(Ice-)Clouds, Circulation and Climate Sensitivity

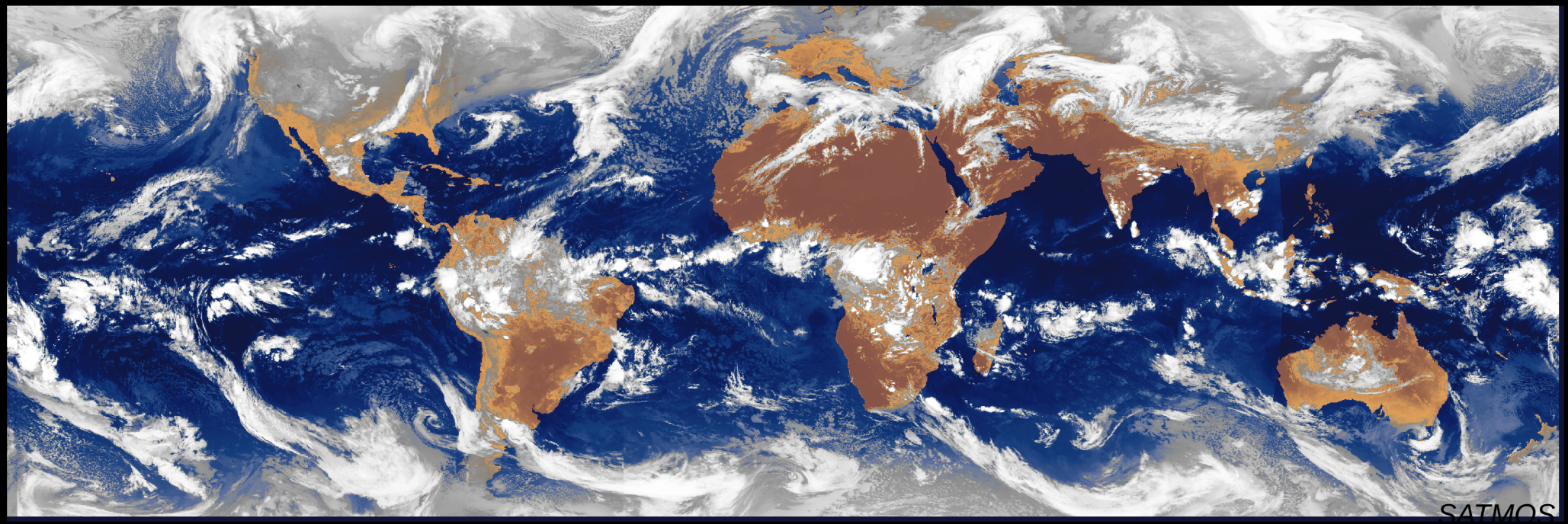
Sandrine Bony
(LMD/IPSL, CNRS, Paris)

in collaboration with many people,
especially Bjorn Stevens (MPI-M, Hamburg)

ISMAR workshop, Observatoire de Paris, 28 Sept 2015

Clouds, Circulation and Climate Sensitivity

Our inability to provide robust assessments of global and regional climate changes
stems to a large extent from our limited understanding of
how clouds, circulation and climate interact



A WCRP Grand Challenge

Emerged after 2 years of community consultation

Culminating in a workshop (Stevens et al., *WCRP report,* 2014)

Presented in a Perspective paper (Bony et al., *Nature Geosci*., 2015)

Clouds, Circulation and Climate Sensitivity

1

What role does convection play in cloud feedbacks?

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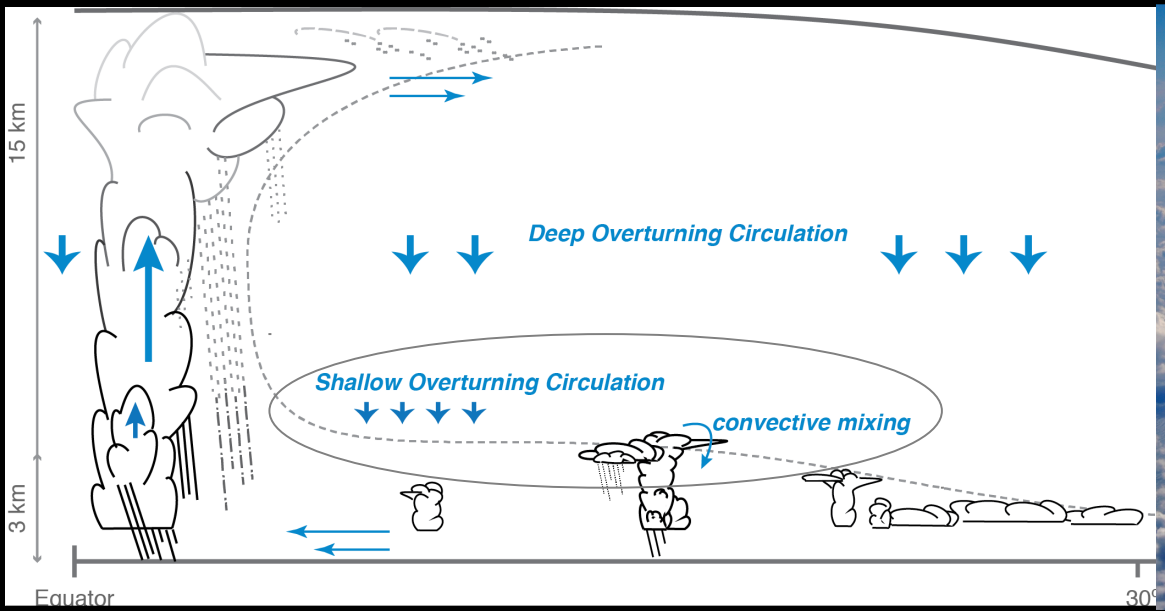
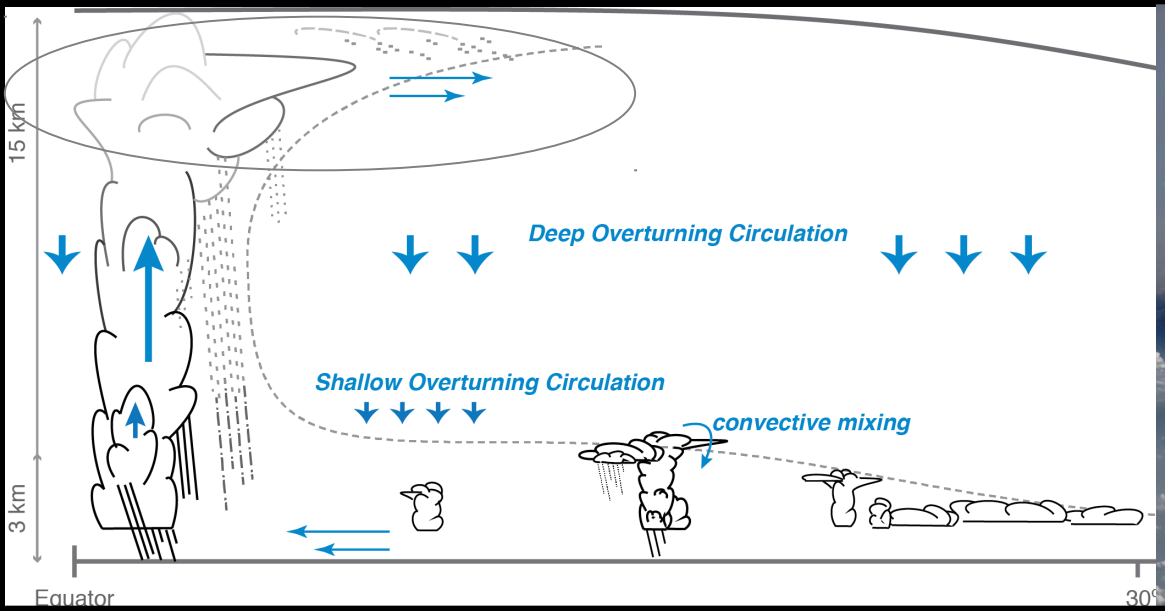


