# Remote Sensing and Estimation

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

**Sponsor**
MIT Lincoln Laboratory, Agreement BX-6433 and BX-7601

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The NPOESS Aircraft Sounder Testbed (NAST) is a cooperative effort by MIT Lincoln laboratory, RLE, NASA Langley, and the University of Wisconsin in which an infrared interferometer sounder, built by Lincoln Laboratory and currently operated by NASA Langley Research Center, and a co-located microwave sounder built by RLE are flown together on high-altitude aircraft for the purpose of answering technical questions related to the National Polar-orbiting Operational Environmental Satellite System (NPOESS). The microwave sounder (NAST-M) is an improved version of the Microwave Temperature Sounder which was flown previously by RLE. The NAST-M has eight channels between 50 and 56 GHz and nine channels near 119 GHz. It is fully scanned cross-track and has a three-point calibration system (two blackbody targets and a zenith view). A third radiometer subsystem with seven channels near an oxygen line at 425 GHz is under development, and will soon be added to the instrument. We also have plans to add a radiometer with six channels near 183 GHz, which is a water-vapor line.

During 2000 the NAST-M flew on the Proteus aircraft as part of the CART-2000, WVIOP3 and AFWEX experiments. These were deployments in which the aircraft flew over the instrumented ground site in Oklahoma of the DOE's Atmospheric Radiation measurement program.

## 2. Earth Observing System: Advanced Microwave Sounding Unit

**Sponsor**
National Aeronautics and Space Administration/Goddard Space Flight Center
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Initial operational software, algorithms, and supporting analyses were provided for the Advanced Microwave Sounding Unit (AMSU) and the Humidity Sounder Brazil (HSB), which will operate together with the Atmospheric Infrared Sounder (AIRS). The AIRS/AMSU/HSB facility instrument is scheduled to be launched near the end of 2001 on the AQUA satellite in polar orbit as part of NASA's Earth Observing System (EOS). AMSU will image the earth in a wide swath with 50-km

resolution at nadir at 15 frequencies sensitive to the water vapor resonance near 183 GHz. Novel retrieval algorithms for estimating precipitation rates using the opaque water vapor and oxygen millimeter-wave bands near 183 and 54 GHz were extended in climate range. Advantages of the new method include potentially improved retrieval accuracies over land or at low precipitation rates, or in the presence of snowfall. Improved accuracy in global monitoring of these parameters could contribute significantly to global studies of the energy and water cycles.

Progress was also made during the year in refining the temperature profile and water vapor profile retrieval techniques which will be used to provide initial profiles, derived from AMSU and HSB, for use in infrared cloud clearing.

## 3. Passive Microwave Spectral Imaging of Atmospheric Structure

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Microwave and infrared sensors have improved in sensitivity to the point that fine structure in atmospheric temperature and humidity profiles is now observable on a scale of tens of kilometers. Three theses address this opportunity using data provided by the NAST-M spectrometer, together with auxiliary data provided by other instruments. A fourth thesis is addressing surface emissivity estimation using visible and near-infrared multispectral data.

R. Vincent Leslie[11] produced accurate temperature retrievals obtained during WINTEX (WINTer EXperiments, Madison, Wisconsin, March/April 1999) using flight data from the NAST-M instrument. Upper bounds to the instrument's sensitivity and accuracy are estimate to be 0.3K and 1.5K, respectively. Temperature profiles were retrieved using a multilayer feedforward neural network trained using radiosonde data and radiance simulations. Initial temperature perturbation images of the lower atmosphere suggest the possible detection of thermal waves on the order of 1K peak-to-peak with a period of ~20-60 km.

Jay B. Hancock has been retrieving profiles of relative humidity from the combination of the MIT NAST-M and NASA GSFC MIR instruments, where MIR operates at several frequencies near the 183-GHz resonance of water vapor plus a few nearby window channels. Early comparisons with radiosonde profiles and NAST-I 9000-channel infrared spectra (roughly 4-15 micron wavelength) are encouraging.

William J. Blackwell has been retrieving temperature profiles using combinations of NAST-M and NAST-I data obtained using the NASA ER-2 and Proteus high altitude aircraft. Cloud clearing of the infrared radiances using microwave data is a major focus of the study. Initial results suggest that a major limitation to cloud-clearing performance is unknown surface emissivities at microwave wavelengths, and the non-linearities introduced by the variable influence of atmospheric transmissivity.

Herbert E. M. Viggh has been developing methods for estimating surface emissivities using hyperspectral visible and near-infrared images. These techniques utilize prior information about the spatial and spectral statistics of the region of interest. Once developed, these techniques should also be relevant to atmospheric imagery.

Work has also begun on the incorporation of 425-GHz channels on the NAST-M spectrometer, and on the potential for geostationary microwave sounders employing water vapor and oxygen resonances at wavelengths near 1 and 2 millimeters.

