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Real Time Monitoring of Flooding From Microwave Satellite Observations

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TABLE OF CONTENTS

LIST OF FIGURES

1. Introduction

The objective of this project is to develop methodologies for making high-resolution flood extent maps (e.g., at DEM 30-100 m scale) in real-time from low resolution (20-70 km) passive microwave observations from satellites. Microwave radiometric measurements are useful for flood monitoring because they sense surface water in clear-or-cloudy conditions and can provide more timely data (e.g., compared to radars) from relatively wide swath widths and an increasing number of available platforms (DMSP, ADEOS-II, Terra, NPOESS). The chief disadvantages for flood mapping is low resolution and the need for local calibration of the relationship between radiances and open-water fraction. In this brief study, we hope to answer the following questions.

1. How precise do open water fraction estimate have to be to produce useful flood extent maps?
2. What techniques (e.g., atmospheric corrections, multi-scale retrievals) or technological improvements (e.g., sensor resolution) are needed to achieve the required open water fraction precision?
3. How can sensor-scale open water fraction estimates be accurately transformed into flood extent maps?

In this report, we review the progress to date including results from data analyses and present a schedule of milestones for the remainder of the project.

2. Progress

2.1. Flood extent dataset

Figure 2-1 shows a map of maximum flood extent for the 1993 Midwest Flood acquired from SAST (Scientific Assessment and Strategy Team, http://edcwww2.cr.usgs.gov/sast-home.html). The map consists of polygons that enclose flooded regions as well as polygons enclosing "islands" and open water within the islands. The SAST project derived the map from high-resolution imagery (i.e., LandSat and SAR) acquired around the time of maximum flooding at St. Louis (July 12, 1993 or day 193). We originally sought to acquire flood imagery for a range of times which would provide a long baseline period against which to calibrate water fraction retrievals from brightness temperatures. Although this is still a goal, we do not expect to have sufficient time available to process this type of data and will only be able to use it if we can find it already available in a readable form.

We have developed tools (in Matlab) for reading the flood extent dataset and calculating the amount of open water present in 70 km circles approximating the effective "footprints" of SSM/I brightness temperature data (discussed below). Because of the size, quality, and complexities of the SAST flood extent dataset, considerable time was required to devise quality control checks and process the all the data Figure 2-2 shows the fractional area of flood water coverage at each of the grid points. (Points with zero water coverage and those near the edge of the SAST analysis region are excluded.) The maximum coverage is about 0.4 and most cells (82%) have less than 10% coverage.

Figure 2-1: Map of maximum flood extent boundaries from high-resolution imagery analysis. 70 km diameter circles correspond to EASE-Grid brightness temperatures.

