Report on second phase of AOARD-03-08
Impacts of Tropical Convection on the Atmosphere and Ionosphere

Introduction

This report concentrates on progress made in the project in the period since the report on the first phase was submitted in December 2004. The aims of the project were extensively presented in the first report and are only repeated briefly here since the goals have not changed. The aims are: (i) To use data acquired in the DAWEX campaign of 2001 to investigate in detail the generation of gravity waves by intense convection in Northern Australia; (ii) To use equatorial radar observations of winds in the MLT (70-100 km) to investigate the spectrum of gravity waves reaching the lower thermosphere; (iii) To make combined observations of gravity waves and ionospheric irregularities in the central Pacific to see whether gravity wave sources can be identified with the generation of specific equatorial spread-F/plasma bubble events.

In the first report the focus was on aims (i) and (ii). In the second phase the focus has been on completing as much as possible the work on aims (i) and (ii) and making a transition to aim (iii), which is the focus of the 3rd contract awarded under this project.

(i) Gravity wave studies in Northern Australia

A series of campaigns in late 2001 used radar, radiosonde, airglow imager and modelling studies of gravity wave generation by strong convection in the vicinity of Darwin (see special issue on the DAWEX campaign in *Journal Of Geophysical Research*, Vol. 109, D20, 2004). We have continued analysis and interpretation of data acquired with our VHF radar on the Tiwi Islands, and in particular we have been working with Dr Joan Alexander (Colorado Research Associates) to use the radar observations to “calibrate” her high-resolution numerical model output. This has proved quite successful for days of strong convection (“Hectors”). We are now working on a period of lower-level convection observed during monsoon conditions (December 2001) as well as observations made with support from this grant during the dry season in 2004.

We are also comparing model predictions of wave fluxes in the lower stratosphere (20-35 km) with observations made using high-resolution balloon soundings. An unanticipated problem has been the impact of the balloon ascent rate (~5 ms^{-1}) on the retrieved vertical wavelengths of waves that have significant vertical phase speeds. We are assessing the effects of this “Doppler” shifting in order to ensure that it does not bias our estimates of wave fluxes. This work is being carried out by Peter Love as part of his Ph D programme. We anticipate one or two further publications to eventuate from this aspect of the project.

Finally, it is worth noting that outcomes from this project will feed into another major campaign (TWP-ICE) in Northern Australia during the monsoon season in January/February 2006. Together with Dr Alexander our group will participate with the aim of observing and modelling gravity wave generation and propagation into the upper atmosphere.

(ii) MF radar studies of gravity waves in the MLT

The motivation for this work has been to investigate broader aspects of the gravity wave source spectrum using an extensive database of MF radar observations at several near

Report Documentation Page

Form Approved
OMB No. 0704-0188

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
11 AUG 2005	**Final Report (Technical)**	**29-04-2004 to 28-05-2005**

4. TITLE AND SUBTITLE
Impact of Small-scale Atmospheric Gravity Waves on the Atmosphere and Ionosphere

5a. CONTRACT NUMBER
FA520904P0314

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Robert Vincent

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
University of Adelaide,Adelaide 5005,Australia,AU,5005

8. PERFORMING ORGANIZATION REPORT NUMBER
AOARD-044037

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
The US Resarch Labolatory, AOARD/AFOSR, Unit 45002, APO, AP, 96337-5002

10. SPONSOR/MONITOR'S ACRONYM(S)
AOARD/AFOSR

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
AOARD-044037

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The aims of this project were to 1) use data acquired in the DAWEX Campaign of 2001 to investigate in detail the generation of gravity waves by intense convection in Northern Australia; 2) use equatorial radar observations of winds in the 70 - 100 km range of the atmosphere to investigate the spectrum of gravity waves reaching the lower thermosphere; and 3) make combined observations of gravity waves and ionospheric irregularities in the central Pacific to see whether gravity wave sources can be identified with the generation of specific equatorial spread-F/plasma bubble events.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**6**	**4**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

equatorial sites. The technique is based on a Monte Carlo method whereby randomly generated gravity waves with known spectral properties are ray traced through the middle atmosphere and the resulting synthesised wave variances compared with observed values. The wave spectrum is varied until satisfactory agreement is reached. The work initially described in the phase 1 report concentrated on two equinoctial months (April 1993 and April 1994) as a proof of concept. The technique appears to be robust and the first paper has been accepted for publication (Kovalam et al., 2005). One reviewer was sufficiently impressed to say that "I will use this method in future."

