How low can you go? Reducing the precision of data assimilation to improve weather forecast skill

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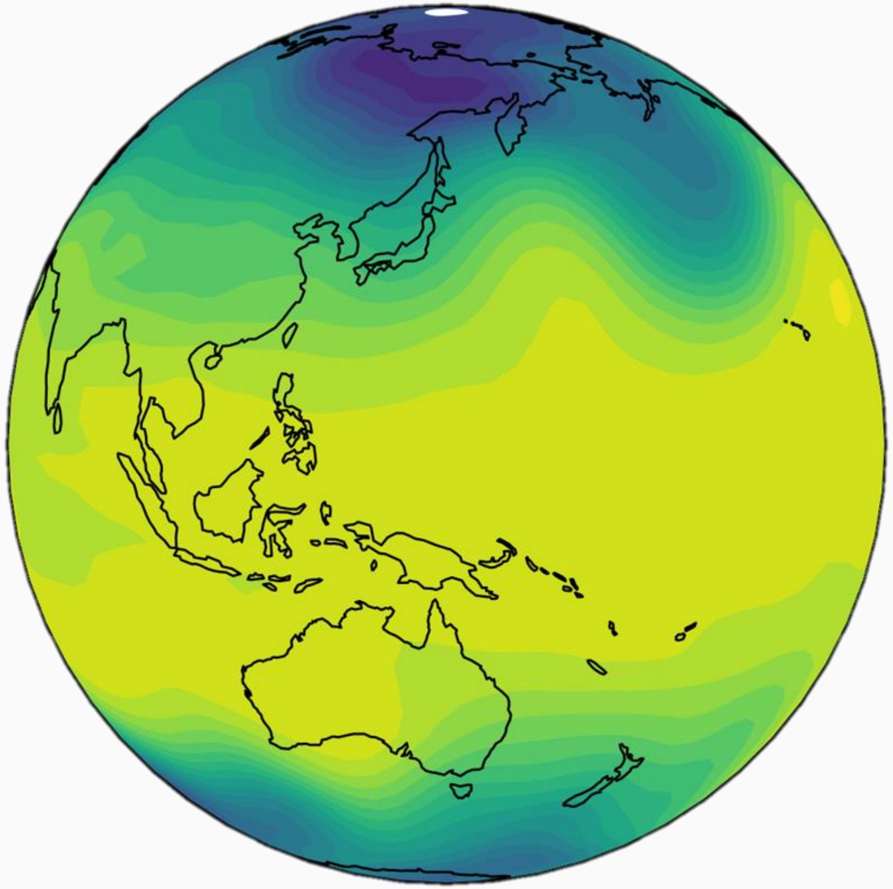
NERC SCIENCE OF THE ENVIRONMENT

Motivation

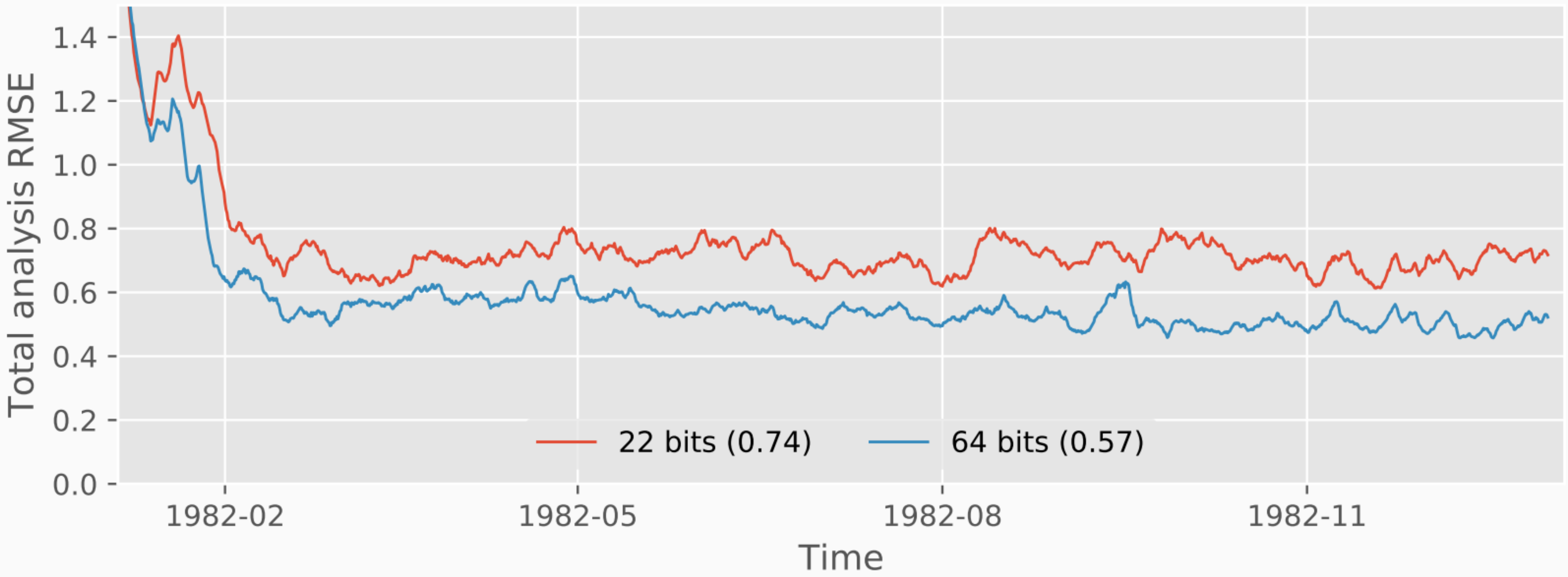
- Studies indicate that precision can be reduced in weather and climate models, without impacting skill scores significantly
- This is because we have **model uncertainty** due to unresolved scales/processes
- Reduced precision models run faster, so we can afford to use higher resolution/larger ensembles etc.
- What about data assimilation?

