Applications of the EPS: Droughts

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Drought impacts

- Droughts caused the highest number of deaths among natural disasters in 1984 Ethiopia/Sudan (450,000 persons), 1974 Sahel (325,000 persons) (UN 2008);

- The recent 2010/11 drought in the Horn of Africa caused an humanitarian crisis affecting about 10 million people;

- The US drought in 2012/13 caused a significant reduction in crop/livestock production and cost more than $35 billion in the Midwest (estimated reduction of the GDP by 0.5-1% of the US as a whole)

Outline

- Droughts indices and seasonal forecasts

- Meteorological drought : Standardized precipitation index (SPI)

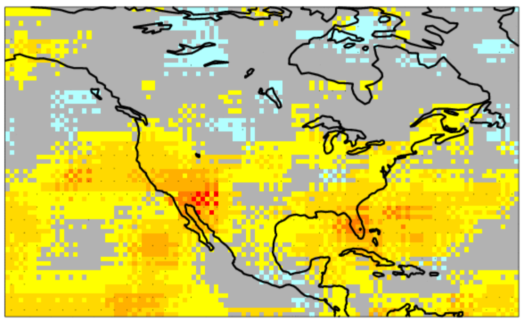
- Monitoring and forecasting meteorological droughts:
  - Probabilistic monitoring of SPI (using ENS precipitation)
  - Merging of ECMWF precipitation products (monitoring + forecasting)
  - Drought onset

- The 2010/11 drought in the Horn of Africa: ECMWF products

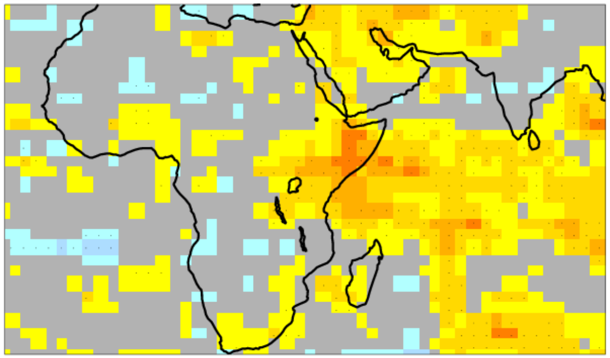
Seasonal forecasts

- **Seasonal forecast: longer time-spatial scales than NWP:** statistical summary of the weather events occurring in a given season.
- **Can seasonal forecasts provide an outlook of the evolution of drought ?**

Precipitation forecasts issued in January valid for Feb-Apr



Precipitation forecasts issued in July valid for Oct-Dec

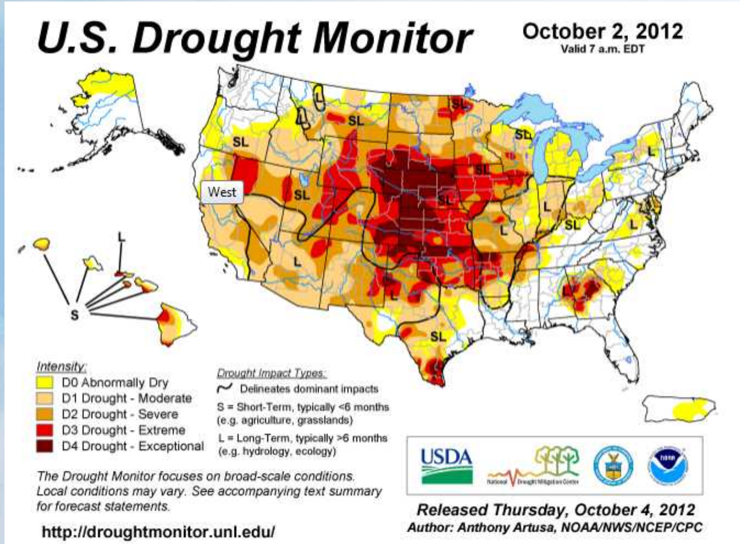


Anomaly correlation (warm colours == skill)

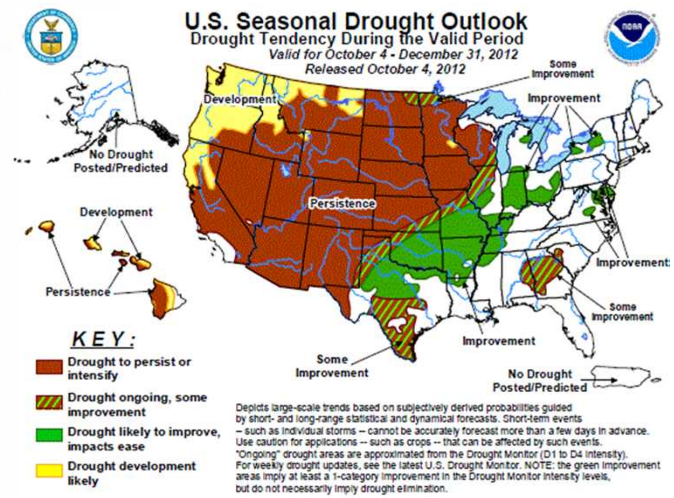
- **Monitoring current drought conditions is also very important (cumulative effect of rainfall deficits).**

- **Can we use ECMWF products to monitor and forecast meteorological droughts ?**

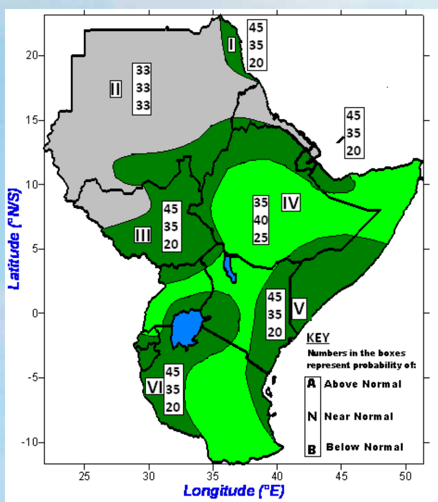
Examples of current systems



http://droughtmonitor.unl.edu/



http://www.cpc.ncep.noaa.gov/products/expert_assessment/seasonal_drought.html



WMO Regional Climate Outlook Products

http://www.wmo.int/pages/prog/wcp/wcasp/clips/outlooks/climate_forecasts.html

Greater Horn of Africa consensus Climate output for Sep-Dec 2012 (ICPAC)
http://www.icpac.net/Forecasts/forecasts.html

These seasonal outlooks merge models with forecasters experience

Can we process model data and provide a useful and straightforward product to forecasters ? A meteorological drought index ?

Drought indices

Why "indices" ?

-Represent an anomaly in terms of the past climate (observations or model)

-Easier to understand / comparable in space and time (60 mm rain anomaly is not the same everywhere / every time).

Drought indices are normally divided in three categories :

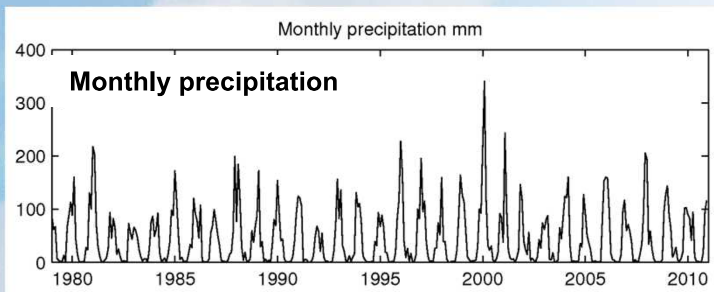
- Meteorological drought :
    - Precipitation anomalies :
        - **Standardized Precipitation Index (SPI);**
        - Drought spells (define thresholds of number of days with no rain);
- Hydrological drought :
    - Soil moisture / discharge / reservoirs:
        - Palmer Drought severity Index (PDSI);
        - Standardized runoff index (SRI);
        - Soil moisture anomalies (SMA);
- Agricultural drought :
    - Crop production / vegetation / available soil moisture:
        - Crop moisture index;
        - Vegetation indexes (e.g. NDVI);

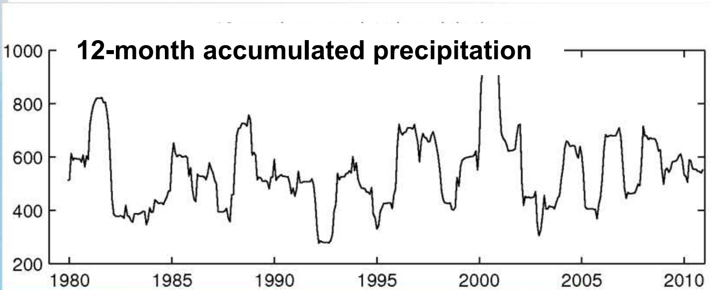
More details in Heim 2002 BAMS

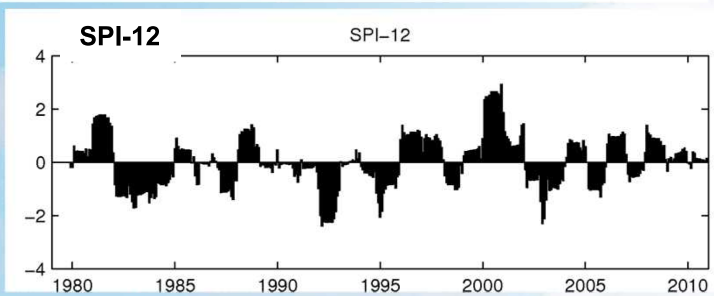
The Standardized Precipitation index (SPI) : Calculation

-Why the SPI ?

- Recommended by WMO;
- -Many weather services and stakeholders know about the SPI.
- -Only based on monthly precipitation (model / observations);
- -Can be calculated for different accumulation periods: related with different affected systems.







From precipitation to SPI:

1) Monthly time series of precipitation:
   - local observation, model grid point, region average;
   - long and homogenous time series (at least 30 years);

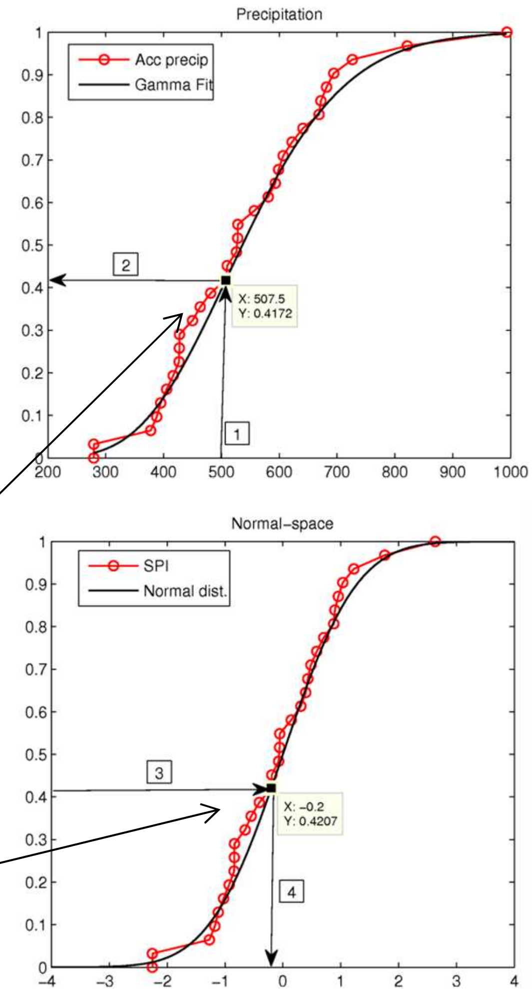
2) Selection of the accumulation time period *k*: e.g. 3, 6, 12 months
 (depend on the particular application)
Accumulate precipitation : P*(m) = sum [P(m-k+1) : P(m)].

