DWD, LfULG Saxony, JRC and NOAA Collaboration Workshop

Sort-out Drought!

Dresden-Pillnitz, 16 to 18 November 2016

In brief: The workshop brings together the Deutscher Wetterdienst (DWD), the Saxon State Office for Environment, Agriculture and Geology (LfULG), the National Oceanic & Atmospheric Administration (NOAA), the European Commission (EC), the World Meteorological Organization (WMO) and other partners in the autumn of 2016 in Pillnitz, Saxony, Germany to present and develop best practices and climate services helpful to deal with droughts, being one of the most costly extremes in Weather and Climate with a strong potential of worsening with Climate Change.

Purpose: Droughts, defined as periods of abnormally low precipitation and negative water balance falling below sector dependent critical thresholds, have grown in frequency, intensity and extent in several regions of the world. There are strong national approaches and well developed services like the NOAA National Integrated Drought Information System (NIDIS) available in particular across the drought affected USA. Similar services are developing in Europe (EDO European Drought Observatory) and Germany, the latter hosting both, the Global Precipitation Climatology Centre (GPCC) operated by Deutscher Wetterdienst (DWD), and the German Climate Forecasting System (GCFS) for seasonal modelling, so we are at an opportune point in time to develop and provide similar and new global services in the field.

To advance our mutual goals it is necessary to collaborate and share lessons and best practices as a contribution to the WMO Global Framework for Climate Services. Challenges so far in that direction result from world-wide heterogeneous levels of observational information, the infancy of seasonal drought forecast, and a lack of harmonized methods, dissemination tools and user engagement, which in total appears as low-hanging fruit compared to other services.

A globally applicable early warning system for droughts, including a seasonal forecast, can be extremely effective in preventing famines, assessing socio-economic damages, and potential migration associated with droughts. As the WMO International Drought Management Programme (IDMP) has shown, many nations would welcome such an additional contribution to their own programs to enhance regional and local resilience. Towards that goal, NOAA, DWD, and EC (JRC) have started an exchange on drought event warning criteria and on exploring other supporting efforts such as data requirements, training and research collaborations, and on building a community of practice to share knowledge and experiences.

For the venue, we choose LfULG premises in Pillnitz, nearby Dresden in the German federation Saxony. Many parts of Saxony experience negative water balances in particular during summer. Climate projections indicate an increasing drought risk for this region and several sectors (e.g., farming) are susceptible to drought.

While the risk is lower than in the South-West US or Mediterranean Europe, the impacts of drought and high temperatures during 2015 have served as a wakeup call to Central Europe. The workshop will begin to integrate best-practices and successful examples from representatives of the at-risk regions (e.g. Texas, California, Spain, Slovakia, and Saxony).

In addressing severe drought periods in the U.S. Mid-West, Texas and California, the US has further enhanced and tested its end to end drought information system that enjoys a high level of acceptance. At the same time, the GPCC operated at the DWD has developed a globally applicable index for drought detection and starts validation of a seasonal forecast of this index through hindcasts for the previous 30 years. For Europe the JRC operates the European Drought Observatory Both of these nations and the EC continue to invest in and work to improve their capabilities that bear the potential for a global early drought warning system.

Workshop Goals:
1. Based on requirements of users from drought susceptible sectors, identify and prioritize needs for observations, monitoring, data, impacts and vulnerability assessments, and possible products to improve drought early warning and prediction systems.

2. Identify research that is needed to advance risk assessment, forecasting, and management of droughts, focusing on key sectors including agriculture and water resources.

3. Discuss ways to advance the foundational capabilities needed to achieve a global drought information portal based on a harmonized state-of-the-art approach.

4. Exchange information, best practices and lessons learned between the U.S., German meteorological associations, the JRC Ispra and the German Federal State of Saxony for developing and delivering effective drought early warning information systems and proper consulting for the economic sectors affected.

Session 1: Setting the scene: Sort-out Drought, Why now and here?

Introductory Remarks

- This is a workshop, not a conference!
- The workshop brings together a variety of expertise and experience from science, management and policy spheres
- The focus is on how we can work together to move from reactive drought crisis management to proactive drought risk management

Questions that are going to be addressed:

- What are the needs and what are our current capabilities?
- Why do some things work and other not?
- Where are the most important gaps?
- What do we need to do to improve on this?
- How do we bring this into the Sendai process, UNFCCC, GFCS, …

Robert Stefanski: Global Framework for Climate Services (GFCS)

- GFCS **priorities**: Agriculture, DRR, Water, Health, and (recently) Energy
- Enables better coordination and greater integration across disciplines, actors and sectors
- Builds on existing capacities → leverage them through coordination
- **Components**: Observation & Monitoring; Research, Modelling & Prediction; Climate Services Information System; User Interface patform; Capacity Building
- **Implementation** priorities: Capacity development (talk to the users!; twinning: Met-services with capabilities support these without); address gaps; observations and data recovery; partnerships across sectors; governance, leadership and management capacity
- Early implementation through focus on a limited no. of vulnerable countries → organisation of workshops
- Expected **benefits**: Better water resources management; improved disaster risk management; improved support for health sector; improved agricultural planning and management

Robert Stefanski: Integrated Drought Management Programme (IDMP)

- IDMP established 2013 by the HMNDP (APFM in 2001)
- Led by WMO and GWP
- Foster move from reactive to proactive management approach
- Draws on principles of integrated water resources management (horizontal integration)
- Fosters exchange of experience between global, regional, national and local level (vertical integration)
- Framework components: "Monitoring and EWS", "Preparedness and Mitigation Actions", "Vulnerability and Impact Assessment"

- World Meteorological Organization (WMO) and Global Water Partnership (GWP), 2016: **Handbook of Drought Indicators and Indices** (M. Svoboda and B.A. Fuchs). Integrated Drought Management Programme (IDMP), Integrated Drought Management Tools and Guidelines Series 2. Geneva.)
- Forthcoming:
  - Integrated Drought Management Framework Document
  - Publication on the benefits of action in drought mitigation (based on the results of a workshop in Sept. 2016)
- Global Drought Infromation System (www.drought.gov/gdm)
  - Includes an online Library (guidelines, tools, case studies, …)
  - Helpdesk under development (-> to be run together with APFM?) → core team at WMO that links to experts in IDMP partner organizations
  - 6 regional programmes

Discussion on session 1

- Cataloguing extremes
  → still work in progress; it is to be determined how the cataloguing in done in detail (e.g.; how to catalogue related extremes?)
  → idea: start simply and build it up more complex
  → build database for subsequent analyses (of the impacts)
- Should we not focus on the full spectrum of extreme weather events?
  → a certain focus on drought is necessary!
- Consider the multi-stressor aspects of drought impacts!
- Consider cascading or combined impacts of droughts and between different extreme weather events (e.g., heat stress and droughts)
- How can we characterize droughts and link this to the variety of impacts?
- Groundwater and stream flow are often not adequately considered!
- The challenge is the implementation!
  - → actively engage with decision-makers from the beginning (drought plans are in place, but people don’t care about them)
  - → this is often difficult (different contact points, staff turn-over, short-term priorities)
  - → why does it not work, what can we do to make it work?
    (e.g., be more effective in making use of the political time frame by addressing politicians in the 2nd and 3rd year after the elections with easy to understand one-pagers)

