Super-Parameterizations:
More Results and More Ideas

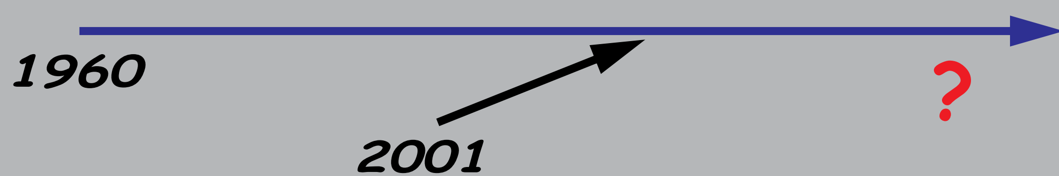
Parameterizability

Can we really parameterize complex cloud processes with quantitative accuracy?

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

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

Empirically, the time scale for significant advances in cloud parameterization appears to be about five years.



"Cloud parameterization is a very young subject."

-- Akio Arakawa
December 2001

Blackbird:Users:randall:Super_Parameterizations:Super_CERES_May01.frame

CSRMs 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. CSRMs 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).

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.

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.

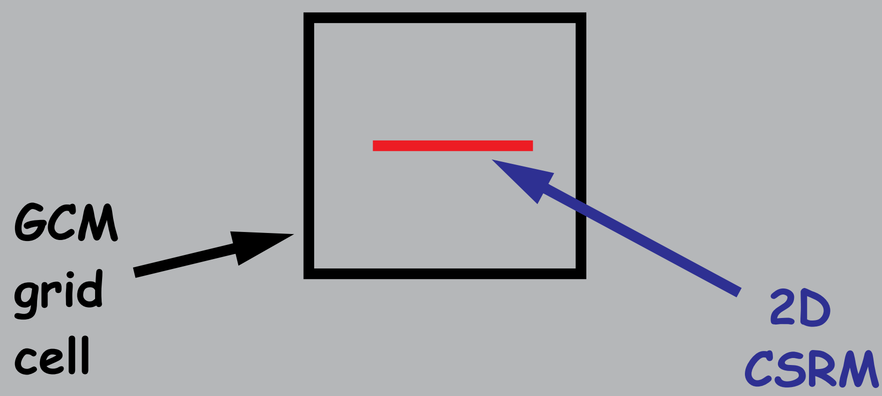
There is another approach, however...

Super-Parameterizations

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

This idea was first suggested by Wojciech Grabowski of NCAR, who did tests with a simplified global model (not a real GCM).

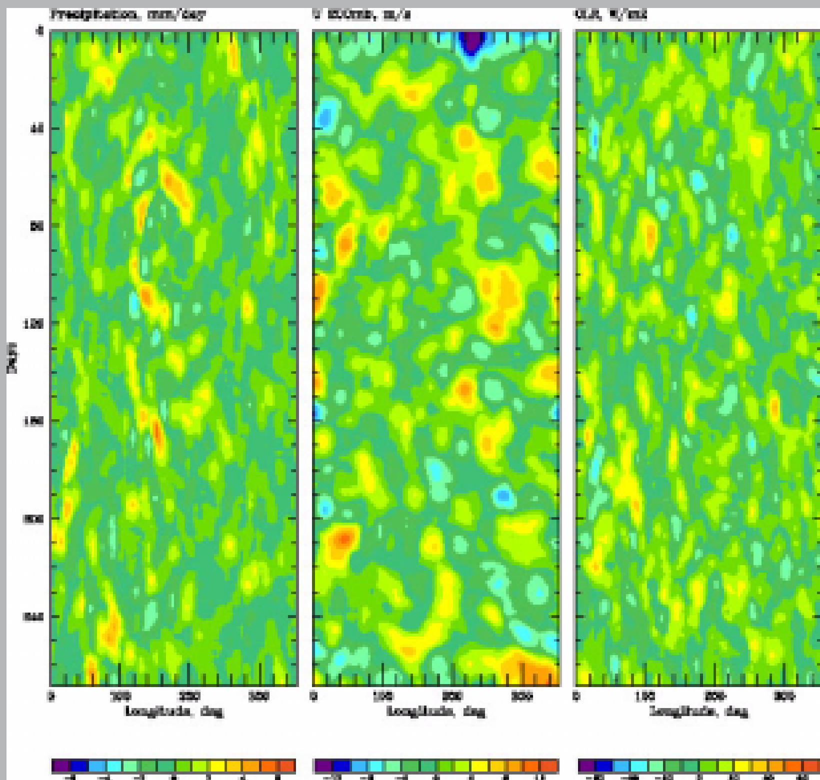
Grabowski's approach...



