Examining Chaotic Convection with Superparameterization Ensembles

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Forecasting with GCMs

Large Scale
- Advective Forcing
- Heating & Drying

Small Scale
- Parameterized
  - Convection
  - Microphysics
  - Radiation
  - Turbulence
Deterministic

Expected Values
- something like -
Ensemble Means

Non-Deterministic

Individual Realizations
with
Sensitive Dependence on Initial Conditions
Issues with SDIC, sample size, false scale separation, memory and time scales limit deterministic parameterizability.

Real physical tendencies have a significant chaotic component.
- They are only partially predictable.
- Grid cell averaged precipitation is intrinsically uncertain.

We confront this by providing the solution wandering space:
- Ensembles
- Stochastic parameterization
- Superparameterization
  - Non-deterministic due to SDIC on the convective scale
Many deterministic parameterizations yield convection that acts too quickly.
   – Poor timing and extremes

A lack of high-frequency, small-scale variability in GCM precipitation and physical tendency fields may limit their ability to simulate low-frequency, large-scale aspects of climate variability.
   – Poor intraseasonal variability, MJO, QBO
Large-scale feature are improving.

Values > 60 indicate useful forecasts.

Precipitation forecasting is quite difficult...
...particularly intense precipitation.

Li et al., JAMES, 2012

Obs

SP-CAM

95th percentile, daily

99.5th percentile, 3-hourly

(e) CPC

(f) CPC

(c) SPCAM

(d) SPCAM
We Wonder…

• Does the large-scale need to feel “jagged,” stochastic tendencies?
• Is it possible for a smoothed, more deterministic tendency to yield the same gains?
• Can we explore the range of possible realizations at the same time?
Superparameterization

- Solves equations of motion
- No closure assumption
- No triggers
- Mesoscale organization
- Convective memory
- SDIC

Computationally Expensive
More Deterministic, Multiple Realizations

See the same GCM state - Slightly different initial conditions - Running independently
Experimental Design

- CAM-FV with $2.5^\circ \times 1.9^\circ$ longitude-latitude grid
- Climatological SSTs
- SP-CAM, 30 years
  - 32×4-km curtain, oriented N-S
- MP-CAM, ~23 years
  - 10 clone CPMs
  - 4 years of 3-hourly data
  - 2 days every GCM time step
- SP-CAM Ensemble “Forecast,” 10 days
Ten realizations at a tropical point

Ten realizations at a midlatitude point

Time

Horizontal

mm day$^{-1}$
A more deterministic superparameterization

Did we really create one?
A more deterministic superparameterization

Standard deviations of averages are smaller than standard deviations of individual time series.

\[
\sigma_{\bar{x}} = \frac{\sigma}{\sqrt{n}}
\]
PDFs with 10 random time series

...But our data is not random...
Standard deviation of local time series

Difference from control →
How do the climates of SP and MP differ?
- More frequent precipitation
- Increased light precipitation
- Decreased heavy precipitation
Locating Strong, Unpredictable Convection

• Exploring, and potentially exploiting, the range of possible realizations using identical large-scale states.

• Use spread measures as indicators of predictability
  – Coefficient of variation (standard deviation/mean, noise/signal)
  – Proportional variability (mean ratio of all combinations of data pairs)

• Look for associated large-scale properties
  – Since we can better predict the large-scale, perhaps we can predict potential predictability.
Locating Strong, Unpredictable Convection

Data: 3648 days
Pseudoadiabatic convective available potential energy [J/kg]

ANN, precip > 5 mm day$^{-1}$
Proportional Variability

$\tau_{av} = 0.788$, $r_p = 0.907$, $r_{av} = 0.465$, $r_{avav} = 0.511$
Local Temporal Correlation (sig @ 99%)

Data: 3648 days
Pseudoadiabatic convective available potential energy [J/kg]

ANN, precip > 5 mm day$^{-1}$
COV

$\tau_{av} = 0.716$, $r_p = 0.842$, $r_{av} = 0.366$, $r_{avav} = 0.430$
Local Temporal Correlation (sig @ 99%)
Locating Strong, Unpredictable Convection

Data: 2133 days
Grid box averaged cloud liquid amount [g kg⁻¹], 600 mb

Data: 3648 days
Vertically-Integrated low cloud [fraction]

ANN, precip > 10 mm day⁻¹
Proportional Variability

Local Temporal Correlation (sig @ 95%)

$\rho_{\text{GT}} = -0.445$, $r_g = -0.083$, $r_{\text{grid}} = -0.452$, $r_{\text{grid}}^\text{sig} = -0.576$

$\rho_{\text{GT}} = -0.803$, $r_g = -0.931$, $r_{\text{grid}} = -0.413$, $r_{\text{grid}}^\text{sig} = -0.528$
Quasi-Conclusions

• Deterministic parameterizations produce weaker, more frequent precipitation.
• This leads to more high cloud, weaker OLR, and lower precipitation amounts.
• Deterministic parameterizations may be able to represent intraseasonal variability. (Even while degrading some statistics)
• Spread around the response is not simply proportional to the mean, has spatial structure, and is associated with L-S features.
• We have useful tools to explore these issues.