Drought Monitoring and Assessment

Professor Bob Su
ITC, University of Twente, The Netherlands
z.su@utwente.nl

ESA–MOST China Dragon 4 Cooperation

2019 ADVANCED INTERNATIONAL TRAINING COURSE IN LAND REMOTE SENSING

中欧科技合作“龙计划”第四期 2019年陆地遥感高级培训班

18 to 23 November 2019 | Chongqing University, P.R. China

培训时间:2019 年11月18日-23日 主办方:重庆大学

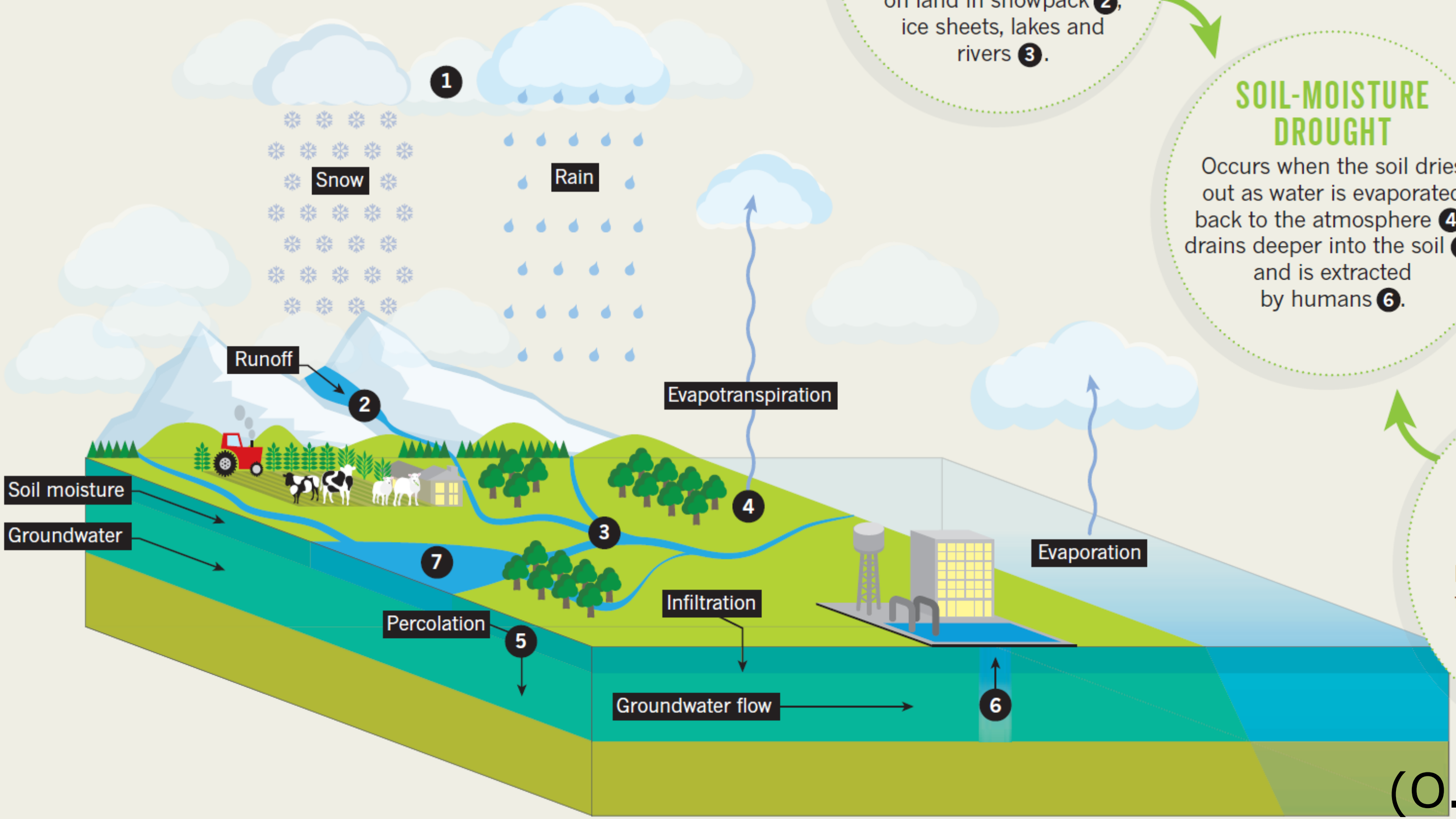
What is the difference?

Learning Objectives

1. Comprehend basic ideas for estimating water availability
2. Be able to identify methods & data products for deriving different water availability terms
3. Familiarize with the applications in drought monitoring and assessment

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.



METEOROLOGICAL DROUGHT

Occurs when a persistent decline in 1 precipitation reduces the water available on land in snowpack 2, ice sheets, lakes and rivers 3.

Meteorological drought causes both soil-moisture and hydrological drought.

SOIL-MOISTURE DROUGHT

Occurs when the soil dries out as water is evaporated back to the atmosphere 4, drains deeper into the soil 5 and is extracted by humans 6.

HYDROLOGICAL DROUGHT

Occurs when water reserves in aquifers, lakes and reservoirs 7 fall below average levels owing to high human demand or low rainfall.

(O. Heffernan)

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.

4,200 YEARS AGO

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.

1876–78

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^2.

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.

