WINDII Atmospheric Wave Airglow Imaging

by

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ABSTRACT. - Preliminary WINDII nighttime airglow wave-imaging data in the UARS rolldown attitude has been analyzed with the goal to survey gravity waves near the upper boundary of the middle atmosphere. Wave analysis is performed on O2(0,0) emissions from a selected 1° x 1° oblique view of the airglow layer at ~95 km altitude, which has no direct earth background and only an atmospheric background which is optically thick for the O2(0,0) emission. From a small data set, orbital imaging of atmospheric wave structures is demonstrated, with indication of large variations in wave activity across land and sea. Comparison ground-based imagery is discussed with respect to similarity of wave variations across land/sea boundaries and future orbital mosaic image construction.

RESUME. - L’expérience WINDII à bord du satellite UARS mesure la luminosité nocturne de l’atmosphère à une haute altitude d’environ 95 km afin de produire des images des ondes de gravité dans cette région. Les données préliminaires obtenus par WINDII ont été analysées avec le but de caractériser les ondes de gravité qui existent près de la limite supérieure de l’atmosphère. L’analyse des émissions de O2(0,0) a été faite. Une vue oblique de 1° x 1°, qui possède un niveau de base atmosphérique avec une épaisseur optique, a été choisie pour éviter le “background” terrestre direct. A partir d’un petit nombre de mesures, on démontre qu’il est possible de construire des images qui font apparaître les larges structures des ondes atmosphériques. Les données indiquent en plus de grandes variations dans l’activité des ondes à travers le sol et la mer. Une discussion comparant des images obtenues avec des instruments basés sur le sol est présentée à propos de la similitude des variations à travers les limites sol/mer et la construction avenir des images mosaïques par satellite.

I. Introduction

An important aspect of mesospheric dynamics and energy balance in atmospheric circulation is the contribution of breaking and dissipating gravity waves [e.g., Holton 1982; Hamilton 1993; McFarlane 1987]. Indeed, a middle atmosphere dynamics workshop held at Loen, Norway in May 1992 highlighted the importance of gravity wave and atmospheric mean flow interactions, the potential for inter-hemispheric coupling and influences, and the importance of wave forcing at large and small scales for global circulation modeling (GCM) [Thrane et al. 1993]. These waves may be studied by direct imaging of the wave-modulated airglow layers at approximately 85-105 km altitude, either from the ground [Taylor et al. 1991; Taylor et al. 1993; Gardner et al. 1996; Swenson et al. 1996] or from orbit [Hersé 1984; Mende 1992]. An orbital wave survey has the potential to establish the global distribution of gravity wave sources and tidal filtering of the wave spectra as a study of wave contributions to departures in zonally averaged circulation predictions. Hence, through surveying of these wave source variations, stronger bounds on gravity wave forcing in atmospheric general circulation models may be made.

The primary sources of gravity waves are tropospheric in origin. These include weather systems [Fritts, Nastrom 1992] and associated thunderstorms [Taylor et al. 1988], tides, and orographic features [Nastrom, Fritts 1992]. Due to the exponential decrease in atmospheric density with height, gravity waves generated in the lower atmosphere and propagating upward
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grow considerably in amplitude in the absence of dissipation. Hence, tropospheric sources of waves exist which can result in a considerable disturbance at airglow altitudes near the mesopause, typically several percent in density and several hundred meters in vertical displacement [Hoppe 1989]. Of particular interest here, are variations in wave activity associated with large orographic changes from sea to land.

Airglow wave analysis for WINDII imaging [Shepherd et al. 1993] from the UARS orbital platform [Reber et al. 1993] has been developed to allow preliminary application of orbital imaging to wave surveys. The very limited amount of rolldown data which is appropriately formatted for wave analysis is restricted to a pass extending from the Caribbean south across Brazil on September 13, 1994. This data is reviewed in demonstrating orbital imaging of atmospheric wave structures with indication of large variations in wave activity across land and sea. Additional comparison to ground-based airglow wave imagery has been made and is reported here in the context of potential future roll-down orbital image collection.

