Remote Sensing for Environmental Monitoring and Change Detection (Proceedings of Symposium HS3007 at IUGG2007, Perugia, July 2007). IAHS Publ. 316, 2007.

Contribution of Earth observation data supplied by the new satellite sensors in flood risk mapping

GHEORGHE STANCALIE, VASILE CRACIUNESCU & ANISOARA IRIMESCU
National Meteorological Administration, 97 Sos. Bucuresti-Ploiesti, Sector 1, 71552 Bucharest, Romania
gheorghe.stancalie@meteo.inmh.ro

Abstract This paper presents the specific methods, developed within the NATO Science for Peace project "Monitoring of extreme flood events in Romania and Hungary using EO data", for deriving satellite-based applications and products for flood-risk mapping. A series of specific image processing operations were performed, using the ERDAS Imagine software. In order to obtain high-level thematic products, the data extracted from Earth Observation (EO) images were integrated with other non-space ancillary data and hydrological/hydraulic model outputs. The application presented will contribute to preventive consideration of extreme flood events by more judiciously planning land-use development, and elaborating plans for flood mitigation, building infrastructure in flood-prone areas and by optimizing the distribution of spatial flood-related information to end-users.

Key words flood; risk mapping; satellite; spatial information

INTRODUCTION

Flooding remains the most widely spread natural hazard across Europe, with significant economic and social impacts. Over recent years, river flooding and related landslides occurred quite frequently in Romania, some of these events being isolated while others affected large areas of the country.

The flood forecasting and monitoring systems within the study area do not accurately reflect the spatial distribution of floods and related phenomena (pertaining to geographic distances or patterns) in both pre- and post-crisis phases. To reduce these limitations, a NATO SfP project was initiated (with representatives from Hungary, Romania and the USA), emphasizing a satellite-based surveillance system connected to a dedicated GIS database that will offer a much more comprehensive evaluation of the effects of extreme floods. The project aims to provide an efficient and powerful flood-monitoring tool to the local and river authorities, as well as to other key organizations, which is expected to significantly improve the efficiency and effectiveness of flood defence action plans (Marsalek *et al*., 2006). Some applications on flood hazard and vulnerability assessment and mapping, developed in the framework of this NATO SfP project, are presented.

