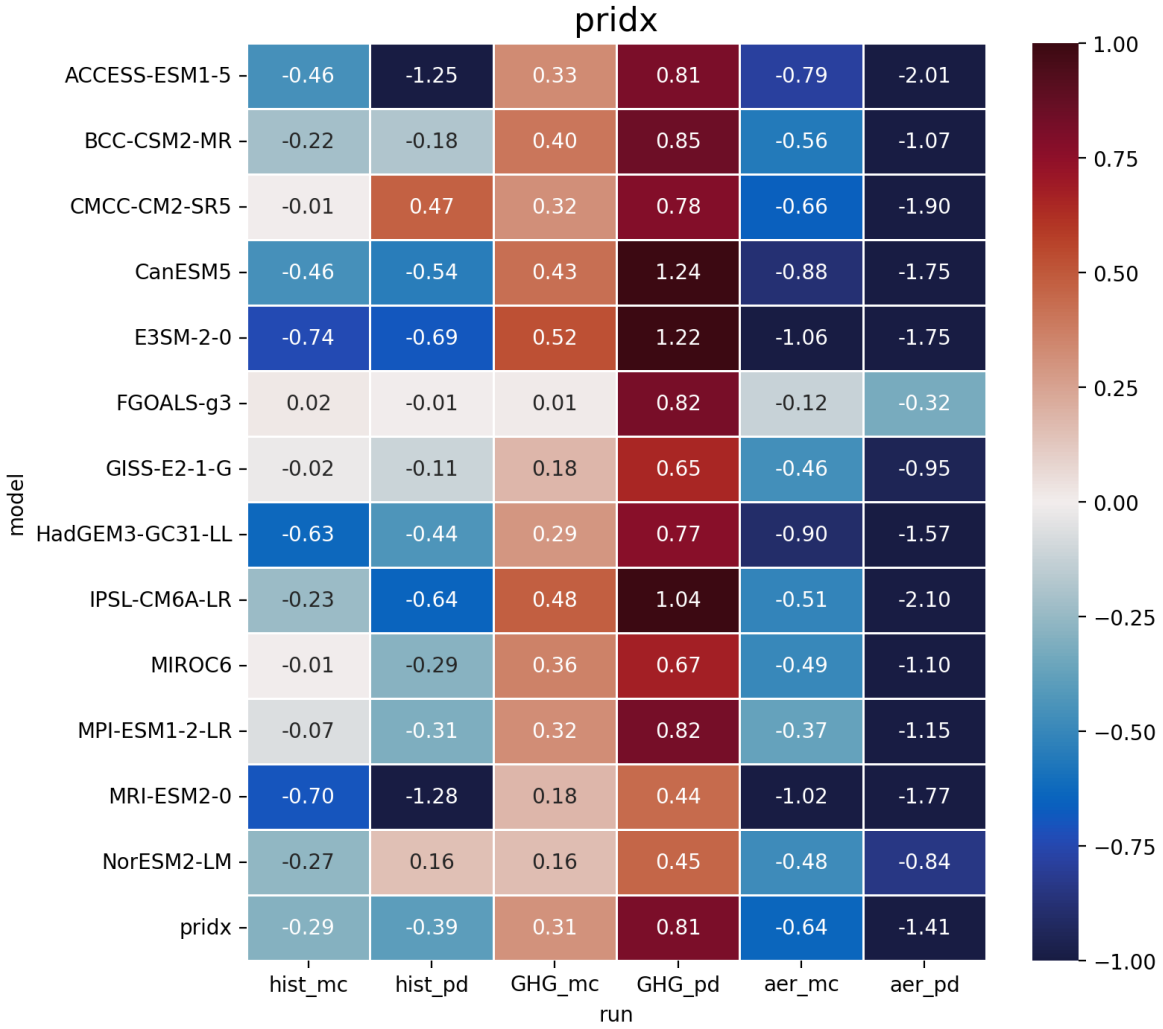


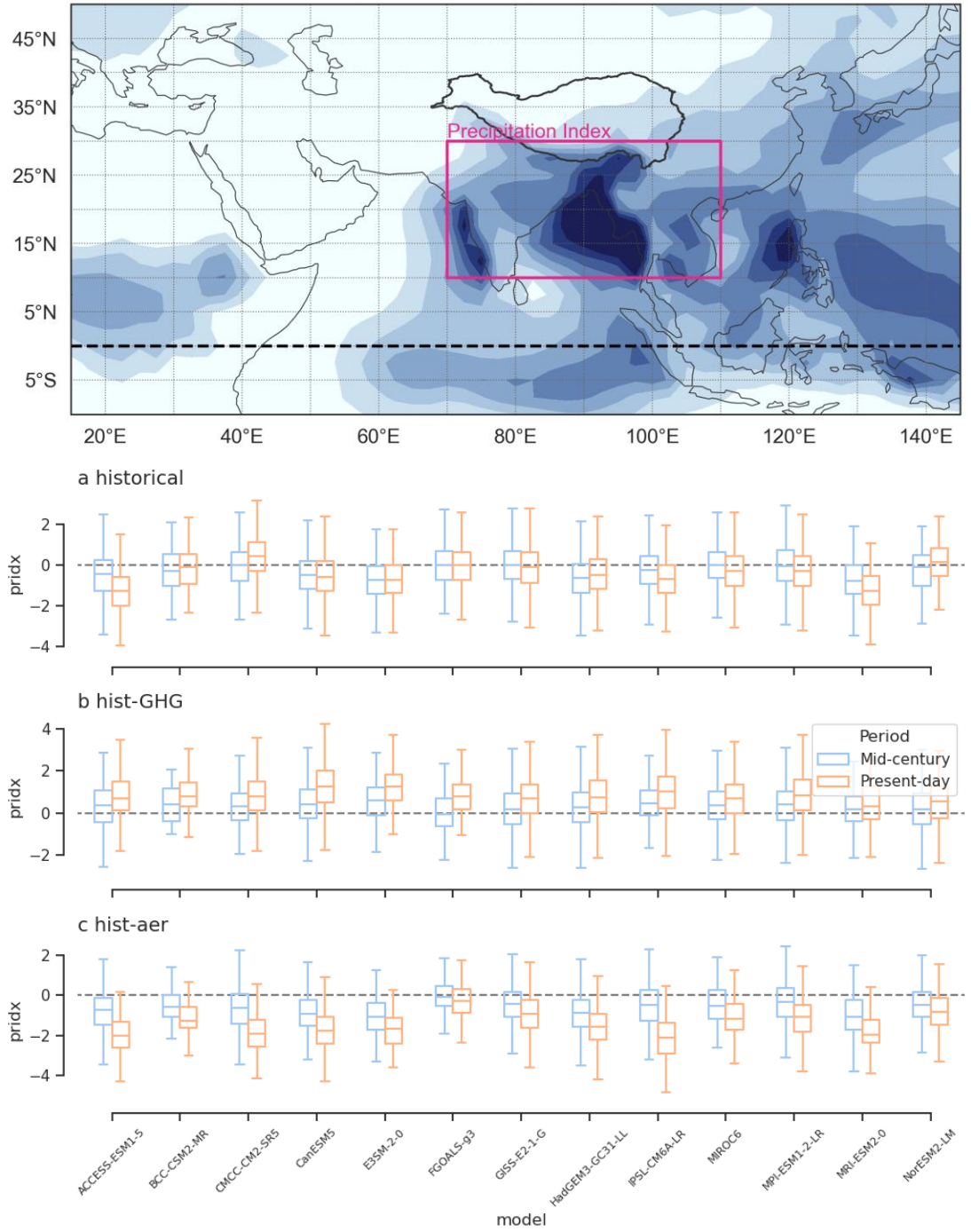


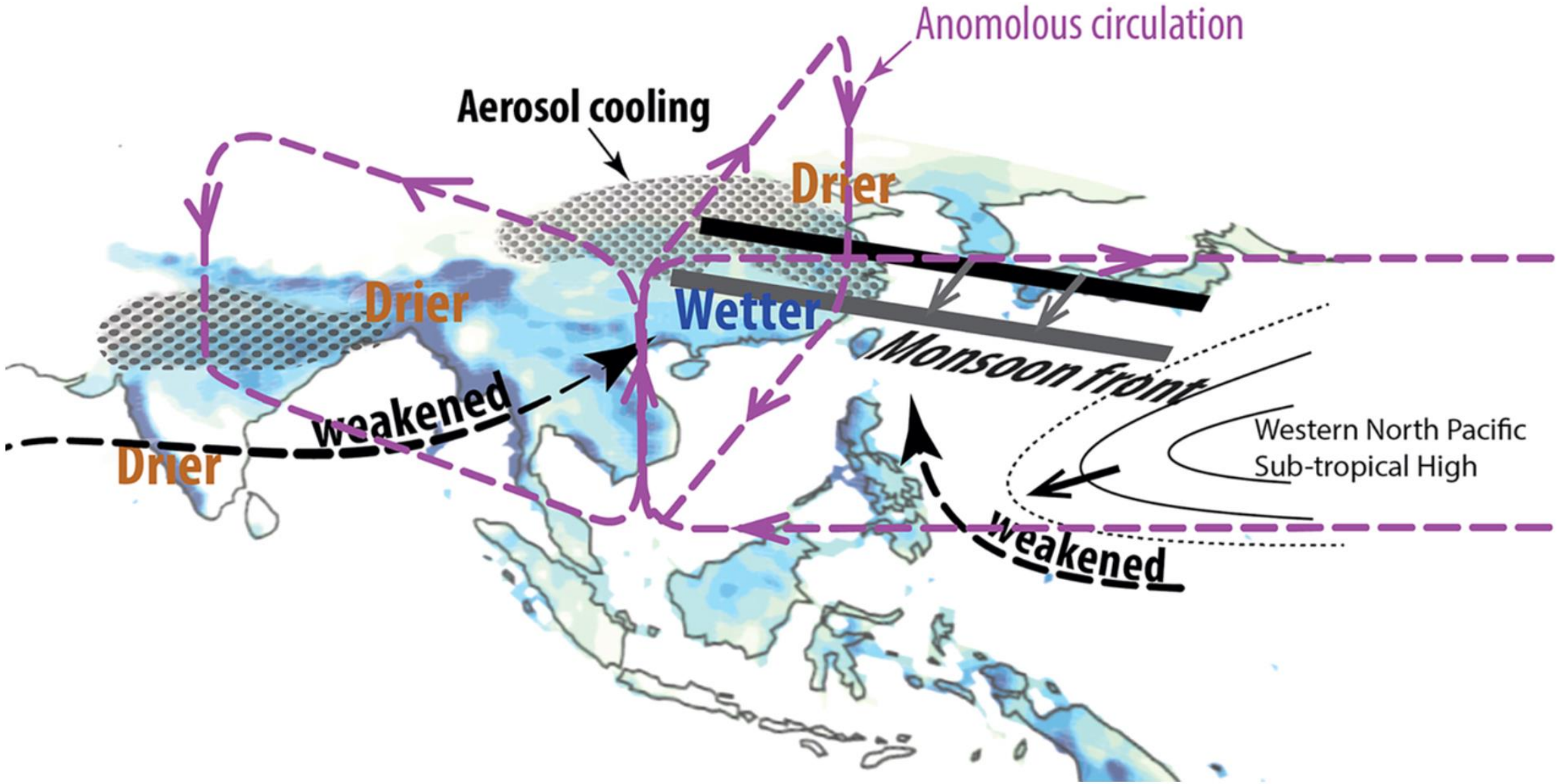


Precipitation index

Greater consistency in this index

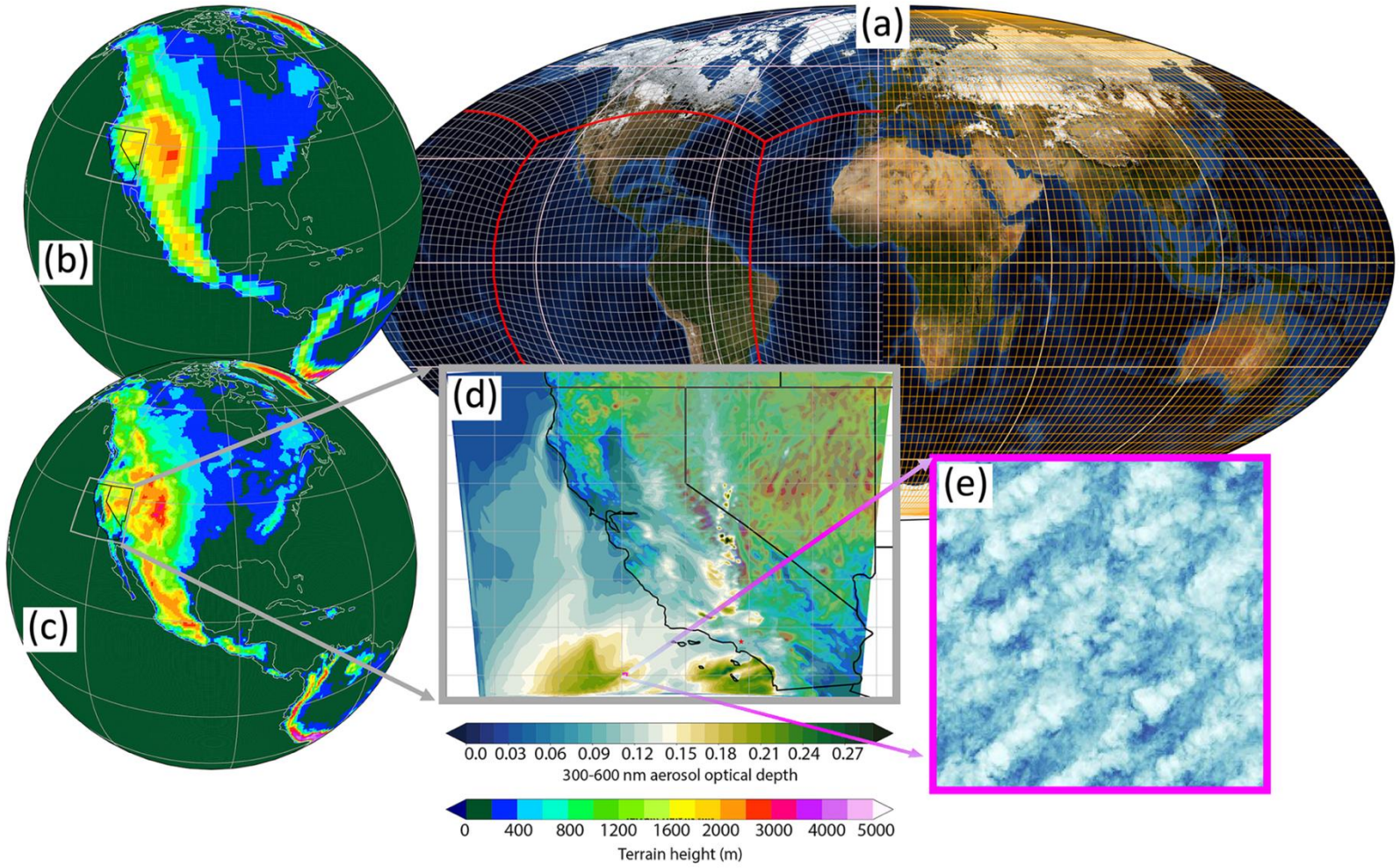


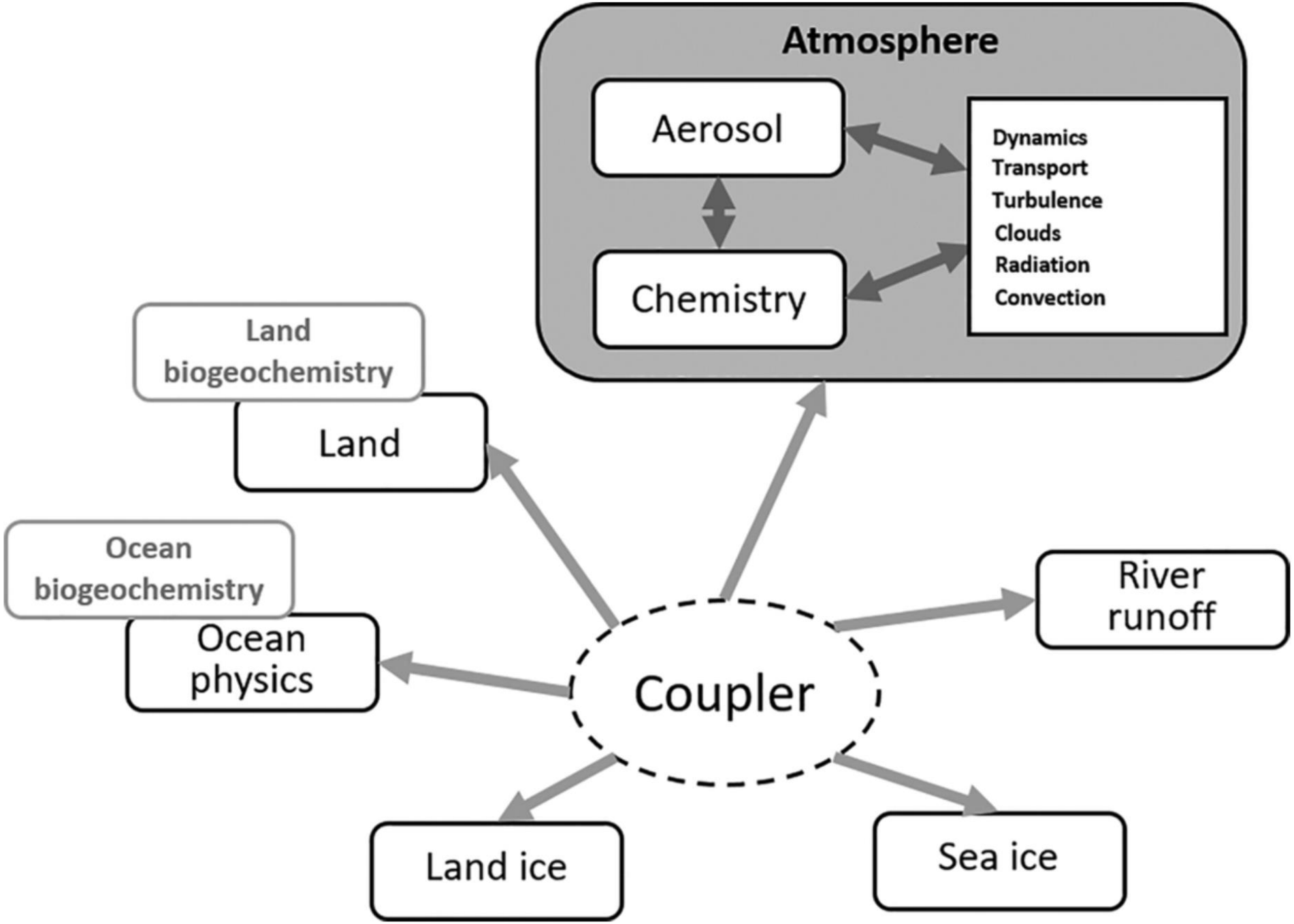



Anomolous circulation
Aerosol cooling
Drier
Drier
Wetter
Monsoon front
Western North Pacific
Sub-tropical High
weakened
Drier
weakened

Models: the hierarchy

- Global
- Regional
- Cloud-resolving
- Large-eddy
- Level of complexity
- Aerosols? Chemistry?