## 4. Reduction of Variance

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The iterative order and noise (ION) estimation algorithm estimates the signal order of multivariate data, e.g. using a scree plot[†], and the unknown noise variances, e.g. using the expectation-maximization (EM) algorithm. These estimates improve principal component analyses, linear regression, and Wiener filtering.

The ION algorithm[1,10] operates on $m \times n$ matrices **X** comprising $m$ unordered vectors $X$ of dimension $n$, each of which is presumed to be the sum of a linearly transformed stochastic signal vector $P$ of order $p$, and an independent noise vector of order $n > p$, as specified by eqn. 1:

$$X = \mathbf{A}P + \mathbf{G}^{1/2}\omega \tag{1}$$

where **A** is the unknown mixing matrix, and $P$ is assumed to be a zero-mean Gaussian signal vector having unity variance for all $p$ non-zero variables. **G** is the unknown diagonal noise covariance matrix. The noise vector $\omega$ is Gaussian with zero mean and its covariance matrix is the identity matrix of order $n$. The algorithm generally performs well even when these assumptions do not fully apply. the ION algorithm estimates $p$, **G**, and the set of $\omega$s based on a single training matrix **X**. It follows from eqn. 1 that the product **A***P* can also be estimated.

Since the ION algorithm utilizes no *a priori* information about $X$, it defines noise as being additive and uncorrelated among variables. Elements which are correlated among variables are presumed to be signal of order $p$.

This work is summarized in [1] and [10]. It was also used by Alterovitz[9] to extract 5 useful degrees of freedom from 31 parameters measured repeatedly for 46 patients exhibiting tachycardia or hypertension during the first hour of their operation under general anesthesia; principal components analysis extracted only 2 degrees of freedom.

[†] Joliffe, I. *Principal Component Analysis* (New York: Springer-Verlag, 1986).

## Publications

### Journal Articles, Published

1. Lee, J. and D.H. Staelin. “Iterative Signal-Order and Noise Estimation.” *Electronics Letters*. 37(2): 134-135, January 18 (2001).

2. Staelin, D.H. and F.W. Chen. “Precipitation Observations Near 54 and 183 GHz Using the NOAA-15 Satellite.” *IEEE Trans. Geosci. and Remote Sensing.* 38(5): 2322-2332 (2000).

### Meeting Papers, Presented

3. Blackwell, W.J., F.W. Chen, R.V. Leslie, P.W. Rosenkranz, M.J. Schwartz, and D.H. Staelin “NPOESS Aircraft Sounder Testbed-Microwave (NAST-M): Results from CAMEX-3 and WINTEX.” paper presented at the IEEE 2000 International Geoscience and Remote Sensing Symposium, Honolulu, HI, July 24-28, 2000.

4. Blackwell, W.J., J.W. Barrett, P.W. Rosenkranz, M.J. Schwartz, and D.H. Staelin. “NPOESS Aircraft Sounder Testbed-Microwave (NAST-M): Instrument Description and Initial Flight Results.” paper presented at the IEEE 2000 International Geoscience and Remote Sensing Symposium, Honolulu, HI, July 24-28, 2000.

5. Leslie, R.V., W.J. Blackwell, and D.H. Staelin. “Novel Three-Point Calibration of a Microwave Radiometer (NAST-M).” paper presented at the PIERS 2000 Progress in Electromagnetics Research Symposium, Cambridge, MA, July 5-14, 2000.

6. Rosenkranz, P.W. “Modeling Microwave Surface Emissivity for the Atmospheric Sounder Retrieval Problem.” paper presented at the PIERS 2000 Progress in Electromagnetics Research Symposium, Cambridge, MA, July 5-14, 2000.

7. Rosenkranz, P.W. “Retrieval of Water Vapor from AMSU-A and AMSU-B Measurements.” paper presented at the IEEE 2000 International Geoscience and Remote Sensing Symposium, Honolulu, HI, July 24-28, 2000.

8. Staelin, D.H., W.J. Blackwell, F.W. Chen, A.J. Gasiewski, and P.W. Rosenkranz. “RAMEX: A Proposed Rain Mapping Experiment Using Microwave Oxygen and Water Vapor Sounding Channels.” paper presented at the IEEE 2000 International Geoscience and Remote Sensing Symposium, Honolulu, HI, July 24-28, 2000

### Theses

9. Alterovitz, G. “Temporal characterization of patient state with applications to prediction of tachycardia in anesthesia with induction of inhaled desflurane.” S.M. Thesis, Department of Electrical Engineering and Computer Science, MIT, February 2001.

10. Lee, J. “Blind noise estimation and compensation for improved characterization of multivariate processes.” PhD thesis, Department of Electrical Engineering and Computer Science, MIT, March 2000.

11. Leslie, R. V. “Temperature Profile Retrievals with the NAST-M Passive Microwave Spectrometer”, S.M. Thesis, Department of Electrical Engineering and Computer Science, MIT, June, 2000.