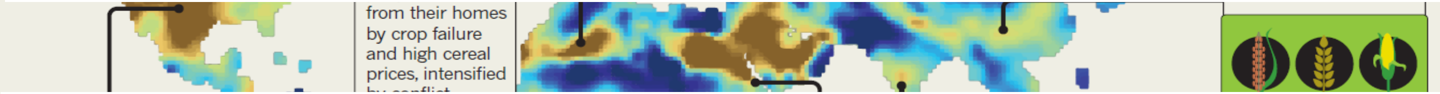
(O. Heffernan)

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 —

How the 'Indian Ocean Dipole' Climate Phenomenon Has Shaped East Africa's Severe Drought

The climate phenomenon is often called the Indian Niño due to its similarity with El Niño.



Climate Change Is Sending Africa's Agriculture Crisis Into a Tailspin

East Africa is already the hungriest place on Earth, and climate change threatens to compound its problems by raising temperatures and disrupting the seasonal rains.

(O. Heffernan)

What Is Drought and How To Detect It?

Drought may be defined as the **lack of water of a certain location in a certain period** compared to a **climatic average**.

From a climatic perspective, we may distinguish **meteorological**, **soil moisture** and **hydrological drought.**

What Is Drought And How To Detect It?

- **Meteorological drought** refers to a shortage of precipitation compared to a climatic average.
- **Soil moisture drought** can be caused by a shortage of precipitation, excessive evaporation and transpiration due to dry weathers and lack of irrigation.
- **Hydrological drought** is caused by a combination of lack of precipitation and excessive use of available water resources.
- *When the impact of drought is also taken into consideration, four types of droughts are usually defined such as meteorological drought, agricultural drought, hydrological drought and* ***socioeconomic drought****.*

Remote Sensing Provides Real-time Spatial Observations

Assessment and monitoring of drought characteristics:

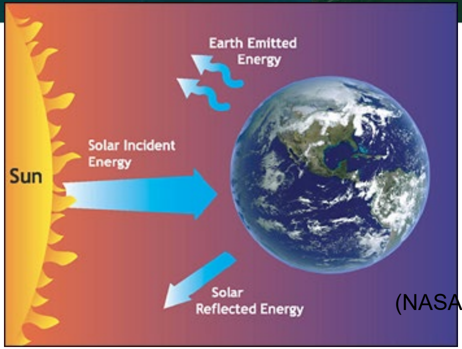
its **intensity, duration and spatial extent** in terms of:

atmospheric and land surface variables - **precipitation, evapotranspiration, soil moisture and vegetation conditions**

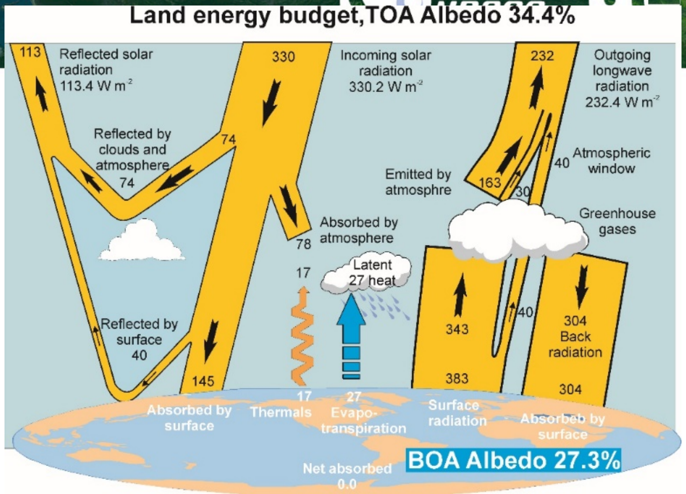
Prediction of drought:

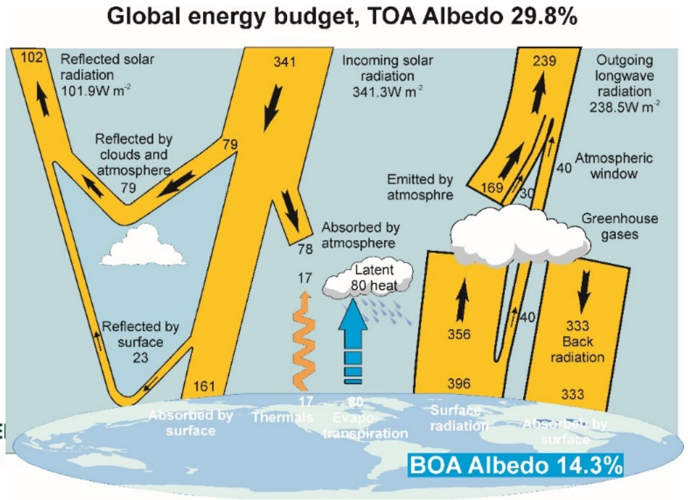
Spatial observations coupled to modelling and forecasting of the water cycle -> information on **future drought** for drought preparedness

