COMPARATIVE INVESTIGATION BETWEEN SOUTHERN AND NORTHERN SSW USING REANALYSIS DATA

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ABSTRACT

Sudden Stratospheric Warming (SSW) is an extreme dynamical event observed in the middle atmosphere. During this event, there will be changes in circulation behaviour in the middle atmosphere followed by a sudden warming in the polar stratosphere. The warming scenario is preceded by the polar vortex disruption due to the non-linear interaction of extra-tropical planetary waves from the troposphere with the mean flow. SSW affects both the upper and lower atmosphere, irrespective of latitude. It is known that warming events are more frequent in the northern hemisphere than in the southern hemisphere. The study investigates the evolution of warming events in both the northern and southern hemispheres. We use the reanalysis data to compare the 2013 - 2014 northern hemisphere and 2002 southern hemisphere SSW. To understand the forcing and responses in both hemispheres, we conducted meteorological and statistical analyses of SSW using temperature, zonal wind, meridional wind, and geopotential height. The factors that modulate the intensity of warming events in both hemispheres have been discussed in detail.

MOTIVATION

- Current definitions of SSWs are not satisfying in explaining its influence over the changes in the ionosphere.
- So, the long term goal of my research is to find the optimal parameters to define changes in the ionosphere during SSWs.
- To study the vertical coupling between the middle and upper atmosphere during the SSW event. For this, we need to understand the basic features of SSW and try to understand the current definitions of SSW.
- **So in this work, we start to apply a methodology to define the warming and hence the SSW using more parameters available.**
- **This work addresses whether defining SSW on a particular pressure scale is accurate.**

DATA AND METHODOLOGY

The study uses the fifth generation of European ReAnalysis (ERA5) with 0.25 x 0.25 spatial resolution and 1-hour temporal resolution for analyzing the parameters at different pressure scales. We choose certain pressure levels and parameters to investigate the conditions of the vortex and its subsequent evolutions. Latitudinal average from 50° N/S - 90° N/S were considered for the investigation.

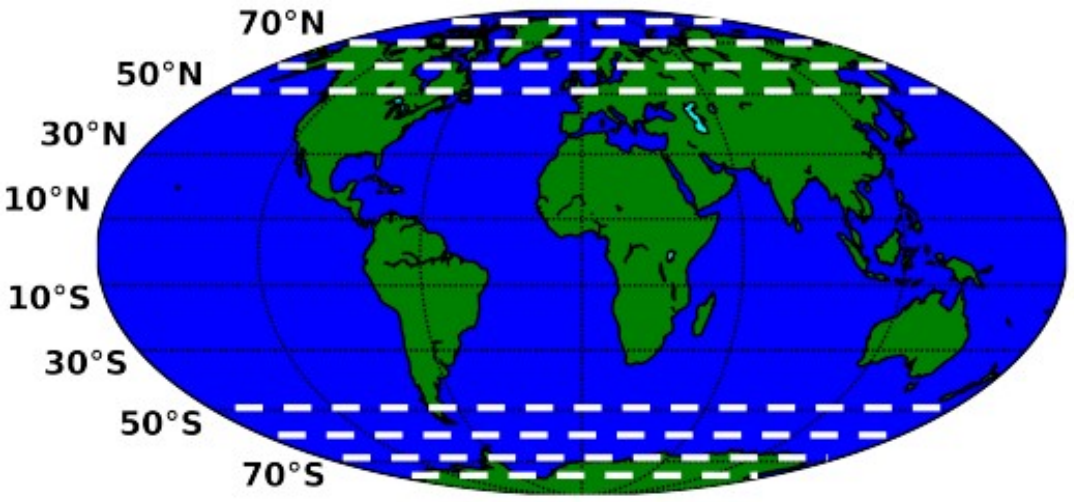


Figure 1: White lines represent the study area for 2002 southern hemisphere (SH) SSW and 2013 – 2014 northern hemisphere (NH) SSW. Latitudinal average from 50°N / S - 90°N / S were considered for the investigation.

Vortex parameters	**Meteorological parameters**
Divergence	**Temperature**
Geopotential	Mean of **zonal mean velocity**
	Vertical velocity

Table 1: Parameters under investigation.

DATA AND METHODOLOGY

- **Temperature** measured in the atmosphere. It has units of kelvin (K).
- **Zonal wind** is the component of the wind that is aligned with the Earth's latitude circles. Negative values indicate easterly wind and positive for westerly wind. The zonal wind is typically measured in meters per second (m/s).
- **Vertical velocity** is the speed of air motion in the upward (negative) or downward (positive) direction. Measured in Pa s^{-1}.
- **Divergence** is the rate at which air is spreading out horizontally from a point per square meter. Positive for divergent and negative for convergence.
- **Geopotential** is the gravitational potential energy of a unit mass at a particular location, relative to mean sea level. It is also the amount of work that would have to be done, against the force of gravity, to lift a unit mass to that location from mean sea level. The geopotential height can be calculated by dividing the geopotential by the Earth's gravitational acceleration, g (=9.80665 m s^{-2}).

DATA AND METHODOLOGY

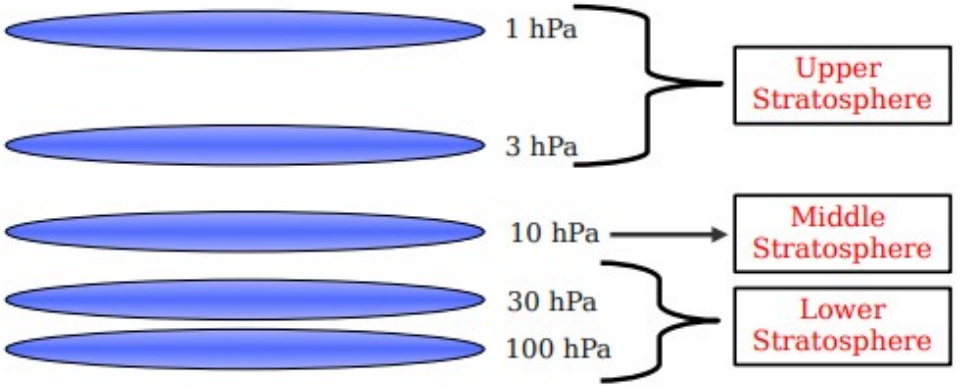


Figure 2: Studied pressure levels with upper, middle and lower stratosphere.

- Sudden stratospheric warming (SSW) is characterized by a sudden change in temperature followed by deceleration or even reversal of the zonal mean of zonal wind.
- Standard definition provided by World Meteorological Organisation (WMO) uses 10 hPa as a standard reference for categorization of SSW.

DATA AND METHODOLOGY

- During SSW, an increase in temperature upto 50 K within one or two weeks is excepted [**1**].
- So this analysis uses the rate of warming as one of the metrics to identify the significant warming during 2002 southern hemispheric and 2013 – 2014 northern hemispheric SSW.
- Only those warmings are considered whose rate of warming is atleast 3.6 K per day provided there should be a deceleration in mean of zonal mean wind. After this first selection we use the parameter geopotential height derived from geopotential to define more precisely significant warming.
- **In conclusion, only those warmings are considered as real significant warmings which satisfy both rate of warming threshold and variations in geopotential values.**

