OPERATIONAL DROUGHT DETECTION AND MONITORING OVER EASTERN MEDITERRANEAN BYUSYNG MSG DATA

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Abstract

The study is focused on exploring possibilities for the operational detection and monitoring of drought terrestrial hazard on a regional scale. Considering the complex nature of drought, a conceptual framework for quantification of agricultural drought severity/duration and its impacts has been developed. Growing season effects are quantified using a variety of indicators developed on the bases of combined use of different source of information: geostationary MSG data, ground observations, a Bulgarian SVAT model outputs, and thermodynamic description of ecosystems functioning. The set of numerical biogeophysical and thermodynamic indexes is involved within a 3-level Alert system, accounting for specific regional and local drought reveals. The capacity of MSG LSA SAF products (ET, LST) and the blended parameter (LST – Air temperature difference) to reflect aspects of terrestrial drought conditions and vegetation water stress in terms of the developed concept is used and in parallel the satellite products are validated for consistency. The concept is developed and applied for different soil and climate environment over Bulgaria, Eastern Mediterranean. The study spans six growing seasons (2007-2012) of winter wheat cultivars with an operational data set of: weather data from synoptic stations, phenological observations from agro network (located in the climatic region of corresponding synoptic station), indicated satellite information. As data truth for drought assessment information for yield production and vegetation water stress (based on volumetric soil moisture measurements and its modeling by a Bulgarian SVAT) is used.

INTRODUCTION:

In common with other natural disasters, droughts vary widely in degree of severity, duration and areal extend. Unlike most other natural disasters, drought onset and termination is difficult to identify (Maybank, J. et al., 1995). Due to the complex nature of drought its monitoring calls for a comprehensive and integrated approach, accounting for its specific regional and local reveals, with possibilities drought extent and impacts numerous indicators to be monitored routinely. A lot of indexes reflecting different aspects of drought are recommended by WMO (Monacelli et al., 2005). Although all types of droughts originate from a precipitation deficiency, it is insufficient to monitor solely this parameter to assess severity and resultant impacts. Physiological and physical signals of terrestrial vegetation water stress are important to be considered and this calls for an interdisciplinary approach in studying drought in the context of geophysical processes. Efforts of scientific community are focused in joint international activities that make use of numerical modeling and satellite data in establishing Drought Information System, Europe, Africa and Latin America (Horion, 2012). As indicators following geophysical indexes are recommended to be used: Soil Moisture Anomalies, Indicators optimized for characterizing vegetation water stress, Satellite observations and products. A combined drought indicator, that combines the Standardized Precipitation Index (SPI), the anomalies of soil moisture and the anomalies of the fraction of Absorbed Photosynthetically Active Radiation (fAPAR) is proposed to detect agricultural drought in European (Sepulcre-Canto et al., 2012).

There is no strong established methodology to identify drought, in particular agricultural drought, studies to give more light and knowledge for its operational assessment at specific climate/land-use environment are needed. The increased capabilities of the meteorological satellites of EUMETSAT provide a set of methods for remote sensing of vegetation drought stress. While EUMETSAT is not a research organisation, research carried out in Member States is fundamental to our long-term development (Schmetz, 2013). An understanding of this research is needed to anticipate the development of future applications of our data and to make sure our own science remains relevant and up to date. The appropriation of the progress in science is important for new programmes because it enables us to see the challenges and the opportunities. The same applies to the continuous improvement of EUMETSAT data and services which is largely based on science. Therefore, keeping a close eye on the relevant science is key to improving and to making informed decisions on the future.

Referring drought as a "dry" biogeophysical cycling anomaly on the land surface, the main goal of this study is focused on a regional scale agricultural drought detection and monitoring with capabilities for its operational processing. Since the agricultural drought is related to soil moisture deficit that limits water availability for crops to such an extent that yield production can reduced, the specific items for solving include:

- To define a set of biogeophysical and thermodynamic indices characterizing terrestrial vegetation state and functioning at different soil, climate environment, and crops (following and extending the experience from literature). New indexes to be developed by using different information sources: meteorological observations and estimates from modeling.
- Based on the combined and interrelated use of these indexes, to build a conceptual framework for an ALERT system.
- Along with this, to evaluate the capacity of involved LSA SAF products based on MSG SEVIRI data: LST, ET parameter and the difference (LST – Air temperature) to reflect vegetation water stress for the region of Eastern Mediterranean.
- To illustrate the agricultural drought concept operation for real situations over Bulgaria.

