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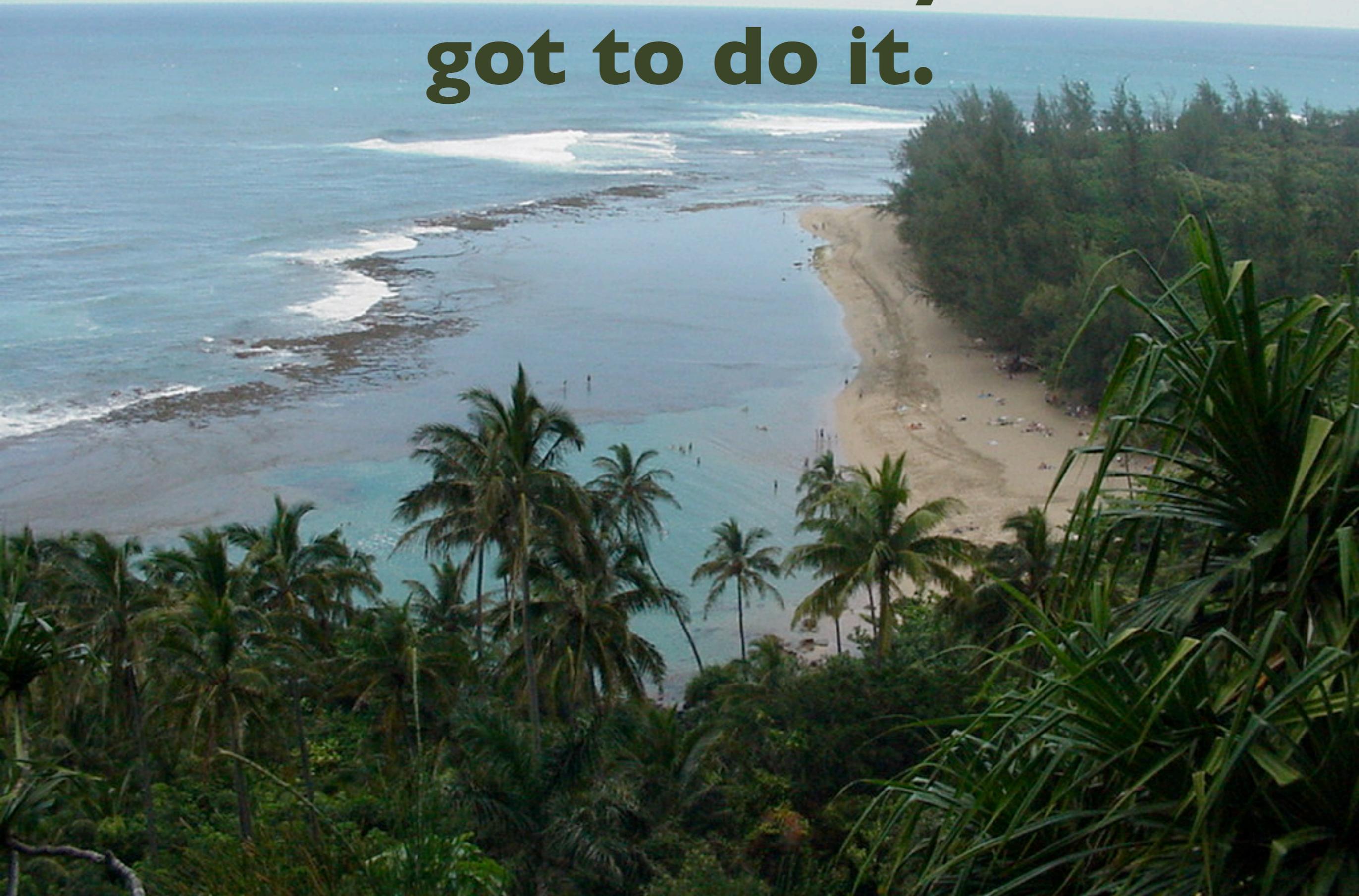


**Workshop on  
The Future of  
Cloud Parameterization**

**Science is hard work.**



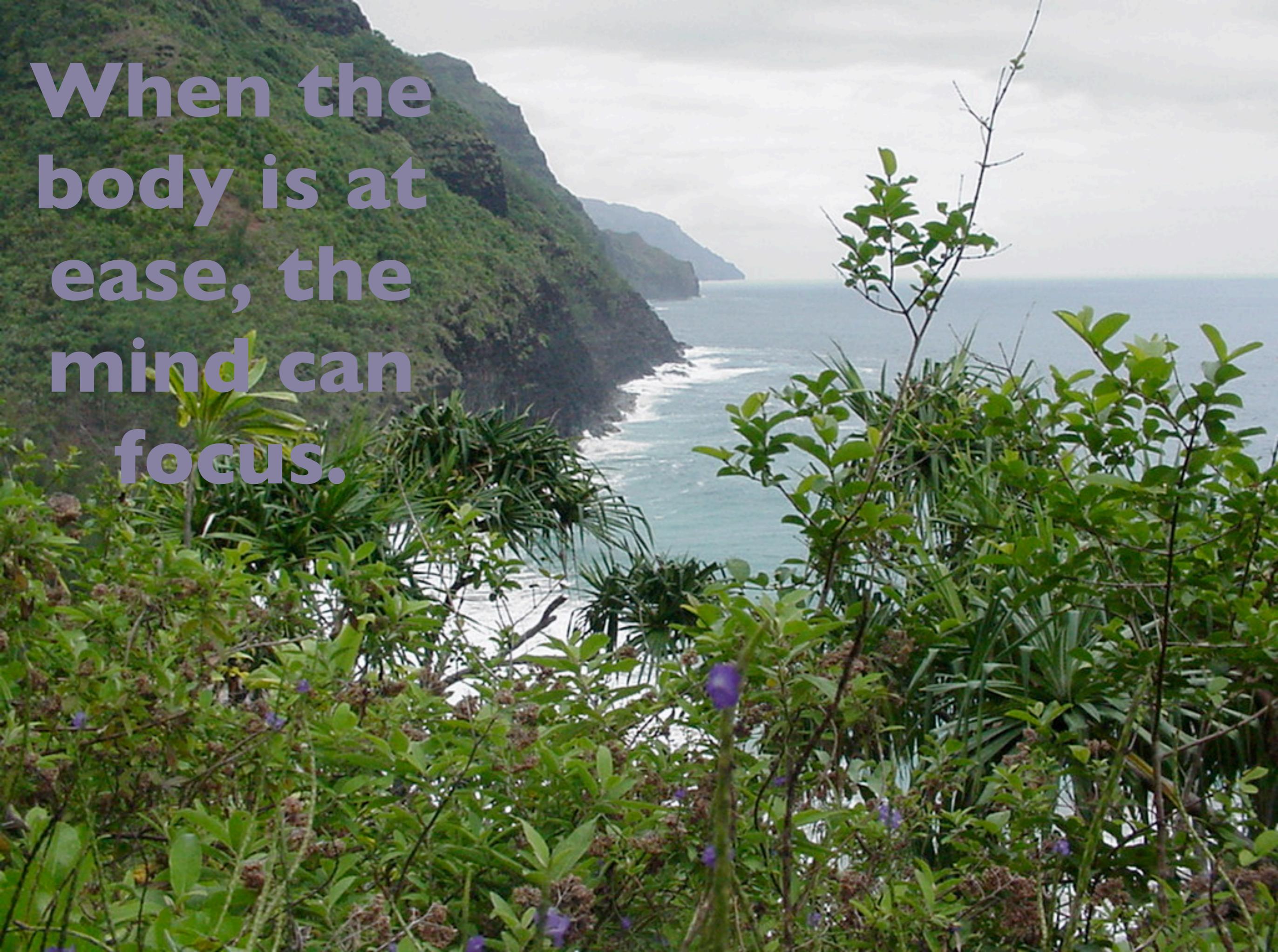
**But somebody's  
got to do it.**



**Science works best in  
pleasant surroundings.**



**When the  
body is at  
ease, the  
mind can  
focus.**



**I'm focusing really  
hard right now.**



# **The Purpose of this Workshop:**

**To continue planning for a proposed**

**NSF Science and Technology Center**

**focused on**

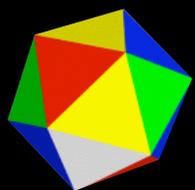
**the future of cloud parameterization**