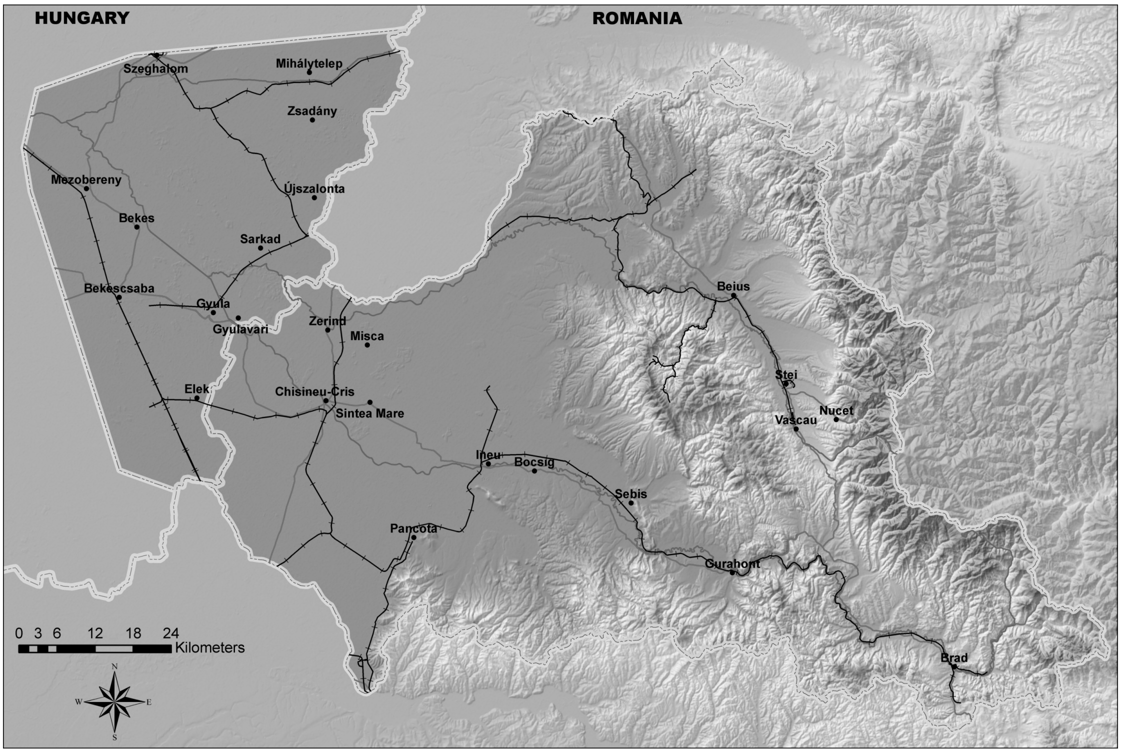

Fig. 1 Study area: the Crisul Alb–Crisul Negru–Kőrős transboundary basin, crossing the Romanian–Hungarian border.

STUDY AREA

The study area is the Crisul Alb/Negru/Kőrős transboundary basin (Fig. 1) spanning across the Romanian–Hungarian border, with a total area of 26 600 km^2. Annual precipitation ranges from 600 to 800 mm/year in the plain and plateau areas to over 1200 mm/year in the mountainous areas of Romania. This precipitation distribution can be explained by the fact that humid air masses brought by fronts from the Icelandic Low frequently enter this area. The orography of the area (Apuseni Mountains) increases precipitation on the western side of the mountain range.

In terms of hydrography, there is a marked difference between the high rates of mountain runoff and the low runoff rates in the plains. Thus, runoff flood waves form quickly in the Romanian part of the basin and move rapidly to the plains in the Hungarian part of the basin, which is characterized by relatively slow flows and a potential for inundation.

Severe floods occurred in June 1974, July–August 1980, March 1981 and December 1995–January 1996, March 2000, April 2000 and April 2001. The spring 2000 flood in Romania caused damage of more than $US 20 million, affecting houses, roads and railways, bridges, hydraulic structures, the loss of domestic animals, and business losses. In Hungary, a particularly severe flood occurred in the summer of 1980, causing total losses of $US 15 million, destroying farmhouses and significantly affecting agriculture.

EO DATA USED

Apart from ground information on the occurrence and evolution of floods, EO data supplied by the satellite orbital platforms (SPOT, IRS, LANDSAT-7, NOAA/AVHRR, RADARSAT, QUIKSCAT, EOS-AM "TERRA" and EOS-PM "AQUA"), in the optical and microwave spectral domains, substantially contribute to determining the flood-prone areas (Brakenridge *et al*., 2003). RADARSAT-1 and -2, based on Synthetic Aperture Radar microwave, penetrate clouds and rain, being very efficient in flood monitoring and structural flood damage assessment. SeaWinds on QuikSCAT, the new spaceborne Ku-band scatterometer, can provide nearly daily global coverage, with a capability to detect where flooding is occurring without necessarily imaging.

Table 1 provides the basic features of important spaceborne remote sensing observation systems such as: spatial resolution for panchromatic (PAN) and multispectral images, swath width and spectral bands (visible, near infrared–NIR, thermal IR).

Table 1 Spectral and spatial characteristics of important satellite sensors.

Satellite/sensor	Spatial resolution PAN (m)	Spatial resolution MS (m)	Swath width (km)	Spectral bands
LANDSAT–etm	15	30	170 × 183	Visible, NIR, Thermal IR
TERRA/ASTER	–	15	60 × 60	Visible, NIR, Thermal IR
TERRA/MODIS	–	250, 500, 1000	2330 × 1350	Visible, NIR,
SPOT 5	2.5 & 5	10, 20	60 × 60	Visible, NIR,
IKONOS	1	4	11	Visible, NIR
QUICKBIRD	0.6	2.5	16.5	Visible, NIR
ORBVIEW 3	1	4	8 × 8	Visible, NIR

The new TERRA and AQUA platforms, equipped with MODIS and ASTER sensors, can provide a comprehensive series of observations on floods, with much higher spatial resolution where available. The information provided by these new sensors is of a higher quality than the previous one, especially taking into account the need for frequently repeated coverage while floods are underway. This information can be used for determining certain parameters necessary to monitor flooding, such as: hydrographic network, water accumulation, size of flood-prone area, and land cover/land-use features.

