Planetary waves modulating the effect of energetic electron precipitation on polar vortex

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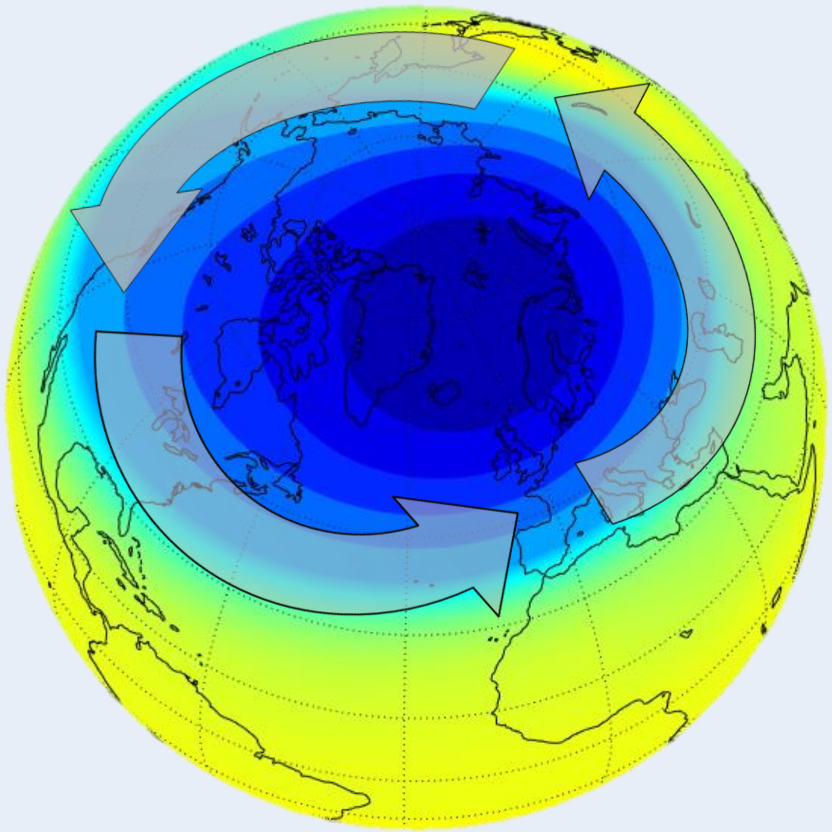
Introduction: Polar vortex & EEP

A strong westerly wind surrounds the cold winter pole in the stratosphere, forming the polar vortex.

- Planetary waves disturb the vortex.

Energetic electron precipitation (EEP) strengthens the polar vortex in the northern hemisphere.

How the EEP effect on polar vortex depends on planetary waves?



PCA for EP-flux

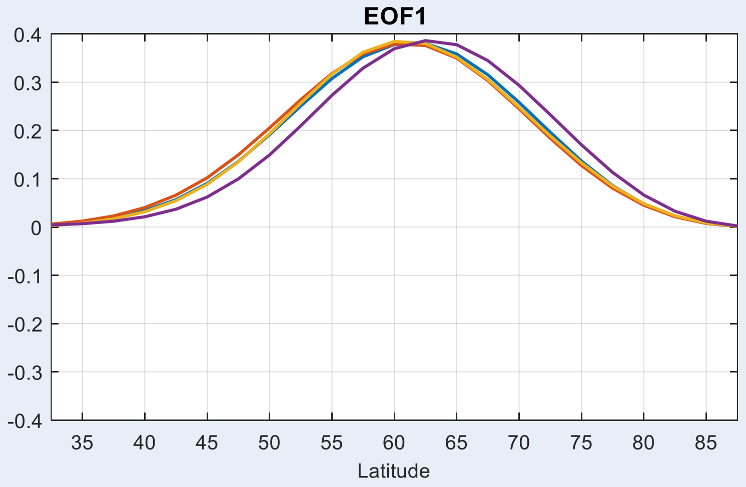
Atmospheric variables:

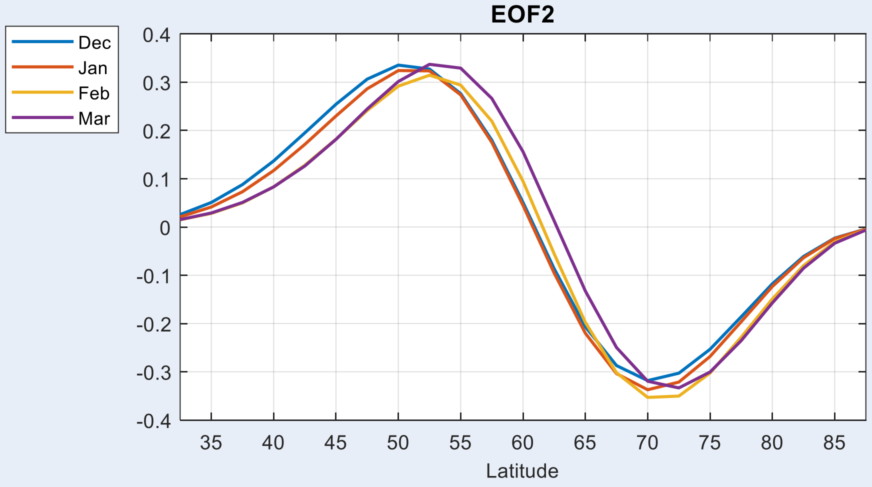
Combined ERA-40/ERA-Interim dataset

- Winters 1957/1958 – 2018/2019

To study planetary waves, we calculate principal component analysis for vertical component of EP-flux $(\boldsymbol{F_z})$ at 30-90N at 30 hPa separately for each northern winter month.

- Two modes explain >95% of variability.





1. EOF/PC

Overall intensity of EP-flux / planetary waves

PC1 positive **(PC1+)**

⇒ Strong overall planetary wave activity

PC1 negative **(PC1-)**

⇒ Weak overall planetary wave activity

2. EOF/PC

Latitudinal difference in EP-flux / planetary wave pattern

PC2 positive **(PC2+)**

⇒ Planetary waves focused to lower latitudes

PC2 negative **(PC2-)**

⇒ Planetary waves focused to higher latitudes

Zonal wind response to EEP in PC1 phases

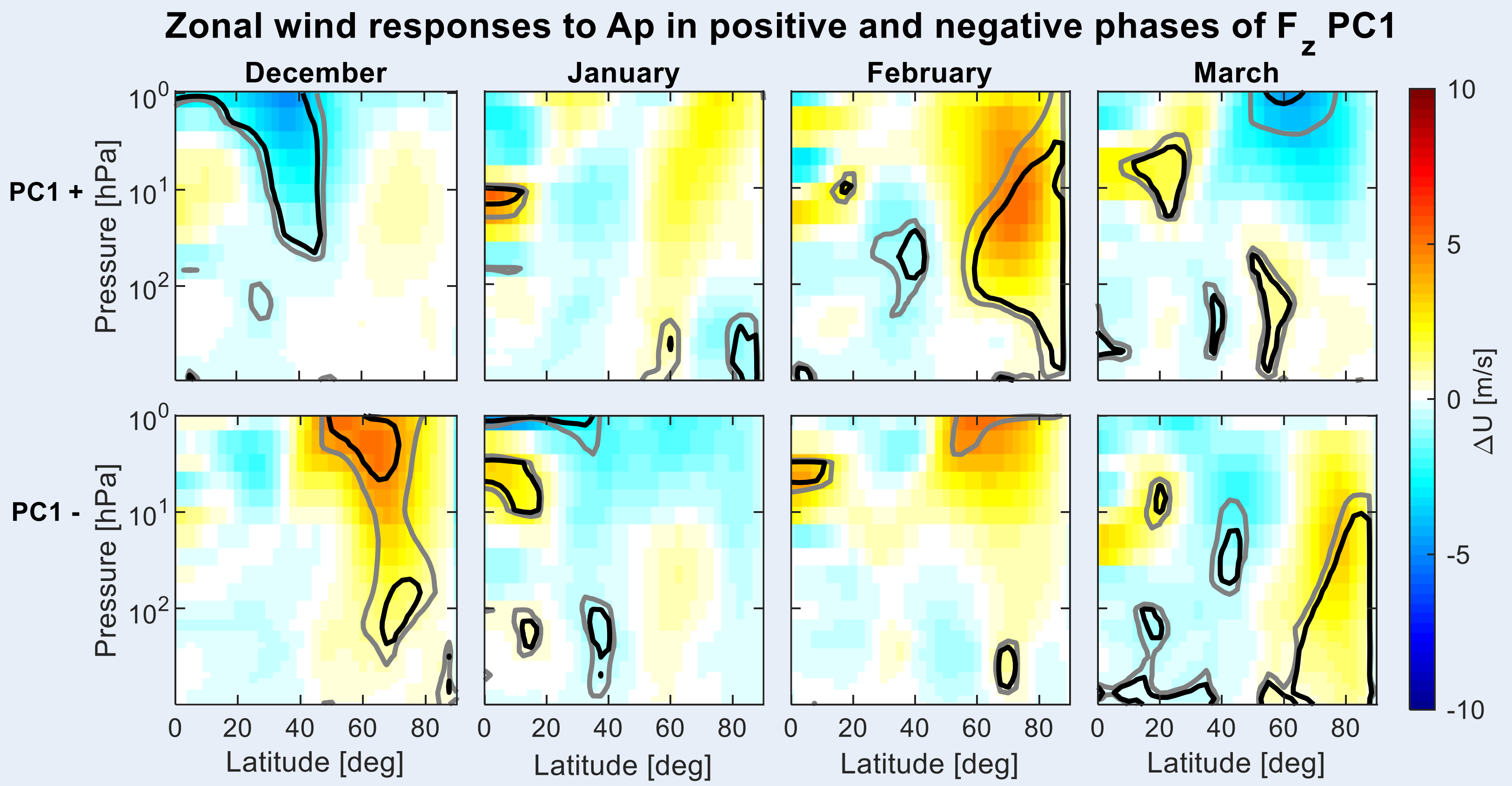
We calculate regressions to estimate zonal wind responses to EEP in the four PC phases (PC1+, PC1-, PC2+, PC2-).