**with an emphasis on**

**“Super-Parameterizations”**

**based on cloud-system-resolving models (CSRMs).**

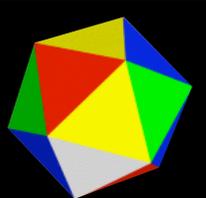
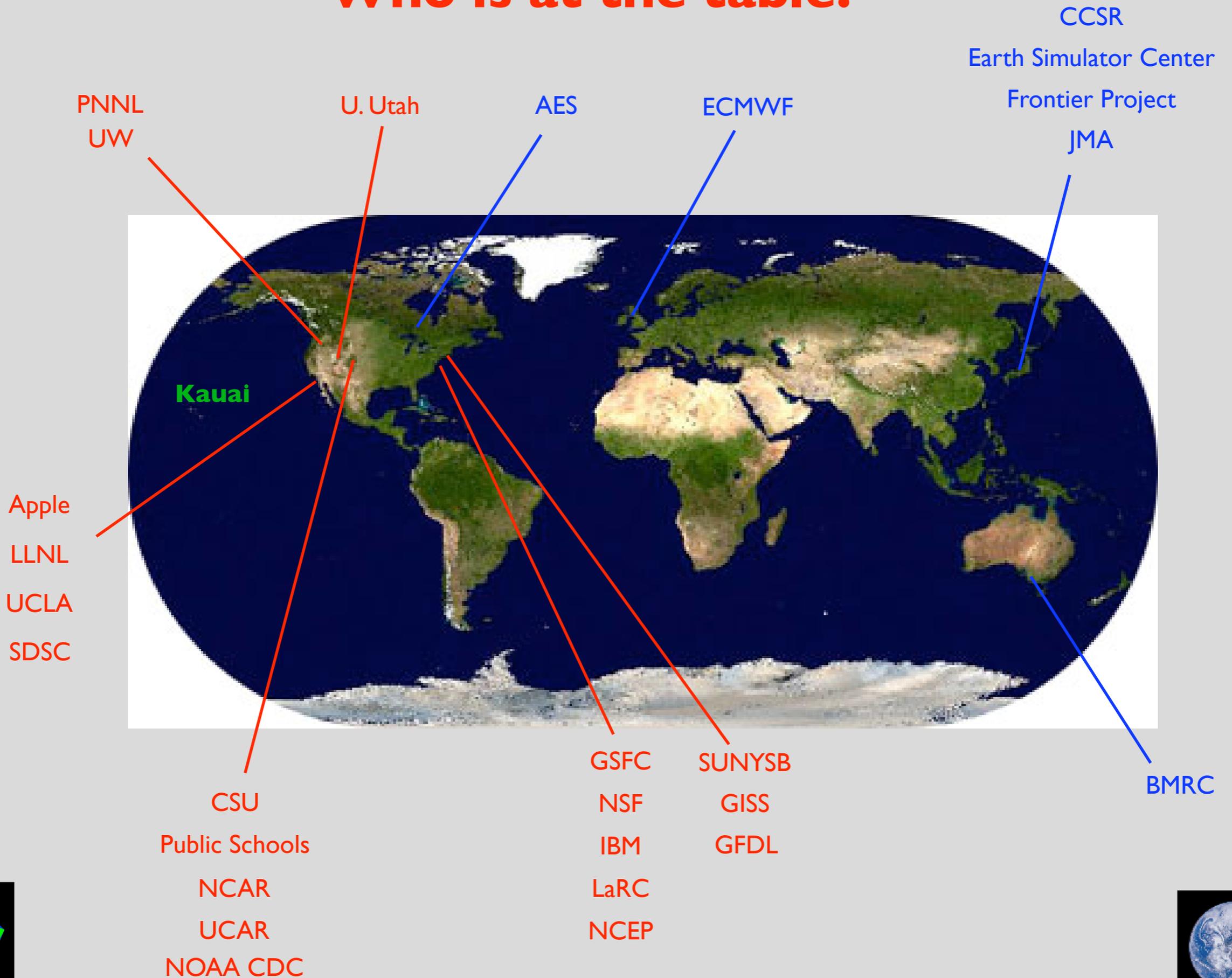
*Support for this Workshop has been provided by CSU’s Department of Atmospheric Science and by CSU’s Vice President for Research.*



# Introductions

An aerial photograph of a coastline. The water transitions from a deep blue on the left to a lighter, white-tinted blue on the right, where it meets a sandy beach. The water's surface is textured with small waves and ripples.

# Who is at the table?



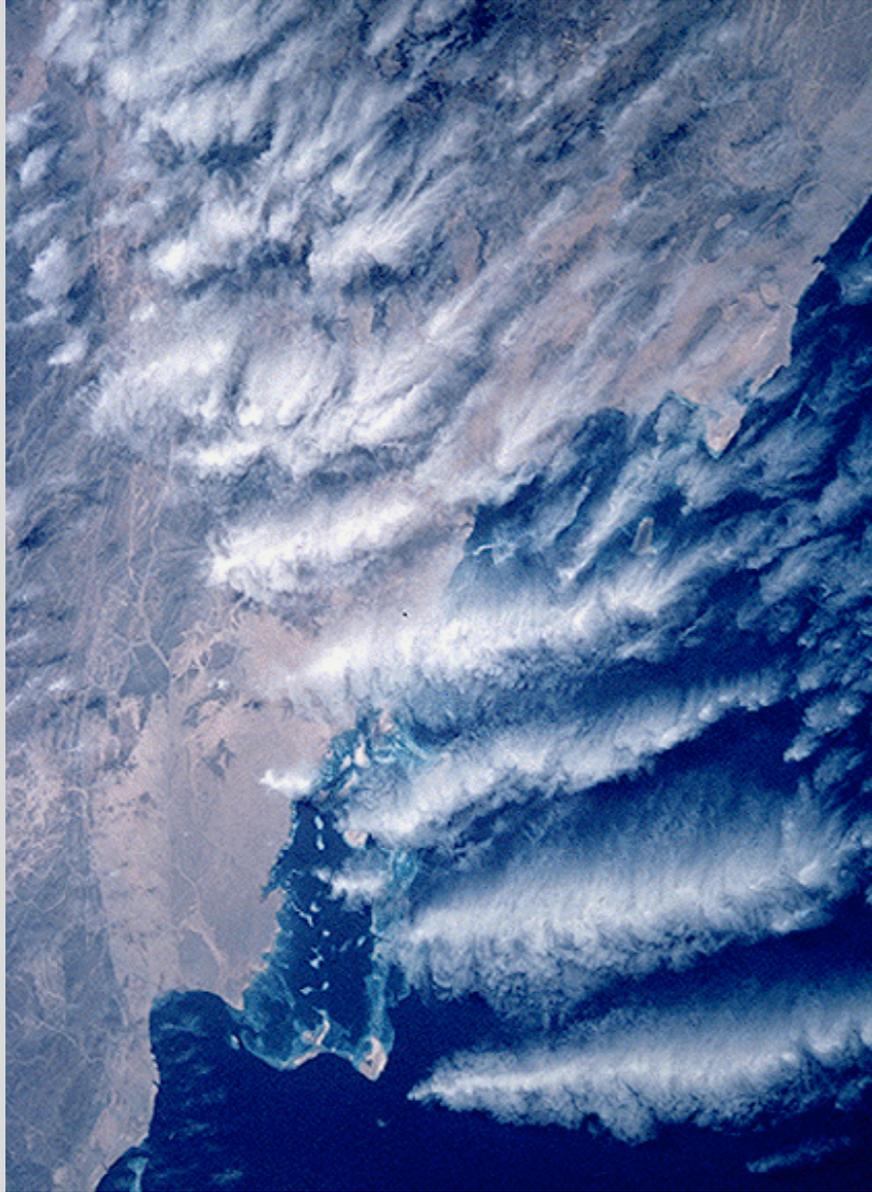
# Comrades who are not here.

- ◆ **Kurt Ackman, Apple Computer**
- ◆ **Howard Barker**
- ◆ **Chris Bretherton**
- ◆ **Paul DeMott**
- ◆ **Jerry Elwood**
- ◆ **Wanda Ferrell**
- ◆ **Laura Fowler**
- ◆ **Jim Abeles, IBM**
- ◆ **Joe Klemp**
- ◆ **Dave Krueger**
- ◆ **Steve Lord**
- ◆ **Steve Rutledge**
- ◆ **Mike Toy**
- ◆ **Stefan Tulich**
- ◆ **Bruce Wielicki**

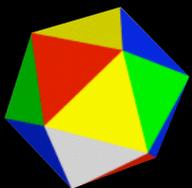


# Logistics

*Presented by Cindy Carrick,  
whose excellent efforts have made this Workshop possible.*



- ◆ **Name tags**
- ◆ **Meal credits**
- ◆ **Group dinner tonight**
- ◆ **Check-out**
- ◆ **Transportation back to the airport**
- ◆ **Travel guides**
- ◆ **Help with other travel issues**



# The Cloud Parameterization Deadlock

*“...The modeling of clouds is one of the weakest links in the general circulation modeling efforts.”*

*–Charney et al., National Academy Report, 1979*



**Deficiencies in the representation of cloud-dynamical processes in climate models drive much of the uncertainty surrounding predictions of climate change.**

**This was true 30 years ago, it's true now, and at the rate we are going it will still be true 30 years from now.**

**What are we doing about this?**

**What can we do about this?**

# The Scope of Cloud Parameterization Research

## Theory

**Parameterization theories**

**Simple models of moist circulation systems**

## Numerical modeling

**Simulations of large-scale circulations using parameterizations**

**Cloud-system-resolving models**

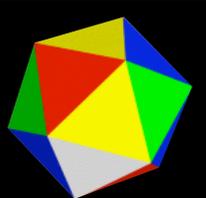
## Observations

**Tests of parameterization theories**

## Practical applications

**Climate-change simulations for policy-makers**

**Numerical weather prediction and data assimilation**



# Motivations for Cloud Parameterization Research

- ◆ **Scientific curiosity about how clouds interact with large-scale circulations**

