The Importance of Toolik Lake for Space Weather Research in Alaska

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Toolik All-Scientists Meeting 2018

[1]And many others...

Motivation: Space Weather

Why Space Physics?

- Earth's upper atmosphere and near-space environment are subject to variable and impulsive driving from the Sun abd solar wind, as well as dynamic forcing from below.
- The resulting upper atmospheric weather has *direct impacts on many technological systems* – communication, navigation, radar tracking, and prediction of spacecraft orbits for example.
- Of particular is the ability to *predict when satellites will re-entr the atmosphere. or will need to conduct maneuvers to avoid collisions* – with space debris, or even with other spacecraft.
- In additional to these technology-driven operational needs, there are of course many fundamental science topics from the fields of fluid dynamics, plasma physics, and astrophysics that can be studied by using Earth's near-space environment as a natural laboratory.

Spacecraft Avoidance of Orbital Debris

- Potentially hazardous space debris encounters now occur roughly daily for a typical LEO satellite. Even in 2007, operators of the Iridium constellation were receiving 400 notifications per week for predicted approaches within 5 km of their satellites.[2]

- *At 16:56 UTC on February 10, 2009 the still operational satellite "Iridium 33" collided at 42,000 km/h with the defunct "Kosmos-2251", at an altitude of 789 kilometers above Siberia.*
- This is the first known accidental hypervelocity collision between two full-size intact satellites orbiting Earth.

- Although a close approach between these two satellites was predicted, of the close encounters being monitored at the time, this one was not assessed to have the highest collision probability.
- *The closest approach prediction was 117 m* (forecast on February 6), and by the next day the forecast distance had grown again, to 1.243 km. It did not subsequently drop below 600 m.
- Space weather is the largest source of uncertainty for these predictions. Large (and expensive) maneuvers are need to guarantee that the collision risk is reduced.

[2] Source information from http://en.wikipedia.org/wiki/2009_satellite_collision

Simulation of the Collision Between Iridium-33 and Kosmos-2251

http://www.youtube.com/watch?v=lSmggU0UOYY

Wind Transport

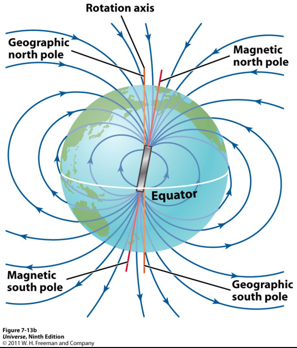
- To understand space weather storms we must be able to predict how air parcels will be transported to by thermospheric winds.
- But tracing wind transport is extremely difficult; accurate, high resolution winds must be measured over a wide geographic area.
- The "balloons" shown here are transported by a very simple empirical model.

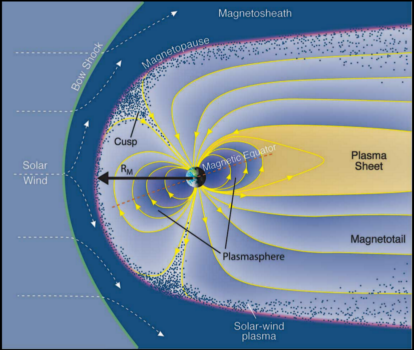
Where Do Most Space Weather Disturbances Impact Earth

Why Toolik Lake?

- Disturbances that cause aurora reach our upper atmosphere from interplanetary space by (mostly) traveling along Earth's magnetic field lines.
- The (roughly) dipole shape of our magnetic field means that *space weather disturbances are only "connected" to our upper atmosphere at high latitudes.*
- Alaska is the only US land mass that experiences these disturbances directly.
- And within Alaska, *Toolik Lake is positioned right where the likelihood of experiencing a significant disturbance maximizes.*

