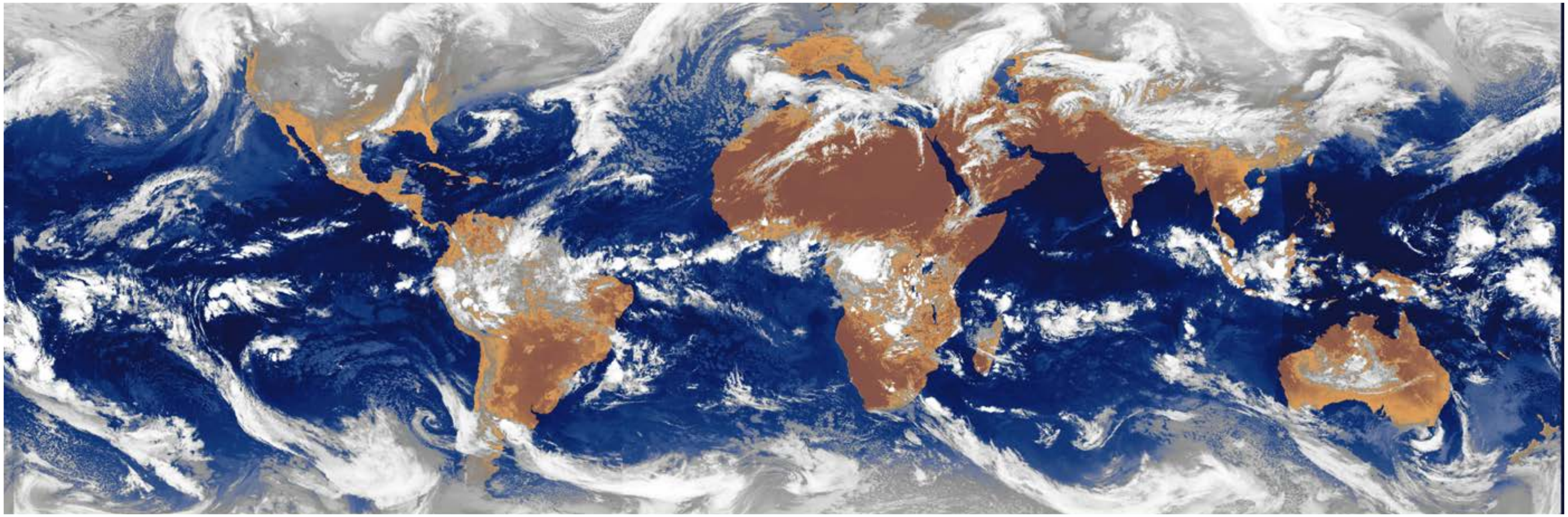
WCRP Grand Challenge on

Clouds, Circulation and Climate Sensitivity



http://www.wcrp-climate.org/index.php/gc-clouds

Sandrine Bony (LMD/IPSL) & Bjorn Stevens (MPI)
WCRP JSC-35, 30 June 2014, Heidelberg, Germany

WCRP World Climate Research Programme

WCRP Grand Challenge on

Clouds, Circulation and Climate Sensitivity

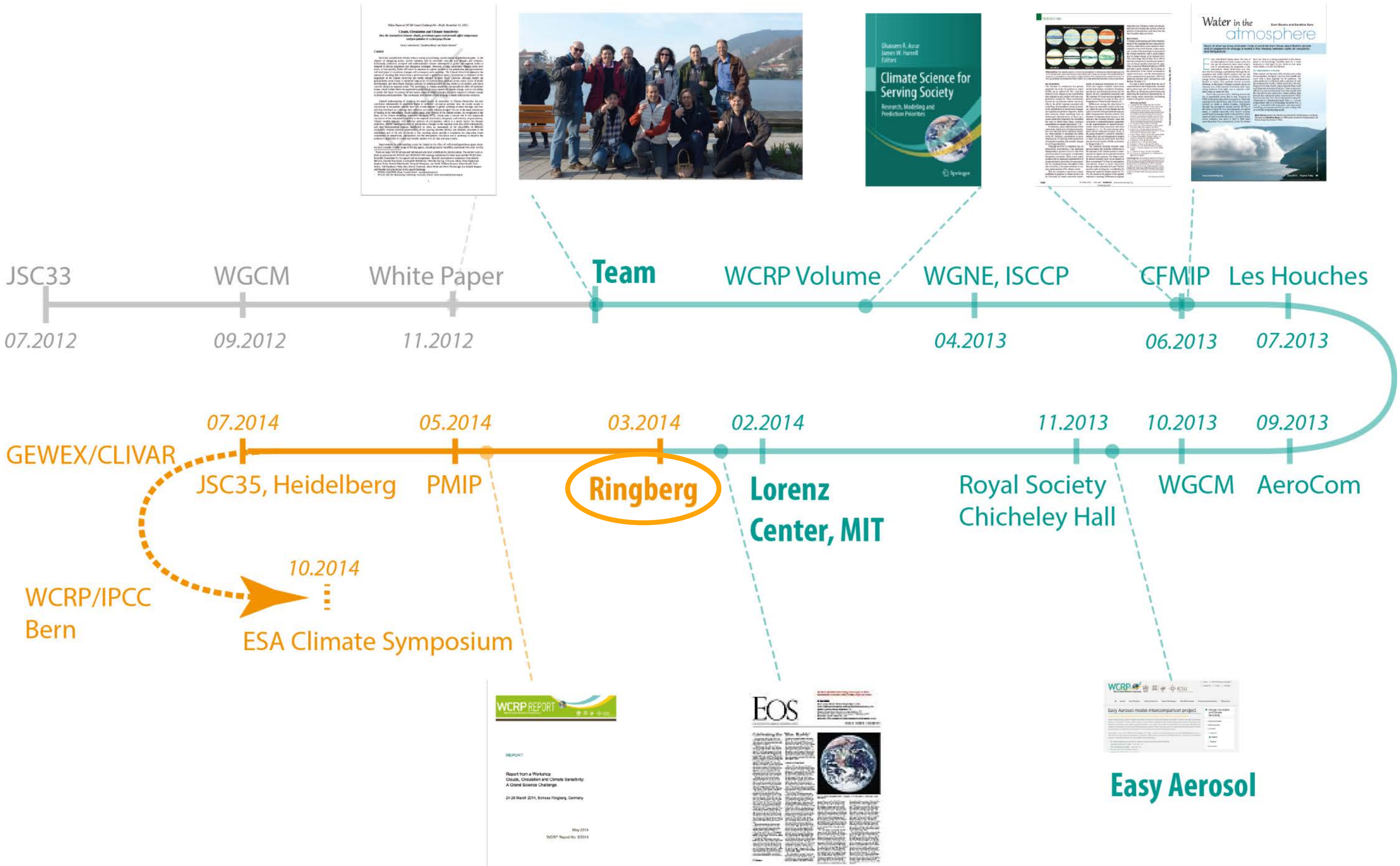
- Current status
- Broad strategic vision
- Articulating science questions
- Opportunities, Implementation & Next steps
- Questions to the JSC

The Clouds & Circulation grandees....

Sandrine Bony & Bjorn Stevens (lead coordinators)

Dargan Frierson, Christian Jakob, Masa Kageyama, Robert Pincus, Ted Shepherd, Steve Sherwood, Pier Siebesma, Adam Sobel, Masahiro Watanabe, Mark Webb (co-coordinators)

Clouds, Circulation and Climate Sensitivity GC

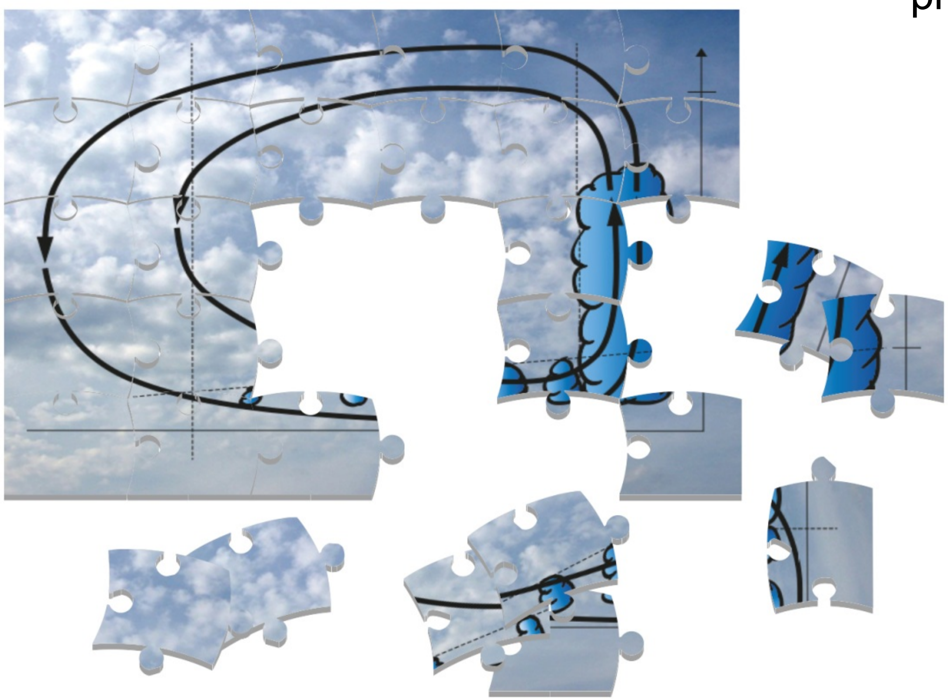


Ringberg Workshop (March 2014)

- Culminating the process of community consultation **to identify a handful of scientific questions through which the grand challenge would be further developed : The Four Questions.**
- Reflecting on and assessing **new opportunities** for coordinated approaches.
- And as a leitmotif for all aspects of the Grand Challenge, recognizing the:
  1. need to **link model development** to all the activities organized by the Cloud-GC;
  2. importance of better **understanding the water budget of lower troposphere** (across scales);
  3. value of more closely **integrating paleoclimate activities** within the Cloud-GC (& WCRP as a whole).

Workshop report: **WCRP No. 08/2014** (Stevens et al., May 2014), available on GC website

GC Credo



Making real progress over time in understanding and predicting climate, and ultimately providing better service to society, requires attacking some fundamental puzzles.

Many of these puzzles relate to our limited understanding of the connection between clouds, circulation and climate.

An historic impediment has been that over the last 50 years, two cultures have developed in parallel, one focused on small-scale cloud processes, and the other on the general circulation, without much interaction.

