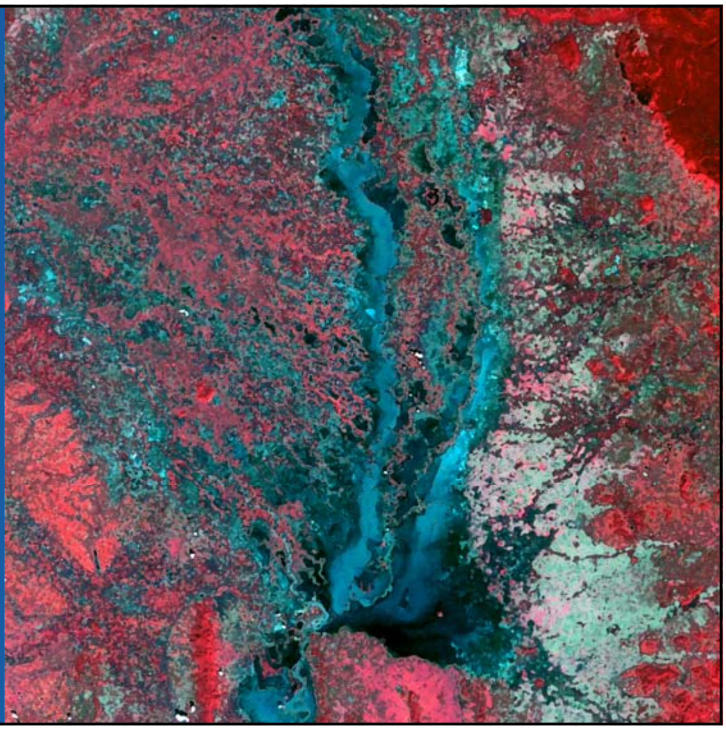
Flood monitoring with Remote Sensing

ESA Training Course, Croatia

21/09/2023



EO data

Crisis (mandatory)

- Optical data
- SAR data relevant for flood extent mapping

Pre-event (optional but highly recommended)

- Recent optical data
- Additional SAR data for flood extent mapping

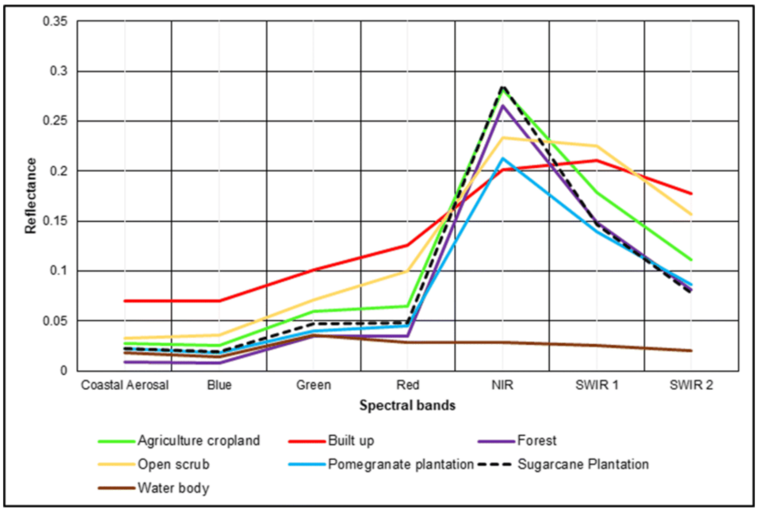
Orthorectification

- **Optical**: data ordered and/or downloaded in ground projection and fitting the topograpic relief
- **SAR**: Range Doppler Terrain Correction operator in SNAP software
  - "Due to topographical variations of a scene and the tilt of the satellite sensor, distances can be distorted in the SAR images. Terrain corrections are intended to compensate for these distortions so that the geometric representation of the image will be as close as possible to the real world."
  - "The algorithm uses orbit state vector information metadata, the radar timing annotations, the slant ground range conversion parameters together with a DEM to derive from the radar geometry the precise gound geolocation information. "

Water body detection – optical data

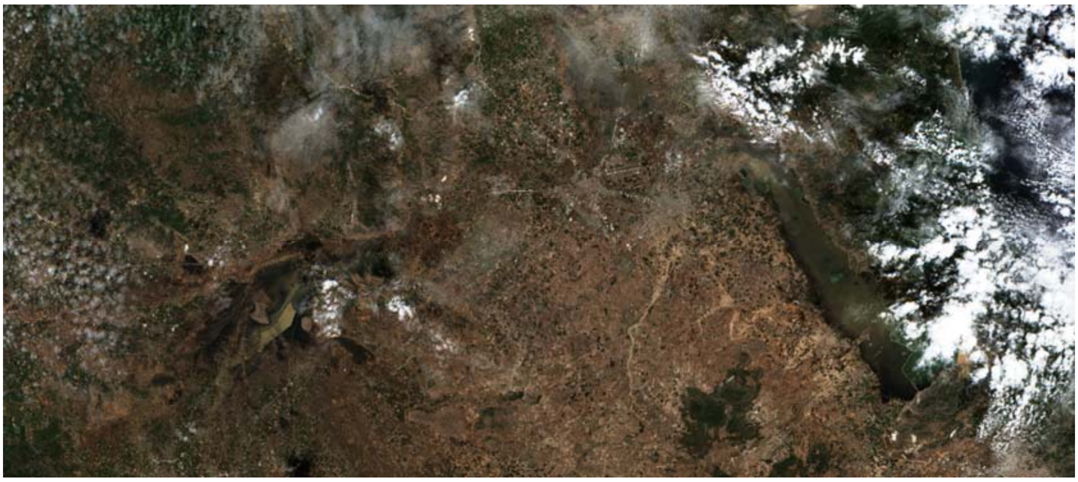
- Spectral characteristics
- Visual interpretation
- Semi-automatic process
  - Thresholding (simple/multiple, spectral bands/indices, pixel/neighborhood)
  - Supervised classification / machine learning

