AGU PUBLICATIONS

JGR

Journal of Geophysical Research: Atmospheres

RESEARCH ARTICLE

10.1002/2014JD021781

Key Points:

- System description of newly installed meteor radar is provided
- First results along with validation using similar radars are provided
- Advantages and limitations of this new system are discussed

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Citation:
Rao, S. V. B., S. Eswaraiah, M. Venkat Ratnam, E. Kosalendra, K. Kishore Kumar, S. Sathish Kumar, P. T. Patil, and S. Gurubaran (2014), Advanced meteor radar installed at Tirupati: System details and comparison with different radars, *J. Geophys. Res. Atmos.*, *119*, 11,893–11,904, doi:10.1002/2014JD021781.

Received 17 MAR 2014
Accepted 2 OCT 2014
Accepted article online 7 OCT 2014
Published online 6 NOV 2014

Advanced meteor radar installed at Tirupati: System details and comparison with different radars

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Abstract An advanced meteor radar, viz, Sri Venkateswara University (SVU) meteor radar (SVU MR) operating at 35.25 MHz, was installed at Sri Venkateswara University (SVU), Tirupati (13.63°N, 79.4°E), India, in August 2013 for continuous observations of horizontal winds in the mesosphere and lower thermosphere (MLT). This manuscript describes the purpose of the meteor radar, system configuration, measurement techniques, its data products, and operating parameters, as well as a comparison of measured mean winds in the MLT with contemporary radars over the Indian region. It is installed close to the Gadanki (13.5°N, 79.2°E) mesosphere-stratosphere-troposphere (MST) radar to fill the region between 85 and 100 km where this radar does not measure winds. The present radar provides additional information due to its high meteor detection rate, which results in accurate wind information from 70 to 110 km. As a first step, we made a comparison of SVU MR-derived horizontal winds in the MLT region with those measured by similar and different (MST and MF radars) techniques over the Indian region, as well as model (horizontal wind model 2007) data sets. The comparison showed an exquisite agreement between the overlapping altitudes (82–98 km) of different radars. Zonal winds compared very well, as did the meridional winds. The observed discrepancies and limitations in the wind measurement are discussed in the light of different measuring techniques and the effects of small-scale processes like gravity waves. This new radar is expected to play an important role in our understanding of the vertical and lateral coupling of different regions of the atmosphere that will be possible when measurements from nearby locations are combined.

1. Introduction

It is now well understood that the thermal structure and dynamics of the mesosphere and lower thermosphere (MLT) and its variability can be determined to a significant degree by studying the large- and small-scale waves propagating into this region from the lower atmosphere [*Fritts and Alexander*, 2003; *Lieberman et al.*, 2004; *Ratnam et al.*, 2008]. Therefore, the need to obtain profiles of atmospheric parameters in the MLT region has increased, especially during the last decade. The driving force behind this is that the climactic changes are expected to be larger in the upper atmosphere [*Venkat Ratnam et al.*, 2013].

During the past few decades the middle atmosphere research community has recognized the role of ground-based radars in delineating the structure and variability of MLT region. Other techniques such as those employing rockets, optical, and space-based observations have limitations in measuring the winds and temperatures accurately. Some of these methods are very accurate (more than radars) but are limited by weather (optical), limited observations (rockets), or temporal resolution (satellite). Mesosphere-stratosphere-troposphere (MST) radars, meteor radars (MRs) and medium frequency (MF) radars that adopt different measurement techniques such as Doppler beam swinging, interferometry, and spaced antenna drift methods, respectively, are proven to be valuable tools to measure the winds continuously in the MLT region over the last two decades. Among these instruments, MR and MF radars are playing a crucial role in obtaining useful information on background winds and waves in the MLT region [*Vincent*, 1984; *Manson and Meek*, 1993; *Gavrilov et al.*, 1995; *Manson et al.*, 1997, 1999a, 1999b; *Nakamura et al.*, 1996].

The era of MST radars has demonstrated the utility of these radars as unique instruments for middle atmosphere dynamics studies with few limitations, mainly the absence of wind information during nighttimes [*Hocking*, 2011]. Following these MST radars, the MF radars have yielded a significant amount of data in

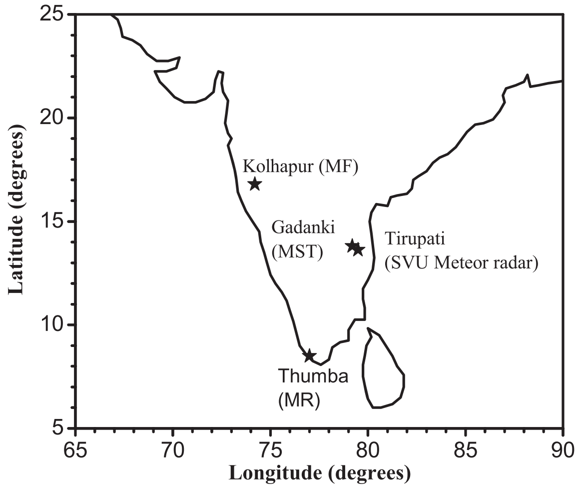

Figure 1. Map showing the location of the SVU meteor radar. Locations of other radars used in the present study are also shown.

MLT, especially between 70 and 100 km [*Meek et al.*, 1985a, 1985b; *Vincent and Fritts*, 1987; *Vincent and Lesicar*, 1991; *Thayaparan et al.*, 1995a, 1995b; *Rajaram and Gurubaran*, 1998; *Manson et al.*, 2002].

Meteor radars for probing the MLT region have a long history [*McKinley*, 1961], with observations starting in the early to middle 20th century [*Nagaoka*, 1929; *Skellett*, 1931] and with different measurement techniques, which include continuous wave forward scatter (bistatic) [*Cevolani*, 1998], direct narrow beam observations [*Cervera and Reid*, 1995; *Singer et al.*, 2008], and all-sky interferometric observations [*Jones et al.*, 1998; *Hocking et al.*, 2001; *Holdsworth et al.*, 2004]. At present, MR observations entail the use of coherent scatter techniques for the detection of meteor trails.

Though there are few MST radars and several MR and MF radars have been in operation over low latitudes, due to their limitations in height and temporal coverage, the MLT region structure and dynamics are less understood. Generally, MST radars provide data on winds only during daytime over the altitude region 65–80 km, whereas MR and MF radars provide information on winds between 80 and 100 km almost throughout the day as well as night. Structure, dynamics, and vertical coupling of the atmosphere through waves over a given geographical location can be studied with both MST radar and MR/MF radar. Very few locations in the world have this combined facility.

