# The interaction between stratospheric sudden warmings and ozone

Steven C. Hardiman, Neal Butchart and Fiona M. O'Connor

Met Office Hadley Centre, Exeter, UK

**Stratospheric sudden warmings** are known to have a large impact on European surface weather, through interaction with the North Atlantic Oscillation. This study looks into the impact of stratospheric sudden warmings (SSWs) on stratospheric ozone concentrations, and then asks whether ozone concentrations can influence the SSWs[1]. If they can, then it may be beneficial to include interactive 3D ozone in seasonal forecast models.

This study uses the HadGEM3-ES model, run with fully interactive stratosphere-troposphere chemistry for the Chemistry-Climate Model Initiative (CCM-I)[2].

## Influence of SSWs on ozone

Following SSWs, there is a significant increase in polar ozone concentrations in the lower stratosphere, shown in ERA-Interim and well simulated in the HadGEM3-ES "long control" simulation (Fig 1).

How does this arise?

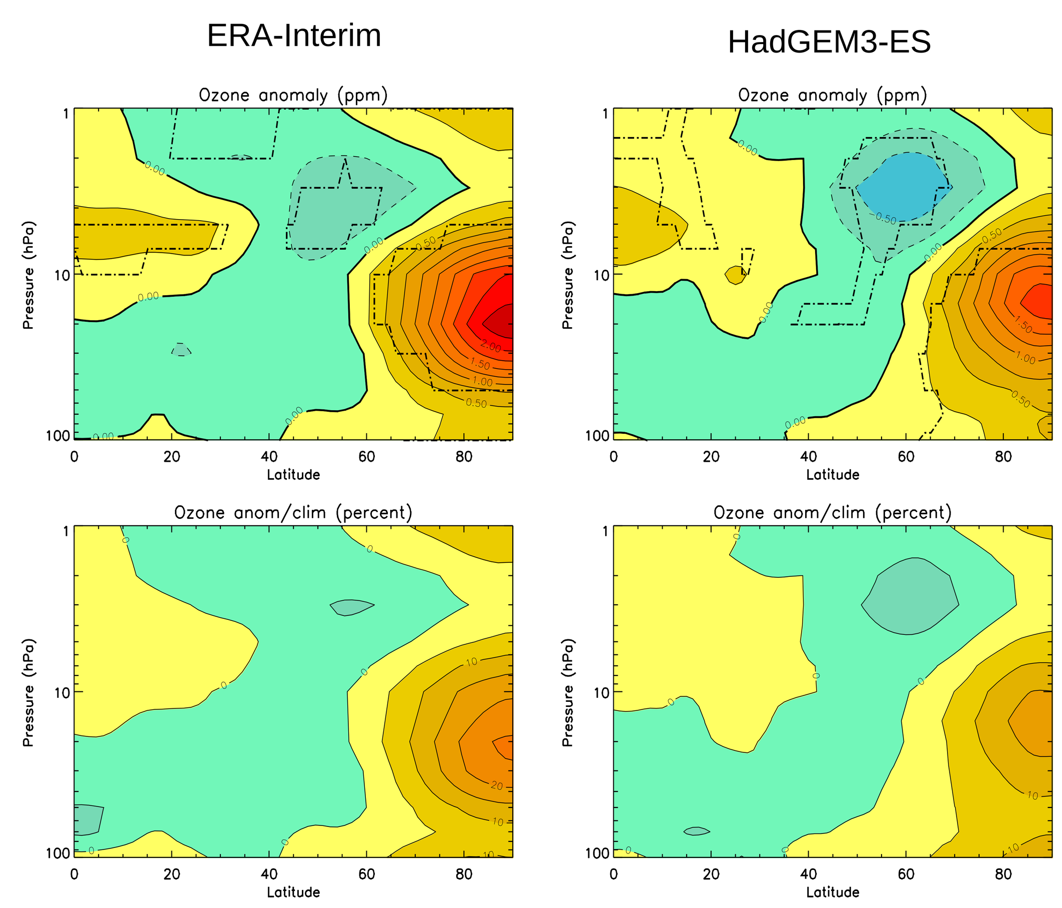



Fig 1: Ozone anomalies (in ppm and as a percentage of climatological values) averaged over the 10 days following SSWs, for ERA-Interim and the HadGEM3-ES CCM-I integration.

