Imaging mesospheric winds with the Michelson Interferometer for Airglow Dynamics Imaging (MIADI)

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Overview

- MIADI is a ground based field widened Michelson interferometer. The design builds on the heritage provided through the development of the WINDII instrument, as well as MICADO, MIMI and ERWIN-2.

- Optimized for the simultaneous observation of two mesospheric airglow emissions: O (^1S) at 557.7 nm and OH (6, 2) P1 (3) at 839.918 nm (~80-90 km).

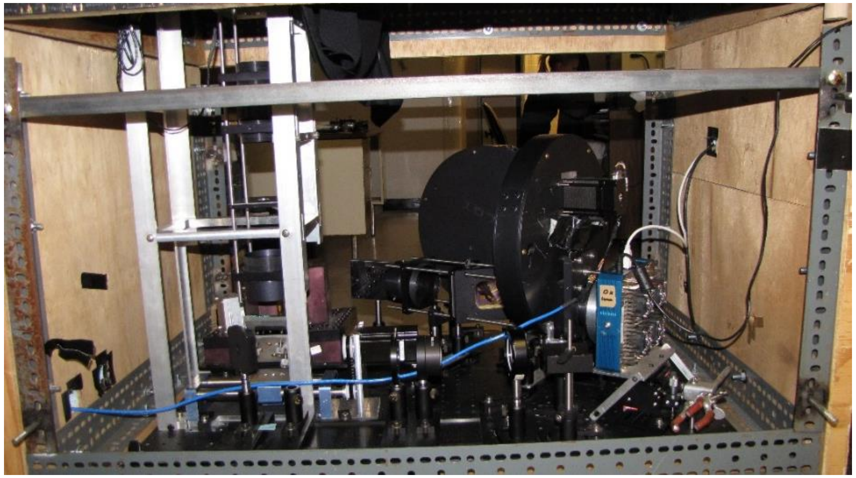
- Images of the LOS Doppler winds and Irradiance in mesosphere are extracted from CCD images of the interference fringes.

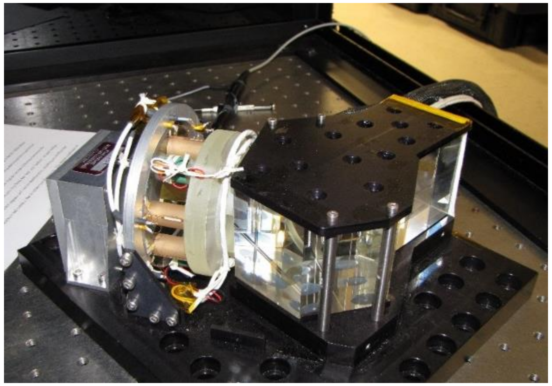
- The mean intensity and background wind and associated perturbation quantities will be obtained and used to diagnose gravity wave signatures in the mesopause region.

- Construction of the field instrument began in 2008 (All sorts of practical problems encountered)

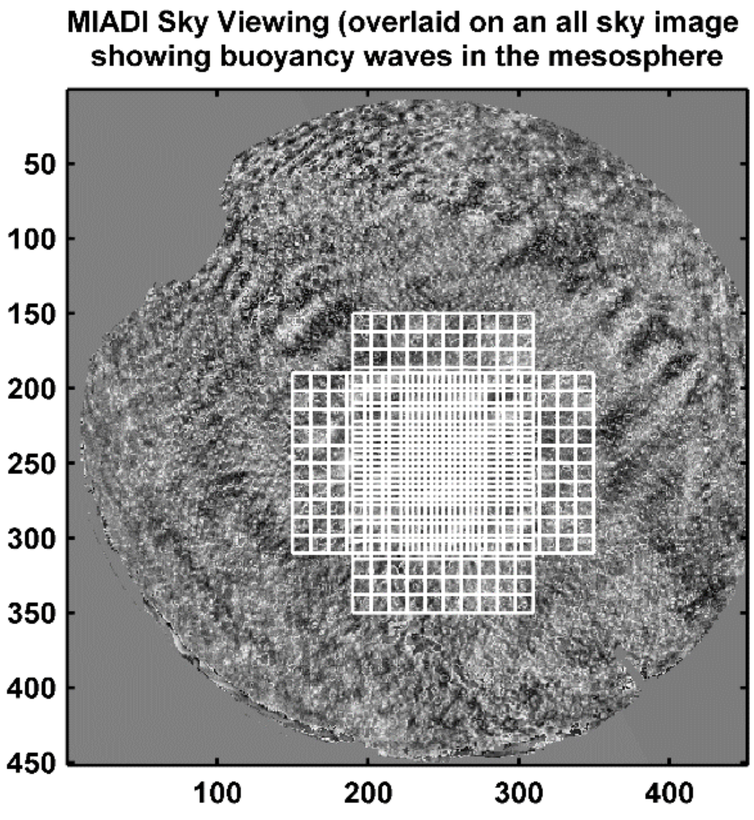
- The instrument has been tested in the lab (Langille, 2013) and now has been validated in the field using observations from July 31, 2014 obtained from a field site outside Fredericton NB.

<u>MIADI Field Implementation 2014</u>
<u>Fredericton, NB (46 N, 66.7 W)</u>





Idealized sky viewing geometry



Courtesy of C. Vail (UNB)

- FOV is 30 degrees ~ 50km x 50km.

- 4 look directions are viewed using a rotating wedge prism pointing 10 degrees off the local vertical with the center of the sky as a common point.

- The sky is imaged through the MIADI optical system onto a CCD detector.