**The purest motive. We all feel this.**

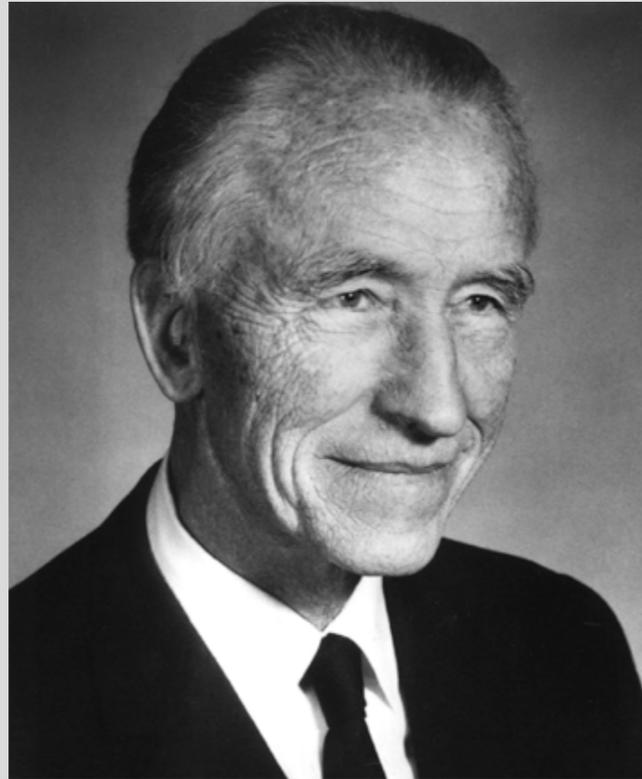
- ◆ **Climate change simulations of the academic kind**
- ◆ **Climate change simulations of the policy-oriented kind**

**Answers needed *right now*.**

- ◆ **Numerical weather prediction including data assimilation**

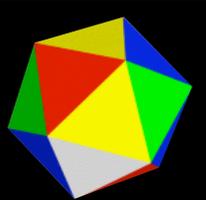


# How Did We Get Here?



*Jakob Bjercknes*

**Updrafts and  
environment**

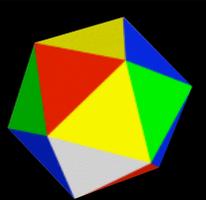


# How Did We Get Here?



*Joseph Smagorinski*

**Stratiform cloud  
amount**



# How Did We Get Here?



*Syukuro Manabe*

**Moist convective  
adjustment**



# How Did We Get Here?



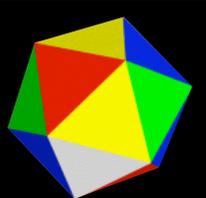
*Akio Arakawa*

**Mass flux**

**Quasi-equilibrium**

**Coupling to the PBL**

**Detrainment of  
condensed water**



# How Did We Get Here?



*Doug Lilly*

**Cloud-turbulence-radiation interactions**

**Cloud-top entrainment**

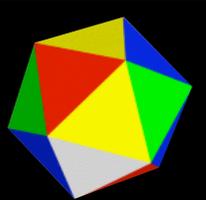


# How Did We Get Here?



*Hilding Sundqvist*

**Prognostic cloud  
water**



# How Did We Get Here?



*Michael Tiedtke*

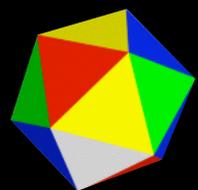
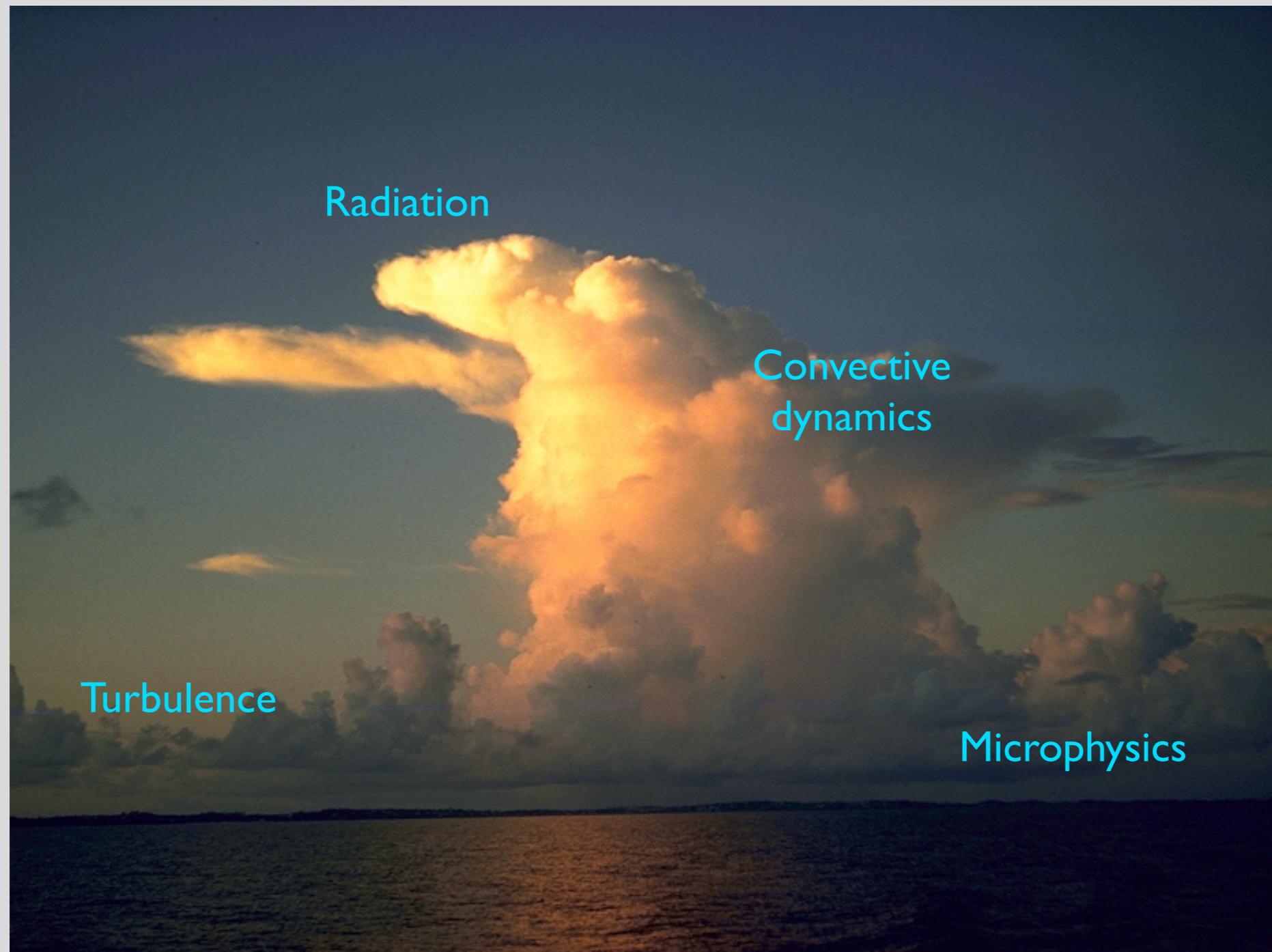
**Prognostic cloud  
amount**



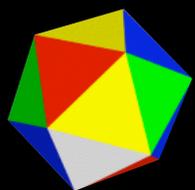
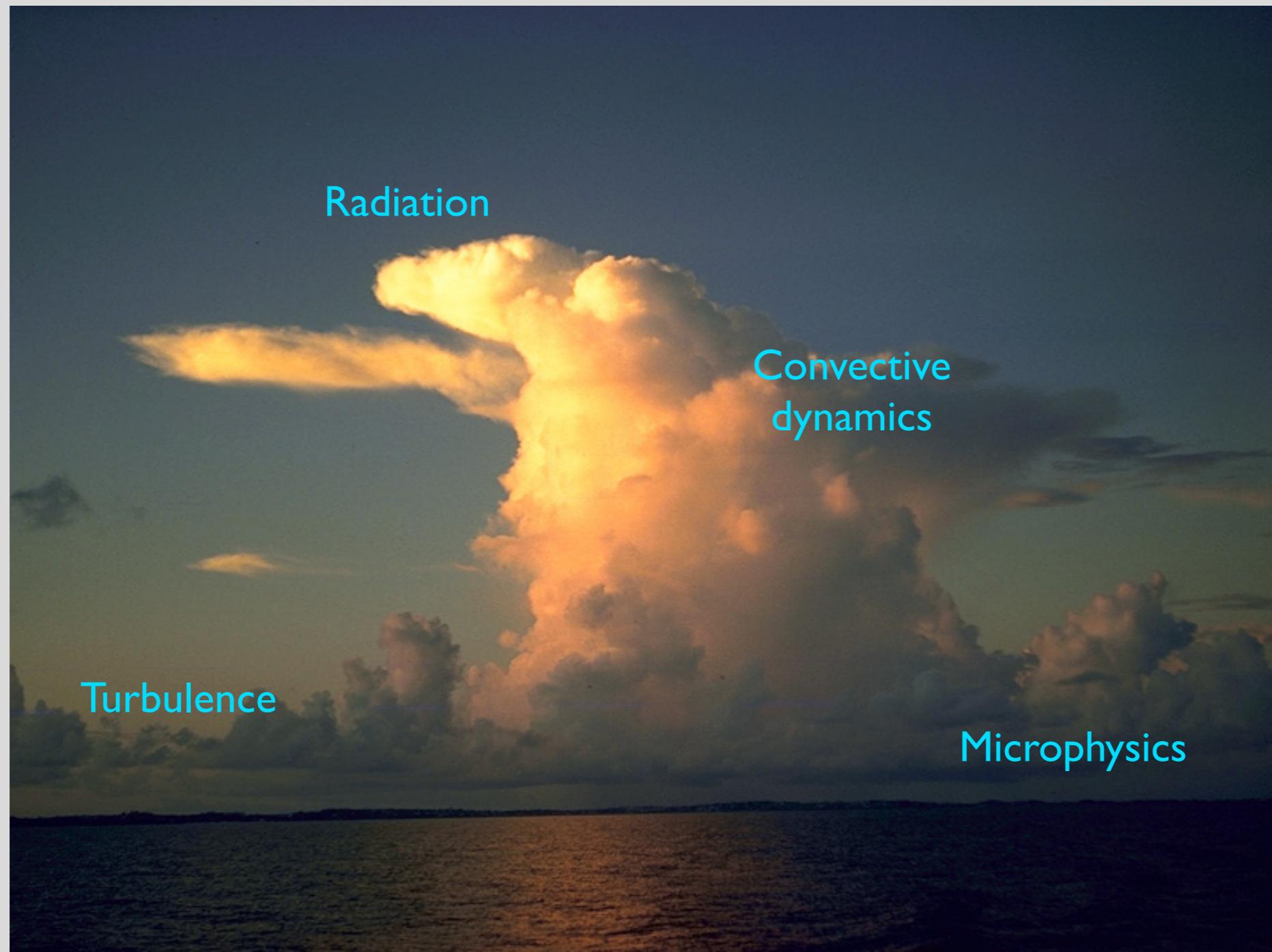
# Where are we going?



