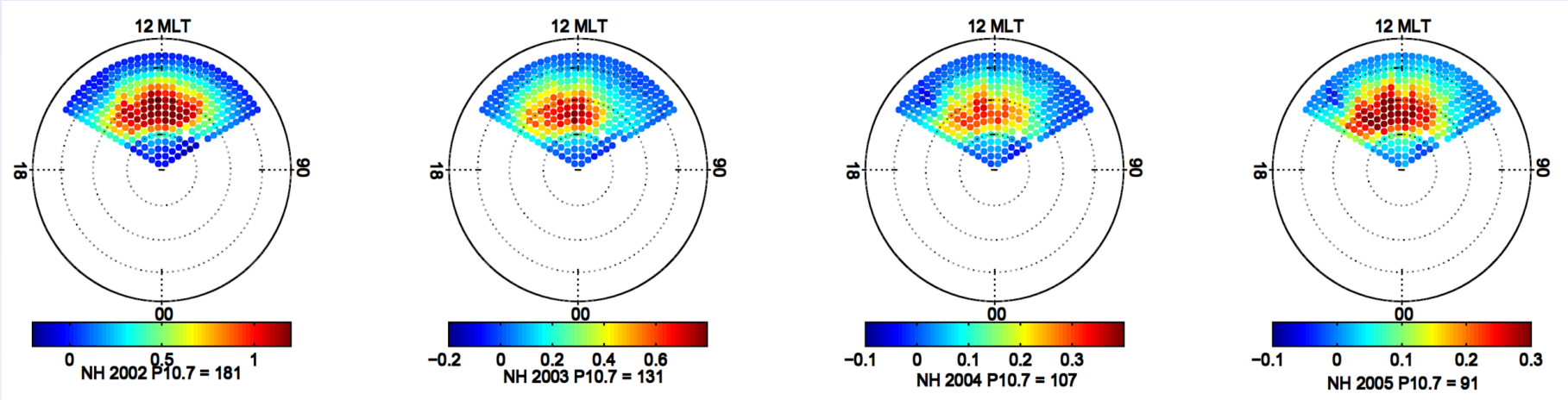
Studying Earth's Cusp-Region Density Anomaly

PI:	Mark Conde	GI/UAF
Co-Is:	Don Hampton	GI/UAF
	Miguel Larsen	Clemson
	Marc Lessard	UNH
	Jonathan Burchill	U. Calgary
	Kristina Lynch	Dartmouth
	Anasuya Arulia	UCL
	Fred Sigernes	UNIS
	Dag Lorentzen	UNIS
	Aaron Ridley	UMich
	Yoshihiro Kakinami	Kochi-Tech

Science Problem



We are working on developing a new mission aimed at addressing the following overall science question:

> *"What mechanism establishes the persistent perturbations of upper thermospheric mass density that have been seen by satellites like CHAMP, GRACE, Streak, and others as they passed through Earth's geomagnetic cusp regions?"*

- Our currently poor understanding of why these density perturbations occur means we cannot model their behavior.
- Consequently,we cannot accurately account for them in predictions of collision probabilities during (frequent) near misses between satellites and space debris.

Is this a Large Anomaly?

Question: So the local density enhancement is about 30% – is that a lot?

[1] This is an unofficial central pressure derived indirectly from satellite data. The lowest central pressure officially measured was 870 mbar, for Super Typhoon Tip in 1979.

Is this a Large Anomaly?

Question: So the local density enhancement is about 30% – is that a lot?

Answer: Well, the central pressure of the deepest tropical storm on record was (probably) 858 mbar – for Super Typhoon Haiyan in 2013.[1] This is a pressure perturbation of only 15% relative to mean sea level pressure.

Since pressure and density roughly co-vary ($P = \rho RT$) we can compare this to the typical 30% density variation in the thermosphere. (The thermosphere is not the troposphere, so the comparison is admittedly not completely fair.)

- Even so, *30 percent is a very big density perturbation*. The extra mass must be supported against gravity; it must be balanced by substantial changes to other terms in the atmosphere's momentum equation.
- But as of today, more than a decade after the density enhancement was discovered, *no observations have yet detected any of these required balancing perturbations*.

