Short notes on the investigation of gravity wave momentum flux variation

By Aurélien Botman,
working at BAS Cambridge
September 2002
under the supervision of Patrick Espé.

Abstract:

The momentum flux of gravity waves as seen by an airglow all-sky camera located at Halley was analysed using three-dimensional fast Fourier transform methods, and averaged over a whole night. The variation of this flux over the winter (April – September) was obtained for 2000 and 2001.

1. Introduction[1]

Acoustic gravity waves are perturbations in the atmosphere at 80-100km. They can be seen as waves propagating in the chemiluminescent atmosphere ("airglow") at that height. They are so called because the air molecules' restoring force in their simple harmonic oscillation cycle is principally due to gravity.

Gravity waves may originate from upward air movement as it approaches a mountainous region, or from other large-scale physical obstruction to smooth air flow along the ground, including storm systems. This block of air would act as a driver for an acoustic wave, whose amplitude increases with the decreasing density of the air with altitude. The wave "breaks" at around 110km, and this mechanism is thought to be of importance in energy transport processes in the upper atmosphere.

The momentum flux of such waves is defined as the mean wave velocity, as integrated over a period of time and frequency components. The integration limits are defined by the observing limitations of the airglow camera. This flux yields important information about the direction of winds at high altitudes, as gravity waves propagate only against such winds (see figure 1).

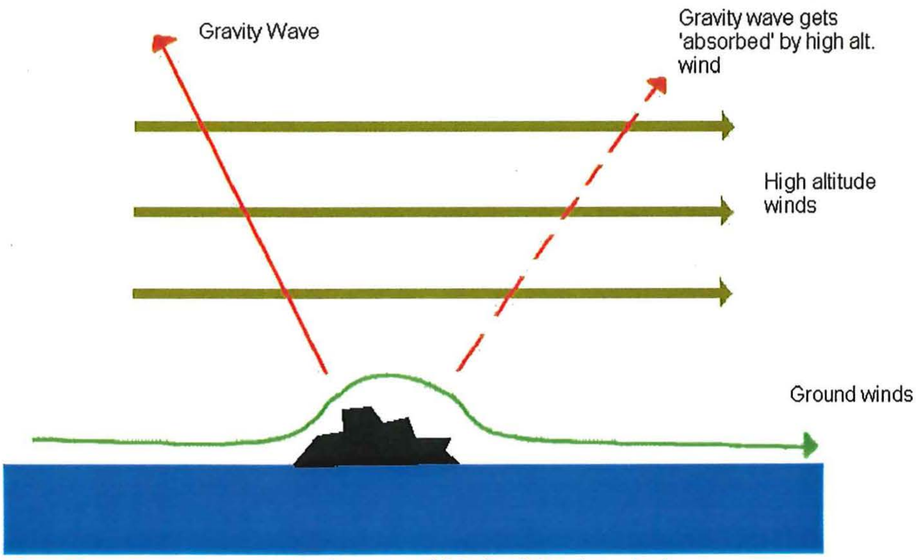


Figure 1: Gravity waves propagate 'against' high altitude winds.

[1] Large parts of this section are adapted from Peter Brooke's report.

2. Method summary

The apparatus consists of a CCD camera equipped with a fish-eye lens. The all-sky images were taken with different filters, namely OH, Na, 02, and background. The Na images being on the whole less contaminated by such events as Aurora and light cloud, the analysis was carried out using images taken with that filter.

The exposure time was 90 seconds every 5.5 minutes. The images were saved as TIFF files, measuring 512 pixels square. Only those images between times determined as 'contamination free' (free from sunlight, moonlight, aurora, cloud) were analysed. The images were fed into set of MatLab scripts developed at the University of Illinois, and (see further) modified for our particular conditions. The scripts performed the following operations on the images:

- Rotation to place North at the top of the image
- Cropping around the zenith pixel (not located at the centre of the image!). Resulting image size: 385 pixels square
- Flipping to interchange East and West to convert to conventional representation
- Finding a raw image average for a particular night
- Flat-fielding and interpolation on each image
- Star removal
- Application of Hamming apodization function for filtering
- Application of temporal and spatial pre-whitening for contrast enhancement
- Calculation of three-dimensional Fast Fourier Transform for both positive and negative spatial frequencies
- Derivation of unambiguous two-dimensional spectrum
- Calculation of zonal and meridional correlation coefficients
- Integration of unambiguous spectrum to yield angular spectrum. Lower limit was inverse of camera's field of view (estimated at 150km), upper limit defined as inverse of smallest observed wavelength.
- Computation of mean cross-correlation coefficient versus angle w.r.t. North