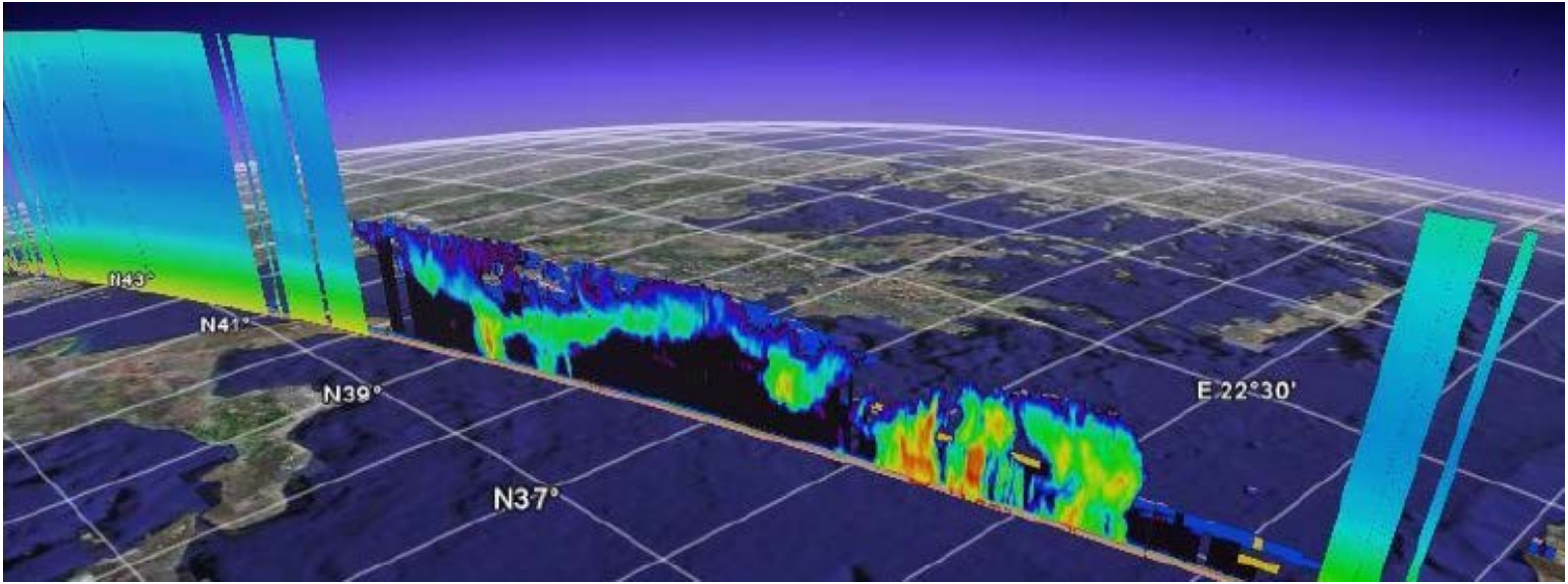
This impediment is progressively falling away...

Revolutionary advances in Earth Observation

Now possible to observe clouds and aerosols through multiple instruments, and in three dimensions

to carry out process studies using space observations

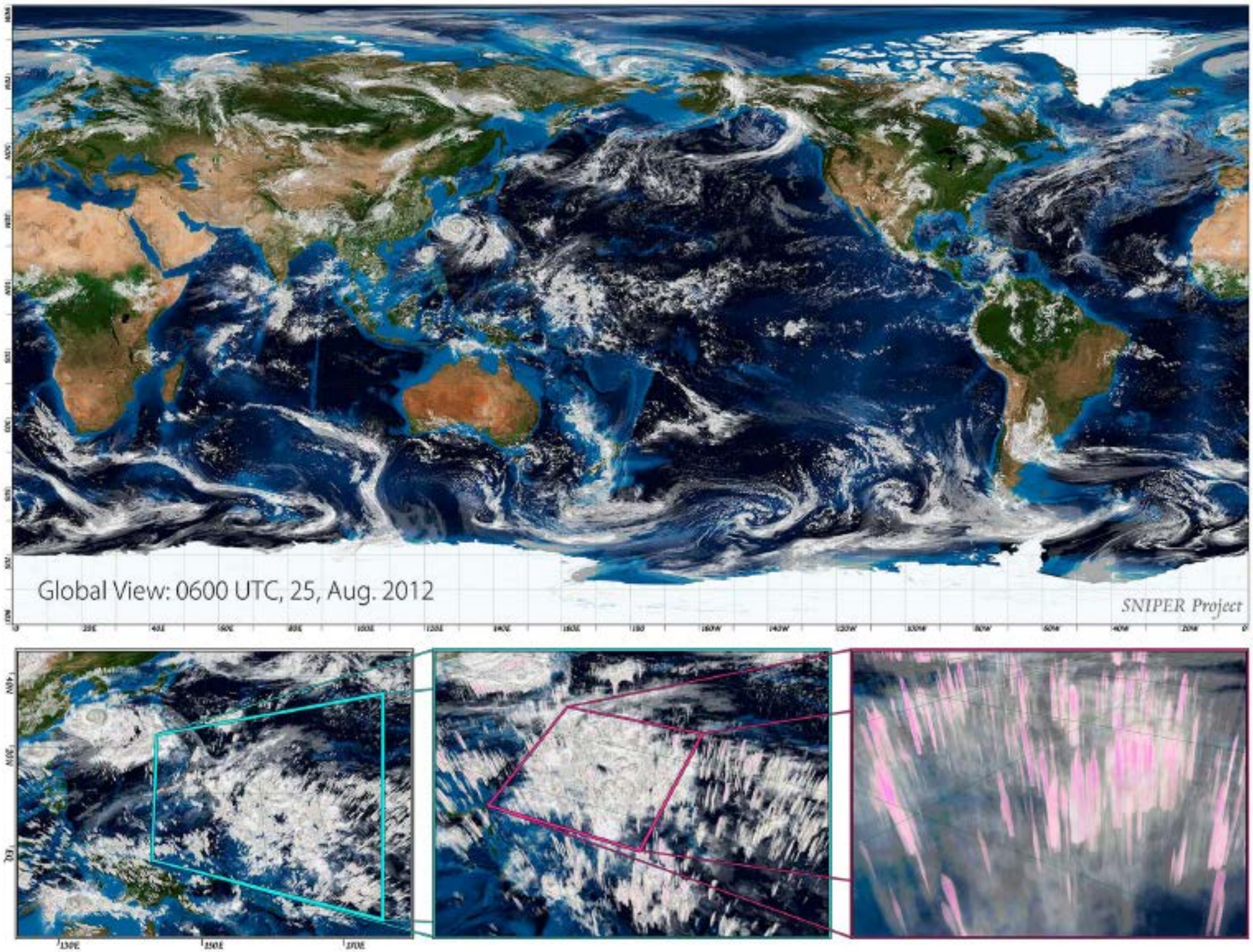
to bridge the cloud and planetary scales



NASA GSFC

Revolutionary advances in numerical modelling

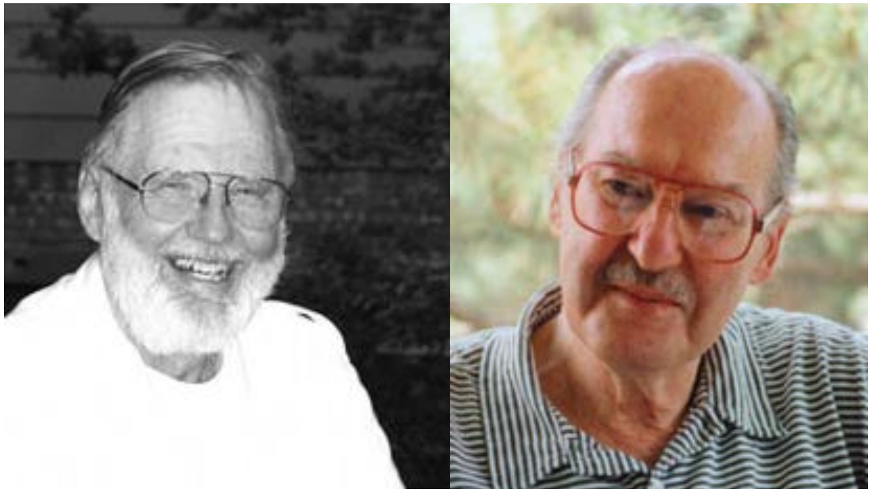
Global Cloud Resolving Model (NICAM) simulation
at **sub-kilometer** resolution (870 m)



Miyamoto et al. (GRL, 2013)

Clouds, Circulation and Climate Sensitivity :

A convergence of scales...and of scientific cultures



Douglas Lilly *Joseph Smagorinsky*

- It is now possible to **bridge scales between individual clouds and large-scale dynamics.**
- **Time to reunite the two cultures (small-scale cloud processes, general circulation)** that developed in parallel over the last fifty years

Clouds, Circulation and Climate Sensitivity :

A convergence of scales...and of scientific cultures

Douglas Lilly *Joseph Smagorinsky* *Suki Manabe*

- It is now possible to **bridge scales between individual clouds and large-scale dynamics.**

- **Time to reunite the two cultures (small-scale cloud processes, general circulation)** that developed in parallel over the last fifty years

- Much as a new accelerator for particle physics, **this convergence is likely to be transformative** regarding our ability to understand the climate system and anticipate its future changes.

Clouds, Circulation and Climate Sensitivity :

However, understanding how the Earth system works remains a daunting challenge....

We argue that the convergence of the cloud and circulation cultures, and hence our ability to understand the Earth's climate and anticipate climate change, can be accelerated by focusing on four science questions :

Q1: How will storm tracks change in the future?

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

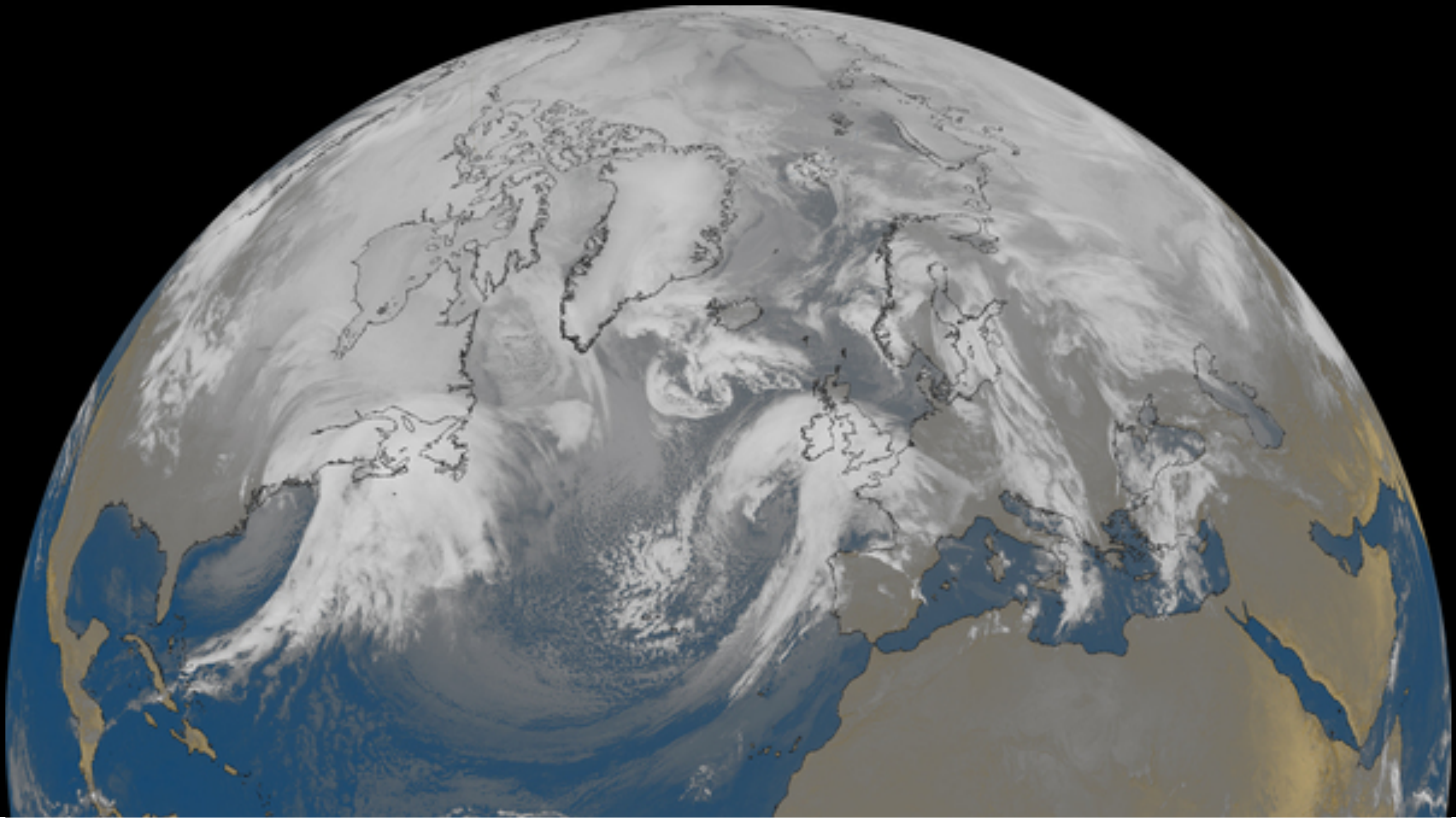
Q3: Is convective aggregation important for climate?

