SALGEE

Drought and Vegetation Monitoring using Satellite derived Climate Data Records

Julia Stoyanova

Christo Georgiev, Plamen Neytchev, Andrey Kulishev

National Institute of Meteorology and Hydrology, Bulgaria

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Outline

1. **Main concepts** adopted in drought monitoring with vegetation from space

    1.1. Evapotranspiration concept

    - Quality monitoring of products
    - Prelyminary climatic analyses

    1.2. Soil Moisture Availability (SMA) concept and drought assessment

    - ET Indexes & SMA Course
    - Land Surface Temperature (LST)-SMA relations

2. **Regional applications** for drought monitoring with vegetation: SVAT model and satellite products

    2.1. To quantify the water demands / water stress in vegetation functioning at different environment on a site/regional scale over Mediterranean (Eastern part, Bulgaria)

    2.2. Drought & Natural Crop Production

    2.3. Drought & Forest health

Biogeophysical indexes for drought assessment & Datasets

Indicators optimised for characterizing vegetation water stress and drought, which are related to energy and water cycles on the land surface, respectively to the ecosystem functioning during the growing season

SVAT model output

- Soil Moisture Availability Index (SMAI), as a reference

Meteosat based products

- Potential evapotranspiration (PET), LSASAF METREF product
- Actual evapotranspiration (AET), LSASAF DMET product
- Skin temperature (LST), LSASAF LST product
- Combination between PET and AET
  - Evapotranspiration deficit index
  - Evapotranspiration stress index

Environmental satellite (Proba V)

- NDVI300m

Time series from the satellite data and model outputs.

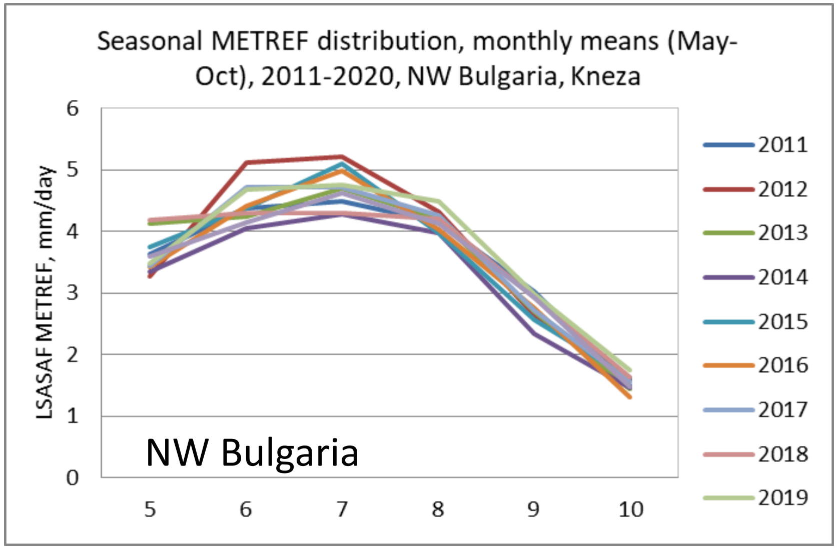
The complex biophysical nature of drought calls for applying an integrated approach, combining different sources of information.

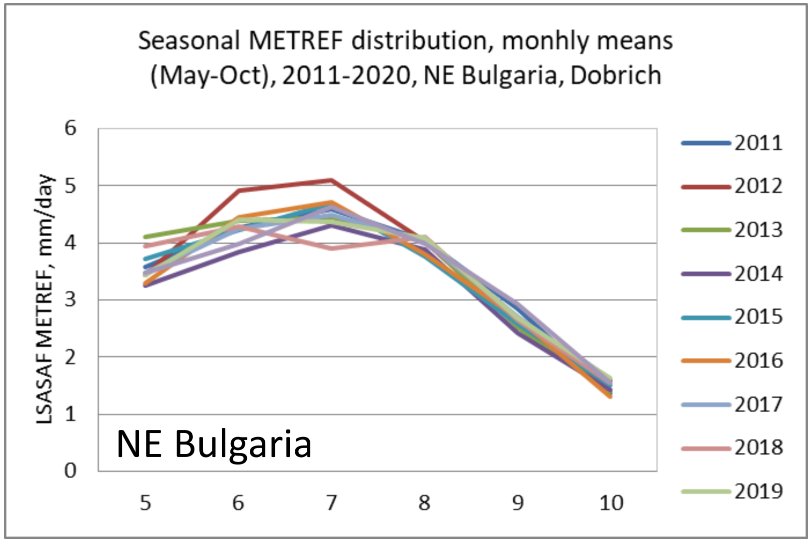
A. Main concepts in drought monitoring with vegetation from space

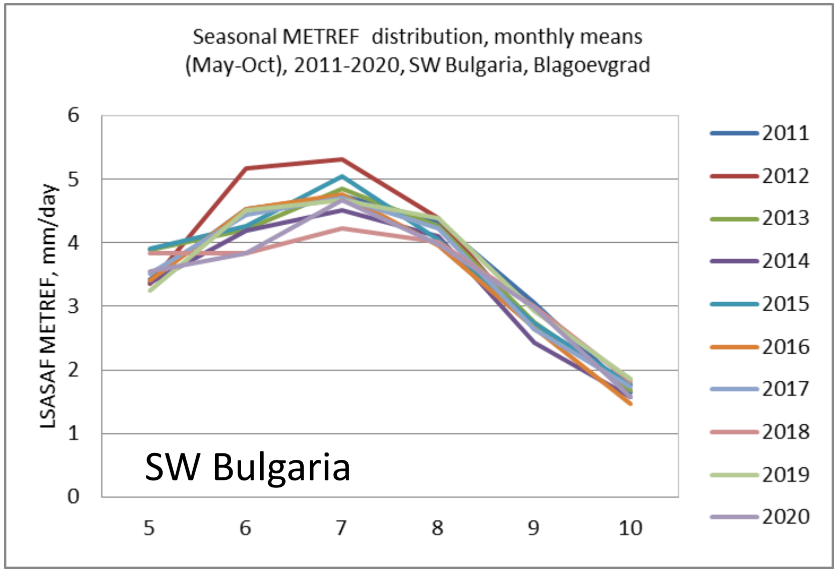
Moisture stress metrics

- Evapotranspiration
  - Evaporative demands, (PET-AET)
  - Evapotranspiration stress index , ESI = (PET-AET)/PET
- Soil Moisture Availability Index (SMAI), SVAT derived
- Land Surface Temperature, LSA SAF LST/ (LSASAFLST-T2)

Potential evapotranspiration concept & LSASAF METREF







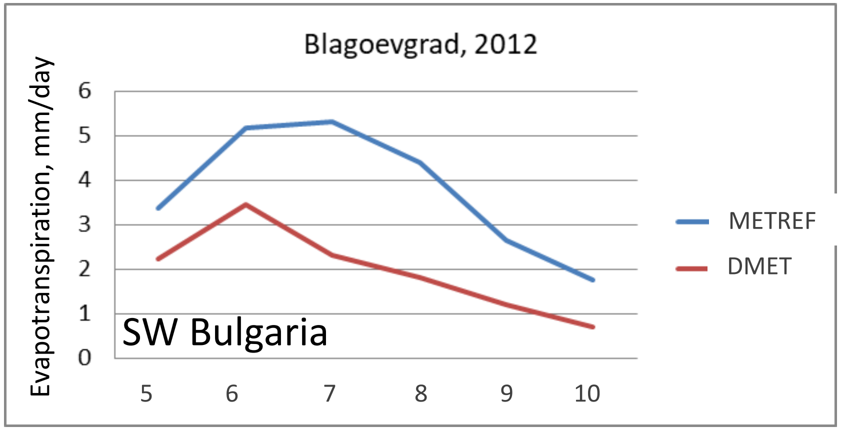
Time series of atmosphere evaporative demands on a mean monthly basis (May-Oct) for different regional climate environment/ years are presented.

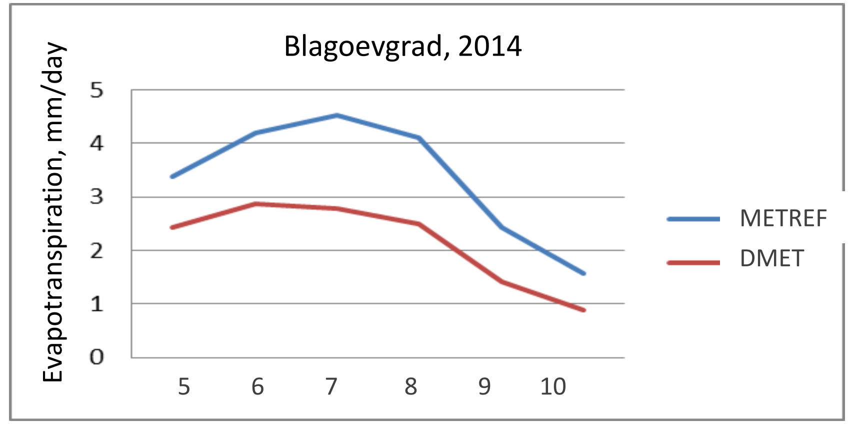
- There is a similarity in METREF course over different regions, with a maximum in July.
- Depending on microclimate, altitude, exposition there are differences in potential evapotranspiration that needs of further research.
- Extremes in METREF for 2012 and 2014 due to high positive/negative temperature anomalies respectively.

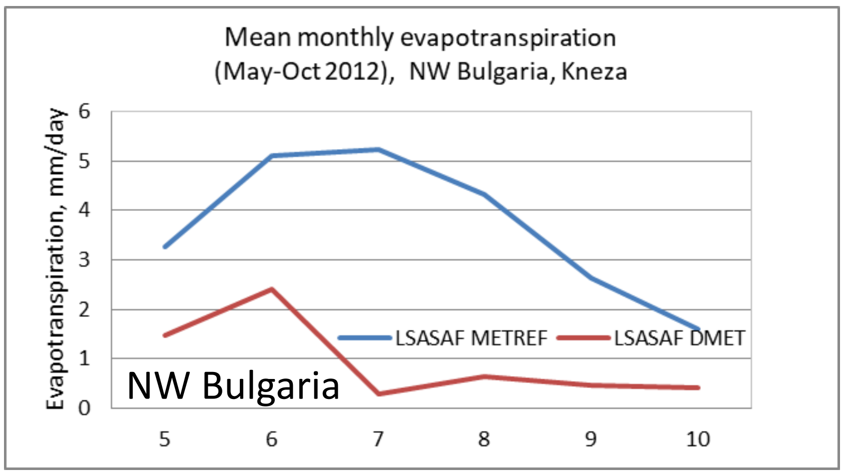
Comparison between LASAF METREF & DMET seasonal course

