Zonal Specular Meteor Radar Binning

A Method for Observing Atmospheric Wave Direction with a Single Monostatic SMR

James Monaco
Dr. John Marino
Dr. Scott Palo

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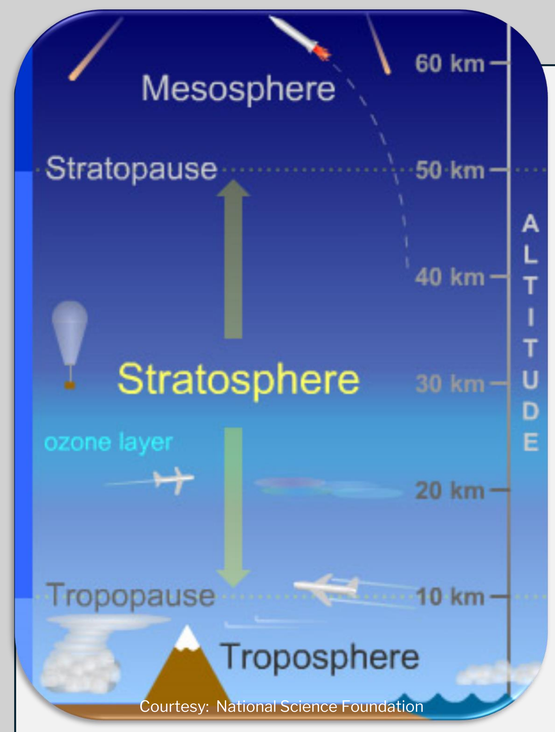
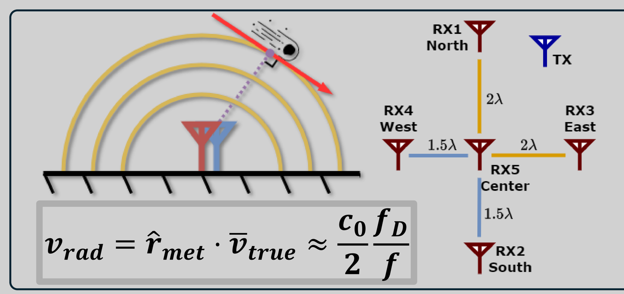


Background

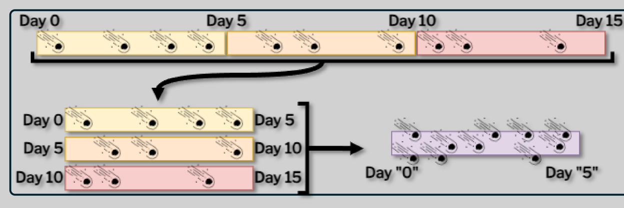
Monostatic specular meteor radars (SMRs) have long been used to investigate atmospheric tides and seasonal waves in the mesosphere/lower thermosphere (MLT)[1-3]. Typical SMR derived winds are estimated over the entire field of view of the instrument, averaged over a slice in time and altitude[4,5]. While standard processing techniques are useful for determining the temporal periodicity and magnitude of atmospheric waves[6,7], the reduction of observations across ~200,000 km^2 to a single wind vector fails to extract all available information — these simplifications obfuscate the waves' spatial propagation[4].

One approach to this problem is to divide the spatial extent of observations into multiple zones, making the progression of waves across the instrument's field-of-view discernible. Given most atmospheric tides propagate zonally[8], this work organizes observations into east-west bins perpendicular to the direction of propagation[1,6]. Stratifying observations into a small number of zonal bins allows the progression of wavefronts to be seen across the instrument's field of view, revealing the waves' direction of travel and its spatial periodicity. This this work is validated by using real meteor distributions to sample a simulated wind field of idealized atmospheric tides.

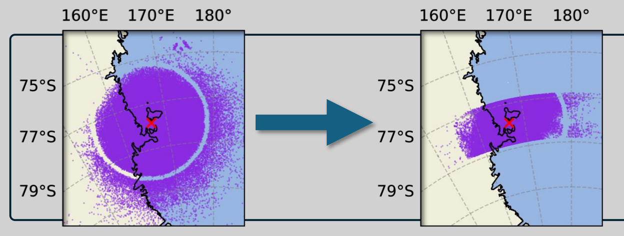
Methods



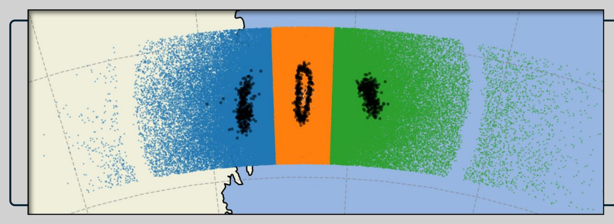
Meteor Collection: Meteor observations are retrieved over 15 days. Each individual meteor observation includes the *time* of observation, meteor's *estimated position*, the *radial wind* at that position, and associated uncertainties [4].