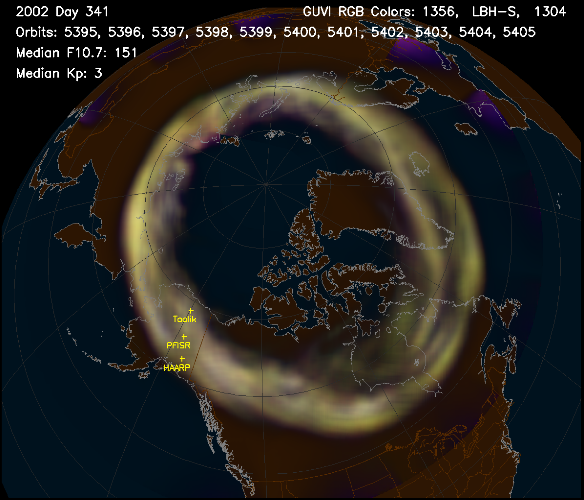
Earth's Magnetic Field





- Within and near Earth, our magnetic field is roughly dipolar. But, further out, the solar wind distorts it into a "comet" shape.
- Roughly speaking, the aurora originates on magnetic field lines with shapes that are intermediate between these two regimes.
- As can be seen, these intermediate field lines reach the ground at magnetic latitudes in the mid-to-high sixties – i.e. *right around the latitude of Toolik Lake.*

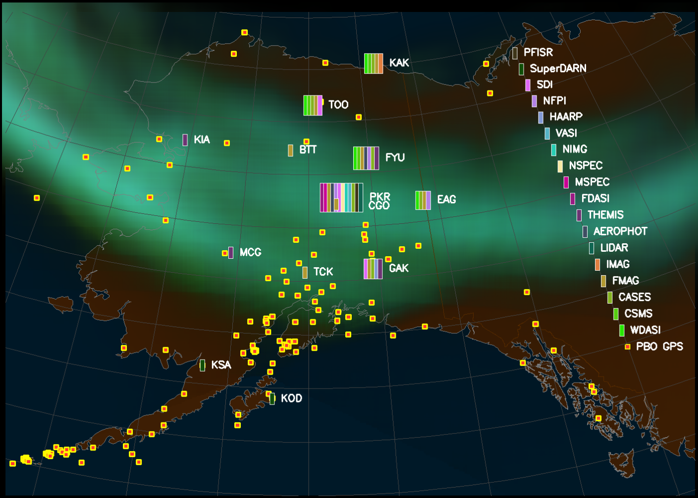
The Location of Toolik Lake Relative to Typical Aurora



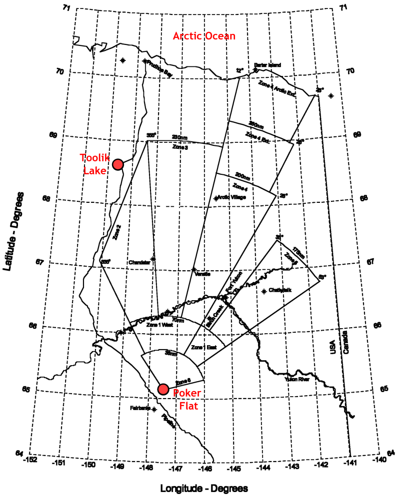
- Earth's aurora as seen by the TIMED spacecraft on December 7, 2002, during moderately disturbed levels of space weather activity.
- During quieter conditions the auroral oval is smaller – it contracts northward.
- The importance of Toolik Lake for US-based auroral studies is obvious from this figure.

