JRC Scientific and Technical Reports

JRC experience on the development of Drought Information Systems

Europe, Africa and Latin America

Horion S., Carrão H., Singleton A., Barbosa P. and Vogt J.

EUR 25235 EN - 2012

EUROPEAN COMMISSION

Institute for Environment and Sustainability

The mission of the JRC-IES is to provide scientific-technical support to the European Union's policies for the protection and sustainable development of the European and global environment.

Contact information
European Commission - Joint Research Centre - Institute for Environment and Sustainability
Address: TP280, Via E. Fermi 2749, I-21027 Ispra (VA), ITALY
E-mail: juergen.vogt@jrc.ec.europa.eu
Tel.: +39 033278 5481

http://ies.jrc.ec.europa.eu/
http://www.jrc.ec.europa.eu/

JRC 68769

EUR 25235 EN
ISBN 978-92-79-23203-9 (PDF)
ISBN 978-92-79-23202-2 (print)
ISSN 1831-9424 (online)
ISSN 1018-5593 (print)

doi: 10.2788/15761

Luxembourg: Publications Office of the European Union, 2012

Suggested citation:
Horion S., Carrão H., Singleton A., Barbosa P. and Vogt J. (2012). JRC experience on the development of Drought Information Systems. Europe, Africa and Latin America. EUR 25235 EN. Luxembourg (Luxembourg): Publications Office of the European Union, JRC68769, doi: 10.2788/15761.

TABLE OF CONTENT

UNDERSTANDING DROUGHT

Drought is one of the major weather related disasters. Persisting over months or years, it can affect large areas and may have serious environmental, social and economic impacts. These impacts depend on the duration, severity and spatial extent of the precipitation deficit, but also to a large extent on the environmental and socio-economic vulnerability of affected regions (Vogt & Somma, 2000). Whether a given deficit of rainfall leads to economic crisis, food insecurity, public health matter or famine depends highly on the capacities of the environment and of the population to cope with it and to recover from it (WMO, 2006). To understand the drought risk in a given region of the world, we need to characterize both the exposure to the hazard itself and the societal vulnerability to drought. Timely information about the onset of drought, its extent, intensity, duration and impacts can limit drought-related losses of life, minimize human suffering and reduce damage to economy and environment (Wilhite, 1993). The assessment of droughts in a given region requires understanding historical droughts as well as the impacts on human activities during their occurrences (Kemp, 1994). Because drought is a multiscale, trans-border and multivariate phenomenon, there is a need to develop and establish decision support tools at the regional scale to analyse data from different sources and summarize it into useful information for drought assessment.

From the definition of drought to its monitoring and assessment, **this report summarizes the main steps towards an integrated drought information system**. Europe, Africa and Latin America are examples, based on the experience of the JRC, that illustrate the challenges for establishing continental drought observatory initiatives. The document is structured in the following way: first an introduction explains what drought is and gives some examples of its impact in society; secondly the framework for establishing a drought monitoring system is described giving examples on the European Drought Observatory and on on-going activities in Africa and Latin America; thirdly the fundamental data and information for measuring drought is described; finally the setting up of an Integrated Drought Information System is discussed and two recent case studies, on Europe and on the Horn of Africa, are presented to illustrate the concept.

1.1. What is drought?

Drought is part of the natural climate variability and therefore can be observed in all climate regimes. Unlike aridity, drought is a temporary abnormal phenomenon, usually characterized by lower than average water availability for the population or for the environment. There is no unique or universally accepted definition of drought. However three types of drought are commonly distinguished (WMO, 2006).

- **Meteorological Drought:** Meteorological drought is defined as a deficit in precipitation over a defined period and region as compared to climatological average values. Meteorological drought can be characterised using meteorological data products on precipitation available from national and international weather services.

- **Hydrological Drought**: A hydrological drought is expressed by reduced stream-flows, lake, or reservoir levels. Time-series of these variables are used to analyse the occurrence, duration and severity of hydrological droughts.

- **Agricultural Drought:** Agricultural drought is the impact of reduced water supply on agricultural crops, leading to a reduction of annual yields in the affected regions. Predicting agricultural droughts requires in-depth knowledge of the crop water requirements and agricultural practices. Often statistical approaches to estimate crop yields and potential yield losses are applied.

The different types of drought occur at different time scales and are intimately interrelated with each other (Figure 1).

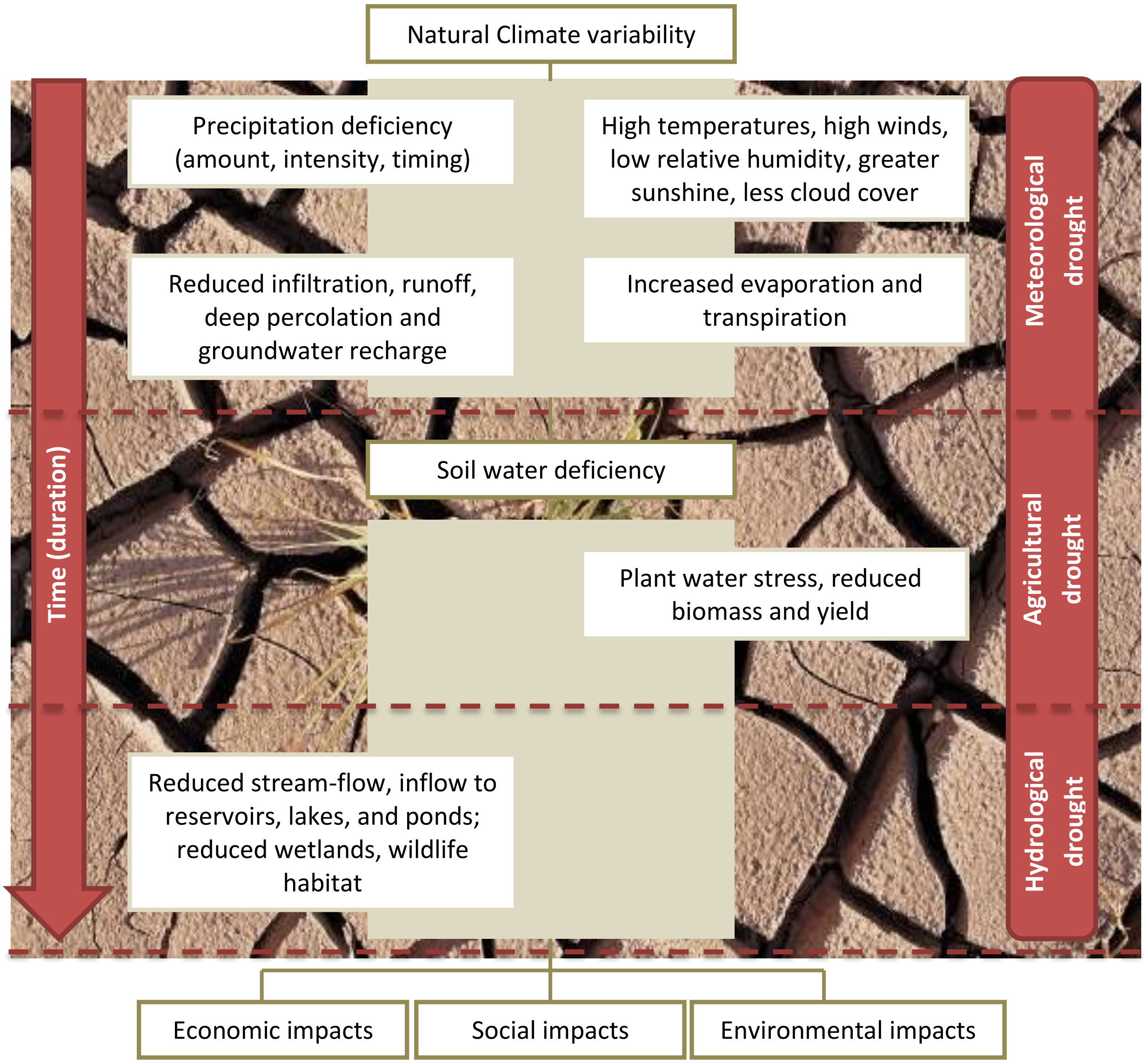


Figure 1: Sequence of drought occurrence and impacts for commonly accepted drought types (Source: National Drought Mitigation Center, University of Nebraska-Lincoln, USA)

1.2. Some facts and figures about drought

Due to the complex nature of drought, collection of objective field information on drought and its direct or indirect impacts is a real challenge. Managed by the Centre for Research on Epidemiology of Disaster (CRED), the **International Disaster Database *EM-DAT*** is gathering information on natural and technological disasters worldwide. To be considered as disaster and therefore to be included in the database, at least one of the following criteria needs to be fulfilled: 10 or more people reported killed, 100 people reported affected, declaration of a state of emergency and call for international assistance (Below et al, 2007). Location, starting date and ending date of the disaster are also registered when available. Comparing with other disaster types that have a quite clear geographical extent and timing, such as flooding, forest fire, earthquake or technological disaster (i.e. chemical spill, building collapse, etc.), droughts are more difficult to assess. Indeed the starting date of a drought event as recorded in the database might correspond to the date of the declaration of a state of emergency. In such case, the real starting date of the drought needs to be anticipated compared to the one registered in the database. Similarly the extent of a drought or the location registered in the EM-DAT might not correspond entirely to the actual drought affected area in the meteorological, agronomical or hydrological sense (see Section 1.1) but to the area where the population is the most affected and therefore needs assistance. Nevertheless EM-DAT remains a very useful tool to analyse historical drought disasters.

Table 1: Summarized table of droughts disasters sorted by continent from 1900 to 2011 (EM-DAT, 2011).

	# of Events	# of Death	Total Affected pers.	Damage (000 US$)
Africa	269	844,143	317,936,829	5,419,593
Asia	147	9,663,389	1,666,286,029	33,823,425
Europe	38	1,200,002	15,482,969	21,461,309
Latin Am. - Caribbean	109	77	65,078,841	8,866,139
North America	14	0	55,000	11,945,000
Oceania	19	660	8,027,635	10,703,000
World	**596**	**11,708,271**	**2,072,867,303**	**92,218,466**

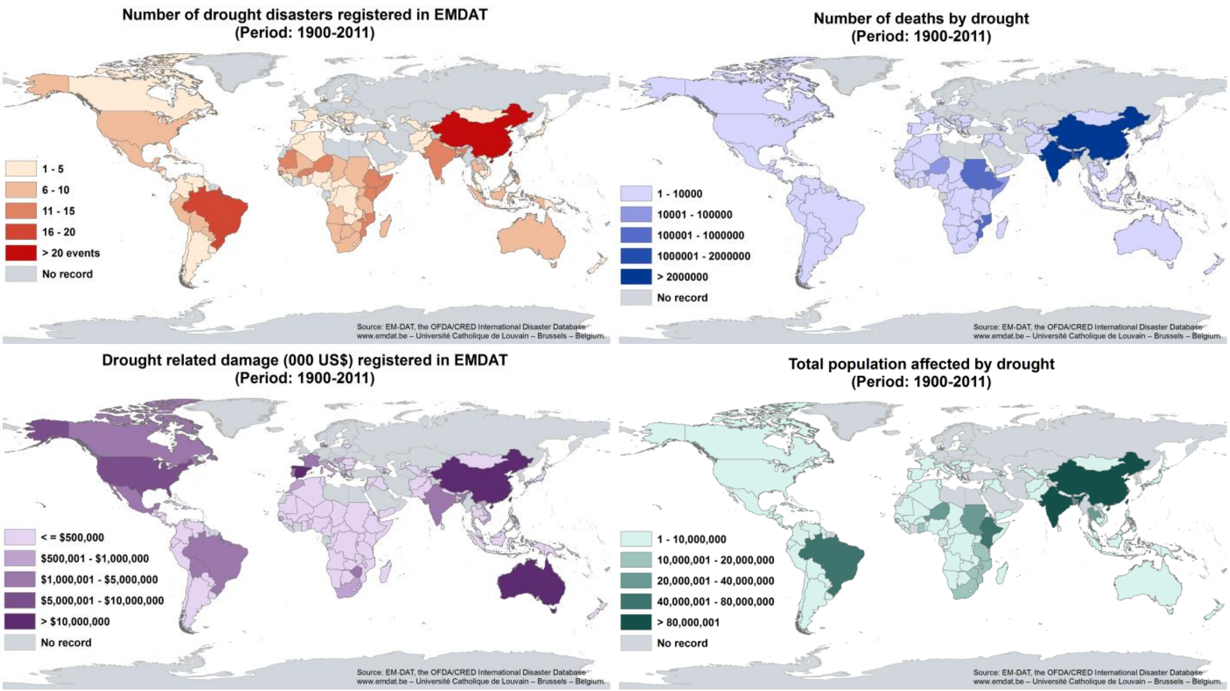


Figure 1: World maps of drought disasters statistics for the period 1900-2011 (Source: EM-DAT, 2011).

According to this database, drought has affected more than 2 billion people worldwide and caused more than 90 billion US$ of damages between 1900 and 2011 (EMDAT, 2011). If we take a look at the statistics per continent, the highest numbers of reported droughts were registered for **Africa** (Table 1). In total, the 269 reported events have affected more than 300 million people, killed more than 800,000 lives and caused about 5.5 billion US$ of damages. **Asia** is the second continent with the largest number of reported droughts (147 events) but the first in terms of affected population (more than 1.6 billion people) and economic losses (more than 33 billion US$). At country level, China and India are the most affected nations (Figure 1). **Latin America and the Caribbean** come third in terms of reported droughts (109 events) and total affected population (more than 65 billion people). In **Europe**, less than 40 droughts were registered in the EM-DAT, however they accounted for important economic damages (more than 20 billion US$). It is important to note that the large number of deaths in the EMDAT database is attributable almost in totality to the very acute famine of 1921 in Russia. In this case, like in most of the dramatic famines in the world, political and economic issues were first accountable for the large number of live loss; the drought episode unfortunately came worsening the already dramatic situation of the population[1].

[1] Source: International Committee of the Red Cross, Press article published in the Swiss daily "Le Temps" on 12 Aug. 2003, available online at http://www.icrc.org/fre/resources/documents/misc/5qkjlh.htm (last visit: 9 Nov. 2011).

FRAMEWORK FOR ESTABLISHING A DROUGHT INFORMATION SYSTEM

2.1. Needs and Challenges

Drought is the most damaging environmental phenomenon (Kogan 1997). Because of its slow-onset characteristics and lack of structural impacts, drought is often disregarded unless serious problems appear (Svoboda et al. 2002, Mishra and Singh 2010). This lack of recognition compared to other natural hazards such as floods, earthquake or tsunami has been an impediment for obtaining adequate research support and, in many cases, an obstacle for building awareness among decision makers at the local, national, regional and international levels.

The comprehensive knowledge of the problem is necessary to erase misunderstandings about drought and society's capacity to mitigate its effects (Keyantash and Dracup 2002). It is known that some regions have greater exposure to drought than others, and we do not have the capacity to alter such exposure. However, we can collect and analyse multiple variables, such as rainfall, stream flow, groundwater levels, soil moisture or socioeconomic data on a variety of time and geographical scales, providing the information necessary for monitoring and forecasting droughts to further mitigate their impacts on human activities.

A major challenge is to convince local, national and supra-national policy and decision makers that investing in regional monitoring and early warning systems is more cost effective than funding only programs for post-disaster assistance and emergency response. Furthermore, a regional cooperation framework is fully legitimate because the climatological and biophysical processes of interest leading to drought are not constrained by national boundaries (Tadesse et al. 2008). It is true that, at national level, each country faces its own unique set of challenges in relation with its specific natural, social, economic, and political conditions. However, the development of an effective drought monitoring system requires that different countries and organizations work in synergy for the survey, collection and harmonization of available data, information, and tools in order to create a common system that is integrated and interoperable.

2.2. Regional networks

Regional networks are made up of representatives from countries in the region, and focus on the specific needs of the region, mainly on "developing countries". The networks try to capture the attention and the support of dedicated national and supranational institutions for unsustainable problems in the region. Regional initiatives are developed subject to the availability of funding and technical capacity of the active members. A basic assumption is that one party is dependent on resources and competencies controlled by another, and that there are gains if the resources and competencies can be pooled. Regional networks work together to improve the assessment, monitoring and mitigation of drought and its impacts on human activities from regional to national scales. They facilitate sharing information, experiences, and best practices through global, regional, and national partnerships, and aim at being:

- a concept – an active, critical, conscientious and updated organization taking visible initiatives on drought mitigation and management;
- a model – for research, exchange of information, testing, assessing, creating information and methods, translating and adapting information, giving courses, seminars and conferences;
- a resource – by providing data, information, products and knowledge;
- a point of reference – for supranational and/or national institutions working on this subject.

In this section we briefly describe some active regional networks in Europe, Africa and Latin America. We focus our description on their organizational structure, mission and goals, and we aim at providing a comprehensive overview of their main efforts, difficulties and successes on assessing and monitoring drought at the regional scale.

2.2.1. Europe

In Europe, the European Drought Observatory is a reference for the development of a European drought information system. Examples of other regional initiatives, are the European Expert Network on Water Scarcity and Drought, the Drought Management Centre for South-Eastern Europe, and a scientific network known as the European Drought Centre.

❒ **European Drought Observatory (EDO)**

Following the serious drought and heat wave in 2003 that affected a large proportion of the European continent, political awareness rose for drought as a natural hazard as well as for the need to develop adequate monitoring, assessment, forecasting and management tools. The European Commission's Communication on Water Scarcity and Drought (COM(2007)414 final) provided a framework for action against the impacts of water scarcity and drought under a changing climate. Among many other actions, the communication calls for the establishment of a European Drought Observatory (EDO, http://edo.jrc.ec.europa.eu/) as well as for a European Information System on Water Scarcity and Drought. While the latter is a yearly or seasonal reporting system, documenting and analysing the situation ex-post, EDO is conceived as a continuous monitoring and forecasting tool providing up-to-date information on the availability of water resources throughout Europe. To this end, EDO needs to manage a series of indicators related to the different types of drought in order to assess and quantify the occurrence, duration and severity of drought events. At the same time, indicators measuring the impact need to be monitored and forecasts should be issued over different time scales, ranging from a few days to a season. In its final form, EDO will be a multi-scale distributed system, combining information systems (i.e. observatories) from local, national, regional and continental levels. In order to allow for a seamless up-and downscaling between the different scales, a set of agreed and standardized indicators is required that are available at all scales. Additional specific indicators, reflecting local conditions, can be added at each individual scale.

❒ European Expert Network on Water Scarcity and Drought

In order to support the development of EDO and its integration across scales, a European Expert Network on Water Scarcity and Drought was established under the Common Implementation Strategy for the Water Framework Directive (WFD-CIS). This expert network, comprising representatives from the EU Member States, the European Environment Agency, industrial organizations, NGOs and the European Commission (DG ENV and JRC), meets on a regular basis to discuss the best way forward for implementing drought monitoring and management structures across Europe. Currently the network is establishing a common set of common indicators for monitoring and assessing drought and water scarcity across the entire European Union. Discussions center on a set of 7 awareness raising indicators, six for drought monitoring and one for assessing and monitoring water scarcity. The drought indicators comprise indicators for precipitation, stream flow, soil moisture, groundwater levels, snowpack and vegetation condition. The water scarcity indicator combines information on water abstraction with information on water availability across administrative entities. Each indicator is described in detail in the form of a factsheet, giving information on its significance, the methodology to calculate it, as well as on advantages and limitations, thus allowing to calculate the indicator according to agreed and scientifically sound methodologies. These indicators will be made available through the map server of the European Drought Observatory and each indicator will be accompanied by the related fact sheet. A set of drought management indicators should follow in due time. All indicators will be made available to the public through the EDO Map Server.

❒ Drought Management Centre for South-Eastern Europe (DMCSEE)

An important regional network has been established for the south-eastern part of Europe through the Drought Management Centre for South-Eastern Europe (DMCSEE, http://www.dmcsee.org/), located in Ljubljana, Slovenia. The DMCSEE was founded by WMO and UNCCD and coordinates and facilitates the development, assessment, and application of drought risk management tools and policies in South-Eastern Europe with the goal of improving drought preparedness and reducing drought impacts. DMCSEE focuses its work on monitoring and assessing drought and assessing risks and vulnerability connected to drought. The centre is closely linked to the European Drought Observatory through a collaboration agreement with JRC and as such is an important partner in Europe.

❒ European Drought Centre (EDC)

A virtual network of scientists working on drought related issues is the European Drought Centre (EDC, http://www.geo.uio.no/edc/). The EDC web site is run by the University of Oslo, Norway. It characterizes itself as a virtual knowledge centre with the aim to coordinate drought related activities in Europe to better mitigate the environmental, social and economic impact of droughts. The EDC promotes collaboration and capacity building between scientists and the user community and thereby increase preparedness and resilience of society to drought.

2.2.2. Africa

In Africa, there is a number of regional and national institutions that are involved directly or indirectly with drought monitoring, assessment and forecasting. The most representative regional institutions are the following:

❒ **Observatory of Sahara and Sahel (OSS)**

The OSS is an independent international organization based in Tunisia. The main objective of OSS is to give impetus to the combat against desertification and the mitigation of drought by providing member countries and organisations with a forum where they can share experiences and harmonise the ways in which data is collected and processed to feed into decision-support tools. The OSS includes 22 member countries, 5 countries in Europe and North America (Germany, Canada, France, Italy and Switzerland), 4 sub-regional organisations— representing West Africa (CILSS and Côte d'Ivoire), East Africa (IGAD) and North Africa (AMU and Egypt)—, a sub-regional organisation covering the whole circum-Sahara (CEN-SAD), regional organisations, as well as organisations part of the United Nations System and Civil Society. [Website: www.oss-online.org]

❒ **IGAD Climate Prediction and Applications Centre (ICPAC)**

In 1989, twenty four countries in Eastern and Southern Africa established a Drought Monitoring Centre with its headquarters in Nairobi (the DMCN) and a sub centre in Harare (Drought Monitoring Centre Harare – DMCH). In October 2003, the Heads of State and Governments of the Intergovernmental Authority on Development (IGAD) held their 10th Summit in Kampala, Uganda, where DMCN was adopted as a specialized IGAD institution. The name of the institution was at the same time changed to IGAD Climate Prediction and Applications Centre (ICPAC) in order to better reflect all its mandates, mission and objectives within the IGAD system. A Protocol integrating the institution fully into IGAD was however signed on 13 April 2007. The system is made up of a network of national meteorological and hydrological services of ten greater Horn of Africa countries: Djibouti, Eritrea, Ethiopia, Kenya, Somalia, Sudan and Uganda as well as Burundi, Rwanda and Tanzania. The network develops the early warning products and organize forum bringing them together with the information users. [Website: www.icpac.net]

❒ **USAID Famine Early Warning Systems Network (FEWS NET)**

The Famine Early Warning Systems Network (FEWS NET) is a USAID-funded activity that collaborates with international, regional and national partners to provide timely and rigorous early warning and vulnerability information on emerging and evolving food security issues. FEWS NET professionals in the Africa, Central America, Haiti, Afghanistan and the United States monitor and analyse relevant data and information in terms of its impacts on livelihoods and markets to identify potential threats to food security. Once these issues are identified, FEWS NET uses a suite of communications and decision support products to help decision makers act to mitigate food insecurity. These products include monthly food security updates for 25 countries, regular food security outlooks, and alerts, as well as briefings and support to contingency and response planning efforts. In Africa there are 3 regional centres: West Africa (covers Burkina Faso, Chad, Liberia, Mali, Mauritania, Niger, Nigeria, Senegal and Sierra Leone), East Africa (covers Burundi, Djibouti, Ethiopia, Kenya, Rwanda, Somalia, Sudan, South Sudan, Tanzania and Uganda) and Southern Africa (covers Malawi, Mozambique, Zambia and Zimbabwe). [Website: www.fews.net]

❒ **SADC Southern Africa Regional Climate Outlook Forum (SARCOF)**

The Southern African Regional Climate Outlook Forum (SARCOF) is a regional seasonal weather outlook prediction and application process adopted by the fourteen countries comprising the Southern African Development Community (SADC) Member States in conjunction with other partners. The process facilitates and information exchange as well as interaction among forecasters, decision-makers and climate information users. Its main objective is to promote technical and scientific capacity building in the region in producing, disseminating and applying climate forecast information in weather sensitive sectors of the region's economic activities.

❒ **SADC Climate Services Centre (CSC)**

The SADC Climate Services Centre (CSC) is an institution of Southern African Development Community (SADC) comprising 15 member states with well over 260 million inhabitants. To contribute to mitigation of adverse impacts of extreme climate variations on socioeconomic development. This is achieved through the monitoring of near real-time climatic trends and generating medium-range (10-14days) and long-range climate outlook products on monthly and seasonal (3-6months) timescales. These products are disseminated in timely manner to the communities of the sub-region principally through the NMHSs, regional organizations, and also directly through email services to various users who include media agencies.

