1) Adding complexity to the dry dynamical core

2) A hierarchy of models for studies of tropical cyclone climatology

3) Some sub-grid closure problems

Isaac Held

DCMIP, Boulder, June 2016

# Importance of Model Hierarchies

## Molecular Biology

- Hierarchy provided by nature
- Experimental science
- Nature of evolution => simpler organisms directly relevant to Man
- Relatively easy to focus on model organisms (E.coli, fruit fly)

## Climate theory

- Must create own hierarchy
- Theoretical science
- Relevance depends on imperfect ability to design appropriate models
- Difficult to focus attention of community on specific models

Hierarchies of models can be of lasting value if they are elegant

Claim: Our understanding of the climate system
in the $21^{st}$ century
will be embedded in elegant hierarchies of climate models

Elegant ⇔ focus on key sources of complexity;
Neither simpler nor more complex than they need to be

Hope: simulation models will eventually become elegant
by being subsumed within these hierarchies

*Science 18 June 2004 on stickleback fish as a model organism*

*… There is a huge body of knowledge on sticklebacks –*
*at least 2000 scientific papers and 7 textbooks …..*
*The fish's fame increased in 1973 when Nikolas Tinbergen won a Nobel Prize based in part on his studies of stickleback behavior, which is now the focus of perhaps 100 labs ….*

focus here is on atmosphere only

## Type I Idealization

start with simplest setup and add complications sequentially with no dependence on details of any particular AGCM

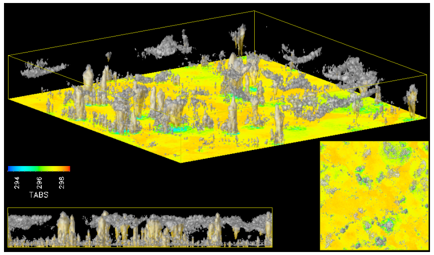
## Type II Idealization

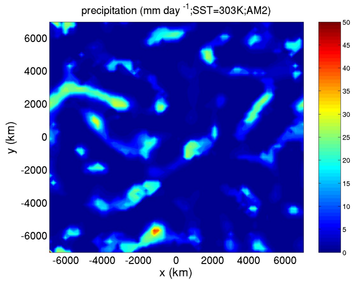
start with AGCM and idealize geometry and/or remove processes sequentially

Hard to close the gap between these two approaches, primarily due to convection/cloud parameterizations in GCMs

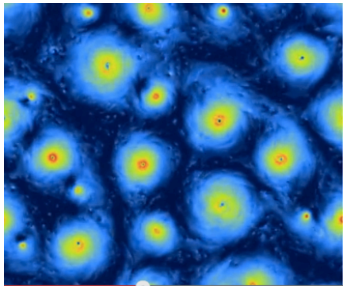
# Type II models

- Non-rotating
  radiative-convective eq

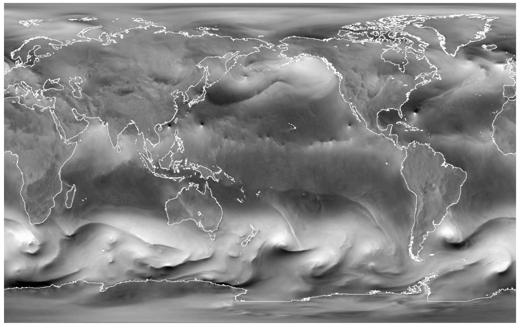





- Rotating radiative-convective eq.

