Probing the lower F-region thermosphere with ionospheric heater emissions

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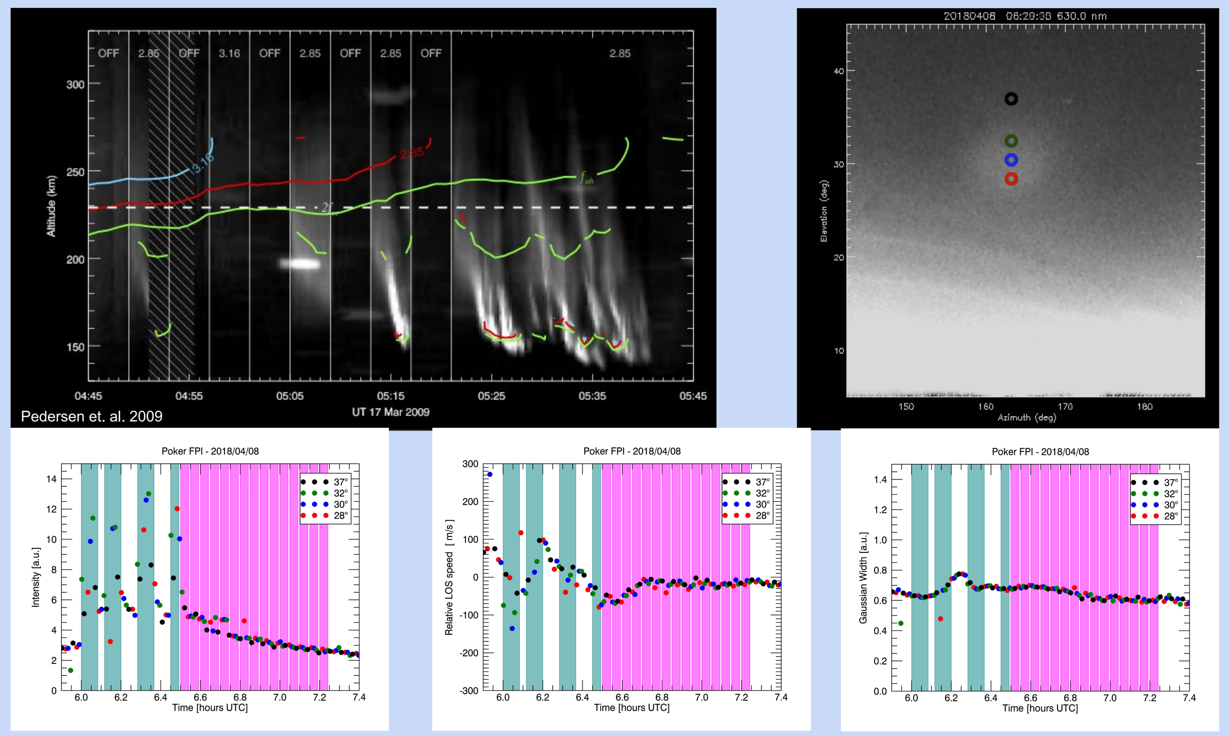
Introduction

Fabry-Perot interferometers (FPIs) are highly sensitive optical instruments and have been used in studies of the atmosphere for over half a century. During this extended period of use, FPIs have been used to determine the wind vector and temperature of neutral atmospheres. FPIs have used naturally occuring emissions to perform their observations. Ionospheric heaters, such as the one at the High-frequency Active Auroral Research Program (HAARP) in Gakona, AK, produce emissions that are very similar to the naturally occurring emissions that FPIs have historically observed. FPIs observe 557.7 nm airglow around 100 km altitude and 630.0 nm airglow around 240 km altitude, but the ionospheric emissions lie in the region between these two (140-200 km), offering an opportunity to bridge the gap between the regions of natural airglow.

Recent efforts have been made to observe ionospheric heater emissions with FPIs, but ionospheric and instrument conditions limited success so far. If future attempts are successful, FPI observation of ionospheric heater emissions would provide an altitude profile of wind vectors and temperatures in a new altitude region for FPI observation.



