Introduction

2015 Site Visit Team

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National Science Foundation

Plan for this morning

- This introduction (Randall, 15 minutes)
- CMMAP's Research Legacy (Randall, 60 minutes)
  - What has been accomplished up to now
  - What we will do in Year 10
  - After the STC's sunset
  - Discussion of Research presentation
- Break (15 minutes)
- CMMAP's Knowledge Transfer Legacy (Krueger, 45 minutes)
  - What has been accomplished up to now
  - What we will do in Year 10
  - After the STC's sunset
  - Discussion of KT presentation
- CMMAP's Education & Diversity Legacy (Denning and Burt, 45 minutes)
  - What has been accomplished up to now
  - What we will do in Year 10
  - After the STC's sunset
  - Discussion of E&D presentation
- Closing discussion (All, 15 minutes)


CMMAP
Reach for the sky.

Poster from Kelley and Claire

A brief “origin story:”

The research idea came first, in 2000.

The plan to make it the basis of an STC came in 2001.

This BAMS article was based on an early draft of the STC pre-proposal.

BREAKING THE CLOUD PARAMETERIZATION DEADLOCK

BY DAVID RANDALL, MARAT KHAIROUTDINOV, AKIO ARAKAWA, AND WOJCIECH GRABOWSKI

Progress on the cloud parameterization problem has been too slow. The authors advocate a new approach that is very promising but also very expensive computationally.

CLOUDS AND CLIMATE: A PROBLEM THAT REFUSES TO DIE. Clouds of many varieties fill the global atmosphere (Fig. 1). They are composed of drops and crystals with scales on the order of microns to millimeters. They are associated with convection and turbulence on scales of meters to kilometers. They are organized within mesoscale and synoptic-scale dynamical systems that interact with the global circulation of the atmosphere.

The representation of cloud processes in global atmospheric models has been recognized for decades

FIG. 1. A full-disk visible image showing many cloud systems, including the intertropical convergence zone of the tropical eastern Pacific Ocean, marine stratocumulus clouds west of both South America and North America, and frontal clouds in the midlatitudes of both hemispheres.

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DOI: 10.1175/BAMS-84-11-1547

In final form 25 March 2003

Planning

We held a total of five planning workshops before submitting the full proposal in February 2004.

Down to the wire

From: fastlane@nsf.gov
Subject: **FastLane Proposal 0338050 submitted**
Date: June 3, 2003 4:58:34 PM MDT
To: David Randall <randall@atmos.colostate.edu>

Your Sponsored Research Office or equivalent at your organization has submitted the following proposal to NSF:

Proposal No: 0338050
Title: Multi-Scale Modeling of Atmospheric Processes
Date Submitted: Jun 3 2003 6:58PM

Once NSF has assigned your proposal to a program officer you will be able to use FastLane to track the status of your proposal. To track the status of your proposal, on the FastLane Home Page (http://www.fastlane.nsf.gov) click on "Proposals, Awards & Status", enter your last name, SSN, and password and click on the "Login" button.

Timestamp:6/3/2003-18:58.34
Submitting Agency: 129.82.172.142

From: fastlane@nsf.gov
Subject: **FastLane Proposal 0424600 submitted**
Date: February 10, 2004 4:57:52 PM MST
To: David Randall <randall@atmos.colostate.edu>

Your Sponsored Research Office or equivalent at your organization has submitted the following proposal to NSF:

Proposal No: 0424600
Title: Center for Multi-Scale Modeling of Atmospheric Processes (MMAP)
Date Submitted: Feb 10 2004 6:57PM

Once NSF has assigned your proposal to a program officer you will be able to use FastLane to track the status of your proposal. To track the status of your proposal, on the FastLane Home Page (http://www.fastlane.nsf.gov) click on "Proposals, Awards & Status", enter your last name, SSN, and password and click on the "Login" button.

Timestamp:2/10/2004-18:57.52
Submitting Agency: 129.82.172.163

Waiting it out

Shortly after we were site-visited in October 2004, all but six proposals were declined. We were not declined.

We went into "limbo."

In summer 2005 we had a limbo party in connection with a workshop organized to keep the team connected.

Things started moving in December 2005, and we were finally funded on July 1, 2006.

Some of the ingredients of a Center

Big research idea

Talent

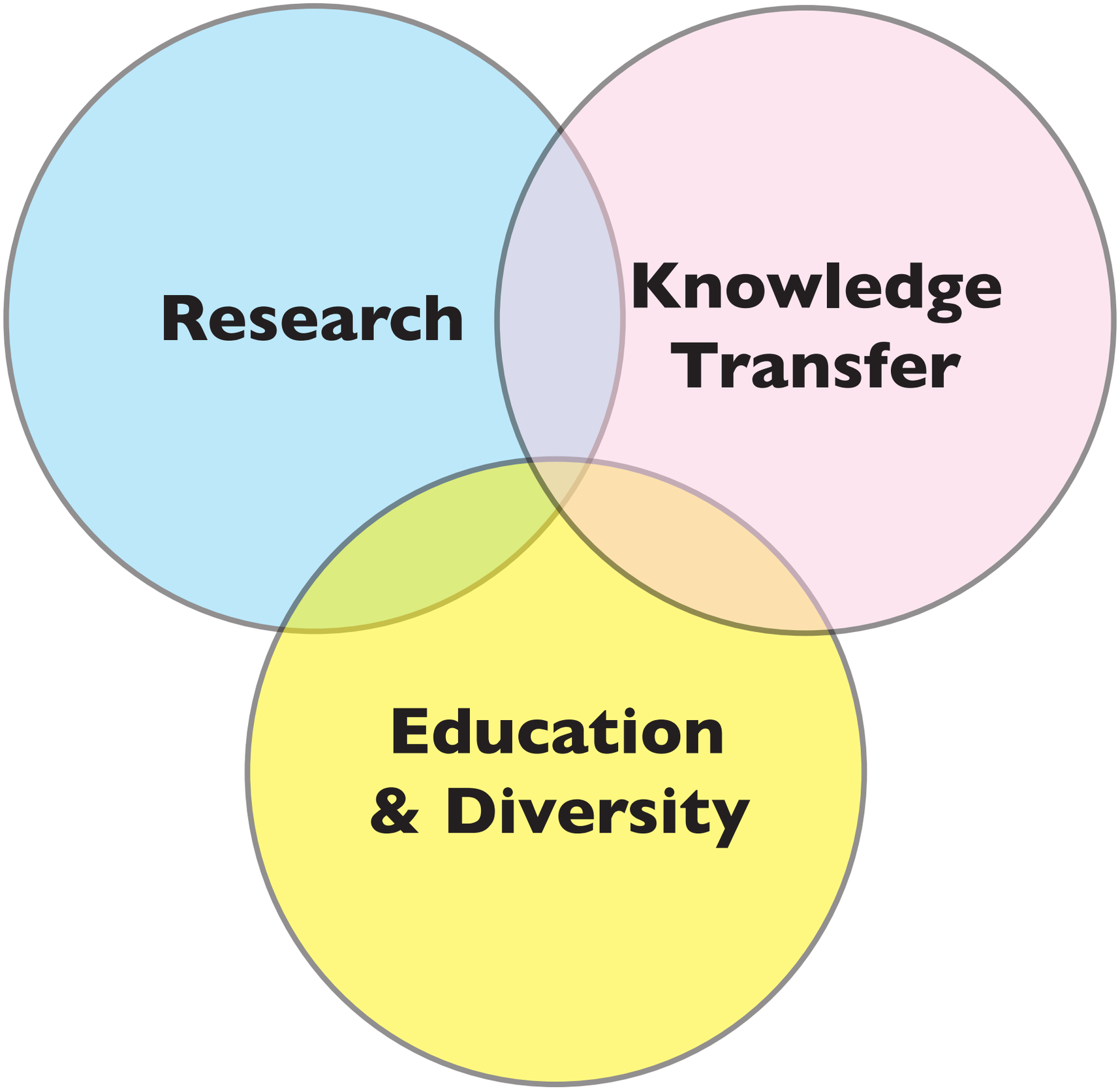
Funding

Extended duration

No operational responsibilities

Centralized direction

I'll return to this later.


Research
Knowledge Transfer
Education & Diversity

CMMAP's Research Legacy

Clouds Are Central to the Earth Sciences

- Climate change
- Weather prediction
- The water cycle
- Global chemical cycles
- The biosphere

We are being held back in all of these areas by an inability to simulate the global distribution of clouds and their effects on the Earth system.

Vision Statement for Research

CMMAP's vision is to take advantage of rapidly increasing computer speed to achieve major advances in our ability to understand and predict the effects of clouds on weather and climate.

Mission Statement for Research

The research mission of CMMAP is to develop a new kind of global atmospheric model that can represent the effects of clouds on weather and climate with greatly improved realism; to evaluate the new model by comparison of model results with observations; and to apply the model to understand the interactions of clouds with other components of the Earth system, including the atmosphere, the vegetated land surface, and the oceans.

— From CMMAP's 2006 Strategic Plan

Clouds are hard to to understand and to simulate, because:

- Wide range of scales
  - Squall lines to ice crystals
  - Thin cirrus, thin capping inversions, etc.

- Wide variety of coupled processes
  - Microphysics
  - Convection & mesoscale dynamics
  - Radiation
  - Turbulence

Once and Future Schemes

"The representation of cloud processes in climate models, which is a key aspect of … the "*cloud- climate problem*," has been recognized for decades … as the festering source of much of the uncertainty surrounding predictions of climate change.

A sober assessment suggests that with current approaches the cloud-parameterization problem will not be "solved" in any of our lifetimes.

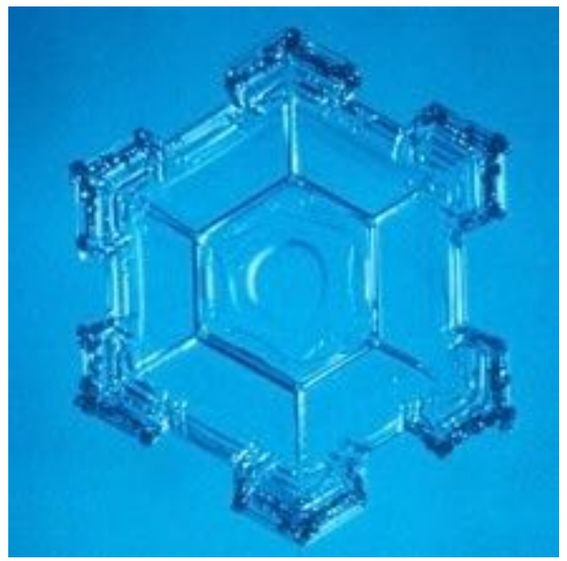
We propose a *revolutionary new approach* that offers the potential for major progress…. We will bring *much-needed focus and organization* to the modeling side of the cloud-climate research problem, and deliver *both scientific understanding and practical applications*. We are going to pull the sword from the stone."

— From the 2004 proposal

Parameterizations for low-resolution models

Global circulation

Cloud-scale &mesoscale processes

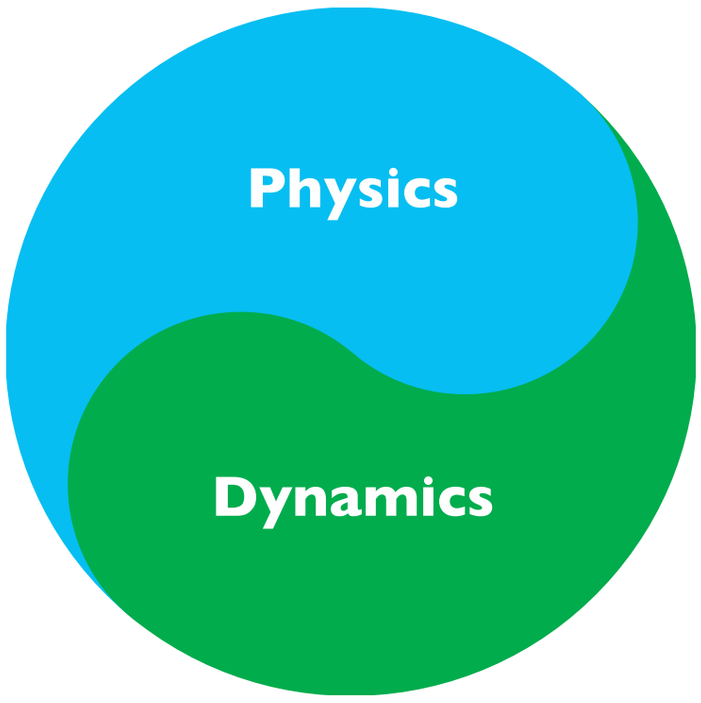


Radiation, Microphysics, Turbulence

Parameterized, with low-resolution input

Where does the computer time go?

50%

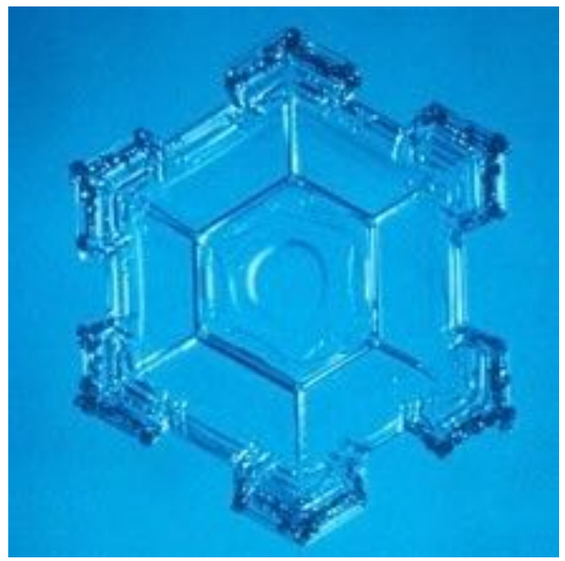


50%

Parameterize less.

