Deriving agrometeorological parameters from the remotely sensed data with the integration with other sources of information for drought monitoring

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- Applications developed for vulnerable agricultural areas to aridization in Romania
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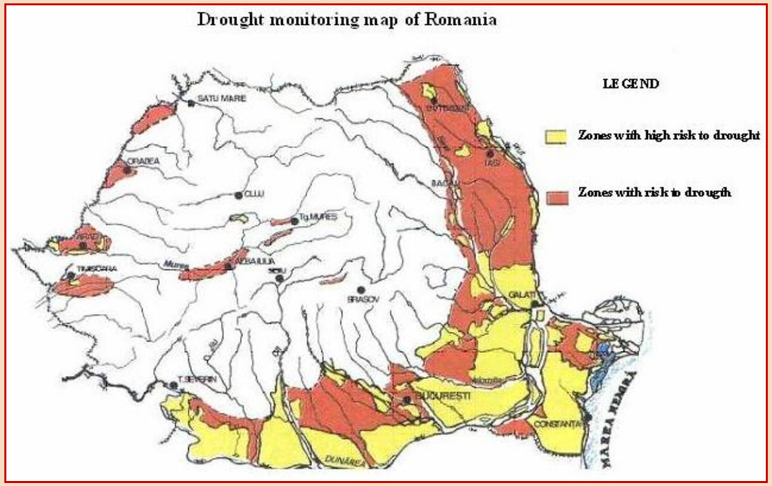
Introduction

Drought is a normal, recurrent feature of climate and occurs in all climatic zones, although its characteristics vary significantly from one region to another.

The drought phenomena and heat waves have affected large agricultural areas in Romania during the recent years 2000, 2001, 2002, 2003, 2007 and 2009.



In the **South and South-Eastern areas of Romania**, the complex agricultural drought is a climatic hazard phenomenon inducing the worst consequences ever occurred in agriculture.

Analysis of drought frequency and intensity during the last 20 years shows the crucial importance of agrometeorological monitoring for early warning systems and for efficient mitigation measures.

Early warning and monitoring may help with proper agriculture practices and decisions. In this respect satellite information has made substantial contribution, newer and more sophisticated sensors have become operational, providing biophysical measurements that are aimed at addressing monitoring of climate impact in agriculture.

Introduction (cont.)

The paper refers to the estimation of some useful parameters issues from remotely sensed data with the integration with other sources of information (meteorological, agro-pedological database, GIS info-layers) for drought monitoring and early warning.

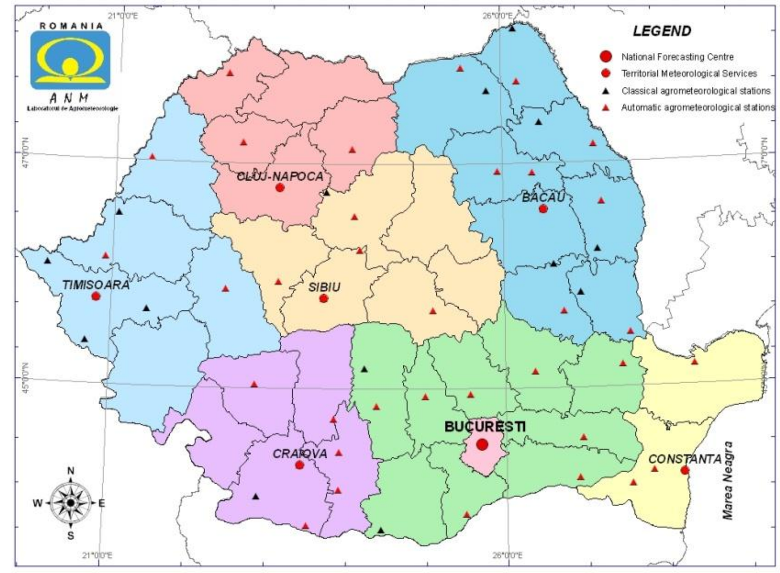
The study includes the inventory and analysis of the theory and general methodologies available for deriving agro-meteorological parameters like, leaf area index (LAI), actual evapotranspiration, vegetation indices (the normalized difference vegetation index - NDVI, vegetation conditions index - VCI, temperature condition index (TCI), etc.

Some applications developed for vulnerable agricultural areas to aridization in Romania, developed in the framework of **COST Action 734** and other European initiatives like the **MIDMURES project** are also presented.

These new data will increase the benefits expected from current and new satellite sensors and could be an appropriate input to some agrometeorological models.

The agro-meteorological activity within the RNMA

- **The Agrometeorological Laboratory from RNMA is a basic component of the operational activity and investigates the impact of climate variability and change on crops (including phenology and yield), and on the main components of soil water balance.**
- **This information is extremely useful in assisting the agricultural producers to choose the appropriate agro-technical solutions.**
- **Modeling and GIS techniques are used to monitor the spatial extent of extreme weather phenomena and to assess most vulnerable areas.**
- **Information provided covers agricultural areas ranging from regional, sub-regional and national level, depending on specific needs of the end-users.**

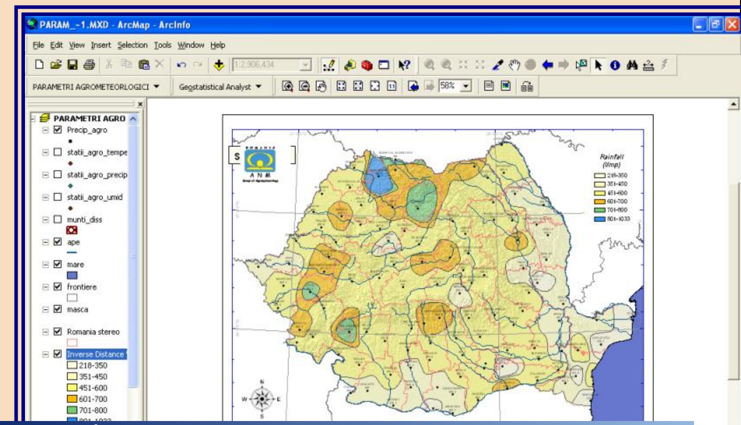


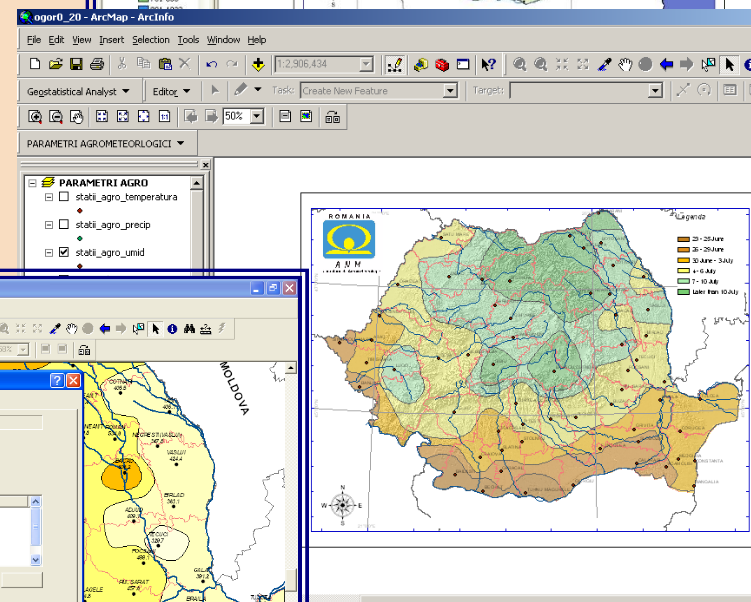
The agrometeorological measurements program includes 55 weather stations, out of which 40 are automatic, representative for surfaces of agricultural interest in Romania.

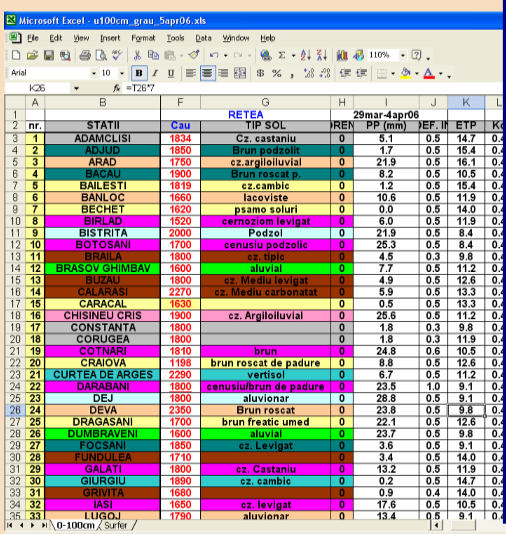
This information is corroborated with in-situ measurements of soil moisture (55 portable soil moisture measuring systems) and field observations of crop development stage and apparition of water stress to plants.