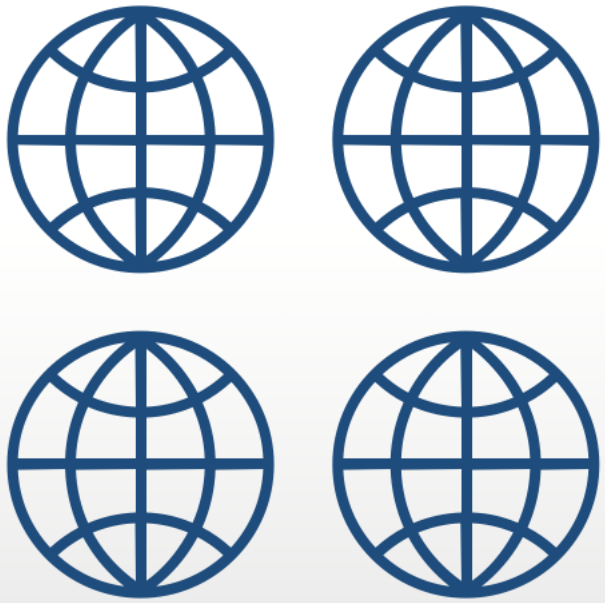

Atmosphere
Aerosol
Chemistry
Dynamics
Transport
Turbulence
Clouds
Radiation
Convection
Land biogeochemistry
Land
Ocean biogeochemistry
Ocean physics
Coupler
River runoff
Land ice
Sea ice

LEADER + EPESC

Large **E**nsembles for **A**ttribution of **D**ynamically-driven **Ext**Remes

LARGE ENSEMBLE

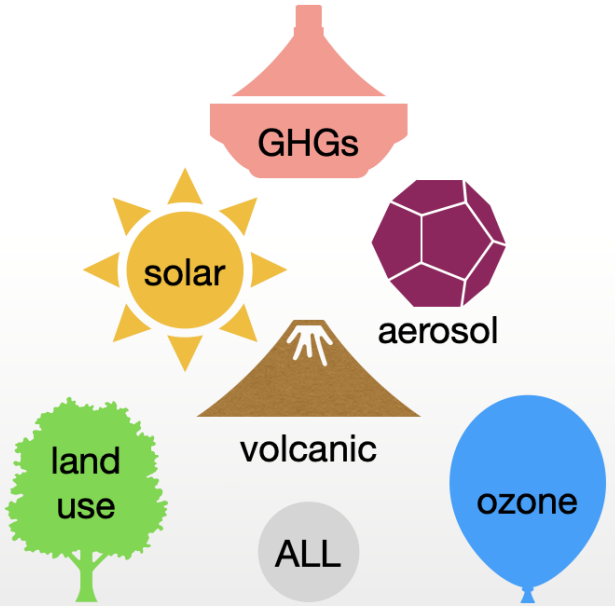
Many realizations of each model scenario



How do monsoons vary?

SINGLE FORCING

Each scenario includes only a single forcing agent



Why have monsoons changed?

MIP

Many different climate models are considered

Where do models agree?

MODEL WORLD

“REAL WORLD”

MODELS

REANALYSIS

OBSERVATIONS

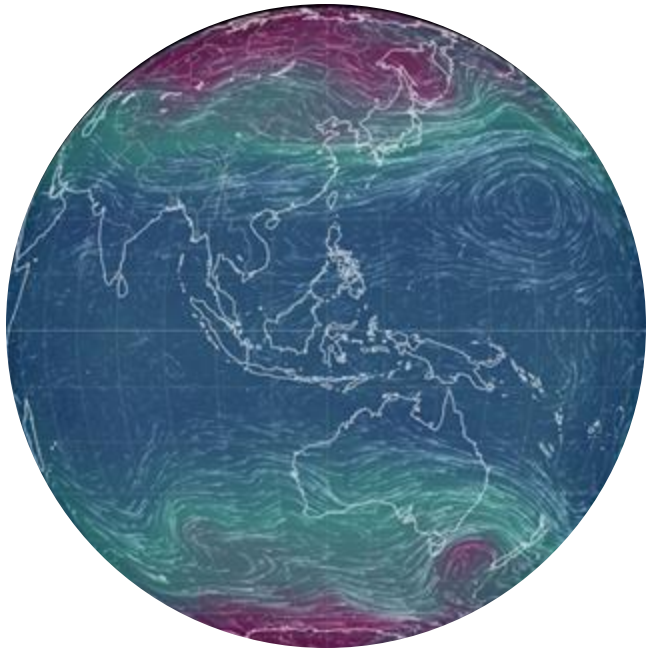
Where Reanalysis Products Fit

what a reanalysis is:

a best estimate

what a reanalysis is not:

observational “truth”



WHAT IS A REANALYSIS?

FORECAST MODEL

- Usually a **well-tested** version of a weather forecast model
- **Fixed over the lifetime** of the reanalysis
- Includes dynamical core, parameterized physics, prescribed forcings and boundary conditions, land surface model…

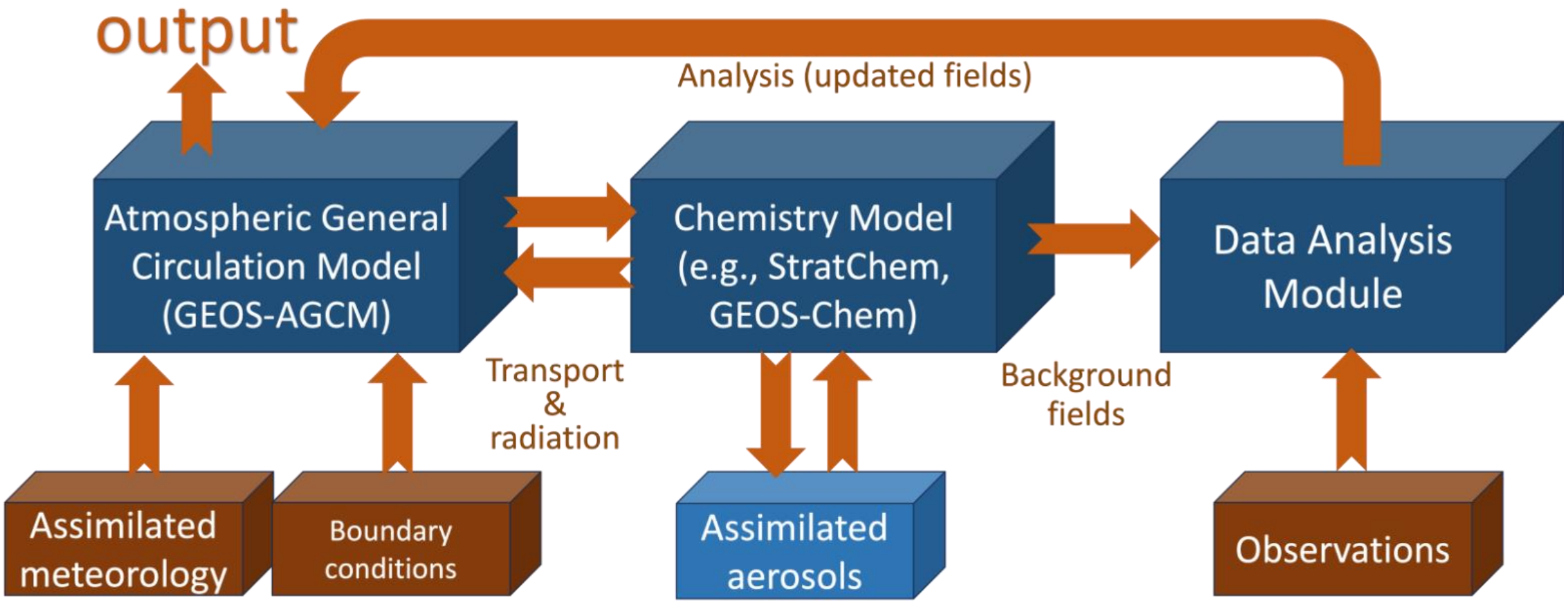
DATA ASSIMILATION SYSTEM

- **Combine** model forecasts and observations
- **Fixed over the lifetime** of the reanalysis
- Account for known errors and **uncertainties in both** model and observations
- **Only a few variables** are directly impacted