METHODS FOR OBTAINING USEFUL PRODUCTS FOR FLOOD RISK ASSESSMENT

It is generally recognized that the management and mitigation of flood risk require a holistic, structural set of activities, approached in practice on several fronts with appropriate institutional arrangements made to provide the agreed standard services to the community at risk (Samuels, 2004).

Flood management includes pre-flood, flood emergency and flood recovery activities. The pre-flood activities are: flood risk management for all flood causes; disaster contingency planning; building flood defence infrastructure and implementing forecasting and warning systems; maintenance of flood defence infrastructure; land-use planning and management within the whole basin; discouragement of inappropriate development within flood-prone plains; public communication and education on flood risk and actions to take in a flood emergency. Operational flood management includes: detecting the likelihood of a flood; forecasting future river flow conditions from hydrological and meteorological observations; warnings issued to the authorities and the public on the extent, severity and timing of the flood; response to the emergency by the public and the authorities. Post-flood activities are: relief for the immediate needs of those affected by disaster; reconstruction of damaged buildings, infrastructure and flood defense; recovery of the environment and economic activities in flooded areas; review of flood management activities to improve planning for future events in the area.

Within the framework of flood surveying, satellite images can provide up-to-date geographical information, which is helpful during different phases of the flood. Thus, before flooding, the satellite images enable the description of the land cover of the studied area under normal hydrological conditions; during flooding the EO data provide information on the inundated zones, mapping flood extent, flood's evolution; after flooding, the satellite images point out the flood's effects showing the affected areas, flood deposits and debris.

In order to obtain high-level thematic products the data extracted from EO images must be integrated with other non-space ancillary data (topographical, pedological, meteorological data) and hydrological/hydraulic model outputs. This approach may be used in different phases of establishing the sensitive areas such as: the database management; the elaboration of risk indices from morpho-hydrographical, meteorological and hydrological data; interfacing with the models in order to improve their compatibility with input data; recovery of results and the possibility to work out scenarios; and presentation of results as synthesis maps easy to access and interpret, adequate to be in addition combined with other information layouts resulting from the GIS database.

The products useful for flood risk analysis include: accurately updated maps of land cover/land-use, comprehensive thematic maps at various spatial scales with the extent of the flooded areas and the affected zones, and maps of hazard-prone areas.

A series of specific image processing operations were performed, using the ERDAS Imagine software: geometric correction and geo-referencing in the UTM or STEREO 70 map projection system, image improvement (contrast enhancing, slicking, spectral band combinations, re-sampling operations), statistic analyses (for the characterization of classes, the selection of training samples, conceiving classifications).

Optical high-resolution data have been used to perform the analysis of land for inventory purposes under normal hydrological conditions as well as for determining the hydrographic network. Using supervised classification methods or advanced segmentation of specific thematic indices, the geographical information was extracted and integrated within the GIS database.

In the case of radar images, multi-temporal techniques were considered to identify and highlight flooded areas. This technique uses radar images of the same area taken on different dates (and a reference image from the archive, showing the "normal" situation) and assigns them to the red, green and blue colour channels in a false colour image. The resulting multi-temporal image is able to reveal changes in the ground surface by the presence of colour in the image, the hue of a colour indicating the date of change, and showing colour intensity the degree of change.

The land cover/land-use mapping

The main stages of the methodology for obtaining land cover/land use maps from medium- and high-resolution images (Stancalie & Craciunescu, 2005) include: selecting medium- and high-resolution images, preliminary activities for data organizing and selection; computer-assisted interpretation and quality control of results; digitization of the obtained maps; database validation on the level of the studied geographic area; obtaining the final documents, in cartographic, statistic or tabular form.

Preliminary activities comprise collecting and inventorying the available cartographic documents and statistic data connected to land cover: topographic, land survey, forestry, and other thematic maps at various scales.