Spectral characteristics, a reminder



Water bodies detection

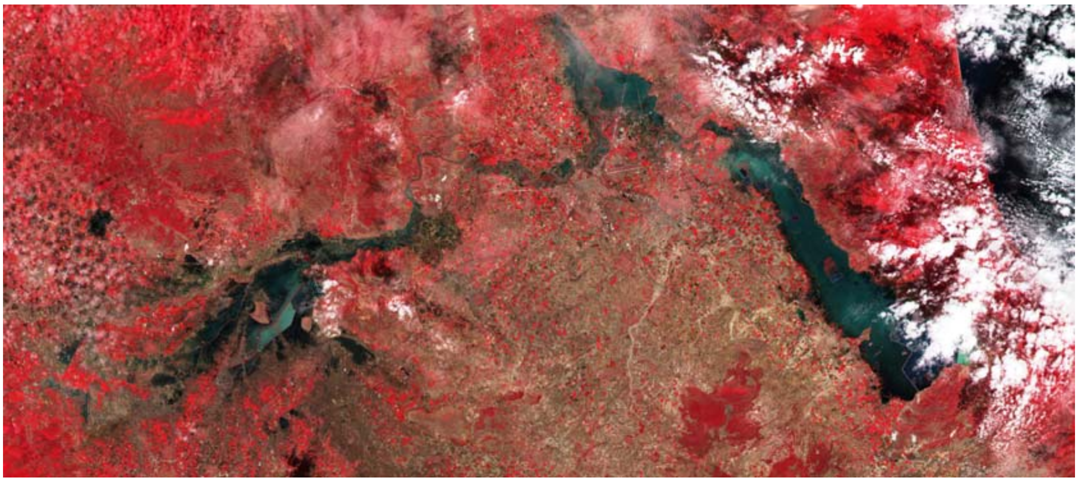
› Visual interpretation



Sentinel-2 - Red, Green, Blue (natural colors)

Water bodies detection

- Visual interpretation



Sentinel-2 - NIR, Red, Green in RVB

Water bodies detection

- Visual interpretation

Sentinel-2 – SWIR, NIR, Green in RVB

Water bodies detection

› Main spectral indices

Index	Source	Formula
NDWI	McFeeters [1]	(G-NIR)/(G+NIR)
MNDWI	Xu [2]	(G-SWIR1)/(G+SWIR1)
$AWEI_{no\ shadow}$	Feyisa [3]	4*(G-SWIR1)-(0.25*NIR+2.75*SWIR2)
$AWEI_{shadow}$	Feyisa [3]	B+2.5*G-1.5*(NIR+SWIR1)-0.25*SWIR2
WI	Fisher [4]	1.7204+171*G+3*R-70*NIR-45*SWIR1-71*SWIR2
…		

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Water bodies detection

- Short-Wave InfraRed (SWIR) bands are decisive for discriminating water (when available)
- NIR band is used as proxy
- Green band is widely used (in all spectral indices)
- Red and Blue bands are also interesting in some cases

› Machine learning job

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Supervised classification

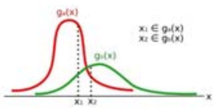
Algorithms build a mathematical model from training data (also known as training samples) and then predict an output classified pixel value for all input pixels

Advantages : The machine analyses faster and better the separability of different classes in all the spectral dimensions in input (spectral bands and/or radiometric indices). Expertise in input to guide the algorithm lead to greater performance, higher development in machine learning

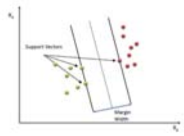
Drawbacks: Not fully automatic process (semi-automatic), operator's job is to pick sample pixels. Performance highly dependent on the quality of input samples

Perspective: Sample selection process can be automatized by deriving them from an existing database

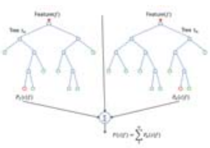
Machine learning algorithms



Maximum likehood algorithm calculates the probability distributions for the classes.



Support Vector Machine (SVM) algorithm constructs a hyperplane that has the largest distance to the nearest training-data point of any class.



Random forests algorithm constructs a multitude of decision trees at training step and outputting the class that is the mode of the classes or mean prediction (regression) of the individual trees.

Also **Decision Tree**, **Artificial Neural Network**, etc. (non-exhaustive list)

ML input data

- **Raster**: spectral bands and/or spectral indices
- **Samples** : Training data digitized directly from the satellite imagery
  - Vector format
  - Digitized directly from the satellite imagery
  - 2 classes recorded in a field: water / non-water (mainly land but can be clouds also)
  - Representation of the variability of the spectral signatures in both classes

SAR preprocessing

- **Geometric**: Orthorectification

The Range Doppler Terrain Correction Operator implements the Range Doppler orthorectification method [5] for geocoding SAR images from a single 2D raster radar geometry. It uses available orbit state vector information in the metadata, the radar timing annotations, the slant to ground range conversion parameters together with the reference DEM data to derive the precise geolocation information.

Due to topographical variations of a scene and the tilt of the satellite sensor, distances can be distorted in the SAR images. Image data not directly at the sensor's Nadir location will have some distortion. Terrain corrections are intended to compensate for these distortions so that the geometric representation of the image will be as close as possible to the real world.

SAR preprocessing

Radiometric : Calibration

The objective of SAR calibration is to provide imagery in which the pixel values can be directly related to the radar backscatter of the scene. Though uncalibrated SAR imagery is sufficient for qualitative use, calibrated SAR images are essential to quantitative use of SAR data.

Typical SAR data processing, which produces level 1 images, does not include radiometric corrections and significant radiometric bias remains. Therefore, it is necessary to apply the radiometric correction to SAR images so that the pixel values of the SAR images truly represent the radar backscatter of the reflecting surface. The radiometric correction is also necessary for the comparison of SAR images acquired with different sensors, or acquired from the same sensor but at different times, in different modes, or processed by different processors.

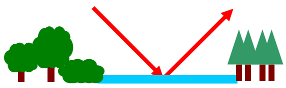
SAR preprocessing

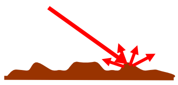
Radiometric : Despeckle

SAR images have inherent salt and pepper like texturing called speckles which degrade the quality of the image and make interpretation of features more difficult. Speckles are caused by random constructive and destructive interference of the de-phased but coherent return waves scattered by the elementary scatters within each resolution cell. Speckle noise reduction can be applied either by spatial filtering or multilook processing.

Water bodies detection from radar data

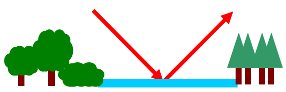
The capability to detect and monitor floods using microwave sensors arises from the very high sensitivity of microwaves to the presence of water in natural media. Unlike the diffuse reflection (high backscatter) from rough and dry soil, for example, the predominant specular or mirror-like reflection (low backscatter) from smooth water results in a high contrast in SAR imagery between flooded and non-flooded areas.

