MULTIDIMENSIONAL ACCURACY ASSESSMENT AND DEVELOPMENT OF AN ESI-BASED WATER STRESS PRODUCT USING MSG-SEVIRI ET DATA ACROSS EUROPE

SALGEE 2024 I DR. BAGHER BAYAT

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OUTLINE

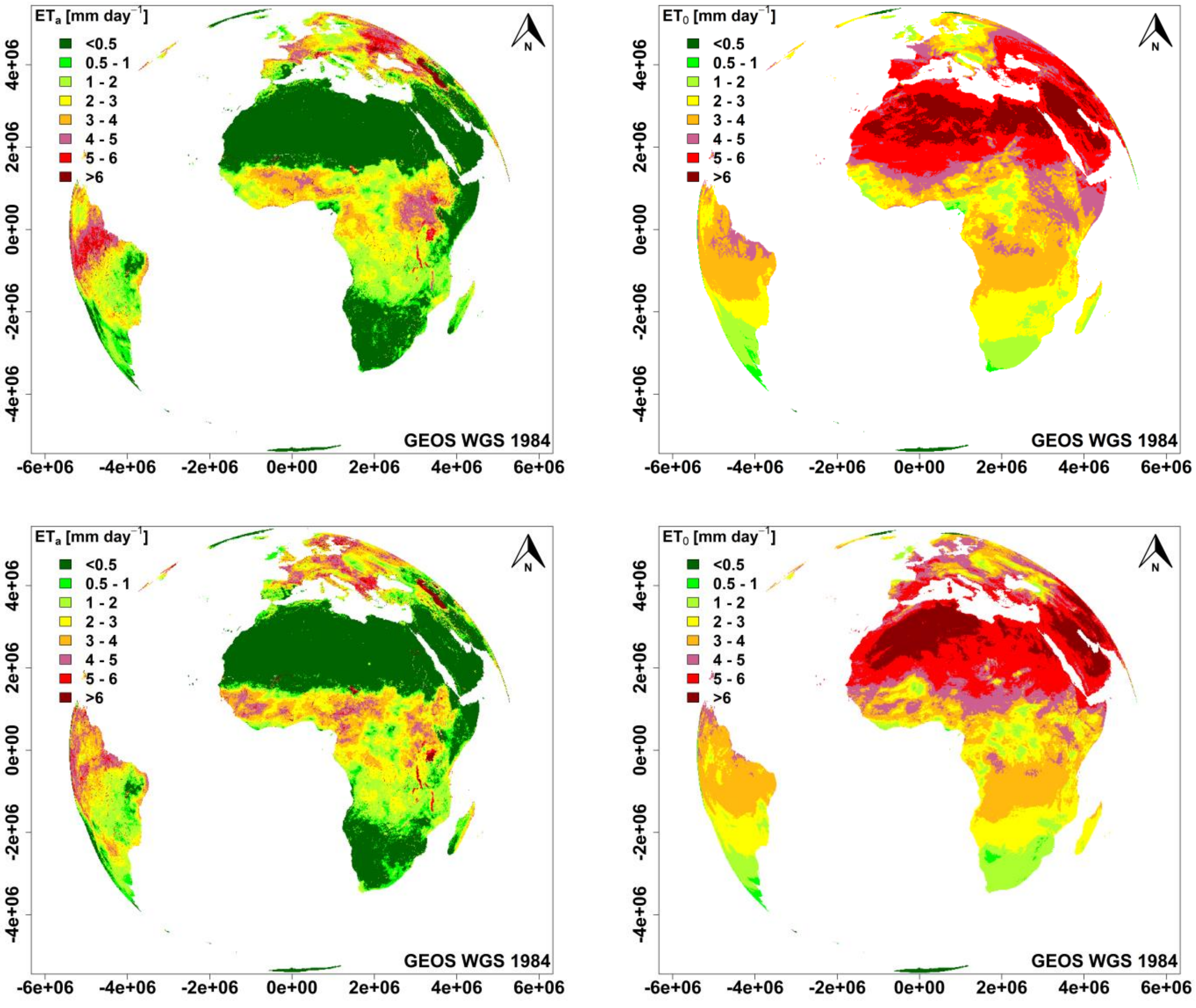
- SEVIRI ET products
- Main objectives
- Ground ET measurements
- Methodology
- Results
- Take home message

SEVIRI ET PRODUCTS 1

- Spinning Enhanced Visible and Infrared Imager (SEVIRI) sensor onboard the geostationary orbit MSG satellites
- SEVIRI-ETa (actual ET) and SEVIRI-ET0 (reference ET) products covering the whole MSG field of view (https://datalsasaf.lsasvcs.ipma.pt)
- Moderate spatial resolution of 0.05° and very high temporal resolutions (diurnal and daily)
- The observational characteristics of SEVIRI make it an ideal choice for sustainable water management and agricultural water stress detection
- Proper accuracy assessment and quantification of the errors associated with SEVIRI ET estimates are necessary.

SEVIRI ET PRODUCTS 2

SEVIRI-ET_a (left panels) and SEVIRI-ET_0 (right panels) sample data (15 of July) for 2016 (first row) and 2018 (second row)



MAIN OBJECTIVES

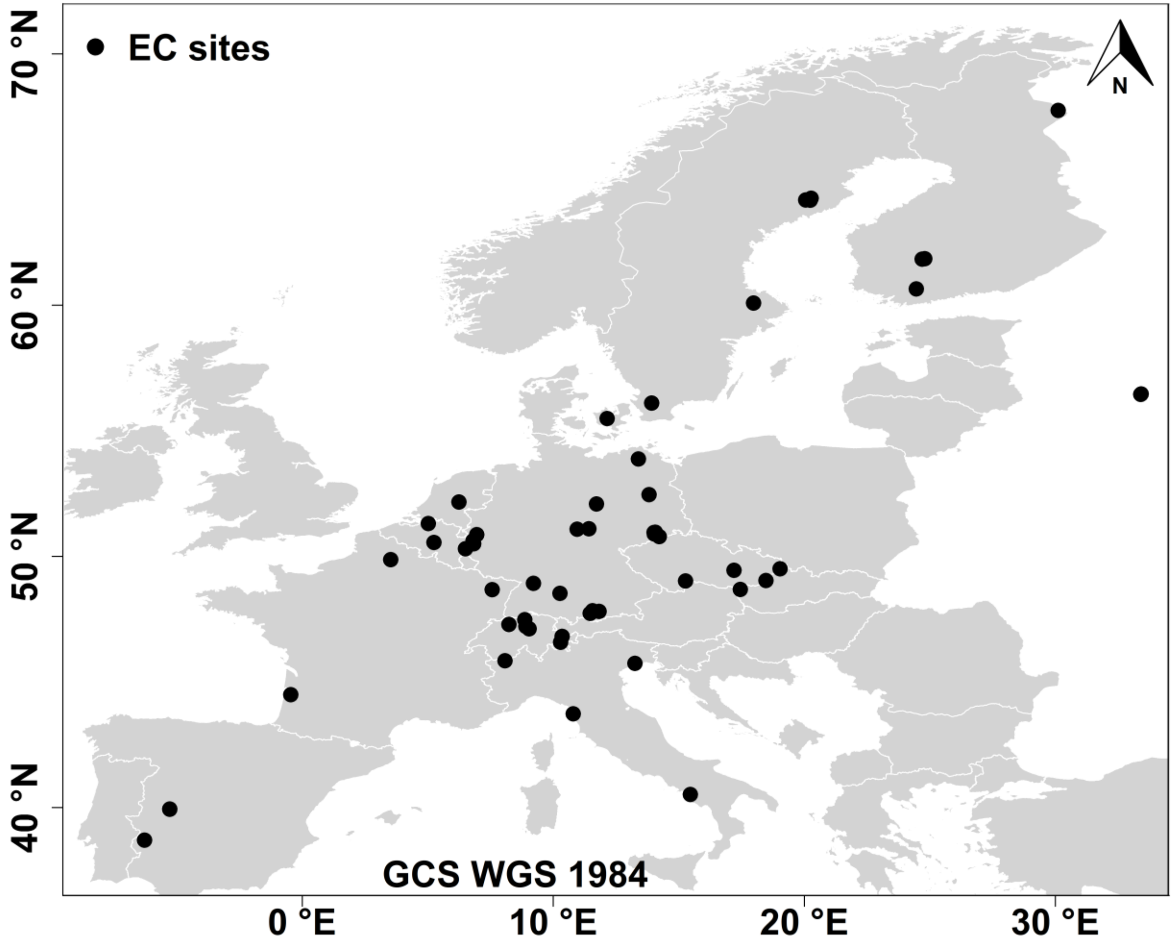
- ❑ To perform an extensive accuracy assessment of sub-daily and daily SEVIRI-ETa and SEVIRI-ET0 products across Europe between 2004-2018
- ❑ To separate the SEVIRI-ET product accuracy into temporal (intra-annual and inter-annual) and spatial (ecosystem, and climate zones) dimensions
- ❑ To compare SEVIRI-ETa products with four global ET products, i.e., MODIS, PML, GLEAM, and BESS.
- ❑ To perform homogeneity analysis of SEVIRI-ET pixels surrounding the in situ sites
- ❑ To quantify agricultural water stress across EU using SEVIRI ET data from 2004-2020