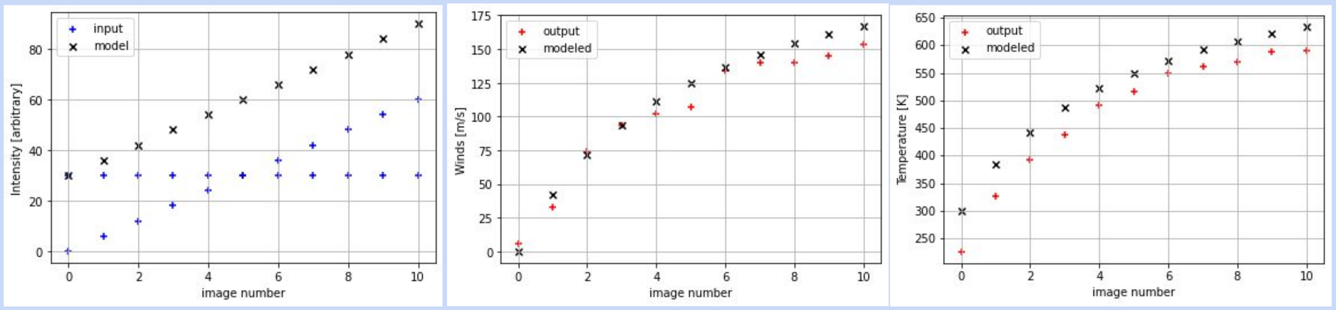
Top left figure shows green line ionospheric heater emissions. While FPI observations are of the brighter red line emissions, both lines are generated in approximately the same region.

Top right figure shows the FPI field of view for 4 different look directions over top of the HAARP spot with one background (black).

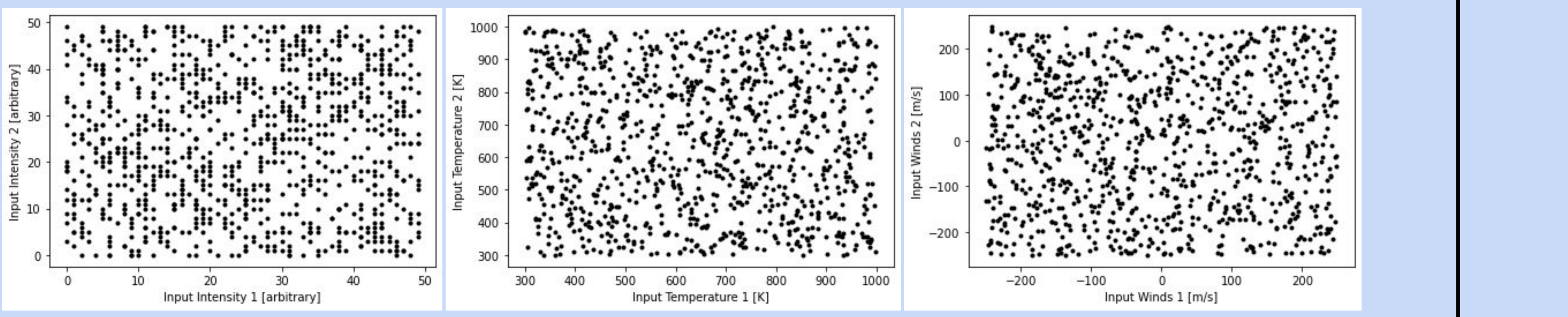
Bottom figures show intensity, line-of-sight speed, and gaussian width (associated with temperature) from left to right. These are products of FPI analysis from a 2018 HAARP campaign.

Modeling

Existing observations of ionospheric heater emissions have been limited to twilight hours due to conditions associated with solar minimum. During twilight, the background natural airglow is a similar brightness, so interferograms contain light from both the ionospheric heater emissions as well as the natural background airglow. Using interferograms with multiple sources of light is a departure from the assumptions of FPI analysis, so the effect of this departure required investigation. A series of pilot cases of multiple emission interferograms were constructed and analyzed. One such case is shown below where the figure on the left shows the intensity of the two input emission lines. The line that was constant in intensity had 0 m/s doppler shift and 300 K temperature source parameters. The line that increases from 0 to 60 units of intensity had 250 m/s doppler shift and 800 K temperature source parameters. In each plot, the black x's show a model prediction.