Recently, a state of the art of advanced meteor radar has been installed at Sri Venkateswara University (SVU), Tirupati (13.63°N, 79.4°E), during August 2013 (hereafter called the SVU meteor radar (SVU MR)) for continuous monitoring of the MLT region dynamics with improved meteor detection rate. The SVU MR was established at a distance of 30 km to the northeast of the Gadanki (13.5°N, 79.2°E) MST radar [*Rao et al.*, 1995] and together with the MST radar will prove to be an advantage for this location for vertical coupling studies by monitoring the complete lower and middle atmosphere during daytime and MLT round the clock.

Since long-period oscillations originating at troposphere, propagate horizontally through the MLT region, there is a scope for studying lateral coupling of the atmosphere with a radar network over the given latitude. In this regard, the SVU MR has the advantage of being located within 1000 km of the Thumba meteor radar (Thumba MR) (8.5°N, 77°E), and MF radars at Tirunelveli (8.7°N, 77.8°E), and Kolhapur (16.8°N, 74.2°E) and thus can form an excellent regional network providing a unique opportunity to study both the vertical and lateral coupling in the low-latitude region. When different radar techniques are used to measure winds in the MLT region, it is important to evaluate the similarities and discrepancies in the wind measurements. The intercomparison of winds measured by Thumba MR and Tirunelveli MF radar in the MLT over the Indian region has been documented [*G. K. Kumar et al.*, 2007; *Sharma et al.*, 2010]. In this communication, we compared the wind measurements from the newly installed SVU MR with those of other MR and MF radars and MST radar (Doppler beam swinging) as well as HWM-07 (horizontal wind model 2007) model estimates.

2. SVU MR System Description and Data Analysis

2.1. System Description

The SVU MR is advanced meteor radar due to its high meteor count rate sensitivity, configured by ATRAD, Australia. This radar was installed at the low-latitude station, Tirupati (13.63°N, 79.4°E), in August 2013. The location of this site is shown in Figure 1. The present location was identified as the source for both small and large-scale motions in the middle atmosphere. The dynamics in the low-latitude middle atmosphere (10–80 km) is well understood with existing MST radar and Rayleigh lidar located close by, at Gadanki (13.5°N, 79.2°E). However, investigations on the MLT dynamics remained a challenge with the

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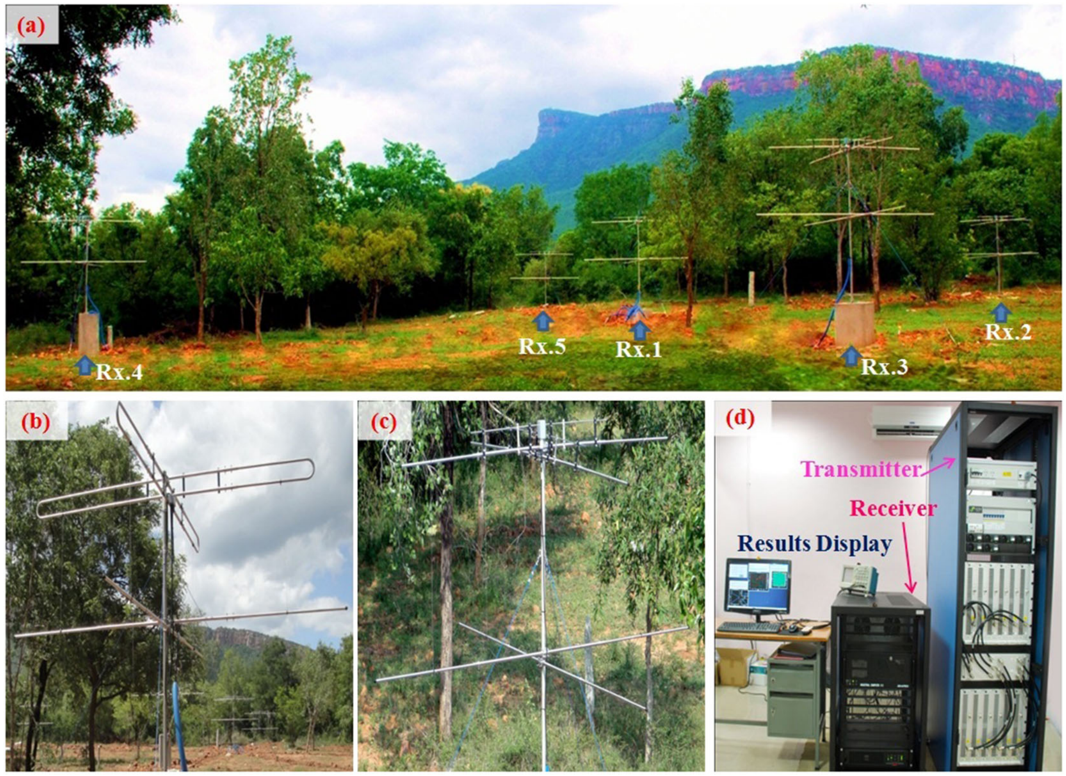

Figure 2. (a) Panoramic view of SVU meteor radar receiving antenna setup, (b) transmitting antenna, (c) receiving antenna and its elements, and (d) in-house transmitter/receiver systems in the radar control room.

available setup at Gadanki. This limitation has been overcome with the installation of the SVU MR close to Gadanki by providing background horizontal winds with excellent temporal and spatial resolution. The panoramic view of the SVU MR antenna system is shown in Figure 2a.