Session 2: Capabilities and Needs

Session 2a, Needs in Europe, US and on global scale

An Overview of the Global Drought Information System – Siegfried Schubert

- GDIS Goals
  - Improve Understanding of drought mechanisms and predictability
  - Advance regional information
  - Advance real-time drought information system
- GDIS Framework
  1) Drought Catalogue
  2) Monitoring and Prediction (real-time); with skill estimates, regular user feedback
  3) Case Studies – international collaboration, high profile recent events, involves users and researches, drive further research
- Key Science issues:
  - What are the (large-scale) drivers of drought?
  - Inter-seasonal predictability
- special collection of the *Journal of Climate*: Global Drought Information System – Drought Characterization, Occurrence, Driving Mechanisms, and Predictability Worldwide (GDIS Worldwide) → Schubert et al. (2014) Northern Eurasian Heat Waves and Droughts. http://dx.doi.org/10.1175/JCLI-D-13-00360.1
- How can we coordinate/advance drought research internationally, while at the same time engaging the user community to ensure relevance?
- Spatial – Time Scale Diagram showing the Landscape of Predictability
  → Limited Overlap between User Needs and Current Skill in the diagram

  Research to move the current skill towards the user needs by
  - Higher resolution, Rossby waves impacts, land atmosphere-coupling, land initial states, improved seasonal cycle (atmosphere and land), weather extremes
  - Improved ENSO prediction and regional response, soil moisture, snow observations
  - Decadal prediction, global warming impacts, role of land use changes and aerosols
- Ask for public-private partnering; US partnership to increase resilience; Resilience dialogues with users;

Discussion:

- Inform GFCS on these developments
- R. Stefanski: Link WCRP Programmes with the Predictability assessment of GDIS
- Case Studies of Flash Droughts show that sub-seasonal scale (Rossby-Waves) play a crucial role
- P. Becker: Likes the Predictability map very much; Skills are related to ENSO but NAO still hard to predict which is important to Europe,
- Land Memory effects are important, NAO has also sub-seasonal time scale and hard to predict, links to SST not too much understood yet
- Persistence of droughts well predictable but onset is still a big challenge

- End of droughts depends on Rossby Waves and land surface information
- C. Prudhomme: Land and ground memory information is crucial and can help improving the predictability

Drought Monitoring and Forecasting in Europe and Globally: Needs and Experiences of the EC – Jürgen Vogt

Needs:

- More sector specific impacts indicators needed
- Set of standardized drought indicators to be completed
- Forecasting and seasonal prediction to be tested and implemented
- Maps on drought hazard and risk (current and future)
- Vulnerability and risk assessments for different sectors
- Up-to-date data for the calculation of exposure and vulnerability
- Standardized data on drought events and drought impacts (links between them?)
- improved forecasting and prediction
- Better links between scales, e.g. continental, national, regional, local observatories
- Regular meetings of user & expert networks

View of the EC on the needs and the experiences in the EC

Drought characteristics:

- Onset challenge, creeping phenomenon → Propagates slowly through the hydrological cycle (rainfall, soil moisture, groundwater, reservoirs, river flows)
- Sector specific definitions
- Substantial damage potential 3 Billion€ / year now, 13 to 27 in the future due to CC
- Variety of impacts, Blauhut et al, 2016, Stahl et al., 2015 on impact diversity in Europe according to report survey

EU Policy Makers (DG Civil Protection and Humanitarian Aid (ECHO), Regional and Urban Policy (REGIO), International Development and Cooperation (DEVCO), Agriculture and Rural Development (AGRI), Environment (ENV), Climate Action (CLIMA)

European Drought Observatory (EDO)

- Customers: National Authorities, River Basin Authorities, Local Water Mangers, Industries (Energy products, tourism, food sector,)
- Overview on Drought Monitors in Europe (Scattered) → EDO to Harmonize on the European Scale
- Web-based Platform
- Continental Scale Indicators
- Every indicator is accompanied by a fact sheet
- Combined Drought Indicator (CDI) for Agricultural Drought

Cause-effect relationships and related warning levels

- WATCH (Precipitation Shortage)

- WARNING (Soil moisture deficit)
- ALERT (Reduced vegetation)

Feedback

- Partially positive:
  - from EC services, from national and regional organizations, from industries,
  - Drought reports are heavily downloaded
  - In 2016 the European system yielded 56k page views from 11k users
- Deficits
  - Enlarge the set of standardized indicators → More sector specific combined indicators
  - New network to be established → more links to national, regional, local observatories to be established
  - Yearly user & experts meetings
  - Add „static“ maps on drought hazards

Global Level

- Currently no comprehensive global system for drought monitoring and early waning)
- Different systems provide individual indicators (e.g SPEI Monitor, GPCC drought indicator)
- Continental monitors to be synthesized

Global Drought Observatory (GDO):

- Evaluates likelihood of drought / impacts based on drought severity (drought indices), exposure and societal vulnerability (multitude of societal indices)
- Done at national level (pdf-reports can be downloaded); possibility to “zoom in”

Discussion

- R. Stefanski: How do you reconcile national drought monitoring capabilities in EDO.
- J. Vogt: EDO links into these areas, but water-sheds are international (14 countries share the Danube)
- R. Stefanski: GDO with the same approach?
- W. Higgins: Terminology (Watches, Warnings, Alerts). How do you deal with them?
- W. Higgins: Security question deferred to Breakout Groups

US presentation I: Building Drought Resilient Communities in Montana – Shaun McGrath

- Vision of the Montana Demonstration Project: Successful drought preparation must be
  - Locally-led
  - reflect the water management issues specific to that watershed, and
  - produce on-the-ground results
- Demonstration Project in Missouri High-Watershed with size of Saxony and Saxony-Anhalt
- 12 Federal Partners, 4 state agencies, 20 watershed groups, etc.
- Work-Plan:
  - Provide Tools for Drought Monitoring, Assessing and Forecasting

  - Develop Local and Regional Capacity to Plan for Drought
  - Implement Local Projects to Build Regional Drought Resiliency

- Include drought in mitigation plans
- How can we sustain a proactive approach during times without drought impacts?
- Lessons learned:
  - Hard to do
  - Massive collaboration – takes a lot of resources
  - Takes leadership (changes in leadership might be critical)
  - Takes resources
  - Takes some vision

US presentation II: Drought Risk Management Around the World– Mike Hayes

- Successful drought policy is based on three pillars:
  1) Monitoring and Early Warning
  2) Vulnerability and Impact Assessment
  3) Mitigation and response
- NDMC’s Drought Impact Reporter → users submit reports (> 900 per week, review process for the reported impacts is ensures)
- Complex network graphic on the linkages between drought and mental health outcomes
- Need to identify stakeholder and decision makers critical for success in advance of drought → drought exercises and tournaments

Session 2a Discussion on the Sustainability of the user relationship

- Users are experts in droughts (at least those in agriculture, maybe not water managers in municipalities) and importance of Indigenous knowledge
  → Co-design solutions and avoid confrontation of interests
- Bottom up reports in the monitoring scheme
- Cross-information among users and user-groups
- Regional collaboration groups
- Consistent leadership in Montana on Drought issue regardless if rep or democrat governor
- Does better communication automatically lead to better decisions?