2.2.3. Latin America

In Latin America, the Water Center for Arid and Semi-Arid Zones in Latin America and the Caribbean (CAZALAC), based in La Serena (Chile), the Water Center for Latin America and the Caribbean (CAALCA), based in Monterrey (Mexico), the International Research Centre on El Niño (CIIFEN), based in Guayaquil (Ecuador) and the Regional Committee on Hydraulic Resources (CRRH), based in San José (Costa Rica) are only some of the most active networks working on operational drought assessment and monitoring in the region.

❒ **CAZALAC**

This Center was conceived as an organization to coordinate and articulate scientific and technological actions aimed at attaining sustainable water management in arid and semi-arid zones in Latin America and the Caribbean, by reinforcing the region's technical, social and educational development.
[Website: www.cazalac.org]

❒ **CAALCA**

The mission of this center is to create a platform that contributes to the water sustainable management in the Latin America and the Caribbean countries. Through the improvement of water management and use, it aims at reducing the environmental impact of climate change in regional environments through research projects, technological developments, consultancy and curricular and continuous education programs.
[Website: http://centrodelagua.org]

- **CIIFEN**

The mission of this International Centre is to promote, complement, and start scientific and application research projects to improve the knowledge on El Niño phenomenon. In addition, it aims at improving climate variability comprehension and early warning at the regional scale, in order to reduce its social and economic impacts and generate a solid base to promote sustainable development policies to cope new climate scenarios. [Website: www.ciifen-int.org]

- **CRRH**

The functions of the Committee are to coordinate and assist projects related to water resources issues, namely on their design, regional and international funding, and executing agencies. The main objectives are to strengthen the policies of the national institutions, improve integral water and trans-border resources demand management, and strengthen Central American ties with regional and worldwide programs for meteorological surveillance, hydrological cycle, climate change follow-up and design of adaptation and mitigation policies. [Website: http://www.recursoshidricos.org/]

2.3. Drought Information Systems: building on JRC experiences

A Drought Information System (DIS) comprises the whole range of information and tools necessary to manage drought events. As such it should include not only monitoring, assessment and forecasting of droughts, but also all the aspects of analysing the natural hazard, the societal and environmental vulnerability and the resulting overall drought risk, including long-term predictions and the analysis of expected climate change impacts. A DIS should further include information on best practices to mitigate droughts and tools for analysing the presented information as a support to decision making. Finally all kind of additional information related to droughts, such as scientific publications, media reports, and bulletins should be easily available or searchable through a DIS. The purpose of a DIS is to provide comprehensive information on drought to decision makers, scientist and the general public. As such it needs to be well structured to enable the different users to quickly find the information and data of interest to them.

The World Meteorological Organization (WMO) highlighted technological challenges for the development of a regional DIS for decision support. The model, the contents, the interface, the use and the institutions behind its development must work together. It is not only about uploading data in a web server, but about asking and answering several questions: What is the purpose of the information system? Who is the audience? What do we want to tell them? What data and information do we need? What properties and behaviours would we like our information to exhibit? In fact, too many systems for disseminating drought information and data to users are often not well developed, limiting their usefulness for decision support, because these questions are not asked at the start of the process but posted as an afterthought. According to WMO (2006), many challenges are commonly faced when establishing an effective technological drought monitoring and early warning system, namely:

- Information systems should be **able to deal with multiple climate, water, and soil parameters and socioeconomic indicators** that fully characterize a drought's magnitude, spatial extent, and potential impact – these types of data are often lacking or incomplete for many countries;

- Data quality is a problem because of **missing data and/or an inadequate length of the records** – data networks (meteorological and hydrological) are often inadequate in terms of the station quality and density for collecting all major climate and water supply variables required for monitoring systems;
- Data sharing between government agencies and research institutions is many times inadequate and involves high costs;
- Information delivered through early warning systems is often too technical and detailed for being used effectively by decision makers;
- **Forecasts are often unreliable on the seasonal timescale** and lack the specificity required to use in agriculture and other sectors;
- Impact assessment methodologies, which are a critical part of drought monitoring and early warning systems, are not standardized or widely available, hindering impact estimates and the creation of regional mitigation and response programs.

This section of the report describes on-going JRC efforts to develop Drought Information Systems at different scales and for different regions of the world. We start presenting the European Drought Observatory which is already at an advanced stage of development to then move to early-stage activities in Africa and Latin America. Finally, international on-going efforts to develop a global drought monitoring system are also presented.

2.3.1. The Experience of the European Drought Observatory

- **Rationale and conceptual framework of EDO**

Following the recommendations of the Communication on Water Scarcity and Droughts (COM(2007)414final, section 2.3.2) the Joint Research Centre is developing and implementing a prototype of a **European Drought Observatory (EDO)** to provide timely and authorized information on the occurrence and evolution of drought situations in Europe as well as predictions for their likely development.

The EDO in its final stage will consist of a web-based information system, integrating information from various sources and disciplines relevant to monitor and detect droughts throughout Europe. As drought events encompass large areas and cross national borders, JRC will provide consistent wide information to the European Commission, Member States and the public in general. Following the subsidiarity principle, the envisaged multi-scale approach will allow for the seamless integration of national and regional information of higher spatial resolution, such as the drought products provided by National Drought Observatories or local River Basin Authorities.

Following this approach, the European Drought Observatory will foster exchange with and among Member States and their competent authorities, and will allow the users of the system to move easily between overview, regional and local scales and to access the appropriate detail of information. The European Drought Observatory will also contribute to preparedness and public awareness within an integral approach to risk management of natural hazards.

The development of the EDO Prototype is performed by the Desertification, Land Degradation and Drought (DESERT) Action. In the frame of its institutional work plan, DESERT develops EDO, benefiting from and integrating JRC experiences in the fields of drought and desertification research and at the same time gives scientific support to the implementation of the United Nations Convention to Combat Desertification (UNCCD).

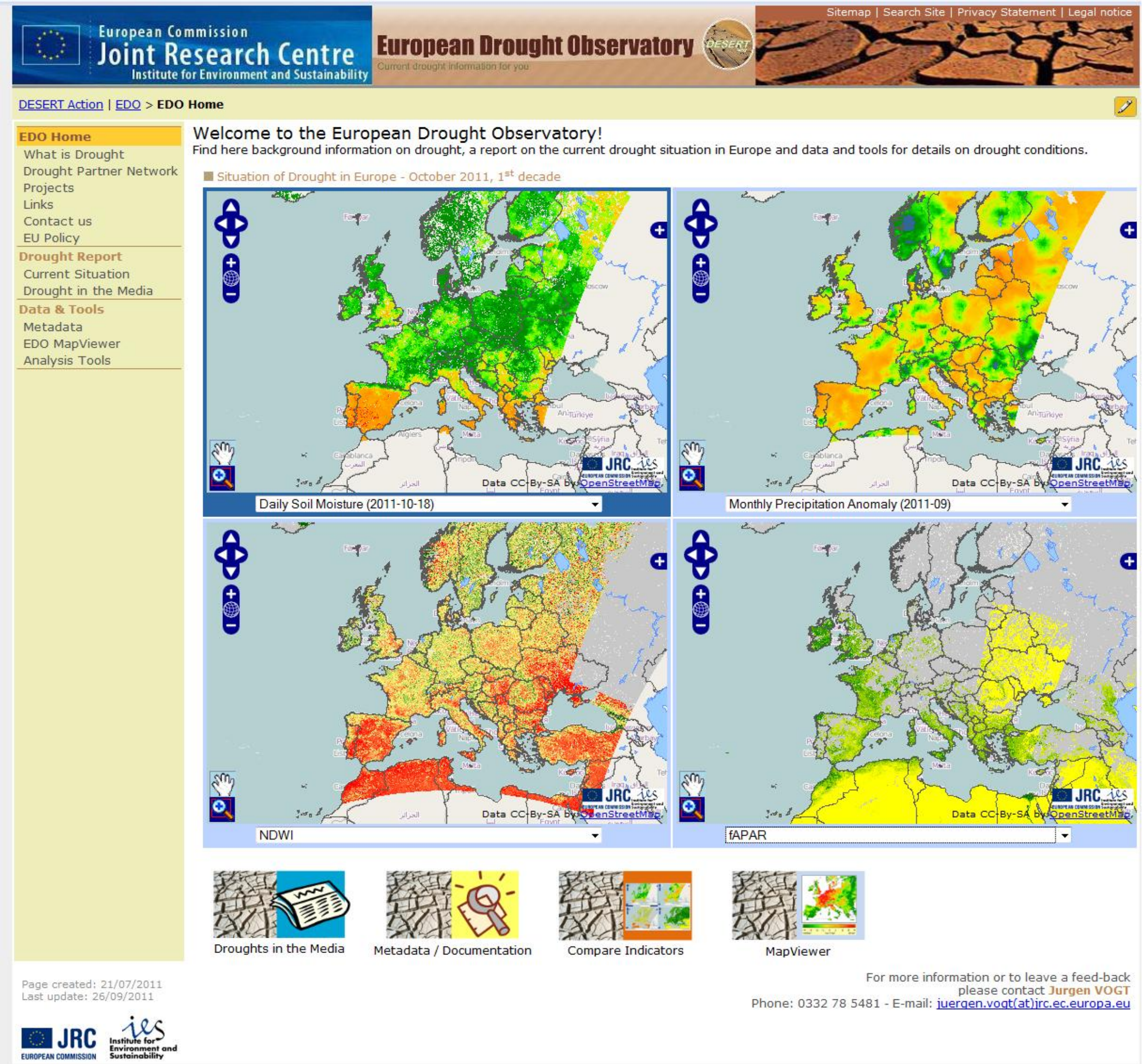


Figure 3: The Web-based map server of the European Drought Observatory (website: http://edo.jrc.ec.europa.eu/)

The European Drought Observatory also takes advantage of the following systems and data platforms already existing at the JRC:

- The **European Flood Alert System (EFAS)**, which provides useful information not only on flooding, but also on the general development of water balance components throughout Europe. In support to EFAS, the collection of meteorological and hydrological data is done at the European level (EU-FLOOD-GIS project). [Website: http://efas.jrc.ec.europa.eu]

- The **European Forest Fire Information System (EFFIS)** compiles information on the risk of ignition of fires, including fuel moisture estimations, a parameter very closely related to drought indices. [Website: http://effis.jrc.ec.europa.eu]

- The **European Soil Data Information System (ESDIS)** provides background information on European soils, including the Soil Database of Europe that is fundamental for consistent estimations on continental soil moisture conditions. [Website: http://eusoils.jrc.ec.europa.eu]

- The project on **Monitoring Agriculture by Remote Sensing (MARS)**, has more than ten years of experience in agricultural yield forecasting in Europe, and as such is monitoring a major economic sector highly sensitive to droughts. [Website: http://mars.jrc.ec.europa.eu]

❒ Architecture of EDO

The development of the EDO started with the set-up of a basic infrastructure at JRC, consisting of an **internet-based map server**, providing various layers of information relevant for drought monitoring (Figure 3). The geographical layers of information within EDO are of two types:

- **Operational layers** or "drought monitoring products" that are updated in near-real time, every 10-days or month depending on the product. Currently four different drought monitoring products are produced operationally within EDO: (1) the *Standard Precipitation Index*, (2) the *LISFLOOD Soil moisture*, (3) the *Normalized Difference Water Index Anomaly*, (4) the *fraction of Absorbed Photosynthetically Active Radiation Anomaly*. Detailed information on the computation and use of those products are given in the Section 3.2 of this report.

- **Auxiliary layers** that are generally static in time or with a low frequency of update (> year), such as land covers map, administrative boundaries, population density, etc.

In the frame of the EUROGEOSS project and in collaboration with JRC a few pilot Member States are developing mechanisms to integrate information produced by their national drought observatories with the continental information produced by JRC. The integration relies on a common set of drought indices to be produced on both the overview and on the more detailed national level, as well as a common data format and transfer mechanism for drought relevant information over the internet. Specific drought indices developed only at national or water basin level can also be included. Furthermore, the Drought Management Centre for South-Eastern Europe (DMCSEE), based at the Environment Agency of Slovenia (EARS) contributes to these developments through a collaboration agreement between EARS and JRC.

2.3.2. Drought observatories in development (Africa and Latin America)

The European Commission (EC) through a number of research and development programmes supports the development and implementation of drought observatories in regions other than Europe.

The DESERT action is involved in the process of developing an African Drought Observatory by applying the same type of tools and developing similar products to those already available in EDO. At the same time the DESERT action is involved in the **DEWFORA** project (Improved Drought Early Warning and FORecasting to strengthen preparedness and adaptation to droughts in Africa). DEWFORA is an FP7 Small or Medium Scale Focused Research Project where 19 different partners from Africa and Europe are participating. The principal aim of DEWFORA is to develop a framework for the provision of early warning and response through drought impact mitigation for Africa. This framework will cover the whole chain from monitoring and vulnerability assessment, to forecasting, warning, response, and knowledge dissemination. The DESERT action is responsible for the implementation of the methodologies developed in the project on four regional case studies (Eastern-Nile basin, Limpopo basin, Niger basin, and Oum-er-Rbia basin) as well as one continental scale African case study based on the experience of EDO.

In the framework of **EUROCLIMA** (http://www.euroclima.org), an Initiative Programme funded by EuropeAid, the DESERT Action is responsible for developing methodologies and tools for monitoring and assessing drought events and the problem of land degradation and desertification from regional to global scales in Latin America (LA). The main objectives of the EUROCLIMA Desertification, Land Degradation and Drought (DLDD) activity are:

- to allow for a coordinated collection, harmonization, analysis, and distribution of relevant data for assessing and monitoring drought and the problem of land degradation and desertification in Latin America;
- to contribute to a regional to global **information system on drought and desertification** in the longer run;
- to improve the **knowledge** of the Latin American decision makers and the scientific community on the problems and consequences of DLDD.

The collected datasets and derived products will be integrated and made available to regional LA partners via a map server, which is currently under development in close coordination with the **New World Atlas of Desertification (WAD)**, coordinated by JRC and the United Nations Environment Programme (UNEP).

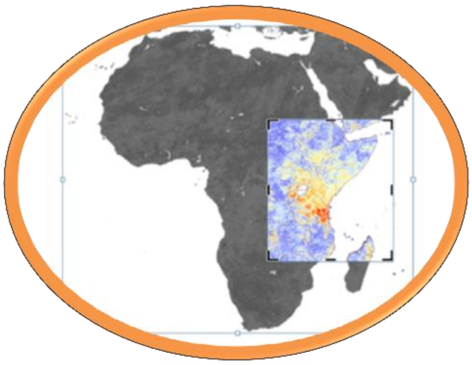
A network of LA institutions are supporting the implementation of the **DLDD Information System** and contributing to this system through their own developed products. The data and tools provided constitute a base platform for comparing and retrieving added value information on DLDD for Latin American countries.

2.3.3. Contribution to the Global Drought Monitor

The JRC is currently contributing to two main activities that are underway to produce global drought information systems. The first one is related to the implementation of GEO/GEOSS and targets the setup of a global drought monitor through the connection of existing drought monitors in different continents (http://www.earthobservations.org/docshow.php?id=129). This initiative is still in its infancy and has implemented a first demonstrator, linking the North American Drought Monitor with the European Drought Observatory and an experimental African Drought Monitor through OGC compliant web mapping services.

The second activity is led by the World Meteorological Organisation and targets the development of adequate national drought mitigation strategies through the development of coordinated drought management plans and efficient political actions. Up to date the initiative has organized a series of expert meetings, discussing the various aspects of drought management, culminating in a compendium for drought management to be discussed during a High Level Meeting on Drought Management, planned for early 2013 at the WMO premises in Geneva.

MEASURING DROUGHT: FROM DATA TO INFORMATION



Tackling the problem of drought assessment and monitoring requires typically the handling of a spring of meteorological, agricultural, hydrological and even socioeconomic data (Dracup et al. 1980, Wilhite and Glantz 1985, McKee et al. 1993, Mishra and Singh 2010).

In the last years, many indices were proposed for assessing drought and monitoring its time evolution from raw meteorological and hydrological station data. Moreover, the availability of remote sensing data, covering wide regions over relatively long periods of time, has progressively strengthened the role of vegetation indices derived from satellite images in environmental studies related to drought episodes.

In this section, a non-exhaustive list of input datasets useful for monitoring drought at the regional scales is presented; and details on their technical characteristics, main strengths and weaknesses are provided to the reader. We then describe the drought indices that are currently used by the Desert Action for operational monitoring at regional and continental scales. We focus on the description of their conceptual construction, input data and outcomes.

3.1. Datasets for drought monitoring

Traditional methods of drought monitoring are based on meteorological indices derived from **weather station data** (Landsberg 1986, Kogan 1997, Ji and Peters 2003, Rhee et al. 2010). The reasons are that weather stations are available worldwide and the length of the observed records is in some cases more than 100 years. However, due to technical, monetary and political limitations, the weather station data accessed by the final user rarely have these characteristics (Sheffield et al. 2006). Indeed, aside from the fact that the ordinary rain gauge is a poor sampling device, the main difficulties relate with interrupted and short lengths of many precipitation time series and/or the inadequate rain gauges geographical density, that make drought monitoring a daunting task (Caccamo et al. 2011). With frequent station shifts or interruptions in the collection of ground observations, the monitoring problem becomes seriously aggravated for arid and semiarid zones where the rainfall regimes are sparse and extraordinarily variable (Landsberg 1986, Rhee et al. 2010). Thus, remote sensing data has recently gained more attention for timely drought detection and impact assessment in large areas where weather stations are sparse or non-existent (e.g. Kogan 1997, Ji and Peters 2003, Rhee et al. 2010, Caccamo et al. 2011).

Remote sensing represents a powerful and cost-effective technique able to support programs for drought assessment and monitoring (Ji and Peters 2003). With the history of operational Earth Observation (EO) sensors reaching back over three decades, it allows retrospective analysis of the state and development of ecosystems at different spatial and temporal resolutions and with different geographical coverage (Hill et al. 2008). Remote sensing data provide spatially continuous measurements of variables related to drought that are periodically updated, such as meteorological or biophysical characteristics of terrestrial surfaces. Indeed, even though no indicator of meteorological, agricultural or hydrological drought is directly inferable from remote sensing data, estimates of precipitation totals, vegetation conditions and soil moisture, which show a direct relationship with the drought process, can be measured from space with a certain reliability and at appropriate temporal and spatial frequencies.

Due to their spectral, spatial and temporal resolutions, optical sensors like SPOT-VEGETATION, NOAA-AVHRR, TERRA- and AQUA-MODIS, and ENVISAT-MERIS are often used for large scale vegetation vigour and phenology investigation (e.g. Kogan 1997, Ji and Peters 2003, Rhee et al. 2010, Caccamo et al. 2011, Horion et al. 2010, Rossi et al. 2008). On the other hand, satellite sensors like TRMM-PR and NOAA-TOVS provide enough data to retrieve calibrated estimations of precipitation totals for large areas on a regular basis (Adler et al. 2003). In the same way, remote sensed data retrieved by AMSR-E, ERS scatterometer and METEOSAT are often used for deriving large scale soil moisture products that are closely related to drought processes (Wagner et al. 2007).

Although it is not feasible yet to use high spatial resolution satellite imagery to monitor wide geographical regions (because of data costs, processing effort and unavailability), we should remark that a multi-scale approach for drought monitoring at the regional to continental scales is desirable: coarse resolution data can be used to monitor large-scale processes and to identify "hotspots", whereas these may be further analysed in detail using higher spatial resolution data. The multi-scale approach allows us to gain an overview about affected areas and to connect the regional dimension with the national and local processes.

We provide here a short, but comprehensive review of the main datasets that could be of interest for drought monitoring at large scales. Although local to national datasets have an important part in any multi-scale drought monitoring system, they are region-dependent and too detailed and specific for our survey in this report. Thus, we focus only in coarse-resolution worldwide data derived from in-situ or remote sensed observations that allow us to monitor meteorological or biophysical characteristics of terrestrial surfaces that are closely related to drought. We divide our survey in datasets used for estimating: (1) precipitation totals, (2) soil moisture and (3) vegetation conditions.

3.1.1. Precipitation totals

In situ rainfall observation networks are a key element for precipitation totals estimation, but this variable is difficult to collect due to technical, monetary and political limitations. The use of remote sensing has provided great potential for the large-scale measurement of rainfall totals, but its use is still restricted to sensors' technical characteristics and data availability.

❒ **Global Precipitation Climatology Centre (GPCC)**

The Global Precipitation Climatology Centre (GPCC) has been established in 1989 and provides a global analysis of monthly precipitation on Earth's land surface based only in situ rain gauge data. The data supplies from 190 worldwide national weather services to the GPCC are regarded as primary data source, comprising observed monthly totals from more than 65,000 stations since 1901 (Rudolf et al. 2010). All GPCC monitoring products are available in a monthly basis at the spatial resolutions ranging from 1.0° x 1.0° to 2.5° x 2.5° (decimal degrees); non real-time products are also available in 0.5° x 0.5° resolution. GPCC is operated by Deutscher Wetterdienst (DWD) under the auspices of the World Meteorological Organization (WMO).

Strengths & Weaknesses: The enhanced spatial resolution and extended time-series records are the main strengths of these products for drought monitoring and assessment at the continental scale. The main weaknesses are the systematic gauge measuring errors and the difficulty in transmitting data in real time from remote regions in Africa and Latin America.

❒ Global Precipitation Climatology Project (GPCP)

Produced at NASA GSFC (Goddard Space Flight Center), the Global Precipitation Climatology Project (GPCP) is a mature global precipitation product that uses multiple sources of observations. Data from over 6000 rain gauge stations, together with satellite observations, have been merged to estimate monthly rainfall on a 2.5° x 2.5° global grid from 1979 to the present. Huffman et al. (1995, 1997) and Adler et al. (2003) describe the monthly GPCP product generating estimates at the 2.5° x 2.5° resolution.

Strengths & Weaknesses: The use of remote sensing information to improve rain gauge data quality is the main strength of this product. The relatively short time series (available only since 1979) and low spatial resolution (2.5° x 2.5°) are obvious weaknesses.

❒ ERA-Interim

ERA-Interim is the latest global atmospheric reanalysis produced by the European Centre for Medium-Range Weather Forecasts (ECMWF). ERA-Interim products, including forecasts of daily precipitation totals, are available at the model resolution (about 75km) by arrangement with ECMWF through the Meteorological Archive and Retrieval System, or through the ECMWF public Data Server with a degraded 1.5° resolution. Data are available for the period 1 January 1979 to the present with a time lag of approximately two months.

Strengths and weaknesses: ERA-Interim replaced the well-known ERA-40 reanalysis, which ends in 2002. The ERA-Interim model uses mostly the same sets of observations as ERA-40, but, it has many advancements in data assimilation and the model parameterizations: ERA-Interim is higher resolution in both the horizontal and vertical, it uses 4-dimensional variational (4DVAR) data assimilation that results in more accurate reanalysis and forecast fields, it has improved model physics and better data quality control (Dee et al, 2011). A drawback in using precipitation from ERA-Interim is that it is forecast accuracy is limited by the representation of topography at the model resolution and the model's ability to parameterize sub-grid scale processes such as convection and cloud physics.

❒ Climate Research Unit (CRU)

The Climatic Research Unit (CRU) product is a 0.5° gridded dataset of monthly terrestrial surface climate variables derived for the period of 1901–00 (Mitchell and Jones 2005) and updated to 2006 (in preparation). The spatial coverage extends over all land areas, including oceanic islands but excluding Antarctica. Primary variables (precipitation, mean temperature, and diurnal temperature range) are interpolated directly from station observations.

Strengths & Weaknesses: The spatial resolution and the temporal coverage are the main advantages of this product. However, because it is not updated on a regular basis, it cannot be used on an operational context for drought monitoring.

❒ Tropical Rainfall Measuring Mission (TRMM)

The Tropical Rainfall Measuring Mission (TRMM) is a joint mission between NASA and the Japan Aerospace Exploration Agency (JAXA) designed to measure rainfall for weather and climate research, in particular to improve understanding of precipitation structure and heating in the tropical regions of the earth (Simpson et al. 1996). The "TRMM and other satellites/sources" (3B-43) precipitation estimate is one of the operational products of TRMM (Huffman et al., 2007). Its purpose is to produce the best-estimate precipitation rate and root-mean-square (RMS) precipitation-error estimates. These gridded estimates are on a calendar month temporal resolution and a 0.25° x 0.25° spatial resolution global band extending from 50°S to 50°N latitude. The gridded estimates are a combination of 3-hourly merged high-quality/IR estimates from various satellites with the monthly accumulated Climate Assessment and Monitoring System (CAMS) or Global Precipitation Climatology Centre (GPCC) rain gauge analysis. The 3-hourly merged high quality/IR estimates are summed for the calendar month, and then the rain gauge data are used to apply a large-scale bias adjustment.

