
NASA
ICON
Ionospheric Connection Explorer
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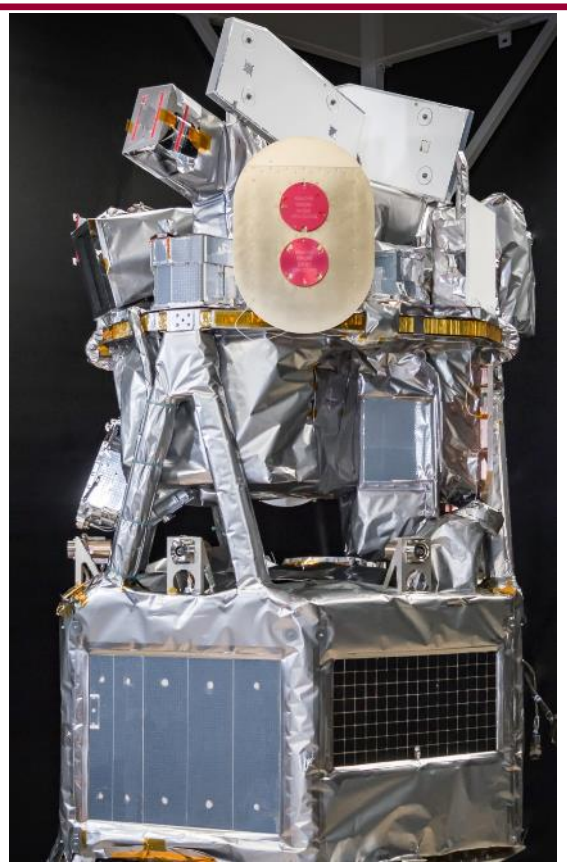
UT DALLAS
ICON Mission Overview
Dr. Thomas J. Immel
The Ionospheric Connection Explorer

ICON : NASA Explorer Mission Programmatics

Mission Summary	
Cost	$184.1 M (RY)
Launch vehicle	Pegasus XL Cape Canaveral AFB
Spacecraft	Northrop Grumman LEOStar-2 3-axis stabilized, no consumables
Launch	October 10, 2019
Orbit	590 km circular, 27° inclination
Ground segment	Berkeley Ground Station, WGS, Santiago
Mission & Science Ops	24 months Phase E Operated from UCB



- ICON is on orbit, in Phase E, and achieved mission success. All instruments green. One safe mode in February 2020.

ICON's Science Objectives require measurements of I-T-M system drivers and responses.

The Ionospheric Dynamo, driven by the neutral atmosphere, governs the motion of the plasma:

- We need to measure the **drivers**:

Neutral winds that carry the energy and momentum that drives the dynamo.

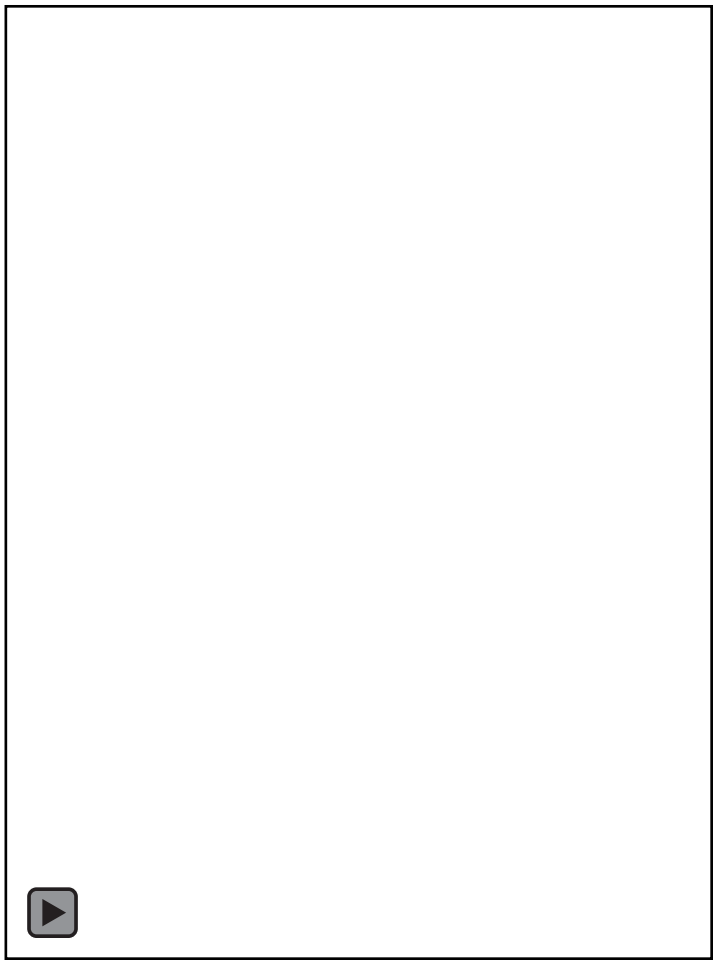
Composition of the atmosphere that controls the chemical production and loss rates of plasma.

Temperature of the atmosphere that reveals the atmospheric waves entering space from below.

- With the **responses**:

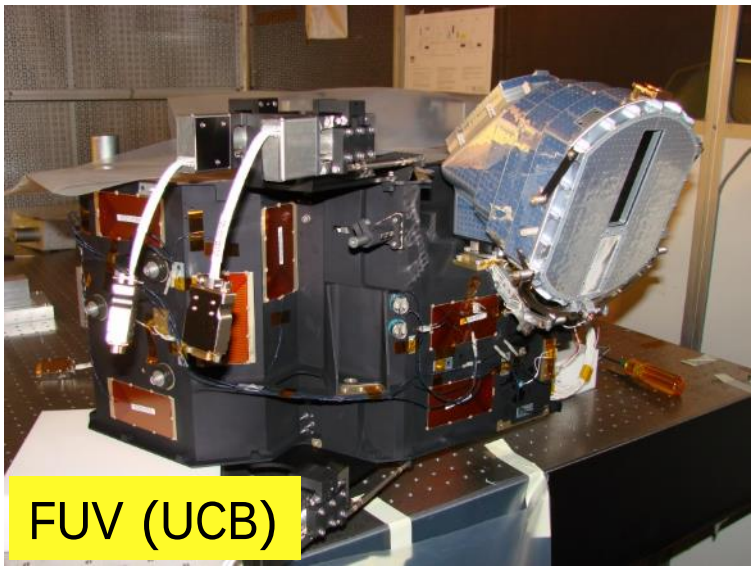
The electric field and **the plasma velocity distribution**, which are directly related.

Plasma density of the ionosphere, the combined result of solar production and plasma motion.

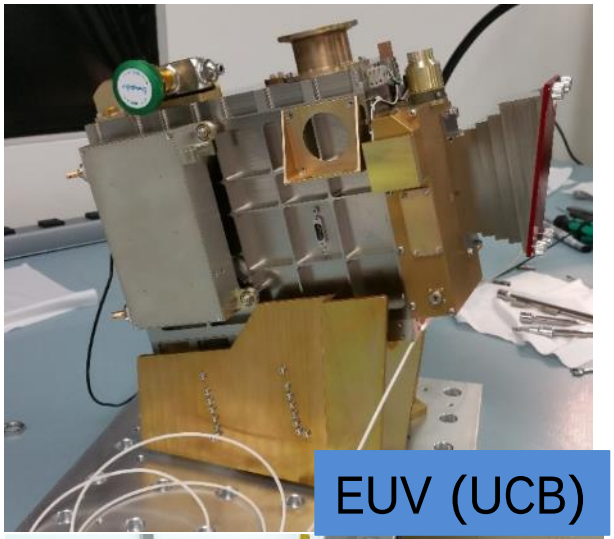


All baseline measurements being made. No science descopes exercised

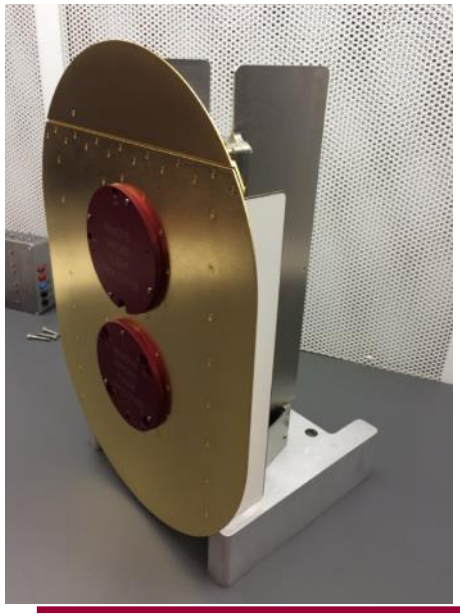
ICON carries a set of instruments to make all the necessary measurements.

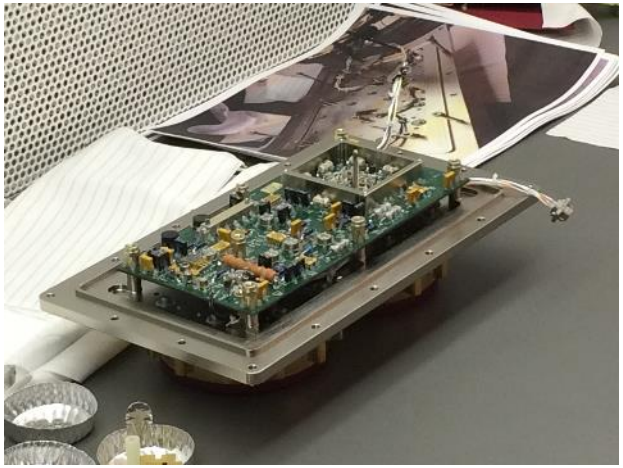


FUV (UCB)

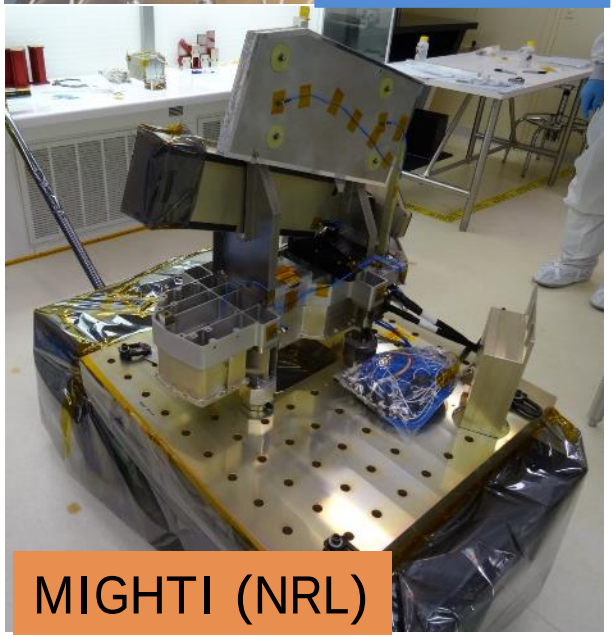


EUV (UCB)



