THE UNIVERSITY OF TOKYO

REEL

DROUGHT INDICES AND CLIMATE CHANGE IMPACT ASSESSMENTS

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OUTLINE

I. DROUGHT: Definition, Types & indices

II. Selected Index: The Standard Anomaly Index

III. Spatial and Temporal drought Quantification

IV. Climate Change and drought: Impact Assessment

Definition of Drought

- Drought is defined as a prolonged and abnormal moisture deficiency.

-American Meteorological Society, 1959 (as cited by Palmer 1965)

TYPES OF DROUGHT:

Atmospheric: too high saturation deficit

Meteorological: a longer period of time with considerably less than average precipitation amounts

Hydrological: refers to a period of below-normal stream-flow

Agricultural: insufficient soil moisture causing plant stress and resulting to lower crop yield

Physiological: plant is unable to take up water in spite of the present sufficient soil moisture

Socio-economic: supply and demand of some economic good with elements of met, hydrological and agricultural drought

Some commonly used indices for quantifying drought

- Percent of Normal (Gibbs and Maher, 1967)
  - Departure from Mean
  - Departure from Median
- Standard Precipitation Index (SPI) (McKee, et al., 1993)
- Palmer Drought Severity Index (PDSI) (Palmer 1965)
- Crop Moisture Index (CMI) (Palmer, 1968)
- Surface Water Supply Index (SWSI) (Shafer and Dezman, 1982)
- Reclamation Drought Index (RDI) (Bureau of Reclamation, as a trigger to release drought relief funds)
- Deciles (Gibbs and Maher, 1967)
- Effective Drought Index (EDI) (Byun and Wilhite, 1996)
- Available Water Resources Index (AWRI)
- Bhalme and Mooley Drought Index (BMDI) (Bhalme and Mooley, 1980)
- Rainfall Anomaly Index (RAI), (van Rooy, 1965)
- Keetch-Byram Drought Index, (KBDI)

Table 2. Temporal and parametric differences of the Flood and Drought Indices

Floods and Drought Indices	*Required Parameters*	*Minimum available data duration*	*Temporal Scale*	*Upside*	*Downside*
% normal	Rainfall	None	Daily, monthly, yearly, etc	Simple can easily be done spatially and temporally	Too general; not normalized
SPI	Rainfall or Q or soil moisture	30 years	3,6, 12,24 and 48 months	Simple, Flexible; can be used for other hydrological parameters (one at a time)	For longer time scales but not reliable if time interval>48months
PDSI	Rainfall, Temperature, AWHC of soil	25 years	Weekly, monthly	Can be used for extreme events	Only for hydrological droughts; requires 25 years data at least; complicated
CMI	Rainfall, Temperature, AWHC of soil	25 years	Weekly, monthly	Can be used for crops; also accounts for evaporation	Can be used for agricultural droughts; requires 25 years data at least; complicated
Deciles	Rainfall	None			Too general
EDI	Rainfall	30 years	Daily, monthly	Can be used for daily calculations, ideally monthly	Too general, requires 30 years data at least
AWRI					
BMDI	Rainfall	None	Daily, monthly, etc		Calibration parameters can be subjective
RAI	Rainfall	None			Too general
RDI	Rainfall, Discharge, Temperature			Basin scale; also accounts for evaporation	
KBDI					
SWSI	Rainfall, Discharge			Basin scale	

Comment: most of these indices have mostly been used in the temperate countries so snowpack is accounted for. This might need adjustment for tropical regions

Drought Quantification using the Standardized Anomaly Index (SA)

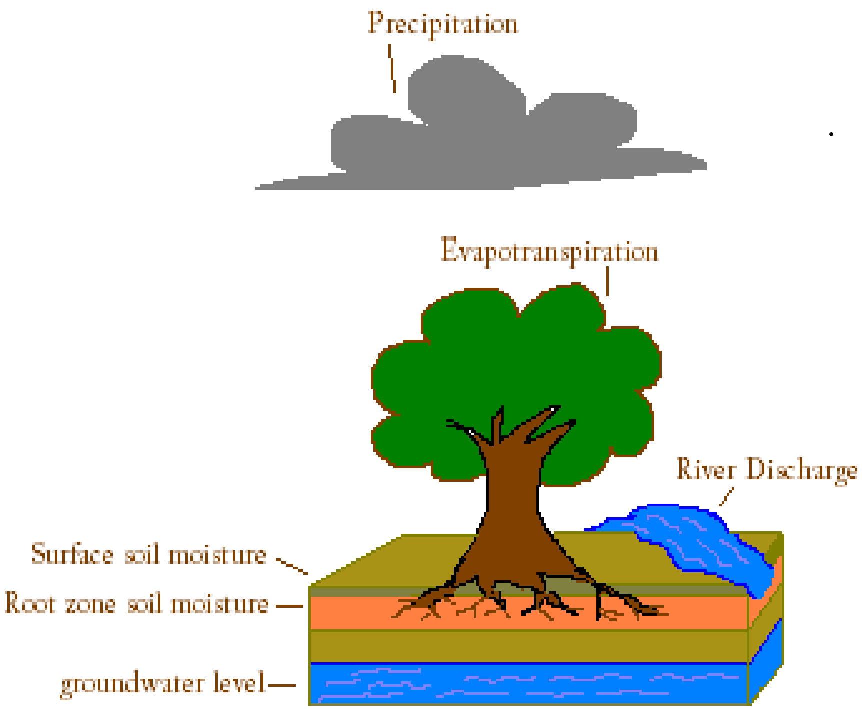
$$SA = \frac{X - \bar{X}_i}{\sigma}$$

where

$$\sigma_i = \sqrt{\mathrm{var}(X)}$$

$$\mathrm{var}(X) = \int (X-\mu)^2 f(X)\,dX$$

$$\mu = \int X f(X)\,dX$$



Drought conditions for the range of SA values
[UNL, available in ttp://www.drought.unl.edu/whatis/indices.htm#spi 2010]

SA Values	Condition
2.0+	extremely wet
1.5 to 1.99	very wet
1.0 to 1.49	moderately wet
-0.99 to 0.99	near normal
-1.49 to -1.0	moderately dry
-1.5 to -1.99	severely dry
-2 and less	extremely dry


Spatial and Temporal Drought
Quantification

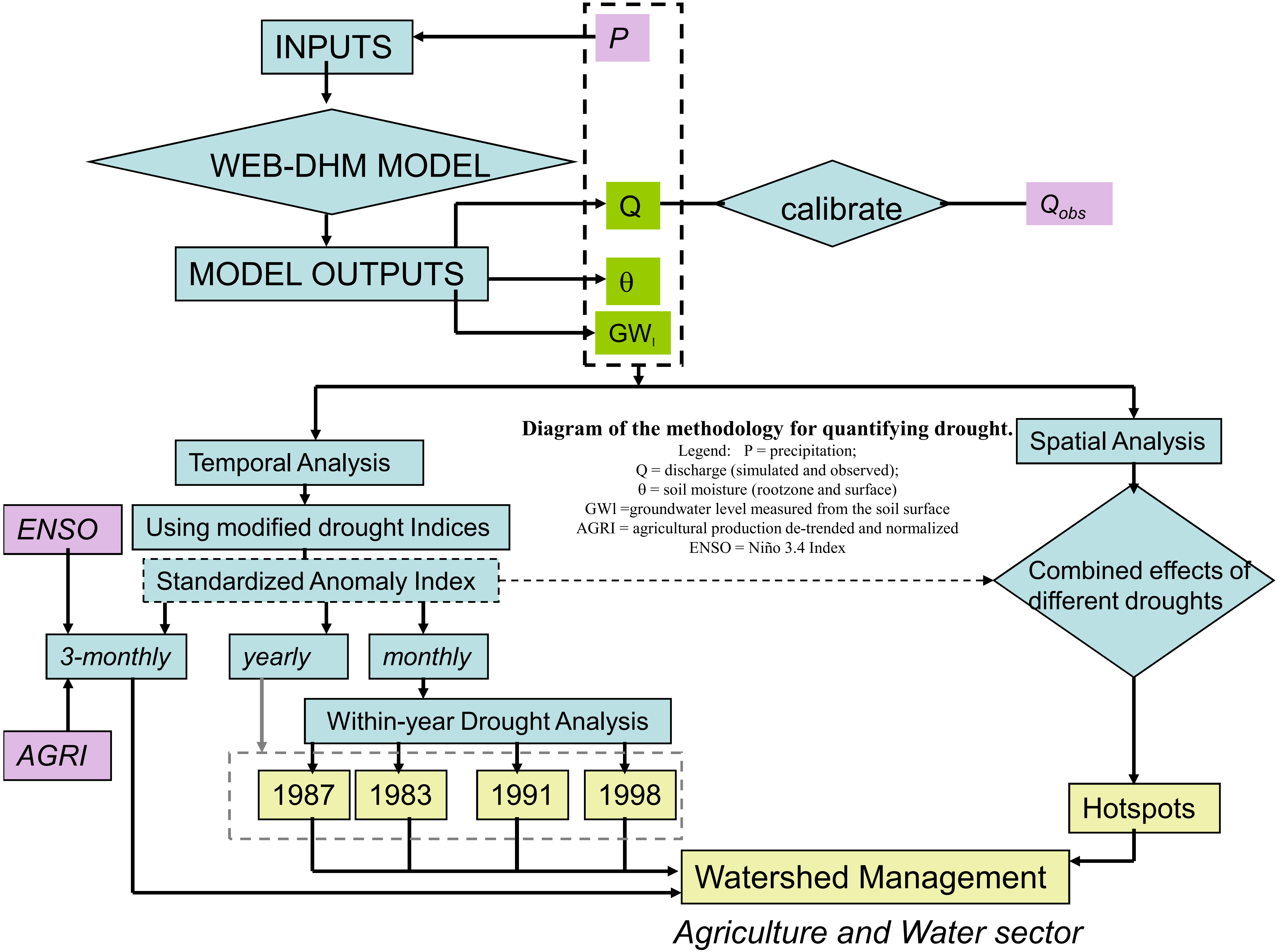
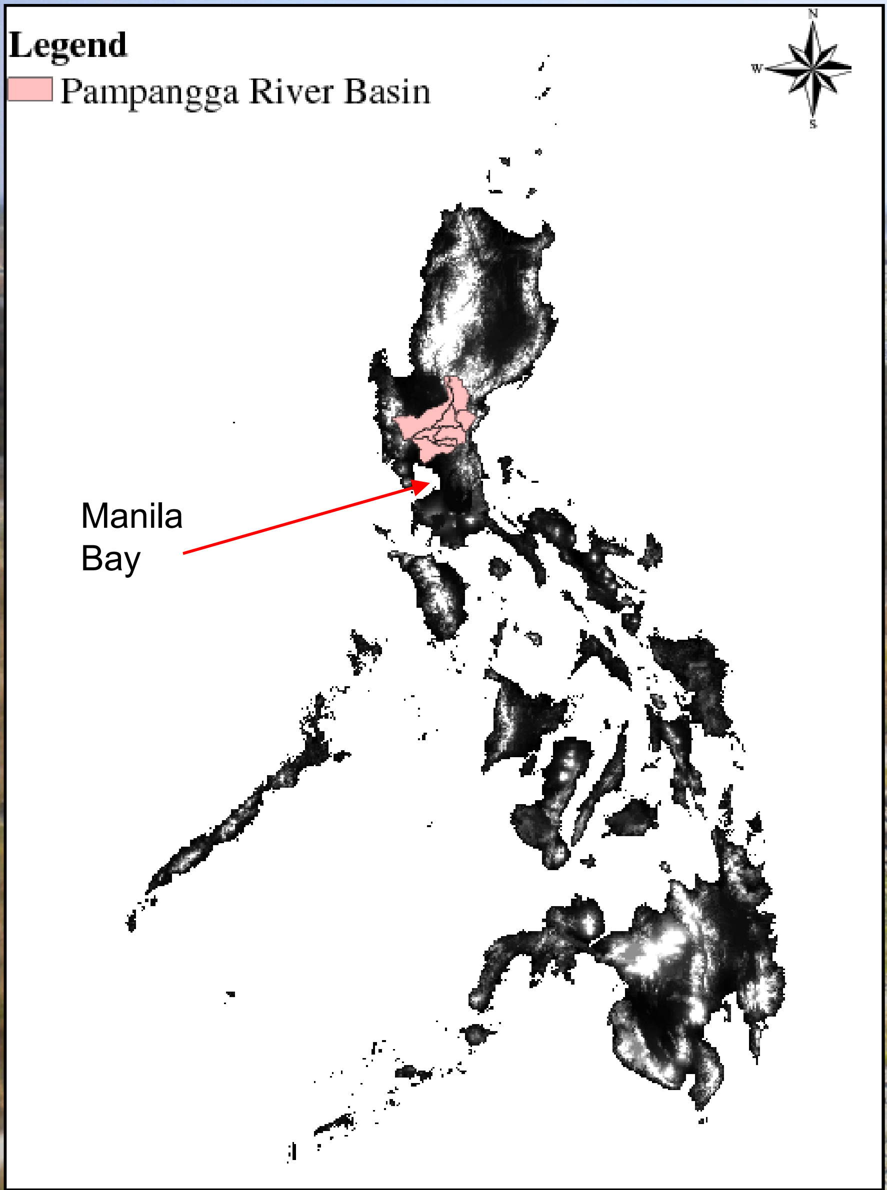


Diagram of the methodology for quantifying drought.

