Remote Sensing and Estimation

RLE Group
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Academic and Research Staff
Professor David H. Staelin, Dr. Philip W. Rosenkranz, John W. Barrett, Seth M. Hall

Research Affiliates
Dr. William J. Blackwell, Dr. Daniel W. Bliss, Jr., Dr. Frederick W. Chen, Dr. R. Vincent Leslie, Dr. Chinnawat Surussavadee

Graduate Students
Siddhartan Govindasamy, Keith T. Herring, Danielle Hinton

Technical Support
Laura M. von Bosau

Self-Organizing Spectrum Allocation

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Project Staff:
Professor David H. Staelin, Dr. Daniel W. Bliss, Seth M. Hall, Siddhartan Govindasamy, Keith T. Herring, Danielle Hinton

This program seeks to determine as a function of link length relative to user density the approximate limits to the average communications rate (bits/second/Hz/user) that can be exchanged between pairs of wireless mobile users randomly distributed over a two-dimensional plane. Of primary interest is the dependence of those bit-rate limits upon coding, numbers of antennas and data streams employed, and multipath characteristics.

This year S. Govindasamy showed that in an infinite interference-limited network where transmitting nodes use single antennas with equal power, and receiving nodes use N antenna elements, the mean spectral efficiency (b/s/Hz/link) for a random-CDMA system depends on the CDMA spreading factor. The optimum spreading factor M* was shown both analytically and via simulations to be approximately proportional to average link rank A, where the rank of a link is A if its transmitter is perceived as the A^{th} strongest in the chosen band; all transmitters interfere with each other because their bands overlap perfectly. He also showed that the expected value of spectral efficiency for M* is inversely proportional to A.

The 8-channel digital software receiver in the 2.422GHz 802.11b (WiFi) band was equipped with software and used to characterize multiple-input-multiple-output (MIMO) wireless channels around MIT and lower Cambridge. The system synchronously samples this band using up to 8 antennas at 67 MHz per channel and 12 bits accuracy. Both an adjustable 8-antenna receiver and the transmitter are independently mobile. Preliminary experiments validated the common model that predicts signals will decay approximately exponentially with distance r, particularly along single straight streets. It was found that the rate of decay for any street could be predicted rather well based on simple analysis of aerial photographs. Also, the most common model for predicting mutual information for MIMO channels based on simple measurements utilizes a channel matrix H; this is the Kronecker model. Over a variety of propagation paths on campus it was found that the Kronecker model tended to underestimate the mutual information by as much as ten percent, but that it was otherwise satisfactory. More extensive observations and modeling will follow.

Journal Papers

1. S. Govindasamy, D. W. Bliss, and D. H. Staelin, "Spectral efficiency in single-hop ad-hoc wireless networks with interference using adaptive antenna arrays," *IEEE Journal on Selected Areas in Communications*, *vol. 25*, No. 7, September, 2007.

AIRS/AMSU/HSB Algorithm Refinement

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Project Staff
Professor David H. Staelin, Dr. Philip W. Rosenkranz, Dr. Chinnawat Surussavadee

The Aqua satellite of NASA's Earth Observing System was launched May 4, 2002. Its instrument complement includes a 2378-channel infrared imaging spectrometer (AIRS) and a 19-channel microwave imaging spectrometer, AMSU-A plus HSB, which are treated as a single facility for the purpose of retrieving profiles of atmospheric parameters such as temperature and moisture. The 4-channel 150-200 GHz HSB failed on February 5, 2003, but AIRS and the 23-90 GHz AMSU-A are still operating. We have developed and delivered algorithms that calculate microwave brightness temperatures based on atmospheric temperature, humidity, and hydrometeor profiles, and that retrieve precipitation, cloud liquid water content, microwave surface emissivity, and profiles of temperature and water vapor from the microwave channels. The latter two profiles constitute the AIRS retrieval product in overcast fields of view. A stochastic algorithm for infrared cloud clearing was developed. Several cloud-cleared tropospheric channels for the better tropical regions differ from numerical weather predictions by ~0.2K rms.

To obtain consistency between the different instruments (i.e. AMSU-A and AIRS) it is necessary to make adjustments for antenna sidelobes and possible forward-model errors. We derive these corrections by comparison of AMSU-A measurements to brightness temperatures calculated from AIRS retrievals in very clear air, which do not require AMSU-A data. The clear-air retrievals were provided by C. Barnet of NOAA/NESDIS. A preliminary version of these corrections is used in version 5 of the operational processing software, and work is continuing on correction coefficients for version 6.

