Module II: Drought Monitoring

Objectives:

- Discussion on the drought indices available
- Discussion on how the SA index was derived

What is drought?

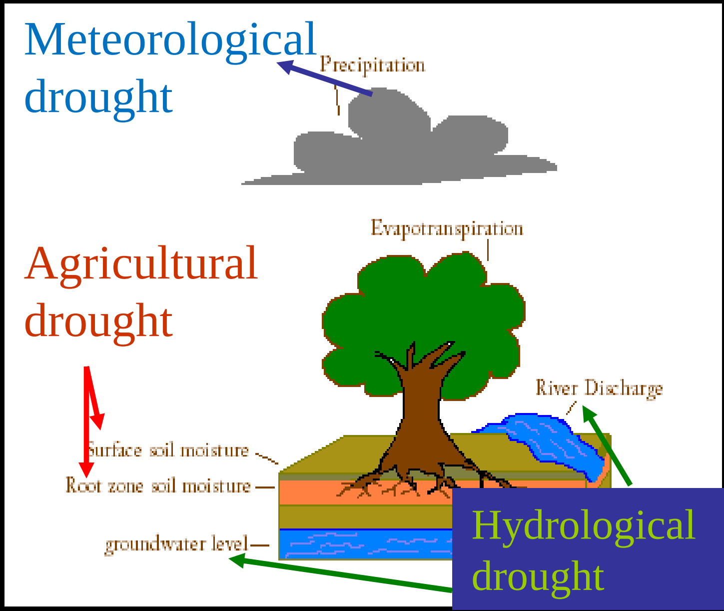
Drought

- prolonged absence or marked deficiency in precipitation resulting in water shortage for some activity; causing serious hydrological imbalance (*Heim, 2002; IPCC AR4WG1, 2007*)
- regional in nature; critical when there is an extreme shortage of water for long durations over large areas (*Tallaksen, et al., 1997*)

What are the different types of drought?

- **Agricultural Drought**: moisture deficits in the topmost one meter or so of soil (the root zone) that impact crops
- **Meteorological Drought**: a prolonged deficit of precipitation
- **Hydrologic drought** below normal streamflow, lake and groundwater levels

IPCC, ARWG1, 2007



What are other indicators of drought?

- ↓ land precipitation and ↑ temperature = ↑ evapotranspiration and drying
- In the tropics: SST through associated changes in the atmospheric circulation and precipitation
- In western USA, diminishing snow pack and reductions in soil moisture
- In Australia and Europe, direct links to global warming inferred from extremely high temperatures and heat waves in recent droughts

Issues: Past Droughts

Drought Quantification: The Standard Anomaly(SA) Index

1) Transform the best-fit distribution pattern into an equivalent normal distribution

$$x_{transformed} = \frac{x - \mu}{\sigma}$$

2) Standardize by calculating SA

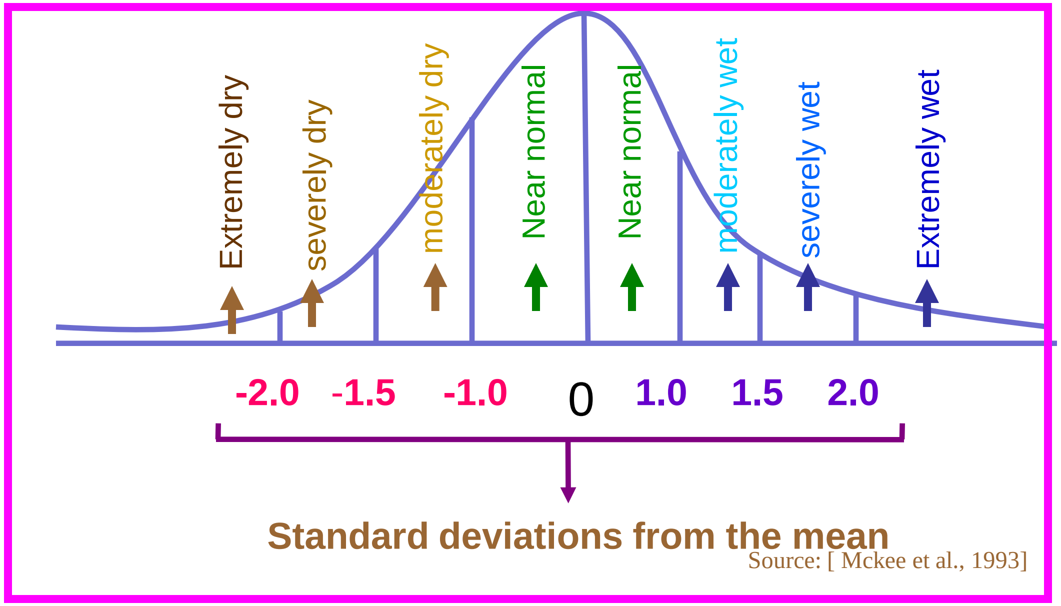
$$SA = Z = \frac{x_{transformed} - \bar{x}_{transformed}}{\sigma_{transformed}}$$

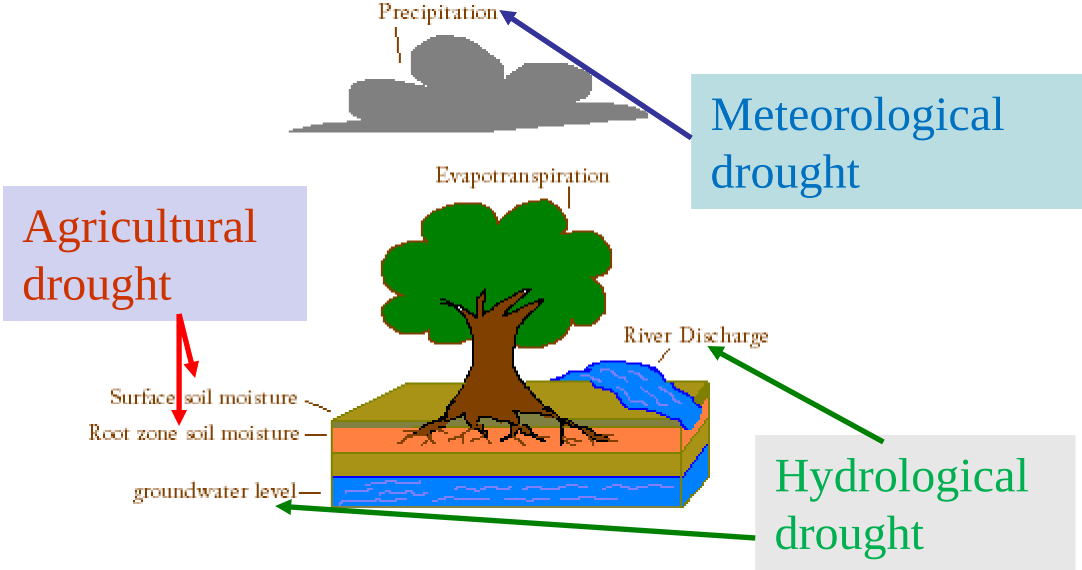
$$\sigma = \sqrt{\mathrm{var}(x)}$$

$$\mathrm{var}(x) = \int (x-\mu)^2 f(x)dx$$

$$\mu = \int x f(x)dx$$

Jaranilla-Sanchez, P. A., et al. (2011), Water Resour. Res.





