Analysis of High-Resolution Wind Fields of the Upper Atmosphere Observed with a Multistatic Meteor Radar Network

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Abstract
Observing the winds in the mesosphere and lower thermosphere (MLT) is crucial to understanding the energetics and coupling processes of the upper atmosphere, but they are difficult to measure with current techniques. The altitude range of interest limits in-situ measurements to rockets, which are infrequent and localized. Optical remote sensing instruments are sparsely located, give only a local view, and are most likely to be nighttime observations. Recent advances in meteor radars, which observe winds from about 80 to 100 km altitude through the Doppler shift of drifting meteor trails, hold the promise of temporally and spatially continuous coverage. A demonstration campaign with a prototype coded-CW (specular) meteor radar network called SIMONE was conducted in early November 2018 in northern Germany in a joint effort between the Leibniz Institute of Atmospheric Physics (IAP) and MIT Haystack Observatory. From this campaign, 224 hours of data were used to compute altitude-resolved mean horizontal winds averaged over the radar field of view using the standard linear least squares method. We observed effective resolutions of approximately 30 minutes and 1 km altitude and spectrally identified the expected tides as well as shorter period waves. We also simulated data for testing of wind field estimation techniques. The results of this work will occur in the future. We conclude that coded-CW MIMO meteor radar networks, along with the new wind field estimation technique, show great promise for resolving outstanding questions about MLT dynamics.

Introduction

- MLT (mesosphere-lower thermosphere) extends from approximately 60-110 km and is under-observed due to limiting technologies.
- Frequent and regional/global MLT wind measurements would:
  - Improve knowledge of coupling between the atmospheric layers.
  - Enhance model prediction of upper atmospheric dynamics.
- Meteors are typically observed between 80-120 km.
- Not always visible to the naked eye.
- Constant and sporadic (not always in showers) bombardment of the atmosphere.
- Meteor radars can detect many sporadic meteor trails.
- Measure Doppler shift (projected velocity) of trails drifting with wind.

Coded-CW Wind Field Observation

- The SIMONE campaign utilized a coded-CW meteor radar network.
- Utilization of multiple transmitters and receivers forms bistatic links, increasing coverage and amount of meteors detected.
- The transmitters use independent pseudorandom codes, allowing the receivers to decode multiple signals and resulting in many link combinations.
- No range-alising – wave is continuous and no range pulsed.
- Non-degenerate wind field sampling.

Simulated Wind Fields

- Developed realistic 2-D wind fields for altitudes 82-98 km
  - Utilizing potential flow to generate various sources such as vortex, line source/sink, and uniform flow.
  - Created 3-D wind fields by interpolating 2-D fields.
  - Assumed no vertical velocity.
- Used SIMONE observations to simulate wind field measurements with 3-D interpolation method.
- Goal: estimate wind fields from simulated measurements.

Mean Wind Estimation

- In order to estimate the mean horizontal winds, we used the method of linear-least squares.
- The utilized equation to obtain an estimate of the mean horizontal wind components:
  
- In the equation,
  - m: Doppler shift vector
  - A: Bragg vector
  - x: horizontal velocity components
- With greater detections, we achieved improved “resolution” of wind spectra.
  - Time windows of 30 minutes for 24 hours local Germany time.
  - Altitude windows of 1 km between 82-98km.
- Spectral analysis of mean winds at varying altitudes allows for further comparison of wind fields.

Conclusion

We simulated wind fields which will be useful for testing 3D field estimation approaches, and we analyzed horizontally-averaged winds and demonstrated higher resolution and altitude resolution than existing systems. Spectral analysis of the mean winds showed the expected tidal components but also lower-period waves which can be further analyzed by wind field estimation techniques. Deploying and operating a coded-CW multistatic meteor radar network will allow us to uncover unknown MLT dynamics and improve model predictions.

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References