Changes in potential temperature suggest a transport of ozone from the midlatitude upper stratosphere to the high latitude lower stratosphere during the 5 days leading up to a SSW (Fig 2). This is backed up by diagnostics of the residual mean circulation in the model (not shown).

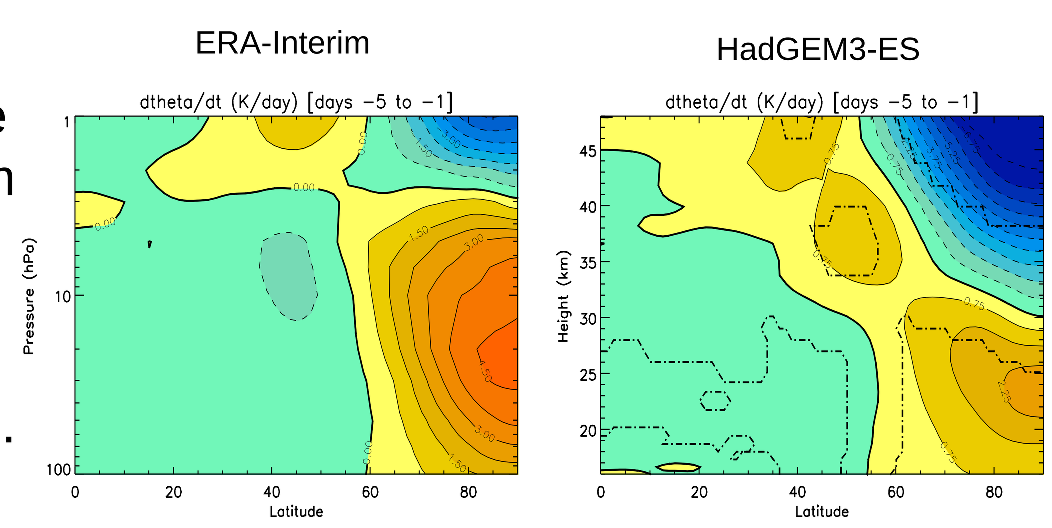



Fig 2: Rate of change of potential temperature (K/day) averaged over the 5 days prior to SSWs, for ERA-Interim and HadGEM3-ES.

