Flood Warnings, Flood Disaster Assessments, and Flood Hazard Reduction: The Roles of Orbital Remote Sensing

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Abstract – Orbital remote sensing is now poised to make three fundamental contributions towards reducing the detrimental effects of extreme floods. Effective Flood warning requires frequent (near-daily) radar observation of the Earth's surface through cloud cover. In contrast, both optical and radar wavelengths will increasingly be used for disaster assessment and hazard reduction. These latter tasks are accomplished, in part, by accurate mapping of flooded lands and commonly over periods of several days or more. We use radar scatterometer data from QuikSCAT to detect changes in surface water area and with a full global coverage every 2.5 days. Also, MODIS, RADARSAT, and other higher spatial resolution data are used for flood mapping and other flood measurements. These records are preserved in a global flood hazard atlas at http://www.dartmouth.edu/~floods/Atlas.html.

Keywords: floods, hazards, radar, scatterometry, MODIS, RADARSAT

1. INTRODUCTION

The mapping of floods from space, however worthwhile, is not the only contribution orbital sensors can make towards reducing the detrimental effects of extreme floods on society. There are actually three major areas of work, and each requires a different suite of sensors, processing methodologies, and end-product dissemination pathways.

The first area of work, detection of new flood events and public warnings thereof, is still experimental but is making rapid progress. Radar sensors are preferred due to their cloud penetrating capability. Relatively low spatial resolution, but wide-area and frequent coverage, are appropriate: the objective is to locate where within a region or watershed flooding is occurring, and not to map the actual areas that are inundated. The second area, rapid-response flood mapping and measurement, provides information useful for disaster assessment, and has become a relatively common activity. A wide variety of sensors have been used. However, the capabilities are still relatively immature, and there is much potential for development of advanced measurement capabilities that can better define flood severity and damage. Finally, the third area of work, flood hazard mapping, is based on the recognition that not only can floods be imaged and mapped as they occur, but these records of extreme events can and must also be preserved in archival form. In this way, maps of lands actually flooded complement maps of land areas predicted via modeling approaches to be subject to flooding.

2. FLOOD DETECTION

2.1. Potential of Satellite Scatterometry

Floods are transient surface events and can occur at the same time over widely separated geographical locations (even on different continents). To record such events, timely information with frequent and large-area coverage is necessary. Even within the U.S., in-situ instrumental data are not abundant. Thus, an event such as the Great Flood of the Upper Mississippi Valley in 1993 destroyed many gaging stations, and was so geographically extensive that assembling a comprehensive, mainly Landsat ETM-based survey of affected rivers and tributary systems took the U.S. government several years. This task depended on the availability of clear-sky optical data, much of which was processed long after the actual flooding. A spaceborne Ku-band scatterometer with a large swath but low spatial resolution, such as SeaWinds on QuikSCAT, can, in contrast, provide near daily global coverage with the capability to see through clouds and darkness. It can, in principle, detect where flooding is occurring without necessarily imaging such flooding in detail.

For QuikSCAT data analysis, we are using an innovative technique that is based on the polarization reversal of radar backscatter, measured by the scatterometer, over flooded areas. The total backscatter over the landscape within the radar footprint consists of: (1) scattering due to rough surfaces, (2) direct scattering from volume scatterers such as vegetation and buildings, (3) scattering of reflected waves, (4) reflection of scattered waves, and (5) double-reflected scattering. Term (5) is generally small in the total backscattering and can be ignored.

Over unflooded landscapes, the reflection from the underlying medium (soil, concrete, or other) is weak and the scattering is dominated by direct volume and rough surface scattering mechanisms (terms 1 and 2). In this case, the polarization ratio VV/HH, where VV is the vertical polarized backscatter and HH is the horizontal component, is about 1 or larger than 1 in linear scale and about 0 or positive in dB scale. However, when the landscape becomes flooded, the reflection becomes strong due to the large permittivity of the underlying water. Moreover, the reflectivities for horizontal polarization (HH) are much larger than those for vertical polarization (VV) at large incidence angles ($>40^o$). Thus for the flooded case, the backscattering is dominated by the reflection terms (3 and 4) and VV/HH is significantly less than 1 in the linear scale, or negative in the dB scale. Note that the total backscatter may or may not change significantly because terms 1 and 2 decrease due to submerged volume and surface scatterers while the reflection terms increase.

As per Nghiem et al., [2000], the current flood detection algorithm uses QuikSCAT data, binned to the resolution of 0.25 x 0.25 degree in latitude and longitude (about 25 km x 25 km). The scatterometer has been collecting data at 13.4 GHz over both ocean and land. Backscatter data, at a radiometric resolution of 7 km x 25 km, are acquired with the vertical polarization (VV) at a constant incidence angle of 54^o over a conical-scanning swath of 1800 km, and with the horizontal polarization (HH) at 46o over a 1400 km swath. The local overpass times are approximately 6:20

and are 12 hours apart in a sun-synchronous orbit. Calibrated science data have been obtained since 19 July 1999 [Tsai et al., 2000].