3) Normalize the precipitation distribution:
 Transform the precipitation distribution in to a standard normal distribution (mean 0 and standard deviation 1)

SPI: normalization

Normalize the precipitation distribution:
Transform the accumulated precipitation distribution in to a standard normal distribution (mean 0 and standard deviation 1).

The normalization is applied separately for each calendar month (i.e. pulling together all the Januarys, Februarys, etc.).



In general:
1) Fit a cumulative distribution function (CDF) to the precipitation (parametric, non-parametric,...)Gamma is commonly used;

2) - For each precipitation value (P*) find the probability (X) (on the fitted cdf);

3) – For each probability (X) find the inverse normal with mean zero and standard deviation 1.

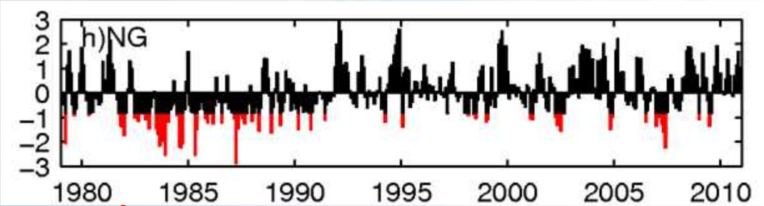
More details: e.g. Lloyd-Hughes 2002 IJC

SPI: selection of the precipitation accumulation period

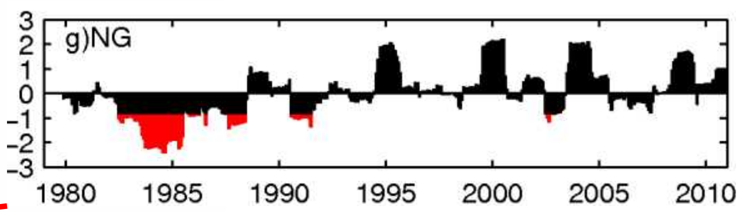
Which accumulation period should be selected: 3, 6, 12 months ? (or others ?)
No rule: depend on the application.
In general:
SPI-3 : 3 months accumulation: soil moisture / crop production in rainfed areas;
SPI-6/12 : 6 to 12 months accumulation: water reservoirs (e.g. river discharge, ground water)

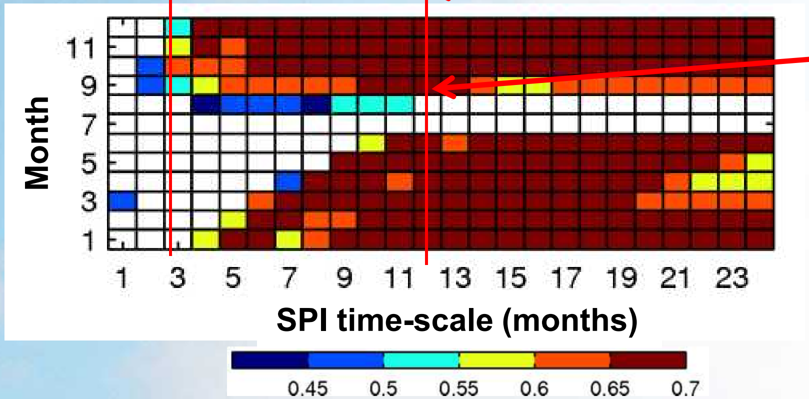
Example: Upper Niger basin

SPI-3 3 months accumulation



SPI-12 – 12 months accumulation





Temporal correlation between:
SPI-12 in September (accumulated precip. October(previous year) to September)
River discharge in September.

White values (low correlations): time delays in the discharge due to inundated areas: SPI does not substitute an hydrological model.

Temporal correlation between SPI (different time scales) and river discharge

More examples:Vicente-Serrano et al 2012 EOS
Vicente-Serrano et al 2012 AG

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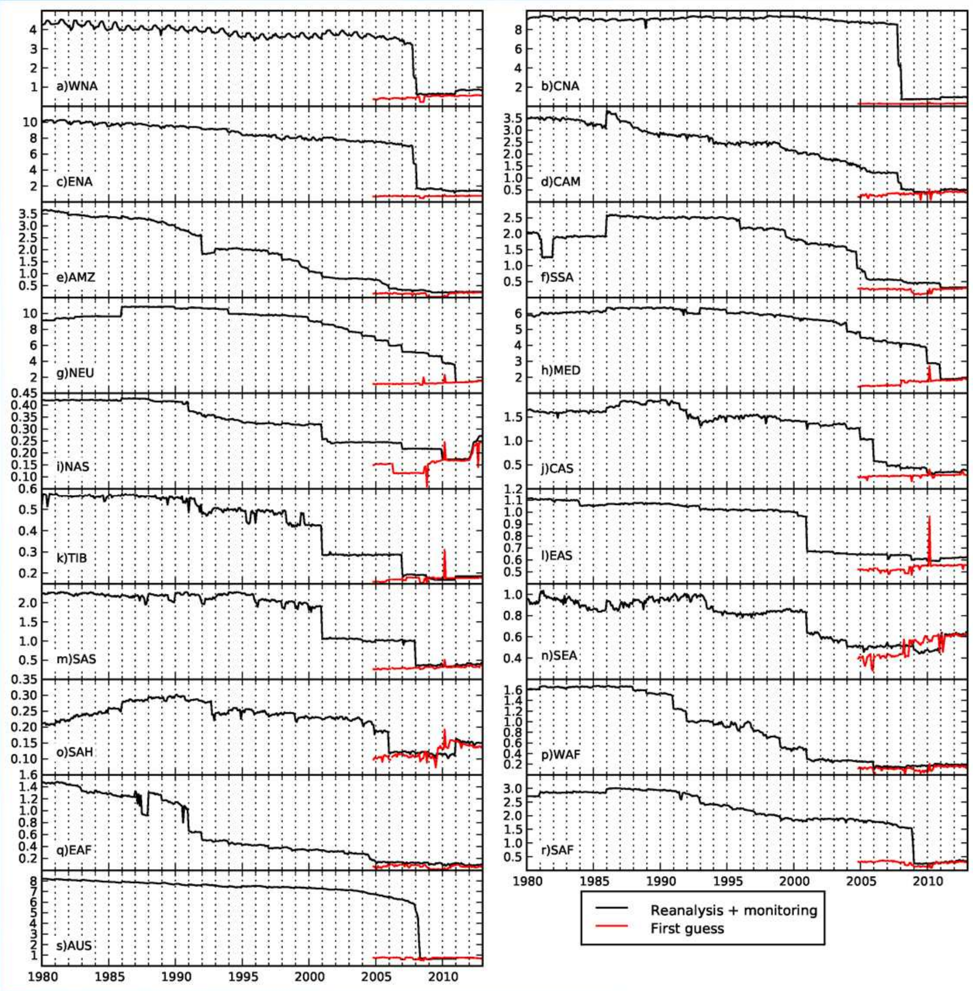
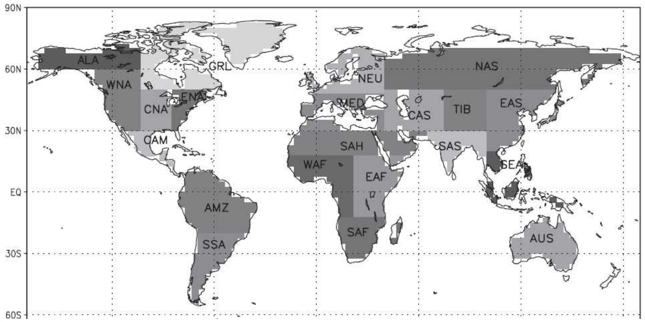
Probabilistic monitoring of SPI

Why probabilistic monitoring ?





Average number of rain-gauges in 1x1 grid-box in **GPCC**
Reanalysis v6 (Doi:10.5676/DWD_GPCC/FD_M_V6_100)
First guess (Doi: 10.5676/DWD_GPCC/FG_M_100)

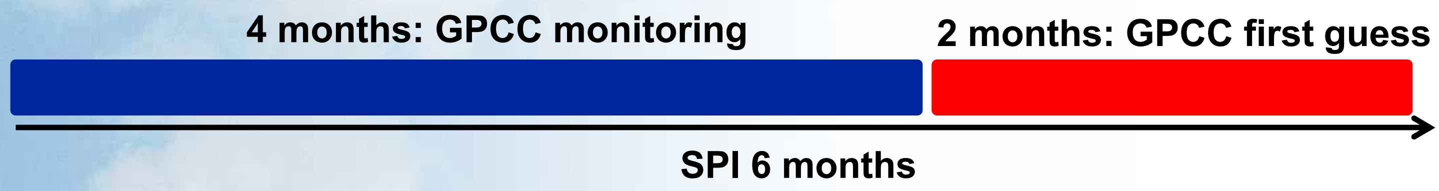
Large reduction of stations reporting in near real time in the last decade.
-> **Uncertainty in near-real time precipitation observations**

This will affect the SPI monitoring.

Could we use the ECMWF ENS short-range forecasts to generate probabilistic monthly means of precipitation anomalies ?

Probabilistic monitoring of SPI

Using GPCC data to monitor precipitation:



GPCC monitoring two months delay (Doi:10.5676/DWD_GPCC/MP_M_V4_100)
GPCC First guess real-time (Doi: 10.5676/DWD_GPCC/FG_M_100)

Using ECMWF ENS precipitation:

ENS short-range forecasts (0-48h) with 51 ensemble members.
Average all the forecasts of a particular month to generate **51 monthly means (F)**

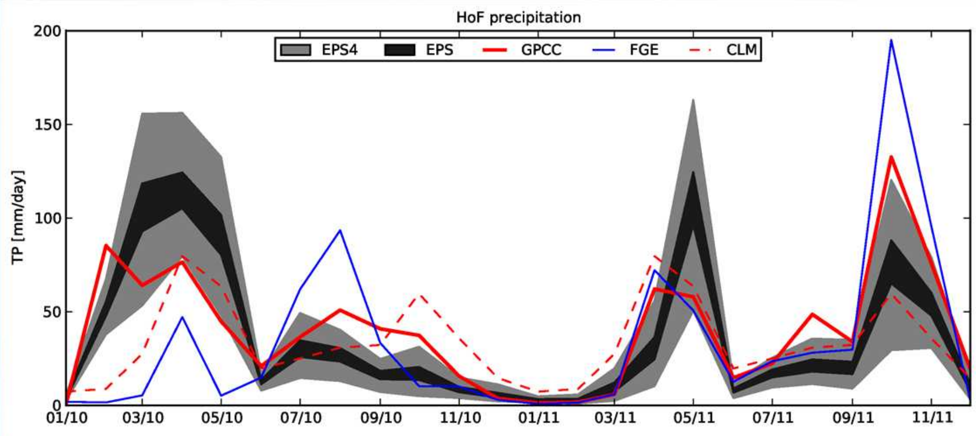
Need to define the **precipitation anomaly** (will be merged with GPCC data)

- Use the **hindcast dataset**, available since March 2008;
- For a particular month, the **model climate** is generated by the 18* past forecast dates +/- 2 weeks : 5 (weeks) x 18* (years) x 5 (ensemble members) : **450 samples (Fc)**

Monthly mean anomalies of F'= F/FC are multiplied by the GPCC climatology.