GROUND ET MEASUREMENTS

In situ EC sites

54 Stations:
Forest = 30 stations
Grassland = 9 stations
Cropland = 9 stations
Peatland = 5 stations

Site	Longitude	Latitude	Mean annual temperature (°C)	Mean annual precipitation (mm)	Elevation (m)	Ecosystem type	Reference
BE-Bra	4.5	51.3	9.8	750	16	forest	(Gielen et al., 2013)
BE-Lon	4.7	50.6	10	800	167	crop	(Buysse et al., 2017)
BE-Vie	6.0	50.3	7.8	1062	493	forest	(Aubinet et al., 2018)
CH-Aws	9.8	46.6	2.3	918	1978	grass	(Zeeman et al., 2010)
CH-Cha	8.4	47.2	9.5	1136	400	grass	(Hörtnagl et al., 2018)
CH-Dav	9.9	46.8	3.5	1046	1639	forest	(Haeni et al., 2017)
CH-Fru	8.5	47.1	7.2	1651	982	grass	(Zeeman et al., 2010)
CH-Lae	8.4	47.5	8.7	1211	689	forest	(Haeni et al., 2017)
CH-Oe2	7.7	47.3	9.8	1155	452	crop	(Emmel et al., 2018)
CZ-BK1	18.5	49.5	6.7	1316	875	forest	(Krupková et al., 2017)
CZ-Lnz	16.9	48.7	9.3	550	150	forest	(Acosta et al., 2017)
CZ-RAJ	16.7	49.4	7.1	681	625	forest	(McGloin et al., 2018)
CZ-Stn	18.0	49.0	8.7	685	550	forest	(Krupková et al., 2019)
CZ-wet	14.8	49.0	7.7	604	425	peatland	(Dušek et al., 2012)
DE-BER	13.3	52.2	9.4	525	61	grass	(Heusinger and Weber, 201
DE-EC2	8.7	48.9	9.4	889	318	crop	(Poyda et al., 2019)
DE-EC4	9.8	48.5	7.5	1064	687	crop	(Wizemann et al., 2015)
DE-Fen	11.1	47.8	8.4	1081	595	grass	(Kiese et al., 2018)
DE-Geb	10.9	51.1	8.5	470	162	crop	(Anthoni et al., 2004)
DE-Gri	13.5	51.0	7.8	901	385	grass	(Prescher et al., 2010)
DE-Hai	10.5	51.1	8.3	720	440	forest	(Knohl et al., 2003)
DE-HoH	11.2	52.1	9.1	563	193	forest	(Wollschläger et al., 2017)
DE-Kli	13.5	50.9	7.6	842	478	crop	(Prescher et al., 2010)
DE-Obe	13.7	50.8	5.5	996	734	forest	(Prescher et al., 2010)
DE-RbW	11.0	47.7	9.0	1160	769	grass	(Kiese et al., 2018)
DE-RuR	6.3	50.6	7.7	1033	515	grass	(Post et al., 2015)
DE-RuS	6.4	50.9	10.2	718	103	crop	(Klosterhalfen et al., 2019)
DE-RuW	6.3	50.5	7.5	1250	610	forest	(Ney et al., 2019)
DE-SfS	11.3	47.8	8.6	1127	590	peatland	(Hommeltenberg et al., 201
DE-Tha	13.6	51.0	8.2	843	380	forest	(Prescher et al., 2010)
DE-ZRK	12.9	53.9	8.7	584	1	peatland	(Franz et al., 2016)
DK-Sor	11.6	55.5	8.2	660	40	forest	(Wu et al., 2013)
ES-Abr	-6.8	38.7	16	400	280	forest	(Luo et al., 2018)
ES-LM1	-5.8	39.9	16	700	265	forest	(El-Madany et al., 2018)
ES-LM2	-5.8	39.9	16	700	270	forest	(El-Madany et al., 2018)
FI-Hyy	24.3	61.8	3.8	709	180	forest	(Mammarella et al., 2009)
FI-Let	24.0	60.6	4.6	627	0	forest	(Launiainen et al., 2016)
FI-Sii	24.2	61.8	3.5	701	160	peatland	(Rinne et al., 2018)
FI-Var	29.6	67.8	-0.5	601	395	forest	(Kulmala et al., 2019)
FR-Bil	-1.0	44.5	12.8	930	0	forest	(Moreaux et al., 2011)
FR-EM2	3.0	49.9	10.8	680	84	crop	(Domeignoz-Horta et al., 201
FR-Hes	7.1	48.7	9.2	820	300	forest	(Granier et al., 2008)
IT-BCi	15.0	40.5	18	600	15	crop	(Vitale et al., 2009)
IT-Cp2	12.4	41.7	15.2	805	6	forest	(Fares et al., 2014)
IT-Lsn	12.8	45.7	13.1	1083	1	crop	(Tezza et al., 2019)
IT-Tor	7.6	45.8	2.9	920	2160	grass	(Galvagno et al., 2013)
NL-Loo	5.7	52.2	9.8	786	25	forest	(Elbers et al., 2011)
RU-Fy2	32.9	56.4	3.9	711	265	forest	(Esquinas-Requena et al., 20
RU-Fyo	32.9	56.5	3.9	711	265	forest	(Kurbatova et al., 2013)
SE-Deg	19.6	64.2	1.2	523	270	peatland	(Nilsson et al., 2008)
SE-Htm	13.4	56.1	7.4	707	115	forest	(van Meeningen et al., 2017
SE-Nor	17.5	60.1	5.5	527	46	forest	(Lindroth et al., 2018)
SE-Ros	19.7	64.2	1.8	614	160	forest	(Jocher et al., 2018)
SE-Svb	19.8	64.3	1.8	614	270	forest	(Chi et al., 2019)



METHODOLOGY 1

Homogeneity analysis

Based on MODIS 2016 land cover and purity index defined as the fraction of the most dominant land cover type:

- ✓ Those pixels that include more than two natural land cover types or those with purity index value lower than 65% were considered heterogeneous,
- ✓ The pixel purity value of 65% was defined as the minimum required purity for the site homogeneity in case of two land cover types being present within the pixel,
- ✓ Those pixels with pixel purity value higher than 80% were directly assumed homogenous.

METHODOLOGY 2

Dimensions information extraction for all EC sites

- ✓ The climate zone information for all EC site locations were extracted directly from the European re-analyzed Köppen-Geiger climate data version 2017
- ✓ Ecosystem dimension information was collected from site principal investigators and the opinions reflected in recent literature, e.g., Graf et al. (2020).
- ✓ For intra-annual and inter-annual dimensions, changes in the accuracy of SEVIRI-ET products were investigated within the year and between the years

METHODOLOGY 3

Error statistics

Kling-Gupta efficiency (KGE) and Root Mean Square Error (RMSE) statistics were employed to evaluate SEVIRI-ET_a and SEVIRI-ET_0 products against measured ET_a and ET_0.

$$\mathrm{KGE} = 1 - \sqrt{(r-1)^2 + \left(\frac{\sigma_s}{\sigma_g} - 1\right)^2 + \left(\frac{\mu_s}{\mu_g} - 1\right)^2} \quad (1)$$

$$\mathrm{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(g_i - s_i)^2} \quad (2)$$

where r is the linear correlation between ground ET measurements and SEVIRI-ET,
σ_s the standard deviation in SEVIRI observations,
σ_g the standard deviation in ground measurements,
μ_s the SEVIRI mean, and μ_g the ground mean.
The g_i and s_i are the ground measurements and SEVIRI observations,
i is the sampling time step, and *n* is the number of samples (n = 5412 [for daily Et_a], 5413 (for daily $ET_{0\ \mathrm{and}}$ 257506 (for diurnal ET_a).