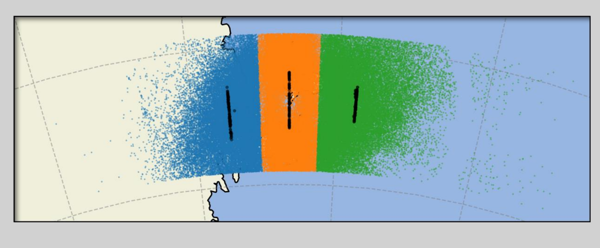
Coherent Integration: Each meteor's time of observation is reset within a 5-day window, enhancing periodic behavior and increasing meteor count for all times.



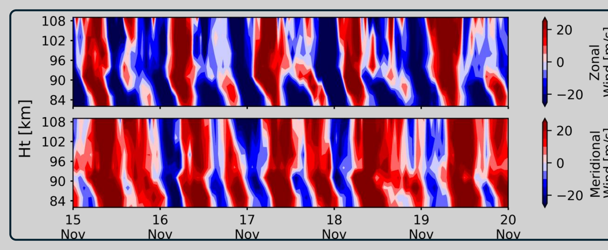
Constraining the Field of View: For more homogenous winds, only meteors with a height of 90+/-6.67km and within ~0.75° latitude are considered.



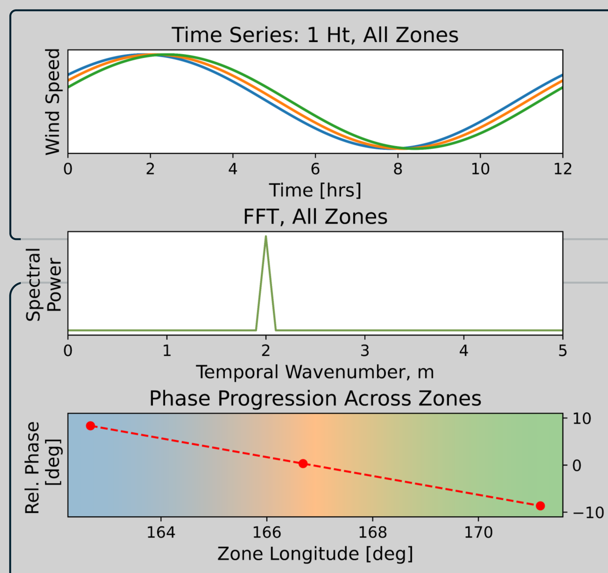
Zonal Binning: Observations are grouped (binned) by their east/west position with respect to the receiver. Each zone contains the same number of meteors.



Temporal Binning and Trimming: For each zone, observations are grouped into hourly bins. For each hour, observations are discarded until *the mean longitude* of observations is consistent with all other times for that zone.



Wind Retrieval: Observations' radial winds are used to estimate hourly wind vectors in a least-squares fashion for each zone[4,5]. The time series is then *filtered* to better elucidate periodic winds.



Frequency Analysis: The time series of wind vectors undergo Fourier analysis to quantify the magnitude and phase of atmospheric tides present within each zone.

Phase Retrieval: The longitudinal progression of an atmospheric tide can be inferred by comparing its relative phase across the zones.

This process is shown to the left for a simulated 12h $m=2, s=-2$ wave.

