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Standard course – Remote Sensing
SR3 – Environmental applications

Lluís Pesquer, Cristina Domingo / CREAF

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Land use Planning

- Land use / land cover
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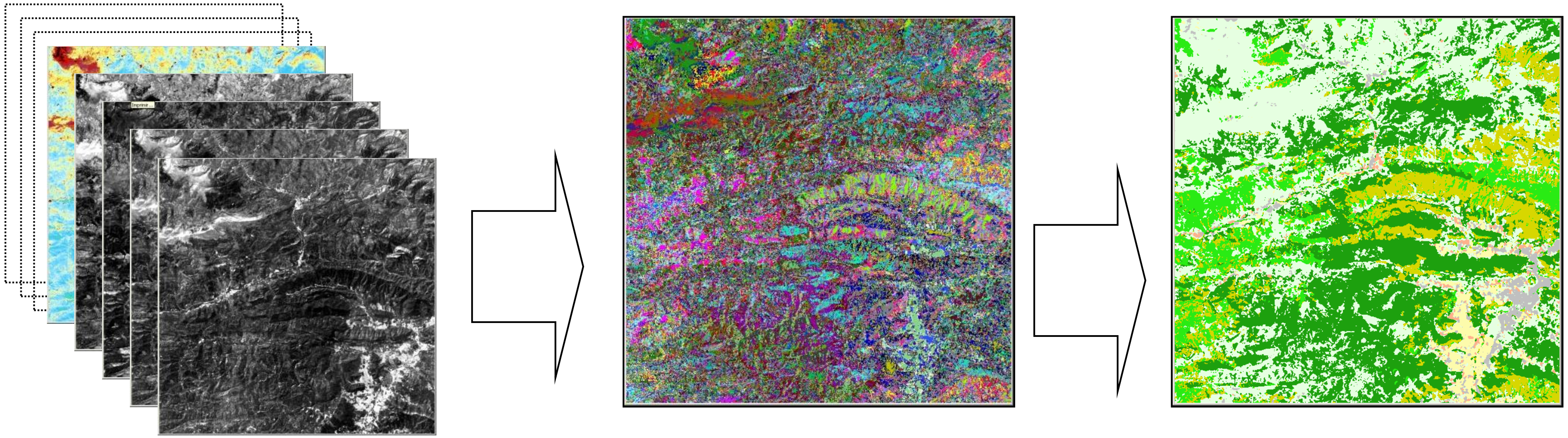
Land use / Land cover

Land cover maps are obtained by classification:

Classification: digital image process analysis, usually of original remote sensing images or derived products, to obtain categorical maps or an inventory of categories under study.

Each object (pixel or segment) of the images is assigned to a class map based on the characteristics of the object.



Original Variables

Informational classes

Land use / Land cover

The source data are strongly multivariate and can include both radiometric (multispectral, hyperspectral and / or multitemporal) and other information (elevations, slopes, shape or segment size characteristics, etc.).

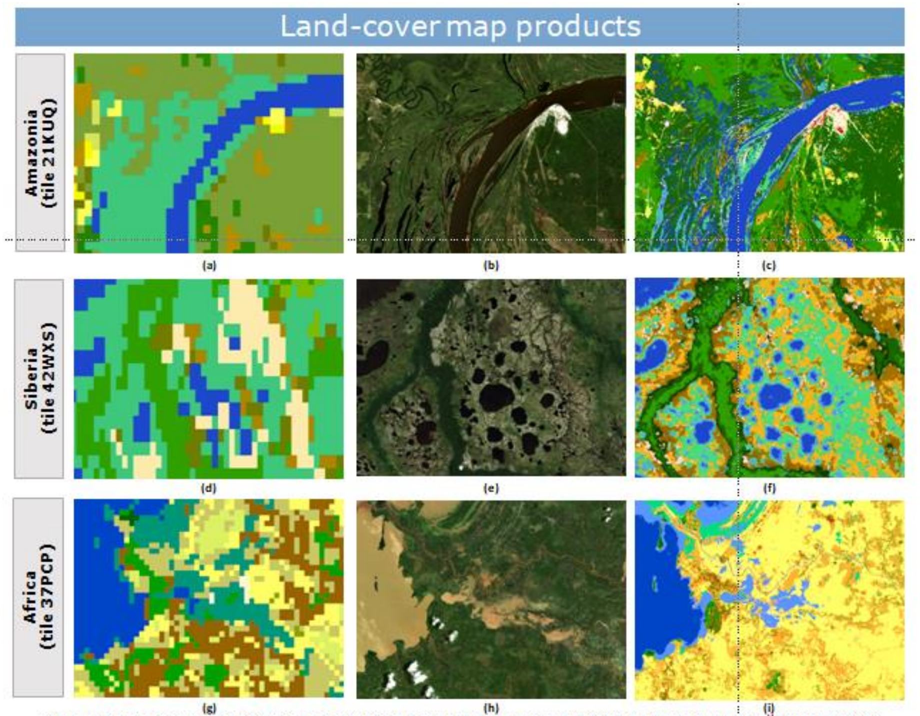


Fig. 3 - Example of comparison between: (a) (d) (g) 2015 ESA CCI MRLC at 300m; (b) (e) (h) Sentinel-2 image; and (c) (f) (i) the preliminary 2019 ESA CCI HRLC map obtained by fusion of Sentinel-2 and Sentinel-1 images from 2019 time series at 10m.

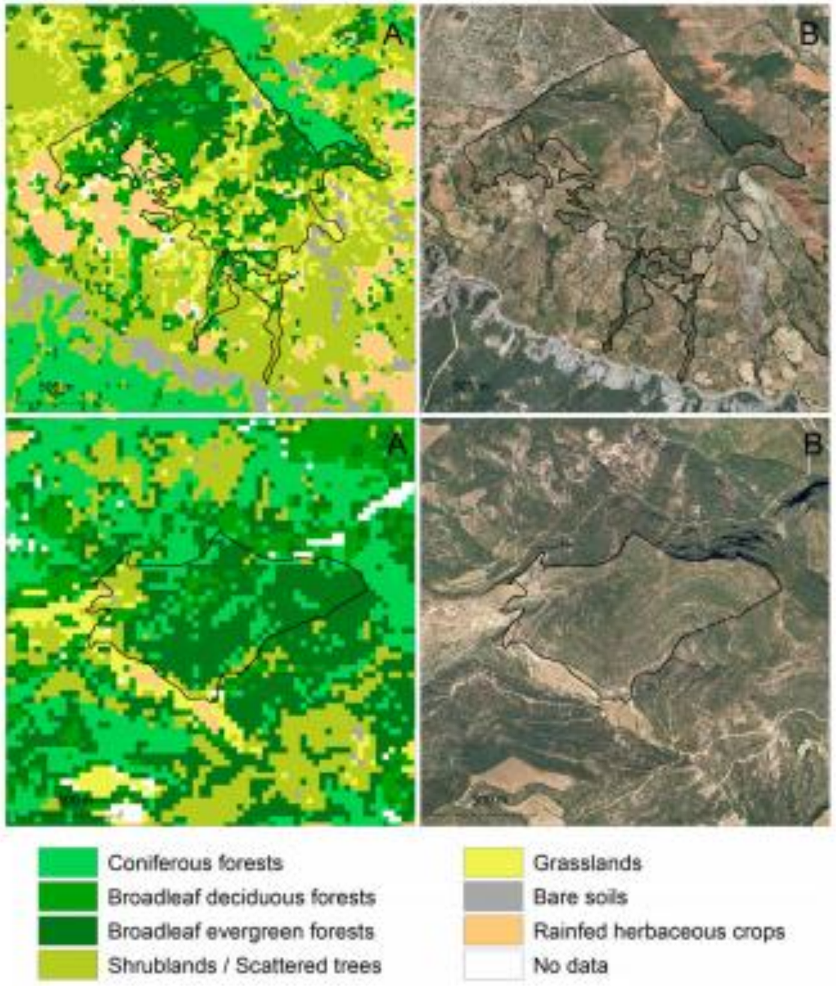
HRLC CLASSES

CODE	DN	1st LEVEL	CODE	DN	2nd LEVEL
10	1	Tree cover evergreen broadleaf			
20	2	Tree cover evergreen needleleaf			
30	3	Tree cover deciduous broadleaf			
40	4	Tree cover deciduous needleleaf			
50	5	Shrub cover evergreen	51	17	Broadleaf
			52	18	Needleleaf
60	6	Shrub cover deciduous	61	19	Broadleaf
			62	20	Needleleaf
70	7	Grasslands	71	21	Natural
			72	22	Managed
80	8	Croplands	81	23	Winter
			82	28	Summer
			83	33	Multicropping
90	9	Woody vegetation aquatic or regularly flooded			
100	10	Grassland vegetation aquatic or regularly flooded			
110	11	Lichens and Mosses			
120	12	Bare areas	121	38	Unconsolidated
			122	41	Consolidated
130	13	Built-up	131	42	Buildings
			132	43	Artificial Roads
140	14	Open Water seasonal			
150	15	Open Water permanent			
160	16	Permanent snow and/or ice	161	44	Snow
			162	45	Ice

The richness and the completeness of this data source allow to identify different classes and different levels of classification.

ESA CCI
High Resolution
Land Cover

Land use / Land cover



The obtained classes must be validated with reference data. The confusion matrix provides information on the quality assessment, detailed for each class.

Table 6. Southern scene 200034. 1985–1989 quinquennium.

	Reference data															
Classified data	1	2	3	4	5	6	7	8	9	10	11	12	14	Total	CE (%)	UA (%)
NoData	6	26	2	23	55	92	50	16	33	209	315	16,449	69	17,345		
(1) Water bodies	11,518	0	0	0	0	0	5	0	0	8	0	117	0	11,648	1.1	98.9
(2) Coniferous forests	0	24,131	0	946	112	0	0	0	0	0	20	249	0	25,458	5.2	94.8
(3) Broadleaf deciduous forests	0	3	1644	39	0	0	0	0	84	0	112	3	0	1885	12.8	87.2
(4) Broadleaf evergreen forests	0	437	16	5311	170	3	0	0	0	0	50	536	0	6523	18.6	81.4
(5) Shrublands	0	87	0	137	3748	257	7	0	0	0	11	2275	0	6522	42.5	57.5
(6) Grasslands	0	0	2	2	221	11,795	151	12	0	208	105	19,729	0	32,225	63.4	36.6
(7) Bare soils	1	0	0	0	0	49	1315	96	0	320	8	7714	42	9545	86.2	13.8
(8) Urbanized areas	0	0	0	0	0	0	0	7884	0	0	0	0	0	7884	0.0	100.0
(9) Irrigated herbaceous crops	0	0	6	0	0	0	0	0	5262	26	183	481	0	5958	11.7	88.3
(10) Rainfed herbaceous crops	4	0	0	0	0	10	4	18	8	130,789	315	30,822	0	161,970	19.3	80.7
(11) Irrigated woody crops	0	0	0	0	0	0	0	0	97	41	20,175	8056	2	28,371	28.9	71.1
(12) Rainfed woody crops	4	0	2	3	1	21	7	48	251	15,970	12,299	1,092,098	9	1,120,713	2.6	97.4
(14) Greenhouses	0	0	0	0	0	0	0	18	0	0	0	13	22,617	22,648	0.1	99.9
Total	11,533	24,684	1672	6461	4307	12,227	1539	8092	5735	147,571	33,593	1,178,542	22,739	1,458,695		OA (%) = 92.8%
OE (%)	0.1	2.2	1.7	17.8	13.0	3.5	14.6	2.6	8.2	11.4	39.9	7.3	0.5			OA_W (%) = 95.9%
PA (%)	99.9	97.8	98.3	82.2	87.0	96.5	85.4	97.4	91.8	88.6	60.1	92.7	99.5			$K = 0.8$

Notes: OE = omission error, CE = commission error, PA = producer's accuracy, UA = user's accuracy, K = Kappa statistics. The shaded values are number of correctly classified pixels in the test areas.

Vidal-Macua JJ, Zabala A, Ninyerola M, Pons X (2017) Developing spatially and thematically detailed backdated maps for land cover studies. International Journal of Digital Earth 10(2): 175-206.

Urban planning

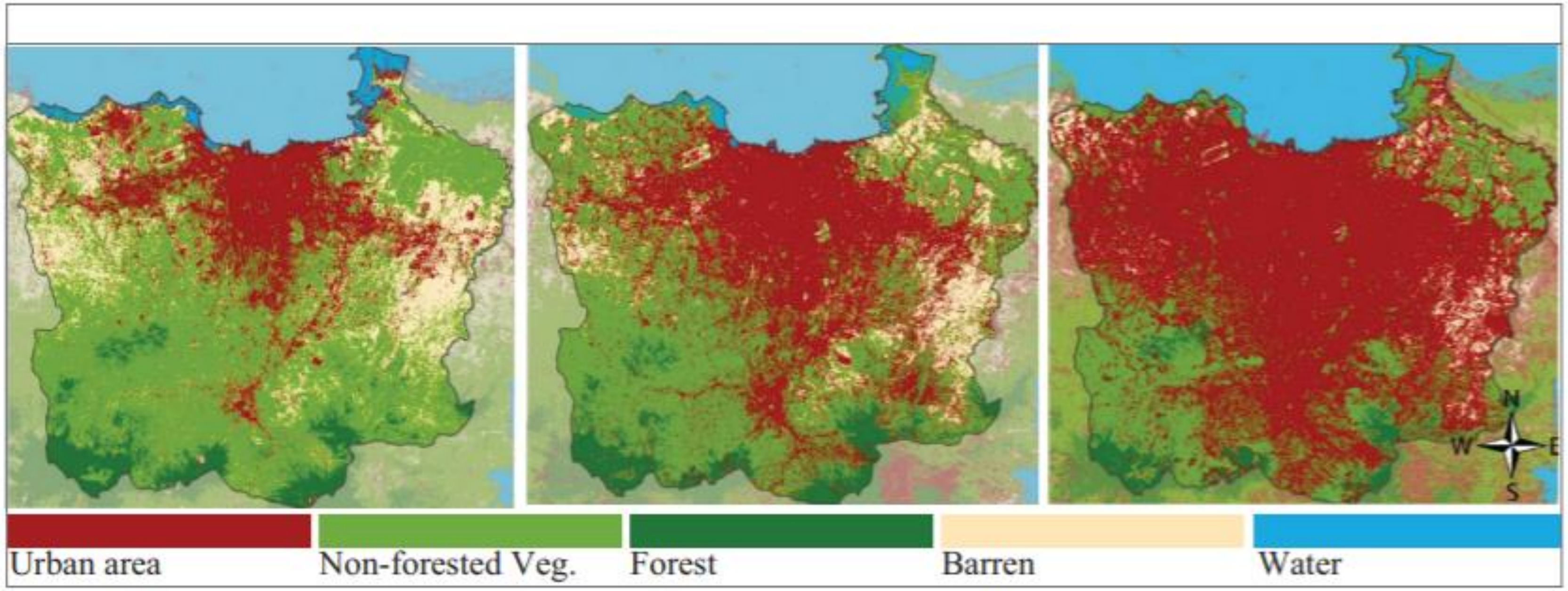
Urban development should be guided by a sustainable planning and management vision with:

- Provision of adequate and affordable housing for all
- Ensuring environmental sustainability
- Aims to obtain a balance between built and natural systems
- Efficient and multi-modal transportation
- Good governance and enhanced urban development
- Planning for flood mitigation

Urban planning

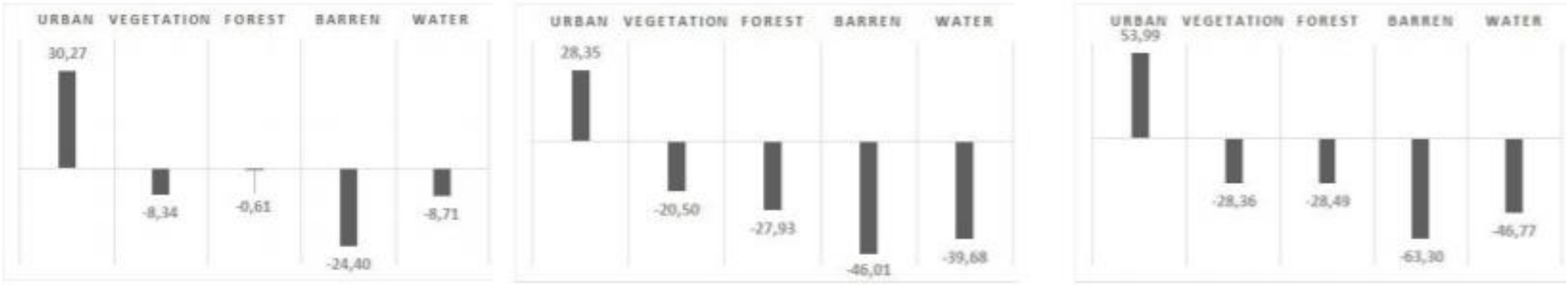
Land cover change, in particular the monitoring and the analysis of the evolution of built-up areas are useful tools for urban planning.

Urban growth: 2001 / 2008 / 2015



I. Fata

Figure 1: Land use in Jabodetabek.



Urban planning

Remote sensing + socio-economic data provides key indicators for the sustainable development goals.

11 SUSTAINABLE CITIES AND COMMUNITIES

SDG 11.3.1: Ratio of land consumption rate to population growth rate

$$LCRPGR = \left(\frac{\text{Land Consumption rate}}{\text{Annual Population growth rate}}\right)$$

Land consumption rate i.e

$$LCR = \frac{LN(Urb_{t+n} / Urb_t)}{(y)}$$

Where

Urb_t	Total areal extent of the urban agglomeration in km^2 for past/ initial year
Urb_{t+n}	Total areal extent of the urban agglomeration in km^2 for current year
y	The number of years between the two measurement periods

Population Growth rate i.e.

$$PGR = \frac{LN(Pop(_{t+n})/Popt)}{(y)}$$

Where

Pop_t	Total population within the city in the past/initial year
Pop_{t+n}	Total population within the city in the current/final year
y	The number of years between the two measurement periods

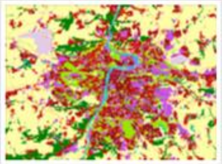
Urban planning

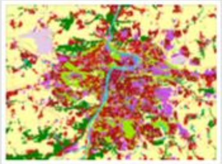
Characteristic	Ua2006	Ua2012
Nr. of FUAs	305	695
Total area	640.500 km^2	1.015.600 km^2
Minimum Mapping Unit (MMU)	0.25ha in urban areas, 1 ha in rural areas	0.25ha in urban areas, 1 ha in rural areas
Min. Mapping Width	10m	10m
MMU change layer		Class 1 to class 1 = 0.1 ha Class 2 - 5 to class 1 = 0.1 ha Class 2 - 5 to Class 2 - 5 = 0.25 ha Class 1 to Class 2 – 5 = 0.25 ha
Positional accuracy	+/- 5m	+/- 5m
Nr. of classes	21	27
Min. overall accuracy for "artificial surfaces" classes	85%	85%
Min. overall accuracy (all classes)	80%	80%

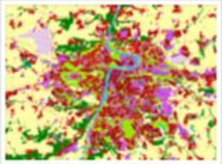
https://land.copernicus.eu/local/urban-atlas

The Urban Atlas is the first service to create harmonised land cover and land use maps over several hundreds of cities and their surroundings in the European Union and EFTA (European Free Trade Association) countries. It is mainly based on the combination of (statistical) image classification and the visual interpretation of Very High Resolution satellite imagery multispectral, SPOT 5&6, and Formosat-2 pansharpened with 2.5 m spatial resolution is used as input data.

Urban Atlas

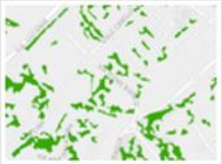

Urban Atlas 2006


Urban Atlas 2012


Urban Atlas 2018


Urban Atlas Change 2006-2012

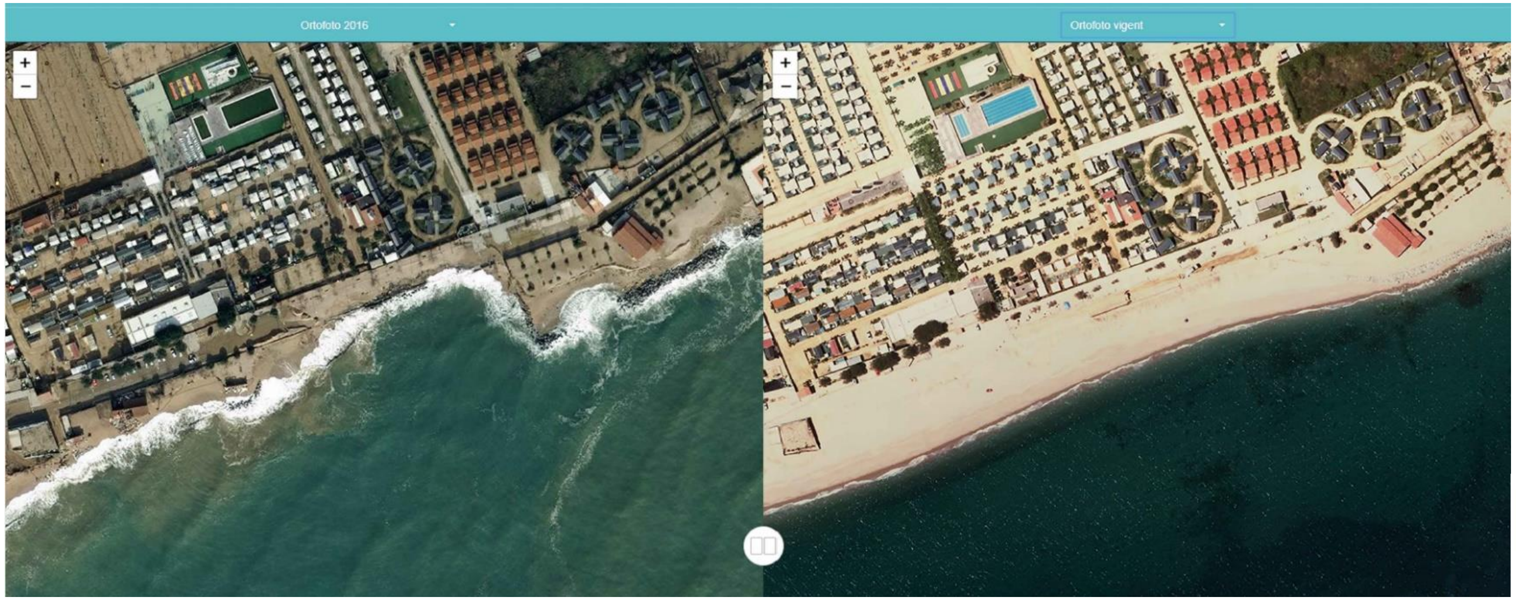

Urban Atlas Change 2012-2018


Street Tree Layer (STL) 2012

Urban planning

At urban costal areas, the monitoring of coastline is specially relevant. Remote sensing collects information on affected areas by extreme events and provides support:

- to emergency management.
- to decision systems for mitigation and adaptation plans.



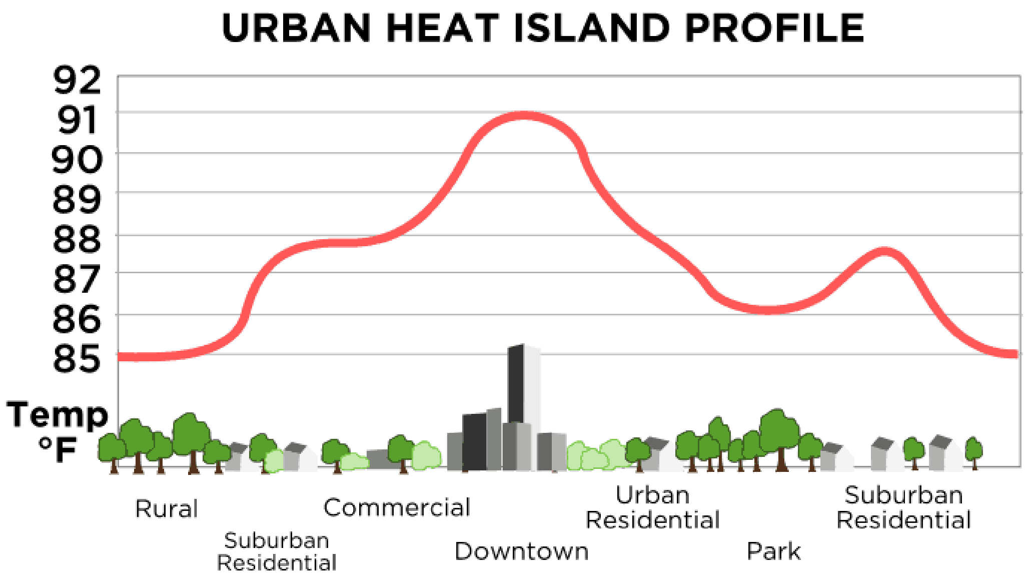
ICGC Institut Cartogràfic i Geològic de Catalunya

Urban heat islands

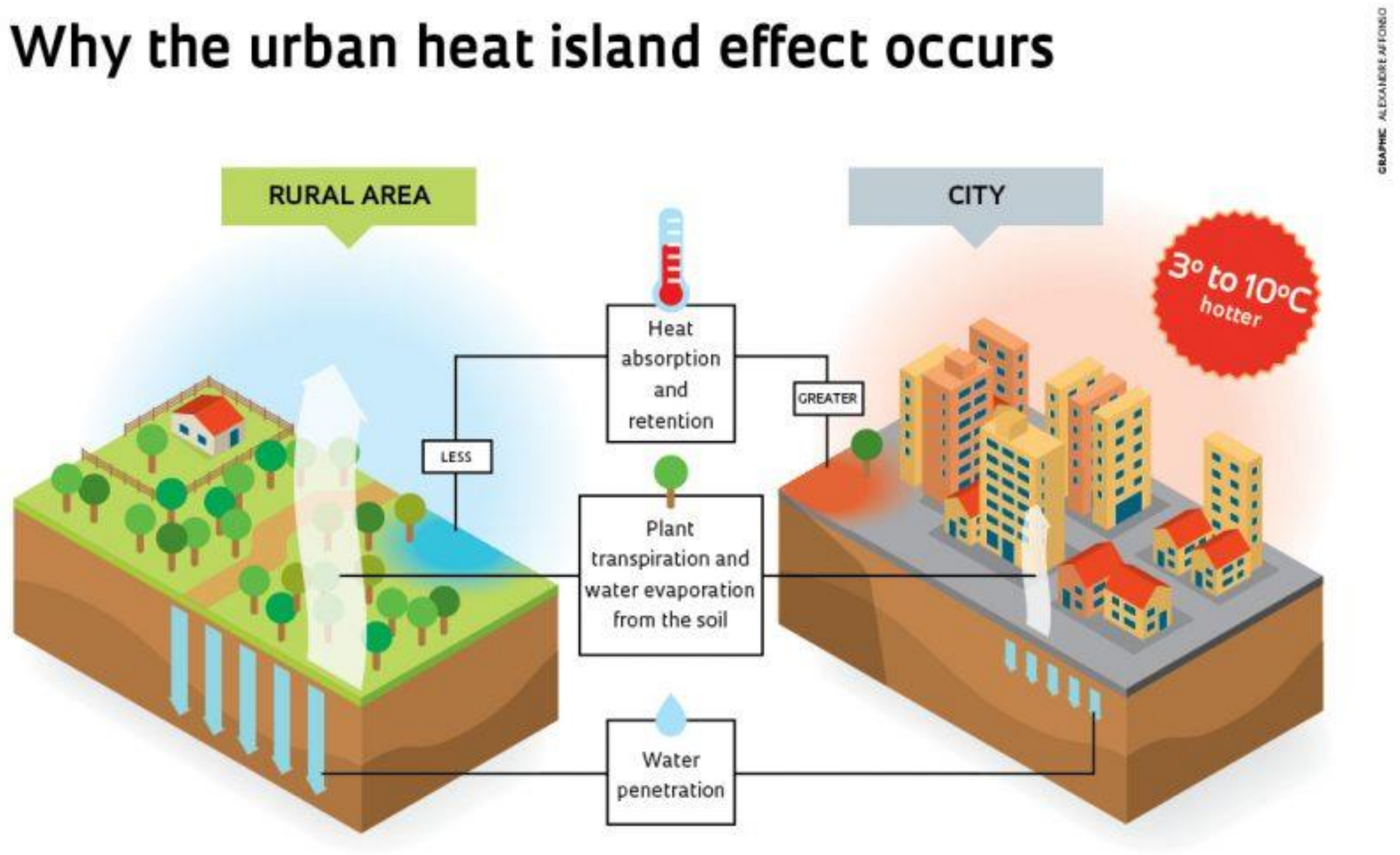
The urban heat island (UHI) is a phenomenon in which temperature tends to be higher in urban zones than surrounding non-urban areas (T.R. Oke).

