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Mean circulation, tides, and planetary waves in the East Siberian lower thermosphere

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Abstract. Ionospheric drift measurements in the LF range, which refer to altitudes between 80 and 100 km, enable the circulation in the lower thermosphere to be permanently monitored. From the results of long-term (1975–1996) continuous daily measurements at the Badary Observatory near Irkutsk, Russia (52°N, 102°E), the prevailing zonal and meridional wind, semidiurnal tidal wind components, and variations with planetary wave periods were derived. The climatic norms for the wind field parameters, their seasonal, intraseasonal, and interannual variations, their possible long-term trends, and dependencies on the solar cycle are presented. The geographical nonzonality of the lower thermosphere wind field, including the response to the stratospheric quasi-biennial oscillations (QBOs) and sudden stratospheric warmings, is considered.

Introduction

It is generally accepted that while the International Reference Models of the zonally averaged upper mesosphere/lower thermosphere wind field are still useful for many purposes, significant discrepancies exist between them and new experimental data. The latter demonstrate in addition to the seasonal and latitudinal variations also the longitude-dependent variations and in addition to the tides also the planetary waves and intraseasonal quasi-periodical fluctuations. It is evident that sometimes specific regional features of the wind regime are very important.

The Badary Observatory, East Siberia, (52°N, 102°E) was the only point between the Ural Mountains and the Pacific Ocean, where long continuous wind measurements were conducted from 1974 to 1997 (unfortunately, this observatory was completely destroyed by fire in May 1997).

The measurements were carried out by the closely spaced receiver technique (D1), using the time displacements of the fading of radio signals reflected from the lower ionosphere (80–100 km), which provide drift motions of electron concentration irregularities. The low-frequency (200 kHz) nighttime broadcast radio signals have experienced a single oblique reflection (one hop), the ground wave being suppressed by the loop aerials, which were set up at the corners of a triangle with the sides 500 m long. The distance between the transmitter and the receivers was about 150 km. The routine processing of continuous records was done by the simple similar-fade method. A particular drift vector was determined from a time displacement of each individual fade, and the displacements averaged over half an hour were taken to calculate the vector and its zonal and meridional components.

A uniquely observational material on drift motions has been obtained from these measurements, though necessarily restricted to nighttime hours (between sunset and sunrise). We believe that the ionized irregularities below about 110 km move with the neutral air. The D1 technique has been calibrated repeatedly and independently by meteor radars and by rocket wind measurements, so we may be sure that the motions which we consider are the neutral winds in the height range 80–100 km. The details of the installation and standard similar-fade analysis were published by *Kazimirovsky et al.* [1976].

It is well known from the first analyses of wind variations at the midlatitude lower thermosphere that the diurnal velocity variation could well be described as the sum of prevailing wind, diurnal wave and semidiurnal wave, [e.g., *Sprenger and Schminder*, 1967]. Moreover, the existence of diurnal and semidiurnal tides was demonstrated in numerous theoretical models [e.g., *Forbes*, 1982].

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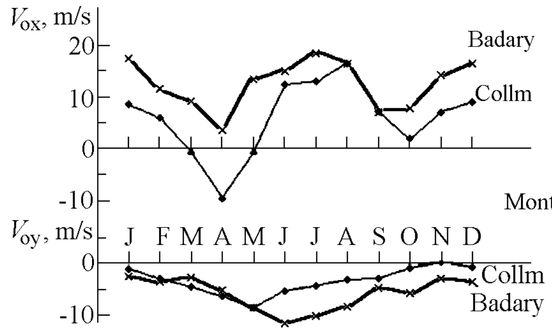

Figure 1. Seasonal variations of the monthly averaged prevailing wind. Badary, 1975–1995; Collm, 1979–1997. V_{0x} is the zonal wind (positive eastward), V_{0y} is the meridional wind (positive northward).

