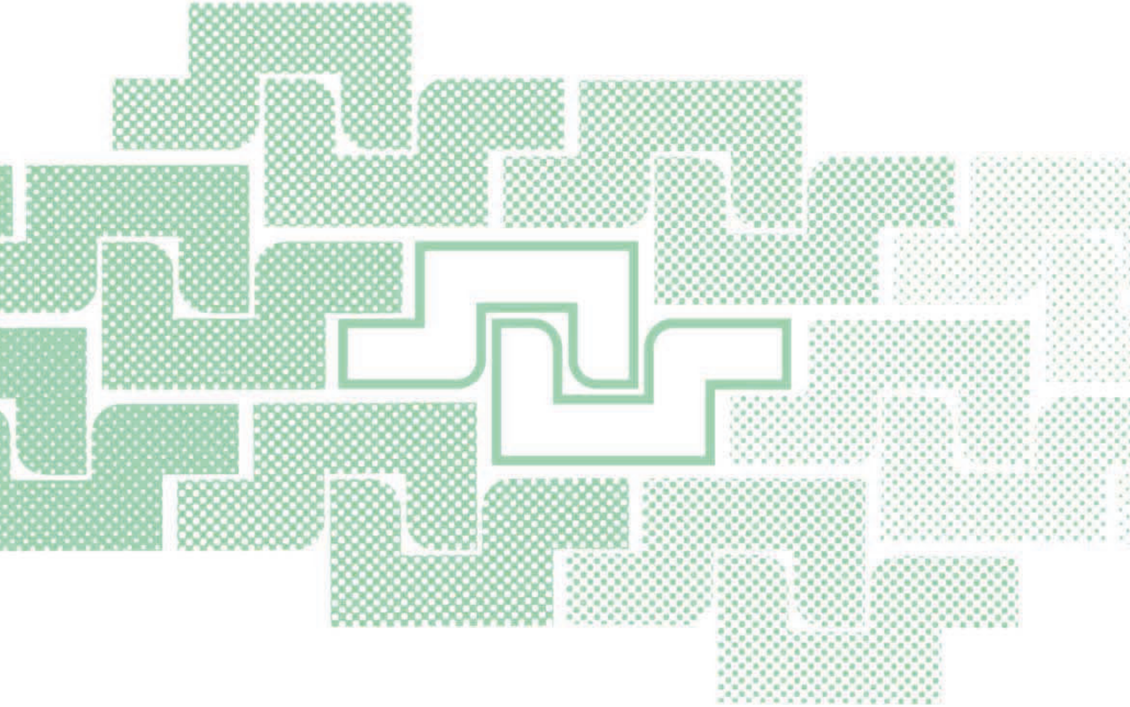

# Transbounday Floods: Reducing Risks Through Flood Management

Edited by

Jiri Marsalek, Gheorghe Stancalie
and Gabor Balint

NATO Science Series

IV. Earth and Environmental Sciences – Vol. 72

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**Series IV: Earth and Environmental Sciences – Vol. 72**

# Transboundary Floods: Reducing Risks Through Flood Management

edited by

Jiri Marsalek
National Water Research Institute, Burlington,
Ontario, Canada

Gheorghe Stancalie
National Meteorological Administration,
Bucharest, Romania

and

Gabor Balint
Environmental and Water Management Research Institute,
Budapest, Hungary

Springer

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# PREFACE

Flood damages are increasing worldwide as a result of frequent recurrence of large floods in many parts of the world, existing and continuing encroachment on flood plains and aging flood protection structures. In the aftermath of recent flood events, the public and experts are looking for ways of protecting life, land, property and the environment, and reducing flood damages. Towards this end, many flood management measures have been practiced, including living with floods, non-structural measures (e.g., regulations, flood defence by flood forecasting and warning, evacuations, and flood insurance), and structural measures (e.g., land drainage modifications, reservoirs, dykes and polders). Such flood management is difficult in river basins controlled by a single authority, and becomes even more challenging when dealing with transboundary floods, which may originate in one country and then propagate downstream to another country, or countries. Under such circumstances, the demands on information and data sharing, and close collaboration in all aspects of flood management are particularly strong and important. Recognising the challenge of transboundary floods, the workshop organisers proposed to the NATO Collaborative Science Program to hold a workshop on this topic. After receiving the NATO grant, the NATO Advanced Research Workshop on Transboundary Floods: Reducing Risks and Enhancing Security was held in Oradea, Romania, from May 4 to 8, 2005.

Preparatory activities included recruiting keynote speakers, selecting workshop participants, finalising the workshop programme, and holding the workshop in Hotel Termal at Baile Felix (Oradea). There were 49 full-time participants from 17 countries at the workshop, and additional observers also audited the workshop program. Extensive experience of workshop participants in this field is reflected in the workshop proceeding, which comprise almost 30 selected papers. Finally, whenever trade, product or firm names are used in the proceedings, it is for identification and descriptive purposes only, without implying endorsement by the Editors, Authors or NATO.

