



# Introductory Overview



# The purpose of this Workshop

To begin planning for a proposed

*NSF Science and Technology Center*

focused on

*Future Cloud Parameterizations*

with an emphasis on

*"Super-Parameterizations"*

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

Support for this Workshop is being provided by CSU's Department of Atmospheric Science and by the office of CSU's Vice President for Research.



# Agenda 1

<b>08:30</b>	<b>Welcome, introductions, and logistics</b>	<b>David Randall</b>
<b>08:45</b>	<b>Introductory overview</b>	<b>David Randall</b>
<b>09:30</b>	<b>Update on super-parameterization work at NCAR</b>	<b>Wojciech Grabowski</b>
<b>10:00</b>	<b>Update on super-parameterization work at CSU</b>	<b>Marat Khairoutdinov</b>
<b>10:30</b>	<b>Break</b>	
<b>10:45</b>	<b>Ongoing work at UCLA</b>	<b>Akio Arakawa and Joon-Hee Jung</b>
<b>11:45</b>	<b>Discussion</b>	<b>All</b>
<b>12:00</b>	<b>Lunch (provided)</b>	



## Agenda 2

- |              |   |  |
|--------------|---|--|
| <b>13:00</b> | <b>Cloud parameterizations, future observing systems, data assimilation, and weather prediction</b>                               | <b>Graeme Stephens and Chris Kummerow</b>    |
| <b>13:45</b> | <b>Parameterization and superparameterization: Using superparameterizations to develop improved “classical” parameterizations</b> | <b>Leo Donner</b>                            |
| <b>14:15</b> | <b>Computational aspects</b>  | <b>David Randall and Marat Khairoutdinov</b> |
| <b>14:45</b> | <b>Break</b>  |  |
| <b>15:00</b> | <b>Discussion of the technical issues</b>   | <b>All</b>                                   |
| <b>16:00</b> | <b>The STC process, and “What’s next?”</b>  | <b>David Randall</b>                         |
| <b>17:00</b> | <b>End of meeting</b>   |  |
| <b>18:30</b> | <b>Dinner at a restaurant for those who are staying until Wednesday</b>   |  |

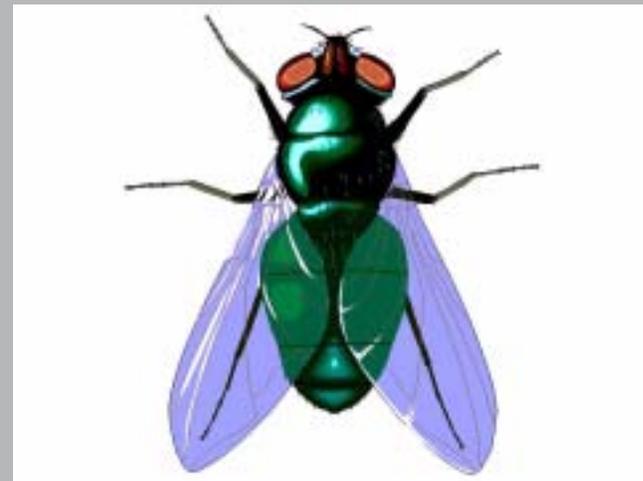


# A provocative stimulus



## Gadfly (n)

1. A persistent irritating critic; a nuisance.
2. One that acts as a **provocative stimulus**; a goad.
3. Any of various flies, especially of the family Tabanidae, that bite and annoy livestock and other animals.



## The problem that will not die

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

*The reason that our field has grown so much.*

*The reason that we are all under the gun.*

- Numerical weather prediction including data assimilation



## The irony of parameterization

Even though the basic physical equations that we have the most confidence in describe small-scale processes, in practice it is the effects of those small-scale processes that are incorporated into our models through the use of uncertain closure assumptions that are, at best, approximations.



