# Drought trends, drought risk and their implementation to the JRC's Global Drought Observatory

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**The European Commission's science and knowledge service**
Joint Research Centre

*DRMKC Drought Workshop – 06 November - Budapest*

European Commission

# Outline

1. **Presentation**
   - *JRC and DRMKC*
2. **Introduction**
   - *Drought and drought impacts*
3. **Drought trends**
   - *Recent past and projections*
4. **Drought Risk**
   - *Risk Concept*
5. **Approach to Drought Risk Assessment**
   - *Contextual framework*
6. **Implementation Example**
   - *Global Drought Observatory*
7. **Discussion**

# JRC sites

Headquarters in Brussels and research facilities located in **5 Member States:**

- Belgium (Geel)
- Germany (Karlsruhe)
- Italy (Ispra)
- The Netherlands (Petten)
- Spain (Seville)

# JRC's Mission

***"As the science and knowledge service of the Commission our mission is to support EU policies with independent evidence throughout the whole policy cycle"***

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# JRC Role

- Boundary organisation
- Independent of private, commercial or national interests
- Policy neutral: has no policy agenda of its own
- Work for more than 20 EC policy departments (DGs)

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# JRC Knowledge Centres

**Disaster Risk Management Knowledge Centre**

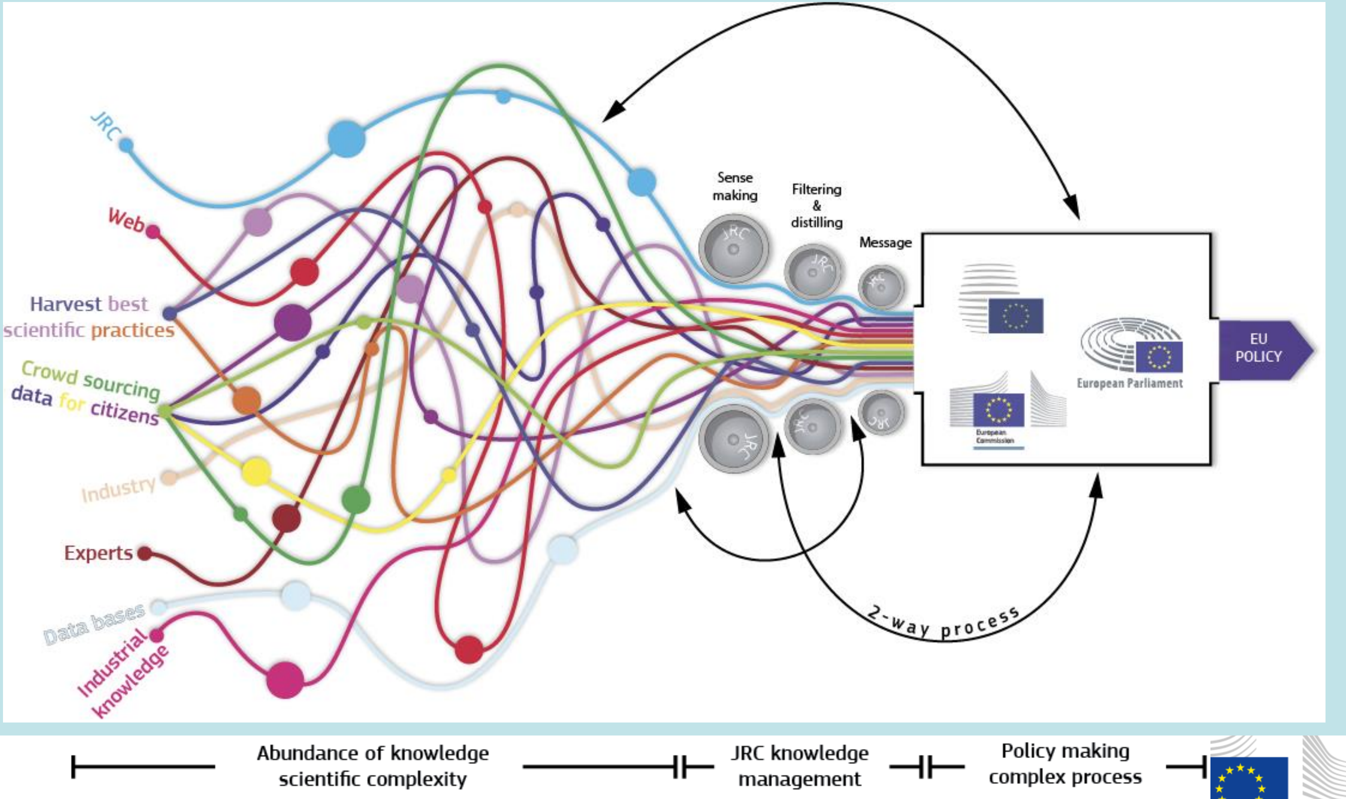
**Knowledge Centre on Migration and Demography**

**Knowledge Centre for Territorial Policies**

**Knowledge Centre on Bioeconomy**

**Knowledge Centre for Food Fraud and Quality**

# DRMKC - Dealing with the information overload



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# DRMKC - Working together: Partnership

- Reinforcing and supporting **scientific partnerships**
  - Scientific WS
  - Trainings
  - Exercises

- Contributing to the **science-policy interface**
  - **Cross-cutting topics** are addressed to facilitate an harmonized approach in support to policies:
    - Damage and Loss Data collection
    - Adaptation strategies
    - Risk Assessment
    - Risk Management Capability Assessment
  - It allows an **enhanced coordination** across policies, increasing their effectiveness

Image: Emilio Morenatti



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# DRMKC - Developing collective knowledge

**Project Explorer** – Learning from research results and identification of gaps.

Visualization of Networks: Who knows what!

*When 79 +194 = >5000 downloads and >2000 copies distributed*


**1380** research DRM related projects

**5324** institutions involved Worldwide

Access to the results

*More to come!*





***Knowing better and losing less***



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# Drought Definition

- *Negative water balance, due to*
  - **A shortfall in precipitation over an extended period of time**
  - **High temperatures → to increased evapotranspiration**

- *The inadequate timing of precipitation*

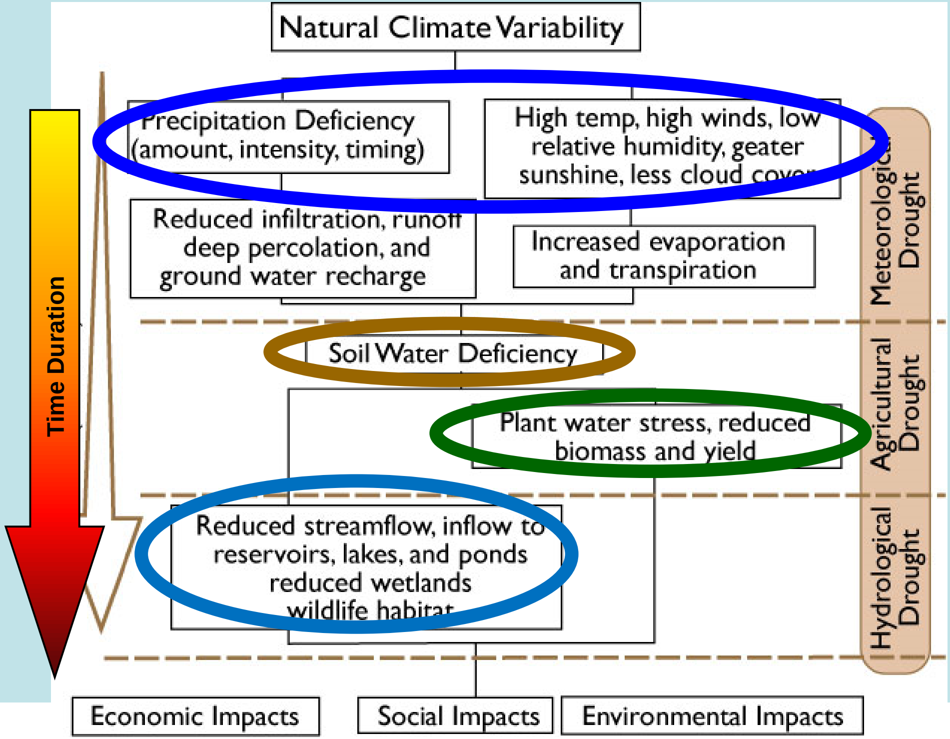
**Unusual and temporary deficit in water availability, resulting in negative economic, social and environmental impacts!**

**To be distinguished from:**

**Aridity: A permanent climatic feature**

**Water Scarcity: Climatologically available water resources are inadequate to meet long-term average water requirements!**

# Drought: Different types




*Source: National Drought Mitigation Center, University of Nebraska-Lincoln, USA*

Variables

**Standardized Precipitation Index, SPEI**

Standardized Snowpack Indicator

**Soil Moisture Anomaly, PDSI**

**Vegetation Response (fAPAR, NDVI)**

**Low Flows, reservoir levels, groundwater (Grace)**



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# Drought Characteristics

- Slow onset, “creeping” phenomenon
- Affects all compartments of the hydrological cycle (rainfall, soil moisture, groundwater, reservoirs, river flows)
- Impacts are non-structural, spread over large areas and long time periods (direct and indirect), affect many people, and depend on the societal and environmental vulnerability

About 15% of the EU territory and 17% of the EU population affected annually

Economic impacts in the EU are estimated to be 3 billion Euros/year on average

With climate change impacts are likely to increase by a factor 5 to 10 by 2100

Environmental impacts are difficult to quantify and not included!

