Contribution of Earth Observation data supplied by the new satellite sensors to flood disaster assessment and hazard reduction

Gheorghe STANCALIE

Vasile CRACIUNESCU

National Meteorological Administration

97 Sos. Bucuresti-Ploiesti, Sector 1,
71552 Bucharest, ROMANIA

Presentation outline

- **Introduction**
- **The NATO SfP Project "Monitoring of Extreme Flood Events in Romania and Hungary Using EO Data"**
- **Study area**
- **EO data used**
- **Methods for obtaining useful products for flood risk assessment**
  - **Land cover/land use mapping**
  - Hydrographic network characteristics and water accumulations
  - **Flooded areas mapping**
  - **Areal extent of snow pack**
  - **Flooding risk maps preparation**
- **Conclusions**
- **Acknowledgement**

INTRODUCTION

- The cost of natural disasters is increasing; their impact is invariably higher in developing countries and where people are concentrated. The risk of **flooding** due to runoff is a major concern in **Romania**.

- There are several technological trends that can serve to decrease the vulnerability to disasters. These include: better understanding of hazardous processes, improved analytical methods and communications.

- Orbital sensing technologies, used in conjunction with traditional means, can greatly contribute to improved management of flood hazards.

- The new satellite platforms (e.g. EOS-Terra/Aqua, DMSP, QuikScat, ADEOS-2, etc.), equipped with different optical or radar sensors such as MODIS, ASTER, SeaWind offer a high quality Earth Observation (EO) information with frequent repeat coverage.

Crisul Alb River – March 2000
Downstream of Ineu bridge,
Max. level: 832 cm

Crisul Negru River – April 2001
Upstream of Tinca bridge,
Max. level : 763 cm

"Monitoring of Extreme Flood Events in Romania and Hungary Using EO Data"

- At the initiative of the Romanian Meteorological Administration, a project on "Monitoring of Extreme Flood Events in Romania and Hungary Using EO Data", proposed to the NATO Science for Peace (SfP) Programme started in 2002. The project, including representatives of Romania, Hungary and USA, considers the setting up of a satellite-based surveillance system connected to a dedicated GIS database that will offer a much more comprehensive evaluation of the extreme flood effects.

- The main goal of the project is to reduce flood damages in the study area by improved flood forecasting and flood defence, and to deliver on other programmatic criteria, including enhancing cooperation among scientific personnel in the participating countries, training young researchers, disseminating results to the international scientific community, and transferring the tools developed in the study area to another river basin.

- Applications, based on EO data supplied by the new satellite sensors, to flood disaster assessment and hazard reduction, developed in the framework of this NATO SfP project are presented.

Study Area: Crisul Alb - Crisul Negru - Kőrős transboundary basins, Romania-Hungary

Total area: 26,600 km2
On the Romanian territory:14,900 km2

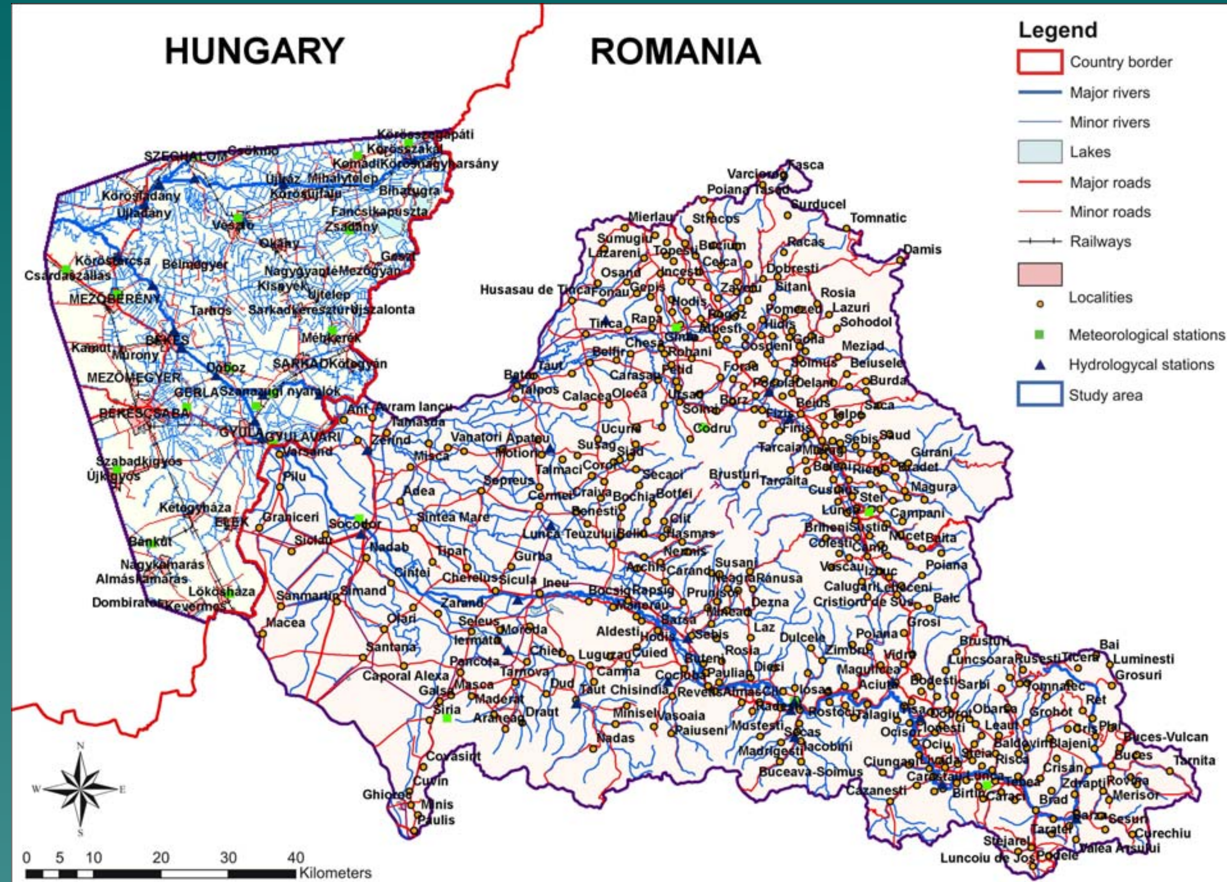
In Romania:
- mountains - 38%;
- hilly areas - 20%;
- plains - 42%.
- 30% of the basin-forested

In Hungary:
the basin relief represents plains.

Hydrography

Marked difference between high rates of mountain runoff and low rates of runoff in plains. Runoff flood waves formed quickly in the Romanian part of the basin move rapidly to the plains in the Hungarian part of the basin which is characterised by relatively slow flows and a potential for inundation.

Study Area



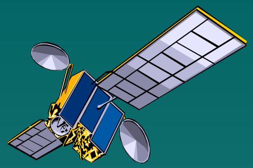
The **Romanian area** is defended by dikes along the Crisul Alb River and Crisul Negru River.
Crisul Negru River and the Teuz River (43 km) – dikes designed for a 50-year return period;
Crisul Alb (67 km) - dikes designed for a 100-year return period.
Other structural flood protection measures include permanent retention storage facilities (total volume of 34 x 106 m3) and temporary storage facilities (a total storage volume of almost 80 x million m3).

In April 2000, the right bank dike of the Crisul Negru broke (a 130 m breach) and caused significant flooding of , and damages in, the adjacent territory.

On the **Hungarian side**, much of the area is protected by flood dikes (440 km). Other structural flood protection measures include reservoirs (188 million m3) and serve to reduce critical flood levels. The reservoirs are activated during floods, by a controlled explosion opening a protected spillway in flood dikes.

The flood forecasting and monitoring systems existing in the study area do not reflect well the spatial distribution of floods and the related phenomena (pertaining to geographic distances or patterns) in both pre- and post crises phases.

To mitigate these limitations, the SfP project was initiated with emphasis on a satellite-based surveillance system connected to a dedicated GIS database that will offer a much more comprehensive evaluation of the extreme flood effects.



