Microwave (118-GHz) Doppler Techniques for Mesospheric Winds: MLS and EZIE

Dong L. Wu[1], Jeng-Hwa (Sam) Yee[2], Jesper W. Gjerloev[2], Rafael Luiz Araujo de Mesquita[2], William H. Swartz[2], Michael J. Schwartz[3], Richard Larsson[4], Heikki Vanhamaki[5], Patrick J. Espy[6], Tyler Summers[1,7], Cornelius (Jude) C. Salinas[1,8], Jae N. Lee[1,8], Astrid Maute[9,10], Wenbin Wang[9], Patrick Alken[10], and E. Lawrence Kepko[1]

[1]NASA Goddard Space Flight Center, Greenbelt, Maryland, USA; [2] Johns Hopkins University Applied Physics Laboratory, Laurel, Maryland, USA; [3]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, USA; [4]Meteorological Institute, Universität Hamburg, Hamburg, Germany; [5]Finnish Meteorological Institute, Helsinki, Finland; [6]Dept of Physics, Norwegian Univ of Science and Technology, Trondheim, Norway; [2]Science Systems and Applications Inc., Lanham, Maryland, USA; [8]GESTAR-2, University of Maryland, Baltimore County, Baltimore, Maryland, USA; [9]High Altitude Observatory, National Center for Atmospheric Research, Boulder, Colorado, USA; [10]CIRES, University of Colorado, Boulder, Colorado, USA.

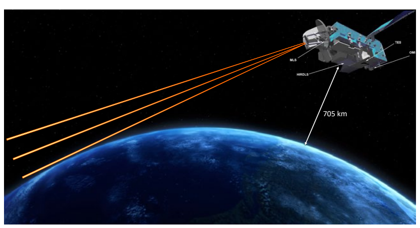
Background

Mesospheric winds play an important role in the coupling of lower-atmospheric forcings and thermospheric/ionospheric variabilities. Lack of upper-atmospheric wind observations leads to poorly-constrained model dynamics in this region, as atmospheric ageostrophic flow becomes increasingly important at higher altitudes. Therefore, direct wind measurements are very valuable for model evaluation and process studies, especially in the equatorial and wave-active regions.

Doppler techniques with passive sensors are widely used for wind remote sensing, using both spectral emission and absorption features from the atmosphere. The 118-GHz Zeeman lines (triplet) from the O2 emission have a narrow linewidth in the mesosphere, which can be used to determine a wind-induced Doppler shift. Two NASA's missions, Aura Microwave Limb Sounder (MLS, 2004-present) and Electrojet Zeeman Imaging Explorer (EZIE, LRD late 2024), use the 118-GHz emission and absorption features to measure mesospheric temperature and geomagnetic field. As a byproduct, Doppler winds can be derived from these 118-GHz radiance measurements.

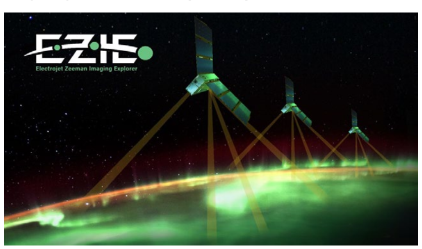
Aura Microwave Limb Sounder (MLS): 2004-present

- NASA Earth Science Aura mission to study stratospheric ozone
- Single antenna for limb scan between surface and 90 km
- Emission and absorption features from 118 GHz O2 spectral line
- 705-km polar orbit
- 8-km vertical resolution



Electrojet Zeeman Imaging Explorer (EZIE): LRD 2024

- NASA Heliophysics Science mission to study the auroral electrojet
- 4-beam nadir/slant views from 3-satellite constellation
- Absorption features from 118 GHz O2 Zeeman-split spectral lines
- 525-625 km polar orbits
- 25-km horizontal resolution



118-GHz O2 Emission and Absorption Features

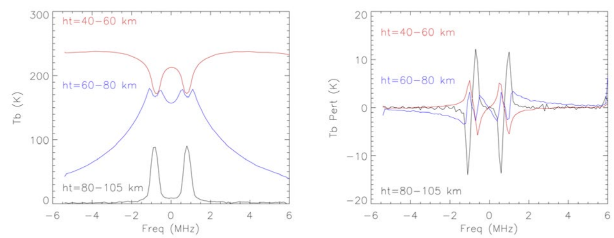


Fig. 1. The 118-GHz O2 radiance (brightness temperature or Tb) spectrum obtained from Aura/MLS (left) and radiance perturbations from a 100-m/s Doppler shift. At high tangent heights (e.g., 60-80 km and 80-105 km) the Zeeman lines appear as an emission feature, whereas at low tangent heights (<60 km) the lines manifest themselves as an absorption feature. Both emission and absorption spectral features can be used to retrieve Doppler winds.