SPEEDY/LETKF

- First stage of project, Lorenz '96, complete
- Now, move on to SPEEDY/LETKF
- Summer goals:
  1. Add model error to SPEEDY, compare with reduced precision error (using reduced precision emulator)
  2. Reduce precision in LETKF, measure speed-up and analysis quality

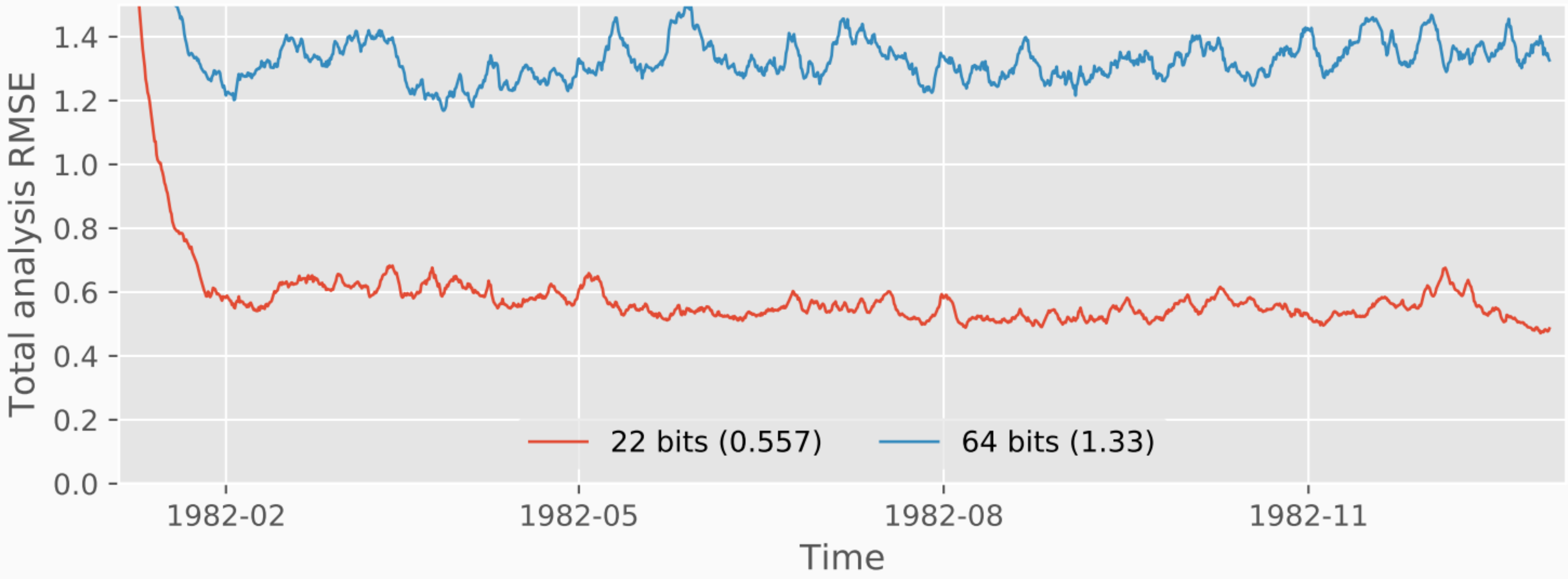


Why do you need model error?



- Error is 25% higher for 22 bit SPEEDY, compared with 64 bit SPEEDY
- **But this experiment is biased towards 64 bit SPEEDY**
- 22 bit model has error (precision error), but 64 bit model does not (nature run is also 64 bits)

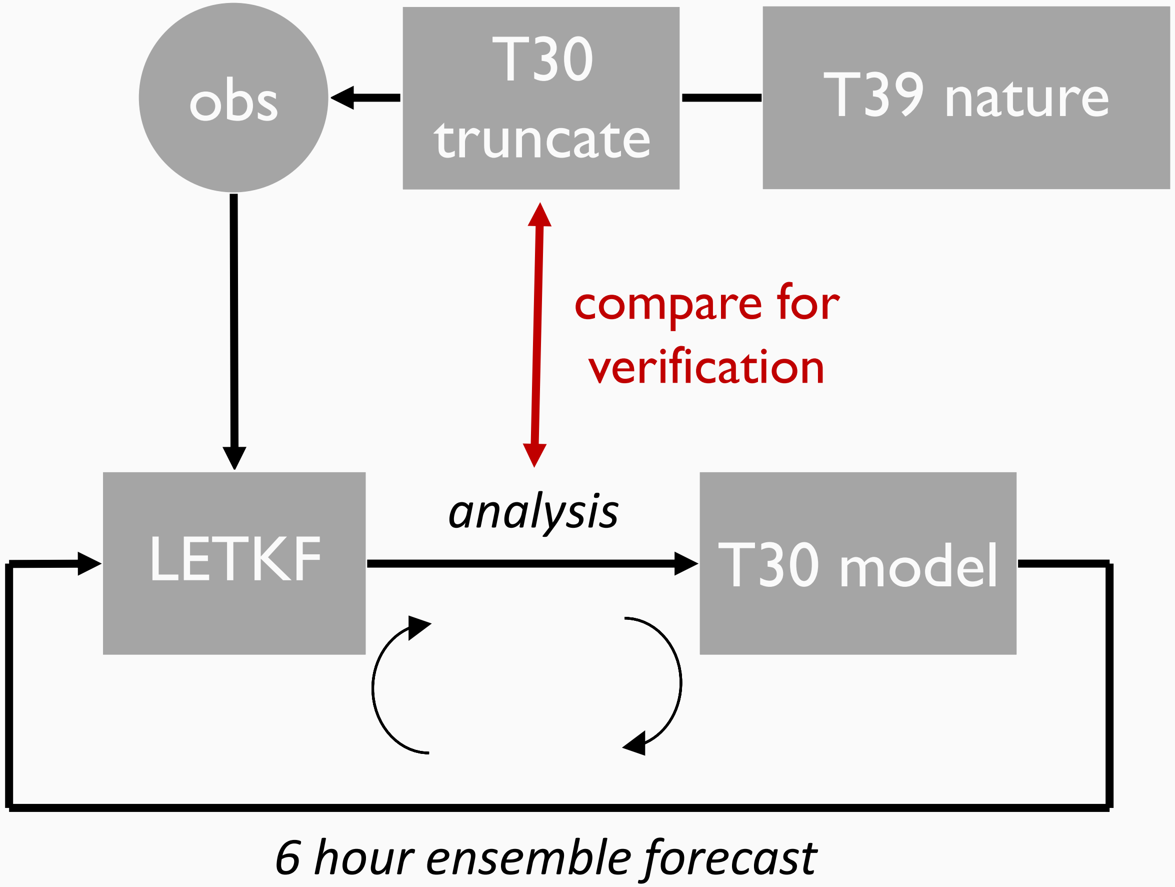
Why do you need model error?