# Drought Impacts


Public Water Supply


Agriculture


Energy Production


Terrestrial & Freshwater Ecosystems


Human Health


Waterborne Transport


Forest/Wild Fires


Forestry


Tourism

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# Drought Impacts in Europe

## Economic Impacts:

Over 30 years: estimated cost of at least **100 billion** Euros

Annual economic impact doubled from 1976-1990 to 1991-2006

| Period | Total Impact | Impact/year |
|---|---|---|
| 1976 – 1980 | 12 340 | 2 470 |
| 1981 – 1985 | 4 360 | 870 |
| 1986 – 1990 | 14 460 | 2 890 |
| 1991 – 1995 | 23 390 | 4 680 |
| 1996 – 2000 | 8 060 | 1 610 |
| 2001 – 2006 | 37 400 | 6 230 |
| **TOTAL** | **100 000** | |

*All figures in million Euros*

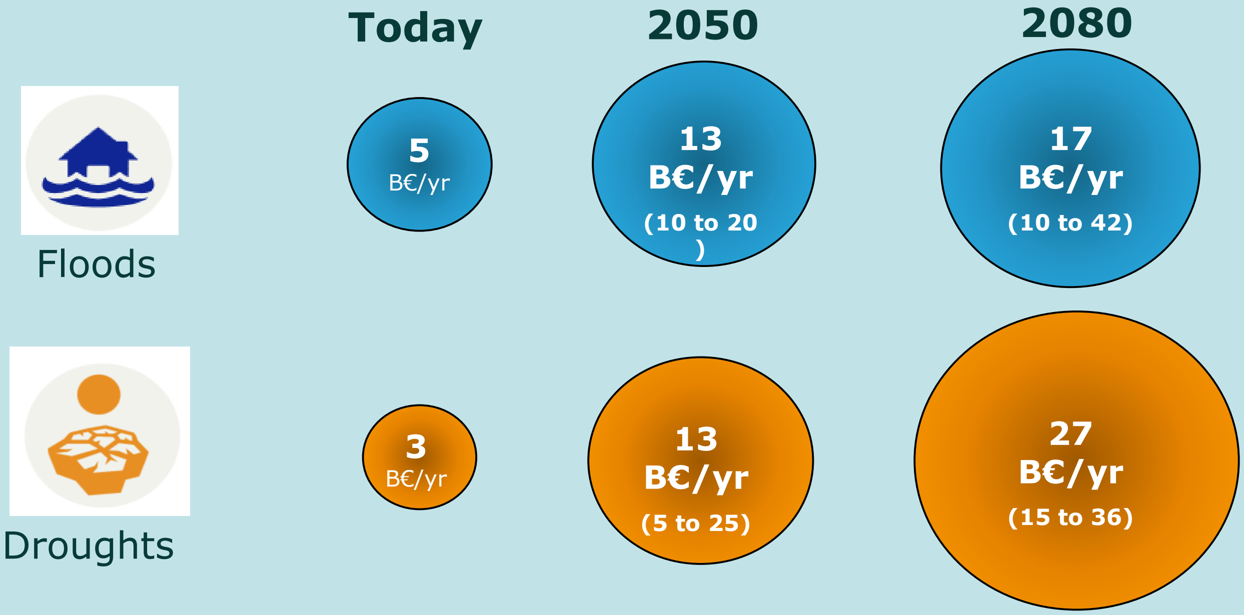
## Environmental Impacts:

Drought can cause serious long-term environmental impacts (e.g., water quality, salinization, desiccation of wetlands, soil erosion, desertification, …)

These impacts are difficult to quantify and data are generally lacking

Source: European Commission, 2007 (WS&D, 2nd Interim Report)

# Drought and Flood Damage Projected in the EU




RCP 8.5, 30-year averages, 7 independent climate models for floods and 6 for droughts

Source: Helix Project, 2016



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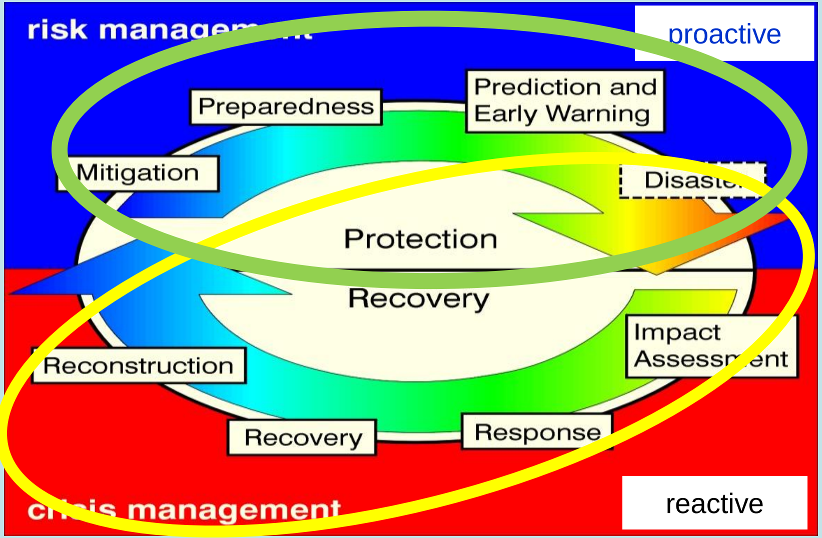
# Drought Management: Changing the Paradigm

**Cycle of Disaster Management**




➡ Risk assessment key for adequate drought management

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# Drought variability

- Sub-seasonal to inter-annual variability
- Past trends
- Climate Change and Future droughts

# Droughts are caused by:

- Persistent atmospheric patterns
- Linked to low frequency sources: SSTs, Madden-Julian Oscillation, NAO, etc.
- ENSO (El Niño Southern Oscillation)

# Past droughts (1951-2017)

## Data and Methods

INPUT DATA

- GPCCv7 RR data (0.5°)
- CRUTSv4 PETPM data (0.5°)
- EOBSv13-17 RR, TN and TX data (0.25°)

DROUGHT INDICATORS

- Standardized Precipitation Index (SPI)
- Standardized Precipitation-Evapotranspiration Index (SPEI)
- From SP(E)I-3 to SP(E)I-72

**DROUGHT EVENTS**

Database of drought events (1951-2017)
Multiple indicators and spatial scales
Country-based and macro-regional
List of mega-droughts of the last decades
Dedicated reports and analysis of impacts
Drought time series at country scale

**DROUGHT QUANTITIES**

Drought Frequency (DF)
Drought Duration (DD)
Drought Severity (DS)
Drought Intensity (DI)
Drought Area involved (DA)
Extreme droughts and Peak Events (PkE)
Drought Impacts (ongoing)



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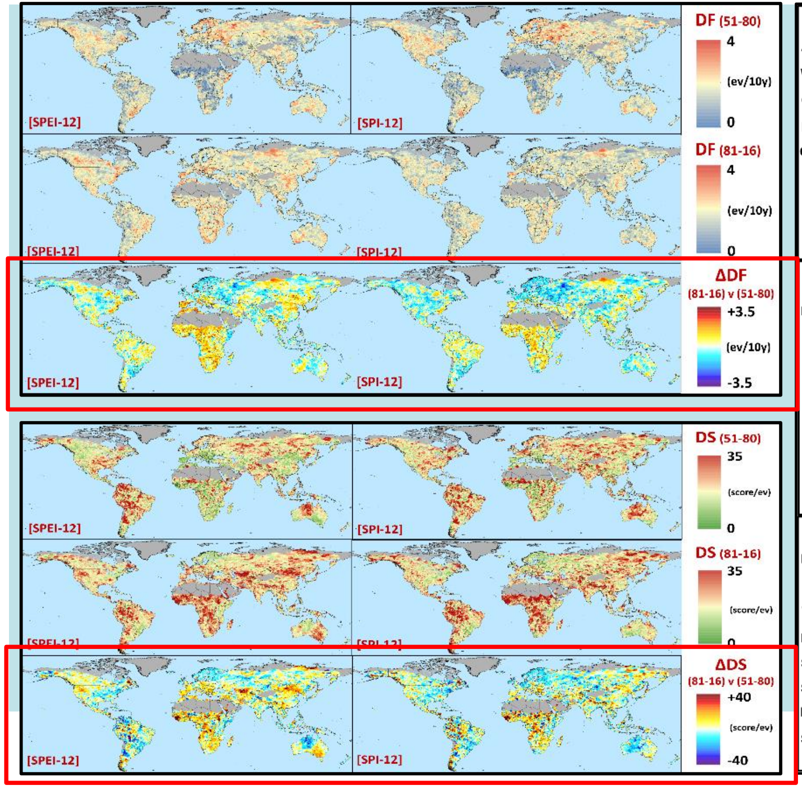
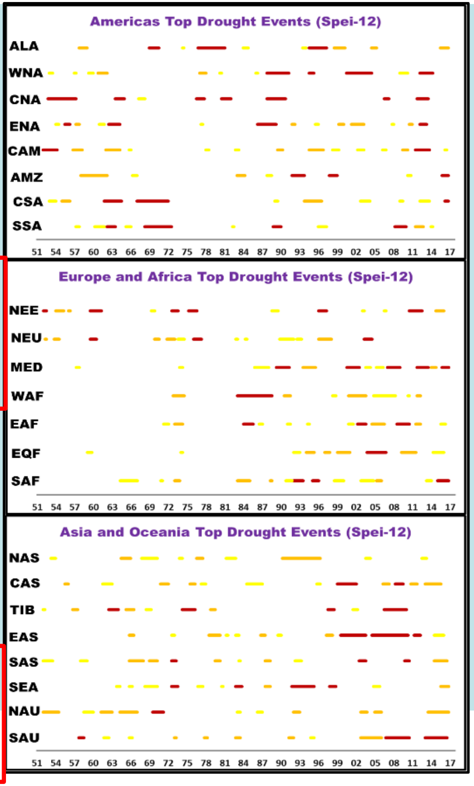
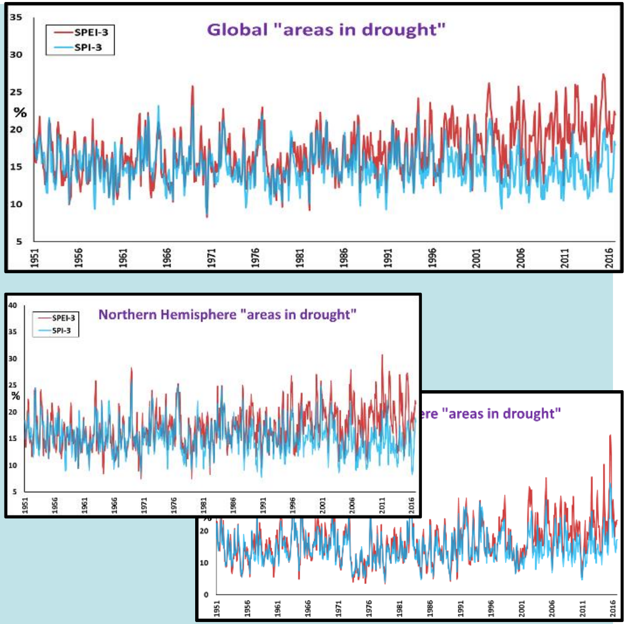
# Global past Drought and Trends




DF & DS (1951-2017)