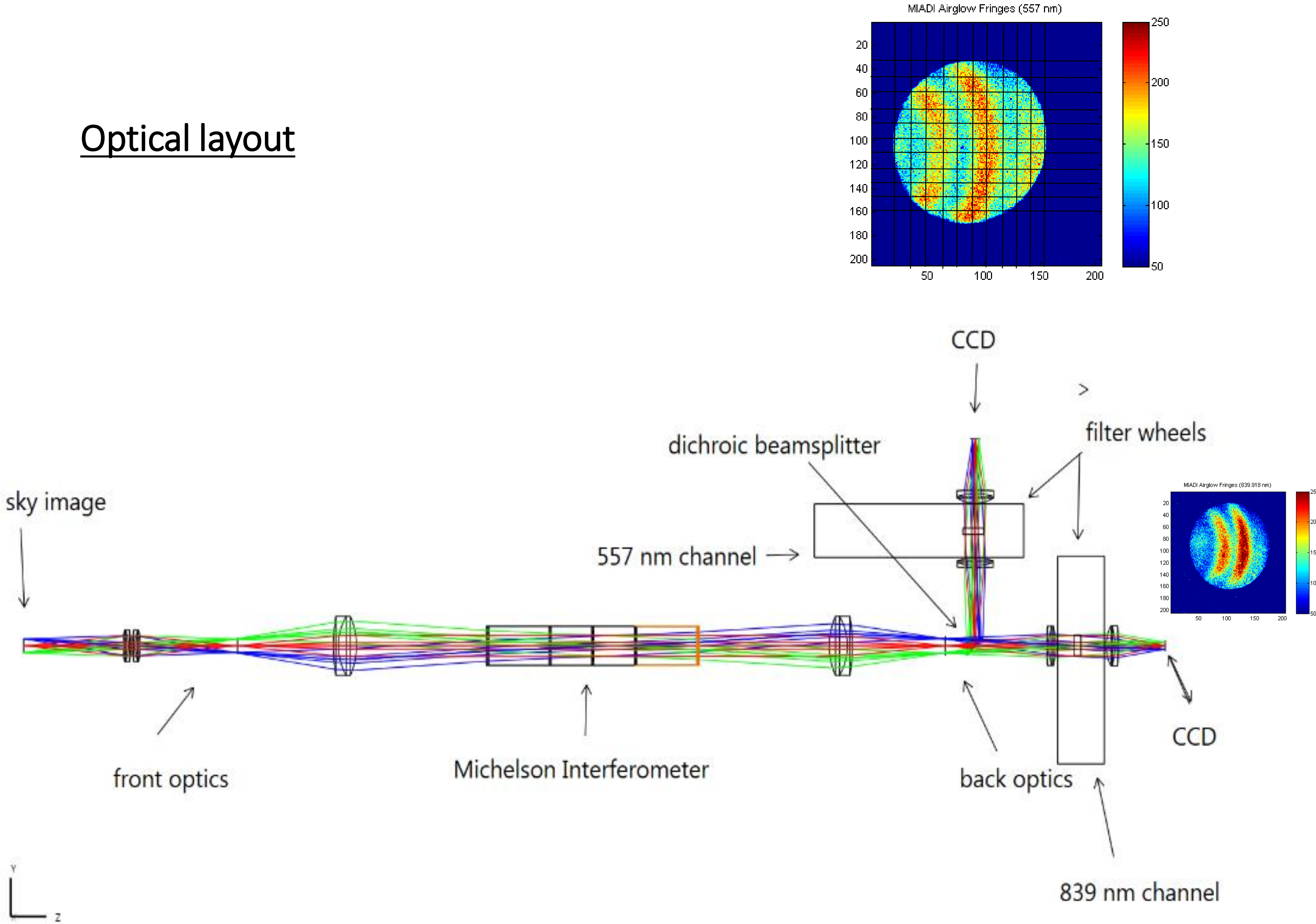
- Each bin on the CCD will correspond to a 5km x 5km region of the sky (some flexibility here).

- Obtain intensity and LOS Doppler wind measurements at each bin

- Extract the field averaged components (background wind) and determine the perturbations due to gravity waves

- Precision is ~2 m/s

Optical layout

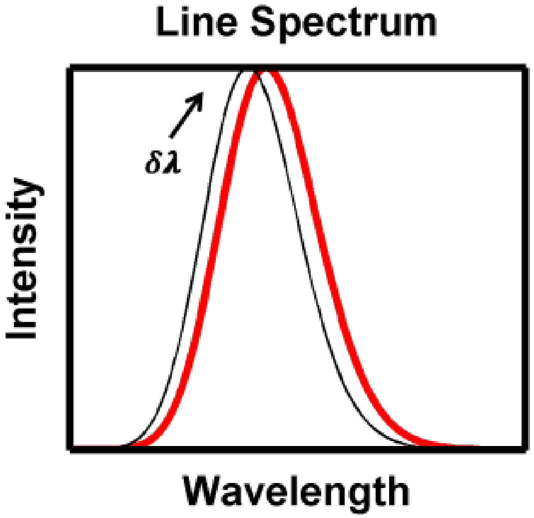


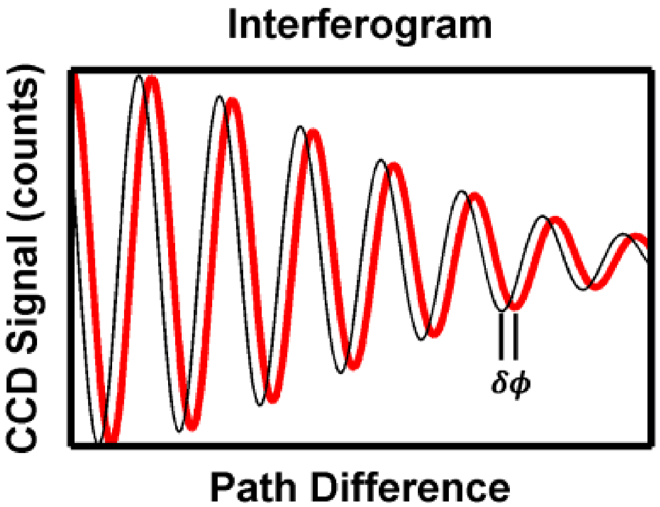
Imaging LOS Doppler winds

- At each bin (x, y) on the CCD image of the interference fringes an interferogram is obtained:

$$I_i(x,y) = I_o(x,y)[1 + UV(x,y)\cos(\Phi(x,y) + \delta S_i)]$$

- LOS Doppler shift results in a phase shift in the interferogram





Use LMS algorithms to obtain images of the fringe parameters:

$$I_o(x,y) \propto \; Emission \;\; Rate$$

$$V(x,y) = \exp(-QT\Delta^2)$$

$$w(x,y) = \frac{c \cdot \lambda_\circ}{2\pi \cdot D}\delta\phi(x,y)$$

Calibration

- LOS Doppler phase shifts must be distinguished from the zero wind background phase and thermal phase drift.