DEVELOPMENT OF METHODOLOGY:

To assess agricultural drought conditions operationally, a methodology has been specially designed applying two types of approaches. Firstly, modelling of both land-atmosphere exchange processes and of the energy conversions of the absorbed solar energy by crops during critical for growth/ and yield production periods and secondly by using meteorological measurements from conventional synoptic network and from meteorological geostationary satellites MSG to reflect vegetation moistening state and functioning conditions. In general, due to the complex nature of drought, all these different sources of information are involved in development of a range of geophysical indexes, which are able to reflect Soil Moisture Availability (SMA) to crops, here accepted as the main trigger parameter of drought onset and severity.

Modelling:

A. Drought as a biogeophysical process:

- **Numerical modeling of LSPs. Use of a SVAT model:**

A simple 1D meteorological model, 'SVAT_bg' that exploits the concept of one layer vegetated land surface and two levels of moisture availability in the root zone depth has been developed (Stoyanova and Georgiev, 2010; 2013) and applied for wheat field. The model is run operationally, as one of the daily outputs is Soil Moisture (SM) along root zone depth (5, 20, 50, 100 cm) further used for development of quantitative indexes in support to the land surface state characteristics.

- **Soil Moisture Availability (SMA) concept. Threshold scheme for quantification:**

For assessing local/regional scale vegetation water status, SMA concept is adopted to serve as information source of "warnings" for environmental constrains. Multiple equilibrium states in the soil-vegetation-atmosphere system are characterised by different levels of SMA. The SMA varies between the permanent wilting point (PWP), which defines the minimal of soil moisture that plant requires to prevent wilting, and the field moisture capacity (FMC), which is the maximum moisture content of capillaries in equilibrium with the force of gravity. Between FMC and PWP, there is a level of capillarity tearing moisture (CTM), below which SMA sharply drops as a result of a salutatory alteration in soil moisture mobility and instead of its usual fluid state, the water movement to the evaporative soil surface becomes via water vapour. The SMA variability through these three equilibrium states depends on soil physics, degree of moisture access to plants and available precipitations a day before, as well as biophysical properties of crops and their dynamics during vegetation season. Based on the above considerations an Index designating Soil Moisture Availability /SMAI/ in the root zone has been developed (Stoyanova and Georgiev, 2010; 2013). This Index is designed as a 6-level threshold scheme to account for moistening conditions of: ‘Drought’ (red colour), ‘Drought risk’ (orange colour), ‘Dry’ (yellow colour), ‘Optimum’ (green colour), ‘Wet’, ‘Soaking wet’. The SMAI is visualized by colour-coded maps covering the main administrative regions of Bulgaria along the root zone depths (e.g. see Fig. 1, Stoyanova and Georgiev, 2013). In current work, the focus is given on using SMAI in the context of terrestrial drought.

B. Coupling of biogeophysical and biogeochemical cycles:

Functional relations between biogeophysical and biogeochemical cycles on the land surface practically means to understand biospheric processes within the context of thermodynamics. Recently in the literature the question “Quantifying the thermodynamic entropy budget of the land surface: is this useful?” (Brunsell et al., 2011) was put. Regarding this far posed question (e.g. Schroedinger, 1945), some recent results confirm that “quantifying the thermodynamic entropy budget and entropy production is a useful metric for assessing biosphere-atmosphere-hydrosphere system interactions”. Actually the key question is not if this approach is useful but how to quantify the ecosystem functioning, which are far from local thermodynamic equilibrium. In the current study the experience and knowledge from a Bulgarian scientific approach in biothermodynamics is applied to characterize agro ecosystems sustainable functioning.