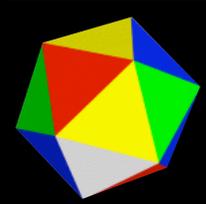
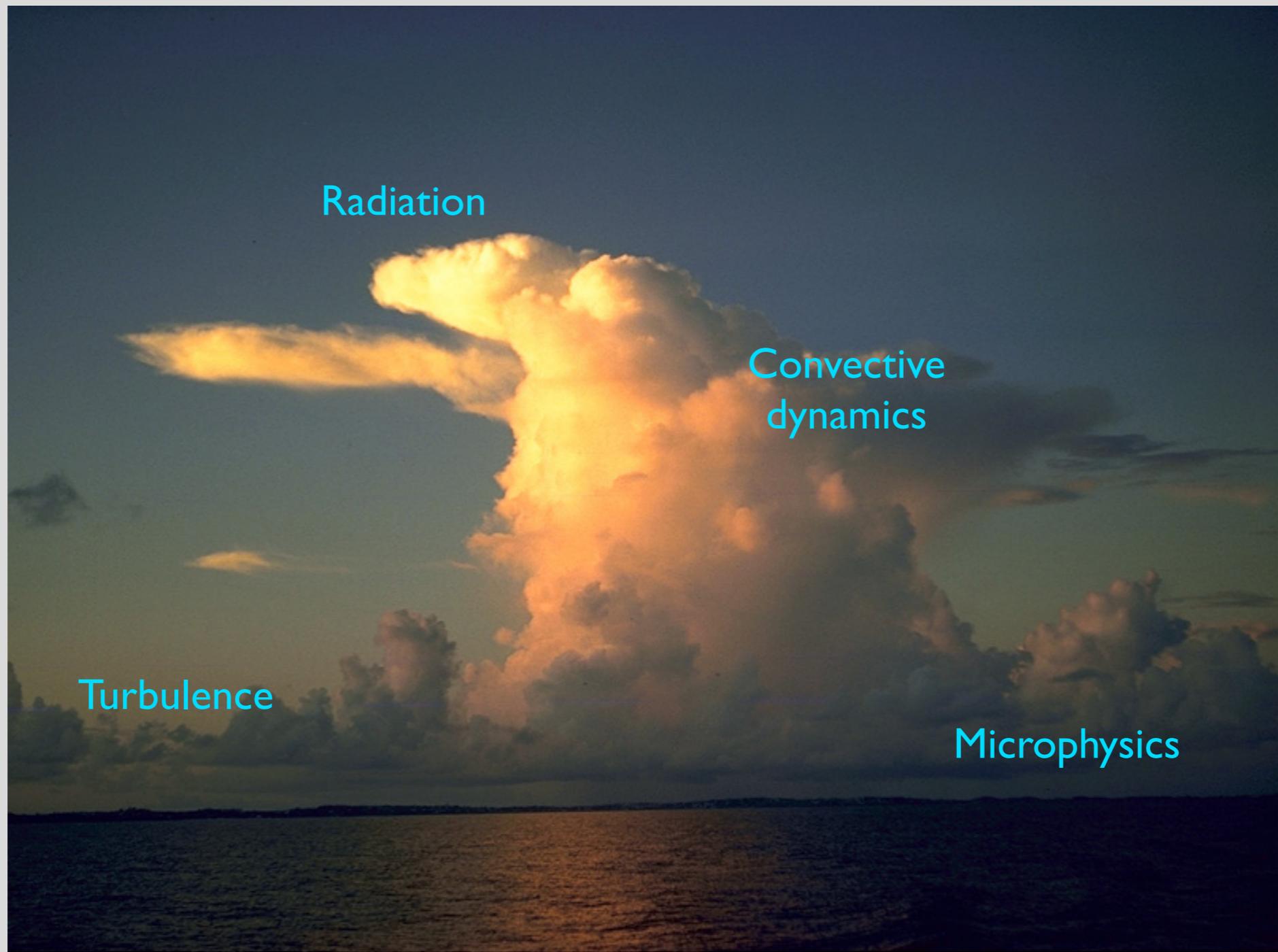
# Processes interact on the cloud scale.



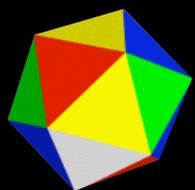
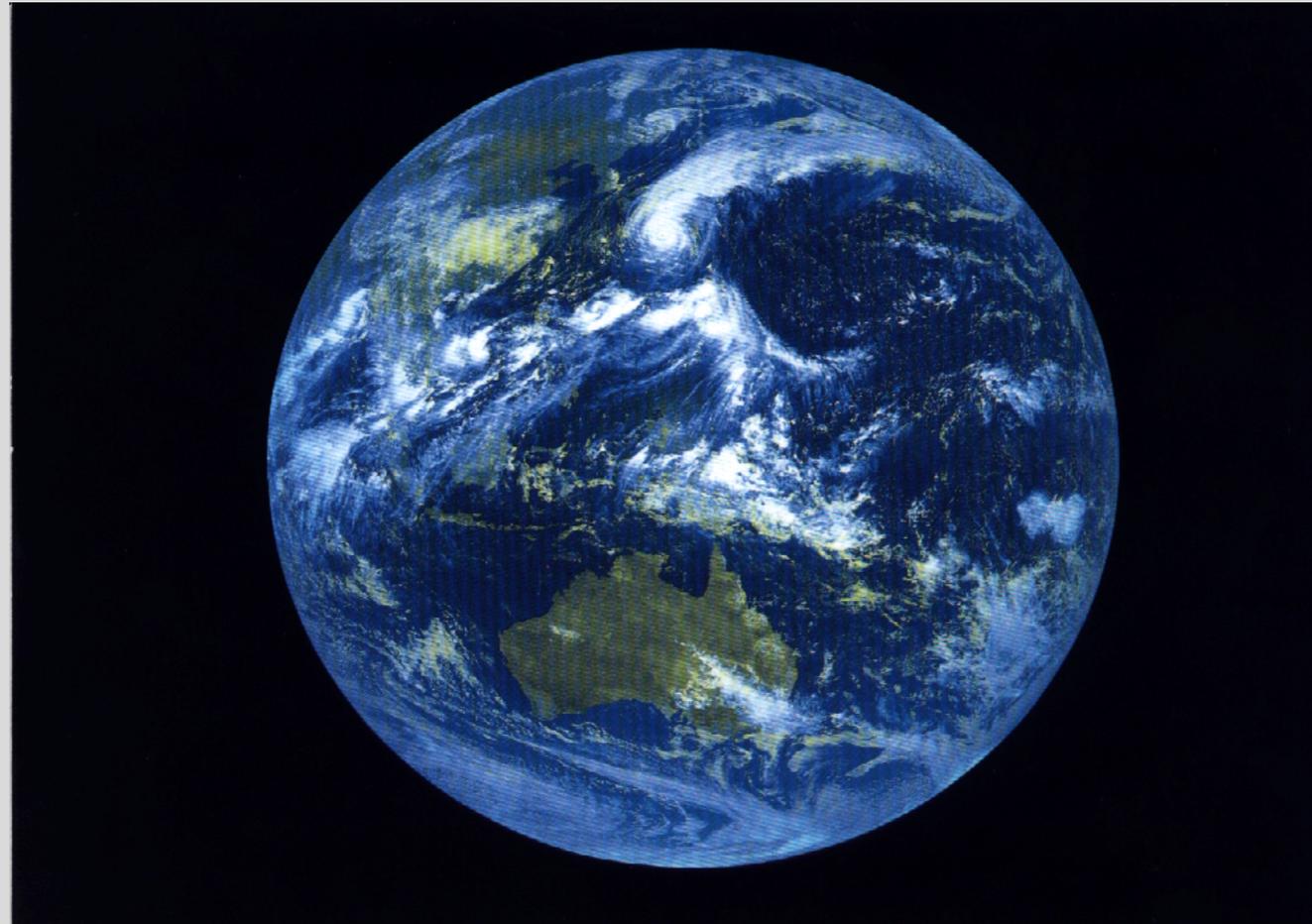
# We observe processes on the cloud scale.



