Implementing stochastic parameterizations:

The noise we want and the noise we don't

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The Future of Cumulus Parameterization,

TU Delft

10–14 July 2017

Or... a more flippant title...

It may be hard to listen to music while stood next to a pneumatic drill

And... the flippant answer...

If this is happening, it may be tempting to turn up the music but it would be better to switch off the drill

The model filter

- Any numerical model of the atmosphere starts from a filter separating the flow into resolved and unresolved parts
- The purpose of a convection parameterization is to feedback effects of the sub-filter convective processes onto the filtered state
- The feedback will depend on the nature of the filter (e.g., “scale-awareness”)

Motivation for stochasticity

- Ensemble-mean filter $\neq$ space-time filter
- An ensemble-mean filter
  - parameterization integrates over sub-filter states and is deterministic
  - fields should be smooth at the filter scale
- For a space-time filter
  - parameterization samples possible physical realizations from sub-filter states and is likely stochastic
  - fields may be highly variable at the filter scale
- Practical benefits: e.g. improves skill of probabilistic ensemble forecasting

The noise we want

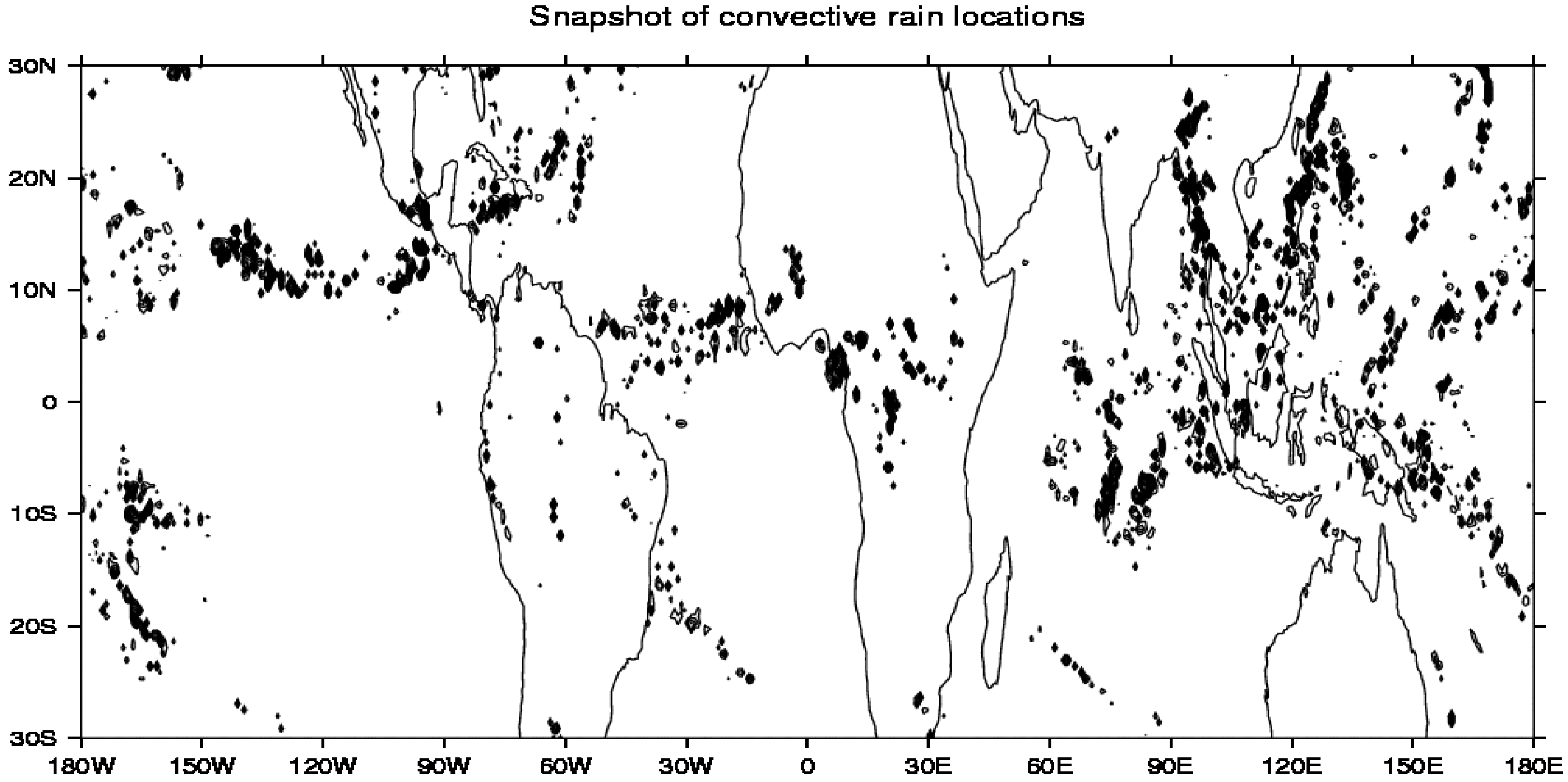
Approaches *include*:

- SPPT (Buizza et al 1999) and iSPPT (Christensen et al 2017)
- Random parameter selction (Bowler et al 2008)
- Stochastic multi-cloud model: focuses on transitions between convective modes (Khouider et al 2013)
- Plant and Craig (2008): focuses on variations due to limited sampling of equilbrium deep convection
- Sakradzija et al (2016): an extension to shallow convection
- Rochetin et al (2014) / Kober and Craig (2016) / Clark et al (2017): extensions to CBL eddies for considerations of triggering
- Dorrestijn et al (2013): statistical emulator for variability in LES of shallow convection
- Shutts stochastic convective vorticity focuses on dynamical signatures of missing organization

The noise we want

- Some of the following remarks apply to any of these methods
- Particular issues occur when the noise to be imposed is a function of the filtered flow
- i.e., when the stochasticity is does not just affect the convection but is also determined by properties of the convection

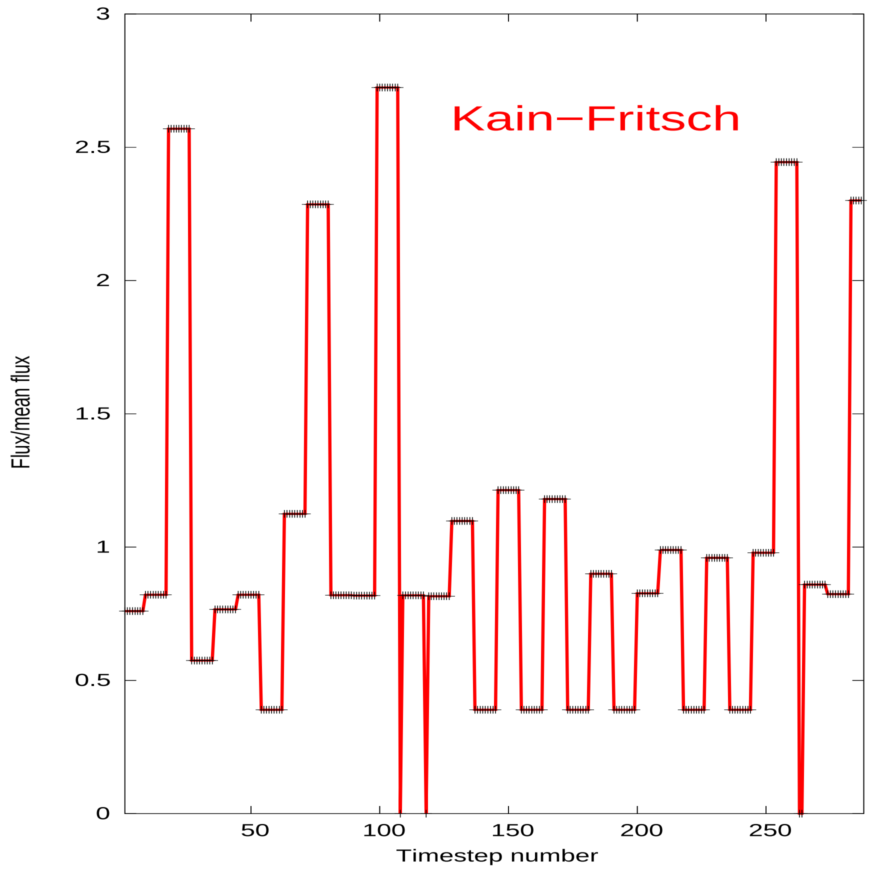
The noise we don't want



Problems with CAPE-based clousre

- A convection scheme can often trigger for one timestep, (over)-stabilize the local column, and so then switch off
- In an extreme case, the closure timescale may have little direct impact on the time-mean mass flux
- Rather it may be the triggering and intermittency (fraction of timesteps when convection is diagnosed) that controls this
- See poster by Mike Whitall for the numerics of how this happens in the UM