Some definitions

- Location (best-fit distribution mean)
- Scale (best-fit departure of the variate from the mean); (best-fit standard deviation)
- μ, mu (normal distribution mean)
- σ, sigma (normal distribution standard deviation)

STATISTICAL EXPLANATION:
Frequency Analysis using Frequency Factors

$$X_T = \mu + \Delta X_T$$

$$\Delta X_T = K_T s$$

$$X_T = \mu + K_T s$$

$$X_T = mean + K_T st.dev.$$

K_T=Frequency Factor (Proposed by Chow, 1951)

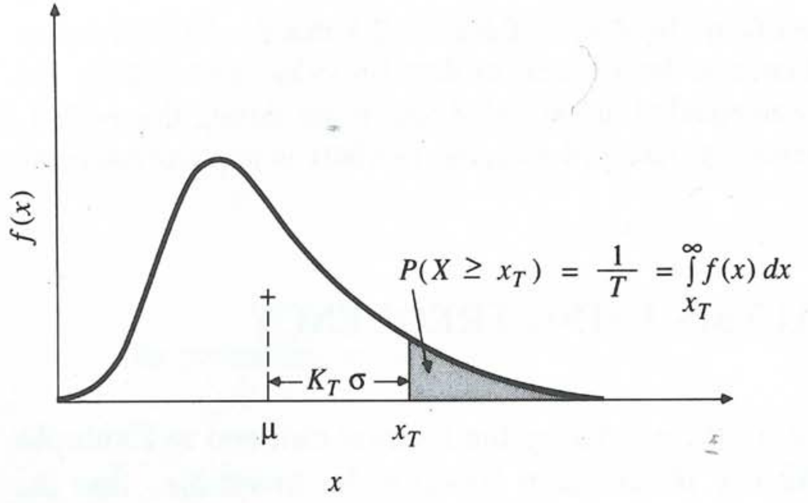
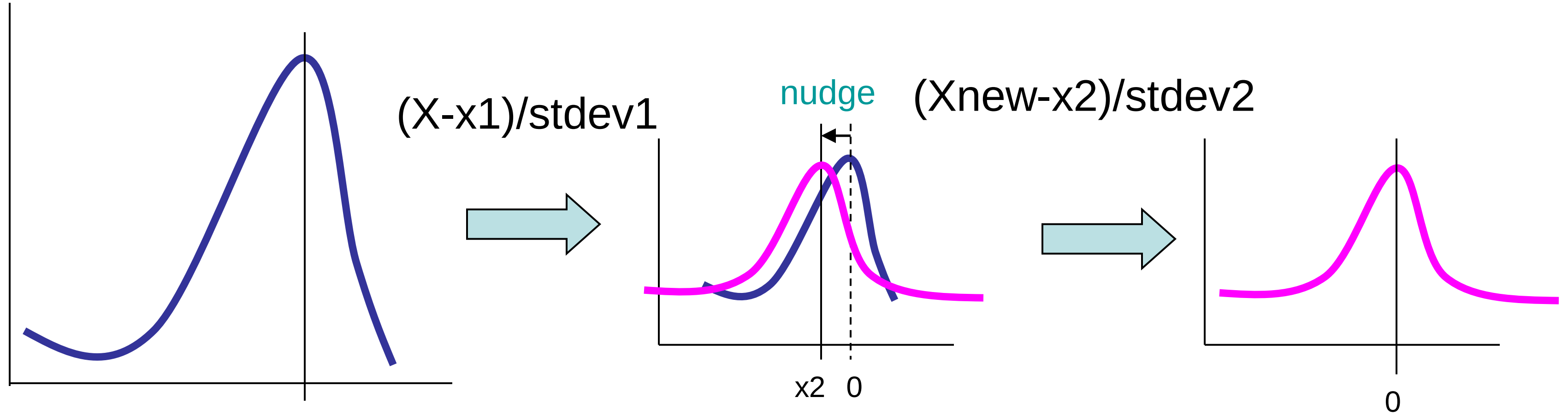


FIGURE 12.3.1 The magnitude of an extreme event x_T expressed as a deviation $K_T\sigma$ from the mean μ, where K_T is the frequency factor.

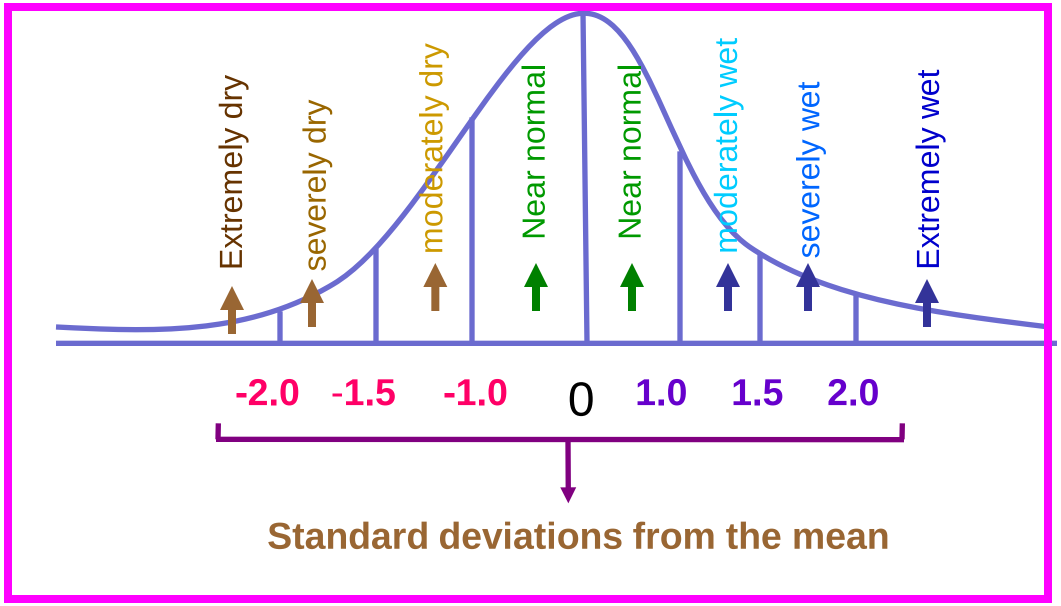
K_T=Frequency Factor (Proposed by Chow, 1951)

$$p(X \geq X_T) = \frac{1}{T} = \int_{X_T}^{\infty} f(x)dx$$

$$K_T(any) = K_T(normal)$$



$$\int fxdx = 1 \qquad \int fxdx = 1$$



Advantage:

Simple, very easy to do (as you will see later)