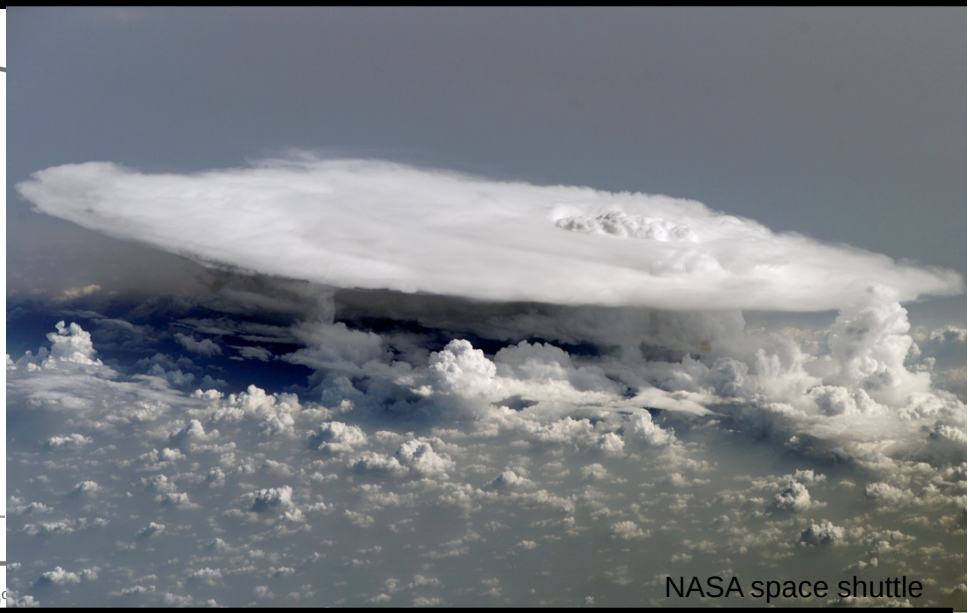

Bony et al. *Nature Geosci.* (2015)

- Most of the inter-model spread in climate sensitivity results from differing low-cloud feedbacks
- Several ideas of cloud-feedback mechanisms have emerged from multiple lines of evidence, and these are leading to hypotheses and story lines which are leading themselves to observational tests (*e.g.* EUREC^{4}A campaign).
- Several of these mechanisms are intimately tied to convection.

Bony et al., Nature Geosci., 2015
Brient and Bony, Clim. Dyn., 2013
Sherwood et al., Nature, 2014
Stevens et al., BAMS, 2015

What role does convection play in cloud feedbacks?





- The impact of climate change on upper-level clouds remains uncertain
- What controls the upper-level cloud amount? Iris effect? Impact on cloud feedbacks?
- Remains an area of investigation...

Bony et al., Nature Geosci., 2015
Mauritsen and Stevens, Nature Geosci., 2014

2

What role does convective aggregation play in climate?

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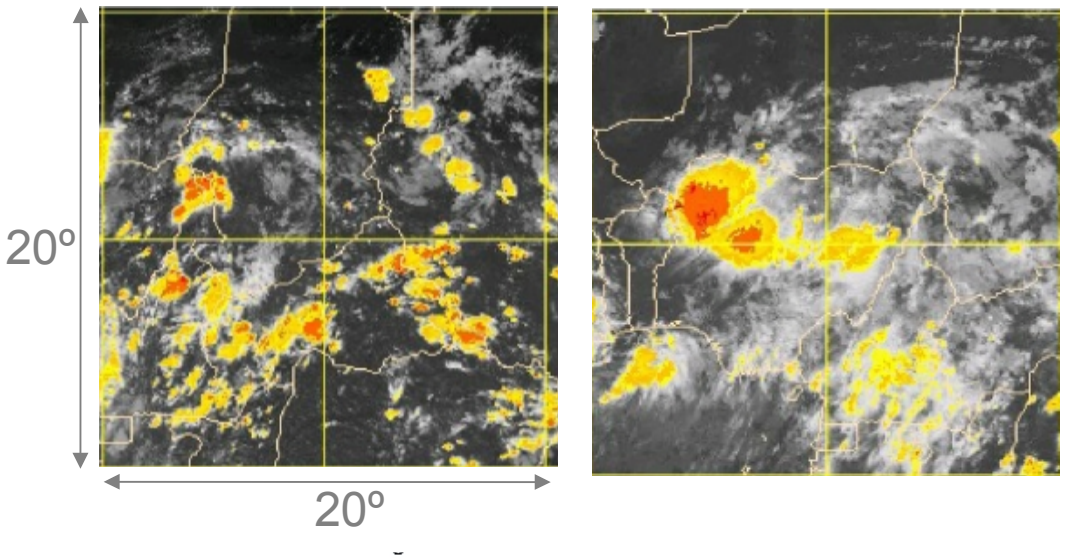
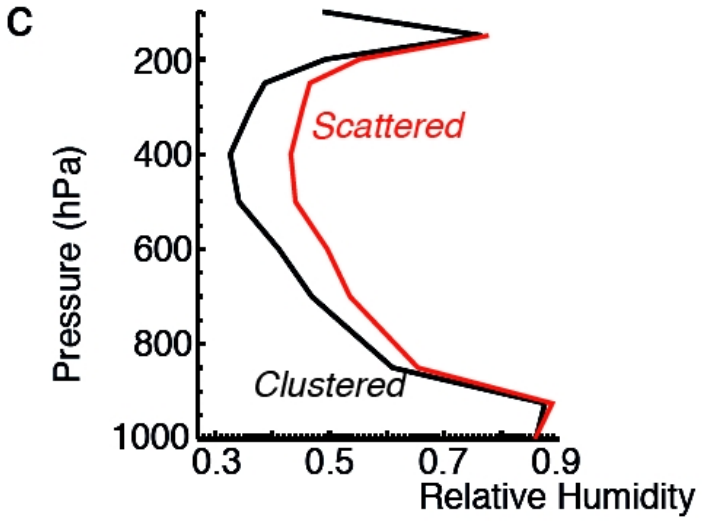


