Drought & Remote Sensing

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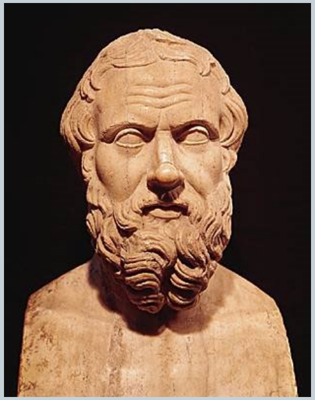
CESBIO

Drought ?

Drought



- *Then seven years passed in Thera without rain, and all the trees died of drought, except one.*

Herodotus – Book 4 - Melpomène, ~-445 av. JC

- *The lands of this small kingdom were not of the same nature: there were some arid and mountainous; and others which, in a low ground, were watered by several streams. This year, the drought was very great, so that the lands which were in the high places missed absolutely, while those which could be watered were very fertile: thus the people of the mountains perished almost all of them of hunger, by the hardness of the others, who refused to share the harvest to them. The following year was very rainy: the high places were found to be extraordinarily fertile, and the low lands were submerged. Half of the people cried out a second time for food; but these wretches found the people as hard as they themselves had been.*

Montesquieu - Lettres Persanes – 1721

Looking for a definition of « drought »

A completely adequate definition of drought is difficult to find. Not only is there disagreement as to the meaning of the word, even its spelling and pronunciation provide room for discussion. It is variously spelled as "drought" and "drouth." Recommended pronunciation for the first spelling is "drout" (as in trout) and the second form becomes "drouth" (as in south) [3]. These interesting sidelights are indicative of the confusion that prevails.

It appears that the press and the general public use the term in a more consistent way than do meteorologists, climatologists, hydrologists, and the other scientists who have done work on the subject. It is worthy of note that the term does not ordinarily appear in the public press until an area has endured an unusual moisture deficiency for an extended period of time. Those journalists who use such expressions as "drought of investment capital" and "man-power drought" must assume their share of responsibility for using "drought" as a synonym for "shortage."

In spite of the differences which exist, the people in humid climates seem to mean much the same thing when they refer to drought as do the people in a semiarid region; viz, that the moisture shortage has seriously affected the *established* economy of their region.

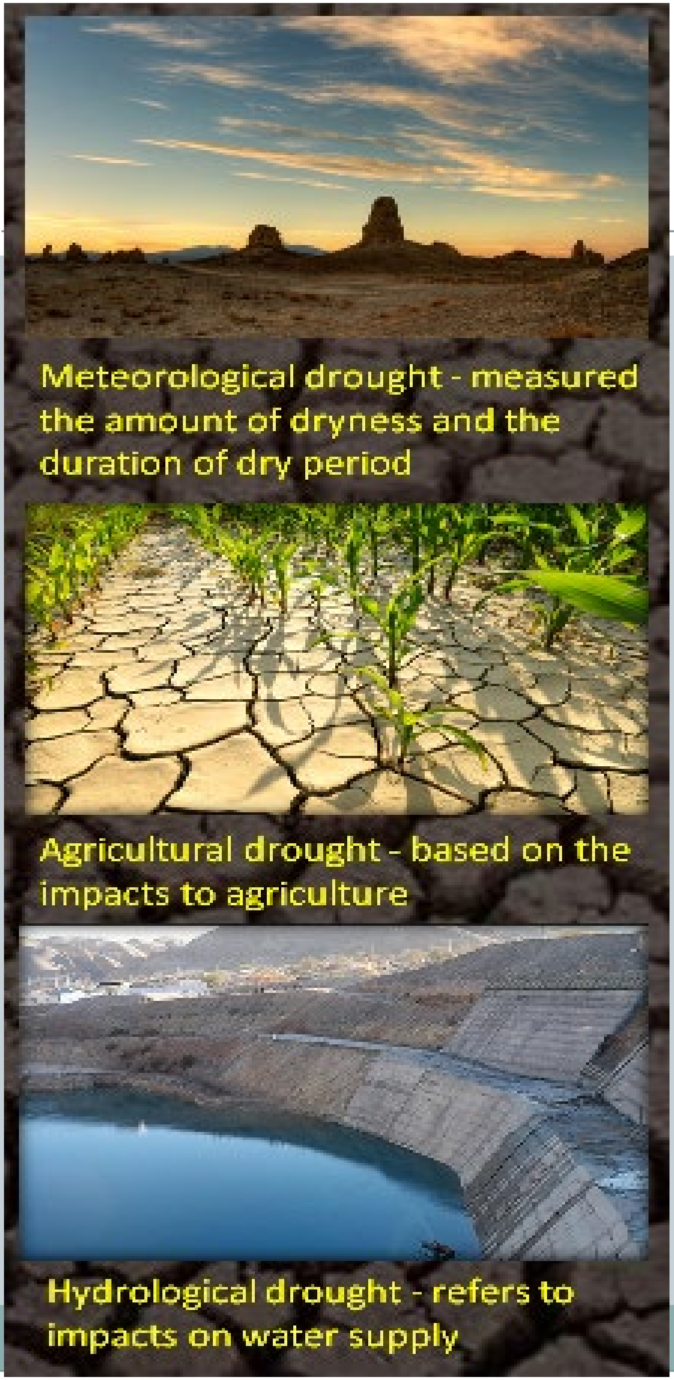
Palmer, 1965

A definition of drought

- **Palmer (1965)** notes that it is difficult to find an adequate definition of the term "drought" ". « drought is defined as a prolonged and abnormal period of moisture deficiency ».
  - Drought corresponds to a **prolonged** period of time: thus a severe drought lasts for months or even years.
  - The drought corresponds to a **lack of moisture**, of course directly related to the immediate rainfall, but also to that of the previous months since the soils, the lakes, the aquifers function as a buffer for the rain.
  - Finally, the drought is **abnormal**, in the sense that the situation is far from the average, far from normality.
- Drought is therefore neither a permanent state of the climate (aridity), nor a short state of water shortage (shortage, water stress).

Drought types

The common point of all the droughts is that they come from a lack of rainfall which causes a shortage of water for certain activities or for certain groups.



Drought types

- **Meteorological drought**

→**Measured in terms of the degree of drought (intensity) and duration of the dry period**

→**Specific region**

Drought types

- **Agricultural drought**

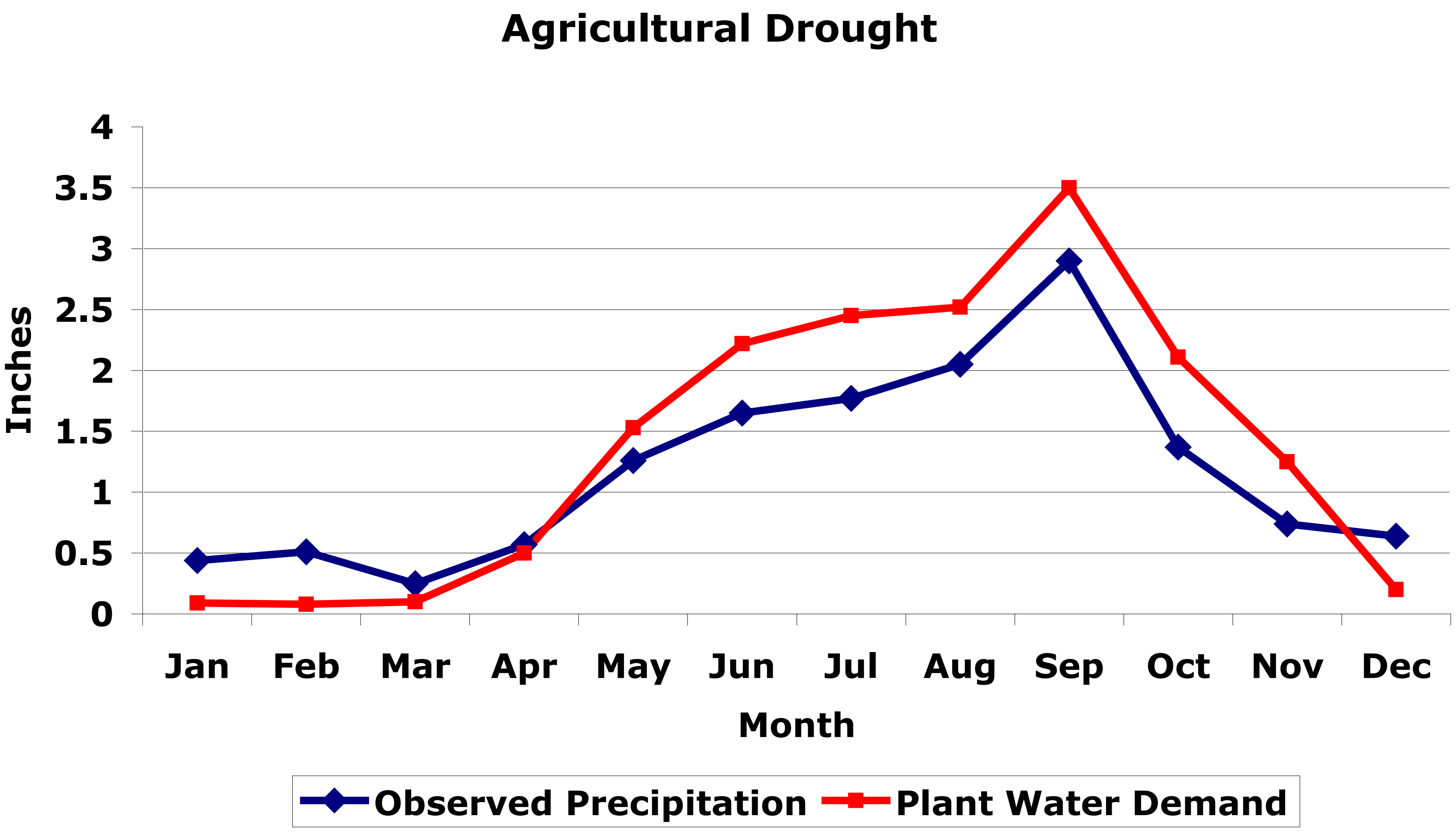
→ Meteorological drought affecting agriculture

→Usually, the first economic sector to be affected

→Shortage of precipitation, ET, soil moisture, etc.

→Demand for water from the plant in relation to available soil moisture

Drought types



Drought types

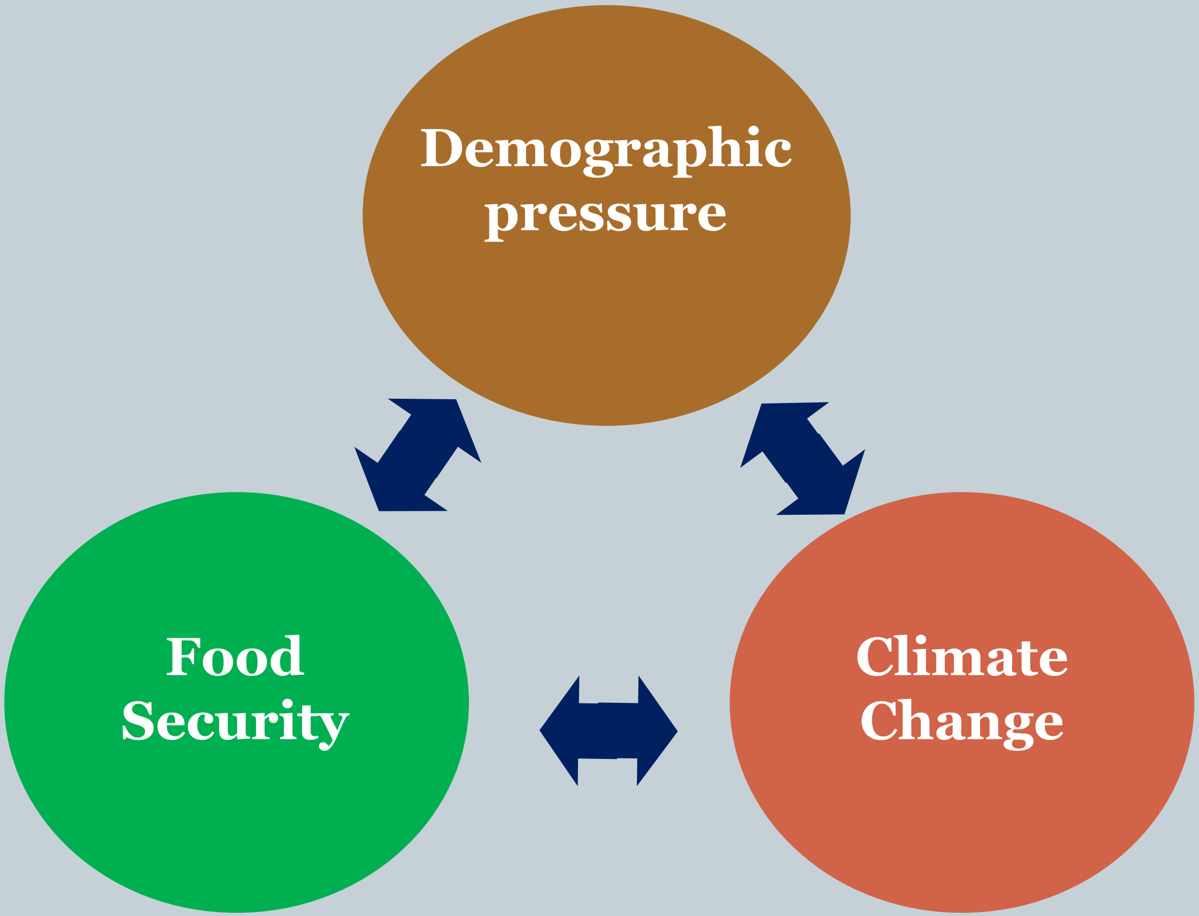
- **Hydrological drought**
  Impacts of rainfall shortages on the hydrological system (groundwater, rivers, lakes, reservoirs)
- Communities vary in degree of vulnerability depending on their water source
  Connections between basins, regions affect other regions
- Meteorological drought delayed

Drought types

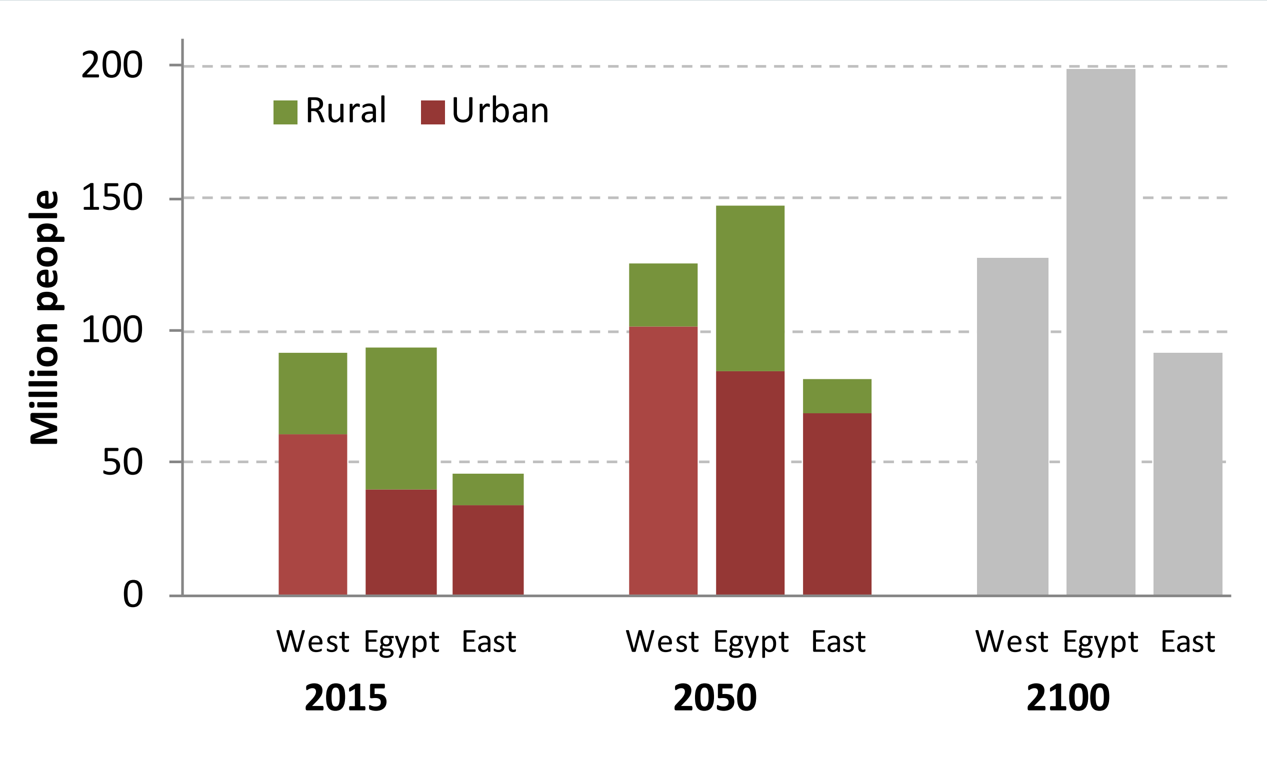
- **Socio-economic drought**
- **Demand exceeds supply of some economic products due to low rainfall**

Today's context of drought

Today's context



Demographic pressure

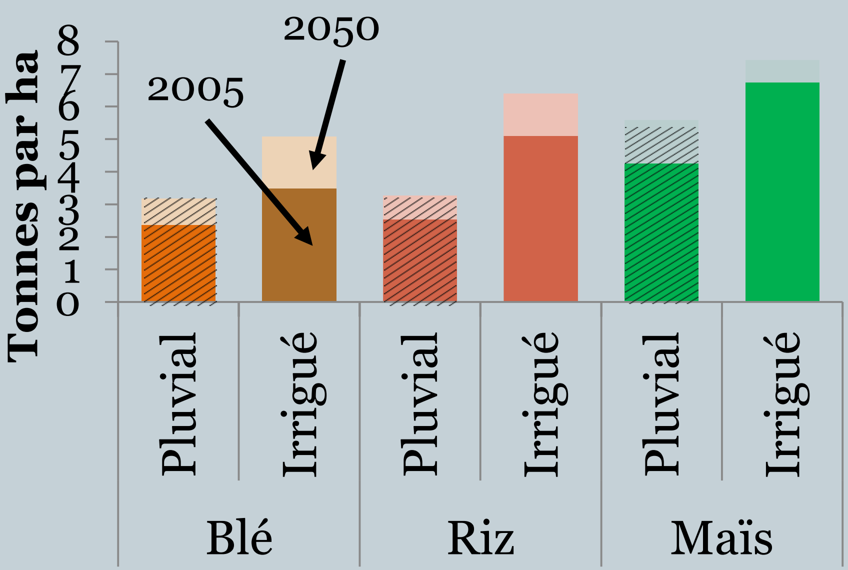


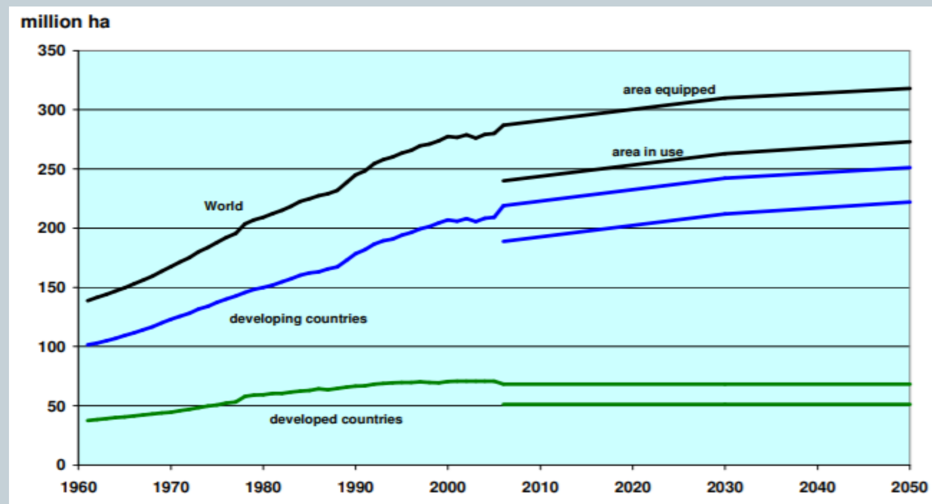
Urban and rural population in the south Mediterranean area

Food security

- In October 2010, the Food and Agriculture Organization of the United Nations (FAO) estimated that 13.6% of the world's population (nearly one billion people, or 1 in 7 people) was malnourished, increasing by 10 million a year and each year of a disease related to hunger before their fifth birthday.
- FAO concluded that global food production must increase by 70% by 2050 to meet the demands of global population growth of more than 30%. About 80% of this increased production must come from existing arable land thanks to higher yields.

