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Benefits of initializing equatorial waves on accuracy of extratropical forecasts

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◆Summary

Large initial uncertainties in the tropics are believed to compromise medium- and extended-range extratropical forecasts. A more reliable analysis of tropical wave circulation requires more tropical observations and improved data assimilation schemes. We aim to elucidate the mechanism by which assimilating tropical observations improves extratropical forecasts. Our main findings are:

- The impact of improved tropical analyses on the extratropics is scale-dependent; more accurate planetary, synoptic, and subsynoptic scales in the tropical analyses have different effects on extratropical forecasts. Improvements at small scales cannot propagate beyond the scale-related turning latitudes. The largest forecast-error reductions occur in synoptic scales, with the affected scales lengths increasing with latitude. Foreacst improvements at extratropical planetary scales requires more accurate planetary scales in tropical analysis.
- Within the tropics, observation memory in forecasts depend on variable; analysis improvements in the wind field produce longer-lasting impact in forecasts compared to the geopotential height in Rossby modes.

◆Tropical Observing System Simulation Experiments

3DVar data assimilation (DA) was developed with the barotropic Transient Inertia-Gravity And Rossby wave dynamics (TIGAR) model [1]. Its advantage lies in using Hough harmonics as basis functions, which have physical meanings; specifically, the Rossby, inertia-gravity (IG), Kelvin, and mixed Rossby-Gravity (MRG) waves are prognostic variables and components of the assimilation control vectors [2].

The poleward propagation of tropical analysis MSE reduction is studied with experiments that assimilated both wind-field and mass-field observations.

• Nature run

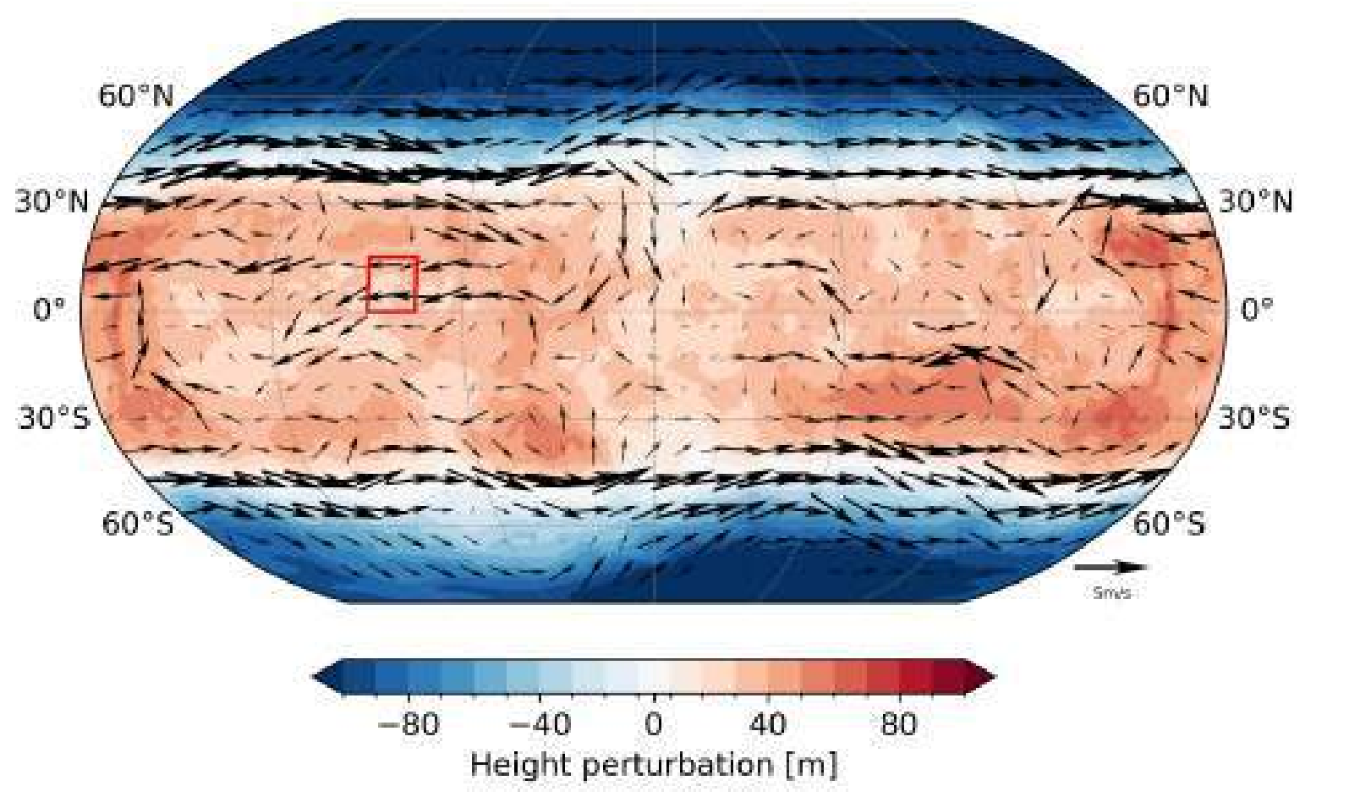


Fig 1. A snapshot of the wind and geopotential height fields in the nature run.