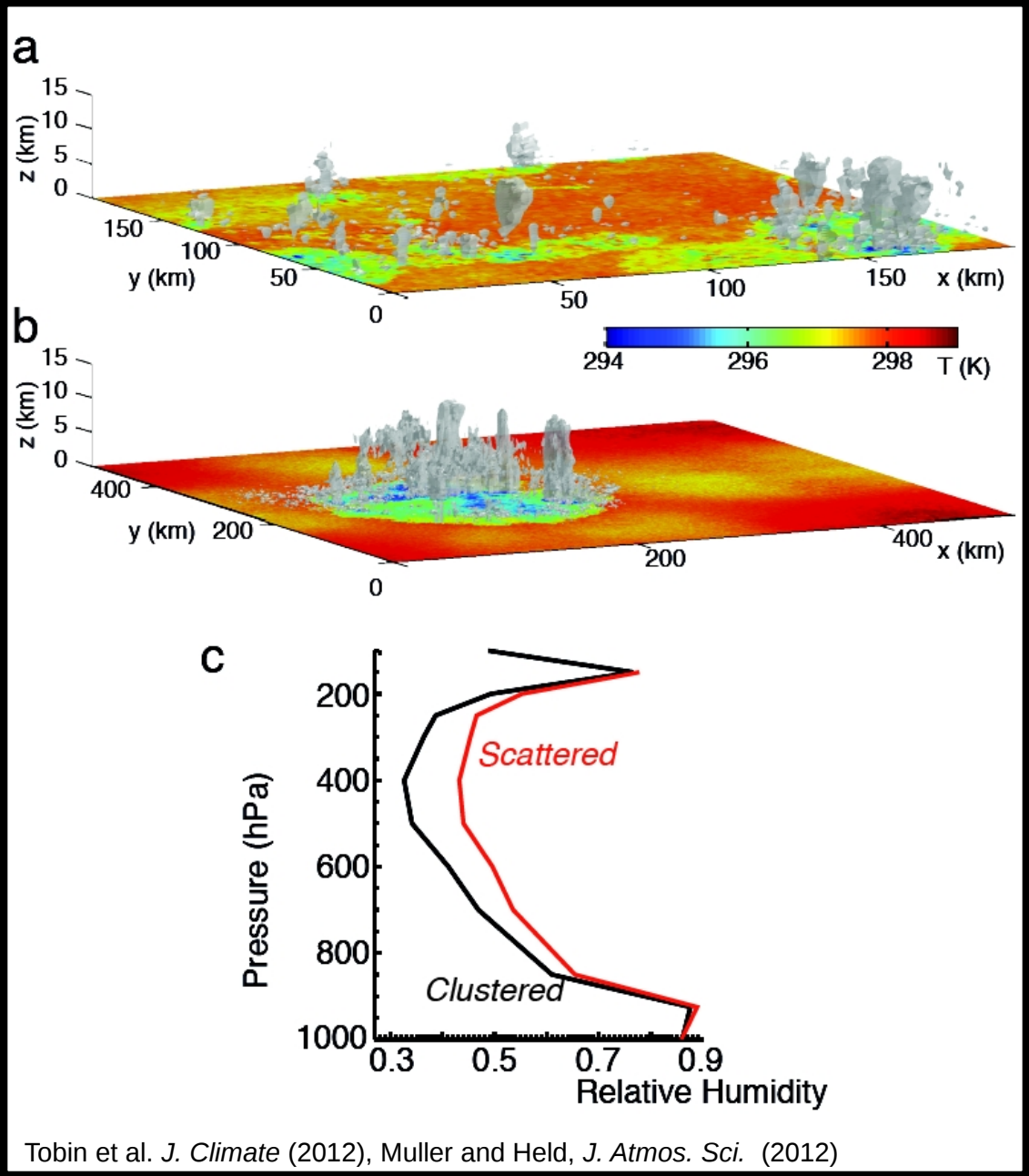


Tobin et al. *J. Climate* (2012)

- Wide range of convective organizations
- Matters for weather and extreme events
- Does it matter also for climate?

Observations and models suggest that the troposphere is drier, clearer, and more efficient at radiating heat to space when convection is clustered

What role does convective aggregation play in climate?



Tobin et al. *J. Climate* (2012), Muller and Held, *J. Atmos. Sci.* (2012)

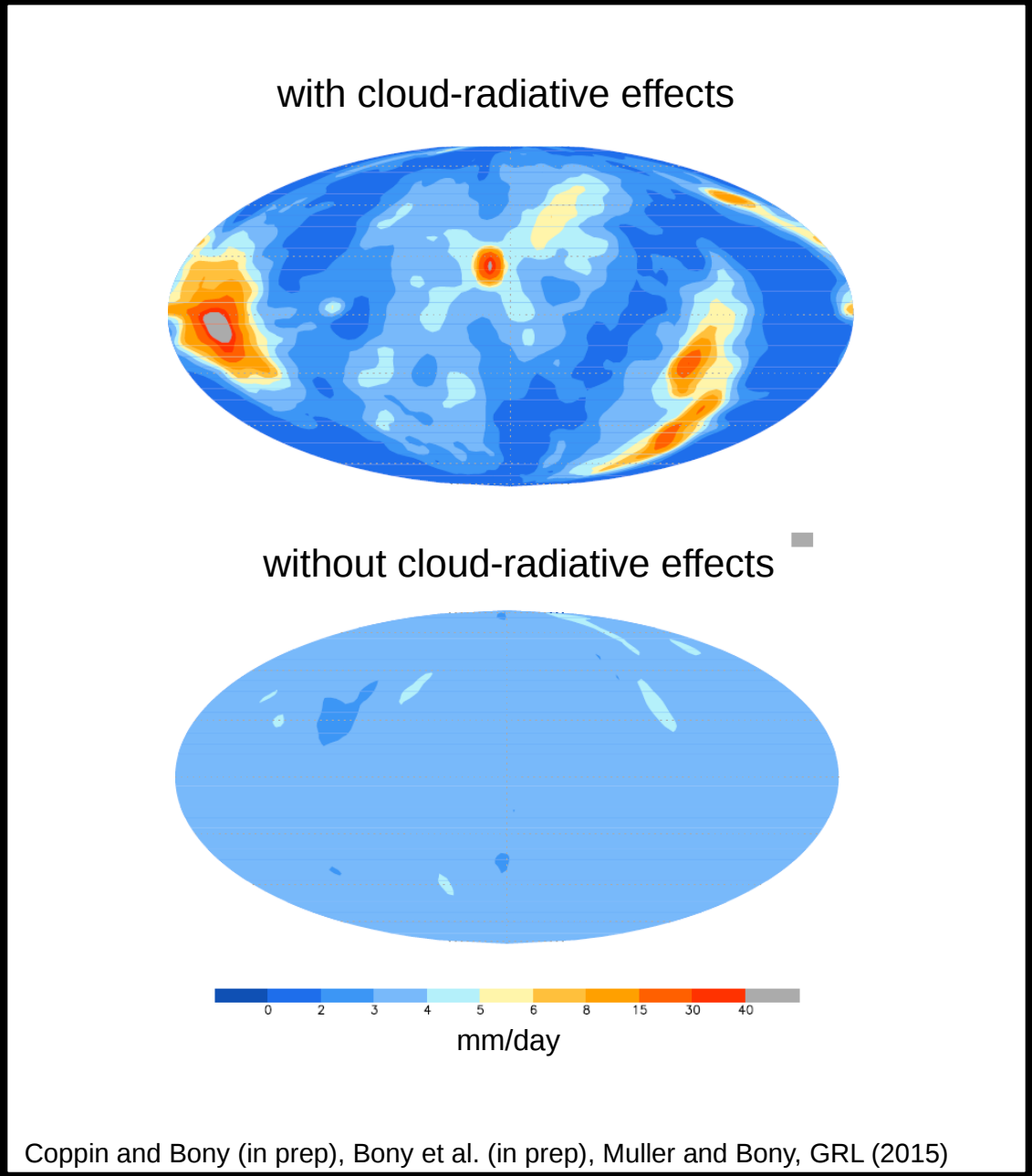
What are the physical processes leading to convective aggregation?

including in the absence of external drivers (self-aggregation)

Does convective aggregation increase with temperature? (as models suggest)

and if so, how does it affect climate sensitivity? circulation?

What role does convective aggregation play in climate?



Coppin and Bony (in prep), Bony et al. (in prep), Muller and Bony, GRL (2015)

In GCMs like in CRMs,
cloud radiative effects play a
critical role in the triggering and
maintenance of convective aggregation

3

What controls the position, strength and variability of tropical rain belts?