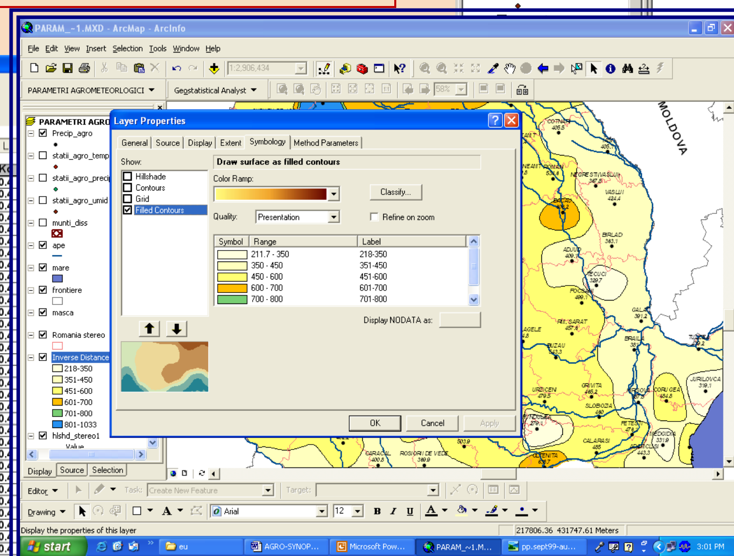
The agro-meteorological activity within the RNMA (cont.)

The **Agrometeorological Bulletin** includes the specific information (air temperature, rainfall, ETP, soil moisture, crop water requirement) needed for assessment of extreme events. This data collected from the National Observation Network is analyzed and compared with the critical thresholds in order to evaluate the threat and make recommendations to decision-makers and farmers.









European Commission
DG Environment

Halting desertification in Europe: pilot project on development of prevention activities to halt desertification in Europe

Mitigation Drought in Vulnerable Area of the Mures Basin (MIDMURES)

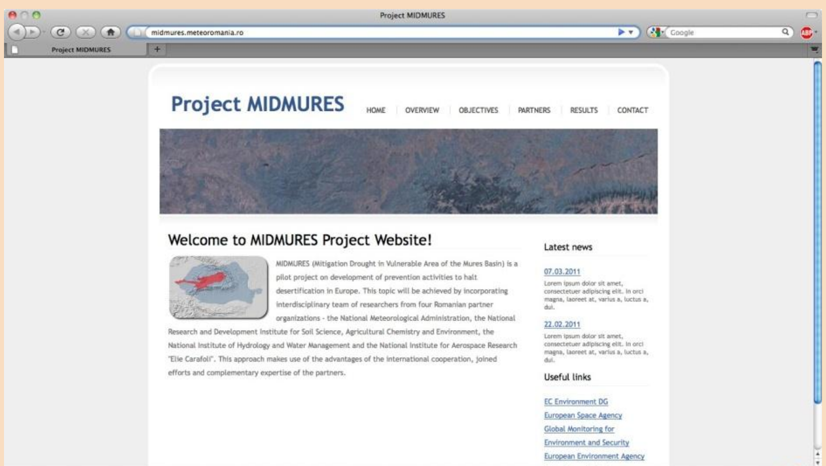
Objectives

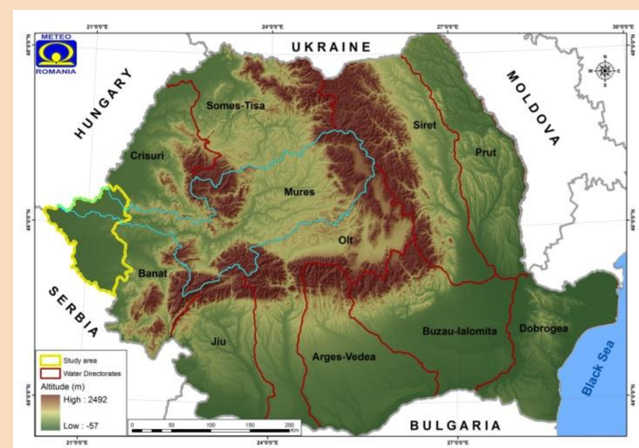
- **Modeling long-term observations and agro-climatic data in order to establish the risk factors and to spot the areas with high vulnerability and provide timely drought forecasts;**
- **Developing a decision support model for the dissemination of drought-related bulletin to the farmers and appropriate methods for early warning information;**
- **Assessing impact of climate changes on soil water availability for wheat and maize crops cultivated in the most vulnerable area of Mures River Basin to drought and water scarcity;**
- **To demonstrate the potential of water saving techniques for improving human and environmental conditions in Mures river basin in Romania, using low-cost approaches based on remote sensing techniques, elaborated in projects funded under the Research Framework Programme (e.g. SIRRIMEDS, WUP-MED, XEROCHORE, PRACTICE, LEDDRA and UNDESERT).**
- **Rainwater conservation in soil for optimizing the water availability according to the plant needs throughout the growing season and in the period with high deficit;**
- **Economic profitability evaluation under various management practices and crop structure.**

Mitigation Drought in Vulnerable Area of the Mures Basin (MIDMURES)

Expected results

- **Adaptation analyses and development options for improved land use systems in agricultural crop production under the water scarcity and drought conditions;**
- **Recommendations to improve effective use of water in the different production systems and specific measures to prevent land degradation and groundwater resources depletion;**
- **To raise awareness about the importance of effective drought preparedness and water management strategies in the affected drought area.**
- **To demonstrate the useful of remote sensing techniques in water saving activities.**
- **Increase crop yields and its productivity by using efficiently the water either in irrigated or non-irrigated areas;**
- **Economic benefits by using appropriate agricultural management practices and crop structure in areas vulnerable to drought.**





Contribution of satellite – derived information to provide biophysical parameters in monitoring the climate impact in agriculture

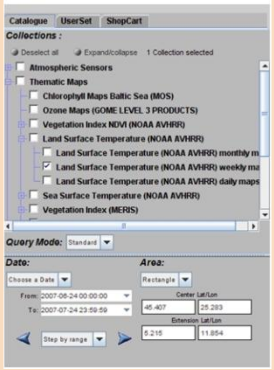
Observations of spectral reflectance from remotely sensed data allows the quantitative characterization of the terrestrial vegetation canopy. Efforts have been made to develop algorithms deriving surface properties from remotely sensed spectral reflectance or their end products. These include both empirical schemes, such as the spectral vegetation indices and model inversion methods.

The agricultural vegetation condition monitoring is currently possible, ranging from medium spatial resolution satellite derived - products, with daily revisit (NOAA-AVHRR, SPOT-VEGETATION, etc.) to high and very-high spatial resolution, offered by environmental satellites (LANDSAT, SPOT, FORMOSAT, IKONOS, QuickScat etc.) with longer revisit period. The new generation of EUMETSAT space sensor systems presents a real challenge to improve the knowledge of surface processes on a short-term basis. These instruments (SEVIRI-MSG, AVHRR3-NOAA, EPS/METOP) offer the opportunity to follow vegetation changes on a daily time scale, due to a high temporal resolution associated with more appropriate spectral bands to assess vegetation status.

The most important parameters are: vegetation indices (VI), maximum greenness during the growing season, total greenness during the growing season, fraction of photosynthetically active radiation (FPAR), absorbed photosynthetically active radiation (APAR) and leaf area index (LAI).

Applications developed for vulnerable agricultural areas to aridization in Romania

Land surface temperature (LST) derived from NOAA-AVHRR



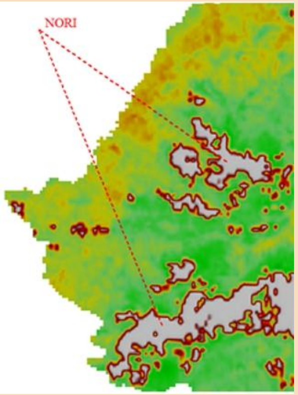
Download NOAA AVHRR satellite images from DLR EOWEB using the EO interface

Satellite image processing with ENVI 4.3 od ERDAS Imagine

Transformation from DN (0-255) în Celsius degrees:

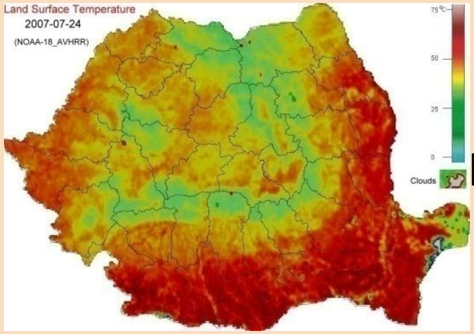
$$T(°C)=(DN*0.5)-40$$

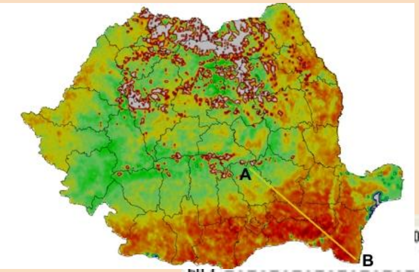
(P.Tungalagsaikhan, Kurt P. Guenther, 2004)