Global circulation

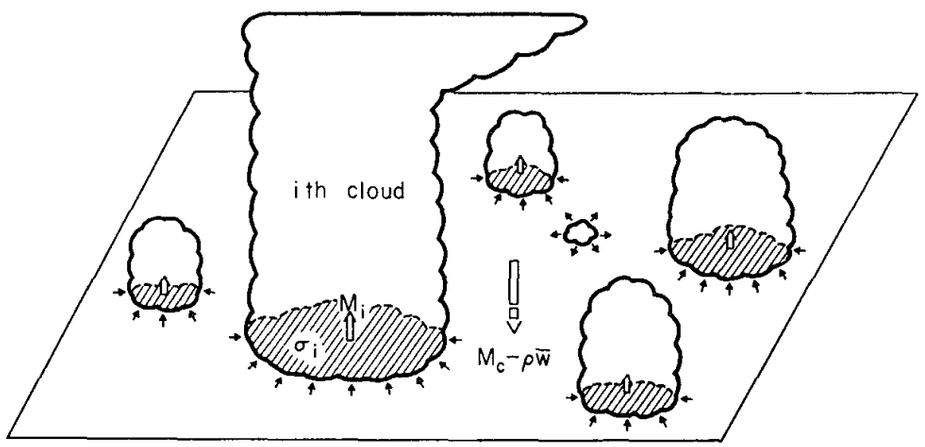
Cloud-scale &mesoscale processes



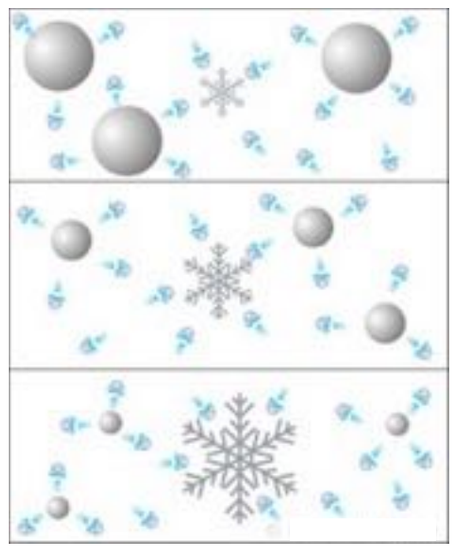
Radiation, Microphysics, Turbulence

Parameterized, with high-resolution input

Parameterizations Must Be Scale-Dependent



Increasing resolution



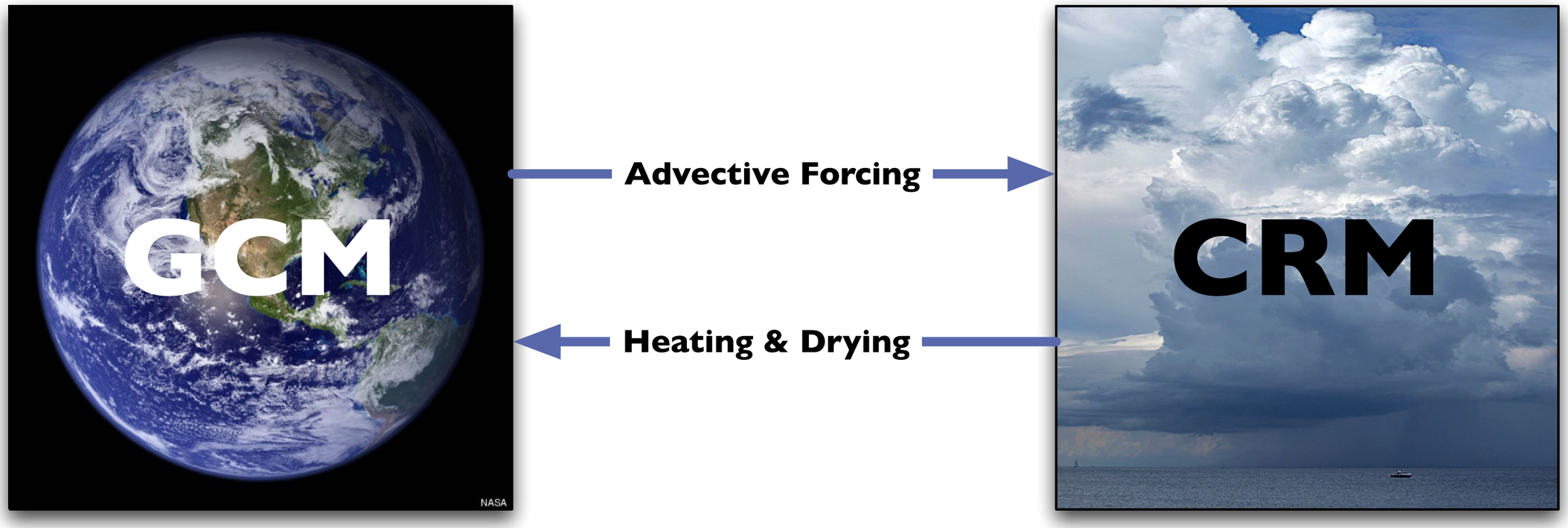
GCM

Parameterizations for low-resolution models are designed to describe the collective effects of many clouds, including strong convective transports.

CRM

Parameterizations for high-resolution models are designed to describe what happens inside individual clouds.

Multiscale Modeling Framework (MMF)



"Super-Parameterization"

Each CRM runs continuously.

The CRMs do not communicate with each other except through the GCM, so *the model is "embarrassingly parallel."*

What's different?

- The equation of motion
  - No closure assumptions
  - No triggers
  - Mesoscale organization

- CRM memory
  - Delay in convective response
  - Sensitive dependence on initial conditions

- Increased computational cost

SP-CAM

We have created an MMF based on the Community Atmosphere Model.

It is able to simulate lots of things that the conventional CAM misses.

“The design, testing, and application of an improved MMF will be the central, organizing component of CMMAP’s research.”

— From the 2004 proposal

Global modeling landscape, 2000

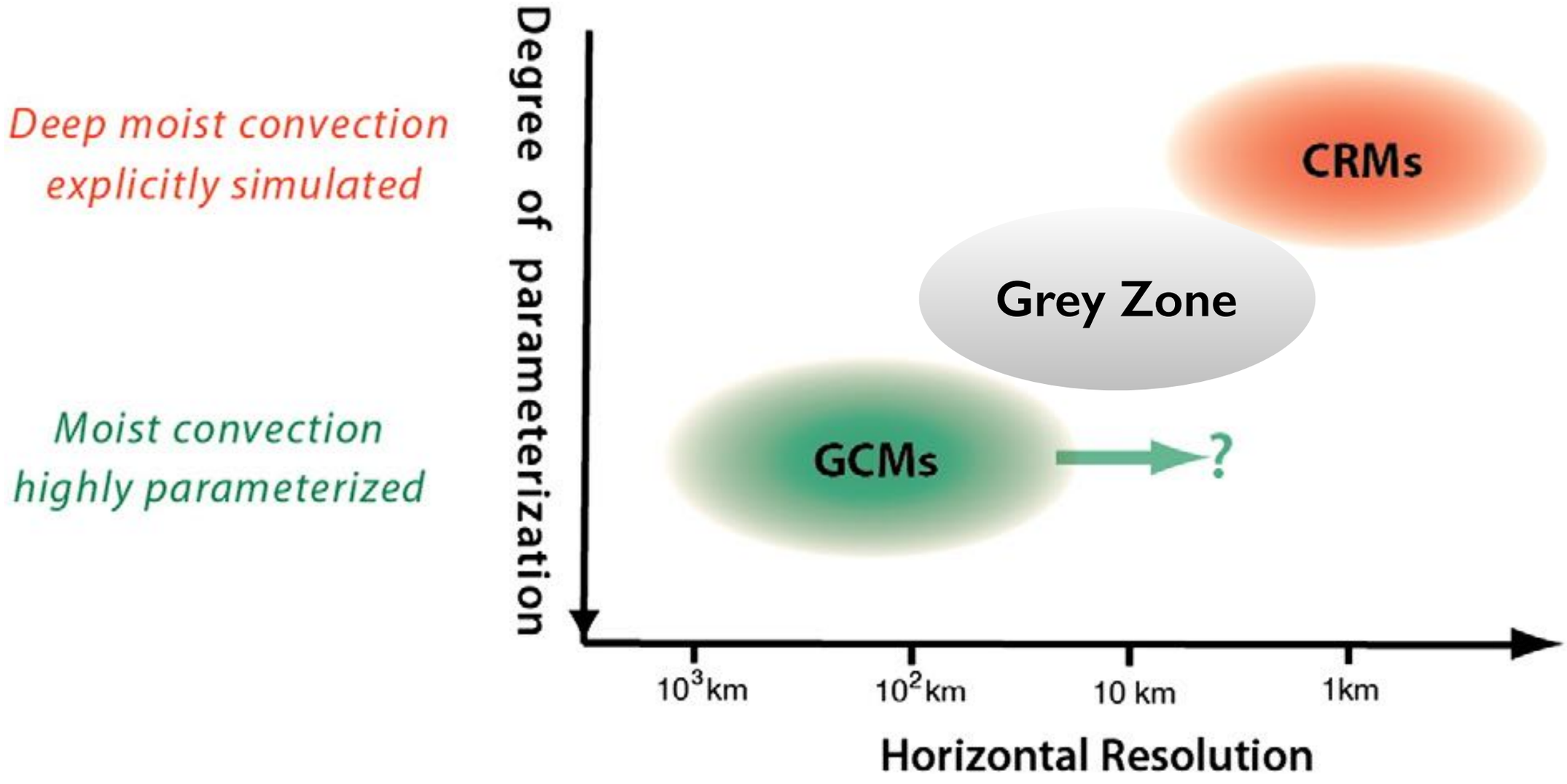


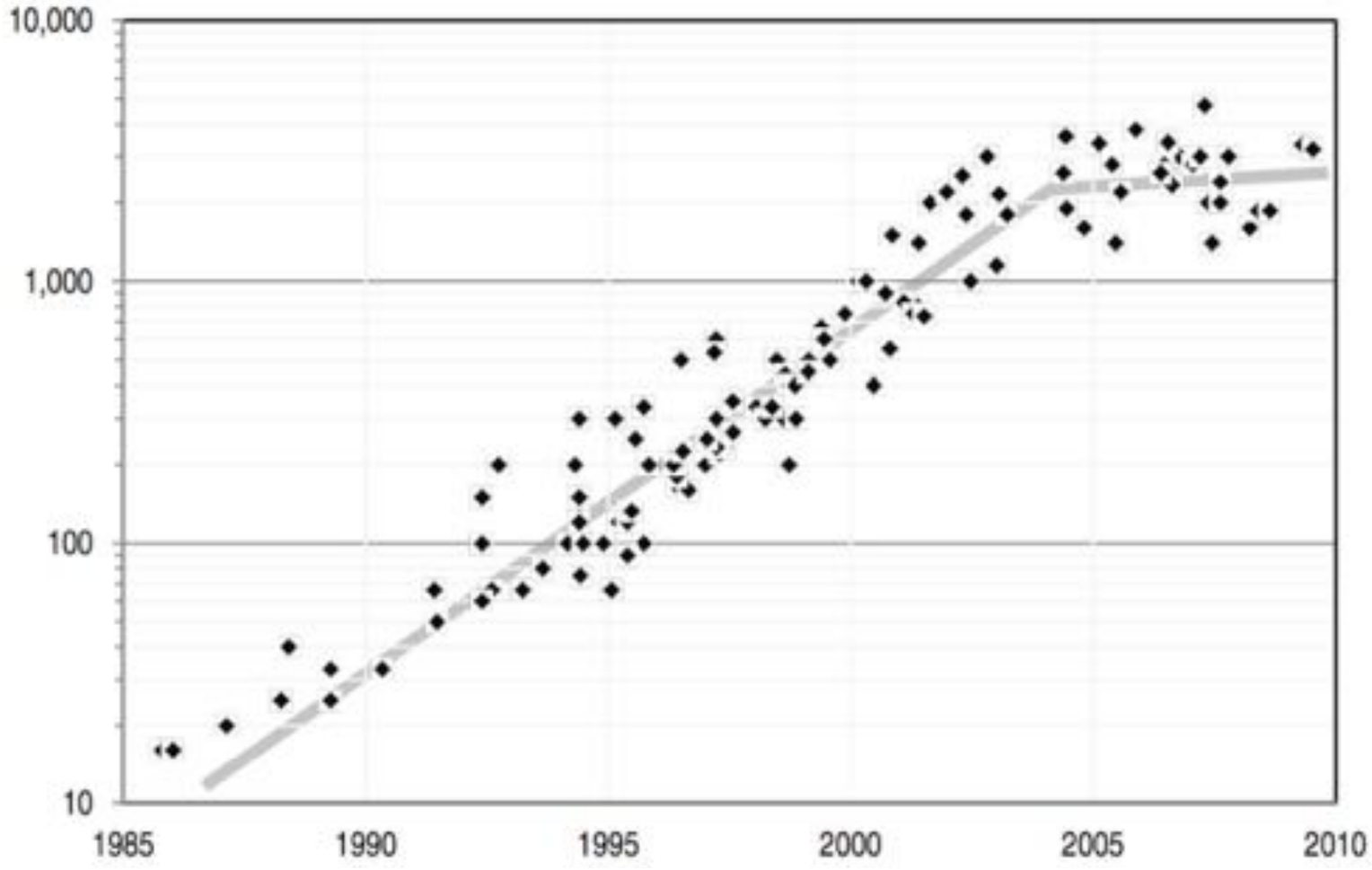
Figure from Akio Arakawa

Resolve clouds?

Modest increases in resolution don't improve the simulation of convective processes.

A horizontal grid-spacing of 4 km or finer is needed.

Where technology is leading us



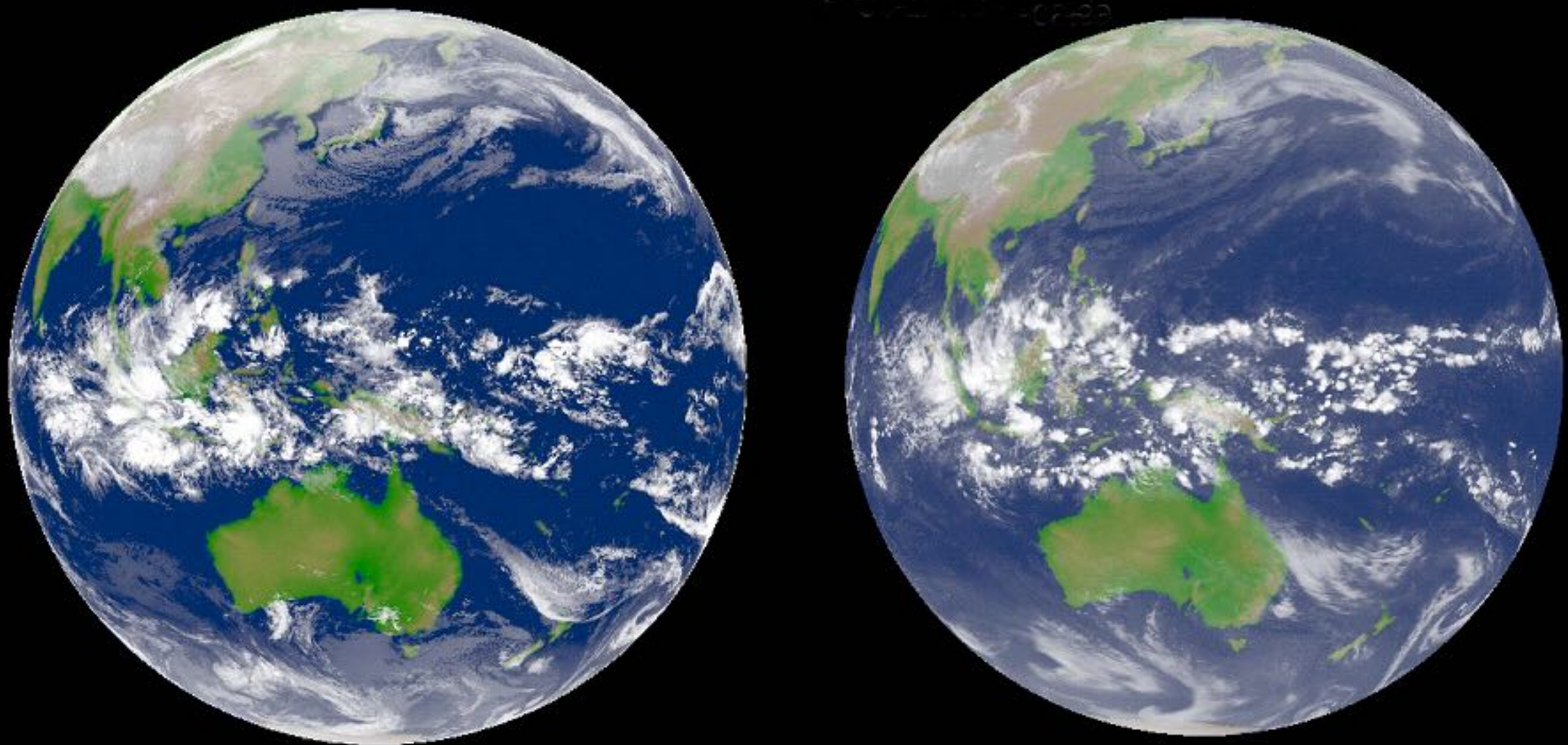
Massive parallelism encourages us to drastically refine our grids.