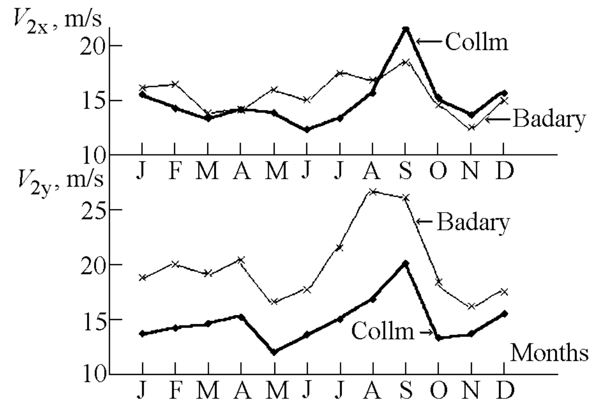

Figure 2. Seasonal variations of the monthly averaged semidiurnal tide amplitudes. Badary, 1975–1995; Collm, 1979–1997. V_{2x} is the zonal wind, V_{2y} is the meridional wind.

We tried to perform a kind of harmonic analysis in order to describe the mean diurnal variation of the wind velocity in terms of at least the prevailing component (V_0) and semidiurnally rotating component (V_2). The 24-hour component (V_1), known to be of minor importance at our latitudes, cannot be determined from our observations, because no daytime measurements are available. A part of this component is certainly involved in the determination of both V_0 and V_2, but probably in most cases, it does not seriously affect them.

During the last two decades we have published some results concerning the wind regime in the lower thermosphere over East Siberia [e.g., *Kazimirovsky*, 1981, 1994; *Kazimirovsky and Kokourov*, 1991; *Kazimirovsky and Vergasova*, 1996, 1997; *Kazimirovsky and Zhovty,* 1989; *Kazimirovsky et al.,* 1982, 1988, 1994]. With respect to the above mentioned references, it is the aim of this paper to present the climatology and some details of the wind field in the East Siberian region (prevailing wind, semidiurnal tide amplitude, periodical structure) using the 20-year homogeneous time series of the wind data over the Badary Observatory.

Results

The results for each month averaged over the entire period of observations are shown in Figure 1 (prevailing wind) and Figure 2 (semidiurnal tide amplitude). The monthly average means that the "typical day" was derived by averaging the daily data for each month and then harmonically analyzed. Then we calculated the averaged V_0 and V_2 for 20 Januaries, 20 Februaries, etc. The mean zonal wind is eastward having maxima in January and July and minima in April and September. The mean meridional wind is southward, having a maximum in July and a minimum in January. The

Table 1. Climatic Norms of Wind Regime (80–100 km)

	Zonal Wind (Positive Eastward)								Meridional Wind (Positive Northward)								
	Prevailing Wind, V_0, m s^{-1}				Semidiurnal Tides, V_2, m s^{-1}				Prevailing Wind, V_0, m s^{-1}				Semidiurnal Tides, V_2, m s^{-1}				Number of
Month	Mean	σ	Max	Min	Mean	σ	Max	Min	Mean	σ	Max	Min	Mean	σ	Max	Min	Days
Jan.	17.3	0.9	24.0	11.7	16.1	0.9	20.9	11.5	−2.6	0.9	4.2	−7.6	18.8	0.2	24.3	14.5	518
Feb.	16.9	0.2	21.3	11.2	−8.5	0.2	0.2	−16.5	16.6	0.2	25.3	11.7	431				
June	14.9	0.0	22.1	6.4	15.0	0.7	21.1	9.7	−11.6	0.2	−3.9	−20.0	17.7	0.7	30.1	11.0	389
July	18.4	1.9	29.2	12.9	17.4	0.1	22.6	13.0	−10.2	1.7	−0.8	−18.0	21.5	0.9	28.6	16.3	400
Aug.	16.3	0.6	24.3	8.5	16.8	0.0	25.2	9.8	−8.3	0.3	1.4	−13.9	26.6	0.9	32.4	17.6	372
Sept.	6.9	1.4	24.2	−1.0	18.4	0.3	28.7	13.5	−4.8	0.2	1.4	−14.6	26.1	0.2	35.2	17.1	449
Oct.	7.8	1.2	16.8	1.7	14.5	0.3	22.8	7.3	−5.8	1.1	1.3	−12.2	18.2	0.9	24.9	11.1	493
Nov.	14.1	0.5	18.3	6.5	12.5	0.6	15.8	8.1	−3.0	0.1	2.4	−7.8	16.2	0.4	21.9	11.2	479
Dec.	16.4	0.2	22.9	9.6	14.9	0.0	19.5	9.9	−3.7	1.2	3.8	−10.6	17.5	0.4	23.7	12.4	524

Badary, East Siberia, 52°N, 102°E.

