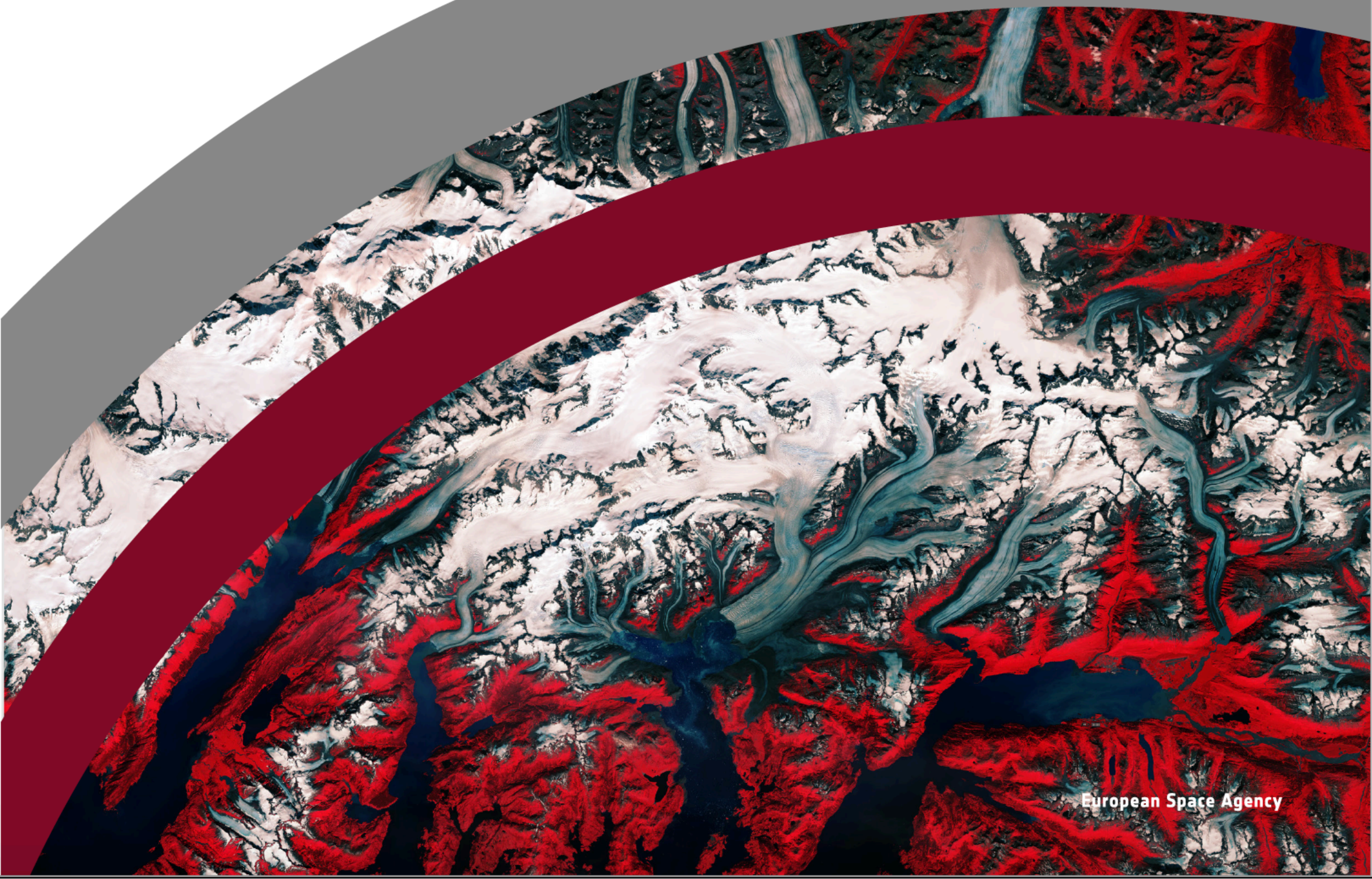
→ EO4SD – EARTH OBSERVATION FOR SUSTAINABLE DEVELOPMENT

Climate Resilience | Service Portfolio

climate resilience
eo4sd



European Space Agency

Cover image taken by Copernicus Sentinel-2B satellite shows Alaska's Columbia Glacier, one of the most rapidly changing glaciers in the world. Image contains modified Copernicus Sentinel data (2017), processed by ESA,

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→ PROVISION OF ESSENTIAL CLIMATE VARIABLES

To support the work of the United Nations Framework Convention on Climate Change (UNFCCC) and the Intergovernmental Panel on Climate Change (IPCC), the Global Climate Observing System (GCOS) created a list of key parameters of the Earth system, known as Essential Climate Variables (ECVs) to meet the climate information needs of the scientific community.

ECVs are physical, chemical, or biological variables (see Table 1) that provide the necessary empirical evidence to understand how our climate is evolving. This information is critical for informed decision making in climate change mitigation and adaptation. The ECVs help assess future risk scenarios, enable the attribution of (extreme) climate events to underlying causes, and form the basis of effective climate services.

GCOS specifies 54 ECVs that are identified based on three criteria (GCOS, 2016):

1. **Relevance**: The variable is critical for characterizing the climate system and its changes.
2. **Feasibility**: Observing or deriving the variable on a global scale is technically feasible using proven, scientifically understood methods.
3. **Cost effectiveness**: Generating and archiving data on the variable is affordable, mainly relying on coordinated observing systems using proven technology, taking advantage where possible of historical datasets.

GCOS establishes product requirements for every ECV that require observations from land-based and airborne in-situ and remote sensing platforms, in addition to satellites. However, satellites can significantly contribute to many ECVs (marked red in Table 1), making Earth observation (EO) a key component of climate monitoring.

There are many international initiatives that attempt to deliver climate information to the decision makers. The Copernicus Climate Change Service (C3S) will soon deliver operational data and climate information services for a range of domains and sectoral areas. The C3S portfolio is currently under development and its dataset provision is designed to be extensible in the future. Under C3S the ECVs will be provided through climate projections, reanalysis, satellite observations and seasonal forecasts.

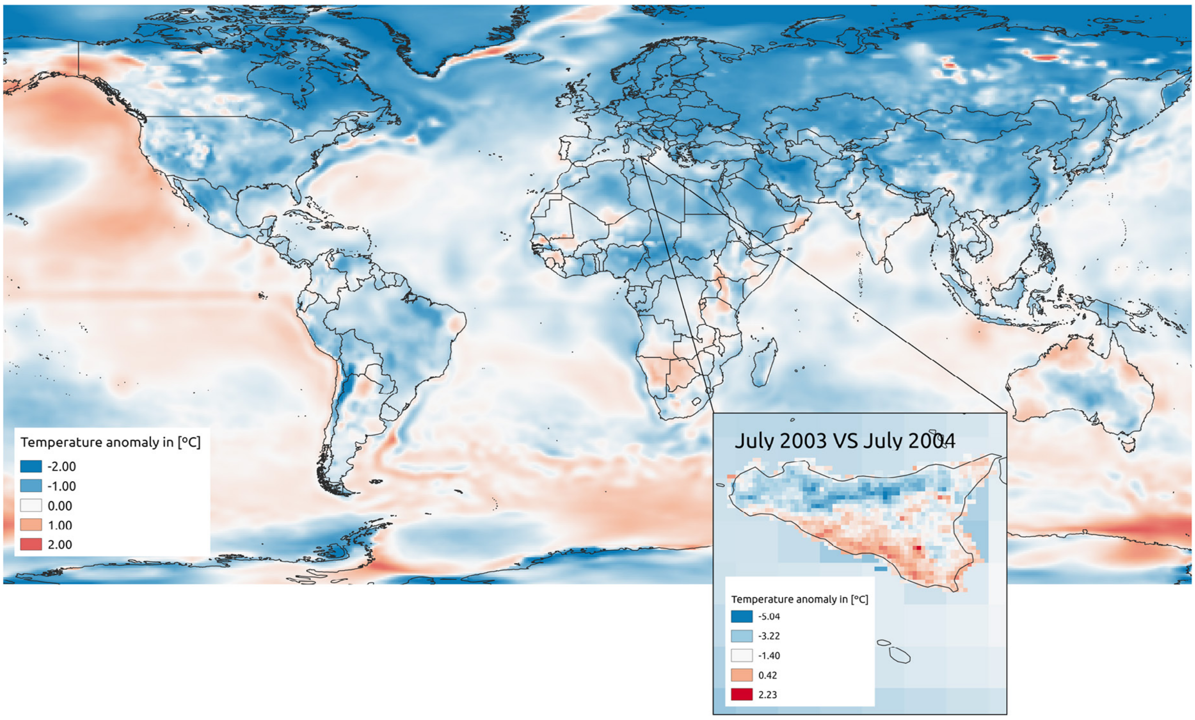
The European Space Agency (ESA) Climate Change Initiative (CCI) has the objective to realize the full potential of the long-term global EO archives that ESA together with its Member States have established over the last thirty years, as a significant and timely contribution to the ECV databases required by the UNFCCC and IPCC. Existing ECV datasets are currently being extended and datasets for new ECVs are planned for the future.