- **Thermodynamic concept of ecosystem functioning:**

Ecosystems are functioning as open thermodynamic systems by mass- and energy- exchange with the environment. A conceptual thermodynamic approach for quantitative description of ecosystem functioning and the related energy flow conversions referred as ‘surface-boundary approach’ (SBA) in biothermodynamics (Florov, 1978) is used. In general, the SBA concept consists in applying of linear irreversible thermodynamic of steady-state to the boundary surface between canopy leaves and environment in consistency to the universal law of Rubner (and a lot of other considerations). As a result, the corresponding energetic looses that accompanies the ecosystem functioning from a thermodynamic point of view are quantified by the entropy production in the main photosynthetic apparatus (or function of dissipation, Φ). Φ is a sum of the entropy produced during the heat- and the water- exchange between leaves and environment (the first and the second terms of eq. (1)):

$$\Phi = T\frac{\Delta_i S}{\Delta t} = \frac{H\Delta T}{T\Delta t} + LE\frac{\Delta q}{\Delta t} \qquad (1)$$

where: entropy production rate in leaves; E – transpiration rate; H – leaf-air heat exchange rate; T – mean leaf-air absolute temperature; leaf-air temperature difference; q_s – specific humidity of saturated water vapour at the leaf surface at corresponding leaf temperature; $\Delta q = q_s – q$ is the difference between specific air humidity at the transpiring leaf level and the surrounding air, respectively, L – latent heat of vaporization of water. ‘SVAT_bg’ outputs and measurements from synoptic network are used for the run of thermodynamic model (eq.1).

- **Entropy production in canopy leaves: A thermodynamic criteria for agro climatic resources assessment:**

From the other side, the capacity of specific soil-ecosystem-atmosphere dynamic system to utilize the solar energy into biochemical energy is strongly related to the intensity/efficiency of energy conversions at a molecular level, which in turn is related to the intensity/efficiency of growth and yield response (Stoyanova, 1985). In these functional coupling, the biogeophysical cycling is the driving process, which determines intensity/efficiency of the biogeochemical cycling (as an effect). Based on these findings for the functional coupling between biogeophysical and biogeochemical cycles, the entropy production in wheat canopy leaves (eq. 1) for different weather/climate/soils/sites is introduced as a quantitative indicator of climatic resources responsible for crop growth and yield response. This is a complex indicator of hydrothermal environmental conditions and the state of main photosynthetic apparatus (leaves) during the growing season. Entropy production in canopy leaves as a biophysical state parameter is a function of both meteorological parameters and soil hydro-physical properties, and thus can reflect the environmental (meteorological–climate) resources and vegetation capacity to accumulate solar energy in biochemical energy (responsible for growth and yield production).

Meteorological observations:

The European Commission's Joint Research Centre with the aim of integrating drought information from the European Member States has agreed a set of standardized indicators for drought monitoring throughout Europe. These standardized indicators currently include: the SPI, anomalies of soil moisture and anomalies of fAPAR (Sepulcre-Canto et al, 2012) that encompasses continental, national, regional and local scales, apart from specific indicators, reflecting local conditions provided by different institutions.

A. MSG satellites for crop stress detection and monitoring:

In our work, the numerical index of SMA along the root zone depth that allows quantification of *agricultural drought* and its dynamic during growing season is used in combination with selected satellite geophysical products LSA SAF developed on the bases of MSG satellite information. As suitable for local and regional scale characterizing vegetation water stress and energy/water cycles dry anomalies (respectively anomalies in the ecosystem functioning) we have selected: The Land Surface Temperature (LST) product for retrieval of surface skin temperature and characterizing thermal environmental conditions of photosynthetic physiological process as well as Evapotranspiration (ET) product (Gellens-Meulenberghs, 2010). Daytime 06, 09, 12 UTC cloudless values are inferred and SEVIRI data are collocated for the pixel nominally containing the latitude/longitude of the synoptic station.

B. Ground measurements:

Satellite observations are jointly used with model outputs and meteorological observations from synoptic stations (the difference between MSG LST and Air temperature at 2 m height, Tair °C). As test sites, specific geographic locations of synoptic stations from NIMH Bulgaria meteorological network /13 sampled sites/ in close vicinity of corresponding agro stations are selected.

For operational drought assessment and monitoring on a regional scale, the following indexes are commonly framed: SMAI at 20 cm, 50 cm; Entropy production in canopy leaves, $\Phi=\Delta S/\Delta t$; MSG LST; (MSG LST - Tair) difference; LSA SAF ET.

Experimental set-up:

The work is organised to infer and calculate daily all selected indicators at the experimental sites with winter wheat over a variety of soil/climate conditions for six growing seasons: 2007 ÷ 2012. Sensitivity analyses include the most drought susceptible period of winter wheat phenology, critical for yield formation (i.e. heading-flowering-beginning grain filling, which on average include end of April - beginning of June). MSG 5x5 pixels inferred numerical values and centered at the locations of synoptic stations from NIMH network are used for cloudless slots in combination with GLCM2000 data. As a reference information in evaluation the concept are used: crop yield production observed at NIMH agro network and mean annual crop production announced by Ministry of Agriculture and Food (MAF) of Bulgaria as well as the surface moistening, characterised by 'SVAT_bg' model Soil Moisture /SM/ and SMA Index.