EO data used

OPTICAL

- **NOAA-AVHRR** (optical, 4 or 5 channel broad band scanner, visible to thermal IR, 2400 km swath, 1 km at nadir);
- **Landsat-ETM+** (optical, visible and near infrared (VNIR) bands - bands 1,2,3,4,and 8 (PAN) with a spectral range between 0.4 and 1.0 micrometer; 15 m (PAN only) and 30 m resolution, Swath width is 185 km);
- **Terra/Aqua-MODIS** (optical, 250 m, 1330 km swath, 36 spectral bands: an imaging spectrometer, same orbit as Landsat 7, sees every point on Earth every 1-2 days);
- **Terra/Aqua-ASTER** (optical, 10 m, 14 channels, swath of 60 km at nadir, spatial resolution: VNIR-15 m, SWIR-30 m, TIR-90 m).

RADAR

- **Radarsat** (SAR, 10-100 m, C- or L-band synthetic aperture radar, not affected by cloud cover or solar illumination, active rather than passive sensor, swaths 45 to 500 km wide, resolutions 8 to 100 m);
- **ERS, Envisat** (SAR, 10-30 m, 405 km swath with 150 m or 1 km resolution, extended operating time at high resolution, dual polarization capabilities);
- **SeaWinds-QuikSCAT** (Ku-band active radar scatterometer, resolution 25 km x 25 km, swath of 1800 km (for a vertical polarization at an incidence angle of 54^{o}) or 1400 km (for a horizontal polarization at incidence angle of 46^{o}), visit period every 2.5 days regardless of cloud cover.

EO Data for Flood Forecasting and Warning

The geo-referenced information, obtained from optical and radar images could be used in determination of certain parameters required in flood forecasting and warning procedures, such as:

- the hydrographic network characteristics (length, width, density) and water accumulations;
- areal extent of flood plain inundation;
- areal extent (and water equivalent) of snow pack;
- size of the flood-prone area;
- land cover/land use features (to derive roughness, forested area, etc);
- soil moisture condition;
- areal rainfall, both qualitative and quantitative indications;
- hurricane movements.

Avantages :

- Possibilities of directly observing areally extensive variables that are otherwise only amenable to point sampling;
- Possibilities to provide observations over inaccessible terrain;
- Determination of certain parameters useful to manage flooding.

Limitations:

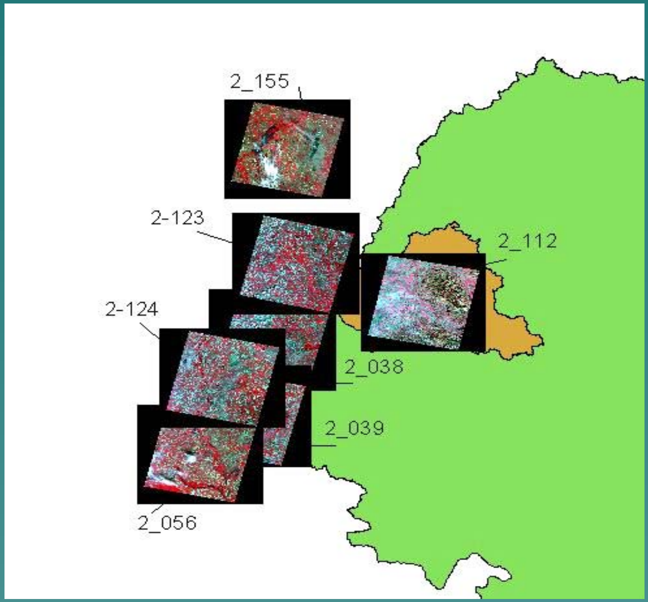
- The frequency of the satellite passing over the area of interest;
- The resolution and nature of sensing equipments;
- Sensitivity to obscuring clouds (especially for optical sensors);

Methods for Obtaining Useful Products for Flood Risk Assessment: Basic Approach for the Creation of Satellite - Derived Data for Flood Forecasting and Warning

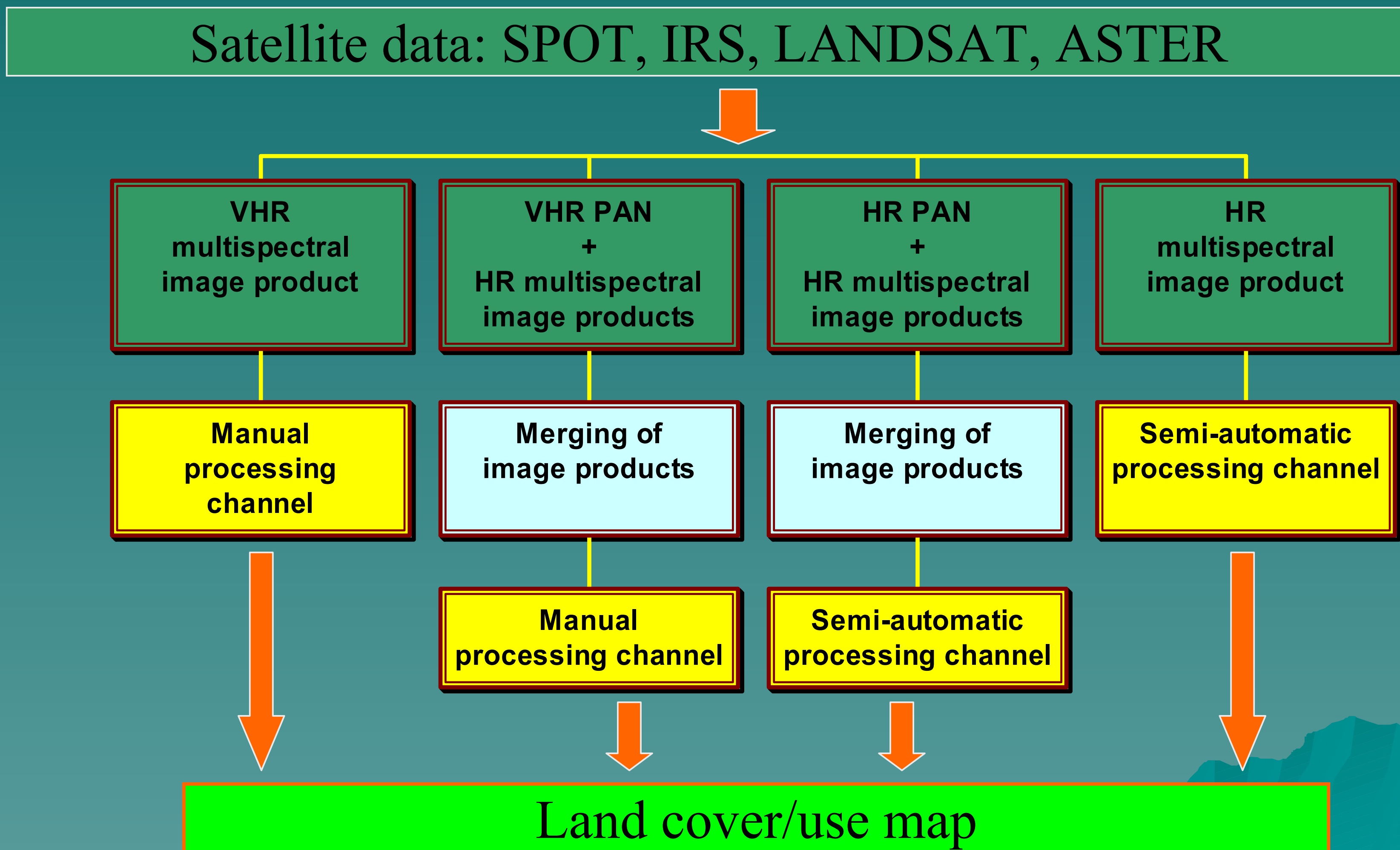
- **Preparation of the EO data:** radiometric, geometric correction and other basic image processing;
- **Combination approach of the interpretation techniques:** automated and photo-interpretation tools, as well as radiometric techniques;
- **Multi-sensor approach:** make the analysis process easier and provide the opportunity to improve the quantity and quality of the information obtained;
- **Multi-temporal approach:** gives the possibility to monitor low frequency (land modification) and high frequency phenomena (evolution of the floods boundaries);
- **Integrated approach:** the high level products are based on the EO derived information combined with other ancillary data, hydrologic/hydraulic models outputs using the GIS facilities.

