Synthetic Airglow All-Sky Imager Data for the Interpretation of Gravity Waves Imaged Over Wide Fields of View

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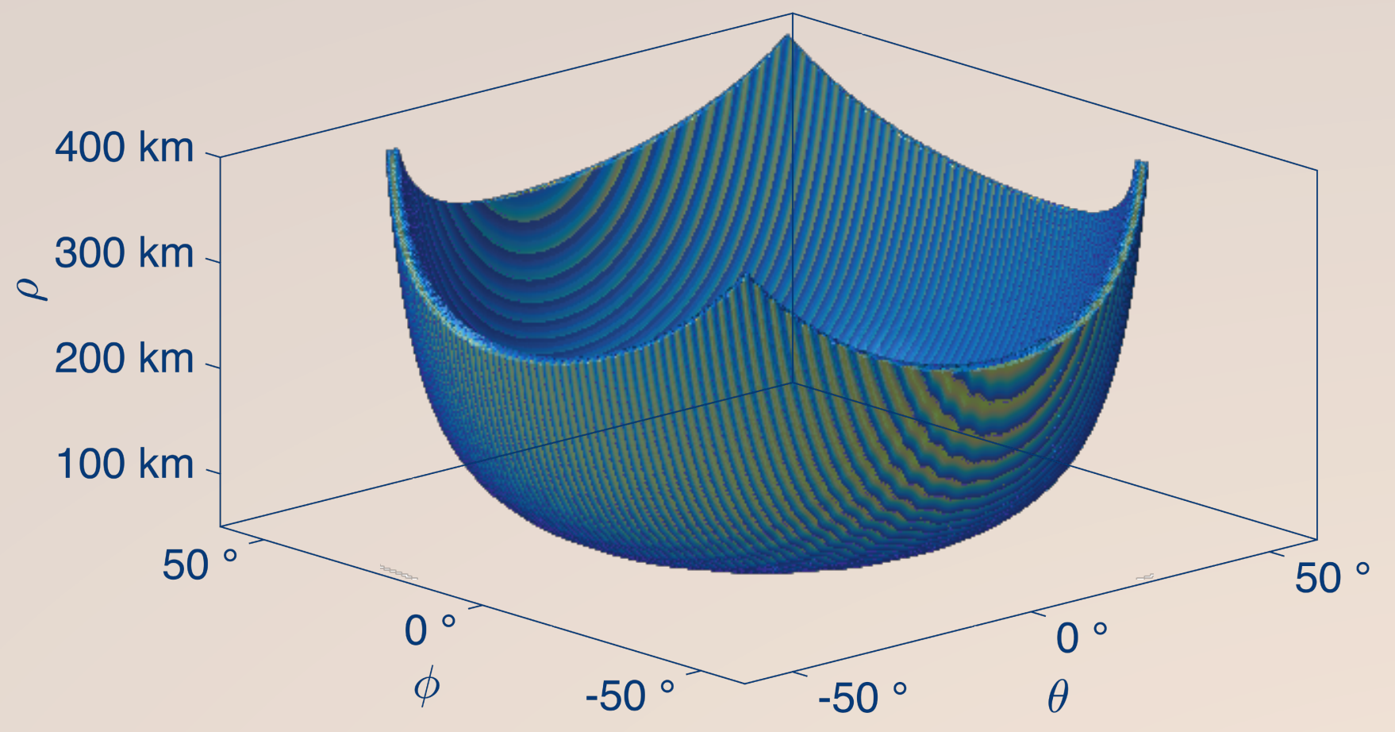
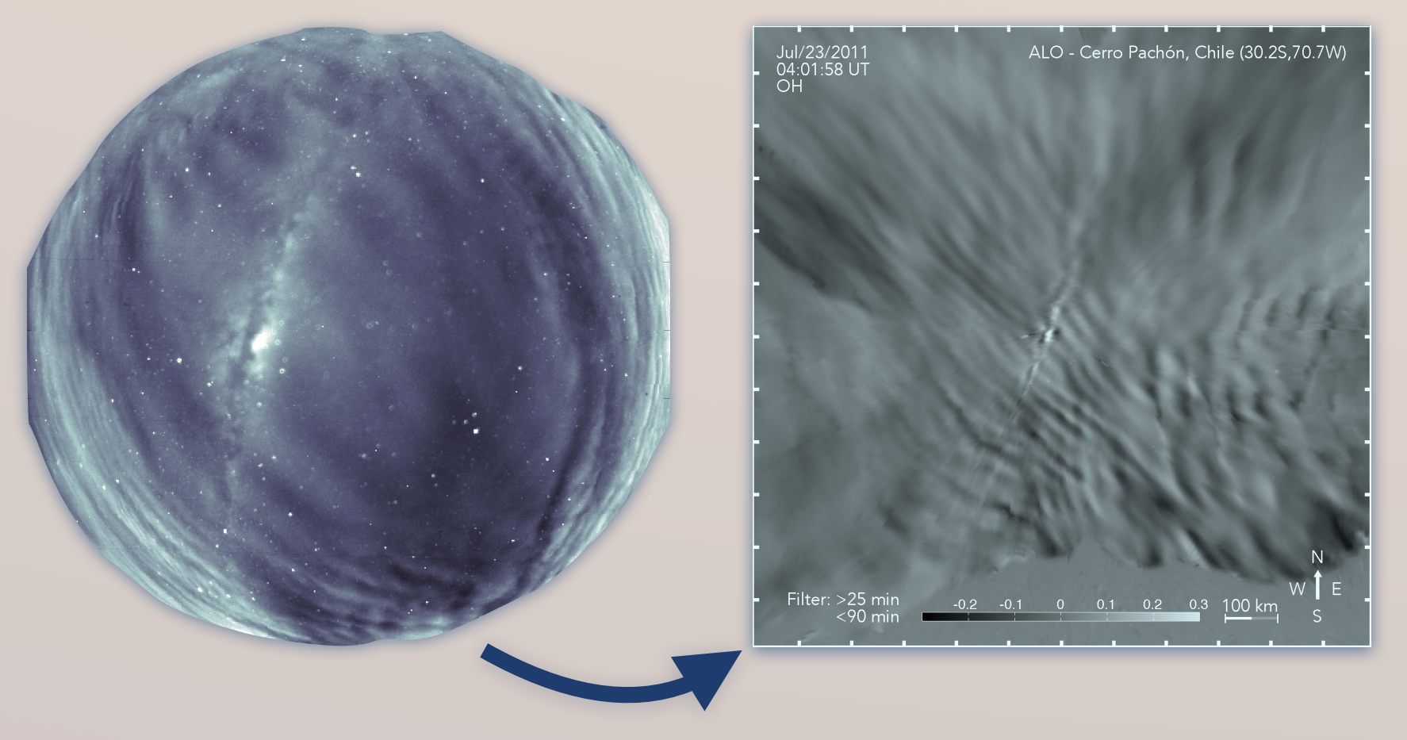


