Automated estimation of dominant horizontal wave parameters appearing in airglow images

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Abstract

It is well known through both observation and theory that internal gravity waves generate signatures in the 630.0-nm airglow. The horizontal properties of these signatures (e.g., wavelength, phase speed, period, orientation) are useful to measure as they provide information about the characteristics of the internal gravity wave. Here, we present a technique that automatically estimates (potentially in real-time) the parameters of the dominant wave features appearing in data from airglow imaging systems. We show results of the technique applied to imaging data from the Cornell All-Sky Imager (CASI) taken during 2015-2016 atop the Haleakala Volcano in Hawaii.

Background

- Wave structures are commonly observed in the 630.0-nm airglow using ground-based imaging systems.
- These wave structures are often the signatures of internal gravity waves, properties of which are a topic of active research.
- The signatures can have weak amplitudes, making them difficult to distinguish and subsequently measure using subjective methodologies.
- Our algorithm removes the "human component" from the measurement process and allows for large-scale studies.

Algorithm Overview

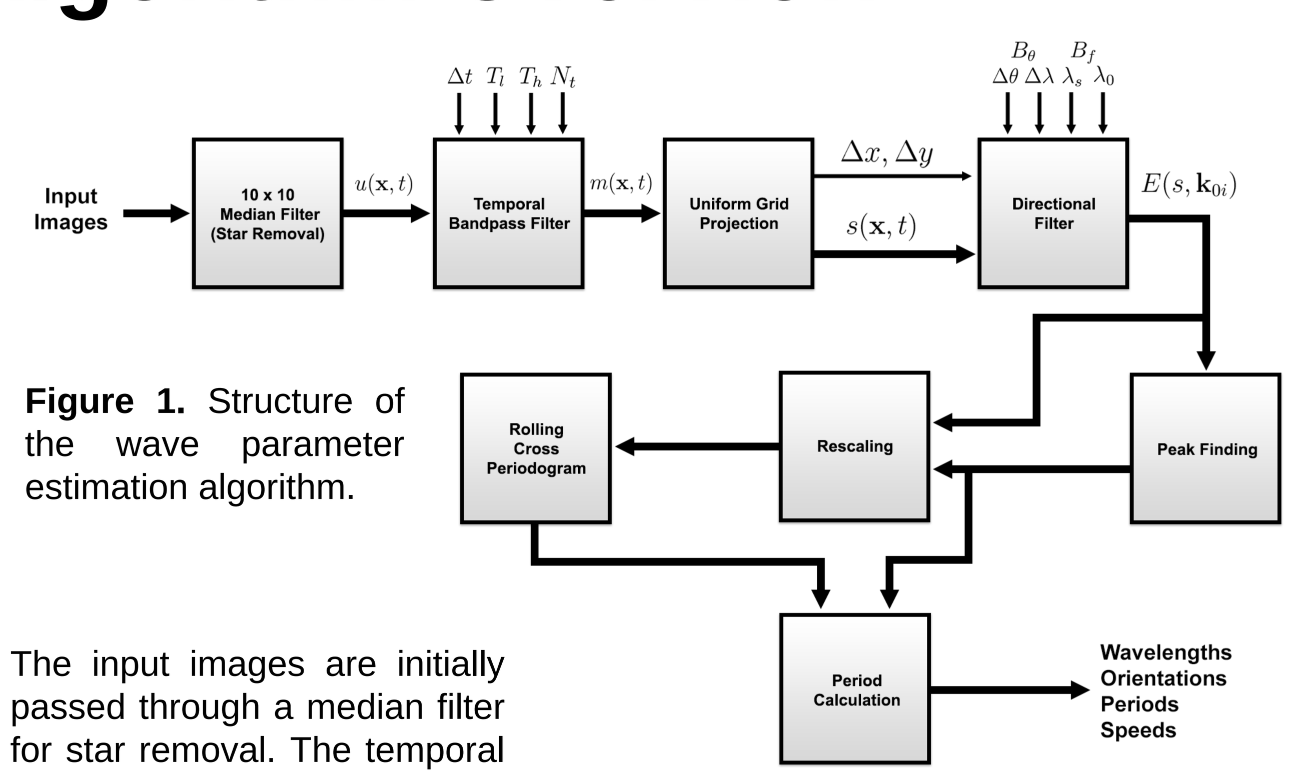


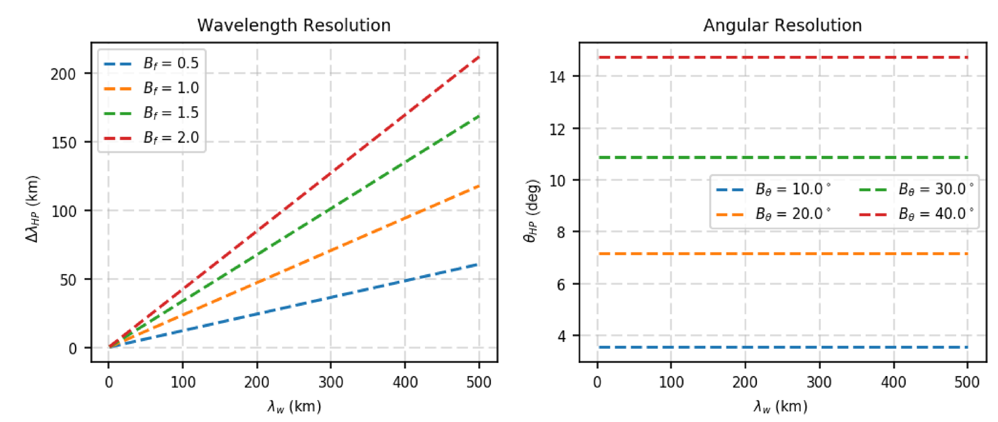
Figure 1. Structure of the wave parameter estimation algorithm.

- The input images are initially passed through a median filter for star removal. The temporal filter is applied to isolate periods of interest (coinciding with typical internal gravity wave periods).
- The directional filtering step determines the wavelength and orientation of the dominant wave feature in each image. The rolling cross periodogram then calculates the period and velocity using the wavelength and orientation measurements.

Δt	Temporal Sampling Period
T_l	Lower Period Filter Cutoff
T_h	Upper Period Filter Cutoff
N_t	Temporal Filter Length
Δx	Spatial Sampling Period (East/West)
Δy	Spatial Sampling Period (North/South)
$\Delta\theta$	Orientation Bin Size
$\Delta\lambda$	Wavelength Bin Size
λ_s	Lower Wavelength Bound
λ_0	Upper Wavelength Bound

Algorithm Overview (Cont'd)

Figure 2. Resolution in orientation and wavelength can be controlled through the frequency bandwidth (B_f) and orientation bandwidth (B_θ) parameters in the algorithm.



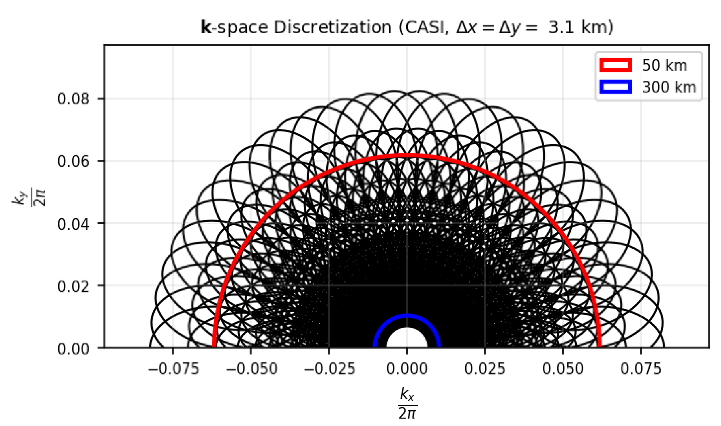
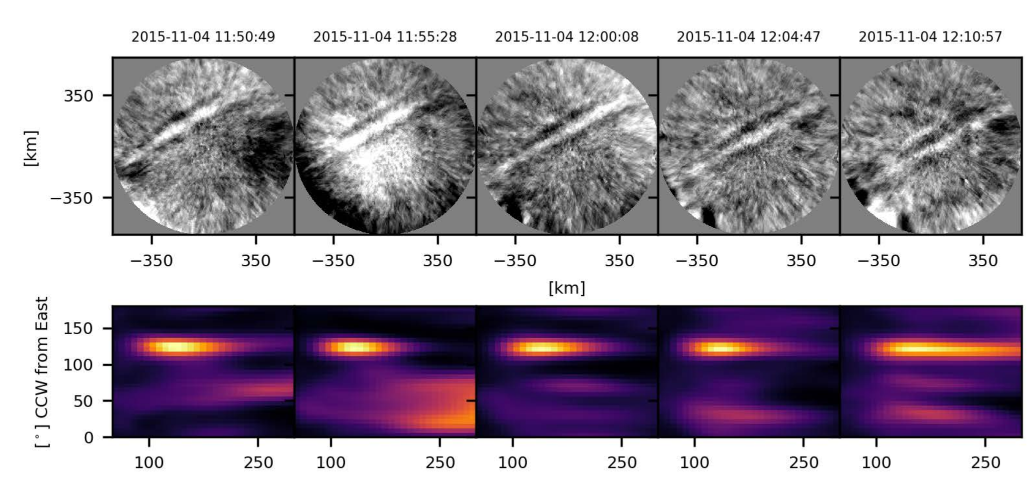