Methods for Obtaining Useful Products for Flood Risk Assessment: Land cover/Land use

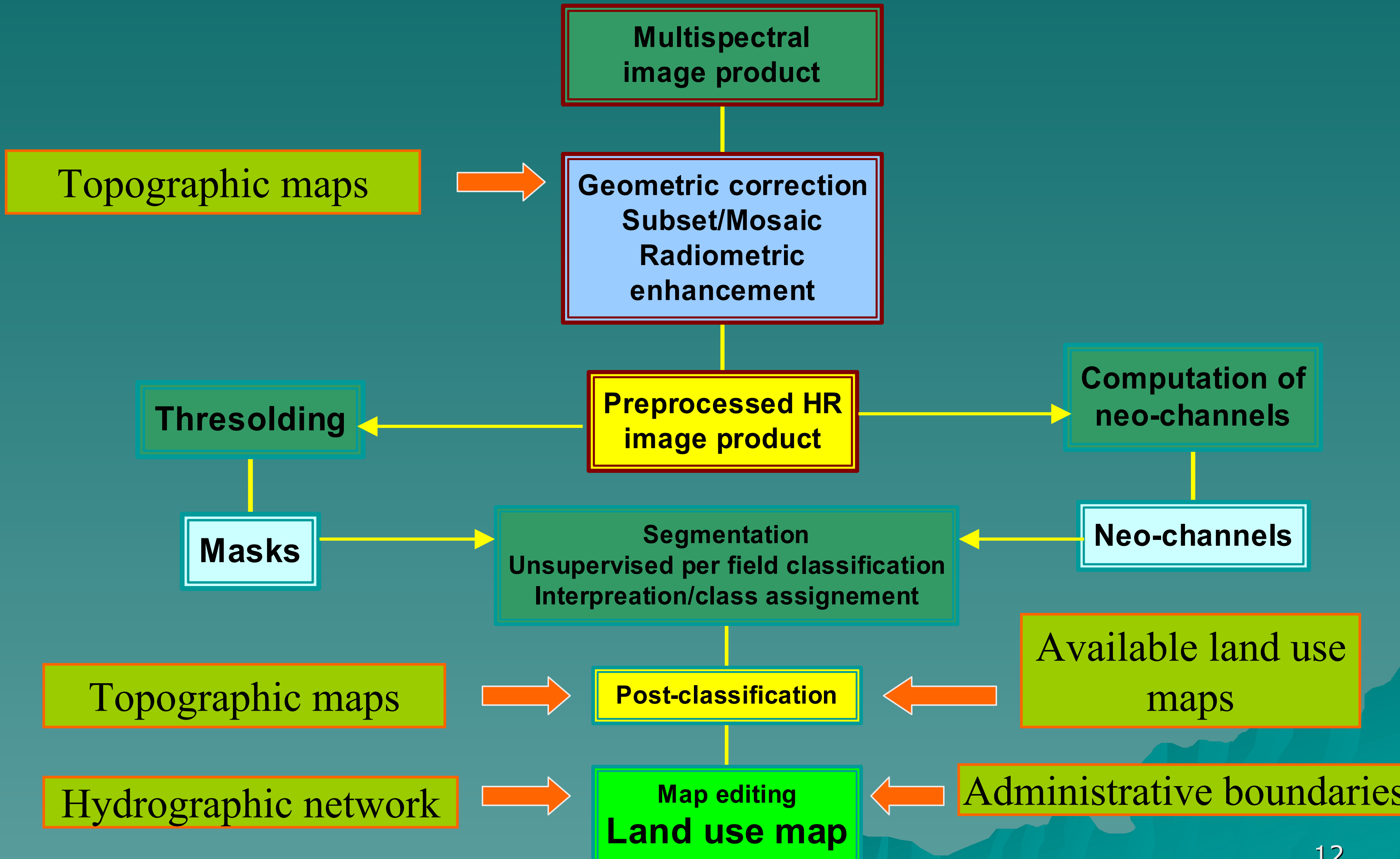
- The satellite-based methods will improve the mapping of geomorphic elements and land cover/land use.
- The land cover/land use classes derived from updating high spatial resolution satellite images are useful for the hydrological forecasting model input and dissemination of the obtained results.
- Land cover/land use maps, combined with satellite derived maps of flood extension or with the outputs of hydrological forecasting model simulations permit a more precise evaluation of the areas affected by the flood hazard. This kind of information is suitable for pinpointing locations and the degree of damages.
- These products are useful also, in the recovery actions, taken to re-building destroyed or damaged facilities and adjustments of the existing infrastructure.



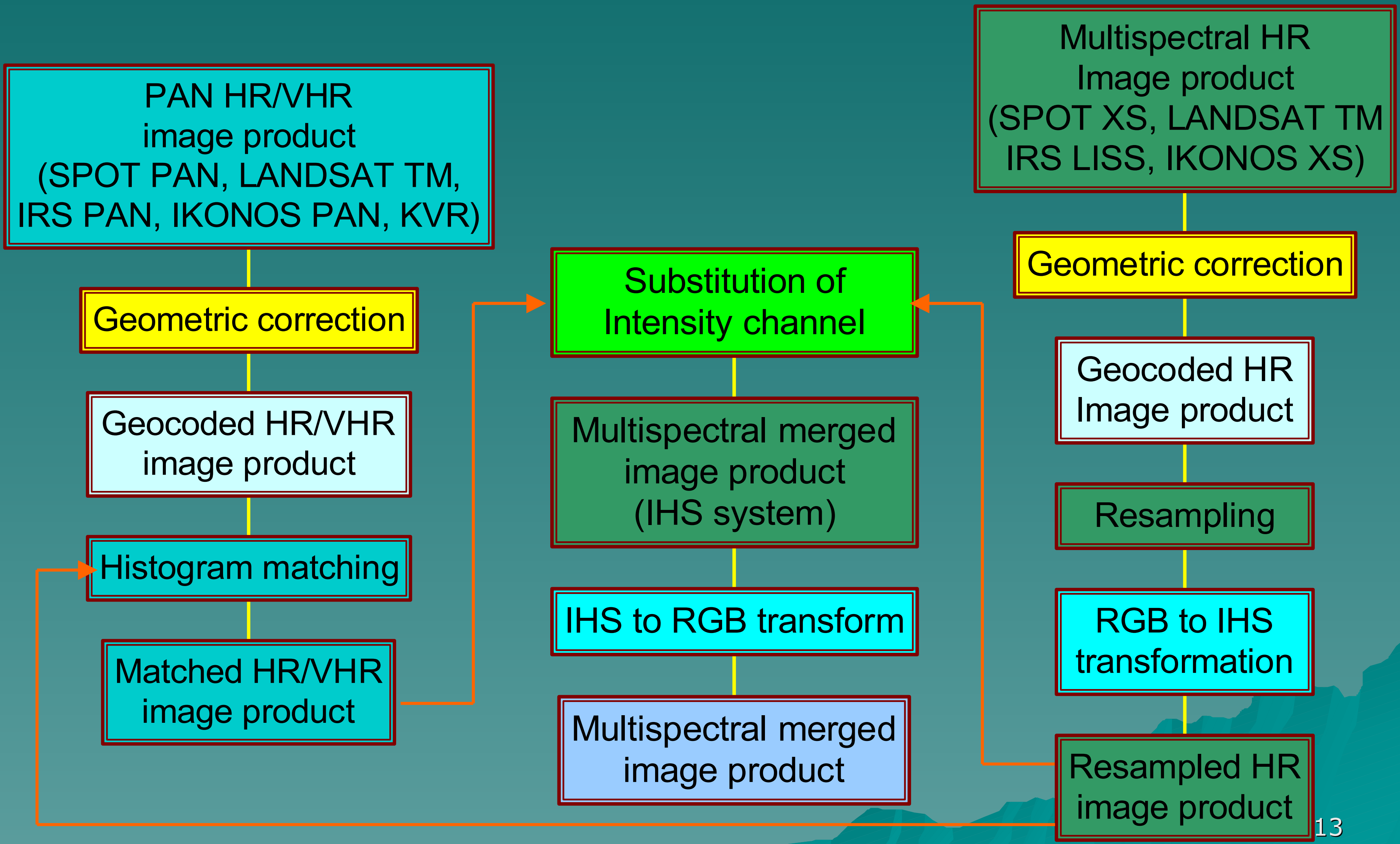
Overall Approach for Generation the Land Cover/Use Map