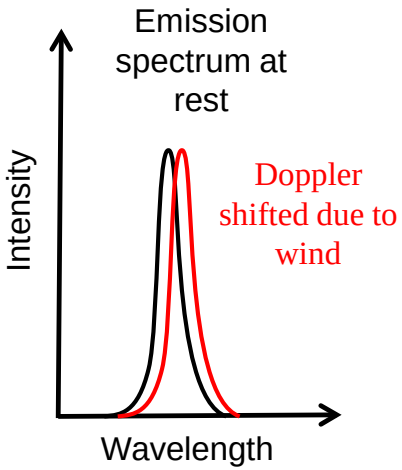


IVM (UTD)



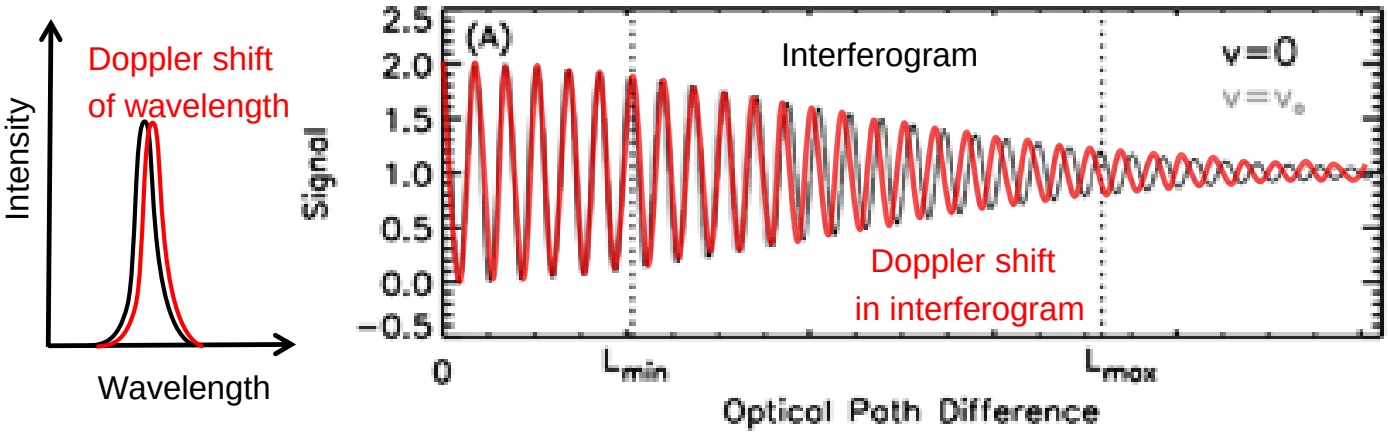
MIGHTI (NRL)

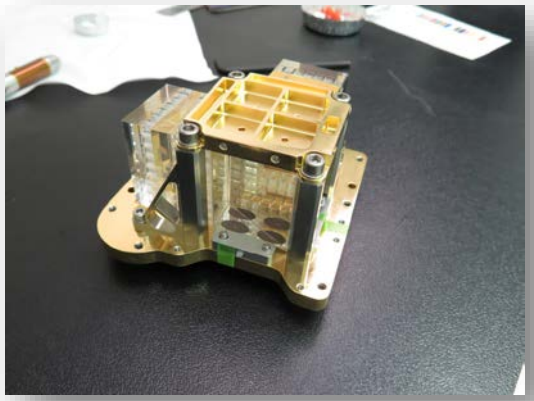
MIGHTI Science Target is Visible Emission of Atomic Oxygen

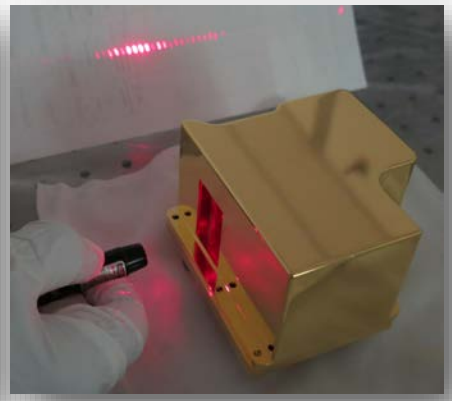


- MIGHTI implements a
- Stray light from Earth, from Earth's atmosphere, from the galaxy
- Doppler shift is a proxy for bulk atmospheric motion

MIGHTI uses DASH (Doppler Asymmetric Spatial Heterodyne) Spectroscopy Technique







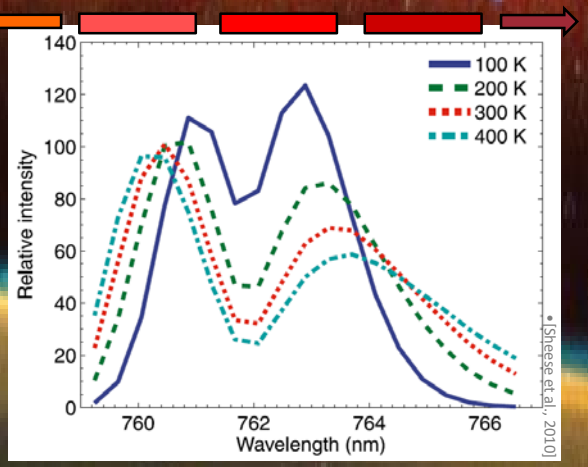
Changes in path difference indicate changes in wavelength of incoming light.

Selection of the region of the interferogram to observe is a trade to maximize 1) signal and 2) path difference

MIGHTI design implements this trade while optimizing for dual-wavelengths.

Multispectral imager to measure temperature: Similar to OSIRIS and RAIDS

- The shape of the bright molecular oxygen A band emission feature is a function of temperature.
- Three filter channels on the band are used to get temperature and common filter drift information.
- Two off-band filters are used to determine the background (baseline).
- Temperatures are available from 90 km to 115 km altitude (105 km at night)



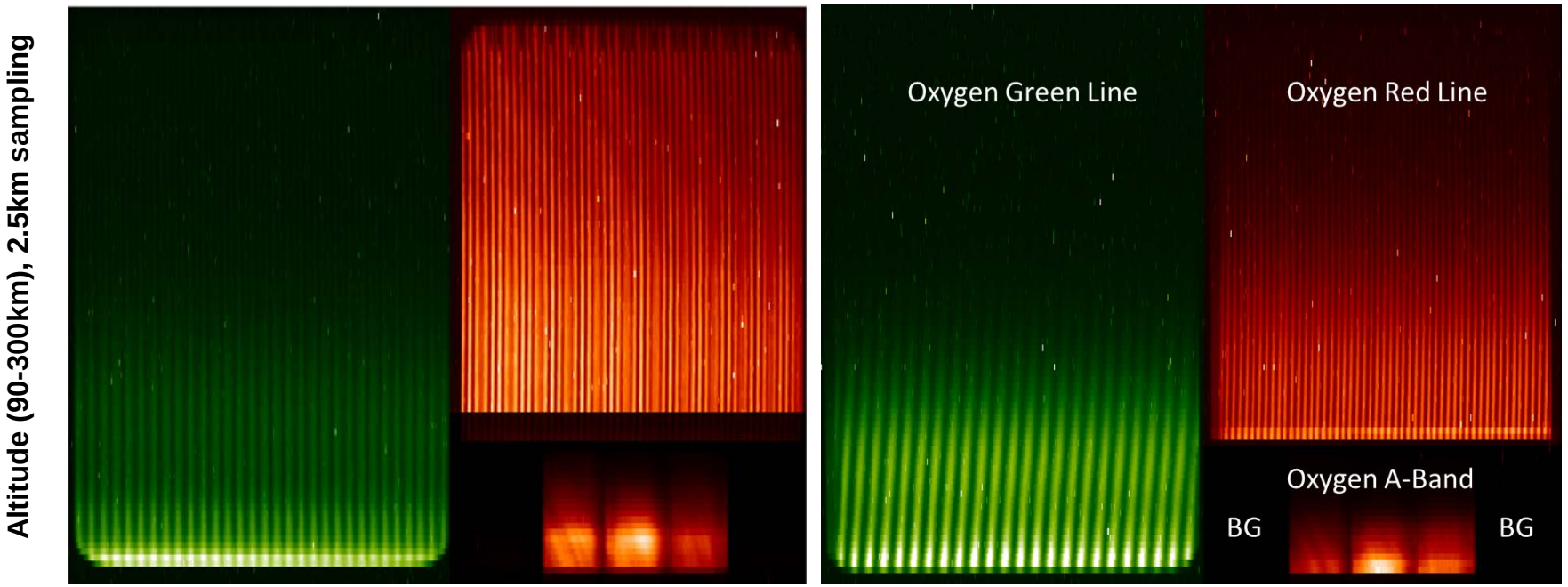
•NASA false color image

MIGHTI Sensor Images

MIGHTI-A

With Calibration Lamp Signal

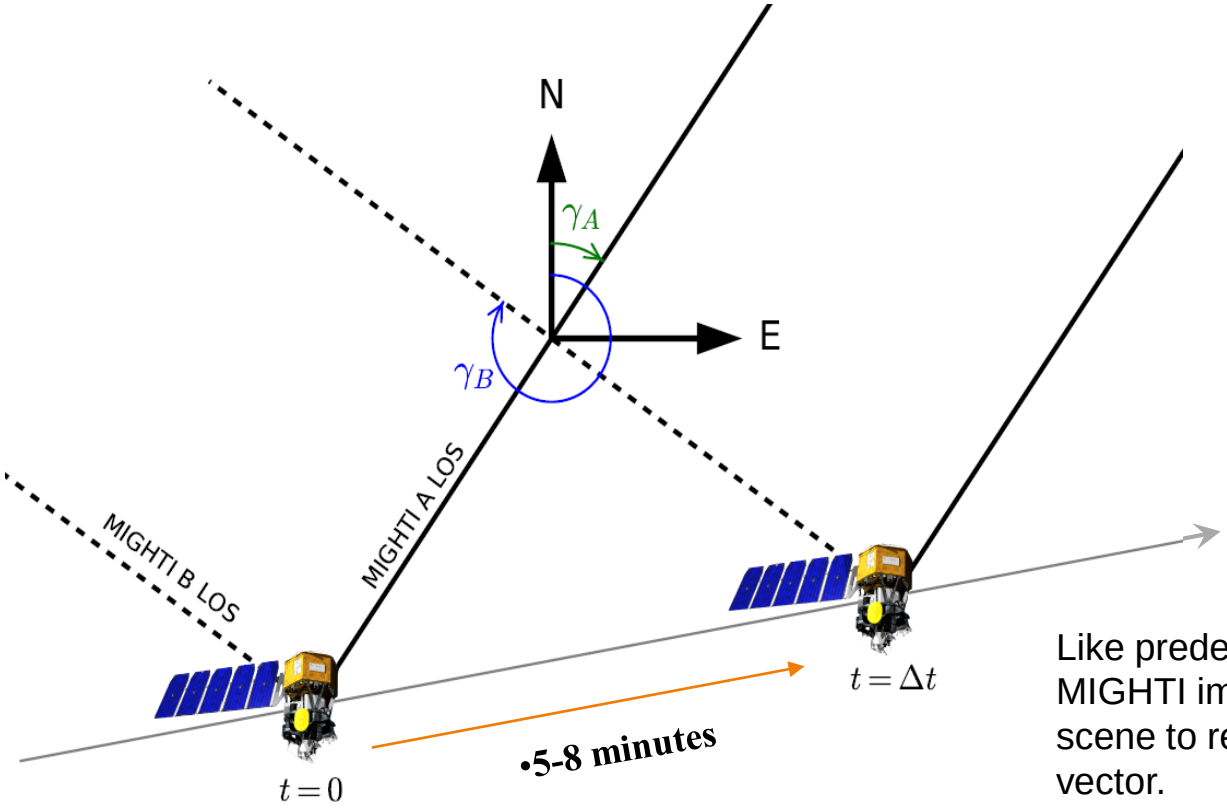
MIGHTI-B



All altitudes are sampled at the same time (no scanning)
All three channels are sampled at the same time (no duty cycling)

MIGHTI provides unprecedented coverage of neutral winds from 90-300 km altitude (~110-210 km at night) with a horizontal sampling of 250-500 km.