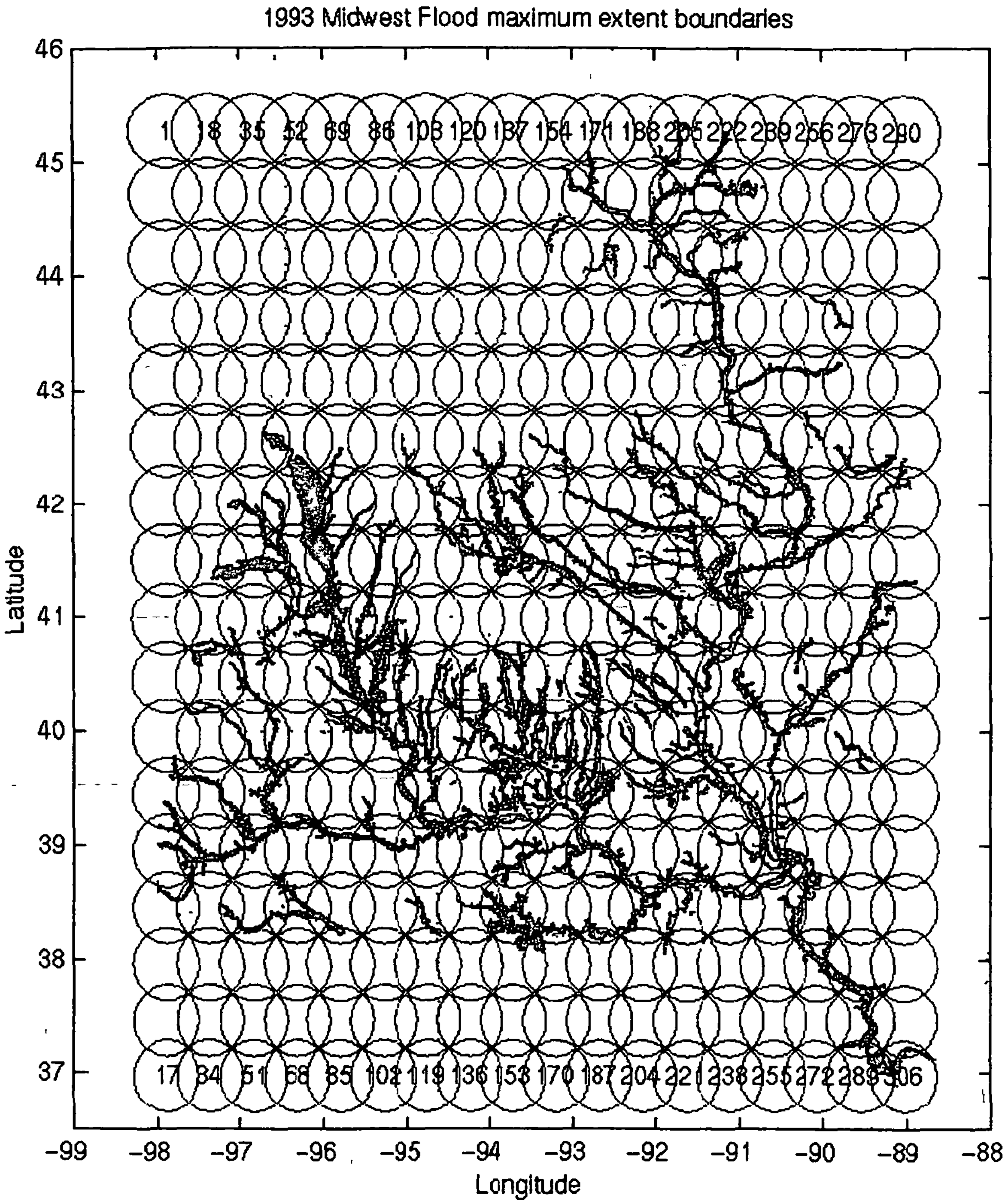
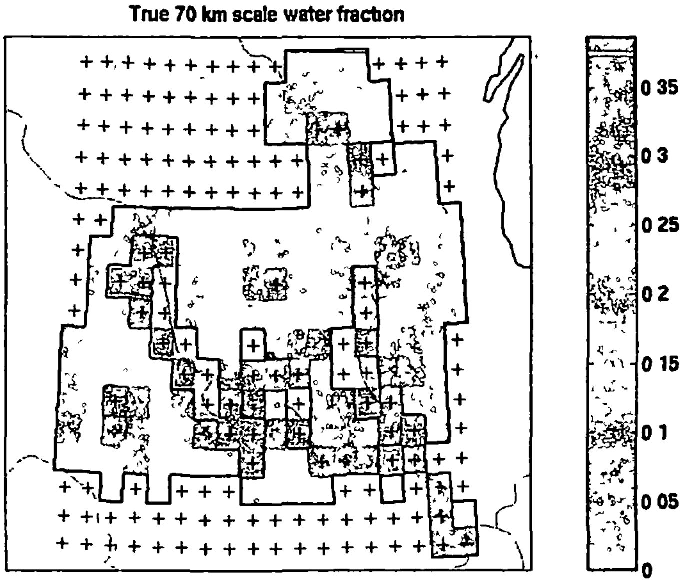


Figure 2-2: Water fraction derived from flood extent map (a bove) in 70 km diameter circles at EASE-Grid locations.