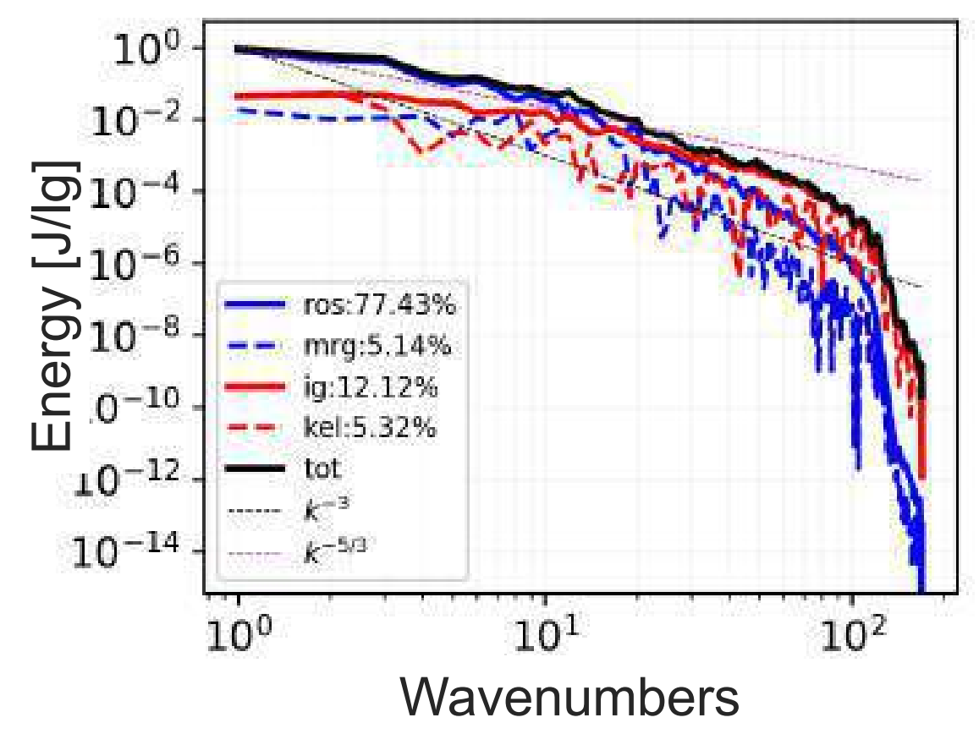
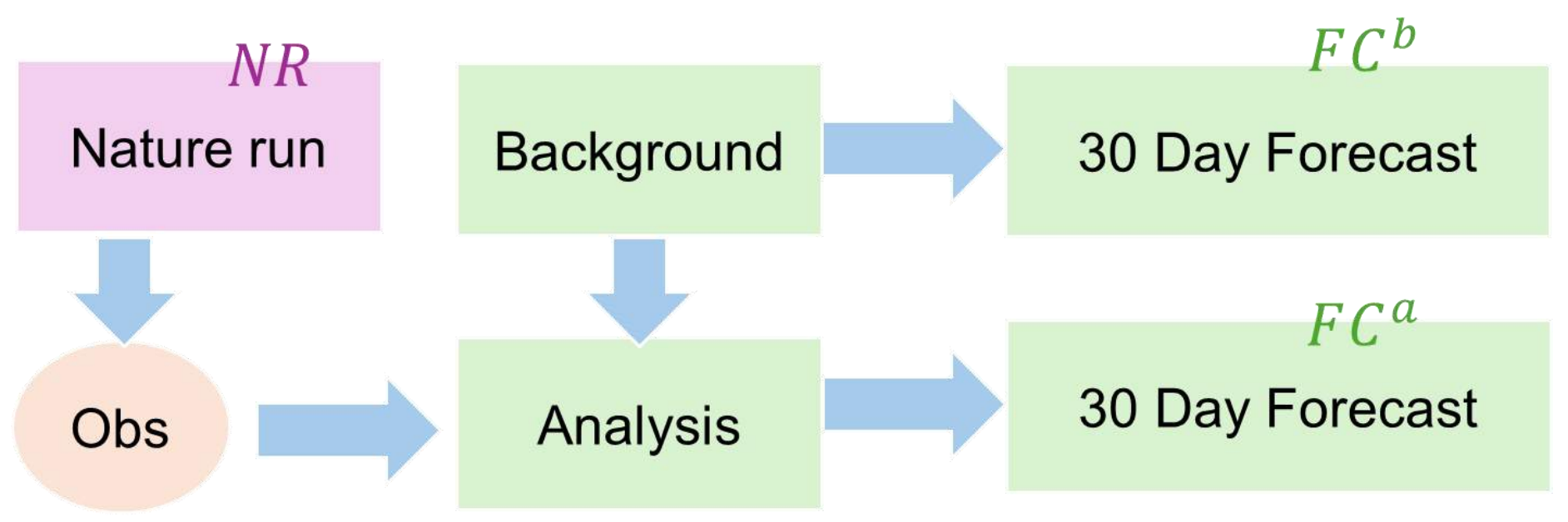


Fig 2. Time averaged energy spectra of the nature run.