METHODOLOGY 4

Evaporative Stress Index (ESI)

$$ESI = \frac{ETa}{ET0}$$

$$< ESI(m, y, i, j) > = \frac{1}{nc} \sum_{n=1}^{nc} < ESI(n, y, i, j) >$$

$$ESIA = \frac{< ESI(m, y, i, j) > - \frac{1}{ny} \sum_{y=1}^{ny} < ESI(m, y, i, j) >}{\sigma(m, i, j)}$$

ETa: Actual ET [mm/day]
ET0: Reference ET [mm/day]
ESI: Evaporative Stress Index [-]
ESIA: Evaporative Stress Index Anomalies [-]
m: monthly time step,
y: year, i,j: grid location
nc: number of observations,
n: value of observation

ESI value	Class
$ESI \geq 2$	Extreme Wet
$1.5 \leq ESI < 2$	Severe Wet
$1 \leq ESI < 1.5$	Moderate Wet
$0 \leq ESI < 1$	Mild Wet
$-1 \leq ESI < 0$	Mild Drought
$-1.5 \leq ESI < -1$	Moderate Drought
$-2 \leq ESI < -1.5$	Severe Drought
$ESI \leq -2$	Extreme Drought

RESULTS 1

Sub-daily and daily overall accuracies

- **For sub-daily SEVIRI-ETa**, the KGE varied between -1.6 to 0.8 across different sites, and the RMSE ranged from 0.04 to 0.14 mm hour^{-1}. Separating homogeneous (and heterogeneous) sites, the KGE exhibited a range of -0.38 (-1.6) to 0.78 (0.8), while the RMSE ranged from 0.04 mm hour-1 (0.04 mm hour-1) to 0.08 (0.14)

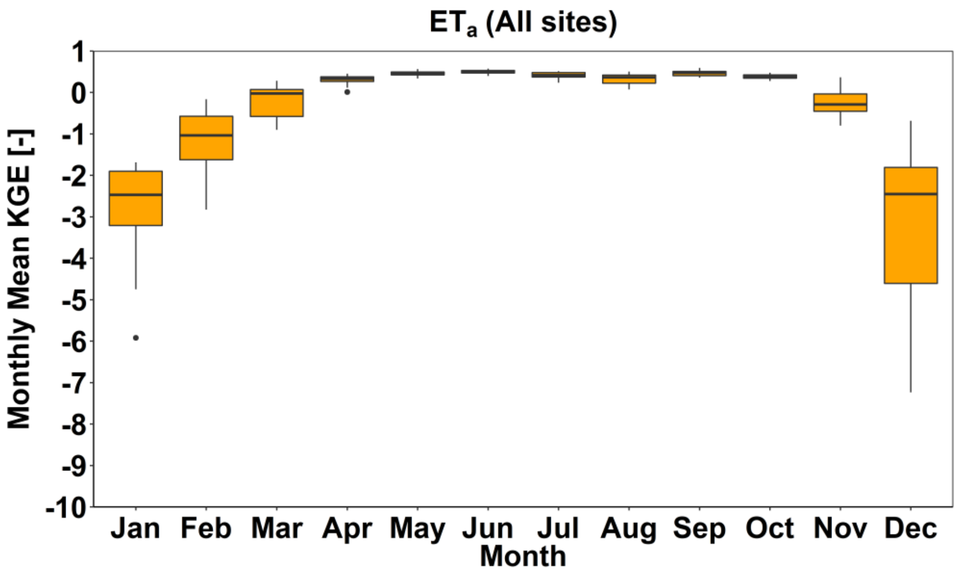
- **For daily SEVIRI-ETa**, the KGE varied between -0.88 to 0.93 across different sites, while the RMSE exhibited a variation range from 0.43 to 1.79 mm day^{-1}. Separating the homogeneous (and heterogeneous) sites, the KGE showed a range of -0.88 (-0.31) to 0.88 (0.93), and RMSE ranged from 0.51 mm day^{-1} (0.43 mm day^{-1}) to 1.25 mm day^{-1} (1.79 mm day^{-1})

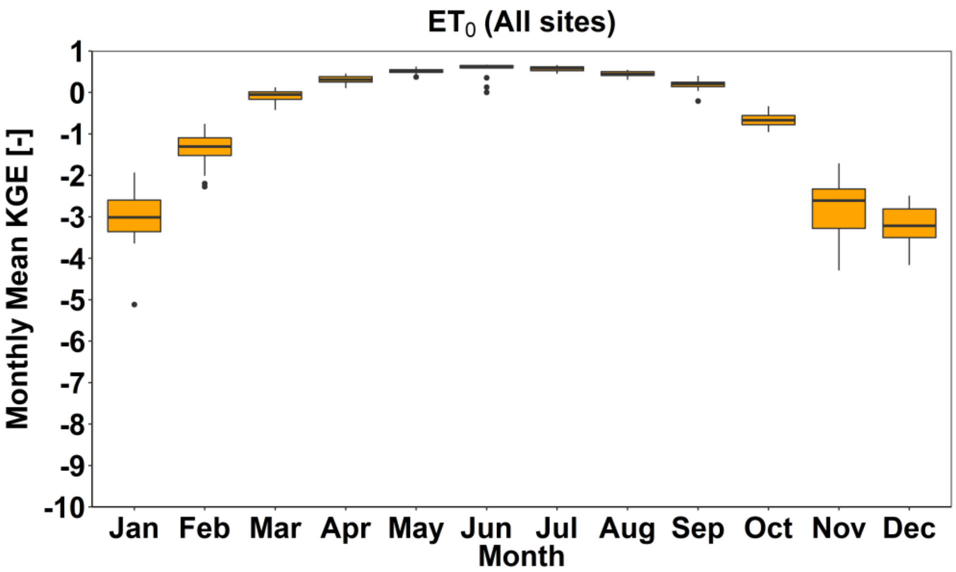
- **For daily SEVIRI-ET0**, KGE changes from 0.51 to 0.94, and RMSE between 0.40 mm day^{-1} to 1.50 mm day^{-1}. Separating the homogeneous (and heterogeneous) sites, the KGE range was 0.51 (0.56) to 0.84 (0.94), and RMSE ranged from 0.44 mm day^{-1} (0.40 mm day^{-1}) to 1.09 mm day^{-1} (1.5 mm day^{-1}).

RESULTS 2

Intra-annual dimension accuracy

- The accuracy was lower in the first quarter of the year (January to March), increased during the mid-year period (April to October), and then started to decline in the last quarter (November to December).