Calibration parameters

$$\delta\phi(x,y) = \Phi(x,y) - [\underbrace{\Phi_o(x,y) + \delta T}]$$

- LOS Doppler wind measurement is obtained at each bin in the image

$$w(x,y) = \frac{c \cdot \lambda_\circ}{2\pi \cdot D}\,\delta\phi(x,y)$$

(2 m/s LOS wind ~ 0.0056 radians)

- Precision for the ideal instrument at each bin

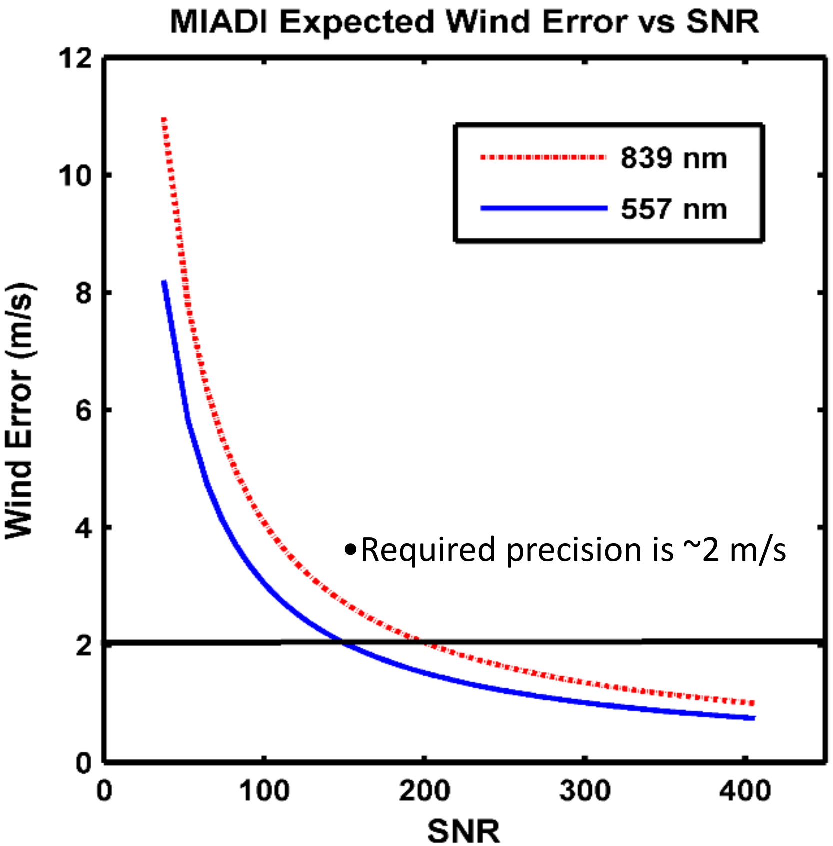
$$\sigma_w = (\sqrt{\frac{2}{7}})\frac{c\lambda}{2\pi \cdot D \cdot U \cdot V(D,T) \cdot (SNR)}$$

Field Implementation: Expected error in LOS wind measurements

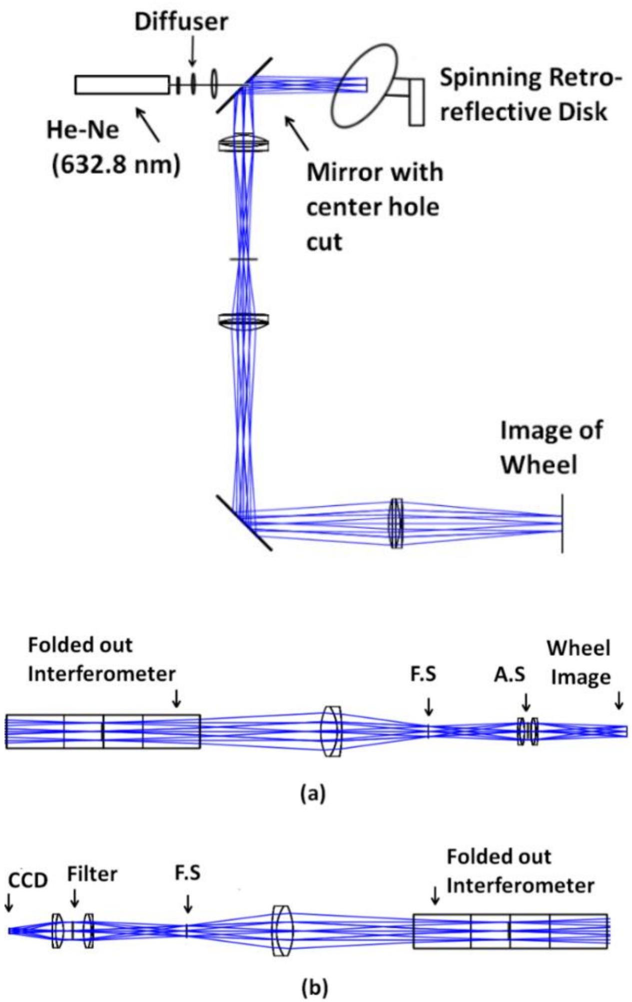
Optimized instrument &
Ideal measurement parameters

