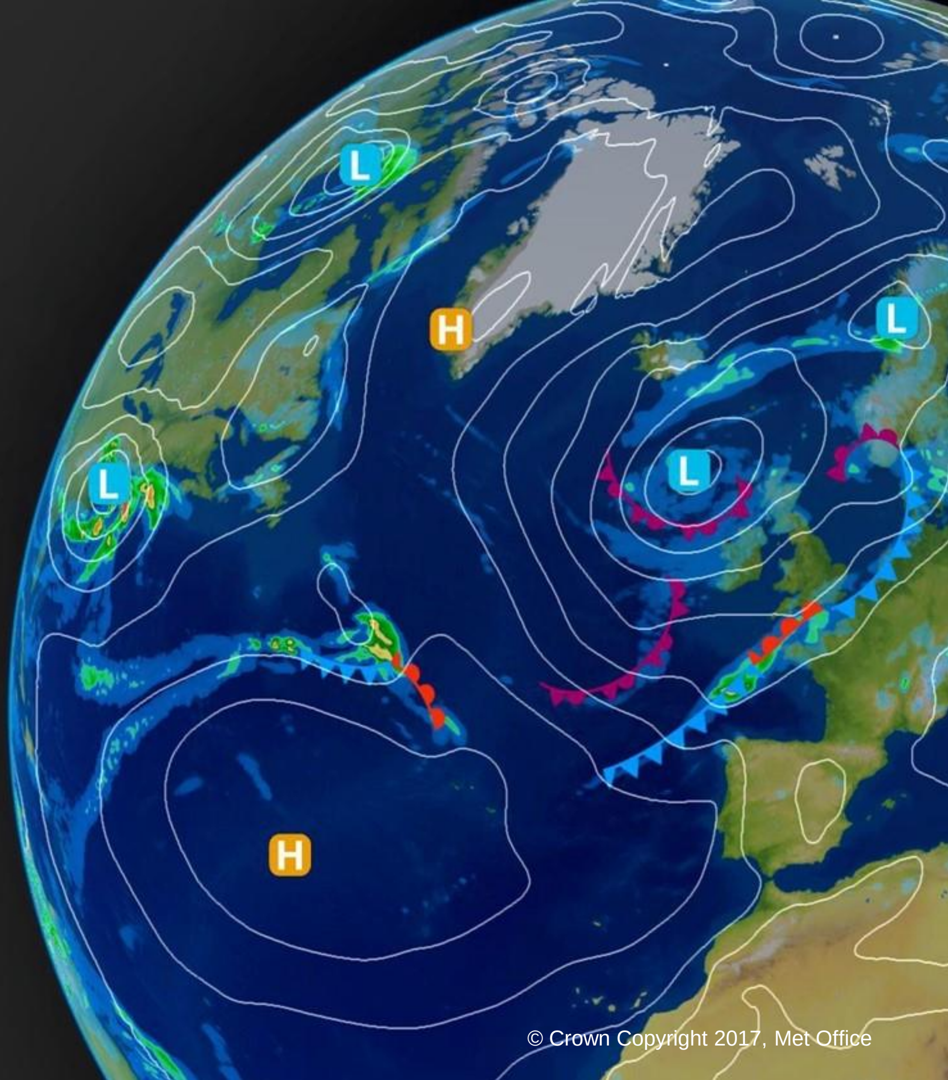
Met Office
Hadley Centre

Stratospheric impact on surface climate on seasonal time scales

Steven Hardiman

on behalf of MDVP team, UK Met Office

ECMWF Workshop on “Stratospheric predictability and impact on the troposphere”, November 2019



© Crown Copyright 2017, Met Office

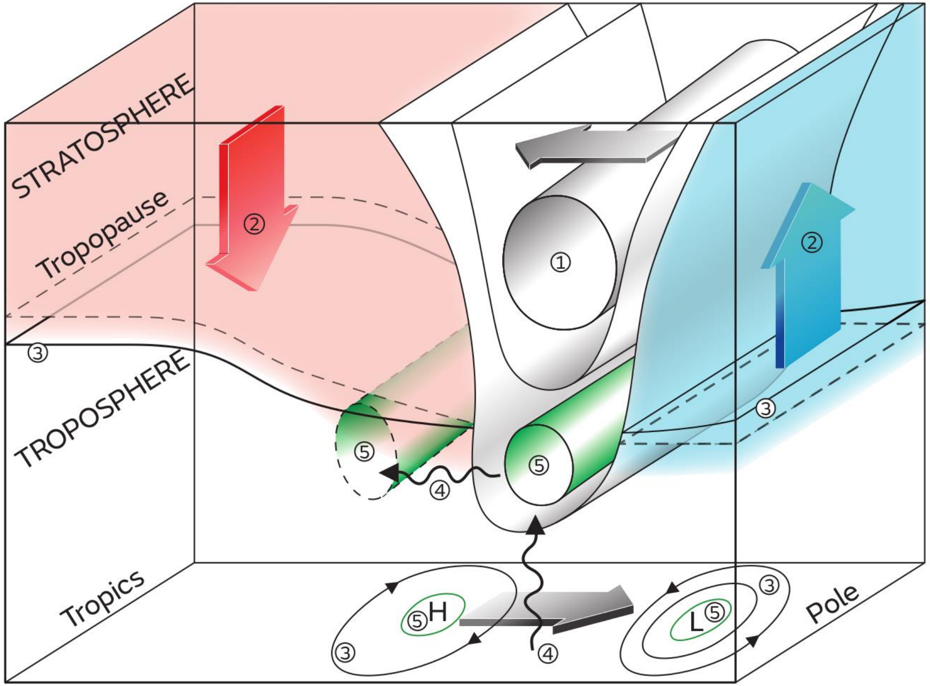
Met Office
Hadley Centre

Stratosphere-Troposphere coupling

Changes in stratospheric polar vortex strength (1) and residual circulation (2) change the tropopause height (3) and surface pressure (5).

Tropospheric eddy feedbacks (4) are linked to a poleward shift of both the tropospheric jet and the tracks of surface cyclones (5).

(*Kidston et al., 2015*)

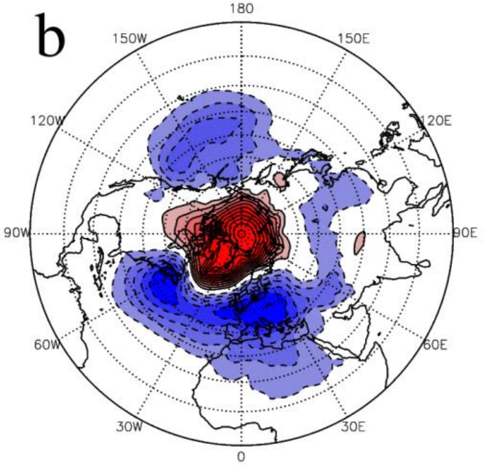


Talk focuses on ENSO and QBO → polar vortex strength → NAO.