Generation of the Land Cover/Use Map: The Semi-automatic Approach



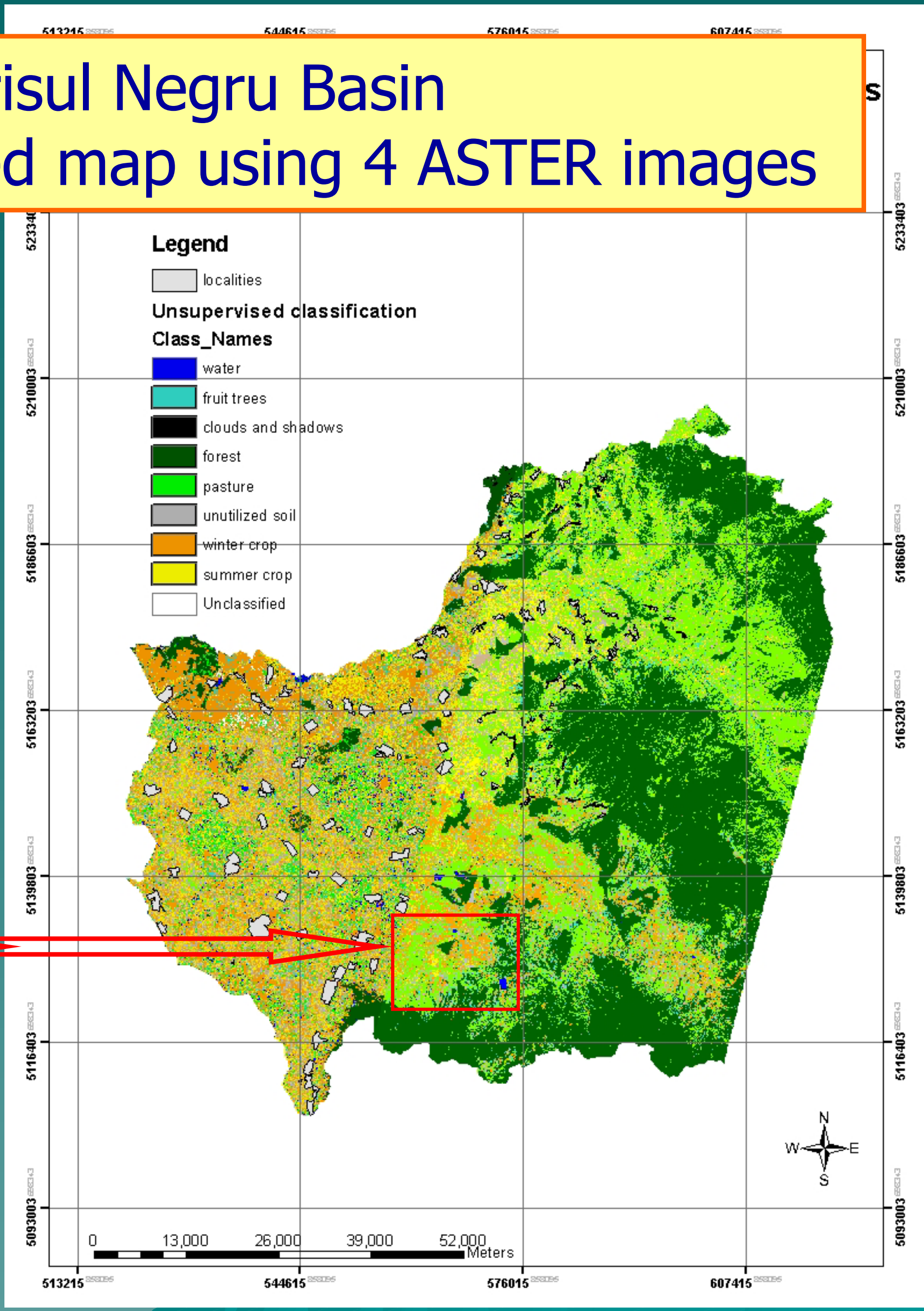
Resolution Enhancement of the Land Cover/Use Products by Merging of Multispectral and PAN Images



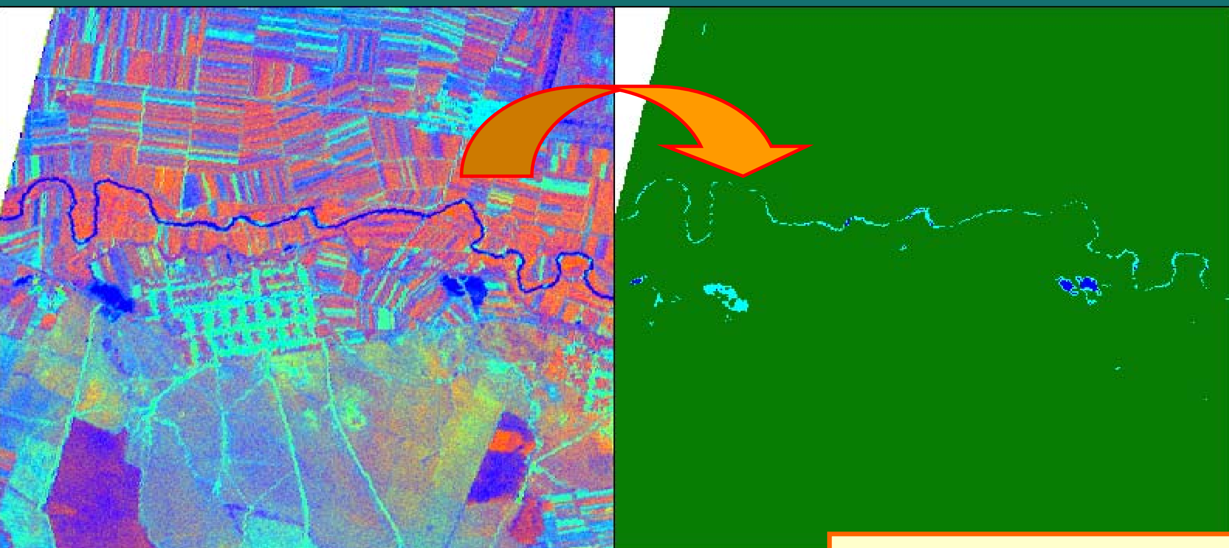
Crisul Alb & Crisul Negru Basin
Land cover-land use updated map using 4 ASTER images

TERRA-AQUA/ASTER data

- visible and near infrared bands (1, 2, 3B)
- 15 m resolution.

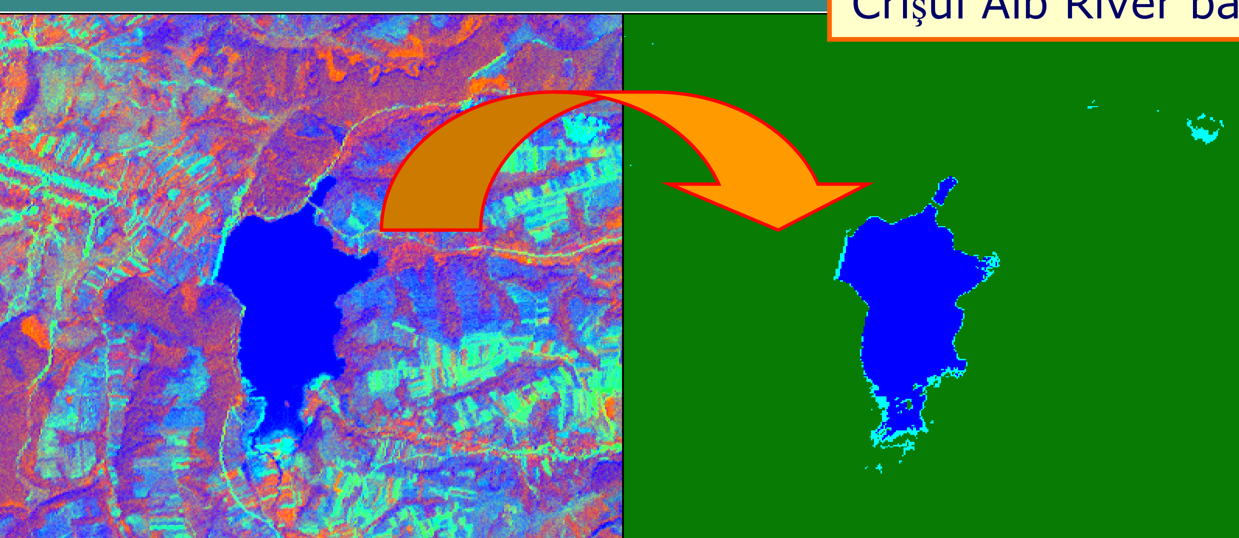


Methods for Obtaining Useful Products for Flood Risk Assessment: Hydrographic Network Characteristics and Water Accumulations



The methodology for the identification, determination and mapping of the rever network and water accumulation areas is based on the supervised classification procedures of the satellite images.

