Stochastic and perturbed parameter representations of model uncertainty in convection parametrisation

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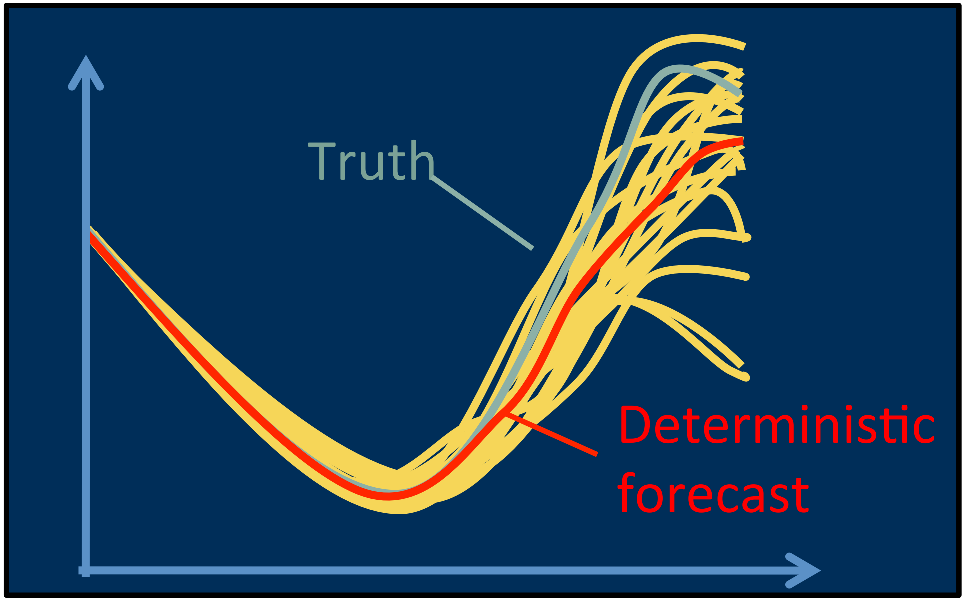
What does it mean to "represent uncertainty in a forecast"

- Instead of issuing a single "best guess" (**deterministic**) forecast, issue a **probabilistic** forecast
- Probability distribution indicates the forecasters uncertainty in the prediction
- Generate an **ensemble** of forecasts
- Representing uncertainty can generate more **useful** and more **accurate** forecasts



Uncertainty in Weather Forecasting

- How did the ensemble members in the previous slide differ? Must represent two kinds of uncertainty:
- Initial condition uncertainty
  - Limited information about current state of atmosphere
  - Initialise forecasts from a range of initial conditions
- Model uncertainty
  - Errors in our forecast arise from limitations in our model

Aims of the study

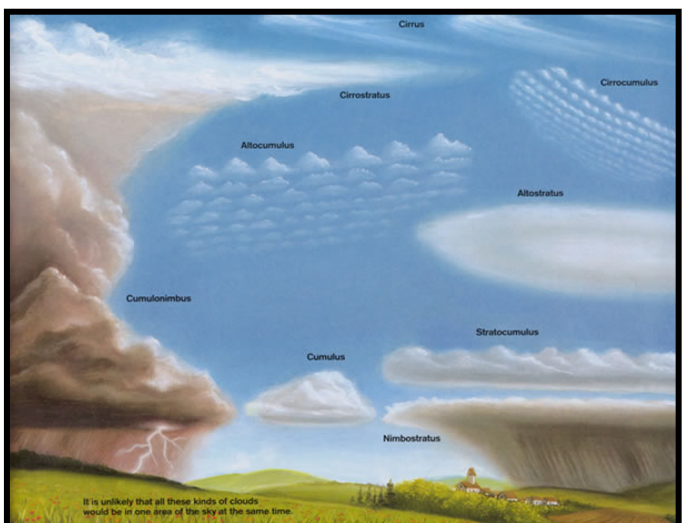
- We will consider representations of model uncertainty in the European Centre for Medium-range Weather Forecasts (ECMWF) NWP model, the Integrated Forecasting System (IFS)

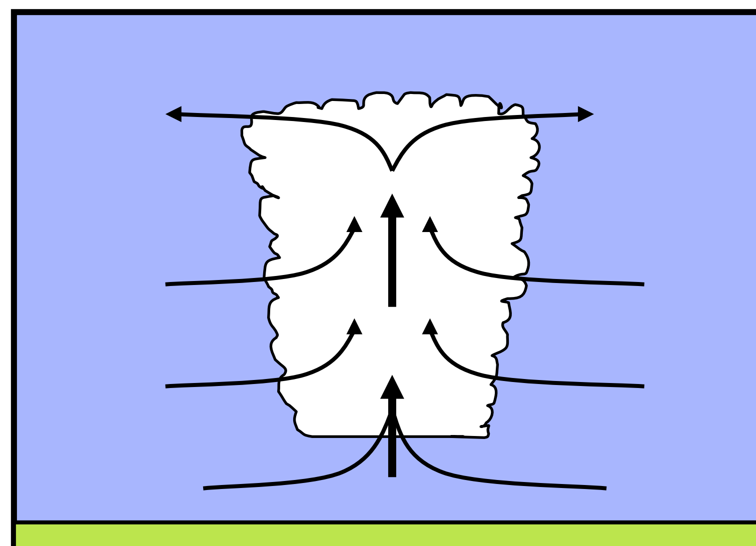
- Parametrisation is a large source of model uncertainty
  - Approximates effects of sub-grid as function of the gridscale
  - Average of possible effects of sub-gridscale
  - Compromise between accuracy and computational constraints
- Convection parametrisation large source uncertainty
  - Must accurately represent uncertainty from convection parametrisation

- Compare perturbed parameter and stochastic representations of model uncertainty in the convection parametrisation scheme

Perturbed parameter schemes

- Common representation of model uncertainty in climate projections
- The parametrisation process introduces many uncertain tuneable parameters
- In a **perturbed parameter scheme**, we change these constants between ensemble members to represent the uncertainty in their value



