# Geomagnetic activity signatures in wintertime stratosphere

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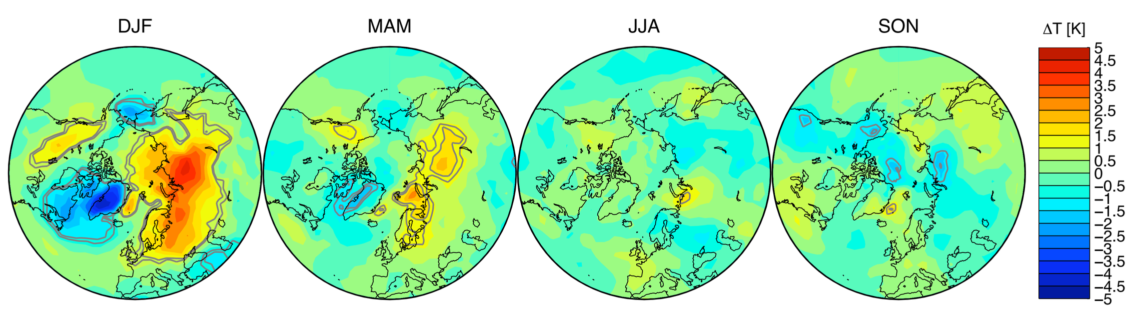
## Introduction

Solar activity in the form of energetic particle precipitation (driven by geomagnetic activity) is known to impact the chemical balance of the middle atmosphere. With many of the chemical changes now being relatively well understood, recent model studies have suggested a further impact on atmospheric dynamics via chemical-dynamical coupling.

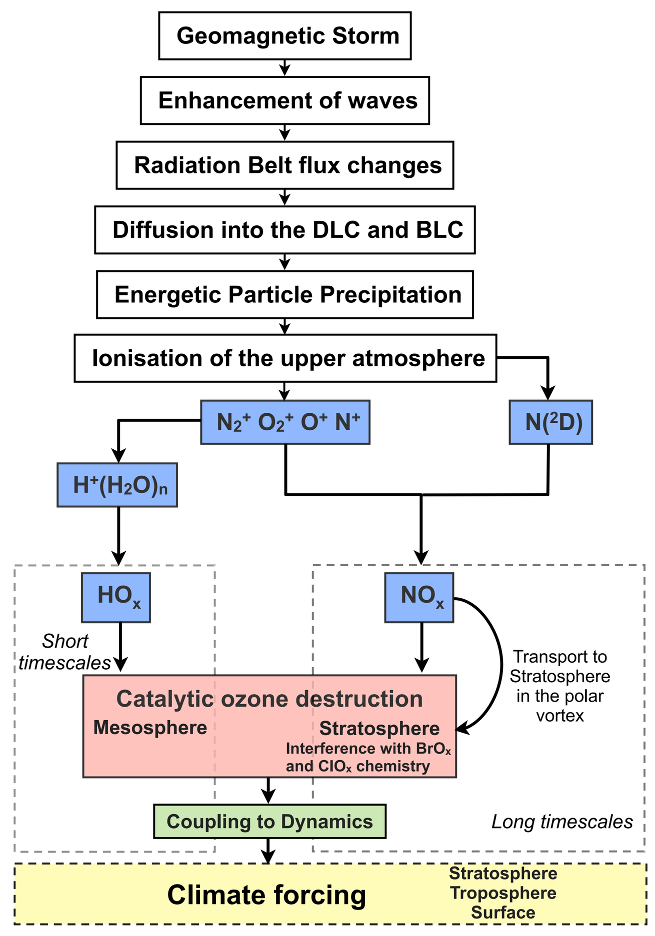
Model simulations (Rozanov *et al.*, 2005; Baumgaertner *et al.*, 2011) indicated towards a link from the initial chemical changes to modulation of polar surface temperatures during the Northern Hemisphere winter months. Seppälä *et al.* (2009) investigated surface temperatures from re-analysis and found signals similar to those predicted by the model simulations (Figure below). To better understand the role of wave-mean flow interaction in linking geomagnetic activity to surface level changes, we analysed stratospheric zonal winds and temperatures together with Eliassen-Palm fluxes for times of high and low geomagnetic activity.