# The overwhelming complexity of cloud processes, 1

- Convective updrafts and downdrafts, and their “environment”
- Interactions of convection with the boundary layer
- Mesoscale anvils and mesoscale dynamical systems

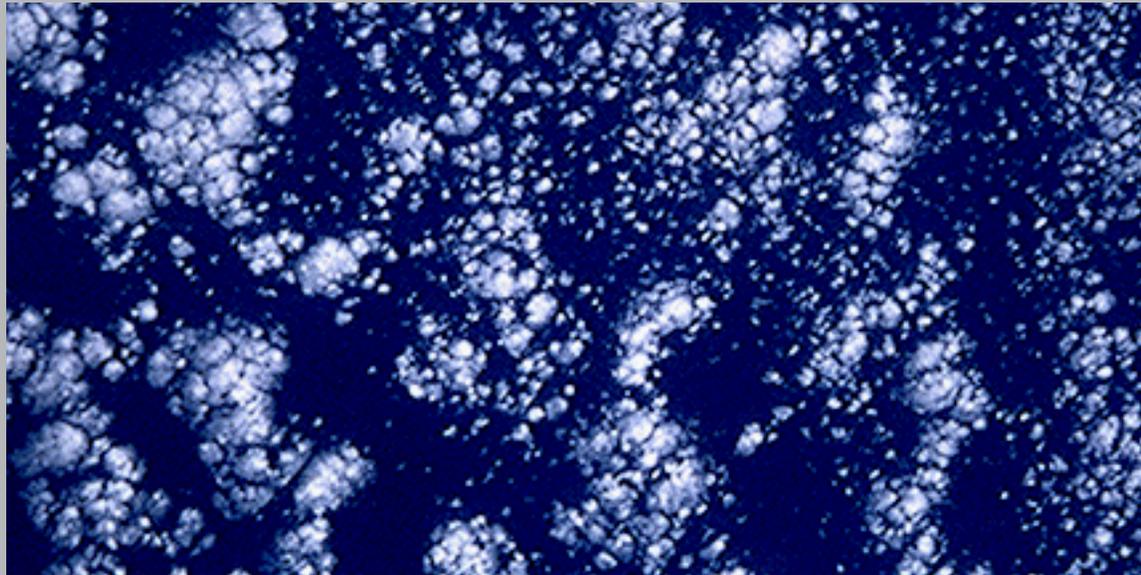


- Tightly coupled radiative and turbulent processes
- Interactions of convection with gravity waves



## The overwhelming complexity of cloud processes, 2

- Interactions of clouds with topography
- Strong dependence of radiation on microphysical parameters
- Cloud overlap in the radiative and microphysical senses
- Aerosol effects, linked to atmospheric chemistry



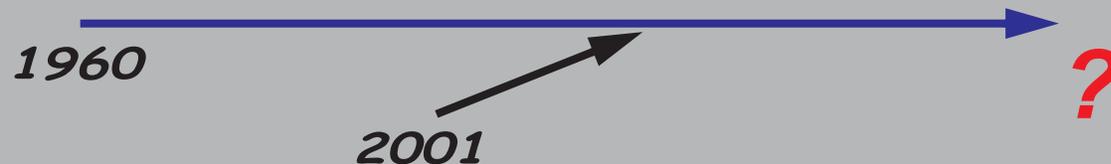
# Parameterizability

Can we really parameterize all of this complexity with quantitative accuracy?

Well maybe, but it's going to take another 100 years.

Our community has already been working on it for about 40 years, and we are still in the early stages of the project.

Empirically, each plodding step forward in cloud parameterization takes about five years to complete.



*"Cloud parameterization is a very young subject."*

-- Akio Arakawa December  
2001



## Modeling tools

**SCMs** are “Single-Column Models,” which are the column-physics components of *GCMs*, surgically extracted from their host *GCMs* and driven by observations of large-scale weather systems.

**CSRM**s are “Cloud-System-Resolving Models,” with resolutions fine enough to represent individual cloud elements, and space/time domains large enough to encompass many clouds over many cloud lifetimes. *CSRM*s can be driven by observations of large-scale weather systems.