Top Events




Areas in drought



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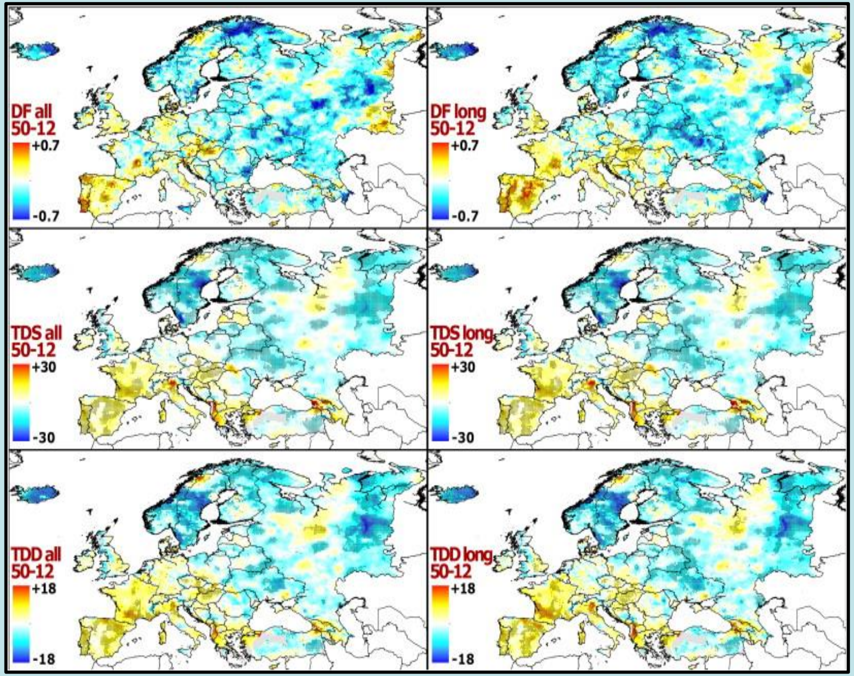
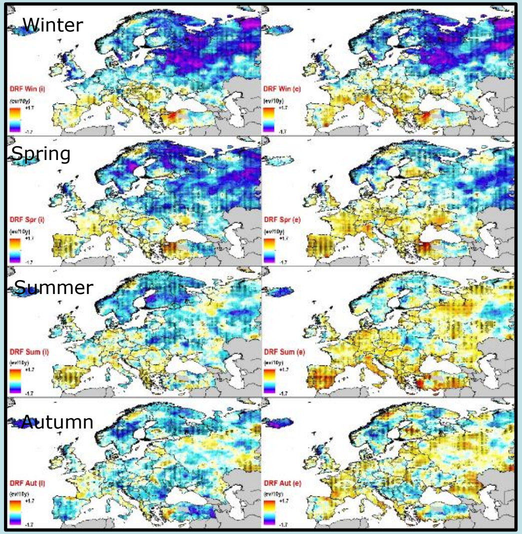
# Global past Drought and Trends

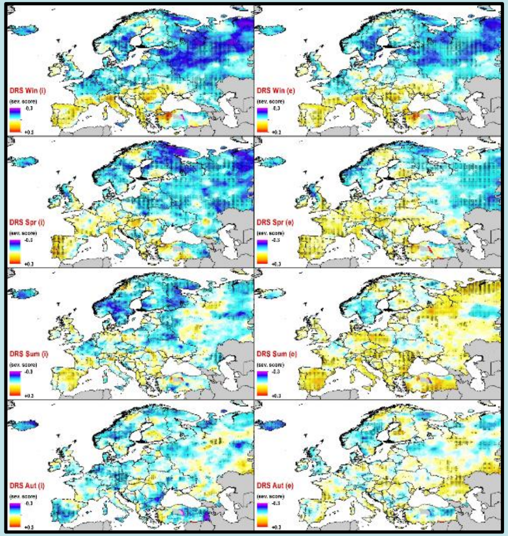
## Europe and Mediterranean Region




DF, DS, DD (Annual)




DF (Seasonal)



DS (Seasonal)

Spinoni et al. 2015

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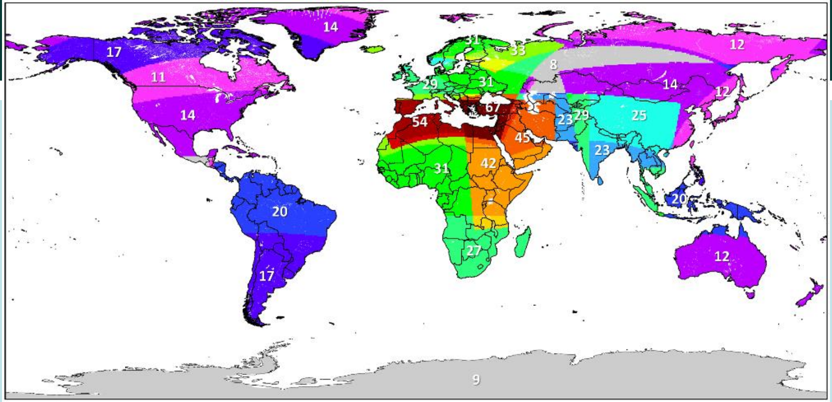
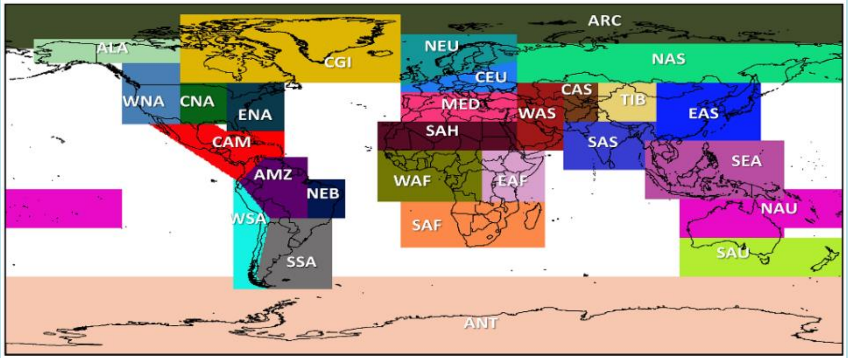
# Future droughts (2021-2100)

## Data and Methods




Number of CORDEX Simulations




Macro-Regions

### INPUT DATA

- 109 CORDEX Simulations (0.44°)
- >15 GCMs combined with >15 RCMs
- RR, TN, TX (PETHS)
- RCP4.5 and RCP8.5

### DROUGHT INDICATORS/VARIABLES

- SPI-12 and SPEI-12
- Drought frequency (DF) & severity (DS)
- Extreme events (PkE)



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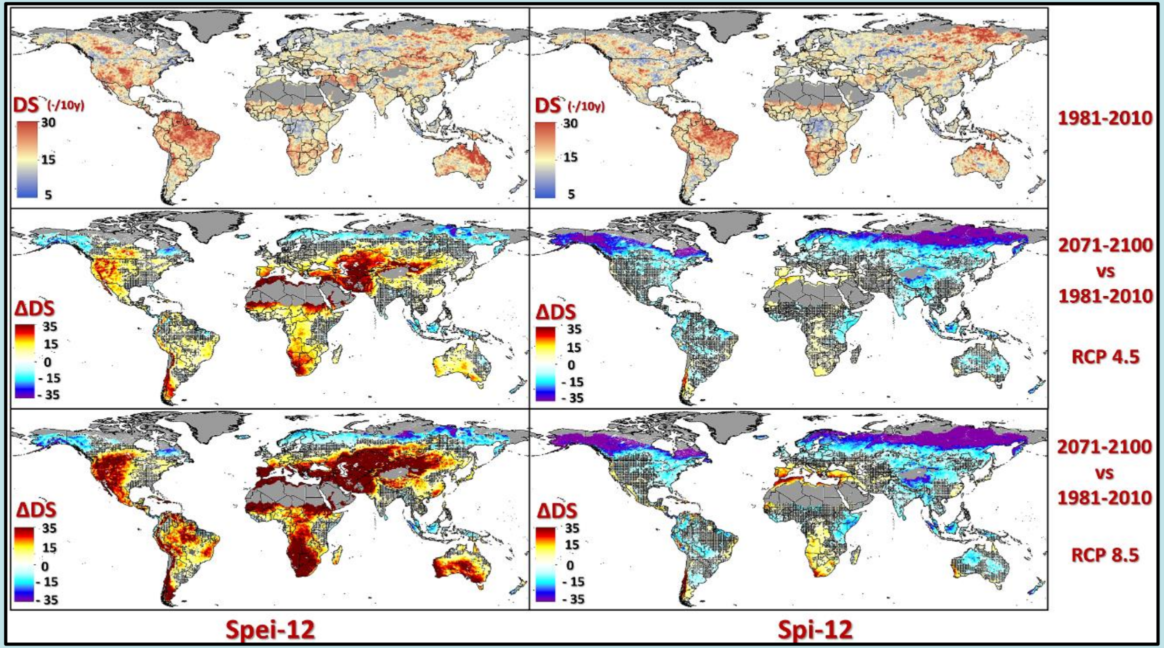
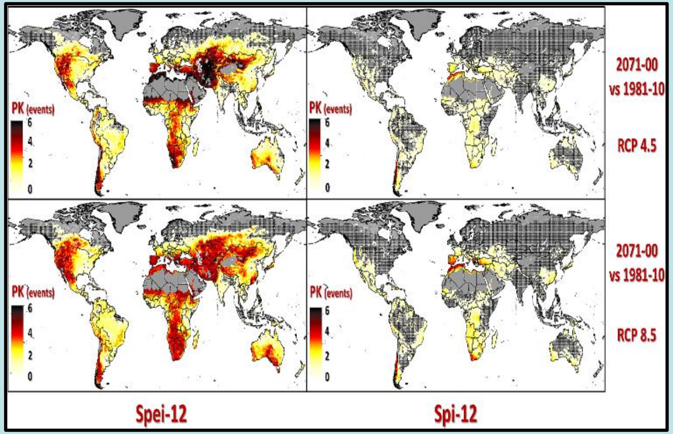
# Global drought projections




2071-2100 vs 1981-2010 (Drought Severity)