INPUT OBSERVATIONS

- Reanalyses can be classified by inputs: **surface** (surface pressure and/or winds), **conventional** (+radiosondes, aircraft), or **full** (+satellites)
- Quality and quantity of observations **vary in time**

Reanalyses of Atmospheric Composition



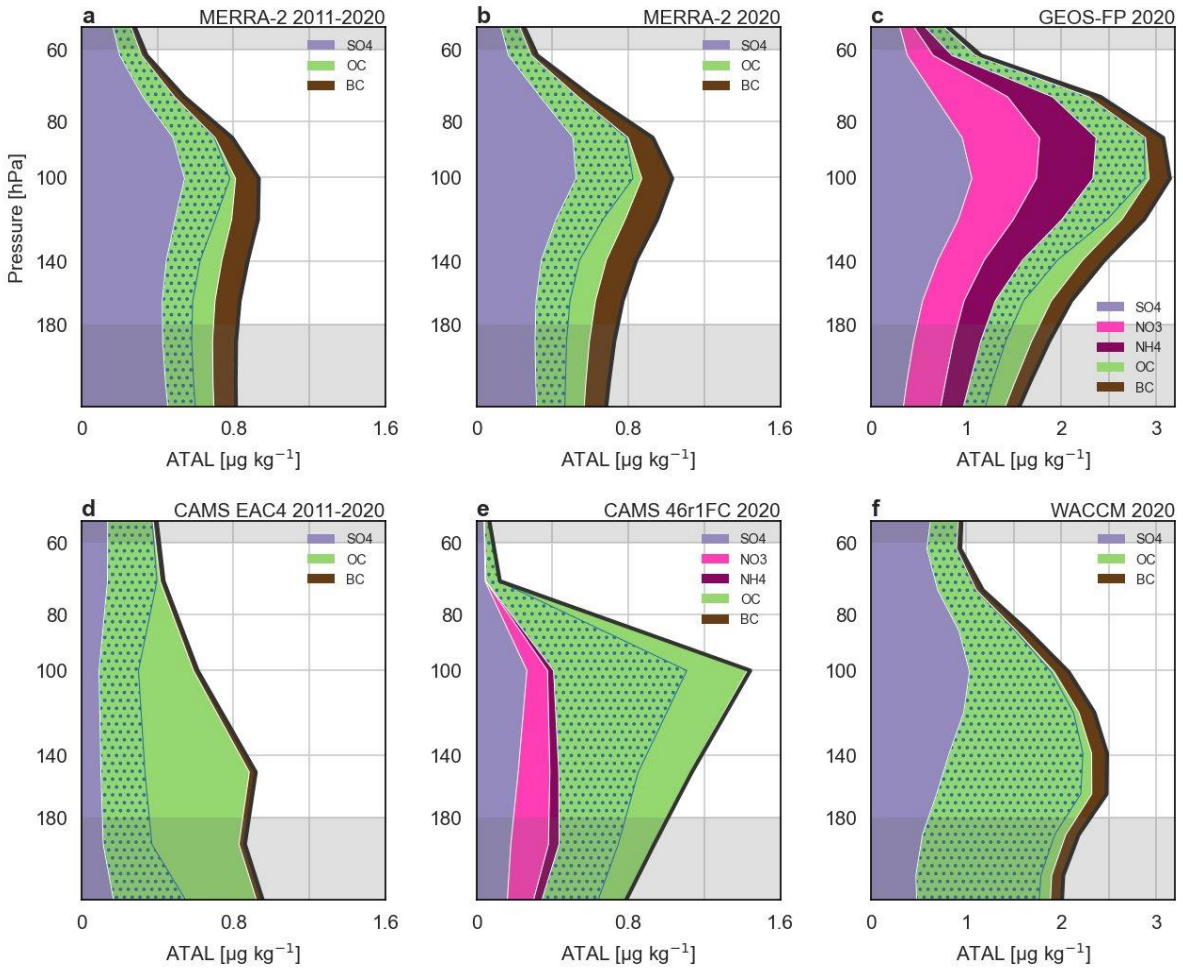
A·RIP APARC Reanalysis Intercomparison Project

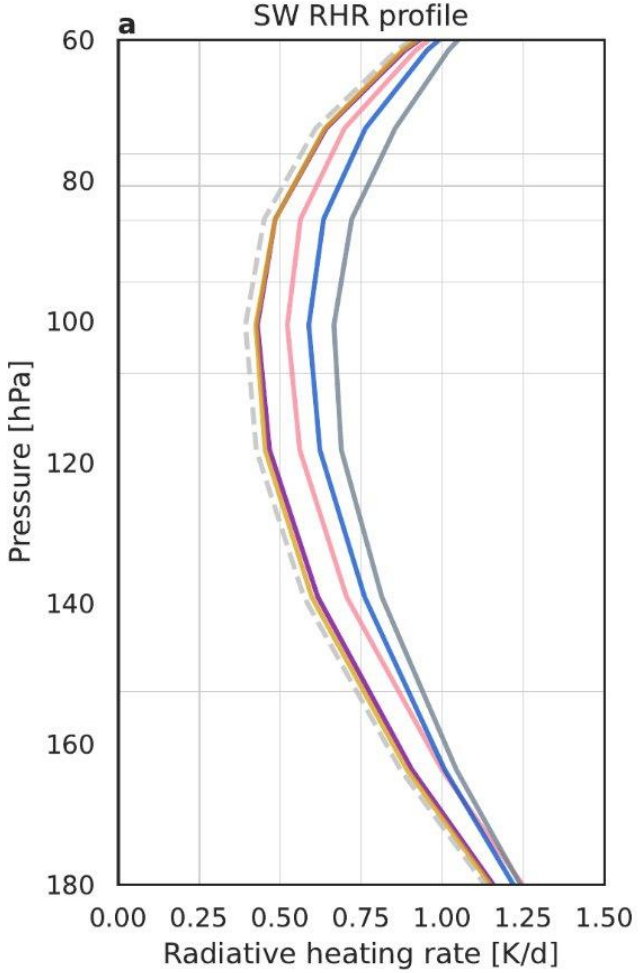
Reanalysis system	Period	Source	Focus area	Grid spacing	Levels
CAMS-EAC4	2003 – 2021	ECMWF	Whole atmosphere	0.75°×0.75°	60
BRAM2	2004.09 – 2019.08	BIRA-IASB	Stratosphere	2.5°×3.75°	37
M2-SCREAM	2004.10 – 2021.12	NASA GMAO	Stratosphere	~50km	72
TCR2	2005 – 2019	NASA JPL	Troposphere	T106 (1.1°)	32

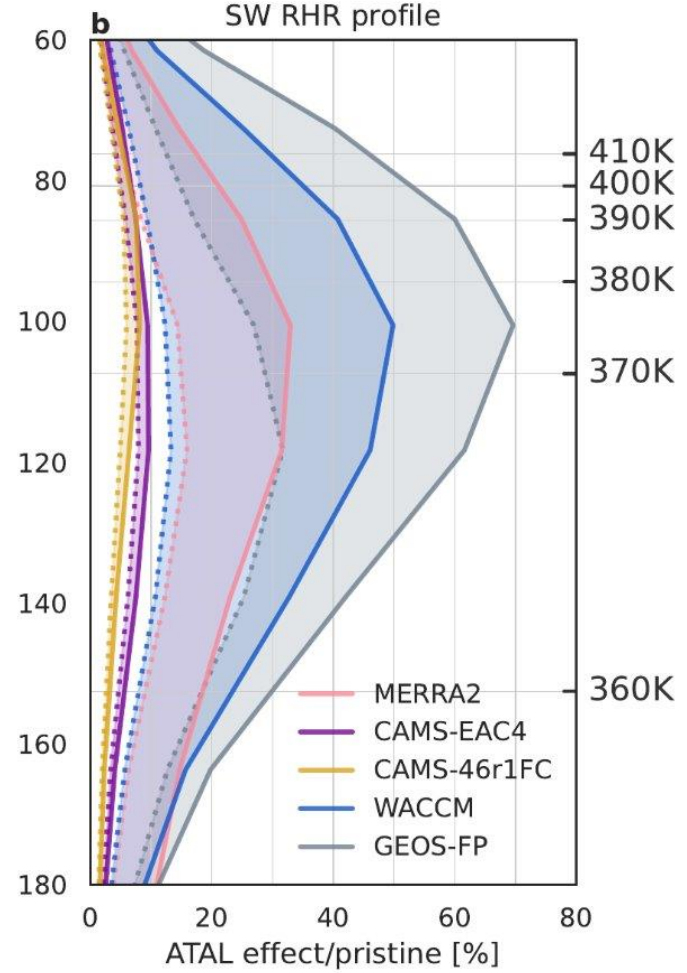
- Detailed information on atmospheric composition variations in troposphere, stratosphere, or both
- Observational information mainly from satellite sensors (O_3, NO_2, CO, HNO_3, SO_2, AOD, …)
- Chemistry-climate models of varying complexity
- Larger differences in assimilation methods and constraints
- Constraints on vertical profiles are generally weak
- Meteorological reanalyses provide O_3 but with simpler models
- Also separate aerosol analyses in MERRA-2, CAMS, etc.