Wayne Higgins: Improving subseasonal to seasonal prediction – A critical timescale for Drought Early Warning

- Bridging the gap between weather and climate predictions
  - Fully coupled air – ocean – land – ice modelling system
  - Improved data assimilation
  - Improved process representation and higher resolution
  - Reanalyses and reforecasts
  - Multimodel ensembles

- Field campaign to Understand MJO (DYNAMO: Dynamics of the Madden Julian Oscillation)
- Understanding atmospheric rivers (AR), which are important for drought breaks – predictability?
- Studies for experimental decadal prediction (e.g., understanding AMOC)
- Integrated Information System (IIS): 1) observations and monitoring; 2) Earth system science and modelling; 3) communication, education and engagement; 4) societal outcomes

Session 2b, Needs in Central Europe

Mirek Trnka: Monitoring of Aridity and Drought in Central Europe through INTERSUCHO

- Short introduction on Research facilities of Czech Globe (high intensity sites, field crops and bioenergy experiments, etc.)
- Credo: From interesting to useable
- Example: wheat – maps show increasing risks over Europe (work with manipulation experiments)
- Importance of perception: Same data → different responses
- **Drought trends** (in CZ) (e.g.; http://www.klimatickazmena.cz/en/)
  - Are the climate dice loaded?
  - Increase of areas affected by droughts in CZ observed
  - Observations for 1805–2012 → increase in last 3 decades
    Drivers of change: e.g., synoptic situation (from April to June increases in drought driving atmospheric pattern observed)
  - from 1500 to today strong temporal variability in grape harvest and a drop in the most recent decades
  - Climate models agree on increased drought risk over Europe during the 21st century
    → based on a five model ensemble a shift to a drier climate was shown within the next 20–30 years
    → water stress level will increase particularly during April to September
  - Decreases in snow cover projected in addition

  ➔ Important to communicate this to the farmers
- Why is agricultural drought important? → The Worlds grain trade depends on exports from a few countries.
- What to do? **Monitor and act!** → Drought monitoring system implemented (www.intersucho.cz)
  - tries to be user oriented – listen to users
  - calculates soil moisture (soil moisture model was constructed around the available data)
  - high resolution maps (500 m) → farmers can find their farm
    (We know that we are going over the edge with this resolution)
  - use data of 200 climate and 400 rainfall stations
  - combine drought monitoring data with portal on climate change information
  - combination with google maps
  - uses remote sensing data → status of vegetation (EVI from Terra satellite, 5 km resolution)
  - reported drought impacts (farmers fill forms on observed drought impacts)
    farmers are fairly pessimistic about drought (more pessimistic than the monitoring system)

- drought forecast based on 5 models (EMCWF/IFS, NOAA NCEP/GFS, CMC/GEM, UKMET/ Global UM, CNRM/ARPEGE) → precipitation forecast uncertainty is fairly high, but drought has a high persistence
- long-term statistical prognosis → outlook for 1, 2, 3, 4 weeks
- system runs also for Slovak republic (www.intersucho.sk)

- idea: Central European monitoring platform (as there are specific drought characteristics and impacts in Central Europe compared to Northern and Southern Europe)
- Czech Adapt – adaptation to drought and climate change
- Statistics on the website-use show that there are peaks during the vegetation period, particularly if there are drought conditions

Discussion

- Mark Svoboda asked for the required measure of success by farmers.
  → M. Trnka: can’t give a hard number. The farmers use the system as an input for their decisions that are strongly based on existing local knowledge
  → Iglesias: The farmers know their vulnerability and are able to compare it to the numbers a climate service provides. The knowledge for the decision is available locally and it is important to provide them the numbers to back-up their decision.
- L. Tallaksen is impressed by comprehensiveness of the system and asks, if there are plans for expanding the system to hydrology sector? → M. Trnka: This is the workside of the Czech Hydrological service.
- M. Trnka points out a special issue in climate research (CR Special 33 Drought in Central Europe – from drought response to preparedness, Vol 70 2-3, October 2016).

Jaroslav Vido (Department of natural environment): Interactive drought monitor – tool for transfer of drought risk knowledge into education and praxis

- Boom in drought monitoring, basic and applied research on drought as well as political declarations, but there seems to be a disconnection and/or misunderstanding between academia and praxis. This might be related to wrong research targeting and/or mistakes in education and training by universities
- Way out? → Interactive drought monitor
  - Start discussion with praxis
  - Students as future specialists – internal part of interdisciplinary discussions
  - Promote how to use drought information
  - Incorporate agro-forester into drought monitoring
  - Educate students in praxis
- Methods:
  1) Change of dictionary towards the people
  2) Explain what is drought (e.g. hydrological cycle)
  3) What are drought indices and how to interpret them?
  4) What are your problems?
  5) Simple version of drought monitor (SPI, SPEI – mostly educational purpose)
  6) Educate students in real challenges through interconnection with praxis

- Act locally, think globally → cooperation in H2020?

Discussion:

- L. Tallaksen points out the big difference between the perception of drought in CZ and Slovakia transported by the presentations of M. Trnka and J. Vido.
- M. Trnka: more severe drought impacts in CZ than in Slovakia in recent years → changed attitude towards drought
- J. Matschullat points out that there are also differences in the cultural traditions of the countries that influence their self-conception
- J. Vogt addressed the importance of the scale, which determines the index choice
  - Awareness rising indicators → for political/administration level
  - Management indicators for farmers level
- K. Stahl stresses the importance of local data/information
- R. Webb: addresses the different temporal perspectives of different stakeholders;
  - farmers are interested in the next 1-2 years, but also in the the mid to long-term perspective
  - there is interest in the long-term development if long-term investments are involved
  - water consumption in 2050 is of high relevance in the hydrology (water management) sector,
- J. Matschullat: parts of industry not fully aware of implications of climate change for their business although this strongly influences their investment strategies → still need to show people why it is of relevance

Tamara Tokarczyk (Institute of Meteorology and Water Management): Drought Monitoring in Poland