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Another Useful Analogy

A bug-eyed "alien Galileo" observing Earth with eyes that could actually see the one of the density anomalies might note the following characteristics of its appearance:

- It would represent a very substantial perturbation relative to the surrounding regions.
- It would be elliptical in shape, with the major axis aligned zonally, and spanning something like 10° of latitude.
- It would be a long-lived, persistent feature.

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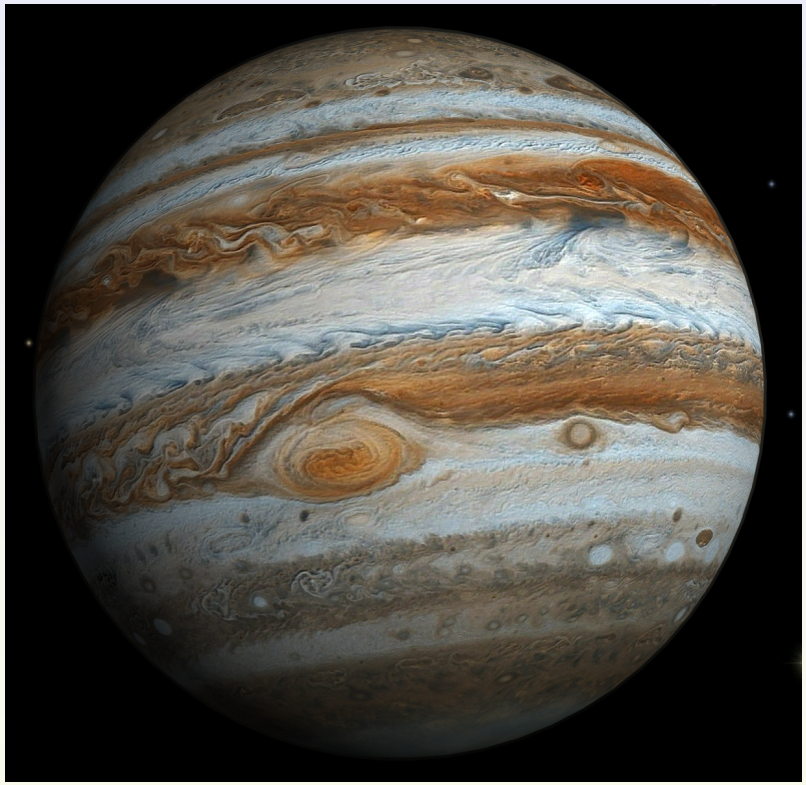
Indeed, it's overall character might lead our alien to describe it as *"Earth's version of the Great Red Spot."* (Nothwitstanding the fact that Earth has two of them...)



However, unlike Jupiter's Great Red Spot, *the cusp-region density anomalies remain fixed in magnetic local time*, and do not co-rotate with the background atmosphere. (At 9 UT, the northern cusp moves south-westward at $\sim 120\,\mathrm{m\,s^{-1}}$.)

Thus, *it is surprising there's no obvious wake or wave activity excited by this!*

Current Scientific Picture

Definition (Hydrostatic equilibrium)

A fluid supported statically against gravity by its internal pressure must satisfy the condition for *hydrostatic equilibrium*, which is usually written as

