BEHAVIOUR OF STRATOSPHERIC TEMPERATURE DURING WINTERTIME REVERSAL OF ZONAL WIND

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OVERVIEW

1. Sudden Stratospheric Warming

2. Motivation: Revising the Definition of SSW

3. Data and Methodology

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Sudden Stratospheric Warming (SSW)

- SSW is an extreme transient dynamical exclusive boreal hemispheric phenomenon.
- Deceleration or the reversal of the Zonal Mean Zonal Wind (ZMZW) leading to rising in Zonal Mean Temperature (ZMT) within few days.
- Non linear interaction of enhanced extratropical planetary-scale waves from the troposphere with the zonal mean flow.
- Classification of SSW:

  a. Major SSW   b. Minor SSW   c. Final Warming

- SSW affects both the upper and lower atmosphere.

References :

1. Scherhag, R. (1952a). Die explosionsartigen Stratosphärenerwärmungen des Spätwinters 1951/52. Berichte des Deutschen Wetterdienstes in der US-Zone, 6(38), 51–63.
2. Baldwin, M. P., Ayarzagüena, B., Birner, T., Butchart, N., Butler, A. H., Charlton-Perez, A. J., et al. (2021). Sudden stratospheric warmings. Reviews of Geophysics, 59,e2020RG000708. https://doi.org/10.1029/2020RG000708.
3. Matsuno, T. (1971). A dynamical model of the stratospheric sudden warming. Journal of the Atmospheric Sciences, 28(8), 1479–1494. https://doi.org/10.1175/1520-0469(1971)028<1479:admots>2.0.co;2

Wintertime Stratospheric Conditions

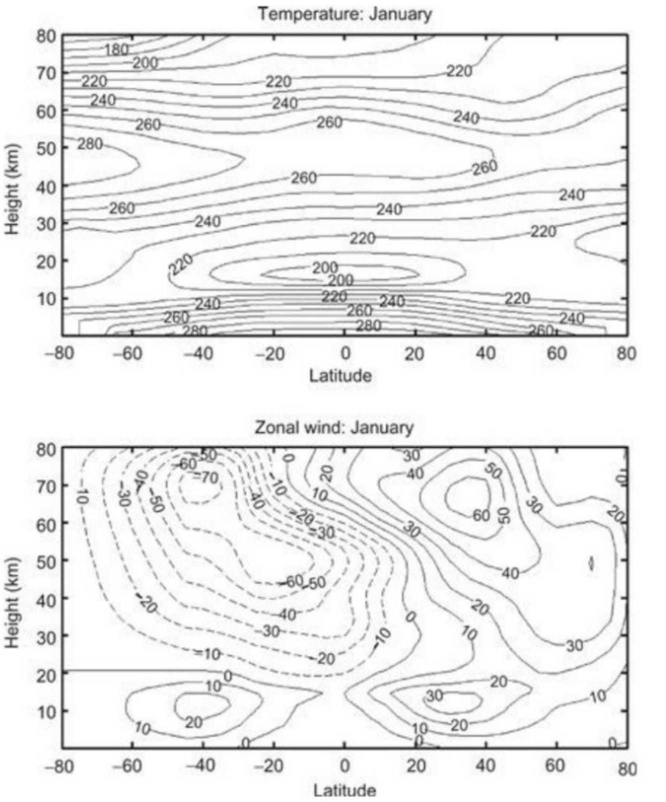


Figure 1: Monthly mean of temperature (K) and zonally averaged wind speed (m s^{-1}).