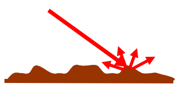




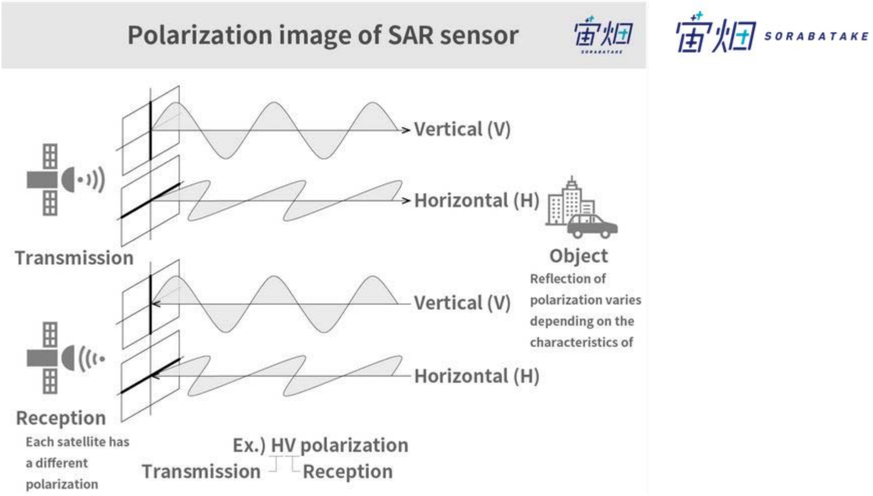
Water bodies detection from radar data

	Scatter Process	Examples of Objects that are Targetted	Amount of Reflections	Intensity of Backscattering (Intensity of the SAR Image)
(1)	Specular Reflection	Water	Once	Little to No
(2)	Surface Scattering	The Ground and Grass	Once	Mild
(3)	Corner Reflection	Man-Made Structures (buildings, bridges)	2 times	Intense
(4)	Volume Scattering	Trees and Snow	Multiple	Mild





Water bodies detection from radar data



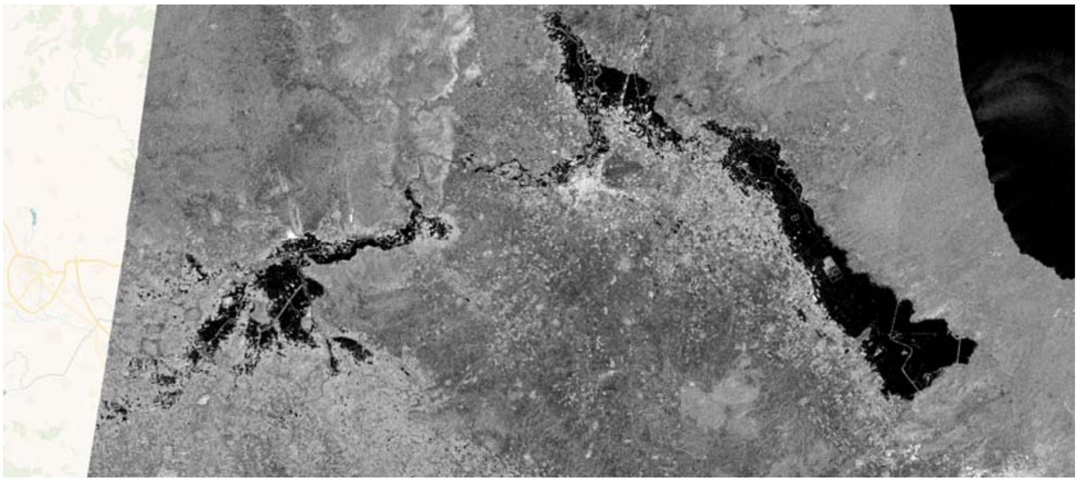
Water bodies detection from radar data

While HH polarisation is generally considered as superior to VV or VH polarisation for flood mapping purposes [6] since it yields the highest contrast between open water and land areas, this polarisation is usually not available for systematically acquired Sentinel-1 data of land surfaces.

VV polarisation performs generally slightly better than VH polarization for water detection [7].