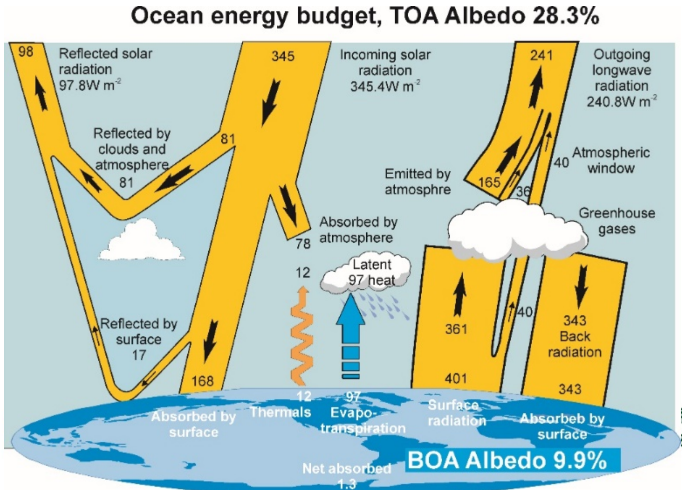
Let there be light



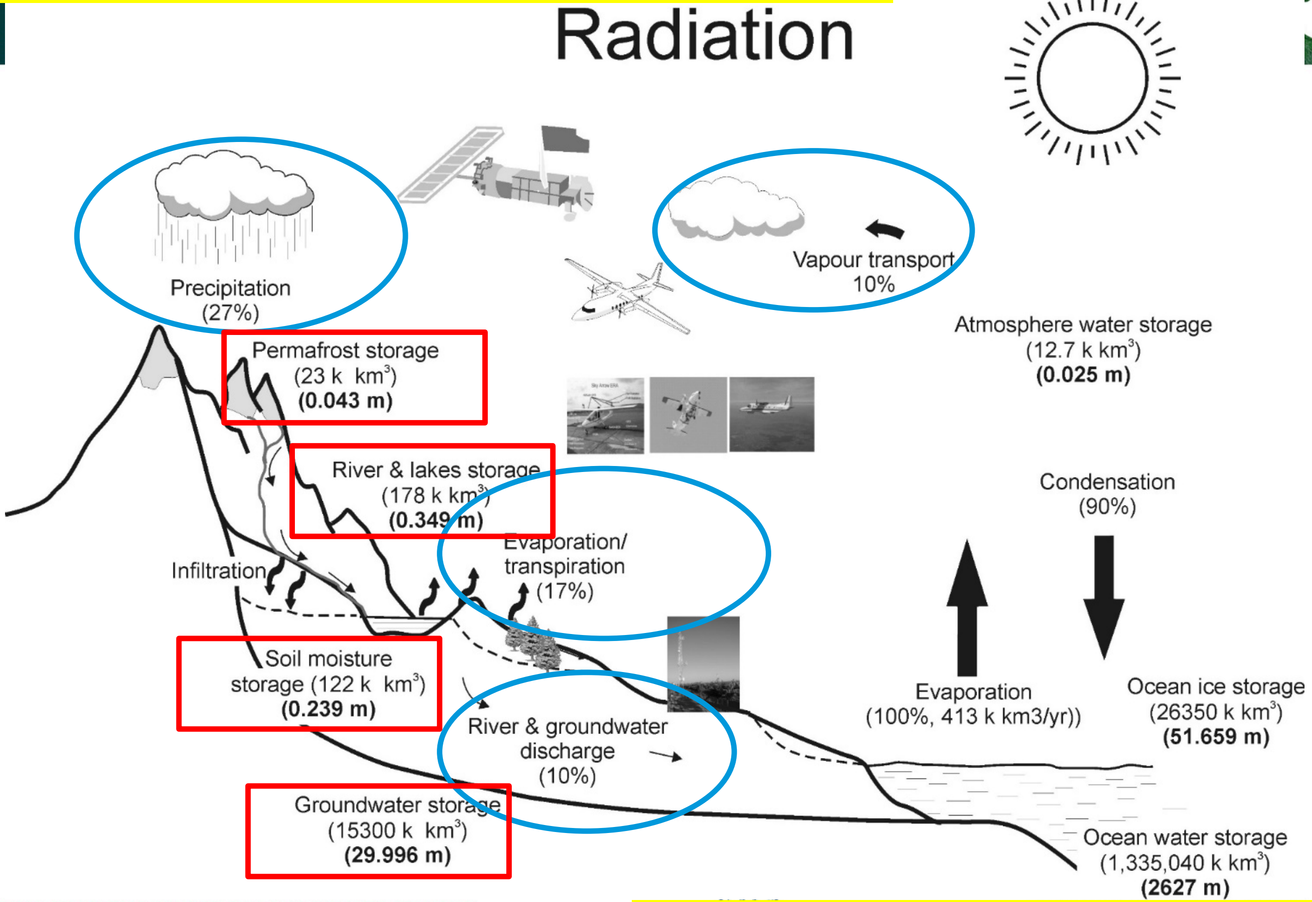
(NASA)







