# Exploring the conservation properties
## of perturbed forecasts from the IFS ensemble

Sarah-Jane Lock[r], Peter Bechtold[b], Tobias Becker[b], Michail Diamantakis[r], Richard Forbes[r], Simon Lang[r], Martin Leutbecher[r], Aristofanis Tsiringakis[b]
[r]ECMWF, Reading, UK; [b]ECMWF, Bonn, Germany

### 1. Introduction

- IFS ensemble forecasts include stochastic perturbations designed to represent the **model uncertainty** (MU) associated with the atmospheric physics parametrisations.
- With IFS CY49R1 (due for release: late 2024), a new MU scheme SPP (Lang *et al.*, 2021) will replace the existing SPPT scheme (Palmer *et al.*, 2009).
- A major advantage of SPP is that it maintains the conservation properties of the unperturbed physics, by allowing fluxes at the surface and top of the atmosphere to respond consistently to the perturbations within the column.

### 2. IFS conservation properties

According to IFS documentation (Part IV: Physical Processes), the (unperturbed) model physics locally conserves water and enthalpy

### 2.1 Conservation of water (Q)

The sum of vertical integrals of prognostic moisture tendencies (vapour, liquid, ice, rain and snow respectively, on the LHS) balance fluxes of precipitation (rain and snow) and evaporation (RHS):

$$\frac{1}{g}\int_{p_{\mathrm{surf}}}^{0}\left(\frac{dq_{\mathrm{v}}}{dt}+\frac{dq_{\mathrm{l}}}{dt}+\frac{dq_{\mathrm{i}}}{dt}+\frac{dq_{\mathrm{r}}}{dt}+\frac{dq_{\mathrm{s}}}{dt}\right)dp = F_{\mathrm{prs}}+F_{\mathrm{e}}$$

### 2.2 Conservation of enthalphy (H, moist static energy)

Vertical integrals of tendencies contributing to H from temperature and moisture (water vapour and melting/freezing due to ice and snow, LHS) balance with the sum of fluxes due to sensible and latent heat (vaporisation and sublimation), net surface/top-of-atmosphere SW+LW radiation and dissipation of kinetic energy (RHS):

$$\frac{c_{\mathrm{pd}}}{g}\int_{p_{\mathrm{surf}}}^{0}\frac{dT}{dt}dp+\frac{L_{\mathrm{v0}}}{g}\int_{p_{\mathrm{surf}}}^{0}\frac{dq_{\mathrm{v}}}{dt}dp-\frac{L_{\mathrm{s0}}-L_{\mathrm{v0}}}{g}\int_{p_{\mathrm{surf}}}^{0}\frac{dq_{\mathrm{i}}+dq_{\mathrm{s}}}{dt}dp =$$
$$F_{\mathrm{s}}+L_{v0}F_{\mathrm{q_v}}-\left(L_{s0}-L_{v0}\right)F_{\mathrm{q_s}}-F_{\mathrm{rad}}^{\mathrm{top}}+F_{\mathrm{rad}}^{\mathrm{surf}}-D_{\mathrm{diss}}^{KE}$$

### 3. Methodology

To construct and compare conservation budgets, we use model fields from ensemble forecasts for a single start date (1 December 2022, 00UTC)

### 3.1 Constructing conservation budgets

Model *tendencies* (the updates to fields that generate the solution at the next time-step) are required to compute the budget terms.

### 3.2 Comparing conservation properties

- Model tendencies and corresponding budget terms (for water and enthalpy) are accumulated at each time-step, and output every 3h.
- **Baseline**: budget residuals of the unperturbed (**control**) physics.
- **Compare**: residuals of forecasts perturbed with a MU scheme (*either* SPP *or* SPPT).

### 3.3 Experimental set-up

- IFS (CY49R1), resolution TCo399L137, to forecast lead-time 48h
- 1 unperturbed (**control**) forecast + 20 perturbed forecasts
- *all* members start from identical initial conditions (IC), i.e. no IC perturbations
- perturbed forecasts include *either* SPP *or* SPPT perturbations

### References

Lang STK, Lock SJ, Leutbecher M, Bechtold P, Forbes RM. 2021. Revision of the stochastically perturbed parametrisations model uncertainty scheme in the integrated forecasting system. *Q J R Meteorol Soc* **147**(735): 1364–1381, doi:https://doi.org/10.1002/qj.3978.