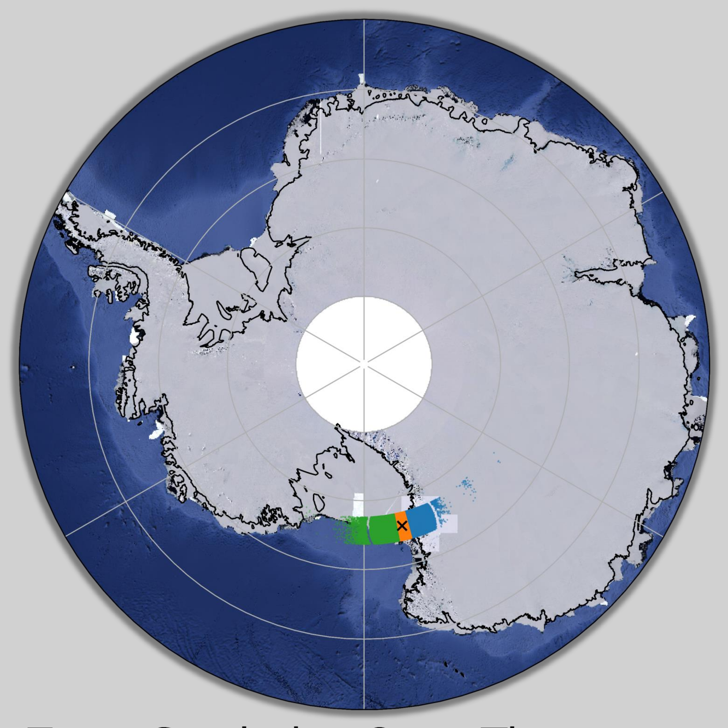
A wave moving quickly westward around the globe will show a fast phase advance across zones, appearing first in the eastern zone, then the center zone, and then the westward zone. The speed and direction of the wave can be inferred by the direction and magnitude of phase progression across the zones

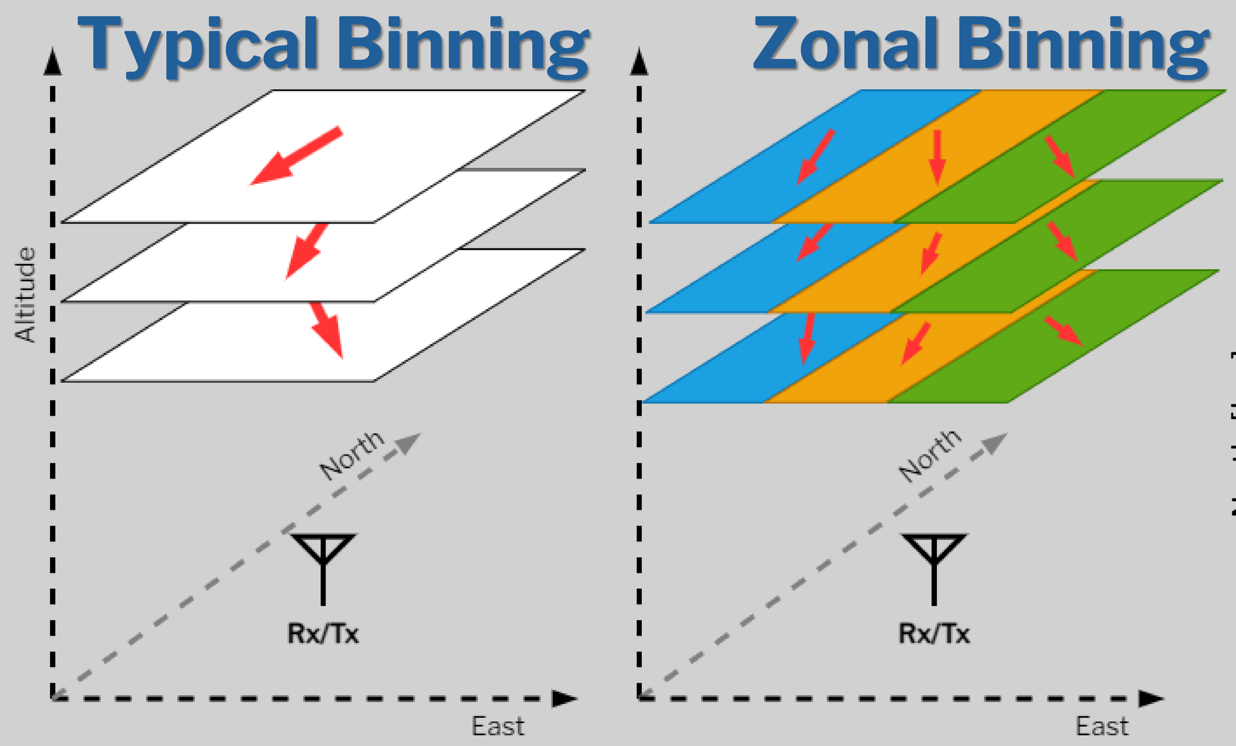
Data: Observations were made by a monostatic specular meteor radar array located near the McMurdo Research Station, Antarctica (77.8°S, 166.7°E) [4]

