Space Physics Laboratory
Vikram Sarabhai Space Centre
Indian Space Research Organisation
Thiruvananthapuram

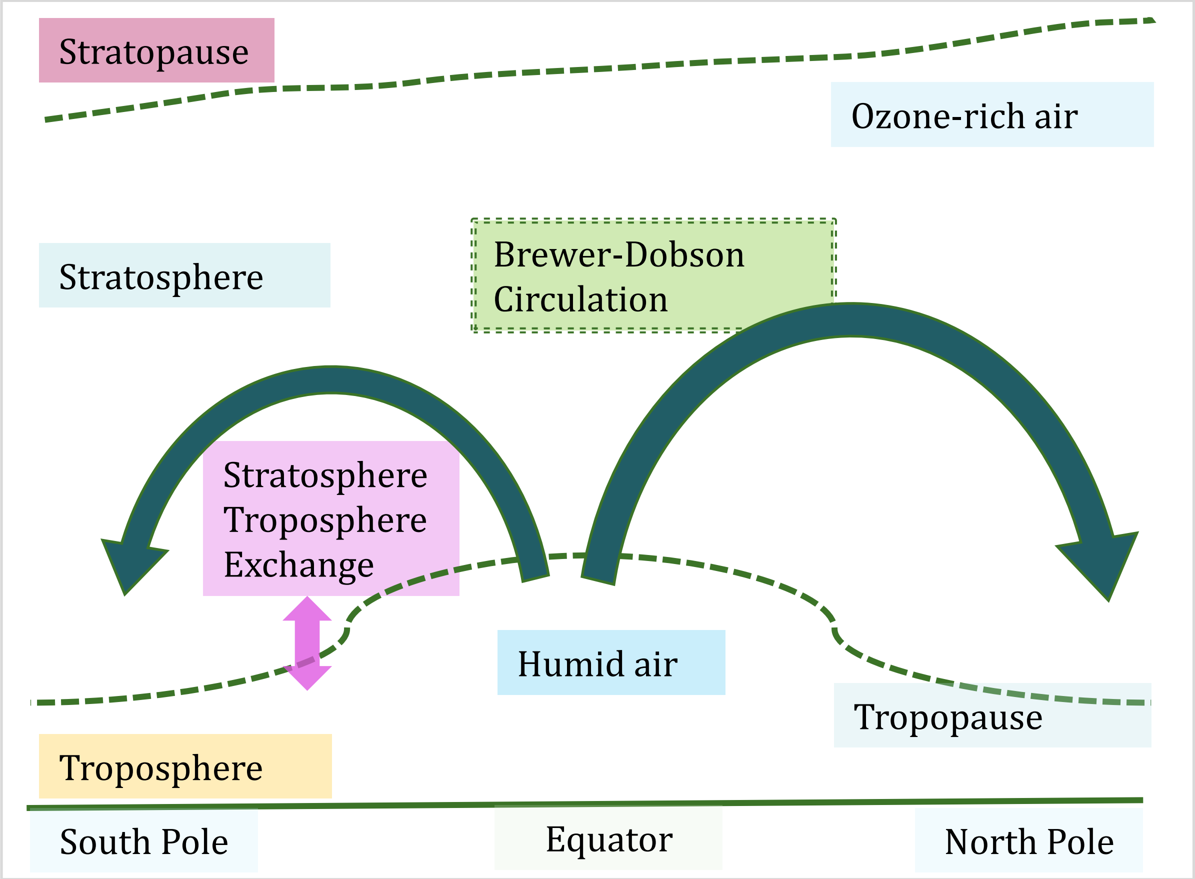
STIPMEX
Indian Institute of Tropical Meteorology
Pune
Maharashtra

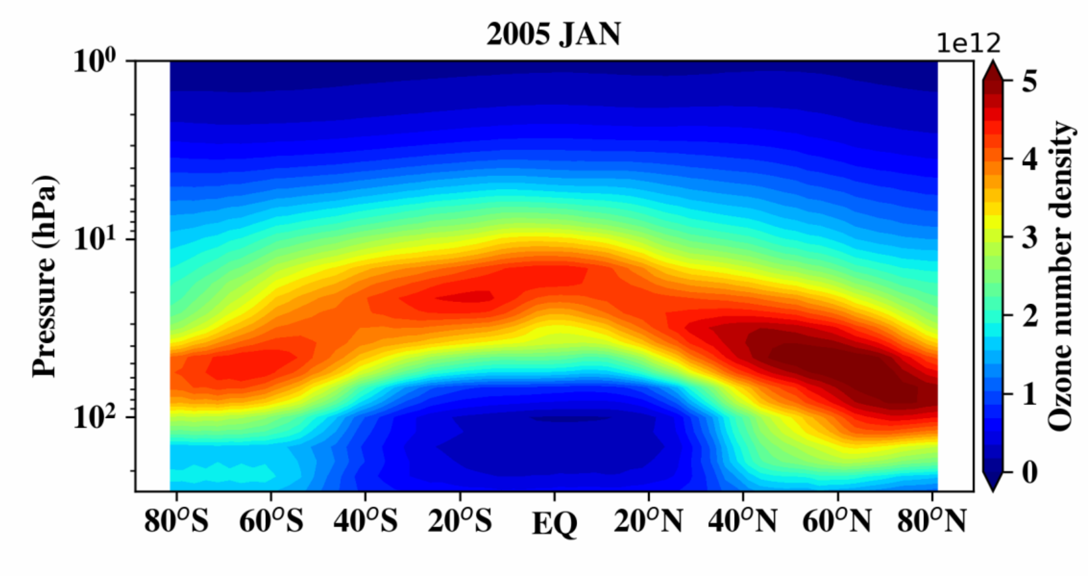
A composite study on the effect of SSW and QBO on stratospheric meridional circulation: Implications on ozone and water vapor distribution

Veenus Venugopal & Siddarth Shankar Das
veenus@vssc.gov.in
4 June 2024

Space Physics Laboratory
Vikram Sarabhai Space Centre
Indian Space Research Organisation
Thiruvananthapuram-695022

Brewer-Dobson circulation





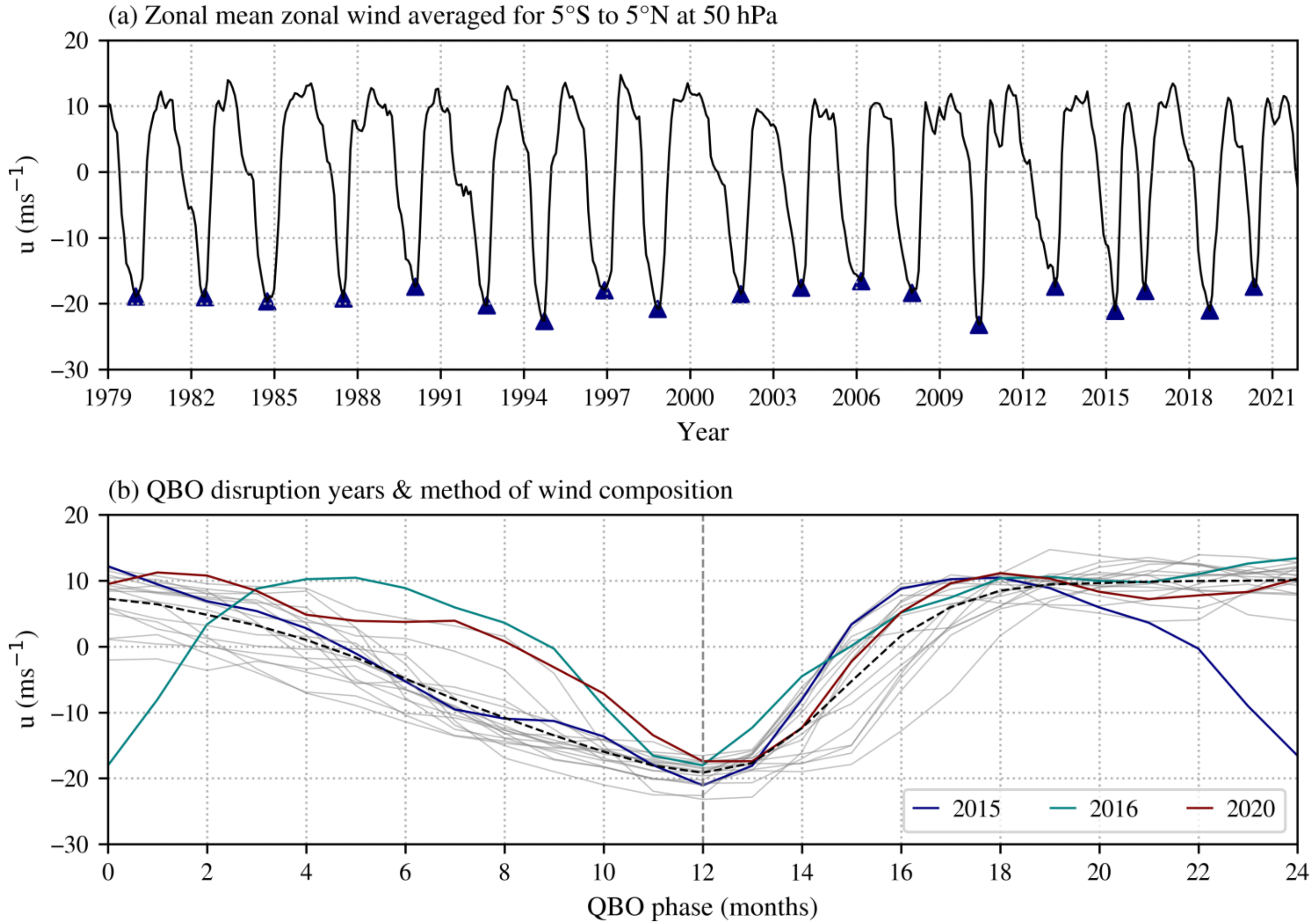
Sense of Brewer-Dobson Circulation from the zonally averaged ozone number density (molecules per cm3) derived from Aura/MLS ozone measurements for 2005 to 2007.