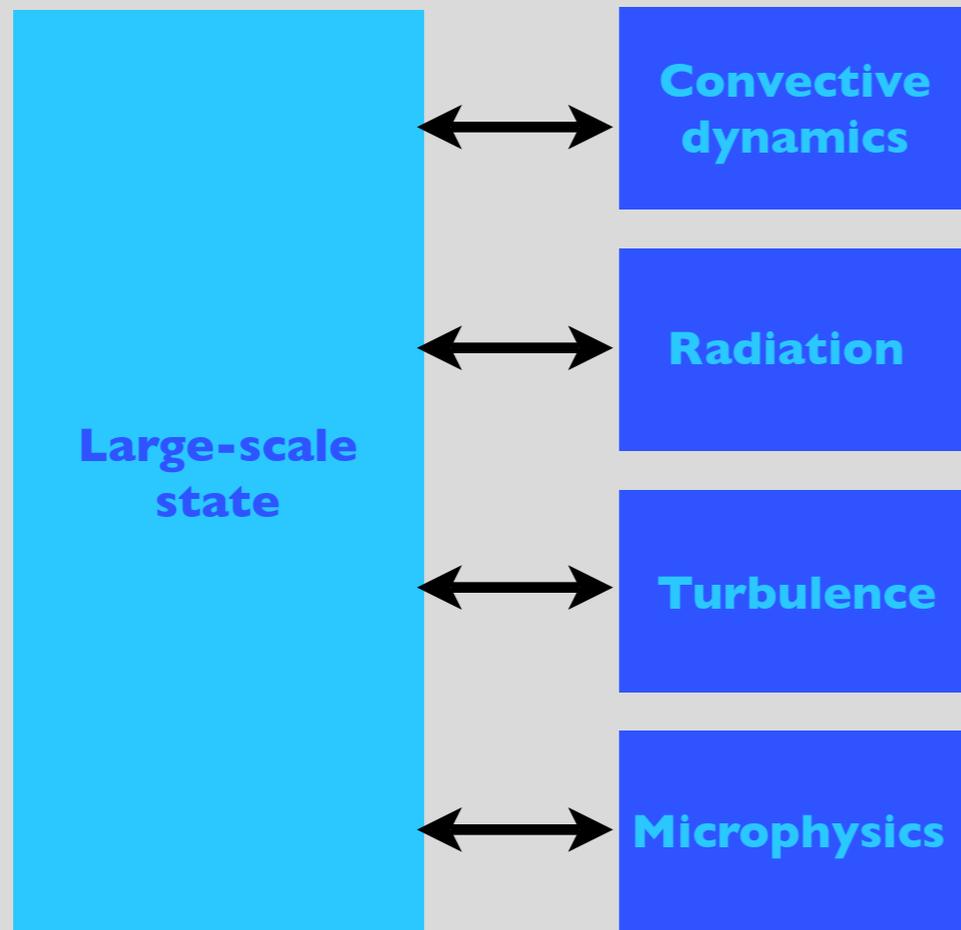
# Cloud models simulate cloud-scale processes.



**Parameterizations are statistical models.**



# A weakness of current parameterizations



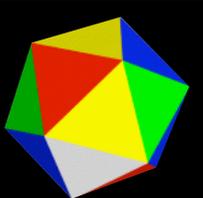
**With just a few exceptions, current GCMs permit process interactions only indirectly, through the large-scale state.**

**We don't have a clear understanding of how to represent the direct, cloud-scale process interactions in statistical models.**

**We need a *framework* for representing the direct, cloud-scale process interactions in statistical models.**

**Someday, we will have such a framework.**

***“Cloud parameterization is a very young subject.”  
-- Akio Arakawa December 2001***



# Trade-offs

| <b>Local physics<br/>(Cloud model)</b> | <b>Statistical physics<br/>(Parameterization)</b> |
|--|---|
| <b>Well understood</b>                 | <b>Partially/imperfectly<br/>understood</b>       |
| <b>Modular</b>                         | <b>Not modular</b>                                |
| <b>Simple</b>                          | <b>Complicated</b>                                |
| <b>Computationally<br/>expensive</b>   | <b>Computationally cheap</b>                      |



# Dreaming of a global CSRM

Current climate-simulation models typically have on the order of  $10^4$  grid columns, averaging about 200 km wide.

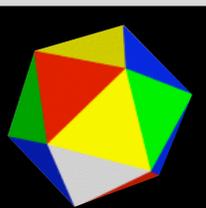
A global model with grid cells 2 km wide will have about  $10^8$  grid columns. The time step will have to be roughly  $10^2$  times shorter than in current climate models.

The cpu requirements will thus be  $10^4 \times 10^2 = 10^6$  times larger than with today's lower-resolution models.

*Even today we could do a short “exploratory” simulation with such a model, and we should be planning to do exactly that.*

The students here today will work with such models, later in their careers.

In the mean time, however, there is another approach...



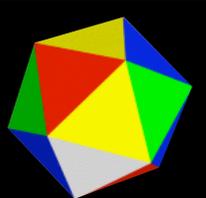
**We can run a  
Cloud-System-Resolving Model (CSRM)  
as a “Super-Parameterization”  
inside a GCM.**

**About five years ago, Wojciech Grabowski of NCAR implemented a 2D CSRM inside a simplified global model with globally uniform SSTs, no mountains, etc.**

**Each copy of the CSRM represents a “sample” of the volume inside a GCM grid column.**



**Statistics computed using the CSRM are based on this sample, in much the same way that statistics from an opinion poll are based on interviews with a sample of the population.**



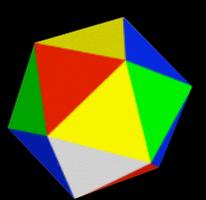
# Grabowski's Approach

**GCM grid cell**

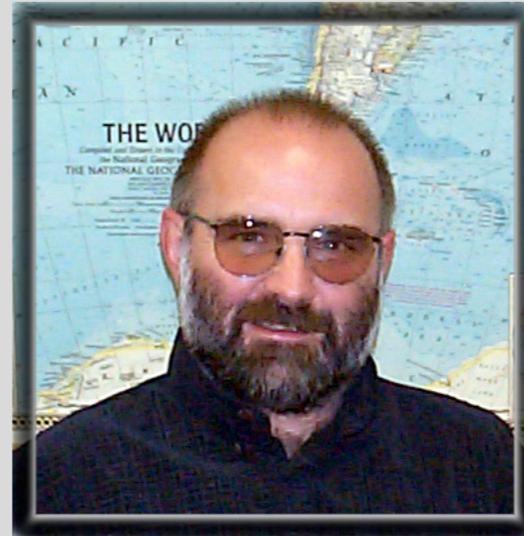
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**2 D CSR**