For full details see Seppälä *et al.* (2013) *Geomagnetic activity signatures in wintertime stratosphere wind, temperature, and wave response*, JGR.

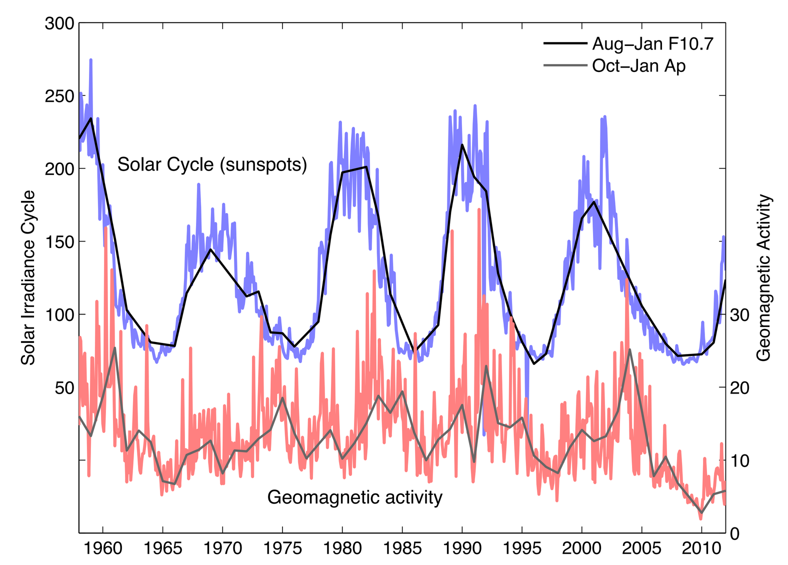
## Understanding the effects on the atmosphere

- Enhanced ionisation in the polar atmosphere increases production of Odd Hydrogen ($HO_x$) and Odd Nitrogen ($NO_x$) in the mesosphere and stratosphere.
- $HO_x$ and $NO_x$ are important for ozone balance in the mesosphere and upper stratosphere.




## What is energetic particle forcing?

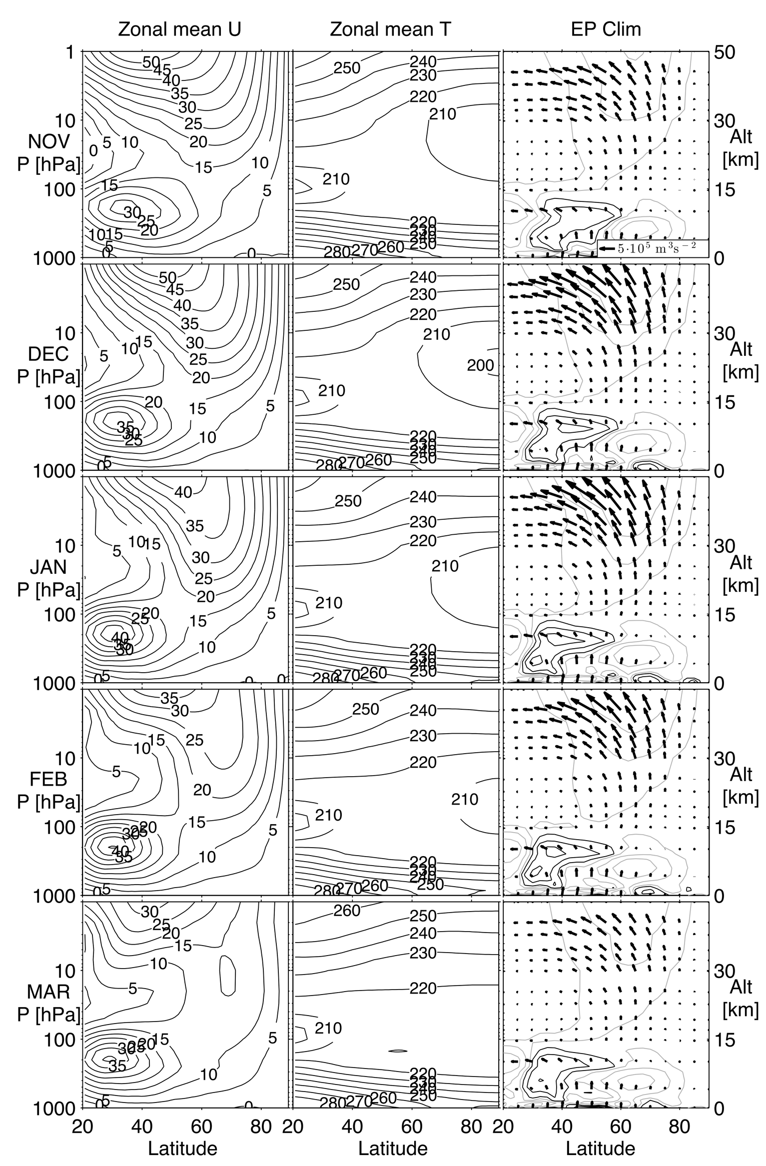
- Protons and electrons from the Sun and magnetosphere.
- Guided by the magnetic field to polar regions where they precipitate into the atmosphere.
- Increases ionisation in the mesosphere and upper stratosphere.
- Highly varying source of activity. Typically peaks during the declining phase of the solar cycle, but not strictly tied to the solar cycle.
- Energetic particle precipitation levels are modulated by geomagnetic activity. **While we don't have good long term observations of particle precipitation, we can use geomagnetic activity as a proxy.**




