Paper

Microwave radiometry in monitoring and emergency mapping of water seepage and dangerously high groundwaters

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Abstract— Detailed and geo-referenced maps identifying the locations of saturated and dry levees can be produced using microwave radiometric measurements from a light aircraft or helicopter, and integrated with GPS for positioning and orientation. The development of synergetic remote sensing technology for raised groundwater and seepage detection by the joint use of microwave and optical data along with GIS databases is an effective and most contemporary way of supporting risk assessment and facilitating disaster prevention and management. In this paper we present a remote sensing microwave technology for monitoring and detection of areas of water seepage through irrigation constructions, levees and dykes as well as for revealing areas with dangerously high groundwater level. The possibility for emergency response mapping, integrated with GPS and GIS data, facilitates the risk assessment and management services. The passive microwave radiometry (PMR) is based on spectral measurements in the millimetre to decimetre range of wavelengths. Compared to other remote sensing techniques, such as colour and infrared photography, thermal images and lidar, PMR is the only technology taking measurements under the earth's surface and therefore is very well suited for water seepage and underground water monitoring in a fast and reliable way.

Keywords— remote sensing, passive microwave radiometry, soil moisture, water seepage, risk assessment.

1. Multilateral agreement

Multilateral agreement on collaboration in the field of remote sensing of the Earth has been developed on the initiative of Prof. Anatoly Shutko between the following institutions:

– Institute of Radioengineering and Electronics (IRE), Russian Academy of Sciences (RAS), Moscow and Friazino, Russia;

– Microwave Radiometer Mapping Company (Miramap) – a Dutch ESA ESTEC Startup Company, Noordwijk, the Netherlands;

– Solar-Terrestrial Influences Laboratory (STIL), Bulgarian Academy of Sciences (BAS), Sofia, Bulgaria;

– Centre for Hydrology, Soil Climatology and Remote Sensing (HSCaRS), Alabama A&M University (AAMU), Huntsville, USA;

– Institute of Applied Physics (IFAC), National Research Council (CNR), Florence, Italy;

– Institute of Market Problems and Econo-Ecological Studies (IMPEES), National Academy of Sciences of Ukraine (NASU), Odessa, Ukraine;

– Politechnical University of Catalunya (UPC), Barcelona, Spain.

Among the issues of collaboration are:

– developing technologies for water seepage detection through levees and dykes;

– joint use of microwave, optical and other remote sensing devices;

– developing joint scientific projects;

– conducting research, experiments and teaching.

2. Fields of application

Following are the main application fields of the project activities:

– multispectral and multitemporal remote sensing monitoring of land covers from mobile platforms and aircrafts;

– hydrology [1, 2, 3];

– agriculture [4];

– forestry [5];

– ecology [6];

– risk assessment, emergency monitoring (levees and dams damage, flooding, etc.) [6].

3. Goals

The goal of the planed work is to create a powerful centralized information and management service by developing and adapting to the real environments of a new geoinformation monitoring system (GIMS) for land surface and water areas monitoring. The GIMS approach has been developed at the Institute of Radioengineering and Electronics, Russian Academy of Sciences (IRE RAS) [7, 8]. It is based on the joint use of the following constituents:

– remotely sensed microwave and optical data;

– *in situ* measurements;

– geographic information system (GIS) and other available database information;

– mathematical modeling of the spatial-temporal variations of land covers biophysical parameters.

Thus the efforts will be focused on the creation of new geoinformation technologies based on the combined use of GIS with measurement and modeling results in accordance with the formula: GIMS = GIS + measurements + models. Final products will include information about:

– soil moisture;

– depth to shallow water table;

– vegetation biomass;

– contours of water seepage through levees;

– contours of flooding;

– contours of areas with destroyed drainage;

– cloudiness;

– rainfall;

– melting: freezing conditions;

– contours of water pollution in the outflow zones, river deltas, lakes and harbors;

– risk assessment and emergency monitoring of situations associated with these phenomena.

4. Expected results

The main expected result of the project will be the development of advanced synergetic methods for microwave and optical remote sensing of land covers. Their utilization along with GIS knowledge-based information will permit the creation of GIMS, will increase data informational content and improve the possibility for emergency situations predicting and mitigating.