The Earth Observation for Sustainable Development (EO4SD) Climate Resilience cluster will tap into the dedicated ECV projects C3S and ESA CCI and provide customized information including baseline analysis to support multilateral development investment projects and their climate resilience.

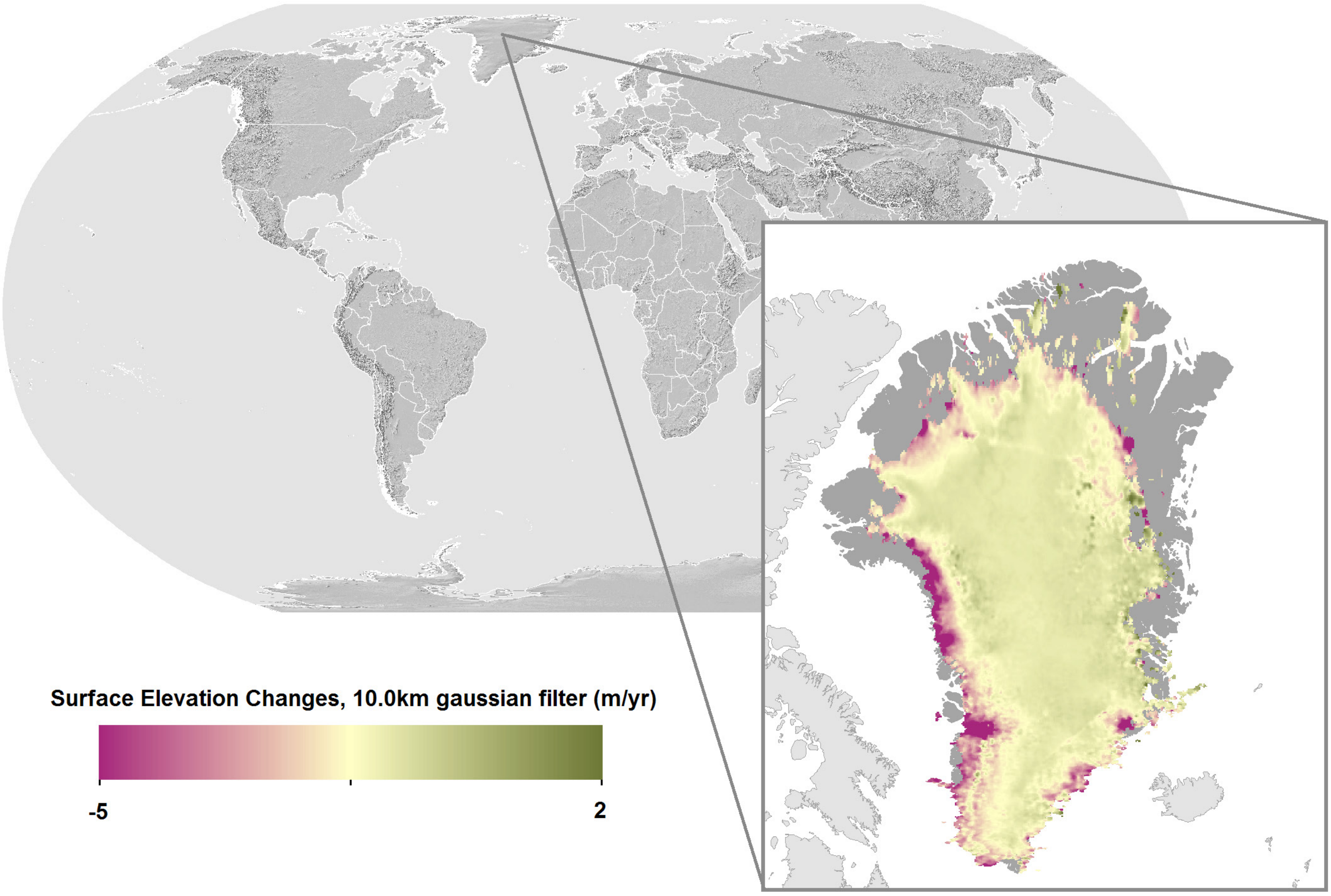
Table 1: List of Essential Climate Variables according to the UNFCCC, ICC and GCOS..

Domain	Essential Climate Variable	
Atmosphere (over land, sea and ice)	**Surface**	Air temperature, surface wind speed and direction, water vapour, pressure, precipitation, surface radiation budget
	Upper atmosphere	Temperature (see p. 3, top), wind speed and direction, water vapour, cloud properties, earth radiation budget, cloud properties (including solar irradiance)
	Atmospheric composition	Carbon dioxide, methane, and other greenhouse gases, ozone, aerosol properties, precursors (supporting the aerosol and ozone ECVs)
Ocean	**Physical**	Sea-surface temperature, subsurface salinity, sea level, sea state, sea ice, surface current, carbon dioxide partial pressure, ocean acidity, phytoplankton
	Biogeochemical	Inorganic carbon, ocean colour (for biological activity), nutrients, oxygen, transient tracers
	Biological & ecosystems	Marine habitat properties, plankton
Land	**Hydrosphere**	River discharge, water use, groundwater, lakes, soil moisture
	Cryosphere	Snow, glaciers, ice sheets and ice caps (see p. 3, bottom), permafrost
	Biosphere	Albedo, land cover (including vegetation type), land surface temperature, fraction of absorbed photosynthetically active radiation (FAPAR), leaf area index (LAI), above-ground biomass, soil carbon, fire, evaporation from land
	Anthroposphere	Anthropogenic Greenhouse gas fluxes, anthropogenic water use

Yearly temperature (2m Temperature from ERA-INTERIM model, 0.5° resolution) anomaly for the period 2006 to 2008. Positive anomalies can be found on the west coast of the US and Canada, some areas in central Russia, the southeast coast of Greenland, parts of northern Australia, the coast of Argentina and most of Antarctica's coast. The detail map shows temperature anomalies (daytime land surface temperature from MODIS, 0.05° resolution) between July 2003 and July 2004 over Sicily (Italy) demonstrating how satellite data can improve the detection of anomalies.



The map shows surface elevation changes of Greenland from 2011-2015 (10km gaussian filter) . The change in elevation is indicative of Greenland's melting ice cap. Data from CryoSat 2.



→ MONITORING OF CLIMATE CHANGE IMPACTS: SLOW-ONSET EVENTS

Climate-related slow-onset events are very dangerous but their full impact potential can take decades to manifest. The UNFCCC Cancun Agreements (Decision 1/CP.16) identify eight slow-onset events: desertification, glacial retreat and related impacts, land and forest degradation, loss of biodiversity, ocean acidification, salinisation, increasing temperatures and sea level rise.