The nature run (NR) reproduces basic features of the real atmosphere including westerly jets in midlatitudes and waves in the tropics. The global energy spectra are red and have energy distribution among wave modes mimicking real atmosphere.

• Evaluation of Forecast Errors



Nature run, Background, 30 Day Forecast, Obs, Analysis, 30 Day Forecast

$$MSE^b = \sum (FC^b - NR)^2$$

$$MSE^a = \sum (FC^a - NR)^2$$

Mean Square Error (MSE) Difference = $MSE^b - MSE^a$

Normalized MSE Difference = $(MSE^b - MSE^a)/MSE^b$

To show the forecast error reduction at different scales, the scale-dependent MSE reduction is computed for various latitudinal bands and forecast lengths.

◆Rossby wave dynamics in barotropic model

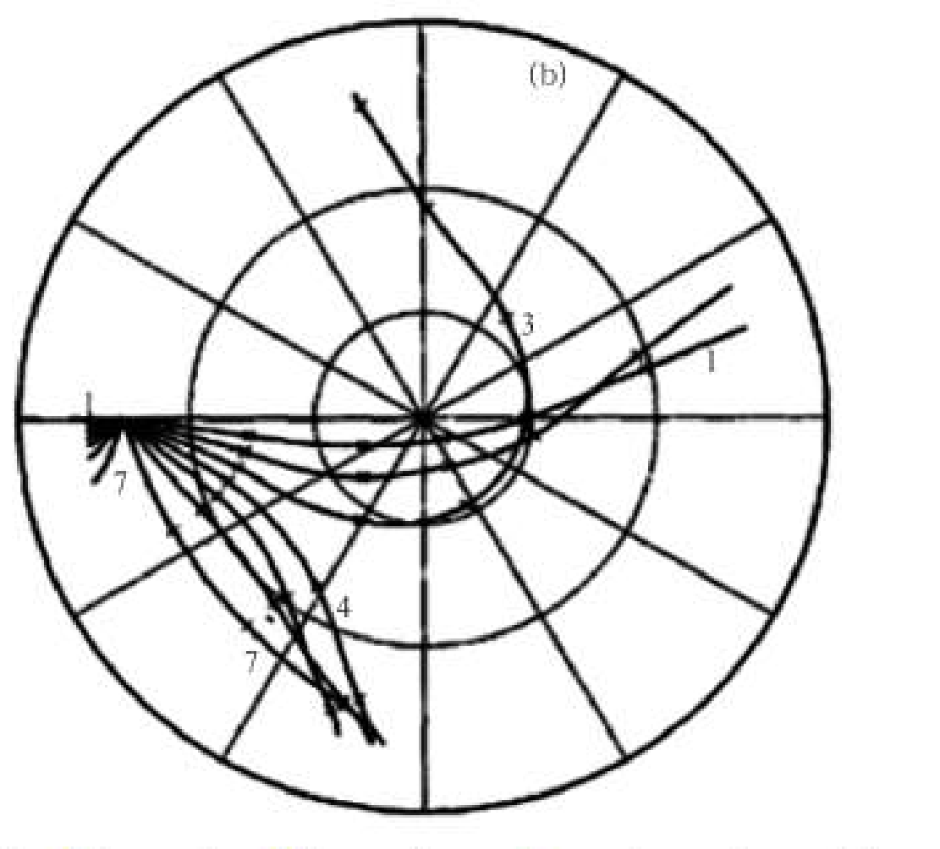


Fig 3. Rays and phases marked by a cross every 180◦ for a source at 15◦ in Northern Hemisphere 300-hPa zonal flow. [Source: [3]]

Large-scale Rossby waves propagate poleward and follow a wavetrain path similar to the great circle, while smaller waves become trapped by the jet.

The turning wavenumber at each latitude given the NR background zonal meanflow can be computed by

$$aK_s = [a^2\beta_M/\overline{u}_M - (a^2\Omega^2/gh)\sin^2 2\phi\,]^{1/2}$$

where β_M is the meridional gradient of the absolute vorticity on the sphere. [3]