Strengths and weaknesses: The main strength of the TRMM product is that it provides continuous spatial estimates of monthly precipitation totals in near real time at relatively high spatial resolution. However, the disadvantages are that the product is limited to tropical and sub-tropical latitudes and that a relatively short time series (1998 – present) means that it may not be suitable for SPI computation.

❒ JRC MARS

The Monitoring Agricultural Resources (MARS) unit of the JRC maintains a database that includes daily precipitation observations from rain gauge stations throughout Europe communicated via the Global Telecommunications System (GTS). The database comprises approximately 5000 stations with historical records of various lengths (see http://mars.jrc.ec.europa.eu/mars/About-us/AGRI4CAST/Crop-yield-forecast/Meteorological-infrastructure for more information).

Strengths and weaknesses: The main strengths are that daily precipitation observations are available in near real-time (approximately 5-day lag) and provide a climatological precipitation for many locations throughout Europe. The weaknesses are that the stations have time series of observations of various lengths with numerous gaps and that the data are subject to only limited quality control. Furthermore the density of the station network limits the representativeness of interpolated products.

❒ E-OBS.

The E-OBS daily gridded precipitation datasets were generated as part of the EU-FP6 project ENSEMBLES (http://ensembles-eu.metoffice.com) and by the data providers in the ECA&D project (http://eca.knmi.nl) (Haylock et al., 2008). The precipitation is based on daily station observations communicated via the GTS and stations provided by agreement with several National Institutions. The data are homogenized for consistency and strict quality controls are applied. The daily station data are interpolated to two regular grids with 0.25° x 0.25° and 0.5° x 0.5° spatial resolutions. The product is available only for Europe from 1950-present with approximately 2-month time lag.

Strengths and weaknesses: The main strength of E-OBS is that it is the highest resolution gridded precipitation product derived from daily rain gauge observations available. Its main weakness is that it is not available in near real-time for monitoring purposes.

3.1.2. Soil moisture

❒ **Modelled soil moisture**

Traditionally, soil moisture has been estimated through hydrological models, i.e. complex representations of the hydrological cycle that take into account a few tens of input variables, such as: precipitation (rain/snow); land surface interception, direct runoff, and infiltration; evapotranspiration; land use/ land cover; topography; and others. The temporal resolution of these models depends on the specific application, but usually it is hourly to 6-12 hourly for flood modelling and daily to monthly for water balance estimation. For operational drought assessment and soil moisture monitoring in Europe, the JRC uses the LISFLOOD hydrological rainfall-runoff model (Van der Knijff et al. 2010). The drought products from LISFLOOD simulations used at the JRC are low flow estimates (applied to climate change scenarios) and soil moisture estimates (i.e. soil moisture anomaly and soil moisture forecasts (medium-range)), provided daily at the 5 km spatial resolution (More details in Section 3.2.2). Another example of model providing estimates of the soil water and energy balances is the Community Land Model (CLM). Community Land Model (CLM) is the land model for the Community Earth System Model (CESM). It is a collaborative project between scientists from the National Center for Atmospheric Research (NCAR) and the CESM Land Model Working Group (Oleson, 2004).

Strengths & Weaknesses: The main strength of LISFLOOD/CLM is that the output results can be really accurate if the input variables are of good quality and the parameters adequately set. The obvious weaknesses are the non-availability of prior data in many regions, and the complexity of the calibration parameters.

❒ **Remote sensing derived soil moisture**

Advances in monitoring soil moisture from operational meteorological satellite platforms have been increasing in recent years. Remotely sensed soil-moisture products that can be used for drought monitoring are derived from sensors like the Advanced Microwave Scanning Radiometer (AMSR-E), which is a passive microwave sensor on-board NASA's Aqua satellite, the European Remote Sensing satellite (ERS) scatterometer, which is an active microwave sensor on-board the two ERS satellites, and visible and thermal images from the METEOSAT satellite.

Strengths & Weaknesses: Wagner et al. (2007) indicate that these satellite datasets contribute effectively for monitoring the trends of surface soil-moisture conditions. However, the current satellite technology is still limiting the accurate estimation of absolute soil-moisture values. It is expected that these sensors, or rather their successors (e.g. SMOS), will be flown on operational meteorological satellites in the near future. With further improvements in processing techniques, operational meteorological satellites will increasingly deliver high-quality soil-moisture data that can be used for agricultural drought monitoring.

3.1.3. Vegetation conditions

Satellite sensors can be used to directly monitor spatially-explicit patterns of drought by mapping drought-related changes in vegetation conditions (Caccamo et al. 2011). Indeed, optical remote sensors with low to medium spatial resolution (1km to 250m, Table 2) are particularly feasible for drought monitoring applications at the regional to continental scales because of their high temporal resolution (up to daily data acquisition) and synoptic coverage.

Table 2. Technical characteristics of low to medium spatial resolution satellite sensors used to monitor vegetation conditions over broad geographical regions.

Satellite Platform	Sensor	Launch Date	Spatial Resolution (km)	Swath (km)	Number of Spectral Bands	Revisit Time (days)	Distribution
ENVISAT	MERIS	2002	0.3 (VNIR)	1150	15 (VNIR)	3	Science
TERRA, AQUA	MODIS	1999	0.25 (VNIR) 0.5 (SWIR) 1 (MIR-TIR)	2330	16 (VNIR) 3 (SWIR) 7 (MIR) 10 (TIR)	1	Science
NOOA 7-18	AVHRR	1981	1.1 (VNIR)	2900	3 (VNIR) 1 (SWIR) 2 (TIR)	1	Science
SPOT	VEGETATION	1998	1.15 (VNIR)	225	3 (VNIR) 1 (SWIR)	1	Commercial
ERS-1/2, ENVISAT	ATSR, AATSR	1991	1 (VNIR)	500	3 (VNIR) 1 (SWIR) 1 (MWIR) 2 (TIR)	3	Science

❒ **AVHRR, VEGETATION and ATSR/AATSR**

Low spatial resolution sensors provide long time-series of NDVI (i.e. since 1981 for AVHRR), offering the best opportunities for long-term studies. NDVI data obtained from these sensors have been used either for land cover mapping or for deriving biophysical indicators, such as Net Primary Production (NPP). Thermal bands available on AVHRR and ATSR/AATSR have also been used for fire detection, despite some technical limitations due to their low saturation temperature. These sensors have been used since the 90's to monitor large scale drought events, e.g. Kogan (1997), Peters et al. (2002), Bayarjargal et al. (2006) and Horion et al. (2010), Rossi and Niemeyer (in press), to cite but a few.

Strengths & Weaknesses: Accordingly to the scientific literature, AVHRR data are far the most used for drought applications, likely due to their easy availability for scientific purposes and long time-series available. Despite their wide application, the use of low resolution sensors is often problematic for accurate and quantitative assessment of vegetation properties, especially in areas with complex topography and fragmented landscapes (Bastin et al. 1995).

MODIS and MERIS

The launch of new generation sensors, such as MODIS and MERIS, characterized by extended geographical coverage, medium spatial and higher spectral resolutions, and equally high temporal resolution, has opened new perspectives to improve drought monitoring studies based on remote sensing data at the regional to continental scales. MODIS data have been acquired since 1999 with maximum spatial resolution of 250 m and 1 day revisit time. MODIS data have been widely used in recent studies for drought assessment at the regional scale, e.g. Gu et al. (2007), Rhee et al. (2010), Caccamo et al. (2011), Rossi and Niemeyer (in press), to cite but a few. Several derived products can be relevant for drought assessment, including:

- **surface reflectance** in the VIS-NIR-SWIR spectral range, provided daily and 8-day maximum composite, from 250 m (band 1-2) to 500 m (band 3-7) maximum spatial resolution;

- **vegetation indices** (NDVI, EVI and NDWI) provided daily and as 8-16 days maximum composite at maximum 250 m spatial resolution;

- **LAI/ fAPAR**: leaf area index is a dimensionless ratio (m2m-2) of leaf area covering a unit of ground area. fAPAR is the radiation that a plant canopy absorbs for photosynthesis and growth in the 0.4 – 0.7 nm spectral range. Both of these variables are computed daily at 1km spatial resolution;

- **Net Primary Production** (NPP): The product is computed at 1km for the global vegetated land surface. These variables provide the initial calculation for growing season and carbon cycle analysis, and are used for agriculture, range and forest production estimates;

- **Evapotranspiration** (ET): land surface evapotranspiration represents all transpiration by vegetation and evaporation from canopy and soil surfaces. ET is computed globally every day at 1km. ET is used for water balance calculations for hydrologic management, as a carbon cycle constraint, and for drought and fire danger mapping;

Concerning MERIS data, available since 2002, they provide similar potential as MODIS data in terms of spatial, spectral and temporal resolution, as well as in data quality (Fensholt et al. 2006, Carrão et al. 2010). MERIS products useful for drought assessment include global surface reflectance in the VIS-NIR and fAPAR (Gobron et al. 1999) at 300 m spatial resolution. Recently, MERIS data have been used to generate the GlobCover product. Despite its potential, few drought applications of MERIS data have been proposed until now (Gobron et al. 2009). Indeed, further studies are needed to evaluate MERIS data time-series and the usefulness of fAPAR for drought assessment. Horion et al. (2010), Rossi et al. (2008), and Rossi and Niemeyer (in press) are some of the studies that evaluated the potential of MERIS fAPAR for drought detection in Africa and Europe, respectively.

Strengths & Weaknesses: MODIS and MERIS exhibit enhanced spectral and temporal resolutions and offer new potentials and challenges to data analysis. Rhee et al. (2010) state that the availability of a large number of spectral bands makes it possible to detect spatial occurrences of droughts with higher accuracy than would be possible with the data from earlier sensors, such as AVHRR. The drawback of these data is the relatively short time-series length that is used to compute reference baselines to identify the occurrence of droughts.

3.2. Selected Indices for operational drought monitoring

Since 2008 important efforts were dedicated to the elaboration of operational processing chains for the different drought indices and to the development of an oracle database and web mapping services. One of results of this work is the European Drought Observatory that provides in near-real time updated information on drought. From the three continents, it represents the most elaborated system of information as it is running fully operationally from the data acquisition to the web mapping. In the case of Africa and Latin America, the operational processing chains for the SPI, the NDWI and the fAPAR are undergoing the final tests. A first prototype should be released by the end of 2012.

Four indices currently used operational by the JRC are presented in this section: the Standardized Precipitation Index, the LISFLOOD Soil Moisture, the fraction of Absorbed Photosynthetic Activity and the Normalized Difference Water Index. Both input data and methodology are presented for each drought index. While the methodology to compute the different indices is the same worldwide the input data used may differ. The standardization of these indices ensures a consistent basis for comparing and combining indicators and triggers (Steinemann and Cavalcanti 2006). For more detailed information on these indices please refer to their Fact Sheets that can be found online at http://edo.jrc.ec.europa.eu - Metadata section.

3.2.1. Standardized Precipitation Index

The Standardized Precipitation Index (SPI) is a statistical indicator comparing the total precipitation received at a particular location during a period of n months with the long-term rainfall distribution for the same period of time at that location (McKee et al., 1993 and 1995). In 2010 WMO selected the SPI as a **key meteorological drought indicator** to be produced operationally by meteorological services. A reduction in precipitation with respect to the normal precipitation amount is the primary driver of drought, resulting in a successive shortage of water for different natural and human needs.

SPI is calculated on a monthly basis for a moving window of n months, where n indicates the rainfall accumulation period, which is typically 1, 3, 6, 9, 12, 24 or 48 months. The corresponding SPIs are denoted as SPI-1, SPI-3, SPI-6, etc. In order to allow for the statistical comparison of wetter and drier climates, SPI is based on a transformation of the accumulated precipitation into a standard normal variable with zero mean and variance equal to one. SPI results are given in units of standard deviation from the long-term mean of the standardized distribution. Negative values correspond to drier periods than normal and positive values correspond to wetter periods than normal. The magnitude of the departure from the mean is a probabilistic measure of the severity of a wet or dry event.

McKee et al. (1993) proposed a classification of the SPI that divides the SPI into moderate, severe and extreme classes as shown in Table 3.

<u>Table 3</u>. SPI Classification following McKee et al. (1993)

SPI Value	Class	Cumulative Probability	Probability of Event [%]
SPI ≥ 2.00	Extreme wet	0.977 – 1.000	2.3%
1.50 < SPI ≤ 2.00	Severe wet	0.933 – 0.977	4.4%
1.00 < SPI ≤ 1.50	Moderate wet	0.841 – 0.933	9.2%
-1.00 < SPI ≤ 1.00	Near normal	0.159 – 0.841	68.2%
-1.50 < SPI ≤ -1.00	Moderate dry	0.067 – 0.159	9.2%
-2.00 < SPI ≤ -1.50	Severe dry	0.023 – 0.067	4.4%
SPI < -2.00	Extreme dry	0.000 – 0.023	2.3%

Since the SPI can be calculated over different rainfall accumulation periods, different SPIs allow for estimating different potential impacts of a meteorological drought:

- SPIs for short accumulation periods (e.g., SPI-1 to SPI-3) are indicators for immediate impacts such as reduced soil moisture, snowpack, and flow in smaller creeks;
- SPIs for medium accumulation periods (e.g., SPI-3 to SPI-12) are indicators for reduced stream flow and reservoir storage; and
- SPIs for long accumulation periods (SPI-12 to SPI-48) are indicators for reduced reservoir and groundwater recharge, for example.

The exact relationship between accumulation period and impact depends on the natural environment (e.g., geology, soils) and the human interference (e.g., existence of irrigation schemes). In order to get a full picture of the potential impacts of a drought, SPIs of different accumulation periods should be calculated and compared. A comparison with other drought indicators is needed to evaluate actual impacts on the vegetation cover and different economic sectors (See Section 4.2).

❒ **Input data used**

- **JRC-MARS daily precipitation totals** collected from SYNOP stations via the GTS (Europe, 0.25° interpolated, Daily – accumulated into monthly totals at the end of each month).

- **GPCC (Global Precipitation Climatology Centre) monthly gridded precipitation** from Deutscher Wetterdienst DWD (Global, 1° , monthly)
    - GPCC Reanalysis – based on the highest density of stations available in the archive with strict automated and manual quality control interpolated to 1° grid. Available from 1901 – 2009.
    - GPCC monitoring – based on GTS stations and some CLIMAT stations with automated and manual quality control interpolated to 1° grid. Available from 1986 to present with 2-month lag.
    - GPCC first guess – based on GTS stations with only automated quality control interpolated to 1° grid. Available from 2005 to present with 5-day time lag.

- **E-OBS daily gridded precipitation** from the EU-FP6 project ENSEMBLES (Europe, 0.25°, 0.50°, monthly) (http://ensembles-eu.metoffice.com) and the data providers in the ECA&D project (http://eca.knmi.nl) (Haylock et al., 2008). The precipitation is based on GTS stations and stations provided by National Institutions, homogenized for consistency and with strict quality controls applied. This product is available from 1950-present with approx. 2-month time lag.

❒ Methodology

As rainfall is not normally distributed, computation of the SPI involves fitting a probability density function to a given frequency distribution of precipitation totals for a station or grid point and for an accumulation period. For EDO we use the gamma probability density function. The statistics for the frequency distribution are calculated on the basis of a reference period of at least 30 years. The current baselines used are 1981-2010 for the JRC-MARS station datasets and 1961-2010 for the other datasets. For consistency matters, SPI derived from GPCC in Europe also uses the 1981-2010 as reference period.

The parameters of the probability density function are then used to find the cumulative probability of the observed precipitation for the required month and temporal scale. This cumulative probability is then transformed to the standardised normal distribution with mean zero and variance one, which results in the value of the SPI. The procedure of transforming the observed rainfall via the cumulative distribution functions (CDF) of the Gamma distribution and the standardised normal variable to the SPI is illustrated in Figure 4.

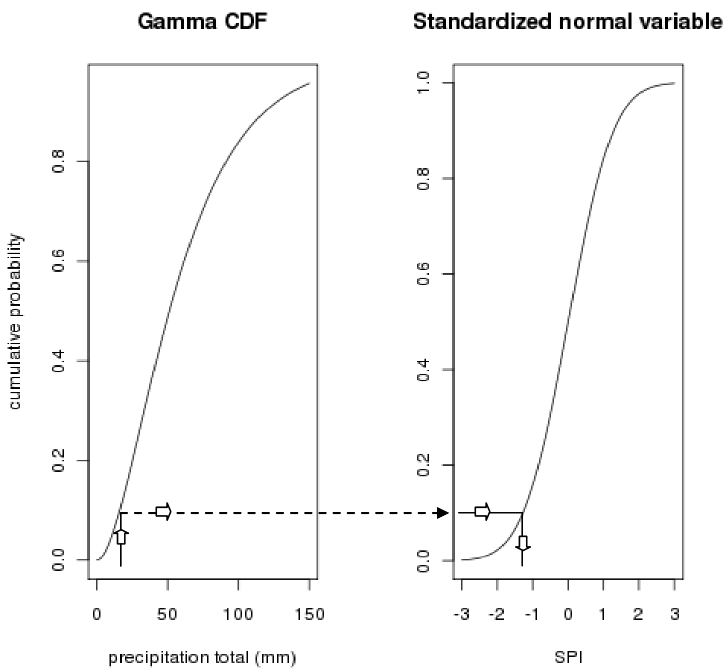


Figure 4: Transformation of the observed rainfall via the Gamma cumulative distribution function (CDF) and the CDF of the standardized normal variable to the SPI.

The Gamma distribution has been adopted by most centres around the world as a model from which to compute SPI. It is described by only two parameters, but offers considerable flexibility in describing the shape of the distribution, from an exponential to a Gaussian form. It has the advantage that it is bounded on the left at zero and therefore excludes the possibility of negative precipitation. Additionally, it is positively skewed with an extended tail to the right, which is especially important for dry areas with low mean and a high variability in precipitation.

❐ **Strengths & Weaknesses:**

[+] SPI gives a **measure of the rainfall deficit** (or surplus) at a location that is unambiguously comparable with other locations and periods in time. SPI is easy to interpret with boundaries set to describe the severity of the rainfall deficit (or surplus). Because the SPI can be computed for a range of accumulation periods it can be made use of by a whole range of user groups, from agriculture to water management.

[-] For SPI computed at station level, depending on the station density, the spatial representativeness of interpolated SPI will vary.

[-] Fitting a distribution to the data is an approximation. If the fit is not good, the SPI value may not be representative. Since the gamma distribution is bounded on the left at zero, it is not defined for zero precipitation. If the data includes observations of zero precipitation a mixed distribution is used that takes account of the probability of zero precipitation and the cumulative probability H(x) becomes:

$$H(x) = q + (1-q)G(x),$$

where q is the probability of zero, calculated from the frequency of zero precipitation observations in the time series, and G(x) is the cumulative probability calculated from the gamma distribution for non-zero observations.

This approach introduces two problems for regions with many observations of zero precipitation. Firstly, the minimum value SPI can take is determined by the probability of zero – for example if the probability of zero is 0.5, the minimum possible value of SPI is 0 (see Figure 1). Secondly, with fewer observations to compute the parameters of the gamma distribution the fit becomes less well defined. Therefore, for regions with a high probability of zero rainfall (e.g. in arid climates), the SPI should be interpreted with care and, where possible, alternative drought indicators should be used in addition (Wu et al. 2007).

3.2.2. Soil Moisture anomaly

Soil moisture is one of the important variables in hydrologic, climatologic, biologic, and ecological processes because it plays a crucial role in the interactions between the atmosphere and land surface. In fact, soil moisture content affects surface evaporation, runoff, albedo, emissivity, and portioning of sensible and latent heat fluxes. Moreover, it represents a vital water reservoir for all the plants buffering their water consumptions in period with rain water supplies are lesser than their requests. In addition, drought in not only a temporary lack of rain but also occurs when the soil moisture decreases considerably, and crops and natural plant communities suffer due to insufficient water availability. Therefore, great efforts have been made to estimate soil moisture using soil water balance model forced with realistic precipitation and other atmospheric data (ground observation, numerical weather prediction, etc.) to be used as direct indicator to assess the drought onset, duration and severity. The aim of this indicator is to provide an instantaneous assessment of the top soil water content as modelled by LISFLOOD across Europe. The **LISFLOOD model** was developed in JRC in regards to the European Flood Alert System (EFAS).

The soil water content can be used as direct indicator for determining the start and duration of drought conditions. Indeed LISFLOOD soil moisture estimates are transformed into soil suction (pF) values by means of means of the Van Genuchten pedotransfer function (Laguardia and Neimeyer, 2008). The soil suction provides **an assessment of the plants difficulty to extract water from the soil matrix** ; with pF values varies varying between 0, when saturated, and 7, when extremely dry. In other terms, it gives an estimation of the soil water availability for the plant's needs.

The soil water content is also obviously related to the plant biomass accumulation (gross primary production) in many environment were the water availability is the main limiting factor (dry, semi-arid, arid).

❒ Data and Methodology

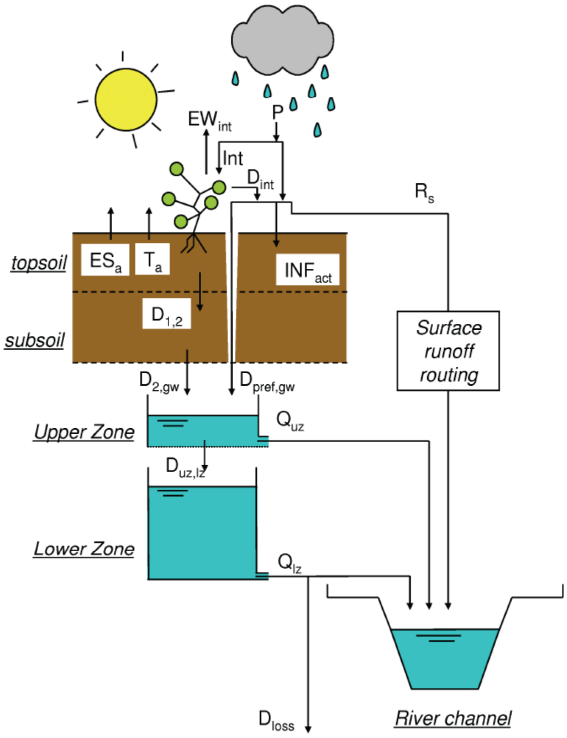
The LISFLOOD model is a hydrological rainfall-runoff model that is capable of simulating the hydrological processes that occur in a catchment (De Roo et al, 2000). LISFLOOD has been developed by the floods group of the Natural Hazards Project of the Joint Research Centre (JRC) of the European Commission. Input data are precipitation, averaged daily temperature, potential (reference) evaporation rate, potential evaporation rate from open water surface, potential evaporation rate from bare soil surface. Their main characteristics of the model in terms of input are:

- Geographic coverage: European continent
- Spatial scale: 5 km
- Temporal scale: daily calculated based on ground observation update with 2 days of delay as of the real time and extended for 7 days with ECWMF numerical weather forecast
- Data source: National Meteo Office, JRC-MARS elaboration and ECMWF numerical weather forecast
- Frequency of data collection: daily

Basically, the model is made up of the following components (Figure 5):

- a 2-layer soil water balance sub-model
- sub-models for the simulation of groundwater and subsurface flow (using 2 parallel interconnected linear reservoirs)
- a sub-model for the routing of surface runoff to the nearest river channel
- a sub-model for the routing of channel flow (not shown in Figure 5)

The processes that are simulated by the model include snow melt (not shown Figure 5), infiltration, interception of rainfall, leaf drainage, evaporation and water uptake by vegetation, surface runoff, preferential flow (bypass of soil layer), exchange of soil moisture between the two soil layers and drainage to the groundwater, sub-surface and groundwater flow, and flow through river channels.



P = *precipitation;* ***Int*** = *interception;* ***EW_int*** = *evaporation of intercepted water;* ***D_int*** = *leaf drainage;* ***ES_a*** = *evaporation from soil surface;* ***T_a*** = *transpiration (water uptake by plant roots);* ***INF_act*** = *infiltration;* ***R_s*** = *surface runoff;* ***D_1,2*** = *drainage from top- to subsoil;* ***D_2,gw*** = *drainage from subsoil to upper groundwater zone;* ***D_pref,gw*** = *preferential flow to upper groundwater zone;* ***D_uz,lz*** = *drainage from upper- to lower groundwater zone;* ***Q_uz*** = *outflow from upper groundwater zone;* ***Q_l*** = *outflow from lower groundwater zone;* ***D_loss*** = *loss from lower groundwater zone.*

Figure 5: Overview of the structure of the LISFLOOD model

Groundwater storage and transport are modelled using two parallel linear reservoirs. The upper zone represents a quick runoff component, which includes fast groundwater and subsurface flow through macro-pores in the soil. The lower zone represents the slow groundwater component that generates the base flow.
Concerning the land use and calculation of the “effective rainfall” as well as the “actual evapotranspiration”, the LAI is calculated from remote sensing data (NDVI). Several years of NDVI are used and averaged; a fixed look-up table of LAI in each 5 km pixel is produced on daily time step. Rooting depth is linked with LAI and it is changing according to phenological phase.