Events in 2071-00 larger than the most extreme in 1981-10



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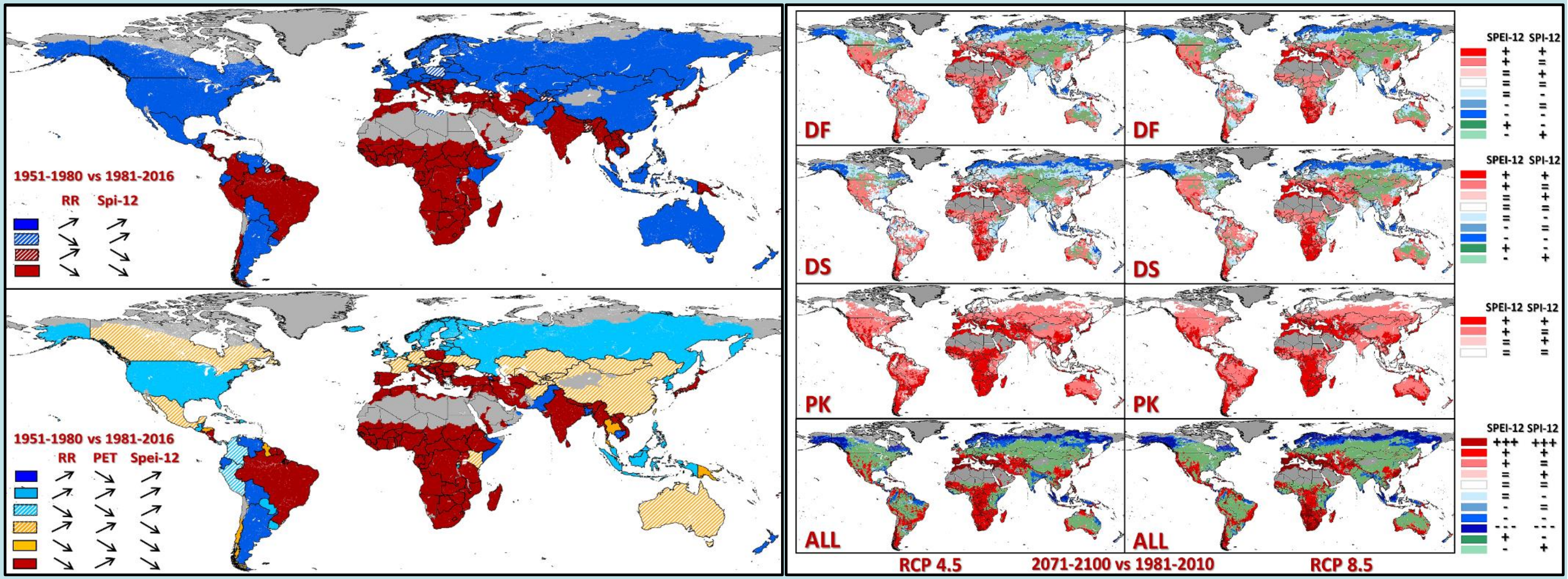
# Global drought projections

## The role of temperature




Past (1951-2017) and Future (1981-2100) drought drivers



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# Drought Trends

## Take home messages

- More than 4,000 meteorological drought events at country and macro-regional scales from 1951 to 2017
- Drought hotspots in 1951-2017: Chile, Mediterranean region, tropical Africa, central Asia, NE China, and southern Australia
- For the SPI, DF and DS will increase in 1981-2100 over Chile, Mediterranean region, southern Africa, SW Australia. For the SPEI over western North America, most of South America and Africa, Mediterranean region, central Asia, central and southern Australia
- The role of temperature (AED) is crucial in meteorological drought projections

***Two new papers just submitted: biggest global drought events in 1951-2017 & CORDEX-based drought projections Spinoni et al 2018a,b***

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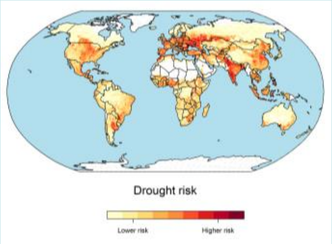
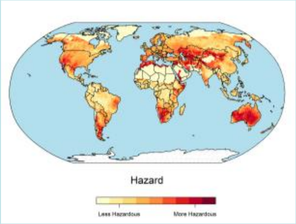
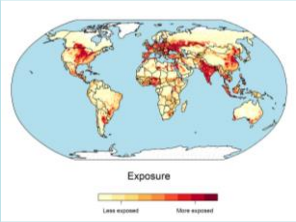
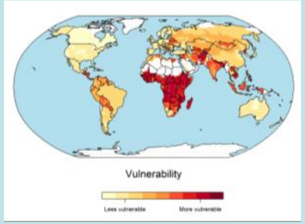
# Drought Risk Concept

**Risk** = Hazard x Exposure x Vulnerability




**Risk**: Risk or Likelihood of drought impact

**Hazard**: Probability of a drought event with a certain severity.

**Exposure**: Amount of population, livelihoods, assets, resources, services potentially affected.

**Vulnerability**: Susceptibility to suffer adverse effects

- Sensitivity
- Coping Capacities

➡ **Risk is sector specific!**

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# Drought Risk Analysis - Components

| | Characterisation | Relevant data | Examples of studies | |
|---|---|---|---|---|
| **Hazard** | Magnitude of a hydrometeorological deficit | Meteorological, hydrological and/or biophysical indicators | Sepulcre-Canto et al. (2012); Vicente-Serrano et al. (2010); Svoboda et al. (2002); Kogan (1995); McKee et al.(1993); Palmer (1965). | ✓ |
| **Exposure** | Amount of elements subject to drought hazard | Amount and location of human populations, activities and/or ecosystems | Winsemius et al. (2015); Christenson et al. (2014). | ✓ |
| **Vulnerability** | Susceptibility of exposed elements to damaging effects of drought hazard | Composite indicators that include environmental, social, economic and/or infrastructural components<br>Impact data | Gonzélez-Ténago et al. (2016); Naumann et al. (2014); Brooks et al. (2005); Cutter et al. (2003). | ? |
| **Overall risk** | Likelihood of impact | Measured in a probabilistic scale linked to intervention policies | Blauhut et al. (2016); Carrão et al. (2016); Kim et al. (2015); Eriyagama et al. (2009); Peduzzi et al. (2009). | |

Source: Van Lanen et al. 2017

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# Drought Risk Analysis - Approaches

**DROUGHT RISK = f(Hazard, Exposure, Vulnerability)**

**Outcome/Impacts Approach**

- End point vulnerability
- Based on relationships between stressor and response
- Responds to who is vulnerable

(statistical model)

**Contextual/Factor Approach**

- Start point vulnerability
- Based on intrinsic factors
- Responds to why the subject is vulnerable

(conceptual model)

**Hybrid/Convergent Approach**

- Mixed factor - impact approach
- Based on both, intrinsic factors and statistical relationships
- Responds to who is vulnerable and why

# Drought Risk Analysis - Outcome/ Impacts Approach

Vulnerability: "the degree to which geophysical, biological and socio-economic systems are susceptible to, and unable to cope with, adverse impacts of climate change". (IPCC)

Recorded damages/losses are statistically linked to drought characteristics → impact functions/damage functions/average annual loss (AAL)/probable maximum loss (PML)

Depends on

(a) Characterization of drought events (drought indicator dependent)

(b) Quantitative data on damage and/or loss on past drought events (impact data dependent)

(c) Context and region specific

Examples: Blauhut et al. (2015), Bachmair et al. (2015), Naumann et al. (2015)



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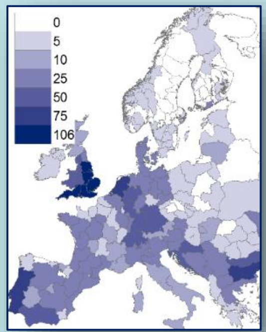
# Outcome/ Impacts Approach Example 1
## Linking reported impacts to drought indices

### LIO: Likelihood of Impact Occurrence

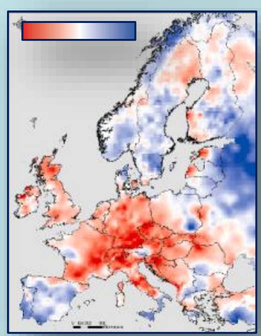
**No. of impacts/sector (e.g. agriculture)**




EDII Database

| NUTS-combo region | Year | Impact | SPEI-12 |
|---|---|---|---|
| DE1 | 1975 | 0 | -1.3 |
| DE1 | 1976 | 1 | -2.1 |
| DE1 | 1977 | 0 | -0.4 |
| … | … | … | … |
| DE1 | 2000 | 0 | -0.8 |
| DE2 | 2001 | 0 | 0.3 |
| DE3 | 2002 | 0 | 0.8 |
| DE4 | 2003 | 1 | -2.8 |
| DE5 | 2004 | 1 | -1.1 |
| … | … | … | … |

**Drought Indicator (e.g. SPEI)**



$$LIO = \log\left(\frac{LIO_N}{1-LIO_N}\right) = \alpha_M + \beta_M \cdot P_N$$

*$\alpha_M$ = intercept by macro region*
*$\beta_M$ = slope by macro region*
*$P_N$ = predictor by NUTS-combo region*

*Blauhut et al. 2015*

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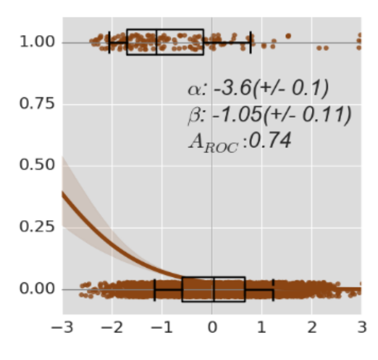
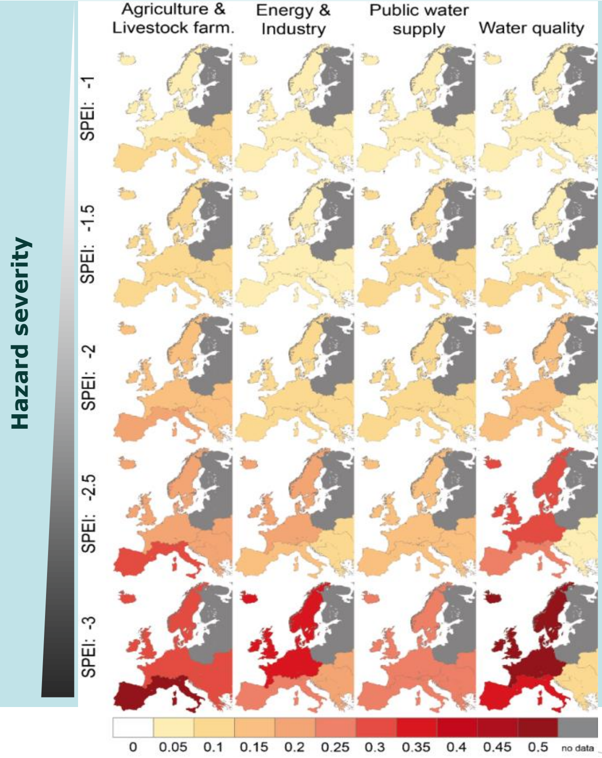
# Example 1 Drought Risk - Maps

