

Operation-ready: Real time turn-key autonomous ground based magnetometer, FPI and all-sky imager arrays at CPI

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Abstract

Monitoring space weather events and their effects on the Earth's atmosphere is crucial for the highly technological society we live in today. Effectively monitoring space weather requires an array of sensors that deliver data as fast and accurately as possible. While satellites provide an in-situ and/or a global view, ground based instrumentation provides localized measurements that are essential to measure highly localized events and dynamics. At Computational Physics Inc. (CPI), we have been developing turn-key industrial grade instrumentation to monitor space weather and upper atmospheric dynamics. Currently, we operate 13 magnetometer stations, 2 all-sky imagers and 2 FPIs across the continental US. We have 2 additional FPIs operating in Brazil. Our magnetometers capture real-time magnetic field data with a 1 second resolution. Our FPIs measure the neutral wind from direct Doppler shift measurements of the 630nm airglow with uncertainties less than 0.5 m/s, an acuity unparalleled by any other measurement technique and system currently available. Our all-sky imager has the capability to calibrate and orient itself and deliver images in real-time. Additionally, it can identify objects in the sky. All of our instrumentation runs autonomously and delivers high quality real-time magnetic field, thermospheric temperature and wind (including vertical wind) data, as well as imagery from different heights of the atmosphere. We will be describing our instruments and their capabilities in this poster.

Instrument Locations



Figure 1: The location of all of CPI's instruments are shown in this figure. Stars indicate our instruments that are currently in operation. Diamonds indicate instruments that will be deployed in the future. Red and yellow indicate the location of our MagStar magnetometers and FPIs respectively. Green shows locations where we have several of our instruments operating in the same location.

Acknowledgements

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Magnetometers

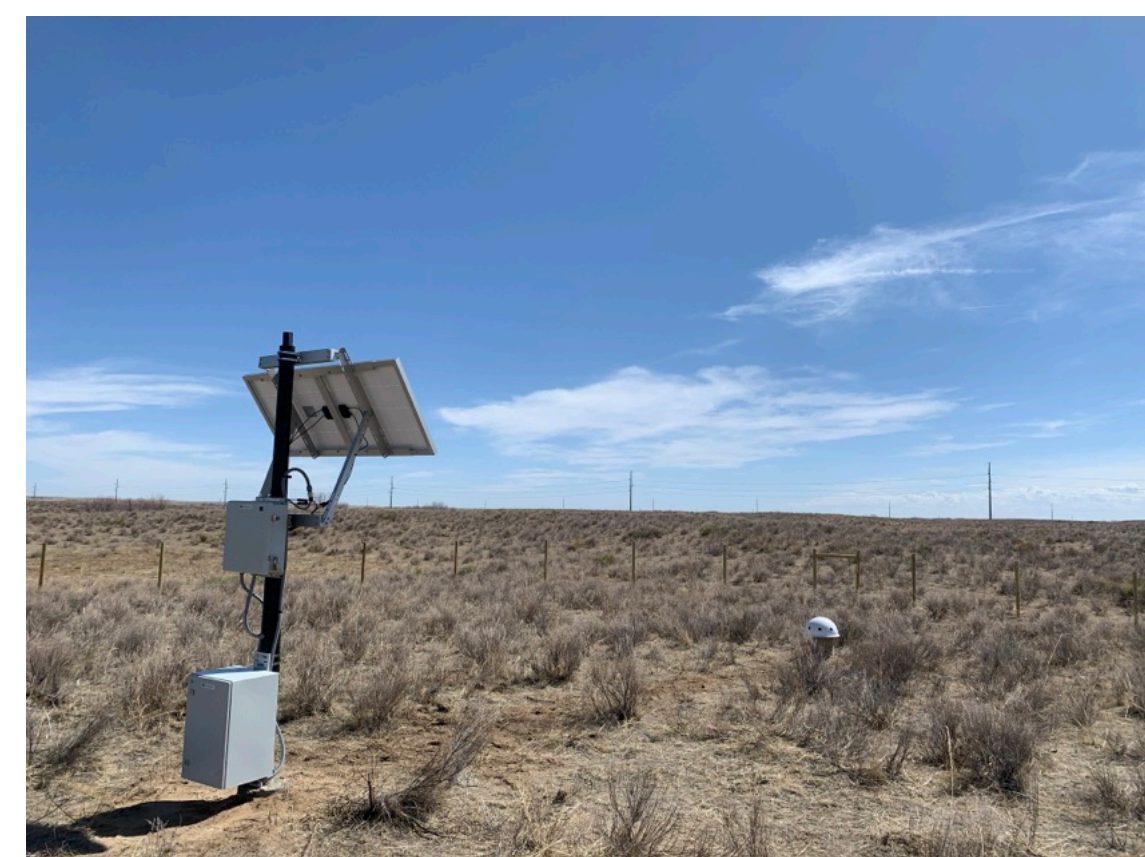


Figure 2: The Pawnee, Colorado magnetometer is shown in this figure. Our magnetometers are fully-autonomous industrial grade instruments that measure the magnetic field of the Earth in real time (1s resolution). For installation, the device itself needs about 10m of land, although it is not a large device.