SAR imagery, water bodies

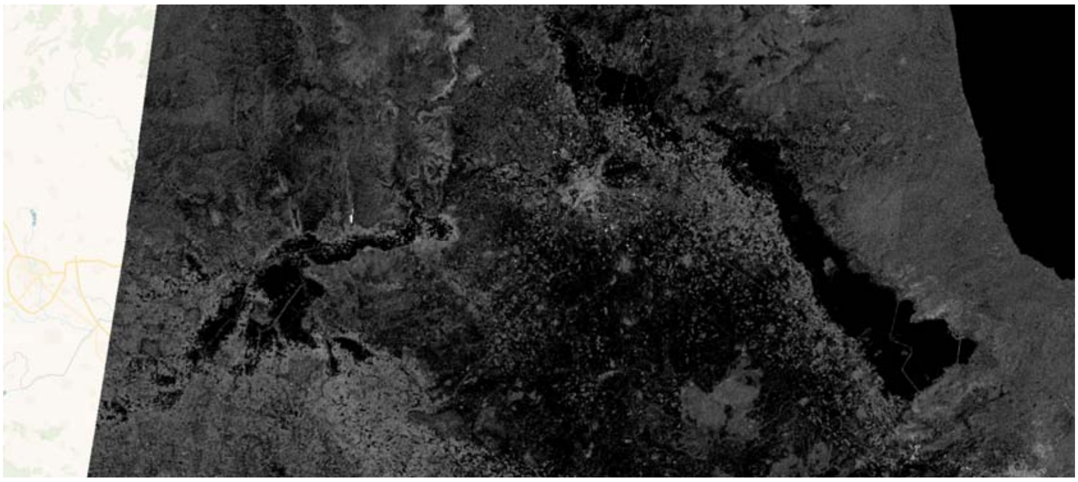
- Visual interpretation



Sentinel-1 – SAR VV polarisation

SAR imagery, water bodies

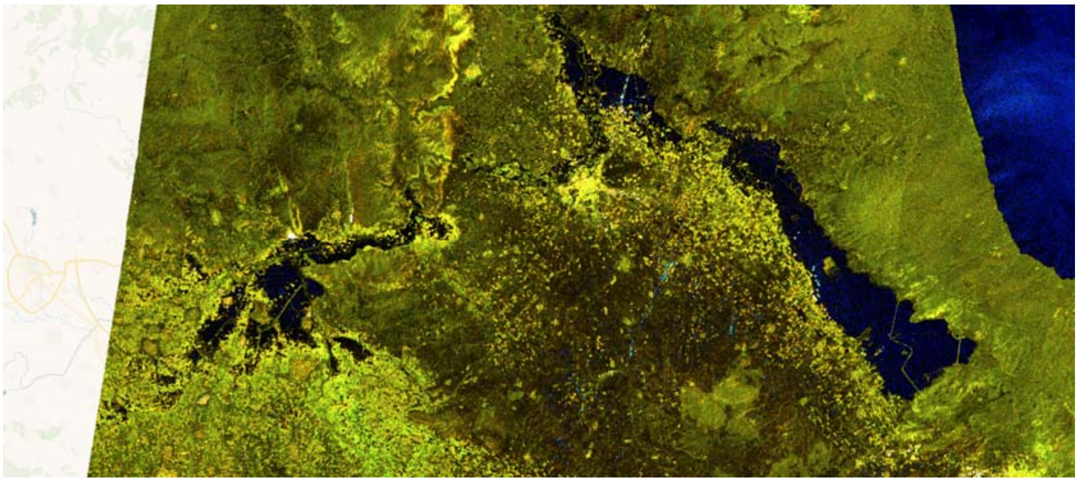
- Visual interpretation



Sentinel-1 – SAR VH polarisation

SAR imagery, water bodies

- Visual interpretation



Sentinel-1 – SAR VV, VH polarisations

Water bodies detection from radar data

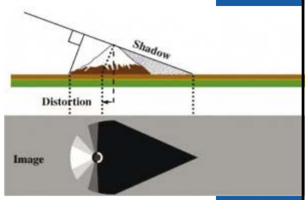
- Manual cleaning step

Potential influence on the SAR-based water mapping of factors such as topography, wind, vegetation, urban areas, permanent low backscatter areas, snow and ice, and atmospheric conditions

Water bodies detection from radar data

Influence of topography

The terms foreshortening, layover, and shadowing refer to the effects of topography on the geometry (i.e. image deformation) and radiometry (i.e. change of backscattered values) of SAR data. In fact, low backscatter from slopes inclined away from the incident SAR signal, can be confused with smooth water. Bright pixels on the slope facing the SAR signal do not produce such errors.



Water bodies detection from radar data

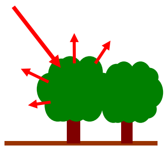
Influence of wind

In the presence of strong wind that roughens the water surface, the contrast between flooded and non-flooded soil in SAR images can be significantly reduced. In flooded land, many different and unknown situations - such as different water depths, or obstacles obstructing wind flow - can arise, where it is difficult to measure the effect on the SAR signal. In extreme cases (very high winds), the contrast between flooded and dry surfaces may even disappear completely.

Water bodies detection from radar data

Influence of vegetation

Due to the weak (or totally absent) backscatter contrast between flooded and non-flooded vegetation, detection of water-bodies under vegetated canopies is challenging. Here, the main mechanism is related to double-bounce, due to multiple reflection from the horizontal surface and vertical structures.



Water bodies detection from radar data

Influence of urban areas

In general, SAR imaging of urban areas is very complex, especially when radar resolution is not very high and many scattering components are included in the same resolution cell. The complexity of the problem - which includes mutual shadowing between buildings in dense urban settlements, higher-order bounces (triple bounces can be very likely), and scattering from other elements like windows - renders SAR-based flood mapping in urban areas very unreliable.

Water bodies detection from radar data

Influence of permanent low backscatter areas

Smooth surfaces such as asphalt roads and flat rock exhibit low backscatter, which may lead to confusion with flooded areas. Times-series of backscatter measurements can be used to identify such areas with permanent low backscatter.

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Water bodies detection from radar data

Influence of atmospheric conditions

At higher microwave frequencies, there is higher absorption and backscattering of the SAR signal due to water drops. Therefore, when using SAR images collected at higher microwave frequency (e.g. X-band), high signal attenuation from heavy rain can produce very low backscatter, and possible confusion with flooding. At lower microwave frequencies (e.g. C-band and especially L-band) this problem is not severe, but can occur occasionally.

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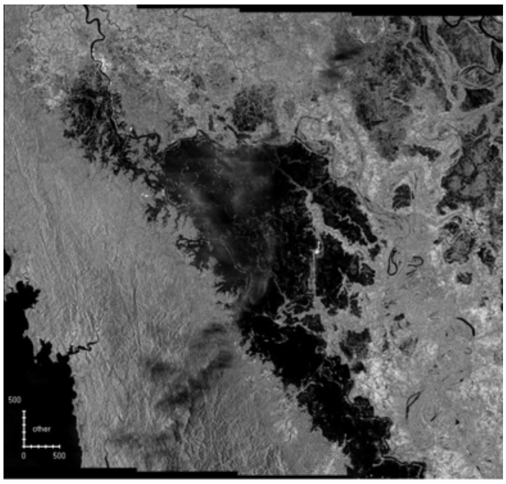
Water bodies detection from radar data

- Influence of atmospheric conditions

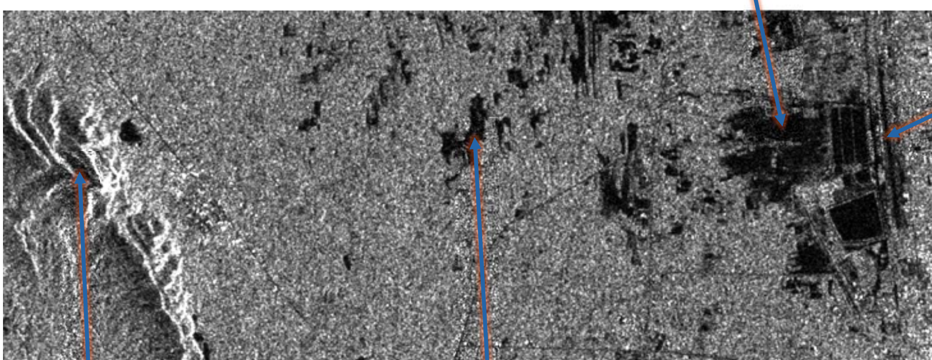
Meteorological particles visible interfere with water detection