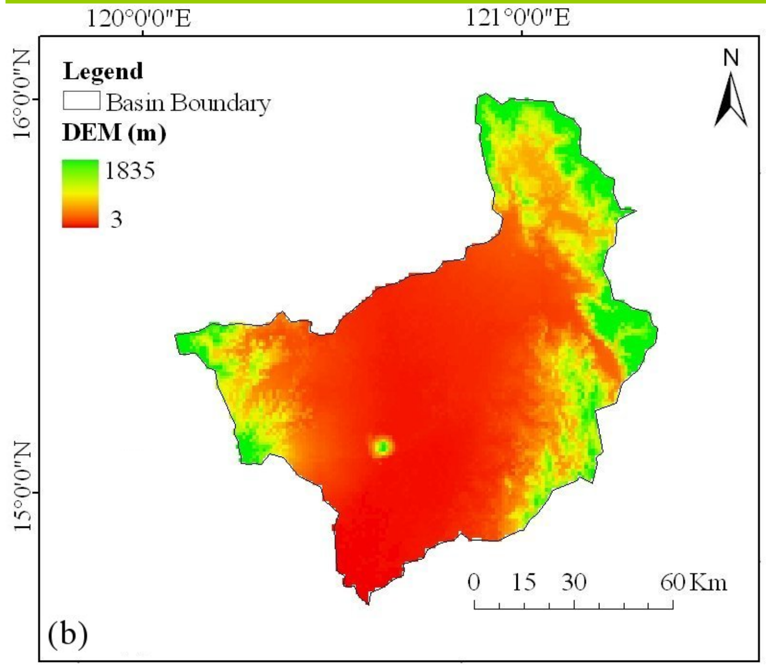
Legend: P = precipitation;
Q = discharge (simulated and observed);
θ = soil moisture (rootzone and surface)
GWl =groundwater level measured from the soil surface
AGRI = agricultural production de-trended and normalized
ENSO = Niño 3.4 Index

Pampangga River Basin

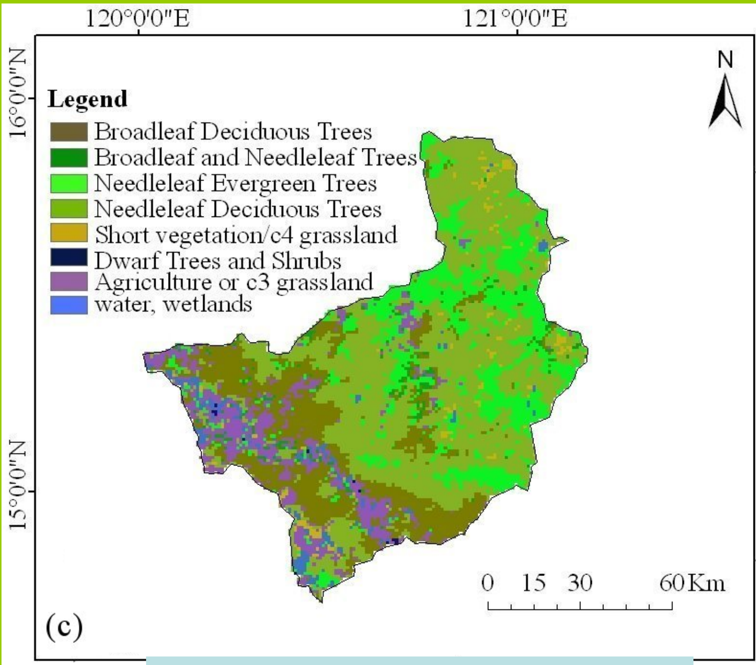


- Lies on the northern shore of Manila Bay
- Bordered by the provinces of
  - Bataan and Zambales to the west,
  - Tarlac and Nueva Ecija to the north and
  - Bulacan to the southeast.
- Area: 9,759 sq. km draining to Manila Bay
- Major agricultural products: Rice, Corn, Sugarcane and tilapia
- a significant 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

