Improving stochastic parametrisation schemes using high-resolution model simulations

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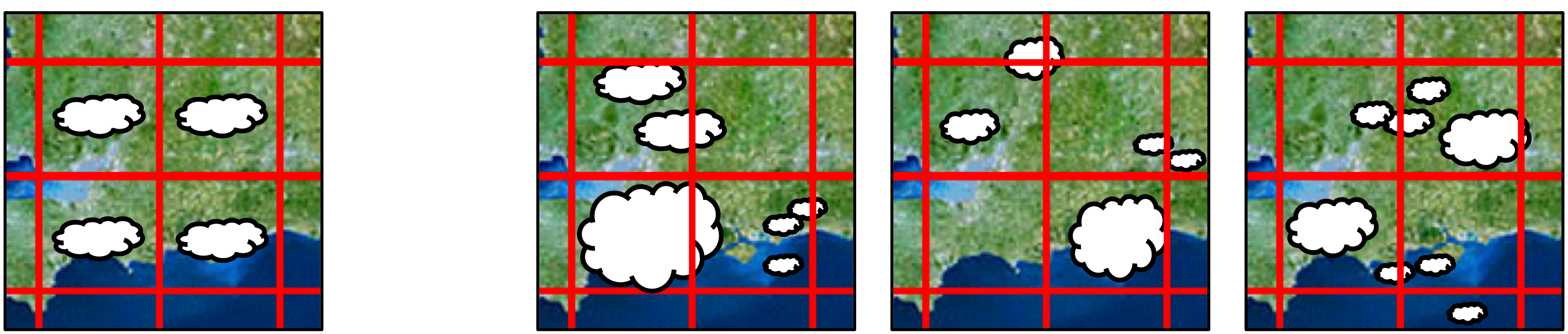
Why stochastic parametrisation?

- Stochastic parametrisation seeks to represent unresolved sub-grid variability
  - Grid-scale variables do not fully constrain sub-grid motions
  - Describe sub-grid tendency in terms of a probability distribution constrained by the resolved-scale flow
  - Include random numbers in our equations of motion
- Necessary in NWP to achieve reliable ensemble forecasts, in which the probability distribution accounts for all uncertainty in the forecast

traditional 'best guess' | stochastic Trial #1 | Trial #2 ... | Trial #N

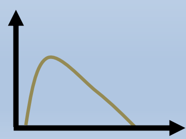


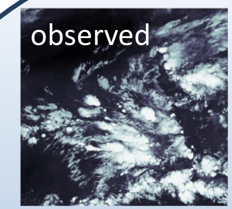
A general framework for stochastic parametrisation

Identify uncertain process in forecast model

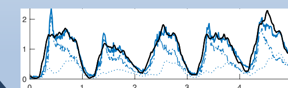
$$\rho\left(\frac{\partial \mathbf{u}}{\partial t} + (\mathbf{u}\cdot\nabla)\mathbf{u}\right) = -\nabla \mathbf{p} + \eta\nabla^2\mathbf{u}$$