5. Approach

Among the various remote sensing instrumentation used in environmental studies microwave and optical systems can be implemented for investigation of vegetation type and biomass, soil moisture, dryness index, depth to shallow water table and buried objects location. Compared to other remote sensing techniques, such as color and infrared photography, thermal images and lidar, microwave radiometry is the only one taking measurements under the earth's surface and therefore is very well suited for levee and hydrological parameters monitoring in a fast and reliable way.

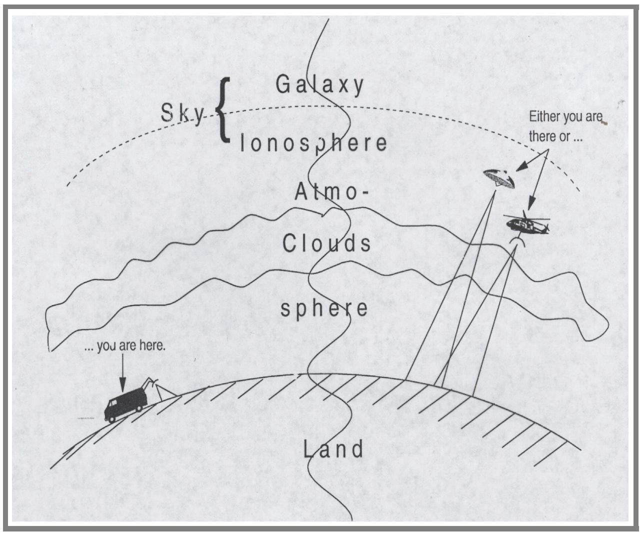

Fig. 1. Different sources of microwave radiation.

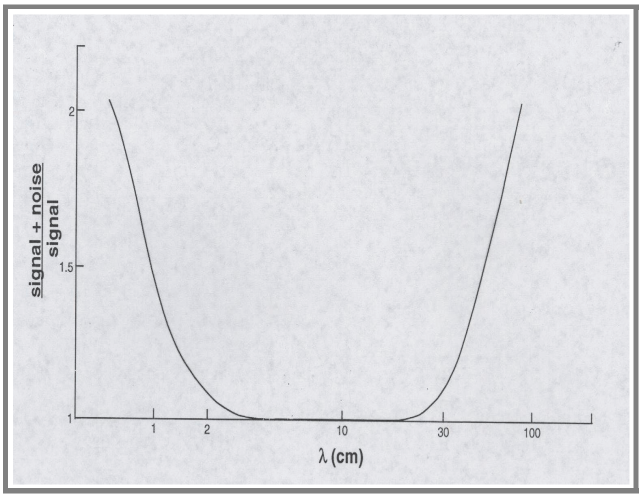

Fig. 2. Microwave windows of transparency.

Passive microwave radiometric systems record the naturally emitted radiation in the centi- to decimetric wavelength range. Different sources of microwave radiation are shown in Fig. 1. Investigations of water and land surfaces are performed in the 0.8–2.0 cm to 18–30 cm spectral bands. Within these bands, land surface and water radiation is

Fig. 3. Field and airborne microwave experiments.

primarily a function of the free water content in soil, but it is also influenced by other parameters, such as vegetation above-ground biomass, shallow groundwater, salinity and temperature of open water. The sensitivity of microwave measurements to these factors depends on the wavelength.

Least influenced by different sources of "radio noise" is the 2-cm to 21-cm wavelength band (Fig. 2). At wavelengths shorter than 0.8 cm, the surface radiation is considerably influenced by the atmosphere (water vapour, clouds, rain). At wavelengths longer than 21 cm, the surface radiation is affected by the ionosphere, galaxy radiation, and technical communication facilities. Agricultural vegetation is practically transparent at wavelengths longer than 21 cm. At shorter wavelengths the microwave radiation is a function of canopy type and biomass.

Optical sensors provide information about, vegetation type and state, soil humus content and erosion, contours of water bodies, floods, cloudiness, etc. Analysis of some experimental studies reveals the high potential and advantage of fusing microwave and optical remote sensing data. To find the best ways of advantageous synergetic use of microwave and optical remote sensing devices with due regard to a prior knowledge-based GIS information will be the main GIMS objective of this project.