COMPARATIVE ANALYSIS

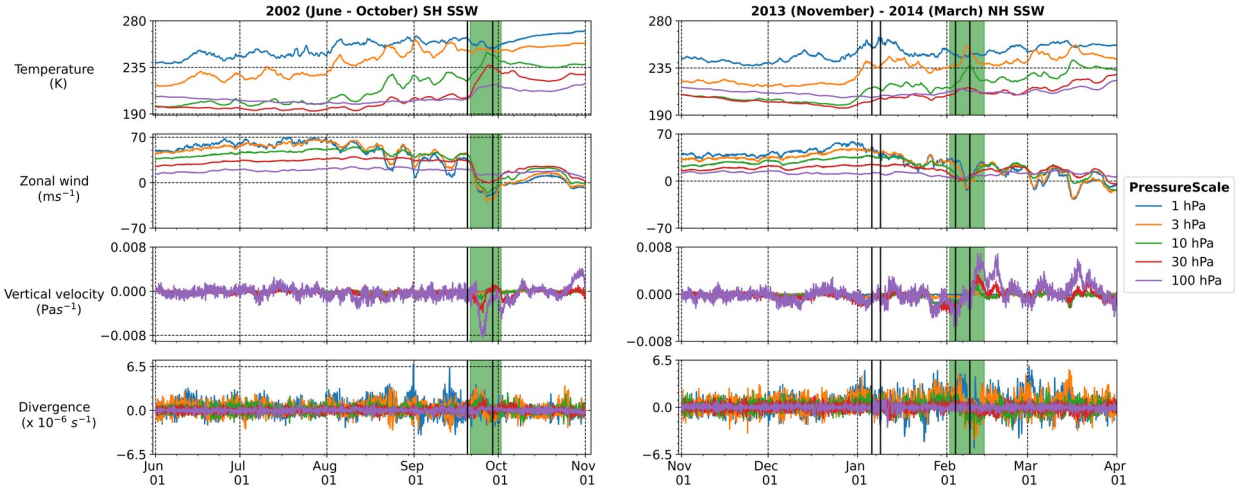


Figure 1: Time series plots of 2002 SH SSW and 2013 – 2014 NH SSW. The region between two dark black lines represents the identification of warming by the rate of warming. The green-shaded region shows the warming period identified by geopotential.

- **Wind reversals are always strongest in the upper stratosphere.**
- Number of reversals is more for NH SSW compared to SH SSW.
- Vertical velocity is comparable and it shows significant variation during the respective identified warming periods.
- Vertical velocity shows considerable variation at the lower stratosphere, and the divergence shows prominent variation at the upper stratosphere.

GEOPOTENTIAL ANALYSIS

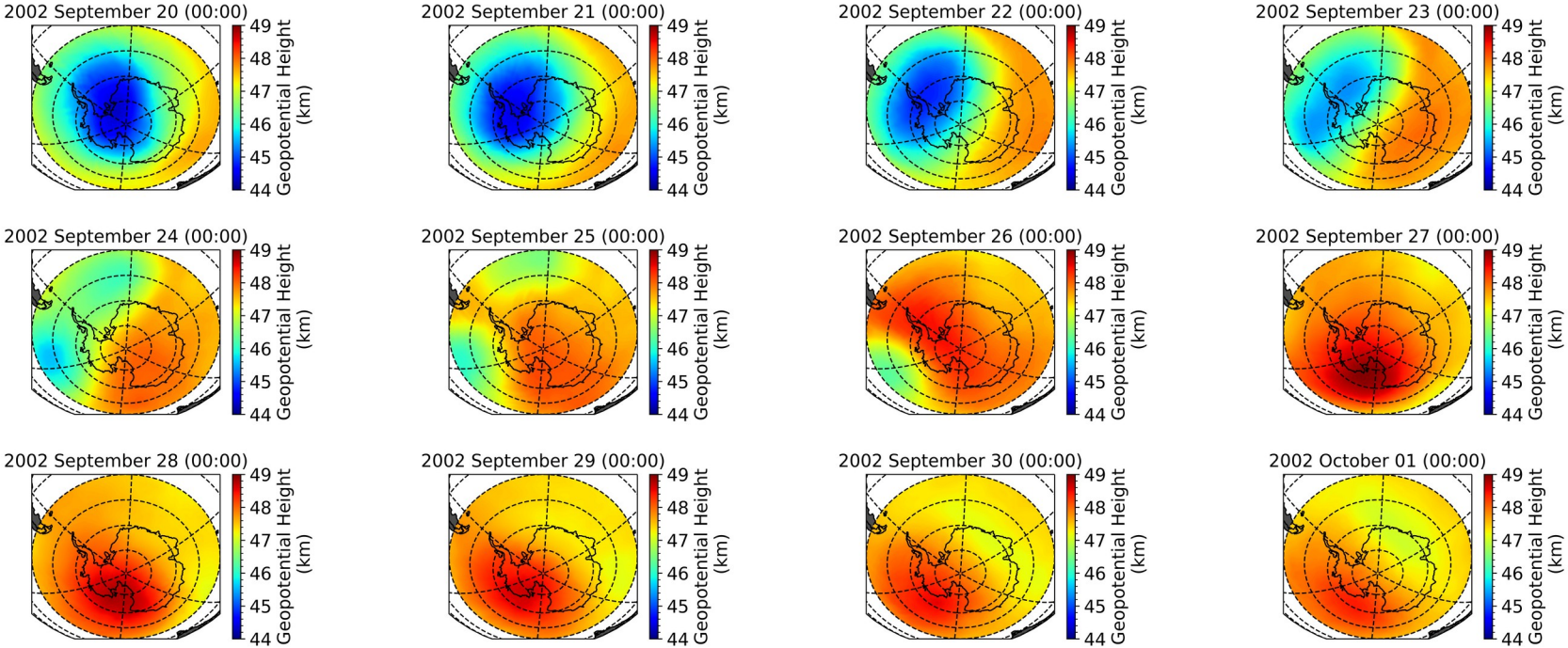
2002 SH SSW

SEPTEMBER WARMING

(IDENTIFIED BY WARMING RATE)