Theoretical ideas





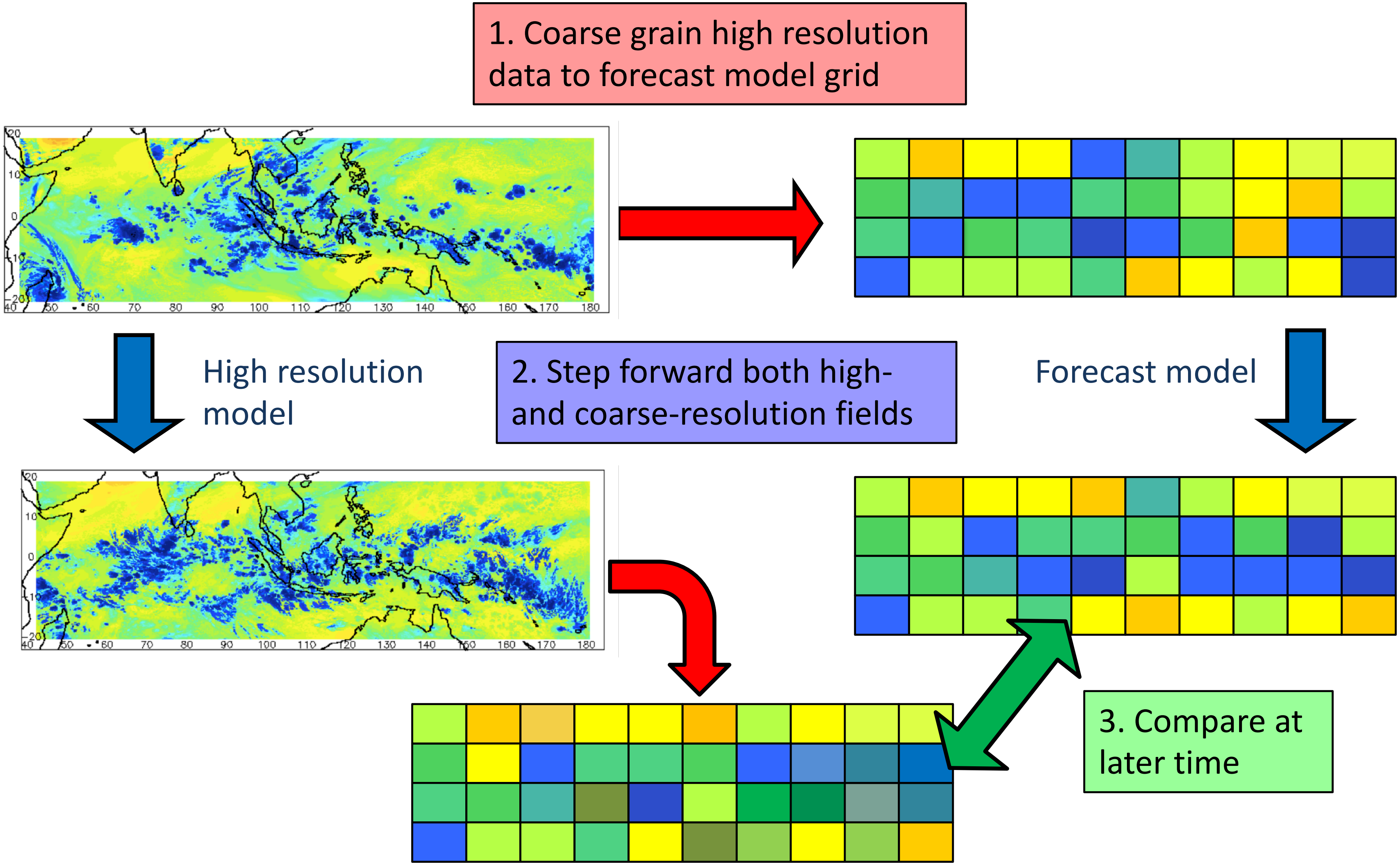
Measurements



Characterise uncertainty in that process

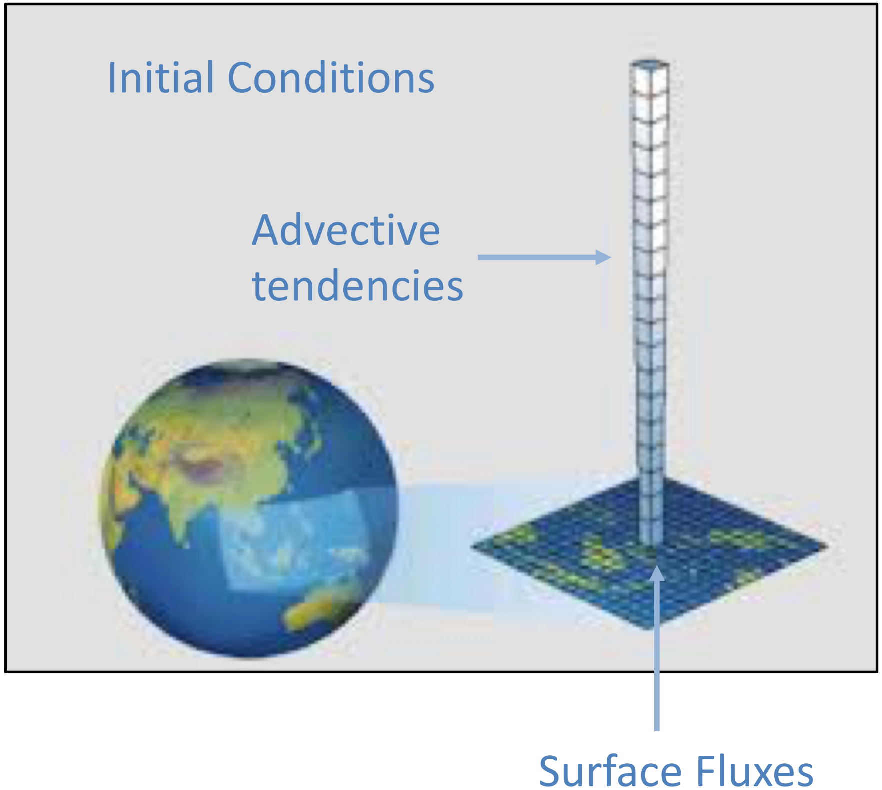
Design stochastic parametrisation to explore this uncertainty

Use a high resolution simulation as ‘truth’



SCM as Forecast Model

- How do we use an SCM?
  - Use coarsened high-res simulation to prescribe Initial conditions, Dynamical Forcing and Boundary conditions
- Benefits of using SCM?
  - Supply dynamical tendencies targets uncertainty in the parametrisation schemes
  - SCM portable and cheap
  - Tile many SCM to cover domain
- IFS SCM CY40R1 at T_L639, 91 vertical levels (available through openIFS)