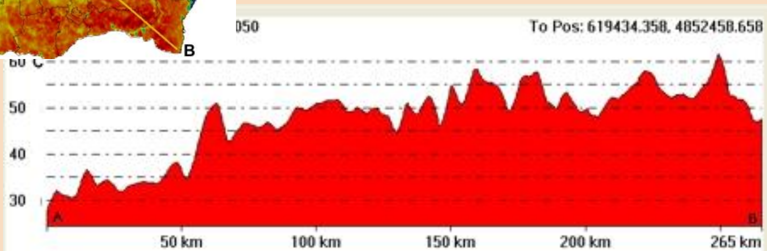


Cloud masking

Daily or weekly composite LST map elaboration



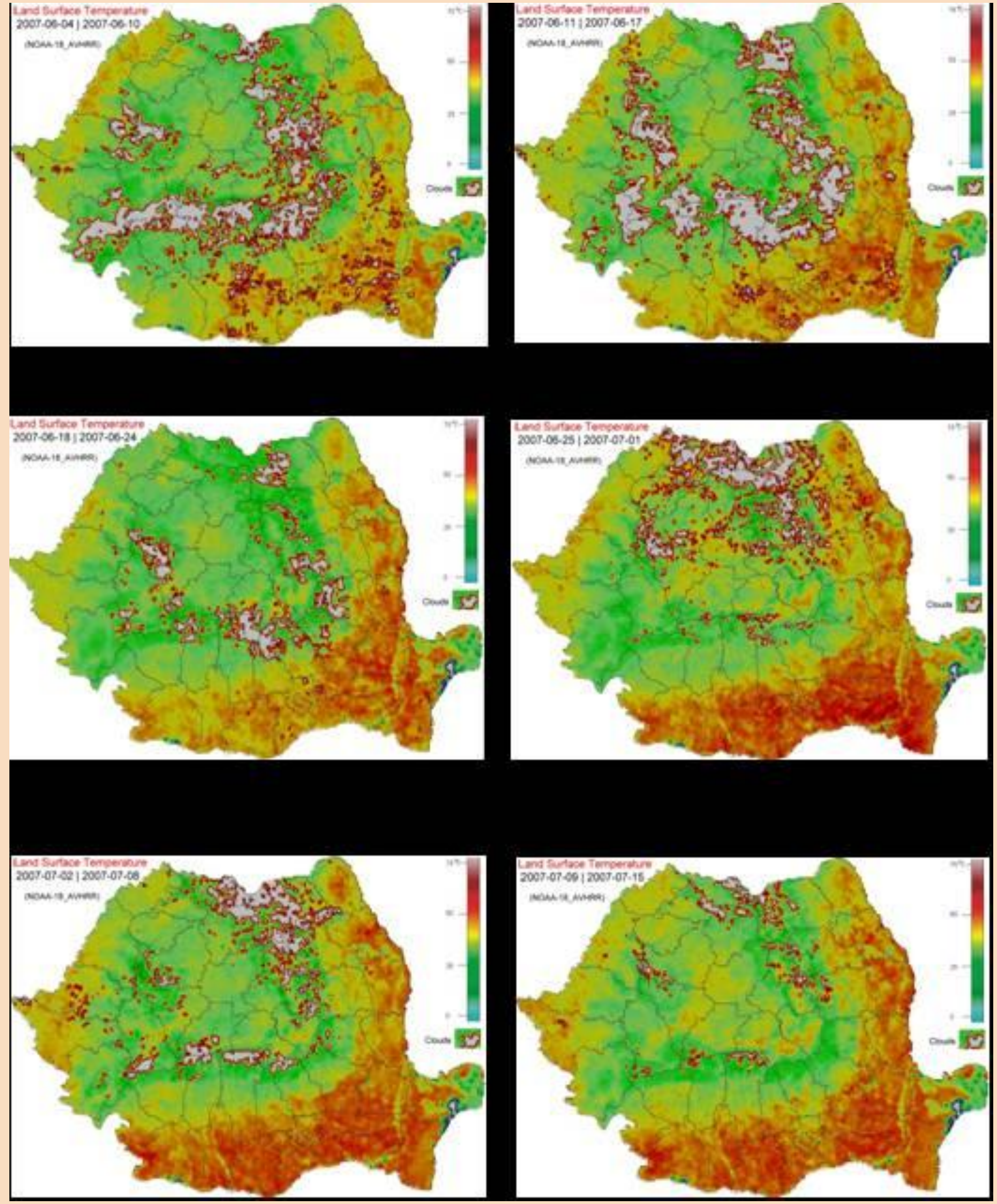




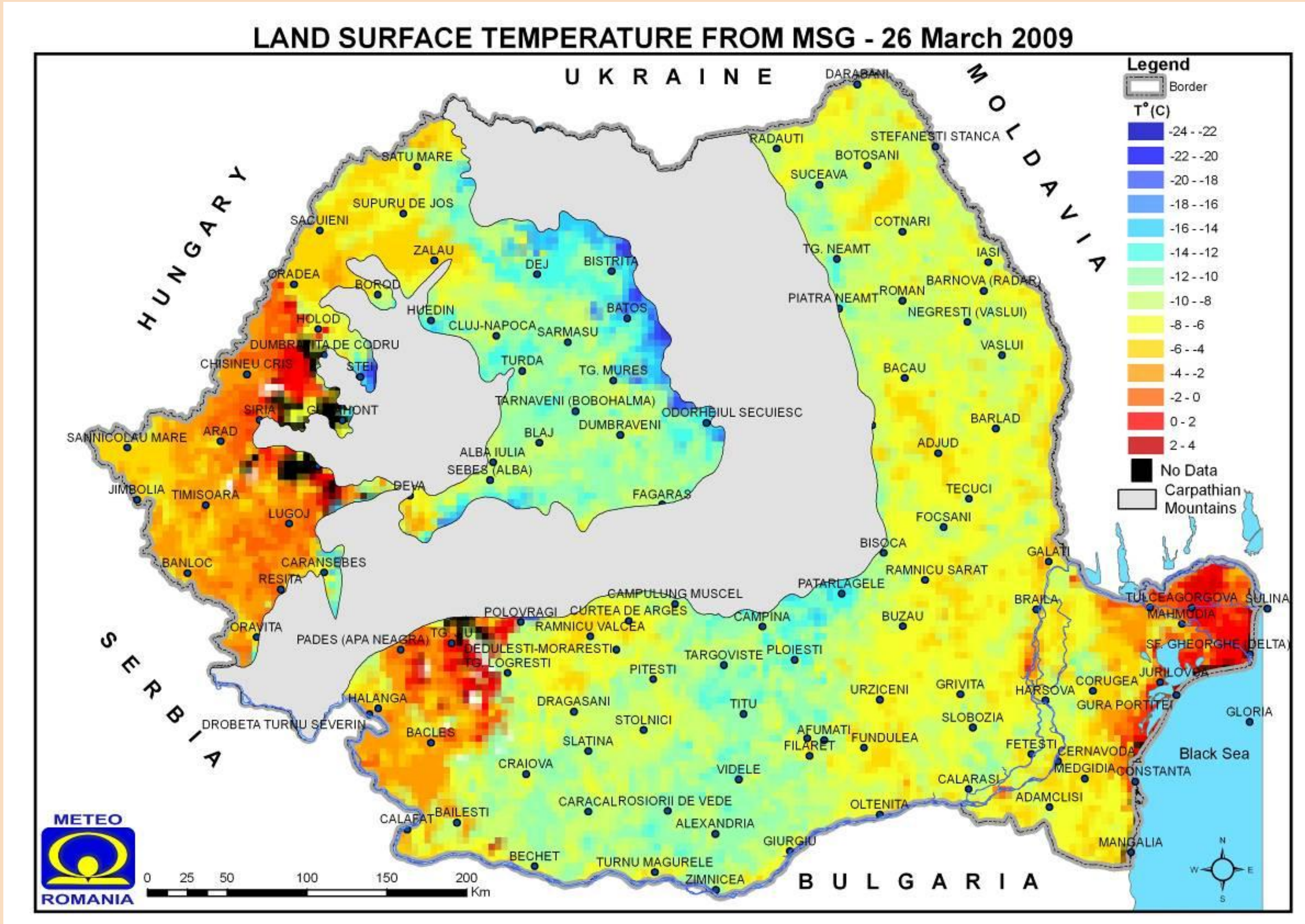
Thermal profile

LST derived from NOAA-AVHRR (cont.)

LST derived of
NOAA-AVHRR
Weekly composites
June – July 2007



LST derived from MSG



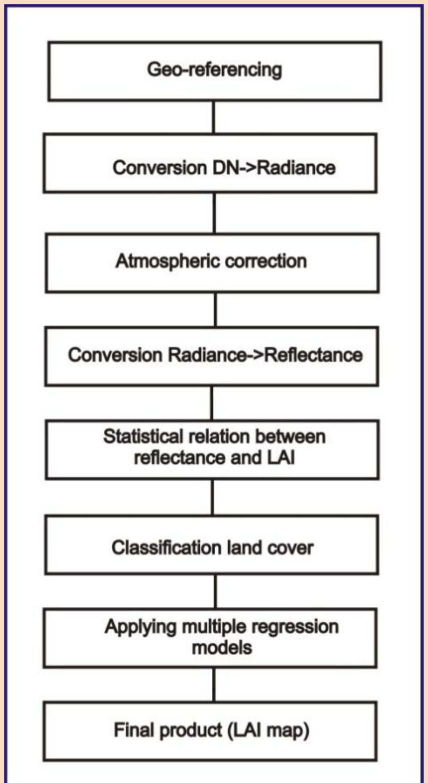
Map of LST derived from MSG for 26 March 2009 over Romania

In order to reduce the cloud cover, a synthesis of 96 LST - MSG images for 26 March 2009 over Europe was first obtained.