2002 SEPTEMBER WARMING

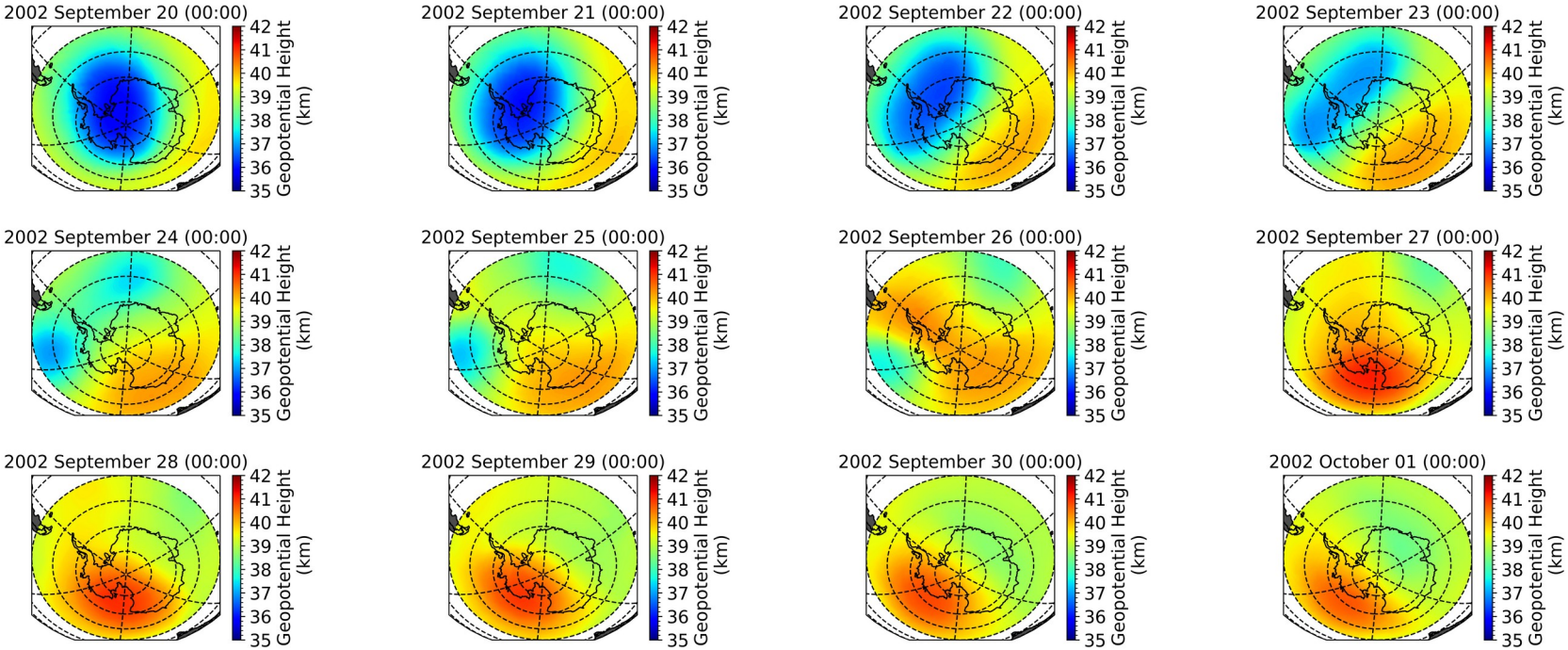
2002 SH SSW 1 HPA



Weakening of the vortex

2002 SEPTEMBER WARMING

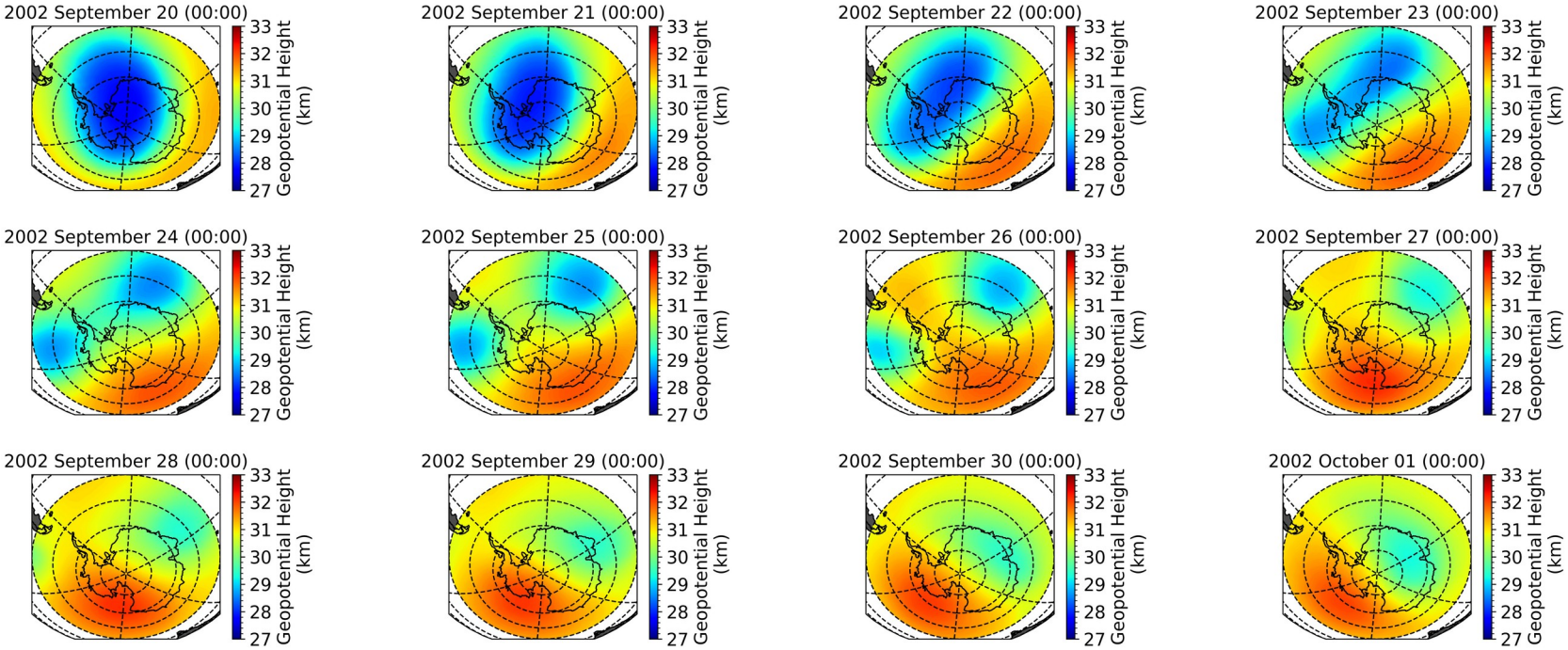
2002 SH SSW 3 HPA



Splitting of the vortex

2002 SEPTEMBER WARMING

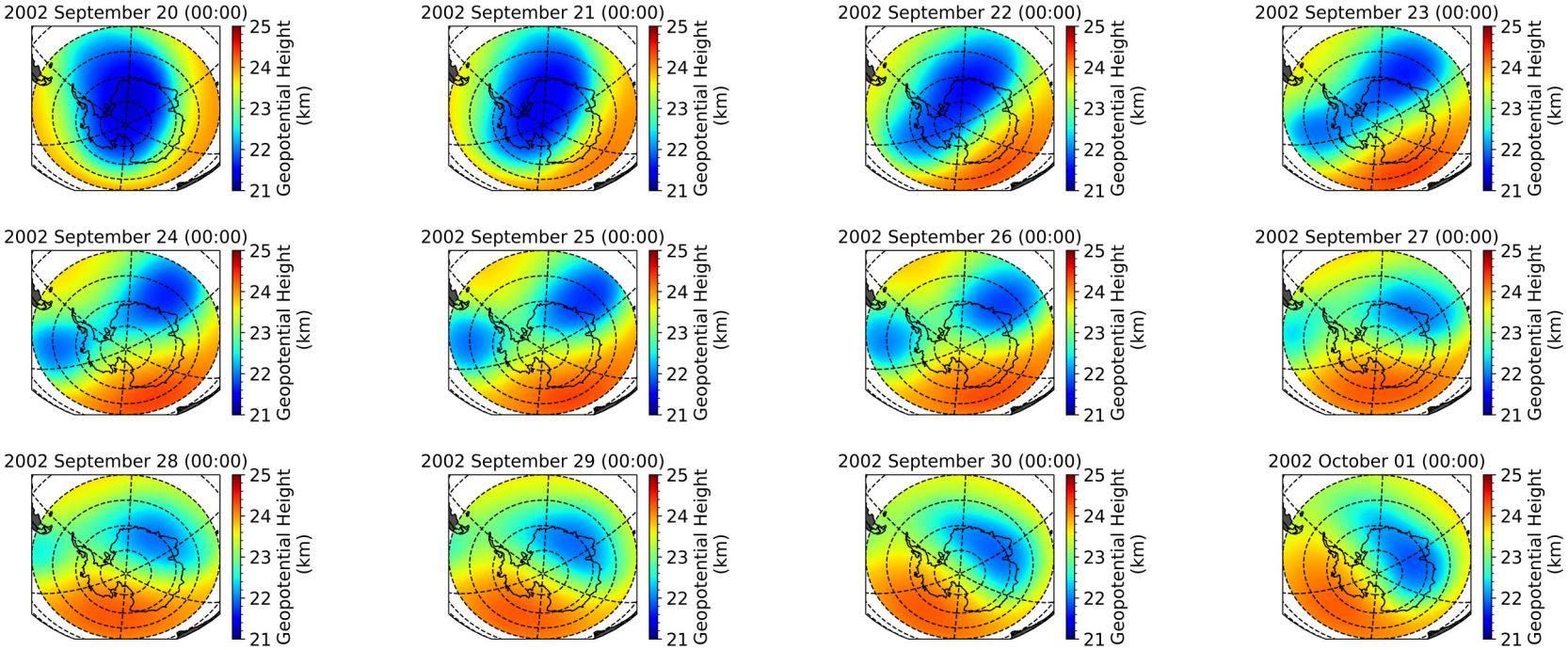
2002 SH SSW 10 HPA



Splitting of the vortex

2002 SEPTEMBER WARMING

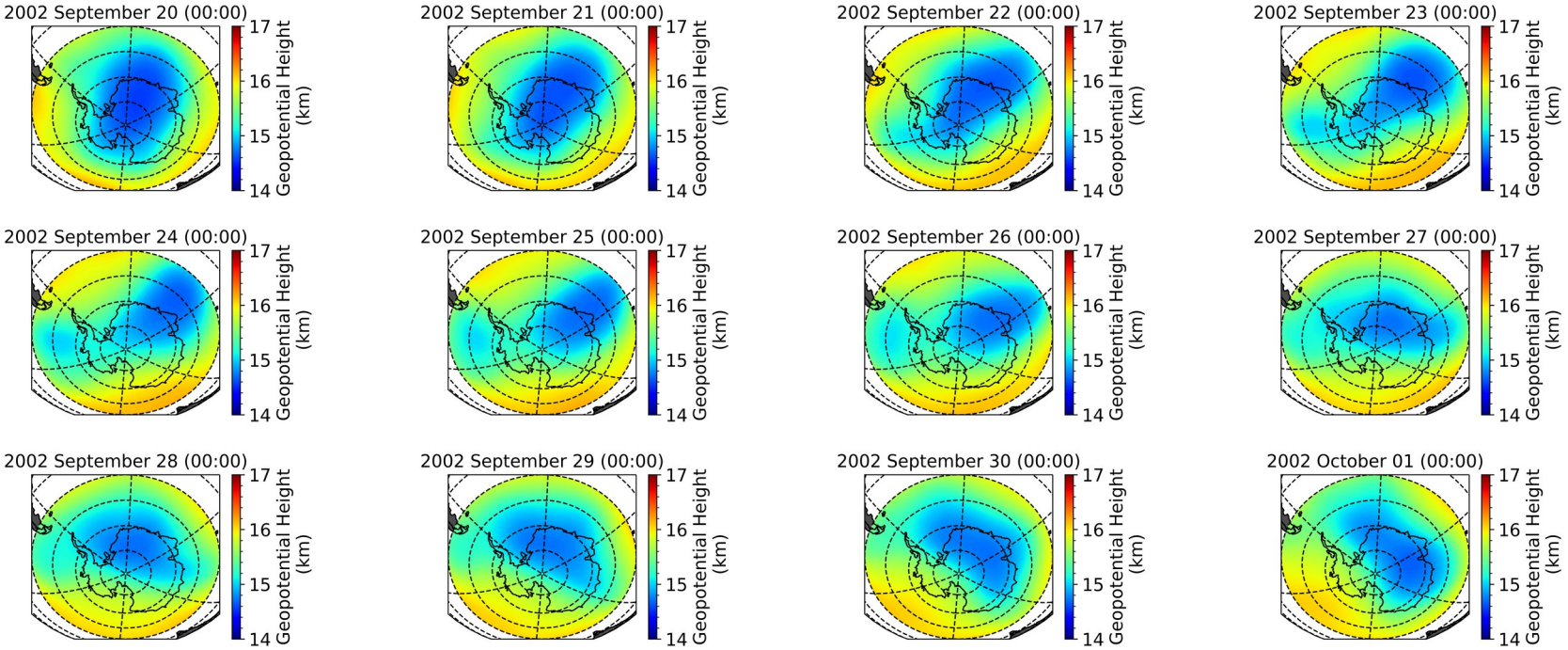
2002 SH SSW 30 HPA



Splitting of vortex visible

2002 SEPTEMBER WARMING

2002 SH SSW 100 HPA



September warming: 21 st September – 01 st October

- **In conclusion this period can be identified as significant warming since it agrees both rate of warming and shows variations in geopotential values.**

GEOPOTENTIAL ANALYSIS

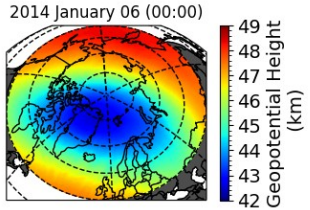
2013 -2014 NH SSW

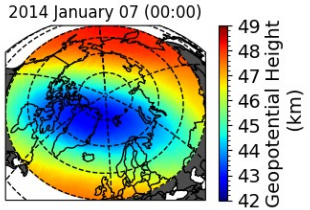
JANUARY WARMING

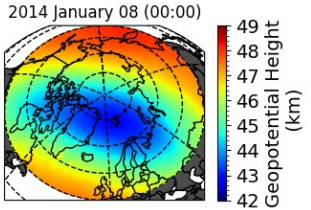
(IDENTIFIED BY WARMING RATE)

