STUDIES OF THE LOWER TROPOSPHERE

By

Simon Peter Alexander, B.Sc. (Hons)

Thesis
submitted for the degree of
DOCTOR OF PHILOSOPHY
at the
UNIVERSITY OF ADELAIDE
(Department of Physics)

July 2004

Contents

Figures

Tables

Abstract

This thesis uses several remote sensing techniques to study properties of the boundary layer and lower troposphere.

For historical reasons, radiosondes are the standard atmospheric sampling technique which other observations are compared against. However, they are limited in time and space and only provide a 'snapshot' of the atmosphere. Due to the remoteness of many areas in Australia, there is a need to obtain more meteorological data than the sporadic radiosonde and surface weather station information provide. As a consequence, different ground-based remote sensing systems are used to increase the spatial and temporal resolution of atmospheric sampling. Radar, Radio Acoustic Sounding System (RASS), Global Positioning System (GPS) and surface weather data are studied to evaluate their potential for remote sensing. If successful, these techniques could compliment current radiosonde observations and be used in forecasting models.

A RASS system was integrated with the two VHF radars at the Buckland Park field site in order to obtain high-resolution temperature profiles of the lower atmosphere. Initial testing showed that the manufacturer's stated orientation of the RASS speakers was incorrect. Changing their orientation increased the power transmitted skyward. RASS echoes were recorded with the Stratosphere-Troposphere radar (ST) RASS system up to 6 km under calm conditions. The Boundary Layer Radar (BLR) measured echoes up to 2.5 km.

An existing acoustic ray-tracing algorithm was expanded into two dimensions and modified for use with the ST radar to allow prediction of the acoustic spot's movement. This facilitated beam-steering of the radar to track the acoustic spot so that it was within a beam. Implementation of this algorithm met with partial success. Beam-steering enabled some RASS measurements to higher altitudes than only using the vertical beam, under meteorologically disturbed conditions. However, the ST radar is still limited by only permitting beam-steering in the cardinal directions. No datasets of sufficient quality were obtainable with either VHF radar, due to acoustic spot distortion and movement. The BLR-RASS coverage was very sensitive to increased wind speeds, due to the small size of the receiving antenna.

The Bureau of Meteorology operates a UHF radar in Western Sydney, which also has a RASS capability. A seven day dataset from this radar was used to study the thermodynamics and structure of the boundary layer below 1 km. A strong diurnal temperature component was evident, the strength of which decreased with increasing

altitude. Second order parameters such as heat flux and Brunt-Väisälä frequency were calculated and results were in general agreement with the structure of the boundary layer. Comparisons between the UHF radar and two VHF Boundary Layer Radars (one at Adelaide and the other at Sydney airport) revealed a better coverage of wind observations in the lowest 1500 m with the UHF. Above this height, the VHF BLRs measured a greater proportion of winds than the UHF radar.

Microwave signals from GPS satellites are delayed in the troposphere due to the effects of water vapour. Certain GPS processing packages calculate this tropospheric delay as a by-product of position determination. Consequently, high temporal resolution estimates of precipitable water vapour (PWV) can be made with GPS. Adelaide-specific regression parameters were derived from the local climatology to increase the accuracy of the GPS PWV. The values of the PWV compared favourably with established radiosonde calculations of water vapour. A study of the passage of a cold front over the Buckland Park field site showed that the changes in water vapour agreed with measurements of other parameters including rainfall and synoptic-scale wind field changes. An annual precipitable water vapour spectrum was dominated by synoptic events, with summer and autumn exhibiting the largest changes in water vapour quantity. Currently, GPS cannot detect the sea-breeze as the uncertainties are too large. Research into *real-time* estimates of water vapour has shown it to be of sufficient quality for potential use in forecasting models. This is believed to be the first demonstration of real-time GPS feasibility in the Australian region.