CSK , Myanmar, 10 August 2015
X band



Water bodies detection from radar data

- Manual cleaning step

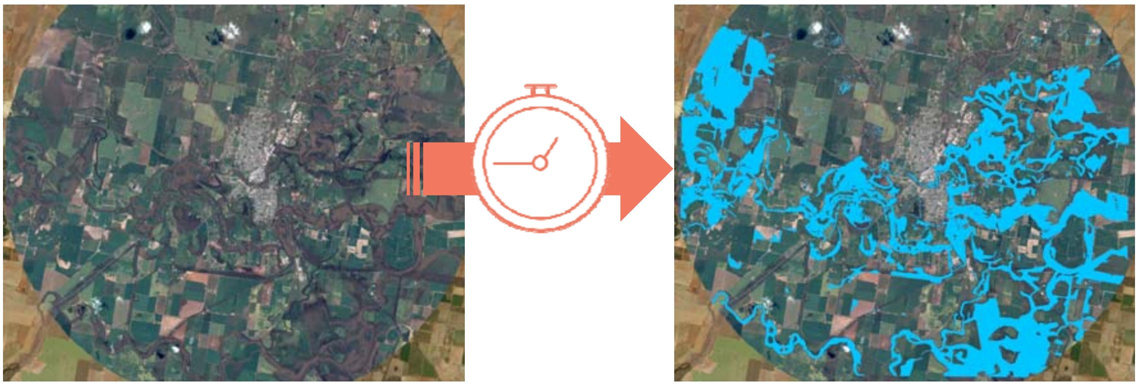


Flood extent

- Flood extent = crisis water bodies – reference water bodies*
- An Erase tool

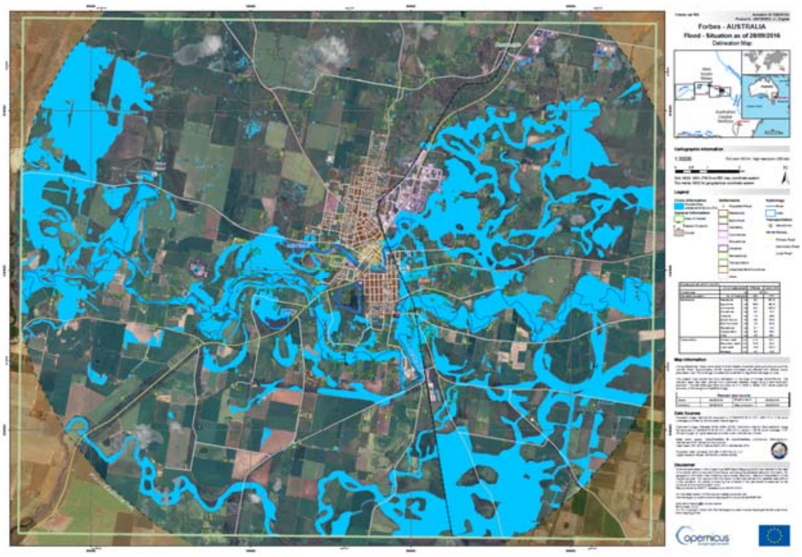
*Reference water bodies are derived from pre-event imagery and/or a vector database (Open Street Map for instance)

Flood extent



Pléiades-1A/B ©CNES/Airbus DS Geo

Flood extent map



Disaster management cycle

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Contribution of remote sensing (pre-event)

Pre-event activities	Contribution of Earth Observation data exploitation
Risk evaluation	Assets, vulnerability and historical hazard mapping
Mitigation	Use of risk evaluation
Prevention	
Training	
Preparation	

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Risk evaluation (pre-event)

Economic exposure map in Morocco
World Bank project
© ICube-SERTIT 2019

Risk index in Thailand
Airbus DS Geo project
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Contribution of remote sensing (event)

Event activities	Contribution of Earth Observation data exploitation
Population assistance	Location of affected settlements, especially isolated ones not yet rescued
Assisting logistics	Reference mapping Damage assessment of transportation facilities (runways, roads, etc.)
Situation analysis	Disaster extent, damage assessment
Event monitoring	Disaster extent monitoring

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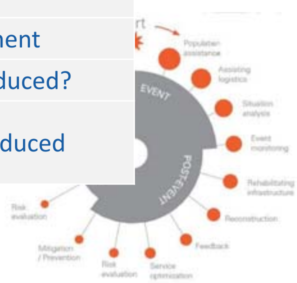
Contribution of remote sensing (post-event)

Post-event activities	Contribution of Earth Observation data exploitation
Rehabilitating infrastructure	Recovery monitoring
Reconstruction	Reconstruction monitoring
Feedback	Detailed damage and loss assessment
Service optimization	Use of all event geo-information produced?
Risk evaluation	Use of all event geo-information produced
Mitigation / Prevention	



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International frameworks

- Copernicus Emergency Management Service (EMS)
- International Charter 'Space and major disasters'

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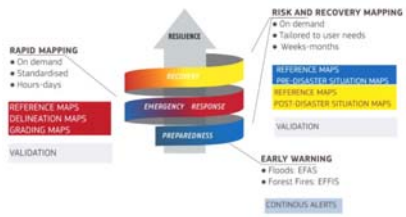
Copernicus EMS

Copernicus
Europe's eyes on Earth

- Early Warning

EFAS/GLOFAS - Hydrological warning and predicted flood,
EFFIS/GWIS - Forest fire danger and extent mapping
EDO/GDO – Drought monitoring



- Rapid Mapping (event phase)

Provision of geospatial information within hours or days from the activation in support of emergency management activities immediately following a disaster

- Risk & Recovery Mapping (pre and post event)

On-demand provision of geospatial information in support of Disaster Management activities not related to immediate response. This applies in particular to activities dealing with prevention, preparedness, disaster risk reduction and recovery phases.