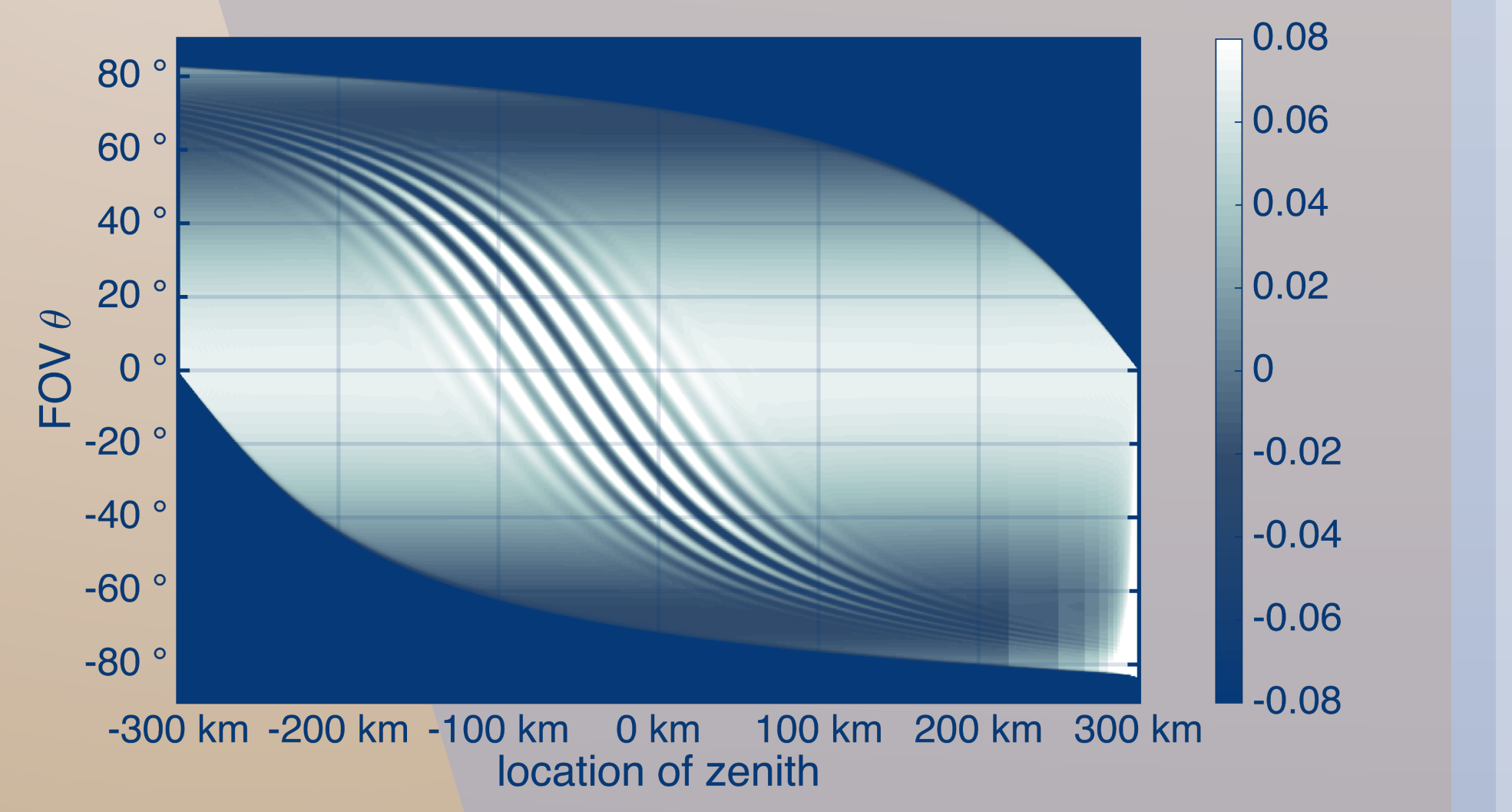
Memory-intensive interpolation

The airglow-observer geometry is a set of equations that map the position of the layer —in relationship to the radius of the Earth— to the zenith angle of the observer. To effectively create a synthetic CCD imager these equations map the cartesian 3D space onto a pseudo-spherical 3D space (with the origin at imager's location) where the zenith angle is related to the true polar spherical angle (with origin at the center of the Earth). Numerical interpolation needs to be performed to apply the mapping to the input airglow layer; this is a memory-intensive procedure. A 3D slice representation of the interpolated layer in uniformly-spaced θ, ϕ, ρ is shown above.