Obama orders effort to build first exascale computer

— *Science*, last week

Global cloud-resolving models

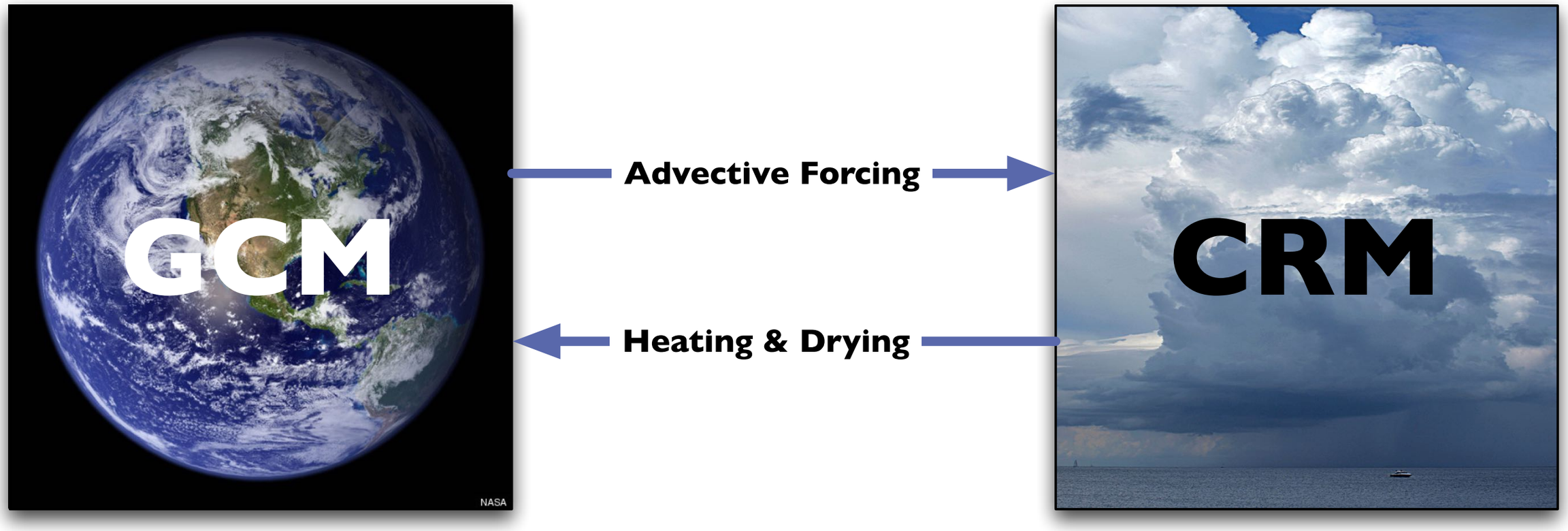
Horizontal grid spacing of 4 km or less



Even with exascale computers, century-long climate simulations with GCRMs will not be feasible, because the computations are not sufficiently parallelizable.

Slide from Hiro Miura

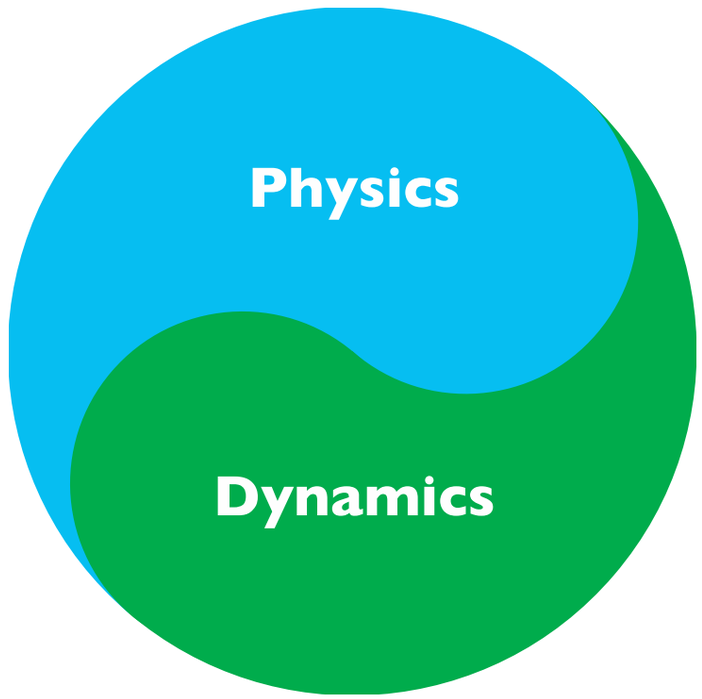
But remember that the MMF is embarrassingly parallel.



“Super-Parameterization”

An MMF can perform century-long climate simulations *today*.
We have already done it.

How an MMF uses the computer time



99%

Embarrassingly parallel

1%

The CPU time needed is much greater than for a conventional model, but the wall-clock time required is comparable to that of a conventional model.

MMFs are the best way forward now, and maybe for many years to come.

We built this.

MMF community

1. Colorado State University
2. NASA Goddard Space Flight Center
3. University of Washington
4. NASA Langley Research Center
5. Lawrence Berkeley National Laboratory
6. Scripps Institution of Oceanography
7. Earth System Research Laboratory
8. National Center for Atmospheric Research
9. Pacific Northwest National Laboratory
10. Scripps Institution of Oceanography
11. State University of New York at Stony Brook
12. Massachusetts Institute of Technology
13. Indian Institute for Tropical Meteorology
14. Harvard University
15. University of Chicago
16. George Mason University
17. University of California at Irvine
18. ECMWF
19. University of Oxford
20. DOE's Accelerated Climate Model for Energy*

Legacy Concepts

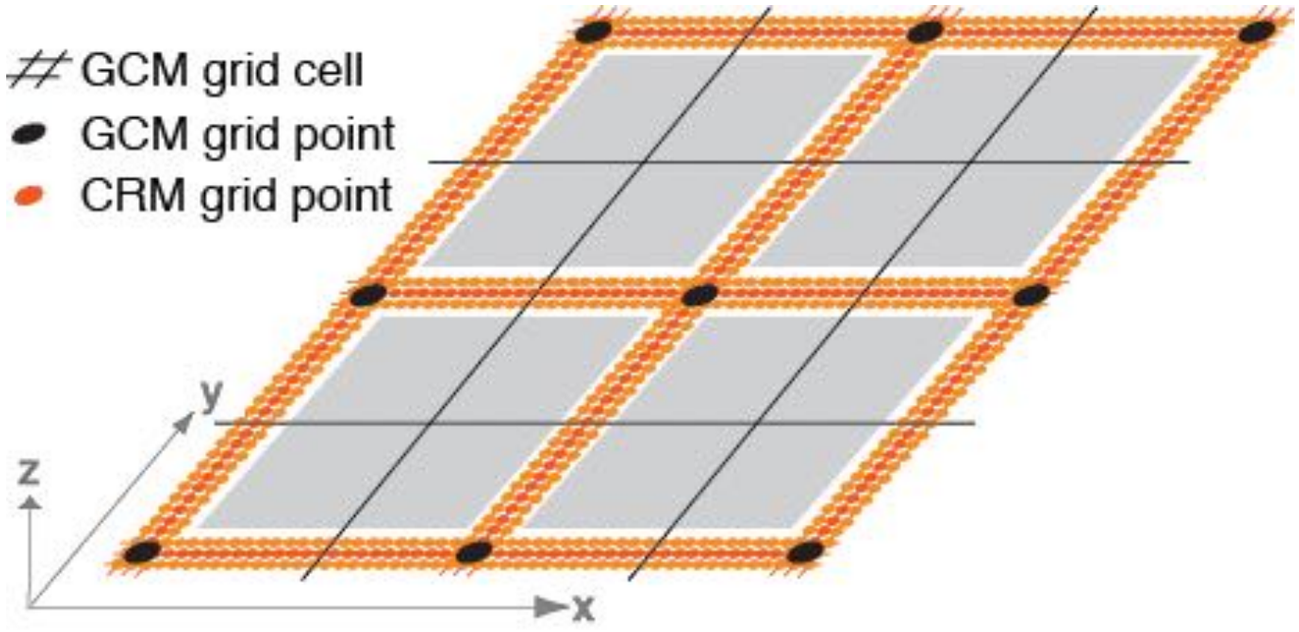
- MMF, as in SP-CAM
- Q3D MMF
- Unified System of equations
- Vector Vorticity Model
- Unified Parameterization

Q3D MMF

The two-dimensional grid of the original MMF is replaced by a minimally three-dimensional grid of CRM "channels."

The artificial periodic boundary conditions of the original MMF are eliminated, so that the CRM channels extend across GCM grid cell boundaries.

The new MMF is called "quasi-three-dimensional," or Q3D for short.



The Q3D MMF allows convection to propagate across GCM cell boundaries.

The Q3D MMF can include the effects of realistic topography, as Joon-Hee showed.

The Q3D MMF can simulate vertical momentum transport by convection and waves.

The Unified System of equations

Arakawa and Konor (2009)

- Filters vertically propagating acoustic waves, but not the Lamb wave.
- Yields *accurate* elastic solutions for large-scale quasi-hydrostatic motion and *accurate* anelastic solutions for small-scale nonhydrostatic motion.
- Uses the thermodynamic and momentum equations *without approximation*. The continuity equation uses the quasi-hydrostatic density.
- Does not need a basic state.
- Conserves total energy.
- Covers a wide range of horizontal scales, so that it is suitable for use in global cloud resolving models.

I believe that the Unified System is pretty close to the final word on the subject.

Game over.

Weather on all scales is dominated by vorticity dynamics.

Vertical component of the vorticity

Horizontal vorticity vector

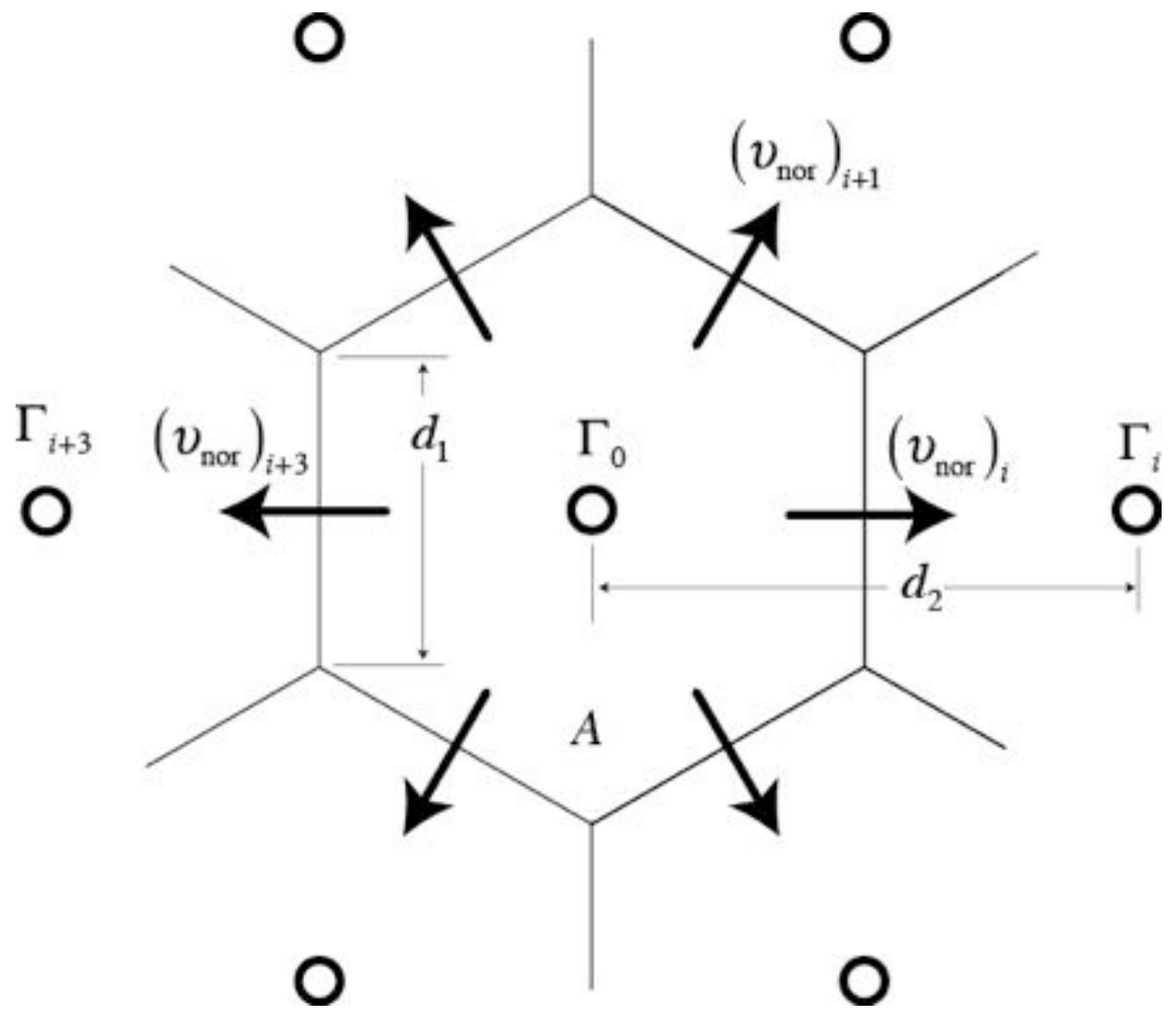
The VVM predicts the horizontal vorticity vector.

- This makes it possible to accurately simulate the vorticity dynamics, which then determines the wind field.
- When combined with the Unified System, the VVM can determine the vertical velocity in a beautifully simple way.

Global VVM

The VVM has been developed and applied as a "regional" model.