* 20 years since July 2012

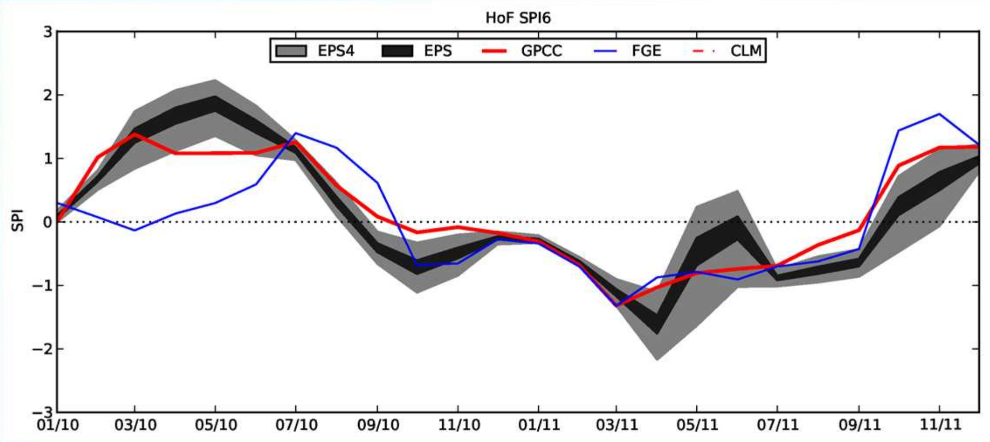
Probabilistic monitoring of SPI



Monthly precipitation in the Horn of Africa

Initial results showed that monthly means of the EPS had a reduced spread:

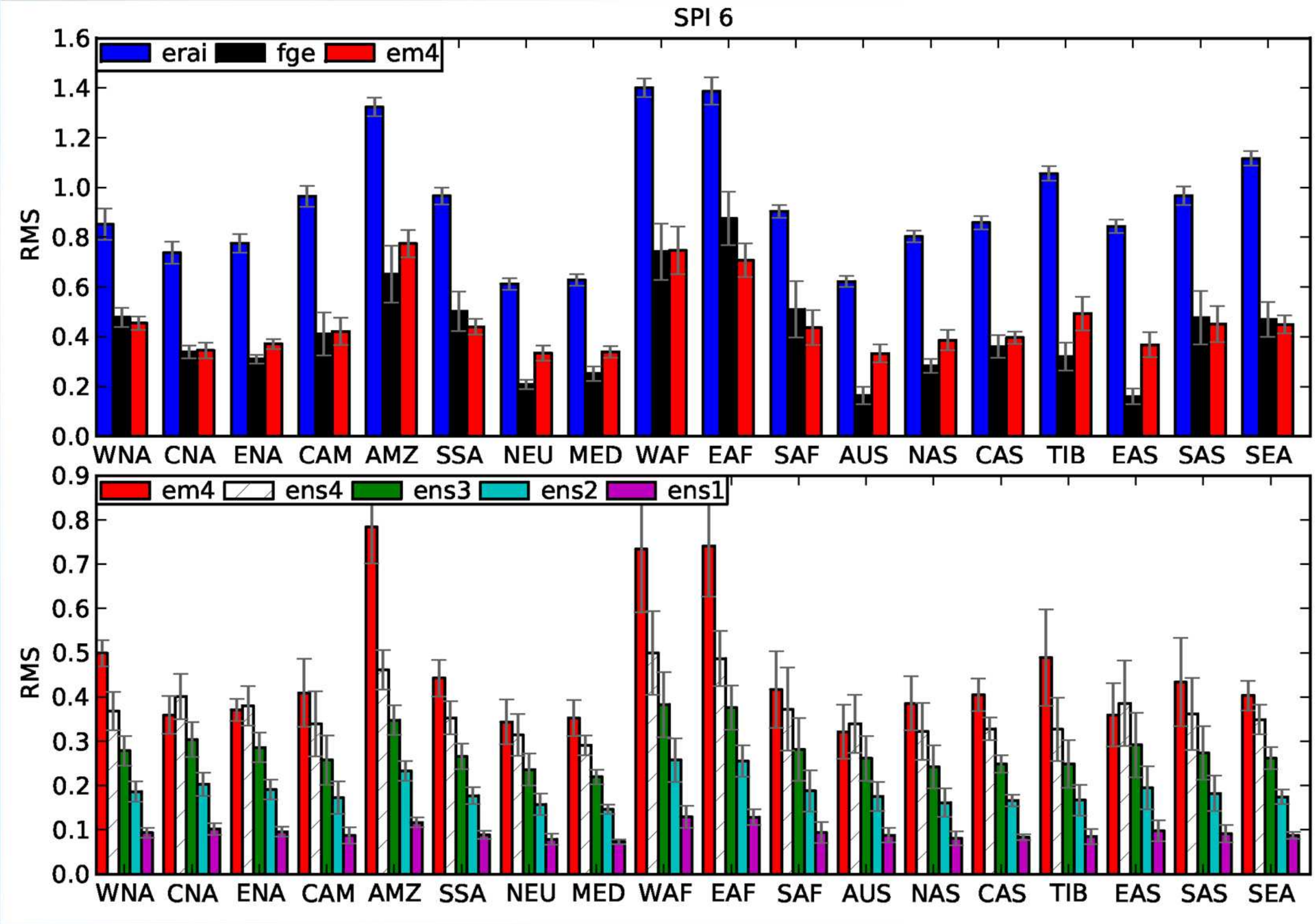
- **The ENS is not designed to generate a large spread in the first forecast hours and/or to generate monthly means;**
- **If we use a longer forecast lead time (e.g. 5 days), we would increase the spread, but loose skill**
- **Artificially increase the monthly means forecast spread:**
- **F' = F a + F* (1-a) ; a – inflation factor (4 was selected), F* the forecast ensemble mean**



SPI6 in the Horn of Africa

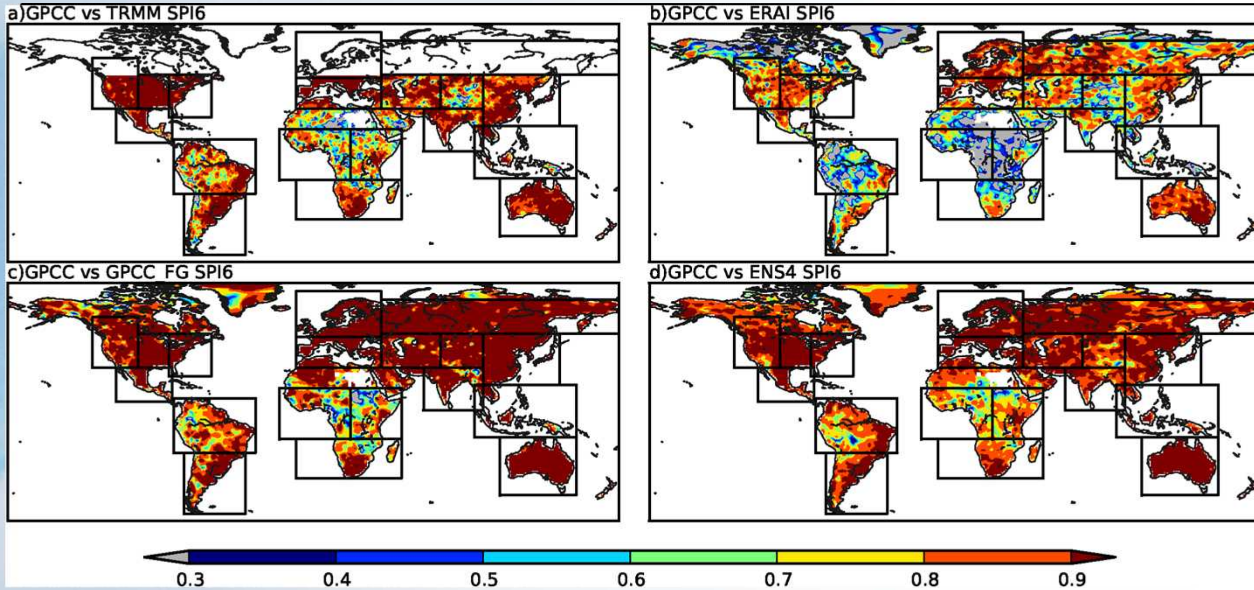
Probabilistic monitoring of SPI

Time mean (2009-12) root mean square error of the ensemble mean SPI



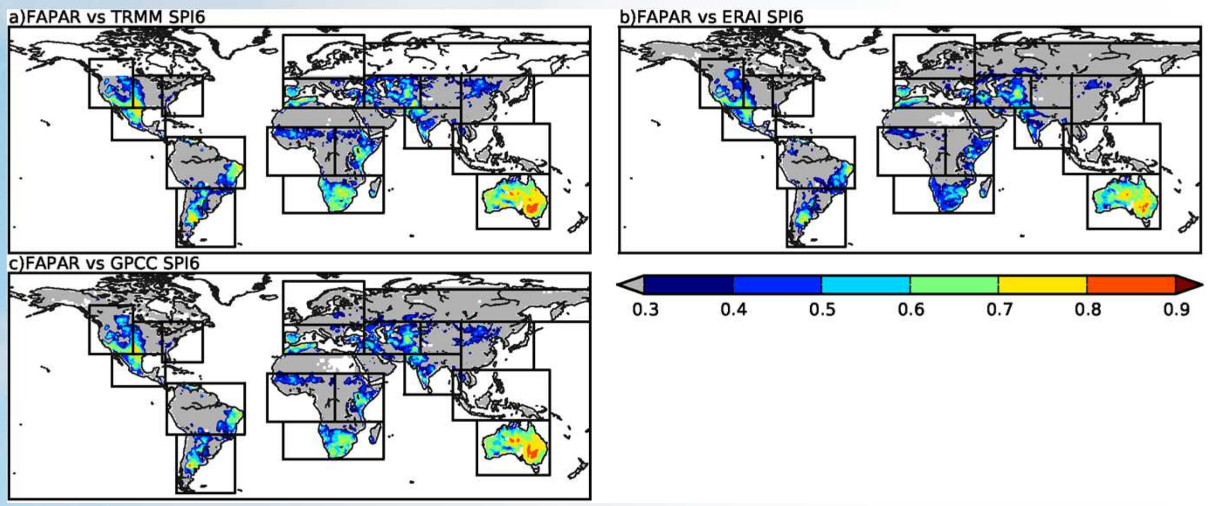
Time mean (2009-12) **root mean square error of the ensemble mean SPI**, compared with the time-mean **ensemble spread about the ensemble-mean SPI** : With 4 times spread inflation the RMS error is similar to the spread in most regions.