Irrigation: intensification de la production, extension des surfaces





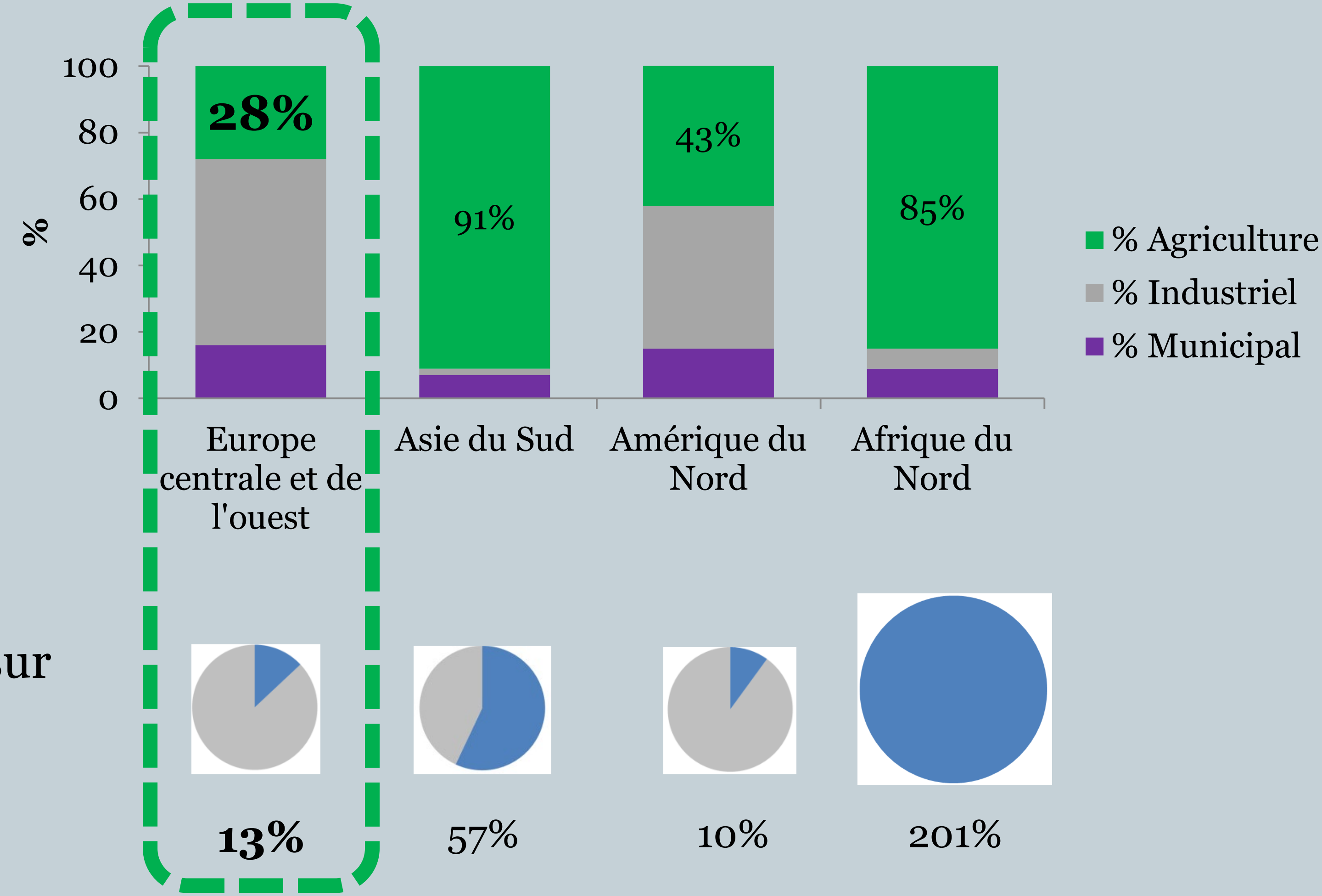
Irrigation ensures better yields *(FAOSTAT)*

Past and future of irrigated areas (*Bruinsma, 2009)*

Agriculture irriguée: une pression très contrastée sur la ressource

Répartition de l'eau mobilisée

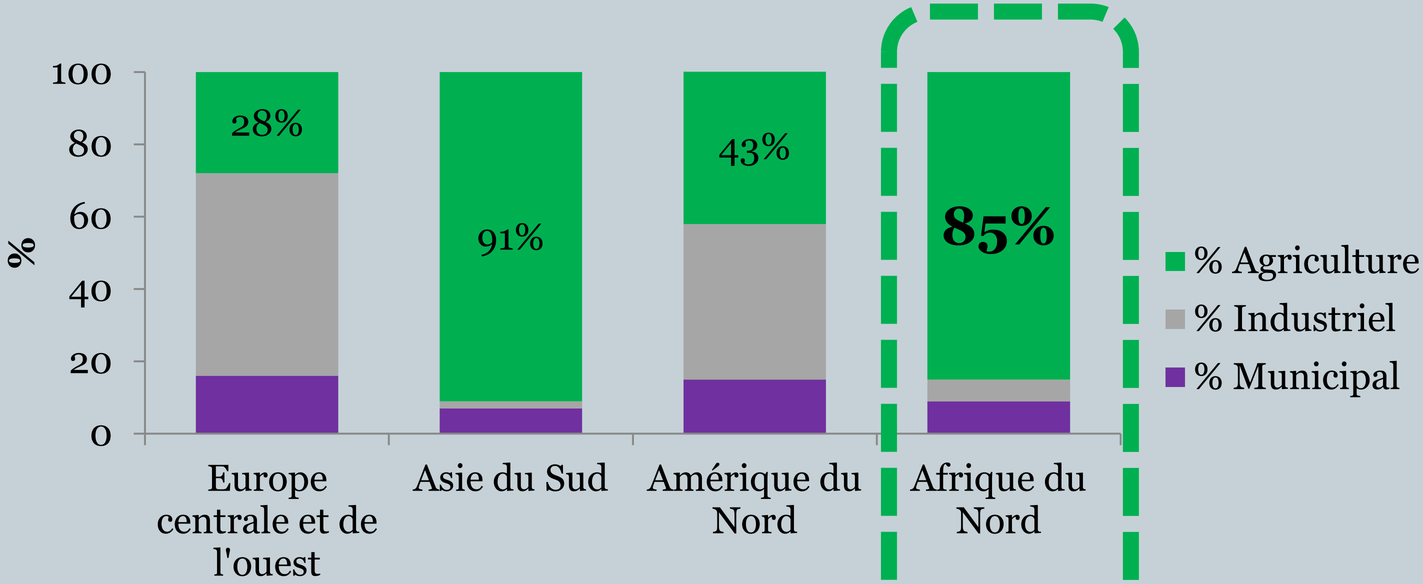
Prélèvement sur ressources renouvelables



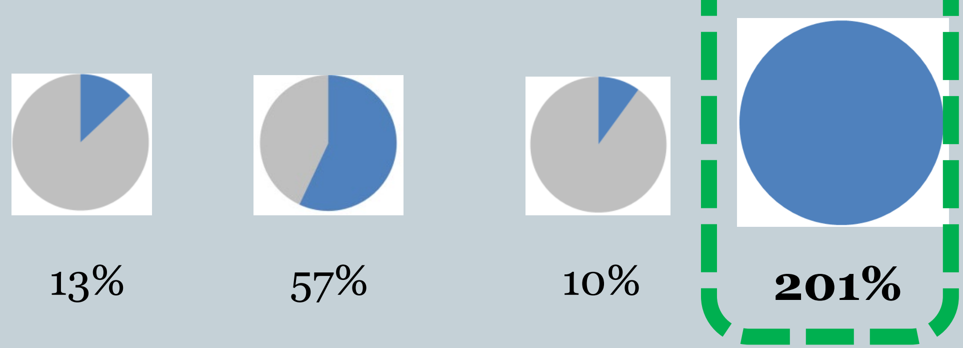
Source des données: FAO 2011

Agriculture irriguée: une pression très contrastée sur la ressource

Répartition de l’eau mobilisée

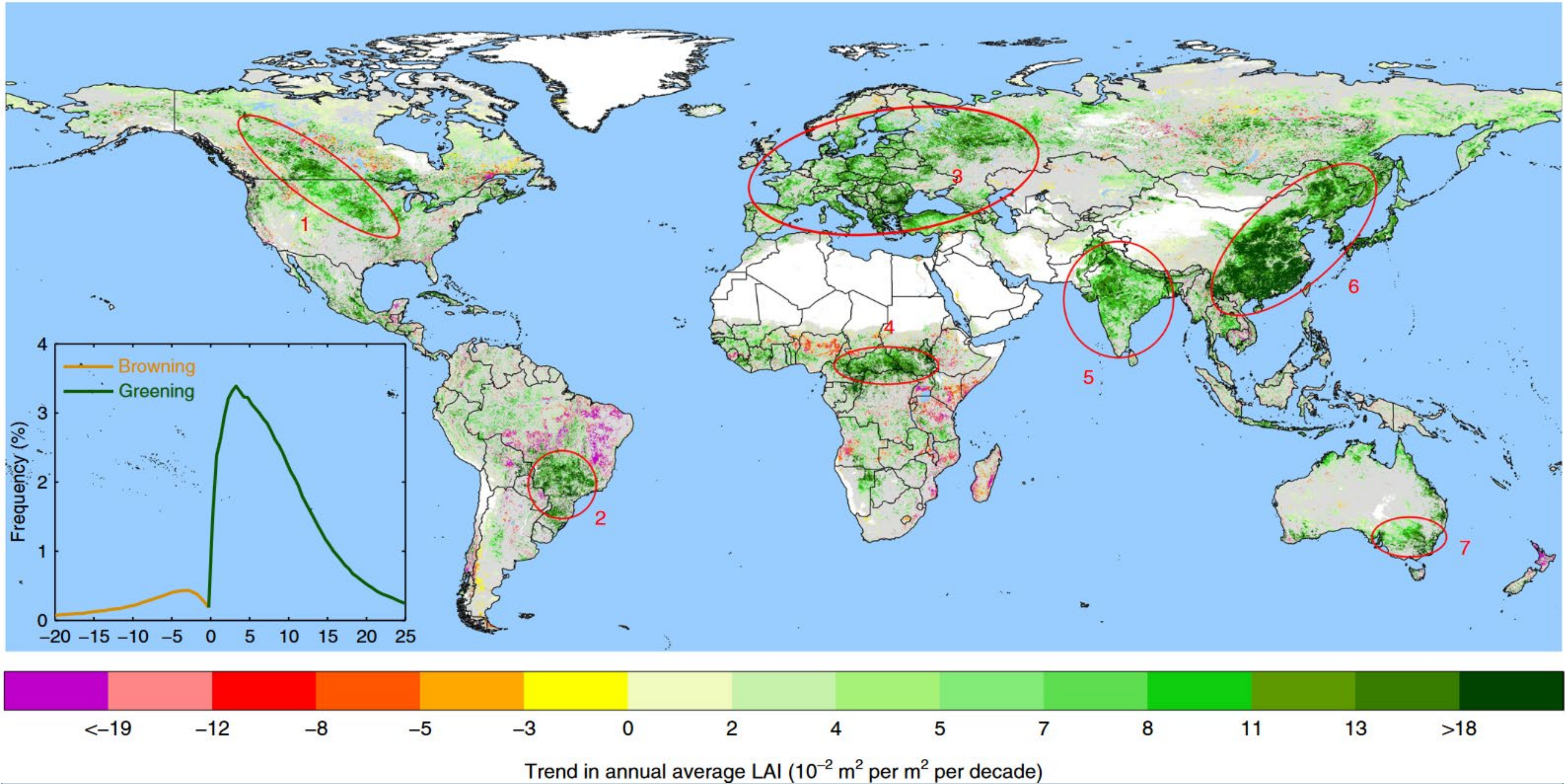


Prélèvement sur ressources renouvelables



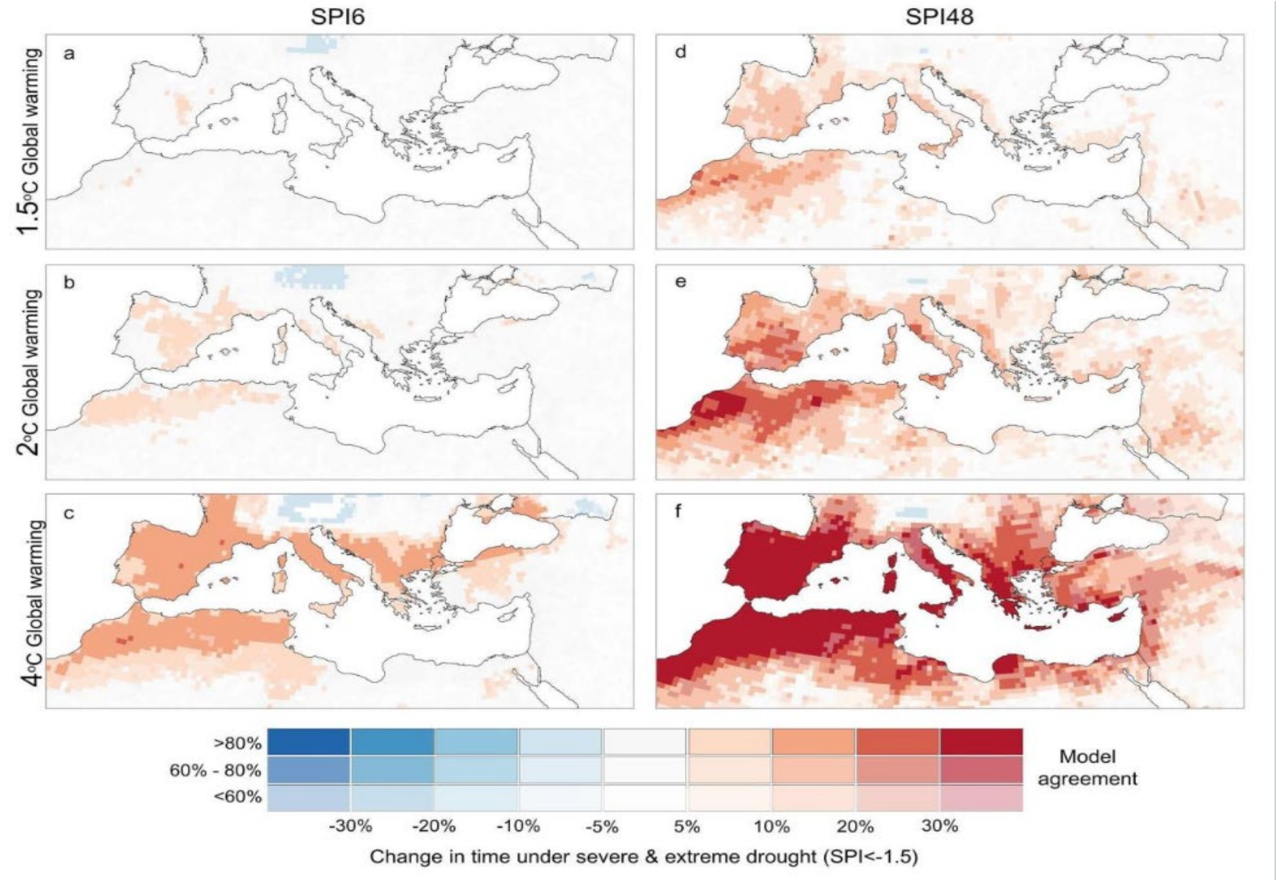
Data Sources: FAO 2011

Consequence: Greening of the world



Chen et al., 2019

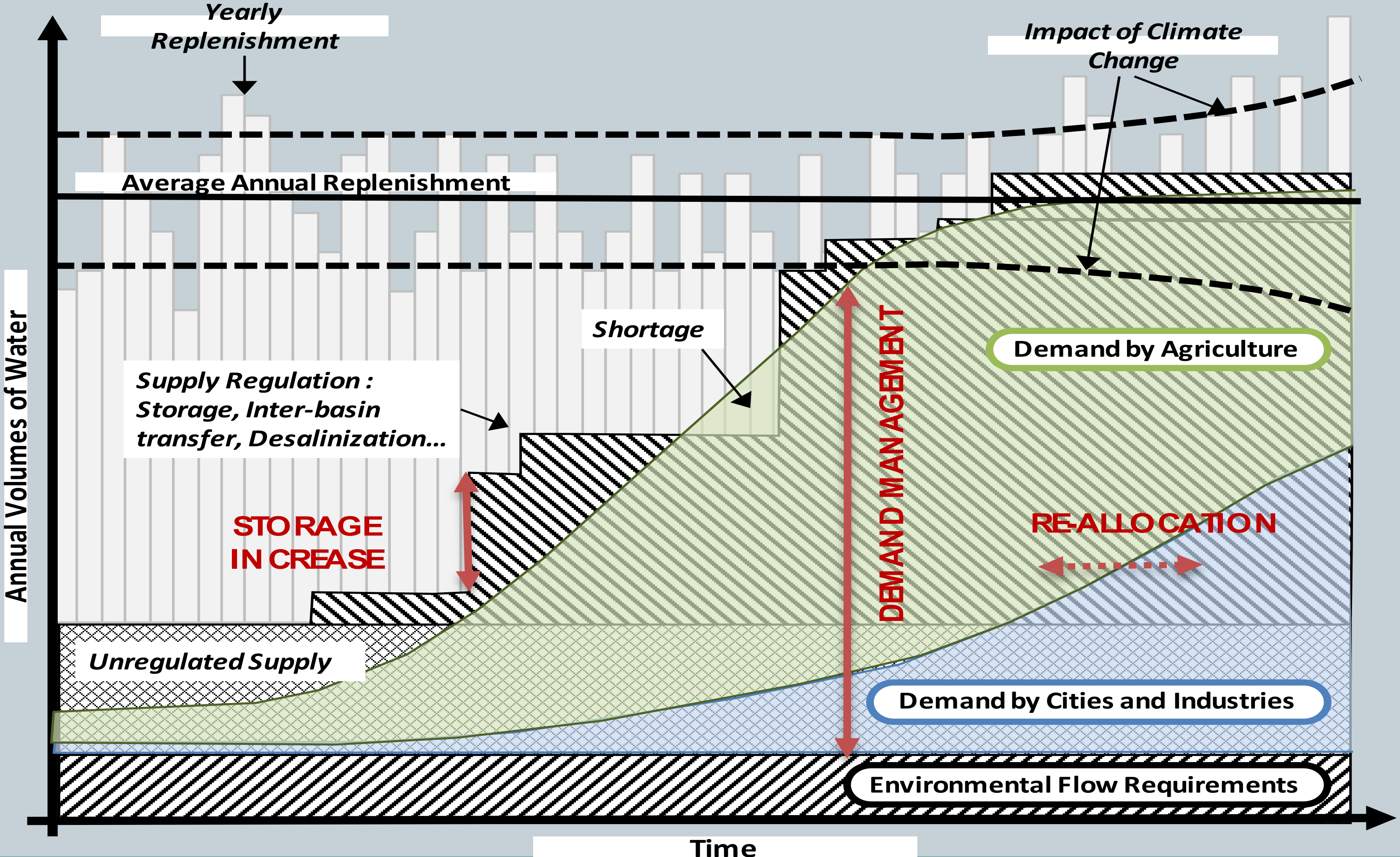
Drought and Climate Change



Mediterranean areas projected to experience increases in time under severe and extreme drought (SPI<-1.5). Changes are shown for short timescale (SPI6 – a, b, c) and long timescale (SPI48 – d, e, f) droughts for specific levels of global warming (1.5 °C, 2 °C and 4 °C above preindustrial levels) relative to the baseline period (1981-2010).
Color saturation denotes the agreement among ensemble members and color hues show the magnitude of change

Tramblay et al., 2020

All and all…



Source: Le Page (2020), modified from FAO, 2012

Drought Management

Protect the people with risk management

- **USA**: During the great droughts of the 1930s (Dust Bowl), the American state set up an aid program for farmers, followed by a federal drought insurance program (Federal Crop Insurance Corporation) to help these farms, which were now more efficient (monoculture) but also more vulnerable to climatic hazards.
- **Australia**: In the 1970s, Australia also classified drought as a natural disaster.
- **France**: Despite the great droughts of 1921, 1949-50, 1976, it was not until the year 2000 that drought was taken into account as a natural disaster, but more for the impacts on buildings than on agriculture.

The need for an assesment of the drought hazard

- The risk management approach (**hazards** vs. **vulnerability**) leads to a better quantification and prediction of these hazards and to reduce the vulnerability of the most exposed regions.
- Like other natural risks (flood risk, seismic risk…) droughts can be characterized in terms of severity, location, duration and timing.

Risks and vulnerability

- **Hazard: probability of occurrence, in a specified area and period, of a potentially damaging natural event (drought)**

Wilhite, 1997

Risques et vulnérabilités

- **Vulnerability: Characteristics of people, activities or the environment that make them vulnerable to the impacts of drought; measuring the ability to anticipate, cope, withstand and recover from the impacts of drought**

Wilhite, 1997

Differences between droughts

- **Intensity**

→ **Degree of precipitation deficit and / or severity of impacts;**

→ **Departure of a normal climatic index;**

→ **related to duration to determine impacts**

Differences between droughts

- **The duration**

→ **Seasonal**

→ **One year**

→ **Many years**

→ **Multiple time scales**

Drought monitoring

- **Why should we monitor drought?**

→ **Determine the current status of specific resources**

→ **Detect changes and long-term trends**

→ **Get knowledge about links and fundamental processes at work**

→ **Enable the development and implementation of early warning indicators**

Drought monitoring

- What is needed to monitor the drought?

