

## → 6th ESA ADVANCED TRAINING COURSE ON LAND REMOTE SENSING

# Drought Monitoring and Assessment

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# What is the difference?

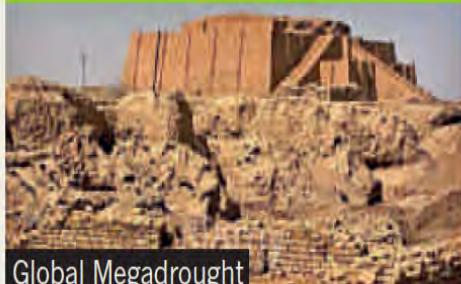


# Learning Objectives

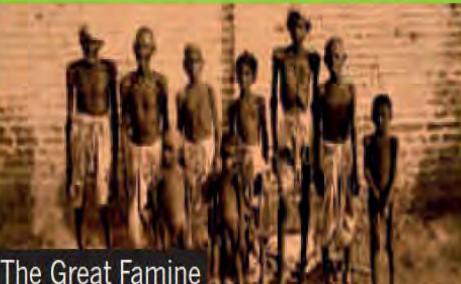
1. Understand basic ideas for estimating water availability
2. Familiarize with data products for deriving different water availability terms
3. Understand the possibilities and limitations for estimating water availability using different approaches
4. Familiarize with the applications

# A LONG HISTORY

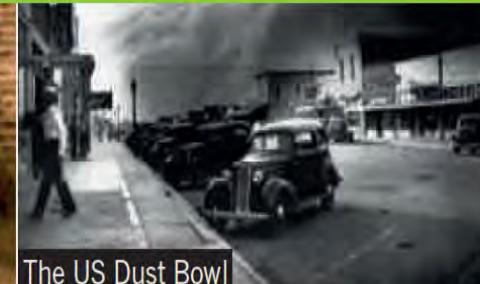
Serious droughts have occurred in Australia and Africa, among other regions, in recent decades, but more severe 'megadroughts' have occurred on virtually every continent throughout history.



Global Megadrought



The Great Famine



The US Dust Bowl



Sahel Drought

## 4,200 YEARS AGO

### 1876–78

#### GLOBAL MEGADROUGHT

**Where:** North America but spread to Europe, Africa and Asia. Lasted for several centuries.

**Cause:** Cooling of the North Atlantic, which reduced rainfall by as much as 30%.

**Impact:** Linked to demise of Akkadian Empire and civilizations in Greece, Egypt and the Indus Valley of Pakistan.

#### THE GREAT FAMINE

**Where:** Began in southern India and spread to the tropics and China.

**Cause:** Severe El Niño that led to the failure of the Asian monsoon. Food shortages for the poor worsened by Colonial-era imperialism.

**Impact:** More than 5 million deaths in India and 30 million in total.

## 1901

#### FEDERATION DROUGHT

**Where:** Australia. It covered half the continent by 1901.

**Cause:** Lack of rainfall.

**Impact:** Reduced cattle from 12 million to 7 million and sheep from 91 million to 54 million. Led to a massive failure of the wheat crop and caused the Darling River in New South Wales to dry up.

## 1930s

#### THE US DUST BOWL

**Where:** Centred on the Great Plains but covered 60% of the United States. Lasted all decade.

**Cause:** Low rainfall and poor land management (deep ploughing).

**Impact:** Agricultural production fell by 17%. Cost the US government US\$13 billion in aid and 2.5 million people left the affected states.

## 1940s

#### CENTRAL EUROPEAN DROUGHT

**Where:** Central and Eastern Europe in 1945–47.

**Cause:** Low rainfall.

**Impact:** Devastated crops. In some countries, such as Romania, 90% of the population went hungry. In parts of the Czech Republic, the cereal yield fell by about 30%.

## 1970s–1980s

#### SAHEL DROUGHT

**Where:** In 1983 it covered 65% of the Sahel, or around 8 million km<sup>2</sup>.

**Cause:** Probably natural variation in ocean temperatures and atmospheric dynamics, coupled with human-driven climate change.

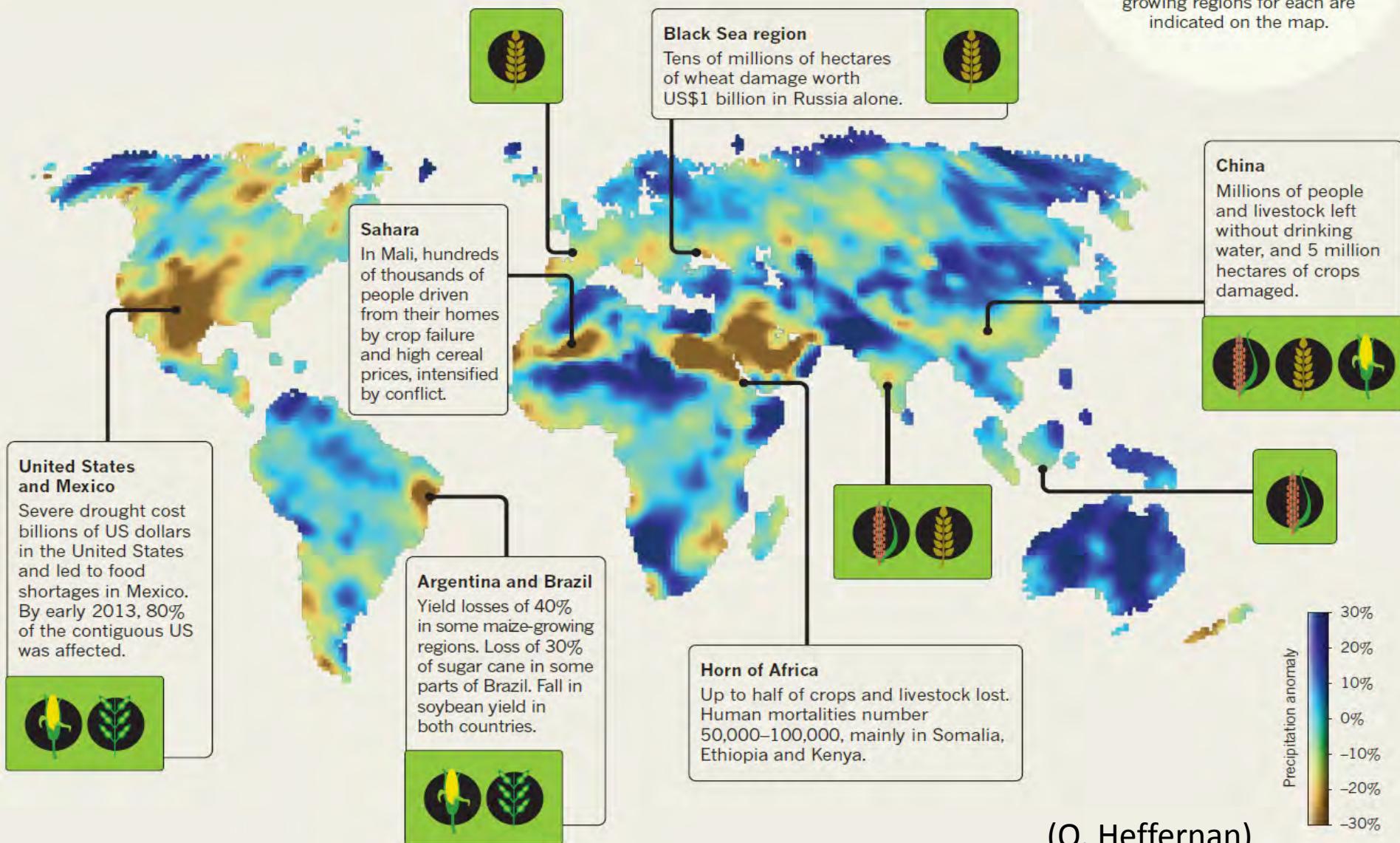
**Impact:** Famine led to 600,000 deaths in 1972–75, and again in 1984–85.

# RECENT DROUGHTS

In 2011 and 2012, drought occurred on almost every continent, partly because of an unusually strong La Niña that caused record rainfall in Australia and led to severe water shortages in Sudan. Hundreds of millions of hectares of crops were destroyed, from wheat in Russia to sugar cane in India. The map shows how rainfall deviated from the norm in this period and highlights the regions most affected by drought — many of which are major growing regions for the world's top four staple crops.

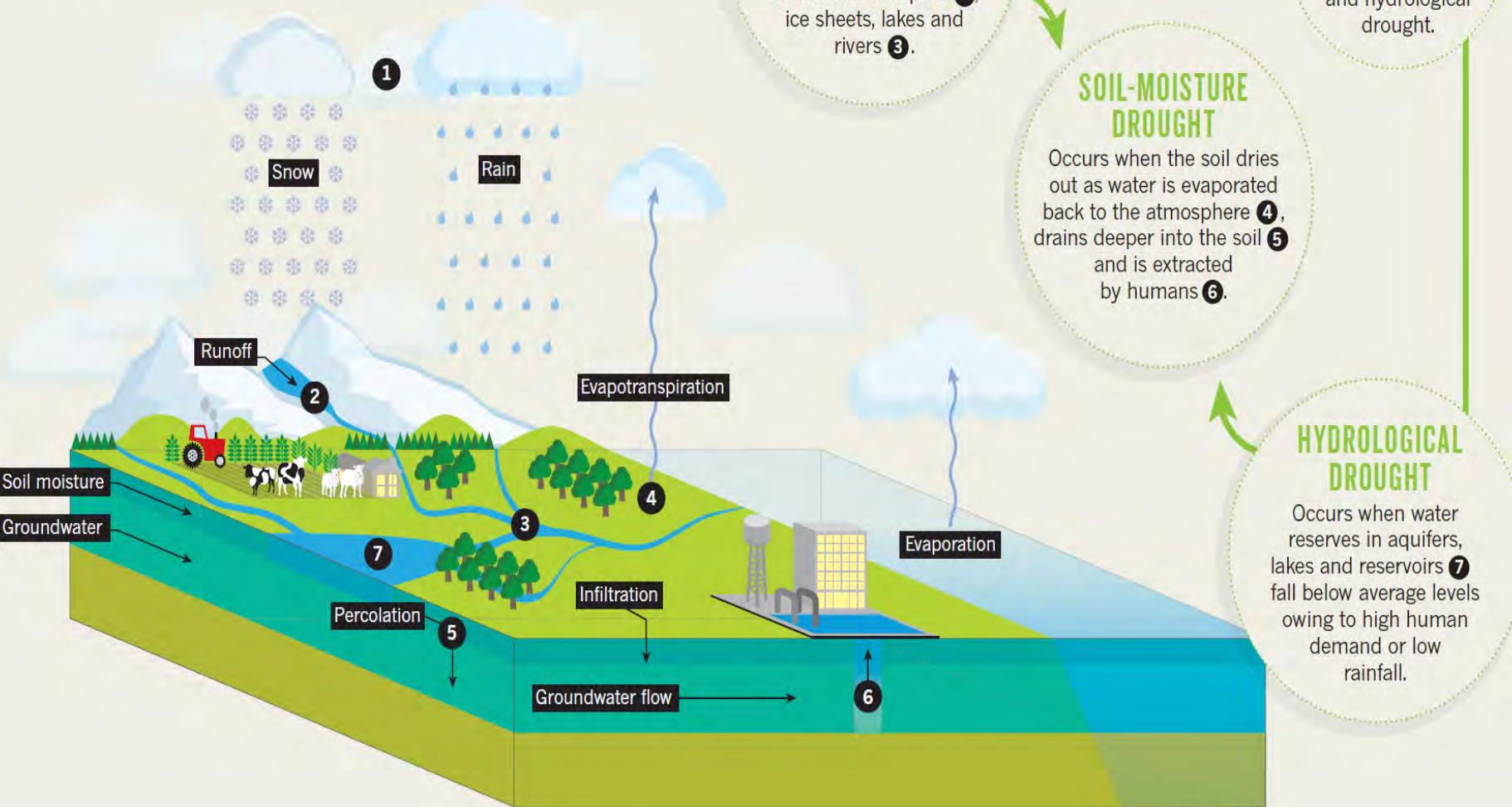


The top four crops account for 45% of all cultivated land and at least 40% of human calorie intake. The main growing regions for each are indicated on the map.



# DEFINING DROUGHT

Characterized by unusual and persistent dry weather, drought is caused by shifts in global weather patterns such as El Niño, but also increasingly by human-induced climate change. Identifying drought is difficult, however, so there is considerable uncertainty about whether it is getting any worse.