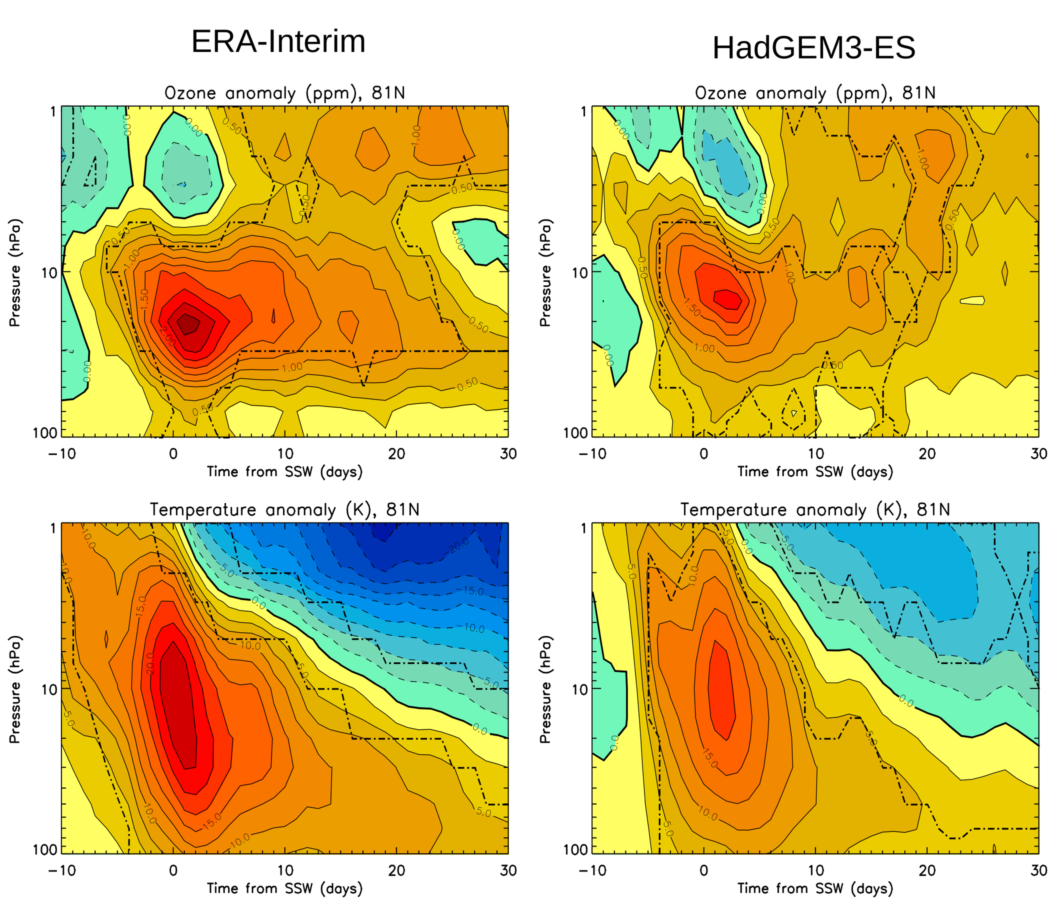



Fig 3: Ozone and temperature anomalies at 81N, composited relative to SSW central warming date for ERA-Interim and HadGEM3-ES

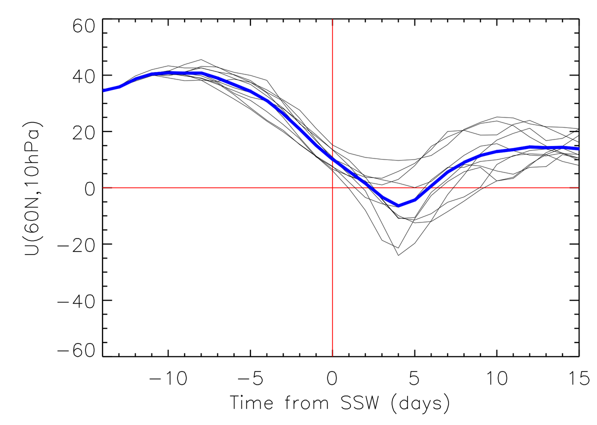
Ozone and temperature anomalies persist to ~25days after SSW central warming date (Fig 3).

Model anomalies are slightly weaker and less persistent than those in ERA-I – an indication that the modelled SSWs are too weak. However, qualitatively the model captures the signal in ozone and temperature very accurately, so can be used to investigate whether ozone concentrations will influence SSWs.

## Influence of ozone on SSWs

For each of the 10 SSWs between 1980 and 2000 in the HadGEM3-ES long control, run 10 member ensembles at lead times of 14, 12, 10 and 8 days, using i) Interactive ozone ii) Prescribed monthly mean climatological ozone

Fig 4: U(60N, 10hPa) for 1 of the 80 ten member ensemble integrations. Black curves show individual members and blue curve shows ensemble mean. SSW time is delayed, on average, by the stochastic perturbations in the ensemble members.