**LIO Curve**




Per macro-region & sector

**How probable is the occurrence of an impact in a given sector as a function of the selected drought indicator**




**Likelihood of Impact Occurrence (LIO)**

*Blauhut et al. 2015*

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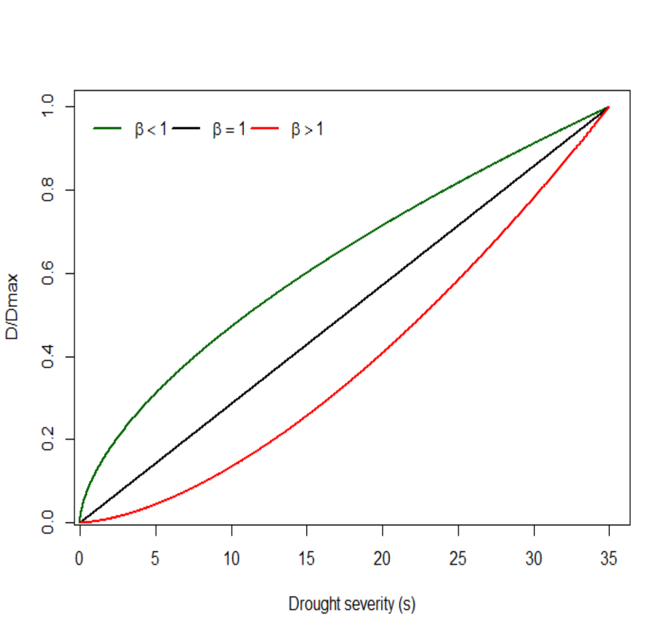
# Outcome/ Impacts Approach Example 2

## Linking quantitative impact information to drought indices




**Drought Damage ≈ $\alpha$ $s^{\beta}$**

*(s: drought severity)*

BETA = 1 linear relation

BETA < 1 limited growth relation

BETA > 1 exponential relation

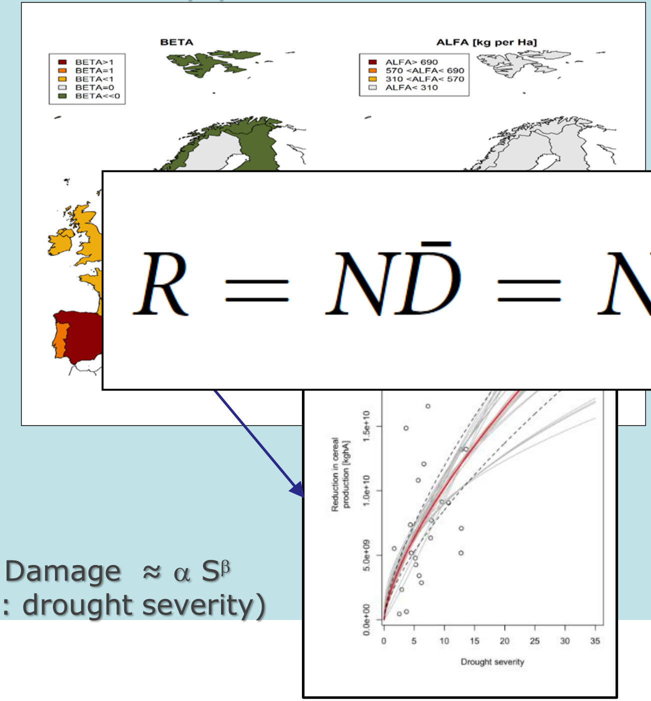
BETA = 0 no relation

BETA << 0 positive effects of droughts?!

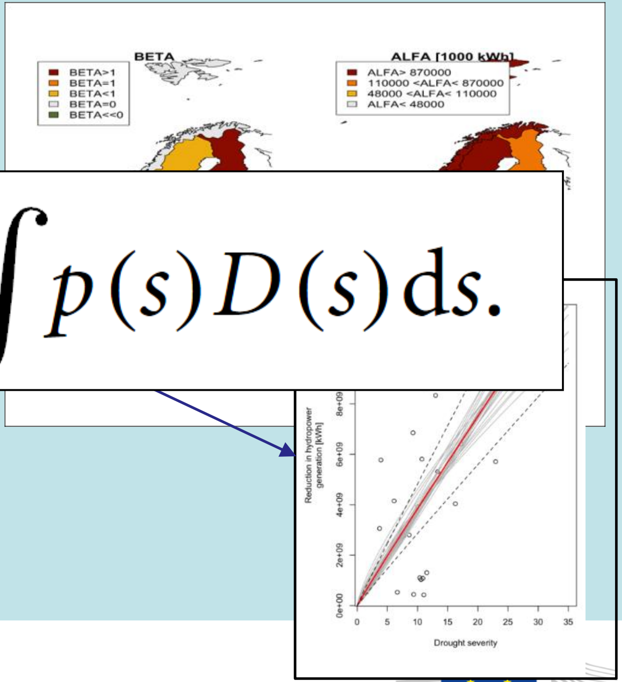
Naumann et al., 2015

# Example 2 Impact Relation - Cereal Production and Hydropower Generation

Drought severity vs reduction in cereal crop production




Drought severity vs reduction in hydropower generation




$$R = N\bar{D} = N\int p(s)D(s)\,\mathrm{d}s.$$

Damage $\approx \alpha\, S^{\beta}$
(S: drought severity)

Naumann et al., 2015

# Drought Risk Analysis - Contextual/ Factor Approach

Vulnerability: "Characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a drought" (UNISDR)

Links vulnerability and exposure factors to the underlying causes of risk

Depends on:

(a) Exposure factors (assets that are potentially affected by drought)
→ sector dependent

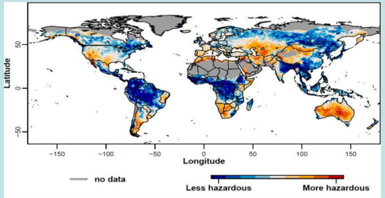
(b) Vulnerability factors (of a farm, community, region, country)
→ scale dependent

(c) All factors are normalized (0 – 1)
→ relative measure (depending on analysed spatial domain)

Examples: Iglesias et al. 2009, Naumann et al. 2014, De Stefano et al. 2015, Carrao et al. 2016

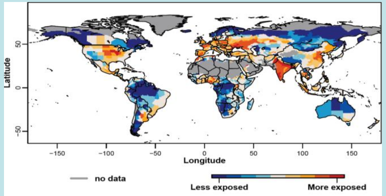
# Contextual Approach – Components

**Drought Hazard (H)**
e.g. rainfall anomalies,
Vegetation vigor,
CDI



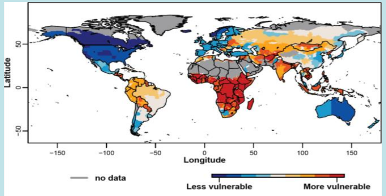

x

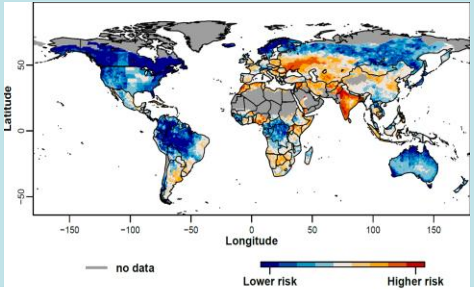
**Exposure (E)**
e.g. Population density
Agricultural areas,
livestock