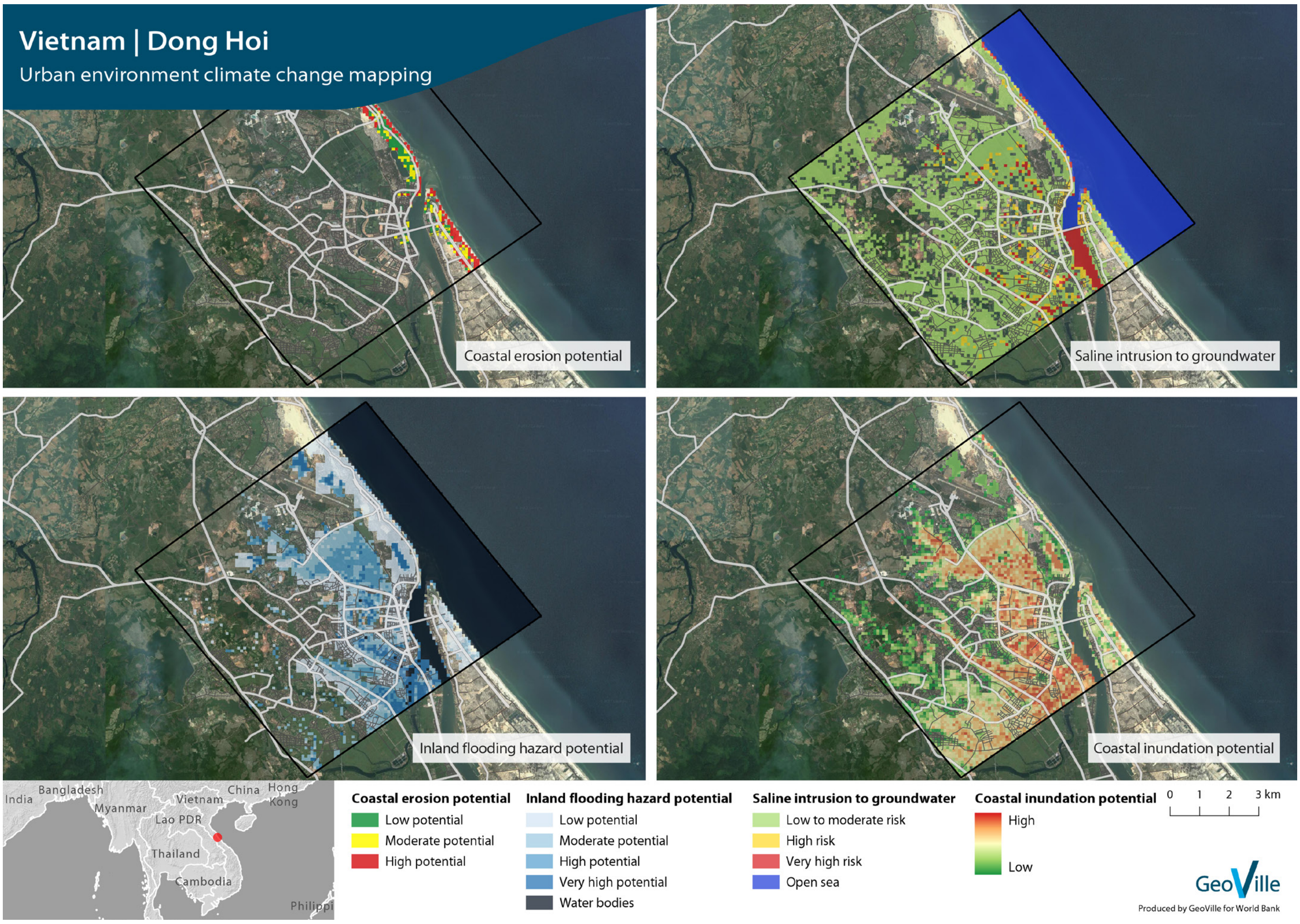
A 2012 UNFCCC technical paper stated that "there are synergistic interactions between rapid-onset and slow-onset events that increase the risk of loss and damage" highlighting the importance of addressing both in order to build climate resilience. The paper also states that slow-onset events were already impacting developing countries negatively.

Most types of slow-onset events identified in the Cancun Agreement have important implications for development. All of them can be monitored using EO. Given their slow evolution, monitoring slow-onset events and building long-term time series showing the otherwise very subtle changes can be an impactful tool for decision making.

Often, these events are interconnected. For example, recent reports suggest that the rate at which land ice is melting is increasing faster than expected because the Arctic is experiencing disproportionate warming compared to the rest of the globe (AMAP, 2017). This will inevitably contribute to an increase in sea level rise (see p. 5, top left) and affect vulnerable island and coastal communities. Long before the sea permanently inundates land, it can cause a number of issues from erosion and salt-water intrusion (which threatens potable water and arable land) to high tides that lead to frequent flooding (see bottom of this page).

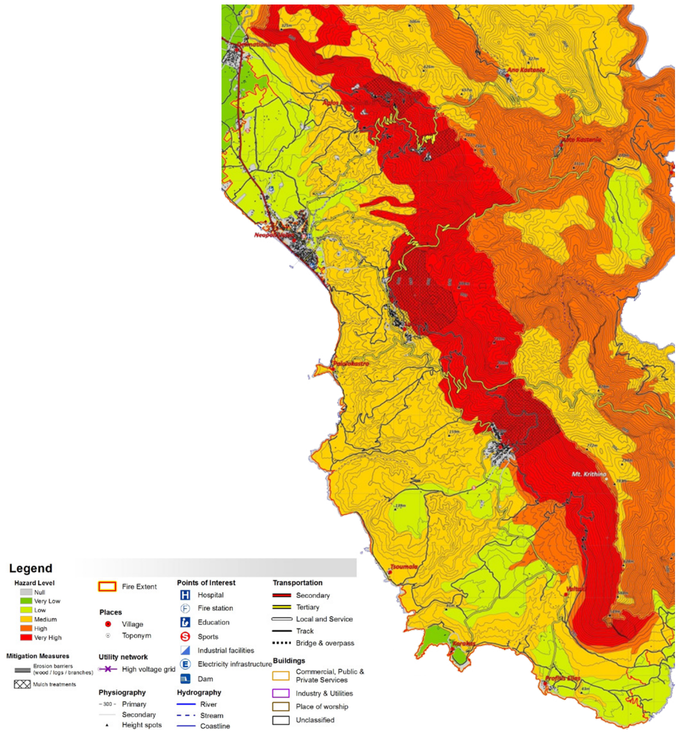
On the other hand, climate change can also impact natural habitats that plants and animals depend upon. Shifts in climatic conditions can lead to habitat changes (including the complete loss of a habitat) and potentially go beyond the migrational capabilities of species. This can alter competitive relationships in an ecosystem, threaten whole species and severly degraded habitat quality (see p. 5, top right and bottom).

Urban environment climate change mapping showing risks related to sea level rise in Dong Hoi, Vietnam. Copyright: GeoVille.