The proceedings that follow reflect only the formal workshop presentations. Besides these presentations, posters, and extensive formal discussions, there were many other ways of sharing and exchanging information among the participants, in the form of new or renewed collaborative links, professional networking and personal friendships. The peaceful atmosphere of the spa resort Hotel Termal contributed to the success of this workshop. For this success, the editors and organisers are indebted to many who helped stage the workshop and produce its proceedings, as listed in the Acknowledgement.

Jiri Marsalek
Burlington, Ontario, Canada

Gheorghe Stancalie
Bucharest, Romania

Gabor Balint
Budapest, Hungary

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This Advanced Research Workshop (ARW) resulted from hard work of many individuals and organisations. The workshop was proposed and directed by Dr. Jiri Marsalek, National Water Research Institute (NWRI), Environment Canada, Burlington, Canada, and Dr. Gheorghe Stancalie, Romanian Meteorological Administration, Bucharest, Romania. They were assisted by three other members of the workshop Organising Committee: Gabor Balint, National Forecasting Services, Environmental and Water Management Research Institute, Budapest, Hungary; Mitrut Tentis, Crisuri River Authority, Oradea, Romania; and, Evzen Zeman, DHI Hydroinform a.s., Prague, Czech Republic.

The ARW was sponsored by NATO, Public Diplomacy Division, Collaborative Programmes Section, in the form of a grant; by the employers of the members of the Organising Committee, who provided additional resources required to prepare and run the workshop and preprint and publish its proceedings.

The workshop preparatory work and secretariat services were provided by Corina Alecu and Anisoara Irimescu, Romanian Meteorological Administration, Bucharest, Romania. Local workshop arrangements in Baile Felix were done by a team from the Crisuri Water Authority, led by Octavian Streng, who was assisted by M. Gale, C. Morar and others.

The editing of proceedings was done by Jiri Marsalek, Gheorghe Stancalie and Gabor Balint, and the camera ready manuscript was prepared by Quintin Rochfort, National Water Research Institute, Burlington, Canada.

Special thanks are due to Dr. D. Beten, Programme Director, Environmental Security, NATO, who provided liaison between the workshop organisers and NATO, and personally assisted with many tasks.

Finally, the organisers are indebted to all the above contributors and, above all, to the participants, who made this workshop a memorable interactive learning experience for all.

## LIST OF PARTICIPANTS

### Directors

| | |
|---|---|
| Marsalek, J. | National Water Research Institute<br>867 Lakeshore Road, Burlington, ON L7R 4A6<br>CANADA |
| Stancalie, G. | Romanian Meteorological Administration<br>97 Sos. Bucuresti-Ploiesti, sector 1, 013686, Bucharest<br>ROMANIA |

### Key Speakers

| | |
|---|---|
| Verdiyev, R. | ECORES, NGO<br>36 Huseynbala Aliyev Str. Apt. 52, Microdistrict, Baku<br>AZERBAIJAN |
| Zeman, E. | DHI Hydroinform a.s.<br>Na Vrsich 5, Prague 100 00<br>CZECH REPUBLIC |
| Spatka, J. | DHI Hydroinform a.s.<br>Na Vrsich 5, Prague 100 00<br>CZECH REPUBLIC |
| Balint, G. | VITUKI,<br>Kvassay J. u. 1. H-1095 Budapest<br>HUNGARY |
| Price, R.K. | UNESCO-IHE<br>Westvest 7, PO Box 3015, Delft 2601 DA<br>NETHERLANDS |
| Drobot, R. | Technical Univ. of Civil Eng. Bucharest<br>B-dul Lacul Tei, NR.124, sector 2, RO-72302 Bucharest<br>ROMANIA |

Lucaciu, M.
Arad County Emergency Situation Inspectorate
Eftimie Murgu Street 3-5, 2900 Arad
ROMANIA

Saul, A.J.
University of Sheffield
Mappin Street, Sheffield, S1 3JD
UK

Bogardi, I.
University of Nebraska
W359 Nebraska Hall, Lincoln NE 68588-05
USA

Mavlyanov, N.
Institute Hydroengeo, State Committee on Geology and Mineral Resources
64, N. Hodjibaev Str., Mirzo Ulugbek district
Taskent 700041
UZBEKISTAN

**Other Participants**

Hakopian, C.
Department of Physical Geography, Yerevan State University
1 Alek Manoukian Street, 375025 Yerevan
REPUBLIC OF ARMENIA

Vardanian, T.
Department of Physical Geography, Yerevan State University
1 Alek Manoukian Street, 375025 Yerevan
REPUBLIC OF ARMENIA

Mustafayev, I.
Institute of Radiation Problems, Azerbaijan National Academy of Sciences
31a H.Javid ave, Baku, AZ1143
AZERBAIJAN REPUBLIC

