Stochastic parameterization: is sophistication useful?

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A practical view

- Near-grid scale in GCM and NWP models is not energetic enough
- Adding near-grid scale noise can correct that
- Some very simple noise generators are beneficial
  multiplicative or random-parameters noise in NWP ensembles
- Are complex methods based on a rethought parameterization strategy necessary or useful in practice?
- i.e., what physical constraints should control the character of the stochastic tendencies?

Scales for parameterization

Three important scales to consider:

1. intrinsic scale of the process to be parameterized (turbulent eddy sizes, cloud dimensions...)
2. a large-scale, sufficient to contain many instances of the process
   i.e., scale at which time average $\approx$ space average $\approx$ ensemble average
3. the model grid box size

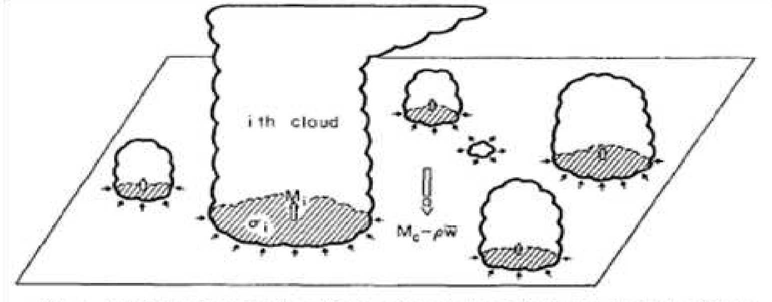
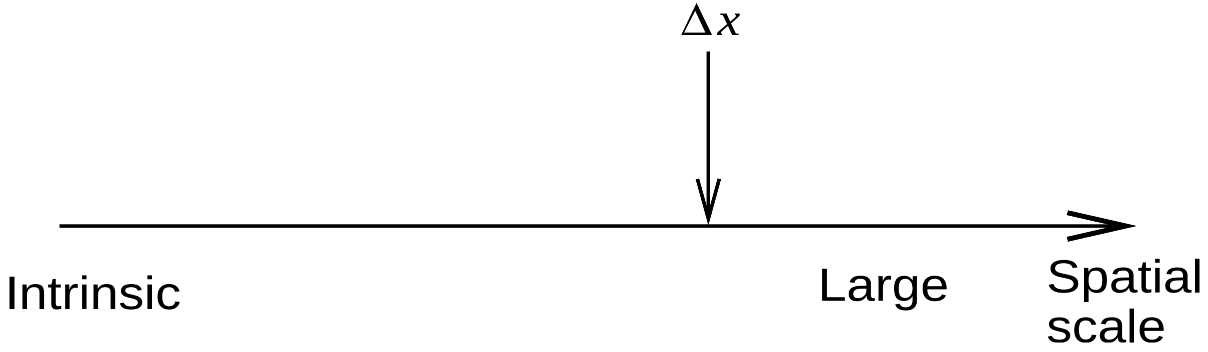


FIG. 1. A unit horizontal area at some level between cloud base and the highest cloud top. The taller clouds are shown penetrating this level and entraining environmental air. A cloud which has lost buoyancy is shown detraining cloud air into the environment.

Parameterization strategy

Is a function of the grid scale



- Determinstic parameterization
- Good scale separation: fluctuations small on scale Δx
- Parameterized process is a function of current state of grid box