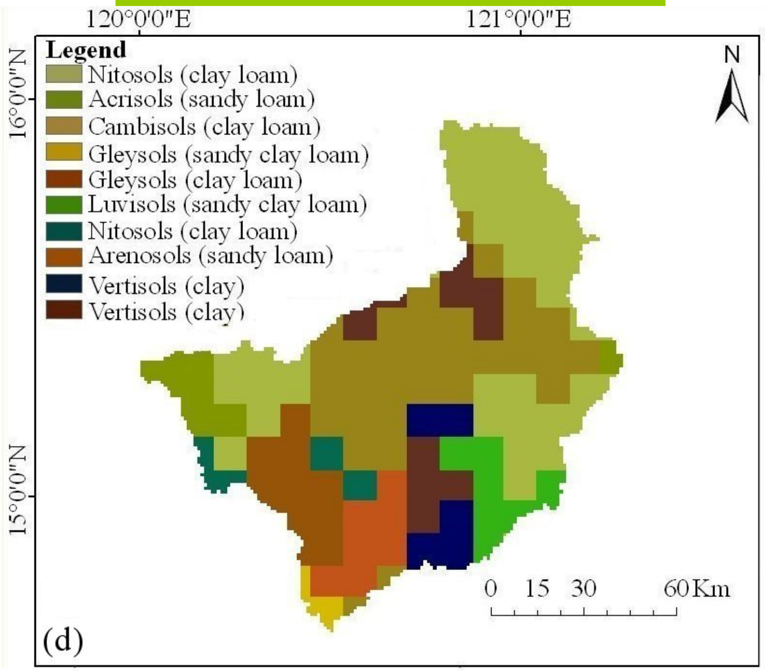
Pampangga River Basin



DEM

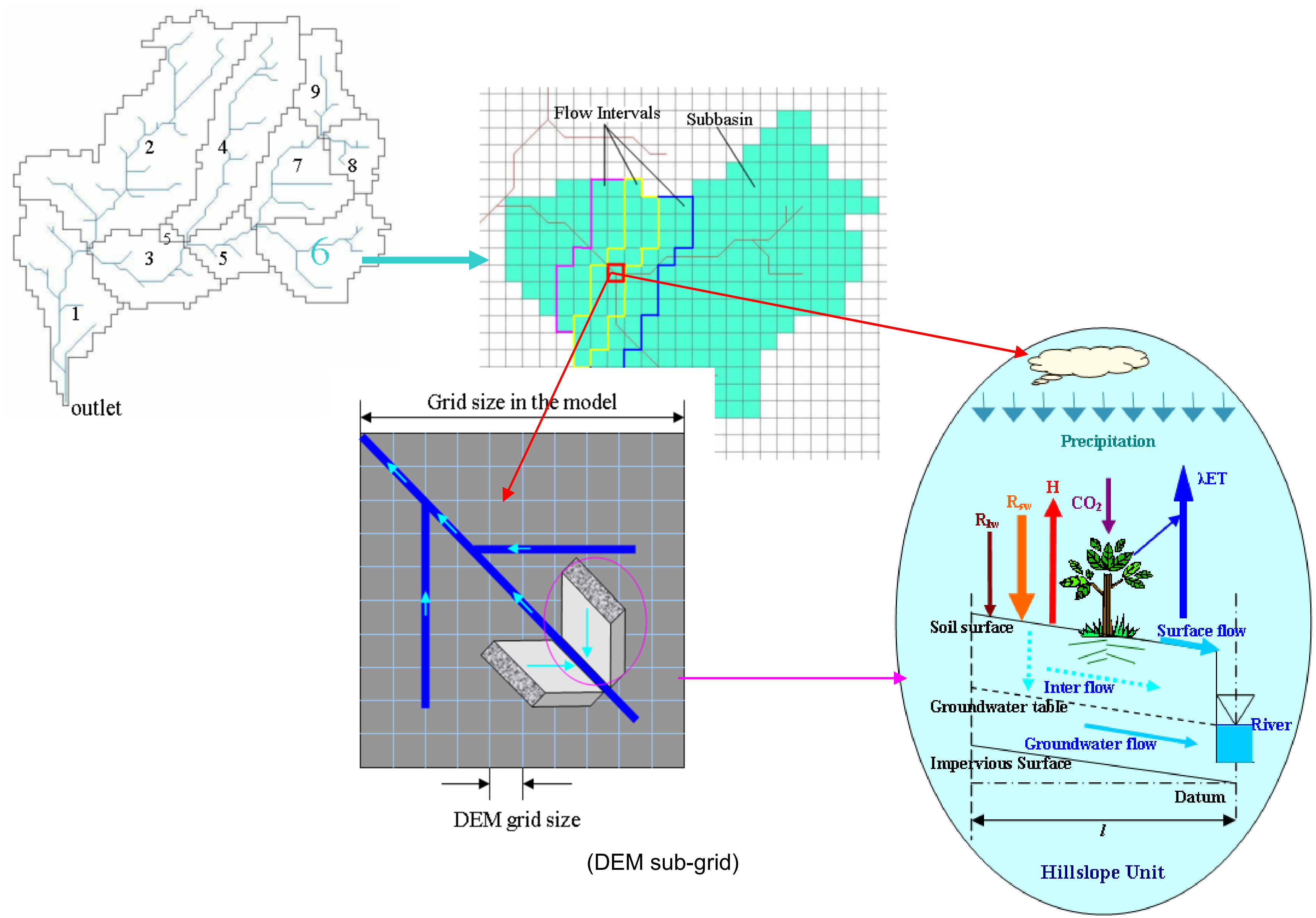


LANDUSE



SOIL TYPE

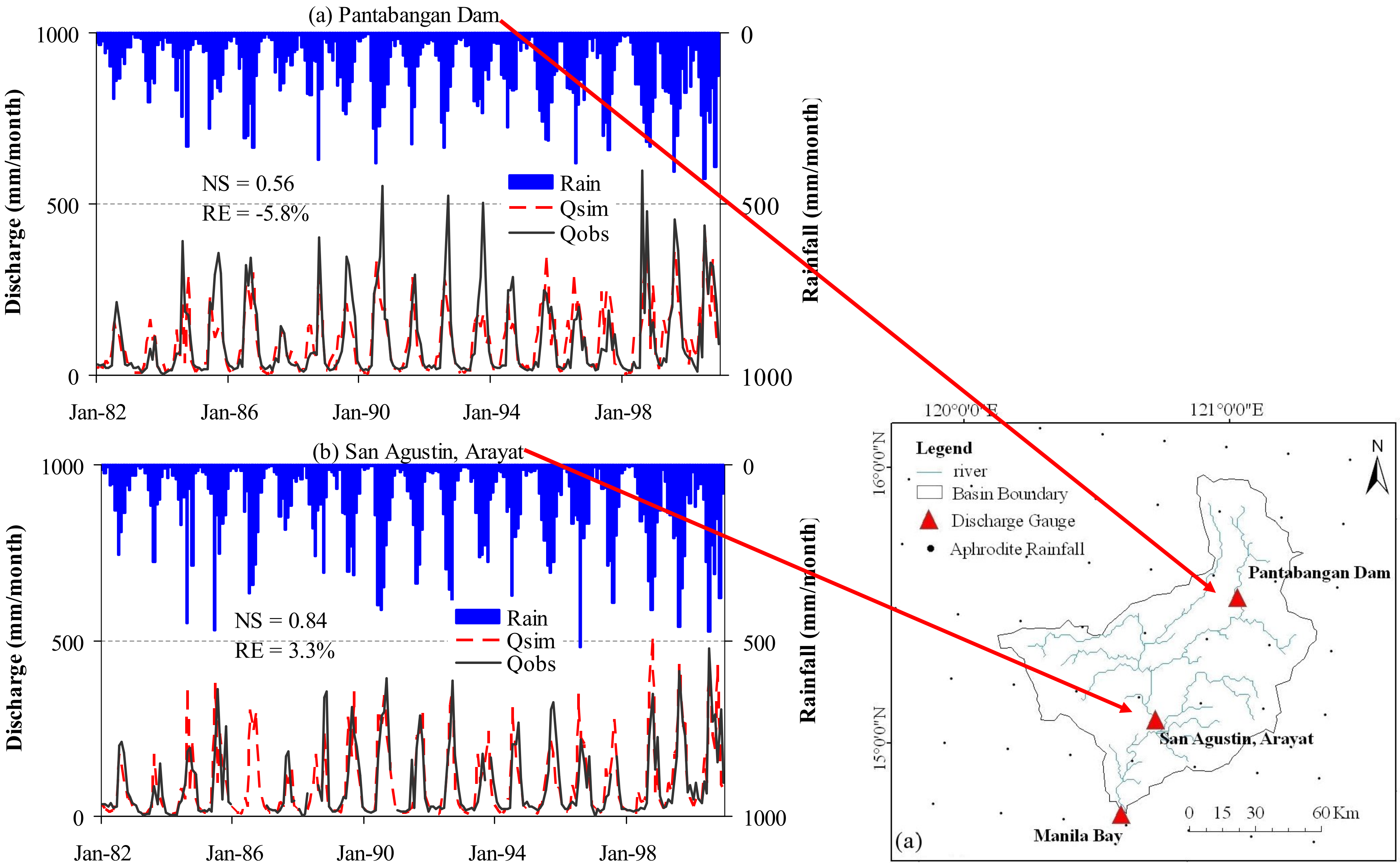
WEB-DHM (Water and Energy Budget-based Distributed Hydrological Model)



(DEM sub-grid)

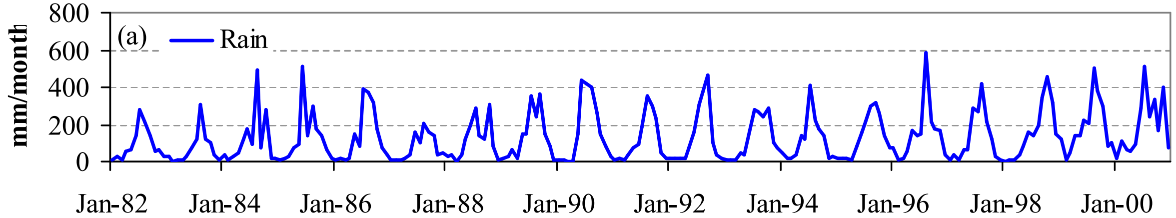
Source of slide: Wang, L. 2007 PhD Thesis Presentation, University of Tokyo

Calibration Curves for streamflow

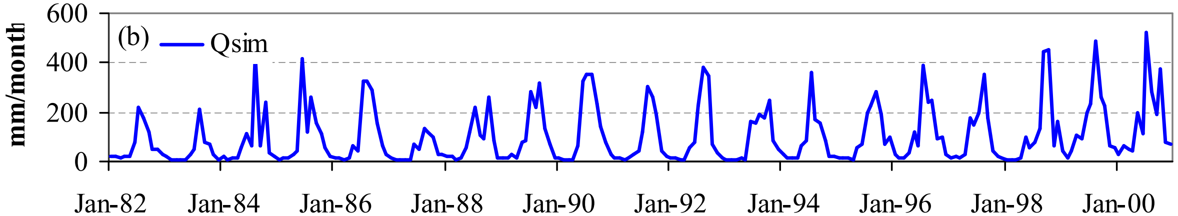


Basin average

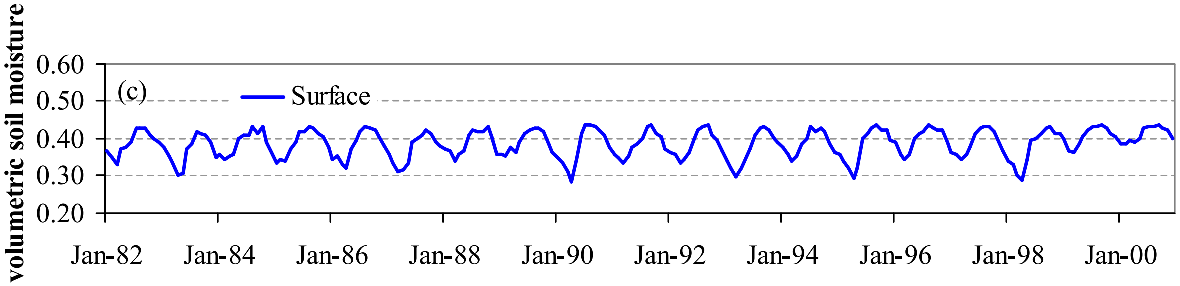
Rainfall



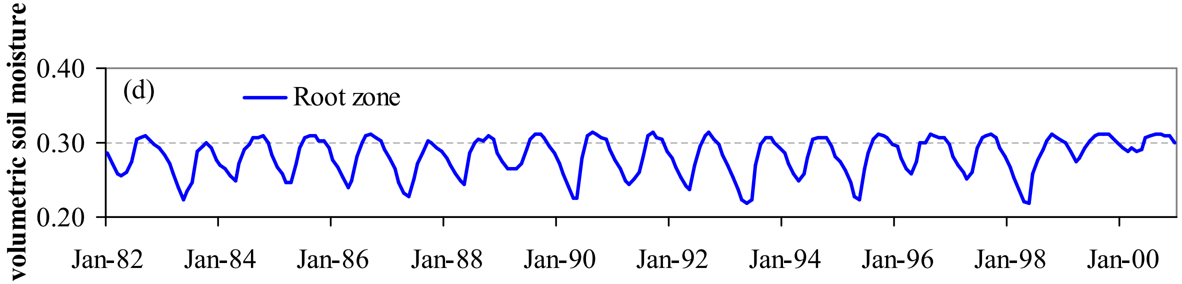
Discharge



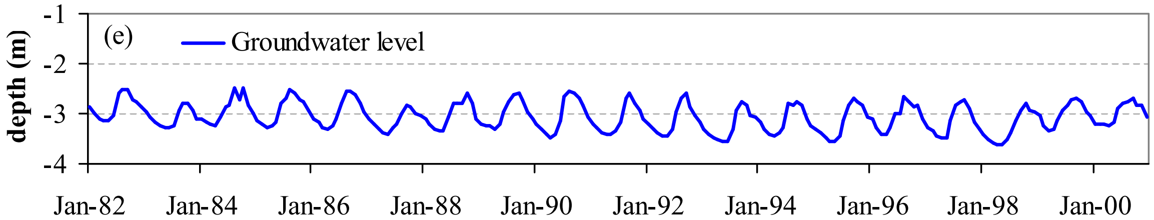
Surface soil moisture



Root zone soil moisture



Groundwater level



Monthly Standardized Anomaly Index

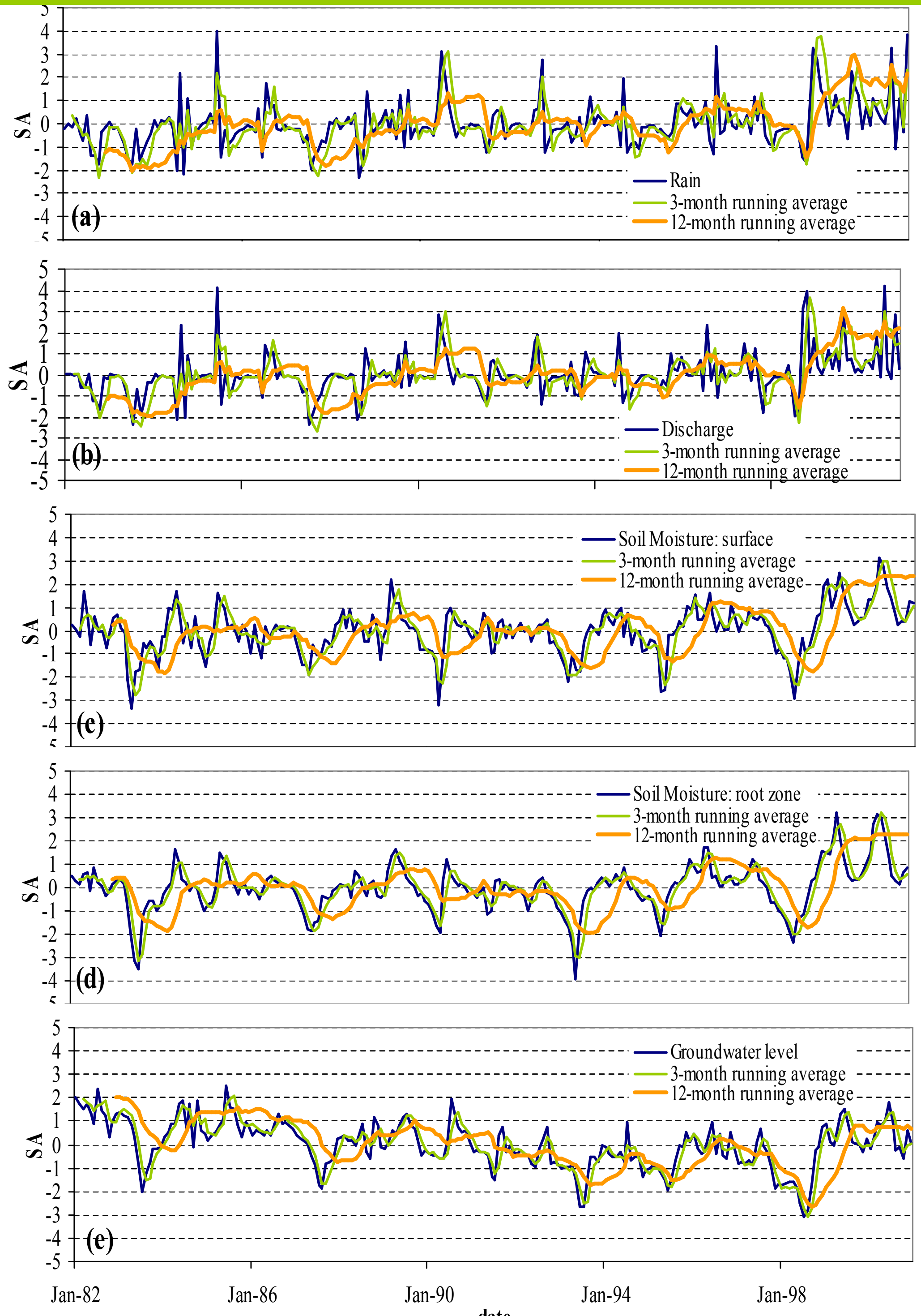
Rainfall

Discharge

Surface soil moisture

Root zone soil moisture

Groundwater level



Monthly

3-Monthly

12-Monthly

Drought: 1983, 1987, 1990-92 and 1998

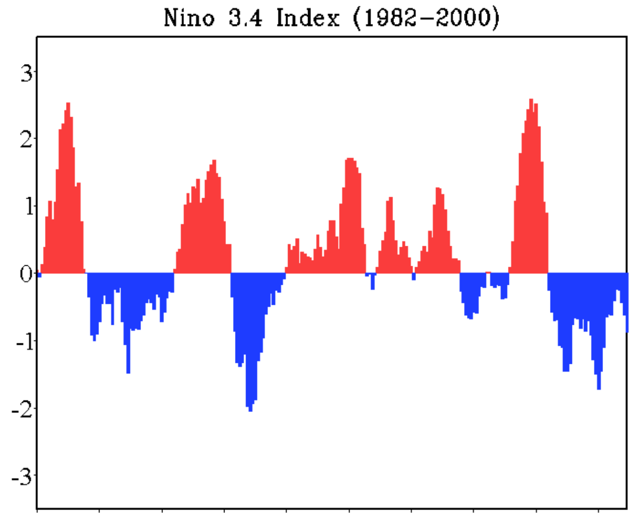
Classification of ENSO events based on the Niño 3.4 SSTs from the Hadley Center sea surface temperature. (Base period: 1870-2009).