Table 2. Results of Periodogram Analysis

Interval for Analysis	Significant Periods, Days								
June 1981 to May 1982	13(2.3)	15(1.5)	19(1.3)	22(1.7)	27(1.9)	30(3.0)	37(2.2)	47(3.3)	56(3.4)
June 1982 to May 1983	12(0.9)	17(1.2)	22(1.1)	27(1.3)	32(1.5)	36(1.6)	45(1.0)		
June 1983 to May 1984	21(1.7)	23(1.8)	28(2.8)	34(2.0)	40(1.8)	54(1.8)			
June 1984 to May 1985	14(2.6)	21(2.9)	27(3.5)	32(2.5)					
June 1985 to May 1986	12(1.7)	14(1.8)	19(1.9)	21(3.1)	36(4.5)				
Sept.1986 to May 1987	19(2.9)	26(3.2)	39(6.0)	50(3.4)					
June 1987 to May 1988	22(2.0)	39(3.1)	58(2.4)						
Dec. 1988 to Nov.1989	19(2.2)	21(2.5)	23(2.3)	27(2.3)	31(2.6)	56(5.3)			
Dec. 1989 to Nov.1990	13(1.6)	17(1.7)	22(2.2)	25(2.2)	28(2.2)	48(1.5)			
Dec. 1990 to Oct.1991	12(1.2)	16(2.2)	23(1.4)	36(1.8)	52(3.3)				

Zonal prevailing wind. Badary, East Siberia, 52°N, 102°E. Confidence level ≥0.95. Corresponding amplitudes (m s^{-1}) are shown in parentheses.

meridional wind as a rule is weaker than the zonal wind. The mean amplitude of the zonal semidiurnal tide is maximal in the autumn equinox (September) and minimal in the spring equinox (March). The mean amplitude of the meridional semidiurnal tide demonstrates one sharp maximum in August–September and two slight minima in May and November. We have calculated the averaged values for each day and each month during 20 years and selected the maximal and minimal values for V_0 and V_2. These climatic norms of the wind regime (mean, standard deviation, maximum, and minimum) are shown in Table 1.

If, as has been demonstrated by many authors, there is a meteorological control of the lower ionosphere, we may expect the existence of a longitudinal effect in the dynamical regime due to the well-known longitudinal inhomogeneity of the lower atmosphere processes and to the longitudinal differences in the conditions of upward propagation of the internal atmospheric waves from the lower atmosphere. The longitudinal effect has really been revealed on the basis of the simultaneous upper mesosphere/lower thermosphere wind measurements at two or more sites along one latitude circle [e.g., *Kazimirovsky et al.,* 1988].

Figure 1 demonstrates monthly mean variations of the prevailing wind at Badary and Collm. Systematic climatological distinctions are evident especially for the zonal circulation. In winter the averaged wind over East Siberia is about twice stronger than over central Europe. The seasonal variation of the zonal circulation depends on longitude as well, the autumn minimum over Siberia occurring earlier than over Europe, and spring minimum being accompanied by a wind reversal only over Europe but not over Siberia. The observed longitudinal effect may be partly interpreted as a result of the large-scale stationary planetary waves formed at lower thermosphere heights. In this case the longitudinal variation of the prevailing wind is due to the existence of such waves. To determine the sources of planetary scale perturbations in the mesosphere and lower thermosphere is one of the principal topics in the International Program PSMOS (Planetary Scale Mesopause Observing System) of the Scientific Commettee on Solar-Terrestrial Physics (SCOSTEP).

Figure 2 shows that the seasonal variations of the amplitudes of the monthly averaged semidiurnal zonal tide at both observatories are very similar with small discrepancies mainly in the summer months. The systematic climatological distinctions (but with a similar character of seasonal variations) are evident for the semidiurnal meridional tide amplitudes, which are systematically larger in East Siberia than in central Europe.