Mammedov, R.
Department of Environment, Association of International Hydrological Programme
4 Academician Hasan Aliyev Street, 190, Baku, AZ1065
AZERBAIJAN REPUBLIC

| | |
|---|---|
| Kukharchyk, T. | Institute for Problems of Natural Resources Use & Ecology of National Academy of Belarus<br>Staroborysovski tract, 10, Minsk, 220114<br>BELARUS |
| Otsla, J. | Parnu County Rescue Service<br>Pikk 20, Parnu 80010<br>ESTONIA |
| Luik, T. | Parnu County Rescue Service<br>Pikk 20, Parnu 80010<br>ESTONIA |
| Csík, A. | VITUKI<br>Kvassay J. u. 1. H-1095 Budapest<br>HUNGARY |
| Kiss, A. | Koros Region Environment and Water Directorate<br>Városház u. 26, H-5700 Gyula<br>HUNGARY |
| Szekeres, J. | VITUKI,<br>Kvassay J. u. 1. H-1095 Budapest<br>HUNGARY |
| Galbats, Z. | Koros Region Environment and Water Directorate<br>Városház u. 26, H-5700 Gyula<br>HUNGARY |
| Konecsny, K. | VITUKI,<br>Kvassay J. u. 1. H-1095 Budapest<br>HUNGARY |
| Luidort, A. | Upper Tisza Valley Environment and Water Directorate<br>19 Szecheny, 4700 Nyiregyhaza<br>HUNGARY |
| Horosz-Gulyás, M. | VITUKI,<br>Kvassay J. u. 1. H-1095 Budapest<br>HUNGARY |

| | |
|---|---|
| Putsay, M. | Hungarian Meteorological Service<br>Kitaibel Pal Street 1, 1024 Budapest<br>HUNGARY |
| Toth, S. | National Directorate for Environment, Nature and Water<br>Marvany u. 1/c., Budapest H 1012<br>HUNGARY |
| Pagliara, S. | University of Pisa<br>Via Gabba 22, Pisa 56100<br>ITALY |
| Szydlowski, M. | Gdansk University of Technology<br>Narutowicza 11/12, Gdansk 80-952<br>POLAND |
| Alecu, C. | National Meteorological Administration<br>97 Sos. Bucuresti-Ploiesti, sector 1, 013686, Bucharest<br>ROMANIA |
| Irimescu, A. | National Meteorological Administration<br>97 Sos. Bucuresti-Ploiesti, sector 1, 013686, Bucharest<br>ROMANIA |
| Craciunescu, V. | National Meteorological Administration<br>97 Sos. Bucuresti-Ploiesti, sector 1, 013686, Bucharest<br>ROMANIA |
| Mic, R. | National Institute of Hydrology<br>97 Sos. Bucuresti-Ploiesti, sector 1, 013686, Bucharest<br>ROMANIA |
| Tentis, M. | Crisuri Rivers Authority<br>Ion Bogdan Street 35, 3700 Oradea<br>ROMANIA |

| | |
|---|---|
| Nitu, A. | National Institute of Hydrology<br>97 Sos. Bucuresti-Ploiesti, sector 1, 013686,<br>Bucharest<br>ROMANIA |
| Pescaru, V. | National Meteorological Administration<br>97 Sos. Bucuresti-Ploiesti, sector 1, 013686,<br>Bucharest<br>ROMANIA |
| Purdel, A. | National Institute of Hydrology<br>97 Sos. Bucuresti-Ploiesti, sector 1, 013686,<br>Bucharest<br>ROMANIA |
| Streng, O. | Crisuri Rivers Authority<br>Ion Bogdan Street 35, 3700 Oradea<br>ROMANIA |
| Hlavcova, K. | Slovak Technical University<br>Radlinského 11, Bratislava 813 68<br>SLOVAKIA |
| Horvat, O. | Slovak Technical University<br>Radlinského 11, Bratislava 813 68<br>SLOVAKIA |
| Papankova, Z. | Slovak Technical University<br>Radlinského 11, Bratislava 813 68<br>SLOVAKIA |
| Anderson, E. | Dartmouth Flood Observatory, Dartmouth College<br>Hinman Box 6017, Hanover, NH 03755<br>USA |
| Shakirzanova, J. | Odessa State Environmental University<br>15 Lvovskaya Street, Odessa 65016<br>UKRAINE |
| Ivashchuk, O. | Remote Sensing Laboratory, Ukrainian<br>Hydrometeorological Research Institute<br>37 Nauki str., Kyiv 03028<br>UKRAINE |

| | |
|---|---|
| Kryvobok, O. | Remote Sensing Laboratory, Ukrainian<br>Hydrometeorological Research Institute<br>37 Nauki str., Kyiv 03028<br>UKRAINE |
| Ovcharuk, V. | Odessa State Environmental University<br>15 Lvovskaya street, Odessa 65016<br>UKRAINE |
| Frank, L. | State Committee for Nature Protection<br>A. Timur 99, Tashkent 700084<br>UZBEKISTAN |