Q4: How does convection contribute to cloud feedbacks?

Q1: How will storm tracks change in the future ?

Storm tracks:

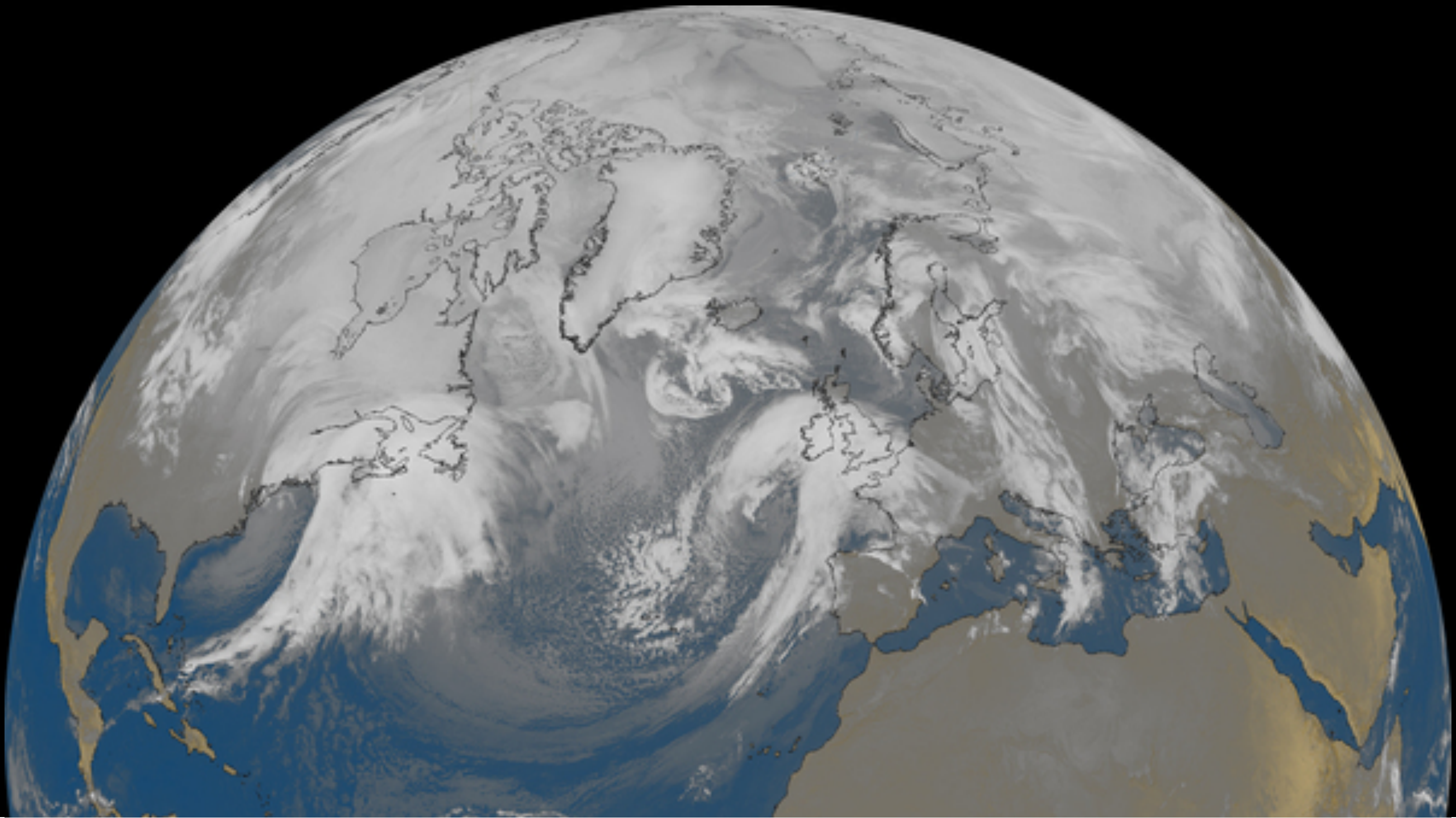
- Major component of the general circulation (e.g. energy, moisture and momentum transport, low-frequency variability)
- Key control of weather-related climate impacts, cause of much severe weather
- Organize precipitation and the formation of clouds in the extratropics



Q1: How will storm tracks change in the future ?

Storm tracks:

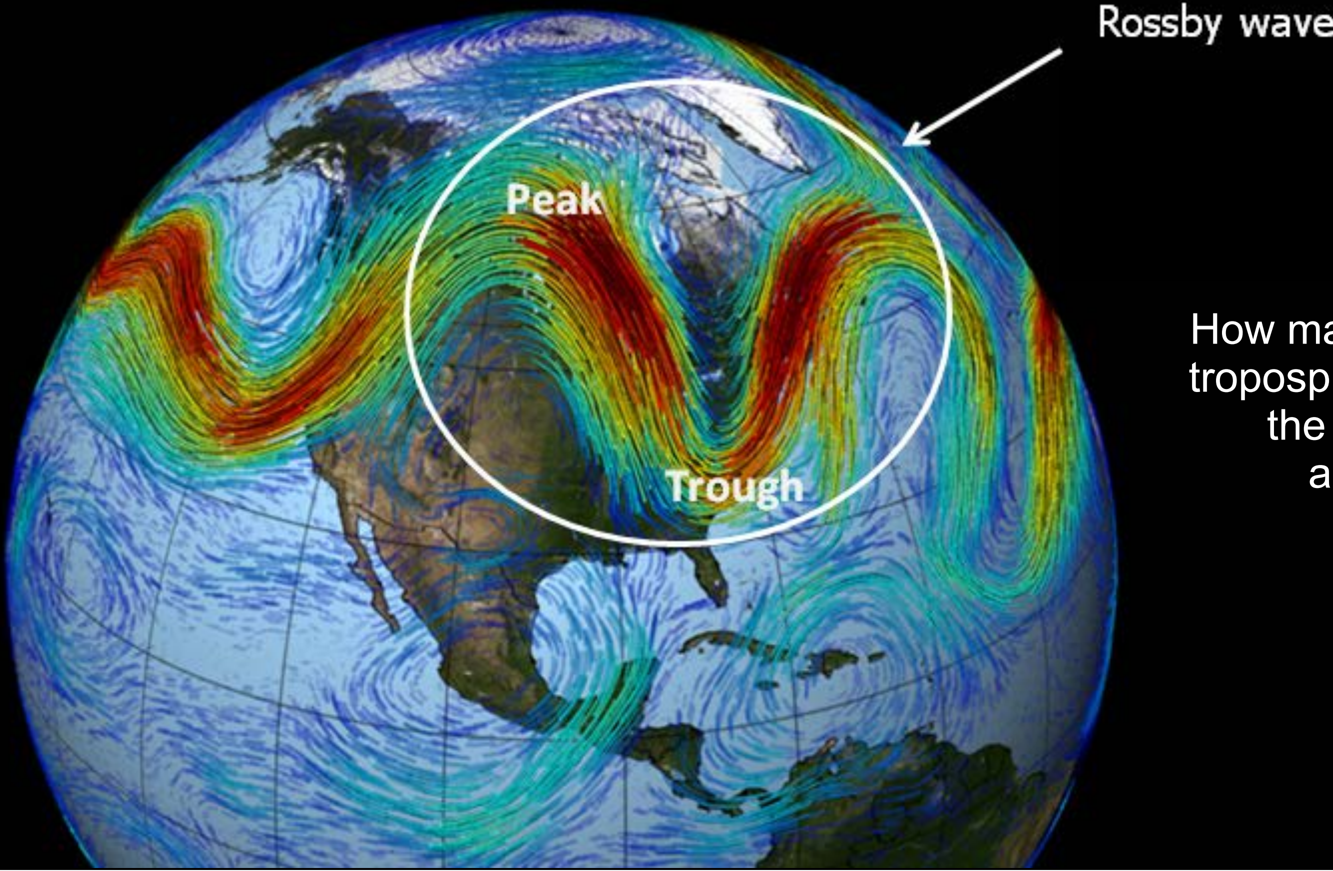
- A source of model biases (e.g. position of the jets, blockings, radiation budget)
- Models suggest that storm tracks respond to external forcings (e.g. GHGs, ozone hole, aerosols)
- A primary control on regional climate changes and impacts



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

Proximate explanation is meteorological

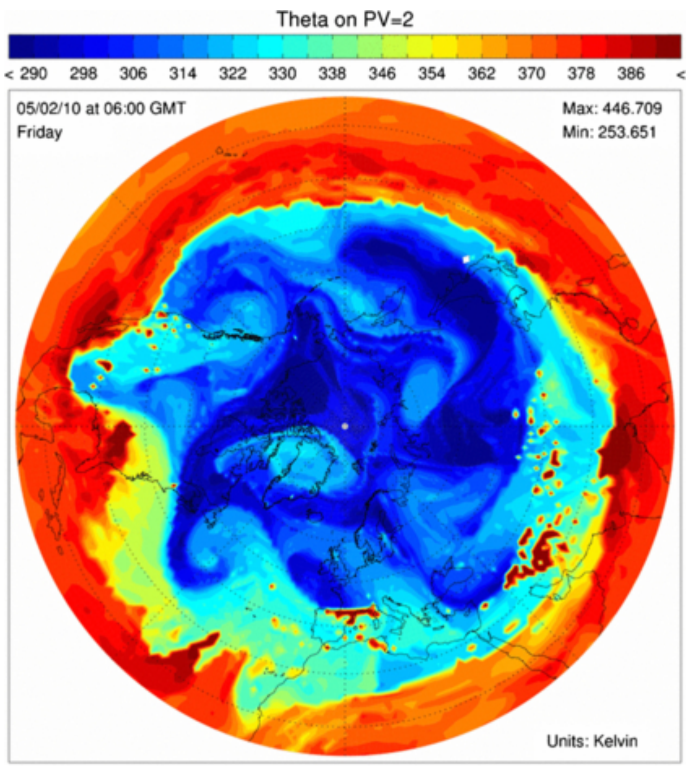
Is this unusual behaviour a harbinger of things to come ?

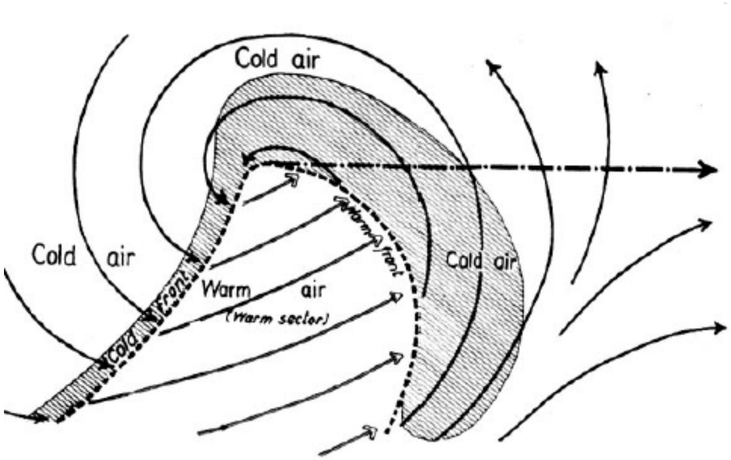


How may the storm tracks change as the troposphere becomes warmer and wetter, the stratosphere becomes cooler, and the cryosphere shrinks ?

