BIRKELAND CENTRE
FOR SPACE SCIENCE

Investigation of solar proton impact on polar stratosphere dynamics: a preliminary study

Jia Jia[1,2]

[1] Norwegian University of Science and Technology (NTNU), Trondheim, Norway
[2] Birkeland Center for Space Science, Bergen, Norway

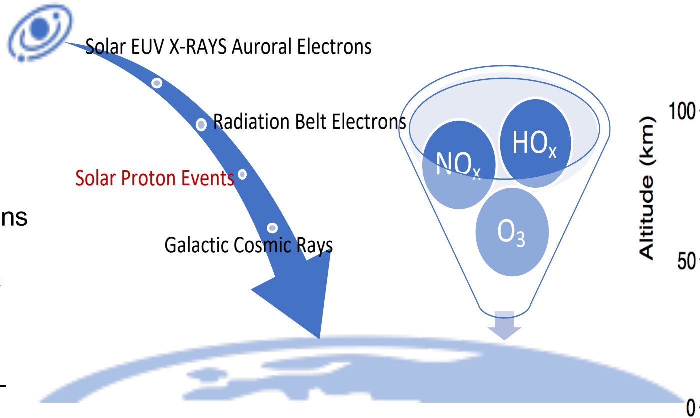
European Research Council

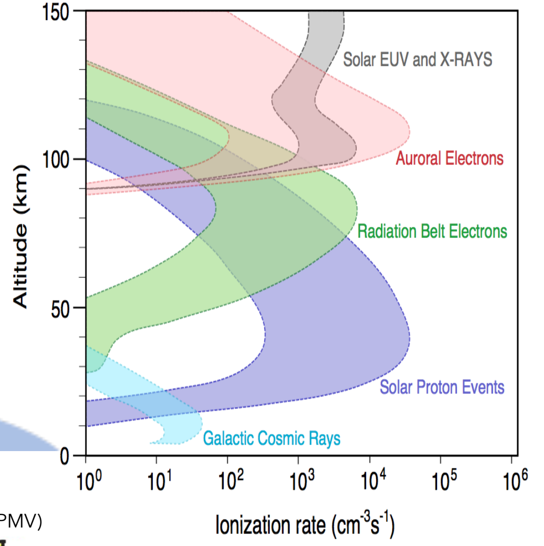
The University Centre in Svalbard

NTNU Det skapende universitet

Solar proton events (SPEs):

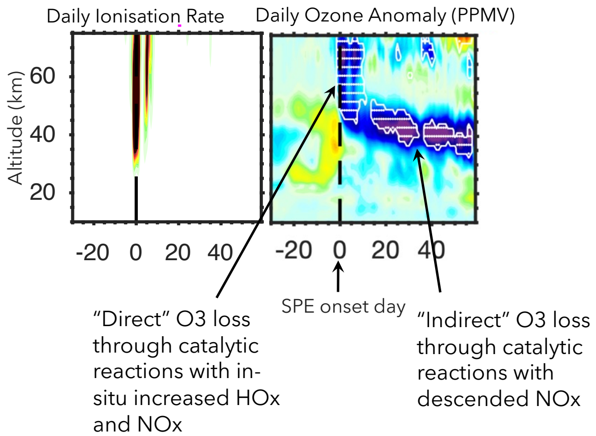
- Together with medium energy electron and auroral electron-> Energetic particle
- Particles (mainly protons) with energies from tens to hundreds of megaelectron volt (MeV) precipitate into the atmosphere at geomagnetic latitudes larger than 60° for days
- Mainly affect the atmosphere at altitudes of 35–90 km
- Precipitation produces considerable amounts of HOx (H, OH, HO2) and NOx (N, NO, NO2) through ion-neutral chemistry
- HOx and NOx increases lead to ozone loss through catalytic reactions in the mesosphere and upper stratosphere, respectively
- Chemical changes after large SPEs have been studied since the 1960s





(Adjusted from Mironova et al., 2015)

SPE @ 2003.10.28 & 2003.11.02



(Adjusted from Jia et al., 2020)

Stratospheric dynamic response

- Ozone loss -> Radiative forcing -> Temperature -> Wind & energy exchange, wave propagation
- to EPP (Energetic Particle Precipitation) -> Climate impacts @ polar winter

  … …

Rozanov_2005: *EEP* (MEE+Aurora)-T, Model **CCM**, annual mean change (NO_y O_3 T) in global latbins &0-105km