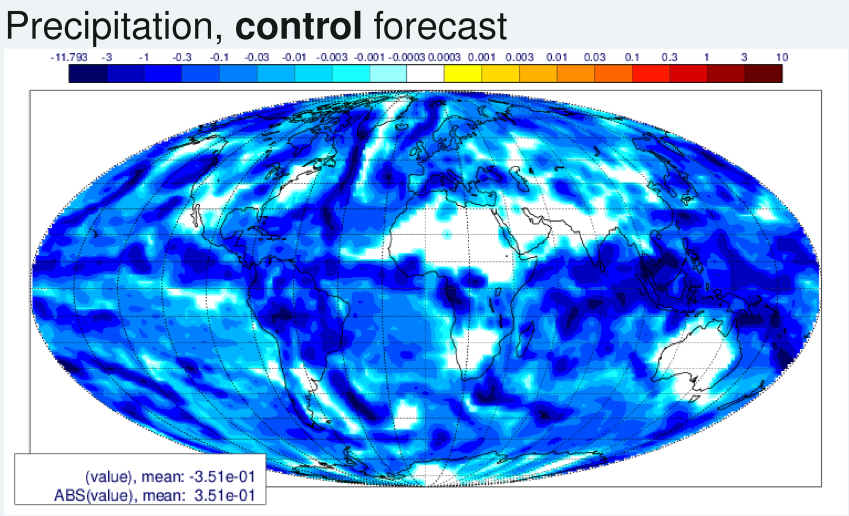
Palmer TN, Buizza R, Doblas-Reyes F, Jung T, Leutbecher M, Shutts G, Steinheimer M, Weisheimer A. 2009. Stochastic parametrization and model uncertainty. *ECMWF Technical Memorandum* (598): 42, doi:10.21957/ps8gbwbdv.

### 4.1 Results: Snapshots of budget term fields

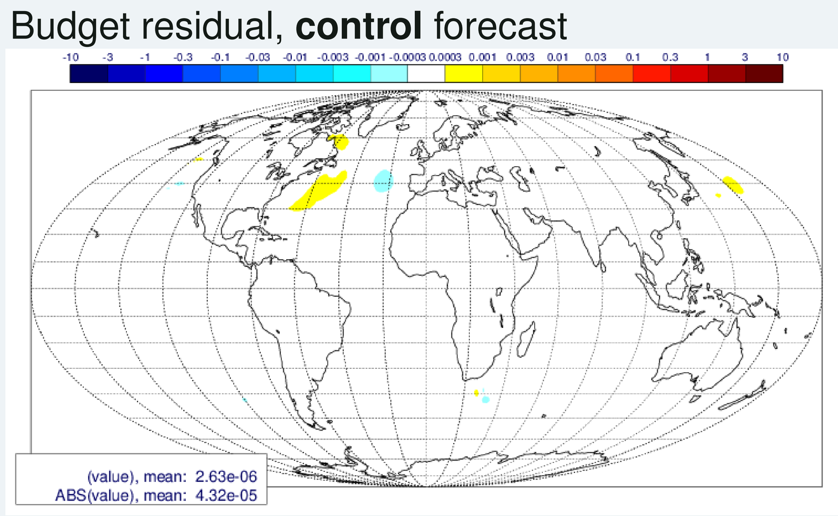
- Terms accumulated during t=45–48h (mm/3h).
- Budget term (control forecast) values, for context.
- Budget residuals for example SPP and SPPT perturbed forecasts.