- Ap index used a proxy for EEP

<u>Positive PC1 (top row):</u>
Positive polar vortex response to EEP, significant only in February

<u>Negative PC1 (bottom row):</u>
Positive and significant response on polar vortex in December and March, weak response in February

⇒ Weak and inconsistent EEP effect on polar vortex in both PC1 phase



Zonal wind response to EEP in PC2 phases

Positive PC2 (top row):

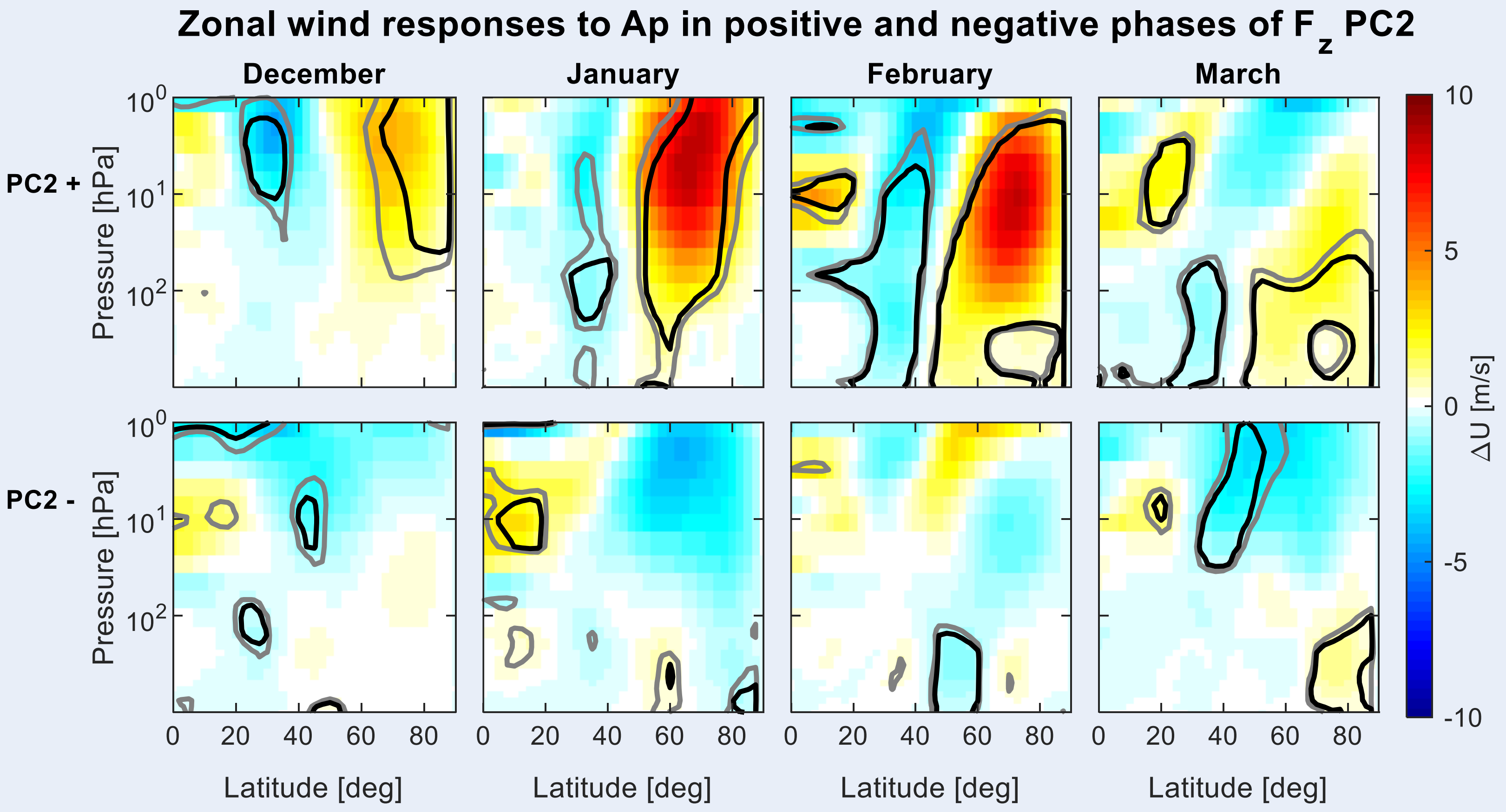
Strong positive response to EEP on polar vortex, significant in all months