The accuracy of AMSU-A temperature profiles near the surface depends on accurate modeling of the contribution of reflected downwelling sky emission to the observed brightness temperature. For the ocean surface, the effect of down-welling emission is represented by an effective zenith angle, which varies with wind speed. Over all other types of surfaces, the current operational software models the surface scattering as Lambertian. However, there are indications in AMSU-A measurements over Antarctica that a better model for some ice-covered areas would be intermediate between specular and Lambertian scattering. The ice in the vicinity of Dome C can best be represented by a linear combination of 90% Lambertian and 10% specular reflection [1]. Some other parts of Antarctica appear more specular.

Journal Articles

1. C. Mätzler and P. W. Rosenkranz, "Dependence of Brightness Temperature on Bistatic Surface Scattering: Model Functions and Applications to AMSU-A," *IEEE Transactions on Geoscience and Remote Sensing*, **45 (7)**, 2130-2138 (2007),

Conference Papers

2. P. W. Rosenkranz, "Satellite-Based Radiometer Measurements at 150 and 183 GHz Compared with Calculated Brightness Temperatures," IEEE International Geoscience and Remote Sensing Symposium, Denver, Colorado, July 29–August 5, 2006.

3. N. Mathew, G. Heygster, and P. W. Rosenkranz, "Retrieval of Emissivity and Temperature Profile in Polar Regions," IEEE International Geoscience and Remote Sensing Symposium, Denver, Colorado, July 29–August 5, 2006.

4. P. W. Rosenkranz, "Line Mixing Effects in the Microwave Spectrum of O_2," 18th International Conference on Spectral Line Shapes, Auburn, Alabama, June 4–9, 2006.

ATMS Contributions to Sounding Products

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Project Staff
Professor David H. Staelin, Dr. Philip W. Rosenkranz, Dr. William J. Blackwell

The NPOESS Preparatory Project (NPP) is developing a satellite designed to ensure that the next generation of U.S. weather satellites will meet NASA's needs for climate data records. Advice is provided on design and testing of instruments, in particular the Advanced Technology Microwave Sounder (ATMS), and on geophysical-parameter retrieval algorithms, particularly with respect to effects produced by clouds and by surface emissivity and roughness. These activities draw on experience with satellite and aircraft instruments such as AIRS, AMSU-A/B, HSB, NAST-M, and NAST-I.

The stochastic cloud clearing algorithm is being evaluated for possible use in NPP. A microwave first-guess retrieval algorithm and rapid transmittance algorithm for ATMS has been provided to other NPP investigators.

NPOESS Program Science Team Support

Sponsor
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Project Staff
Professor David H. Staelin, Dr. Philip W. Rosenkranz, Dr. William J. Blackwell, Dr. Frederick W. Chen, Dr. R. Vincent Leslie, Dr. Chinnawat Surussavadee, Seth M. Hall

This program supports Lincoln Laboratory and NOAA Integrated Program Office efforts to develop a National Polar Orbiting Environmental Satellite System (NPOESS). The NPOESS Sounding Operational Algorithm Team (SOAT) is being supported through membership and participation by Prof. Staelin, and Instrument, algorithm, and calibration/validation issues are being addressed. The main scientific efforts involved continued development and evaluation of improved rain rate and hydrometeor path retrieval algorithms using millimeter-wave spectra observed by current NOAA and NASA satellites. Both efforts are also separately supported by NASA.

A near-real-time precipitation retrieval system was developed and is becoming operational in August 2007, serving researchers around the globe. It receives all passive microwave spectral image data observed by operational NOAA weather satellites and estimates surface precipitation rates (mm/h) and retrieved water paths (mm) for rain water, snow, graupel, and other constituents, as well as peak layer vertical wind speed (m/s). The spatial resolution is 0.5 degrees in longitude and latitude, or about 50 km. Each of the NOAA-15, NOAA-16, and NOAA-17 satellites observes most points on the globe twice per day, and eventually data back to 2000 will be archived. The latency is currently less than two hours most of the time, limited primarily by NOAA data handling systems. This system is based largely on the PhD. thesis of Chinnawat Surussavadee.

Conference Papers

1. C. Surussavadee and D. H. Staelin, "AMSU millimeter-wave precipitation retrievals trained with MM5 simulations: sensitivity to physical assumptions," IEEE International Geoscience and Remote Sensing Meeting, Denver, Colorado, July 29–August 5, 2006.

Retrievals and Global Studies of Precipitation Rate and Cloud-Base Pressure

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Project Staff
Professor David H. Staelin, Dr. Philip W. Rosenkranz, Dr. Frederick W. Chen, and Dr. Chinnawat Surussavadee

This year development of precipitation estimation methods using AMSU/HSB and AMSU-A/B passive microwave satellite observations focused on training neural-network retrievals using the physics-based global cloud-resolving MM5 mesoscale numerical weather prediction model running at 5-km resolution. Realistic surfaces and scan-angle effects were incorporated for the first time. The surface effects were mitigated by observing global images of principal components computed for surface sensitive channels and preserving only those that showed limited surface or scan angle dependences. Also, the radiances were all converted to their nadirial equivalents using neural networks trained with MM5. Retrievals of surface precipitation rates and of water paths (mm) for snow, graupel (~hail), cloud ice, and rain water were found to be usefully accurate at all angles, where this retrieval accuracy was found to be relatively insensitive to a reasonable range of model assumptions. This work was also supported by other NASA and NOAA programs [1-4].

