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Sensitivity to convective parameterization and resolution in simulations of tropical cyclones

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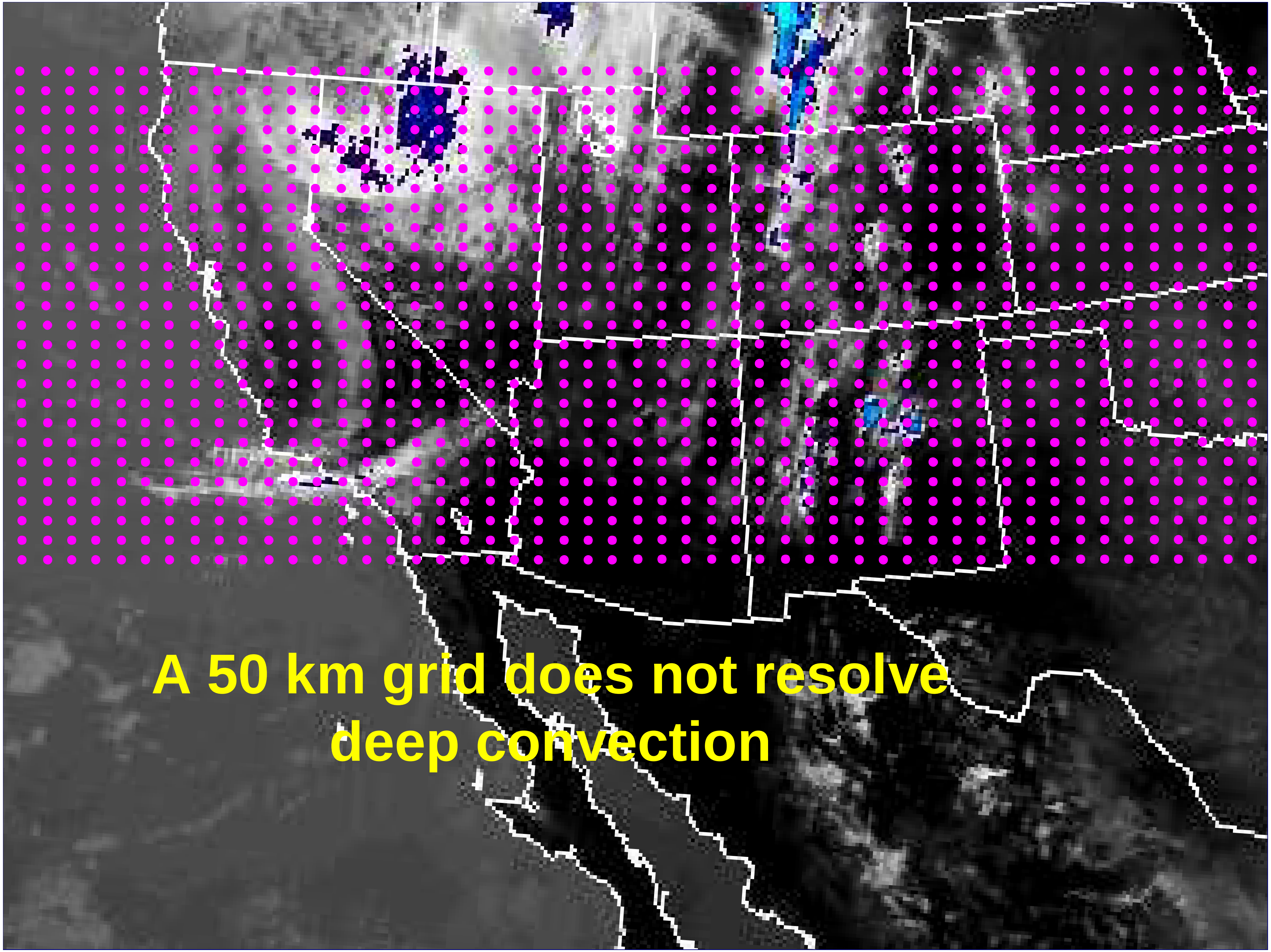
Overview

- Survey of convection schemes in RegCM3.
- Sensitivity of simulated tropical cyclones to the choice of convection scheme in 20-year simulations over the tropical Southwest Pacific Ocean.