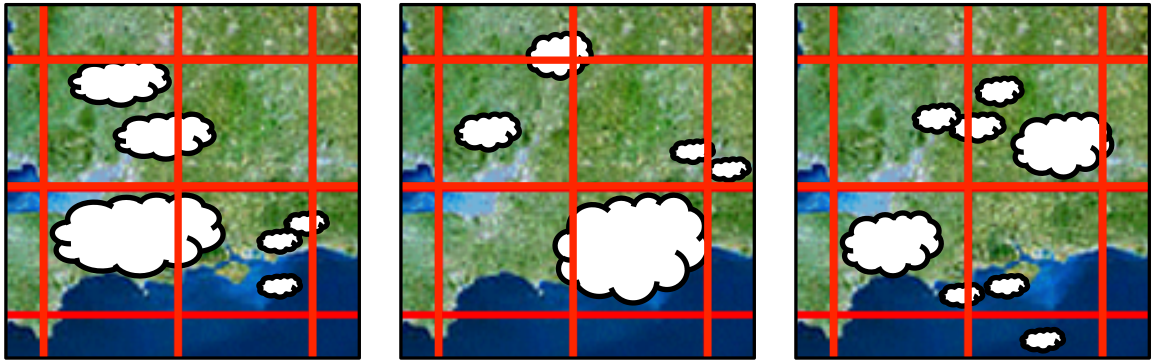


Stochastic parametrisation schemes

- Increasingly used in weather and seasonal forecasting
- Recognise that grid-scale variables do not fully constrain sub-grid scale motions
- Describes the sub-grid tendency in terms of a probability distribution constrained by the resolved-scale flow
- In a stochastic parametrisation, instead of representing the bulk average of possible effects of sub-grid scale, represent **one potential realisation**

Include random numbers in equations of motion to represent uncertainty

Ens #1 Ens #2 ... Ens #N



Representation of model uncertainty in IFS

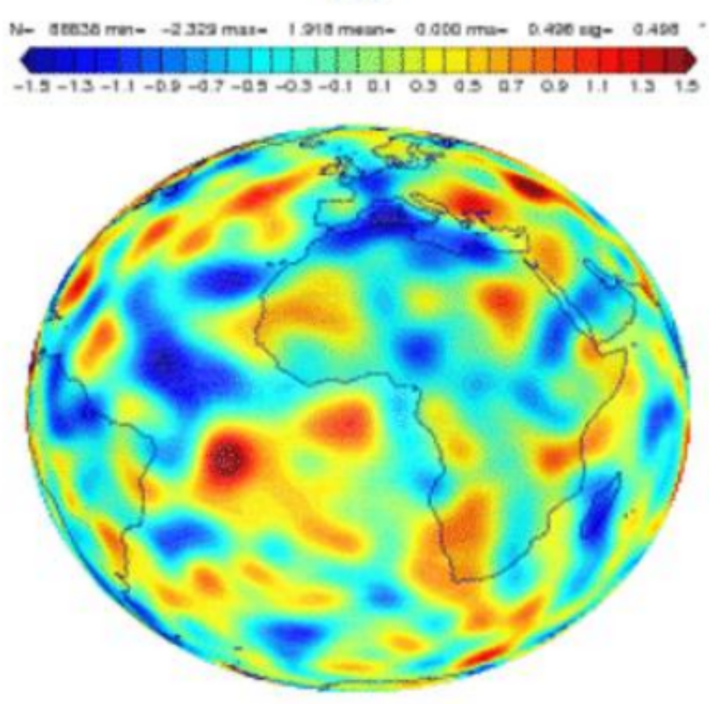
- Two operational schemes – both stochastic
- **Spectral Backscatter Scheme (SPBS)**
  - Represents process absent from model
  - streamfunction is randomly perturbed to represent upscale kinetic energy transfer (Berner et al., 2009).
- **Stochastically Perturbed Parametrisation Tendencies (SPPT)**
  - represents random errors due to the model's physical parametrisation schemes,
  - Multiplicative noise used to perturb the total parametrised tendencies (Palmer et al., 2009)

Stochastic representation of uncertainty

Standard SPPT

$$T = D + (1+e)\sum_{i=1}^{5} P_i$$

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



5 Physics Schemes:

1. Radiation
2. Turb. & Grav. Wave Drag
3. Non-Orog. Grav. Wave Drag
4. Clouds
5. Convection

Stochastic representation of uncertainty

Standard SPPT

$$T = D + (1 + e)\sum_{i=1}^{5} P_i$$

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

New SPPT

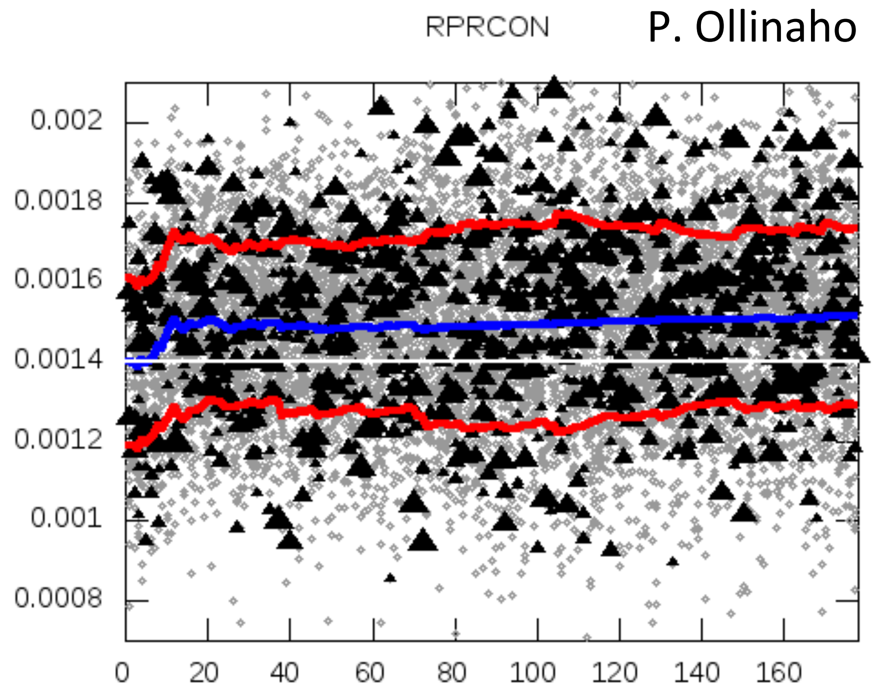
$$T = D + \sum_{i=1}^{5} (1 + e_i) P_i$$

- Perturb physics schemes separately
- Can turn off noise for particular scheme (e.g. **Convection**) and compare different schemes $\mathbf{e_{convection} = 0}$

Perturbing Convection Parameters

- Ollinaho (FMI/ECMWF) & Bechtold (ECMWF):
  - Bayesian parameter estimation approach → posterior probability densities of closure parameters (Ensemble prediction and parameter estimation system - EPPES)
  - Estimation of four parameters in the convection scheme: ENTRORG, ENTSHALP, DETRPEN RPRCON.
  - **Joint distribution** of parameters