Seppälä_2009: **ERA40** HighAp-LowAp, NH, $T_{surface}$ pattern

Baumgaertner_2011: chemistry general circulation model **EMAC**, EPP modulate NAM (Northern Annular Mode) to positive (thus relate to stronger vortex) and $T_{surface}$

Seppälä_2013: High/low Ap - NH winter stratospheric wind, temperature and wave propergation (EP) (**ERA40+Interim** 1958-2008, Nov-Mar)

Arsenovic_2016: *MEE*-T/U response using **SOCOL** model (include nice catelog of EPP types in intro)

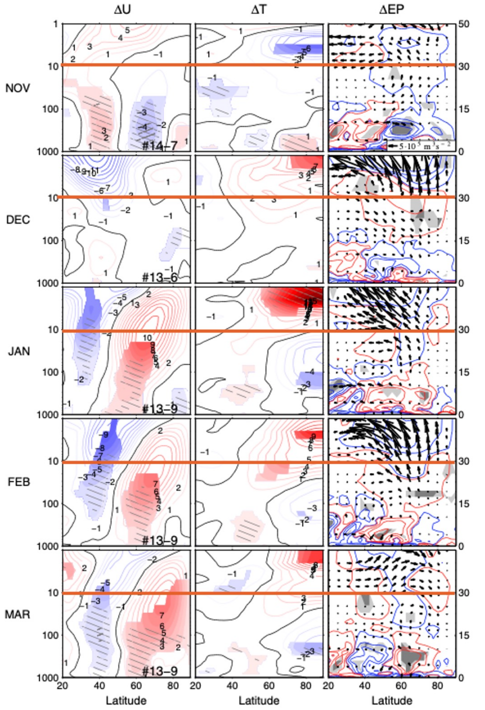
Meraner&Schmidt_2018: Climate impact from EPP, model **MPI-ESM**, no siganificant surface signal

Tartaglione..Orsolini_2020: Japanese 55-year **Reanalysis**, T, remove temporal and spatial autocorrelation impact, strato T not siginificant. Some significant surface signal.

Asikainen_2020: *EEP* (MEE+Aurora)-Add SSW into discussion, **ERA40+Interim** 1957-2017

Guttu_2020: *MEE*-climate response, **WACCM4**, solar cycle 23, NH and SH

(HighSolarRadiation) HighAp-LowAp



(Seppälä et al., 2013)

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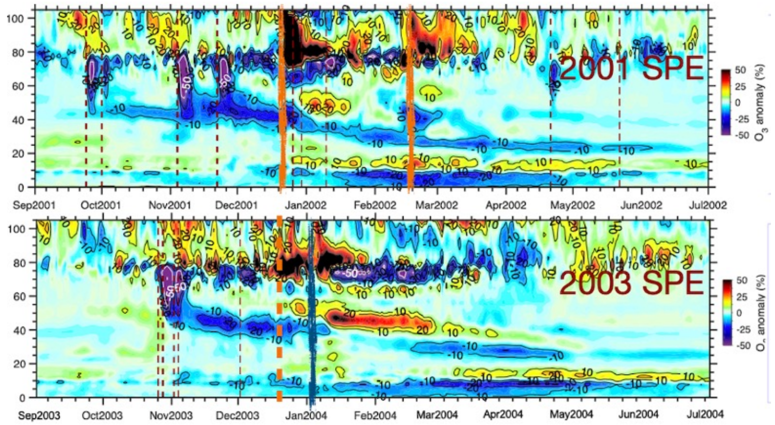
Stratospheric dynamic response

- Ozone loss -> Radiative forcing -> Temperature -> Wind & energy exchange, wave propagation
- to EPP (Energetic Particle Precipitation) -> Climate impacts @ polar winter
- to SPE (Solar proton event) -> Local time impact @ Arctic polar cap



Our motivation

What: Extreme SPE (>5,000 pfu)
Where: Arctic winter (stratosphere)
Why: SPE influence a lower altitude
New solar cycle with new (extreme) SPE

Climate (no) Winter of the event (yes)

How: T, U, wave -> 39 yrs MERRA-2 reanalysis T data 1980.01-2019.04

Ap High Ap vs Low Ap (no)