- Same experiment but with **22 bit nature run**
- Now, 64 bits is worse than 22 bits!

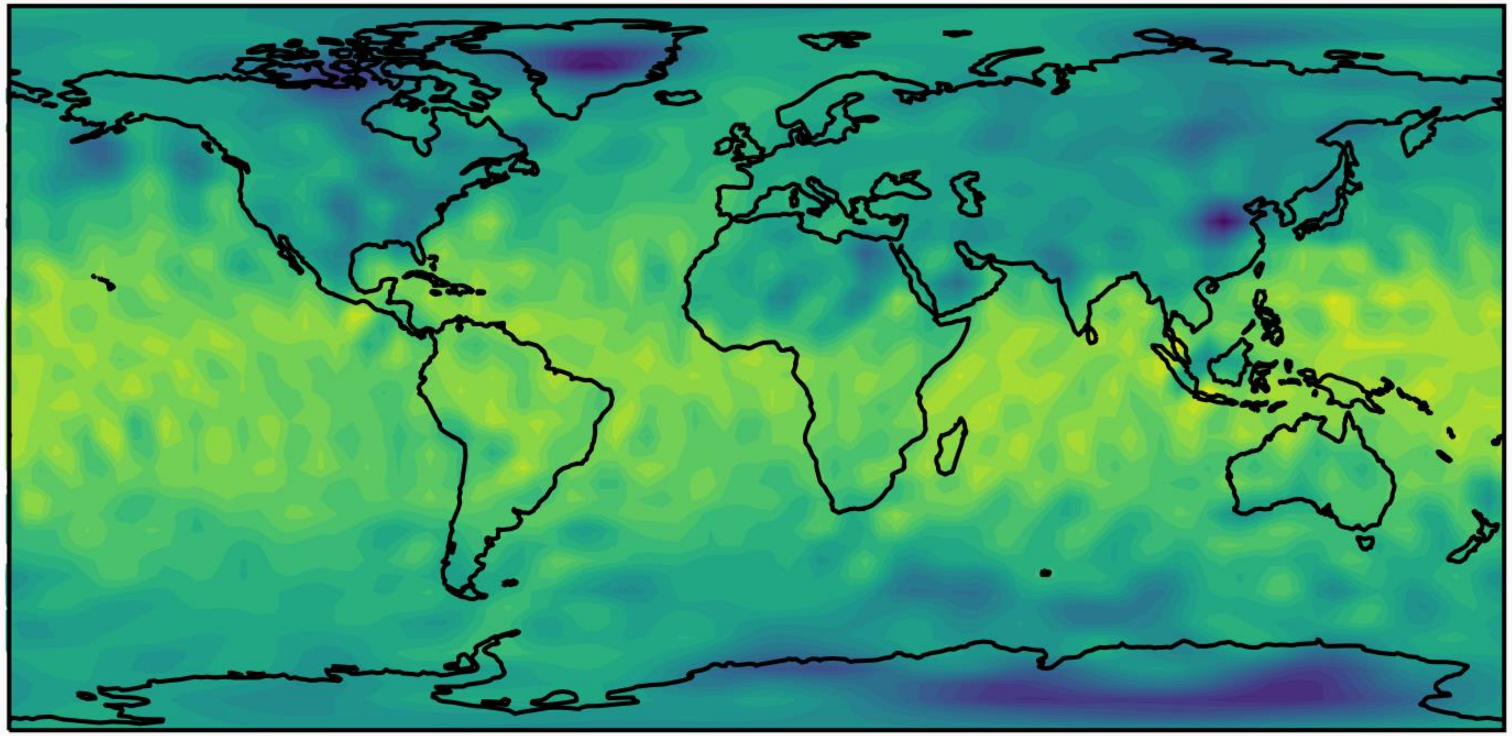
Adding model error (attempt 1)

- First attempt to add model error: **use a higher resolution nature run (T39 nature vs T30 in LETKF)**
- Run model at T39, truncate to T30, generate synthetic observations as before
- Now, there is error due to **unresolved scales**, and **representativity error** in the observations



Adding model error (attempt 1 result)

- It didn't work!
- A strange spherical harmonic pattern appears in Q and T fields, and the model eventually crashes
- I'll come back to this later