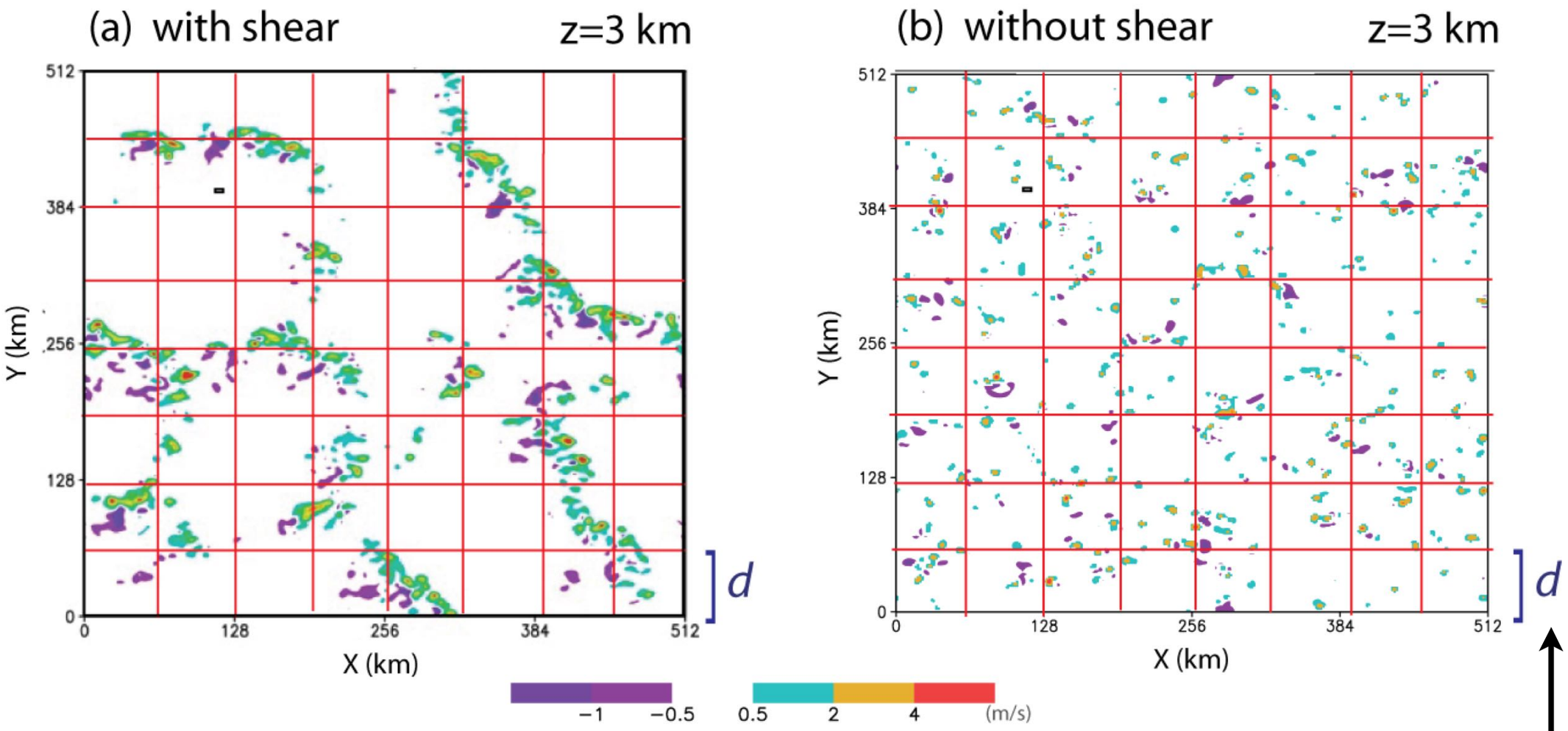
On Thursday morning, Celal Konor will discuss recent work towards the creation of a global (non-hydrostatic) VVM.



Into the grey zone:
The Unified Parameterization

- Grow individual clouds when/where the resolution is high.
- Parameterize convection when/where resolution is low.
- Continuous scaling.
- One set of equations, one code.
- Physically based.

Use a CRM to test ideas.



Vertical velocity 3 km above the surface

Subdomain size, used to analyze dependence on grid spacing

Starting point

For the case of a top-hat PDF, we can derive

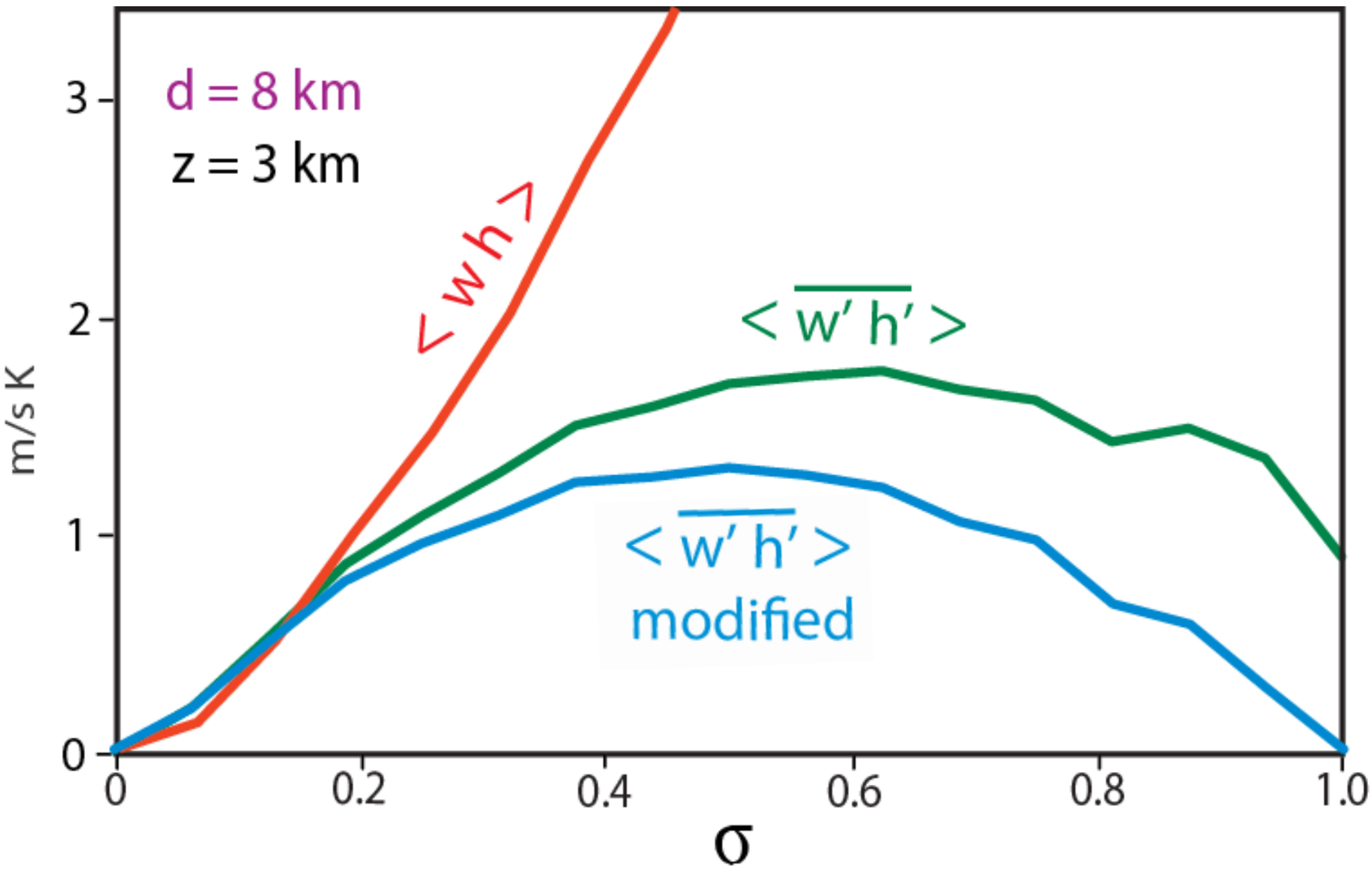
$$\overline{w'\psi'} \equiv \overline{w\psi} - \overline{w}\,\overline{\psi} = \sigma(1-\sigma)\Delta w \Delta\psi \,, \tag{1}$$

where

$$\overline{(\,)} \equiv \sigma(\,)_c + (1-\sigma)\tilde{(\,)} \text{ and } \Delta(\,) \equiv (\,)_c - \tilde{(\,)} \,, \tag{2}$$

σ is the fractional area covered by the updraft, an overbar denotes a domain mean, the subscript c denotes a cloud value, and a tilde denotes an environmental value. We expect Δw and $\Delta\psi$ to be independent of σ. In that case, (1) implies that $\overline{w'\psi'}$ is a parabolic function of σ.

Flux partitioning as function of sigma



$$\overline{w'\psi'} \equiv \overline{w\psi} - \overline{w}\,\overline{\psi} = \sigma(1-\sigma)\Delta w \Delta\psi$$

"Modified" means that the data is averaged over updrafts and environment before computing the flux. In other words, a "top-hat" structure is imposed by averaging.

Closure assumption

Define $\left(\overline{w'\psi'}\right)_E$ as the flux required to maintain quasi-equilibrium. The closure assumption used to determine σ is

$$\boxed{\sigma = \frac{\left(\overline{w'\psi'}\right)_E}{\Delta w \Delta\psi + \left(\overline{w'\psi'}\right)_E}}. \tag{3}$$

The quantities on the right-hand side of (3) are expected to be independent of σ. Eq. (3) is guaranteed to give

$$0 \le \sigma \le 1. \tag{4}$$

By combining (3) and (1), we obtain

$$\boxed{\overline{w'\psi'} = (1-\sigma)^2 \left(\overline{w'\psi'}\right)_E}. \tag{5}$$

This shows that the actual flux is typically less than the value required to maintain quasi-equilibrium. In fact, the actual flux goes to zero as $\sigma \to 1$.

The Unified Parameterization is being tested in both the CAM and the GFS.

Global modeling landscape, 2000

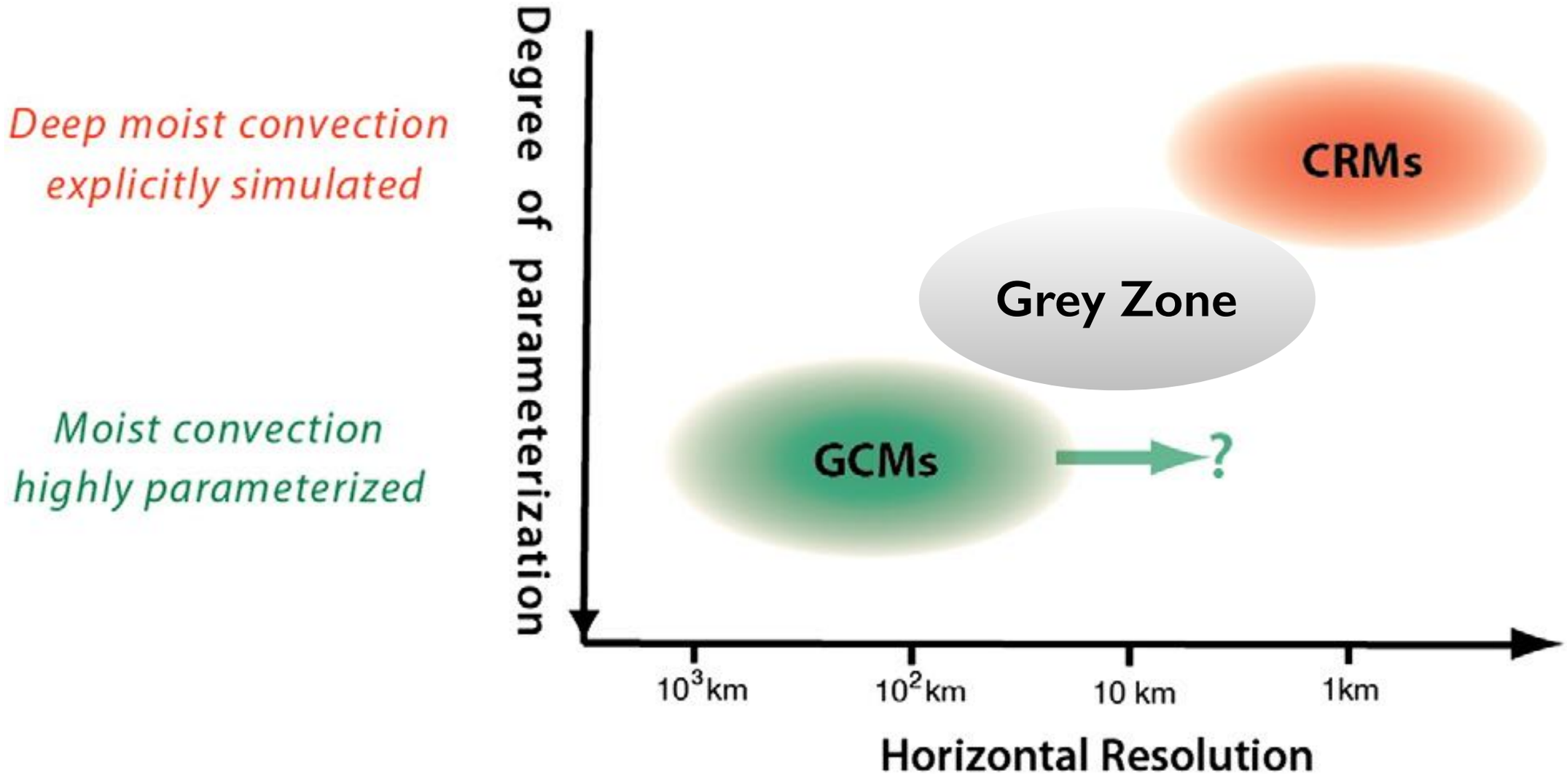
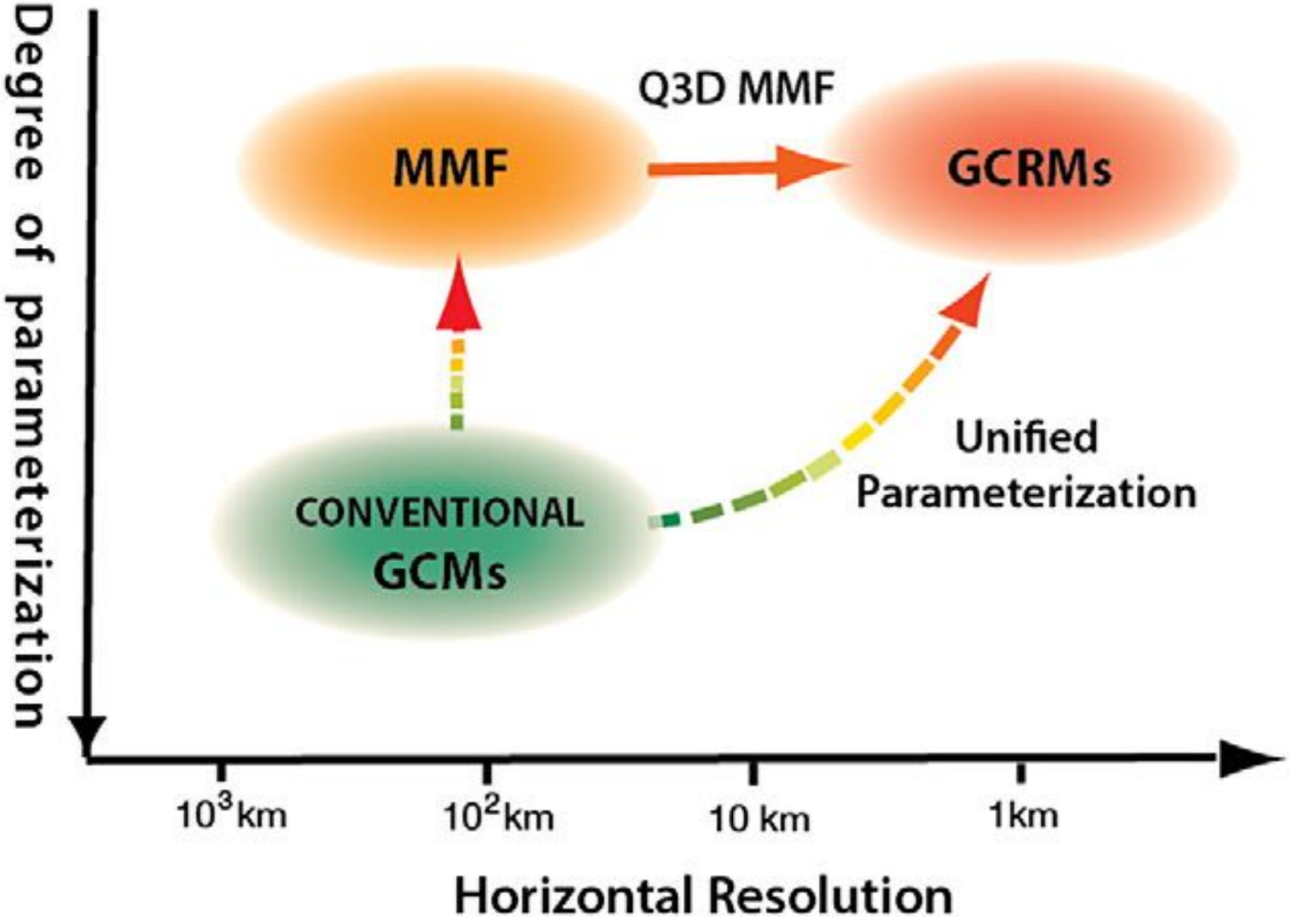