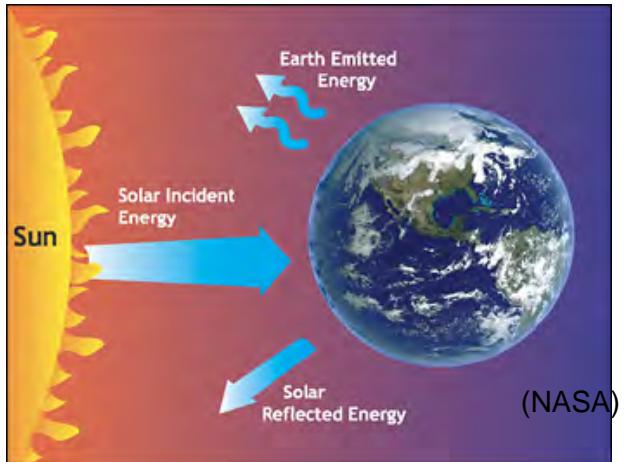


# DROUGHT INDICES (LOTS OF THEM)

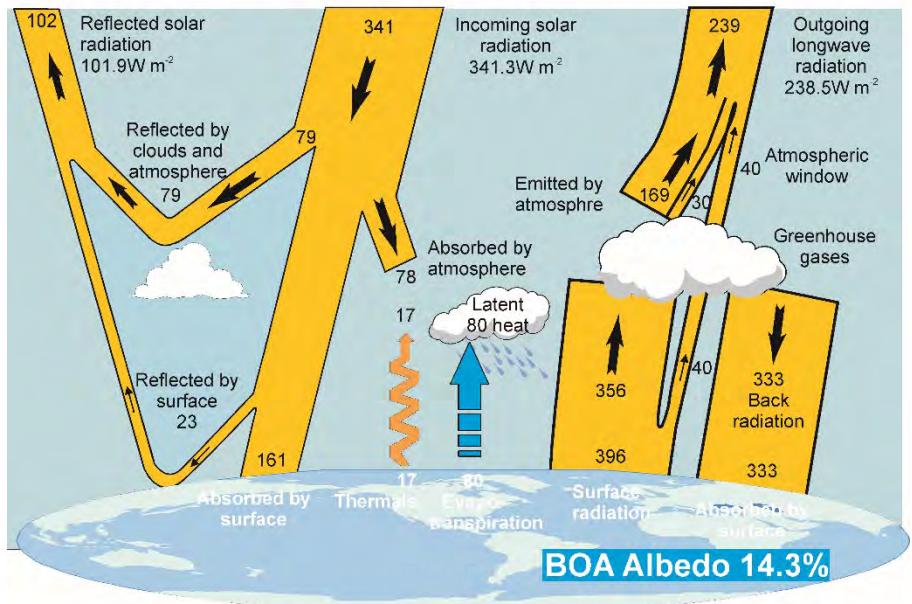
- Percent of Normal (PN)
- Standard Precipitation Index (SPI)
- Palmer Drought Severity Index (PDSI)
- Crop Moisture Index (CMI)
- Surface Water Supply Index (SWSI)
- Reclamation Drought Index (RDI)
- Evapotranspiration Deficit Index (ETDI)

[Eden, U. \(2012\)](#) Drought assessment by evapotranspiration mapping in Twente, the Netherlands. Enschede, University of Twente Faculty of Geo-Information and Earth Observation (ITC), 2012.