P. Ollinaho

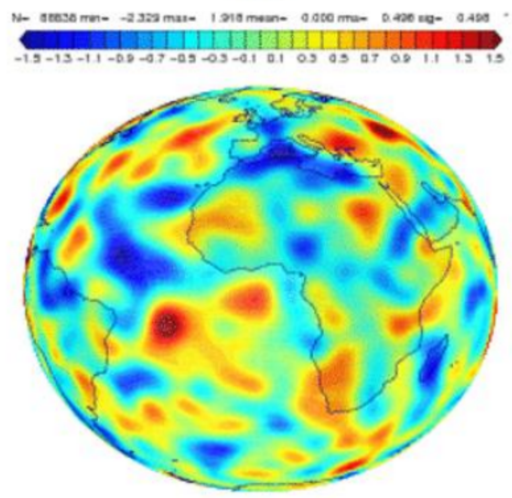


Järvinen, Laine, Solonen & Haario, 2012, Q. J. Roy. Met. Soc., 138, 281–288

Ollinaho, Bechtold, et al, 2013, Nonlinear Processes Geophys., 20, 1001–1010

Perturbing Convection Parameters

- Use joint PDF to construct perturbed parameter ensemble
- Static in time and space (cf. e.g. Climate*Prediction*.net)
  - Each ensemble member always assigned the same set of parameters, drawn from joint distribution
- Stochastically varying perturbed parameters
  - Parameters co-vary in space and time following the SPPT pattern generator



Experiments in the IFS

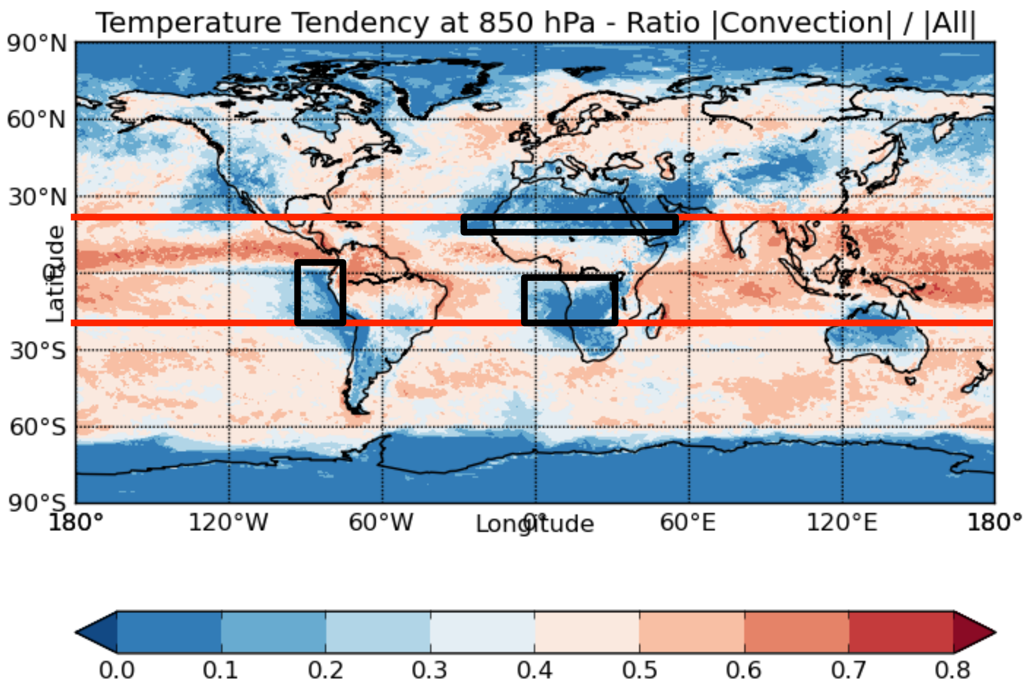
- For convection, compare:
  - No representation of uncertainty: "deterministic convection"
  - Stochastic representation of uncertainty
  - Perturbed parameter schemes
- Use SPPT to represent uncertainty in the other four physics schemes
  - How good is this representation...?

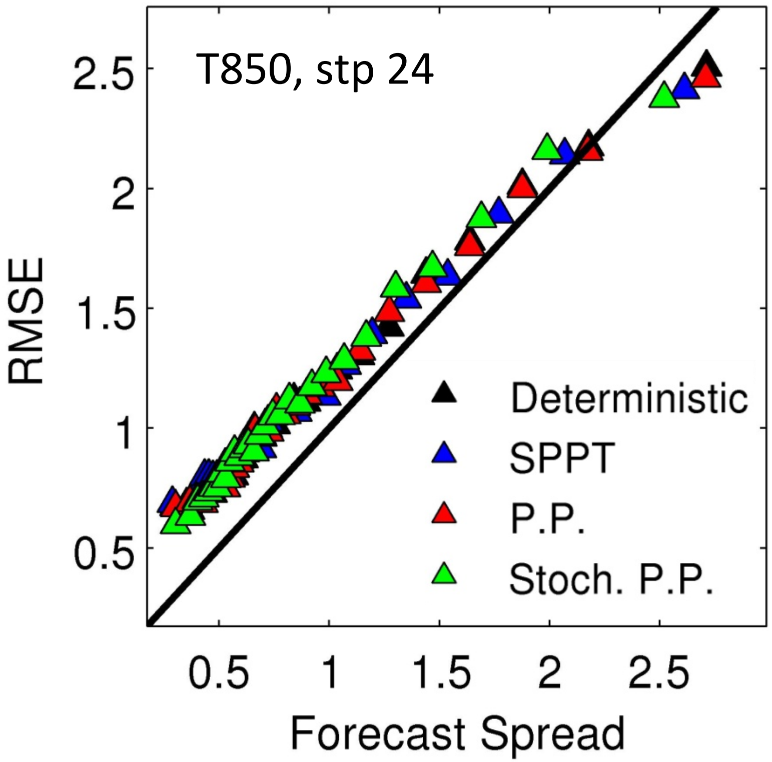
- Tested at resolution of **T159 = 120km** grid box
- 30 start dates from April-Sept 2012
- Considered T850, U850, U200, Z500, TCWV, precip, ...