ENSO occurrence	JFM	AMJ	JAS	OND
1982		E-	E	E+
1983	E+	E		L-
1984	L-	L-		L
1985	L-	L-		
1986	L-			E
1987	E	E	E+	E
1988	E-	L-	L	L+
1989	L	L-		
1990				
1991		E-	E-	E
1992	E+	E		
1993		E-		
1994				E
1995	E-			L-
1996	L-			
1997		E-	E+	E+
1998	E+	E-	L-	L
1999	L	L-	L-	L
2000	L	L-		L-

Legend: E+ strong El Niño; E moderate El Niño; E- weak El Niño
L+ strong La Niña; L moderate La Niña; L- week La Niña

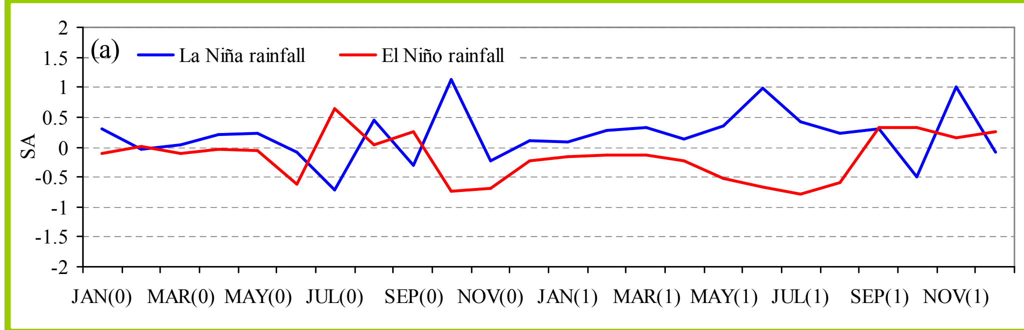
List of warm (El Niño) and cold (La Niña) ENSO events considered in the 2-year composites for the years (1982-2000)

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

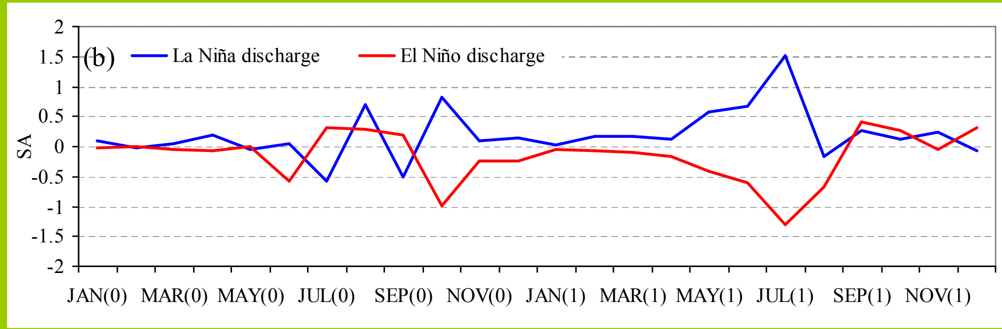


El Niño (red) and La Niña (blue) events based on the Niño 3.4 Index (longitude: 190ºE to 240ºE, latitude: 5ºS to 5ºN) from the Hadley Center sea surface temperature dataset (1870-2009) for the period 1982-2000.

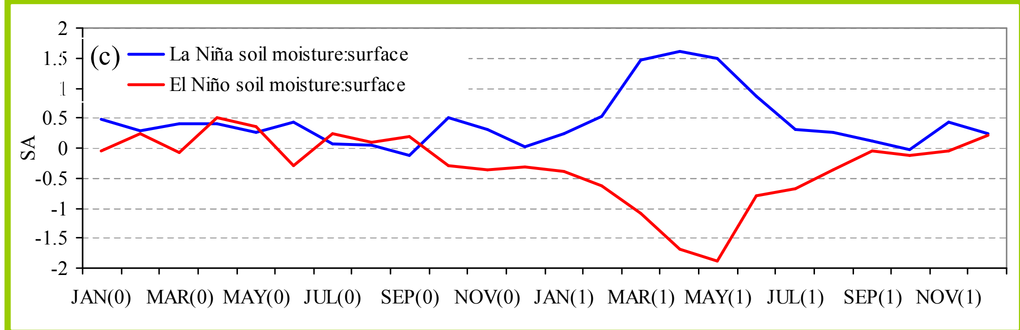
rainfall



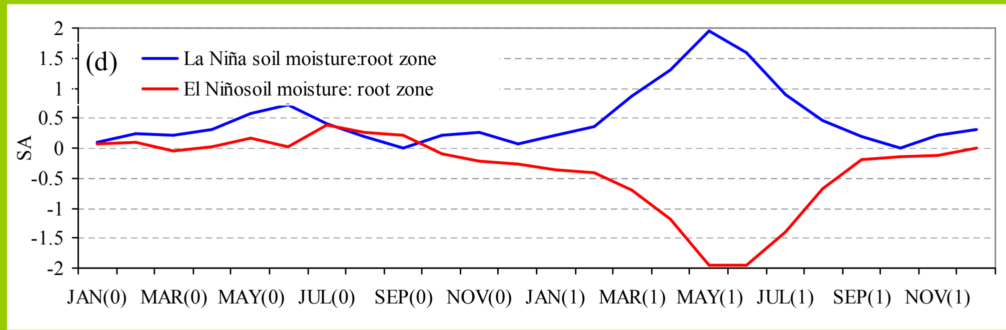
discharge



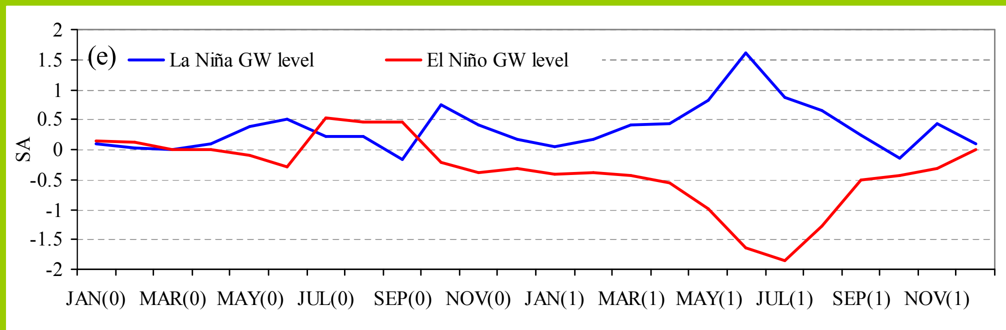
Surface soil moisture



Root zone soil moisture



groundwater level



Standardized Anomaly Index categorized in the **2-year long-term average of SA for ENSO year composites**

P-values for the student t-test comparing El Niño & La Niña (2-year composites)

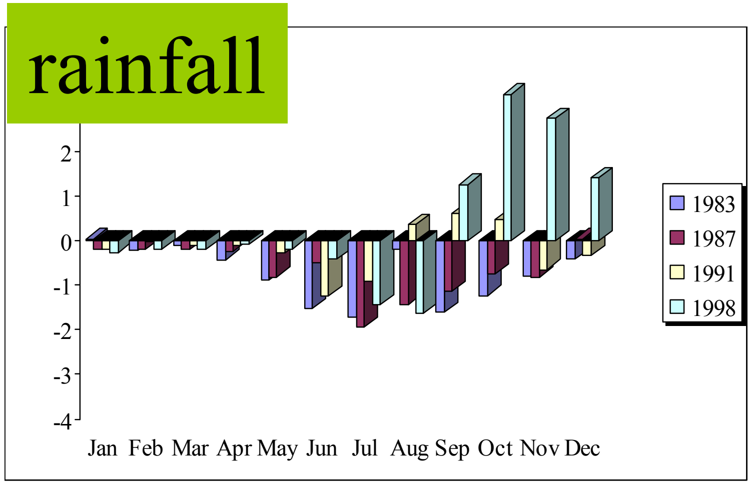
(α=0.05)

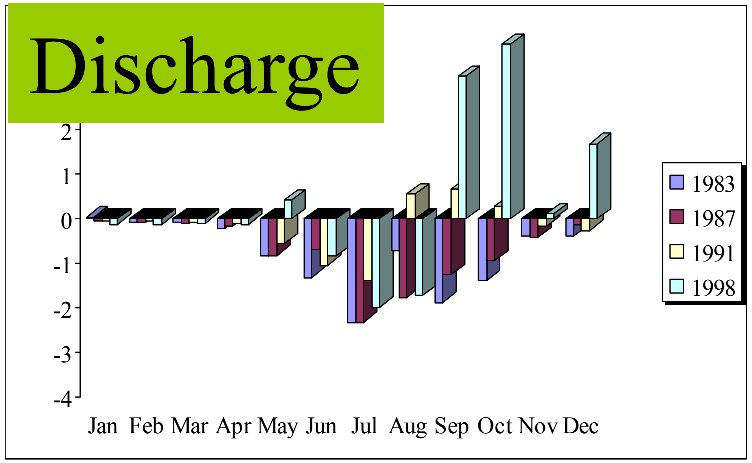
El Niño vs. La Niña: using SA for year 1

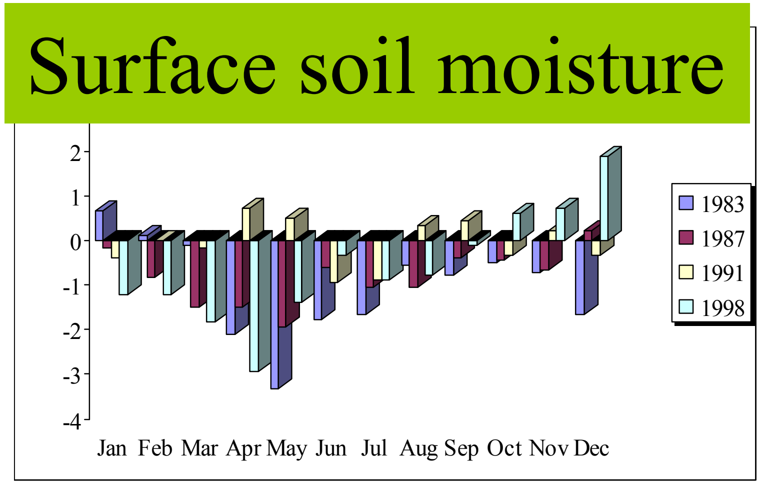
Drought Parameter	Jan (1)	Feb (1)	Mar (1)	Apr (1)	May (1)	Jun (1)	Jul (1)	Aug (1)	Sep (1)	Oct (1)	Nov (1)	Dec (1)
Rainfall	0.22	0.98	0.34	0.46	0.34	0.21	0.08	0.98	0.92	**<0.01**	**0.02**	0.16
Discharge	0.25	0.65	0.33	0.38	0.93	0.17	0.37	0.99	0.71	**<0.01**	**<0.01**	0.13
Soil Moisture (surface)	0.30	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

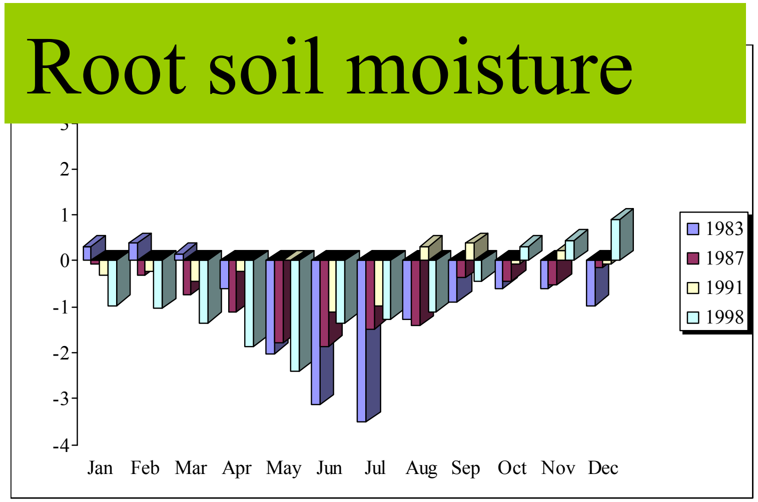
El Niño vs. La Niña: using SA for year 2