The SVU MR is a five-channel coherent-pulsed detection radar, which employs the use of interferometer technique for the detection of meteor echoes. The parameters and measurement capabilities include a radar frequency of 35.25 MHz corresponding to a wavelength (λ) of 8.5 m and a peak transmitter power of 40 kW with a duty cycle up to 12%. The transmitter and receiver antenna array is shown in Figure 2 along with radar in-house equipment. The SVU MR that consists of a single transmitting antenna (Figure 2b) with a two-element Yagi circular crossed folded dipoles with a Coaxial Hairpin Balun as feeder, directed toward the zenith, is used to illuminate the meteor trails and five receiving antennas each having circular crossed dipoles and reflectors as shown in Figure 2c. The location of five receiving antennas is shown in Figure 2a. Meteor trail reflections are coherently received on five Yagi antennas positioned on two orthogonal baselines, with one antenna in the center of the array common to both baselines, forming an interferometer. On each baseline, the outer antennas are separated from the center by 2λ and 2.5λ. A schematic layout showing the configuration of the five receiving antennas with their spatial separation in terms of radar wavelengths and distances is shown in Figure 3. This arrangement reduces the mutual antenna coupling, and the phase differences between antenna pairs are combined to produce a

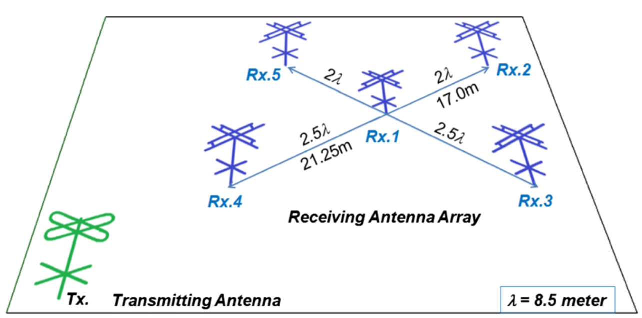

Figure 3. Schematic layout showing the configuration of five Rx antennas along with their spatial separation in terms of radar wavelengths. Location of Tx antenna is also shown.

Table 1. SVU MR Radar Experimental Specifications Used for the Present Study

Parameter	Specification
Frequency	35.25 MHz
Output power	40 kW
Transmission mode	Circular
Pulse shape	Gaussian
Transmitter Modules	6
RF LO	115.25 MHz
IF LO	80 MHz
Receiver Antennas	5
Type	two-element Yagi (circular, crossed dipole)
Feed	T-match combined as 2:1
Transmitter Antennas	1
Type	two-element Yagi (circular, crossed folded dipole)
Feed	Coaxial Hairpin Balun

virtual half-wavelength baseline to unambiguously determine the azimuth and elevation of the meteor echoes and provide excellent angular resolution for position determination [*Jones et al.*, 1998]. The transmitting antenna is located 50 m away from the center of the receive array. Figure 2d shows the radar control room with transmitter and receiver along with display and data storage units. More details of its configuration are given in Table 1. Since it was commissioned, the SVU MR has employed a 4 bit code, a pulse repetition frequency of 430 Hz with four sample integrations. This configuration covers the altitude range from 70 to 110 km.

2.2. Data Analysis

In general, MR observations entail the use of coherent scatter techniques for the detection of meteor trails. The meteor trail interaction with radio waves exhibits certain characteristics like echo decay times and phase drifts combined with Angle of arrival (AoA) enabling determination of atmospheric parameters such as wind velocity and allows estimation of atmospheric temperature using pressure models [*Takahashi et al.*, 2002; *Hocking et al.*, 2007]. Since meteor trails are sporadic in nature and their number varies throughout the course of the day and within the meteor region (70–110 km), the SVU MR system detects sufficient meteor echoes from different directions throughout the day to provide wind fields between 70 and 110 km with a vertical resolution of 2 km. From the radial component of wind velocity for individual meteor echoes, the zonal and meridional wind velocities are calculated with 1 h temporal resolutions in a default mode. However, data can also be analyzed using a reduced resolution of 30 min for investigating short-period waves typically between 80 and 100 km altitudes particularly during early morning hours where meteor counts are significantly higher than the rest of the day.

A typical example showing the altitude distribution of meteor counts and their AoA observed on 30 August 2013 is shown in Figure 4. During the first 5 days of observations, an average count of ~35,000 meteors per day was observed in the 70–110 km region. Among these 5 days, interestingly on 30 August 2013, 41,634 meteor counts were detected in 24 h and the same was shown in Figure 4. As shown in Figure 4a, meteors are detected from 70 to 110 km with a peak around 92 km. This is a very high count when compared to other MRs of this type. The recent MRs are capable of measuring ~16,000 to 25,000 meteor echoes/day [*G. K. Kumar et al.*, 2007]. However, the SVU MR is capable of measuring an average count of 35,000 to 40,000 meteor echoes per day, with minimum echo rates at the lower (70–80 km) and upper altitudes (100–110 km). This demonstrates the potential application of the radar for wind measurements throughout the 70–110 km altitude region.

The distribution of meteor counts with respect to time (in UT = LT + 0530 h) observed on the same day is shown in Figure 4b. The variation of the number of counts in a particular interval of time in a day can be attributed to the variation of dominant sporadic meteor sources, i.e., the hellion/antihellion sources and the apex sources. The variation in meteor detection rates is due to the detection area (sky above the radar) rotating to face toward and away from these streams. Hence, in the local morning hours, i.e., 0530 to 0630 h (0000 to 0100 UT), the present location of the radar will be pointing toward the stream of meteors which supplement the normal meteor activity. In the local evening hours, i.e., 1730 to 1830 h LT (1200 to 1300 UT), the radar location will be pointing away from the stream of meteors, which leads to the decrease in meteor detections. From Figure 4b, the meteor count amounts to 3600–3800 per hour and 100–200 per hour during local midnight and noon hours, respectively. The distribution of meteors with respect to range for the same day depicted in Figure 4c shows that the detection range varies from 80 km to 350 km with a peak between 100 and 200 km at which the number of counts amount to more than 2000 per hour.