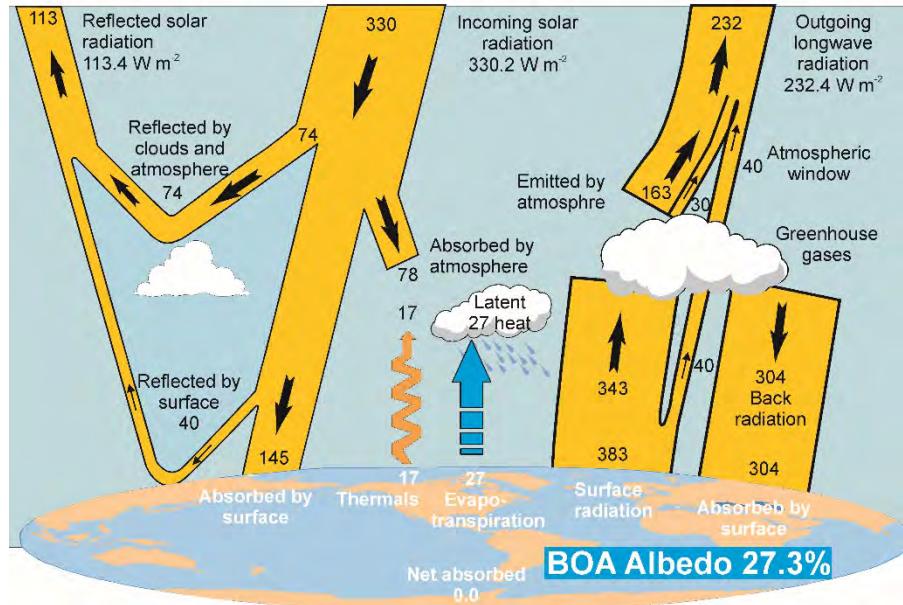
# Let there be light



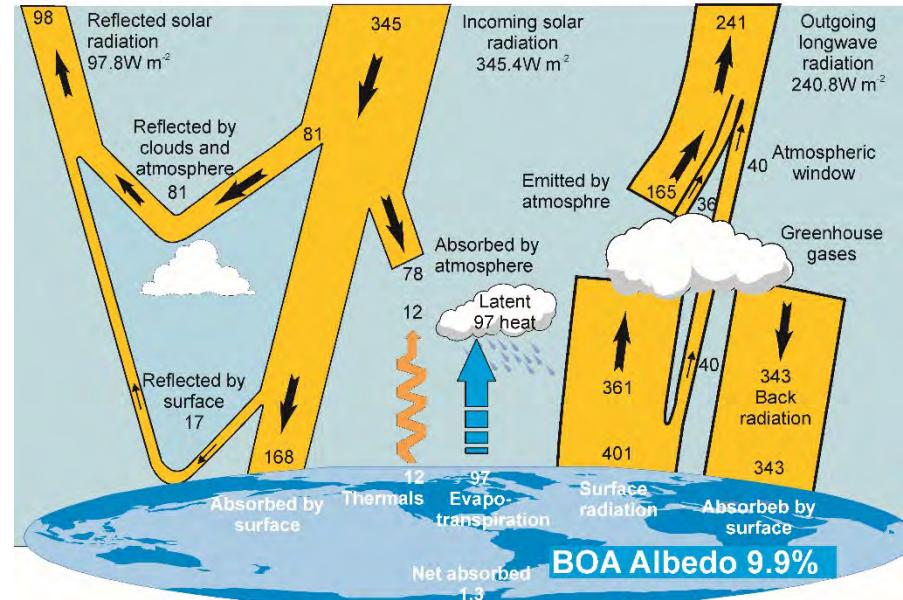
Global energy budget, TOA Albedo 29.8%



Land energy budget, TOA Albedo 34.4%

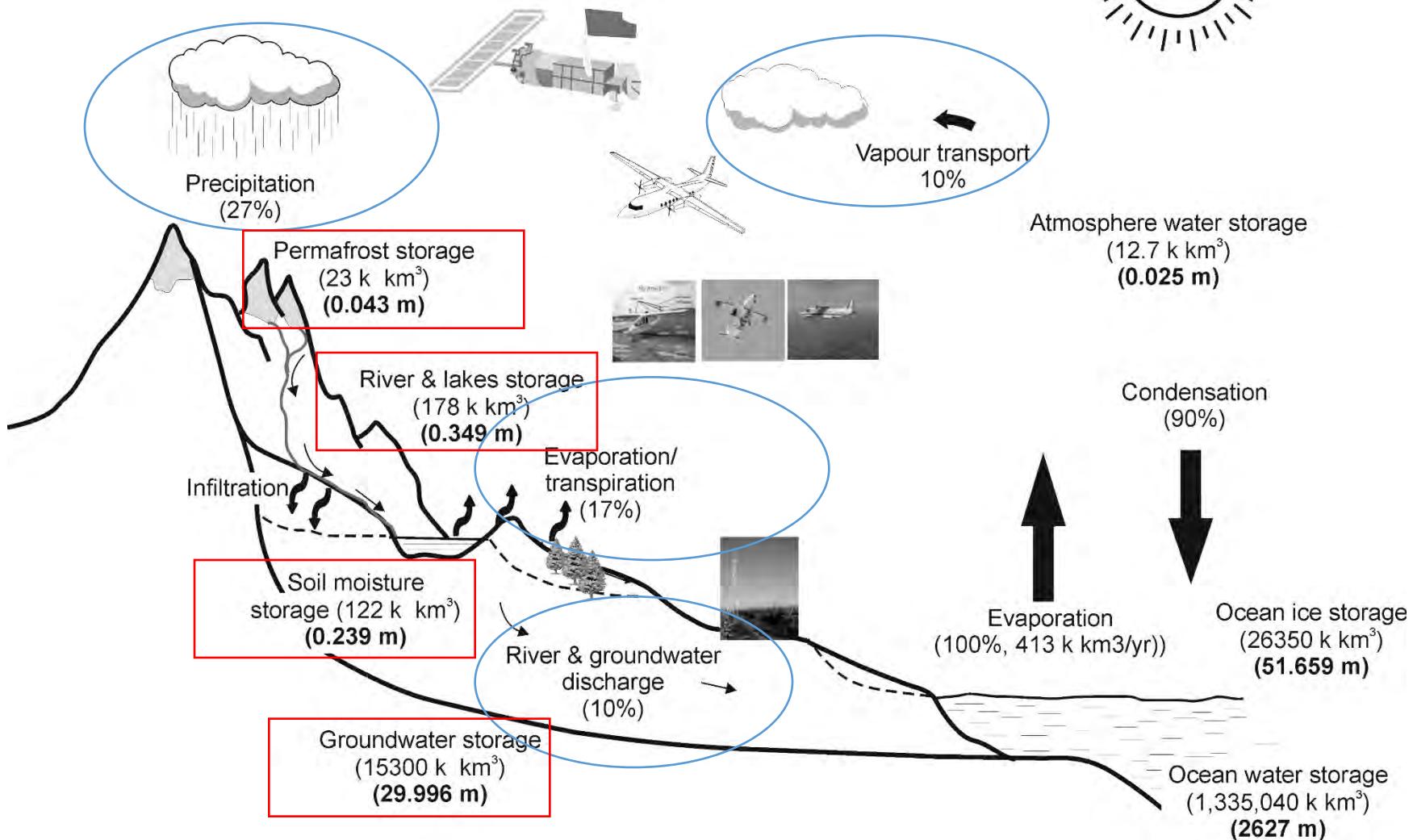


Ocean energy budget, TOA Albedo 28.3%



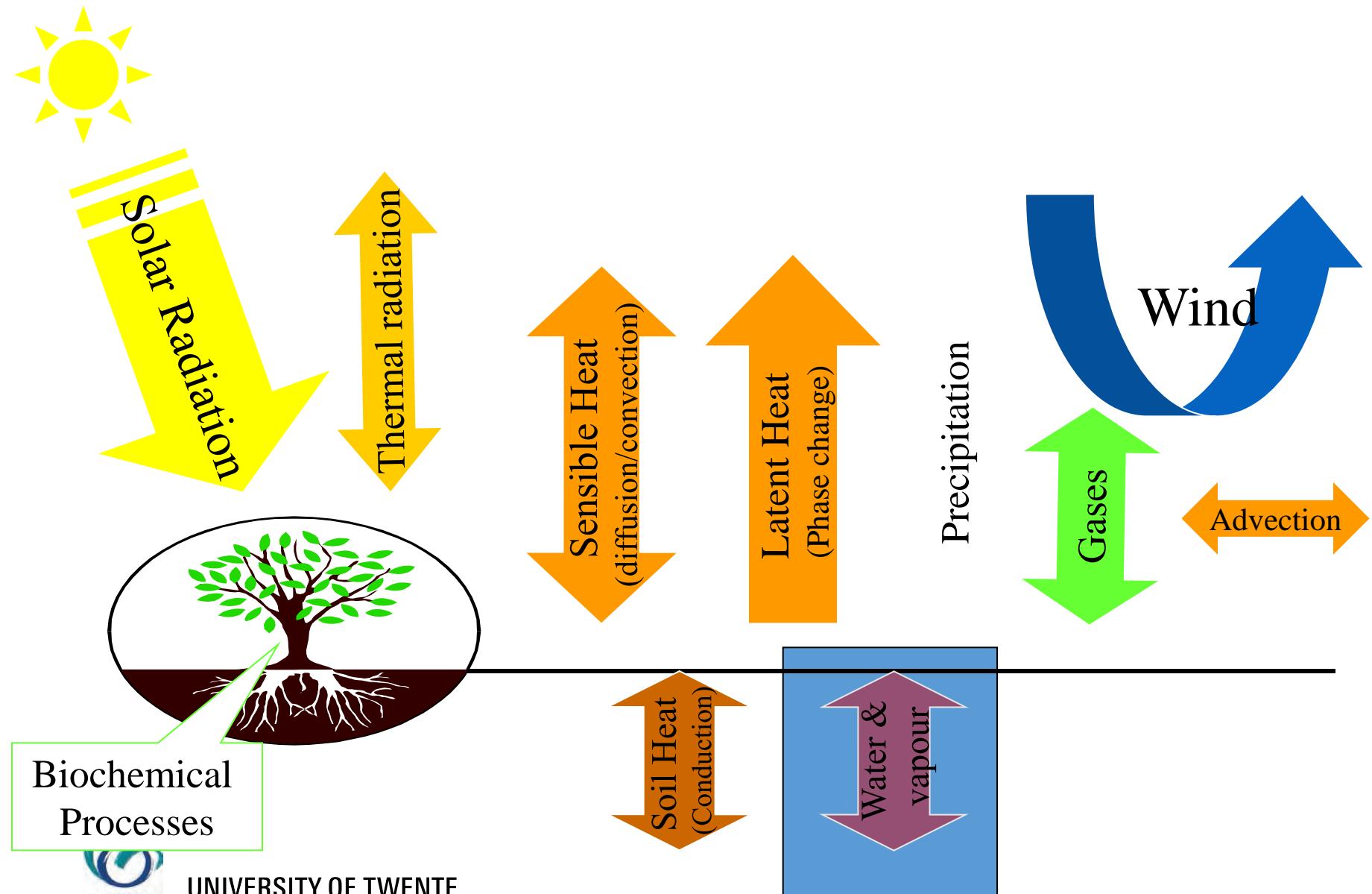
# Water cycle and its link to climate

## Radiation



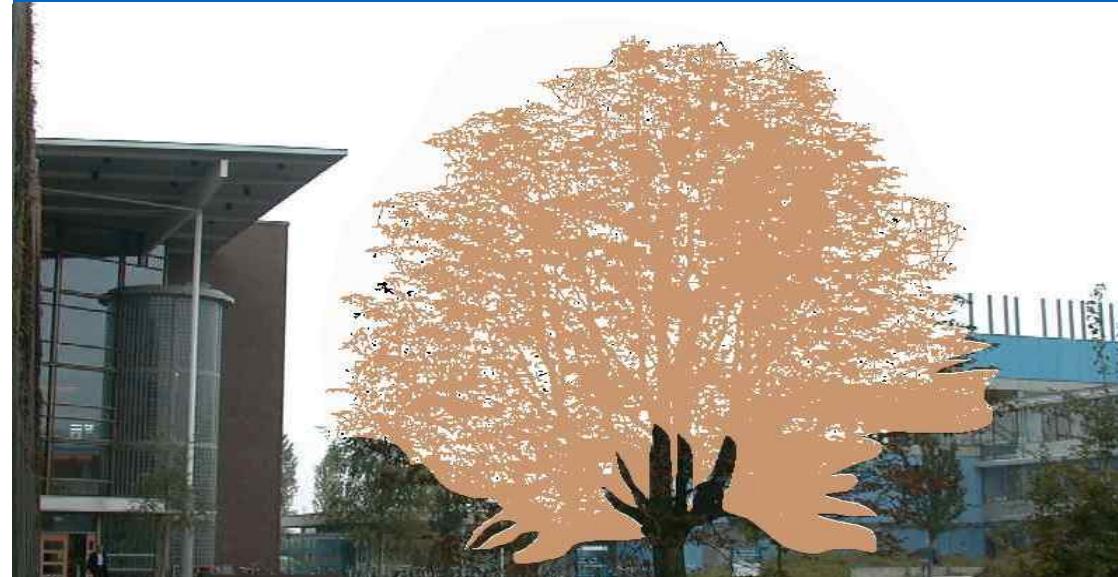
# Land-Atmosphere Interactions

## - Terrestrial Water, Energy and Carbon Cycles



# What is Drought ?

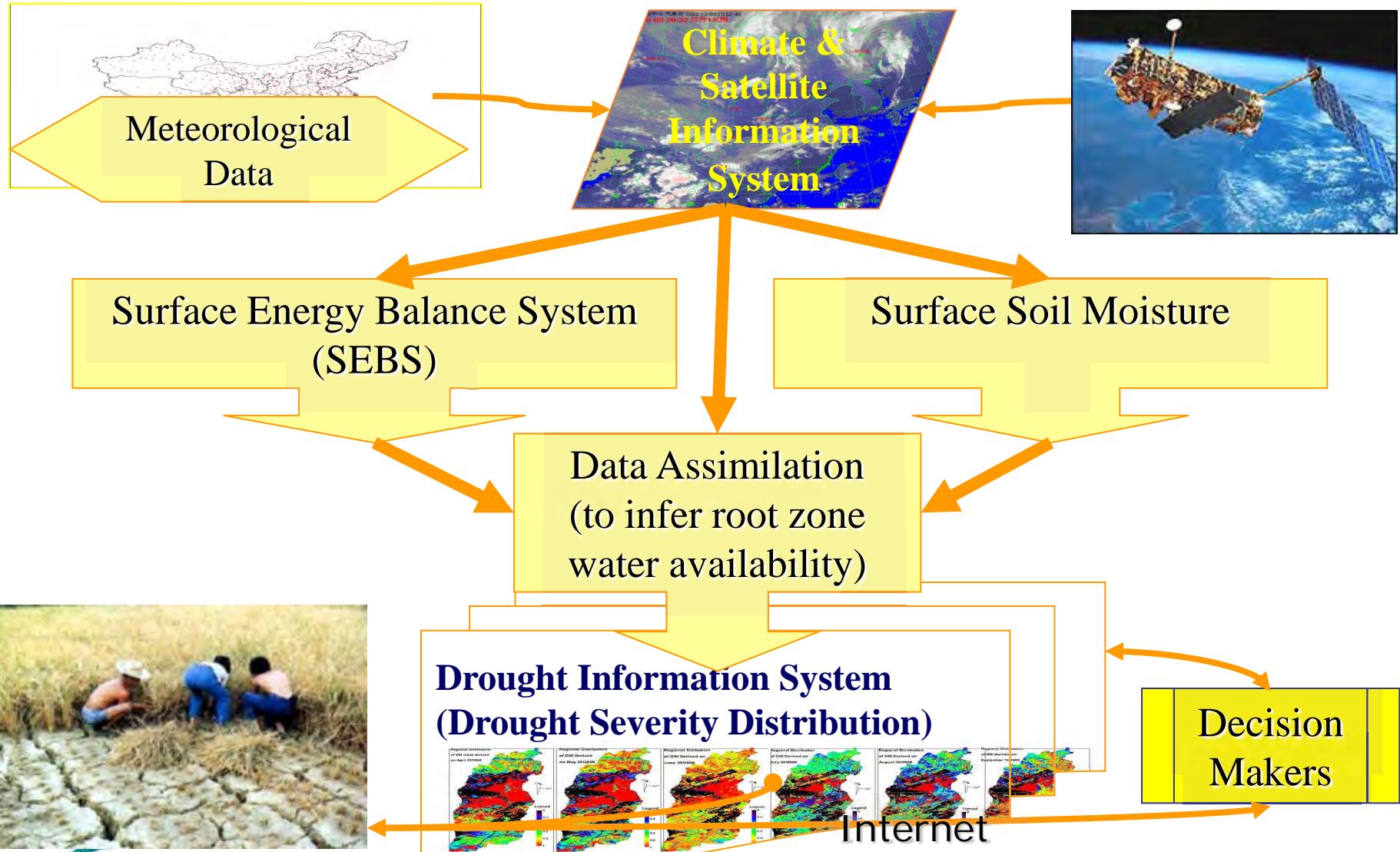
Dry Condition: No transpiration



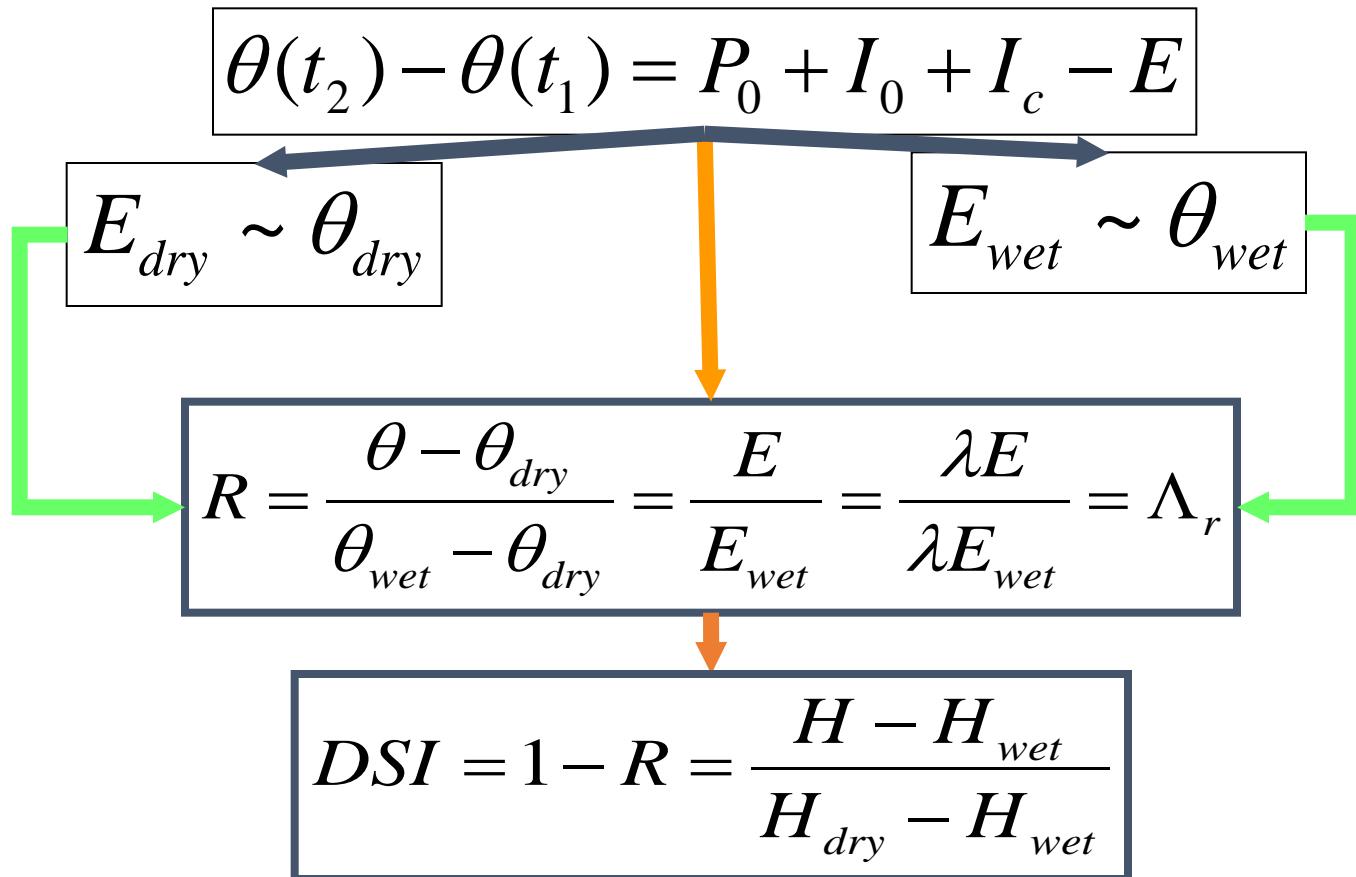
# Quantitative Approaches for Drought Monitoring and Prediction

- Approach 1: Surface Energy Balance
  - To derive relative evaporation & relative soil moisture in the root zone from land surface energy balance
  - To define a quantitative drought severity index (DSI) for large scale drought monitoring
- Approach 2: Soil Moisture Retrieval
  - To determine surface soil moisture
  - To assimilate surface SM into a hydrological model to derive root zone soil moisture
- Approach 3: Total water budget

# Drought Monitoring & Prediction



# From Energy Balance to Water Balance



R: Relative Plant Available Soil Water Content

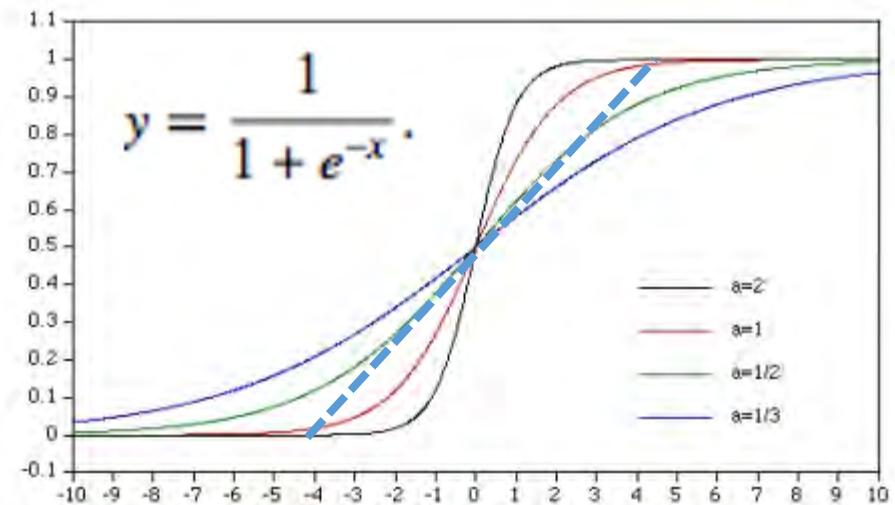
DSI: Drought Severity Index

# Relationship of evaporative fraction to surface variables (albedo, fractional vegetation coverage and surface temperature)

- The relative evaporation is given as

$$\Lambda_r = \frac{E}{E_{wet}} = s \left( \frac{\theta - \theta_{dry}}{\theta_{wet} - \theta_{dry}} \right)$$

$$\Lambda_r = \frac{E}{E_{wet}} \cong \frac{\theta - \theta_{dry}}{\theta_{wet} - \theta_{dry}}$$



# Relationship of evaporative fraction to surface variables (albedo, fractional vegetation coverage and surface temperature)

- The relative evaporation is given as

$$\Lambda_r = 1 - \frac{H - H_{wet}}{H_{dry} - H_{wet}}$$

$$\Lambda_r = 1 - \frac{\frac{(\theta_0 - \theta_a)}{r_e} - \frac{(\theta_0 - \theta_a)_w}{(r_e)_w}}{\frac{(\theta_0 - \theta_a)_d}{(r_e)_d} - \frac{(\theta_0 - \theta_a)_w}{(r_e)_w}}$$

The SEBS algorithm (Su, 2002; Jia et al., 2003)

