Comparison between Ground Based Techniques for 1-D Height Profiling and 4-D Wind Mapping to Resolve Thermospheric Neutral Wind Responses to Auroral Forcing

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Objectives

- Introduce height profiling and wind mapping techniques for winds in the lower thermosphere.
- Explain limitations and benefits of each technique.

Motivation

Few techniques are available for measuring neutral winds at E-region altitudes, especially in the height range from approximately 120 to 200 km (Figure 1). In-situ probes are typically unable to remain aloft at these heights for more than a few hours, and remote sensing is largely ineffective in this range. Rocket-borne chemical release methods can provide absolute measurements for winds in this region; however, the cost of such experiments is too high for routine applications. The consequent scarcity of observations is a problem, because winds in this region are of scientific interest (due to the transition from atmospheric behavior to space-like behavior) and of operational interest (because of their impact on radio propagation and on higher altitudes where satellites orbit).

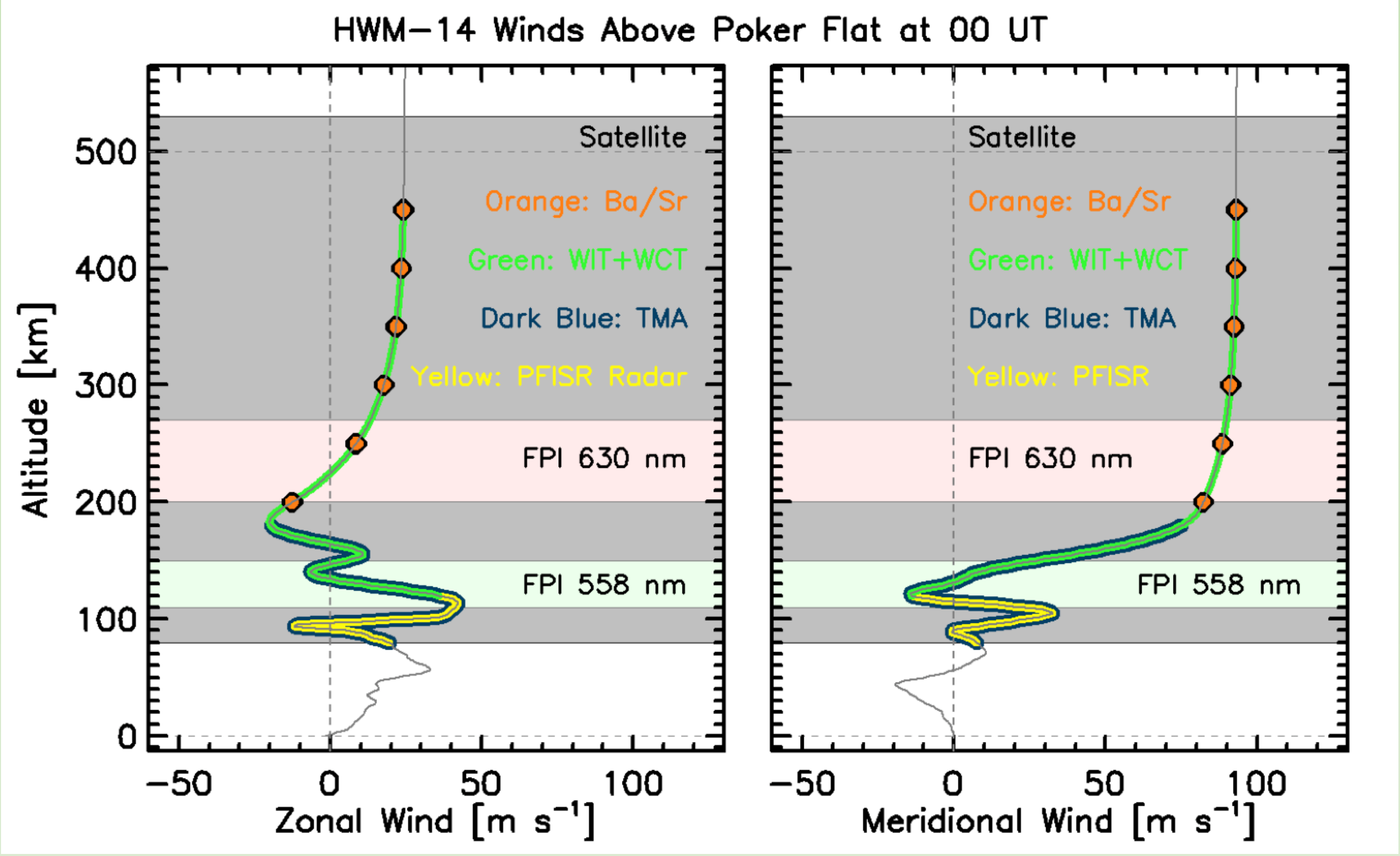

Figure 1: A brief summary of measurement techniques used at various altitudes in the thermosphere. Winds in Track (WIT) and Winds Cross-Track (WCT) instruments are an example of possible in-situ instruments being developed for sounding rockets and orbital platforms. Additionally, lithium chemical releases provide measurements in the upper thermosphere and are particularly useful for daytime measurements. Note that in the 120 km to 150 km altitude only Fabry-Perot interferometry and rocket techniques are applicable.