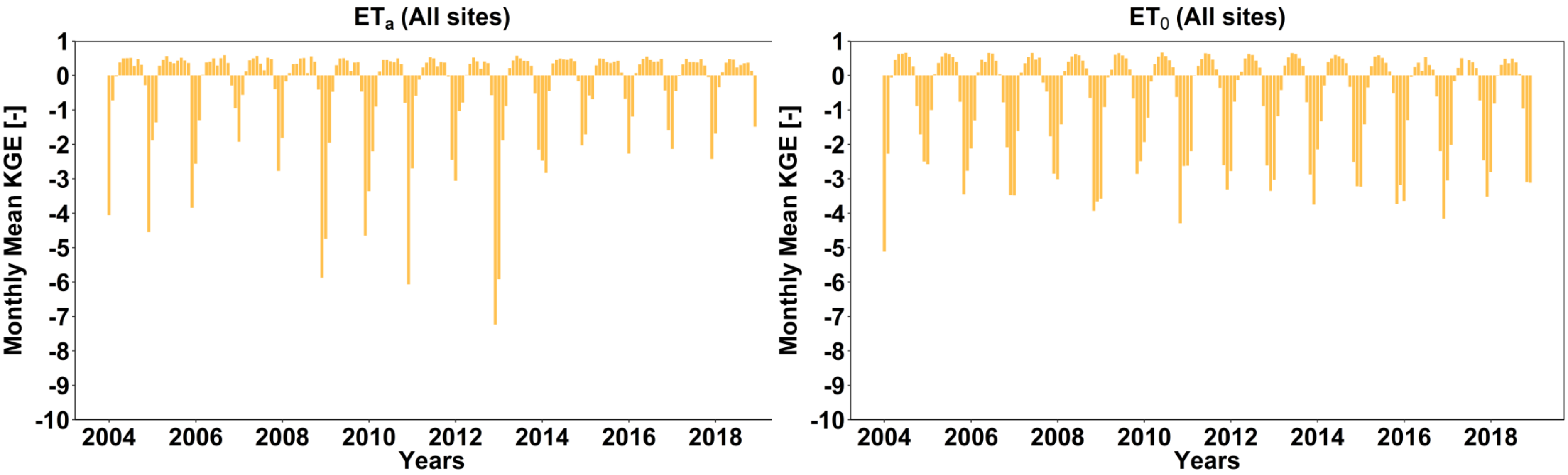
- Similar trends in the accuracy of SEVIRI-ET (both ETa and ET0) were observed in heterogeneous and homogeneous pixels separately.

RESULTS 3

Inter-annual dimension accuracy

- The agreement between SEVIRI-ET and in situ ET was low in the first quarter of the year, increased in the mid-year, and then declined in the last quarter.

- SEVIRI-ET0, the positive KGE values during the mid-year were relatively stable and did not exhibit significant changes from one year to another.

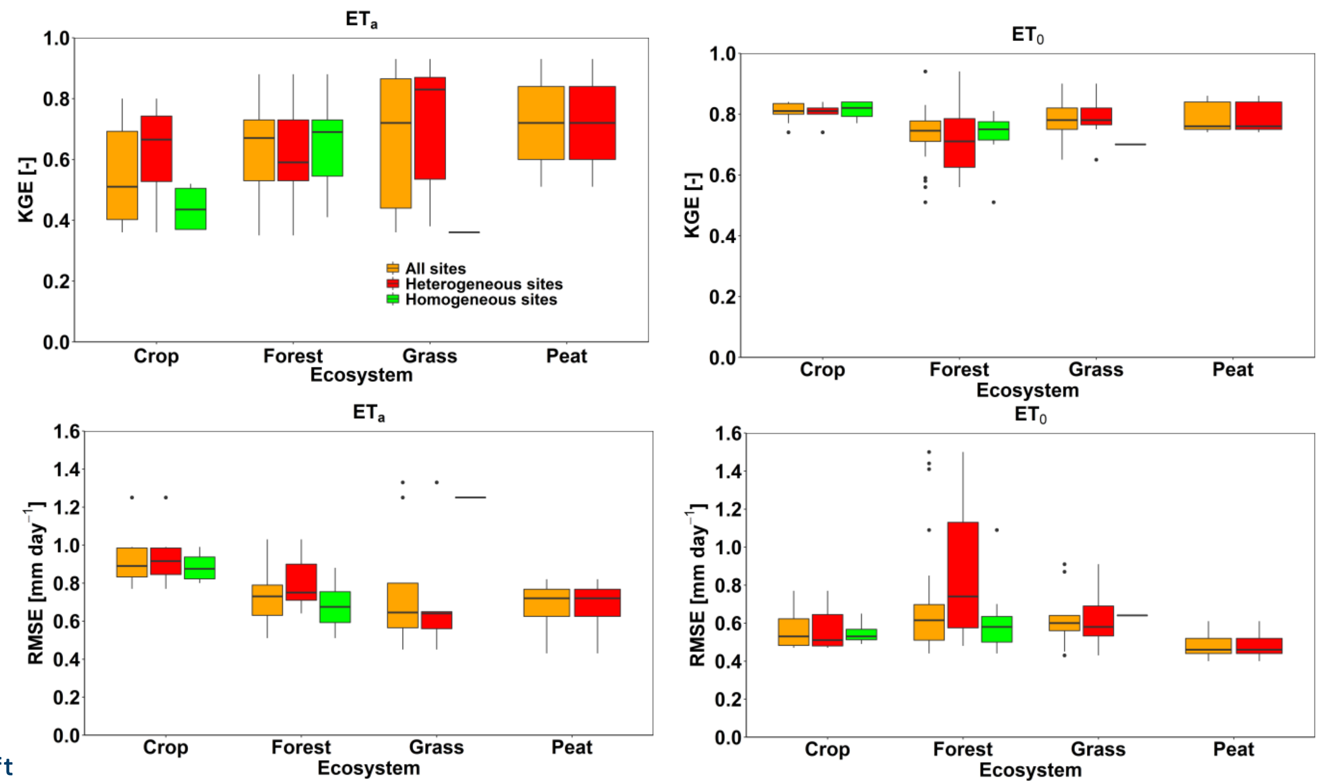


- A similar trend was observed in heterogeneous and homogeneous sub-groups

RESULTS 4

Ecosystem dimension accuracy

- For SEVIRI-ETa, the highest agreement was found for peat and grassland ecosystems (median KGE ≈ 0.72).
- For SEVIRI-ET0, the highest agreement was observed in crop and grassland ecosystems (0.81 > median KGE > 0.78).

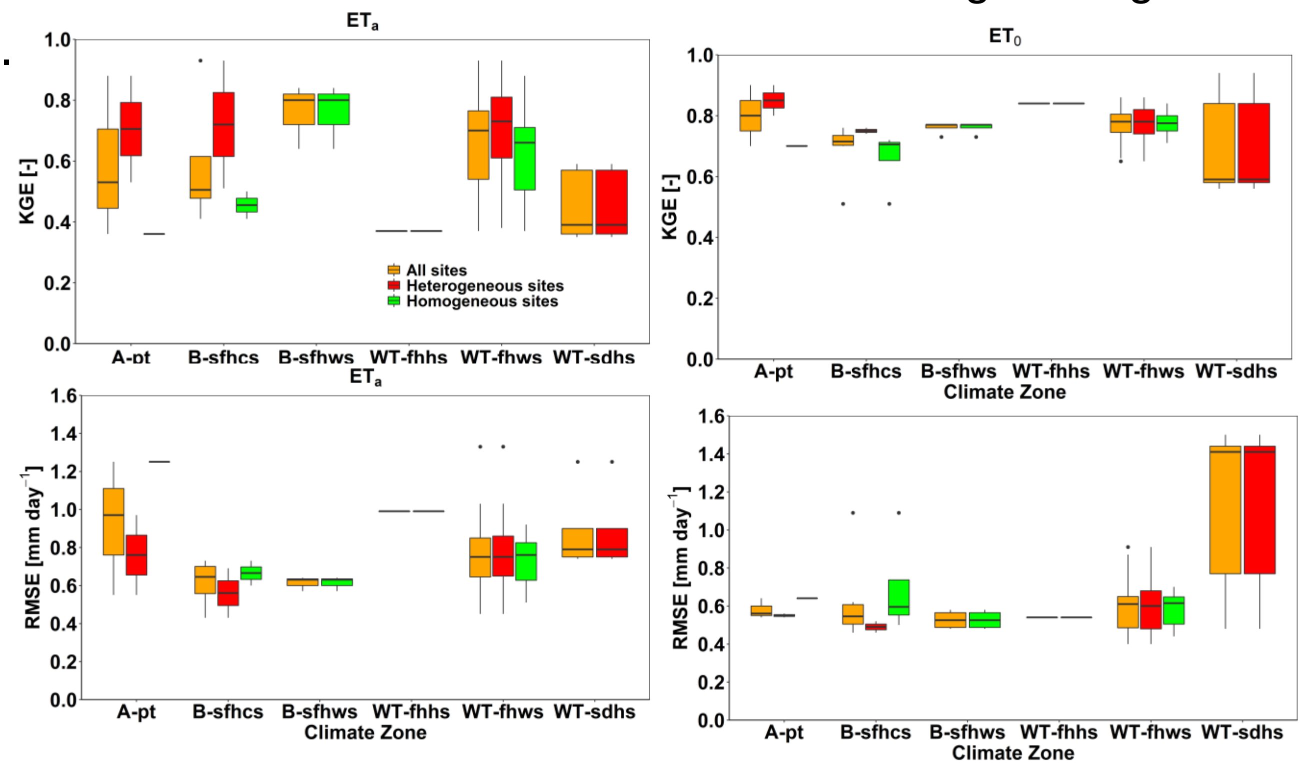


RESULTS 5

Climate dimension accuracy

- For SEVIRI-ETa, The highest agreement (KGE ≈ 0.80) was observed for the Boreal Snow fully humid warm summer (B-sfhws) climate zone and the lowest in two: he Warm Temperate fully humid hot summer (WT-fhhs) and Warm Temperate summer dry hot summer (WT-sdhs) climate zones