can be used on different parameters and different basins

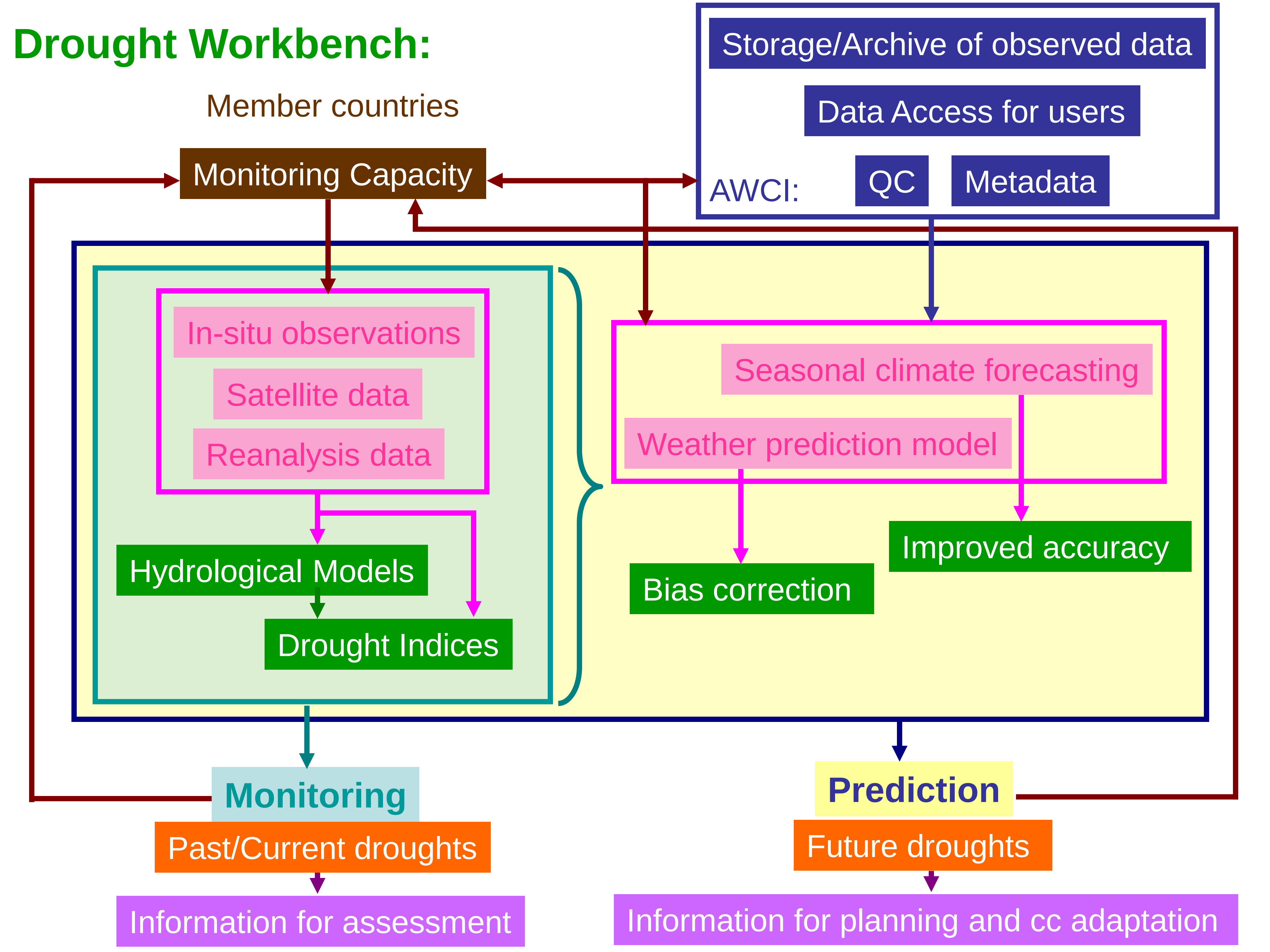
Limitation:

Dependent on the quality of the long term datasets

Classification is based on the available sample distribution

(more data=more general picture)

No magic number for best sample size but commonly at least 30 years or more


Drought Workbench:
Member countries
Storage/Archive of observed data
Data Access for users
AWCI:
QC
Metadata
Monitoring Capacity
In-situ observations
Satellite data
Reanalysis data
Seasonal climate forecasting
Weather prediction model
Hydrological Models
Drought Indices
Improved accuracy
Bias correction
Monitoring
Past/Current droughts
Information for assessment
Prediction
Future droughts
Information for planning and cc adaptation

Drought Monitoring Framework:

Member countries

Monitoring Capacity

Storage/Archive of observed data

Data Access for users

AWCI: QC Metadata

In-situ observations

Satellite data

Reanalysis data

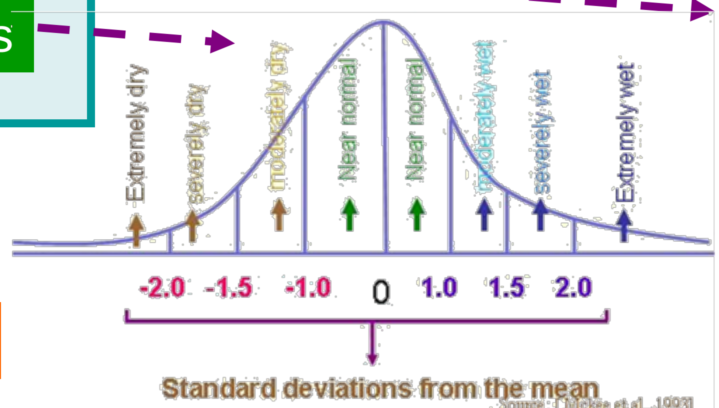
(Long-term)
- Rainfall
- Temperature
- Evapotranspiration
- Discharge
- Soil Moistures
- Groundwater

- GRACE (total water)
- TRMM (rainfall)
- GsMap (combined satellite + obs)
- APHRODITE
- SSM/I (microwave brightness temperature)
- MODIS (LAI/FPAR)
- AVHRR (LAI/FPAR)
- GMS= MTSAT (met. Parameters)
- AMSR-E (brightness temp. converted to soil moisture)