6. Microwave radiometers

Through laboratory, field and airborne experiments (Fig. 3) it has been documented [1–4, 7, 8] that the passive microwave radiometers, and processing/retrieval algorithms developed at the IRE RAS are feasible to determine the listed below soil, water and vegetation related parameters:

- surface soil moisture;
- underground moistening;
- depth to a shallow water table (down to 2 m in humid areas and down to 3–5 m in arid/dry areas);
- located on the surface and shallowly buried metal objects of a reasonable size under dry ground conditions;
- contours of water seepage through hydrotechnical constructions (levees, dams, destroyed drainage systems, different kinds of leaks);
- biomass of vegetation above water surface or wet ground;
- temperature increase of land, forested and volcano areas;

– changes in salinity/mineralization and temperature of water surfaces;

– water surface pollution, oil slicks on water surfaces;

– on-ground snow melting;

– ice on water surfaces, roads and runways.

The operating range and errors of some land cover features retrieval are given in Table 1.

Table 1

Range and errors of land cover parameters retrieval

Parameter	Operating range	Maximum absolute error
Soil moisture content [g/cc]:	0.02–0.5	
– vegetation biomass less than 2kg/m^2		0.05
– vegetation biomass more than 2 kg/m^2		0.07
Depth to shallow water table [m]:		0.3–0.6
– humid, swampy areas	0.2–2	
– dry arid areas, deserts	0.2–5	
Plant biomass [kg/m^2]	0–3	0.2
Water salt and pollutant concentration [ppt]	1–300	1–5

7. Participants' resources

Following are today's participants and their currently available resources:

- **Institute of Radioengineering and Electronics, Russian Academy of Sciences, Russia**:
  - a set of microwave radiometric sensors consisting of three non-scanning radiometers, operating at the wavelengths of 6, 18 and 21 cm, a three-channel scanning radiometer operating at the wavelengths of 0.8, 2 and 5.5 cm and a twin-beam 21 cm radiometer (Tables 1, 2 and 3, Fig. 4);
  - software for surface soil moisture assessment (Fig. 5);
  - software for detecting areas with high groundwater level and water seepage through levees (Fig. 6);
  - data acquisition system;
  - data mapping software.

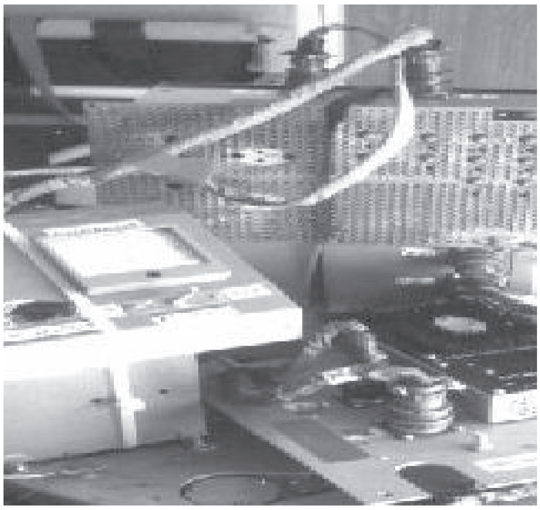

Fig. 4. Scanning microwave radiometer inside a fixed-wing aircraft.

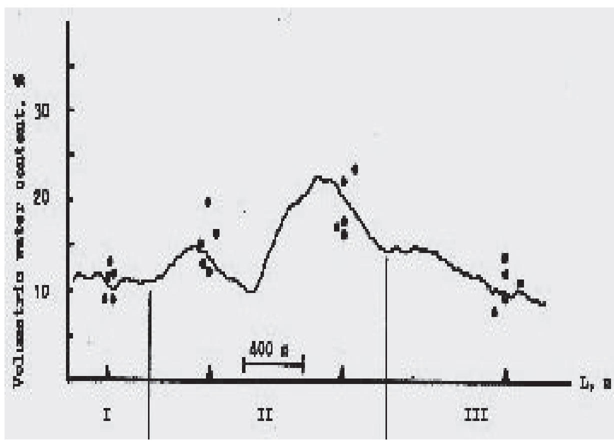

Fig. 5. Soil moisture from airborne microwave (—) and ground-truth measurements (•) along a transact with different soil types (I-III).

