Remote Sensing and Estimation

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1 Algorithms for Operational Meteorological Satellite Instruments

Sponsor:

MIT Lincoln Laboratory
Agreement CX-22325

Project Staff:

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This project provided scientific support to the National Oceanic and Atmospheric Administration (NOAA) for the Advanced Microwave Sounding Units A and B (AMSU-A, AMSU-B), which were launched on the NOAA-15 polar orbiting weather satellite in 1998. This year's work focussed on precipitation sensing and on comparison of measurements with calculations from radiosondes. Detection and characterization of precipitation intensity used channels from both instruments; however, some AMSU-B channels were strongly affected by interference. An asymmetry, as yet unexplained, has been detected in the scan-angle dependence of one AMSU-A channel.

2 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, 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 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 which was flown previously by RLE. The NAST-MTS 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).

During 1999, we participated in the WINTEX experiment, in which the ER2, based in Wisconsin, flew over cold-weather atmospheric conditions; and a deployment at Wallops Island, VA which had clear-air targets. Some of the WINTEX data was co-located with NOAA-15 overpasses.

2.1 References

Chen, F.W, J.W. Barrett, W.J. Blackwell, P.W. Rosenkranz, M.J. Schwartz, and D.H. Staelin. "Millimeter-wave Spectral Observations of Clouds and Precipitation from Aircraft and Spacecraft," *National Radio Science Meeting*, Boulder, Colorado, January 4-8, 1999.

3 Earth Observing System: Advanced Microwave Sounding Unit

Sponsor:

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

Project Staff:

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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 2000 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 ranging from 23.8 to 89 GHz. HSB will image the same swath with 15-km resolution at nadir at 4 frequencies sensitive to the water vapor resonance near 183 GHz. Principal accomplishments during the year include development of novel retrieval algorithms for estimating precipitation rates using the opaque water vapor and oxygen millimeter-wave bands near 183 and 54 GHz. This contrasts with more conventional radar observations and passive microwave techniques that use more transparent window channels. 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.

Supporting studies were conducted using the NPOESS Aircraft Sounder Testbed Microwave Temperature Sounder (NAST-MTS) which flew missions based in Wisconsin and Maryland. Comparisons with radiances measured by AMSU on the NOAA-15 satellite yielded agreement within ~1.5K. Progress was also made during the year in refining the temperature profile and water vapor profile retrieval techniques which will be used to interpret the data from AQUA.

3.1 References

Cabrera-Mercader, C.R., *Robust Comparison of Multispectral Remote Sensing Data.* Ph.D. thesis, Department of Electrical Engineering and Computer Science, MIT, 1999.

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,* Sept. 2000, in press.

Staelin, D.H., F.W. Chen, and A. Fuentes. "Precipitation Measurements Using 183-GHz AMSU Satellite Observations," *IGARSS '99, Vol. 4,* pp. 2069-2071.

4 Passive Microwave Spectral Imaging of Atmospheric Structure

Sponsor:

National Aeronautics and Space Administration/Goddard Space Flight Center
Grant NAG5-2545

Project Staff:

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A new method for detecting and estimating precipitation which was developed last year was further improved and tested. Retrievals based on AMSU data from NOAA-15 were compared with 3-GHz NEXRAD data smoothed to 50-km resolution. The new method yielded rms discrepancies for two frontal systems and two passes over Hurricane Georges of ~1.1 mm/h, and ±1.4dB for those precipitation events over 4 mm/h. Approximately 5.6 percent of the over-0.3-mm/h NEXRAD rain fell in areas where AMSU registered less than 0.3 mm/h, and 7.2 percent of the over-0.3-mm/h AMSU rain fell in areas where NEXRAD registered less than 0.3 mm/h. This suggests neither AMSU nor NEXRAD has significant blindspots to precipitation.

In testing this new technique at more polar latitudes, it was noticed that there was no visible boundary between snowfall and rain in the radiometric signatures seen in the opaque water vapor and oxygen resonances near 183 and 54 GHz. Physical considerations suggest that this result might be expected, and that snowfall rates (mm/h) might be estimated with accuracies comparable to those demonstrated for rainfall. This also could have significant implications for climatological studies, for no good measurement technique exists for well-sampled global studies of instantaneous snowfall rate. Radar techniques and those passive methods using microwave window channels at wavelengths longer than 3 mm are too sensitive to the detailed morphology of the falling snow and its melt condition. As a result, current radar systems can significantly misjudge snowfall rates if the scattering behavior of the hydrometeors is atypical. In contrast, the opaque microwave channels appear to be more directly sensitive to the convective activity of the storm, and therefore to be more directly linked physically to precipitation rates. The challenge will be to establish a satisfactory validation technique for these new snowfall estimation methods.

During this period additional improvements were made to the NAST-M spectrometer and data analyses were begun for the new data obtained on the WINTEX and Wallops missions of the NAST-MTS. Preparations for installing the instrument on the new NASA Proteus Aircraft were also begun.

4.1 References

Staelin, D.H., and F.W. Chen, *op. cit.*

Staelin, D.H., F.W. Chen, and A. Fuentes, *op. cit.*

5 Reduction of Variation

Sponsor:

MIT Leaders for Manufacturing Program

Project Staff:

Professor David H. Staelin, Junehee Lee

Data mining is a topic of broad interest and applicability. Data obtained from manufacturing processes conceal much information relevant to product variation, but which can be extracted by appropriate statistical analysis. A new algorithm which significantly improved our ability to extract hidden systematic behavior in large multivariate data sets was developed. This Iterated Order Noise (ION) algorithm iteratively estimates signal order, e.g., using a scree plot, and the unknown noise variances, e.g., using the expectation-maximization (EM) algorithm. These estimates of signal order and noise variances improved principal component analyses, linear regression, and Weiner filtering.

In one sample of data from a manufacturing plant 575 variables were normalized and then the principal components (PC's) were computed for several thousand vectors. The first eight eigenvectors all contained significant contributions from a majority of the variables being monitored, and therefore none of these PC's provided useful information as to how groups of them might be behaving in synchrony. After use of the ION algorithm, approximately 30 physical revealing eigenvectors were produced. These typically involved small groups of variables which clearly exhibited correlated behavior.

The ION algorithm has also been applied successfully to hyperspectral remote sensing data and it appears to have applications to any poorly understood multivariate data set for which the observed data vectors contain perhaps twenty or more variables. For example, ION-assisted filtering of 8000-channel hyperspectral data, obtained from the NAST-I infrared scanning spectrometer, has approached the performance of Weiner filtering with perfect *a priori* process order and noise models.

Principal component analysis also helped to reveal the sources of unexplained variability in a biopharmaceutical process, with the result that manufacturing process productivity was ultimately improved more than 4 percent, together with potential plant capacity.

5.1 References

Lee, J. *Blind Noise Estimation and Compensation for Improved Characterization of Multivariate Processes.* Ph.D. thesis, Department of Electrical Engineering and Computer Science, MIT, 1999.

Steltenpohl, K.M., *Variation Reduction in Biopharmaceutical Manufacturing.* M.S. in Management and M.S. in Mechanical Engineering, MIT, 1999.