The Aurora Seen from the Ground at Toolik Lake

The Location of Toolik Lake Relative to Other Instrumentation



Support for NASA Rocket Missions

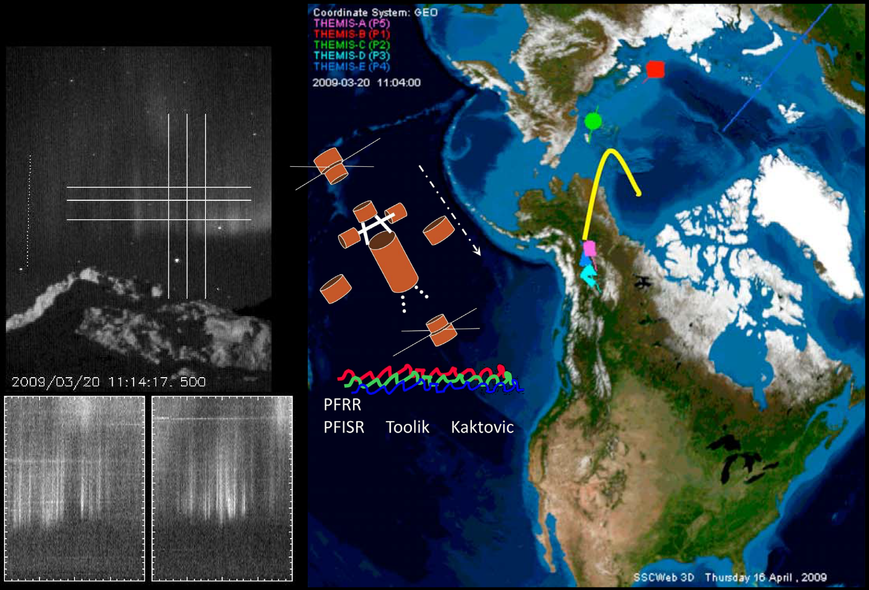


- Toolik Lake is well positioned to support NASA sounding rocket missions – especially chemical release experiments for tracking winds and ion drifts.

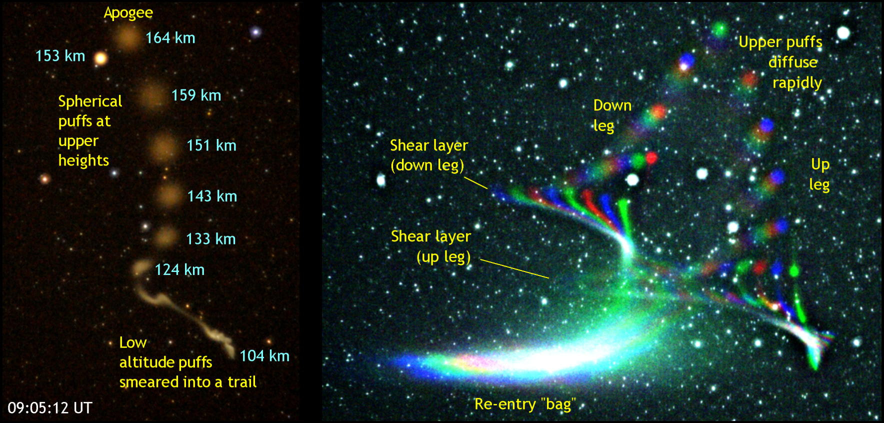
Toolik Lake Support for the 2003 HEX Mission

TMA "puffs" released at $\sim 150\,\mathrm{km}$ altitude by the 2003 "HEX" rocket, and subsequently drifting with the wind. *This video was shot from Toolik Lake.*