## Datasets

- Zonal mean wind ($U$), zonal mean temperature($T$), Eliassen-Palm ($EP$) flux
  - ERA-40 re-analysis, 1958 - 1988
  - ERA Interim re-analysis 1989 - 2008
  - Means for 1958-2008 shown on the right.
- Particle precipitation levels: Geomagnetic activity index $A_p$
- Median normalised $A_p$: High activity: $A_p > 0.1$ Low activity: $A_p < -0.1$
- Solar irradiance cycle phase (Solar max/min): Solar radio flux $F_{10.7}$

### 1958-2008 means




## Why study geomagnetic activity influence on atmosphere?

Understanding how all the different sources of solar variability affect the Earth's climate helps us to separate natural climate variability and anthropogenic climate change.

Understanding our Sun's role as natural climate driver will help improve climate predictions and to predict regional climate variations.

## References

Rozanov et al. (2005) Atmospheric response to $NO_y$ source due to energetic electron precipitation, GRL, 32, L14811, doi:10.1029/2005GL023041

Baumgaertner et al. (2011) Geomagnetic activity related $NO_x$ enhancements and polar surface air temperature variability in a chemistry climate model: modulation of the NAM index, ACP, 11, 4521–4531, doi:10.5194/acp-11-4521-2011

Seppälä et al. (2009) Geomagnetic activity and polar surface air temperature variability, JGR, 114, A10312, doi:10.1029/2008JA014029

Seppälä et al. (2013) Geomagnetic activity signatures in wintertime stratosphere wind, temperature, and wave response, JGR, 118, doi:10.1002/jgrd.50236