One measurement technique that is effective between 110 and 150 km use Doppler spectra of oxygen 558 nm and 630 nm emissions. Various instruments can be used to record such spectra; here data was recorded from an all-sky viewing Fabry-Perot interferometer (FPI). This instrument and observing technique has been described in detail previously by Conde and Smith (1995)[1]. There have been relatively few studies of thermospheric winds derived from auroral 558 nm Doppler spectra because it is known that the characteristic energy of electron precipitation can change by many keV on time scales of minutes or less causing aurorally excited 558 nm emission heights to vary by tens of km both across the sky and over time. This behavior coupled with the strong altitude gradients of wind that are known (from chemical releases) to occur at these heights would violate assumptions usually used to reconstruct wind vectors. Previous techniques for deriving vector wind fields from Doppler spectra typically cannot account for these height variations and vertical gradients and so produce noisy, unphysical wind fields during periods when auroral height variations are occurring. The purpose of current work is to overcome this restriction and, further, to exploit auroral height variations to resolve height profiles of the wind field.

1-D Height Profiling

The MSIS atmosphere model predicts the height profile of temperature based on the prevailing F10.7 and Ap values. This profile is used to assign an emission height to each 558 nm spectrum by comparing fitted Doppler temperature to the MSIS model's prediction. Outcomes of this process are shown in Figure 2. During times when these observations span a range of heights, it is possible to invert the line-of-sight wind components to create a height profile of the two-component horizontal vector wind. Results from this height profiling technique have been shown to agree with absolute measurements of wind using a chemical release from sounding rocket missions shown in Figure 3.