Negative PC2 (bottom row):

No significant effect on polar vortex

⇒ **The EEP effect on polar vortex is enhanced in the positive PC2 phase.**

⇒ **EEP does not affect the vortex in the negative PC2 phase.**



Conclusions

Planetary wave modulation of the EEP effect on the northern polar vortex:

Overall intensity of planetary waves is high (PC1+)
$\Rightarrow$ Weak EEP effect

Overall intensity of planetary waves is low (PC1-)
$\Rightarrow$ Weak EEP effect

Planetary waves focused to the equatorward side of the polar vortex (PC2+)
$\Rightarrow$ Strong & significant EEP effect in all winter months

Planetary waves focused inside the polar vortex (PC2-)
$\Rightarrow$ No EEP effect

QR for abstract

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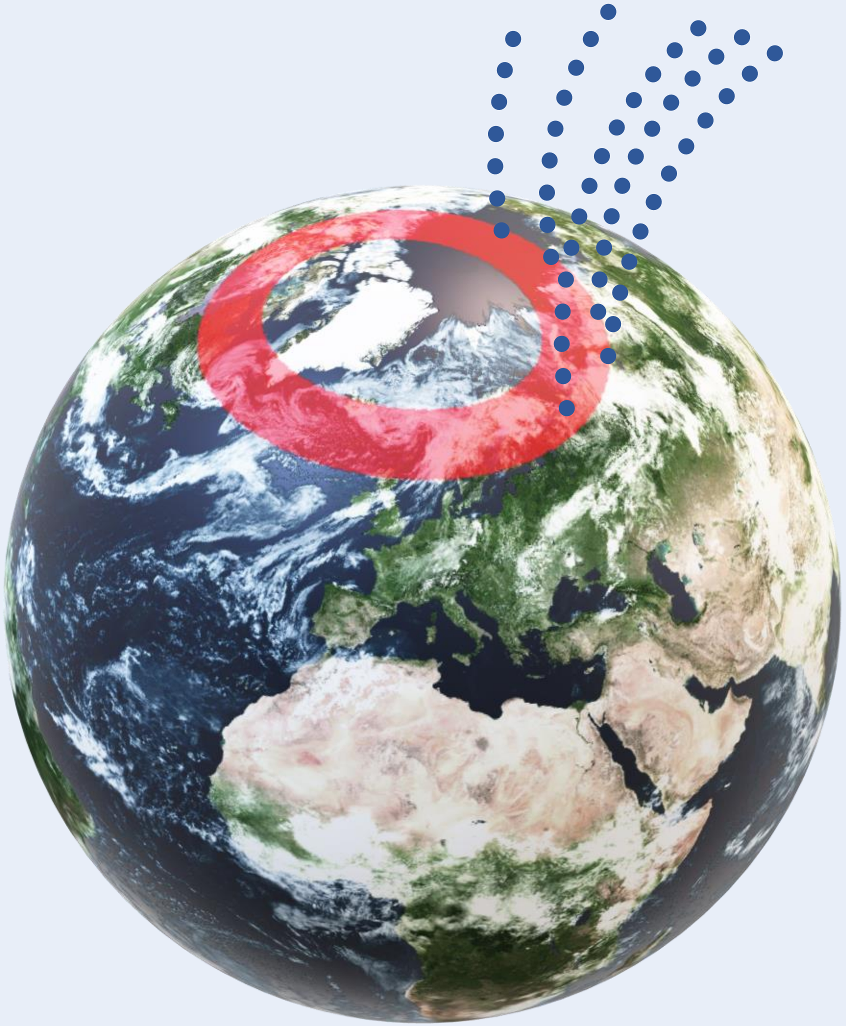
Thank you!