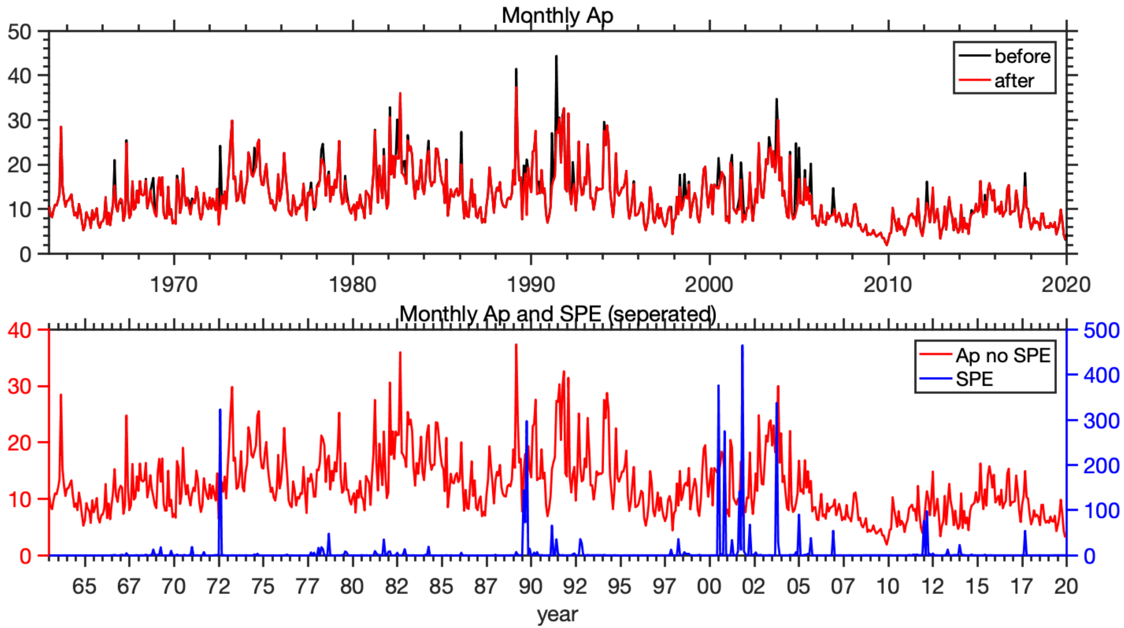
Ap as Multiple Linear Regression fitting proxy (yes) → Direct fitting

Multiple proxies (i.e. F10.7, QBO, NINO3.4, EESC +EPP)

EEP + SPE

Separating EEP (energetic electron precipitation) and SPE (solar proton event)

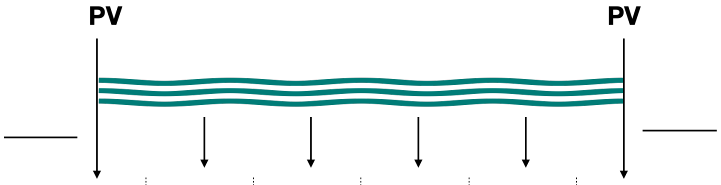
- Daily Ap: remove days according to Ionisation Rate from Jackman
- New Daily Ap → New Monthly Ap



Lagging Ap and SPE proxy according to heights and months

- Ap

  Electron produced NOx relies on winter polar vortex to transport downward; summer impact is not expected



