Using Stochastic Physics to Determine the Required Numerical Precision for Parametrization Schemes

Leo Saffin | leo.saffin@physics.ox.ac.uk

UNIVERSITY OF OXFORD

Atmospheric, Oceanic and Planetary Physics

- It is a waste of computational resources to represent uncertain processes with high precision
- Stochastic physics is an explicit representation of inherent model uncertainty
  - Therefore, we can use stochastic physics to determine when rounding errors are producing unacceptable results
  - We use SPPT (stochastic perturbation of parametrization tendencies) in an intermediate-complexity atmospheric model (SPEEDY)
- Deterministic forecasts (no SPPT) give similar error growth for a large range of precisions (rounding errors)
- Ensemble forecasts (different random seed, same initial conditions) show that these errors are within the uncertainty of SPPT
- Two parametrization schemes (convection and surface fluxes) dominate the errors at low precision in SPEEDY
- Some minor code changes, to express fields as anomalies, can reduce these errors and allow us to use lower precision

1 SPEEDY

SPEEDY (Simplified Parametrizations, primitivE-Equation DYnamics) [Molteni, 2003]. Spectral-transform dynamical core with simplified physics, T30 spectral resolution and 8 vertical levels.

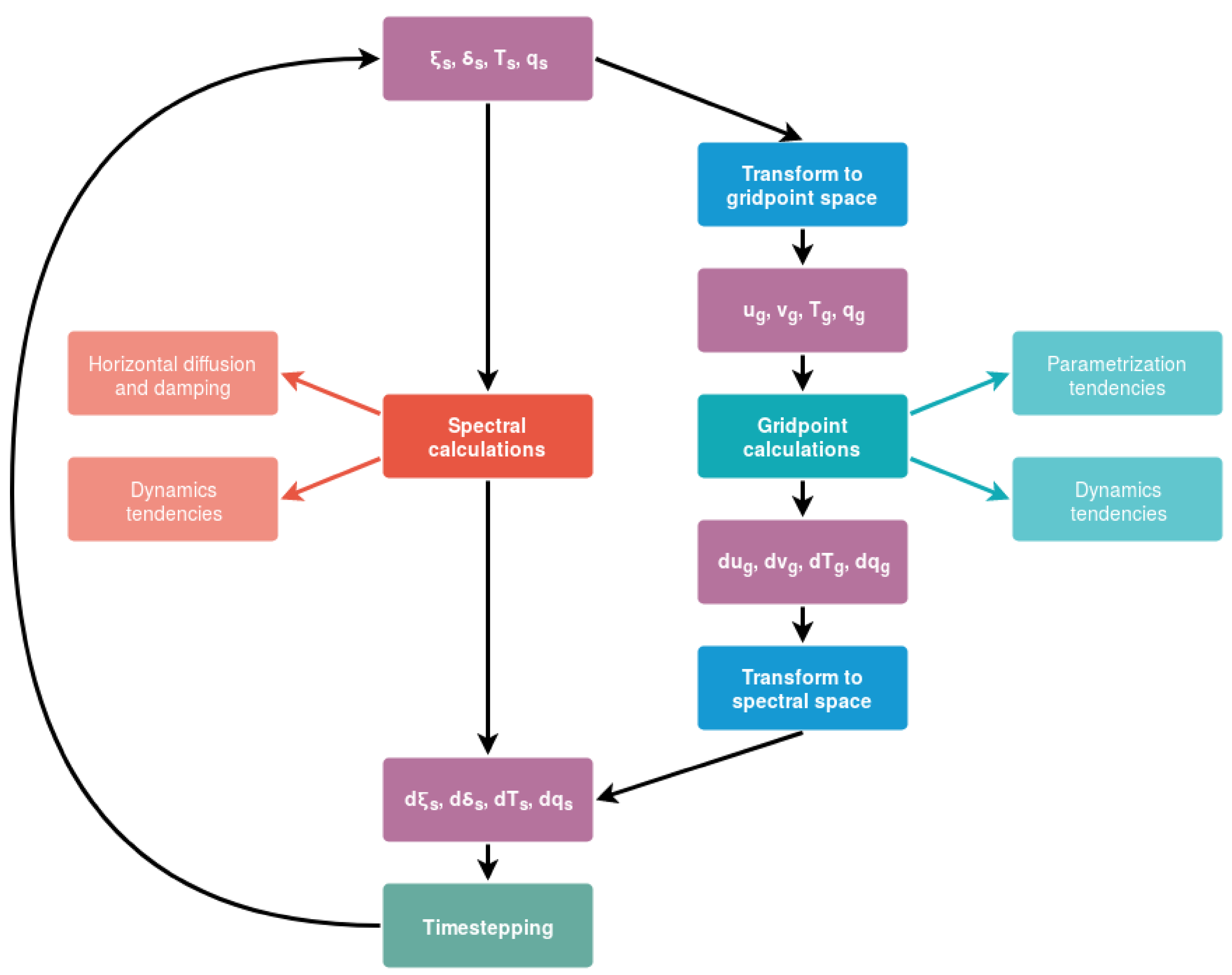

Figure 1: Single timestep of SPEEDY.

- Reduce precision in each parametrization scheme using the emulator from Dawson and Düben [2017]
  - Focus on reducing significand bits (sbits, i.e. decimal places)
  - Note that 52 sbits=double Precision, 23 sbits=single precision, and 10 sbits=half precision
- Added SPPT (stochastic perturbation of parametrization tendencies) scheme of Palmer et al. [2009] to SPEEDY to represent "model uncertainty'

2 Impacts of Rounding Errors

- Run forecasts with all parametrizations in reduced precision and individual parametrizations in reduced precision
  - Any difference between forecasts is due to the rounding errors

Errors in initial parametrization tendencies

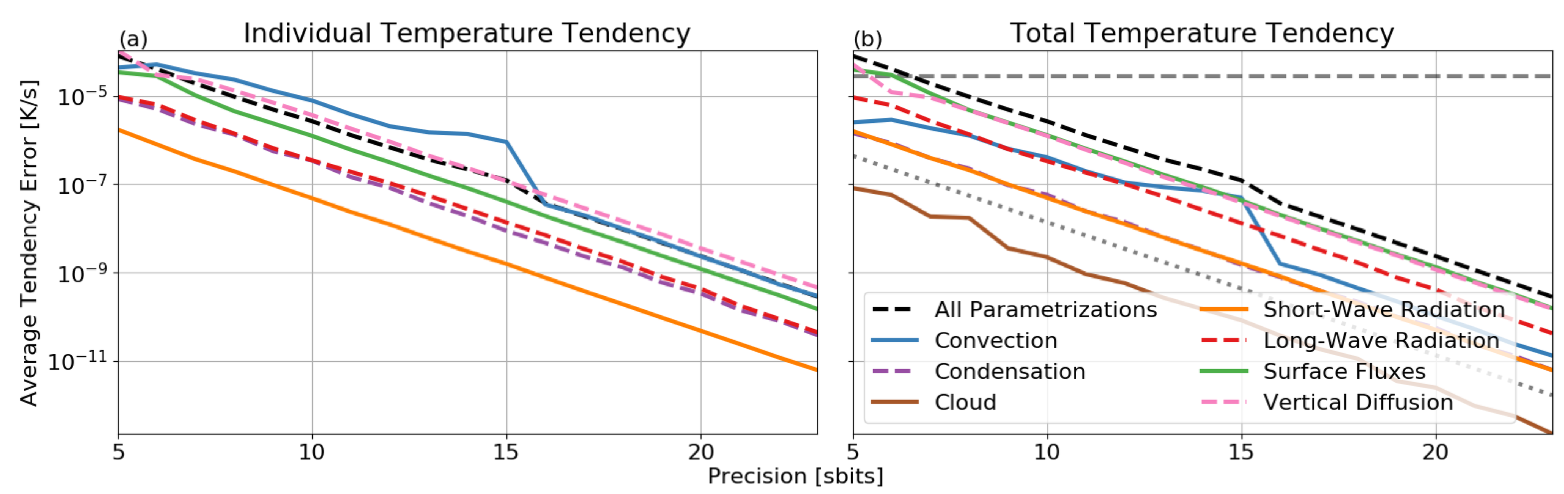

Figure 2: Root-mean-square error in the boundary-layer temperature tendencies with different parametrization schemes in reduced precision. (a) The error in the parametrization's temperature tendency. (b) The error in the total temperature tendency. The dashed grey line in (b) shows the average temperature tendency and the dotted grey line in (b) shows the average temperature tendency multiplied by the machine rounding error ($2^{-(sbits+1)}$)