Aerosol reanalyses subject to large uncertainties

Only AOD assimilated; nitrates only starting to be represented







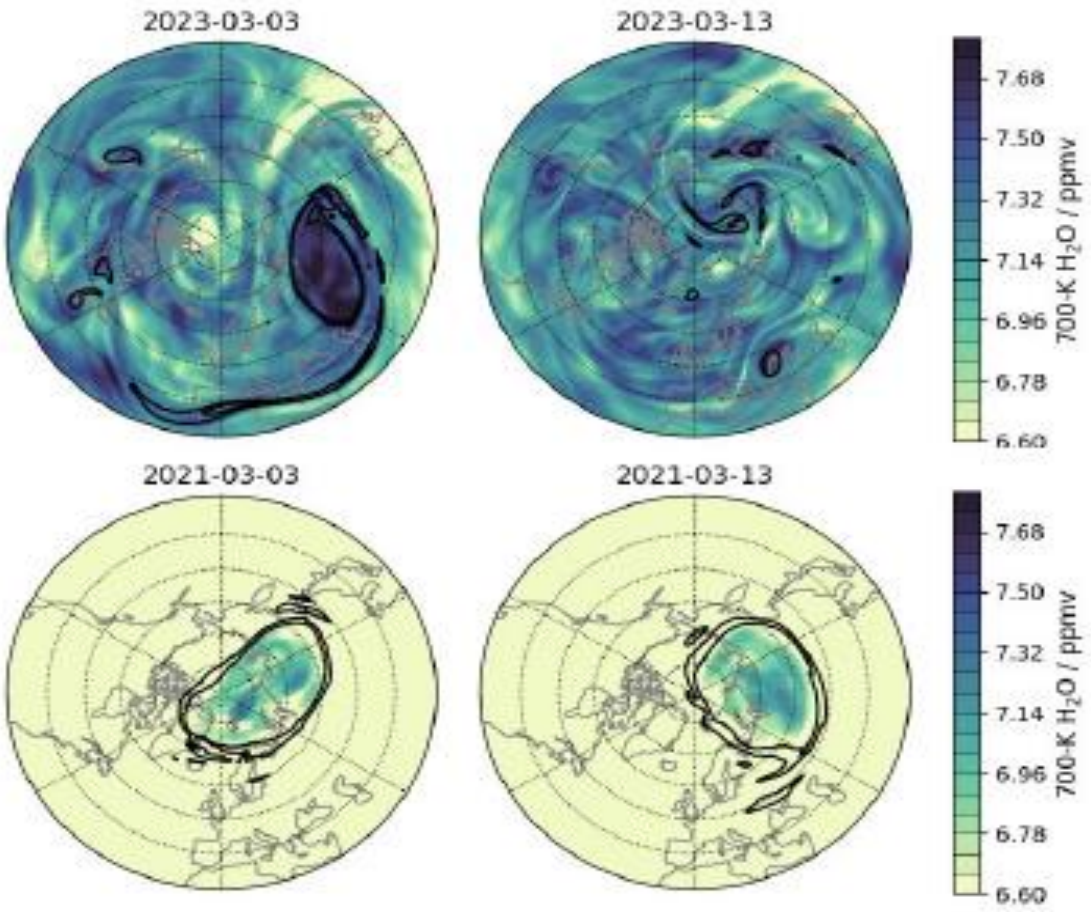
Sensor	Molecules	Observation type
OMI, TROPOMI, OMPS	NO_2, SO_2, O_3	Column
GOSAT, TROPOMI	CH_4	Column
GOSAT, OCO-2	CO_2	Column
MOPITT	CO	Column
MLS	O_3, HCl, HNO_3, N_2O, H_2O, CH_3Cl, CO	Stratospheric limb profiles
OMPS LP	O_3	Stratospheric limb profiles
SAGE III/ISS	O_3, H_2O	Stratospheric profiles from solar occultation

Column, good coverage
Near-global, high vertical resolution
Sparse, high vertical resolution

MLS: Microwave Limb Sounder on NASA's EOS Aura; observations of stratospheric composition profiles
OMI: Ozone Monitoring Instrument on EOS Aura; observations of total column ozone
OMPS: Ozone Monitoring and Profiler Suite on Suomi NPP and NOAA satellites; total and profile ozone

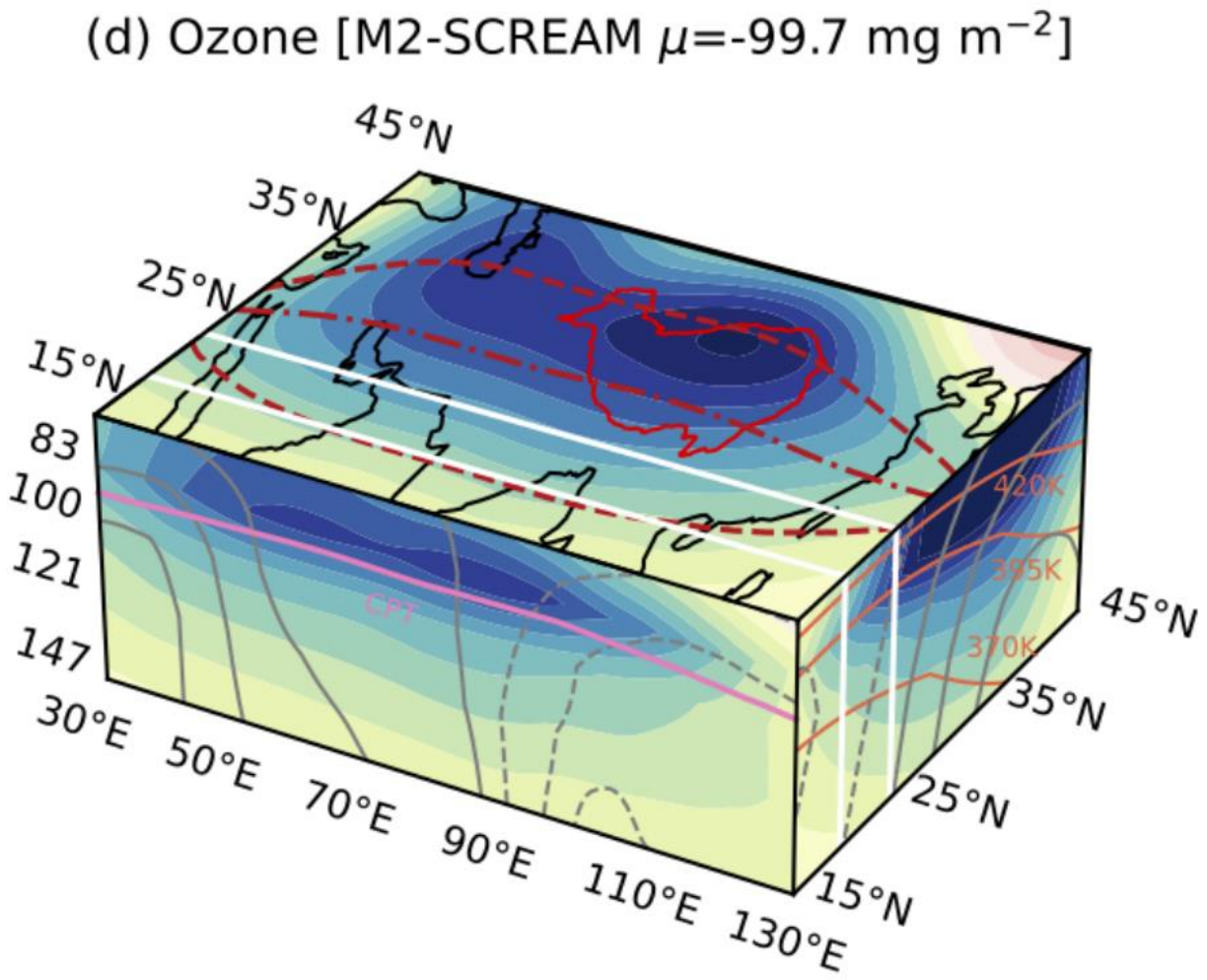
[Slide courtesy of K. Wargan]

M2-SCREAM: Stratospheric Composition Using Aura MLS



[M2-SCREAM water vapor before and after HTHH eruption; K. Wargan]