Look at error-spread diagnostic in areas with little convection

- Spread-error diagnostic looks good
  - SPPT does a reasonable job of capturing uncertainty in the other tendencies

Region with little convection

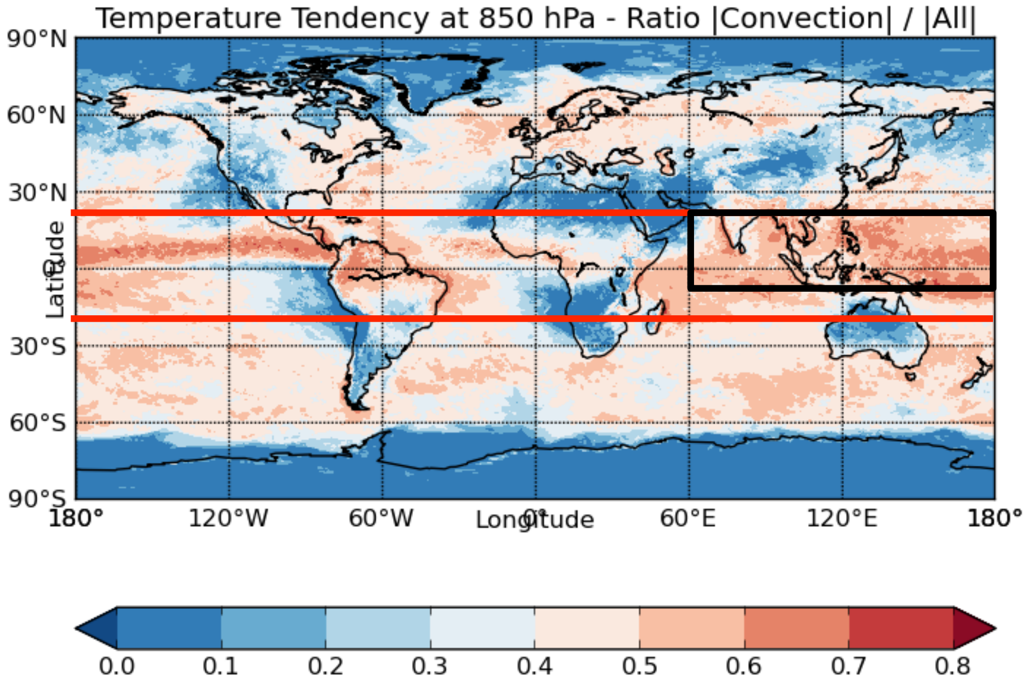




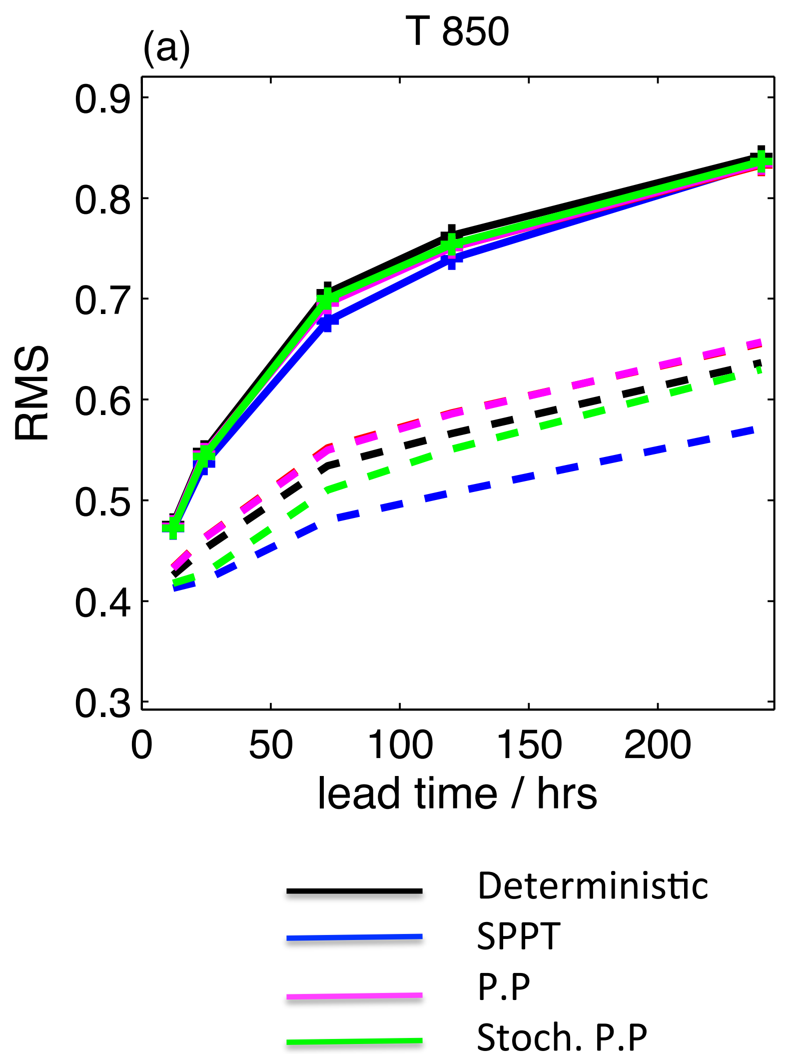
T850 = Temperature at 850 hPa (top of boundary layer)