Figure from Akio Arakawa

Global modeling landscape, 2015

Deep moist convection explicitly simulated

Moist convection highly parameterized



Applications of SP-CAM

Focus on variability

- Diurnal cycle
- Extreme precipitation
- African Easterly Waves
- Tropical cyclones
- Monsoon variability
- MJO
- ENSO
- Climate change

http://www.cmmap.org/research/pubs-mmf.html

Diurnally forced, eastward-moving summer storms

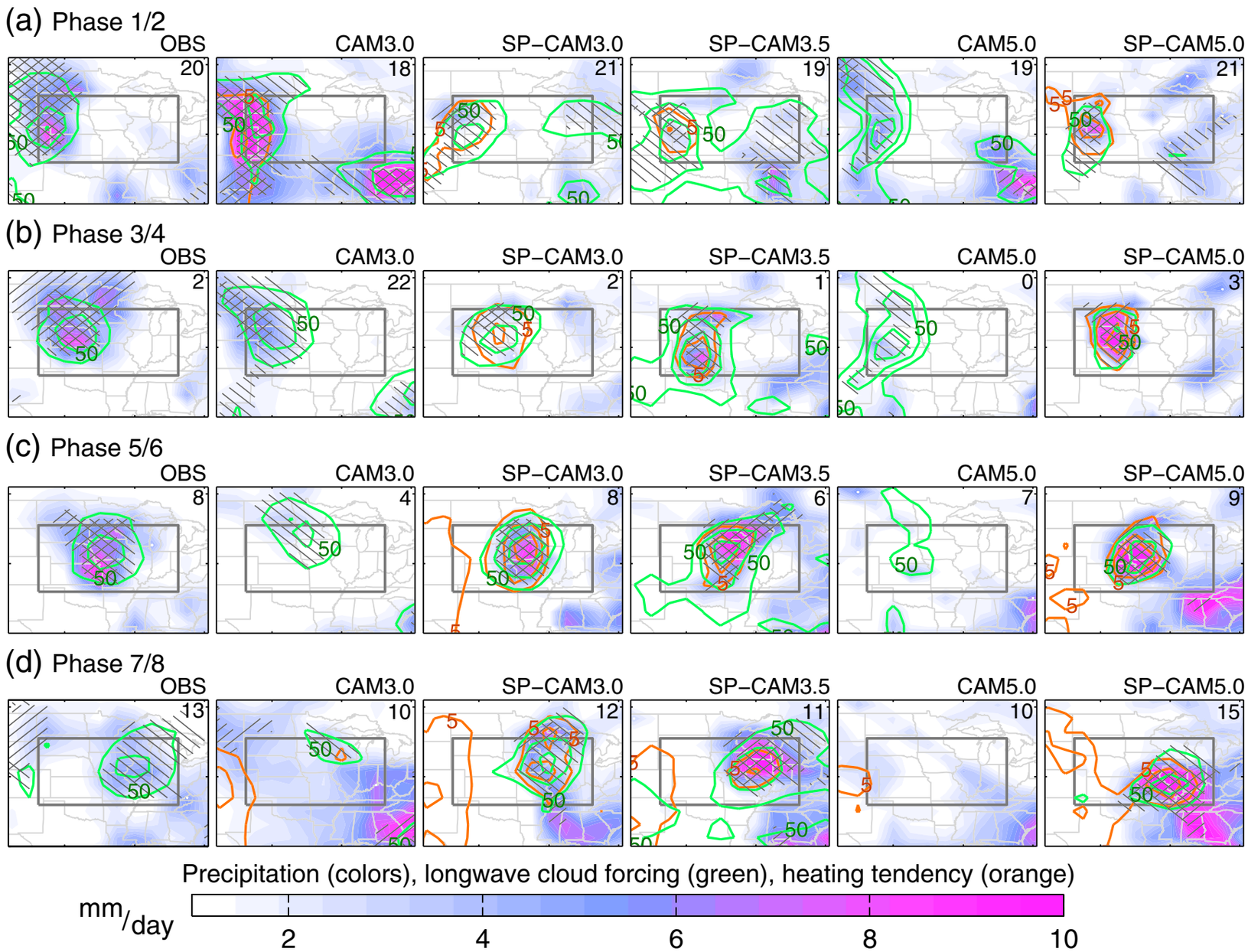
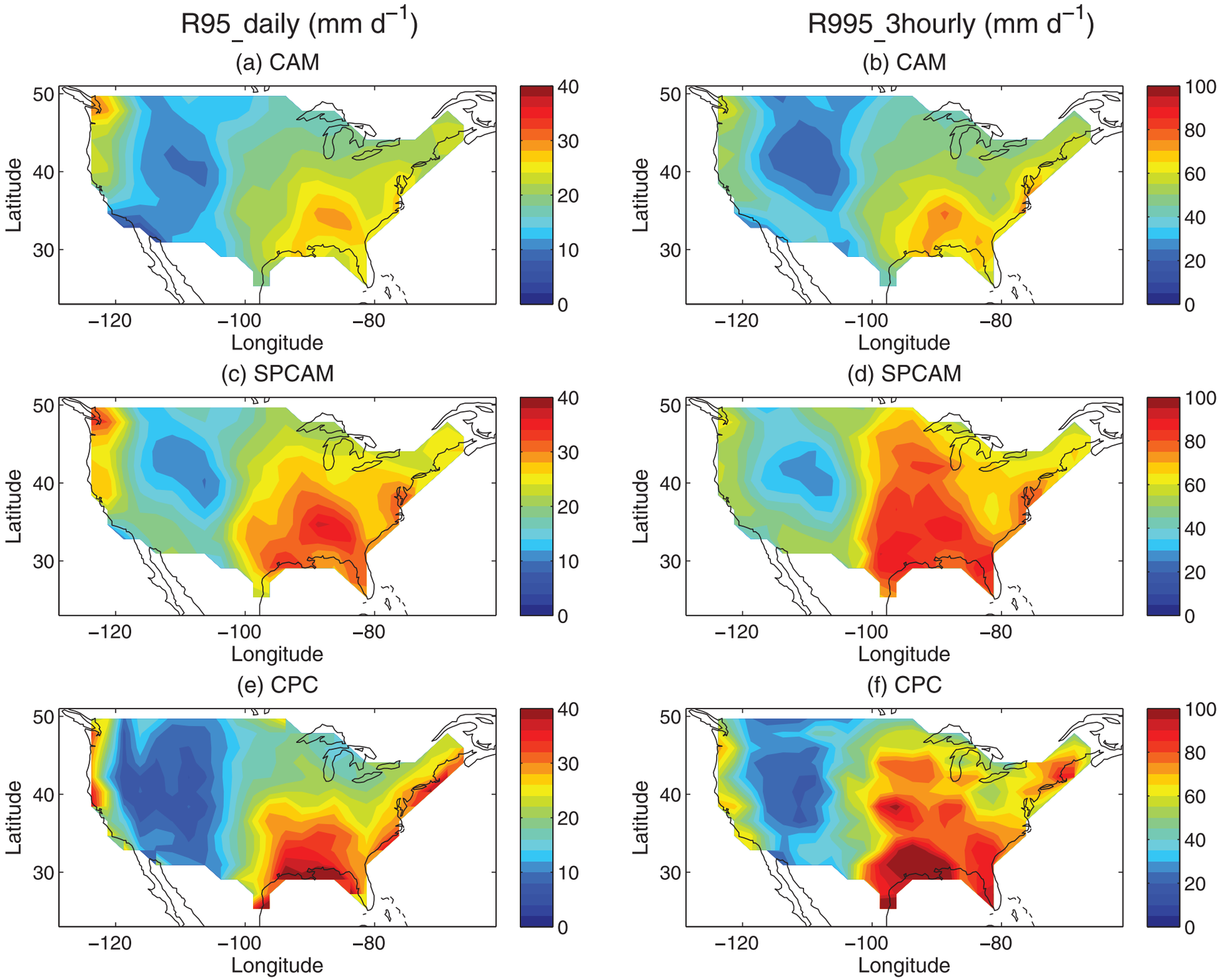


Figure 3. Composite event phase average of precipitation (colors, mm/d), longwave cloud forcing (green, increments of 25 W/m^2), and vertical standard deviation of model heating tendency (orange, increments of 2.5 K/d) for phases (a) 1 and 2, (b) 3 and 4, (c) 5 and 6, and (d) 7 and 8 in observations and models; right/45° (left/−45°) slashes indicate that precipitation (longwave cloud forcing) is significant at 95% confidence interval, the gray box is the EOF analysis region, and the numbers are the mean local diurnal time (CST).

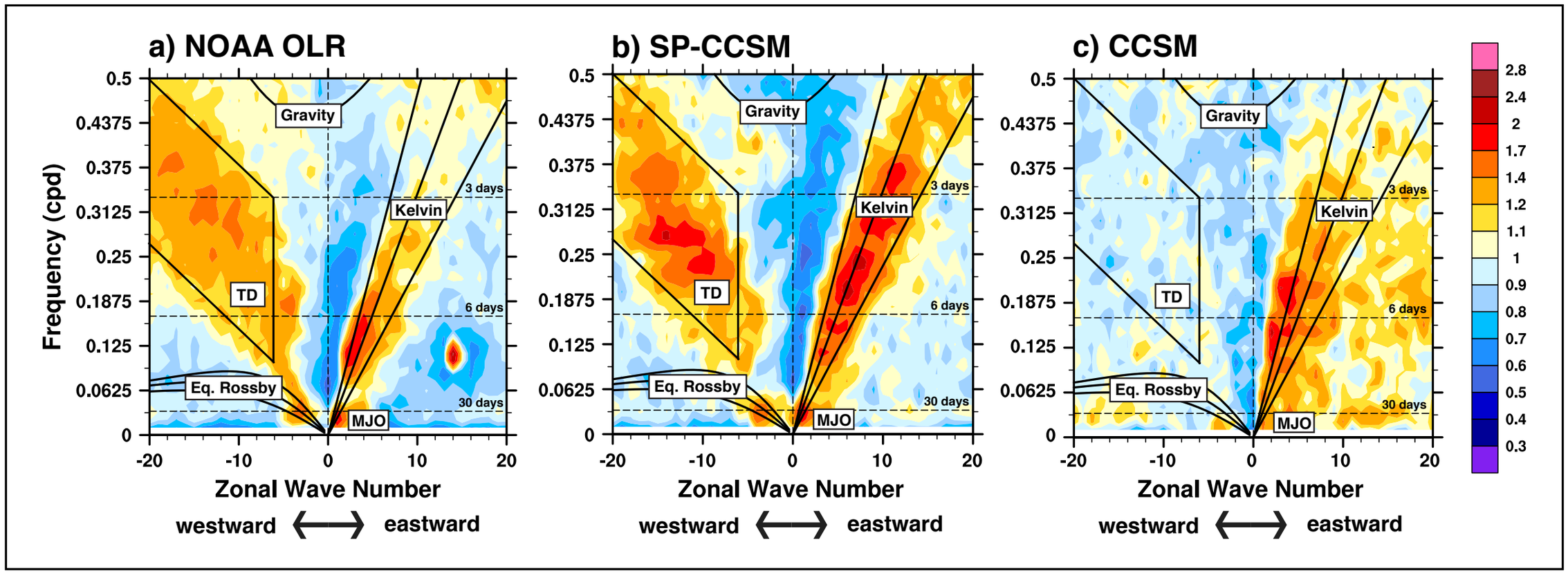
Kooperman et al. 2013

Extreme precipitation



Li, Rosa, Collins & Wehner, 2012

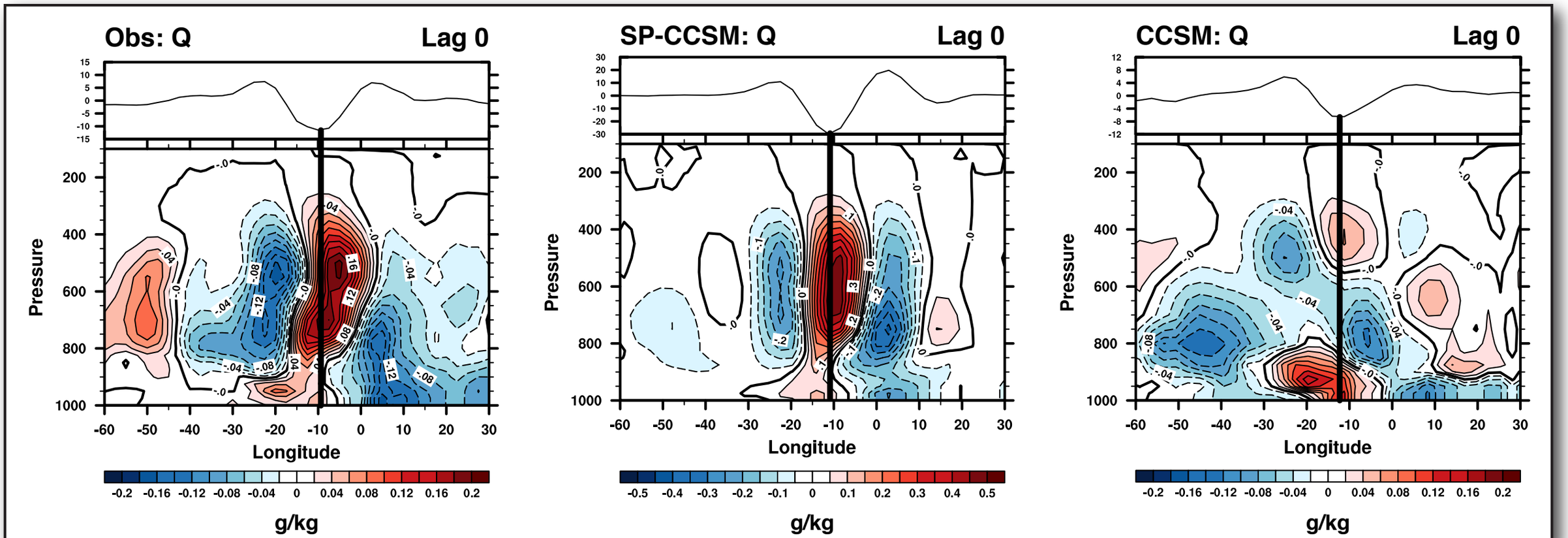
African Easterly Waves



Symmetric signal to noise, 15ºN to 15ºS

Slide from Rachel McCrary

Once again, moisture is critical.