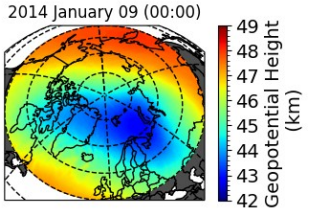
2014 JANUARY WARMING

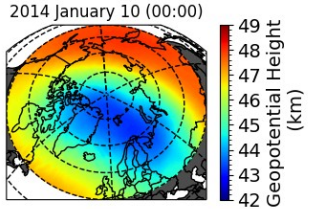
2013 -2014 NH SSW 1 HPA

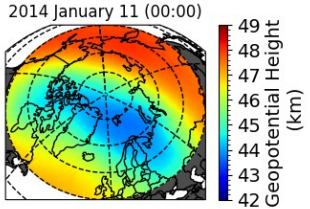


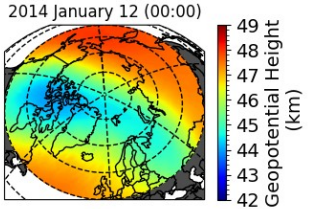


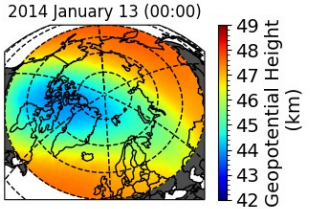


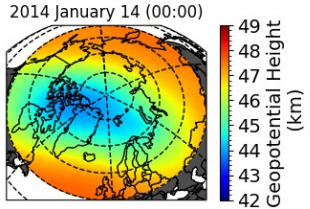


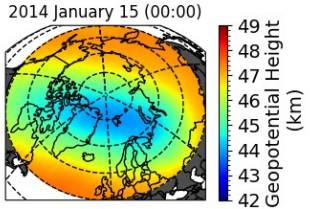


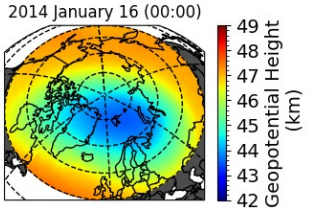


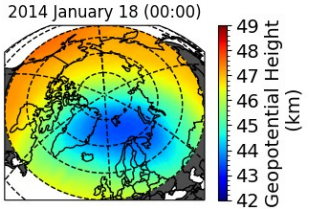






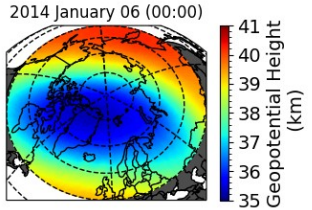


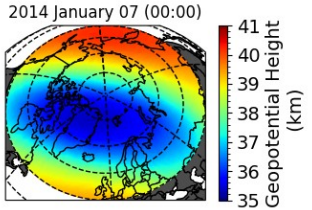


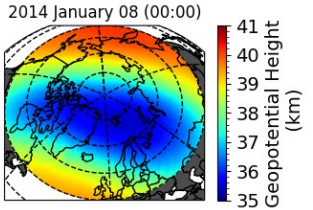


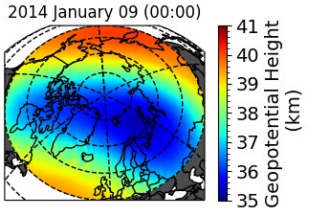
2014 JANUARY WARMING

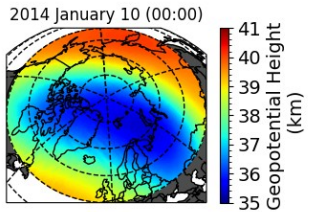
2013 -2014 NH SSW 3 HPA

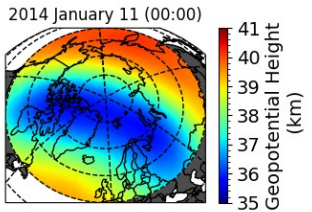


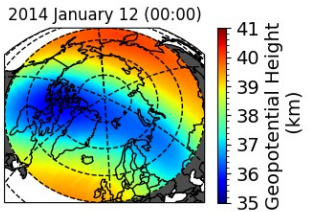


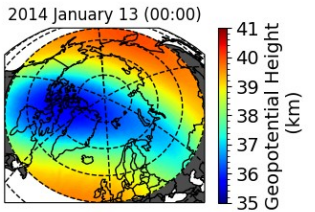


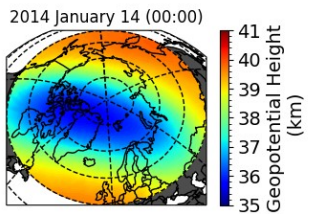


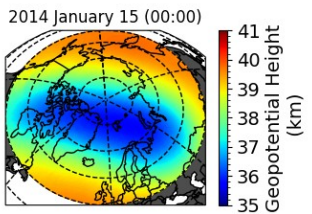


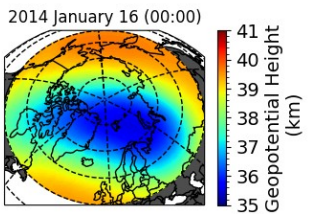


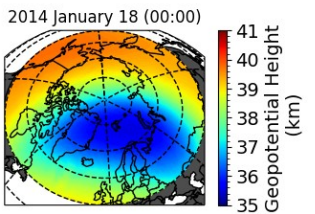






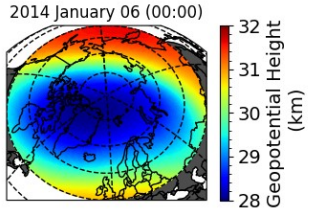


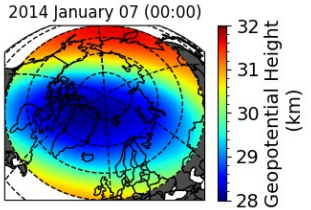


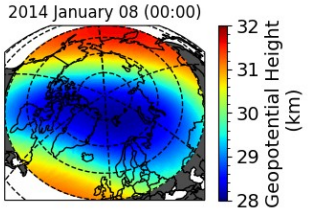


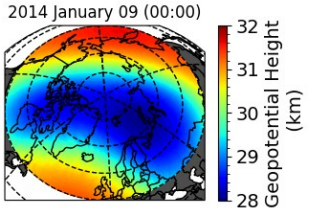
2014 JANUARY WARMING

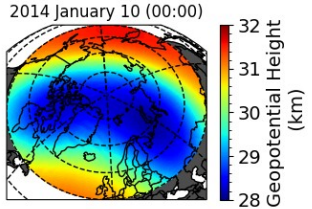
2013 -2014 NH SSW 10 HPA

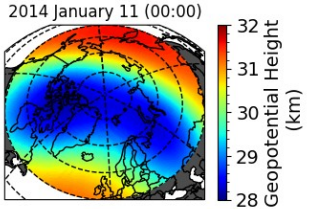


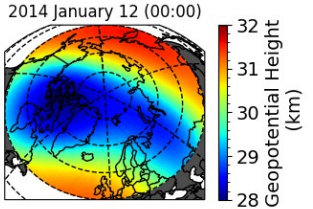


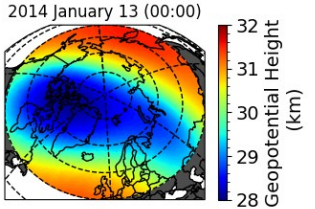


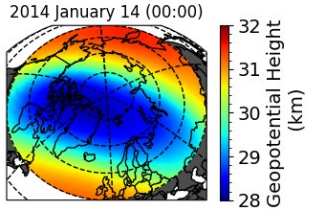


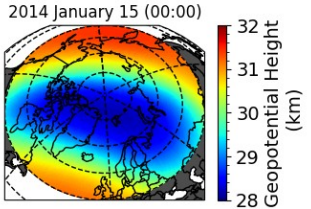


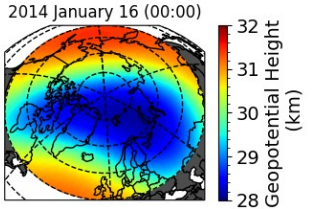


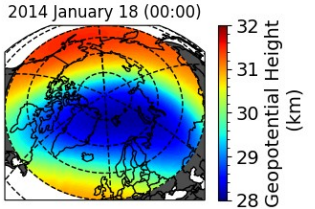






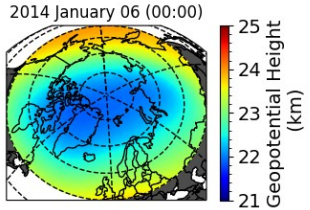


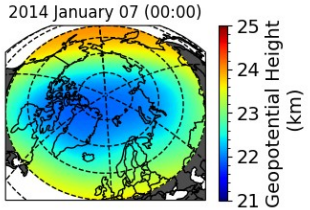


