IN-46-CR
146045
P- 8

PROGRESS REPORT

High-Spatial-Resolution
Passive Microwave Sounding Systems

NASA Grant NAG 5-10

covering the period
August 1, 1990 - January 31, 1991

Submitted by

D. H. Staelin
J. W. Barrett
P. G. Bonanni
W. J. Chiarchiaro II
P. W. Rosenkranz

April 2, 1991

Massachusetts Institute of Technology
Research Laboratory of Electronics
Cambridge, Massachusetts 02139

(NASA-CR-192228) HIGH-SPATIAL-RESOLUTION PASSIVE MICROWAVE SOUNDING SYSTEMS Progress Report, 1 Aug. 1990 - 31 Jan. 1991 (MIT) 8 p
N93-18704
Unclas
G3/46 0146049

High-Spatial-Resolution

Passive Microwave Sounding Systems

1. INTRODUCTION

During this period the emphasis was on 1) further design, construction, and testing of the improved 54-GHz portion of the 54-118 GHz microwave temperature sounder (MTS) aircraft radiometer system in preparation for ER-2 observations in July 1991, and 2) final analysis and documentation of procedures for detecting and analyzing thermal waves in our 118-GHz MTS imagery.

In addition, H.J. Liebe has provided us with new unpublished measurements of dry-air attenuation at frequencies of 54 to 66 GHz and over a temperature range of 280K to 326K; these measurements should enable us to improve further our atmospheric transmittance models. P.W. Rosenkranz further noted that the proposed SSMIS conical-scanning microwave spectrometer on the military DMSP Block 5D-3 spacecraft designed to measure stratospheric and mesospheric temperature profiles will be observing the Zeeman-split oxygen lines with sufficient spectral resolution that the changing doppler shifts with view angle will substantially degrade the potential system performance unless remedied; this was briefly studied and documented.

2. RECEIVER IMPROVEMENTS

The improved 54-GHz radiometer is nearly ready for radiometric testing and calibration.

Testing of the Watkins-Johnson 54-GHz Gunn oscillator and mixer continued after its return from the manufacturer. Using a different power measurement system than before we found ~4-5 dB of local-oscillator power variation across the oscillator's tuning range, which normally should not preclude acceptable operation. This measurement used rotary-vane attenuators and a diode detector, together with appropriate isolation and tuning. This result is inconsistent with Watkins-Johnson's claim that the oscillator's output power versus frequency was flat to within one dB.

Design and construction of the interface between the radiometer and the IBM AT clone computer which will control it was completed. This interface includes 1) the varactor amplifier drive board, which controls the radiometer microwave frequency and enables it to duplicate at least three possible AMSU-A channels, 2) the ferrite switch demultiplexer, which commands the various switch elements within the ferrite switch assembly, 3) four temperature sensor interfaces, 4) a VHF synthesizer for the phase-lock mode of operation, plus an input port for a sign bit indicating whether the local oscillator is locked, and 5) the synchronous detector and gated integrator drive circuits.

The computer can also be host for the autocorrelator board, permitting observations of narrow spectral features in Zeeman-split oxygen lines. Further testing revealed a microcode error in the autocorrelator control engine which resulted in only 31 of the 32 autocorrelator taps being fed to the computer; a software modification now ensures the 31 taps are interpreted correctly, and a remedy to achieve 32 taps was devised but not implemented. In addition special chips to facilitate testing of the board were added, and can be activated by manually placed jumpers when desired.

The square-law detector was also calibrated and a few new cables were built and tested.

Additional work was done on the circular-to-linear polarizer which will connect the antenna to the front end of the radiometer. This quarter-wave plate is being implemented by means of a suitably sized and oriented thin dielectric slab in a section of circular waveguide. A polystyrene slab has been fabricated and should be tested shortly.

3. DETECTION AND MEASUREMENT OF RADIANCE WAVES IN 118-GHZ SPECTRAL IMAGES OF THE ATMOSPHERE

The primary activities during this period were the final analysis of the search for thermal atmospheric waves in the 118-GHz ER-2 spectral imaging data, and final documentation of this research effort. The results are summarized succinctly in the abstract of P.G. Bonanni's doctoral thesis, and are suggested in his table of contents, both of which are attached here as Appendix A.

The most important results of this thesis were 1) development of sensitive new methods for detecting faint waves in spectral imagery and for discarding certain wavelike interference, 2) use of these methods to place an upper limit of 0.17K on thermal waves in a large set of 118-GHz ER-2 spectral data from GALE and COHMEX, and 3) adaptation of these methods to ground-based use to yield vertical resolution of wave behavior in microwave absorption of only a few kilometers.

APPENDIX A

Atmospheric Wave Detection and Parameter Estimation using Passive Measurements of Thermal Emission near 118 GHz

by

Pierino Gianni Bonanni

Submitted to the Department of Electrical Engineering
and Computer Science on December 21, 1990
in partial fulfillment of the requirements for the degree of
Doctor of Philosophy in Electrical Engineering and Computer Science

Abstract

Measurements of atmospheric thermal emission near the 118.75-GHz (1^-) oxygen line were made with a scanning multi-channel spectrometer and used to measure thermodynamic effects of buoyancy wave motions in the lower atmosphere. A system model incorporating the physics of radiative transfer with the geometry and timing of the observation process is derived and then interpreted for small perturbations in atmospheric temperature and composition. A set of properties specific to plane wave inputs, which include an altitude-dependent distortion of the planar wavefronts and a viewing-angle-dependent amplitude attenuation, is developed, and the implications of these properties on the mathematical inversion process are investigated.