The study is performed at the following assumptions: Uniform level of agro technical measures is implied and winter wheat field biophysical properties are approximated as grass cover.

RESULTS:

Conceptual framework for severity of agricultural drought assessment and impacts on crops:

The concept is based on the exploitation of the functional relations between SMA threshold level and the resulting drought severity (accumulated vegetation water stress and their effects on sustainability of agro ecosystem functioning respectively). Three levels of drought warnings–"Watch", Warn", "Alert"–are introduced in line with Sepulcre-Canto et al. (2012) but a different meaning is involved behind them. The meaning of each one-drought level is illustrated on Fig. 1, Fig. 2 and Fig. 3, as follows:

Level 1: Watch. Meteorological drought initiates SMA depletion in the upper surface soil layer. Meteorological drought establishment is revealed after the SMA in the upper surface soil layer (of 20-30 cm soil depth) is initially depleted. The situation is illuminated by examination of SMA dynamics for the test period 29 April-10 June 2011 on Fig. 1 (station Plovdiv, South Bulgaria). Comparison with precipitation rate shows: SMA at 20 cm soil depth is initially depleted during the 1st decade (Fig.1a) – 'yellow' colour), while SMA at 50 cm remains optimal ('green', Fig.1b)). In May 2011 precipitation is 65 % from the monthly norm, being irregular distributed: 1st decade (121-130 DOY) is 30.8 mm, small quantities for 6 days; 2nd decade (131-140 DOY) is 7.9 mm (small quantities for 5 days) and 3rd decade (141-150 DOY) is 0 mm.

(a) (b) (c)

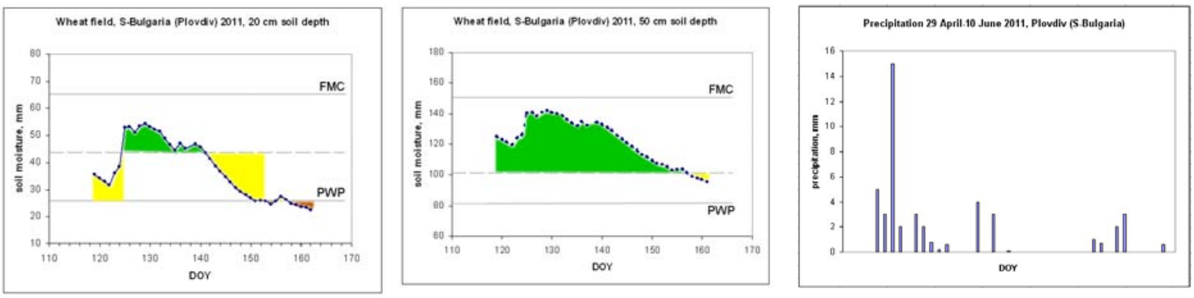

Figure 1: SVAT model derived Soil Moisture Availability (SMA) dynamics, 29 April – 10 June 2011, at winter wheat field located near to synoptic station Plovdiv (24.55E; 42.16N), South Bulgaria: (a) At 20 cm and (b) At 50 cm soil depths along with (c) Daily precipitation.

Level 2: Warn. SMA in the upper surface is exhausted, drought starts to extend to lower 50 cm soil layer and vegetation water stress is occurred.

The case is illustrated for drought occurrence in 2007 for North/South Bulgaria (Fig.2), where for the test period 29 April - 10 June, due to precipitation deficiency and active evapotranspiration of wheat field, SMA at 20 cm is exhausted ('orange') and for 50 cm it starts to decline ('yellow'). In parallel to SMA depletion, the blended parameter (MSG LST - Tair) difference increases (Fig. 4) as well as LSA SAF ET is steadily decreasing (Fig. 5). As an example, for the region of synoptic station Kneza, North Bulgaria (2007, 2011) at optimal 'green' SMA, the temperature difference varies between/up to 1.5-5.0 °C; at initial SMA depletion ('yellow') the difference is 7.73-13.93 °C and when the SMA is fully exhausted for 5 or more days, the temperature difference increases up to 12.5-17.0 °C.

