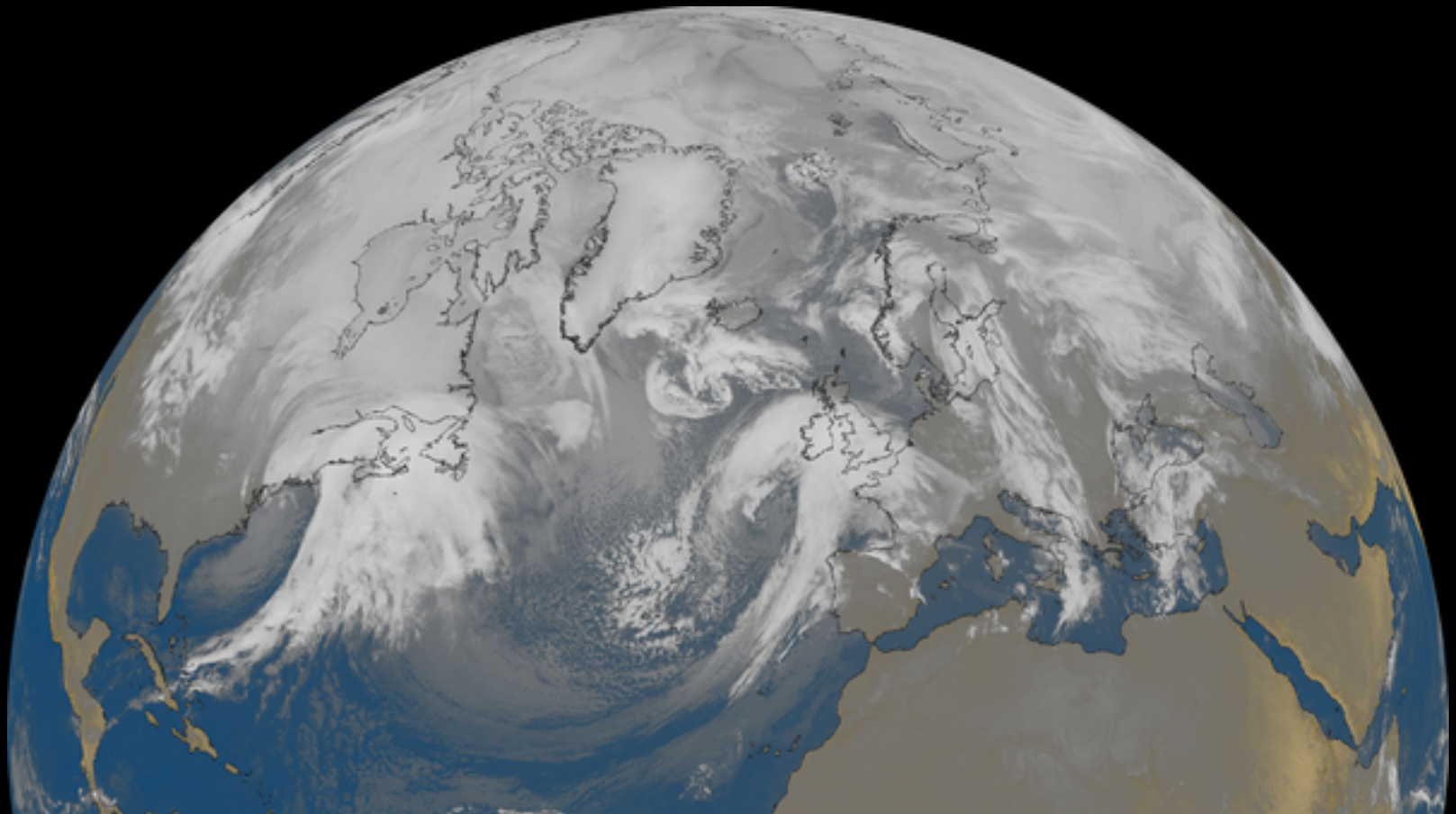
The Four Questions

Q1: How will storm tracks change in the future ?

Storm tracks:

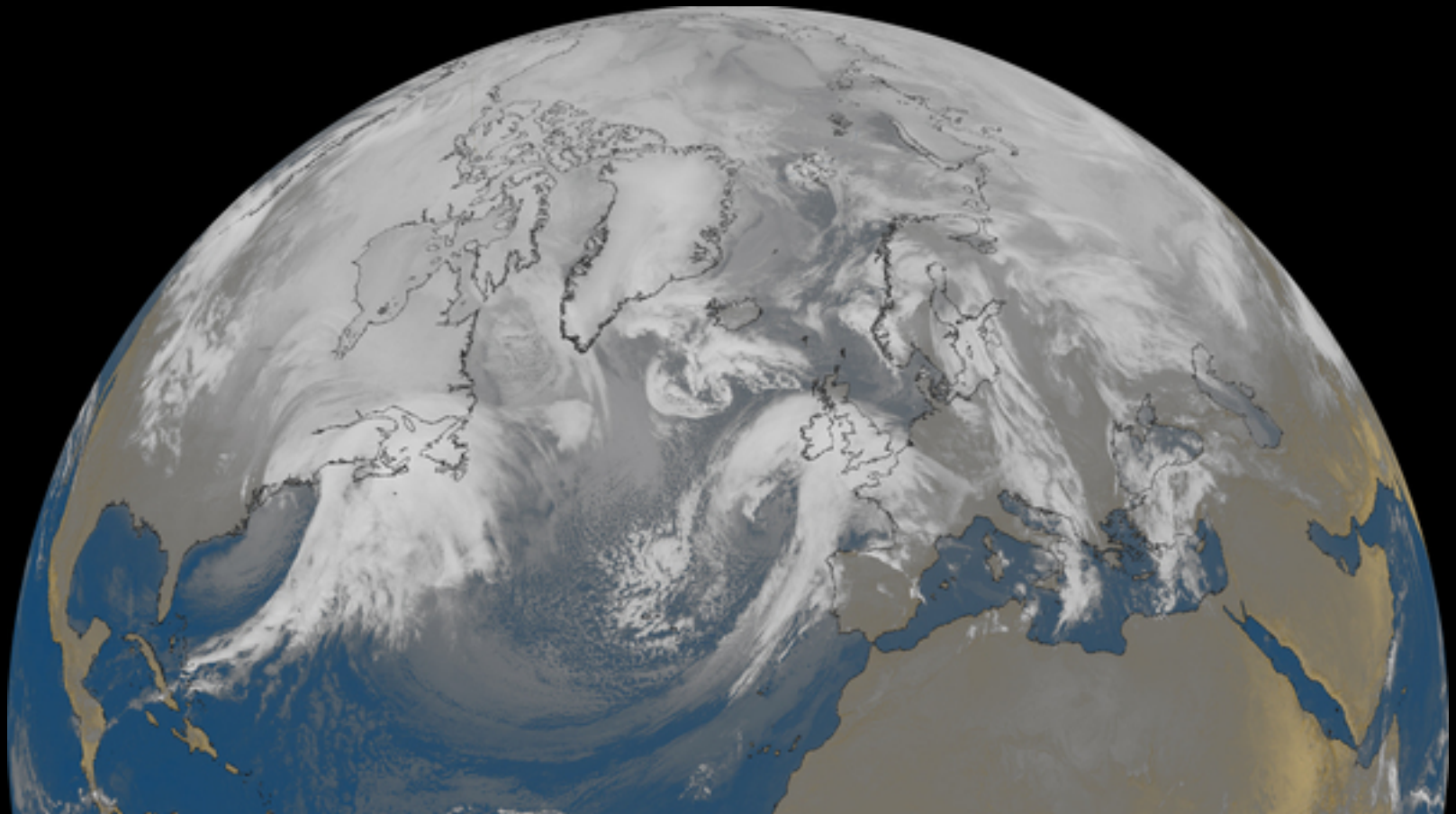
- Major component of the general circulation
  (e.g. energy, moisture and momentum transport, low-frequency variability)
- Key control of weather-related climate impacts, cause of much severe weather
- Organize precipitation and the formation of clouds in the extratropics



Q1: How will storm tracks change in the future ?

Storm tracks:

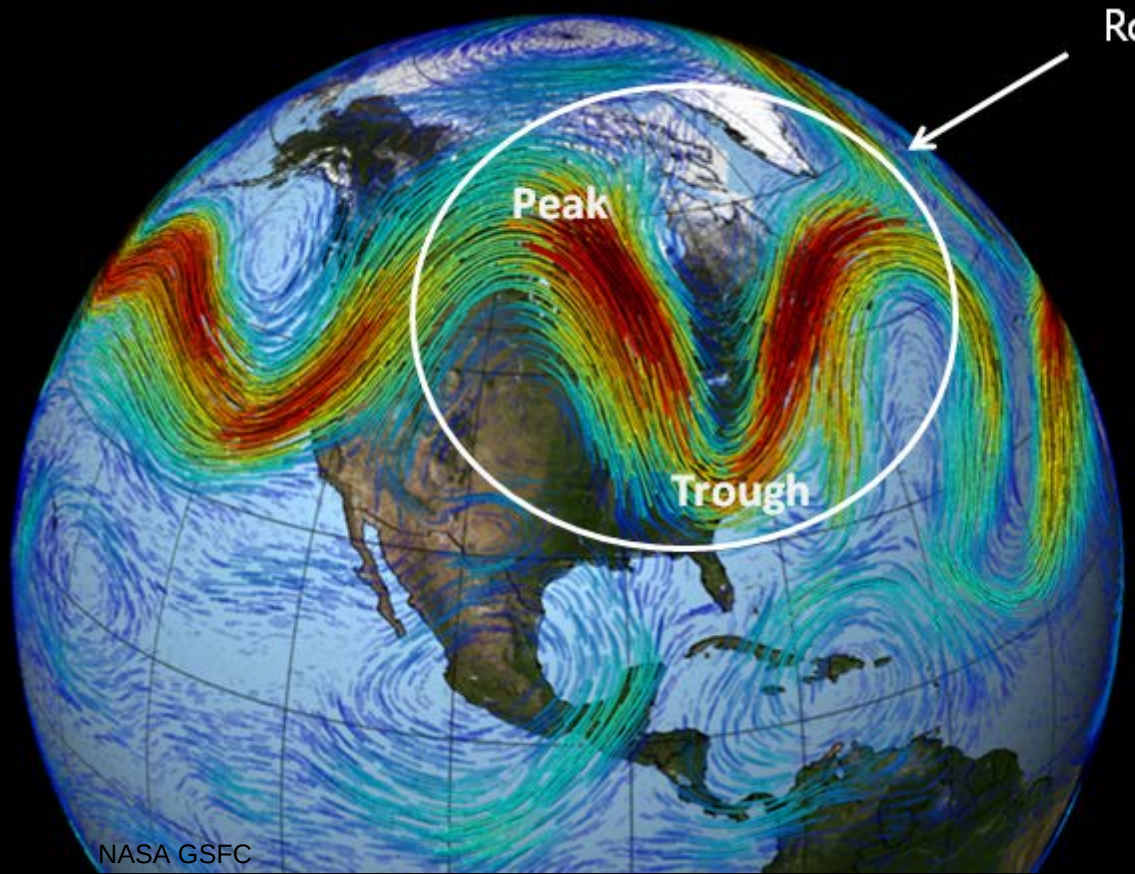
- A source of model biases (e.g. position of the jets, blockings, radiation budget)
- Models suggest that storm tracks respond to external forcings (e.g. GHGs, ozone hole, aerosols)
- A primary control on regional climate changes and impacts



A case in point is the recent winter: US cold snaps, UK floods

Proximate explanation is meteorological

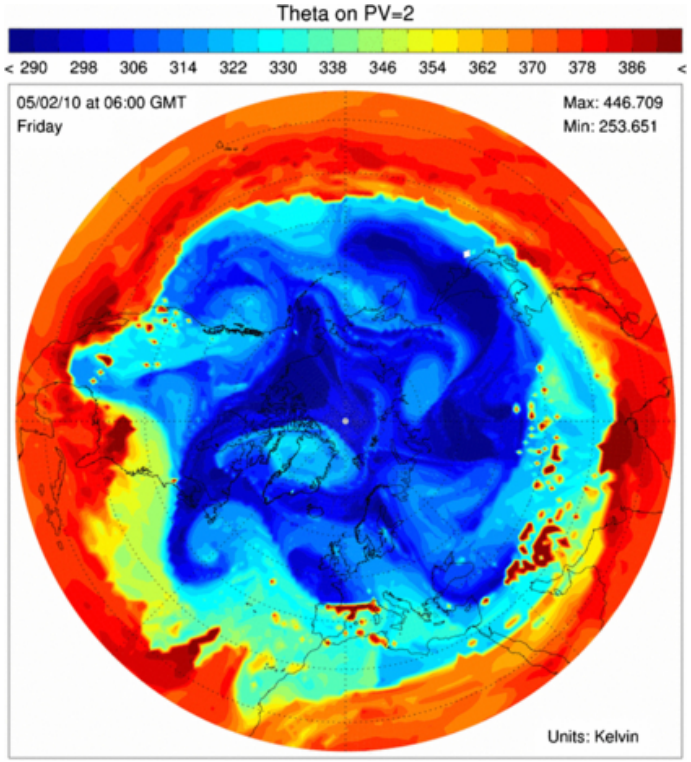
Is this unusual behaviour a harbinger of things to come ?

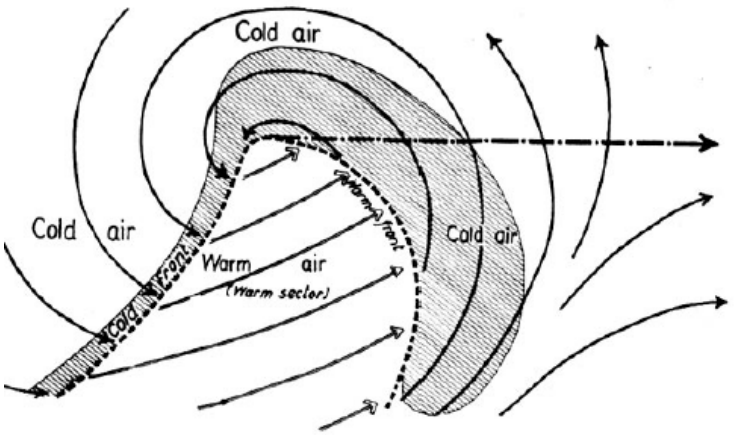


How may the storm tracks change as the troposphere becomes warmer and wetter, the stratosphere becomes cooler, and the cryosphere shrinks ?

A long history of storm tracks studies

$$PV = -g(\zeta_g + f)\frac{\partial \theta}{\partial p}$$

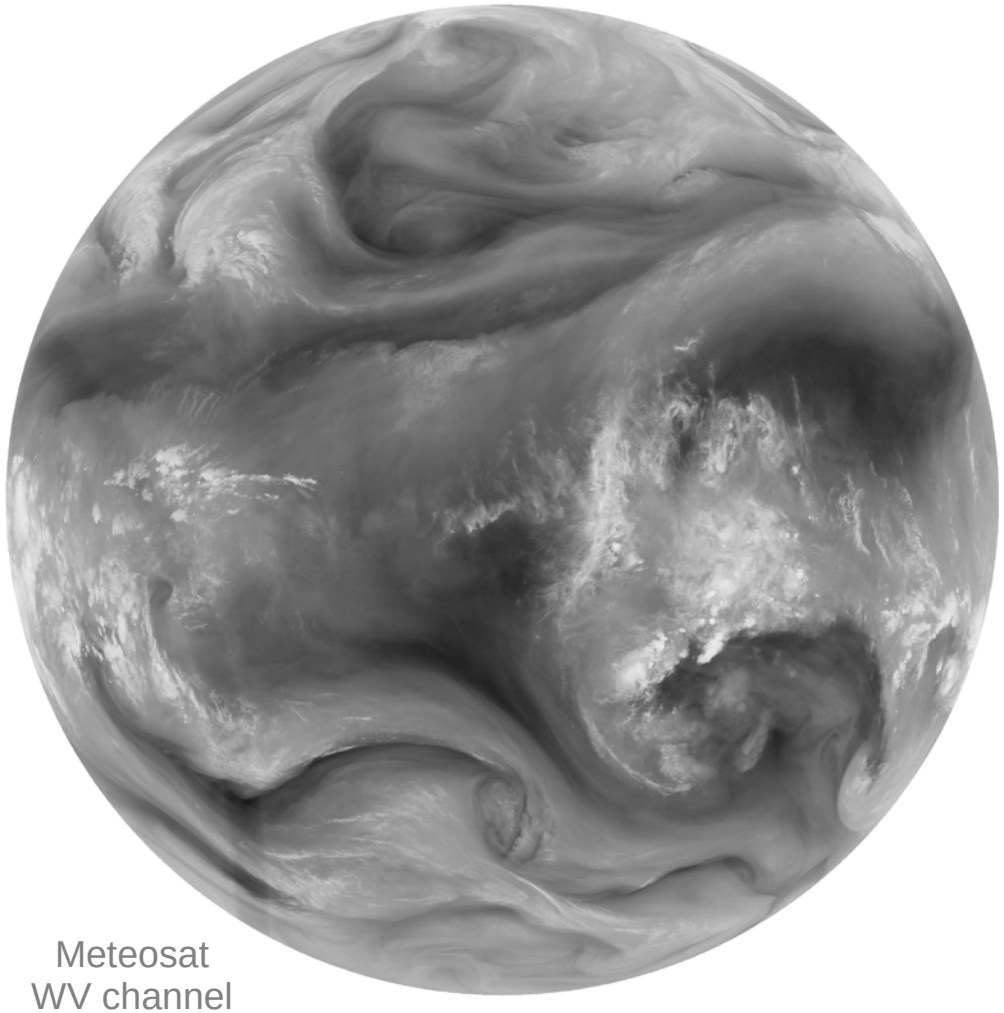




Bjerknes 1922

Most theoretical understanding of storm tracks, their role in the general circulation and their response to external forcing **is based on dry dynamics...**

What is the role of moist, diabatic processes ?



Meteosat
WV channel

What is the role water, phase changes and radiative processes (clouds) in the storm tracks?

NB: T-NAWDEX / DOWSTREAM mission (THORPEX North Atlantic Waveguide and Downstream impacts EXperiment)

How might the balance between moist and dry dynamics change as climate warms?
(latitudinal temperature gradients weakening, atmospheric moistening)

How do the storm tracks interact with the changing tropics and polar regions?
(rapidly warming Arctic, role of the stratosphere)

Implications for climate modelling and climate change studies ?

Persistent biases in the simulation of storm tracks (position of the jets, blockings..)
What dependence on model representations of moist, diabatic processes? How do them distort climate projections?