# Relationship of evaporative fraction to surface variables (albedo, fractional vegetation coverage and surface temperature)

The surface-air potential temperature difference is given as

$$\theta_0 - \theta_a = \frac{\frac{r_i + r_e}{\rho_a c_p} (R_n - G) - \frac{e^* - e}{\gamma}}{1 + \frac{\Delta}{\gamma} + \frac{r_i}{r_e}}$$

$$(\theta_0 - \theta_a)_w = \frac{\frac{r_{e,w}}{\rho_a c_p} (R_n - G) - \frac{e^* - e}{\gamma}}{\left(1 + \frac{\Delta}{\gamma}\right)}$$

$$(\theta_0 - \theta_a)_d = \frac{r_{e,d}}{\rho_a c_p} (R_n - G)$$

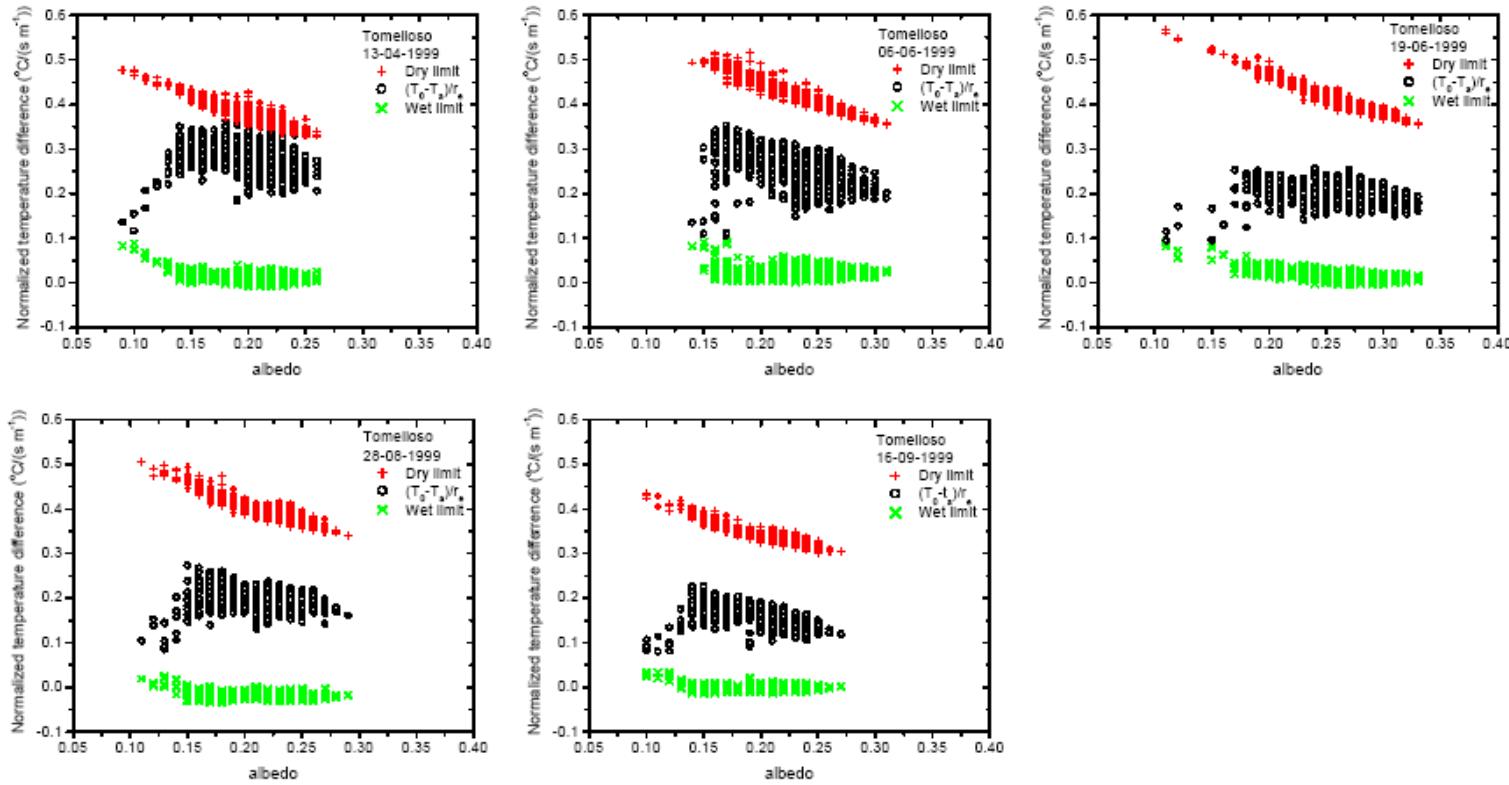


# Relation of evaporative fraction to surface variables (an example)

Table 1 Input parameters for SEBS.

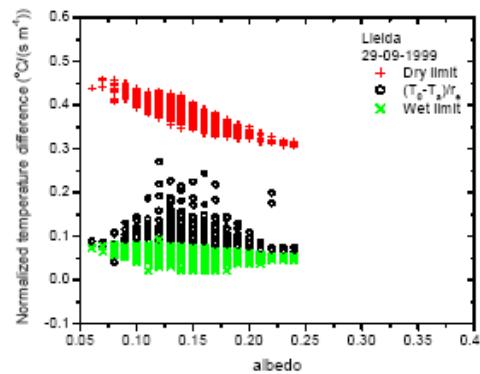
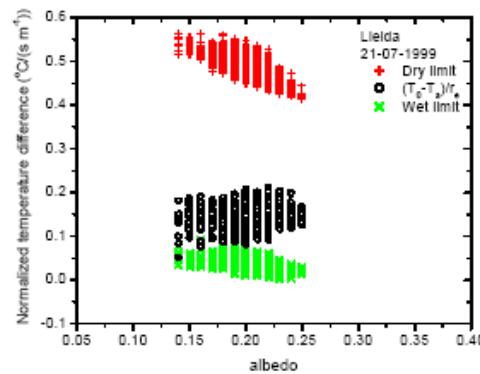
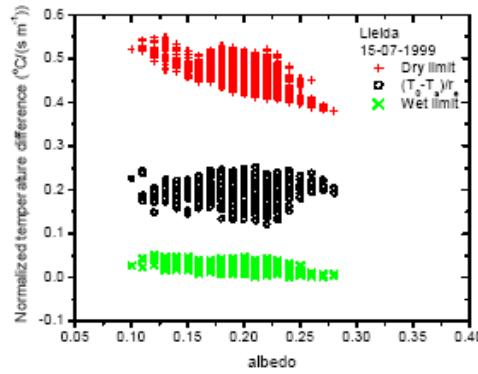
Parameters	Estimation from
Surface temperature (K)	ATSR derivative
Surface albedo (-)	ATSR derivative
NDVI (-)	ATSR derivative
Fractional vegetation cover (-)	ATSR derivative
PBL Depth (m)	RACMO output
PBL pressure (Pa)	RACMO output
PBL potential temperature (K)	RACMO output
PBL specific humidity (%)	RACMO output
PBL wind speed (m/s)	RACMO output

# Normalized temperature difference versus albedo



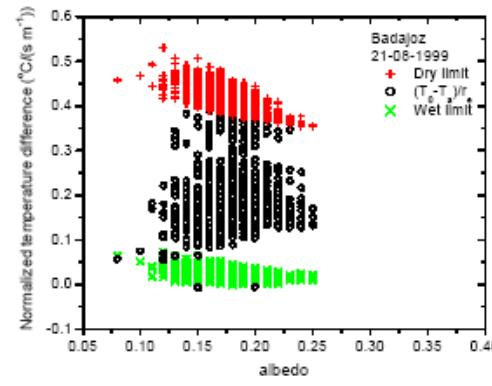
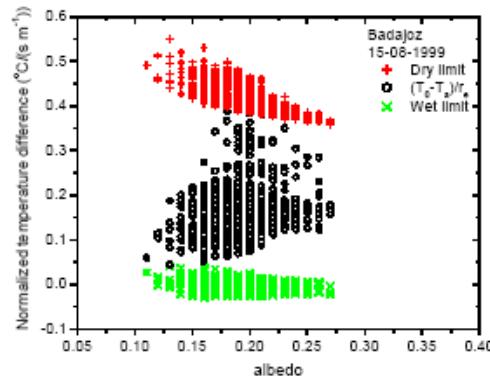
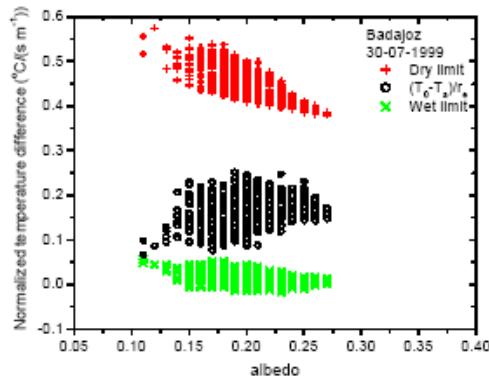
a)

# Normalized temperature difference versus albedo



b)

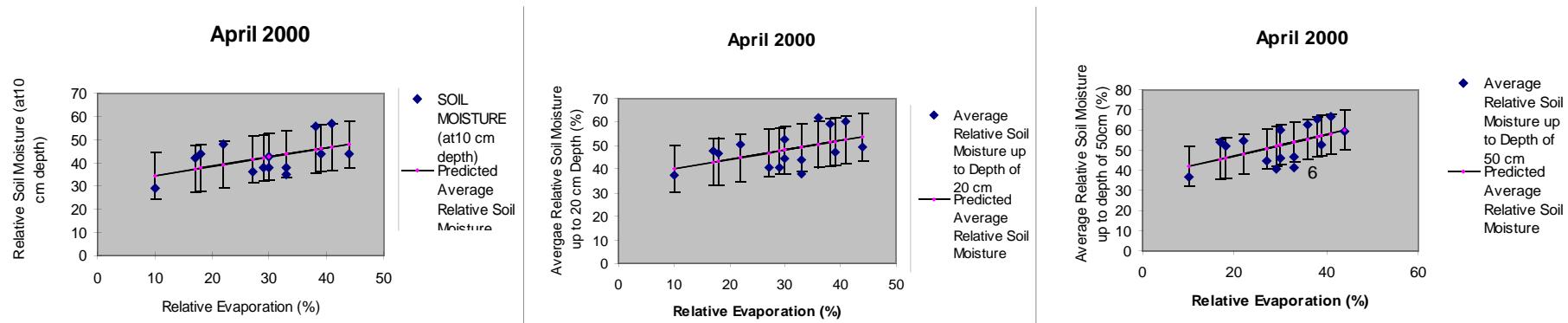
# Normalized temperature difference versus albedo



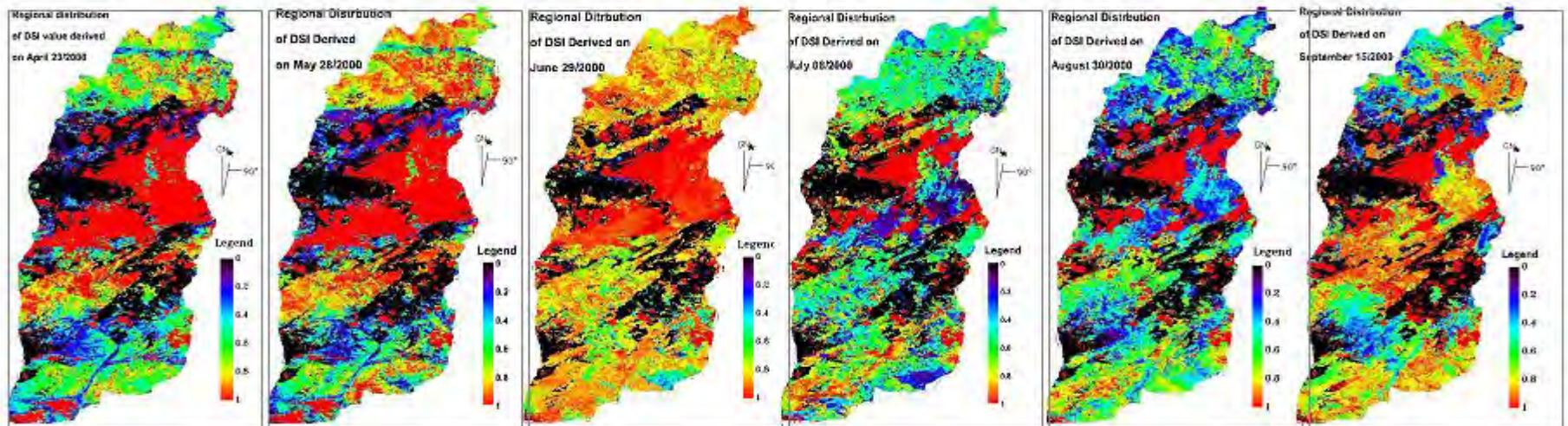
c)