Probabilistic monitoring of SPI



Assuming GPCC as baseline: correlations with the different SPI products: 2009-2012

ENS4 – comparable results with GPCC First guess



An independent dataset: FAPAR Fraction of Absorbed Photosynthetically Active Radiation

- Proxy for vegetation conditions

There is not a 1-to-1 relation between SPI/FAPAR.
With this independent dataset, it is not possible to rank the different SPI products:

Validating/ verifying SPI is not straightforward. The global scale data should be evaluated locally.

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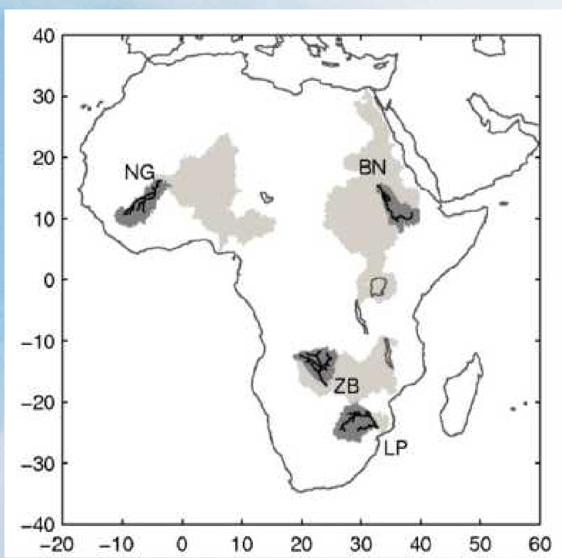
Monitoring and forecasting SPI: African basins



Products: Monthly means of precipitation:

ERA-Interim reanalysis Jan 1979 to present (near real-time update): monitoring

EMCWF System 4 seasonal forecasts: 6 months lead time, issued once per month.
Hindcast: 1981 to 2010 (evaluate system performance)

Other products:
CAMS-OPI: monthly means of precipitation 1979 to present (alternative for monitoring), based on rain-gauges/satellite (reduced number of stations reporting in real time)

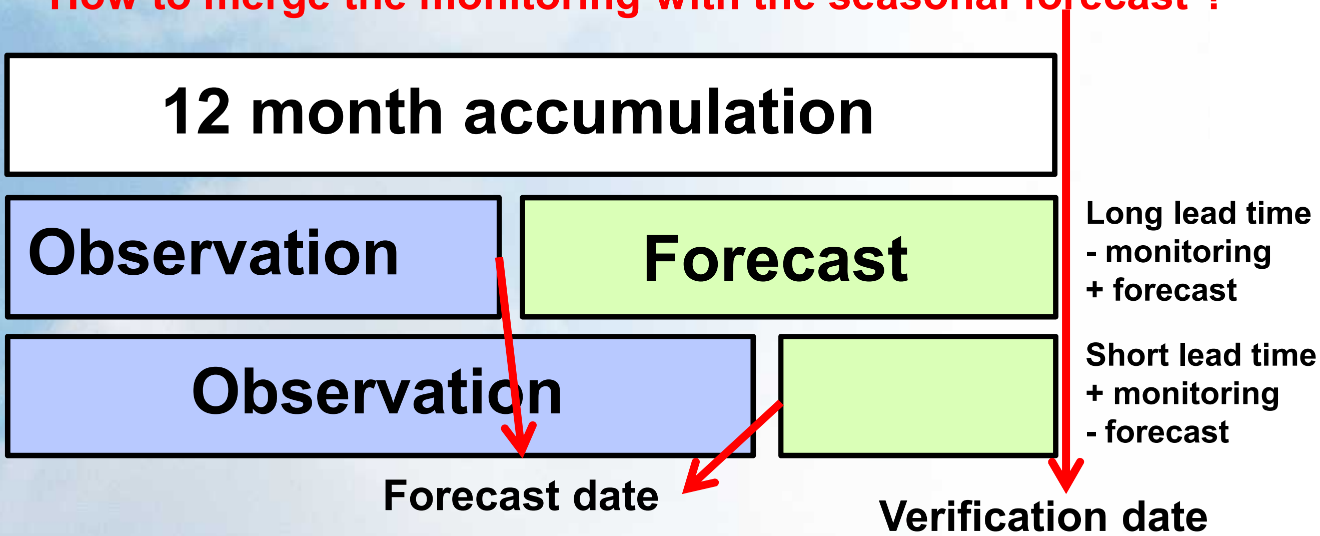
GPCP: monthly means of precipitation 1979 to 2010: Verification
Rain-gauges/satellite (quality control)

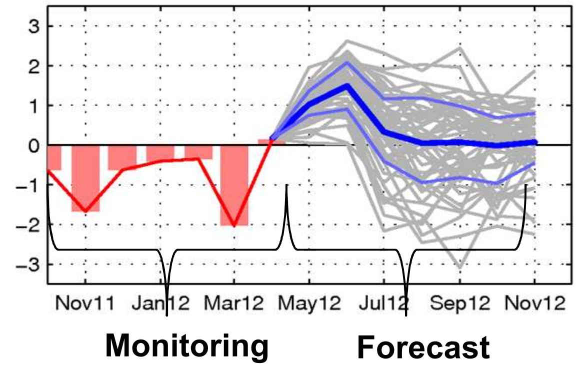
ERA-Interim: www.ecmwf.int/research/era/do/get/index
Seasonal forecasts S4: http://www.ecmwf.int/products/forecasts/seasonal/documentation/system4/index.html

More details: datasets, methods: Dutra et al. 2013 HESS

Monitoring and forecasting SPI: merging data

How to merge the monitoring with the seasonal forecast ?





Probabilistic forecasts

Probabilistic monitoring not used. Short period (only since 2008) to evaluate the skill of seasonal forecasts

1) Spatial averaging of monitoring and forecast to the target region

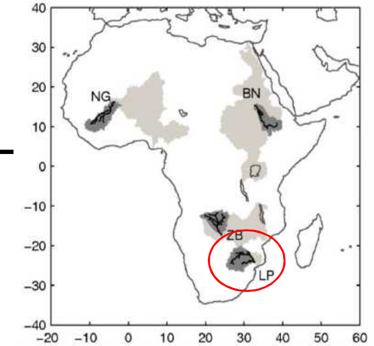
2) Bias correct seasonal forecast

$$P'_{m,l} = \alpha_{m,l} P_{m,l} \qquad \alpha_{m,l} = \overline{P}_m^{mon} / \overline{P}_{m,l}$$

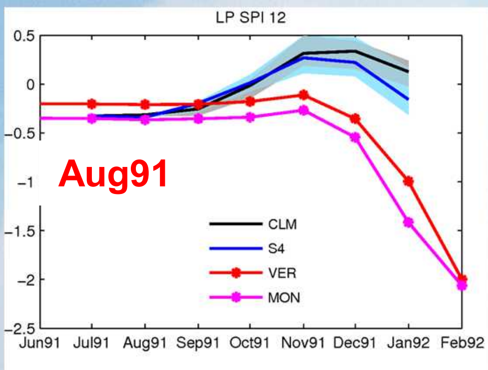
3) Merge monitoring and forecasts to create the SPI

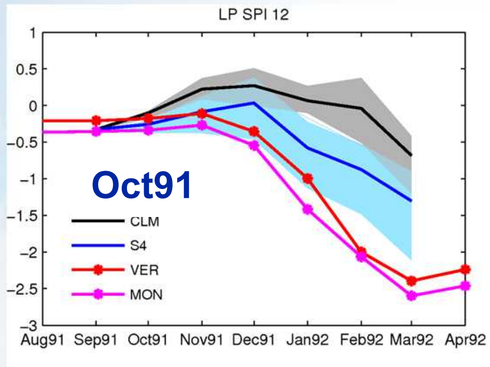
Yoon et al 2012, *J. Hydrometeor*
Dutra et al. 2013 HESS

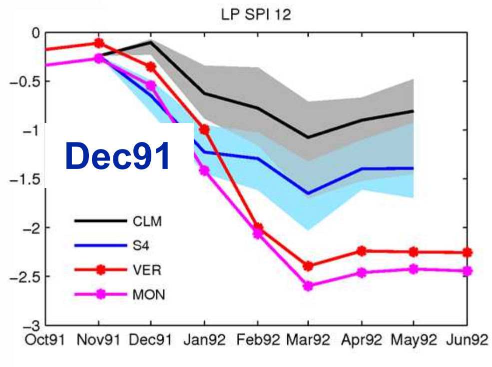
Monitoring and forecasting SPI: merging data

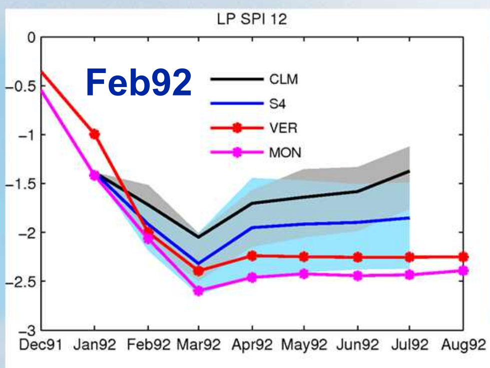


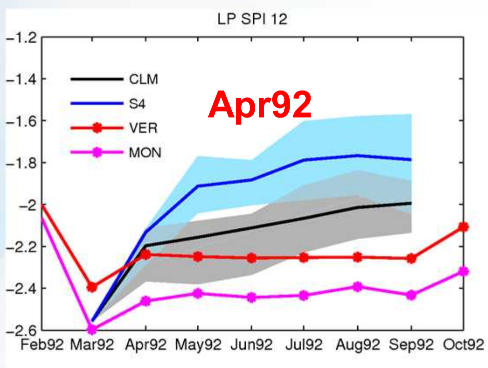
Limpopo 1991/1992 drought: SPI-12
Example of displaying the seasonal forecasts, S4 (blue), CLM (gray).

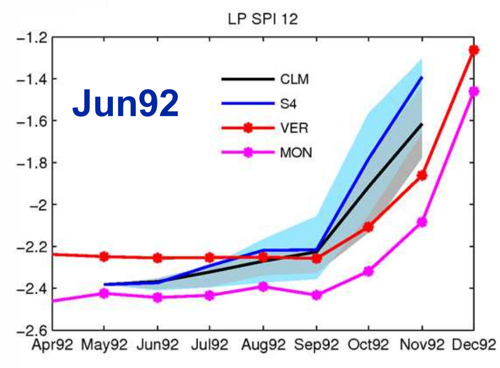












Monitoring (magenta: ERA-Interim) in good agreement with verification (red, GPCP)

Monitoring and forecasting SPI: forecast skill

How to evaluate skill of the SPI forecasts ?

Many methods and tools available to evaluate skill of probabilistic forecasts
Anomaly correlation, ROC and REL diagrams, etc...
e.g. see the ECMWF training course material:

Potential skill vs. Real skill

We merge a monitoring product, that might have problems (e.g. ERAI), with the seasonal forecasts.