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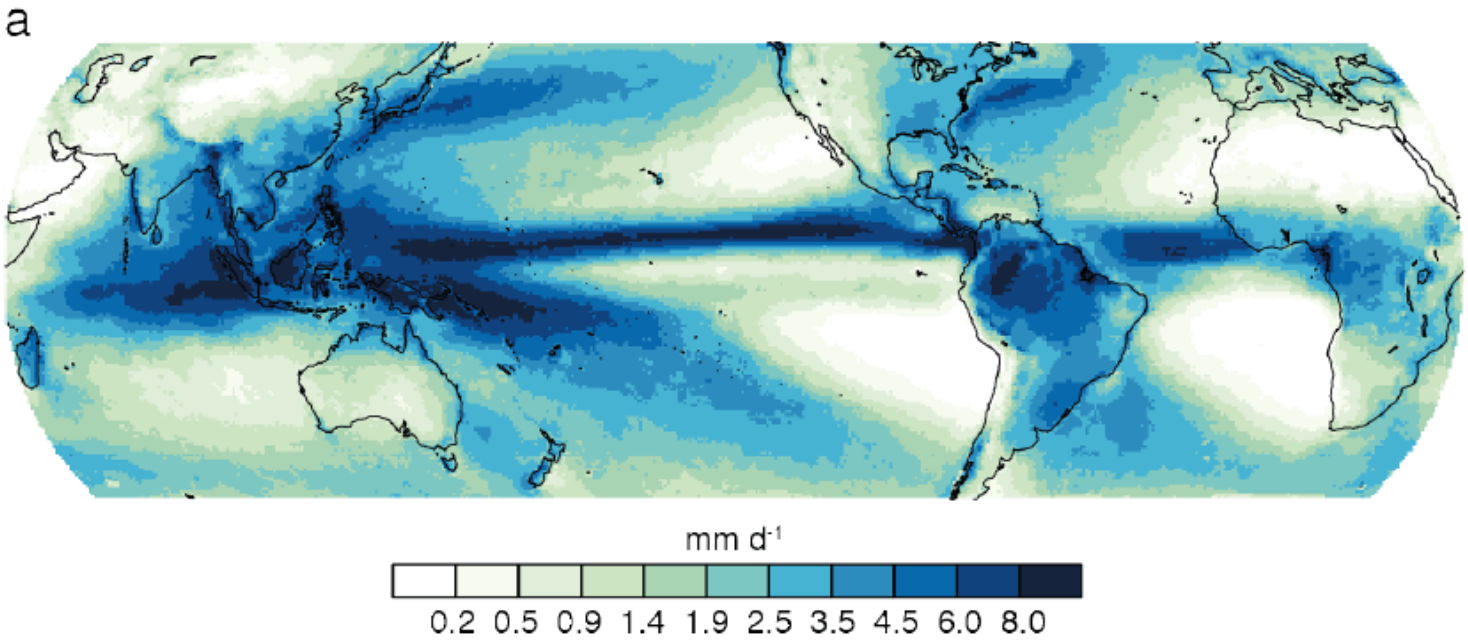
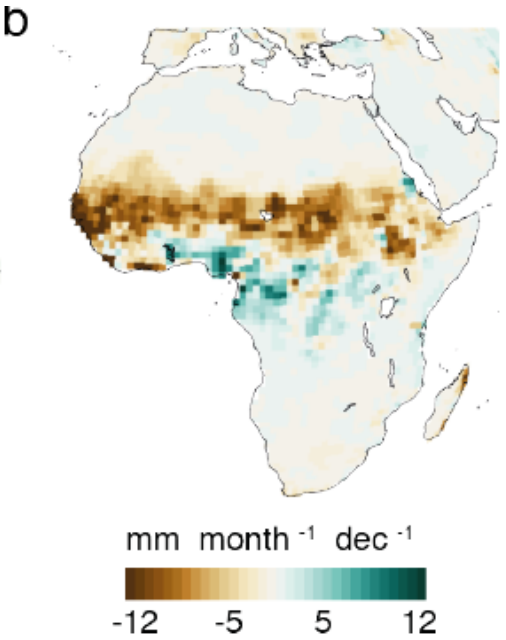
Present-day distribution of tropical precipitation



Observed rainfall trends from 1950 to 2000

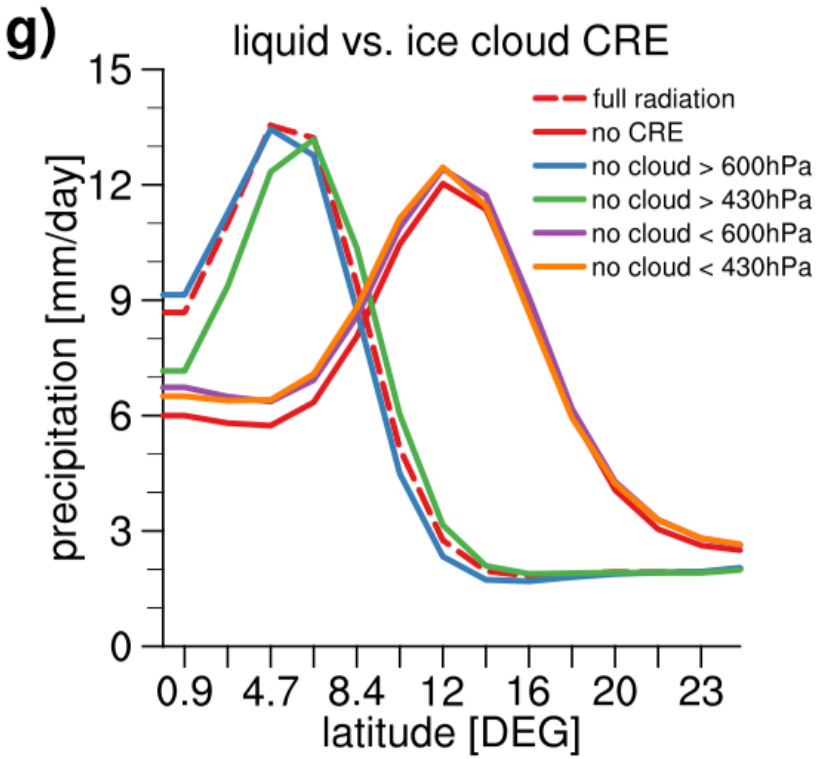


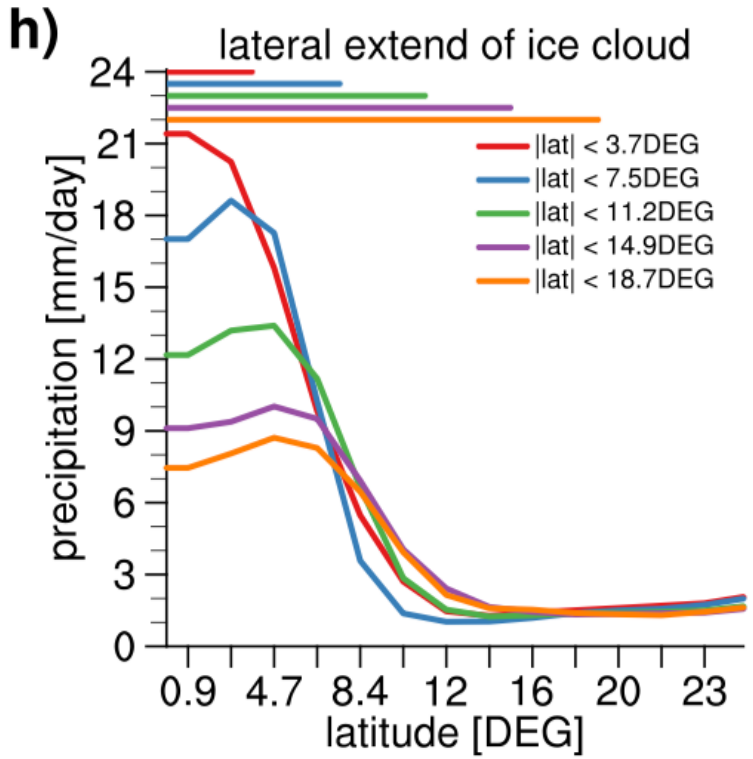
Shifts of rain belts responsible for severe droughts (*e.g.* Sahelian drought)

How will the rain belts (ITCZ, monsoons..) respond to anthropogenic forcings?

Held et al., PNAS (2005); Bony et al. *Nature Geosci.,* (2015)

What controls the position, strength and variability of tropical rain belts?