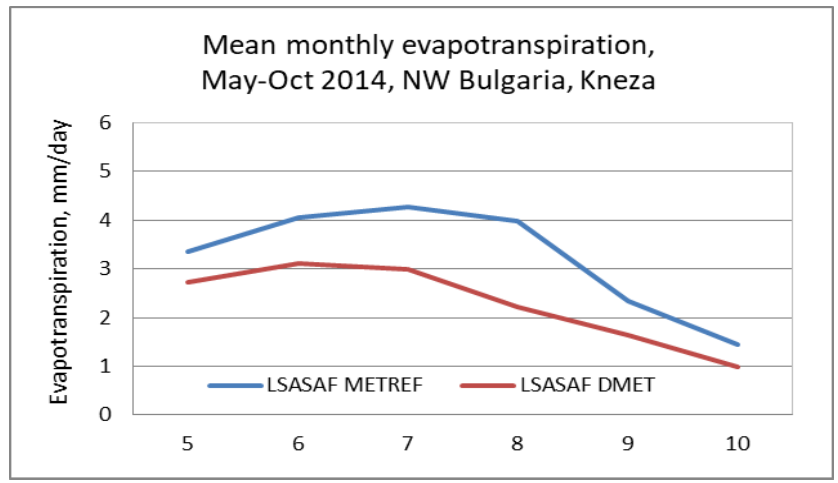
Dry year 2012

Wet year 2014







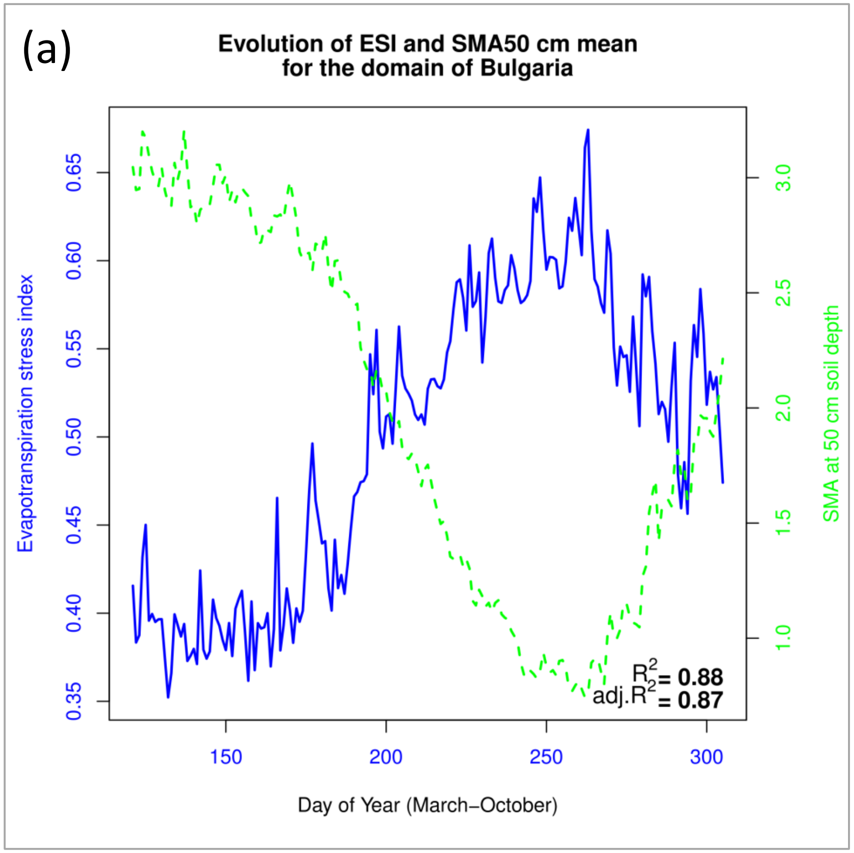


The difference between PET and AET is greater in ‘dry’ years

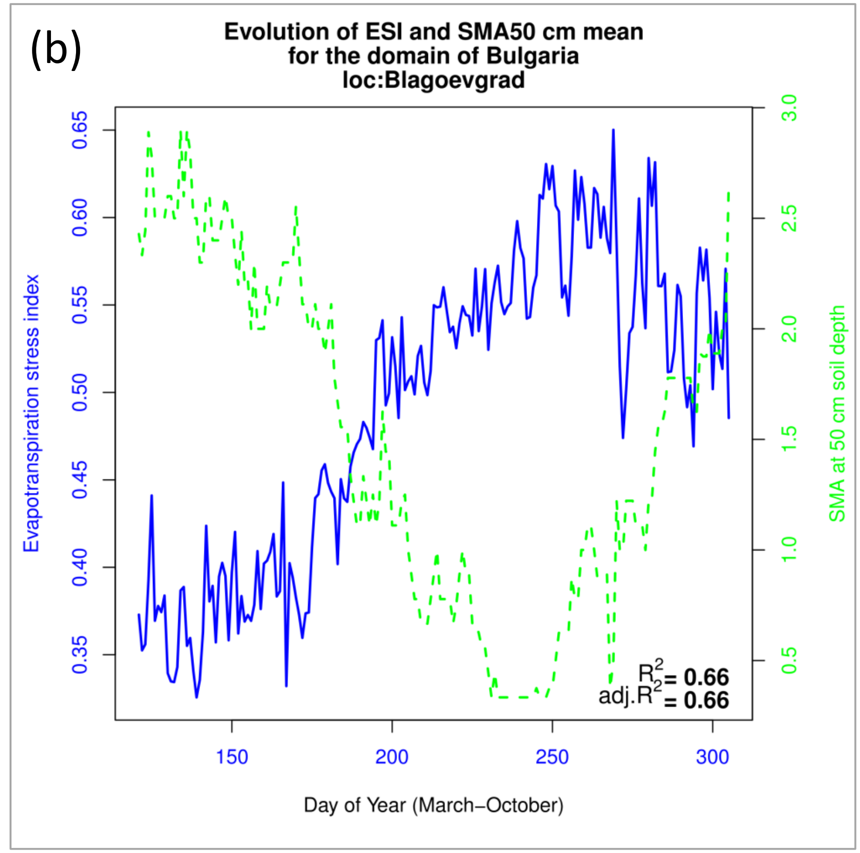
- (PET-AET) as a measure of drought
- Examples for different microclimates

Evapotranspiration & Soil Moisture Relations

Time series (May-Oct) of ESI and SMAI



Monthly mean values from 26 stations in Bulgaria, 2011–2020.

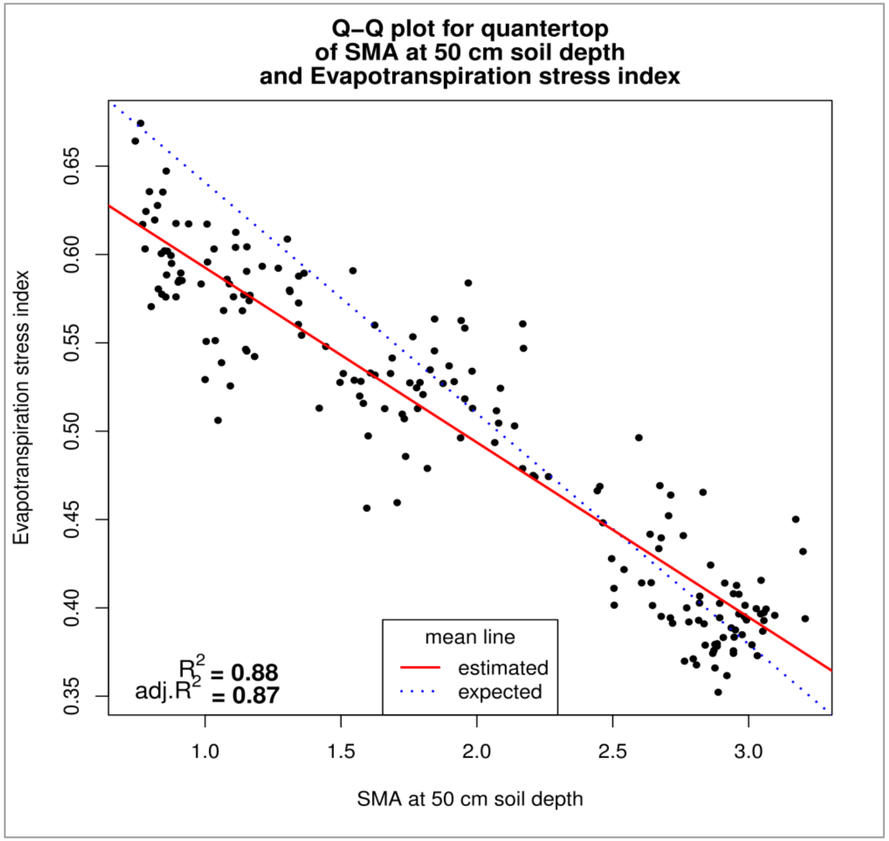


Monthly mean values from single Synop station Blagoevgrad, SW Bulgaria, 2011–2020.

- There is an opposite seasonal course (May-October) for the ESI and SMAI.
  - At high SMAI (high soil moisture content), the ESI has low values
  - At low SMAI (low soil moisture content), the ESI is high due to low AET values.
- High positive correlation of correspondence is observed for: (a) the whole Bulgaria; (b) specific sites.

Q-Q (quantile-quantile) plot of monthly means between ESI and SMAI

Evapotranspiration Stress Index, ESI & SMAI relation



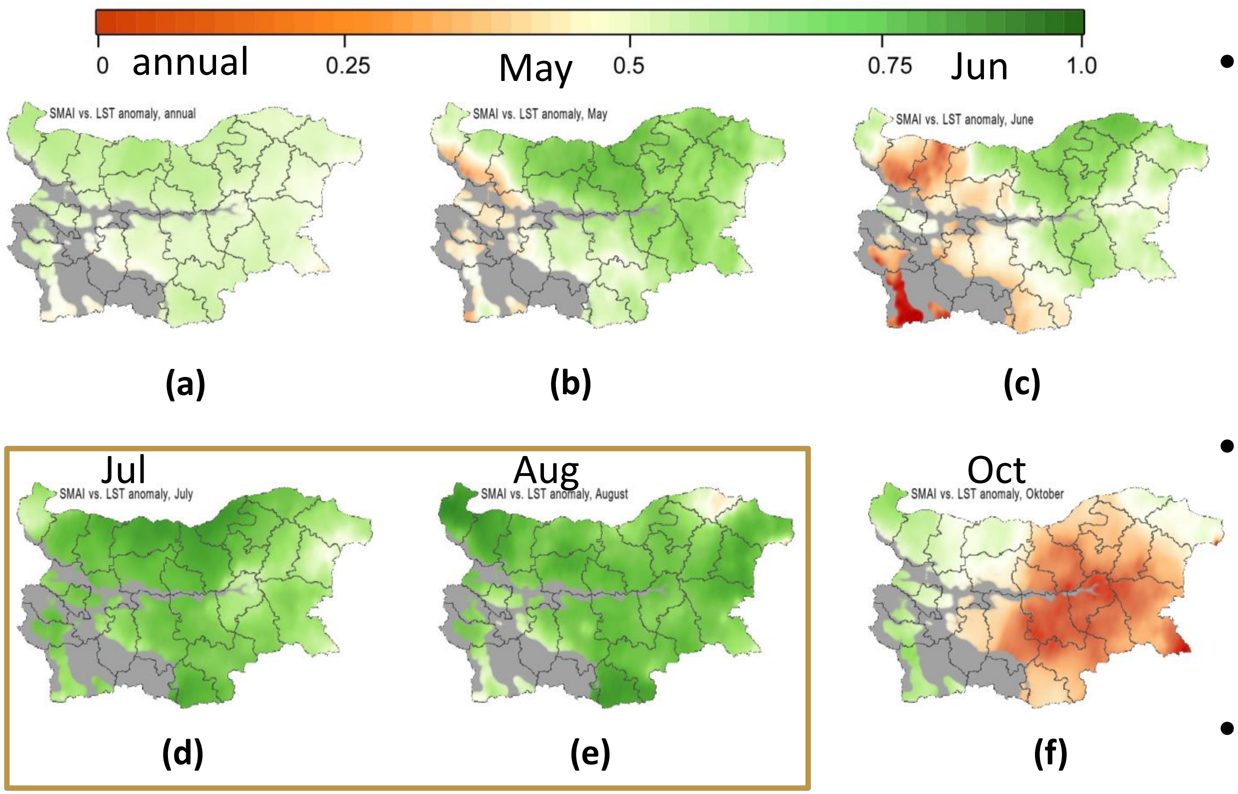
Q–Q plot comparing the distributions of Evapotranspiration Stress Index and SMAI at 26 stations in Bulgaria, May-October (2011-2020).