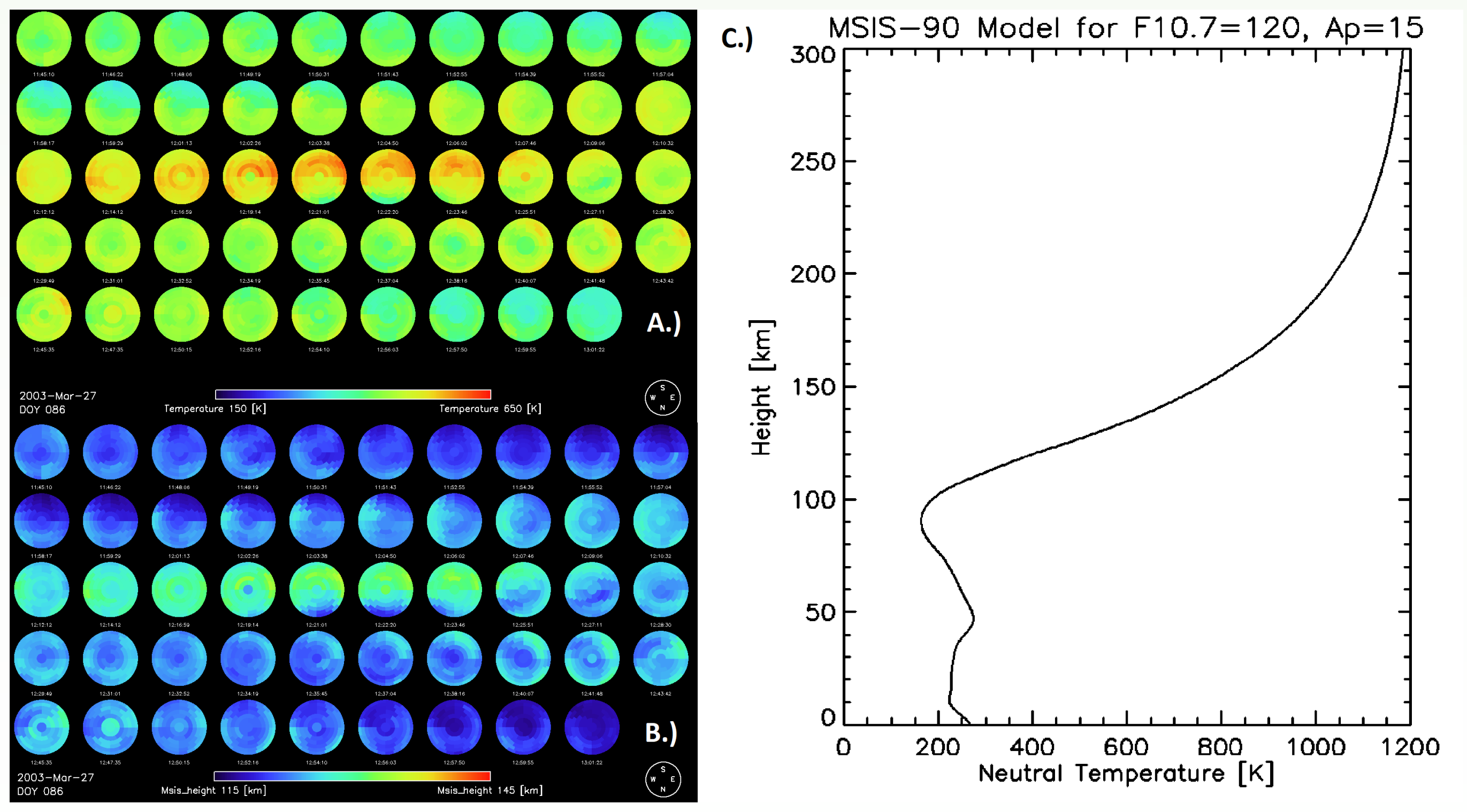

Figure 2: A.) Time evolving sky maps of temperature derived from Doppler widths of the Poker Flat 558 nm SDI spectra on the night of the JOULE sounding rocket launch March 27th 2003. B.) Time evolving maps of emission heights inferred from the Doppler temperature and the MSIS model, over the same time period. Note that similarities in temperature and height distributions occur because temperatures from 3A are used to assign altitudes in 3B. C.) Example MSIS height profile to demonstrate the swiftly changing temperature with altitude.