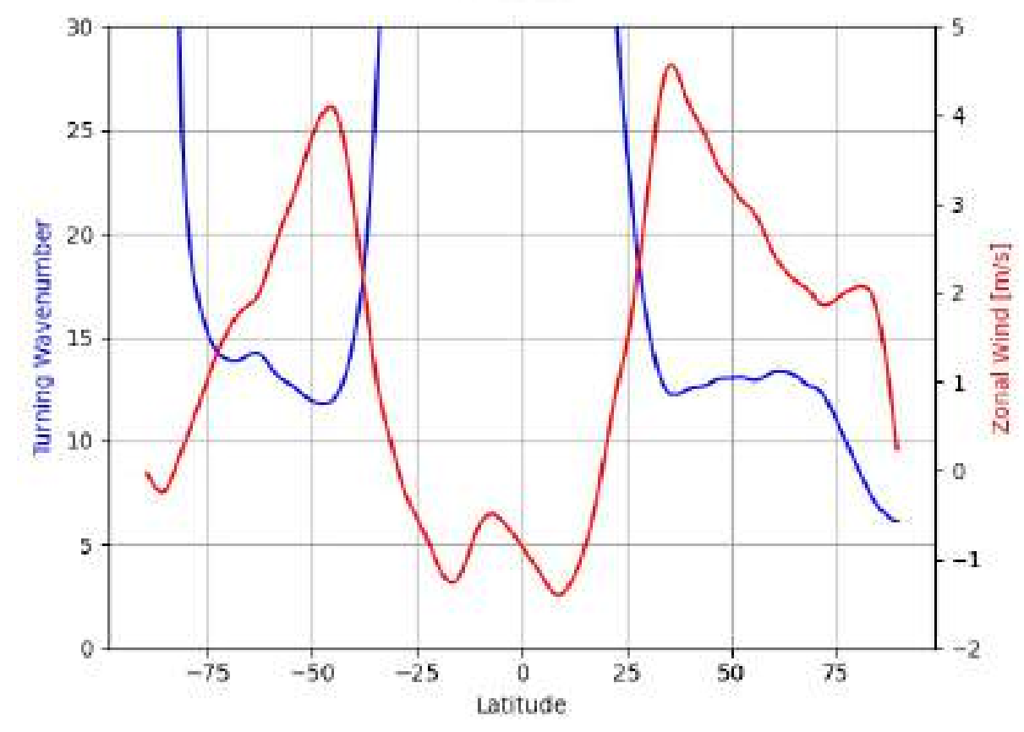


Fig 4. The turing wavenumber and mean zonal wind at different latitudes

The stationary wavenumber K_s is smallest at the jet axes in both hemispheres, approximately wavenumber 13.5. This suggests that with our NR zonal mean flow, planetary and synoptic scale Rossby waves can penetrate the jet while subsynoptic scales are trapped and cannot propagate poleward beyond the jet axes.

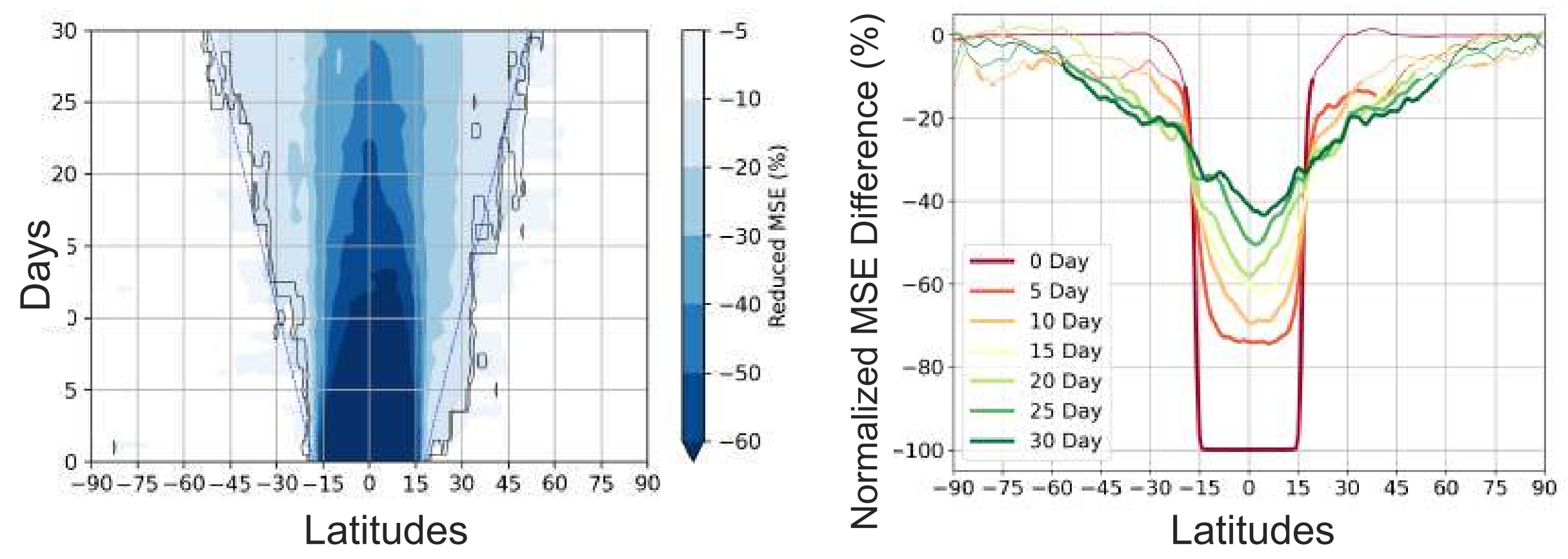
◆Acknowledgement and references

We thank Andreas Rhodin for his work on the development of 3D-Var data assimilation with TIGAR .