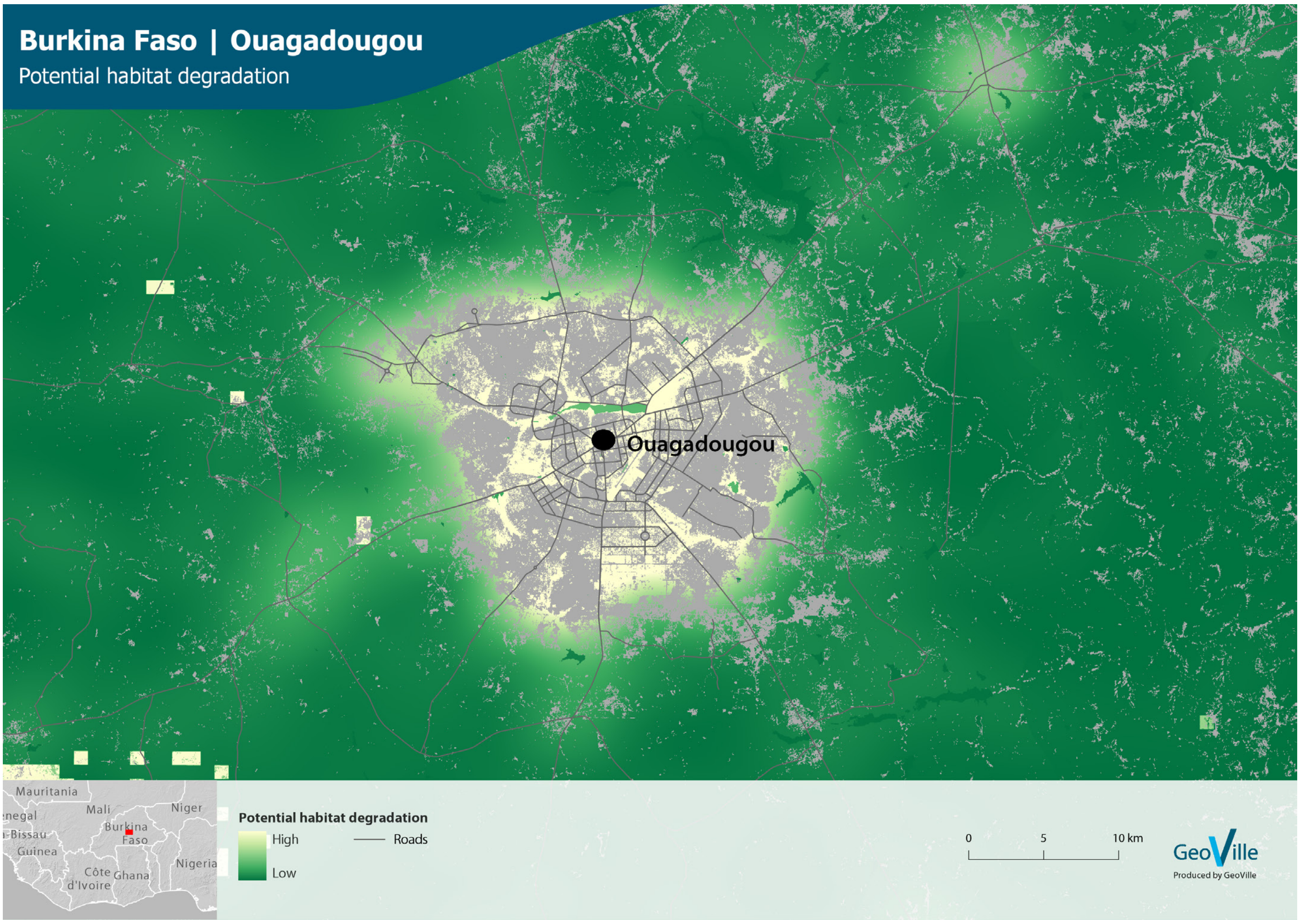


Winter sea level anomaly of Bangladesh's coast from 1993-2017 showing a clear upward trend. Data from Copernicus plotted by Telespazio Vega UK.

Mapping of soil loss in Monemvasia, Greece, ranging from dark green indicating very low losses to dark red, which indicate very high losses. Copyright: National Observatory of Athens.



Potential habitat degradation map of Ouagadougou, Burkina Faso and surroundings. Copyright: GeoVille.



→ MONITORING OF CLIMATE CHANGE IMPACTS: EXTREME EVENTS

As opposed to slow-onset events, extreme weather and climate-related events have very obvious and dramatic sudden impacts. Extreme events include hazards such as heatwaves, extreme rainfall, tropical cyclones, droughts, floods and wildfires.

In the past, the scientific community was very reluctant to attribute single extreme events to climate change. But as attribution science improves, the link between climate change and extreme events becomes better understood. Climate change can act as a booster for extreme events, potentially increasing their frequency and intensity.

Extreme events can often have catastrophic impacts. Historically, preparation for, and recovery from, weather-related disasters has been largely, though not exclusively, handled by the disaster risk reduction (DRR) community. The DRR discipline largely assesses disaster risk by relying on climate and weather risk scenarios that are based on past extreme events. However, these scenarios are becoming less reliable in a non-stationary climate. The climate change adaptation (CCA) community can offer valuable support as it incorporates climate projections and assesses how risks change over time. These changes in risk scenarios are crucial for the management of slow onset disasters.

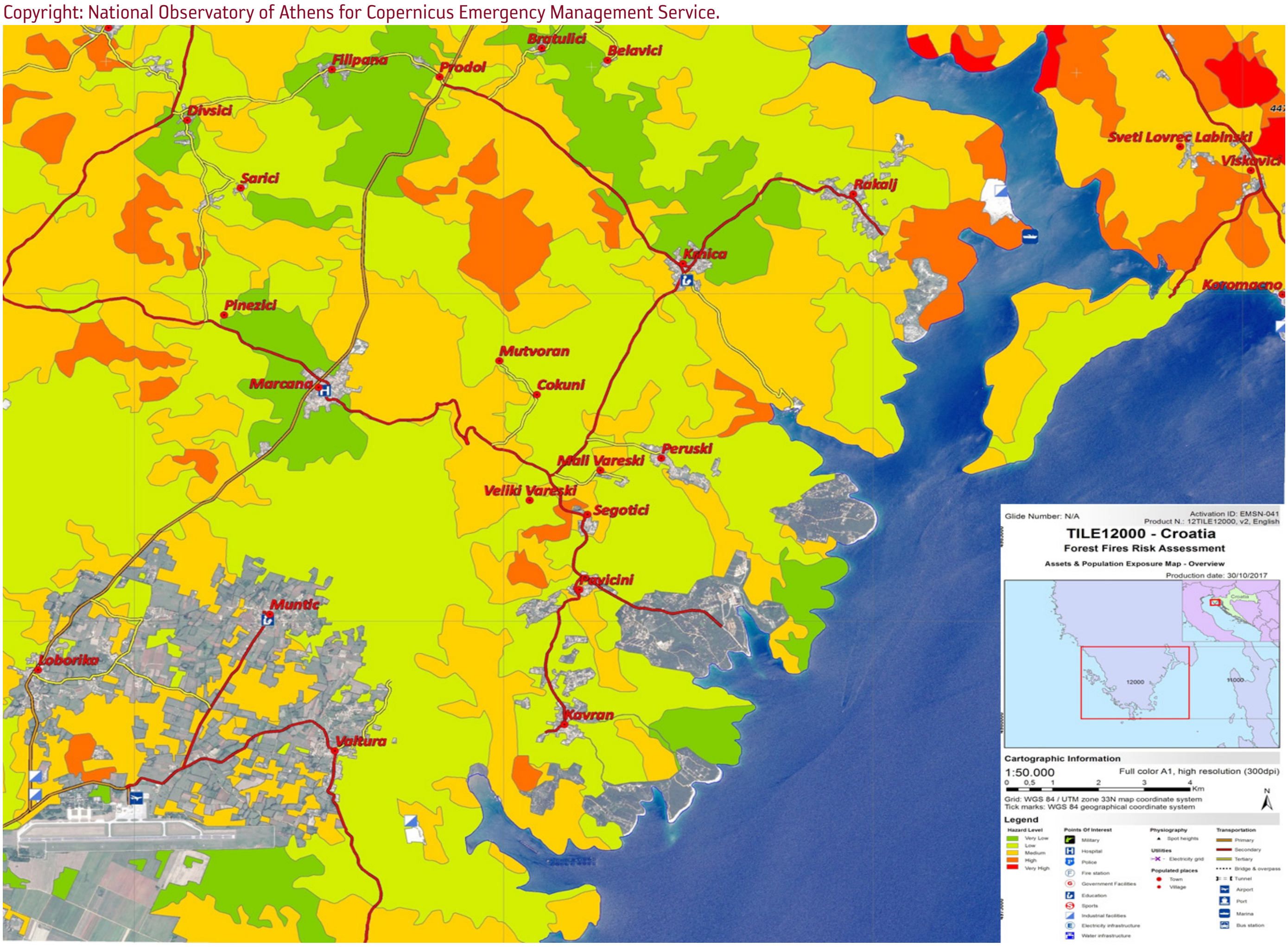
One example would be the increasing frequency and severity of droughts with abnormally hot temperatures as well as a lack of precipitation, as experienced across Europe in summer 2018 (see p. 7, bottom).

Connected to the issue of drought and heatwaves are wildfires, which are much more likely to happen and spread in dry and hot conditions where there is the presence of fuel, such as bushland. (see bottom of this page). These effects could be seen in summer 2018 across the Northern Hemisphere with major wildfires raging in large parts of Europe and the United States.