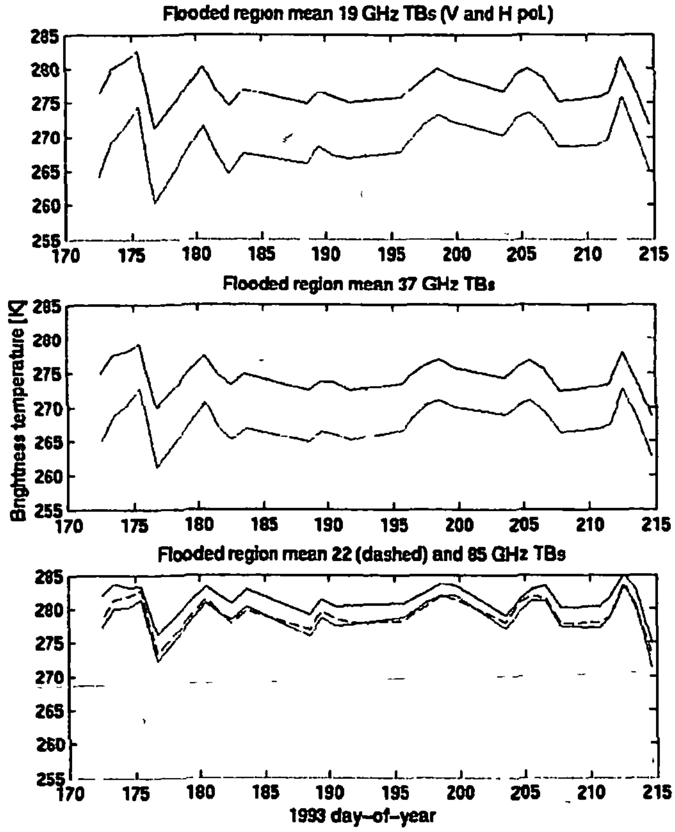


2.2. Brightness temperature datasets

Historical SSM/I data is readily available in gridded form (EASE-Grid) from the National Snow and Ice Data Center (http.//www.nsidc.org). However, because complete control of the spatial characteristics of the brightness temperatures may be important in minimizing retrieval errors, our objective is to use swath-format data in this analysis. Although much of the SSM/I historical dataset is available in swath format from the Satellite Active Archive at NOAA (http.//www.saa.noaa.gov), the dataset does not reach back to 1993 at this time. Consequently, we are currently using the EASE-Grid brightness temperatures and will acquire a smaller subset of the SSM/I data in swath format after we have identified key orbits for more rigorous analysis

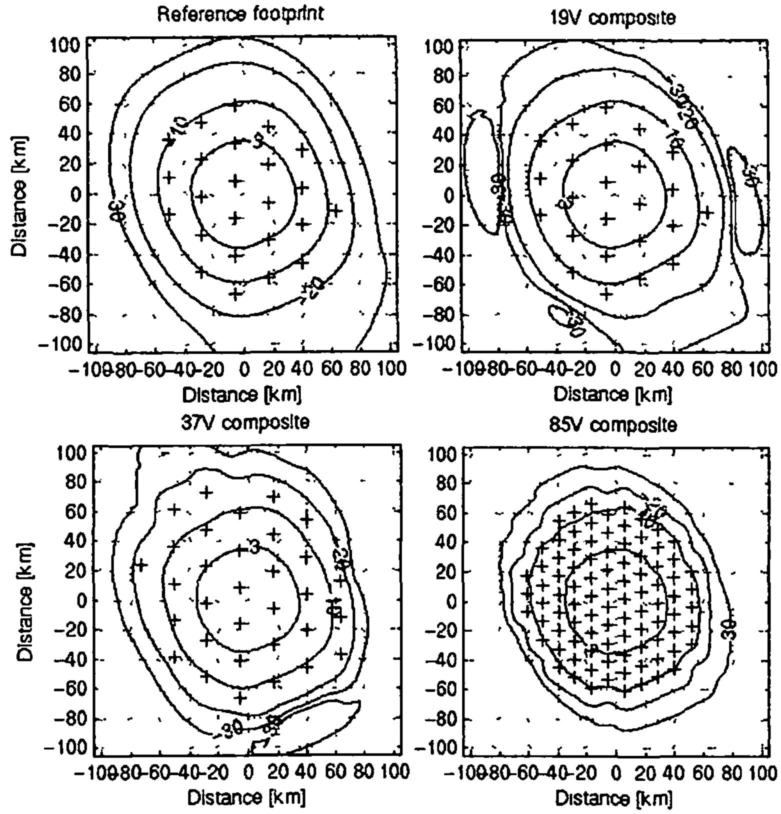
Figure 2-3 shows brightness temperatures of the seven SSM/I channels averaged over the study area delineated in Figure 2-2 on days 172-215 of 1993. The plot includes only descending (morning) passes of the satellite and only days where >50% of the cells are covered by SSM/I data Only descending passes are used to minimize diurnal effects and because most ascending passes for this region were missing from the EASE-Grid dataset, perhaps because of a flaw in data processing at NSIDC. Also, cells with rain detected using a brightness temperature threshold effect have been eliminated. Although maximum flood levels were reached on day 193 at St. Louis, most of the study area is up-river of this point and reached maximum flooding earlier This may be reflected by the lowest brightness temperatures occurring prior to day 193 Low points around day 177 and 215 will require further examination but may be due to 1) undetected rain events which tend to lower brightness temperatures at all channels, 2) temperature changes (which can be checked against temperature records), or 3) variations in the portion of the study region covered by the SSM/I swath. Note the trend in increasing 19 and 37 GHz brightness temperature from day ~183 to 205. We interpret this as a signal of decreasing flooding on average over the study area. Atmospheric effects at 22 and 85 GHz minimize any trends due only to surface conditions.