→Combination of climate, soil and water data

→Local and regional hedges

→Impact assessments

→Drought indices

Monitoring of drought

- **Importance of drought indices**

→ **Simplify complex inter-relationships and provide a good communication tool for many audiences**

→ **Quantitative assessment of climatic conditions**

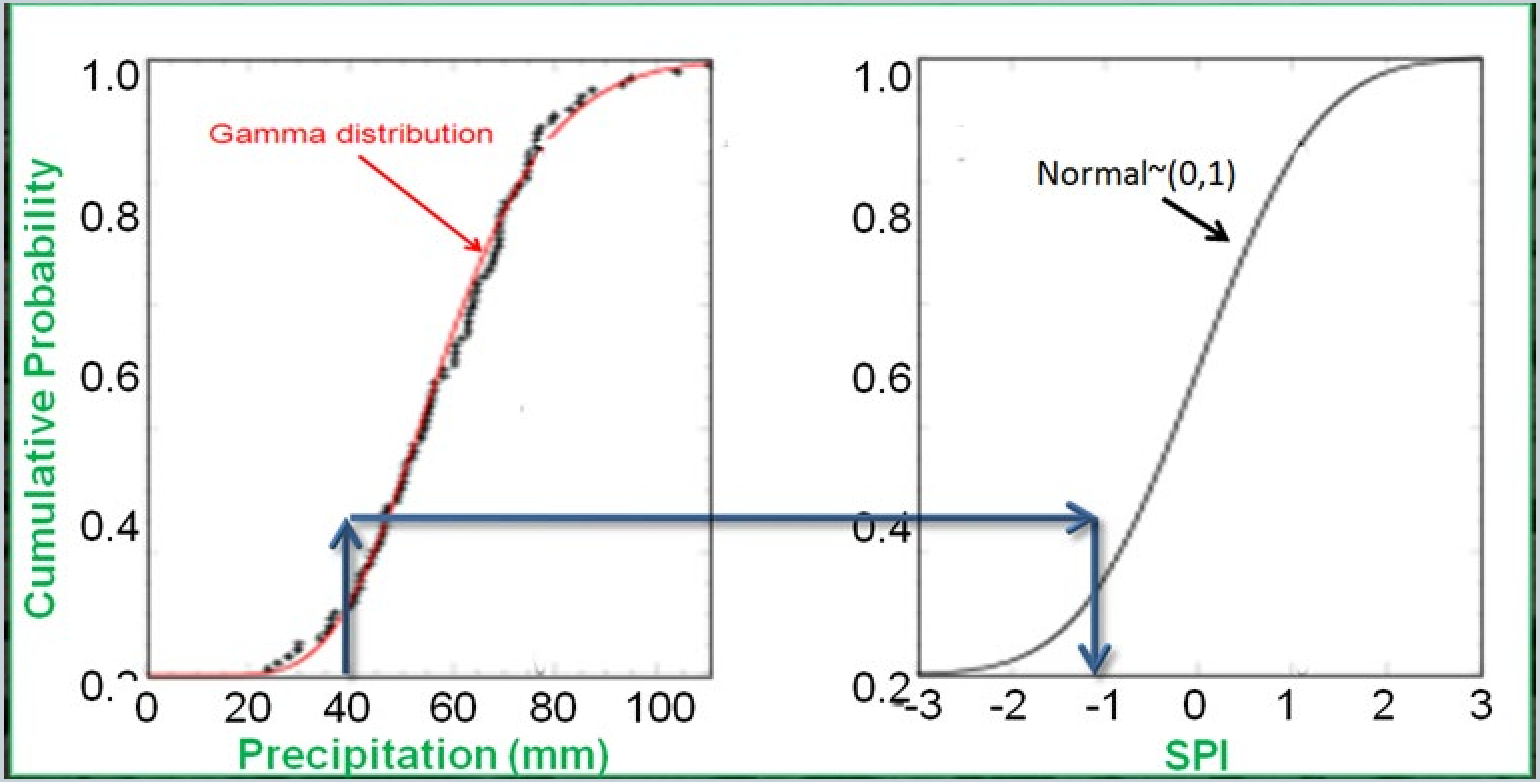
→ **Provide a historical perspective that can be used in planning and design applications**

SPI, (McKee et al., 1993)

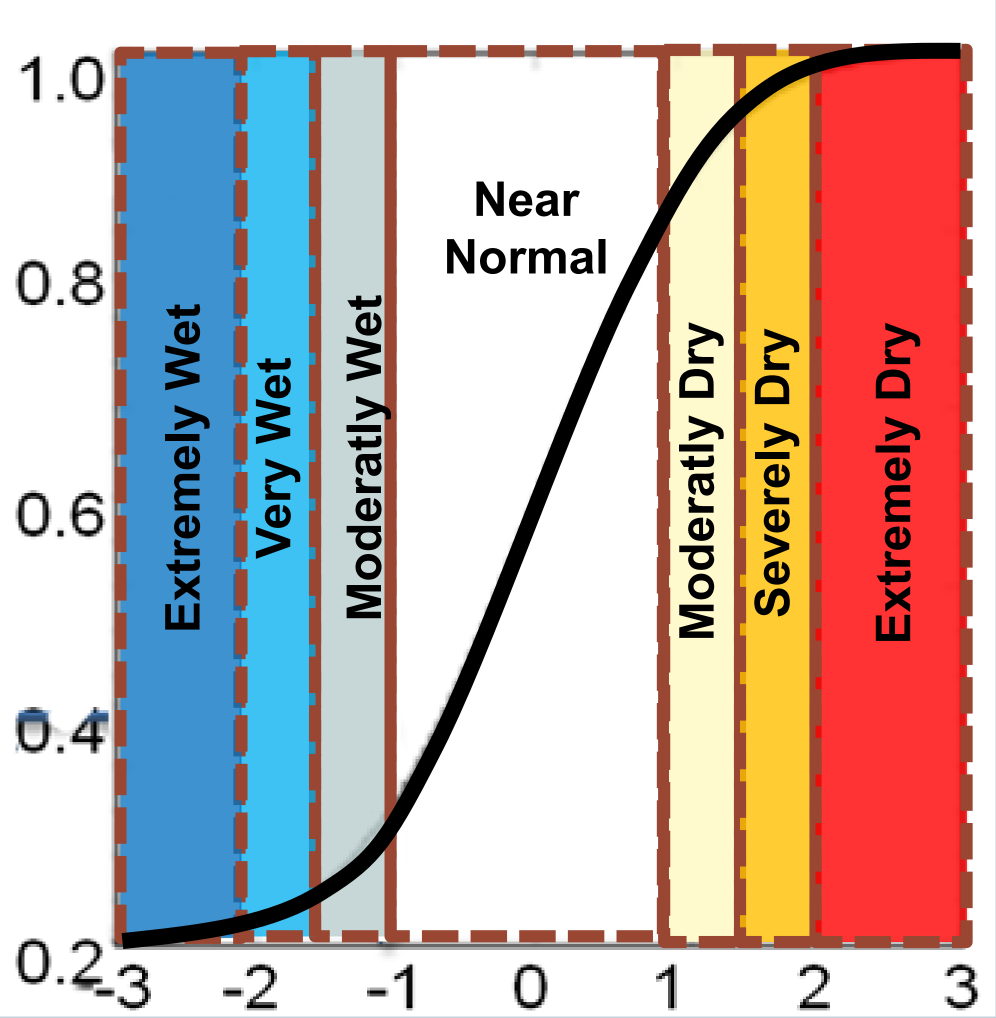
- In the probabilistic Standardized Precipitation Index (SPI, McKee et al., 1993), only rainfall is used.
- SPI provides a simple mechanism to evaluate the severity, location and duratio n of drought
- WMO recommends the use of this index and describes it as "powerful, flexible and simple to calculate".

SPI, Standardized Precipitation Index

Based on the cumulative probability of rainfall amount for any time scale
Fitted to a gamma distribution
Transformed into standard normal (mean=0 and sd=1)



SPI



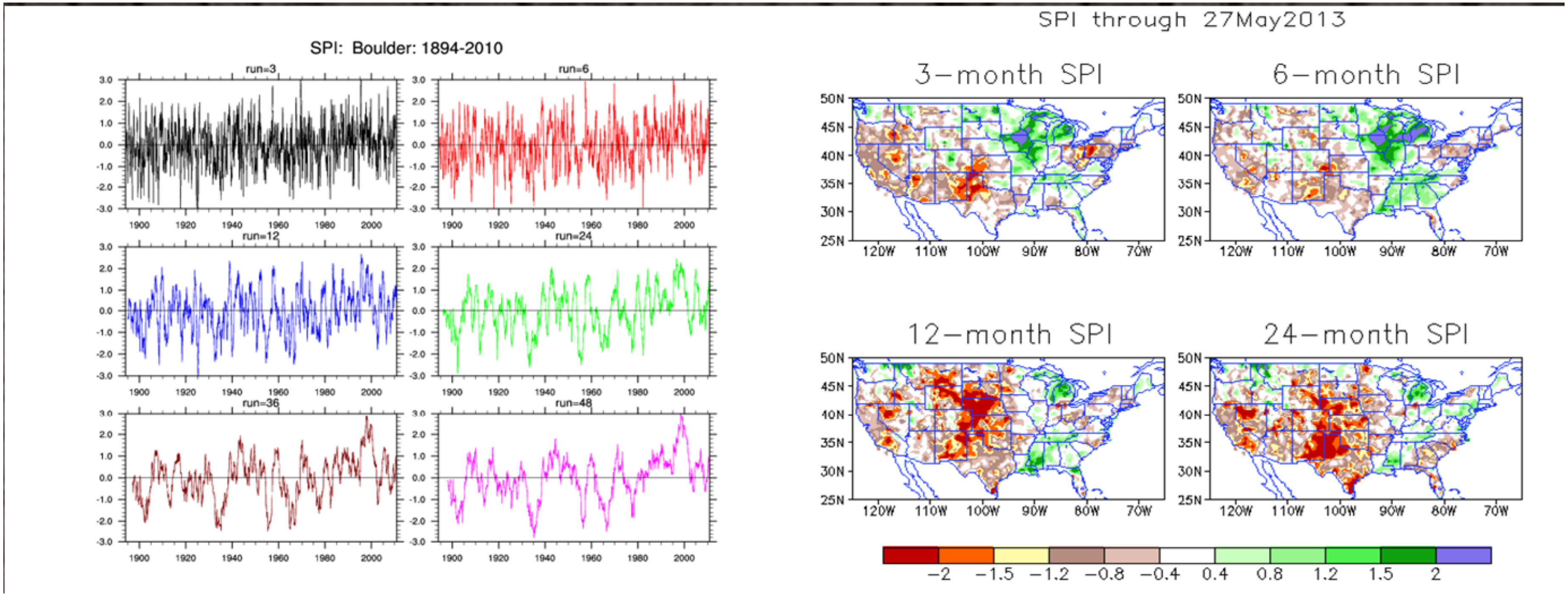
1.0
0.8
0.6
0.4
0.2
-3
-2
-1
0
1
2
3
Extremely Wet
Very Wet
Moderatly Wet
Near Normal
Moderatly Dry
Severely Dry
Extremely Dry

"Using the SPI as the indicator, a **functional and quantitative definition** of drought can be established for each time scale. A drought event for time scale i is defined here as **a period in which the SPI is continuously negative and the SPI reaches a value of -1.0 or less**. The **drought begins when the SPI first falls below zero and ends with the positive value of SPI following a value of -1.0 or less**. Drought intensity is arbitrarily defined for values of the SPI with the following categories:"

SPI Values	Drought Category	Time in Category
0 to -0.99	mild drought	~24%
-1.00 to -1.49	moderate drought	9.2%
1.50 to -1.99	severe drought	4.4%
≤ -2.00	extreme drought	2.3%
		~40%

Source: McKee, Doesken and Kleist 1993

SPI analysis



SPEI (Vicente-Serrano et al., 2010)

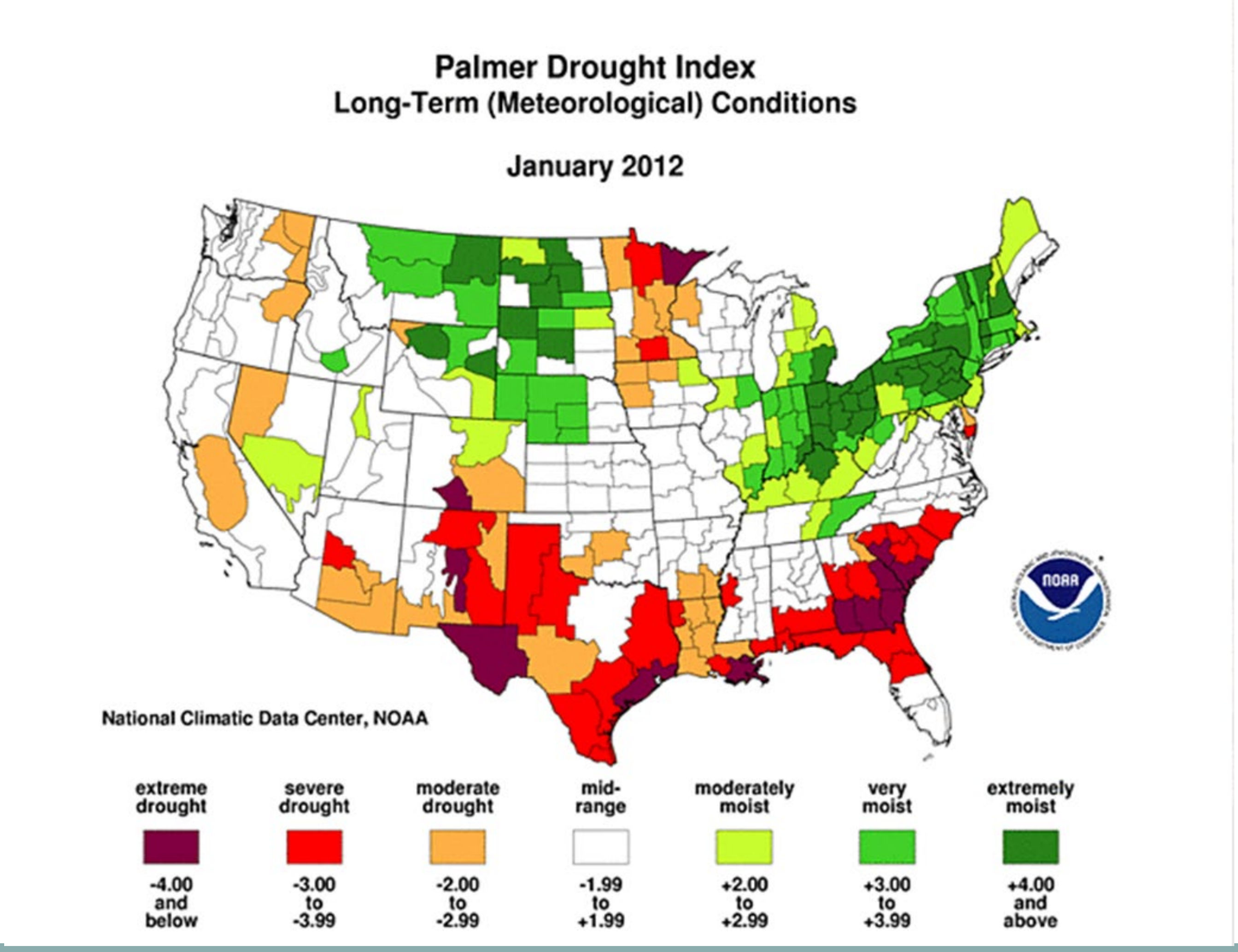
- The Standardized Precipitation Evaporation Index (SPEI) is similar to SPI.
- The main difference is that the P-ETp difference is used instead of precipitation.
- For simplicity, ETp is calculated only through temperature according to the Thornwaite method.
- The general concept of SPEI can also be compared to PDSI, the main difference is that it is a probabilistic approach instead of an arithmetic approach.

Indices based on soil moisture

- Soil moisture-based indicators such as the Standardized Soil Wetness Index (SSWI) are more recent.
- **Andreadis et al, (2005)** used soil moisture data from the VIC model over the United States.
- **Vidal et al, (2010)** used ISBA soil moisture data over France. Vidal shows that the soil moisture index is very complementary to meteorological drought indices.
- During the 1976 drought in France, the severe rainfall deficit could already be observed as early as December 1975, whereas the severe soil drought did not become widespread until May 1976. Conversely, during the drought of 2003, the meteorological and agronomic drought were very synchronous.

PDSI (Palmer, 1965)

- The Palmer Drought Severity Index (PDSI) was the first index (1965) to provide a method for quantifying and comparing drought between different regions.
- The PDSI was originally developed with the intent to measure the cumulative departure in surface water balance. It incorporates antecedent and current moisture supply (precipitation, P) and demand (potential evapotranspiration, PE) into a hydrological accounting system, which includes a 2-layer bucket-type model for soil moisture calculations.
- The PDSI is a standardized measure, ranging from about -10 (dry) to +10 (wet) with values below -3 representing severe to extreme drought. ntent des sécheresses sévères à extrêmes. (https://climatedataguide.ucar.edu/climate-data/palmer-drought-severity-index-pdsi)



Palmer Drought Index
Long-Term (Meteorological) Conditions
January 2012
National Climatic Data Center, NOAA
NOAA
extreme drought
severe drought
moderate drought
mid-range
moderately moist
very moist
extremely moist
-4.00 and below
-3.00 to -3.99
-2.00 to -2.99
-1.99 to +1.99
+2.00 to +2.99
+3.00 to +3.99
+4.00 and above

Deciles

Groups monthly precipitation occurrences in to deciles
Easy to calculate and requires less data and fewer assumptions than PDSI

Decile Classifications	
deciles 1-2: lowest 20%	much below normal
deciles 3-4: next lowest 20%	below normal
deciles 5-6: middle 20%	near normal
deciles 7-8: next highest 20%	above normal
deciles 9-10: highest 20%	much above normal

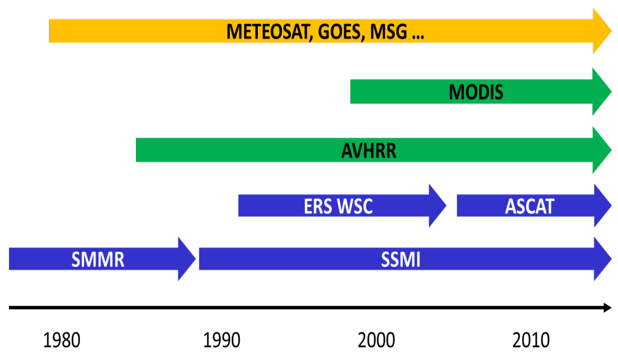
Drought monitoring based on remote sensing observations

Drought type and satellite observations

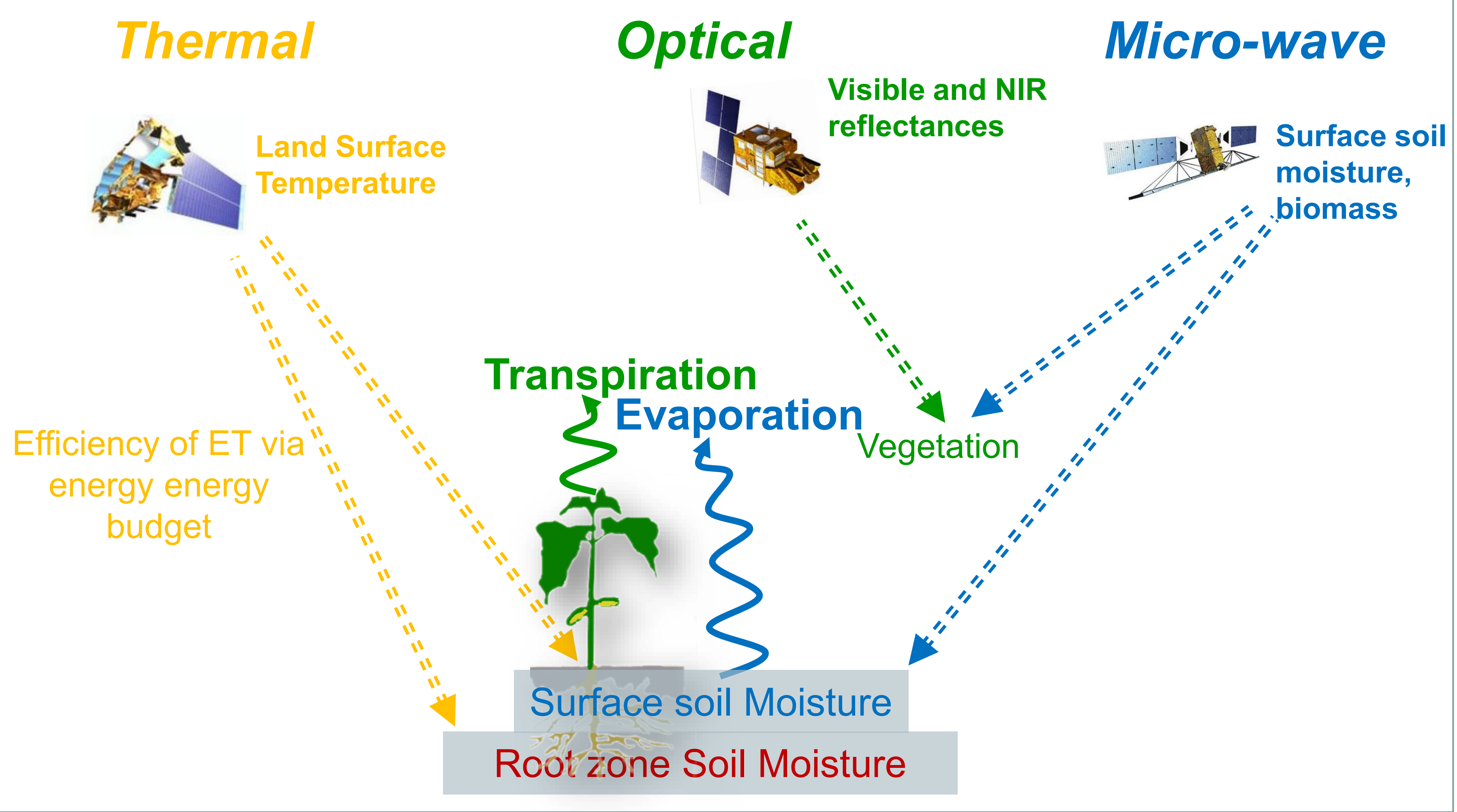
- **Météorologiques**: l'intensité, la fréquence et la durée de la période sèche.
- **Agronomiques**: les cultures sont habituellement les premières touchées par la sécheresse.
- **Hydrologiques**: les stocks d'eau (aquifères, barrages, manteau neigeux …) sont touchés par un déficit de recharge et une augmentation de la demande en eau.