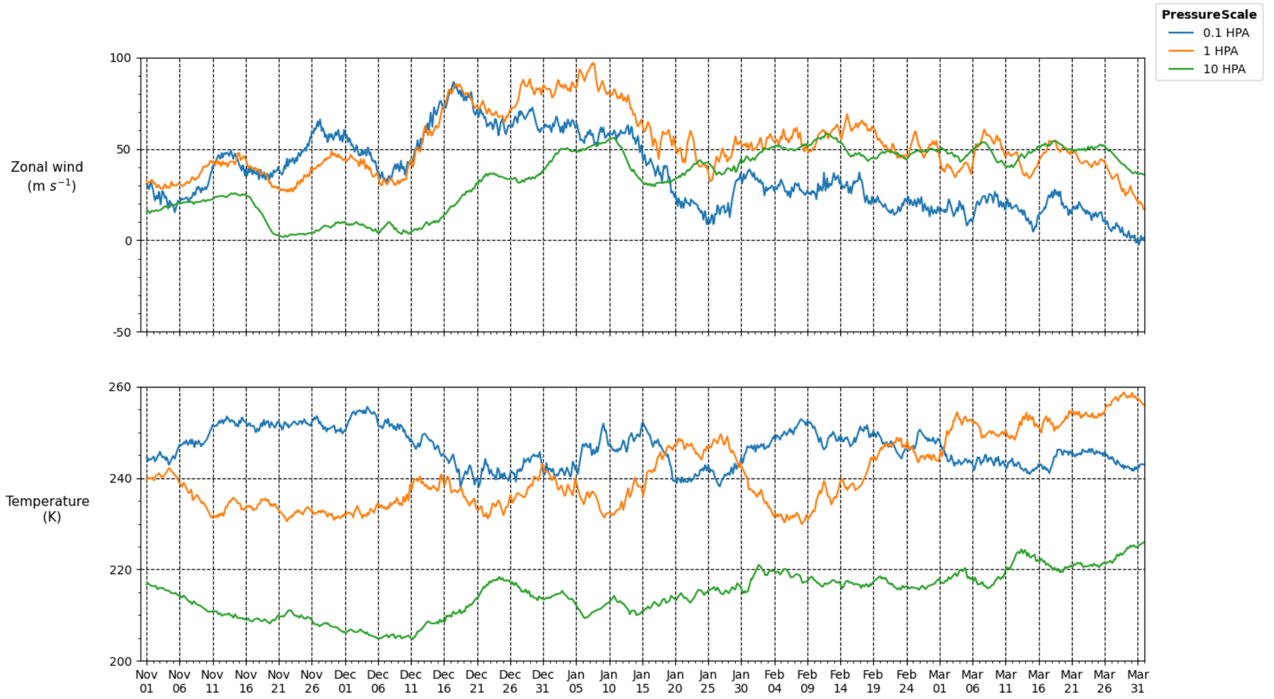


Figure 2: A normal winter case of 1995 – 1996 winter where one can observe deceleration of wind but not reversal in the early or mid winter period. But at the end of the winter (transition period) one can observe longtime reversal which is the usual transition of winter to summertime condition in the stratosphere.

References :

1. E.L. Fleming, S. Chandra, J.J. Barnett, M. Corney, Zonal mean temperature, pressure, zonal wind, and geopotential height as functions of latitude Adv Space Res, 10 (1990), pp. 11-59.

Motivation: Revising the Definition of SSW

- World Meteorological Organization (WMO) distinguishes the major SSWs from minor events:

  (a) A complete reversal of the zonal winds poleward from 60^{o} latitudes at 10 hPa.

  (b) There is an increase in the zonal-mean temperature poleward from 60^{o} latitudes at 10 hPa.

- The current classification of SSW at 10 hPa doesn’t help to understand the SSW effects on the ionosphere.

- **Goal of thesis**: Finding the best parameters for introducing a new scheme for classifying SSW based on the ionosphere.

References :

1. WMO/IQSY. (1964). International years of the quiet sun (iqsy) 1964–65. alert messages with special references to stratwarms (Report No. 6).

STRATEGY

Step 1 **Impose rules.**

Step 2 **Create a database.**

Step 3 **Classify the events within the database.**

Step 4 **Study the effects in the ionosphere.**

If the Step 4 doesn't work for the classification of the events make changes in Step 1 and Step 2.

DATA AND METHODOLOGY

- 43 winters are considered for the study starting from 1980 – 1981 winter to 2022 – 2023 winter.

- Used Modern-Era Retrospective analysis for Research and Applications version 2 (MERRA - 2) reanalysis datasets having 0.5° x 0.625° as spatial resolution and 3 hours as the temporal resolution.

- From MERRA - 2, we used temperature and zonal wind at 0.1 hPa (Ionospheric altitude), 1 hPa (Stratopause) and 10 hPa (Standard Reference Level). For the study, we computed the zonal averages of both zonal wind and temperature.

- Two criteria are used to select important events:

  a. The events must persist for at least 5 days or more.

  b. Magnitude of easterly wind equals or exceeds 10 m/s to be considered significant.

References :
1. Global Modeling and Information Office (GMAO) (2015), MERRA-2 3D IAU State, Meteorology Instantaneous 3-hourly (p-coord, 0.625x0.5L42), version 5.12.4, Greenbelt, MD, USA: Goddard Space Flight Center Distributed Active Archive Center (GSFC DAAC), Accessed on 10 th December 2023 at doi: 10.5067/VJAFPLI1CSIV.
2. Maury, P., Claud, C., Manzini, E., Hauchecorne, A., & Keckhut, P. (2016). Characteristics of stratospheric warming events during northern winter. Journal of Geophysical Research: Atmospheres, 121(10), 5368–5380. https://doi.org/10.1002/2015JD024226

‘2D’ SELECTION OF EVENTS

- With these criteria we select the events in two methods:

  a. **Constant pressure level with variable latitude**: Reversal of ZMZW observed across all latitudes from 60°N to 85°N at a given pressure level.

  b. **Constant latitude with variable pressure**: Reversal of ZMZW observed in all three pressure levels at a given latitude.

- Using the superposed epoch analysis, we study the correlation between ZMZW and ZMT at different pressure levels.

References :

1. Samuel D Walton and Kyle R Murphy. Superposed epoch analysis using time-normalization: A python tool for statistical event analysis. Frontiers in Astronomy and Space Sciences, 9:1000145, 2022.