A *CSRM* explicitly represents cloud-dynamical processes, such as formation and dissipation, on their “native” space and time scales (kilometers and minutes).

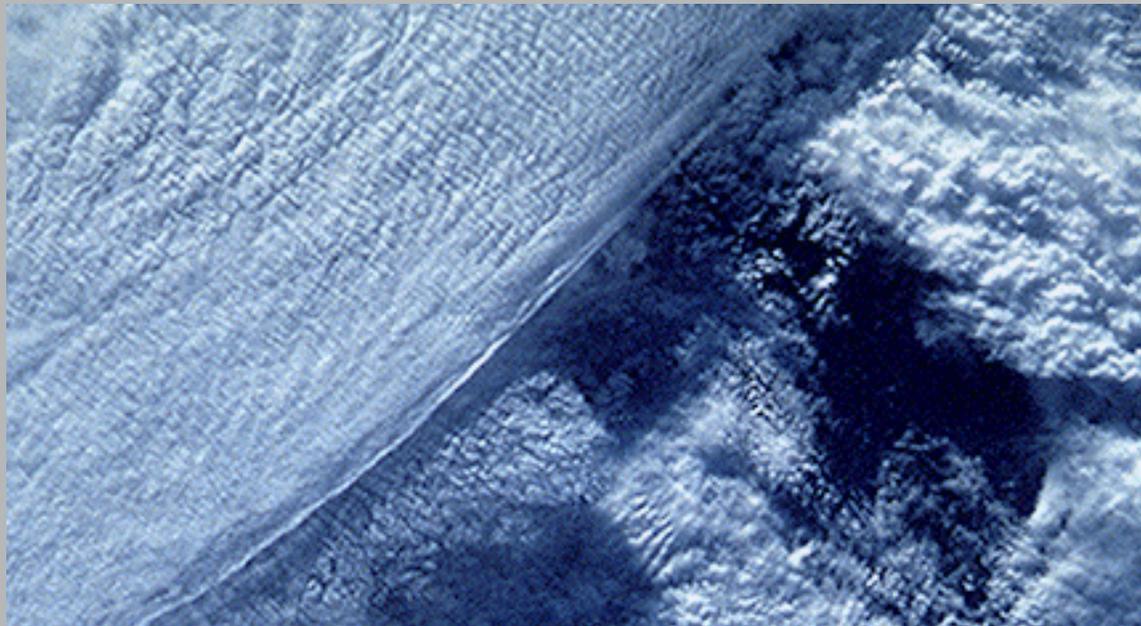
*CSRM*s have been a central focus of *GCSS* from the beginning.



## CSRMs give better results than SCMs

One would certainly hope so, considering that the computational cost of running a CSRMs is hundreds or thousands of times greater than that of running an SCM.

Nevertheless, GCSS has actually *demonstrated* that CSRMs give better results than SCMs, through a number of case studies.



## Too bad we can't run 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.

In a few more decades such global CSRMs will become possible.

There is another approach, however...



We can run a CSRM as a “super-parameterization” inside a GCM.



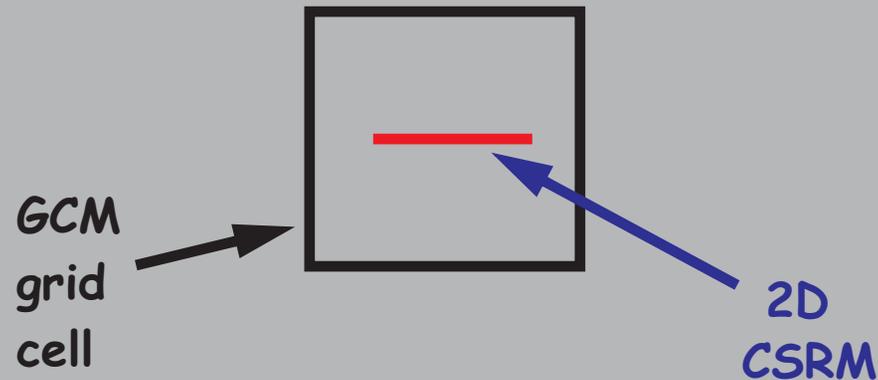
Wojciech Grabowski of NCAR, who is currently Chair of GCSS WG 4, implemented a 2D CSRM inside a simplified global model with globally uniform SSTs, no mountains, etc.