We must use grid scale variables to infer the effects of cumulus convection

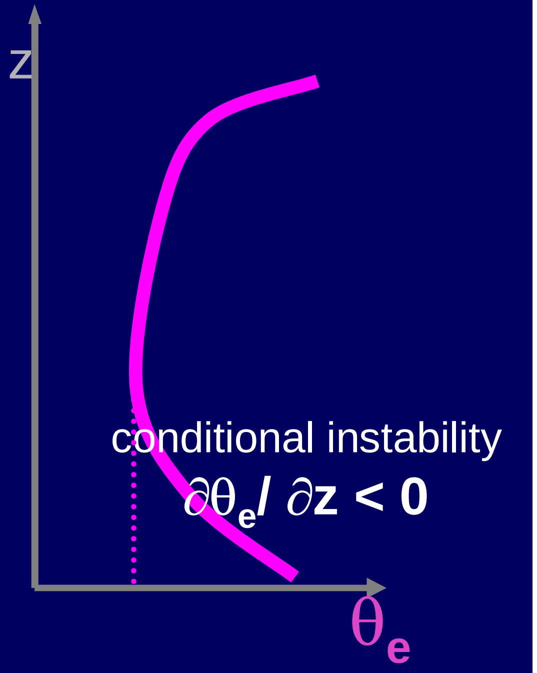
- Convection occurs on scales too small to be resolved in current regional climate models:
  - ❑ typical convective updraft ~ 0.2 - 2 km
  - ❑ typical RegCM3 grid length ~ 20 km or more
- But deep convection is important both for climate impacts and for dynamics.
- We must **indirectly infer** the existence and effects of deep convection – we **parameterize** convection based on grid-scale variables.



A 50 km grid does not resolve deep convection

Early models used moist convective adjustment

- ☐ If the atmosphere is conditionally unstable and a "trigger" criterion is satisfied, adjust the grid-scale temperature and moisture profiles to remove the instability.
- ☐ Typically, adjust to a moist adiabat.
- ☐ Adjustment leaves some excess water (precipitation) and releases latent heat.
- ☐ Adjustment must be gradual to avoid generating large amplitude gravity waves.



Later approaches attempted to remove convective instability in a more realistic way

- Examples:
  - ❑ Carefully link the energetics of large-scale and cumulus-scale processes (Arakawa-Schubert; Grell).
  - ❑ Base the final adjusted profile on observed thermodynamic evolution (Betts-Miller).
  - ❑ Do the adjustment in a way that reflects the dynamics and thermodynamics of deep cumulus clouds (Kain-Fritsch-Chappell; other "mass flux" type schemes).

Convective parameterizations in RegCM3

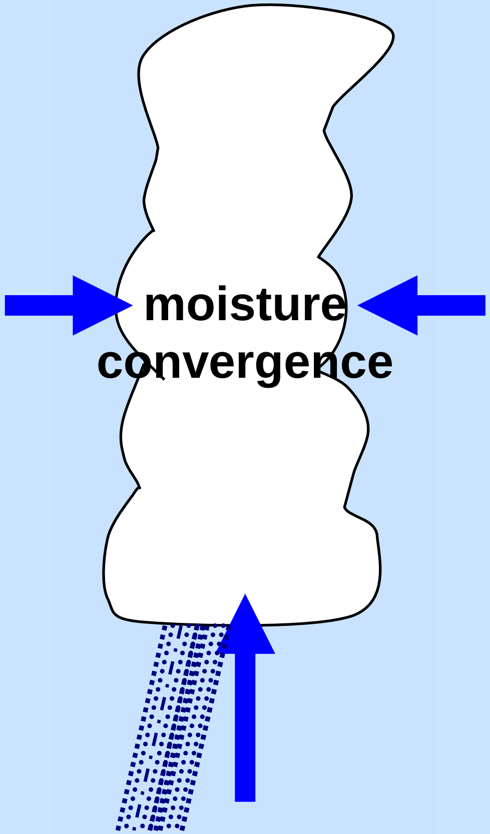
- Kuo-Anthes
- Grell
  - With choice of closure assumption: Arakawa-Schubert or Fritsch-Chappell.
- Emanuel
- Betts-Miller scheme ("not ready" according to the source code)

The Kuo-Anthes scheme is mainly concerned with moisture and its redistribution

- Originally developed by Kuo (1965) with refinements by Anthes (1974, 1977)
- Assume:
    - Convection is caused by moisture convergence (this is **wrong** in a basic physical sense).
    - When convection occurs, moisture convergence into a column is partitioned between column moistening and precipitation.
    - Thermodynamic profiles are relaxed toward a moist adiabat over time scale τ.

$$Q_c = \frac{\theta_a - \theta}{\tau}$$

Partitioning of moisture convergence in the Kuo scheme is controlled by the b parameter



column moistening
= **b** × moisture convergence

precipitation
= **(1-b)** × moisture convergence

Anthes: **b** varies (inversely) with column relative humidity.
As RH → 1 the column can't hold any more water so **b** → 0.