x

**Vulnerability (V)**
e.g. Social, Economic,
Infrastructural Indicators




$$Risk = HxExV$$

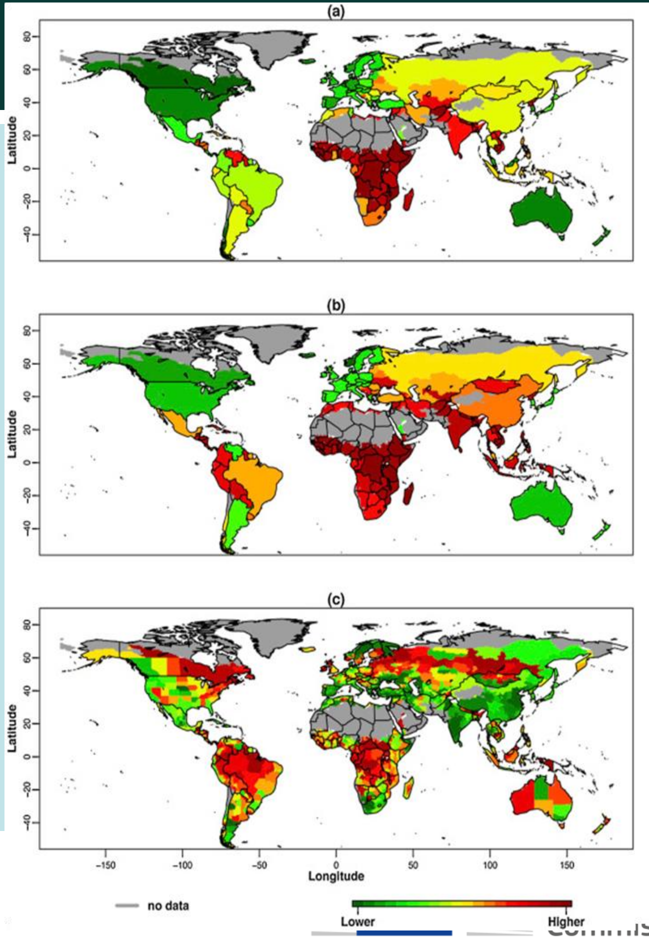
Carrão et al., 2016

# Proxy Indicators for Computing Contextual Vulnerability Factors

**Social Factor:**
Level of well-being of individuals and communities

**Economic Factor:**
Economic status of individuals, communities and nations

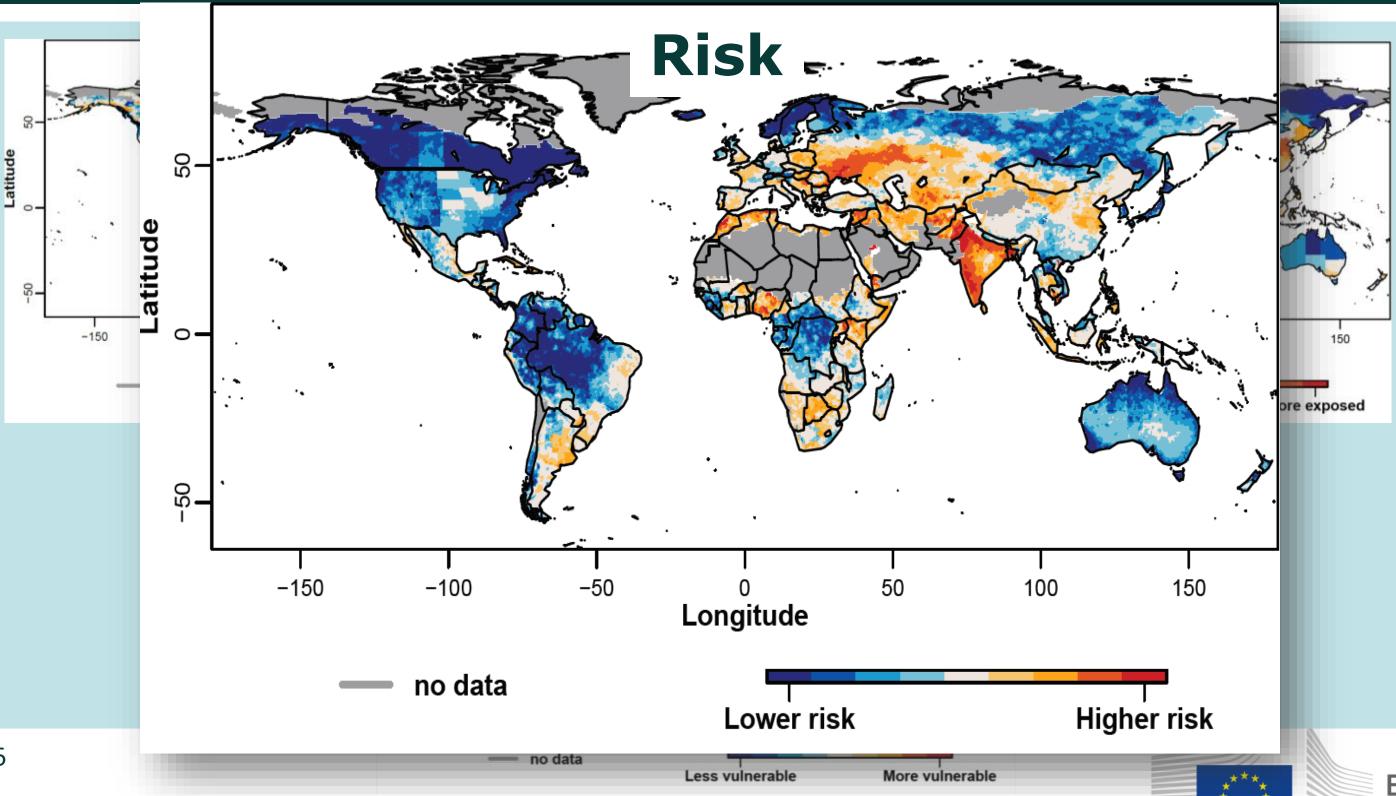
**Infrastructural Factor:**
Infrastructures needed to support the production of goods and sustainability of livelihoods




$$dv_i = \frac{Soc_i + Econ_i + Infr_i}{3}$$

# Drought Risk Evaluation

**Agriculture**




Carrao et al., 2016

# Drought Risk - Scale Dependency

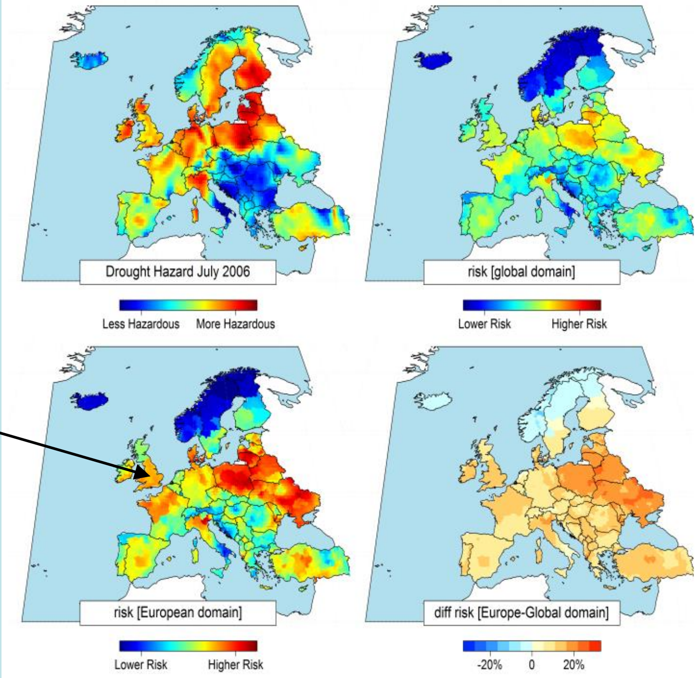
**Drought Risk computed with the contextual approach for different spatial domains**

Example for **July 2006** (Drought in NW Europe):

- Normalized SPEI-12 for JULY 2006 (top left)
- Vulnerability and exposure normalized at global level (top right)
- Vulnerability and exposure normalized at European level (bottom left)
- Difference between both (Europe-Global) (bottom right)

Low water levels at Derwent Water, Cumbria UK, July 2006

(Source Wikipedia)



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# Drought Risk: Hybrid/ convergent approach

- Risk assessment based on a combined statistical relation between impact occurrence and hazard/vulnerability factors (stepwise regression)
- Sector dependent
- Potential bias in areas with predominance of impact data or vulnerability factors?

Examples: Blauhut et al. 2016, Nuñez et al, 2017

# Hybrid/ convergent approach Example

**Risk (LIO) = Hazard x Vulnerability Factors**

$$\textbf{LIO} = \log\left(\frac{LIO_N}{1 - LIO_N}\right) = \alpha_M + \sum_i (\beta_{i,M} \cdot H_N) + \sum_j (\beta_{j,M} \cdot V_N)$$

*$\alpha$ & $\beta$ = model parameters by macro region*

*$H_N$ = selection of hazard indicators by NUTS region*

*$V_N$ = selection of vulnerability factors by NUTS region*

≤ 2 Hazard Indicators

≤ 3 Vulnerability factors

- Hazard predictors: **mix of long and short temporal aggregation**, majority covers summer month May- Aug (SPEI)
- Vulnerability factors: 40% describe **landsurface characteristics** related to agriculture & semi natural areas; 16% describe adaptive capacity
- ~**50%** of vulnerability factors quantify **water resources** or usage

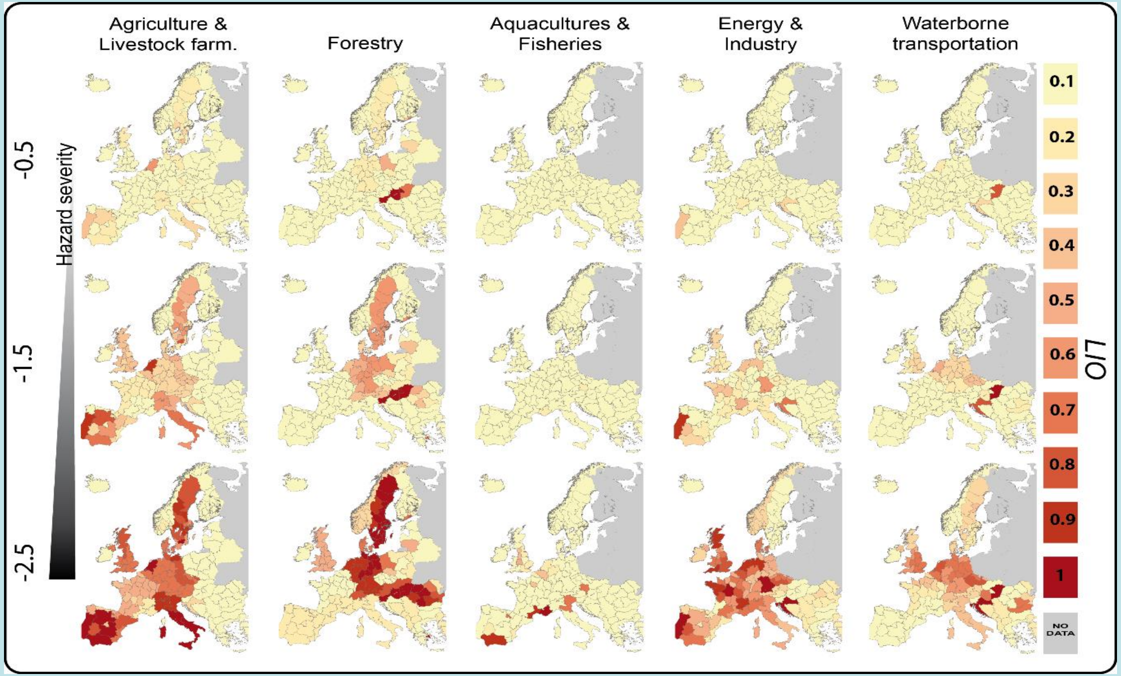
Blauhut et al. 2016

# Drought Risk Maps *(Hybrid approach)*

Near normal

Severely dry

Extremely dry




*Blauhut et al. 2016. HESS, 20, 2779–2800.*

Drought risk maps with the likelihood of impact occurrence (LIO) for three hazard levels of SPEI

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# Outline

1. **Presentation**
   - *JRC and DRMKC*
2. **Introduction**
   - *Drought and drought impacts*
3. **Drought trends**
   - *Recent past and projections*
4. **Drought Risk**
   - *Risk Concept*
5. **Approach to Drought Risk Assessment**
   - *Output, Contextual and Hybrid framework*
6. **Implementation Example (dynamic Contextual risk analysis)**
   - *Global Drought Observatory*