To obtain the land cover (map)/land-use map, satellite images of fine spatial resolution and rich multispectral information have to be used. In case of IRS and SPOT data, the preparation stage consisted in merging data obtained from the panchromatic channel, which supply the spatial detail (spatial resolution of 5 m for the IRS, 10 m for the SPOT), with the multispectral data (LISS for IRS, XS for SPOT), which contain the multispectral richness. For this application TERRA/ASTER data have also been used. These data proved to be suitable for detailed maps of land cover/land-use, especially the visible and near infrared bands (1, 2, 3B) with 15 m resolution. Figure 2 shows a flowchart on the generation of land cover/land-use maps using high-resolution satellite data.

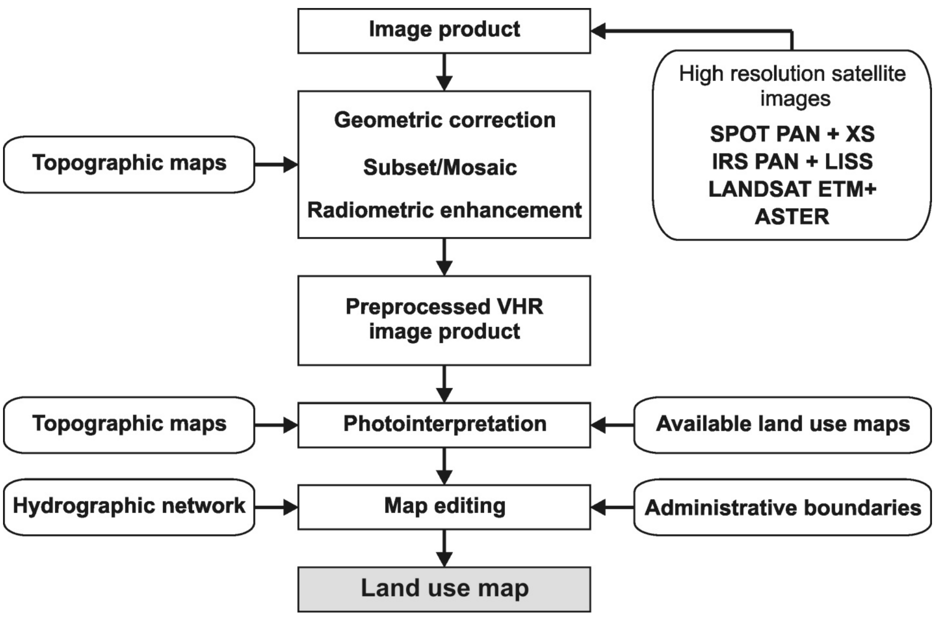

Fig. 2 Flowchart on the generation of land cover/land-use maps.

Discriminating and identifying various land occupation classes rely on the classical procedures of image processing and lead to a detailed management of the land cover/land-use, followed by a generalizing process. The satellite-based cartography of the land cover/land-use is important because it allows for periodical updating and comparisons, and thus evaluates the human presence and provides elements of vulnerability, at the same time assessing the impact of the flooding.

METHOD FOR IDENTIFYING AND MAPPING FLOODED AREAS

The methodology to identify, determine and map areas affected by floods is based on the different classification procedures regarding satellite images. The advantage of using high-resolution satellite images consists of the possibility to select precise spatial information upon the respective area and to localize and define the flooded or flooding-risk areas. Radar images can bring useful information regarding flooded areas, even during periods of abundant rainfall and clouds. The multi-temporal image analysis combined with the land cover/land-use information enable us to identify the water-covered area including the permanent water bodies) and then the flooded areas. Figure 3 presents the flowchart on the generation of flood-extent maps using satellite radar (SAR) images.

Using this methodology to identify and map flooded areas allows monitoring and investigating flood evolution during different phases, but especially after the crisis, in order to make damage inventory and to take recovery actions.