**Cyclic lateral  
boundary conditions**

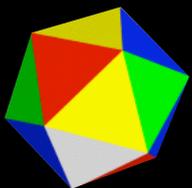


**Poor Wojciech.**



**This is obviously a crazy idea.**

***Or is it?***



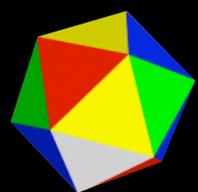
## CSU jumps in



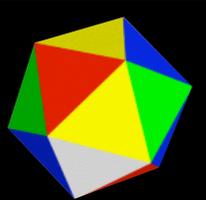
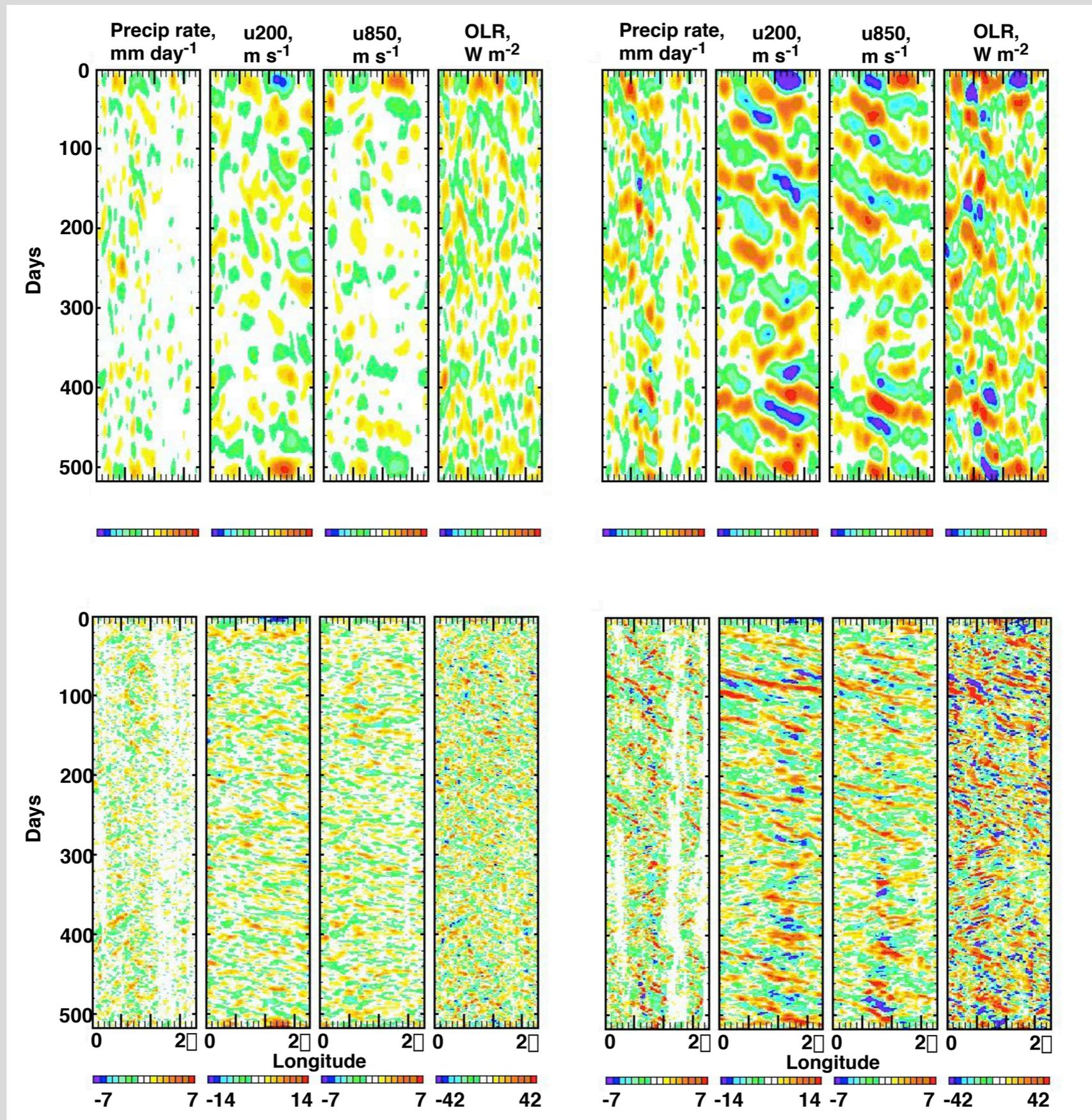
Inspired by Wojciech's idea, Marat Khairoutdinov of CSU embedded his own 2D CSRМ as a super-parameterization in the atmosphere sub-model of the Community Climate System Model (the "CAM" for short). This global model has realistic topography, SSTs, etc.

The CSRМ takes the place of the stratiform and convective cloud parameterizations, and in the future will also replace the PBL parameterization.

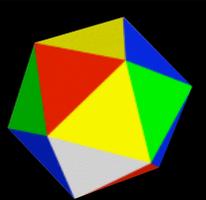
Because he was already familiar with both the CAM and the CSRМ, Marat was able to get the super-parameterization working in the CAM in about a month.



# Marat got some intriguing results.

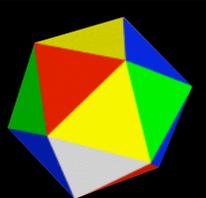


**Marat Khairoutdinov and Charlotte DeMott will show a lot of additional results later this morning.**



# What do we get? I

- ◆ **Explicit deep convection, including mesoscale organization (e.g., squall lines), downdrafts, anvils, etc.**
- ◆ **Explicit fractional cloudiness**
- ◆ **Explicit cloud overlap in the radiative sense**
- ◆ **Explicit cloud overlap in the microphysical sense**
- ◆ **Convective enhancement of the surface fluxes**
- ◆ **Possible explicit 3D cloud-radiation effects**



## What do we get? 2

- ◆ **Convectively generated gravity waves**
- ◆ **The ability to compare global model results on the statistics of mesoscale and microscale cloud organization with observations from new platforms such as CloudSat**
- ◆ **The ability to assimilate cloud statistics based on high-resolution observations**
- ◆ **The ability to compare results obtained with the super-parameterization to results obtained with conventional parameterizations**



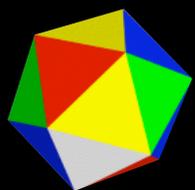
# Inter-Related Issues

- ◆ **Resolution of the CSRM?**
- ◆ **Everywhere, all the time?**
- ◆ **Consistency between the GCM and the CSRM?**
- ◆ **Lateral boundary conditions of the CSRM?**
- ◆ **CSRM communications between GCM grid columns?**
- ◆ **Lower boundary conditions?**
- ◆ **Dimensionality of the CSRM?**
- ◆ **Ultimate convergence to a global CSRM?**



# Arakawa's "Quasi-3D" approach

**Arakawa is proposing a new approach to super-parameterization that addresses all of these issues.**



## What shall we call it?

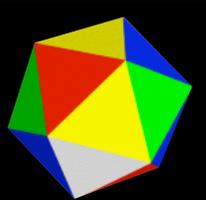
Some people don't like the name "*Super-Parameterization*."



So, OK, we can call it a "*Multi-Scale Modeling Framework*."

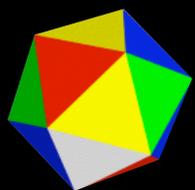


But I have a feeling that "*Super-Parameterization*" is going to stick.



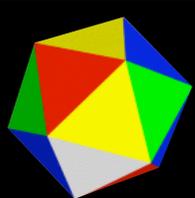
# Conventional Parameterization or Super-Parameterization?

| <b>Local physics<br/>(Cloud model)</b> | <b>Statistical physics<br/>(Parameterization)</b> |
|--|---|
| <b>Well understood</b>                 | <b>Partially/imperfectly<br/>understood</b>       |
| <b>Modular</b>                         | <b>Not modular</b>                                |
| <b>Simple</b>                          | <b>Complicated</b>                                |
| <b>Computationally<br/>expensive</b>   | <b>Computationally cheap</b>                      |



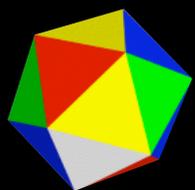
## Compared to what?

| <b>Super-Parameterizations</b>  | <b>Conventional Parameterizations</b>   |
|---|---|
| <b>2D or Quasi-3D</b>   | <b>ID</b>   |
| <b>Periodic boundary conditions</b>   | <b>Boundary <i>whats?</i></b>   |
| <b>Shallow convection and turbulence must be parameterized.</b>                   | <b>Same</b>   |
| <b>Microphysics is simplified but the required input is in pretty good shape.</b> | <b>Microphysics is typically less sophisticated, and the required input (e.g., local vertical velocity) is not available.</b> |



# Continuing roles for “classical” cloud parameterizations

- ◆ **Classical parameterizations will still be needed as encapsulations of our (gradually improving) understanding of how clouds interact with the large-scale circulation.**
- ◆ **Classical parameterizations can be improved by studying the results obtained with super-parameterizations.**
- ◆ **Classical parameterizations will still be used wherever very large computing resources are not available, and especially for very long simulations, e.g. of Milankovich cycles.**



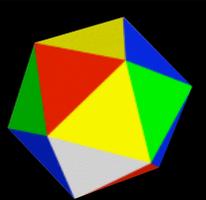
**We need both approaches.**



**Super-Parameterizations**



**“Classical” Parameterizations**



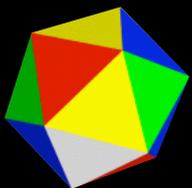
## What does it cost?



**In our earliest tests with the CAM, the embedded CSRМ slowed the model down by about a factor of 180.**

**With this configuration, a simulated century would take about four years of wall-clock time on 64 processors.**

*Marat will give an update later this morning.*



# Computational Issues

*(CISE does matter.)*



IBM 7094



**Machines are getting faster.**



IBM SP



**And faster.**



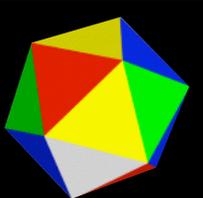
Earth Simulator



# Here's the deal.

- ◆ **Conventional parameterizations can do everything eventually (we hope), but for now we are frustrated by their limitations.**
- ◆ **Many of these limitations can be avoided through the use of super-parameterizations.**
- ◆ **Increasing computer power is rapidly making super-parameterizations a practical option.**
- ◆ **Super-parameterizations were not possible until essentially now.**