Figure 2-3: Mean SSM/I brightness temperatures over flooded region for 1993 days 172 - 215. V-pol. is always greater than H-pol. at each frequency. Line marks day 193, highest water at St. Louis.



Accurate spatial processing of the brightness temperature data is important wherever there is high spatial variability in the water fraction at the sensor resolution. We can see from Figure 2-2 that in much of the study area this is the case. We have developed tools to "footprint match" SSM/I data to a desired reference shape (e.g , see Poe, 1990). For practical reasons, this shape is chosen to be similar to the 19 GHz sensor footprint in the across-scan direction (i.e., the direction closest to the sensor line-of-sight) and the along-scan shape is derived by numerically dragging the 19 GHz footprint along scan until the 3 dB dimensions of the footprint are roughly 70 km. (The 19 GHz sensor footprint is roughly 69x43 km.) Figure 2-4 shows the resulting reference pattern and example composite patterns designed to match the reference. The examples represent a position at about the ¼ point in the scan arc with the direction of spacecraft travel parallel to the vertical dimension and the scan arcs tracing a line from lower right to upper left. The +-marks indicate the center positions of the sensor samples that contribute to the composite brightness temperature calculation. The composite brightness temperature corresponding to each composite field of view (CFOV) is calculated as the weighted sum of the brightness temperatures sampled by the sensor at each location. Hence, the CFOV represents the effective spatial weighting function of a virtual measurement centered at the plot origins. Note that this method allows us to control not only the CFOV shape but also its location, providing a way to interpolate between sensor measurements (as required for gridding) while minimizing distortion of the spatial weighting function.

Figure 2-4: Reference (i.e., objective) footprint and example composite footprints achieved from the weighted sum of sensor footprints (centered on + marks).