3. Script alterations

A number of alterations had to be made in the scripts.

a. The zenith pixel location had to be altered
b. The angle of rotation had to be altered. It was discovered that the angle of rotation should be entered as number of degrees *anticlockwise* to rotate, and not clockwise as previously thought. This simple fact invalidated all previous results obtained with the scripts.
c. Latitude had to be corrected (this was used in the Coriolis force calculations)
d. Atmosphere inertial frequency calculation was modified
e. Sampling period was set as a variable, previously hard-coded

After these alterations the scripts seemed to run satisfactorily on a test set of images containing a pure sine wave of well-defined frequency travelling in a well-defined direction.

A further issue relating to script execution was that rather large data files were generated during the calculation. This meant that for nights when there was abundant data, in order to avoid hitting the (admittedly also large) file space quota, only every other image was analysed. This resulted in images analysed actually being 11 minutes apart. Nights processed this way did not seem to show any major deviation from nights analysed with images 5.5 minutes apart.

4. Results

Appendix 2 shows the plots generated by the scripts. In addition the calculation yielded four numbers, the zonal and meridional correlation coefficients and their respective errors. These numbers were fed into plotting software, with the results shown in figures 2 and 3 for 2000, and 4 and 5 for 2001.

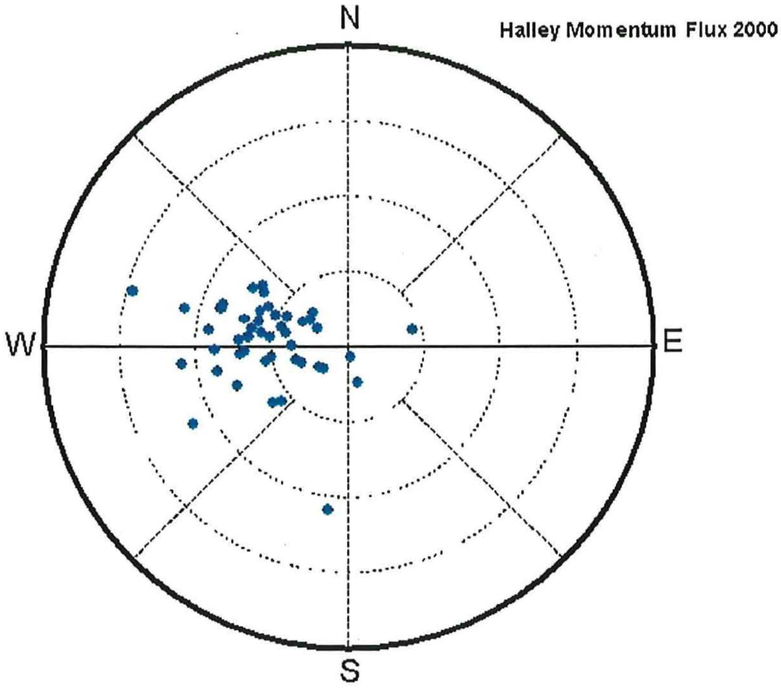


Figure 2: Gravity wave forcing at 90km, Halley, March-September 2000.

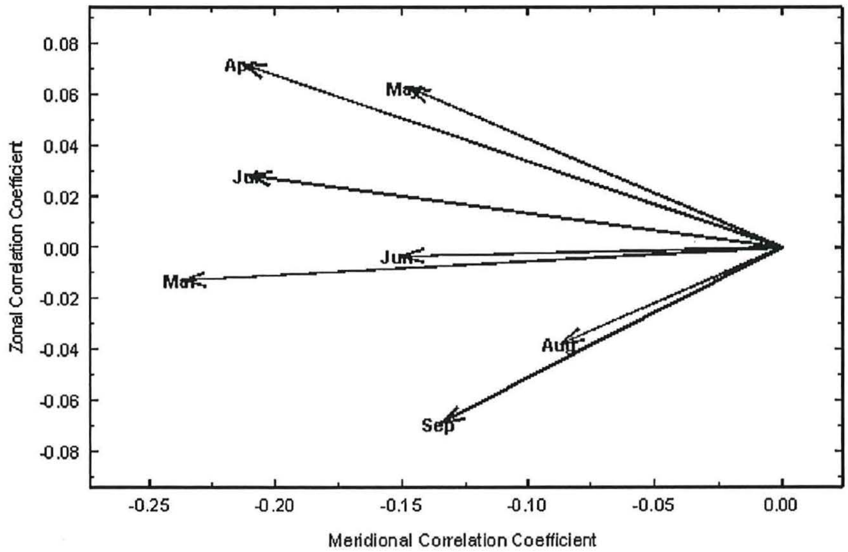


Figure 3: Monthly averages for 2000.