## Results

### Anomalies: High and Low geomagnetic activity levels. No solar cycle filtering.

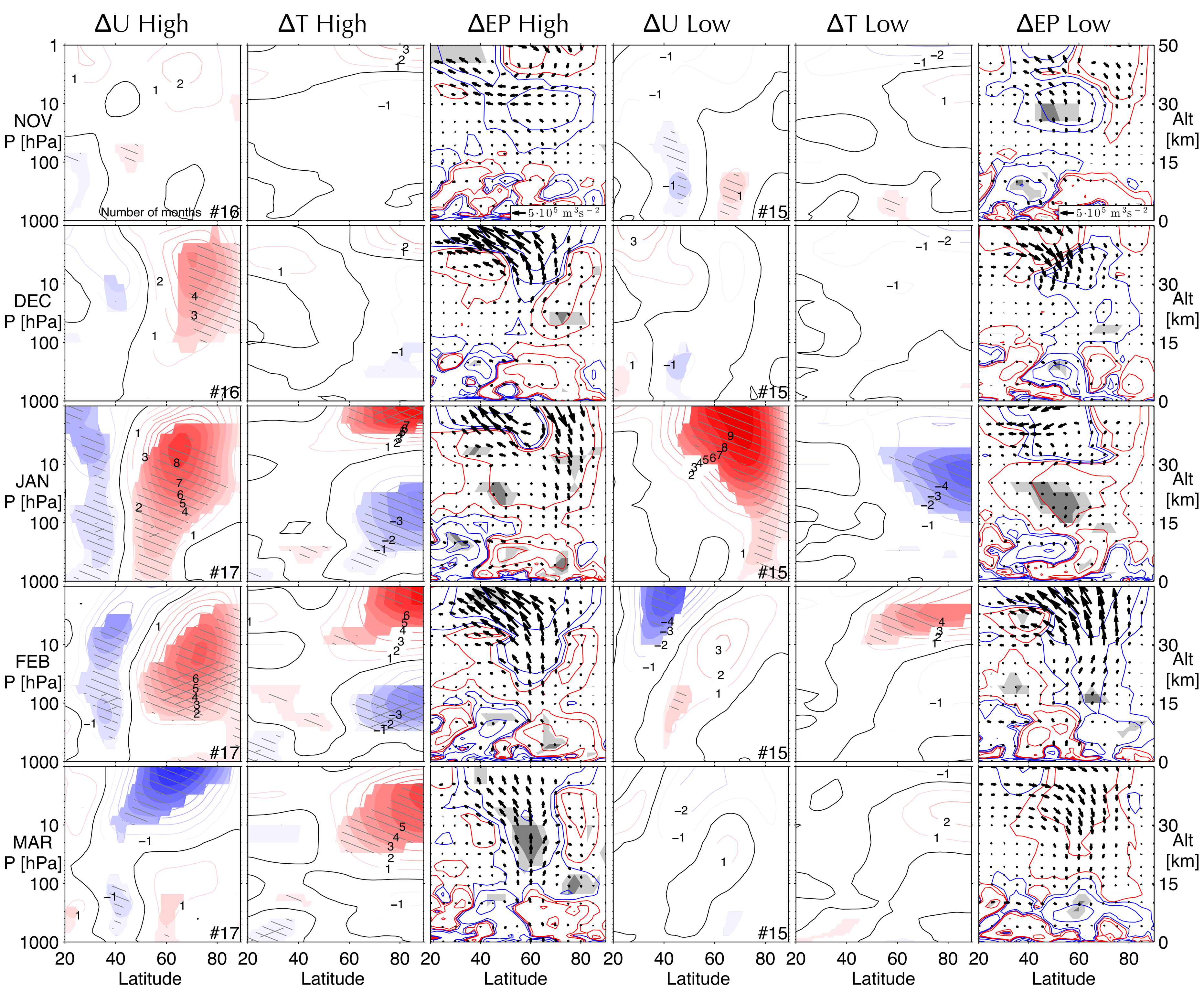



Figure 1. Monthly Northern Hemisphere zonal mean zonal wind ($\Delta U$, [m/s]), temperature ($\Delta T$, [K]) and Eliassen-Palm flux and EP flux divergence ($\Delta EP$) **anomaly relative to the mean**. Left panels: High geomagnetic activity. Right panels: Low geomagnetic activity. Colour shading on $U$ and $T$, and grey shading in EP flux indicates statistically significant values.