### Snapshots I: Moisture (mm/3h)

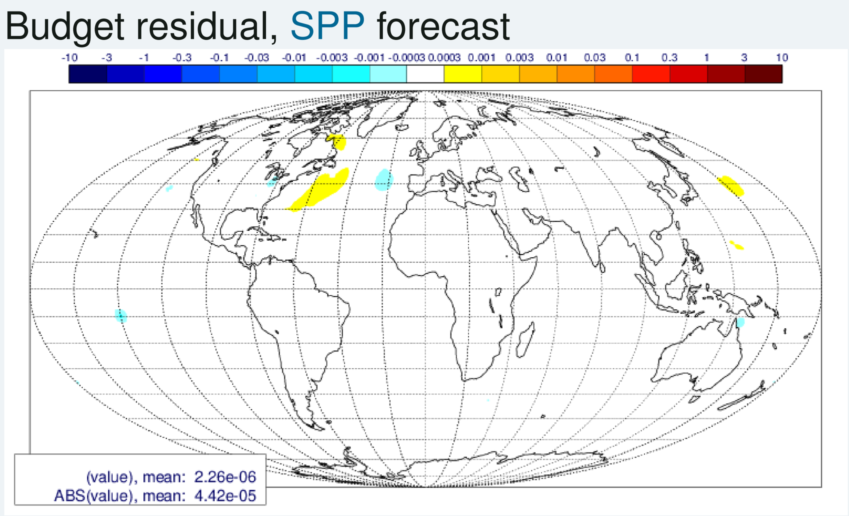
Precipitation, **control** forecast



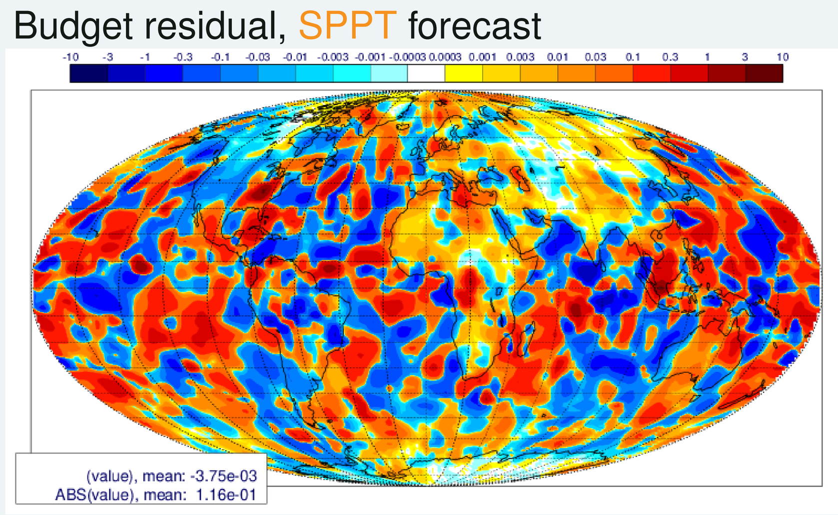
Budget residual, **control** forecast



Budget residual, SPP forecast