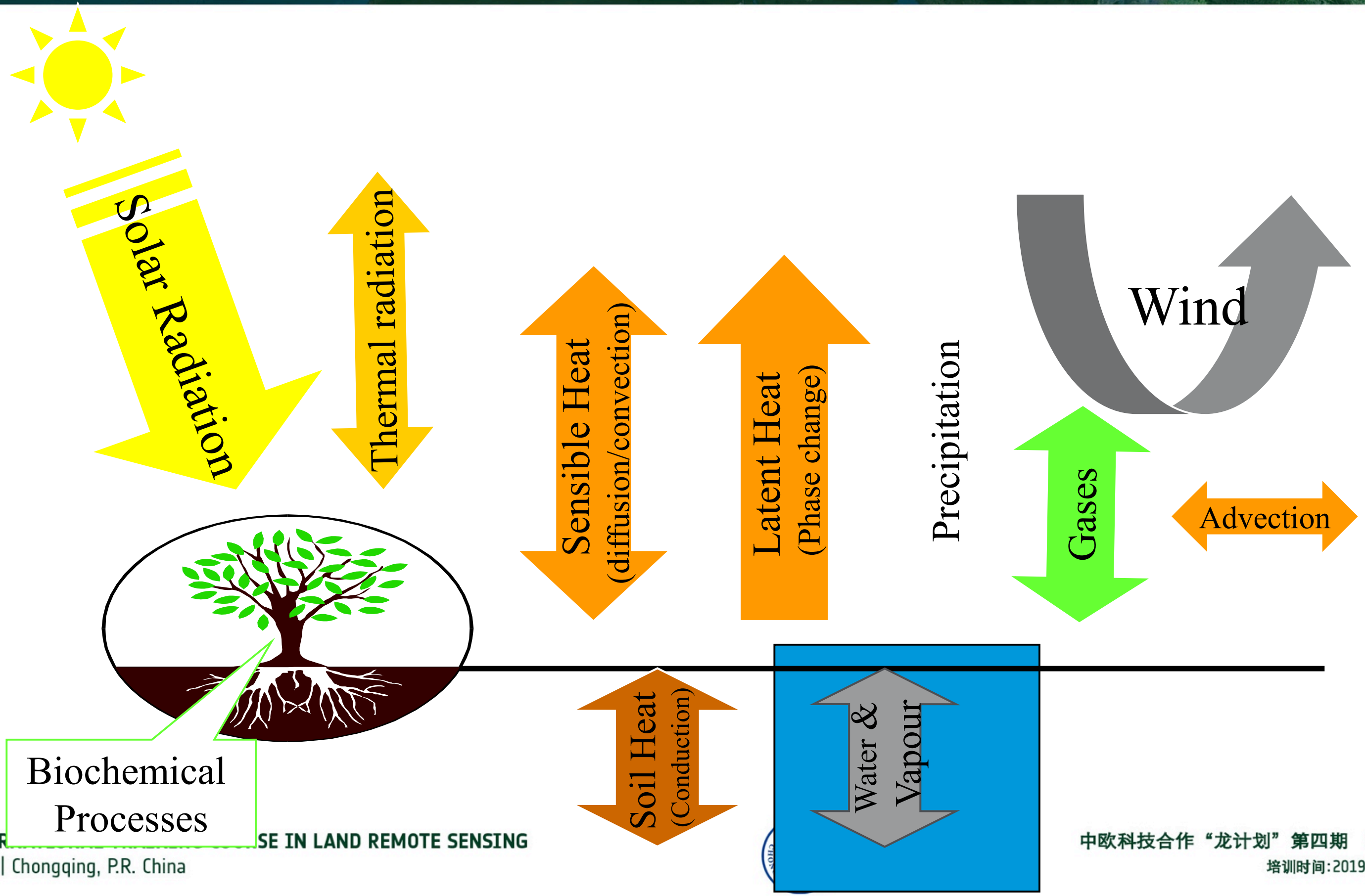
Water cycle and its link to climate



(Su et al., 2010, Treatise on Water Science)

Land-Atmosphere Interactions
- Terrestrial Water, Energy and Carbon Cycles

esa



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)

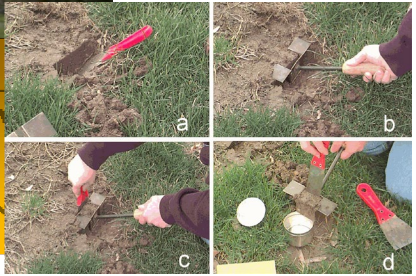
Reclamation Drought Index (RDI)

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.

What is Drought ?