Figure 3: De-Gap algorithm - uses a Gaussian Process (GP) surrogate model to fill in data gaps due to missing or noisy magnetic field measurements, while preserving the high-frequency content of the original measurements and provide uncertainty quantification of the filled-in data. On the upper panel we show a car that perturbed the magnetometer measurement (green spike). In dark grey, we show the De-Gap results. In blue, we have the uncertainties. The lower panel shows another example of our model.

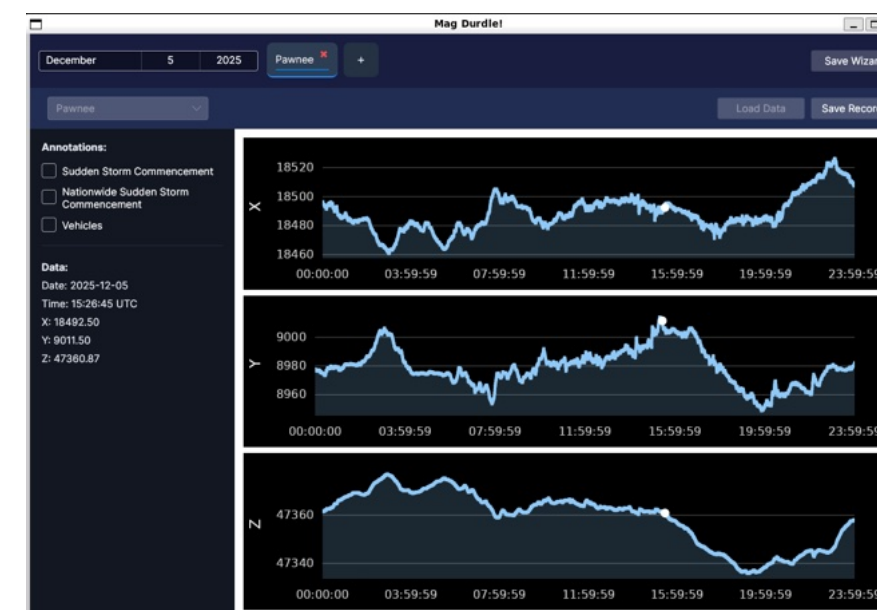
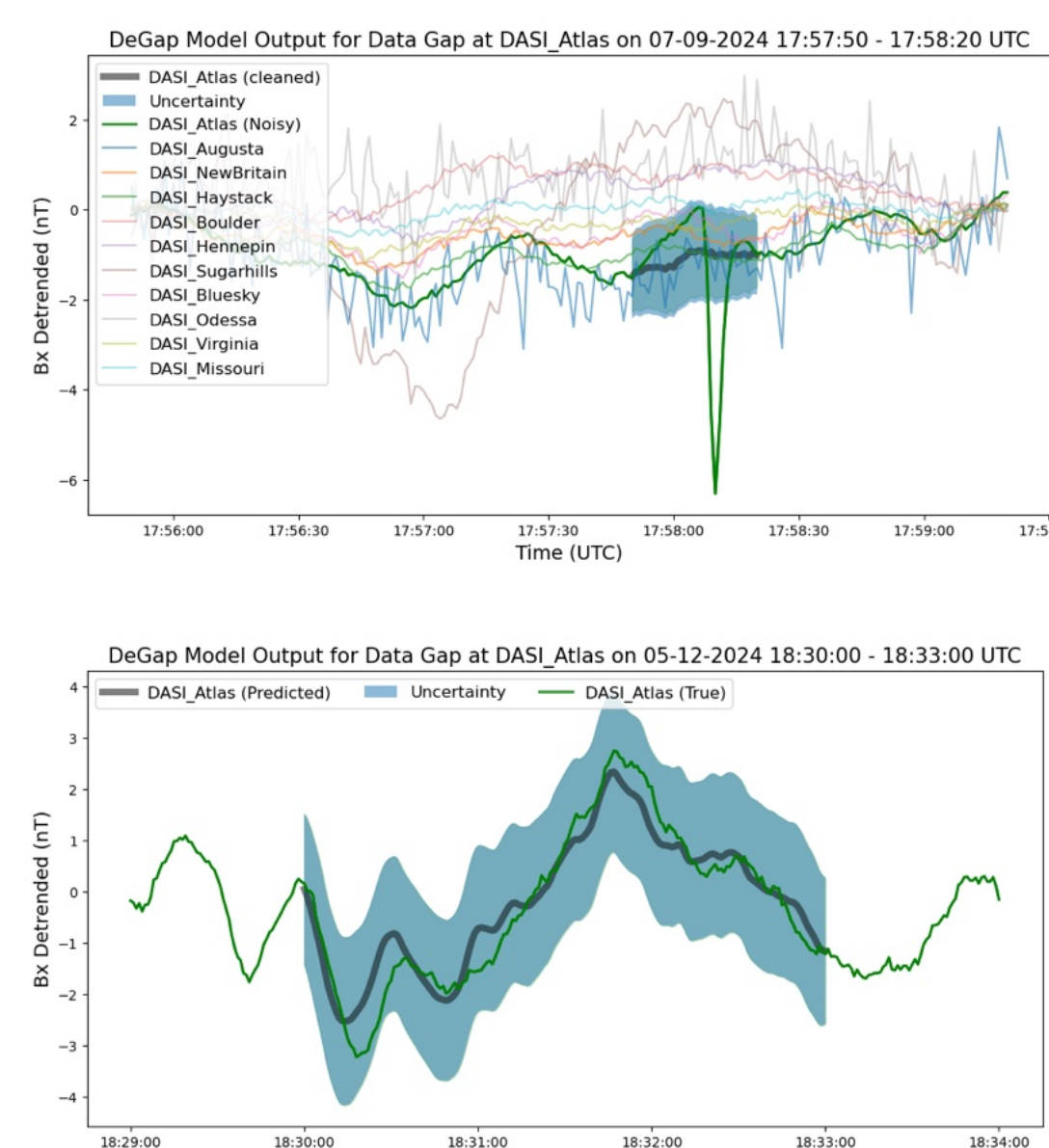


