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OpenIFS simulations for Sudden Stratospheric Warming 2018: Effect of gravity waves parameterizations

1. Background

Sudden Stratospheric Warming (SSW) - an event in which the zonal mean zonal winds at 10 hPa and 60°N reverse to easterly (i.e. negative) from Nov to Mar; the stratospheric temperature rises by several tens of Kelvins over the course of a few days. SSW is driven by enhancements of planetary and gravity wave activity. Such anomalous events are one of the key sources of predictability in wintertime (Karpechko et al., 2018). Here we consider forecasts of an SSW that occurred in February 2018.

SSW 2018

- Central date: Feb 12
- Planetary wave 1 (PW1) and enhancement of gravity waves (GW) is seen on Feb 1 (Fig. 1a)
- On Feb 8 (Fig. 1b) PW2 starts to develop, two localized GW enhancements appear (20°–80°W and 50°–90°E)
- On Feb 12 (Fig. 1c) polar vortex is broken down, GW activity weakens and is extinguished by Feb 25 (Fig. 1d)

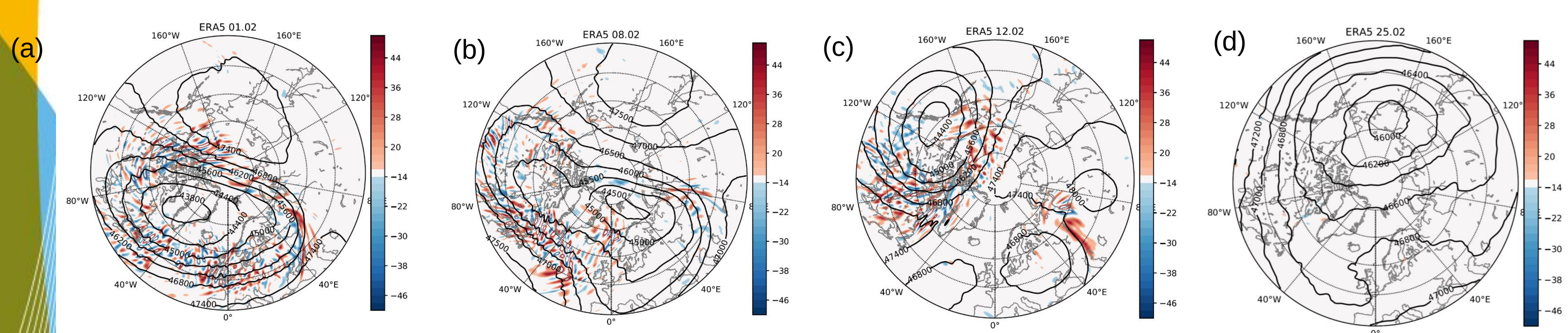


Figure 1. Vertical winds (cm/s, filled contours) and geopotential height (m, line contours) at 1 hPa on (a) Feb 1, (b) Feb 8, (c) Feb 12, (d) Feb 25. ERA-5 re-analysis, only vertical winds larger than ±14 cm/s plotted

Two control OpenIFS simulations chosen for analysis:

1. forecast initialised on **Feb 1** did not capture the reversal of the 10 hPa wind and, therefore, did not simulate the SSW well
2. forecast initialised on **Feb 7** is good at capturing the onset and gets the switch back to westerlies reasonably well too