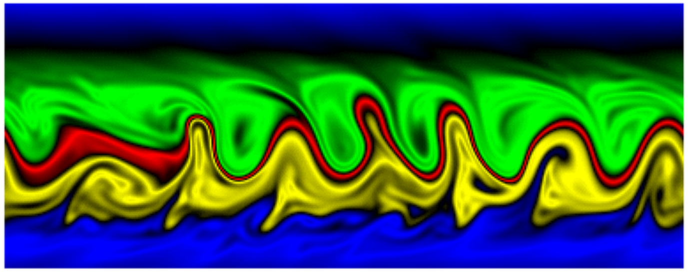


- aquaplanet

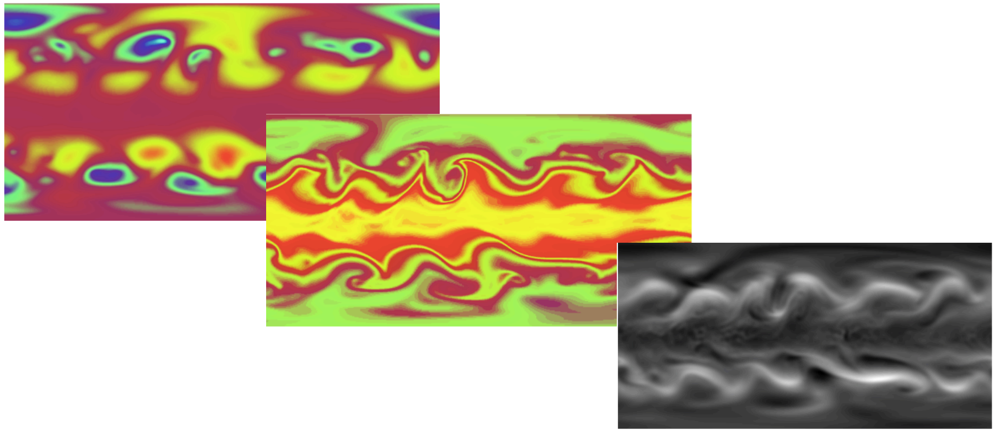


# Type I models

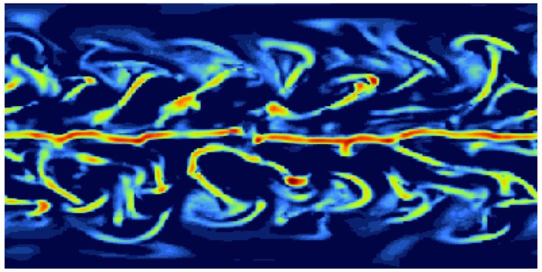
- QG



- Idealized dry dynamics on sphere



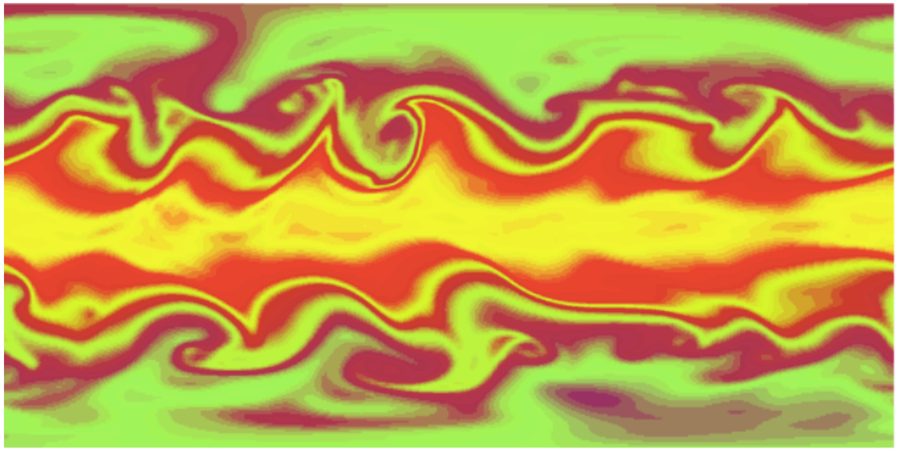
- Idealized moist dynamics on sphere



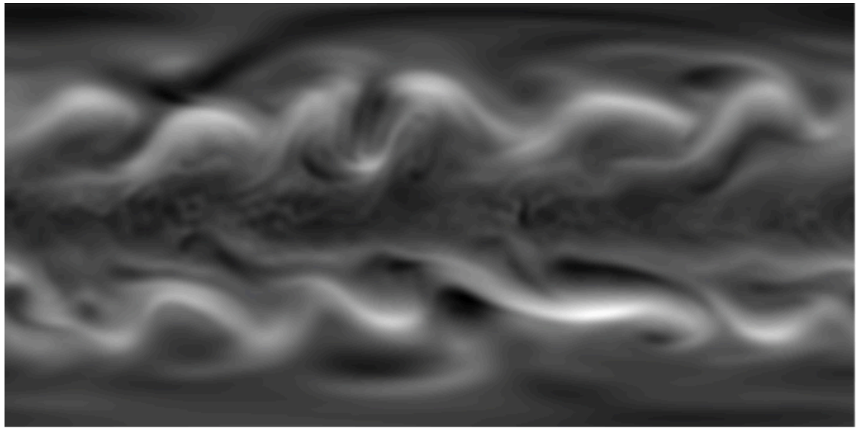
Dry atmosphere, zonally symmetric climate, no seasons, no diurnal cycle

Linear radiative damping to a specified radiative equilibrium temperature

Linear momentum damping near surface



850mb Temperature

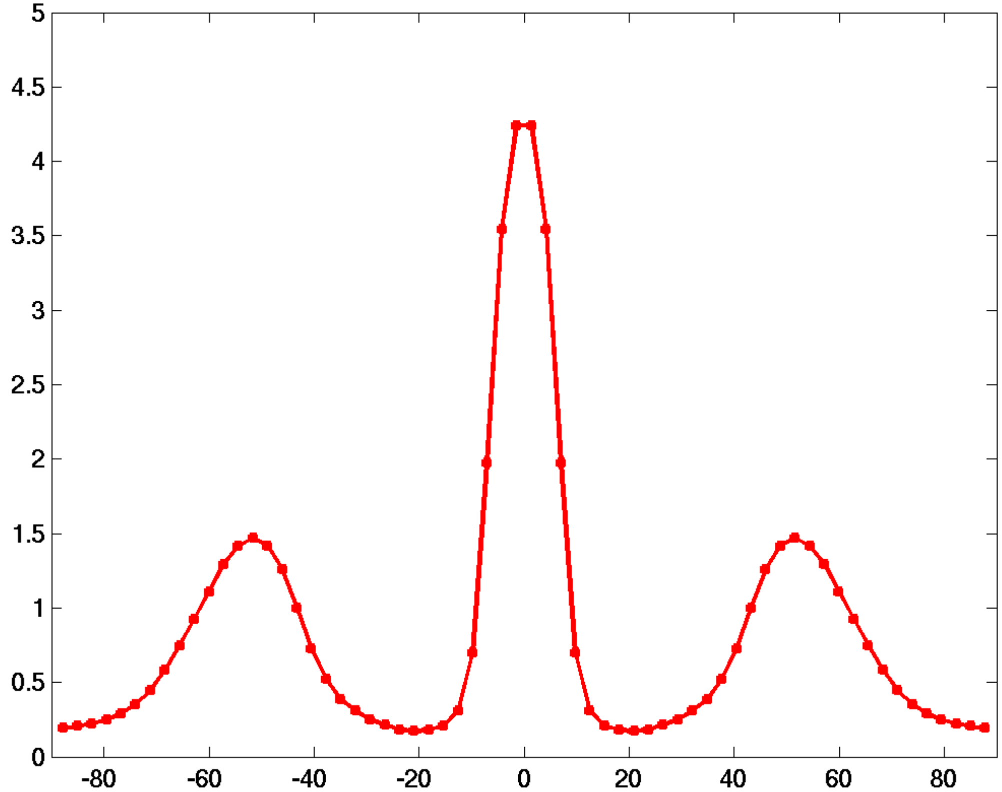


250mb winds

Dry dynamical core plus passive water-like tracer

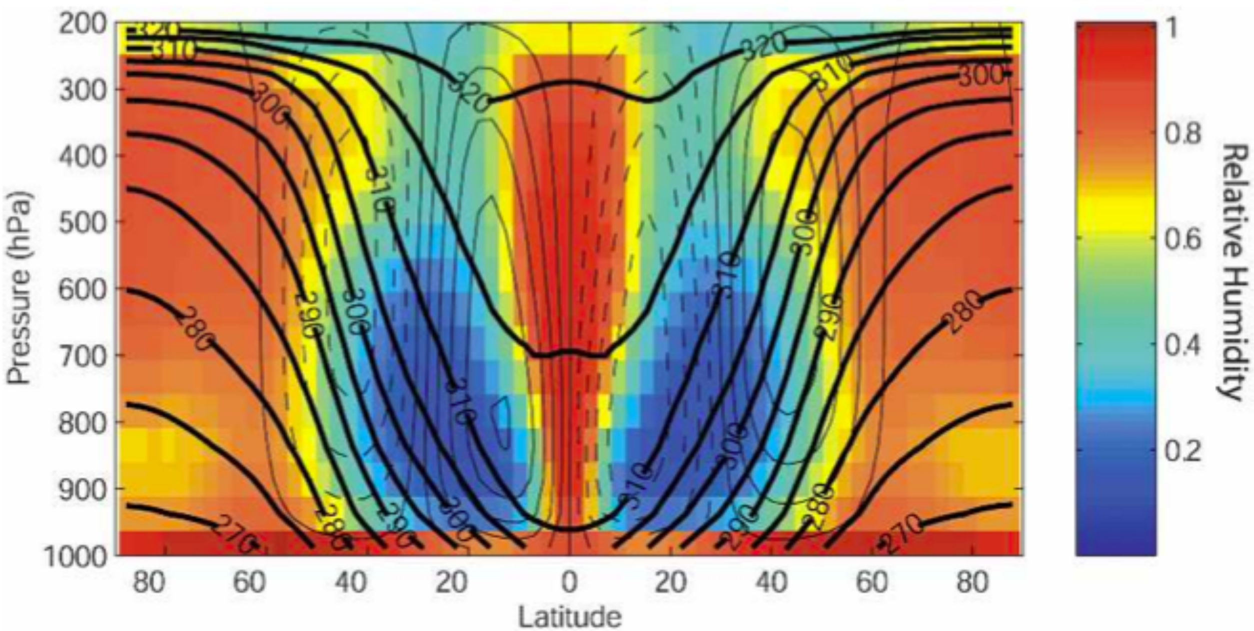
Source: relaxation to saturation near surface