Figure 4: CPI has developed a state of the art data pipeline to process the magnetometer data. The data is acquired, processed and flagged to deliver the most accurate and reliable operational data for our users. This data is used to analyze the real-time impacts of GICs and safeguard the US power grid.



Space Weather Report
Week of May 29, 23:00 UTC to Jun 5, 23:00 UTC

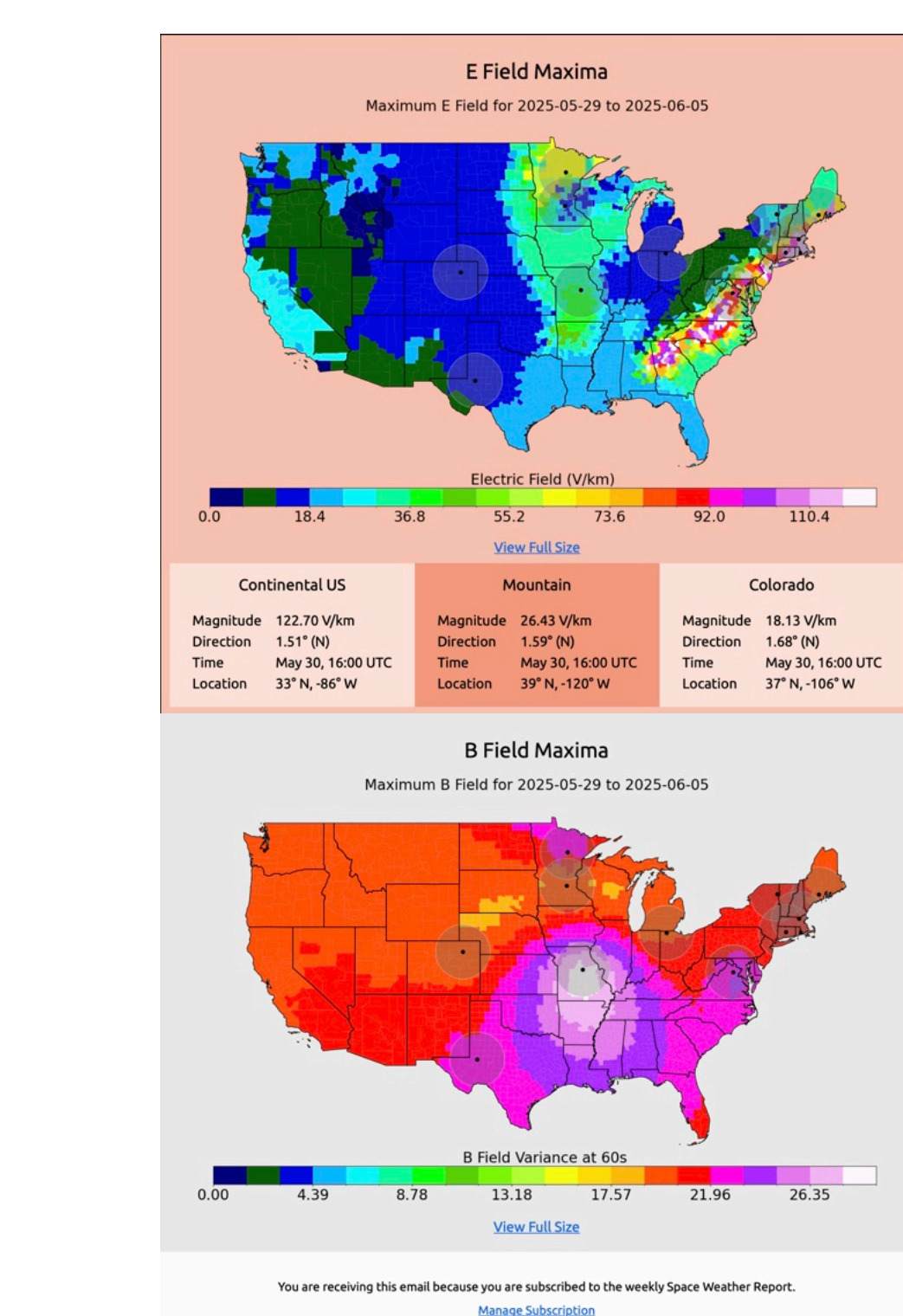
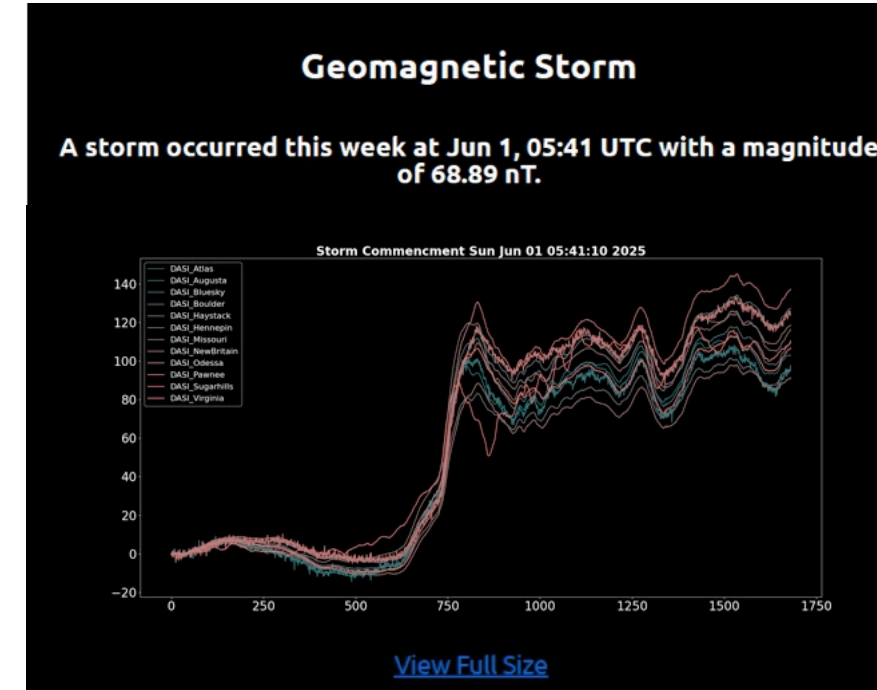