The 2009 CASCADES Mission

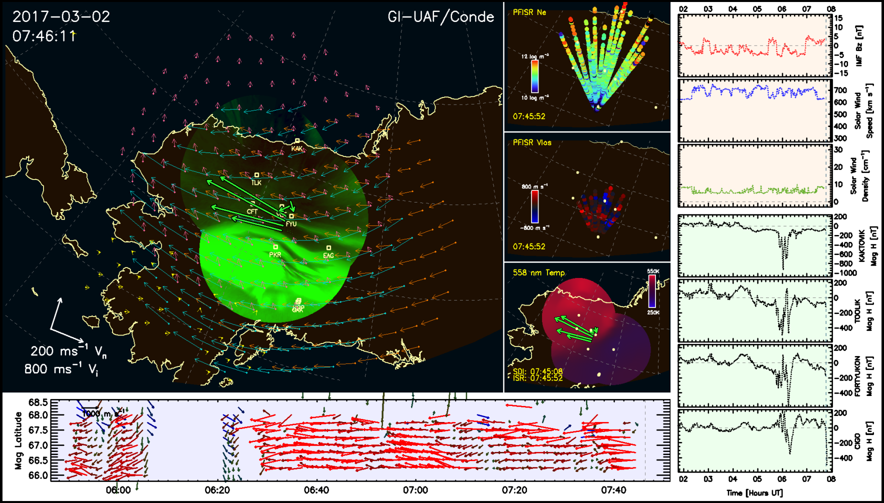


The 2010 AMPULES Mission



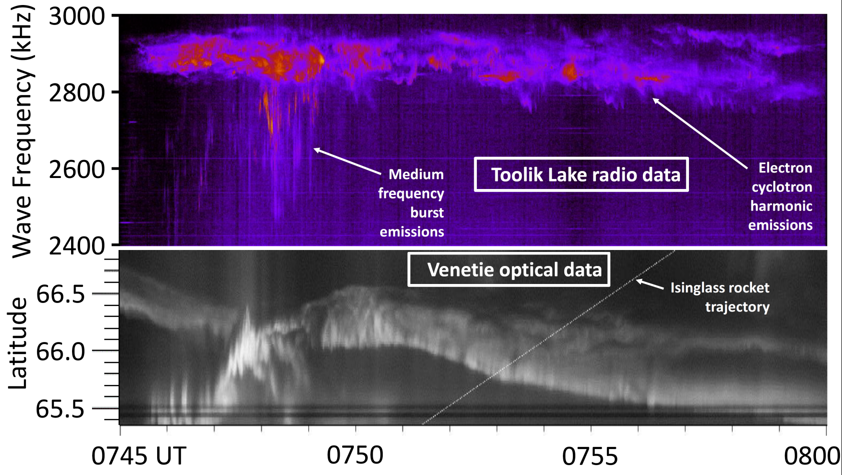
- Images taken from Toolik Lake showing TMA puffs deployed during the February 9, 2010 AMPULES flight.
- The left panel is a single still image, whereas the right panel was created by superimposing images taken a time period of 7.5 minutes.

The 2017 ISINGLASS & JETS Missions



ISINGLASS Beacon Triangulations

ISINGLASS Radio Spectrometer at Toolik

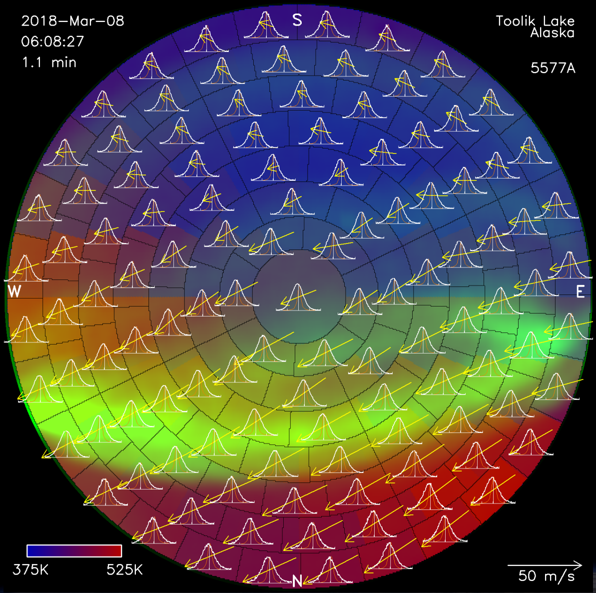


An HF radio spectral receiver was used at Toolik during the 2017 ISINGLASS mission to study plasma waves.

Toolik Lake All-Sky Fabry-Perot Interferometer

This instrument at Toolik measures winds and temperatures at heights of $\sim 120\,\mathrm{km}$ and $\sim 240\,\mathrm{km}$, acrosss regions $1000\,\mathrm{km}$ and $500\,\mathrm{km}$ in diameter respectively.

All-Sky Thermospheric Weather Measurements



- The Toolik SDI measures optical Doppler spectra of airglow/aurora from multiple “zones” across the sky.
- This figure shows spectra, auroral brightness, Doppler temperature, and fitted wind vectors.
- Note the correlation between the aurora, the Doppler temperature, and the wind field.