Sink: precipitation to avoid supersaturation




Precipitation

# Dry dynamical core plus passive water-like tracer –Type I

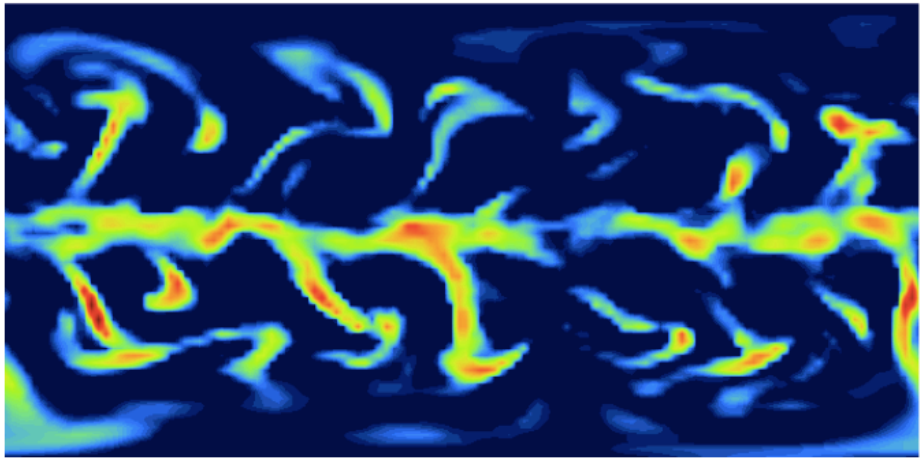



Relative humidity

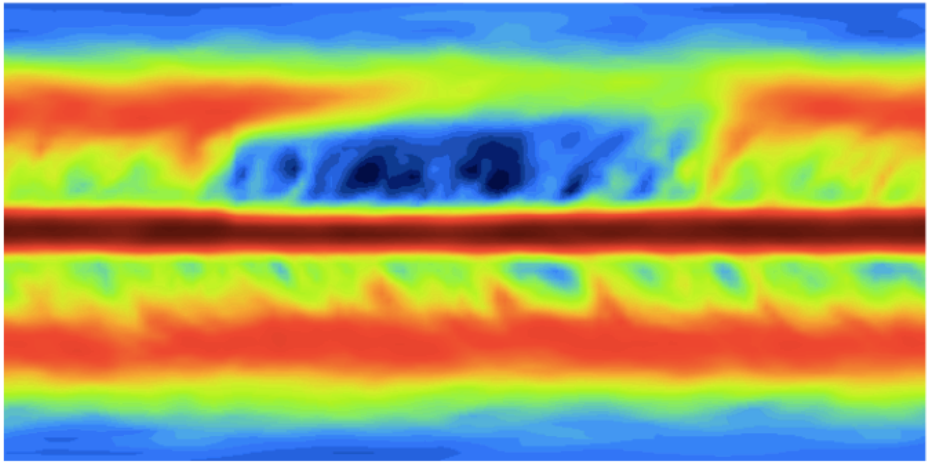
Dry dynamical core with passive water vapor

Add surface hydrology (couple evaporation to precipitation)

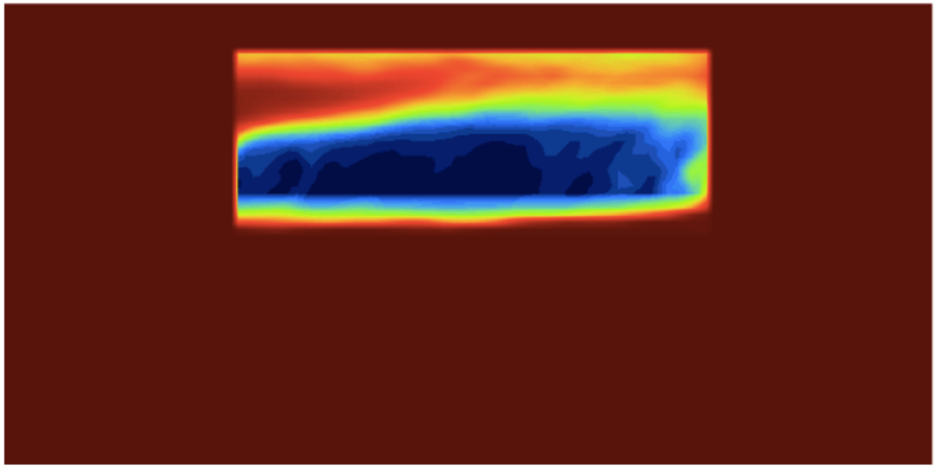
# Dry model with zonally symmetric climate and passive water with bucket hydrology over rectangular continent



Daily precipitation



100-day average precipitation



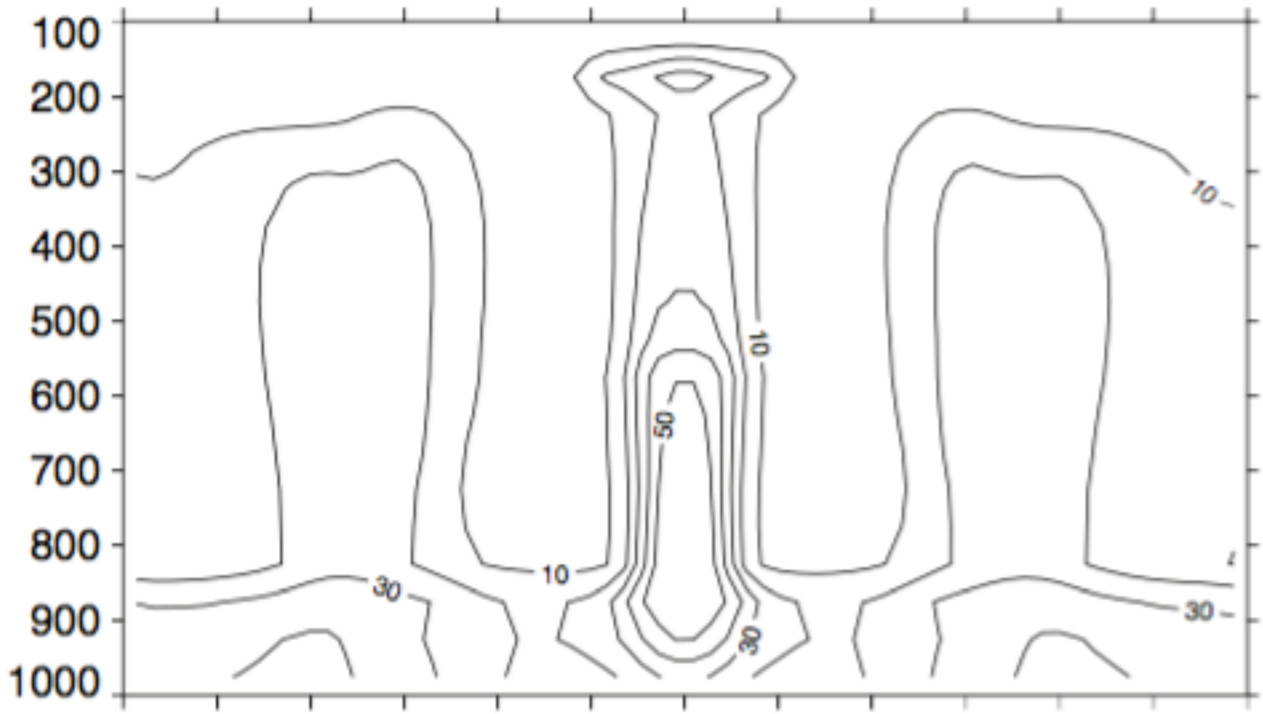
100-day average “soil moisture”