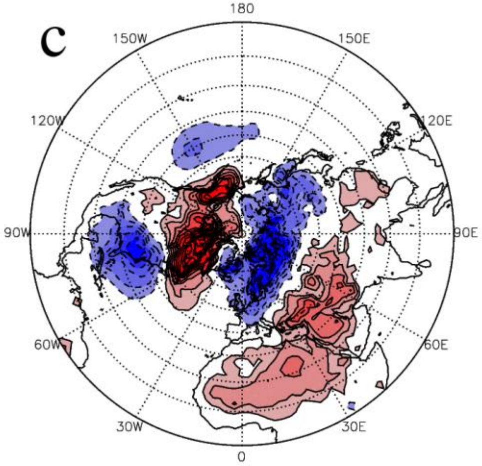
Kidston, J., A. A. Scaife, S. C. Hardiman, D. M. Mitchell, N. Butchart, M. P. Baldwin and L. J. Gray (2015), Stratospheric influence on tropospheric jet streams, storm tracks and surface weather, Nature Geoscience, 8, 433–440, doi:10.1038/NGEO2424

Average impact of SSWs on surface

MSLP



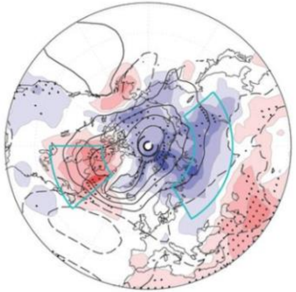
T



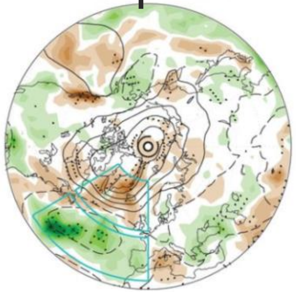
Impact on NAO and surface T (anomalies averaged over the month following an SSW for all SSWs from 1958–2002 in ERA-40)

(*Hardiman et al., 2012*)

T



Precipitation



Anomaly averaged over days 16–60 after all SSWs of SLP (contours), surface temperature (shading in a) and precipitation (shading in c).

(*Sigmond et al., 2013*)

Hardiman, S.C., N. Butchart, T.J. Hinton, S.M. Osprey, and L.J. Gray, 2012: The Effect of a Well-Resolved Stratosphere on Surface Climate: Differences between CMIP5 Simulations with High and Low Top Versions of the Met Office Climate Model. J. Climate, 25, 7083–7099, https://doi.org/10.1175/JCLI-D-11-00579.1

Sigmond, M., J. F. Scinocca, V. V. Kharin, and T. G. Shepherd, 2013: Enhanced seasonal forecast skill following stratospheric sudden warmings. Nat. Geosci., 6, 98–102, doi:https://doi.org/10.1038/ngeo1698.

Predictability of SSWs in seasonal forecasts

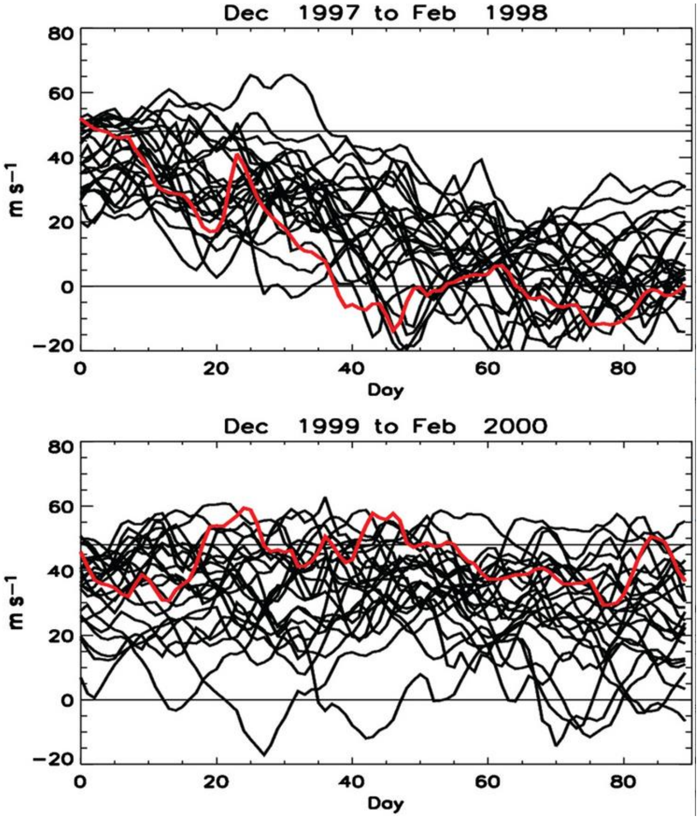
Deterministic prediction (exact warming date) possible with a lead time of around **12 days**.

(*Marshall and Scaife, 2010*)

Probabilistic prediction (will there be an SSW this winter or not?) potentially possible with around a **1 season** lead time

(*Scaife et al., 2016*)

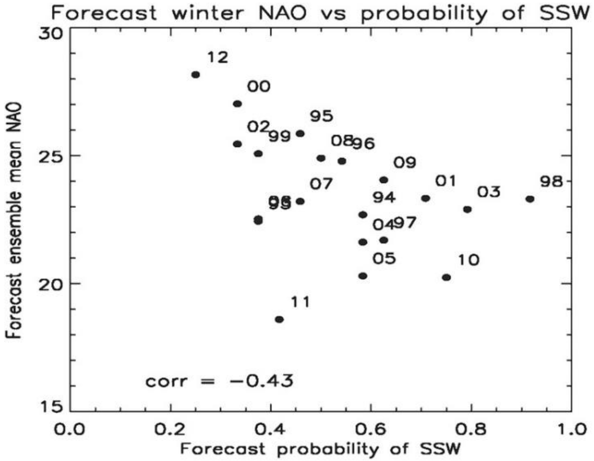
(Red line shows example ensemble member)



Marshall, A. G. & Scaife, A. A. Improved predictability of stratospheric sudden warming events in an atmospheric general circulation model with enhanced stratospheric resolution. J. Geophys. Res. 115, D16114 (2010).
Scaife, A. A., Karpechko, A. Y., et al. (2016), Seasonal winter forecasts and the stratosphere. Atmos. Sci. Lett., 17: 51-56. doi:10.1002/asl.598

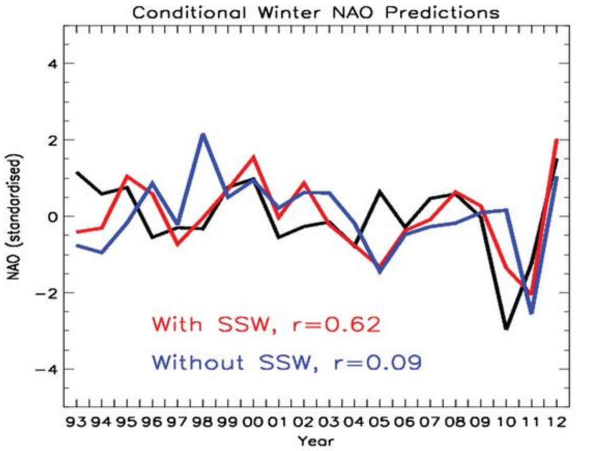
Prediction skill

Forecast probability of an SSW correlates with forecast ensemble mean NAO.