- **Précipitations**: TRMM, GPM
- **Humidité du sol en surface**: ASCAT, SMOS, SMAP …
- **Développement et rendement de la végétation**: MODIS, SPOT, Sentinel …
- **Stress de la végétation**: Landsat, MODIS …
- **Niveau de l'eau dans les lacs et les rivières**: JASON, SWOT
- **Stockage des eaux souterraines**: GRACE
- **Couverture neigeuse**: MODIS, Sentinel …

- Echelle globale
- Plusieurs décennies

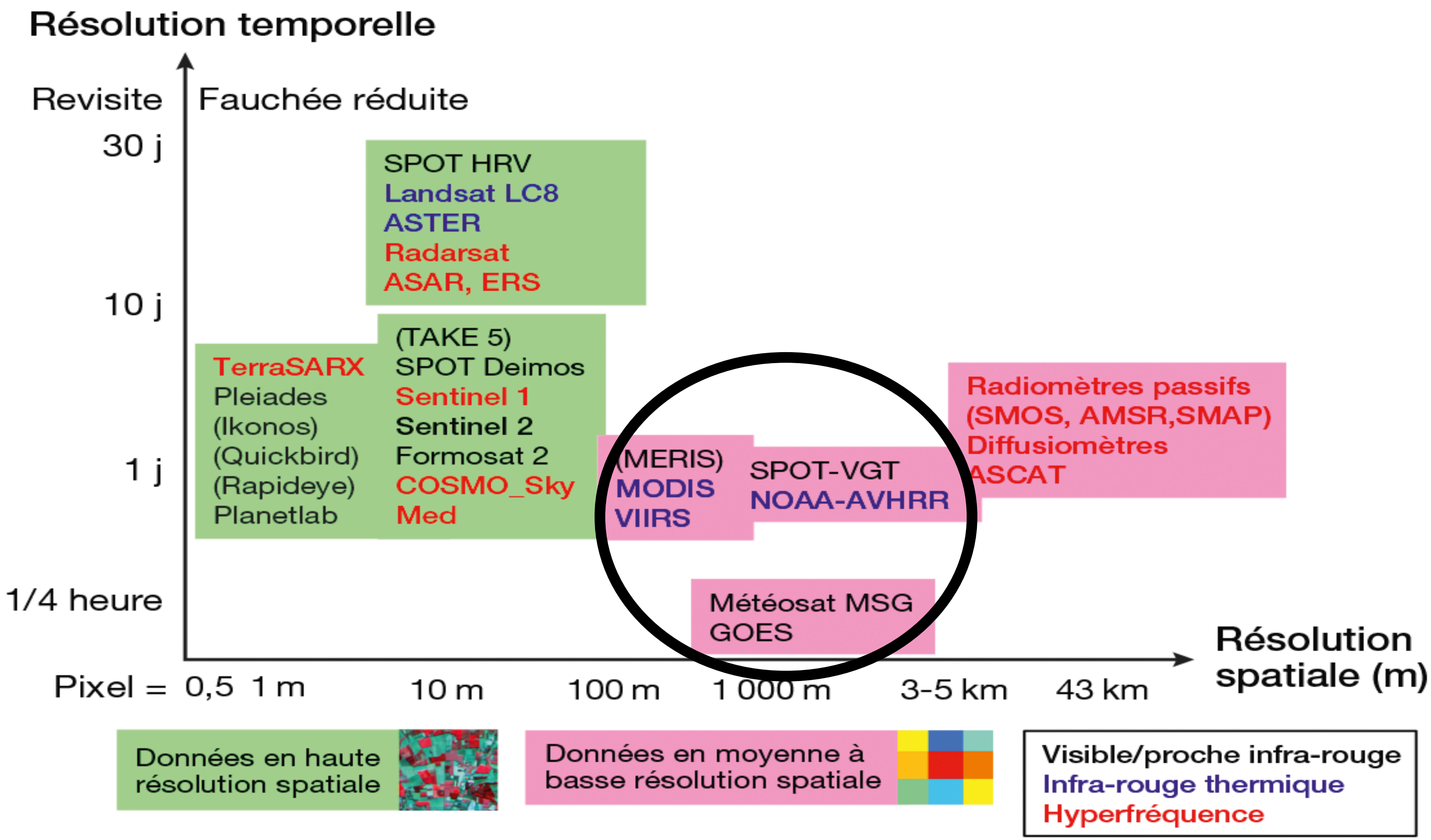


Satellite observations and vegetation water status



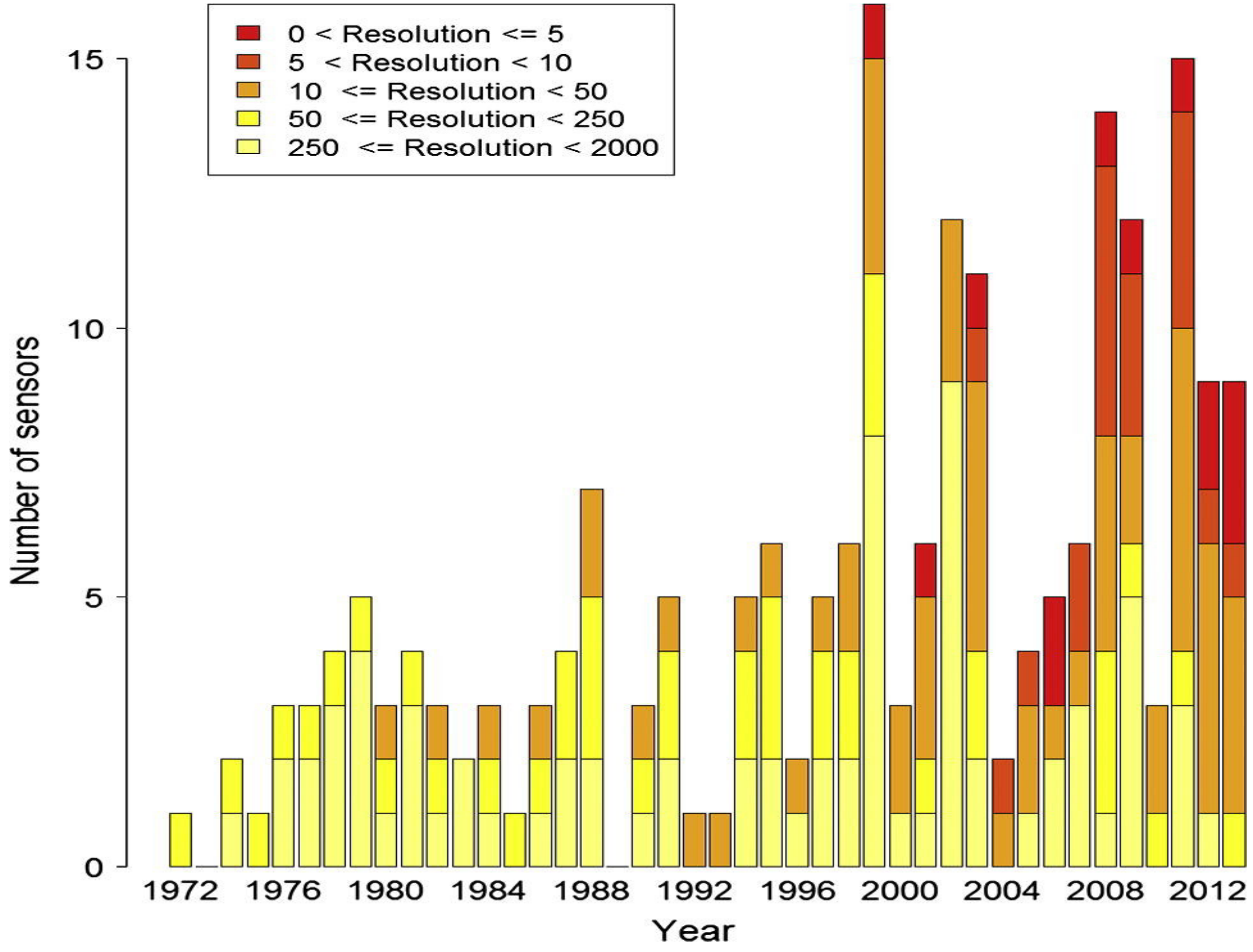
Source: L. Jarlan, CESBIO

Satellite resolutions



Source: Courault et al. 2020

The problem of temporal depth



Source: Belward et al. 2015

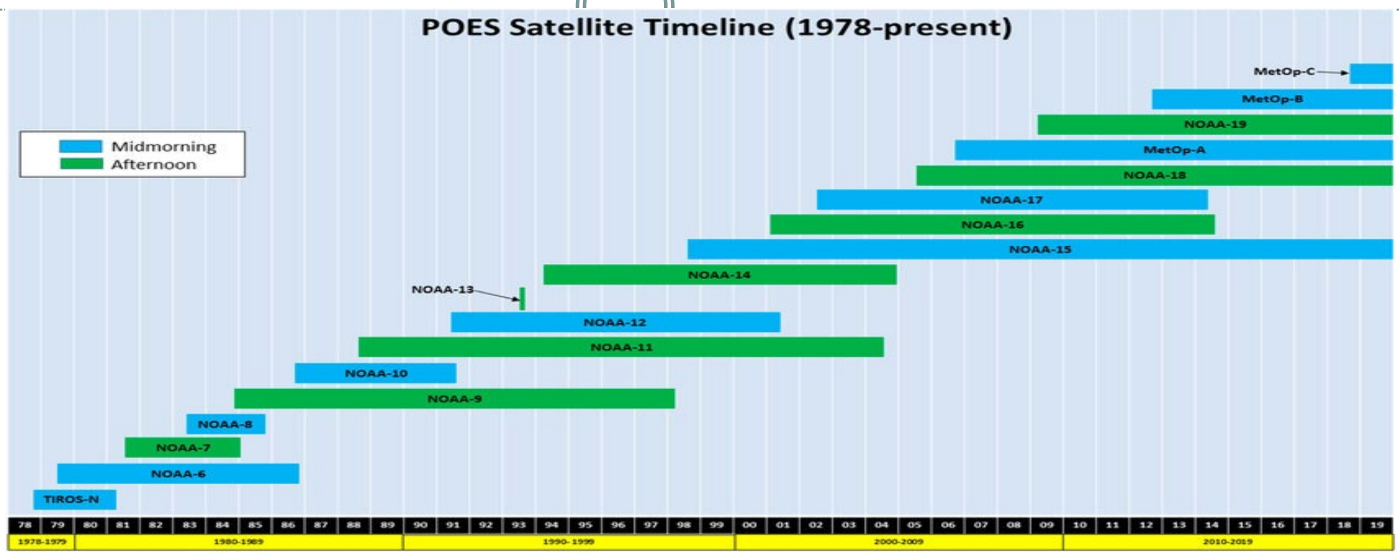
Meteorological satellites NOAA AVHRR

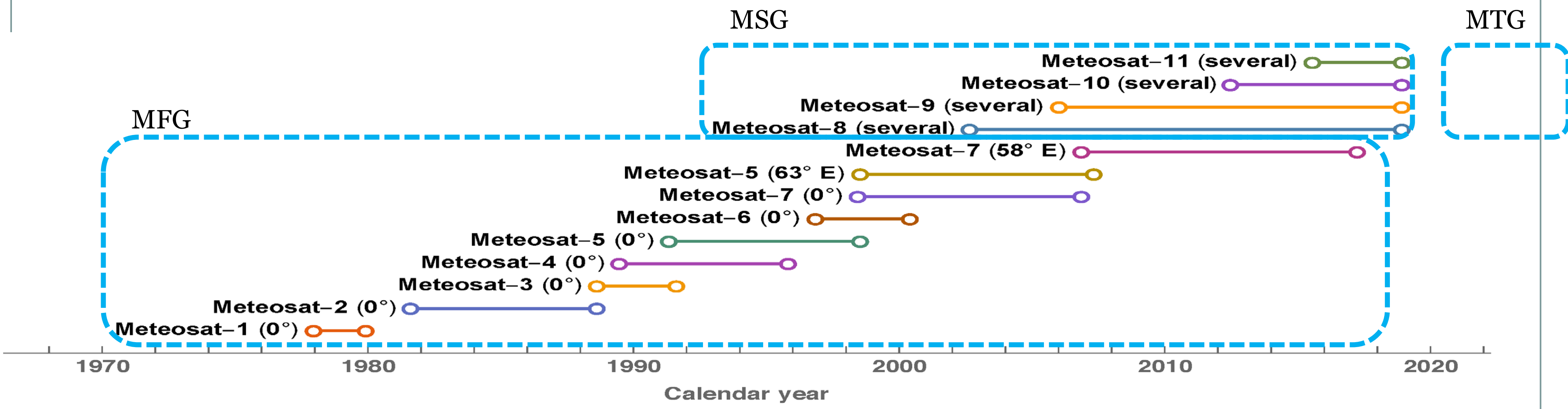
NOAA AVHRR Bands	Wavelength (µm)	Resolution at Nadir	Typical Use
1	0.58 - 0.68	1.09 km	Daytime cloud and surface mapping
2	0.725 - 1.00	1.09 km	Land-water boundaries
3A	1.58 - 1.64	1.09 km	Snow and ice detection
3B	3.55 - 3.93	1.09 km	Night cloud mapping, sea surface temperature
4	10.30 - 11.30	1.09 km	Night cloud mapping, sea surface temperature
5	11.50 - 12.50	1.09 km	Sea surface temperature

Meteorological satellites
Meteosat

	Meteosat 1st Generation			Meteosat 2nd Generation			Meteosat 3rd Generation		
Core channels	Central wavelength micron	Width (FWHM) micron	Spatial Sampling (km)	Central wavelength micron	Width (FWHM) micron	Spatial Sampling (km)	Central wavelength micron	Width (FWHM) micron	Spatial Sampling (km)
VIS 0.4							0.444	0.06	1.0
VIS 0.5							0.510	0.05	1.0
VIS 0.6	0.7	0.35	2.5	0.635	0.08	3.0	0.640	0.08	0.5
VIS 0.8				0.81	0.07	3.0	0.865	0.07	1.0
VIS 0.9							0.914	0.06	1.0
NIR 1.3							1.380	0.03	1.0
NIR 1.6				1.64	0.14	3.0	1.610	0.06	1.0
NIR 2.2							2.250	0.05	0.5
IR 3.8				3.9	0.44	3.0	3.800	0.40	1.0
IR.6,3	6.1	1.3	5.0	6.2	1.0	3.0	6.300	1.00	2.0
IR 7.3				7.35	0.5	3.0	7.350	0.50	2.0
IR 8.7				8.7	0.4	3.0	8.700	0.40	2.0
IR 9.7				9.66	0.3	3.0	9.660	0.30	2.0
IR 10.5	11.5	1.9	5.0	10.8	1.0	3.0	10.500	0.7	1.0
IR 12.3				12.0	1.0	3.0	12.300	0.50	2.0
IR13.3				13.4	1.0	3.0	13.300	0.60	2.0
Repeat cycle	30 min			15 min			10 min		

Meteorological satellites timeline





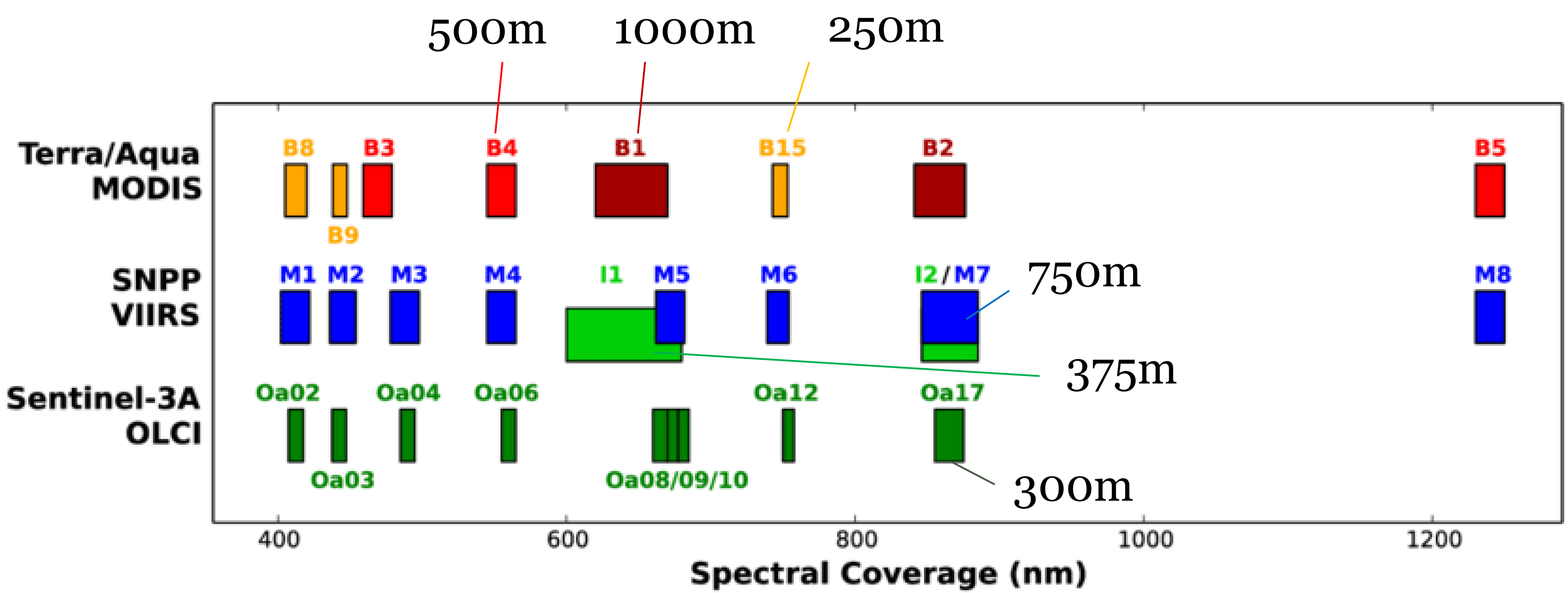
Medium Resolution

- Daily observation
- ~300 m of spatial resolution

- SPOT VEGETATION: 1998-2014
- ENVISAT MERIS : 2002-2012
- PROBA-V: 2013-2021
- Sentinel-3 OLCI: 2016-today