Q-Q (quantile-quantile) probability plot of monthly means ESI and SMAI distribution:

- The Q-Q distributions are linearly related
- The curve pattern suppose that ESI increase with a bit delay towards the decreasing of SMAI.
- The high correlation coefficient of the probability plot indicates a high level of agreement of a fitted distribution of SMAI towards ESI and related level of water stress.
- The data cover the period 2011–2020, monthly mean values.

LSASAF LST utility to characterize spatial-temporal variability of dry land surface state anomalies

Spatial variability of correlation between SMAI and LST anomalies



Spatial distribution over Bulgaria of correlation between the monthly mean anomalies of root zone SMAI and LSASAF LST (MSG retrieval) for: **(a)** whole growing season; **(b)** May; **(c)** June; **(d)** July; **(e)** August; **(f)** October. Anomalies are calculated towards (2007-2018) period. Mountain regions above 800 m altitude are excluded with a mask.

- On a mean annual bases **(a)** the increasing dry SMA anomalies are related to increase of land surface temperature anomalies. The color map indicates correlations above moderate, r = -0.45.
- A strong correlation between the anomalies of the two indexes in July and August **(d), (e)** (coefficients mostly around --0.8, maximum -0.84).
- The behavior of LST closely corresponds to the drought severity as indicated by SMAI for the whole country, **the lower SMAI, the higher LST**.

Stoyanova et al., 2019

B. Quality monitoring of LSASAF evapotranspiration products

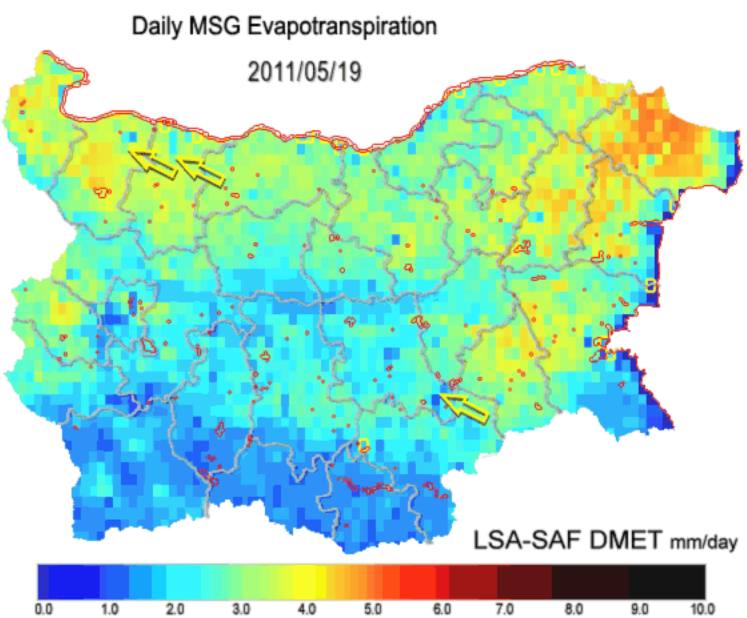
Questions?

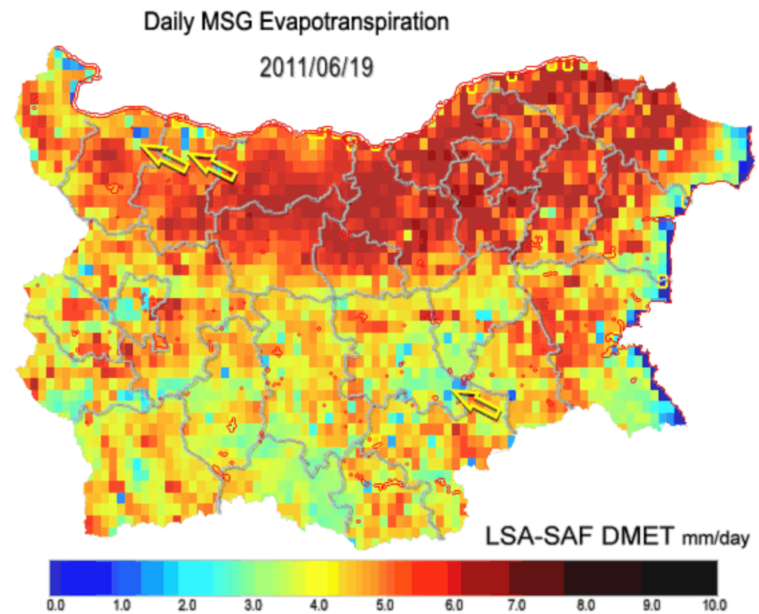
1. Some gaps in LSASAF DMET
2. LSASAF DMET-METREF visualization

LSASAF DMET Quality monitoring

Example 1: SAF Europe files, LSASAF DMET May, June 2011

HDF5_LSASAF_MSG_DMET_Euro_201105190000 - 201105250000
HDF5_LSASAF_MSG_DMET_Euro_201106190000 - 201106250000

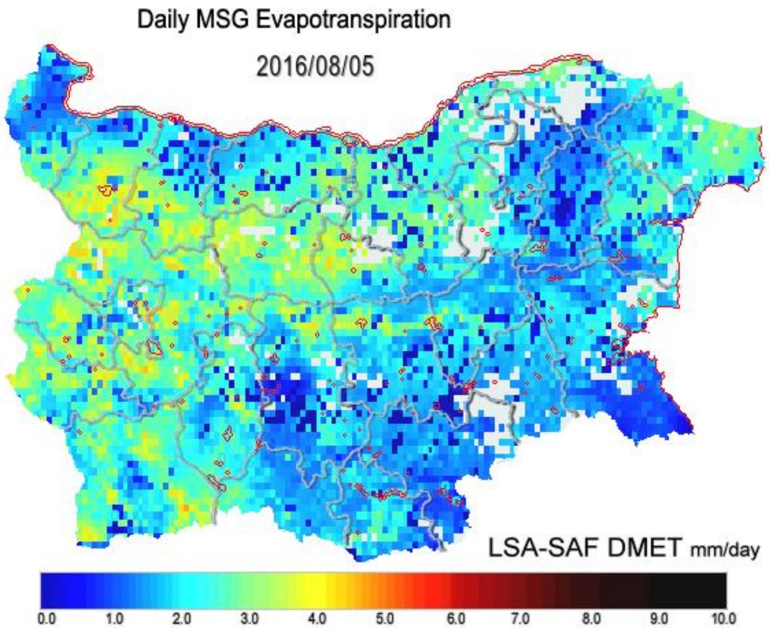




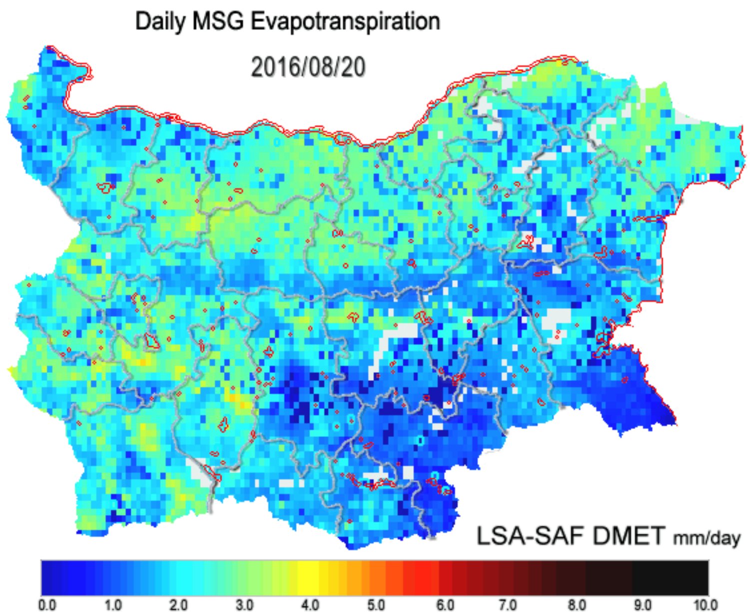
- In May, Jun DMET is still undisturbed
- Arrows indicate persistant locations with missing DMET values ?
- Red circes indicate the water basins

Example 2: MSG-Disk files, LSASAF DMET Aug 2016
(*since 2016 DMET product*)

HDF5_LSASAF_MSG_DMET_MSG-Disk_201608050000



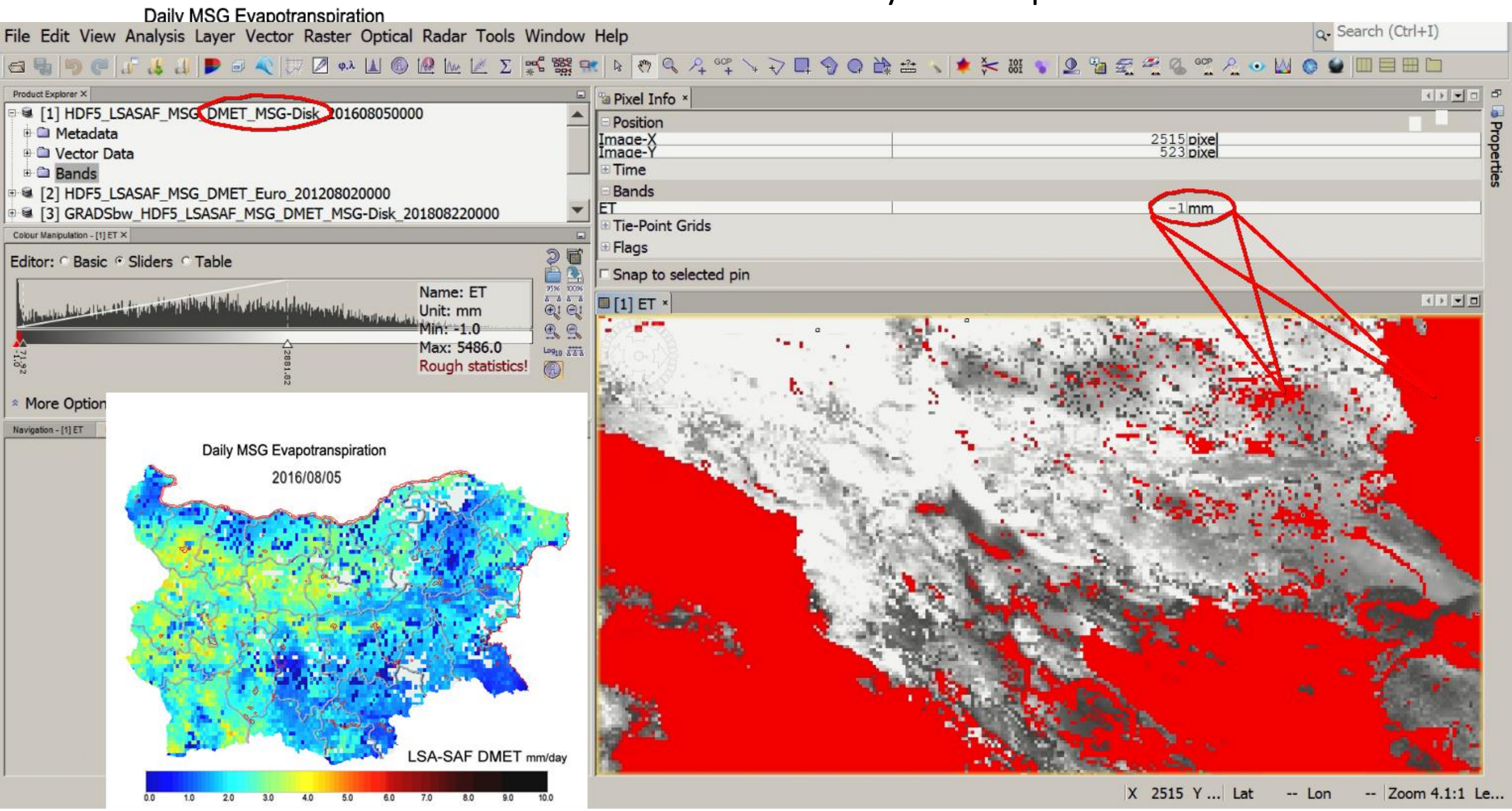
HDF5_LSASAF_MSG_DMET_MSG-Disk_
201608200000 - 201608250000