Parameterization strategy

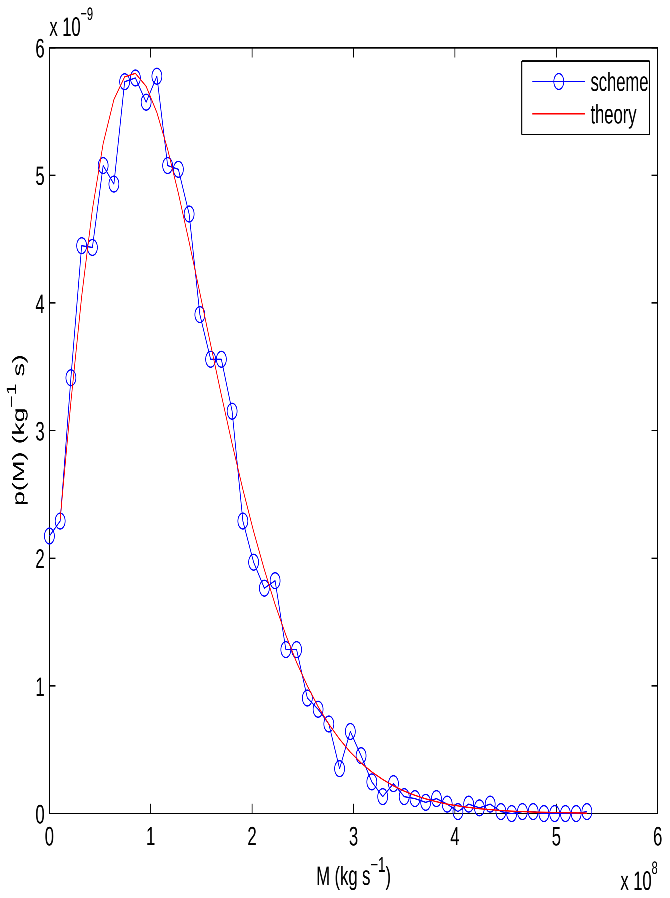
Is a function of the grid scale

- Stochastic parameterization
- Parameterized process is a function of large-scale state
- Grid-box state $\neq$ large-scale state
  space average over $\Delta x \neq$ ensemble average
- Process as realized on grid-box scale is a sub-sampling of the full ensemble so fluctuations important

Plant and Craig parameterization

- Deep convection scheme, explicitly designed to be stochastic following this conceptual framework
- Number of cumulus clouds $\langle N \rangle$ in GCM grid box need not be large
- Mass-flux formalism with spectrum of plumes of varying sizes
- Select a random sample of plumes
- Stochastic part of $\partial_t X \sim \sqrt{\langle N \rangle}$
- cf. multiplicative noise in which it $\sim \langle N \rangle$

