The impact of vertical resolution on gravity wave drag in sub-seasonal hindcasts during sudden stratospheric warmings

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Motivation S2S Models underestimate stratospheric SSW signal

- Aggravated cold bias during weak vortex conditions means underestimated SSW amplitude in the stratosphere (Lawrence et al., 2022).

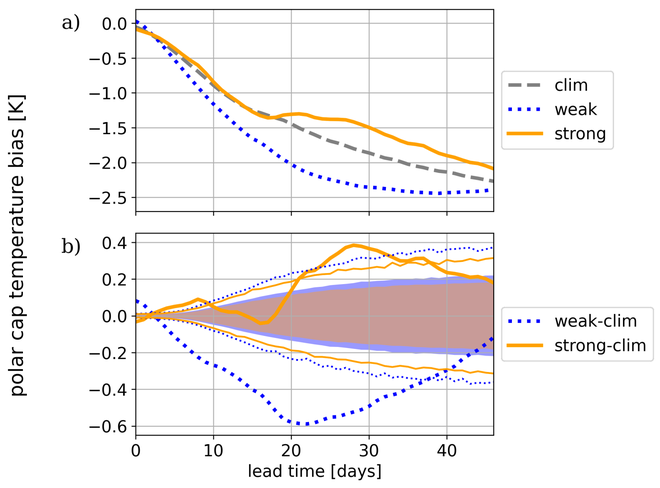

Fig. 1: *Composite mean temperature bias (50hPa, 60°N-90°N) for climatology and weak and strong vortex conditions in IFS hindcasts from S2S database (Vitart et al., 2017); composites are selected based on the state of the vortex during initialization (Tripathi et al., 2015); lower panel contains Monte Carlo distribution for randomly selected composite means.*

1. Experiments with two different IFS model configurations

Sub-seasonal hindcast experiments

- ECMWF Integrated Forecasting System (IFS CY47R3)
- Horizontal resolution TCo639 equivalent to 18km grid spacing
- Vertical resolution either L91 or L198
- 51 ensemble members initialized on 08 Feb 2018, run for 46 days.

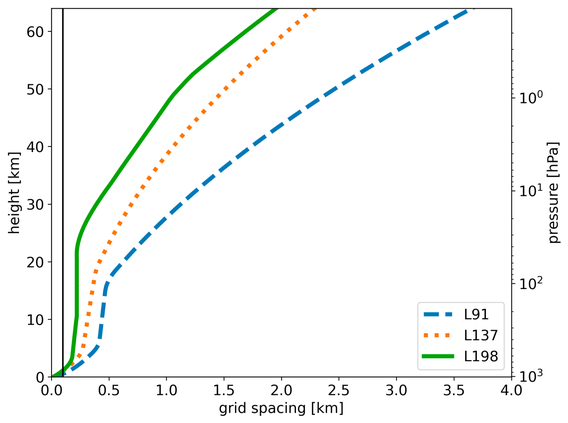

Fig. 2: *Approximate vertical grid spacing for three IFS grid configurations.*

2. Reduced forecast error with increased vertical resolution

Reversal of westerlies at 10hPa on 12 Feb 2018

- High amplitude warming (~20K) in the first two weeks ↔ positive anomalies ~5K sustained for 6 weeks.
- With low resolution, sustained anomalies are underestimated by 2-4K even though all ensemble members predict a major SSW.
- Increased vertical resolution reduces cold bias and prolongs the warming.

Limited predictability of planetary wave flux on sub-seasonal time scales. Hence, no significant sensitivity to vertical resolution.