- Red circes indicate the water basins
- In Aug DMET shows lower values
- Water basins are indicated by ‘-1‘ in meta data
- In MSG-Disk files appers to have more spots with missing values (white spots) on the land surface (not coinsistent with water bodies)
- The white spots are appear on different places from day to day?

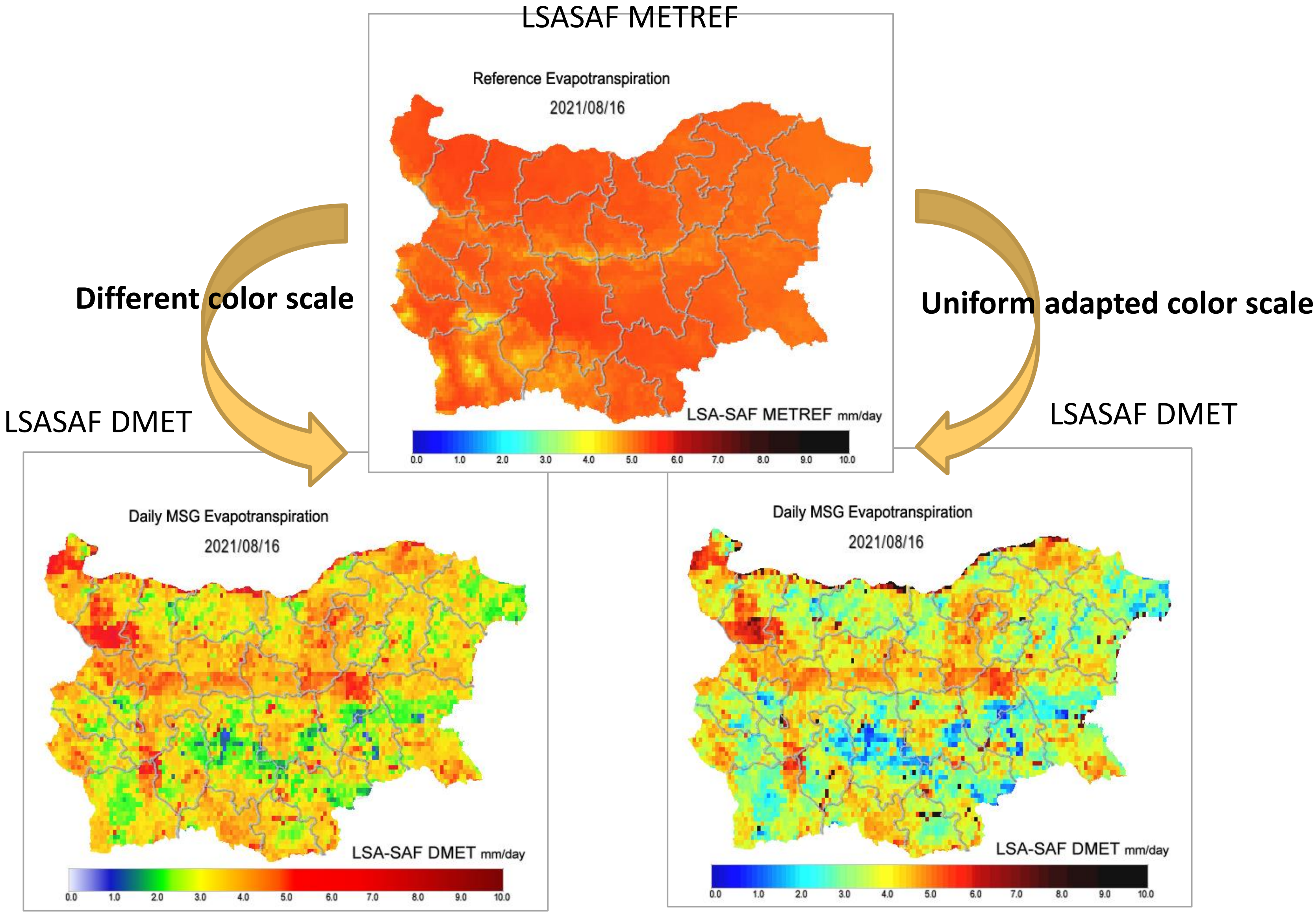
HDF5_LSASAF_MSG_DMET_MSG-Disk_201608050000

- White spots correspond to missing values, i.e. '-1' as seen by the metadata and here illustrated by the red points?



LSASAF DMET & METREF visualization

Question: Should the visualization of LSASAF DMET & METREF be synchronized ?



C. Drought & Vegetation Monitoring Satellite Applications

- ❑ Drought & Crop Productivity (Yield)
- ❑ Drought & Forest health

❑ Drought effect on crop yield production

Work Concept

Biogeochemical nature of Yield

→ *Potential productivity (crop yield)*

→ *Specific climatic bioenergetic resources*

↔

Yield ≡ Accumulated solar energy = f(Dissipated energy like heat, Φ)

Entropy production in canopy leaves Φ (*in terms of thermodynamics)* is introduced as a complex biophysical state parameter that can reflect the climatic resources and vegetation capacity to accumulate solar energy in biochemical energy (responsible for growth and yield production) at specific site environment.

1) Energetic efficiency of ecosystem functioning at climate gradient: Functional coupling between Biogeophysical and Biogeochemical cycles.
   - Biogeophysical cycle is the signature of functioning of the ecosystems as open thermodynamic systems through mass- and energy- exchange at the specific site environment (soil, climate, topography, etc.)
   - It is the **cause** for the intensity/efficiency of biogeochemical processes at molecular level (**as a consequence**).
2) Meaning & Significance of Entropy production in canopy leaves **(Φ)**
   - A parameter of thermodynamic description of ecosystem functioning *(Surface-boundary approach in biothermodynamic)*
   - A measure of the energetic looses in the main photosynthetic apparatus (*canopy leaves*) and thus to be a measure of energetic efficiency of ecosystem functioning.

Entropy production as a measure of energetic efficiency of ecosystem functioning

Entropy production in canopy leaves as a complex indicator of hydrothermal environmental conditions and the state of main photosynthetic apparatus (leaves) during the growing season is a function of:

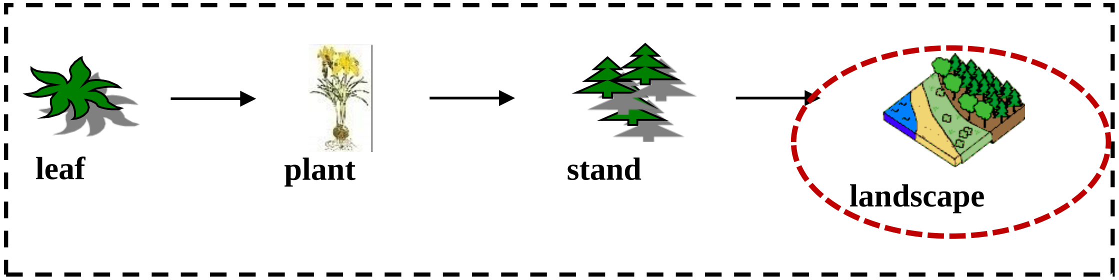
- Meteorological parameters
- Geophysical parameters
- Soil hydro-physical properties
- Crops phenology

Quantification of entropy production in canopy leaves: **Φ** is a sum of the entropy produced during the heat- and during the water- exchange between leaves and environment (Eq. 1), i.e. during the biogeophysical cycling *(Florov, 1983, 1988; 2002).*

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

Φ - function of disipation; S - entropy production in leaves; E – evapotranspiration rate; H – leaf-air heat exchange rate; T – mean leaf-air absolute temperature; Δ T- leaf-air temperature difference; Δq is the difference between specific air humidity at the transpiring leaf level and the surrounding air, L – latent heat of vaporization of water.

Evaluation is performed from laboratory experiments to environmental conditions.



Experimental design

1) Quantification of thermodynamic indexes assessing the efficiency of ecosystem functioning, i.e:

- Accumulated entropy production Φ in agro ecosystems at SYNOP sites for microclimate/environmental gradient of Eastern Mediterranean (Bulgaria), Eq.(1)
- (LSASAF LST-T2m), temperature difference between land surface temperature LST from Meteosat satellite and air temperature at 2m, used as a first order proxy of Φ at a landscape spatial scale (sensible heat).

2) Comparative analyses and ranking the link between thermodynamic indexes and crop yield (*reference information from measurements*).