***We find ourselves at a fork in the road.***



**“When you come to a fork in the road,  
take it.”**

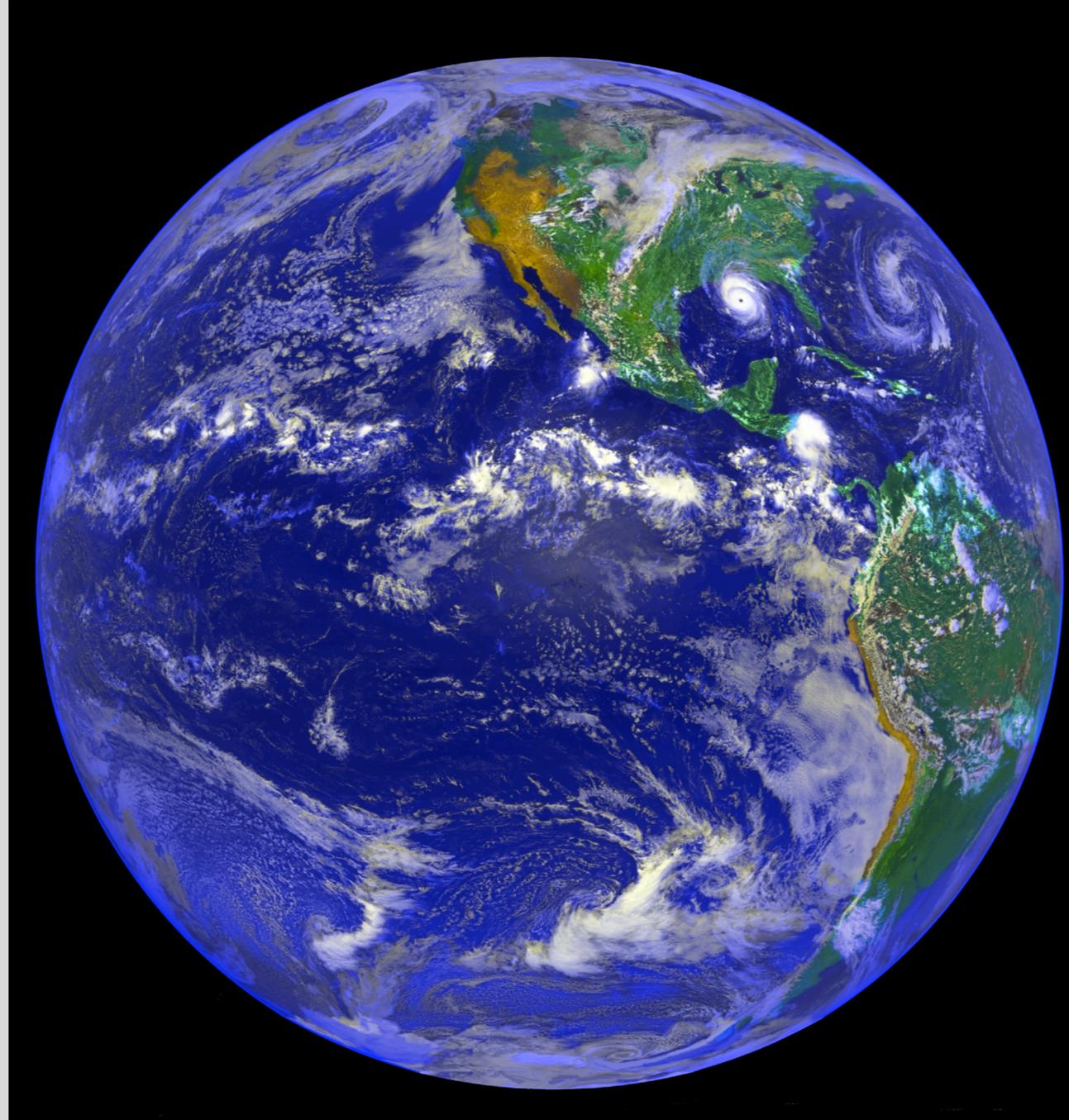
**--Yogi Bera**



**Following the ideas  
outlined above,  
our community  
can undertake a  
new, broader  
program of cloud  
parameterization  
research.**



**OK, so we need to change the world.**



## There is plenty to go around.

**Super-parameterization research cannot be a single research project, carried out by a single team of investigators; it has to involve many projects, many teams of investigators, and many institutions.**

**It is essential that super-parameterization research not “cannibalize” existing cloud-parameterization research. We need to make the pie bigger.**



# We Propose:

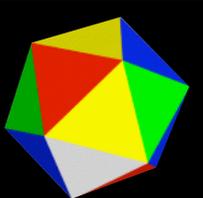
**An STC aimed at breaking the cloud-parameterization deadlock.**



# Why an STC?

## STCs involve

- ◆ **Innovative research and education projects of national importance that require a Center mode of support to achieve their research, education, and knowledge-transfer goals.**
- ◆ ***Partnerships* among academic institutions, national laboratories, industrial organizations, and/or other public/private entities.**

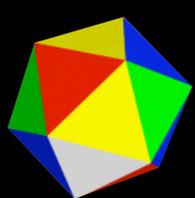


# A natural fit

**An STC needs a research focus.**

**Often the plan for an STC comes first, followed by brainstorming sessions to come up with a research focus.**

**In the present case, the research focus came first. The STC is just a way of getting it done.**



# STC Program History

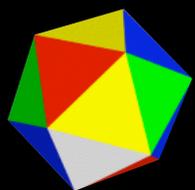
**Late 1980s and early 1990s: 25 Science and Technology Centers**

**C<sup>4</sup> and CAPS**

**1999: Five new Centers.**

**2002: Six new Centers**

***Current total: 11 Science and Technology Centers.***



# **The eleven current STCs**

***Center for Behavioral Neuroscience***

***Center for Embedded Networked Sensing***

***Center for Advanced Materials for Water Purification***

***The Nanobiotechnology Center***

***National Center for Earth-Surface Dynamics***

***Center for Integrated Space Weather Modeling***

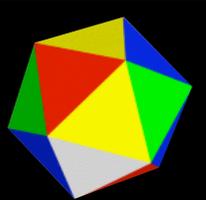
***Sustainability of Water Resources in Semi-Arid Regions***

***Center for Adaptive Optics***

***Center for Biophotonics Science and Technology***

***Center for Environmentally Responsible Solvents and Processes***

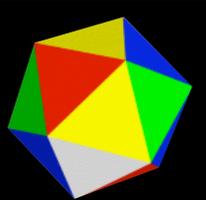
***Center on Materials and Devices for Information Technology Research***



# STC Elements

- ◆ **Research**
  - ▲ **Physics**
  - ▲ **Computation and applied mathematics**
- ◆ **Education/Outreach**
- ◆ **Knowledge Transfer**

***This Workshop deals almost exclusively with the Research aspects of the proposed Center, but we have been working very hard on the Education/Outreach and Knowledge Transfer aspects too, and the third Workshop will deal with them in some detail.***

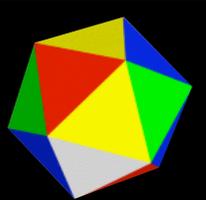


**Jay Fein**

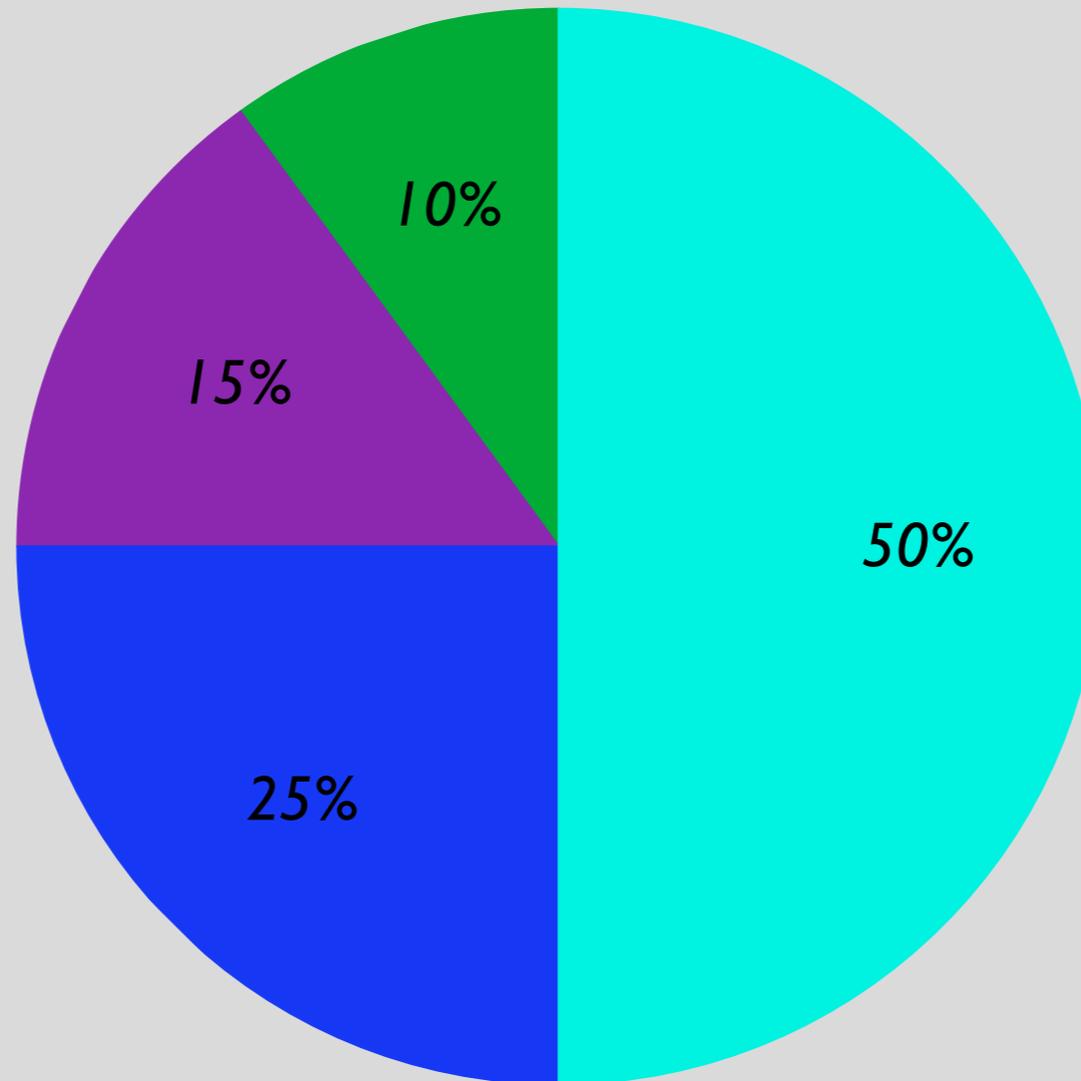


# The scope of a cloud-parameterization STC

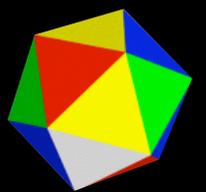
- ◆ Development and applications of super-parameterizations
- ◆ Development and applications of classical parameterizations
- ◆ Theory
  - ▲ Parameterization theories
  - ▲ Simple models of moist circulation systems
- ◆ Use of observations for the evaluation of parameterization theories and numerical results
- ◆ Practical applications *through partnerships*
  - ▲ Climate-change simulations (CCSM, DOE)
  - ▲ Numerical weather prediction and data assimilation (NCEP, NASA, ECMWF, BMRC, JMA)