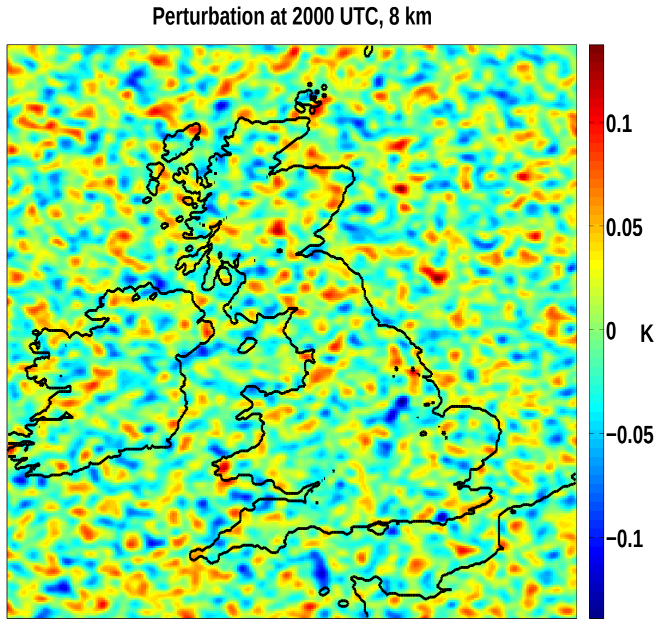
Example pdf of mass flux

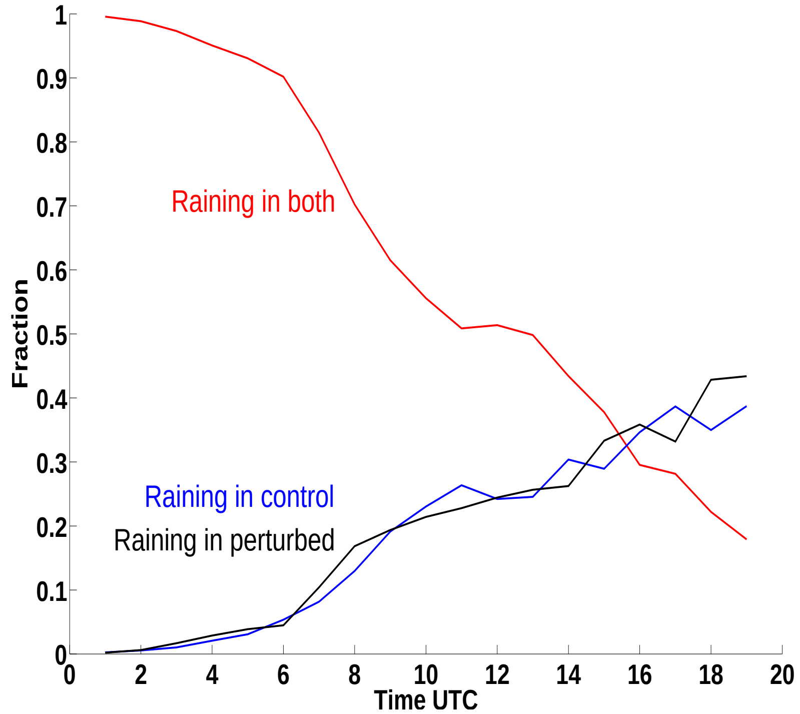


- $p(M)$ produced by Plant-Craig scheme, over area (64km)^2
- 3D simulation of radiative-convective equilibrium at $\Delta x = 32$km
- Agrees with theory and CRM results

Simple additive noise good enough

Convective scale NWP at $\Delta x = 1 - 4\text{km}$





- Perturbations in boundary-layer θ alter triggering and displace storms
- Can produce ensemble rainfall spread similar to ensembles representing parameter/structural uncertainty

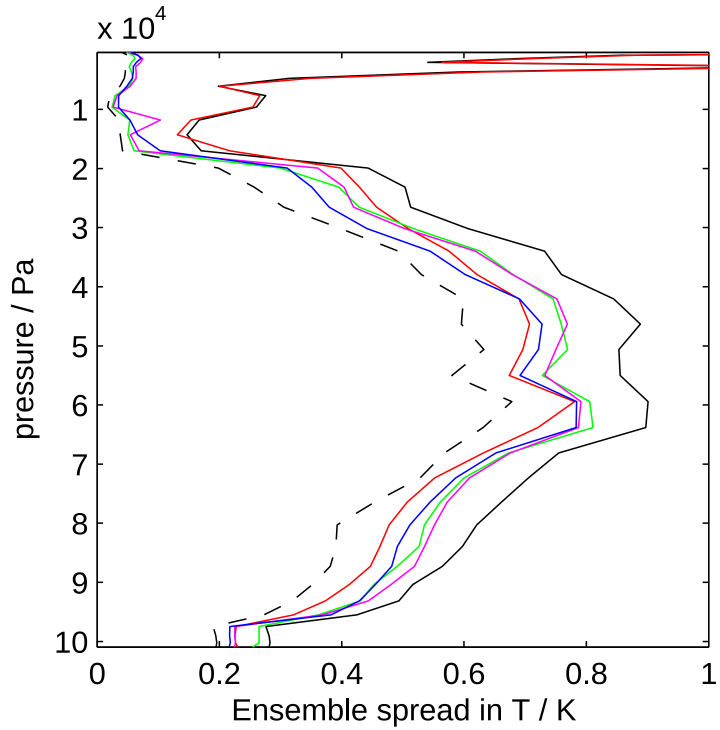
Framework of tests

Single-column tests for tropical west-Pacific warm pool, based on TOGA-COARE

- 39-member ensembles used
- includes small initial condition perturbations to boundary-layer temperature
- different random number seed for the stochastic method in each run
- vary the character of multiplicative noise, and compare with Plant-Craig