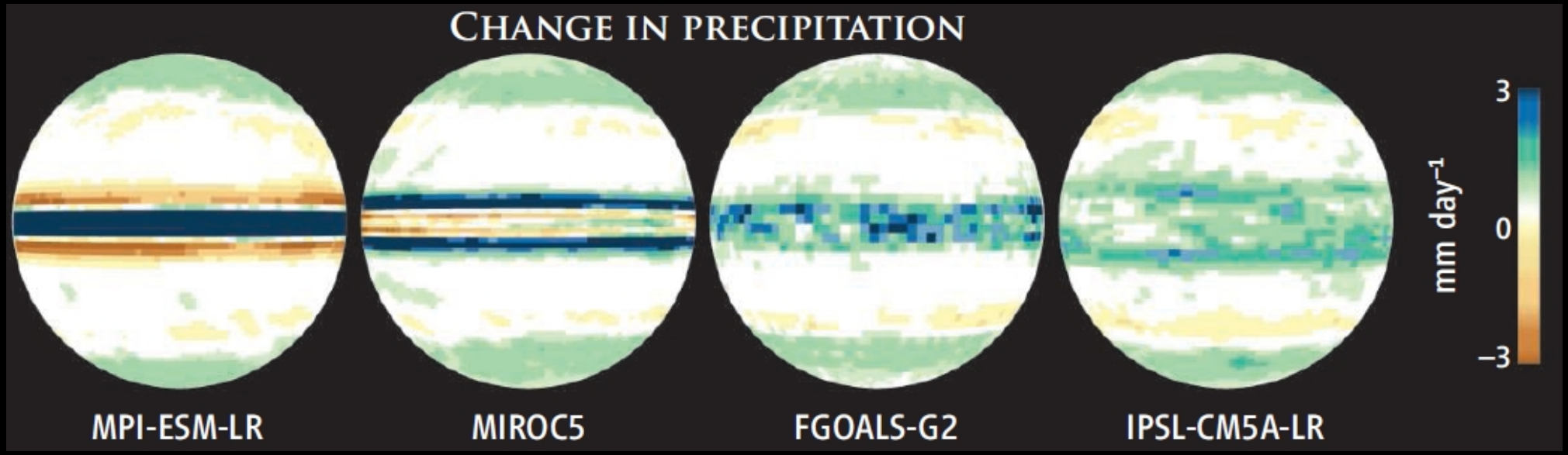




Ice clouds influence very strongly the structure and the amplitude of the ITCZ

Mobis and Stevens (in prep)

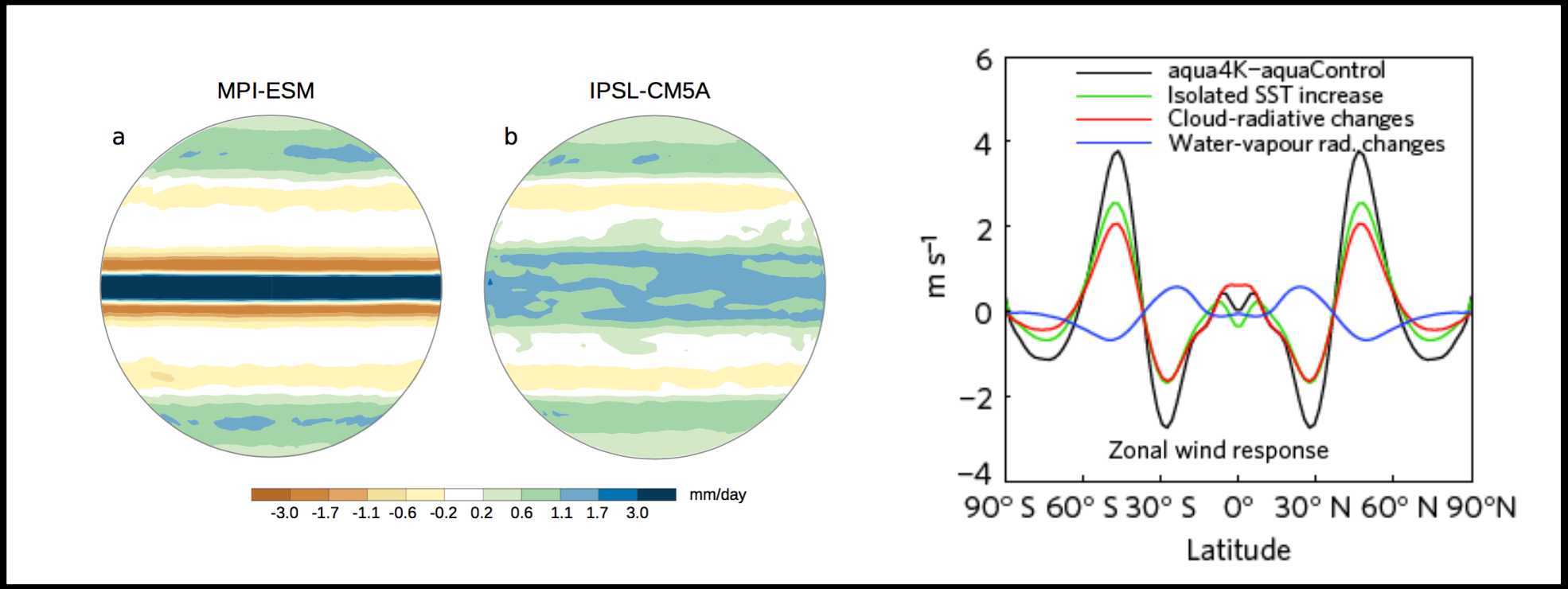
Response of tropical convergence zones to global warming (CMIP5 aqua-planet experiments, +4K)



In models: the position of the ITCZ, its shifts and its response to global warming strongly depend on the representation of cloud processes (e.g. convection, cloud-radiative effects)

Stevens and Bony, *Science*, 2013

Response of tropical convergence zones to global warming (CMIP5 aqua-planet experiments, +4K)



- Cloud changes amplify a poleward shift of the extratropical jet, whereas water vapour changes oppose such a shift.; The degree of compensation is model-dependent.

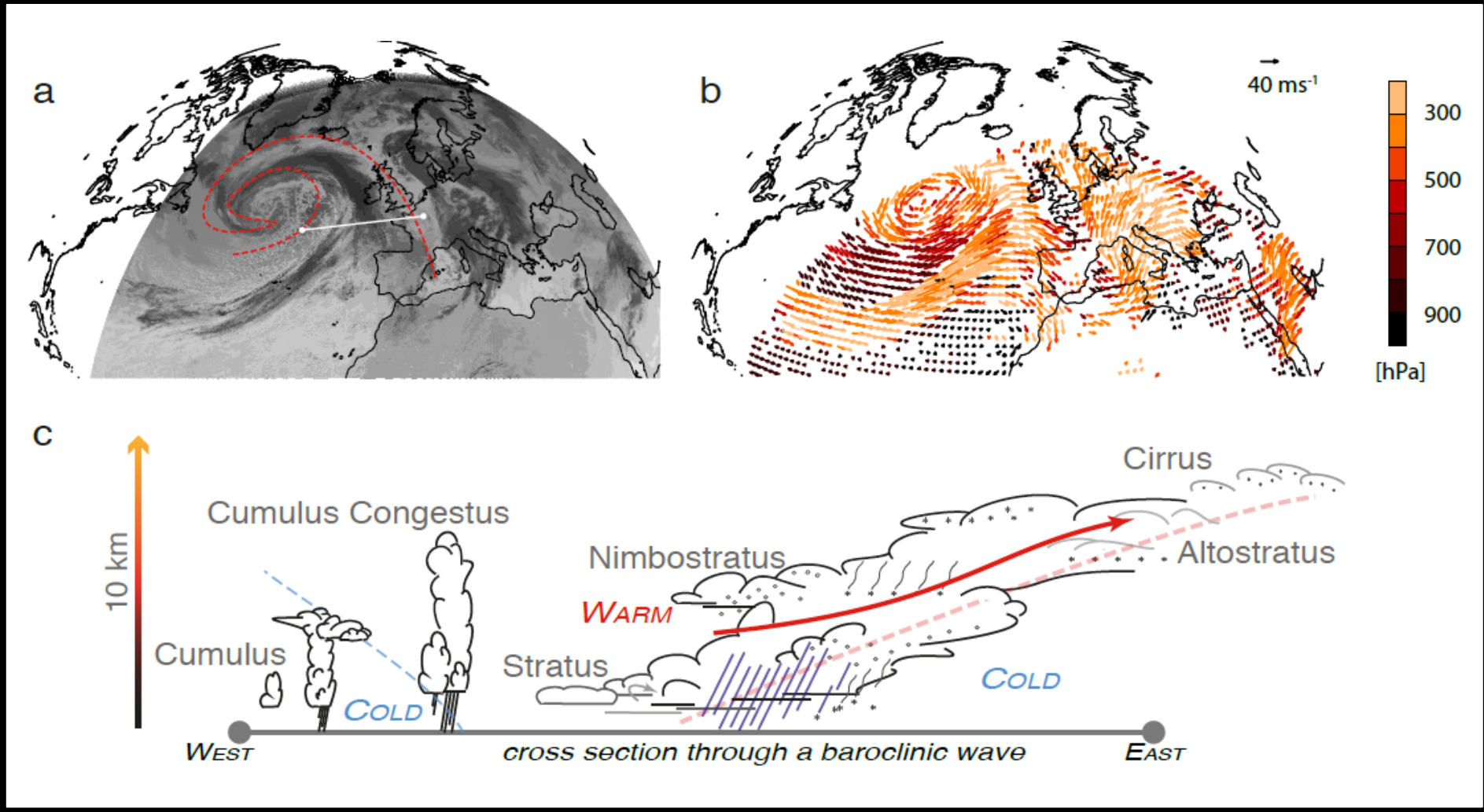
- Different circulation response across models arises from disagreement in radiative changes of tropical ice clouds and their coupling to the circulation.