The anomaly of soil moisture are computed as a z-score (Snedecor and Cochran, 1980) which is a dimensionless quantity derived by subtracting the population mean from an individual raw score and then dividing the difference by the population standard deviation (Eq 1).

$$Anomaly_t = \frac{X_t - \bar{X}}{\sigma} \qquad \text{[Eq. 1]}$$

where X_t is the Soil Moisture of the day t of the current year, $\bar{X}$ is the long-term average, and σ is the standard deviation, both calculated for the same period t over the available time series (1975-2010). According to the definition, soil moisture anomalies are expressed as units of standard deviation.

The forecasted values are calculated over the ECMWF numerical weather forecast. In practice, the LISFLOOD model goes on the calculation of the soil moisture since the last observation up to 7 following days. The forecast provides the tendency during the coming days in terms of pF variation between the last day of simulation on the observed data (t0) and the day t0+7.

❐ **Strengths & Weaknesses:**

[+] The daily update and the use of weather forecast gives continuous information on the simulated status of the soil moisture and the spatial extension of the area affected by drought or under risk. Moreover, the analysis of the time series allows to estimate the duration and the severity of drought.

[-] The generalizations and the scientific assumption (soil physic, land use, canopy cover, meteorological data interpolation, etc.) embedded in the soil water balance model, and at the same time, the calibration of the model could produce in some case large approximation of the real soil moisture and progressive divergence with the real conditions

3.2.3. Vegetation Index Anomaly

Two different remote sensing derived indices have been used for drought monitoring: the **Fraction of Absorbed Photosynthetic Solar Radiation** (fAPAR) and the **Normalized Difference Water Index** (NDWI).

Droughts affect the vegetation canopy and specifically its capacity to intercept solar radiation. The fAPAR is known to be strongly related to water stress. fAPAR and fAPAR anomalies (the deviation from the long term mean for a certain period of time) are considered good indicators to detect and assess drought impacts on vegetation canopies both for agricultural or natural vegetation (Gobron et al., 2005 and 2007 ; Rossi and Niemeyer, in press). Therefore it can provide stakeholders with information potentially usable for water and agricultural management.

The NDWI is a good indicator for vegetation liquid water content and, according to Gao (1996), is less sensitive to atmospheric scattering effects than NDVI (Normalized Difference Vegetation Index). NDWI has been used to detect and monitor the moisture condition of vegetation canopies over large areas (e.g. Delbart et al. 2005, Jackson et al. 2004) and tested as a drought indicator (Gu et al. 2008). Gu et al (2007) found that NDWI values exhibited a quicker response to drought conditions than NDVI. Contrary to NDWI, NDVI has limited capability for retrieving vegetation water content information, since provides information on vegetation greenness (chlorophyll), which is not directly and uniformly related to the quantity of water in the vegetation (Ceccato et al 2002).

❐ **Fraction of Absorbed Photosynthetic Active Radiation (fAPAR)**

The fAPAR represents the **fraction of the solar energy absorbed by the vegetation**. fAPAR is a biophysical variable directly correlated with the primary productivity of the vegetation, since the intercepted photosynthetic active radiation is the energy (carried by photons) underlying the biochemical productivity processes of plants. It is also one of the Essential Climate Variables recognized by the UN Global Climate Observing System (GCOS) and by the FAO Global Terrestrial Observing System (GTOS) as of great potential to characterize the climate of the Earth. Due to its sensitivity to vegetation stress, fAPAR has been proposed as a drought indicator (Gobron et al., 2005 and 2007 ; Rossi and Niemeyer, in press). Indeed droughts can cause a reduction in the vegetation growth rate, which is affected by changes either in the solar interception of the plant or in the light use efficiency.

The **MERIS Global Vegetation Index (MGVI)** is a remote sensing derived index estimating fAPAR at canopy level with the following characteristics:

- Geographic coverage: available for Europe
- Spatial scale: c.a. 1.2 km
- Temporal scale: every 10 days aligned on the first day of each month, which corresponds to 3 images per month (day 1-10, day 11-20, day 21-last day of month).
- Data source: MGVI data are delivered as a subscription service within the Service Support Environment (SSE) of the European Space Agency. This service is called "MGVI Catalogue Search and Download" and can be access via this link: http://services.eoportal.org/portal/service/ShowServiceInfo.do?serviceId=7180CB90&categoryId=89802980
- Frequency of data collection: every 10 days

fAPAR is difficult to measure directly but can be inferred from models describing the transfer of solar radiation in plant canopies, using Earth Observation information as input data. fAPAR estimates are retrieved using EO information by numerically inverting physically-based models. The fAPAR estimates used within the DESERT Action are operationally produced by the European Space Agency (ESA). They are derived from the multispectral images acquired by the Medium Resolution Imaging Spectrometer (MERIS) on board ENVISAT by means of the MERIS Global Vegetation Index (MGVI) algorithm, developed at the JRC (Gobron et al. 2004).

MGVI is a physically based index which transforms the calibrated multispectral directional reflectance into a single numerical value while minimizing possible disturbing factors. It is constrained by means of an optimization procedure to provide an estimate of the fAPAR of a plant canopy. The objective of the algorithm is to reach the maximum sensitivity to the presence and changes in healthy live green vegetation while at the same time minimizing the sensitivity to atmospheric scattering and absorption effects, to soil colour and brightness effects, and to temporal and spatial variations in the geometry of illumination and observation.
The MGVI level-3 aggregation processor routinely operated on ESA Grid Processing on Demand (G-POD), has been developed and is maintained by the European Commission Joint Research Centre (JRC). More information on the algorithm can be found in Pinty B. et al. (2002) and Gobron N. et al. (2004).

❐ Normalized Difference Water Index (NDWI)

The NDWI (Gao, 1996) is a satellite-derived index from the Near-Infrared (NIR) and Short Wave Infrared (SWIR) channels. The SWIR reflectance reflects changes in both the **vegetation water content** and the spongy mesophyll structure in vegetation canopies, while the NIR reflectance is affected by leaf internal structure and leaf dry matter content but not by water content. The combination of the NIR with the SWIR removes variations induced by leaf internal structure and leaf dry matter content, improving the accuracy in retrieving the vegetation water content (Ceccato et al. 2001). The amount of water available in the internal leaf structure largely controls the spectral reflectance in the SWIR interval of the electromagnetic spectrum. SWIR reflectance is therefore negatively related to leaf water content (Tucker 1980).

The Normalized Difference Water Index (NDWI) can be derived both from the **MODIS** and from the **VEGETATION satellite data**.

- Geographic coverage: global (tailored processing chain available for MODIS data over Europe)
- Spatial scale: ca. 1 km
- Temporal scale: every 10 days aligned on the first day of each month, which corresponds to 3 images per month (day 1-10, day 11-20, day 21-last day of month).
- Data source: MODIS spectral bands 2 (NIR) and 6 (SWIR) are provided by the German Aerospace Centre, DLR; VEGETATION spectral bands 3 (NIR) and 4 (SWIR) are provided by VITO.
- Frequency of data collection: daily

❒ Vegetation Index (VI) anomaly

Identically to soil moisture anomalies, anomalies of fAPAR and NDWI are computed as z-scores for every 10-day period (Eq 2).

$$Anomaly_t = \frac{X_t - \bar{X}}{\sigma} \qquad \text{[Eq. 2]}$$

where X_t is the Vegetation Index (fAPAR or NDWI) of the 10-day period t of the current year, $\bar{X}$ is the long-term average, and σ is the standard deviation, both calculated for the same 10-day period using the available time series minus the current year as reference period. According to the definition, VI anomalies are expressed as units of standard deviation.

The **time length of the archive** is depending on the sensor used. fAPAR (MGVI) archive covers the period from June 2002 to current day. In Europe, the archive has been extended backward to mid-1997 using fAPAR estimations obtained from (Gobron et al. 2002) the Sea-viewing Wide Field-of-view Sensor (SeaWiFS). The NDWI archive from VEGETATION covers the period from January 2006 to the present. The NDWI archive from MODIS covers only the period January 2006 to the present. The archives cover between 6 (for MODIS) to 15 years (for VEGETATION). However in regions with dense cloud cover or with seasonal snow cover, the number of valid records of the vegetation indices is highly reduced. For example, in Europe during winter months, the number of MERIS images available to calculate the long-term averaged vegetation conditions are sometimes reduce 5 or less, especially in Northern European regions (Figure 6). In order to avoid this problem the minimum number of images used to compute anomalies was set to 6.
As final step, cities, deserts, water bodies are systematically masked out using GLC2000 products (Bartholomé and Belward, 2005). Indeed Vegetation Indices do not give relevant information over non vegetated areas or outside the growing season, i.e. when the vegetation fraction cover is not sufficient (Gao, 1996).

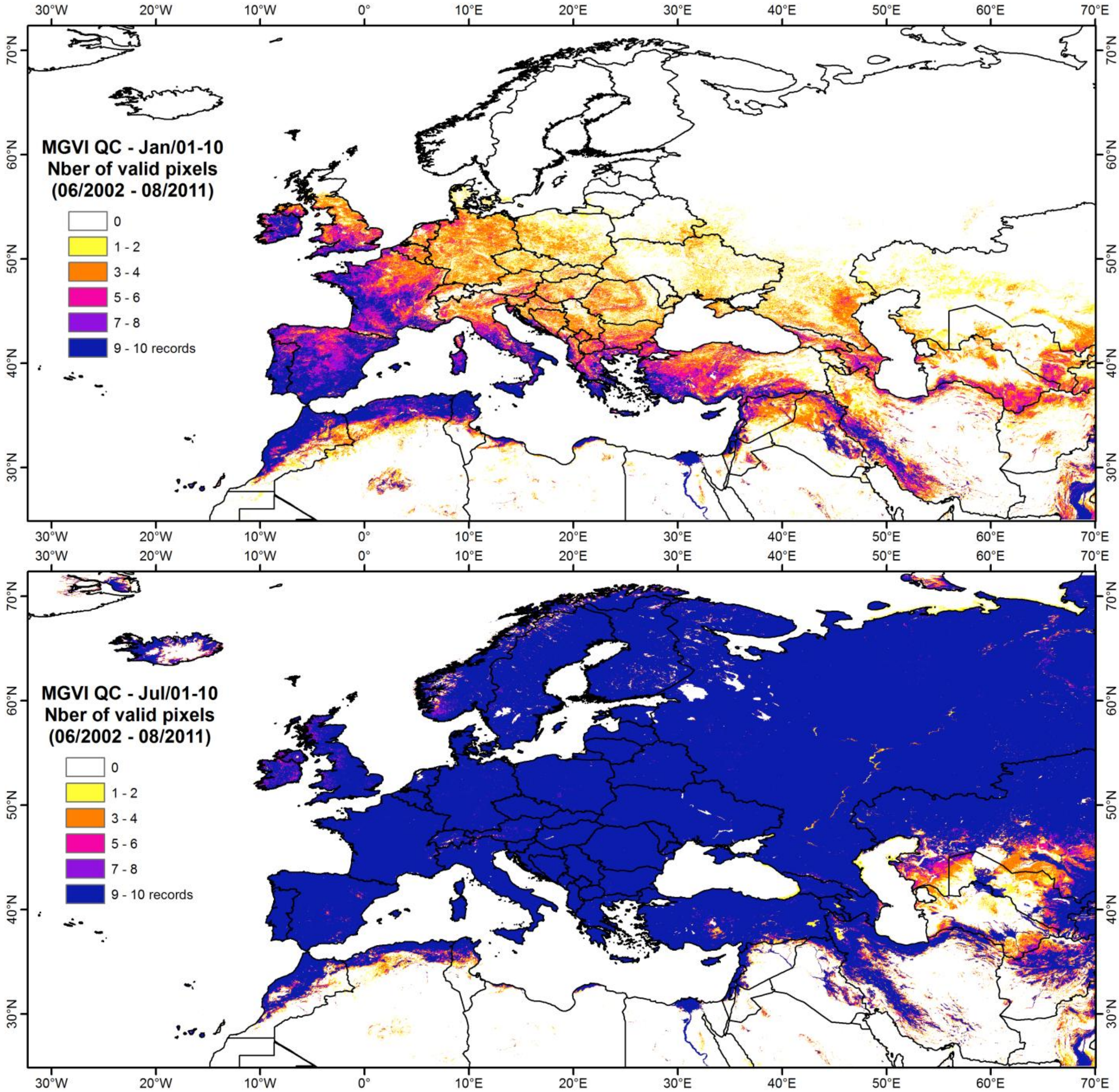


Figure 6. Number of valid pixels of fAPAR (according to MGVI level 3 quality flags): [top] 1-10 January and [down] 1-10 July. The archive covers June 2002 to August 2011. A number of 10 valid pixels means that for the given 10-day period the pixel has been systematically recorded as valid (no cloud cover, good radiometry, etc.) year after year.

❐ Strengths & Weaknesses

[+] Vegetation Indices are derived from satellite measurements of the solar radiation reflected by the vegetation canopy at certain wavelengths. As such, they can provide **information on the vegetation biomass and health** which has been related to vegetation conductance and photosynthetic capacity (Myneni et al., 1995). When transformed into standardized values, they inform on the vegetation conditions (development and health) compared to previous years. They are therefore useful for monitoring the impact of drought on vegetation.

[-] Drought is not the only factor (driver) leading to vegetation stress or biomass loss (Ji and Peters, 2003). Diagnosing a drought using solely Vegetation Indices anomaly is therefore somehow hazardous and the risk of false alarm (i.e. drought alert in normal or wet conditions) is quite high.

[-] The **availability of a long archive of satellite data remains a limitation** to estimate how abnormal the vegetation conditions are. The longer the period, the more accurate will be the standardized value. At this stage, the six year criteria may seem not rigorous enough as the probability of catching the inter-annual variability of the vegetation conditions in six years is relatively low. However this choice was made as compromise between optimization of the geographical extent and the quality of the estimation of the vegetation anomaly.

3.3. Summary tables per geographic window

The following tables present the different indices selected for operational drought monitoring in Europe (Table 4), Africa (Table 5), Latin America (Table 6) and globally (Table 7).

Table 4: Drought indices selected for Europe

EUROPE	
Standardized Precipitation Index (SPI)	▪ Extent: EU27 ▪ Temporal resolution: monthly value ▪ Spatial resolution: at station locations and at 5 km ▪ Archive: variable between stations ▪ Reference period: 01/1981 - 12/2010 ▪ Data source: SYNOP stations in JRC-MARS database
Soil Moisture Anomaly	▪ Extent: EU27 ▪ Temporal resolution: daily and 10-daily values ▪ Spatial resolution: 5 km ▪ Archive from: 01/1990 to current day ▪ Reference period: 01/1990 to 12/2010 ▪ Data source: SYNOP stations in JRC-MARS database
Anomaly of fraction of Absorbed Photosynthetically Active Radiation (fAPAR anomaly)	▪ Extent: EU27 ▪ Temporal resolution: 10-daily value ▪ Spatial resolution: ca. 1.2 km ▪ Archive from: 06/2002 to current day ▪ Reference period for year 2011: 09/1997 – 12/2010 ▪ Data source: derived from ENVISAT-MERIS (provided by ESA)
Anomaly of Normalized Difference Water Index (NDWI anomaly)	▪ Extent: EU27 ▪ Temporal resolution: ▪ Spatial resolution: 1000 m ▪ Archive from: 01/2006 to current day ▪ Reference period for year 2011: 01/2006 – 12/2010 ▪ Data source: derived from AQUA/TERRA MODIS (provided by DLR)

Table 5: Drought indices selected for Africa

AFRICA	
Standardized Precipitation Index (SPI)	▪ Extent: Africa ▪ Temporal resolution: monthly value ▪ Spatial resolution: 0.5°, 1.0° and 2.5° ▪ Archive from: 01/1901 to current day ▪ Reference period: 01/1961 – 12/2010 ▪ Data source: derived from GPCC full reanalysis, monitoring and first guess products (provided by DWD)
Soil Moisture Anomaly	n/a
Anomaly of fraction of Absorbed Photosynthetically Active Radiation (fAPAR anomaly)	▪ Extent: Greater Horn of Africa and Pan Africa ▪ Temporal resolution: 10-daily value ▪ Spatial resolution: ca. 1.2 km ▪ Archive from: 06/2002 to current day ▪ Reference period for year 2011: 06/2002 – 12/2010 ▪ Data source: derived from ENVISAT-MERIS (provided by ESA)
Anomaly of Normalized Difference Water Index (NDWI anomaly)	▪ Extent: Africa ▪ Temporal resolution: 10-daily value ▪ Spatial resolution: ca. 1 km ▪ Archive from: 04/1998 to current day ▪ Reference period for year 2011: 04/1998 – 12/2010 ▪ Data source: derived from SPOT-VEGETATION (provided by JRC via the Geoland2 project)

Table 6: Drought indices selected for Latin America (LA)

Latin America	
Standardized Precipitation Index (SPI)	▪ Extent: : LA region ▪ Temporal resolution: monthly value ▪ Spatial resolution: 0.5°, 1.0° and 2.5° ▪ Archive from: 01/1901 to current day ▪ Reference period: 01/1961 – 12/2010 ▪ Data source: derived from GPCC full reanalysis, monitoring and first guess products (provided by DWD)
Soil Moisture Anomaly	n/a
Anomaly of fraction of Absorbed Photosynthetically Active Radiation (fAPAR anomaly)	▪ Extent: LA region ▪ Temporal resolution: 10-daily value ▪ Spatial resolution: ca. 1.2 km ▪ Archive from: 06/2002 to current day ▪ Reference period for year 2011: 09/1997 – 12/2010 ▪ Data source: derived from ENVISAT-MERIS (provided by ESA)
Anomaly of Normalized Difference Water Index (NDWI anomaly)	▪ Extent: LA region ▪ Temporal resolution: 10-daily value ▪ Spatial resolution: ca. 1 km ▪ Archive from: 04/1998 to current day ▪ Reference period for year 2011: 04/1998 -12/2010 ▪ Data source: derived from SPOT-VEGETATION (provided by VITO)

Table 7: Drought indices selected for the globe

Global	
Standardized Precipitation Index (SPI)	▪ Extent: Globe ▪ Temporal resolution: monthly value ▪ Spatial resolution: 0.5°, 1.0° and 2.5° ▪ Archive from: 01/1901 to current day ▪ Reference period: 01/1961 – 12/2010 ▪ Data source: derived from GPCC full reanalysis, monitoring and first guess products (provided by DWD)

3.4. Future developments

The indicators presented in this report are the core of the information used y the JRC for drought monitoring in Europe, Africa and Latin America. Ensuring their accuracy is therefore a priority. Future research effort will be first dedicated to the following tasks:

- **Improve the quality and the length of the current archives of rainfall records.** Daily precipitation observations from the JRC-MARS database are characterised by variable length and incomplete time-series. Stations with more than 20% missing observations in the period 1981-2010 are discarded. This results in around 400 stations in Europe with SPI data. The following steps will be taken to address this problem:

  - Spatial resolution of the SPI interpolated from stations will be degraded to 0.25° x 0.25° ;
  - Precipitation data from other sources will be sought to fill in the gaps in the database and improve station density.

- **Add a soil moisture component for Africa and Latin America**. The development of soil-water balance models, such as LISFLOOD, has been hampered by the lack of reliable meteorological observations. Indeed good networks of weather stations are not always existing or well-maintained. In addition national governments are sometimes reluctant to share information. Soil moisture products derived from remote sensing represent definitely a good alternative as they can provide timely and spatially continuous information on soil moisture conditions.

- **Improve the quality and the length of the fAPAR and NDWI archives**
  - In Europe, by testing NDWI data derived from other sensors, such as SPOT-VEGETATION, in order to extend the length of the time series ;
  - In Africa and Latin America, by using SeaWIFS data to create a coherent long-term fAPAR dataset based on multiple sensors ;
  - The identification of seasonal snow cover remains problematic in some areas, especially in Europe. Therefore snow cover products will be investigated in order to ensure that anomalies of vegetation indices will be calculated only over areas free of snow.

- **Test new drought indicators and methodologies**
  - Develop indicators based on low flows measurements and other indicators optimized for characterizing vegetation water stress (e.g. using Land Surface Temperature and Evapotranspiration).
  - Develop non-parametric approaches for deriving drought indicators (e.g. neural network, machine-learning, bootstrap, etc.); these are less sensitive to data outliers and to short time series than the parametric methods currently used.

- **Develop methods for drought forecasting at global scales**

ASSESSING DROUGHT: FROM INFORMATION TO KNOWLEDGE

4.1. The need for an integration of drought information

Development of advanced drought monitoring and early warning systems is an important prerequisite for efficient drought risk management (Wilhite, 2000; Tadesse, 2006). Such systems should focus on the assimilation of in-situ and Earth Observation data in order to better understand the natural drivers of drought, as well as its severity and impacts. So far, a large majority of drought studies are driven by a single definition of drought type (meteorological, agricultural or hydrological) and therefore are limited to the analysis of a single aspect of the drought hazard. However, given the complex nature of drought and the gradual accumulation of related impacts, the evaluation of a potential drought situation can only be complete if we consider together the duration of the event, its intensity and the affected area.

In Africa and in Latin America, existing meteorological and hydrological in-situ networks are characterized by a very low spatial density, as well as by temporally discontinued measurements (WMO, 2006). Therefore drought assessment based on hydro-meteorological data alone may not provide precise results, especially when the availability of hydro-meteorological data falls below the minimum requirements for spatial and temporal representativeness. Meteorological drought indices are based on weather station observations that are spatially interpolated in order to provide information over a continuous larger area. With appropriate Earth Observation data, these spatial and temporal information gaps can potentially be filled.

Based on Geographic Information System and data mining technologies, new systems for the integrated assessment of drought should help to detect faster the onset of drought, to monitor more efficiently its evolution in time and space, and therefore to better trigger timely and appropriate actions on the field. In 2006, WMO introduced the concept of *Comprehensive (Integrated) Drought Monitoring System* to define the system aiming at the integrated assessment of drought. According to them, an **Integrated Drought Information System (*IDIS*)** is an essential component of national strategy to reduce the economic, social and environmental impact of drought. This approach was already set up successfully by the U.S. National Drought Mitigation Center in the frame of the U.S. Drought Monitor and the North American Drought Monitor (Svoboda et al. 2002).

In the next section we discuss the challenges of building an IDIS, including the selection of relevant layers of information and the elaboration of the theoretical framework or conceptual design of the system.

4.2. Challenges for building an Integrated Drought Information System

An Integrated Drought Information System (*IDIS)* should provide a consistent framework to combine multiple layers of drought information at various spatial and temporal scales. However knowing that the effectiveness of a drought monitoring system depends on its indicators and triggers (Steinmann, 2006) and that each indicator has limitations that can be region and/or time dependent (Whilite, 2000), the setting-up of an IDIS is challenging and not straightforward. Two issues are discussed in this section: (i) identifying the key layers of information, (ii) building the theoretical framework of the IDIS.

4.2.1. Key layers of Information

As already mentioned, a comprehensive characterization of a drought event requires considering simultaneously information on the on-going rainfall shortage, soil moisture deficit, vegetation health status, and water resources. Ideally – when data quality and availability are not an issue - the system should be composed of four components: ***Atmosphere*** / ***Soil Moisture*** / ***Vegetation*** / ***Water Resources*** (Figure 7).