- Introduction on IMGWs operational components and products and services (hazard assessment, risk analysis, early warning systems, sectoral and operational planning)
- National stakeholders (government, non-governmental organizations, etc.)
- Risk assessment – risk reduction – risk transfer
- Drought effects (cascade from meteorological over agricultural and hydrological drought towards socioeconomic drought)
- Drought hazard assessment via POSUCH@ Webpage
  - Use of different indices (Effective Drought Index EDI, flow index (flow duration curve), SPI and SRI (Standardized Runoff Index; based on observed streamflow → Standardized Streamflow Index SSI would be the correct naming) at different timescales)
  - Daily time step for some indices like EDI and monthly for others like the Standardized Precipitation Index (SPI)
  - The system is integrated in the existing IT-infrastructure
  - Detect various stages of drought (by the use of different indices and timescales)
  - some information is station based
  - Mapping of droughts spatial distribution (information can be also displayed for different districts)
  - Presents drought information in maps, graphics and tables
  - Includes a forecast (e.g., 3-day-forecast for EDI)

- Probabilities of moving towards dry, normal, wet conditions used for long-term drought hazard prediction
- Climatological vulnerability is addressed– expected return period (severe and extreme drought)
- Shows long-term trends of meteorological/hydro conditions for entire country
- Combined analysis of SPI-SRI using 5 classes of moisture and drought hazard level

Discussion

- M. Trnka asks if there is coordperation between POSUCH@ and the existing agricultural drought monitoring system in Poland → cooperation just started with the POSUCH-system
- A. Becker: The data show a strong decadal variability. How can drought trends be better visiulized?
- H. van Lanen: handling of non-stationarities in the SSI series due to human influences in the river basins? → only use stations that have been tested (homogeneous ones); stations representing natural conditions in the rivers
- H. van Lanen points out that these undisturbed basins are mainly upstream, while the impacts are much stronger in the more urban downstream areas → the information obtained for the gauges representing natural conditions might be biased
- Tamara: POSUCH@ aims at a general drought evaluation and no a specific sector; an evaluation of water scarcity aspects is not within the scope of the portal

Andreas Völlings: Climate Change – Options for estimating the trend of drought characteristics in Saxony – state of regional level

- Short presentation of the Saxon State Agency for Environment, Agriculture and Geology (LfULG) → no research institution, but technical authority to collect and support scientific information
- Build on the expertise of mainly three regional research institutions TU Dresden, TU Bergakademie Freiberg and CEC Potsdam (+DWD) that are actually doing the regional analyses
- Legal and administrative basis of the work of LfULG
  - Saxon Program on Energy and Climate 2012 (Energie- und Klimaprogramm Sachsen)
    - Analyze regional climate development
    - Identify vulnerabilities, estimate climate risks and impacts, develop adaptation strategies
    - Promote research, strengthening of knowledge and development of cooperation
  - Regional Climate Information System (ReKIS)
    → assembles all existing information on the regional climate development
    - Climate analyses for 1981–2010 vs. 1961–1990 show different precipitation trends between the first (April, May, June → decrease) and second vegetation period (July, August, September→ increase)
    - Increases in heavy precipitation (R90p, R95p) during the second vegetation period from 1961–1990 to 1991–2015 (→ may be connected with erosion → challenge for agriculture)
    - in the last 3 years Saxony has experienced a comparatively high temperature level in combination with significant water deficits
- 2 research projects on the meteorological characterization and analysis of drought
  - 100 drought indices described and categorized

- spatio-temporal drought analysis conducted (→ strong increase of severe and extreme drought conditions during the first vegetation period)
- first steps for linking drought indices with observed impacts
- stakeholder interviews on their needs of drought information

- Next activities
  - Satisfy the needs for a good and stable data base (long-term observations – medium term forecast [MiKlip] – long-term projections) → Set up reference data set for observations
  - Enhance the use remote sensing data for evaluating drought conditions at ground
  - Combination of drought characteristics according to stakeholder needs

Discussion

- C. Prudhomme: What about the winter rainfall trends? Isn’t winter rainfall important for the recharge of the aquifers? → Yes it is and winter precipitation in Saxony shows a positive trend with an increase in liquid over solid precipitation, which strongly influences regional water regimes
- Van der Schrier: Are the users also interested how an actual events compares to the historical series, e.g. by providing time series data
  → discussion showed that this depends on the different disciplinary perspectives of drought
  - K. Stahl: experiences from a recent workshop in the UK show that there is great interest in historical analogues
  - M. Trnka: Farmers don’t think that strongly in analogues, as their operational cycles are shorter

Session 3a: Demonstrate Capabilities of EC, Germany, US, and Saxony: Monitoring and Prediction

Christophe Lavaysse: EC Capabilities in drought monitoring and prediction

- Background**:**
  - Have a strong expertise in monitoring at JRC, using various ground-based and satellite observations, and combined drought index
  - To complete this product need to complement with forecasts that are adaptable, seamless, comprehensible and reliable (at various lead times)
- Monitoring**:**
  - precipitation (SYNOP,GPCC) – SPI, snow pack
  - soil moisture (modeled, LISFLOOD)
  - vegetation status (MODIS)
- Forecasting:
  - SPI from ECMWF ensemble forecasts (51 members twice a week up to 45 days)
  - Skill score is key!

1) *Forecast flash droughts*: SPI -10 day, dry spells/flash droughts
   - Relevant for rainfed agriculture

- after 15 days no skill in Europe,
- skill is region dependent, e.g., worse in Africa

2) *Drought forecasts (1 month), SPI-1*

- relevance – stages of crop growth; onset, extension and end of long term drought,
- testing different indices, statistics (mean, quantiles, ensemble spread), also testing use of weather regimes (based on height fields) to predict meteorological drought – shows some promise
- Key issue: How to assess uncertainties?

3) *Forecasting long term drought*

- currently very little skill in precipitation forecasts
- need to develop other predictors – e.g., oceanic

Markus Ziese: DWD Capabilities in drought monitoring and prediction

- National monitoring – support for agrometeorology
  - SPI, STI (Standardized Temperature Index) – based national observational network
  - SCI (Standardized Combination Index), SPEI and flash droughts, under development
  - For flash droughts – soil moisture – research status
  - Monthly calculation of SPI,STI, SPEI and SCI
- Global drought monitoring – support for climate science and relief organizations
  - GPCC-DI (combination of SPI and SPEI) gridded precipitation and temperature data
    - Precip from GPCC, Temp from CPC
    - Aggregated 1, 3, 6, .. - 48 months
    - Operational since 2013
- Global drought climatology – support climate science
  - 1952-2013, from GPCC and CPC data DI
  - Aggregated 1,3, 6, .. - 48 months
  - Allows computing anomalies, trends in drought GPCC- DI <=-1
- Global drought prediction – support for relief organizations
  - GPCC-DI based on seasonal forecasts
  - DWD seasonal forecasting system – model MPI-ESM
  - ensemble mean evapotranspiration and precipitation
  - flash drought: soil moisture < 40% available field capacity; STI > 1

NOAA Capabilities in drought monitoring and prediction (Robert Webb / Mark Svoboda)