METHOD I

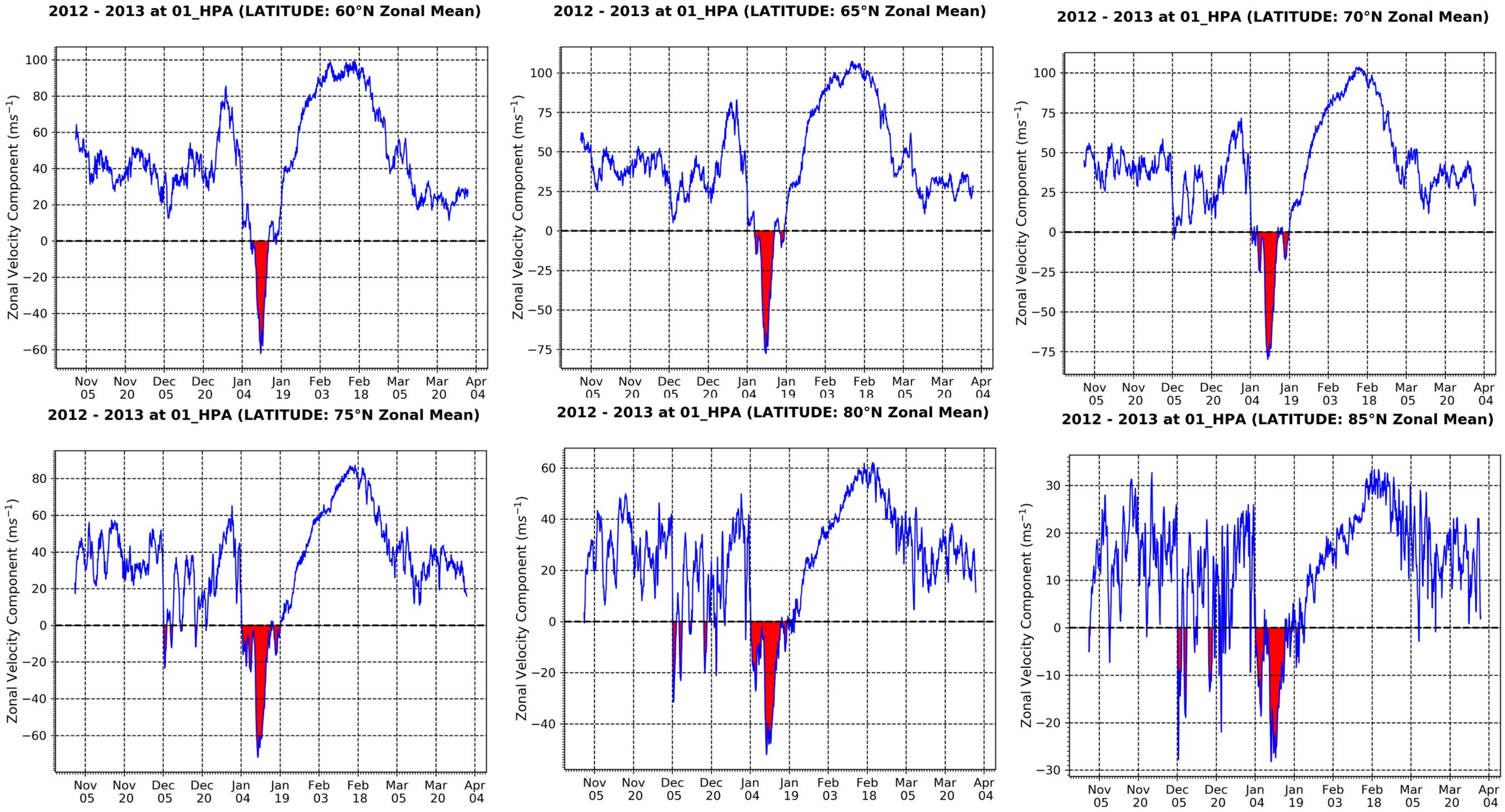


Figure 3: Selection method I.

METHOD II

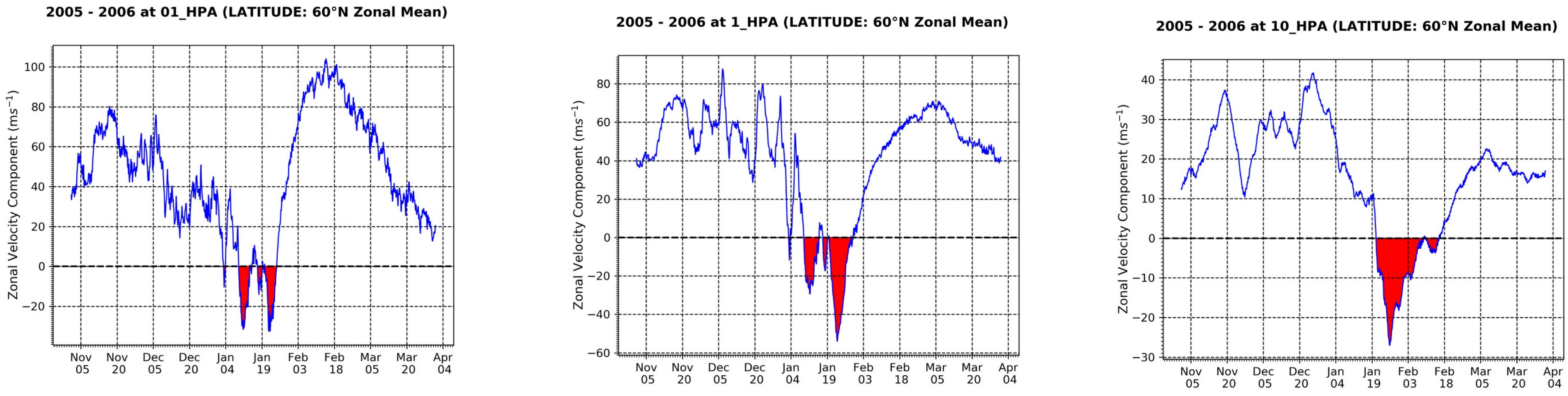
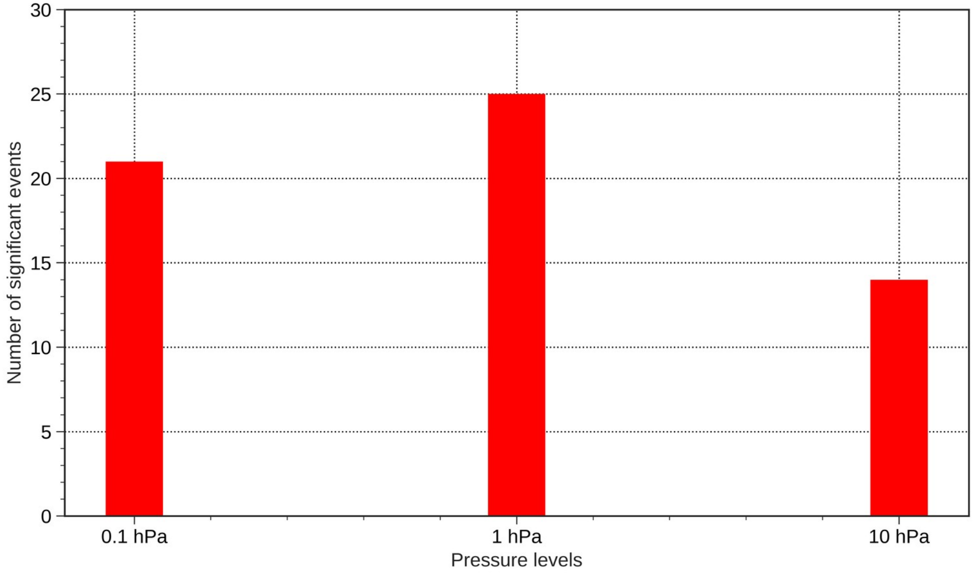