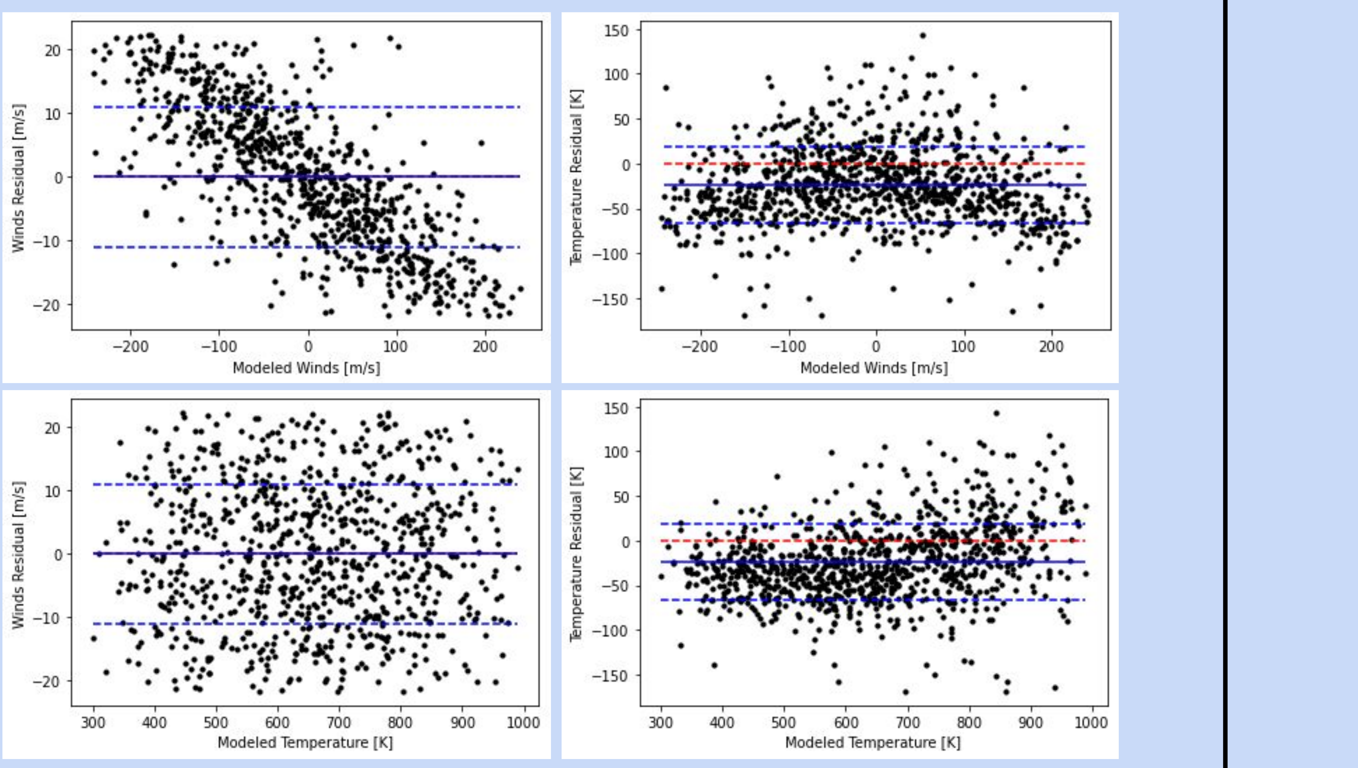
$$W_a = \frac{W_b I_b + W_h I_h}{I_b + I_h} \qquad T_a = \frac{T_b I_b + T_h I_h}{I_b + I_h}$$



A collection of 1000 simulated multiple emission interferograms was created to gauge further the effect of multiple emissions in analysis. The three figures above show the input parameters for the 1000 synthetic multiple emission interferograms that were created. Each interferogram is represented with a dot, so each interferogram has a pair of input intensities with a pair of temperatures and wind speeds. The 1000 images were then sent through FPI analysis.

The figures to the right show plots of the residuals (output-model) between the model and the analysis output.

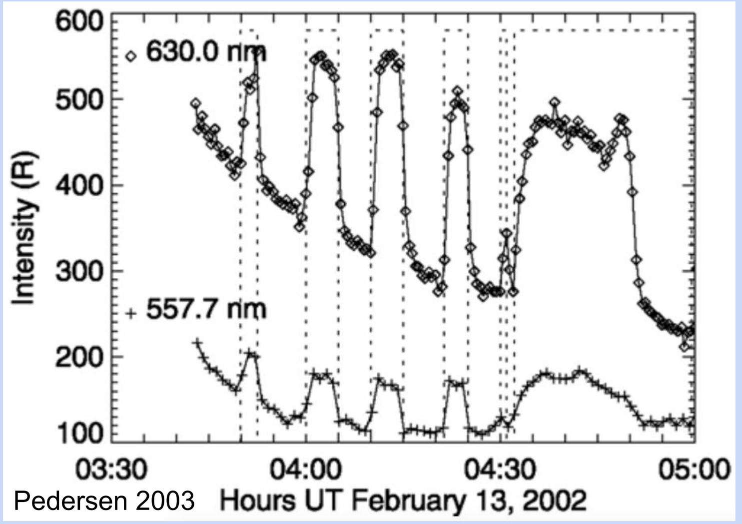
Future work looking into subtracting background profiles from the multiple emission interferograms is currently being looked into.