Operational Space Weather Modeling

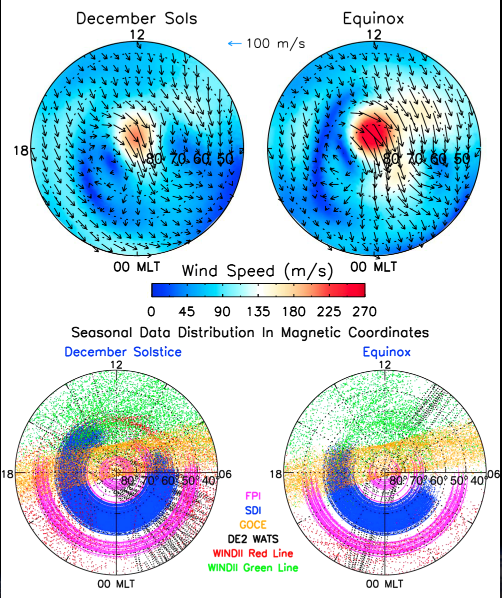


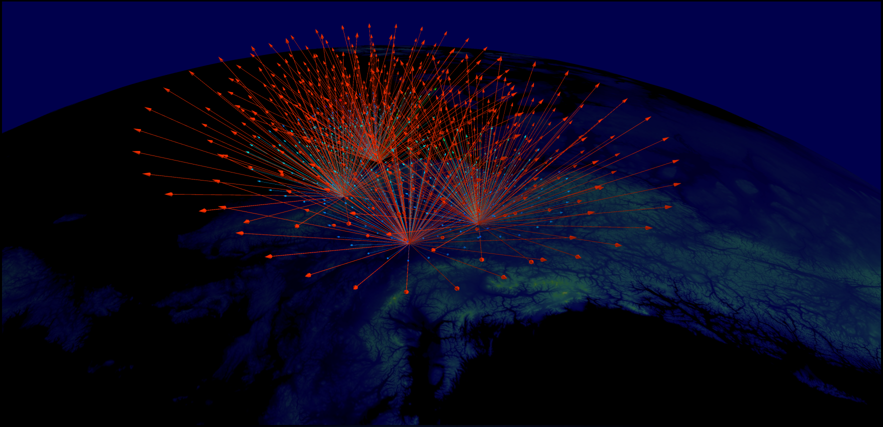
Table 1. Quiet Time Observational Wind Data Sets Used[a]

Station	Magnetic Latitude	Years of Data	Height (km)	Local Time	Days	Data Points
		Fabry-Perot Interferometers (Ground-Based)				
Thule	84.6°N	1987	250	night	57	4,949
Resolute Bay	83.4°N	2004–2007	250	night	216	8,176
Søndre Strømfjord	73.3°N	1983–1984, 1987–1995, 2002–2004	250	night	566	26,708
Millstone Hill	53.1°N	1990–2002	250	night	533	13,267
Peach Mountain	52.1°N	2012–2015	250	night	507	32,968
Urbana	52.1°N	2007–2008, 2012–2015	250	night	648	53,621
		Scanning Doppler Imaging Fabry-Perot Interferometers (Ground-Based)				
Toolik Lake	68.3°N	2012–2014	250	night	198	123,801
Poker flat	65.2°N	2010–2012	250	night	303	114,933
		Space-based Instruments				
DE2 WATS	89.5°N–89.8°S	1981–1983	210–320	both	55	4,781
WINDII 557.7 nm	81.6°N–88.0°S	1991–1997	210–320	day	198	16,582
WINDII 630.0 nm	80.1°N–86.0°S	1991–1997	210–320	night	77	3,402
GOCE	90.0°N–89.8°S	2009–2012	253–295	twilight	571	51,203

- Toolik Data is contributing to operational thermospheric wind models.
- Modelers at NRL could only use a (randomly chosen) sample of 2.5 percent of our data – the full data set would overwhelm all other observations used to build the model.

Toolik Lake is Part of a Larger FPI Instrument Array

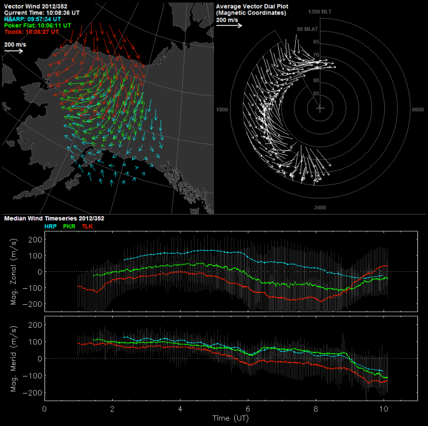
- LOS winds seen from one site cannot uniquely constrain all 3 wind components.
- Improved wind reconstructions require wind components measured along multiple independent lines of sight – which we now do, using an array of Scanning Doppler Imagers located across Alaska,[3] with overlapping fields of view.