Crişul Alb River basin



Detection of river network and water accumulation from **ASTER** images (15 m spatial resolution) with false color band combination: R=3N, G=2, B=1

Methods for Obtaining Useful Products for Flood Risk Assessment: Areal Extent of Flood Plain Inundation

- **Pre-processing of satellite images: geometric, radiometric corrections;**
- **Clouds detection and masking;**
- **Methods to detect water bodies:**

⇒ *Classification methods:*

♦ Unsupervised procedures:
  - Iso data non-supervised;
  - K-Means;
  - Iterative Self-Organizing Data Analysis

♦ Supervised procedures

⇒ The NDVI method

- **Elaboration of the water mask using a threshold technique**

Methods for Obtaining Useful Products for Flood Risk Assessment: Areal Extent of Flood from Moderate Resolution Satellite Images (TERRA-AQUA/MODIS)

The NDVI method

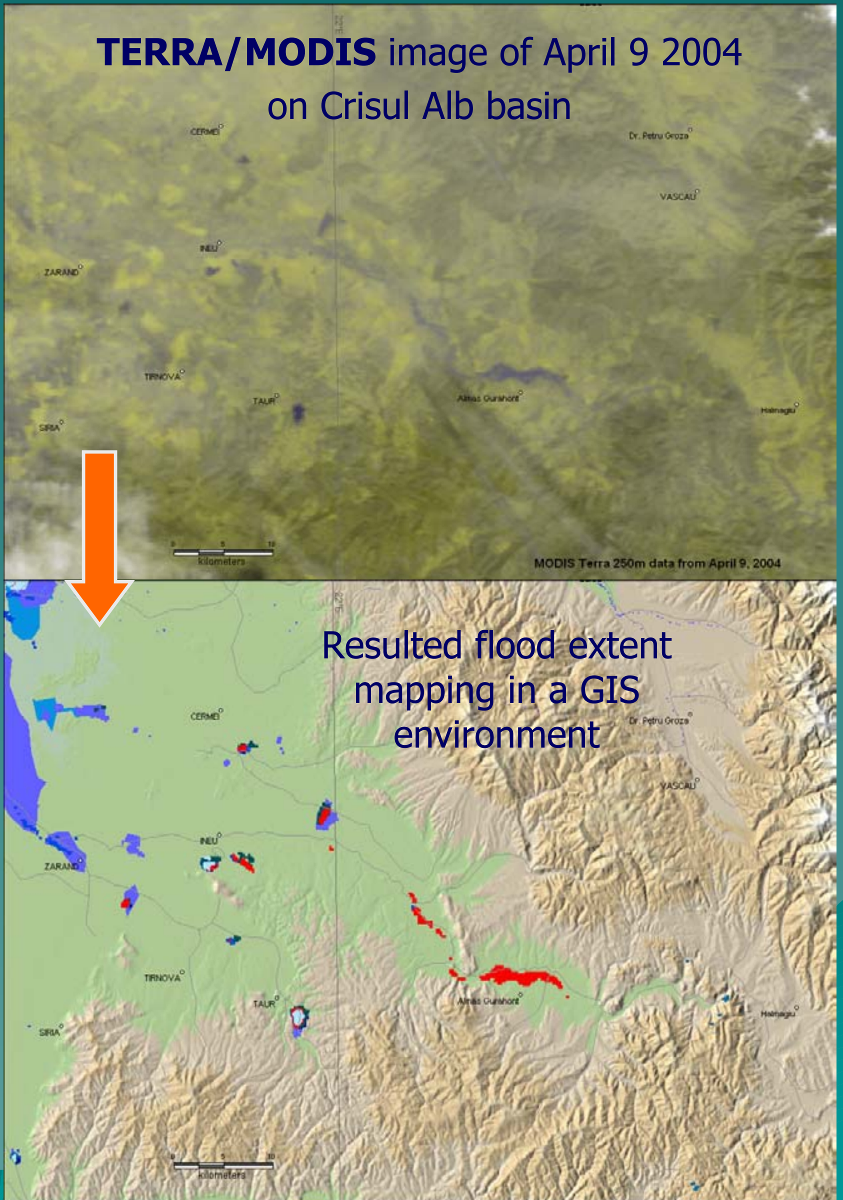
Is based on the construction of a water mask using a threshold technique on multispectral MODIS images, using the Normalised Difference Vegetation Index (NDVI).

- Pixels with clear water surfaces without vegetation have the NDVI < - 0.2 and can be easily separated from shadows.
- Pixels with high vegetation fractions, turbid waters, and mixed pixels along the coasts have the NDVI > -0.2.

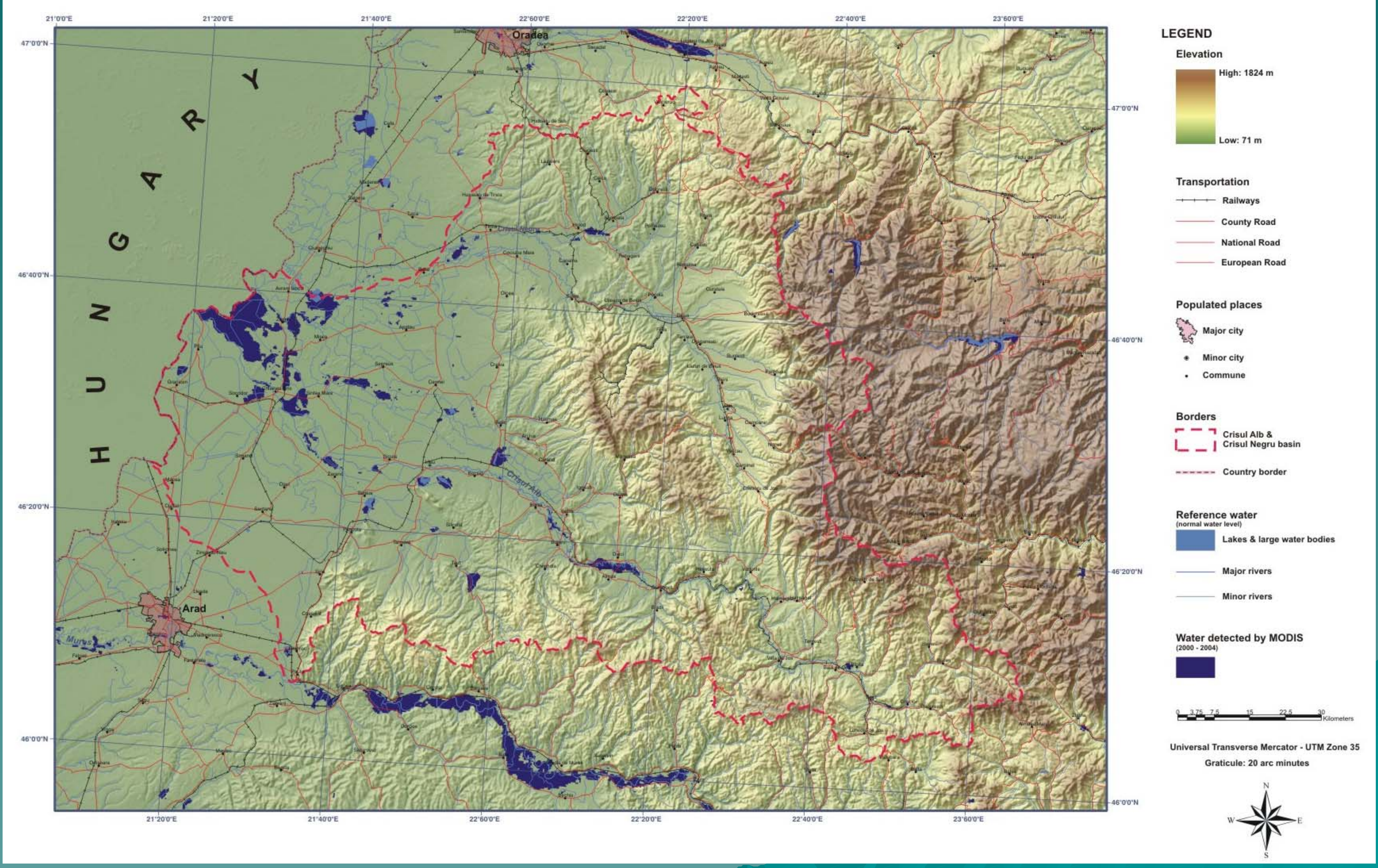
After some experiments with different threshold values, a set of best-suited values was adopted.