# Allocations



● SP ● CP ● Theory ● Obs

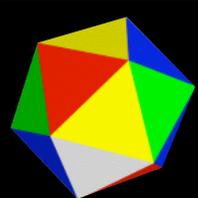


# Agenda

Revised May 1, 2003 1:27 pm

Wednesday May 7

| Morning session chaired by David Randall   |                                   |                              |   |
|--|-----------------------------------|------------------------------|---|
| 08:30                                      | David Randall and Jay Fein        | CSU and NSF                  | Introductory overview   |
| 09:30                                      | <b>Marat Khairoutdinov</b>        | CSU                          | Ongoing super-parameterization work at CSU  |
| 10:15                                      | <b>Break</b>                      |                              |   |
| 10:35                                      | Charlotte DeMott                  | CSU                          | Tropical variability in the Super-CAM   |
| 10:55                                      | Kazuo Saito                       | JMA                          | Cloud and convection in the JMA NWP models  |
| 11:15                                      | <b>Steve Lord</b>                 | NCEP                         | Operational Cumulus Parameterization Requirements at the NCEP Environmental Modeling Center 2003-2009 |
| 12:00                                      | <b>Lunch</b>                      |                              |   |
| Afternoon session chaired by Steve Krueger |                                   |                              |   |
| 13:30                                      | <b>Wojciech Grabowski</b>         | NCAR                         | Using super-parameterization in the clouds-in-climate problem   |
| 14:15                                      | Mitch Moncrieff                   | NCAR                         | A Dynamical Model of MJO-like Coherence   |
| 14:35                                      | Hiroaki Miura and Masahide Kimoto | CCSR                         | Cumulus ensemble simulation using a cloud resolving model.  |
| 14:55                                      | Leo Donner                        | GFDL                         | Large-Scale Convective Sources from Two- and Three-Dimensional Cloud-System-Resolving Models          |
| 15:15                                      | <b>Break</b>                      |                              |   |
| 15:35                                      | Kuan-Man Xu                       | NASA Langley Research Center | A satellite cloud, radiation and precipitation data set for cloud-model evaluation                    |
| 15:55                                      | Ming-Hua Zhang                    | SUNY Stonybrook              | Cloud parameterizations: How good is good enough, and design of observational tests                   |
| 16:15                                      | Christian Jakob                   | BMRC                         | Evaluating Cloud Resolving Model simulations - Where are the gaps and how do we fill them?            |
| 16:35                                      | <b>Discussion</b>                 |                              |   |
| 17:30                                      | <b>Adjourn for the day</b>        |                              |   |
| 19:00                                      | <b>Group dinner</b>               |                              |   |

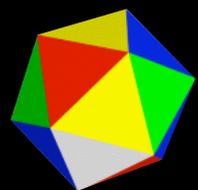


# Agenda

Revised May 1, 2003 1:27 pm

**Thursday May 8**

| <b>Morning session chaired by Tom Ackerman</b>   |                                       |                   |   |
|--|---------------------------------------|-------------------|---|
| 08:30  | <b>Akio Arakawa and Joon-Hee Jung</b> | UCLA              | The Convergence Problem of Model Physics and Design of a Quasi-3D Super-Parameterization  |
| 09:15  | Joon-Hee Jung and Akio Arakawa        | UCLA              | A Preliminary Test of Super-parameterization in an Idealized Framework  |
| 09:35  | Steve Krueger                         | U. Utah           | 2D cloud system resolving models: Simulation or parameterization?   |
| 09:55  | Chin-Hoh Moeng                        | NCAR              | Parameterization of turbulent transport and cloud properties in PBLs over complex terrain and heterogeneous land use              |
| 10:15  | <b>Break</b>                          |                   |   |
| 10:30  | <b>Akimasa Sumi</b>                   | CCSR              | Comparison of convective heating in the simulation of super cluster on an aqua-planet by using a regional model                   |
| 11:15  | Sonia Kreidenweis                     | CSU               | Future directions in modeling aerosol-cloud interactions  |
| 11:35  | Andy Heymsfield                       | NCAR              | Parameterizations of Ice Particle Size Distributions and Bulk Microphysical Properties for Cirrus and Stratiform Ice Cloud Layers |
| 11:55  | Howard Barker                         | Met. Serv. Canada | Radiative transfer calculations in regular and super-parameterized GCMs   |
| 12:15  | <b>Lunch</b>                          |                   |   |
| <b>Afternoon session chaired by Akimasa Sumi</b> |                                       |                   |   |
| 13:30  | <b>Bjorn Stevens</b>                  | UCLA              | Adjustment Revisited  |
| 14:15  | Tomoe Nasuno and Teruyuki Kato        | FRSGC and MRI/JMA | Estimation of subgrid scale processes using a cloud-resolving model.  |
| 14:35  | Cara-Lyn Lappen                       | CSU               | The future PBL parameterization of the Colorado State University GCM  |
| 14:55  | Tom Ackerman                          | PNNL              | Testing Super-parameterization Results with ARM Data: Initial Results and Plans for Future Research.                              |
| 15:15  | <b>Break</b>                          |                   |   |
| 15:30  | Ric Cederwall and Jerry Potter        | LLNL              | Evaluation of Climate Model Parameterizations Using the DOE CCPP-ARM Parameterization Testbed (CAPT)                              |
| 15:50  | Christian Jakob                       | BMRC              | The use of cloud radar observations for model evaluation: A probabilistic approach.   |
| 16:20  | Steve Krueger and Y. Luo              | U. Utah           | Using cloud radar and satellite measurements to evaluate CSRMs  |
| 16:40  | <b>Discussion</b>                     |                   |   |
| 17:30  | <b>Adjourn for the day</b>            |                   |   |

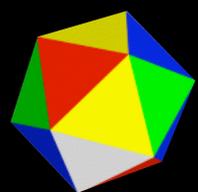


# Agenda

Revised May 1, 2003 1:27 pm

**Friday**

| <b>Morning session chaired by Christian Jakob</b> |  |                                       |  |
|---|--|---------------------------------------|--|
| 08:30   | <b>Wayne Schubert</b>  | CSU                                   | Dream GCMs and Super-Parameterizations   |
| 9:15  | Jim Hack   | NCAR                                  | Idealized Frameworks for the Diagnosis and Evaluation of Parameterized Physics   |
| 9:35  | Robert Pincus  | NOAA CDC                              | Looking over each others shoulders: What can explicit and traditional cloud parameterizations learn from one another?                              |
| 9:55  | Wei-Kuo Tao, Arthur Hou, Robert Atlas, David Starr and Yogesh Sud                        | NASA GSFC                             | Precipitation Processes Observed During ARM, TOGA COARE, GATE, SCSMEX, and KWAJEX: Consistent 2D, semi-3D and 3D Cloud Resolving Model Simulations |
| 10:15   | <b>Break</b>   |                                       |  |
| 10:30   | <b>Masaki Satoh, Hirofumi Tomita, Koji Goto, and Tomoe Nasuno</b>                        | FRSGC/Saitama Institute of Technology | Development of the nonhydrostatic icosahedral atmospheric model in Frontier Research System for Global Change                                      |
| 11:15   | Tsuneaki Suzuki, Seita Emori, Teruyuki Nishimura and Shinji Matsumura                    | FRSGC                                 | The role of convective triggering in an AGCM   |
| 11:35   | Phil Duffy, Balasrabrumanian "Bala" Govindasamy, Jeremy Coquard, John Iorio, Karl Taylor | LLNL                                  | High resolution simulations of global climate  |
| 11:55   | Martin Miller  | ECMWF                                 | TBD  |
| 12:15   | <b>Lunch</b>   |                                       |  |
| <b>Afternoon session chaired by David Randall</b> |  |                                       |  |
| 1:30  | <b>Graeme Stephens and Norm Wood</b>   | CSU                                   | Diagnosing Cloud Radiation Feedbacks with Super-Parameterization   |
| 14:15   | Bill Rossow  | NASA GISS                             | Some Ideas on How to Evaluate a Cloud Parameterization in a GCM  |
| 14:35   | Chris Kummerow   | CSU                                   | Rainfall monitoring in 2010 - Prospects for a synergistic approach between model and observation.  |
| 14:55   | Scott Denning  | CSU                                   | Cloud-scale mass fluxes and tracer transport inversions: New ways to study the global carbon cycle from the air                                    |
| 15:15   | <b>Break</b>   |                                       |  |
| 15:35   | <b>What happens next</b>   |                                       |  |
| 17:00   | <b>Workshop ends</b>   |                                       |  |



# Questions?