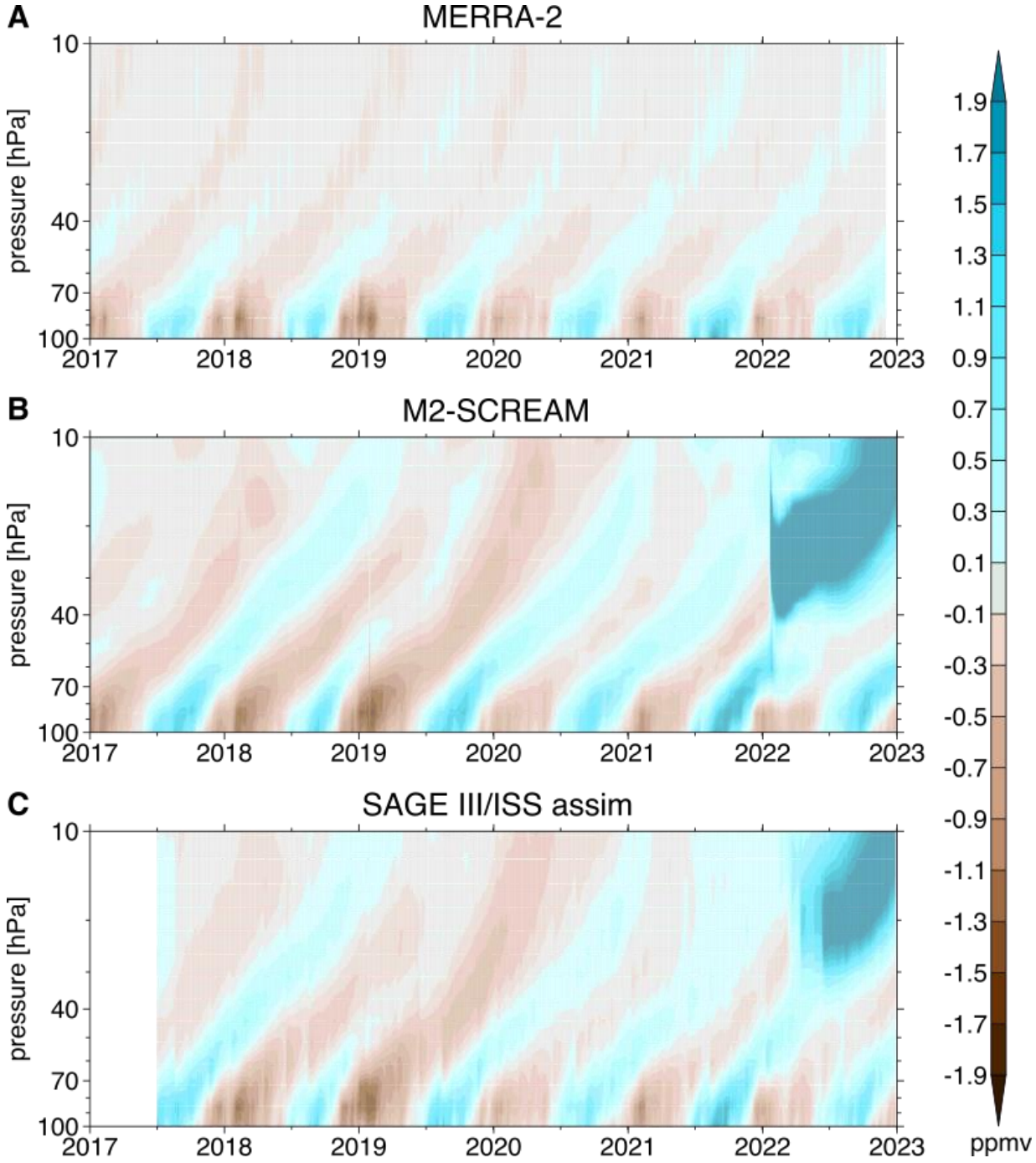
[Asian monsoon "ozone valley" in M2-SCREAM]

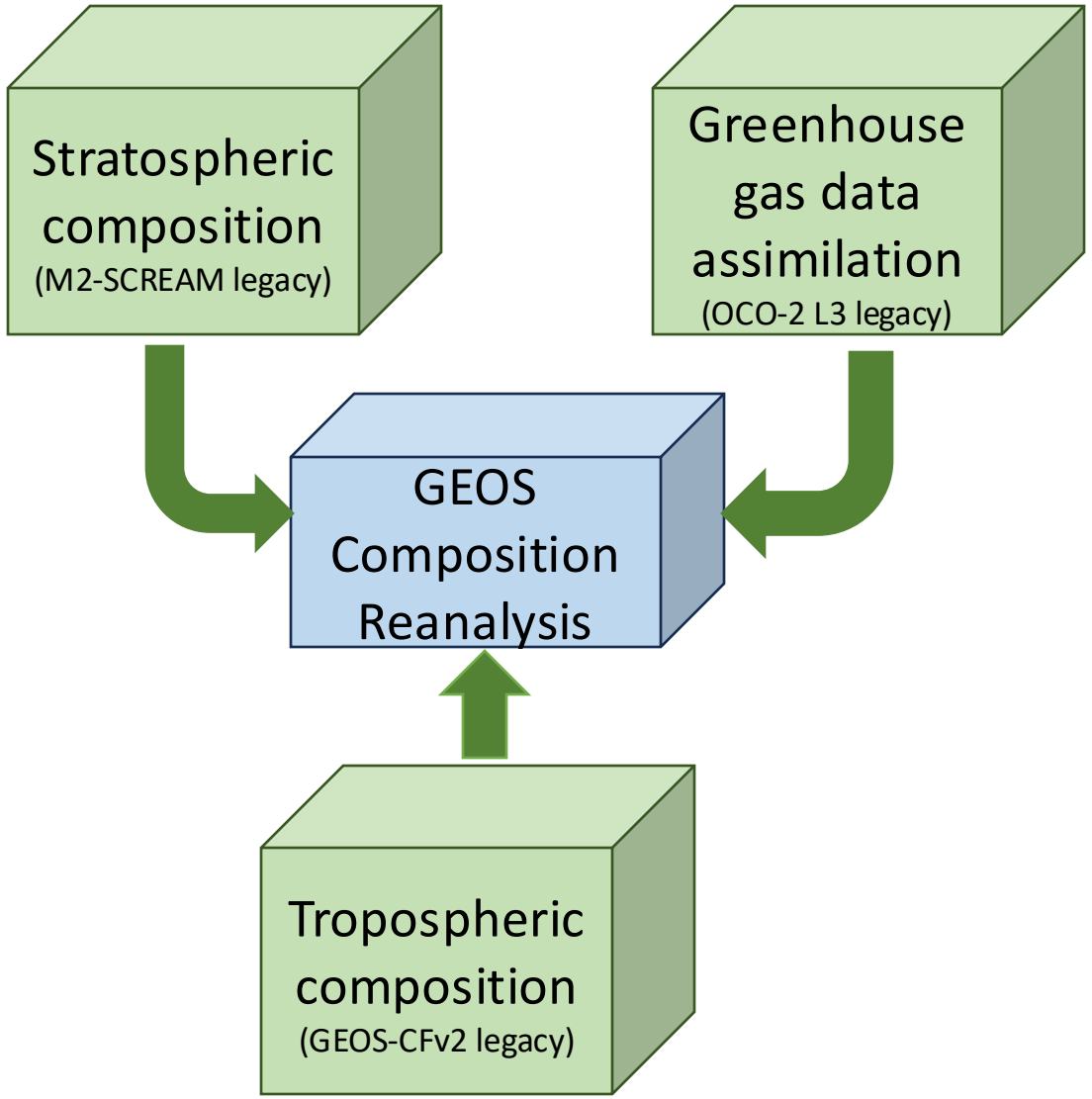


Post-MLS

MLS will be retired next year – can these reanalyses still be useful?

- Stratospheric water vapor evolves slowly – just a few high-quality measurements are enough to constrain (see SAGE III at right)
- Ozone products are less dependent on Aura MLS, although MLS is useful for profiles
- Other constituents are more difficult – many questions unanswered!