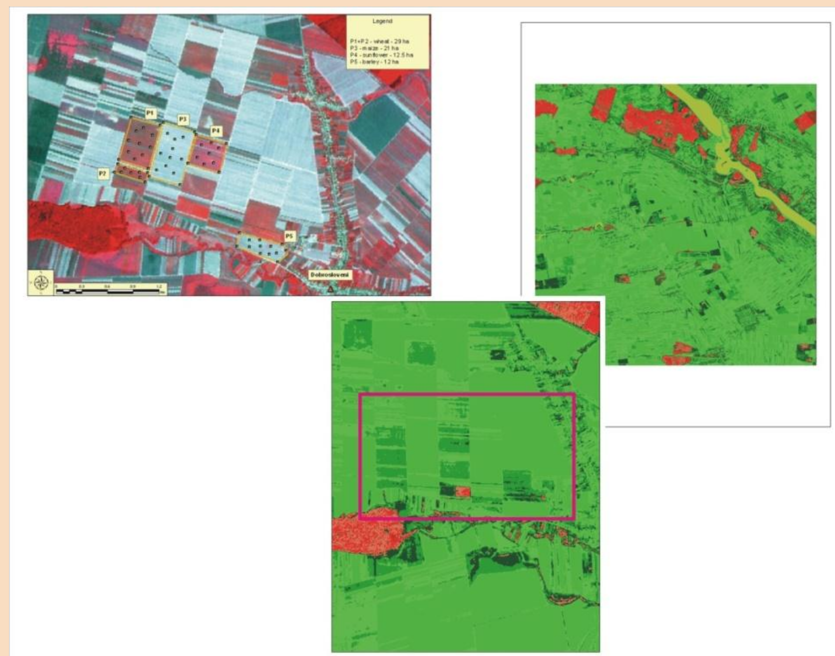
Leaf Area Index (LAI) maps derived from high resolution satellite data

Remote sensing with the increasing imagery resolution is a useful tool to provide such information on plant water status over various temporal and spatial scales.

Recent satellites such as IRS, FORMOSAT-2, QuickBird, etc offer both a high spatial and temporal resolution, since they can revisit a same area, every day with a constant viewing angle, with a pixel of high spatial resolution (e.g. FORMOSAT - 8m in multispectral range or 2 m in panchromatic).



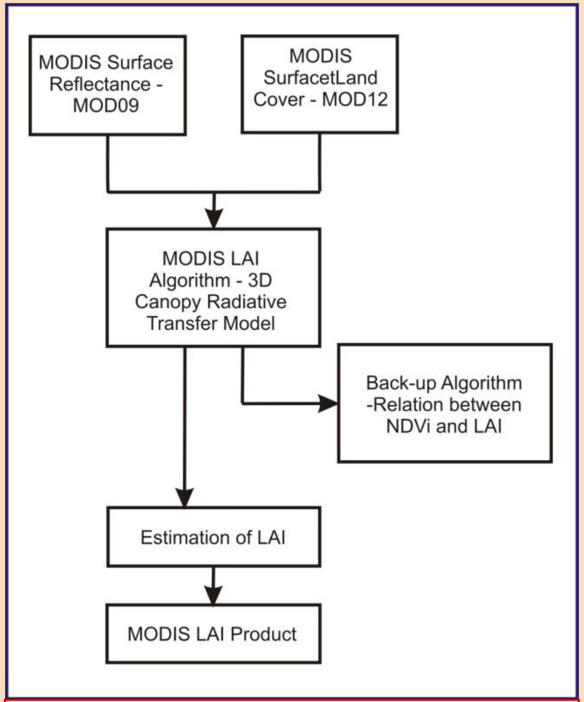
Algorithm for LAI map elaboration using high resolution satellite image and field data



LAI map obtained from the FORMOSAT2 image of 05.07.2008

LAI maps derived from moderate resolution satellite data

Remote sensing observations acquired with moderate resolution optical sensors (with pixel sizes from 250 m to 1 km) allow monitoring the seasonal and inter-annual variability of LAI fields over regional to global domains.
The algorithm for generating the MODIS LAI products use surface reflectance (MOD09) and land cover (MOD12) products. The MODIS LAI algorithm is based on three-dimensional radiative transfer theory and is developed for inversion using a look-up table (LUT) method.



Flowchart for producing MODIS – derived LAI products

The 1-D radiative transfer model SAIL was used to create the LUTs in order to obtain canopy reflectance for MODIS bands 1 and 2 (Andrieu et al., 1997; Combal et al., 2002). The SAIL model simulates canopy reflectance in the direction of the sensor, using information about LAI, leaf angle distribution (LAD), leaf reflectance, leaf transmittance, hot spot parameter and background soil reflectance.
LAI values were derived from the LUT by finding the smallest value of the merit function (Weiss et al., 2000):

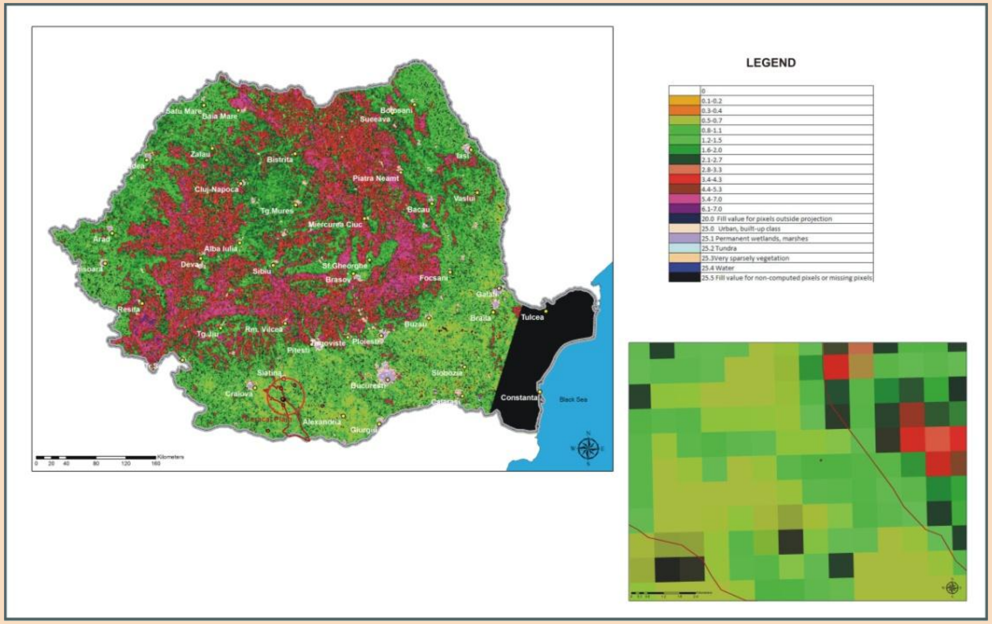
$$F = \sum_{i=1}^{2}\left(\frac{R^{i}_{LUT}-R^{i}_{MODIS}}{\varepsilon^{i}_{MODIS}}\right)^2 + \sum_{j=1}^{4}\left(\frac{P^{j}_{LUT}-P^{j}_{measured}}{\varepsilon^{j}_{measured}}\right)^2$$

where R^{i}_{LUT} **i - band number and j is the parameter number.**
R^{i}_{MODIS} **- the reflectance from LUT**
ε^{i}_{MODIS} **- the reflectance from MODIS image and**
P^{j}_{LUT} **- the reflectance standard deviation from MODIS image.**
$P^{j}_{measured}$ **- parameters from LUT,** $\varepsilon^{j}_{measured}$
- measured parameters and standard deviation for measured parameters.

Leaf reflectance and transmittance in the two MODIS band wavelengths are input parameter used in the merit function.

LAI maps derived from moderate resolution satellite data (cont.)

