Multipoint Thermospheric Wind Observations: Networks of Fabry-Perot Interferometers and Plans for ICON

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- Daniel Fisher
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- ICON Team
- NATION Team

ECE ILLINOIS

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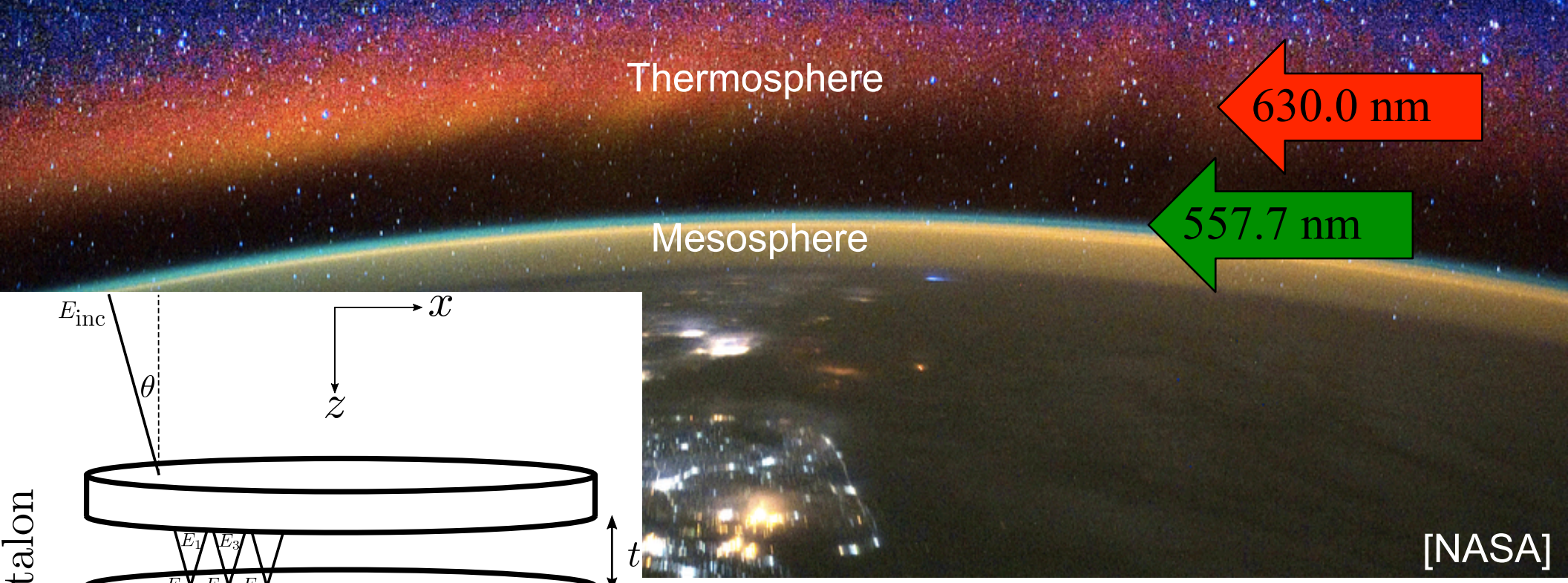
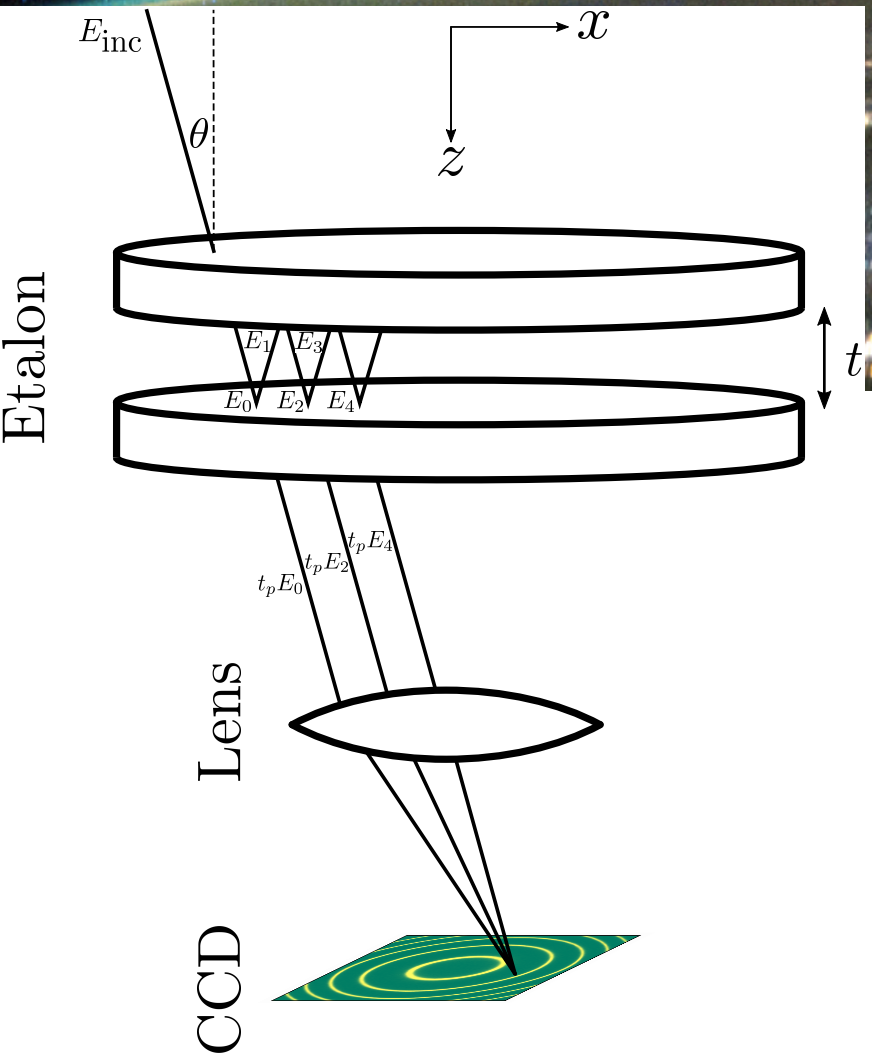
Outline

- Networks of ground-based wind instruments
- Midnight temperature maximum
  - Direct evidence of converging wind field
  - Propagation to midlatitudes
- ICON wind measurements

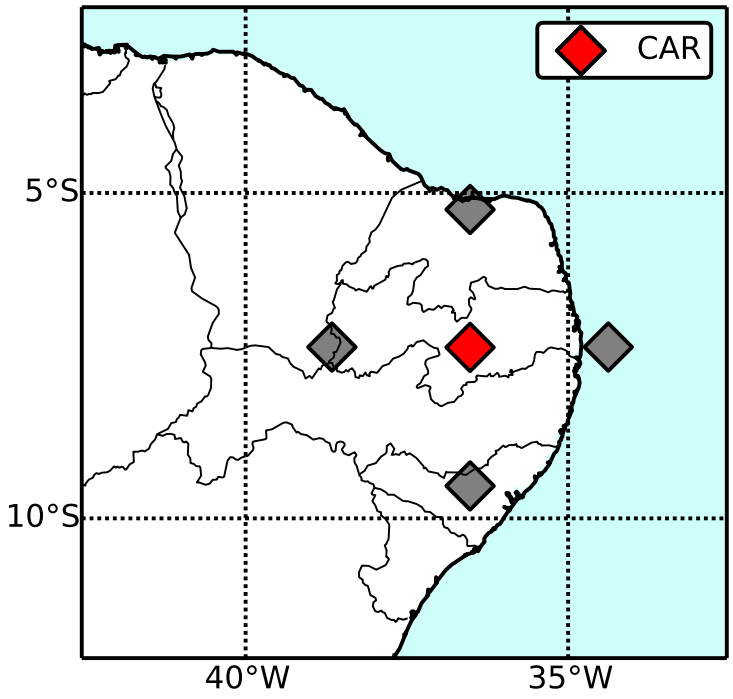


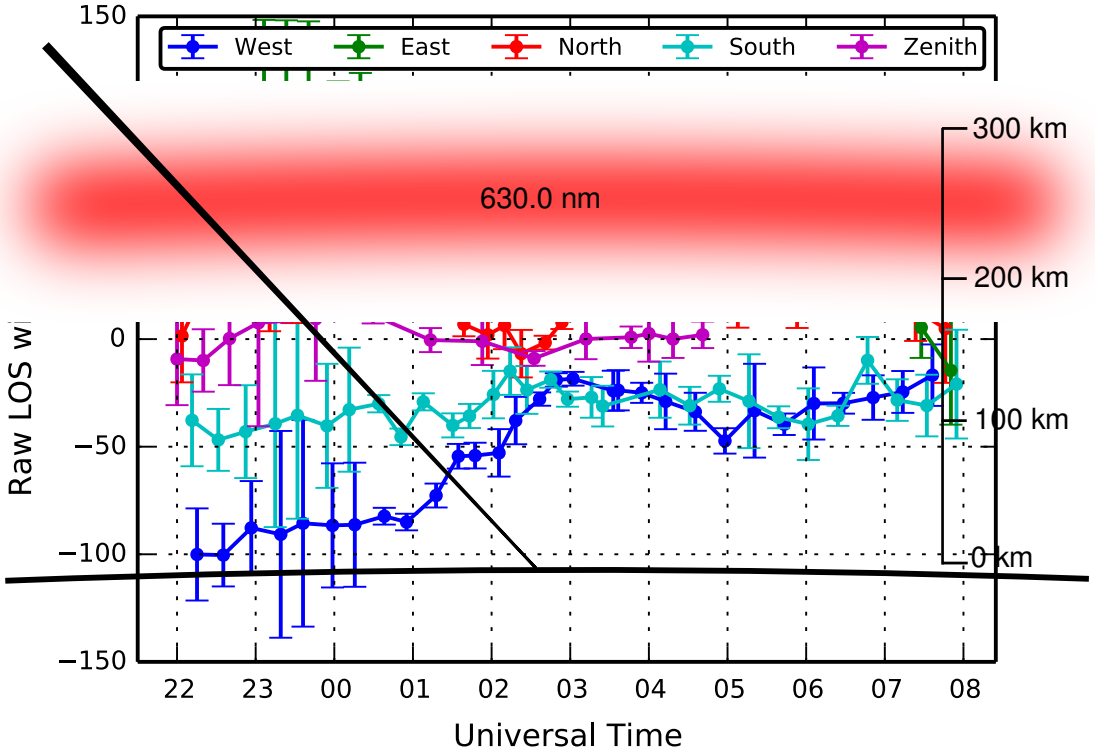


Doppler shift → Wind

Doppler width → Temperature

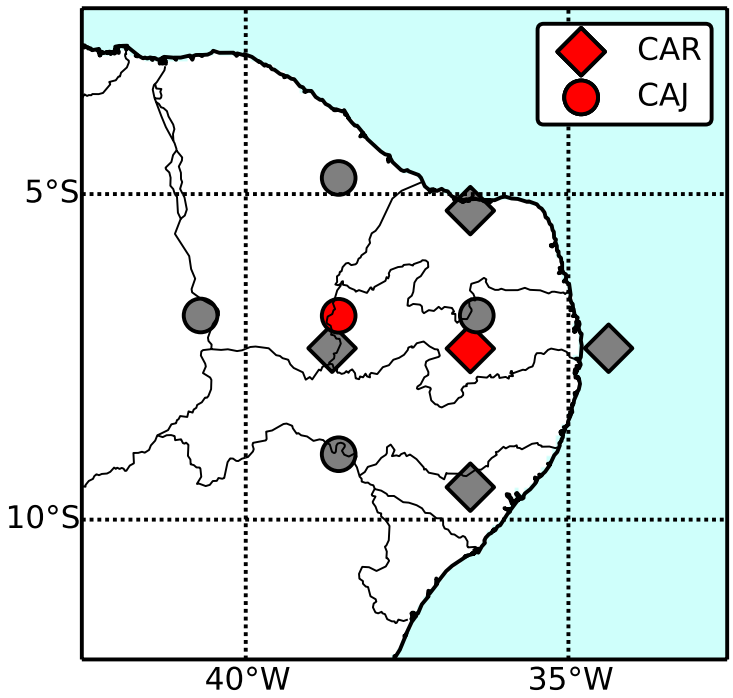
A single Fabry-Perot interferometer (FPI)