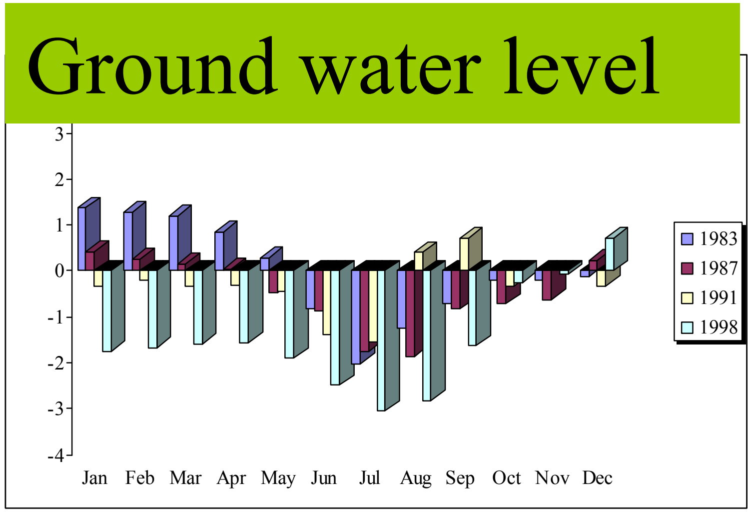
Drought Parameter	Jan (2)	Feb (2)	Mar (2)	Apr (2)	May (2)	Jun (2)	Jul (2)	Aug (2)	Sep (2)	Oct (2)	Nov (2)	Dec (2)
Rainfall	0.17	0.18	**0.04**	0.13	**0.01**	0.19	0.17	0.42	0.74	0.33	0.28	0.41
Discharge	0.07	0.19	0.07	**0.05**	**0.04**	0.35	**0.01**	0.39	0.92	0.95	0.05	0.40
Soil Moisture (surface)	0.10	**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





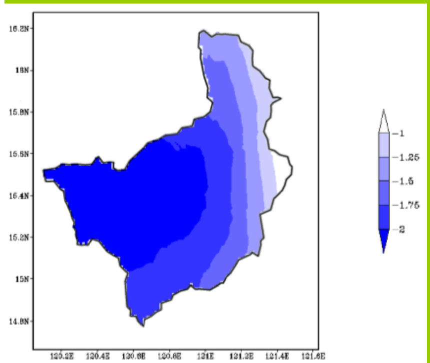




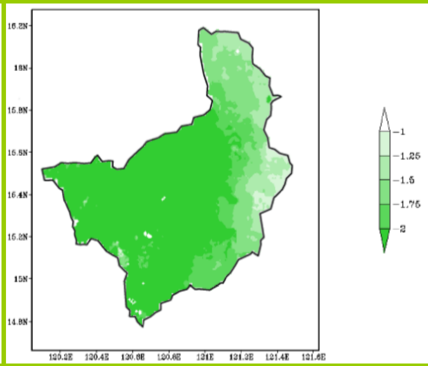


Standardized Anomaly Index
(1983, 1987, 1991 & 1998)

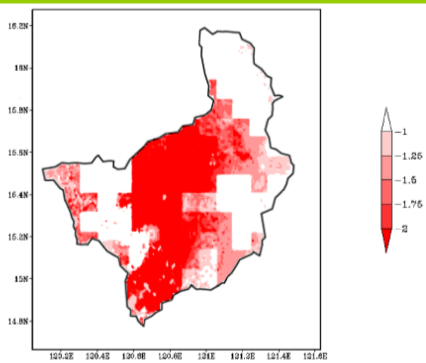
Spatial analysis: Hotspots for July 1983



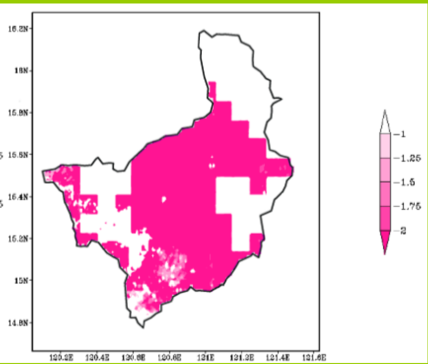
Rainfall



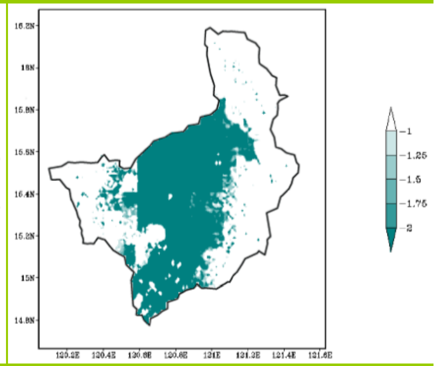
Discharge



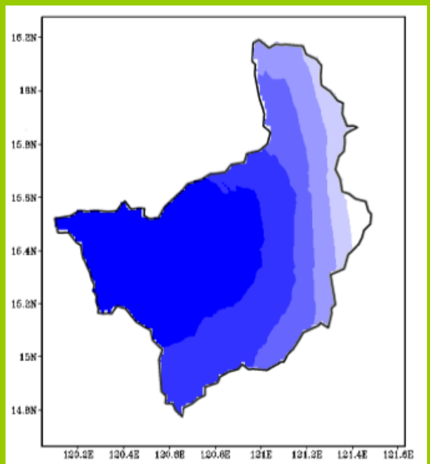
Surface soil moisture



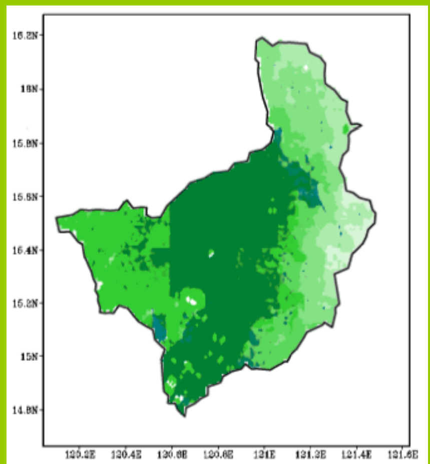
Root zone soil moisture



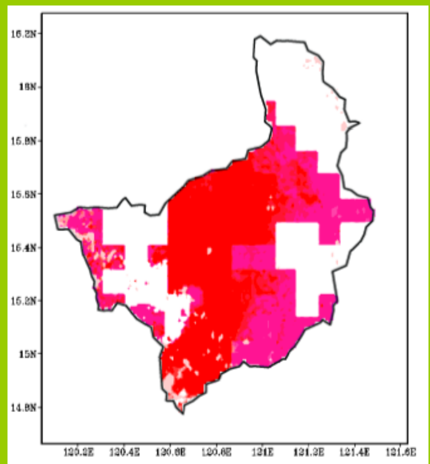
Groundwater level



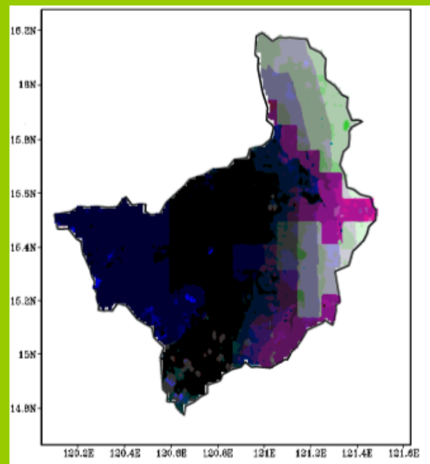
Meteorological



Hydrological

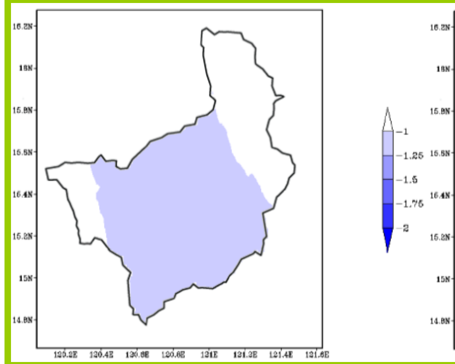


Agricultural

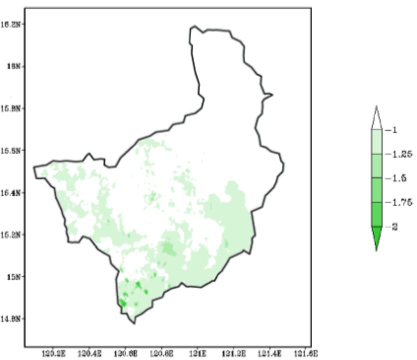


Combined

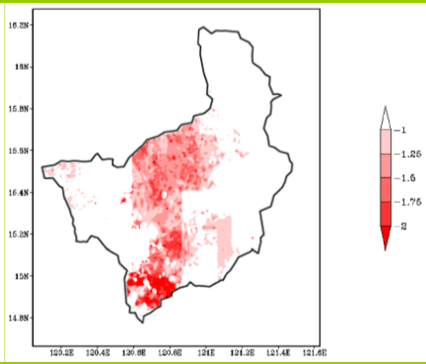
Spatial analysis: Hotspots for June 1991