The amount of the heat differential between the city and the surrounding environment depends on how much of the ground is covered by trees and vegetation.

Understanding urban heating will be important for building new cities and retrofitting existing ones (M. Imhoff).

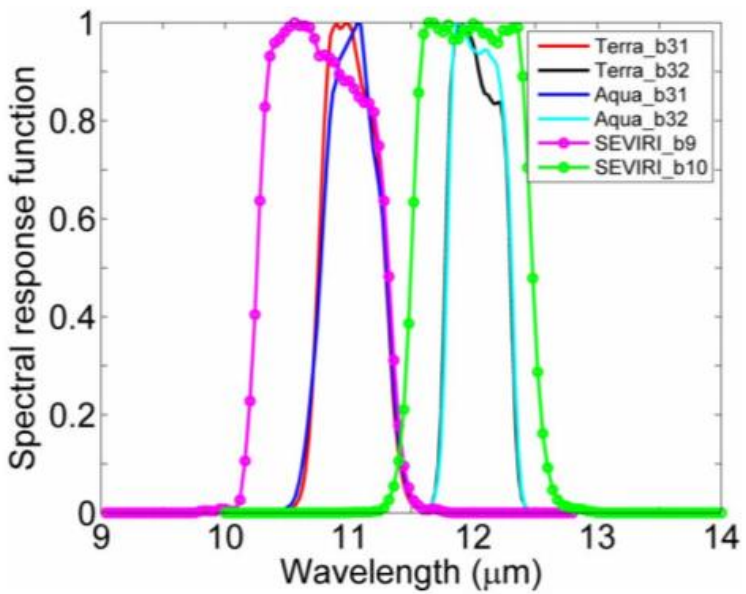


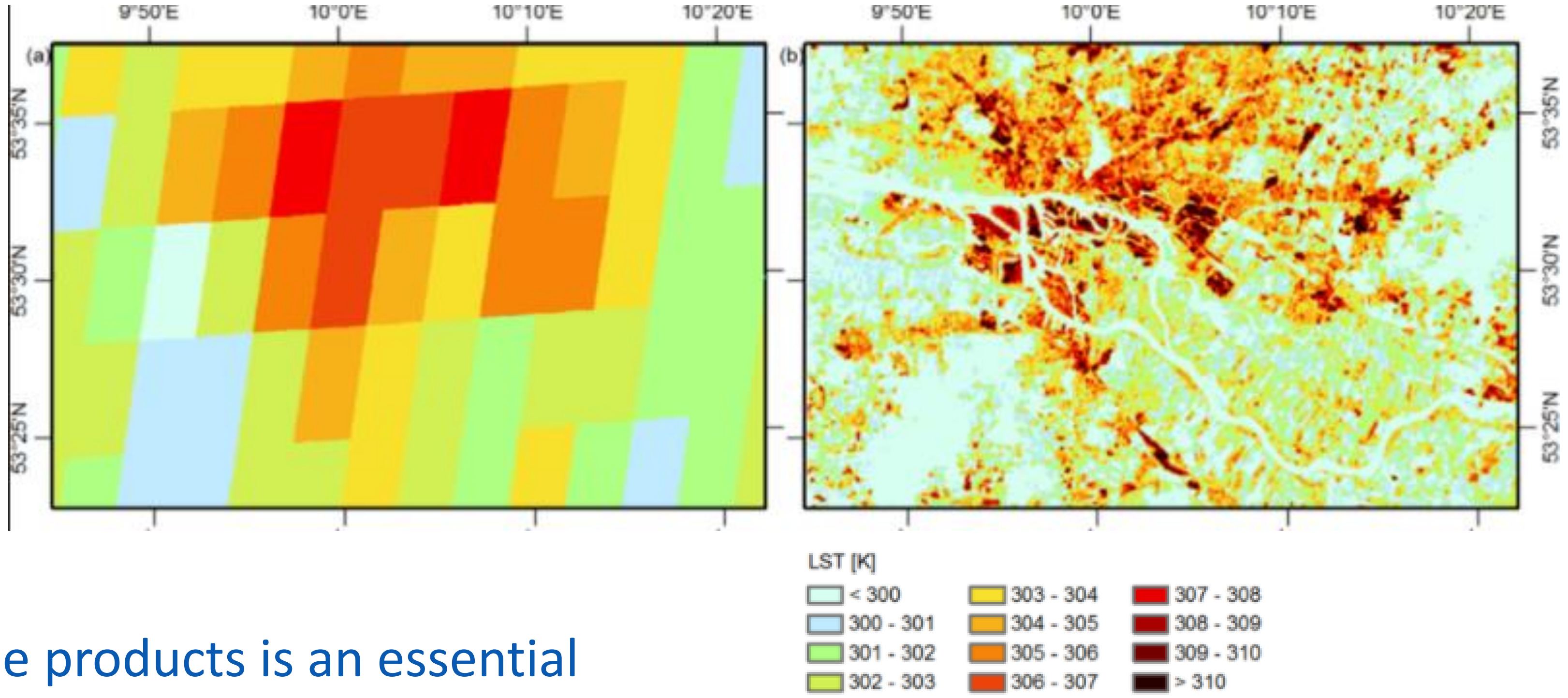
Urban heat islands



Urban heat islands

Remote sensing provides Land Surface Temperature products coming from processing of thermal (TIR) bands of some sensors.





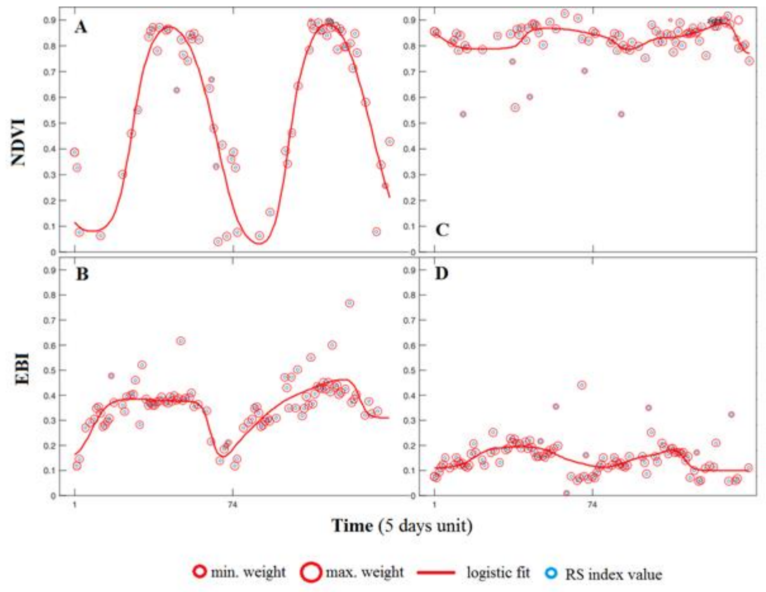
The spatial resolution of these products is an essential feature in urban applications.

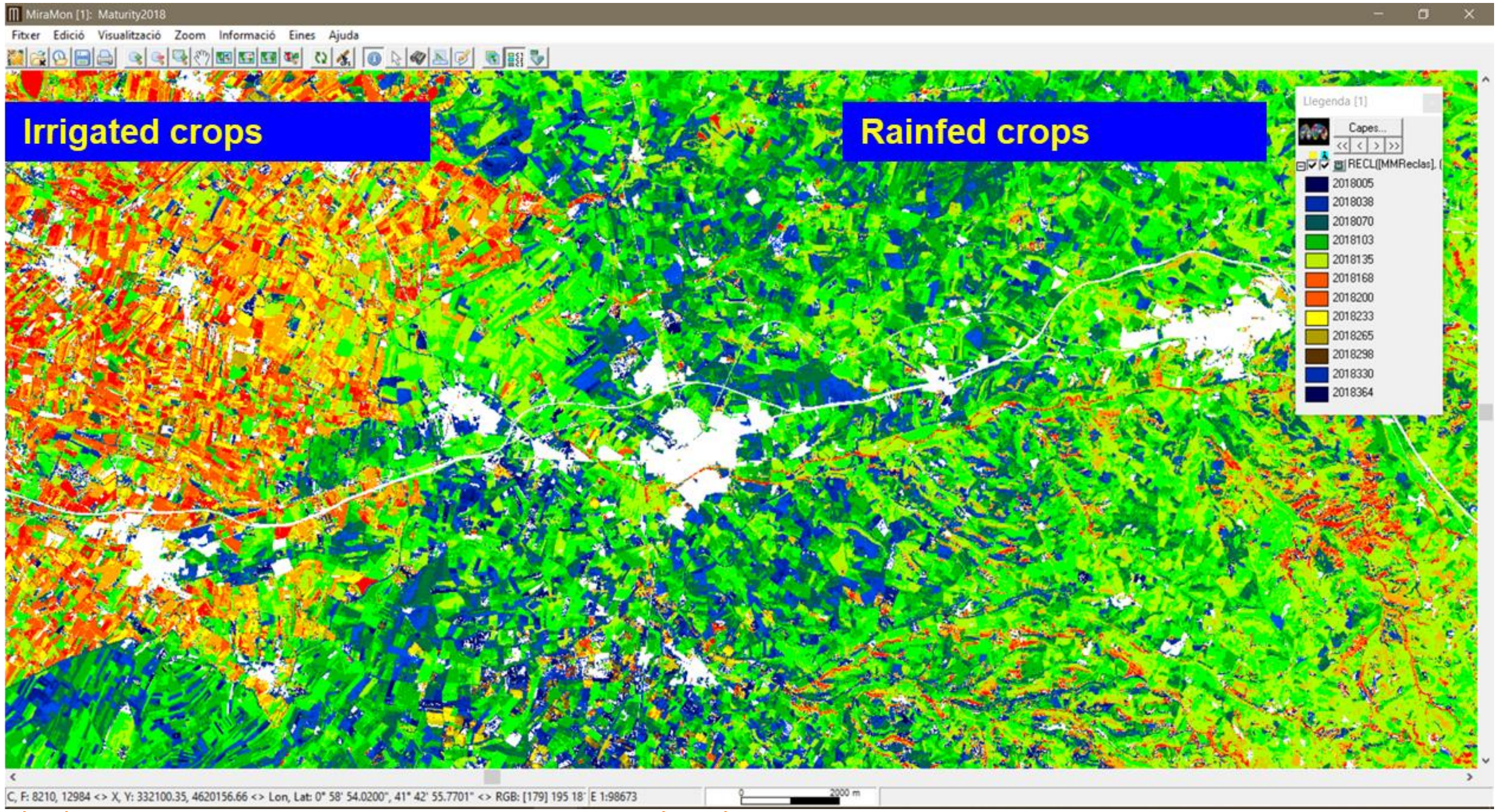
B. Betchel

Agriculture

- Seasonal patterns – phenology

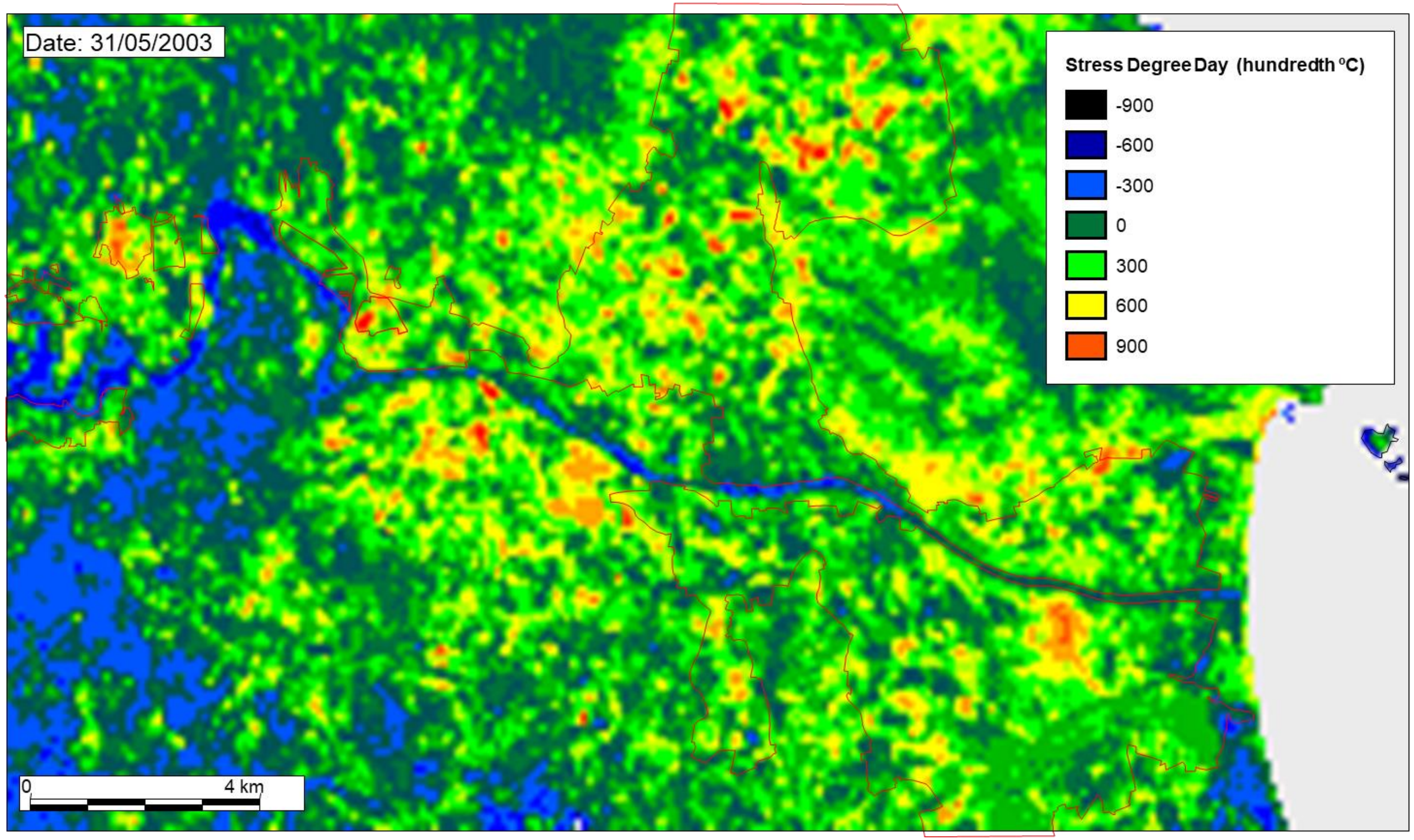
Computation of phenological Remote Sensing (RS) derived high level products is possible: e.g. green-up, maturity, senescence and dormancy to monitor irrigation practices and crops stage of growth.