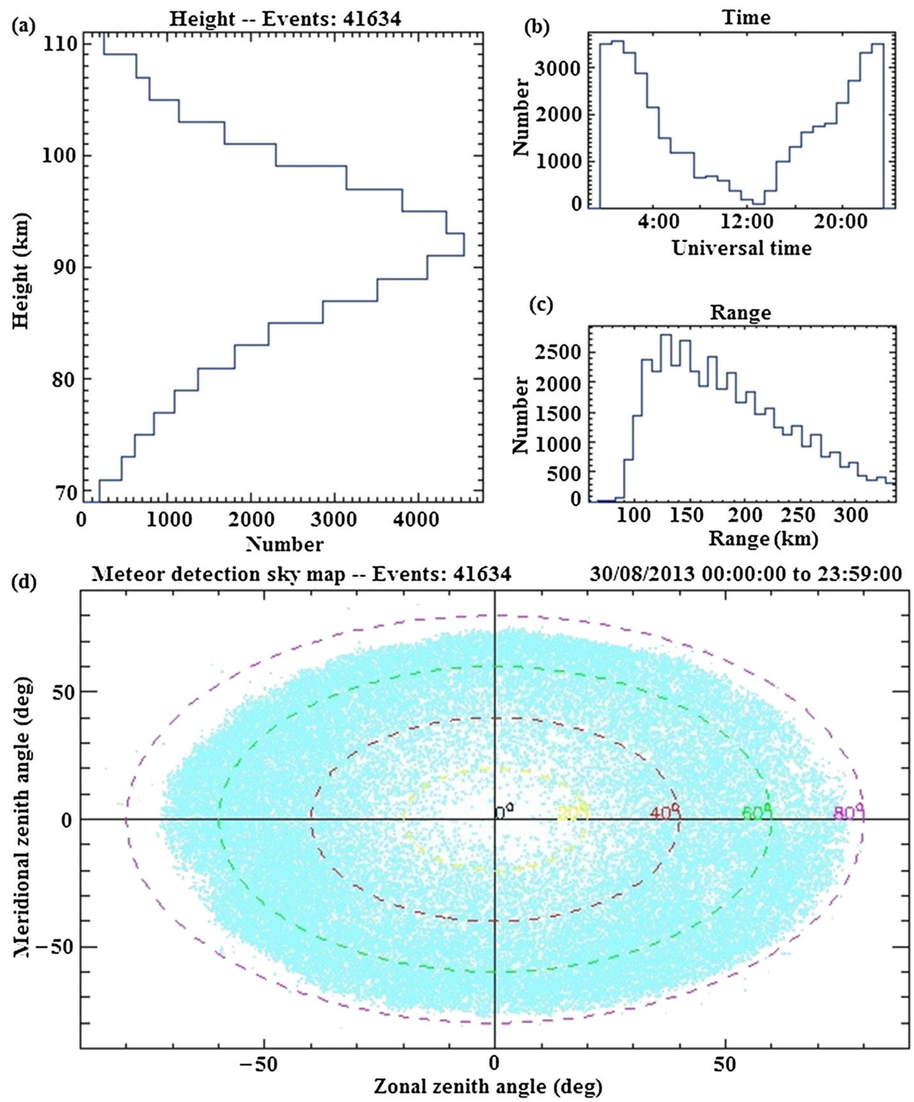

Figure 4. (a) Typical height distribution of all meteors detected on 30 August 2013. (b) The distribution of meteors with respect to the universal time and (c) with range for the same day. (d) Angle of arrival of individual meteors in terms of zonal and meridional zenith angles on the same day.

The AoA of individual meteors in terms of azimuth and zenith angles observed on the same day is shown in Figure 4d. In the present radar, the transmitter antenna power distribution is such that the majority of meteor detections are at off-zenith angles between 25° and 70°, providing wind fields for both large- and small-scale motions in the MLT region. The distribution seen is due to the increasing horizontal extent of the meteor region at lower elevation angles. Meteors are not seen below 70° due to the extreme detection range of low elevation angle meteors. Meteors are also not seen near the zenith due to the grazing geometry of meteor trajectories for trail detections around the zenith.

The horizontal wind fields (zonal (u) and meridional (v) velocities) over the altitude region 70–110 km are estimated by implementing a least squares fit of meteor detection radial wind components as depicted by *Holdsworth et al.* [2004]. According to this algorithm, a minimum of six echoes per hour is required for each 2 km altitude bin to estimate and maintain a degree of statistical reliability in the wind velocity. But the ATRAD software used in the SVU MR system uses a minimum of four echoes per hour for each 2 km altitude bin. A typical example of radar-estimated hourly zonal and meridional winds observed on 30 August 2013 in the altitude region 70–110 km estimated with the above mentioned criteria is shown in Figures 5a and 5b, respectively. The data gaps in the wind at local noon are due to diurnal fluctuation in

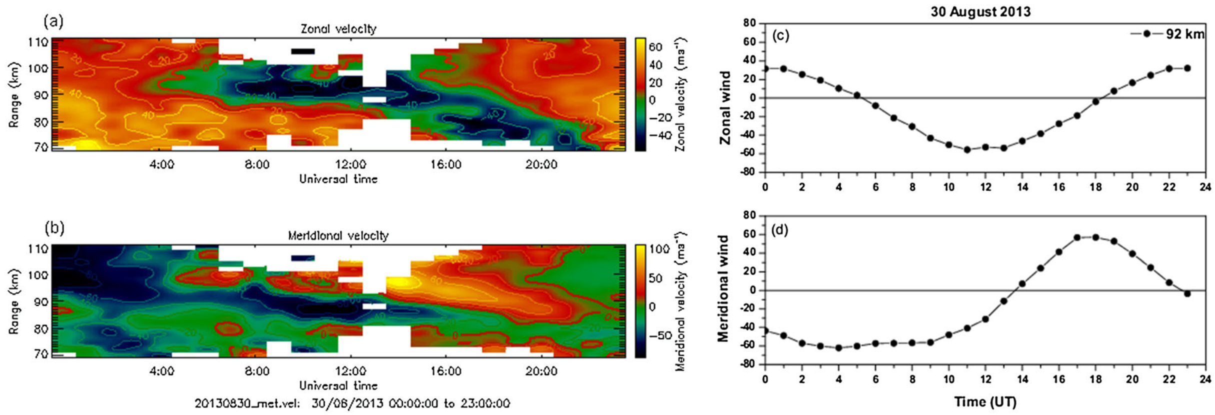

Figure 5. Time-altitude section of hourly (a) zonal wind and (b) meridional wind observed on 30 August 2013. Diurnal variation of (c) zonal and (d) meridional winds observed at meteor count peak altitude (92 km) on the same day.

meteor detection rate [*Cervera et al.*, 2004; *Cervera and Elford*, 2004]. In general, large zonal and meridional wind velocities ranging up to ±70 m/s can be seen on this day. Zonal (meridional) velocities are eastward (southward) throughout the altitude region during local day hours, and above 80 km during night hours, but changes westward (northward) during local night hours above 90 km, revealing strong diurnal variation. Temporal variation of zonal and meridional winds observed at the peak altitude of meteor count (92 km) is shown in Figures 5c and 5d, respectively. At this altitude, zonal winds are westward during day hours and eastward in the nighttime, whereas meridional winds are southward throughout the day and change to northward during nighttime.