Multiplicative noise

Apply multiplicative noise to one scheme only

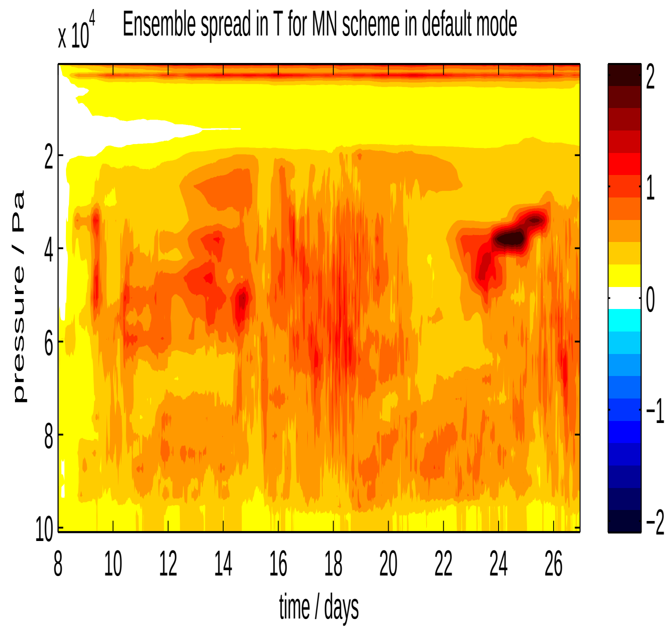


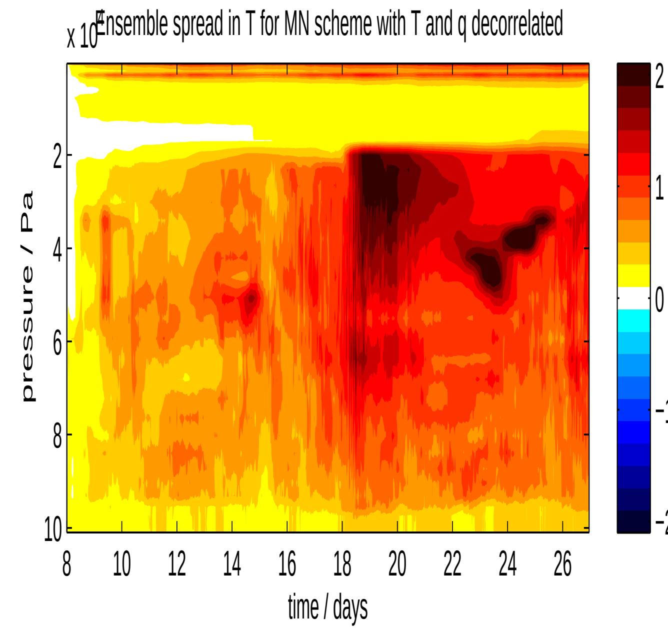
Dotted: IC, Black: all, Red: radiation, Green: boundary layer, Purple: convection, Blue: large-scale cloud

- Similar vertical profiles of spread
- Model propagates uncertainty: perturbing one scheme induces noise in input to the next
- Spread from perturbing any one scheme $\sim$ 70% spread from 4 schemes together