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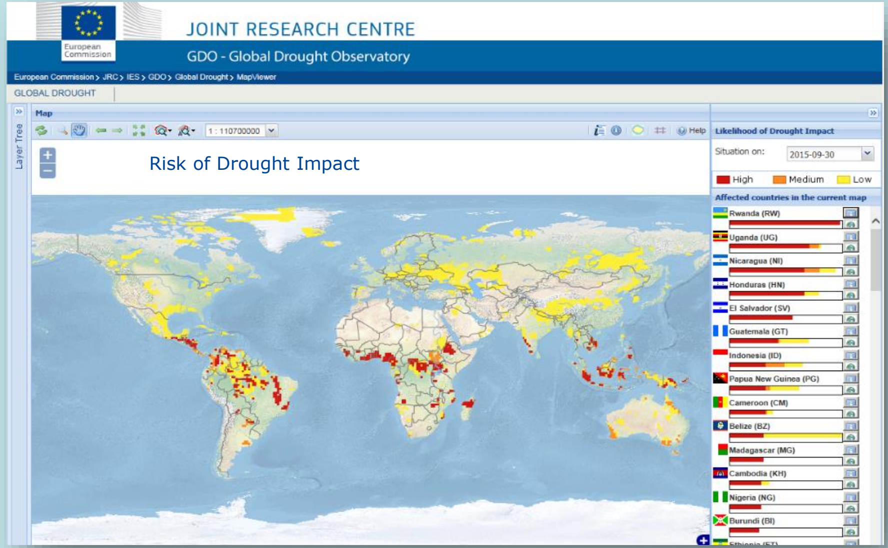
# Global Drought Observatory (GDO)




http://edo.jrc.ec.europa.eu/gdo

- JRC development for Emergency Response Coordination Centre (ERCC) at DG ECHO
- Targeted monitoring, forecasting and impact assessment for different sectors
- Based on sectorial risk assessment (hazard, exposure, vulnerability)
- Landing page: global map of RDrI for the Agricultural sector



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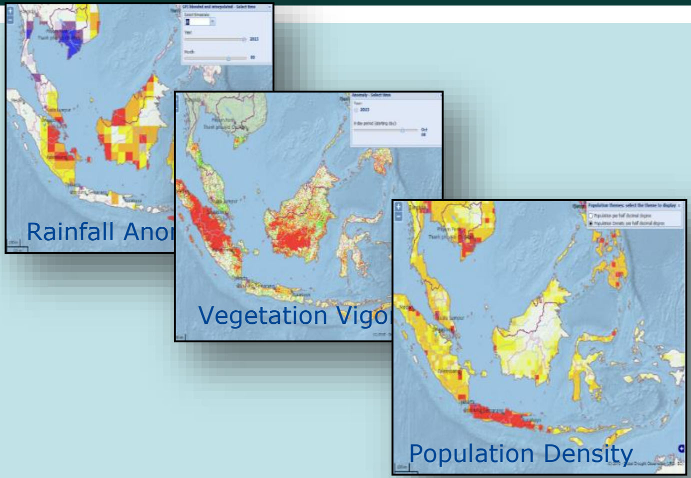
# Global Drought Observatory (GDO)

## *What is behind the GDO Risk of Drought Impact?*




(A) Drought Hazard

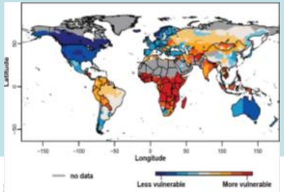
- Rainfall Anomalies
- Vegetation Vigor
- Soil Moisture Anomalies
- Temperatures
- Low Flows

(B) Exposure

- Population Density
- Agricultural area
- Waterways, Reservoirs, Power plants, etc.

(C) Societal Vulnerability

- Social Indicators (Age, Poverty, Infant Mortality, etc.)
- Economic Indicators (GDP, Energy Consumption, etc.)
- Infrastructural Indicators (Irrigation, Accessibility, etc.)



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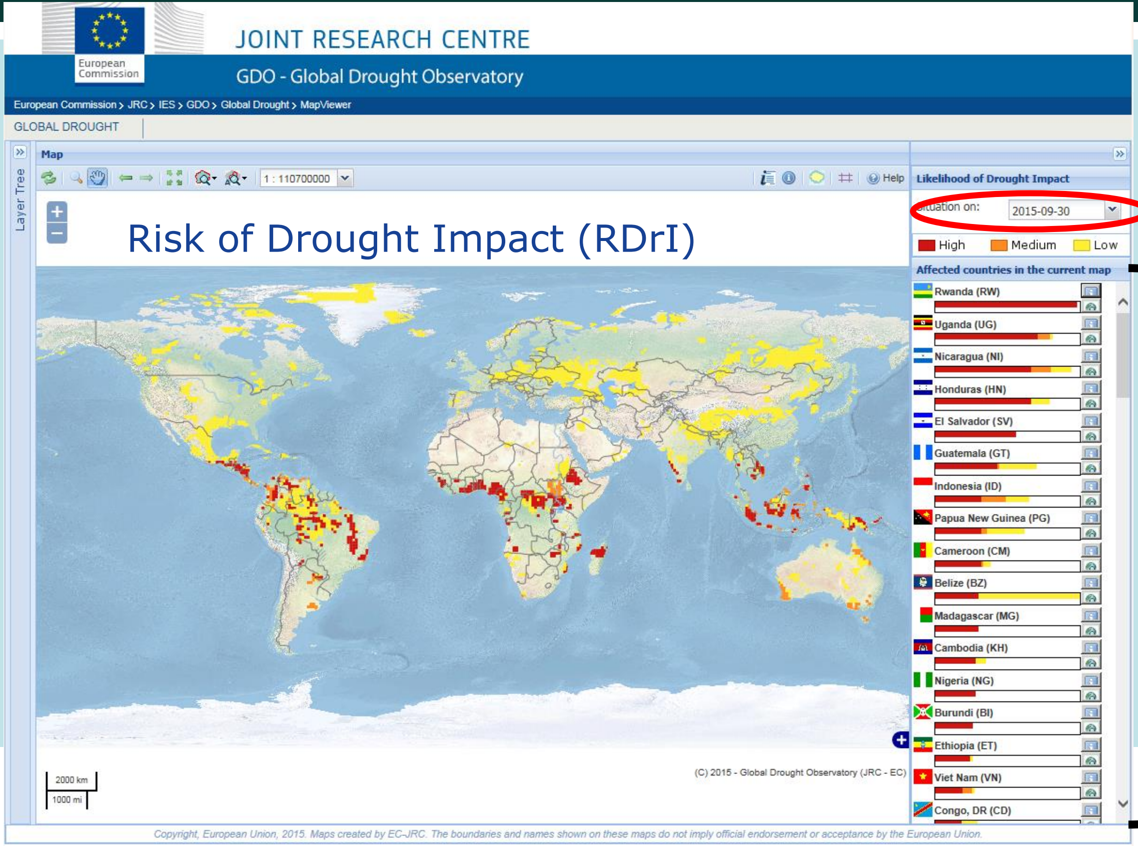
# Global Drought Observatory (GDO)

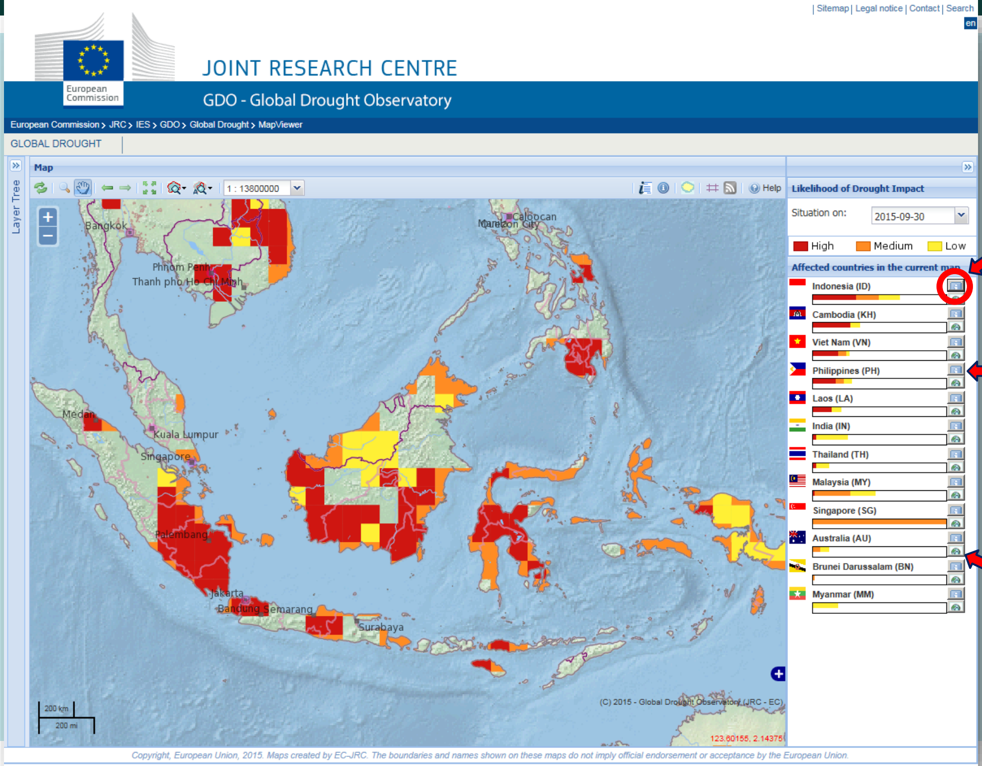



Dynamic Risk Ass.