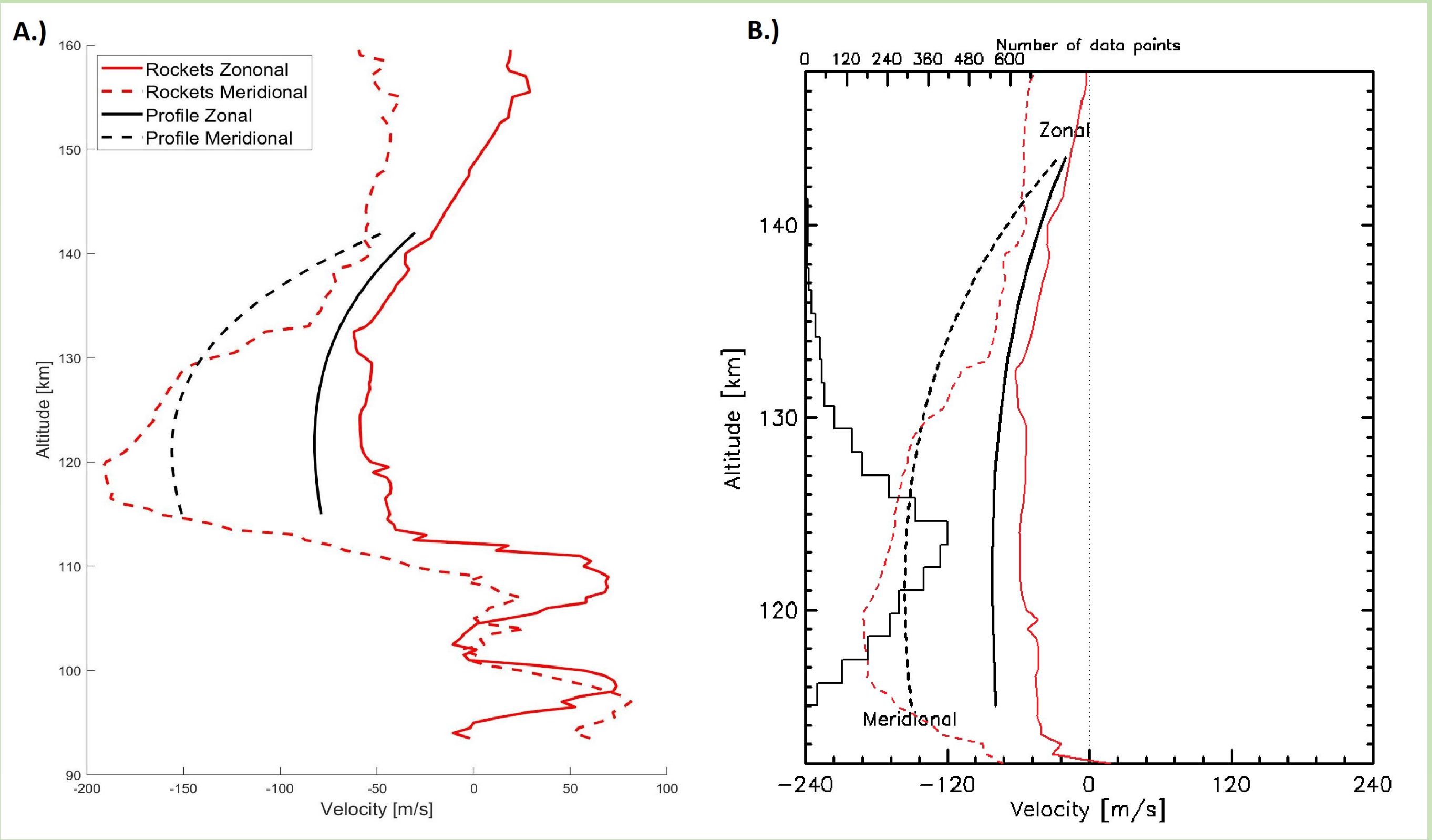

Figure 3: Zonal and meridional component comparison of absolute wind measurements from the JOULE rocket Trimethyl Aluminum (TMA) release at 12:13 UT (red) [2] with the one-dimensional height profiling technique results (black). 4A shows the full altitude range of the rocket profile versus the limited range of the height profiling technique. 4B emphasizes technique profiles and shows the histogram of data points contributing to each altitude. Note that even though the histogram is very skewed towards lower altitudes, agreement with absolute measurements is still present throughout the height profile.

Sampling a range of altitudes requires spatial and temporal variation in the characteristic energy of electron precipitation during that measurement period. The technique used to generate wind profiles shown in Figure 2 ingests data from a brief time period (typically 30-60 minutes) and builds a height profile, based on assumptions of uniformity in the wind field over the remaining three dimensions of longitude, latitude, and time. While it is usually possible to choose data spanning time periods short enough for the assumption of temporal uniformity to be reasonable, the horizontal spatial averaging assumption is only valid for a spatially uniform wind field such as that seen in Figure 4A. Despite the mediocre altitude coverage seen in the histogram on Figure 3B, profiles in this case were stable and in agreement with the TMA profiles. However, a nonuniform wind field (Figure 4B) will cause the horizontal spatial averaging to produce erroneous profiles because it is not valid to merge line-of-sight components from different look directions under the assumption that they are sampling the same winds. For these reasons, the 1-D technique is limited.