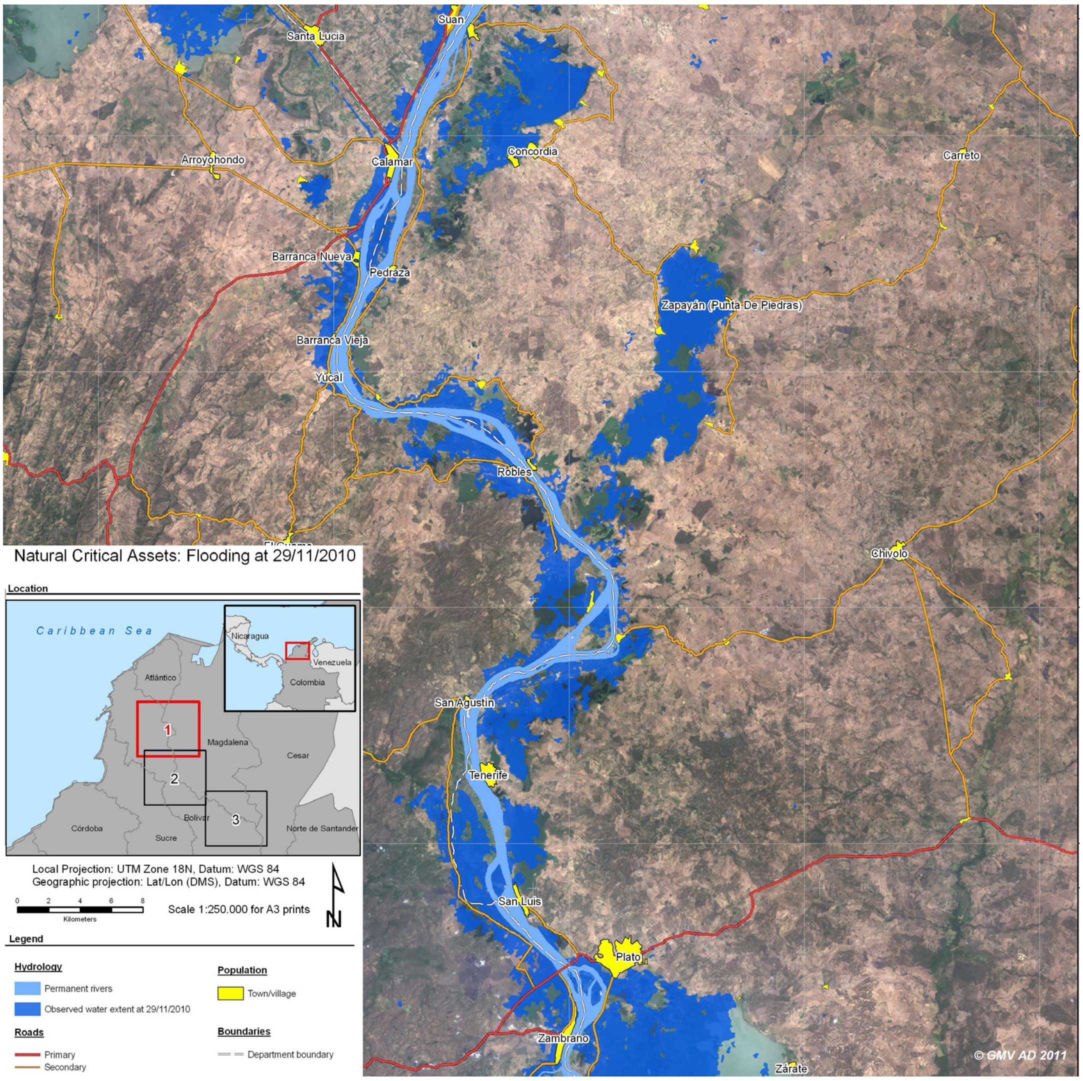
The risk thresholds for floods are also affected (see p. 7, top). For example, changes in precipitation patterns suggest that fewer but more intense rainfalls might become more likely. Thus, drainage systems might have to cope with larger water amounts than before.

While DRR has decades of experience working with communities on the ground, CCA offers expertise in managing climate risk increments; collaboration and knowledge exchange between the two could, thus, significantly improve resilience building.

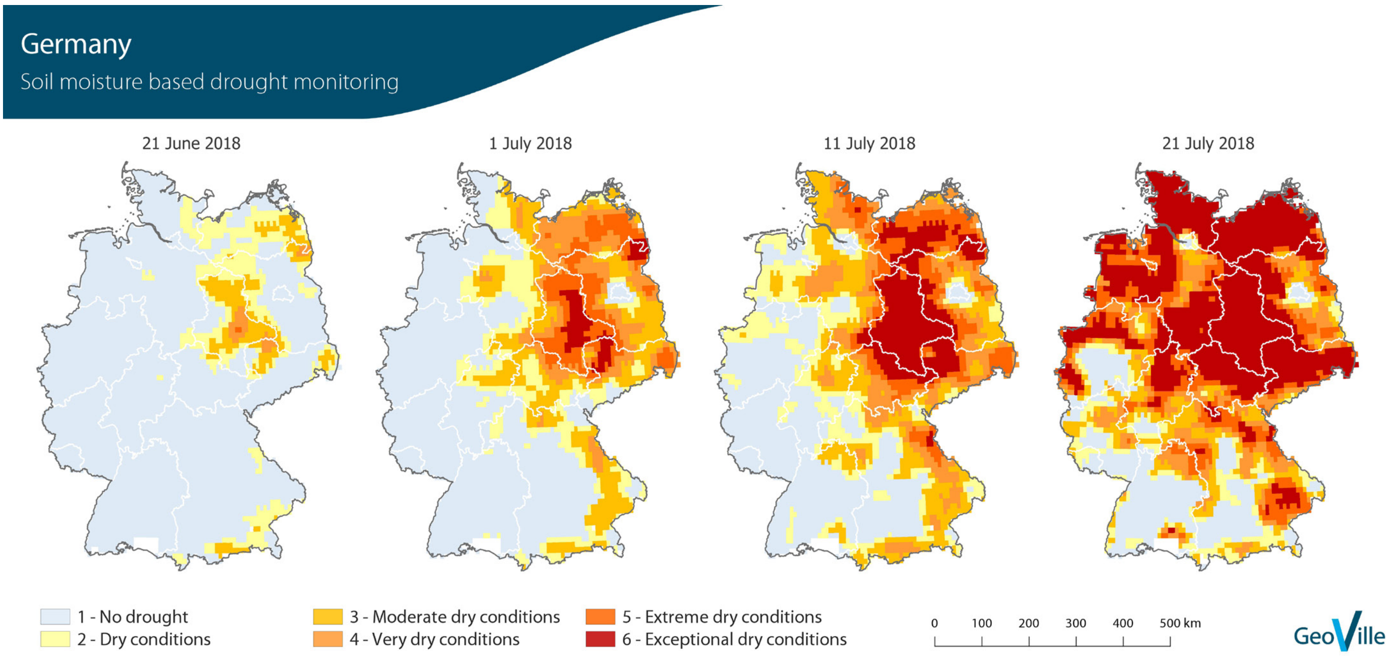
Map segment of a forest fire risk assessment of asset and population exposure in Croatia. The hazard level goes from dark green (very low) to dark red (very high). Copyright: National Observatory of Athens for Copernicus Emergency Management Service.



Detailed flood delineation map of Northern Departments of Colombia. Copyright: GMV for GMES Pilot Services for Security.



Map of Germany showing soil moisture anomalies (drought indicator) for June-July 2018. Copyright: GeoVille.