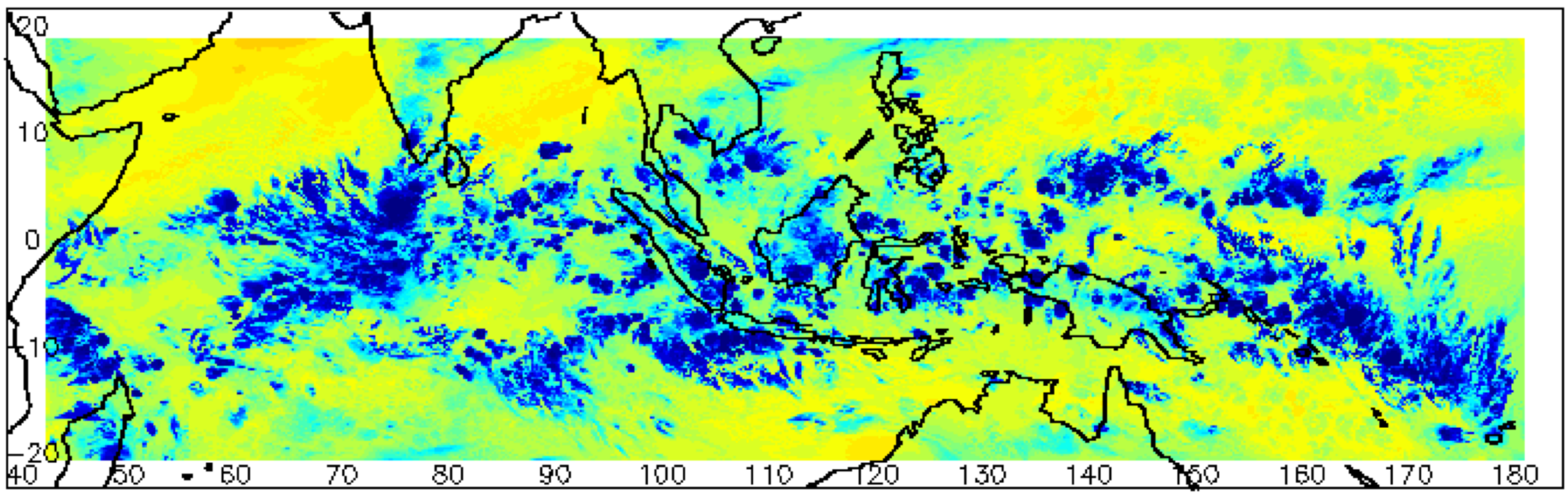


Christensen, Dawson and Holloway, 2018, JAMES

Existing high resolution dataset: Cascade

thanks to **Chris Holloway, U. Reading**

- UK Met Office atmospheric model setup
- Semi-Lagrangian, non-hydrostatic dynamics, 4km resolution
- Large tropical domain (15,500 km x 4,500 km), 9 days of data. Hourly dumps.
- Prescribe observed SST; boundary conditions from ECMWF 25 km analysis
- Convection scheme switched on but only active in low CAPE environments



Holloway et al, 2012; 2013

What we do

- Coarse-grain Cascade to T_L639
- Run an independent SCM simulation, initialised every hour, from every lat-lon point in the coarse-grained domain (>68,000)
- Compare evolution of SCM over **one hour** with CASCADE
- Repeat for entire 9-day Cascade simulation

Case study: is there any physical basis for SPPT?

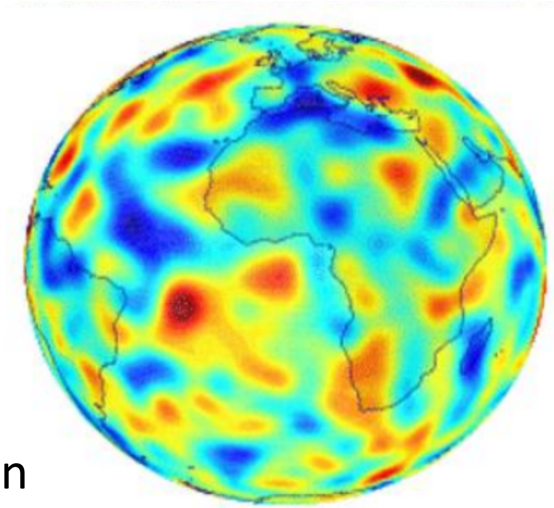
- **Stochastically Perturbed Parametrisation Tendencies (SPPT)**
  - represents random errors due to model's physical parametrisation schemes
  - Implemented in models worldwide

$$T = D + (1+e)\sum_{i=1} P_i$$

T – Total tendency
D – Dynamics tendency
P – Physics tendency

Pattern correlated in space & AR(1) in time:

σ	L (km)	τ (days)
0.52	500	0.25
0.18	1000	3
0.06	2000	30



All parametrisation schemes see same perturbation
All variables see same perturbation
Perturbation constant in height

Palmer et al, 2009.
ECMWF Tech Memo 598

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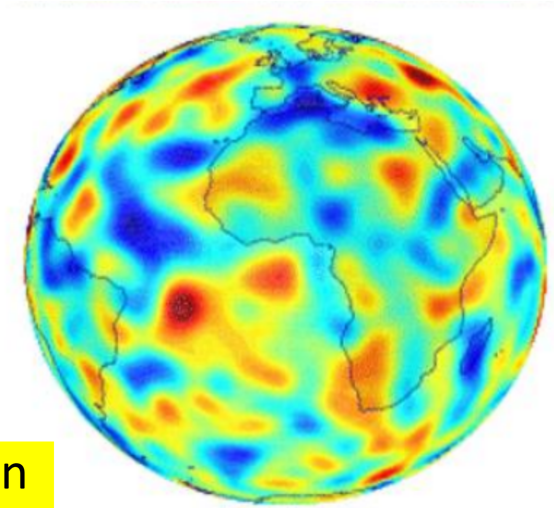

Palmer et al, 2009.
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Analysing the data: multiplicative noise?

SPPT:

$$T = D + (1+e)\sum_{i=1} P_i$$

Calculate 'true' total tendency from CASCADE

Assume SCM dynamics tendency is 'correct'

Consider error in SCM physics tendencies

$$\underbrace{T - D}_{\text{'true' physics tendency}} = (1+e)\underbrace{\sum_{i=1} P_i}_{\text{parametrised physics tendency}}$$