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...



- 2D CRM, whose orientation must be selected somehow
- Cyclic lateral boundary conditions



## And so, inspired by Grabowski's idea...



Marat Khairoutdinov of CSU embedded his 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.

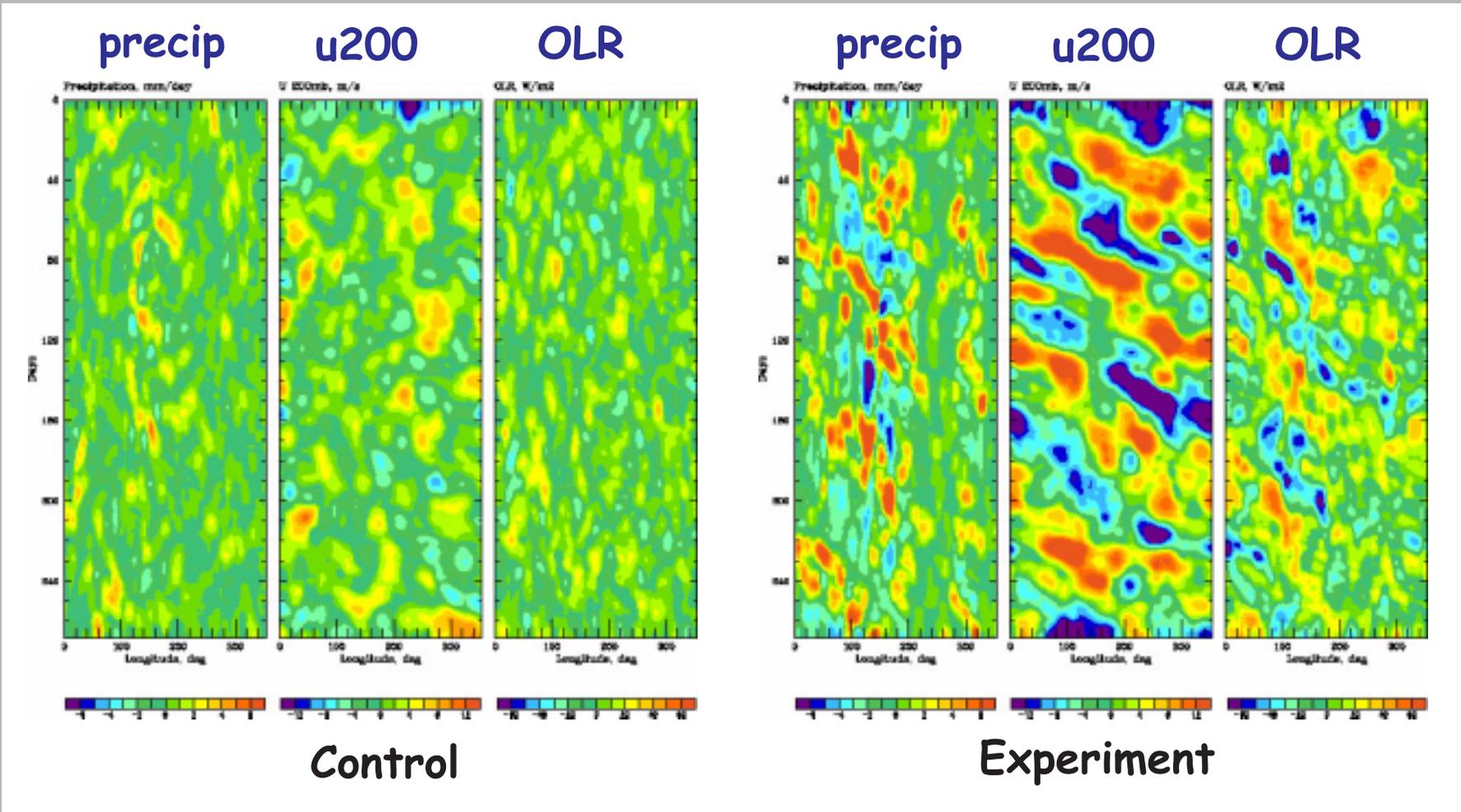
The CSRМ takes the place of the stratiform and convective cloud parameterizations, and in the future will also replace the PBL parameterization.