Mark Svoboda on the US Drought Monitor:

- drought monitor – since 1999, collaborative effort (NOAA, USDA ,NDMC) – 12 authors, **400 experts on ground for sanity checks**, now integrated in farm bill
- 5 drought categories defined: based on ranking percentile – allows combining disparate data

- product is based on **convergence of evidence** – many types of drought information, experts add information – started in 1999 using (snow, SPI/PDSI, soil moisture, streamflow, expert local input, remote sensing)
- now have more robust information - 50-60 indicators, at least 400 experts
- impacts – drought impact reporter (DIAR) – since 2005 42,000+ media reports, and 21, 000+ impacts in database - agriculture and water supply/quality have most of the impacts
- bringing in new products
- final thoughts for DEWS: emphasized the importance of monitoring to the forecast problem

Robert Webb on US drought forecasting and prediction:

- reviewed links between ocean, atmosphere, land (the hydrological cycle), emphasizing that drought is associated with precipitation deficits, soil moisture deficits, stream flow/ground water changes.
- Why do some regions have more droughts than others? – one explanation is the sensitivity to SST changes for some regions – e.g. ENSO (e.g., western US/California and southern Great Plains are impacted)
- it was noted that monitoring should include the monitoring of SSTs for droughts lasting a season and longer (at shorter time scales soil moisture and moisture fluxes may be more important)
- Drought prediction - requires atmospheric, oceanic, and land initial conditions; forecasts of say T, P require bias correction and in some cases down-scaling
- Seasonal forecasting at NCEP-CPC:
  - use reanalysis, dynamical and statistical tools to produce forecasts
  - final products: biweekly NOAA drought outlooks, based on various short and long term forecasts including both dynamical and statistical methods that are "mashed" together; this is combined with the drought monitor to produce the final drought outlook.
  - reviewed the various forecasting tools including NMME
- Showed example of forecasting to inform reservoir operations – they used forecast guidance to optimize water usage (emphasized importance of forecasting short term extreme precipitation events)

Outlined priorities:

- simulate climate variability and impact on drought (How well do operational systems exploit the known climate variability–drought relationships?)
- Sub-seasonal to seasonal timescales – Are some flash droughts more predictable than others? (opportunistic forecasting)
- post processing strategies
- land initial conditions and modeling
- communication and linkages

Proof-of-concept project EDGE (Christel Prudhomme)

- EU Copernicus initiative on seasonal forecasting and climate change projections – should be operational in 5 years; funding various proof of concepts

- Christel has one of the projects dealing with stakeholder engagement
  - 3 focus regions with different stakeholders (Norway, UK, Spain)
  - 4 workshops within 2 years,
  - use existing tools (no research)
  - seasonal outlooks 1-6 months (NMME, ECMWF products), various hydro models
  - climate projections – focus on a couple of different scenarios, should be modular enough to allow easy use of new tools as they become available
  - Perform case studies to assess usefulness (e.g. 2003)
  - emphasized importance of producing uncertainty/skill estimates
  - display information in web delivery systems (adjust the interface based on stakeholder dialogues)
  - document lessons learned

General Discussion:

- For US - Suggest focus on forecasts of opportunities – e.g., atmospheric rivers/MJO link – to help river water managers, can help with onset and persistence of drought
- US drought monitor – question about the nature of the 400+ experts (they are volunteers, no contract, are vetted, promise to embargo info before release)
- Flash drought – no uniform definition
  - Characterized by low soil moisture, high winds,
  - evolves quickly – not necessarily short,
  - often connected with agricultural and ecological drought

  → suggestion: work towards better definition
- Soil moisture versus soil moisture storage (take advantage of slower time scales)– need to improve global hydrological models
- What about the North American drought monitor? Started 2 years after US monitor, now have more common indicators but still lack the capability to produce products weekly (still only monthly)
- Impacts monitoring → move towards predicting impacts needed to inform policy makers (they understand that more)
- Definitions – early warning system
  - needs to be both monitoring and prediction
  - monitoring is very important to that – best forecast we make is a nowcast!,
  - taking advantage of slow drought onset
- While SPI doesn’t work in dry regions, there is increased evidence that SPEI also does not work in dry regions – too strongly linked to T
- Regarding various indicators of drought – key issue is to use a convergence of evidence (as is done in the US drought monitor)
- Need for verification on the global scales

Session 3b: Demonstrate capabilities of EC, Germany, US and Saxony: vulnerability and impacts assessment

Hugo Carrao: Drought exposure, vulnerability and risk assessment at the global scale

- Framework for modelling global drought risk
- Definition of Risk (likelihood of drought impact)
  = hazard (probability of exceeding a drought event with a certain severity)
  * exposure (amount of population, livelihoods, assets, resources, services, etc. that could be (in)directly affected by a drought)
  * vulnerability (Propensity of individuals, groups and/or nations to suffer adverse effects when impacted by a drought event)
- Statistic for ranking regions following the hazard – exposure – vulnerability for several applications (humanitarian aids …)
- Calculation of the exposure at global level with different resolution and based on proxy indicators:
  - agricultural droughts (data on crop and livestock production)
  - hydrological droughts (data on offtake water rates in relation to normal operations)
  - socio-economical droughts (relationship between demand and supply)
- derive composite measure of drought exposure
- multiscale approach (output maps are focused on a specific scale and may change if another scale is addressed)
- Proxy indicators of vulnerability factors:
  - social (level of well-being of individual and communities)
  - economic (economic status of individuals, communities and nations)
  - infrastructural (infrastructures needed to support production of goods and sustainability of livelihoods)

→ likelihood of drought impacts mainly driven by the regional magnitude of exposure

→ Infrastructural capacity relatively low for all risk classes

- Perspective: definition/optimization of thresholds and triggers/weighting of indicators based on experts

Taryn Finnessey: Agricultural economic impact assessment after drought

- Impacts of droughts in Colorado:
- Colorado is very sensitive: past events (especially in the Eastern Colorado) + climatological trend toward an increase of droughts
- Quantitative and qualitative vulnerability assessment
- Objective: Assess the economic impacts of the droughts and more specifically the drought occurred in 2012.
- strong direct/indirect impacts of livestocks, crop producing (-48% of cows, increase of price …)
- Adaptation ?
- Some changes of production during events over regions regularly affected.

- Final cost of the drought in 2012:
  - direct (only 2012) ~ 400 000 000 $
  - direct and indirect (2011-2013) ~ 726 000 000 $
- Alter production practices before/durin drought → Take action to
  - decrease expenses
  - increase cash flow
  - increase asset turnover
- *“Everybody* wants *monitoring information, but no one wants to pay for it”*

Rodrigo Maia: Drought vulnerability and impact assessment in transboundary river basins

Drought vulnerability and impact assessment in transboundary river basin.