2.3. TB-derived water fraction analysis

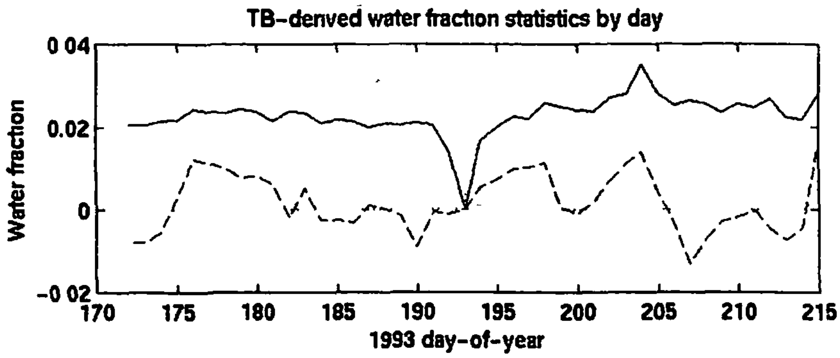
We have developed a simple model relating brightness temperatures to water fraction using the SAST flood extent database (Figure 2-2) and the EASE-Grid SSM/I data. As noted above, we currently lack the data to calibrate the model to time-varying flood maps in each retrieval cell. Instead, we have simply removed the bias in each cell using data from day 193. Hence the model for the water fraction f_w in cell i at time t can be written as:

$$f_{wi}(t) = \mathrm{fw}(T_{Bi}(t)) - [\mathrm{fw}(T_{Bi}(t = 193)) - f_{wi,true}(t = 193)] \qquad (1)$$

where the function fw is a linear regression in brightness temperature (using all seven channels), and the bracketed expression represents the model bias estimate for day 193 The function fw was derived empirically by lumping all the brightness temperature data together and using the single flood extent map as truth for the whole study period (day 172-215). The regression alone provided a poor representation of flood conditions from TBs across the domain necessitating the bias correction applied above.

Figure 2-5 shows the RMS error and bias between the TB-derived water fraction (equation 1) and the true water fraction. Note that because of the bias correction, the error is zero by definition on day 193. Hence, the errors on other days are due to the following sources: 1) TB measurement errors including spatial representation, radiometric noise, and atmospheric, temperature, and other scene changes and 2) changes in the true flooded area vs. day 193. Although the brightness temperature trend between days 183 and 205 (Figure 2-3) is represented ın the bias by a correspondıng ıncreasing water fractıon trend, there ıs enough noise around the trend to suggest that it may not be statıstıcally sıgnıficant

Figure 2-5: RMSE and bias (dashed) in TB-derived water fraction, days 172-215



Further work on thıs project will focus on selected cells where high-resolution flood mapping wıll be tested TB-derived water fraction trends for the four wettest cells are shown ın Figure 2-6. All the cells except the up-rıver cell 58 (dash-dot line) show sıgnıficant upward trends with the largest trend evıdent ın cell 165 (dotted lıne). Still, there ıs considerable noise around the trends. The remaınder of our work wıll focus on minımizing the noise and estımatıng an acceptable noıse level for derıvation of the high-resolution maps. Sınce we know from past work (e.g., Sippel et al., 1994) that inundation area can be accurately derived from TBs under certain condıtıons, our approach emphasızes adapting to the particular conditions encountered here and determınıng the ınput error requirements of the DEM-based mappıng scheme.

Figure 2-6: TB-derived water fraction for the four wettest cells normalized by the true fraction in each cell