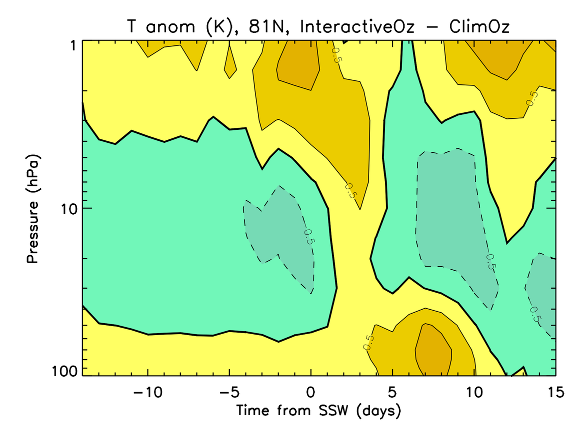




Fig 5: Ensemble mean difference in temperature anomaly (c.f. lower right hand panel of Fig 3) between interactive ozone and climatological ozone ensembles, averaged over the 100 pairs of integrations with a 14 day lead time. SSW is stronger in upper and lowermost stratosphere due to interactive ozone.

Assuming long control to be "perfect model", ensemble members using interactive ozone are closer to "truth".

Comparison to long control suggests atmosphere needs at least 12 days, before SSW occurs, to respond to differences in ozone.

Whilst SSW is occurring, dynamics are thought to dominate the model evolution.

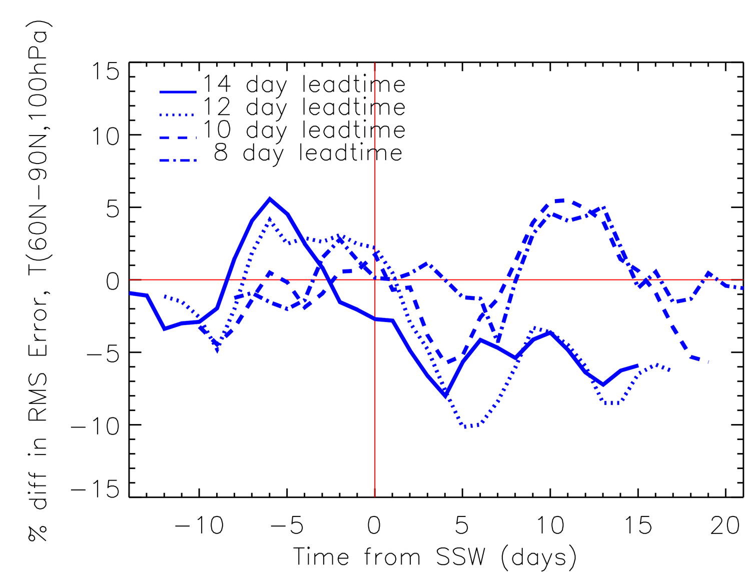



Fig 6: Percentage difference in polar cap T root-mean-square error due to using interactive ozone. Curves show ensemble mean difference across all 100 pairs of integrations for each lead time. A reduction in RMS error, due to interactive ozone, is seen after the SSW for the 14 and 12 day lead time ensemble members.

Using 14 and 12 day lead time integrations, the reduction in the NAM following SSWs (due to interactive ozone) is statistically significant at the 90% level for 150hPa – 70hPa.

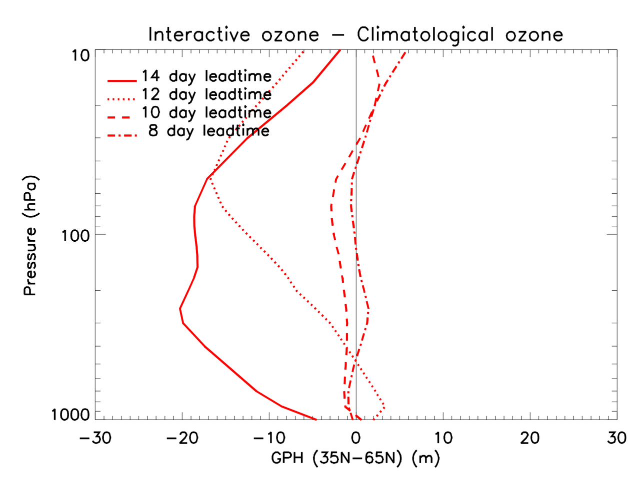



Fig 7: Difference, due to interactive ozone, in NAM and surface NAO, averaged over 10 days following SSW. Impact of increased SSW magnitude is seen in MSLP response.