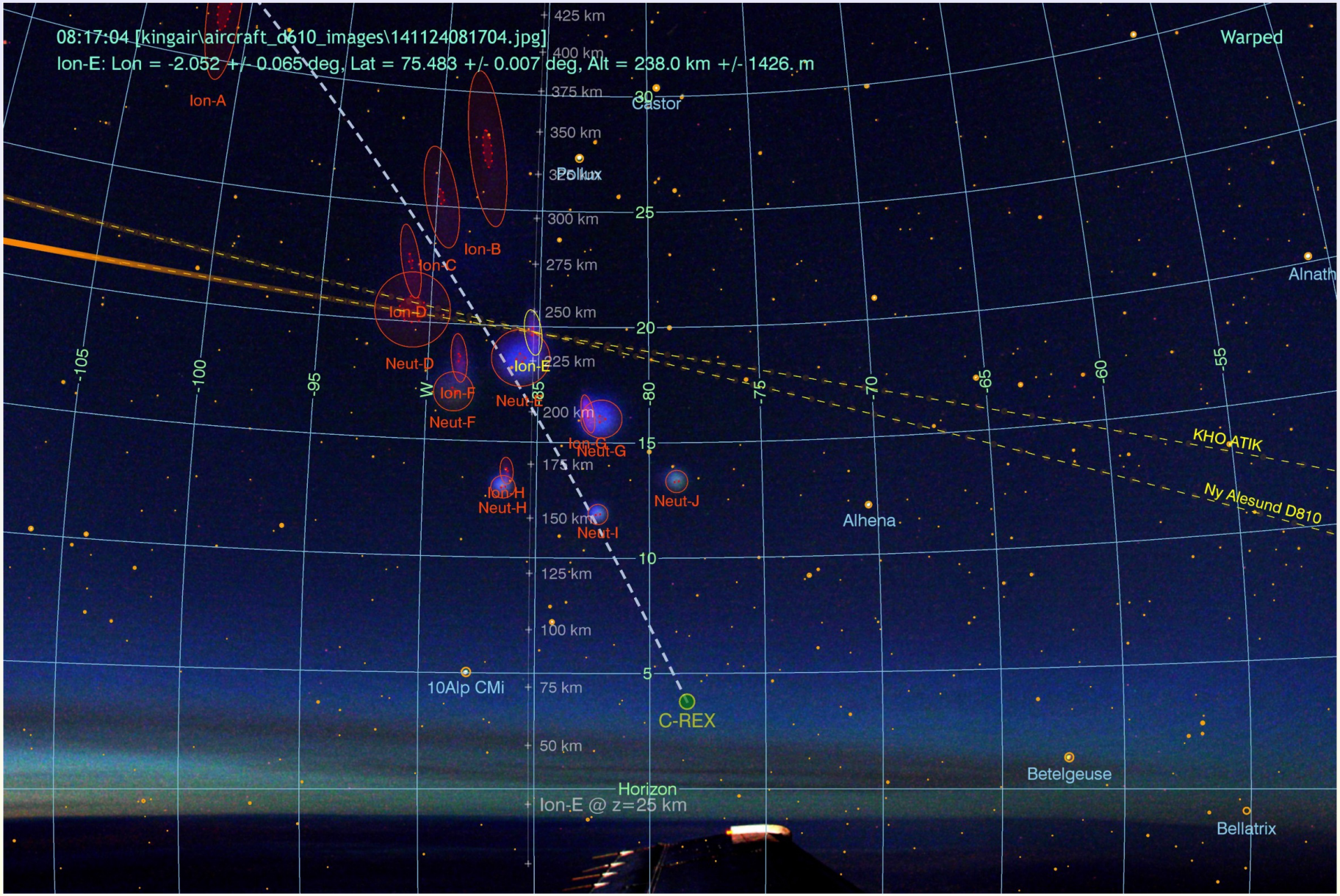
$$\frac{\partial p}{\partial z} = -\rho g \tag{1}$$

- Inspection of this equation shows that an increase in mass density must be balanced by *pressure decreasing faster with altitude*.
- It is possble to find plausible vertical profiles of pressure and density that could support the anomaly hydrostatically. However, of necessity, *they introduce a divergent horizontal pressure gradient* which must then drive substantial divergent hirizontal winds – and, to conserve mass, corresponding vertical flow.