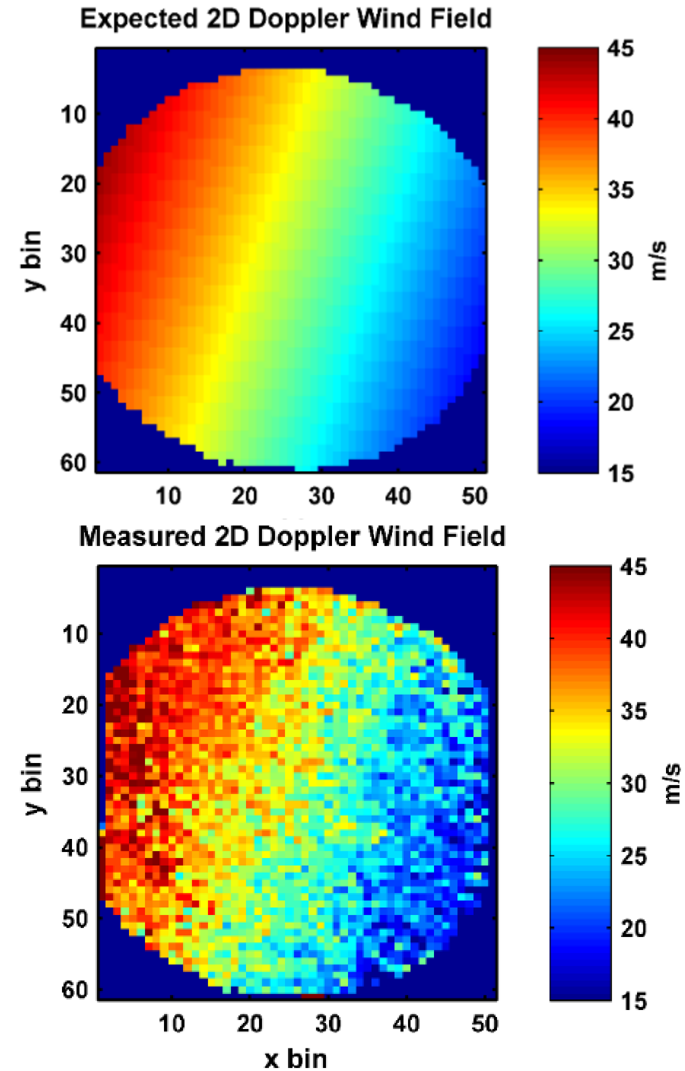
$$\sigma_w = \left(\sqrt{\frac{2}{7}}\right)\frac{c\lambda}{2\pi \cdot D \cdot U \cdot V(D,T) \cdot (SNR)}$$

D (effective path difference)	**7.4 cm**
U (Instrument visibility)	**~0.9**
V_{557} (line visibility)	**~0.7**
V_{839} (line visibility)	**~0.84**
τ (transmission)	**~0.1**
η (quantum efficiency)	**~0.8**
I_{557} (Intensity)	**220 Rayleigh**
I_{839} (Intensity)	**250 Rayleigh**
AΩ (throughput)	**0.0864 cm²sr**



Imaging two dimensional LOS Doppler winds with a field widened Michelson Interferometer





Error on LOS Doppler wind measurements: $\sigma_w \sim \pm 2.5\,m/s$

Summary of observations from July 31, 2014

Prior to airglow observations

- 7 (phase stepped) images of the interference fringes produced while viewing the 557.73 airglow emission through the airglow channel with a diffuser placed at the entrance aperture
- An image of the star field is obtained in each direction

- **Diffuser measurements are used to obtain a zero wind background phase**

$$\Phi_o(x, y)$$

- **Star images are used to map CCD coordinates to sky coordinates**

$$(x, y) \leftrightarrow (\theta, \phi)$$

For each N,E,S,W cycle of the instrument

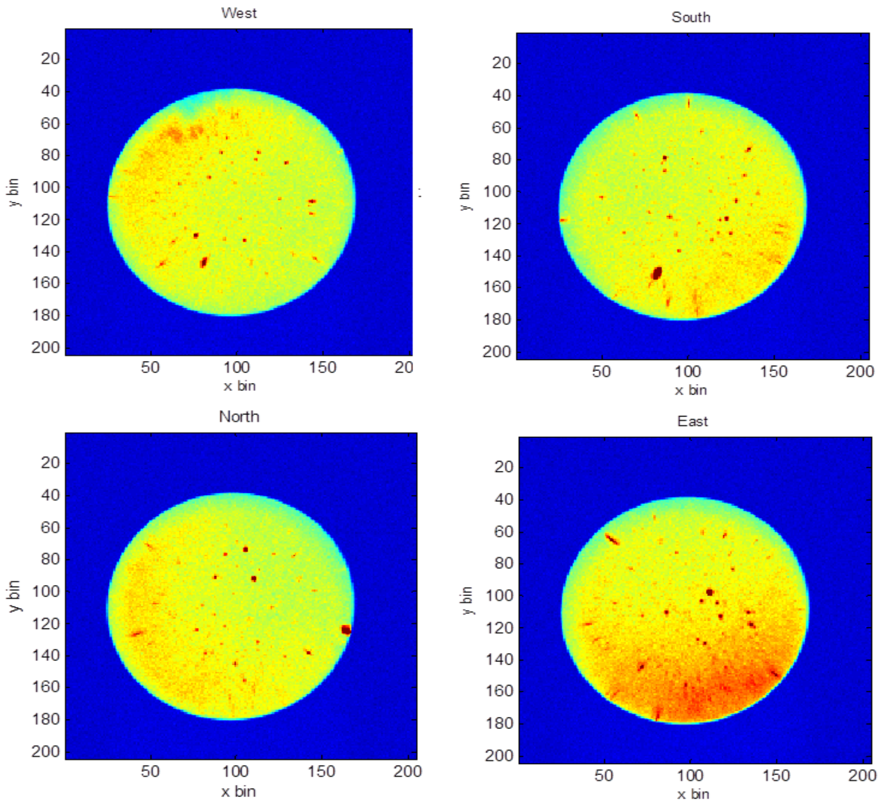
- 7 (phase stepped) images of the interference fringes produced while viewing the 557.73 airglow emission through the airglow channel
- 1 CCD image of the sky through the background filter
- 1 CCD dark image
- 7 (phase stepped) images of the interference fringes produced while viewing the 557.03 Kr calibration lamp through the calibration channel.