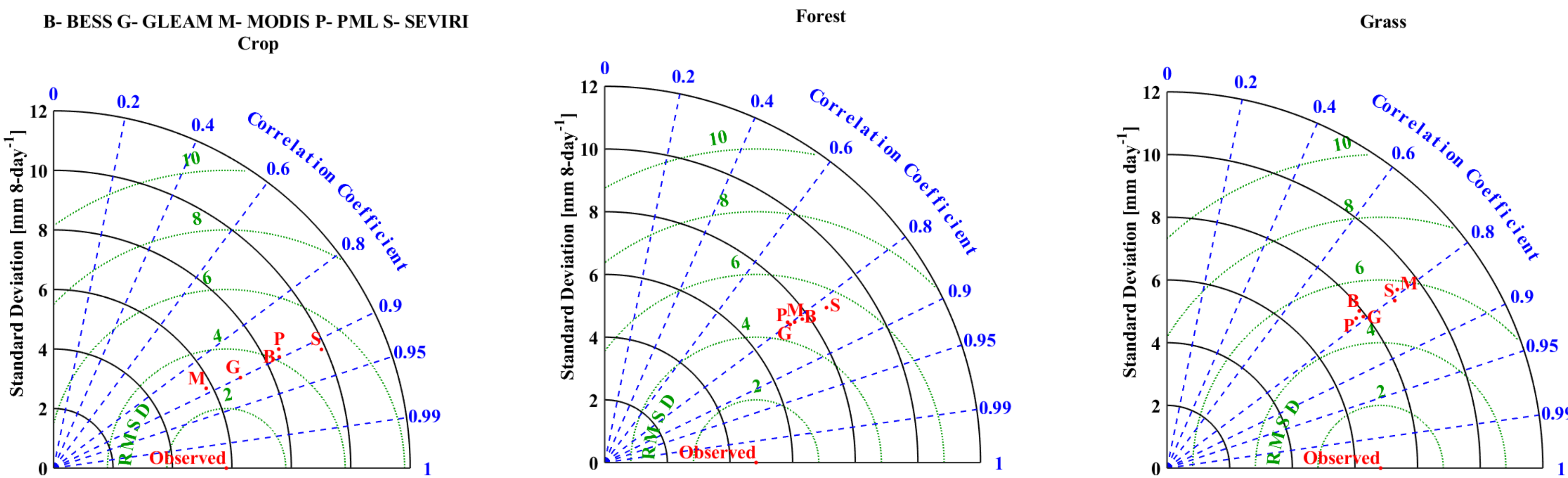
- For SEVIRI-ET0, the WT-fhhs climate zone was identified as having the highest agreement (KGE ≈ 0.85).



RESULTS 6

Products intercomparison @ecosystems

- In croplands and forests, SEVIRI ET_a estimates had the highest correlations with the ground ET and PML ET the lowest one.
- In grasslands, SEVIRI ET_a estimates had the highest and BESS ET the lowest correlation with the ground ET.



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DETAILED INFORMATION

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ELSEVIER

Comprehensive accuracy assessment of long-term geostationary SEVIRI-MSG evapotranspiration estimates across Europe

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Intercomparison
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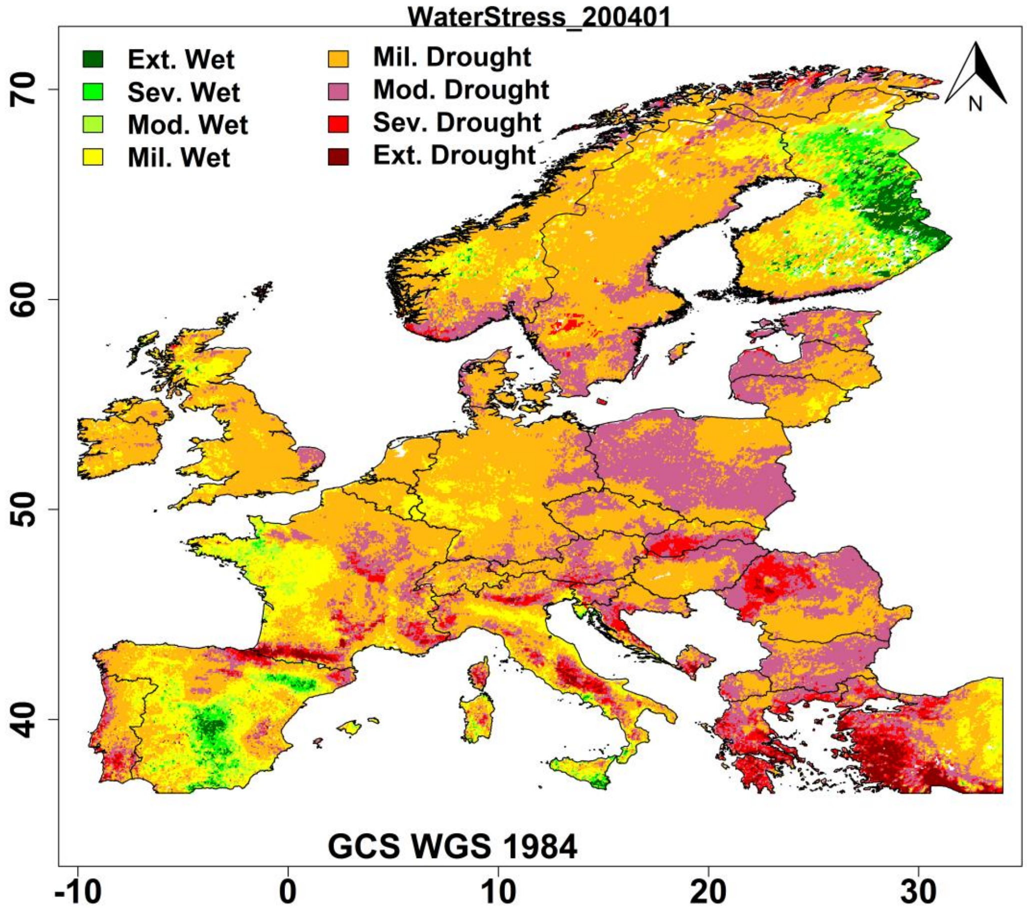
ABSTRACT

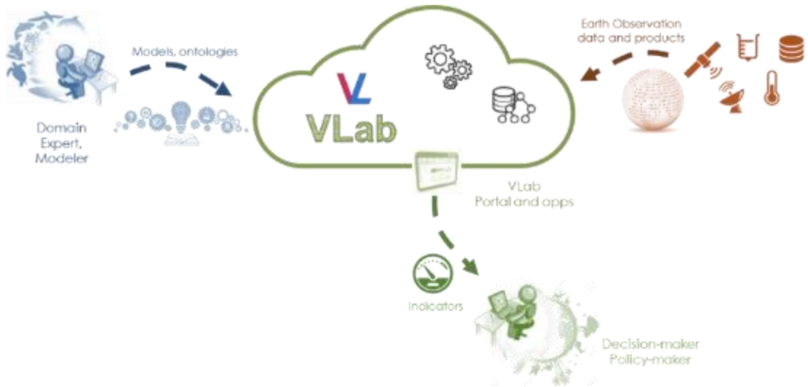
This study quantifies the accuracy of evapotranspiration (ET) estimates from the Spinning Enhanced Visible and Infrared Imager (SEVIRI) geostationary sensor onboard the Meteosat Second Generation (MSG) satellites, along seven key dimensions, i.e., diurnal cycle, daily, intra-annual, inter-annual, ecosystem, climate zone, and products intercomparison. In situ measurements were collected at 54 eddy covariance (EC) sites to evaluate the accuracy of SEVIRI actual ET products (diurnal and daily SEVIRI-ET_a) as well as reference ET (daily SEVIRI-ET_0) covering the period from 2004 to 2018 across Europe. SEVIRI-ET_a is produced by the Tiled ECMWF Surface Scheme of Exchange processes at the Land surface (TESSEL) model, while SEVIRI-ET_0 is estimated by a combination of a