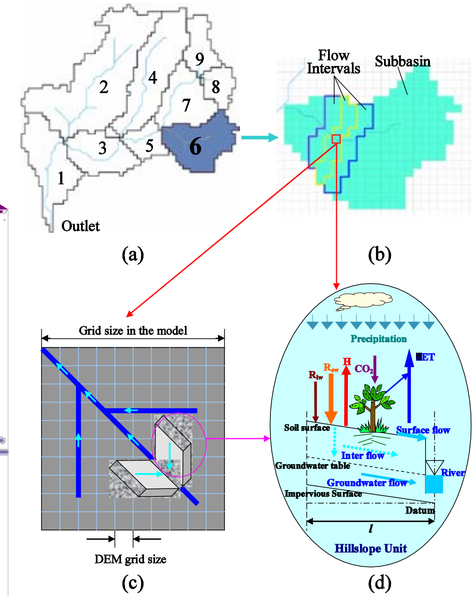
- JRA25; JRA55
- NCEP/NCAR

Hydrological Models

Drought Indices



SA



- WEB-DHM

Monitoring

Past/Current droughts

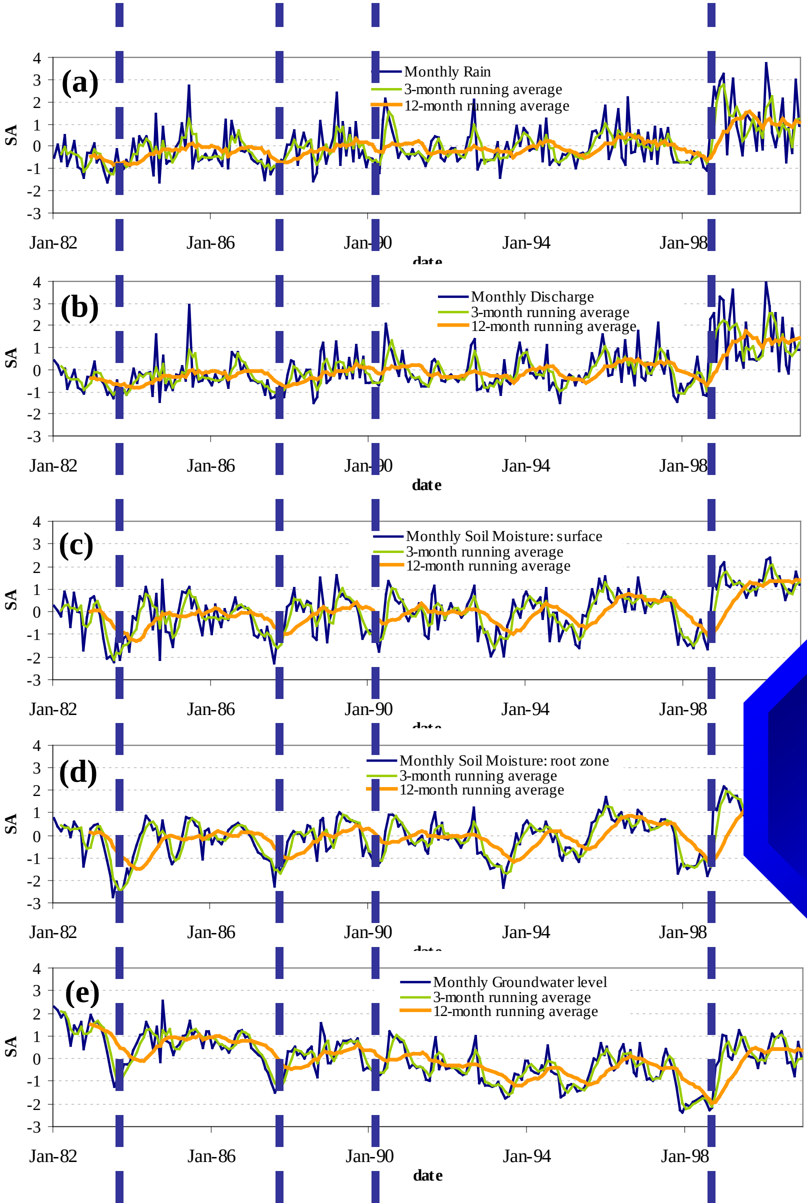
Information for assessment

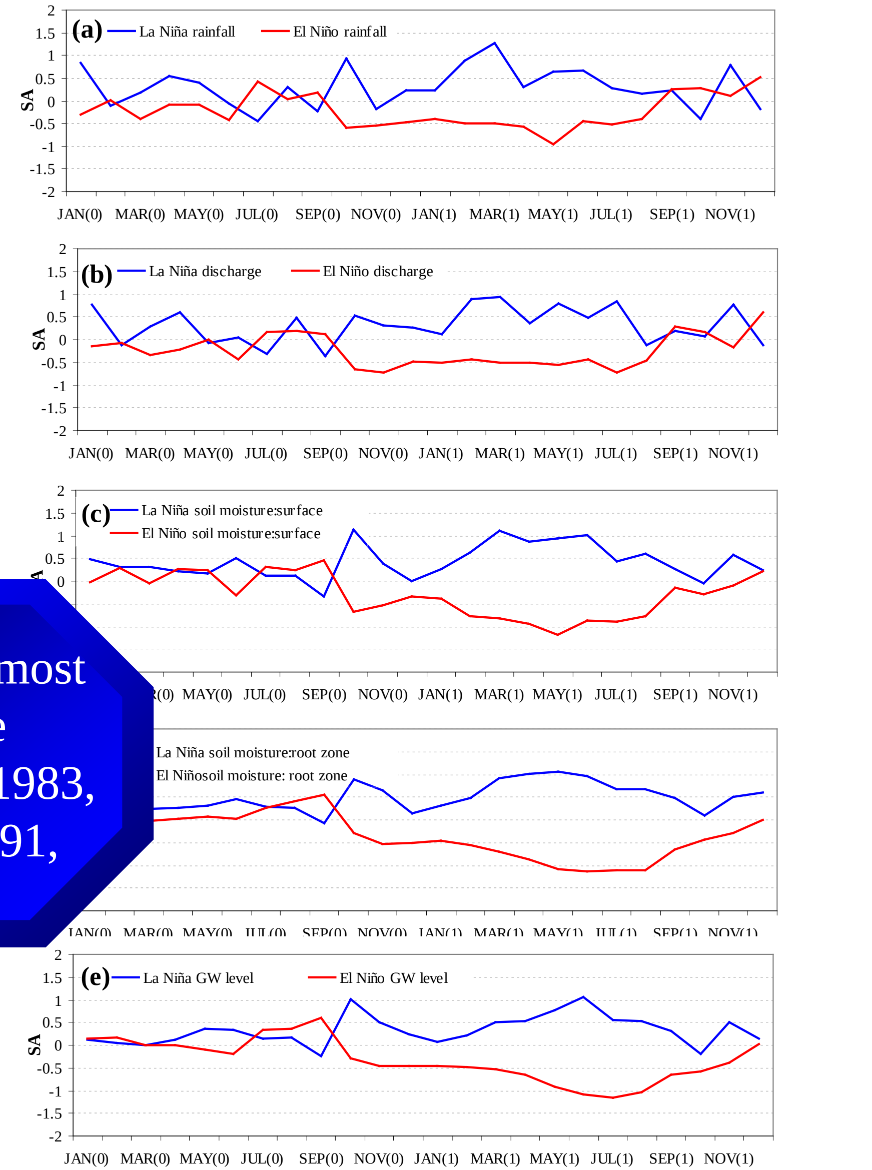
CASE STUDY: *The Pampanga River Basin, Philippines*

- Lies on the northern shore of Manila Bay
- Area: 10,033 sq. km draining to Manila Bay
- Major agricultural products: Rice, Corn, Sugarcane and tilapia
- a significant water resource for irrigation, hydropower, domestic water use and industrial use
- Metro Manila gets around 97% of its water supply from this basin
- Type II climate type
  - Wet season: May to Nov
  - Dry Season: Dec-April

Temporal SA: Philippines

Drought From literature and reports: 1982, 1983, 1987, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1997, 1998





Reported most severe droughts: 1983, 1987, 1991, 1998

P-values for the student t-test comparing a. El Niño and b. La Niña two-year composites for rainfall, discharge, soil moisture at the surface, soil moisture at the root zone and groundwater using SA. (α=0.05).

a.El Niño vs. La Niña: using SA for year 1

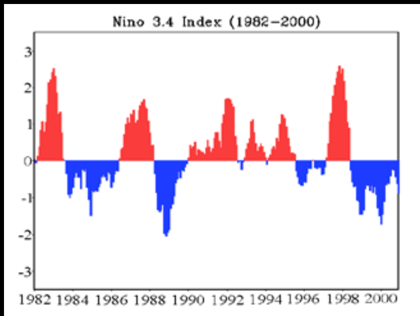
Drought Parameter	Jan (1)	Feb (1)	Mar (1)	Apr (1)	May (1)	Jun (1)	Jul (1)	Aug (1)	Sep (1)	Oct (1)	Nov (1)	Dec (1)
Rainfall	0.22	0.98	0.34	0.46	0.32	0.21	0.08	0.98	0.92	**<0.01**	**0.02**	0.16
Discharge	0.25	0.65	0.33	0.38	0.93	0.17	0.37	0.99	0.71	**<0.01**	**<0.01**	0.13
Soil Moisture (surface)	0.30	0.67	0.54	0.86	0.65	0.07	0.99	0.59	0.59	**<0.01**	**0.01**	0.41
Soil Moisture (root zone)	0.63	0.52	0.54	0.70	0.90	0.40	0.94	0.50	0.36	**0.01**	**0.01**	0.13
Groundwater level	0.89	0.67	0.64	0.84	0.84	0.61	0.61	0.15	0.09	0.15	0.21	0.42