BDC during different phases of QBO

QBO & BDC

- Method
- BDC metrics
- Stratospheric changes

Quasi-Biennial Oscillation - QBO

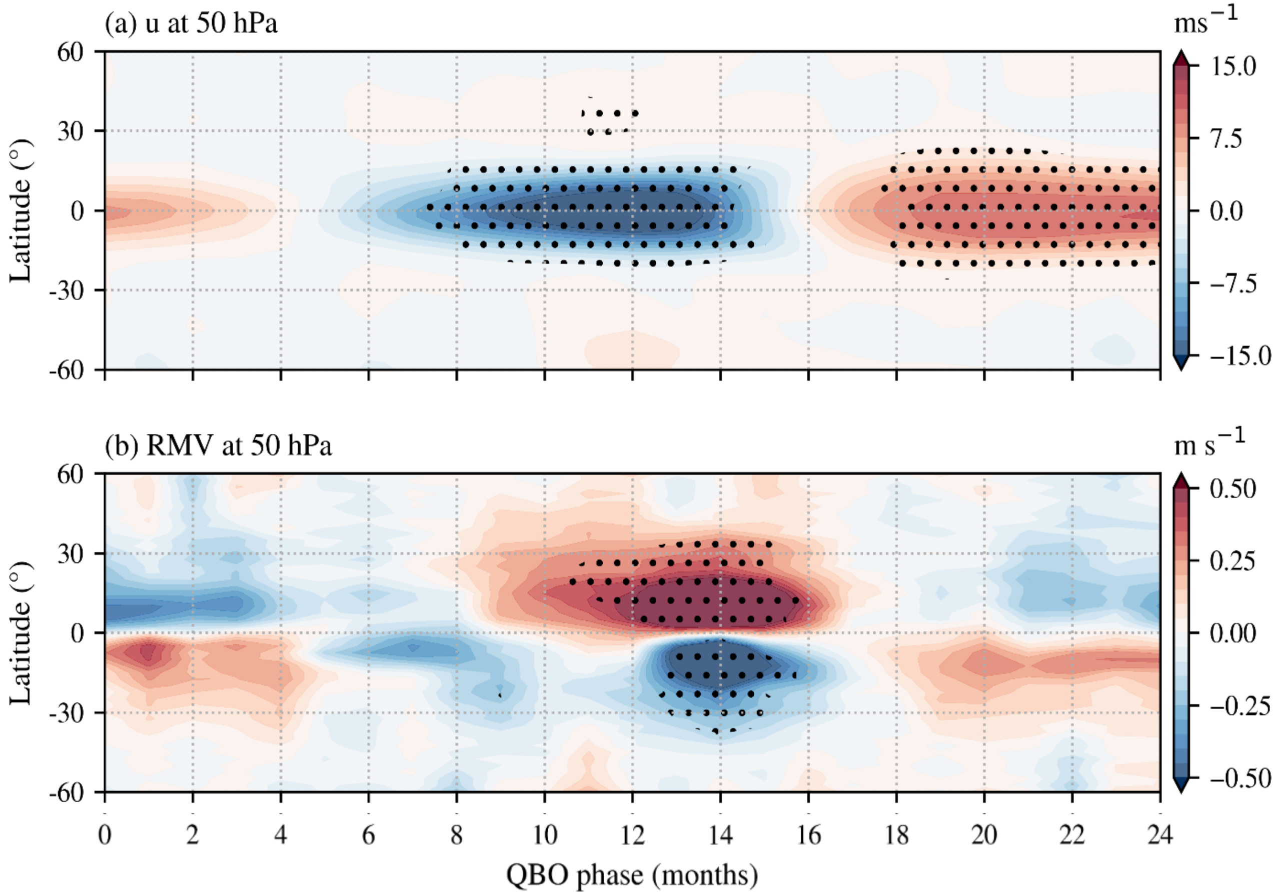


The zonally averaged zonal wind for the tropical region from the ERA5 reanalysis and the method followed for the QBO composite study.

QBO & BDC

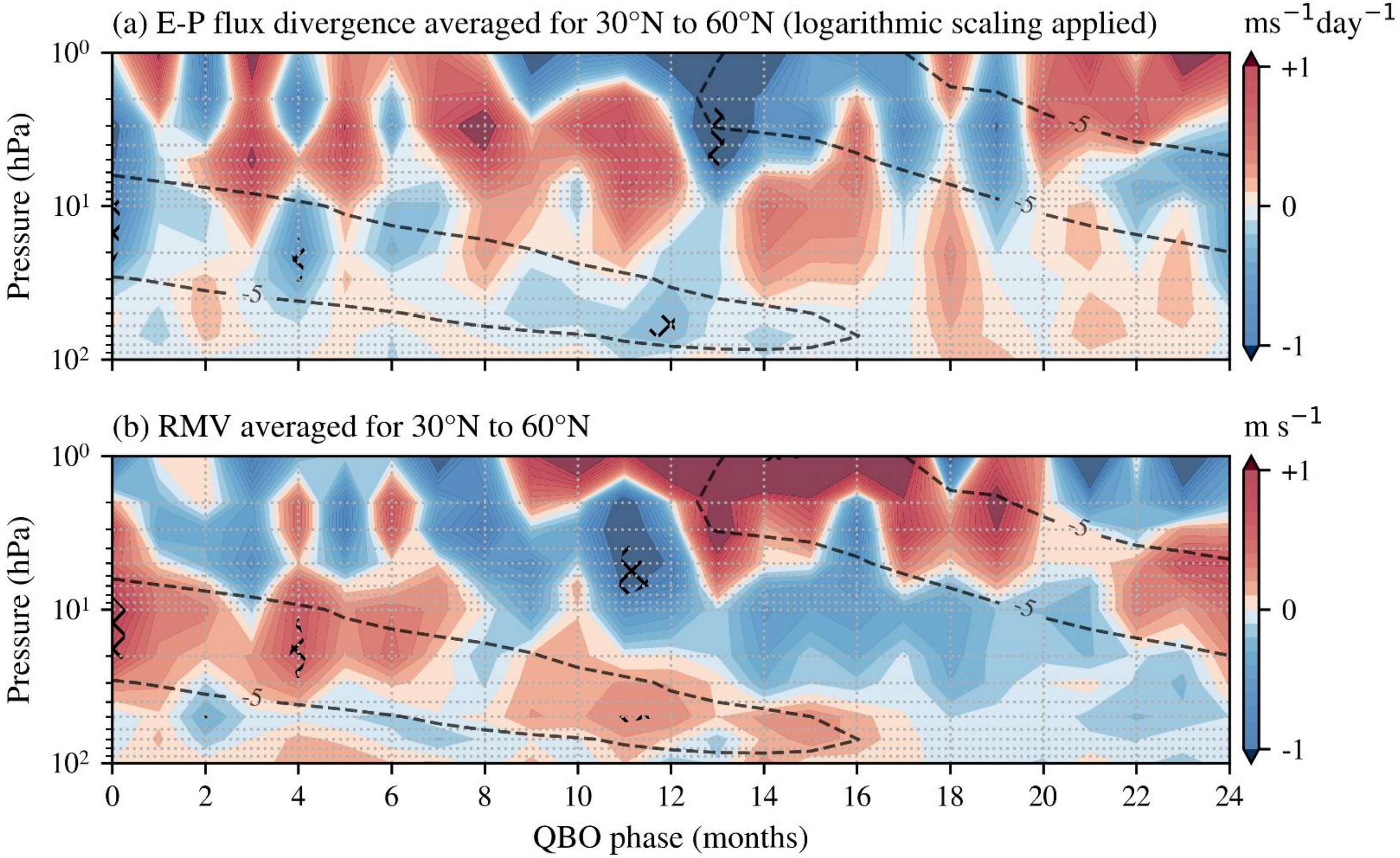
- Method
- BDC metrics
- Stratospheric changes