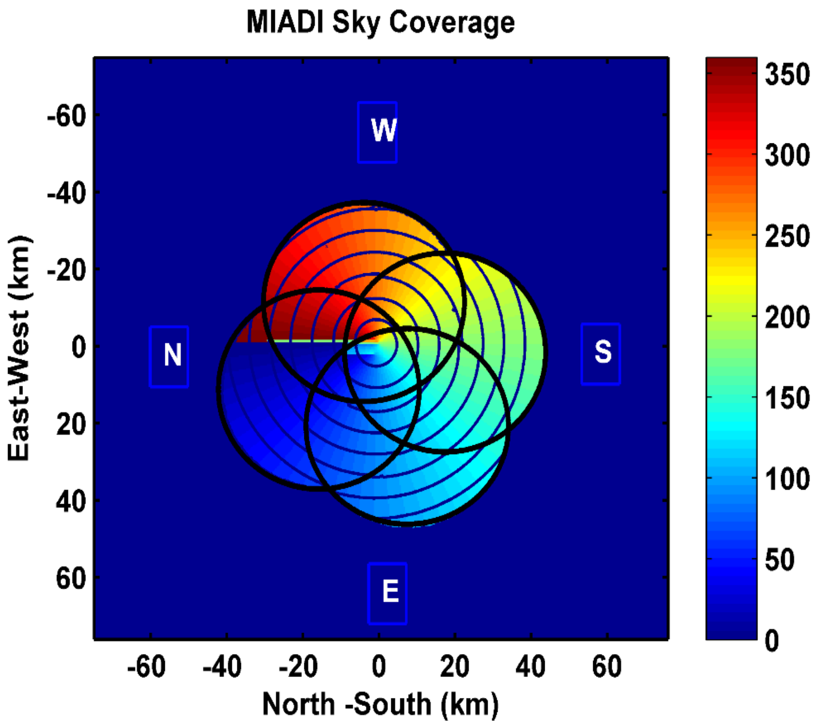
- **Ten full cycles of the instrument were obtained**

$$I_o(x, y), UV(x, y), \Phi(x, y)$$

Sky viewing geometry (July 31, 2014)

Unfiltered star images





- **Each N, S, E, W direction is viewed for <u>8.23 minutes</u>**
- **Total cadence in each cycle is <u>33 minutes</u>**