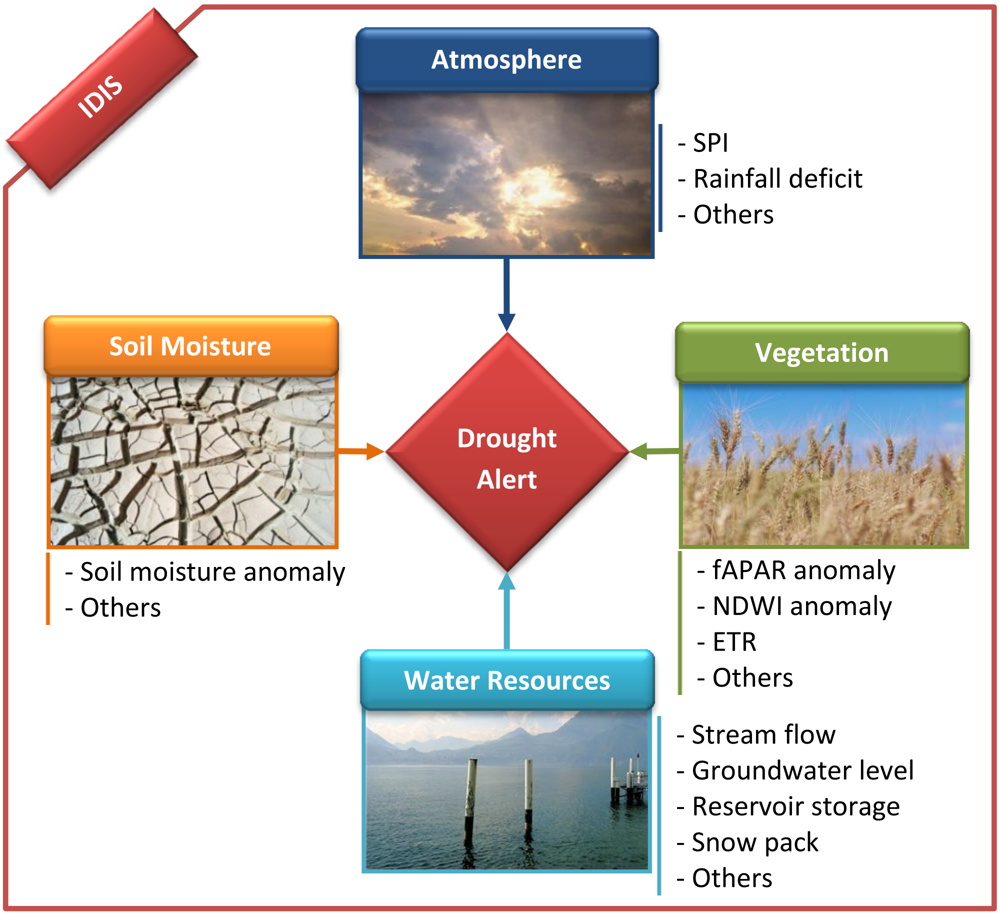


Figure 7: Components of the IDIS and examples of operational datasets

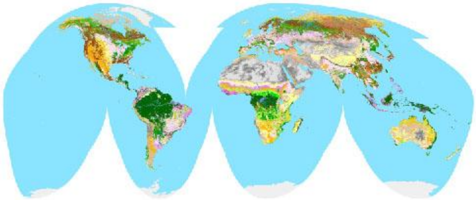
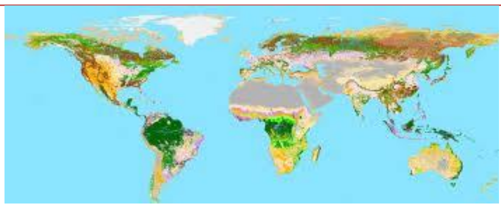
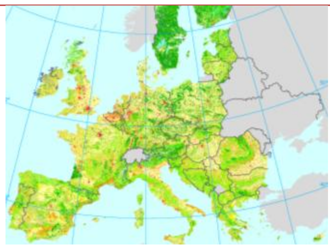
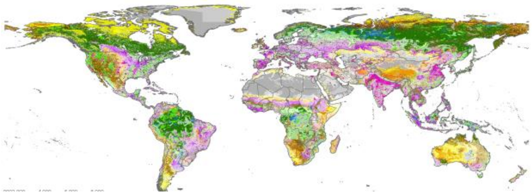
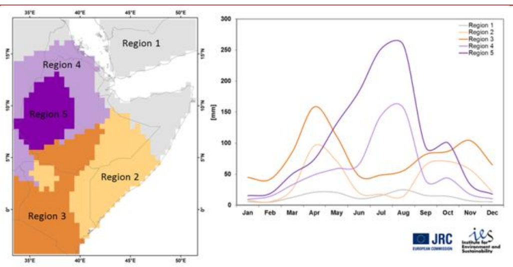
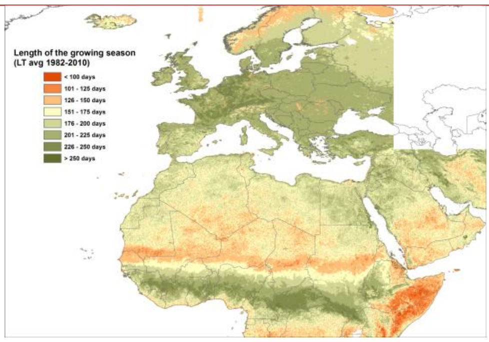
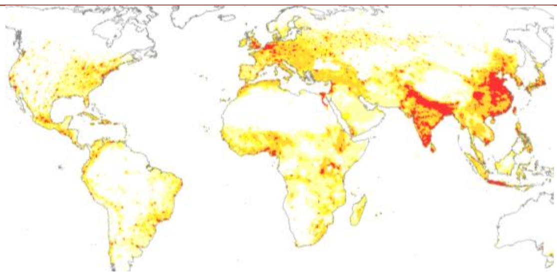
Every component of the IDIS contributes to the detection and characterization of the drought situation (drought type, severity, affected area or duration). A meteorological or a hydrological drought can be defined by using solely information from the '***Atmosphere***' or from the '***Water Resources***' components; however, the identification of an agricultural drought requires inputs from several components. Indeed the severity of an agricultural drought will depend on factors such as timing of rainfall deficit in relation with the development stage of the plants (crops), water holding capacity of the soils, the ground water storage, management practices, etc. (White and Walcott, 2009). Moreover, as discussed in the next sections, indices used for detecting drought have limitations. Their relevance for drought monitoring is variable in time and space. Therefore a major advantage of bringing together meteorological, hydrological, and agricultural information is to reduce false alarms by finding a convergence of different types of drought indices.

From a more technical point of view, IDIS inputs can be divided in two different types: the operational and the auxiliary datasets.

- **Operational datasets** include indicators that are produced on a regular basis (monthly, 10-daily or daily indicator) to characterize in near-real time the development of drought conditions. Some of these indicators, that are embedding the four components of the IDIS (Figure 7), are those currently used by the DESERT action for drought monitoring in Europe, Africa and Latin America.

- ***Auxiliary datasets*** describe the socio-economic and biophysical characteristics of the region of interest. They serve for evaluating the vulnerability of a given region to drought, as well as to identifying the period and location where a given indicator provides reliable information on the development of a drought (Cf. Section 4.2.2.). Examples of auxiliary datasets are land cover or land use maps, rainfall regimes, crop calendar, population density maps, etc. Table 8 describes some of the auxiliary datasets used by the Desert action for drought monitoring in Europe (within EDO), in Africa and Latin America.

Table 8: Examples of auxiliary datasets for drought monitoring

Auxiliary Datasets	
Global Land Covers 2000 Short Description: Land cover map for year 2000 Spatial resolution: 1km Coverage: Globe Reference: Bartholome E. and Belwart A.S., 2005	
GLOBCOVER 2006/2009 Short Description: Land cover map for year 2006/2009 Spatial resolution: 1km Coverage: Globe Reference: Arino et al., 2008	
CORINE Land Cover 2000/2006 Short Description: Land cover map for the year 2000/2006 Spatial scale: 1:100000 Coverage: Europe Reference: EEA & ETC/Land Cover, 1999	
Land Use Systems of the World Short Description: Land Use map Spatial resolution: 0.08333deg. Coverage: Globe Reference: LADA FAO, at http://www.fao.org/nr/lada/	
Map of rainfall regimes Start, end and length of rainy season(s) Spatial resolution: 0.5deg Derived from GPCC Coverage: Greater Horn of Africa Reference: Horion et al., 2010	
Phenological indicators Short Description: Start, end and length of growing season(s) derived from NDVI Spatial resolution: 1km Derived from GIMMS Coverage: Globe Reference: Desert Action, unpublished results Contact: Eva Ivits (eva.ivits-wasser@ext.jrc.ec.europa.eu)	
Population Density Short Description: Gridded Population of the World Spatial resolution: 0.5deg. Coverage: Globe Reference: SEDAC, hosted by CIESIN at The Earth Institute of Columbia University, available at http://sedac.ciesin.columbia.edu/gpw/	

4.2.2. Building the theoretical framework of the IDIS

After selecting the individual indicators, the next step is the elaboration of the theoretical framework (i.e. conceptual design) that will serve as the basis for building the operational system. During this step, several issues need to be discussed and methodological choices need to be made. The core issue is the understanding of the complementarity/synergy between the selected layers ; in other words how to go from a set of (semi-) independent indicators to a 'holistic knowledge' of the drought situation by optimizing the use of each component of the IDIS and their related indicators. Indeed the overall performance of the IDIS will depend on how deeply we apprehend the inter-relationships between the different components.

Moreover the quality of the information retrieved from drought indicators is not spatially or temporally constant. A good understanding of the limitations of each indicator will help defining the spatial and temporal domain of use of each indicator, i.e. when and where can we use a specific indicator.

Relations between SPI and VI were analysed in many studies. In general it has been found that the direct correlations between SPI and VI are quite low (Ji and Peter, 2003; Rossi et al., in press, Horion et al., 2010).

Ji and Peter (2003) also used the SPI as a reference drought indicator to "validate" the capacity of NDVI to monitor drought in the US Great Plains. They found that the correlation between NDVI and SPI varies depending upon the time-scales. Larger correlations were observed with the 3-montly SPI than with the 1-monthly SPI, which they interpreted as an indication that the vegetation is not reacting instantaneously to precipitation. Moreover they also showed that the vegetation response to moisture availability depend on the plant growth stage. During the water-sensitive periods the impact of a water shortage on plant will be larger than during other development stages of the plant.

Rossi et al. (in press) also found better correlations between fAPAR anomalies and 3-months SPI than with the 1-month SPI or with the 6-months SPI. They attributed this to the fact that water deficits have a cumulative impact on vegetation, generating therefore a time lag in the response of plants to precipitation.

In the case of the Horn of Africa, Horion al. (2010) also showed that the relationships between 3-months SPI, fAPAR anomaly and NDWI anomaly is time dependent, region dependent and land cover dependent. Although significant correlations exist between SPI-3 and both NDWI and MGVI anomalies, they were generally low (Pearson's $r < 0.5$). When considering the differences in term of rainfall regimes, correlations were increasing. Indeed, the timing and the repartition of the rains through the growing season is key information for monitoring drought. The impacts on the vegetation will differ largely if the rainfall deficit occurs during or outside the growing season. Moreover within a same climate zone, the highest correlation was usually observed for a land cover with high biomass density and the lowest for bare soil.

Figure 8 presents a synthetic view of the different factors (or issues) identified in the previous studies as crucial for drought characterization. All together they characterize the temporality (onset, duration, sequence) and the geography (Land cover, climate zones) of the drought as seen by the monitoring indices. Here below we discuss the role of each factor in the characterization of the drought situation. In many cases it is the combination of factors that is important for the drought characterization, and not a single factor. In this sense, by considering all those aspects during the drought diagnosis process, the final outcome will be a result of the convergence of evidences.

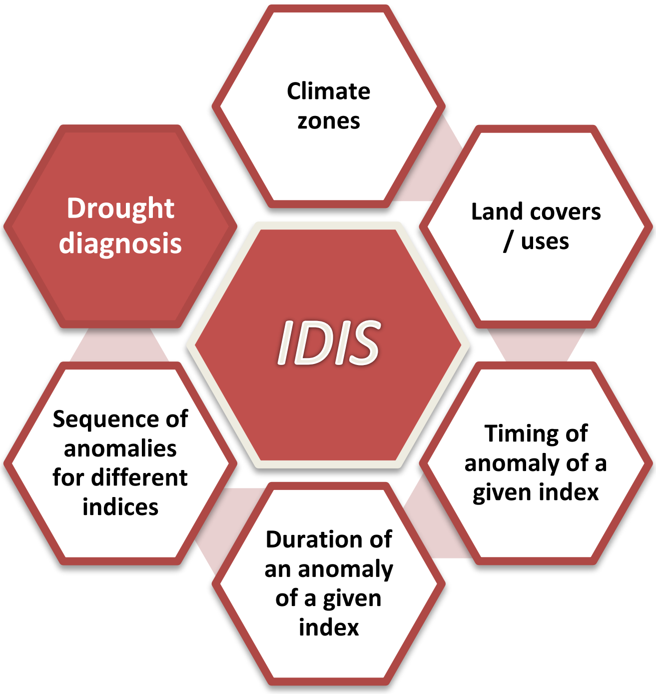


Figure 8: Scheme of the drought diagnosis process within the Integrated Drought Information System (IDIS).

- **Climate zone**: working at national/regional/continental levels lead us to consider at the same time areas that belong to different climate zones. It is therefore important to be aware of the variation in terms of annual timing and number of rainy seasons. Indeed, as the annual growth of natural vegetation or rainfed croplands matches climate characteristics, impact on the vegetation of a rain shortage will not be the same if occurring during or outside the rainy season.

- **Land cover/land use**: the strategy for combing or considering information coming from vegetation indices should vary depending on the types of land covers and land uses. Firstly, it should take into account the fact that over non vegetated areas or irrigated areas, the Vegetation Indices Anomalies are not providing sound information related to the impact of drought on vegetation. Secondly, over vegetated areas, the response of vegetation might be delayed in time. Finally, this time lag in the vegetation response to water shortage is variable depending on the vegetation type and on the phenological stage. In order to optimise the *IDIS*, this variation should be analysed in detail and incorporated (implemented) into the final system.

- **Timing of an anomaly of a given index**: depending on the time of the year, some indicators should be discarded, such as the vegetation indices that do not give reliable or relevant information on the drought status outside the growing season. Identically, SPI value should be analysed with caution in regions or periods of the year where the precipitation is close to zero (in arid regions or during dry seasons). In both cases (VI and SPI), very negative anomalies might be observed giving a misleading message to the user.

- **Duration of an anomaly of a given index**: closely linked with the discussion on the types of land cover/use and on the timing, the duration of a water shortage (or of a vegetation water stress) occurring at a given period of the growing season will be determinant in the final impact of the drought.

- **Sequence of anomalies for different indices**: the order in which the different indicators will go from a normal situation (no drought) to a potential drought situation is important, especially to identify the nature or cause of a vegetation stress. In a logical sequence, vegetation stress can be only attributed to drought if an abnormal deficit in rainfall or soil moisture is observed during the previous months. By differentiating logical/expected sequence from non-logical ones (in terms of drought development), it allows the system to reduce false alarms. For example, biotic stresses due to plant pathology or harmful insects will inhibit vegetation growth in a similar way than water shortage would do. In both cases, negative vegetation anomalies will be registered. However biotic stresses are not directly linked with a dry period or a lack of water for plants. It is therefore important to consider if water shortage was preceding the episode of abnormal vegetation growth in order to attribute correctly the reduction of vegetation growth to drought.

4.3. Way forward

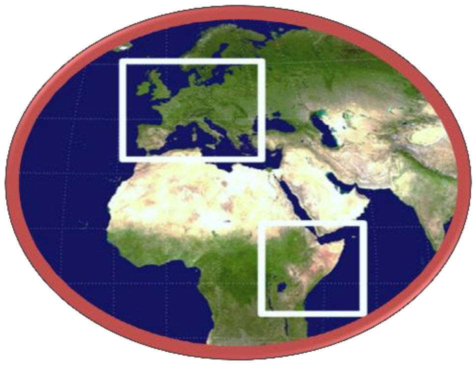
The on-going researches are focusing on the development of a new **Combined Drought Indicator *CDI*** for drought monitoring. More specifically, research efforts are currently put into:

- the correct establishment of triggers (threshold) for SPI, anomaly of VI and of soil moisture
- the elaboration and the implementation of the theoretical framework
- Categorization of alert levels

Conceived as a data mining tool, the CDI should serve as primary source of information for identification of drought affected area. It should give a synthetic overview of the drought situation by analysing simultaneously the rainfall deficit, the soil moisture deficit and the anomalies of vegetation conditions.

The prototype of the CDI is already available online (http://edo.jrc.ec.europa.eu/). For further details on this synthetic indicator, you can refer to the *Combined Indicator Fact Sheet* available online.

ASSESSING DROUGHT: TWO RECENT CASES STUDIES



In 2011 the DESERT Action has been reporting on the development of drought in East Africa and in North-Western Europe. In both cases meteorological and remote sensing derived information were analysed together in order to identify drought affected areas and to report on the potential future development of the drought. The first example is the case of the drought in the Horn of Africa that started in October 2010 and led to a disastrous famine in Somalia. The second example is the case of the spring drought encountered in Northern Europe this year. In both cases specific bulletins were produced by the DESERT Action.

5.1. The drought in East Africa

The severe drought affecting some regions East Africa since the end of 2010 has triggered an important food crisis across Somalia, Ethiopia and Kenya. The severe impact of the drought was not only due to the shortage of rain that has occurred since October 2010, but also to an unfavourable combination of different elements: poor crop harvests linked to rain seasonality, a second consecutive anomalously dry rainy season in southern Somalia, high population densities concentrated around the main cropping affected areas, fighting and an unstable political situation forcing the suspension of humanitarian aid in some areas (http://www.unhcr.org/4cd961cf9.html), and an increase in food commodity prices (http://www.fao.org/worldfoodsituation/wfs-home/foodpricesindex/en/). According to UNOCHA, about 13.3 million people required emergency assistance. Moreover the IPC[2] threshold for Famine has been crossed in several regions in Somalia.

In the next sections we present a summary of the main facts and observations collected during the operational monitoring of the drought.

[2] IPC stands for Integrated Food Security Phase Classification, a standardized tool that aims at providing a "common currency" for classifying food security. The implementation of IPC is led notably by CARE, JRC, FAO, FEWS NET. More info: http://www.ipcinfo.org/.

5.1.1. Description of operational [OPE] and auxiliary [AUX] datasets

[OPE] Standardized Precipitation Index. Rainfall conditions were assessed using the Standardized Precipitation Index (SPI). The SPI provides a measure of the deviation of observed rainfall for a given location and accumulation period from “normal” conditions for that location and accumulation period. SPI values lower than -1.5 are indicative of severe drought, and values lower than -2 are indicative of extreme drought. For our analysis we use rainfall data from the Global Precipitation Climatology Centre (GPCC) [http://gpcc.dwd.de] reanalysis product for the years 1960-2009 to define normal conditions and rainfall data from the GPCC monitoring (up to June 2011) and first guess (July – August 2011) products for the observed rainfall. For more detailed information about the SPI, refer to Section 3.2.

[OPE] Vegetation Indices. Vegetation conditions in the Greater Horn of Africa were evaluated using two vegetation indices: (1) the Normalized Difference Water Index, NDWI which is related to the water content of the canopy ; (2) the fraction of Absorbed Photosynthetically Active Radiation, fAPAR, which is related to the total green biomass. For both indices, anomalies were calculated for 10-day periods using the available data archives April 1998. Anomalies lower than -1.0 are indicative of a moderate to severe vegetation stress. For more detailed information about those indices, refer to Section 3.2.

[AUX] Map of the rainfall regimes. Regions with similar rainfall conditions were identified by a cluster analysis using long-term (1975-2004) average monthly precipitations. The Iterative Self Organizing Data Analysis Techniques (ISODATA) method was used to estimate multivariate statistics of each cluster (or region). For each cluster (corresponding to a different rainfall regime), long-term monthly rainfall were spatially averaged. Map of the rainfall regimes and their specific intra-annual rainfall distribution are presented in Figure 10.

5.1.2. Monitoring of drought affected area: summary

The map of the drought affected areas reflects the severe anomalies in both meteorological and remote sensing indicators, implying a significant drought impact on vegetation, including crops.

In June 2011, the analyses of different meteorological and remote sensing indicators show that the territories mostly affected were located between southern Somalia, southern Ethiopia, eastern Kenya, and north-eastern Tanzania (Figure 9). This area was delimited considering the failure of the 2 previous rainy seasons (September-December 2010 and March-May 2011 ; Figure 10 – Regions 2 and 3), which was reflected in severe anomalies in both meteorological and remote sensing indicators, implying a significant drought impact on vegetation, including crops. No irrigation is available in this area and therefore local food production is completely dependent on the rainfall. Due to the relatively short rainy periods, the cultivated crops are mainly cereals characterized by fast growth (maize, millets, sorghum, etc.). The shortage of rain during the last two crop growing seasons contributed to the complete failure of the seasonal food production.

Our indicators also highlighted a large **area under threat** in June 2011 between South Sudan, southern Sudan and western Ethiopia where the peak of rainfall normally occurs in July but were already showing evidence of an impact on vegetation in recent months.

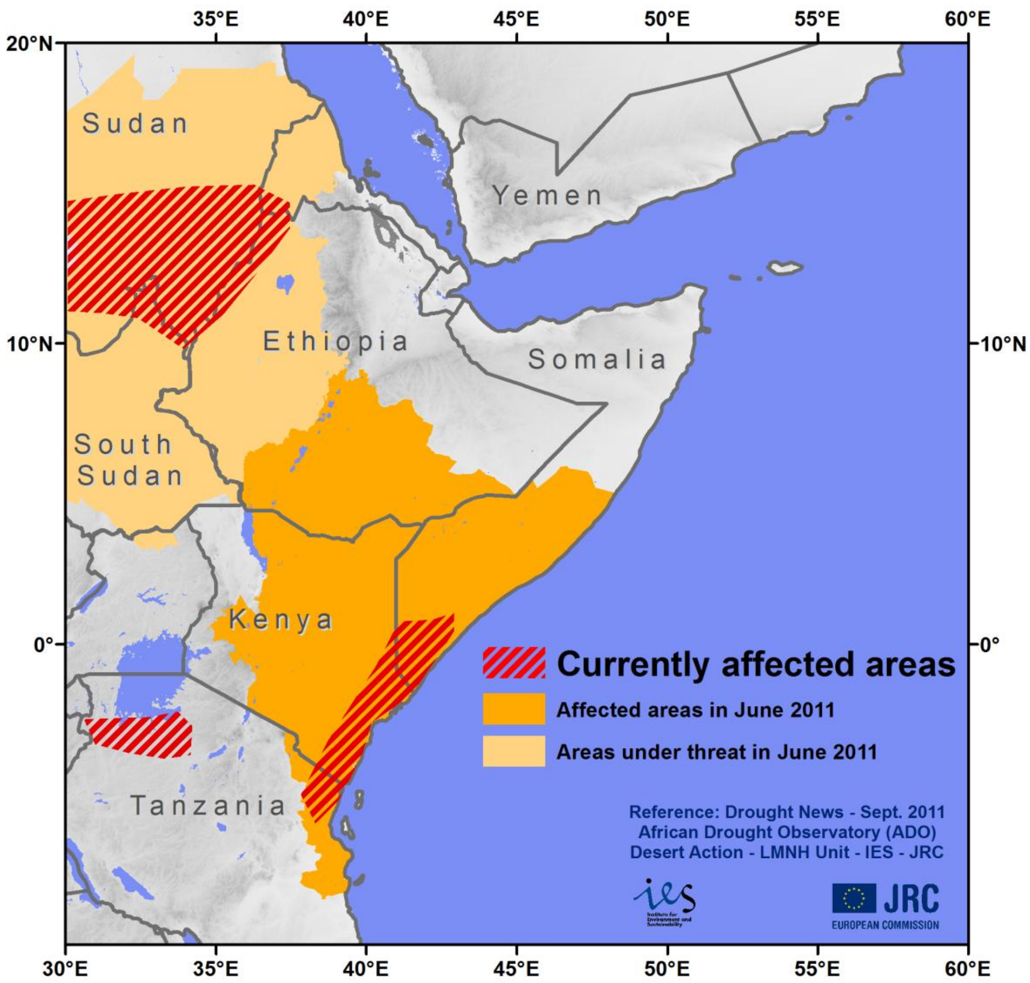


Figure 9: Map of drought affected areas – Situation in September 2011 as compared with June 2011.

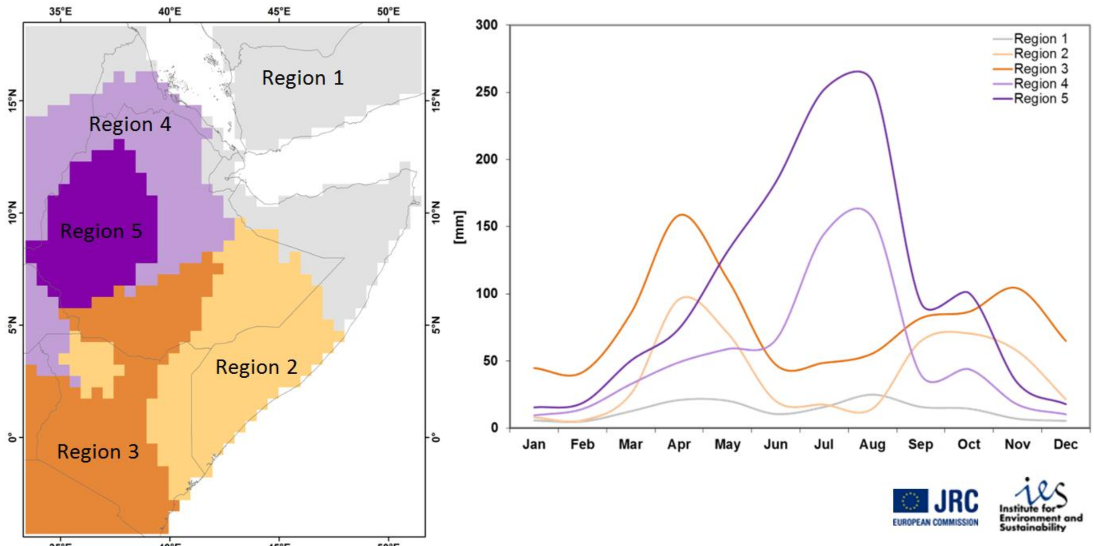


Figure 10: Rainfall regimes in the Greater Horn of Africa. [Left] Regions identified by rainfall based clustering; [Right] Long-term average monthly precipitations for each region (Period 1975-2008).