Site	Measured LAI	Retrieved LAI	RMSE
P3 – maize	2.9	1.9876	0.2561
P3 – maize	3.0	2.0466	0.2802
P3 – maize	3.4	2.8914	0.3146
P3 – maize	2.6	1.6827	0.2441
P3 – maize	2.3	1.8420	0.2564
P3 – maize	3.1	2.6430	0.2207
P3 – maize	3.2	2.6742	0.2432
P3 – maize	3.4	2.7020	0.2897
P3 – maize	3.1	2.0030	0.2994
P3 – maize	2.8	1.9067	0.3004
P4 – sunflower	2.1	1.7863	0.2668
P4 – sunflower	2.4	1.0463	0.3125
P4 – sunflower	1.9	0.9081	0.2992
P4 – sunflower	1.9	0.8965	0.2860
P4 – sunflower	2.2	1.1240	0.8940
P4 – sunflower	1.6	0.6064	0.3453
P4 – sunflower	2.0	1.0372	0.3002



MODIS derived LAI product in Romania, on 03.07.2008

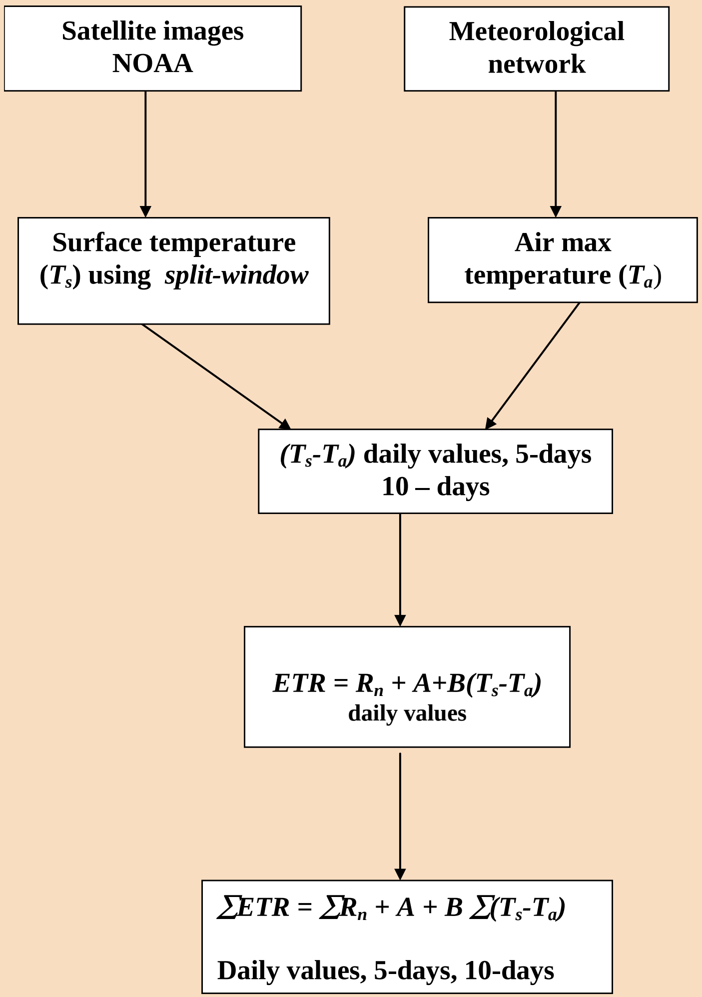
Estimation of evapotranspiration (ETR) using satellite data and the surface energy balance

The method used for the estimation of the daily crop actual evapotranspiration, ETR_j, is based on the energy balance of the surface data (Batra et al., 2006; Courault et al., 2005; Wood et al., 2003, Stancalie et al., 2010).
The method uses the connection between evapotranspiration, net radiation and the difference between surface and air temperatures measured around 14:00 h (the time of the satellite passage), local time.

Satellite data

There is a strong dependence between evapotranspiration and surface temperature, thus thermal images meteorological satellites METEOSAT, NOAA, MODIS are adequate for mapping of regional evapotranspiration.
The application of NOAA AVHRR data seems to be more successful because of the higher spatial and spectral resolution.
Multichannel algorithms are routinely used for atmospheric correction of the AVHRR data. Efforts are directed towards the estimation of surface temperatures by considering the effects of emissivity.

Estimation of ETR using satellite data and the surface energy balance (cont.)



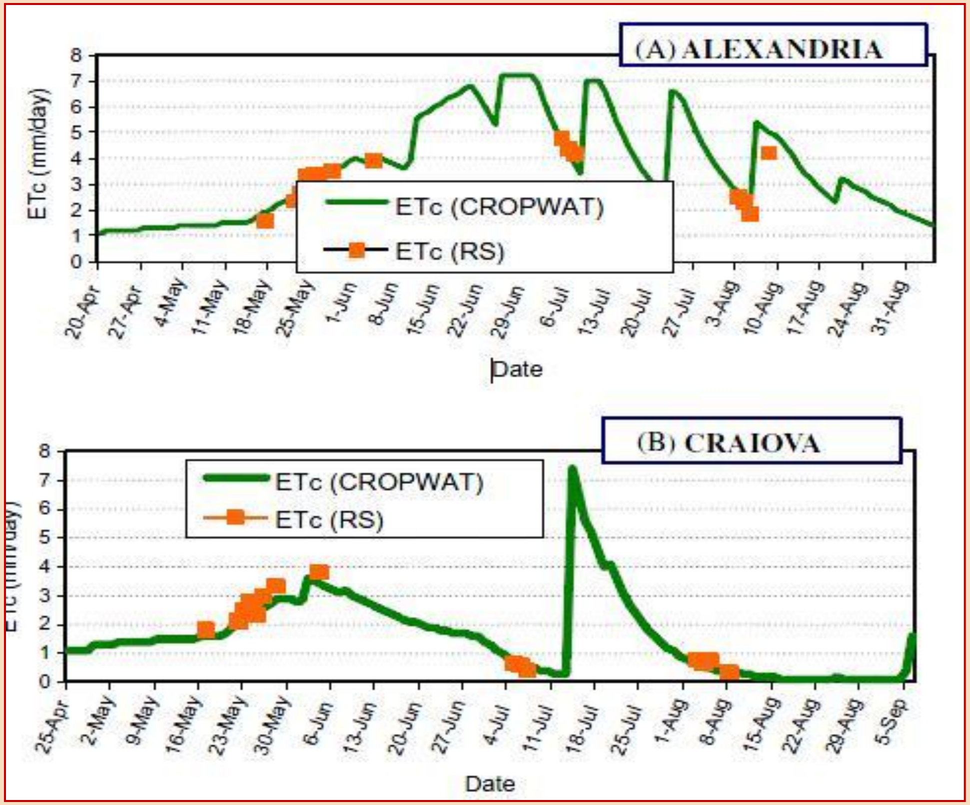
Daily crop actual evapotranspiration:
ETRj - Rnj = A - B.(Ts - Tamax)

Where:
Rnj is the daily net radiation;
Ts and Tamax is the surface and air maximum temperature
A, B = coeficients dependding of surface type (rugozity z_0) and daily wind speed (vj).
Coeficients A and B are can be analitically, using Lagouarde and Brunet (1991) equations, or statistically. The coefficients A and B are stable in the case of mature crop vegetation cover and in clear sky conditions. The coefficient B varies considerably, function of the land vegetation cover percent.

Daily net radiation:
Rnj = Rgj.(1 - a) + e.Raj - e.Rsj

Where:
Rgj = daily global radiation (W/m^2);
Raj = mean daily atmospheric radiation (W/m^2);
e = = emisivity;
a = surface albedou ;
Rsj = daily terrestrial surface radiation

Estimation of ETR using satellite data and the energy balance of the surface (cont.)



Comparison between daily crop actual evapotranspiration, computed by the CROPWAT model and by the energy balance method using satellite data, at Alexandria (A) and Craiova (B) test-areas, situated in south of Romania, for the maize vegetation period in 2000.

The ETR_c calculated by theCROPWAT model is very similar to the estimated one. The results obtained can constitute the premise of an ETR_c data validation process, determined by the CROPWAT model

Monitoring the crop growth using the NDVI 10-days composite products derived from SPOT/VEGETATION