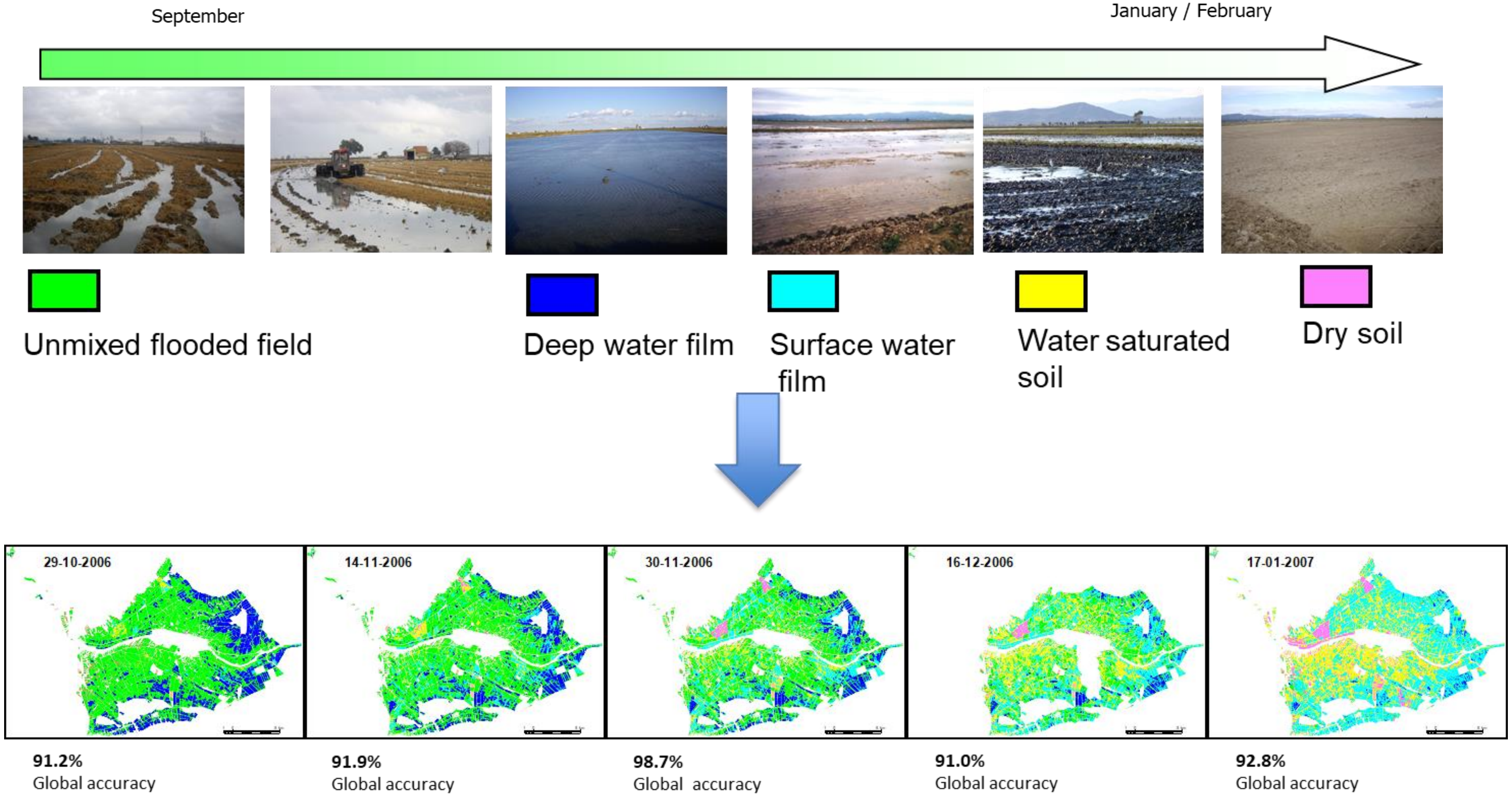
Agriculture

•Monitoring of crop evapotranspiration to predict future crop water requirements based on Landsat Thermal data.



Agriculture

- Use of Land cover classification (canonical components) and crop monitoring systems to monitor rice crops dynamics using optical data.



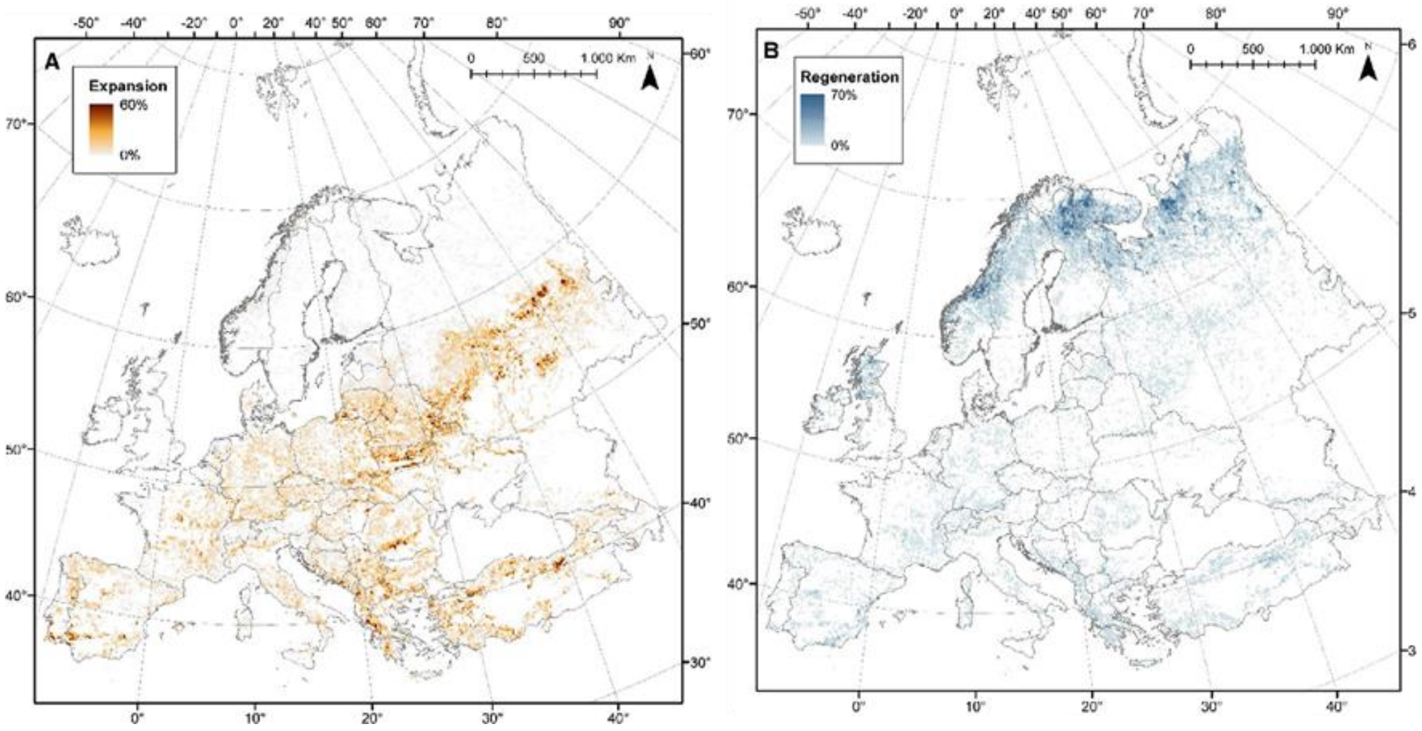
Serra et al

Forestry

Long term forest ecosystem monitoring

- Use of Land cover and EVI (Enhanced Vegetation Index) to monitor evolution of forest area in Europe.

- Recent forest area increase in Europe is mostly caused by forest expansion into former less productive agricultural areas.
- Increase of 1.4% from 1992 to 2015.
- The 66% of this forest area increase corresponded to forest expansion mostly in Mediterranean and temperate regions, while regeneration (34%) dominated in boreal areas.

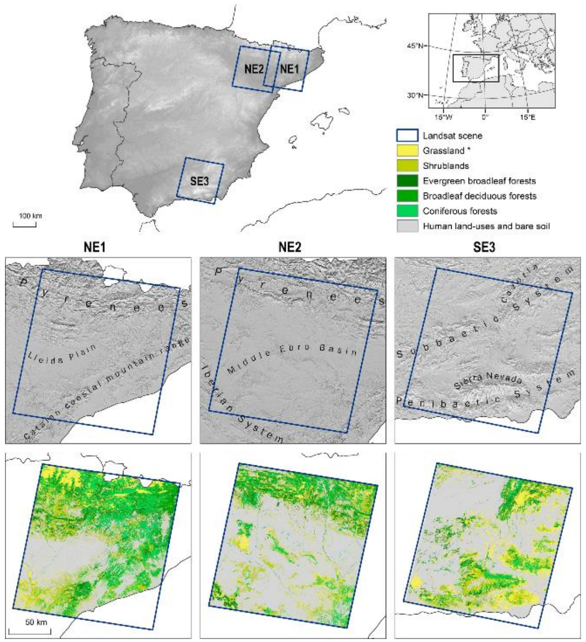


Palmero-Iniesta, M., Pino, J., Pesquer, L. et al. Recent forest area increase in Europe: expanding and regenerating forests differ in their regional patterns, drivers and productivity trends. *Eur J Forest Res 140, 793–805* (2021).

Forestry

Long term forest ecosystem monitoring

- Use of Landsat time series to monitor changes in forests during the last 25 years.
- Boosted regression trees applied to forest dynamics.
- At Iberian Peninsula, increase of drought episodes and lack of water favoured Mediterranean species.



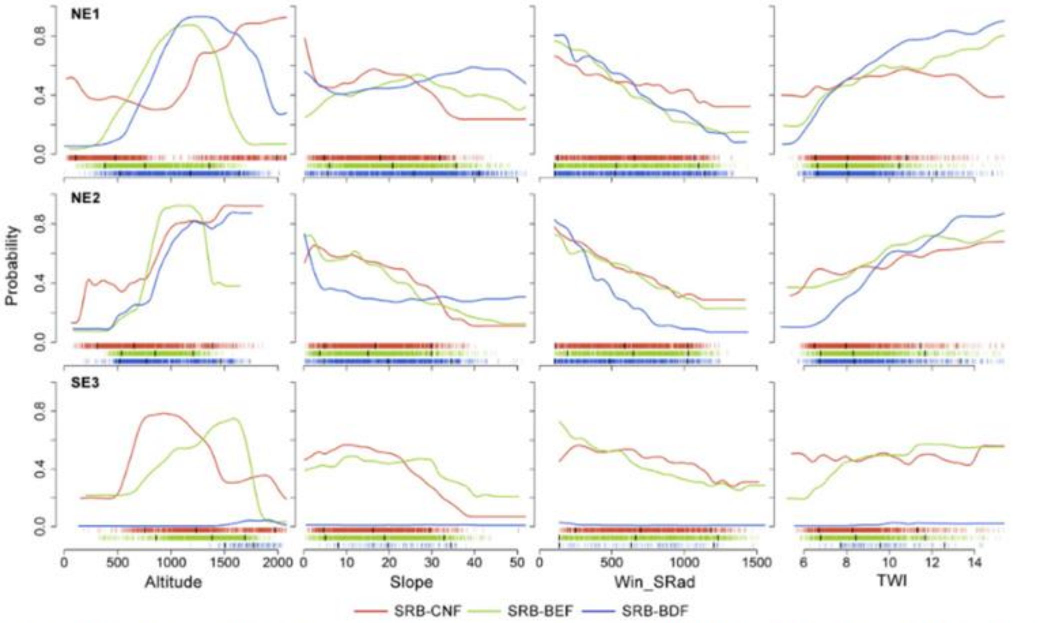


Fig. 2. Response of SRB-CNF, SRB-BEF and SRB-BDF transitions to altitude, slope, solar radiation and soil moisture (TWI) for the three ambits in the 1987–2012 period. Density of presence events is represented by vertical lines above the x-axes, and overlaid solid black ticks depict the 0.05, 0.5 and 0.95 percentiles.

Vidal-Macua J.J., Ninyerola M., Zabala A., Domingo-Marimon C., Pons X. (2017). Factors affecting forest dynamics in the Iberian Peninsula from 1987 to 2012. The role of topography and drought. *Forest Ecology and Management 406 290-306*

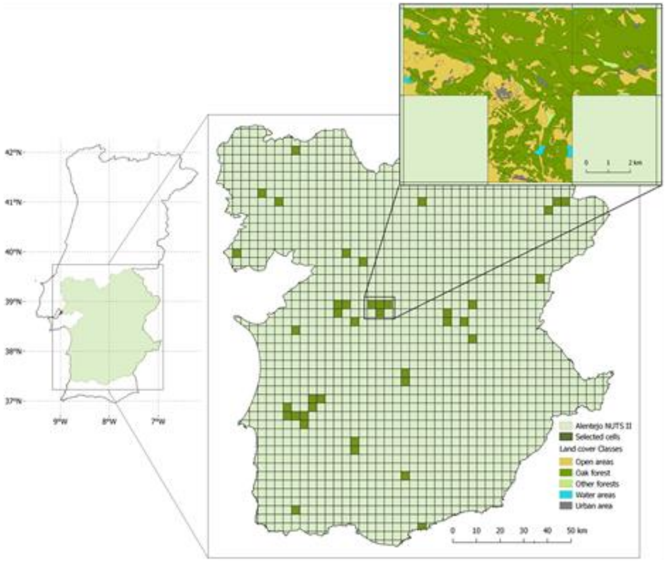
Biodiversity

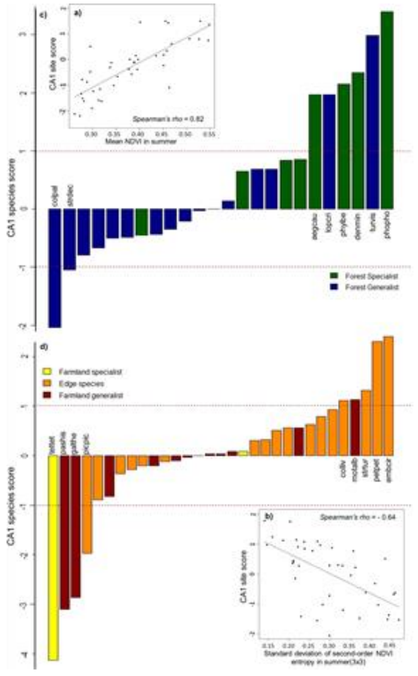
Use of optical data and biodiversity data to investigate the relationship between the richness and dissimilarity of forest and open-land bird communities and variables of habitat extent and structure.