SSWs are essential for skilful prediction of NAO

(Black line = observations, red line includes model members with SSWs, blue line excludes members with SSWs)



(*Scaife et al., 2016*)

Scaife, A. A., Karpechko, A. Y., Baldwin, M. P., Brookshaw, A. , Butler, A. H., Eade, R. , Gordon, M. , MacLachlan, C. , Martin, N. , Dunstone, N. and Smith, D. (2016), Seasonal winter forecasts and the stratosphere. Atmos. Sci. Lett., 17: 51-56. doi:10.1002/asl.598

Increased skill due to SSWs

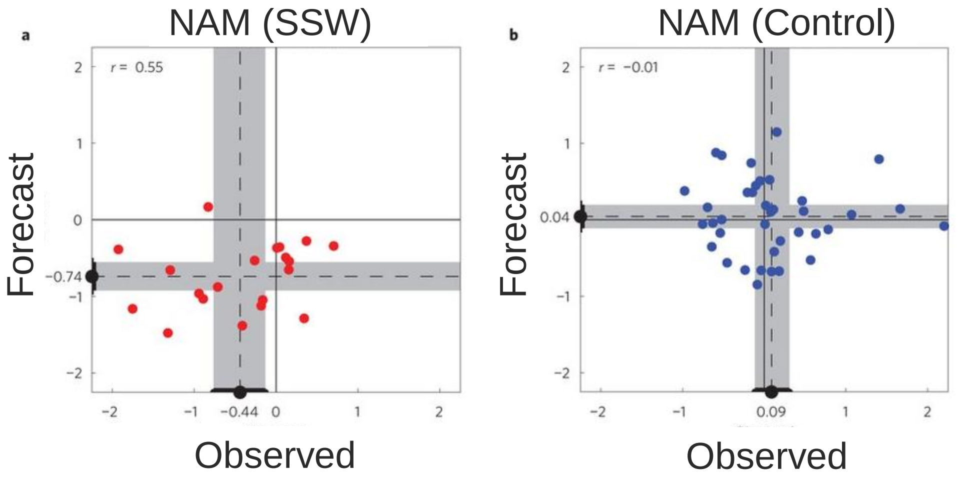
Increased seasonal forecast skill from initialisation after SSWs. Hence, initialise more frequently – Glosea currently runs 4 members every day.

Scatter plot of the observed versus forecast NAM index, averaged over 16–60 days following the 20 SSWs (a) and the 38 control dates (b).

Controls are initialised on same day but 1 year either side of SSW simulations.

r=0.55 in (a) and r=-0.01 in (b).

(*Sigmond et al., 2013*)

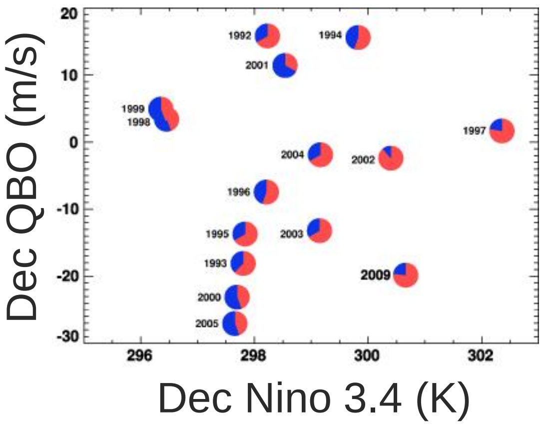


Sigmond, M., J. F. Scinocca, V. V. Kharin, and T. G. Shepherd, 2013: Enhanced seasonal forecast skill following stratospheric sudden warmings. Nat. Geosci., 6, 98–102, doi:https://doi.org/10.1038/ngeo1698.

ENSO and QBO impact on SSWs

- El Nino leads to more SSWs
- QBO(E) leads to more SSWs
- ENSO has bigger impact than QBO on SSWs

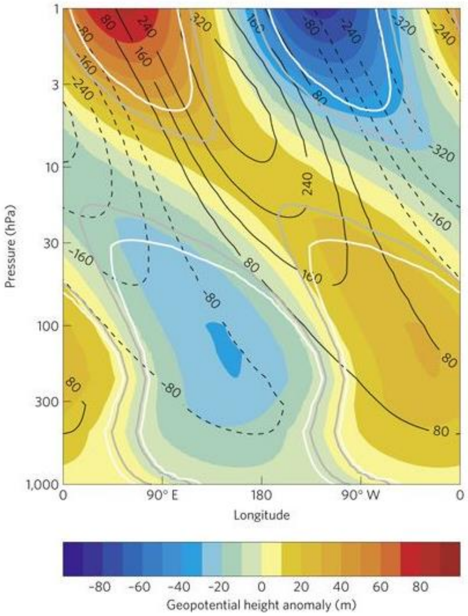
(*Fereday et al., 2012*)

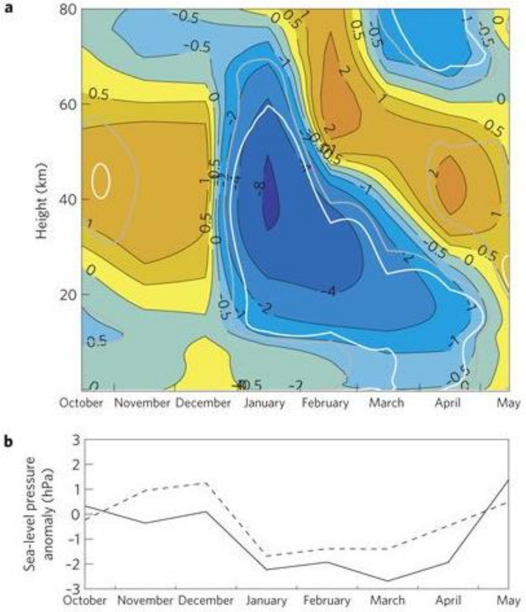


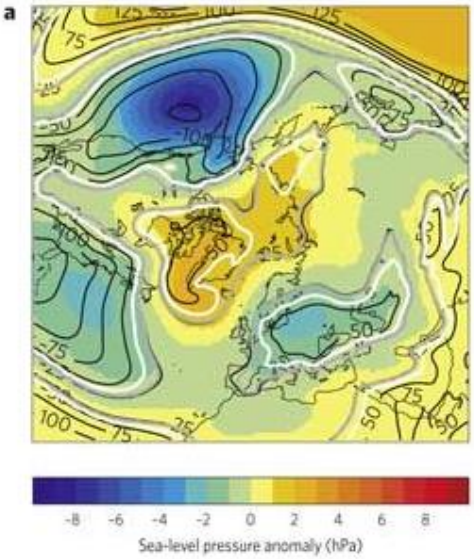
Proportion of hindcast members with (red) and without (blue) SSWs for each year

D R Fereday, A. Maidens, A. Arribas, A. A. Scaife and J. R. Knight (2012), Seasonal forecasts of northern hemisphere winter 2009/10. Environ. Res. Lett., 7 034031. doi:https://doi.org/10.1088/1748-9326/7/3/034031