QR for abstract

Extra

Energetic electron precipitation

- Magnetospheric electrons are accelerated toward the Earth.
  - Energetic electron precipitation (EEP)
  - EEP is driven by solar wind
- EEP forms NOx and HOx compounds in the high-latitude thermosphere and mesosphere.
  - NOx and HOx catalytically destroy ozone
- EEP-NOx descends to the stratosphere during the winter.
  - Indirect EEP effect



Wintertime stratosphere

A strong westerly wind surrounds the cold winter pole in the stratosphere.

- ➢ Polar vortex

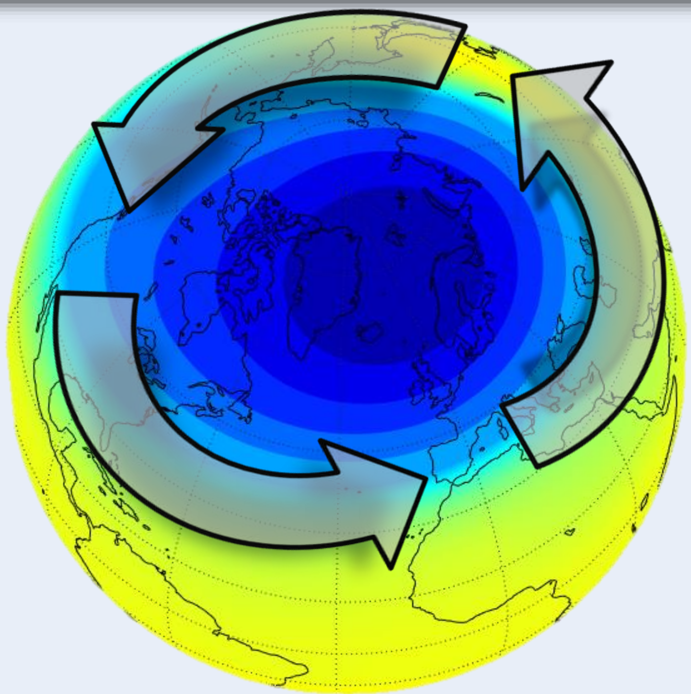
Polar vortex is disturbed by planetary waves.

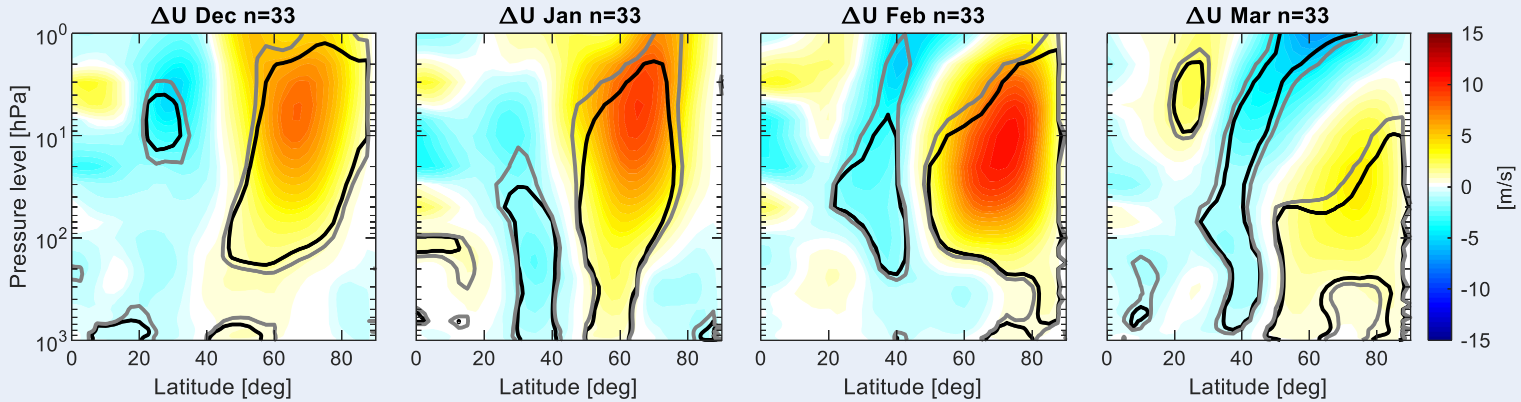
- ➢ Sudden stratospheric warming (SSW)

EEP strengthens the polar vortex in the northern hemisphere.