Dry dynamical core with passive water vapor

Add condensed phase with focus on
extratropical clouds above boundary layer

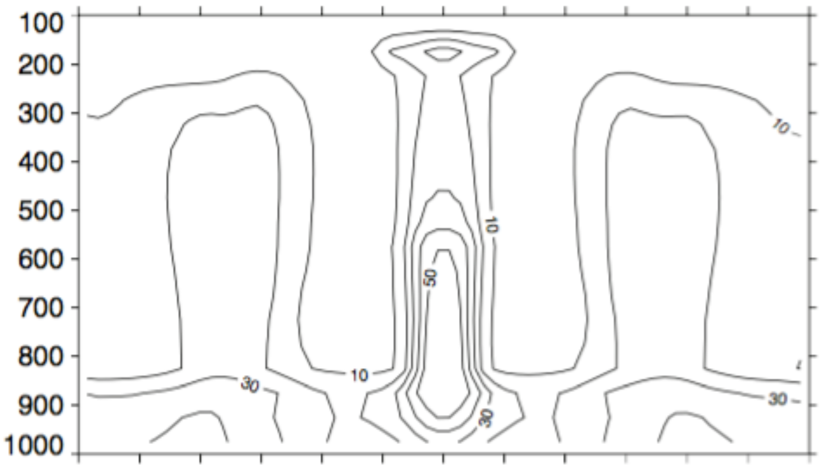
(with Yi Ming (GFDL), Michelle Frazier (Princeton))