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Copernicus EMS – Rapid Mapping

- 24/7/365 service
- Night and week-end service

Product type	Crisis information package (hours)
Reference	10
First estimate (FEP)	2
Delineation	7
Grading	10
Situational Reporting	4*

T0: satellite data reception

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Copernicus EMS – Rapid Mapping

- European funding
- Coordinated by JRC for European Commission (Joint Research Center)
- Authorised Users: NFPs, EC services plus other countries and international institutions through DG-ECHO/ERCC
- Operated by 9 companies in Europe (Italy, France, Germany, Spain, Portugal, Greece)
- Service lead by e-GEOS with management help from SERTIT

https://emergency.copernicus.eu/mapping/list-of-activations-rapid

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Copernicus EMS – Rapid Mapping

Standardisation

- Authorised Users
- 24/7 on-call
  - Satellite image provision
  - Rapid mapping team (OdO + PS)
- Map types and content specifications
- Free Delivery to All (Web)

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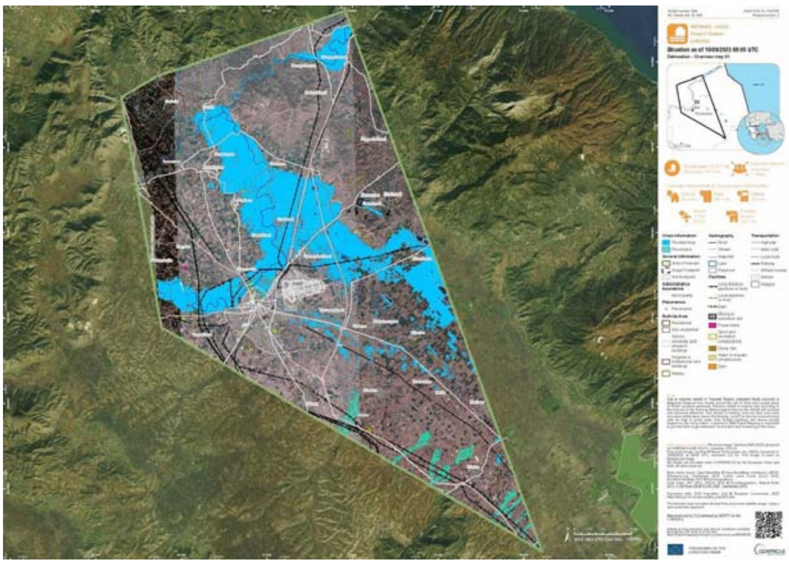
CEMS RM EMSR692 AOI03



Copernicus Emergency Management Service (© 2023 European Union), EMSR692

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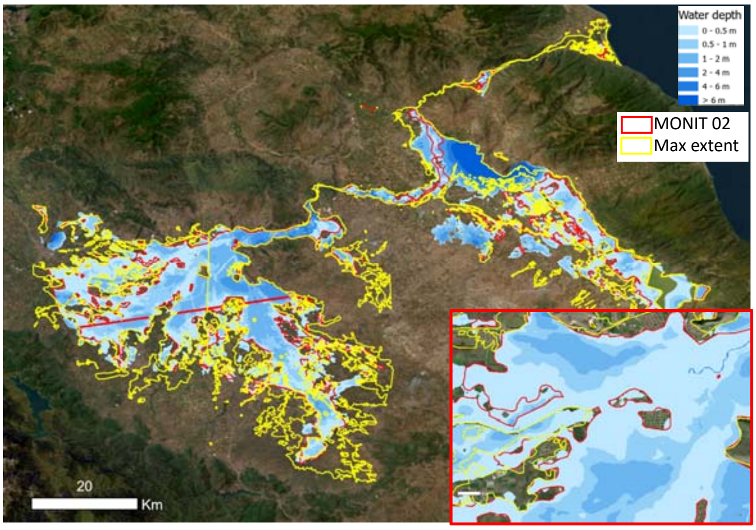
From flood extent to flood depth

Copernicus Emergency Management Service (© 2023 European Union), EMSR692

Flood modelling - CEMS RM EMSR692

- Flood interpolation from MONIT02 product
- DSM: FABDEM, 30m



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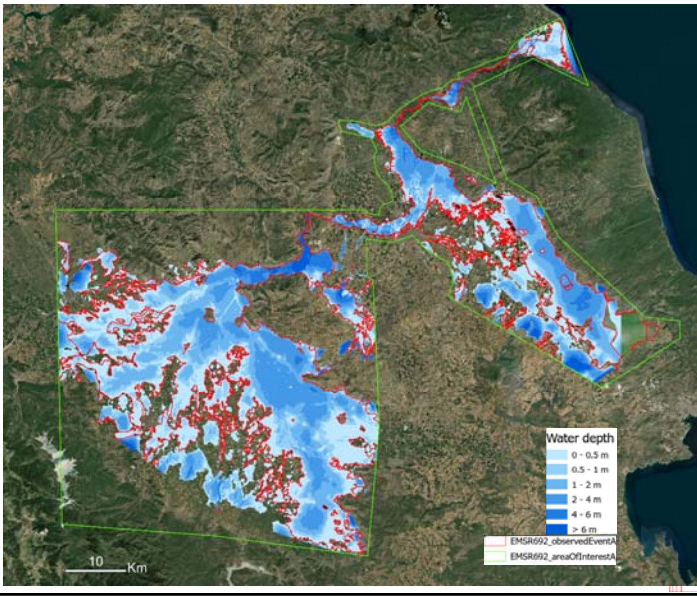
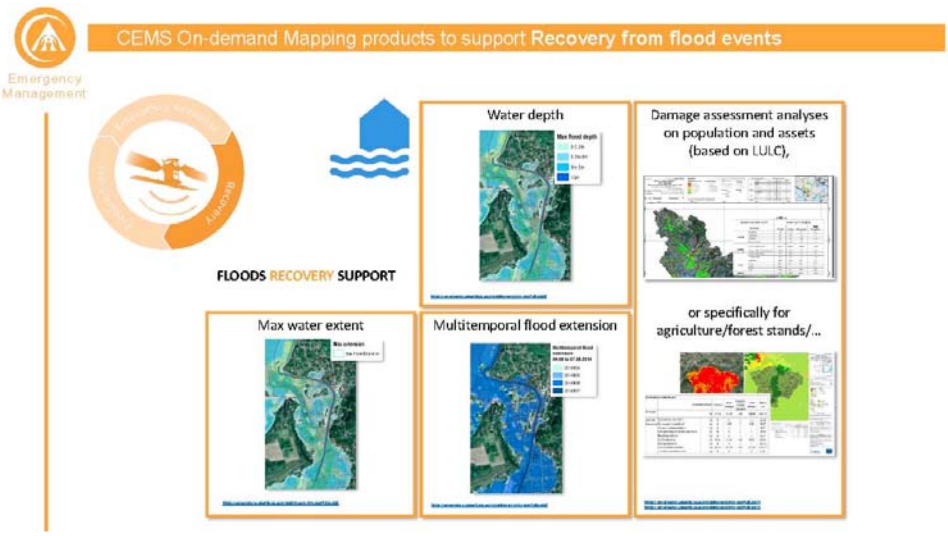
Flood modelling - CEMS RM EMSR692