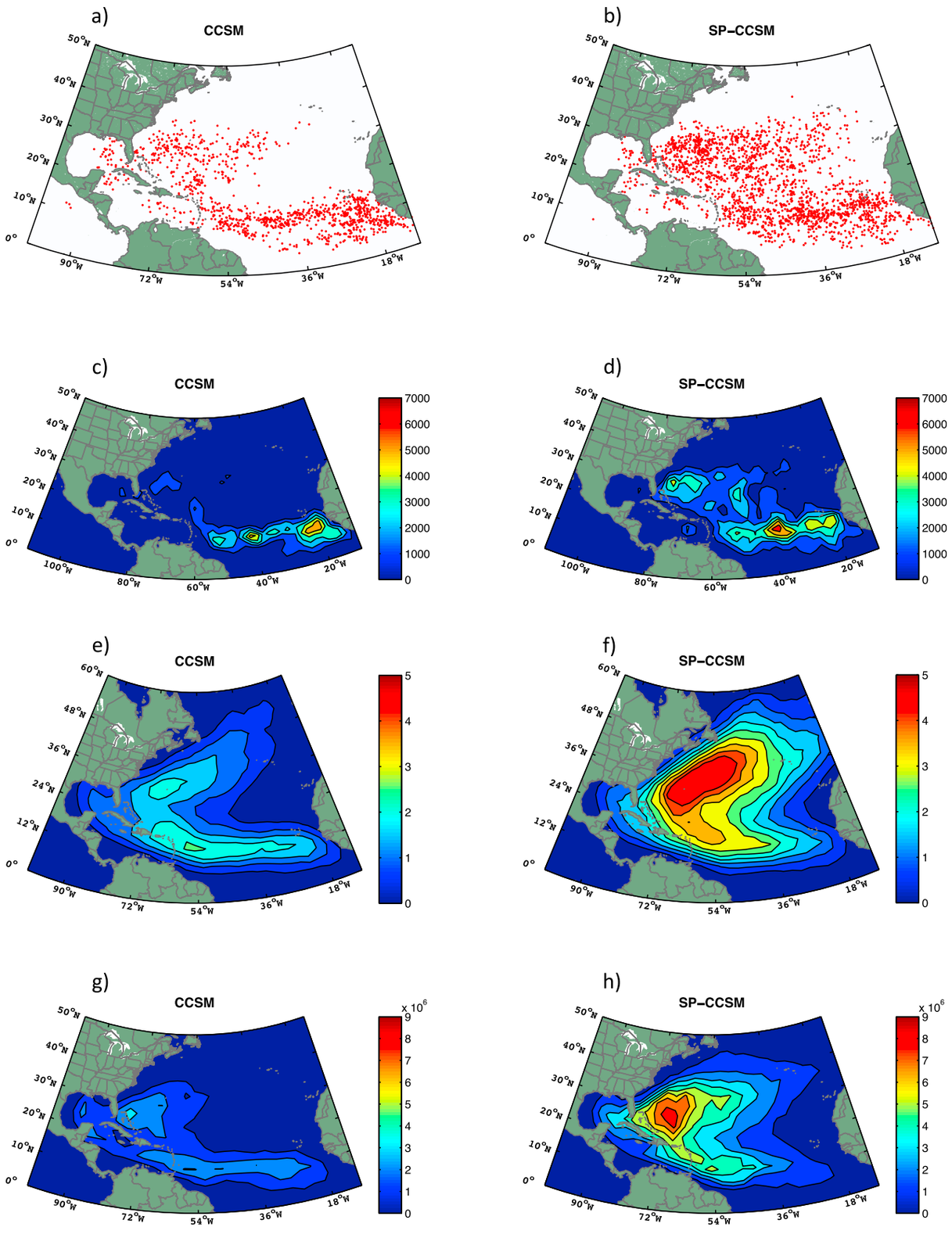


Specific humidity anomalies along 10°N regressed onto the TD filtered time series of OLR from the basepoint 10°N, 10°W.

Slide from Rachel McCrary

Down-scaled tropical cyclones

Kerry Emanuel's downscaling scheme



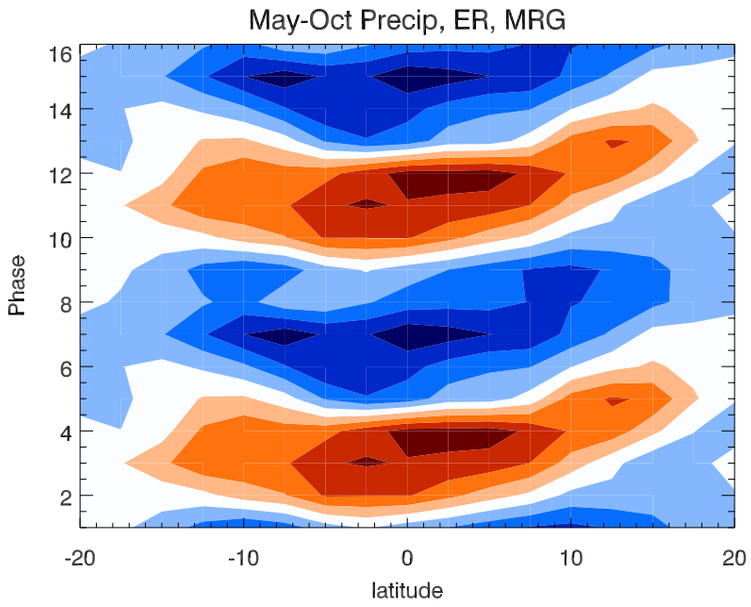
Comparison between the TC activity simulated by CCSM (left) and SP-CCSM (right). (a, b) Genesis points, (c, d) genesis density accumulated in a $5^{\circ} \times 5^{\circ}$ area, (e, f) track density accumulated in a $5^{\circ} \times 5^{\circ}$ area, and (g, h) power dissipation.

Stan GRL 2012

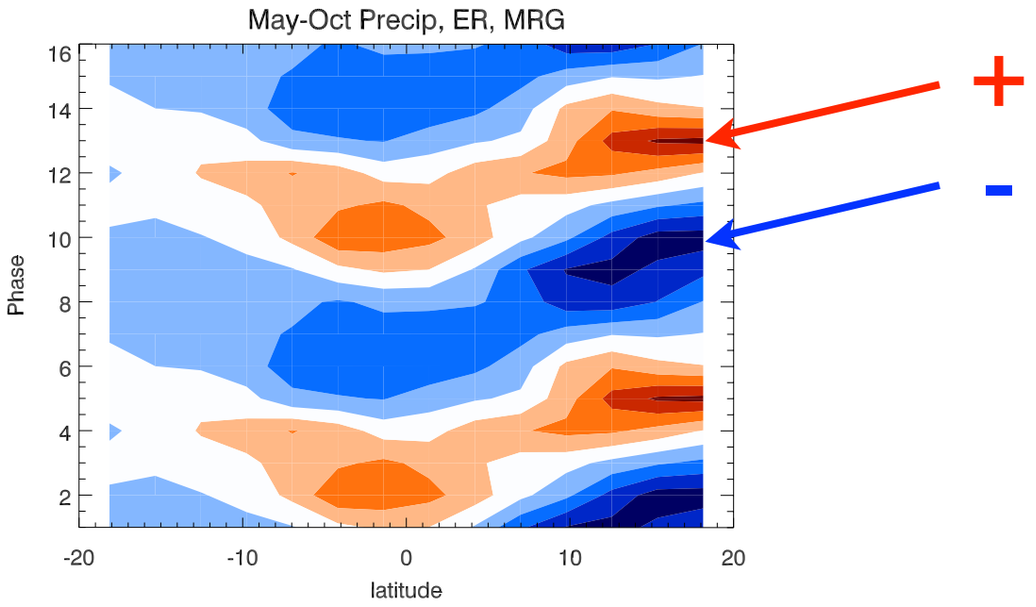
Northward propagation of Asian monsoon rainfall

(2 cycles shown)

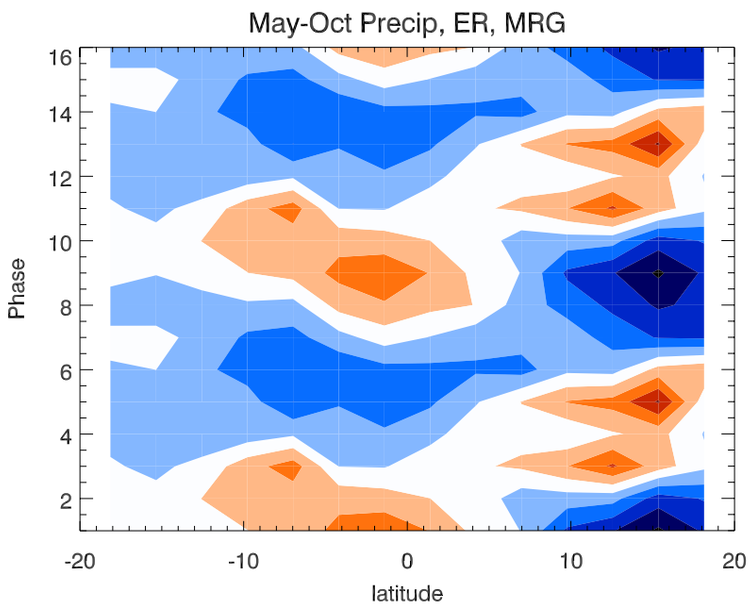
OBS



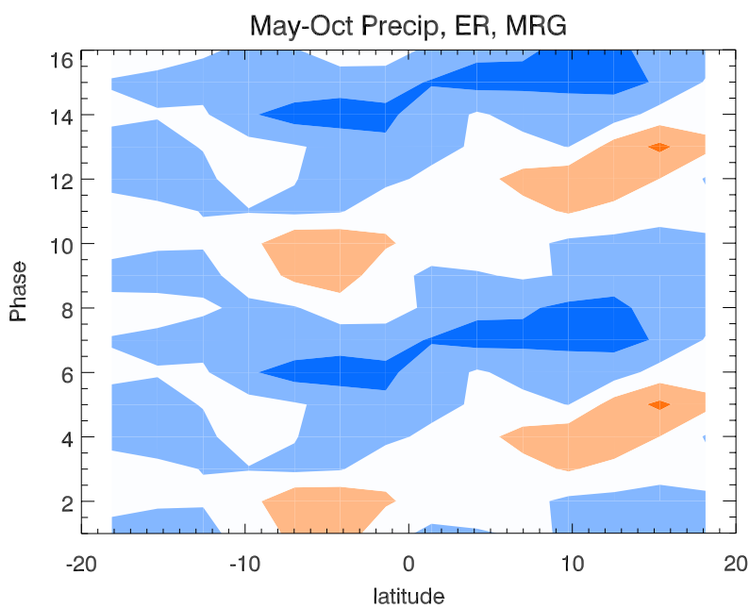
SpCCSM



SpCAM



CCSM



Precip' (red= positive anomaly)

Slide from Charlotte DeMott

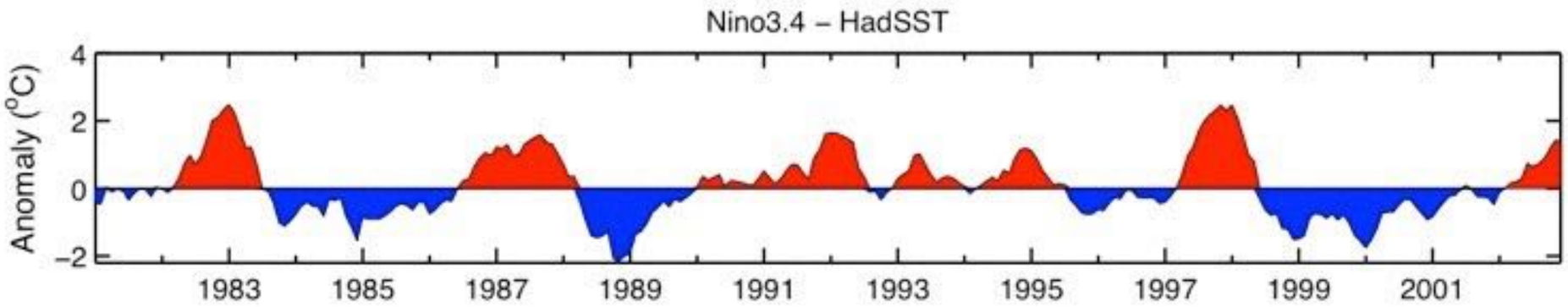
MJO

When CMMAP started, we had a model that could produce a realistic *simulation* of the MJO.