Two case studies of gravity waves emitted by cold fronts are also presented. VHF BLR data as well as a network of surface Automatic Weather Stations (AWS) were used to determine the wave parameters. Both waves preceded the fronts by at least one hour and propagated perpendicularly to the background wind field. Neither gravity wave event appeared to be associated with observed precipitation. The first event in January 2003 had excellent BLR radar coverage, allowing use of the wind perturbations for wave parameter calculations. However, during the second event (in March 2003), the BLR had a low signal to noise ratio, resulting in large data gaps. This meant that AWS data was relied on for wave parameter calculations. Radar data of insufficient quality resulted in no other waves being identified during other frontal events.

In summary, the limits of the VHF-RASS systems were reached during these studies. In their present configurations, the VHF radars are not able to consistently observe temperature profiles. The GPS water vapour measurements and the gravity wave detection from radar wind data demonstrated the success of these techniques for obtaining information. Further investigation of these methods may enable a better understanding of the weather in Australia and potential integration into the observation network.

This work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

I give consent to this copy of my thesis, when deposited in the University Library, being available for loan and photocopying.

Signed: .... dated: ....

Simon P. Alexander, B.Sc. (Hons)

Acknowledgements

I would like to start by thanking Professor Bob Vincent, for supervising me throughout this thesis. His comments, suggestions, proof-readings and guidance along the way are much appreciated. I also thank Associate Professor Iain Reid in his role as co-supervisor and for his useful comments while proof-reading my thesis.

There are some other members of the Atmospheric Physics group whom I shall thank individually. Dr. Chris Lucas was of great assistance with the meteorological aspects of this thesis. Dr. Andrew MacKinnon introduced me to the Buckland Park radar systems and the principles of RASS. Dr. Jonathon Woithe wrote the software for obtaining binary data from the GPS receivers, and provided support and upgrades for this over time.

I also had many discussions on a wide range of matters with the other members of the Atmospheric Physics group. Over the period of my candidature, the group has also consisted of: Dr. Daniel Badger, Dr. Laurence Campbell, Dr. Graham Elford, Dr. Stephen Grant, Dr. Charles James, Dr. Sujata Kovalam, Andrew Dowdy, Nixon Kua, Peter Love, Pham Nga and Donna Riordan. Thanks also to Dallas Kirby for her presence in the group. The Buckland Park radars and other instrumentation were kept operational with the help of Alex Didenko.

Data used in this thesis came from the field site at Buckland Park as well as from outside sources. I thank Dr. Peter May, from the Bureau of Meteorology Research Centre, Melbourne, for providing me with the Sydney UHF-RASS dataset. The surface weather data was supplied by Dr. John Nairn from the Adelaide branch of the Bureau of Meteorology. Dr. Chris Lucas provided some of his disdrometer data for comparison with the GPS water vapour. Donna Riordan provided three years of radiosonde data from Adelaide airport. I am grateful for the GPS conversations I had with Dr. Yuan Hong, who was on leave from the Chinese Academy of Sciences, Wuhan, and also for the use of some of his ephemeris code.

Adelaide is an interesting town to move to. Apart from the flies, mosquitoes, snakes, spiders, 44°C days and Aussie Rules supporters, it was good living here. This is due to the people I met and the interesting adventures I had around the place. So a big 'thank you' to all of those who made me feel welcome here. However, the number of people who I had to explain the concept of rugby to was quite disturbing, especially since this country has won the Rugby World Cup twice. In retrospect, maybe this isn't such a bad thing given the intermittent form of the All Blacks over the last few years (or any other New Zealand national sports team, come to think of it . . .).

It is also appropriate to mention my friends back home and those that are now spread to the four corners of the world. Thank you all for your interest in what I have been up to over the last few years. Hopefully my conversations about my studies made some degree of sense! Thanks to Catherine and Colin for some superb camping trips around the countryside. The total solar eclipse in Woomera was awesome! A big thank you to Ceridwen for her interest in and support during this project. Also, thank you for helping set up the thesis templates.

Thank you to my sister Rachel, for proof-reading and commenting on parts of this thesis; it was good to have a non-physicist's perspective. Also, thank you for coming over and visiting me in 2001. Thanks to Jason and David, for having great senses of humour, which is always appreciated. Finally, thank you to my parents, Geraldine and Ian Alexander, and grandparents, Doreen and Gerald Wright, for all of the support and encouragement you have given me over the years.