In September 2011, the **areas affected by drought** as identified by our indicators had decreased (Figure 9) and were restricted to southern Somalia and a coastal area stretching throughout Kenya. From the areas previously considered as "areas under threat" in June, we only registered a worsening of the situation for a part of it, mainly in southern Sudan and bordering Ethiopia. Furthermore the northern part of Tanzania, south of Lake Victoria, was also identified as being affected by drought in September 2011 (Figure 9).

The integrated use of two different sources of information, meteorological and remote sensing data, shows great potential to synergistically monitor drought events in the Horn of Africa. The analysis of the SPI (Standardized Precipitation Index) over the last 25 years showed that although the rainfall shortage for the most recent rainy season (SPI-3, Figure 14) was comparable to many previous events, it is the sustained rainfall shortage over the last 12 months that has made this event comparable only to droughts in 1992, 1994 and 2000/2001 (SPI-12, Figure 14). Moreover severe vegetation conditions over the south-east of the Horn of Africa were also clearly visible on the satellite images (Figures 15 and 16). For both fAPAR and NDWI anomalies, we have recorded for this area the largest negative anomalies ever since 1998 (Figure 17).

The following sections present a more detailed overview of rainfall and of vegetation conditions, as registered by meteorological and remote sensing drought monitoring products.

5.1.3. Evolution of precipitation anomalies

The evolution of the SPI for 3-month rainfall accumulations (SPI-3) is shown in Figure 11. Severe drought conditions in terms of the SPI-3 began in eastern Kenya in October 2010 and spread eastwards to southern Somalia into the beginning of 2011. In April 2011 extreme drought conditions were evident in the Kenya-Somalia border region becoming more extreme by June 2011. In July and August, although the famine situation in Somalia continued, the extent of the drought affected area was reduced; however we should take in consideration that the rainy season in Somalia should start only in September; at the same time an area on southern Sudan and bordering Ethiopia, previously identified as under threat, as well as northern Tanzania became drought affected. A time series of the spatial average of SPI-3 for the most affected area in June 2011, which corresponds to the rainfall region with peak rainfall in March, April, May (MAM) (Regions 2 and 3, Figure 10), is shown in Figure 14. For the SPI-3 a more severe rainfall deficit was observed for MAM in 2000 than in 2011, although with more spatial variation, as shown by the error bars. This means that although some parts of the region experienced more severe rainfall deficits in MAM 2000, such severe rainfall deficits were not as widespread throughout the region compared to MAM 2011.

The evolution of the SPI for 6-month (SPI-6) rainfall accumulations is shown in Figure 12. Severe drought conditions were evident in southern Ethiopia from September 2010 and continued to June 2011 becoming more widespread, with the most extreme conditions observed in the Somalia-Kenya border area and Uganda. In July and August this indicator also showed southern Sudan and bordering Ethiopia as being drought affected, as well as northern Tanzania. The time series of the mean SPI-6 for the most affected area in June 2011 showed that the conditions were comparable to previous 6-month rainfall deficits (Figure 14), although a more extreme SPI-6 was observed in mid-2000, corresponding to the extreme SPI-3 value that was observed around the same time.

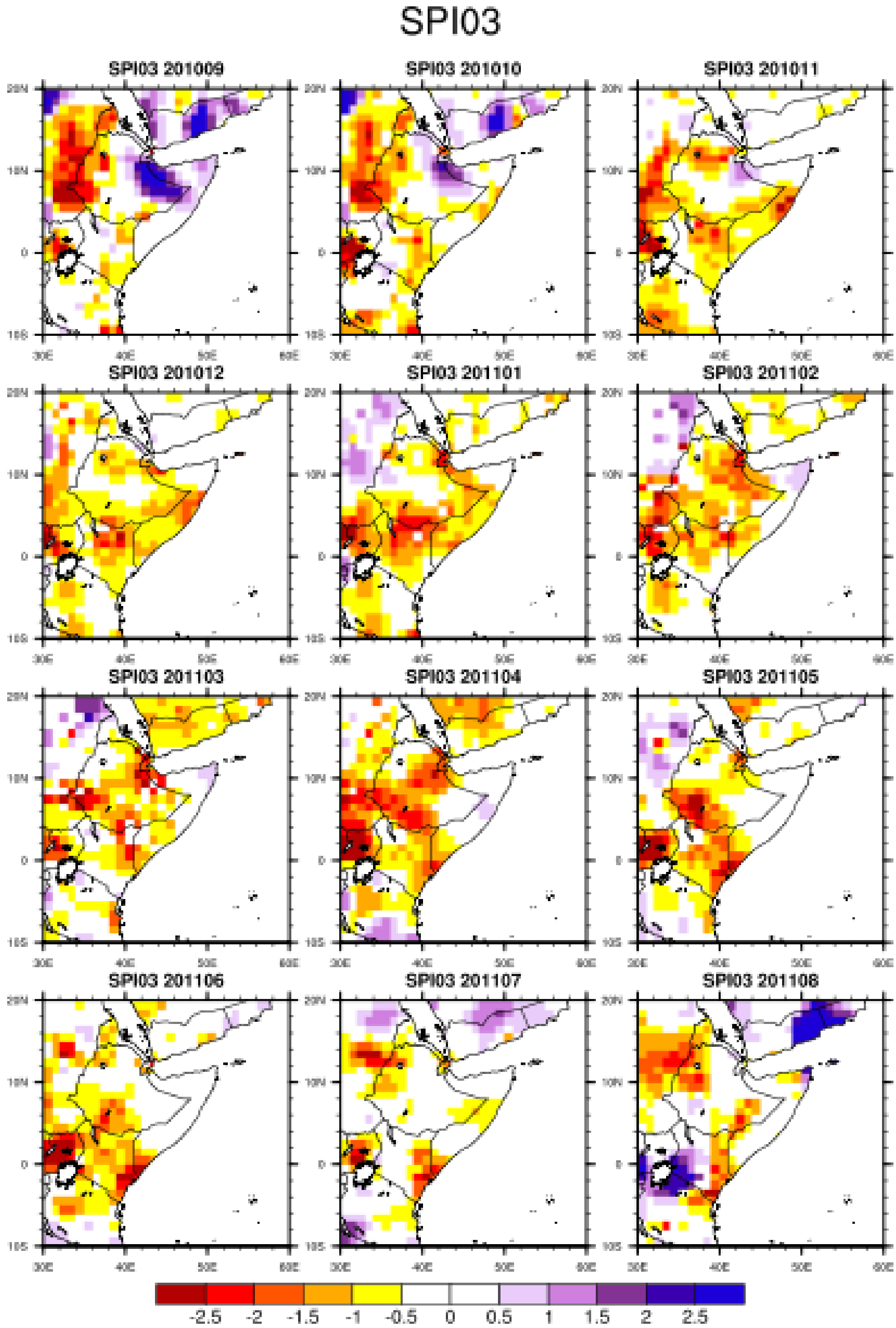


Figure 11: Evolution of the SPI for 3-month rainfall accumulations (SPI-3).

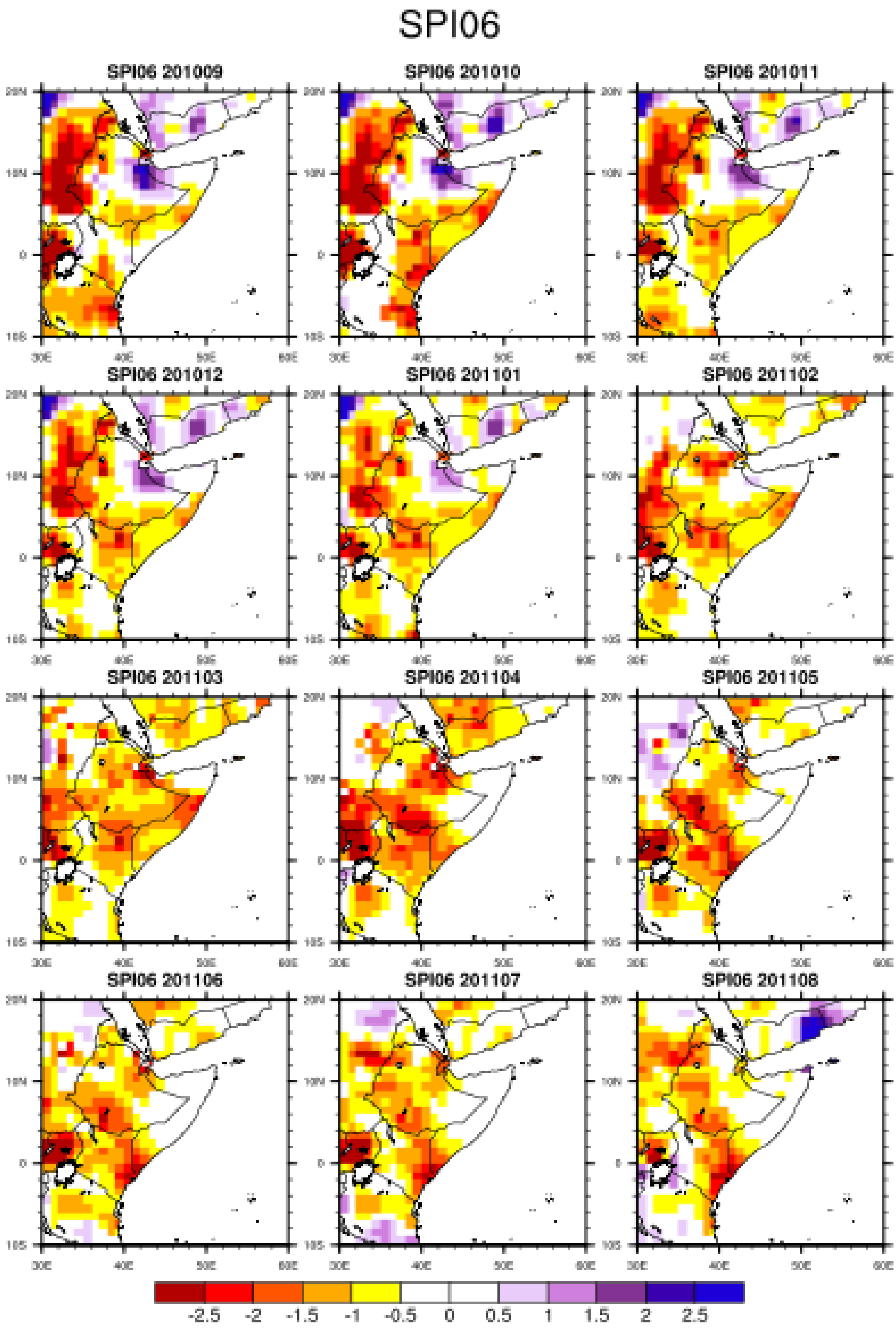


Figure 12: Evolution of the SPI for 6-month rainfall accumulations (SPI-6).

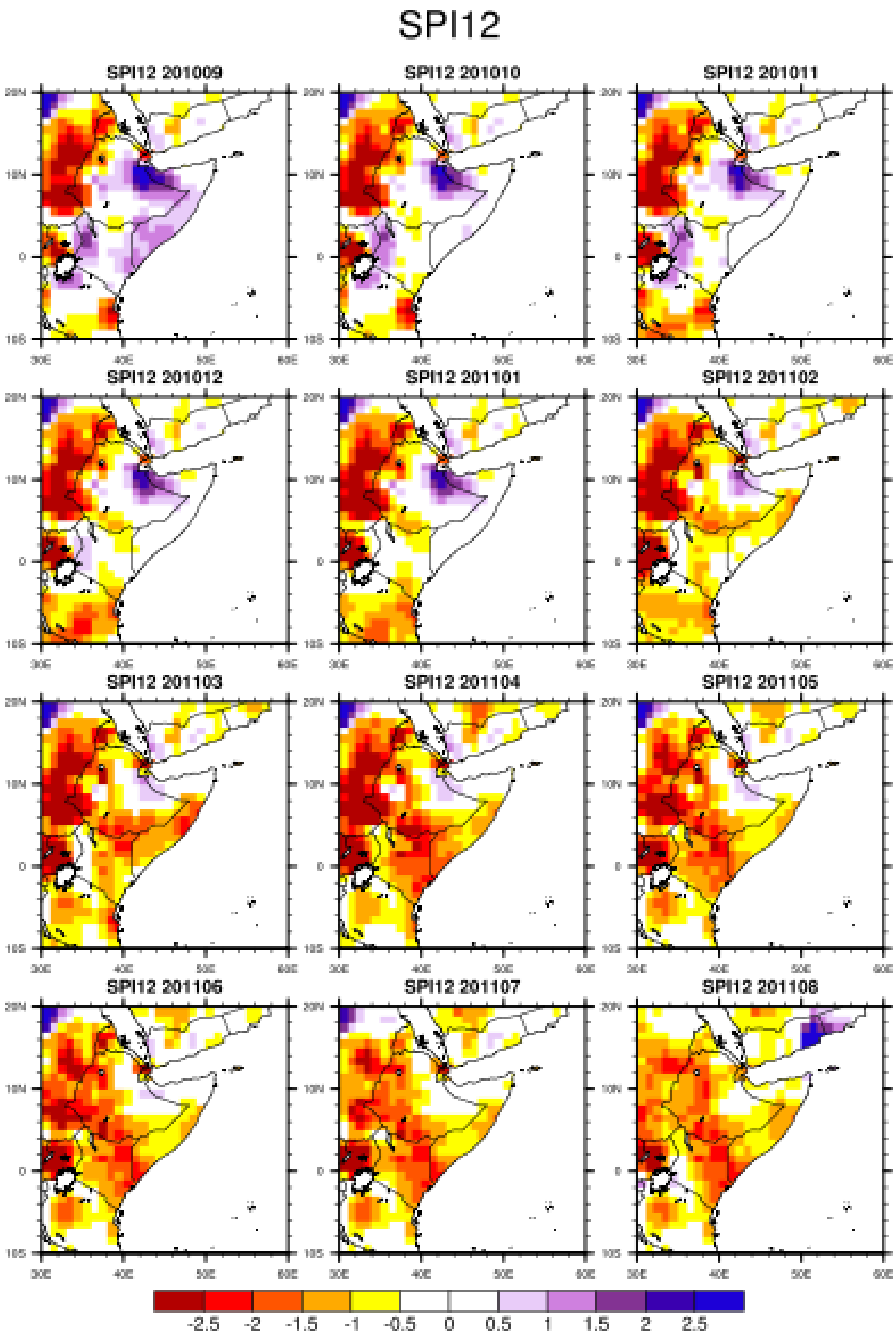


Figure 13: Evolution of the SPI for 12-month rainfall accumulations (SPI-12).

The SPI-12 showed a similar evolution (Figure 13). In July 2010, extreme 12-month drought conditions were already evident in Sudan and western parts of Ethiopia. Severe 12-month drought conditions began in southern Ethiopia around December 2010 – January 2011 and spread throughout much of the Greater Horn of Africa by April 2011. These conditions remained also throughout the months of July and August confirming the findings of SPI-3 and SPI-6. The persistence of the rain deficit into the wet season for southern Sudan and neighbouring areas of western Ethiopia has led to drought conditions in these areas, as well as in northern Tanzania. The time series for mean SPI-12 for the most affected region until June 2011 showed that current conditions were only comparable with the long-term rainfall deficit observed in 1992, 1994 and 2000/2001 (Figure 14).

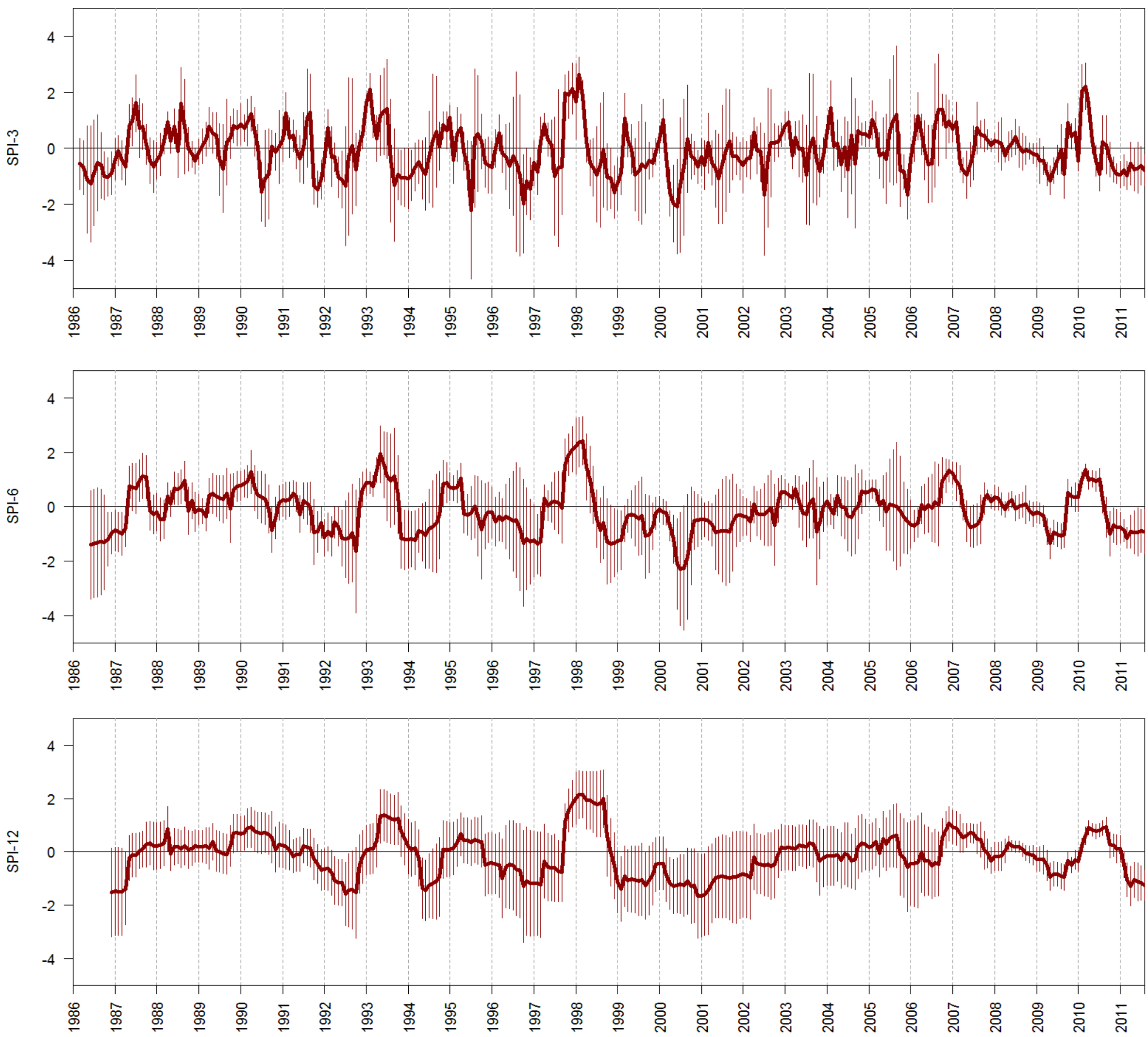


Figure 14: Time series of the spatial average of SPI-3/6/12 for the most affected area in June 2011 (the vertical lines represent ± 1 standard deviation).

5.1.4. Monitoring of the vegetation conditions since October 2010.

At the end of September 2010, the vegetation conditions as depicted by the NDWI anomalies in the Horn of Africa were close to normal (Figure 16). At the end of October and beginning of November, negative NDWI anomalies began to be recorded in Somalia (central and southern parts), Ethiopia (mainly the south-eastern part) and in Kenya (northern and eastern parts). In December, the spatial extension of the drought as recorded by the NDWI anomalies remained relatively constant, with a very spatially coherent negative signal registered for South Somalia. From January until the end of April 2011, NDWI anomalies became more negative in the above mentioned regions. In terms of extent and intensity, the peak of the drought was observed around end of April. Additionally, negative NDWI anomalies also began to be recorded in northern Tanzania (Figure 15).

From May onwards, an improvement of the vegetation conditions was observed in Ethiopia. In July, the drought situation remained quite stable in Somalia, Kenya and Tanzania. Conditions of major vegetation water stress were still observed in the Juba-Shabelle regions in Somalia, in the districts of Ijara and Lamu in Kenya, and on the southern banks of Lake Victoria (Mwanza Region) in Tanzania. However during August 2011, we observed that the drought affected area has been declining, especially in Somalia (Figure 15). The latest NDWI anomaly product from the first 10 days of September 2011 (Figure 16) shows that negative anomalies of NDWI in this region were then restricted to a narrow band stretching along the coast from South Somalia to Kenya.

In southern Sudan and bordering Ethiopia, severe negative anomalies have been registered since the end of July 2011, confirming that the late onset of the seasonal rainfall reported by FEWSNET (source: http://www.fews.net/docs/Publications/afr_Sep15_2011.pdf) had an impact on water stress conditions at canopy level. This impact was still visible on the latest NDWI anomaly product corresponding to the first 10 days of September 2011 (Figure 16).

The particularly poor vegetation conditions in Somalia and northern Kenya result from shortage of rainfall during the rainy season of March to May (Regions 2 and 3, Figure 10), while the more recent drought events in southern Sudan are related to a shortage of rainfall during the rainy season of July and August. The time series of spatially averaged NDWI anomalies, extracted for the most affected area in June, comprising Somalia, Ethiopia and Kenya, is presented in Figure 17. It confirms that the 2010-2011 drought was the most severe recorded for that region since April 1998 (largest negative anomalies). An improvement of the vegetation conditions is also shown in August and beginning of September. Although the archive of NDWI is relatively short, it can be seen that the drought was quite exceptional in terms of impact on the vegetation in this area. A similar time series over southern Sudan (Figure 17) showed that, after Somalia, Ethiopia and Kenya, the vegetation in southern Sudan registered in September 2011 its largest negative anomalies ever recorded by the available time series; i.e. the drought was the most severe in term of vegetation water stress.

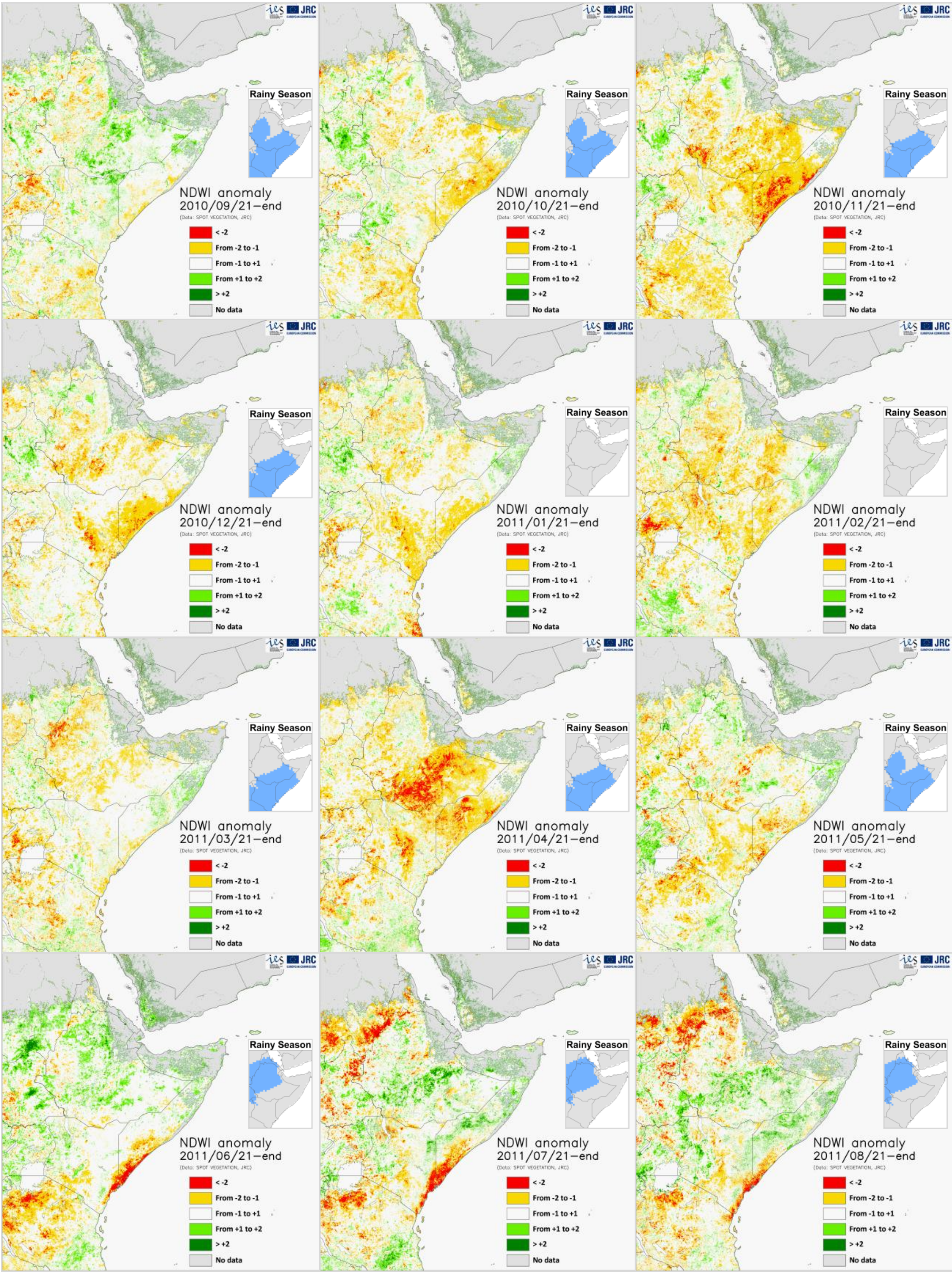


Figure 15: NDWI 10-day anomaly from end of September 2010 to end of August 2011 (only the last 10-day period of each month is shown). Green corresponds to positive anomalies (vegetation greener than normal), white to near-normal vegetation conditions and yellow and red to negative anomalies (vegetation less green than normal). Grey corresponds to "no data". The small window shows in blue where rain is expected for that time period.