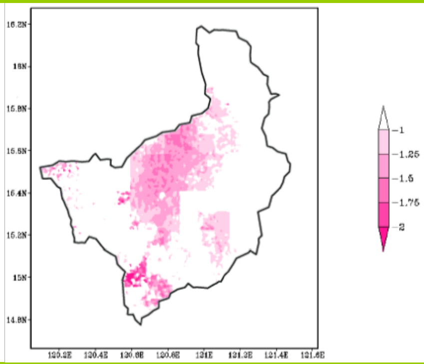
Rainfall



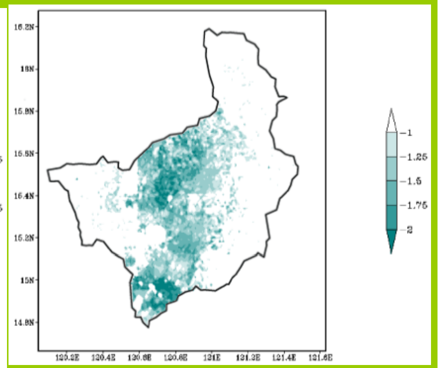
Discharge



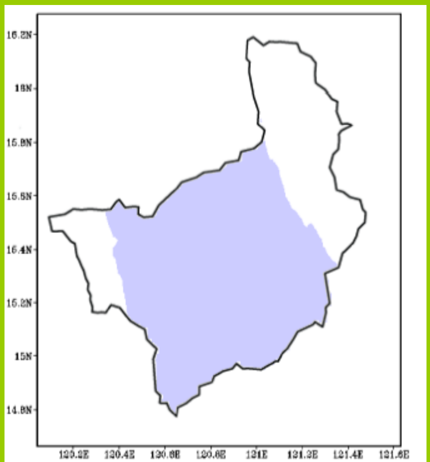
Surface soil moisture



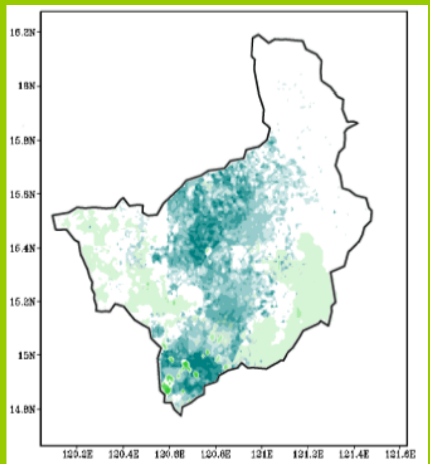
Root zone soil moisture



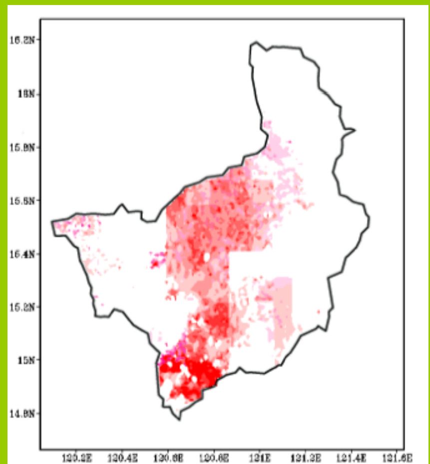
Groundwater level



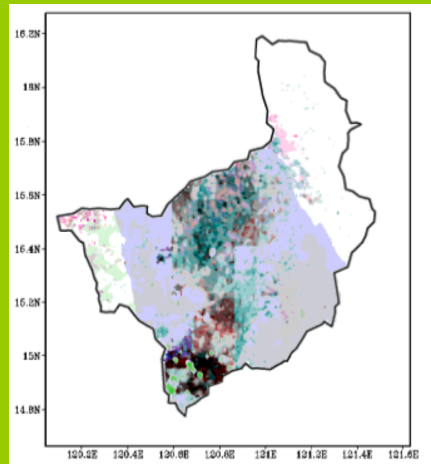
Meteorological



Hydrological

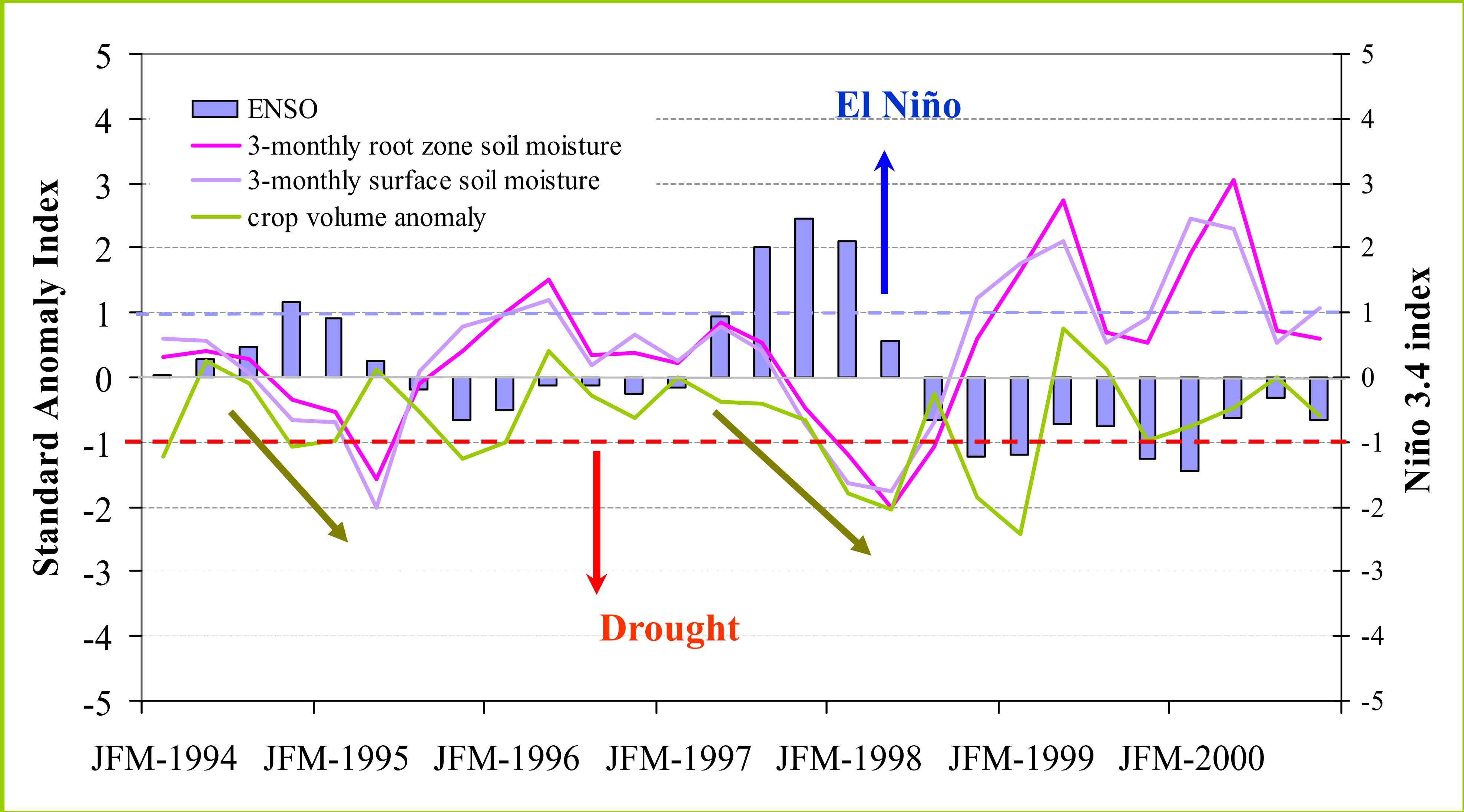


Agricultural



Combined

ENSO, Drought Index & crop volume anomaly (1994-2000)



Niño 3.4 Index, 3-monthly **soil moisture and crop anomaly**

watershed management practices

ADAPTATION STRATEGIES FROM PREVIOUS STUDIES

•Water reuse by recycling of drainage water and groundwater use (Maraseni, et al., 2010)

•optimize irrigation practices (alternate wetting and drying of the soil)

•supplemental or micro irrigation (Rockstrom, et al., 2002)

ADAPTATION STRATEGIES suggested by the local communities in the UPRIIS area: (Lasco, et al., 2010)

•reforestation/AF farming
•soil and water conservation measures
•water impoundment
•well construction

•use of appropriate crops/varieties (e.g. more drought resistant crops)
•irrigation management
•tap other water sources (e.g. rivers, groundwater)

•shift in livelihood

•capacity building activities

Climate Change and Drought

IPCC Working Group I report states that:

Phenomenon[a] and direction of trend	Likelihood that trend occurred in late 20th century (typically post 1960)	Likelihood of a human contribution to observed trend[b]	Likelihood of future trends based on projections for 21st century using SRES scenarios
Warmer and fewer cold days and nights over most land areas	*Very likely*[c]	*Likely*[d]	*Virtually certain*[d]
Warmer and more frequent hot days and nights over most land areas	*Very likely*[e]	*Likely (nights)*[d]	*Virtually certain*[d]
Warm spells/heat waves. Frequency increases over most land areas	*Likely*	*More likely than not*[f]	*Very likely*
Heavy precipitation events. Frequency (or proportion of total rainfall from heavy falls) increases over most areas	*Likely*	*More likely than not*[f]	*Very likely*
Area affected by droughts increases	*Likely* in many regions since 1970s	*More likely than not*	*Likely*
Intense tropical cyclone activity increases	*Likely* in some regions since 1970	*More likely than not*[f]	*Likely*
Increased incidence of extreme high sea level (excludes tsunamis)[g]	*Likely*	*More likely than not*[f,h]	*Likely*[i]

IPCC Working Group II report states that:

- *it is very likely that drought occurrences will increase as a result of climate change.*
  - *"It is projected with high confidence that the projected changes in the frequency and the severity of extreme climate events have significant consequences for food and forestry production, and food insecurity, in addition to impacts of projected mean climate".*
  - *"There is also high confidence that smallholder and subsistence farmers, pastoralists and artisanal fisherfolk will suffer complex, localized impacts of climate change".*

Droughts are regional in nature and critical drought conditions occur when there is an extreme shortage of water for long durations over large areas (Tallaksen, et al., 1997)

23 Models GCM Ensemble

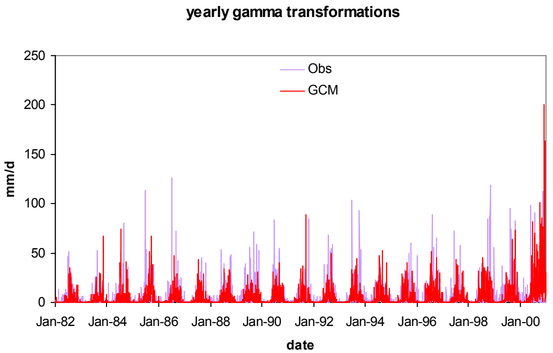
- Precipitation: 2-step bias correction

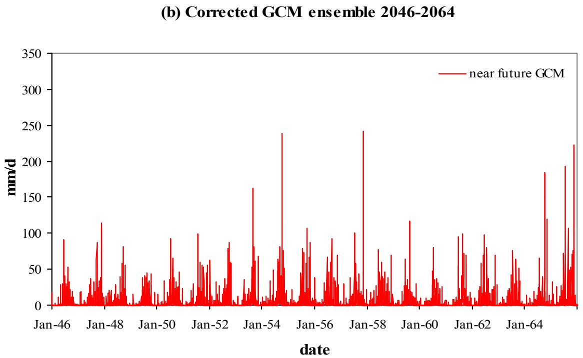
$$\tilde{x}_{GCM} = F_{GCM}^{-1}\left(F_{OBS}(\tilde{x})\right)$$

$$x'_i = \begin{cases} F_{I,OBS}^{-1}\left(F_{I,GCM}(x_i)\right), & x_i \geq \tilde{x} \\ 0, & x_i < \tilde{x} \end{cases}$$

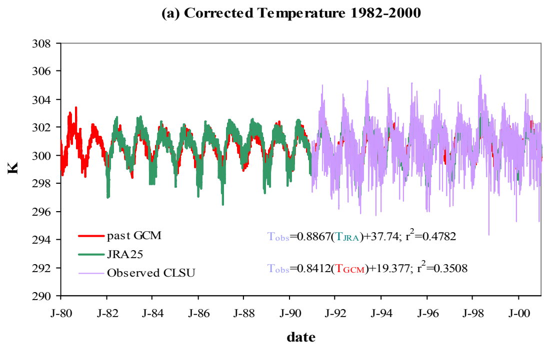
$$F(x,\alpha,\beta) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} \exp\left(-\frac{x}{\beta}\right); x \geq \tilde{x}$$

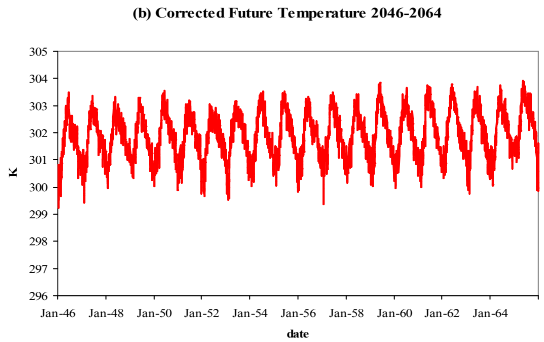
$$F(x,\alpha,\beta) = \int_{\tilde{x}}^{x} f(t)\,dt$$