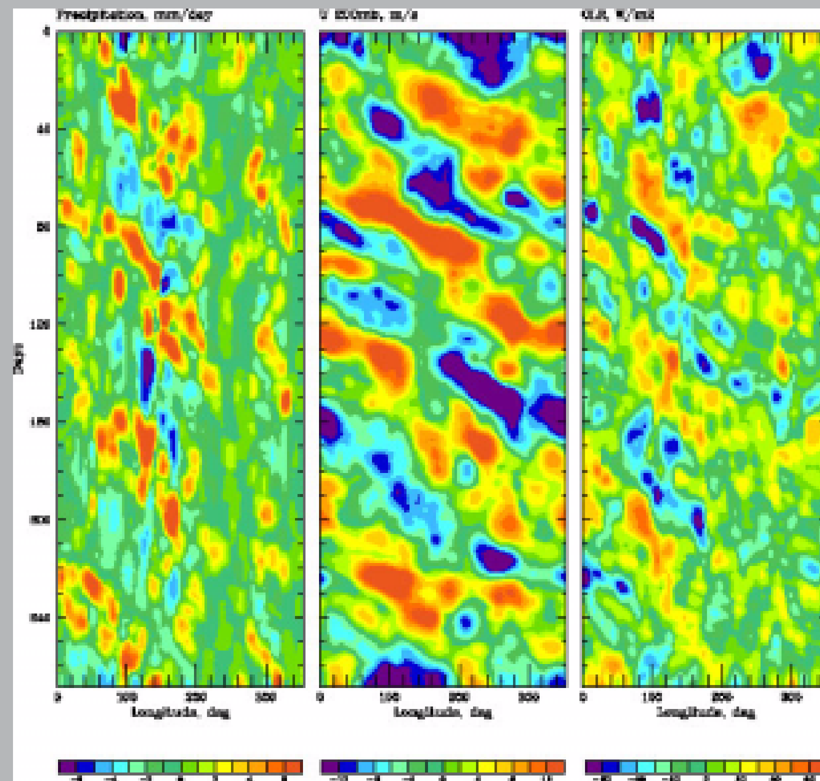
- 2D CRM, whose orientation must be selected somehow
- Cyclic lateral boundary conditions

Marat Khairoutdinov and I have installed Marat's CSRM as a super-parameterization in the CAM (the Community Atmosphere Model).

We get a pretty nice looking Madden-Julian Oscillation.