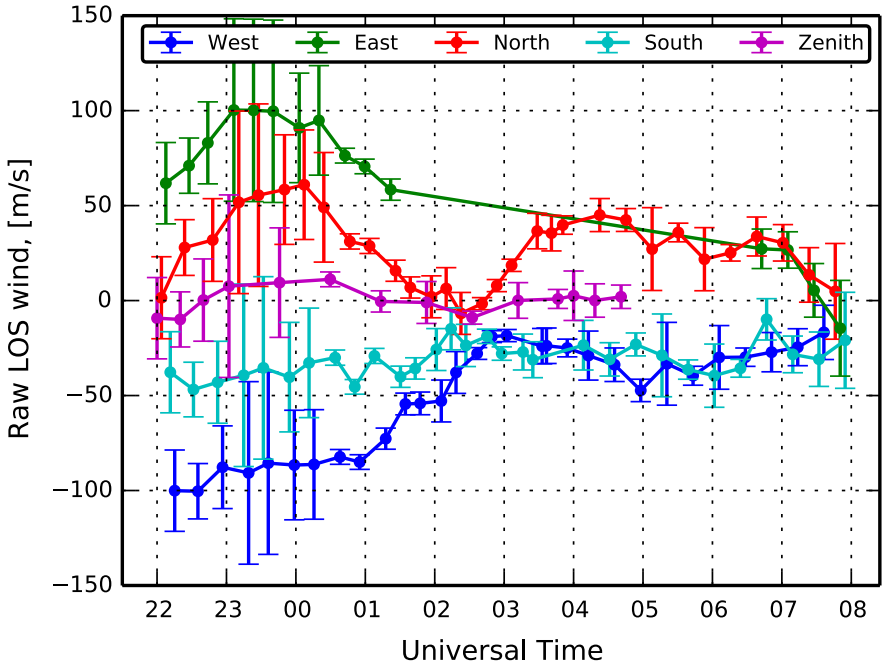


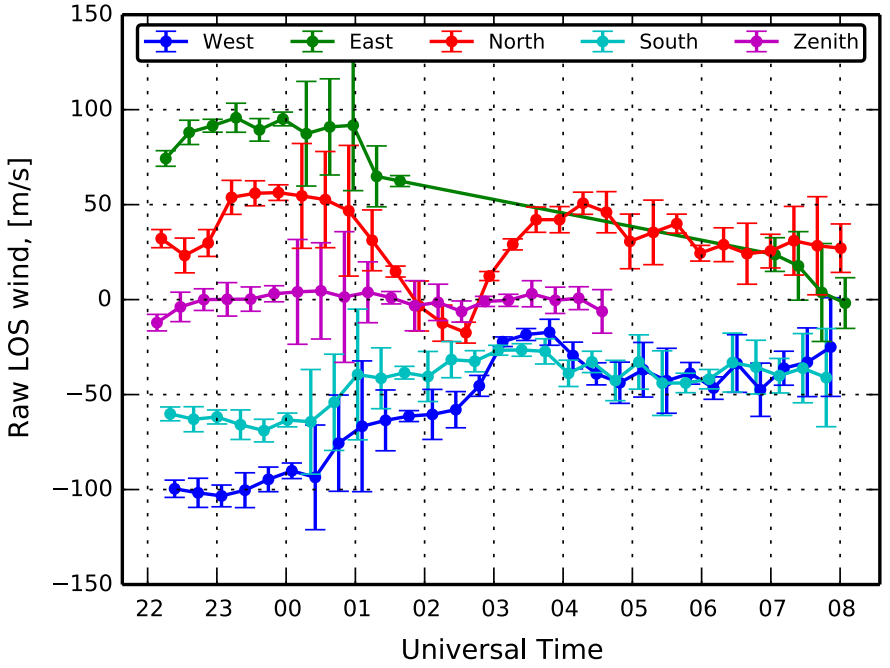
Estimate temporal evolution of the wind over a small (~500km) region.

A network of FPIs

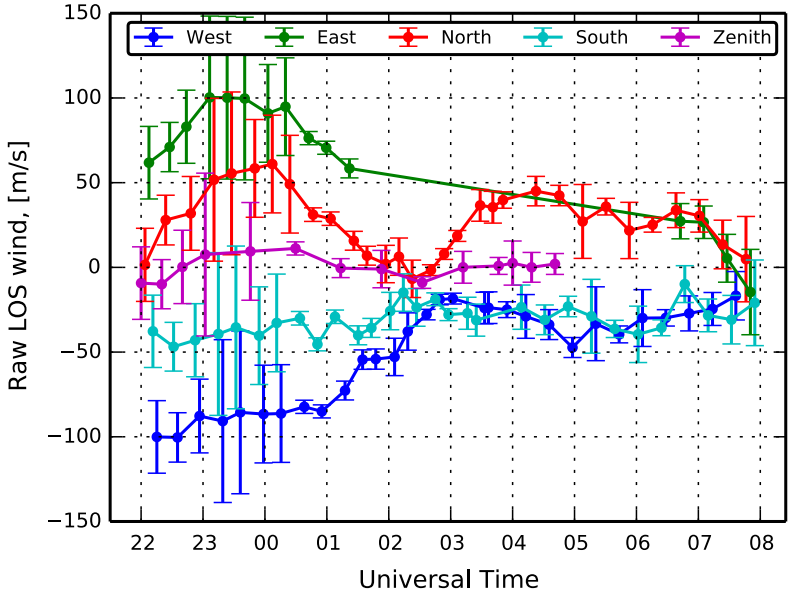


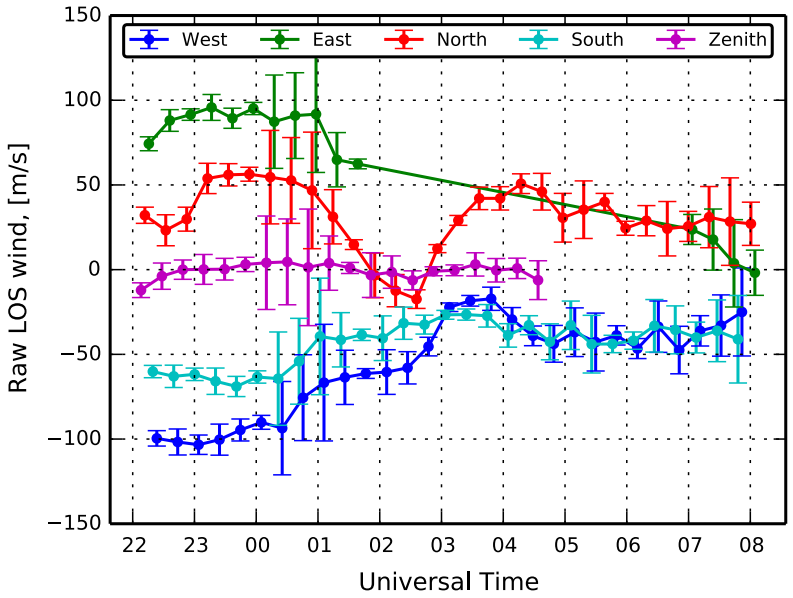
Observe temporal **and spatial** distributions



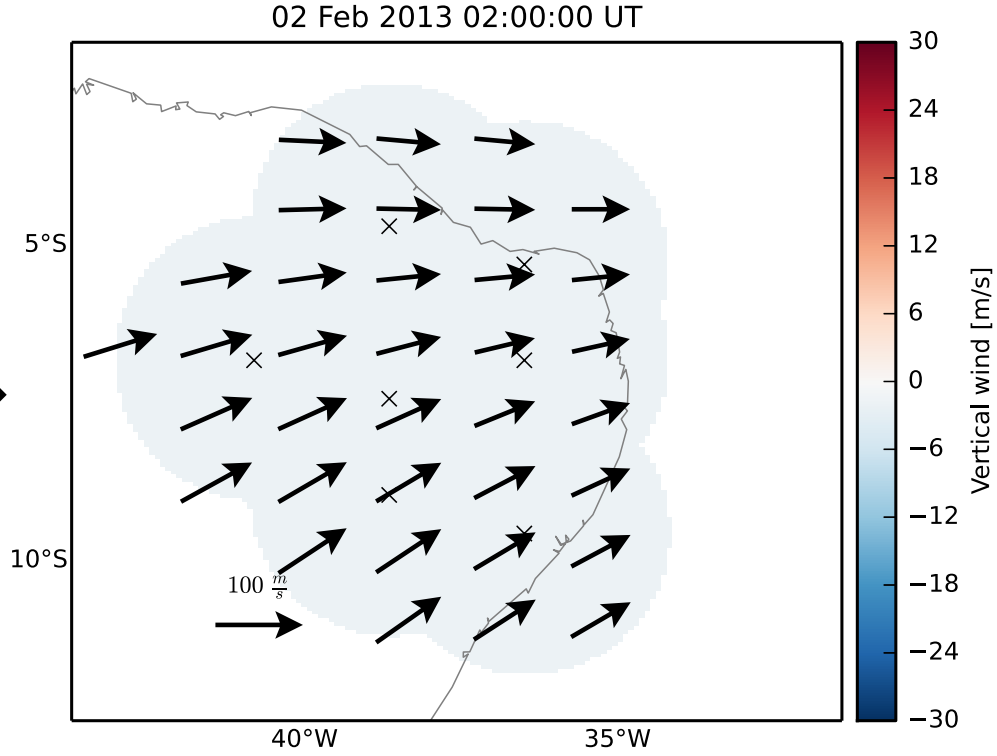


Wind Field Estimation





?