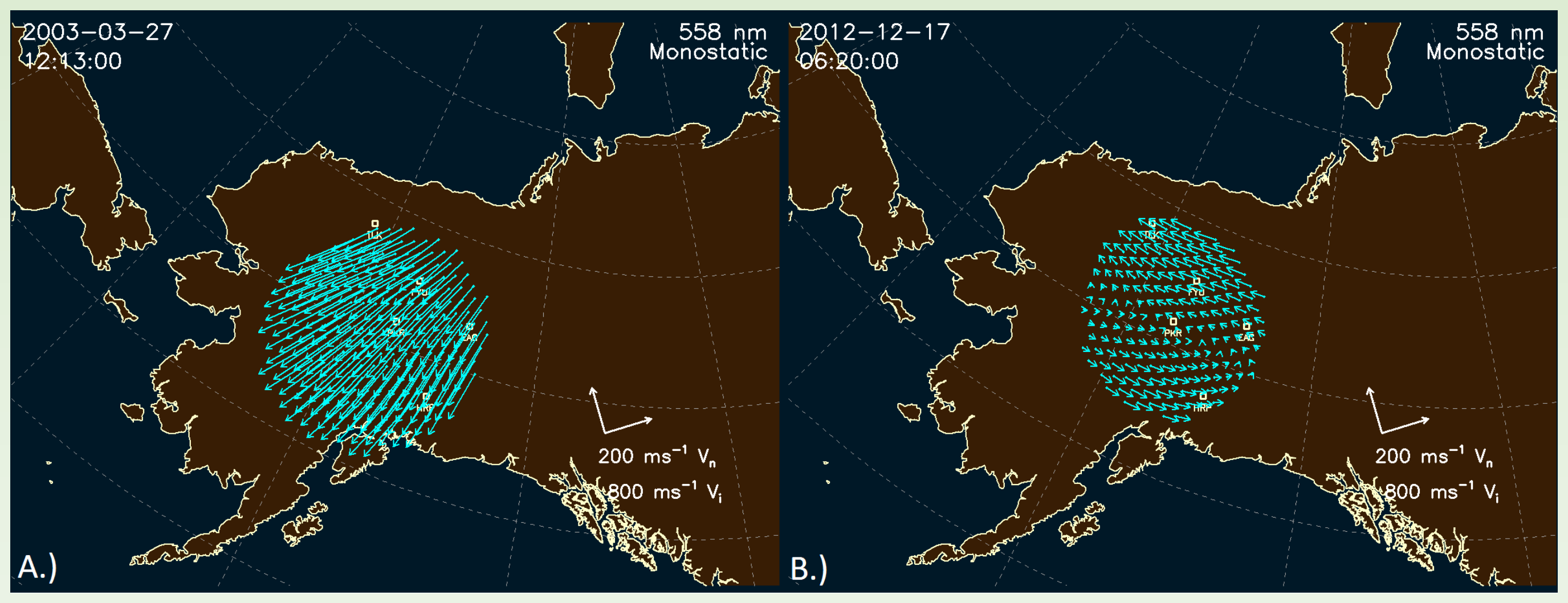

Figure 4: A.) Reconstructed wind vectors at the time of the JOULE rocket TMA release. These vectors would qualify as a uniform wind field. B.) Reconstructed wind vectors from the night of December 17th 2012. The sheer through these vectors and the ununiform vectors on either side cause the spatial averaging to produce inaccurate height profiles.

4-D Wind Mapping and Height Profiling

In order to better resolve the spatio-temporally varying winds over a large region, it is possible to create a four-dimensional wind field using Doppler spectra of oxygen 558 nm and 630 nm emissions. This technique starts with a base-line initial wind field that is easily generated from the data as a very crude approximation. Using an evolutionary algorithm, repeated small perturbations are applied throughout a reconstruction domain that spans a range of longitudes, latitudes, altitudes, and times. The algorithm determines a (signed) magnitude for each perturbation that will best improve goodness of fit. The effect repeated application of this process can be seen through the series of panels in Figure 5.