The seasonal variations of the observed maximal and minimal daily values of the prevailing wind (zonal V_{0x} and meridional V_{0y}) and semidiurnal tide amplitudes (zonal V_{2x} and meridional V_{2y}) are shown in Table 2 (see also Table 1). It is evident that for the prevailing wind the character of these seasonal variations is similar. The difference between the maximal and the minimal values varies from 11.4 m s^{-1} in May to 25.2 m s^{-1} in September for the zonal wind and from 10.2 m s^{-1} in November to 17.2 m s^{-1} in July for the meridional wind. For the semidiurnal tide amplitudes the difference between the maximal and the minimal values varies from 6.8 m s^{-1} in April to 15.5 m s^{-1} in October for the zonal wind and from 9.2 m s^{-1} in February to 19.1 m s^{-1} in June for the meridional wind.

Long-term studies of wind parameters could be used to study the interannual variability and solar cycle dependency. We can state nothing unambiguous concerning the solar cycle dependency. The correlation between the prevailing wind V_{0x} and the solar activity (the Wolf number index R) is statistically significant but very low. Moreover, the correlation coefficients may be positive for 1975–1984 and negative for 1985–1995. The correlation may be higher (up to 0.9) for a time lag between R and V_{0x} of about 1–3 years. As for V_{2x}, the statistically significant high positive correlation without time lag was observed only for 1975–1995 in May (0.62) and June (0.78).

The correlograms (cross-correlation diagrams) are shown in Figure 3. The confidence level is 0.95 (by the Fisher's criterion). We have high positive correlation (0.79) between V_{0y} and Wolf number with a time lag of 1 year and negative correlation (−0.75) between V_{2y} and the Wolf number with the same time lag.

The variability of the wind regime may be described in terms of the deviations from the long-term mean values.

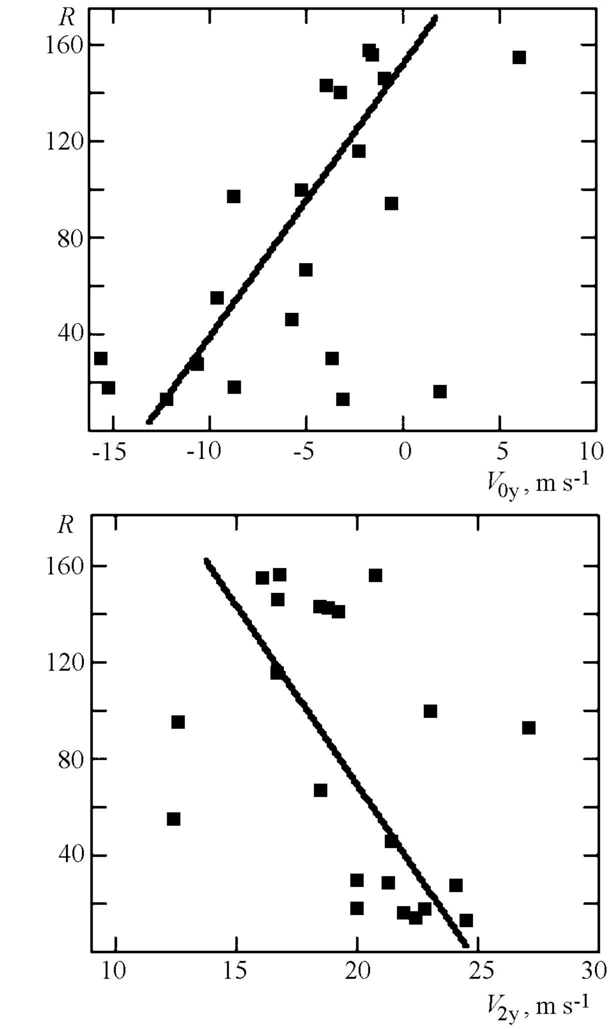

Figure 3. Correlograms for the prevailing meridional wind velocity V_{0y}, semidiurnal meridional tide amplitude V_{2y}, and the Wolf number R (annually averaged). Badary, 1975–1995.

The occurrence of rather small deviations (± 10 m s^{-1}) in the zonal prevailing wind is the largest for the years of low solar activity. However, the number of large deviations (± 20 m s^{-1}), although they are comparatively rare, correlates well with the number of geomagnetic storms ($Ap > 20$). It is visual in Figure 4. This fact serves to support the well-known data on the magnetic storm influence on the upper middle atmosphere winds, including the variability of the wind regime at middle latitudes [*Lastovička and Kazimirovsky*, 1995].