Wind Field Estimation

Unknowns: Zonal wind, Meridional wind, Vertical wind

$$m_i = u_i \sin\theta\cos\phi + v_i \sin\theta\sin\phi + w_i \cos\theta \qquad \bar{m} = A\bar{u}$$

Knowns: m_i: Measured LoS velocity; ϕ: Azimuth angle; θ: Zenith angle

$$\text{minimize} \quad \|D\bar{u}\|_2$$

Matrix operator measures "roughness" via gradient and curvature

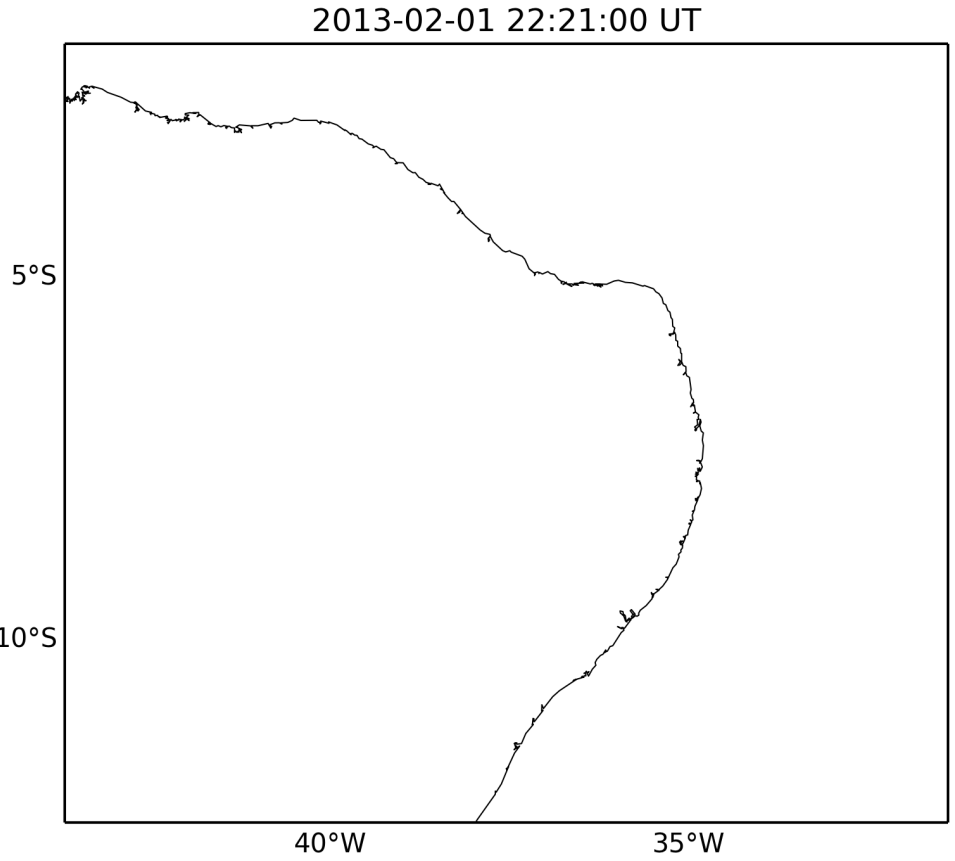
$$\text{such that} \quad \|\Sigma^{-\frac{1}{2}}(A\bar{u} - \bar{m})\|_2 \leq M$$

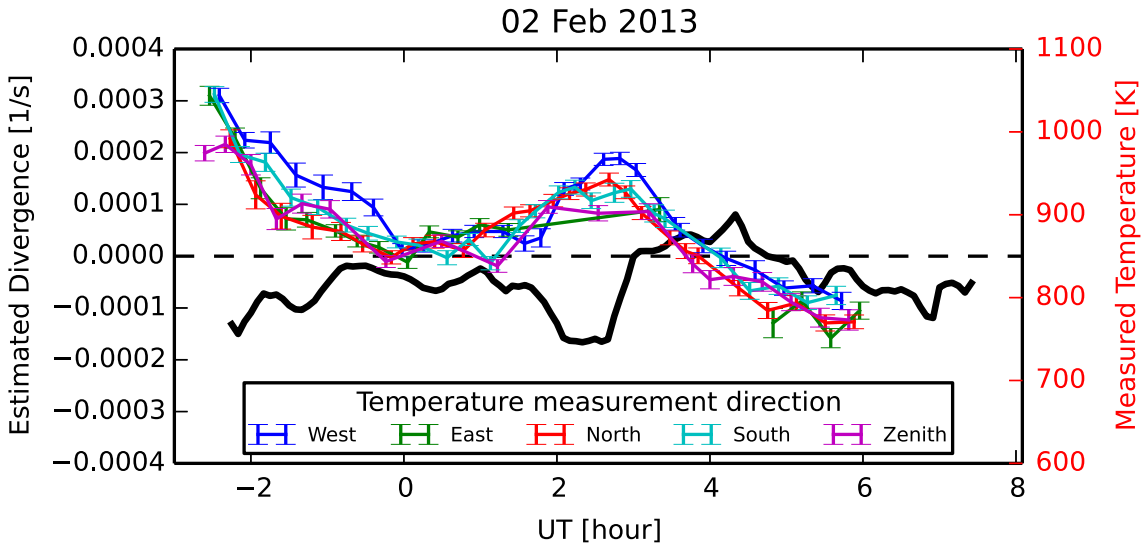
$\Sigma^{-\frac{1}{2}}$: Weight matrix incorporates measurement uncertainty

M: Number of measurements

Of all wind fields that match the data, choose the smoothest.

Midnight Temperature Maximum



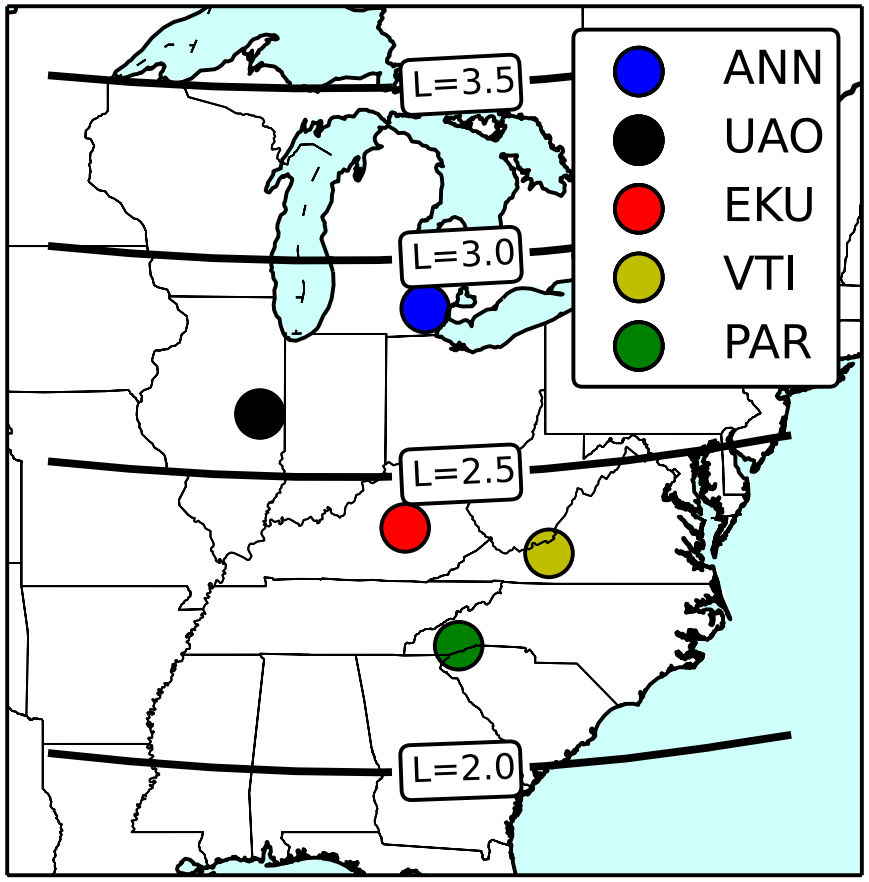


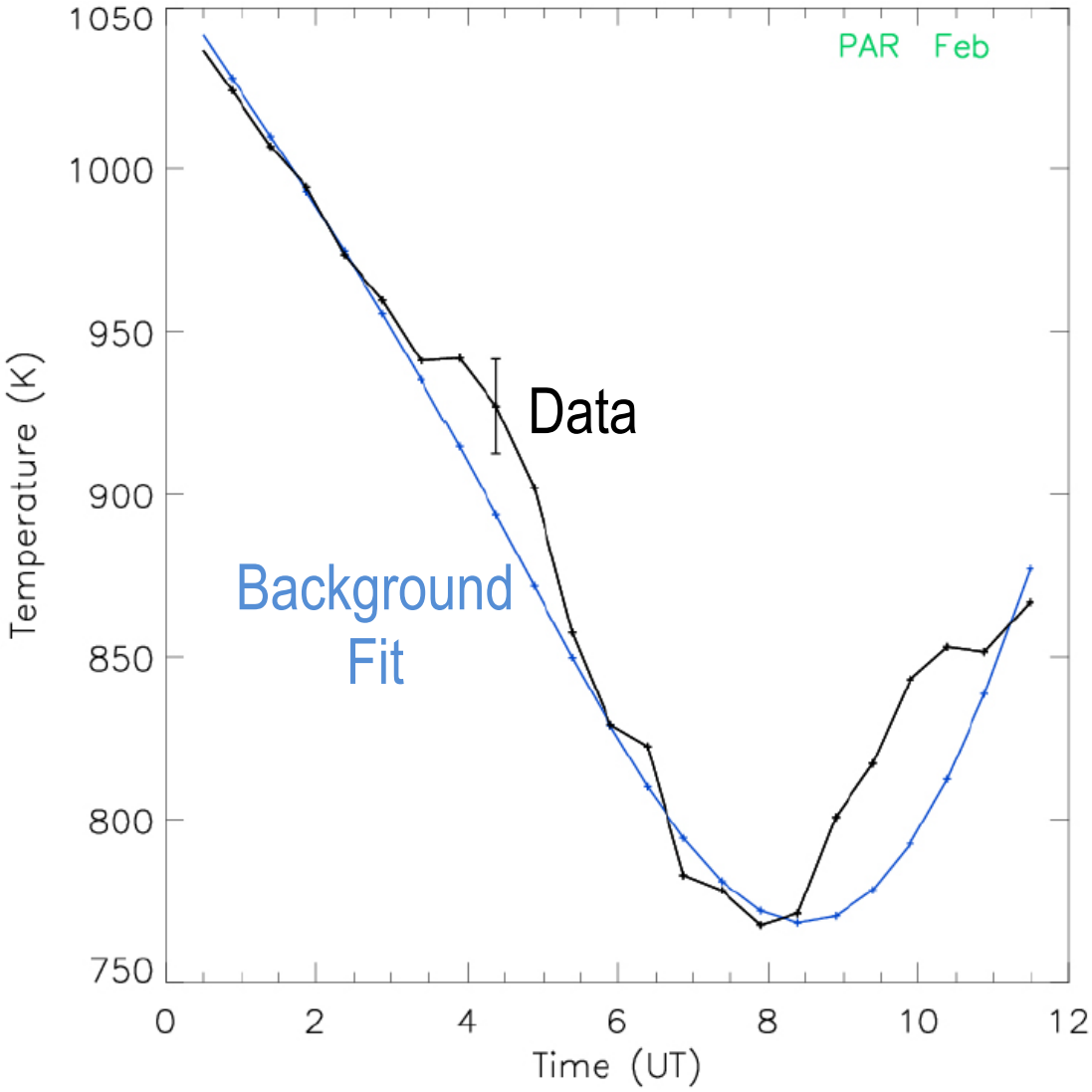
3 UT = 0 LT

Direct evidence of convergent wind field during MTM

Midnight temperature maximum… at midlatitudes?