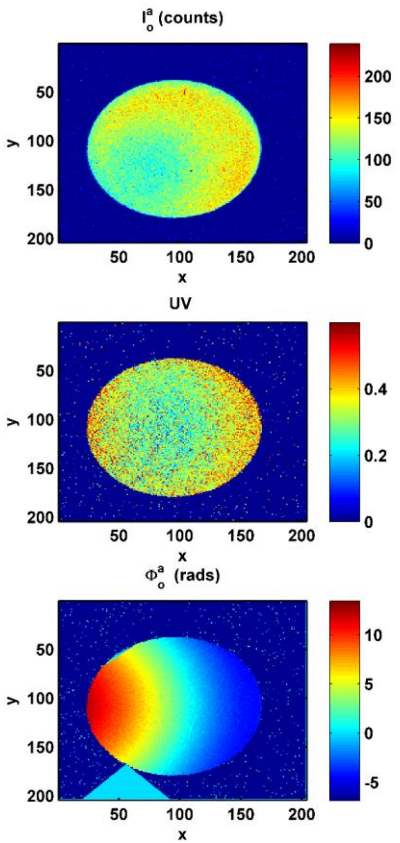
Calibrations

Example airglow measurement

Intensity

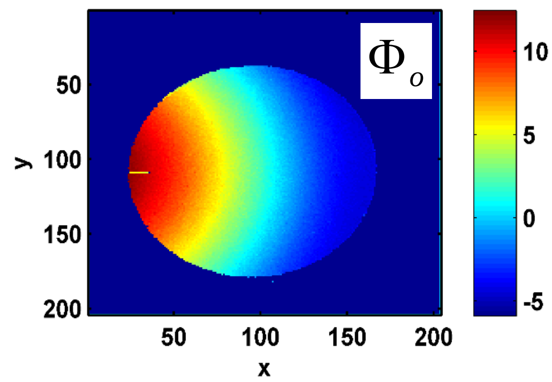
Visibility

Phase



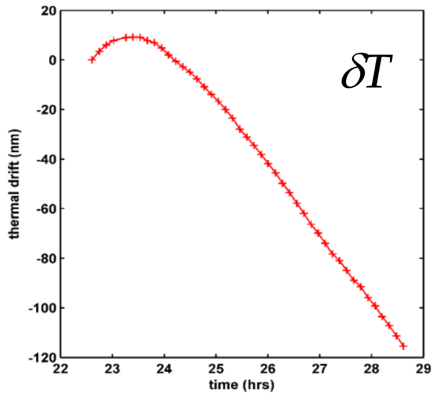
Using the Diffuser measurements

Zero wind phase

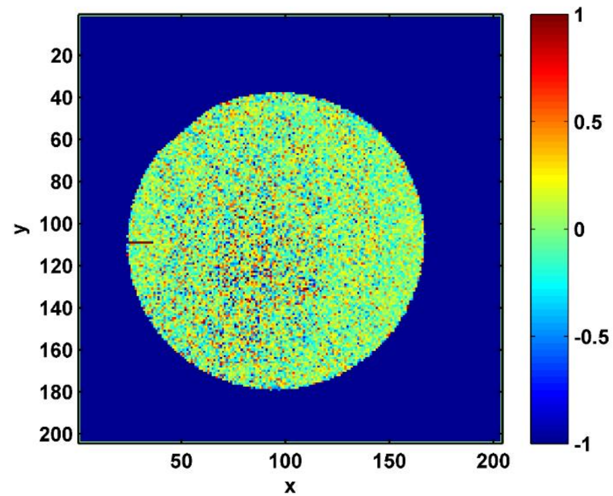


Using the Kr Calibration lamp

Thermal phase drift



Doppler Phase variations



$$\delta\phi(x,y) = w(x,y)\frac{2\pi\cdot D}{c\cdot\lambda_o}$$

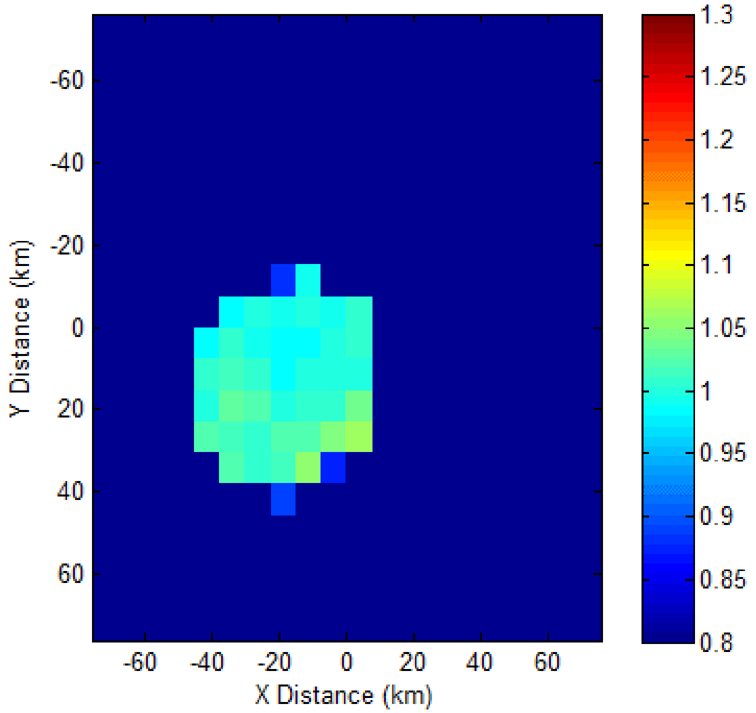
$$\sigma \sim \pm 68.6\, m/s$$

Bin 20x20

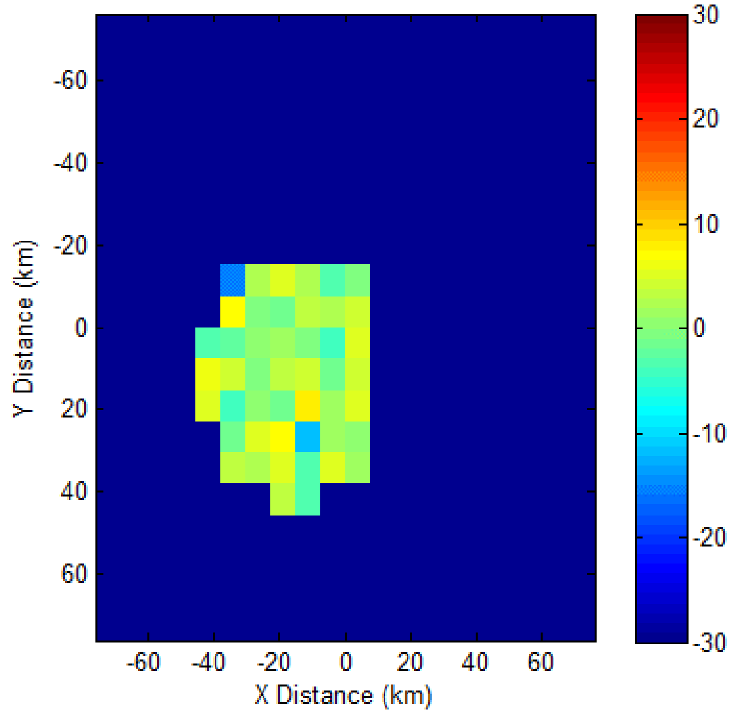