Figure 4: Selection method II.

DISTRIBUTION OF EVENTS

METHOD I



METHOD II

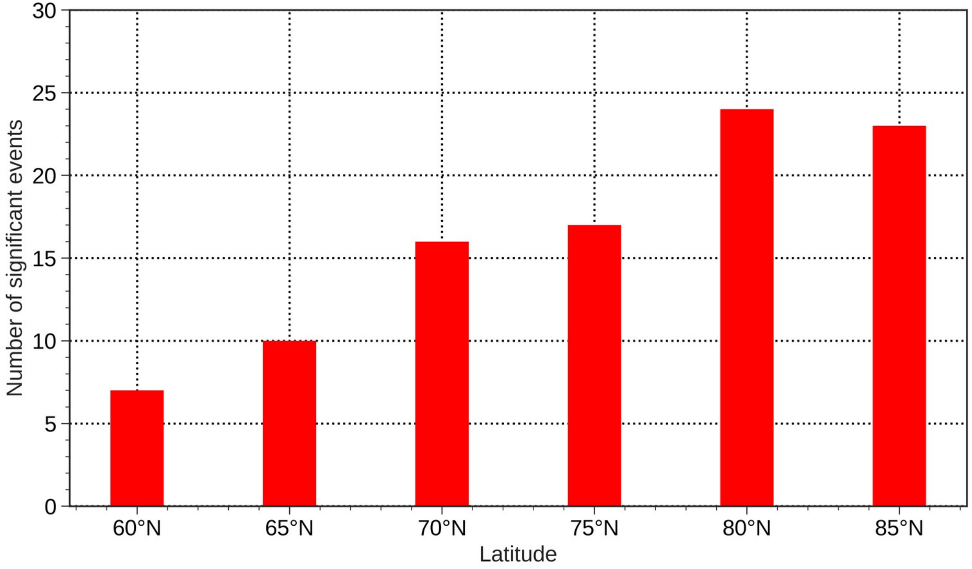


Figure 5: Significant events.

EPOCH ANALYSIS: METHOD I

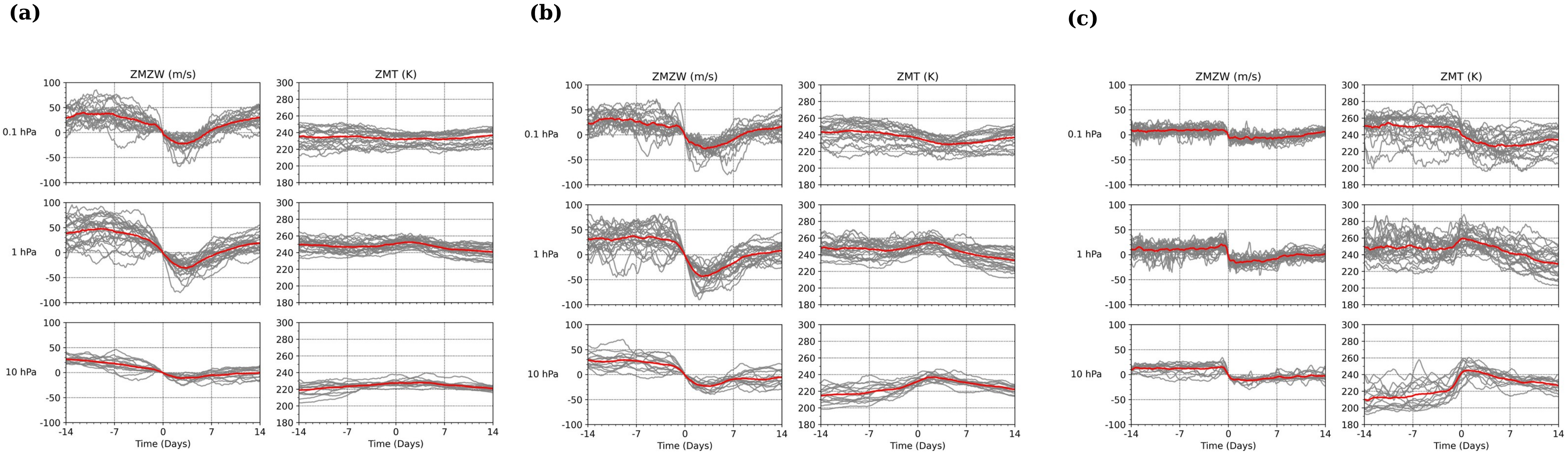


Figure 6: **(a)** 60^0 N **(b)** 70^0 N **(c)** 85^0 N. Epoch time = 14 days.

