



RADAR STUDIES
OF
ATMOSPHERIC
GRAVITY WAVES

by
I.M. Reid, B.Sc. (Hons)

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

CONTENTS

SUMMARY

PREFACE

ACKNOWLEDGEMENTS

	<u>Page No.</u>
CHAPTER 1 - INTRODUCTION AND AIM	1
1.1 Introduction	2
1.2 The Formation of the D-region	3
1.3 The Middle Atmosphere	6
1.4 Note on Doppler Radar Techniques	18
1.5 Summary	20
CHAPTER 2 - EQUIPMENT AND EXPERIMENTAL PROCEDURE	21
2.1 Introduction	22
2.2 Topography	23
2.3 Buckland Park Equipment	25
2.3.1 Transmitting Equipment	25
2.3.2 Receiving Array	26
2.3.3 Receiving Equipment	30
2.3.4 Data Acquisition Programs	35
2.3.5 Beam Configurations and Nomenclature	36
2.3.6 Systematic differences between beams	44
2.4 SA Equipment	46
2.4.1 Receiving Array	46
2.4.2 Receiving Equipment	47
2.4.3 November 1980 Doppler/SA comparison	47
2.5 Summary and Conclusions	49
CHAPTER 3 - BASIC DW DATA ANALYSIS	51
3.1 Introduction	52
3.1.1 Basic Ideas	52
3.1.2 The Doppler Spectrum	56
3.1.3 The Discrete Doppler Spectrum and Autocorrelation Function	58
3.2 Rejection Criteria	70
3.3 Basic Analysis of Radial Velocity time series	78
3.4 Summary and Conclusions	81

CHAPTER 4 - THE COPLANAR DOPPLER RADAR BEAM EXPERIMENT	82
4. Introduction	83
4.1 The Measurement of Dynamical Parameters	83
4.1.1. Small Scale Motions	86
4.1.1.1 Vertical and Off-vertical Beams	90
4.1.1.2 Complementary Coplanar Beams	104
4.1.2 Larger Scale Motions	113
4.1.3 Sensitivity of the Technique	119
4.1.4 Summary of Parameters	122
4.2 The Measurement of Horizontal and Vertical Scales of Motion	128
4.2.1 Complementary Coplanar Beams	129
4.2.2 Vertical and Off-vertical Beams	132
4.2.3 Three Coplanar Beams	135
4.3 Some Practical Considerations	136
4.3.1 Horizontal Direction of Propagation	136
4.3.2 Significance and Spatial Resolution	141
4.3.3 The Ambiguity in Horizontal Scale in the DCC Beam Configuration	147
4.3.4 Perturbation Velocities	148
4.3.5 Finite Beam Widths and Height Resolution	151
4.4 The Measurement of Momentum Flux for Scales Smaller than the Radar Pulse Volume	153
4.5 Summary and Conclusions	155
CHAPTER 5 - THE MEASUREMENT OF MESOSPHERIC WIND VELOCITIES WITH THE DW METHOD AT BP	159
5. Introduction	160
5.1 Backscatter from 60-100km and its importance for the DW experiment	161
5.1.1 Backscatter from 60-100km	161
5.1.2 The effective beam angle	164
5.2 Finite Beam Width and DW measurements at BP	176
5.3 The Spaced Antenna Technique	177
5.4 November 1980 comparison of SA and DW derived horizontal wind components	180

	<u>Page No.</u>	
5.4.1	Results	181
5.4.2	Power Spectral Analysis of November 1980 results	183
5.4.3	Discussion of November 1980 results	192
5.5.1	The Mean DW derived winds for other periods of observation	197
5.5.2	Discussion of the Mean DW results	205
5.6	Measurement of the Mean Vertical Wind component	206
5.6.1	Measurement of Vertical wind with wide and narrow beams	207
5.6.2	Other measurements of the mean vertical wind	210
5.7	Summary and Conclusions	214
CHAPTER 6 - OBSERVATIONS OF MOMENTUM FLUX		217
6.1	Introduction	218
6.2	Data Analysis and Quality Assessment	219
6.2.1	Data Analysis	219
6.2.2	Quality Assessment	221
6.3	Summary of Momentum Flux Measurements	225
6.4	Correction for Alignment of the Array and the Effective Beam Angle	227
6.5	Calculation of the Body Force	230
6.6	Mean Meridional Winds and the Coriolis Torque	232
6.7	Comparison of the Zonal Body Force with the Meridional Coriolis Torque	233
6.7.1	Results	234
6.7.2	Discussion	246
6.8	Shorter Term Variations in Monemtum Flux and Evidence of Wave Saturation	250
6.8.1	Shorter Term Variations	250
6.8.2	Evidence of Wave Saturation	256
6.9	Alignment of the Gravity Wave Drag	259
6.9.1	Results	260
6.10	Contribution to the Momentum Flux from High and Low Frequency Motions	262
6.10.1	Results	265
6.11	Summary and Conclusions	267

	<u>Page No.</u>
CHAPTER 7 - OBSERVATIONS OF THE HORIZONTAL SCALE OF MESOSPHERIC GRAVITY WAVES	270
7.1 Introduction	271
7.2.1 Data Analysis	273
7.2.2 Importance of the Effective Beam Direction	276
7.3 Results	277
7.3.1 Discussion	289
7.4 Summary and Conclusions	293
CHAPTER 8 - CONCLUSIONS	294
8.1 Measurement Techniques	295
8.1.1 Ideal Case	295
8.1.2 DW Measurements with Relatively Wide Beamwidths	296
8.1.3 Vertical Velocities	297
8.2 Observations	297
8.2.1 Vertical Velocities	297
8.2.2 Momentum Flux and Gravity Wave Drag	298
8.2.3 Horizontal Scale	299
8.3 Future Work	300
 BIBLIOGRAPHY	
 APPENDIX 1	

SUMMARY

The thesis is concerned with the dynamics of the upper mesosphere and lower thermosphere (i.e. the height region between 60 and 100km). Two methods of investigation using radio waves at MF have been used. These are the Spaced Antenna (SA) and Doppler Radar Techniques.

The Doppler radar technique was the main method of investigation used in this research, and because of this, its reliability as a means of determining winds in the D-region at a frequency of 2 MHz was established by comparison with the much tested and proven SA method.

Once this had been done, measurements of mesospheric gravity wave horizontal wavelengths and phase velocities were obtained using a Doppler radar with dual beams and a new analysis technique over a period of two years and over a range of heights, typically 80-94km.

This method also allowed the mesospheric momentum fluxes $\overline{u'w'}$ and $\overline{v'w'}$ to be obtained. From the vertical profile of $\overline{u'w'}$ values of F (the zonal wave drag) were computed and compared with the zonal acceleration due to the Coriolis torque acting on the mean meridional circulation. The comparisons show that gravity waves play a major role in determining the mean zonal circulation in the mesosphere.

Vertical velocities were also obtained from the same observations. The mean velocities are much larger than those predicted by theory, and appear to be downward for most of the year.