# CHAPTER 1 COLLECTION AND TRANSMISSION OF DATA USED IN FLOOD MANAGEMENT

# MODIS-BASED FLOOD DETECTION, MAPPING AND MEASUREMENT: THE POTENTIAL FOR OPERATIONAL HYDROLOGICAL APPLICATIONS

R. BRAKENRIDGE[1]
*Dartmouth Flood Observatory, Department of Geography,*
*Dartmouth College, Hanover, NH, 03755, USA*

E. ANDERSON
*Dartmouth Flood Observatory, Department of Geography,*
*Dartmouth College, Hanover, NH, 03755, USA*

**Abstract.** The internationally available and free rapid response data from NASA's two MODIS sensors have considerable potential for operational applications in applied hydrology, including 1) flood detection, characterisation, and warning, 2) flood disaster response and damage assessment, and 3) flood disaster prevention or mitigation. Each requires different strategies for operational implementation. Successful transition to routine use requires start-up investments in personnel time, training, computing, and other infrastructure. However, because comparable follow-on sensors are already planned (e.g. the NASA/NOAA VIIRS sensor aboard NPOESS), such investment can provide permanent enhancements to hydrological measurement and forecast capabilities. In regions where rivers and streams cross international boundaries, MODIS flood detection capabilities are especially useful: they provide consistent and independently verifiable information. However, even within relatively well-gauged regions, such as the U.S., the capability to characterise inundation as it occurs is an important and economical enhancement to flood warning and flood response. We provide pilot study examples for a region entirely

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[1] To whom all correspondence should be addressed. G. Robert Brakenridge, Dartmouth Flood Observatory, Dept. of Geography, Dartmouth College, Hanover, NH, 03755, USA; e-mail: G.Robert.Brakenridge@Dartmouth.EDU

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within the central U.S and also an international transboundary region within Eastern Europe.

**Keywords:** MODIS, remote sensing, floods, rivers, disaster response, flood hazard

## 1. Introduction

The two MODIS (Moderate Resolution Imaging Spectroradiometer) sensors aboard the U.S. satellites Terra and Aqua are nearly ideal region-scale flood mapping and surface water measurement tools (Brakenridge et al. 2003). Operating since early 2001, MODIS data include numerous spectral bands at 500 m and 1 km (at nadir) spatial resolution, but also two (visible and near IR) spectral bands at 250 m resolution. These latter provide excellent water/land discrimination in many settings at acceptable spatial resolution for many applications.

The georeferencing data provided with each "Level 1b swath" scene are accurate to +/- 50 m: this means that the satellite data can be transformed, in "batch mode" (without further human attention) to georectified image-maps, in user-specified map projection. Subsequent image maps prepared for the same areas are, in our experience, in nearly exact registration, so that image change detection approaches can be economically employed and provide maximum sensitivity to small surface water changes.

MODIS data offer frequent (more than daily) coverage, and are provided by NASA free to the international public via the world-wide-web at the following two locations: http://delenn.gsfc.nasa.gov/~imswww/pub/-imswelcome/, and http://rapidfire.sci.gsfc.nasa.gov/. Typical individual scene swath file sizes are 250 megabytes; swath width is 2330 km; only the central portions of the swath provide the full spatial resolution. Recent versions of Envi™, among other commercial remote sensing software, can read, rectify, and re-project MODIS data without further modification. Also, unsupervised classification algorithms supported by Envi™ can identify water image pixels consistently, and groups of water pixels can be translated via vectorisation algorithms into GIS vectors, or outlines. This allows MODIS-observed water to be exported as map layers and integrated with a wide variety of other map displays. The success in water classification is largely due to spectral characteristics of the band 2 data (841 - 876 nm); this band was in fact chosen by the sensor design team to provide excellent water/land discrimination.

Because the data are freely available, and all data obtained since launch are also archived and accessible, and because MODIS data are frequent, well-calibrated, and of spatial resolution adequate to map many small and large river floods, there is high potential for operational applications in applied hydrology (Marsalek et al. 2004). These include: 1) flood detection, characterisation, and warning, 2) flood disaster response and damage assessment, and 3) flood disaster prevention or mitigation. Each requires different strategies for operational implementation.

## 2. Flood detection, measurement, and warning

### 2.1. GENERAL COMMENTS

The first area of potential operational use of MODIS also requires the most investment in developing appropriate processing methodologies, including analysis and display techniques. The practical challenge is to accomplish routine and frequent comparison of new MODIS 250 m image data to previous scenes: in order to discover newly flooded areas and to measure the changes.

There is no unique spectral signature for floods (Mertes et al. 2004). However, topography and the record of prior events provide important spatial restrictions to the areas of interest for future flooding. It is possible, using this record, to establish “alarm” thresholds at these locations, wherein particular changes in the remote sensing signal reliably indicate the onset of flooding (Brakenridge et al. 2005).

On a pilot basis, we have begun testing the following work steps towards this purpose. The labour needed depends very much on the total land area to be included for frequent observation. We have implemented this approach for two regions (Figs. 1, 2) measuring approximately 300 x 300 km: in the central U.S. (central Indiana and Illinois), and in central Europe (eastern Hungary, southern Ukraine, and western Romania).