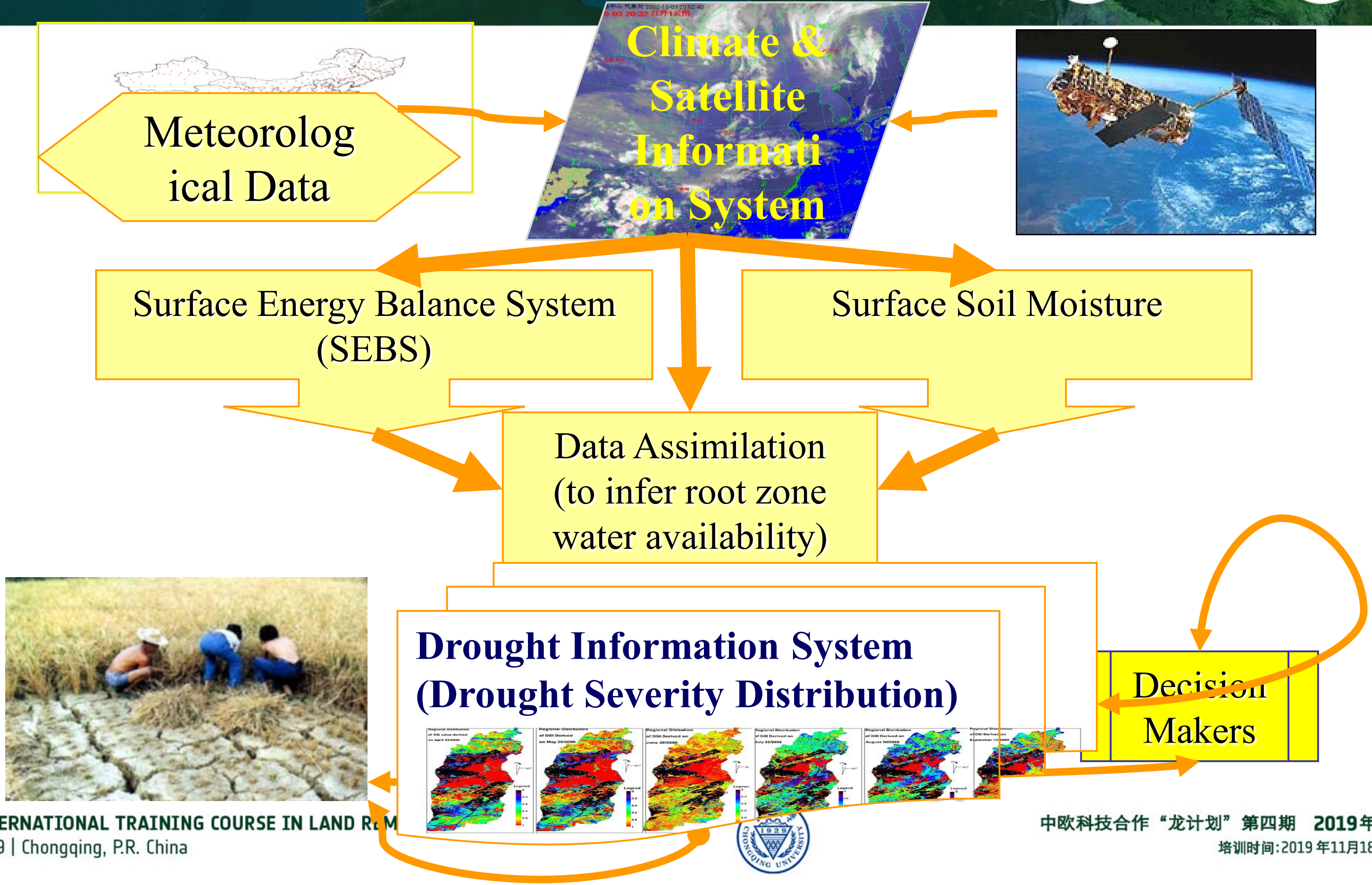
Dry Condition: No transpiration



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

$$\theta(t_2) - \theta(t_1) = P_0 + I_0 + I_c - E$$

$$E_{dry} \sim \theta_{dry}$$

$$E_{wet} \sim \theta_{wet}$$

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

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

R: Relative Plant Available Soil Water Content

DSI: Drought Severity Index

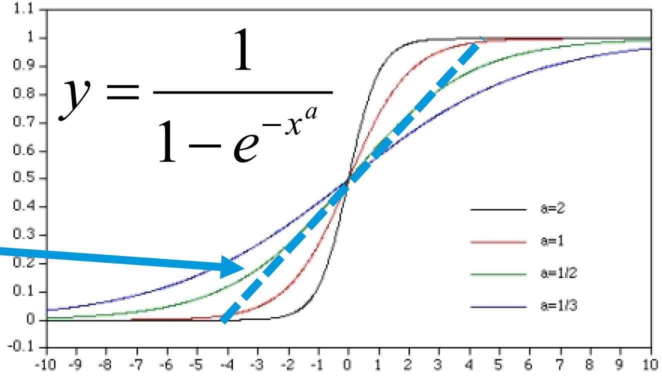
(Su et al., 2003, PCE)

Relationship between evaporative fraction to surface variables (albedo, fractional vegetation coverage and surface temperature) -> root zone soil moisture

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

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

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

The SEBS algorithm (Su, 2002, HESS)