(a) (b) (c)

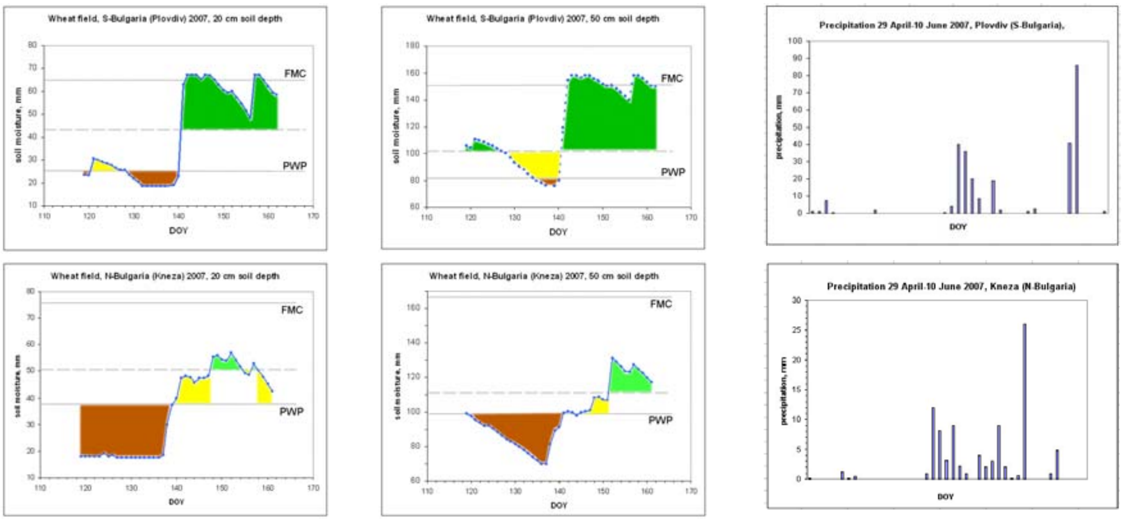

Figure 2: SVAT model derived Soil Moisture Availability (SMA) dynamics, 29 April – 10 June 2007 at winter wheat field located near to synoptic station Plovdiv (24.55E; 42.16N)/Kneza (24.031E; 43.467N), South/North Bulgaria: (a) At 20 cm and (b) At 50 cm soil depths with (c) Daily precipitation.

Level 3: Alert. Risk of yield reduction.
High level of drought severity/duration as indicated by the quantified entropy production in leaves of wheat field during the period of heading-flowering-beginning grain filling, leads to yield reduction.

Drought, entropy production and yield:
In case of 'dry anomalies' of crops energy/water balance, (MSG LST-Tair) difference increases. For illustration: data for the region of synoptic station Russe, North Bulgaria (25.967 E; 43.85 N) show the following tendency: for 2007 precipitation in May is 69.2% from norm; for 2011 – 84.9%; for 2012 – 181% and the corresponding mean values of (MSG LST-Tair) differences are increasing: 2.93 °C / 3.45 °C / 4.91 °C. In parallel, drought increases the energetic looses and decreases the efficiency of metabolic processes and yield production respectively (Fig. 3 a; b).

Comparison between dissipated energy and annual country yields for the period 2007-2012, as given by MAF of Bulgaria annual census data shows a high correlation between these two quantities: R^2 = 0.677. Using data for mean yield (from 13 sample sites included in the current study) as reported by the NIMH Bulgaria agro network, R^2 = 0.671 (Fig. 3a). Comparison between dissipated energy and mean (2007-2012) annual yields at selected sites as given by NIMH agro network annual census data, R^2 varies between 0.495 and 0.825 depending on climate, soil, wheat variety, etc. (Fig. 3b).