Measurement Geometry



Like predecessors WINDII and TIDI, MIGHTI implements two views of the scene to retrieve a horizontal wind vector.

Thus cardinal winds (zonal and meridional components) are retrieved.

Two temperature measurements are retrieved from the same regions (so they better be in agreement).

One orbit of MIGHTI temperatures

•**MIGHTI daytime temperatures** compared to **MSIS 2.0** [*Emmert et al.*, submitted] at the same times and locations

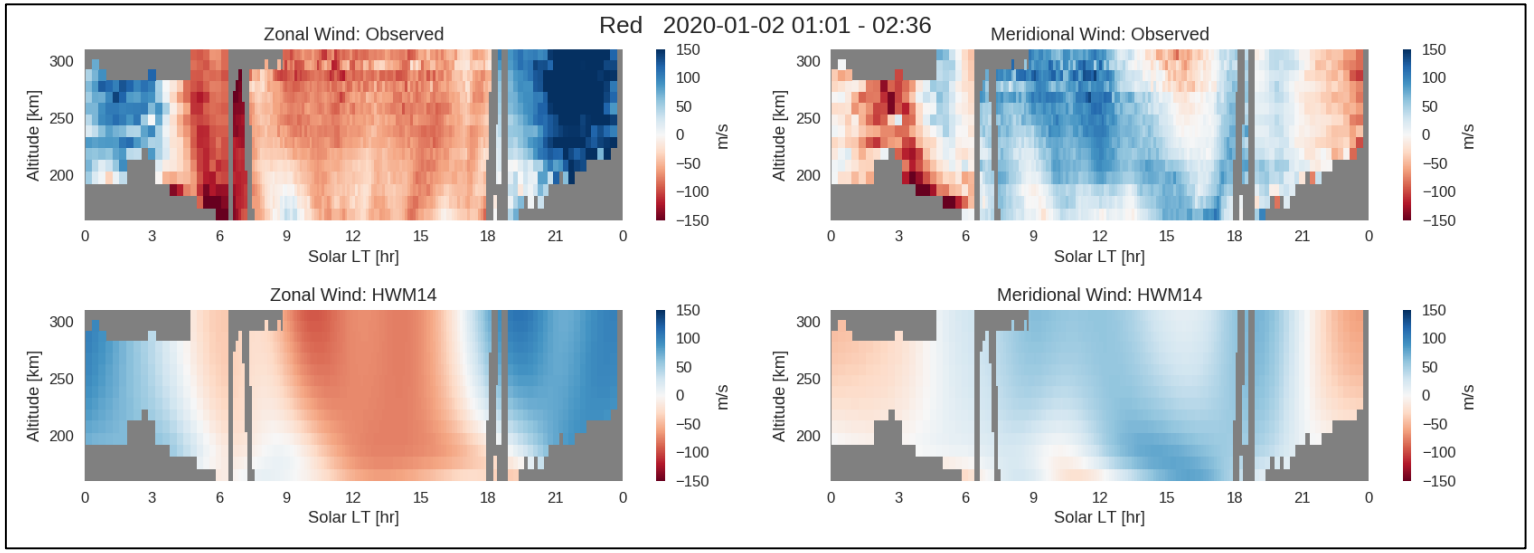
•MSIS 2.0 empirical model includes TIMED/SABER temperatures, among other datasets.

•Temperature **precision is ~1 K**

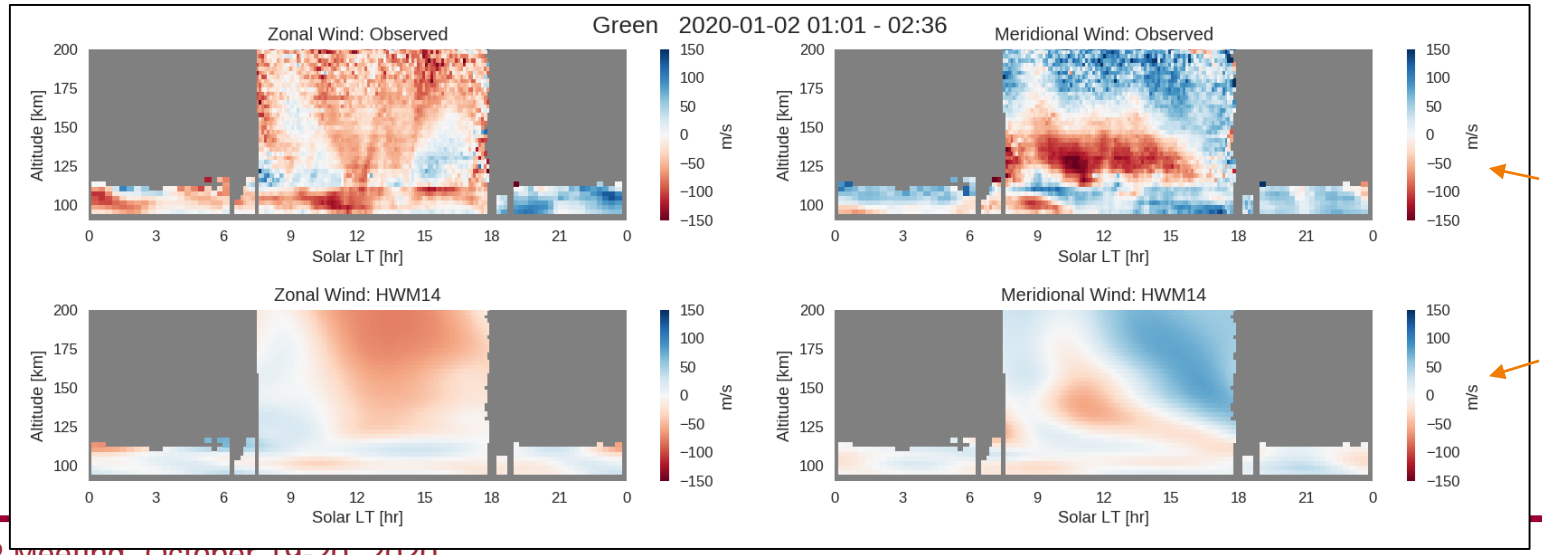
MIGHTI Temperatures – Example

One orbit of MIGHTI winds

•Red emission



•Green emission

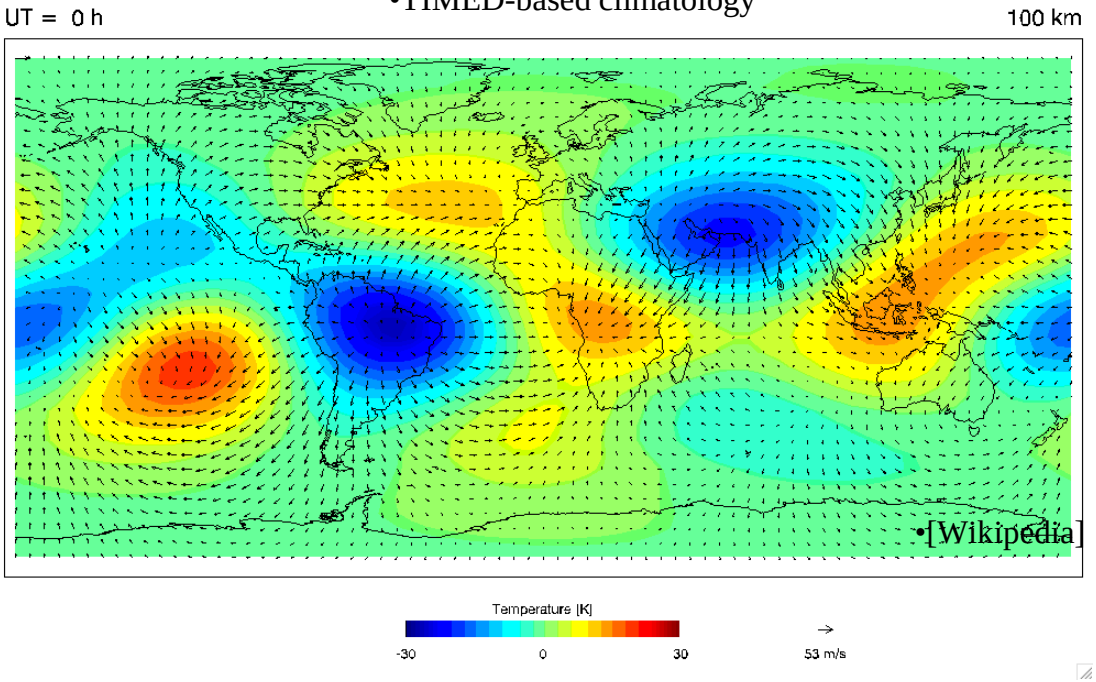


•**Data** shows significant variability compared to **climatology** (HWM14, *Drob et al.*, 2015)

Background: Tides

- Atmospheric tides are the normal modes of an idealized atmosphere
- Waves are a function of:
  - Altitude
  - Latitude
  - Longitude
  - Time
- Waves with longitudinal phase speeds of
  360 deg / 24 h
  are called "**migrating**"
- Other waves are called "**nonmigrating**" or "**stationary**"