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.

An MJO in the T21 CAM



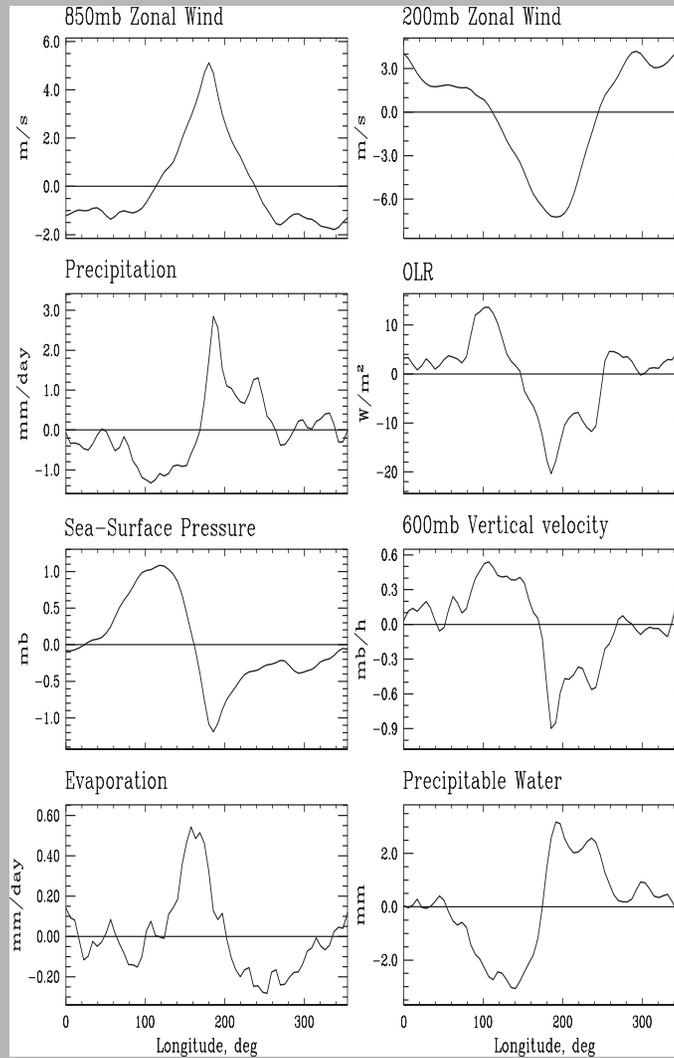
# An MJO in the T21 CAM



*20-100 day band-pass filtered*



# Composite MJO structure



850 mb u

200 mb u

precip

OLR

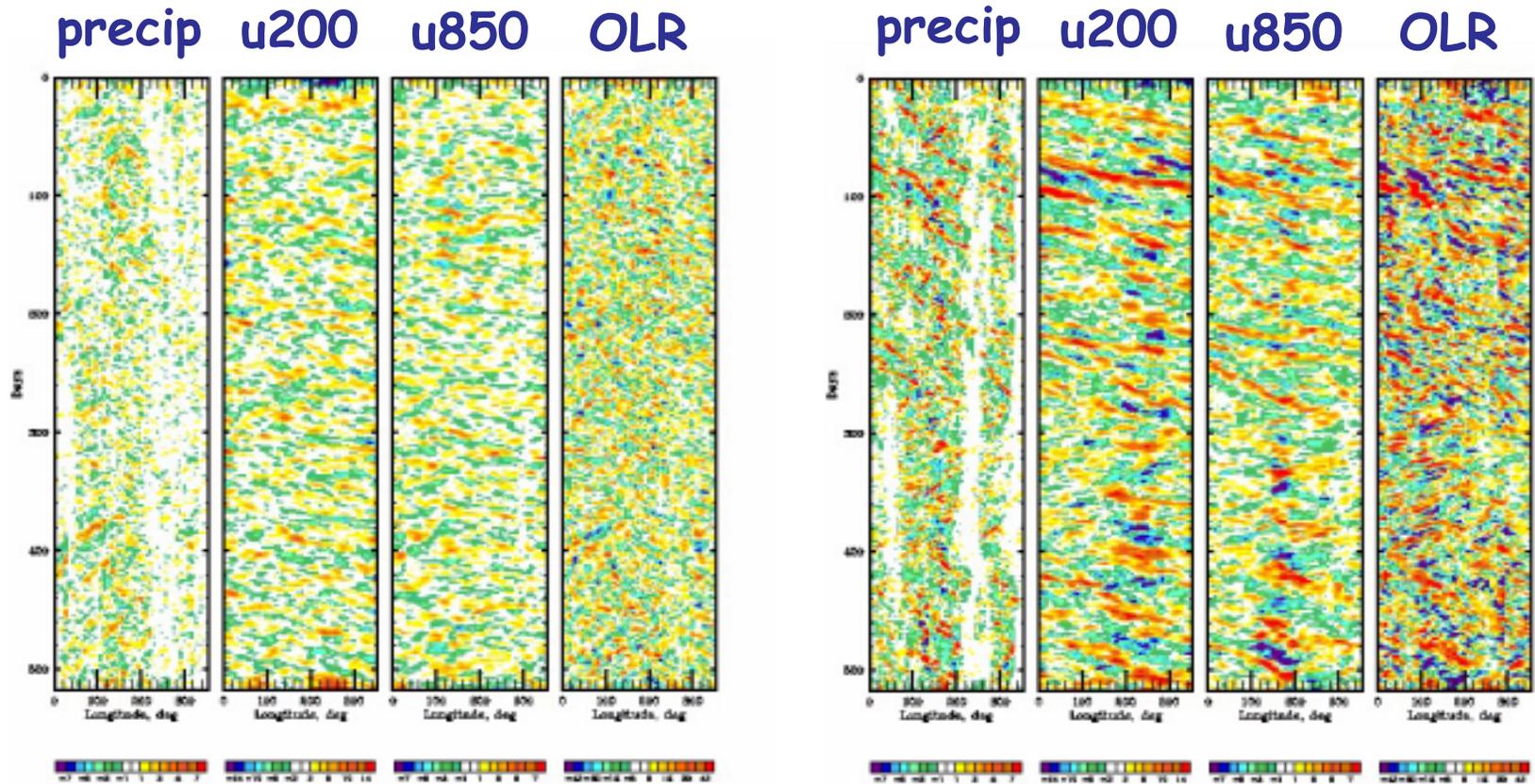
500 mb omega

sfc evap

precipitable water



# Kelvin waves in the T21 CAM



Control

Experiment

*2-20 day band-pass filtered*



## What are we claiming?

- Results to date suggest that super-parameterizations can enable more realistic simulations of important climate processes such as the MJO.
- We have demonstrated that super-parameterizations can be incorporated into GCMs with a modest effort.
- There are many *a priori* reasons to believe that super-parameterizations have the potential to provide more realistic and more reliable simulations of climate.

Wojciech and Marat will show new results later this morning.