(a) (b)

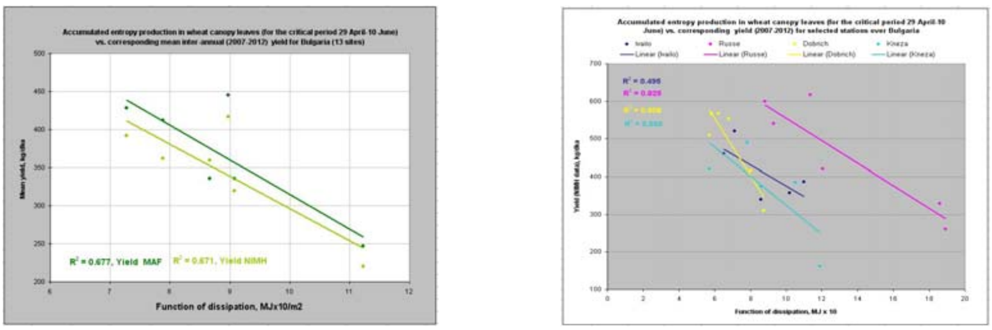

Figure 3: Comparison between accumulated entropy production in winter wheat canopy leaves for the drought sensitive period 29 April- 10 June and corresponding mean inter-annual 2007-2012 yield for Bulgaria according: (a) MAF of Bulgaria annual census data; (b) reported by the NIMH Bulgaria agro network.

Towards operational drought assessment and monitoring by MSG LSA SAF indicators:

***LSA SAF 1200 UTC MSG LST and air temperature (Ta) difference vs. SMA*:**
The methodology developed provides a platform for a combined use of MSG SEVIRI temporal frequency observations and local energy and water balance dry anomalies quantification. There is a strong correlation between SMA at upper and lower surface layers (20 and 50 cm) and (1200 UTC MSG LST-Tair) difference, r=0.718 and r=0.84 correspondingly (Fig. 4a).

(a) (b) (c)

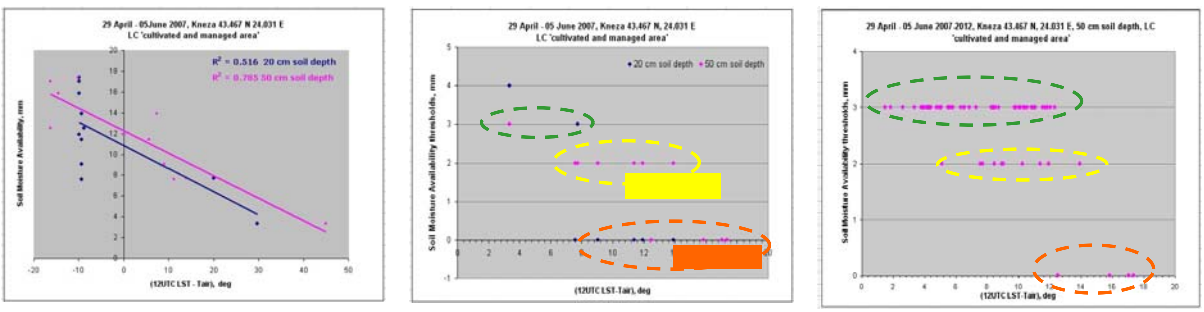

Figure 4: Comparison between SVAT derived Soil Moisture Availability (SMA) and (1200UTC LST–Tair) temperature difference at winter wheat field located near to synoptic station Kneza (24.031E; 43.467N), North Bulgaria: (a) Scatter plot for 20 cm (magenta) and 50 cm (blue) soil depth, 29 April – 10 June 2007; (b) (12UTC MSG LST-Tair) range at different SMA thresholds for 2007; (c) the same as (b) for 2007 and 2012 dataset.

At different SMA threshold levels, this temperature difference is strongly variable showing the following trends: At optimal conditions ('green', SMA level 3), (MSG LST-Ta) is up to 7.5 °C at the specific environmental conditions of 2007 (Fig. 4b); after SMA at 20 cm is exhausted ('yellow', SMA level 2), i.e. warning Level 1: Watch, temperature difference is increasing, varying between 7.5-16 °C. After SMA at 50 cm becomes equal or lower than PWP, Level 2: Warn is reached ('red' SMA level 0). Similar trend is preserved when the analyzed dataset include 2007 and 2012 all together (Fig. 4c). Using this approach and based on the initial results, further analyses will be performed to quantify the LSA SAF ET and (MSG LST–Tair) response to regional drought conditions.

***LSA SAF 1200 UTC MSG ET product and SMA*:**

Comparing SMA threshold levels with corresponding digital 12 UTC values of LSA SAF ET product, the following trends are revealed (Fig. 5): A strong relation between MSG ET and SVAT derived SMA in the top 20 (blue) and 50 cm (magenta) soil layers exist with correlation coefficients of 0.659 and 0.558 correspondingly (Fig. 5a). Meanwhile, at optimal moistening ('green', SMA level 3), LSA SAF ET varies in a wide range (depending on atmosphere conditions) within the 0.32-0.5 mm/h range (Fig. 5b). At limited moistening observed during Level 1: Watch of our Drought Warning System (DWS), 12 UTC ET is steadily decreasing as its upper limit becomes lower at dryer conditions.