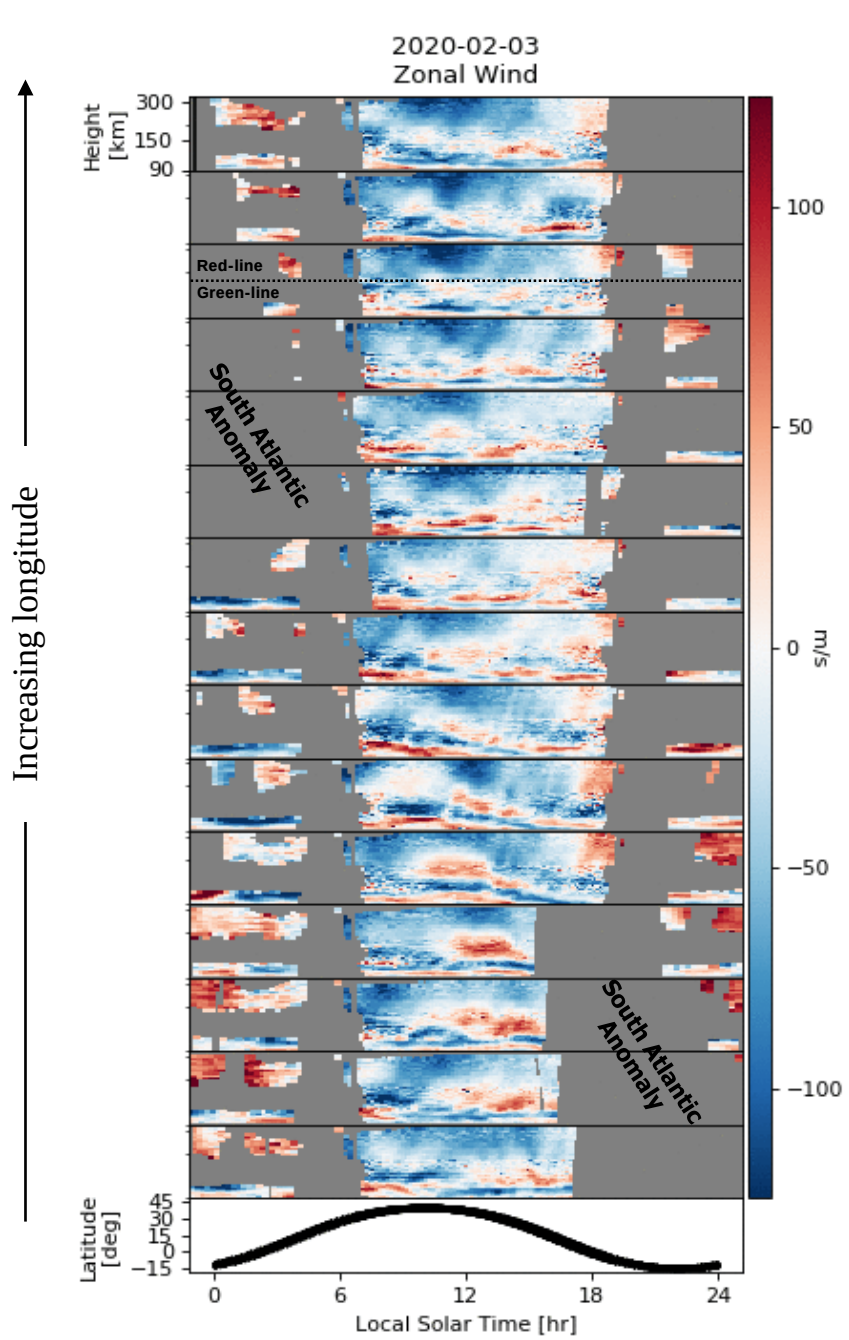
•TIMED-based climatology

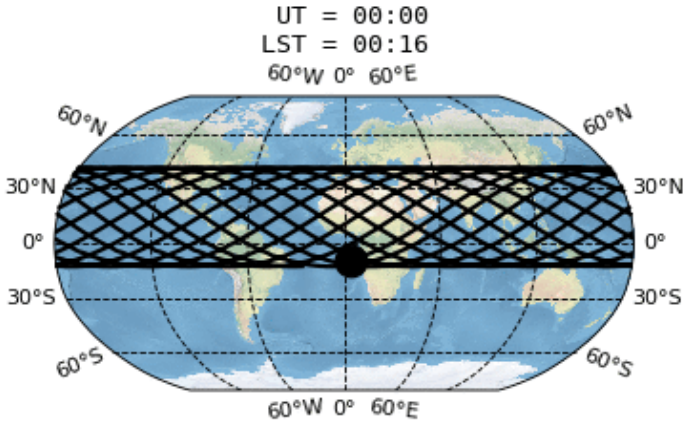


•[Wikipedia]

•Tides are a significant pathway for energy and momentum transport from the lower atmosphere to space

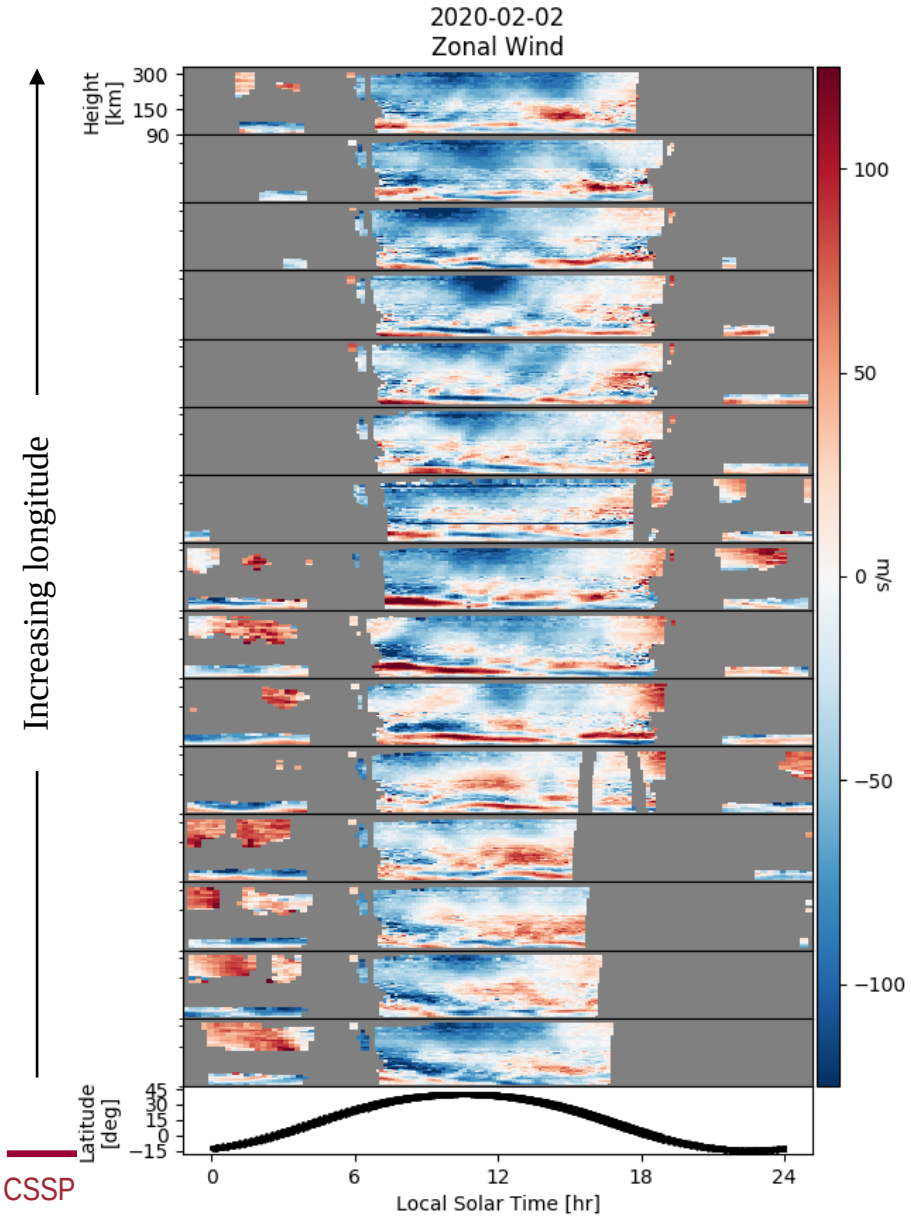
One day of MIGHTI zonal winds

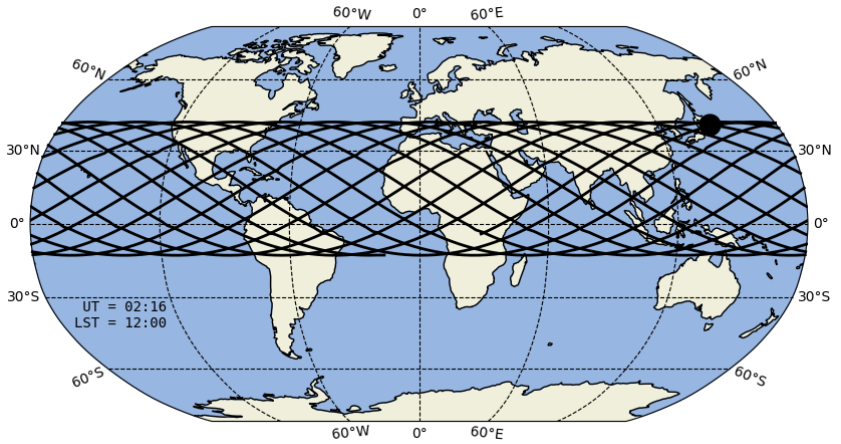




- If all structures were sun synchronous (e.g., migrating tides), all 15 orbits would exhibit the same pattern
- Significant variability is observed at multiple spatial and temporal scales
- Narrow layers of strong winds are ubiquitous below ~150 km and extend over 1000s of km horizontally