- Spring and summer images are especially relevant.
- Availability of tree cover is more important than extent or structure of forest.

	Significant variables	Relative importance	% Deviance explained
Forest species			36.947
	NDVI_mn_SU	0.514	
	Geographic distance	0.090	
Open-land species			23.874
	NDVI_ent3x3_sd_SU	0.240	
	Geographic distance	0.154	
All species			39.844
	% OpnAr	0.208	
	NDVI_var3x3_mn_SU	0.169	
	Geographic distance	0.122	
	NDVI_sd_SU	0.120	

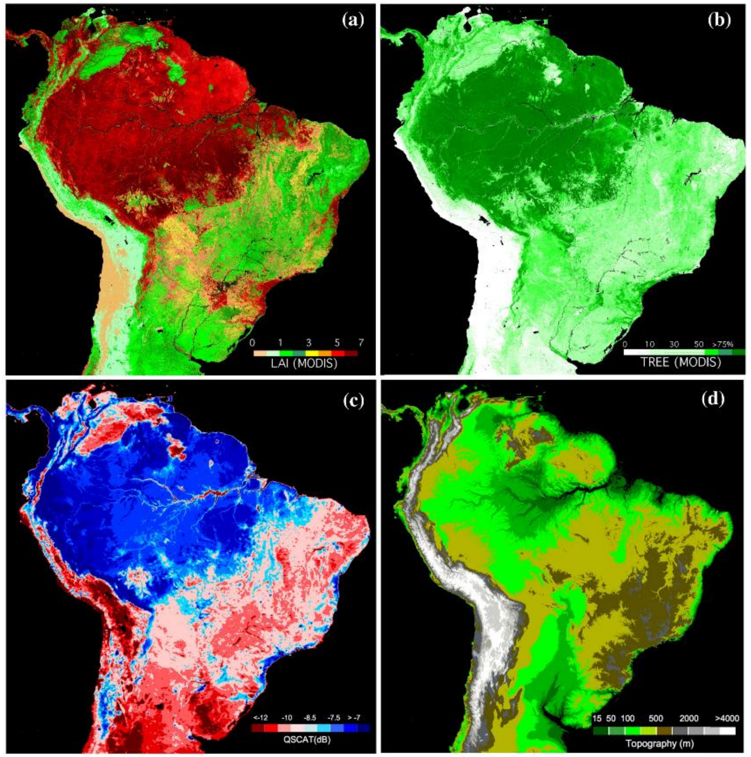
Ribeiro, …, Domingo-Marimon et al. (2019) Remotely sensed indicators and open-access biodiversity data to assess bird diversity patterns in Mediterranean rural landscapes. *Scientific Reports 9, 6826*



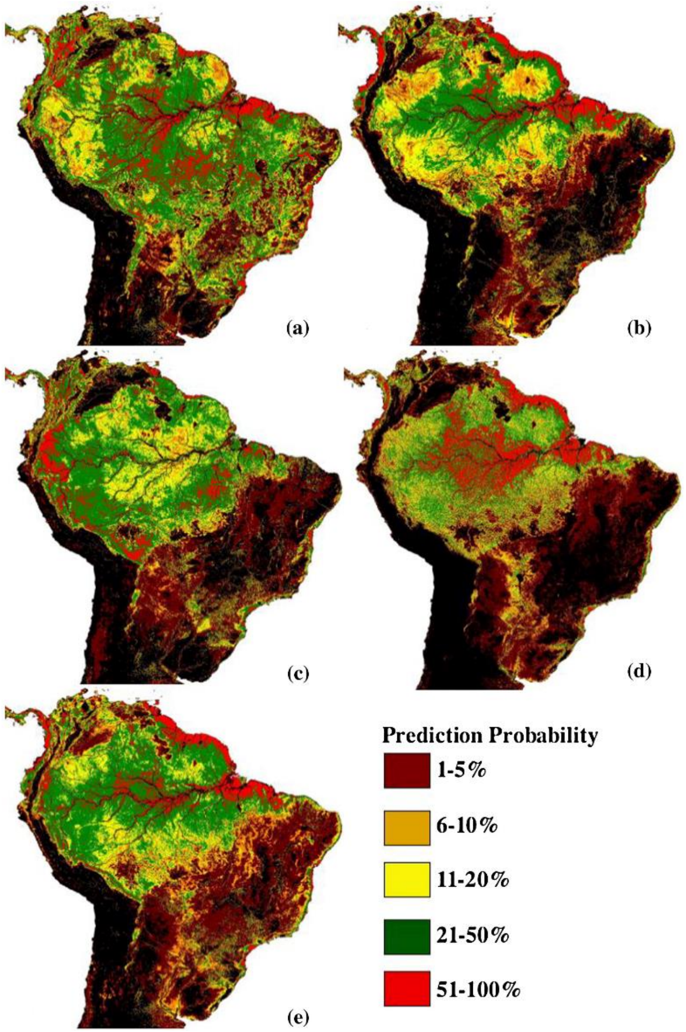


Biodiversity

Modelling distribution of tree species using MaxEnt model and simulations based on RS products.



Remote Sensing data layers



Maxent Prediction of potential geographic distribution of five tree species

Saatchi, S., Buermann, W., Ter Steege, H., Mori, S. & Smith, T. B. Modeling distribution of Amazonian tree species and diversity using remote sensing measurements. Remote Sensing of Environment 112, 2000-2017 (2008)

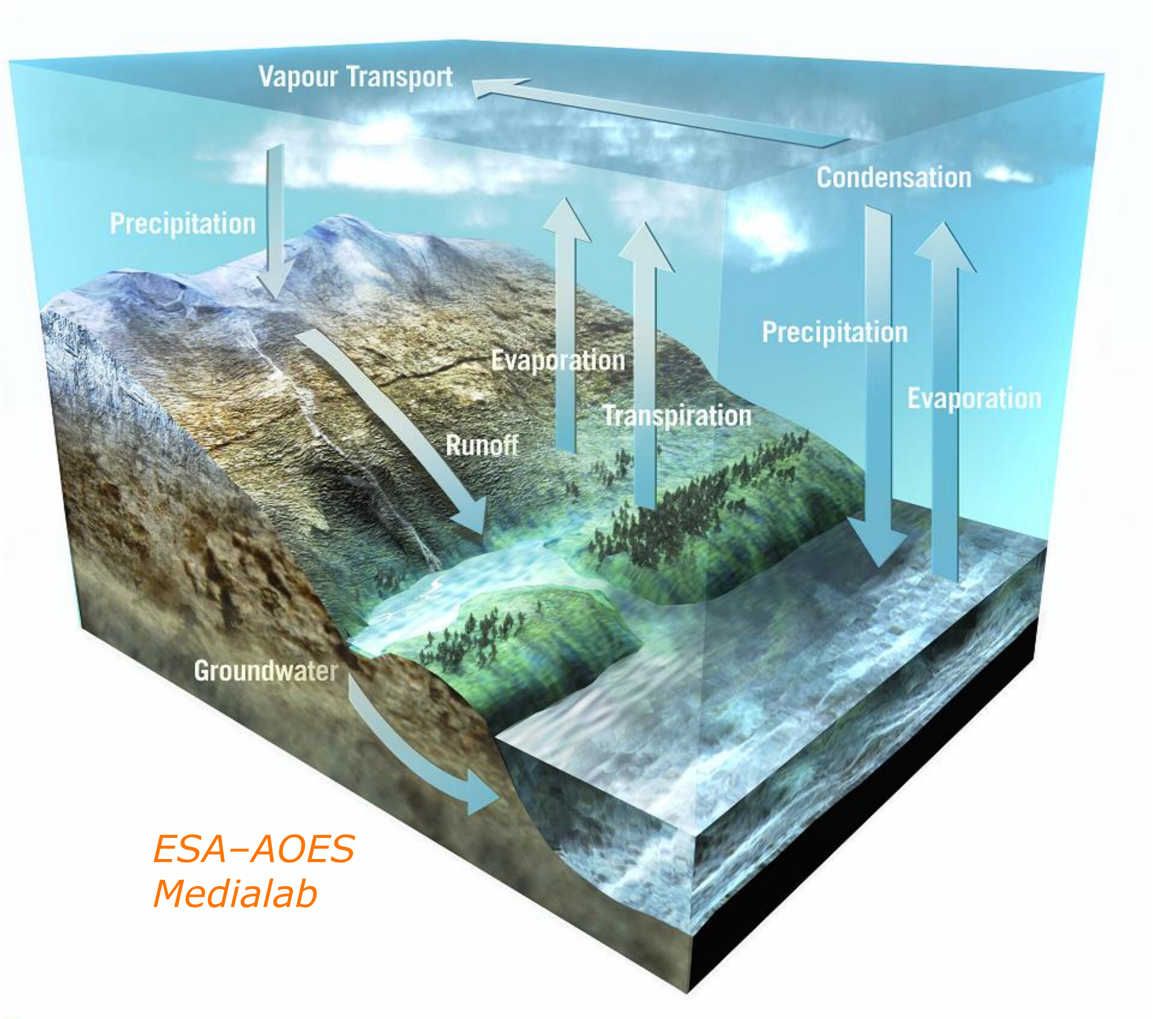
Water applications

- Scope and challenges
- Water Quality
- Soil moisture
- Snow
- Wetlands
- Groundwater

Water applications

Earth Observation provides information on all components of the water cycle: the water continuum circulation between the land, the atmosphere and the oceans.

The circulation and conservation of Earth's water is a crucial component of our weather and climate.



ESA–AOES Medialab

Water applications

The **main challenges** of Remote Sensing on Water sector are:

- Real-time hydro-meteorological monitoring and forecasting
- Flood monitoring and analysis
- Water scarcity and droughts events
- Water quality monitoring and analysis
- Snow cover and sea-ice mapping
- Monitor soil moisture
- Status of riparian ecosystems

Water applications

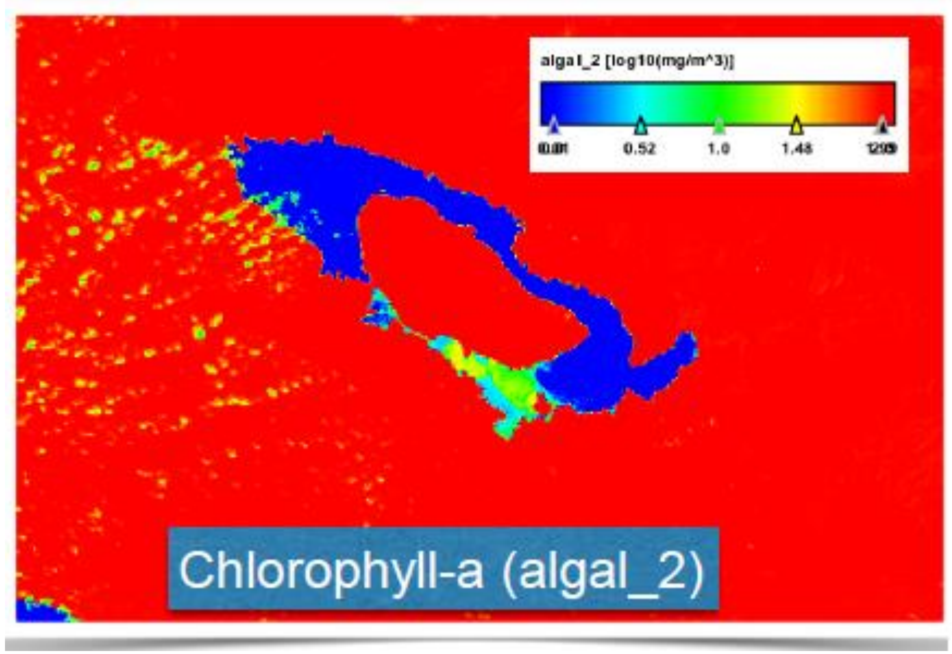
The review of Water applications has some overlaps with natural hazards and with climate applications. Droughts and floods events are an example of this 3-sides overlapping.

Essentially, this course follows the same solution of the Early Warning and Monitoring component of the **Copernicus** Emergency Service **(EMS),** that includes:

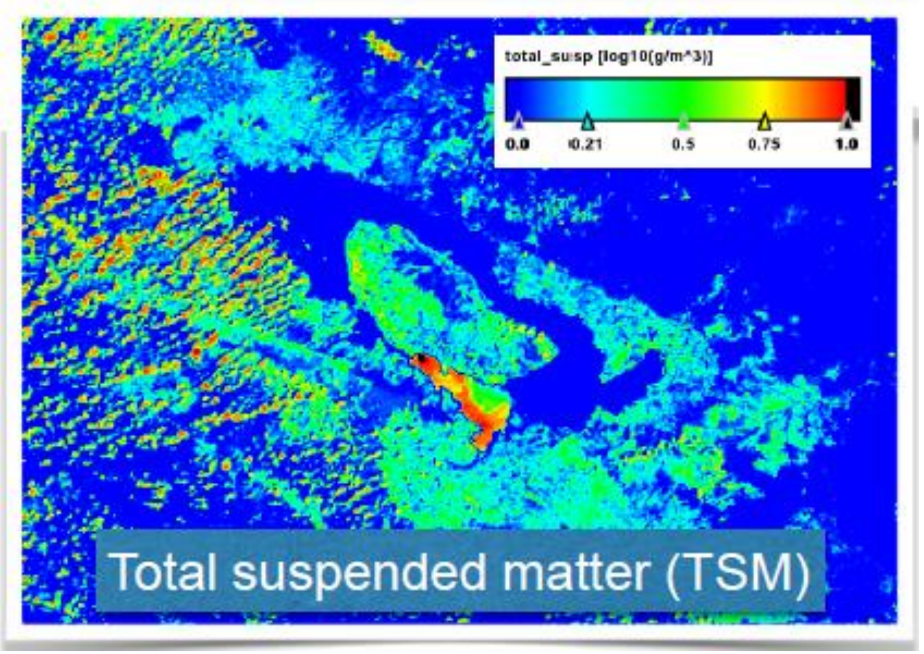
- The European Flood Awareness System (**EFAS**), which provides overviews on ongoing and forecasted floods in Europe up to 10 days in advance.
- The European Drought Observatory (**EDO**), which provides drought-relevant information and early-warnings for Europe.

