Estimation and forecast of winter wheat yield in Hungary using Direct Broadcast MODIS data

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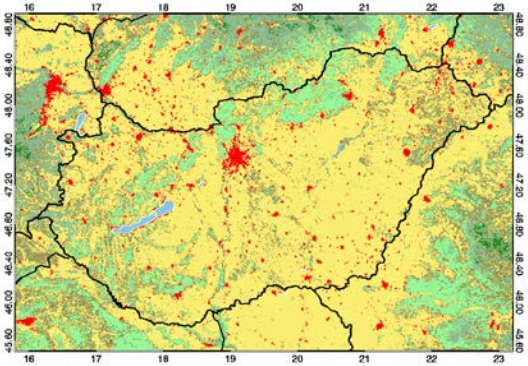
Winter wheat in Hungary

- One of the **most important crop** in Hungary
- Area: on ~11.000 km^2
  = ~25% of the entire agricultural areas
- Production: 3-6 million tons/year (2000-2015)
  = ~40% of the cereals
- Yield: 4-5 tons/ha, which is **strongly affected by the extreme weather events**
- Effecting also the market and the export
- **Relationship between spectral properties** of plant species **and their yield** do exist (*Tucker et al., 1980*)
- Yield estimation procedures has a wide range for the different agricultural plants



MCD12 Land cover - Hungary

Mean temperature:
~10°C

Mean precipitation:
~500-700 mm

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The applied winter wheat estimation method

→ Our aim was to develop a yield estimation method, which is:

- **simple** and **easily adaptive,**
- based only on remotely sensed **daily MODIS data** (preferable DB data to be independent),
- **robust**: does not require either meteorological, biophysical or agronomical input parameters, **neither the location of the cultivated** fields of the given agricultural plants (small parcels!),
- **using only land cover** information (MOD12) and **official yield** data,
- taking advantage of the daily data (in contrast to the temporal composite datasets (eg. MOD13/MYD13)),
- appropriate for **forecasting** as well.

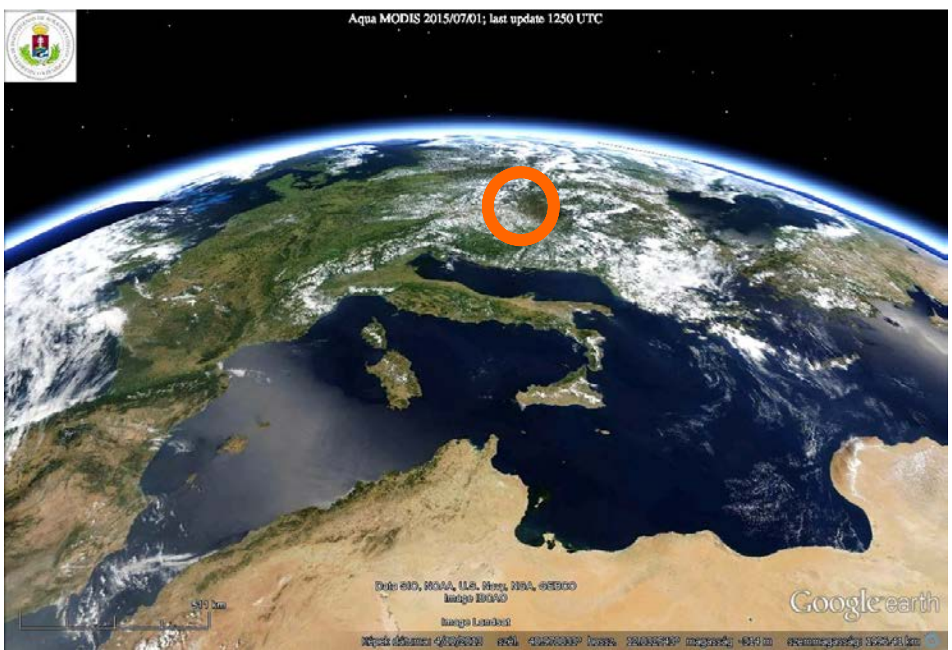
The HRPT - MODIS receiving station at Budapest

Foundation: **2002**

Location: Eötvös Loránd University, Budapest, Hungary

Received data:

- data of self-build satellite sensors (onboard Chibis and Relec) measuring electromagnetic waves of the magnetosphere
- NOAA HRPT, FY CHRPT, Direct Broadcast **MODIS data** (since 2004)

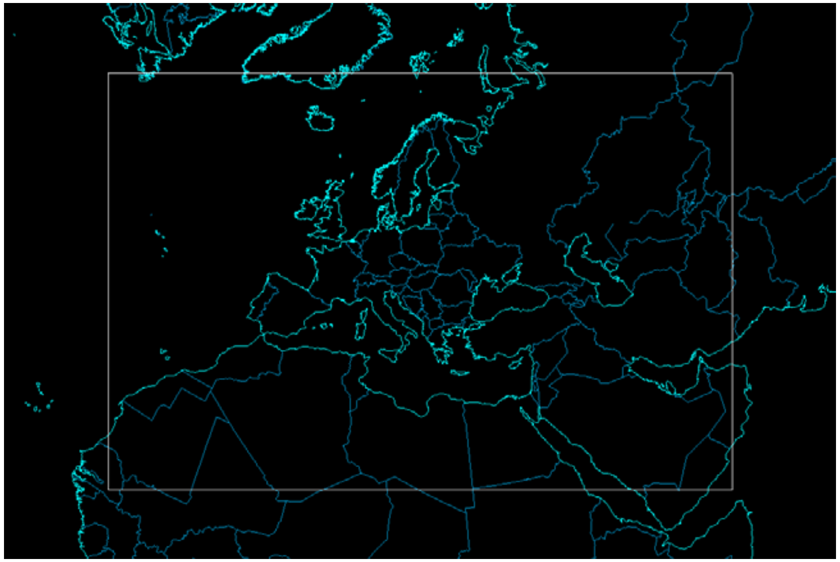


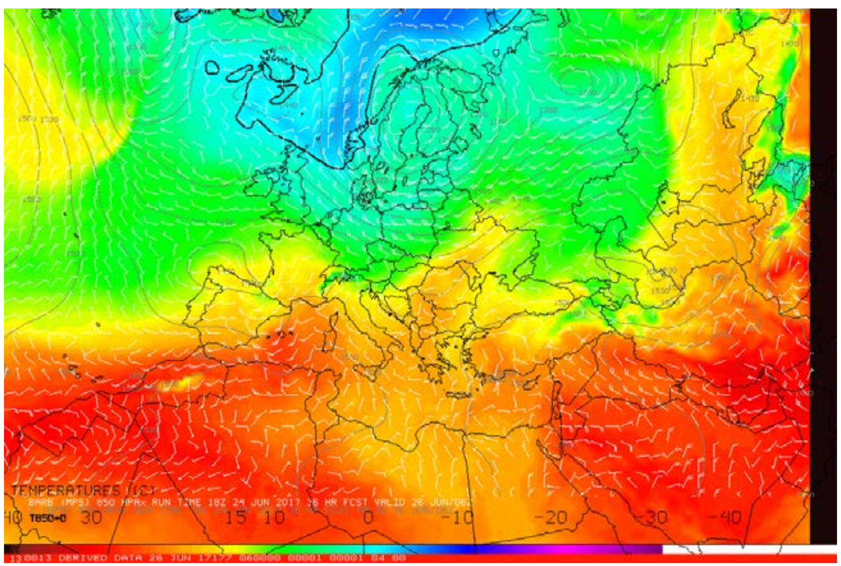
Automatic real-time processing chain for the DB MODIS data