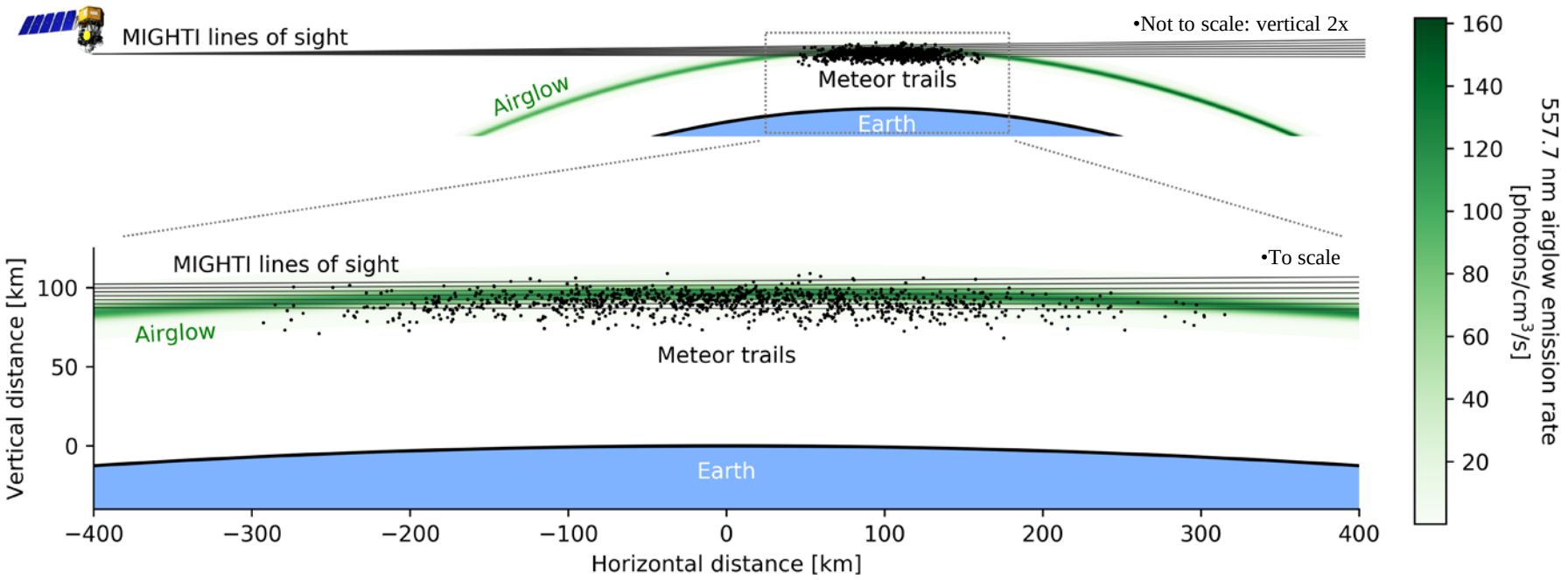
Two days of MIGHTI zonal winds

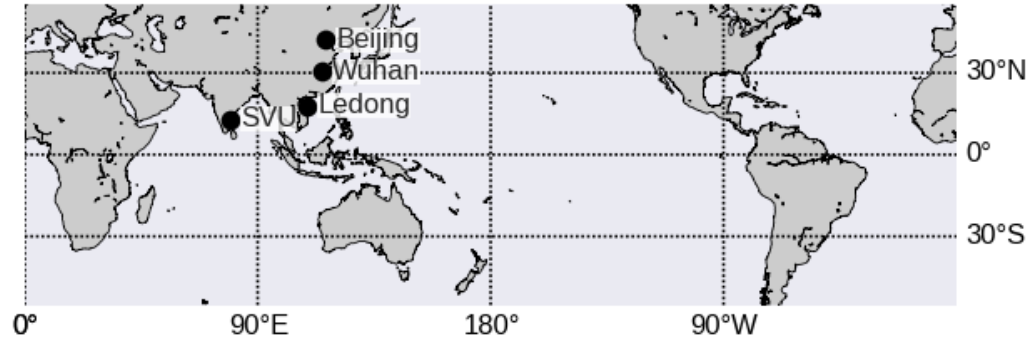




•Some localized structures persist for at least 24 hours, and some vary from day to day

Ground-based validation 1: Meteor Radars

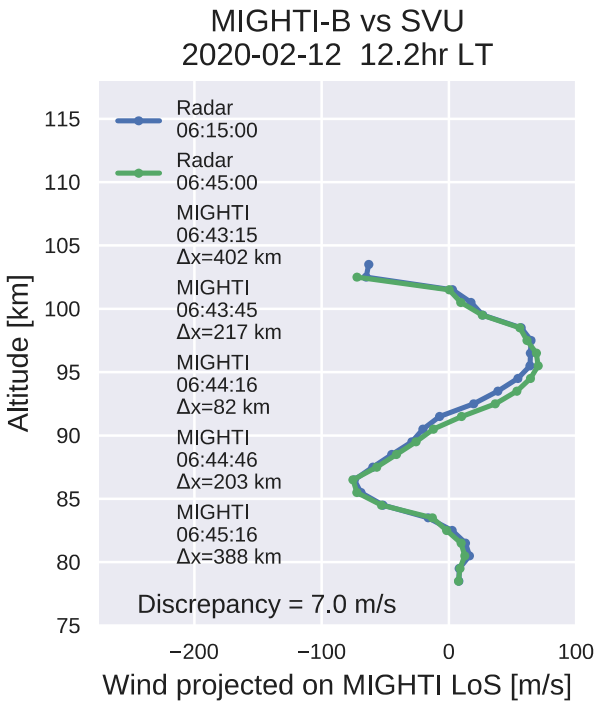




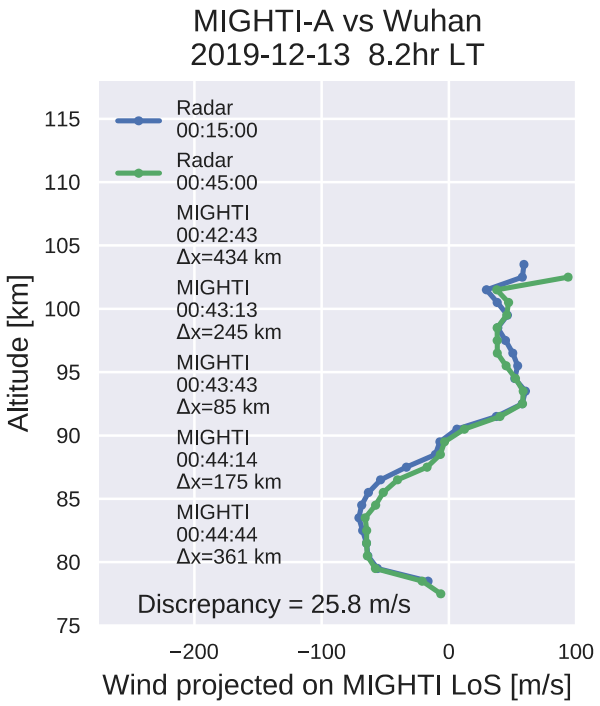
- MIGHTI and meteor radars sample the atmosphere with similar **horizontal** and **vertical** resolution
- (but different **temporal** resolution)

Example Conjunctions

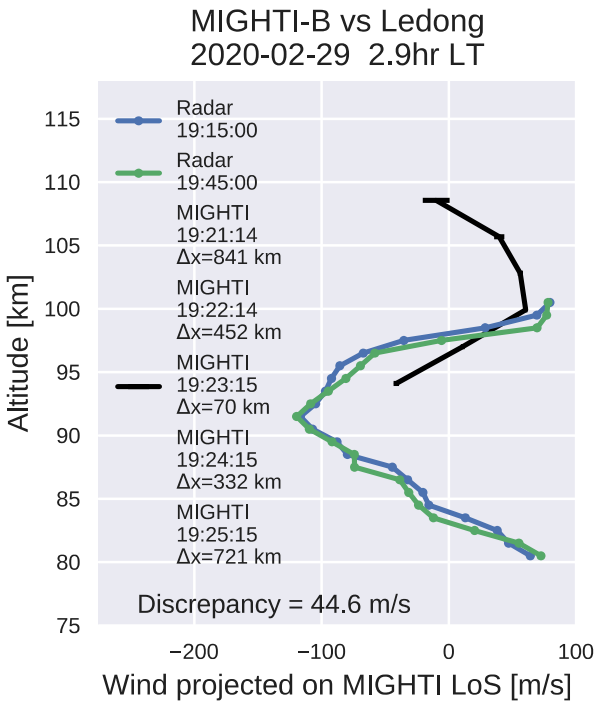
Good



Average

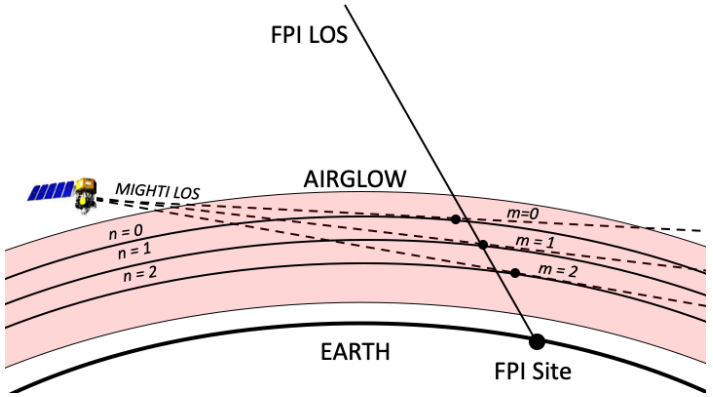


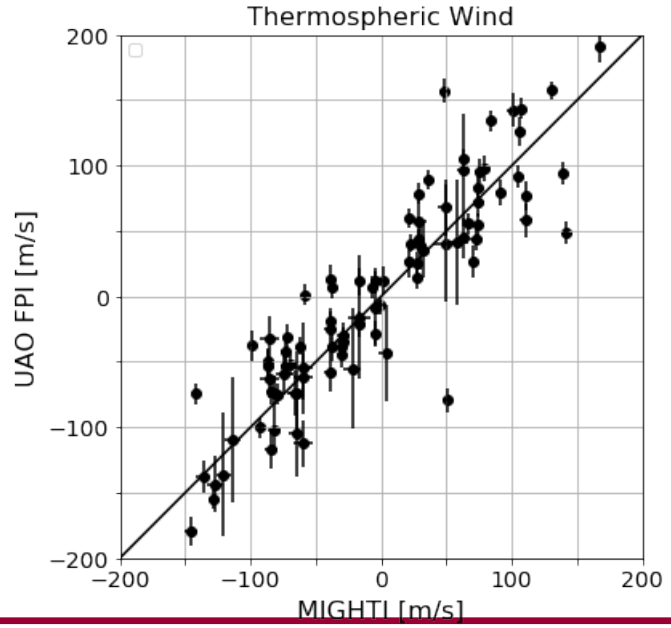
Bad

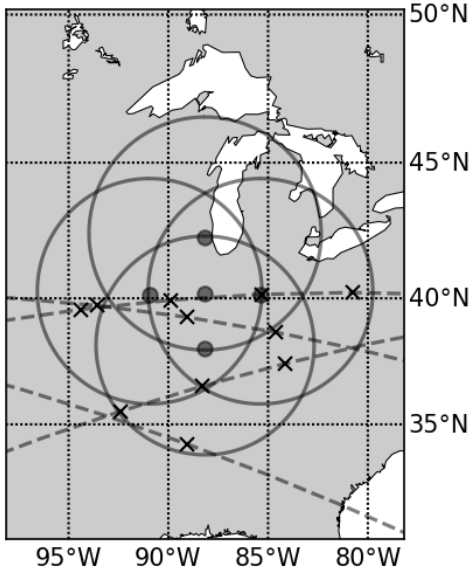


Ground-based validation 2: Fabry-Perot Interferometers

- Comparisons with 2 ground-based Fabry-Perot interferometers (FPIs) in Urbana, IL, USA and Oukaimeden Observatory, Morocco
  - Red line at night
  - **188 conjunctions showing high correlation (r=0.85-0.9)**
  - Mean offsets are 2-11 m/s