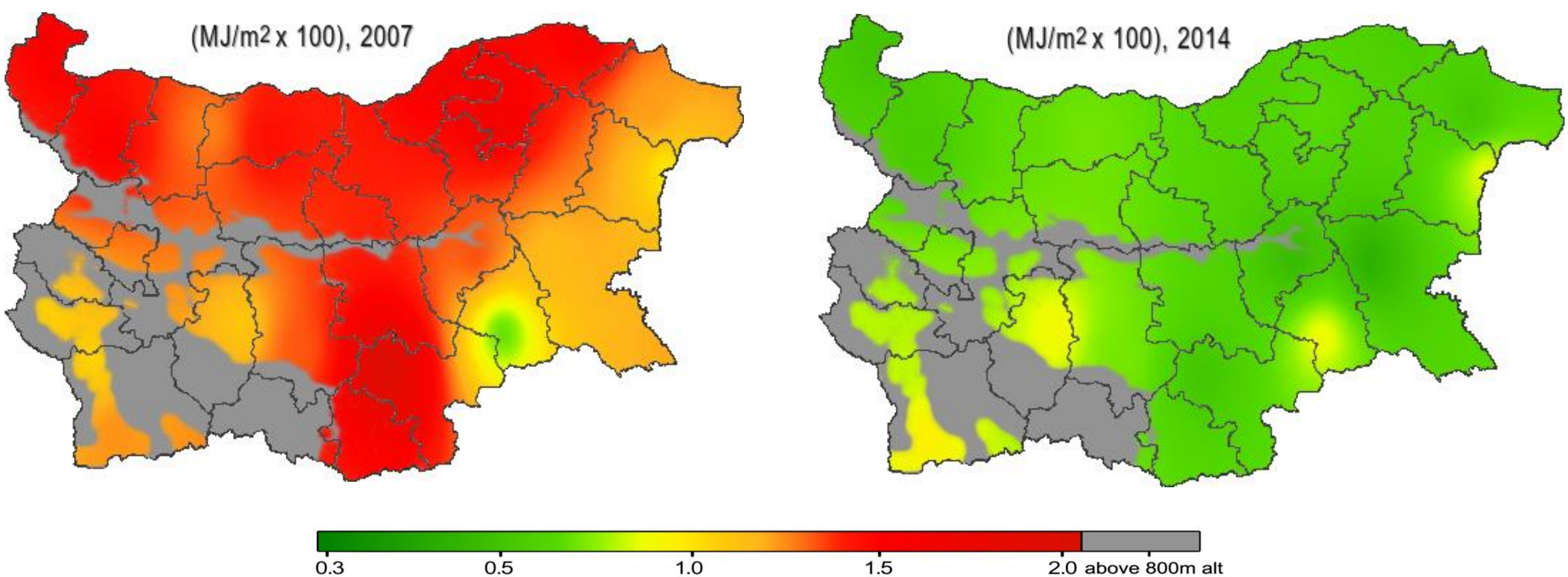
Calculations for growing season 2007-2020, covering the critical for yield formation period of wither wheat field are performed.

Accumulate entropy production in plant canopy, Φ (derived by modeling).

Spatial/interannual variability at different microclimate environment

Dry year/period

Wet year/period



(a) Climatically dry periods in 2007 lead to high Φ values (*orange to red*), while during
(b) wet environment in 2014 Φ has low values (*green*).

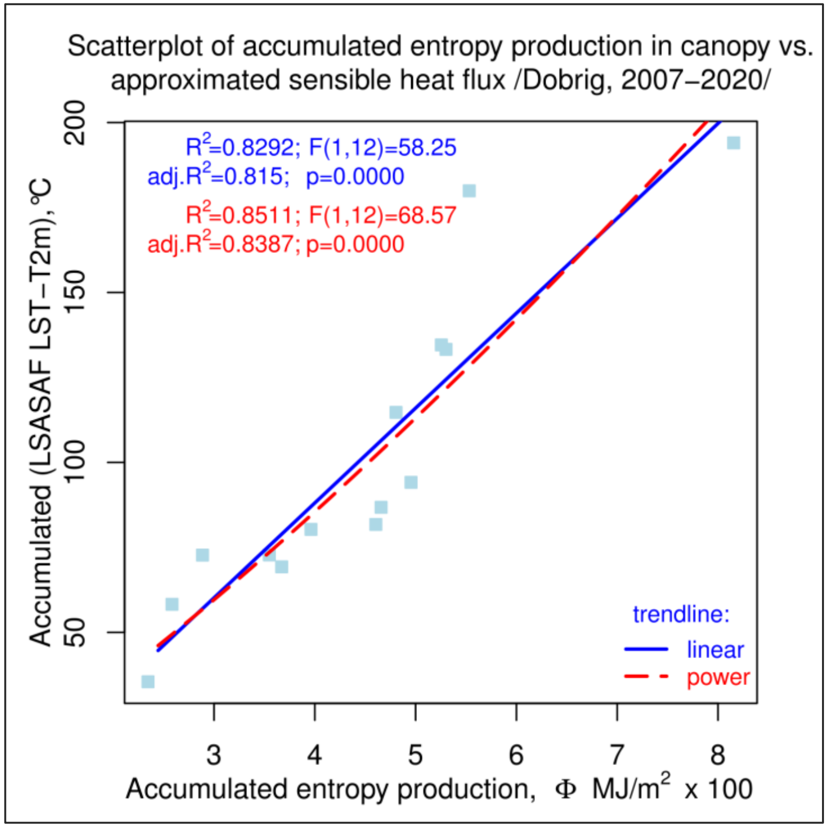
(LSASAF LST-T2m) temperature difference as a first order proxy of Φ

- modeling, Φ vs.
- its first proxy *via* sensible heat flux using MSG information, (LSASAF LST-T2m)

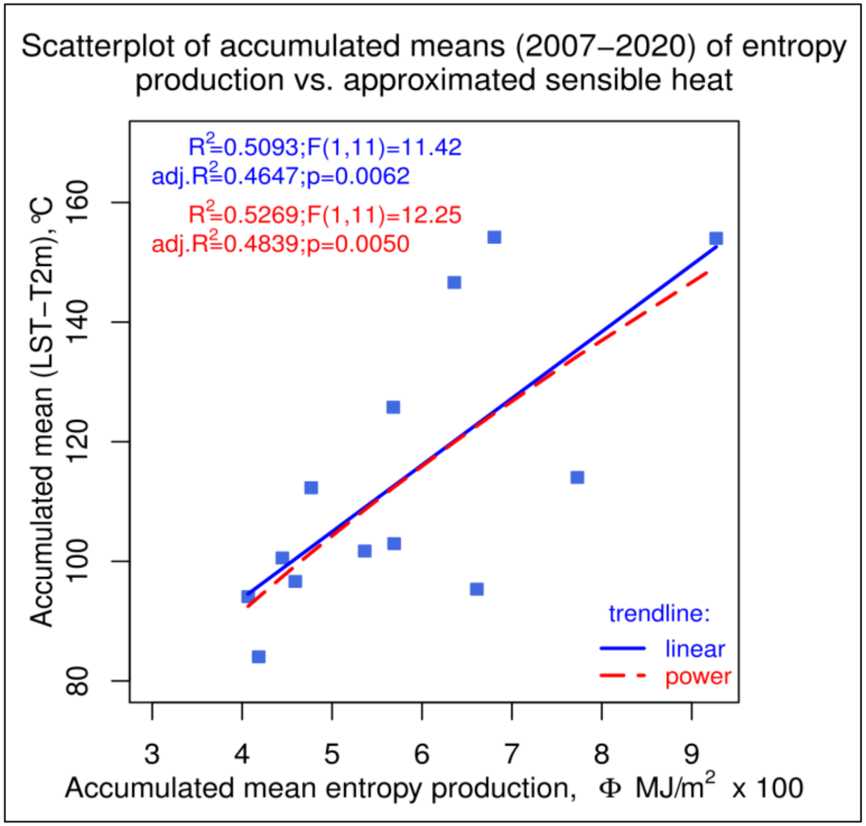
N-Bulgaria, site scale

Bulgaria, regional country level

(a)



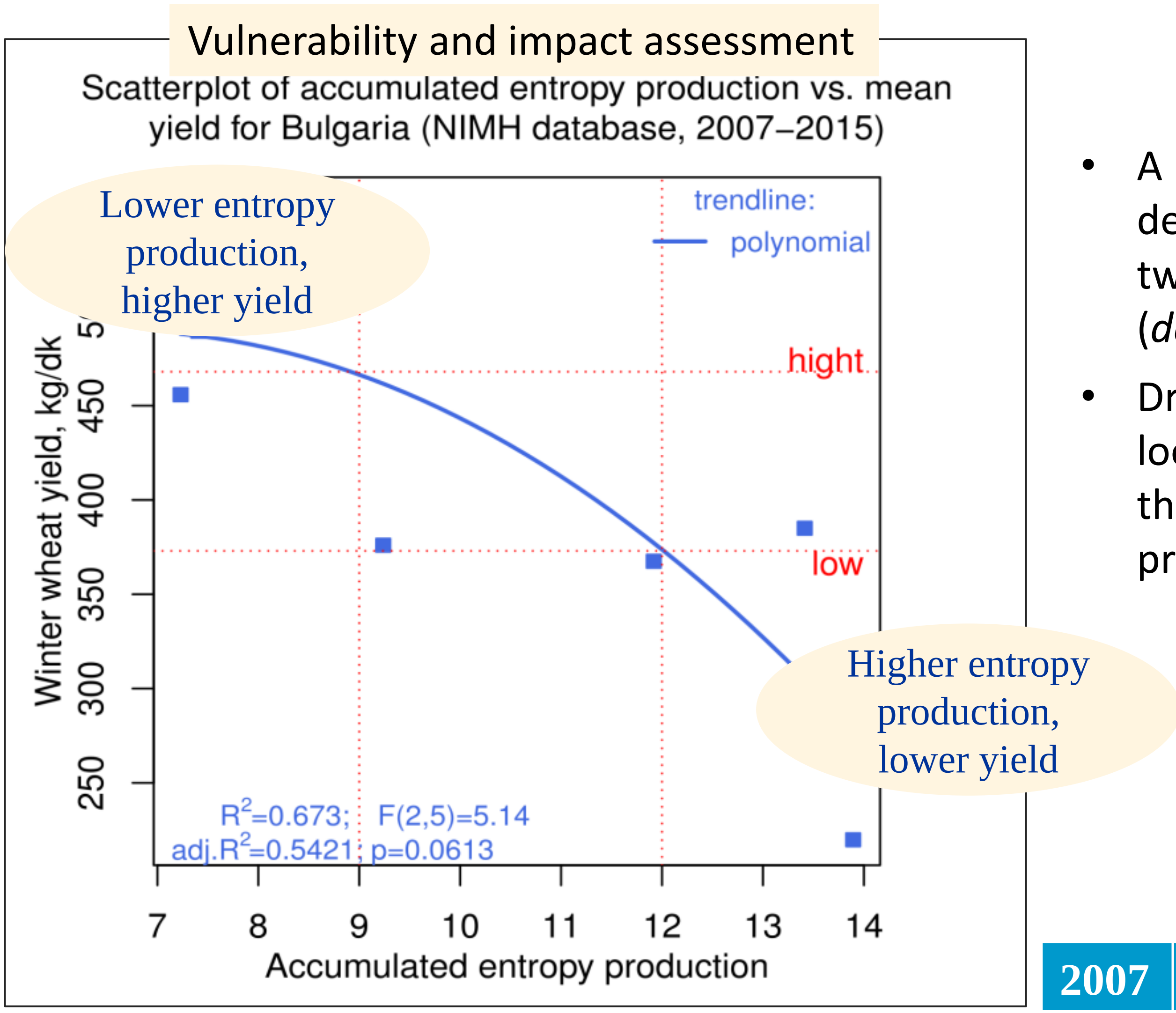
(b)



- There is a strong coincidence between Φ and (LST-T2m) for site scale
- Valid for all separate SYNOP regions

- There is a strong coincidence between Φ and (LST-T2m) for regional (country) level means (2007 - 2020)