The noise we don't want



- *Equilibrium response to a constant forcing* by Kain-Fritsch scheme over one day in a SCM
- Many deterministic schemes produce grid-scale, timestep-level noise

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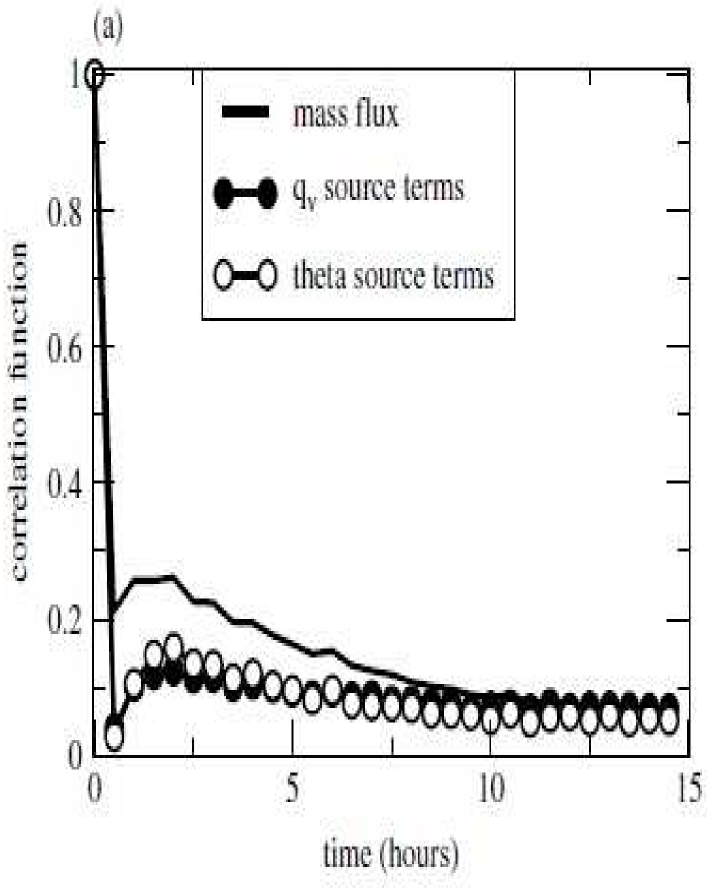
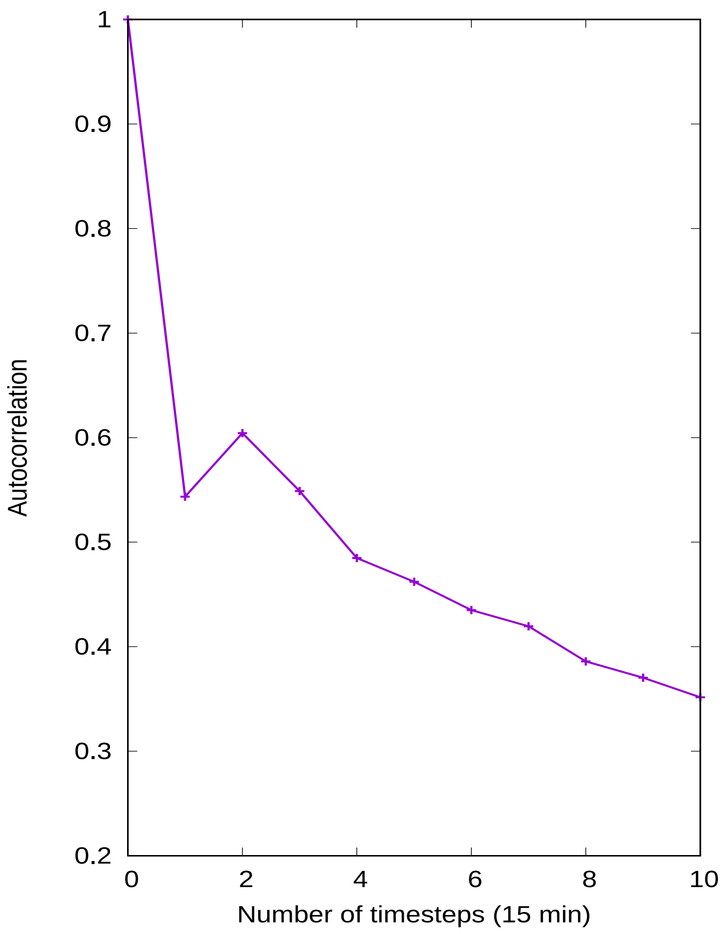
Correlation between timesteps





Stiller (2009), global UM

Current global UM: GA7 settings

Issues

1. Even in the absence of anything stochastic, our models have unwanted noise that may be upscaling to have unwanted resolved-scale effects
2. The addition of some physically–motivated stochastic effect may depend on the combination of noise sources
3. Unwanted noise may damage our ability to calculate wanted noise
4. Wanted noise may damage our ability to calculate wanted noise

Consequences?

