# Section 4   Radio Astronomy

## Chapter 1   Remote Sensing and Estimation

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## 1.1  Geostationary Microwave Sounder Study

**Sponsor**

MIT Lincoln Laboratory
    Agreement CX-19383

**Project Staff**

Dr. Philip W. Rosenkranz, John W. Barrett

This project provides supporting studies of candidate sounder designs to the Geosynchronous Microwave Sounder Working Group (GMSWG), which is composed of government and university personnel. GMSWG was formed at the behest of NOAA for the purpose of identifying requirements, determining technology readiness, and making recommendations for a microwave sounder to be added to the Geostationary Operational Environmental Satellite (GOES) program. These recommendations were distributed in the form of a Lincoln Laboratory report.

GMSWG, chaired by Professor Staelin, has developed a reference sounder design that envisions a 2-m diameter antenna and four frequency bands, which include the oxygen lines at 119 and 425 GHz and the water lines at 183 and 380 GHz. Simulations of temperature and humidity retrievals from this instrument predict accuracies comparable to low-earth-orbit sounders, except that the 425 and 380 GHz bands are limited by continuum water-vapor absorption to parts of the atmosphere with water-vapor overburden less than 0.3-0.6 kg/m². The 119- and 183-GHz bands, in contrast, allow sounding down to the surface. Subsatellite horizontal spatial resolution would be ~20 km for the 380-425 GHz bands, however, compared with ~66 km at 119 GHz.

## 1.2  Algorithms for Operational Meteorological Satellite Instruments

**Sponsor**

MIT Lincoln Laboratory
    Agreement BX-6178

**Project Staff**

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This project provides scientific support to the National Oceanic and Atmospheric Administration (NOAA) for the Advanced Microwave Sounding Units A and B (AMSU-A, AMSU-B), which are scheduled for launch on NOAA polar-orbiting weather satellites starting in 1998, and also for improved instruments. The effort emphasizes issues related to instrument design and specification, development of radiative transfer algorithms, including the effects of atmospheric gas transmittance, surface emissivity, and precipitation; and methods of correcting satellite measurements for the effects of emissivity and precipitation.

## 1.3  Development and Operation of an NPOESS Aircraft Sounder Testbed Passive Microwave Sensor

**Sponsor**

MIT Lincoln Laboratory
    Agreement BX-6433

**Project Staff**

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The NPOESS Aircraft Sounder Testbed (NAST) is a cooperative effort by MIT Lincoln Laboratory, RLE, and the University of Wisconsin in which an infrared

interferometer sounder built by Lincoln Laboratory and a co-located microwave sounder built by RLE will be flown on the NASA ER-2 aircraft, for the purpose of answering technical questions related to the National Polar-orbiting Operational Environmental Satellite System (NPOESS). The microwave sounder is an improved version of the microwave temperature sounder (MTS) which has been flown previously by RLE. The new MTS has eight channels between 50 and 56 GHz and nine channels near 119 GHz. It is fully scanning and has a three-point calibration system (two blackbody targets and a zenith view) for accurate calibration.

## 1.4 Earth Observing System: Advanced Microwave Sounding Unit

### Sponsor

National Aeronautics and Space Administration/
    Goddard Space Flight Center
    Grant NAS5-31376

### Project Staff

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The advanced microwave sounding unit (AMSU) and the Brazilian humidity sounder (HSB) will provide microwave-band measurements together with the atmospheric infrared sounder (AIRS), which jointly comprise a facility instrument on NASA's planned Earth observing system (EOS). The RLE effort is directed toward developing algorithms for the retrieval of temperature and humidity profiles, precipitation, sea ice, land snow cover, and other parameters. The temperature and humidity profiles obtained from AMSU and HSB are intended to provide initial conditions for the AIRS infrared cloud-correction and profile retrieval algorithms, and the observed AMSU/HSB radiances will also refine the final retrieval results.

Numerical simulations and data from aircraft and satellite instruments are being used to develop and test the microwave algorithms. 118-GHz spectral images obtained by the MIT microwave temperature sounder (MTS) on the ER-2 were analyzed in a preliminary way to develop an improved microwave-only cloud flag that is relatively insensitive to surface emissivity and other non-cloud environmental variations. By deriving a first principal component of the radiance vector in the absence of clouds and filtering it out

from all radiance data, including clouds and precipitation, a second first principal component for all filtered data has yielded a good cloud flag for 118-GHz spectral data. This technique will be improved and then extended to data from an improved MTS (designated NAST-M) which is under construction.

A data compression method was developed for application to high-data-rate atmospheric sounders such as AIRS which can exhibit instrument or data anomalies outside the nominal *a priori* statistical envelope. It compresses the geophysical component of the data in a non-deleterious way by means of "noise-adjusted" principal components analysis (PCA), but codes losslessly any instrument channels exhibiting anomalies greater than (approximately) three standard deviations above the noise level. Noise adjustment precedes PCA and consists of normalizing each channel so that its noise variance is unity. This compression method, described as "semi-lossless," has some of the robustness of lossless coding, but can approach the high compression performance of lossy coding. The algorithm is being refined using AIRS thermal-vacuum test data. Preliminary tests based on this data suggest that raw compression ratios of ~25 might become 10-15 once the random uncalibrated 1/f drifting of each channel has been accommodated by the algorithm.