EPOCH ANALYSIS: METHOD I

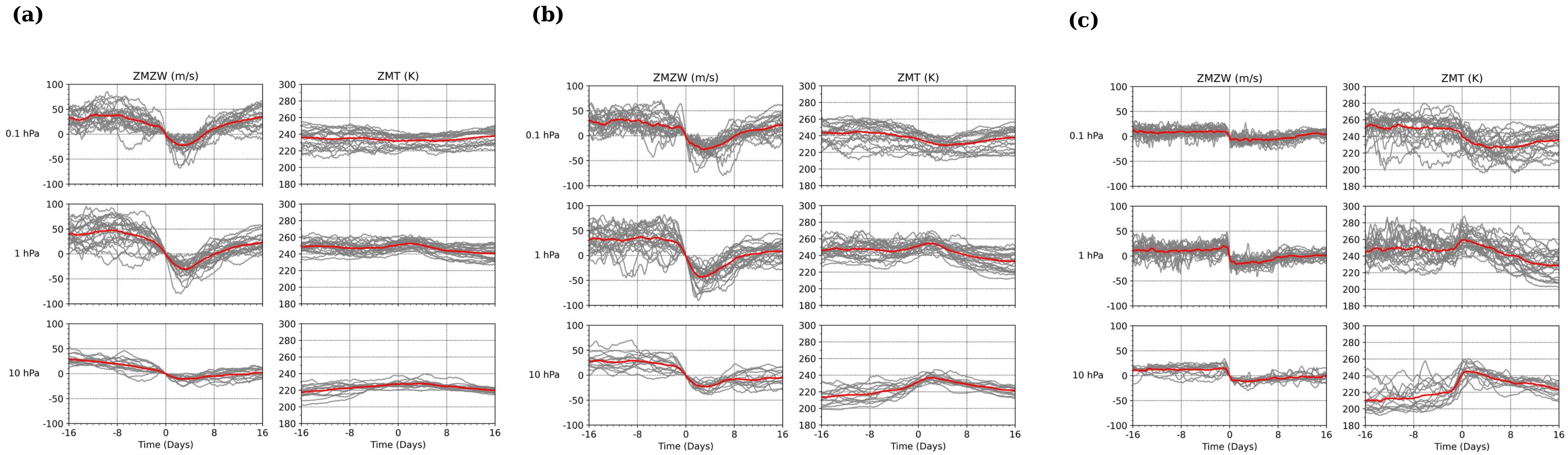


Figure 7: **(a)** 60^0 N **(b)** 70^0 N **(c)** 85^0 N. Epoch time = 16 days.

EPOCH ANALYSIS: METHOD I

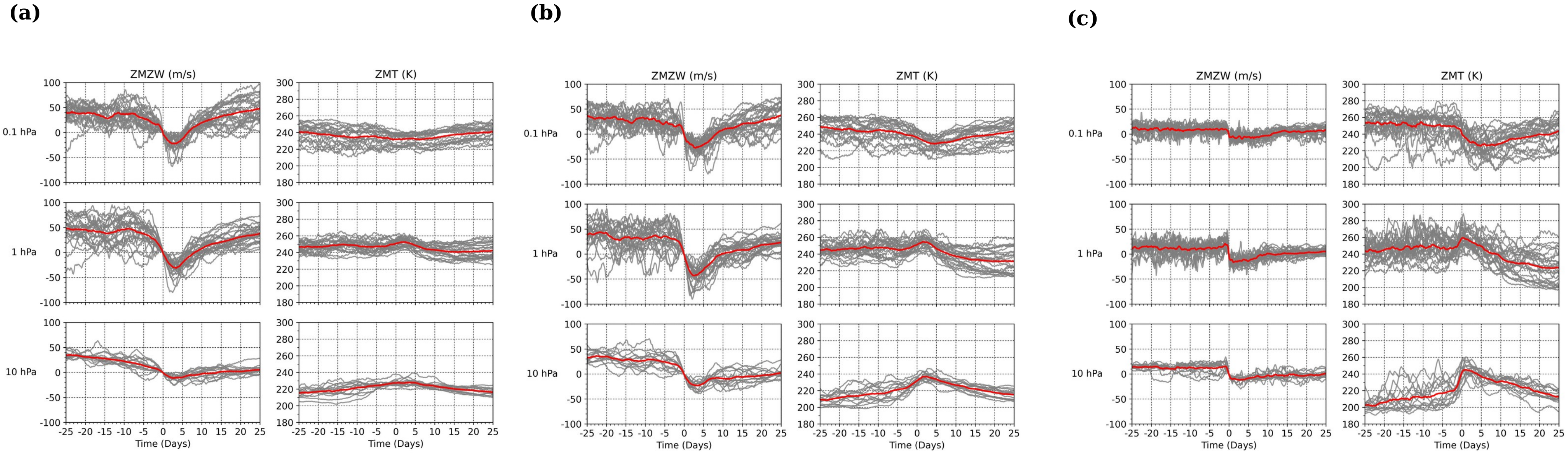


Figure 8: **(a)** 60^0 N **(b)** 70^0 N **(c)** 85^0 N. Epoch time = 25 days.