In general, wind information is available between 80 and 100 km with MR/MF radars. However, the wind information over the altitude region of 100–110 km is very crucial for atmospheric coupling studies and is rarely available. In this comparison, the SVU MR has proven its merit and significance with its improved sensitivity in providing wind information between the heights 100 and 110 km as it exactly follows the model predictions over this region.

3. System Description of Other Radars and Model Data Used in the Present Study

Before using the wind fields derived from SVU MR for scientific studies, it is desirable to know how they compare with observations from similar/different radars located nearby. Hence, for comparison, simultaneous observations obtained from the MST radar (53 MHz) located at Gadanki, the Thumba MR (35.25 MHz) located at Thumba (8.5°N, 77°E), and MF radar (1.98 MHz) located at Kolhapur (16.8°N, 74.2°E) were used. The locations of these radars are also shown in Figure 1 along with the SVU MR. The MST radars at VHF are capable of providing information on winds only during daytime (due to insufficient *D* region ionization during nighttime). Other radars mentioned above could provide horizontal winds continuously for the observational campaign (29 August 2013 to 2 September 2013) with a few data gaps. As mentioned earlier, the Gadanki MST radar [*Rao et al.*, 1995] is about 30 km away from the SVU MR and is a well-known observational tool with its unique capability of measuring winds in the troposphere, the lower stratosphere (1.5 to 21 km) and the mesosphere (65 to 85 km) [*Ratnam et al.*, 2001]. This is a high-power coherent-pulsed Doppler radar operating at 53 MHz with a peak transmitter power of 2.5 MW [*Rao et al.*, 1995]. This radar was operated with 16 μs pulse width and interpulse period of 1000 μs with 128 fast Fourier transform points and 64 coherent integrations and two incoherent integrations with 1.2 km altitude resolution for the present study. A detailed description of the data and signal detectability at mesospheric altitudes has been provided by *K. K. Kumar et al.* [2007], and the derivation of horizontal and vertical winds for mesospheric altitudes and their accuracies are discussed in *Ratnam et al.* [2001], *Kishore Kumar et al.* [2008] and *Eswaraiah et al.* [2011].

The Thumba MR located 500 km south of the SVU MR has the same configuration of the present radar and has been functioning since June 2004. This radar is a multichannel coherent-pulsed radar system, operating at a frequency of 35.25 MHz with a peak power of 40 kW and duty cycle up to 15% to derive the

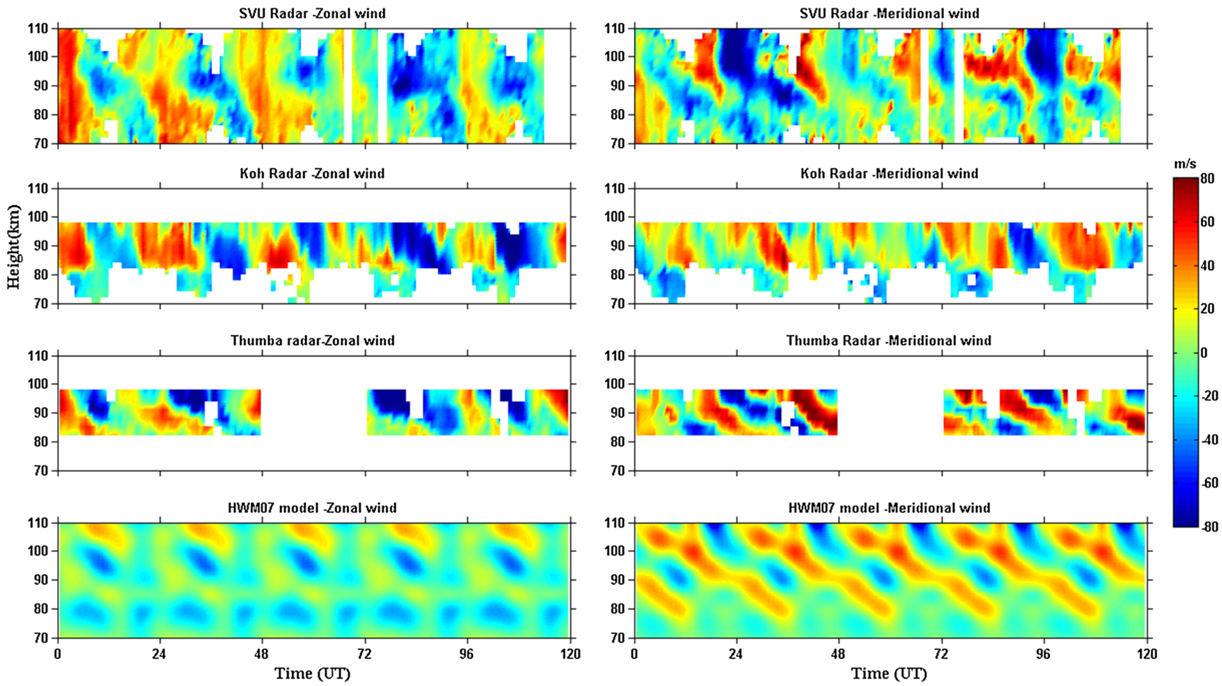

Figure 6. Time-altitude sections of (left) zonal and (right) meridional winds observed using (first row) SVU meteor radar, Kolhapur MF radar and Thumba MR (second and third rows) observed during 29 August 2013 to 2 September 2013. White color patches show data gaps. (fourth row) HWM-07 model-estimated winds for Gadanki region during the same period.

winds from 82 to 98 km. A detailed description of this commercialized radar and the meteor detection algorithm is explained by *Hocking et al.* [2001] and also in *G. K. Kumar et al.* [2007]. The Thumba MR measured winds have also been compared with MF radar wind measurements located at Tirunelveli (8.7°N, 77.8°E), and excellent agreement has been found below 90 km but not above 90 km [*G. K. Kumar et al.*, 2007].

The MF radar at Kolhapur (16.8°N, 74.2°E) is also ~500 km away from SVU MR but to the northwest. This radar operates in a spaced antenna mode. The system is similar to that installed at Tirunelveli [*Rajaram and Gurubaran*, 1998]. More information about this kind of a radar system is given by *Vincent and Lesicar* [1991]. This system utilizes a full correlation analysis [*Briggs*, 1984; *Holdsworth and Reid*, 1995] to determine the wind field in the MLT region between 70 and 98 km. Some of the results of mean winds and tidal climatology observed by this radar were reported by *Rajaram and Gurubaran* [1998], *Gurubaran and Rajaram* [1999], and *Sharma et al.* [2010].