Water quality

Water Quality: Remote Sensing provides spatial and temporal information about turbidity, chlorophyll, phosphorus, nitrogen, oxygen content, total suspended solids, etc.



Chlorophyll-a (algal_2)



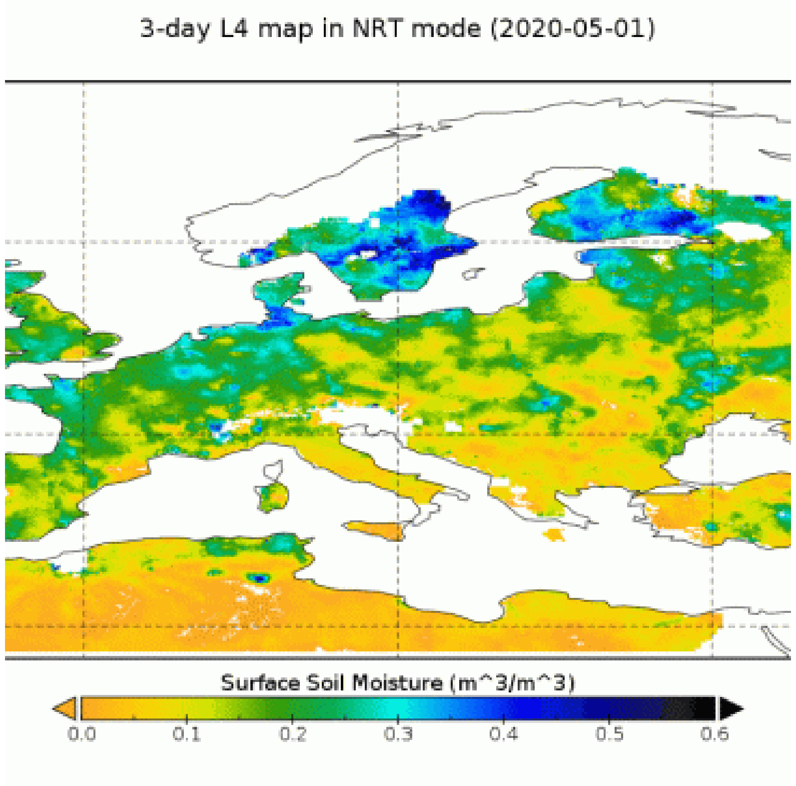
Total suspended matter (TSM)

Lake Toba
Sentinel-3A
products

Soil Moisture

SMOS Soil Moisture and Ocean Salinity mission provides global observations of variability in soil moisture and sea surface salinity.

It contributes to scientific knowledge of the Earth's water cycle and for an enhanced understanding of ocean circulation that is vital for climate change models.

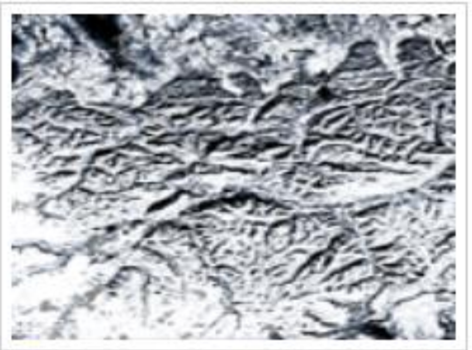


*BEC SMOS Soil Moisture **1 km** product covering Europe (35 km original product)*

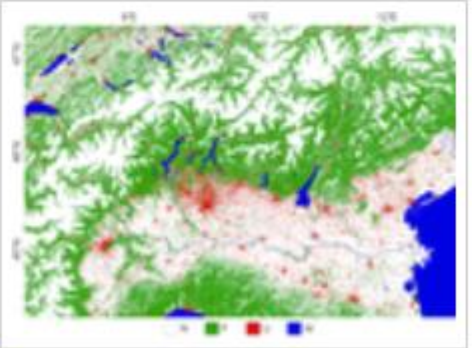
Snow

Snow cover is major component of the water budget in many parts of the world. Accurate and timely information on snow parameters is very relevant in climate analysis and modelling. Different snow products are available, such as:

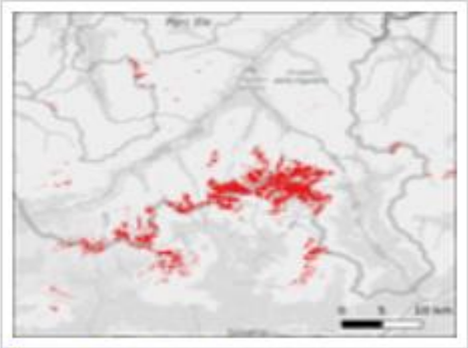
- Fractional snow cover (FSC) and snow water equivalent (SWE) by ESA CCI and GlobSnow.
- FSC at the Top Of Canopy (FSCTOC) and On Ground (FSCOG), SAR Wet Snow (SWS) and Persistent Snow Area (PSA) by Copernicus.



Snow cover



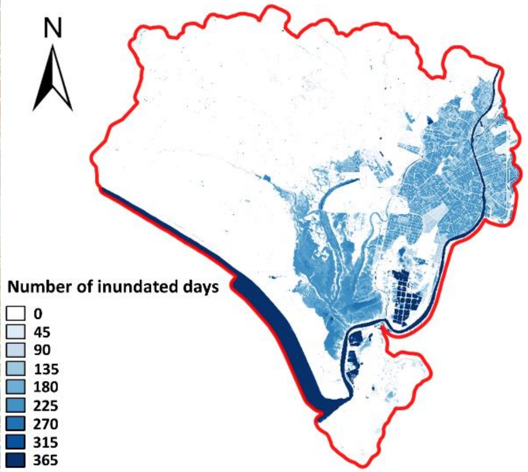
Snow state conditions

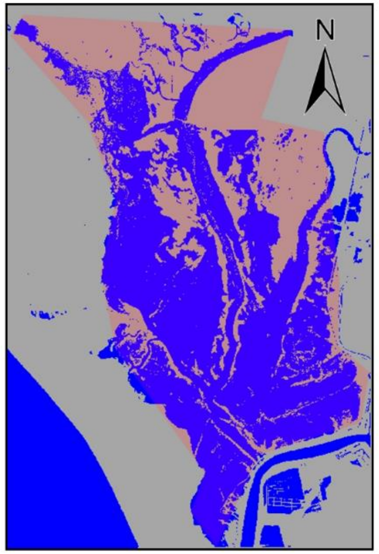


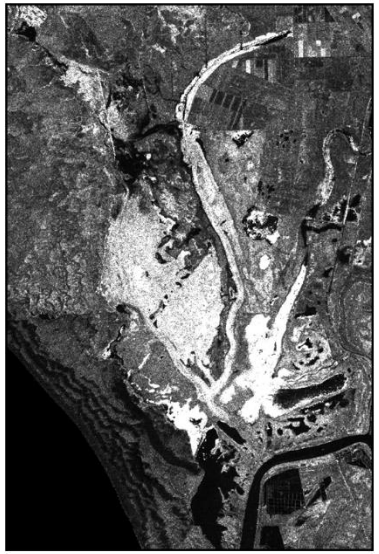
Persistent snow area

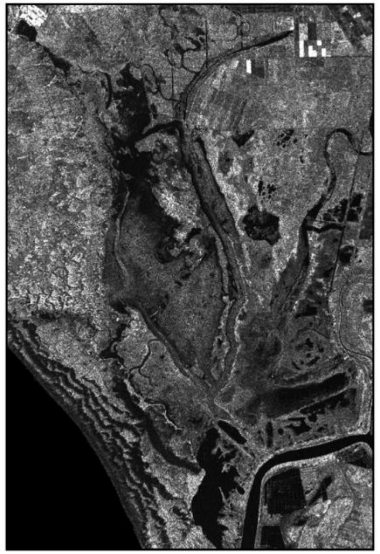
Wetlands

Study wetland seasonal dynamics and hydroperiods duration and trends of Mediterranean wetlands via the utilization of satellite data (especially Copernicus ones, Sentinel-1 and Sentinel-2).









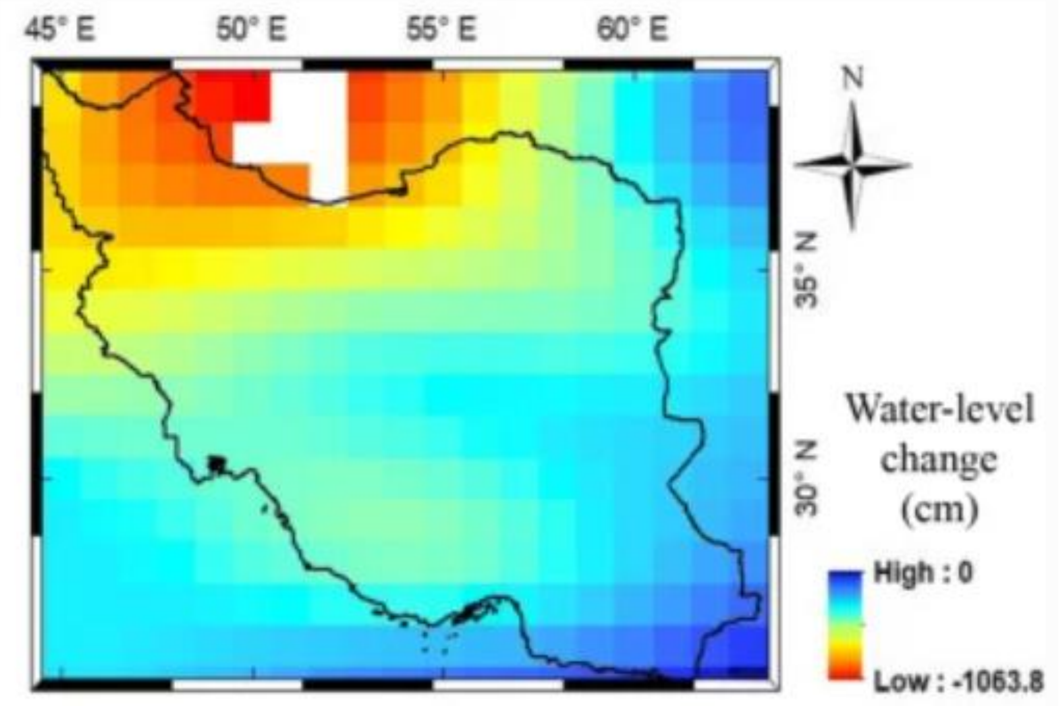
https://sentinel.esa.int/web/success-stories/-/copernicus-sentinels-improve-hydroperiod-estimations-of-mediterranean-wetlands

Groundwater

The conventional satellite instruments are not capable of measuring electromagnetic radiation below the ground surface.

M. Rahimzadegan

Satellite gravimetry is capable of measuring tiny changes of the gravity field, thus it can obtain information about the dynamics of groundwater depletion and storage.



Gravity Recovery and Climate Experiment (GRACE) is monitoring groundwater reservoirs.

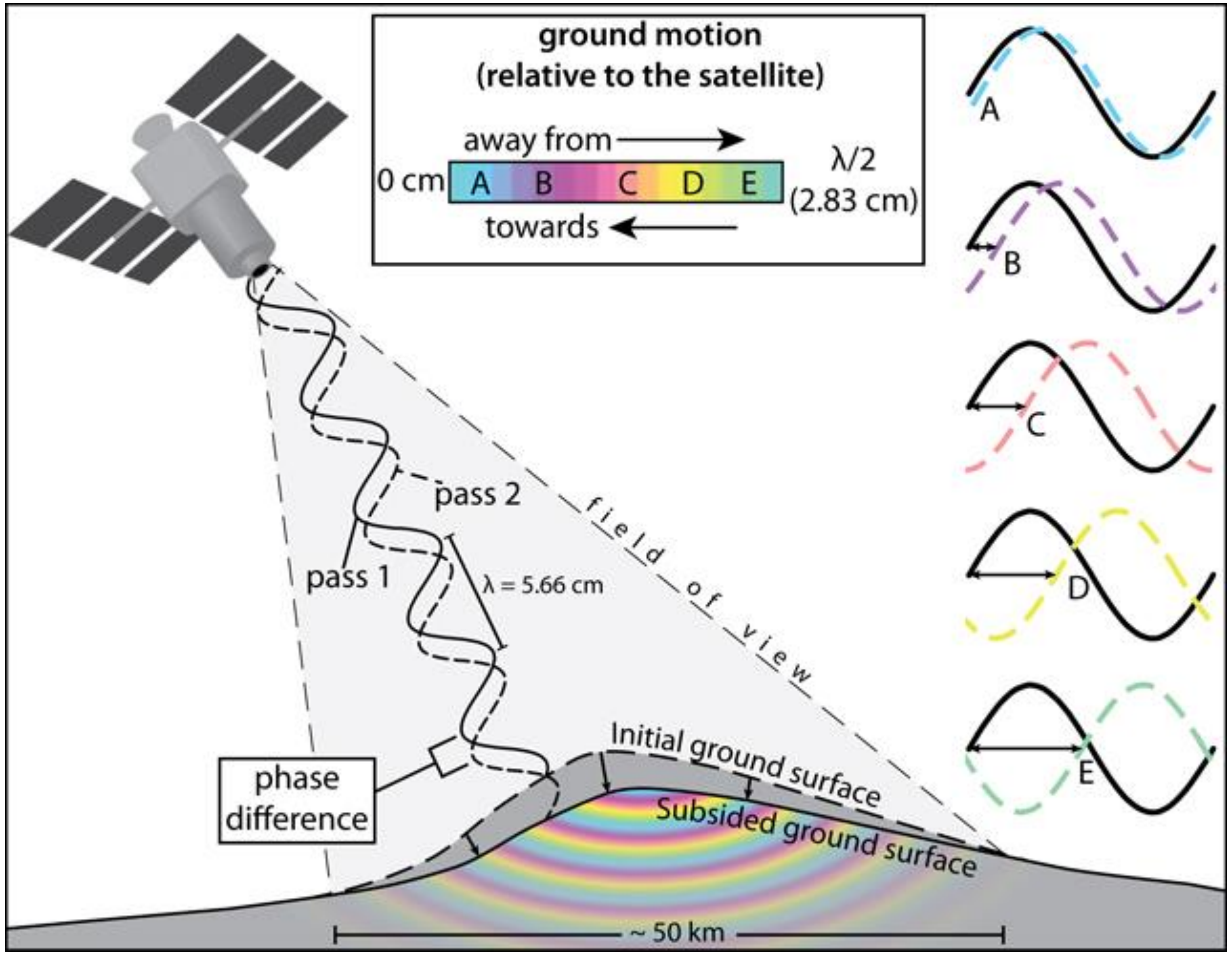
Groundwater

An alternative is the measurement of the effect of changes in groundwater storage by measuring its effect on land movement.