Resulting forecast errors

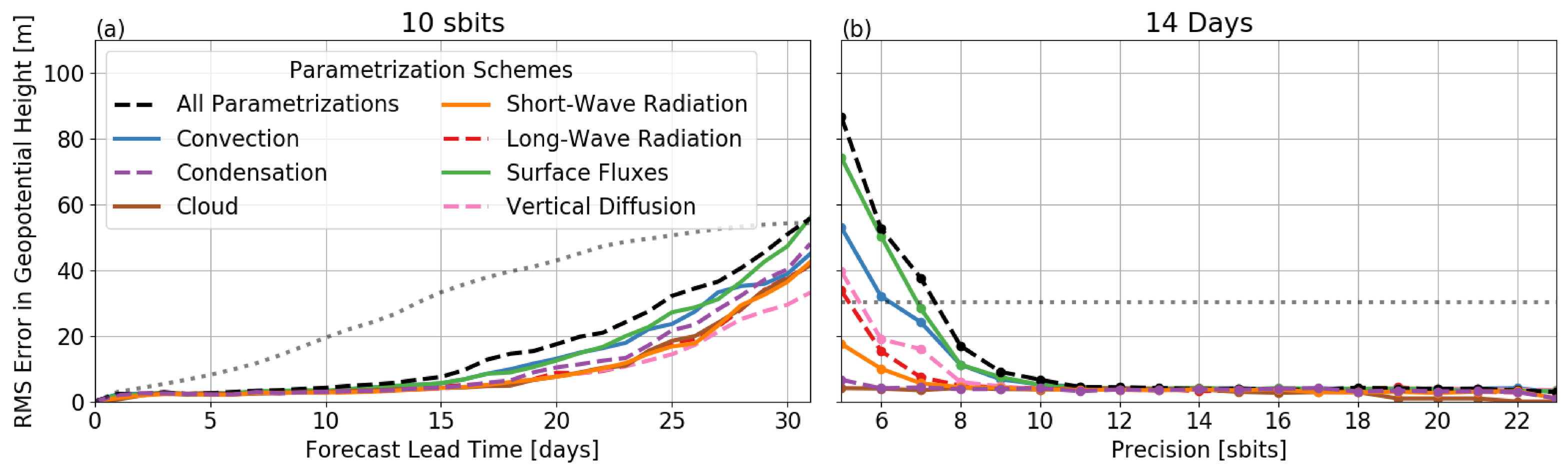

Figure 3: Root-mean-square error in 500 hPa geopotential height for forecasts with parametrization schemes in reduced precision relative to a double-precision reference forecast. The dotted grey line in (a) shows the ensemble spread from a 20-member double-precision ensemble. The dotted grey line in (b) shows the same but fixed at 14 days.

- Errors in the parametrization tendencies largely follow the machine rounding error
- Resulting forecast errors less simple
  - Forecast errors similar for a large range of sbits
  - Rapidly increasing errors below a threshold precision
- Convection and surface fluxes are the dominant source of errors at low precision
  - Other parametrizations have increased errors at a lower precision dependant on the parametrization

References

A Dawson and P D Düben. rpe v5: an emulator for reduced floating-point precision in large numerical simulations. *Geosci. Model Dev.*, 10(6):2221–2230, 2017. doi: 10.5194/gmd-10-2221-2017.

F Molteni. Atmospheric simulations using a GCM with simplified physical parametrizations. I: model climatology and variability in multi-decadal experiments. *Clim. Dyn.*, 20(2):175–191, 2003. doi: 10.1007/s00382-002-0268-2.

T N Palmer, R Buizza, F Doblas-Reyes, T Jung, M Leutbecher, G J Shutts, M Steinheimer, and A Weisheimer. Stochastic Parametrization and Model Uncertainty. *ECMWF Tech. Memo.*, 598:1–42, 2009.