BDC metrics



The composites of zonal wind, residual meridional velocity (RMV) composited based on the tropical zonal mean zonal wind

BDC metrics



The composites of Eliassen-Palm (E-P) flux divergence and residual meridional velocity (RMV) composited based on the tropical zonal mean zonal wind.

The Eliassen-Palm flux divergence gives zonal force per unit mass.

The components of the vector are given by,

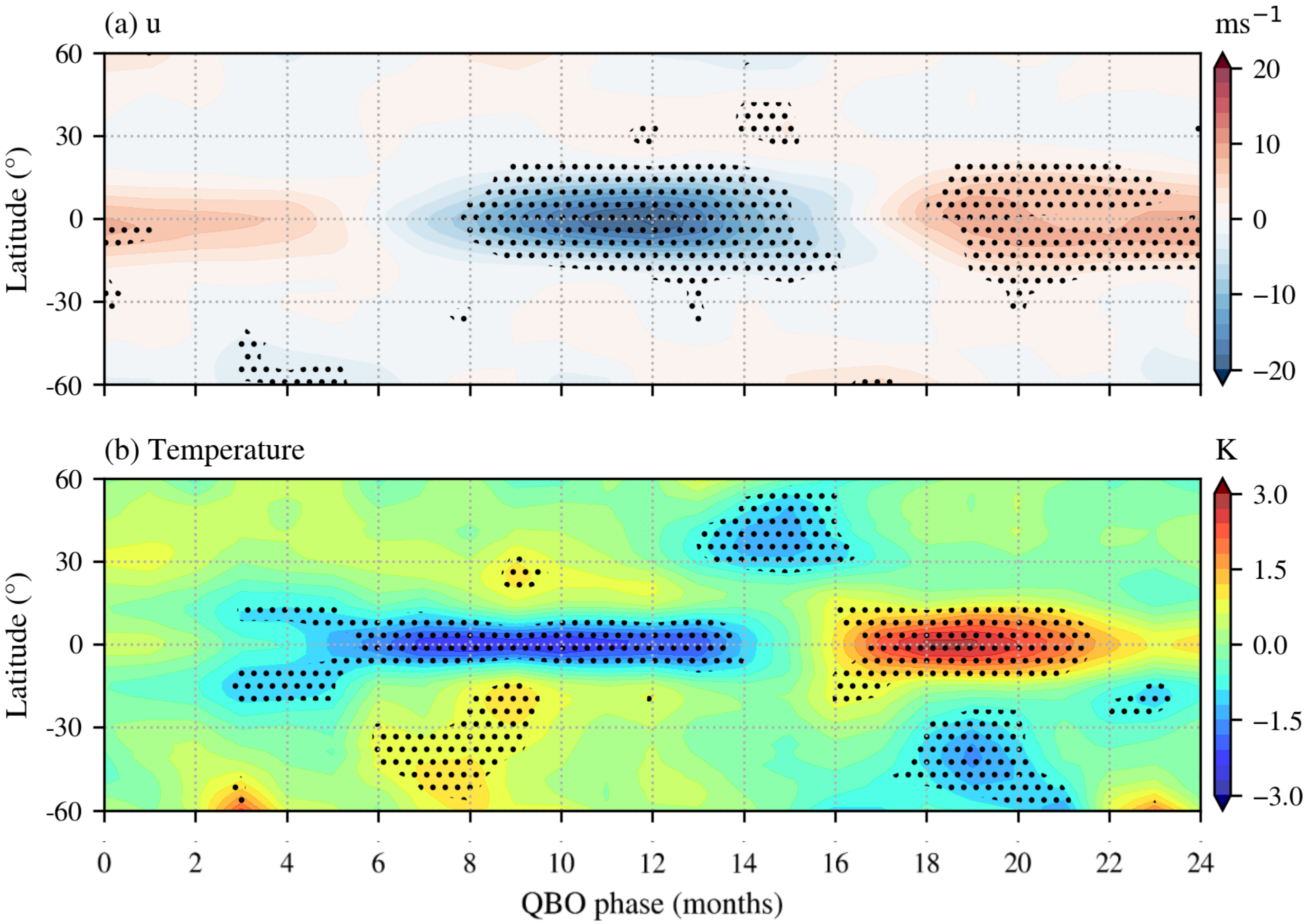
$$F_{\phi} = -\rho a \cos \varphi \overline{u'v'}$$

$$F_z = f\rho a \cos \frac{(\overline{v'\theta'})}{\overline{\theta_z}}$$

QBO & BDC

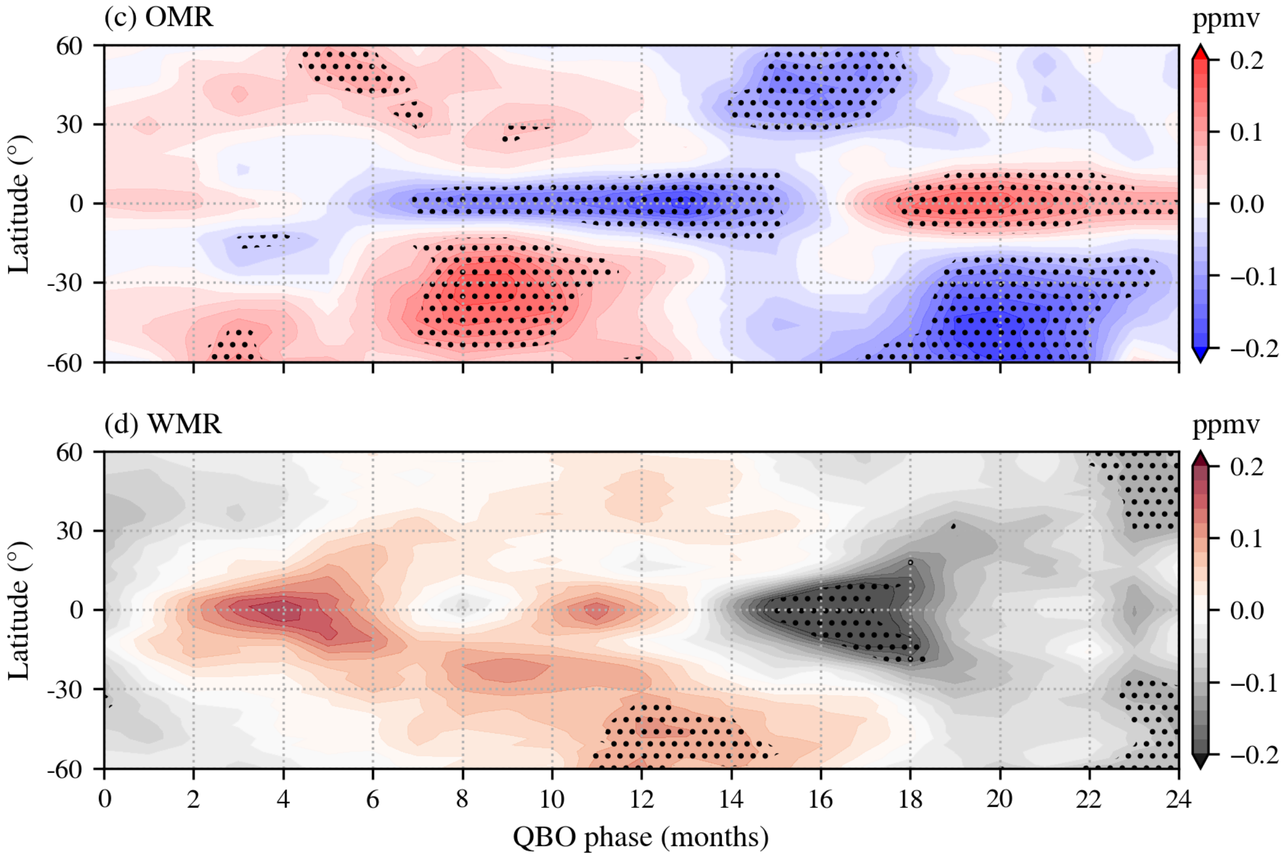
- Method
- BDC metrics
- Stratospheric changes