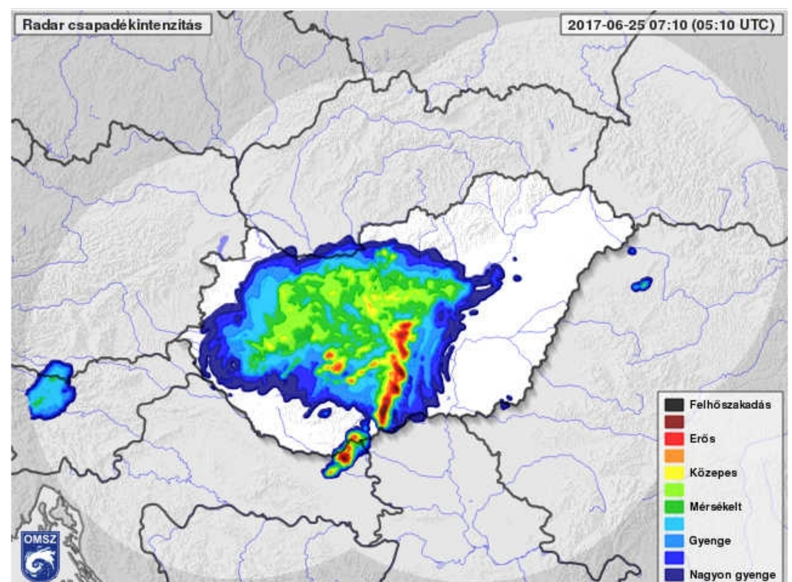
The applied MODIS related software:

(1) SeaDAS MODIS Level1DB Software Package (v1.8) → OCSSW
(2) MODIS Destripe Direct Broadcast Software
(3) IMAPP MODIS Level2 (v3.0)
(4) DBCRAS numerical weather prediction software
(5) + Nested DBCRAS
(6)
(7)
(8)
(9)
(10)

(4-5) DBCRAS & NDBCRAS – since 2009

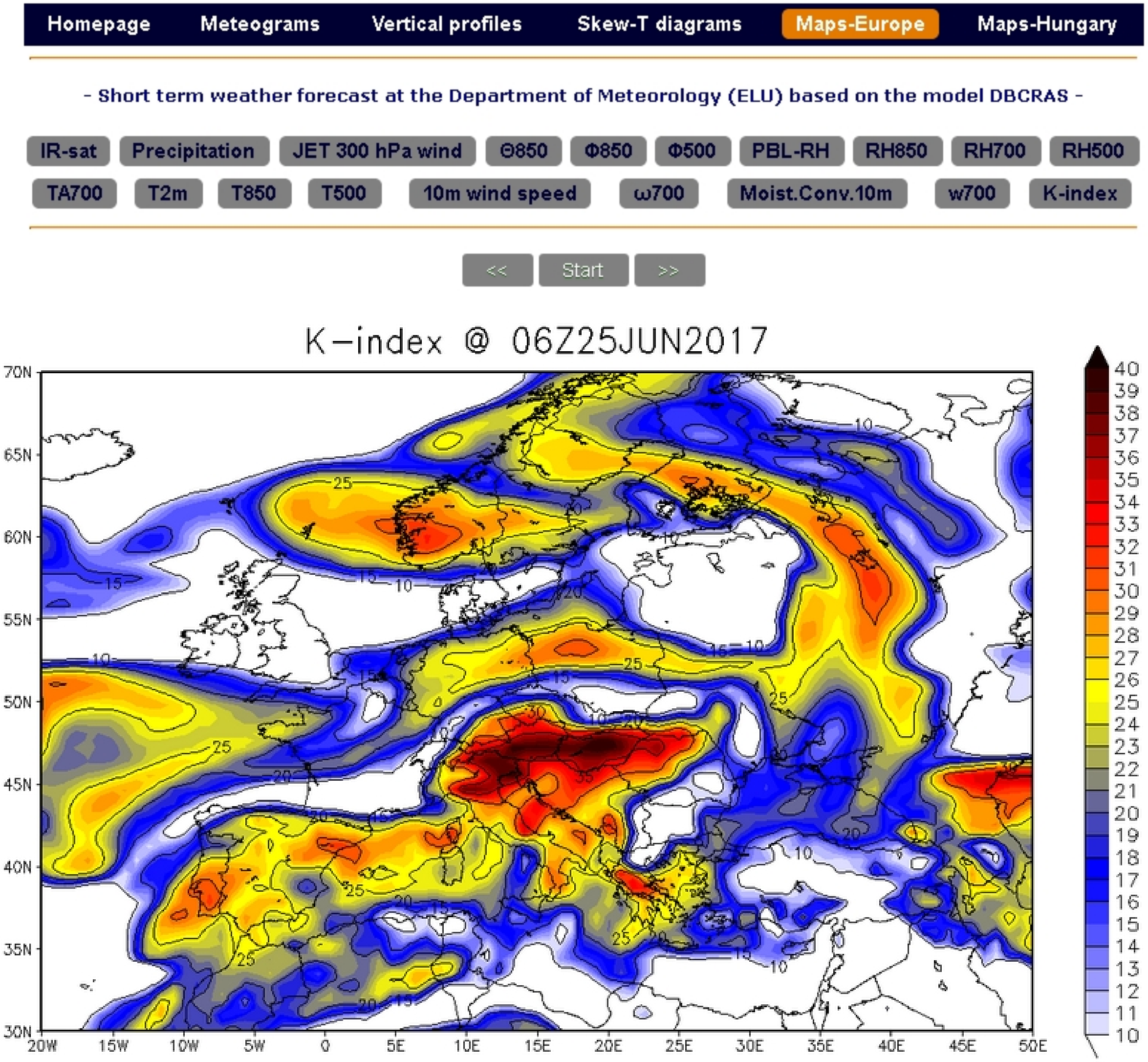






http://nimbus.elte.hu/kutatas/sat/dbcras-en.html

(4-5) DBCRAS & NDBCRAS



http://nimbus.elte.hu/~cras/

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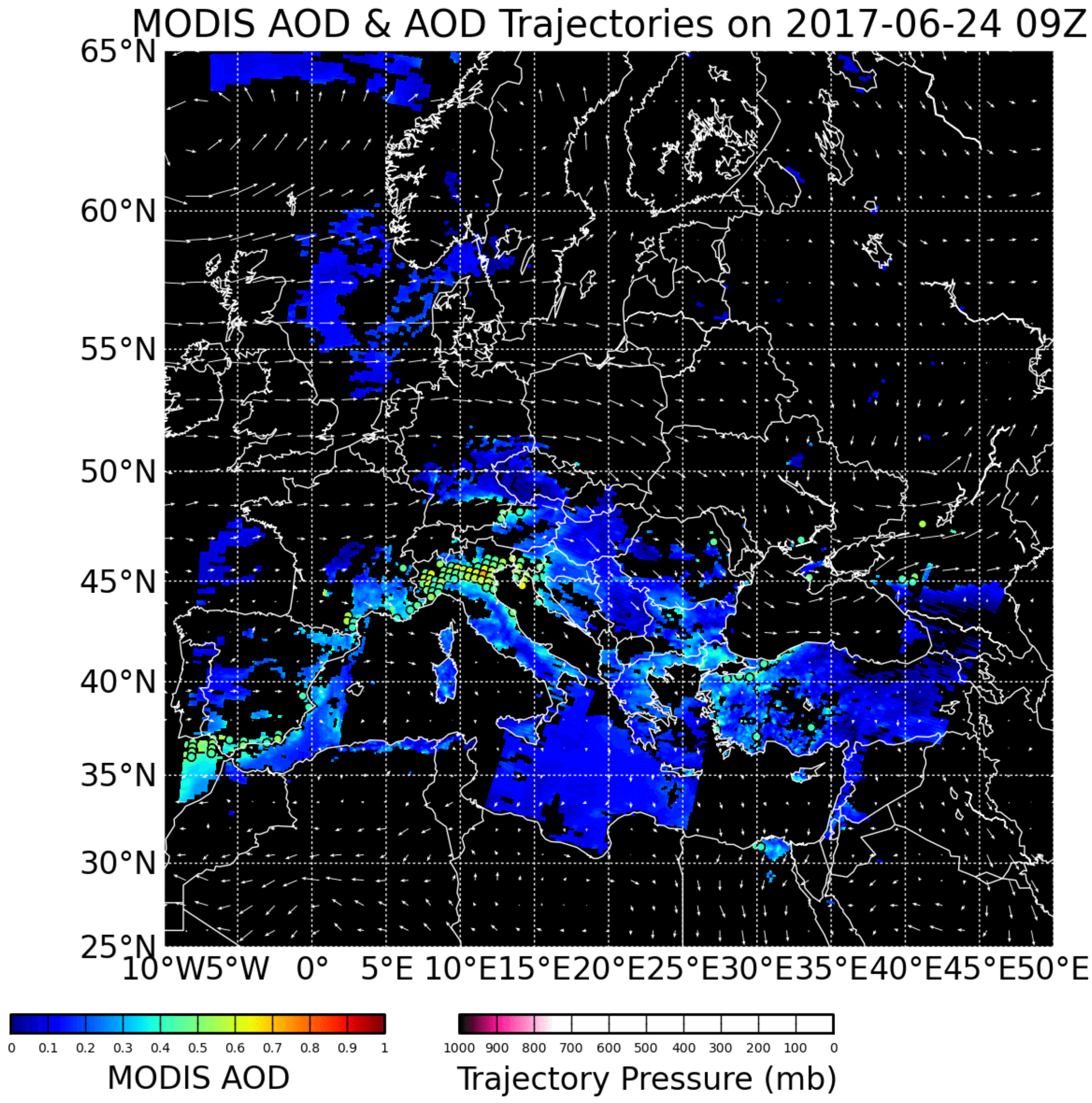
(6) IDEA-I air quality forecast (v1.1)
(7)
(8)
(9)
(10)