## 1.5 High-Resolution Passive Microwave Imaging of Atmospheric Structure

### Sponsor

National Aeronautics and Space Administration/
    Goddard Space Flight Center
    Grant NAG5-10

### Project Staff

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Fundamental to the proper interpretation of passive microwave spectral data from satellite instruments is accurate knowledge of atmospheric transmittance characteristics in terms of composition and temperature. A major effort was concluded this year involving measurements of the microwave transmittance of atmospheric oxygen near its 54-GHz resonance band and its isolated resonance near 118.75 GHz. These measurements were performed with a zenith-scanning airborne imaging spectrometer, the microwave temperature sounder (MTS), which incorpo-

rates eight double-sideband channels centered on the 118.75-GHz oxygen resonance, and an associated switched-frequency radiometer operating 52-54 GHz. The MTS 118-GHz channels have nominal single-sideband widths of 270 MHz and center frequencies located 470-1880 MHz from the line center. Observations were obtained continuously as a NASA ER-2 aircraft ascended to ~20 km altitude and descended on four flights. Nearby radiosondes plus navigational and air temperature data from the aircraft permitted comparison of the radiometric measurements with predictions of microwave transmittance models.

Results of this transmittance study[1] are that the oxygen transmittances observed near 54 GHz are consistent with recent previous expressions within a few percent. However, expressions currently used near 118 GHz can be slightly improved by increasing the exponent of the temperature dependence of the oxygen line width from a value of 0.8 to a value near 0.98. In addition, these results indicate that operational atmospheric temperature sounders near 54 GHz may require corrections to their calibration procedures in order to bring radiosonde-based predictions of radiances into better agreement with these microwave satellite observations. Such corrections should improve the utility of microwave data now being collected routinely by operational weather satellites.

During this period, work began on an improved MTS (designated NAST-M) which will produce multichannel images near both 54 and 118 GHz. Among the initial tasks of NAST-M will be confirmation of the earlier demonstrations of retrievals of precipitation cell-top altitudes using oxygen-band microwave spectral data.[2]

### 1.5.1 Publication

Spina, M.S., M.J. Schwartz, D.H. Staelin, and A.J. Gasiewski. "Application of Multilayer Feedforward Neural Networks to Precipitation Cell-Top Altitude Estimate." *Trans. Geo. Rem. Sens.* 36(1): 154-62 (1998).

## 1.6 Reduction of Variation

**Sponsor**

MIT Leaders for Manufacturing Program

**Project Staff**

Professor David H. Staelin, Ronald Cao, Junehee Lee

Reduction of process and product variation through use of statistical analysis is a primary goal of this research effort. Developing methods to extract physically meaningful behavior from noisy data sets is the principal challenge here. The Karhounen-Loeve transform, related to principal component analysis, is frequently used when "data mining" data-rich processes for this purpose. These techniques were employed to characterize a data set collected from a paper manufacturing process for which 732 variables were recorded at 2000 periodically spaced instants of time. The derived principal components for this data set, which was purged of most defective or missing data, revealed systematic behavior in the time domain, suggesting each principal component was associated with a different physical aspect of the process. Absent physical constraints, systematic behavior is unexpected since the principal components are mathematically independent of the sequence in which the 732-element observations are arranged.

One weakness of traditional principal component analysis techniques was clearly evident. The eigenvector coefficients did not reveal which process variables were primarily associated with which principal component. That is, there was enough "clutter" in the process data that every principal component had nontrivial contributions from almost every process variable. Ronald Cao's thesis[3] demonstrated two different techniques for preprocessing the data set so that the source of the resulting principal components not only corresponded to physical processes which behaved differently in time, but also the set of variables physically associated with each principal component was much more clearly delineated without spurious contributions from the entire list of variables.

1   M.J. Schwartz, J.W. Barrett, P.W. Fieguth, P.W. Rosenkranz, M.S. Spina, and D.H. Staelin, "Observations of Thermal and Precipitation Structure in a Tropical Cyclone by Means of Passive Microwave Imagery near 118 GHz," *J. App. Meteor.* 35(5): May 1996.

2   M.S. Spina, M.J. Schwartz, D.H. Staelin, and A.J. Gasiewski, "Application of Multilayer Feedforward Neural Networks to Precipitation Cell-Top Altitude Estimate," *Trans. Geo. Rem. Sens.*, forthcoming.

3   R. Cao, *Multivariate Analysis of Manufacturing Data*, M.S. thesis, Department of Electrical Engineering and Computer Science, MIT, May 1997.

The first method which yielded this improvement involved bandpass filtering in the time domain each variable before the variable correlation matrix was computed. Thus *a priori* information was utilized prior to the principal components analysis; this *a priori* information consists of the known preference for physical processes to be correlated in time and to (often) exhibit band-pass characteristics.

The second approach was to utilize the *a priori* information that many of the physical variables being recorded were physically uncorrelated with each other. This information was incorporated into the principal components analysis by noting that many elements in the variable correlation matrix should in truth be zero, although data clutter made them otherwise. By setting ten to twenty percent of the smallest correlation coefficients to zero, many of the principal components were again reduced to smaller sets of variables which exhibited significant contributions. In many cases these small sets of variables were similar to those revealed when using the bandpass analysis. These results reinforce the validity of the original hypothesis that *a priori* information can facilitate clutter reduction when principal component analysis is used in data mining.

### 1.6.1 Thesis

Cao, R. *Multivariate Analysis of Manufacturing Data.* M.S. thesis, Department of Electrical Engineering and Computer Science, MIT, May 1997.