## What do we get? (1)

- 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



## What problems don't go away?

- Microphysics, aerosol effects, etc. must still be parameterized.  
But these problems are much more tractable with explicit cloud elements.
- Radiative transfer must still be parameterized.  
But some aspects of the problem are drastically simplified as already noted.
- Turbulence and small-scale convection must still be parameterized.  
Simulations of stratus clouds are a particularly important issue.  
High resolution facilitates the parameterization of turbulence and shallow clouds.
- The usual issues related to the numerical simulation of large-scale dynamics still remain.



## What does it cost?

In our earliest tests with the CAM, the embedded CSRM 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.

The computational aspects of the problem will be discussed this afternoon.



## Inter-related issues

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



# Arakawa's "Quasi-3D" approach

Arakawa is proposing an approach to super-parameterization that essentially disposes of all of these issues.



## Compared to what?

Although super-parameterizations are far from perfect, the only existing alternatives are conventional parameterizations.

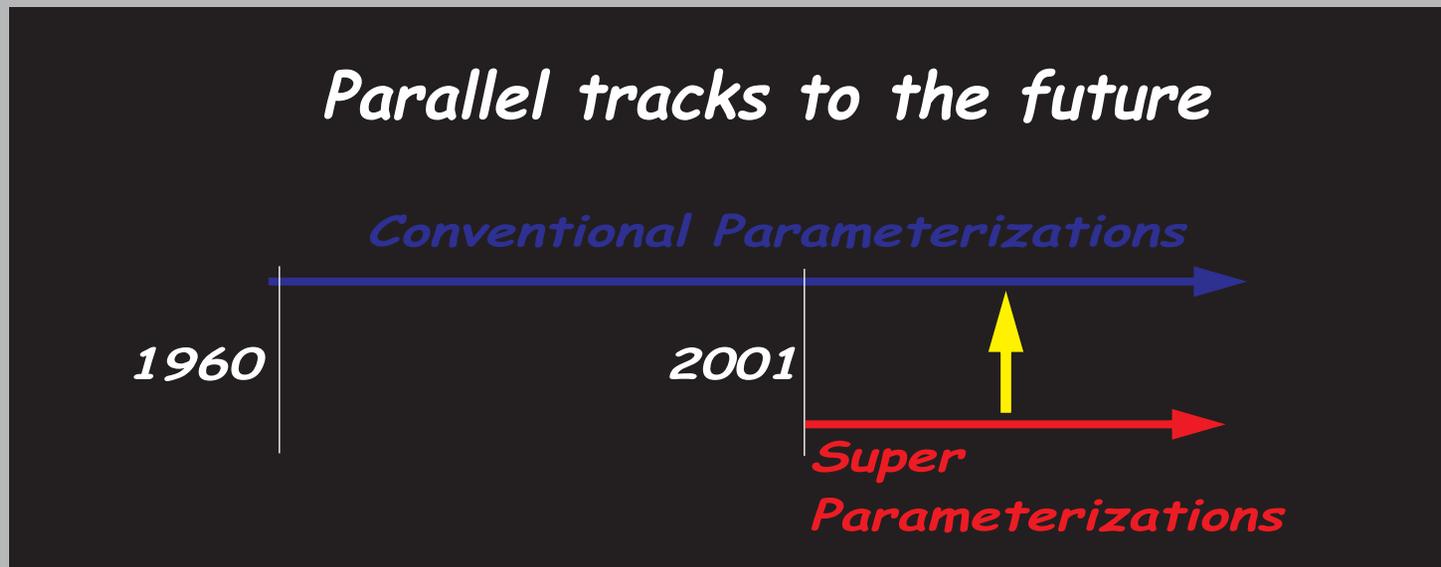
Super-parameterizations are *far superior* to conventional parameterizations.

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



## Continuing roles for “classical” cloud 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.
- 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.



## Summary to this point 1

- Although we are making important scientific progress via the “classical” approach to parameterization, the rate of progress is too slow to provide quantitatively accurate climate-change simulations before the climate changes.
- Super-parameterizations represent a new and very promising approach to cloud parameterization.
- Super-parameterizations were not possible until essentially now.
- A GCM with a super-parameterization can use thousands of processors with good computational efficiency.