Real imager data

The image on the left shows the original OH layer as seen by a real 512×512 imager. On the right, we can see the unwarped-flattened image. The flat fielding technique used here is a temporal moving average, which is a process that requires many images at previous/subsequent times; it also introduces temporal frequency filtering for the imaged waves. If the extra temporal data is not available, other flat-fielding techniques must me employed.[2]



A moving observer

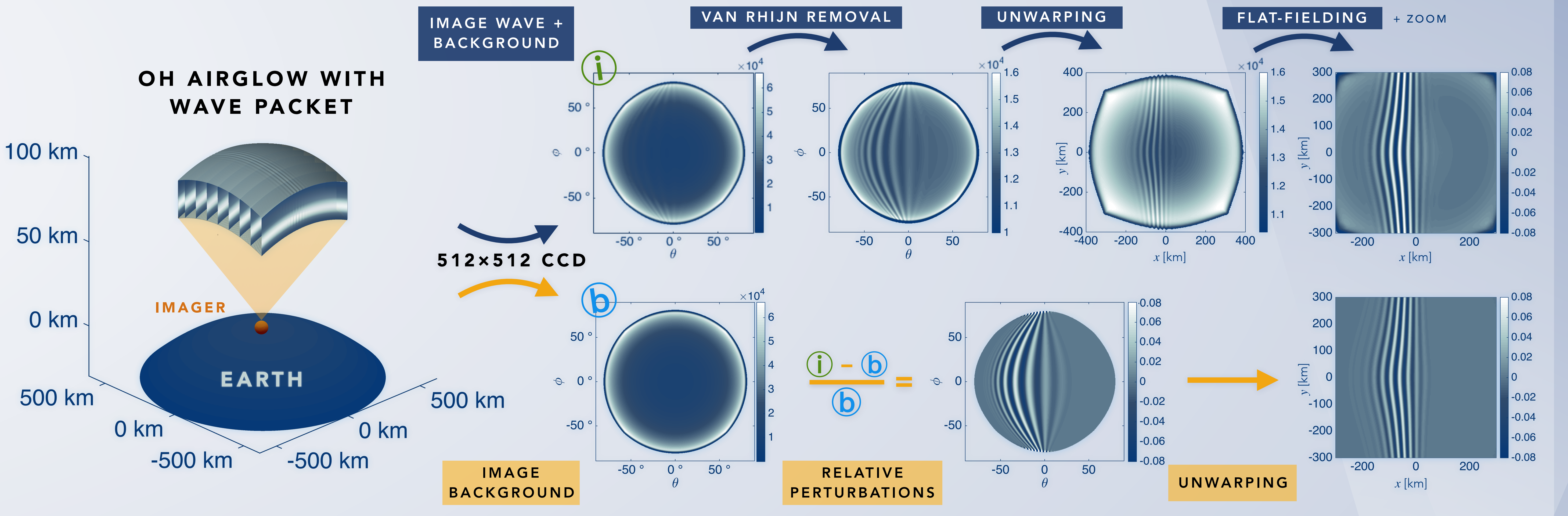
The plot above shows the effects a moving observer (conversely, the observer might be stationary while the wave feature is traversing through the layer) for the same perturbation as in the flowchart. The x-axis shows the position of the moving observer from the origin. The y-axis depicts a composite image where every column represents the 1D IVER as imaged by a 512×1 pixels, 180° FOV imager: for example, the 0° line is always the IVER of Zenith. If the domain had been infinite, there would be data extending up to 90° FOV. This image clearly shows that gravity wave features and scales can only be optimally imaged at certain FOVs or at certain off-zenith angles.

Introduction

All-sky airglow imager data provides the clearest insight into processes centered on its zenith. At large fields-of-view (FOVs) there is an expected decrease in spatial resolution but also significant line-of-sight (LOS) effects as the integration path lengths extend deeply and obliquely through the perturbed airglow emission layers. The integration (imaging) of the vertical emission rates represents loss of information regarding the structure of the airglow layer as it effectively "flattens" it. While this process is non-invertible for real airglow data, the use of simulated airglow structures enables direct comparisons to the structures present within the emitting layers.