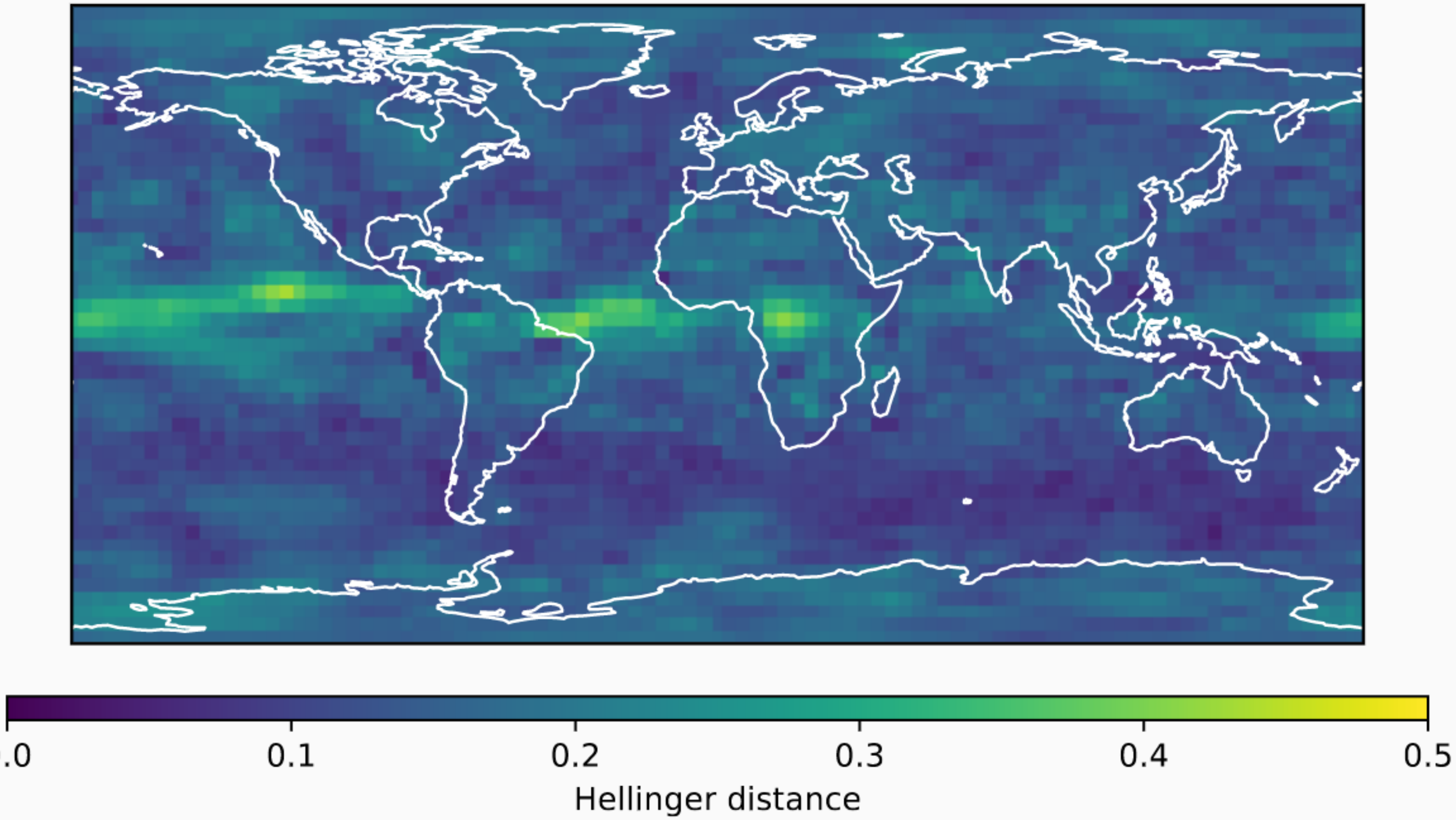


Lowest level specific humidity after 2 months of assimilation

Adding model error (attempt 2)

- Easier way to add model error: perturb parameters
- I perturb some parameters in convection scheme and diffusion and wind drag
- To check climatological changes, I compute **Hellinger distance**
- This measures "distance" between two PDFs
- HD = 0 → identical, HD = 1 → completely different