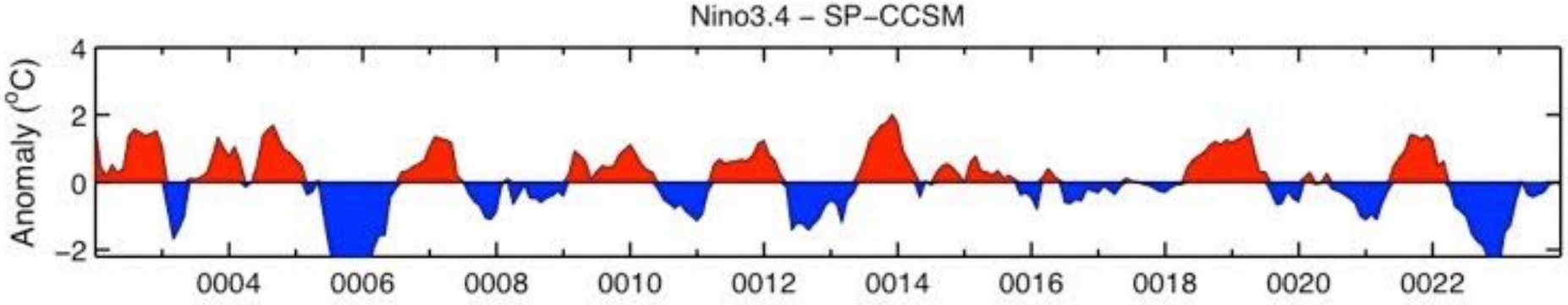
As a result of the work summarized by Eric Maloney yesterday afternoon, we now have a much better *understanding* of the MJO.

ENSO

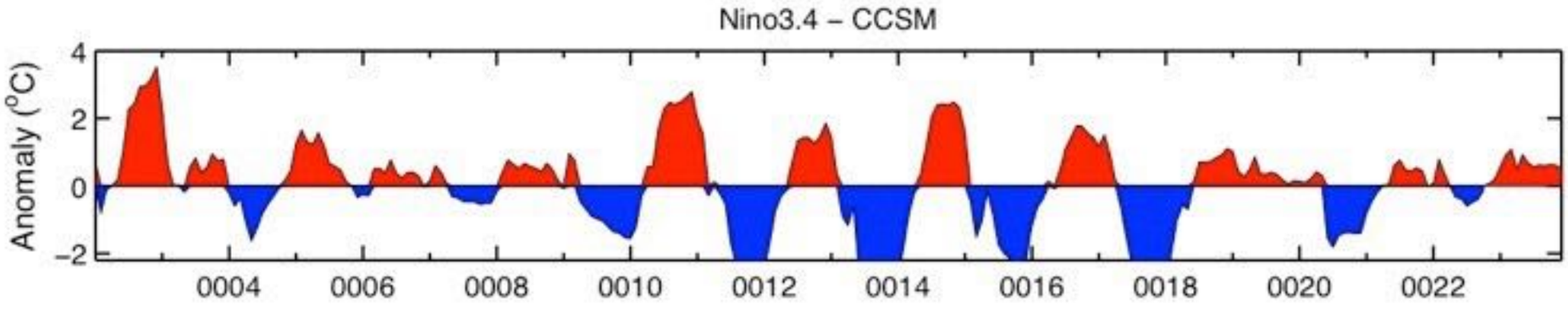
Niño 3.4 (5S-5N,170W-120W)



OBS



SP-CCSM

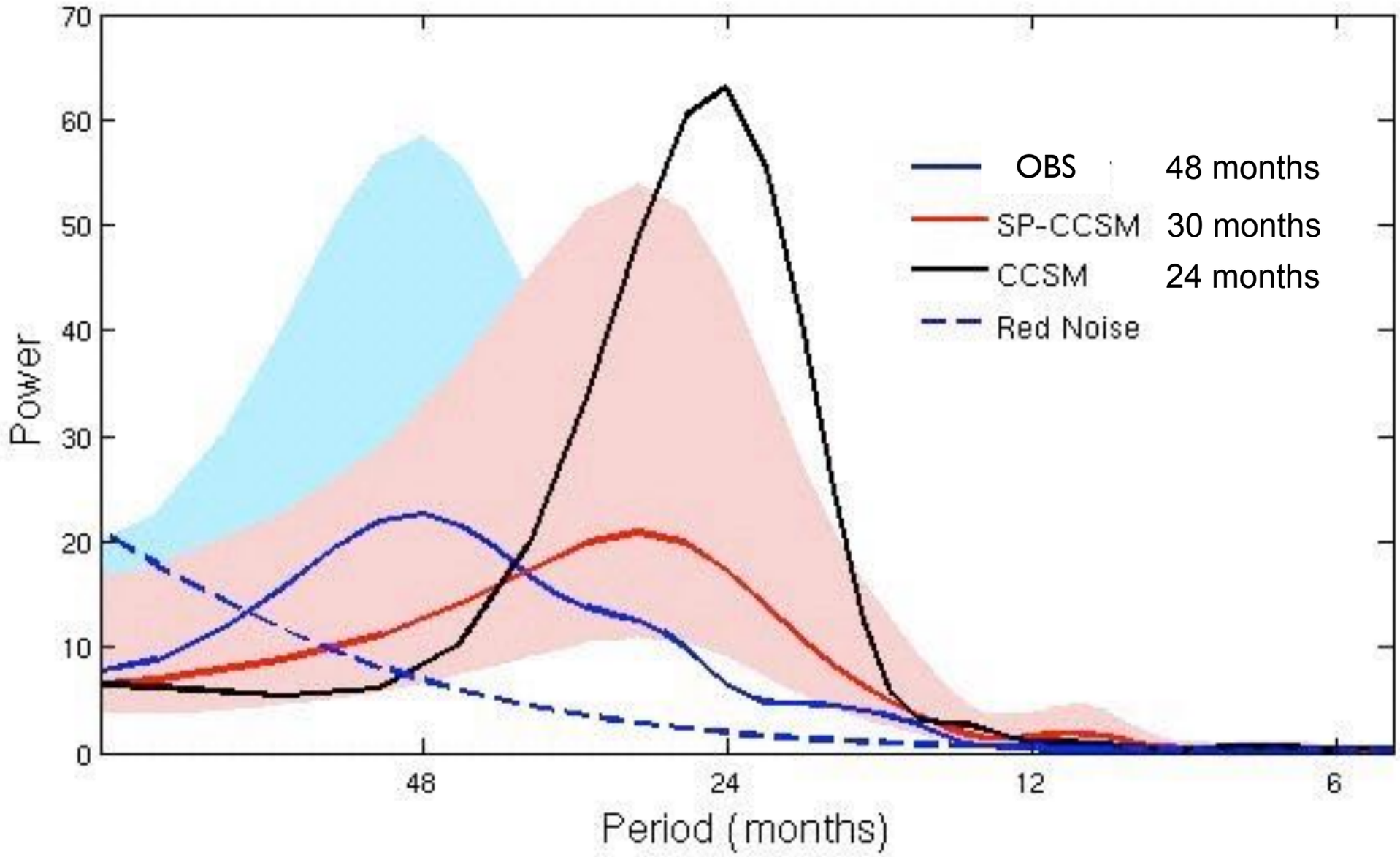


CCSM

Slide from Cristiana Stan

ENSO Simulation

Niño 3.4 (5°S-5°N,170°W-120°W)

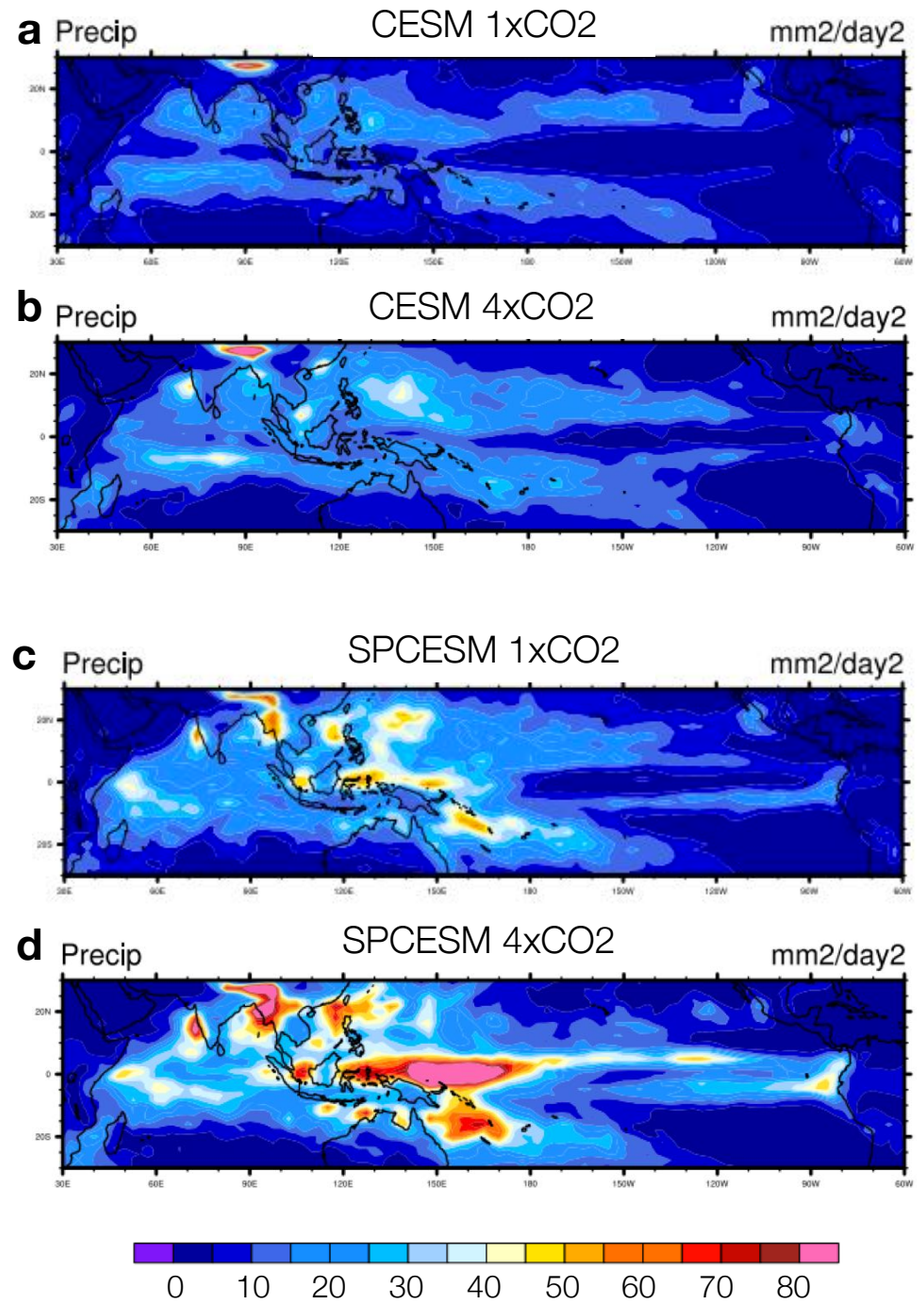


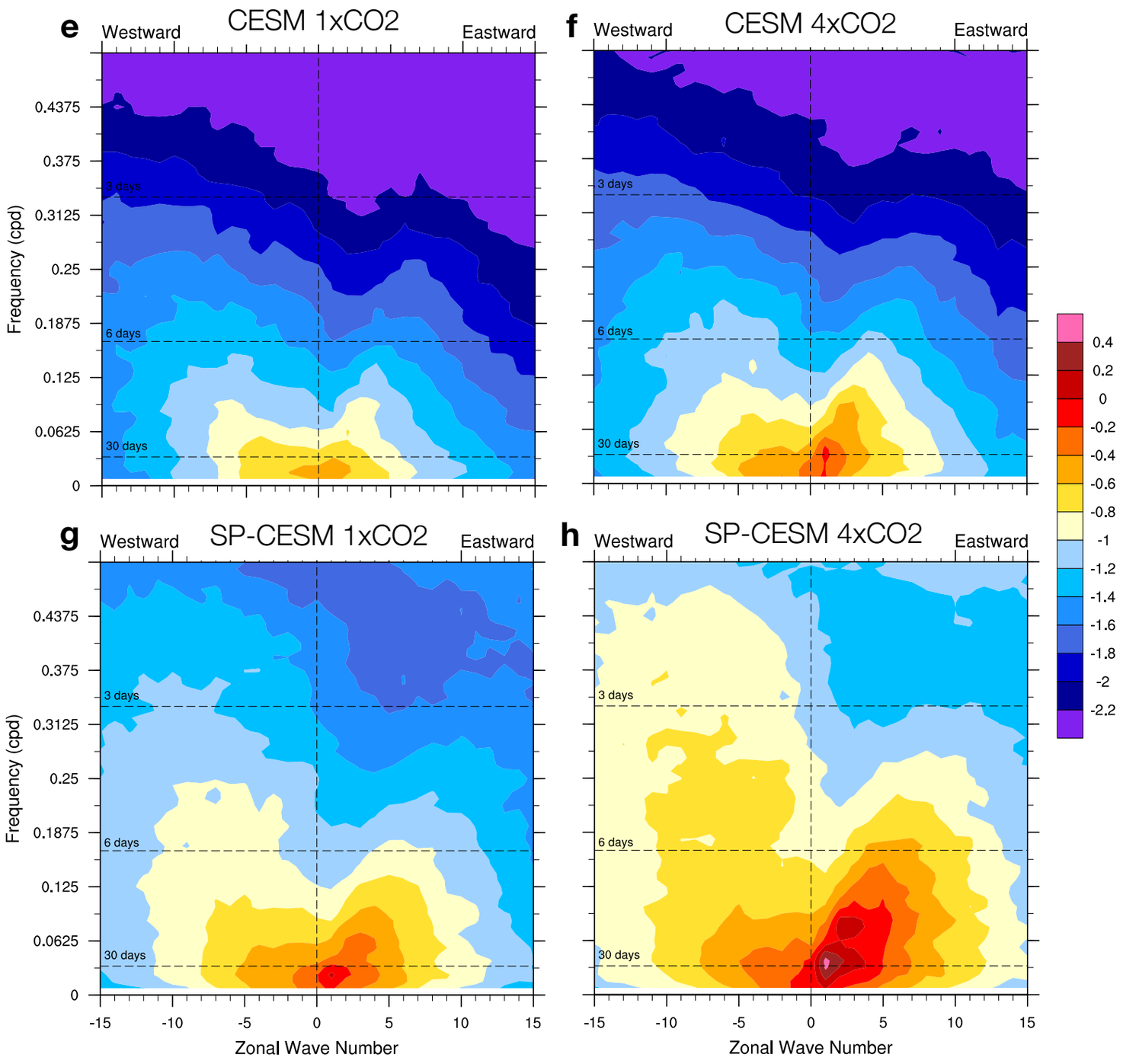
Slide from Cristiana Stan

How will the MJO change in a warmer climate?