- Comparison of drought management in Spain and Portugal according to the EU water framework
- How do the countries manage the water resources
- Albufeira convention → established flow regime that defines minimum inflows at the border (not applicable in exceptional years)
- Comparison of the two countries for :
  - drought monitoring (same standards)
  - drought management (during current situation/declared drought situations)
  - socio-economic impact assessment.

Some remarks:

- drought monitoring and planning management (2 different stages for the two countries)
- common set of drought indicators
- need to adapt minimum flow regimes
- needed: link water quality aspects of the Water Framework Directive to water quantity aspects connected with drought

Kerstin Stahl: Towards impact prediction: lessons from exploring links between drought indices and drought impacts

- review on drought information systems and their use of drought indices published in WIRES (DOI: 10.1002/wat2.1154)
  - most systems use precipitation based indices (less often used are agricultural, hydrological and groundwater drought indices)
  - 54% of studies on drought collect data on drought impacts but not automatic, not very detailed and some uncertainties.
- Data collection in Europe with spatio/temporal profiles
  → European Drought Impact Report Inventory
  - Source of information → location → impact occurrence → impact categorization → Archive
  - Produce a large archive of events and linked with impact categories
  - Textual evidence links cause (drought) and effect (impact)
  - Coding guaranties consistency

- Use of damage functions:
  - linking a damage variable to the hazard intensity
  - start with impact functions (as economic impacts are hard to quantify)
  - impacts diverse / regions
  - still key challenge to make it compatible
- Results: overlap of the scatter plot of SPEI/likelihood of impacts → not easy to separate damage/no damage → need to think in probabilistic terms (deal with the noise in the data)
  - Impacts may persist during wet conditions (e.g. water restrictions due to low groundwater levels)
  - Consider lags in the occurrence of impacts
- Development of a model to catch the damages and can decompose / sector
- To get a complete explanation of the damages need to use different cumulative periods (short time SPEI for beginning, long term for capture the complete duration of damages)
- Historical analougues → reconstruction of drought beyond the indices

Lena Tallaksen: The European drought impact report database (EDII) – A quick survey on recent developments and new features

- Short presentation on the EDII and the EDC website.
- Bottom up initiative started in 2004 to develop a database of drought impact inventory
- European Drought Reference (EDR) database
- EDC web page :
  - Impact data are online available in tables
  - encourage to communicate past events
  - collaboration with different institutes (JRC…)
  - different resources available (books)

Discussions:

- R. Pulwarty: How does learning take place How do we adapt to impacts? How can we deliberately influence and advance learning?
  A. Iglesias: level of response depends on what is socially acceptable (this level changes with time)
- vulnerability: very sensitive/subjective choice – often the “winners of drought” are neglected
- Disaster Risk Management Knowledge Center at the JRC → knowledge transfer from research to policy makers (regular meetings)
- Links to European Media Monitor
  - Screens media every 10 minutes
  - Keyword based search and costumer build requested
  - Reports are recently not stored, but maybe it would be useful for EDII (person for quality control would be needed)

Session 3c: Cases and new tools

Falk Böttcher: The risk of yield loss due to drought – the impact of changes of water balance variables

- Overview of the climate properties of Saxony (precipitation gradient: from 500 mm to 1200 mm per year)
- significant decrease of precipitation during summer (13%)
- working data:
  - yield (last year)
  - water demand of crops
  - soil water storage capacity
  - aggregation to municipalities/villages
- climate water balance CWB = difference between precip. and ET0 (calculated for the actual vegetation period lasting from early spring [not before February 15th) till June 30th)
- yield loss risk approximated as ratio between CWB and soil water holding capacity (5 classes)
  - calculated for past decades
  - calculated for CC scenarios (deteriorating situation in south Saxony; depends on the soil depth)

Mike Hobbins: The evaporative demand drought index (EDDI): an emerging drought monitoring and early warning tool

- relationship between (actual) evapotranspiration and reference (potential) evapotranspiration is different in moisture-challenged and energy-challenged regions
- ET0 is calculated with Penman-Monteith formula
- EDDI is defined as standardized departure from long-term mean of ET0 (same standardization procedure like SPI, but dry conditions are connected to positive EDDI)
- leading indicator of drought onset → can spot flash drought developing (demonstration shows 2 weeks ahead of USDM); gaining popularity
- Connection between EDDI6 and SRI12 (case study in California)
  → EDDI is able to well detect hydrological drought, although it contains no precipitation information
  → Forecasting potential for drought as temperature can be better predicted than precipitation
- It is possible to analyze drivers of ET0 change based on differentiation of P-M formula; case studies show that air humidity is most important factor in initial stage of ET0 growth, followed by increased importance of temperature (and to lesser degree SW radiation)

Gregor Gregoric: Drought monitoring in SE Europe

- Use of satellite products – problem: land use is very scattered and different land use types react differently to drought conditions
- Project needed for gaining experience with the vast amount of data supplied by the new sentinel satellite with high resolution
- Satellite data as an independent source of information for monitoring the vegetation state

Session 4: Address Workshop Goals 1 and 2

Session 4a: Working Group on Goal 1

Goal 1: Develop a list of requirements from relevant sectors to identify and prioritize needs for observations, monitoring, data, impact assessments, and possible products to improve drought early warning systems.

Data needs

- Need data daily to 10-day period onward (use moving window)
- Data have to be freely available
- Long-term consistent climatology needed: problems long-time series → homogeneity aspects, data often gappy
- Near real time data needed
- Reanalysis may be the way forward
- Metadata is key! Meteorological stations but perhaps more so for streamflow, river catchments have seen dramatic changes, anthropogenic changes.
- Try to reconstruct specific landmark drought events (understanding surprises). But: How well do we understand past events and impacts given the absence of data & metadata outside the modern period?
- Data from agriculture and forestry (agricultural data almost non existing on a local scale in Europe, changes in administrative units)
- Soil moisture is king! However, there are hardly any direct measurements and it is a blend between satellite and model.
- Trend in soil moisture is important in early warning system (relative) – models do well here
- Large variety in indices, since existing indices have a history of being designed by/for users (but many are a proxy of soil moisture)
- Need to make clear that monitoring is key if early warning is required. Low station density will not pick-up early signals (and delays warnings).
- Availability of streamflow data and groundwater resources data is problematic (data do exist but difficult to access).
- We need to be more clear on why having specific data will improve our products/decisions?

Requirements

- Requirements of drought monitoring relate to the user of the warning: e.g., politicians want maps, but farmers want point information
- Many operational products available (for the agricultural sector), but in other sectors data and services are missing (e.g. hydrology, groundwater, tourism)
- Damage figures of hydropower companies and agriculture are available, but gappy and not for every country. There is a movement toward making these data available, but we’re not there yet.

What is missing?

- Coordination on data availability and sharing is critical → Accessability of data
- Putting the existing pieces together

  → Resources needed!