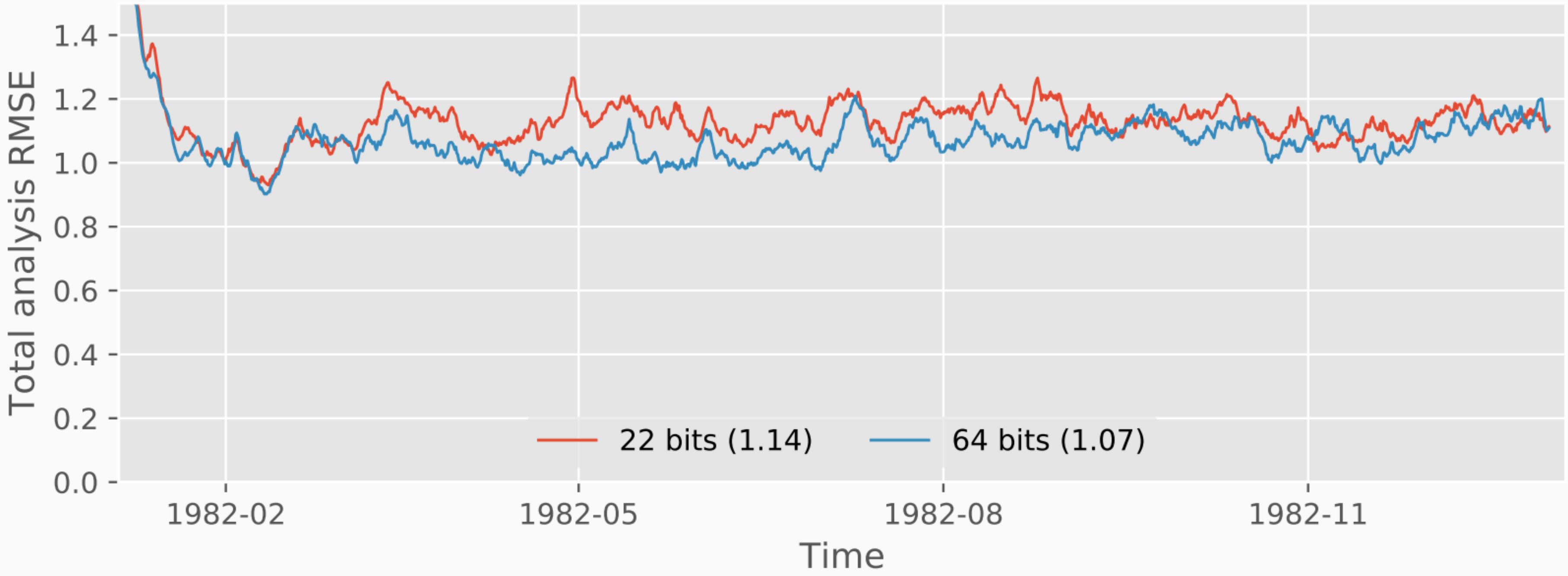
Climatological changes



Lowest level temperature climatological change after perturbing parameters

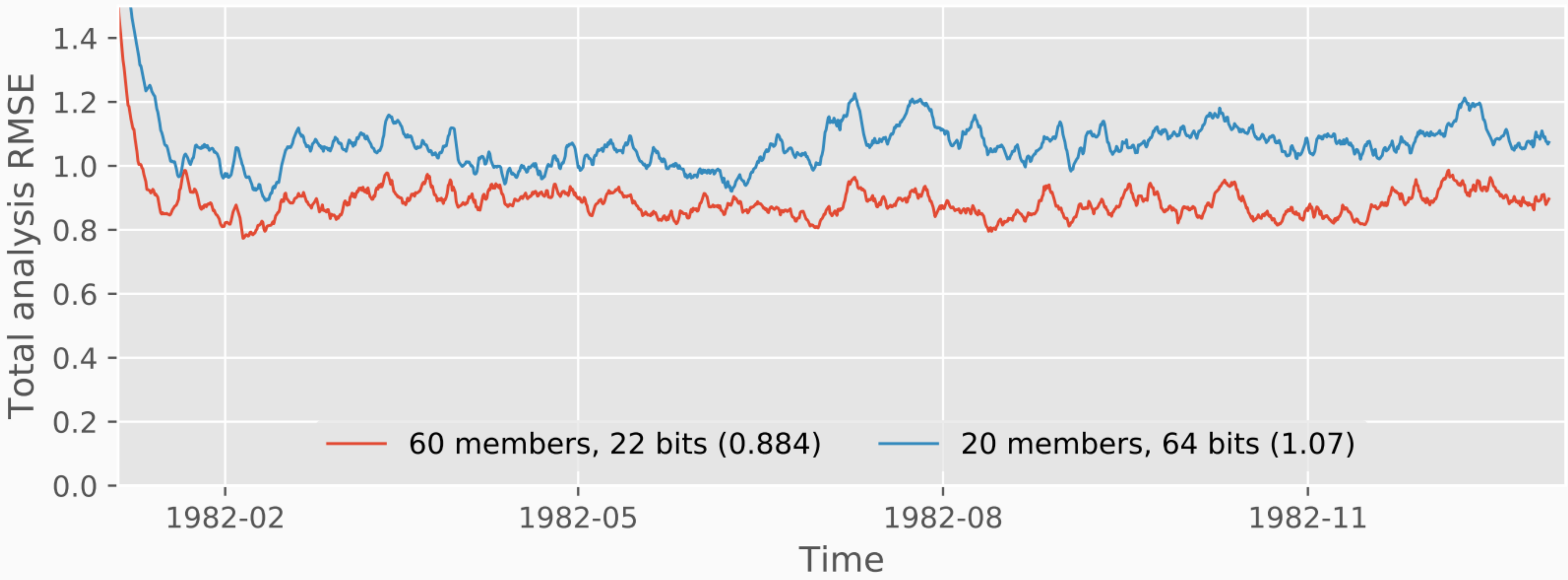
- Biggest difference in tropical convective regions

Adding model error



- After perturbing parameters, 22 bit SPEEDY is only about 5% worse than 64 bit SPEEDY
- **When there is model error, you can reduce precision further**