...variations in the perceived effectivenes of different [stochastic] schemes... one should not assume that small impact in one forecast system will imply small impact in other forecast systems

(ECMWF Workshop on Model Uncertainty Proceedings, 2016, p15)

Implementing wanted noise

- Direct implementations of stochastic effects on closures may make less difference than expected, because of numerical problems
- To implement wanted noise, it should dominate over unwanted noise
- There are two approaches to this...
  1. Turn up the volume of the wanted noise in the hope that it drowns out the unwanted noise
  2. Try to remove (reduce) the artificial, unwanted noise

Averaging the input to the closure

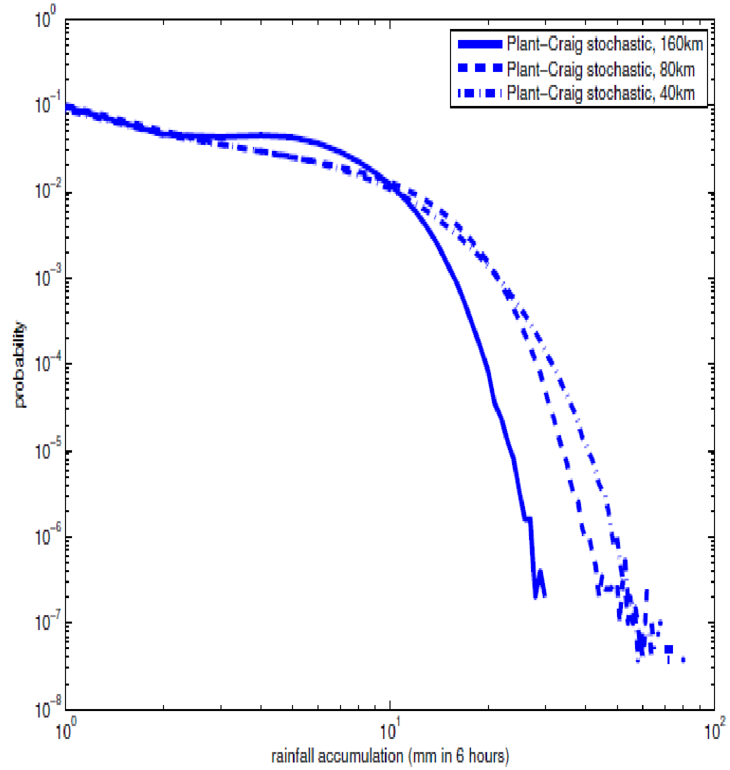
For Plant-Craig, what ultimately worked was to realize that...

- The output will be intentionally noisy on a limited spatial scale
- But the input should represent an averaged state
- i.e., there may be local stochastic departures from equilibrium, but an equilbrium closure should be applied only at equilibrium scales

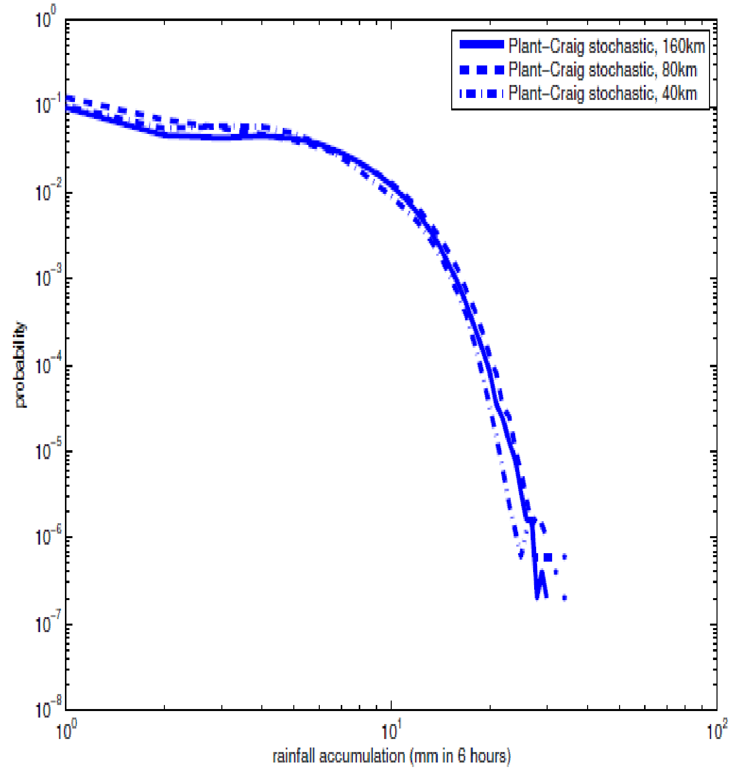
To exert control on the characteristics of a noisy output, one should not be feeding in a noisy input