$$\sigma \sim \pm 3\, m/s$$

LOS Doppler wind and relative Intensity images: ~8.23 minute cadence

Relative Intensity

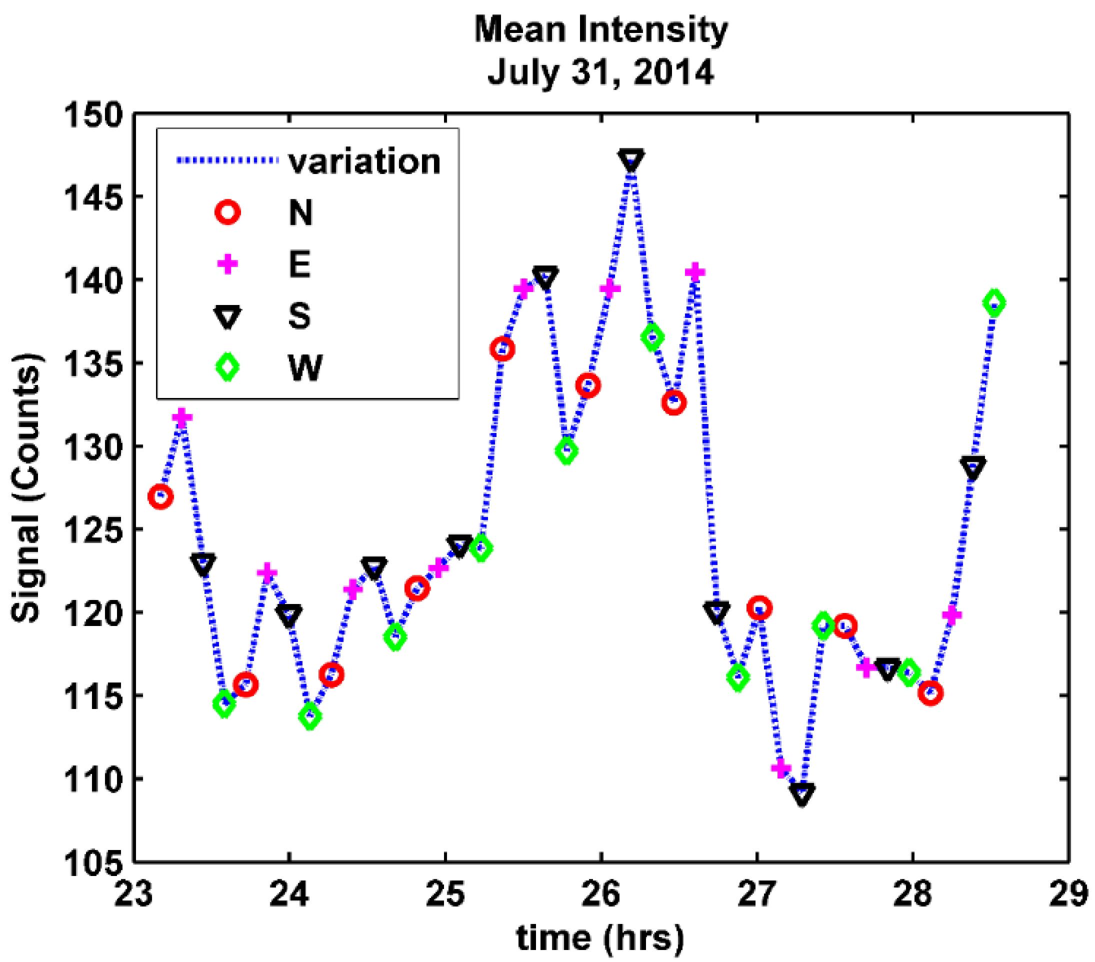


LOS Doppler winds (m/s)



- **σ ~ ± 3 m/s**
- **64 bins (8x8)**
- **~6.25 km x 6.25km**

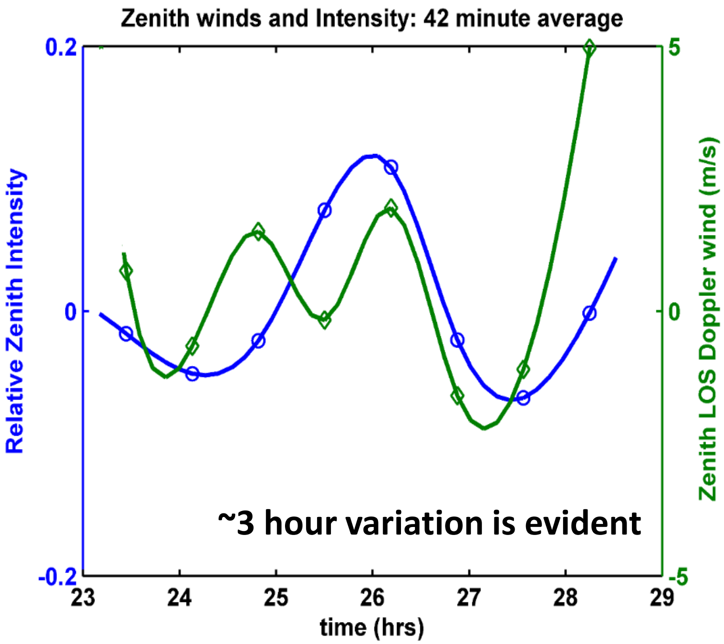
- Significant variability is observed
- Intensity appears correlated with LOS Doppler winds



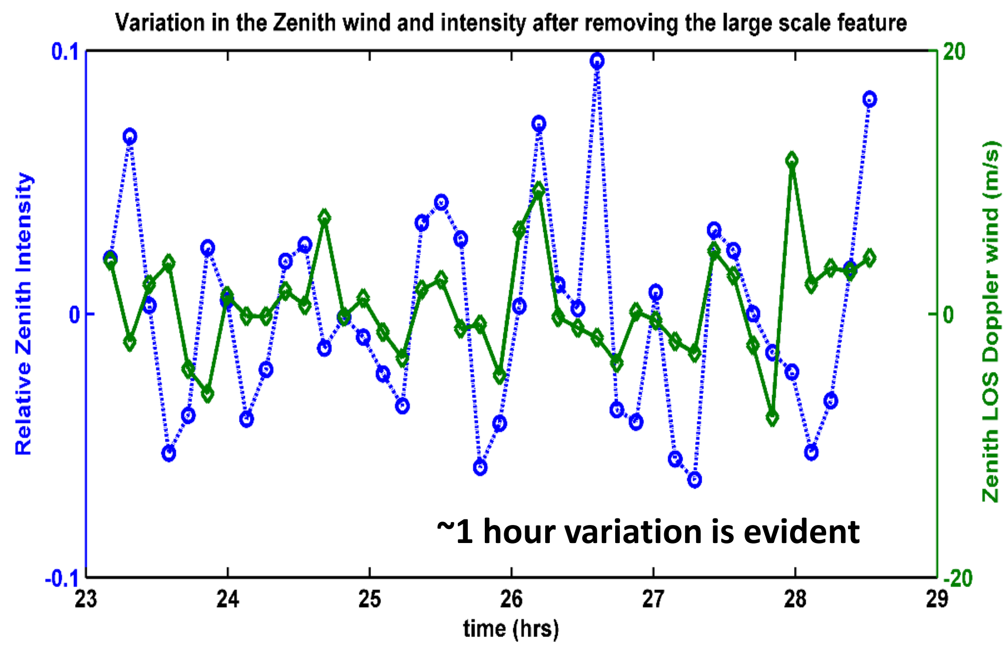
- ~3.5 hour variation is evident
- ~1 hour variation is also observed
- Spatial scale of these variations is larger than the viewing region (~50 km)