- Temperature: linear regression



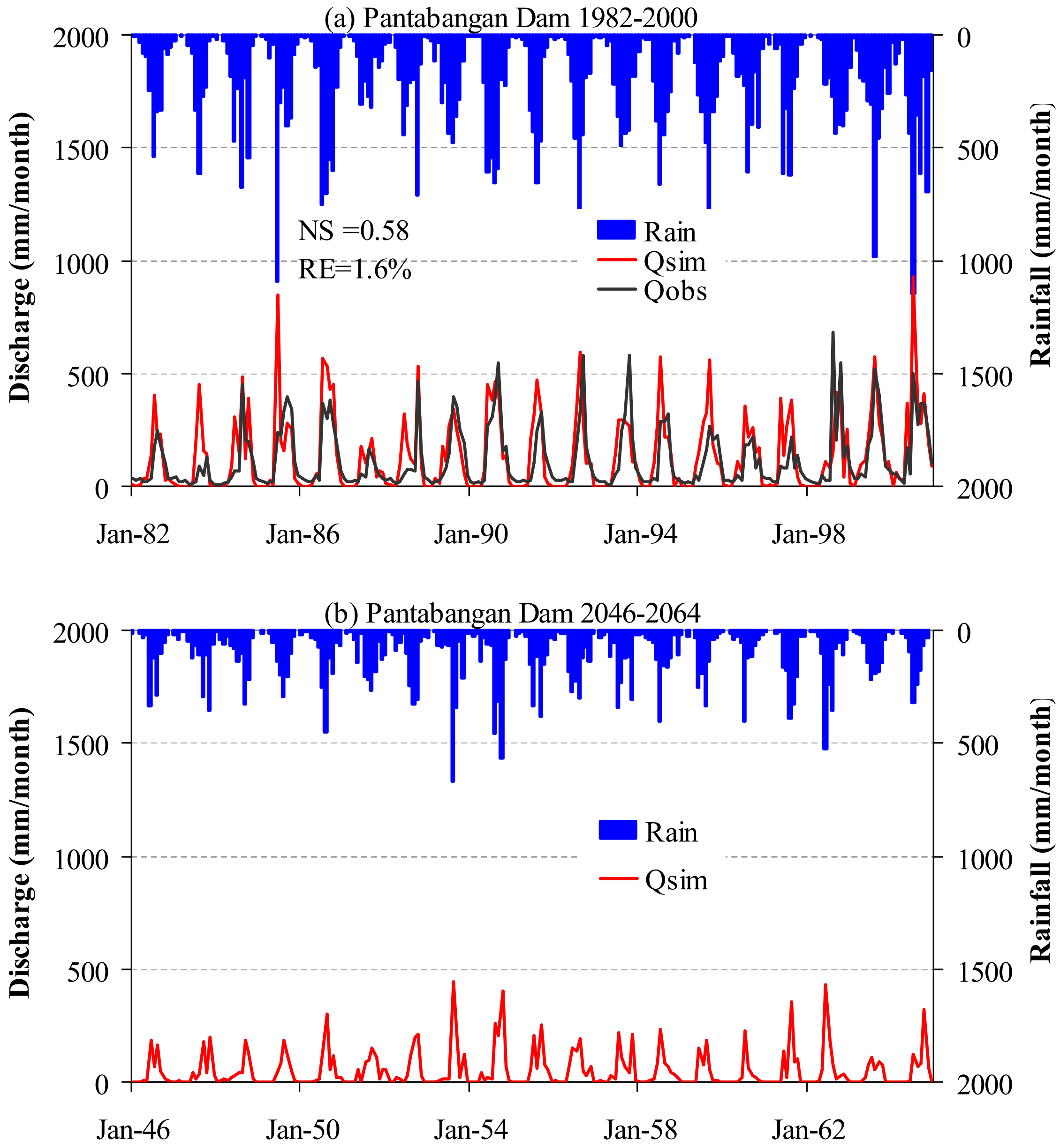


Corrected GCMs vs. observed precipitation

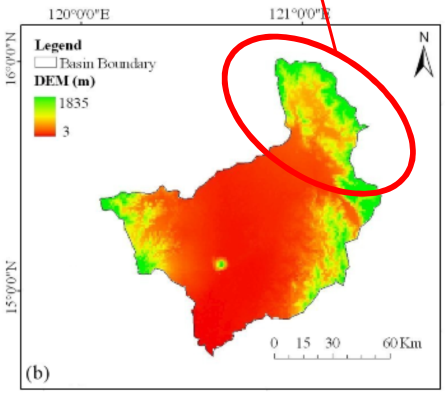
SRESa1b scenario

Bias estimators	Values	units
MBE	62.24	mm/year
MABE	432.93	mm/year
RMSE	1089.60	mm/year
MAPE	27.67	%

Past and Future Streamflow



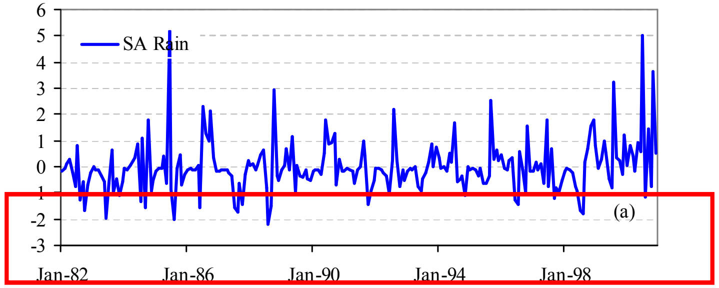
Pantabangan Watershed

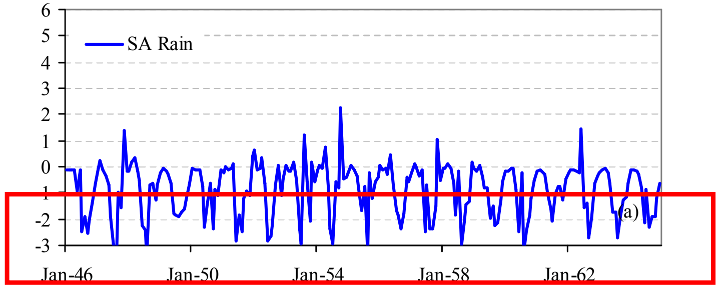


Sample simulation: Pantabangan Dam

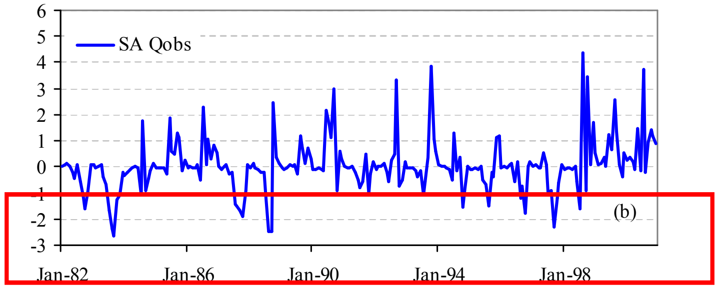
1992-2000 | **1946-1964**

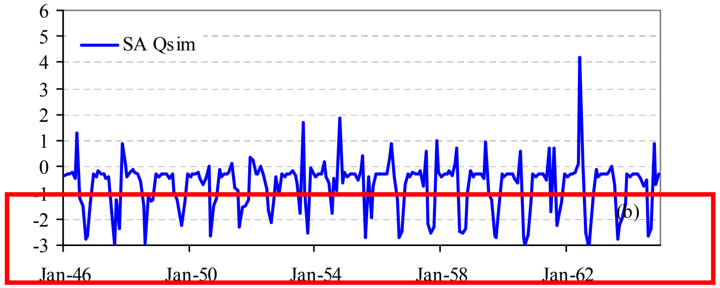
RAIN



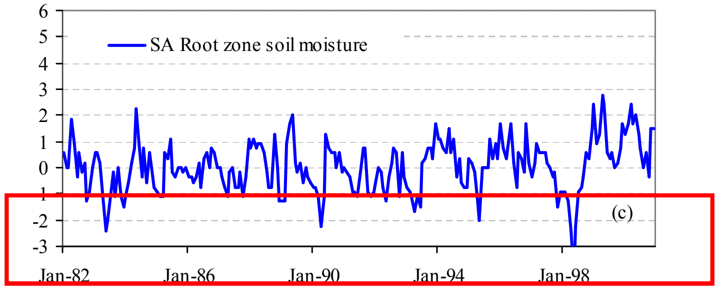


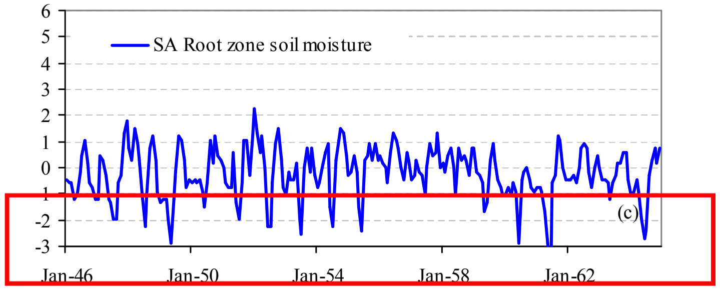
DISCHARGE



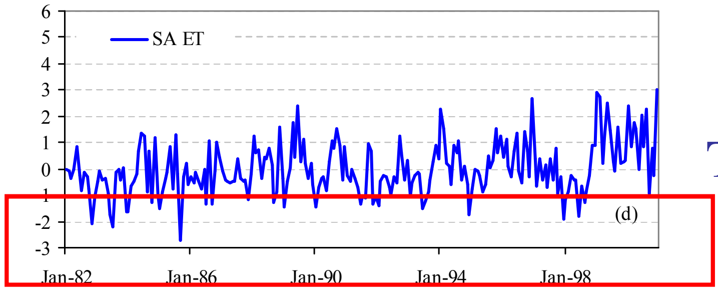


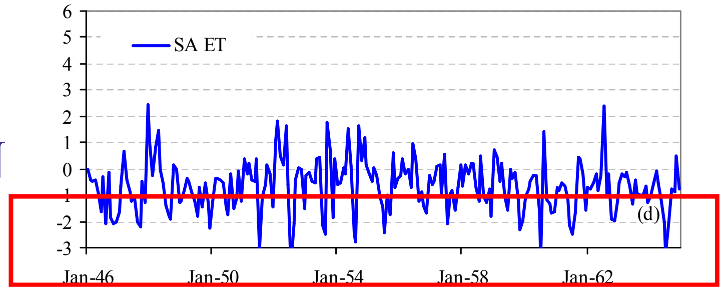
ROOTZONE





EVAPO-TRANSPIRATION

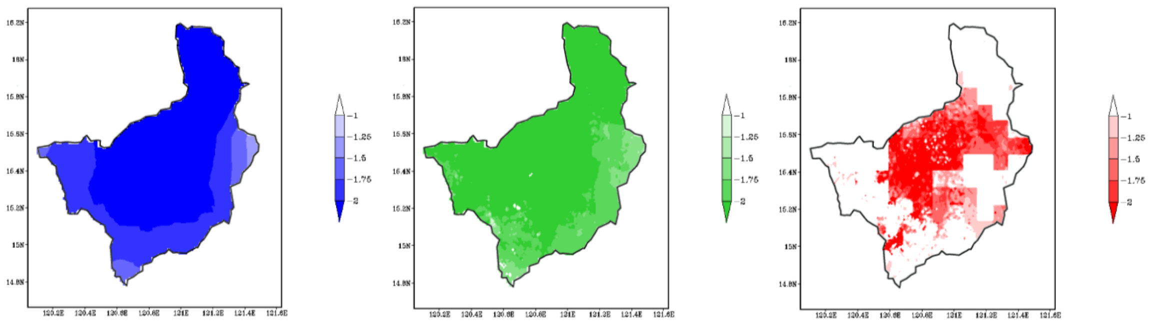




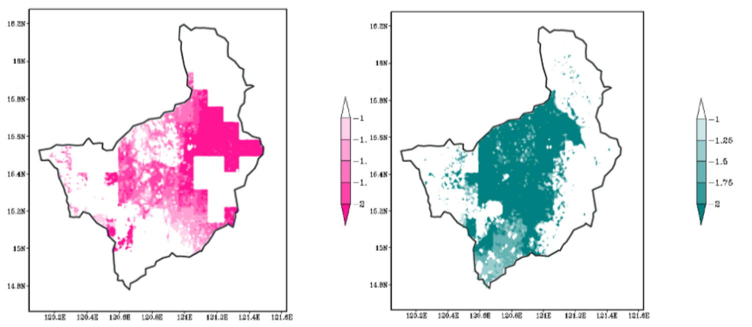
Impact Assessment: Drought

- GHG emissions cause CO_2 concentrations in the atmosphere to rise and increase heat absorption resulting to ΔT (↑), ΔP (d ↓)
- From our simulations, this results further to ΔET, ΔQ, ΔSM
- For SRESa1b scenario in this watershed, ΔT and ΔP resulted to rainfall deficit, more frequent lower than normal discharge, soil moisture and evapo-transpiration