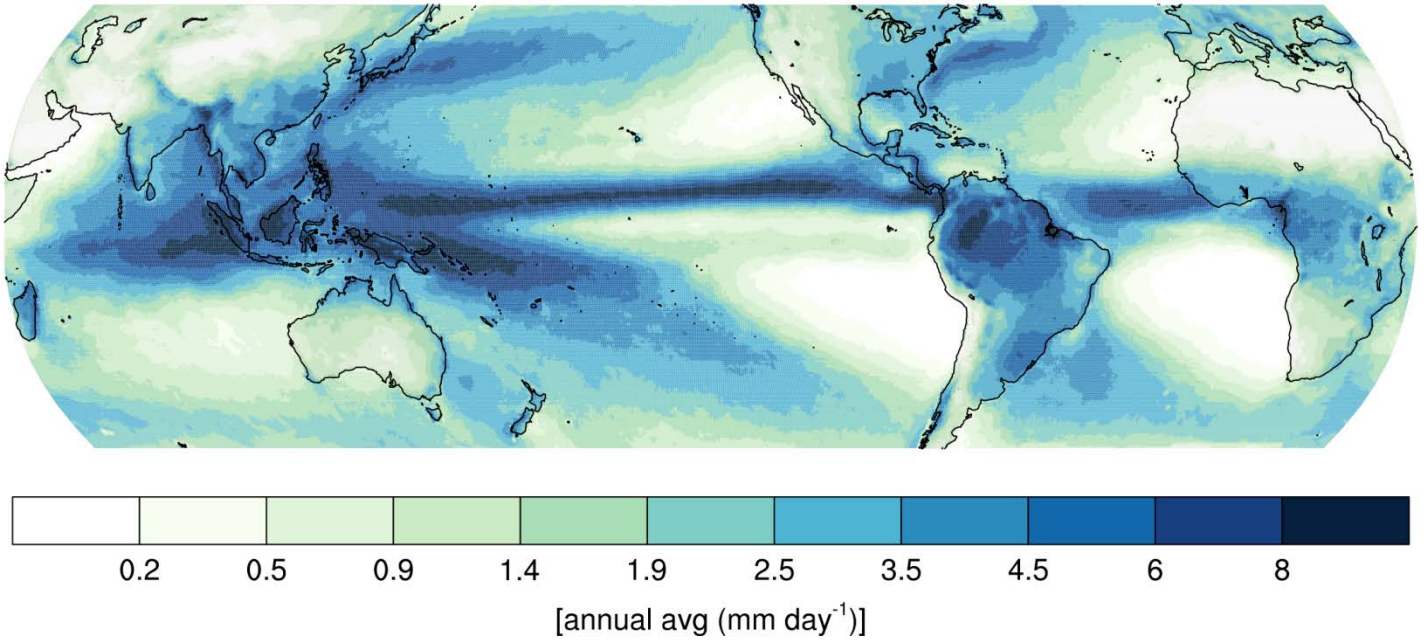
How do changes in storm tracks induce changes in cloud, and do those in turn feed back on the storm tracks?

Does regionally localized aerosol forcing affect the storm tracks?
NB: Easy Aerosol GC initiative (cf GC website)

Can we develop dynamical story lines of plausible changes in regional climate and extremes?

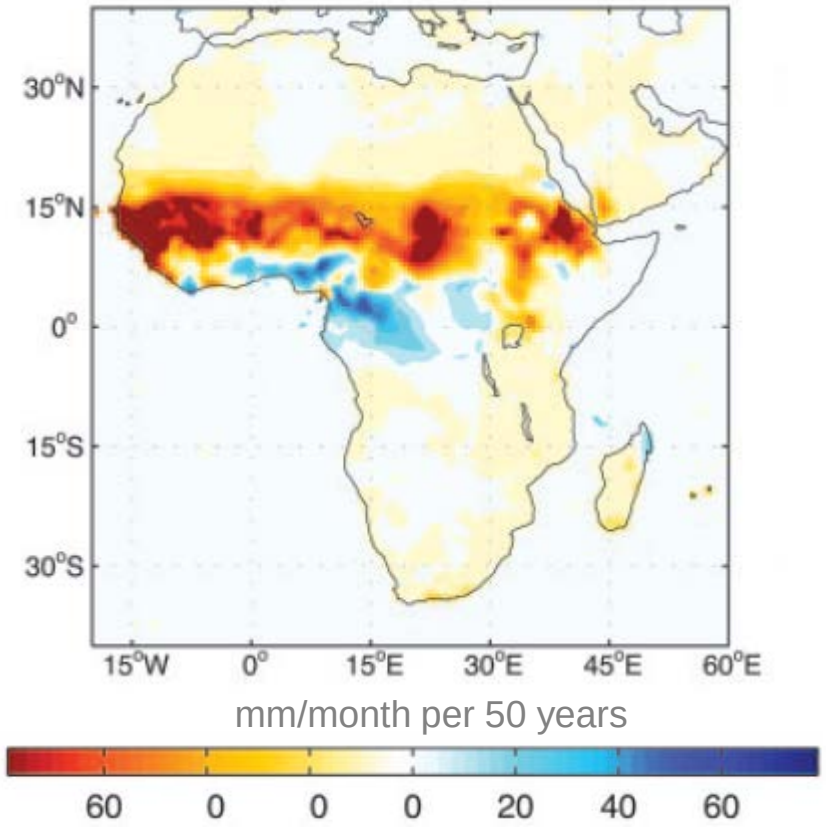
Q2: What controls the position and strength of tropical convergence zones ?

Precipitation derived from TRMM measurements



Q2: What controls the position and strength of tropical convergence zones ?

Observed rainfall trends from 1950 to 2000
(Jul-Aug-Sep, CRU data)



ITCZ shifts responsible for severe droughts
e.g. Sahelian drought

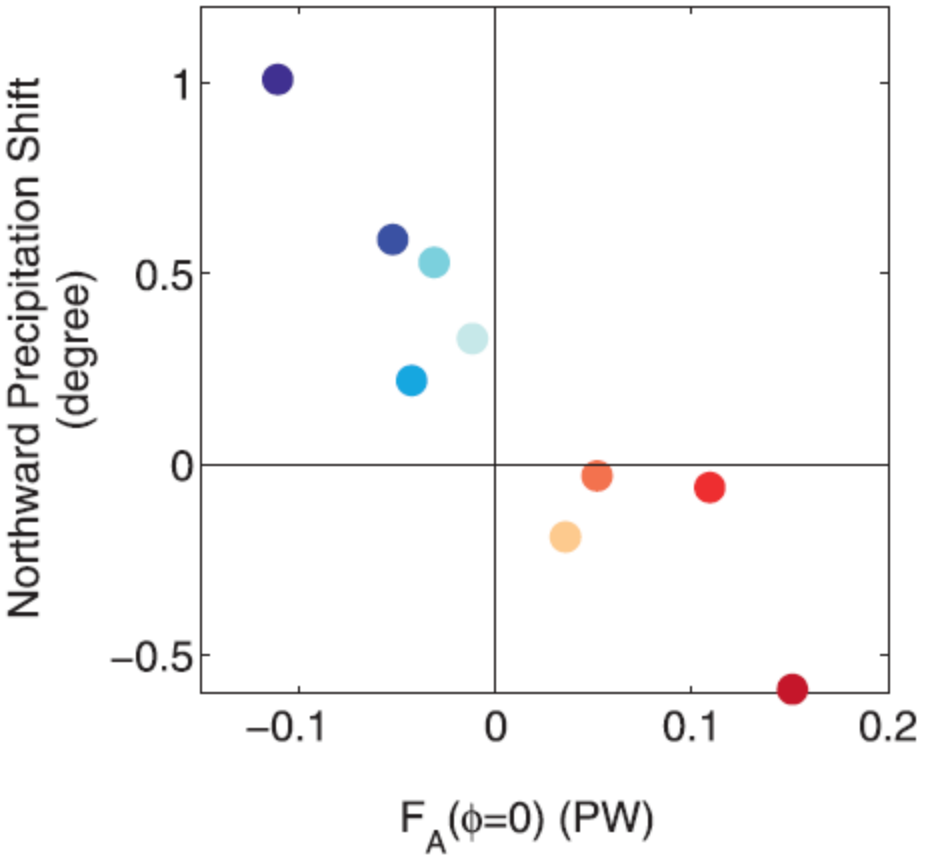
How will convergence zones (ITCZ, monsoons..)
respond to anthropogenic forcings
(e.g. GHG, aerosols, land use)?

Mid-Holocene Green Sahara enigma:
How was there rain all the way to 30N?

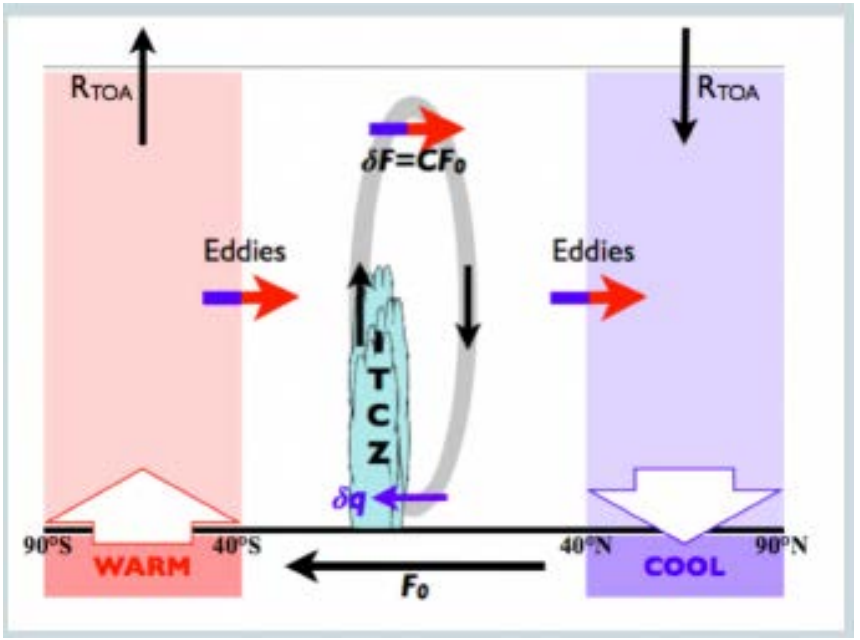
Held et al., PNAS, 2005

Q2: What controls the position and strength of tropical convergence zones ?