Observations

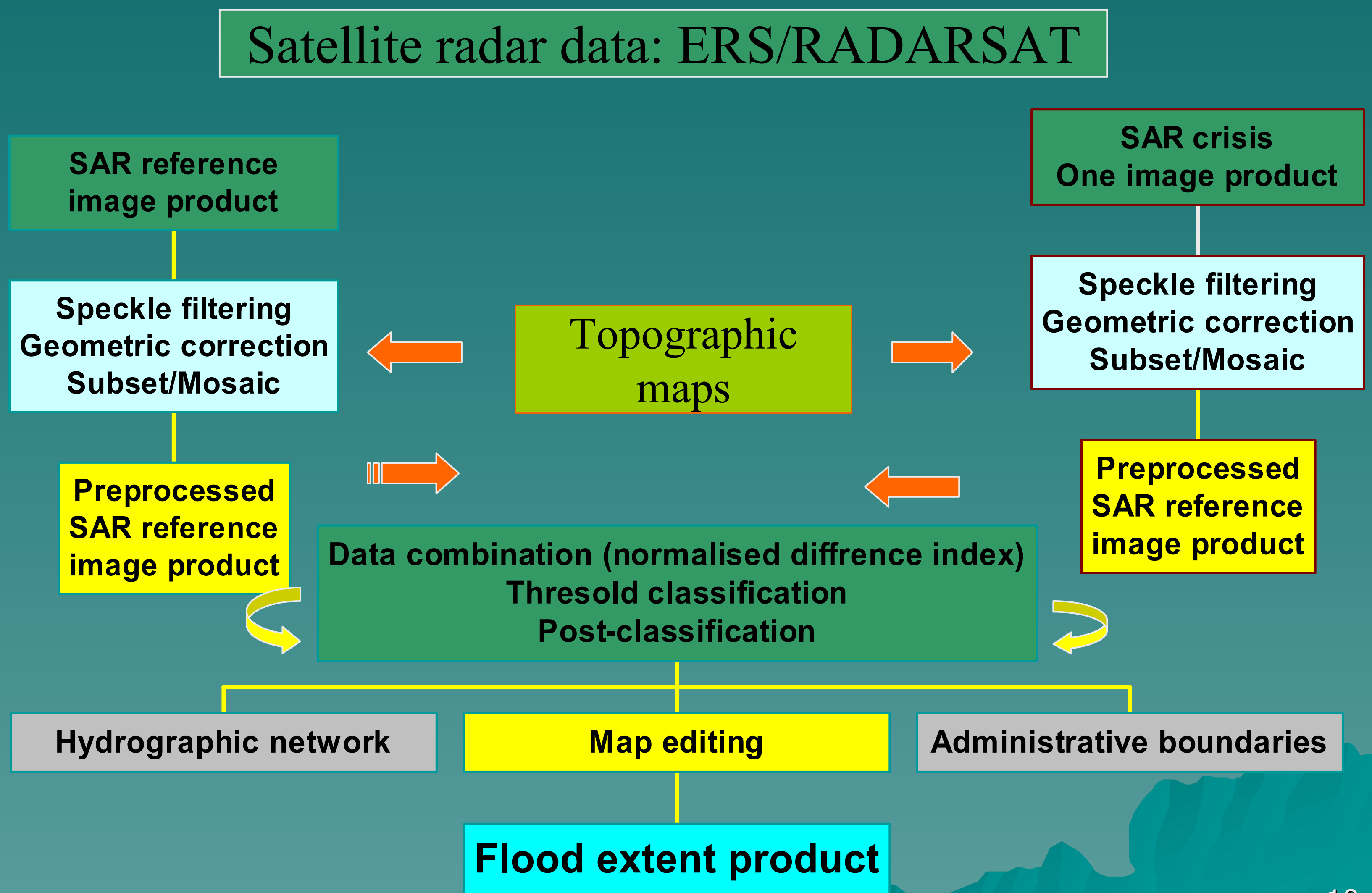
- Flood in mountains regions are difficult remote sensing target;
- Cloud and other constraints sometimes restrict the ability to capture peak flood;



Methods for Obtaining Useful Products for Flood Risk Assessment: Crisul Alb and Crisul Negru Basin MODIS-Derived Flooded Areas

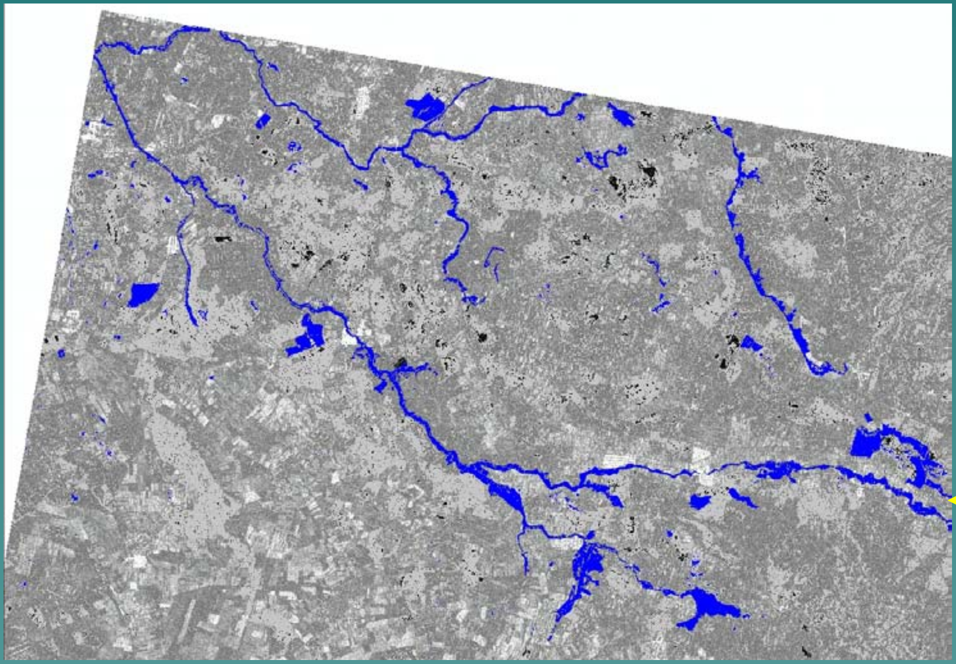


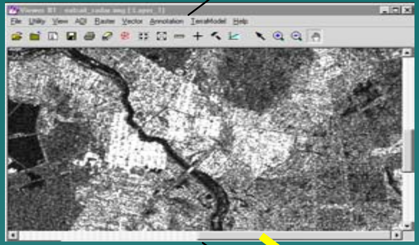
Methods for Obtaining Useful Products for Flood Risk Assessment: Generation of the Flood Extent Using Radar Data

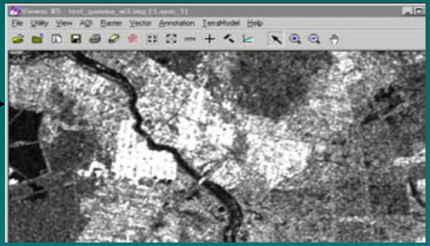


Flood Extent Mapping Using RADARSAT Image

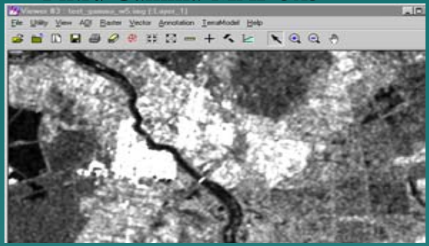
Flood extension on 7 April 2000 in the Crisul Alb basin