(6) IDEA-I – since 2009



http://nimbus.elte.hu/kutatas/sat/idea-en.pl

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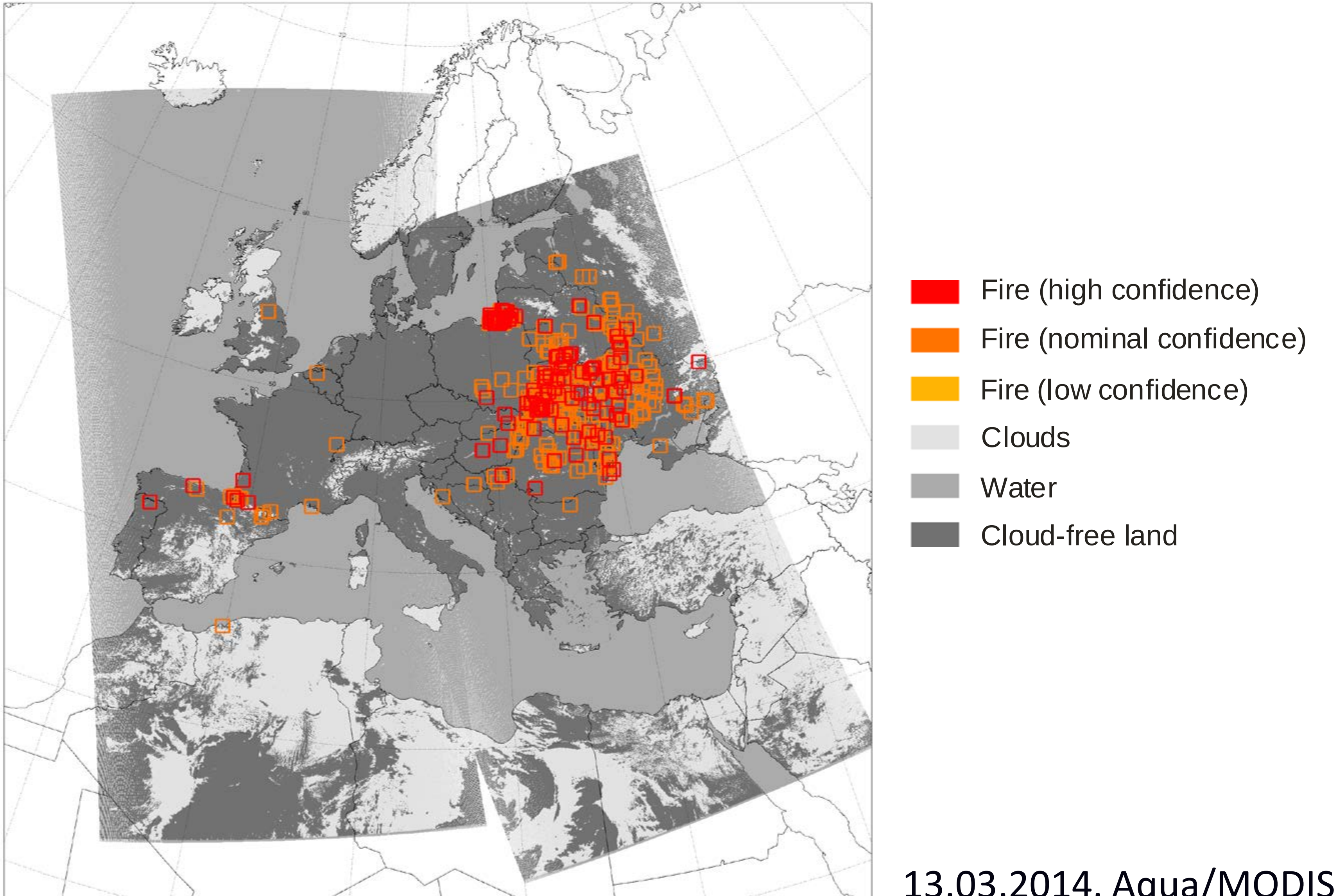
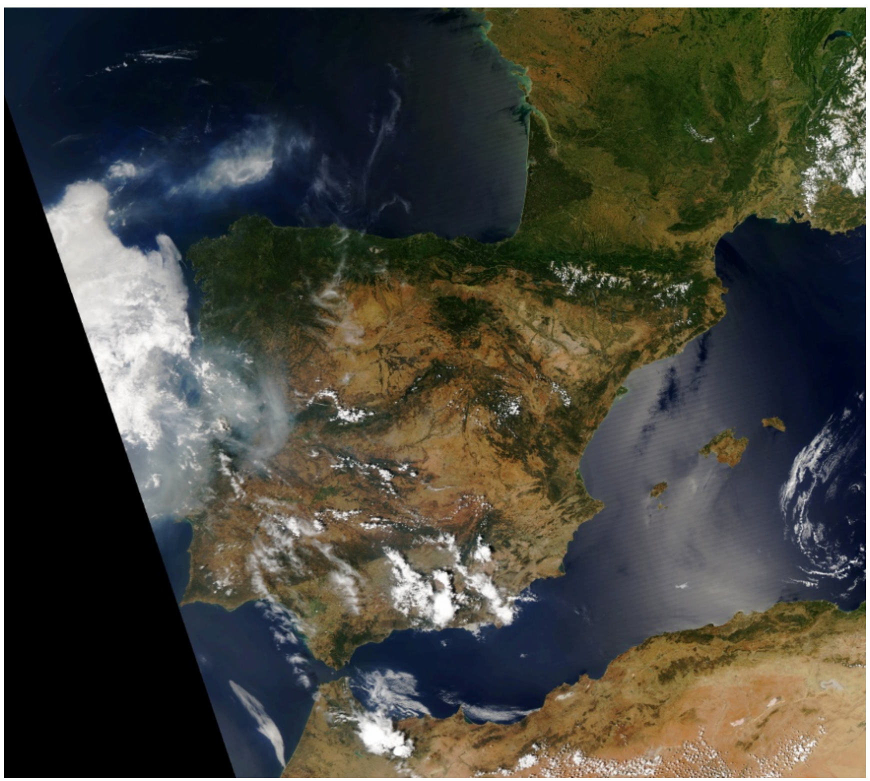
(8)
(9)
(10)