The following tasks must be accomplished: 1) preparation of the initial “wide area hydrological monitoring display”, 2) collection of MODIS time series data, and 3) initiation of operational monitoring over the defined area and for flood detection purposes.

### 2.2. PREPARATION OF WIDE AREA HYDROLOGICAL MONITORING DISPLAYS

The tasks include:

- An initial reference MODIS 250 m image covering the region is obtained, rectified, and geocoded (Figs. 1, 2).
- The complete time series of MODIS data is selected (cloudy scenes are not used) and then obtained via ftp from web site data distribution

locations. These are each geocoded and co-registered to the initial scene.

- Water pixel "classification" is accomplished using a threshold approach and "NDVI" band ratio (band 2-band 1/band 2+band 1) values, for typical or average conditions, and also for flooded conditions. The latter will commonly require several scenes obtained over a period of several days to provide complete coverage, due to cloud cover.
- Vectorisation of high water limits and low water limits is then accomplished. The resulting GIS vector files are then incorporated into the wide area monitoring display.

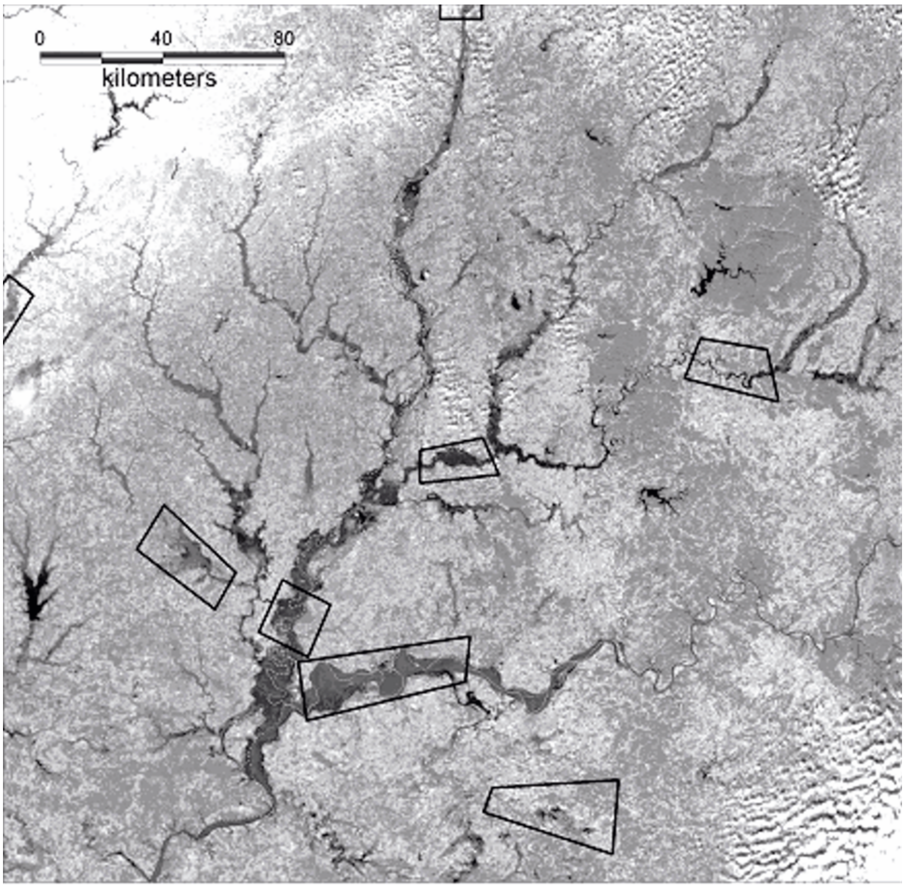

**Fig. 1.** Wide-area hydrological monitoring display for the central U.S., including the Wabash, Little Wabash, and White Rivers. Gauging reach locations are shown as black outlines. The region was experiencing significant flooding when this MODIS band 2 scene was acquired: January 14, 2005