In RegCM3, the "b parameter" is **`c301`** in subroutine `cupara.F`

The Grell scheme considers production and release of convective instability

- Adapted from the Arakawa and Schubert (1974) scheme:
  - Convective instability is **produced** on the large scale (resolvable / grid scale).
  - Convective instability is **dissipated** by the small scale (subgrid / cumulus scale).
  - Closure assumption : There is a quasi-equilibrium between large-scale generation and cumulus-scale dissipation of instability.
- Simplification (Grell):
  - Consider only a single dominant cloud type; add downdraft effects.

The Grell scheme in RegCM

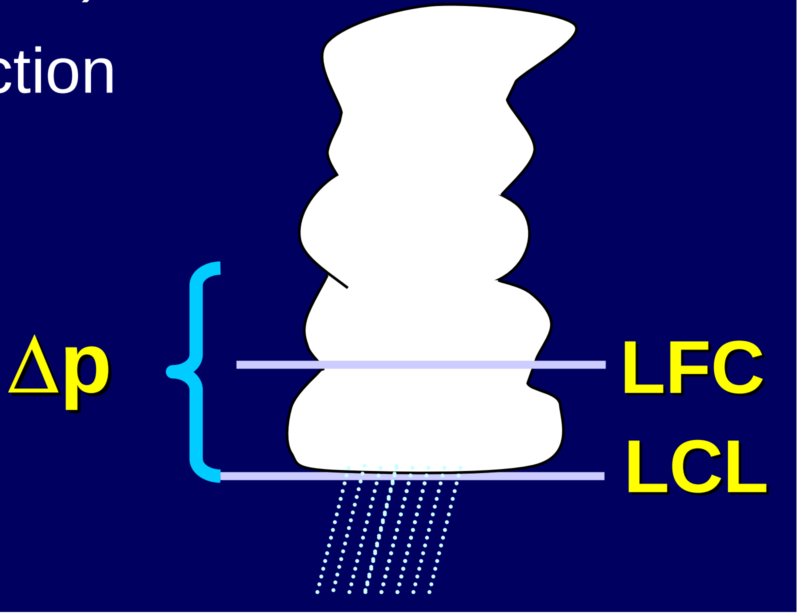
- Two choices of closure assumption:
  - Arakawa-Schubert closure: The convective scale dissipates instability at the same rate that the large scale produces it (this is the "quasi equilibrium" hypothesis).
  - Fritsch-Chappell closure: The convective scale dissipates instability over a fixed time period (`GWDXF#`= 30 minutes in the default RegCM3).
  - The difference is one line of code!

Choosing the Fritsch-Chappell closure does NOT mean that you are using the Fritsch-Chappell convection scheme!

- The Fritsch-Chappell scheme has many other differences from the Grell scheme such as:
  - different trigger function
  - different source level for the updraft
  - different representations of entrainment and detrainment
  - a detailed 1-D cloud model with ice phase microphysics

Trigger function in the Grell scheme

- Lifting depth trigger:
  - ❑ Vertical distance between the lifted condensation level (LCL) and level of free convection (LFC) is smaller than a specified threshold depth **Δp**
  - ❑ **Δp** is `sefpd{` in `sdudp1I` and in namelist `'juhoosdudp` (default 150 mb)
  - ❑ Larger **Δp** means that convection can occur more easily.



The Emanuel scheme is different from most other convection schemes

- **VERY** different.
- Instead of a single "plume" that entrains or detrains, it considers convective drafts that can move between all layers from cloud base to cloud top.
- Each draft entrains or detrains depending on the buoyancy of a mixture of its air and the environment.
- Many other differences, such as convective momentum transport.

So: what effect does all this have on the results we get?

- Use the schemes in simulations for the Pacific Climate Change Science Program (PCCSP):
  - ☐ The goal of PCCSP is to examine climate change for the Southwest Pacific region.
  - ☐ One interest is how the frequency, distribution and strength of tropical cyclones in this region will change in future climates.
  - ☐ Tropical cyclones are driven by **the release of latent heat in deep convection.** So we expect they could be sensitive to the convection scheme.