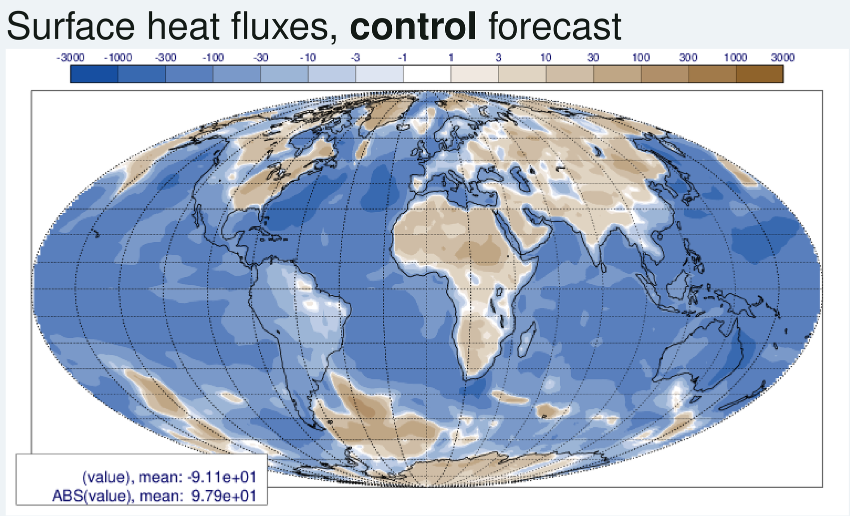


Budget residual, SPPT forecast

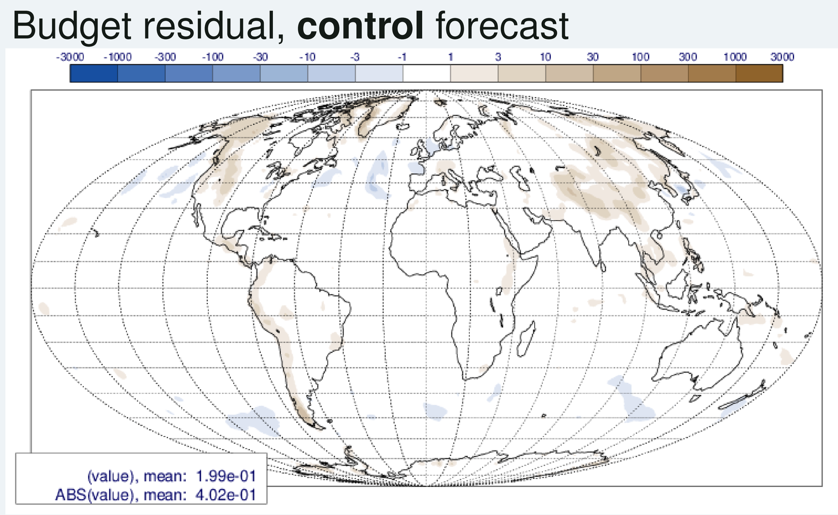


### Snapshots II: Enthalpy (W/m$^2$)

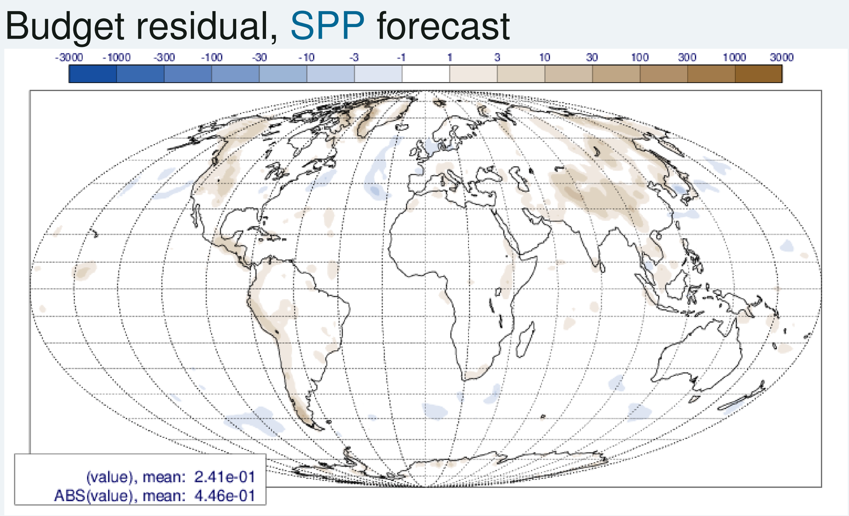
Surface heat fluxes, **control** forecast