A long history of storm tracks studies

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

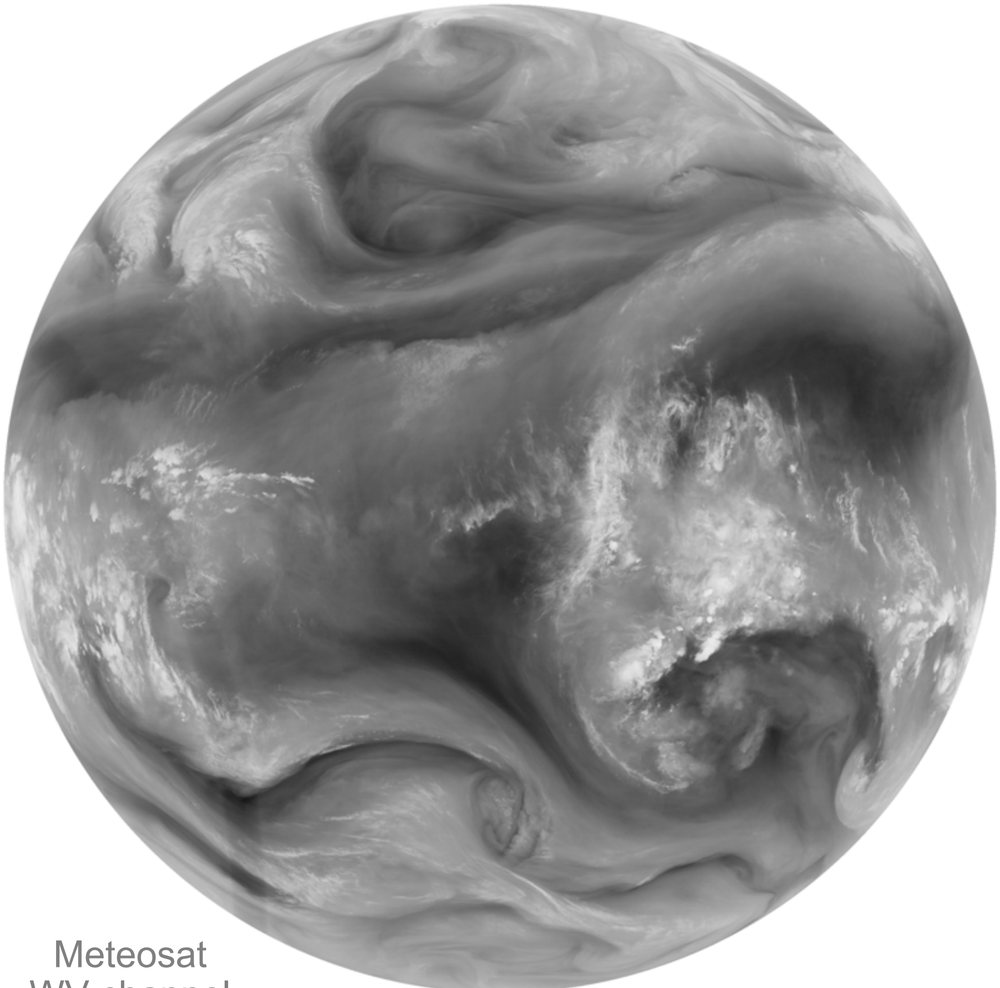




Bjerknes 1922

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 ?

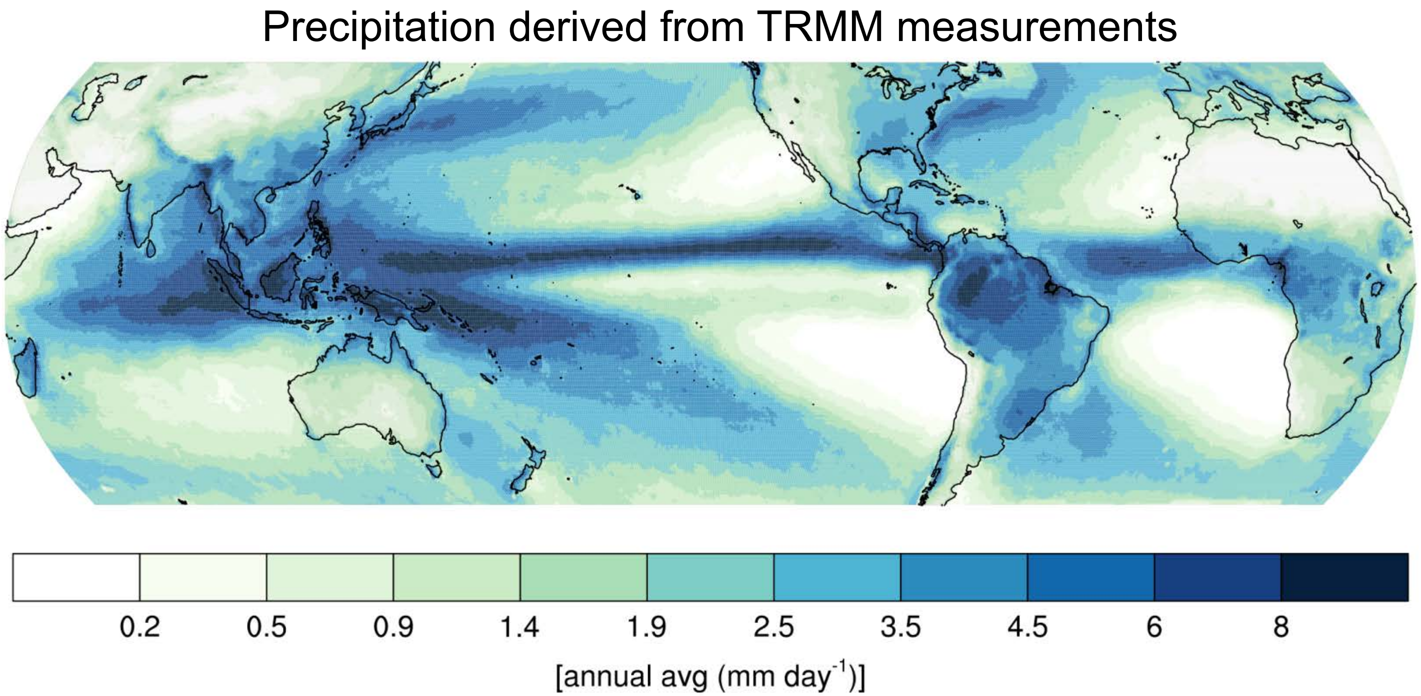
Persistent biases in the simulation of storm tracks (position of the jets, blockings..)
What dependence on model representations of moist, diabatic processes? How do them distort climate projections?

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)

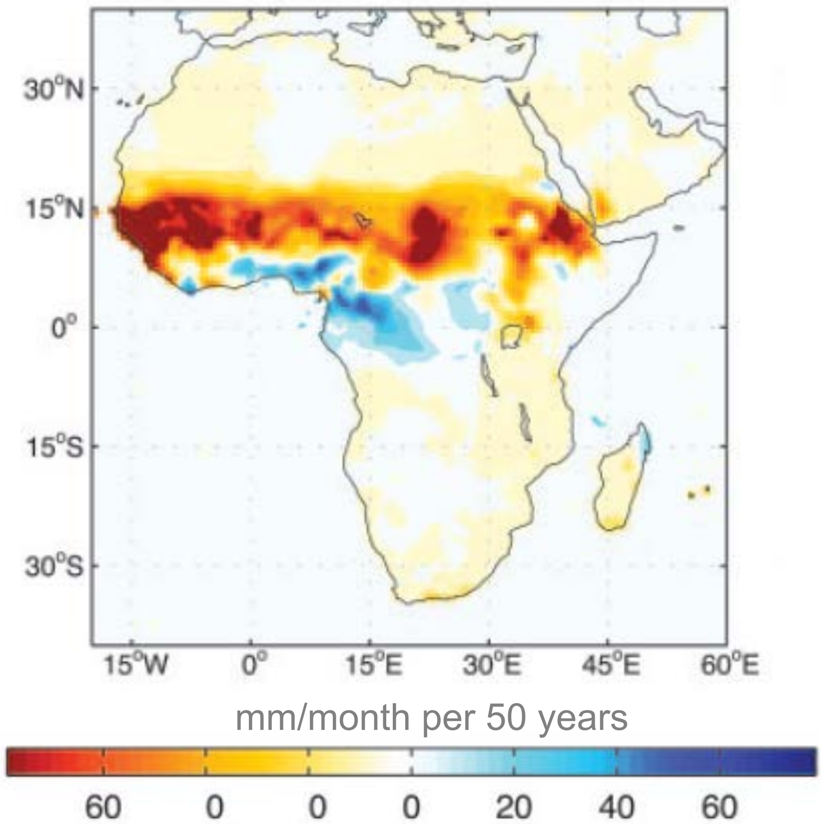
Can we develop dynamical story lines of plausible changes in regional climate and extremes?

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



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

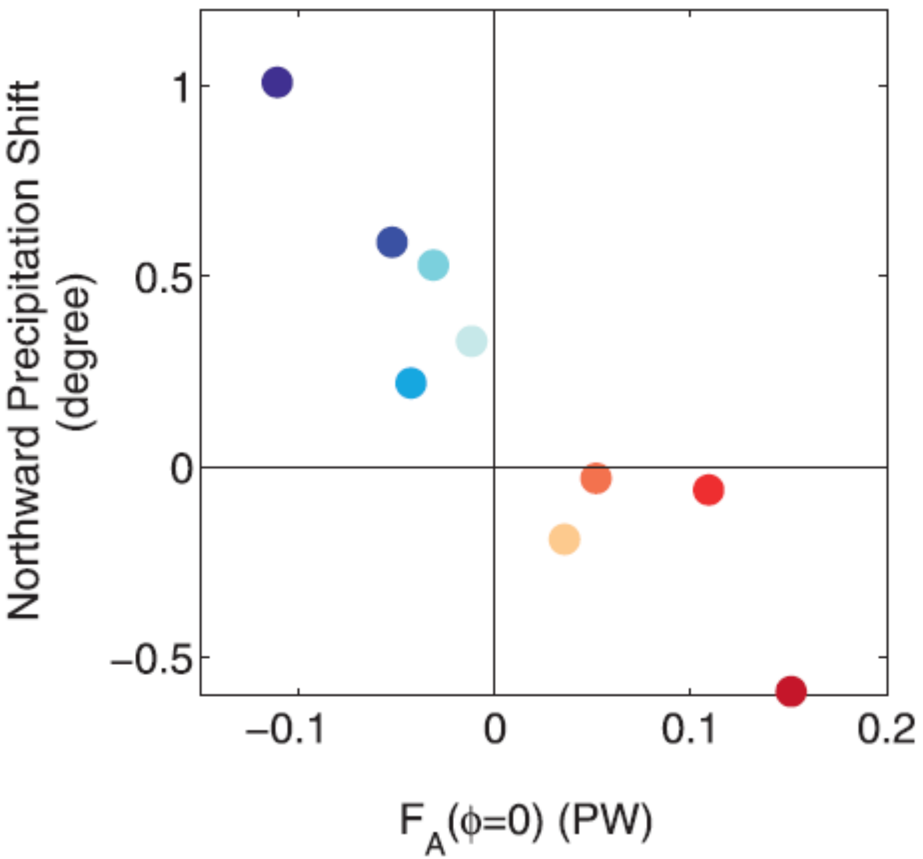
How will convergence zones (ITCZ, monsoons..) respond to anthropogenic forcings (e.g. GHG, aerosols, land use)?