Stratospheric pathway of ENSO (winter)







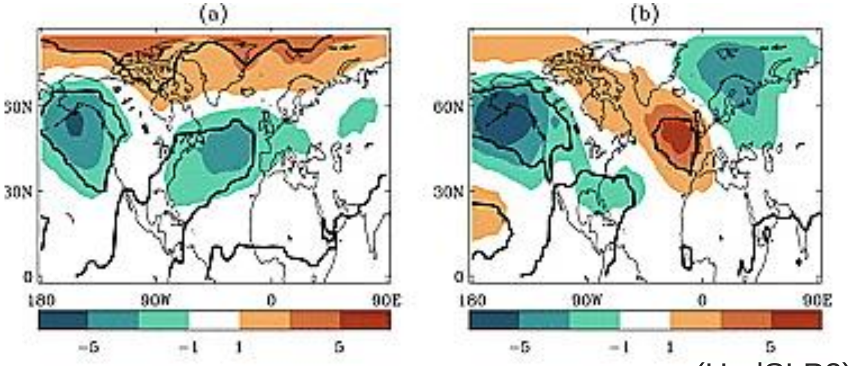
(HadGAM1)

El Nino deepens Aleutian low and constructively interferes with stationary wave forcing. Resulting weaker vortex propagates down leading to negative NAO (*Ineson and Scaife, 2009*).

SSWs are key for simulating negative NAO response to El Nino (*Cagnazzo and Manzini, 2009*).

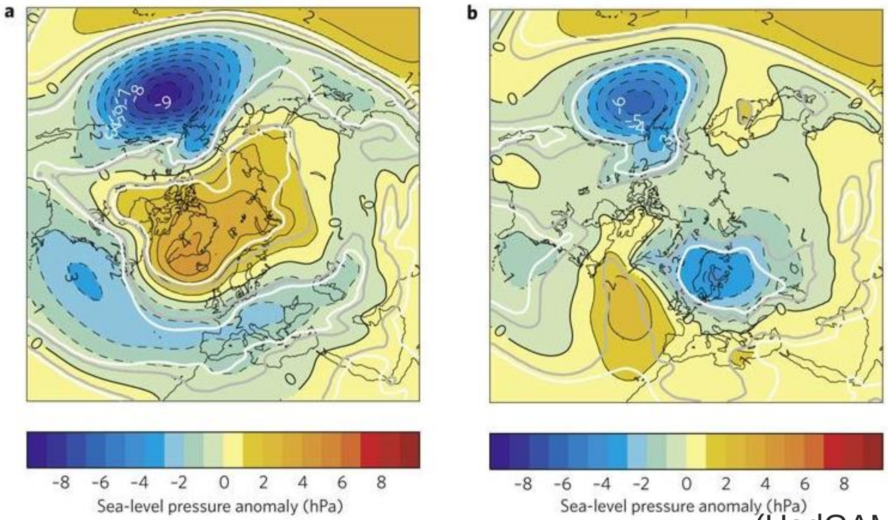
Ineson, S., & Scaife, A. A. (2009). The role of the stratosphere in the European climate response to El Niño. Nature Geoscience, 2, 32– 36. https://doi.org/10.1038/ngeo381
Cagnazzo, C., & Manzini, E. (2009). Impact of the stratosphere on the winter tropospheric teleconnections between ENSO and the North Atlantic and European region. Journal of Climate, 22, 1223– 1238. https://doi.org/10.1175/2008JCLI2549.1

ENSO teleconnection pathways



(HadSLP2)

Response to El Nino is negative NAO for moderate events, but wavelike for strong events (*Toniazzo and Scaife, 2006*).



(HadGAM1)

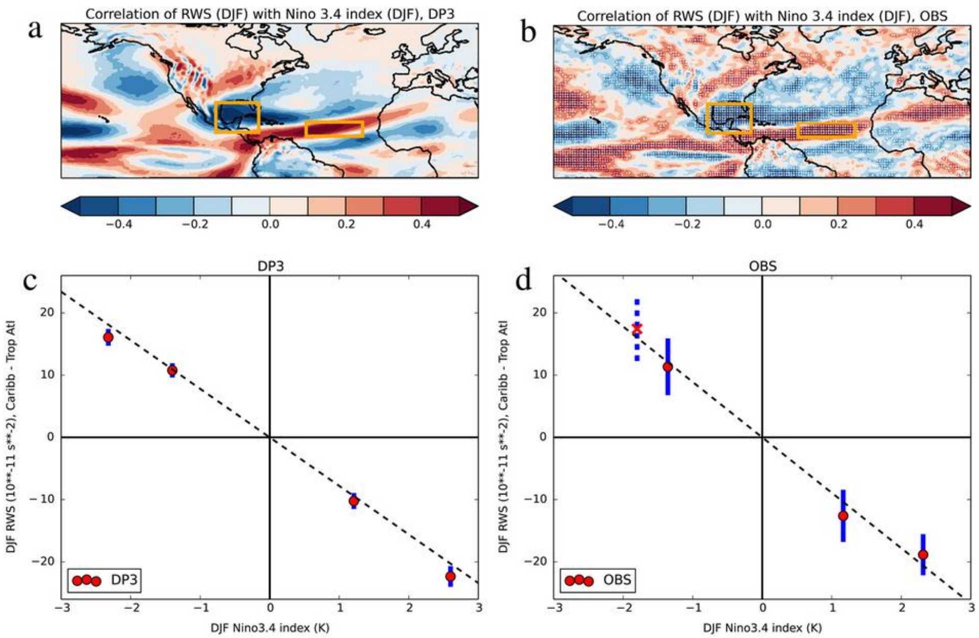
Negative NAO in winters with SSWs, wavelike in winters without SSWs (*Ineson and Scaife, 2009*)

Suggest tropospheric (wavelike) and stratospheric (NAO) pathways, and that stratospheric saturates for strong El Nino whilst tropospheric keeps growing (*Bell et al., 2009*).

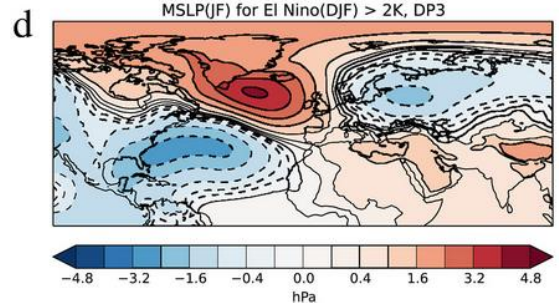
Toniazzo, T., & Scaife, A. A. (2006). The influence of ENSO on winter North Atlantic climate. Geophysical Research Letters, 33, L24704. https://doi.org/10.1029/2006GL027881
Ineson, S., & Scaife, A. A. (2009). The role of the stratosphere in the European climate response to El Niño. Nature Geoscience, 2, 32– 36. https://doi.org/10.1038/ngeo381
Bell, C. J., Gray, L. J., et al. (2009). Stratospheric communication of El Niño teleconnections to European winter. J. Climate, 22, 4083– 4096. https://doi.org/10.1175/2009JCLI2717.1