Example: resolution-independence

Keane et al (2013): ie. aqua-planet 6 h rain-rate pdf is resolution independent with consistent averaging strategy



pdf on native grid



pdf on 160km grid

- Also Keane and Plant (2012), Wang et al (2016)

Illustrative runs

A 3 month SON run of global Unified Model at N216 ($0.83^\circ \times 0.56^\circ$) with GA7.0 settings

- With standard UM convection scheme
- With stochastic effects applied directly
- With averaging of the input state supplied to the convection scheme
- With both the averaging and stochastic effects applied

The averaging

- The averaging is over the previous 2 hours ($8\Delta t$) and over the nearest neighbours on the grid ($3\Delta x$)
- There are debates in physics–dynamics coupling about whether physics and dyamics should be evaluated on the same grid
- Lander and Hoskins (1997) “believable scales”
- Recent discussions in Gross et al (2017) arxiv:1605.06480v2

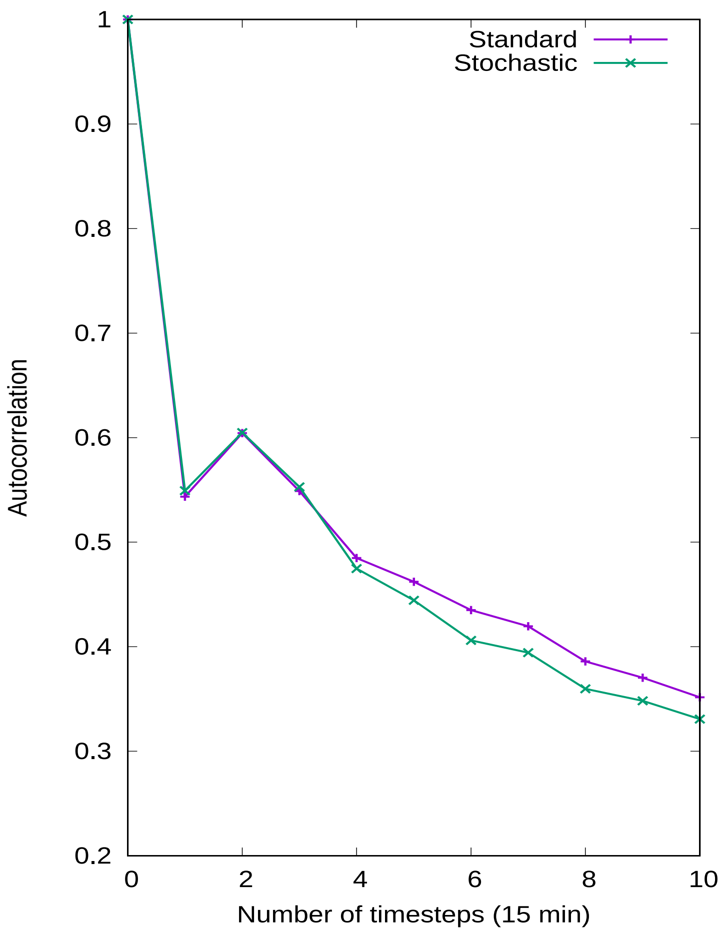
The stochastic part

The stochasticity is a simplified form of Plant-Craig variability inspired by Machulskaya et al (see poster)