Figure 3. Half-power ellipses of each Gabor kernel used in the directional filtering step. Frequency and orientation bandwidth affect the size and shape of the kernels. $B_f, B_\theta, \Delta\lambda$, and $\Delta\theta$ all need to be chosen to cover the region of interest in **k**-space.

Results

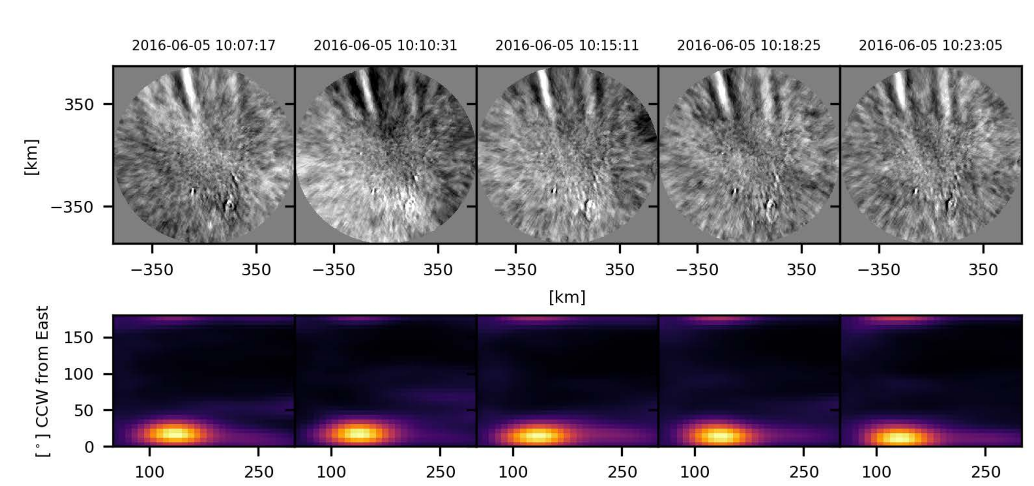
For each of the dates, the top row in each figure show 5 temporally filtered frames from the event. The bottom row shows the energy surface output from the directional filtering step for each frame. The actual wave measurements are provided in the rightmost tables.