ENSO teleconnection pathways

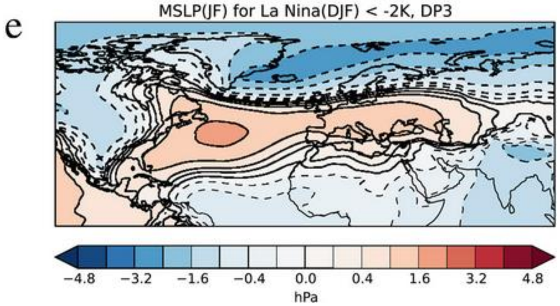
Tropospheric pathway



Strong El Niño



Strong La Niña



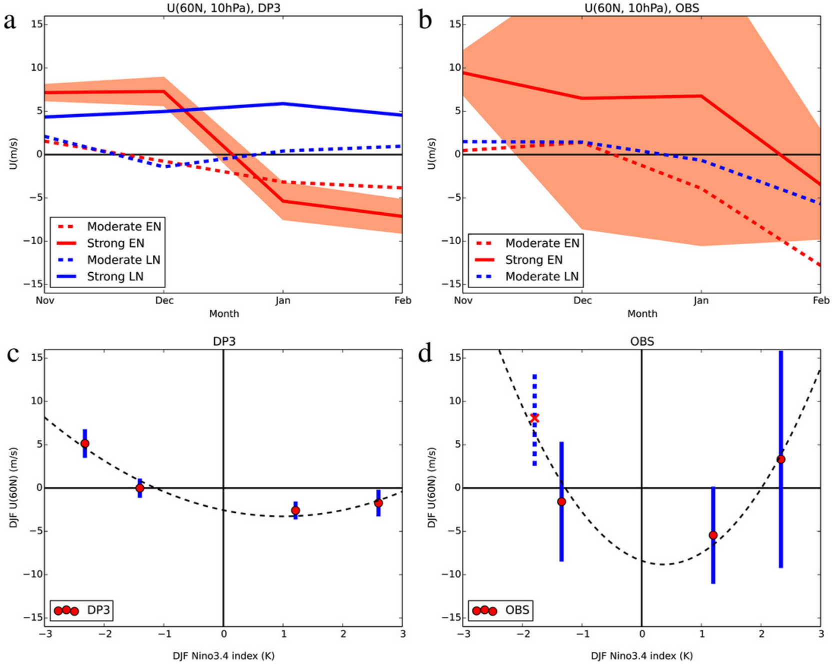
Tropospheric response (composite over strong/moderate El Nino/La Nina) **does keep growing**…

(Hardiman et. al., 2019)

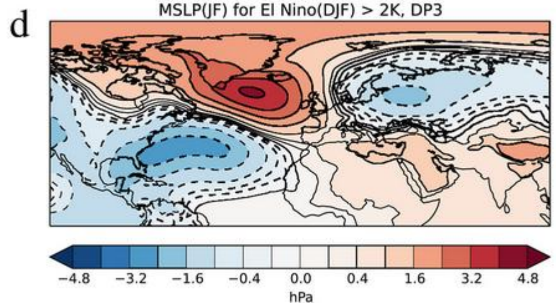
Hardiman, S. C., Dunstone, N. J., Scaife, A. A., Smith, D. M., Ineson, S., Lim, J., & Fereday, D. (2019). The impact of strong El Niño and La Niña events on the North Atlantic. Geophysical Research Letters, 46, 2874– 2883. https://doi.org/10.1029/2018GL081776

ENSO teleconnection pathways

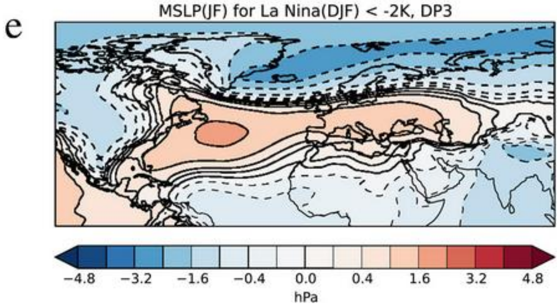
Stratospheric pathway



Strong El Niño



Strong La Niña



Don't find that stratospheric response saturates for strong El Nino (see also *Trascasa-Castro et al., 2019*), but starts with strong November vortex (don't yet understand why!)

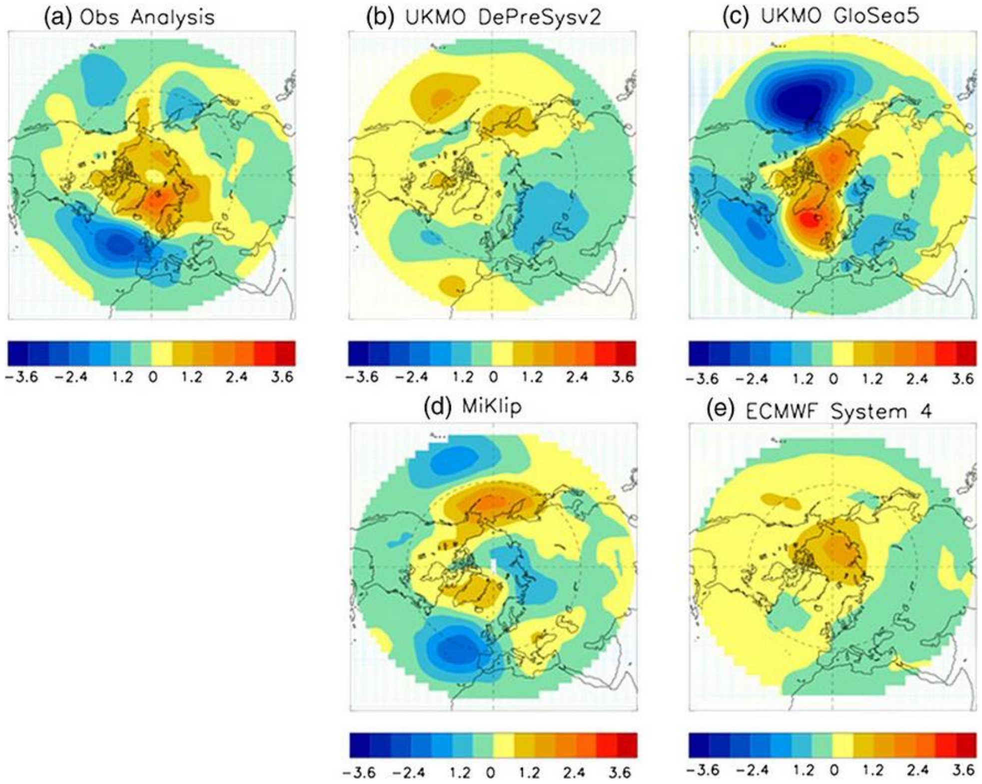
Hardiman, S. C., et al. (2019). The impact of strong El Niño and La Niña events on the North Atlantic. Geophysical Research Letters, 46, 2874– 2883. https://doi.org/10.1029/2018GL081776
Trascasa-Castro, P., A.C. Maycock, Y.Y. Scott Yiu, and J.K. Fletcher: On the linearity of the stratospheric and Euro-Atlantic sector response to ENSO. J. Climate, https://doi.org/10.1175/JCLI-D-18-0746.1