NATION: North American Thermosphere Ionosphere Observing Network

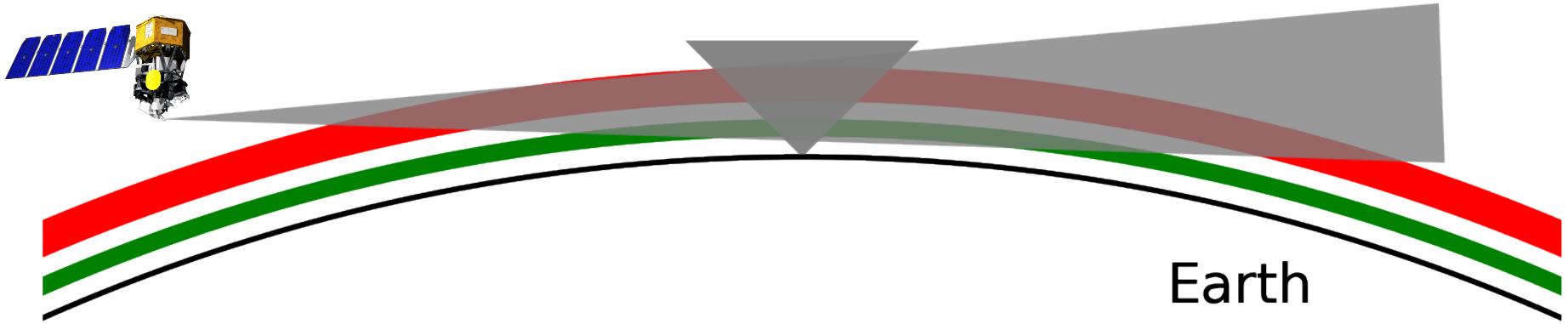




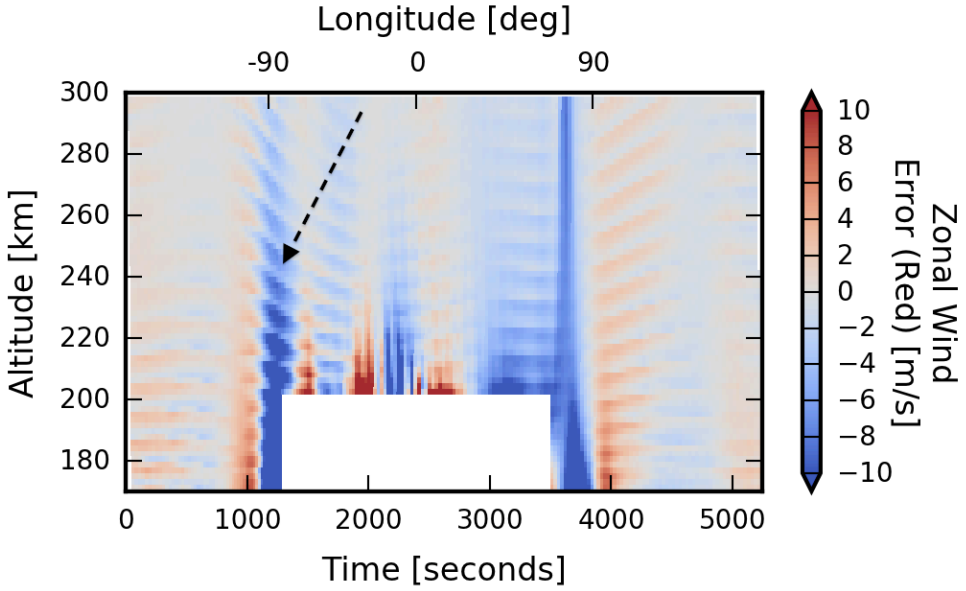
[R. Mesquita]

Midnight temperature maximum… at midlatitudes?

- Direct observation of winds, propagation
- Consistent with timing reported by *Hickey et al.* [2014] (ion and neutral temperatures)
- Propagation to 45°N



- MIGHTI is ICON's wind instrument
- System simulations suggest:
  - Expected Precision: **1-4 m/s** (1σ)
    - At 5x500km (Vert x Horz) res (Red 30x500)
  - Systematic Error: **3-6 m/s** (80th prctile)



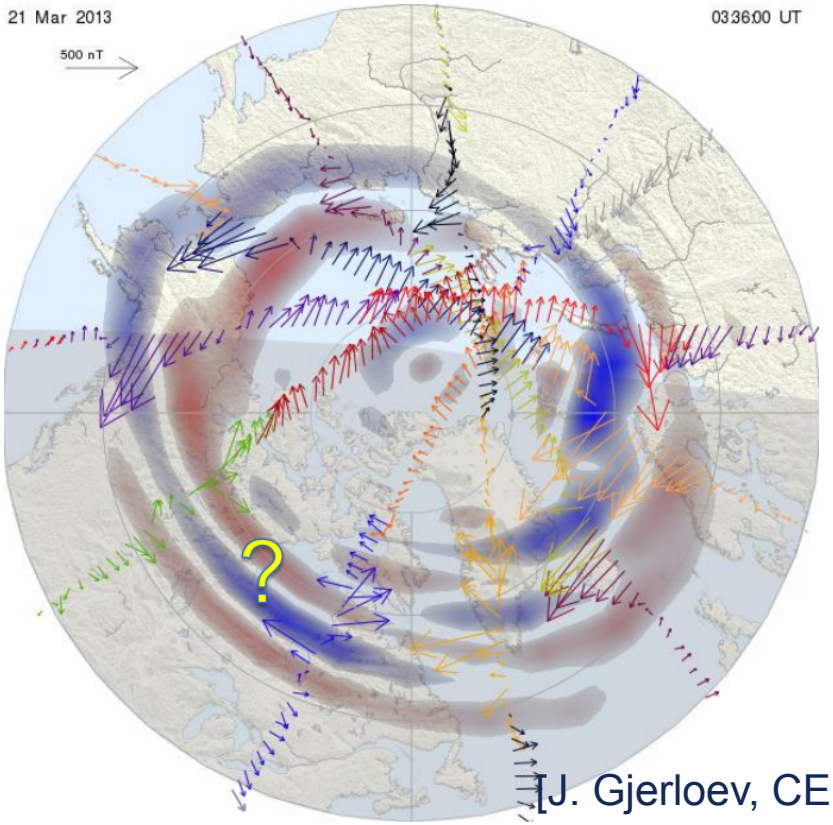
Bias

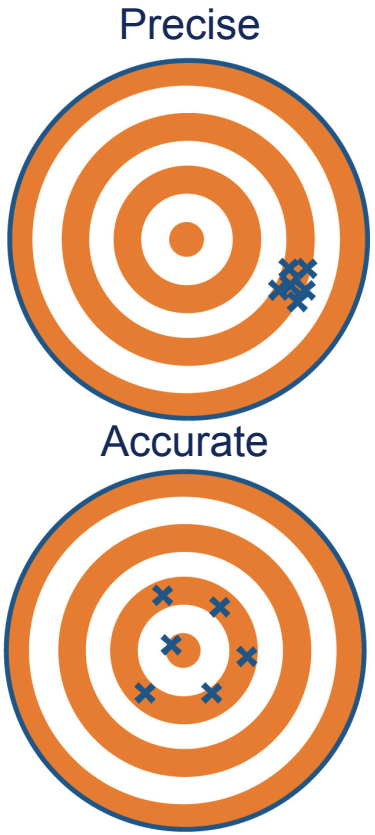
- Error
  - 2nd moment: precision, statistical uncertainty
  - 1st moment: accuracy, bias
- Data providers rarely report 1st moment
  - Important for assimilation and data fusion
- Geophysical data often have a bias towards "smoothness"
- Can quantify with resolution matrix:

$$\text{if} \quad y = Ax + n$$

$$\text{and} \quad x^* = A^p y$$

$$\text{then} \quad R = A^p A$$





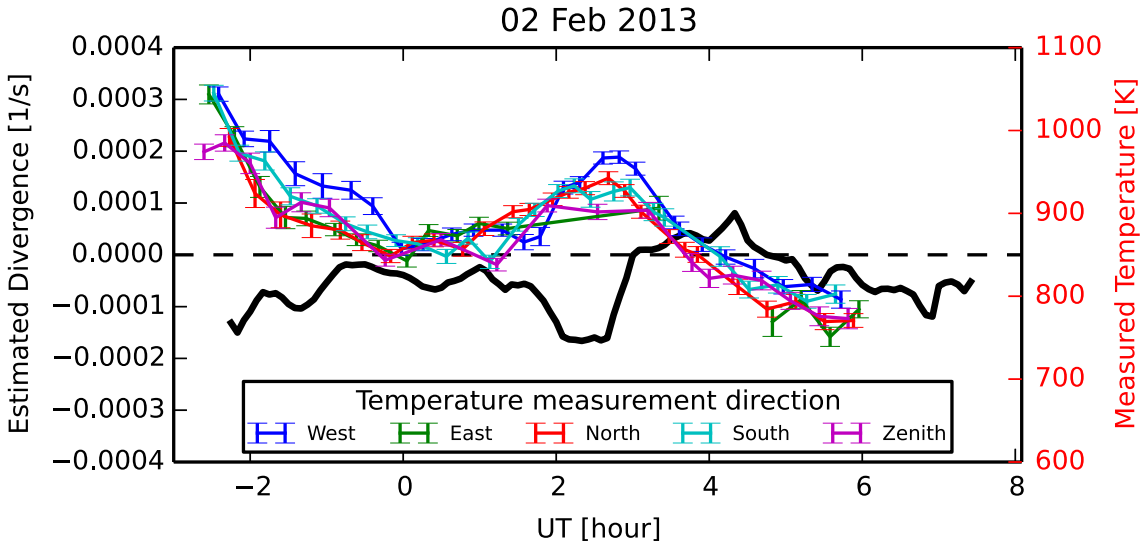
[J. Gjerloev, CEDAR Prize Lecture 2016]