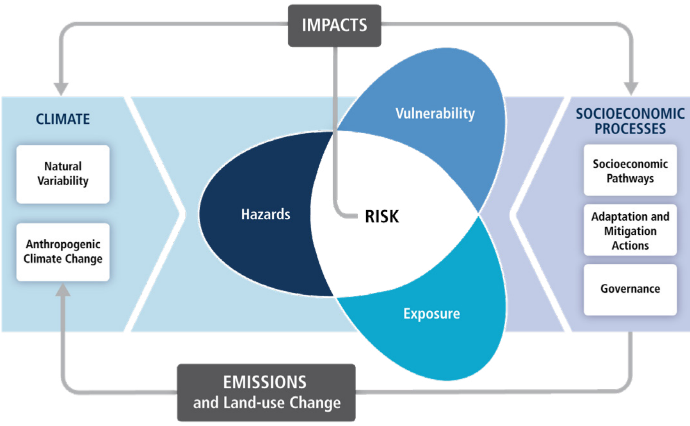
→ INDICATORS FOR CLIMATE CHANGE RISK SCREENING

In its 5th Assessment Report, the IPCC put the focus of effective adaptation on a comprehensive understanding of climate change risk. Its risk concept brought climatic and socioeconomic processes together in an effort to capture all the relevant dimensions of climate risk management.

The EO-based climate services of the EO4SD Climate Resilience Cluster will adopt a comprehensive view of risk as promoted by the IPCC's risk model (see diagram on the right). This also means integrating EO-based, socioeconomic, and other relevant data in order to achieve a holistic view of climate-related risks.

The combination of climate indicators – comprised of EO-based data, in-situ data, and climate projections – with socioeconomic indicators, provides information about actual climate risks. This in turn can be applied to climate-resilient decision making in development cooperation.

Table 2 offers a few examples of exposure and socioeconomic indicators for one of the cluster's target countries, Bangladesh. The indicators can be combined in order to form a comprehensive understanding of climate risks in a given location and identify potential hot spots (see also p. 9).



The IPCC risk framework illustrates the risk of climate-related impacts as a result from the interaction of climate-related hazards with the vulnerability and exposure of human and natural systems. Changes in both the climate system (left) and socioeconomic processes including adaptation and mitigation (right) are drivers of hazards, exposure and vulnerability.

Table 2: Examples of exposure and socioeconomic indicators for climate risk assessments in Bangladesh.

Exposure indicators: Bangladesh			
Indicator	*Data*	*Rationale*	*Key sector*
Growing season length variability	Annual count of days between first span of at least six days where daily mean is higher than threshold high temperature and first span in second half of the year of at least six days where daily mean is lower than threshold low temperature. Land surface temperature (LST) monitoring through e.g. Sentinel 3 SLSTR. LST data is also available from the Copernicus Land Monitoring Service and the EU-METSAT Land-SAF	High variability could affect the ability of farmers to plan and could reduce/damage crop yields. The standard deviation of the annual growing season length provides the measure of inter-annual variability.	Agriculture/food security
Extremely wet days number and variability	Precipitation due to extremely wet days. Monitoring using e.g. GPM (precipitation) and SMOS (soil moisture). Additional information can be obtained from the EUMETSAT H-SAF.	A large amount of precipitation falling in short periods is associated with hazards such as pluvial and fluvial flooding, contamination of water courses, mudslides and soil erosion. The arithmetic provides an indication of where extremely heavy precipitation events are most common. The standard deviation suggests where there is most variability.	Public health, water resources, agriculture
Flood	Extent of major flood events. Monitoring flooded area through e.g. Sentinel 1 C-SAR and water levels using Sentinel 2 SRAL.	Bangladesh is prone to flooding due to its location on the Ganges Delta and the many distributaries flowing into the Bay of Bengal. Coastal flooding, combined with the bursting of river banks is common. Extensive floodplains and coastlines increase the countries exposure to flood risk significantly.	Public health, coastal zones, agriculture
Socioeconomic indicators: Bangladesh (socioeconomic data not provided by EO4SD's CR cluster)			
Poor population	Number of people living below defined poverty line	Roughly 12 million people live in poverty in Bangladesh's coastal zones. Their vulnerability and exposure increase their risk of being negatively impacted by floods significantly.	Key hazard: Floods

→ SECTORAL CLIMATE SERVICES: INFRASTRUCTURE

Development organisations, humanitarian agencies and governments are faced with tough decisions about how to prioritise measures to reduce risks to infrastructure and settlements driven by extreme climate-related events. This process is particularly challenging in data-sparse regions with few surface-based meteorological and hydro-meteorological stations, gaps in datasets, and complex topography.

In light of these challenges, the application of EO data to identify climate change hot spots and to develop forecasting systems for extreme events can provide valuable evidence to decision-makers. It can help them to focus climate resilience and development efforts which protect vulnerable communities and their livelihoods, as well as the infrastructure (energy, water and transport) that supports socio-economic development. Climate change hot spots include semi-arid regions and deltas in Africa and Asia, and river catchments fed by glaciers and snowmelt in Central and South Asia, among others (De Souza et al, 2015).

EO data can be applied to identify hot spots and develop forecasting systems for a range of climate-driven hazards, including heat waves (especially in urban areas), flash floods, river floods, coastal flooding and erosion, soil erosion, landslides, mudflows, Glacial Lake Outburst Floods (GLOFS) and avalanches. Such systems have already been developed and applied in various geographies. The image on the top right demonstrates an output of such a hot spot analysis for Yemen, where flash floods and soil erosion significantly affect the livelihoods of smallholder farmers. The system was developed by a member of the Acclimatise team, Professor Rob Wilby (Wilby and Yu, 2013 a & b).

Input data

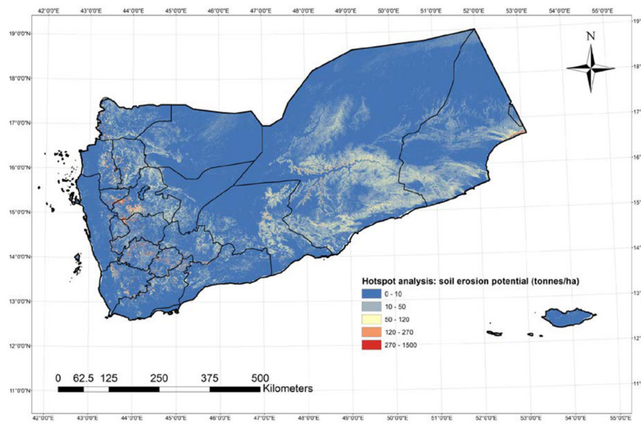
Forecasts and hot spots of flash flood risk can be produced using only public-domain datasets, which is highly useful in countries lacking robust in-situ datasets. The Yemeni example blended surface meteorological observations and soil survey data, remotely sensed (precipitation and vegetation) indices, topographic information, and geo-statistical techniques to produce hazard maps for flash flooding (and also soil erosion, water harvesting, and cropping potential).

The input datasets were:

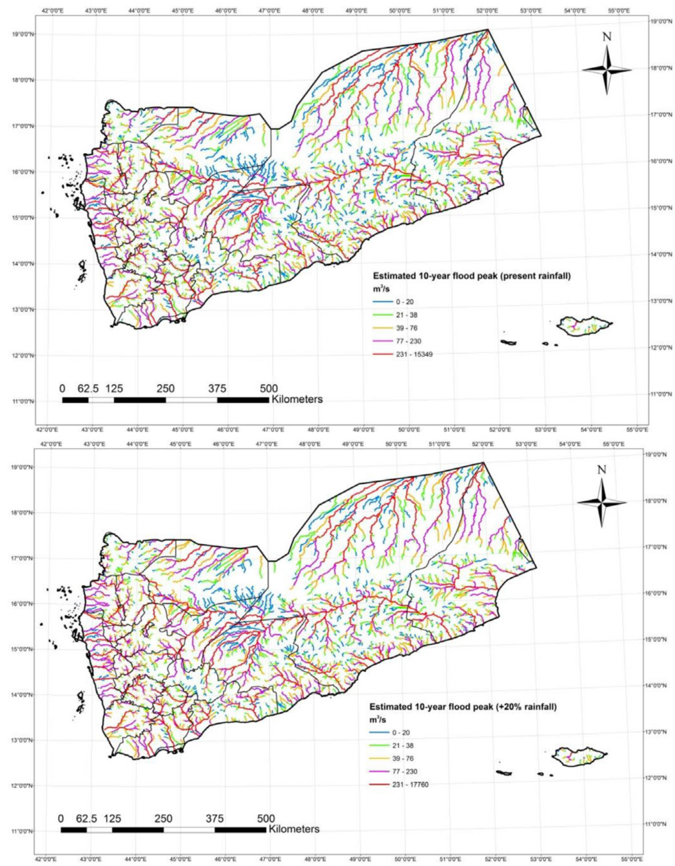
- Administrative and topographic information for Yemen, mapping the locations of governorates, districts, major roads, cities and settlements (villages), provided by the Food and Agriculture Organization (FAO) and Ministry of Public Health and Population of Yemen.
- Land elevation: The Digital Elevation Model (DEM) at 30 m resolution was obtained from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Map (GDEM).
- Land cover: Global Land Cover (GLC) 2000 map from the Joint Research Centre (JRC) of the European Commission.
- Soil type obtained from the Digital Soil Map of the World (DSMW), a classification of soil units developed by the FAO
- Surface observations of meteorological data, namely precipitation and temperature
- Tropical Rainfall Measuring Mission (TRMM) multi-satellite precipitation analysis