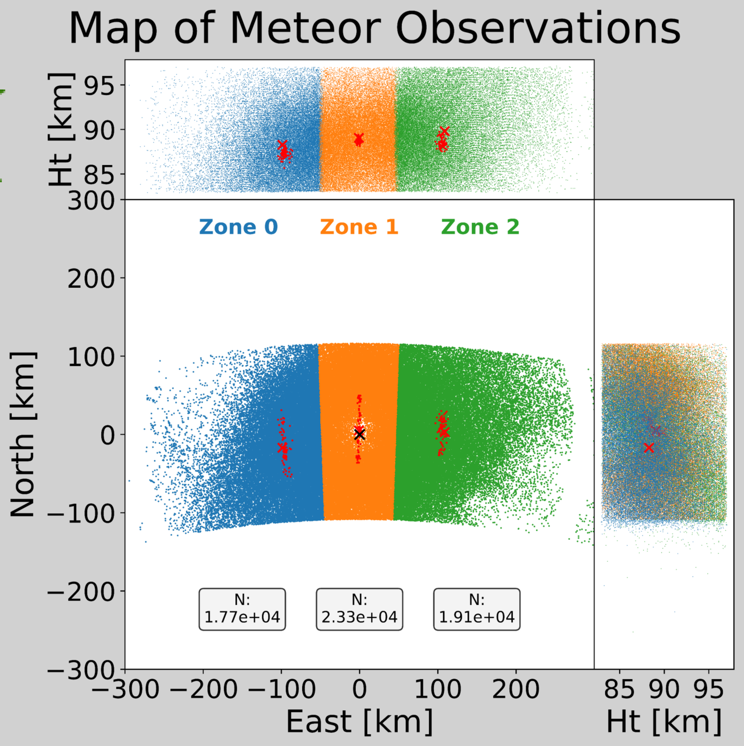
- SKiYMET-type radar built by Genesis Software
- 32kW transmitter operating at a frequency of 36.17MHz
- 1 transmit antenna co-located with a 5-element Jones cross receive array for interferometric meteor position solutions
- *Meteor observation data is publicly available upon request*