EPOCH ANALYSIS: METHOD I

Method	Latitude	Pressure (hPa)	PCC (Epoch time = 14)	PCC (Epoch time = 16)	PCC (Epoch time = 25)
I	60^ON	0.1	0.786	0.831	0.912
		1	**-0.920**	**-0.936**	**-0.905**
		10	0.864	-0.911	-0.961
	70^ON	0.1	0.741	0.819	0.922
		1	**-0.902**	**-0.920**	**-0.948**
		10	-0.805	-0.829	-0.908
	85^ON	0.1	0.445	0.580	0.805
		1	**-0.902**	**-0.921**	**-0.951**
		10	-0.848	-0.866	-0.849

Table 1: Pearson Correlation Coefficient (PCC) at 60^0 N, 70^0 N, 85^0 N at different pressure levels and epoch time.

EPOCH ANALYSIS: METHOD II

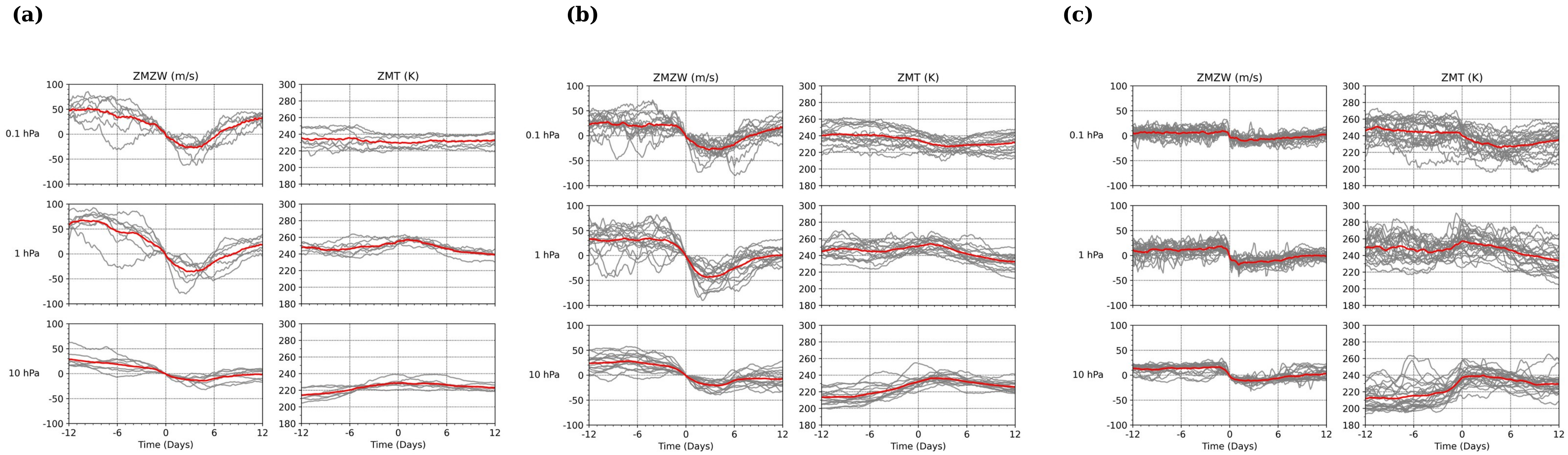


Figure 9: **(a)** 60^0 N **(b)** 70^0 N **(c)** 85^0 N. Epoch time = 12 days.

EPOCH ANALYSIS: METHOD II

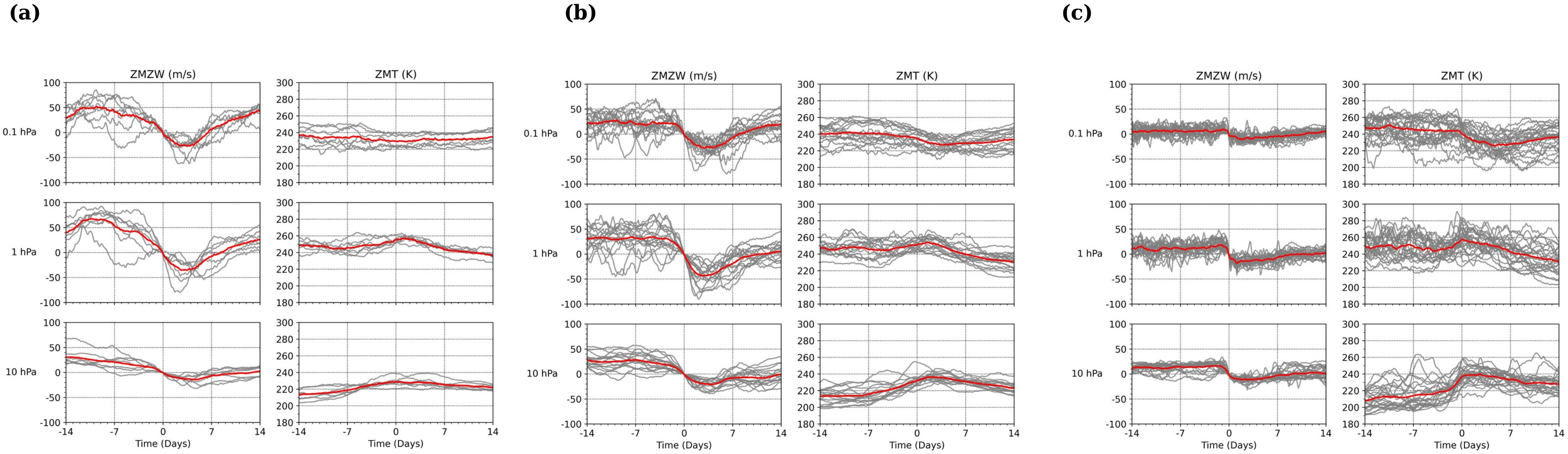


Figure 10: **(a)** 60^0 N **(b)** 70^0 N **(c)** 85^0 N. Epoch time = 14 days.