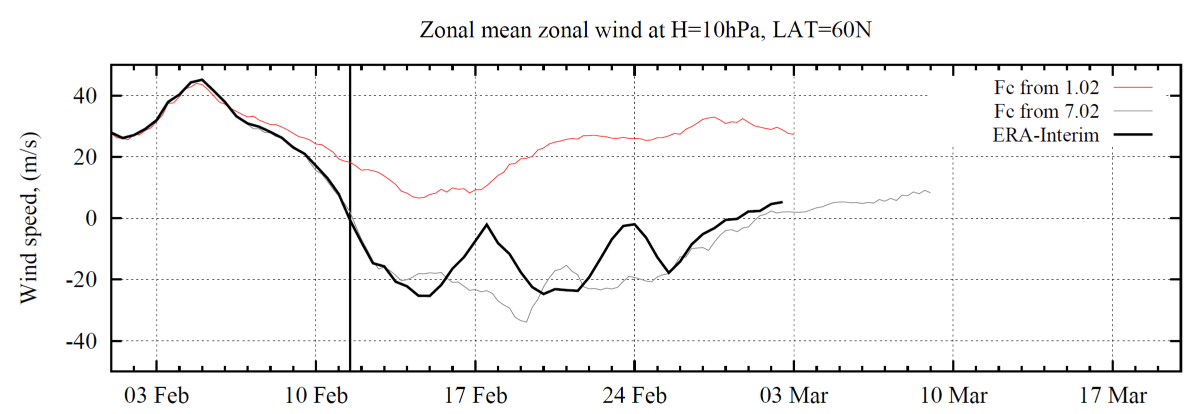


Figure 2. Zonal mean zonal wind at 10 hPa 60°N. Forecasts initialized on Feb 1 and Feb 7 and ERA-Interim re-analysis. Vertical line denotes SSW2018 central date