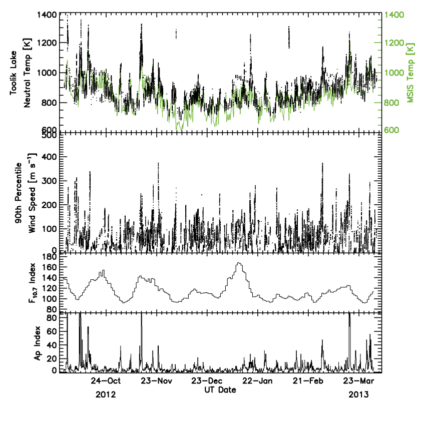


[Figures in This Style Were Provided by John Elliott]

[3] At Poker Flat, Eagle, Toolik Lake, and Kaktovik.

Example Data





The left panel shows winds measured on one night from three sites in Alaska, including Toolik. The right panel shows data for the entire 2012-2013 winter.

Toolik Data assimilated with Many Other Measurements

This movie is based in part on Toolik data. It shows the complex relation between winds, ionospheric motion, and the aurora.

Latest Work: "Evolutionary" Fitting Winds in Four Dimensions

Tracing Air Parcel Trajectories

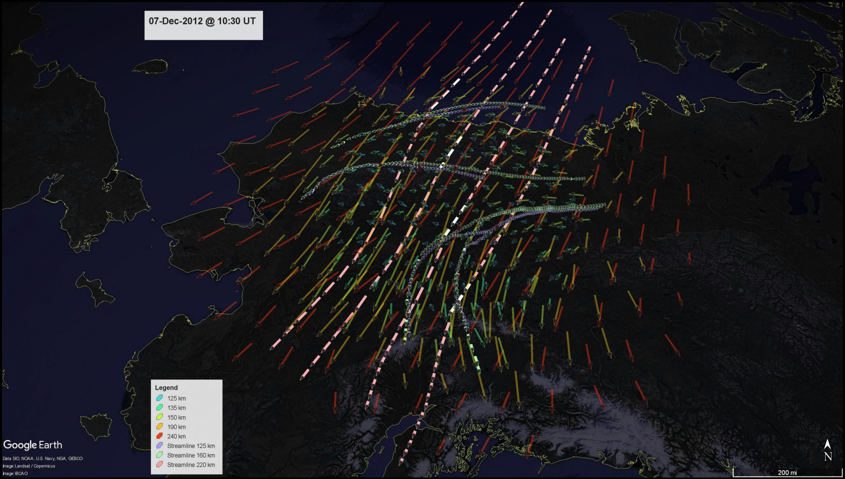
- Once we have an estimate of the full three-component vector field resolved over all four dimensions, it is computationally simple to follow the trajectories of any number of hypothetical "tracer particles" carried by the flow.

For a given time and spatial location, there two questions that can be asked:

- Where did the air parcels passing here now *come from*?
- Where will these air parcels *go in the future?*

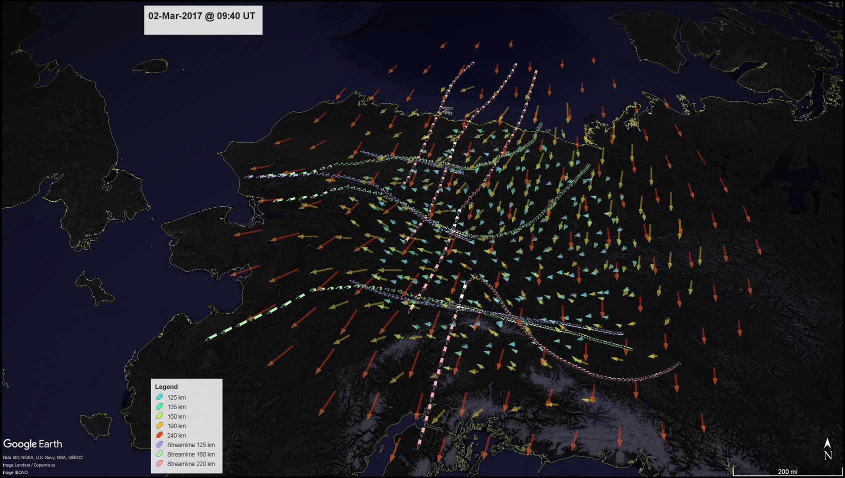
- Pathline arrows in the following figures address both questions.
- White pathline arrows are *the only ones that correspond to the time of the background wind field.*
- Arrows upstream of those in white show where these air parcels came from, whereas downstream arrows show where they will go subsequently. Each pathline arrow corresponds to 5 minutes of wind transport.