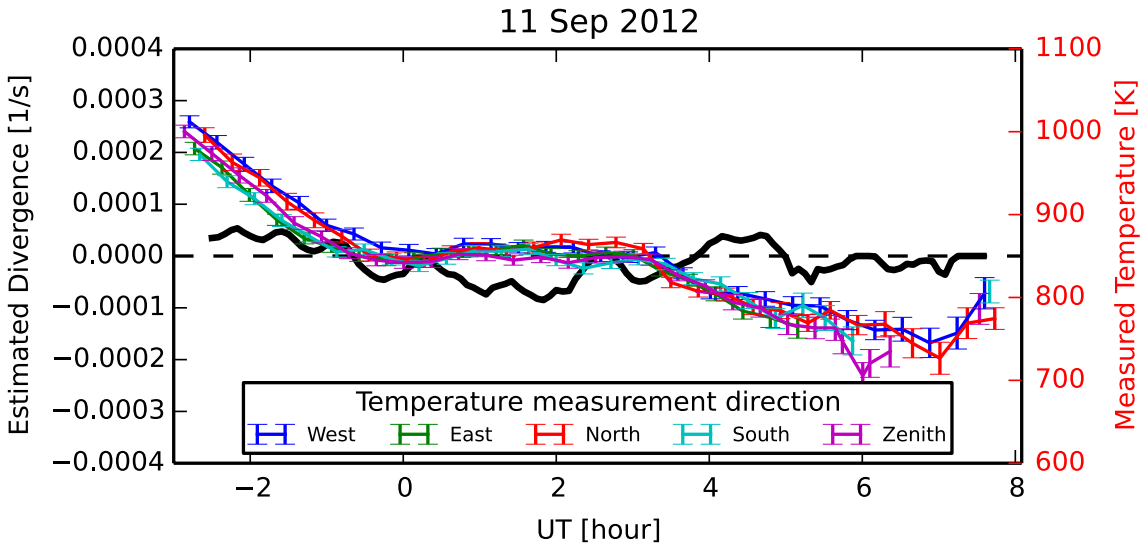
Conclusions

- Networks of FPIs allow us to see spatial structure, revealed by statistical estimation techniques
  - Direct evidence of converging wind field during MTM
  - Extension up to midlatitudes
- ICON/MIGHTI will provide global coverage
- Bias is just as important as uncertainty, especially for disparate data sets

Backup Slides

Application 1: Midnight Temperature Maximum

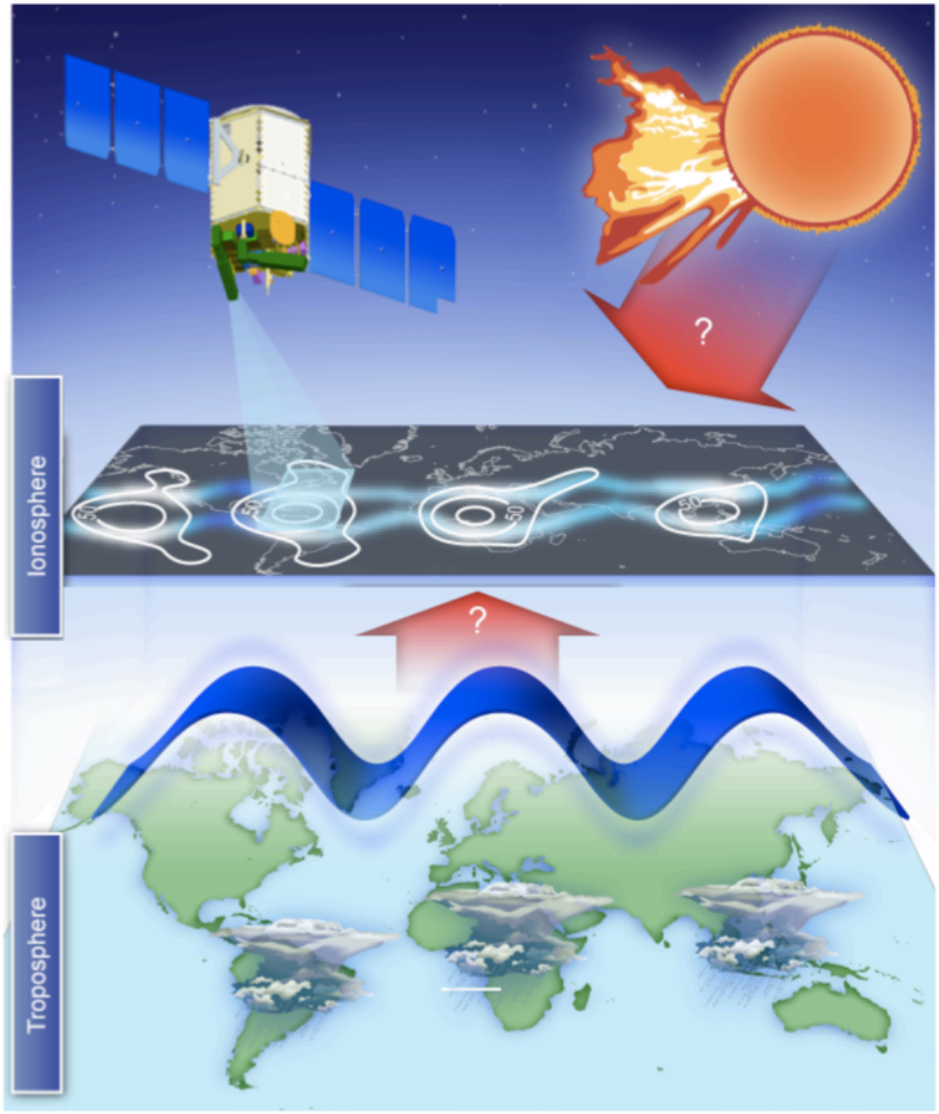




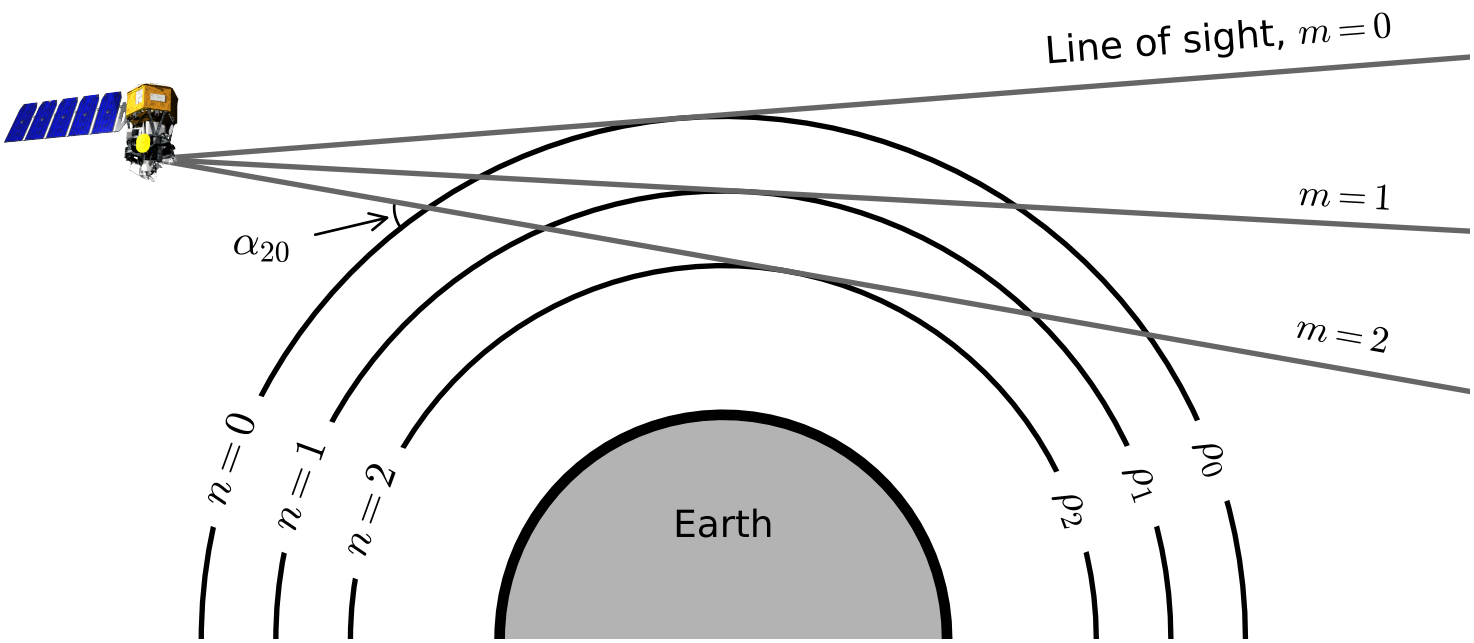
- Significant variability in amplitude of MTM
- Thought to be related to terdiurnal tide

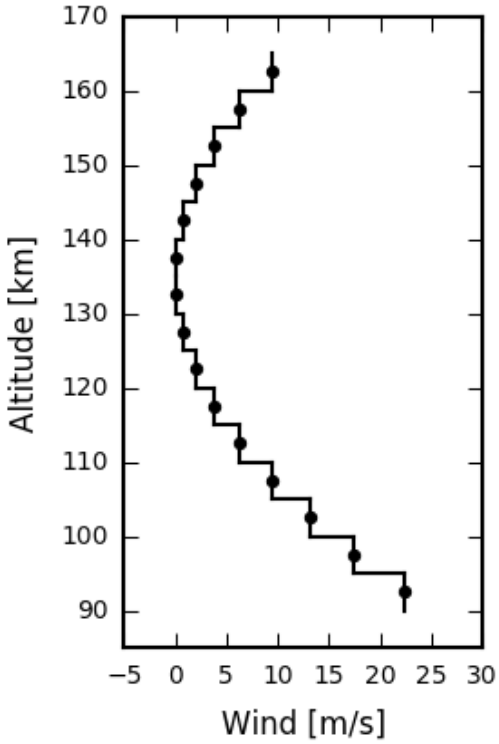
ICON Mission Goal

- Identify drivers of extreme ionospheric variability
  - Cause of structure at low latitudes during quiet times
  - Coupling processes with large-scale atmospheric waves
  - Competition of these internal drivers with external drivers during geomagnetic storms