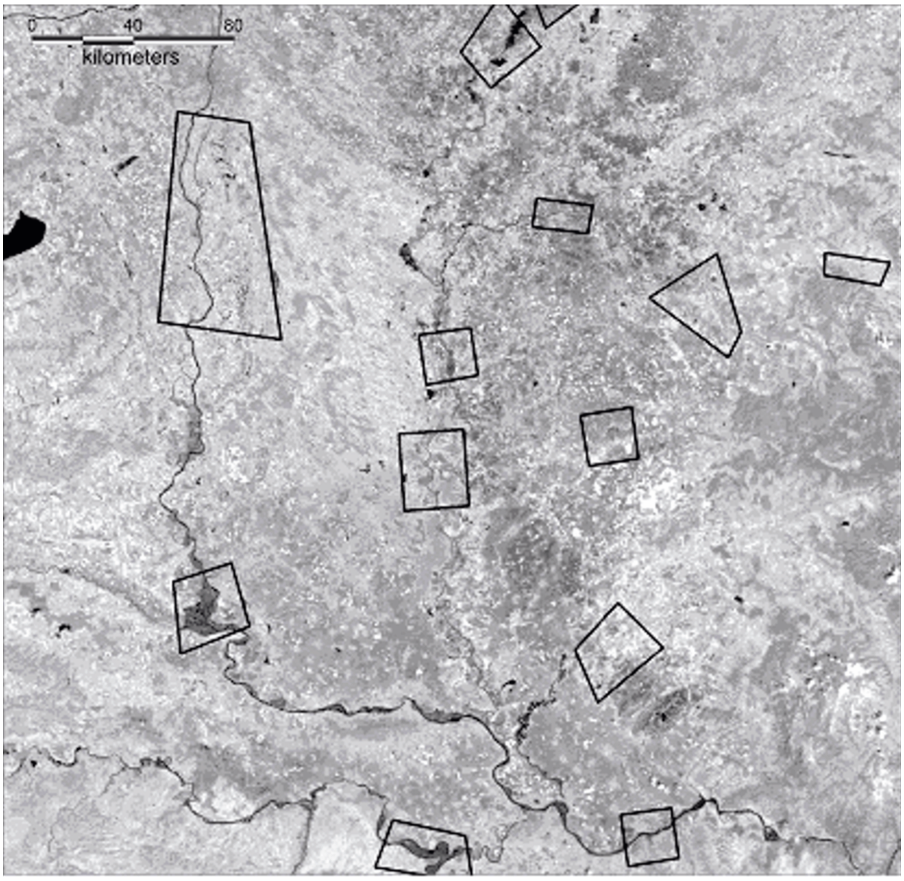

**Fig. 2.** Wide-area hydrological monitoring display for a portion of Eastern Europe, including the Danube and Tisza river valleys. Gauging reach locations are shown as black outlines. The region was experiencing significant flooding when this MODIS band 2 scene was acquired: April 3, 2005

### 2.3. COLLECTION OF MODIS TIME SERIES DATA

The tasks include:

- Gauging reach locations are selected and defined. Measurement subreaches (areas sometimes flooded within each reach) and calibration subreaches (areas within the reach but not subject to flooding) are also defined for each reach (Fig. 3).