- MODIS TERRA & AQUA: 2000-today
- SUOMI NPP VIIRS: 2013-today

Better resolutions and narrower bandwidth for modern instruments

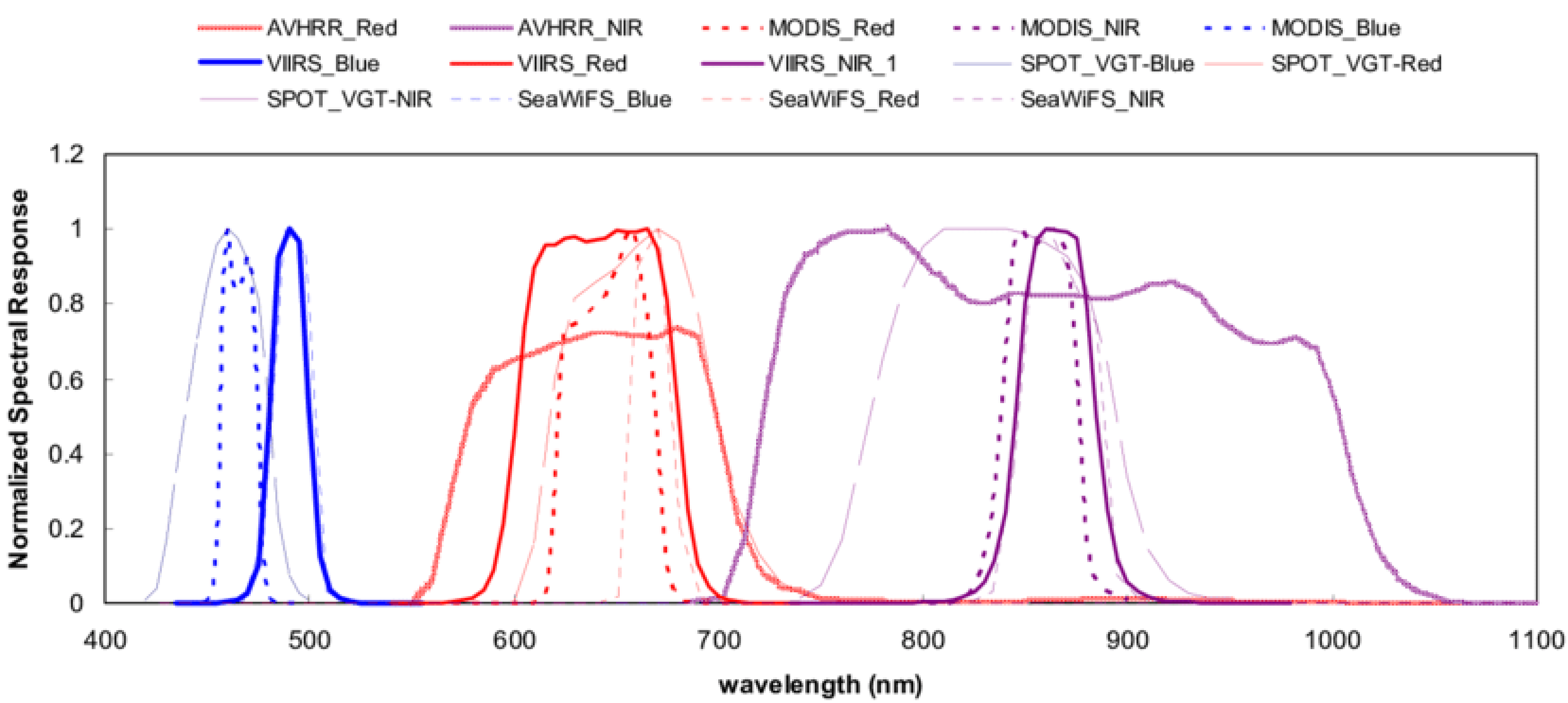


MODIS

Band	Wavelength (µm)	Resolution (m)	Primary Use
1	620–670	250	Land/Cloud/Aerosols Boundaries
2	841–876	250	
3	459–479	500	Land/Cloud/Aerosols Properties
4	545–565	500	
5	1230–1250	500	
6	1628–1652	500	
7	2105–2155	500	
8	405–420	1000	Ocean Color/ Phytoplankton/ Biogeochemistry
9	438–448	1000	
10	483–493	1000	
11	526–536	1000	
12	546–556	1000	
13	662–672	1000	
14	673–683	1000	
15	743–753	1000	
16	862–877	1000	
17	890–920	1000	Atmospheric Water Vapor
18	931–941	1000	
19	915–965	1000	

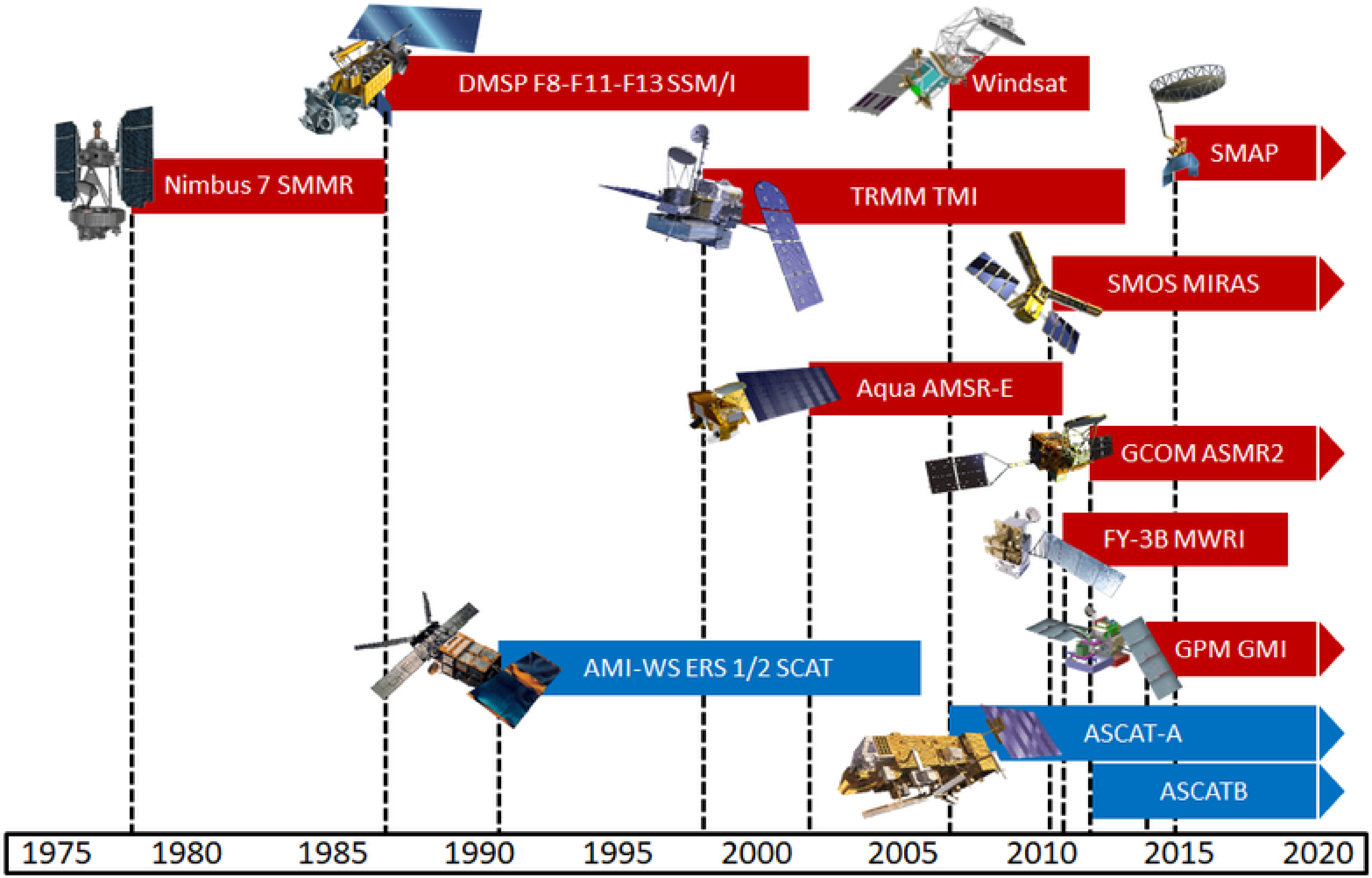
Band	Wavelength (µm)	Resolution (m)	Primary Use
20	3.660–3.840	1000	Surface/Cloud Temperature
21	3.929–3.989	1000	
22	3.929–3.989	1000	
23	4.020–4.080	1000	
24	4.433–4.498	1000	Atmospheric Temperature
25	4.482–4.549	1000	
26	1.360–1.390	1000	Cirrus Clouds Water Vapor
27	6.535–6.895	1000	
28	7.175–7.475	1000	
29	8.400–8.700	1000	Cloud Properties
30	9.580–9.880	1000	Ozone
31	10.780–11.280	1000	Surface/Cloud Temperature
32	11.770–12.270	1000	
33	13.185–13.485	1000	Cloud Top Altitude
34	13.485–13.785	1000	
35	13.785–14.085	1000	
36	14.085–14.385	1000	

Inter-calibration for long term studies



Source: Datla et al., 2016

Merging of satellite observations
The example of the ESA CCI soil moisture project



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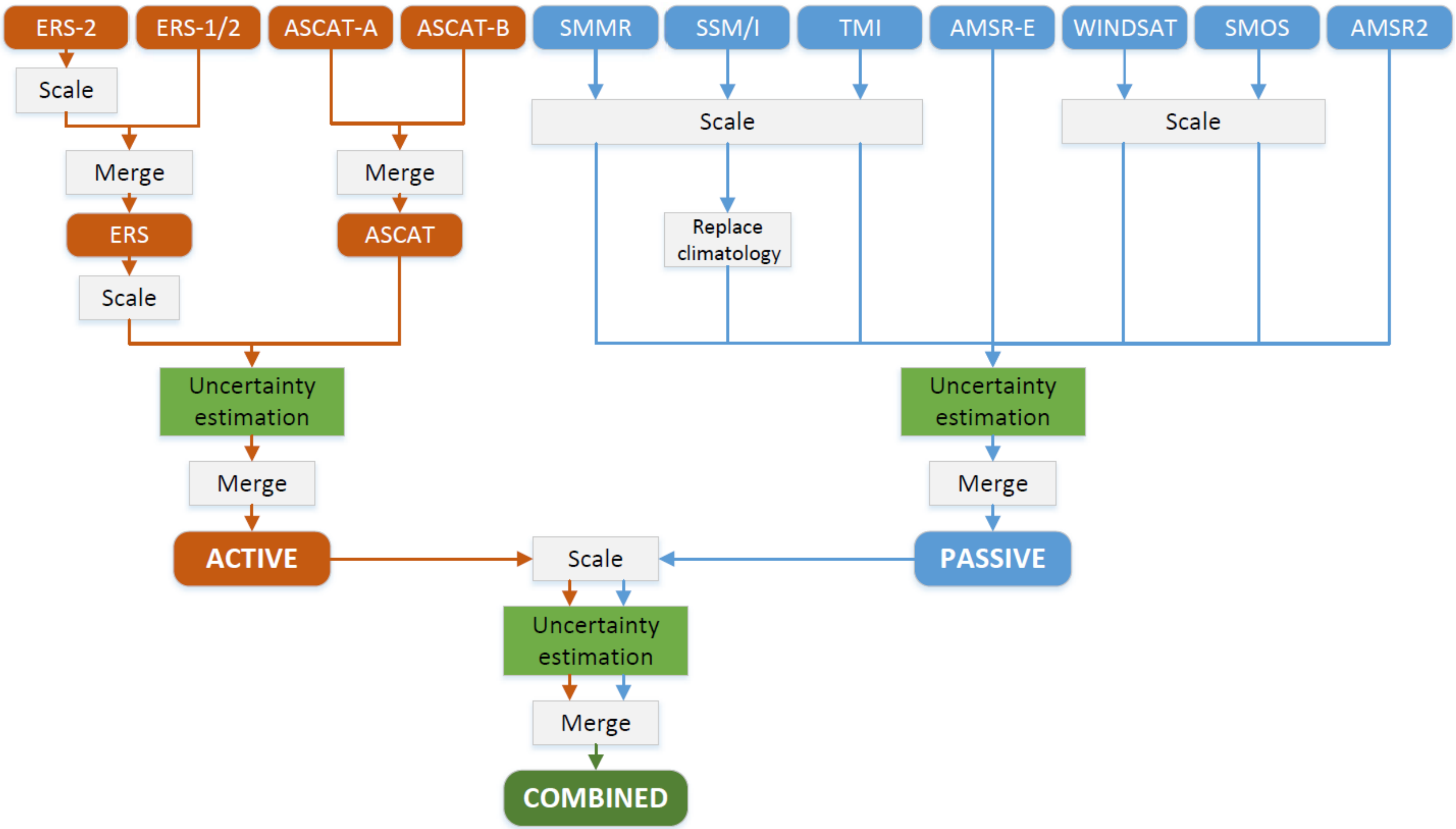
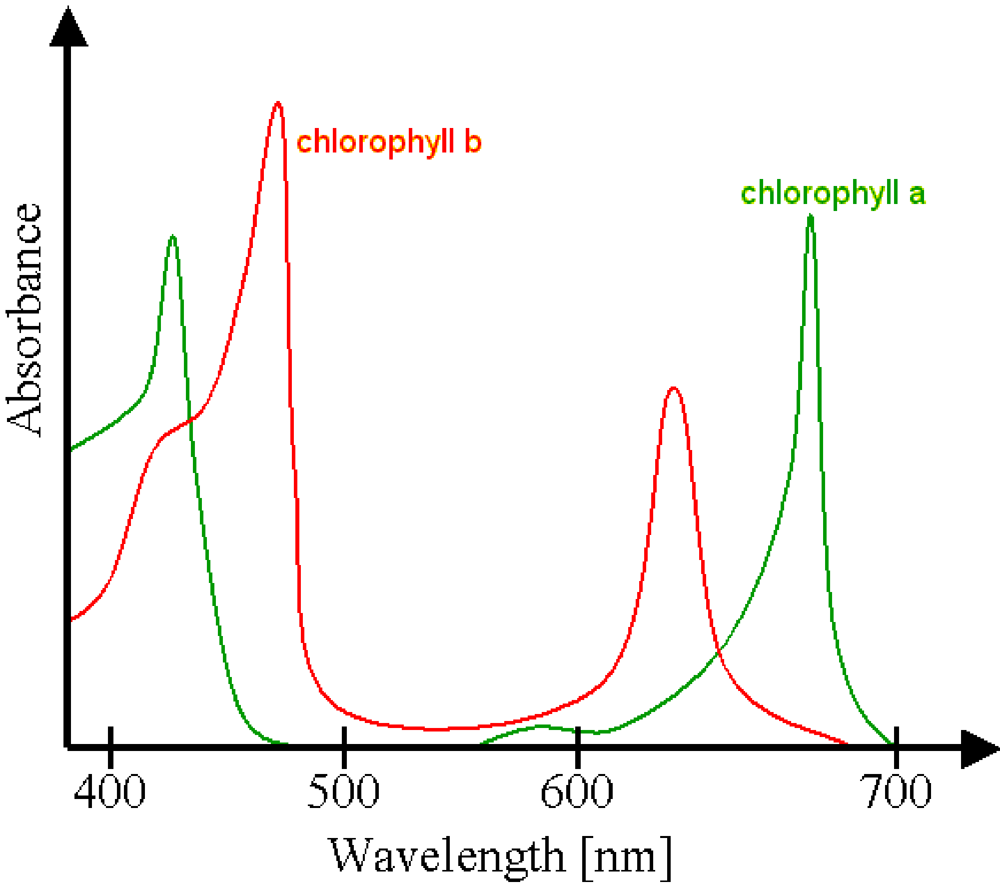
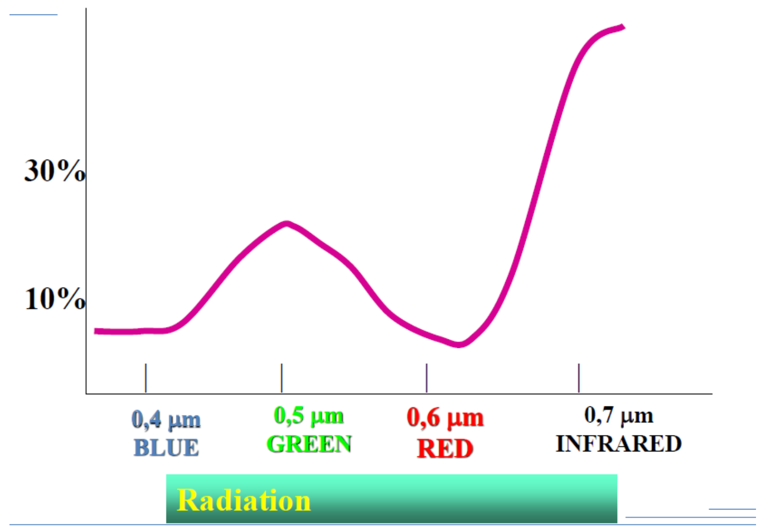


0,40 µm : purple
0,45 µm : blue
0,50 µm : green
0,55 µm : yellow
0,60 µm : orange
0,65 µm : red





NDVI: Normalized Vegetation Index

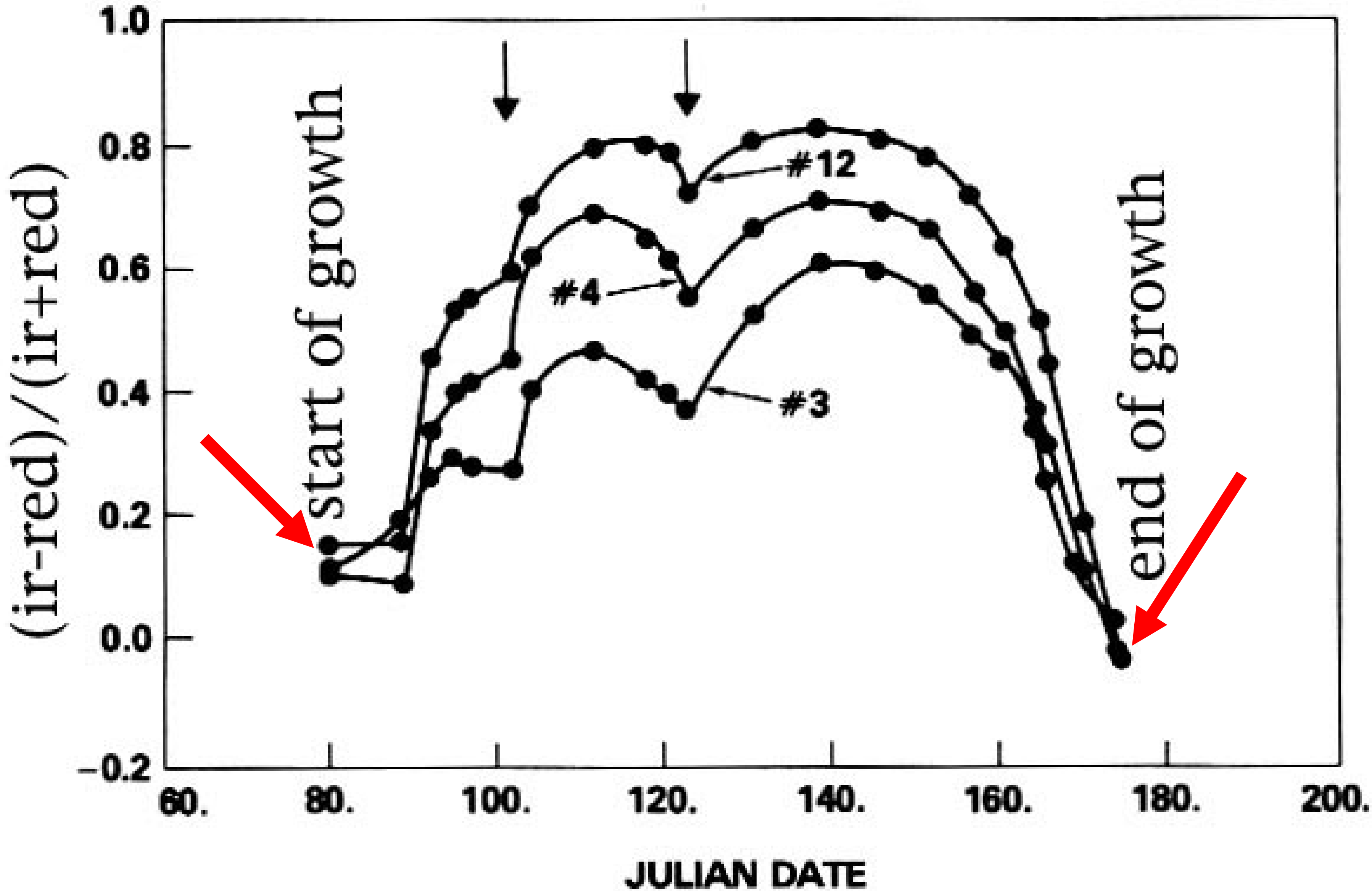
$$NDVI = \frac{NIR - R}{NIR + R}$$

R: red band

NIR: Near infrared band

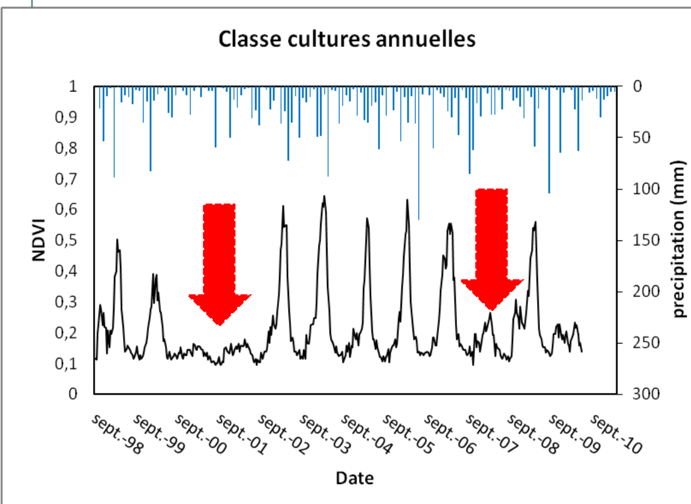
NDVI: Normalized Vegetation Index

Beltsville USA winter wheat biomass



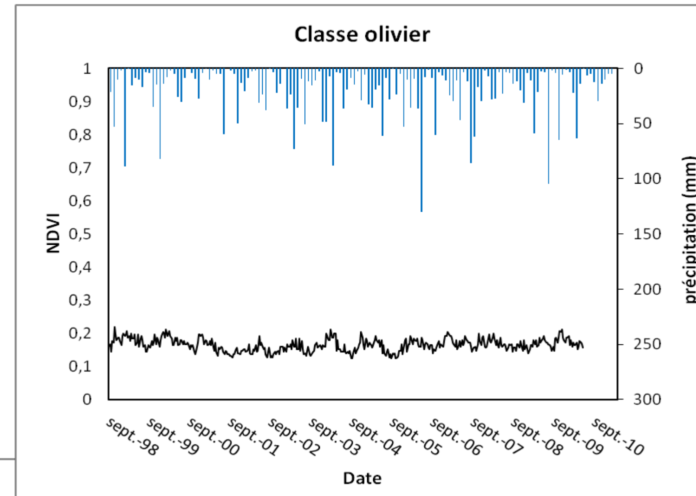
Vegetation dynamic monitoring

- **Available long time series** (VEGETATION → 1998; AVHRR → 1981)