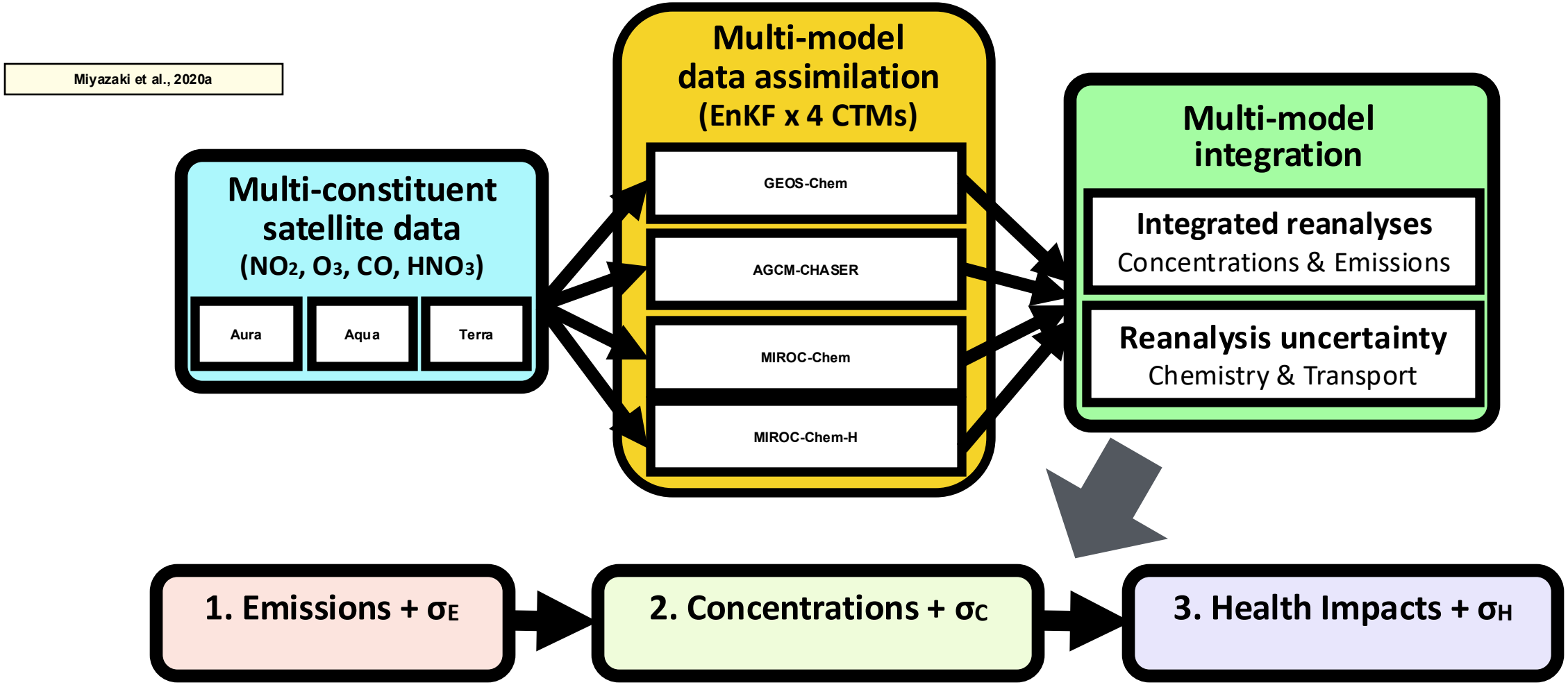
"All-atmosphere" composition reanalysis under development

- GEOS-Chem chemistry model
- Meteorology replayed to a recent GMAO's reanalysis product (GEOS-IT)
- Assimilation of stratospheric, tropospheric and GHG data
- Production to start later in 2024
- Assimilated species: O_3, HCl, HNO_3, N_2O, H_2O, CH_3Cl, CO, NO_2, SO_2, CO_2, CH_4
- Aerosol assimilation (AOD) coupled to chemistry and radiation

[Slide courtesy of K. Wargan]

[Slide courtesy of K. Miyazaki]

TCR: Tropospheric Composition Reanalysis



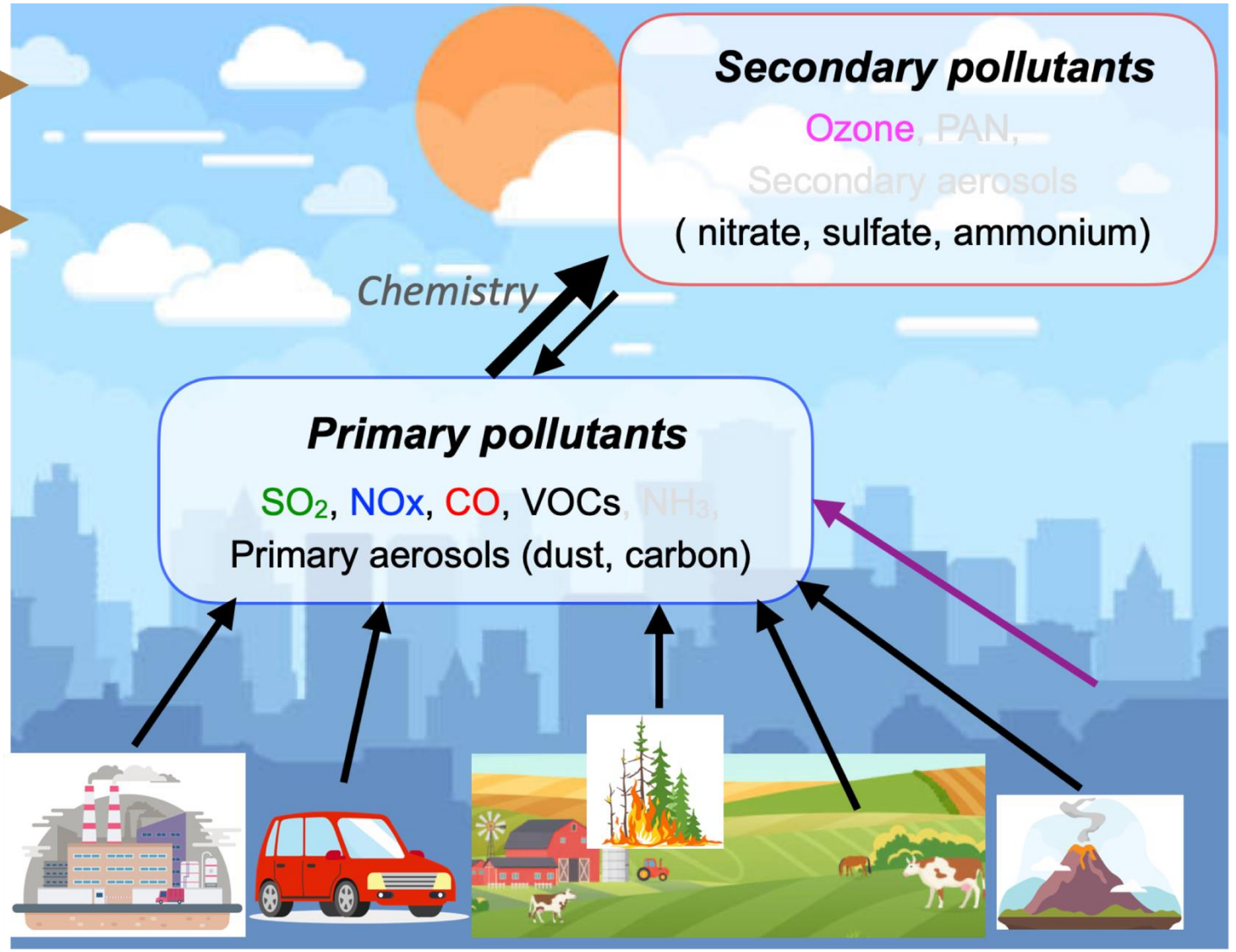
Multi-mOdel Multi-cOnstituent CHEMical data assimilation (MOMO-Chem)

TCR-2

Miyazaki et al. 2020a

MLS
(O_3, CO, HNO_3)

TES
(O_3)



Improve estimates of emissions because of reduced model errors unrelated to emissions.

"Decadal Aura era" chemical reanalysis

Assimilation

OMI (SO_2, NO_2, CH_2O)

MOPITT (CO)

[Slide courtesy of K. Miyazaki]

TCR-3

Miyazaki et al., In prep.

MLS (O_3, CO, HNO_3)

TES, AIRS/OMI (O_3)

Secondary pollutants

Ozone, PAN,

Secondary aerosols

(nitrate, sulfate, ammonium)

Chemistry

Validation

VIIRS (AOD)

CrIS (O_3,PAN)

OMPS (SO_2,NO_2)

Primary pollutants

SO_2, NOx, CO, VOCs, NH_3,

Primary aerosols (dust, carbon)

Assimilation

OMI, TROPOMI (SO_2,NO_2,, CH_2O)

CrIS (NH_3)

MOPITT (CO)

Long-lived GHGs

Oxidation capacity (OH)