Look at error-spread diagnostic in areas with convection

- Spread-error diagnostic shows effect of different parametrisation schemes



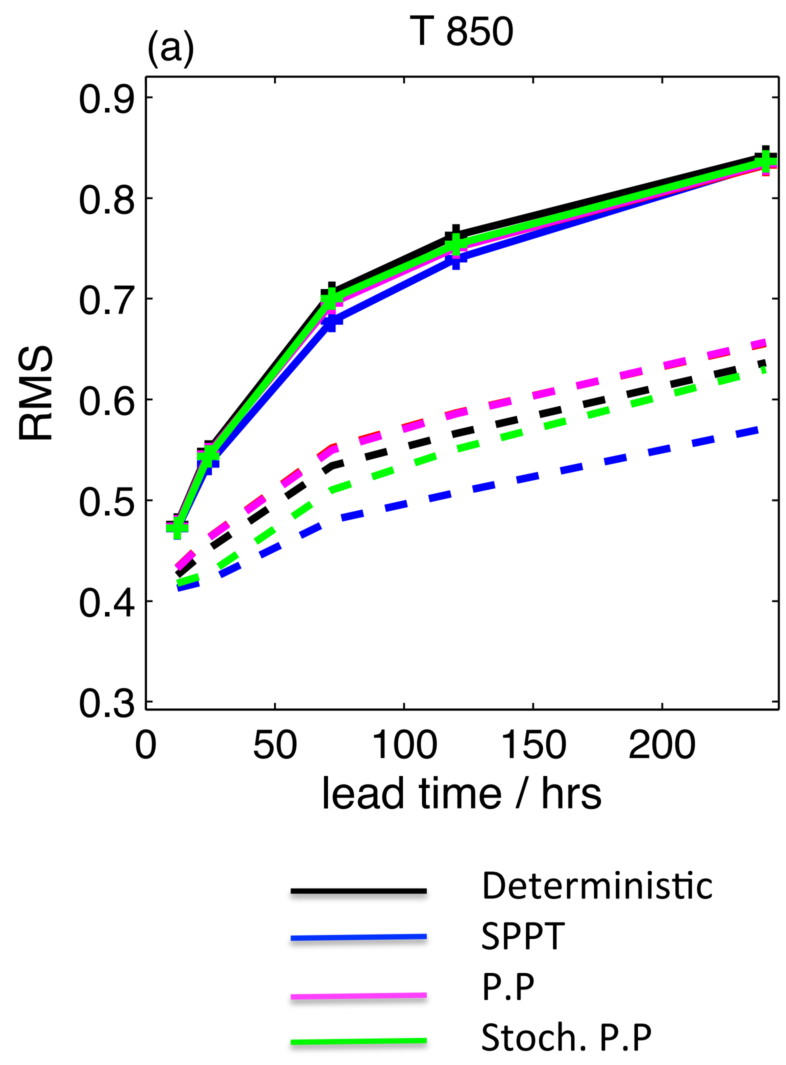
Region with significant convection



Look at error-spread diagnostic in areas with convection

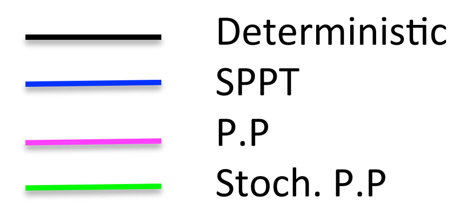
- Perturbed parameter scheme significantly increases spread over SPPT
- ...BUT still under-dispersive
  - Fixed parameter uncertainty is **not only source of model uncertainty**
- In fact, 'Deterministic convection' shows almost as much spread increase as PP
- Varying perturbed parameter scheme has smaller impact
- Both give slight increase in error

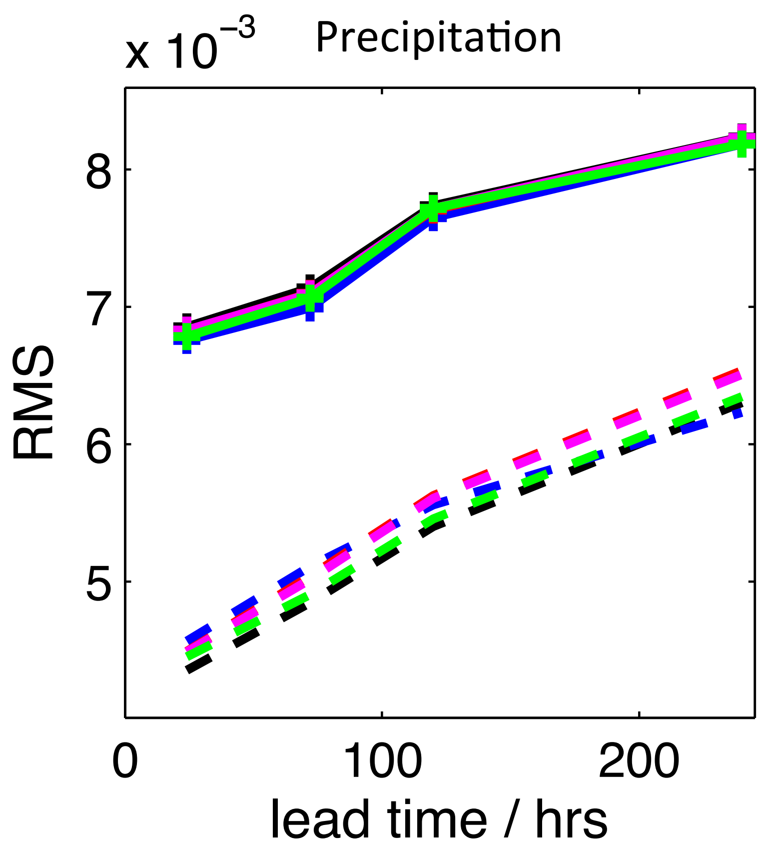
Region with significant convection

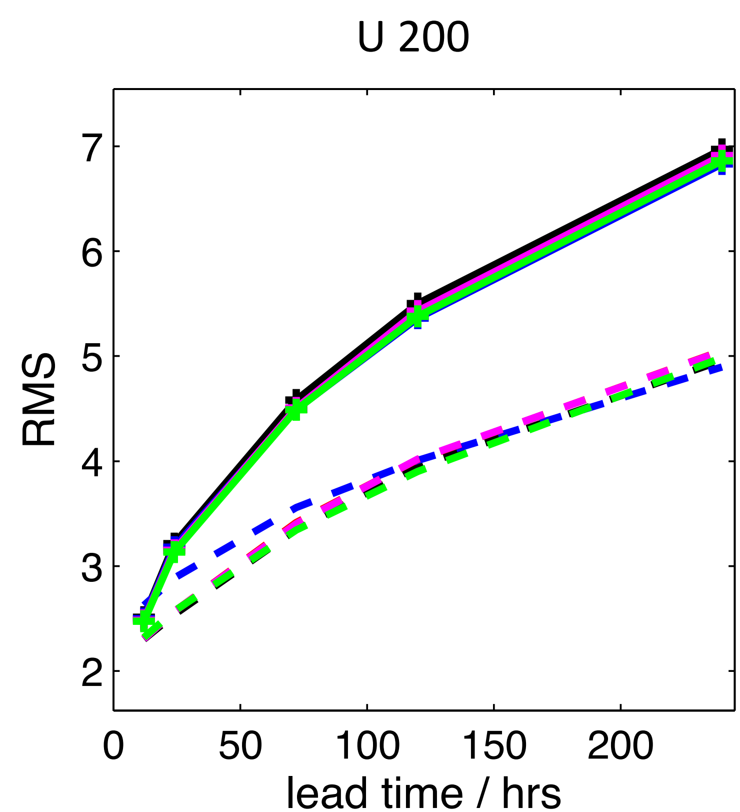


Look at error-spread diagnostic in areas with convection

- Consider diagnostics particularly sensitive to convection
- At short lead times SPPT slightly better than PP