    - We are competing for existing resources: coordination?
    - Continuous support
    - Joining forces
- Many indices developed for specific user needs → linking back incides to impacts needed (likelihood of specific impacts connected with specific index-thresholds)
- No more indicators are needed, but the relation indicator to damage/impact function is required.
- Connect actions to the drought index categories/warning levels:
  - Forecasting impacts (not only the indices) is needed by the users

Example: Public water supply

- *A* high-profile sector like water supply and energy brings the message home to policy makers
- Important variabes
    - River flow (timing, shape)
    - Storage in reservoirs
- Many data not public
- early warning is sometimes for the public, making decisions of companies or governmental bodies more acceptable
- Farmers can act directly on the warning (foresters not so much)
- Competing needs of groups of water users
- Negotiating about water uses – where does it take place? (often no clear prioritization of users; no compliants for illegal actions, law enforcement ineffective)

Ideas to pursue?

- Explicit discussion of one case study, e.g. Ecosystem services, on data requirements to monitor impact. (for the white paper)
- Use agricultural drought as early warning for drought in hydrology sector
- Do the prototype first and then you get the resources (show the decision makers that your system works and is useful)
- Take advantage of COPERNICUS? – resistance from member states, as they have their own systems running
- Early warning systems also for information and awareness rising (use other terms like information system or observatory)
- Quickly responding indices like EDDI
- More high resolution satellite data (processing capacity is a challenge, have to manage to put it in existing systems)
- Outlook is often more important than the current situation

- Take advantage of products others are providing
- Common data sharing platform – What stops us from cooperating? (time, resources, acceptability)
- Can share at least our products (processed data), if sharing the basic data is not possible

Wrap-up:

- There are clear need for high-density, high-quality, free and easily accessible data and metadata
- There are already many datasets out there – we just need to piece them together.
- … sounds easy, but there are many hurdles to take
- We need to identify those hurdles and find innovative ways of overcoming them

Session 4b: Working Group on Goal 2

Goal 2: Identify research that is needed to advance risk and vulnerability assessments, forecasting, and management of droughts focusing on key sectors including agriculture and water resources

What is needed to sufficiently understand risks?

- Understand the relevant time-scale of the decision maker in charge to mitigate a risk
- Exposure is time dependent and user dependent
- Thresholds for the assessment of the criticality of a risk is also dependent from societal values and behaviors
- Economic factors alike cost of in-action
- Cost / efficiency ratio with regard to the mitigation measure of regard
- Understand the political landscape in the region of regard.
- Understand the societies’ response to risk
- Intendent outcome of risk mitigation (or elimination) tool determines the information needed
- Understanding of drought events from the historic perspective

What is needed to sufficiently understand vulnerabilities?

- Understand the resilience and the adaptive capacity of the region at risk
- Understand the temporal behavior of vulnerabilities
- Understand the multiple dimensions of vulnerability (anticipation, cope and recovery capacity)
- Governance, state economics, available infrastructure
- Improve on the drought impact data base
- What is the relevance of individual stressors in the multi-stressor environment?
- Antecedent conditions to be taken into account
- Resilience of people is different to resilience of natural systems and both and their interactions are crucial to be understood
- Research on better communication tools to convey risk and vulnerability information

What is needed to tailor forecasting products in their specs (parameters, resolution, lead time, etc.)?

- Historical analysis (Evaluation of past extreme events)
- Relevance of individual stressors in a multi-stressor environment
- Improved monitoring of the current conditions and the impacts related to drought
- Presentation of forecast parameters should be dependent on the lead time of regard (so they are useful)
- Reliability skill assessment of forecasting products
- Understanding (& quantifying) the value of information
- Product specs (lead time, resolution, etc.) designed for the decision making process
- Information on systems memory to be included into the forecast products
- More research on seamless forecasting
- Innovative communication methods
- Twinning between user and provider

Can we prioritize the required research according to user needs?

- Impact data
- Priorities to reflect the users’ needs
- (Result of query into the group to provide their top 3 favorites)

How do we get there?

- Define the scope of the effort in terms of time and resources
- Assessment of existing information
- Identify existing initiatives (e.g. on Extreme Weather, e.g. GC on Weather and Climate Extreme WCRP)
- Be opportunistic with regard to where droughts are currently emerging and the highest vulnerability is
- Understanding the leadership and governance, to create momentum
- Engage also with the actors, e.g. those of the DRR community to learn about their needs and co-design products
- Map projects and follow where they overlap for the purpose while filling gaps where needed
- Define a demonstrator project on continental (e.g. Europe) and ultimately global scale
- Seek partners beyond US and Europe
- Distinguish between over-arching and local and sub-regional application of methods

Session 5: Address Workshop Goals 3 and 4

Goal 3: Identify ways to synthesize and coordinate drought monitoring capabilities towards a globally harmonized capability

What is available? What is even redundant?

- National Integrated Drought Information System (NIDIS)
    - Interagency coordination
    - Network coordination
- Regional Climate Centers (WMO)
- IDMP Integrated Drought Management Programme
- JRC Activities
- NDMC (international)
- Global gridded satellite-modeled products
- Global Drought Information System (GDIS)
    - Scalable-drill down to region-country
- Look at other global systems (GLOFAS)
- Global SPI mapping interface (formerly housed at Univ. London)….where now?
- MVDI (UC-Irvine)
- SPEI (CSIC)

What should be the target resolution for the global scale?

- Coarser resolution
- Hot Spot detection

What should be coordinated and harmonized to reach a one-stop shop?

- Stakeholder forums
- Portal interface
    - Interoperability
    - OGC
    - Services (WMS, Featured coverage services)
    - Standardized reference periods
    - Continuity
    - Operational
    - 5-8 key parameters (streamflow, snowpack, runoff, soil moisture, SPI/SPEI, vegetation condition-stress, groundwater) → Becomes a standard set of forecast products

Are their direct users of global scale products beyond validation of climate models

- NGOs
- Aid agencies
- Development Banks
- Commodity brokers

- Reinsurers

How do we hand-shake the information to regional entities and suppliers? What depth of information is required to become useful for further downscaling into the regional scale?

- Make sure we don’t step on national missions-mandates → Coordinate with them
- Consistency: between global and regional-local systems and products

Goal 4: Identify untapped sources of synergies in the current landscape of suppliers

Identify low hanging fruits: WMO resolution (next June) on the concept

How do we get there?

- Explore WMO resolution on the concept
- White paper to set the course/issue
    - Case study: Perfect Drought Storm? Scenario
    - Vulnerable regions
    - Human influence
    - Food, water, energy security
    - Global time series of drought

Session 6: What’s to be done now, mid-term, strategic?