Problem: Scrambled spectra from different altitudes



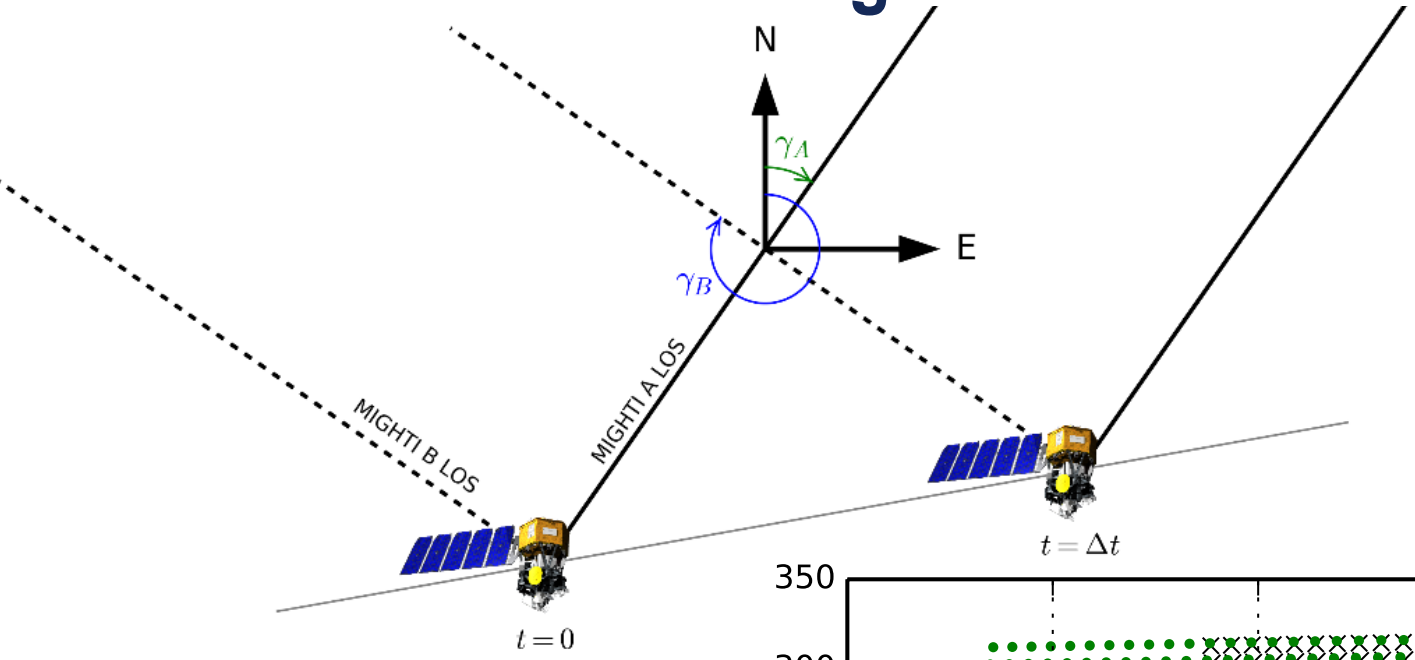


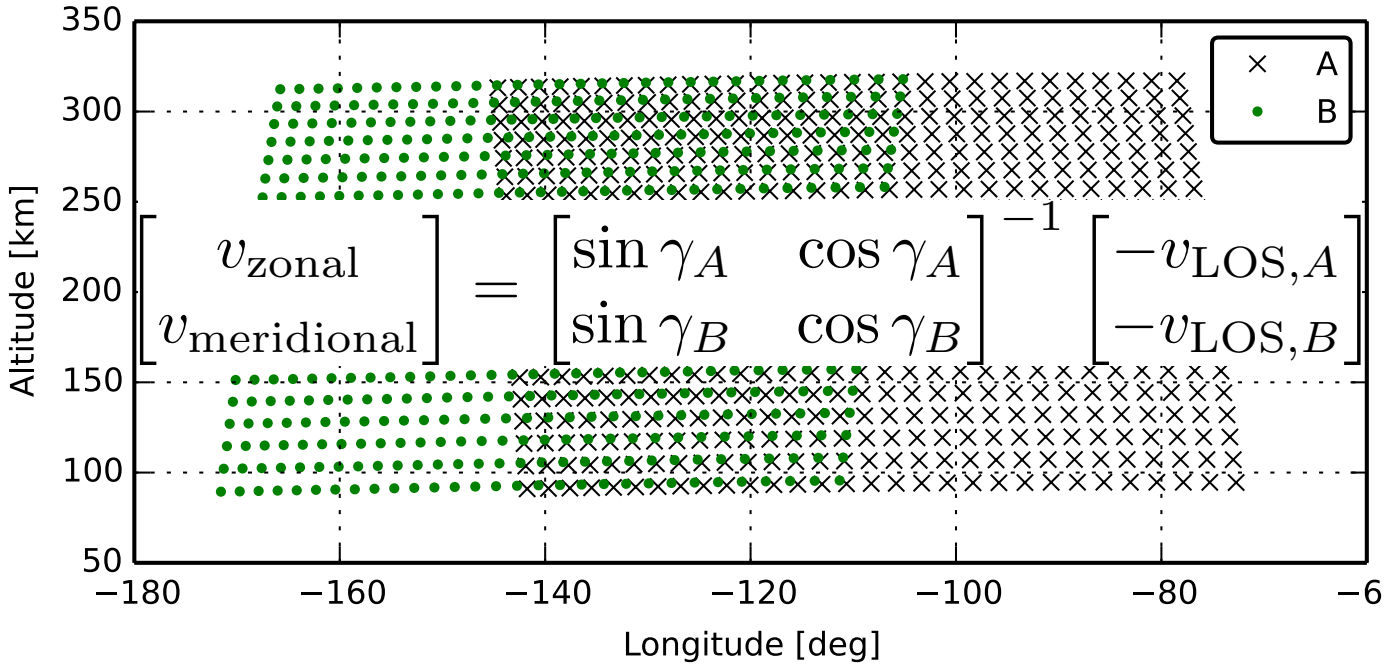
Solution: Abel-like inversion

Assume spherical symmetry and piecewise constant altitude dependence

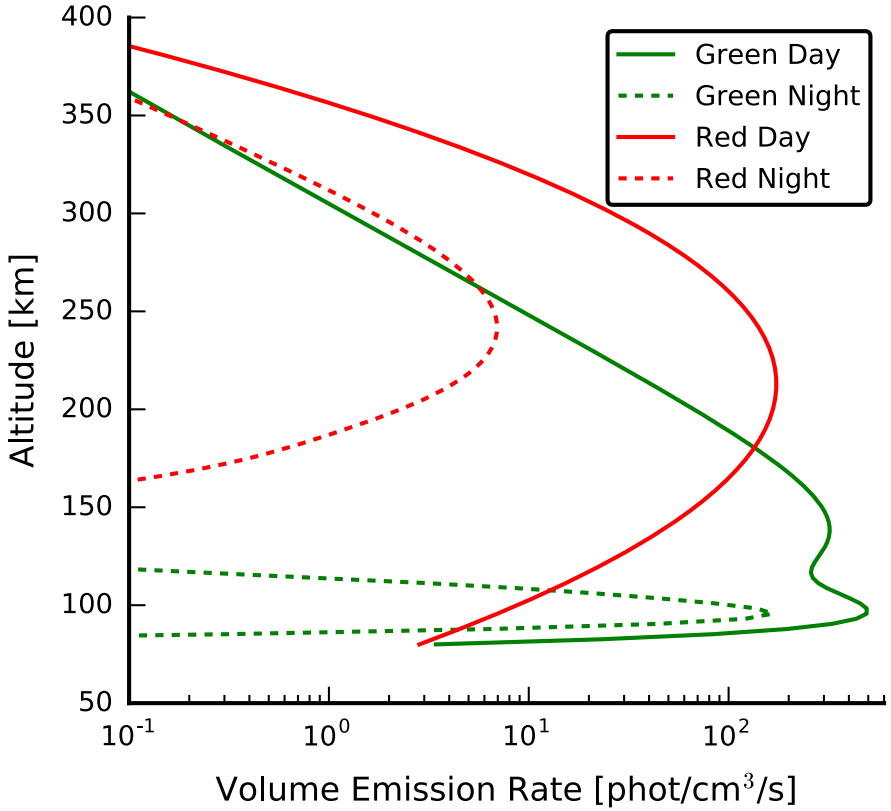
$$g = \int_0^\infty f(r)\,ds \longrightarrow g = \sum_{n=0}^{N-1} f_n\,\Delta s_n \longrightarrow \mathbf{g} = \mathrm{Sf}$$

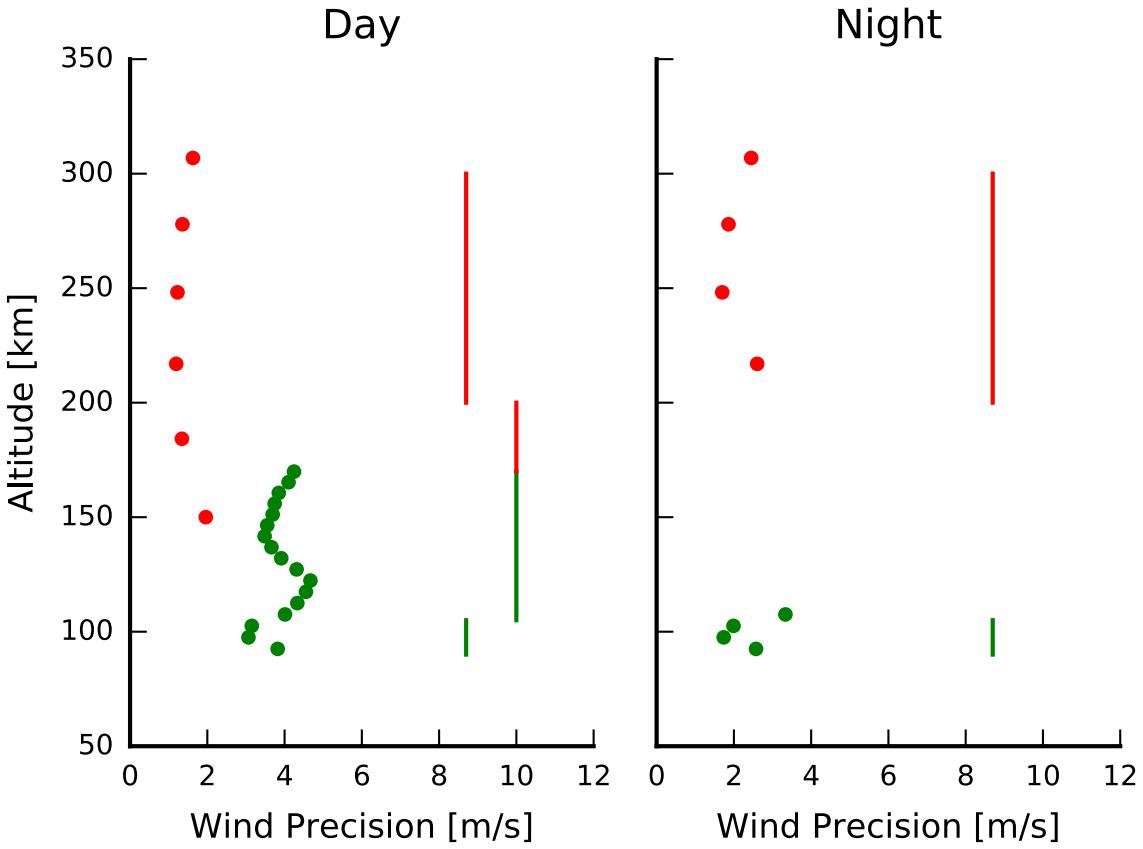
Problem: Only one component measured
Solution: Use two orthogonal sensors