METHOD TO PREPARE FLOODING-RISK MAPS

The flooding-risk assessment requires a multidisciplinary approach; coupled with the hydrological/hydraulic modelling, the contribution of geomorphology can play an exhaustive and determining role using GIS tools (Townsend & Walsh, 1998). The GIS

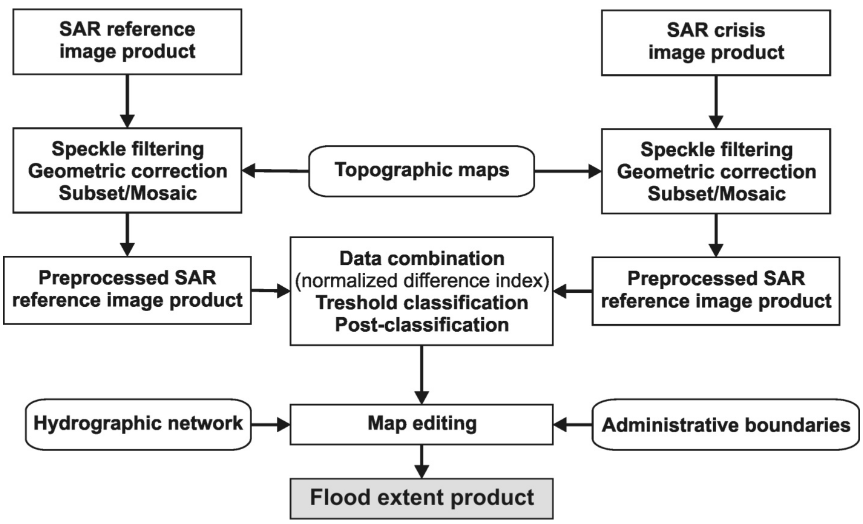

Fig. 3 Flowchart on the generation of flood-extension maps using satellite radar (SAR) images.

database structure for the study area was designed to be used for the study, evaluation and management of information on flooding occurrence and development, as well as for the assessment of damage inflicted by flooding effects. In this regard, the spatial geo-referenced information ensemble (satellite images, thematic maps and series of meteorological and hydrological parameters, other exogenous data) was structured as a set of file-distributed quantitative and qualitative data focused on the relational structure between the info-layers. The GIS database is connected with the hydrological database, which will allow synthetic representations of the hydrological risk, using separate or combined parameters. Figure 4 summarizes the procedure using hydrological/hydraulic model outputs and GIS info-layers for the preparation of flooding-risk maps.

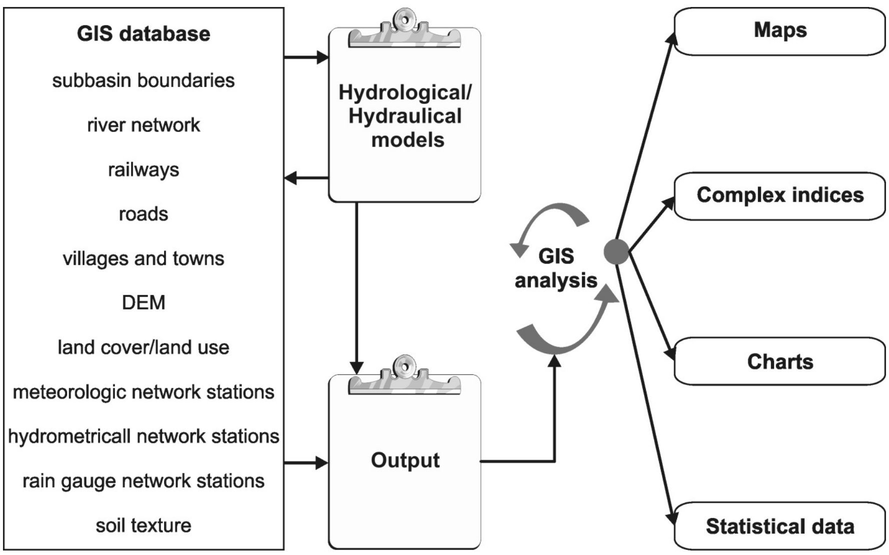

Fig. 4 Integration of hydrological model outputs and GIS info-layers for preparing flooding-risk maps.