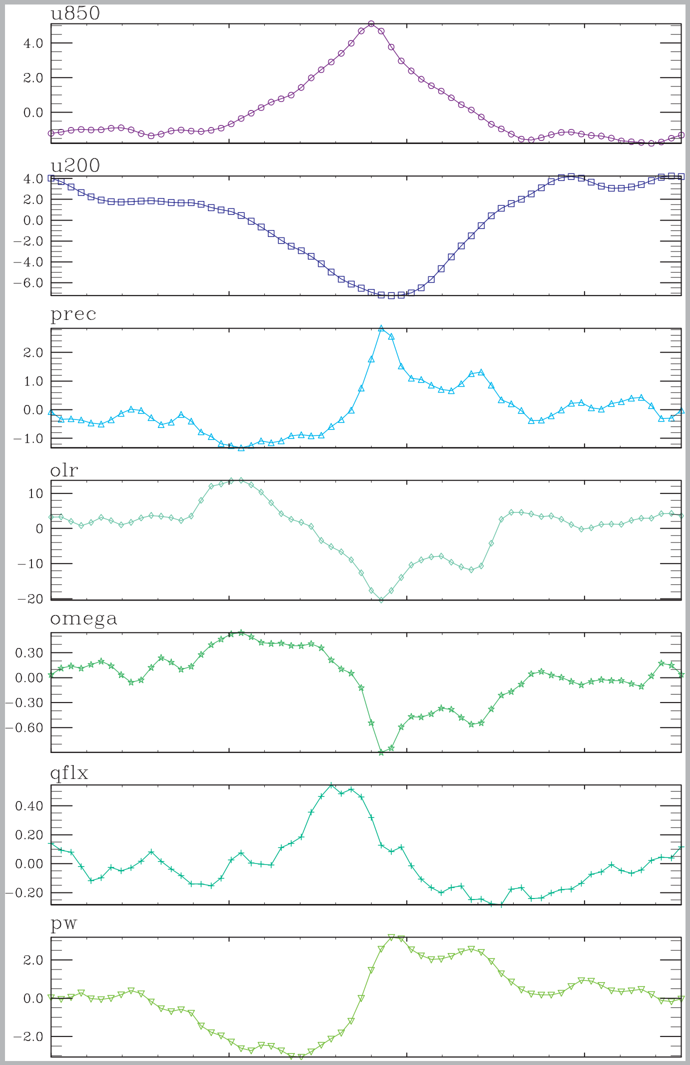


Control



Experiment

Composite MJO structure



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 does it cost?

In our tests to date with the CAM, the embedded CSRM slows the model down by a factor of about 180.

A one-day simulation with CSRM embedded in a T42 GCM takes about one hour on 64 processors of an IBM SP.

> One copy of the CSRM takes ~30 secs per simulated day on one processor.
>
> Here we are running ~100 copies of the CSRM on each processor.
>
> Therefore the model uses about one hour per simulated day.
>
> The run time for the GCM itself is negligible.

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

Rescued by massive parallelism

Super-parameterizations provide a way to utilize more processors for a given GCM resolution.

Number of processors	Conventional CAM			Current Super CAM			Near-Future Super GCM		
	Phys	Dyn	Sum	Phys	Dyn	Sum	Phys	Dyn	Sum
1	1	1	2	360	1	361	360	1	361
32	1/30	1/30	1/15	12	1/30	12	12	1/30	12
1024	1/30	1/30	1/15	12	1/30	12	1/2	1/100	1/2

What problems don't go away?

- **Microphysics must still be parameterized.**

  But the problem is more tractable with explicit cloud elements. More sophisticated microphysics parameterizations can be "plugged in" to the CSRM.

- **Radiative transfer must still be parameterized.**

  But some aspects of the problem are drastically simplified as already noted. Work in this area is currently under way at Penn State, AES Canada, and CSU.

- **Turbulence and small-scale convection must still be parameterized.**

  But high resolution facilitates this too. Work in this area is currently underway at CSU and NASA LaRC.