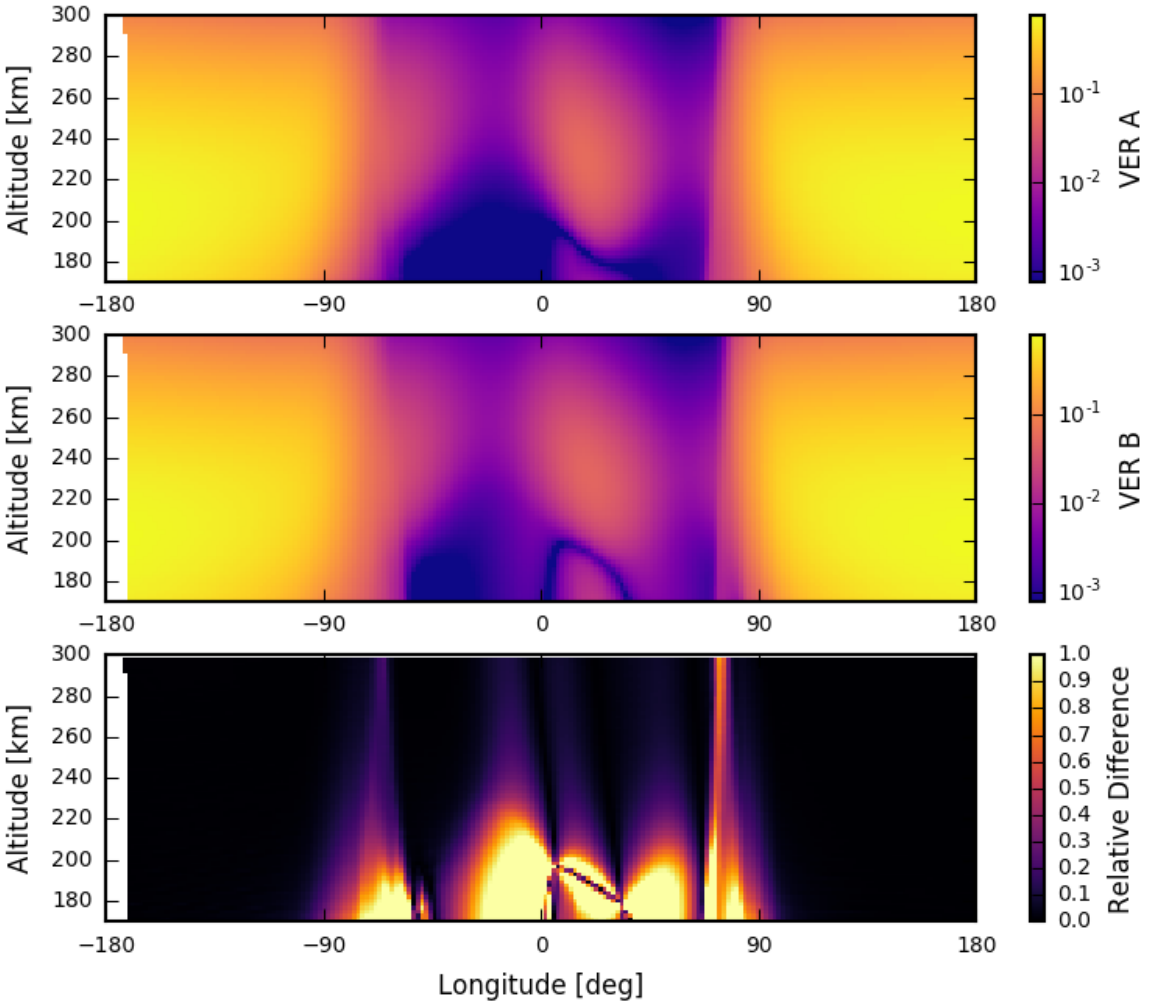


Expected Precision

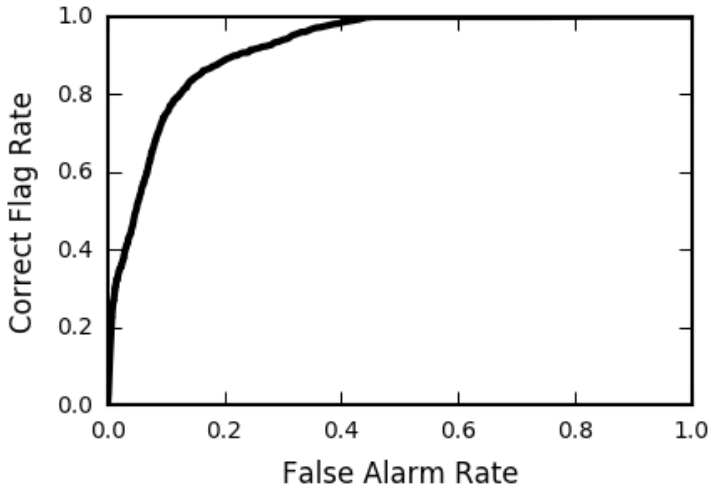


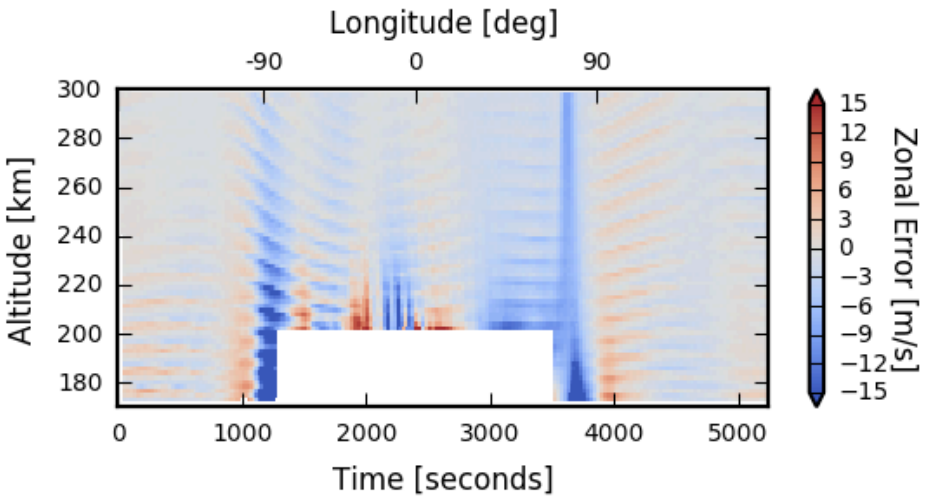


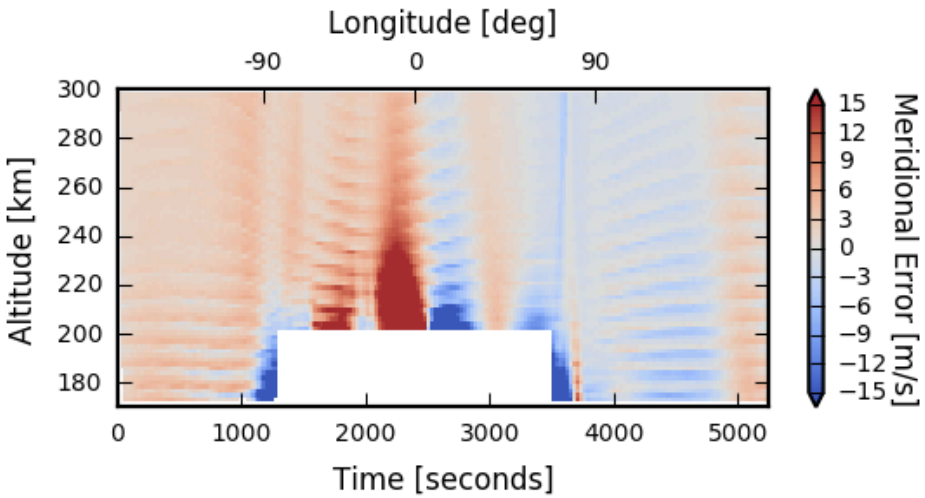
Spherical Asymmetry Flag – Red

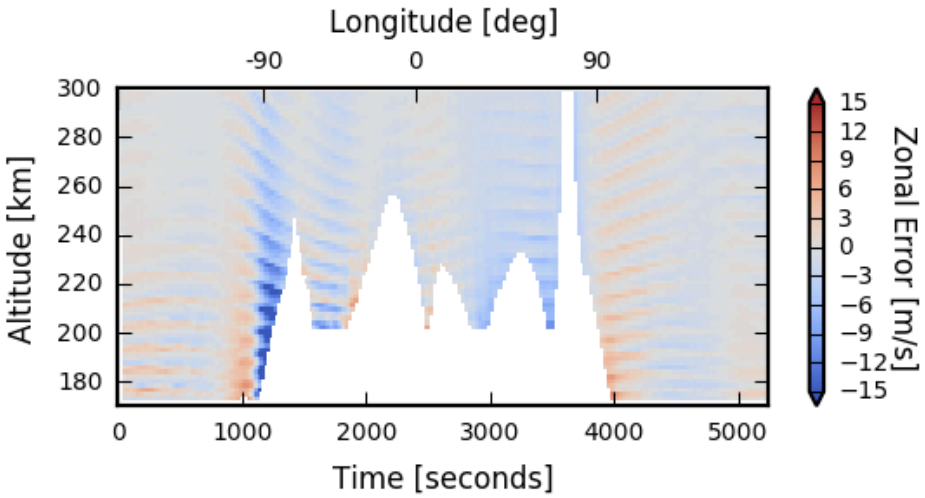


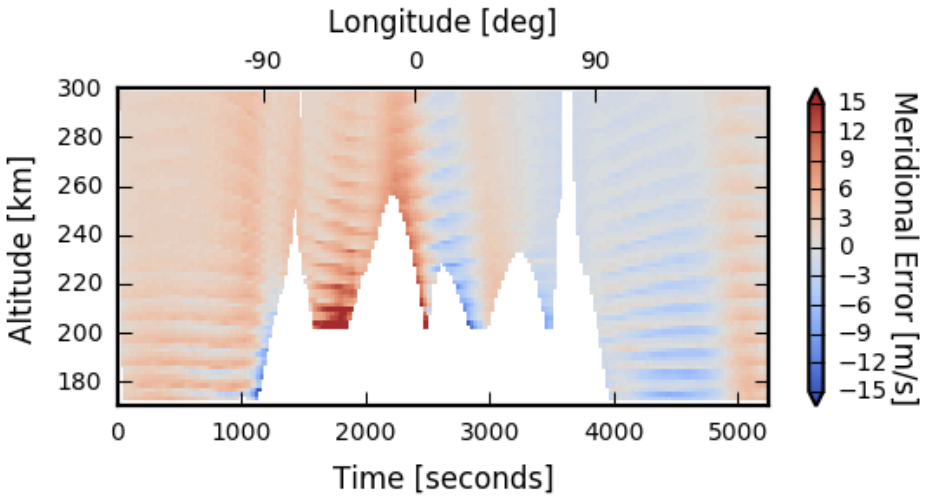
- Compare VER estimates from A and B
- Use threshold to flag expected errors in wind estimate