Figure 5: The data acquired from our magnetometers is used as an input into our AVERT electric field model. This model calculates electric field data across the entire United States. This data, along with the magnetic field is sent to our users through our Space Weather Alert System. This system sends email and text alert to our users when our magnetometer array detects a storm. Included in the message are electric and magnetic field maps of the entire US.

Fabry-Perot Interferometers



Figure 6: CPI provides the highest fidelity neutral wind measurements available to Space Weather operations (statistical wind uncertainties of < 0.5 m/s). Apart from our neutral wind measurements, we also obtain temperature measurements in all our locations. We show the FPI located at the Francis Malcom Science Center in Easton, MA.

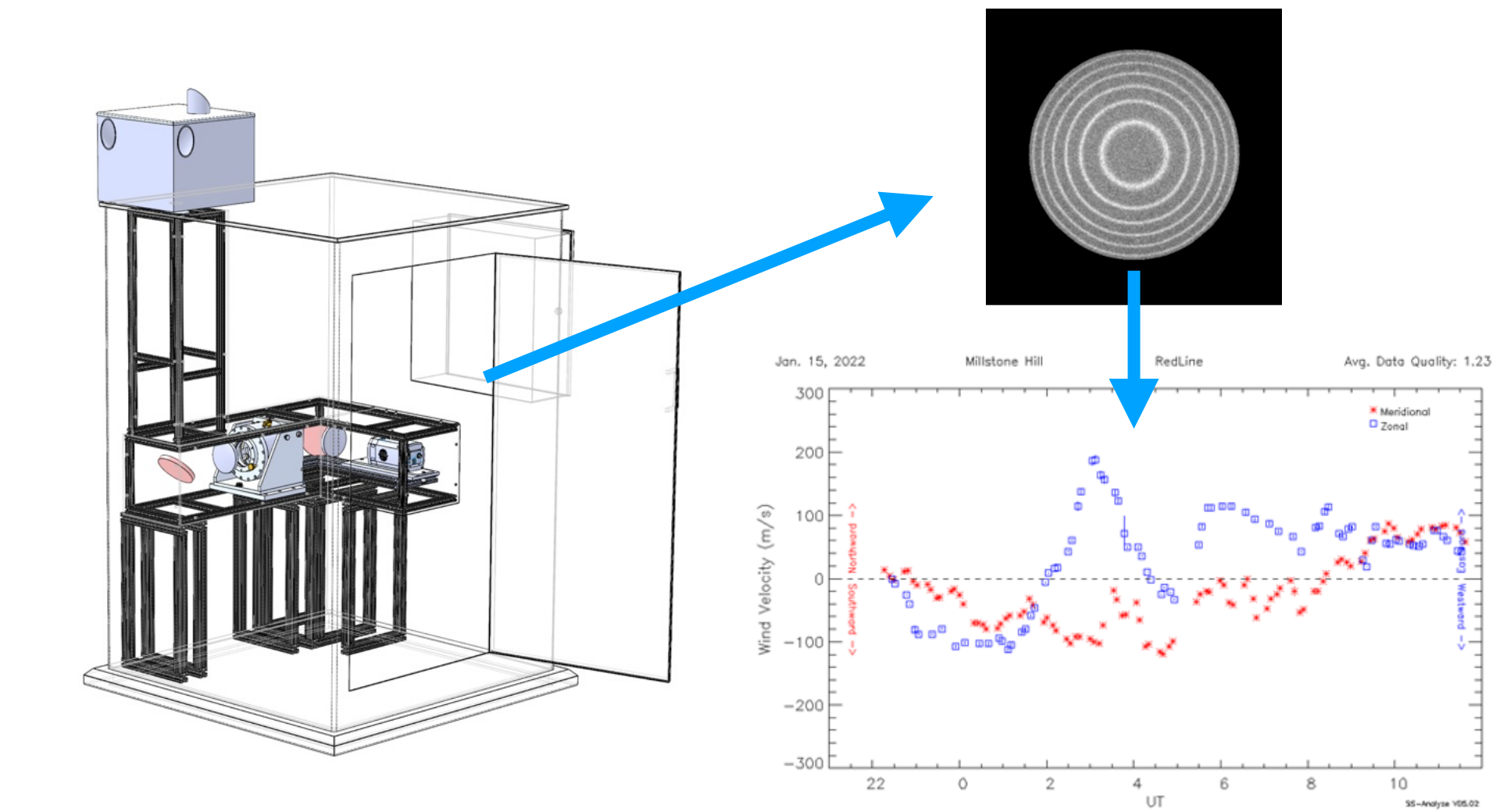


Figure 7: Our FPIs currently operate in a temperature regulated room. Currently, we are working to produce land-based, modular and globally deployable FPIs. This new system will be completely motorized and will self align/calibrate every night once deployed, delivering neutral winds and temperatures in real time. This new generation of FPIs, as shown above, will operate at or above the standards CPI is known for.