# Comparison to Soil Moisture Measurements

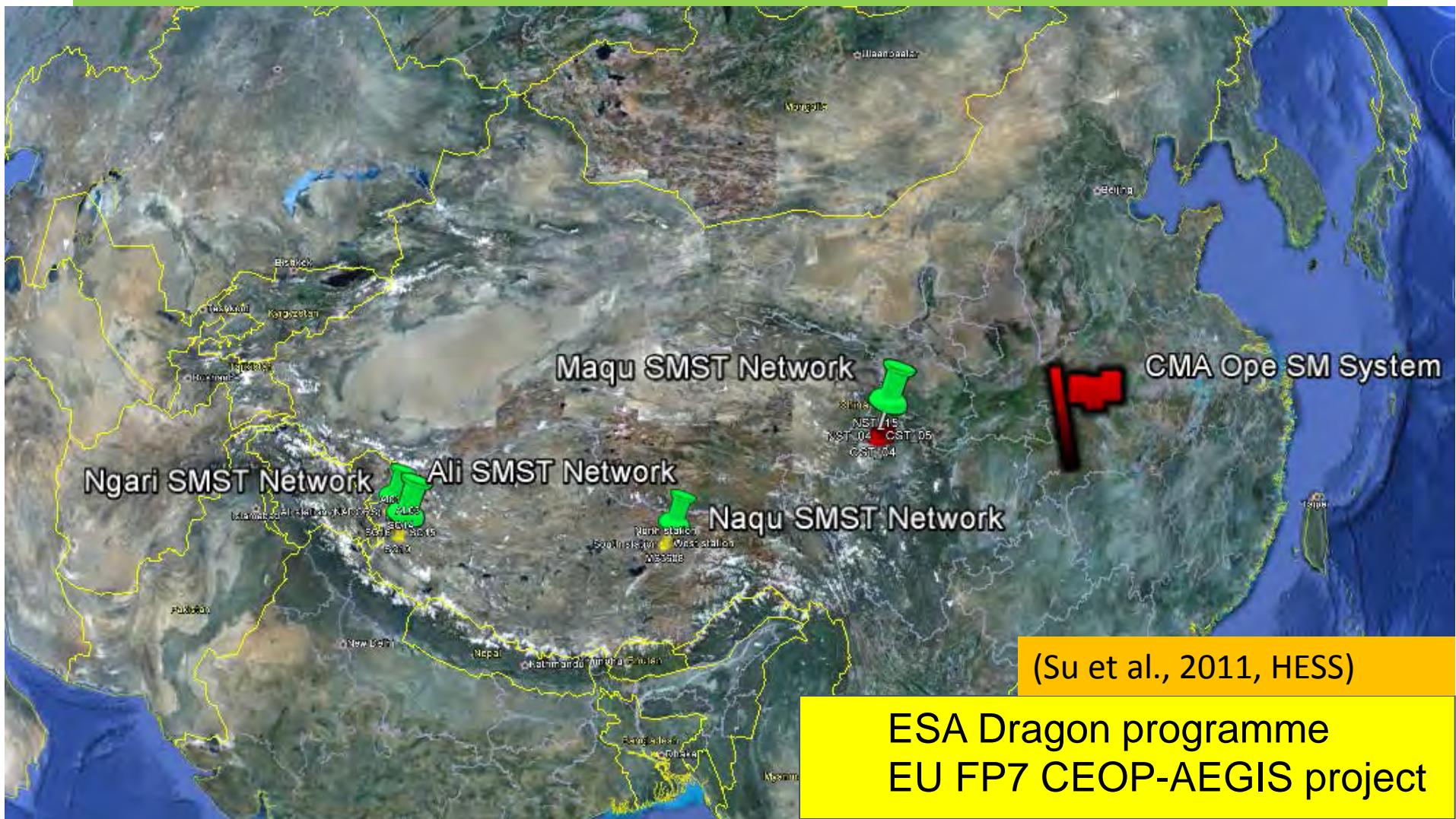
## Relative evaporation vs relative soil moisture



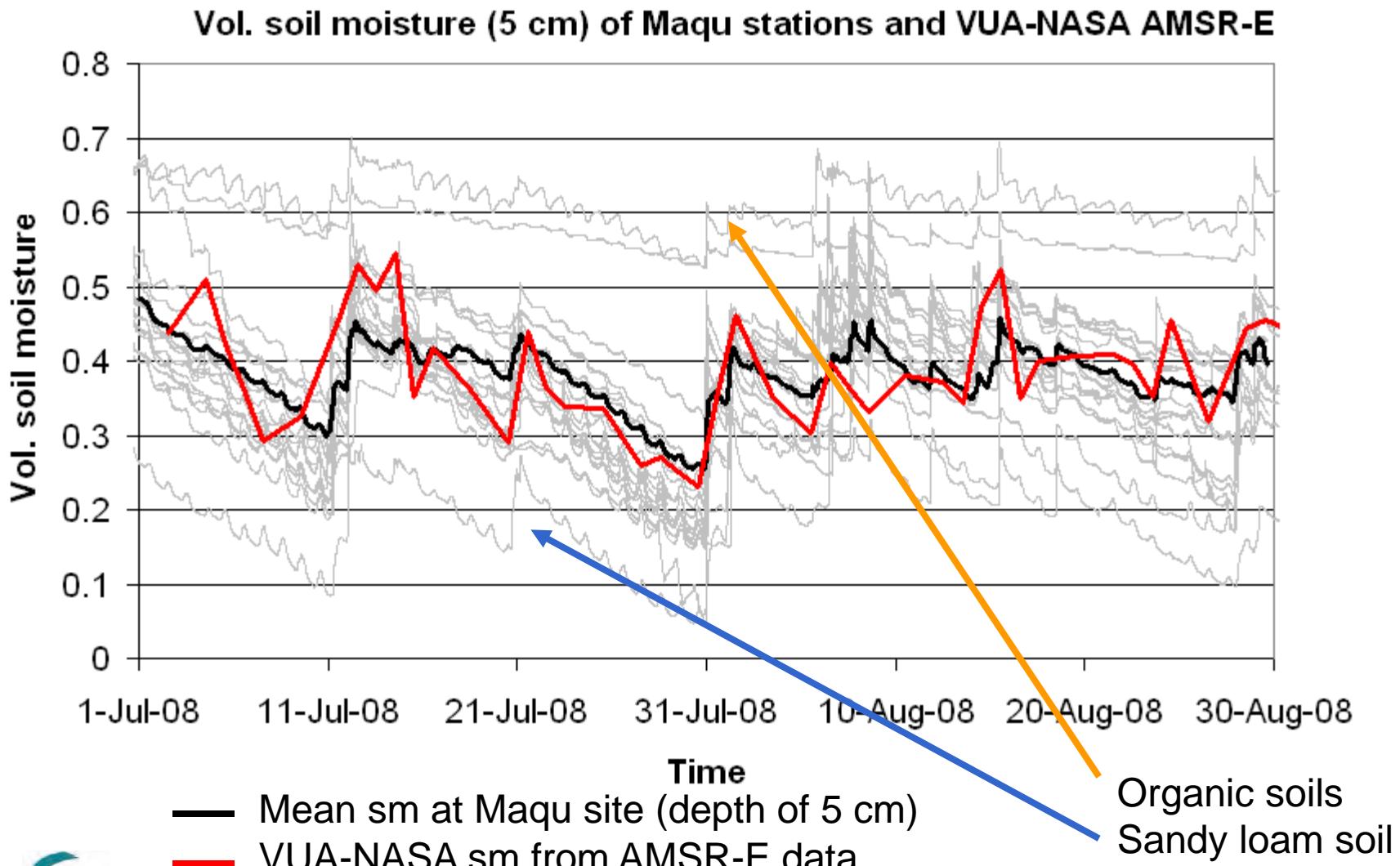
## Time Series of Drought Severity Index



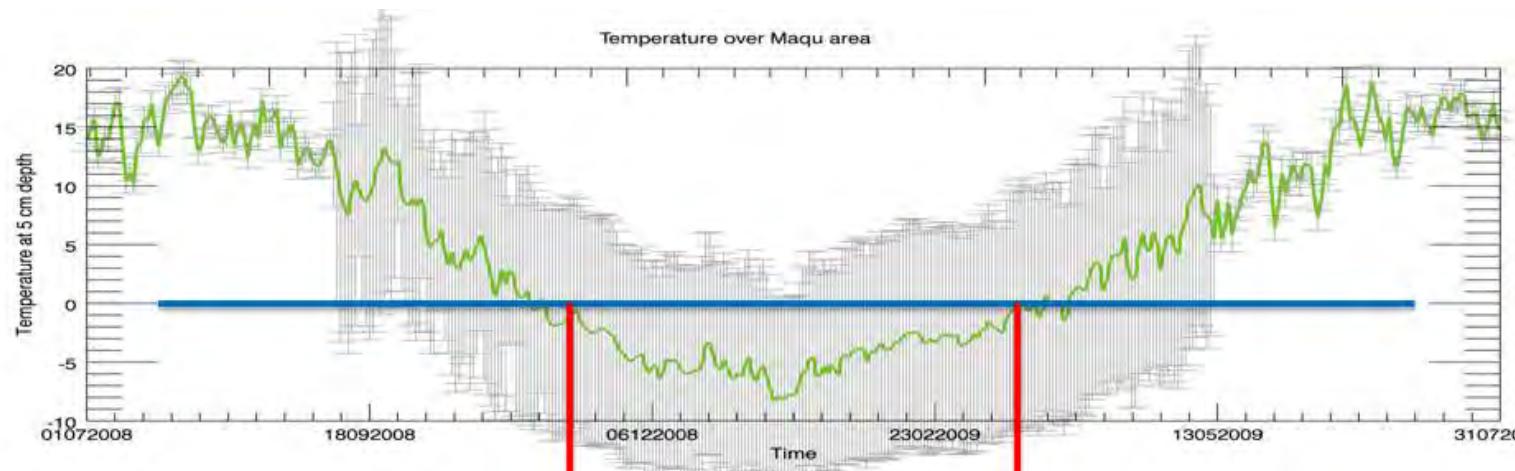
# Tibetan Plateau observatory of plateau scale soil moisture and soil temperature (Tibet-Obs)