Stratospheric wind and thermal structure

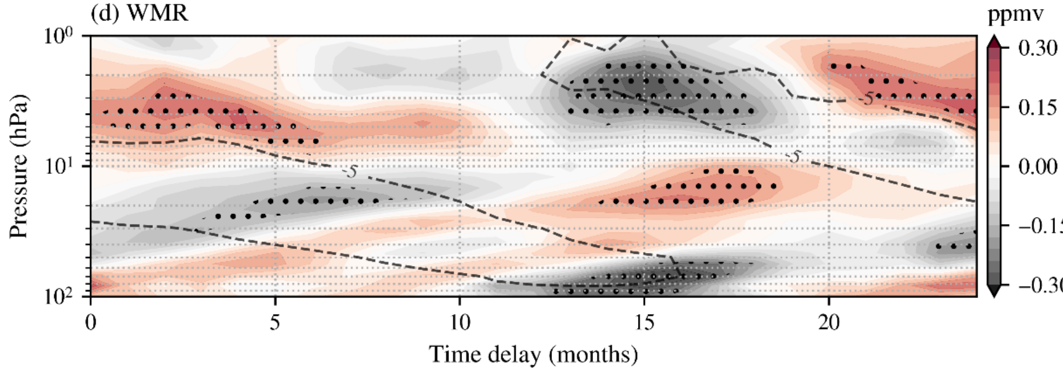


The composites of zonal wind and temperature based on the tropical zonal mean zonal wind.

Stratospheric ozone and water vapor



The composites ozone mixing ratio (OMR) and water vapor mixing ratio (WMR) based on the tropical zonal mean zonal wind.



QBO impact on BDC

a) The westward phase of QBO supports more wave breaking in the stratosphere and results in a increased intensity of BDC than eastward phase of QBO.

b) The varying wind condition in the QBO-W and changing position of zero-wind line supports wave propagation and breaking in the mid-latitudes in the stratosphere which will lead to more meridional transport.

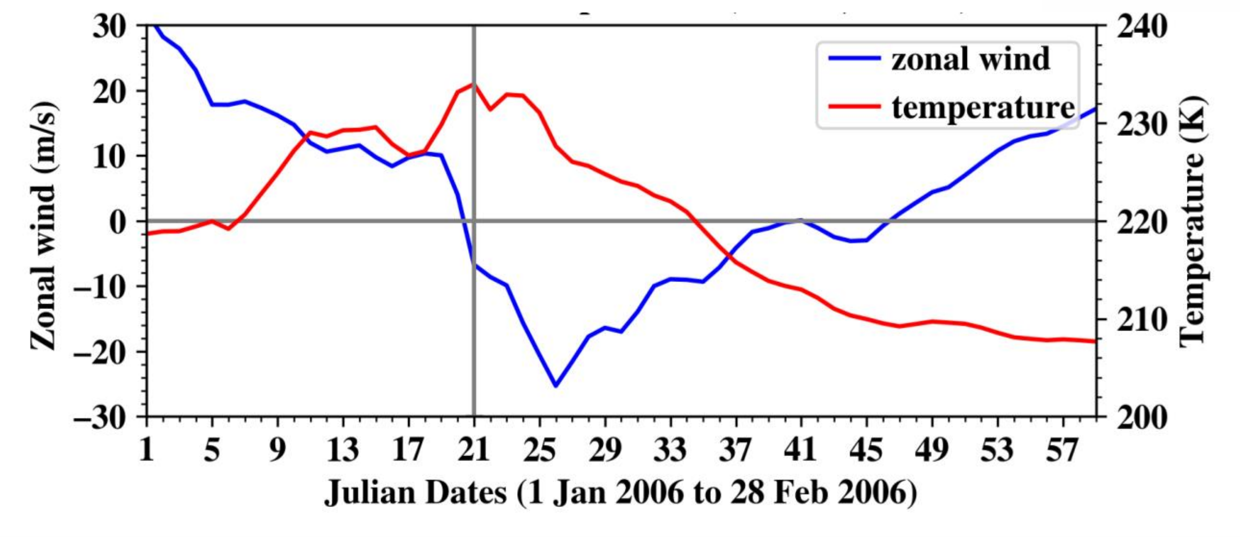
c) The downward propagation of wave activity with wave convergence during QBO-W in both hemisphere is observed in high latitudes in line with QBO wind patterns over the tropics.

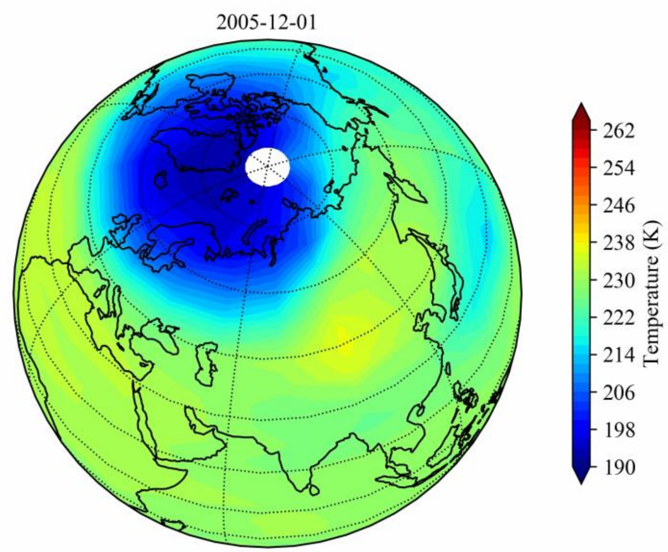
d) In NH, during westward wind phase in tropics, the wave breaking over 30°N to 60°N latitudes closely follows the tropical wind pattern. And enhanced meridional transport towards the higher latitudes is observed.

e) The temperature and ozone show a similar propagation as QBO in the lower and middle stratosphere.

QBO induced BDC changes in the thermal structure and stratospheric ozone distribution

Sudden Stratosphere Warming - SSW





The sudden stratospheric warming events are characterised by a rapid increase of polar cap temperatures within a few days during winters.

Time evolution of zonal-mean zonal wind at 60^{o} North at 10 hPa and zonal-mean temperature at 10 hPa averaged for latitudes 65^{o} N to 90^{0} N taken from ERA-5 reanalysis.

Composite Analysis

Year	Central Date
2006	21 January
2007	24 February
2008	22 February
2009	24 January
2010	9 February
2016	6 March
2018	12 February