Imaging a 3D airglow simulation

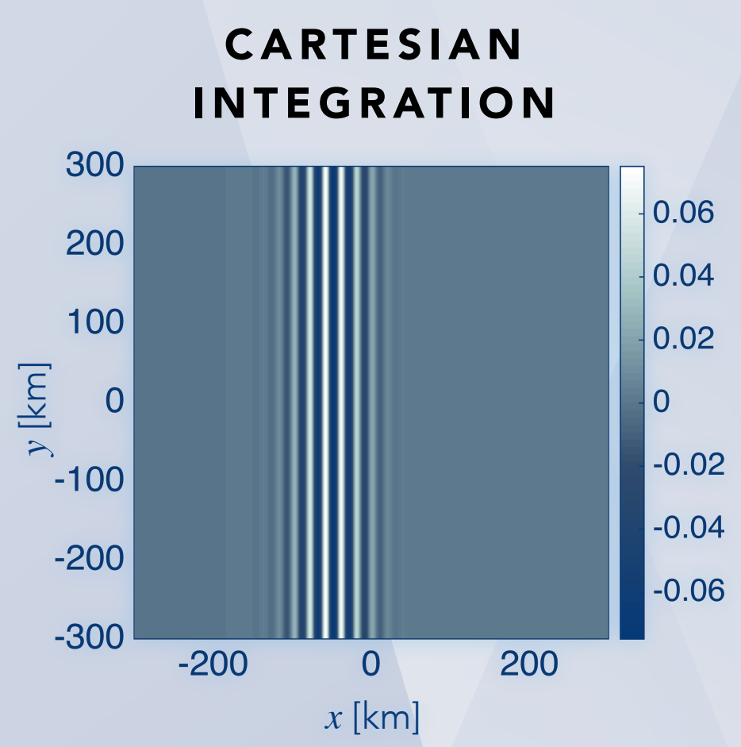
The flowchart to the right shows the step-by-step process of simulating an airglow imager using modeled data. The airglow perturbation sits above the observer's zenith and consists of a 2D output that has been replicated along the third (y or ϕ) dimension to create the 3D structure. The two different diagram paths show some of the challenges and techniques used to enhance the imaged wave. In many cases background information is not available in real imager data (lower yellow path) and the background must be eliminated using other techniques (upper blue path) that typically won't show the wave features just as well and my reduce the accuracy of ensuing spectral analyses.