Hierarchical list of affected countries (visible on the map)

# Global Drought Observatory (GDO)

## Country Summary




**Country details**

**Indonesia** — drought impact

Total area: 1.888.757 km$^2$
Population: 239.870.937
G.D.P.: 3.514,6
energy: 25,7
poverty: 16,2 %

| | population |
|---|---|
| 16 % (Low) | 39.098.963 |
| 17 % (Medium) | 41.257.801 |
| 32 % (High) | 75.559.345 |

**Country details**

**Philippines** — drought impact

Total area: 295.669 km$^2$
Population: 93.260.798
G.D.P.: 2.843,1
energy: 12,4
poverty: 19 %

| | population |
|---|---|
| 6 % (Low) | 5.688.909 |
| 6 % (Medium) | 5.502.387 |
| 17 % (High) | 15.947.596 |

**Country details**

**Australia** — drought impact

Total area: 7.687.151 km$^2$
Population: 22.268.384
G.D.P.: 61.887
energy: 283
poverty: 0 %

| | population |
|---|---|
| 7 % (Low) | 1.536.518 |
| 5 % (Medium) | 1.068.882 |
| 0 % (High) | |



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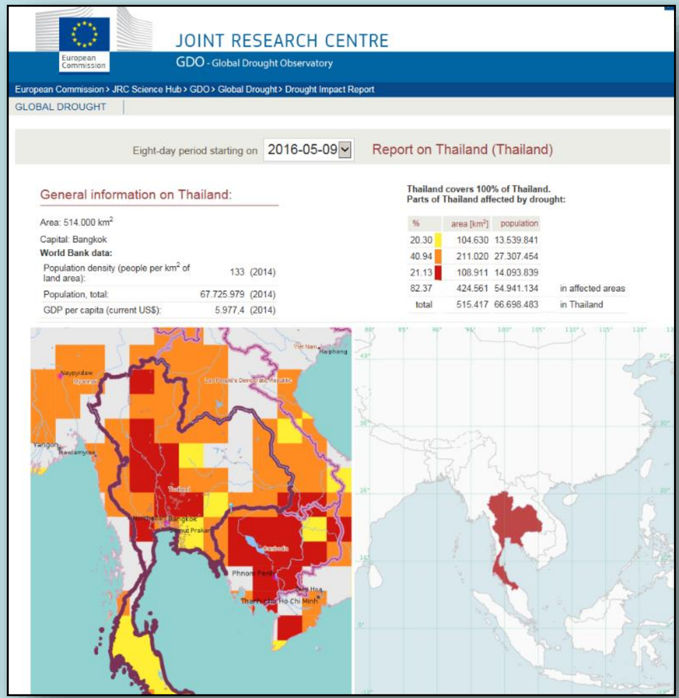
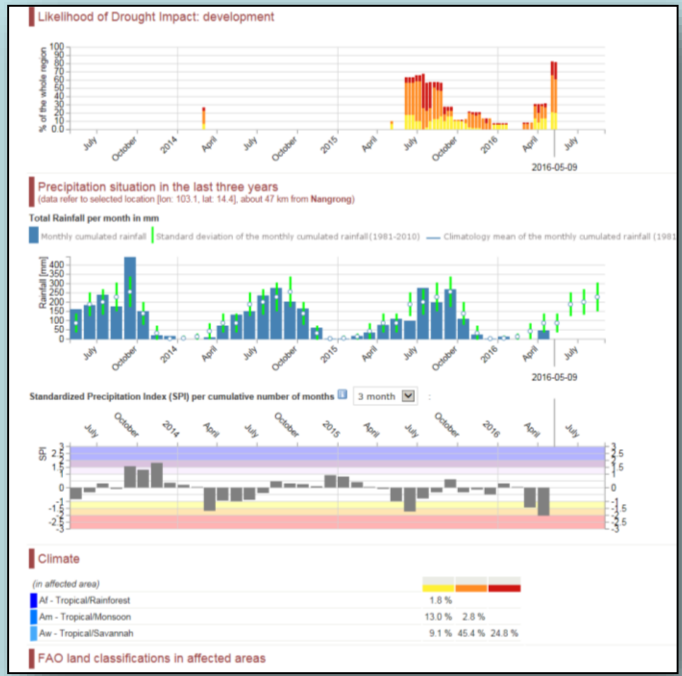
# Global Drought Observatory (GDO)

## Report Generation

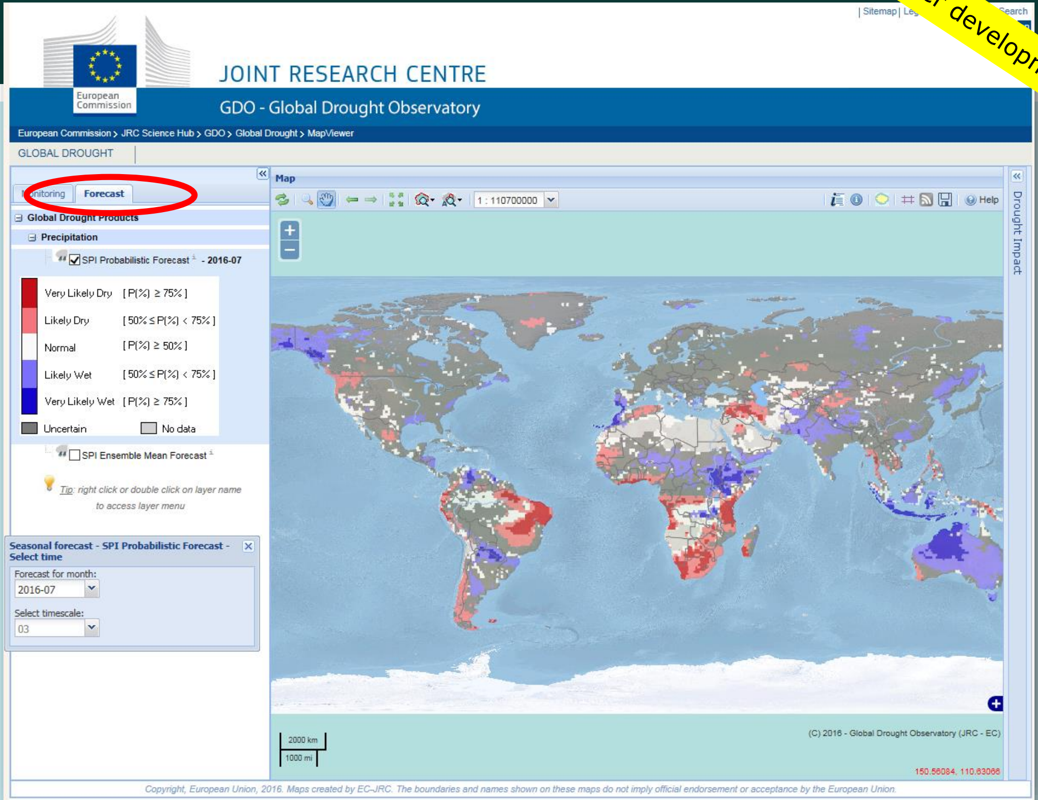



+ selectable pie charts on land cover types and other surface characteristics in the affected areas

# Global Drought Observatory (GDO)

## Probabilistic Forecasting




Forecast menu open

Probabilistic forecast of SPI-3 for July 2016

Based on ECMWF S4 seasonal forecast

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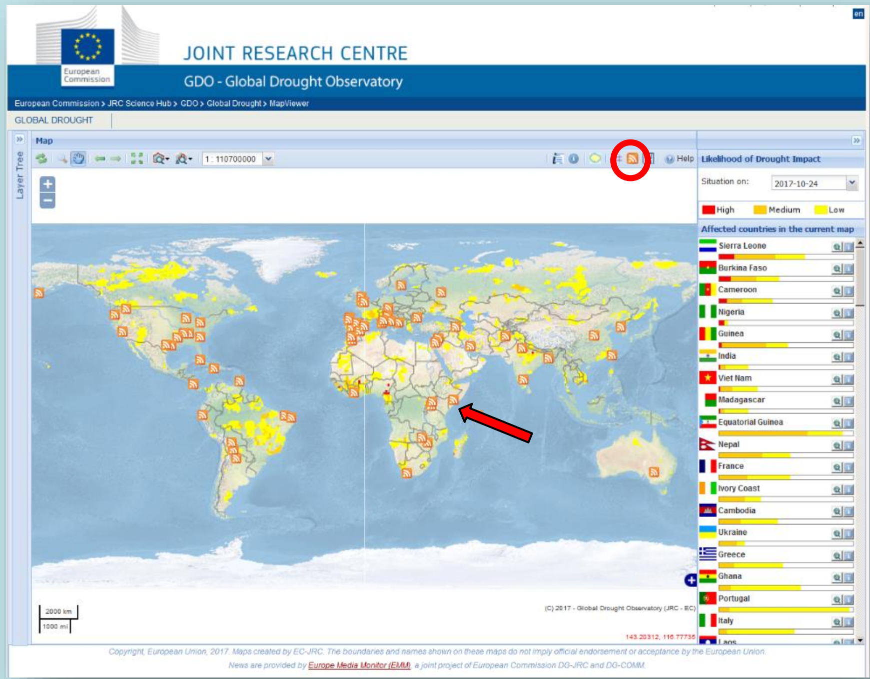
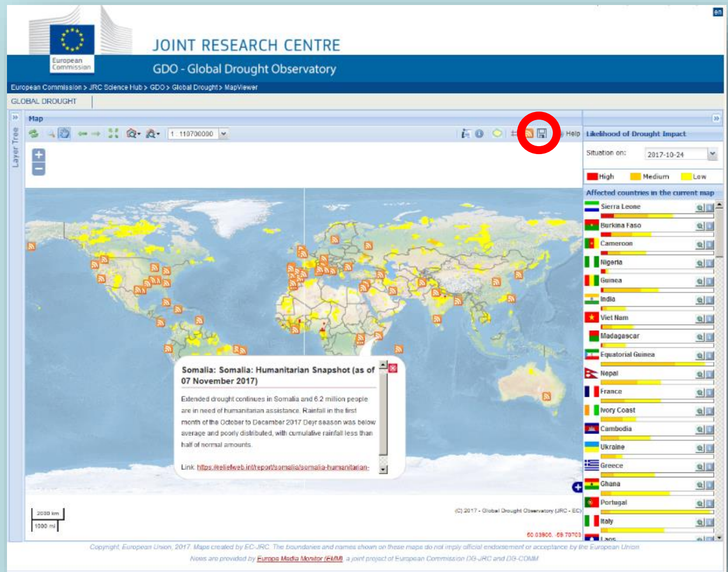
# Global Drought Observatory (GDO)

## Linking to Media News



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# Global Drought Observatory (GDO)

## Take home messages (1)

- Drought has wide-spread impacts in many different sectors
- Reducing drought impacts requires a paradigm shift from crisis management to risk management
- Drought risk management requires sector specific Drought Risk Assessments (DRA)
- The critical part of DRA is linked to the vulnerability assessment
- Approaches to DRA include:
    - Impact- based approach (outcome) → statistical
    - Factor based approach (contextual) → conceptual model
    - Hybrid approach → combination of both

# Global Drought Observatory (GDO)

## Take home messages (2)

- The impact-based approach suffers from a lack of high-quality, consistent and quantitative impact data
- The contextual approach is scale dependent and includes subjective factor weighting → expert & stakeholder knowledge
- The collection of qualitative and quantitative impact data is crucial for improving risk assessments
- Adequate spatially and temporally resolved exposure and socio-economic data are crucial for the contextual vulnerability assessments
- Sector specific conceptual risk models need to be developed

# Any questions?

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