Ranking of Φ –Yield relations

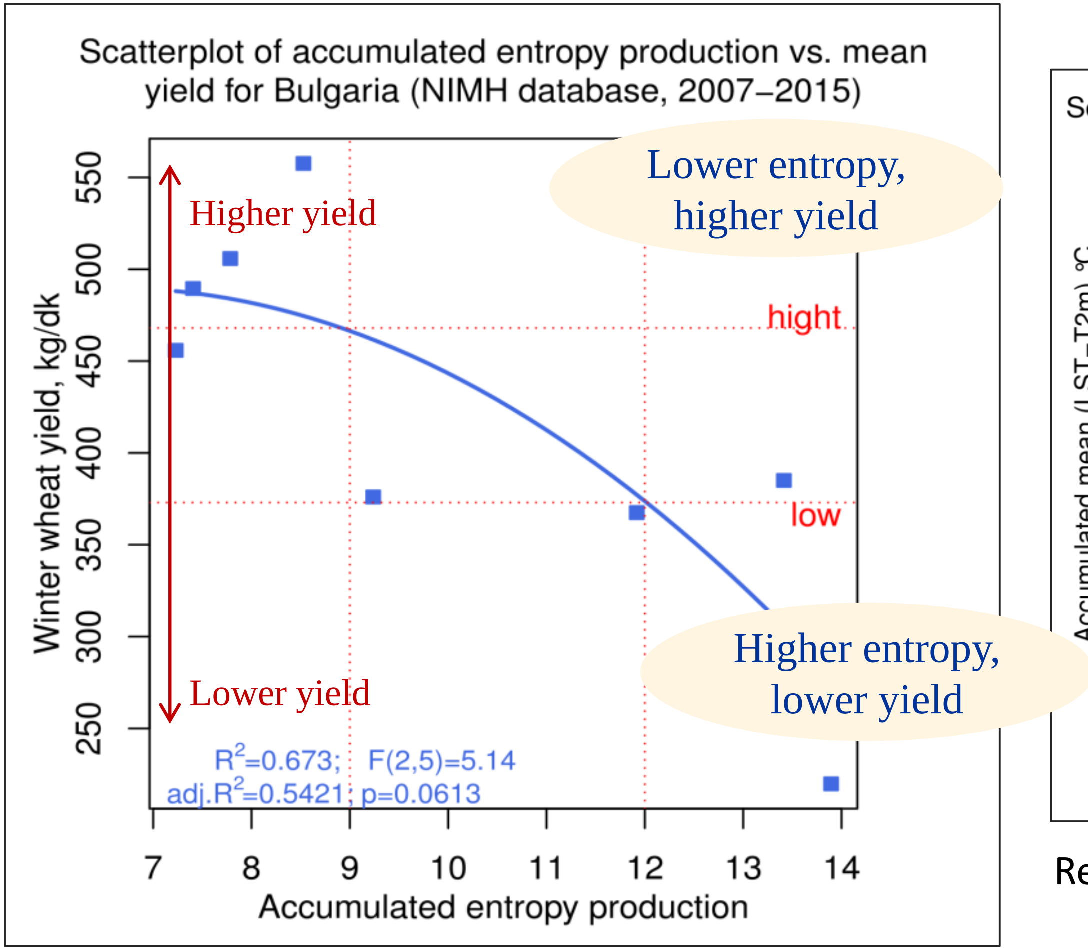


- A polynomial trendline well describes the link between the two parameters: Φ –Yield (*determimed by climate*).
- Drought increases energetic looses (Eq. 1) and decreases the efficincy of metabolic processes and yield.

	2007	2009	2013	2018	2020
High Φ	13.7	13.4	11.9	12.6	12.2
Low/ Intermediate Yield	220	319	450	481	392

Ranking of Φ–Yield relations

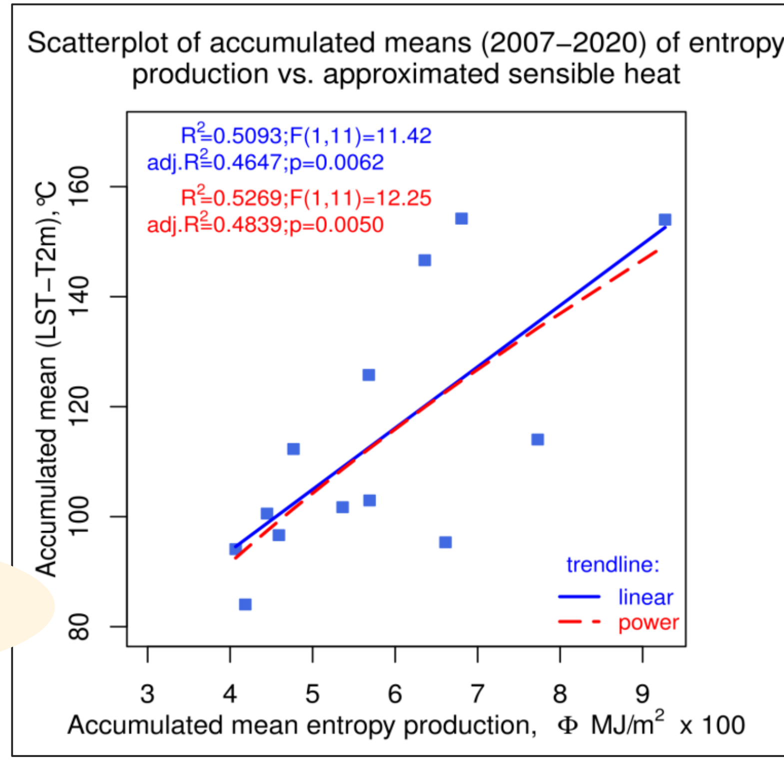
Drought vulnerability and impact assessment



Lower entropy production

Higher entropy production

Scatterplot of Φ vs. (LST-T2m)



Regional (country) level means (2007-2020).

The surface-air temperature difference (LSASAF LST-T2m) can be used a first order proxy of sensible heat flux, respectively Φ.

Drought effect on climatic determined crop yield production

Considering that the carbon cycle is fundamental to life on Earth and it determines the amount of carbon in particular accumulated in yield, the spatial and temporal dynamics of the biogeophysical-biogeochemical interplay at different thermophysical conditions indicates:

- The surface-air temperature difference (LSASAF LST-T2m) might be useful for assessing the climatic potential for crop yield production.
- Satellite information is promising to be used for characterizing yield capacity on a landscape level.
- Further studies on the applicability of the approach at different climate environment would be beneficial.

❑ Drought and disease effects on ecosystem resilience

- The spatial and temporal evolution of forest functioning before,
    - during and
    - after a disease hazard.

are examined using capabilities of Meteosat and the developed on this basis LSA SAF biogeophysical products, compared with independent reference information.

- The concept adopted is applied to capture differential functional response of deseased/water stressed compared with health forest sites.

Application

Conifer forest disease and desiccation, SE Bulgaria

The study concerns a real problem with health disturbance and patch wilting of conifer forests in the lower forest belt in Bulgarian (Eastern Mediterranean) observed during recent decade. A selected region with progressive mass wilting of conifers is tested: conifer forests in Forest Estate Ardino (SE Bulgaria) are influenced by heavy snow conditions in 2015, causing damages of trees. Broken trees are affected by disease (2016, 2017) and start to become dry due to *Corolla infections.*

Photo of affected by disease forest is provided by State Forest Agency, Bulgaria.

It was requested by Executive Forest Agency (EFA) of Bulgaria, NIMH to identify the affected by diseased coniferous forest (*December, 2018*).

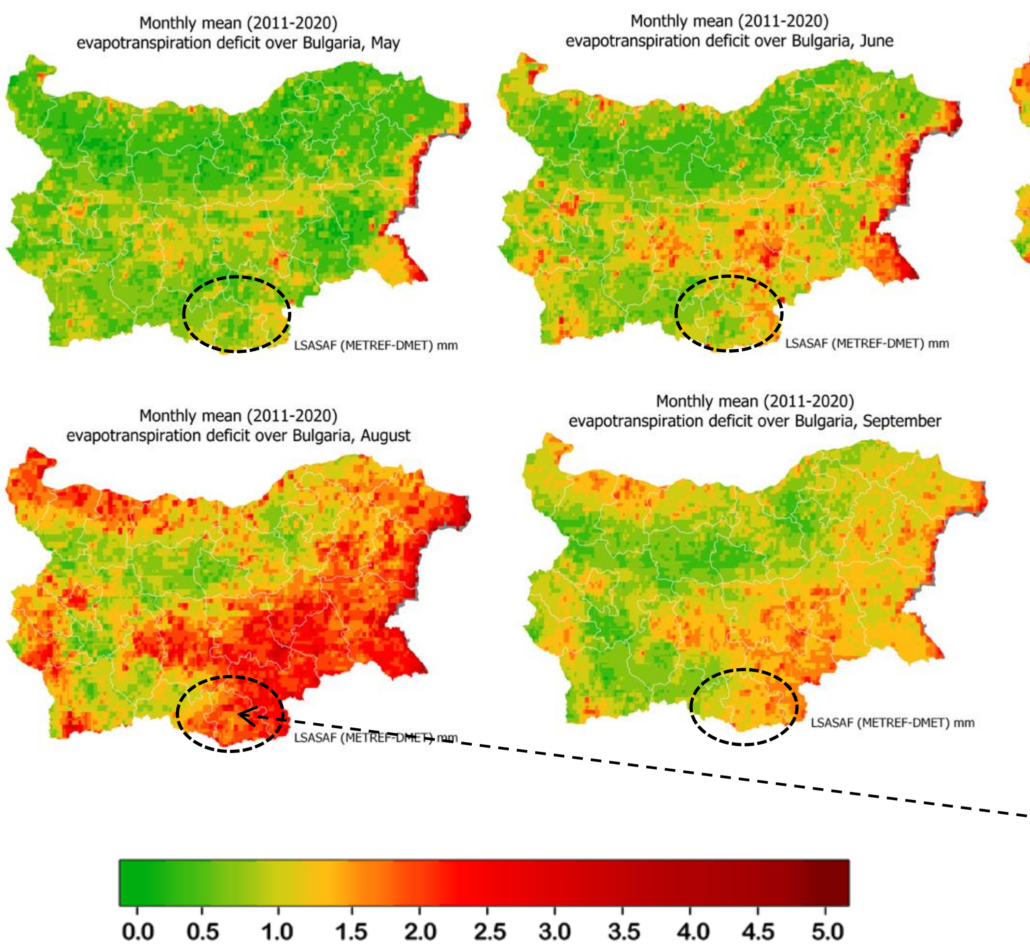
Work concept

- For diagnosis, the Evapotranspiration Stress Index (ESI) is elaborated on the bases of the LSASAF products for daily values of reference PET (METREF) and actual AET (DMET) evapotranspiration.
- Evaluation is based on the:
    - Comparison of the ESI on a site scale for a selected health and ill forest is applied for the whole target region of Ardino.
    - Comparison with alternative satellite information with a higher spatial resolution, The Global Land NDVI 300m from PROBA-V 10-daily synthesis reflectance products generated through VITO (http://proba-v.vgt.vito.be/).
    - Soil Moisture Availability Index (SMAI) dataset

Data source

- (2011-2020) reanalysis data from MSG reprocessing chain, METREF and DMET.
- Map of forests types distribution in Ardino Forest Estate, http://www.procurement.iag.bg:8080/cgi-bin/lup.cgi
- Coordinates of a health forest site and two infected forest sites, provided by EFA, Bulgaria.
- Soil Moisture Availability Index (SMAI) in the root zone (2011-2020) (*from SVAT model*).