Vertical winds and Intensities

Longer period variation

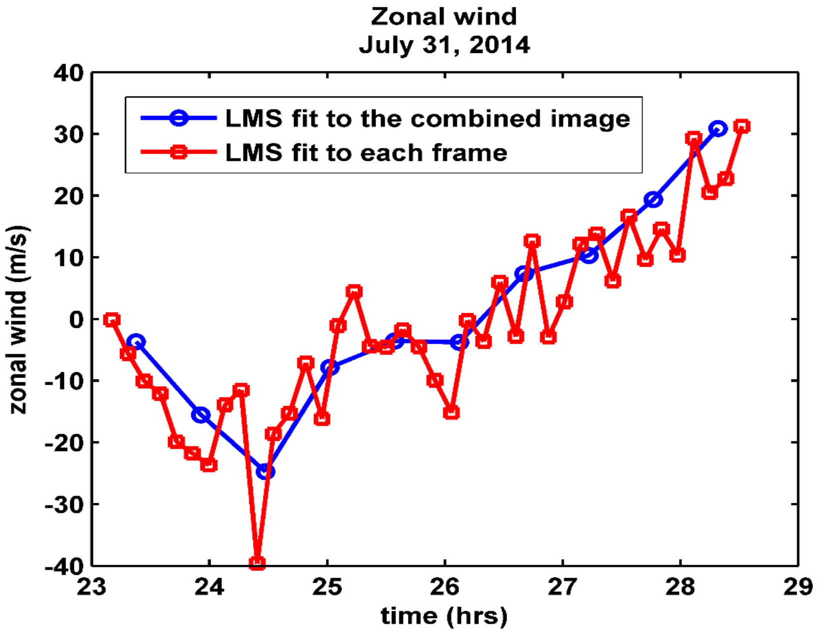


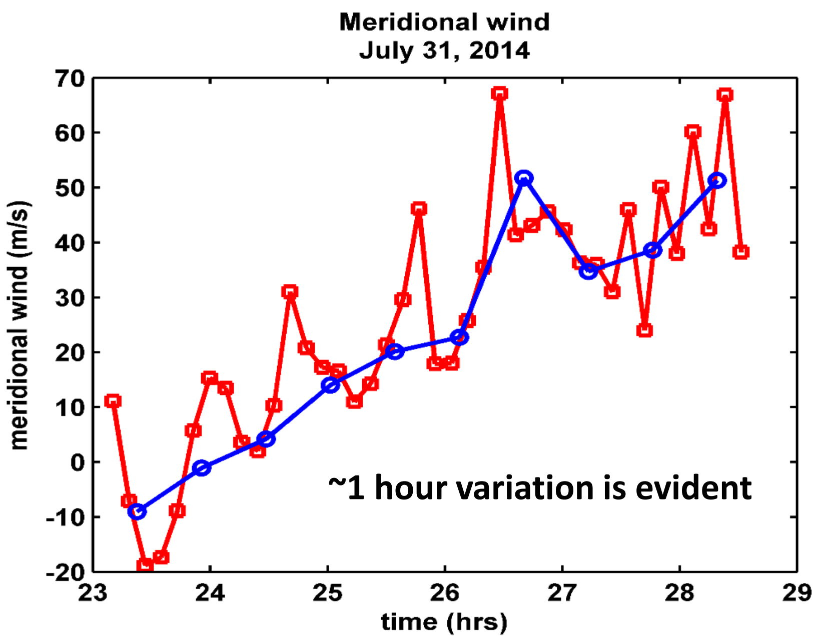
Shorter period variations

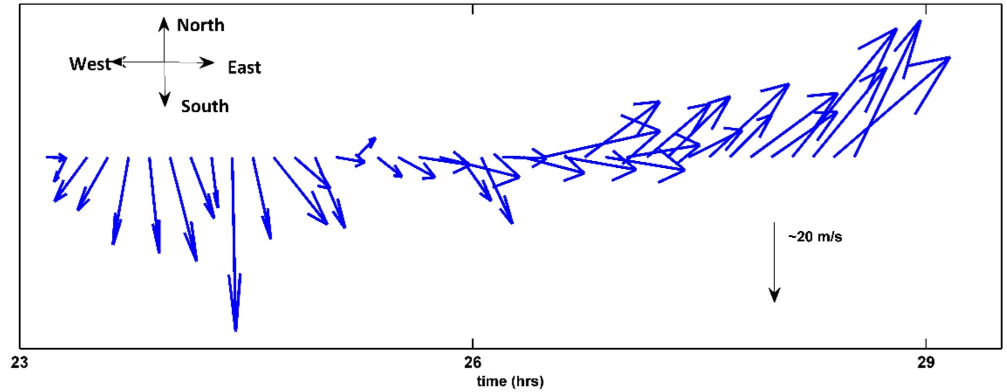


- **Intensity variations correlate with the LOS vertical winds**
- **Variations are indicative of the presence of gravity waves and convection**

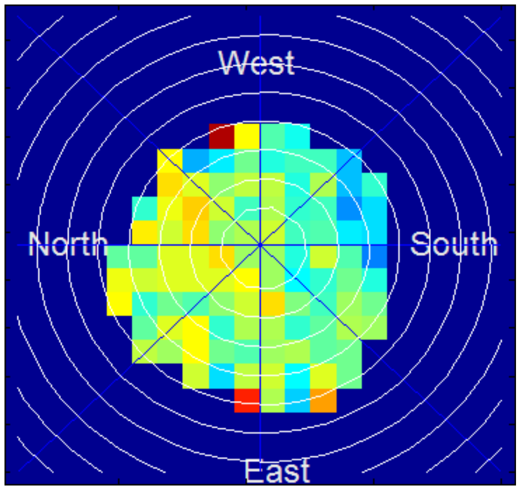
Field averaged horizontal wind







Large scale variation is consistent with a 6 hour "window" of a semi-diurnal tide



HRDI and Fort Collins

Expected	u	v
A(m/s)	20-30 (~20)	20-30 (~30)
Phase (hrs)	7-8 (6-7)	4-5 (3-4)

MIADI

Measured	u	v
A(m/s)	20-30	35-45
Phase (hrs)	6	4

Summary

- MIADI has been fully validated
- First images of LOS winds in mesospheric airglow have been obtained
- Precision and spatial and temporal resolution is suitable to diagnose the presence of gravity waves.
- Variation in the field averaged horizontal wind is consistent with a semi-diurnal tide
- Smaller scale variability (5-10 m/s) is observed that is indicative of the presence of gravity waves or convective processes
- More work is required to extract gravity waves parameters and interpret the smaller scale variability in the images

THANK YOU !!

Acknowledgements

1) William Ward (Supervisor, UNB)
2) Alan Scott (COM DEV Ltd)
3) Bill Gault (DB Reflections Associates)
4) Ian Miller (Light Machinery Ltd)
5) Takuji Nakumura- (NIPR)

This work has been funded by the Canadian Foundation for Innovation (CFI), the Canadian Space Agency (CSA), NSERC IPS, and the CREATE trainee program