[1] Vasylkevych, S et al (2021). Q. J. R. Meteorol. Soc., 147(736).
[2] Žagar, N. et al (2004). Q. J. R. Meteorol. Soc., 130(596).
[3] Hoskins, B J., and D J. Karoly (1981). J. A. S. 38.6

◆Propagation of the effect of improved tropical analyses to extratropical regions

Propagation speed is about 1.1^o per day



Initial 95% analysis MSE reduction in the tropics becomes about 20% forecast MSE reduction in the midlatitudes after 30 days.

Fig 5. Evolution of zonally-averaged normalized MSE differences as a function of forecast length.

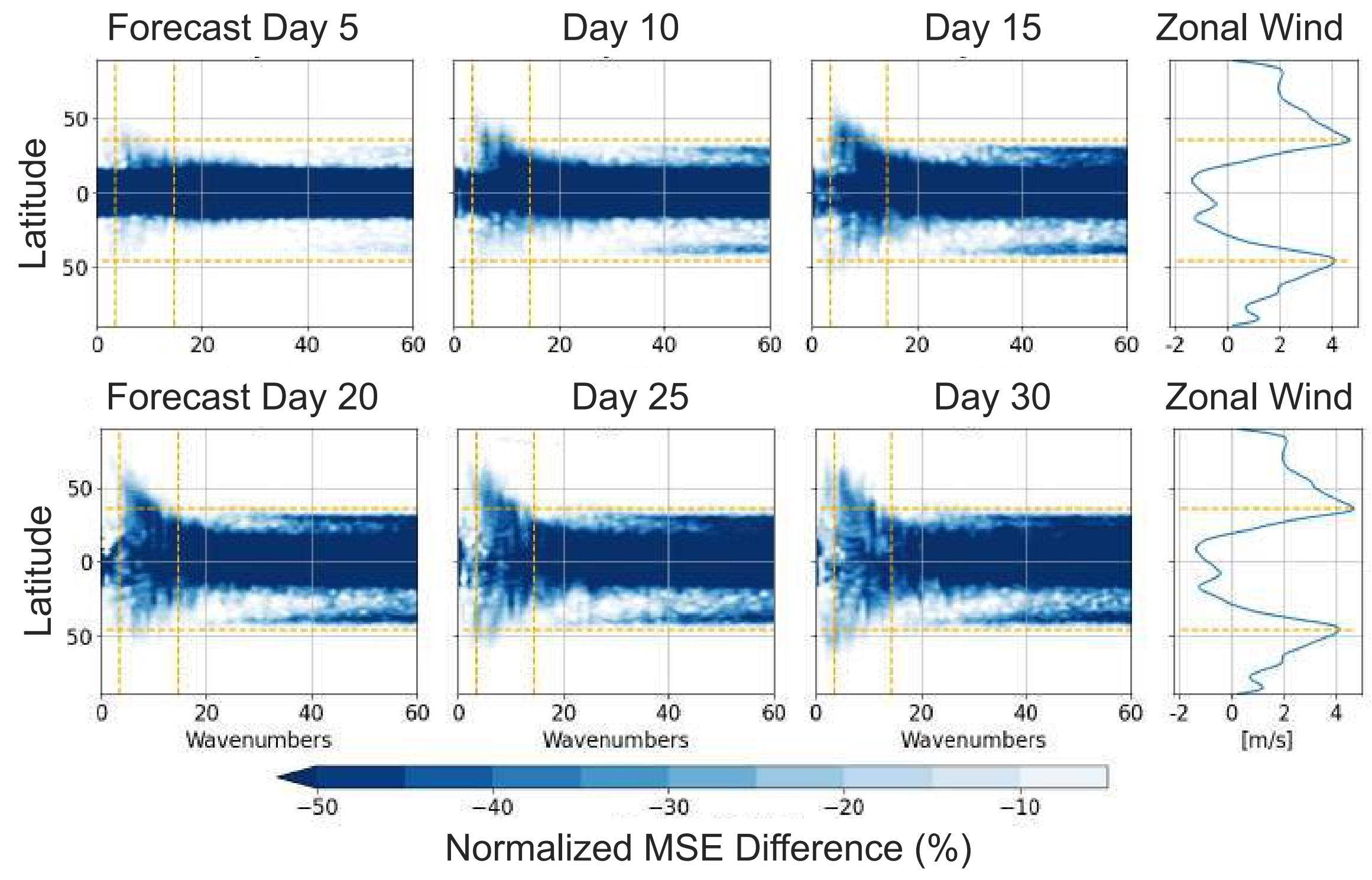


Fig 6. Normalized MSE reduction as a function of the zonal wavenumber and latitude for different forecast lengths

Subsynotipc scale (k>14) MSE reductions propagate to the jet region but not beyond.