Changes in groundwater storage in confined aquifers result in an elastic response of the soil matrix noticeable as either subsidence (groundwater withdrawal) or heave (recharge).

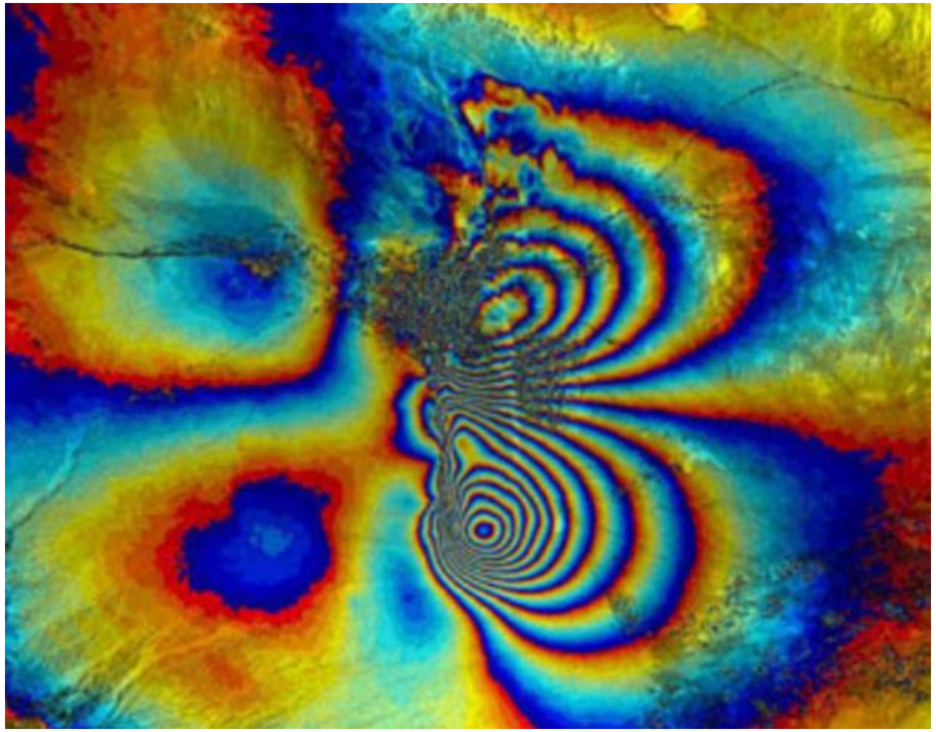
This response can be measured by active microwave sensors, using interferometric SAR-imagery.

Groundwater



volcano.si.edu

Interferometric SAR-imagery



Natural and man-made hazards

- Floods
- Droughts

Droughts

Drought indices:

The standardized indices SPI and SPEI classify the precipitation and water balance anomalies with respect to the long term observations. Most of these observations are in-situ. Remote sensing provides proxies and auxiliary variables for extending, downscaling and mapping these observations and derived products/indices.

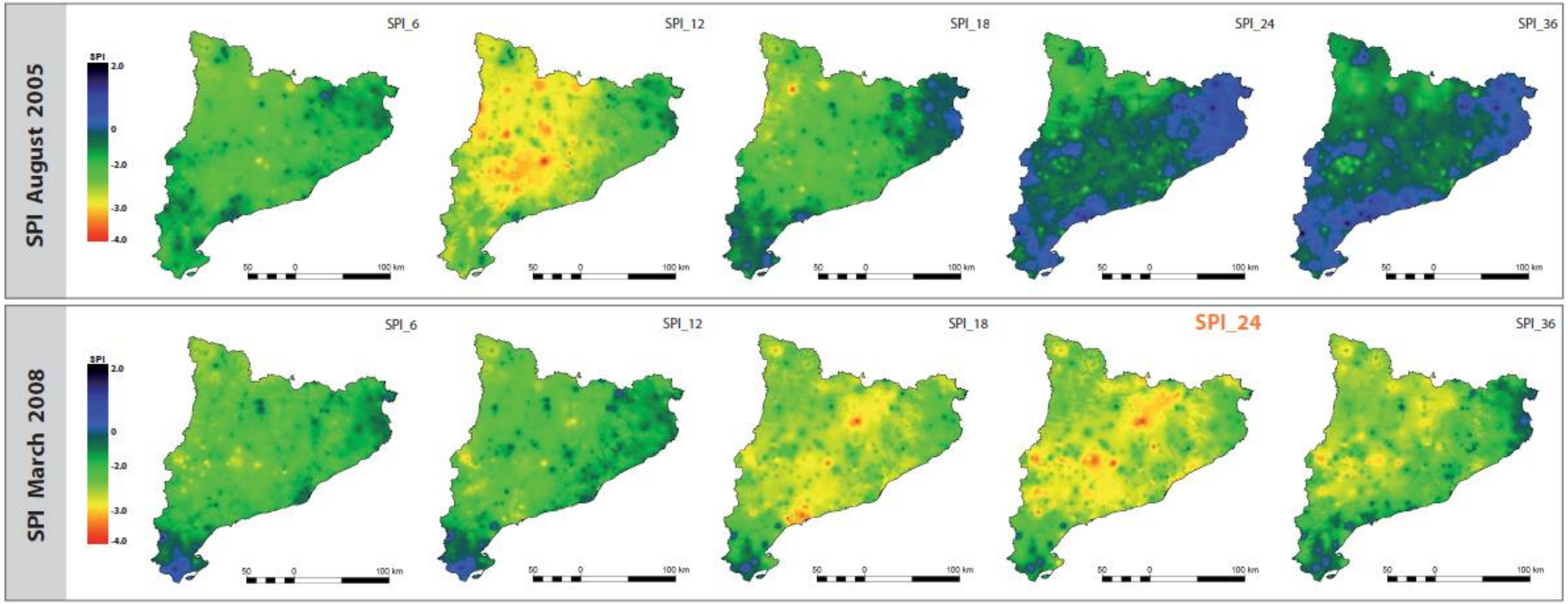
The **SPI** (standardized precipitation index) is a multiple time scale precipitation index that classifies the precipitation sums on a particular date with respect to the sums of the same month in all years of the measurement record.

The **SPEI** (standardized precipitation evapotranspiration index) is calculated in analogy to the SPI, using the cumulative water balance. It is based on precipitation and temperature.

Droughts

Monitoring and understanding the spatio-temporal **drought patterns**

Value	Category	Value	Category
2.00 or more	Extremely wet	0 to -0.99	Mild drought
1.5 to 1.99	Severely wet	-1.00 to -1.49	Moderate drought
1.00 to 1.49	Moderately wet	-1.5 to -1.99	Severe drought
0 to 0.99	Mildly wet	-2.00 or more	Extreme drought



Domingo

Floods

Remote sensing techniques are used

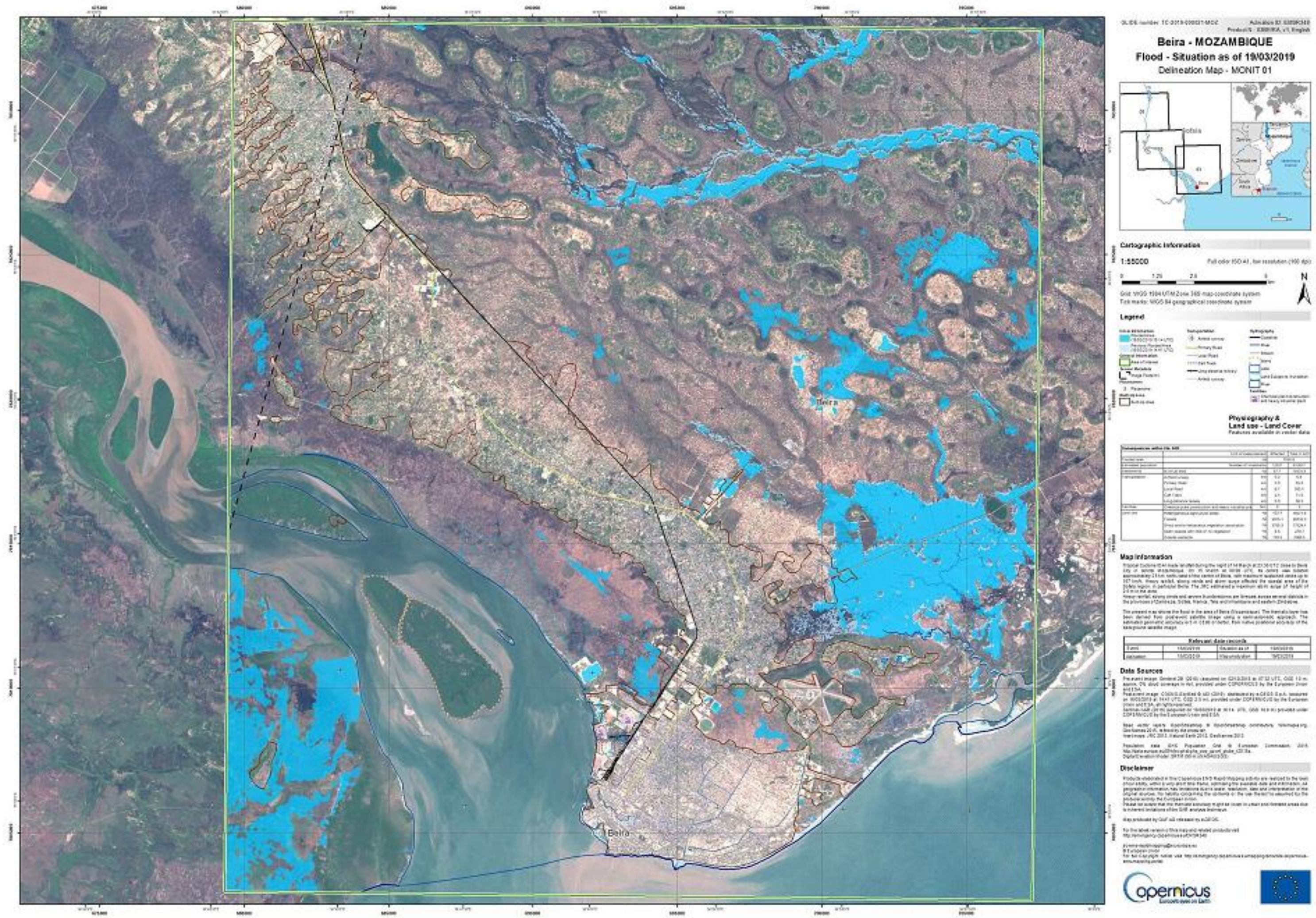
- to measure and monitor the areal extent of the flooded areas.
- to efficiently target rescue efforts.
- to provide quantifiable estimates of the amount of land and infrastructure affected.

Flooding conditions are relatively short term and with complex weather conditions for optical sensors, although typically having high information content for this purpose, can not penetrate through the cloud cover to define the flooded region below.

For these reasons, active SAR sensors are particularly valuable for flood monitoring.

A second relevant requirement is the near-real time: Images acquired before and after flooding offer immediate information on the extent of inundation, while supporting assessments of property and environmental damage.

Floods



Copernicus Sentinel-1 allows to define the extent of flooding around the port town of Beira in Mozambique caused by Cyclone Idai, in the west of Madagascar.