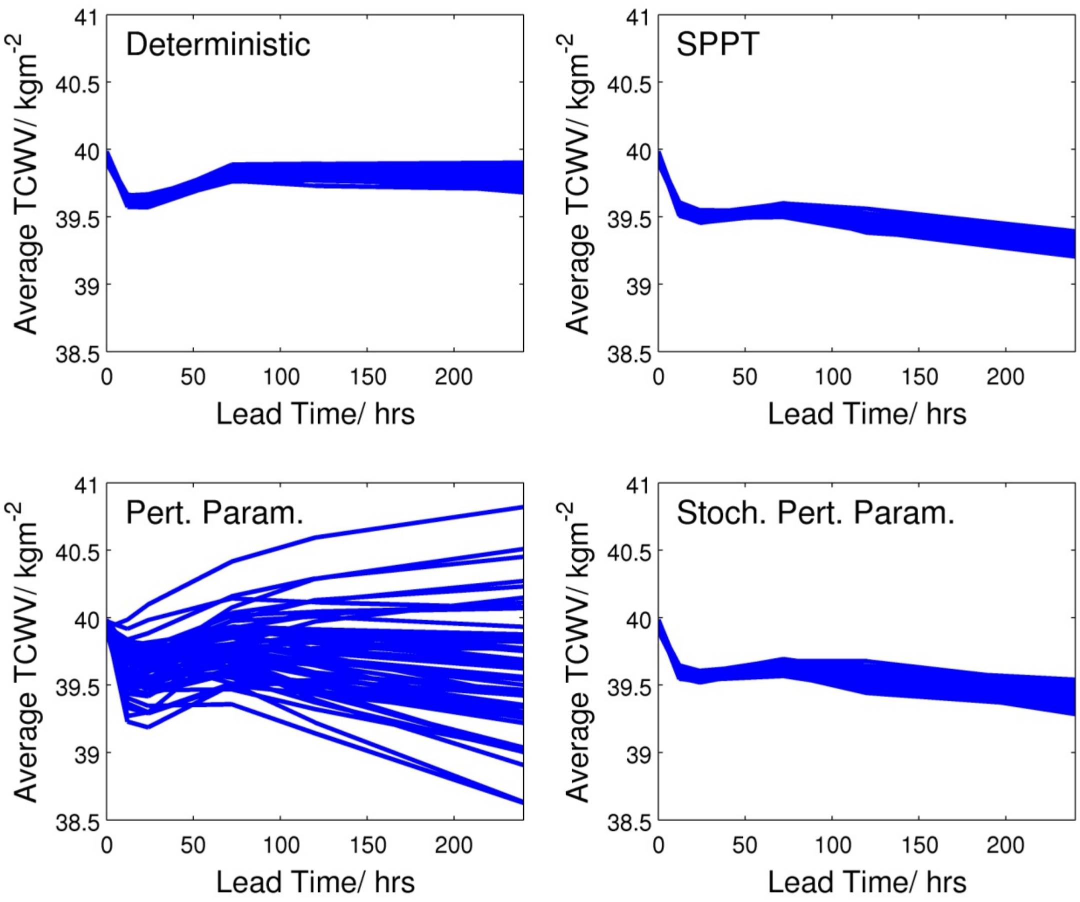






Systematic trends in tropical moisture

- Calculate average Total Column Water Vapour between 20S-20N



Ensemble members with different perturbed parameters behave very differently (over 10 days!)

➢ Some show drying, some moistening

Summary

- Considered representations of model uncertainty in the ECMWF convection scheme
- Fixed perturbed parameter ensemble results in slight improvement of spread-skill relationship, but results in systematic trends in water vapour in the tropics
- Stochastically perturbed parameter ensemble has no trends but remains underdispersive → trade off
- Perturbing parameters does not account for all model uncertainty in the convection scheme
- SPPT more skilful than perturbed parameter schemes for convection diagnostics

Thank you for listening

Reference:

Christensen, H. M., Moroz, I. M. and Palmer, T. N., 2015. Stochastic and perturbed parameter representations of model uncertainty in convection parametrisation. J. Atmos. Sci, 72, 2525–2544.

Independent SPPT

New SPPT

$$T = D + \sum_{i=1}^{5} (1 + e_i) P_i$$

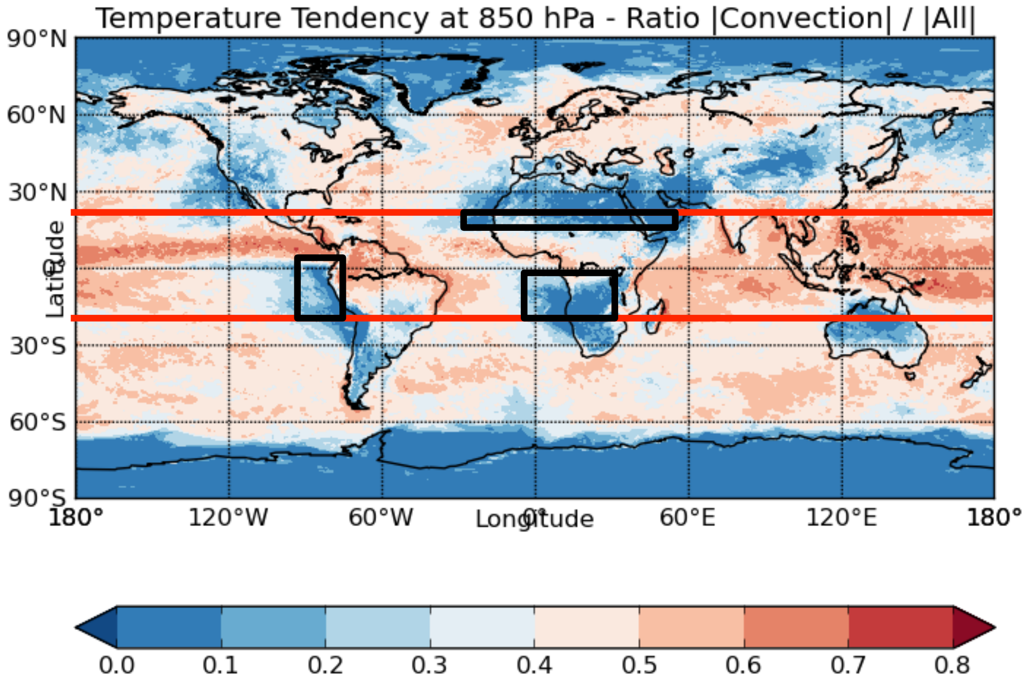
T – Total tendency
D – Dynamics tendency
P – Physics tendency

- Now also have ability to perturb five IFS physics schemes with independent random fields
  - "independent SPPT" = **SPPTi**
  - Assumes errors from different schemes are uncorrelated