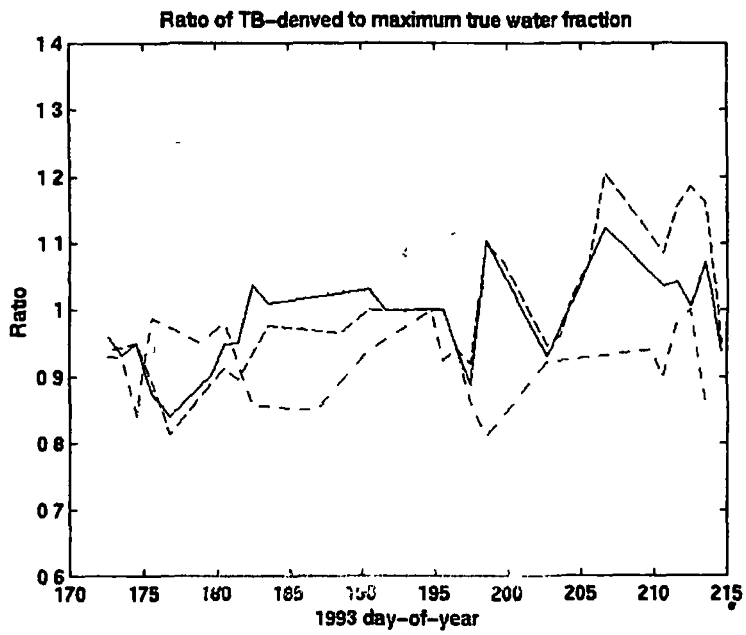


Figure 2-7 shows maps of TB-derıved water fractıon on day 180 and 206. The trend of ıncreasıng water fraction in the wettest cells (e.g., dark blue cluster at center of regıon) ıs evıdent as ıs a more subtle ıncrease in some down-rıver cells (lower rıght). Because of the bıas removal usıng truth data from day 193, the scatter plots ın Fıgure 2-8 are a mısleadıng representation of the errors in the TB-derived water fraction What they illustrate is that the changing conditions in the region are being reflected in TB-derived water fraction measurements.

Figure 2-7: Water fraction derived from SSM/I EASE-Grid brightness temperatures on day 180 and day 206. Note that bias from day 193 retrieval has been removed (see t ext).

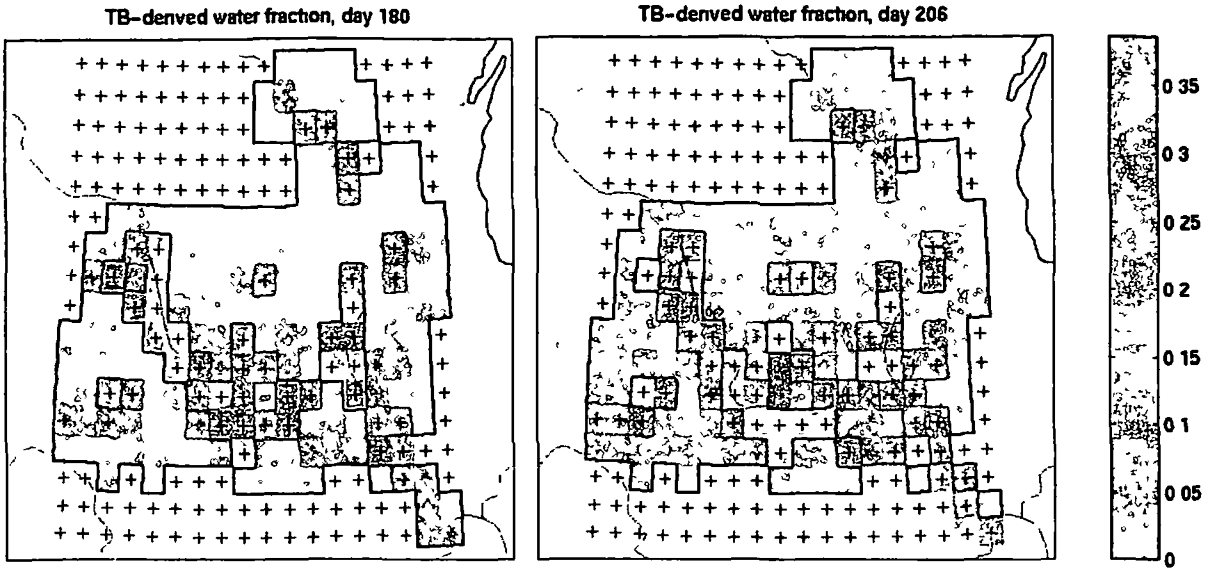
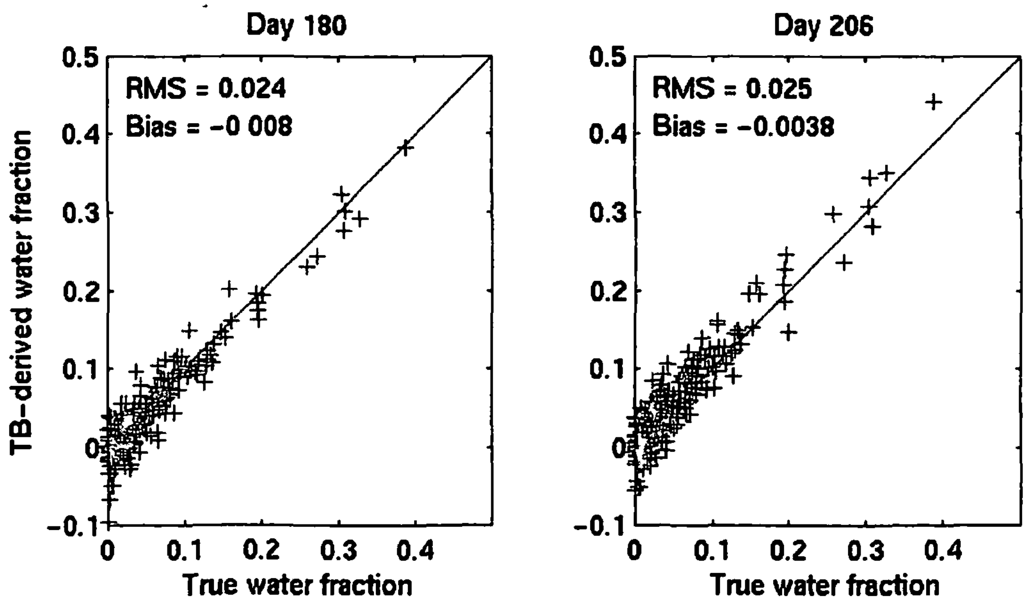