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

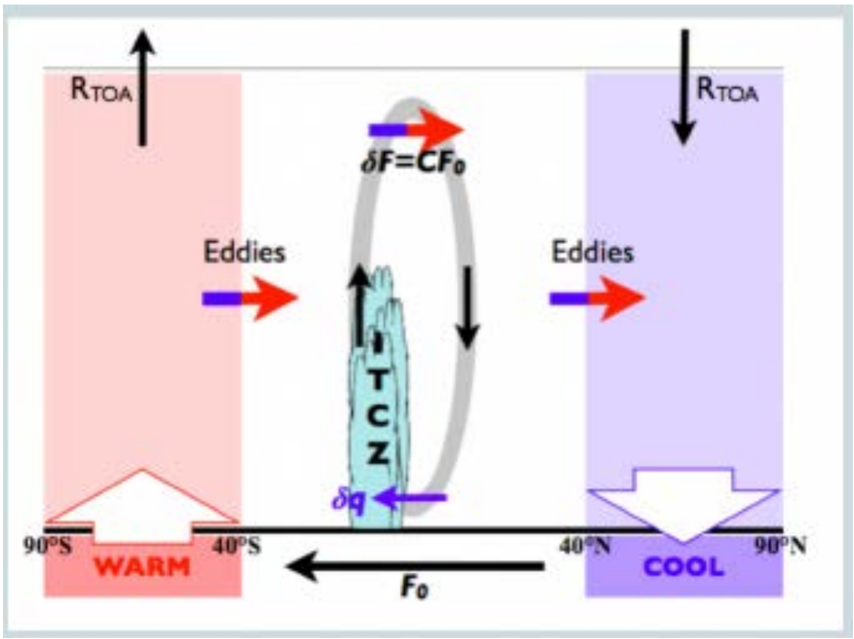
Held et al., PNAS, 2005

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

Energetic frameworks are being developed to interpret ITCZ shifts



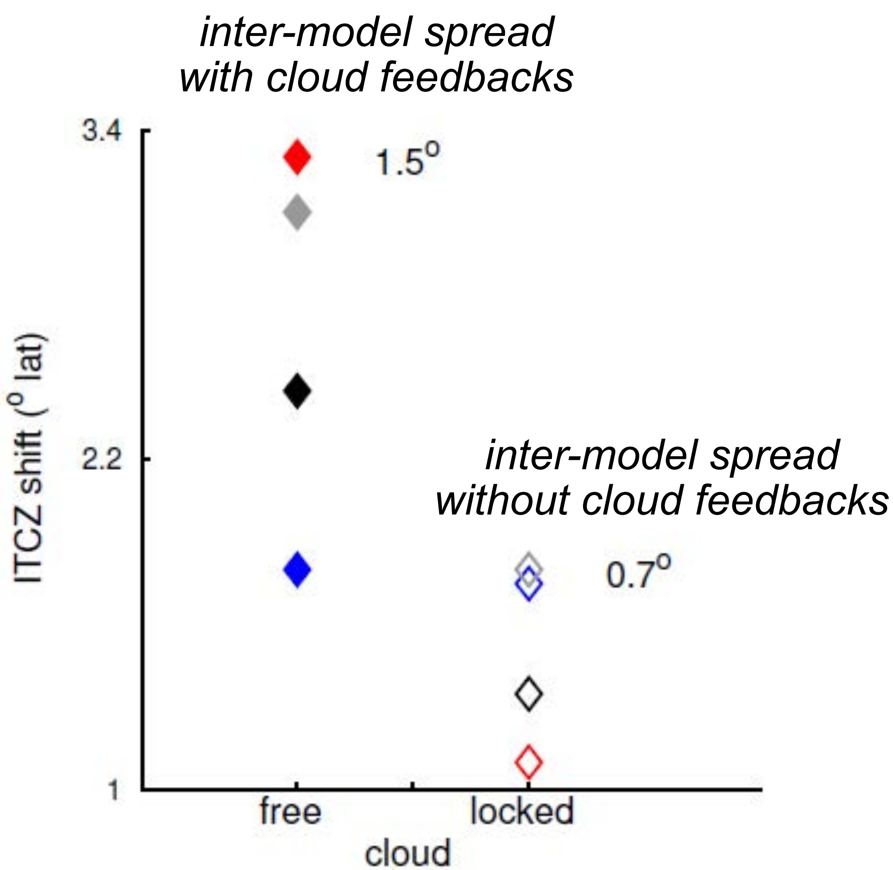
equatorial inter-hemispheric energy transport



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 ?

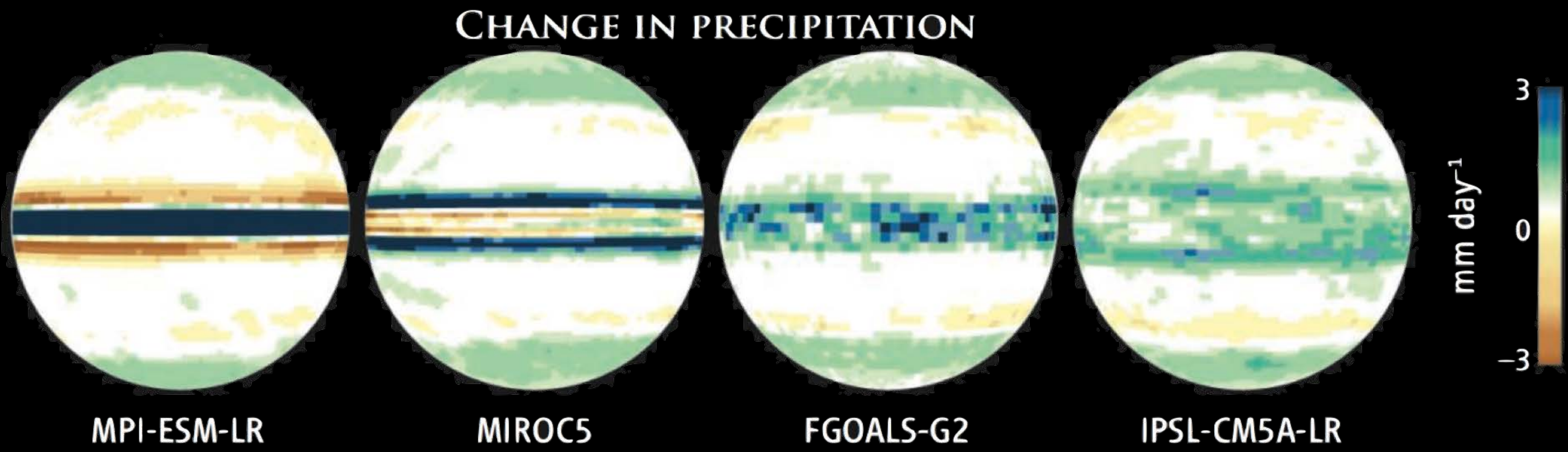
Increasing evidence that the magnitude of ITCZ shifts depend on cloud processes



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 ?

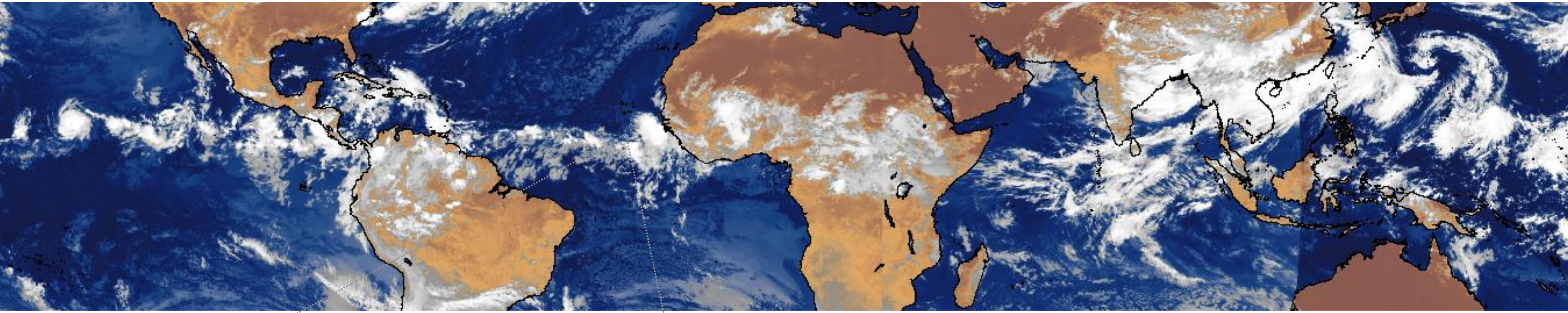


In simple aqua-planet configuration (CMIP5) : large inter-model differences in the position of tropical convergence zones (present-day climate & response to +4K)

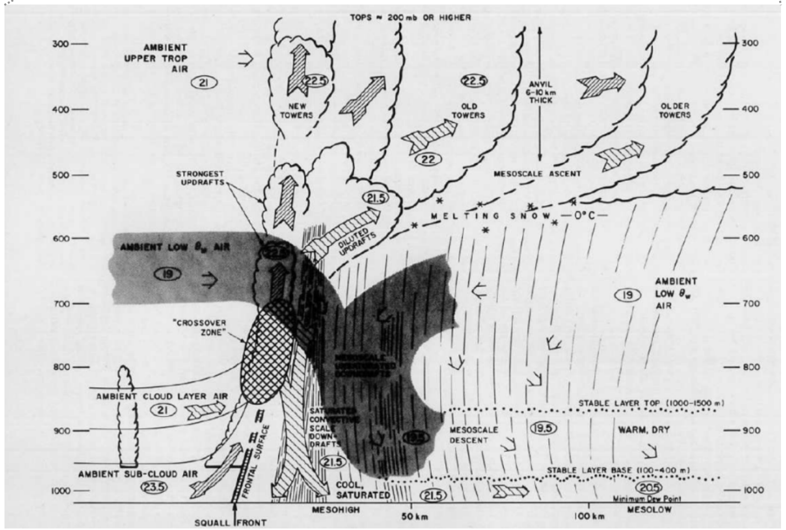
We have to understand this, as it is relevant to regional climate changes

Stevens & Bony, Science, 2013

Q3: Is convective aggregation important for climate ?