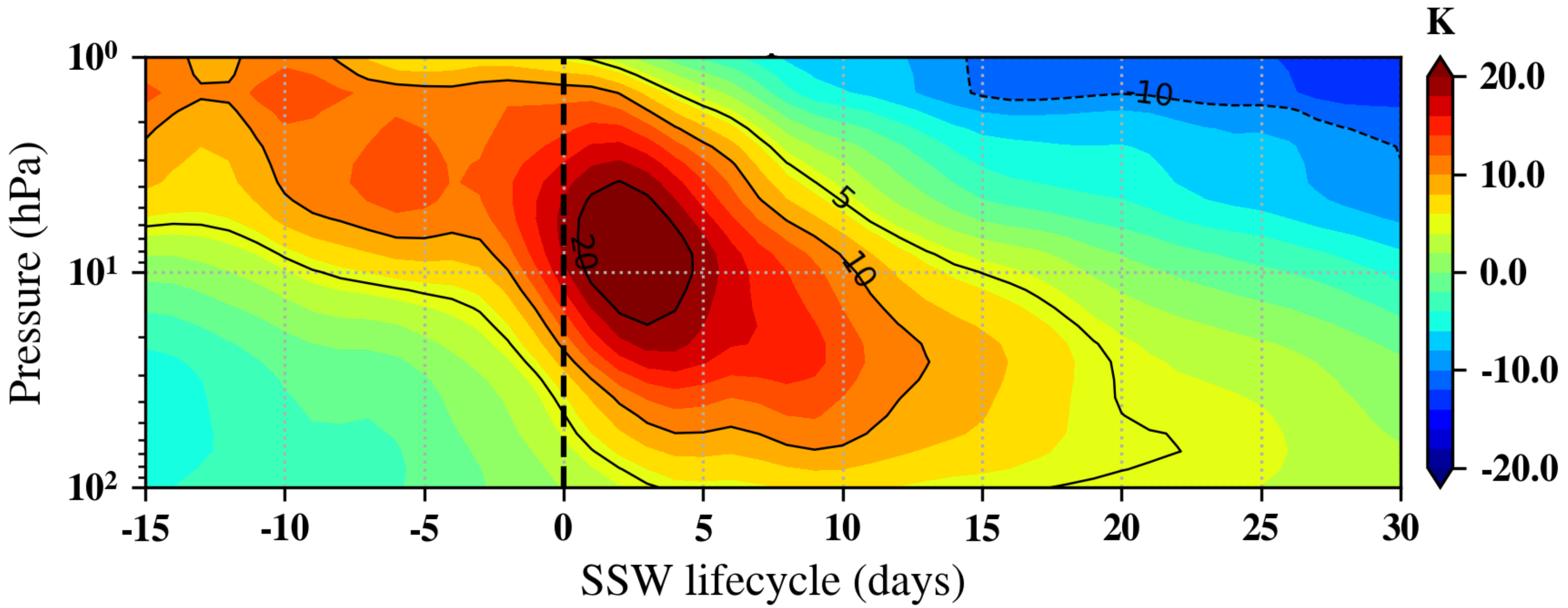
SSW & BDC

- Atmospheric background
- BDC metrics
- Stratospheric changes

SSW & BDC

- Atmospheric background
- BDC metrics
- Stratospheric changes

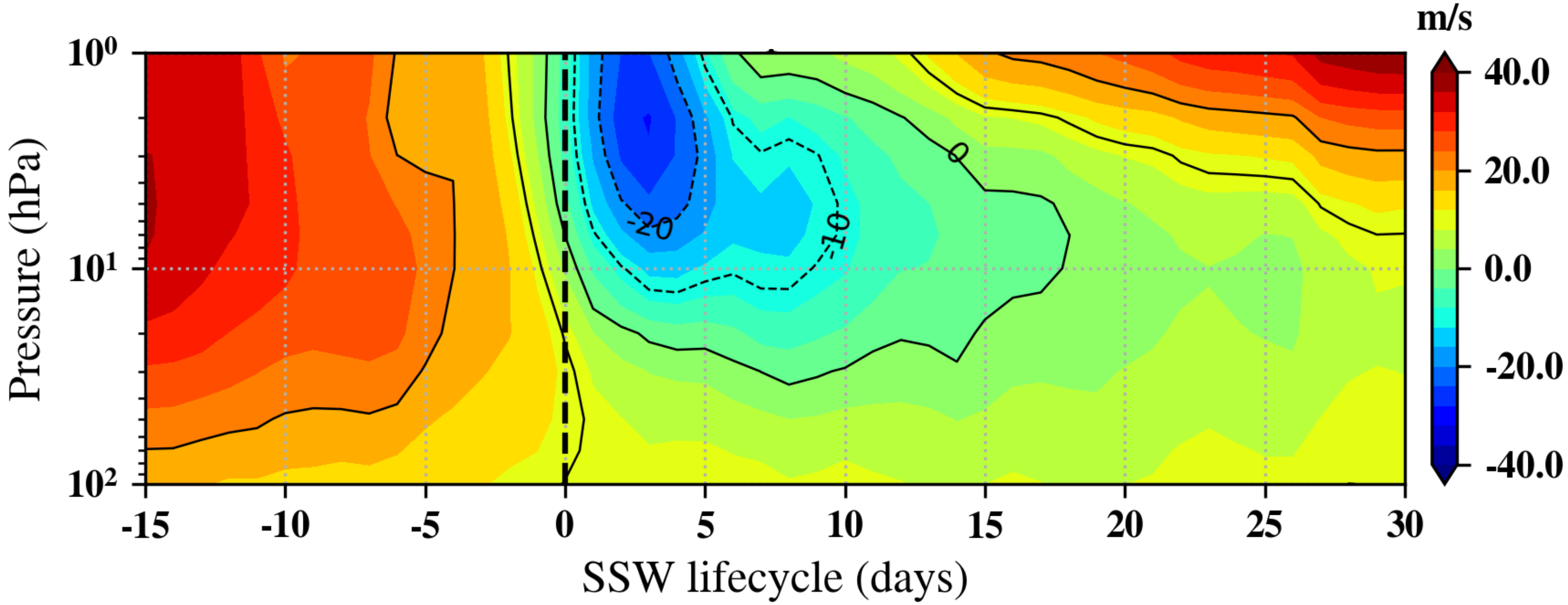
Polar stratosphere temperature during warming



The composite thermal structure of polar stratosphere averaged zonally and 65°N to 90°N.

The y-axis shows stratospheric pressure levels. The x-axis shows the SSW lifecycle, with ‘0’ denoting the central date of SSW.

Zonal wind

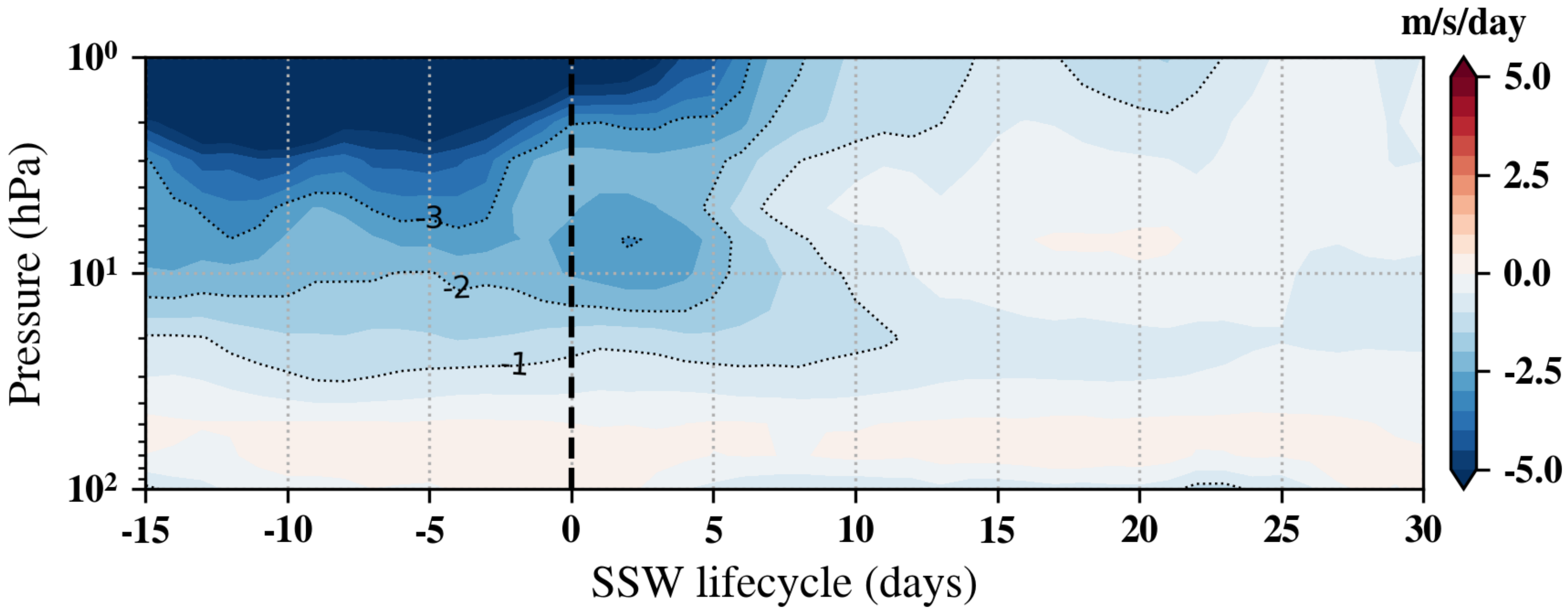


Time evolution of zonal-mean zonal wind at 60° North at 10 hPa and zonal-mean temperature at 10 hPa averaged for latitudes 65° N to 90° N taken from ERA-5 reanalysis.