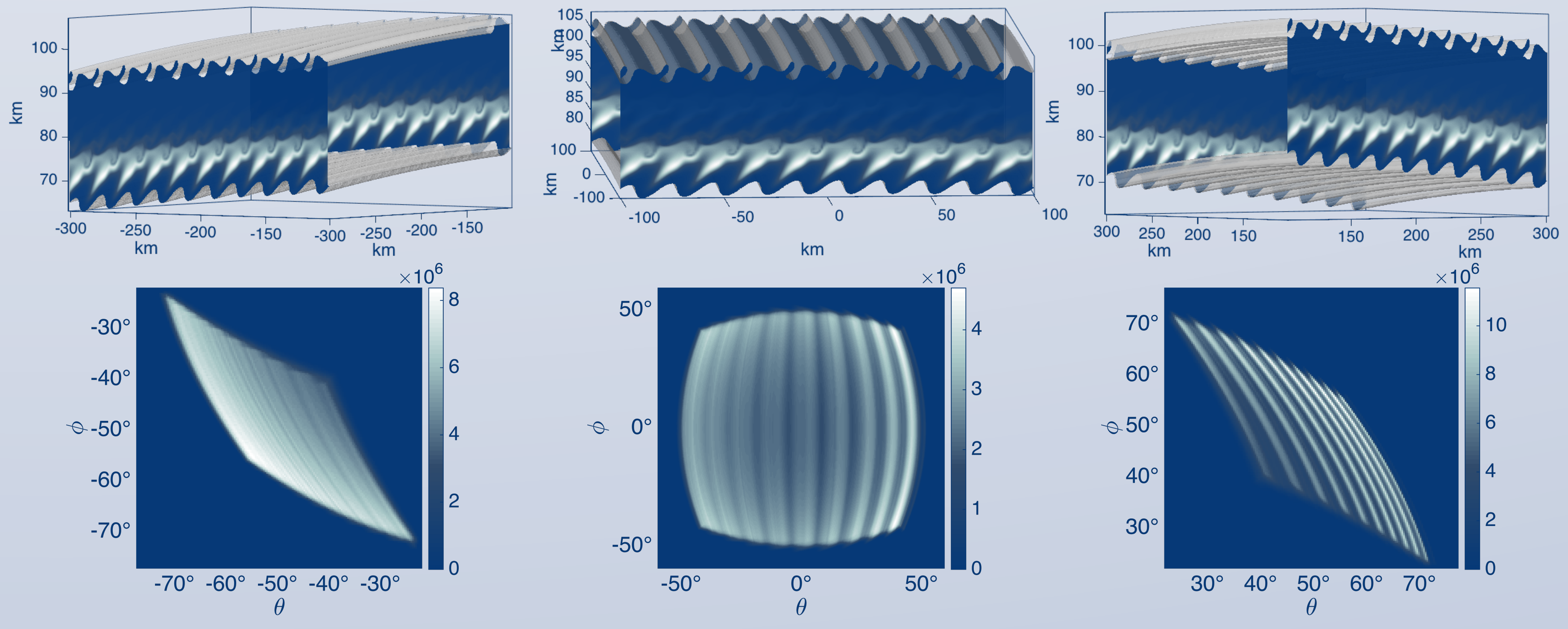


The upper blue path: ❶ Line-of-sight integration of the airglow perturbation using a 512×512 imager. ❷ Removal of the van Rhijn geometric intensity enhancement. ❸ Mapping to geographic coordinates at OH mean layer height of 87 km. ❹ Normalized flat-fielding by fitting a 2nd degree polynomial: van Rhijn removal alone is not good enough and extra flat-fielding techniques are necessary.

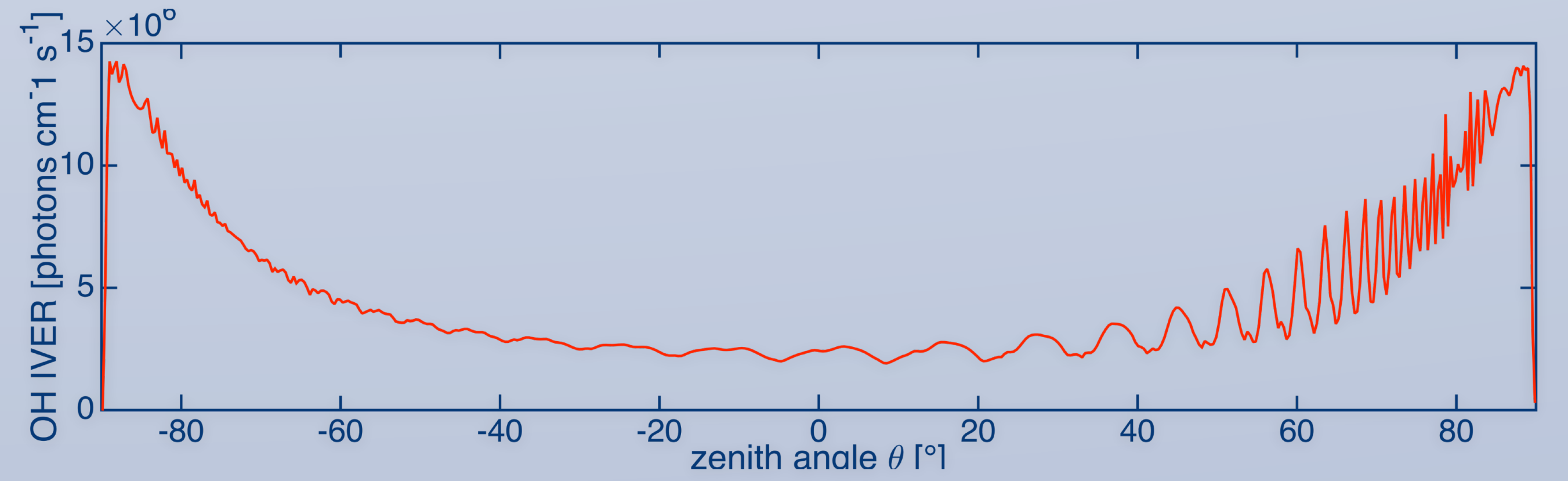
The lower yellow path: ❶ Line-of-sight integration of the background (unperturbed airglow layer) using a 512×512 imager. ❷ Relative perturbations for image ⓘ using the previous background image ⓑ. ❸ Mapping to geographic coordinates: no further flat-fielding is necessary, wave feature clearly defined and ready for spectral analysis. Also, the intensity scale is more accurate.