Figure 2-8: Comparison of true water fraction (day 193) to TB-derived water fractions on days 180 and 206. Note that bias from day 193 retrieval has been removed (see text).



3. Schedule and level of effort

The level of effort for the PI was approximately half-time from April 1 (start of work) through June and is currently continuing at full-time. Additional staff (S. Boukabara) are to be added in July at approximately half-time.

The current work schedule provides for the completion of the project by September 30 with the available funding The two main project tasks are:

1. Develop and test (in simulation and with real data along known coastlines) refinements to an existing atmosphere-surface parameter physical retrieval algorithm (Unified Retrieval, UR) that will facilitate retrievals in the presence of partial open water coverage,
2. Apply and validate water fraction retrievals for the Great Midwest Flood of 1993 and create a prototype for high resolution mapping of flood extent that integrates the water fraction retrieval and a DEM.

We have allotted minimal time (less that 2 weeks total) to task 1 because much of the required work (e.g., algorithm configuration and test setup) has recently been accomplished under our CMIS project for NPOESS. We are now working toward the following schedule milestones:

1. July 15: Complete preliminary correlation of gridded SSM/I brightness temperatures to maximum flood extent map for test region (1993 Midwest Floods).
2. August 1: Complete task 1 above (minimizing effect of atmosphere and surface temperature on open water estimates from brightness temperatures). Test flood extent mapping technique using DEM and simulated water fraction estimates. Assess water fraction precision required to provide "useful" resolution for flood mapping with DEM.
3. September 1 Apply flood mapping technique to selected portions of the study area and refine where possible Use simulated water fraction estimates to assess potential improvements from higher-resolution sensor data or better local calibration of the water fraction retrieval model. If time allows, acquire ungridded (swath format) SSM/I data and regrid with improved footprint-matching techniques.
4. September 15: Apply flood mapping technique to entire study area. Identify any additional error sources. If time allows and the data are available, use flood extent maps derived from individual high-resolution imager scenes in addition to baseline maximum-extent map.
5. September 30: Prepare final report.

4. References

Poe, G. A., Optimum interpolation of imaging microwave radiometer data, *IEEE Trans Geosci Rem Sens.*, 28(5):800-810, 1990.

Sippel, S. J., S. K. Hamilton, J. M. Melack, and B. J. Choudhury, Determination of inundation area in the Amazon River floodplain using the SMMR 37 GHz polarization difference, *Remote Sens Environ*, 48:70-76, 1994.

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13. ABSTRACT (Maximum 200 words)

In this report, we review the progress to date including results from data analyses and present a schedule of milestones for the remainder of the project. We discuss the processing of flood extent data and SSM/I brightness temperature data for the 1993 Midwest Flood We present preliminary results from the derivation of open water fraction from brightness temperatures

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