EPOCH ANALYSIS: METHOD II

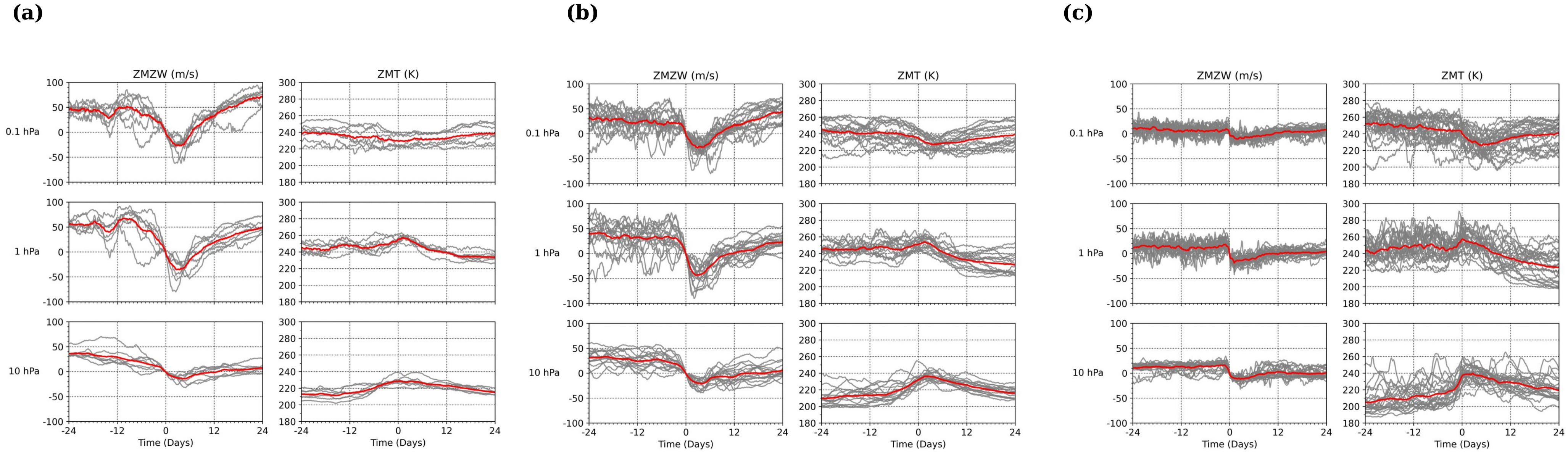


Figure 11: **(a)** 60^0 N **(b)** 70^0 N **(c)** 85^0 N. Epoch time = 24 days.

- Strongest reversal observed at 1 hPa but intense warming observed at 10 hPa.
- Peak warming is observed at 85^0 N.

EPOCH ANALYSIS: METHOD II

Method	Latitude	Pressure (hPa)	PCC (Epoch time = 12)	PCC (Epoch time = 14)	PCC (Epoch time = 24)
II	60^{O}N	0.1	0.495	0.680	0.908
		1	**-0.831**	**-0.876**	**-0.938**
		10	-0.741	-0.826	-0.921
	70^{O}N	0.1	0.669	0.694	0.917
		1	**-0.776**	**-0.860**	**-0.929**
		10	-0.908	-0.837	-0.935
	85^{O}N	0.1	0.340	0.559	0.835
		1	**-0.899**	**-0.923**	**-0.938**
		10	-0.950	-0.959	-0.784

Table 2: Pearson Correlation Coefficient at 60^{0} N, 70^{0} N and 85^{0} N at different pressure levels and epoch time.

- During reversal time, the upper atmospheric temperature shares a linear positive relation with upper atmospheric wind.
- Not compatible with method I. Hence determining the relation of ZMZW with ZMT using PCC from SEA is not helpful. So we use another approach using the events selected from method I and method II.