↓

CH_4

AQ-GHG co-emissions

↓

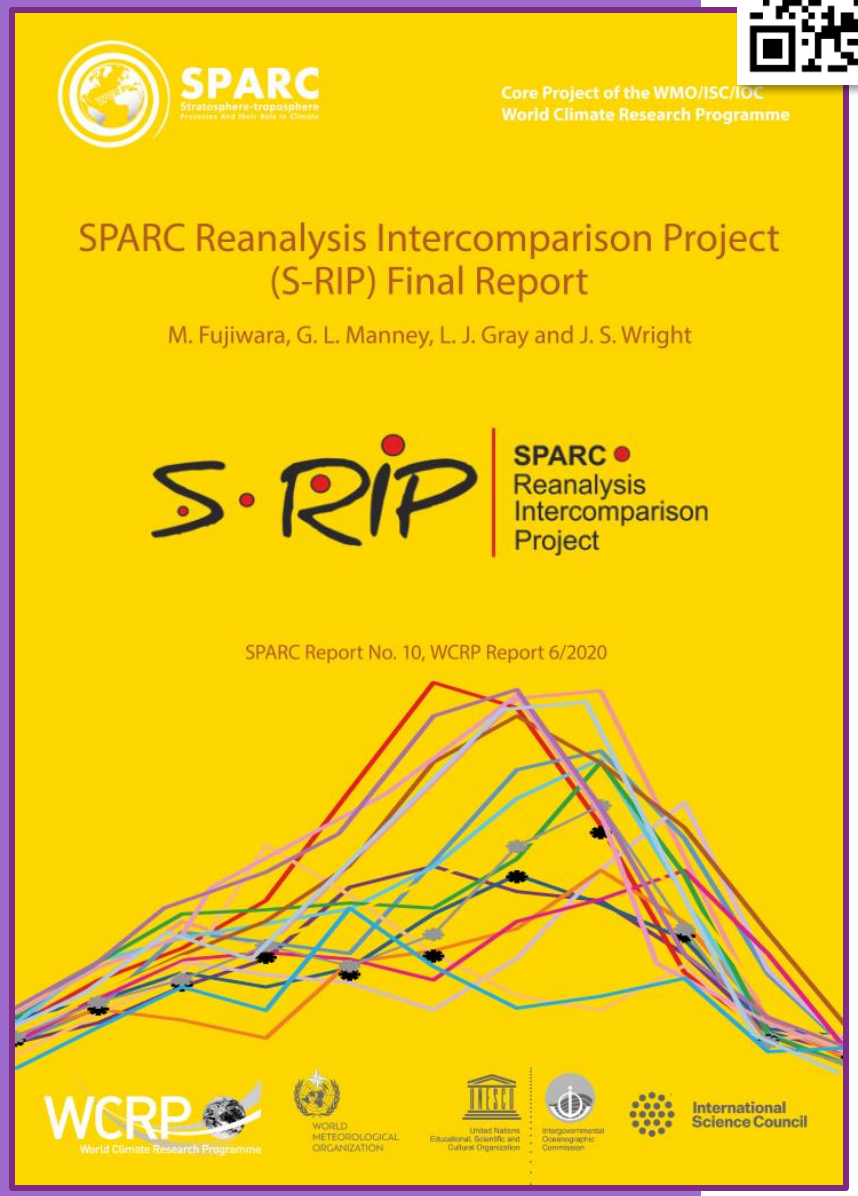
CO_2

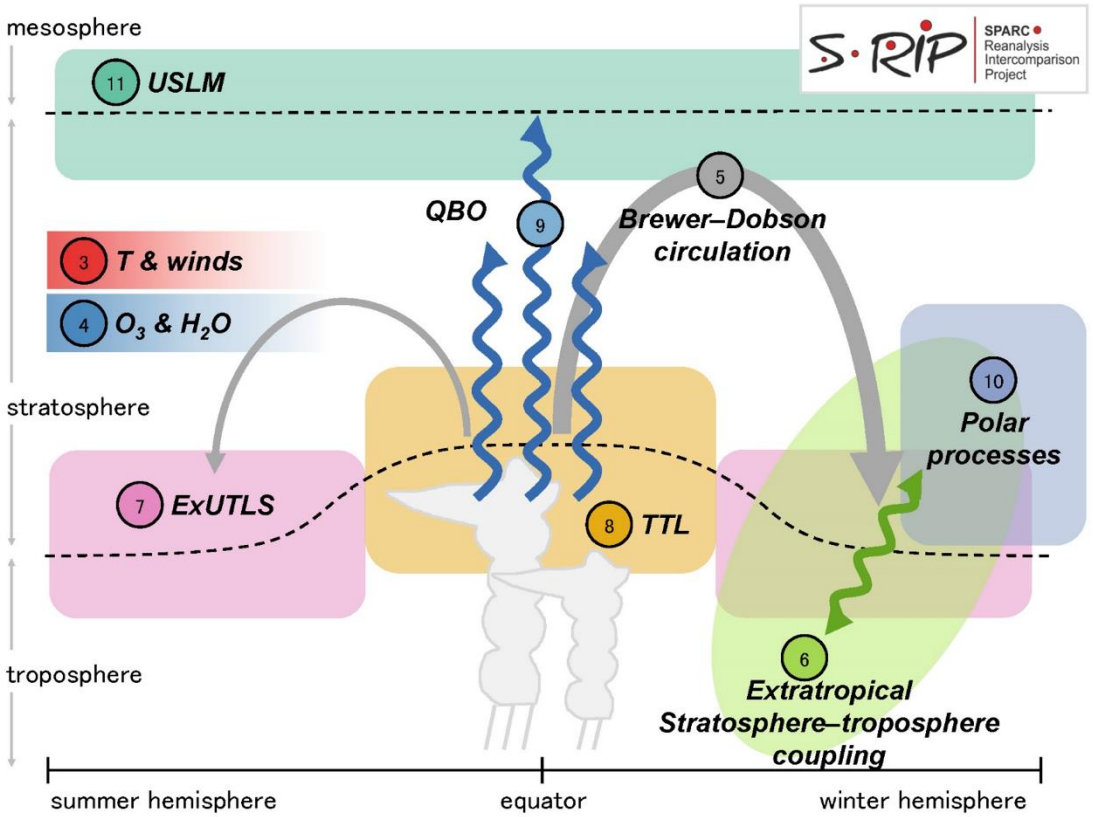
"Decadal Aura + New satellite era" chemical reanalysis

[Slide courtesy of K. Miyazaki]

[report website]

S-RIP Final Report





Resources: S-RIP Chapter 2

An introduction for new users and a reference for experienced users:

Chapter 2 should be helpful for anyone using reanalysis products!

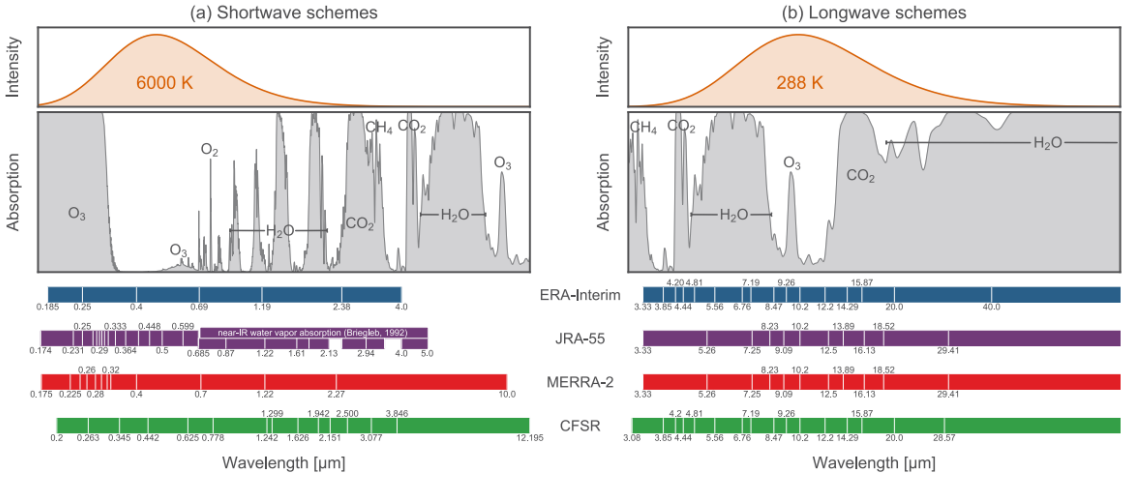
Information on key components of 12 global atmospheric reanalysis systems is summarized, including:

- the forecast models and their major components
- assimilation schemes
- observational data
- execution streams
- archived data products

Now working on an online repository for this information for increased flexibility as new reanalyses are released.

Table 2.2: *Basic details of the forecast models used in the reanalyses. Horizontal grid spacing is expressed in degrees for regular grids and in kilometres for reduced grids.*

Reanalysis system	Model	Horizontal grid	Vertical grid
ERA-40	IFS Cycle 23r4 (2001)	N80: ~125 km (TL159)	60 (hybrid σ–p)
ERA-Interim	IFS Cycle 31r2 (2007)	N128: ~79 km (TL255)	60 (hybrid σ–p)
ERA-20C	IFS Cycle 38r1 (2012)	N80: ~125 km (TL159)	91 (hybrid σ–p)
ERA5	IFS Cycle 41r2 (2016)	N320: ~31 km (TL639)	137 (hybrid σ–p)
JRA-25 / JCDAS	JMA GSM (2004)	F80: 1.125°(T106)	40 (hybrid σ–p)
JRA-55	JMA GSM (2009)	N160: ~55 km (TL319)	60 (hybrid σ–p)
MERRA	GEOS 5.0.2 (2008)	1/2° latitude, 2/3° longitude	72 (hybrid σ–p)
MERRA-2	GEOS 5.12.4 (2015)	C180: ~50 km (cubed sphere)	72 (hybrid σ–p)
NCEP-NCAR R1	NCEP MRF (1995)	F47: 1.875° (T62)	28 (σ)
NCEP-DOE R2	Modified MRF (1998)	F47: 1.875° (T62)	28 (σ)
CFSR **CFSv2**	NCEP CFS (2007) NCEP CFS (2011)	F288: 0.3125° (T382) F440: 0.2045° (T574)	64 (hybrid σ–p) 64 (hybrid σ–p)
NOAA-CIRES 20CR v2	NCEP GFS (2008)	F47: 1.875° (T62)	28 (hybrid σ–p)



Resources: Special Issues

ACTIVE:

A-RIP: ACP & WCD
2023–
Link

EGU Special Issues

S-RIP: ACP & ESSD
2015–2022
Link

53 PAPERS:

S-RIP Website

A·RIP APARC Reanalysis Intercomparison Project

Final Report

THANK YOU!

Comments, questions, suggestions to:
Jonathon S. Wright: jswright@tsinghua.edu.cn