- Influence on tropical rainfall
- Coupling to the Asian Summer Monsoon
- Modulation of tropical cyclones

A tremendous future intensification of the MJO



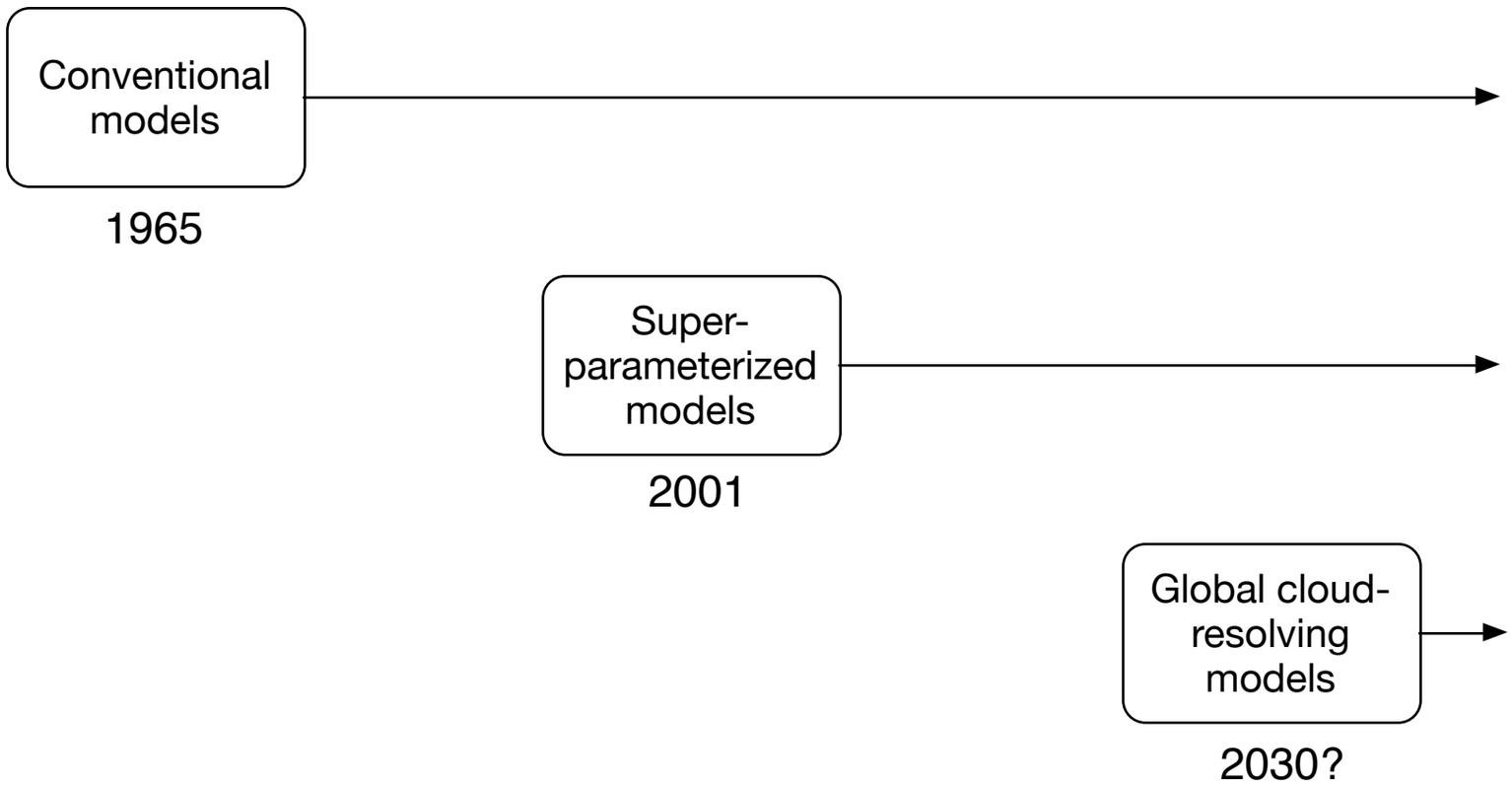


Arnold, N., M. Branson, M. A. Burt, D. S. Abbot, Z. Kuang, D. A. Randall, and E. Tziperman, 2014: Significant consequences of explicit representation of atmospheric convection at high CO_2 concentration. *Proc. Nat. Acad. Sci.*, **111**, 10943-10948.

MMF community

1. Colorado State University
2. NASA Goddard Space Flight Center*
3. University of Washington
4. NASA Langley Research Center
5. Lawrence Berkeley National Laboratory
6. Scripps Institution of Oceanography
7. Earth System Research Laboratory**
8. National Center for Atmospheric Research
9. Pacific Northwest National Laboratory
10. Scripps Institution of Oceanography
11. State University of New York at Stony Brook
12. Massachusetts Institute of Technology*
13. Indian Institute for Tropical Meteorology*
14. Harvard University
15. University of Chicago
16. George Mason University
17. University of California at Irvine
18. ECMWF*
19. University of Oxford
20. DOE's Accelerated Climate Model for Energy*

Coexistence going forward



- Conventional parameterizations are not going away, but will become resolution-independent (following the example of the Unified Parameterization) and better overall.
- Super-parameterized models are being used for century-long climate simulations now. CMMAP has made this possible.
- GCRMs will be used for century-long climate simulations someday.

About super-parameterization

- Even a simple CRM is much better than a conventional parameterization of 2015.
- Super-parameterized models are evolving. Version 2 is coming.
- Super-parameterization is a powerful tool for climate modeling, and maybe weather prediction too.

Nightfall

Funding ramp down

Year 1
$3,004,702

Years 2- 8
$4,000,0000/year

Year 9
$3,200,000

Year 10
$2,656,000

Years 11-99
$0

The Year 10 budget is set.

- We have made numerous funding cuts over the past two years.
- How are projects being "closed out?"
- How and to what extent is work being transitioned to other sources of support?

We will stay in our building.

After the STC's sunset, what happens to the

- Research ideas?
- Models?
- Data?
- E&D initiatives?
- KT activities?
- People?

We are not retiring.

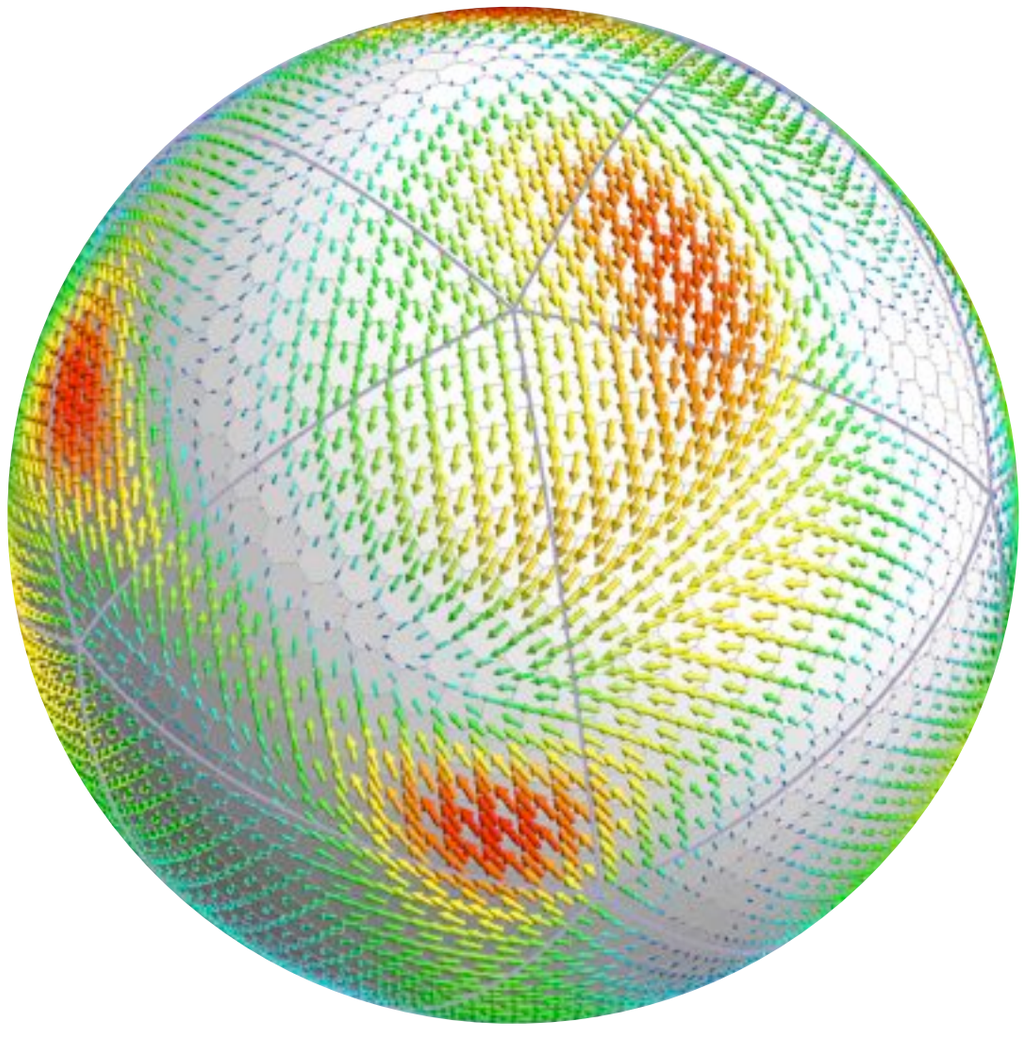
We will continue developing our ideas, but will struggle to pay for it.

Some downscaling is inevitable.

ESMEI

(Earth System Modeling and Education Institute)

To ensure that CMMAP will lead to a sustainable and identifiable research and education enterprise at Colorado State University (CSU), CSU has created an *Earth System Modeling and Education Institute (ESMEI)*, as CMMAP's institutional legacy.

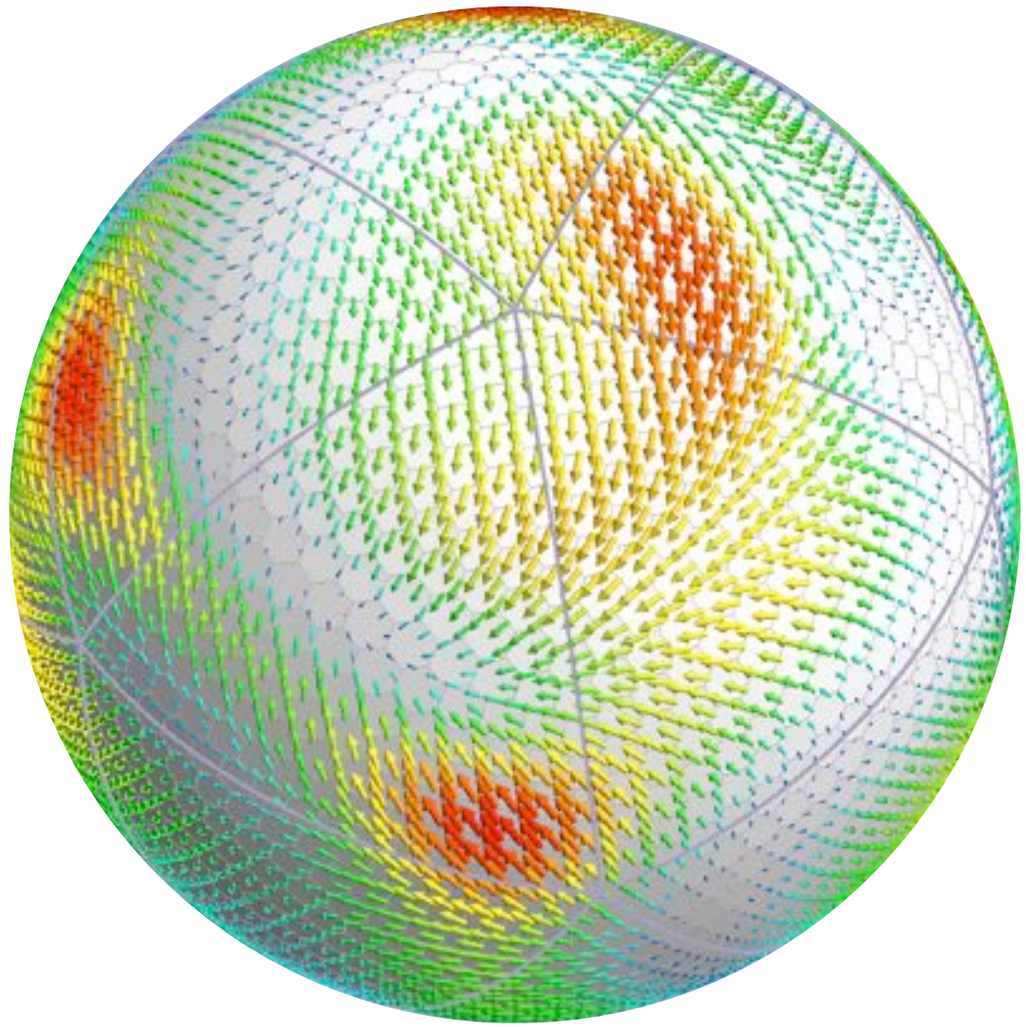


The “Earth System” in ESMEI

ESMEI is closely associated with CSU’s Department of Atmospheric Science, but will also welcome participation by faculty and staff from other CSU units. Our intention is that the Institute will have a broad Earth Science focus, and will help to make connections among Earth scientists, across the University.

ESMEI

- Support for 15-20 graduate student modelers-in-training
- Two international workshops per year
- Visiting scientists
- Research and administrative staff



The launch date for ESMEI was July 1, 2014, so that ESMEI is ramping up as CMMAP ramps down. ESMEI has been chartered for seven years (out to five years after the end of CMMAP), with the possibility of renewal.

Base funding for ESMEI

CSU is providing base funding to ESMEI, in part to support costs that cannot be paid by direct charges to external grants.

This generous support is coming from CSU's Department of Atmospheric Science, the College of Engineering, and the Vice President for Research.

The base funding is ramping up over three years: $60 K the first year (starting July 1, 2014), $120 K the second year, and $240 K per year thereafter.

This is a done deal.

It won’t be enough.

ESMEI’s external funding will come from federal agencies and private foundations.

Skunkworks

The model development work that CMMAP has done would be difficult if not impossible in a laboratory environment.

Some of us have been discussing the possibility of proposing a multi-university global modeling consortium, with multi-agency support.

Teach your children well.

CSU is ***the only university in the U.S.*** that does in-house global atmospheric model development.

CSU is ***the only university in the U.S.*** where students can learn about climate modeling from faculty members who build climate models.

There used to be others.

We are the last man standing.

How to make progress

Big idea

Talent

Funding

Extended duration

No operational responsibilities

Centralized direction

Why should this be the exception?

nature International weekly journal of science

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Archive > Volume 477 > Issue 7366 > Comment > Article

NATURE | COMMENT

More time for research: Fund people not projects

John P. A. Ioannidis

Nature **477**, 529–531 (29 September 2011) | doi:10.1038/477529a

Published online 28 September 2011

John P. A. Ioannidis proposes ways to save scientists from spending all their time writing grants.

Subject terms: Research community

The research funding system is broken: scientists don't have time for science any more. Because they are judged on the amount of money they bring to their institutions, writing, reviewing and administering grants absorb their efforts[1]. The requirement that they promise taxpayers specific results to justify research tends to invite either exaggeration or boringly predictable projects. Yet the research behind 30% of the pivotal papers from Nobel laureates in medicine, physics and chemistry was done without direct funding[2].

Every scientist recognizes this problem and hopes for a solution. Although detailed proposals may be indispensable for some projects, such as rigorous clinical trials and large-scale collaborative research, ideas abound for more efficient ways to fund general research. Some organizations are already experimenting. Multiple options could co-exist, with portions of the budget earmarked for different schemes.