4 November 2015



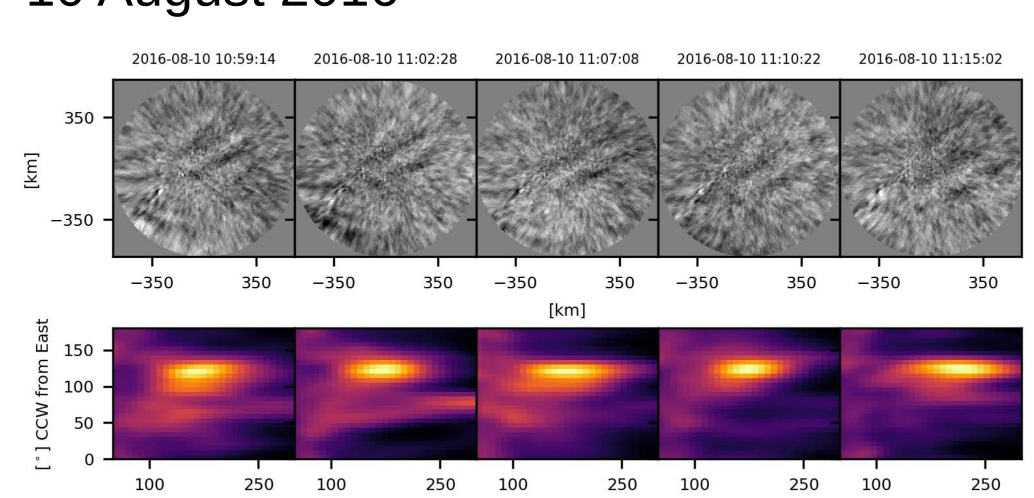
Measurements	
Wavelength	$164\ (\pm 44)\ km$
Orientation	$297\ (\pm 2)\ ^\circ$
Period	$13.9\ (\pm 2.2)\ min$
Phase Speed	$194\ (\pm 24)\ m/s$

5 June 2016



Measurements	
Wavelength	$154\ (\pm 25)\ km$
Orientation	$186\ (\pm 4)\ ^\circ$
Period	$21.8\ (\pm 5.4)\ min$
Phase Speed	$106\ (\pm 34)\ m/s$

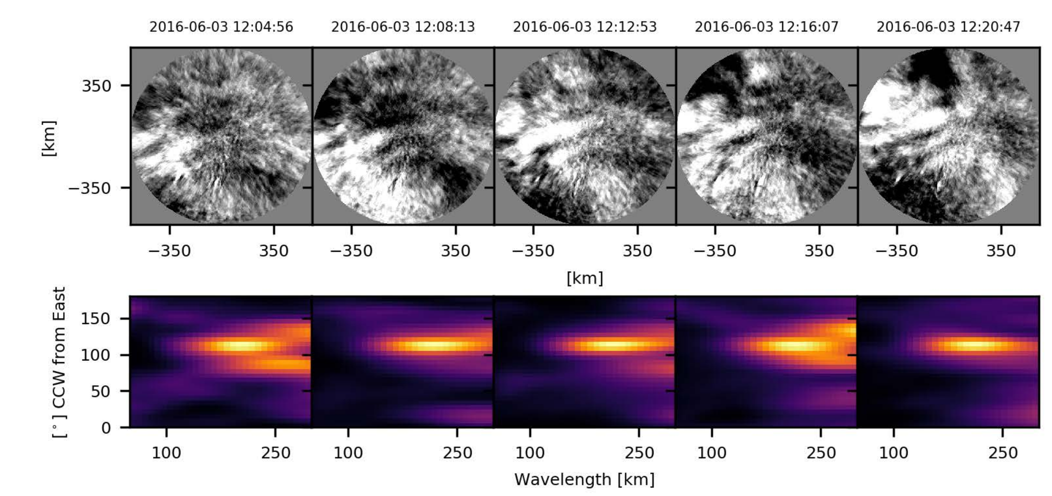
10 August 2016



Measurements	
Wavelength	$175\ (\pm 25)\ km$
Orientation	$301\ (\pm 3)\ ^\circ$
Period	$14.8\ (\pm 3.0)\ min$
Phase Speed	$210\ (\pm 26)\ m/s$