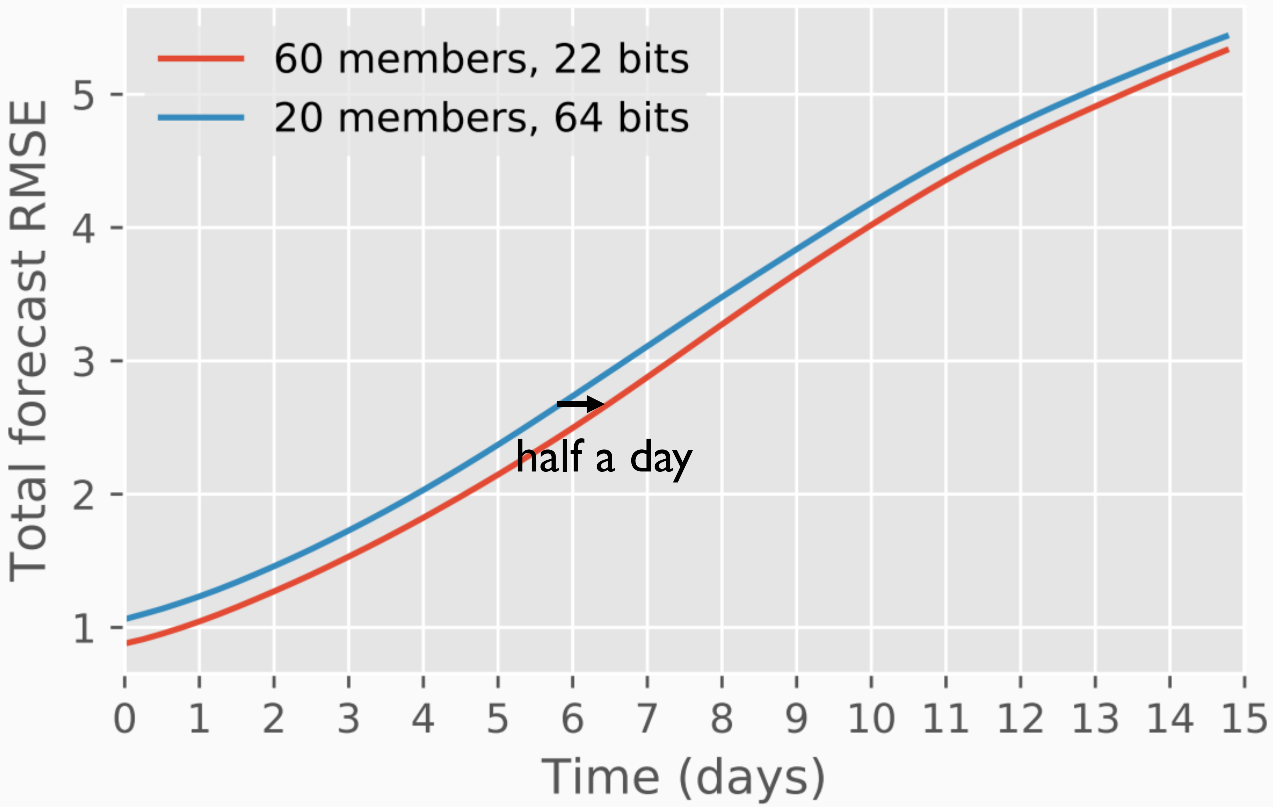
Trading precision for ensemble size



- Cost(22 bits, 60 members) ≈ cost(64 bits, 20 members)
- **Trade precision for ensemble size**
- This reduces error by 17% for (hypothetically) no extra cost

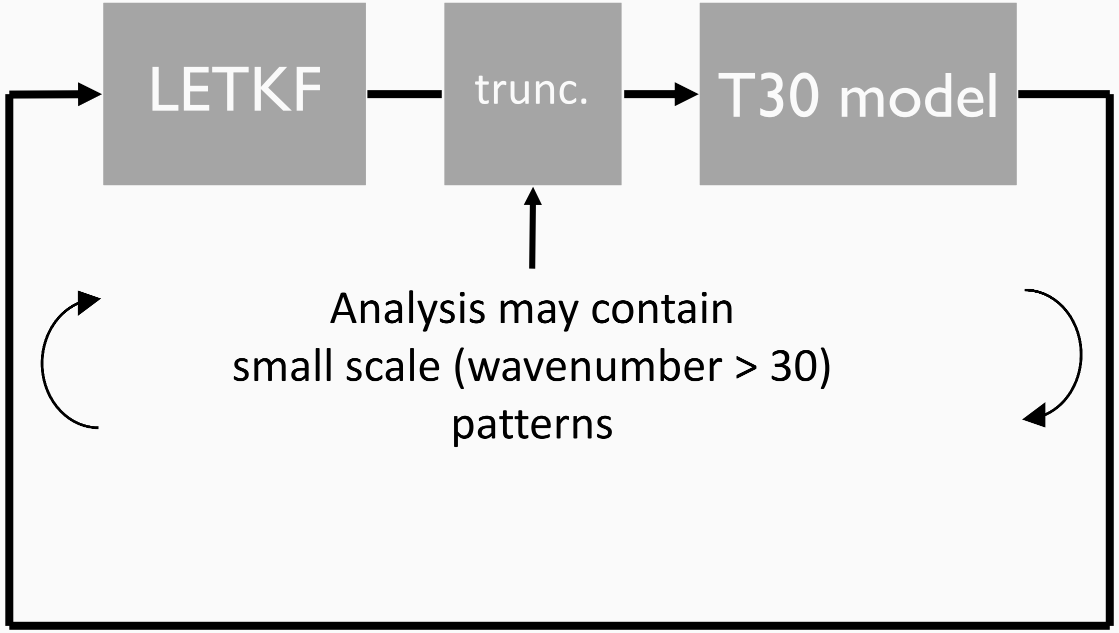
Improved forecasts

- This gives improved forecasts
- Forecast horizon is extended by **half a day**



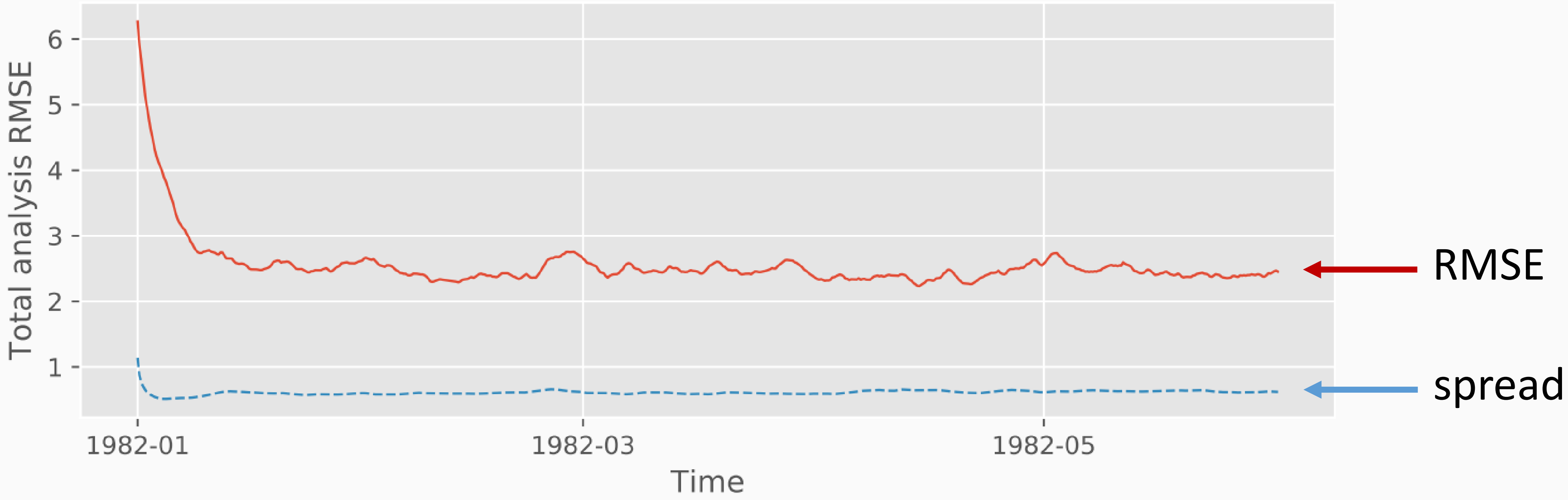
Adding model error (attempt 1 again)