We also make use of data sets of the horizontal wind model 2007 (HWM-07) [*Drob et al.*, 2008] for comparing the horizontal winds obtained by the SVU MR. HWM-07 is a new generation model which can provide horizontal neutral winds from the ground to an altitude of 500 km. The responses of neutral winds to the geographical location, local time, season, geomagnetic activity, and the seasonal variability of tides and planetary waves are also considered in this model.

4. Comparison of SVU MR Observations With Nearby Radars and HWM-07 Model

The SVU MR was commissioned on 27 August 2013, and after finishing initial calibrations, it started giving data from 29 August 2013. For the present study, the first 5 days (29 August to 2 September 2013) of data have been used where the information on horizontal winds are also available with the above mentioned radars. We made use of these data sets for the comparison of zonal and meridional winds obtained from the SVU MR. In order to verify the performance of the SVU MR, we first made a comparison of diurnal variation of zonal and meridional winds with other radars and HWM-07, and later, day-to-day comparisons have been made.

Figure 6 shows the time-altitude sections of the hourly zonal (left) and meridional (right) winds obtained for the above mentioned period. The white patches in the contours are the data gaps. In general, SVU MR zonal

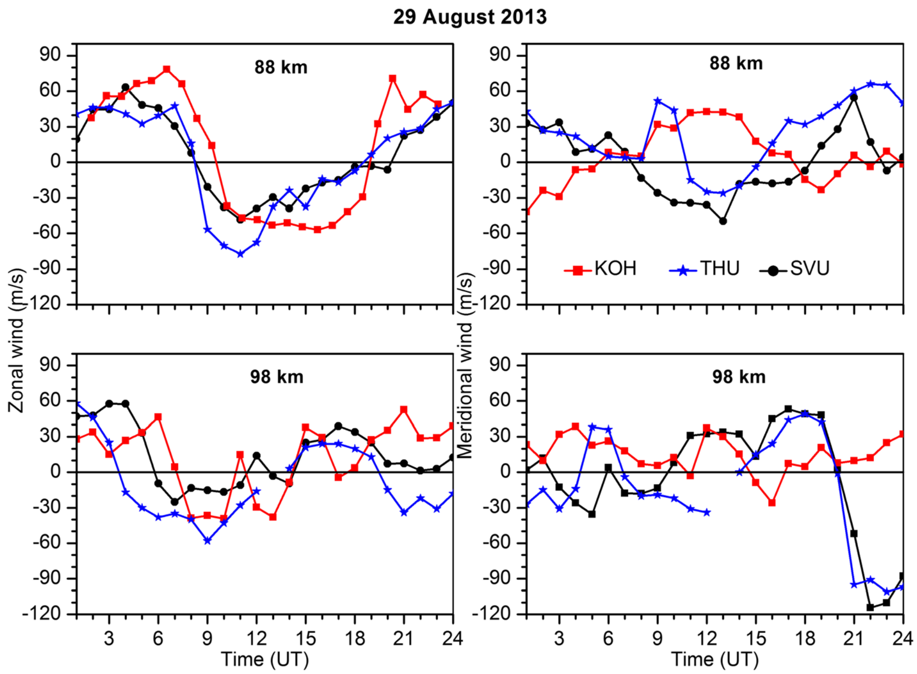

Figure 7. Diurnal variation in the (left) zonal and (right) meridional winds observed by SVU meteor radar and other radars for (top) 88 km and (bottom) 98 km on 29 August 2013.

winds clearly show strong diurnal and day-to-day variation closely following that observed by other radars. Though trends match well, the amplitudes differ largely from station to station. HWM-07 underestimates the zonal winds largely, though the trends match. In general, good agreement in winds between 82 km and 98 km can be noticed among different radars. SVU MR-observed meridional wind also exhibits strong diurnal and day-to-day variation but not like zonal winds. Day-to-day comparisons are good between SVU MR and Thumba MR but not with Kolhapur MF radar. The largest difference in meridional winds between SVU MR and Kolhapur MF radar is noticed, and it could be due to geographic separation of the radars. Interestingly, the HWM-07 meridional wind matches well with Thumba MR than SVU MR between 70 and 100 km. It is also interesting to see good agreement over 100–110 km between HWM-07 and SVU MR where this information is completely absent in observations from other radars. Detailed analysis of this region may throw light on the neutral and ion coupling [*Ratnam et al.*, 2010] due to high sensitivity covering the altitudes up to 110 km which will be taken up in future studies. The strong diurnal variation noticed in both zonal and meridional winds is due to tidal activity, and the difference between stations may be due to localized effects such as gravity waves or nonmigrating tides.

To further ascertain the degree of diurnal variation of winds among different radars and model data sets, the diurnal variation of zonal and meridional winds have been compared at different altitudes, namely, 78 km, 88 km, 98 km, and 108 km, for 29 August 2013 and is shown in Figure 7. In general, the trend matches well among different radars in the zonal wind at 88 km with peak zonal wind appearing at the same time in SVU MR and Thumba MR but appearing at a slightly different time over Kolhapur. A large shift can be noticed at 98 km with a peak in zonal wind appearing first at Thumba MR, then in SVU MR and finally over Kolhapur. During local nighttimes, the zonal winds were quite different over the three sites. Thus, though large-scale winds seem to be similar around these stations, when examined closely, the dynamics differ considerably. This is expected mainly due to small-scale variations like gravity waves that will differ significantly among the stations. Simultaneous observations from these radars forming a network on a long-term basis may unravel several issues related to the structure and dynamics of the MLT region.

Coming to the diurnal variation in the meridional winds, both at 88 km and 98 km, the SVU MR measured winds are in good agreement with the Thumba MR, similar to those observed in the zonal winds, but differ largely with the Kolhapur MF radar, particularly during local nighttimes at 98 km. It can be seen that Kolhapur winds are completely out of phase with those observed by SVU MR and Thumba MR at 88 km.