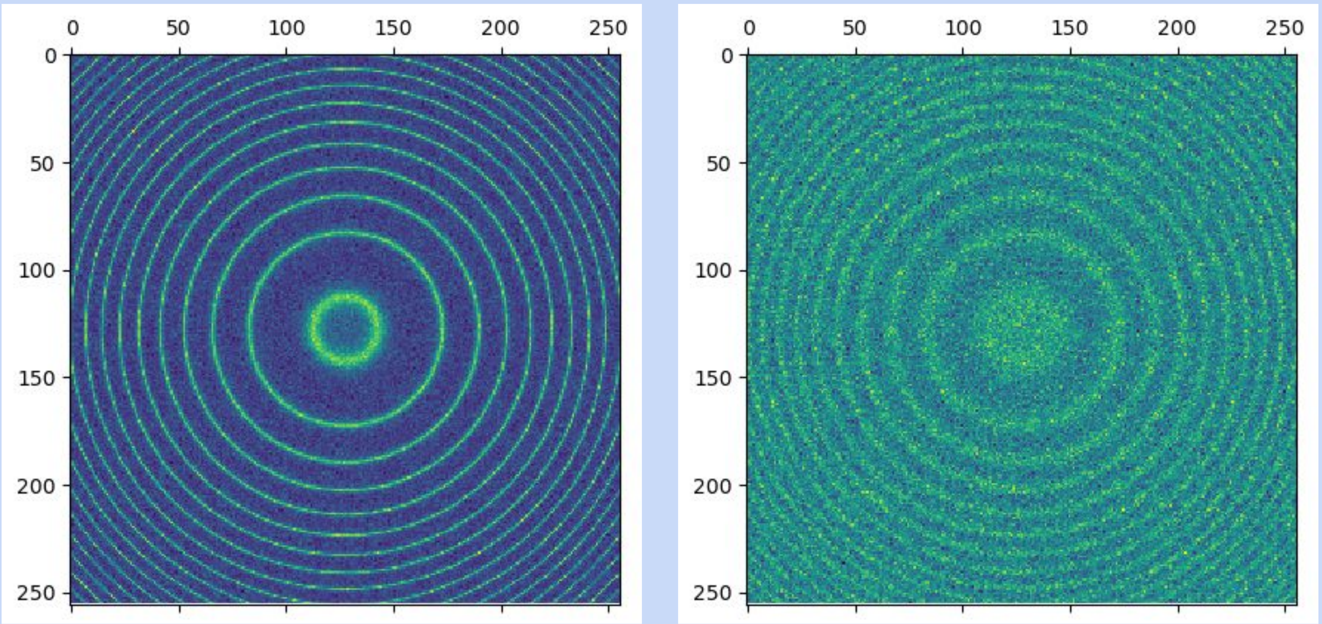


Instrumentation

Narrow-field FPI: The Fabry-Perot interferometer uses constructive and destructive interference of light to create an interference pattern like those shown below. The field of view of the FPIs here is a narrow 1°. This allows the instrument to be directed in localized areas of the atmosphere. Below are synthetic interferograms generated with an integral including the Airy function and a source function with Poisson noise added to the result. The image on the left is a laser calibration image, so the source function is a delta function. The image on the right is a sky image, so the source function depends on the temperature and mass of the emitting species and broadens the rings in the interference pattern.

Ionospheric Research Instrument (IRI): At HAARP there is a large array of radio transmitters called the Ionospheric Research Instrument. This array is capable of producing 3.6 MW of radio wave propagation. One feature the IRI is capable of generating is a region of ionospheric heater emissions. The intensity of these emissions can be seen in the figure to the right, where there are enhancements of each line while the IRI is operating (indicated by the dotted line). Below is an image of the IRI at the HAARP facility in Gakona, AK.





Conclusion

The response of the FPI analysis to multiple emission interferograms is predictable and in a high volume of cases follows an intensity weighted average for wind speed and temperature within +/-10 m/s and +/-50 K. While FPI observations during future HAARP campaigns will unavoidably contain both ionospheric heater emissions and natural background airglow, using the weighted average model will yield wind speeds and temperatures in the 140 - 200 km altitude range, provided the temperatures and wind speed in the background airglow region are reliably tracked. Another method of extracting HAARP winds and temperatures in HAARP emission region altitudes from multiple emission interferograms via subtracting the background image from the multiple emission image is being investigated. It is possible that both methods are viable and yield the same result.

Using the IRI at HAARP to produce observable emissions is an exciting and unique prospect to track winds and temperatures in an otherwise difficult and expensive region to make observations.

Acknowledgements

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