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

The surface-air potential temperature difference is given as

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

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

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

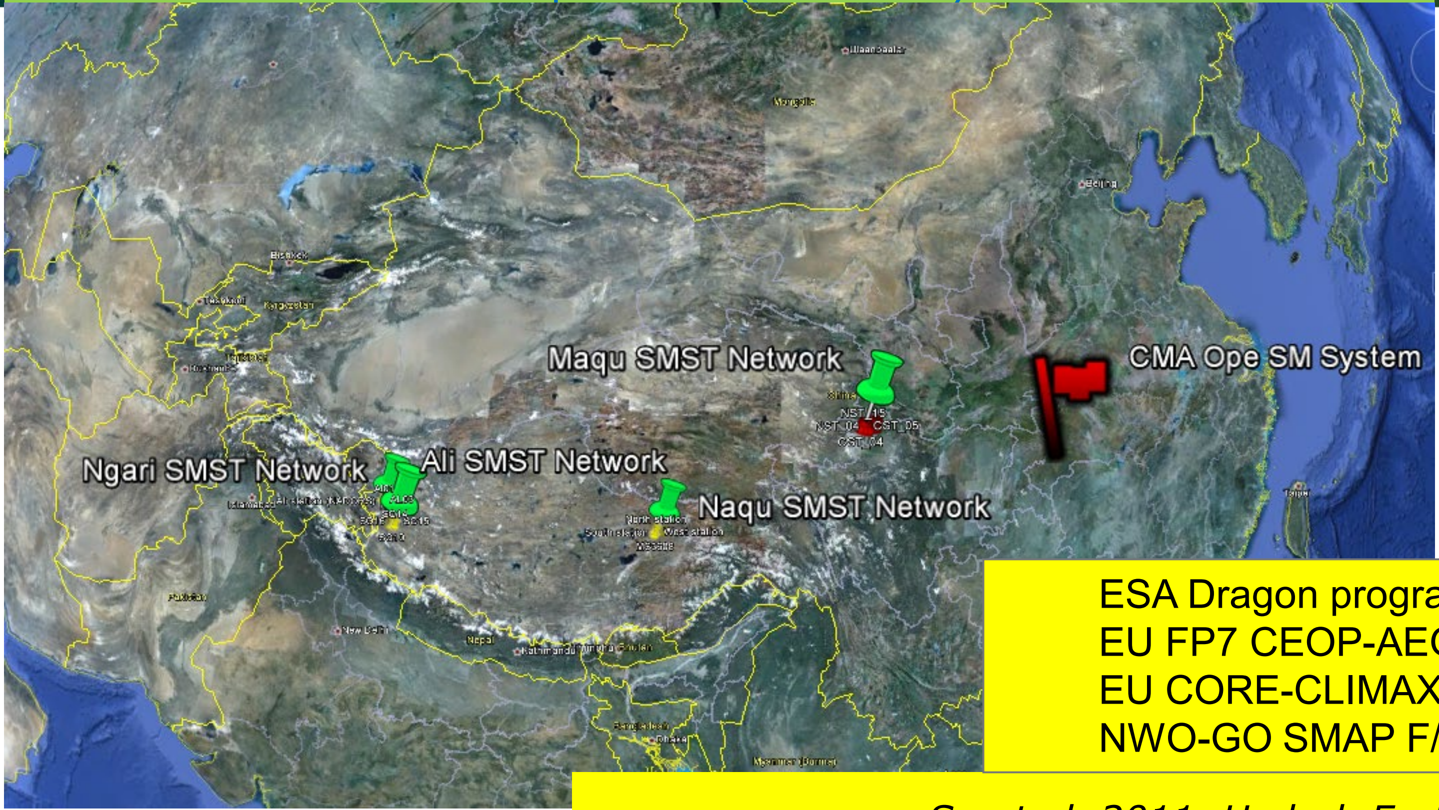
Normalized temperature difference versus albedo

Q&A:

What else shall we do?

What other information can we use?

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

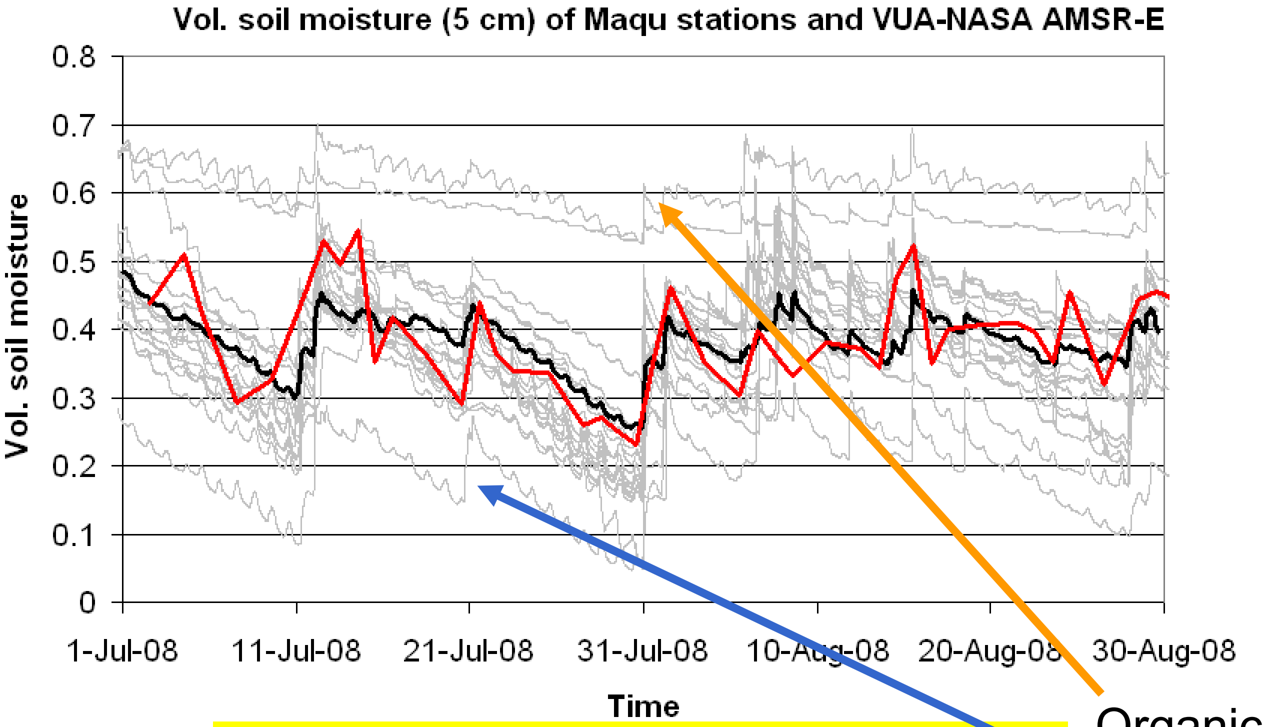


ESA Dragon programme
EU FP7 CEOP-AEGIS
EU CORE-CLIMAX
NWO-GO SMAP F/T

Su et al. 2011, Hydrol. Earth Syst. Sci.