b. El Niño vs. La Niña: using SA for year 2

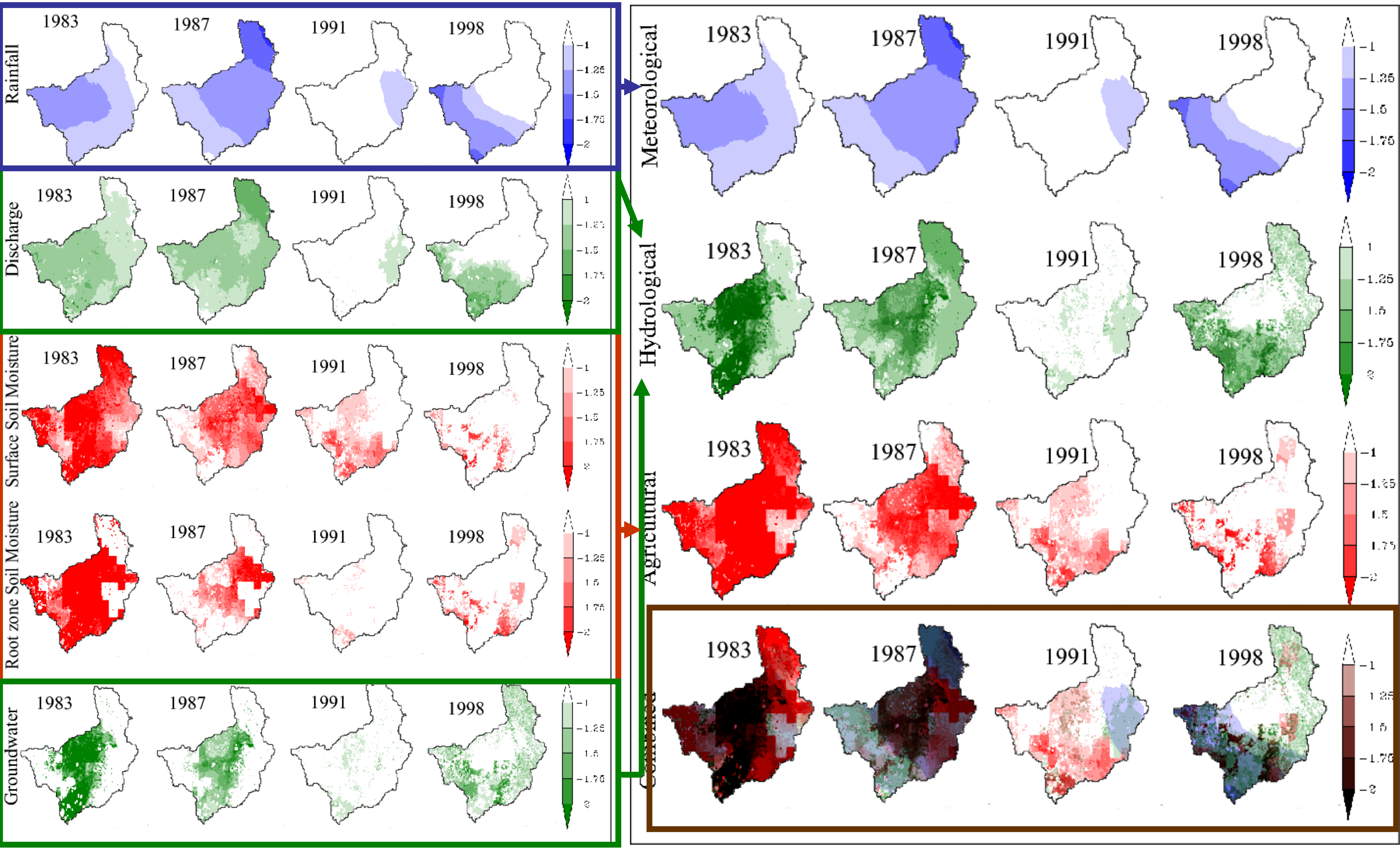
Drought Parameter	Jan (2)	Feb (2)	Mar (2)	Apr (2)	May (2)	Jun (2)	Jul (2)	Aug (2)	Sep (2)	Oct (2)	Nov (2)	Dec (2)
Rainfall	0.17	0.18	**0.04**	0.13	**0.01**	0.19	0.17	0.42	0.74	0.33	0.28	0.41
Discharge	0.07	0.19	0.07	**0.05**	**0.04**	0.35	**0.01**	0.39	0.92	0.95	0.05	0.40
Soil Moisture (surface)	0.10	**0.03**	**0.01**	**<0.01**	**<0.01**	**<0.01**	**0.01**	**0.03**	0.37	0.37	0.39	0.90
Soil Moisture (root zone)	0.11	0.06	**0.02**	**<0.01**	**<0.01**	**<0.01**	**0.01**	**0.01**	0.10	0.20	0.27	0.34
Groundwater level	0.40	0.30	0.14	0.07	**<0.01**	**<0.01**	**<0.01**	**0.01**	0.19	0.50	0.10	0.68

List of warm (El Niño) and cold (La Niña) ENSO events considered in the two-year composites for the years 1982-2000 *(Jaranilla-Sanchez et al., 2009, JSCE).*

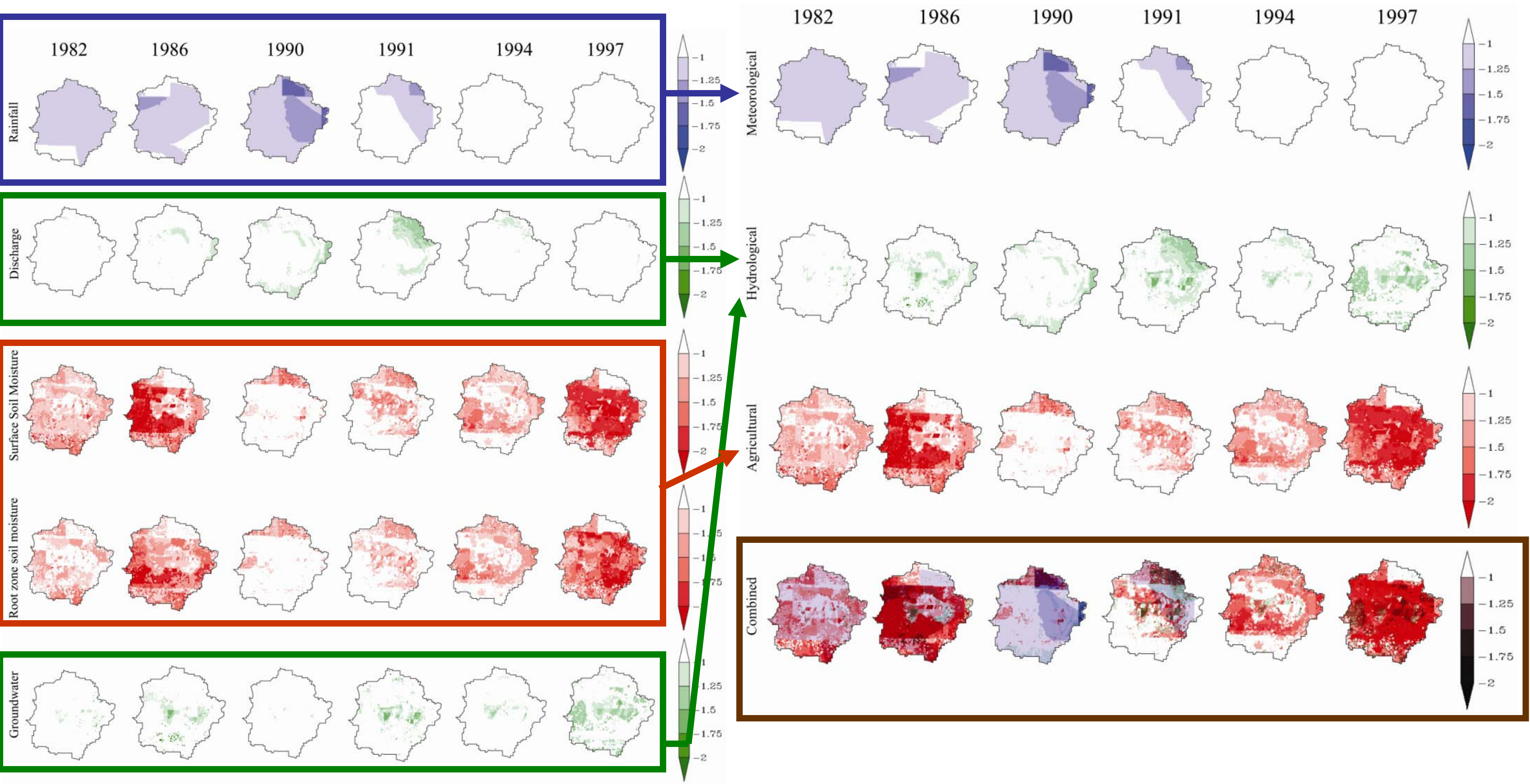
Warm ENSO events, or El Niño *(6 cases)*	1982/83, 1986/87, 1991/92, 1992/93, 1994/95, 1997/98
Cold ENSO events, or La Niña *(4 cases)*	1984/85, 1988/89, 1995/96, 1999/2000