Meteorological/Climate applications

- Weather
- Climate

Weather applications

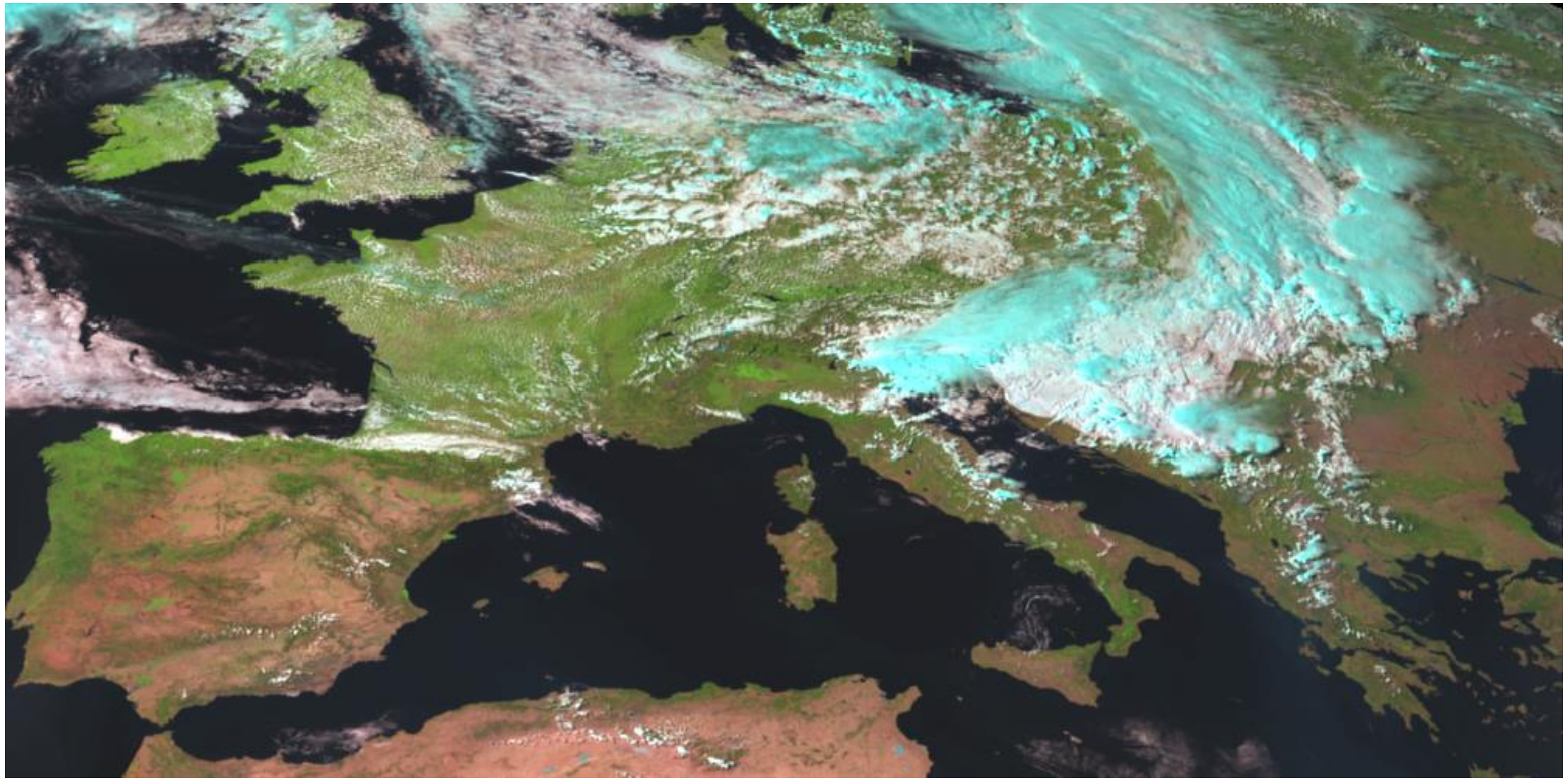
Weather remote sensing imagery is characterized by:

- **high temporal resolution**: providing frequent observations of the Earth's surface, atmospheric moisture, and cloud cover, which allow for near-continuous monitoring of global weather conditions, and hence - forecasting.
- **low spatial resolution**: forced by the high temporal resolution. Downscaling methods are used in case of mid spatial resolution is needed.

Relevant satellite imagery that provides inputs for weather prediction models are:

- Metop: Meteorological Operational Polar Satellite by ESA /EUMETSAT
- GOES: Geostationary Operational Environmental Satellite by NOAA
- MeteoSat: METEOrological SATellite by ESA / EUMETSAT
- Suomi NPP: National Polar-orbiting Partnership by NOAA

Weather applications



3-2-1 MSG image obtained on 30/07/2007

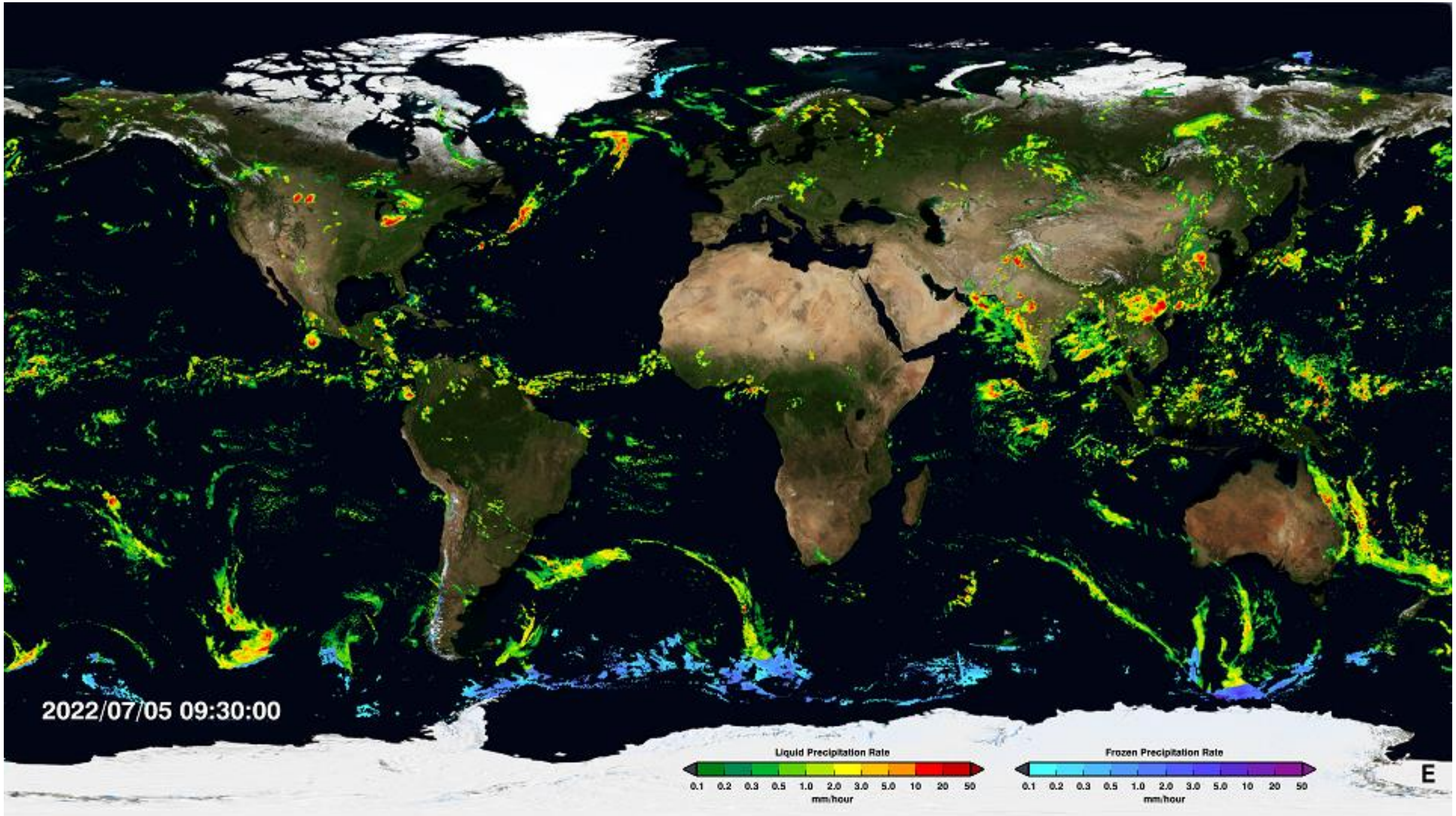
In geostationary orbit 36.000 km above the equator, the Meteosat satellites: Meteosat-9, -10 and -11, currently operate over Europe, Africa and the Indian Ocean. Meteosat-8 retired on 1 July 2022.

Weather applications

IMERG: The Integrated Multi-satellitE Retrievals for the Global Precipitation Measurement (GPM) algorithm combines information from the GPM satellite constellation to estimate precipitation over the majority of the Earth's surface.

The precursor was the **TRMM:** the Tropical Rainfall Measuring Mission is the first Earth Science mission dedicated to studying tropical and subtropical (within 35 degrees north and 35 degrees south) precipitation that falls of the equator.
The satellite uses several instruments to detect rainfall including radar, microwave imaging, and lightning sensors.

Weather applications



GPM

Grant Agreement 952111, H2020 WIDESPREAD-05-2020 (Twinning)

Climate applications

The climate system is complicated, and understanding it requires long time series of measurements made across the globe.
The climate is the product of interacting variables which create natural cycles that play out over a day, a year, decades or thousands of years.

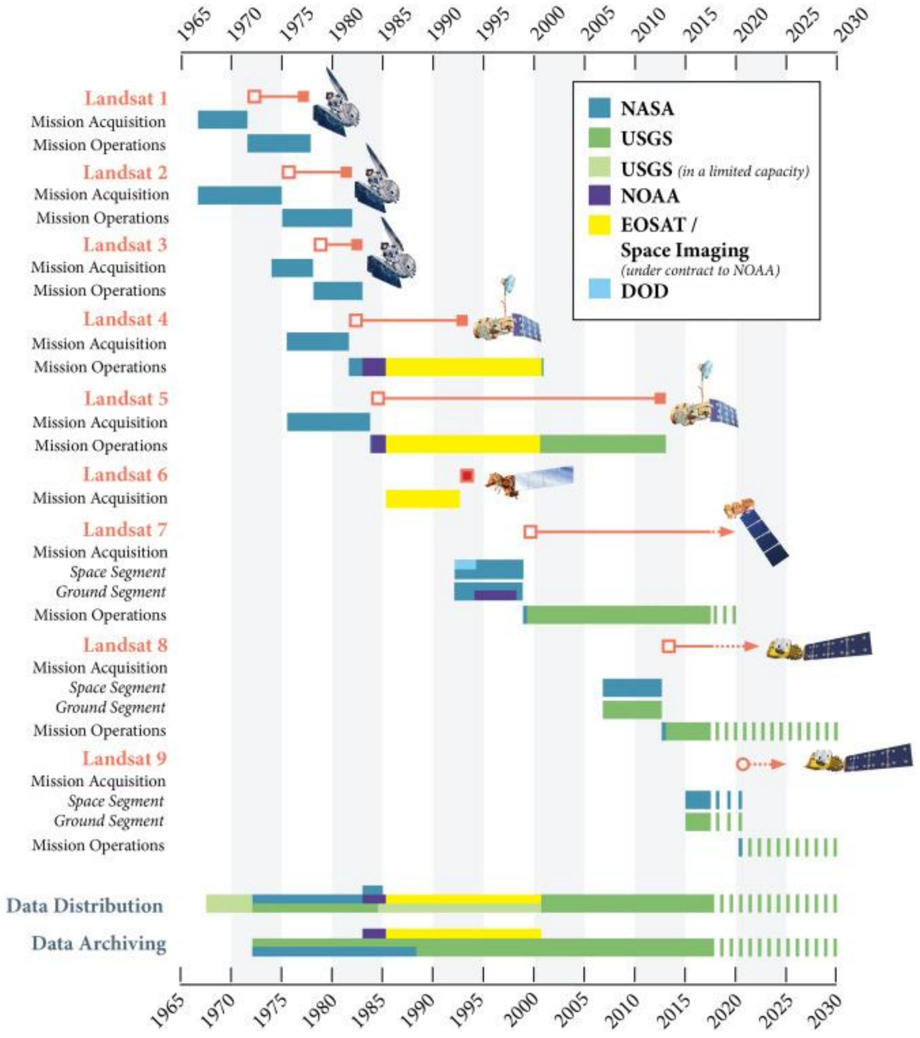
Earth Observation data from satellites make a major contribution to the understanding of the processes driving climate change.
Climate modelling helps us assessing future changes and estimating the impact of actions we might apply to mitigate its effects.

Climate applications

Remote sensing is useful to:

- monitor the effects of climate change.
- indicate the drivers of climate change.
- provide measurements and indices of climate change severity.

Some of these effects can be detected in a short analysis period, but most of them correspond to mid or long term processes thus **long (and consistent) time series** of satellite imagery are needed.



Climate applications

The **Climate Change Initiative** (CCI) is one of the more relevant EO science climate programmes.

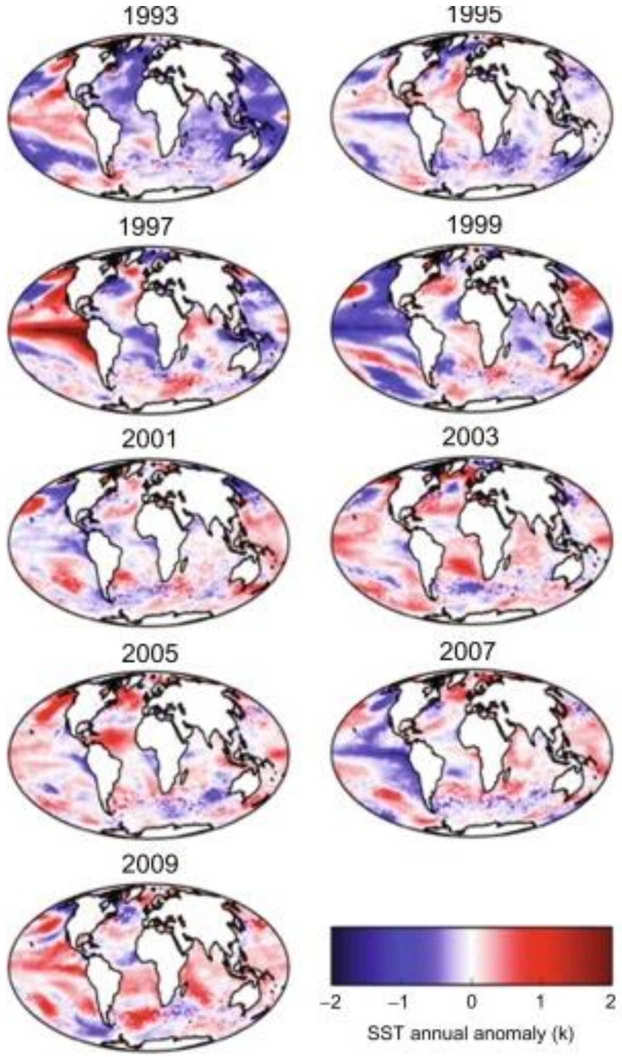
The European Space Agency (ESA) CCI aims to increase the availability and use of global, satellite-based climate data records as a major contribution to the evidence base for climate change that drives international action.

ECVs addressed by the ESA Climate Change Initiative.

Domain	GCOS ECV
Atmosphere	Cloud properties
	Aerosol properties
	Carbon dioxide, methane and other GHGs
	Ozone
Ocean	Sea surface temperature
	Sea level
	Sea ice
	Ocean colour
Terrestrial	Glaciers & ice caps
	Land cover
	Fire disturbance
	Ice sheets
	Soil moisture

Climate applications

Merchant, C.J.,



Sea surface temperature (SST), one example of these ECVs, is a strong indicator of productivity, pollution, and **global climate change**.

In particular, SST annual anomaly over a period of years, allows to illustrate the warming tendency of ocean temperatures.

SST can be measured using thermal infrared (IR) bands from optical satellites.