Synotic scale (3<k<14) effects on MSE reduction propagate beyond the jet, and the scales with largest effects get larger in higher latitudes.

At subsynoptic scales (k>13), reducing tropical analysis errors cannot affect forecasts in high latitude regions, as these regions lie beyond the turning latitudes.

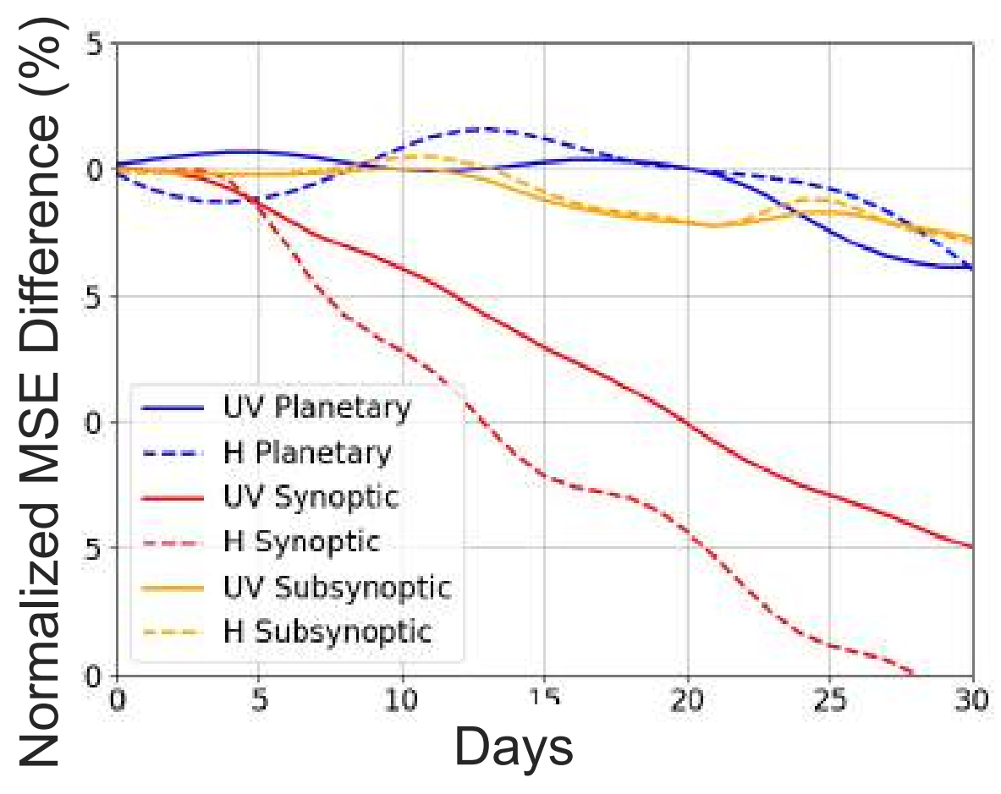
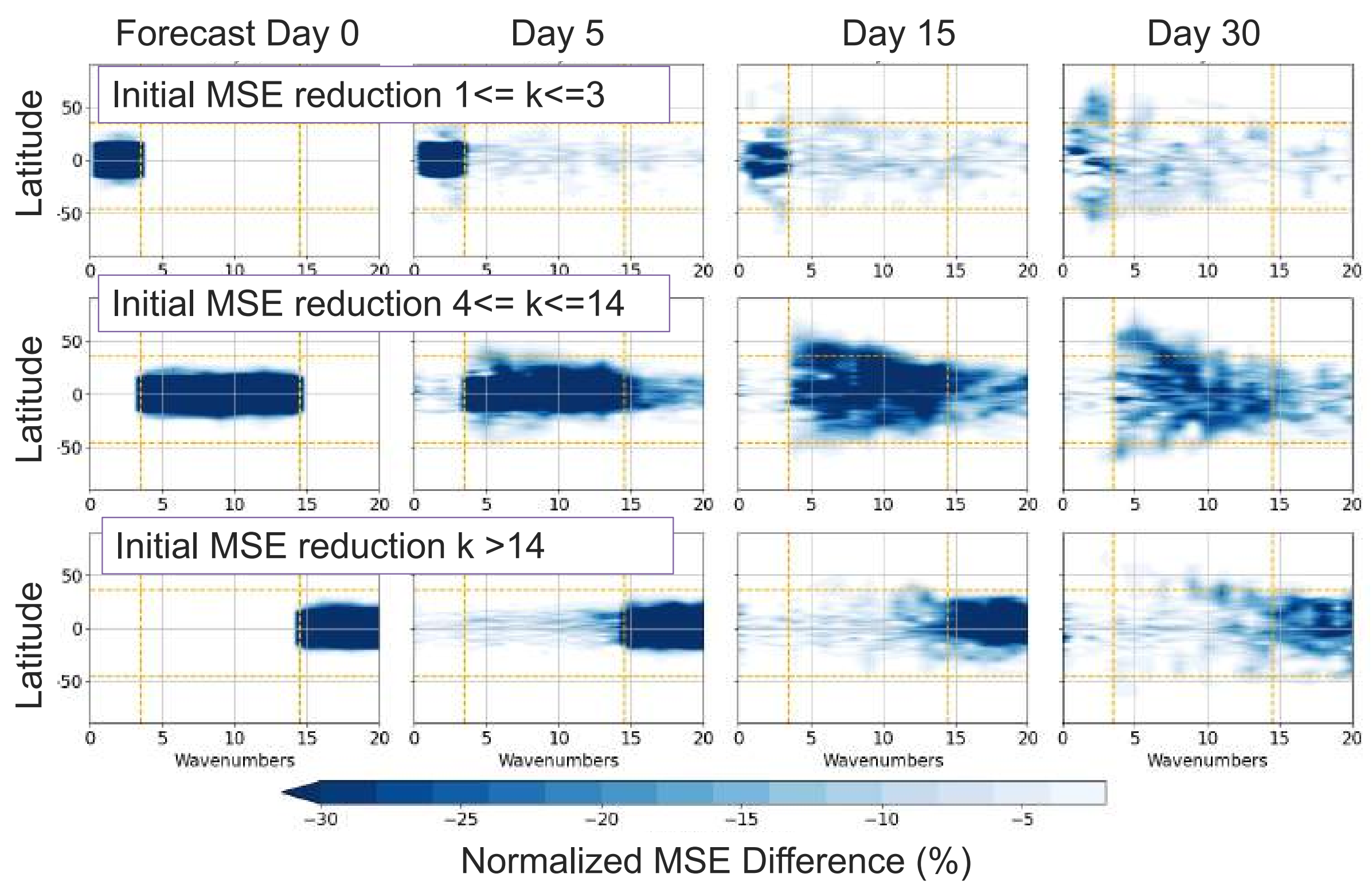