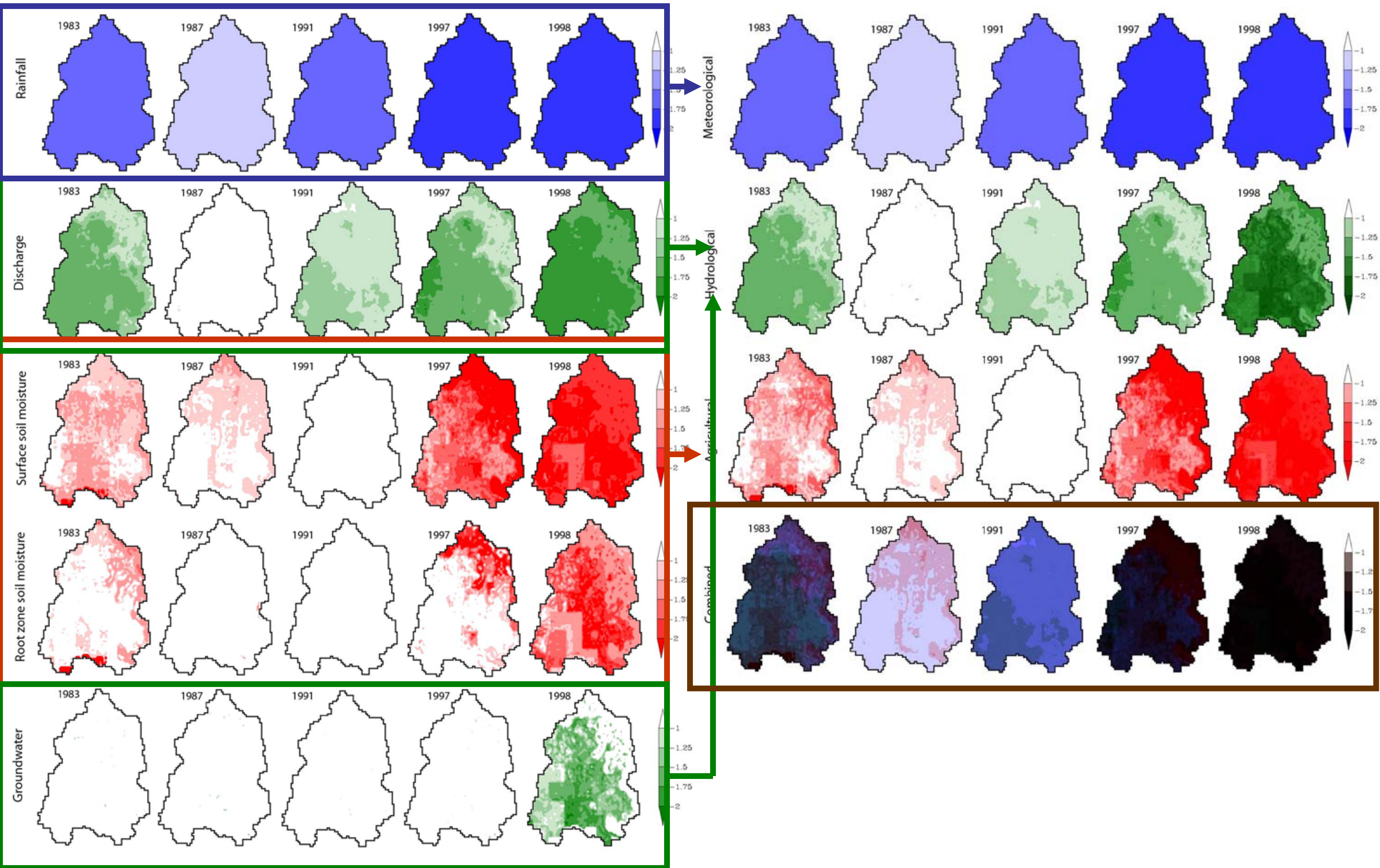
SPATIAL SA FOR THE PAMPANGA RIVER BASIN, PHILIPPINES



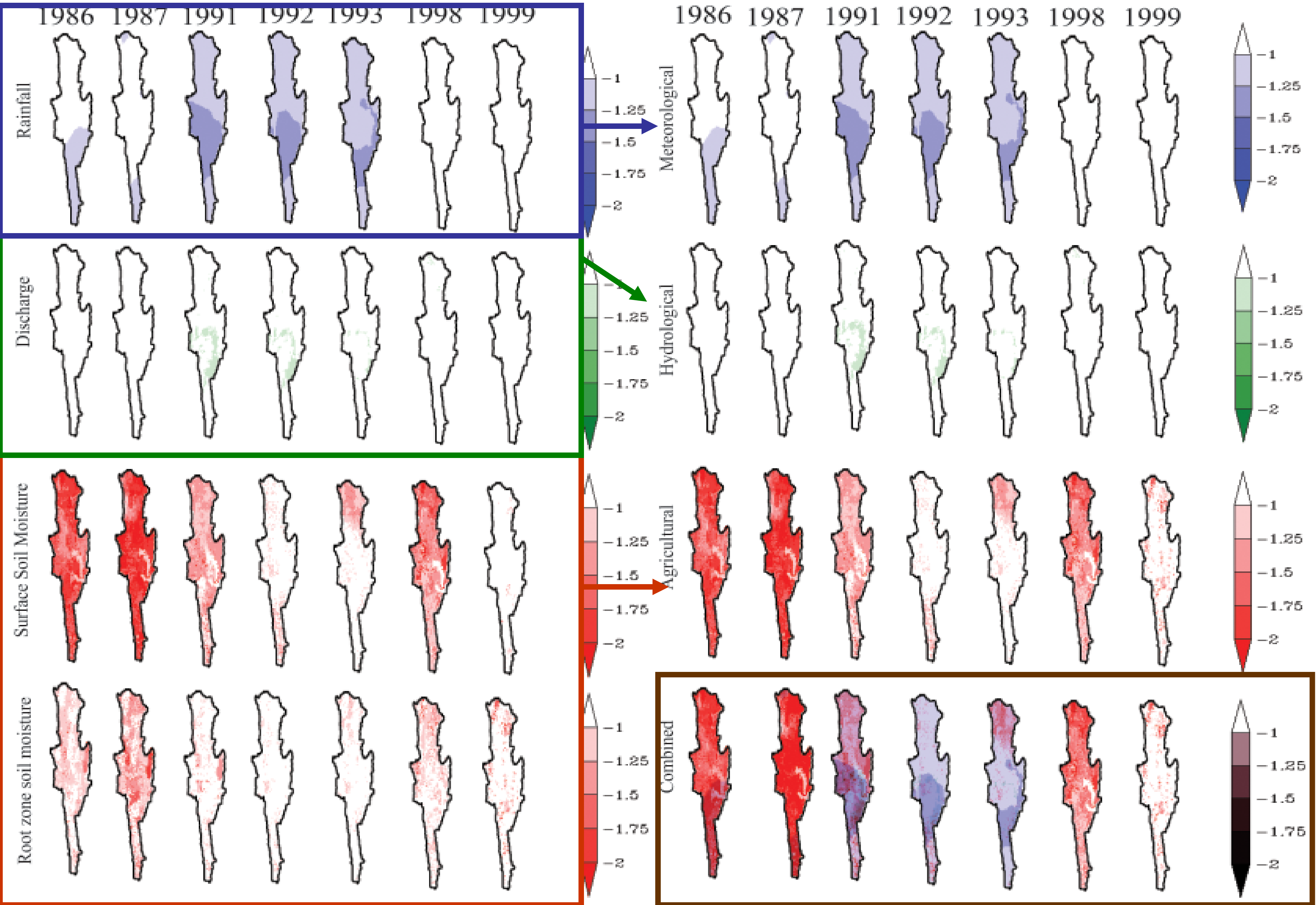
SPATIAL SA FOR THE UPPER CITARUM RIVER BASIN, INDONESIA