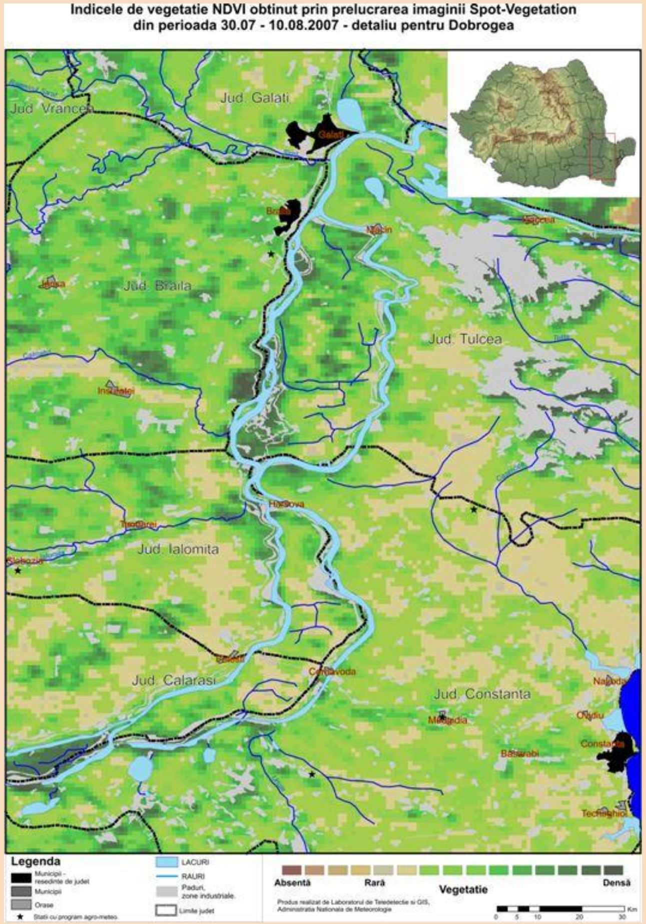
SPOT VEGETATION Products

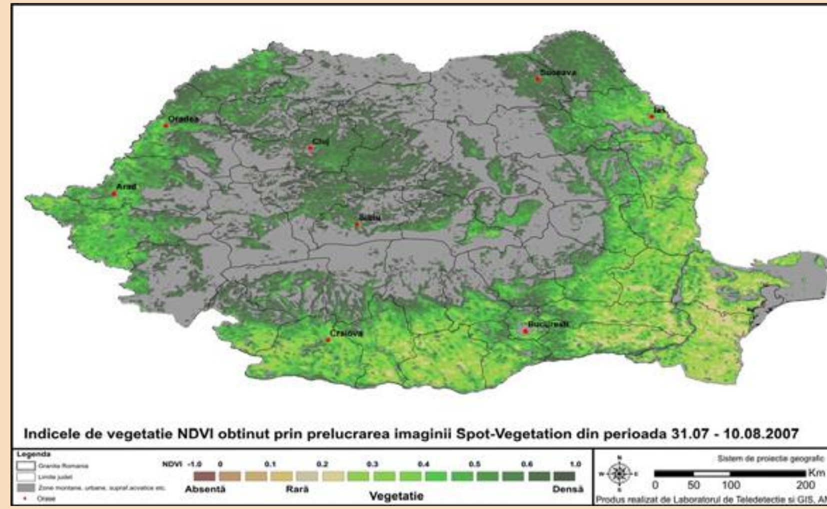
- *Radiometry*
  - Four spectral bands
    - Blue
    - Near InfraRed
    - Red
    - ShortWave InfraRed
- *Geometry*
  - Spatial resolution 1km in the entire field of view
  - Off nadir observations up to 50°
  - Geometrically and atmospherically corrected
  - Global coverage almost everyday on land areas
  - Central archiving and processing through onboard solid state memory and X band downlink to one principal receiving station
  - Regional receiving stations (L band downlink)
- Available data 1998 – present
- Temporal resolution 1 day
- Decadal synthesis of NDVI – S10 products

For a better operative surveillance of the agricultural areas and in order to work out new information products, starting with 2005 RNMA benefits of SPOT/VEGETATION data, transmitted in real time (via FTP) from March to October.

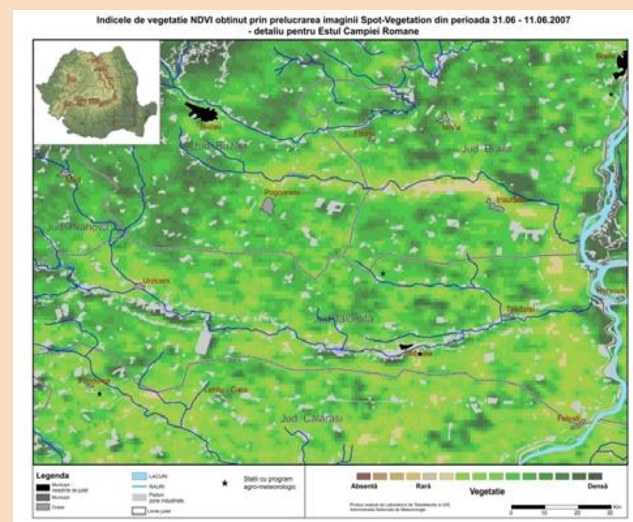
Beginning from the last decade of March 2005 these maps have been included and analyzed in the Agrometeorological Bulletin.

Monitoring the crop growth using the NDVI 10-days composite products derived from SPOT/VEGETATION

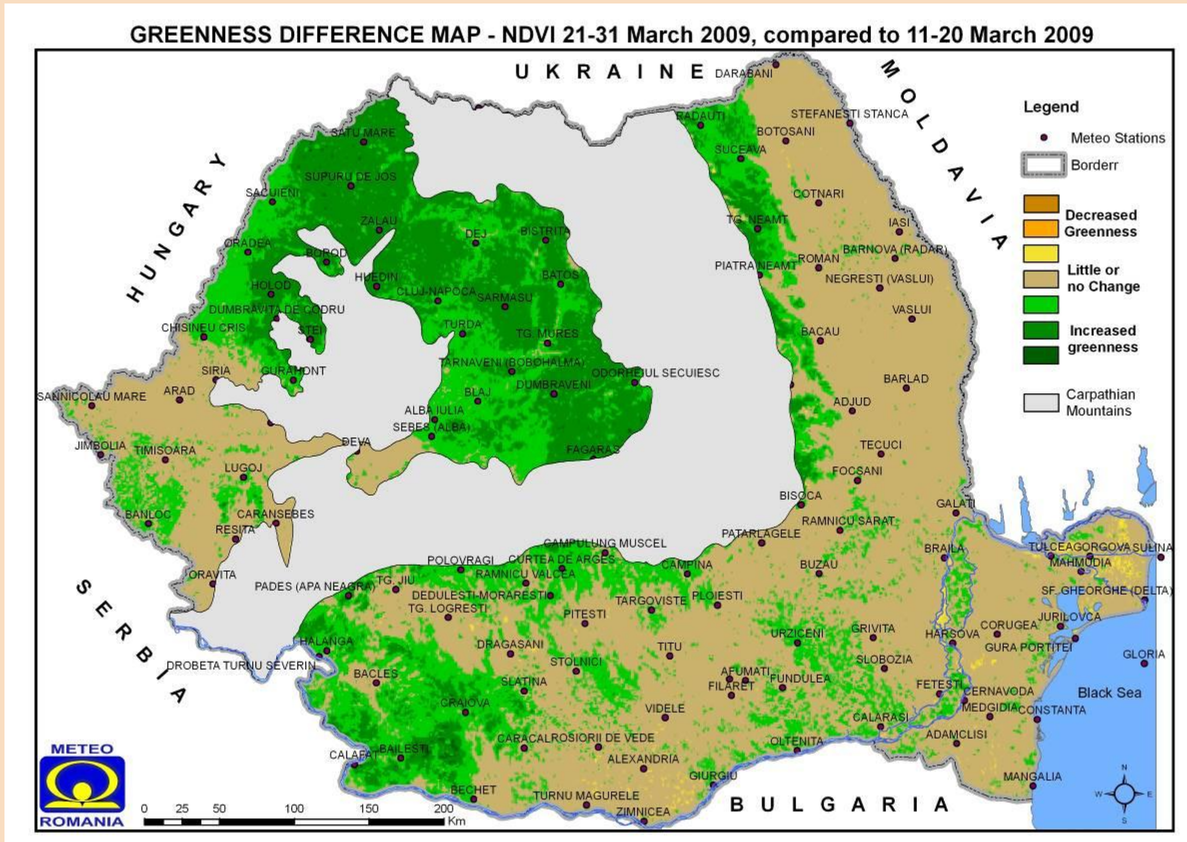




2007 / Extremely droughty year



Monitoring the vegetation using greenness difference, computed using SPOT/VEGETATION NDVI 10-days composite products



Greenness difference map, computed using NDVI 10 days synthesis from SPOT VEGETATION images (1km resolution), proved to be a reliable satellite-derived information for the estimation of zones possible affected by drought .
In resulted map there are three classes: decrease of greenness, little or no changes and increase of greenness.

Using SPOT VEGETATION NDVI time series of for drought monitoring

Time-series analysis of vegetation index data has allowed scientists to examine global scale phenological phenomena such as:

- green-up (which occurs when an area's vegetation index breaks a 15% threshold of its historically determined range);
- duration of green period;
- onset of senescence;
- changes in biophysical variables (LAI, biomass, net primary productivity).

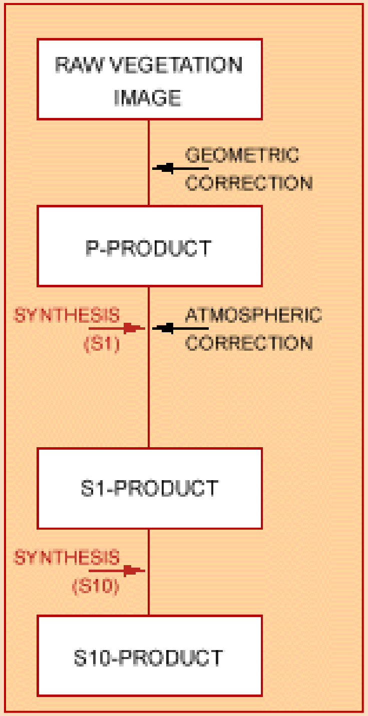
METHOD:

- extraction of NDVI values for test zones;
- temporal smoothing of the annual NDVI curves using linear regression in moving the temporal window;
- compute the vegetation condition index:

$$VCI = (NDVI - NDVI_{min})/(NDVI_{max} - NDVI_{min}) * 100$$

- compute the average curve as well as the curve of minimum and maximum values;
- compute the differences between annual values and linear regression.