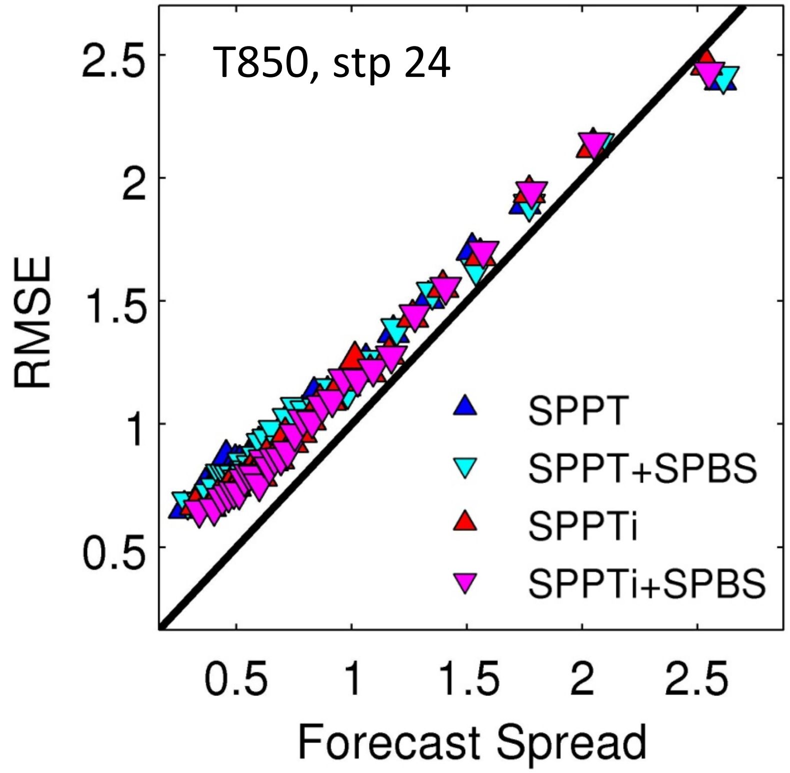
- Tested at resolution of T159 = 120km grid box
- Considered global diagnostics, but very little impact observed in extra tropics, so focus on tropics here

Look at error-spread diagnostic in areas with little convection

- Spread-error diagnostic looks good
  - SPPT does a reasonable job of capturing uncertainty
  - SPPTi doesn't change this

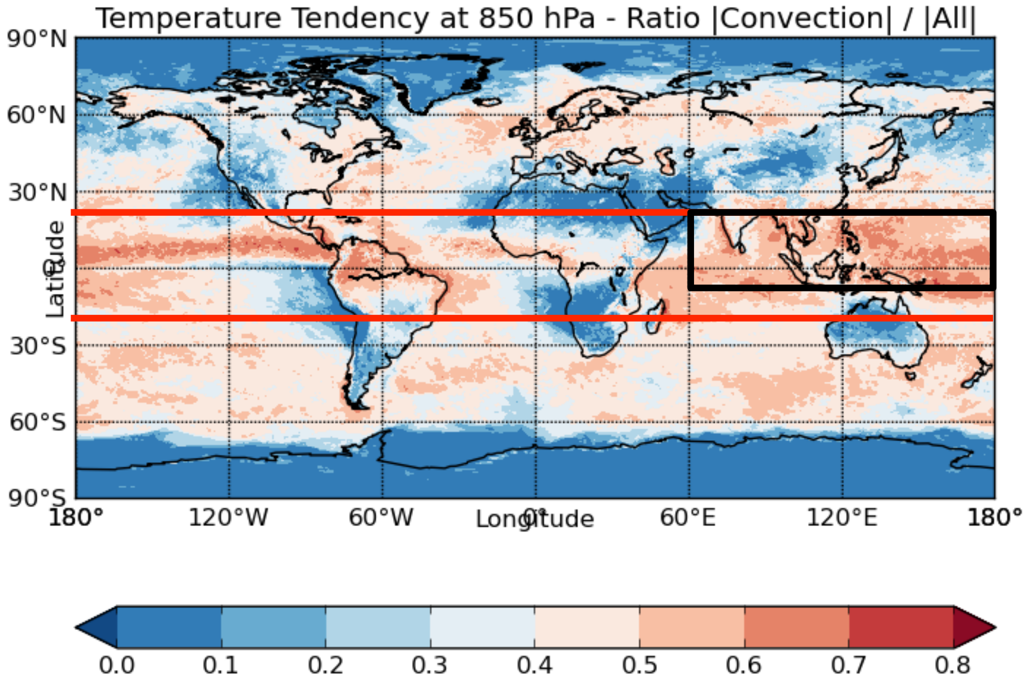


Region with little convection

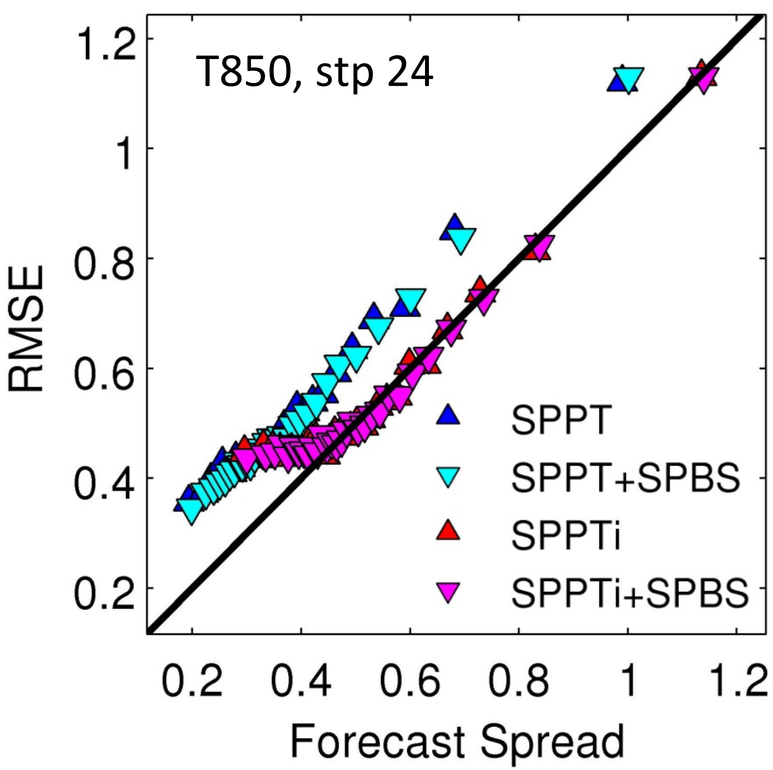


Look at error-spread diagnostic in areas with convection

- Spread-error diagnostic shows large effect of different SPPTi
  - Impact mostly seen in **areas with significant convection**