2. Forecasts vs ERA-Interim

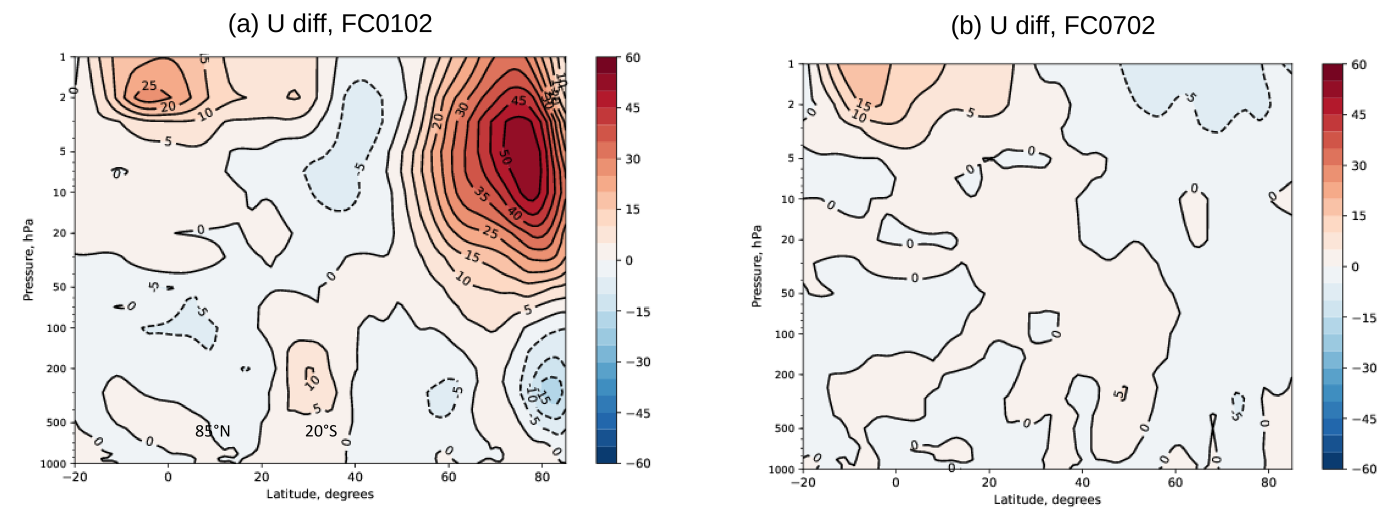


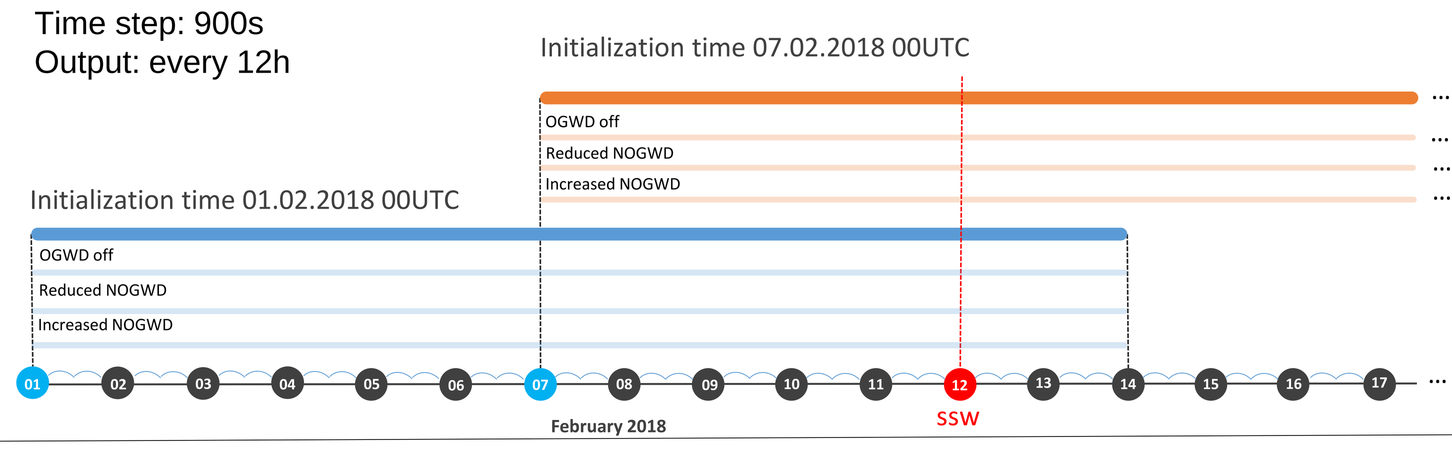
Figure 3. Latitude-pressure cross section of zonal wind for (a) forecast initialized on Feb 1 and (b) forecast initialized on Feb 7 (control fc valid for Feb 12 minus ERA-Interim).

Significant error in zonal winds and temperature (not shown) is seen in the fc initialized on Feb 1 (lead time is 12 days).

3. Perturbed runs

Each of the two control runs was accompanied by **three modified runs**

Resolution: T639L137
Forecast time: 2 weeks
Time step: 900s
Output: every 12h



4. Simulations with Orographic Gravity Wave Drag (OGWD) off

Orographic gravity waves are forced by flow travelling over mountains.

The **subgrid orography scheme** in OpenIFS model follows Lott and Miller scheme (1997).
It consists of two parts:

1. The low level blocking part
2. The gravity wave part

Switching off the OGWD scheme leads to a stronger vortex (Fig.4a-b).
In the forecast from 1.02 (Fig. 4a) the vortex is 8 m/s stronger at 60°N 10 hPa after 12 days

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the SSW forecast is less possible