1 month / 1 month / 1 month

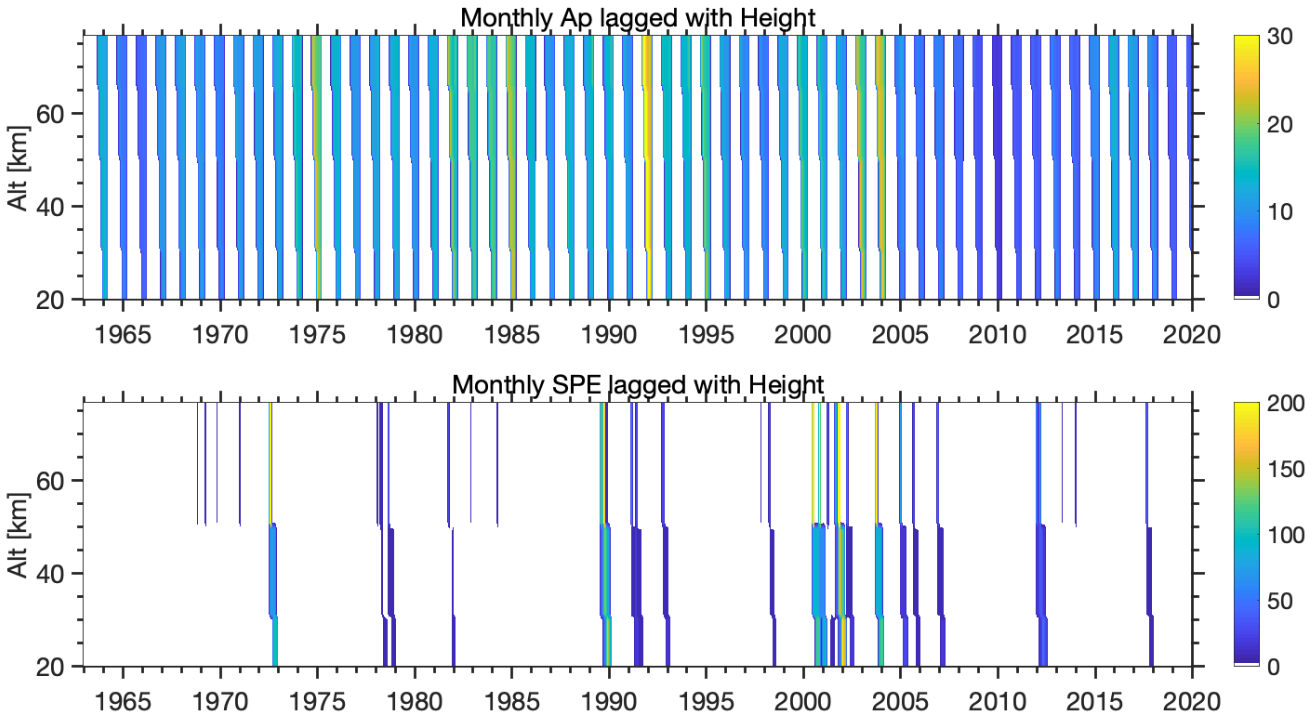
[km]	Oct	Nov	Dec	Jan	Feb	Mar	[hPa]
	0	0,-1	0,-1,-2	0,-1~-3	0,-1~-4	0,-1~-5	
65							0.1
	-	-1	-1,-2	-1,-2,-3	-1~-4	-1~-5	
50							1
	-	-	-2	-2,-3	-2,-3,-4	-2~-5	
30							10
	-	-	-	-3	-3,-4	-3,-4,-5	
20							100

- SPE

  Proton doesn't rely on polar vortex that much, during onset of SPE, it reaches stratosphere, and influence ozone @ 30-50 km for the next months; if in winter, the downward transport could bring the impact down

[km]	On set month	month +1	month +2	month +3	month +4	month +4	[hPa]
	0	-	-	-	-	-	
65							0.1
	0	-	-	-	-	-	
50							1
	0	0,-1	0,-1,-2	0,-1~-3	-2,-3,-4	-2~-5	
30							10
	-	-	-	-3	-3,-4	-3,-4,-5	
20							100