The system in Yemen was used to produce a national atlas of flash flood risks (and other factors such as soil erosion potential). The resultant maps were used to identify hot spots of vulnerability – for instance, where flash flood risk coincides with settlements and the road network. The atlas was produced for present climate conditions (image in the middle right) and future scenarios (image on the bottom right).

Soil erosion hot spot analysis for Yemen. Source: Wilby and Yu (2013a).



Estimated 10-year maximum flood peak (QMAX10, m^3/s) based on modelled local annual maximum daily rainfall totals with a 10-year return period (RMAX10) under (top) present conditions and (bottom) a future climate scenario with a +20% increase in RMAX10.Source: Wilby and Yu (2013a).



Index-based insurance is an effective way to build agricultural resilience to climate variability and change, covering risks at various levels. Especially in developing countries insurance products and services protect farmers against losses from climate shocks, helping to cope with severe weather risks and optimize production.

Index insurance pay-out is made when a pre-determined index (e.g. soil moisture, rainfall) that can be measured remotely with EO, and other means, falls above or below a predetermined threshold. Detailed verification of losses at field level are not necessary once the index is tuned to a region and pay-out thresholds are defined. Satellite-based soil moisture has been found to be an effective index insurance parameter as it displays the actual available water on the ground needed for vegetation development.

This example highlights an index insurance service that comprises different levels of output products, depending on the user requirements and available input data. Apart from the tangible raw data products, the end users will receive different levels of index insurance products, making them more resilient to climate shocks and enabling them to fulfil the contractual agreements with banks and microfinance institutions.

Level 1: A first indication of the climatic situation in a region can be derived from historic soil moisture trend analyses and anomaly observations. This is based on coarse resolution surface soil moisture data, indicating changes in moisture pattern. Completed by observing trends and anomalies in rainfall and vegetation parameters, a comprehensive picture of the region of interest can be drawn.

Level 2: The next level is the derivation of the start of the wet season information based on satellite soil moisture data, both historic and near-real time.

Level 3: This information can then be refined by employing ground information (yield data) as well as satellite based vegetation dynamics. By incorporating yield data the response of different crop types to varying levels of soil moisture availability can be observed.

Input data

Historic and near-real time global soil moisture observations (low and medium spatial resolution), global vegetation indices, global rainfall estimates (optional), crop yield data (optional).

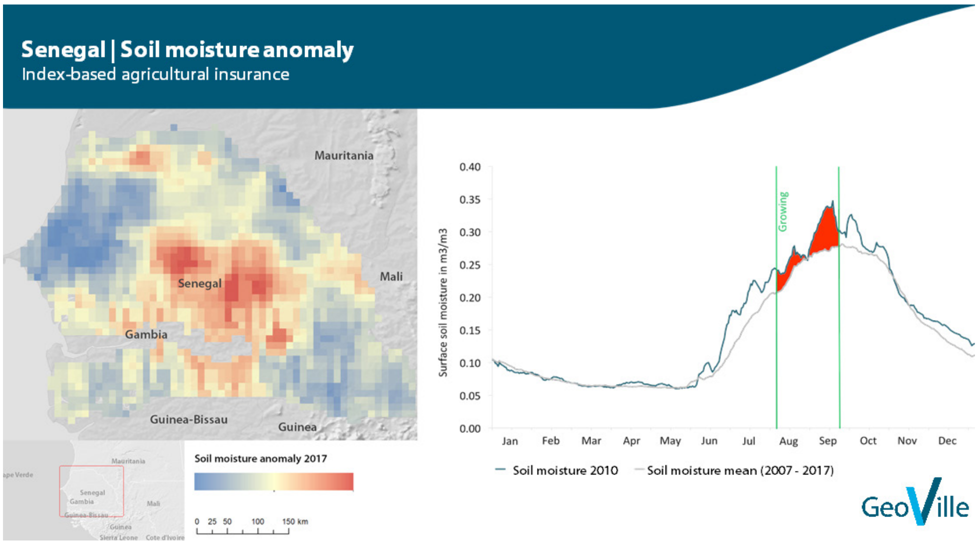
The important role of soil moisture for the environment and climate system is well known and it was recognized by GCOS as an ECV in 2010. Satellite measurements integrate this rather heterogeneous variable over relatively large areas, but temporal resolution is very high and thus ideally suited for index insurance applications.

For long-term trend analyses and anomaly detection the ESA CCI soil moisture dataset can be employed. This most complete and most consistent global soil moisture data record is based on active and passive microwave sensors providing the soil moisture content in the first 5-10cm of the soil in absolute values (m^3/m^3). The data is provided at a spatial resolution of 0.25 degree for the period of 1978 to 2017. By the time of the ESA EO4SD project the data series will also cover the year 2018. Via the European Centre for Medium-range Weather Forecasts (ECMWF), the C3S will continue the provision of the gridded soil moisture observations, extending the observations in the coming years (see Dorigo et al 2017, Gruber et al 2017, Liu et al 2012).

For near-real time, operational monitoring soil moisture data is available at two resolutions.

- The Copernicus Land Service provides operational, near-real time Soil Water Index (SWI) data from 2007 at daily to 10 daily resolutions, representing the soil moisture content in the first meter of the soil in relative units (0-100%) ranging between wilting level (dry - 0%) and field capacity (wet - 100%). It is provided at approximately 0.1 degree spatial resolution for the period 2007 to present.
- A globally available, 5-daily, 10m soil moisture commercial service will be available (Dec 2018) from GeoVille stating with volumetric (m^3/m^3) soil moisture observations from Sentinel-1. Besides the observations also anomalies are provided.

Global vegetation indices can be derived from various sources such as Copernicus and C3S, amongst others.



Soil moisture anomaly map for index-based insurance. Copyright: GeoVille.

→ SECTORAL CLIMATE SERVICES: ECOSYSTEMS

The resilience of many ecosystems is likely to be exceeded by 2100 due to an unprecedented combination of changes in climate, associated disturbances such as floods and droughts, and other global change drivers, for example, land-use change and over-exploitation of natural resources. Developing countries are especially prone to rapid ecosystem degradation and thus the loss of related regulating services that are particularly critical for climate change adaptation and disaster risk reduction.

Effective ecosystem management plays a central role in climate change adaptation and DRR as it increases the resilience of natural systems and human societies to climate change impacts. Ecosystem-based adaptation (EbA) involves a wide range of ecosystem management activities to increase resilience and reduce the vulnerability of people and the environment to climate change. This includes integrated water resource management, sustainable forest management interventions, and sustainable agriculture.

Besides the benefits for climate adaptation, the value of ecosystems and their services in contributing to a countries wealth as natural capital is well established. Wealth accounting, including natural capital accounting (NCA), is needed to sustain growth. The basis for effective ecosystem management and the development of ecosystem accounts is a detailed yet large-scale assessment of the natural resources and changes in those.

This example highlights how EO and advanced Geographical Information System (GIS) analyses as well as dedicated ecosystem models, such as the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST), support effective EbA, management, and valuation. It comprises different levels of output products, depending on the user requirements and available input data.