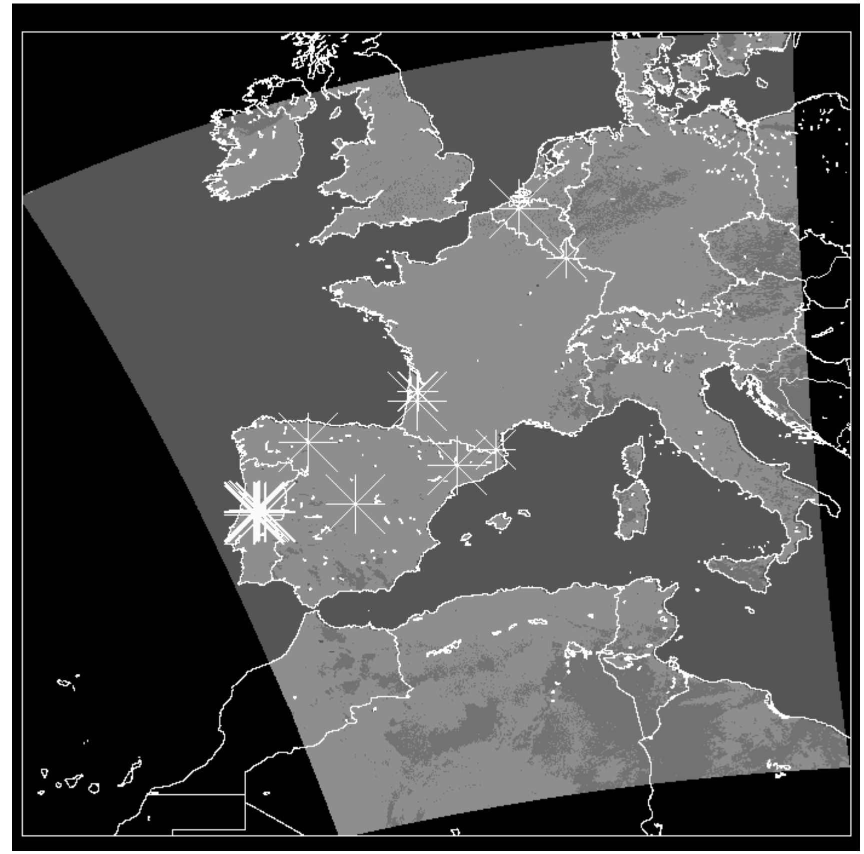
(7) MOD14 – Id. of thermal anomalies – since 2009



13.03.2014. Aqua/MODIS

(7) MOD14 – Id. of thermal anomalies – since 2009





18.06.2017. Aqua/MODIS

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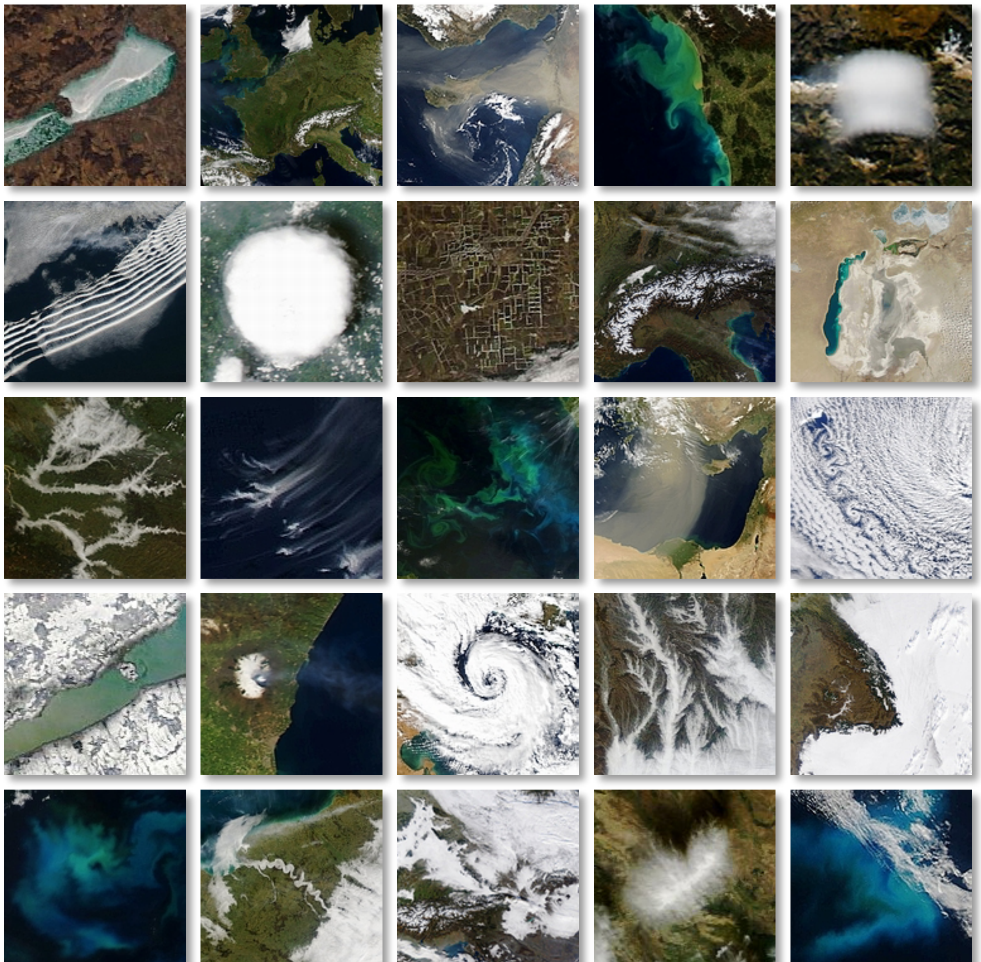
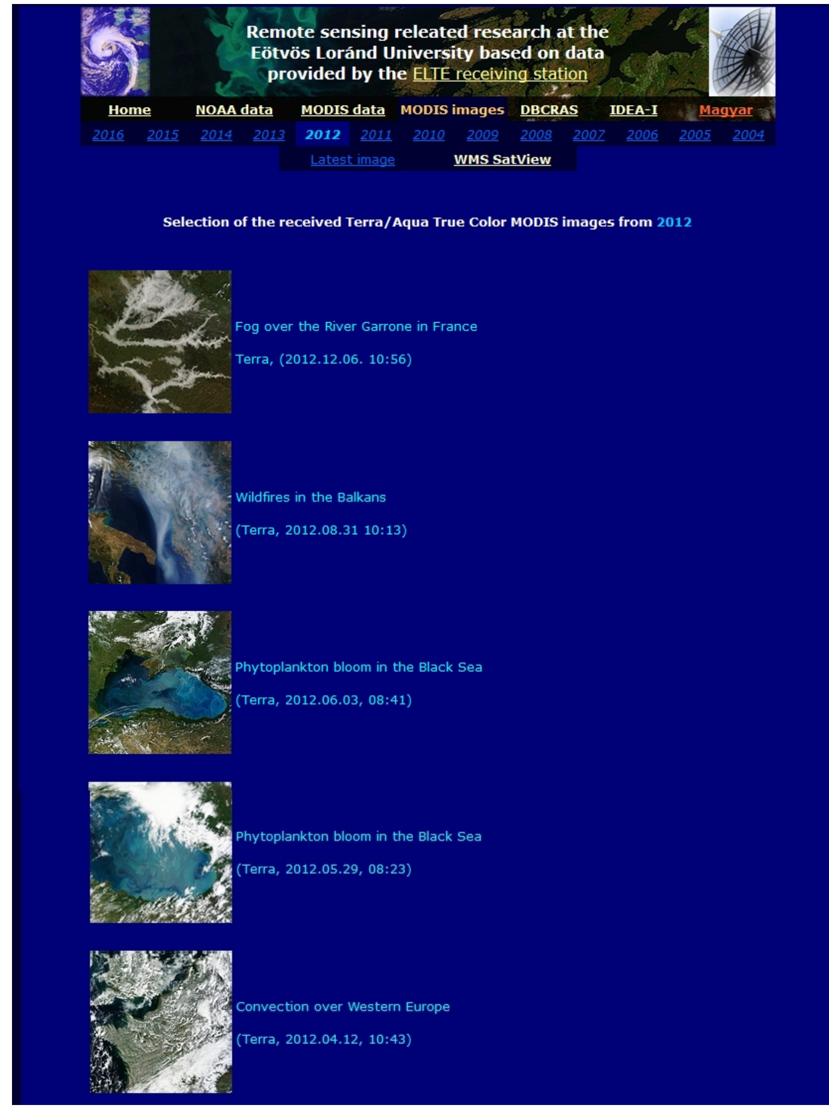
(6) IDEA-I air quality forecast (v1.1)
(7) MOD14, Identification of fire and thermal anomalies
(8) MODIS True Color software
(9) Direct Broadcast Google Earth software (v1.2)
(10) Polar2grid & IMAPP MODIS GeoTIFF Web Mapping Service