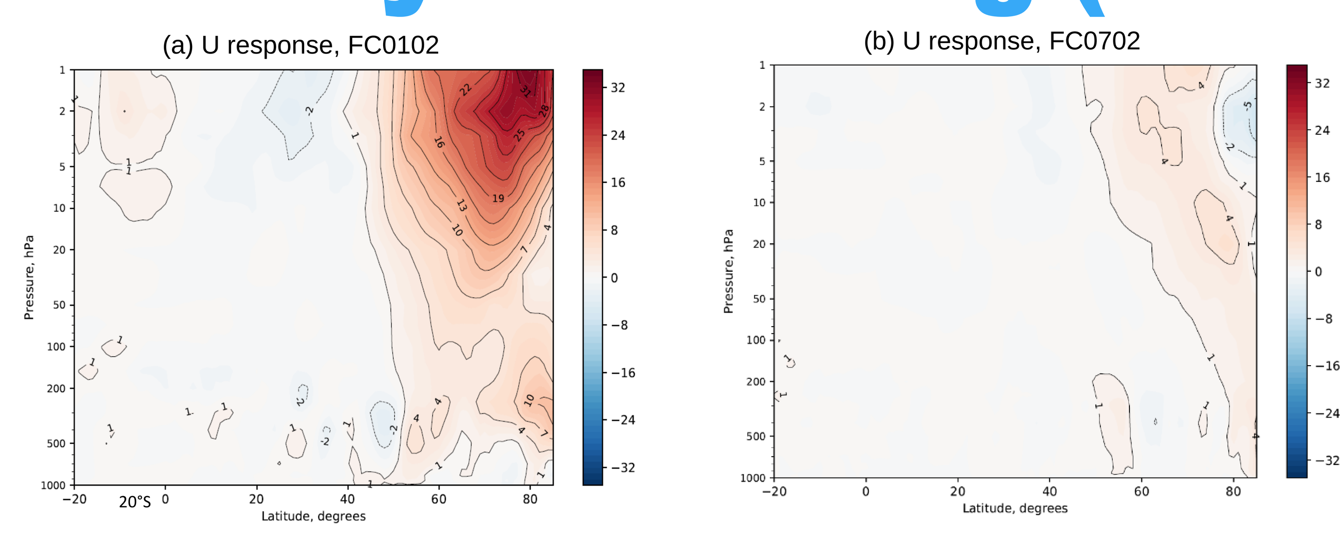

Figure 4. Latitude-pressure cross section of zonal wind response (perturbed fc valid for Feb 12 minus control) to switching off the OGWD scheme in OpenIFS. (a) for forecast initialized on Feb 1; (b) for fc initialized on Feb 7

5. Non-orographic gravity wave drag (NOGWD): reduced and increased

- **Non-orographic gravity waves' sources:** frontogenesis, jet stream activity, deep convection, shear zones.
- NOGW are generally unresolved or under-resolved in general circulation models ➡ need to be parameterized

In OpenIFS the spectral Scinocca scheme (2003) is used.
It consists of **three basic wave mechanisms**:

1. Conservative propagation
2. Critical level filtering
3. Non-linear dissipation

Default setting

Globally uniform and constant spectrum of wave speeds is launched towards the middle atmosphere

- Launch momentum flux $\rho_0 F^0_{launch}$ = 3.75 × 10^{-3} Pa
- Launch elevation p_{launch} = 450 hPa