- ➢ The EEP effect depends on the QBO and SSWs [Seppälä et al., 2013; Maliniemi et al., 2013; Salminen et al., 2019; Asikainen et al., 2020].

How the EEP effect on polar vortex depends on planetary waves?





Zonal wind (U) response to EEP in December-March [Salminen et al., 2019]

Multi linear regression

We calculate multi linear regressions (MLR) to estimate **zonal wind response to EEP**.

Explaining variables:

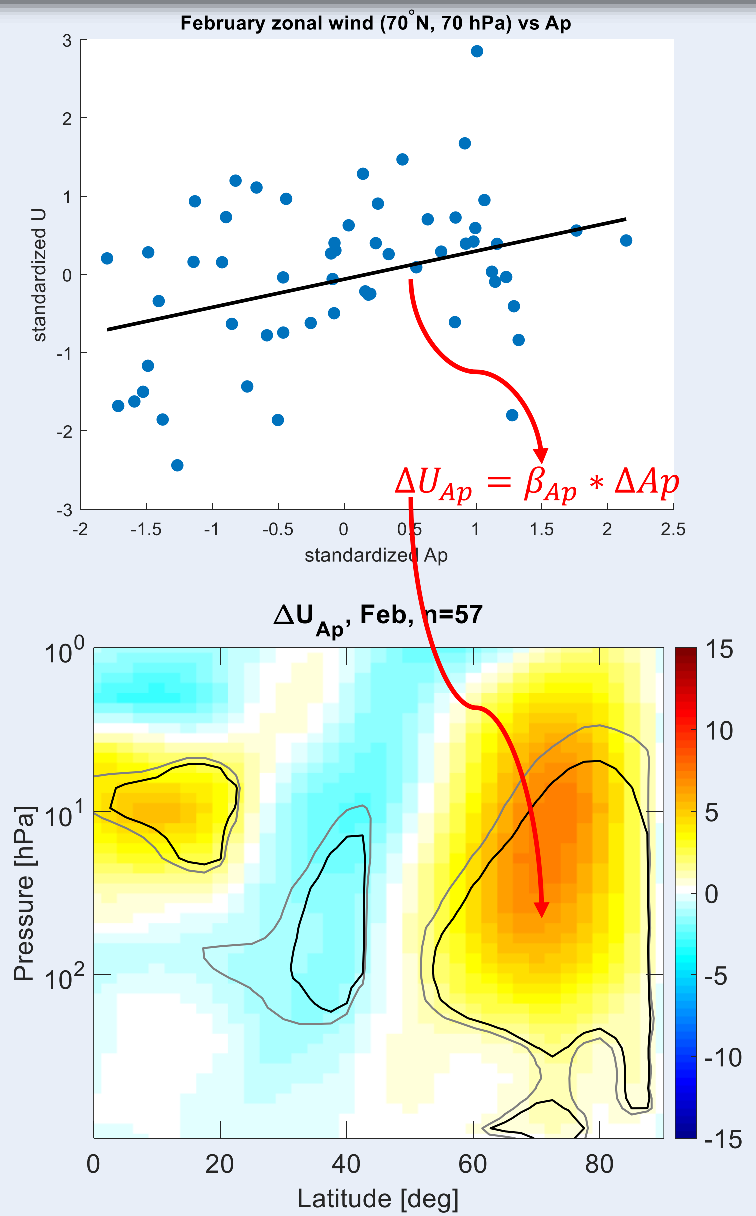
- Ap (proxy for EEP)
- Sunspot numbers (proxy for solar irradiance)
- Nino 3.4
- Aerosol optical depth (proxy for volcanic activity)

MLRs are calculated separately at each latitude-pressure grid point for each northern winter months (December,January,February,March).

Monthly $\boldsymbol{F_z}$ **PC1 and PC2** values are used to classify months to positive and negative phases of PC1 and PC2.