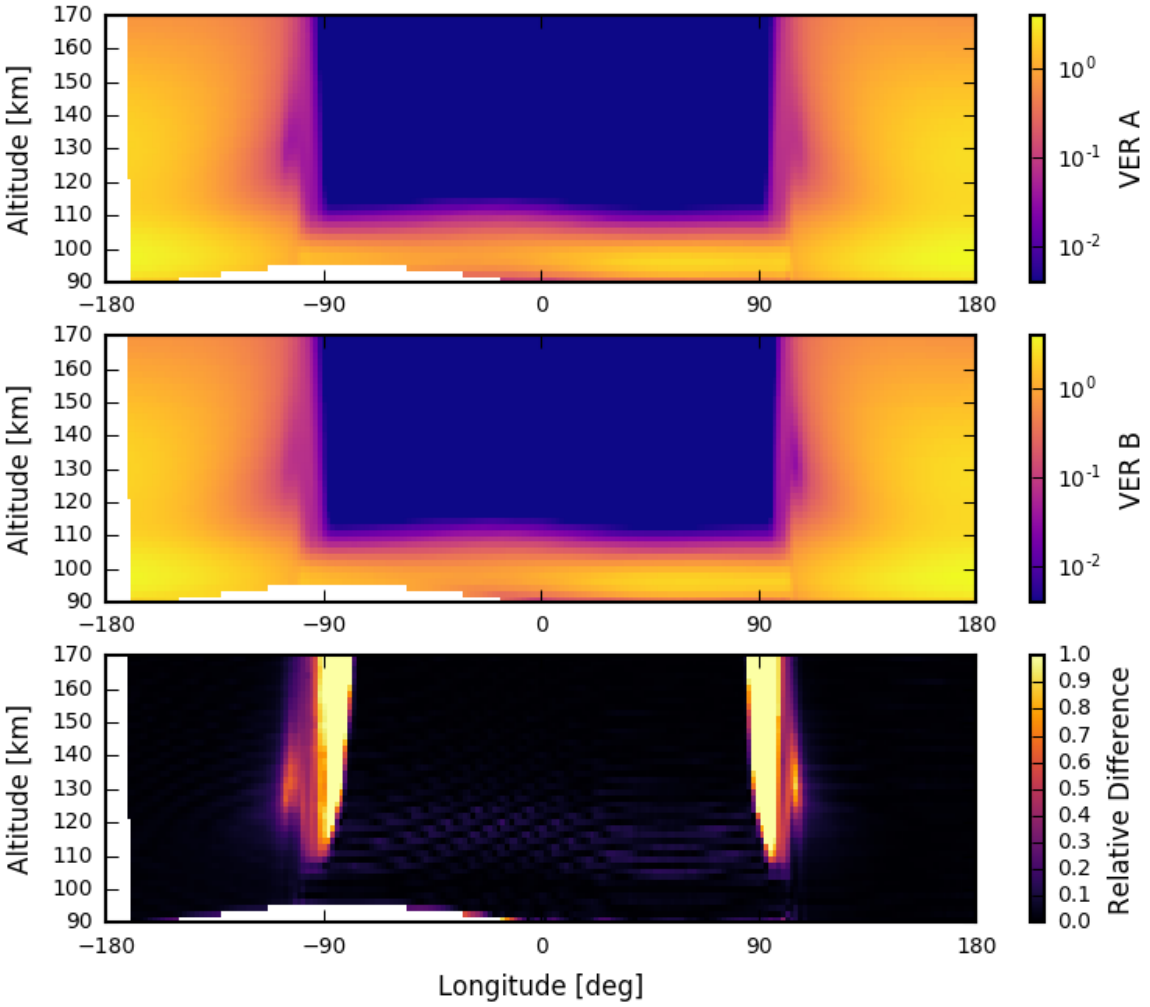






6.5 → 3.9 m/s rms error

Spherical Asymmetry Flag – Green



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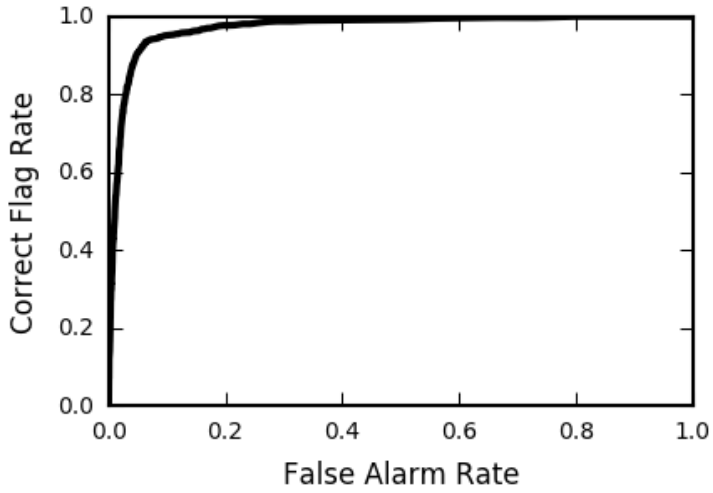

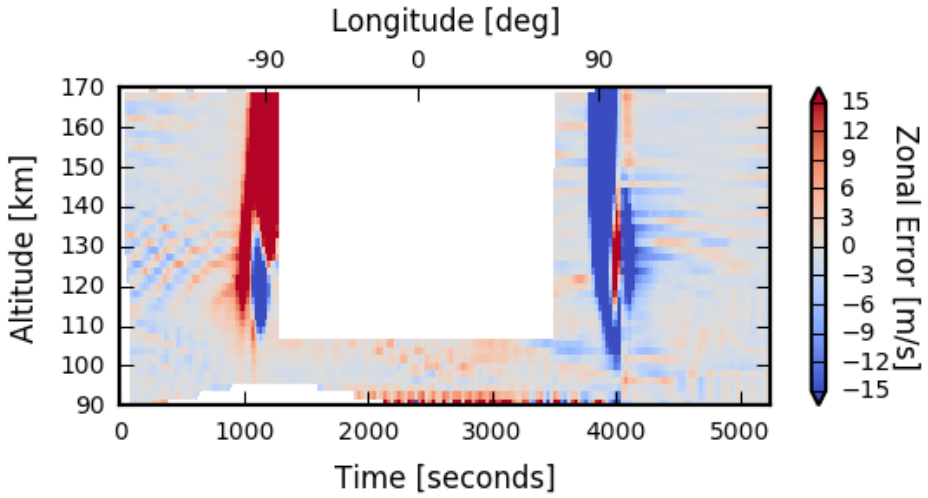

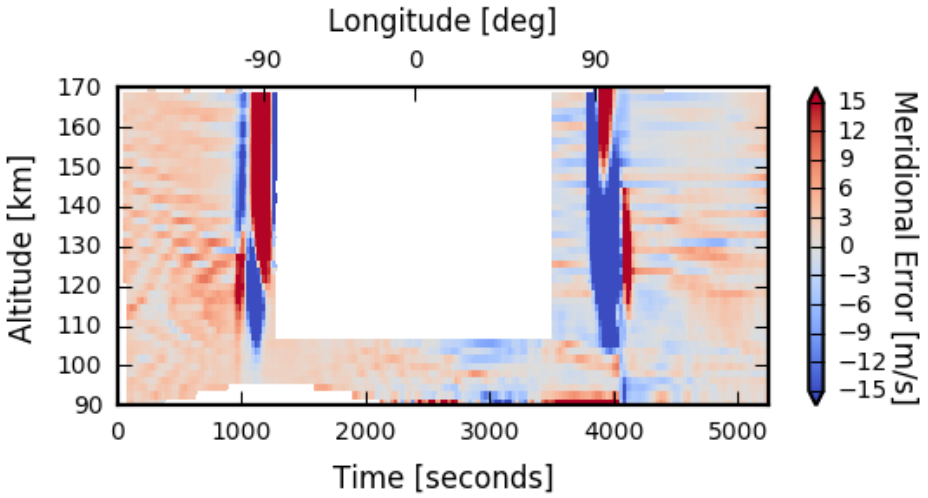

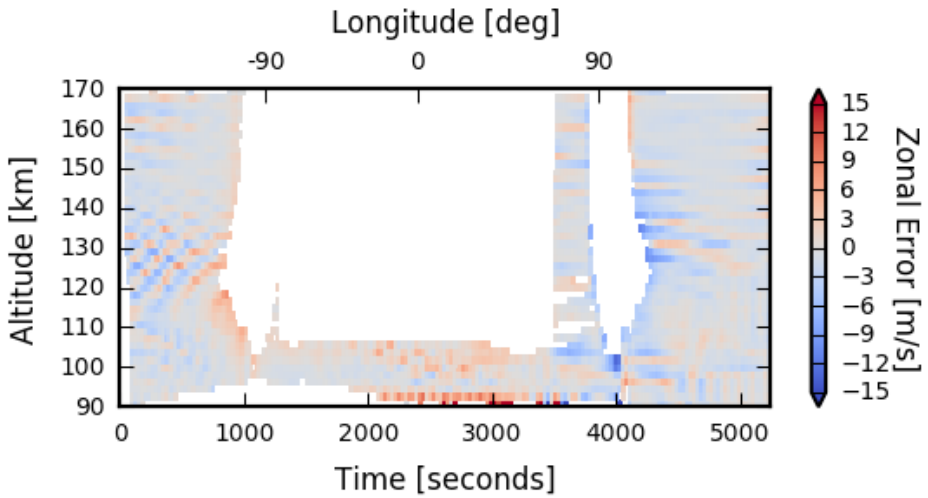

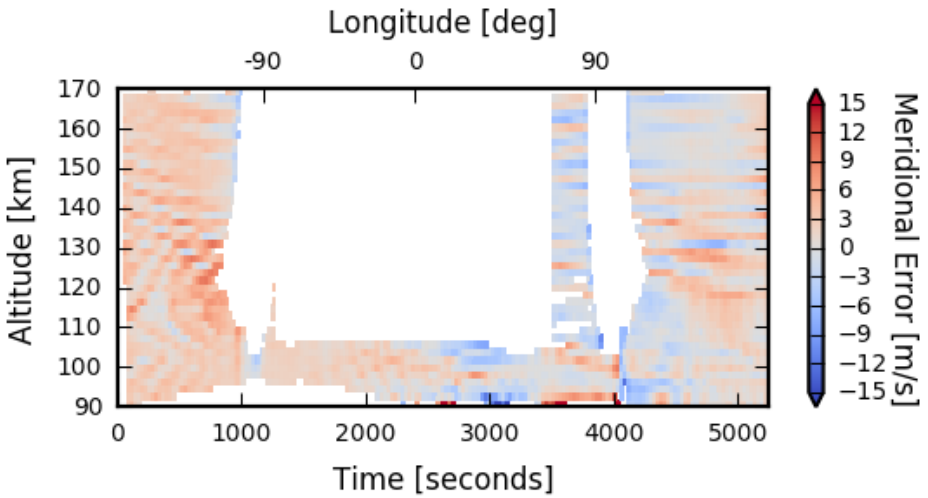

26.0 → 4.5 m/s rms error

Airglow above 300 km

- Assuming:
  - Constant wind & temp. above 300km
  - Exponential falloff in VER (H=26km)
- Effective path length in top layer:
- New algorithm works well for contrived cases
- Doesn't make a difference in our realistic end-to-end simulation

$$w_{m0}^{\text{above}} = \int_{\sqrt{r_0^2 - r_m^2}}^{\infty} e^{-\frac{1}{H}\left(\sqrt{x^2 + r_m^2} - r_0\right)} dx$$