Modified settings

Reduced NOGWD

- $\rho_0 F^0_{launch}$ = 1.0 × 10^{-3} Pa

Increased NODWG

- $\rho_0 F^0_{launch}$ = 14.0 × 10^{-3} Pa

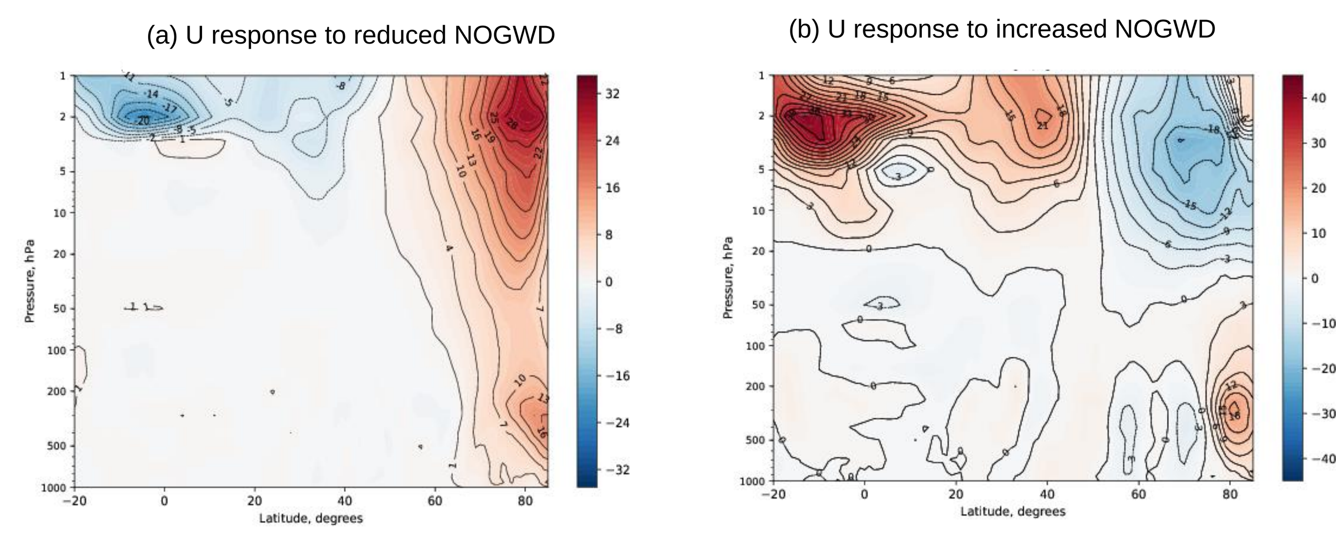

Figure 5. Latitude-pressure cross section of zonal wind response (perturbed fc initialized on Feb 1 valid for Feb 12 minus control) to (a) reduced NOGWD and (b) to increased NOGWD

Reduced NOGWD ➡ Less NOGWD induced downwelling ➡ Dynamical cooling over the winter pole ➡ Acceleration of zonal winds ➡ Stronger vortex (less chance of SSW)

Increased NOGWD ➡ More westward NOGWs enter the middle atmosphere ➡ More negative momentum flux convergence is induced over the pole ➡ Strong downwelling ➡ Adiabatic warming ➡ SSW

6. Gravity wave potential energy density (GW-Ep) analysis

GW perturbations:

- Wavelengths < 1000 km ➡ wavenumbers m > 14
- Extracted using Fourier transformation

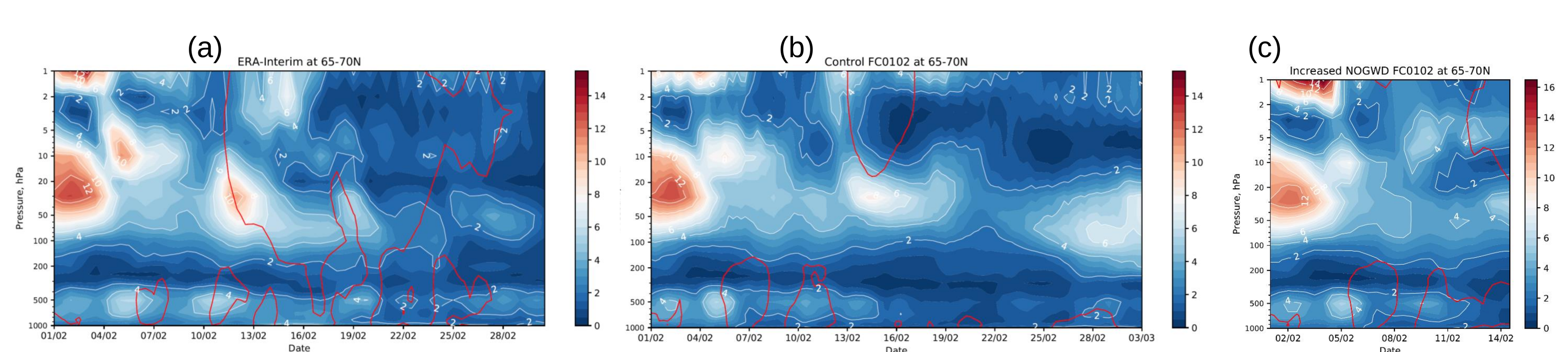

Figure 6. Time series of zonal mean GW-Ep [dJ/kg] at 65-70°N obtained by (a) ERA-I ; (b) control forecast initialised on Feb 1 and (c) increased NOGWD run initialised on Feb 1. The red lines are the zero zonal mean zonal wind line.