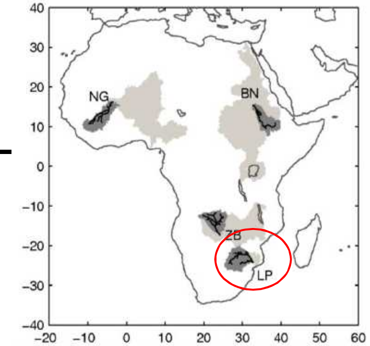
The potential skill can be evaluated by merging the forecasts with the "perfect" monitoring, i.e. our verification (GPCP).

Benchmark the forecast

Can our merged forecasts beat a simple climatology ?

Create a forecast ensemble based on previous years of the monitoring:
SPI evolution in case the next months are "normal" : difficult to beat (previous slide)

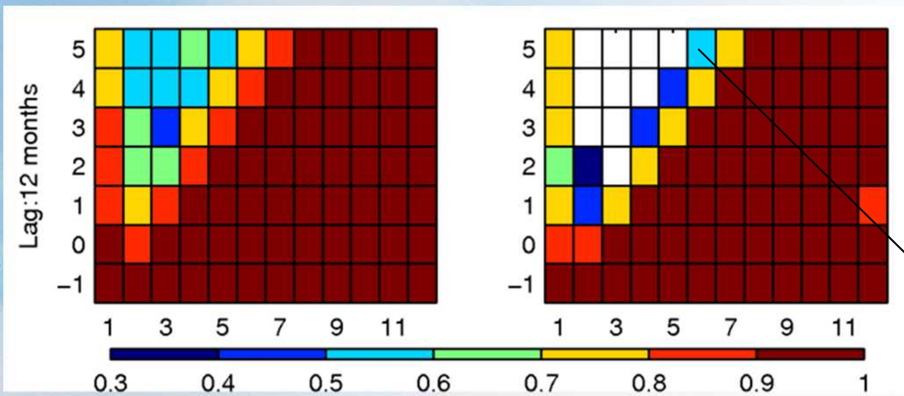
Monitoring and forecasting SPI: forecast skill



Example of forecast benchmark and potential vs. Real skill (1)

Climate forecasts (CLM) : select past 15 years (S4 hindcast ensemble size)

ACC – S4 **ACC – CLM**



SPI-12 in the Limpopo Basin

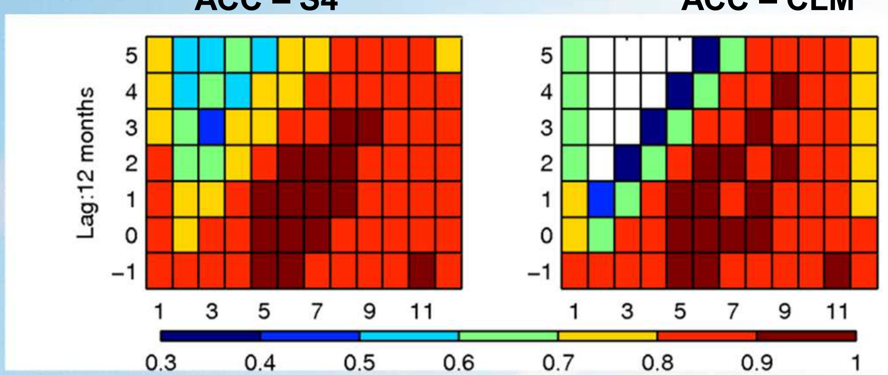
Potential skill: Merge the S4 and CLM forecasts with the verification, in this case GPCP (not available in real time)

ACC- Anomaly correlation coefficient
Better closer to 1.

Horizontal axis: verification calendar month
Vertical axis: Lead time

Forecast valid for June
5 months : issued in January

ACC – S4 **ACC – CLM**



Real skill: Merge the S4 and CLM forecasts with the monitoring product, in this case ERAI.

Monitoring and forecasting SPI: forecast skill

ROC (Relative Operating Characteristics)

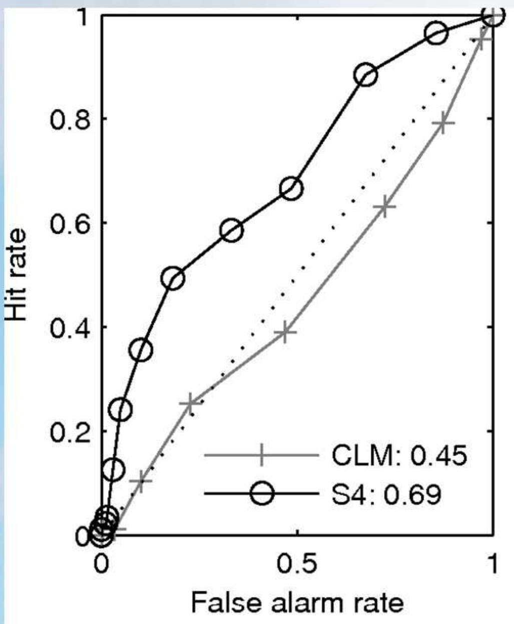
1) Define a treshold: e.g SPI < -1 (moderate/extreme drought)
2) Calculate **False alarm rate** and **hit rate** for different probabilities.

	e observed	
e predicted	Yes	No
yes	a	b
no	c	d

hit rate $H_i = \frac{a}{a+c}$

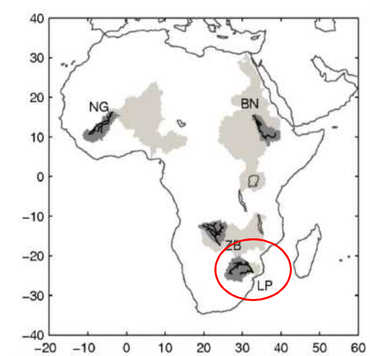
false alarm rate $F_i = \frac{b}{b+d}$

SPI-6: 5 months lead time

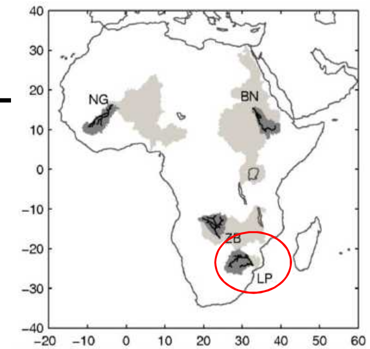


No monitoring, first 6 months of forecasts

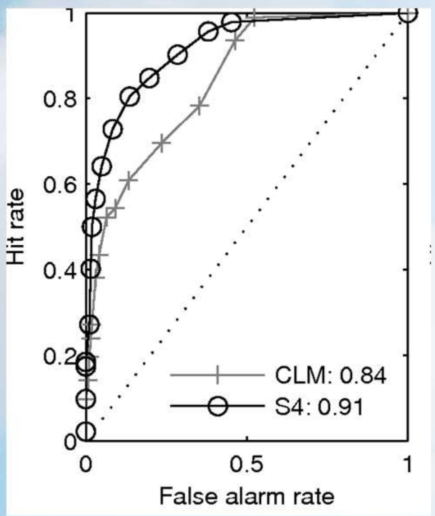
Gray: CLM forecast no skill (ROC≈ 0.5)
Black: S4 , forecast has skill (ROC 0.69)



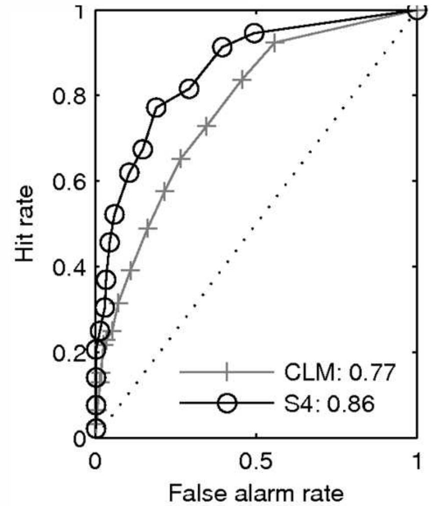
Monitoring and forecasting SPI: forecast skill



SPI-12: 5 months lead time
6 months monitoring + 6 months forecasts



Potential skill (using GPCP to monitor)



Real skill (using ERAI to monitor)

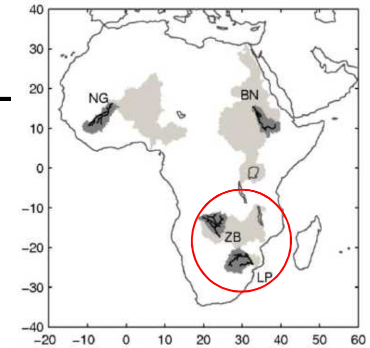
Gray: CLM has skill (ROC 0.84), coming from the monitoring
S4: higher skill than for SPI-6 (ROC 0.91), better than CLM

Both CLM (0.77) and S4 (0.86) have lower skill

Drop in skill due to the monitoring.

For long accumulation SPI time-scales, difficult to beat a climatology based forecast. Skill dependent on the underlying skill of precipitation in the seasonal forecast.

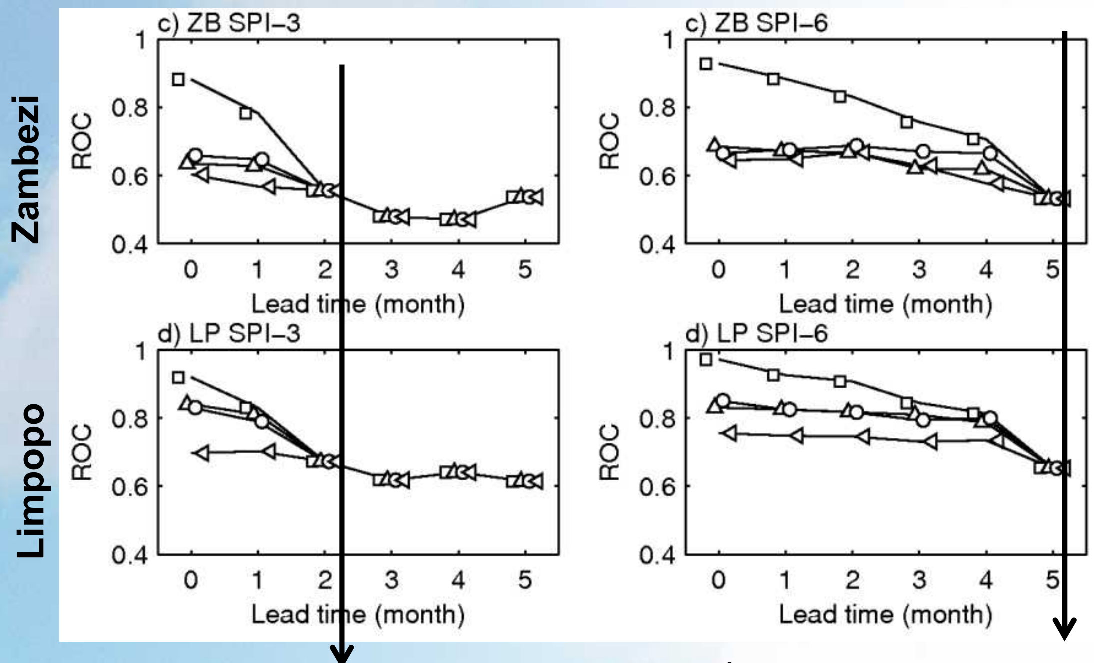
Monitoring and forecasting SPI: forecast skill



Potential vs. Real skill : Importance of good quality monitoring

ROC scores (0.5 -> no skill ; 1 -> perfect

SPI-3 **SPI-6**



- □ **Perfect monitoring (GPCP)**
- ○ **ERA-Interim**
- △ **CAMS-OPI**
- ◁ **Seasonal forecast (first month)**

Forecast lead time

Good quality monitoring can increase the skill of the forecasts in 1 to 2 months lead time.