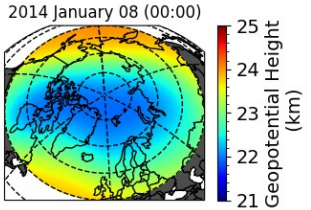


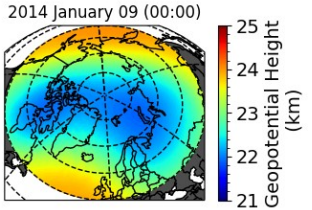
2014 JANUARY WARMING

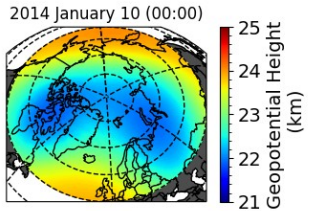
2013 -2014 NH SSW 30 HPA

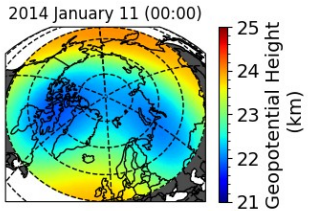


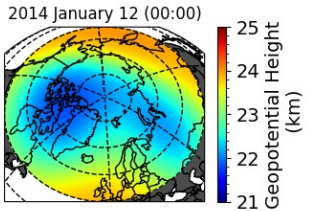


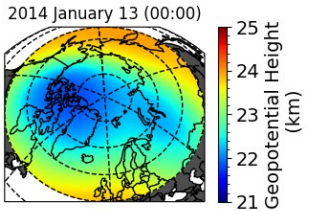


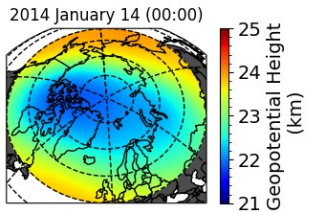


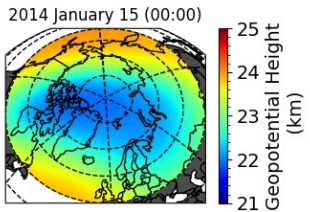


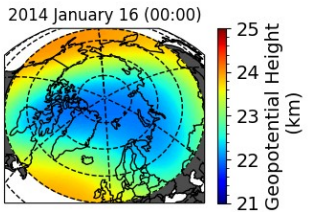


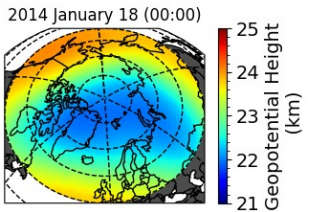






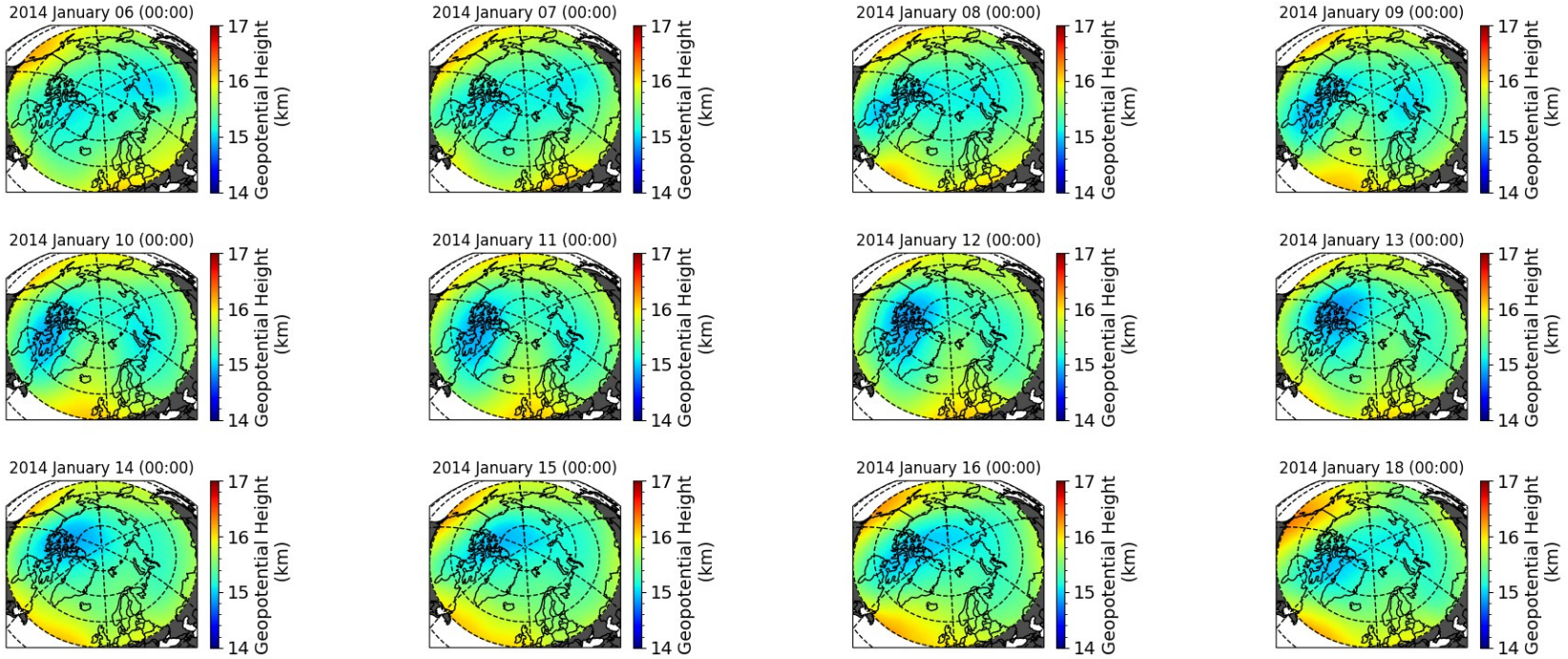






2014 JANUARY WARMING

2013 -2014 NH SSW 100 HPA



- **No variations in the polar vortex during the January period identified by the warming rate metric. So it can't counted as a significant warming period since it fails in the variation of geopotential values.**

GEOPOTENTIAL ANALYSIS

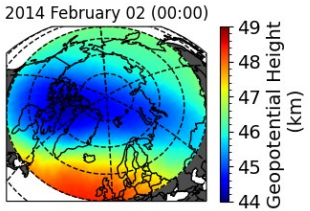
2013 -2014 NH SSW

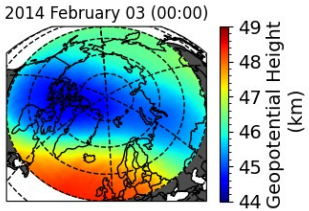
FEBRUARY WARMING

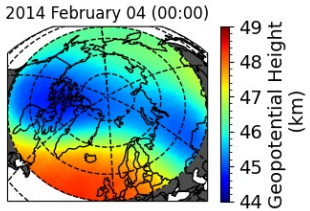
(IDENTIFIED BY WARMING RATE)

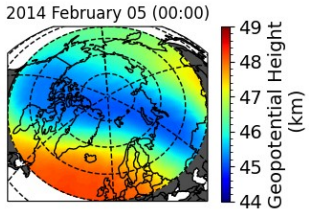
2014 FEBRUARY WARMING

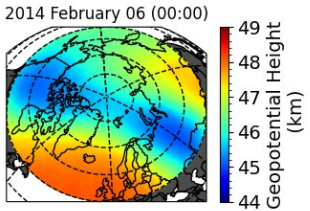
2013 -2014 NH SSW 1 HPA

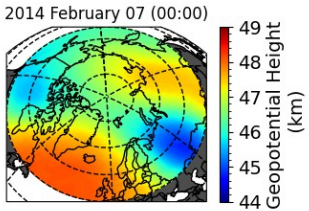


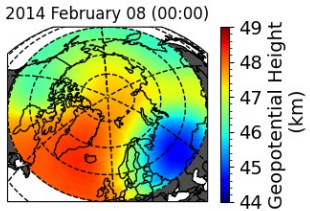


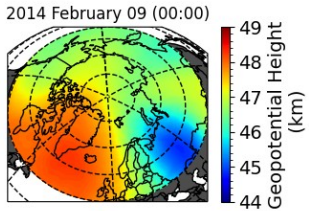


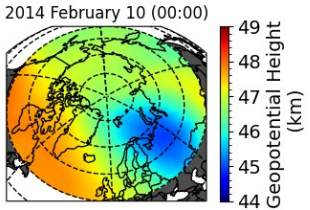


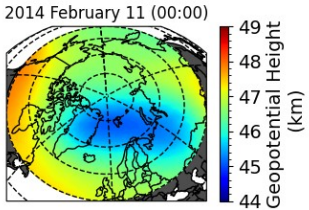


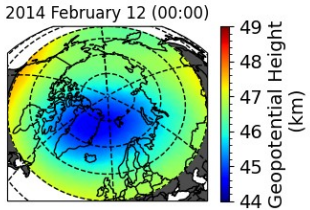


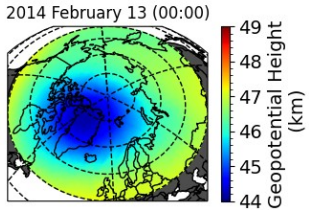








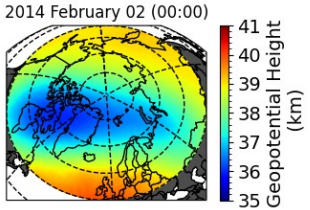


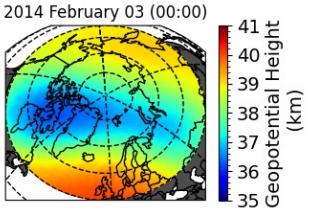


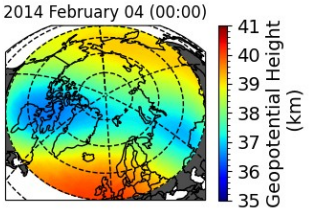
Significant variation in polar vortex conditions