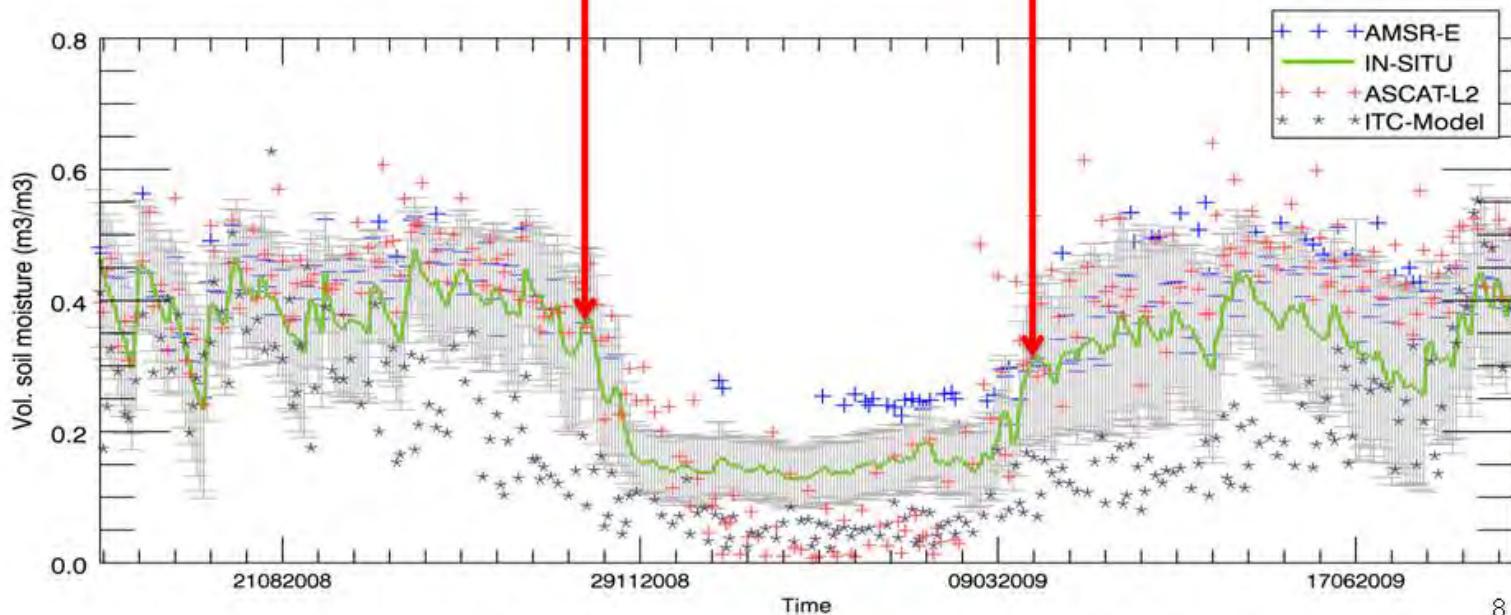
# Preliminary validation results



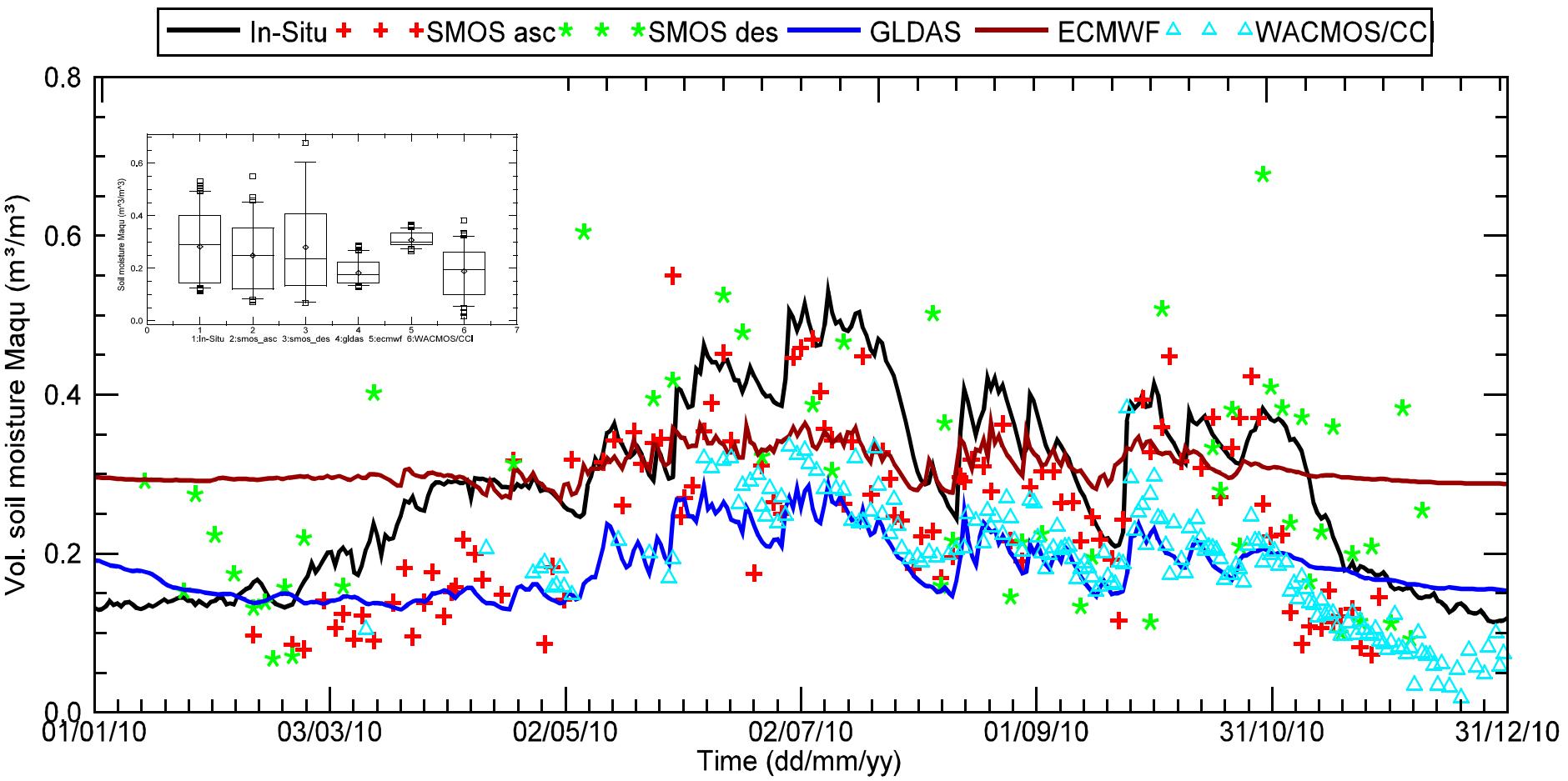
# Quantification of uncertainties in global products (Su, et al., 2011)



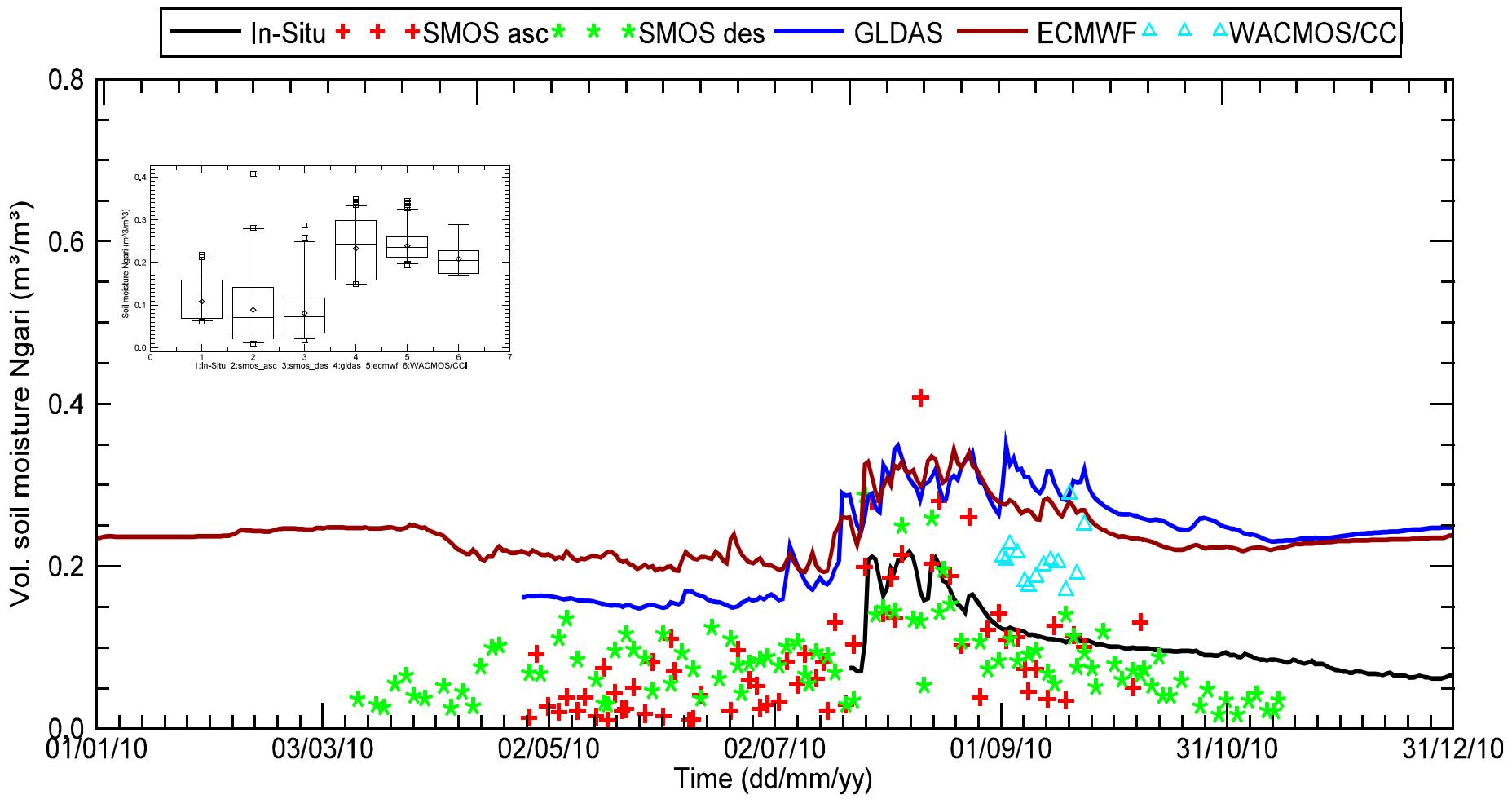
(Su et al., 2011, HESS)



## Maqu SMST Network – validation results



## Ngari SMST Network – validation results



How can we use this information  
for drought monitoring and  
prediction?



# WACMOS

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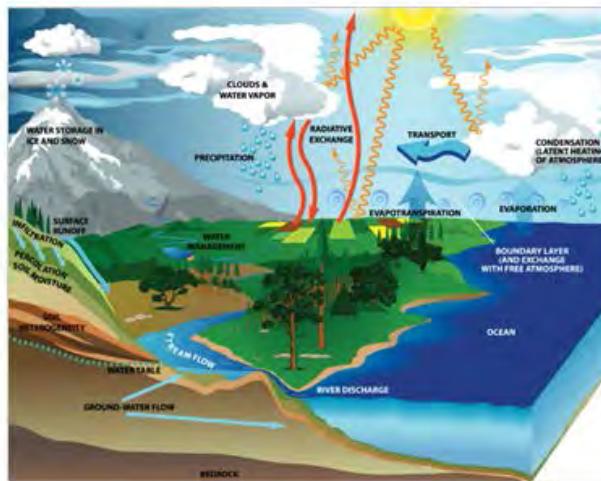
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## Bob Su

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## The WACMOS project

WACMOS is an ESA initiative to produce global products for the whole water cycle (Evapotranspiration, Soil Moisture, Clouds, Water Vapour). The project aims to set up a solid scientific basis for the creation of coherent long-term datasets of water relevant geo-information.



# WACMOS.org



# Continental scale simulations

1 Jan – 9 Dec 2009, grid resolution 25 KM

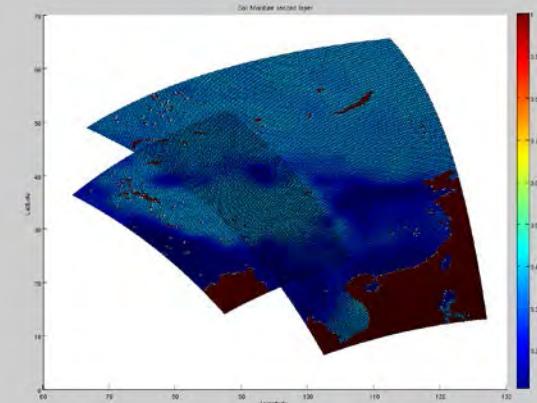
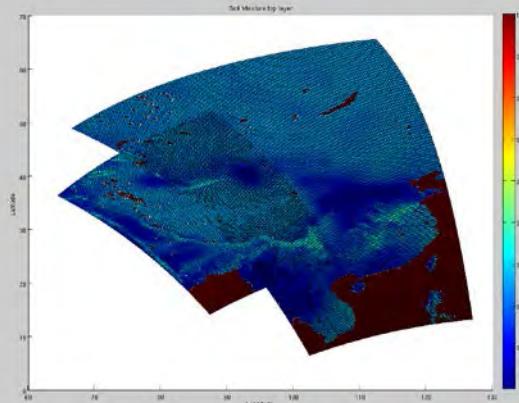
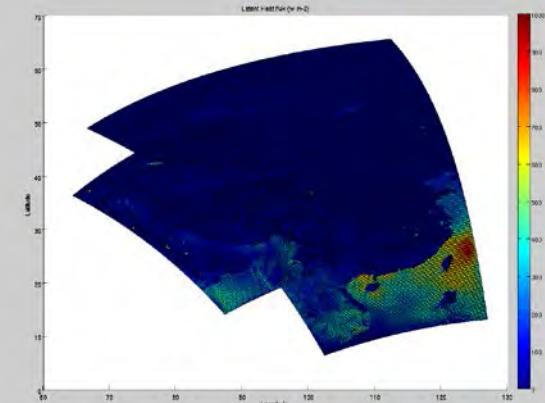
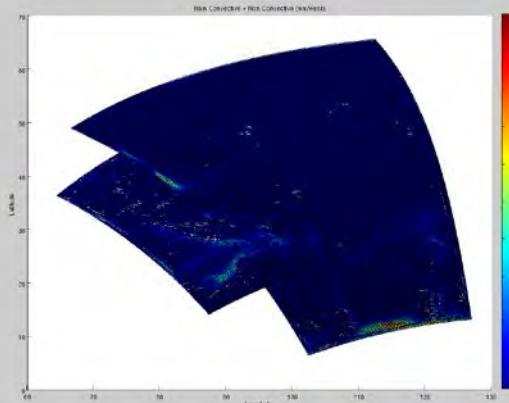
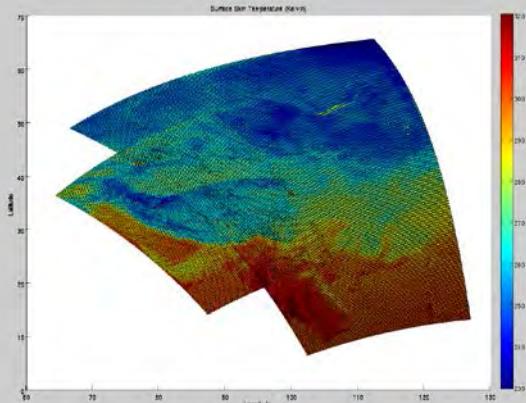
Skin temperature

Precipitation  
(convective + non-convective)

Latent heat flux  
(Evaporation/transpiration)