QBO on NAO skill (via stratosphere)

QBO predictable in models, with r=0.7 after 12 months and skill still significant after 3 years

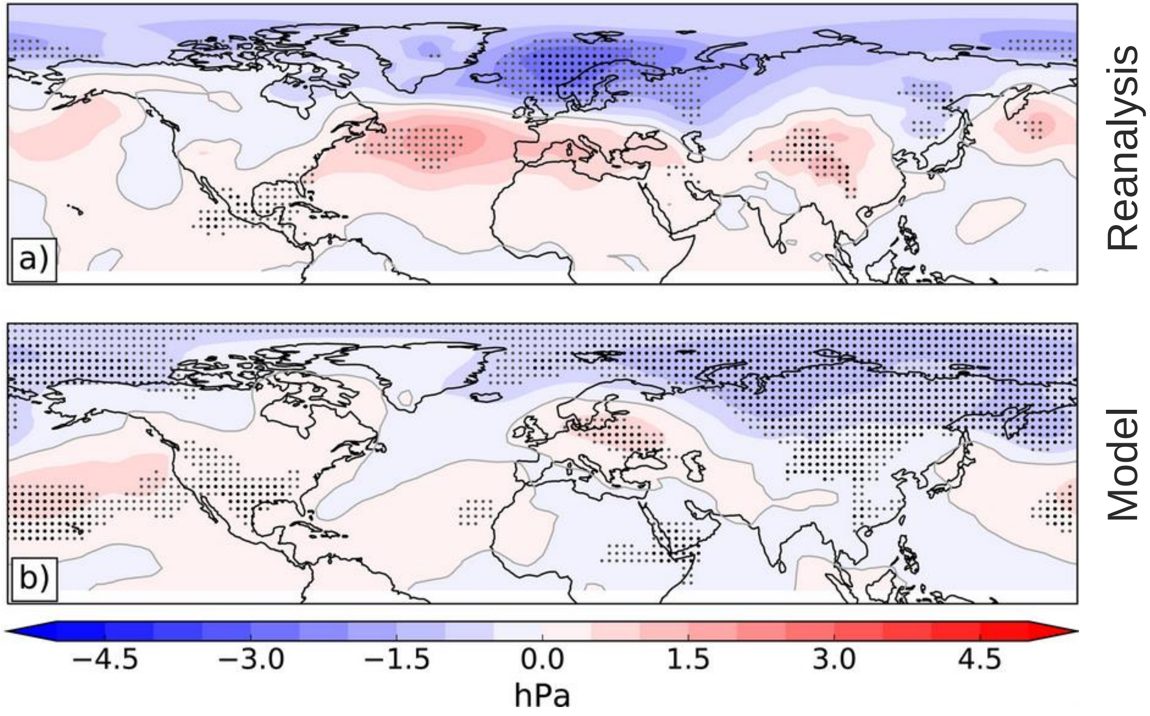
Teleconnection to the surface is too weak in models

(*Scaife et al., 2014*)



Scaife, A. A., et al. (2014), Predictability of the quasi-biennial oscillation and its northern winter teleconnection on seasonal to decadal timescales, Geophys. Res. Lett., 41, 1752– 1758, doi:10.1002/2013GL059160

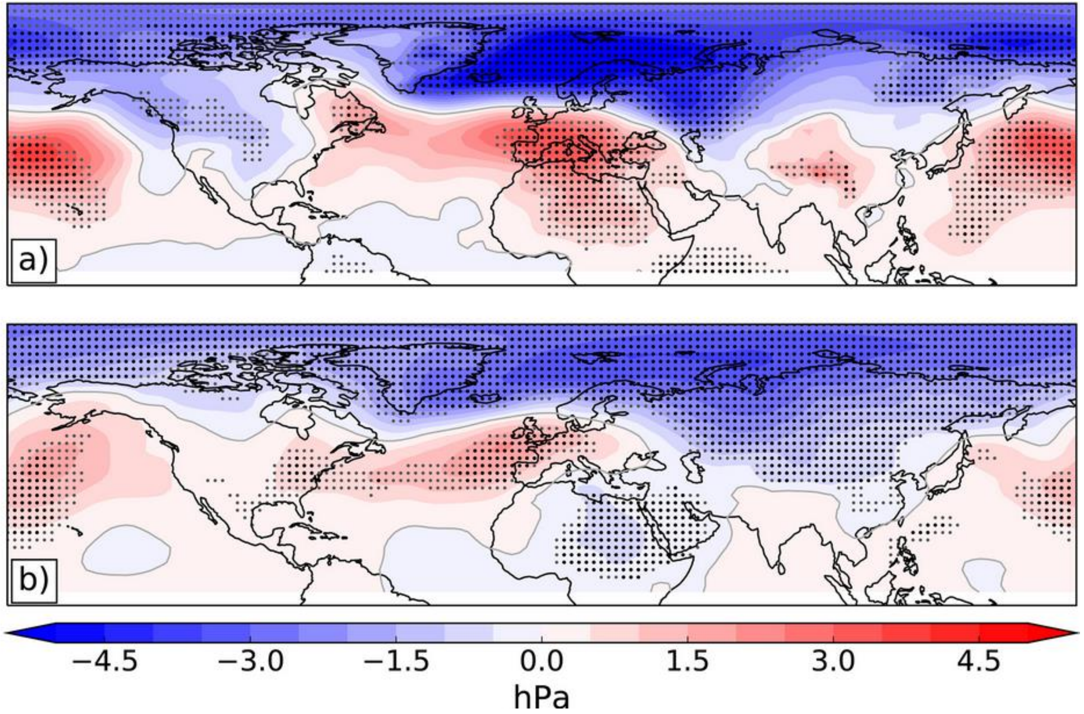
QBO on NAO skill (via stratosphere)



Teleconnection to surface (probably via polar vortex) confirmed still to be too weak in latest model (*Andrews et al., 2019*)

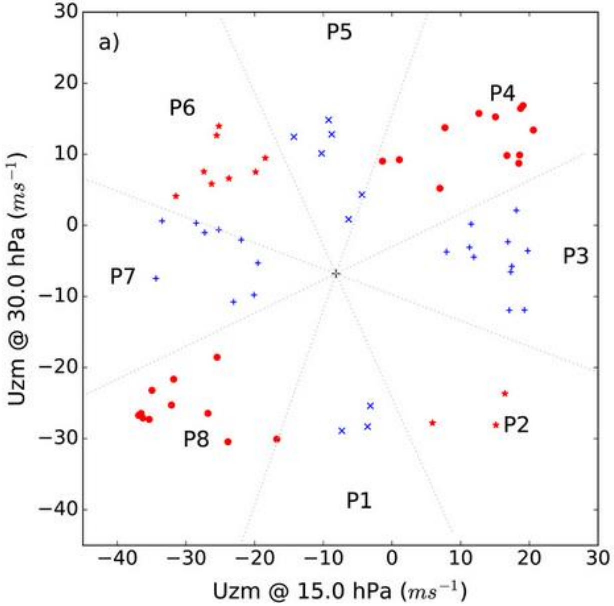
Andrews, M. B., Knight, J. R., Scaife, A. A., Lu, Y., Wu, T., Gray, L. J., & Schenzinger, V. (2019). Observed and simulated teleconnections between the stratospheric Quasi-Biennial Oscillation and Northern Hemisphere winter atmospheric circulation. Journal of Geophysical Research: Atmospheres, 124, 1219– 1232. https://doi.org/10.1029/2018JD029368