During the second phase of this grant we have extended the methodology to cover other seasons. The results are similar to those for the equinoctial months already tested and show an asymmetric spectrum, as illustrated in Figure 1. The main feature is that there is a bias toward waves propagating in the eastward direction. While the exact reason for this bias is not known it is probably due to a shear in the zonal winds in the lower atmosphere. We are now preparing to write up this work, including the interactions between gravity waves and atmospheric tides in the 80-100 km region. While the latter aspect is incidental to the overall thrust of the project it does improve our understanding of the role of gravity waves in the MLT.

(iii) Extending Gravity Wave Ray Tracing into the Thermosphere

An important outcome from the work summarised in (ii) is that waves having horizontal wavelengths of the scale apparently associated with equatorial spread-F do appear to be present in all seasons in the lower thermosphere. The next stage is to see whether these waves can propagate into the thermosphere to heights of at least 200 km. During the second phase of the grant we have been extending our gravity wave ray tracing techniques to include the effects of molecular viscosity and thermal diffusivity. The approach adopted is based on the work of Vadas and Fritts (2004) that describes a new method of including these effects in ray tracing.

We are using a systematic approach in developing the methodology. Initially, constant temperatures were used, similar to the examples given in Vadas and Fritts (2004). The next stage has been to use more realistic temperature profiles derived from the MSIS90 model. The results so far are promising. They show that under these conditions only longer horizontal waves with large vertical wavelengths will propagate to heights of 200 km or above (see Figure 2).

The next stage is to use the best available temperature profiles that will reflect the conditions that pertain when we try to see whether specific EsF/plasma bubble events could be triggered by gravity waves propagating from known convective sources. To this end we are starting to obtain data from the SABER instrument operating on the TIMED satellite. It will also be necessary to use the best available wind profiles, since the background winds significantly affect the spectrum of waves reaching the lower thermosphere and subsequent propagation to higher altitudes. Several different ways of putting together suitable wind profiles are being investigated in the 3rd phase of the grant.

Travel

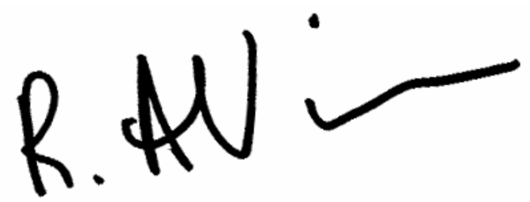
With some support of the grant, I attended the C/NOFS workshop held in Estes Park in January 2005. This proved invaluable in understanding more about the goals of the mission and the role we might play in supporting it once the satellite is launched. Contact was made with Drs Ed Dewan and Keith Groves (AFRL, Hanscom AFB) and we have agreed to collaborate as appropriate in support of C/NOFS.

The meeting also enabled me to discuss Christmas Island observations of EsF/bubbles with Drs Jonathon Makela (University of Illinois) and Roland Tsunoda (SRI). They have airglow and VHF radar instruments directly measuring ionospheric irregularities. We have agreed to collaborate in investigating the *potential* for gravity wave seeding of instabilities by pooling our observations. The initial focus is on September 2004 when spread-F was prevalent, but not ubiquitous, at Christmas Island. For example, strong spread-F was observed by the CI VHF radar on 13 September between 0530 and 1000 UT (1900-0000 LT), but appeared to be absent on 15 September. As part of the 3rd phase of this grant we have started to investigate the conditions on these and other nights.