Soil moisture of top layer

Soil moisture of second layer



# Climate change impacts and adaptation in River Basins

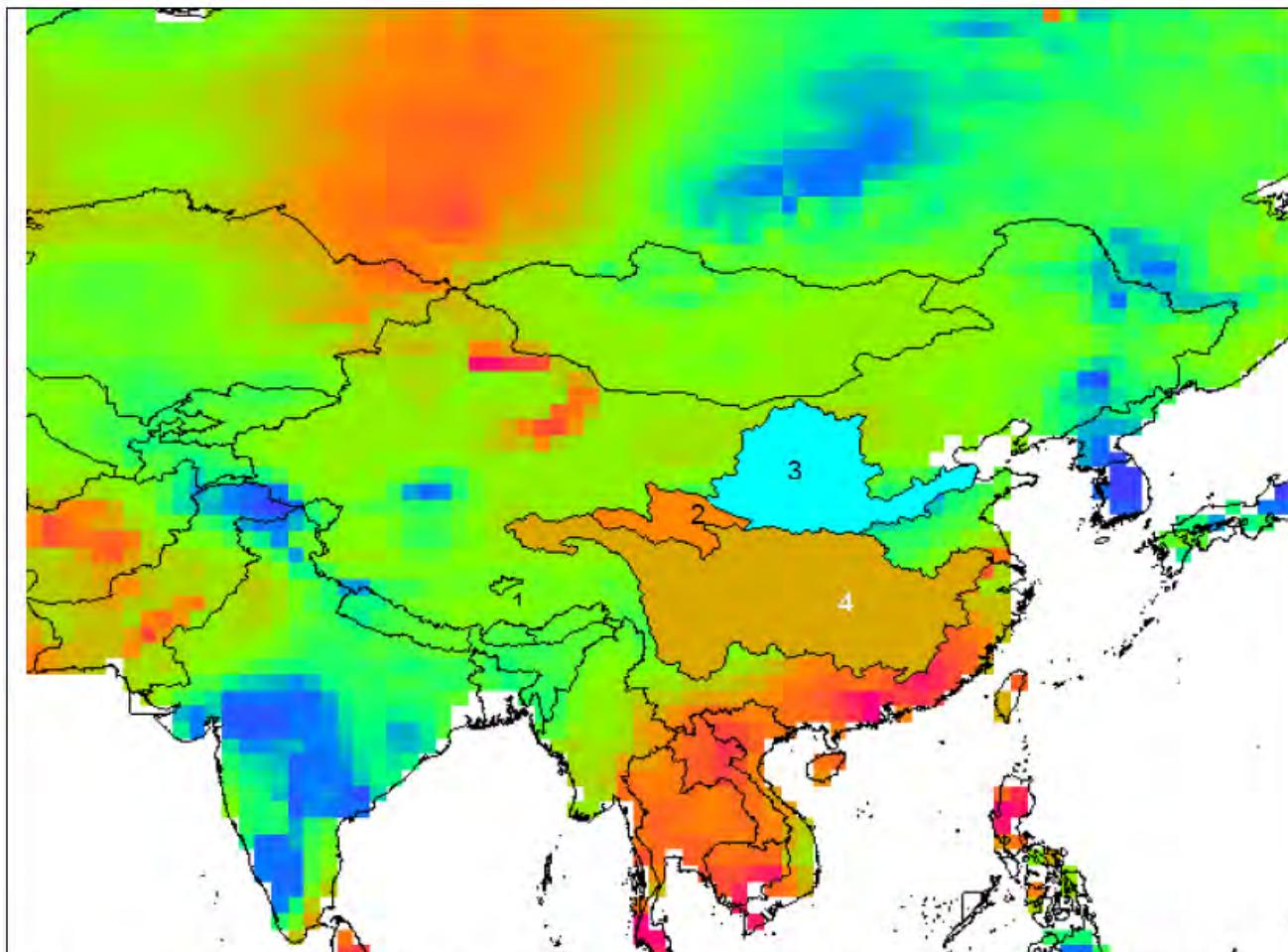
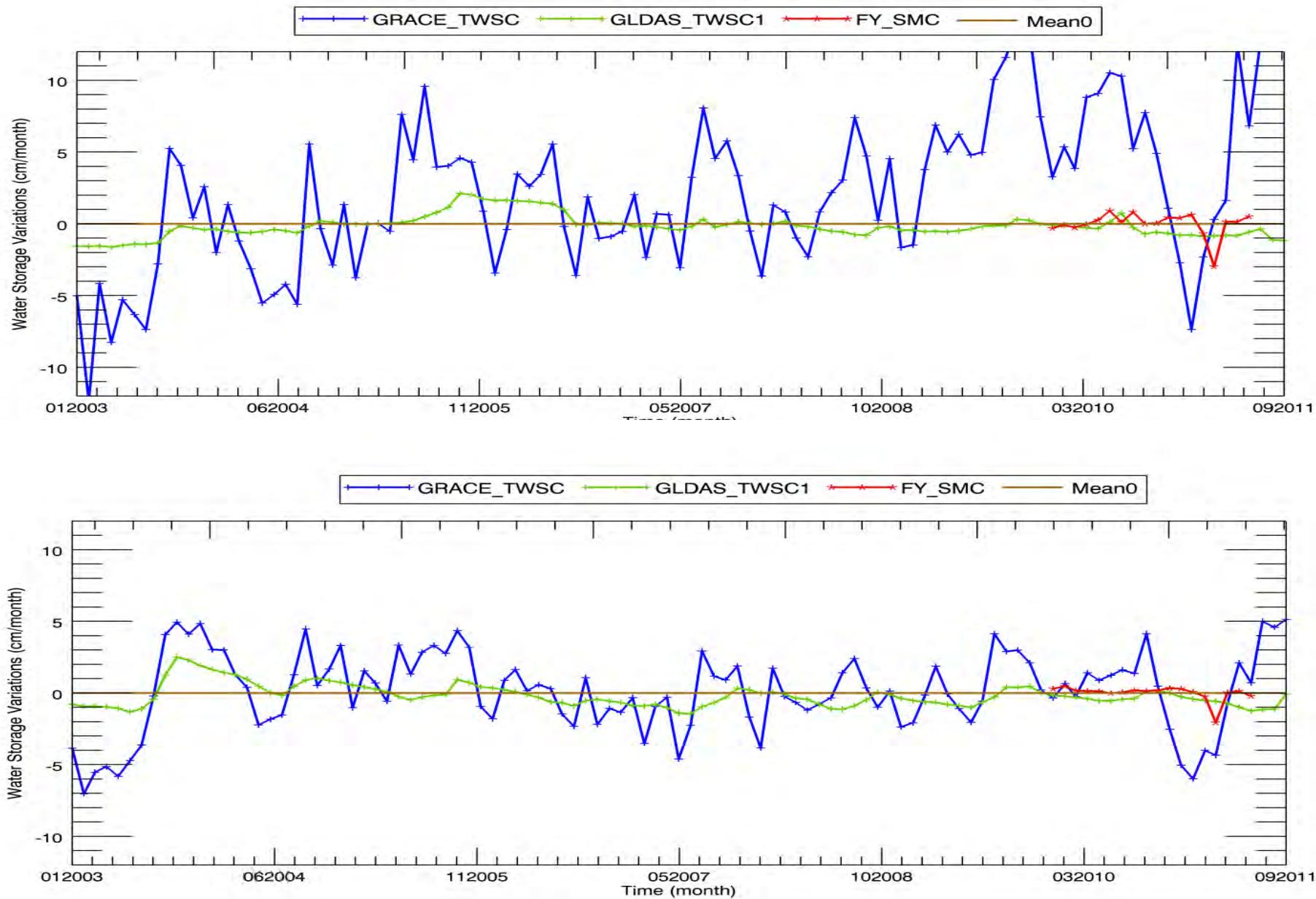
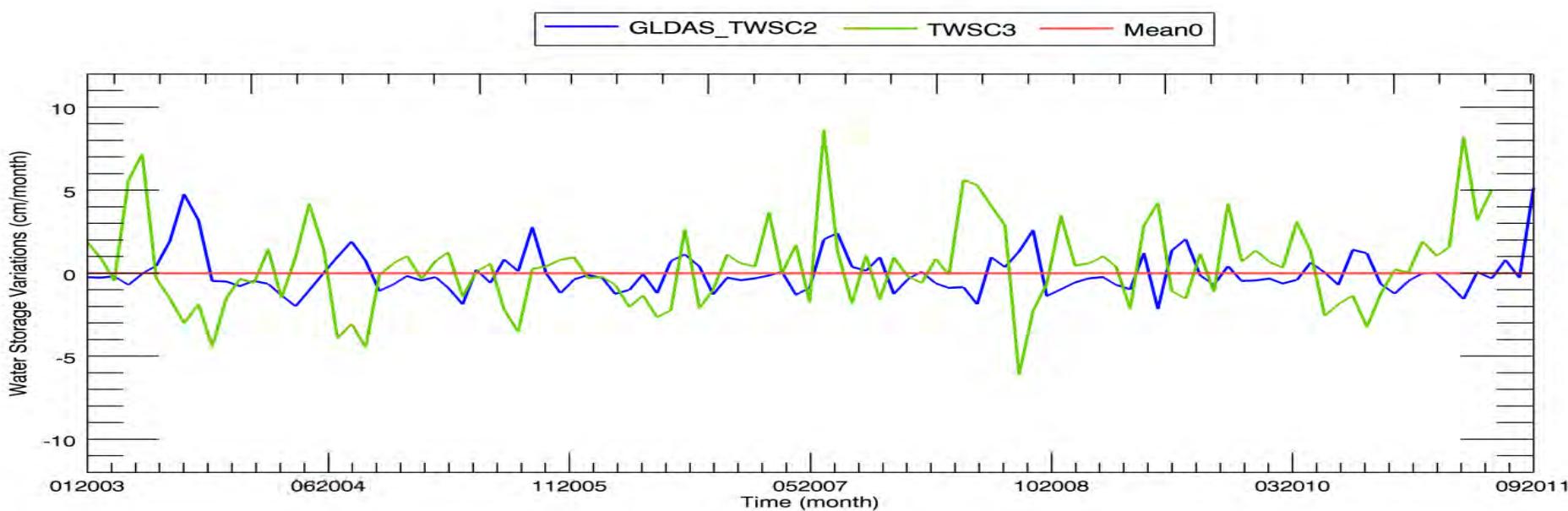
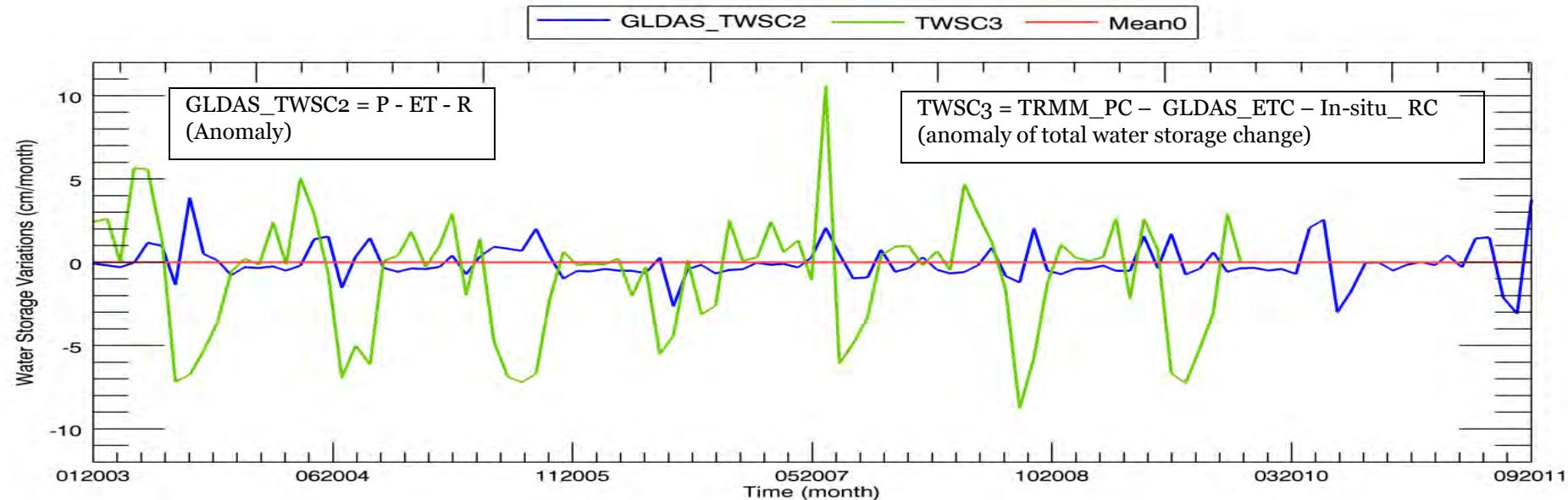


Figure 1. River basins refer to in the following graphs: (1) Namoco basin; (2) the Upper Yellow river basin;( 3) the whole Yellow river basin (including the upper part (2) ;( 4) Yangtze river basin.