P_{CAS} **P_{SCM}**

SPPT: standard deviation proportional to mean

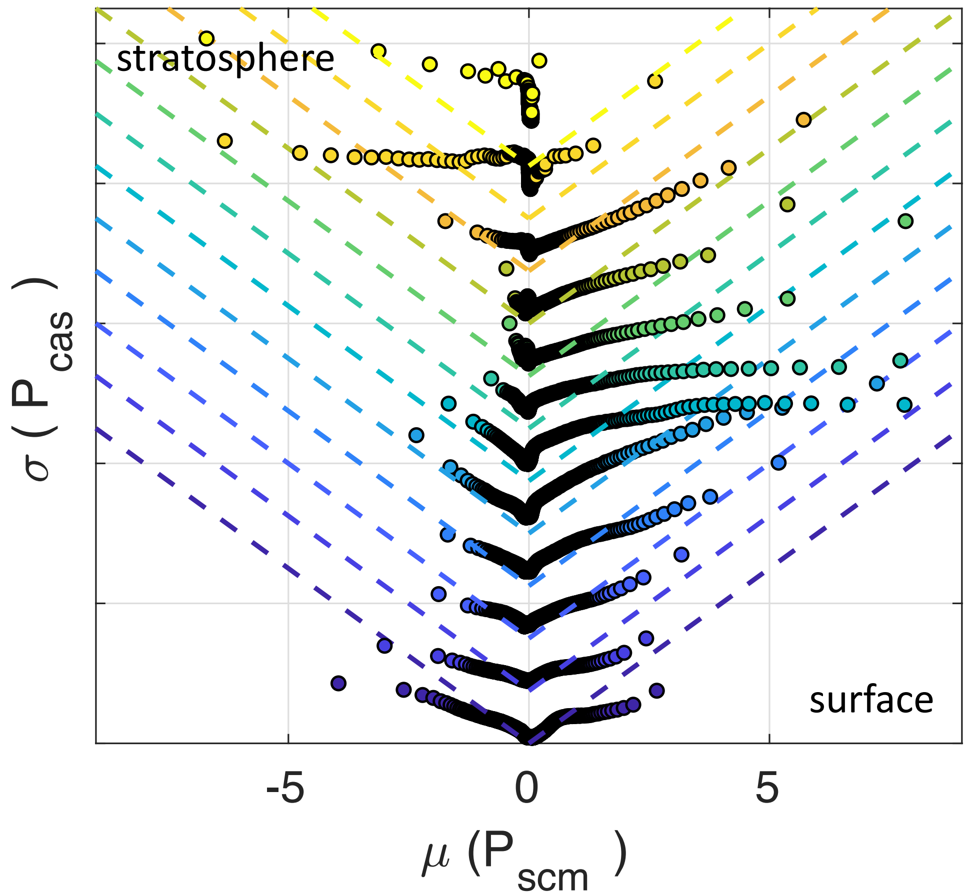
Hypothesis:

$$\underbrace{T - D}_{\mathbf{P_{CAS}}} = (1+e)\underbrace{\sum_{i=1} P_i}_{\mathbf{P_{SCM}}}$$

If this is true:

$$\sigma(\mathrm{P_{CAS}} \mid \mathrm{P_{SCM}}) = \sigma_e \, \mathrm{P_{SCM}}$$

Uncertainty in T tendency



Data grouped by level.
Dark blue: levels 91—87 (ground—995 hPa)
Yellow: levels 32—36 (86—60 hPa)

Two analysis approaches

1. **SPPT seems like good first-order representation of uncertainty in IFS**
   - Measure optimal parameters for SPPT to improve scheme
2. **Can we move beyond/generalise SPPT to find a better representation for the IFS?**
   - Relax each SPPT assumption in turn and assess whether we have found a better noise model

1. Analysing the data: characteristics of *e*

SPPT:

$$T = D + (1 + e)\sum_i P_i$$

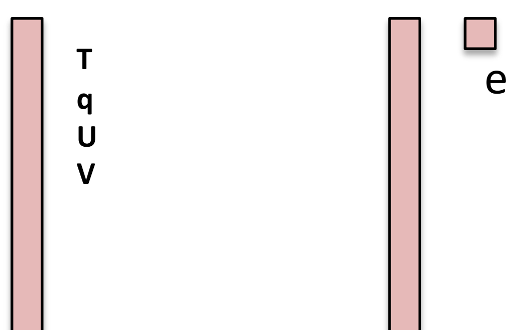
Calculate 'true' total tendency from CASCADE

Assume SCM dynamics tendency is 'correct'