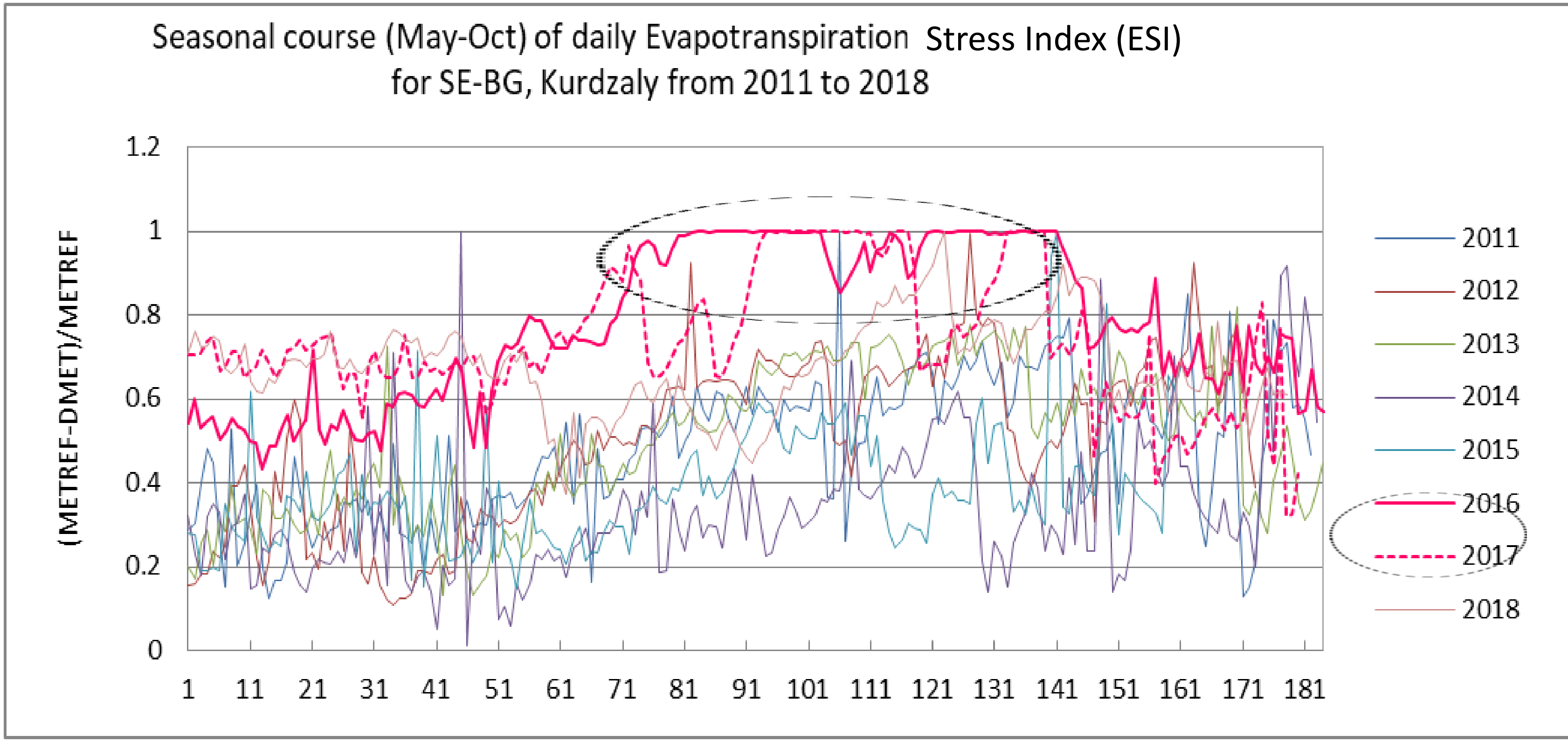
Monthly mean (2011-2020) difference between satellite derived PET and AET over Bulgaria, May-September



(METREF-DMET) maps over Bulgaria

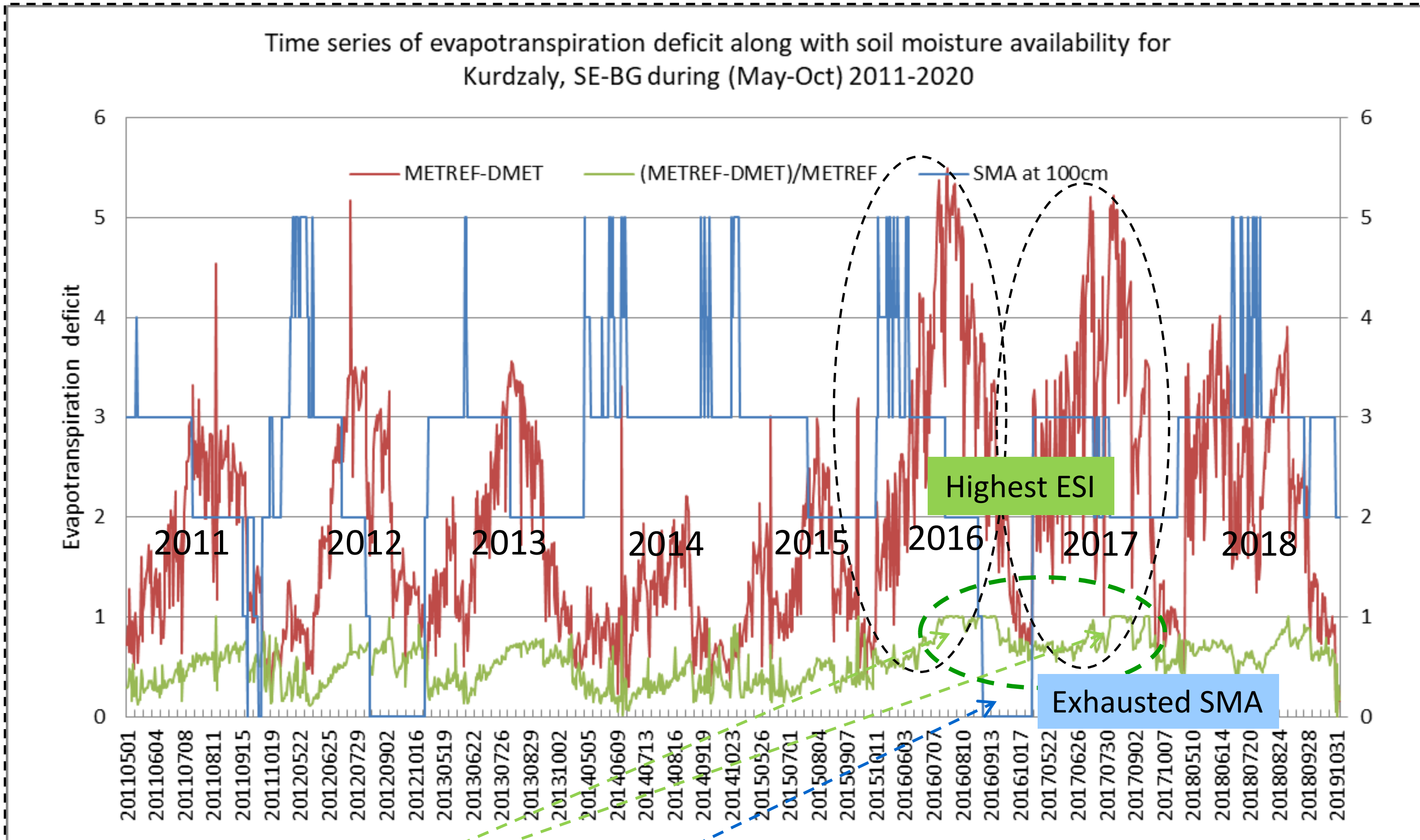
- Target region is one of the regions with highest vegetation water stress.
- The highest descripancy between mean monthly evaporative demands according to LSASAF METREF and actual evapotranspiration according to LSASAF DMET due to SMA shortage is in July and August.

Seasonal course (May-Oct) of Evapotranspiration Stress Index (ESI) for the region of Kurdzaly (Ardino) during 2011-2018, on a daily basis



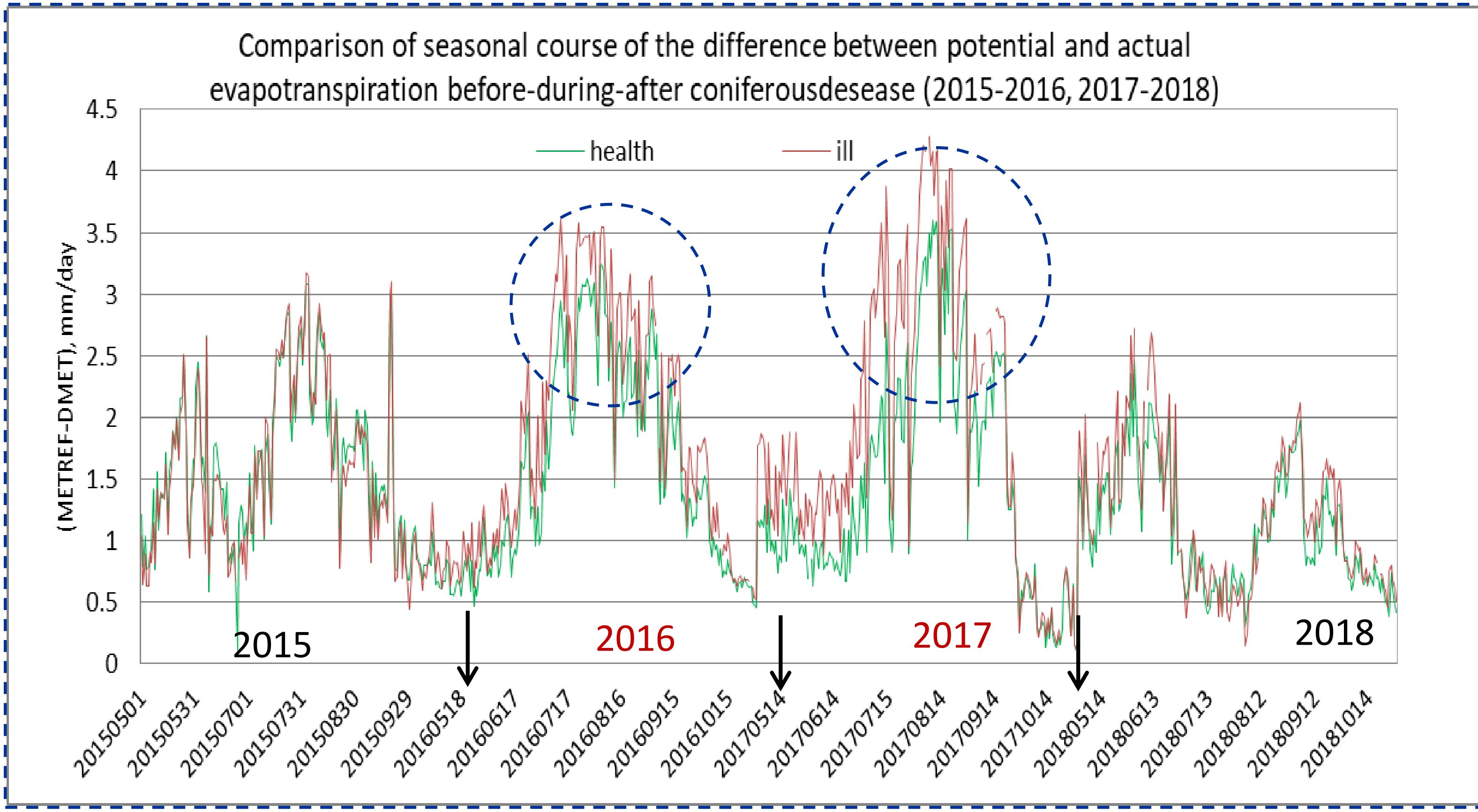
- The highest ESI values are observed usually during Jul and Aug for each one of the tested years (with small exeptions).
- ESI shows highest water stress for 2016, 2017 (Jul, Aug), i.e. during the observed *Corolla infections* attack.
- For 2018, the water stress declines and becomes comparible with other years as indicated by ESI.