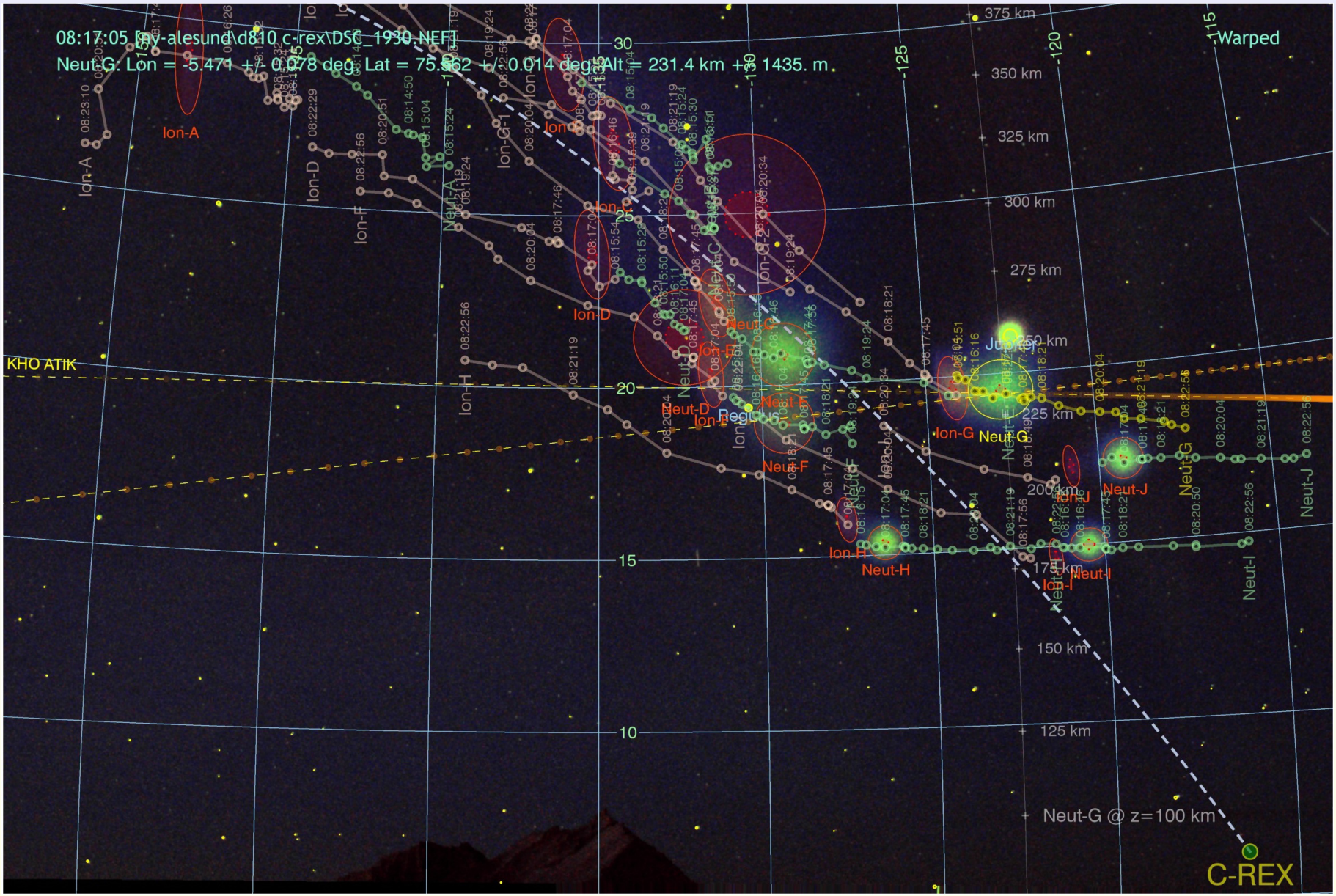
C-REX Ion and Neutral Tracer Motion

- This shows the C-REX chemical releases seen from Ny-Alesund. Motion of the neutral and ion clouds is clearly visible, and the ion motion in particular is very complex.