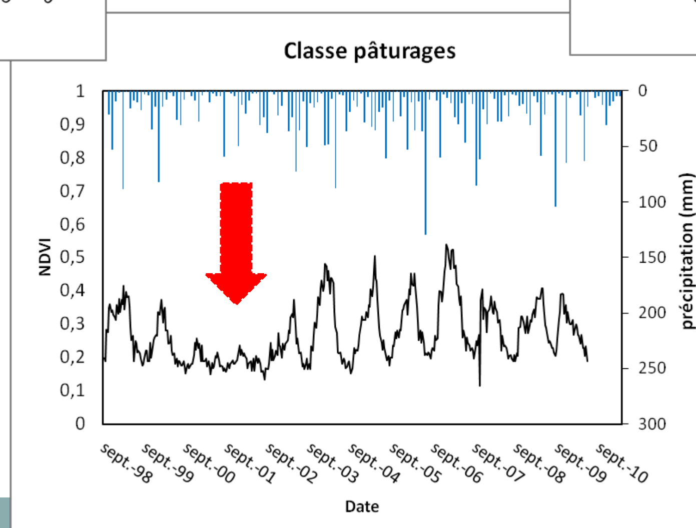


Annual cultures

Drought periods



Olive groves



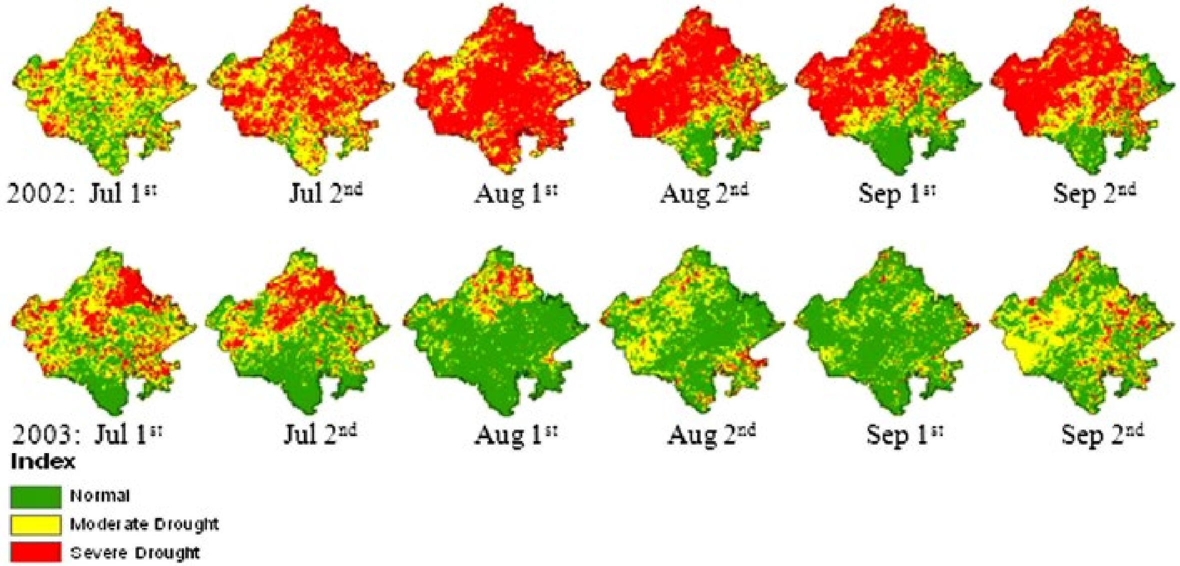
Pastures

VCI: Vegetation condition index

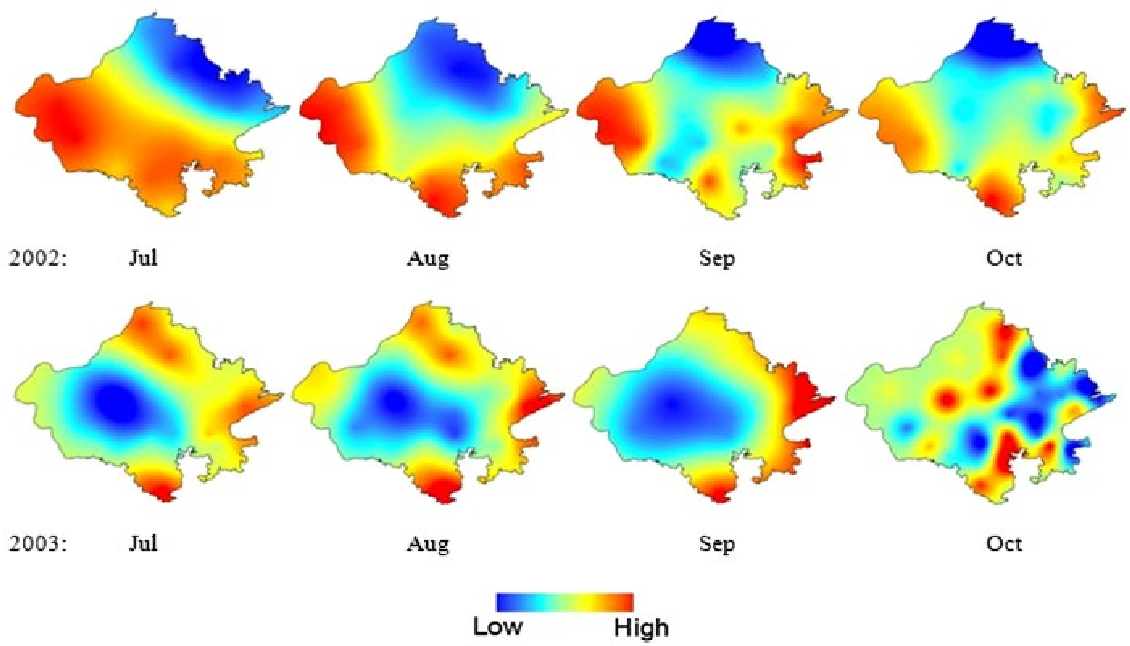
$$VCI = \frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}} \times 100$$

NDVI: NDVI at one date
$NDVI_{min}$: minimum value of NDVI at the same period
$NDVI_{max}$: maximum value of NDVI at the same period

VCI


2002: Jul 1st
Jul 2nd
Aug 1st
Aug 2nd
Sep 1st
Sep 2nd
2003: Jul 1st
Jul 2nd
Aug 1st
Aug 2nd
Sep 1st
Sep 2nd
Index
Normal
Moderate Drought
Severe Drought

SPI


2002: Jul
Aug
Sep
Oct
2003: Jul
Aug
Sep
Oct
Low
High

VAI: Vegetation Anomaly Index

$$VAI = \frac{NDVI - NDVI_{mean}}{\sigma}$$

NDVI: NDVI at one date

$NDVI_{mean}$: meanof NDVI for a selected period

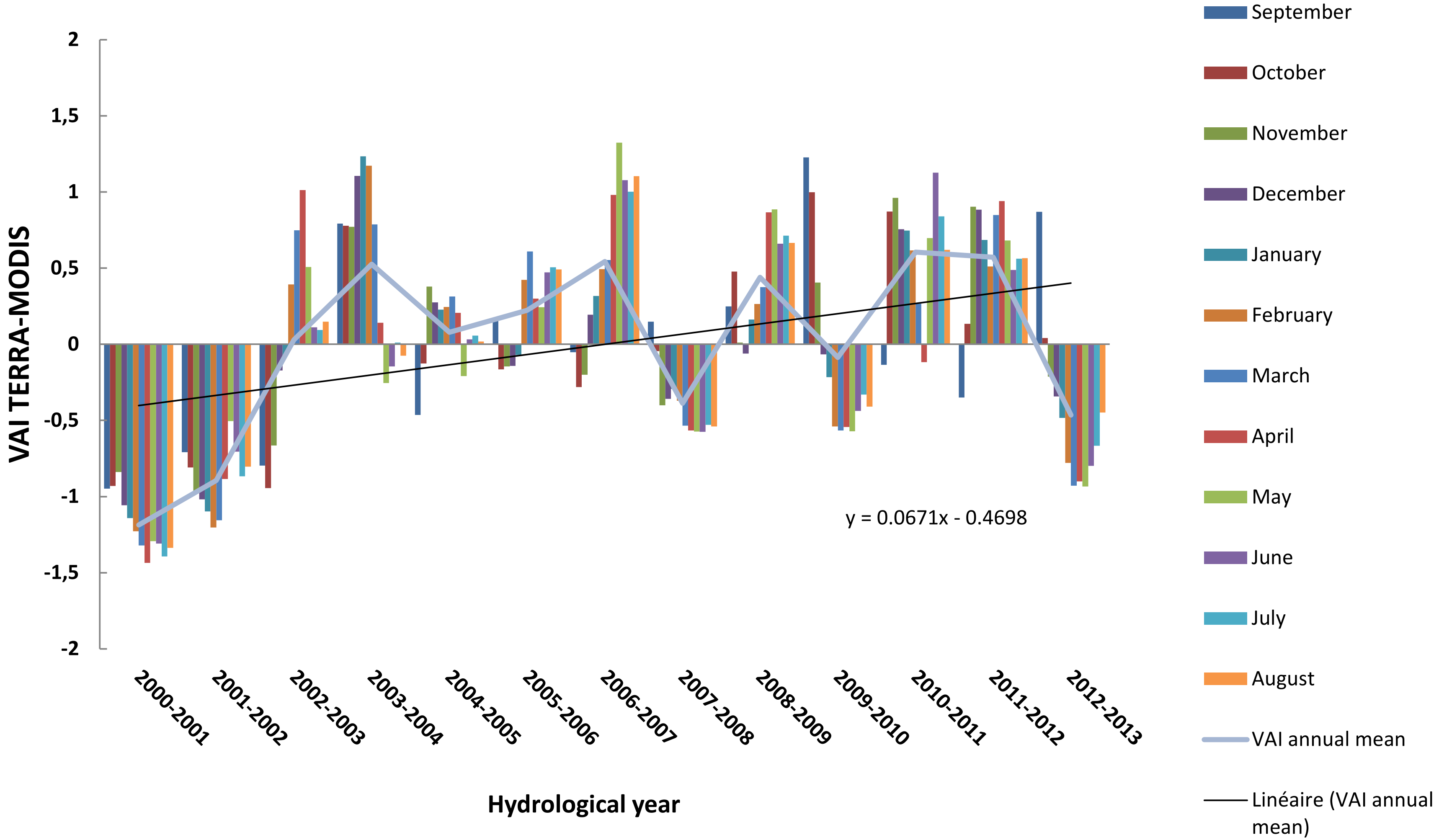
σ: standard deviation of NDVI

Vegetation Anomaly Index

$$VAI_i = \frac{NDVI_i - (NDVI_i)_{mean}}{\sigma_i}$$ **Vegetation Anomaly Index**

VAI>0 Absence of stress

VAI<0 presence of stress



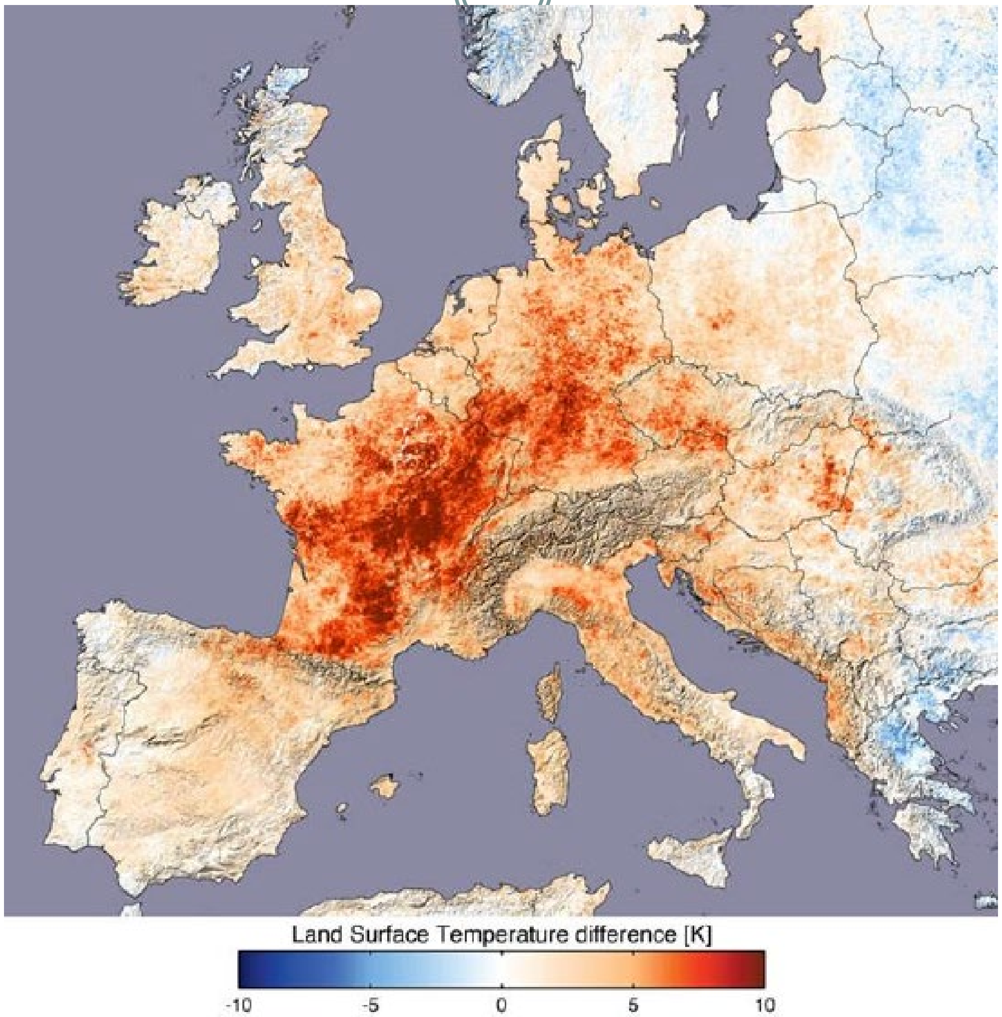
(Zribi et al., 2016)

TCI: Temperature Condition Index

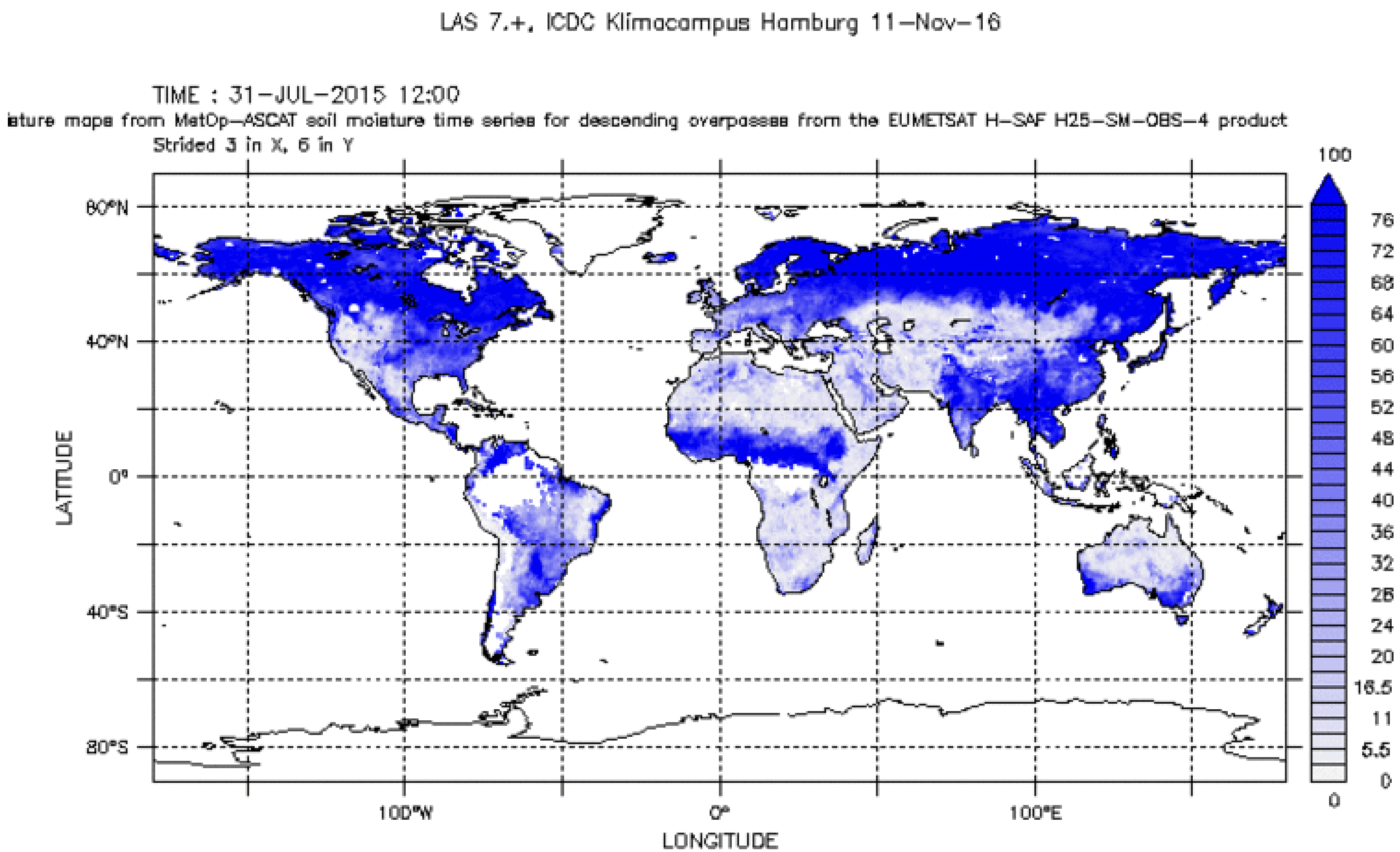
$$TCI = \frac{T - T_{min}}{T_{max} - T_{min}} \times 100$$

T: temperature at one date
T_{min}: minimum value of temperature at the same period
T_{max}: maximum value of temperature at the same period

Drought in Europe, 2003

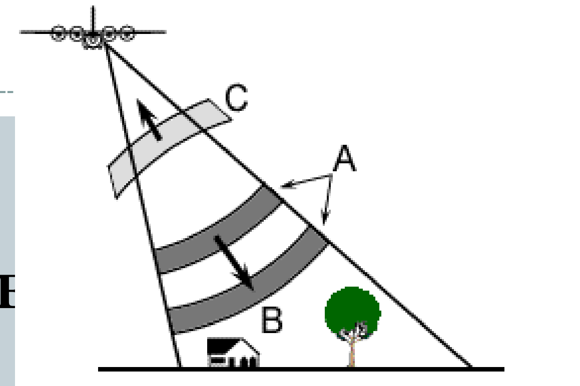


Moisture products



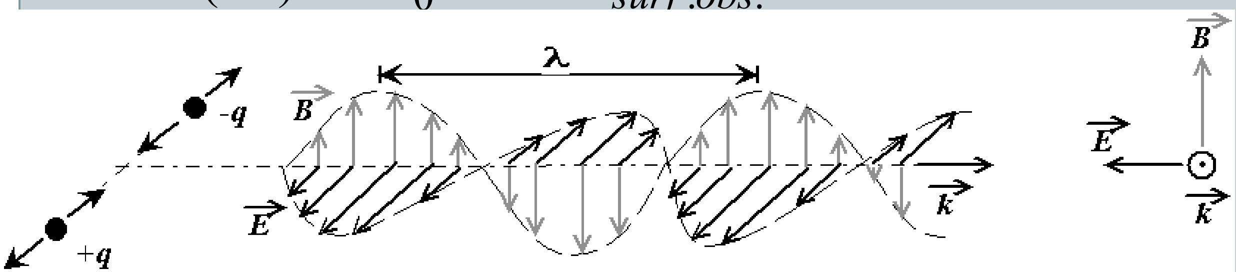
Soil_Moisture_Extended Desc 2015 (%)