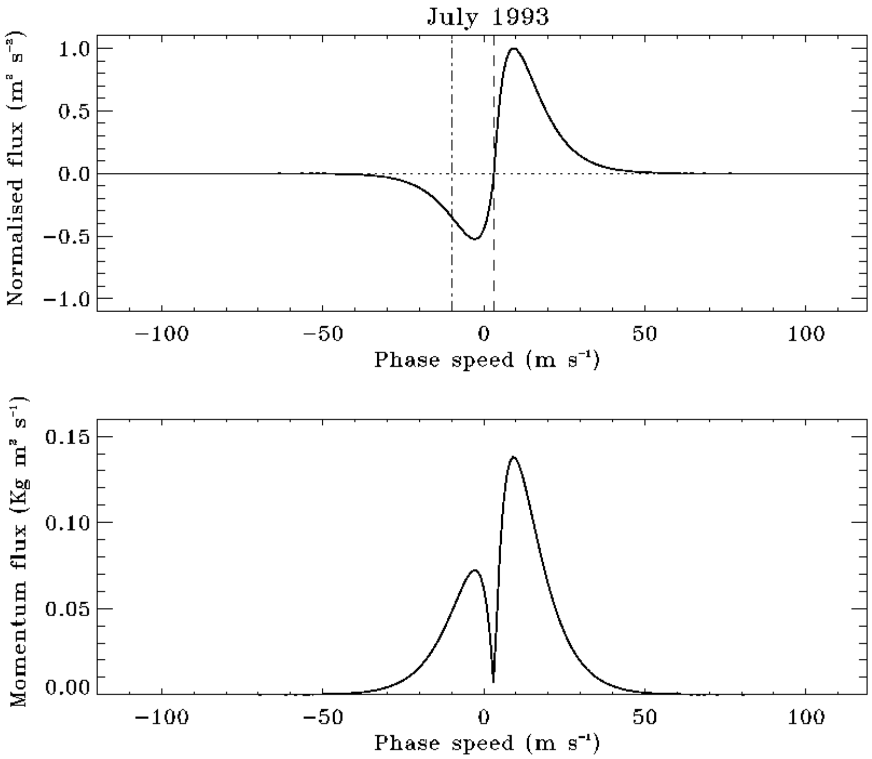
References

Kovalam, S, R. A. Vincent and P. Love, Gravity Waves in the Equatorial MLT Region, *J. Atmos. Solar-Terr. Phys.* (In Press), 2005.

Vadas, S. and D. C. Fritts, Thermospheric responses to gravity waves: Influences of increasing viscosity and thermal diffusivity, *J. Geophys. Res.*, (Submitted), 2004.



Robert A. Vincent



<u>Figure 1</u>: Inferred spectrum of convectively generated gravity waves in the 20-120 min period band and propagating in the zonal direction at an altitude of 20 km in the vicinity of Christmas Island (2ºN, 157 ºW) in July 1993.

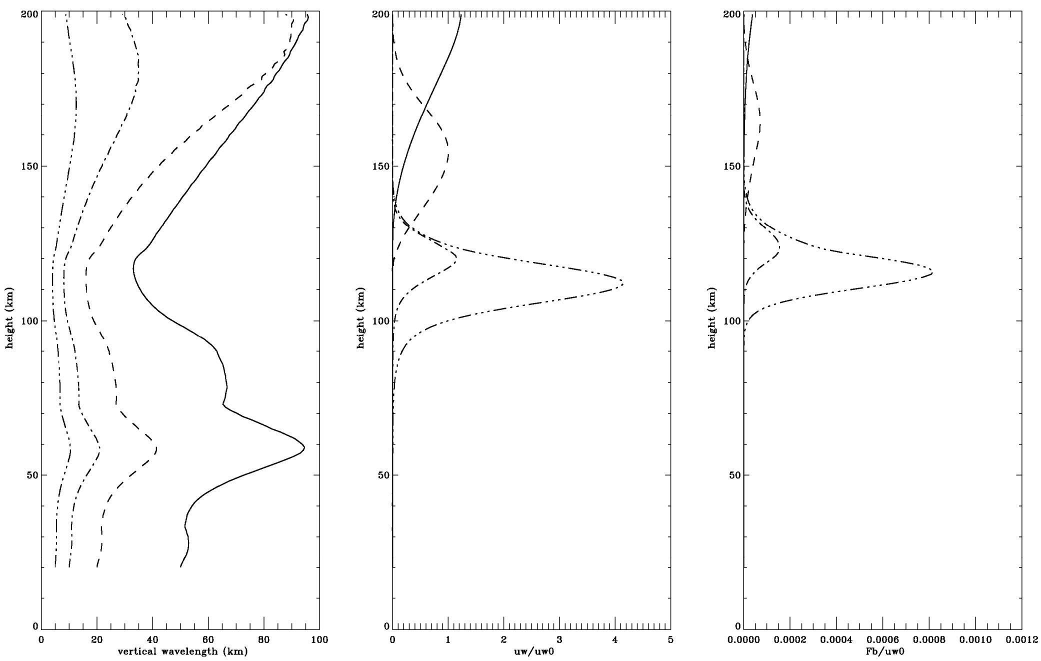


Figure 2: Height profiles of four gravity waves traced through the middle atmosphere into the thermosphere in a no wind situation. The waves have horizontal wavelengths of 100 km (solid), 40 km (dashed), 20 km (dash-dot) and 10 km (dash-dot-dot-dot). The panels show vertical wavelength (left), normalized wave amplitudes (center) and normalized body force (right). The key result is that only the 100 km wave reaches heights above 200 km when realistic molecular viscosity and diffusivity is included.