The wave detection and parameter estimation problems are posed in a maximum-likelihood (ML) framework whose structure is similar to that used in the classical bearing estimation problem. The wavefront distortion and attenuation effects are accommodated using a signal model in which individual spatial frequency components are mapped to distinct altitudes in the atmosphere. The strict ML solution and two suboptimal but efficient variants of this method are derived. A complete analytical evaluation of estimator performance and minimum detection thresholds follows. For a typical 8-channel, 10-minute observation segment, assuming a single-spot brightness accuracy of 0.5 K rms, theoretical detection thresholds of ~0.05 K and vertical profile accuracies of 0.1 K (at 4-km resolution) are achieved for a 10-km wavelength disturbance. Three methods for discriminating between the radiometric signatures of atmospheric waves and periodic interference are also developed and evaluated.

The detection and parameter estimation methods are applied to an extensive database of 118-GHz imagery gathered from high-altitude aircraft and ground-based platforms. A statistical survey of the aircraft-based database elicits fewer than 14 wave candidates in a 33-hour statistical sample, and no evidence of wave activity above 0.17 K amplitude. Ground-based imagery from the New Hampshire White Mountains region reveals an abundance of ~5–10 K periodic brightness structure which is demonstrated to be consistent with 2–10 km-wavelength modulations in either relative humidity or cloud liquid density.

Thesis Supervisor: David H. Staelin
Title: Professor of Electrical Engineering

Contents

1 Introduction **1**
1.1 Motivation . . . 1
1.2 Contributions of this Research . . . 3
1.3 Thesis Overview . . . 4

2 Background **7**
2.1 Introduction . . . 7
2.2 Waves in the Atmosphere . . . 8
2.2.1 The Dynamic Equations . . . 9
2.2.2 Wave Perturbation Model . . . 12
2.3 Theory of Passive Microwave Remote Sensing . . . 13
2.3.1 Blackbody Radiation . . . 13
2.3.2 Atmospheric Radiative Transfer . . . 14
2.3.3 Atmospheric Remote Sensing . . . 17
2.4 Prior Wave Observation Methods . . . 21
2.5 Observation Method Employed in this Thesis . . . 24
2.5.1 Instrument Description . . . 24
2.5.2 Meteorological Experiments . . . 29
2.5.3 Preliminary Results . . . 34
2.5.4 Data Analysis Objectives . . . 39
2.6 Summary . . . 41

3 System Model Derivation **43**
3.1 Introduction . . . 43
3.2 Model Derivation . . . 44
3.2.1 Radiative Transfer . . . 44
3.2.2 Antenna and Receiving System . . . 45
3.2.3 Geometry and Timing . . . 47
3.2.4 Input-Output Description . . . 52
3.3 Perturbation Analysis . . . 54
3.4 Measurement Error . . . 61

3.4.1 Background Brightness 65
3.4.2 Interference 66
3.4.3 Noise 66
3.5 Summary 67

4 System Model Interpretation 68
4.1 Introduction 68
4.2 Model Structure and Spatial-Domain Properties 69
4.2.1 Cascade System Model 69
4.2.2 The "Distorting Sampler" Process 72
4.2.3 The "Altitude Weighting" Process 86
4.2.4 The Complex Tapering Function 95
4.3 Spectral Properties 99
4.3.1 Sampled-Field Spectrum 99
4.3.2 Altitude-Weighted Spectrum 104
4.4 Summary 108

5 Wave Detection and Parameter Estimation 109
5.1 Introduction 109
5.2 Signal Model and Problem Statement 110
5.2.1 Wave Signal Model 110
5.2.2 Matrix Formulation 113
5.2.3 Problem Statement 115
5.3 Maximum-Likelihood Formulation 120
5.3.1 Wave Parameter Estimation 121
5.3.2 Wave Signal Detection 135
5.3.3 Implementation Issues 144
5.3.4 Performance Evaluation 148
5.4 Alternative ML-Based Methods 169
5.4.1 Method 2: Frequency-Wavenumber Signal Separation 169
5.4.2 Method 3: Parameter-Based Amplitude Profile Model 181
5.4.3 Method 4: DFT Processing 193
5.5 Multiple Signal Case 195
5.5.1 Introduction of Deterministic Constraints 196
5.6 Full Frequency-Wavenumber Estimation 197
5.6.1 Physical vs. Observable Wave Parameters 197
5.6.2 Estimation from Multiple Scan Orientations 198
5.7 Summary 200

6 Interference Discrimination **201**
6.1 Introduction 201
6.2 Interference Signal Model 202
6.3 Interference Discrimination Methods 206
6.3.1 Method A: Calibration Signal Analysis 207
6.3.2 Method B: Scan Reorientation 213
6.3.3 Method C: ML-Based Signal Discrimination 217
6.4 Summary 223

7 Upper Limit on Weak Thermal Waves **224**
7.1 Introduction 224
7.2 Survey and Segmentation of Experimental Data 225
7.3 Data Reduction 229
7.3.1 Review of Analysis Method 229
7.3.2 Sensor Noise Estimation 230
7.3.3 Spectral Analysis 236
7.4 Interference Tests 249
7.4.1 Review of Discrimination Methods 249
7.4.2 Discrimination Thresholds 251
7.5 Statistical Results 252
7.5.1 Peak Surveys 253
7.5.2 Upper Limit on Thermal Wave Amplitudes 255
7.5.3 A Statistical Interference Model 261
7.6 Summary 263

8 Estimation Applied to Absorption Waves **266**
8.1 Introduction 266
8.2 Data Survey 267
8.3 Frequency-Wavenumber Analysis 272
8.4 Estimation of Vertical Structure 281
8.5 Summary 299

9 Conclusions **301**
9.1 Summary of Approach and Conclusions 301
9.2 Suggestions for Further Research 309

References **312**