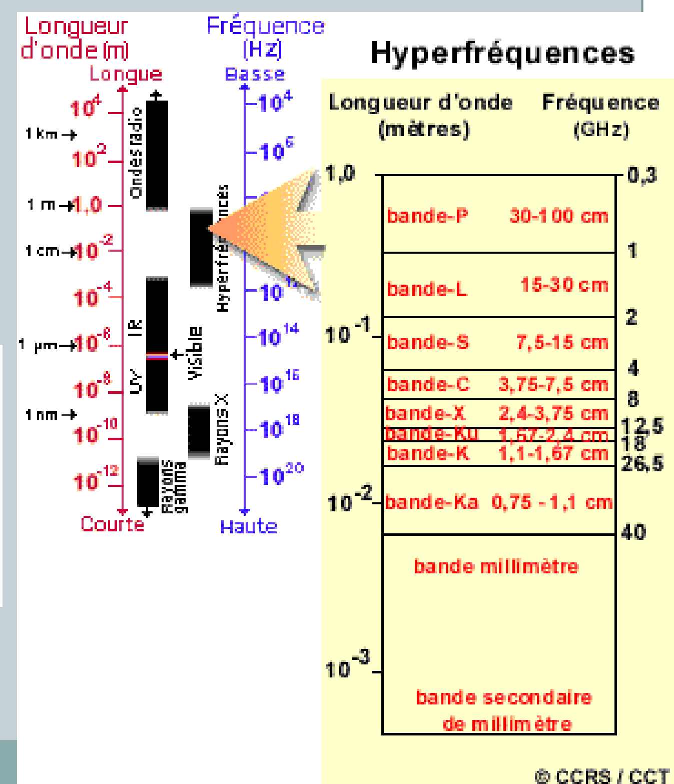
RADAR SYSTEM



- **RADAR = «RADIO DETECTION AND RANGING»**
- **ACTIVE SYSTEM=EMISSION OF ELECTROMAGN POWER**
- **IMAGES ALL THE TIME (DAYS AND NIGHTS)**
- **TRANSPARENCY OF ATMOSPHERE**

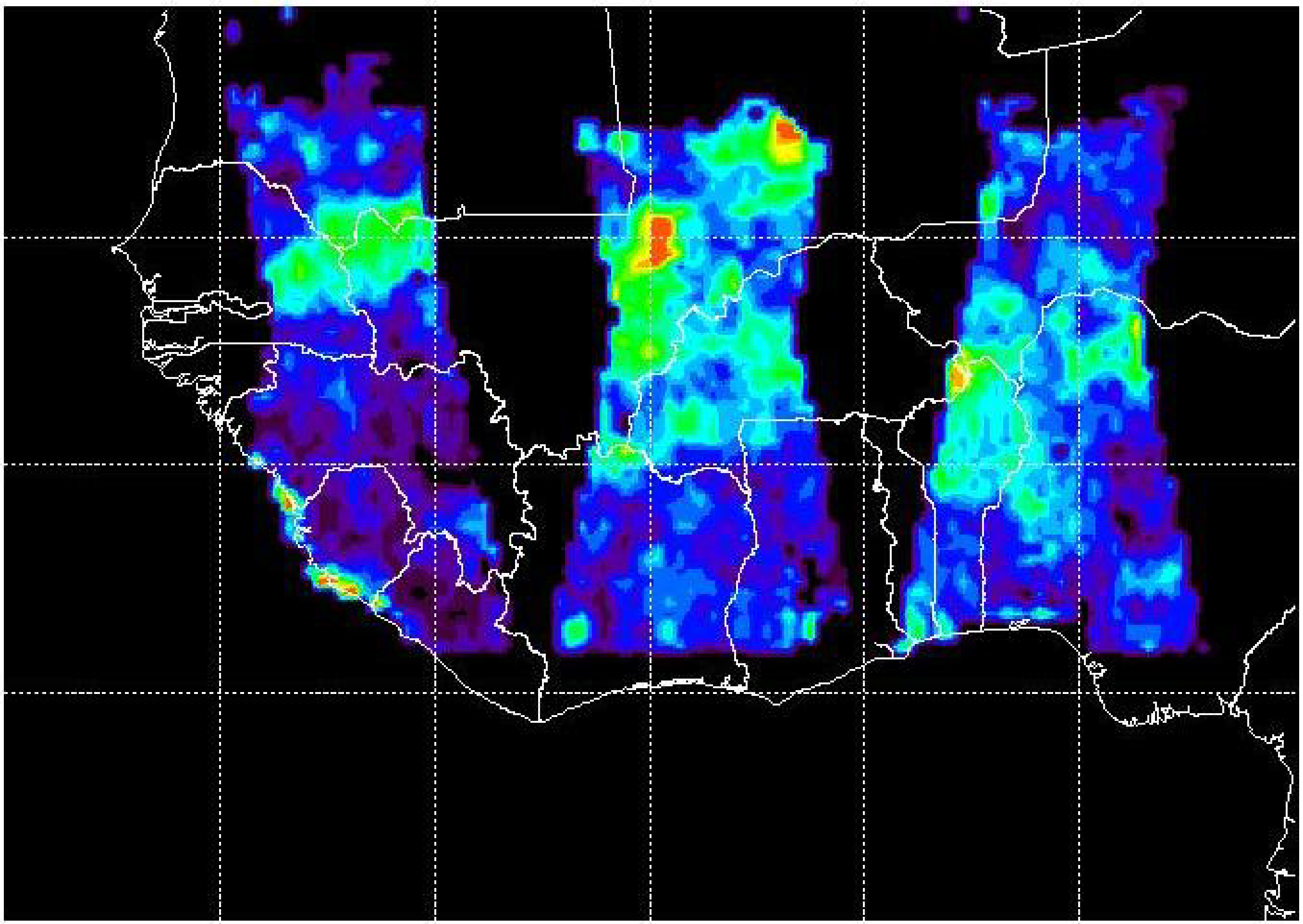
$$\langle \mathrm{Pr} \rangle = \frac{\lambda^2}{(4\pi)^3} P_e \frac{1}{r_0^4} \sigma^0(r0) \iint_{surf.obs.} G_{ek}(r) G_{Rk}(r) dS$$





Inversion algorithms to estimate soil moisture

Change detection approach combining ERS/WSC and AVHRR data to estima soil moisture at 25km resolution (AMMA project), 1992-2007



(Zribi et al., IEEE TGARS, 2008)

Objective: Analysis of interactions between African monsoon and moisture dynamic

MAI: Moisture Anomaly Index

$$MAI = \frac{SWI - SWI_{mean}}{\sigma}$$

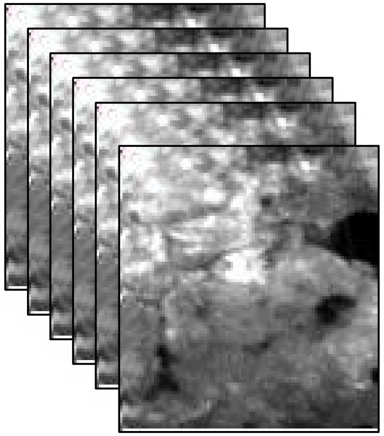
SWI: SWI at one date

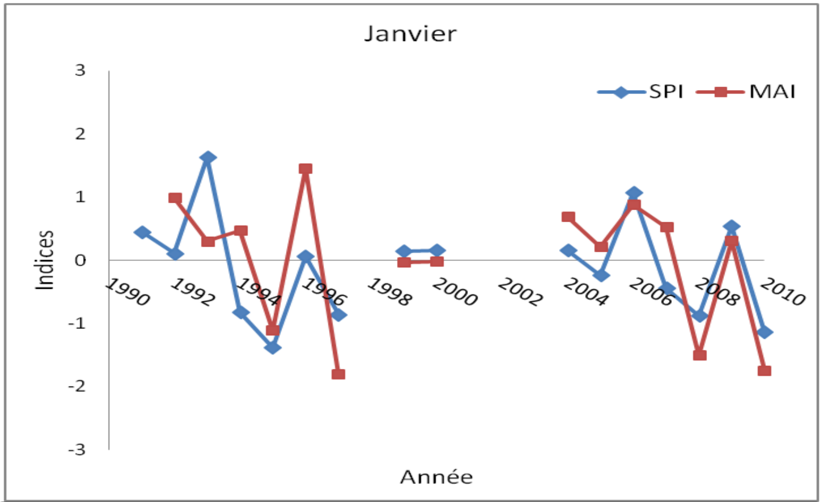
SWI_{mean}: mean of SWI for the same period

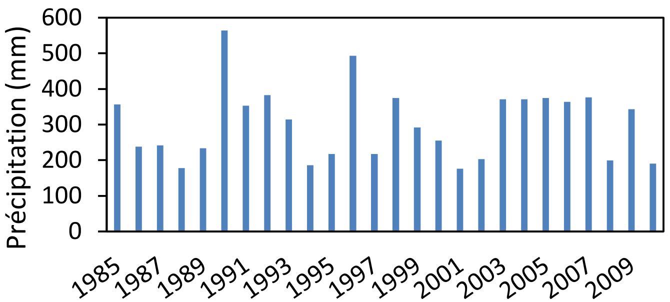
σ: standard deviation of SWI

Moisture anomaly index or MAI

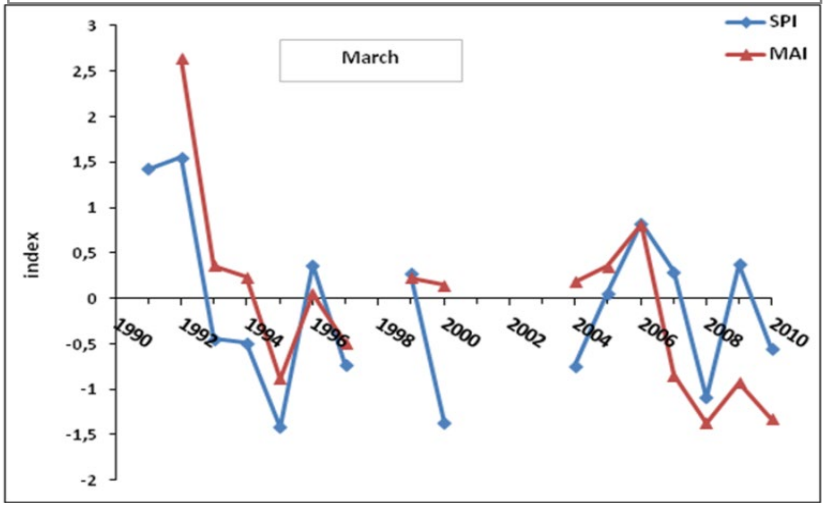
- **Soil moisture product derived from ERS and ASCAT data (→1992)**







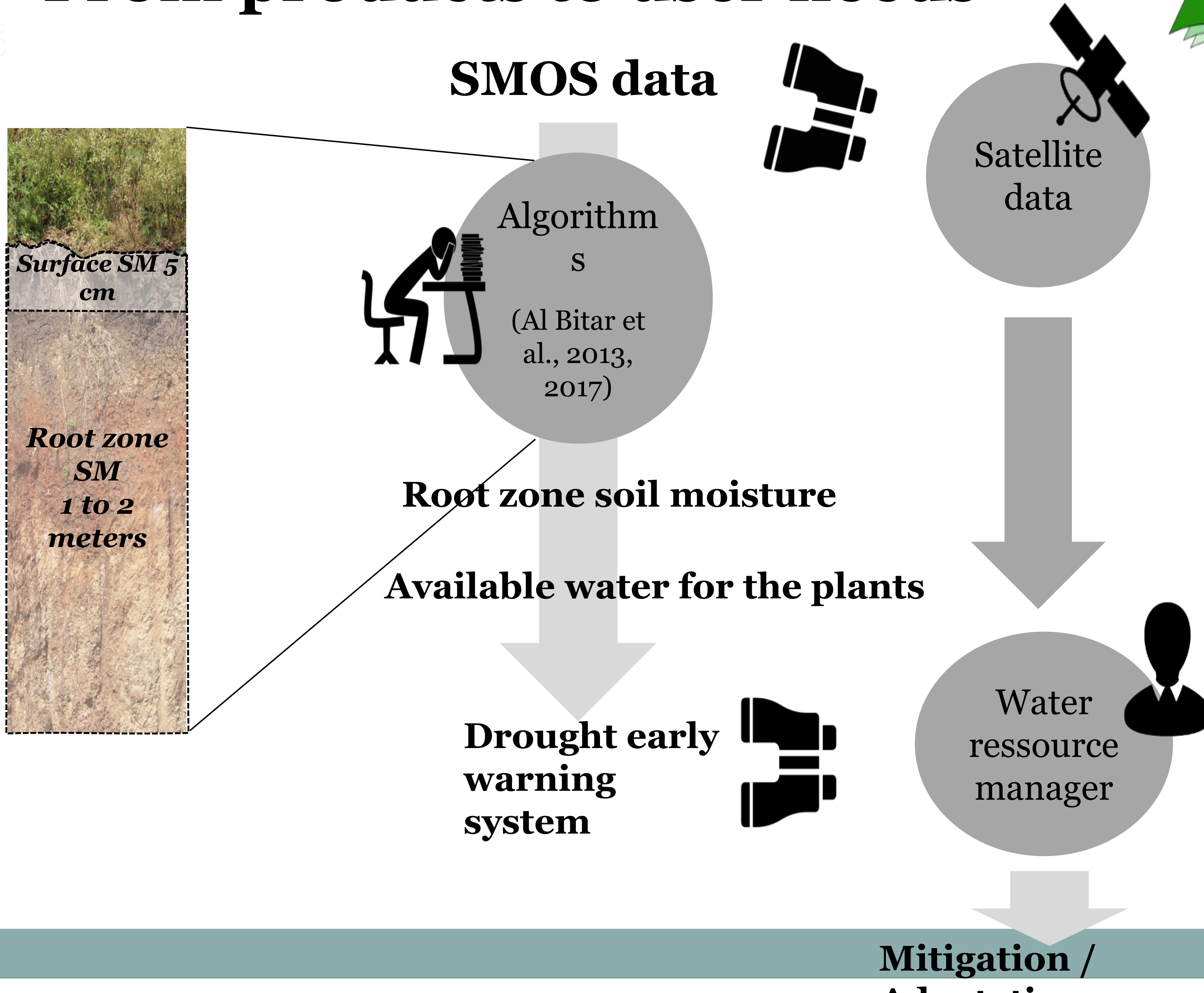
Precipitation time series, 30 years



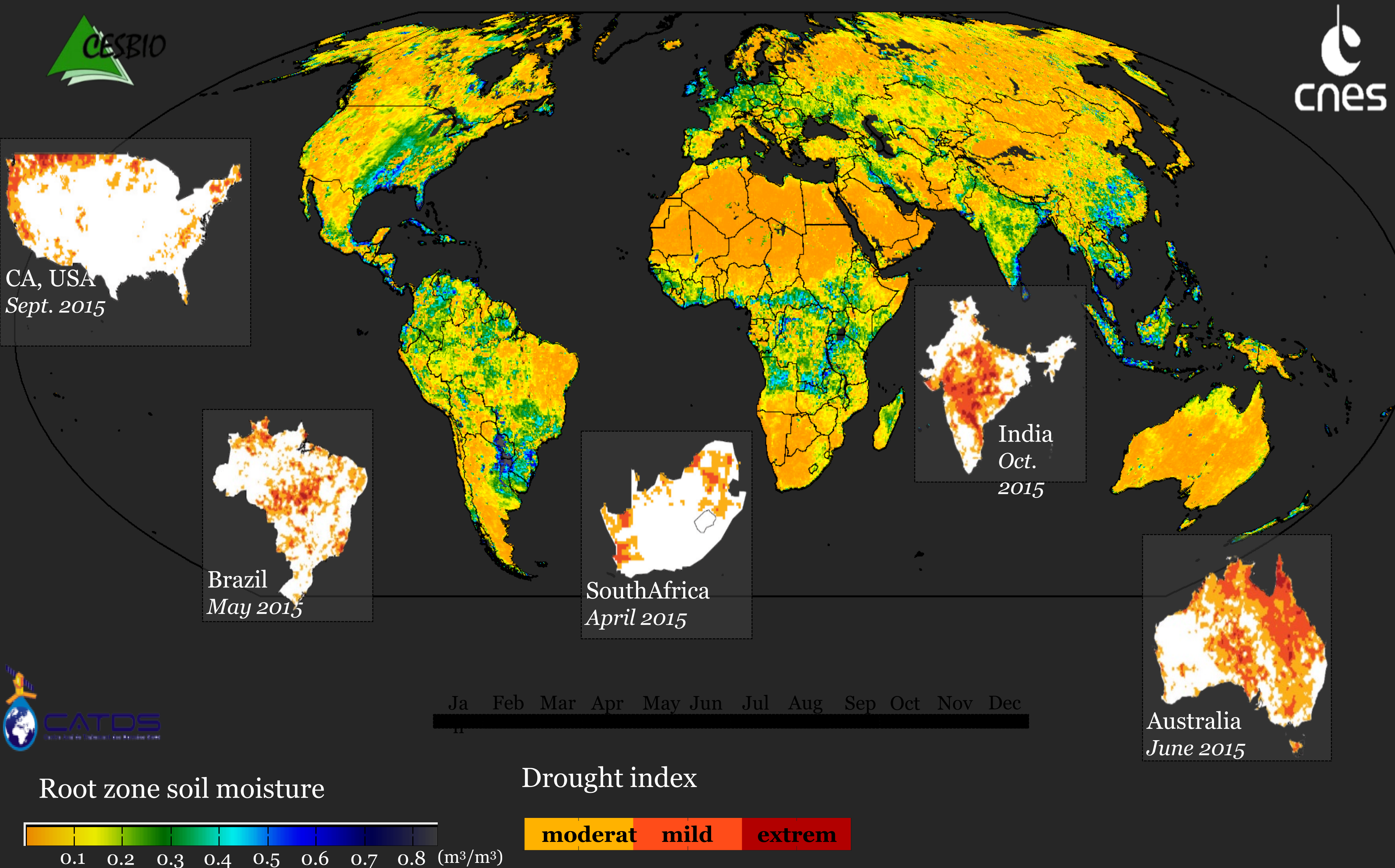
Amri et al., IEEE TGARS, 2012

Inter comparaison between SPI and MAI (over Merguelli

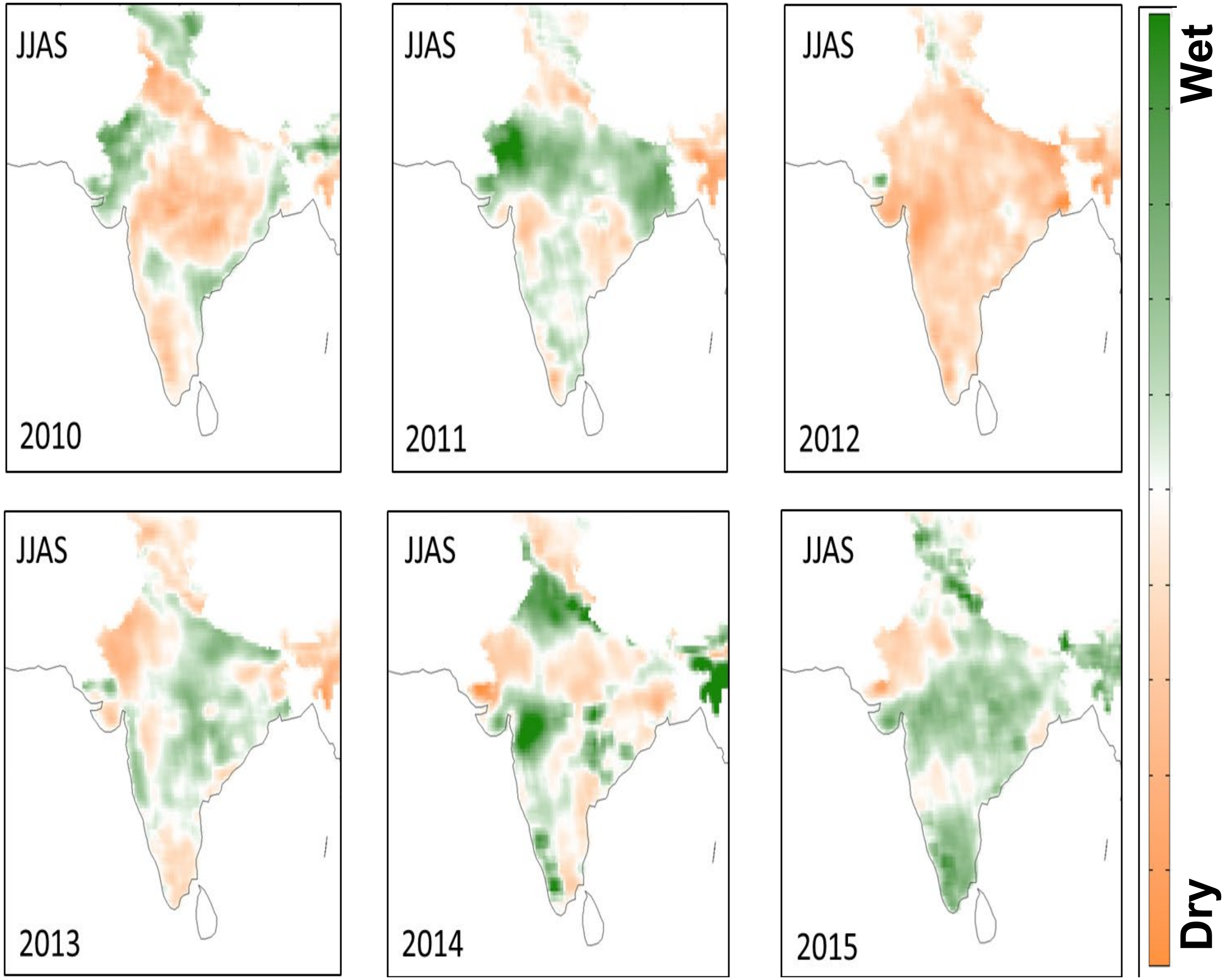
From products to user needs



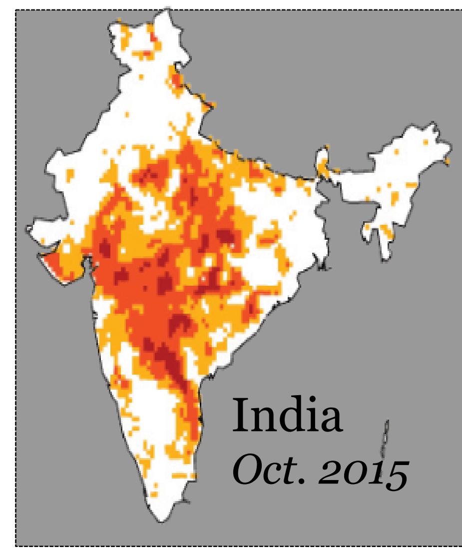
Year 2015 was major drought year… also in India