T/q correlations

- Decorrelate multiplicative noise to $\partial_t T$ and $\partial_t q$

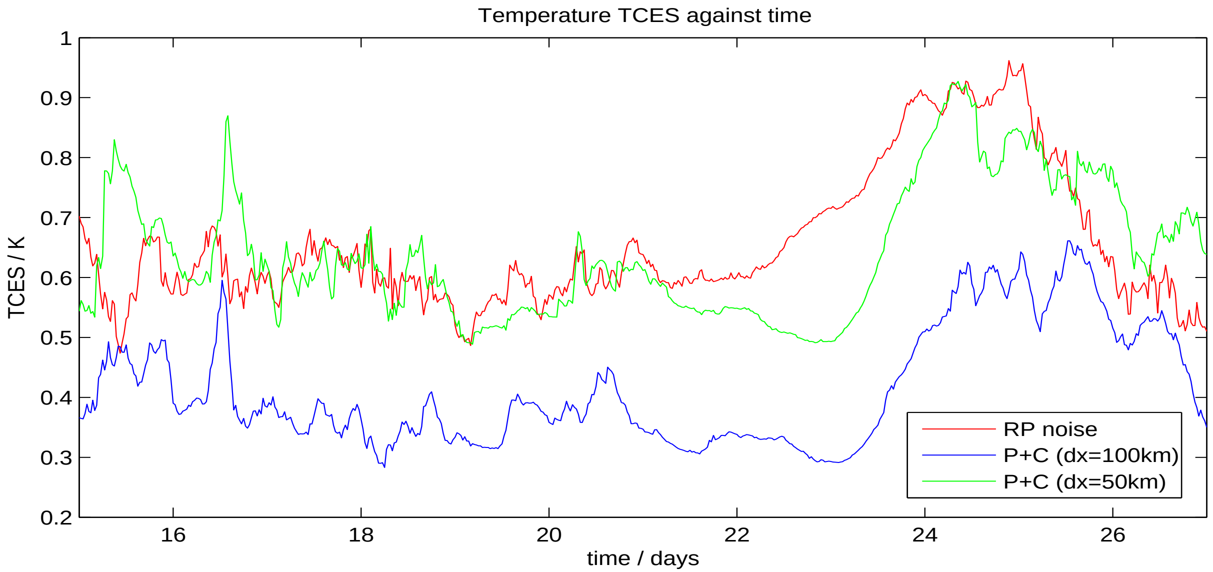




- Unphysical spread beyond 18th: stronger than with quenched random numbers
- Decorrelated noise violates energy conservation, $L\Delta q \neq C_p \Delta T$ when a cloud condenses/evaporates

Sampling uncertainty

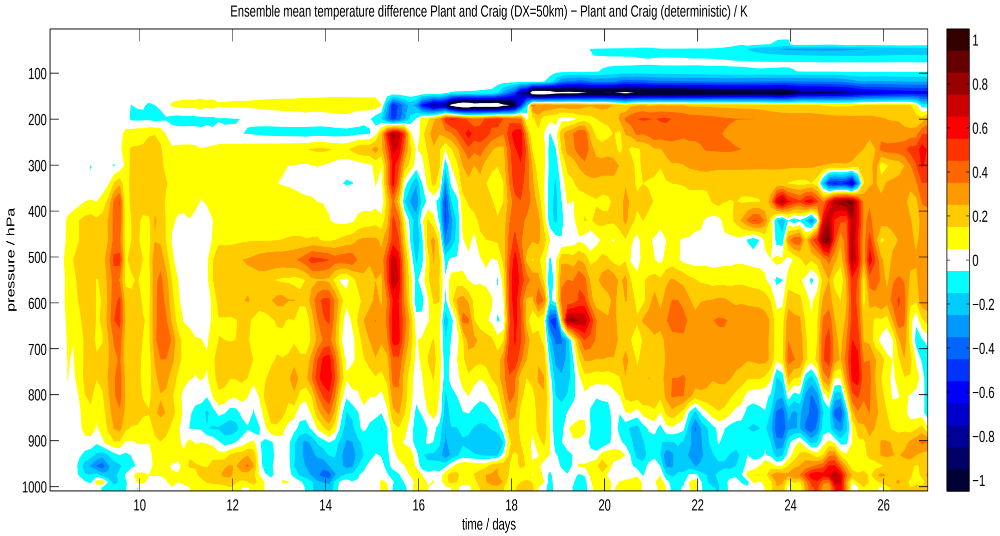
- Spread in column-average T from Plant-Craig as function of grid-box size



Similar to mult. noise or random parameters for $\Delta x = 50\text{km}$

Stochastic drift

- Effect of noise on mean-state with Plant-Craig



- Ensemble mean T difference: Plant-Craig at $\Delta x = 50$km $-$ Plant-Craig deterministic
- Stochastic drift almost like having a different parameterisation

Conclusions

- Simple additive or multiplicative noise source sufficient for some purposes
- i.e., can use generic method and may not be necessary to address all sources of GCM uncertainty
- But some physical constraints are necessary

  e.g. $L\Delta q = C_p \Delta T$ when cloud condenses/evaporates is useful to know
- Parameterization strategy properly depends on intrinsic scales and on Δx
- For deep convection, cloud-sampling uncertainty becomes as important as the uncertainty in representing a cloud at $\Delta x \sim 50$km
- An explicitly stochastic parameterization scheme is then required