$\Rightarrow$ **EEP responses in four different phases (PC1+, PC1-, PC2+, PC2-)**

Same kind of MLRs were calculated considering QBO phases in [Salminen et al., 2020].



EP-flux differences between PC phases

We classify months to positive and negative phases of both F_z PC1 and PC2

Differences in EP-flux (constant length arrows) and EP-flux divergence (background color) between PC1 positive and negative phases (1. row) and PC2 positive and negative phases (2. row).

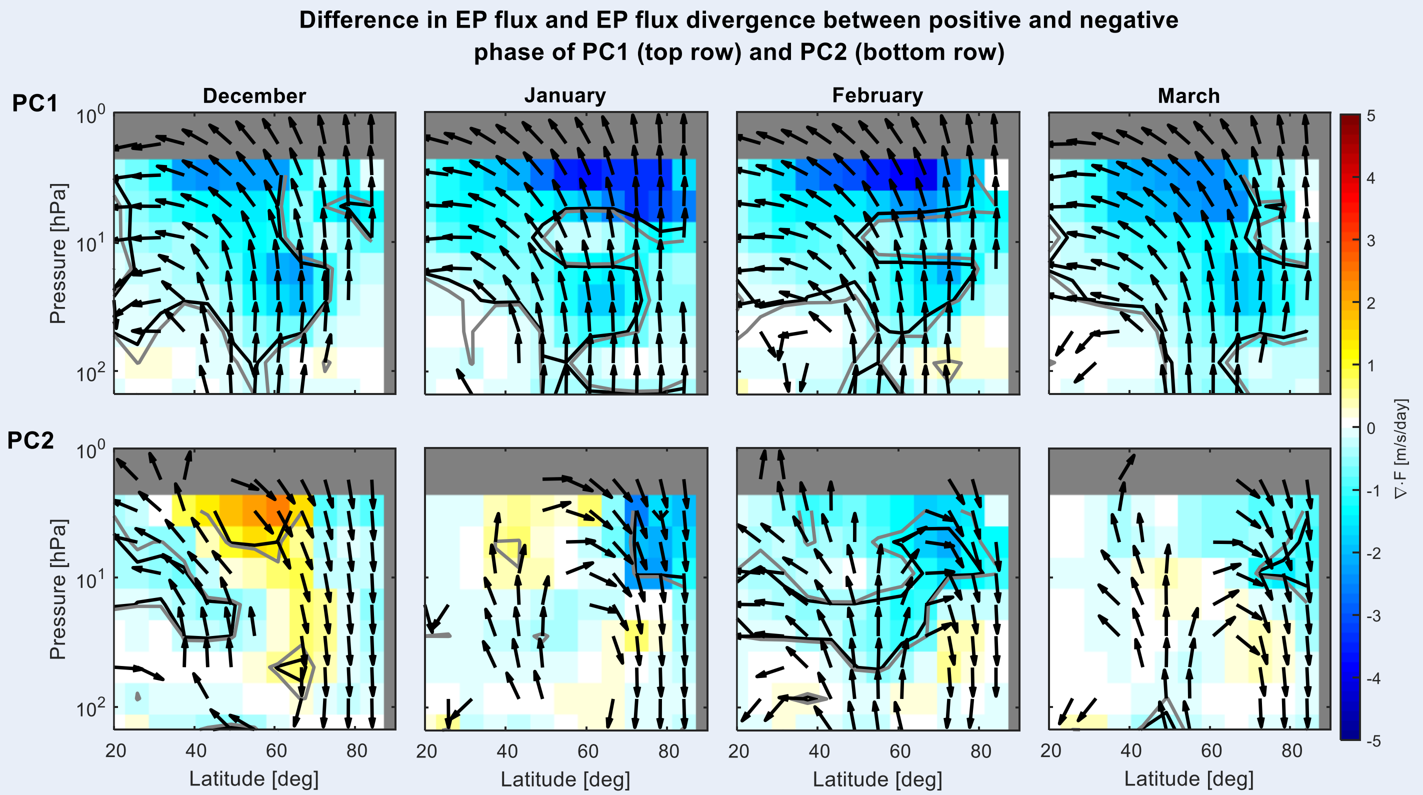
Confirm earlier interpretation of PCs

PC1+ : overall planetary wave activity increased in the stratosphere

PC1- : overall activity decreased

PC2+: more waves at lower latitudes, less at higher latitudes