Input data

Input data can include EO and non-EO input data such as:

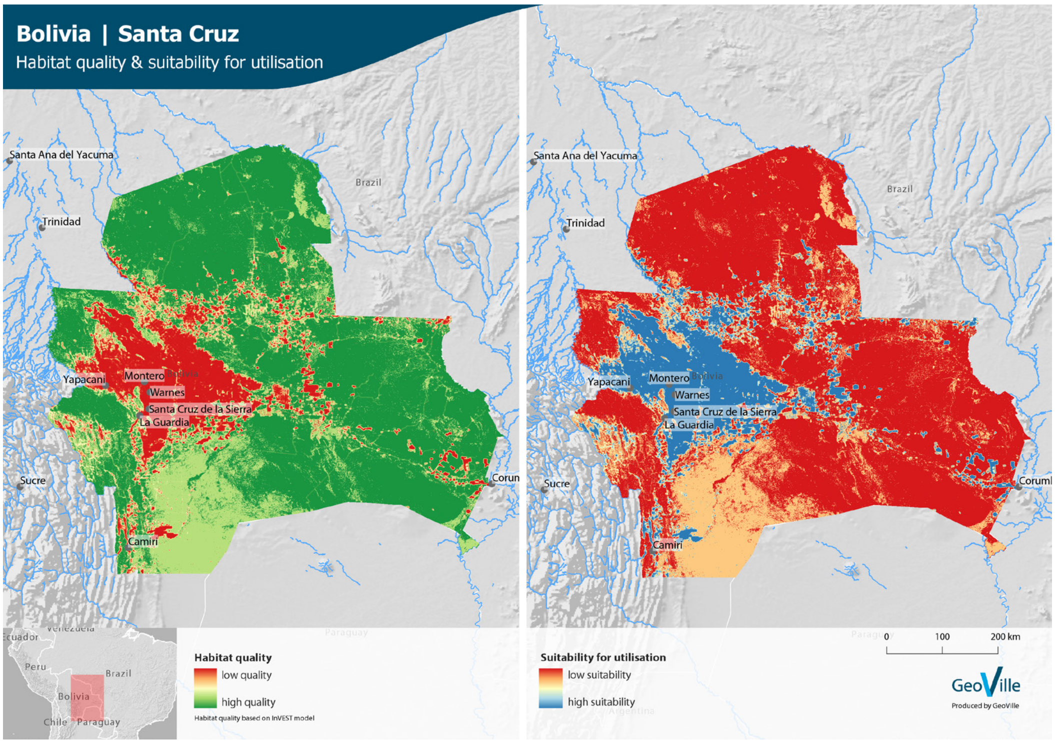
- Delineation of important/critical habitats and threats (e.g. land cover/use mapping, flood and drought risk mapping based on soil moisture, vegetation and/or rainfall)
- Reference data for interpretation and validation (e.g. in situ data, pictures, local expert knowledge)
- Transportation network (derived from land cover mapping or Open Street Map)
- Settlements (derived from land cover mapping or Open Street Map)
- Administrative boundaries
- Soil erosion mapping based on satellite based digital terrain information, soil maps and climate data (rainfall)

Apart from the tangible land cover/use products, the end users will be able to receive different levels of information and products supporting ecosystem-based adaptation measures, effective ecosystem management and valuation.

A habitat quality map (see below, left) shows pixel values ranging from 0 (low quality) to 1 (high quality). Fragmented or degraded patches will show lower quality and associated biodiversity values due to a high intensity of threats. Areas with high habitat quality are generally concentrated in less modified areas (less road access, settlements and agricultural land use).

Such information can be used to derive a map indicating suitability for utilisation purposes as knowledge about biodiversity can drive land use planning, and areas of low biodiversity will be used first. In the proposed site utilisation suitability map areas shown in red indicate areas of low conservation value that are more suitable for utilisation purposes. From a nature conservation perspective areas shown in blue are of importance, indicating large patch size and high habitat quality (see below, right).

Habitat quality model result (left) and areas indicating suitability for utilisation purposes (right) for Bolivia. Copyright: GeoVille.



→ EARTH OBSERVATION FOR SUSTAINABLE DEVELOPMENT

Latin America and Caribbean

Regional Office:
Barbados - Acclimatise Project Office

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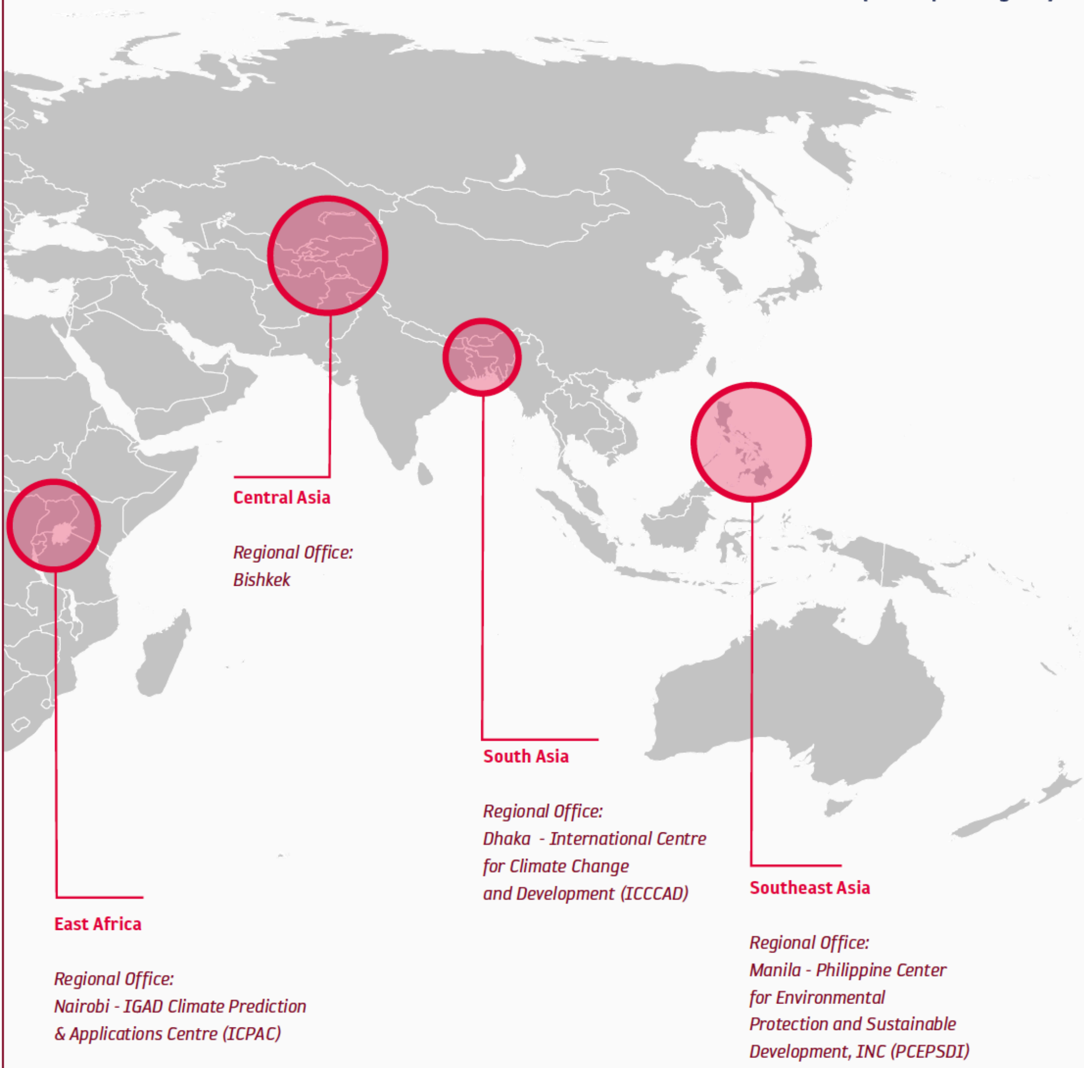

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