(a) b)

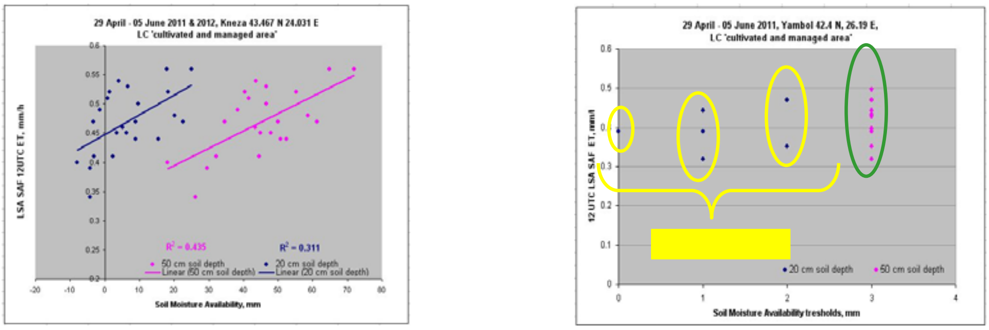

Figure 5: **Comparison between SVAT derived Soil Moisture Availability (SMA) and Evapotranspiration LSA SAF (1200UTC ET) at winter wheat field: (a) Scatter plot for 20 cm (blue) and 50 cm (magenta) soil depth, 29 April – 10 June 2011 and 2012, close to synoptic station Kneza (24.031E; 43.467N), N-Bulgaria; (b) 12UTC MSG ET range at different SMA thresholds for 2011, close to synoptic station Yambol (26.19E; 42.4N), SE Bulgaria.**

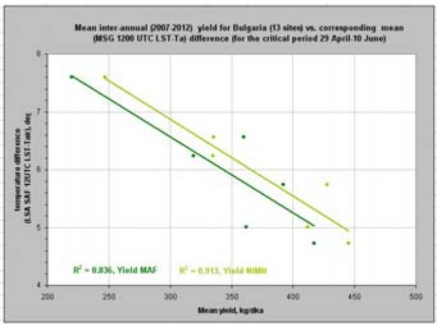

Figure 6: **Mean inter-annual (2007-2012) for the critical in yield formation period (29 April – 10 June) yield for Bulgaria (13 sites) vs. corresponding mean (MSG 12UTC LST-Tair) difference.**

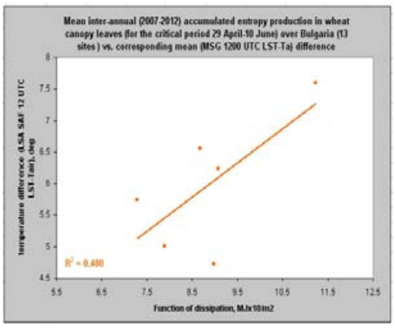

Figure 7: **Mean inter-annual (2007-2012) accumulated *entropy* production in winter wheat leaves for the *critical in* yield formation period (29 April–10 June) vs. *corresponding* mean (MSG 12UTC LST-Tair) difference.**

***(MSG LST-Tair) difference relation to yield and entropy production*:**

There is a strong correlation between the mean (29 April – 10 June) inter-annual (2007-2012) (MSG 12UTC LST-Tair) temperature difference and the crop yield production (Fig. 6). The correlation coefficient is to 0. 914 in case of using information for wheat yield from the national MAF, and to 0.955 using information from the NIMH agro network and bulletins. For example (station Russe, 43.85N, 25.967E) in 'dry May' of 2007 temperature difference is significantly higher than this in 2011 -

6.93/3.45 °C, that corresponds to yield reduction – 261/600 kg/dk, respectively. From the other side, the mean (n= 13 test sites) (LSA SAF 12UTC LST-Tair) difference is correlated to corresponding mean inter-annual 2007-2012 accumulated entropy production in wheat canopy leaves (for the critical period 29 April–10 June), Fig. 7 (r = 0.693).