www.hydrol-earth-syst-sci.net/15/2303/2011/

Preliminary validation results



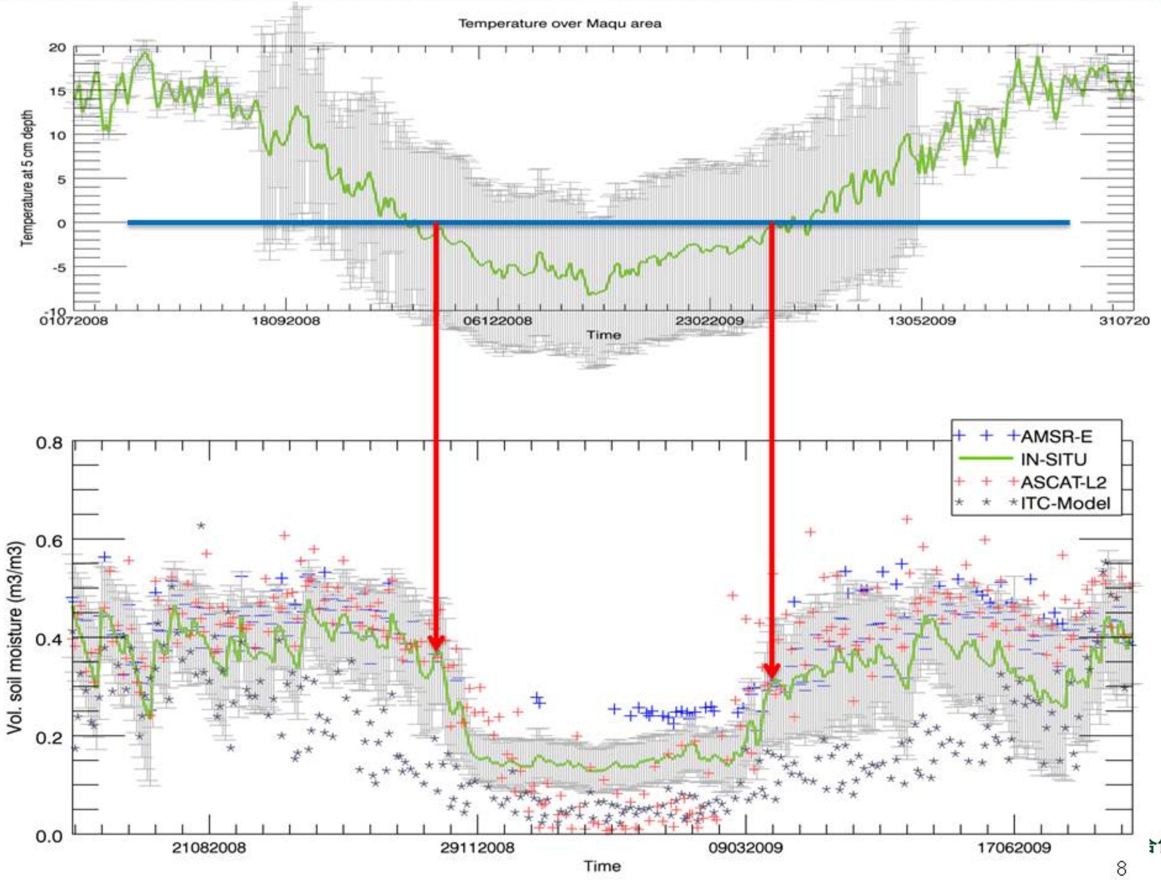
Mean sm at Maqu site (depth of 5 cm)

