Evaluation of ML emulators for covariance propagation in realistic DA workflows

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Research question and configuration

Emulators produce skillful forecasts, but can they also predict differences between forecasts and evolve ensemble perturbations[a,b,c]?

Forecast models

Physical model: MPAS[d]
- 120km quasi-uniform horizontal mesh
- 55 vertical levels, 30 km model top

Emulator: Graphcast[e]
- 1° horizontal resolution
- 13 pressure levels, 50 hPa (approx. 20 km) model top
- Interpolated to MPAS mesh, and extrapolated above 50 hPa, for DA step
- Missing soil state supplied by GFS

DA

1 month of cycling: 2018-04-15 – 2018-05-14

Leverages JEDI framework[f]

GETKF:
- Follows clear-sky configuration of Sun et al.[g]
- 20 member ensemble

3d EnVar:
- Similar to clear-sky configuration of Liu et al.[h]
- Includes variational bias correction

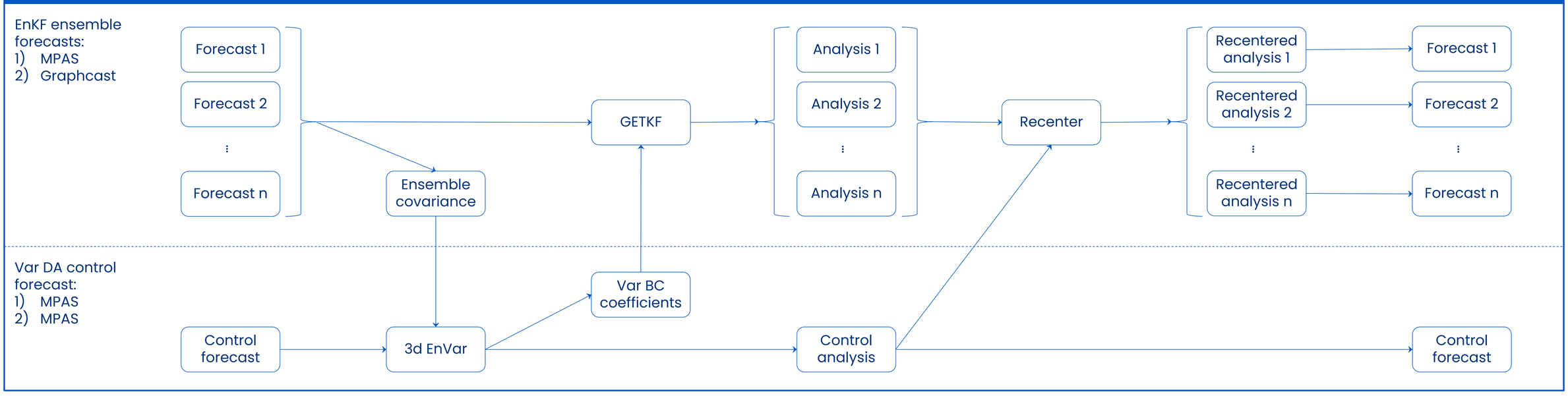
Assimilated observations

Conventional observations:
- Aircraft
- Radiosondes
- Atmospheric motion vectors
- Surface pressure
- GNSS radio occultation