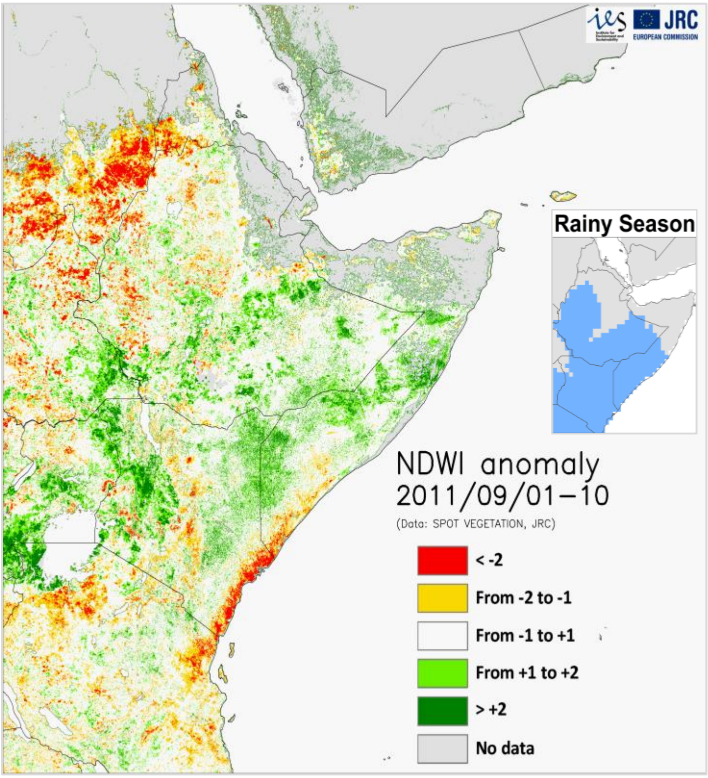


Figure 16: 10-day NDWI anomaly of the 1st-10th of September 2011. Green corresponds to positive anomalies (vegetation water stress lower than normal), white to near-normal conditions and orange-red to negative anomalies (vegetation water stress higher than normal). Grey corresponds to no data. The small window shows in blue where rain is expected for that time period.

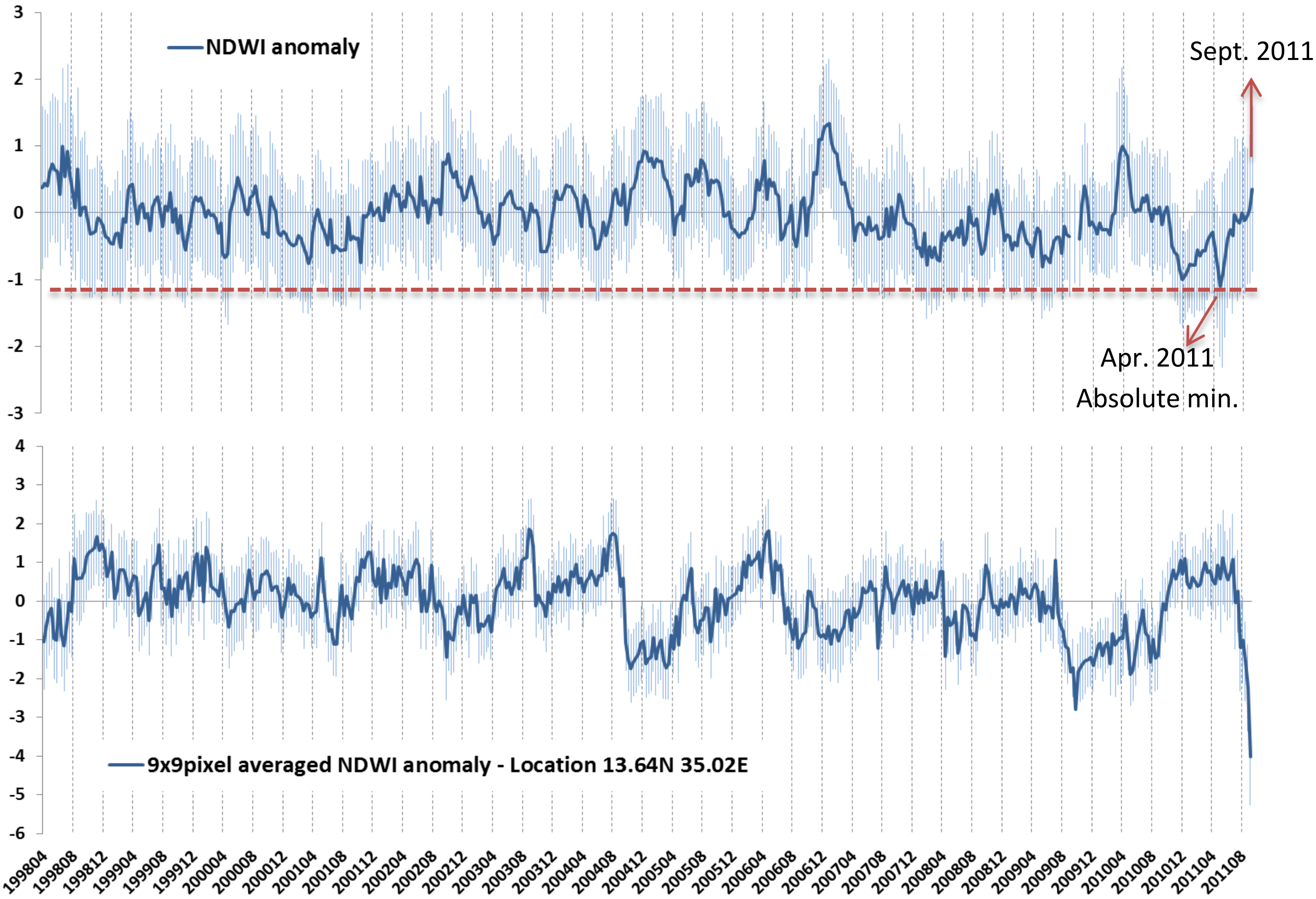


Figure 17: Time series of the spatial average of NDWI anomalies: (upper graph) for the most affected area in June 2011; (lower graph) for the most drought affected area in southern Sudan (the vertical lines represent ± 1 standard deviation).

5.2. The drought in Europe in spring 2011

5.2.1. Description of operational [OPE]

[OPE] Standardized Precipitation Index. Rainfall conditions were assessed using the Standardized Precipitation Index (SPI). SPI values lower than -1.5 are indicative of severe drought, and values lower than -2 are indicative of extreme drought. For more detailed information about the SPI, refer to Section 3.2.

[OPE] Vegetation Indices Anomalies. Vegetation conditions in the Greater Horn of Africa were evaluated using two vegetation indices: (1) the Normalized Difference Water Index, NDWI which is related to the water content of the canopy; (2) the fraction of Absorbed Photosynthetically Active Radiation, fAPAR, which is related to the total green biomass. For both indices, anomalies were calculated for 10-day periods using the available data archives April 1998. Anomalies lower than -1.0 are indicative of a moderate to severe vegetation stress. For more detailed information about those indices, refer to Section 3.2.

5.2.2. Overview on rainfall

The standardized precipitation index for 1-month rainfall totals (SPI-1) (Figure 18) in May shows that the drought conditions of April continued over much of France and Germany with a strengthening of the negative SPI-1 in many areas. Over England and northern parts of Italy, however, the rainfall deficit became less severe.

The SPI-3 (Figure 19), for 3 month rainfall accumulations, which is important for agriculture, shows that accumulated rainfall deficit in the 3 months to May was more severe than in the 3 months to April. In particular western Germany, the Netherlands, Belgium and northwest France have received considerably less rainfall than is climatologically expected over this period. The drought conditions that have existed over the Ukraine, Belarus and the Baltic countries since March have persisted into May.

Additionally, the SPI-12 (Figure 20) shows a persistent shortage of 12-month rainfall over northern England, Wales, central-southern England, Denmark, northern Germany, central parts of the Ukraine and the western half of France with the affected areas spreading eastwards from there during May. Rainfall shortages over this extended period may lead to impacts on reservoir storage levels in these regions.

The accumulated rainfall for the period 01 January to 06 June for 2011 is comparable to historical minima for the following countries (Figure 21):

- Belgium: comparable to 1996 and 1976 ;
- Germany: comparable to 1996 ;
- France: comparable to 1976 ;
- The Netherlands: comparable to 1991, 1982, 1976 ;
- The United Kingdom: comparable to 1997 ;
- Ukraine: absolute minimum since 1975, comparable to 2007, 2003, 1989.

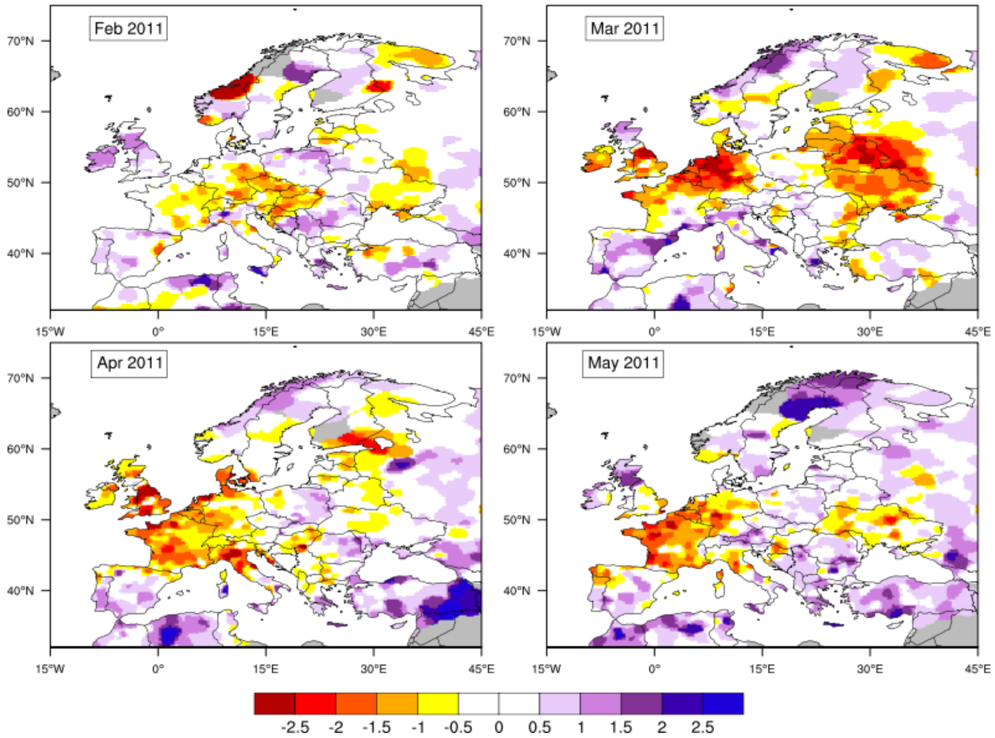


Figure 18: Evolution of the 1-month Standardized Precipitation Index (SPI-1) from February to May 2011. Values below -1.5 indicate a severe meteorological drought. Grey shading indicates areas with insufficient reliable data to compute the SPI.

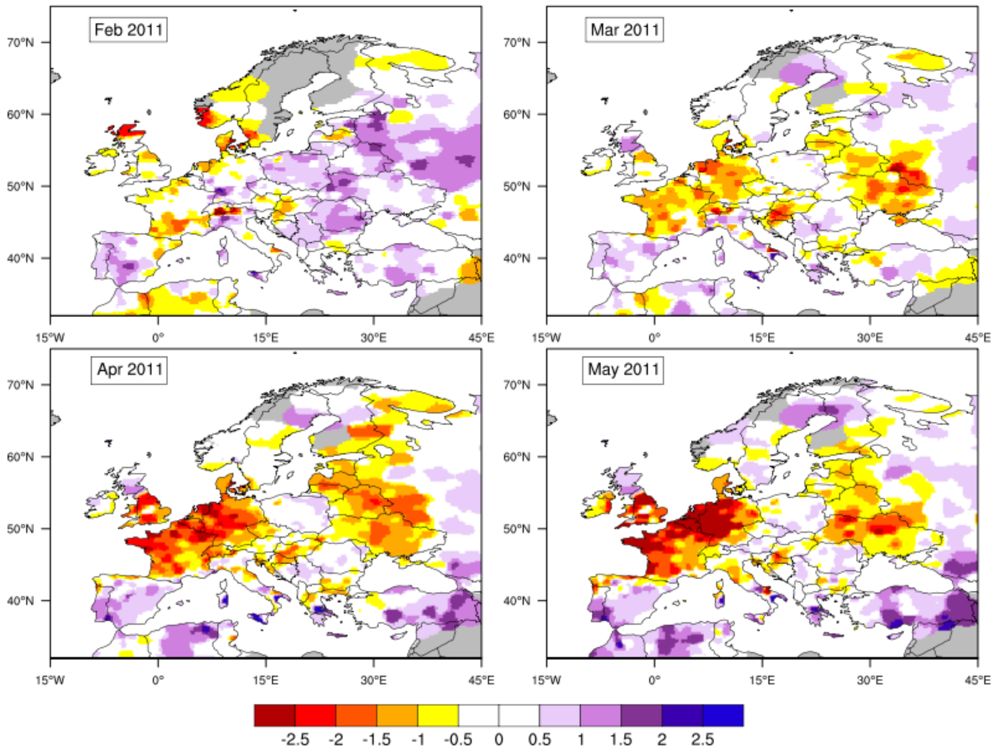


Figure 19: Evolution of the 3-month Standardized Precipitation Index (SPI-3) from February to May 2011. Values below -1.5 indicate a severe meteorological drought. Grey shading indicates areas with insufficient reliable data to compute the SPI.

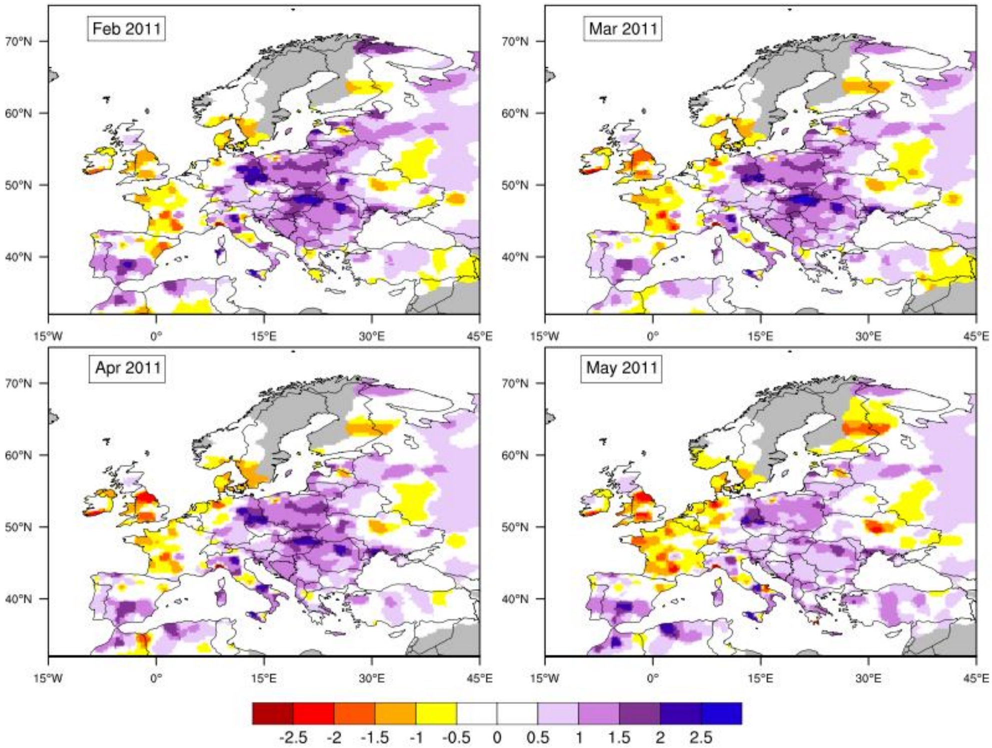


Figure 20: Evolution of the 12-month Standardized Precipitation Index (SPI-12) from February to May 2011. Values below -1.5 indicate a severe meteorological drought. Grey shading indicates areas with insufficient reliable data to compute the SPI.

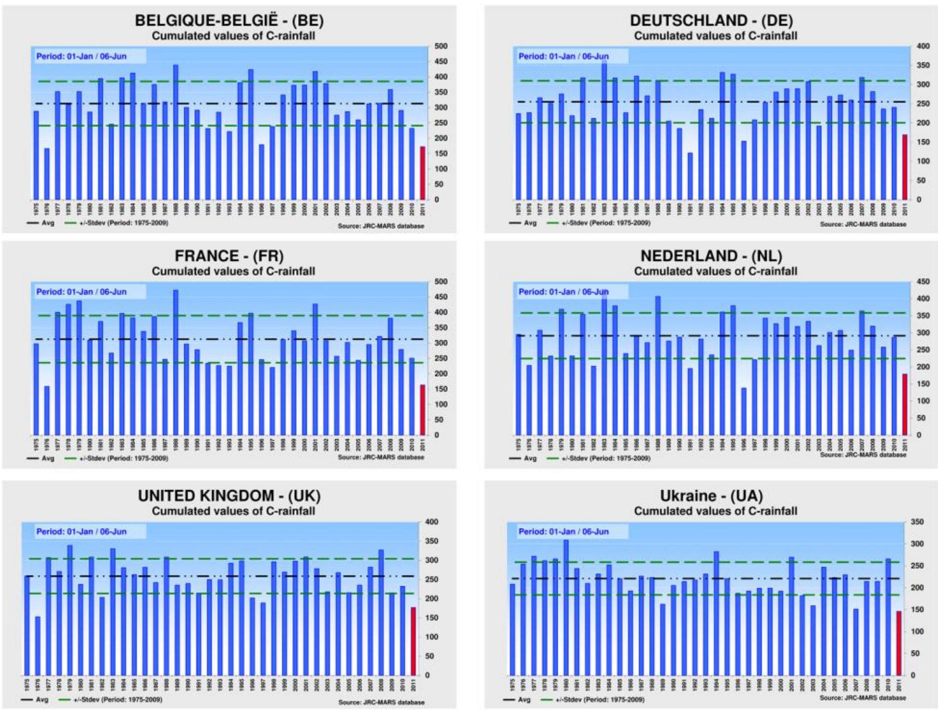


Figure 21: Accumulated rainfall for 1st of January to 6th of June for the years 1975 to 2011. 2011 is highlighted in red. Black dot-dashed line: Average rainfall 1975-2010, green dashed lines: One standard deviation above and below the average (1975-2010).

5.2.3. Overview on vegetation status

To evaluate the change in vegetation conditions during the month of May, a trend in green biomass anomaly was estimated using the images of the fraction of Absorbed Photosynthetically Active Radiation (fAPAR) between end of April and end of May (Figure 22). Important negative trends in fAPAR anomaly were recorded in France, Belgium, the Netherlands, southeast England and Central-East Germany. This observation is confirmed when looking at the overall evolution of the fAPAR anomalies between the end of April and the end of May (Figure 23).

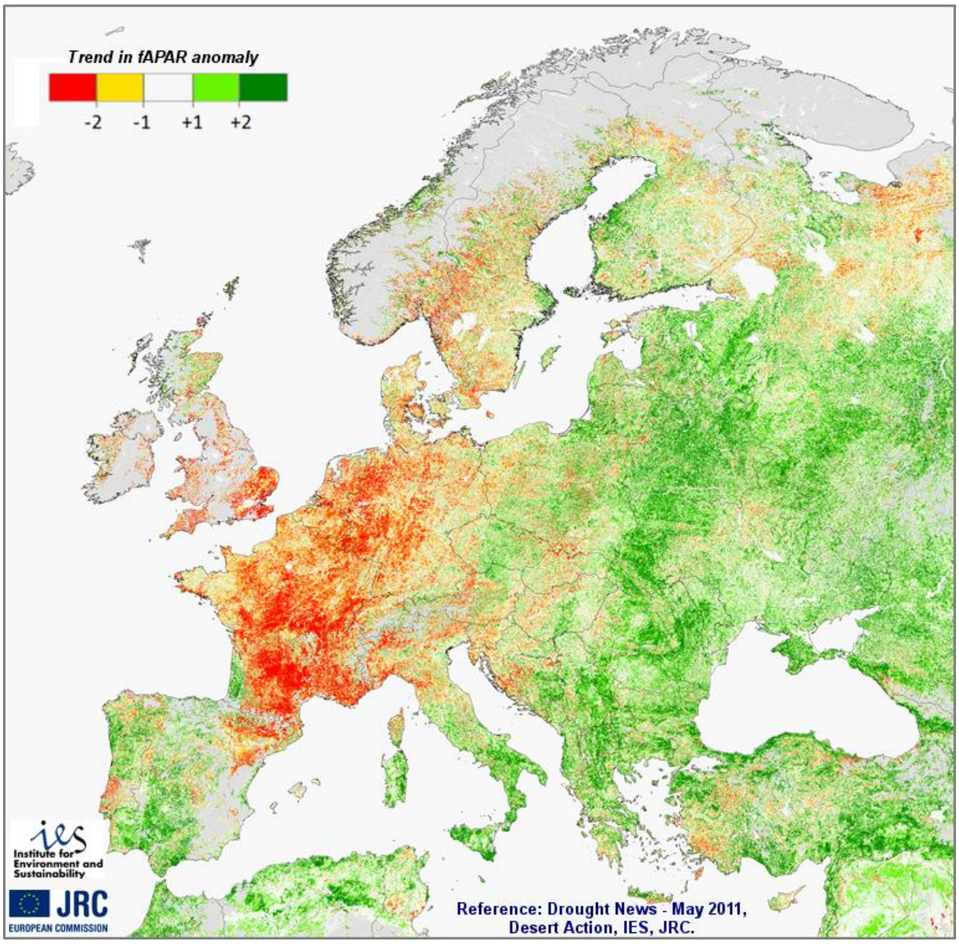


Figure 22: Difference between the fAPAR anomalies for the last 10-day period of May 2011 and last 10-day period of April 2011. Red indicates a negative trend in the fAPAR anomalies (i.e. deterioration of the vegetation health) and green indicates a positive trend in the fAPAR anomalies (i.e. improvement in the vegetation health).

At the end of April, no severe impact on the vegetation cover was visible over most parts of Western Europe. However, during May, the 10-day fAPAR images showed abnormally low values in some EU countries. For France, the fAPAR anomalies (observed fAPAR compared with the 1997-2008 average) remained positive (healthy vegetation conditions) until the end of April, but the signal became increasingly negative during the month of May, especially in central parts of the country. Similar situations were observed for the south-eastern part of the UK, Belgium and the Netherlands.

In North Germany, North Italy, and in several countries in Western Europe, early signs of drought impact on the vegetation cover were observed at the end of April. During May, the negative vegetation anomalies observed in North Germany spread over much of the country. While in Ukraine, Poland and in the Baltic countries, the situation seemed to be back to near normal or better vegetation conditions, even though locally negative fAPAR anomalies are still recoded. In North Italy, the vegetation conditions slightly improved towards the end of May, due to favourable rainfalls during the month.