Consider error in SCM physics tendencies

SOLVE

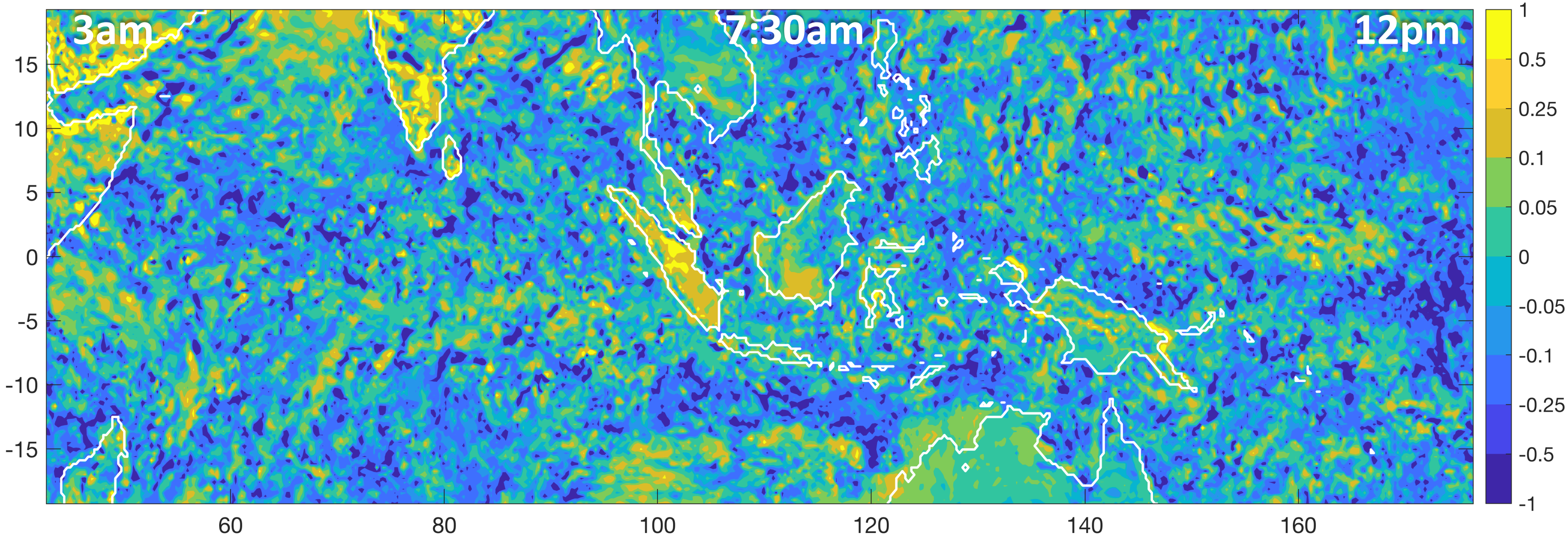
$$T - D - \sum_i P_i = e\sum_i P_i$$



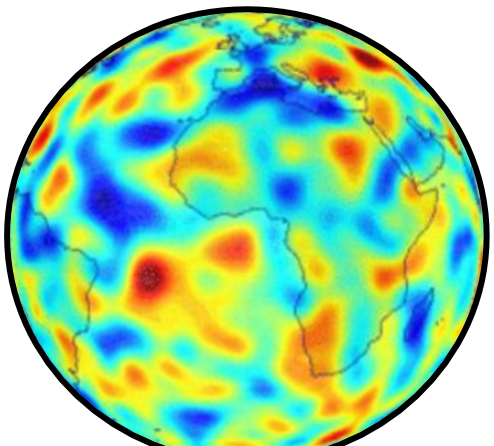
Do not use data from BL or stratosphere (tapered)

i.e.
Following the assumptions of SPPT, can we measure the statistical characteristics of the perturbation ***e***

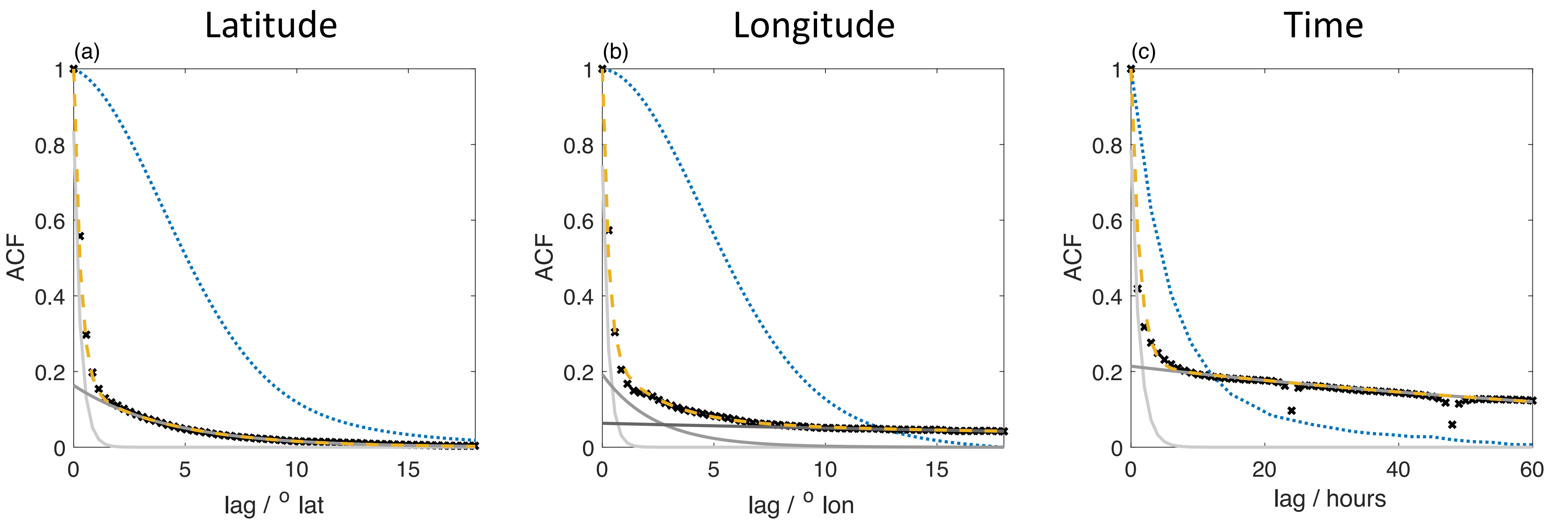
Snapshot of optimal SPPT '*e*' perturbation