ANOMALY IN ZMZW AND ZMT

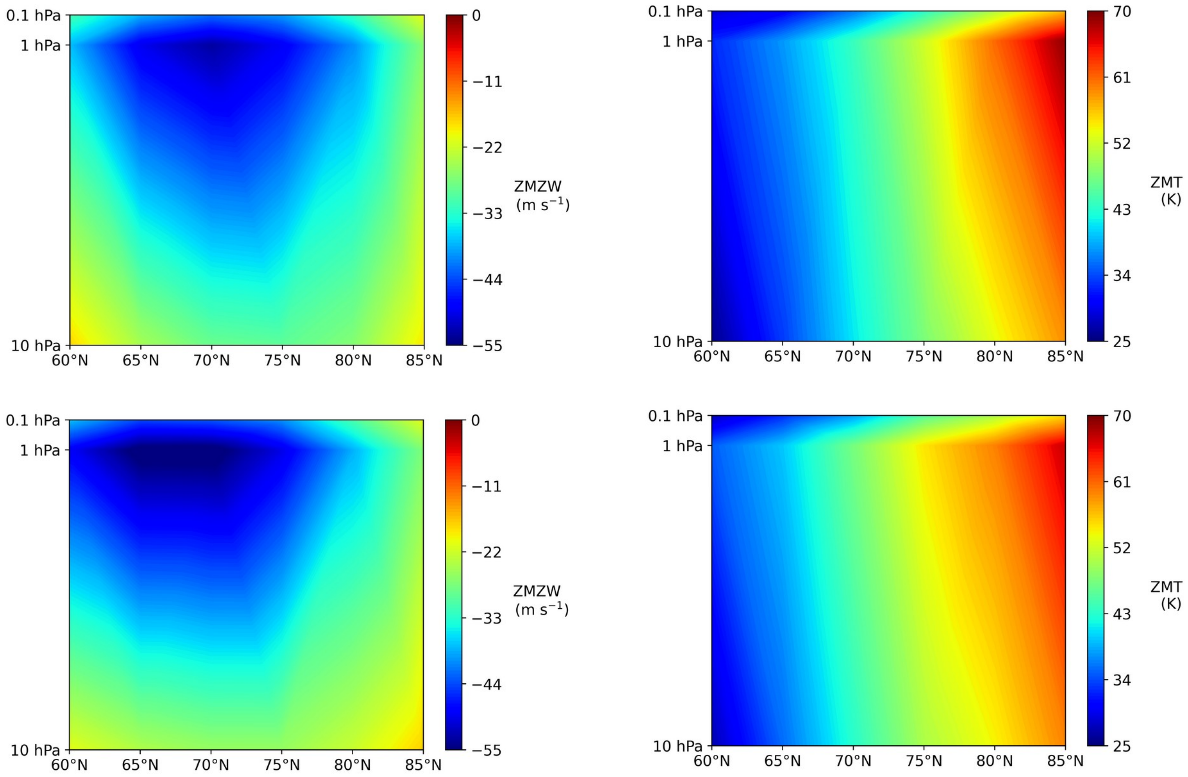


Figure 12: Average minimum wind and change in temperature ($ZMT_{max} - ZMT_{min}$) for **(a)** Method I and **(b)** Method II.

- Strongest anomaly in ZMZW and ZMT is observed at 1 hPa not at 10 hPa. Hence the inherent feature of SSW is observed for 1 hPa.

SUMMARY

- **Stratospheric peak warming and reversal of wind**: Peak warming at higher latitudes, strongest wind reversal at vortex edge, both these anomalies are at 1 hPa.

- **SSW definition**: Validation of defining SSW at 1 hPa enhances its suitability for ionospheric studies.

- **ZMZW - ZMT relation**: Different behaviour at 0.1 hPa compared to the polar vortex during reversal.

DATABASE BASED ON METHOD I & II

YEAR	WMO (10 HPA)	01 HPA	1 HPA	10 HPA
1980 – 1981	Feb, Mar			
1981 – 1982	Dec			
1982 – 1983				
1983 – 1984	Feb			
1984 – 1985	Dec, Jan			
1985 – 1986				
1986 – 1987	Jan			
1987 – 1988	Dec, Mar			
1988 – 1989	Feb			
1989 – 1990				
1990 – 1991	Jan, Feb			
1991 – 1992				
1992 – 1993				
1993 – 1994				
1994 – 1995				
1995 – 1996				
1996 – 1997				
1997 – 1998				
1998 – 1999	Dec, Feb			
1999 – 2000				
2000 – 2001	Feb			
2001 – 2002	Dec, Feb			
2002 – 2003	Jan			
2003 – 2004	Jan			
2004 – 2005				
2005 – 2006	Jan			
2006 – 2007	Feb			
2007 – 2008	Feb			
2008 – 2009	Jan			
2009 – 2010	Jan			
2010 – 2011				
2011 – 2012	Jan			
2012 – 2013	Jan			
2013 – 2014				
2014 – 2015				
2015 – 2016				
2016 – 2017				
2017 – 2018	Jan			
2018 – 2019				
2019 – 2020				
2020 – 2021				
2021 – 2022	Mar			
2022 – 2023				

Method I

YEAR	WMO (10 HPA)	60 N	65 N	70 N	75 N	80 N	85 N
1980 – 1981	Feb, Mar						
1981 – 1982	Dec						
1982 – 1983							
1983 – 1984	Feb						
1984 – 1985	Dec, Jan						
1985 – 1986							
1986 – 1987	Jan						
1987 – 1988	Dec, Mar						
1988 – 1989	Feb						
1989 – 1990							
1990 – 1991	Jan, Feb						
1991 – 1992							
1992 – 1993							
1993 – 1994							
1994 – 1995							
1995 – 1996							
1996 – 1997							
1997 – 1998							
1998 – 1999	Dec, Feb						
1999 – 2000							
2000 – 2001	Feb						
2001 – 2002	Dec, Feb						
2002 – 2003	Jan						
2003 – 2004	Jan						
2004 – 2005							
2005 – 2006	Jan						
2006 – 2007	Feb						
2007 – 2008	Feb						
2008 – 2009	Jan						
2009 – 2010	Jan						
2010 – 2011							
2011 – 2012	Jan						
2012 – 2013	Jan						
2013 – 2014							
2014 – 2015							
2015 – 2016							
2016 – 2017							
2017 – 2018	Jan						
2018 – 2019							
2019 – 2020							
2020 – 2021							
2021 – 2022	Mar						
2022 – 2023							

Method II

FUTURE OUTLOOK

Created database based on method I and II which is later calibrated and modified based on the ionospheric studies.

THANK YOU FOR YOUR ATTENTION