Energetic frameworks are being developed to interpret ITCZ shifts



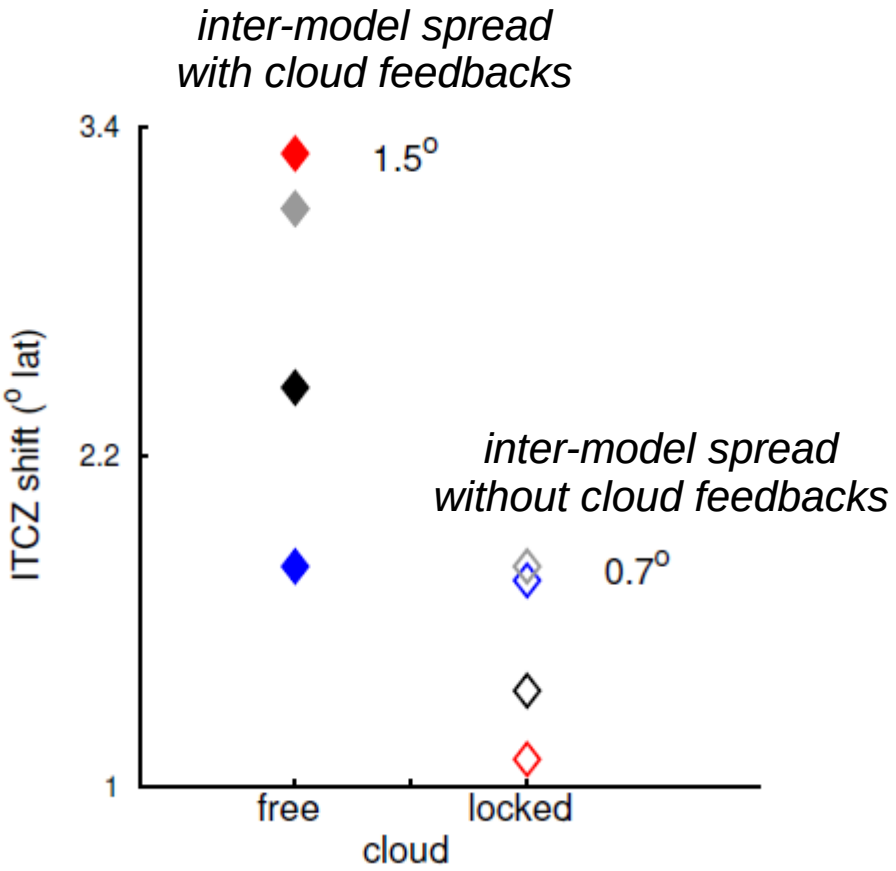
equatorial inter-hemispheric energy transport



Kang et al., J. Atmos. Sci., 2009
Frierson and Hwang, J. Clim., 2012
Frierson et al., Nature Geosci. 2013

Q2: What controls the position and strength of tropical convergence zones ?

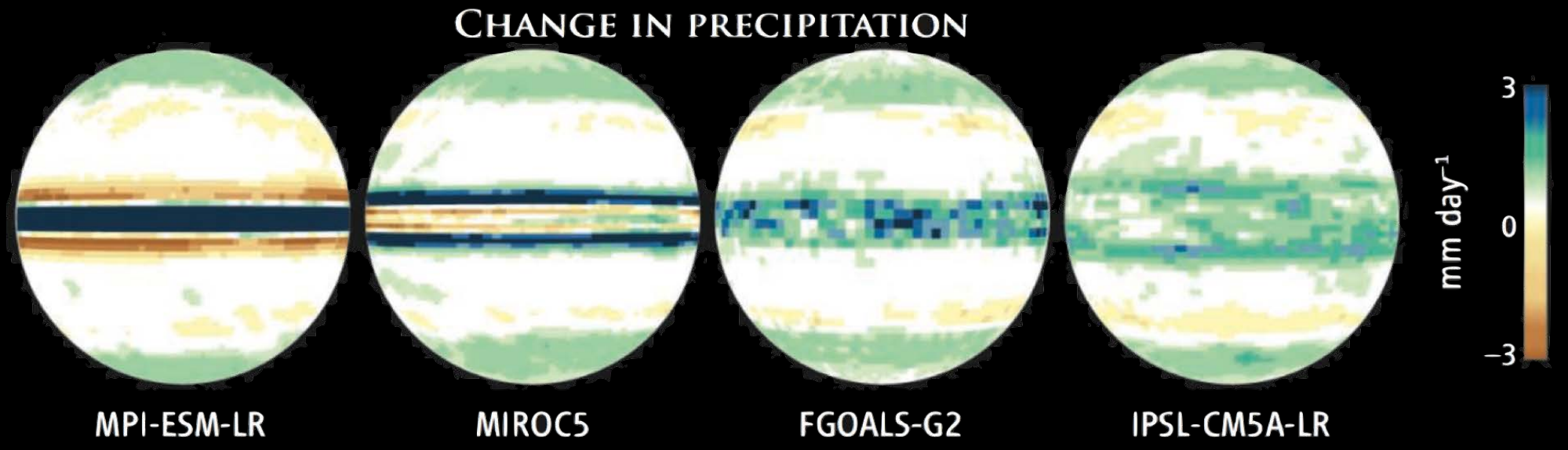
Increasing evidence that the magnitude of ITCZ shifts depend on cloud processes



Cloud-radiative effects explain
a large fraction of
the inter-model spread

Voigt et al., GRL, 2014
Frierson and Hwang, J. Climate, 2012
Kang et al., J. Climate, 2009

Q2: What controls the position and strength of tropical convergence zones ?

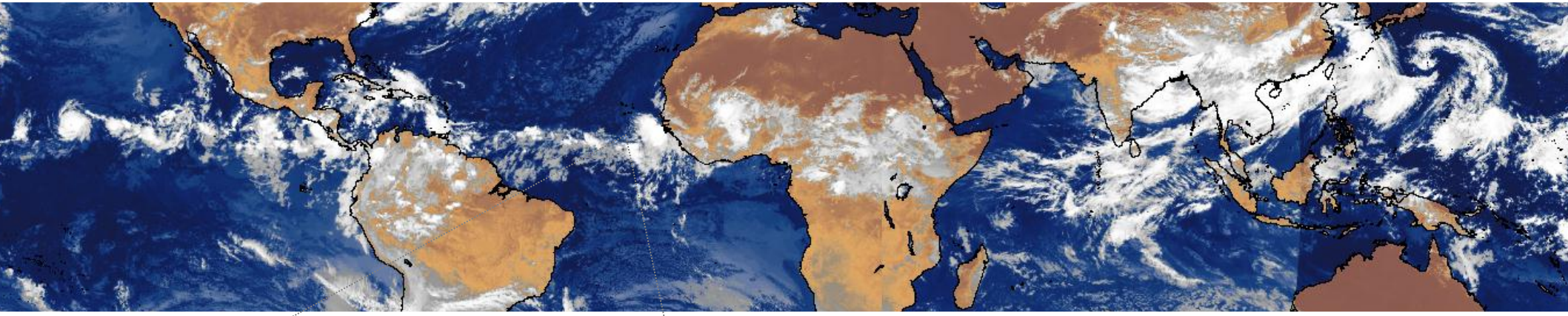


In simple aqua-planet configuration (CMIP5) : large inter-model differences in the position of tropical convergence zones (present-day climate & response to +4K)

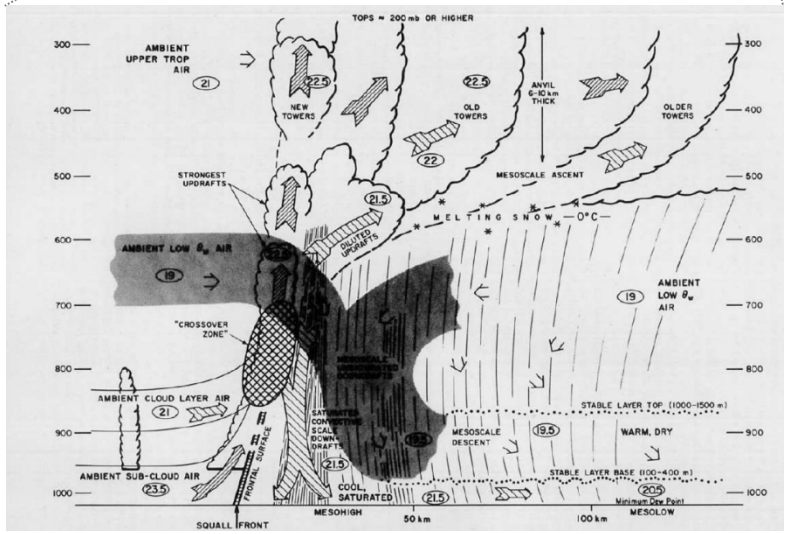
We should understand this..., as it is relevant to regional climate changes

Stevens & Bony, Science, 2013

Q3: Is convective aggregation important for climate ?