SATMOS



Zipser 1977

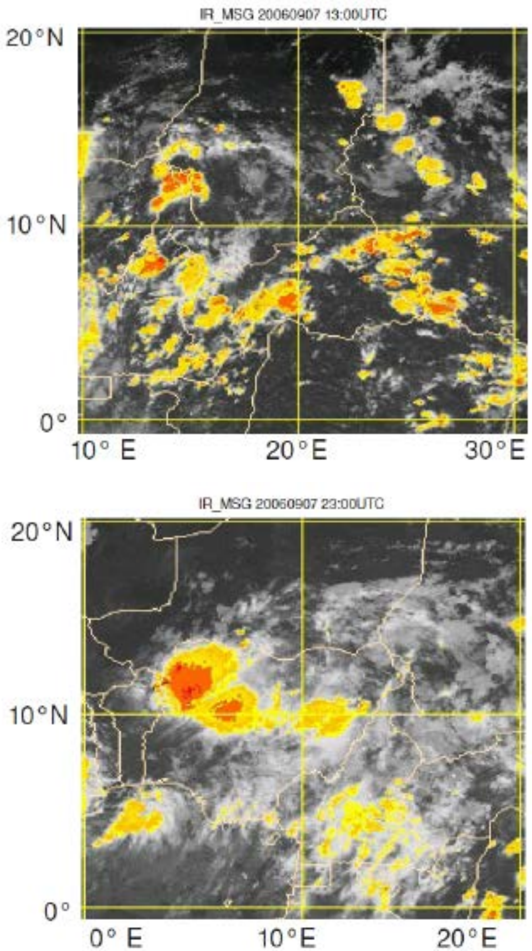
Convective aggregation / organization
has long been studied at the process level,
related to the variability of weather and
to the occurrence of extreme rainfall events.

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

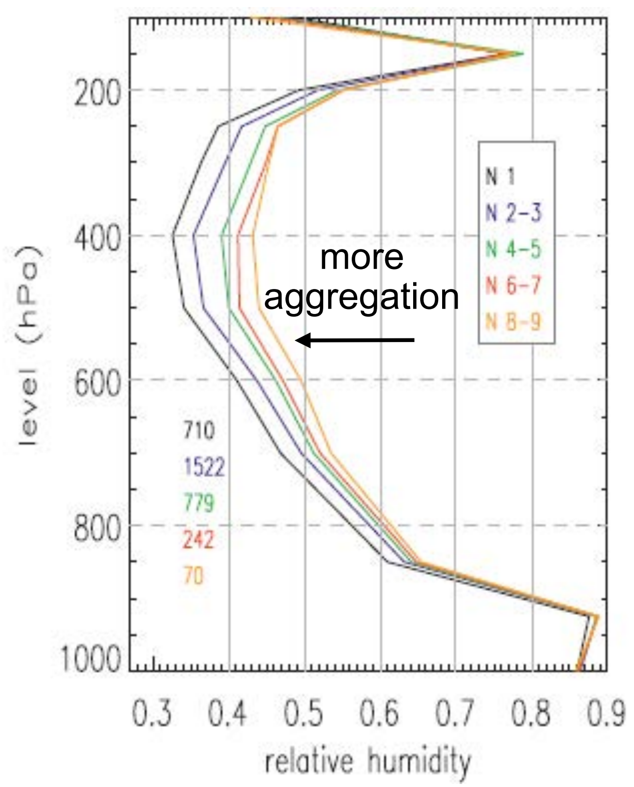
Q3: Is convective aggregation important for climate ?

Does convective aggregation affect the mean climate state ?

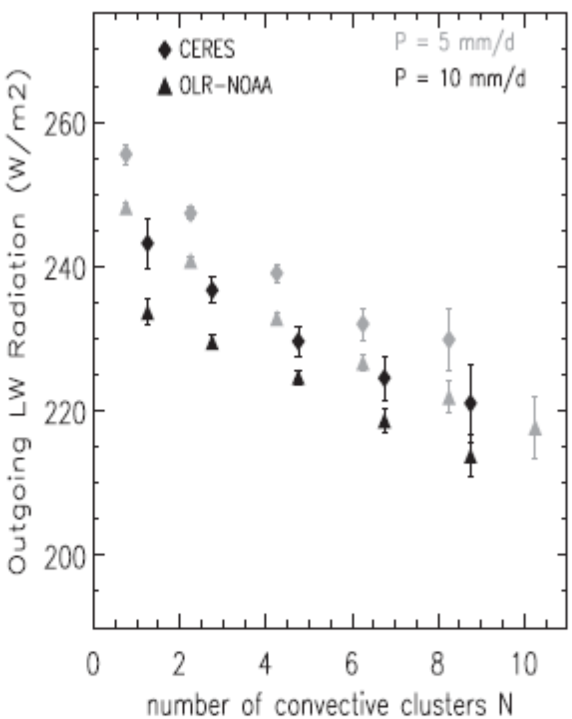
Numerical and observational studies suggest so...



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



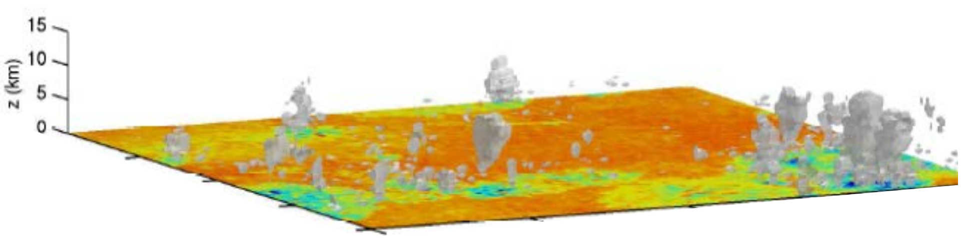
more efficient at radiating
heat to space
(OLR, CERES data)



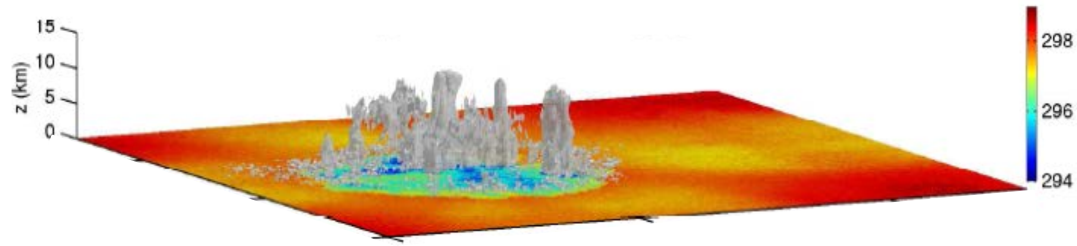
Tobin, Bony & Roca, J. Climate 2012
Tobin et al., JAMES, 2013

Q3: Is convective aggregation important for climate ?

Does convective aggregation matter for Climate Sensitivity ?



low SST



high SST

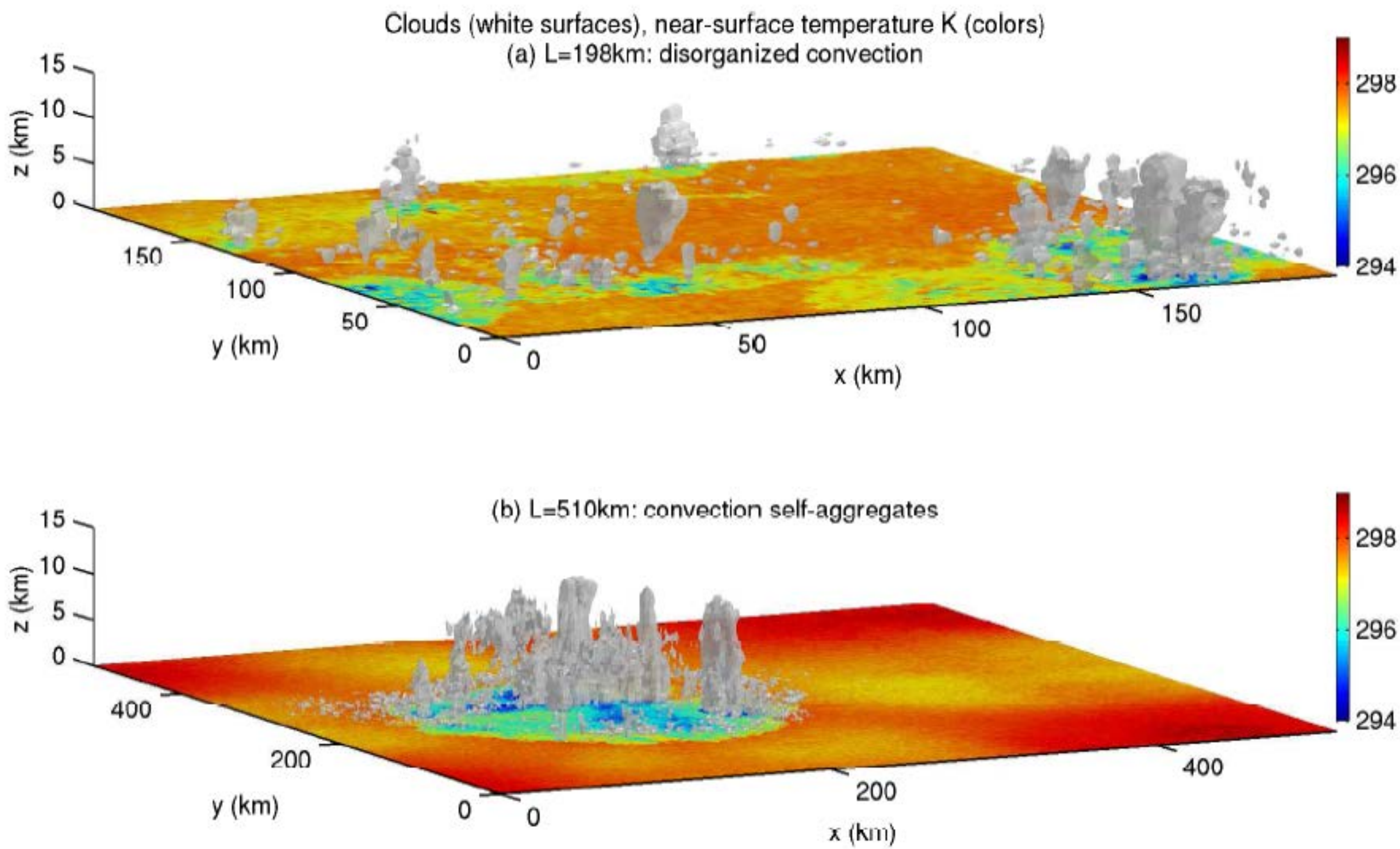
Models suggest an easier occurrence of convective aggregation at high temperatures → Atmospheric drying and enhanced OLR → Negative feedback on Climate Sensitivity?

- **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 ?

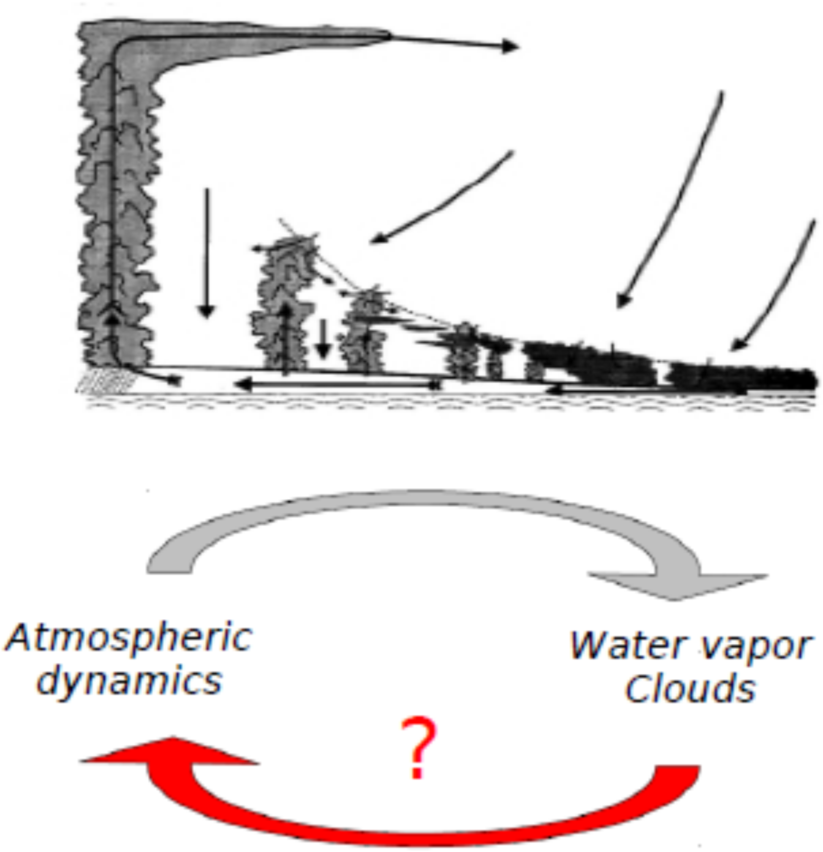
Numerical studies show that even in the absence of external drivers (*e.g.* rotation, shear),
convection can aggregate spontaneously : "self-aggregation".