The geographic cartesian integration: This LOS integration is done for a layer that doesn't curve with the Earth. This is our reference image to examine the accuracy and precision of the synthetic imager. As we can see from the yellow path, there are visible geometry effects in the synthetic imager including bulging and line broadening.





OFF ZENITH: 200 KM WEST & SOUTH
ON ZENITH
OFF ZENITH: 200 KM EAST & NORTH



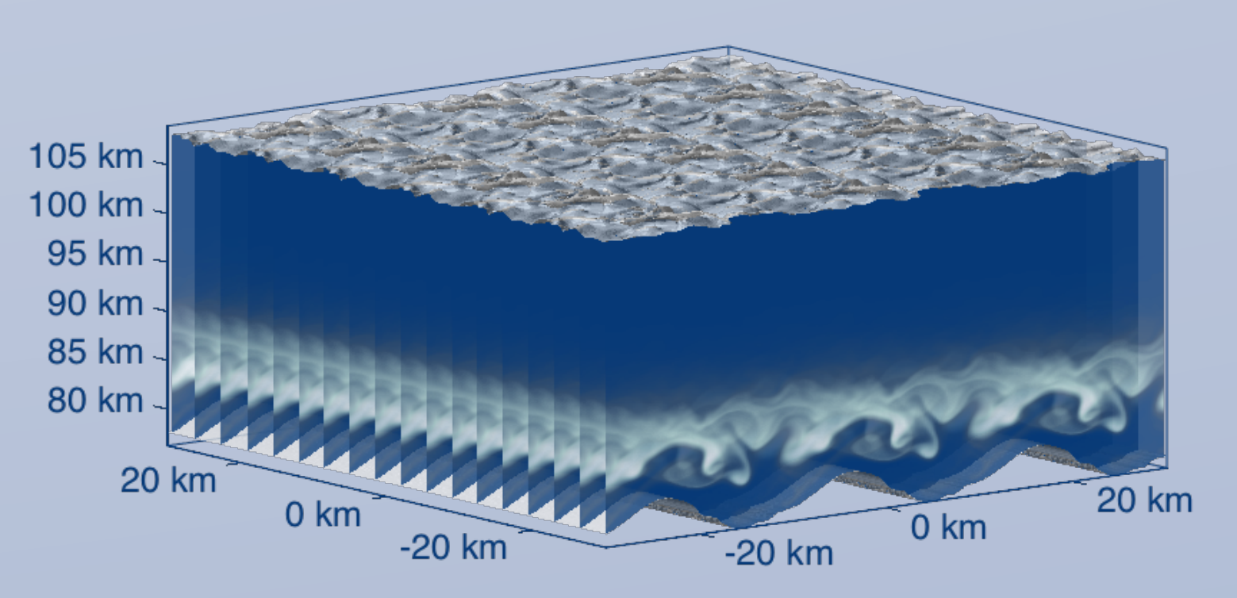
Cancelation effects due to line-of-sight integrations

In addition to the 3D structures and 2D images shown above, we can show a 2D plot of an airglow layer that has been further extended above zenith. Using a slice of the 3D data, the domain is extended up to 2000 kilometers to further enhance the cancelation effect that happens when the LOS aligns (or not) with the wavefronts. These effects, therefore, greatly depend on the shape of the observed wave structure and other dynamical phenomena.