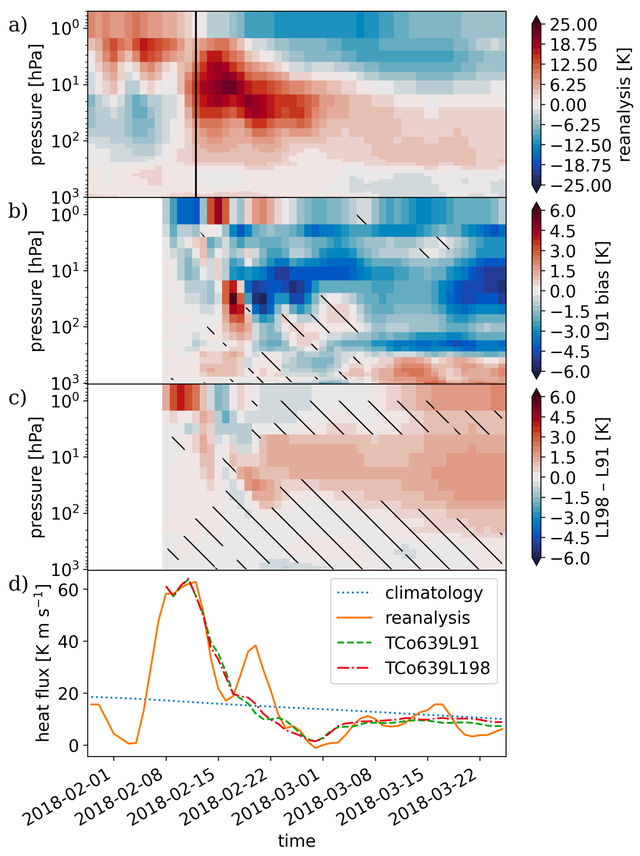

Fig. 3: *Polar cap temperature anomalies in ERA5 (Hersbach et al., 2020), the L91 ensemble-mean bias, and the ensemble mean difference with 95% significance hatching; the lowest panel shows meridional eddy-heat flux by zonal wavenumber 1-3 at 100hPa.*

3. Critical layer during weak vortex conditions

Positive feedback between stratospheric gravity wave drag and zonal-mean zonal wind

- Usually, gravity waves have their biggest impacts in the mesosphere.
- During weak vortex conditions, gravity wave vertical wavelength shrinks to zero.
- Beneficial for predictability on long time scales.

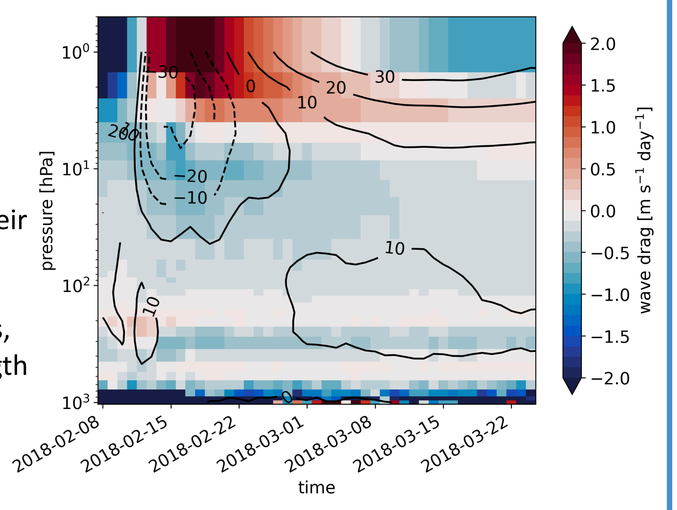

Fig. 4: *L198 ensemble-mean gravity drag (45°N-70°N) and contours of zonal-mean zonal wind (60°N).*

4. Gravity wave drag sensitivity

Ability to make use of the positive feedback for sub-seasonal prediction depends on vertical model resolution.

- Resolved gravity waves need high vertical resolution to reach upper stratosphere.
- Both resolved and non-orographic parameterized wave drag contribute to enhanced deceleration of the mean flow.