•Figures from *Makela et al. [Submitted]*

Space-Based validation: TIDI-MIGHTI Comparisons

Space-time window around TIDI measurements used for finding conjunctions

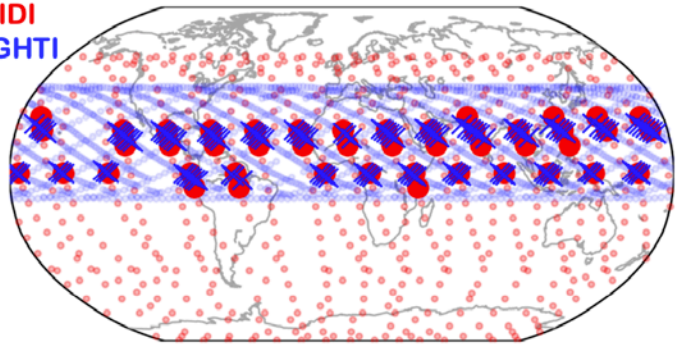
TIDI LST ± 15min

TIDI LAT ± 4 degree

TIDI LON ± 4 degree

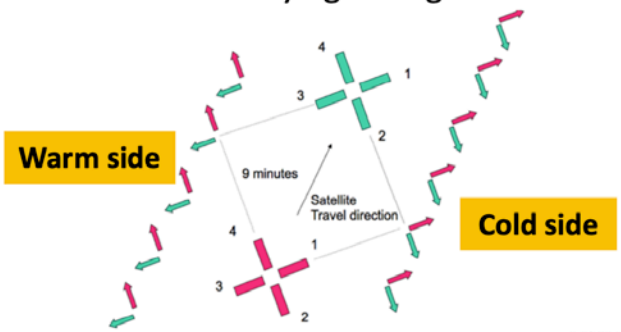
Dhadly et. al., in preparation

TIDI
MIGHTI



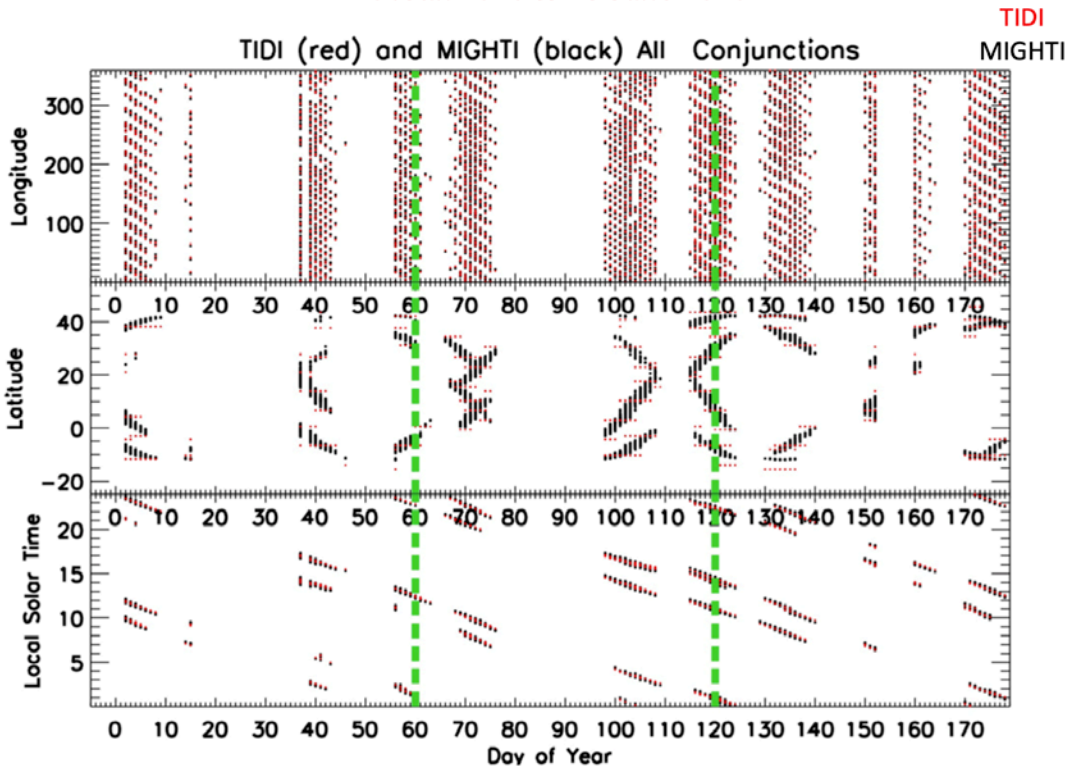
Example - 2nd Jan 2020 - MIGHTI (blue) and TIDI (red) conjunctions shown in bold colors. The light colors represent all the TIDI and MIGHTI measurements (90-95km) taken on this day.

TIDI Flying Configuration



TIMED/TIDI and ICON/MIGHTI - All Conjunctions

01Jan 2020 to 26 June 2020



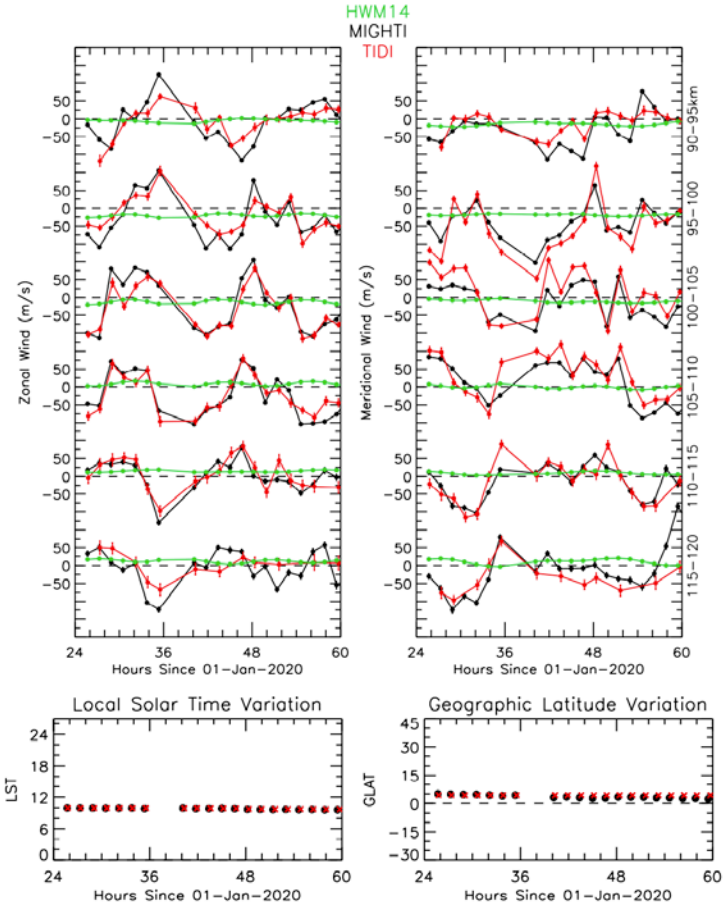
The green lines mark the TIDI yaw cycles

Space-Based validation: TIDI-MIGHTI Comparisons

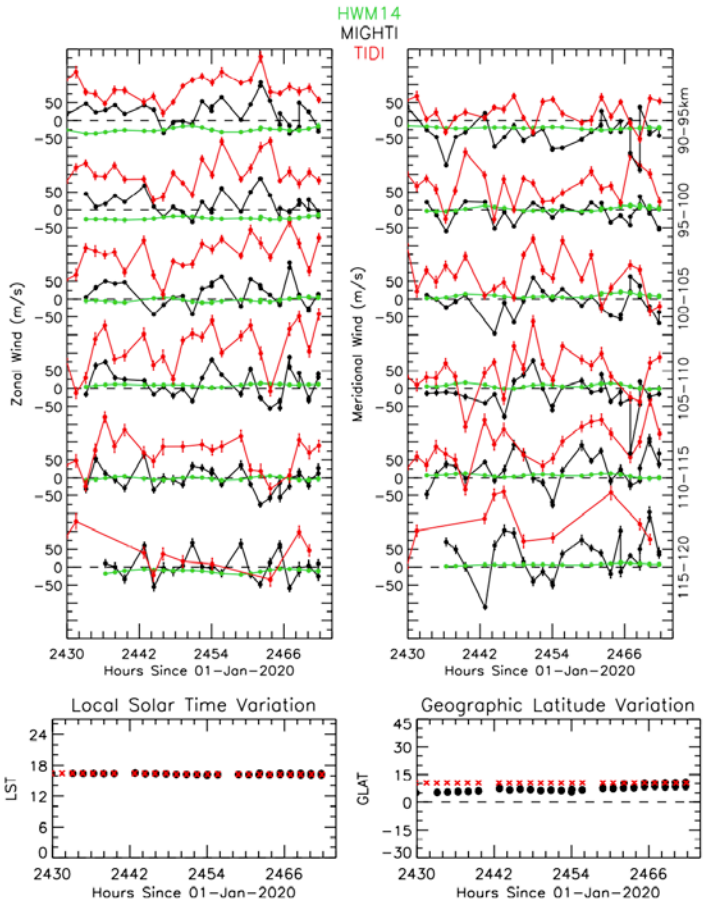
MLT Wind Comparisons - Two Example Conjunctions between MIGHTI and TIDI

Dhadly et. al., in preparation

A Good Agreement Case - Day 2-3, 2020



Bias (looks Additive) Case - Day 102-103, 2020



After analyzing all the conjunction days individually, we found that:

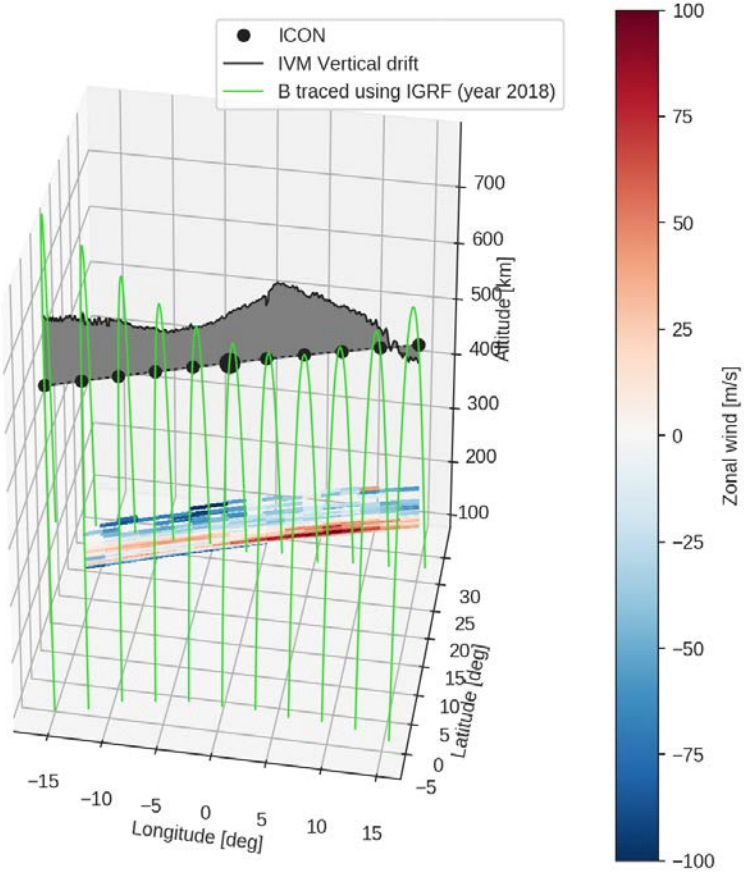
1. TIDI warm side winds always agree with MIGHTI.