Comparison of seasonal courses of:
(METREF-DMET), ESI, and SMAI during 2011-2018



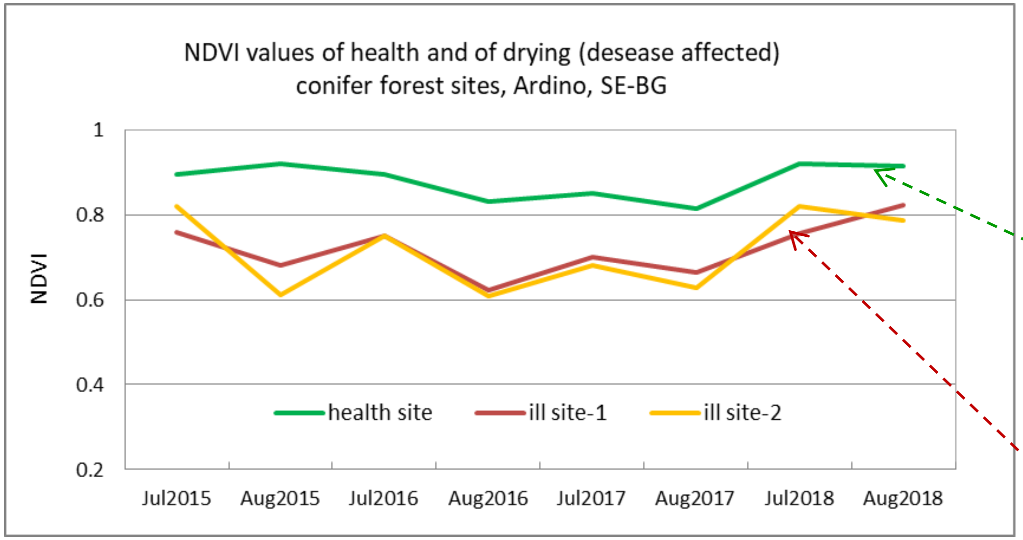
- Higher difference between METREF and DMET corresponds to a higher water stress according ESI, and lower SMA at the root zone.
- Difference between potential and actual evapotranspiration in 2016 and 2017 appears to be highest, ESI is close to 1.0, and SMA is fully exhosted (Jul, Aug).

Time series of (METREF-DMET) at health and ill forest sites before (2015)-during (2016, 2017)-after (2018) conifer forests disease from *Corolla* infection

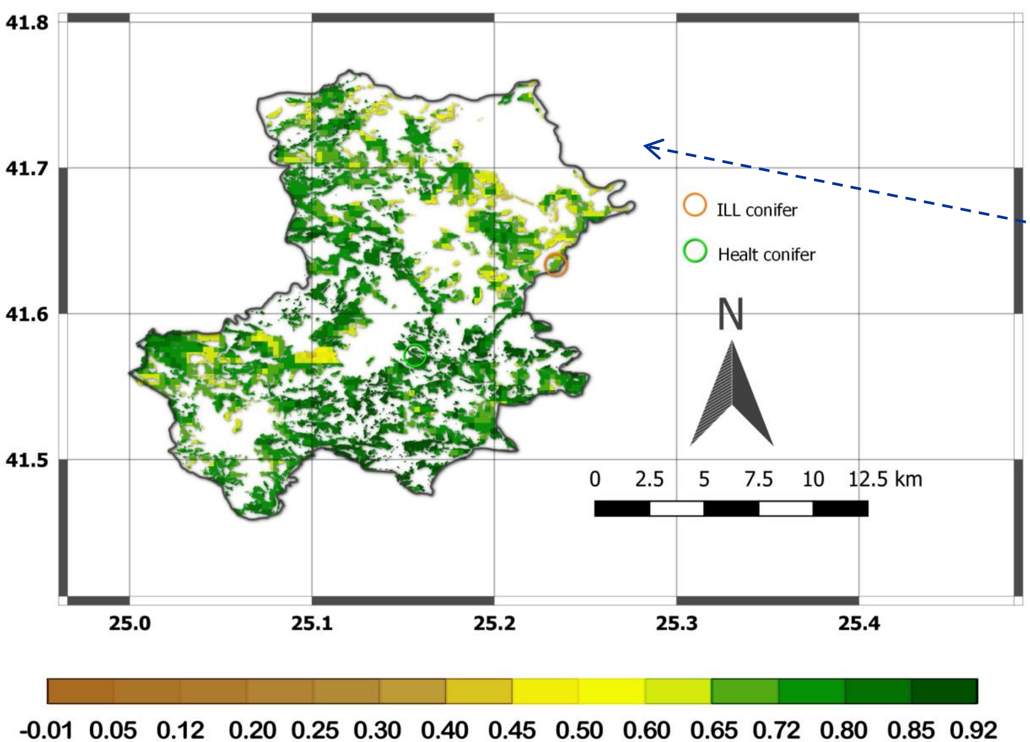


- (METREF–DMET) differences show similar and close courses at health and ill sites before the wilting process (2015) as well as after the wilting process (2018).
- During dry conditions in 2016 and 2017, this difference appears to be higher at the disease affected site.
- In 2018 the difference is gradually recovered after restored water cycle at stand scale.

Evaluation of spatial-temporal distribution of NDVI300m, Proba V

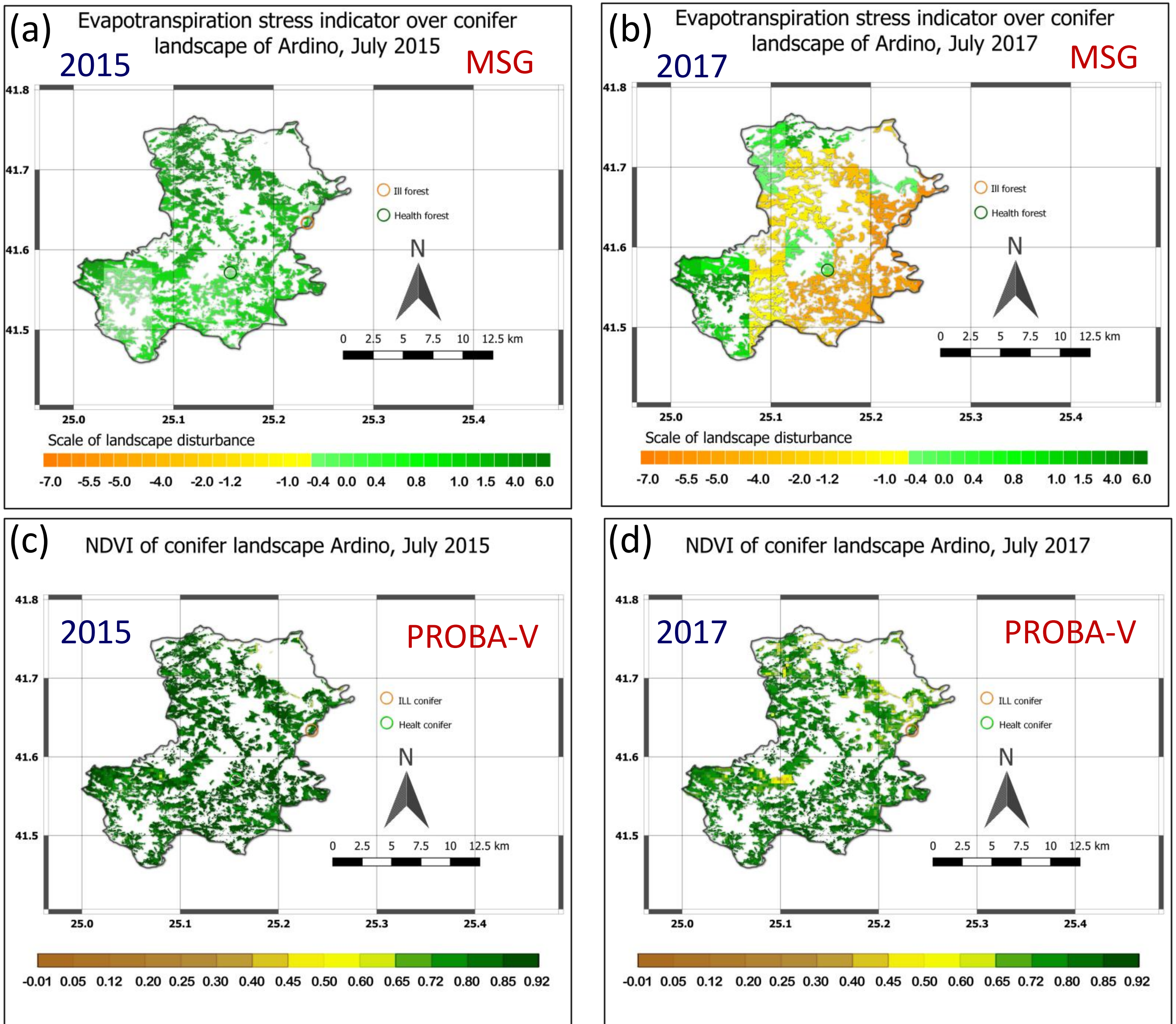


NDVI of conifer landscape Ardino, August 2017



- Healthy vegetation absorbs most of the incident visible light (emitted by the Sun), and reflects a large portion of the near-infrared light.
- Unhealthy (non-green) or sparse vegetation, where the contribution of the soil dominates the signal, reflects more visible light and less near-infrared light.
- This difference in reflectance for different wavelengths, allows remote sensing instruments **to measure the vulnerability of a forest site to drought driven disease.**

Spatial distribution of ESI and NDVI300m over Ardino before (July 2015) and after disease (July 2017)



Although different spatial resolution of MSG and Proba V, comparison between ESI and NDVI indicates:

- In July 2015 both indexes (a) and (c) are ‘green’, non disturbed forest cover.
- In July 2017 both indexes (b) and (d) indicate for spatial distribution of water stress/illness related with forest cover desiccation.

There is typically a decline in the vegetation functioning subsequent to persistent ecological water deficit for a certain period of time.

Drought & Forest health

The analyses of georeferenced satellite information MSG (ESI) and PROBA-V (NDVI300m) can capture signals of **combined effect from ecological drought and disturbances by *Cofolla* infection**, both leading to water stress and related forest cover desiccation.

- Using satellite information, analyses confirm differential response to water stress of conifers in health and infected areas.
- ESI constructed on the bases of Meteosat dataset can be used as an effective index for assessing water use disturbances and their monitoring in forested landscape.
- The impacts of drought-disease disturbances are confirmed by using higher spatiotemporal resolution remotely sensed data of NDVI300m from PROBA V environmental satellite.