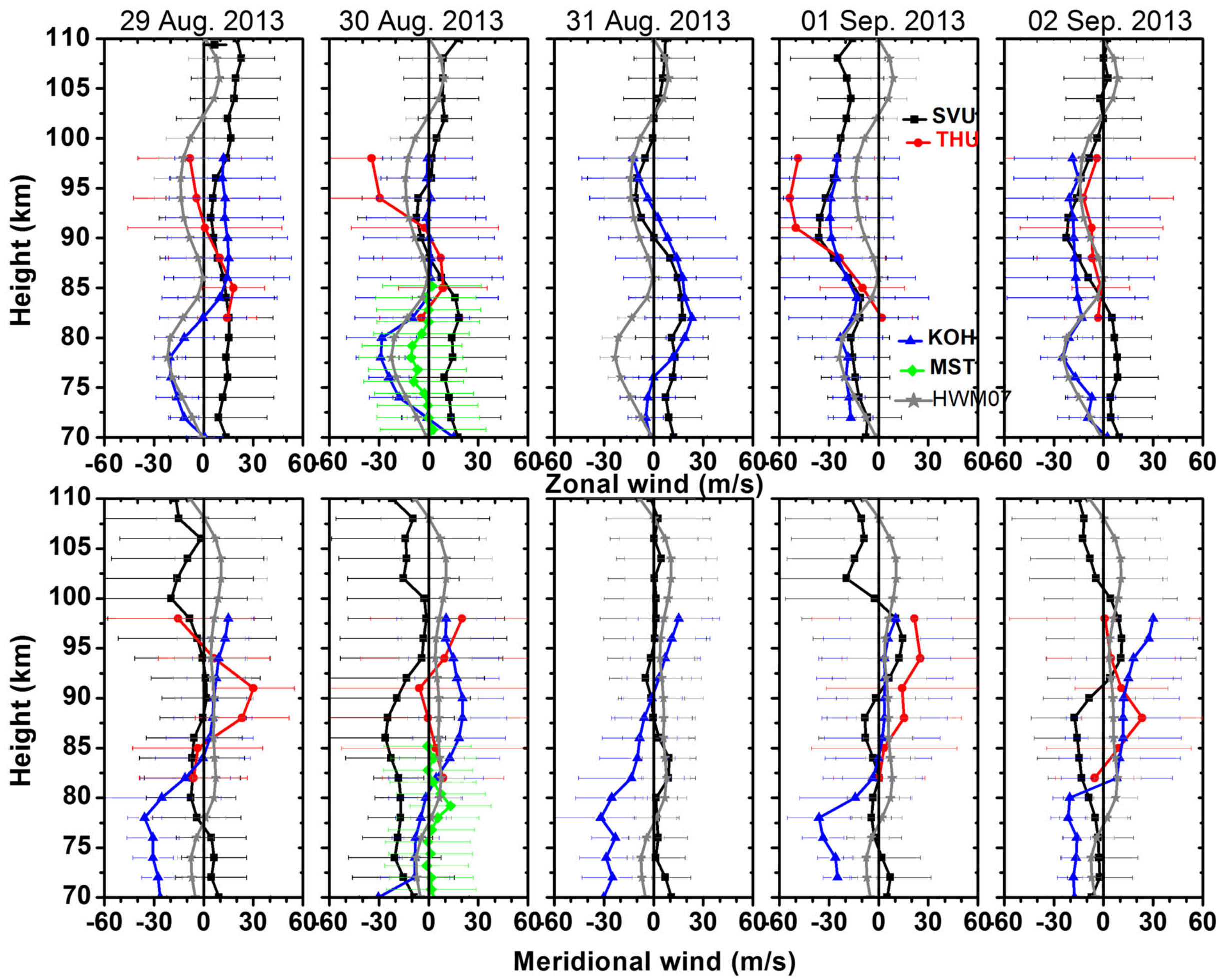

Figure 8. Profiles of (top) zonal and (bottom) meridional winds observed by the radars and model during 29 August 2013 to 2 September 2013.

The reason for this can be attributed at least partly to the different measurement techniques. The similar comparison between Thumba MR and Tirunelveli MF radar which are located close to one another was made earlier by *G. K. Kumar et al.* [2007], wherein a large difference in meridional winds was seen. It may be noted that the SVU MR and the Thumba MR are meteor radars, whereas the radar at Kolhapur is an MF radar. The MF radar uses the spaced antenna technique and hence provides no variations in wind estimation during the course of a day, but for the meteor radars the case is different which uses the interferometer technique and the radar returns are due to meteor trails using least squares method and hence reveals the variation within a day.

Daily mean zonal and meridional winds obtained by averaging hourly winds are further compared among different radars and are shown in Figure 8. This figure shows the profiles of daily mean zonal and meridional winds along with standard deviations observed during 29 August 2013 to 2 September 2013. HWM-07 model data sets are also superimposed in respective panels. Except for Thumba MR, comparisons were made for the complete altitude region, i.e., between 70 and 110 km. The MST radar was operated in mesospheric mode only on 30 August 2013, and hence, the data used are only of 1 day for comparison between 70 and 85 km. The comparison clearly shows that, in general, the zonal wind profiles of SVU MR are in good agreement with Thumba MR measurements between 82 and 90 km and thereafter differ largely with higher values in Thumba MR. SVU MR measured zonal winds match well with those observed with Kolhapur MF radar winds between 82 and 98 km. Interestingly, HWM-07 zonal winds between 86 and 110 km are in better agreement with SVU MR except on 29 August 2013 and 1 September 2013. Below 80 km, Kolhapur zonal winds match well with HWM-07 on all days except on 1 September 2013. Though large differences