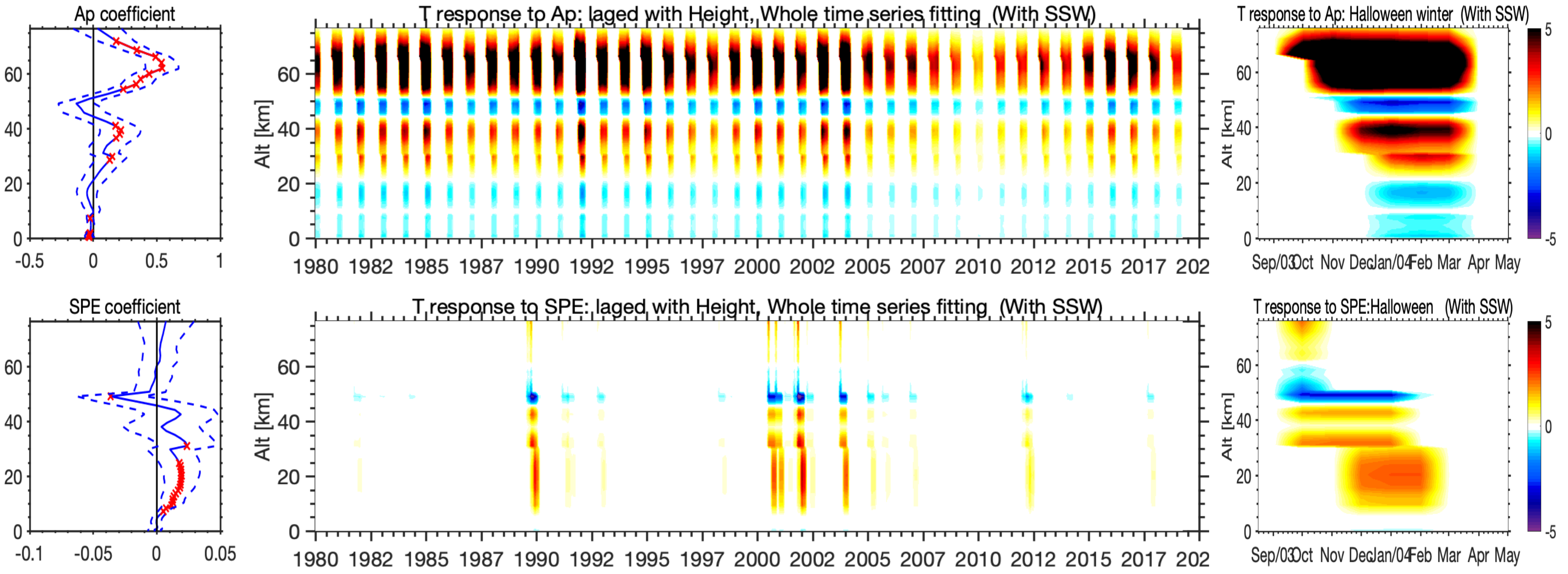
Lagging Ap and SPE proxy according to heights and months



Fit the whole timeseries

MLR @ each altitude

Winter 2003-2004



Sudden Stratospheric Warming's impact to the results:

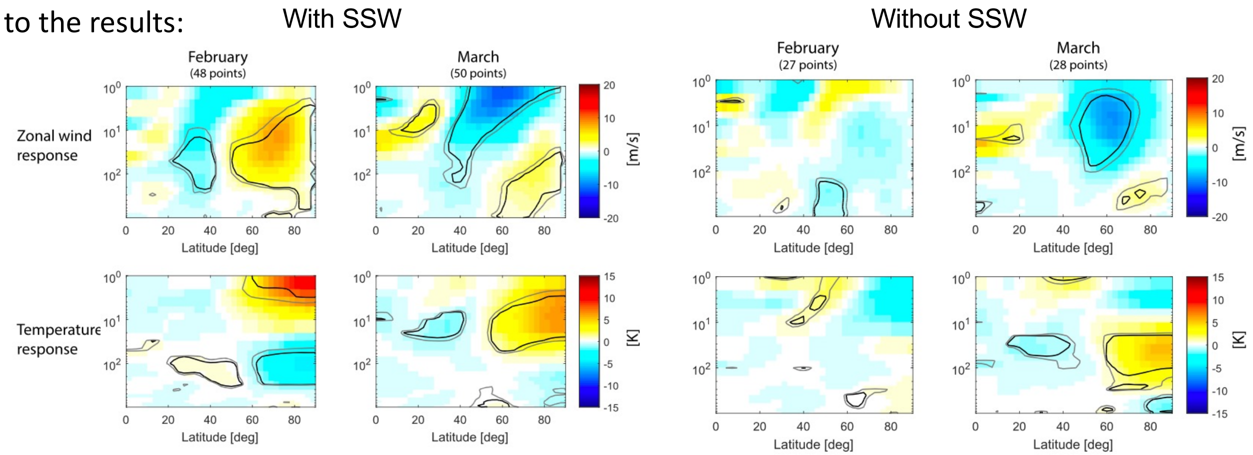
Ap signal is more pronouncing when including SSW winters

investigate SSW's impact to our results

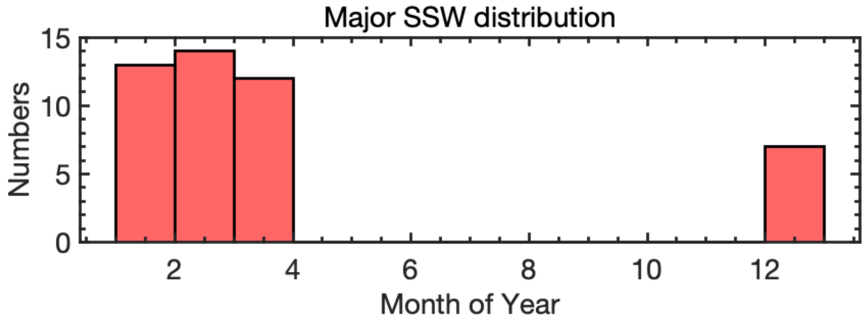
Major SSW commenly derived from reanalysis data are used here (46 events in total)