- Overall zonal mean GW-Ep is enhanced during the SSW onset
- **ERA-I** (Fig. 6a): GW-Ep amplitudes are largest on ~ Feb 2-3 at 40-20 hPa altitude and in the upper stratosphere (1-2 hPa); the third peak in the middle stratosphere corresponds to the central date of the event
- **Control forecast initialized on Feb 1** (Fig. 6b): only one peak in the middle stratosphere in the beginning of February
- **Perturbed run with increased NOGWD initialized on Feb 1** (Fig. 6c): GW-Ep amplitude becomes larger in the upper stratosphere on ~ Feb 2-4 compared to ERA-I. GW-Ep enhancement around the central date of the SSW is not captured
- After the SSW GW-Ep becomes significantly weaker in both ERA-I and OpenIFS simulations

7. Conclusions

- Forecasts initialized on the Feb 7 (control and perturbed ones) predicted wind reversal and start to diverge only after ~7-8 days of running
- Neither of the forecasts initialized on the Feb 1 predict wind reversal, although they have large spreading (start to diverge after ~2-3 days of running)
- Only increasing the NOGW flux improved the zonal wind forecasts (Fig. 7), however the SSW remained unpredicted in the simulations initialized on Feb 1
- GW-Ep amplitude amplification in the upper stratosphere on ~ Feb 2-4 played crucial role in SSW prediction

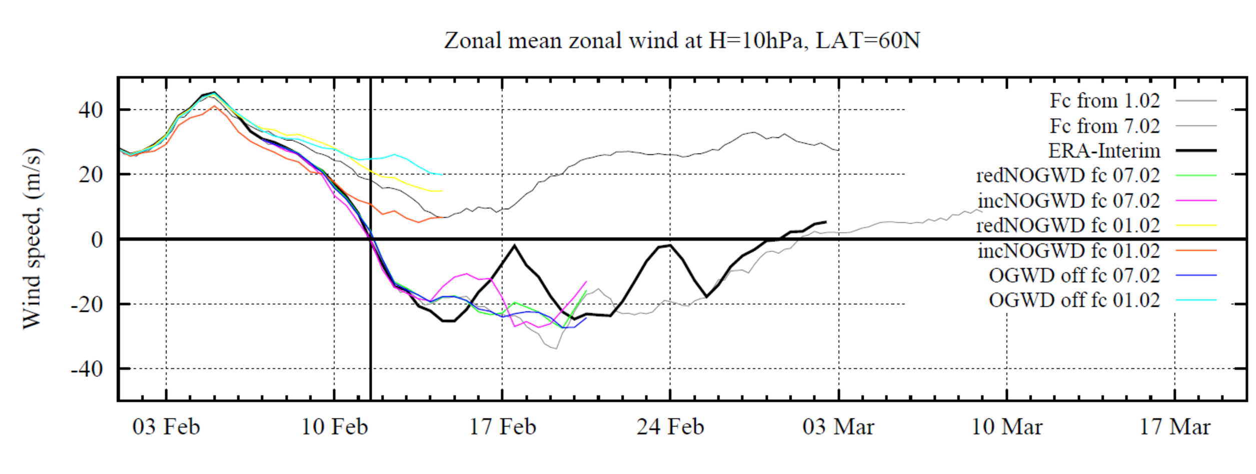

Figure 7. Zonal mean zonal wind at 10 hPa 60°N for control and perturbed runs initialized on Feb 1 and Feb 7. Solid black line denotes ERA-I re-analysis. Vertical line denotes SSW2018 central date.

References:
Karpechko, A. Yu. & Charlton-Perez, A. & Balmaseda, M. & Tyrrell, N. & Vitart, F. (2018). Predicting Sudden Stratospheric Warming 2018 and Its Climate Impacts With a Multimodel Ensemble. Geophysical Research Letters. 10.1029/2018GL081091.
Scinocca, J. F. (2003), 'An accurate spectral nonorographic gravity wave drag parameterization for general circulation models', Journal of the atmospheric sciences 60(4), 667–682.
Lott, F. & Miller, M. J. (1997), 'A new subgrid-scale orographic drag parametrization: Its formulation and testing', Quarterly Journal of the Royal Meteorological Society 123(537), 101–127.

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