Satellite Meteorological Sensing As A Replacement For The Radiosonde Network

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A major aspect of remote sensing to be addressed at the symposium on this subject in Anaheim May 19-20, is the global sensing of meteorological parameters from a satellite platform as a substitute for radiosondes. Although papers on other aspects of remote sensing are included in the meeting agenda, I wish here to focus on this issue and hope that my comments may help to stimulate discussion.

The concept of remote sensing of meteorological parameters was first seriously proposed in the late 1950's, although astronomers were aware of the technique many years earlier. In the past 15 years, great strides have been made in this endeavor, with a number of satellites launched containing sensors capable of measuring thermal emission in various portions of the infrared and microwave regions.

Although a great deal of time, effort, and money has been spent, it appears that we are still a long way from replacing radiosondes with satellite coverage as the primary means for gathering the pertinent global meteorological parameters for use in numerical weather prediction. Indeed, we are told that the numerical modelers are reluctant to use our data because of the feeling that the satellite data are less reliable than the currently used radiosonde data. If this feeling is correct, we must improve the technique, paying careful attention to all details. If satellite sounding is to succeed, the burden is on us to demonstrate both the utility and the limitations of the technique. I think our goal should be as stated above: "For global dynamical weather forecasting models, radiosonde data should be completely replaced by satellite data." Let's take a look at some of the problems that should be addressed:

MEASUREMENTS

For the current purposes, I will assume that radiance measurements can be made at a reasonable absolute accuracy (perhaps ~1%). Generally, on-board calibration assures that the intended accuracy is maintained. One problem is that some inference techniques may require higher absolute accuracies in order to insure stable solutions. The great majority of measurements to date have been made in the 15-μm CO_2 band for temperature-sounding purposes and in the water-vapor absorption region from 18-30μm for humidity sounding. Measurements at shorter wavelengths (4-7μm) may provide improved or additional information ultimately leading to improved atmospheric soundings and an improvement in information on surface-emissive properties and clouds. However, because of the strong temperature dependence of the Planck function, calibration problems may be more severe in this region. This problem may be offset by the fact that a small temperature change will lead to a relatively large change in emitted radiation. Thus the accuracy requirement of measurement may be relaxed.

The development of measuring instrumentation becomes particularly significant in the microwave region where power and weight limitations are the major obstacles. The additional problem of surface emissivity fluctuations will require that this quantity be monitored with one or more independent channels so that the vertical structure of temperature and moisture can be determined in the lower half of the troposphere independently of the type of underlying space.

TRANSMITTANCE

We must be able to compute the transmittance of the atmosphere for any given atmospheric path, given a complete physical description of the atmosphere. The current state of affairs is that no adequate comparison of transmittance measurements and calculations has been done over the atmospheric paths representative of the satellite-sounding problem by using the latest available molecular parameters and computational techniques. Indeed, attempts to compute the outgoing radiance in

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the 15-μm CO_2 band with current transmittance models have failed, and the blame has been implicitly placed on the transmittance functions. It may belong there, but that point has never been clarified. Because of this inability to compute the outgoing radiance, transmittances have been empirically adjusted and most users have resorted to statistical techniques of inversion to obtain temperature (or humidity) from the measured radiances. Thus the danger arises that the resulting inferences may be drawn largely from the statistical data and may not be a true result of the measurements at all. It would seem that our initial aim should be to validate transmittance calculations against transmittance measurements. Then we should validate radiance calculations against radiance measurements. Only then, if we are successful, can we hope to gain the best possible inferences from the satellite measurements.

The transmittance problem is not limited to the 15-μm region. A total approach must be developed so that all possible spectral regions in both the infrared and microwave regions are explored to define the best possible channels for measuring radiances associated with the desired meteorological and surface parameters.

RADIANCE VALIDATION

As noted, radiance validation is a key step along the road toward the complete understanding of the underlying physics. By radiance validation, I mean the comparison of outgoing radiance calculations with satellite measurements after carefully documenting the atmosphere and surface properties with auxiliary meteorological measurements. For example, in order to compute the upwelling radiance in the 15-μm CO_2 band, we must know the temperature distribution from the surface to the 1-mb level in sufficient detail that small-scale vertical structure will not significantly affect the computed radiance. We must also know the water-vapor distribution, the ozone distribution, the surface (ground) temperature and pressure, and the horizontal and vertical distribution of clouds in the field of view. We have to understand the limitations of our assumption that CO_2 is uniformly mixed, and the possible impact of nonequilibrium processes at the higher altitudes. We need to consider the possible impact of aerosols on the emission. Having adequately considered all of these effects, we are prepared to define the total set of auxiliary measurements required as "ground truth" in conjunction with the satellite pass over a particular point. Some limited attempts have been made to perform this analysis, but to date satisfactory results have not been forthcoming and a follow-up analysis of the cause has not been accomplished.