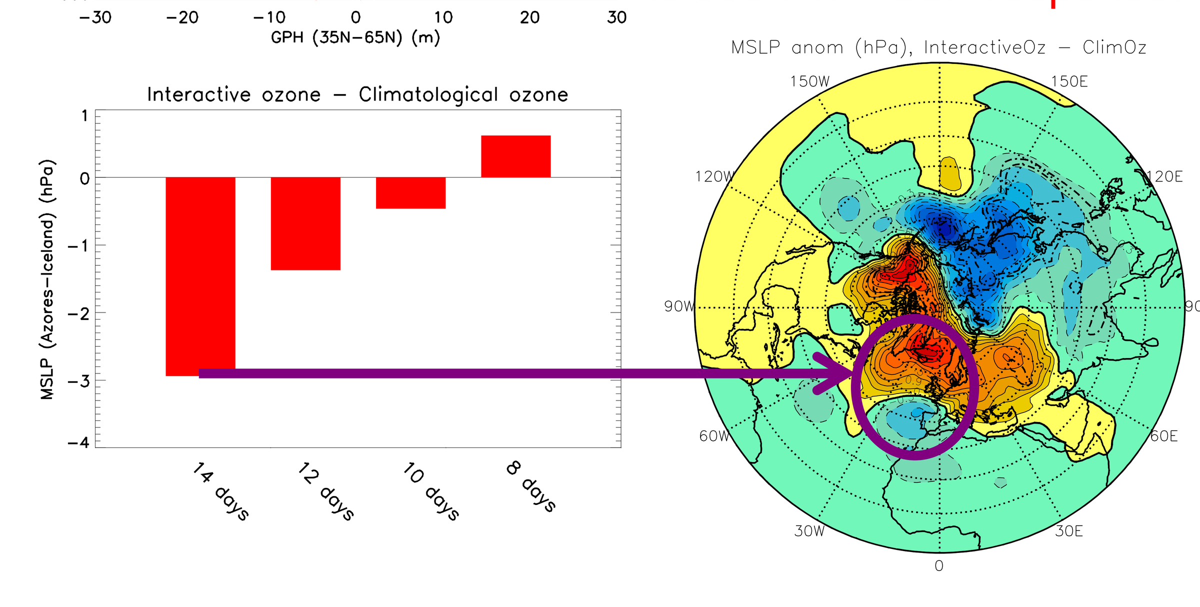



Fig 3 shows SSWs are too weak in the long control (w.r.t. ERA-I). Interactive ozone increases strength of simulated SSWs in lower stratosphere, bringing this closer to observations.

## Conclusions

- SSWs lead to significantly increased polar ozone concentrations in the lower stratosphere that persist for ~25 days following the central warming dates.
- Interactive ozone increases the strength of SSWs in the lower stratosphere, improving the simulation of SSWs and the resulting MSLP response.
- At least 12 days, prior to the SSW, are required for the atmosphere to respond to different ozone concentrations.

  Including interactive 3D ozone in seasonal forecasts may increase forecast skill.

**Steven Hardiman**
Afill: **Met Office** FitzRoy Road, Exeter, Devon, EX1 3PB, United Kingdom
Email: steven.hardiman@metoffice.gov.uk

References

[1] Albers, JR, JP McCormack, and TR Nathan, 2013: Stratospheric ozone and the morphology of the northern hemisphere planetary waveguide. *J. Geophys. Res.*, **118**, 563-576, doi:10.1029/2012JD017937.
[2] Eyring, V., et al., 2013: Overview of IGAC/SPARC Chemistry-Climate Model Initiative (CCMI) Community Simulations in Support of Upcoming Ozone and Climate Assessments, *SPARC Newsletter*, **40**, 48-66.

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