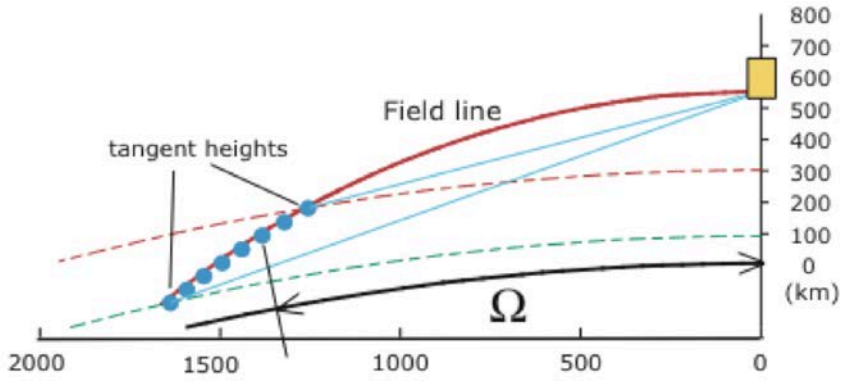
2. TIDI cold side MLT winds during yaw cycle 2 (day 61-120) are biased w.r.t MIGHTI winds.

A possible source of bias is TIDI zero wind calibration, which is currently under investigation.

The most likely sources of minor discrepancies are differences in measurement time/location and sensor sensitivity.

ICON Electrodynamics



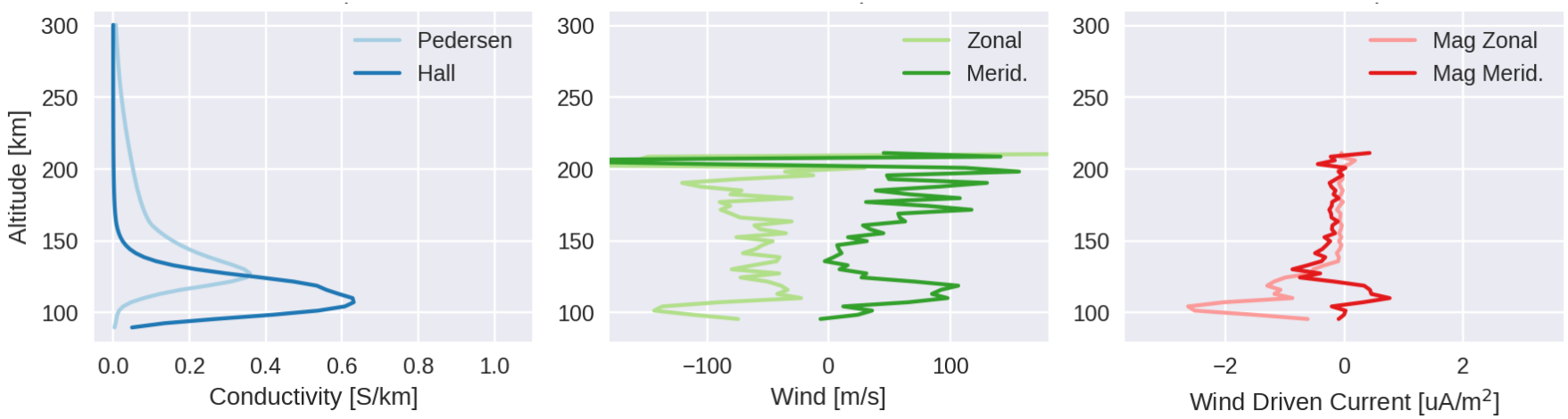


- **IVM and MIGHTI** observe the same field line twice per orbit
- One daytime, one nighttime
- 15 daytime passes per day, ~450 per month
- Observe the lower thermospheric wind drivers, and the ionospheric dynamo response, at the same place at nearly the same time (+/- a few minutes)

Calculation of Ionospheric Current

Ohm's Law in the ionosphere

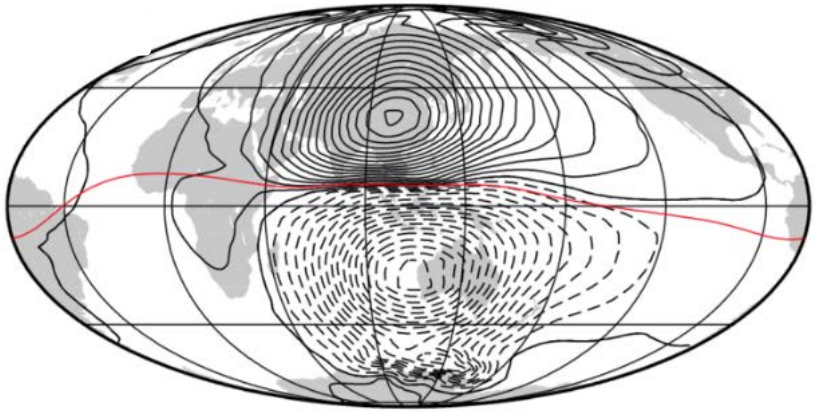
$$\bar{j} = \underline{\sigma} \cdot \left(\bar{E} + \bar{u} \times \bar{B} \right) \quad \text{where} \quad \underline{\sigma} = \begin{pmatrix} \sigma_P & \sigma_H & 0 \\ -\sigma_H & \sigma_P & 0 \\ 0 & 0 & \sigma_0 \end{pmatrix}$$



- ICON (MIGHTI+IVM) provides ability to calculate **ionospheric currents** – over many longitudes, local times, and low latitudes
  - *Previous observations were largely point measurements or height-integrated quantities*
- Large wind shears imply that the wind-driven dynamo is **inefficient**
- The important quantity is not the wind, but rather the **conductivity-weighted wind**

Comparing Winds and Plasma Motion

•Ionospheric Sq current system
•*Sabaka et al.* [2015]



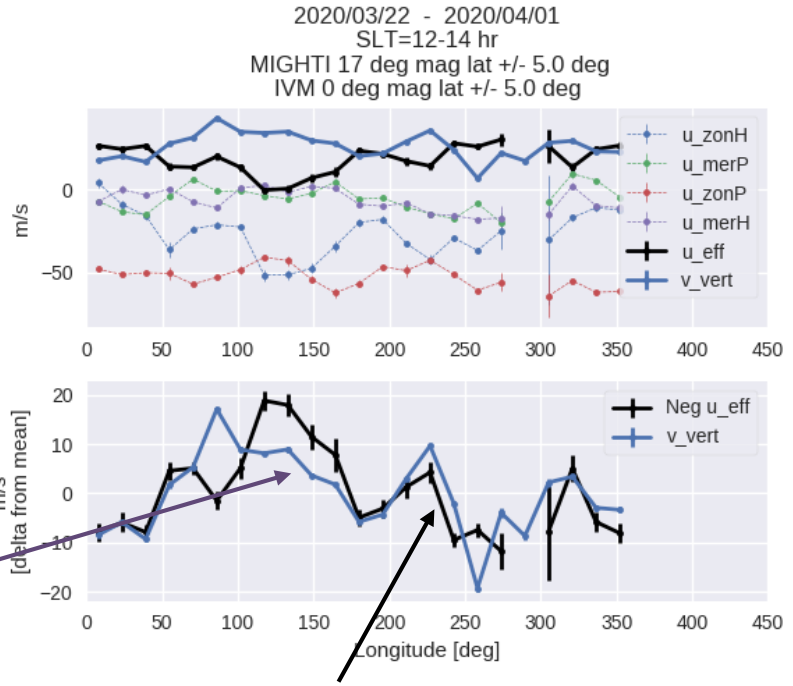
$$\bar{j} = \underline{\sigma} \cdot \left(\bar{E} + \bar{u} \times \bar{B}\right)$$

Performing field line integration of Ohm's law one can show:

$$v_2 = -\left(\frac{\Sigma_H}{\Sigma_C} U_1^H + \frac{\Sigma_P}{\Sigma_C} U_2^P + \frac{\Sigma_H^2}{\Sigma_C \Sigma_P} U_2^H - \frac{\Sigma_H}{\Sigma_C} U_1^P\right) + C_{ext}$$

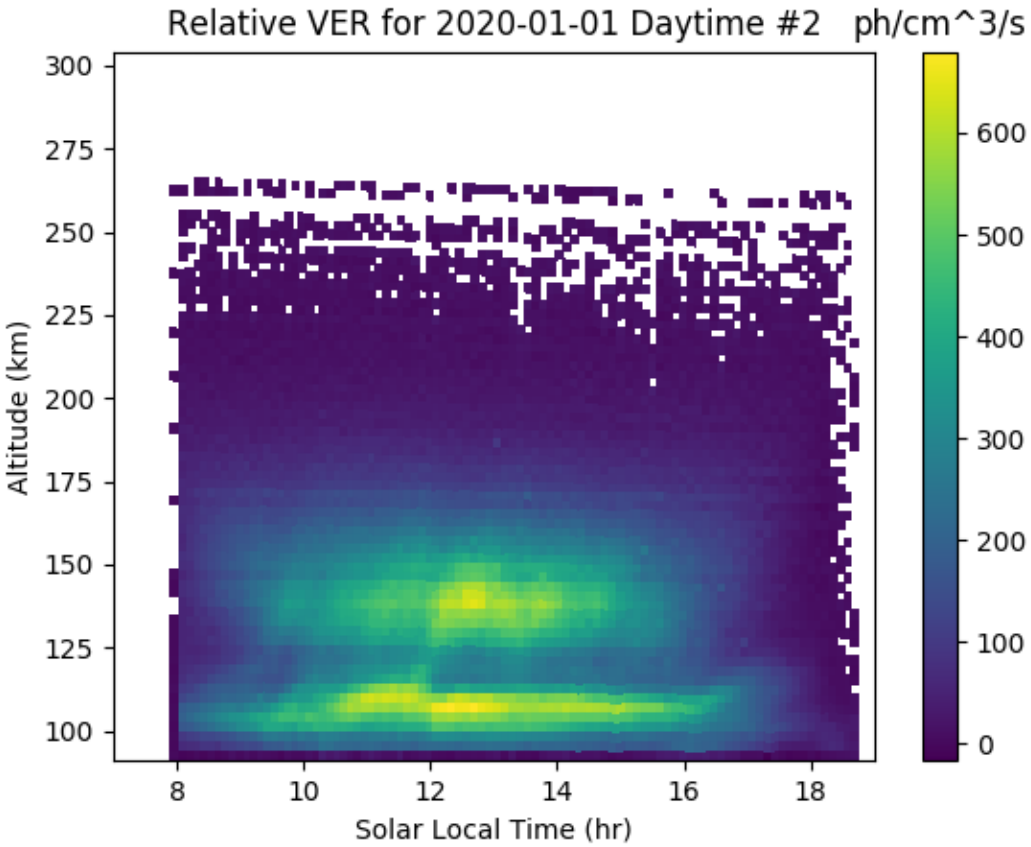
"Effective wind" includes all 4 wind-driven current terms