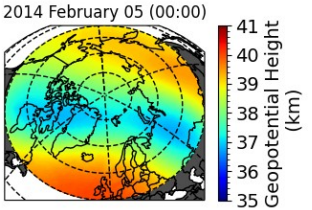
2014 FEBRUARY WARMING

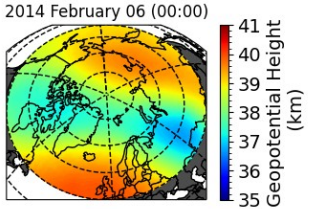
2013 -2014 NH SSW 3 HPA

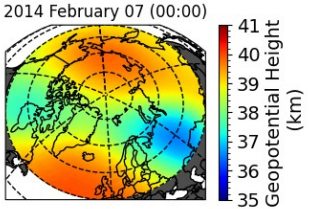


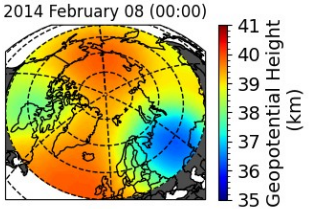


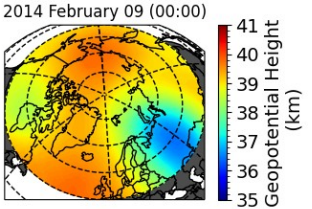


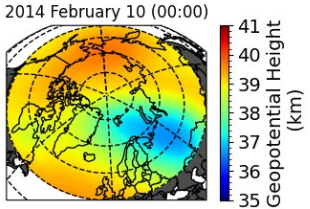


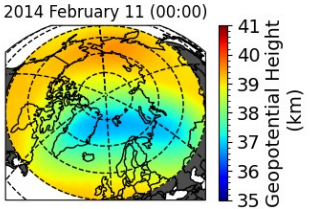


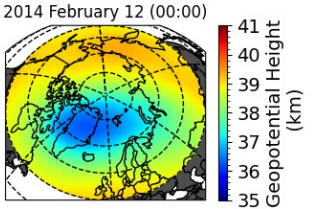


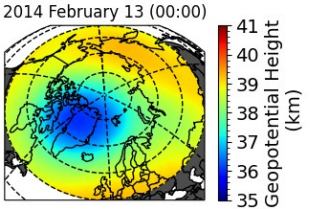






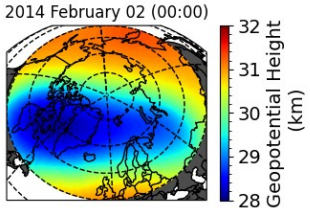


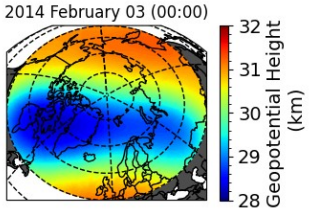


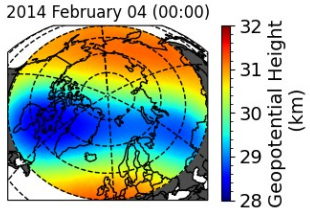


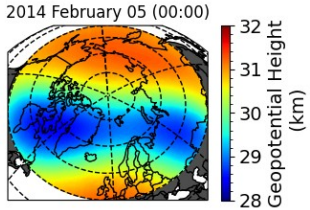
2014 FEBRUARY WARMING

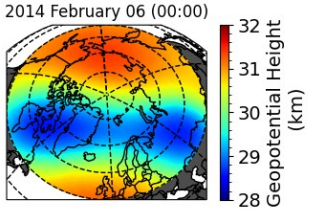
2013 -2014 NH SSW 10 HPA

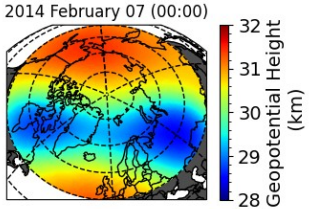


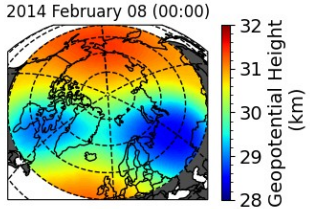


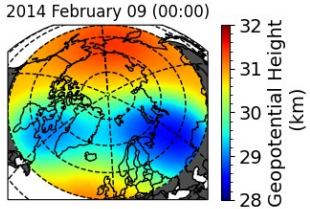


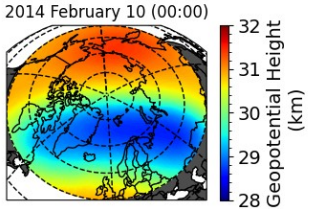


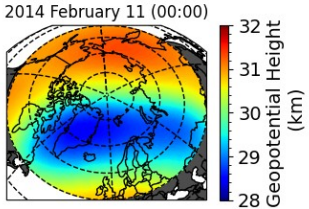


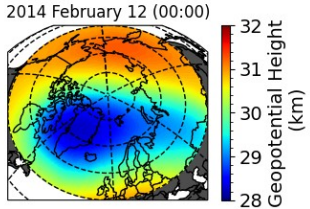


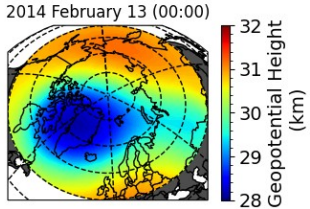








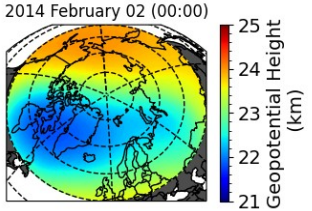


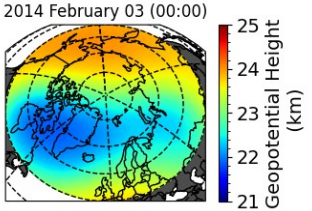


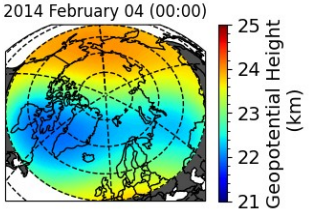
Splitting of the vortex

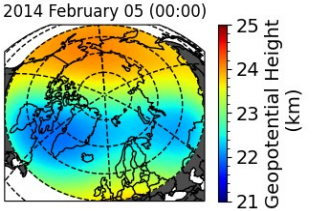
2014 FEBRUARY WARMING

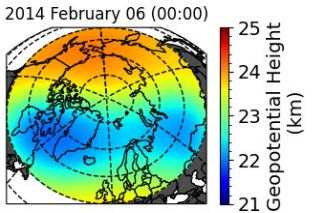
2013 -2014 NH SSW 30 HPA

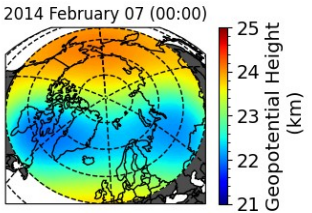


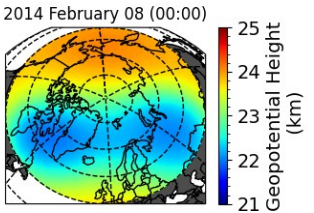


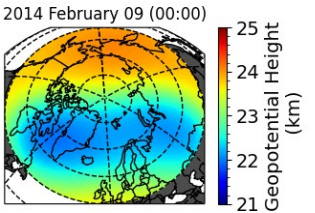


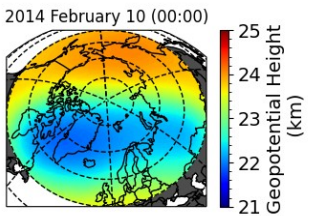


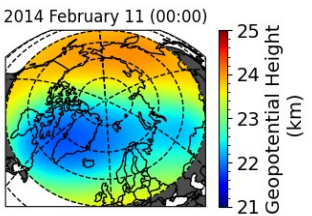


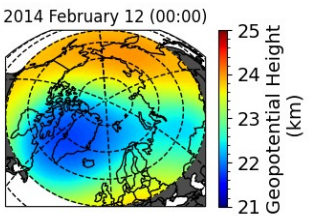


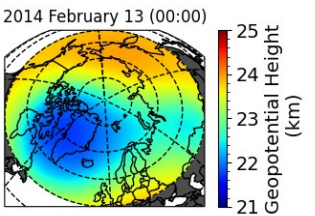






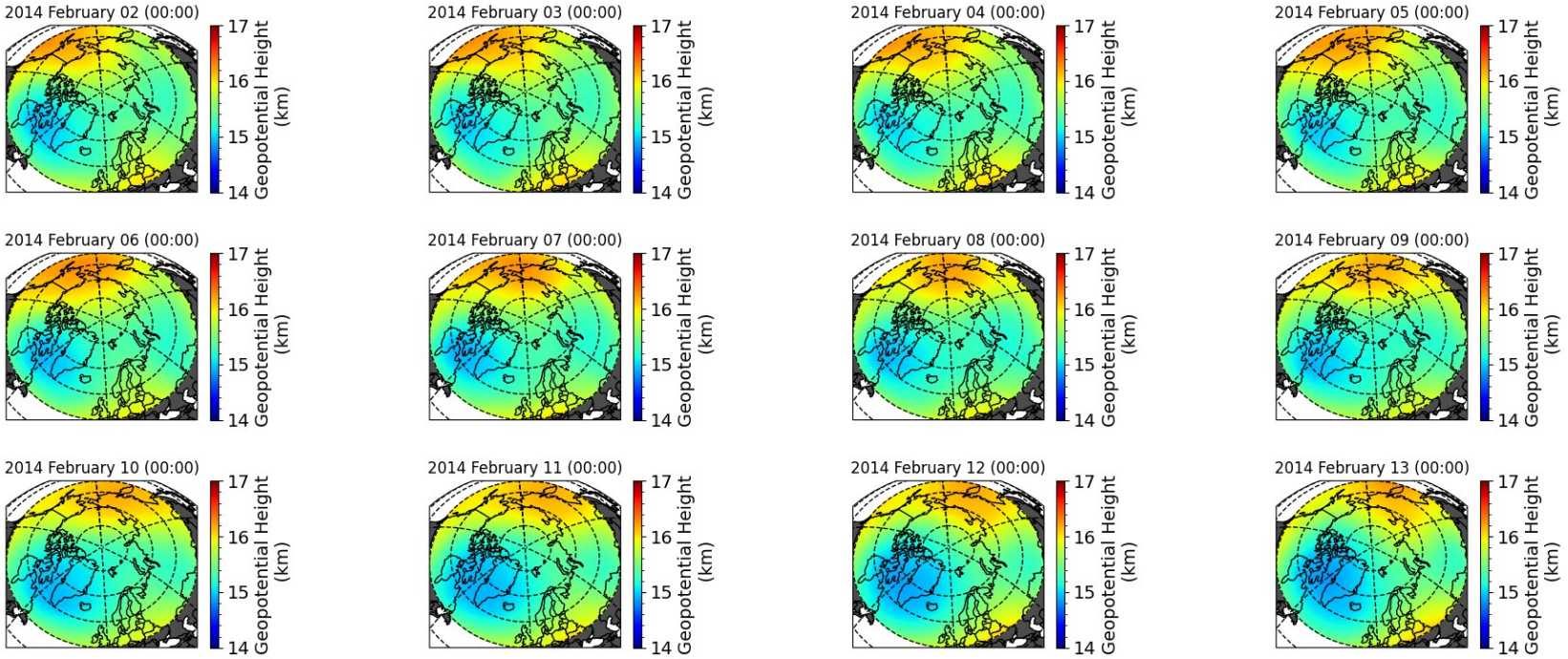






2014 FEBRUARY WARMING

2013 -2014 NH SSW 100 HPA



February warming 02 th February – 13 th February

- **February warmings is counted as a significant warming since it agrees both rate of warming and geopotential variations.**

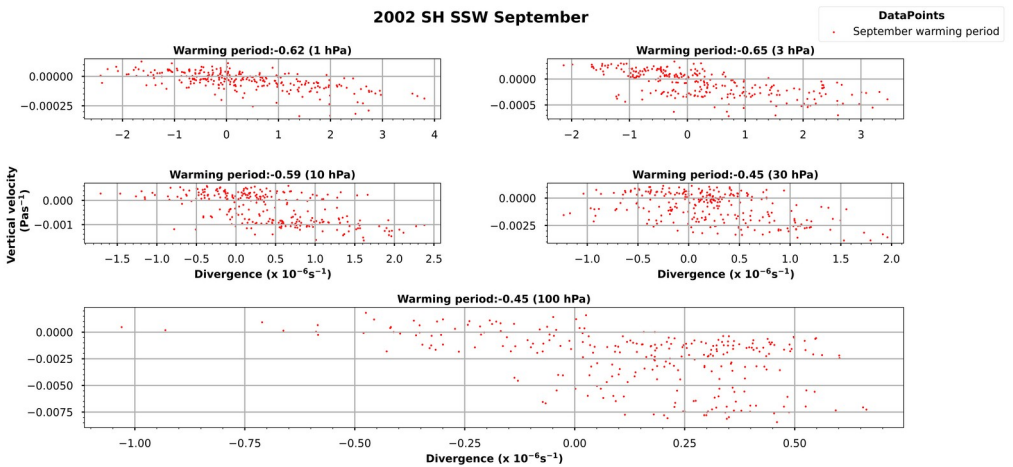
SUMMARY - WARMING PERIODS

Year	Warming Rate	Geopotential
2002	20th Sep – 28th Sep (30 hPa)	21st Sep - 01st Oct (September warming)