Imaging a turbulent layer

To the left are 3D visualizations of the OH emission layer from a 3D nonlinear simulation. The input data are blocks fixed in time of 20x10x160 km (x, y, z and periodic in x and y) and 125 m resolution; the blocks have been replicated along x and y to further extend the domain. The upper images show the 3D structure while the lower images are the LOS integration using synthetic imagers respectively. For a clear visualization, intensity units (photons$\cdot$cm$^{-3}\cdot$s^{-1}) and integrated intensity units (photons $\cdot$ cm^{-2} $\cdot$ s^{-1}) are preferred rather than using relative perturbations (which are up ±~15% for this example). **Left**: oblique LOS leads to filtering. **Center**: imaging over the zenith provides the most straightforward depiction of the wave. **Right**: parallel LOS produces clear enhancements.

In this study we used results from a fully nonlinear, compressible, 2D and 3D model by Snively et al., 2010[1] to generate distinct wave packets that are then integrated along the LOSs of simulated CCD pixels and a varying FOV all-sky lens. For details of 2D/3D airglow modeling, see *Snively CEDAR Talk in the GW session, Thurs.*].



MIXING IN TURBULENT DATA AT LARGER TIME-STEPS

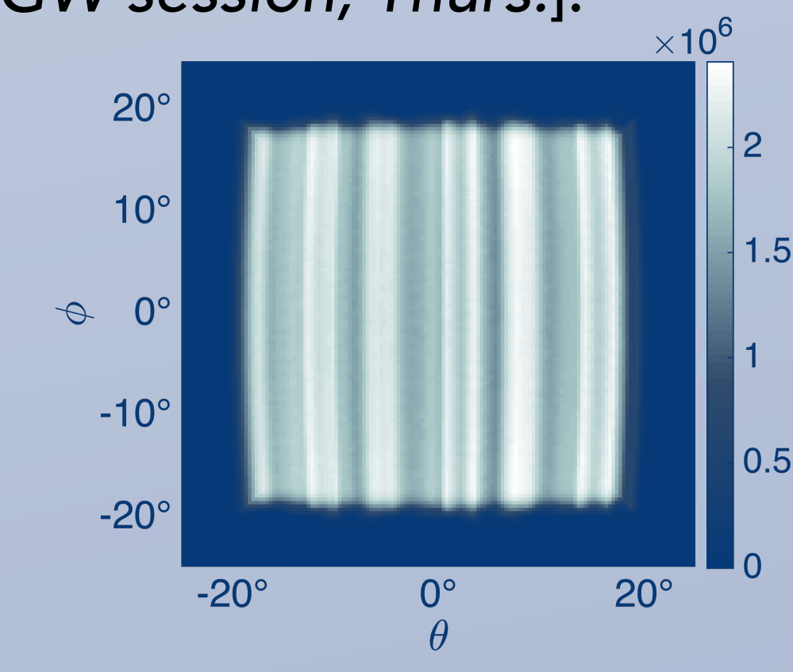


IMAGE CENTERED ON ZENITH

The importance of off-zenith imaging and simulations | further research

Using modeled data we can understand how to improve on the interpretation of imager data (or even the design of imagers and observations). There are many geometric effects that depend on the airglow-observer configuration, rather than the observed wave perturbation; some of the most important are: **line-of-sight enhancements, cancellation effects, geometric distortions, intensity variations, filtering of scales** and even the inability to register wave signatures at all. Further research using modeled data can inform observational campaigns on how to better target certain wave processes. This includes **off-zenith observations using a moving observer** (such as an airplane or a satellite) and may be able to provide insight on optimal configurations or guidance in the interpretation of fortuitous data. This research aims to provide a **framework** to enable model comparisons with data from **diverse experimental configurations.**

References: [1]Snively et al. (2010), J. Geophys. Res., 115, A11311.
[2]Andes Lidar Observatory (ALO) at Cerro Pachón,Chile: lidar.erau.edu

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