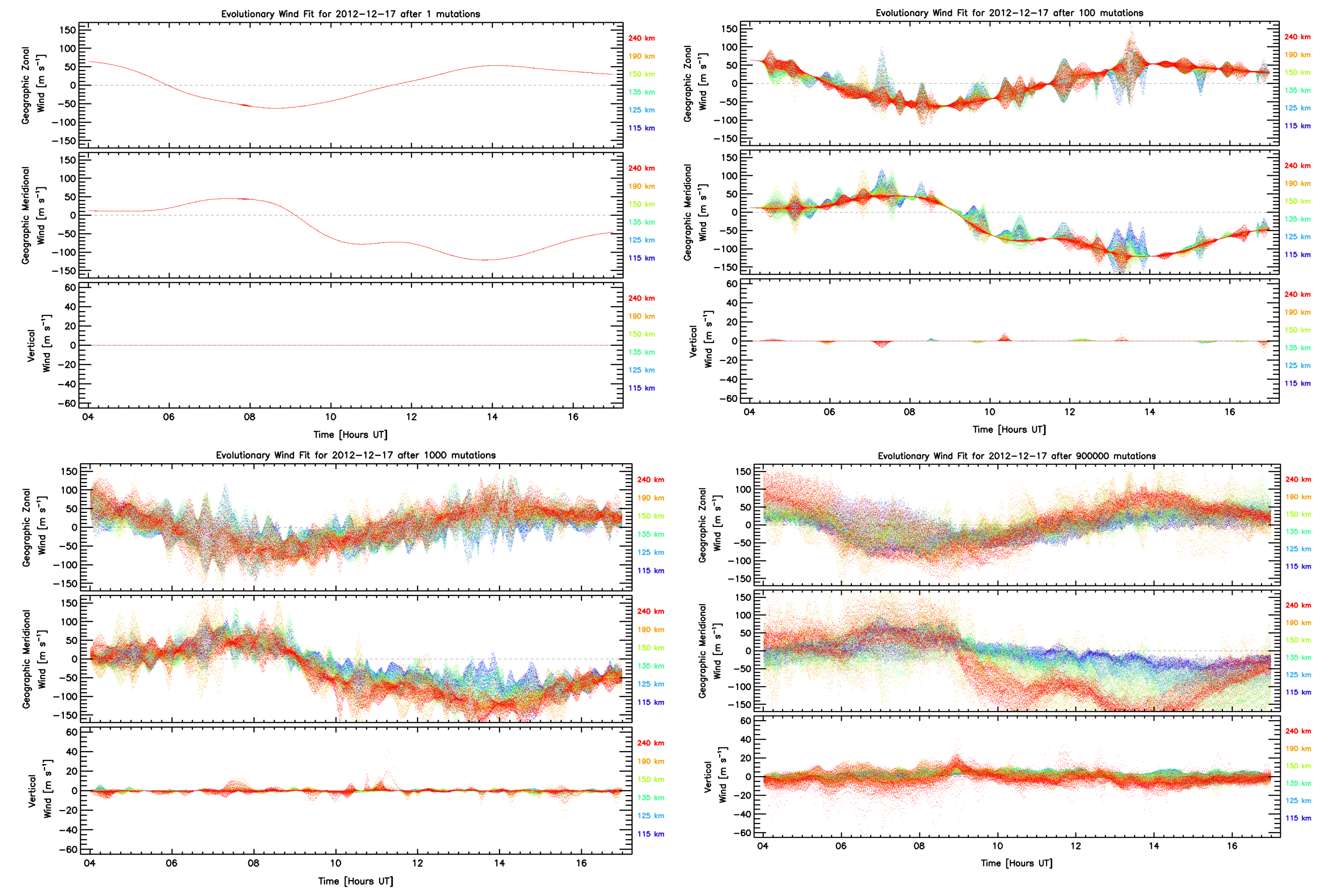

Figure 5: Resultant wind field after various number of perturbations have been applied on the night of December 17th 2012. After one applied perturbation, the base line wind field is still dominate. Once thousands of iterations have occurred, the wind variation with altitude becomes more defined.

The evolutionary method has shown to be more versatile than the one-dimensional technique as it can generally be used on any night that data are available. It also combines all available data from active sites. This example includes data from Gakona, Poker Flat, and Toolik Lake, Alaska. The results of this 4-D height profiling technique can be clearly displayed in an interactive Google Earth environment shown from different viewing perspectives in Figures 6 and 7.