Extra slides

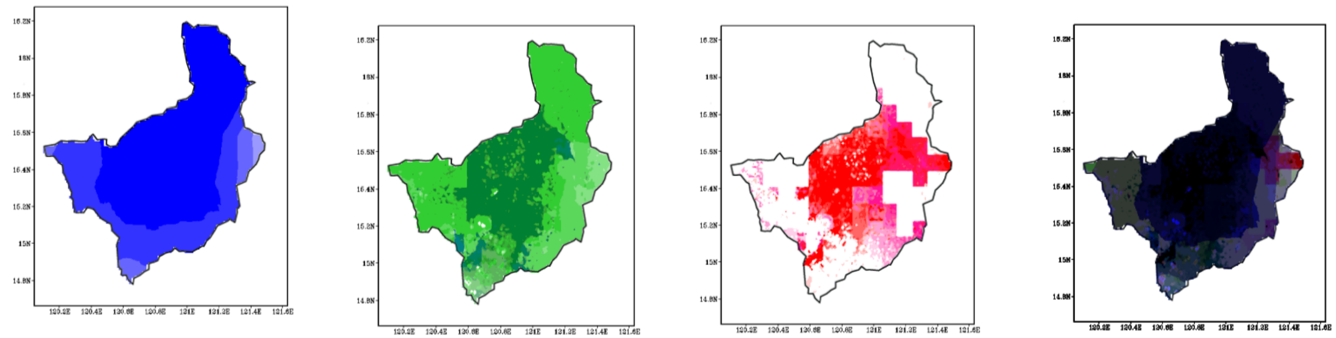


Rainfall Discharge Surface soil moisture



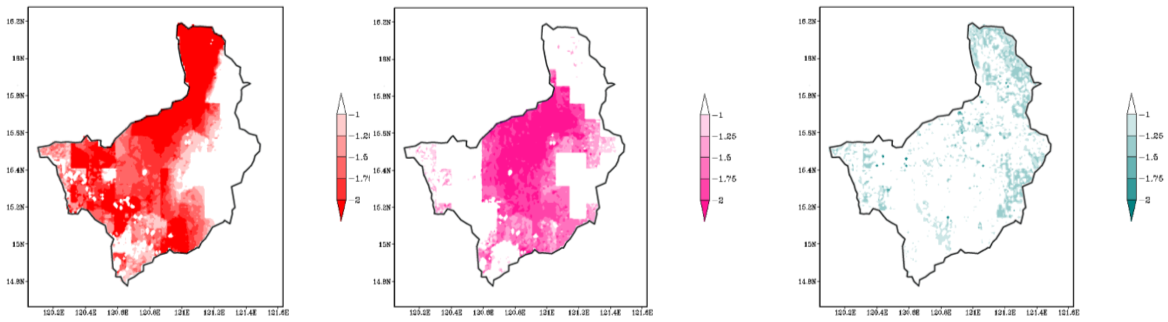
Root zone soil moisture Groundwater level

Spatial analysis showing mild to severe drought in **July 1987** for rainfall, discharge, surface soil moisture, root zone soil moisture and groundwater level.



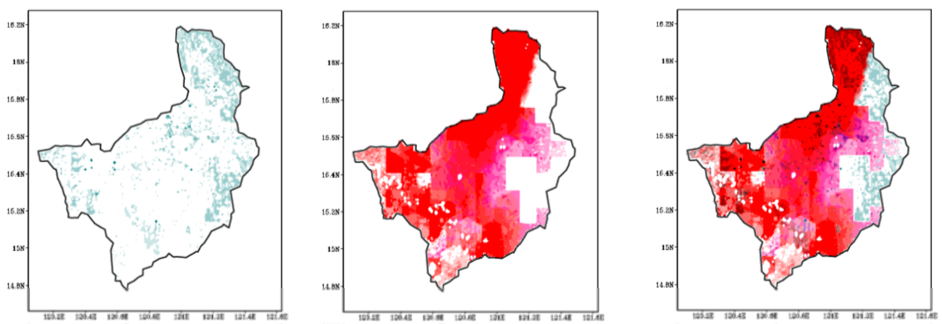
Meteorological Hydrological Agricultural Combined

Hotspots: Spatial representation of the effects For **July 1987** for meteorological drought (using rainfall parameter), hydrological drought (using the combined effects of discharge and groundwater level), agricultural drought (using soil moisture), and the combined effects of the different drought types.



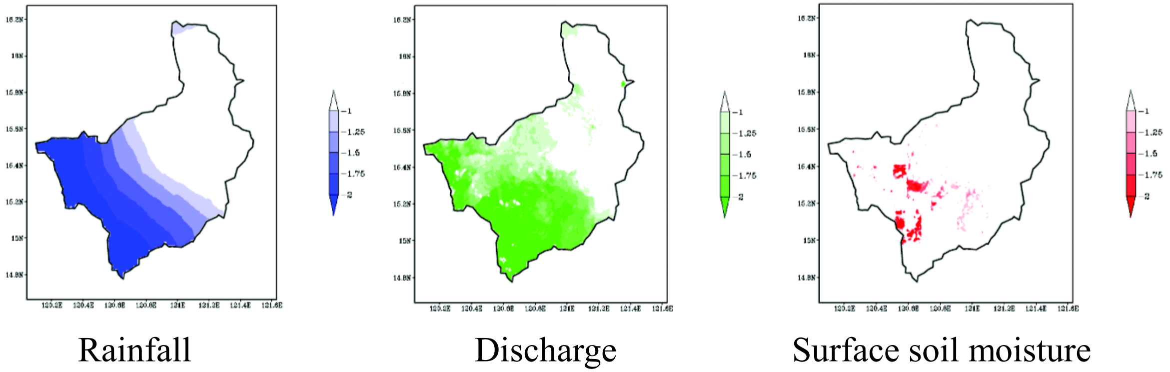
Surface soil moisture   Root zone soil moisture   Groundwater level

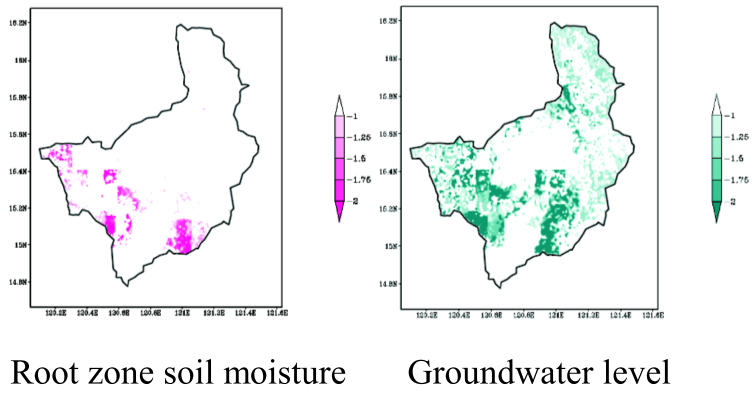
Spatial analysis showing mild to severe drought in **April 1998** for surface soil moisture, root zone soil moisture and groundwater level.



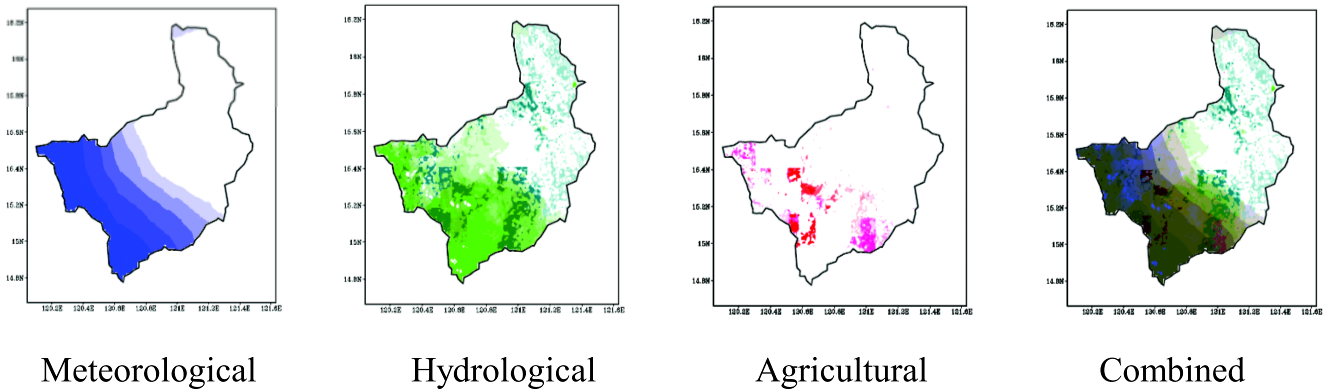
Hydrological   Agricultural   Combined

Hotspots: Spatial representation of the effects For **April 1998** for hydrological drought (using the combined effects of discharge and groundwater level), agricultural drought (using soil moisture), and the combined effects of the different drought types.

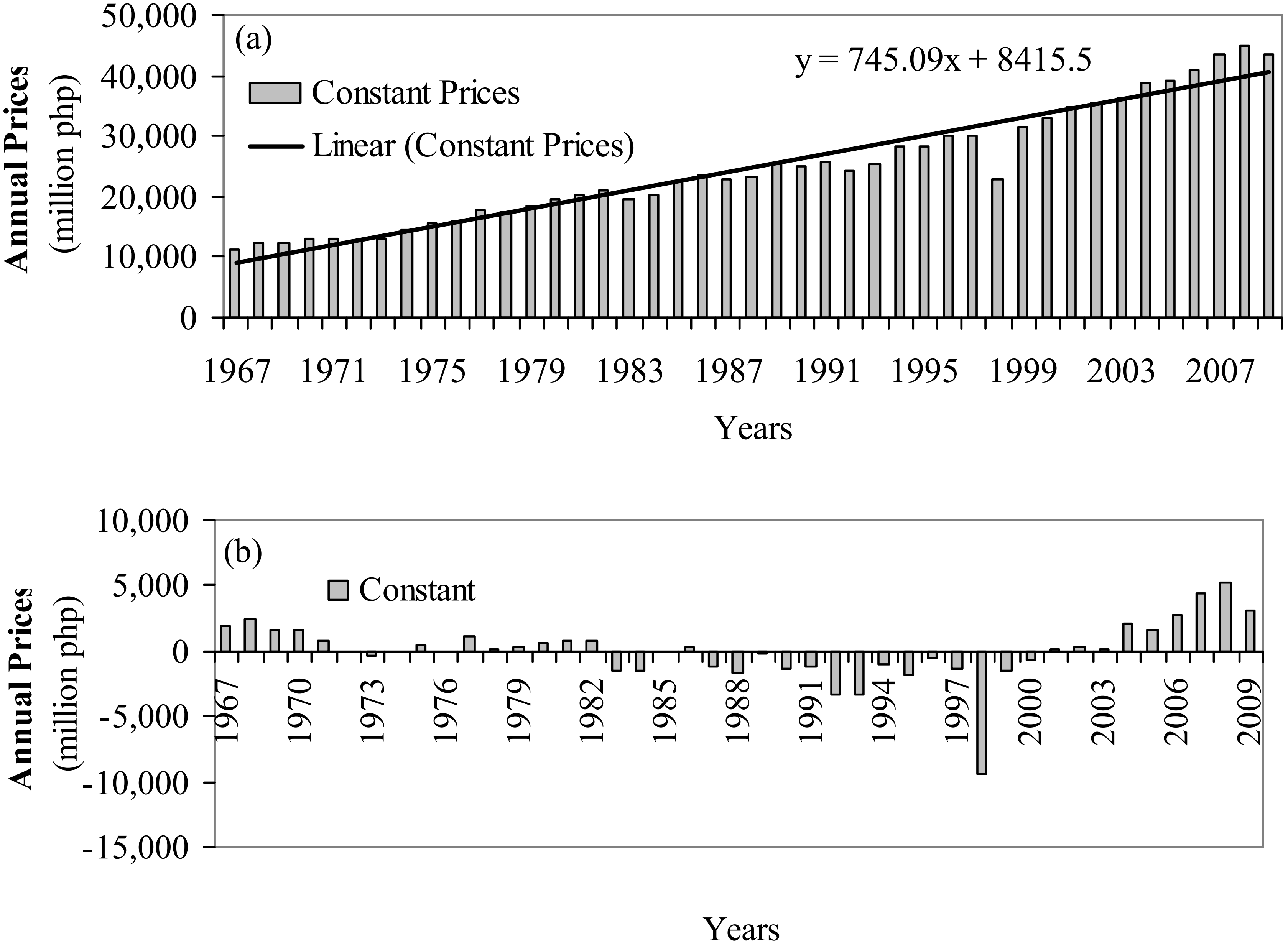




Spatial analysis showing mild to severe drought in **August 1998** for (a) rainfall, (b) discharge, (c) surface soil moisture, (d) root zone soil moisture and (e) groundwater level.



Hotspots: Spatial representation of the effects For **August 1998** for meteorological drought (using rainfall parameter), hydrological drought (using the combined effects of discharge and groundwater level), agricultural drought (using soil moisture), and the combined effects of the different drought types.



Agricultural production of palay (un-milled rice) from 1967-2009 detrended using simple linear correlation (a) to calculate annual production gains/losses (b).