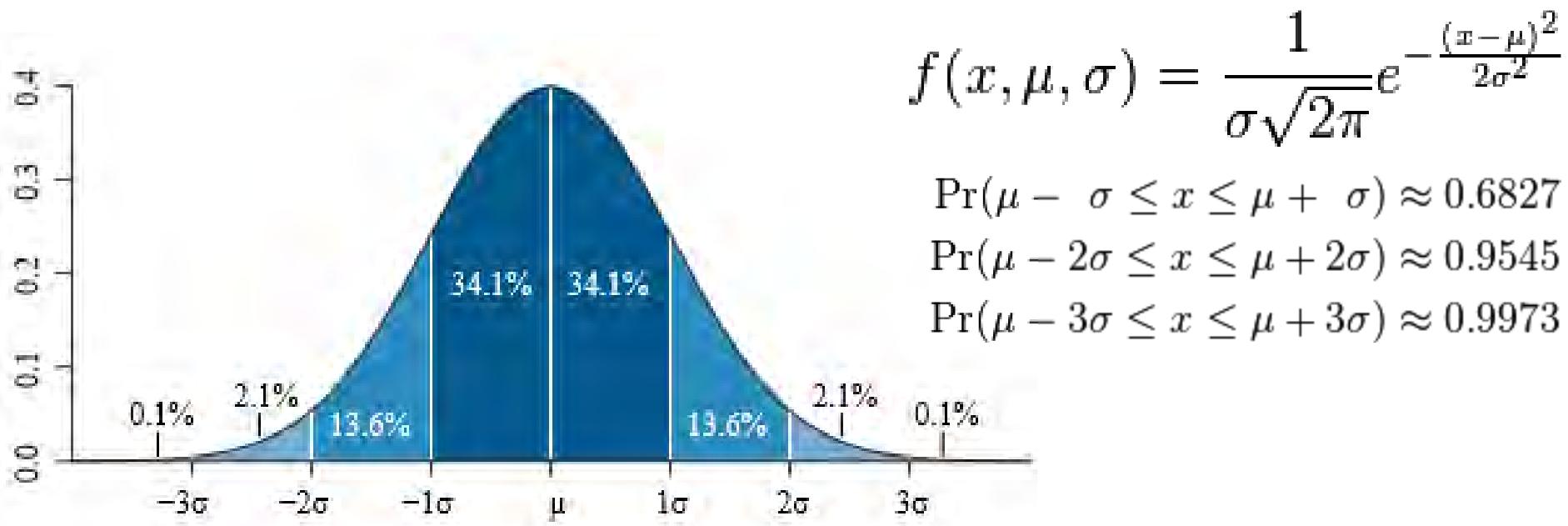
# Example of the Yellow River Basin (upper basin vs whole basin)



# Example of the Yellow River Basin (upper basin vs whole basin)



# How shall we define droughts?



Dark blue is less than one standard deviation from the mean. For the [normal distribution](#), this accounts for 68.27% of the set; while two standard deviations from the mean (medium and dark blue) account for 95.45%; and three standard deviations (light, medium, and dark blue) account for 99.73%. (wikipedia)

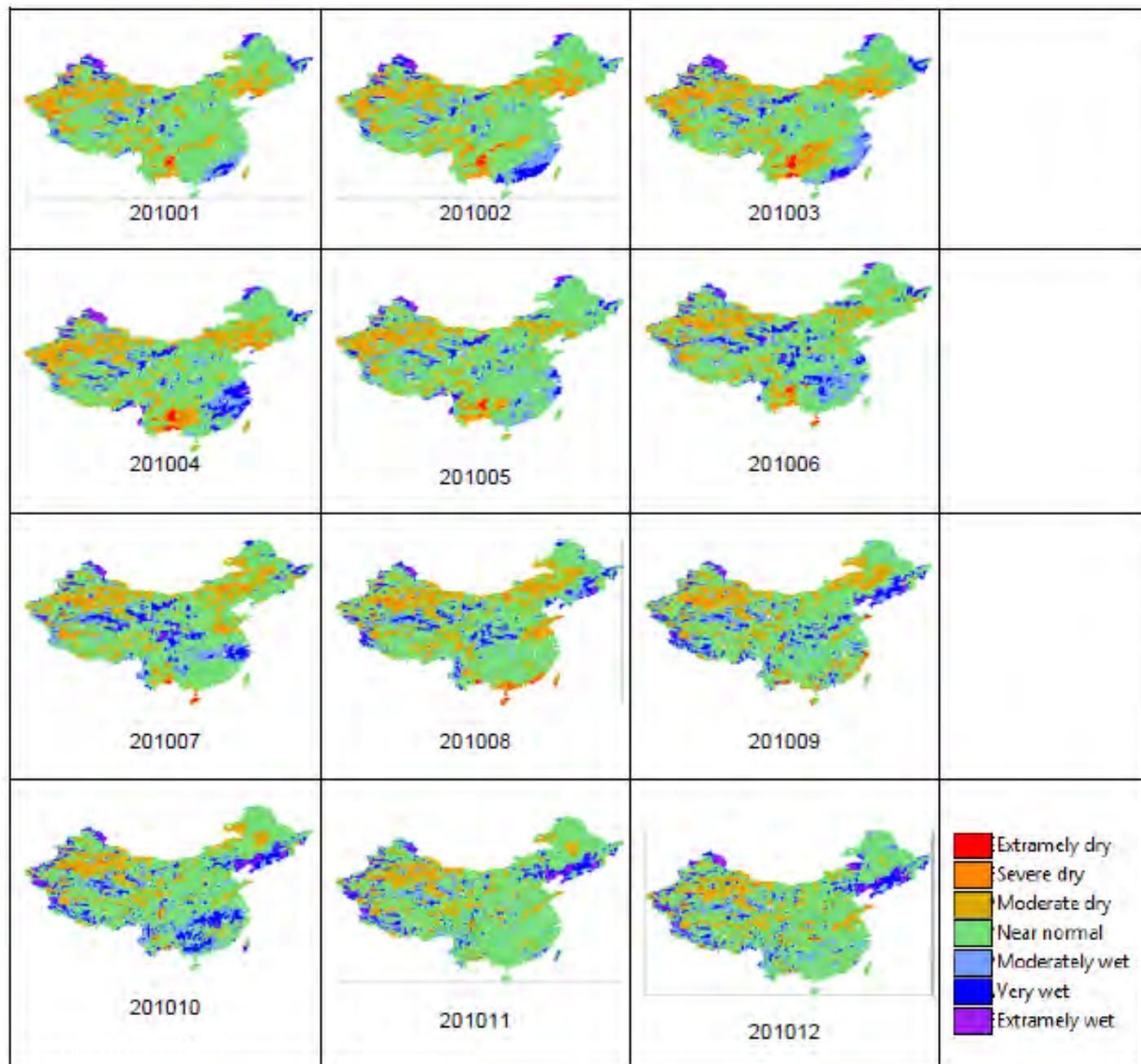
# How shall we define droughts?

The probability that a normal deviate lies in the range  $\mu - n\sigma$  and  $\mu + n\sigma$  is,

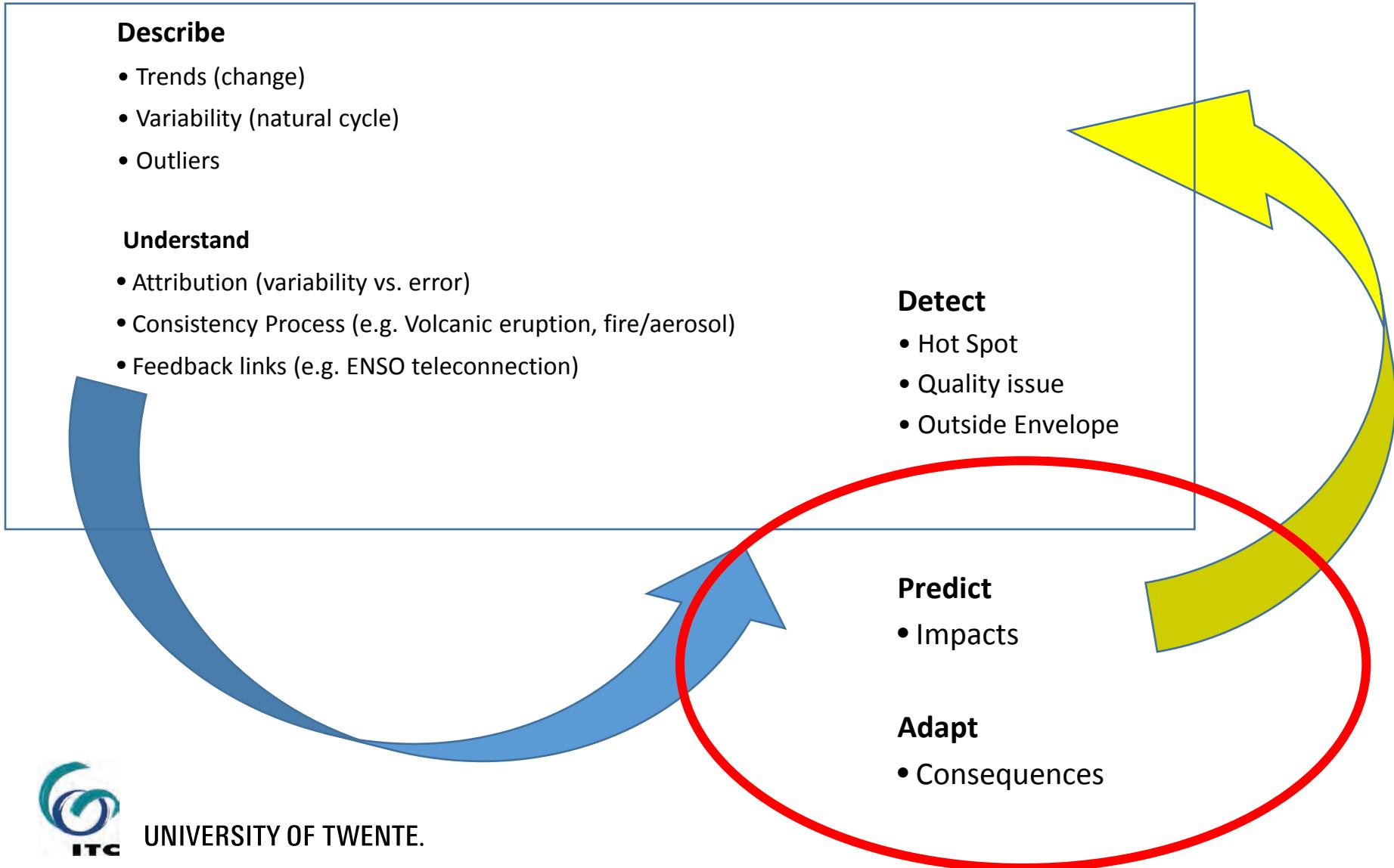
$$F(\mu + n\sigma) - F(\mu - n\sigma) = \Phi(n) - \Phi(-n) = \operatorname{erf}\left(\frac{n}{\sqrt{2}}\right),$$

$n$	$F(\mu+n\sigma) - F(\mu - n\sigma)$	i.e. 1 minus ...	or 1 in ...
1	0.682 689 492 137	<b>Value range</b>	<b>category</b>
2	0.954 499 736 104	$\mu - 1\sigma < F > \mu + 1\sigma$	Near normal
		$\mu - 2\sigma < F \leq \mu - 1\sigma$	Moderately dry
		$\mu - 3\sigma < F \leq \mu - 2\sigma$	Severely dry
		$F \leq \mu - 3\sigma$	Extremely dry
		$\mu + 1\sigma \leq F < \mu + 2\sigma$	Moderately wet
		$\mu + 2\sigma \leq F < \mu + 3\sigma$	Severely wet
		$\mu + 3\sigma \leq F$	Extremely wet

# GLDAS derived Standardized total water storage index – drought situation

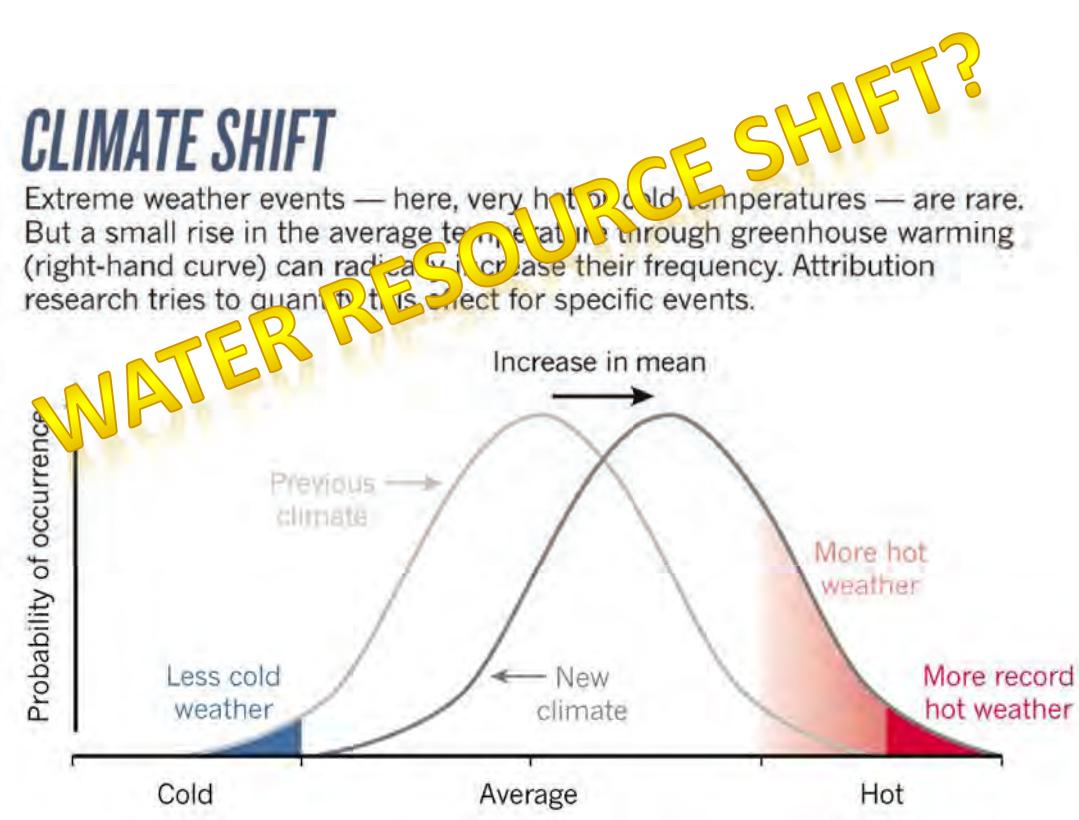


# A Roadmap From Process Understanding To Adaptation



# Impacts and projections in water resources

- Q1: *What are observed impacts to water resources in Yangtze due to climate and human changes ?*
- Q2: *Will the changes in the Yangtze River Basin influence the East Asian monsoon patterns?*
- Q3: *What will be the spatial/temporal distribution of water (sediment) resources in 21st century ?*



# Yes, it is water availability!



# Referances/Further Readings

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