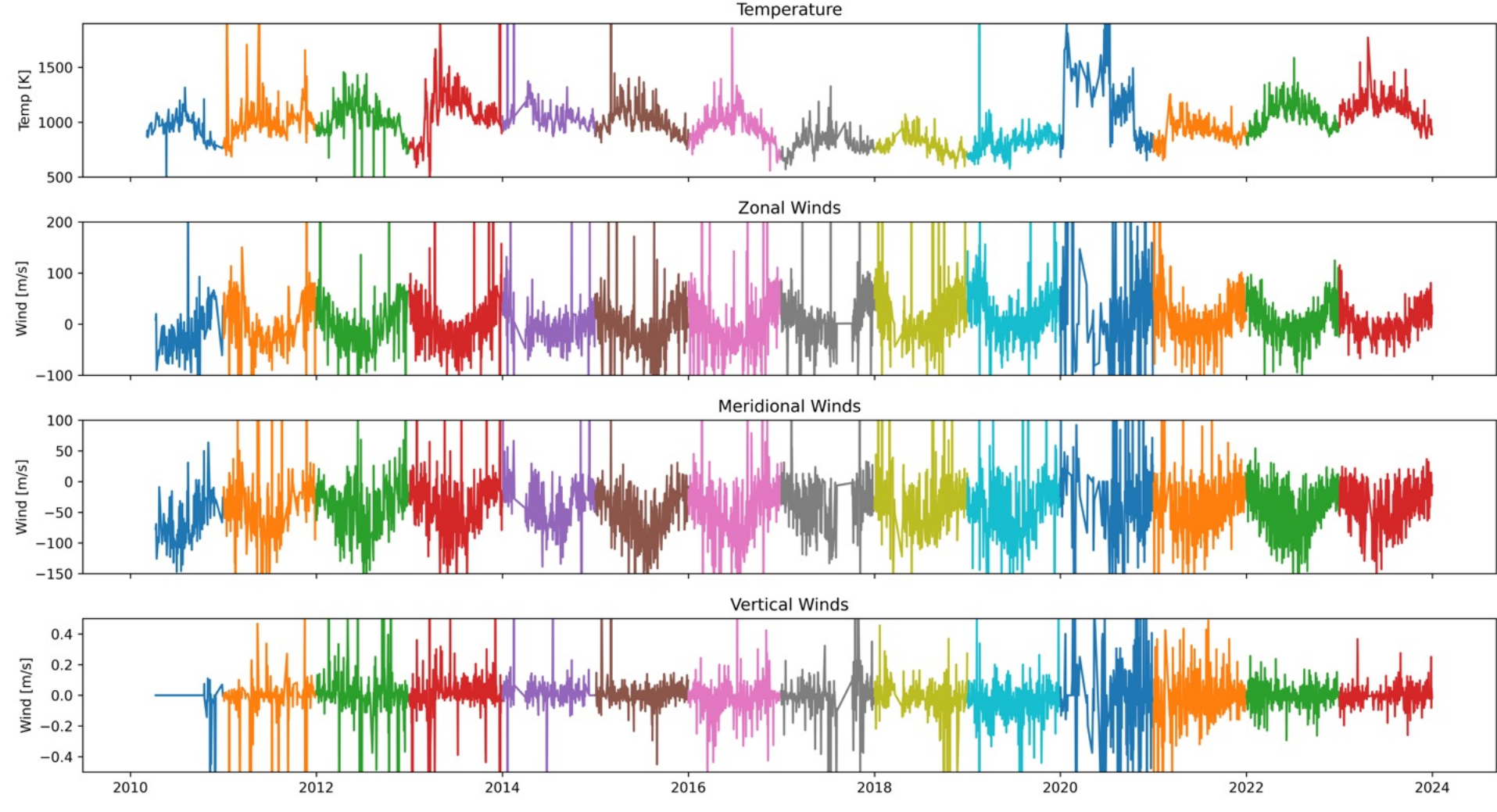


Figure 8: Above we show almost 14 years of historical red line (630.0 nm) data from our Millstone Hill station. Each color represents a different year. We show temperatures, zonal, meridional and vertical winds of this location. We have data available for our 4 stations.

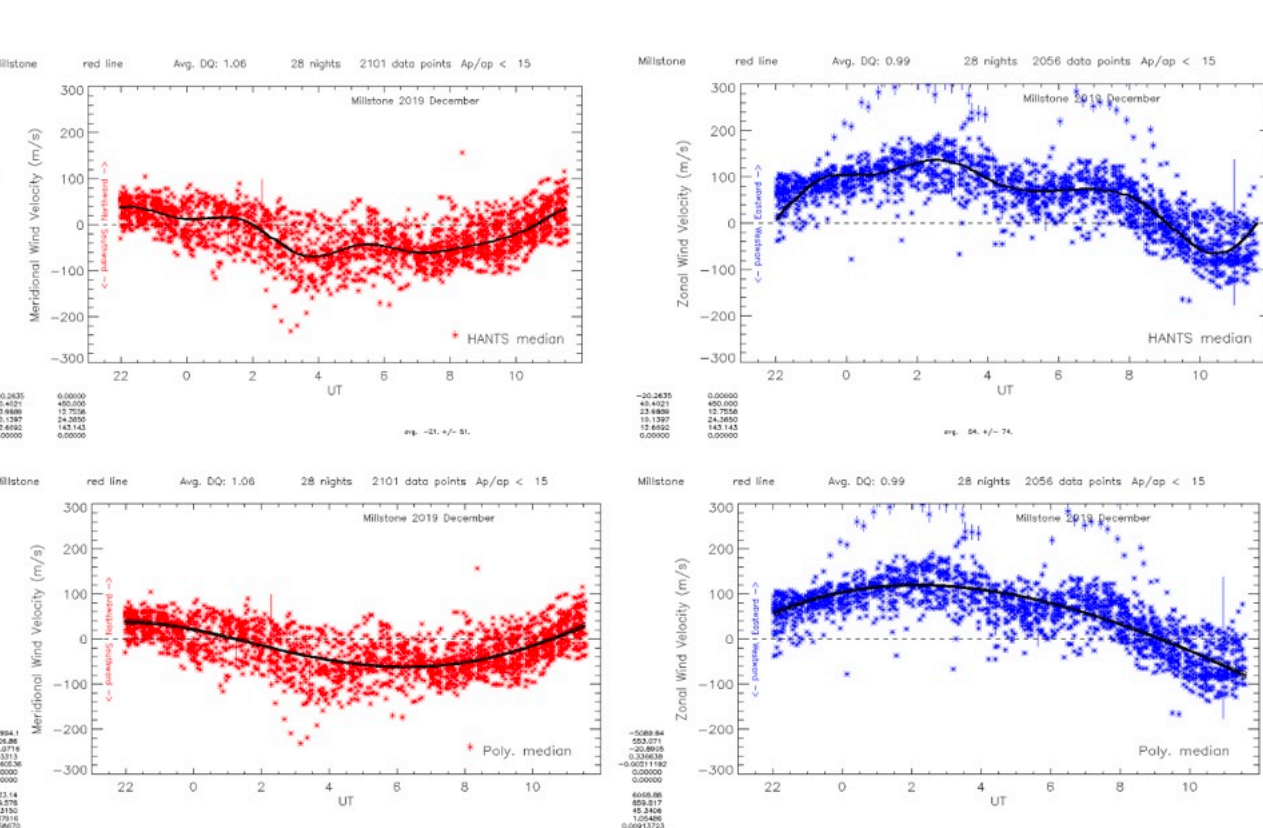


Figure 9: These long-term data sets provide climatological information from which CPI has developed quiet time, regional, three dimensional neutral wind models - the 3DWM.

All-Sky Imagers



Figure 10: Our all-sky fisheye spectral imagers (ASIs) have a telecentric design that ensures all the chief rays are at normal incidence at the image plane, allowing the use of narrow bandpass interference filters (< 2nm) in the five-position filter wheel. We use the all-sky imagers to detect the position, morphology and evolution of the aurora and its characteristics, monitor for clouds, astronomical extinction measurements, meteor imaging and detection, aerosol and pollution monitoring and for security and surveillance.