The cloud-liquid water profiles retrieved from AMSU and HSB contain information about cloud mean pressure and base pressure, although vertical resolution is a limiting factor. Over a tropical ocean background, correlation coefficients between surface-based measurements and the cloud mean or base pressures from AMSU/HSB lie in the range 0.5 to 0.6. Land surfaces are less favorable for the cloud-liquid retrieval.

Journal Articles

1. C. Surussavadee and D. H. Staelin, "Comparison of AMSU Millimeter-Wave Satellite Observations, MM5/TBSCAT Predicted Radiances, and Electromagnetic Models for Hydrometeors," *IEEE Transactions on Geoscience and Remote Sensing*, 44 (10), pp 2667-2678, October, 2006.

2. C. Surussavadee and D. H. Staelin, "Millimeter-Wave Precipitation Observations versus Simulations: Sensitivity to Assumptions," *Journal of Geophysical Research*, in press, 2007.

Conference Papers

3. C. Surussavadee and D. H. Staelin, "Global Satellite Millimeter-Wave Precipitation Retrievals Trained with a Cloud-Resolving Numerical Weather Prediction Model", IEEE International Geoscience and Remote Sensing Meeting, Barcelona, Spain, July 23–27, 2007.

4. Chinnawat Surussavadee, David H. Staelin, Virat Chadarong, Dennis McLaughlin, and Dara Entekhabi, "Comparison of NOWRAD, AMSU, AMSR-E, TMI, and SSM/I Surface Precipitation Rate Retrievals over the United States Great Plains", IEEE International Geoscience and Remote Sensing Meeting, Barcelona, Spain, July 23–27, 2007.

Multi-Year Global Precipitation Statistical Studies

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Project Staff
Professor David H. Staelin, Dr. Philip W. Rosenkranz, Chinnawat Surussavadee

This effort supports preparations for the NASA Global Precipitation Measurement (GPM) mission, which involves development of satellites and algorithms for monitoring global precipitation for climate and related purposes. Such precipitation and violent storms are among the key variables that might be affected by global warning and perhaps influence it.

One project is exploring the potential performance of geostationary satellites that could monitor precipitation at ~15-60-minute intervals at millimeter and sub-millimeter wavelengths located in various oxygen and water vapor absorption bands. Such microwave spectrometers would image the visible earth from geostationary orbit with ~15-25 km resolution and retrieve surface precipitation rates and the water paths (mm) of snow, graupel, cloud ice, and rain water. Cassegrain antenna systems with a nutating subreflector, and aperture synthesis systems were both analyzed [1]. The unexpected result was that parabolic antennas less than 2 meters in diameter might enable hurricanes such as the one that destroyed much of New Orleans to be continuously monitored, thus potentially improving detailed forecasts.

A second project involves development of near-real-time reduction of all AMSU passive microwave spectral data from operational NOAA weather satellites so as to make available to the research community retrievals of surface precipitation rates and water paths of rain water, snow, graupel, and other hydrometeors, plus peak vertical winds. The retrieval method has been documented [2], together with comparisons with other products using the same and different satellite instruments. As a result of evaluations by researchers around the world, improved versions of these algorithms are expected to become operational NOAA weather products.

Journal Articles

1. D. H. Staelin and C. Surussavadee, "Precipitation retrieval accuracies for geo-microwave sounders," *IEEE Transactions on Geoscience and Remote Sensing*, in press, 2007.

2. C. Surussavadee and D. H. Staelin, "Global Millimeter-Wave Precipitation Retrievals Trained with a Cloud-Resolving Numerical Weather Prediction Model, Part I: Retrieval Design," *IEEE Transactions on Geoscience and Remote Sensing*, in review, 2007.

3. C. Surussavadee and D. H. Staelin, "Global Millimeter-Wave Precipitation Retrievals Trained with a Cloud-Resolving Numerical Weather Prediction Model, Part II: Performance Evaluation," *IEEE Transactions on Geoscience and Remote Sensing*, in review, 2007.

Conference Papers

1. C. Surussavadee and D. H. Staelin, "Precipitation Retrieval Accuracies for Geo-Microwave Sounders", to be presented at the 2006 IEEE International Geoscience and Remote Sensing Meeting, Denver, Colorado, July 29–August 5, 2006.

Theses

2. C. Surussavadee, *Passive millimeter-wave retrieval of global precipitation utilizing satellites and a numerical weather prediction model,* Ph.D. diss., Department of Electrical Engineering and Computer Science, MIT, November 2006.