Fig 7. Normalized MSE reduction at planetary, synotipc, and subsynoptic scales, computed for wind and geopotential height fields

Largest forecast MSE reductions in the midlatitudes are in *synoptic scales*. The geopotential height field has larger MSE reduction than wind fields.

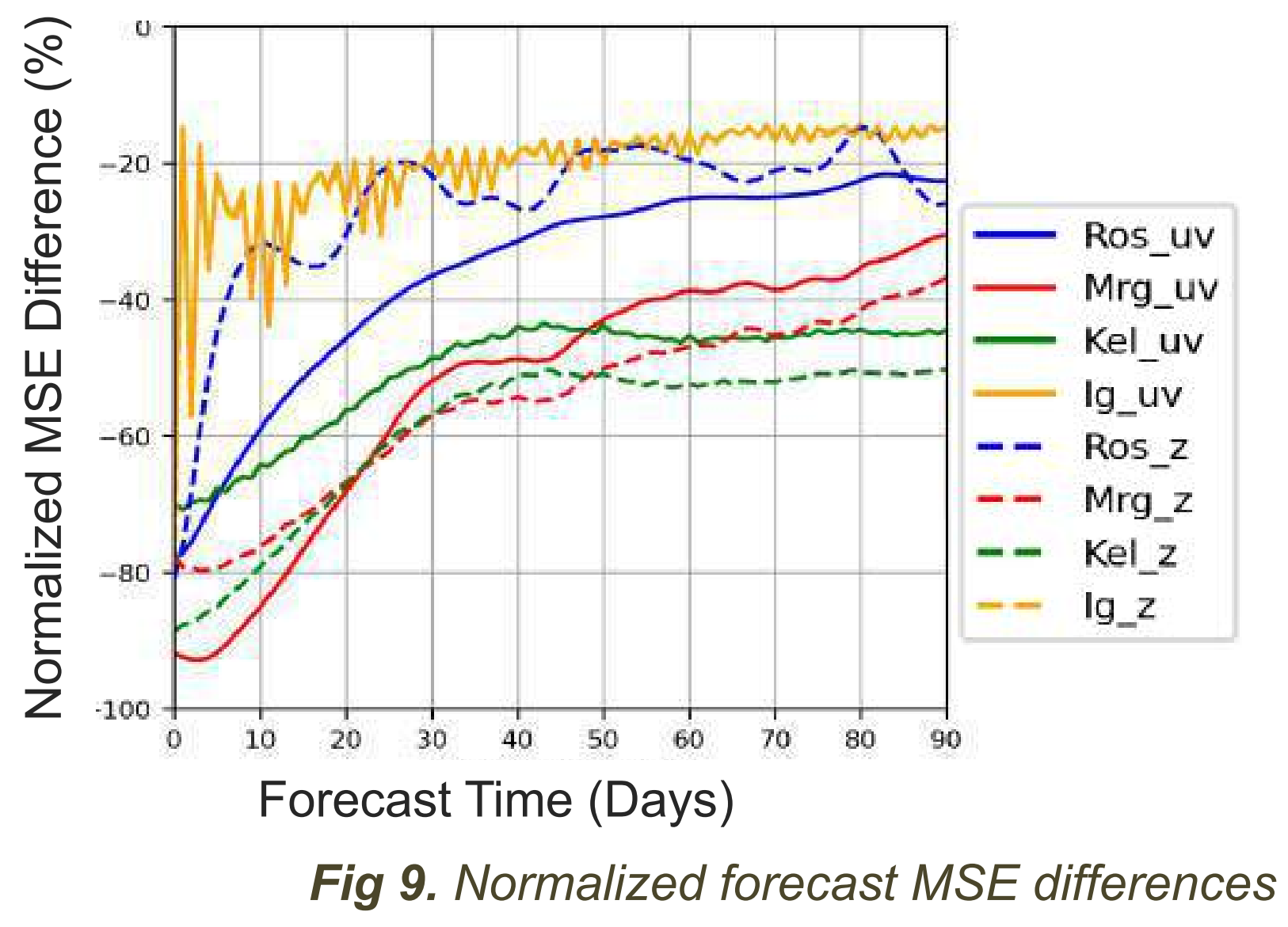


Planetary scale forecast MSE reduction in the midlatitudes can only occur by improving the planetary scales in tropical analyses.

The synoptic scales in the model in mid-latitudes can benefit from interactions with various scales in the tropics.

Fig 8. As in Fig. 4, but with initial tropical error reduction at plantery, synoptic, and subsynoptic scales.