## Summary to this point 2

- Super-parameterizations can be used for climate-change simulations in the near future. It will be expensive at first, but the cost will come down rapidly.
- Through the use of super-parameterizations we can improve our understanding of the interactions of clouds with the large-scale circulation. This will increase our rate of progress in the development of improved classical parameterizations.
- Up to now, super-parameterizations have been implemented in a fairly simple way. These implementations are useful, but better approaches are both possible and necessary.
- Super-parameterizations have the potential to enable the assimilation of new types of data:

*TRMM, GPM, CloudSat, Calipso, etc.*

- Super-parameterizations have the potential to improve weather forecasts.



## 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.





## Research involving the current approach 1

- Couple the existing super-parameterization with the radiation and land-surface parameterizations of the CAM.
- Implement the super-parameterization in a planned new version of the CAM (currently being developed at the Oak Ridge National Laboratory) that will be able to use more processors efficiently at the same resolution. Systematically evaluate the scalability of this new version of the CAM with the super-parameterization.
- Develop a revised version of the CSRM that can simulate PBL clouds more realistically.
- Implement an improved radiative transfer parameterization in the CSRM.
- Test a method for performing multi-dimensional radiative transfer computations inside the CSRM, for possible use in the super-parameterization.



## Research involving the current approach 2

- Develop and implement an improved cloud microphysics parameterization within the super-parameterization, taking into account the effects of aerosols, and coupling with the radiation parameterization.
- Test the super-parameterization in multi-year simulations with the CAM, using prescribed sea-surface temperatures.
- Test the super-parameterization in one or more annual cycles with the coupled ocean-atmosphere version of the CCSM.
- Apply the model to a simulation of the observed variations of the Earth's radiation budget over the period 1985-2000.



# Developing an improved super-parameterization

*It is both possible and necessary to develop greatly improved super-parameterizations.*

- Test the quasi-3D coupling concept in a simplified model built expressly for that purpose.
- Develop a new version of the CSRM that uses the elastic system of equations with a more exact moist thermodynamics and an improved PBL parameterization.
- Construct a modified GCM that is based on the same non-hydrostatic governing equations as the new CSRM.
- Implement Arakawa's quasi-3D coupling concept using the new CSRM and new GCM.



## Applications (with either version, or both)

- Perform simulations of anthropogenic climate change.  
    Cloud feedbacks from a super-parameterization.
- Investigate the utility of super-parameterizations for data assimilation, taking advantage of the simulated micro-scale cloud structures as mentioned above.



# Which brings us to Science and Technology Centers...

Super-parameterizations can be one of the main foci of an NSF Science and Technology Center dedicated to speeding the development and applications of future cloud parameterizations.



# The objectives of the STC Program 1

- Support research and education of the highest quality;
- Exploit opportunities in science, engineering and technology *where the complexity of the research agenda requires the advantages of scope, scale, change, duration, equipment and facilities, that a Center can provide;*
- Support frontier investigations at the interfaces of disciplines, and/or *fresh approaches* within disciplines;
- Engage the Nation's intellectual talent, robustly drawn from its full human diversity, in the conduct of research and education activities;



## The objectives of the STC Program 2

- Promote *organizational connections and linkages* within and between campuses, schools and/or the world beyond (state, local, federal agencies, national labs, industry, international);
- Focus on integrative learning and discovery and the *preparation of U.S. students* for a broad set of career paths; and
- Foster science and engineering in *service to society* especially with respect to new research areas, promising new instrumentation and potential new technologies.



# The Scope of a Cloud Parameterization STC

- Theory

*Parameterization theories*

*Simple models of moist circulation systems*

- Numerical modeling

*Work with both classical parameterizations and  
super-parameterizations*

- Observations

*Evaluation of parameterization theories and numerical results*

- Practical applications

*Climate-change simulations*

*Numerical weather prediction and data assimilation*



We will talk more about STCs and the STC proposal process this afternoon.