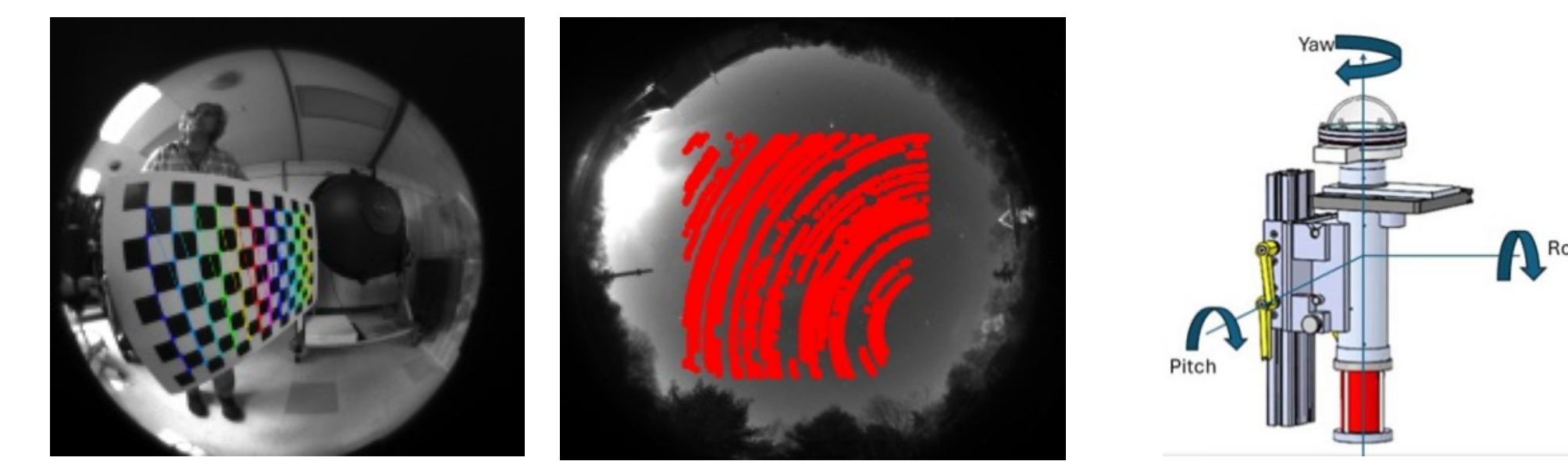


Figure 11: What makes our imagers unique is their turn-key capability. Once powered on, it will observe the night sky, identify where north is, correct itself for any tilt the camera could have and start taking images. Once the image is taken, an algorithm will automatically run to correct for the distortion of the lens and calibrate the image. This makes the imager operationally ready with real-time corrected data output.

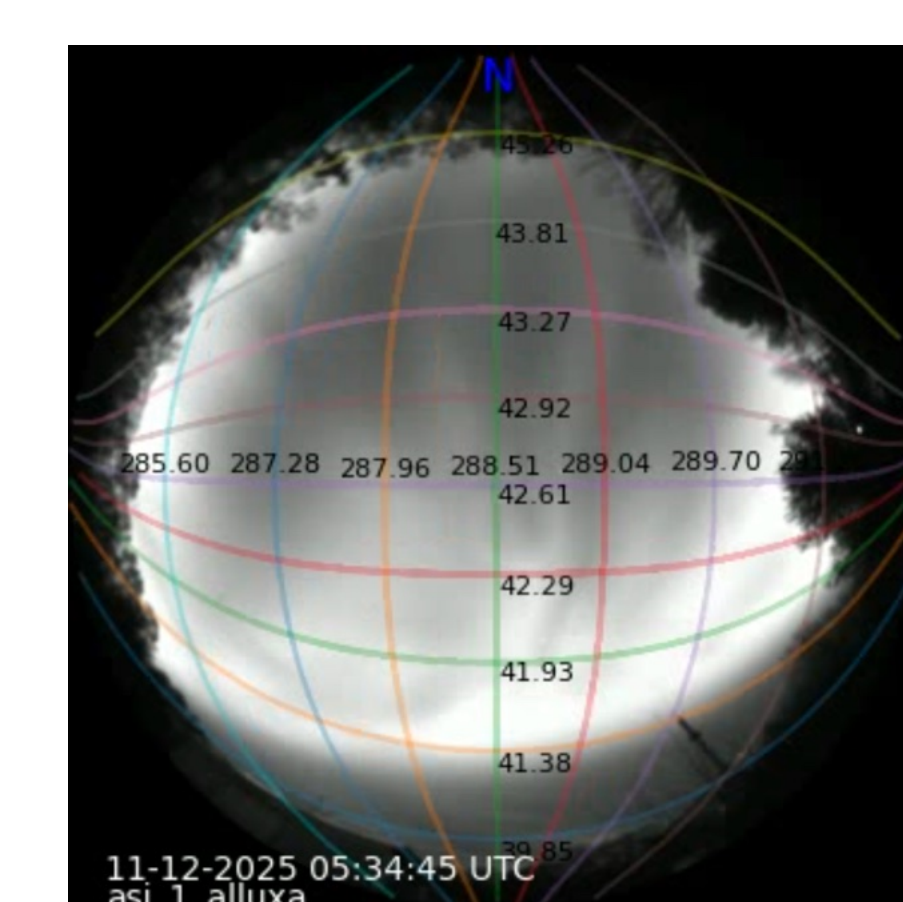


Figure 12: In this figure, we show the aurora with our red line filter as observed from Millstone Hill on November 11, 2025. We currently have two instruments deployed: one in Easton, Maine and one at Millstone Hill in Massachusetts. One of our goals is to create an array of imagers across the northern border of the United States to be able to detect the border of the auroral circle in real time.