SPATIAL SA FOR LANGAT WATERSHED, MALAYSIA



SPATIAL SA FOR PING RIVER BASIN, THAILAND



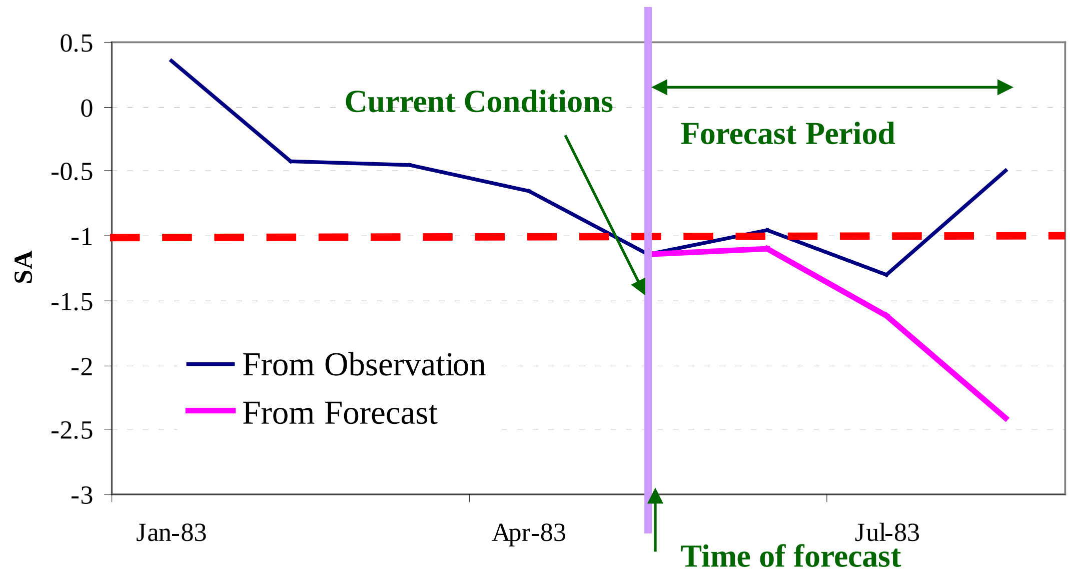
IV. SEASONAL CLIMATE FORECASTING (SCF)

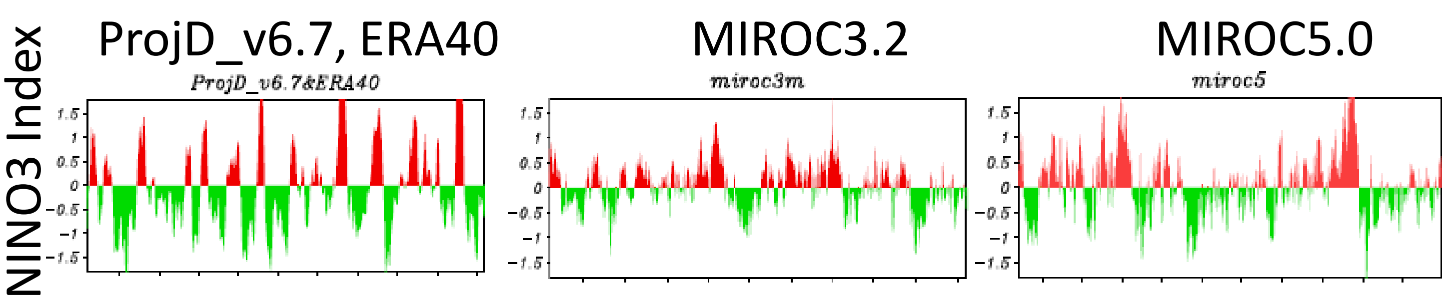
drought conditions can be forecasted

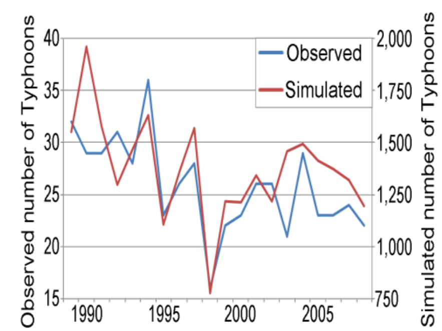
Month	SA Q_{obs}	SA $Q_{forcast}$
June	-0.954	-1.010455
July	-1.30505	-1.61425
August	-0.4937	-2.41276

Too extreme because high rainfall cannot be captured by the forecast in this grid scale

DISCHARGE Drought Quantification







Figures were reproduced from Kimoto, et al. presentation 2010.

Dataset: MIROC (SPAM) by CCSR
MIROC by NIES-JAMSTEC

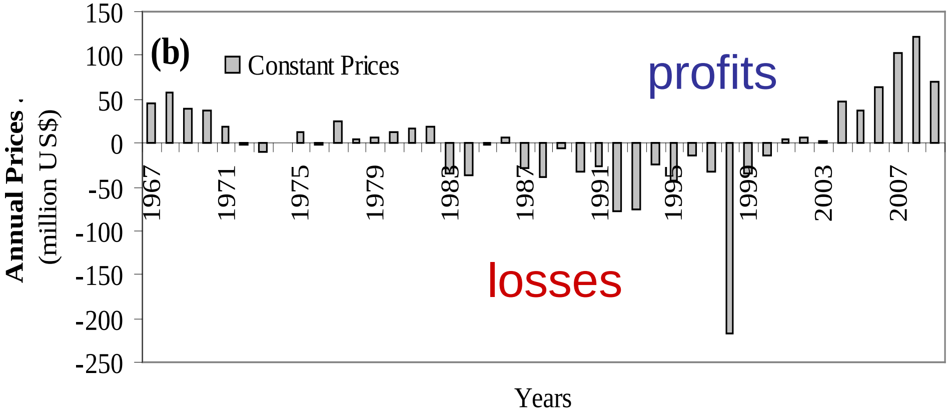
Discharge: Observed VS. SCF

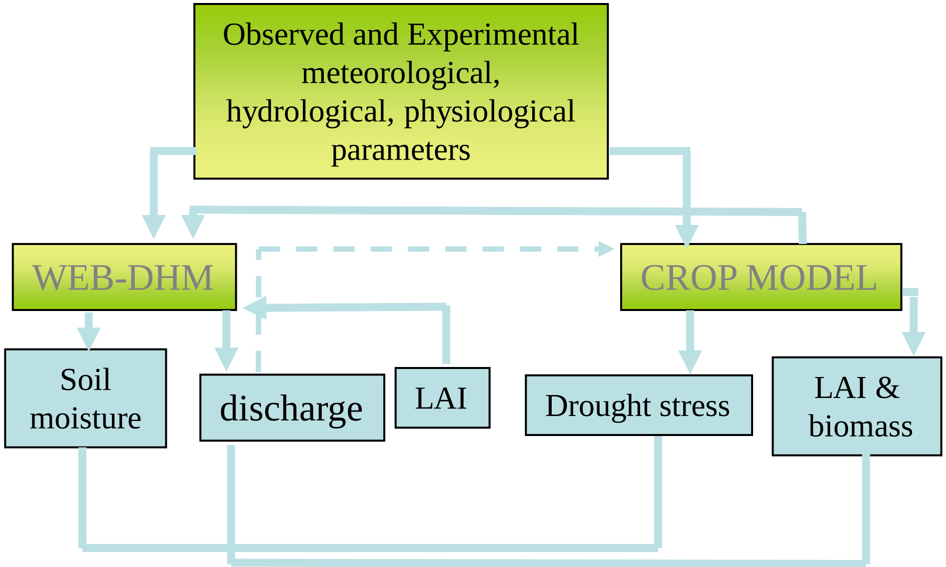
	Months	1^{st}		2^{nd}		3^{rd}	
	Year	Observed	SFC	Observed	SCF	Observed	SCF
El Niño year	*1983*	↗ (red)	↗ (red)	↘ (red)	↘ (red)	↗ (green)	↘ (red)
normal year	*1991*	↘ (green)	↘ (green)	↗ (green)	↗ (green)	↘ (green)	↘ (green)
El Niño year	*1997*	↘ (green)	↘ (red)	↘ (green)	↘ (red)	↘ (red)	↘ (red)
La Niña year	*1999-2000*	↗ (green)	↘ (green)	↗ (green)	↗ (green)	↗ (blue)	↗ (blue)