SATMOS



Zipser 1977

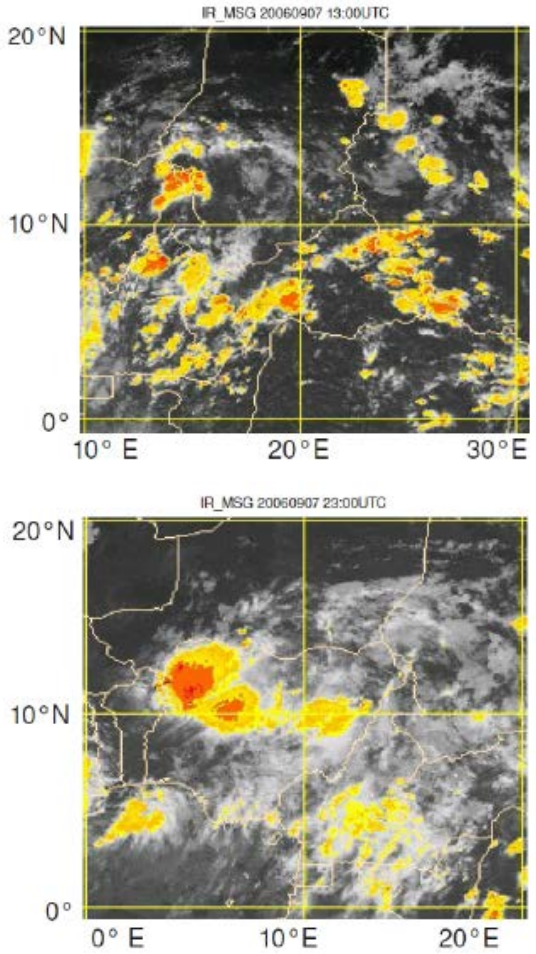
Convective aggregation / organization
has long been studied at the process level,
related to the variability of weather and
to the occurrence of extreme rainfall events.

It is now becoming a climate issue as well....

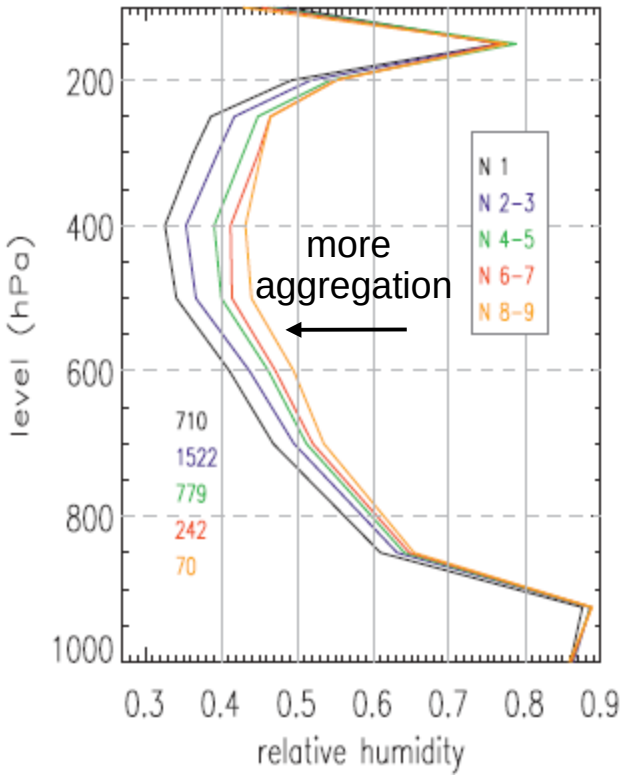
Q3: Is convective aggregation important for climate ?

Does convective aggregation affect the mean climate state ?

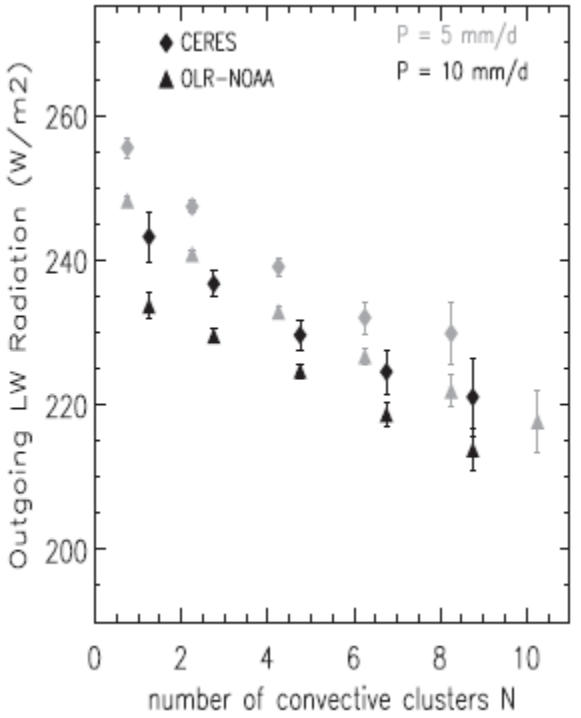
Numerical and observational studies suggest so...



the atmosphere is drier, clearer
(RH, AIRS data)



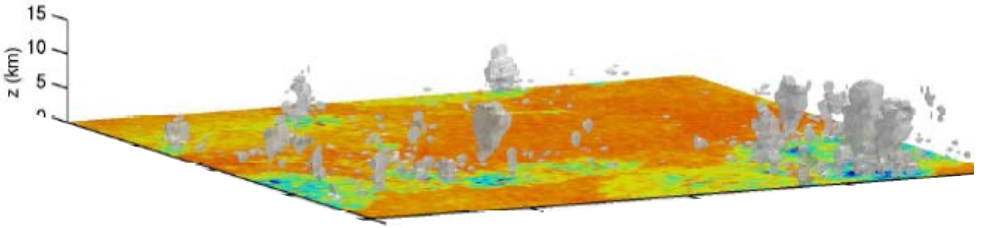
more efficient at radiating
heat to space
(OLR, CERES data)



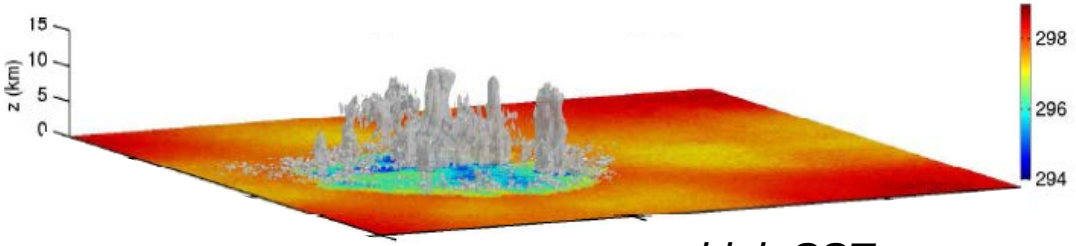
Tobin, Bony & Roca, J. Climate 2012
Tobin et al., JAMES, 2013

Q3: Is convective aggregation important for climate ?

Does convective aggregation matter for Climate Sensitivity ?



low SST



high SST

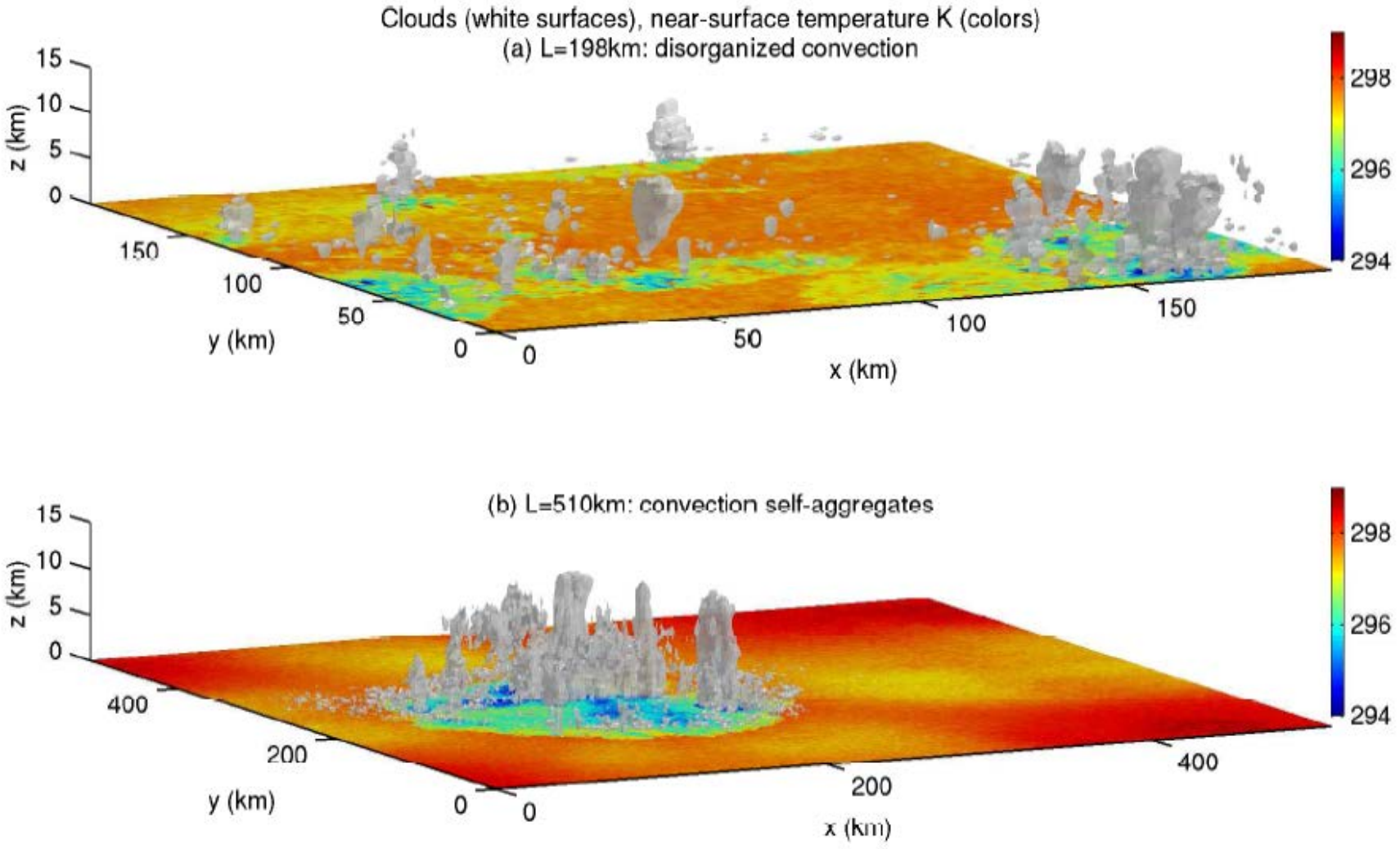
Models suggest an easier occurrence of convective aggregation at high temperatures → Atmospheric drying and enhanced OLR → Negative feedback on Climate Sensitivity?