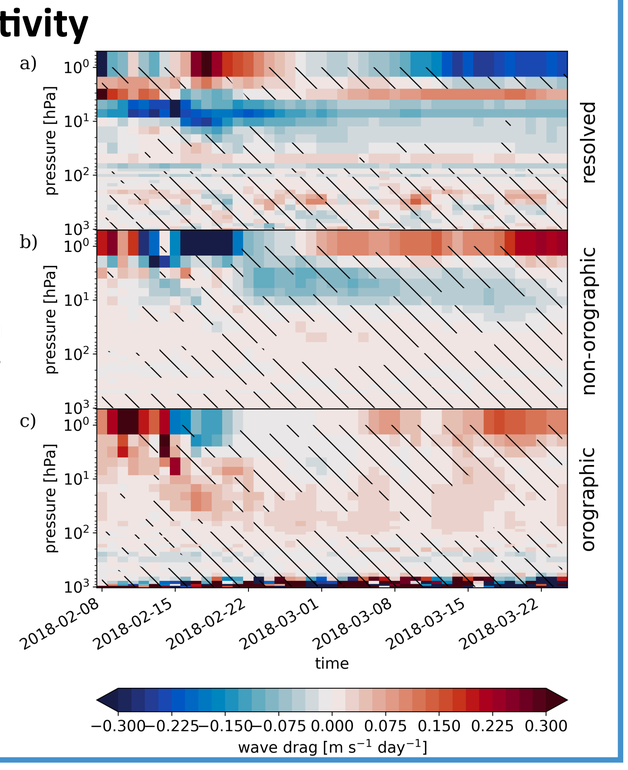

Fig. 5: *Ensemble mean wave drag difference (L198-L91) for resolved and parameterized gravity waves.*

5. Small vertical scale waves

Wavelet analysis of normalized potential temperature

- Spectral power is proportional to gravity wave potential energy per unit volume, which is proportional to gravity wave momentum flux.
- Enhanced gravity wave momentum flux is associated with small vertical scales (wavelength ~2-6km).

Conclusion: L137 largely sufficient for TCo319 (not shown), with TCo639 at least L198 are needed.

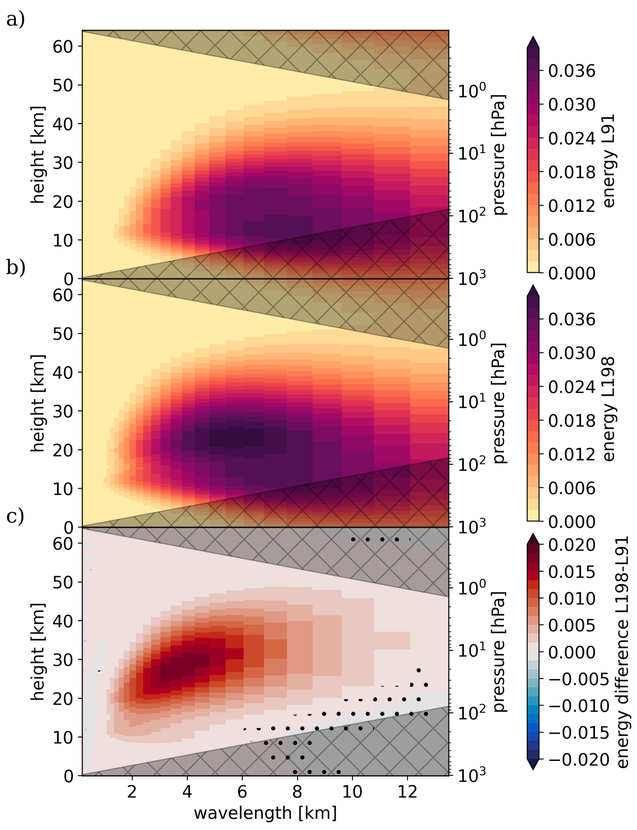

Fig. 6: *Ensemble-mean non-dimensional potential energy wavelet spectrum for the period 2018-02-22 to 2018-03-22; stippling the the lowest panel indicate whare ensemble-mean energies are not significantly different estimated by a parametric bootstrap.*

Wicker, W., Polichtchouk, I., and Domeisen, D. I. V.: Increased vertical resolution in the stratosphere reveals role of gravity waves after sudden stratospheric warmings, Weather Clim. Dynam. Discuss. [preprint], https://doi.org/10.5194/wcd-2022-41, in review, 2022.

References

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Any questions? Please ask! (wolfgang.wicker@unil.ch)