Planetary waves contribute significantly to the variability of atmospheric parameters in the middle atmosphere. In the mesosphere and lower thermosphere the wave fluctuations are sufficiently large to mask often the prevailing or mean state of the atmosphere. The waves manifest themselves in wind, density, pressure, ionization and airglow fluctuations in the 80–120 km height range. Tropospherically forced planetary waves with the periods between 2 and 30 days have been observed to penetrate up to heights of about 110 km under favorable conditions. A range of the wave periods has been identified, but the periods reported most frequently fall into four well-defined intervals that are 14–20 days, 9–12 days, 4–7 days, and 1.6–2.2 days. These are often referred to as the "16-day," "10-day," "5-day," and "2-day" oscillations, respectively, although precise determination of the periods involved is often impossible. It should be noted that waves of other periods have also been reported. It is usually assumed that these transient oscillations of the wind field in the lower thermosphere are caused by the Rossby gravity-normal modes generated in the lower atmosphere [*Vincent*, 1990].

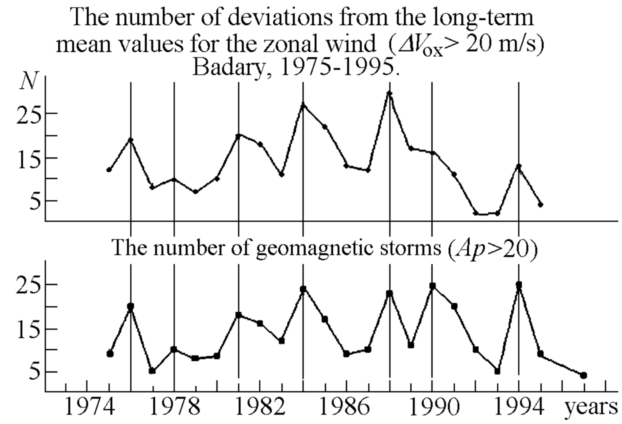

Figure 4. Number of large deviations from the long-term mean values for the zonal prevailing wind and the number of geomagnetic storms.

We have used daily mean values of V_{0x} and V_{0y} and correloperiodogram analysis [*Vitinsky et al.,* 1986] to reveal the

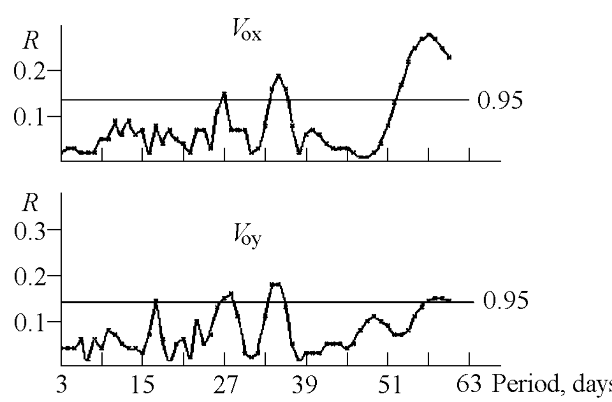

Figure 5. Periodograms for the mean annual row. V_{0x} is the zonal prevailing wind. V_{0y} is the meridional prevailing wind. Badary, 1975–1995. The confidence level is 0.95.

Table 3. Seasonal Variation of the Long-Term Maximal and Minimal Daily Values Observed at Badary (1975–1995)