	Operational SPPT	Fitted SPPT
μ(e)	0.0	-0.07
σ(e)	0.55	0.40
skew(e)	0.0	0.6

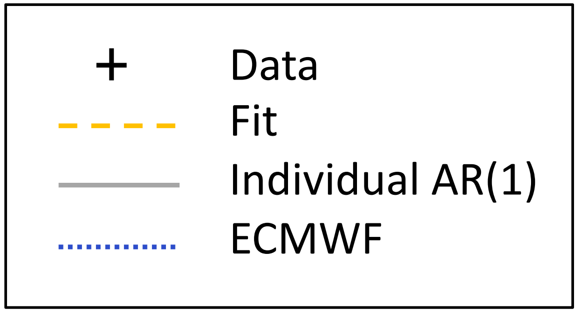


Spatio-temporal correlations



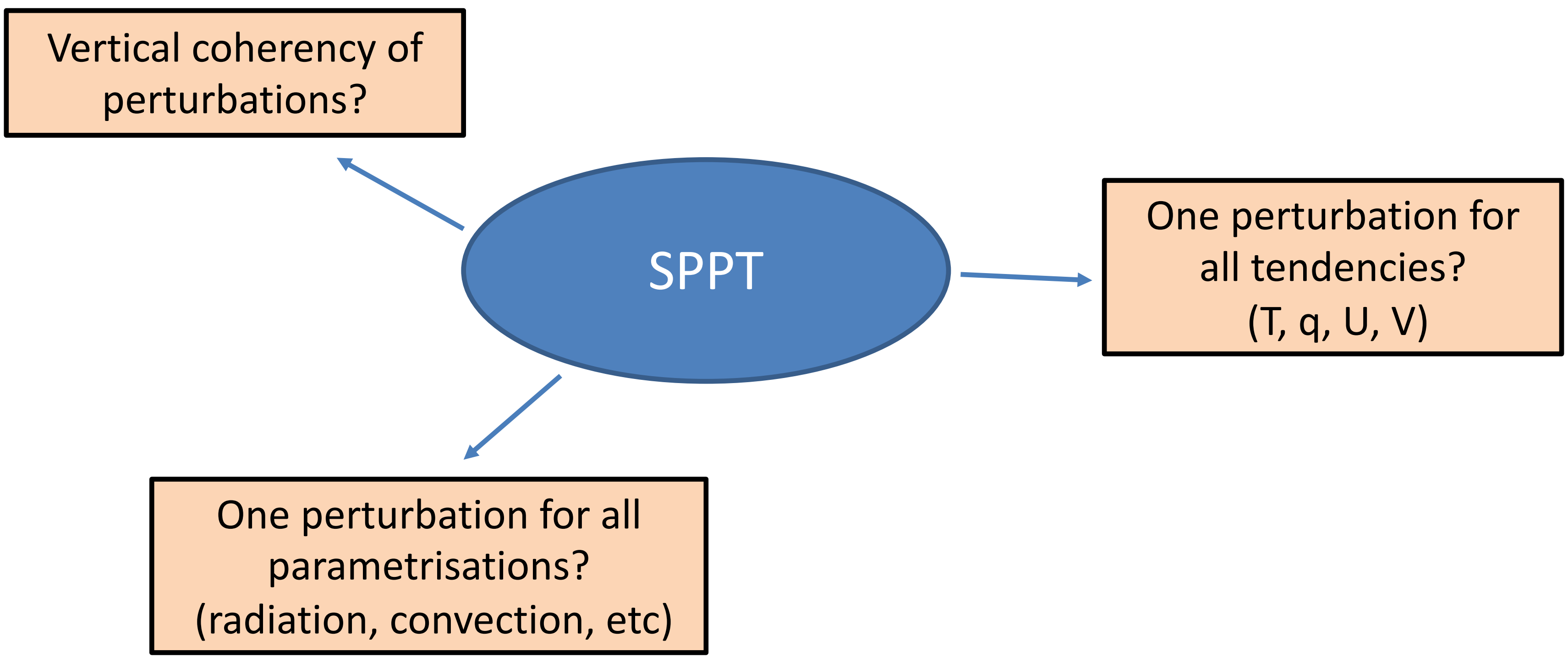
- Model spatio-temporal correlations as a sum over *n* AR(1) processes with different scales

	Operational SPPT			Fitted SPPT		
σ_i	0.52	0.18	0.06	0.35	0.17	0.10
L_i (km)	500	1000	2000	32	370	-
τ_i	6 h	3 d	30 d	1.2 h	4.3 d	-



2. Beyond SPPT?

- SPPT is not a perfect representation of uncertainty in the IFS – can we improve on it?
- Have not yet assessed other assumptions made in SPPT – are these valid?



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Vertical coherency of perturbations?