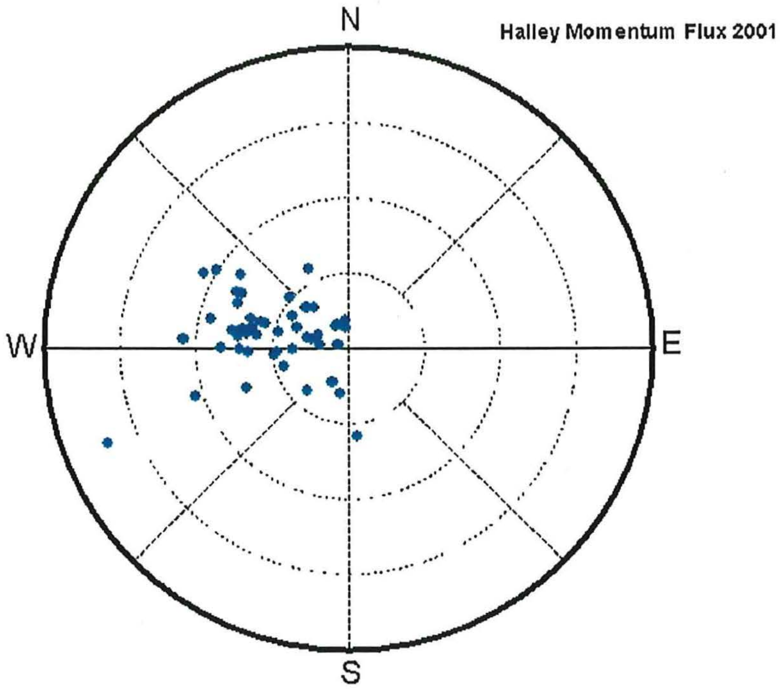


Figure 4: Gravity wave forcing at 90km, Halley, April-September 2001.

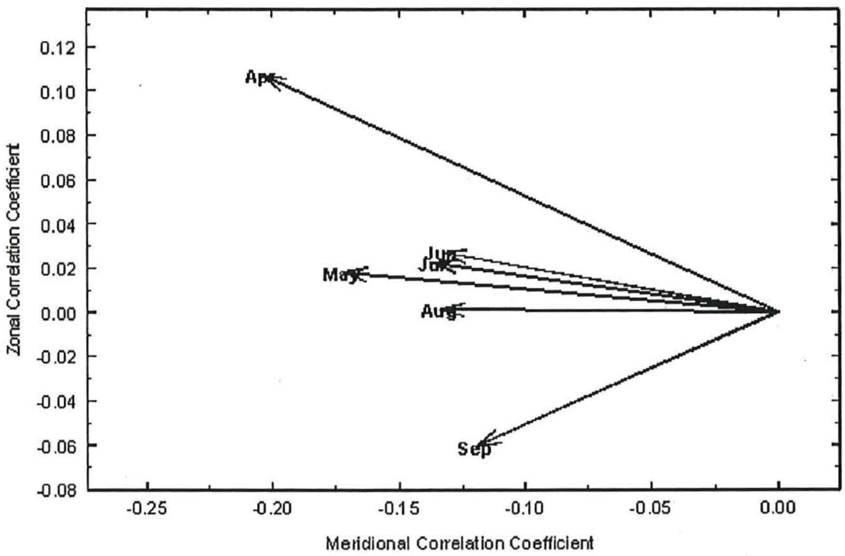


Figure 5: Monthly averages for 2001.

5. Conclusions

The first thing one should notice is how remarkably similar the results for both years are.

The nightly averaged fluxes seem to be predominantly Westward. This is in accordance with the observation that the predominant wind at high altitude during this part of the year is Eastward, as one expects from the effect of the Coriolis force on the air masses moving South.

The monthly averages show the flux moving Northward between March and May, having little significant zonal component between May and August, and moving Southward between August and September.

This agrees with observations to date and with current models of that part of the atmosphere, indicating that the scripts are working correctly following the small corrections made.

Further work could include using the modified scripts to analyse data from other years and locations, to establish global patterns and trends in the atmospheric system.

