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RECENT SCIENTIFIC ADVANCES IN THE USE OF RADAR IN SCIENTIFIC HYDROLOGY

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ABSTRACT

The data needs in scientific hydrology involve measurements of system states and fluxes. The microwave region is particularly well suited for measuring the system states of soil moisture and snow and the major flux into the earth as rainfall. This paper discusses the unique data needs for hydrology and presents some recent examples from AIRSAR experiments.

INTRODUCTION

Historically hydrology has developed as an engineering discipline to solve water resources problems such as flood protection and water supply. Evidence of the success of engineering hydrology can be found throughout well developed societies by their relatively high standards of living. Although there are still many water related problems to be solved worldwide, the realizations that water problems are no longer constrained to local drainage basins and the recent concern about climate change have asked completely new questions about hydrology; questions that traditional engineering hydrology is not equipped to answer.

SCIENTIFIC HYDROLOGY

According to Chahine (1992), the hydrologic cycle within the framework of climate change encompasses much more than the classical surface hydrologic framework (precipitation, evaporation, runoff, etc.). In addition to these land surface processes, scientific hydrology must focus on the interactive processes of clouds and radiation, precipitation, oceans, and atmospheric moisture. This conception of the hydrologic cycle not only addresses the transport

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and storage of water in the global system, but also the energy needed and released through the phase changes.

If we attempted to phrase these new concerns in the form of a single statement it would most likely be: "The major problem facing scientific hydrology is the tremendous spatial and temporal variability of hydrologic processes across the globe" (National Research Council, 1991). Thus it is primarily a scale effect that separates engineering hydrology from todays needs in scientific hydrology. However it is more than just a scale effect. We are now being asked more detailed questions about the intermediate stages of the hydrologic cycle in contrast to the engineering questions that have been frequently answered empirically. Thus in scientific hydrology we literally are asked where each drop of water resides and for how long and how this drop moves through the Earth's system. That is, we need to quantify fluxes and storages of both water and energy.

ROLL OF SARS

One of the more revolutionary aspects of SAR (Synthetic Aperture Radar) for hydrologists is the potential for measuring and monitoring various states of the hydrologic system. The major state variables that appear to be useful are the soil moisture, snow water content, snowpack condition, frozen soils. For the most part, hydrologists have modeled the hydrologic system pretty much as a "black box," using only input data (usually rainfall and maybe potential evaporation) and the output hydrograph. The unit hydrograph is a good example of a hydrologic "black box." Even though the development of the comprehensive hydrologic models exposed the interior of the black box and subdivided the rainfall-runoff process into a number of so called physical processes, this type of model was still pretty much a black box because there were no provisions for monitoring or measuring any system states or internal processes.

Soil moisture is a system state that can be measured with microwave remote sensing. Techniques for measuring soil moisture include both the passive and active microwave approaches with each having distinct advantages. The theoretical basis for measuring soil moisture by microwave techniques is based on the large contrast between the dielectric properties of liquid water and dry soil. Future applications of soil moisture to hydrologic questions and applications are bound to become more common. Temporally frequent spatial measurement of soil moisture will some day be available on a routine basis. Hydrologists are going to have to learn how to use these new data. In general, existing models have represented soil moisture in a way to make the model work but have not considered the possibility of independent determination of soil moisture or of soil parameters. For the most part, this approach has been justified because soil moisture data would not be available and hydrologists have not been able to deal with the spatial variability of soil moisture and soil properties. This may change with new microwave measurements.

Snow, the amount and its condition, are important inputs to models the amount of snow in storage and its phase change to snowmelt runoff. Like soil moisture, microwave data appear very promising to the snow hydrologist. Not only can a microwave sensor be an all-weather instrument because it penetrates cloud cover, it can also penetrate the snow pack, which presents one with the opportunity of inferring many of the properties of the snow pack and the under-lying soil. These include depth and water content as well as the degree of ripeness, crystal size, and the presence of liquid water in a melting snow pack. As with soil moisture, the microwave measurement reflects several characteristics at once.