- Given the closure mass-flux $\langle M \rangle$ and the mean mass flux flux of one cloud $\langle m \rangle$, partition it as the convolution of...
  - A Poisson-distributed number of elements N with mean $\langle N \rangle = \langle M \rangle / \langle m \rangle$
  - An exponential distribution $\sim \exp(-m_i/\langle m \rangle)$ for each element
  - A lifetime of 45 min$= 3\Delta t$ for each element
  - Actual $M = \sum_{i=1}^{N} m_i$ rescales $\langle M \rangle$

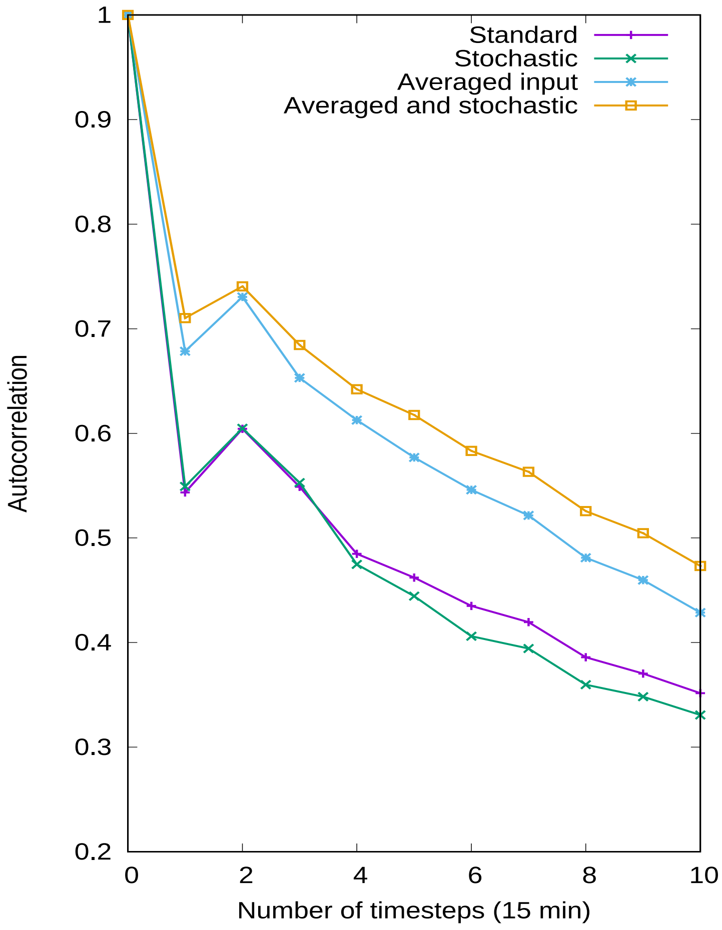
Correlation between timesteps

- Direct application of this stochastic rescaling reduces the timestep-to-timestep correlations beyond $3\Delta t$