(8) MODIS True Color – since 2004



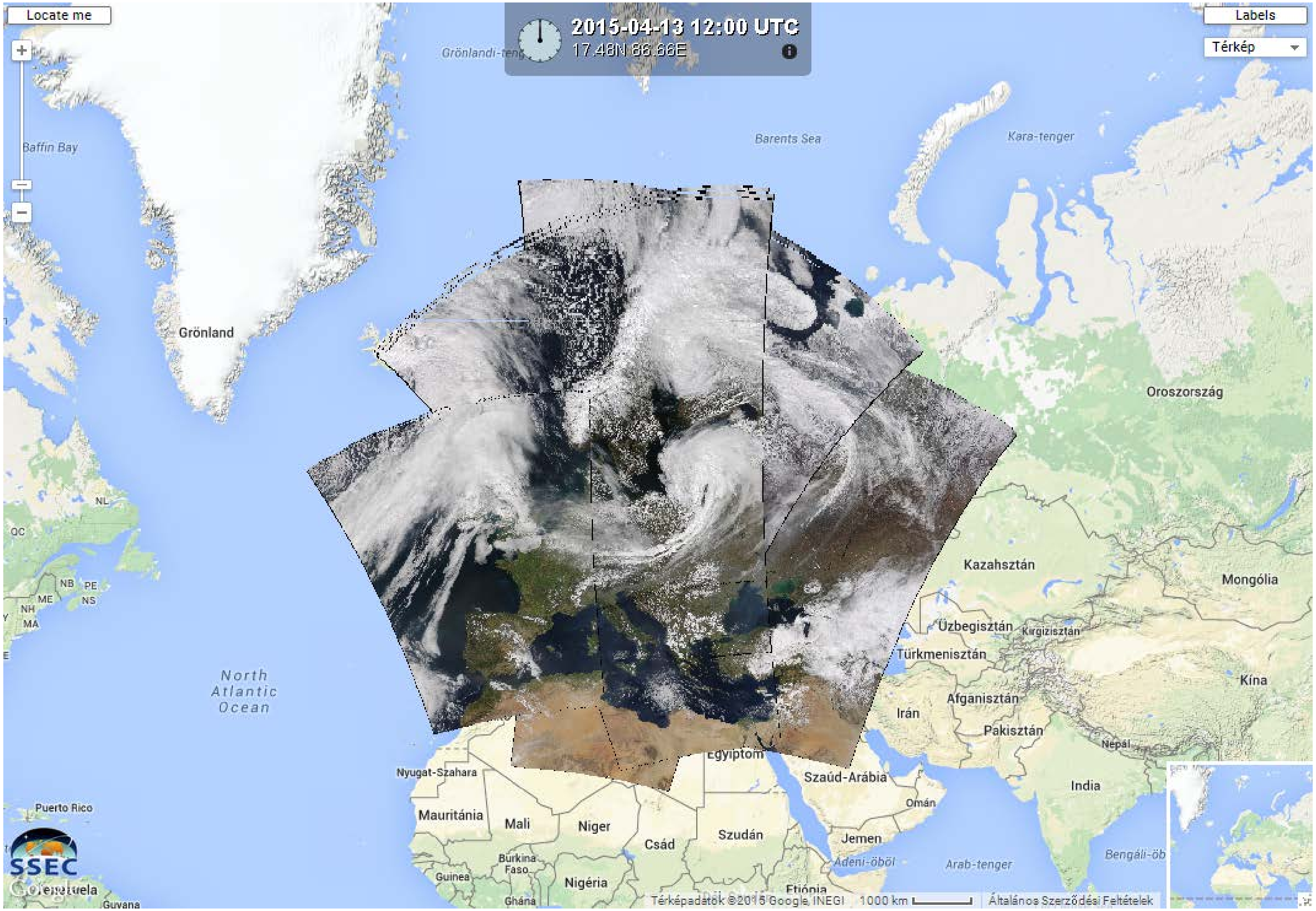


http://nimbus.elte.hu/kutatas/sat/modis-en.html

(9) Direct Broadcast Google Earth – since 2009

http://nimbus.elte.hu/kutatas/sat/modis-en_latest.pl

(10) IMAPP MODIS GeoTIFF Web Mapping Service (WMS) – since 2014



http://regcm.elte.hu:8001/

Post-processing for crop yield estimation

<u>Applied steps:</u>

(1) SeaDAS MODIS Level1DB Software Package (v1.8) → OCSSW

(2) MODIS Destriping Software

(3) IMAPP MODIS Level2 (v3.0)

→ **determining the cloudmask**

(4) MOD09 DB MODIS Land Surface Reflectance software

→ **calculating atmospherically corrected surface reflectances**

\+ Resampled cropland-mask from the IGBP MODIS land cover classification (MOD12), improved by the CORINE 2000 database

→ **to calculate <u>cropland specific</u> area-averaged NDVI values** for B1 and B2 with a maximum cloud coverage of 50%.

<u>For:</u>

2005 – 2015: archived Terra & Aqua received DB data

2003 – 2004 + lack of DB: Level1b data from NASA/Reverb Echo

→ ~ 2500 overpasses

Crop yield estimation – I.

Based on the methodology developed for AVHRR GN data (*Ferencz et al., 2004*):

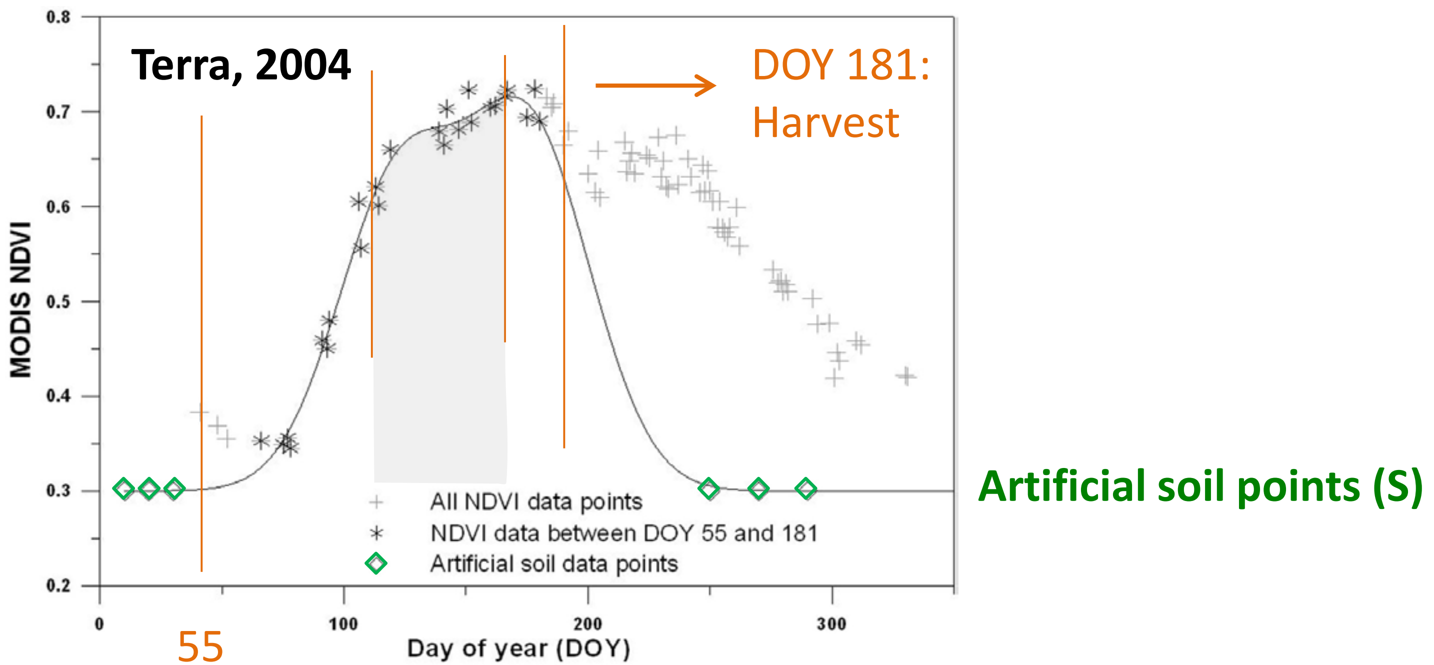
(1) Terra, Aqua, and a **mixed dataset** (with its combination)

(2) **vegetation period** for wheat: between DOY 55 and 181, + ***soil points***

(3) in case of data gaps (>20days) ***extra points*** were **inserted** (in 2006 and 2010)

(4) **curve fitting**: double-Gaussian function: $NDVI_t = A_1 e^{-((t-t_{01})/\Delta t_1)^2} + A_2 e^{-((t-t_{02})/\Delta t_2)^2} + S$
(Lagrange interpolation, cubic spline and smoothing were also tested)