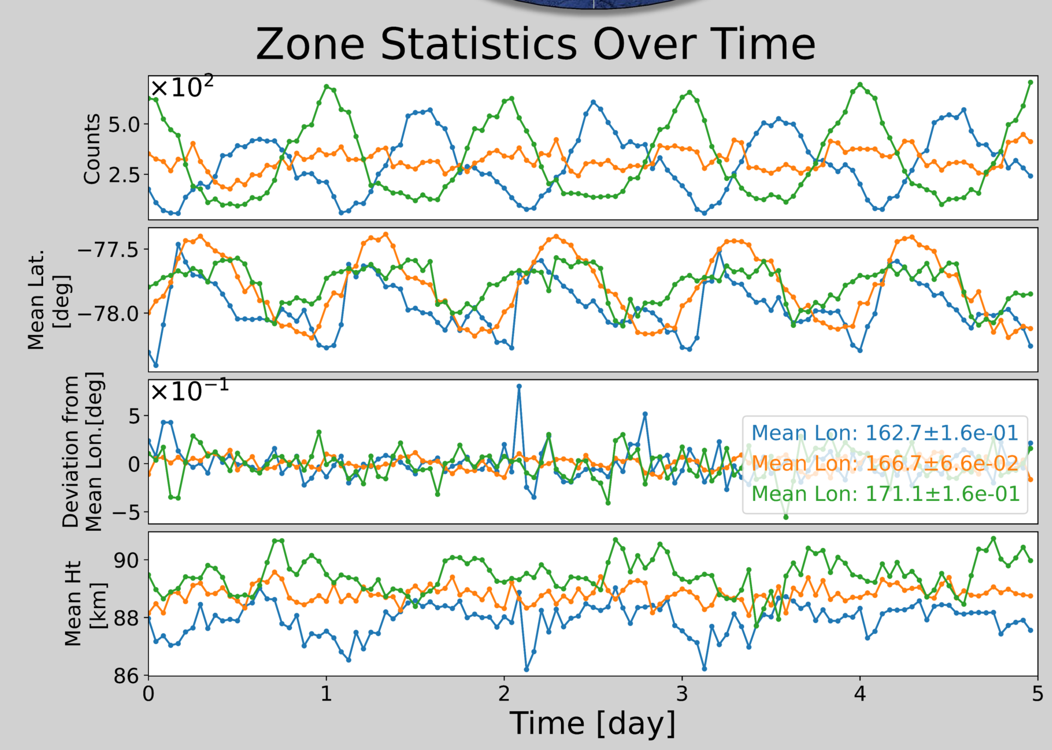
Summary

- Atmospheric winds in the mesosphere-lower thermosphere (MLT, 70-110km) can be observed via specular meteor radar (SMR).
- A monostatic SMR traditionally infers winds across its entire FOV for a given time and altitude range
- Atmospheric tides are periodic wind waves that propagate longitudinally around the Earth
- Traditional wind retrieval can only infer the frequency and magnitude of these waves, but not their direction or speed of spatial propagation
- **Binning meteor observations in longitude in addition to altitude and time enables a single SMR to infer the spatial propagation of atmospheric waves**
- **This technique was used to observe migrating semi-diurnal tides (m=2, s=-2.05+/-0.22) and diurnal tides (m=2, s=-0.25+/-0.75) during the summer of 2019 at the McMurdo research station.**



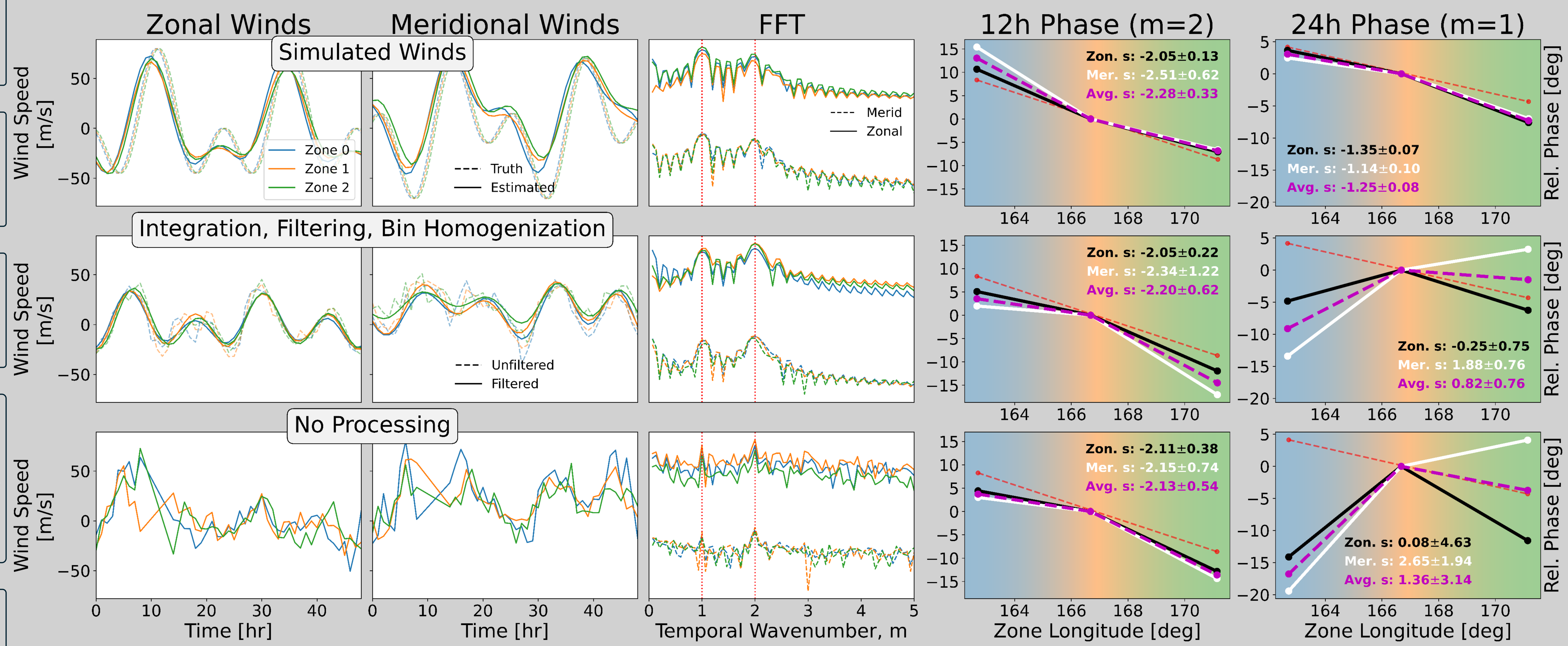






Wind Analysis

- 15 days of observations starting 11/15/2019, coherently integrated to 5 days
- Observations divided into 3 longitudinal (east-west) zones
- Winds inferred every 60 minutes at a height of 90 +/- 6.67km



Simulated winds derived from idealized atmospheric tides are imposed on the real observations to show these waves' expected phase progression across zones.