	Zonal Wind (Positive Eastward)								Meridional Wind (Positive Northward)							
	Prevailing Zonal Wind, V_{0x}, m s^{-1}				Semidiurnal Zonal Tides, V_{2x}, m s^{-1}				Prevailing Meridional Wind, V_{0y}, m s^{-1}				Semidiurnal Meridional Tides, V_{2x}, m s^{-1}			
Month	Max	σ	Min	σ	Max	σ	Min	σ	Max	σ	Min	σ	Max	σ	Min	σ
Jan.	34.4	2.3	−2.3	1.2	33.2	6.1	3.8	1.2	17.9	0.8	−21.9	1.8	40.1	4.3	4.1	1.7
Feb.	33.2	0.5	−9.9	0.3	34.6	0.1	3.4	0.2	19.8	0.3	−27.0	2.4	44.4	1.9	4.3	0.3
March	26.4	1.9	−10.0	3.3	32.3	1.7	2.5	0.2	14.5	1.0	−21.0	2.7	35.9	0.2	5.5	0.5
April	22.4	0.9	−15.2	2.1	30.2	2.5	3.2	0.1	20.3	1.4	−26.8	7.7	40.7	4.5	4.9	1.2
May	29.1	0.9	−5.8	5.8	34.4	3.5	2.9	0.1	12.9	0.9	−28.5	6.1	35.4	5.0	3.5	0.5
June	28.0	1.7	−3.8	4.8	30.6	4.2	3.7	0.1	8.0	0.9	−29.5	1.3	36.0	1.0	5.1	0.5
July	34.6	2.2	−4.6	0.1	34.5	0.1	5.9	0.2	16.7	1.3	−31.0	1.4	41.5	2.2	6.4	1.0
Aug.	35.4	5.0	−5.8	1.6	39.3	2.1	5.6	2.2	20.4	5.8	−37.2	2.9	52.1	2.4	7.1	1.2
Sept.	23.9	0.3	−9.6	0.5	35.3	1.0	7.6	0.7	13.8	0.4	−25.2	3.5	42.2	1.0	8.6	0.7
Oct.	23.0	0.1	−9.8	4.4	29.3	1.4	3.4	0.2	11.1	1.4	−23.4	0.2	36.0	4.8	4.7	2.7
Nov.	29.3	3.1	−5.5	0.4	28.3	0.9	2.6	0.0	12.5	6.1	−22.6	0.3	33.2	2.6	3.4	1.6
Dec.	32.5	1.9	−4.6	2.3	33.2	1.0	3.1	0.2	15.2	3.2	−24.9	0.1	36.4	2.5	4.6	0.6

Prevailing wind: V_{0x} is zonal, V_{0y} is meridional. Semidiurnal tides: V_{2x} is zonal, V_{2y} is meridional.

fluctuations with periods of planetary waves and intraseasonal variations. This analysis as a special case of the classical periodogram analysis makes it possible to compute the probability of existence for the harmonics under study. The description and results of application of this method can be found also in the works of *Apostolov et al.* [1995] and *Pancheva* [2000]). This method provides a simultaneous assessment of the amplitude, phase, and probability of presence (i.e., the significance of the fluctuation) for every harmonic component by selection of all reasonable values of the probe periods with an increment, ensuring the required precision. The advantage of this method is that we can obtain high-resolution spectral estimates in the desired period range with an arbitrarily small period step. In fact, we calculate the coefficient of plural linear correlation between the real variation and the probe harmonics $R(T)$. It is evident that the maxima of $R(T)$ correspond to the periodicities of T existing in the initial process. The results are shown in Figure 5. One can see that the spectrum is rather wide but we can identify only a few periods with a confidence level higher than 0.95, including the 27-day, quasi-monthly, and quasi-bimonthly periodicities. It may be noted that periods close to 27 days are clearly seen in the wind variations during one year or so (see Table 3). The origin of the 27-day planetary wave periods is still a controversial subject. It may be connected with the solar rotation period or with internal atmospheric processes?

There are interannual differences in the spectra of fluctuations in the wind field. Table 3 shows the most significant periods for 10 particular years.

We have analyzed the time variations of the amplitudes for the most interesting waves ($T = 16$ days; $T = 27$ days) for the zonal prevailing wind. The spectra of these variations contain half-year and quasi-biennial periods.

Conclusion

Extending the earlier analysis, we described in this study some upper mesosphere/lower thermosphere wind field peculiarities in the East Siberian region. We demonstrated the nonzonality of the prevailing wind and semidiurnal tide, and also the richness and variability of the planetary scale variations in the dynamical regime. The variations may be due to the nonstationarity of the processes under consideration. Considerably more observations are required before the structure and role of the atmospheric waves in the 80–120 km region could be fully elucidated.

There is a need to organize an effective monitoring system that would be reasonably intensive and extensive. What is desired from future research is a qualitative assessment of all the significant couplings, trigger mechanisms, and feedback processes.

In conclusion, it should be noted that the lower thermosphere dynamics response to meteorological processes, solar and geomagnetic activity remains a stimulating challenge to scientists. Although individual investigators have much to contribute, it would seem that now is an appropriate time (for instance, in the frames of the PSMOS projects) to attempt to improve the collaboration among observationalists, theoreticians, and modelers in order to maximize our knowledge of this important problem.

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