### Composite differences: High - Low geomagnetic activity during Solar max

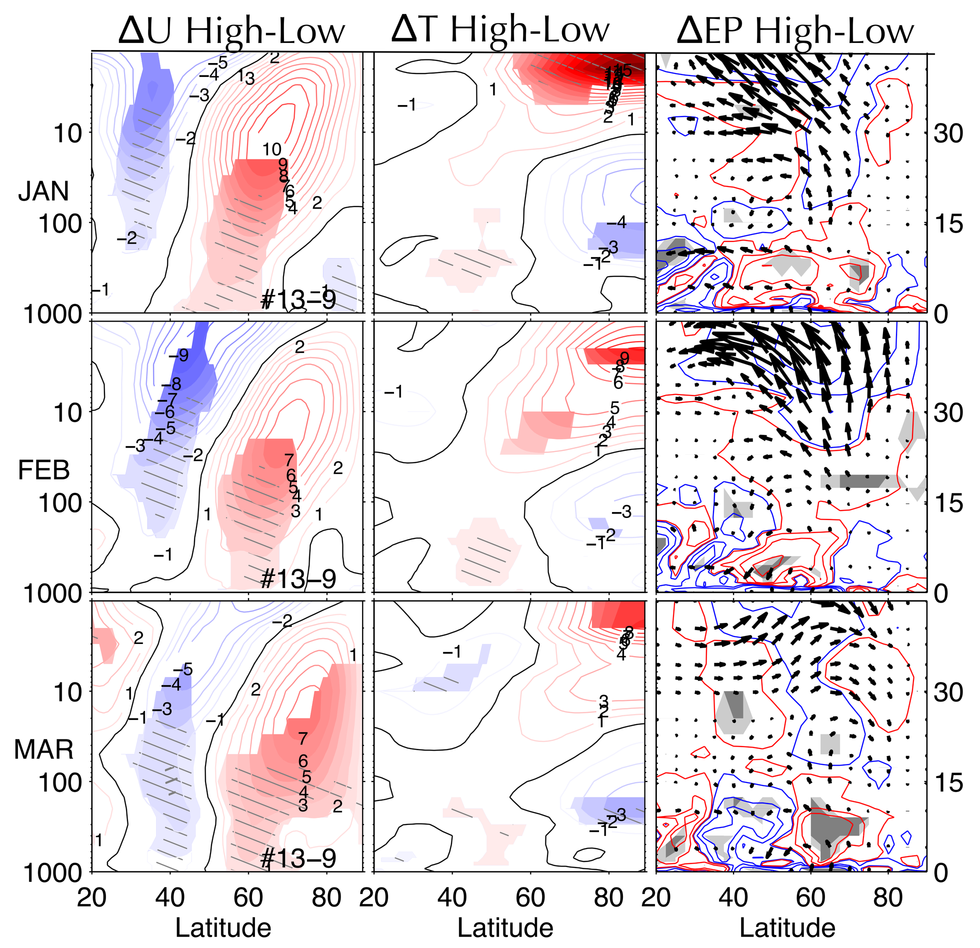



Figure 2. Monthly $\Delta U$, $\Delta T$, $\Delta EP$ **composite differences** (High geomagnetic activity - low geomagnetic activity) for **Solar max (irradiance) conditions**.

For high geomagnetic activity, the dynamical signals are marked by the following:

1. **Reduced upward propagation of waves into the stratosphere in early winter, followed by**
2. **Enhanced equatorward reflection of waves from the polar vortex edge,**
3. **Warming of the polar upper stratosphere and cooling below, starting in Dec–Jan and continuing into Mar,**
4. **Descent of the warming signal from Jan to Mar,**
5. **Anomalously strong polar vortex in late winter, as measured by changes in zonal mean zonal winds, leading to positive Northern Annular Mode anomalies.**

These results suggest that energetic particle forcing may affect wave propagation, zonal mean temperatures and zonal winds in the Northern Hemisphere winter stratosphere. Signals are observed during Nov-Mar, and are strongest when the stratosphere background flow is relatively stable, or when the polar vortex is stronger and less disturbed in early winter (e.g. solar max or westerly QBO).

**For details on the analysis, statistics and data grouping see: Seppälä et al. (2013) Geomagnetic activity signatures in wintertime stratosphere wind, temperature, and wave response, JGR, 118, doi:10.1002/jgrd.50236 or scan the code!**