Building this GIS for the study area was based mainly on maps and topographic plans, updated on the basis of recent satellite images (e.g. the hydrographic network, land cover/land-use) or by field measurements (e.g. dikes and canals network). The GIS database contains the following info-layers: sub-basin and basin limits; land topography (organized in a Digital Elevation Model—DEM); hydrographic network, dikes and canals network; network of communication ways (roads, railways), localities, network of weather stations, rain-gauging network, network of hydrometric stations; land cover/land-use, updated from satellite. Various morphological parameters have been extracted from the DEM, such as altitudes, slopes, transversal profiles, etc. This information is useful in evaluating local or cumulated potential flowing into a zone of the basin, as well as in obtaining a realistic simulation of floods, taking into account terrain topography, the hydrological network and water levels in different transversal profiles on the river, obtained from the hydraulical modelling. Using the GIS database for the study area, several simulation outputs of hydrological or hydraulic models could be superimposed in order to elaborate the flooding-risk maps.

CONCLUSIONS

Flood-risk analysis needs to make use of, and integrate, many sources of information. This approach is more demanding in the case of a transboundary river. The integrated flood management approach is in harmony with the recommendations of the International Strategy for Disaster Reduction and those of the EU Best Practices on Flood Prevention, Protection and Mitigation (Balint, 2004).

The optical and microwave satellite data supplied by the new European and American orbital platforms like the EOS-AM "Terra" and EOS–PM "Aqua", DMSP, Quikscat, SPOT, ERS, RADARSAT, Landsat7 provide information and adequate parameters contributing to the improvement of hydrological modeling and warning.

Considering the necessity of improving the means and methods of flood hazard and vulnerability assessment and mapping, this paper presents the capabilities offered by EO data and GIS techniques to manage flooding and related risks. The study area is situated in the Crisul Alb-Crisul Negru-Kőrős transboundary basin, across the Romanian–Hungarian border.

The specific methods, developed within the NATO SfP project "*Monitoring of extreme flood events in Romania and Hungary using EO data*", to derive satellite-based applications and products for flood risk mapping (maps of land cover/land-use, thematic maps of flooded areas and affected zones, flooding risk maps) have been presented.

The satellite-based products will contribute to a preventive consideration of extreme flood events by elaborating plans for flood mitigation, building infrastructure in flood-prone areas, and by optimizing the distribution of spatial flood-related information to end-users. At the same time the project will provide decision-makers with updated maps of land cover/land-use, hydrological networks and with more accurate/comprehensive thematic maps at various spatial scales showing the extension of flooded areas and affected zones.

REFERENCES

Brakenridge, G. R., Anderson, E., Nghiem, S. V., Caquard, S. & Shabaneh, T. B. (2003) Flood Warnings, Flood Disaster Assessments, and Flood Hazard Reduction: The Roles of Orbital Remote Sensing. In: *Proc. of the 30th Int. Symp on Remote Sens Environ* (Honolulu, Hawaii), 131–140.

Balint Z. (2004) Flood protection in the Tisza basin. In: *Proc. of the NATO Advanced Research Workshop – Flood Risk Management Hazards, Vulnerability, Mitigation Measures* (Ostrov u Tise, Czech Republik), 171–183.

Marsalek, J., Stancalie, G., Brakenridge, G. R., Putsay, M., Mic, R. & Szekeres J. (2006) Overview of the NATO Science for Peace Project on Management of Transboundary Floods in the Crisul-Körös River System. NATO Science Series IV: Earth & Amp. *Environ. Sci.***72**, 11–24.

Samuels, P. G. (2004) A European perspective on current challenges in the analysis of inland flood risks. In: *Proc. NATO Advanced Research Workshop–Flood Risk Management Hazards, Vulnerability, Mitigation Measures* (Ostrov u Tise, Czech Republik), 3–12.

Stancalie, G. & Craciunescu, V. (2005) Contribution of Earth Observation data supplied by the new satellite sensors to flood disaster assessment and hazard reduction. In: *Geo-information for Disaster Management* (ed. by P. van Oosterow, S. Zlatanova & E. M.Fendel), 1315–1332. Springer Berlin, Heidelberg, New York, USA.

Townsend, P. & Walsh, S. J. (1998) Modeling of floodplain inundation using an integrated GIS with radar and optical remote sensing. *Geomorphology* **21**, 295–312.