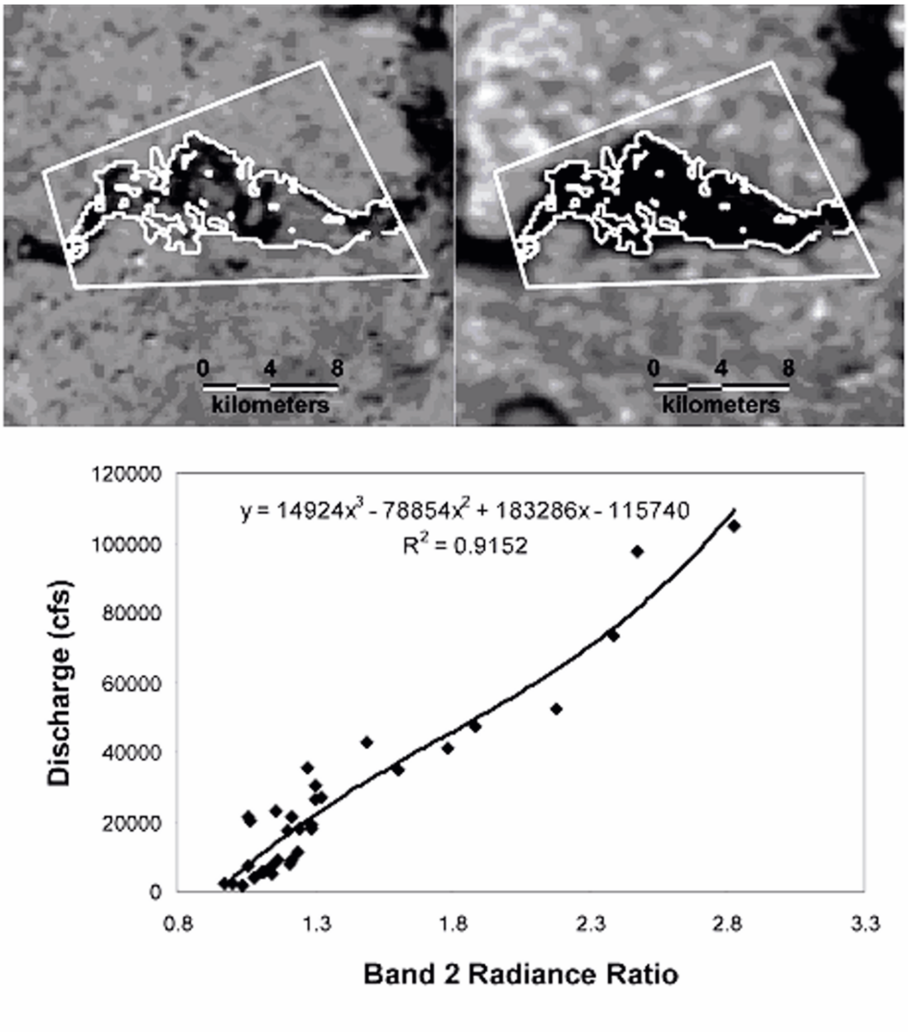

**Fig. 3.** Top: MODIS band 2 images during minor flooding (left, July 17, 2003, 42,900 cfs) and major flooding (right, January 13, 2004, 97,600 cfs), visually showing surface water changes along a White River, Indiana, USA gauging reach. Bottom: MODIS band 2 calibrated radiance ratios from this reach versus the discharge measured at a US Geological Survey gauging station at Petersburg (located at east end of gauging reach)

- Either band 2 average reflectance or band 2 average radiance values are retrieved for the assembled time series, and for both the measurement and the calibration subreaches. A ratio time series is calculated for each reach. Lower radiance or reflectance values in band 2 are associated with larger water surface area. Therefore, higher values for the ratio (calibration reach/measurement reach) indicate higher reach water surface areas, higher river stages, and, thus, higher river discharges (Brakenridge et al. 2005; Brakenridge et al. 2003).

- Ratio values associated with "bankfull" conditions, immediately below overbank flooding, are estimated by comparison to the associated classified water pixels.
- The time series of overbank floods at each gauging reach can now be determined by the dates of each exceedance of this alarm threshold.

### 2.4. INITIATION OF OPERATIONAL MONITORING

The tasks include:

- After realistic MODIS band 2 radiance or reflectance thresholds are established for each gauging reach, implementation of a MODIS-based flood detection and warning capability depends on near real time re-calculation of the subreach ratio immediately upon receipt of new MODIS data. The new value is compared to the alarm threshold. For example, for the data displayed in Fig. 3, the bankfull alarm threshold occurs at a ratio of 1.8, and as indicated by comparisons of mapped inundation extent (not shown) to the radiance ratio.
- The same approach can be used to establish reach "hydrologic status", including low flow as well as high flow conditions, and based on the ranking (percentile) location of the newly observed values compared to the complete time series. This is, however, beyond the scope of the present paper.

Operational use of MODIS can provide several benefits to current flood forecasting and warning activities within many government agencies or ministries. For example, it is not limited by national borders. Also, river reaches that are not otherwise being measured can be monitored via this approach. However, this application is also constrained in one important way: cloud cover is commonly associated with the surface conditions leading to flooding.

The frequency of MODIS data collection helps to alleviate this constraint because temporary breaks in cloud cover provide intermittent access to surface conditions and for many flood events. However, the sensor cannot always be relied upon, as is the case for in situ gauging stations. Due to cloud cover, MODIS observation may, for particular events at particular reaches, not be possible at all. In regions such as used in our pilot studies, data can be obtained at some gauging reaches within the region nearly every day, but at particular reaches there can occur longer time periods without new data. Operational use must consider these limitations. The denser the array of gauging reaches, the better the temporal as well as spatial coverage for a region. Fortunately, a dense array is economical to support once operational. Thus, after the time series is gathered for each reach, new data collection can be automated such that 100 gauging reaches can be monitored as easily as 10.

## 3. Disaster response and damage assessment

The MODIS data stream can provide very useful near-real time information to disaster responders and to damage assessment. Because the sensors are always on, there is no need to schedule sensor data acquisitions, and because of the wide-area coverage, and frequent repeat, there are commonly good opportunities to map flood inundation even if intermittent cloud cover is occurring. Fig. 4 is one example of several hundred flood events so far mapped by Dartmouth Flood Observatory personnel using MODIS. Illustrated is a portion of the complete map.

**Fig. 4.** Rapid response inundation map of the Wabash Valley (left portion of map) based on MODIS data. The light grey tones show areas flooded, the dark grey outline encloses water imaged by MODIS during non-flooded conditions. Shaded relief base material was generated from NASA Shuttle Radar Topography Mission (SRTM) topographic data

The wide-area nature of MODIS should not obscure the fact that it can be used for inundation mapping even at relatively large map scales. For both large and small-scale map products, a similar operational methodology is employed:

- The rectified, geocoded, bands 1 and 2 MODIS swath data are subjected to a non-supervised pixel classification algorithm, such as the isodata classifier supported by Envi™.
- One or more of the resulting classes are visually identified as water pixels, and combined into one class, if necessary.
- The same software is used to fit geographic information system (GIS) digital vector polygons around all "water" pixels.
- The inundation vectors are superimposed onto false colour composites using both bands of the same MODIS scene, and "false positive" vectors (commonly, cloud shadows) are deleted. Also, in this quality control step, areas of the map missing due to heavy cloud cover are delineated for depiction on the final map.
- The edited GIS vectors are then superimposed on map base material, and over previously mapped water, in order to produce the rapid response map (Figs. 4, 5).