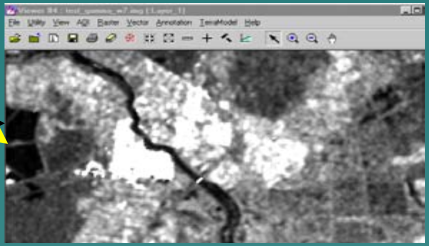




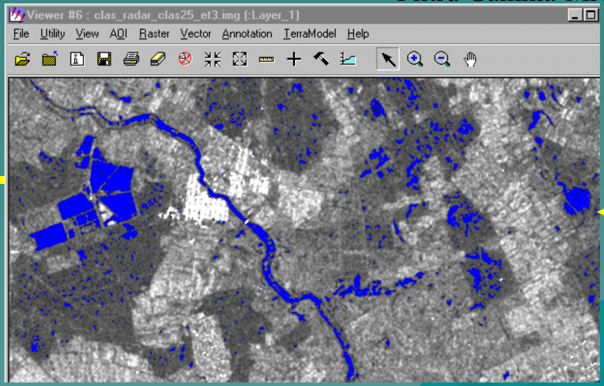
Filtru Gamma-MAP 3x3



Filtru Gamma-MAP 5x5

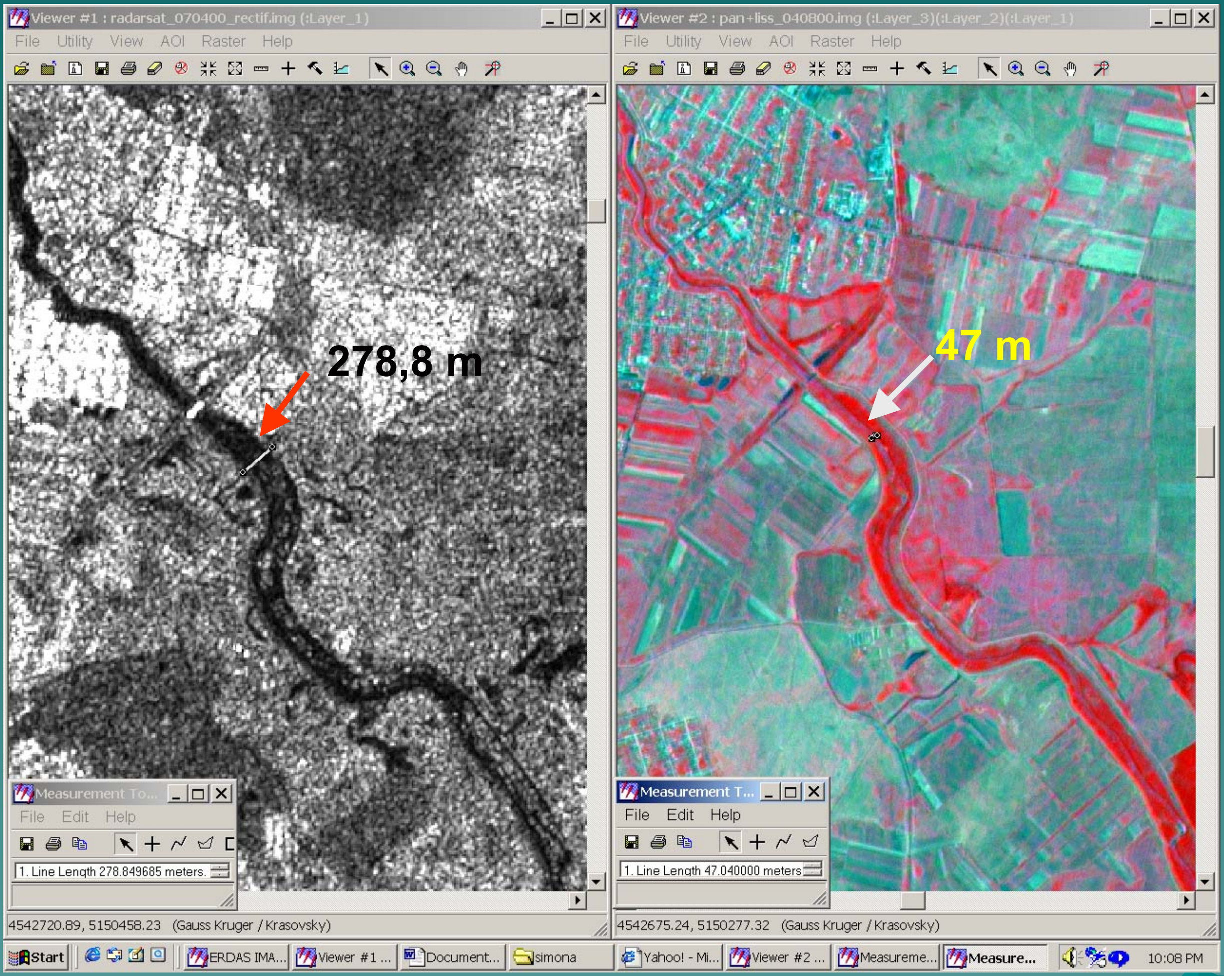


Filtru Gamma-MAP 7x7



Flood Extent Mapping Using RADARSAT Image - detail

Extension of the flood:
RADARSAT
7 April 2000



Normal situation:

IRS
Pan+LISS
4 Aug. 2000

Crisul Alb basin - Chisineu Cris zone

Methods for Obtaining Useful Products for Flood Risk Assessment: Areal Extent of Snow Pack

The satellite data offer valuable information to identify and mapping areas with snow through differentiation from other bodies in the image having close spectral reflectance, especially the clouds and to delimitate and monitor the snow-covered areas evolution.

The southern Carpathian mountain basins of Romania: Snow distribution in May 2003 obtain from the MODIS image

The achievement of the mentioned objectives, involve the processing of two kind of satellite images:

(i) with **high temporal resolution**, but **coarse spatial information** (like NOAA-AVHRR,TERRA-MODIS or SPOT-VEGETATION);

(ii) with **high spatial resolution** but with **more rare visiting periods** (like LANDSAT ETM, SPOT, IRS, etc.).

Snow Cover Mapping

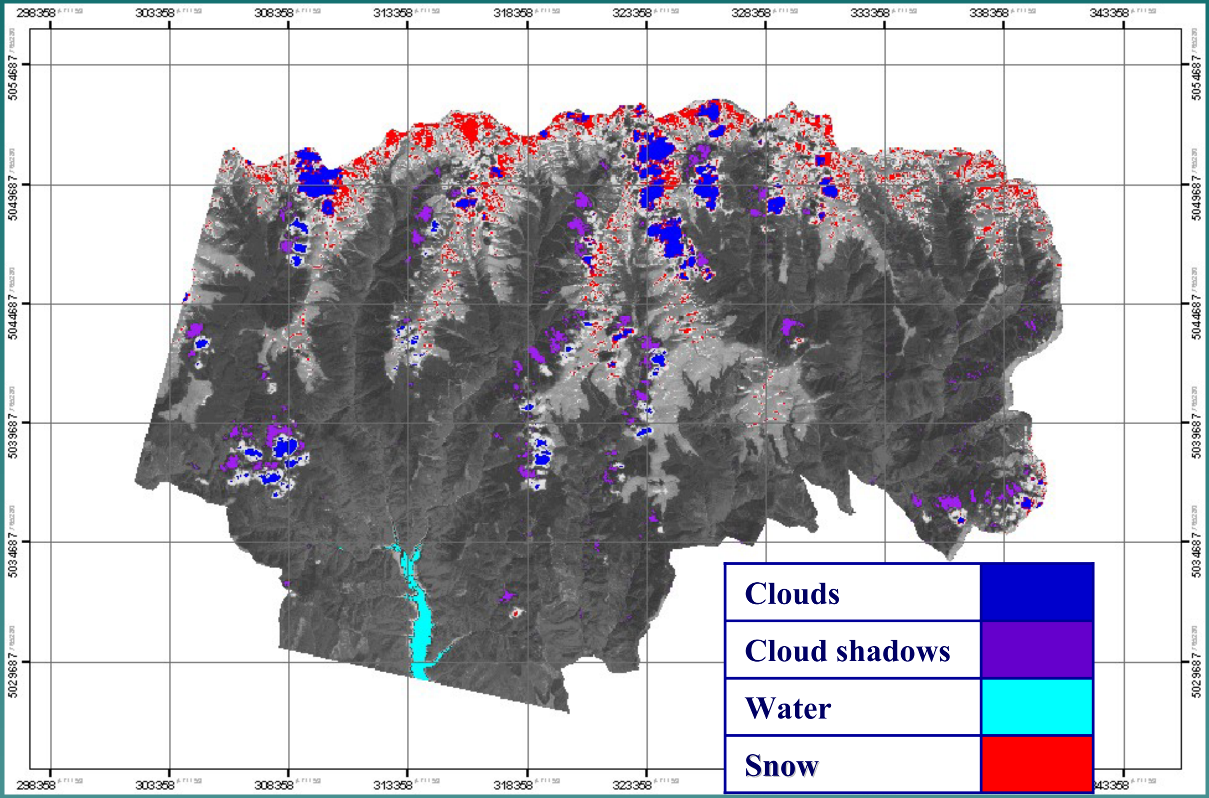
Involve the processing of satellite images, using the visible,near IR and thermal channels.