◆Effect of improved tropical analyses on tropical forecasts



In Rossby modes, the memory of initial state (and its improvements) is longer compared to the geopotential height.

Assimilation benefits in MRG, Kelvin, and Rossby waves have effects of different lengths in forecasts and effects are scale dependent.

Fig 9. Normalized forecast MSE differences in wind and geopotential height of tropical waves

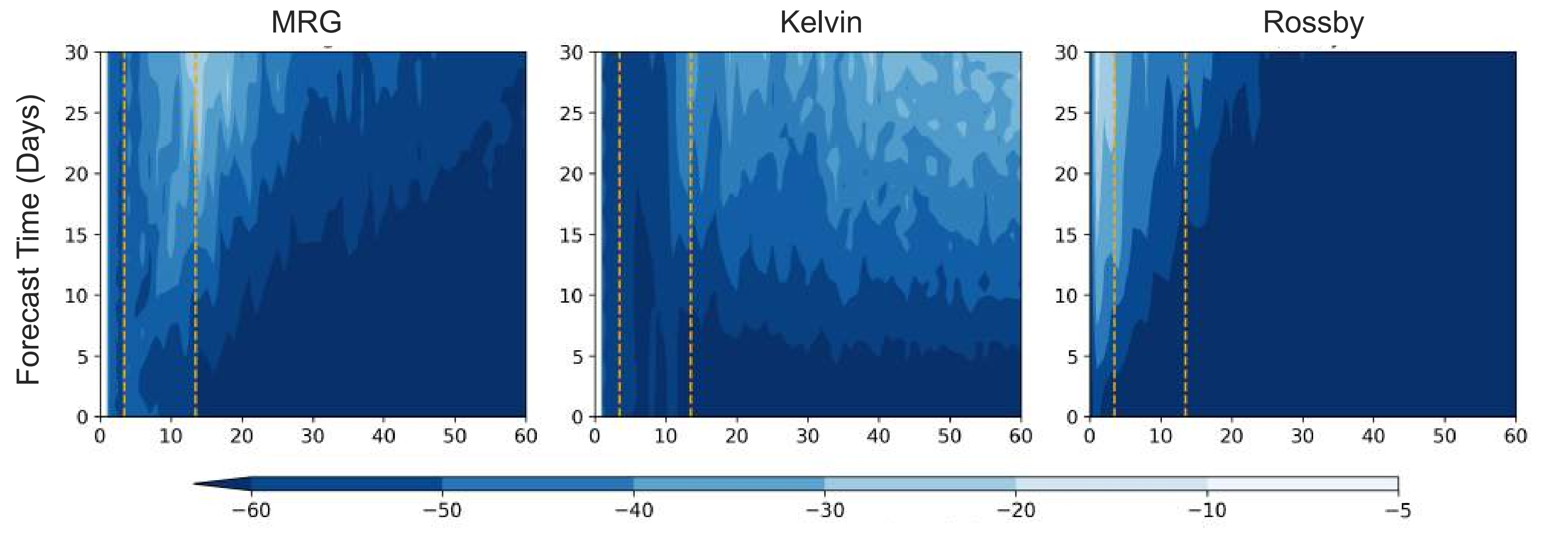


Fig 10. Normalized forecast MSE differences in the MRG, Kelvin, and Roosby waves at as a function of the zonal wavenumber.