SPPT

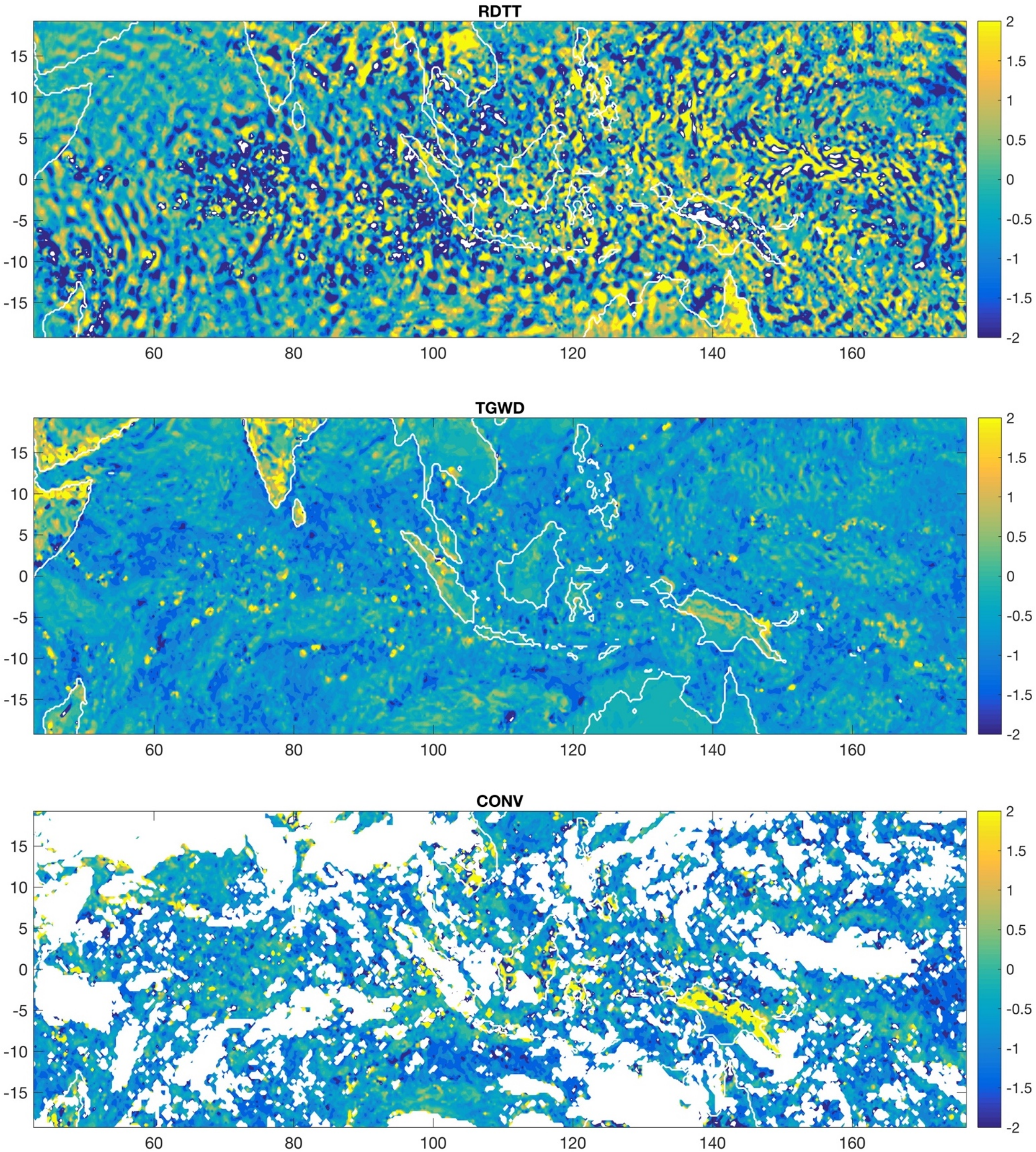
One perturbation for all tendencies? (T, q, U, V)

One perturbation for all parametrisations? (radiation, convection, etc)

"independent SPPT" (iSPPT)

$$T = D + \sum_{i=1} (1 + e_i) P_i$$

iSPPT: Consider different schemes



0100 UTC: image spans 3am-12pm
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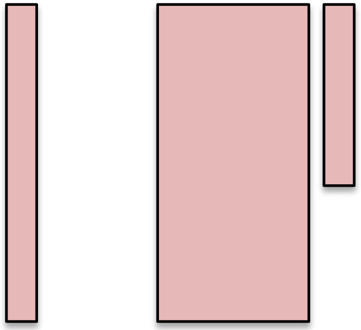
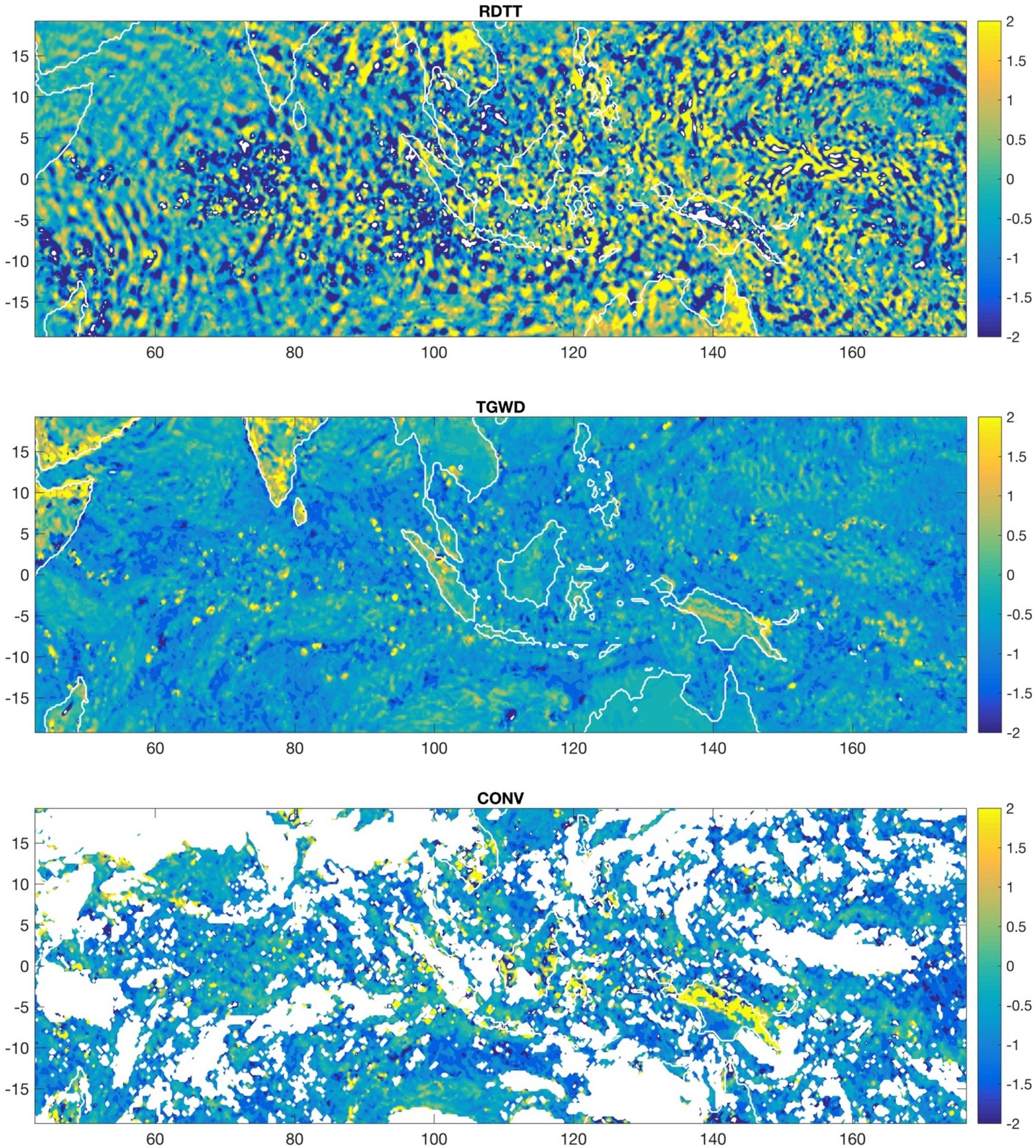
$$T - D - \sum_{i=1} P_i = \sum_{i=1} e_i P_i$$