SSW & BDC

- Atmospheric background
- BDC metrics
- Stratospheric changes

Eliassen-Palm flux divergence



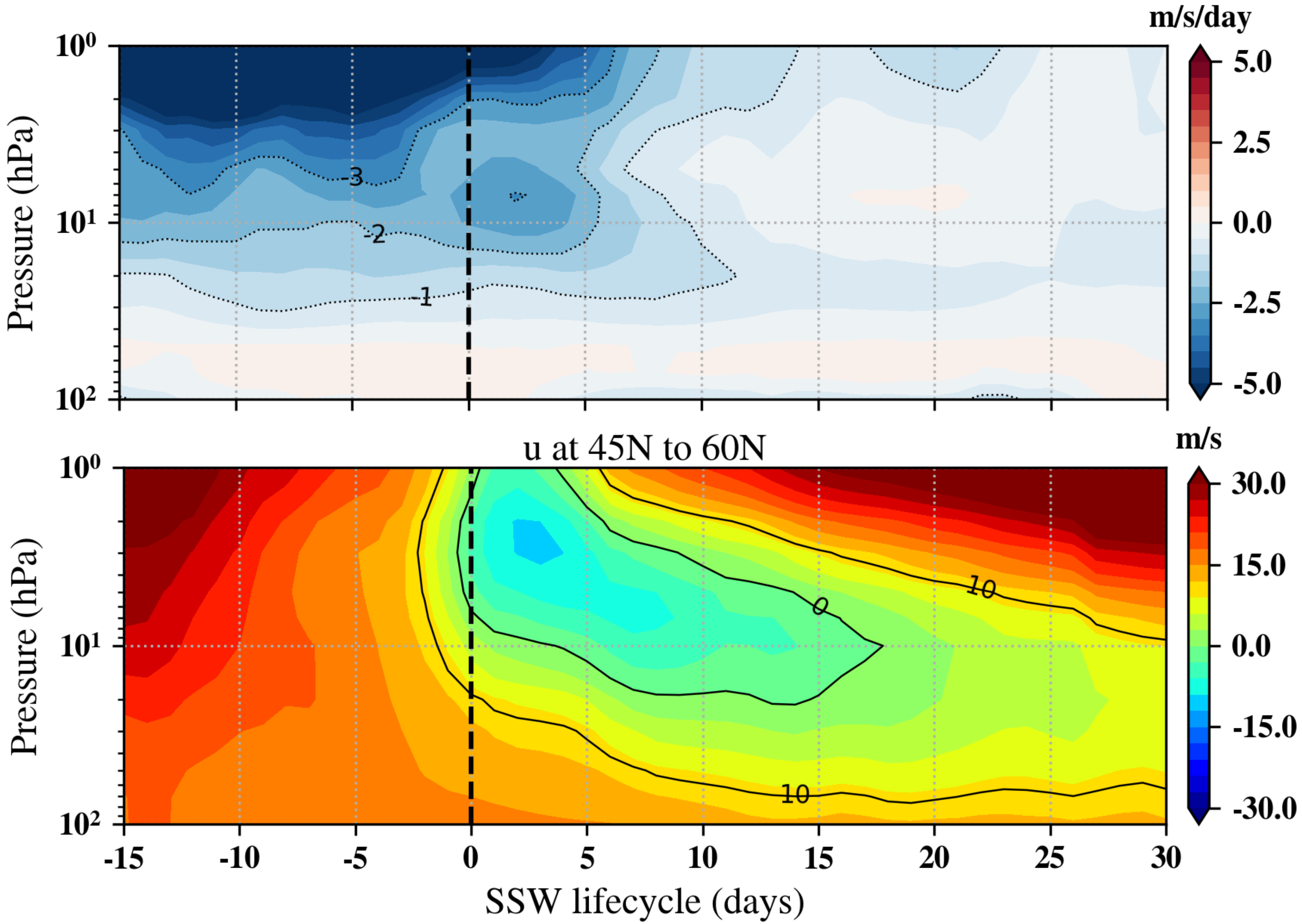
The Eliassen-Palm flux divergence gives zonal force per unit mass.

The components of the vector are given by,

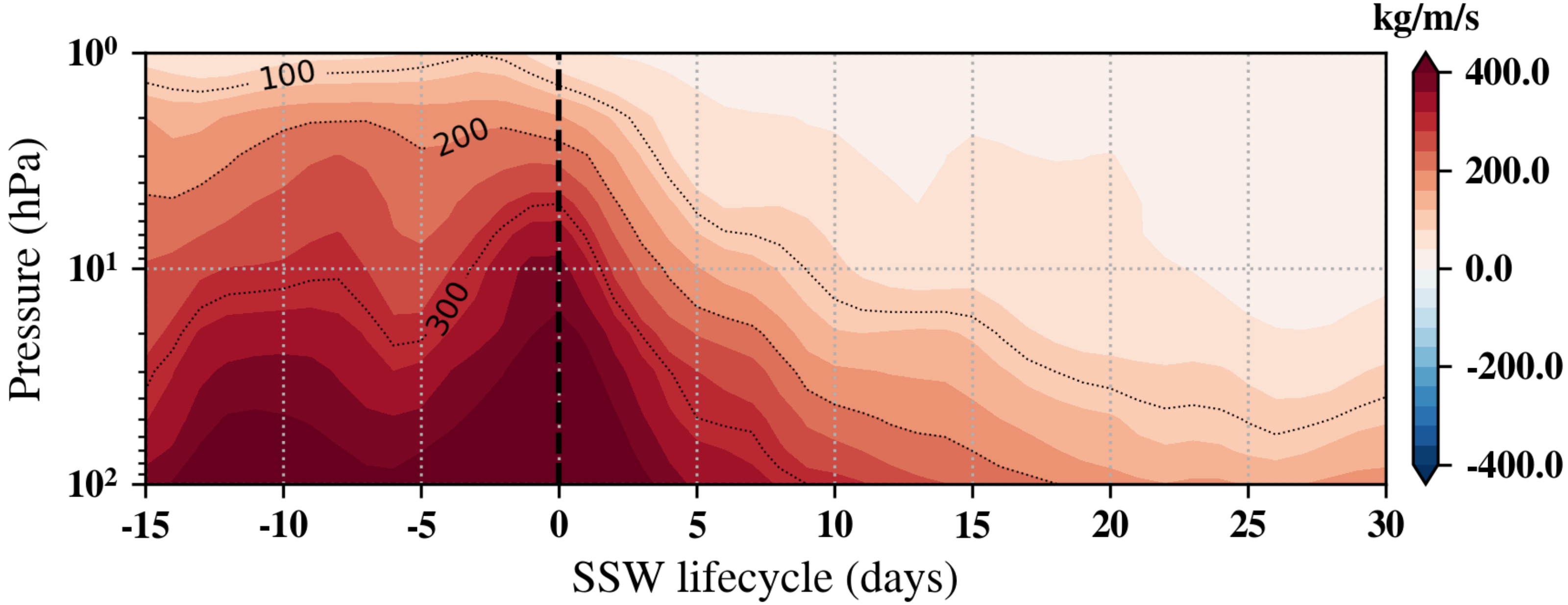
$$F_\phi = -\rho a \cos \varphi \overline{u' v'}$$