Voigt and Shaw, Nature Geoscience (2014)

4

What controls the position, strength and variability of extra-tropical storm tracks?

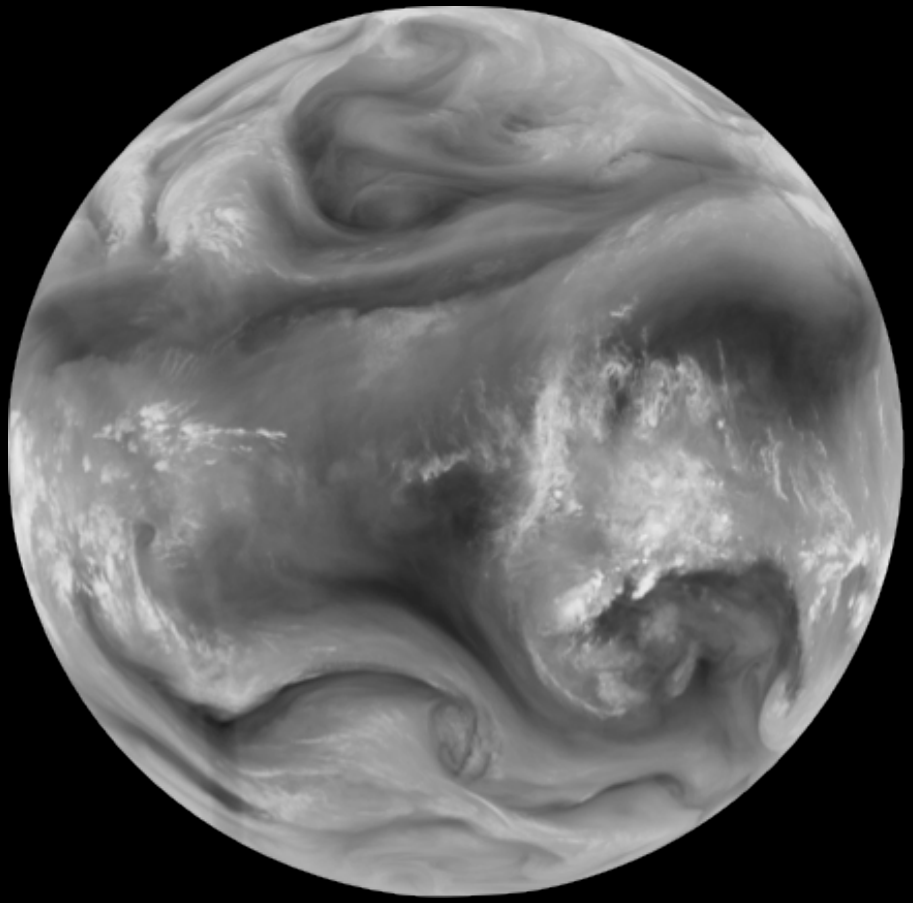
What controls the position, strength and variability of storm tracks?



What is the role of cloud and moist processes in the storm tracks?

Bony et al. *Nature Geosci.*, (2015)

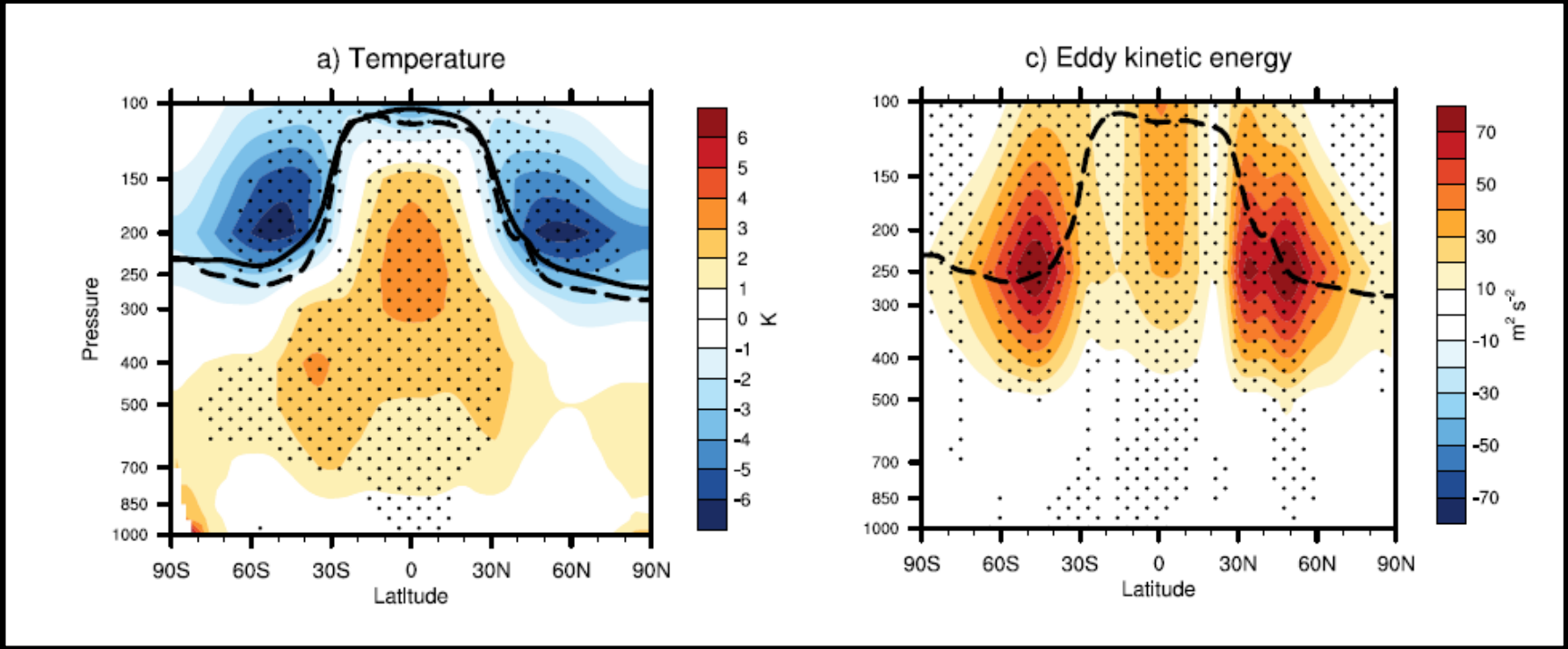
What controls the position, strength and variability of storm tracks?



- What is the role water, phase changes and radiative processes (clouds) in the storm tracks? (T-NAWDEX, DOWNSTREAM)
- How might the balance between moist and dry dynamics change as climate warms? (latitudinal temperature gradients weakening, greater role for liquid processes)
- How may the storm tracks change as the troposphere becomes warmer and wetter, the stratosphere becomes cooler, and the cryosphere shrinks ?