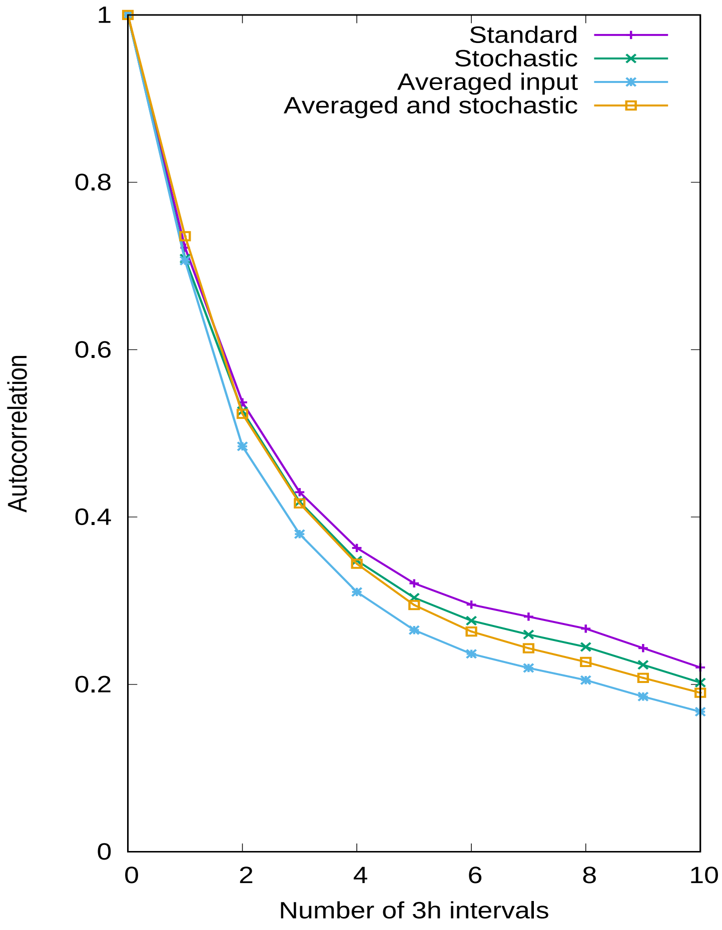
Correlation between timesteps

- Averaging the input increases the correlations
- And now introducing the stochastic rescaling further increases the correlations
- i.e., change of sign of stochastic impact



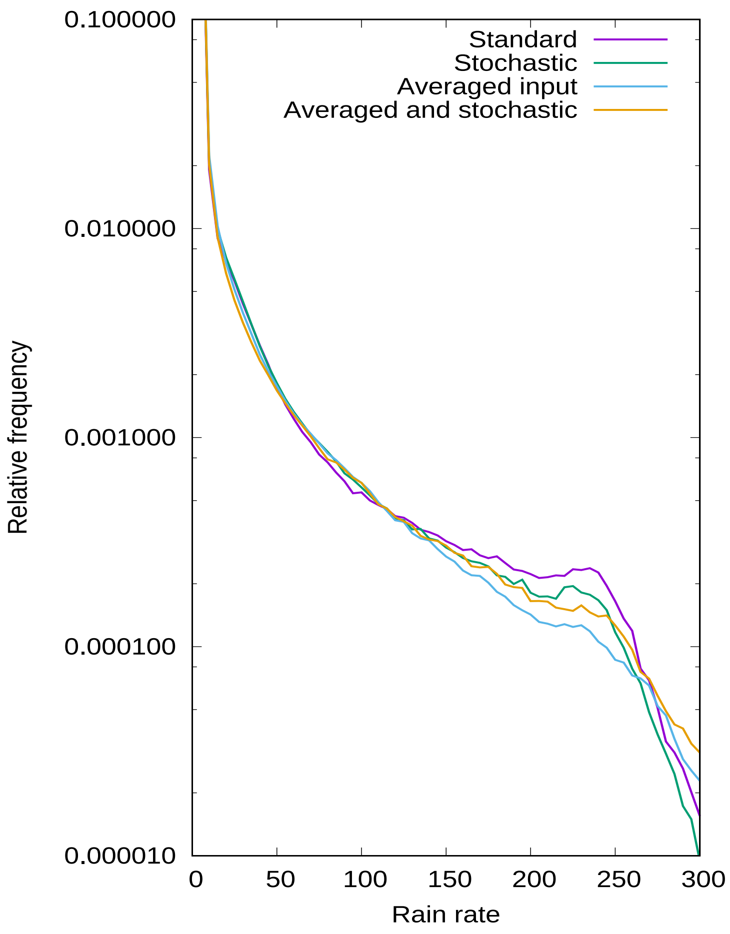
Correlations on longer scales

- For 3 hourly mean rain rates, direct stochastic application again reduces correlation
- Stochastic term again increases correlation if input has been averaged, now partly offseting the reduction due to averaging



Tropical rain rate distribution

- Directly-applied stochastic scaling reduces extreme values of the rain rate
- If input to scheme is averaged, extremes reduced, but now they are increased by the stochastic scaling



Distributions on larger scales

- The sense of these effects is retained after upscaling to 2.5° areas
- For 3-hourly (or daily means) main effect obtained by averaging, with some enhancement from stochastic rescaling if applied alongside the averaging

Conclusions I

- Convection parameterizations were originally designed to give an ensemble-mean response
- They naturally become stochastic if redesigned to give a space-time filtered response
- Many of our parameterizations exhibit unwanted, unphysical grid-scale and timestep-level noise, probably due to numerics issues in the physics–dynamics coupling
- We do not have a clear sense of what that unwanted noise may be doing

Conclusions II

- I have shown a cautionary example with a simple strategy providing the convection parameterization input on a scale $3\Delta x, 9\Delta t$
  - The averaging alone has comparable effects to a stochastic rescaling of the parameterization due to limited sub-sampling at N216
  - Effects of stochasticity on simple rain rate statistics *change sign* depending on whether noise is retained or reduced in the parameterization input
- Do explore stochastic methhods but do ensure that the method as implemented matches the method as designed