Only the vegetation period was considered, defined as April – beginning of November (decades 9 - 31).

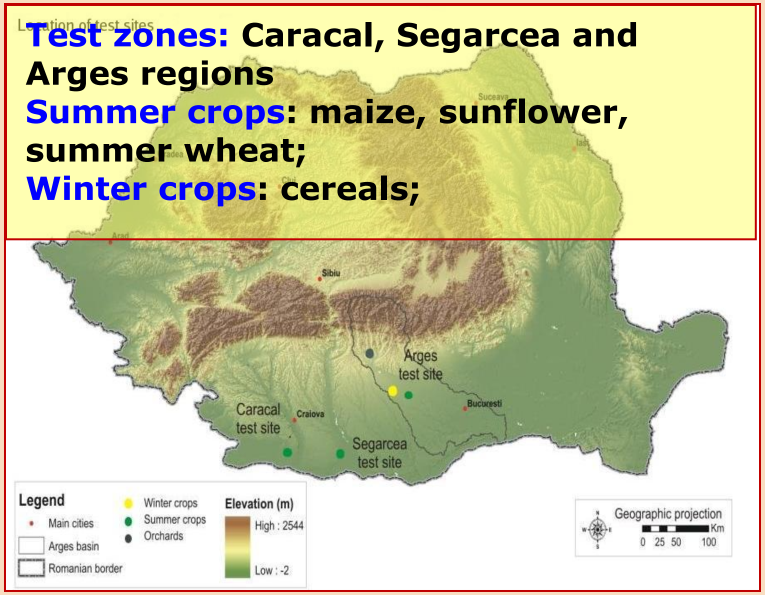


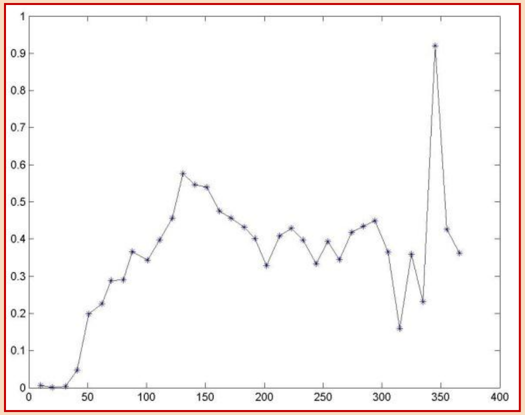
Using SPOT VEGETATION NDVI time series of for drought monitoring (cont.)

The smoothing procedure:

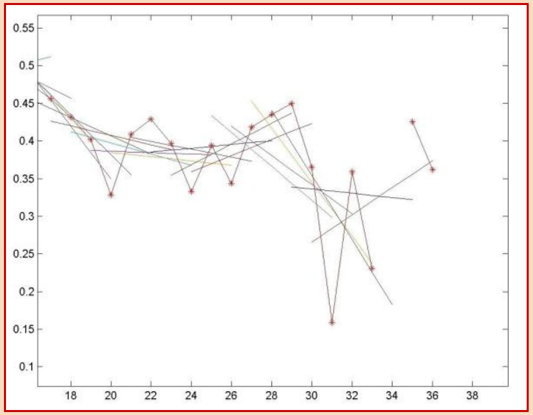
- ✓ For each test area the NDVI values for each decade has been derived.
- ✓ Using the temporal window and with linear regression these data have been smoothed.
- ✓ The resulting curve is smoothed well and is comparable to the other years.

Test zones: Caracal, Segarcea and Arges regions
Summer crops: maize, sunflower, summer wheat;
Winter crops: cereals;

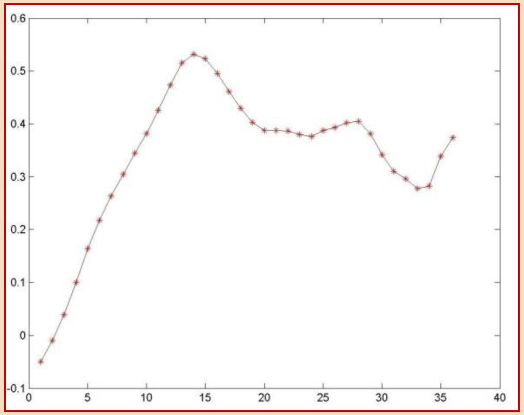




Original annual curve of NDVI values



Average value of the linear regression functions



The resulting smoothed curve

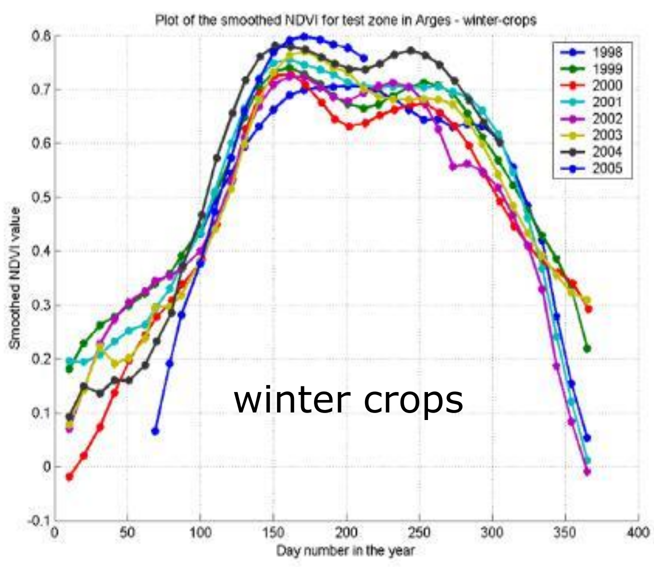
Using SPOT VEGETATION NDVI time series of for drought monitoring (cont.)

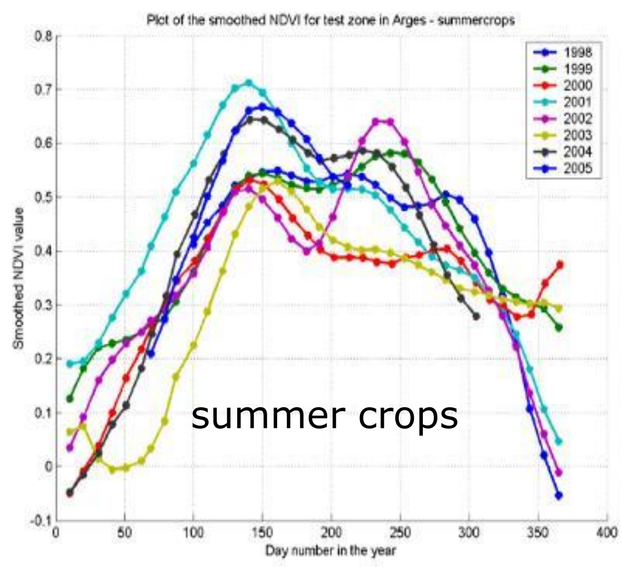
Annual time series show the differences in vegetation amounts by comparing the values of the same site, at different times within a year and also the years with each other.

Simply comparing the annual curves with the average one, the years much under the average are associated with droughty years.

The difference between winter and summer crops is clear: the summer crops have a more marked dispersion of values, and the drought years 2000 and 2003 are easily distinguished. Also the different behaviors of these two dry years can by noticed.