India suffered very high extremes in the last decade



..and End of 2015



Extremes are Clearly depicted by the root zone soil moistures from SMOS

Others, Composed indices

- DSI: Drought Severity Index

$$Ratio = \frac{ET}{PET}$$

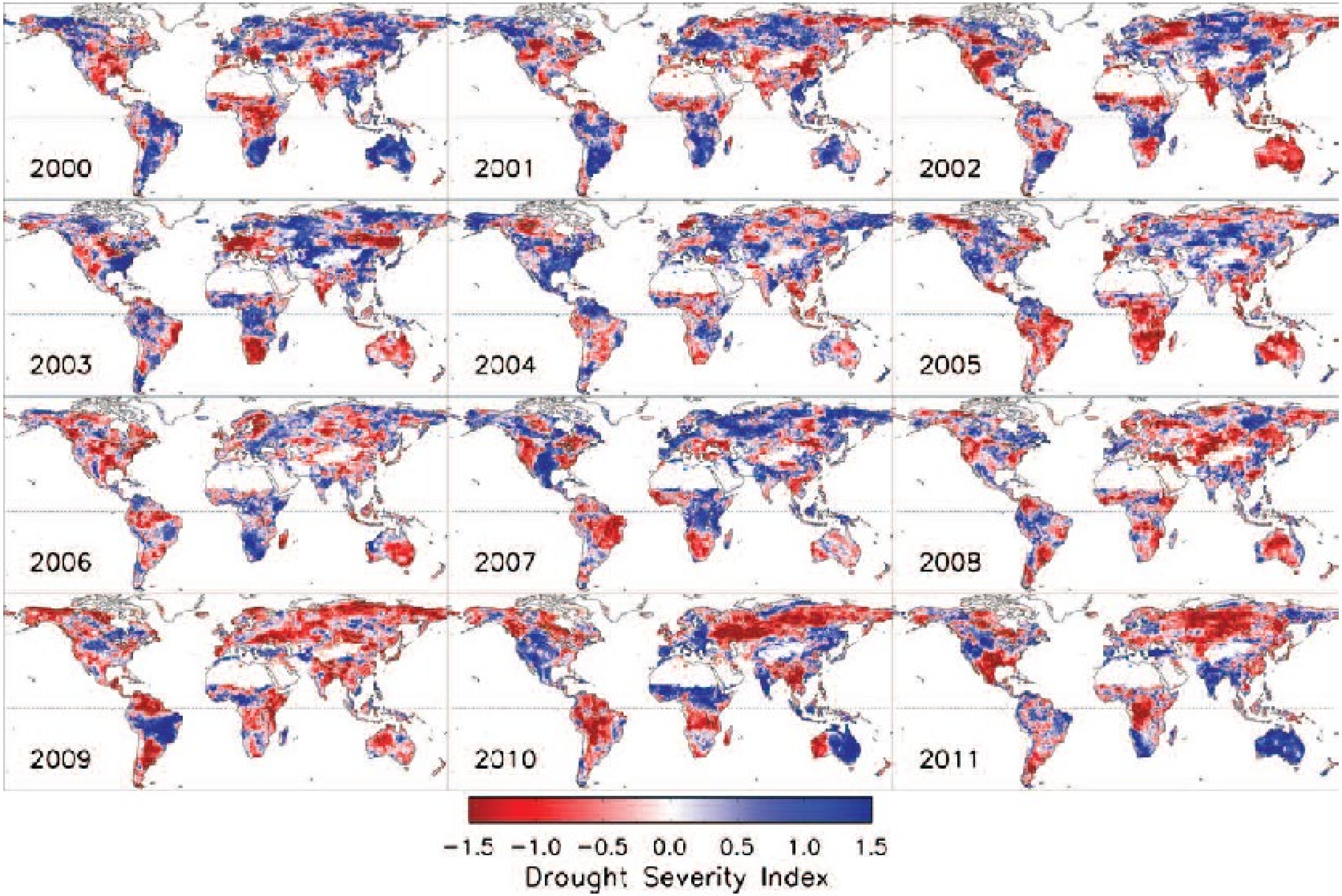
$$Z_{ratio} = \frac{Ratio - \overline{Ratio}}{\sigma_{ratio}}$$

$$Z_{NDVI} = \frac{NDVI - \overline{NDVI}}{\sigma_{NDVI}}$$

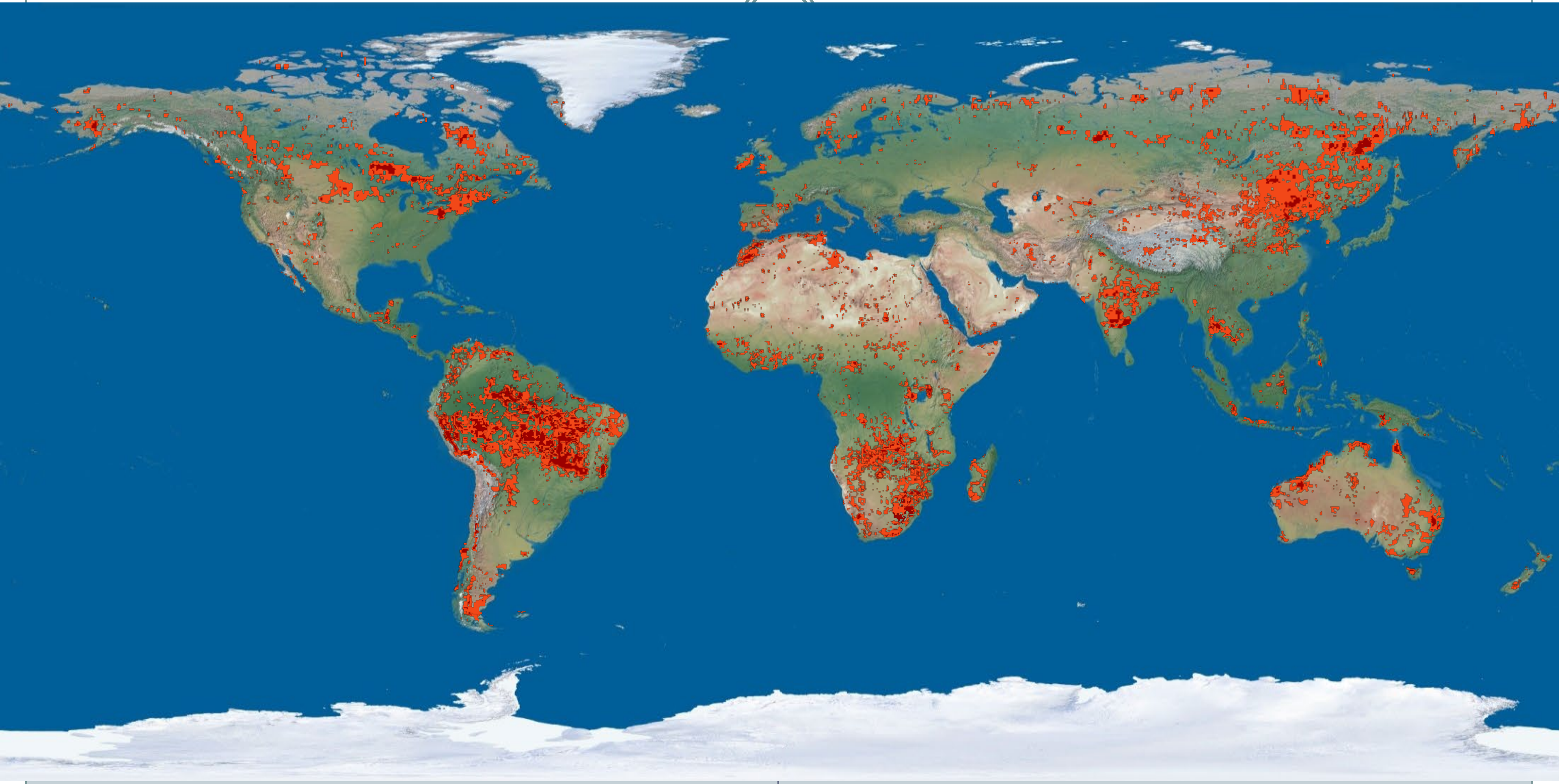
$$Z = Z_{ratio} + Z_{NDVI}$$

$$DSI = \frac{Z - \bar{Z}}{\sigma}$$

DSI


2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
−1.5 −1.0 −0.5 0.0 0.5 1.0 1.5
Drought Severity Index

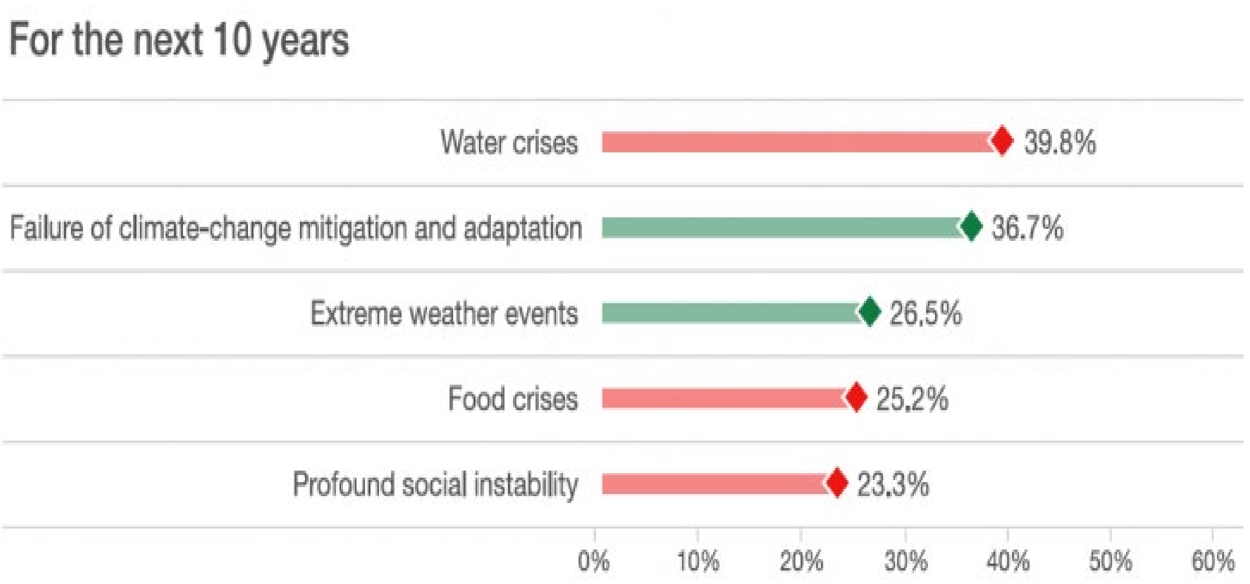
Thank you for your attention



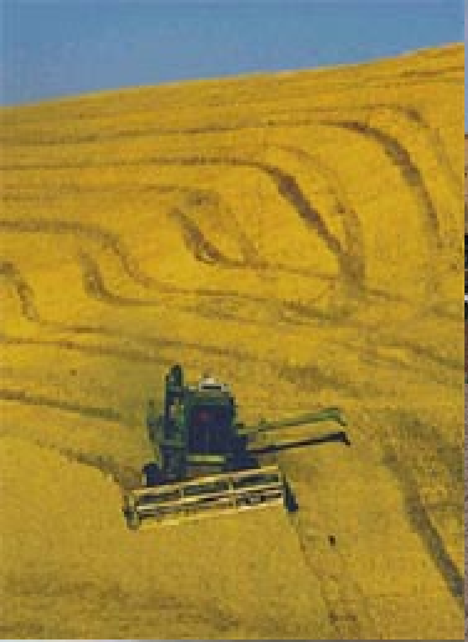
Drought in the world in 2016

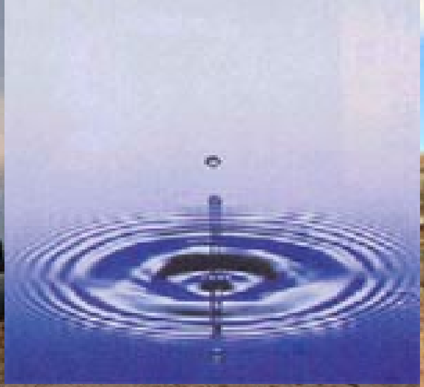
Agricultural drought, a major problem of the international community

World Economic Forum - Global Risks Perception Survey

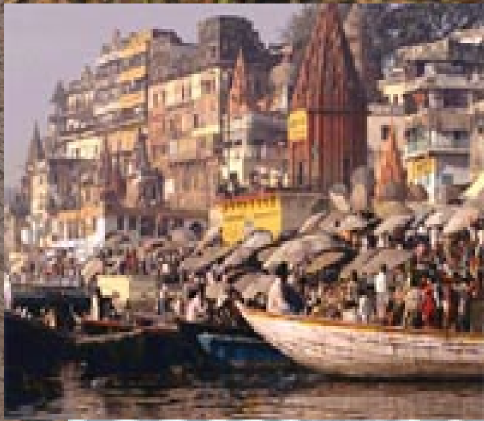


The agricultural sector uses 70-80% of the total water resources used



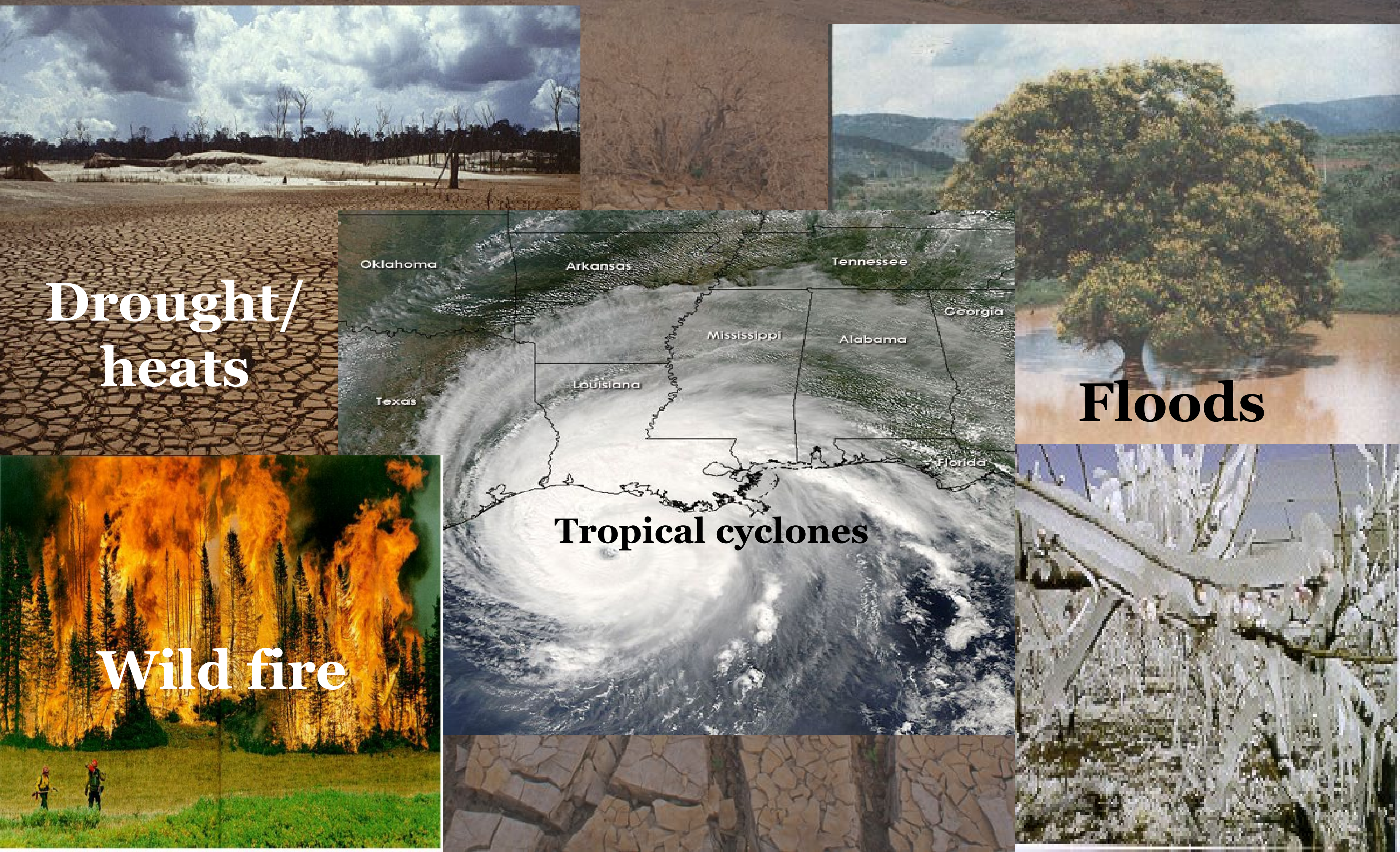





The challenge: sustainable agriculture in a changing climate

Major natural risks



Natural risks and Agriculture

- **The current agricultural sector faces complex challenges:**

→ **produce more food while using less water per unit of production;**

→ **contribute productively to the local and national economy by understanding local Aboriginal customs;**

→ **protect the health of the ecosystem and ensure the sustainability of the environment through "ecological farming";**

→ **to reduce food shortages, hunger and hunger while facing climate change and the increasing frequency of natural hazards that threaten our water resources and agricultural resources.**

Impacts of drought

- **Economic**
- **Social**
- **environmental**
- **Impacts increase in response to increasing vulnerability resulting from increased pressure on limited water resources, population growth and many other factors.**
- **Post-crash response increases vulnerability.**
- **The impacts differ from one country to another.**

Drought characteristics

- Normal component of climate variability
- No universal definition
- Complex
- Interdisciplinary
- Impacts can be economic, social, environmental
- Impacts can persist for years

Drought comparing to other natural risks

- **The beginning and end of the drought are difficult to determine**
- **No precise and universally accepted definition of drought**
- **Non-structural impacts and spread over a large geographical area**

Drought indices

- Percentage of normal precipitation
- Simple measurement of rainfall
- Effective when used for a single region or season
- Disadvantage: The average is not the same as the median

SWSI: Surface Water Supply Index

$$SWSI = \frac{aP_{snow} + bP_{prec} + cP_{strm} + dP_{resv} - 50}{12}$$

- Based on probability distributions of monthly time series of individual component indices
- Rescaled weighted sum of non-exceedance probabilities (in percent) from individual components
- Ranges from -4.2 to +4.2 (to have similar values as the Palmer index)
- Weights determined subjectively or from normalizing procedure but not optimized to predict a certain variable

SWSI

$$SWSI = \frac{P_{fcst+resv} - 50}{12}$$

- Single probability of summed expected streamflow (over an appropriate time horizon) and current reservoir storage
- Component weightings are done implicitly within the streamflow forecast
- Streamflow forecast component varies throughout the year and switches to upcoming year at beginning of water year

Copernicus constellations

Copernicus constellation program