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 ?

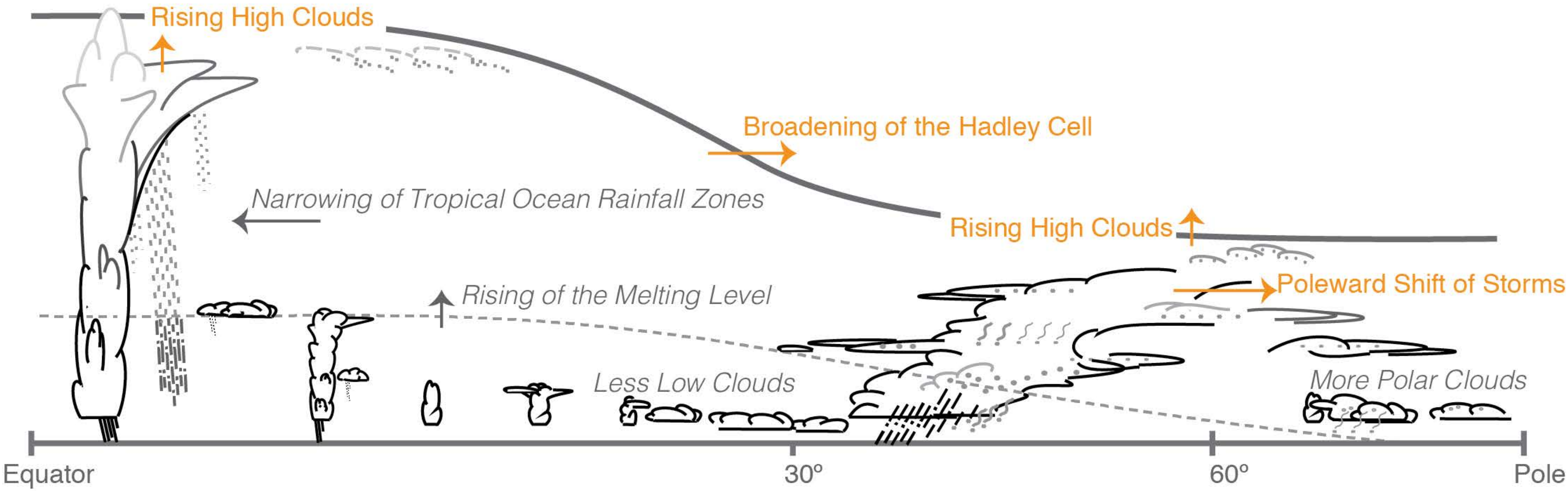
- Has the role of external drivers in tropical circulations been over-emphasized ?
- Are phenomena such as the MJO a large-scale manifestation of convective self-aggregation ?

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 HALO)

Q4: How does convection contribute to cloud feedbacks?

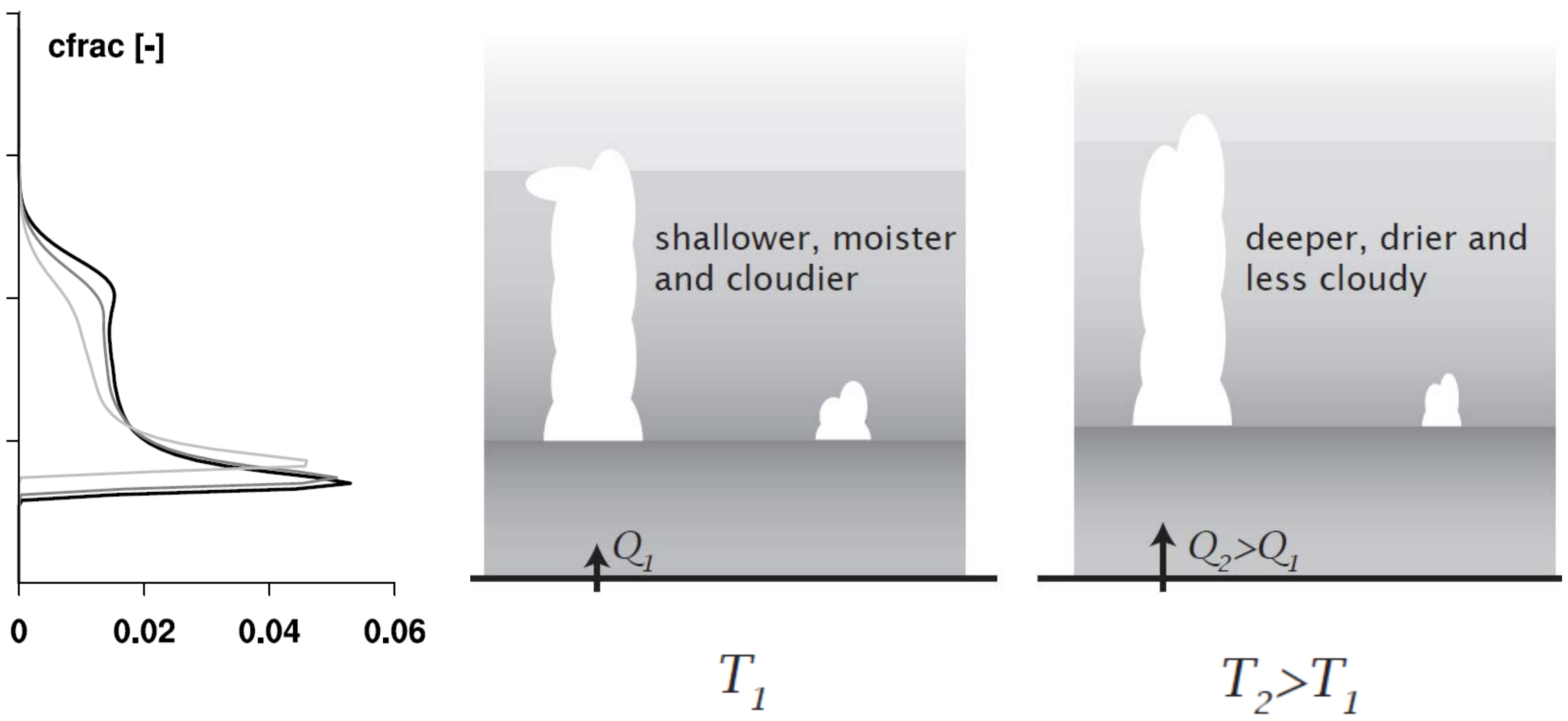


IPCC 2013
Fig. 7.11

- 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.
- Most of the inter-model spread in climate sensitivity results from differing low-cloud feedbacks.

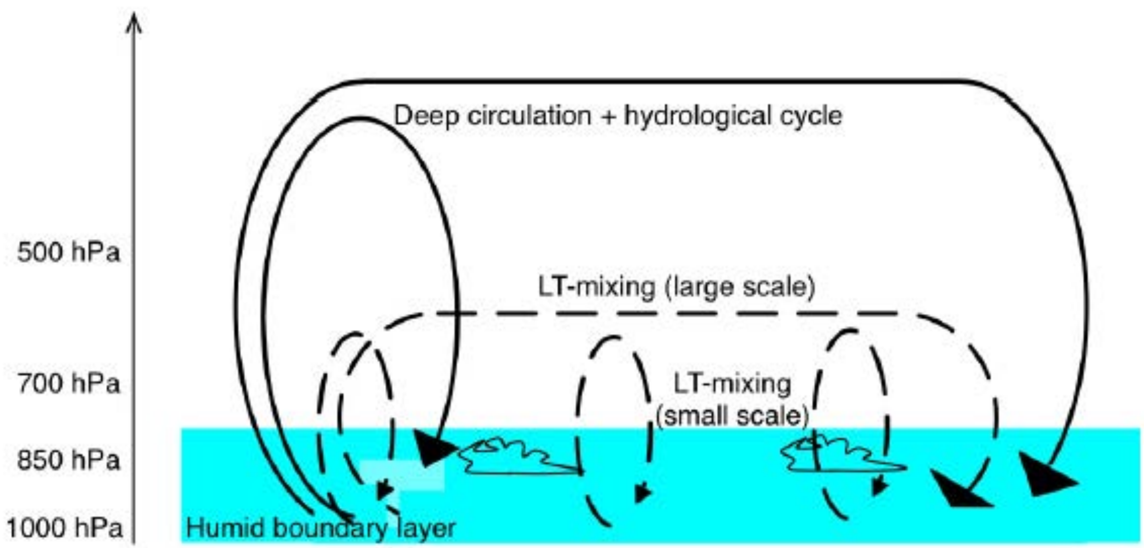
Q4: How does convection contribute to cloud feedbacks?

Very-high resolution process models (LES) suggest that in a warmer climate, enhanced mixing by shallow convection dehydrates the boundary-layer and reduces the low-level cloud cover.

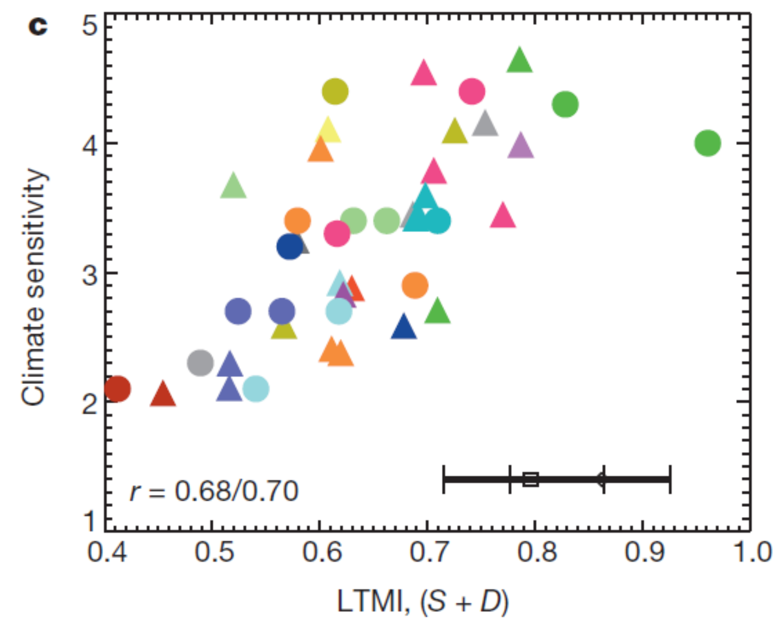


Rieck, Nuijens and Stevens, JAS, 2012

Q4: How does convection contribute to cloud feedbacks?



Climate Sensitivity vs
mixing strength in present-day climate



- Mechanism potentially explaining widespread positive low-cloud feedback in GCMs
- Transport of water vapour out of the low-cloud layer by shallow circulations intensifies in warmer atmosphere
- Suggests that models with more shallow circulation have higher sensitivity

Sherwood, Bony & Dufresne, Nature, 2014

Q4: How does convection contribute to cloud feedbacks?