RESULTS 7

Water Stress Maps

- ✓ 3-5 km spatial resolution
- ✓ Monthly temporal resolution
- ✓ 17 years (2004-2020)

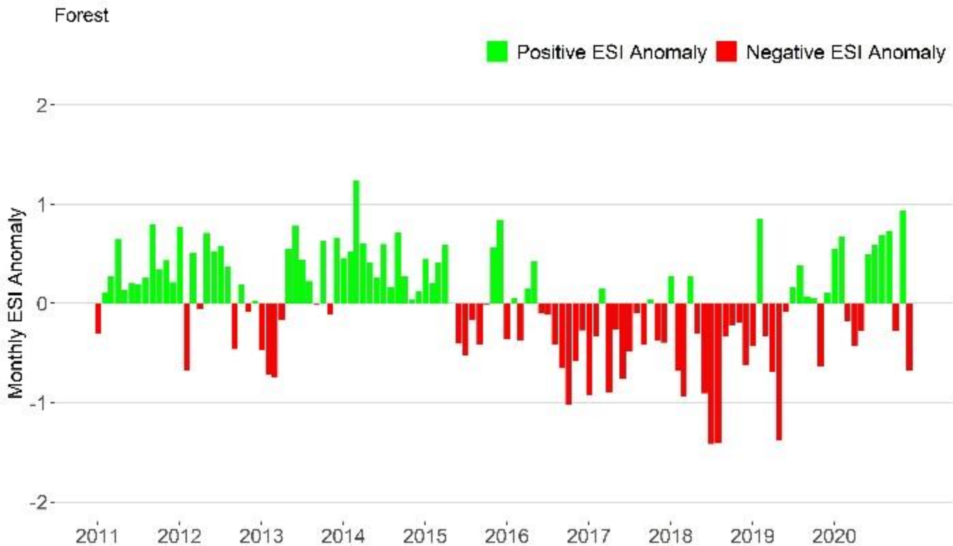


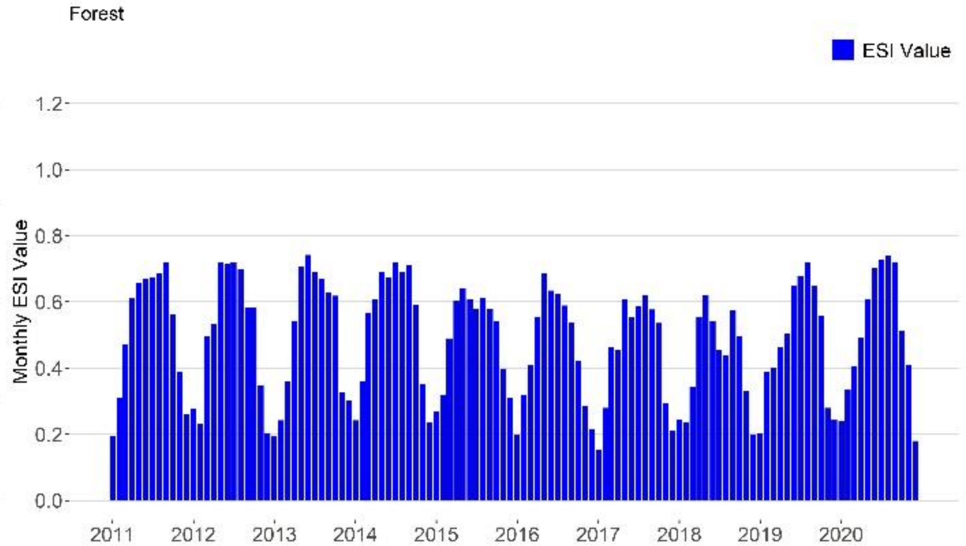


Ref: Bayat et al. (2022)

RESULTS 7

Water Stress Maps: Ecosystems responses*: Forest





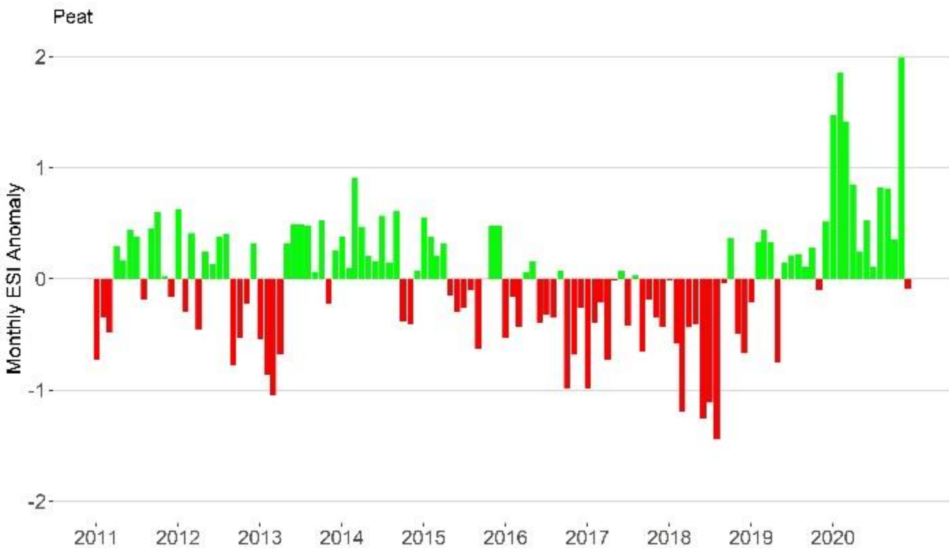
- ✓ 57 months with negative anomalies during the selected time series.
- ✓ 7 episodes at least three consecutive months exhibiting negative anomalies.

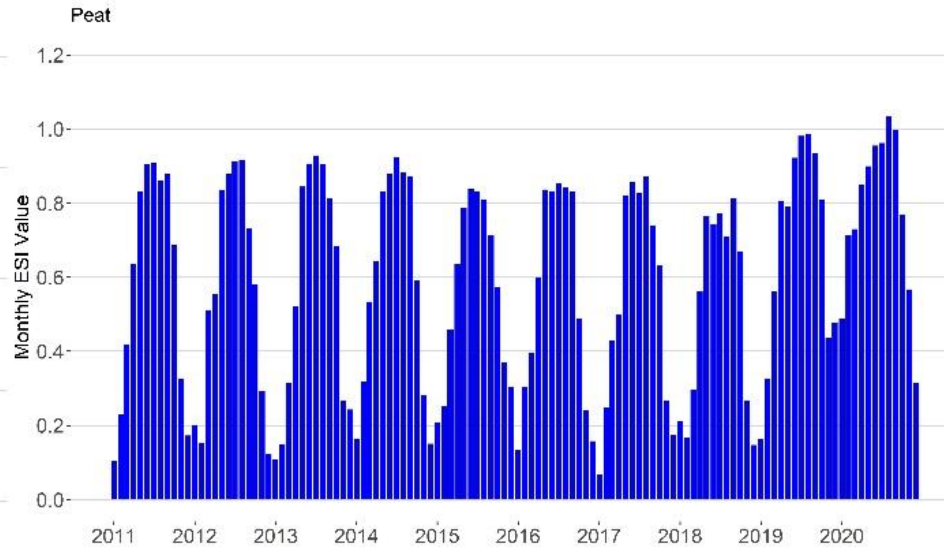
- ✓ higher values in summer than winter, with a minimum peak ESI in the drought year 2018
- ✓ behaved more **conservatively**, saving water already during the unusually dry and warm spring, and **benefitting** from the **saved water** as well as from their **deep root systems** (Teuling *et al.* 2010, Wolf *et al.* 2013)