QBO on NAO skill (via stratosphere)



Reanalysis

Model

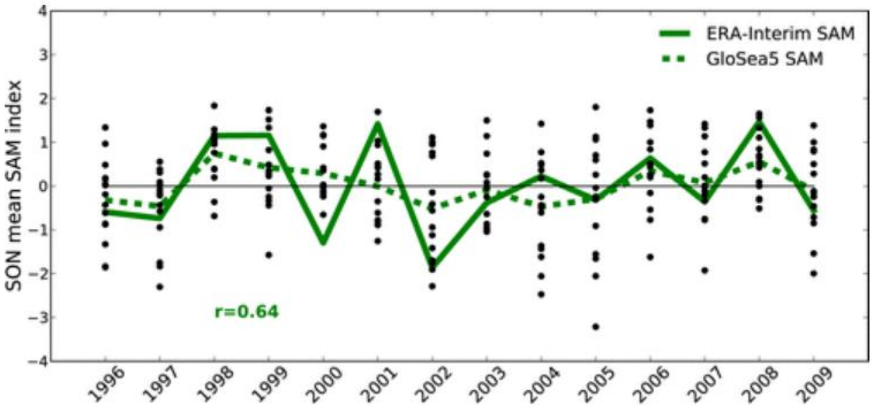


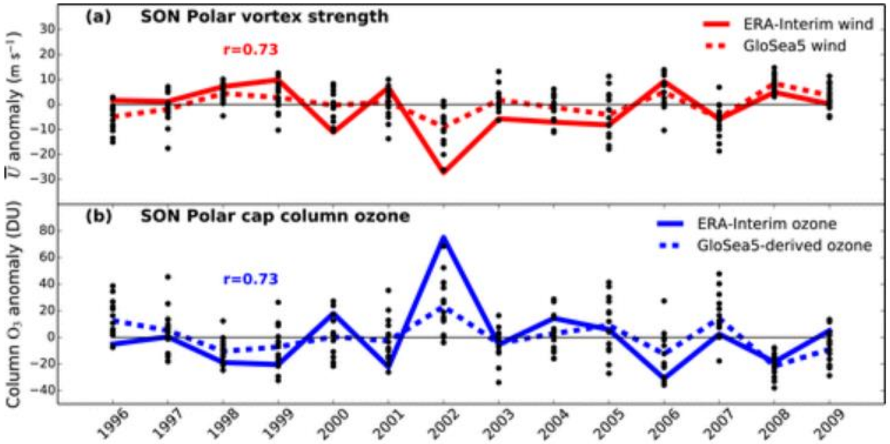
Reanalysis

The vertical structure of the QBO should be considered rather than just 1 level. The **only** significant surface response (in observations or model) is for “deep” QBO phases.

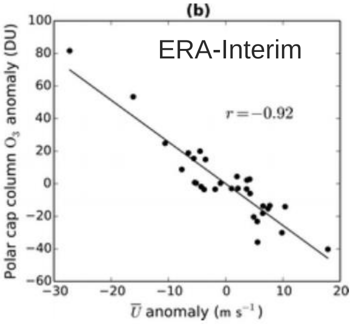
Andrews, M. B., Knight, J. R., Scaife, A. A., Lu, Y., Wu, T., Gray, L. J., & Schenzinger, V. (2019). Observed and simulated teleconnections between the stratospheric Quasi-Biennial Oscillation and Northern Hemisphere winter atmospheric circulation. Journal of Geophysical Research: Atmospheres, 124, 1219– 1232. https://doi.org/10.1029/2018JD029368

SAM / Ozone





SAM impacted by stratospheric anomalies at 2 month lead time.



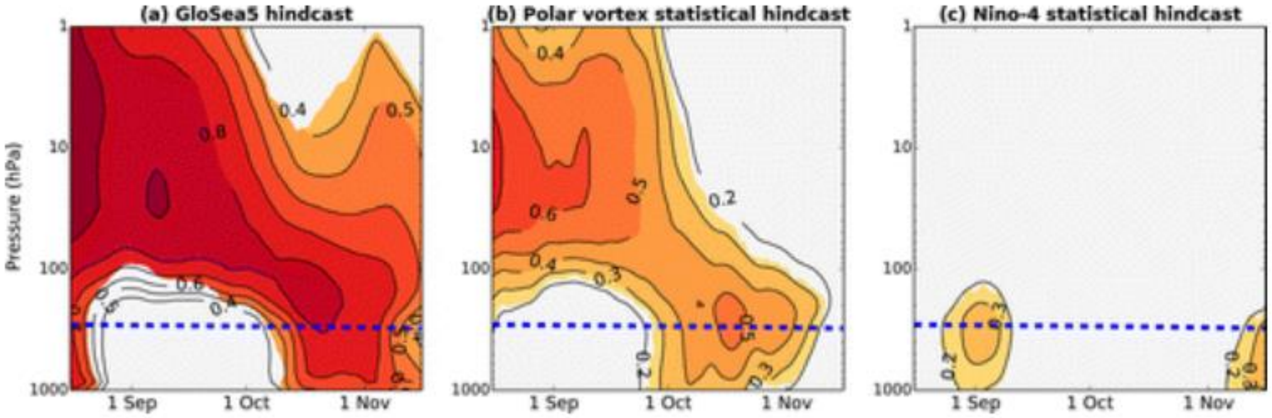
Significant skill is also found in the prediction of the strength of the Antarctic stratospheric polar vortex.

Possible to make skillful predictions of Antarctic column ozone amounts as polar cap total column ozone correlates strongly to U (10hPa, 60S).