**Fig. 5.** Flooding along the Somes River in Romania, March 19, 2005, as recorded by MODIS (black outline). ASTER band 2 provides the base map

For large scale maps, we use NASA-provided clear sky Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) data, with a spatial resolution of 15 m. Note that the MODIS data are at much coarser spatial resolution, but still provide very useful information when superimposed over the large scale base material. This is the best approach to identify, for example, human settlements and transportation links likely to be affected by the flooding.

## 4. Flood disaster prevention and mitigation

Routine MODIS-based mapping of the land inundated by floods, each year since early 2001, and continuing to the present, can and should be accomplished by local, regional, and national government agencies. The motivation for such work is uncomplicated: through such work, it is possible to objectively document those lands subject to flood hazard. Fig. 6 is an example of such a MODIS-derived flood hazard map, for a transboundary area in Southeast Asia. In this case, the river itself forms the international boundary.

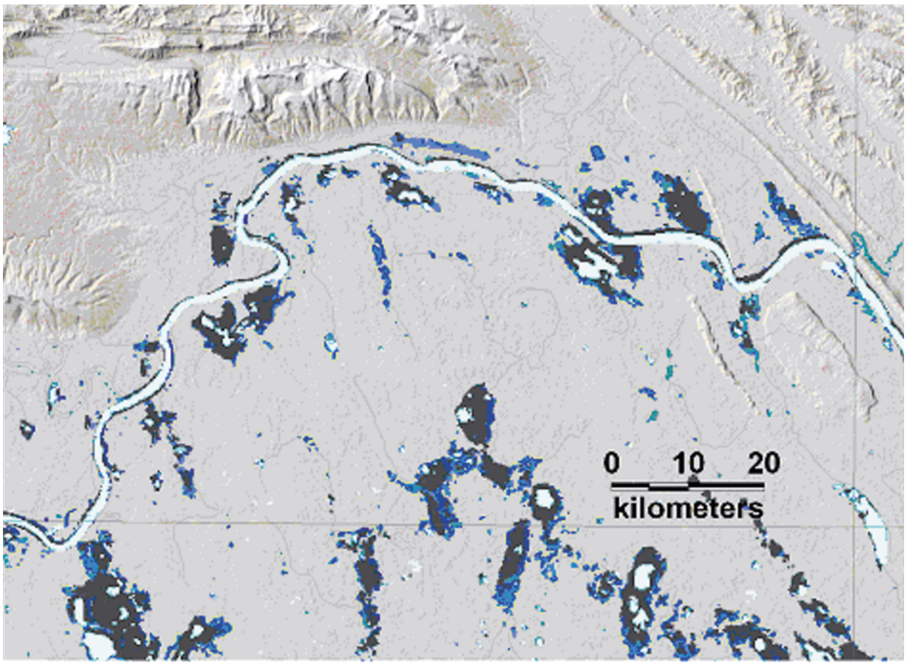

**Fig. 6.** Multi-year MODIS-based mapping of flood inundation, Mekong River, where it forms the boundary between Laos (north) and Thailand (south). Shaded relief base material was generated from NASA Shuttle Radar Topography Mission (SRTM) topographic data

Operational implementation of MODIS for flood hazard mapping commonly serves different user communities and is also, primarily, a GIS rather than remote sensing technical activity. The final outcome is high quality maps that are suitable for international agency (Caquard et al. 2004), government regulatory, insurance company and for other commercial users. In the example shown, flooding that occurred in different years is depicted by varying colours: maps using this cartography allow the user to determine in which year maximum flooding occurred. However, there are other methods for displaying the same information to emphasize other information. Also, these maps are not static end-products but should be updated each year, as new flooding occurs.

We emphasise the synergy between rapid response mapping, utilising the always-on MODIS sensor, and the use of GIS software, which can manipulate and store inundation information. Even as real-time inundation maps are provided for the use of government ministries and the affected populations, the data can be incorporated into GIS-based flood hazard maps. Preservation of such maps within a geographic information system provides exceptionally valuable and objective basic information for evaluating flood hazard on an international basis and also for forecasting the inundation effects of future flooding.

## 5. Conclusions

Three potential operational applications of MODIS-based observations of inland flooding along streams and rivers have been presented, and their implementation steps outlined. The applications include flood detection and warning, rapid response flood inundation mapping, and flood hazard assessment (by map compilation, over time, of MODIS-observed inundation).

All of these applications, but perhaps especially compilation of region-wide coverage of many regional floods, over time, would be very expensive using traditional orbital remote sensing data. Individual scenes covering relatively limited land areas must be purchased, and personnel time required for their analysis is much higher than for MODIS information. A revolution of orbital sensor capability is now underway, however, and because the MODIS 250 m spectral bands, with contained geocoding information, provide frequent, wide-area, and free coverage of water area changes. Such changes can now be observed internationally using some of the same methodologies long used by meteorologists and climatologists applied with weather satellite data.

Operational application of MODIS and the planned follow-on sensors (for example, the NASA/NOAA Visible/Infrared Imager/Radiometer Suite,