Appendix 1. How to process airglow data

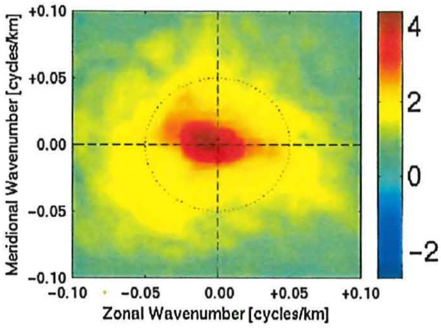
This appendix leads the reader step-by-step through the technical details of processing an airglow data as described above.

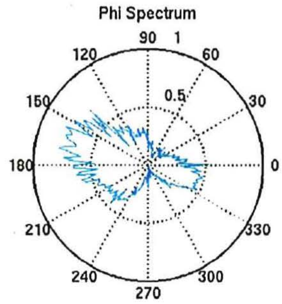
1. If available, the OH movies give a pretty good idea of whether the night is cloudy or not.
2. Use `Zimview.pro` (an IDL program written by Owen Jones) to determine the time limits between which there is no contamination. It has been found that relying on theoretical sunrise and sunset times based on solar depression angles was not to be recommended.
3. If this is NOT the first run for a particular data set, skip to step 4. Otherwise, modify the file `settings.m` to set the correct field of view, and run `weights.m` from MatLab. Also, the following command should be executed from within MatLab:
   ```
   mex -O -f $MATLAB/bin/mexopts.sh sincint_mex.c
   ```
   Note that this is different to the command suggested in Peter Brooke's report, since the cxx options file seems to generate errors under MatLab version 5.3.

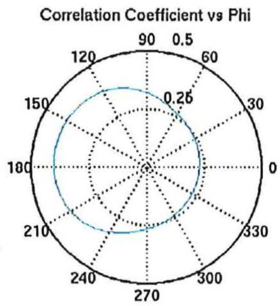
4. Modify the file `settings.m` and alter the following variables:
   `fini`: index of first file to analyse
   `fend`: index of last file to analyse
   `finc`: increment between files
   (note: total number of files to analyse must be EVEN)
   `deltaT`: time between raw images img000x and img000y, where y=x+1, multiplied by the variable `finc`.
   `data_dir`: where the original images are stored (see further)
   `data_directory`: location of temporary folder to use
   `final_dir`: where the final output should be stored
   `qqqlat`: latitude of camera
   `zx,zy`: zenith pixel coordinates
   `angl`: rotation angle to use, ANTICLOCKWISE
   `spec`: filter used
   `file_pre`: file prefix system used
5. Check original location directory, the full paths to the data is stored in `paths.txt`; it's often easier to create symbolic links to the folders as then less editing is involved. Also, the final output folder should be created if it does not already exist.
6. Run the program `master.m` from MatLab. It will typically take around 15 minutes to process a night's worth of data. Matlab will produce four files, one with the four correlation coefficient numbers, and three containing raw data to reproduce any intermediary plots using the method described in the next step.
7. At any later time, to view the plots produced, use the programs `fft_plot_VIEW.m`, `phi_plot_VIEW.m`, `corr_plot_VIEW.m`. The scripts will ask which date to view the data for; the file `VIEW_settings.m` can be modified to reflect the paths used. To export the plot as a JPEG use the 'export' facility in the window in which the plot appears.
8. The program `phi_plot_SAVE.m` will ask for a date then save that date's phi plot directly as a JPEG file. It also includes the day number on the plot.
9. The correlation coefficients are stored as ASCII and are easy to extract 'by hand' for inclusion for example in an EXCEL spreadsheet. However, the C program `get_corr.c` can be compiled and used if the user has the CYGWIN system installed on their computer.

Appendix 2. An example output plot

This appendix shows the reader what sort of output to expect from the MatLab script `master.m`.







The first plot is the two dimensional unambiguous spectrum computed from the three dimensional Fast Fourier Transform. The dashed line represents a wavelength of 30km.

The second plot (top right) is the phi spectrum plot. This shows the directions of momentum flux which have been found, and their amplitudes. It is to be noted that the representation is logarithmic.

The last plot (bottom) is the correlation coefficient plot. Essentially an integration of the phi spectrum plot, the direction of maximum amplitude of this plot is taken as the mean direction of the momentum flux vector for that night. An amplitude is also calculated from this plot, allowing direct comparison between different nights.

Each of these plots can be separately reproduced with the data files saved and the programs `xxx_plot_VIEW.m` as described in Appendix 1, step 7.