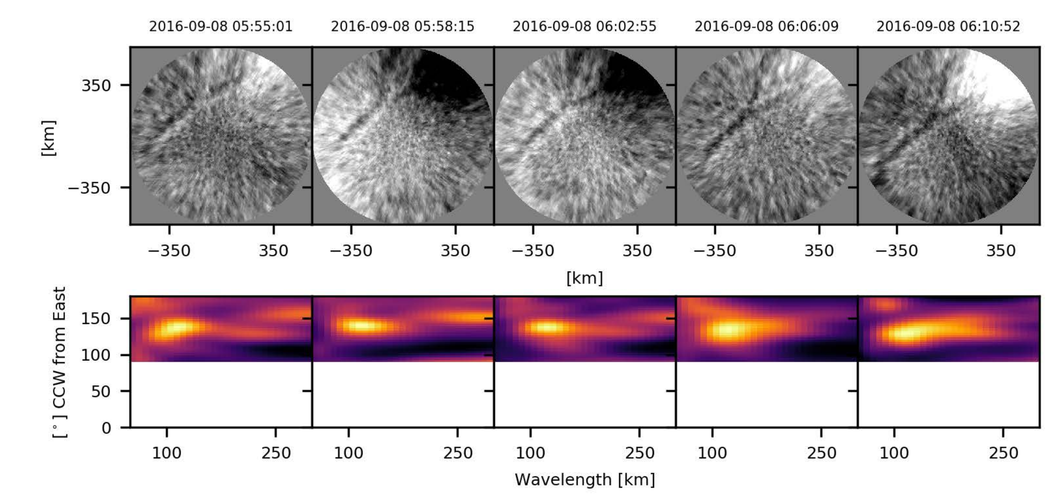
Results

3 June 2016



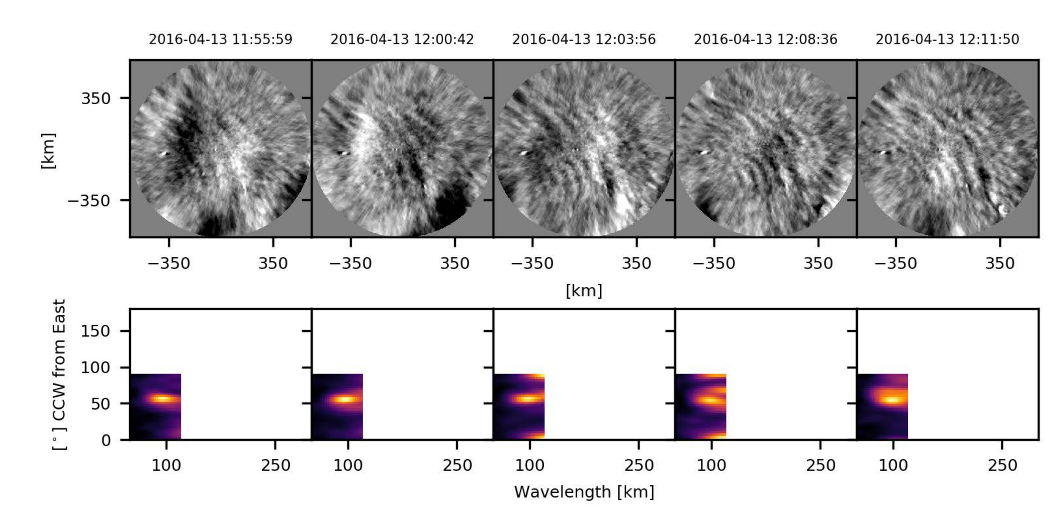
Measurements	
Wavelength	$156\ (\pm 20)\ km$
Orientation	$123\ (\pm 25)\ ^\circ$
Period	$18.2\ (\pm 3.2)\ min$
Phase Speed	$139\ (\pm 22)\ m/s$

8 September 2016



Measurements	
Wavelength	$113\ (\pm 4)\ km$
Orientation	$313\ (\pm 4)\ ^\circ$
Period	$11.9\ (\pm 2.3)\ min$
Phase Speed	$164\ (\pm 30)\ m/s$

13 April 2016



Measurements	
Wavelength	$98\ (\pm 10)\ km$
Orientation	$22.8\ (\pm 1.5)\ ^\circ$
Period	$10.3\ (\pm 1.8)\ min$
Phase Speed	$163\ (\pm 30)\ m/s$

Conclusions

- Airglow wave parameter measurement can be automated using wavelet-based signal processing techniques.
- The algorithm ran at around 21 seconds/frame on a 16 core machine. This is faster than the imaging cadence (3-4 minutes/frame), meaning that real-time operation is a possibility.
- When the wave-of-interest is not the dominant feature in the image sequence, a more sophisticated peak-finding block will be necessary (likely based on clustering) in order to separate out different wave events across space and time.

Acknowledgements

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