(*Seviour et al., 2014*)

Seviour, W.J., S.C. Hardiman, L.J. Gray, N. Butchart, C. MacLachlan, and A.A. Scaife (2014), Skillful Seasonal Prediction of the Southern Annular Mode and Antarctic Ozone. J. Climate, 27, 7462–7474, https://doi.org/10.1175/JCLI-D-14-00264.1

SAM / Ozone



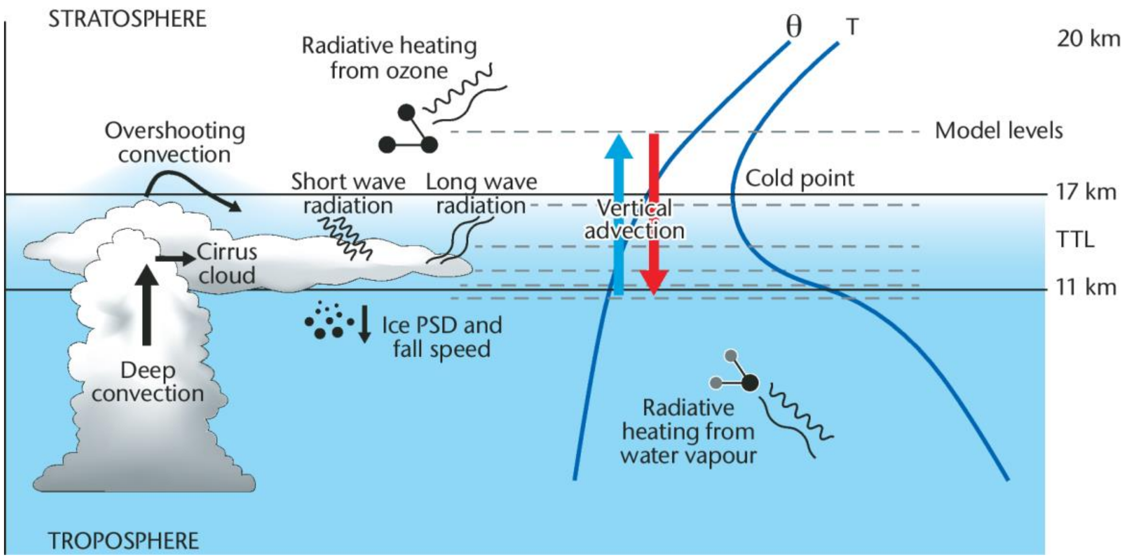
Skillful statistical forecasts of the October-mean SAM are produced based only on mid-stratosphere anomalies on 1 August (b).

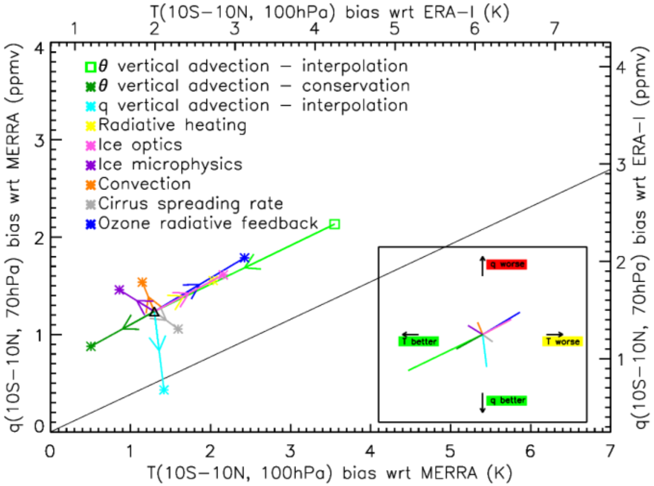
Limited skill from ENSO in October (c).

(*Seviour et al., 2014*)

Seviour, W.J., S.C. Hardiman, L.J. Gray, N. Butchart, C. MacLachlan, and A.A. Scaife (2014), Skillful Seasonal Prediction of the Southern Annular Mode and Antarctic Ozone. J. Climate, 27, 7462–7474, https://doi.org/10.1175/JCLI-D-14-00264.1

Stratospheric water vapour





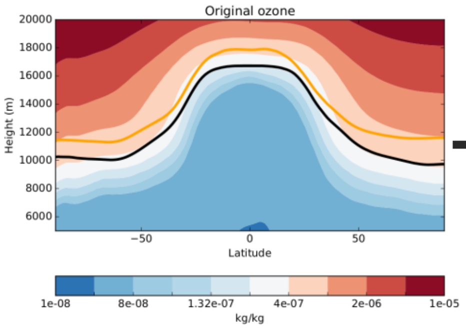
Stratospheric water vapour has direct influence on radiative balance and climate sensitivity at the surface, it can influence decadal changes in global mean surface temperature, and directly impact the tropospheric jet streams. In addition it impacts stratospheric ozone which can, in turn, influence surface climate and radiation.

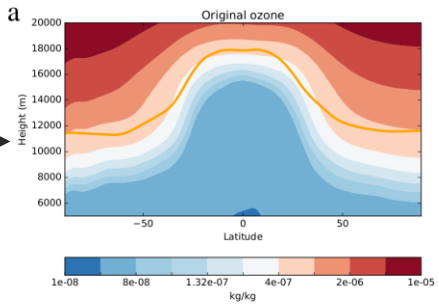
Stratospheric water vapour is influenced by many model processes, either directly or via changes in tropical tropopause temperature.

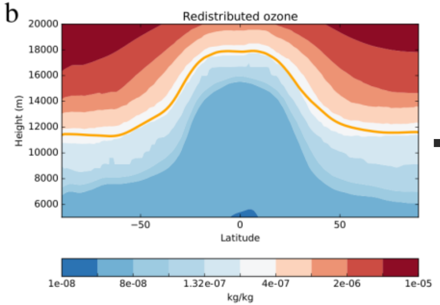
(*Hardiman et al., 2015*)

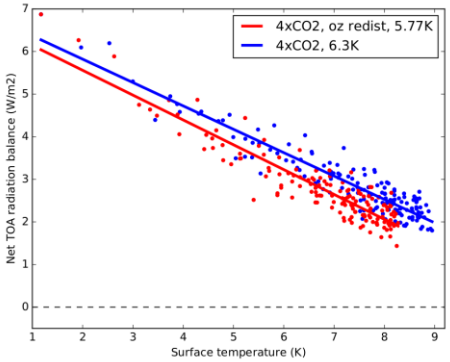
Hardiman, Steven C., et al. (2015), Processes controlling tropical tropopause temperature and stratospheric water vapor in climate models, J. Climate, 28, 6516–6535. doi:http://dx.doi.org/10.1175/JCLI-D-15-0075.1

Ozone redistribution in CMIP6









Thermal tropopause rises due to climate change, prescribed ozone tropopause stays fixed

Redistribute ozone to avoid: ozone → cold point T → SWV → downwelling LW → surface temperature and ECS

Removing unphysical consequences of tropopause mismatch → significant reduction in ECS

(*Hardiman et al., 2019*)

Hardiman, Steven C., et al. (2019), The impact of prescribed ozone in climate projections run with HadGEM3-GC3.1, JAMES, accepted, doi:10.1029/2019MS001714

Summary

- SSWs can be predicted deterministically around 12 days in advance, and probabilistically around 1 season in advance.
- Simulating SSWs is essential for a skilful prediction of the NAO.
- Moderate El Nino events lead to negative NAO, via stratospheric polar vortex. For strong El Nino, tropospheric pathway dominates due to strong polar vortex at start of winter.
- QBO impact on NAO is simulated in models but is too weak. Only significant impact of QBO on NAO in observations or model is during QBO deep easterly and westerly phases.
- SAM impacted by stratosphere at 2 month lead time - stratosphere has bigger impact than ENSO. Also significant skill forecasting polar vortex strength and stratospheric ozone concentrations.
- Stratospheric water vapour has influence on surface climate, and is affected by many dynamical, physical and chemical processes around the tropical tropopause (including ozone!).