A great deal of progress has been made in demonstrating our capability to measure these storage terms. All measurement approaches, from the laboratory, to truck, aircraft and satellite and shuttle platforms have been successful to some degree In addition there has been a great deal of increased understanding in the areas of theory, radar target interaction and algorithm development

FUTURE SARS FOR HYDROLOGY

The previous sections have discussed the basis of microwave remote sensing for soil moisture and snow and discussed their implications with respect to scientific hydrology. As promising as these new data seem, the future for using microwave data for scientific use is somewhat uncertain. For the next few years, researchers will be limited by the lack of suitable data. Only intensive and science-driven aircraft experiments will be available for collecting soil moisture and snow that hydrologists will find useful. Fortunately, there are a few experiments and satellites with SARs (ERS-1 and JERS-1) that should be invaluable for providing sample data for developing and testing application models as well as answering some of the target-sensor questions.

Looking ahead to when there may be microwave sensors on orbiting platforms, one confronts the basic differences between passive and active instruments and the intended use of the data. Comparing the instruments simplistically, the active sensors have the capability to provide high spatial resolution data (on the order of tens of meters) but their sensitivity to soil moisture may be confused more by roughness, topographic features, and vegetation than the passive systems. On the other hand, the passive systems, although less sensitive to target features, can provide spatial resolutions only on the order of tens of kilometers from a space platform. However, before the various potential microwave instruments can provide a stream of valuable data for scientific hydrology a number of questions must be addressed.

RESEARCH NEEDED

Although it appears that there will be more and more microwave measurements available in the future, there are a number of research questions that must be addressed before these data are available on a routine basis. The research questions can be split up into two categories for the purpose of discussion, one focusing on the microwave response and the other on hydrologic modeling.

Microwave response: There are a number of unanswered questions regarding the microwave-target interactions that need to be answered before soil moisture and snow can be routinely determined with microwave instrumentation. There is a need to develop algorithms to abstract volumetric soil moisture directly from the microwave measurement (backscatter coefficient) . To do this, the other target characteristics of vegetation and surface roughness will have to be parameterized although recent work by Oh et al, (1992) indicate that polarimetric radar may provide a means for handling the roughness question. Connected directly to this need is a need to better understand the effects of surface roughness on the measured microwave response with respect to incidence angle, azimuth angle, wavelength, and polarization. Also, there is a need to understand the effect of the vegetation canopy on the microwave response. Vegetation variables include the geometry for the individual plant as well as the canopy as a whole, the water content (and perhaps the biochemical makeup) of the plant, and its stage of growth. Microwave variables would include the incidence angle, the azimuth angle, wavelength, and polarization.

There is a need to investigate the use of change detection algorithms for determining the relative soil moisture of an area and whether or not this information can be useful for hydrologists. Change detection should minimize the influence of target variables such as roughness and vegetation, at least over short time intervals. There is also a reasonable basis for expecting change detection methods to provide adequate data for hydrologic applications if the data are collected from a long term orbiting platform. Long term (multi-season or year) data will establish the upper (wet) and lower (dry) limits for the change algorithm.

There is a need to develop software procedures for correcting the effects of terrain on the microwave response. Active microwave (SAR) is especially sensitive to this. This includes foreshortening, layover, and local incidence angle effects. Also, a potential issue is the relative accuracy of the DEM data with respect to the spatial resolution of the microwave data and the potential effect of subpixel variability on the measured signal.

There is also a need to further investigate the potential for polarimetric SAR and its potential for abstracting target information such as the surface roughness and vegetation characteristics. Studies of this technique need to be carried out with carefully conceived ground data collection programs.

HYDROLOGIC MODELING

Because soil moisture has not been used as measured data in hydrologic modeling, there are a number of issues that hydrologists must address and solve in anticipation of actually working with spatial and temporal soil moisture. Existing hydrologic models and engineering techniques have been developed to solve specific water resource problems (i.e., water supply, flood protection, etc.). As such, many of these are lumped models that have been developed from point measurements. Models with this structure are not capable of using the spatial nature of remote sensing data. Before soil moisture data of this nature can be used in hydrology, there is a need to modify existing models or develop new models that reflect soil moisture in a way that is more physically realistic and so that soil moisture data can be used as input or to verify output. Also, there is a need to develop procedures for modeling or estimating profile soil moisture from time series near surface measurements and/or using multifrequency data.

Equally important to the research associated with modeling is a necessity to make the remote sensing data easily accessible and usable to the hydrologist. There is a need to develop software, perhaps within a work station concept, that can truly integrate GIS, remote sensing data from several sensors, and the hydrologic models so that all the calibration, scale, format, and so on, problems become transparent to the scientist and he can concentrate on the hydrologic analysis.

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