Next steps to be taken

- Action: Draft WMO Resolution (Bob) – 31 Dec 2016
- White paper – lessons from the cases (June 2017)
    - Monitoring
    - Impacts (urban / rural areas)
    - Vulnerability
    - Obtain inputs from Regions (Europe, US, Africa/South America??) 3 regions
- Building on GDIS – WCRP, GEO, GFCS, JRC and other efforts
- Evaluation of drivers of drought at different time scales

Missing Topics

- How do you sustain and replicate projects? Examples from IDMP CEE, NDMC
- → Windhoek Declaration (ADC)
- “stamp” (by WMO and partners): Drought resilient community
- More interaction with ecosystem groups (wildlife, biodiversity)

Brain Storming on Innovative actions

- There are barriers to doing things; how do we overcome them (coordination)
- Developing an integrated drought project that also characterizes water management risks and benefits

- Why are drought issues less known than those of other natural hazards?
- Test case MHEWS – Southern and Eastern Europe including drought
- Make drought simpler (why have different types of drought)

Session 7: Inreach and Outreach

Spread the news

- Draft Note (JRC, WMO, others) Deadline: 30 Nov?? at least by 31 Dec
- Dissemination: JRC, DWD, NOAA, WMO, partner organizations and others,
- Better links between Colorado, NDMC
- Are droughts climate change or not?? Many questions on this. Attribution issues
- Decadal Causes of drought (Pacific, Atlantic)
- Drought termination and "drought busting" → Forecasting heavy rainfall events that can end a drought
- Global Change (Global Warming) and droughts
- EU Joint Programming Initiative (JPI) – Water and Climate

Plan feedback to GFCS

- *IBCS* – through Paul and Wayne – RCCs, DMCSEE, IDMP members,
- Input to GFCS Organizational Resource Plan (ORP)
- BAMS meeting summary (15 Jan 2017*) can also be used for GFCS*

A joint paper?

Conclusions and Recommendations

The workshop brought together a variety of expertise and experience from science, management and policy spheres in order to discuss on how we can work together to move from reactive drought crisis management to proactive drought risk management. Currently there is no comprehensive global system for drought monitoring, but a multitude of continental, regional, national and local initiatives. On the way towards an international drought information system we need to answer the question: How can we coordinate and advance drought research internationally, while at the same time engaging the user community to ensure relevance?

A drought early warning system needs to include both monitoring and prediction. Drought monitoring is seen as a key element of drought early warning. We should take advantage of the slow onset of drought by using quickly responding indices or utilizing information on agricultural drought as early warning indicator for hydrological drought. For drought monitoring a good database is needed. Drought predictions need to be improved, e.g. by exploring the opportunities of forecasts (e.g., atmospheric rivers/MJO link, ENSO, NAO, etc.).

Important **activities** in moving towards a meaningful international drought information system identified during the workshop are

- ***Satisfy data needs***: There is a clear need for high-density, high-quality, free, easily accessible and easily transferable data and metadata. There are already many datasets out there – we just need to piece them together. Data integration should be used to take advantage of all data, e.g. blends of satellite and in-situ observations.
- Build on the ***convergence of evidence*** (with regard to the multitude of existing drought indicators).
- Focus on the ***knowledge transfer*** from research to policy makers.

Research areas that need to be advanced on the way towards a proactive drought risk management are:

- ***Linking of impacts to index values***: The values of drought indices used in the drought information systems need to be linked to specific impacts at place. This helps in predicting real drought impacts, which is needed to inform policy and decision makers. An important prerequisite is the advancement of drought impact databases.
- ***Improving soil moisture estimates***: Many of the existing drought indices have been designed as a proxy of soil moisture, as there are hardly any direct measurements. Instead modelled values and blends between satellite and model data are used and the forecasted tendency in soil moisture development is important in early warning systems.
- ***Working towards a better definition of flash drought***: So far there is no uniform definition of flash drought. Characteristics of flash droughts described during the workshop are that these are quickly evolving – not necessarily short events – with low soil moisture values.

In proving the value of a drought information system it helps if we can show how the intended new information would have helped in mitigating the impacts of a specific event. After all, building a global drought information system is hard to do; it takes leadership, massive collaboration, a lot of resources and some vision. Let’s move forward and overcome the manifold hurdles!

More details

Questions that have been addressed:

- What are the needs and what are our current capabilities?
- Why do some things work and other not?
- Where are the most important gaps?
- What do we need to do to improve on this?
- How do we bring this into the Sendai process, UNFCCC, GFCS, …

- Utilize the knowledge of experts on a voluntary base for validating and improving drought information at the regional scale as shown by the example of the US drought monitor (400+ experts; they are volunteers, no contract, are vetted, promise to embargo info before release)
- More research on linking drought index values to impacts and on predicting drought impacts is needed to inform policy makers – they understand that more
    - Enough indices available, but linking actions to index thresholds is needed
    - first lessons learned from exploring links between drought indices and drought impacts
    - Data collection in Europe (European Drought Impact database EDID) with spatio-/ temporal profiles → produce a large archive of events and linked with impact categories
    - Use of damage functions (impacts are very diverse and region dependent, compatibility is still a key challenge)
    - To get a complete explanation of the damages need to use different cumulative periods (short time SPEI for beginning, long term for capture the complete duration of damages)
- Definitions – early warning system
    - needs to be both monitoring and prediction
    - Monitoring is key for early warning. (Low station density will not pick-up early onset)
    - best forecast we make is a nowcast!
    - taking advantage of slow onset, e.g. use agricultural drought as early warning indicator for hydrological drought
    - Quickly responding indices like EDII to be utilized
- Regarding various indicators of drought – key thing is to use a convergence of evidence (as is done in the US drought monitor)
- Need for verification on the global scales
- Improve capabilities on drought onset (e.g. through new methods alike EDDI)
- Focus more on the knowledge transfer from research to policy makers (e.g., Disaster Risk Management Knowledge Center at the JRC)
- Satisfy data needs: There is a clear need for high-density, high-quality, free, easily accessible and easily transferable data and metadata
- Data integration: take advantage of all data
    - There are already many datasets out there – we just need to piece them together … sounds easy, but there are many hurdles to take → need to think about how to overcome or bypass these hurdles)

  - Use blends of satellite and in-situ observations (stations as anchor points) for precipitation, soil moisture, run-off → evidence case of SST shows that it works

- Need to show how new information would have helped in mitigating the impacts of an specific event
- Ideas: One explicit case study, e.g. Ecosystem services, on data requirements to monitor impact (for the white paper) – also use other high profile sectors/events like water management or wildfires/megafires
- How can we coordinate/advance drought research internationally, while at the same time engaging the user community to ensure relevance?
- Lessons learned:
  - Hard to do
  - Massive collaboration – takes a lot of resources
  - Takes leadership (changes in leadership might be critical)
  - Takes resources
  - Takes some vision
- Flash drought – no uniform definition, soil moisture, high winds, evolves quickly – not necessarily short, often connected with agricultural and ecological drought
  → suggestion: work towards better definition
- Soil moisture versus soil moisture storage (take advantage of slower time scales)– need to improve global hydrological models
- need to predict impacts – need to inform policy makers – they understand that more
- Definitions – early warning system
  → needs to be both monitoring and prediction – monitoring is very important to that – best forecast we make is a nowcast!, taking advantage of slow onset
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