- **Near local noon**, meridional current is negligible
- → *Zonal current is constant*
- **Near equinox,** northern and southern conductances are similar
- **During quiet times**, the magnetosphere has little influence on low latitude electric fields



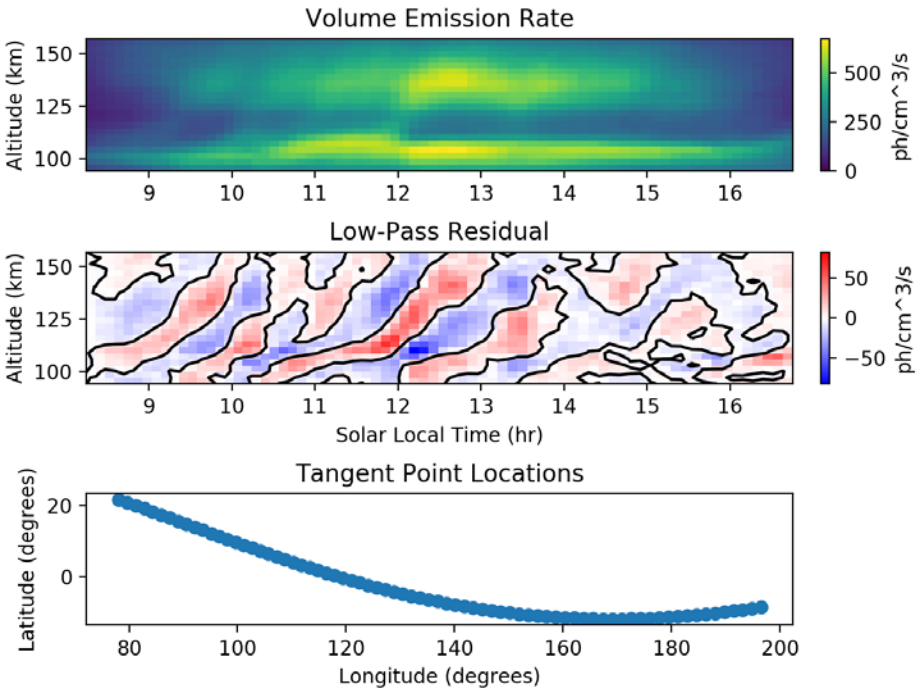
•**Topside ionospheric motion** reflects the **lower thermospheric wind drivers**, in terms of the longitudinal pattern, likely caused by non-migrating tides

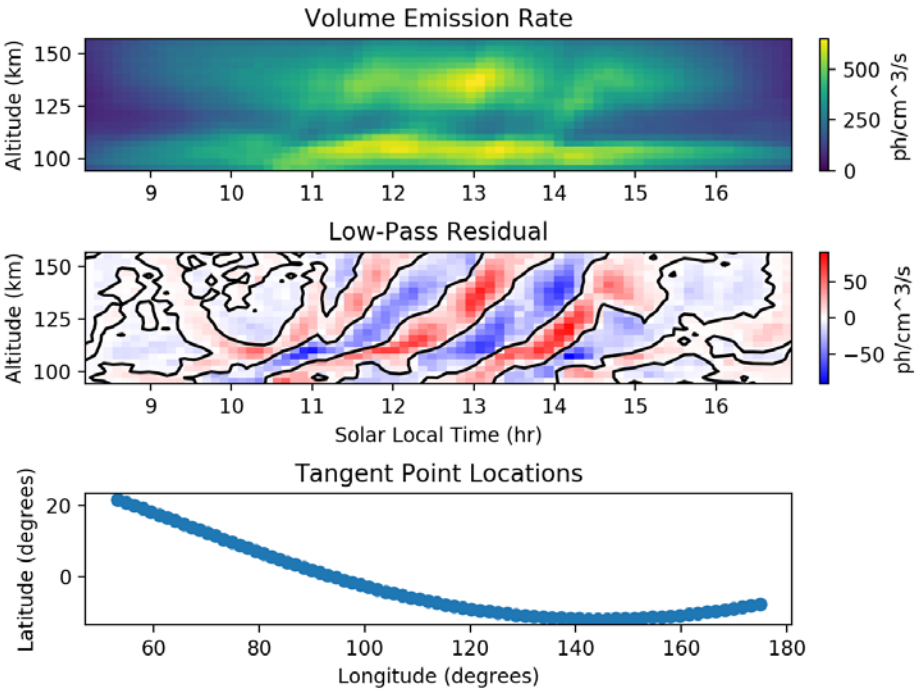
Small-Scale variations seen in MIGHTI Data



- MIGHTI green line daytime volume emission rate show small-scale variations throughout the whole dataset.
- These are too structured and frequent to be tides.
- Could be gravity waves, but they are very large amplitude.

Two Orbits – Airglow Structures



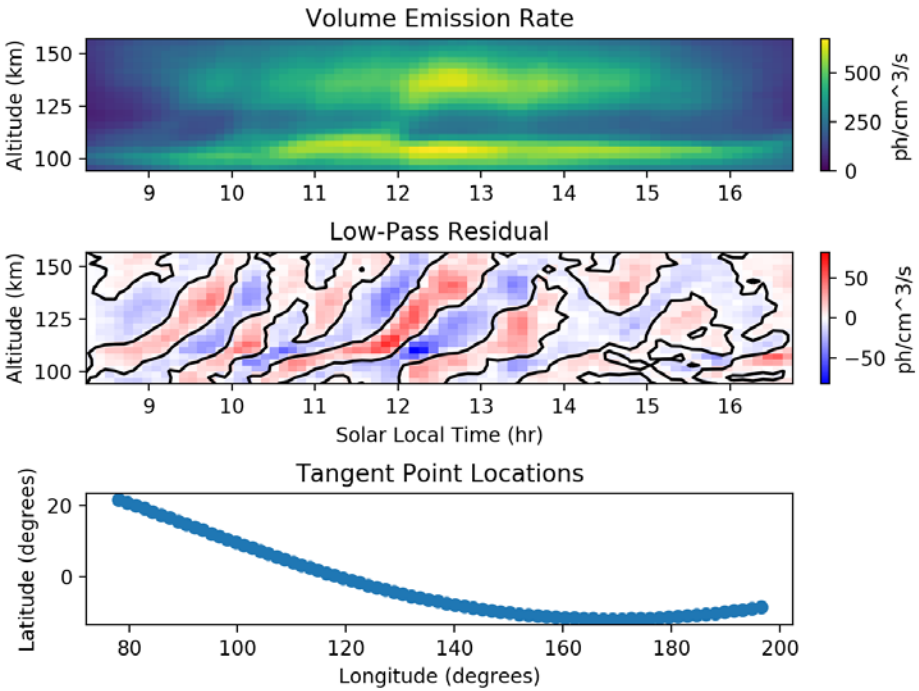


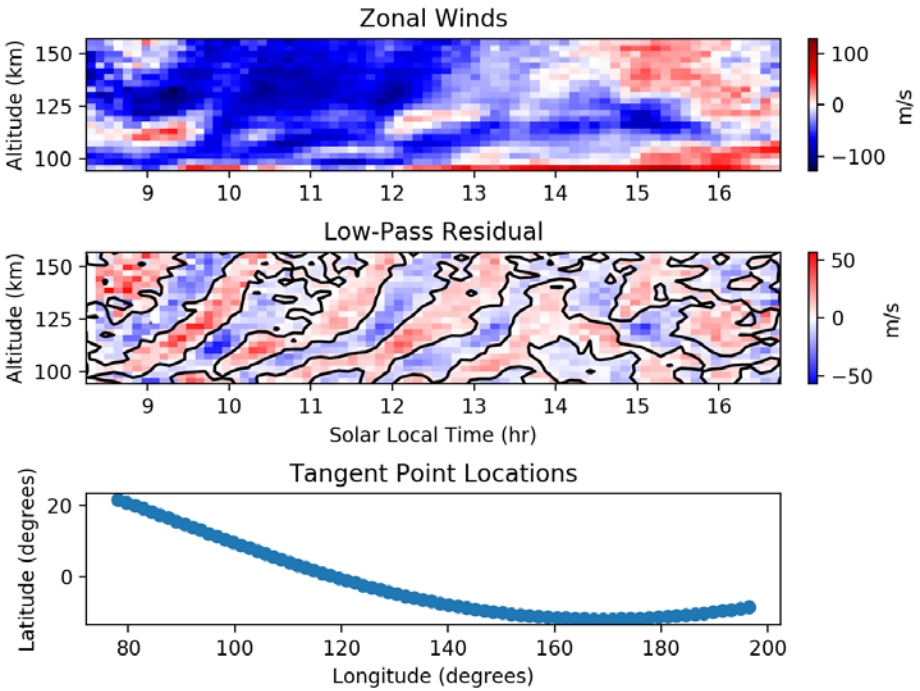
- Data over UTC times:
- 2020-01-01 02:59:17.830Z
- 2020-01-01 03:35:42.842Z

- Data over UTC times:
- 2020-01-01 04:35:32.589Z
- 2020-01-01 05:12:57.838Z

- Variations show consistency between orbits
- After low-pass filtering the data, we see waves throughout the daytime.

Emission Rates vs Winds





- Data over UTC times:
- 2020-01-01 02:59:17.830Z
- 2020-01-01 03:35:42.842Z

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- Variations show consistency in wave parameters between VER and MIGHTI winds.
- Both zonal and meridional winds show wave structures though not always with the same parameters.

ICON at T+365

- ICON's a healthy observatory and collecting data as expected to support all planned science investigations.
- The 2+ year launch delay put ICON Phase E at the start of solar cycle – one good outcome!
- ICON and GOLD starting to work together toward cross-validation of UV products.
- Looking forward to year 2 on orbit!