$\Rightarrow$ Snapshot of optimal stochastic perturbation, if different schemes can have different perturbations

iSPPT: Consider different schemes



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Measure standard deviations, temporal correlations and spatial correlations for each process

Generally little correlation between e_i for different schemes

Conclusions and relevance for SPPT

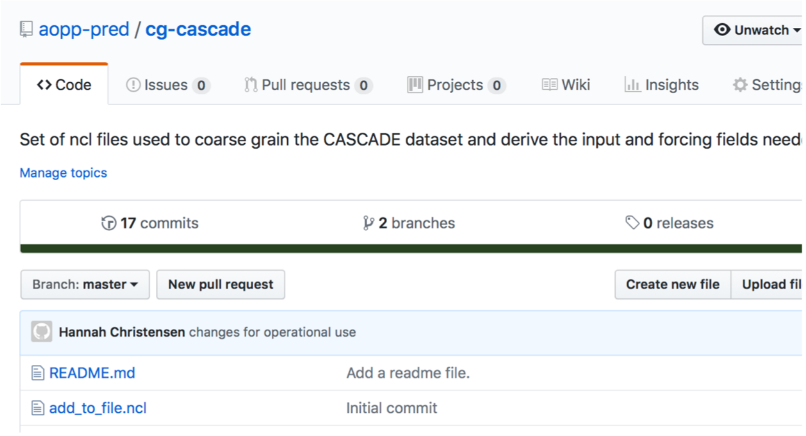
- Proposed a general technique for assessing model error
  - Can be used to constrain existing stochastic parametrization schemes and potentially motivate new approaches

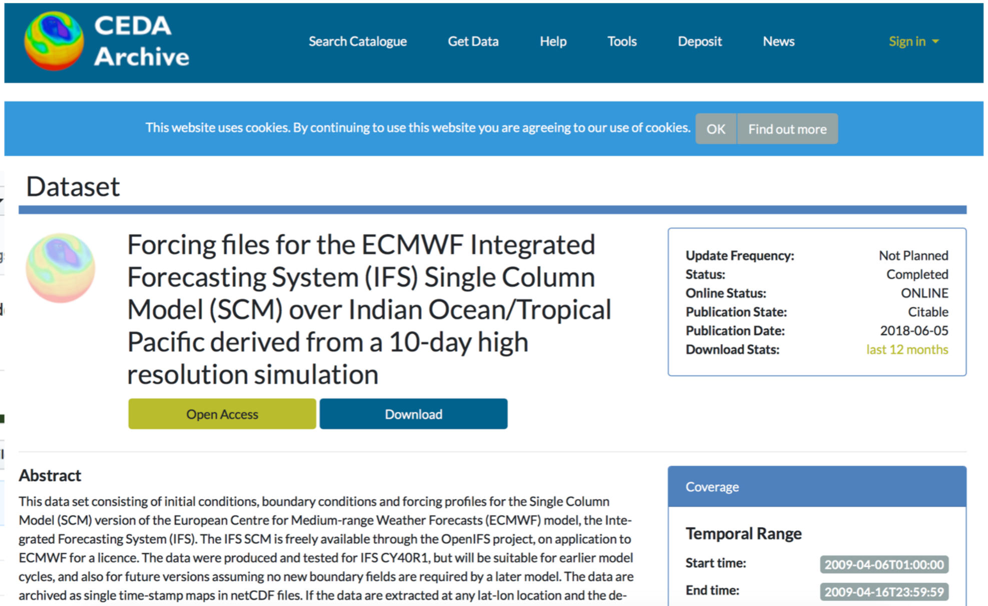
- Multiplicative noise reasonable first-order approach
  - Convection in particular could benefit from a separate stochastic scheme
- Spatio-temporal correlation scales used in stochastic parametrisations have a physical basis
  - Not just pragmatic solution to get decent ensemble spread
- To tune SPPT, reduce standard deviation but include skewness
- The simple generalisation iSPPT looks promising
  - Different schemes show very different noise characteristics

References

- Christensen, Dawson and Holloway, 2018, JAMES, ‘Forcing Single-Column Models Using High-Resolution Model Simulations’ 10(8) 1833-1857
- Christensen, ‘Improving Stochastic Parametrisation Schemes using High-resolution Model Simulations’. submitted to QJRMetS

- Coarse-grained Cascade data published on UK CEDA archive
- NCL coarse graining scripts, and python SCM deployment scripts available on github





Thanks for listening