- **Can observations or proxies provide evidence for such a dependence ?**
- **May changes in convective aggregation feed back on global warming ?**
- **If so, are climate models missing an essential ingredient ?**

Wing & Emanuel, JAMES, 2014
Khairoutdinov & Emanuel, AMS, 2010
also Held et al. 1993, Muller and Held 2012

What are the physical processes underlying aggregation ?

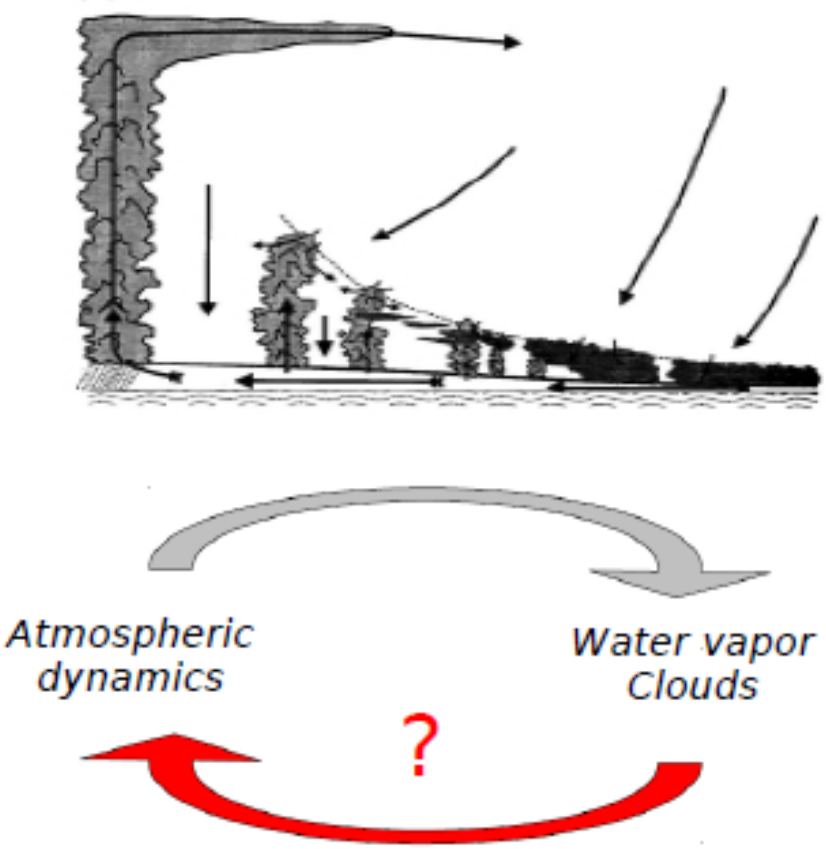
Numerical studies show that even in the absence of external drivers (*e.g.* rotation, shear), **convection can aggregate spontaneously : “self-aggregation”.**



Courtesy Caroline Muller (LadHyX)

Q3: Is convective aggregation important for climate ?

Does convective aggregation affect the general circulation?



Recognized to have a role in the diurnal cycle of rainfall in the Sahel, in the structure of monsoons, etc.

How, and by how much, does convective organization affect the large-scale circulation ?

- Has the role of external drivers in tropical circulations been over-emphasized ?

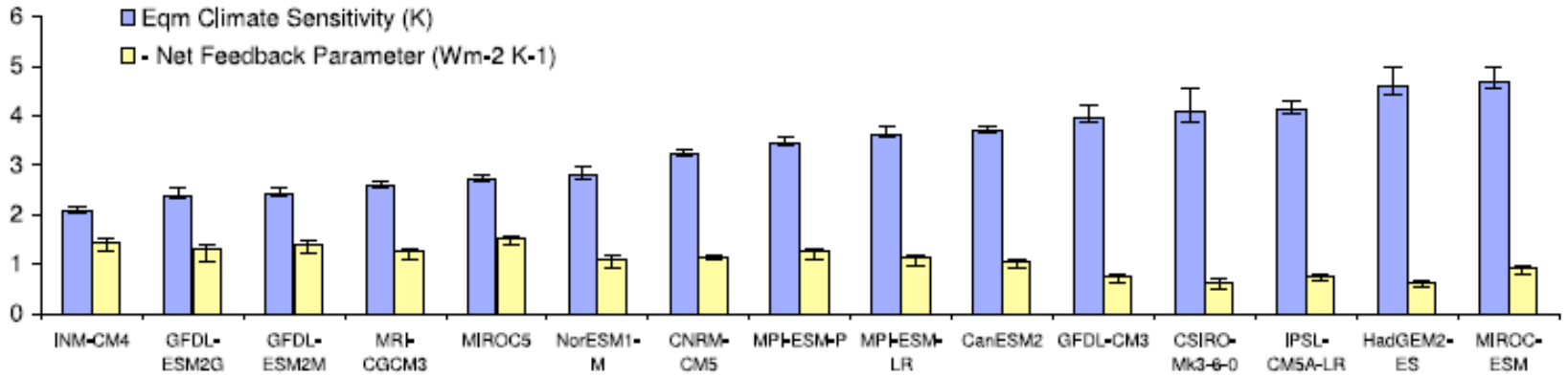
- Are phenomena such as the MJO a large-scale manifestation of convective self-aggregation ?

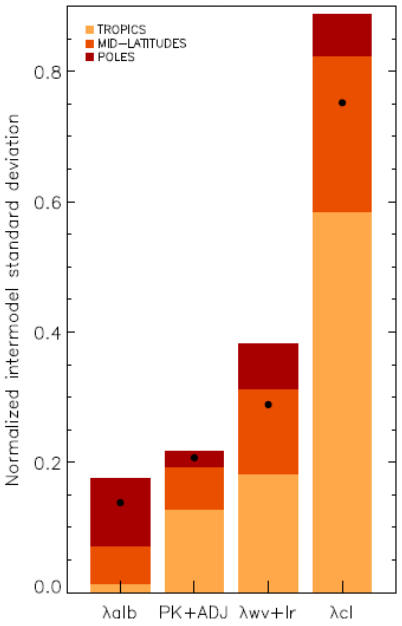
How much do persistent biases of global models in simulating the tropical circulation result from a poor or incomplete representation of convective organization ?

Q4: How does convection contribute to cloud feedbacks?

Photo Bjorn Stevens (from the HAL

Q4: How does convection contribute to cloud feedbacks?