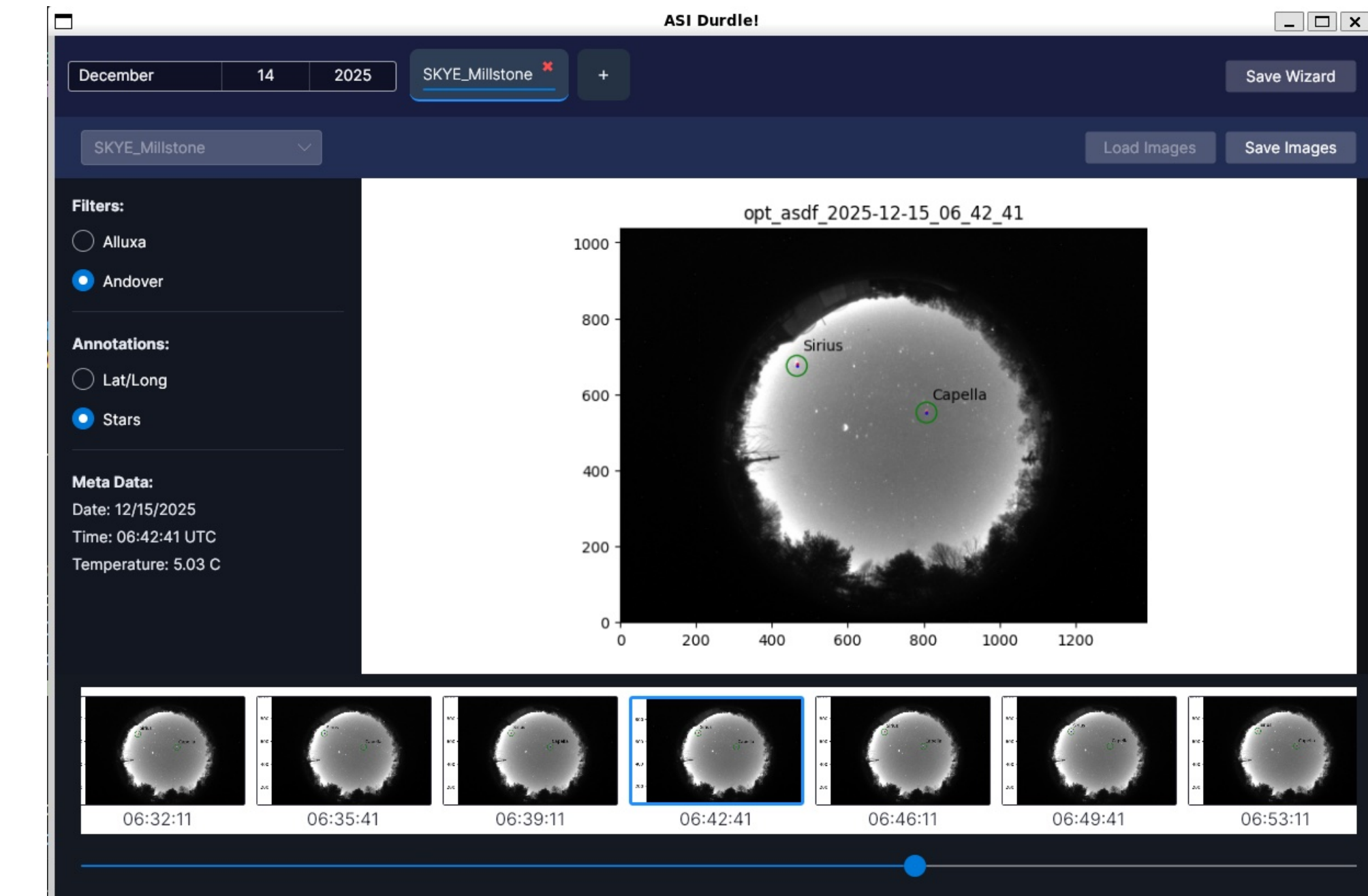


Figure 13: In addition to probing the aurora and other atmospheric phenomena, our ASI can also automatically identify celestial objects. This capability will be used in the future to identify satellites in the sky. We are currently working to expand the network across the entire CONUS and be able to observe and characterize disturbances in the upper atmosphere like Traveling Ionospheric Disturbances (TIDs). In this figure, we show our visualization software that allows the user to easily browse all-sky imager data and download images of interest. This software is available for Windows, Linux and Mac operating systems.