$$F_z = f \rho a \cos \frac{(\overline{v' \theta'})}{\overline{\theta}_z}$$

Eliassen-Palm flux divergence



Residual mean meridional stream function



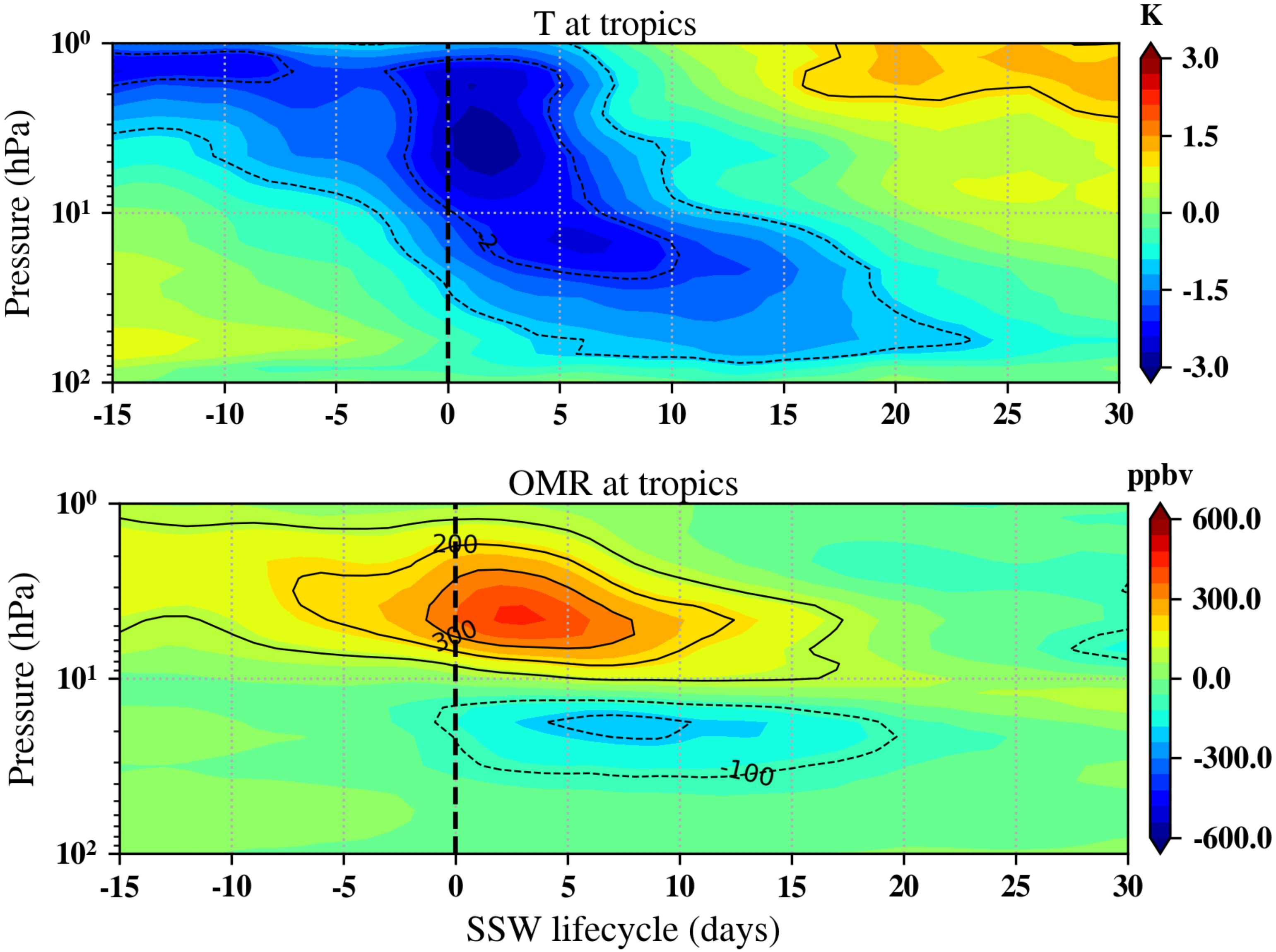
The residual mean meridional stream function (RMMSF), ψ^*, provides an approximation to the mean advective transport of trace substances.

$$\psi^* = \int_x^\infty \overline{v^*}\,\rho a \cos\varphi \; dz$$

SSW & BDC

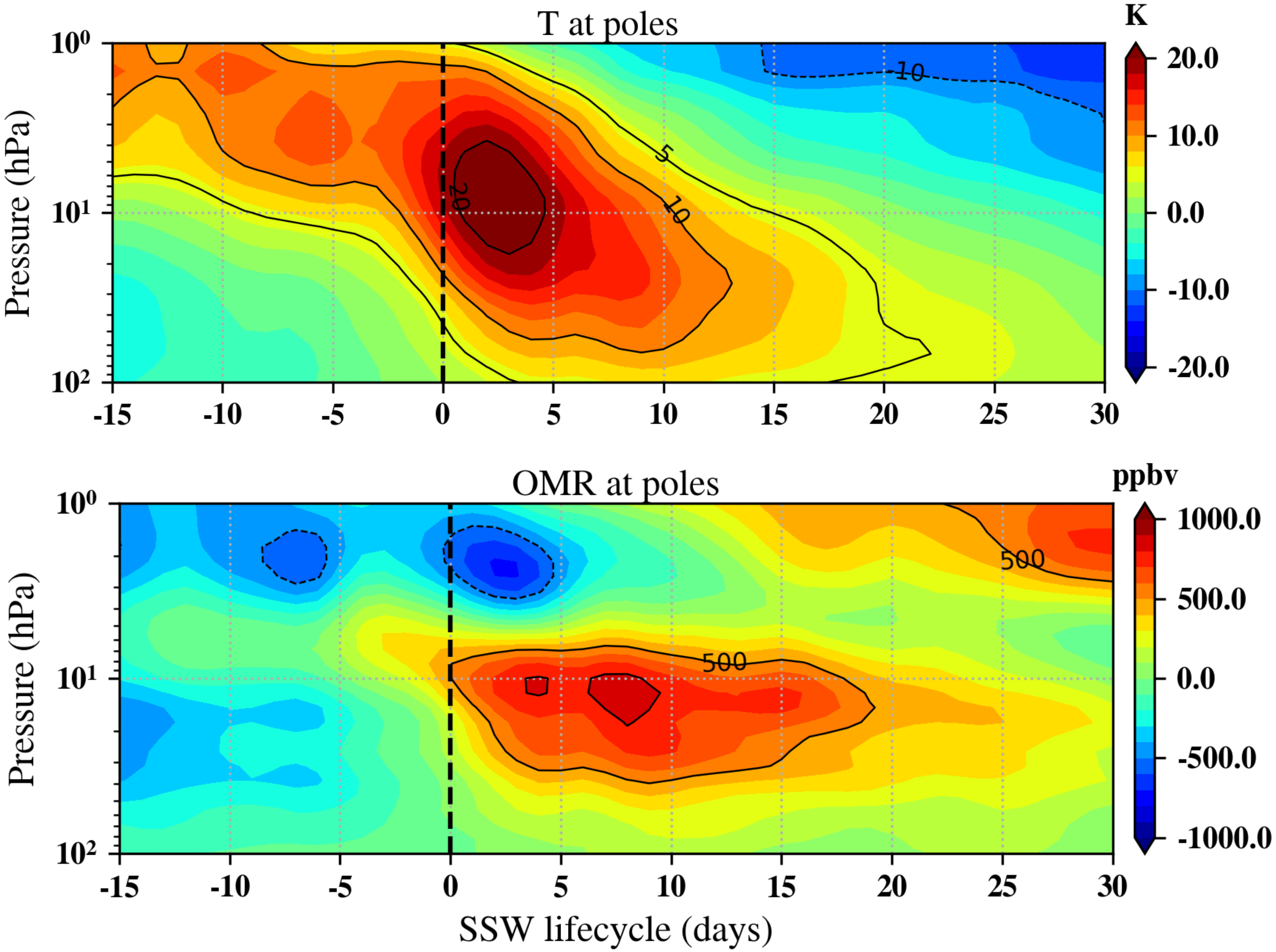
- Atmospheric background
- BDC metrics
- **Stratospheric changes**