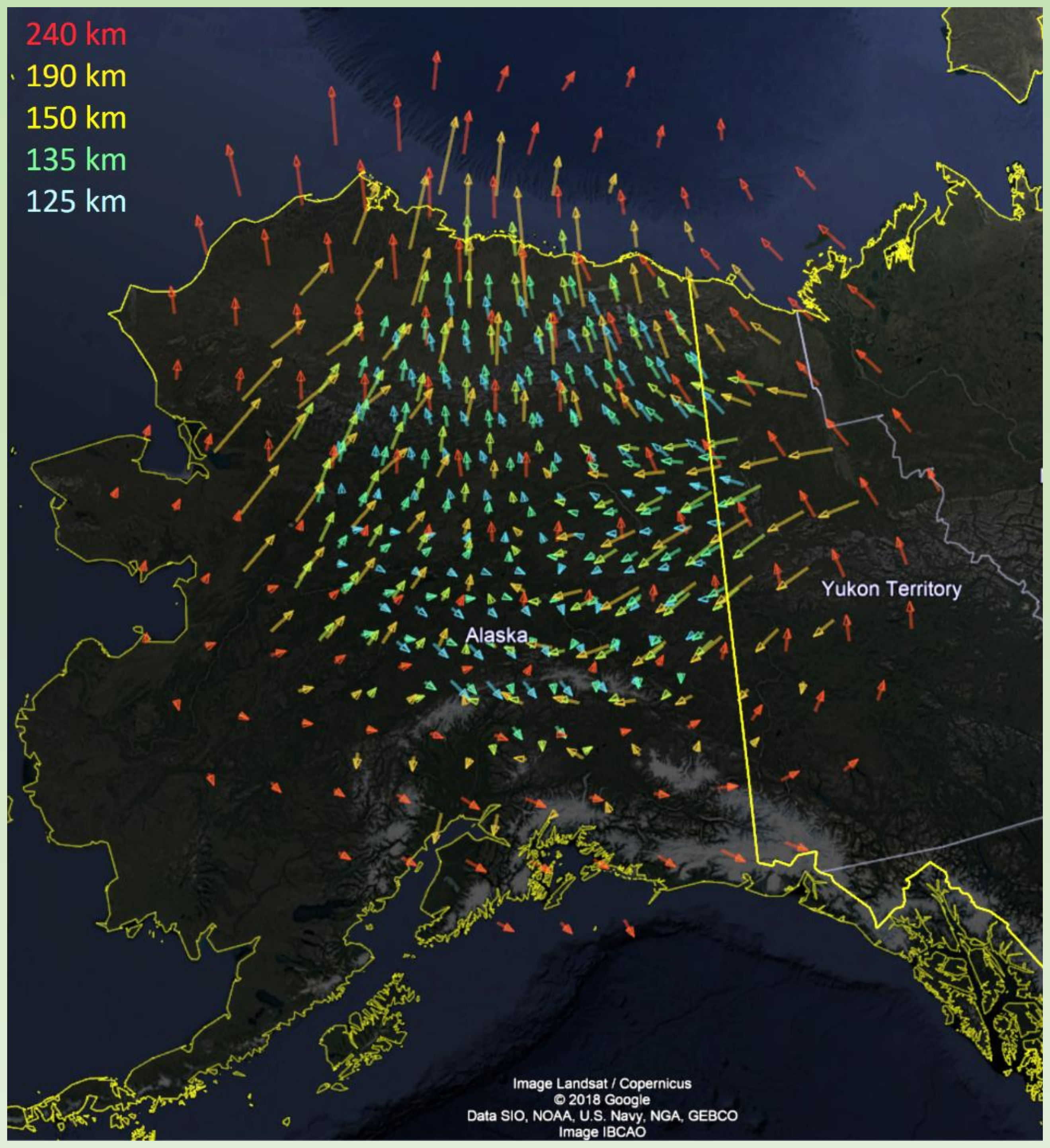

Figure 6: Overhead view of the 4-D evolutionary algorithm winds using data from Gakona, Poker Flat, and Toolik Lake, Alaska on the night of December 17th 2012.