The polarization ratio data are processed at the Jet Propulsion Laboratory, in California, and then shipped daily via ftp to Dartmouth. There, the global raster is rotated, inverted, and subset to produce two rasters for the eastern and western hemisphere that can be integrated into the observatory's geographic information system. Because rainfall events, particularly over urban areas, produce strong but short-lived negative polarization anomalies, 7 day running means are computed in order to dampen such effects. Then, for year 2003 data, a difference result is computed comparing the present weekly mean to the appropriate bimonthly mean for the year 2002. The influence of non-transient land surface variables affecting the polarization results, such as topography, is thereby reduced. We obtain "flood alert" map products, where current wetter-than-last year land areas are contrasted with dryer-than-last year land areas.

Similar displays are produced for all other continental land areas, are updated daily, and are currently available at the observatory web site (http://www.dartmouth.edu/~floods). Also being disseminated at this address and with the same frequency are 7 day animations of these displays, and other regional maps showing the location of strongly negative but undifferenced polarity ratios (including, for example, large permanent wetlands such as the Sudd marsh in southern Sudan). Together, these results provide the rudiments of a global flood alert system.

Inland river flooding is spatially extensive and restricted, at the same time. Flooded river reaches can extend for hundreds of km, but widths may be only on the order of a few km or tens of km. Although regional displays are useful in localizing areas of excess moisture receipts, there remains an additional step needed for further constraining the locations of actual flooding. We are exploring a two-pronged approach towards this end:

1) As part of NASA's "Sensor-Web" demonstration project, wherein different orbital sensors are inter-connected through artificial intelligence technology, QuikSCAT-determined areas of anomalous surface water are being intersected each day with the geographic locations of the Flood Observatory's "Global Hydrographic Array". The array consists of several hundred river reaches, each measuring approximately 20 km in river length. We can now identify, for imaging by high spatial resolution satellites, specific reaches that are experiencing excess surface water. As the period of observation lengthens, we hope thereby to specify, for each reach, thresholds in the polarization ratio data that indicate reach-specific overbank flooding and as corroborated by independent data.

2) The entire time series of QuikSCAT data for each of the reaches is also being examined, and compared with optical image data such as from MODIS and ASTER, and also to in situ river gaging station data. Preliminary results indicate seasonal variation in the polarization ratio signal, due to surface soil moisture and to changes in vegetation and agriculture. These trends can be removed in order to better define flood thresholds.

2.2. Potential of MODIS Rapid Response

MODIS Rapid Response data are available from Terra and Aqua in near real time at: http://rapidfire.sci.gsfc.nasa.gov/. The spectral bands at spatial resolutions of approximately 250 and 500 m are appropriate for accurate discrimination of water from land. Excluding the effects of cloud cover, there is also global coverage on a near-daily basis. In principle, MODIS could serve as a global flood alarm technology in the same manner at which it presently is providing near-real time information about fire via the Rapid Response web site.

In practice, the spectral signature of river flooding is more complex than that of fire. Floods affect tropical riverine forests as well as agricultural lands; they occur in desert and steppe and urban areas and with varying degrees of visibility of the substrate below the water column; they occur with abundant sediment concentrations and also as, for example, clear water in low gradient, bare-soil areas such as the Red River Valley of northern Minnesota, U.S. This spectral variability poses difficult challenges to automated flood detection.

Cloud shadows also intefere with accurate discrimination of water from land, and particularly using the critical band 2. Finally, and unlike the case for fire, surface water is also a permanent feature of the Earth's land surface. Therefore, a change detection approach is essential to recognize new water. This in turn requires new MODIS data to be precisely registered to older data and/or to "permanent water" masks (which have not yet been created). Indeed, seasonal changes bring large scale changes in surface water extent over many areas of the Earth's surface and "normal" conditions in map view have never been rigorously defined. Even as MODIS and QuikSCAT are revealing the dynamics of such large scale changes, these technologies raise the question of how to define flooding in order to isolate unusual changes.

The change detection requirement has inhibited progress in flood detection using MODIS and due to the very large spatial coverage and data volumes. However, the globally-distributed gaging reach approach provides a path forward. At such reaches, a time series of MODIS data are being assembled, and normal versus flood conditions can be defined: a MODIS flood threshold can be established. We are developing spectral unmixing techniques to estimate total reach water surface areas, and we are validating such estimates with intermittent ASTER optical data, whose much higher (15 m versus 250 m) spatial resolution provides effective "ground truth". It will not be possible to monitor each reach on a predictable and frequent basis using MODIS, because unusual cloud cover conditions can obscure individual reaches for days and even weeks at a time. However, it will be possible to continually update all clear-sky reaches scanned by new MODIS scenes, using change detection and standard reference scenes, and this can allow sensitive detection of surface water area changes. Ultimately, it may be possible for such "satellite gaging reaches" to also measure smaller flow fluctuations and thus assist in monitoring the global hydrologic cycle: low water as well as high water conditions should be detectable using both QuikSCAT and MODIS techniques.

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