A histogram of the SSW distribution in month of year is showed below

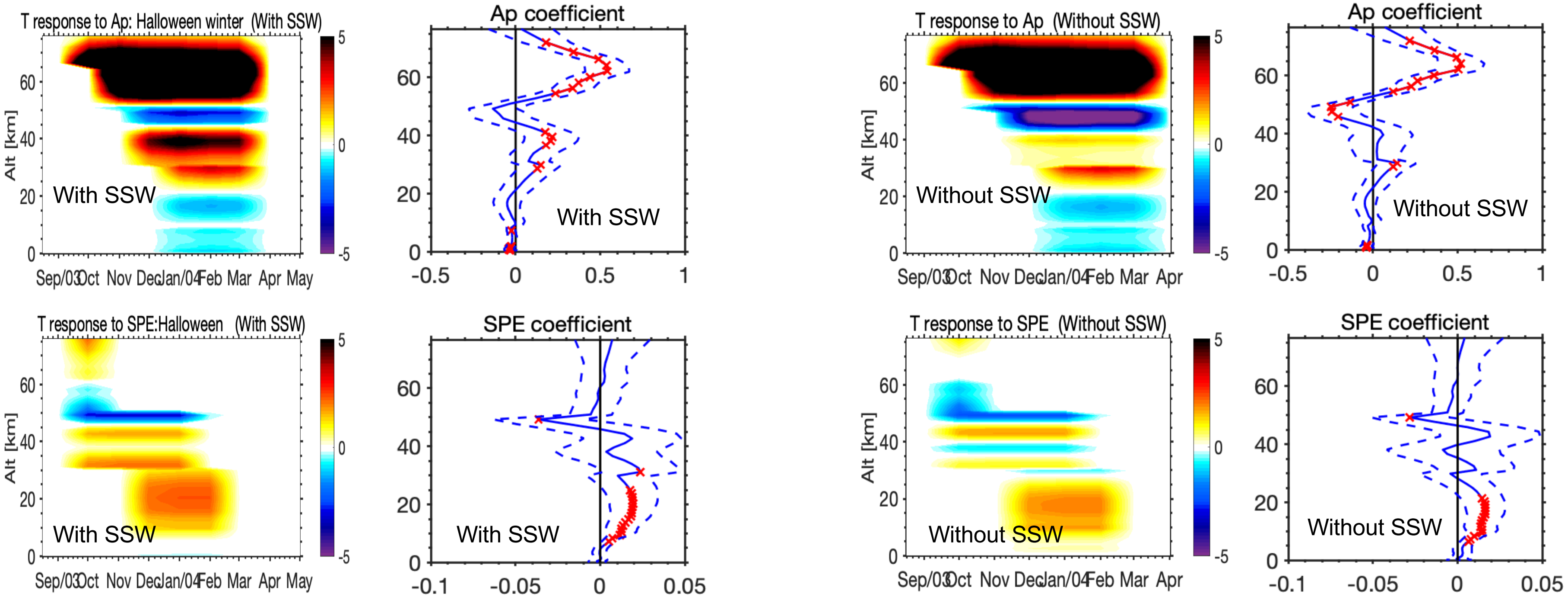
Removing SSW: 10 days before onset, and 40 days after onset



(Asikainen et al., 2020)



SSW’s impact to the results: Exp. Winter 2003-2004



Fit the whole timeseries

Take home message:

- Study extreme Solar Proton Events' contribution to stratospheric temperature variation (wind and wave in the future study)
- For the first time distinguish SPE's contribution to temperature changes from Energetic Particle Precipitation (EPP)'s, while the remaining EPP impact to temperature variation is in line with previous studies
- SPE mainly affect the temperature at below 30 km, the effect is opposite to EPP's dynamical cooling result, SPE increase temperature, for Halloween SPE, ~ 2 degrees increase was observed
- Major Sudden Stratospheric Warming enhance remaining EPP's effects in the upper stratosphere, consistent with previous study; SPE's effects to stratosphere are slightly enhanced compared to the result without SSW, however, the signal remains significant in both scenario