ERA-Interim, with a global coverage and near real-time update can be used for monitoring (particular assessment should be performed for each region)

ECMWF

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Drought onset

Drought event: SPI-6 < thr for at least 3 months
Drought onset month: first month SPI6 < thr

Given a non drought condition: SPI6 (t-1) > thr, what is the probability of drought occurrence in the next 3 months based on the seasonal forecasts:
SPI6(t-1) > thr & (SPI6(t)<thr, SPI6(t+1)<thr,SPI6(t+2)<thr
Thr == -0.8

Create a contingency table (global):

Hit rate a/(a+c) (probability of detection)
False alarm ratio : b/(a+b)
(not the false alarm rate as we use for ROC)

A=24161 B=19995 C=113741 D=3864955

	e observed	
e predicted	Yes	No
yes	a	b
no	c	d

Citation: Yuan, X., and E. F. Wood (2013), Multimodel seasonal forecasting of global drought onset, *Geophys. Res. Lett.*, *40*, doi:10.1002/grl.50949.

Drought onset

Model	$p(y_1\|o_1)$	$p(o_0\|y_1)$	*ETS*
ESP	0.16	0.36	0.14
CCSM3	0.21	0.46	0.17
CM2.2	0.27	0.49	0.20
ECHAMA	0.21	0.42	0.17
ECHAMD	0.21	0.42	0.18
GEOS5	0.27	0.45	0.21
CFSv1	0.23	0.41	0.19
CFSv2	0.23	0.37	0.19
CanCM3	0.27	0.49	0.20
CanCM4	0.29	0.49	0.21
NMME1	0.22	0.33	0.19
NMME2	0.32	0.42	0.24

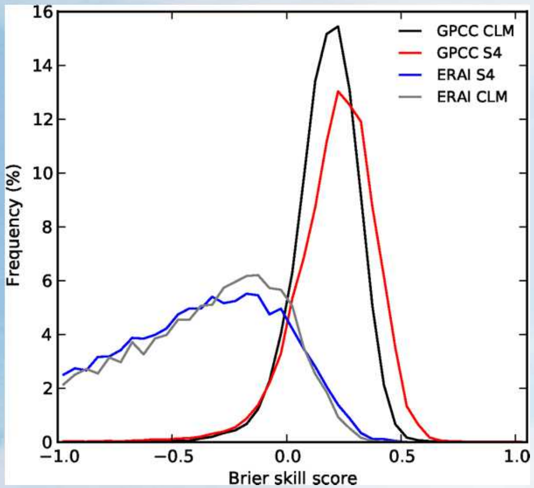
Our GPCC CLM forecast have similar scores to the ESP forecasts: shows that this analysis is not dependent on the datasets used;

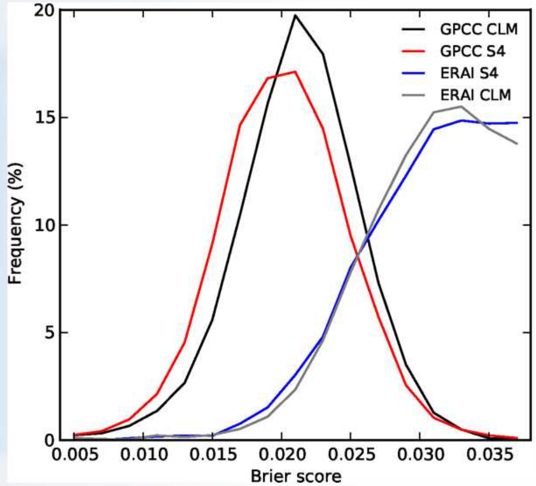
GPCC S4 with similar results to the NMME2 (multi-model with post-processing (110 ensemble members) – north American multimodel ensemble)

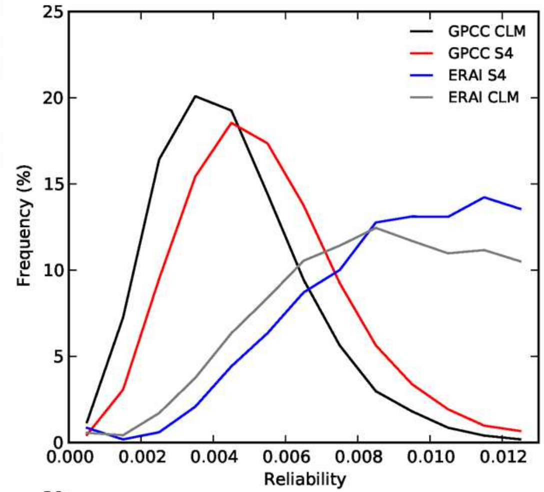
Model	POD	FAR	ETS
GPCC CLM	0.17(0.27)	0.40(0.57)	0.15(0.21)
GPCC S4	0.30(0.42)	0.47(0.57)	0.25(0.29)
ERAI CLM	0.14(0.25)	0.85(0.87)	0.09(0.12)
ERAI S4	0.22(0.31)	0.82(0.84)	0.13(0.14)

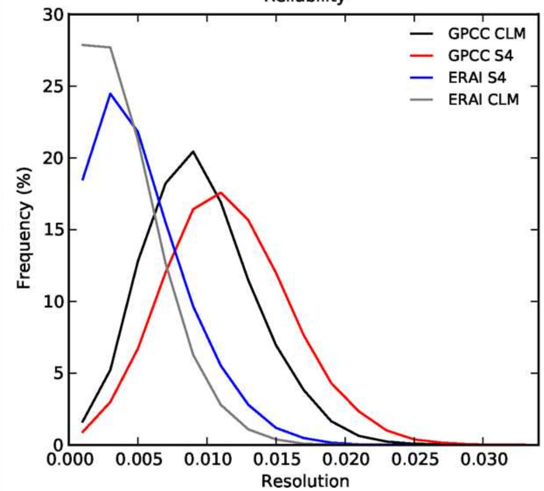
This analysis is only based in the SPI ensemble mean forecasts – when we “rescale the ensemble mean to have a standard deviation == 1( ):
Increase POD but also FAR, with some increase in the ETS.

Drought onset - brier score and decomposition





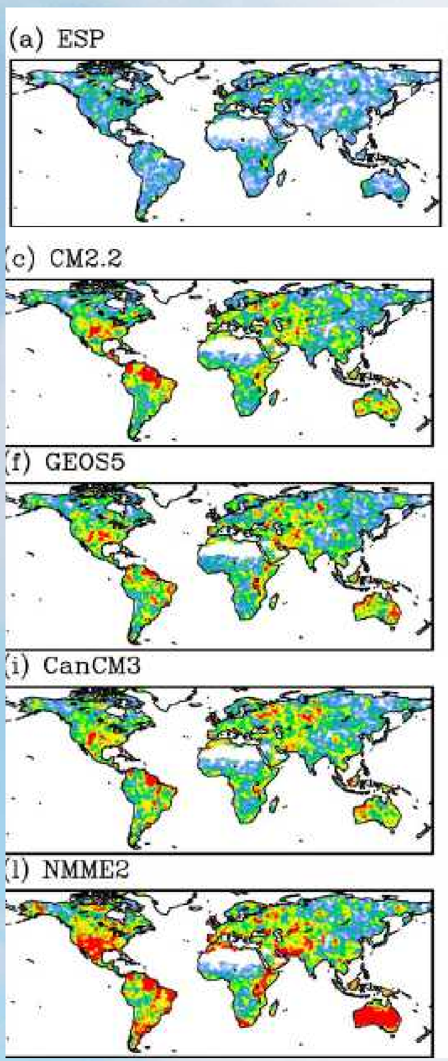


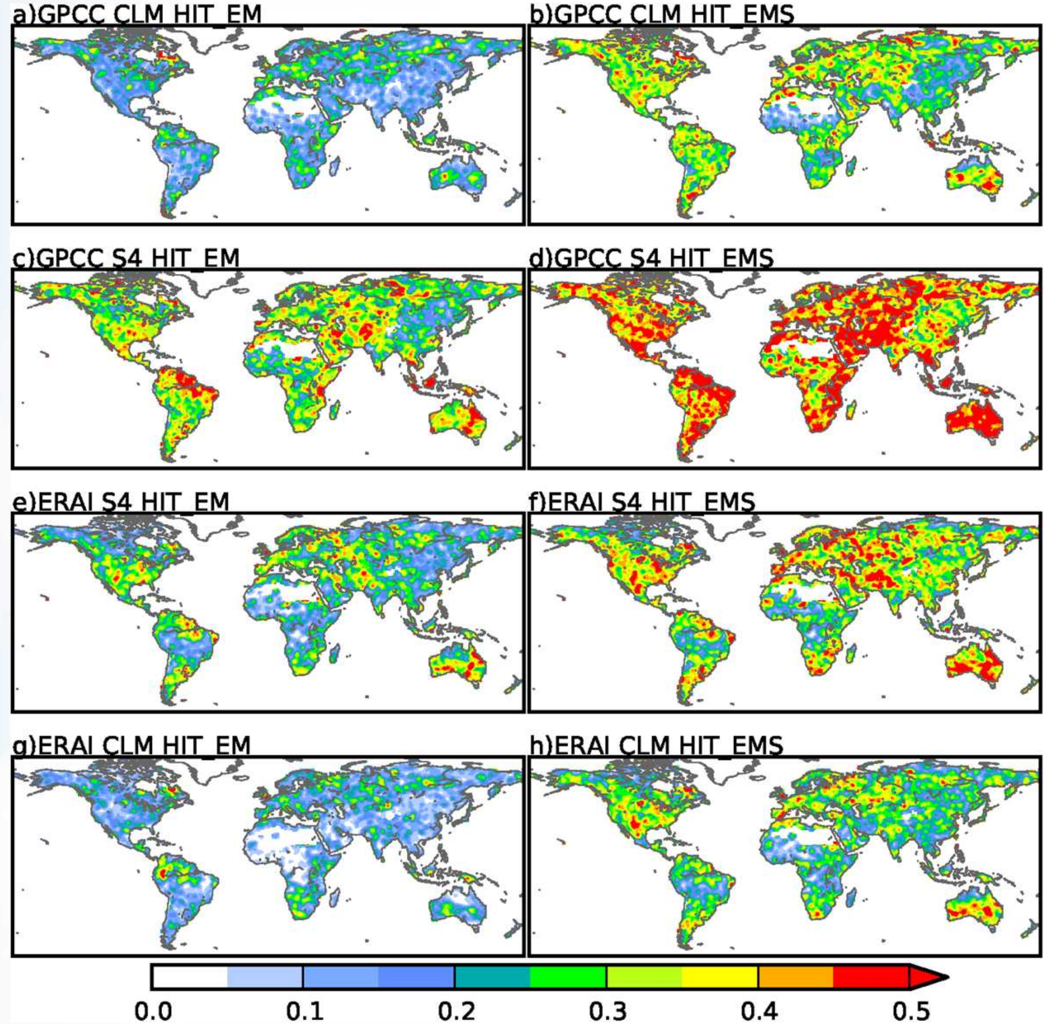


$$BS = REL - RES + UNC$$

GPCC S4 lower Brier score than GPCC CLM: worst reliability (climate is better), better resolution (use of S4).