(5) **calculating the integral** of the fitted NDVI curve between DOY 113 and 166

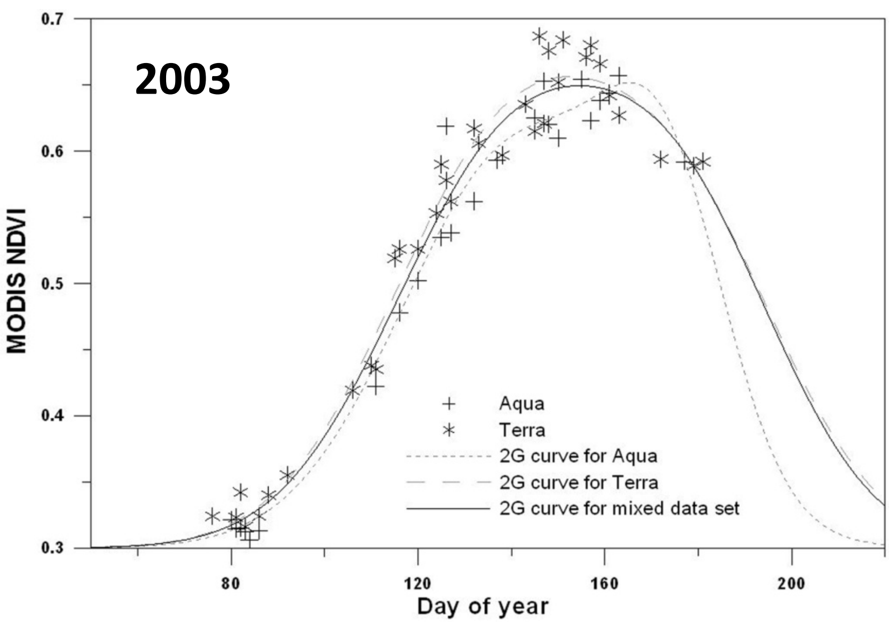


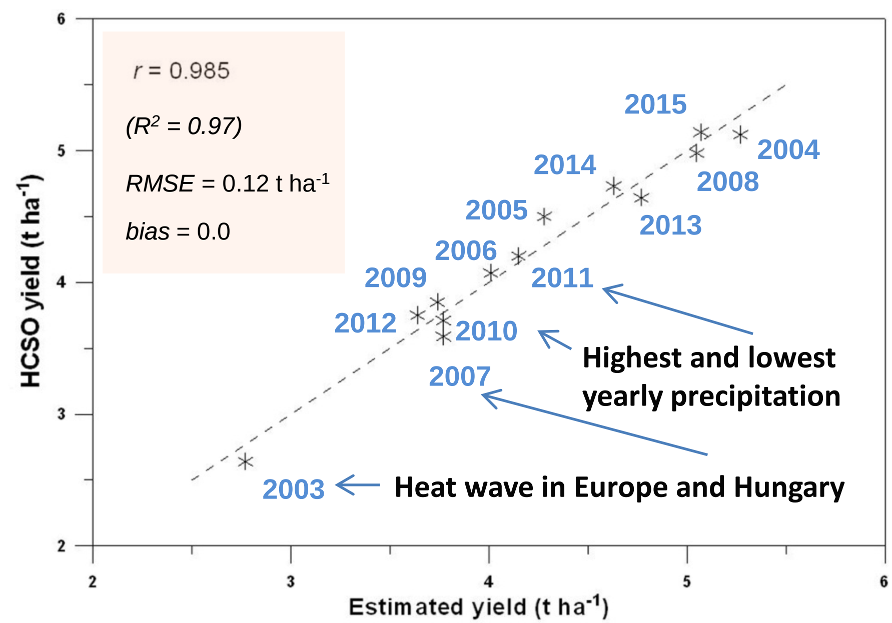
Crop yield estimation – II.

Linear regression between:

- the calculated **integral values** (*GYURRI*)
- and the official area-avaraged **yield data** (provided by the Hungarian Central Statistics Office, HCSO).

Curve fitting for the different datasets → **Yield estimation (with gap filling)**





- **Less than 5% deviation** from the official yield data during the 13 years
- Mean absolute difference is 2.7%

Crop yield estimation – III.

For other curve fitting (with 20-day averaging):

- Lagrange interpolation: r = 0.947
- cubic spline: r = 0.944
- smoothing: r = 0.936

Simulating of a real operative yield estimating process:

- Starting from the regression for years 2003-2005 until 2003-2015 the deviations were always less than 5%

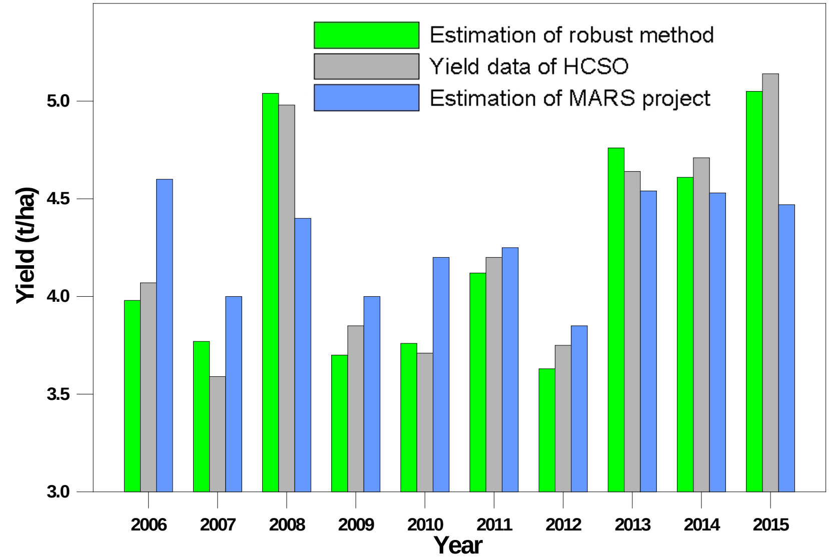
Comparing with the estimations of MARS (Monitoring Agriculture with Remote Sensing) **programme** (1988), which provides:

- area and yield estimation over Europe.

<ins>During 2006-2015:</ins>

⇨ RMSE of 0.104 t ha^{-1} (estimated vs. HCSO)

⇨ RMSE of 0.326 t ha^{-1} (MARS vs. HCSO)



Comparison of the end of June estimations

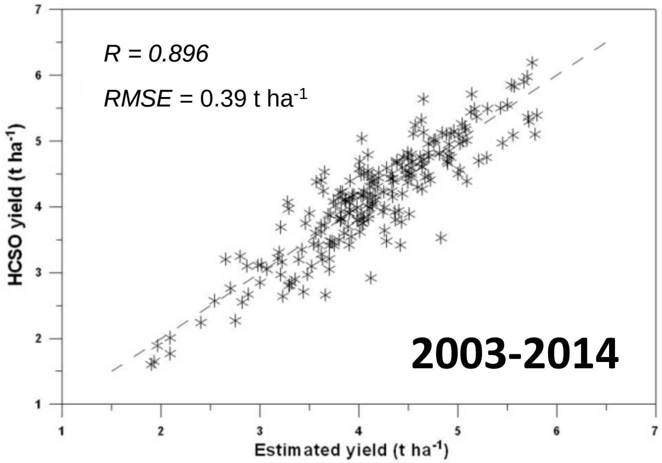
Crop yield estimation for smaller areas

Estimation for the 19 counties of Hungary (NUTS-3 level):

- calculating again all the cropland specific NDVI time-series at county level, and
- investigating also the different curve fitting methods:
  - ⇨ not uniformly the double-Gaussian is the best,
  - ⇨ different integral periods gave the best correlation,
  - ⇨ where the averages of the r values was 0.883,

⇨ **the stability of the process is reduced on smaller scale,**

⇨ the robust yield forecasting method becomes less reliable for smaller areas.