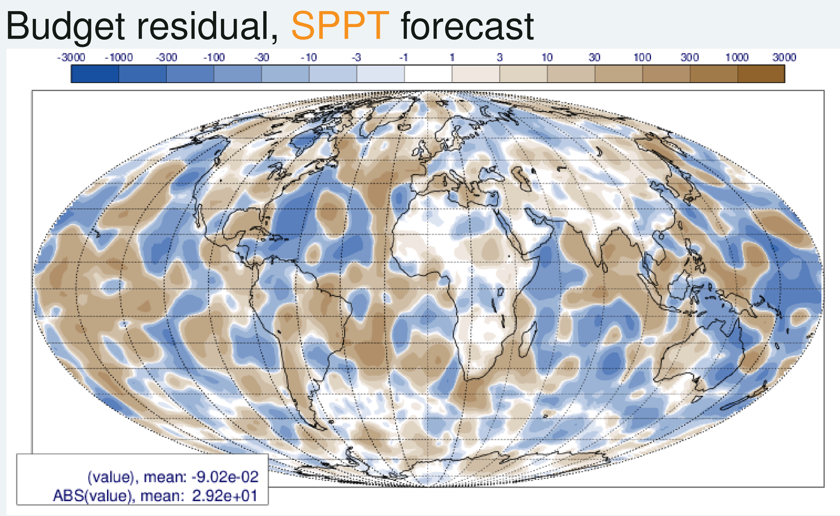
Budget residual, **control** forecast



Budget residual, SPP forecast



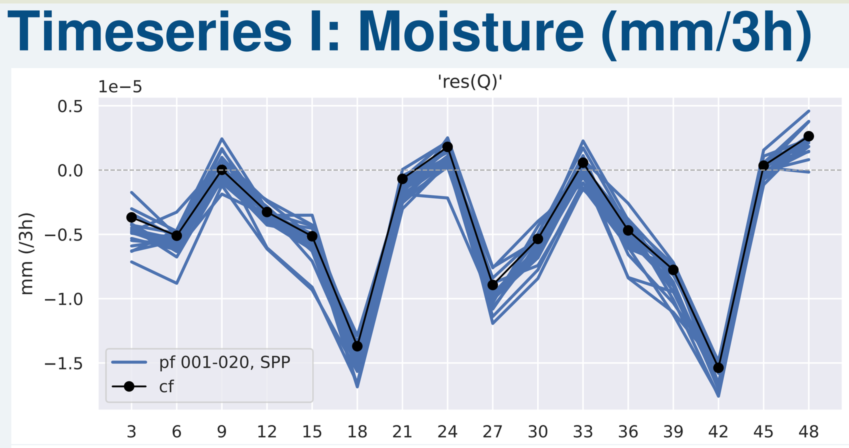
Budget residual, SPPT forecast

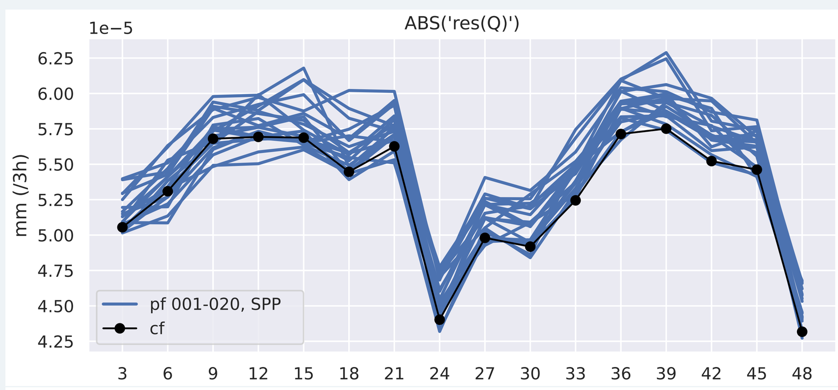


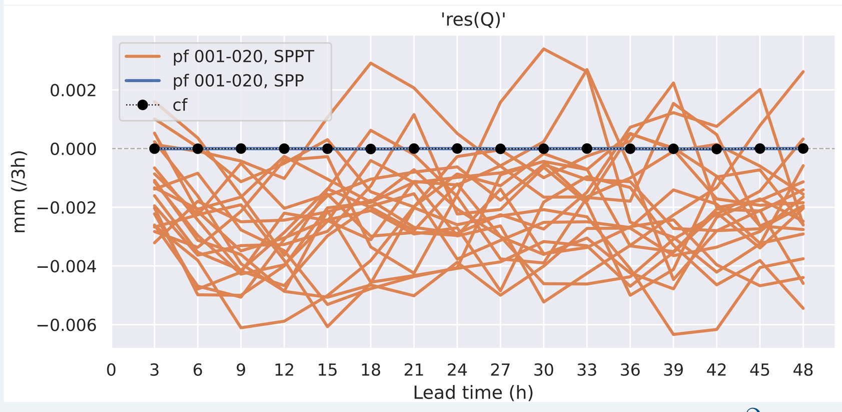
### 4.2 Results: Time-series of global mean budget residuals

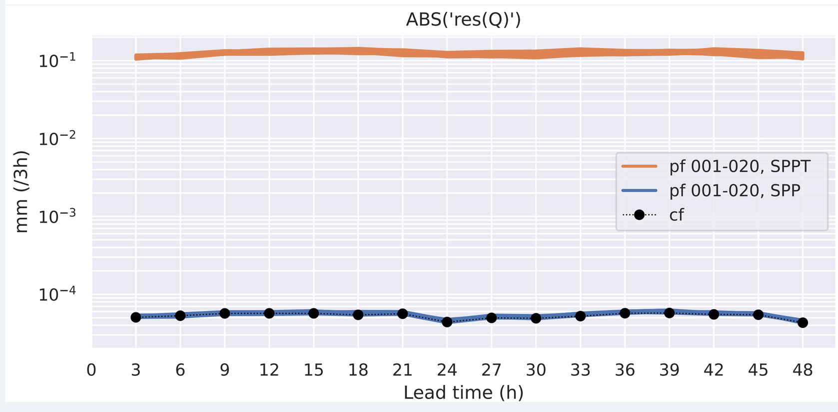
- (left) mean of grid-point residuals (⇒ level of **global** conservation)
- (right) mean of *absolute values* of grid-point residuals (⇒ level of **local** conservation)
- **control** forecast (black), SPP (blue) and SPPT (orange) perturbed forecasts

### Timeseries I: Moisture (mm/3h)




### Timeseries II: Enthalpy (W/m$^2$)