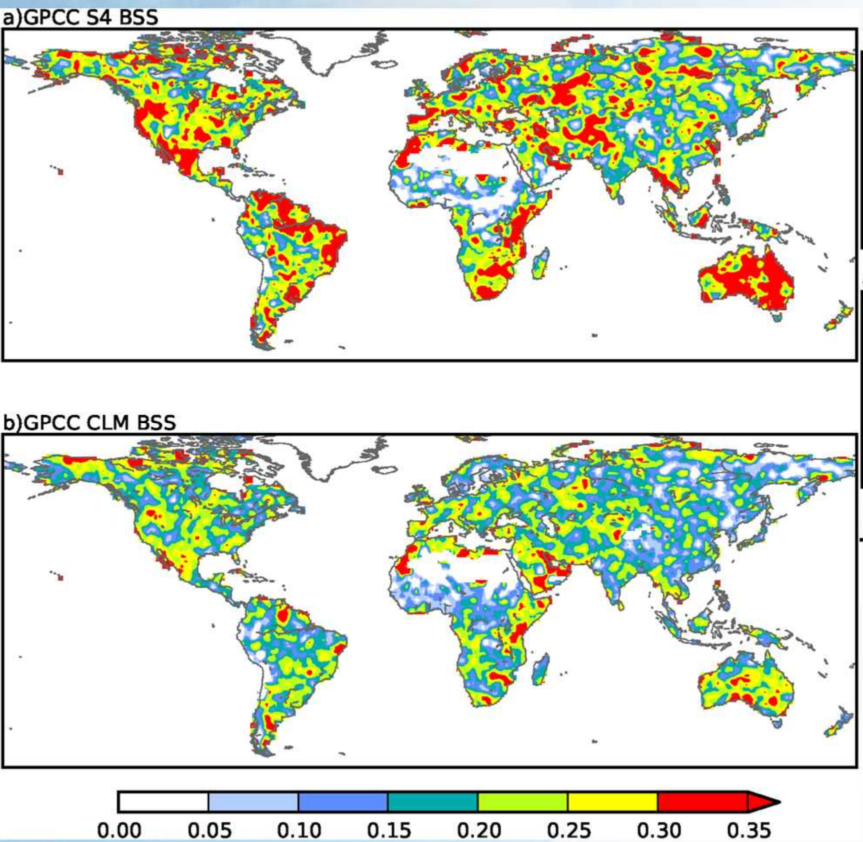
Drought onset – Probability of detection

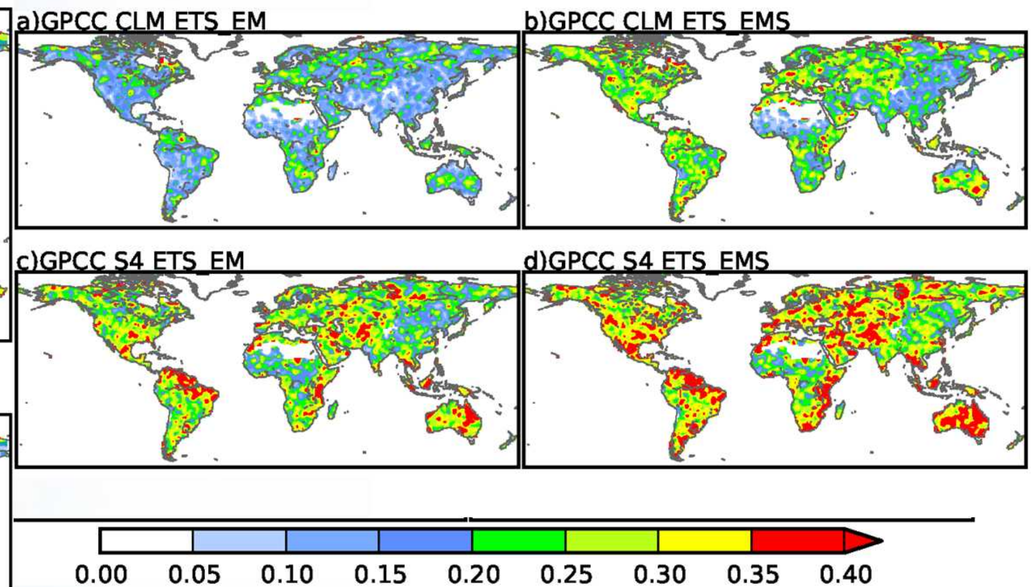




Citation: Yuan, X., and E. F. Wood (2013), Multimodel seasonal forecasting of global drought onset, *Geophys. Res. Lett.*, *40*, doi:10.1002/grl.50949.

Drought onset - brier skill score and Equitable threat Score



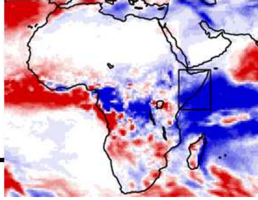


Brier skill score with similar spatial patterns to ETS. Still the fields are a bit noise (even after a 3x3 smoothing). Regions vs. maps evaluation ? How should be the best way ?

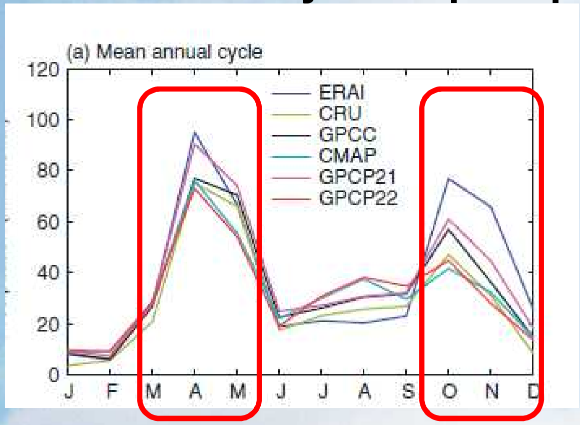
Outline

- Droughts indices and seasonal forecasts
- Meteorological drought : Standardized precipitation index (SPI)
- Monitoring and forecasting meteorological droughs:
  - Probabilistic monitoring of SPI (using EPS precipitation)
  - Merging of ECMWF precipitation products (monitoring + forecasting)
  - Drought onset
- The 2010/11 drought in the Horn of Africa: ECMWF products

Horn of Africa 2010/11: Monitoring

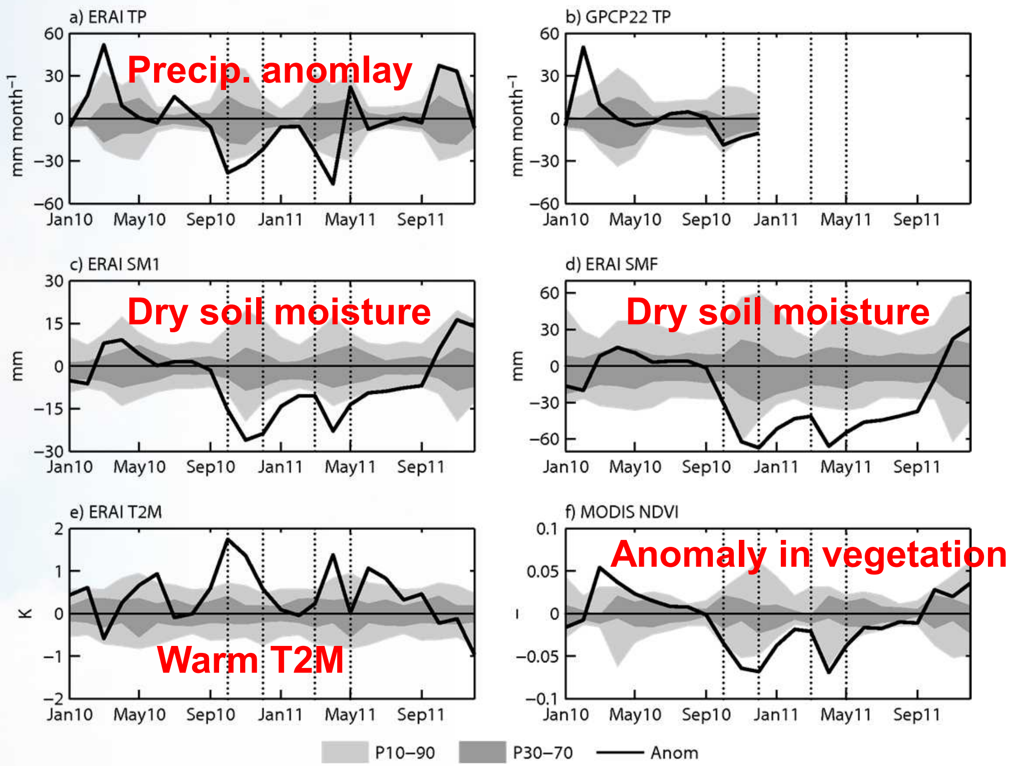


Mean annual cycle of precipitation in the HoA region



Long rains **Short rains**

Drought monitoring is not restricted to precipitation, what about soil moisture, vegetation, etc...