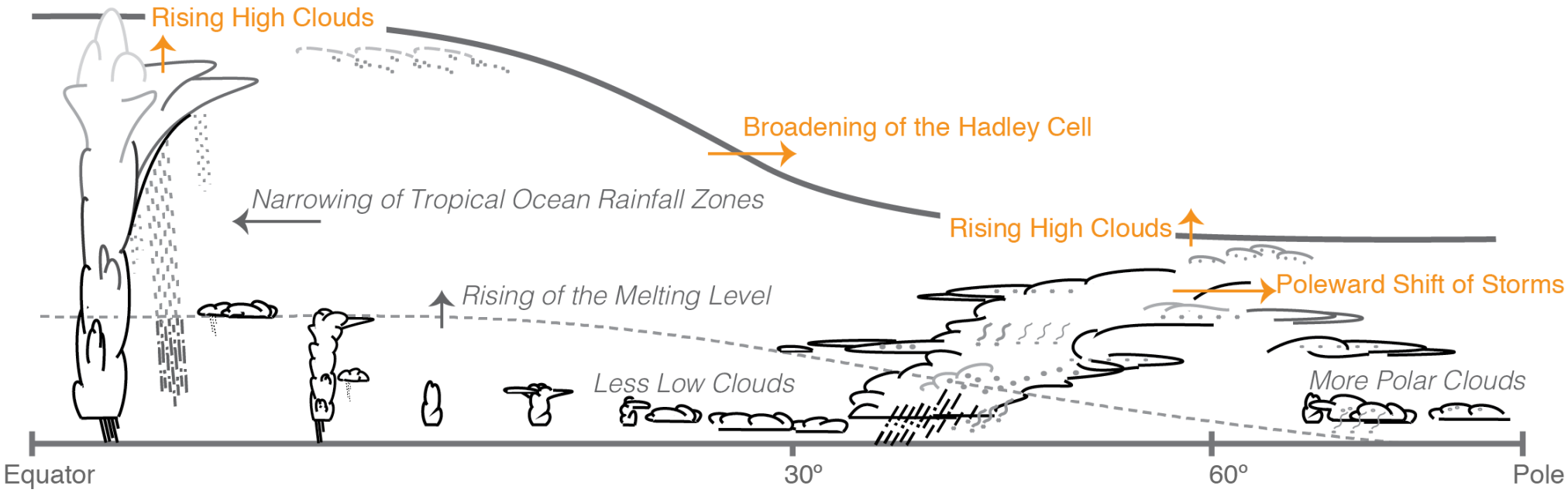
cloud feedbacks

Still a wide range of model estimates of Climate Sensitivity

Primarily related to the spread of model cloud feedbacks

Andrews et al., GRL, 2012
Vial et al., Clim. Dyn., 2013

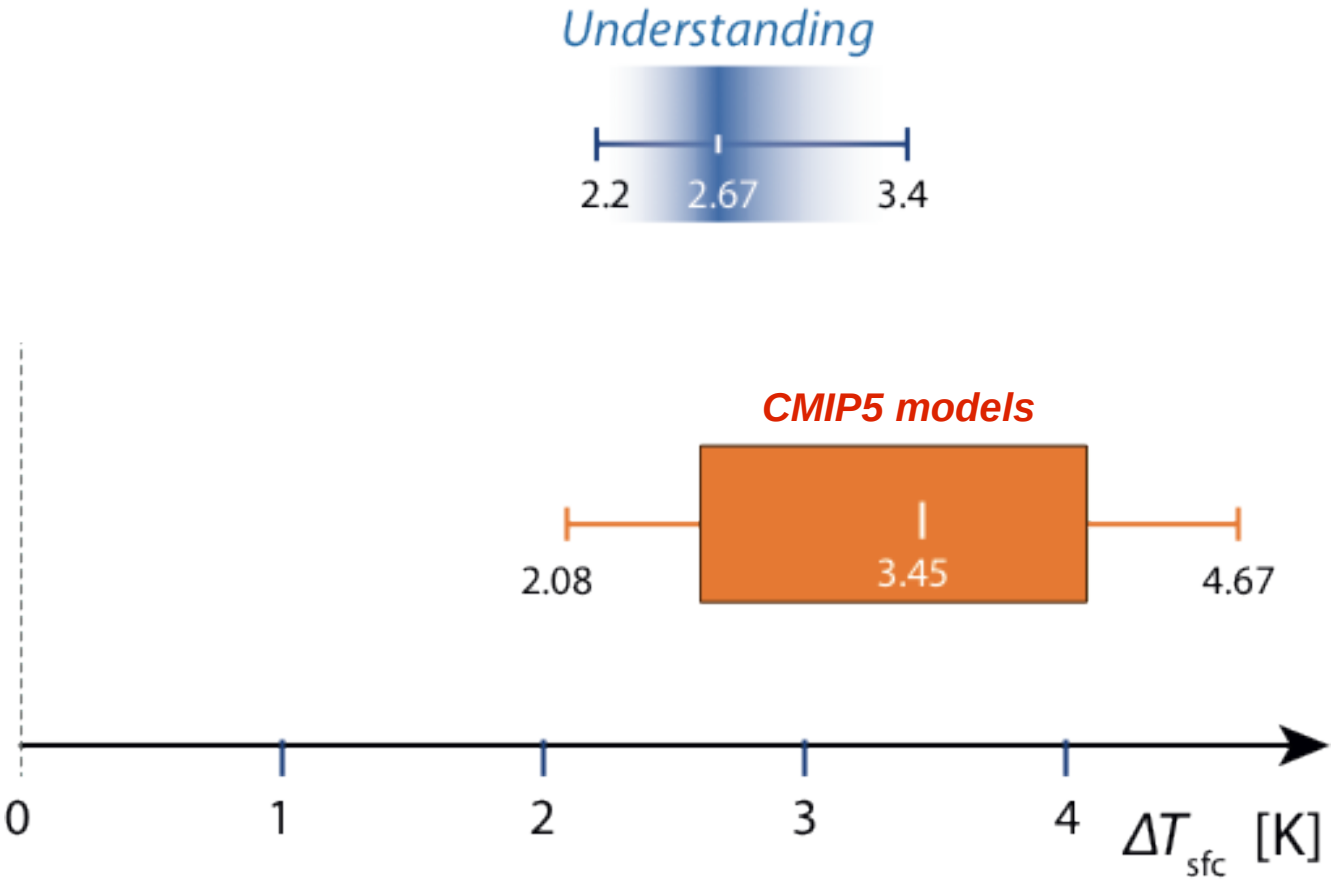
Q4: How does convection contribute to cloud feedbacks?



IPCC 2013
Fig. 7.11

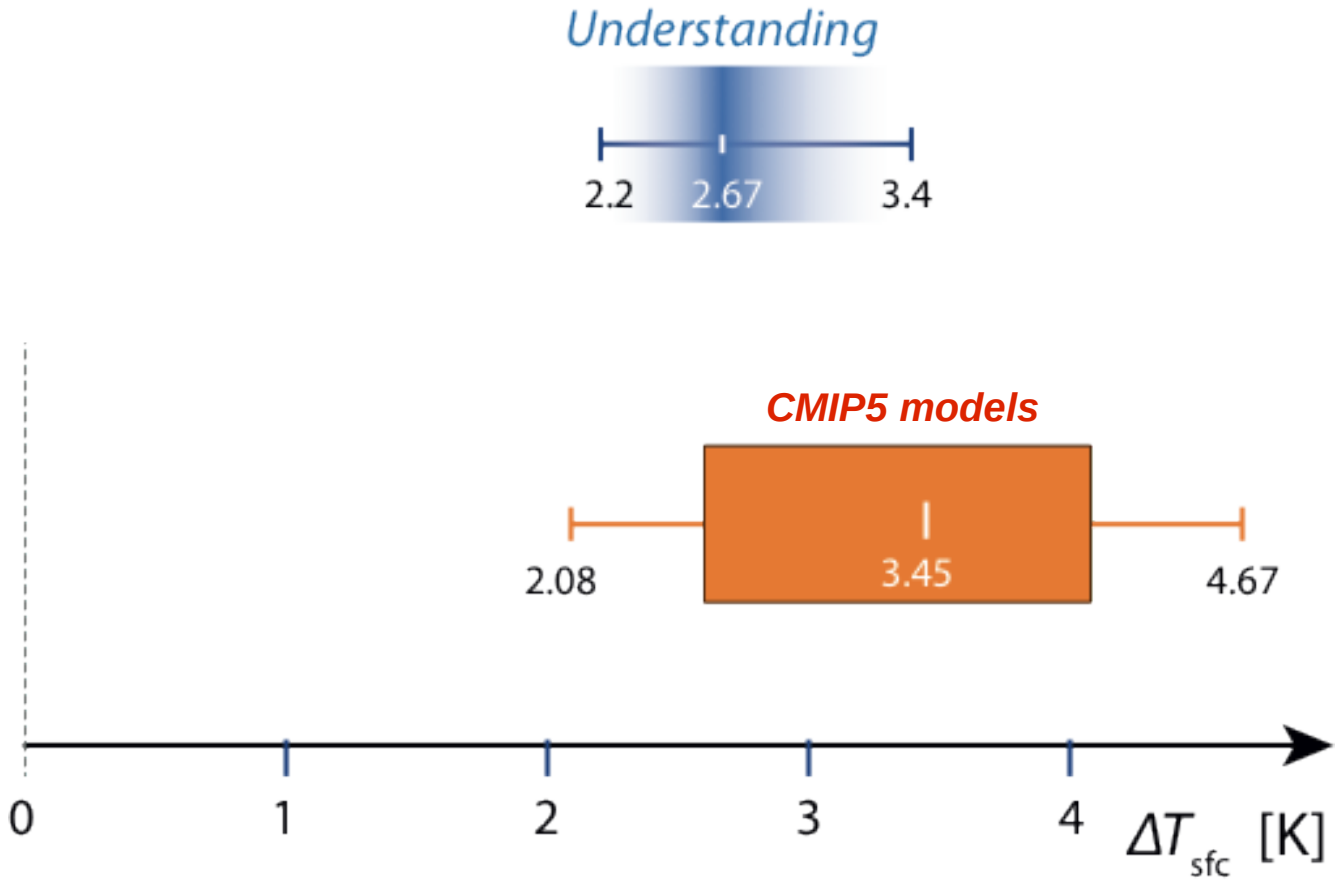
- Several cloud-feedback mechanisms have been identified and are now independently corroborated by multiple lines of evidence.
- Most of them involve changes in large-scale dynamics and convection.
- Still a large inter-model spread in climate sensitivity estimates from climate models

Q4: How does convection contribute to cloud feedbacks?



Stevens & Bony, Physics Today, 2013

Q4: How does convection contribute to cloud feedbacks?



- Feedback associated with changes in convective cloud cover?