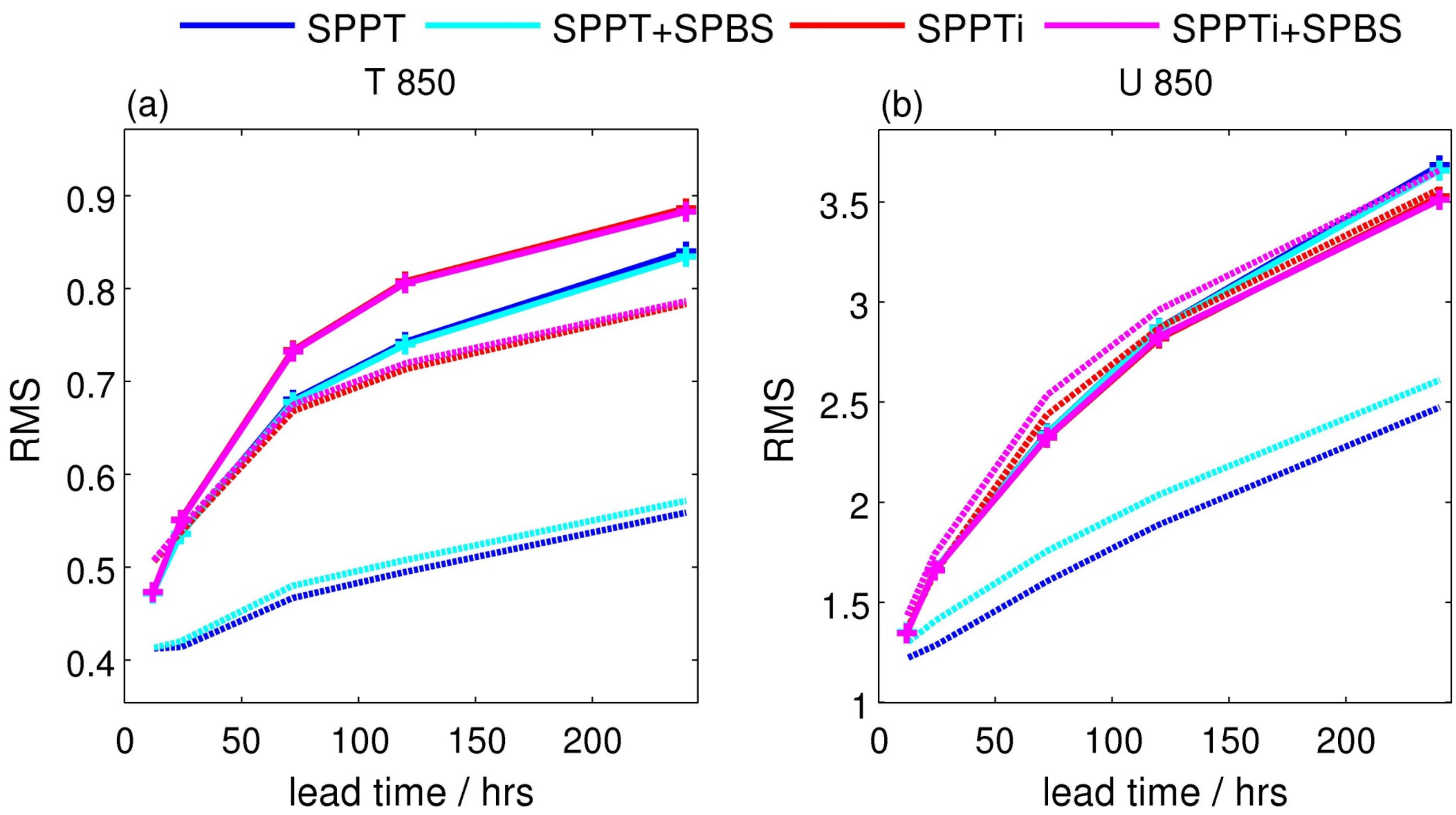


Region with significant convection



Look at error-spread diagnostic in areas with convection

- Large improvement in spread (esp. temporal evolution)
- T850 alone shows increase in error



Why?

- Only see in areas with significant convection
- Convection seems to be the key mechanism through which SPPTi affects ensemble
  - Supports results from Pert. Param. expts
- Why? In areas where the convective tendency is large, the other tendencies act in the opposite direction

SPPT

$$\sigma_{tend}^2 = \sigma_n^2 \left(\sum_{i=1}^{5} P_i \right)^2$$

Independent SPPT

$$\sigma_{tend}^2 = \sum_{i=1}^{5} \left(\sigma_i^2 P_i^2 \right)$$

SPPT only has larger spread than SPPT(inde) if physics tendencies in same direction

Why?

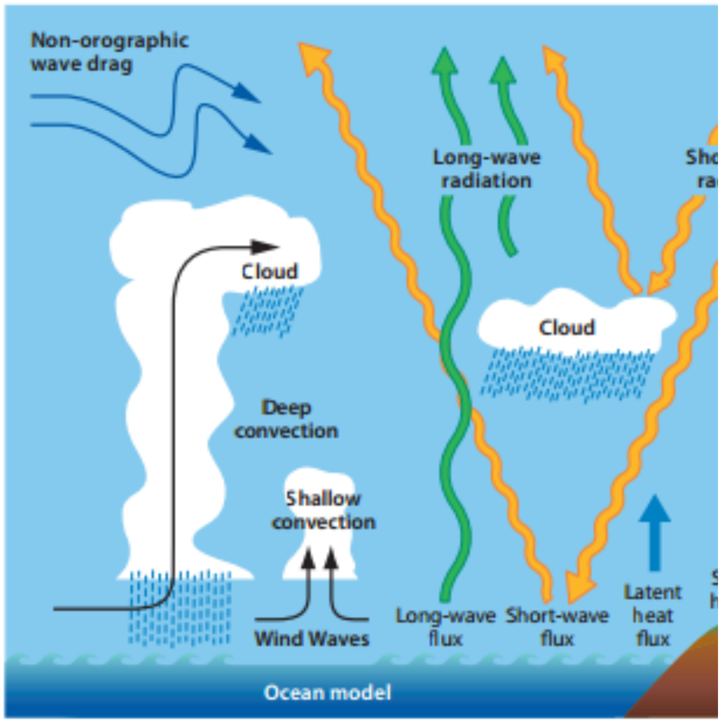


Figure 1.1 *Schematic diagram of the different physical*

- e.g. Warming from convection associated with cooling from clouds

- If you apply a different pattern to each tendency, the large convection tendency correctly has a large associated uncertainty, which will then dominate the spread