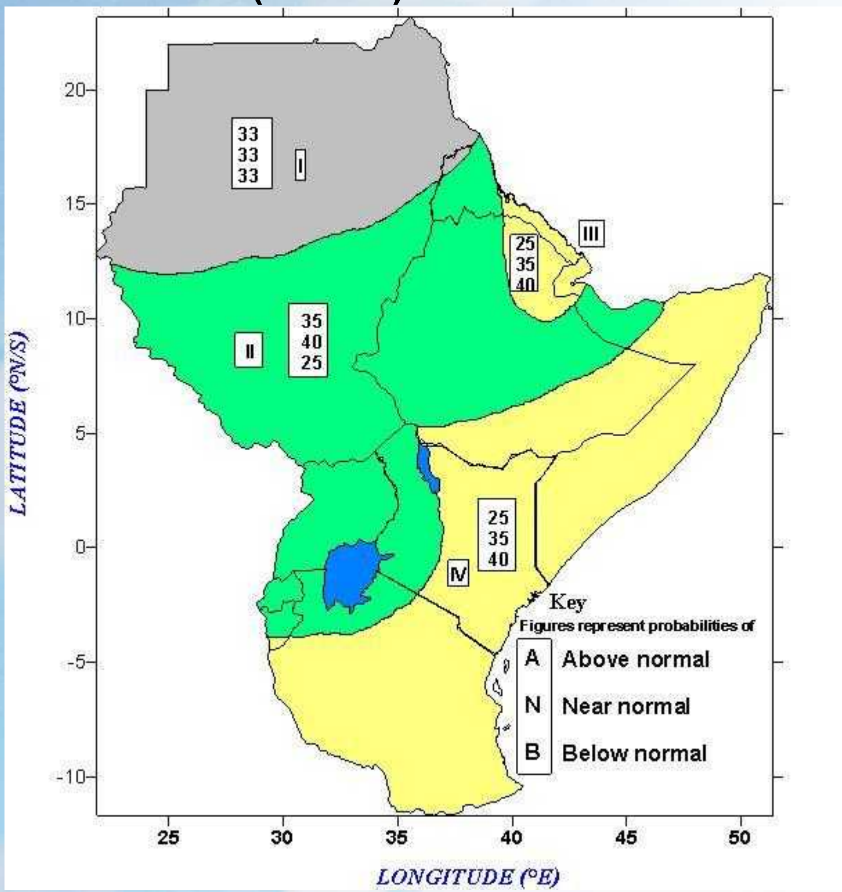
The 2010/11 event was so extreme due to the failure two consecutive rainy seasons: Oct-Dec 2010 and Mar-May 2011

Captured by ERA-Interim (precipitation / soil moisture)

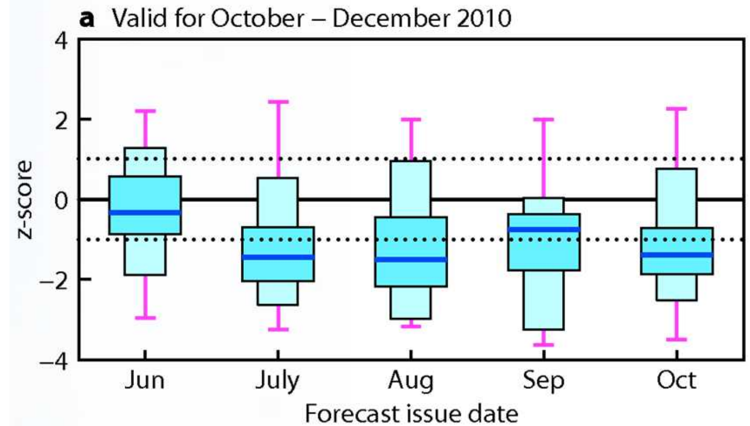
More details: Dutra et al. 2012 IJC

Horn of Africa 2010/11: Oct-Dec 2010 forecasts

Greater Horn of Africa Consensus Climate Outlook for September to December 2010 GHACOF26 (ICPAC)



Precipitation forecasts for Oct-Dec 2010

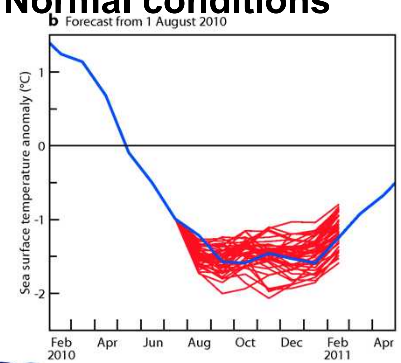


z-score
Remove mean and divide by standard deviation

(Similar to SPI-3)

Jun	July	Aug	Sep	Oct	
31	12	14	7	9	**Above normal (%)**
26	15	18	33	18	**normal (%)**
43	73	68	60	73	**Bellow normal (%)**

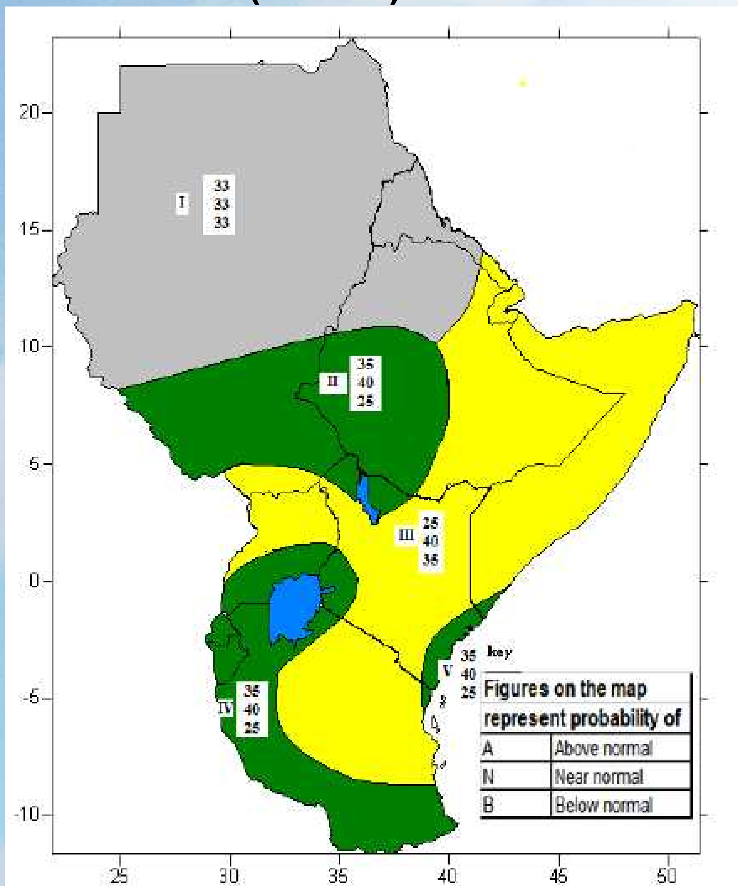
Probabilities between 20-40 : Normal conditions



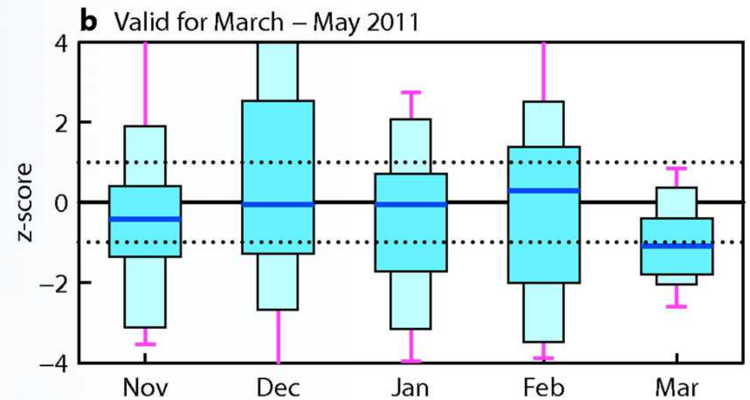
Dry conditions in Sept-Dec 2010 in the HoA associated with La-Nina, that was correctly forecasted by ECMWF seasonal forecasts from June 2010 onwards.

Horn of Africa 2010/11: Mar-May 2011 forecasts

Greater Horn of Africa Consensus Climate Outlook for the March May 2011 GHACOF27 (ICPAC)



Precipitation forecasts for Mar-May 2011
3 months means anomaly: equivalent to May SPI-3



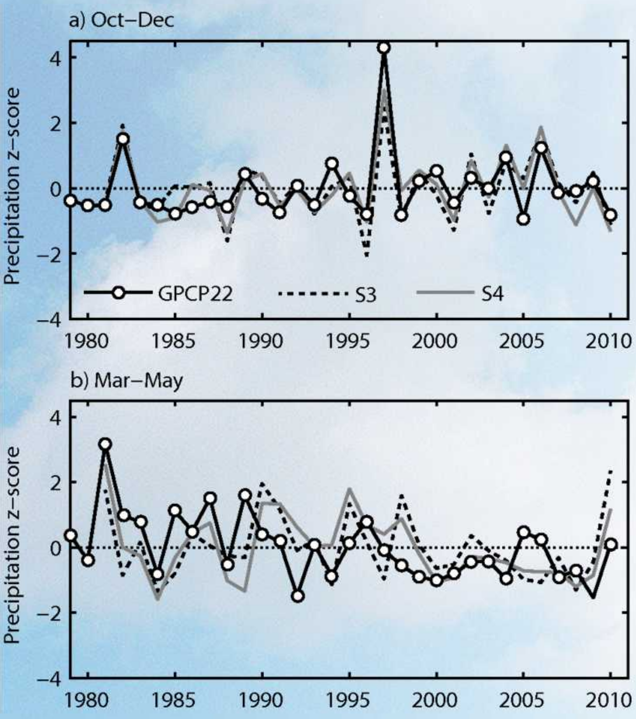
Nov	Dec	Jan	Feb	Mar	
29	**41**	**41**	**46**	**5**	**Above normal (%)**
23	**18**	23	**11**	27	**Normal (%)**
48	**41**	36	**43**	**68**	**Bellow normal (%)**

Probabilities between 20-40 : Normal conditions

Dry conditions in Mar-May 2011 were not forecasted in advance (expect for the forecasts starting in Mar 2011)

ECMWF

Horn of Africa 2010/11



Looking at the past performance:

ECMWF seasonal forecasts for the Oct-Dec season have skill (strong connection with El Nino)

The forecasts for the Mar-May season do not have skill.

In each particular application, the performance of the monitoring and forecasting products should be carefully evaluated

Finding that there is no skill can be also useful:
Try to understand why, and avoid misleading use.

Merging observations with ECMWF products?

Observations of monthly precipitation are available for a long period (20-30 years)?

1) Quality control of the station data;
2) Is the data continuously updated in near real time ?
   - No: Maybe ERA-Interim could be used for the near real time forecasts: Compare it with observations.

3) Seasonal forecasts of SPI:

3.1 Using “climatological” benchmark forecasts:
Selection of past years: random or analogue (years with similar conditions to 2012)
What will be the evolution of the SPI if the next months are normal ?

SPI-6 Dec 2012

July+Aug+Sep 2012 **Monitoring** + Oct+Nov+Dec **Past years**

3.2 Using ECMWF seasonal forecast:
Forecast*: Forecast issued in October 2012;
Bias correct the mean using the hindcast data;

SPI-6 Dec 2012

July+Aug+Sep 2012 **Monitoring** + Oct+Nov+Dec **Forecast***

Point 3.2 can be extended by using other forecasts (dynamical / statistical)

Extend 3.1 and 3.2 for the past, and compare the skill of both: Are they skilful ? Reliable ? This is an important information to consider when communicating the forecasts.

Final Remarks

- Drought forecasting is strongly dependent on good quality monitoring and seasonal forecast products;
- For monitoring, local observations should be used, when available. If ERAI is used, a careful validation should be performed;
- ENS short-range forecasts can be used to generate a probabilistic monitoring of SPI:
  - Increase the ensemble spread, and rely in the skill of short-range precipitation forecasts.
- Take advantage of the past forecasts (hindcasts) of the seasonal system:
  - Allow a robust verification of the forecast system;
  - Apply bias correction methods, tailor made for the application/region ;
- Use probabilistic information (e.g. % of members bellow a threshold), not only the ensemble mean;
- Forecasts of SPI strongly dependent on the underlying skill of precipitation (reduced in some regions).
- Consider other fields other fields such as near surface temperature and soil moisture.

Further Reading

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