Clear-sky radiances:
- AMSU-A
- MHS

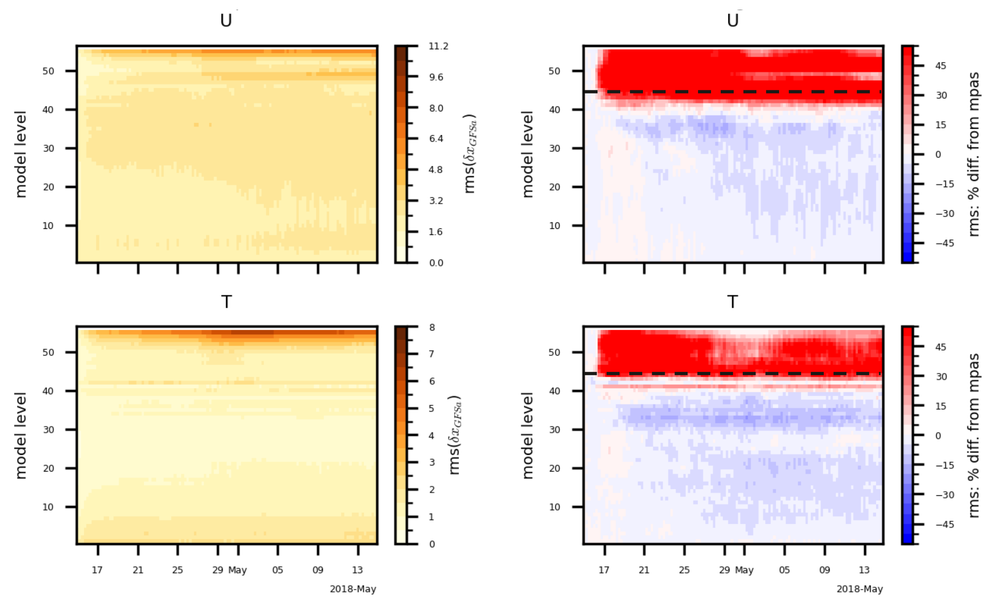
[a] Penny et al. (2022), JAMES, DOI: 10.1029/2021MS002843
[b] Tian et al. (2024), arXiv:2411.14677
[c] Slivinski et al. (2025), Geophys. Res. Lett., DOI: 10.1029/2024GL114396
[d] Skamarock et al. (2012), Mon. Weather Rev., DOI: 10.1175/MWR-D-11-00215.1
[e] Lam et al. (2023), Science, DOI: 10.1126/science.adi2336
[f] Trémolet & Auligné (2020), JCSDA Q. Newsletter, DOI: 10.25923/RB19-0Q26
[g] Sun et al. (2025), Geosci. Model Dev., DOI: 10.5194/gmd-18-8569-2025
[h] Liu et al. (2022), Geosci. Model Dev., DOI: 10.5194/gmd-15-7859-2022

DA workflow



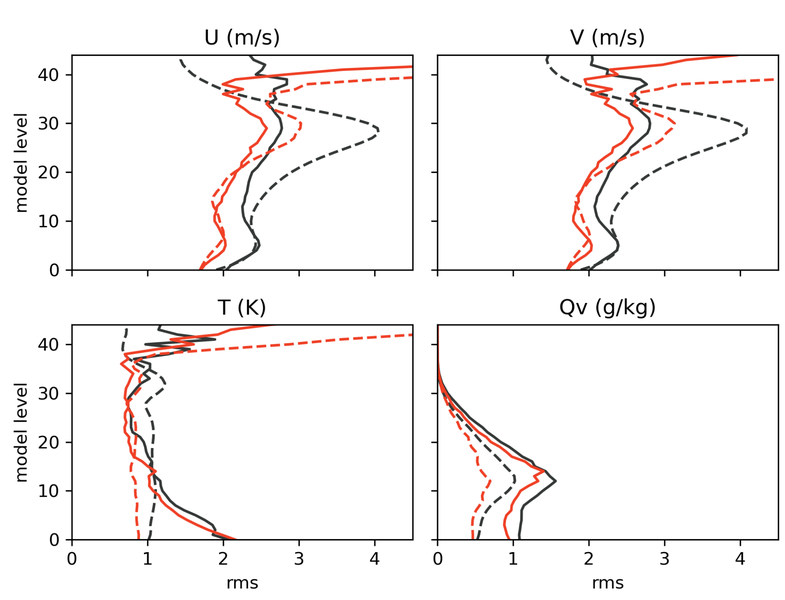
Results

Despite limitations as full forecast replacement in DA workflows[c], Graphcast can accurately evolve ensemble perturbations in DA cycling experiments



Verification of the 6-hourly control background vs. GFS. Left: rms difference (GFS vs. config 1: MPAS ensemble). Right: relative rms change (config 1 vs config 2: Graphcast ensemble).

The Graphcast ensemble is stable and improves relative to MPAS over time. The degradation in the stratosphere is likely due to the lower Graphcast model top (dashed line)



6-hourly background ensemble spread (final week average, levels below the Graphcast model top). Dashed lines: ensemble spread; solid: RMS vs. GFS analysis (optimal spread). Black: MPAS ensemble, orange: Graphcast ensemble.

The Graphcast ensemble maintains a realistic spread over time.

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