3 Ensembles

- Ensembles of forecasts where the only difference is the random seed used in SPPT (the model uncertainty)
- Precision is acceptable if an ensemble is indistinguishable from a double-precision ensemble

Ensemble Overlap

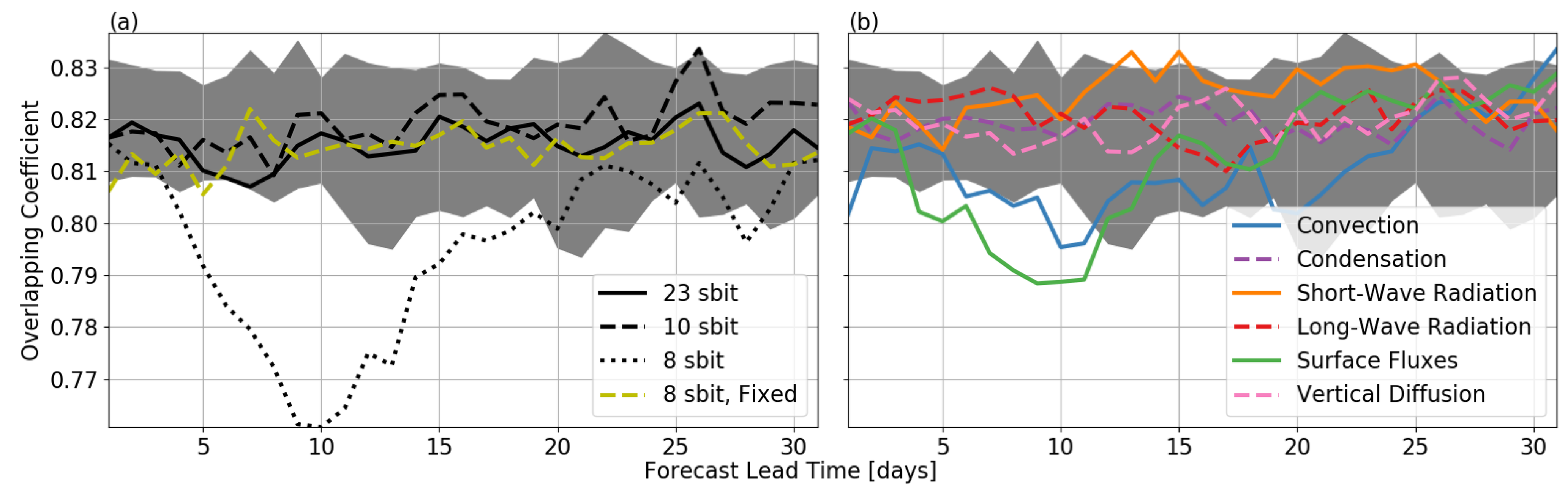

Figure 4: Overlap between 20-member reduced-precision ensemble forecasts and a reference double-precision ensemble. (a) Ensembles with all parametrizations reduced to 8 sbits. (b) Ensembles with individual parametrizations reduced in reduced precision. The grey shading is the range of the overlapping coefficient found from repeatedly randomly selecting two 20-member ensembles from 40 double-precision ensemble members.

- Single precision (23 sbits) and half precision (10 sbits) are within the uncertainty of the double-precision ensemble.
- Low precision (8 sbits) is outside the uncertainty of the double-precision ensemble.
- Convection and surface fluxes are the problem parametrizations at low precision

4 Fixes

Calculation: Convection is diagnosed where the saturation moist static energy (MSE_s) decreases with height.

Problem: The difference in MSE_s between levels is small compared to the value of MSE_s. As precision is reduced $MSE_s(k+1) < MSE_s(k)$ increasingly becomes $MSE_s(k+1) == MSE_s(k)$

Solution: Express moist-static energy as an anomaly. We are only interested in the differences in MSE_s so we can reduce rounding errors by removing a large offset.

Calculation: The temperature tendency due to surface fluxes is proportional to the difference between the surface temperature (T_s) and the boundary-layer temperature (T_0)

Problem: T_s and T_0 are similar compared to their absolute value so the difference ($T_s - T_0$) is increasingly likely to be zero at low precision

Solution: Express temperatures in Celsius so the difference is comparable to the magnitude.

These changes move the problem to lower precision rather than removing it entirely. This is still good as it allows us to use lower precisions than previously expected (see "8 sbit, Fixed" in Fig. 4)