Dry dynamics, passive water and clouds, using cloud macro/microphysics from GCM



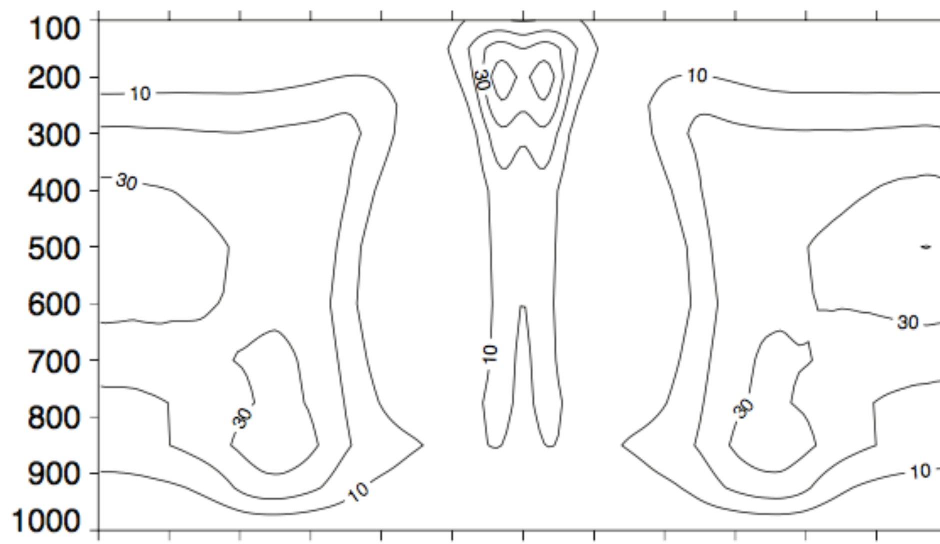

Cloud fraction

# Dry dynamics, passive water and clouds, using cloud macro/microphysics from GCM




“Dry” Cloud fraction

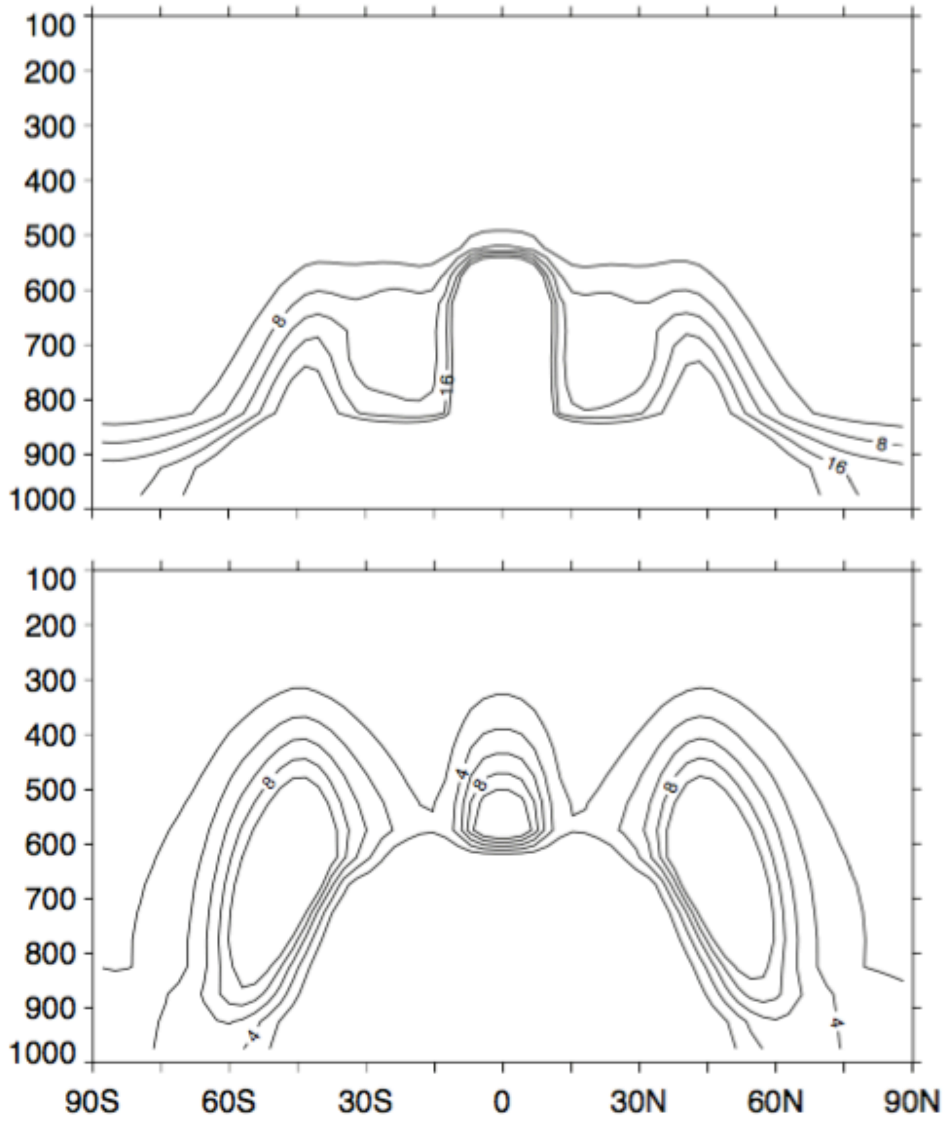
AMIP Cloud fraction

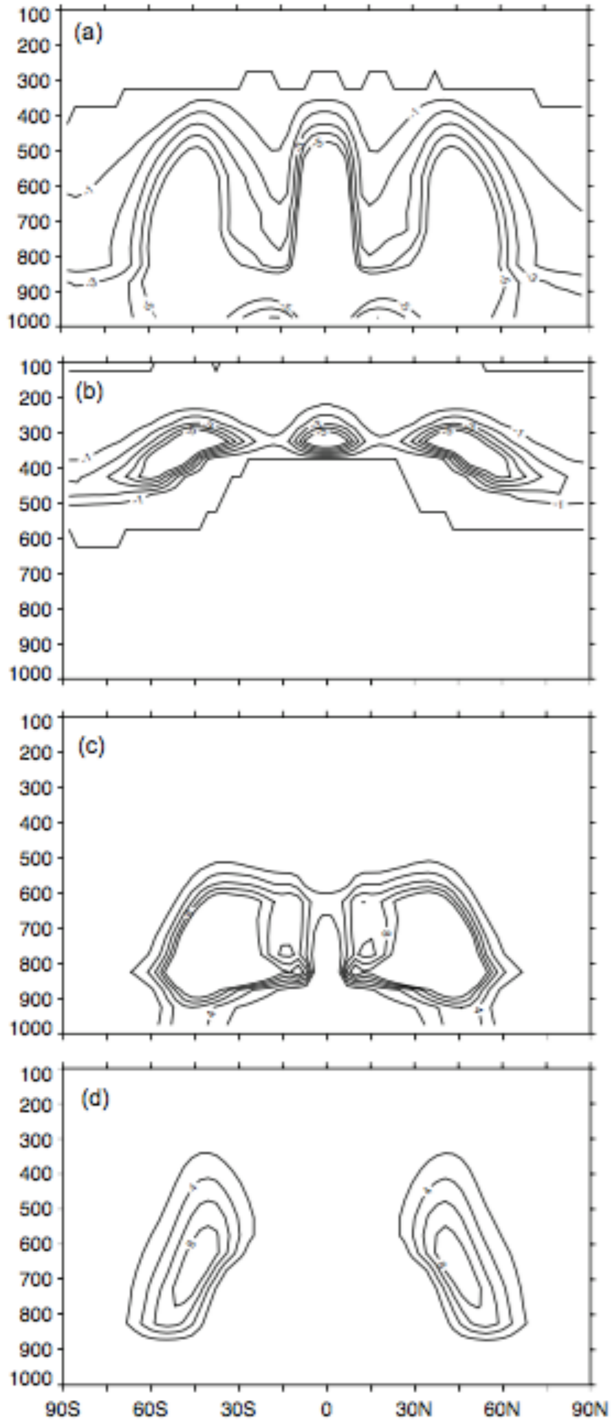


# Dry dynamics, passive water and clouds, using cloud macro/microphysics from GCM

water

ice





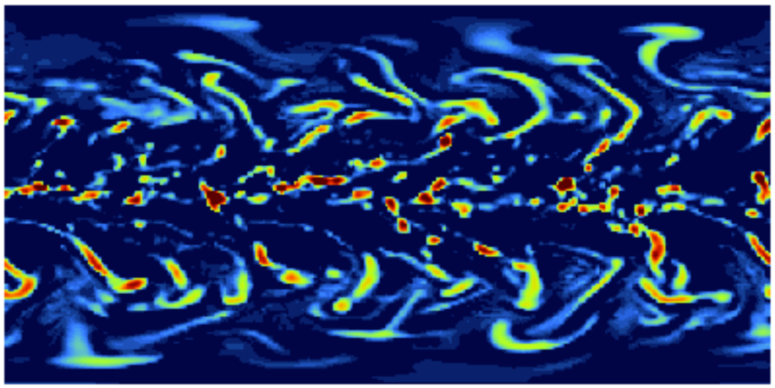

Condensation

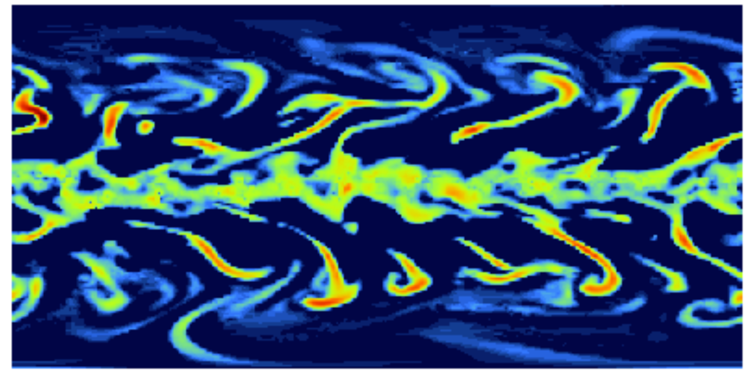
Ice Deposition x 10

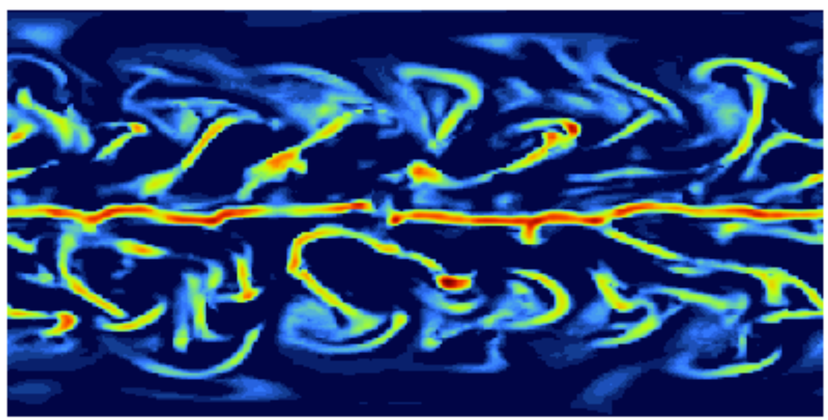
Rain re-evaporation x $10^2$

Ice sublimation x $10^2$

Idealized moist atmospheric model
Zonally symmetric climate,
No seasons, no diurnal cycle, no clouds
3 different idealized convection schemes shown