PC2-: less waves at lower latitudes, more at higher latitudes



EEP responses in EP-flux divergence

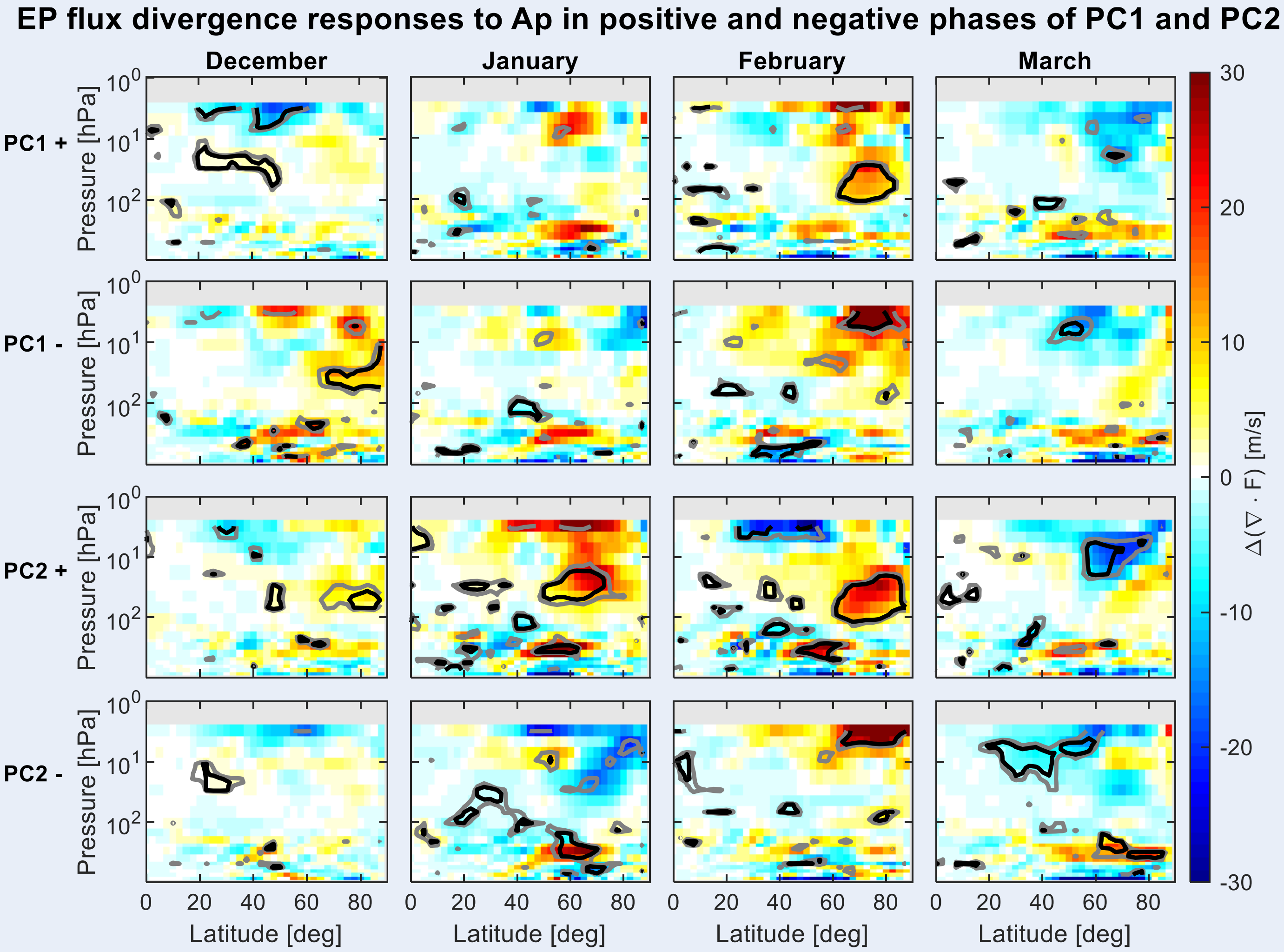
EP-flux divergence responses to EEP/Ap in positive and negative PC1 phase (rows 1-2) and in positive and negative PC2 (rows 3-4)

Positive significant response to EEP at high-latitudes in positive PC1 February and in negative PC1 December and February

In positive PC2, significant responses at high-latitudes in December-February

In negative PC2, limited positive response in the polar upper stratosphere in February

=> Planetary waves are diverted from the vortex region most consistently when planetary waves propagate at lower latitudes than on average



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