*Preliminary results

RESULTS 7

Water Stress Maps: **Ecosystems responses*: Peat**

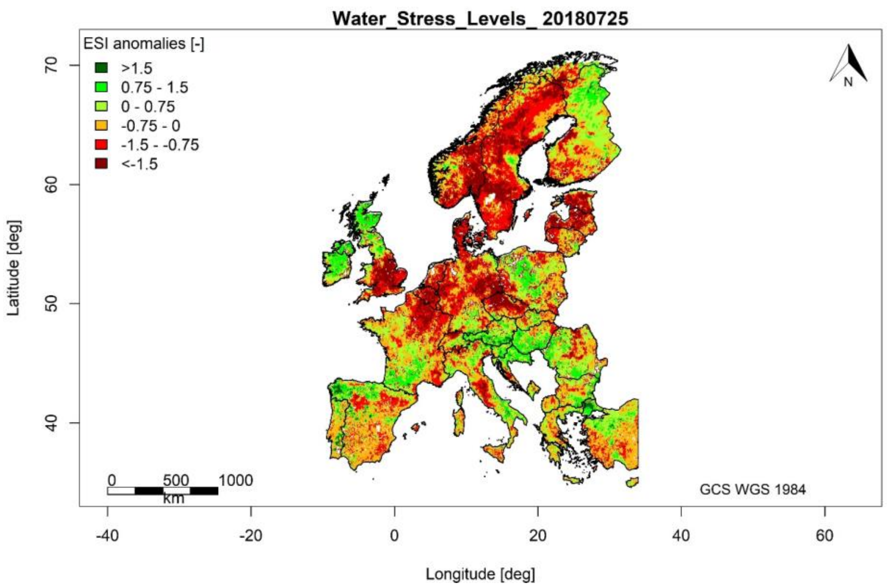


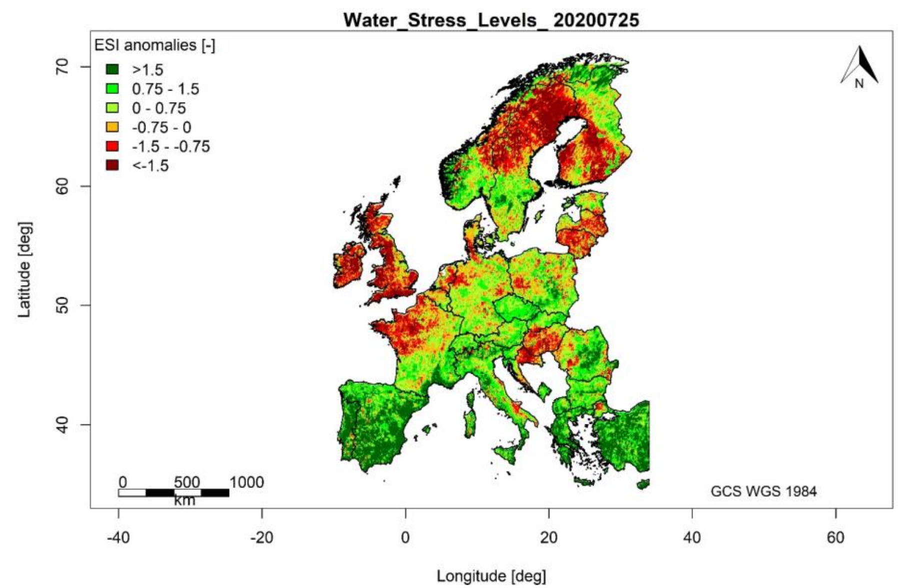


- ✓ 57 months with negative anomalies during the selected time series.
- ✓ 10 episodes at least three consecutive months exhibiting negative anomalies.
- ✓ Not only the **highest ESI value**, but also managed to sustain **high** values during the **2018 drought** since there was a large **water reserve** in the subsurface, from previous years or the surrounding, to provide sufficient ET_a water.

RESULTS

Water Stress Maps: National-level reports





Country	[>1.5]	[0.75 - 1.5]	[0 - 0.75]	[-0.75 - 0]	[-1.5 - -0.7	[<-1.5]
Austria	8.25235	28.97881	40.4174	14.27433	4.1899	3.887207
Belgium	0	0	0.253915	7.321202	39.35675	53.06813
Bulgaria	2.386059	13.68633	36.83646	31.20643	11.64879	4.235925
Cyprus	0.42735	5.982906	31.19658	62.39316	0	0
Czechia	0	1.323408	9.644334	22.4483	23.22581	43.35815
Switzerlar	0.693069	8.712871	25.41254	32.50825	19.40594	13.26733
Germany	0.129529	2.763286	14.84546	27.16871	32.32109	22.77192
Denmark	0.226464	0.226464	1.164672	13.94371	49.88677	34.55192
Spain	3.376903	9.513561	16.66297	47.69757	21.44191	1.307086
Greece	1.759685	5.003283	34.02495	50.40053	8.260013	0.551543
Estonia	0	0.955161	6.394269	13.71717	30.22022	48.71319
France	0.262147	7.347739	24.965	33.90853	22.63368	10.8829
Finland	0.770492	10.14655	37.36106	31.257	15.80811	4.656793
Italy	1.47865	10.46623	27.93844	35.99054	18.36745	5.758688

Country	[>1.5]	[0.75 - 1.5]	[0 - 0.75]	[-0.75 - 0]	[-1.5 - -0.7	[<-1.5]
Austria	8.544153	37.86794	38.01114	12.79236	2.593477	0.190931
Belgium	0	7.804674	40.40067	38.9399	12.77129	0.083472
Bulgaria	15.15072	47.05805	27.48453	8.437541	1.869159	0
Cyprus	92	7.157895	0.842105	0	0	0
Czechia	8.424134	61.99382	28.36234	1.138396	0.081314	0
Switzerlar	13.22996	39.16199	34.67502	8.578027	2.408446	1.946552
Germany	0.747697	16.6017	44.4224	27.67186	9.312544	1.243799
Denmark	2.359694	12.56378	30.38903	42.92092	11.47959	0.28699
Spain	59.95089	25.81952	9.779006	3.529773	0.819521	0.101289
Greece	62.16955	28.38911	7.357729	1.940357	0.143248	0
Estonia	2.603093	18.09278	39.69072	25.43814	11.57216	2.603093
France	8.326395	15.7167	26.4199	25.94555	17.90427	5.68718
Finland	5.25552	12.73712	23.3285	23.95563	19.56826	15.15497
Italy	25.44325	35.14475	22.42312	10.95362	5.424221	0.611039

DETAILED INFORMATION

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RESEARCH ARTICLE

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One decade (2011–2020) of European agricultural water stress monitoring by MSG-SEVIRI: workflow implementation on the Virtual Earth Laboratory (VLab) platform

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ABSTRACT

Cloud computing facilities can provide crucial computing support for processing the time series of satellite data and exploiting their spatio-temporal information content. However, dedicated efforts are still required to develop workflows, executable on cloud-based platforms, for ingesting the satellite data, performing the targeted processes, and generating the desired products. In this study, an operational workflow is proposed, based on monthly Evaporative Stress Index (ESI) anomaly, and implemented in cloud-based online Virtual Earth Laboratory (VLab) platform, as a demonstration, to monitor European agricultural water stress. To this end, daily time-series of actual and reference

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KEYWORDS
ET; SEVIRI; ESI; water stress workflow; Europe; VLab demonstration

TAKE HOME MESSAGE

- Close agreement observed between daily (and sub-daily) in situ ET and SEVIRI-ET, for both ET_a and ET_0 products.
- Intra-annual accuracy was low in the first quarter of the year, increased in the mid-year (the second and third quarter), and then began to decline in the last quarter.
- The highest SEVIRI-ETa accuracy was achieved in the peat and grassland ecosystems, and the Boreal snow fully humid warm summer climate zone
- SEVIRI ET outperformed MODIS, PML, GLEAM, and BESS ET products in terms of achieving the highest (the best) correlation across ecosystem types and climate zones.
- The water stress workflow based on Evaporative Stress Index (ESI) anomalies can be used in operational applications to quantify various water stress levels.
- The results from this study highlight the value, support the potentials, and unlock the full capacity of SEVIRI-ET products and the VLab platform for agricultural water stress detection at larger domains.