Effects on the tropical stratosphere

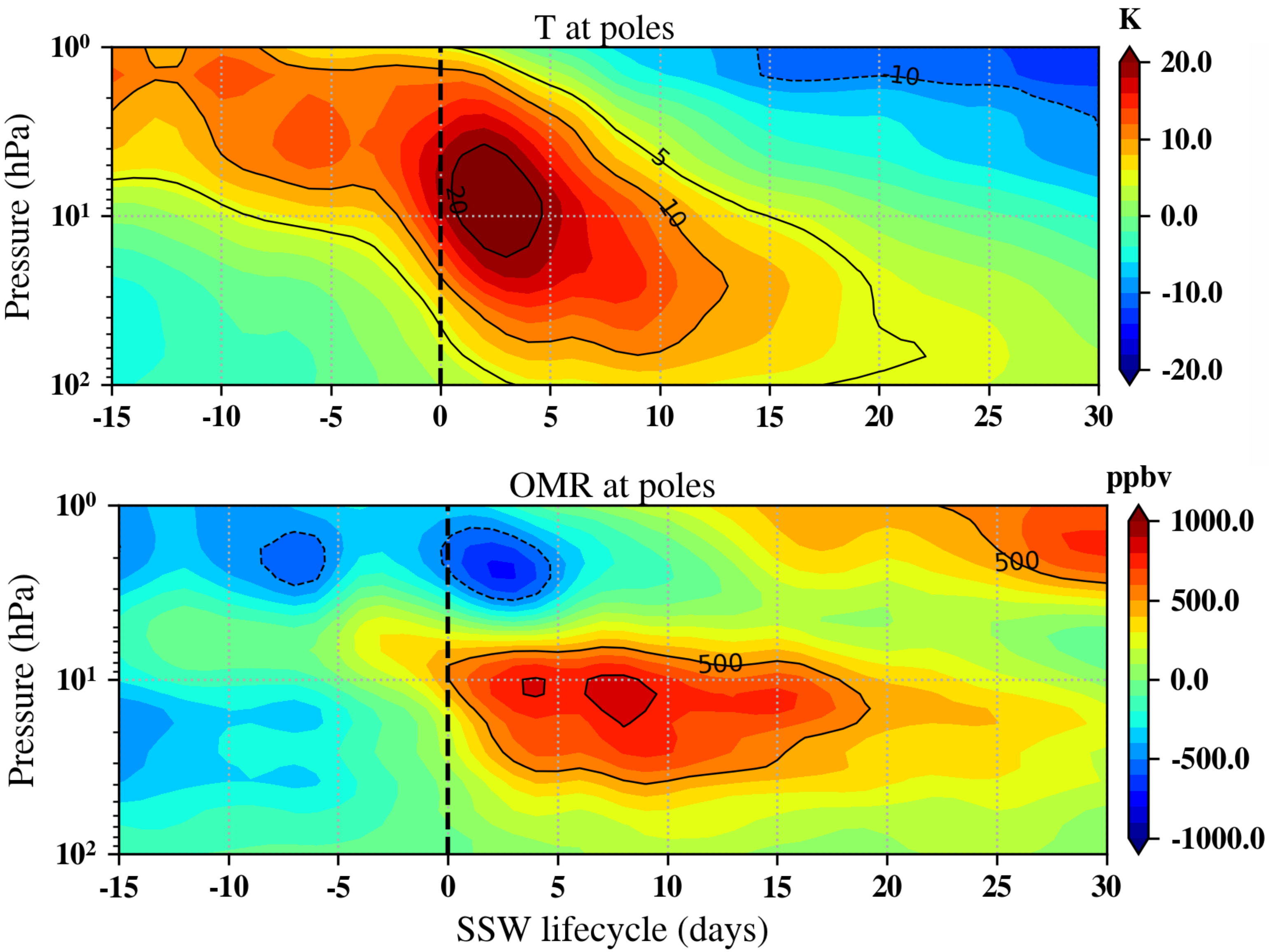


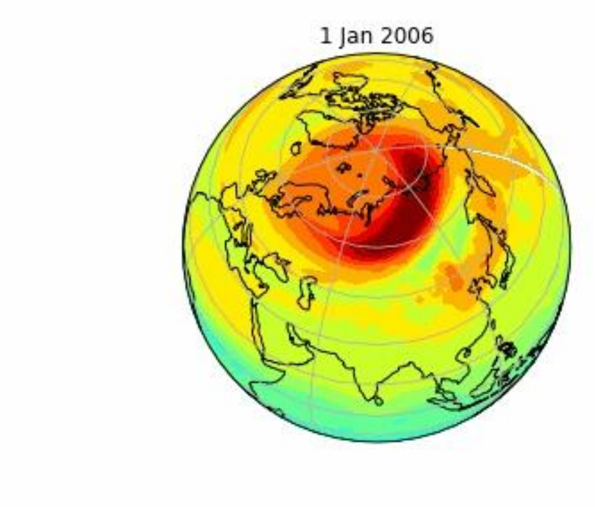
Increased upwelling cools the atmosphere as well as reduces the ozone mixing ratio.

Effects on the polar stratosphere



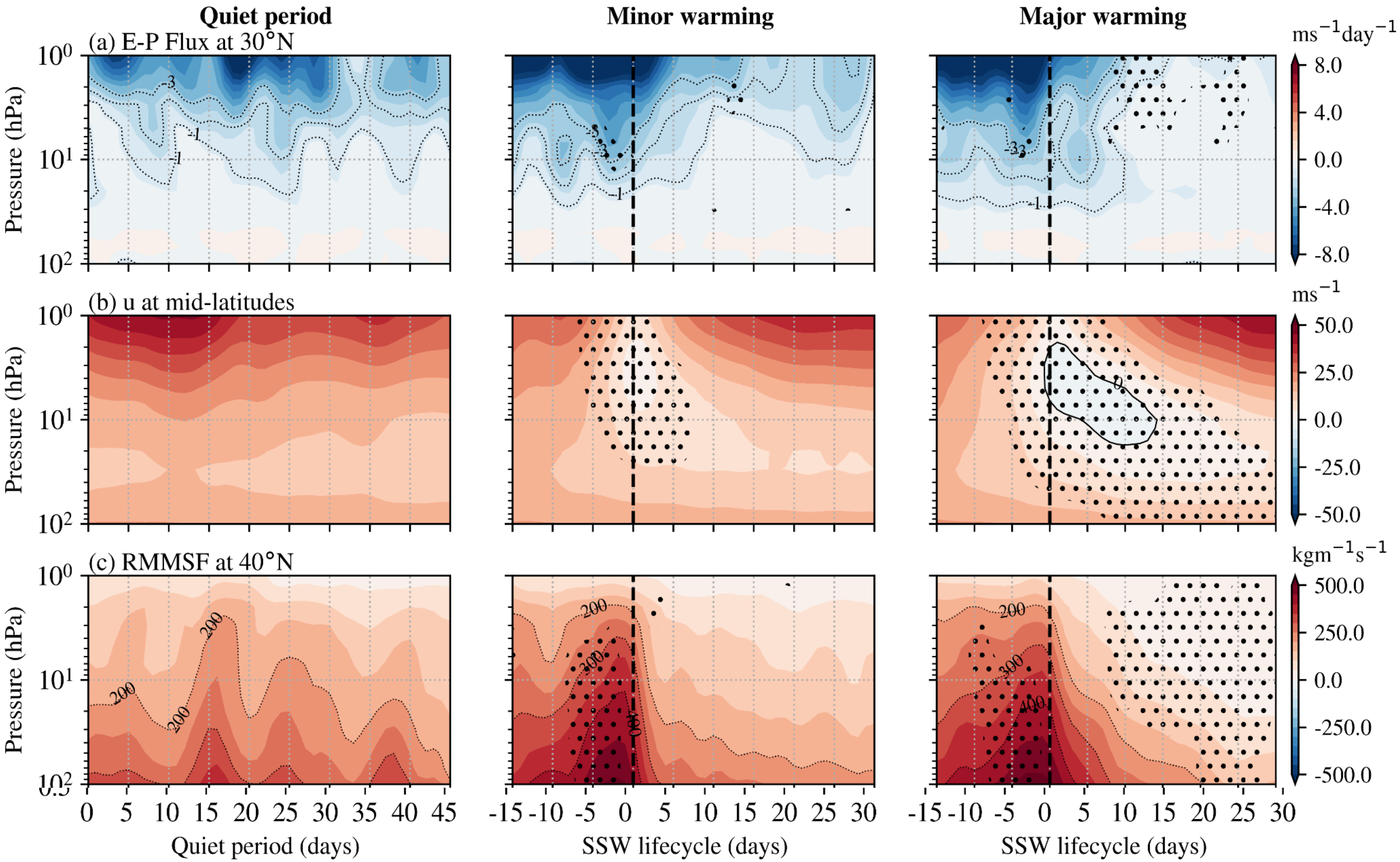
Effects on the polar stratosphere





Downwelling of mass from upper stratosphere and breaking of the vortex brings ozone rich air.

BDC & SSW



Veenus et al, GRL, 2022

SSW impact on BDC

a) The BDC strength increases during SSW.

b) Enhancement in wave driving during the warming causes the strengthened BDC. After SSW the reversal of zonal wind prevents further propagation and BDC strength decreases, as observed in RMMSF also.

c) The lower stratosphere region experiences the transport further and ozone is transported to polar region which leads to the observed reduction in ozone.

d) The enhanced downwelling results in increased ozone concentrations over polar stratosphere, whereas in the polar upper stratosphere mesosopheric air intrusion leads to ozone depletion.

Thank you