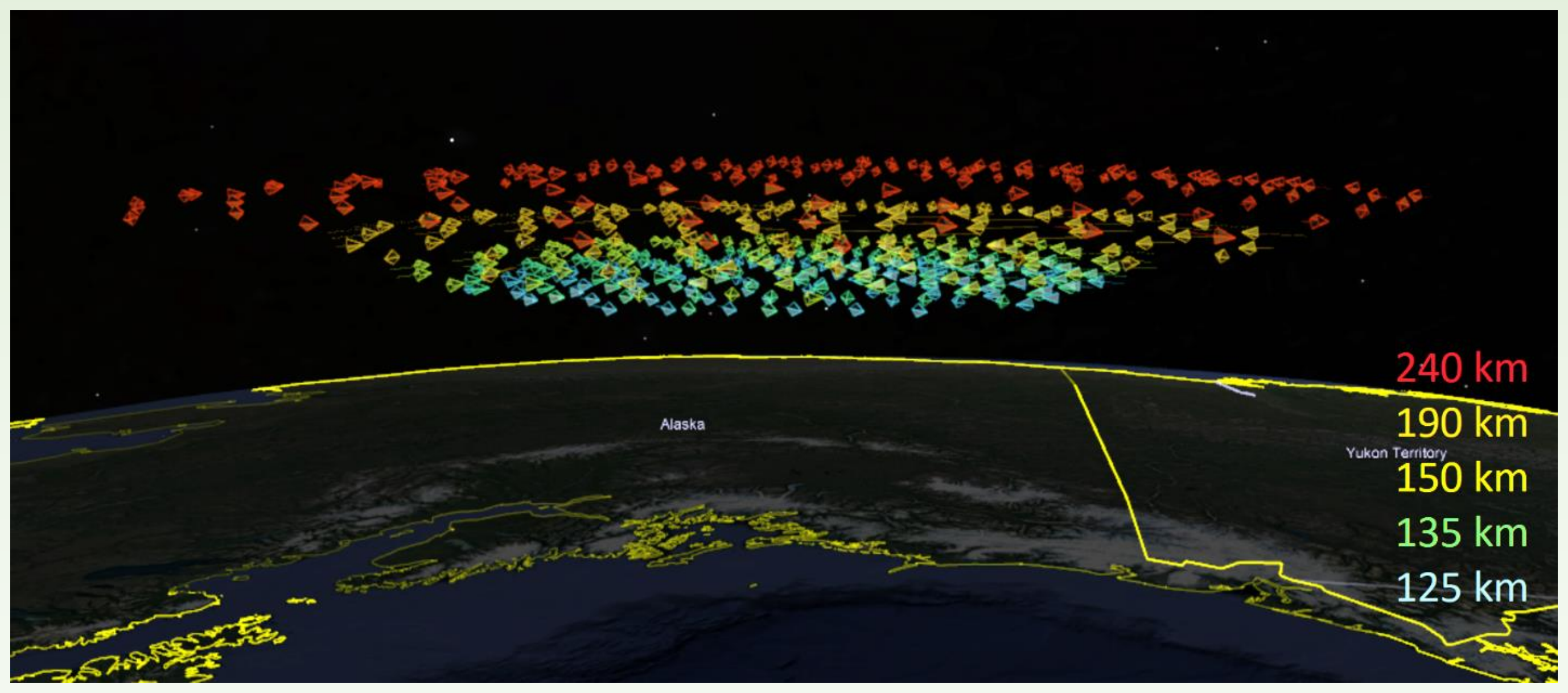

Figure 7: Side view of the 4-D evolutionary algorithm winds using data from Gakona, Poker Flat, and Toolik Lake, Alaska on the night of December 17th 2012.

While it may initially seem that the 4-D evolutionary algorithm is more effective, it requires the use of multiple SDI's within a close-range sampling both oxygen 558 nm and 630 nm emissions. This algorithm also takes a considerable amount of time (days) to converge to a somewhat stable result making real time applications impossible.

Conclusions

Making use of both 1-D height profiling and 4-D wind mapping algorithms with the preexisting SDI data can provide better coverage and more insight into a difficult region of thermospheric neutral winds to study. The examples presented highlight strengths and weakness of each algorithm. On the day of the JOULE rocket TMA release, the only data available was Doppler spectra of oxygen 558 nm emissions from Poker Flat making the 4-D technique unusable for that day. However, on December 17th 2012 the favorable technique to use was the evolutionary algorithm due to the various working data sites and non-uniform wind fields causing the 1-D technique to fail. Continued comparisons of both techniques with future rocket data as well as Horizontal Wind Model (HWM) prediction comparisons could help improve current models.

References

[1] Conde, M., and R. W. Smith. "Mapping thermospheric winds in the auroral zone." *Geophysical research letters* 22.22 (1995): 3019-3022.

[2] Larsen, Miguel. Rocket Wind Profiles. 2017.

Acknowledgement

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