- The strange pattern was caused by a bug
- The analysis fields were not truncated to T30 before running the 6 hour forecast
- Small scale waves amplified and crashed the model
- After fixing this, I can successfully assimilate obs. from the T39 nature run



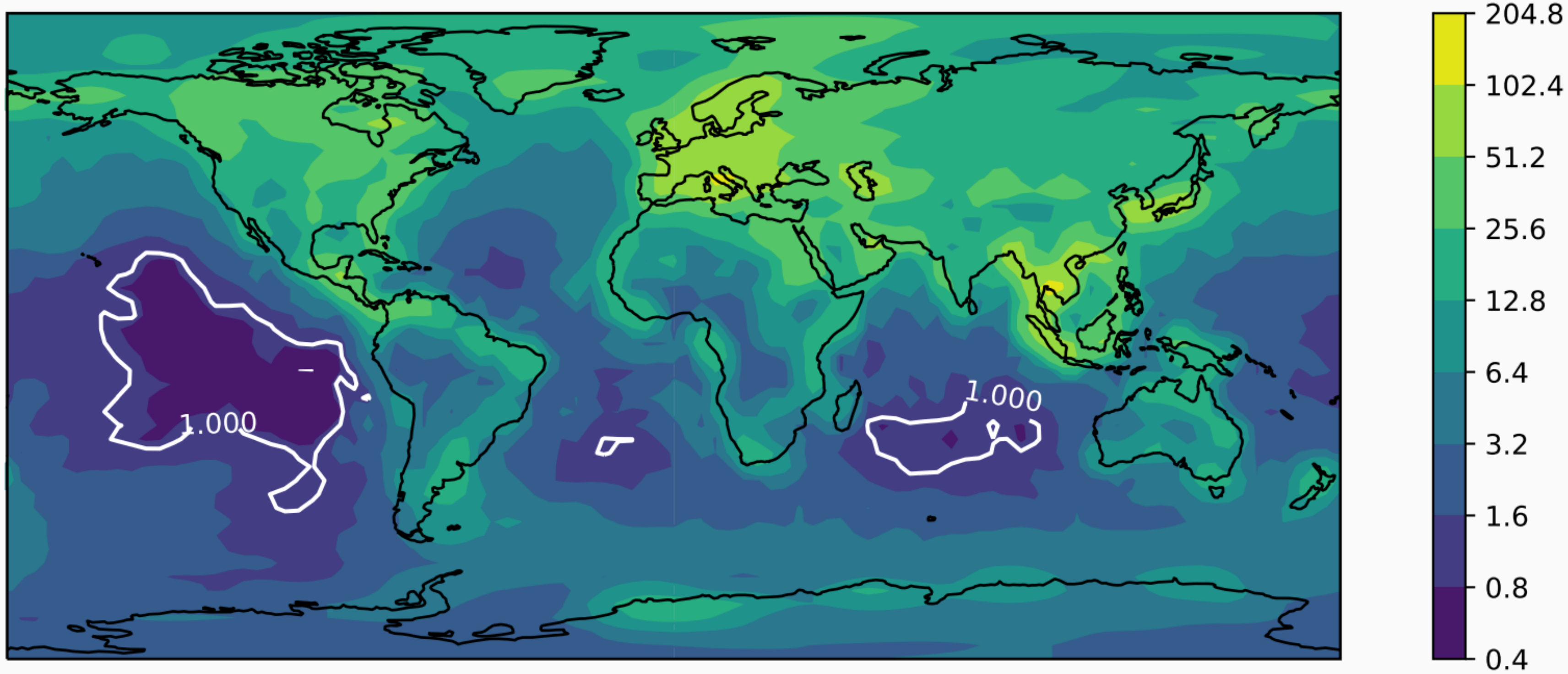
6 hour ensemble forecast

Adding model error (attempt 1 again)



- After truncating the fields, it works!
- But it's very underdispersive, especially over land/sea boundaries
- Work in progress… (RTPP, RTPS?)