Many questions remain:

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

Can paleoclimates help us constrain cloud feedbacks and sensitivity?

WCRP Grand Challenge on

Clouds, Circulation and Climate Sensitivity

- Current status
- Broad strategic vision
- Articulating science questions
- Opportunities, Implementation & Next steps
- Questions to the JSC

Opportunities

Scientific connections and convergences :

Modeling strategy :

- idealized configurations to bridge large spectrum of models (e.g. theoretical, LES, GCMs)
- design of CMIP6 experiments and outputs

Development of (very) high-resolution models :

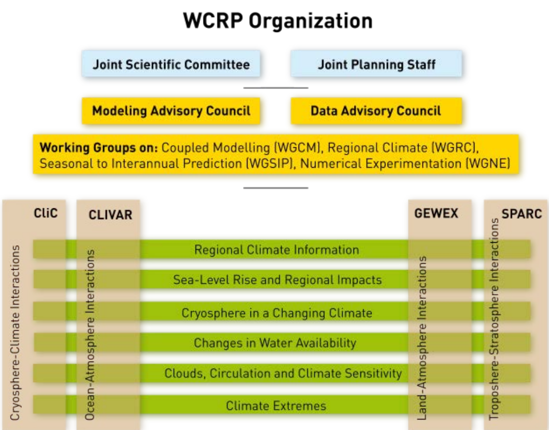
- benchmark calculations
- synergy between climate and weather communities
- short-term forecasts from realistic initial states to help interpret model biases

New / future observations :

- new capabilities offered by active remote sensing (lidars, radars), constellations (A-Train, GPM)
- field experiments related to GC questions (e.g. T-Nawdex)

Implementation

- **We feel a lot of interest for this GC in the community.**
- **We are working to phrase questions in such a way that we can later recognize progress**.
- **Our strategy :**
  - generate momentum, stimulate the field by phrasing questions, and attract young scientists
  - organize (or help organize, or promote) workshops around exciting science questions, write papers
  - connect to existing WCRP activities, strengthen them, and fill gaps
- **Connections to WCRP projects and working groups** [not exhaustive]**:**



Q1 (storm tracks): *SPARC, WGCM (CFMIP, PMIP, CMIP), WGNE, WGSIP, CLIC*

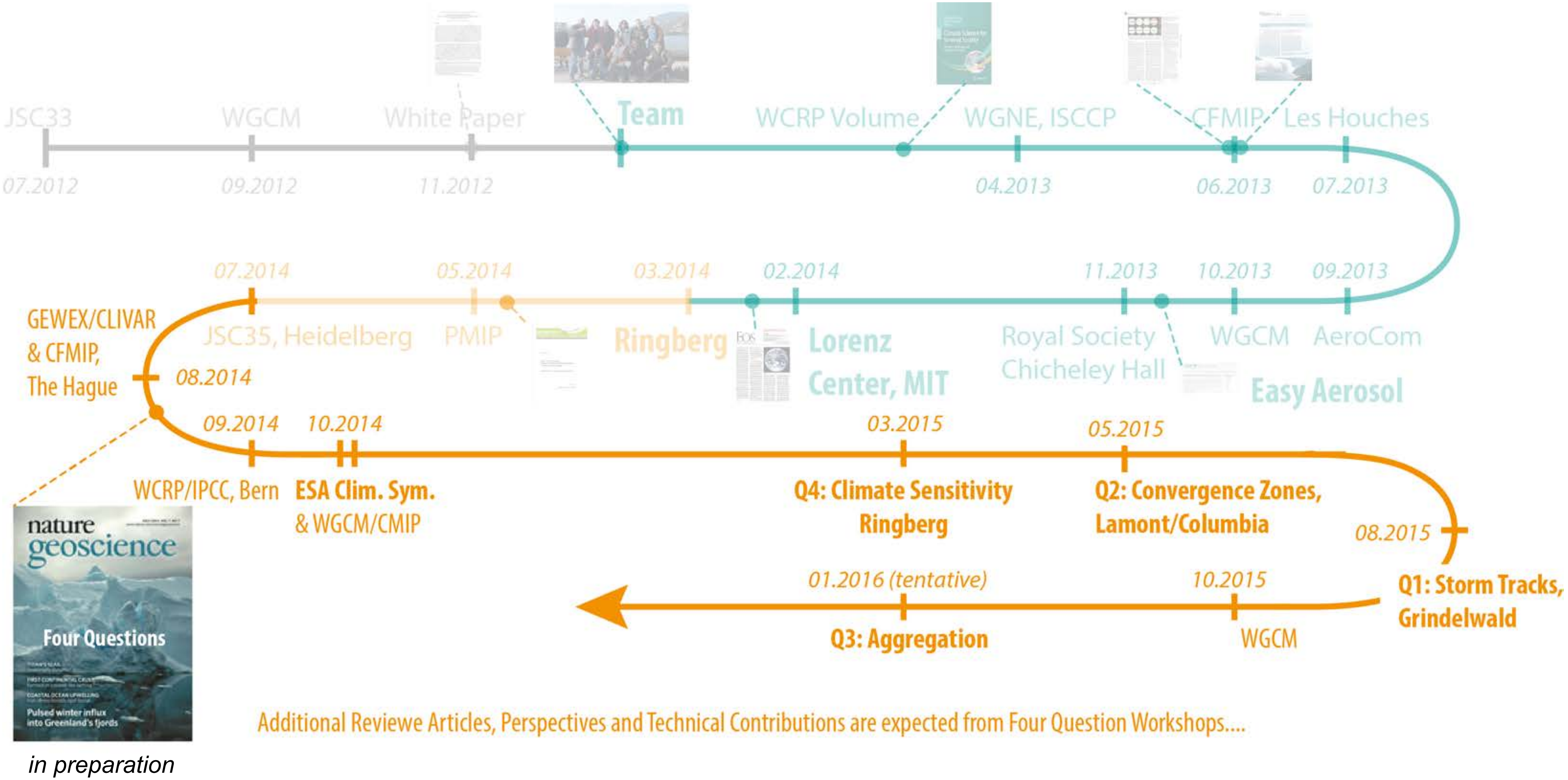
Q2 (convergence zones): *GEWEX, CLIVAR, WGNE, SPARC*

Q3 (convective aggregation): *GEWEX, CLIVAR, WGCM (CFMIP), WGNE*

Q4 (cloud feedbacks): *WGCM (CFMIP, PMIP, CMIP), GEWEX (GASS), WGNE*

We hope that the core projects and WGs will feed off the energy generated by this GC,
will explore ways of contributing to answering the four questions of this GC.

Next Steps


JSC33
WGCM
White Paper
Team
WCRP Volume
WGNE, ISCCP
CFMIP
Les Houches
07.2012
09.2012
11.2012
04.2013
06.2013
07.2013
07.2014
05.2014
03.2014
02.2014
11.2013
10.2013
09.2013
GEWEX/CLIVAR & CFMIP, The Hague
JSC35, Heidelberg
PMIP
Ringberg
Lorenz Center, MIT
Royal Society Chicheley Hall
WGCM
AeroCom
Easy Aerosol
08.2014
09.2014
10.2014
03.2015
05.2015
WCRP/IPCC, Bern
ESA Clim. Sym. & WGCM/CMIP
Q4: Climate Sensitivity Ringberg
Q2: Convergence Zones, Lamont/Columbia
08.2015
Q1: Storm Tracks, Grindelwald
01.2016 (tentative)
10.2015
Q3: Aggregation
WGCM
nature geoscience
Four Questions
Pulsed winter influx into Greenland's fjords
in preparation
Additional Reviewe Articles, Perspectives and Technical Contributions are expected from Four Question Workshops....

Should help address some of the key uncertainties highlighted by IPCC assessments

Especially :

- **Assess cloud feedbacks and Climate Sensitivity**

  A fundamental scaling factor of global and regional climate changes; Long-standing uncertainty

- **Understand changing patterns of temperature and precipitation in a changing climate**

  A first-order control on regional climate changes, air quality and biogeochemical feedbacks

  Most reported impacts of climate change are attributed to warming and/or to shifts in precipitation patterns. -- WGII AR5 TS

- **Identify robust climate responses to anthropogenic forcings**

  Including the impact of GHG and aerosol radiative forcings on 20C and 21C climates

- **Improve the predictive capabilities of models on all time scales, linking weather to climate**

  Including extreme events, regional features (monsoons, ITCZ), modes of natural variability

To the JSC

- **Retain focus on Grand Challenges !**

- **Thank you for supporting our workshops**

- **Communication to the stakeholders and funding agencies :**

need to explain why basic research is so crucial for advancing policy & societal issues

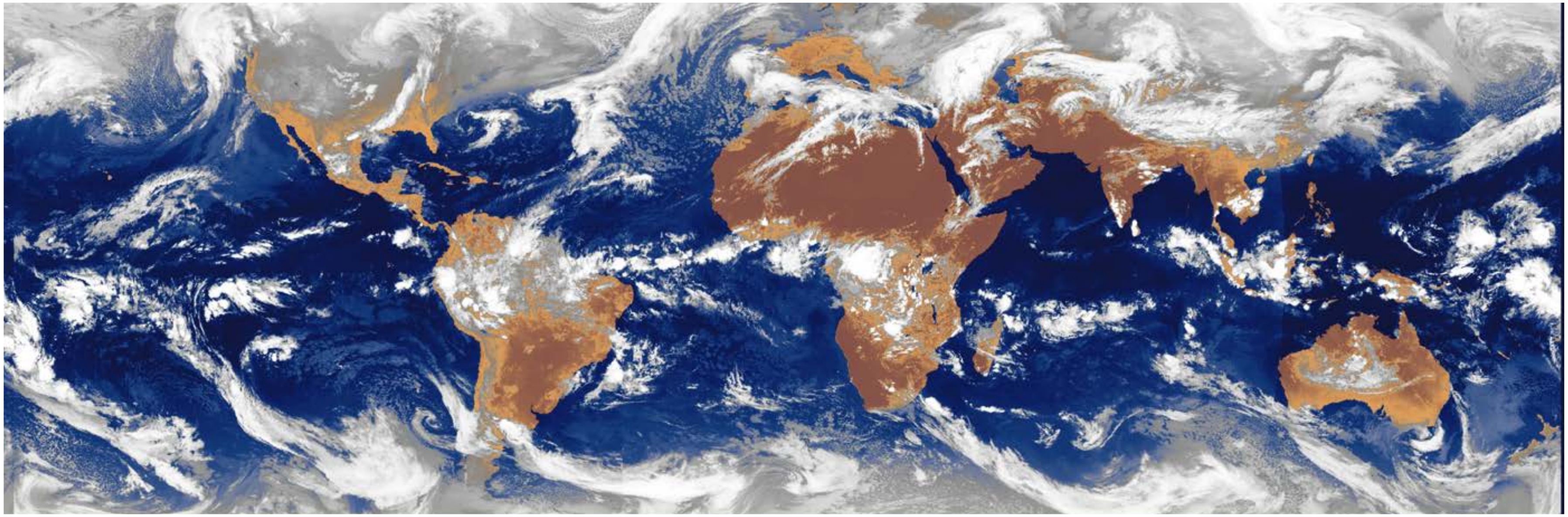
- **Time to think of a major WCRP field experiment for 2020-2022?**

focusing on one or two tropical basins for a period of two years

- **Should WCRP think of organizing scientific assessments?**

to complement and help IPCC assessments

Thank You



http://www.wcrp-climate.org/index.php/gc-clouds

WCRP
World Climate Research Programme