MLS Doppler-Wind Algorithm

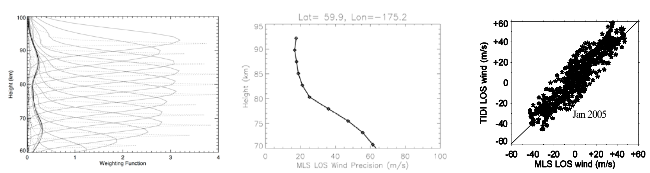
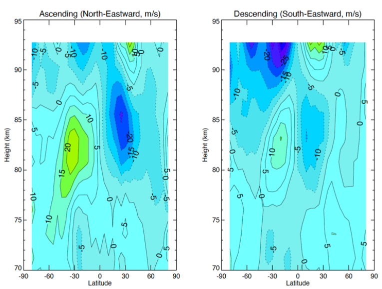


Fig. 2. (left): The weighting functions (WFs) of the LOS wind for different tangent heights between 60 and 90 km during MLS nominal scan. The dotted curves represent the functions as if it has an infinitely narrow FOV whereas the solid curves represent realistic MLS WFs for a 5.8 km FOV. **(Middle):** Estimated precision of MLS LOS wind. **(Right):** TIDI wind perturbations interpolated onto the MLS LOS direction (namely, TIDI LOS wind) in comparison with MLS LOS wind perturbations during 24–27 January 2005

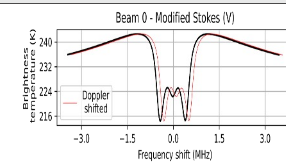
A research algorithm was successfully developed to retrieve line-of-sight (LOS) Doppler winds from Aura MLS 118.75 GHz measurements at 70–92 km altitudes [Wu et al., 2008]. The wind retrieval has a precision of 17 m/s at 80–92 km, which corresponds to radiometric noise from 1/6 s integration time. The MLS LOS winds are mostly in the meridional direction at low- and mid-latitudes with vertical resolution of 8 km after convolving the Abel weighting function and the instrument antenna field of view (FOV). Comparisons between the MLS LOS winds and the TIDI (Thermosphere Ionosphere Mesosphere Energetics and Dynamics Doppler Interferometer) winds show excellent agreement for the perturbations induced by a strong quasi 2-day wave (QTDW) in January 2005.

MLS Wind Highlights:

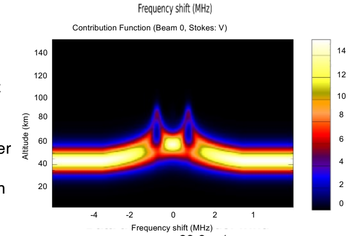
- Daily planetary wave features, including the diurnal (see figure on the right), semidiurnal tides, and the QTDW.
- Interactions between the tides and the QTDW and structural evolution in dynamics (Limpasuvan et al., 2005)
- Long-term climatology of mesospheric dynamics (2004-present)



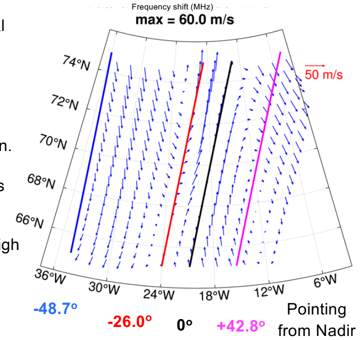
EZIE Doppler Winds



- EZIE microwave electrojet magnetogram (MEM) has 4 beams from each CubeSat, to measure horizontal winds from off-nadir pointings.
- MEM measures full Stokes polarization spectra with low-power digital spectrometers at 50-100 kHz resolution.
- Sensitivities to wind-induced Doppler shift and magnetic-field-induce Zeeman split are orthogonal to each other.



- Radiometric calibration is not critical for the Doppler wind and magnetic field measurements.
- Wind-induced Doppler shifts are contributed mostly from altitudes of 60-80 km in the cross-track direction.
- Estimated precision of LOS winds is ~2 m/s from 3-s integration.
- 3-CubeSat constellation provides high spatial resolution sampling in 10-15 min.



References

Limpasuvan, **V.,** D. L. Wu, M. J. Schwartz, J. W. Waters, Q. Wu and T. L. Killeen, The two-day wave in EOS MLS temperature and wind measurements in 2004-2005. *Geophys. Rev. Lett.* **32**, L17809, doi:10.1029/2005GL023396, 2005.

Wu, D. L., et al., Mesospheric Doppler Wind Measurements from Aura Microwave Limb Sounder (MLS) , *Adv. Space Res.*, **42,** 1246–1252, 2008.

Yee, J. H., Gjerloev, J., **Wu, D.,** and Schwartz, M. J. (2017). First application of the Zeeman technique to remotely measure auroral electrojet intensity from space. *Geophy Res Lett*, 44. https://doi.org/10.1002/2017GL074909