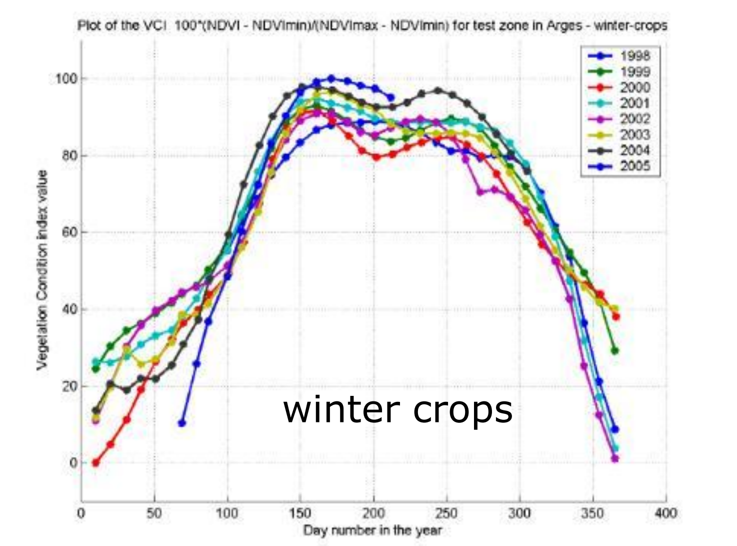
Smooth the annual NDVI curves

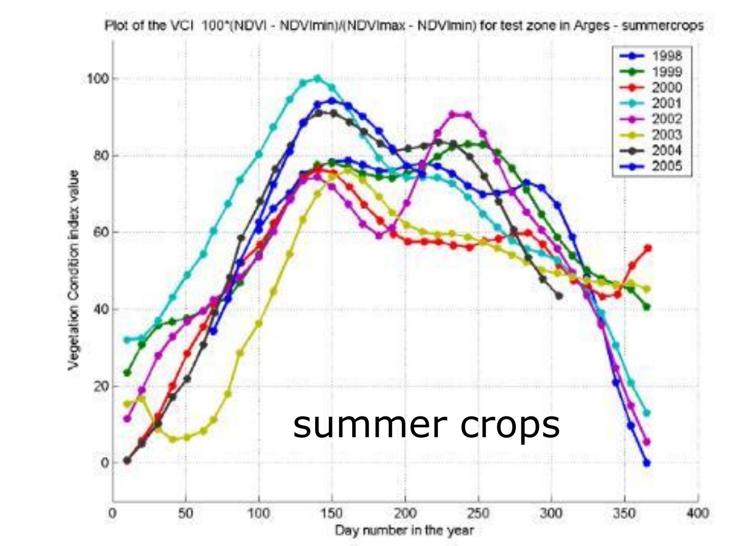




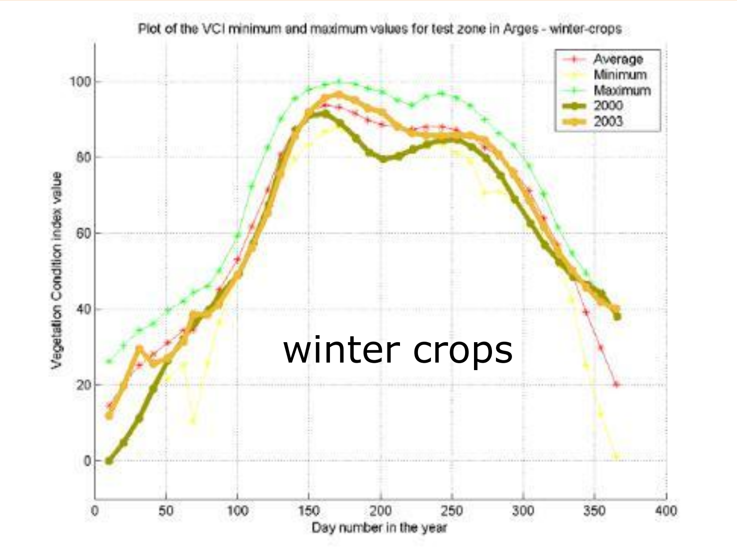
Using SPOT VEGETATION NDVI time series of for drought monitoring (cont.)

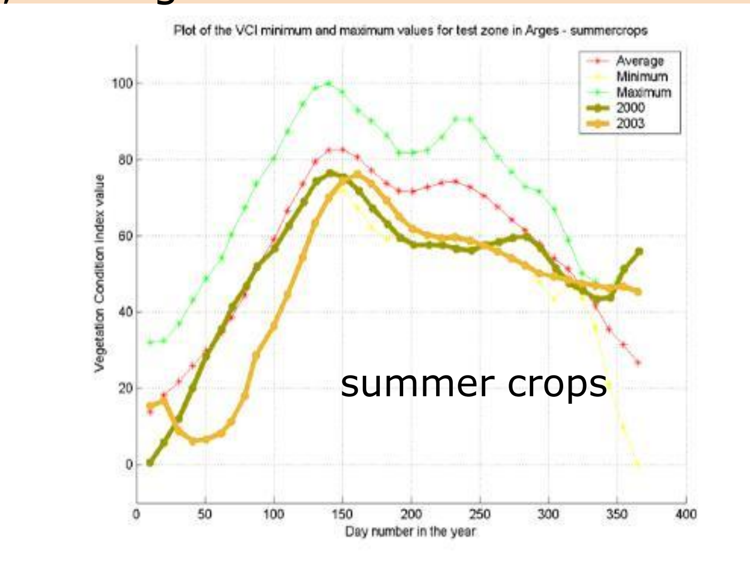
Vegetation condition index (VCI) annual curves





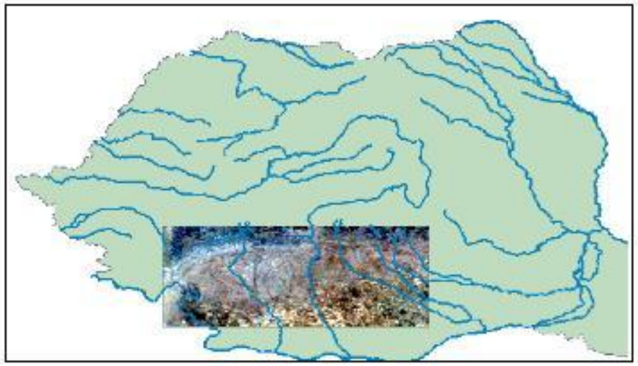
VCI annual curves of minimum, average and maximum values

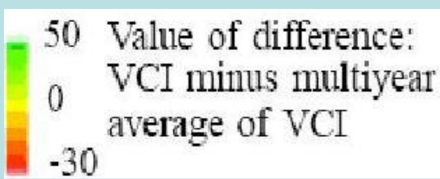


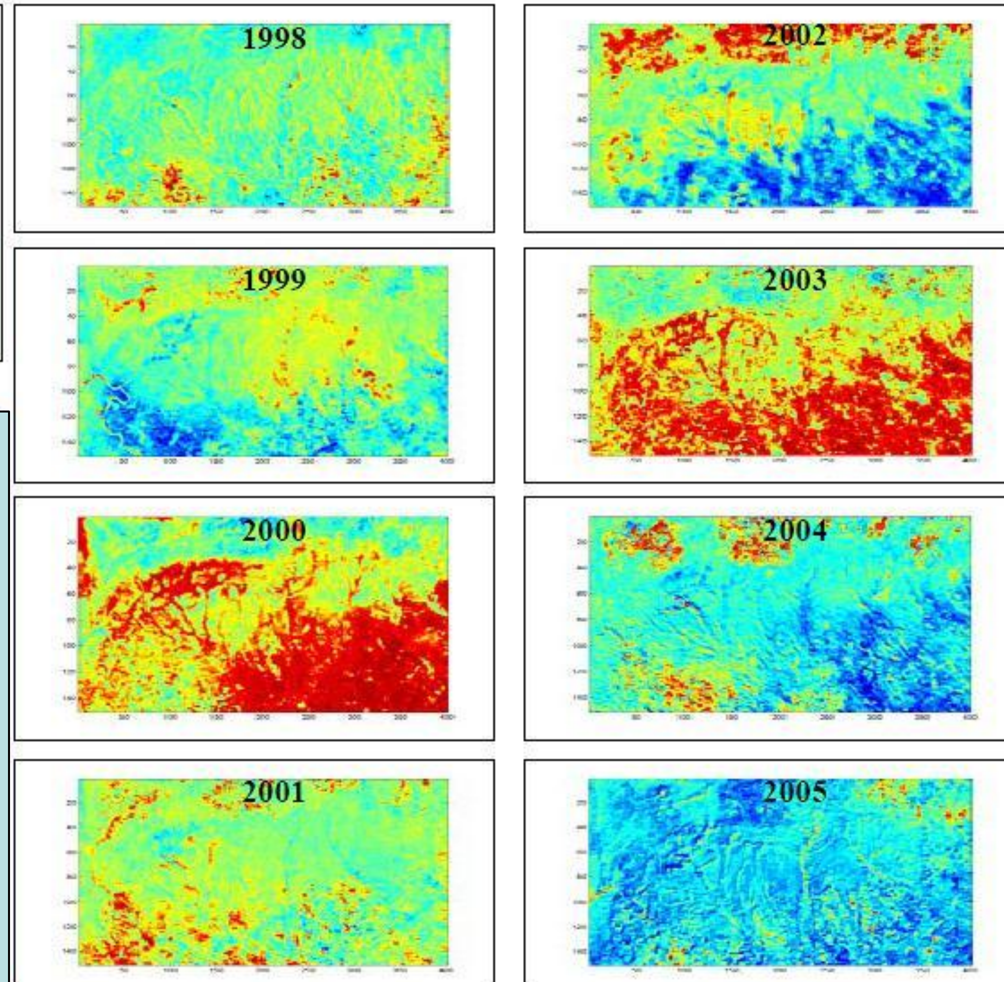


Using SPOT VEGETATION NDVI time series of for drought monitoring (cont.)

Comparison of differences [VCI – multiyear average] for the decade 23 (middle of August)







The droughty years 2000 and 2003 are clearly emphasized

Conclusions

- Droughts are normal recurring climatic phenomena that affect people and the landscapes they occupy at many scales (locally, regionally, and nationally) for periods of time varying from weeks to decades. The spatial and temporal variability and multiple impacts of droughts present challenges for mapping and monitoring on all scales.
- Operational drought monitoring, by its very nature, requires repetitive measurements. Monitoring tools require reliable sources of time-series data at effective spatial and temporal scales to provide accurate and timely information.
- Satellite remote sensing is an obvious data source, supplying synoptic coverage of the land surface with objective, automated data collections for use in spatially specific models. Satellite information is especially appropriate over remote areas or areas with sparse field instrumentation.
- Remotely sensed data can provide important information to better understand and predict the effects of drought and are now key components of the environmental observing system.

Thank you for your kind attention !