II. Analysis

The image data consists of different contributions assumed to be related by

\[ I(x, y) = N(x, y) + G(x, y)[S_0(x, y) + S_1(x, y)] \]  

where \( I \) is the recorded image, \( N \) is the CCD total noise, \( G \) is the instrument total response, \( S_0 \) is the airglow mean signal, and \( S_1 \) is the airglow perturbation signal of interest. Working with the data available to date, detailed CCD readout noise, dark noise, and gain have not been fully compensated. Approximate compensation has been achieved in the regression analysis solution by assuming \( N \) is a constant and \( G \) is the interference filter function, as provided by the WINDII team. \( S_0 \) has been assumed to be given by the van Rhijn effect as calculated by a path-integral through a spherically laminar airglow layer, resulting in a relative intensification of

\[ \nu(x, y) = \left\{ 1 - \left[ \frac{R + t(x, y)}{R + h} \right]^2 \right\}^{-\frac{1}{2}} \]  

where \( R \) is the earth radius, \( h \) is the airglow altitude (~95 km), and \( t \) is the tangent height for different locations in the image designated by \((x, y)\). A least-squares fit is performed to arrive at a calculated image

\[ I = N + GS_0. \]  

The airglow perturbation is then calculated as either a difference image, \( I_{diff} = I - I \approx GS_1 \), or residual image, \( I_{res} = (I - I)/G \approx S_1 \). Low signal-to-noise and small \( G \) values can sometimes lead to residual images dominated by instrument noise. Hence, the results consist primarily of difference images, cropped so as to minimize the remaining filter function variation. A 3 x 3 bin median filter is finally applied to reduce single bin CCD noise.

Results of this analysis are shown in figure 1, for both a simulated wave and an example image pair. The simulated wave was constructed with wavelength of 25 km, and a projection consistent with the WINDII line of sight (los) and field of view (fov) 1. The image pair consists of images 5752 and 5760, in fov 2, and with interferometer phase settings of 3 and 4, respectively. These images were taken at 04:30:01 and 04:30:05 on 13 Sep '94 with 4 sec exposures, located at a pairwise center location of 1.46 degree latitude and -62.26 degree longitude, and at the airglow intercept altitude of ~95 km, as indicated in figure 2a). The subframes of figure 1 consist of the raw cropped image, the calculated image, the difference image, and the final orthographic
projection image. The projected image for the example pair is presented as a mosaic, wherein the average of the two images is formed where they overlap. Image overlap is generally not available in the data sequence, precluding larger mosaic construction.

Additional wavenumber analysis was also performed. For the restricted, elongated fov available in these images, 2-D FFT analysis is impractical. Hence, an alternative spatial evaluation was performed using cross-image averages combined with 1-D FFT analysis for different headings of the projected images. The resulting k vs. heading product indicated dominant structures of 25 km in the simulation and ~100 km in the image pair. Validation of the analysis is demonstrated by the correct recovery of the simulated wave. The example image pair analysis indicates continuity of observed structures across displaced images and scale sizes of 50 to 100 km, consistent with an interpretation of the structure as gravity waves. Suppression of the interferometric pattern in this analysis is good, but incomplete. Improved data, compensated for imager responsivity, is anticipated to improve the analysis overall, and to allow more general use of the residual image in mosaic composition.

III. Trends

Use of the existing data and analysis was made in seeking geographic trends in the data by extracting the peak-to-peak (p-p) modulation intensity in image pairs. The trial data sequence for this trend analysis bracketed the example images of figure 1, as the fov 2 moved from the eastern Caribbean to southern Brazil. Results of this trend analysis is shown in figure 2. Subframe a) presents the viewing geometry, and subframe b) plots the p-p modulation vs. latitude.