Can be explained by the **less number of cloud-free measured data** of the smaller regions

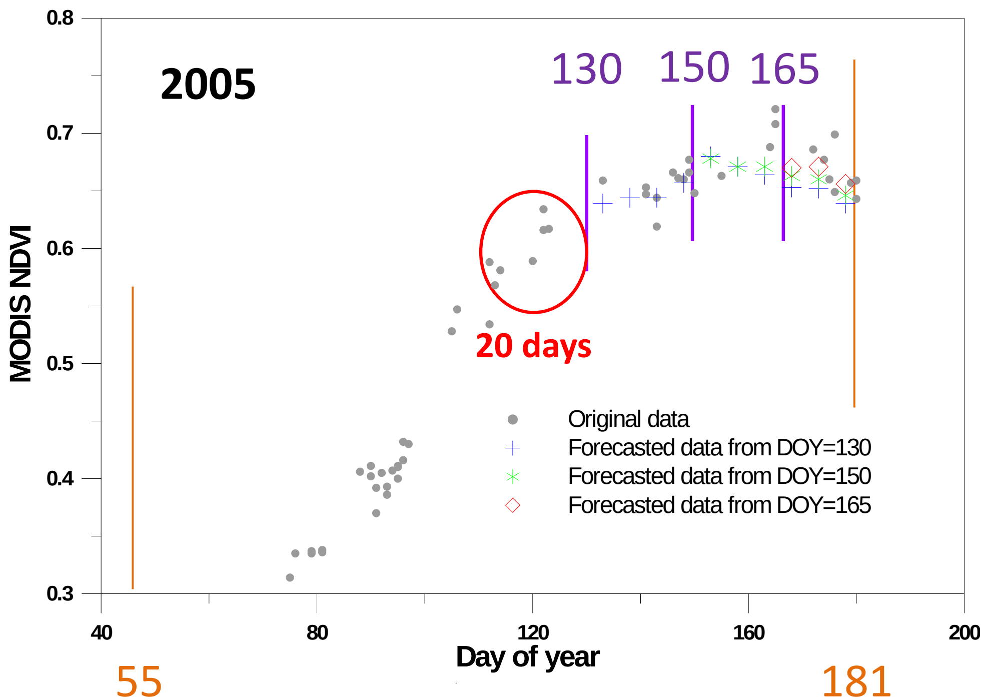
NUTS – *Nomenclature des unités territoriales statistiques* – EU standard for referencing the subdivisions of countries

Crop yield forecasting – I.

Based on the same methodology:

(+) **extrapolating in time** from different forecasting dates, using all the NDVI data of the previous years (through *prediction coefficients*) from the antecedent 20 days:

- from DOY 130 for DOY 133, 138, 143,… 178
- from DOY 135 for DOY 138, 143,… 178
- from DOY 175 for DOY 178



Accurate enough, if:

- there is a **sufficient amount of data** prior to the forecast date, and
- **no extreme weather event** occurs after the forecast date.

Crop yield forecasting – II.

Forecasting results from different prediction days:

(averages of the years, where extreme yeras can have higher deviation)

DOY	r	RMSE (t ha^{-1})	Difference (%)	
130	0.737	0.47	10.2	
135	0.832	0.39	8.5	→ -18.1% (2007)
140	0.853	0.36	7.7	
145	0.873	0.34	6.6	
150	0.855	0.36	6.8	
155	0.843	0.37	6.7	
160	0.926	0.26	5.4	
165	0.955	0.21	4.5	→ +9.6% (2012)
170	0.964	0.18	4.0	
175	0.970	0.17	3.6	

Results of the forecasting method in period of 2003-2015

INTERNATIONAL JOURNAL OF REMOTE SENSING, 2017
VOL. 38, NO. 11, 3394–3414
http://dx.doi.org/10.1080/01431161.2017.1295482

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Yield estimation and forecasting for winter wheat in Hungary using time series of MODIS data

Péter Bognár[a], Anikó Kern[a], Szilárd Pásztor[a], János Lichtenberger[b], Dávid Koronczay[a] and Csaba Ferencz[a]

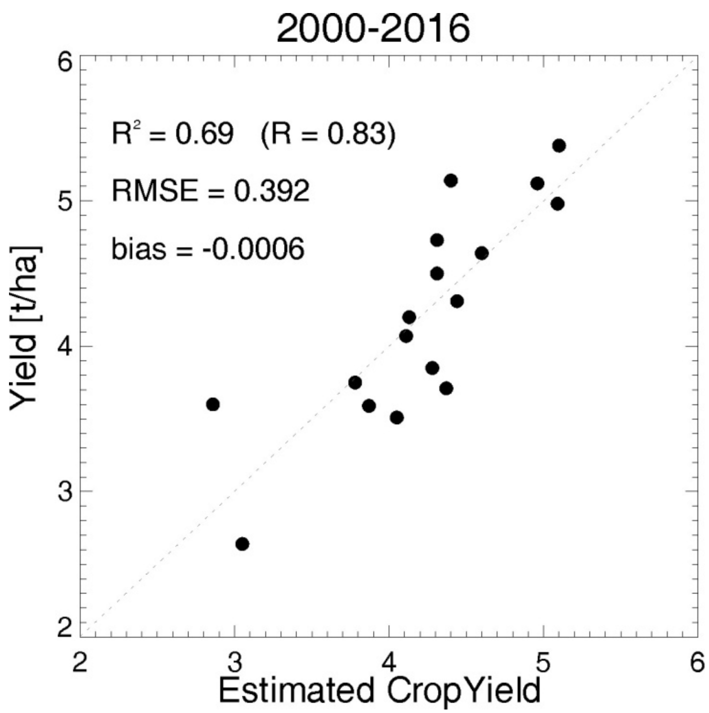
[a]Department of Geophysics and Space Sciences, Eötvös Loránd University, Budapest, Hungary; [b]Geodetic and Geophysical Institute, Research Centre for Astronomy and Earth Sciences, Hungarian Academy of Sciences, Sopron, Hungary

Crop yield estimation from MOD13 data

To compare with the usefulness of the DB data, based on:

- **raw C5 1KM MOD13 16-day NDVI data** for 2003-2015 (with the mean julian date of a given 16-day period)
- **post-processed C6 HKM MOD13 NDVI** data interpolated into a **8-day dataset** (using the julian day information) for 2000-2016

Based on cropland pixels from dominant Corine land cover, ⇨ resulting 62% coverage of the country



Even if they are not fully comparable:

⇨ **less accurate results!**

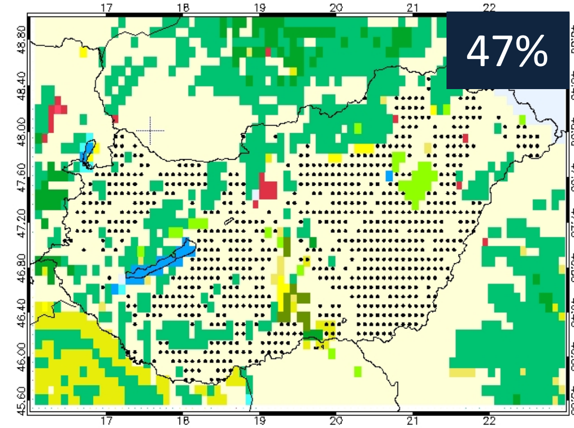
Supposed reason: the less number of data during the years

Crop yield estimation from the GIMMS NDVI3g dataset

NDVI3g (*Pinzon and Tucker, 2005*) global dataset:
– 1/12° x 1/12° spatial, and
– 15-day temporal resolution,
– based on AVHRR GAC data for 1982-2013.

Winter wheat yield was estimated also based on:
– the **original NDVI3g**,
– the BISE-filtered one,
– the **harmonized NDVI3g***,
– and the resampled MOD13 NDVI dataset.

(first three: **1982-2013**; all four: **2000-2013**)

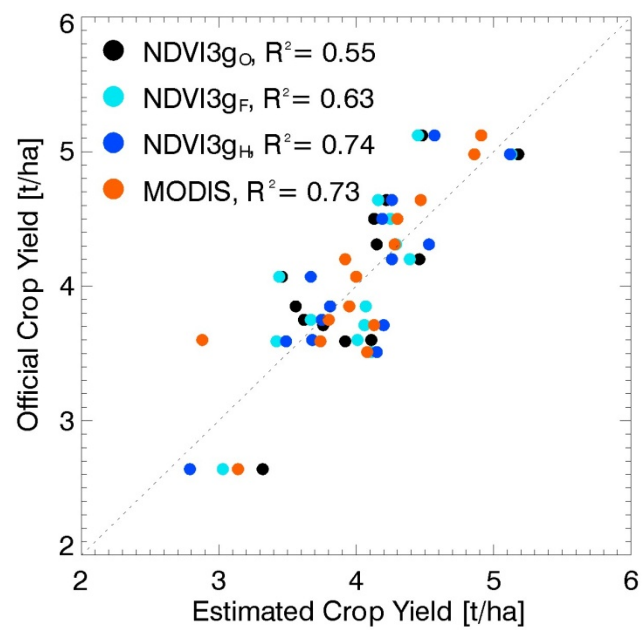


Using cropland pixels based on CLC2012

The selection of the pixels were made based on the **CORINE 2012 land cover dataset**, with at least 60% present of agricultural aeras.