Stevens & Bony, Physics Today, 2013

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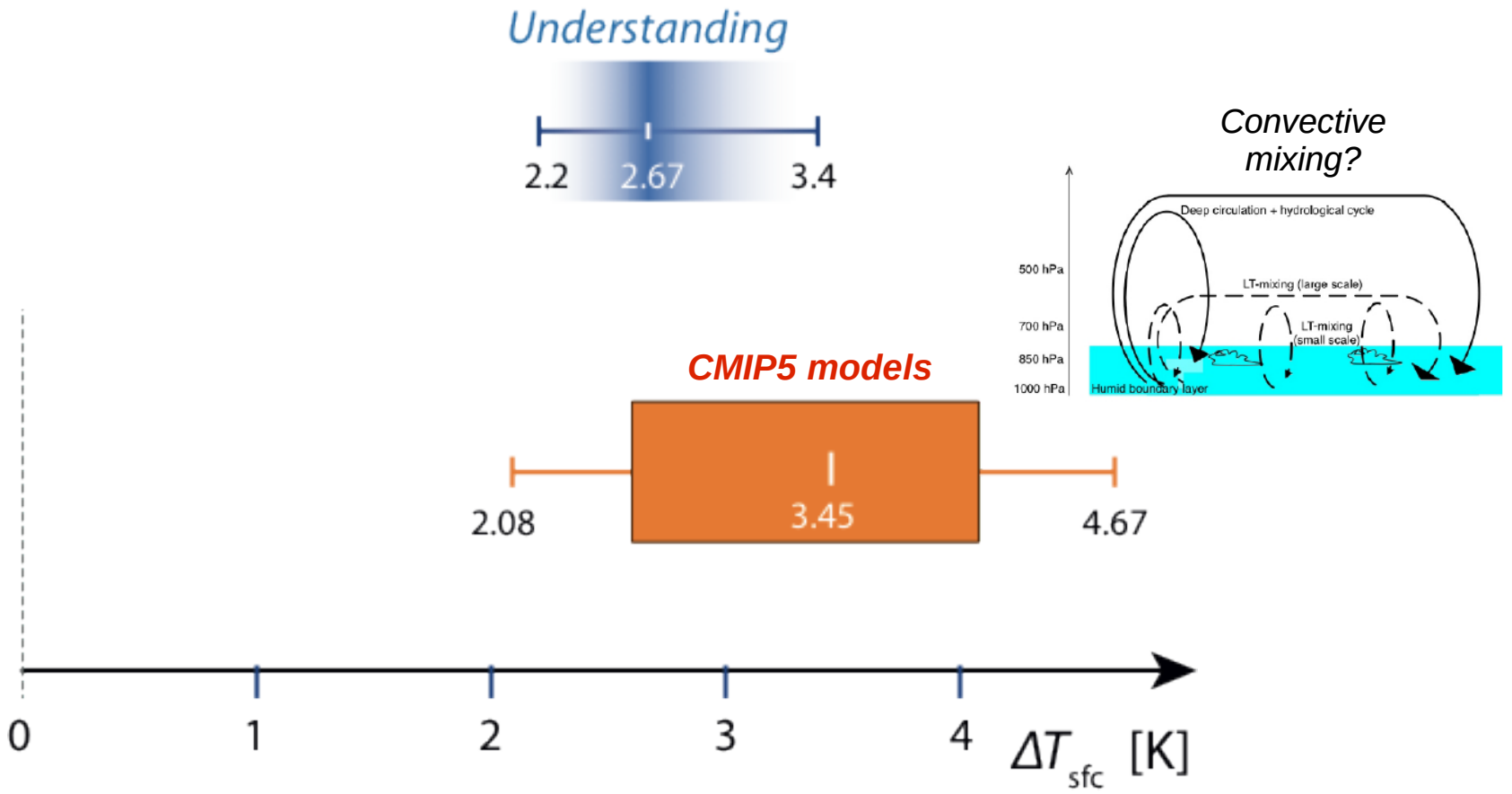
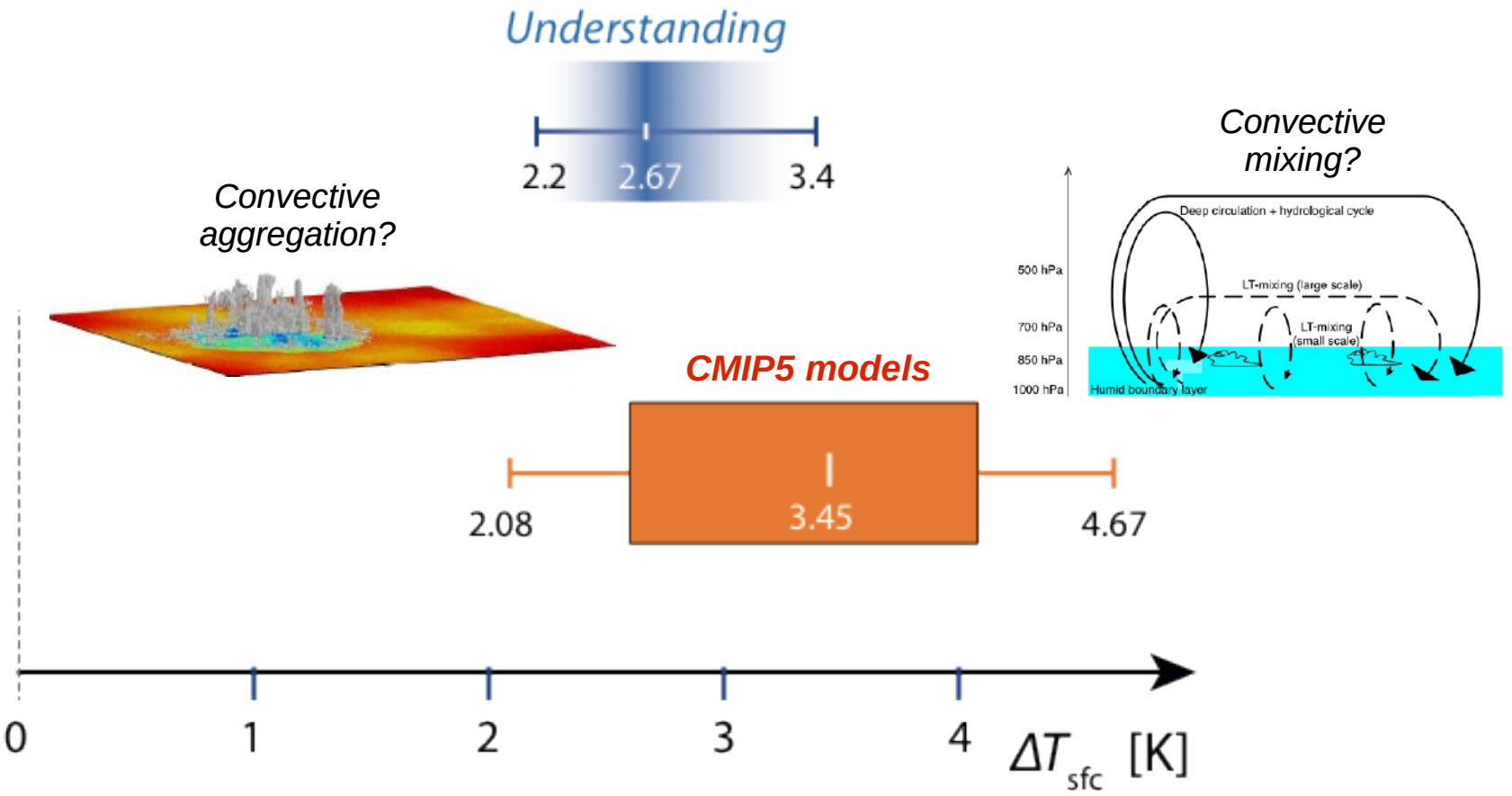


- Feedback associated with changes in convective cloud cover?
- How does convective mixing influence low-cloud feedbacks and Climate Sensitivity?

Stevens & Bony, Physics Today, 2013

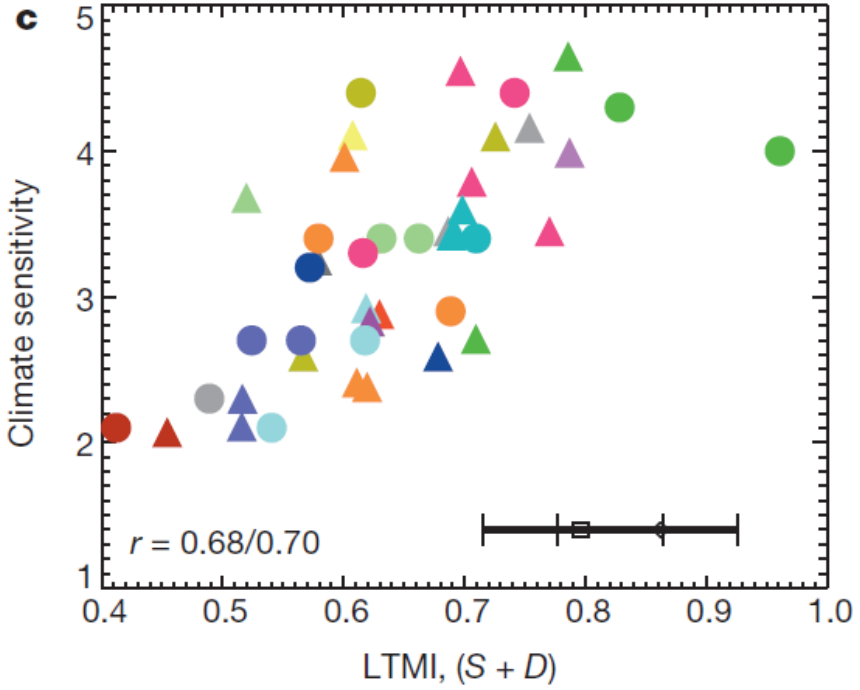
Q4: How does convection contribute to cloud feedbacks?



- Feedback associated with changes in convective cloud cover?
- How does convective mixing influence low-cloud feedbacks and Climate Sensitivity?
- Can changes in convective organization influence Climate Sensitivity?...and Hydrological Sensitivity?

Stevens & Bony, Physics Today, 2013

Q4: How does convection contribute to cloud feedbacks?



Does convection act locally or remotely on low-cloud feedbacks?

How does convection influence the structure of the lower troposphere? ... and the hydrological sensitivity?

Can we test emergent constraints?

Can we interpret and evaluate unusual behaviours?

Can paleoclimates help us constrain cloud feedbacks and sensitivity?

Can idealized modelling frameworks be used to help constrain parameterized convection in more realistic configurations?

Sherwood et al., Nature, 2014

WCRP Grand Challenge on Clouds, Circulation and Climate Sensitivity :

We argue that our ability to understand the Earth's climate and to anticipate climate change at global and regional scales, can be accelerated by focusing on the following four science questions :

Q1: How will storm tracks change in the future?

Q2: What controls the position and strength of tropical convergence zones?

Q3: Is convective aggregation important for climate?

Q4: How does convection contribute to cloud feedbacks?

Questions to CFMIP :

- Any general comment about this Grand Challenge ?
- How can CFMIP contribute to the four questions ?
- Does CFMIP want to take “ownership” of one (or more) of the four questions?
- May these questions trigger new CFMIP activities?
- Influence on the experimental design (and outputs) of CFMIP3/CMIP6 experiments?
- Opportunities to strengthen CFMIP – PMIP connections ?