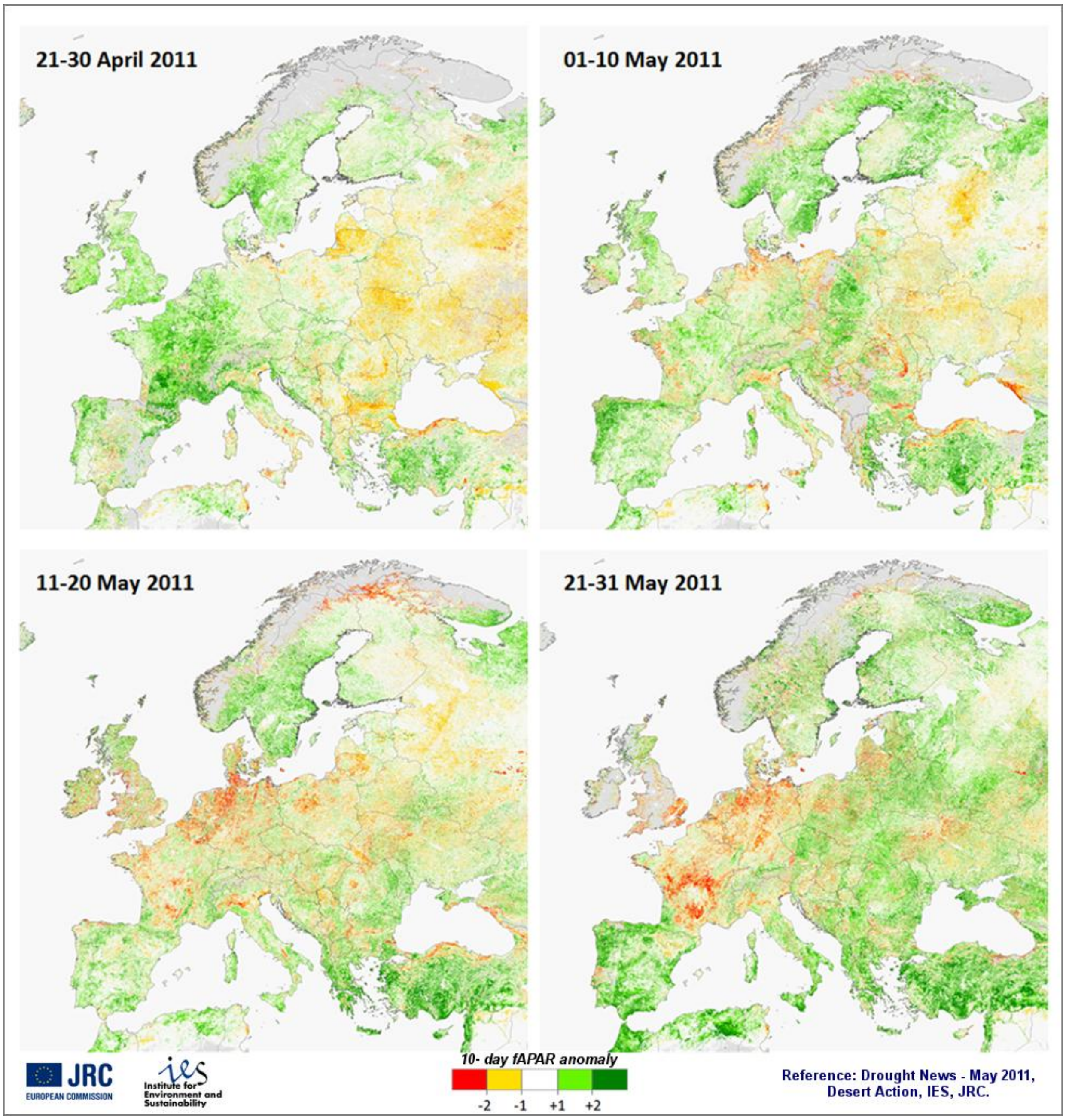


Figure 23: 10-day fAPAR anomaly for (top left) 21-30 April 2011, (top right) 01-10 May 2011, (low left) 11-20 May 2011, (low right) 21-31 May 2011. Green corresponds to positive anomalies (vegetation greener than normal), white to near-normal vegetation conditions and yellow and red to negative anomalies (vegetation less green than normal).

REFERENCES

Adler, R.F., G.J. Huffman, A. Chang, R. Ferraro, P. Xie, J. Janowiak, B. Rudolf, U. Schneider, S. Curtis, D. Bolvin, A. Gruber, J. Susskind and P. Arkin (2003). The Version 2 Global Precipitation Climatology Project (GPCP) Monthly Precipitation Analysis (1979-Present). *Journal of Hydrometeorology*, 4: 1147-1167.

Arino O. , Bicheron P., Achard F., Latham J., Witt R., Weber J.-L. (2008). GlobCover: The most detailed portrait of Earth. *European Space Agency Bulletin*, Vol. 2008(136): 24-31.

Bartholome E. and Belward A.S. (2005). GLC2000: A new approach to global land cover mapping from earth observation data. *International Journal of Remote Sensing*, 26 (9): 1959-1977.

Bastin, G.N., Pickup, G. and Pearce, G. (1995). Utility of AVHRR data for land degradation assessment: a case study. *International Journal of Remote Sensing*, 16: 651-672.

Bayarjargal, Y., A. Karnieli, M. Bayasgalan, S. Khudulmur, C. Gandush and C.J. Tucker (2006). A comparative study of NOAA-AVHRR derived drought indices using change vector analysis. *Remote Sensing of Environment*, 105: 9-22.

Below R., Grover-Kopec E., Dilley M. (2007). Documenting drought-related Disasters: A global reassessment. *Journal of Environment and Development*, 16 (3): 328-344.

Caccamo, G., L. A. Chisholm, R. A. Bradstock and M. L. Puotinen (2011). Assessing the sensitivity of MODIS to monitor drought in high biomass ecosystems. *Remote Sensing of Environment*, 115: 2626-2639.

Carrão, H., A. Araújo, P. Gonçalves and M. Caetano (2010). Multitemporal MERIS images for land cover mapping at national scale: the case study of Portugal. *International Journal of Remote Sensing*, 31: 2063-2082.

Ceccato, P., Flasse, S., and Gregoire, J.M. (2002). Designing a spectral index to estimate vegetation water content from remote sensing data: Part 2. Validation and applications. *Remote Sensing of Environment* 82: 198-207.

Ceccato, P., Flasse, S., Tarantola, S., Jacquemond, S., and Gregoire, J.M. (2001). Detecting vegetation water content using reflectance in the optical domain. *Remote Sensing of Environment* 77: 22–33.

De Roo, A.P.J., Wesseling, C.G. and Van Deursen, W.P.A. (2000). Physically based river basin modelling within a GIS: The LISFLOOD model. *Hydrological Processes*, 14: 1981–1992.

Dee, D. P., Uppala, S. M., Simmons, A. J., Berrisford, P., Poli, P., Kobayashi, S., Andrae, U., Balmaseda, M. A., Balsamo, G., Bauer, P., Bechtold, P., Beljaars, A. C. M., van de Berg, L., Bidlot, J., Bormann, N., Delsol, C., Dragani, R., Fuentes, M., Geer, A. J., Haimberger, L., Healy, S. B., Hersbach, H., Hólm, E. V., Isaksen, L., Kållberg, P., Köhler, M., Matricardi, M., McNally, A. P., Monge-Sanz, B. M., Morcrette, J.-J., Park, B.-K., Peubey, C., de Rosnay, P., Tavolato, C., Thépaut, J.-N. and Vitart, F. (2011). The ERA-Interim reanalysis: configuration and performance of the data assimilation system. *Quarterly Journal of the Royal Meteorological Societ*y, 137: 553–597. doi: 10.1002/qj.828.

Delbart, N., L. Kergoat, T. L. Toan, J. Lhermitte, and G. Picard (2005). Determination of phenological dates in boreal regions using normalized difference water index. *Remote Sensing of Environment* 97: 26-38.

Dracup, J. A., K. S. Lee and E. G. Paulson Jr. (1980). On the definition of droughts. *Water Resources Research*, 16: 297–302.

EEA and ETC/Land Cover (1999). Corine Land Cover Technical Guide. At http://etc.satellus.se/the_data/Technical_Guide/index.htm.

EM-DAT (2011). The OFDA/CRED International Disaster Database - www.emdat.be – Université Catholique de Louvain – Brussels – Belgium.

Fensholt R., Sandholt I. and Stisen S. (2006). Evaluating MODIS, MERIS, and VEGETATION - Vegetation indices using in situ measurements in a semiarid environment. *IEEE Transactions on Geoscience and Remote Sensing*, 44: 1774-1786.

Gao B.-C. (1996). NDWI - A normalized difference water index for remote sensing of vegetation liquid water from space. *Remote Sensing of Environment*, 58 (3): 257-266.

Gobron N., Aussedat O., Pinty B., Taberner M., and Verstraete M. M. (2004). *Medium Resolution Imaging Spectrometer (MERIS) - An optimized FAPAR Algorithm - Theoretical Basis Document. Revision 3.0.* Institute for Environment and Sustainability, EUR Report No. 21386 EN, 20 p.

Gobron N., Pinty B., Mélin F., Taberner M., and Verstraete M. M. (2002). *Sea Wide Field-of-View Sensor (SeaWiFS) - Level 2 Land Surface Products - Algorithm Theoretical Basis Document*. Institute for Environment and Sustainability, EUR Report No. 20144 EN, 23 p.

Gobron, N., Pinty, B., Verstraete, M. M. and Govaerts, Y. M. (1999). The MERIS Global Vegetation Index (MGVI): Description and Preliminary Application. *International Journal of Remote Sensing*, 20: 1917–1927.

Gobron, N., Verstraete, M., Pinty, B., Taberner, M. and Aussedat, O. (2009). Potential of long time series of fAPAR products for assessing and monitoring land surface changes: Examples in Europe and the Sahel. In J. Hill and A. Roeder (Eds.), *Recent Advances in Remote Sensing and Geoinformation Processing for Land Degradation Assessment* (pp. 89-101), London (UK): Taylor & Francis Ltd.

Gu, Y., Brown, J.F., Verdin, J.P. and Wardlow, B. (2007). A five-year analysis of MODIS NDVI and NDWI for grassland drought assessment over the central Great Plains of the United States. *Geophysical Research Letters*, 34.

Gu, Y., Hunt, E., Wardlow, B., Basara, J.B., Brown, J.F., Verdin, J.P. (2008). Evaluation of MODIS NDVI and NDWI for vegetation drought monitoring using Oklahoma Mesonet soil moisture data. *Geophysical Research Letters* 35.

Haylock, M.R., N. Hofstra, A.M.G. Klein Tank, E.J. Klok, P.D. Jones and M. New. (2008). A European daily high-resolution gridded dataset of surface temperature and precipitation. *J. Geophys. Res (Atmospheres)*, 113, D20119, doi:10.1029/2008JD10201.

Hill, J., Stellmes, M., Udelhoven, T., Roder, A. and Sommer, S. (2008). Mediterranean desertification and land degradation mapping related land use change syndromes based on satellite observations. *Global and Planetary Change*, 64: 146-157.

Horion S., Barbosa P. Kurnik K. and Vogt J. (2010). Comparison of remote sensing and meteorological drought monitoring indicators in the Greater Horn of Africa (extended abstract) In: AARSE 2010 : 8th AARSE conference on earth observation for Africa's development agenda : abstracts book : scientific symposium, exhibition and workshops, 25-29 October 2010, Addis Ababa, Ethiopia. - [s.l.] : United Nations Conference Center (UNCC) ; United Nations Economic Commission for Africa (UNECA), 2010.

Huffman, G.J., R.F. Adler, B. Rudolf, U. Schneider and P.R. Keehn (1995). Global precipitation estimates based on a technique for combining satellite-based estimates, rain gauge analysis, and NWP model precipitation information. *Journal of Climate*, 8: 1284-1295.

Huffman, G.J., R.F. Adler, D.T. Bolvin, G. Gu, E.J. Nelkin, K.P. Bowman, Y. Hong, E.F. Stocker, D.B. Wolff, 2007. The TRMM Multi-satellite Precipitation Analysis: Quasi-Global, Multi-Year, Combined-Sensor Precipitation Estimates at Fine Scale. *J. Hydrometeor*., 8: 38-55.

Huffman, G.J., R.F. Adler, P.A. Arkin, A. Chang, R. Ferraro, A. Gruber, J. Janowiak, R.J. Joyce, A. McNab, B. Rudolf, U. Schneider and P. Xie (1997). The Global Precipitation Climatology Project (GPCP) Combined Precipitation Data Set. *Bulletin of the American Meteorological Society*, 78: 5-20.

Jackson, T.J., Chen, D., Cosh, M., Li, F., Anderson, M., Walthall, C., Doriaswamy, P., and Hunt, E.R. 2004. Vegetation water content mapping using Landsat data derived normalized difference water index for corn and soybeans. *Remote Sensing of Environment* 92: 475−482.

Ji, L. and Peters, A. (2003). Assessing vegetation response to drought in the northern Great Plains using vegetation and drought indices. *Remote Sensing of Environment*, 87: 85−98.

Kemp, D.D. (1994). *Global Environmental Issues: A Climatological Approach*. London: Routledge (2nd ed.), 220 pp.

Keyantash, J., Dracup, J.A. (2002). The quantification of drought: An evaluation of drought indices. Bulletin of the American Meteorological Society, 83 (8): 1167-1180.

Kogan, F. N. (1997). Glogal drought watch from Space. *Bull. of the American Meteorological Society*, 621-636.

Laguardia G., Niemeyer S. (2008). On the comparison between the LISFLOOD modelled and the ERS/SCAT derived soil moisture estimates. *Hydrology and Earth System Sciences*, 12(6): 1339-1351.

Landsberg, H. E. (1986). Potentialities and limitations of conventional climatological data for desertification monitoring and control. *Climate Change*, 9: 123-128.

McKee, T. B., J. Nolan, and J. Kleist, 1993: The relationship of drought frequency and duration to time scales. Preprints, Eighth Conf. on Applied Climatology, Anaheim, CA, Amer. Meteor, Soc., 179-184.

McKee, T. B., J. Nolan, and J. Kleist, 1995: Drought monitoring with multiple time scales. Preprints, Ninth Conf. on Applied Climatology, Dallas, TX, Amer. Meteor. Soc., 233-236.

Mishra A. K. and V. P. Singh (2010). A review on drought concepts. *Journal of Hydrology*, 391: 202-216.

Mitchell T.D and P. D. Jones (2005): An improved method of constructing a database of monthly climate observations and associated high-resolution grids. *International Journal of Climatology*, 25: 693-712.

Myneni, R.B., Maggion, S., Iaquinta, J., Privette, J.L., Gobron, N., Pinty, B., Kimes, D.S., Verstraete, M.M., Williams, D.L. (1995). Optical remote sensing of vegetation: Modeling, caveats, and algorithms. *Remote Sensing of Environment*, 51 (1): 169-188

Oleson, K. W., Dai Y., Bonan G., Bosilovich M., Dickinson R., Dirmeyer, P., Hoffman F., Houser P., Levis S., Niu G.-Y., Thornton, P., Vertenstein M., Yang Z.-L., and Zeng X, 2004:.Technical Description of the Community Land Model (CLM). Technical Note NCAR/TN-461+STR, National Center for Atmospheric Research.

Peters A. J., Walter-Shea, E. A., Ji, L., Vina, A., Hayes, M. and Svoboda, M. D. (2002). Drought Monitoring with NDVI-Based Standardized Vegetation Index. *Photogrammetric engineering and remote sensing*, 68: 71-76.

Pinty B., Gobron N., Mélin F., and Verstraete M.M. (2002). *Time Composite Algorithm Theoretical Basis Document*. Institute for Environment and Sustainability, EUR Report No. 20150 EN, 8 pp.

Rhee J., Im J., and Carbone G. J. (2010). Monitoring agricultural drought for arid and humid regions using multi-sensor remote sensing data. *Remote Sensing of Environment*, 114: 2875-2887.

Rossi, S., and Niemeyer, S. (in press). *Drought Monitoring with estimates of the Fraction of Absorbed Photosynthetically-active Radiation (fAPAR) derived from MERIS*. In Wardlow, B., Anderson, M., and Verdin J. (eds.), “Remote Sensing for Drought: Innovative Monitoring Approaches”, CRC Press-Taylor & Francis (book in preparation, publication foreseen in March 2012).

Rossi, S., C.J Weissteiner, G. Laguardia, B. Kurnik, M. Robustelli, S. Niemeyer and N. Gobron (2008). Potential of MERIS fAPAR for drought detection. 2nd MERIS/(A)ATSR User Workshop, 22 - 26 September, Rome, Italy, unpaginated CD-ROM.

Rudolf, B., A. Becker, U. Schneider, A. Meyer-Christoffer and M. Ziese (2010). *GPCC Status Report December 2010, Global Precipitation Climatology Centre (GPCC)*. Available at: http://www.dwd.de/bvbw/generator/DWDWWW/Content/Oeffentlichkeit/KU/KU4/KU42/en/Reports__P ublications/GPCC_status_report_2010,templateId=raw,property=publicationFile.pdf/GPCC_status_report_2010.pdf (last accessed 20 October, 2011).

Sheffield, J., G. Goteti and E. F. Wood (2006). Development of a 50-Year High-Resolution Global Dataset of Meteorological Forcings for Land Surface Modeling. *Journal of Climate*, 19: 3088–3111.

Simpson, J., C. Kummerow, W.-K. Tao and R. F. Adler (1996). On the Tropical Rainfall Measuring Mission (TRMM). *Meteorology and Atmospheric Physics*, 60: 19–36.

Snedecor G. W. and W. G. Cochran (1980). *Statistical Methods*. 7th ed. Iowa University Press Ames, Iowa, 507pp.

Steinemann A.C. and Cavalcanti L.F.N. (2006). Developing multiple indicators and triggers for drought plans. *Journal of Water Resources Planning and Management*, 132 (3): 164-174.

Svoboda, M., LeComte, D., Hayes, M., Heim, R., Gleason, K., Angel, J., Rippey, B., Tinker, R., Palecki, M., Stooksbury, D., Miskus, D., Stephens, S. (2002). The drought monitor. *Bulletin of the American Meteorological Society*, 83 (8): 1181-1190.

Tadesse, T., Haile, M., Senay, G., Wardlow, B.D., Knutson, C.L. (2008). The need for integration of drought monitoring tools for proactive food security management in sub-Saharan Africa. *Natural Resources Forum*, 32 (4): 265-279.

Tucker, C. J. (1980). Remote sensing of leaf water content in the near infrared. *Remote Sensing of Environment* 10: 23-32.

Van der Knijff J.M., J. Younis and A.P.J. De Roo (2010). LISFLOOD: a GIS-based distributed model for river-basin scale water balance and flood simulation. *International Journal of Geographical Information Science*, 24 (2): 189-212.

Vogt, J.V. and F. Somma (Eds.) (2000). *Drought and Drought Mitigation in Europe.* (Kluwer Academic Publishers) Dordrecht, Boston, London, 336 p.

Wagner, W., V. Naeimi, K. Scipal, R. de Jeu and J. Martinez-Fernandez (2007). Soil moisture from operational meteorological satellites, *Hydrogeology Journal*, 15: 121-131.

White D.H. and Walcott J.J. (2009). The role of seasonal indices in monitoring and assessing agricultural and other droughts: A review. *Crop and Pasture Science*, 60 (7): 599-616.

Wilhite D. (1993). The enigma of drought. In: Wilhite D. (Ed.), *Drought Assessment, Management and Planning: Theory and Case Studies* (pp. 3-15). Boston: Kluwer Academic Publishers.

Wilhite D. and M. H. Glantz (1985): Understanding the drought phenomenon: The role of definitions. *Water International*, 10: 111–120.

Wilhite, D.A. (2000). Drought preparedness and response in the context of Sub-Saharan Africa. *Journal of Contingencies and Crisis Management*, 8 (2): 81-92

World Meteorological Organization – WMO (2006). *Drought monitoring and early warning: Concepts, progress and future challenges*, WMO No. 1006. Available at: http://www.wmo.ch/pages/publications/showcase/documents/1006_E.pdf (last accessed 20 October, 2011).

Wu, H., M. D. Svoboda, M. J. Hayes, D. A. Wilhite and F. Wen, 2007. Appropriate application of the standardized precipitation index in arid locations and dry seasons. *Int. J. Climatol*., 27, 65-79.

European Commission

EUR 25235 EN – Joint Research Centre – Institute for Environment and Sustainability
Title: JRC Experience on the Development of Drought Information Systems
Author(s): Horion S, Saiote Carrao H, Singleton A, Barbosa Ferreira P, Vogt J.
Luxembourg: Publications Office of the European Union
2012 – 70 pp. – 21 x 29.7 cm
EUR – Scientific and Technical Research series – ISSN 1831-9424 (online), ISSN 1018-5593 (print)
ISBN 978-92-79-23203-9 (PDF)
ISBN 978-92-79-23202-2 (print)
doi:10.2788/15761

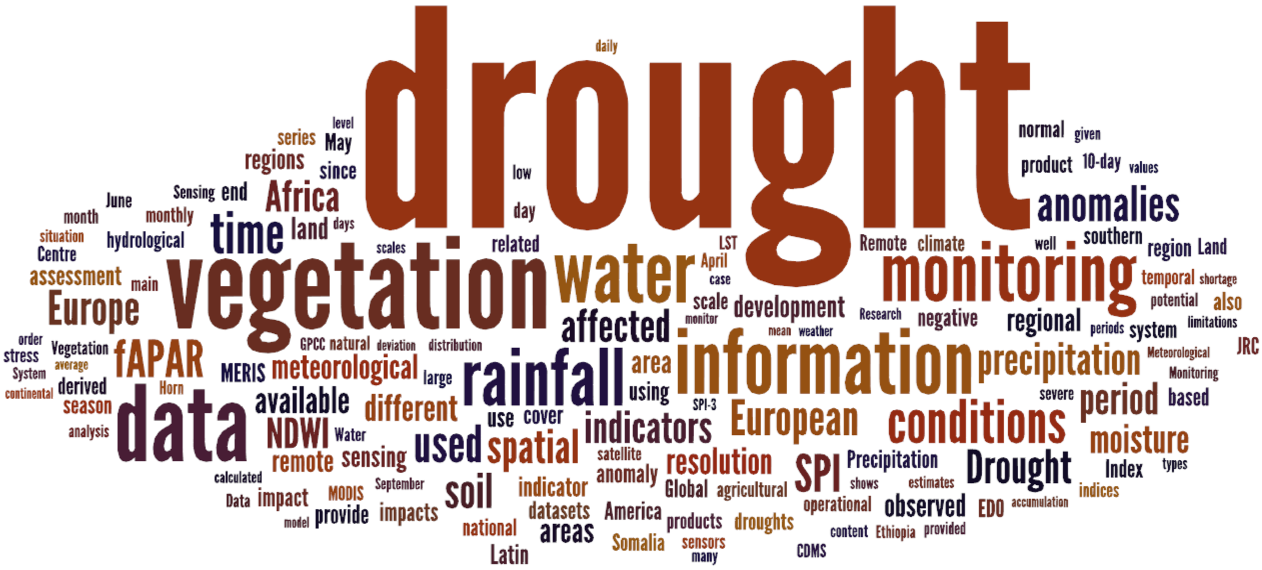
Abstract
From the definition of drought to its monitoring and assessment, this report summarizes the main steps towards an integrated drought information system. Europe, Africa and Latin America are examples, based on the experience of the JRC, that illustrate the challenges for establishing continental drought observatory initiatives. The document is structured in the following way: first an introduction explains what drought is and gives some examples of its impact in society; secondly the framework for establishing a drought monitoring system is described giving examples on the European Drought Observatory and on on-going activities in Africa and Latin America; thirdly the fundamental data and information for measuring drought is described; finally the setting up of an Integrated Drought Information System is discussed and two recent case studies, on Europe and on the Horn of Africa, are presented to illustrate the concept.

Acknowledgements
The authors would like to acknowledge all the colleagues who are or were intensely involved in the development of the European Drought Observatory, namely: Laura Calcagni, Alfred de Jager, Barbara Hofer, Blaz Kurnik, Giovanni Laguardia, Diego Magni, Mirko Marioni, Fabio Micale, Olga Nitcheva, Stefan Niemeyer, Simone Rossi, Guadalupe Sepulcre, Elena Sokolova and Christof Weissteiner.

The mission of the JRC is to provide customer-driven scientific and technical support for the conception, development, implementation and monitoring of EU policies. As a service of the European Commission, the JRC functions as a reference centre of science and technology for the Union. Close to the policy-making process, it serves the common interest of the Member States, while being independent of special interests, whether private or national.

LB-NA-25235-EN-N

JRC
EUROPEAN COMMISSION



Generated by worlde.net

Publications Office

ISBN 978-92-79-23203-9