- Flood interpolation from max extent of MONIT products
- DTM: FABDEM, 30m

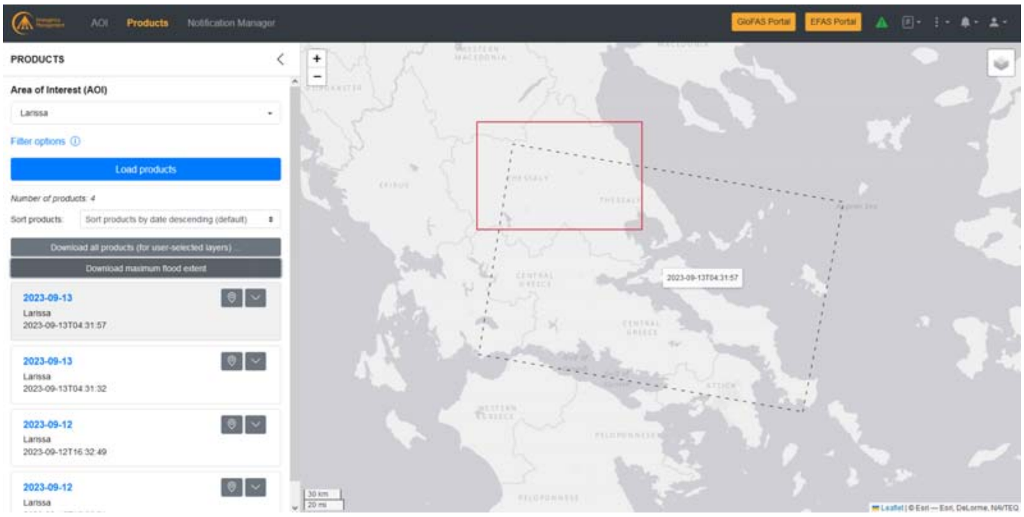


Copernicus EMS Risk & Recovery - Floods

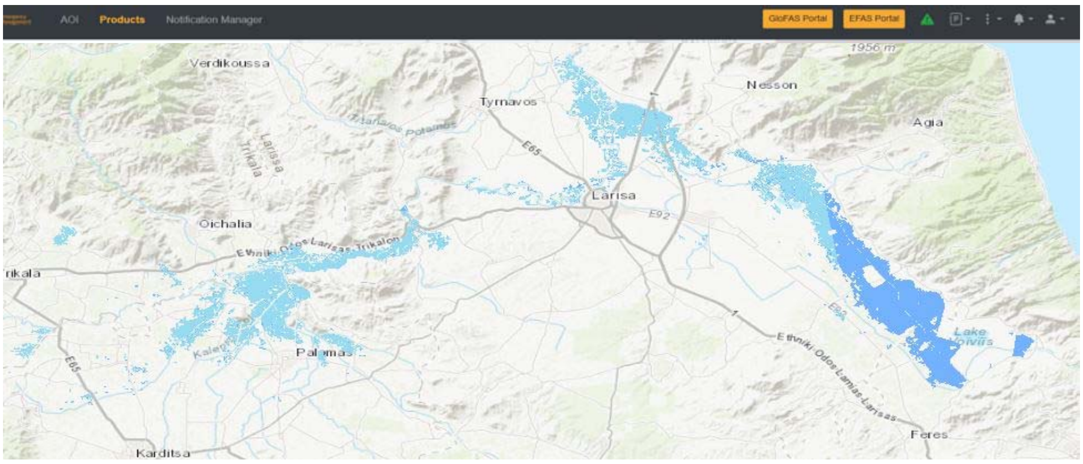


https://emergency.copernicus.eu/mapping/list-of-activations-risk-and-recovery

Global flood monitoring



Global flood monitoring



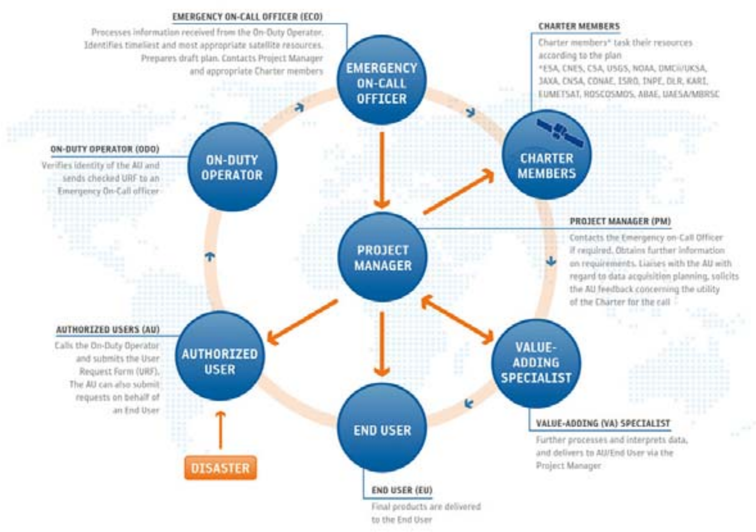
GFM extracts the 12 & 13 September 2023

Charter Space and Major Disasters

The International Charter is a worldwide collaboration, through which satellite data are made available for the benefit of disaster management

20 in 2020	17 members

Charter Space and Major Disasters



Rapid mapping products portfolio

- **Disaster extent** // Delineation of the event's geospatial extent

  (+ monitoring)

- **Damage assessment** // Damage grading of urban areas, transportation, facilities and land cover