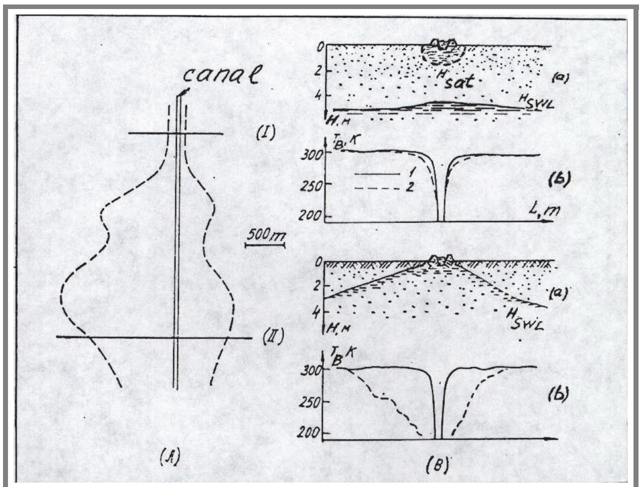

Fig. 6. Seepage/leakage detection through levees/dikes.

Table 2
Technical characteristics of the scanning
(H – height above ground)

Frequency [GHz]	Wavelength [cm]	Band	Pixels/scan	Resolution	Mode
37	0.8	Ka	32	$0.04 \cdot H$	Scanning
15.2	2	X	16	$0.08 \cdot H$	Scanning
5.5	5.5	C	6	$0.13 \cdot H$	Scanning
1.4	21	L	2	$0.65 \cdot H$	Twin-beam

Table 3
Parameters of twin-beam radiometers

Parameter	Scanning system
Ground swath	$1.3 \cdot H$
Power consumption	300 W
Power supply	27 V_{DC}
Aircraft mounting hole	50 cm
Weight	130 kg

- **Microwave Radiometer Mapping Company (Miramap), the Netherlands**:
  - light aircraft (Fig. 7);
  - avionics;
  - geodetic global positioning system (GPS) receiver;
  - flight management system;
  - portable digital optical colour camera Axis 2100 to be used for tracking on-ground objects and for use of optical data along with microwave radiometric data.

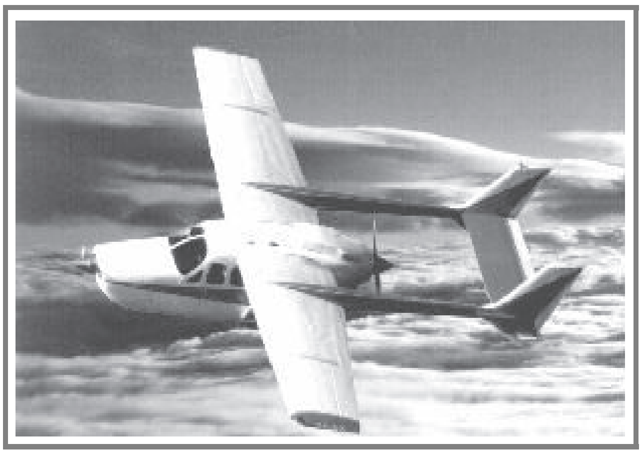

Fig. 7. Aircraft operation: Skymaster.

- **Solar-Terrestrial Influences Laboratory, Bulgarian Academy of Sciences, Sofia, Bulgaria**:
  - optical spectrometer;
  - data processing algorithms.
- **Centre for Hydrology, Soil Climatology and Remote Sensing, Alabama A&M University, Huntsville, USA**:
  - unmanned helicopter (Fig. 3);
  - data interpretation.
- **Institute of Market Problems and Econo-Ecological Studies, National Academy of Sciences of Ukraine, Odessa, Ukraine**:
  - hosting autumn 2005 experiments.
- **Institute of Applied Physics, National Research Council, Florence, Italy**:
  - thematic data interpretation.
- **Polytechnical University of Catalunya (UPC), Barcelona, Spain**:
  - thematic data interpretation.

8. Conclusions

There exists a fundamental background for bringing together an international team of experts ready to conduct research, development, application and teaching in microwave radiometry for soil surface and underground moisture investigations as well as in optical spectrometry for soil-vegetation land covers assessment. The added-value of the collaboration will be the implementation of advanced technologies based on data fusion for such important and urgent tasks as the detection of areas of water seepage through irrigation constructions, levees and dykes and the revealing of areas with dangerously high groundwater level. It is our belief, that this collaboration will provide a beneficial impact on research, application and teaching in the field of remote sensing technologies and their operational use.

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