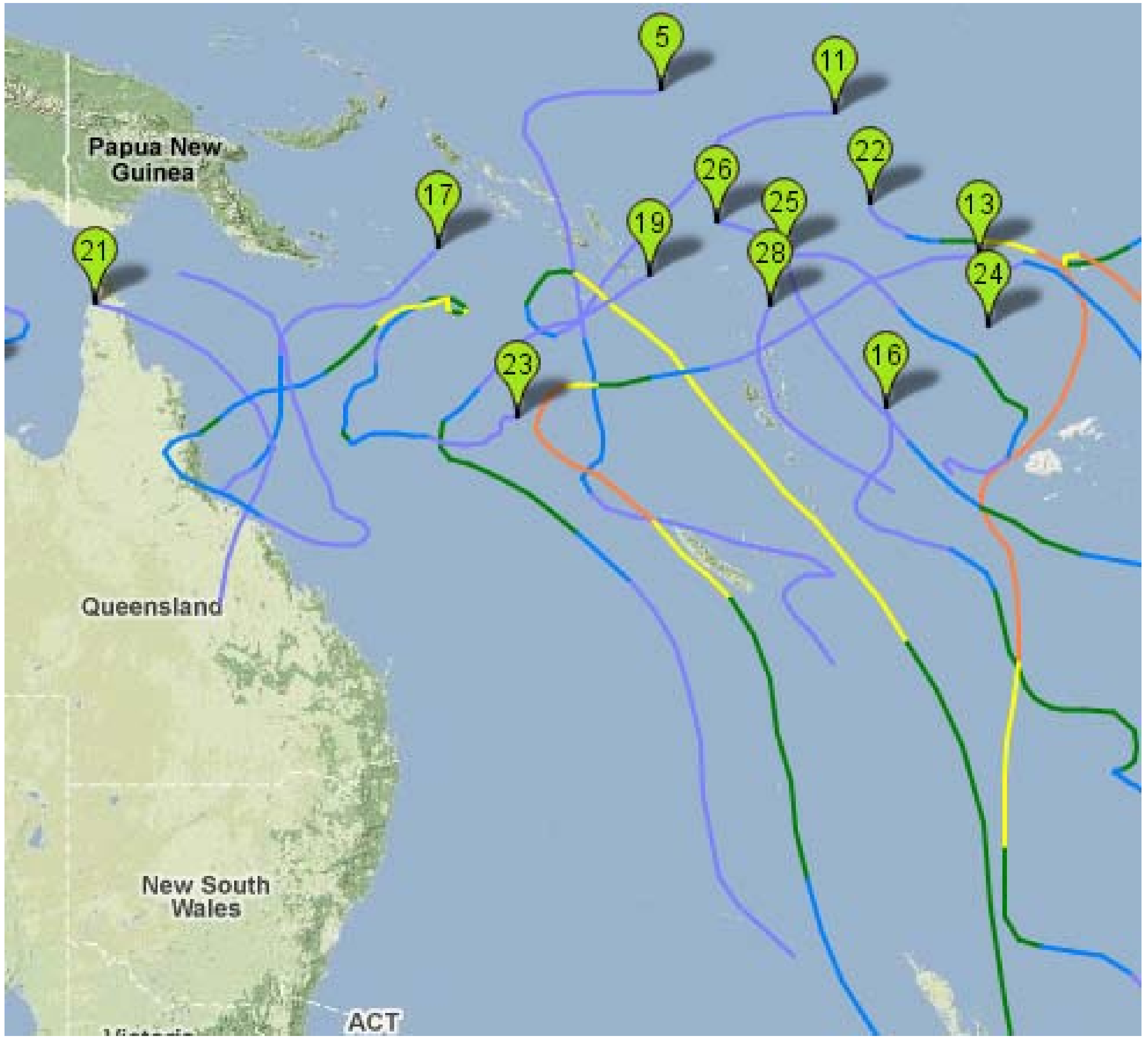
Model configuration

- RegCM3 at 50 km and 25 km resolution.
- For each resolution, do runs with:
  - Anthes-Kuo scheme
  - Grell scheme (using both Arakawa-Schubert and Fritsch-Chappell closures)
  - Emanuel scheme
- Period of simulation is 1 Jan 1982 through 1 Jul 2002 (20 tropical cyclone seasons).
- Initial and boundary conditions are NCEP-DOE reanalysis (NNRP2) and OISST (Reynolds).

Animations of model results during tropical cyclone season

- Plot precipitation and wind vectors at the lowest model level for November-April.
- Look at results for each convection scheme, first at 50 km then at 25 km:
  - ❑ Anthes-Kuo
  - ❑ Grell with Arakawa-Schubert closure
  - ❑ Grell with Fritsch-Chappell closure
  - ❑ Emanuel

The most active season: 1996



An inactive season: 1989

Summary

- Convective parameterization cannot be avoided in regional climate modeling at current resolution.
- Different convection schemes use different basic assumptions about how convection works.
- The convection schemes in RegCM3 produce very different climatologies of tropical cyclones in the southwest Pacific.
- We see different behaviors amongst the schemes at both 50 km and 25 km resolution. Choice of convection scheme appears to have more effect on the results than resolution.

Much more work is needed!

- These are preliminary results and I do not have many answers yet. Future work:
    - ☐ Use an automated routine to compute tropical cyclone statistics (number, intensity, etc).
    - ☐ Understand why different parameterizations produce such different results: perform diagnostics of physical processes.
- Use AOGCM results as initial/boundary conditions to simulate present and future climates.

THANK YOU
for your attention!