THE INVERSION PROBLEM

A number of mathematical techniques have been proposed (and tried) for inverting the equation of radiative transfer. Given the radiance measurements and an appropriate transmittance function, the problem is to determine the vertical temperature profile, or, given the measured radiance and the temperature profile, to determine the vertical distribution of water vapor. Attempts to perform this inversion without recourse to *a priori* information about the atmosphere have largely failed. The reason for this is unclear, but is probably related to the non-uniqueness of solution associated with a given measurement and transmittance accuracy. As a result, workers developing operational reduction techniques have opted for statistical techniques in which a large bank of climatological data is used in the inversion process. In some cases the resulting profiles are dependent on the first guess. In other cases the results can be changed by using a different initial set of climatological data. In any event, the results are not completely satisfactory, and there is the concern that the statistical-data set somehow unduly influences the final result. It seems desirable to renew our attempts to develop inversion techniques that are independent of the requirement for climatological statistics and dependent only on some general constraints regarding the gross characteristics of the atmosphere and surface. If this is done hand in hand with the development of improved transmittances and the validation of upwelling radiances, we would then have the most convincing demonstration of the viability of satellite remote sensing as a substitute for the radiosonde.

CLOUDS

Perhaps the most difficult problem associated with defining the vertical structure of the atmosphere relates to clouds. In the infrared, all but thin cirrus clouds are opaque, and the ability to determine vertical structure below clouds requires that "holes" be found through which radiation from the underlying atmosphere is transmitted. This objective can be gained by developing instrumentation with high spatial resolution or by mathematically removing cloud effects from measurements in two adjacent fields of view. Another attractive approach is the use of microwave emission measurements to sound the lower (cloudy) portion of the troposphere. The optimum technique may involve some combination of infrared and microwave channels and the subsequent development of a combined inversion technique.

I have tried to indicate my con-

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DIGESTS OF TOPICAL MEETINGS

Authors' summaries of papers presented at topical meetings of the Society have been offset into digests of the meetings. Digests from the following meetings are still available, and may be ordered from the Optical Society of America, Suite 620, 2000 L Street, N.W., Washington, D.C. 20036.

Topical Meeting on the Use of Optics in Microelectronics — January 25-27, 1971
Twenty-three papers cover such subjects as: artwork generation and inspection, device and mask fabrication, lens technology, coherence, and design problems. Staple binding, 89 pp. $5.00 prepaid; $5.75 invoiced.

Topical Meeting on Integrated Optics: Guided Waves, Materials, and Devices — February 7-10, 1972
The 51 papers cover such subjects as: materials, passive and active integrated elements, fabrication techniques, nonlinear interactions, fibers, and integrated sources and amplifiers. Perfect bound, 170 pp. $10.00 prepaid; $11.00 invoiced.

Topical Meeting on Illumination Optics — September 5-7, 1972
Areas covered by the 16 papers include: reflector design, theoretical and experimental results on equivalent-sphere illumination, design of condensor systems, and design of compound-illumination systems. Perfect bound, 60 pp. $3.00 prepaid; $3.50 invoiced.

Topical Meeting on Optical Storage of Digital Data — March 19-21, 1973
The 34 papers discuss such subjects as: bit-serial storage, materials for optical recording, holographic memories, systems, page composers, and digital recording. Perfect bound, 143 pp. OSA members: $10.00 prepaid; $11.00 invoiced; nonmembers: $12.50 prepaid; $13.50 invoiced.

Topical Meeting on Integrated Optics — January 21-24, 1974
There are 76 papers covering the following areas: couplers, diffractors, fabrication techniques, feedback structures, fibers, filters, lasers, materials, modulators, periodic structures, and waveguides. Perfect bound, 312 pp. OSA members: $12.00 prepaid; $13.00 invoiced; nonmembers: $15.00 prepaid; $16.00 invoiced.

Topical Meeting on Optical Propagation Through Turbulence — July 9-11, 1974
The 46 papers cover such subjects as: frozen moments, saturation, linear and nonlinear studies, planetary boundary layers, measurement of C_n^2 and MTF, scintillation, adaptive systems imaging, and beam spread and wander. Perfect bound, 177 pp. OSA members: $12.00 prepaid; $13.00 invoiced; non-members: $15.00 prepaid; $16.00 invoiced.

Topical Meeting on Optical Fiber Transmission — January 7-9, 1975
The 56 papers discuss the following subjects: fiber materials, fabrication processes, fiber waveguides, cabling, coupling, splicing, and transmission systems. Perfect bound, 215 pp. OSA members: $12.00 prepaid; $13.00 invoiced; nonmembers: $15.00 prepaid; $16.00 invoiced.

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cept of the state of remote sounding as applied to the remote sensing of meteorological parameters. I am certain that I have omitted reference to many problems, and in addition I have not mentioned other sounding techniques such as limb scanning and selective chopping. In general, these other techniques are variants of the basic concept requiring solutions of the same problems outlined above.

Once our ability to solve the direct problem (outgoing spectral radiance computation) has been established, our credibility will improve, and progress will be achieved in solving the inverse problem with its much greater impact on the meteorological community.

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study suggests that the demand for scientists and engineers in domestic production of energy may more than double by 1985 over that in 1970 if dependence on foreign sources of energy is reduced to 9%. Employment in this area accounted for 140,000 scientists and engineers in 1970. The largest growth in manpower requirements is anticipated in the areas of chemistry, physics, and mathematics. The report is available for $1.00 from the National Planning Association, 1606 New Hampshire Avenue, N.W., Washington, D.C. 20009.