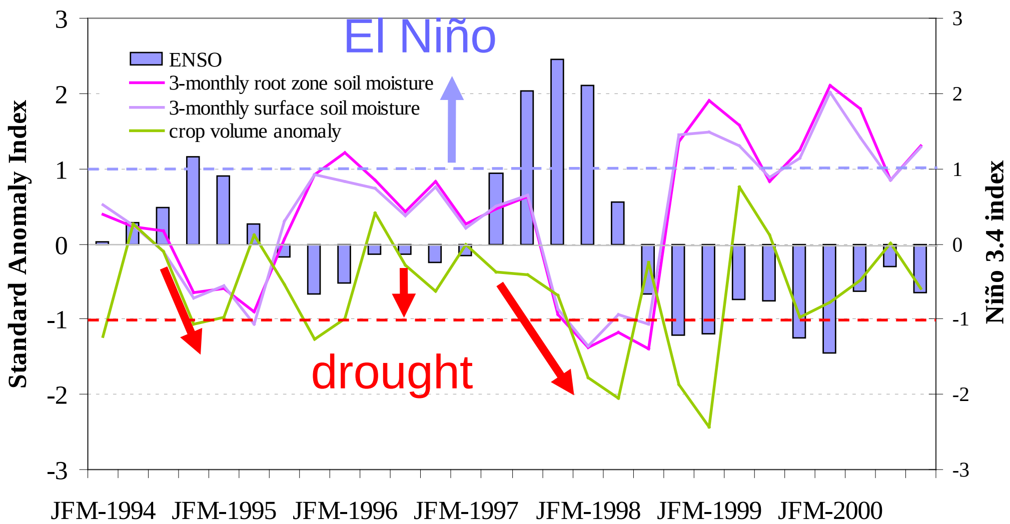
ARROW Legends: red= drought; green=normal; blue=wet

e.g. increase towards drought conditions ↗ (red)

Sample Application: Agricultural Production and Drought Monitoring







Sample output for rice production simulation:

year	Actual	simulated
1983	--	7012 kg/ha
1987	--	7247kg/ha
1991	--	6900kg/ha
1998	34164 metric tons (BAS, 2011)	6903kg/ha (34116 metric tons)

FUTURE???

USING SA FOR DROUGHT ANALYSIS

Summary of steps in calculating SA:

AFTER PREPARING long-term datasets…

1.) convert hourly/daily values of the hydrological parameters into monthly values

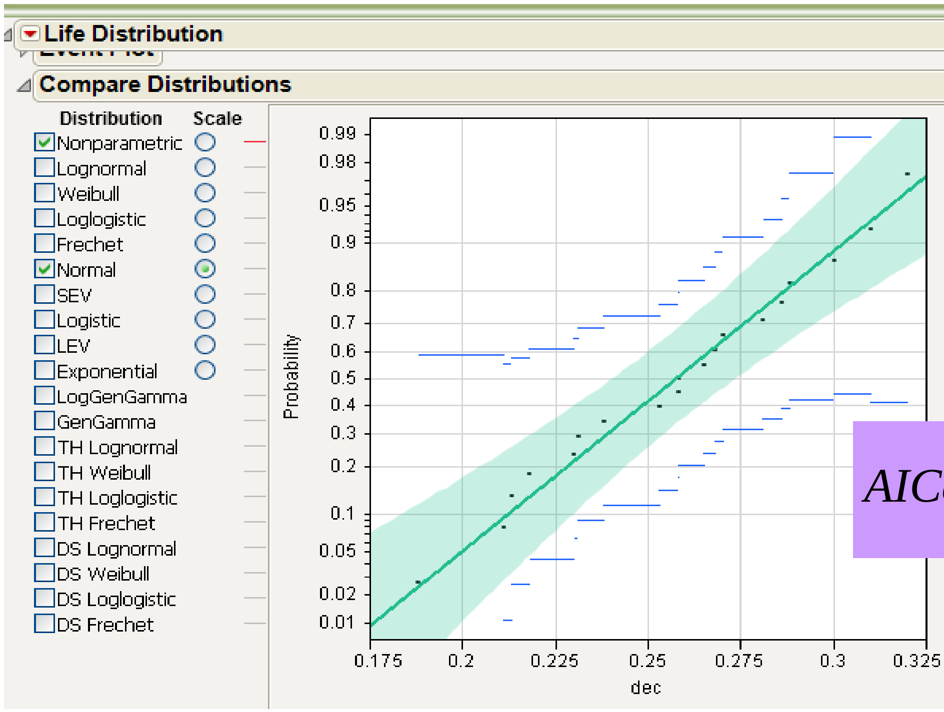
2.) combine all values for each month, get CDF

3.) fit a distribution pattern for each month of each hydrological parameters

4.) select the best distribution pattern that is predominant on all the months for each hydrological parameter

5.) get the location and scale depending on the parameter’s distribution

6.) Calculate SA



Automatic fitting of the best-fit distribution function

$$BIC = -2\log likelihood + k\ln(n)$$

$$AICc = -2\log likelihood + 2k\left(\frac{n}{n-k-1}\right)$$

$$AICc = AIC + \frac{2k(k+1)}{n-k-1}$$

Statistics

Model Comparisons

Distribution	AICc	-2Loglikelihood	BIC
Normal	-68.55801	-73.30801	-67.41913
Weibull	-6[illegible]7756	-73.12756	-67.23868
Lognormal	-68.03649	-72.78649	-66.89762
Logistic	-67.36625	-72.11625	-66.22737
SEV	-67.33616	-72.08616	-66.19728
Loglogistic	-67.00789	-71.75789	-65.86901
LEV	-66.21866	-70.96866	-65.07978
Threshold Weibull	-66.18281	-73.78281	-64.94949
Generalized Gamma	-65.81724	-73.41724	-64.58392
Log Generalized Gamma	-65.75268	-73.35268	-64.51936
Threshold Lognormal	-65.65969	-73.25969	-64.42638
DS Weibull	-65.52756	-73.12756	-64.29424
DS Lognormal	-65.18649	-72.78649	-63.95318
Threshold Loglogistic	-64.47987	-72.07987	-63.24655
DS Loglogistic	-64.15789	-71.75789	-62.92457
Frechet	-64.14205	-68.89205	-63.00317
Threshold Frechet	-63.15746	-70.75746	-61.92414
DS Frechet	-61.29205	-68.89205	-60.05873
Exponential	-11.37118	-13.60647	-10.66203

Distributions with the lowst AIC, BIC and -2log*likelihood* are considered best-fit

-2loglikelihood = -2log(likelihood function evaluated at the best-fit parameter estimates)