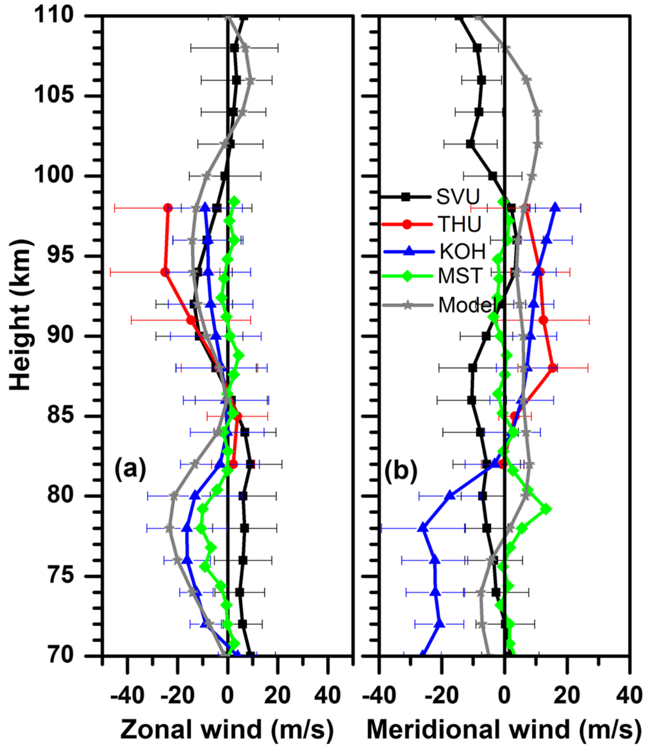

Figure 9. Mean profiles of (a) zonal wind and (b) meridional wind along with standard deviation obtained by averaging individual mean of each day from 29 August 2013 to 2 September 2013 of different radars along with profiles of HWM-07 model.

between Kolhapur zonal winds and SVU MR winds are observed from this plot below 80 km, in general, several gaps that occur below 80 km (Figure 6) with Kolhapur MF radar exists. When mean profiles are extracted with the available data, it ends up in poor agreement with SVU MR where near-continuous observations are available. MST radar-observed zonal wind also does not match well with SVU MR, which is mainly due to availability of winds in the *D* region, only during daytime in the case of MST radar.

Meridional wind profiles are in good agreement with the Kolhapur MF radar for the height region 88–98 km on 29 August and 2 September 2013 and with Thumba MR between 90 and 98 km on 1 September 2013 and are in poor agreement with the rest of the MLT region. The model-estimated mean meridional wind is in agreement with the SVU MR meridional wind on only 1 day, i.e., on 1 September 2013; these observations reveal that meridional winds exhibit large day-to-day variations in the MLT region, and the reason for this is to be studied. MST radar measured zonal and meridional wind profiles follow Kolhapur MF radar wind measurements rather than SVU MR, and this is again an interesting result. Large discrepancies in meridional winds could be due to several reasons, and the manifestation of gravity waves (GWs) could be among those since they are localized phenomena.

To verify the large-scale wind field signatures, individual day mean profiles are averaged to get 5 day mean profiles. Figure 9 shows the comparison of the height profiles of zonal (Figure 9a) and meridional winds (Figure 9b) obtained by averaging individual day mean profiles from 29 August to 2 September 2013. The comparison reveals that the averaged wind for the 5 days is in good agreement with the Thumba MR and Kolhapur radars and the model winds between 84 and 98 km and up to 110 km with model, respectively. Poor agreement is noticed when compared to MST radar zonal winds. Again, the MST radar zonal wind profile matches well with the Kolhapur MF radar wind profile. The meridional wind profile in the height region 94–98 is in good agreement with the HWM-07 model and partial/poor agreement with Thumba and Kolhapur radars. Overall, the zonal wind obtained from the SVU MR is in good agreement with the same obtained by other radars in the network, whereas the meridional wind comparison shows discrepancies.

5. Summary

The present communication describes a state of the art, the advanced meteor radar referred as the SVU MR in this work, which was specially designed to provide continuous high-resolution wind measurements around the clock for observing both small- and large-scale oscillations in the MLT region (70–110 km), temperatures at low-latitude mesopause region, and could also be used for advanced meteor studies. Already, one MR at Thumba and two MF radars at Tirunelveli and Kolhapur are operational in the peninsular India. In addition to these, the present location is close to the Gadanki MST radar which has been providing high-resolution mesospheric winds during daytime. Thus, with the SVU MR radar, the low-latitude MLT region over the Indian region can be evaluated, and it also provides an opportunity to elucidate the vertical and lateral coupling of the MLT region.

In the present study a comparison was made between the initial wind measurements of the SVU MR with the other MLT radar measured winds and also with the HWM-07 model-estimated winds for the period 29 August to 2 September 2013, and the results are summarized as follows:

1. Comparisons were made for both diurnal variation and mean wind field, and the results show that the SVU MR measured zonal winds clearly follow the diurnal cycle as with other radars and the model; the observed meridional winds follow the Thumba MR and the model.
2. In particular, at 88 km the diurnal cycle of the zonal winds is in very good agreement with Thumba MR and slightly varying with Kolhapur MF radar. The diurnal variation of zonal winds at 98 km, in particular, is in poor agreement with other radars.
3. With regard to the diurnal variation of meridional wind at 88 km, the SVU MR measured diurnal wind is in good agreement with the Thumba MR winds, whereas the Kolhapur MF radar wind deviates significantly from the SVU MR measured winds, and again, this feature is strong around local evening hours. At 98 km the meridional wind diurnal cycle is in poor agreement with other radars.
4. The mean zonal wind is in good agreement in the height region 82–92 km with the Thumba MR and in the height region 82–98 km with the Kolhapur MF radar. On 31 August 2013 and 2 September 2013, the height profiles of zonal wind over 86–110 km are in good agreement with model zonal wind profiles, while the meridional wind shows considerable discrepancies. There also exists a significant day-to-day variation in various data sets.
5. The 5 day mean zonal wind is in very good agreement with Thumba and Kolhapur radar zonal winds between the height regions 84 and 98 km and with model between 84 and 110 km, whereas the agreement for the meridional wind with the HWM-07 model is good for the height region 94–98 km and not so good with other radars.

From the above discussion, it is clear that the SVU MR wind measurements are in agreement with model predictions from 84 to 110 km and with other meteor and MF radar measurements in the height region 88–98 km. However, the discrepancies in the meridional wind comparison, though small, are intriguing and the reason for this need to be examined. Since low counts to measure winds are available from MR during local noon hours, measured winds during this time may have biases, and this can be verified using simultaneous wind measurements from MST radar. The combination of MST and MR along with Rayleigh lidar makes this unique location for investigating the vertical coupling and with other MLT radars located in peninsular India form unique network for investigating the lateral coupling.

Acknowledgments
We are grateful to Chris Adami, Engineer, ATRAD, Australia, for the successful installation of the SVU meteor radar. Our sincere thanks to the University Grants Commission (UGC), New Delhi, for providing a grant to procure the SVU meteor radar and authorities of S.V. University, Tirupati, for providing necessary support. The data used in this paper will be opened for public use after 2 years of its generation.

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