***Limitations of the Drought Warning System*:**

Some discrepancies in applying the proposed approach might occur due to: Regional specific agrotechnical activities; other factors except drought that might destroy yield production in a specific year or region (e.g. overmoistening, frost, snow, etc; technical mistakes in field data collection, etc.

CONCLUDING REMARKS:

The study presents a conceptual framework for agricultural drought assessment, ranking its severity and related agroclimatic effects on crop growth/yield production. Combining model outputs and ground/satellite measurements for Eastern Mediterranean (Bulgaria), the Drought Warning System, DWS basically developed around the thermodynamic description of ecosystem functioning includes:

- Three levels of drought warnings: ‘Watch’, ‘Warn’, ‘Alert’ (at specific climate/soil/vegetation type) based on ranking of SMA and corresponding climatic resources for agroecosystems functioning, considered as open thermodynamic systems.
- Ranking agricultural drought regarding its severity, duration, widespread in the soil surface and more deep horizons, as well as its economic effects, i.e. yield anomalies (for winter wheat) by introduction a set of functionally related quantitative indexes: Meteorological drought effects on SMA – Evapotranspiration – Temperature difference between the canopy leaves and air – The entropy production ($T\Delta S/\Delta t$) in canopy leaves (introduced as a complex index for agroclimatic resources). Based on the dynamics of this set of indexes considered in their unity, the ranking of environmental conditions and constrains for yield production as ‘Low’, ‘Moderate’, ‘High’ (Fig. 6) is possible.
- Evaluation of LSA SAF products based on MSG data, (LST-Tair) difference and ET as functional indexes of vegetation water stress in the context of proposed DWS.

Further research to improve the regional DWS will include more directly use of indexes based on MSG data and operational mode of System exploitation.

REFFERENCES:

Brunsell, N. A., Schymanski, S. J., Kleidon, A. (2011) Quantifying the thermodynamic entropy budget of the land surface: is this useful? Earth Syst.Dynam., 2, 71-103.

Florov, R.I. (1978) Investigations about the application of irreversible thermodynamics in plant physiology and ecology. DrSci Theris, [In Russ], Moskva,66 p.

Horion, S., Carrão, H., Singleton, A., Barbosa, P., Vogt, J. (2012) JRC experience on the development of Drought Information System. Europe, Africa and Latin America. JRC Sci & Tech Reps, EUR 25235 EN.

Gellens-Meulenberghs, F., Arboleda, A., Sepulcre-Canto, G. (2010) Evapotranspiration process as the result of land-surface-atmosphere interaction. EGU General Assembly 2010, Geophys. Res. Abstr., v.12, EGU2010-8622

Horion, S., Carrão, H., Singleton, A., Barbosa, P., Vogt, J. (2012). JRC experience on the development of Drought Information System. Europe, Africa and Latin America. JRC Sci & Tech Reps, EUR 25235 EN.

Maybank, J., et al. (1995) Drought as a Natural Disaster. Atmospheric-Ocean, 33, 2, 195-222.

Monacelli, G., Carmela Galluccio, M., Abbafati, M. (2005) Drought assessment and forecasting World Meteorological Organization Report: Drought within the context of the region VI, WGH/RA VI /Doc. 8.

Schmetz, J. (2013) Providing scientific guidance and leadership to EUMETSAT. Image, 38, 7 p.

Schroedinger, E. (1945) What is life? Cambridge Univ. Press, 73 p.

Sepulcre-Canto, G., Horion, S., Singleton, A., Carrao, H., Vogt, J. (2012) Development of a combined drought indicator to detect agricultural drought in Europe. Nat. Hazards Earth Syst. Sci., 12, 3519-3531.

Stoyanova, J.S. (1985) Free energy balance and dark metabolism of leaf system of some broadleaved spp. PhD Thesis, [In Bulgarian], Sofia.

Stoyanova, J.S. (2010) Use of satellite land surface products for assessment of vegetation fire conditions over Bulgaria. 4th LSA SAF User workshop, Toulouse, France, 15-17 November 2010. http://www.meteo.fr/cic/meetings/lsasaf/presentations/session1_05.pdf.

Stoyanova, J.S., Georgiev, C.G. (2010) EUMETSAT Meteorological Satellite Conf. (Córdoba 20 – 24 September 2010). ISSN 1011-3932.

Stoyanova, J. S., Georgiev, C. G. (2013). SVAT modelling in support to flood risk assessment in Bulgaria. Atmos. Res., 123, 384-399.