Climate change raises new questions, or colors old questions differently.

Impact of atmospheric cloud-radiative effects on the extra-tropical circulation



Cloud-Radiative Effects in the upper troposphere increase baroclinicity and eddy activity in the extratropical upper troposphere (by up to 30%)

Li, Thompson and Bony, J. Climate (2015)

A Grand Challenge of climate science

Four Questions:

1. What role does convection play in cloud feedbacks?

2. What controls the position, strength and variability of storm tracks?

3. What controls the position, strength and variability of the tropical rain belts?

4. What role does convective aggregation play in climate?

Bony, Stevens, Frierson, Jakob, Kageyama, Pincus, Shepherd, Sherwood, Siebesma, Sobel, Watanabe and Webb, 2015 : *Clouds, Circulation and Climate Sensitivity*, *Nature Geoscience*, 4, 261-268

EUREC^{4}A *(Elucidating the role of cloud-circulation coupling in climate)*

Primary objective :

Improve understanding of what controls the shallow-cumulus cloud amount
in present and future climates.

More specifically : assess the interplay between low-level clouds and
- shallow convective activity (convective mixing, mesoscale organization)
- large-scale subsidence
- other environmental factors (SST, surface turbulent fluxes, radiative cooling)

The campaign data will be used to test the strength of low-cloud feedbacks in models (LES, GCMs)

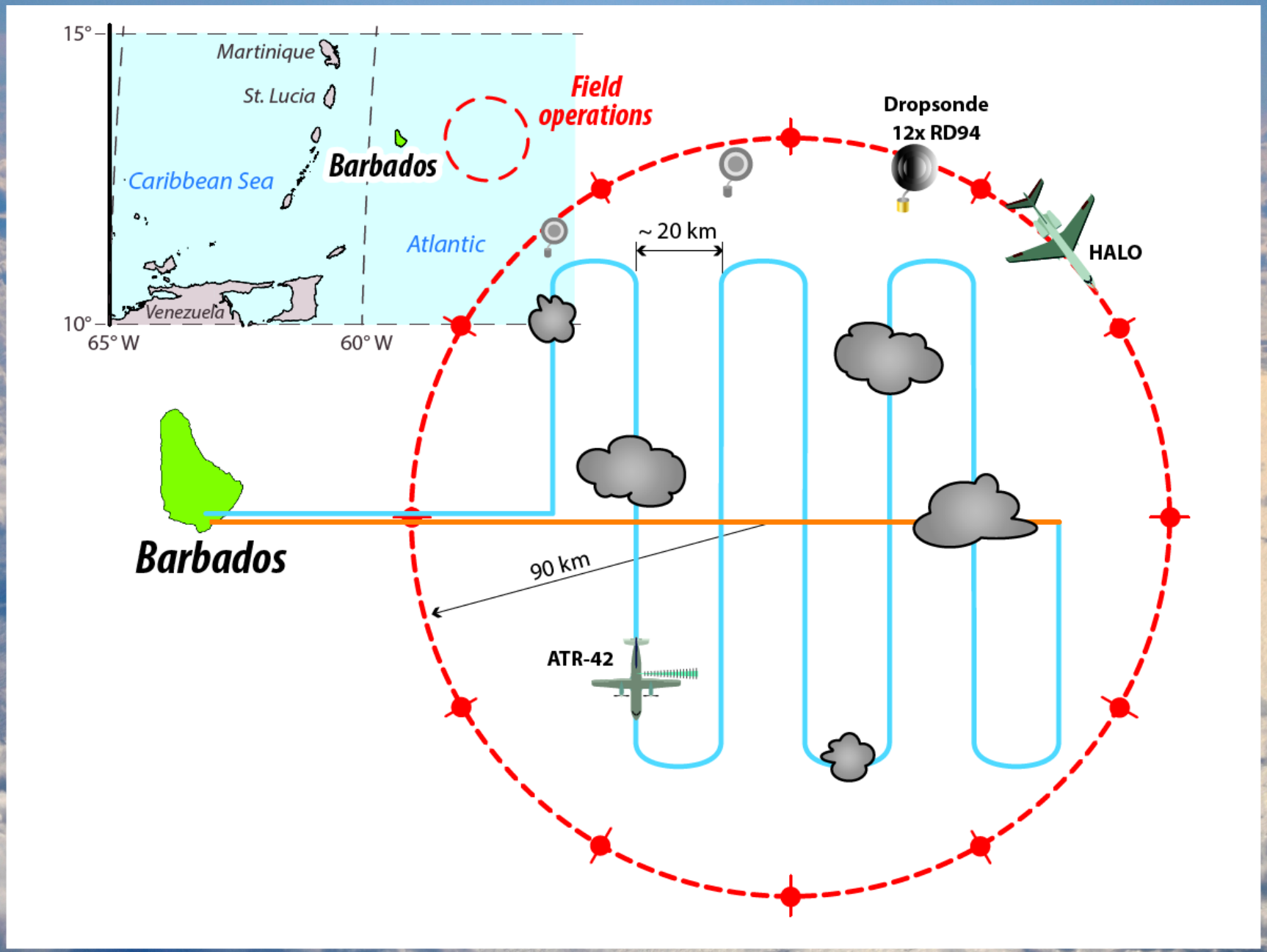
Where and when :

Atlantic trades, East of Barbados (13N, 59W), Early 2019.

Proposing team :

Sandrine Bony (LMD/IPSL), Bjorn Stevens (MPI-M)
Cyrille Flamant (LATMOS/IPSL), Safire (Toulouse)
...plus hopefully many others. Discussions within WCRP (e.g. ISSI workshop in Feb 2016)

EUREC^{4}A (Elucidating the role of cloud-circulation coupling in climate)



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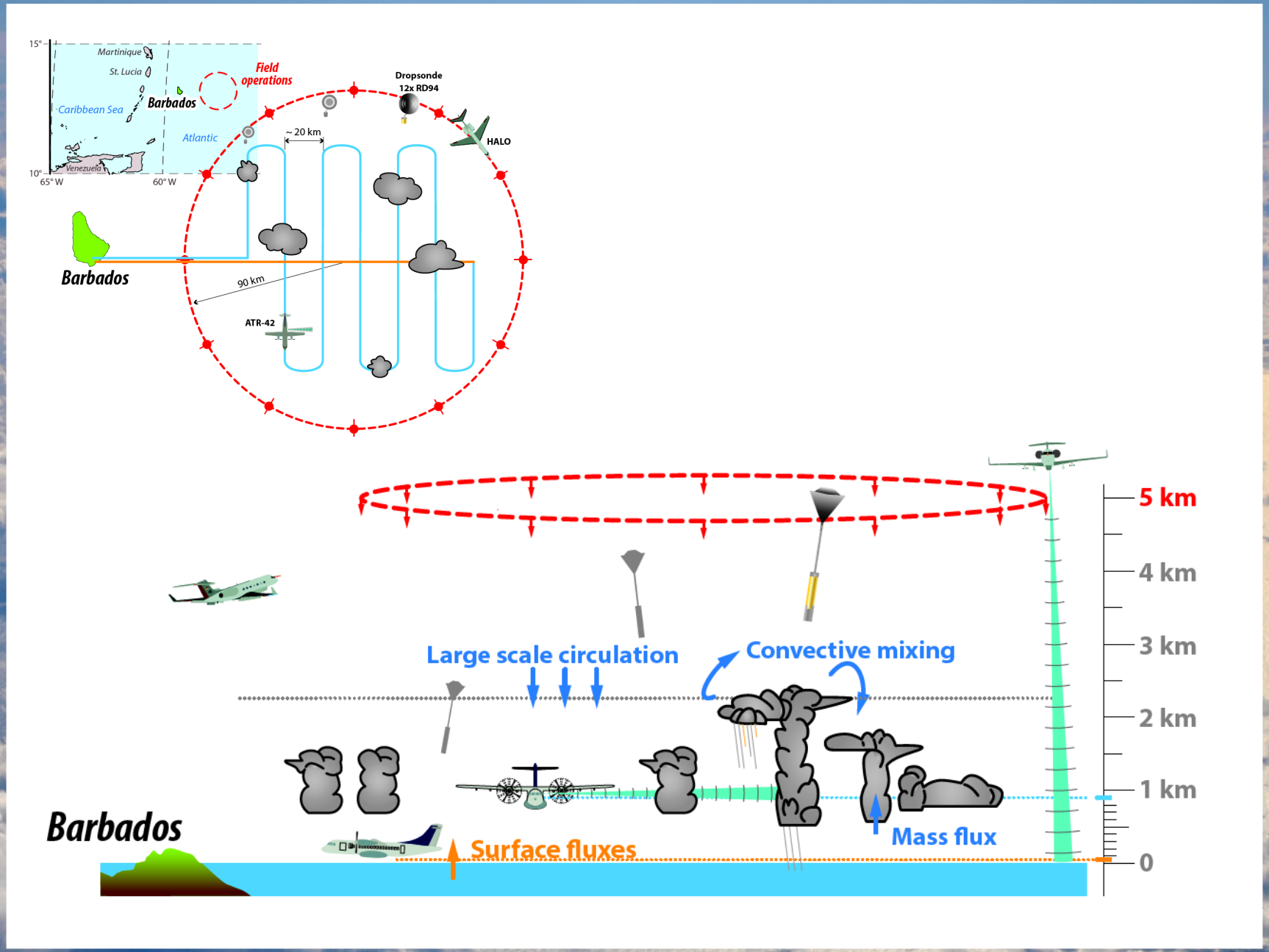