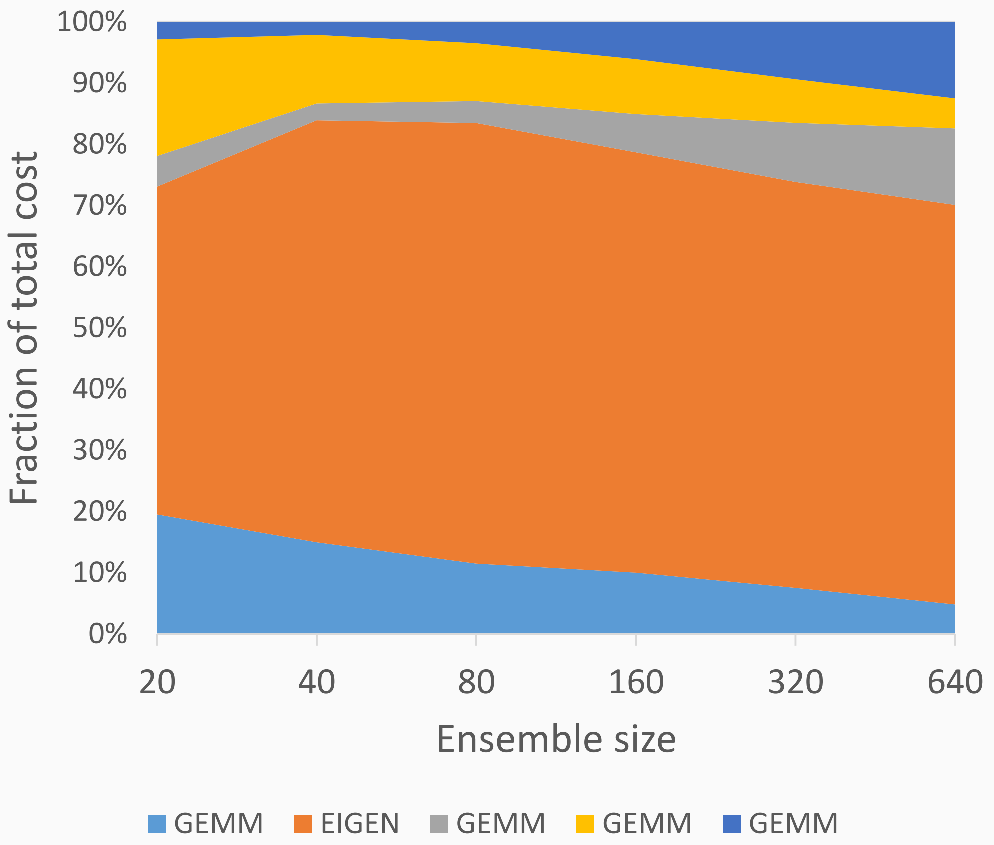
Underdispersiveness



- Time mean RMSE ÷ spread, specific humidity, bottom level
- The pattern doesn’t appear to be correlated with observation density

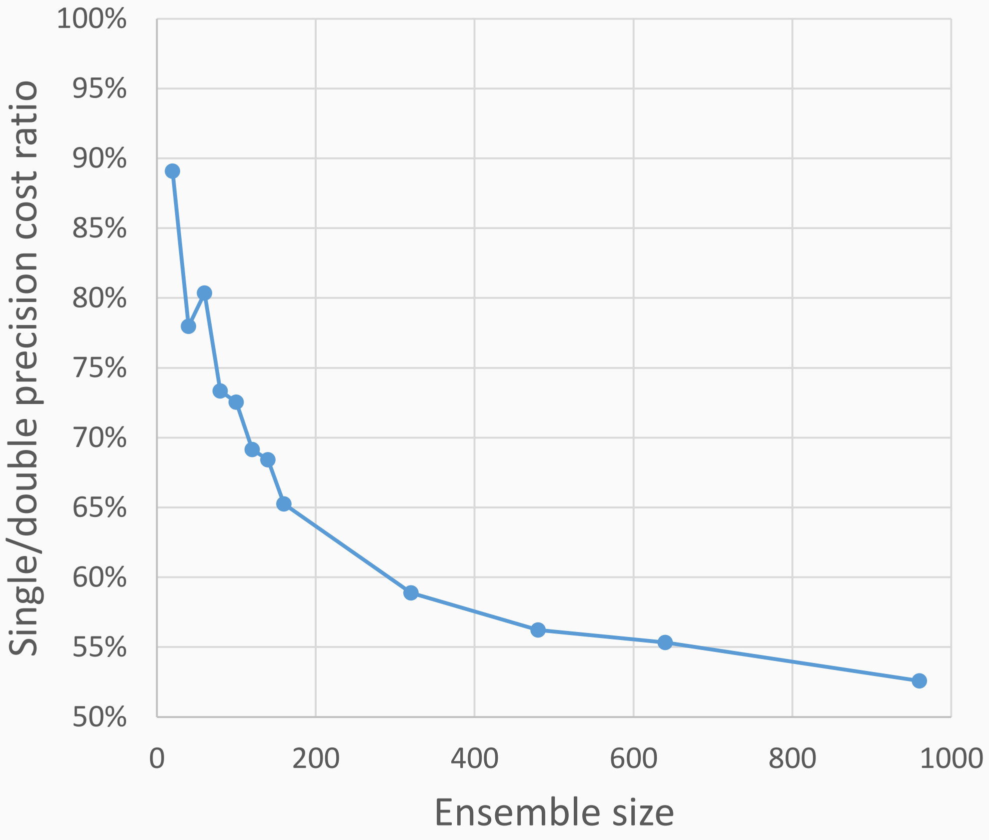
Reducing precision in LETKF

- The LETKF consists of five expensive operations
  - 4 general matrix multiplications (“GEMM”)
  - 1 eigenvalue/vector decomposition
- The cost ratio depends on ensemble size
- The eigendecomposition is ~60% of the total cost



Reducing precision in LETKF

- I measure the total time for all 5 operations at single and double precision (**per gridpoint**)
- Setup: Intel Fortran, MKL library (i.e. optimized BLAS/LAPACK), only 20 nodes
- As ensemble size increases, single/double precision cost ratio **approaches 50%**
- With 240 members, single is ~40% faster than double



Impact on error scores

- No measurable impact on RMSE when reducing precision of LETKF to single precision
- Table shows RMSE averaged over 4 months after 2 months assimilation spin-up
- But, for now, it's still safer to check single and double are the same → especially for larger ensembles

ensemble size	single	double
20	0.335	0.335
40	0.266	0.265
80	0.213	0.221

Conclusion

- If you have model error, you can lower precision further
- Low precision, large ensembles are better than high precision, small ensembles
- LETKF is feasible at single precision
- Up to 50% reduction in wall clock time for large ensembles
- **Future work:**
  - Make high-res nature run experiment work
  - Do assimilation with single precision SPEEDY and LETKF, measure speed up
  - Half precision LETKF?