Observed winds after processing exhibit phase progressions most similar to migrating tides:

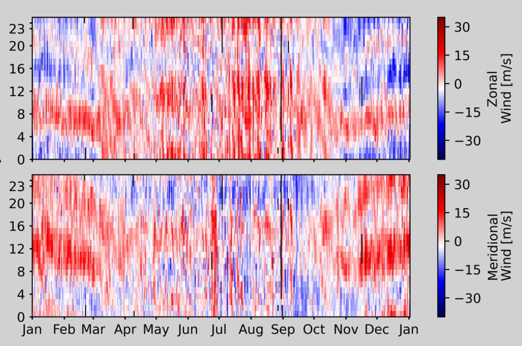
- 12h tide: m = 2, s = -2
- 24hr tide: m = 1, s = -1

Without processing the meteor observations and derived winds, temporal periodicity and spatial advance across zones are not obvious.

The geometry of the zonal bins case most observations to span further N/S than they do E/W. This causes poorer retrieval of meridional winds (right) compared to zonal winds (left), as the true meridional winds are less homogenous across great distances.

A power spectrum of observations show the presence of atmospheric tides of different temporal wave numbers.

The speed and direction of a given atmospheric wave can be seen by looking the relative phase progression across zones. The slope of phase vs. longitude should be equal to the spatial wave number. The **red** lines show the expected phase progression of a migrating tide.



Winds: Simulated and Observed

Winds in the upper atmosphere are largely dominated by *atmospheric tides*. These winds are periodic in time and space, classified by their temporal and spatial wave numbers[6].

Temporal wave number (*m*) describes a wave's repetition period, indicating how many times that wave repeats over a fixed location over the course of a day. The temporal wavenumber is related to its period in hours via: $P = \frac{24}{m}$

Spatial wave number (s) describes how many times the wave repeats around the circumference of the earth, indicating the number of peaks itself around the globe at any given time. The sign of s indicates the direction of travel of the wave, with a positive s indicating an east to west travel.

For a given longitude λ [deg] and time t [hr], the tidal winds can be expressed via[9]:

$$\bar{W}(\lambda, t) = A_0 + \sum_m A_m \cos\left(2\pi \frac{m}{24} t + 2\pi \frac{s_m}{360^o} \lambda + \phi_m\right)$$

Where A and ϕ are the amplitude and phase offset, respectively, for wave m.

The strongest atmospheric tides are generally semi-diurnal ($m=2, s=\pm 2$) and diurnal ($m=1, s=\pm 1$). A tide whose wavenumbers match in magnitude and propagates westward is *migratory*[6,7]. Confirming the direction of these tides are of particular interest, as there is some speculation of tides switching directions with season[8].

For simulations, a simple wind model calculates the wind vector at the time and position of each meteor if only pure atmospheric tides of known wave numbers are present. Simulated radial winds for each real observation are then imposed by projecting the simulated winds along the line-of-sight vector to the meteor. This artificial dataset gives an idea of the expected phase progression across the zones while also demonstrating the viability of this technique in the best case of pure winds.

Results

After coherent integration of observations and filtering of the estimated winds, phase progression of 12- and 24-hour tides across the three east-west zones match most closely with migrating semi-diurnal () and diurnal () tides, respectively. The phase progression of the semi-diurnal winds showed great agreement with both the simulated winds and the expected phase progression. The diurnal wind's spatial progression was not as clear in either the real data or simulation, but zonal phase progression suggests a westerly wind that is the most similar to a migrating tide

While not shown here, other times of the year were investigated to try to understand the waves' seasonal variability in direction and strength. It is clear that the diurnal tide is strongest in the summer, and future work will be spent looking for seasonal trends in direction for a variety of wavenumbers.

References and Contact