The main procedures consist on:

- Contrast enhancement;
- Binary/multi-threshold segmentation of images;
- Classifications procedures based on spectral reflectivity of snow;
- Superimposing on the Digital Elevation Model.

Observation

The mapping of snow cover becomes limited in areas where snow cover is obscured by forest canopies.



Fagaras Mountains – Arges basin:
The snow distribution for the10th May 2003 based on un-supervised classification of LANDSAT 7 ETM satellite image

Methods for Obtaining Useful Products for Flood Risk Assessment: Soil moisture Condition Based on the Seawinds/Quikscat Data

The total backscatter 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;

(5) **double-reflected** scattering;

Term (5) is generally small in the total backscattering and can be ignored.

Over normal landscapes

- The **reflection** from the underlying medium (soil, concrete,or other) is **weak**;
- The scattering is dominated by **direct volume** and **rough surface scattering** mechanisms (terms 1 and 2);
- The **polarization ratio** VV/HH is ≈ 1 or > 1 in linear scale.

  Where:

  VV is the vertical component;

  HH is the horizontal component.

Over wetlands

- The **reflection becomes strong** due to the large permittivity of the underlying water;
- The reflectivities for **horizontal polarization** (HH) are **much larger** than those for vertical polarization (VV) at large incidence angles (>40^{o});
- The backscattering is dominated by the **reflection terms** and VV/HH is significantly < 1 in the linear scale.

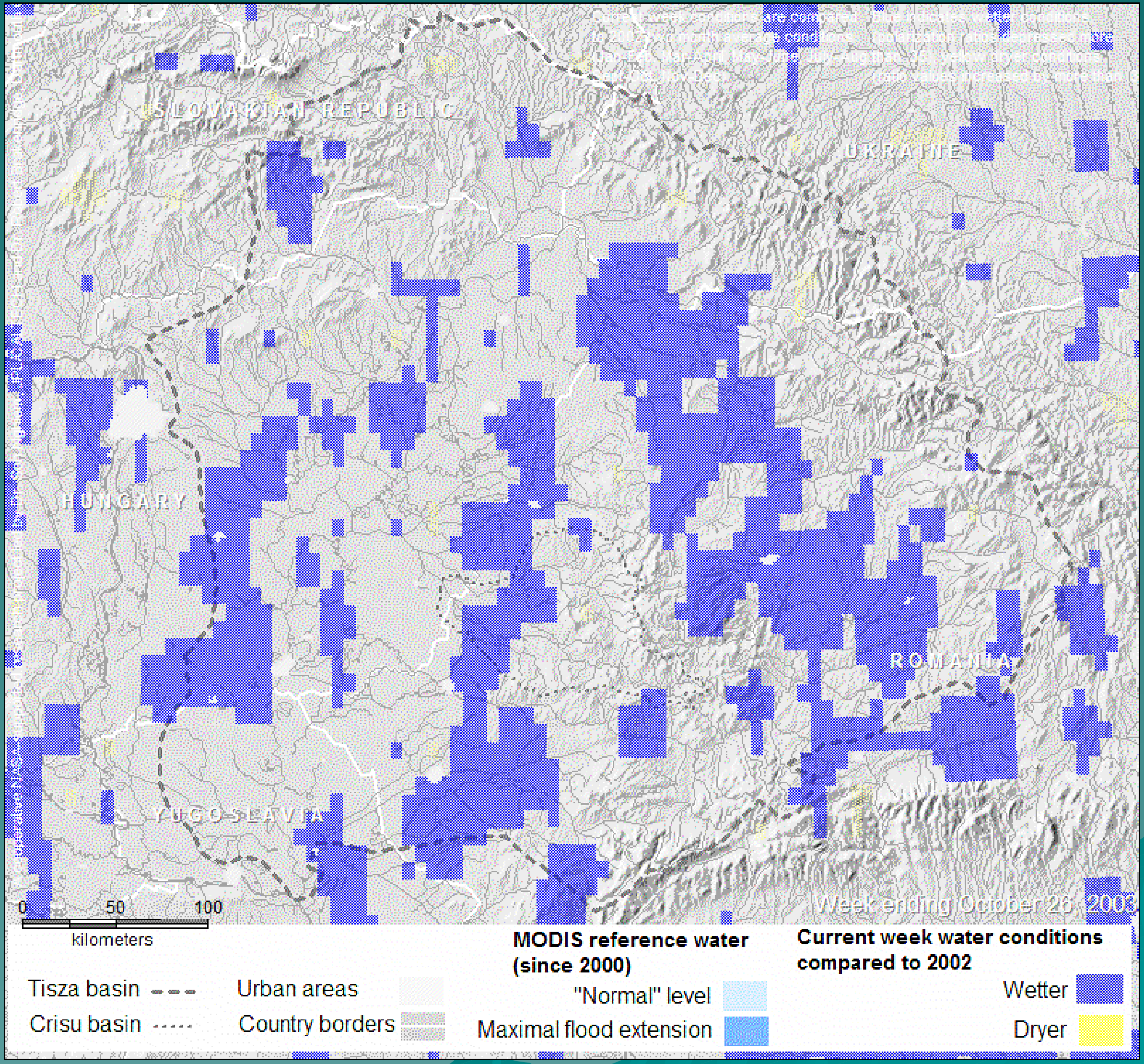
Wetness anomalies monitoring using QUICKSCAT data

Blue areas on the displays are accumulated weekly wetness anomalies from the prior four weeks.
(DFO web site: http://www.darthmouth/edu~flood)

Regional displays are useful in localizing **areas of excess moisture** receipts.

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.



Tisza basin

Conclusions

- Orbital sensing technologies, used in conjunction with traditional means, can contribute to improved management of flood hazards. Although satellite sensors cannot measure the hydrological parameters directly, remote sensing can supply information and adequate parameters to flood forecasting and warning;
- In the framework of the NATO SfP project, “Monitoring of Extreme Flood Events in Romania and Hungary Using EO Data”, some capabilities offered by remotely sensed data, to improve the means and methods to forecast, assess and monitor flooding, applied to the Crisuri basin in Romania, have been develop and tested.
- Information extracted from satellite images of high spatial resolution represents useful data for the determination of certain parameters such as: the hydrographic network characteristics and water accumulations; areal extent of flood plain inundation; areal extent and water equivalent of snow pack; size of the flood-prone area; land cover/land use features; soil moisture condition, etc;
- The satellite – derived parameters could be included in, or interfacing with the hydrological models in view to improve them as regards compatibility with classical input data, recovering results and the possibility to achieve forecasting and scenarios.

ACKNOWLEDGEMENT

We thank the Dartmouth Flood Observatory, Department of Geography, Dartmouth College, for hosting some Romanian researchers, for their thoughtful and competent inputs, Prof. Robert Brakenridge, Elaine Anderson and Emily Bryant.