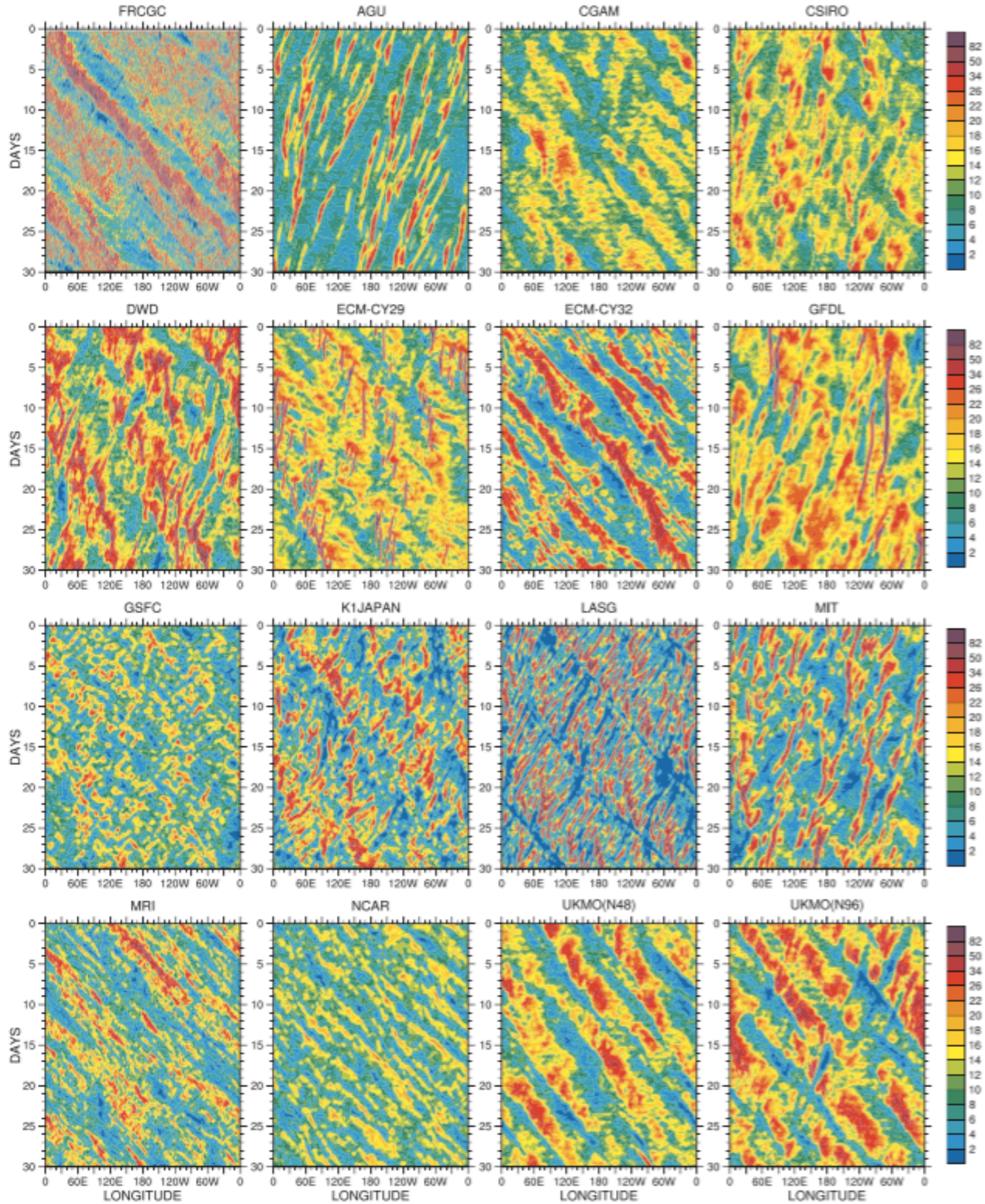




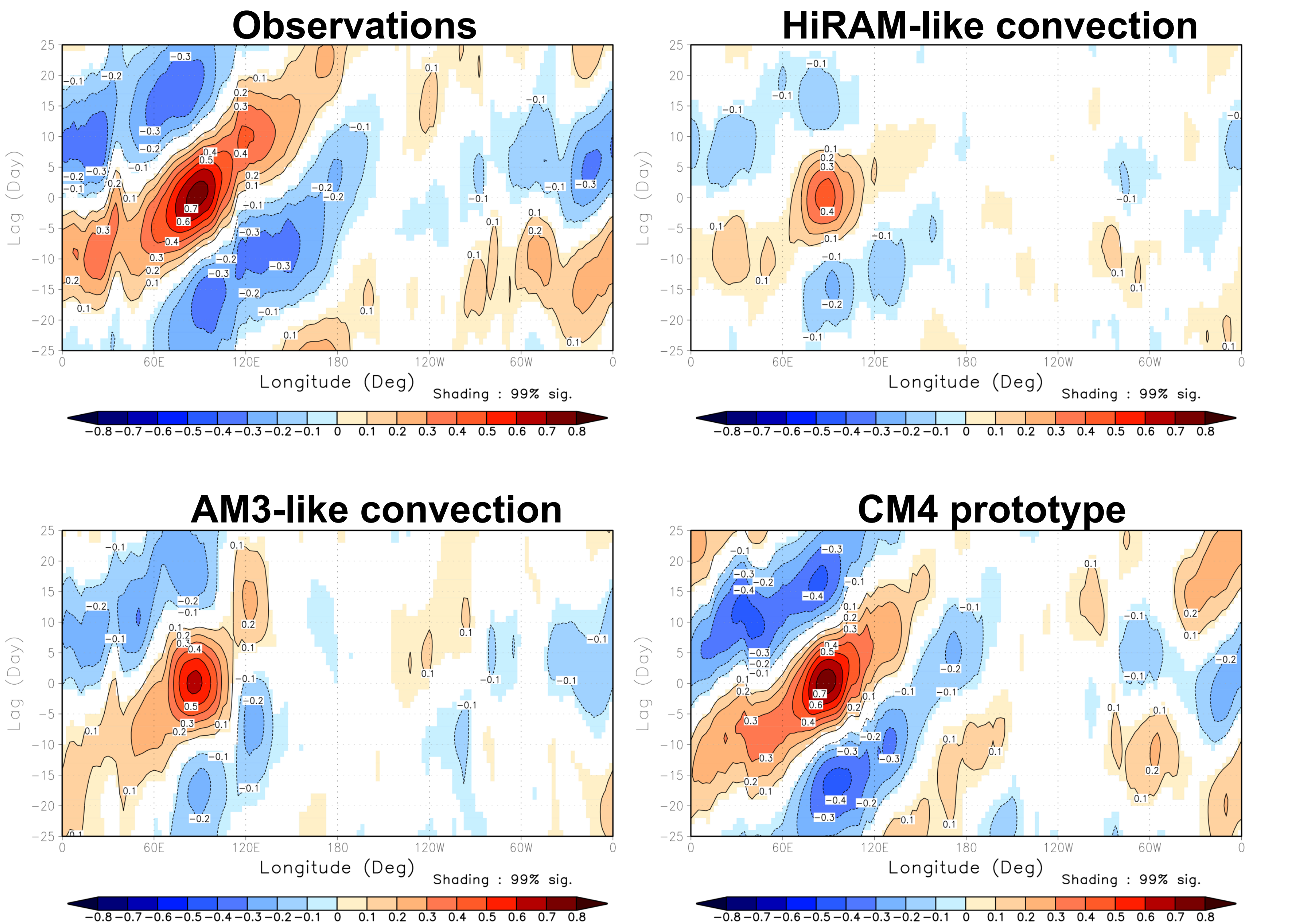
Aquaplanet Intercomparison Project
(zonally symmetric SSTs)