Though a small data set, there is still indication of large variations in wave activity, from negligible wave amplitude in the Caribbean to large wave amplitudes over South America. Source of the enhanced wave activity over Brazil is presumably an orographic effect from the Andes mountains. Similar identification of increased inferred wave activity on the lee side of the Andes coastal region has been reported elsewhere [Meriwether et al. 1996] and is indicated in the ground based imagery near the Norwegian coast taken during a campaign of Feb. '96, discussed below.

IV. Comparison with Ground-Based Imagery

A ground campaign for comparison with WINDII imaging was performed during Feb. '96, which employed a CCD all-sky imager located at the ALOMAR lidar research station in northern Norway. WINDII imaging did not become available during this campaign but is anticipated in future campaigns. This ground based imagery work is briefly mentioned here as it strongly indicates the characteristics of the data, analysis, and scientific benefit potentially offered in additional optimized WINDII airglow imagery. This imager recorded the OH airglow from ~86 km altitude in the region near the Norwegian Sea and the Scandinavian peninsula mountain range at 69° latitude.

Figure 3 presents one result of this data analysis. Subframe a) plots the time difference of two 90 sec exposure images, with a 30 sec separation, and an initial start time of 18:02 UT on 9 February 1996. The resulting image is transformed to an orthographic view, spatially median filtered to remove stars, and overlaid on a trace of the Norwegian coastline with imagery retained to a radius of ~400 km. Strong wave activity is observed over the SE land area, in contrast to weak wave activity over the SW ocean area. An auroral display is present in the northern region of the image. This land/sea geographic distinction of wave activity persisted for the hour of recording and analysis. A hypothetical, sequence of a WINDII 100 x 400 km fov is superposed to indicate the potential format of data available in additional mosaic satellite imagery. The k-spectrum for the central 90 km region of the image is shown in subframe 3b), averaged over an hour free of auroral activity. North and east are indicated with lines to the upper right and left, respectively. The dominant spectral content appears to be aligned NNW with wavelengths greater than 20 km. MF radar measurements at the nearby Tromsø site indicate winds are ~ENE at ~60 m/s at ~88 km altitude, courtesy of C. Meek, U. of Saskatchewan. This data would be representative of the comparison data sought for additional roll-down WINDII imagery.
V. Summary

Orbital airglow imaging analysis has been performed with compensation of interferometric pattern and mean image structure in demonstrating the presence of wave-like features in O\textsubscript{2}(0,0) imagery from ~95 km altitude. Image transformation and spatial analysis has been developed and utilized to indicate wave activity trends with geographic location, which is of interest in studies of wave forcing of atmospheric circulation. Continuing work will concentrate on attempting to record and analyze additional roll-down imagery in a format consistent with achieving a continuous mosaic image of wave structure. Analysis of variations of wave structure over geographically disparate regions will be emphasized.

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References


I. Figure 1.
Image analysis for simulated wave data (left) and WINDII example data pair with interferometer settings 3 & 4 (right). Subframes consist of the raw cropped images, a) and e), the calculated images, b) and f), the difference images, c) and g), and the final orthographic projection images, d) and h). The maximum dimension in h) is 340 km corresponding to a range of tangent height in the raw images of 0 to ~ 65 km.

Figure 2.
Transformation of images to global view. A cylindrical projection of the example images are shown in a), where the diamond is the satellite nadir location, the solid and dashed lines represent the los to the tangent height location of fov 1 and fov 2, respectively, and the example image is shown at the los intercept with the O$_2$ airglow layer for fov 2. P-P modulation of transformed mosaic image pairs is shown as a function of latitude in b).

Figure 3.
Comparison to groundbased airglow wave imaging. An orthographic projection of time-differentiated, median-filtered OH airglow wave structure is shown in a), where a hypothetical, optimized sequence of a WINDII 50 x 200 km fov is superposed. Strong wave activity is visible over the SE land area, in contrast to weak wave activity over the SW ocean area. An auroral display is in evidence in the northern regions. The k-spectrum for the central 90 km region of the image is shown in b), averaged over an hour free of auroral activity. North and east are indicated with lines to the upper right and left, respectively.