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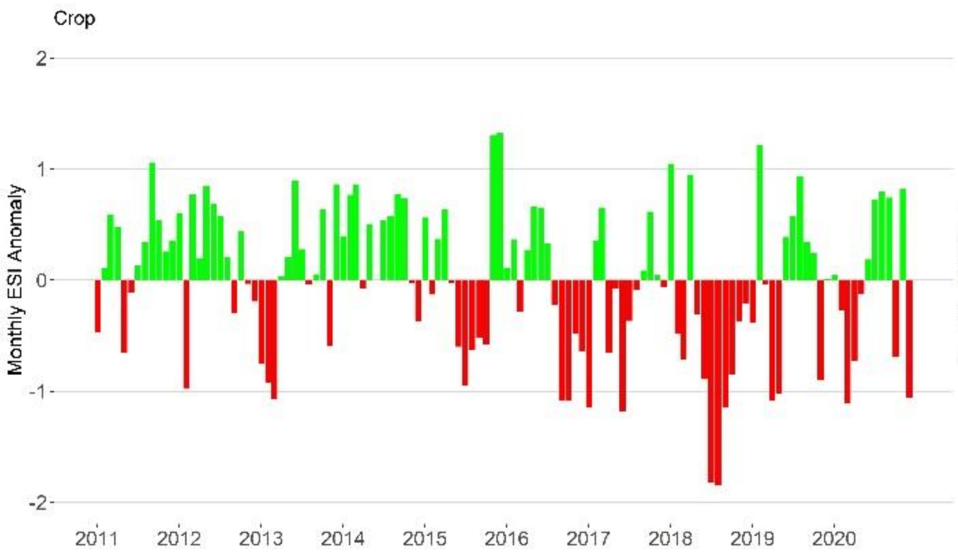
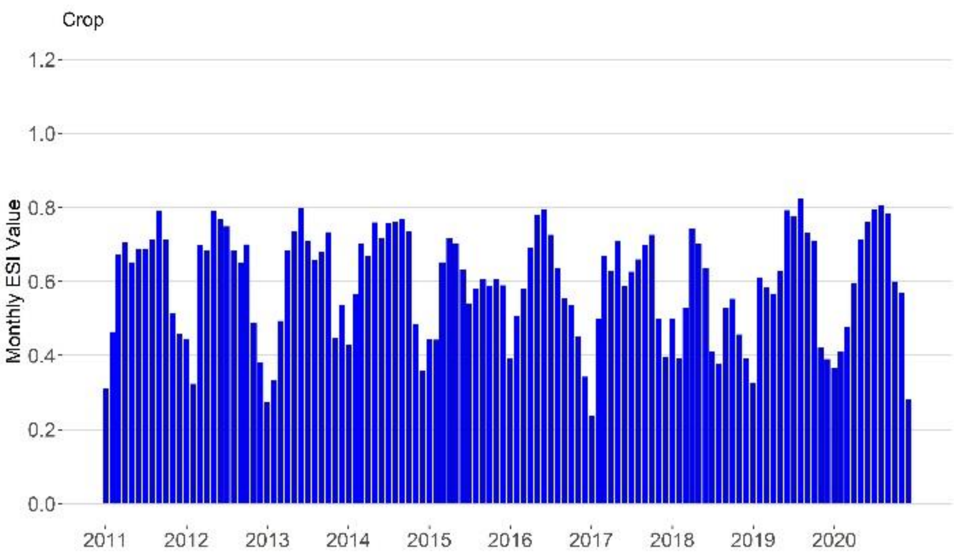
Back-up slides

RESULTS 7

Water Stress Maps: Ecosystems responses*: Crop



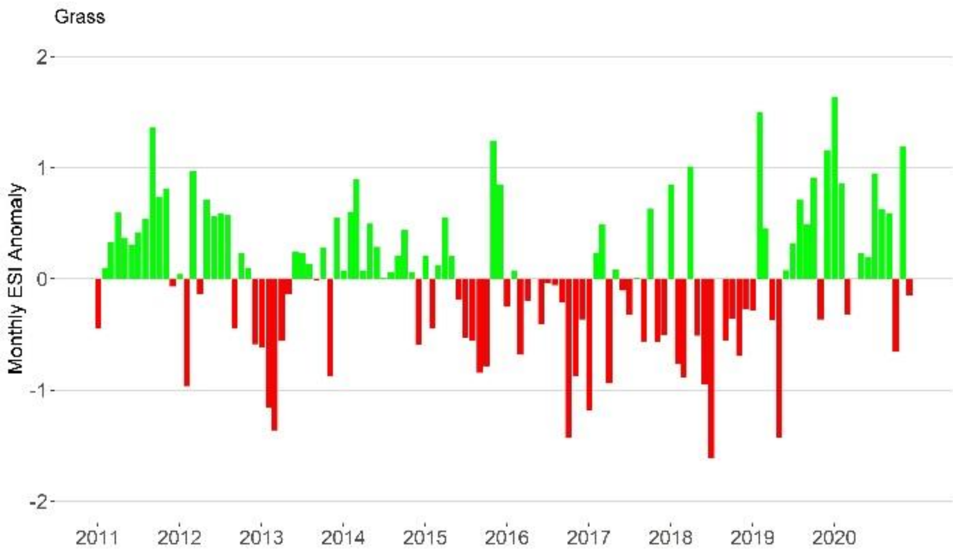


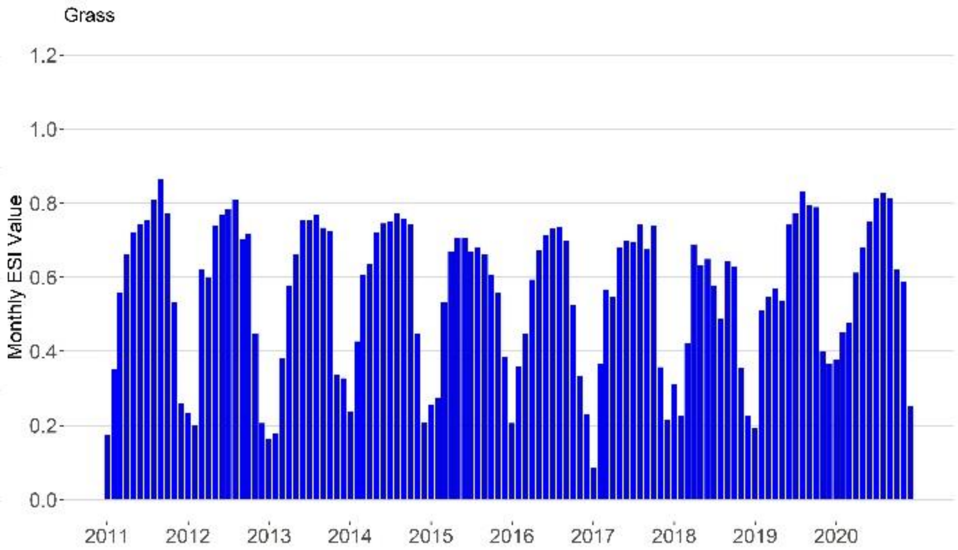
- ✓ 57 months with negative anomalies during the selected time series.
- ✓ 7 episodes at least three consecutive months exhibiting negative anomalies.

- ✓ Started with a **high ESI value in spring**, because **fertilization and plant type** initially enabled growth.
- ✓ As soil water becomes depleted during **summer**, however, crop **ESI** becomes particularly **low** because of **early maturity and harvest**.

RESULTS 7

Water Stress Maps: Ecosystems responses*: Grass





- ✓ 56 months with negative anomalies during the selected time series.
- ✓ 4 episodes at least three consecutive months exhibiting negative anomalies.
- ✓ Higher values in summer than winter, with a minimum peak ESI in the drought year 2018
- ✓ The response of **grassland** is **intermediate** between forests and crops!