Tropical meteorology is NOT robust

(time vs lon precip plots)

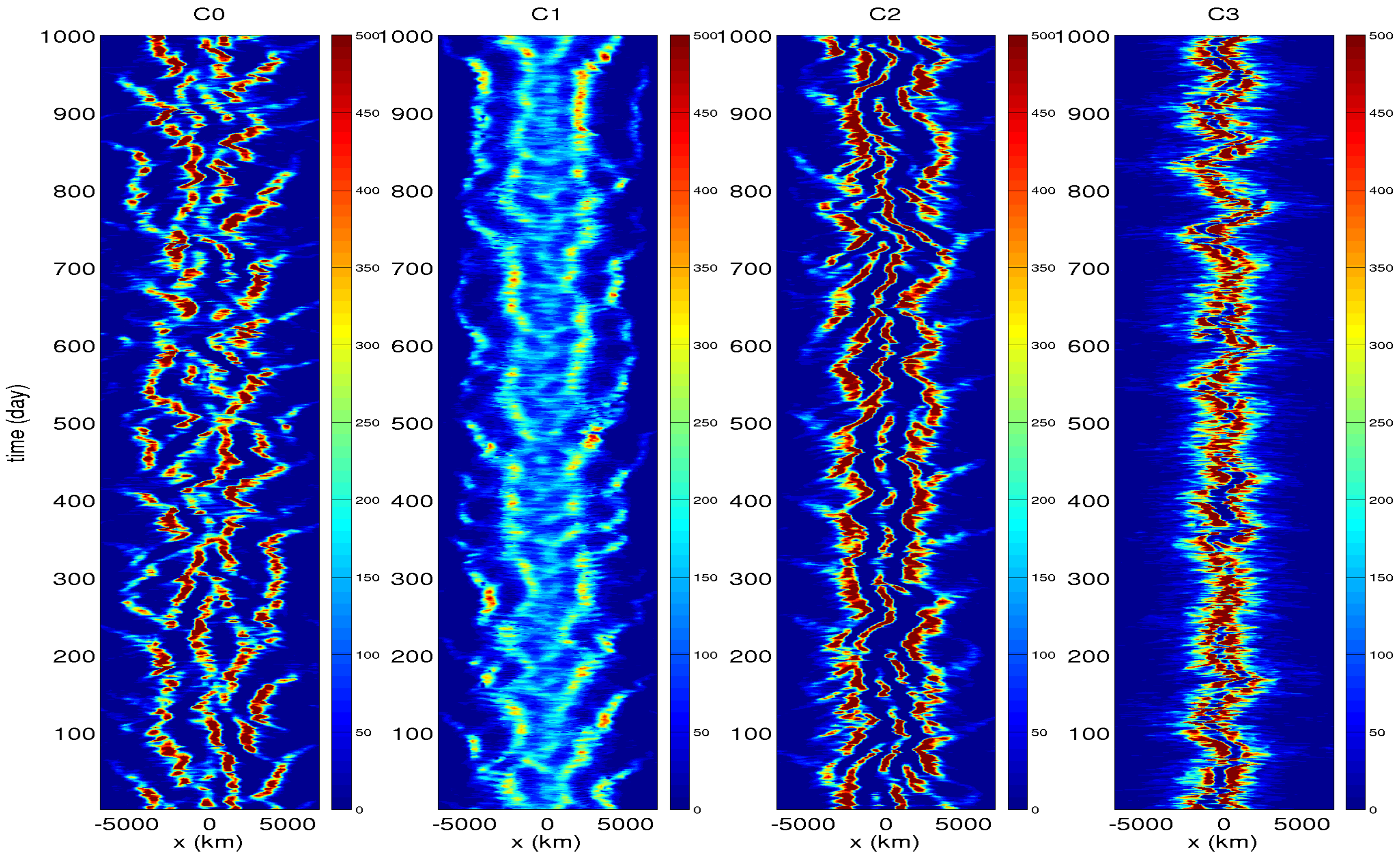


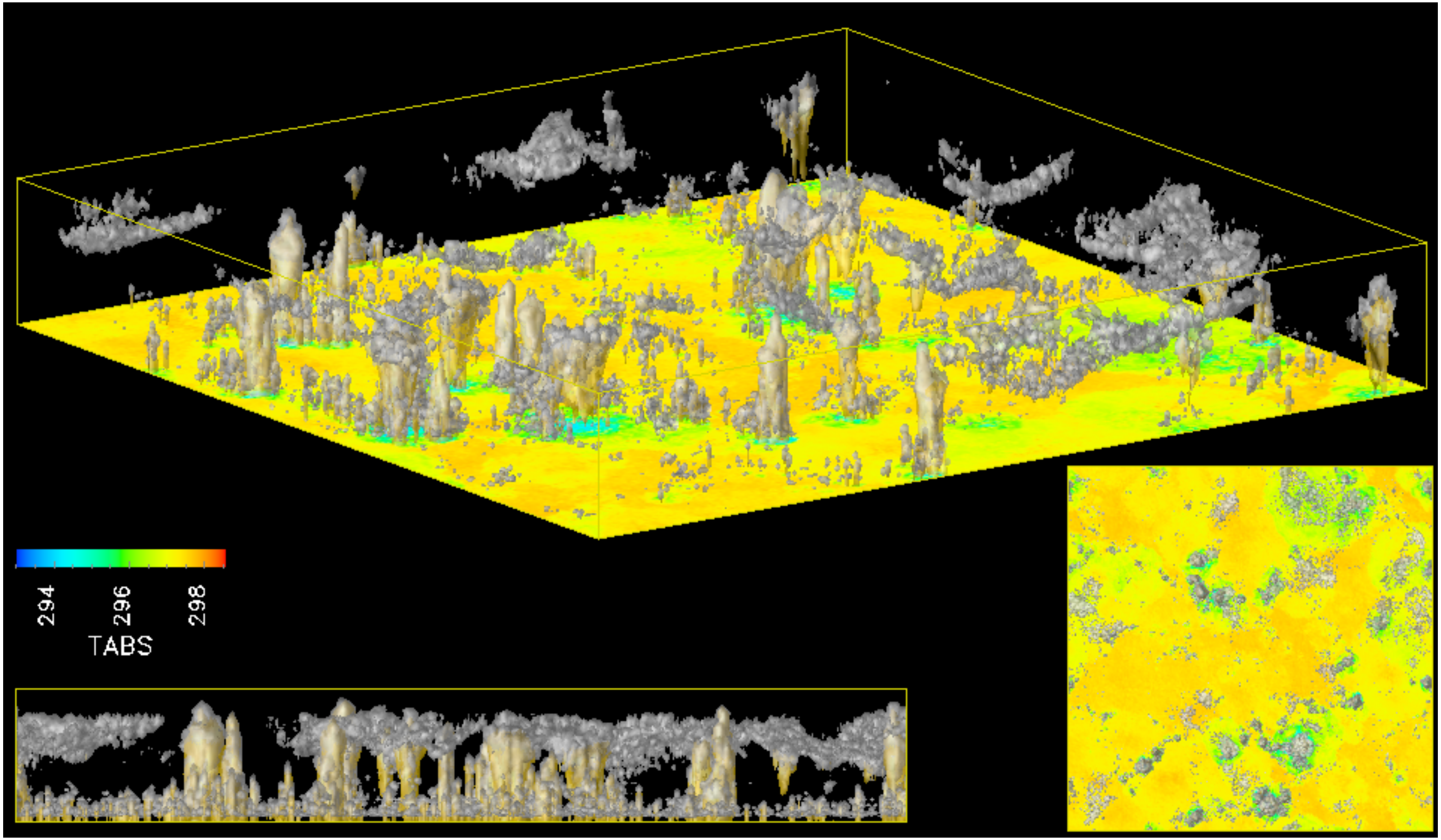
# Madden-Julian Oscillation (MJO)
# OLR Lag correlation, Winter (Nov-Apr)




Zhao et al. (in prep.)

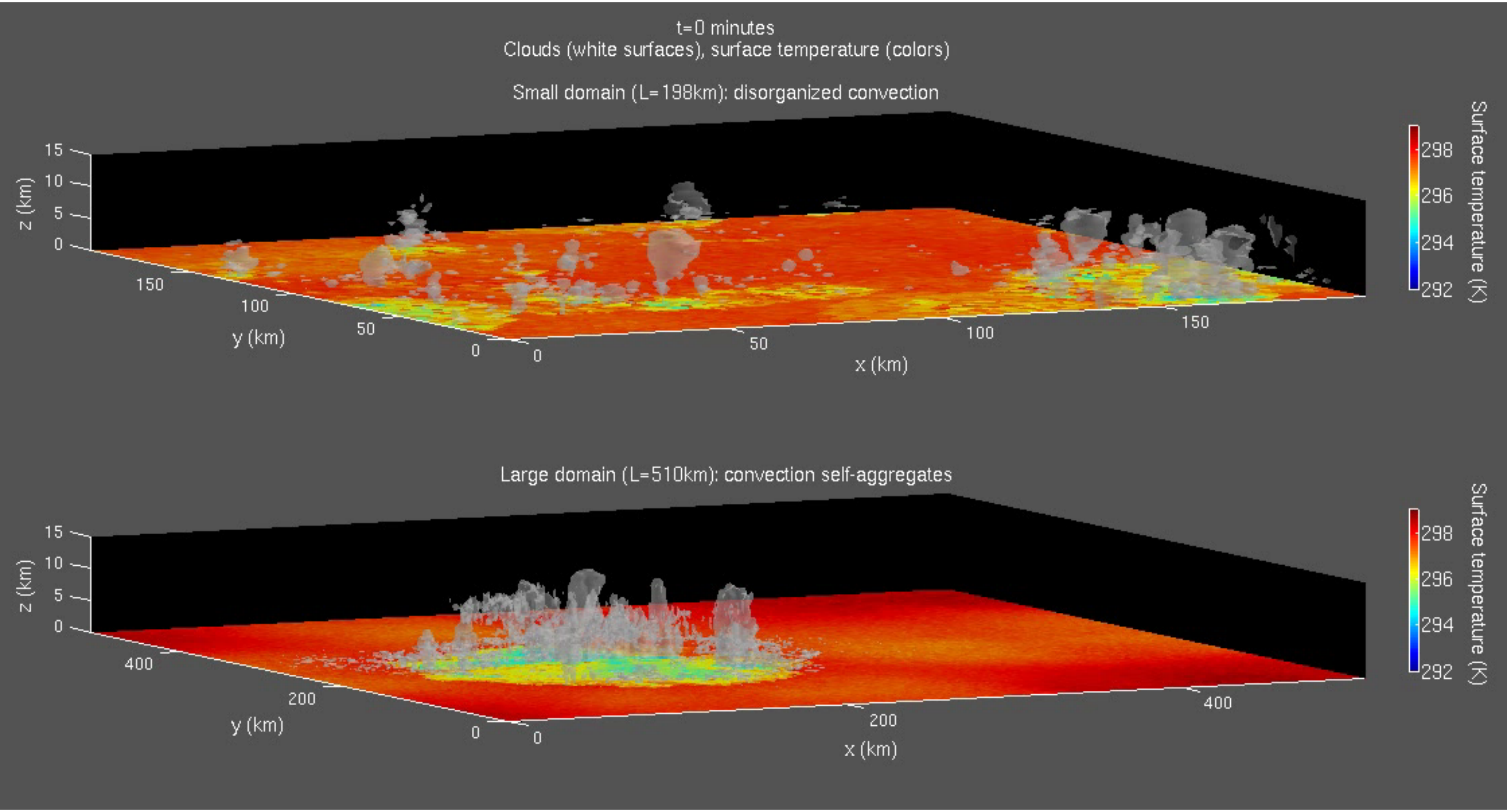
AM2 default | No Tok.&CCWF=0 | Conv. gustiness | Non-local CMT






# Radiative-Convective Equilibrium

Courtesy of P. Blossey, C. Bretherton




Non-rotating radiative-convective equilibrium
courtesy of Caroline Muller

Lower domain twice
As large as upper domain

In addition to trying to find the best
convection parameterization, define interesting classes
of schemes and try to map out how climate varies
across this space of models

Madden-Julian oscillation
Convectively-coupled waves
Tropical cyclones

Embedding a system within a larger class of systems
can be absolutely essential as a path towards understanding