2013 - 2014	06 th Jan – 08 th Jan (1 hPa) 04 th Feb – 08 th Feb (3 hPa)	02 th Feb – 13 th Feb (February warming)

Table 2: Identified warming period using both warming rate and geopotential

- Both September **[2]** and February **[3]** warmings are confirmed by previous literature studies.

CORRELATION STUDIES



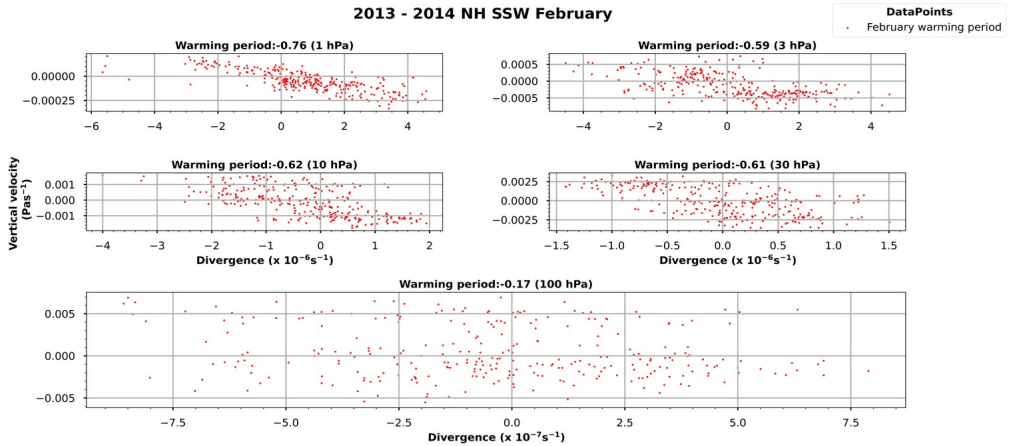


Figure 6: Pearson's correlation values and plots between vertical velocity and divergence at different pressure levels during the warming period of 2002 SH and 2013 – 2014 NH SSW.

- For 2002 SH SSW, a moderate correlation is found between vertical velocity and divergence for the upper and middle stratosphere. The correlation is weak at the lower stratosphere.

- In 2013 – 2014 NH SSW, the correlation between vertical velocity and divergence at all studied pressure levels are moderate except for 100 hPa.

CONCLUSIONS & FUTURE SCOPE

- **Significant warmings during the SSWs are identified by considering both the rate of warming and the geopotential values. Multiple parameters should be used in the definitions of SSW.**
- Identified warmings in both cases were confirmed by literature [2][3].
- **The identified significant warmings are observed at 30 hPa and 3 hPa for 2002 and 2013 – 2014 SSWs, respectively. So the two SSWs shows significant warmings at different pressure levels. So the debate arises is defining SSW at pressure levels a good way.**
- Both SSWs show a moderate correlation between vertical velocity and divergence at the upper and middle stratosphere.
- Vertical velocity shows considerable variation at the lower stratosphere, and the divergence shows prominent variation at the upper stratosphere.
- In both cases, wind reversals are always strongest at the upper stratosphere.

FUTURE SCOPE

- Applying this methodology to more SSWs.
- Studying the polar vortex at each latitude band from 50^0 N/S – 90^0N/S using ERA5, MERRA2, and JRA3Q.
- Variations in the ionospheric parameters will be studied before, during, and after the identified warming time.

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