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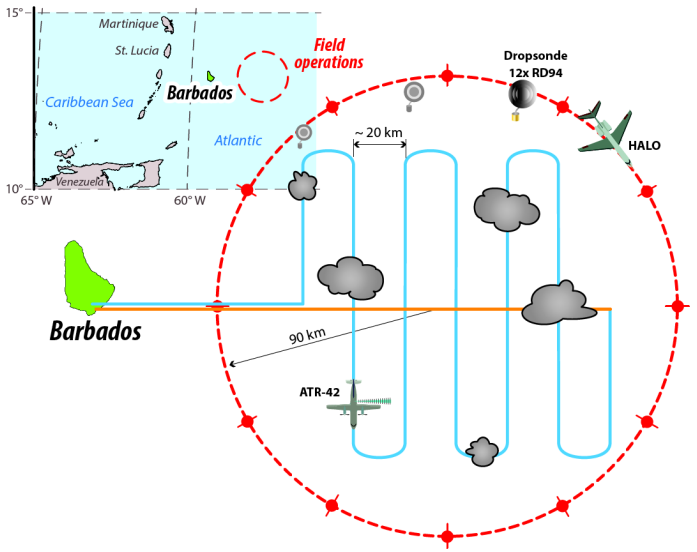


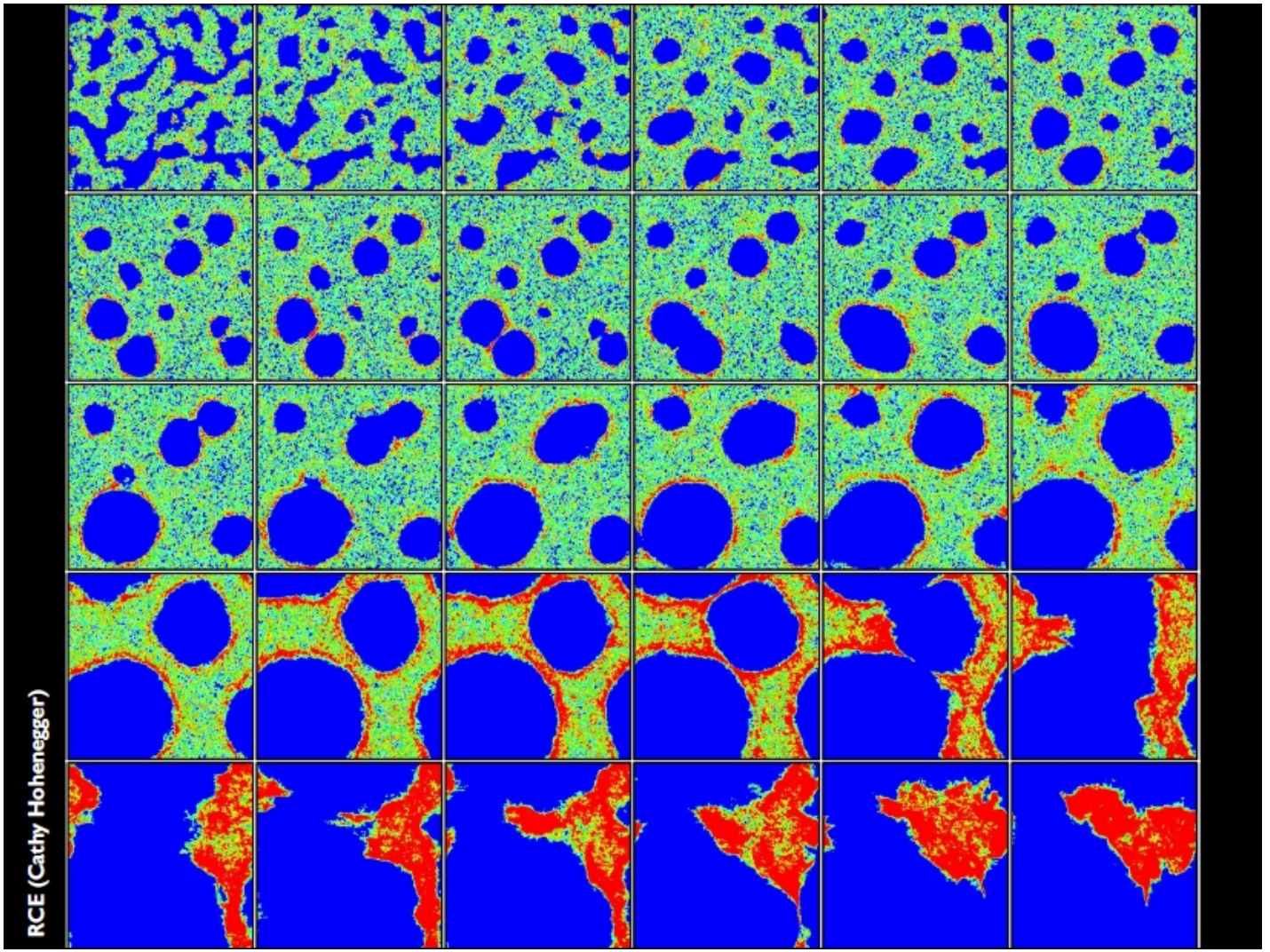
The EUREC^{4}A campaign can be an opportunity to address additional issues such as :

- the role of cloud-radiative effects in the organization of tropical convection (shallow to deep transition, aggregation of deep convection in surrounding area), especially the role of low, mid and high clouds.
- the dependence of cloud-radiative effects on ice concentration and properties (e.g. liquid-ice transition vs temperature, ice water path, size of ice crystals)
- the role of high-clouds in breaking up low clouds through their radiative effects, and thus the interaction between high clouds and low clouds (a potentially important issue for cloud feedbacks).

Using either the HALO aircraft (long autonomy) and/or another aircraft.


Thank you

RCE simulation with a Cloud-Resolving Model



Courtesy Cathy Hohenegger (MPI)

The onset of instability manifests itself as a dry patch, mostly devoid of deep convection, that amplifies and expands to cover most of the domain, isolating deep convection into a single or a few clusters.

Hohenegger et al. (in prep); Emanuel et al., JAMES (2014)

Atmospheric Cloud-Radiative Effects (vertically integrated)

CERES observations [annual, W/m2]