A Simple Example of Transport Trajectories



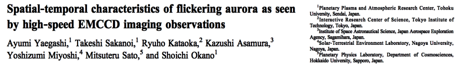
- F-region trajectories (pink) indicate uniform transport toward the south-west.
- E-region transport (olive & cyan) was more complex. All E-region air parcels passing the white reference locations originated from the east.
- Downstream transport remained westward over northern Alaska. But over southern Alaska, the downstream transport turned strongly southward.

A More Complex Example



- The wind field varies in four dimensions: longitude, latitude, altitude, and time.
- Our data shows that transport trajectories resulting from these winds can often become very complex.

Flickering Aurora


Spatial-temporal characteristics of flickering aurora as seen by high-speed EMCCD imaging observations

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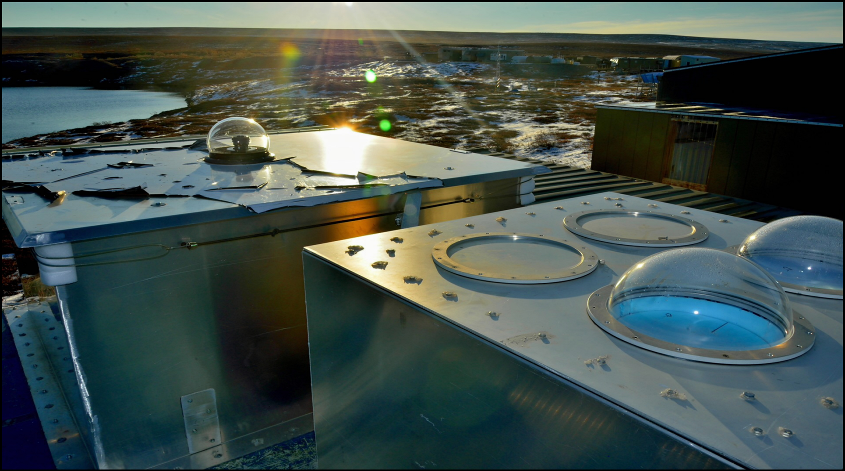
- Toolik Lake is well positioned for studying flickering aurora that occurs during auroral breakups.
- These studies have been conducted by research groups from Tohoku University in Japan, and from the US Air Force Academy in Colorado.
- The video shown here was recorded at 100 Hz frame rate, looking in the magnetic zenith at a region spanning $16\,\mathrm{km} \times 16\,\mathrm{km}$.
- These studies show flickering at frequencies in the range 15 Hz to $\gtrsim 40$ Hz, which is significantly faster than previously expected.

Space Physics Lab Space at Toolik

Left: All-sky camera and spectrometer box mounted on a building roof.
Right: The "Smurf Hut" that houses the interferometer (and a couple of other instruments.).

Moisture in the "Smurf Hut"



- The inner layer of insulation in the "Smurf Hut" has no vapor barrier, which means it accumulates moisture whenever the building is occupied in cold weather.
- Condensation on the inside of our viewing domes is thus a constant concern.

No Facilities to Host Instruments for Short-Term Campaigns

- Currently, we do not have lab space available to host instruments and scientists conducting short-term observing campaigns at Toolik Lake.
- So until now, a number of guest instruments have had to be deployed using portable boxes setup outside on the snow. Needless to say, this is not ideal in winter!

Conclusions

- Toolik Lake is ideally located for studies of the aurora and its impact on upper atmospheric weather.
- It is also very attractive logistically; it offers easy road access, AC power, good network bandwidth, accommodation for scientists, and support from technicians.
- It has been an excellent site for supporting NASA rocket studies, for long-term UAF studies, and for a number of shorter guest investigator campaigns.
- However lab space for space physics insruments is limited, and has issues relating to moisture in the building
- *The Space Physics community would benefit greatly if we could establish a better lab facility at Toolik Lake for hosting instruments and visiting scientists.*