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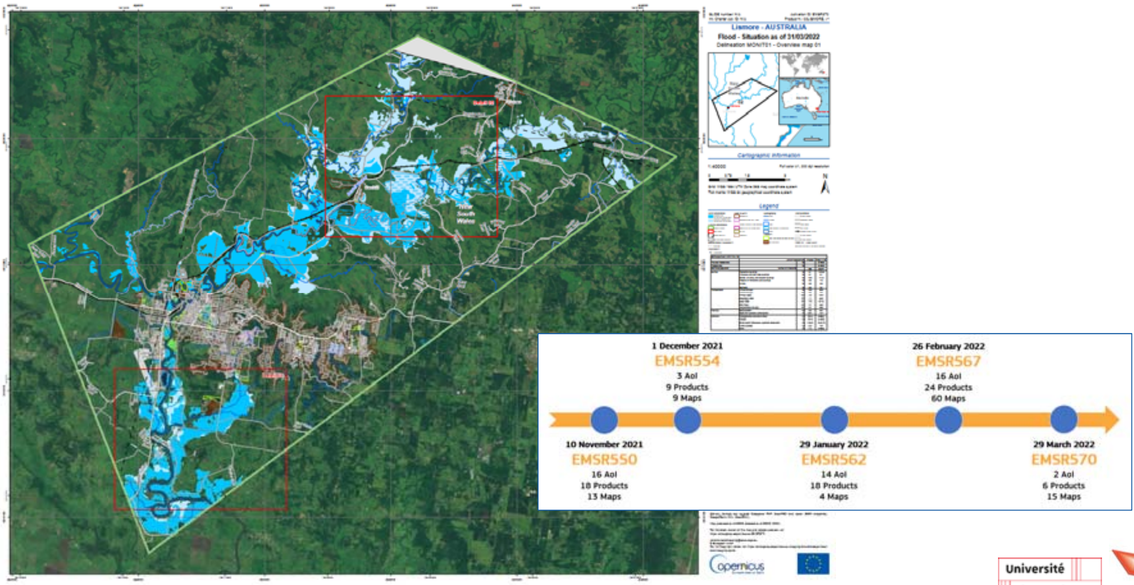
Floods in Australia, 2022



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Floods in Pakistan, Aug./Sep. 2022

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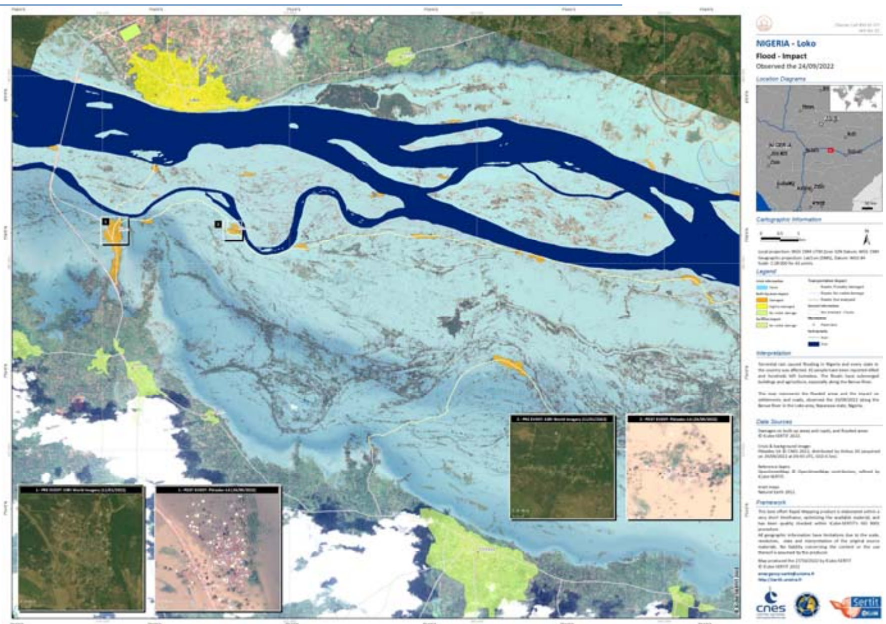
Flood in Nigeria, Sep. 2022



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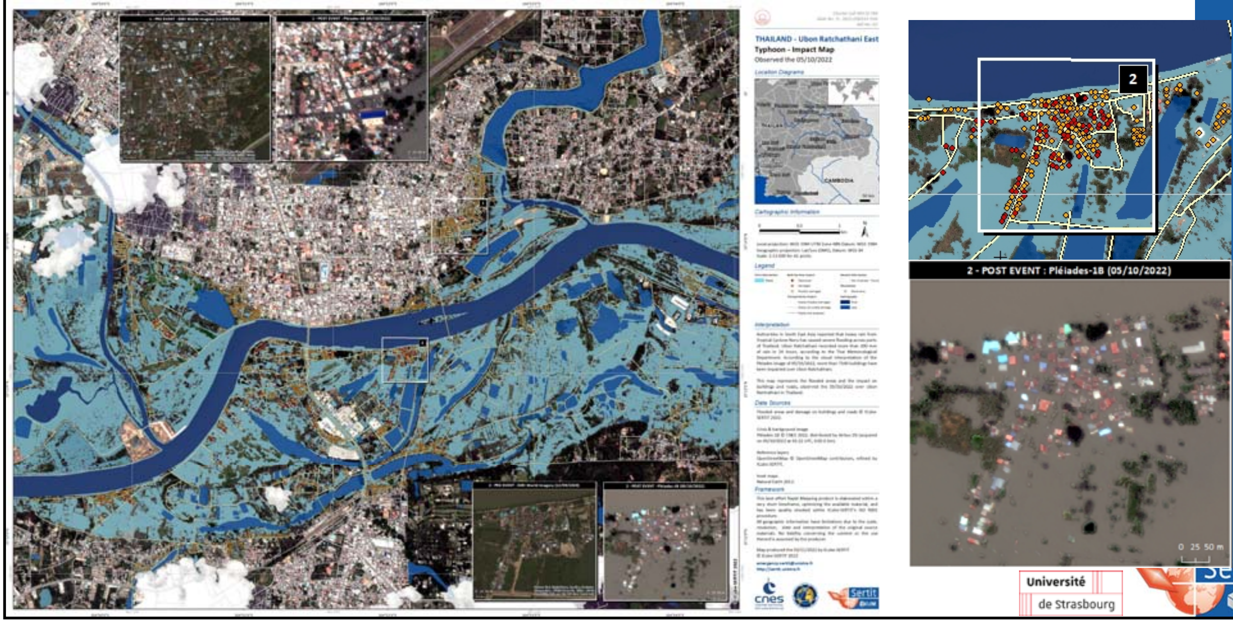
Tropical Cyclone in Thailand, Oct. 2022



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