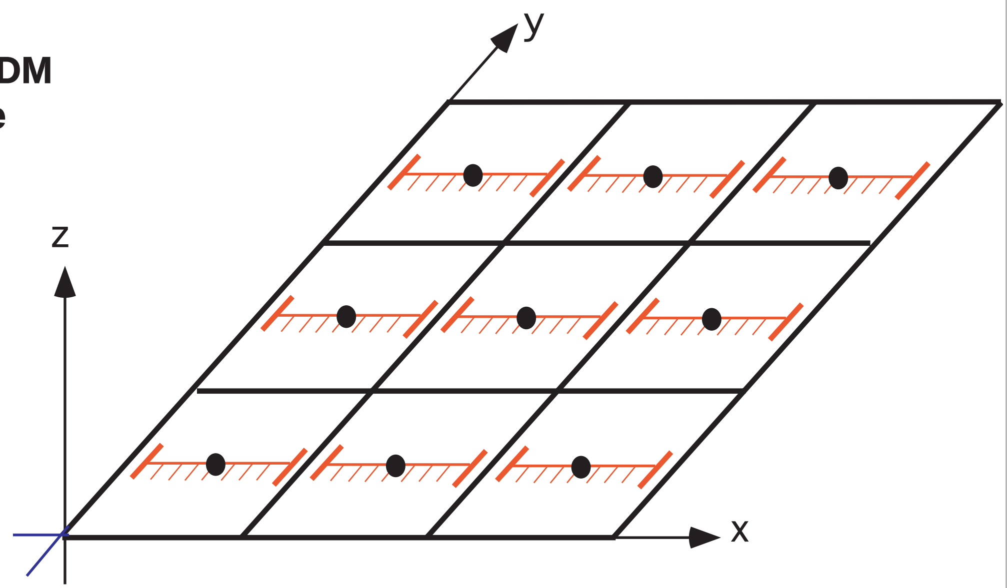
- **Issues related to the numerical simulation of large-scale dynamics still remain.**

Cloud-Resolving Convection Parameterization or Super-Parameterization

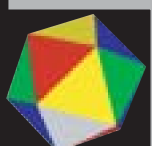
Grabowski (2001), Khairoutdinov and Randall (2001)

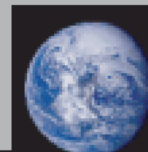
**Application of
a 2D CSRM within each column of a large-scale dynamical model (LSDM)
with periodic lateral boundary conditions**

At the ● points, the LSDM and the domain-average of the CSRM interact.



Concept and viewgraph from Akio Arakawa



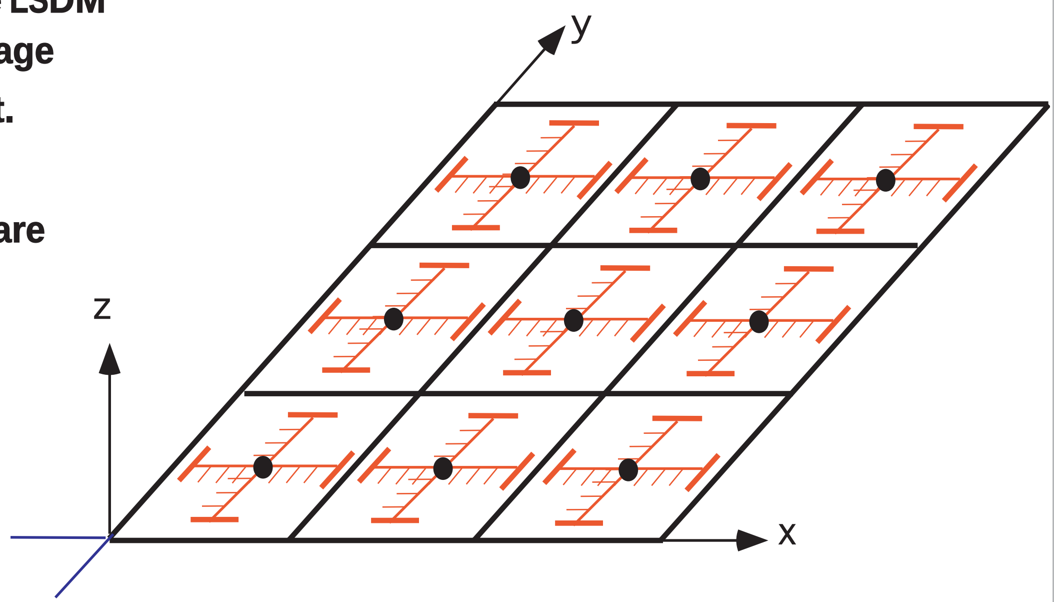


Variant I

Application of two 2D CSRMs to each column of an LSDM with periodic lateral boundary conditions

At the ● points, the LSDM and the domain-average of the CSRMs interact.