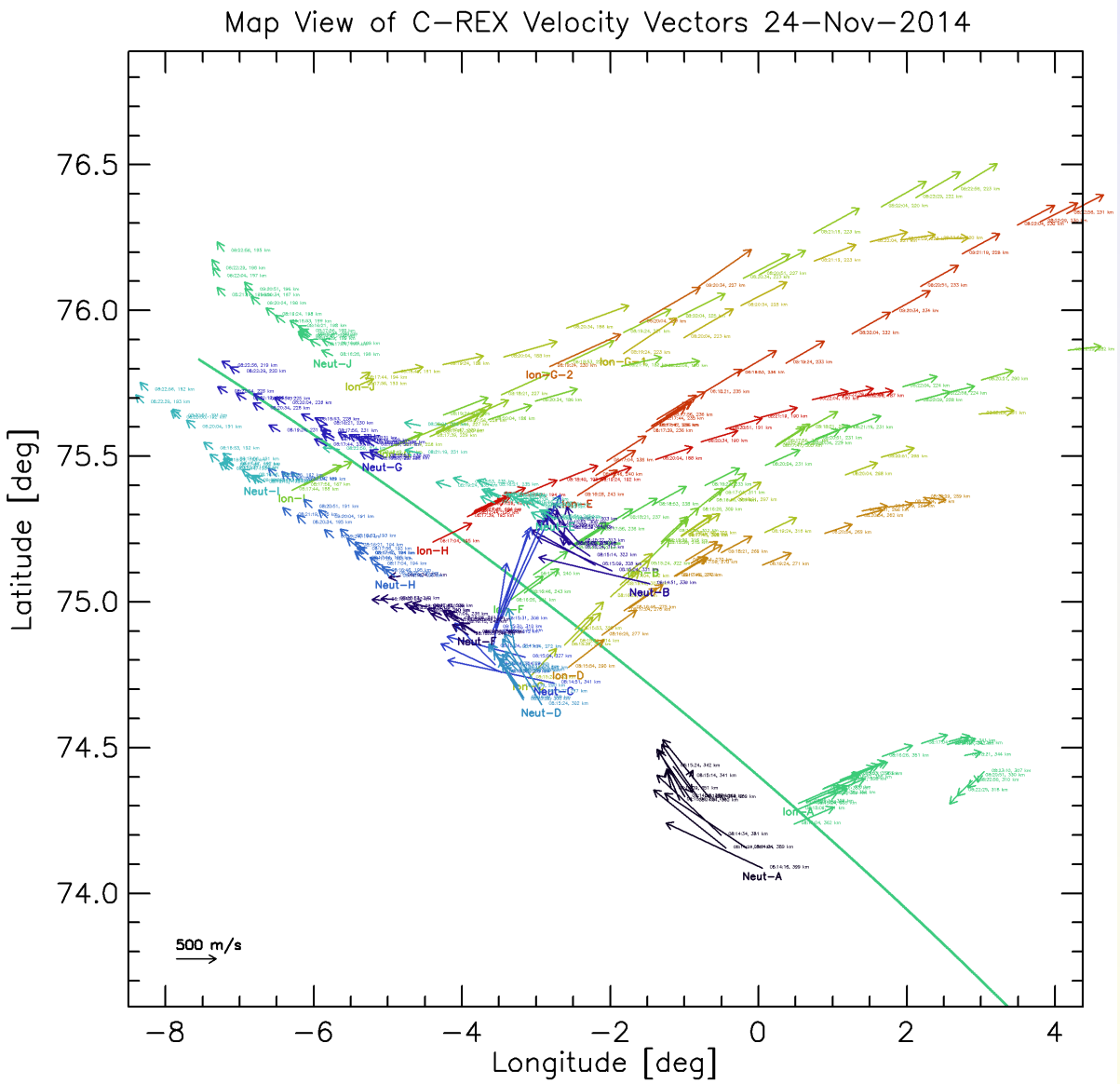
Triangulation Example



Tracer Trajectories



Computed Tracer Drift Velocities – Map View



- This map shows the cloud velocities calculated so far.
- *The neutrals are drifting north-west, whereas the ions are drifting north-east.*
- No other technique can give these direct in-situ measurements – they show important spatial and temporal detail that is unavailable any other way.
- Analysis is ongoing.

An Unresolved Puzzle

- The observed ion-neutral velocity differences were substantial, and capable of producing significant Joule heating.
- The mechanism(s) that operate in Earth's thermosphere to support the observed increase in cusp-region mass density should themselves correspond to substantial and easily observed perturbations in other atmospheric fields, like pressure, temperature, wind, ion drift velocity, composition, etc.
- Pressure and density profiles that support a 30% density enhancement and satisfy hydrostatic equilibrium produce a horizontal pressure perturbation that even in the best cases varies by at least 15% between the center and the edge of the anomaly. This must produce some local signature in winds and, possibly, waves.
- C-REX-1 showed that (despite very quiet geomagnetic conditions) substantial heating likely was occurring – but *no wind obvious wind signatures were seen*.
- Indeed, to date, nobody has actually observed any viable candidate perturbations in winds (or in any parameters) to indicate what is supporting this extra mass.
- Attempting to fill this observational gap is the motivation for our new mission proposal.