	R^2	Slope	Intercept	Bias	RMSE
$NDVI3g_O$	0,55	1,00	0,01	0,00	0,42
$NDVI3g_F$	0,63	1,00	0,00	0,00	0,39
$NDVI3g_H$	0,74	1,00	0,00	0,00	0,32
MODIS	0,73	1,00	0,00	0,00	0,33

For the period of 2000-2013

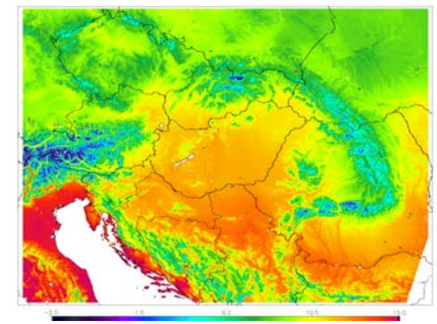


* *Kern et al., 2016, Remote Sensing, 8(11) 955, doi:10.3390/rs8110955.*

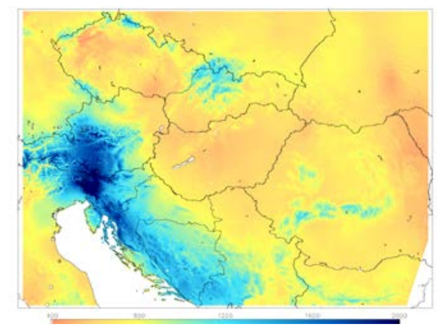
Relationship with meteorology

Using the FORESEE meteorological database:

- Observed (1951-2014) and projected
  - − daily max. & min. temperature
  - − and precipitation
  - \+ VPD (Vapour Pressure Deficit)
  - \+ global radiation
- for Central Europe, on a regular grid of 1/6° × 1/6°



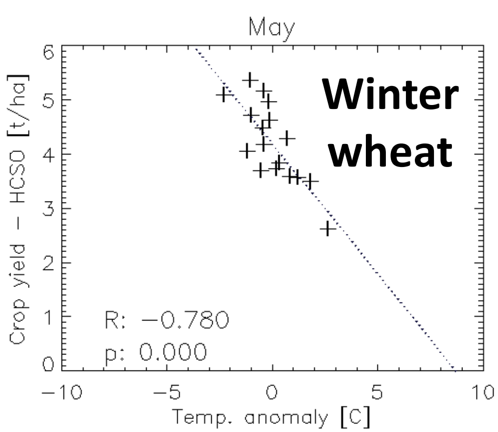
Mean annual temperature (1999-2014)

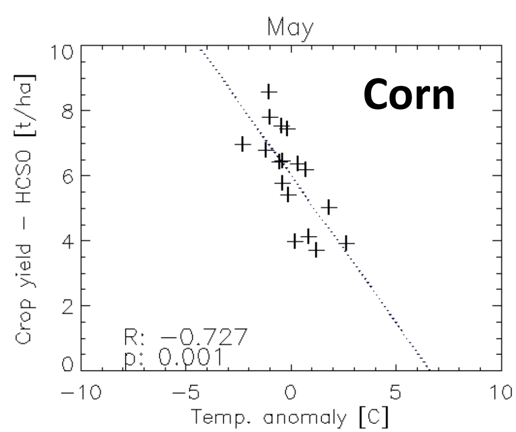


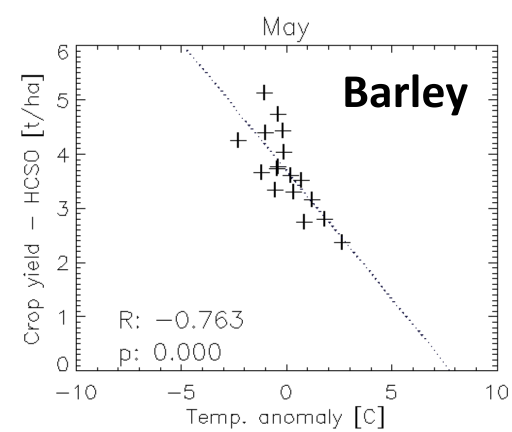
Mean annual precipitation (1999-2014)

Investigating the relationship between:

- the meteorological anomalies
- crop yield values







Summary and future plans

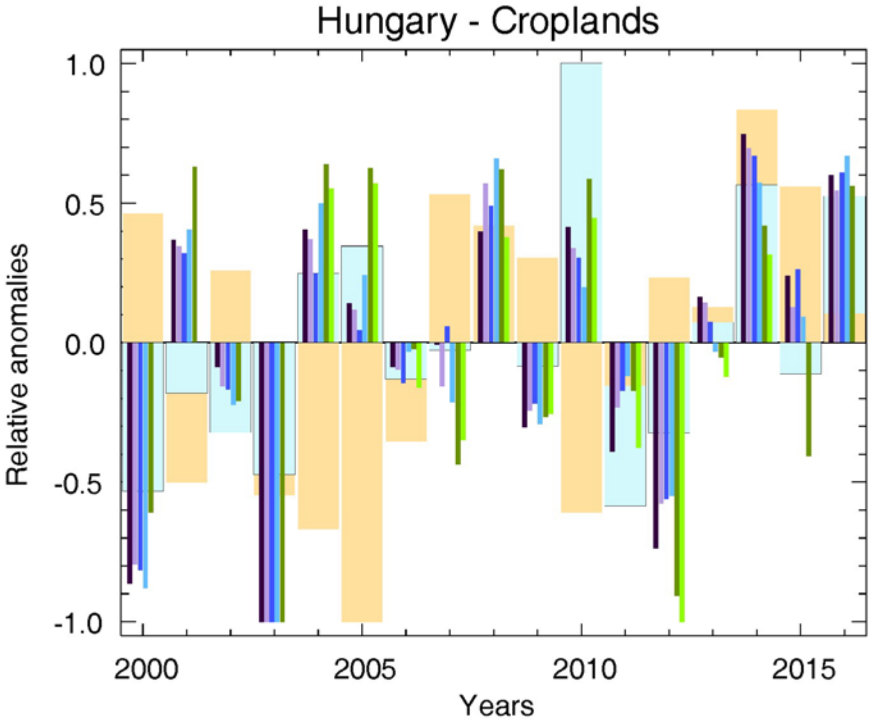
- With the presented robust method it is possible:
  - **to estimate** the yield of winter wheat at the end of June (beginning of the harvest) **with an accuracy of 5%**, and
  - **to forecast** several weeks before.
- The method is **applicable for other crop types as well** (corn, rye, barley, etc.).

Plans…

- **to implement the effect** of the current **weather** into the forecast,
- **to upgrade** the receiving **station:** real-time **Suomi-NPP data.**

Thank you for your attention! ☺

Acknowledgements: Kathy Strabala, Liam Gumley, and the IMAPP-Team
NASA & EOSDIS for the MOD02, MOD03, MOD12 and MOD13 products
GIMMS-team for the NDVI3g dataset
EC & ESA for CORINE-2012 database, and Hrvoje MARJANOVIĆ for its resampling
Hungarian Statistical Office for the official crop yield data
Hungarian Scientific Research Fund (OTKA PD-111920)
Zoltán BARCZA & Richárd KOVÁCS



Hungary - Croplands
1.0
0.5
0.0
-0.5
-1.0
Relative anomalies
2000
2005
2010
2015
Years

Remote Sens. **2016**, *8*, 955; doi:10.3390/rs8110955 www.mdpi.com/journal/remotesensing

remote sensing

Article

Evaluation of the Quality of NDVI3g Dataset against Collection 6 MODIS NDVI in Central Europe between 2000 and 2013

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