Also, the two CSRMs are directly coupled to form a 3D CSRM



Concept and viewgraph from Akio Arakawa

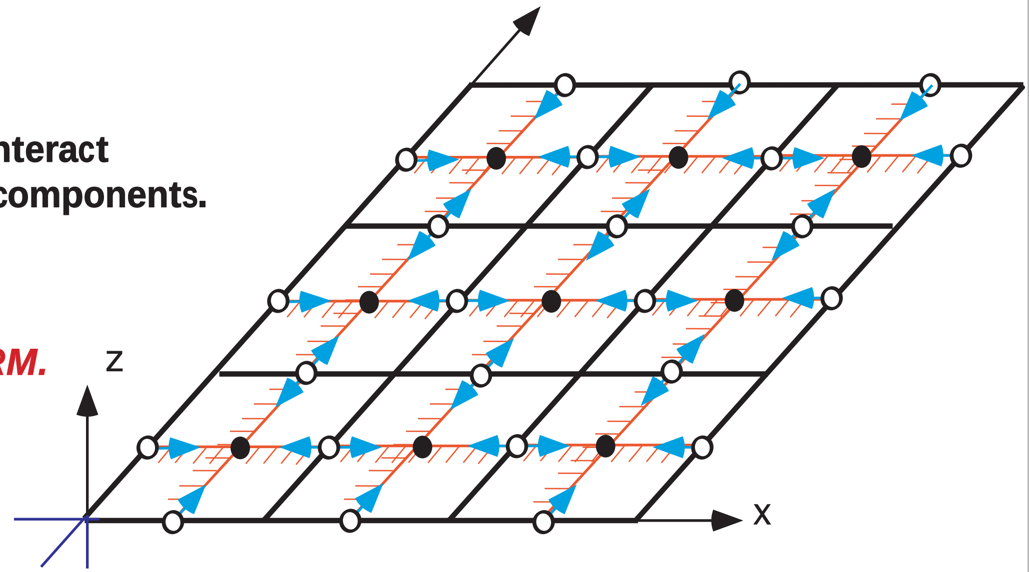
Variant II

Application of two sets of 2D CSRMs with the continuity equation shared with the LSDM

At the points, two CSRMs are directly coupled to form a 3D CSRM, and the LSDM and the domain-averaged CSRMs interact through scalar variables.

At the points, the LSDM and CSRMs interact through their velocity components.

The coupled system converges to a 3D CSRM.



Concept and viewgraph from Akio Arakawa

Why this revised coupling is better

- 2D is replaced by quasi-3D.
- The orientation problem goes away.
- Convective systems can propagate from one GCM grid column to the next.
- When the GCM's resolution is increased, there is no reason to alter the formulation of the embedded CSRM. In this sense, the super-parameterization is "resolution-independent."
- Observed topographic forcing can be prescribed and used to generate orographic gravity waves and orographic clouds.
- A GCM with a super-parameterization *converges* to a global CSRM.

Where do we go from here?

- **More tests of the current configuration or slightly modified versions of it**

Longer runs

Computational benchmarking

Short coupled runs

- **Data assimilation**

DAO, NCEP

CloudSat, Calypso, TRMM

- **New CSRM in new GCM**

Designed from the beginning to work together

Same equations, same vertical coordinates

Quasi-3D approach

Summary and conclusions 1

- To take conventional parameterizations much beyond where we are now, it seems likely that we will have to make the parameterizations very, very complicated -- in some respects *more* complicated than CSRMs.
- A CSRM can be used as a super-parameterization inside a GCM.
- The same CSRM can be driven off-line using ARM data. Super-parameterizations thus provide a radically new way to make connections between ARM data and GCMs.
- Results to date suggest that super-parameterizations can *give* significantly more realistic climate simulations than conventional parameterizations do.

Summary and conclusions 2

- A GCM using a super-parameterization is two to three orders of magnitude more expensive than a GCM that uses conventional parameterizations.

- A GCM with a super-parameterization can use thousands of processors with good computational efficiency.

- Super-parameterizations represent a distinctly new approach to climate simulation. They are not “more of the same, only better.”

Super-parameterizations are the only approach that can break the cloud-parameterization deadlock.