VUA-NASA sm from AMSR-E data

Organic soils

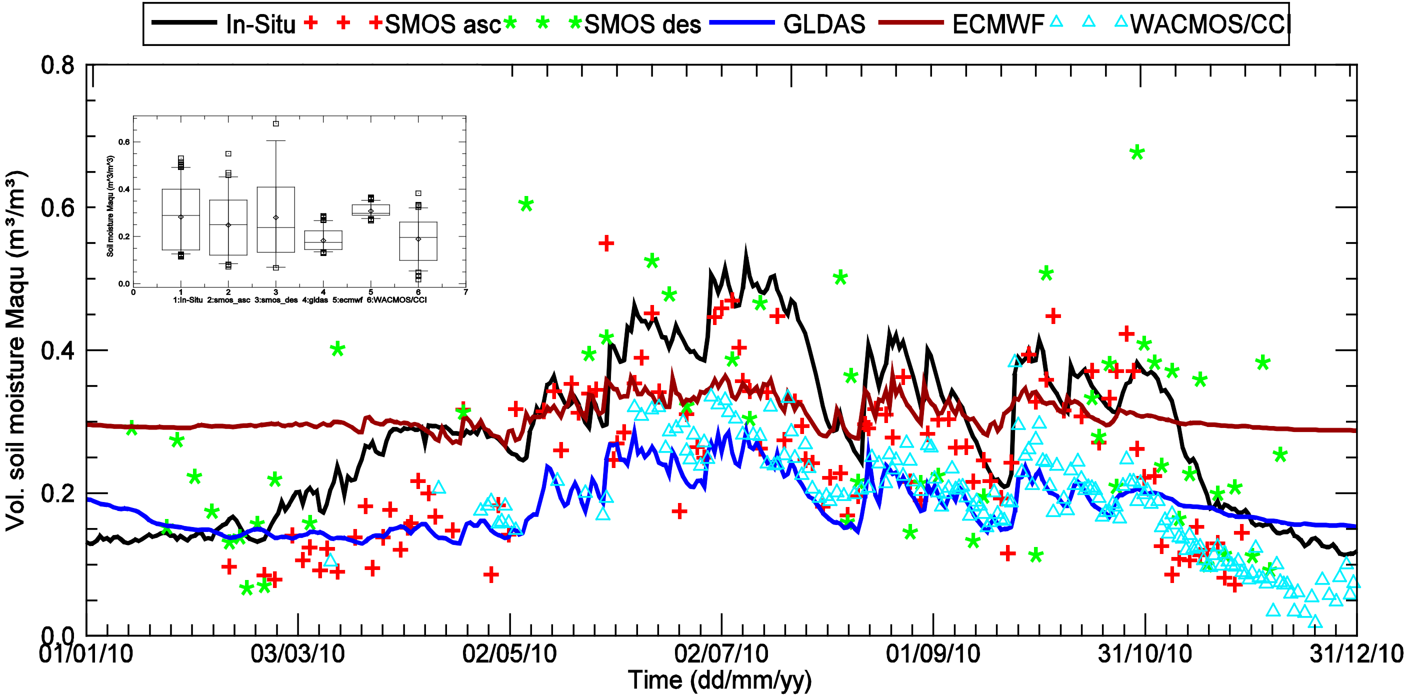
Sandy loam soil

Quantification of uncertainties in global products

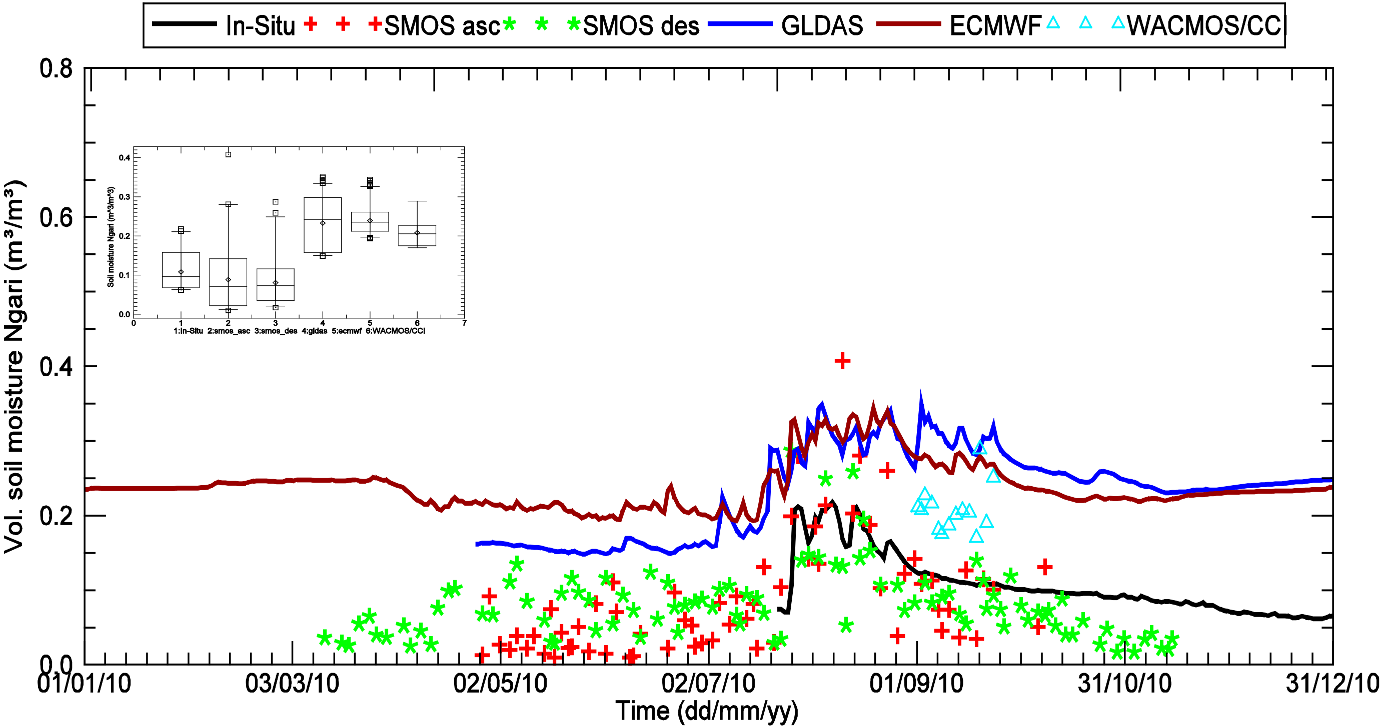


(Su et al., 2011, HESS)

Maqu SMST Network – validation results



Ngari SMST Network – validation results



Q/A: any other way to combine information?

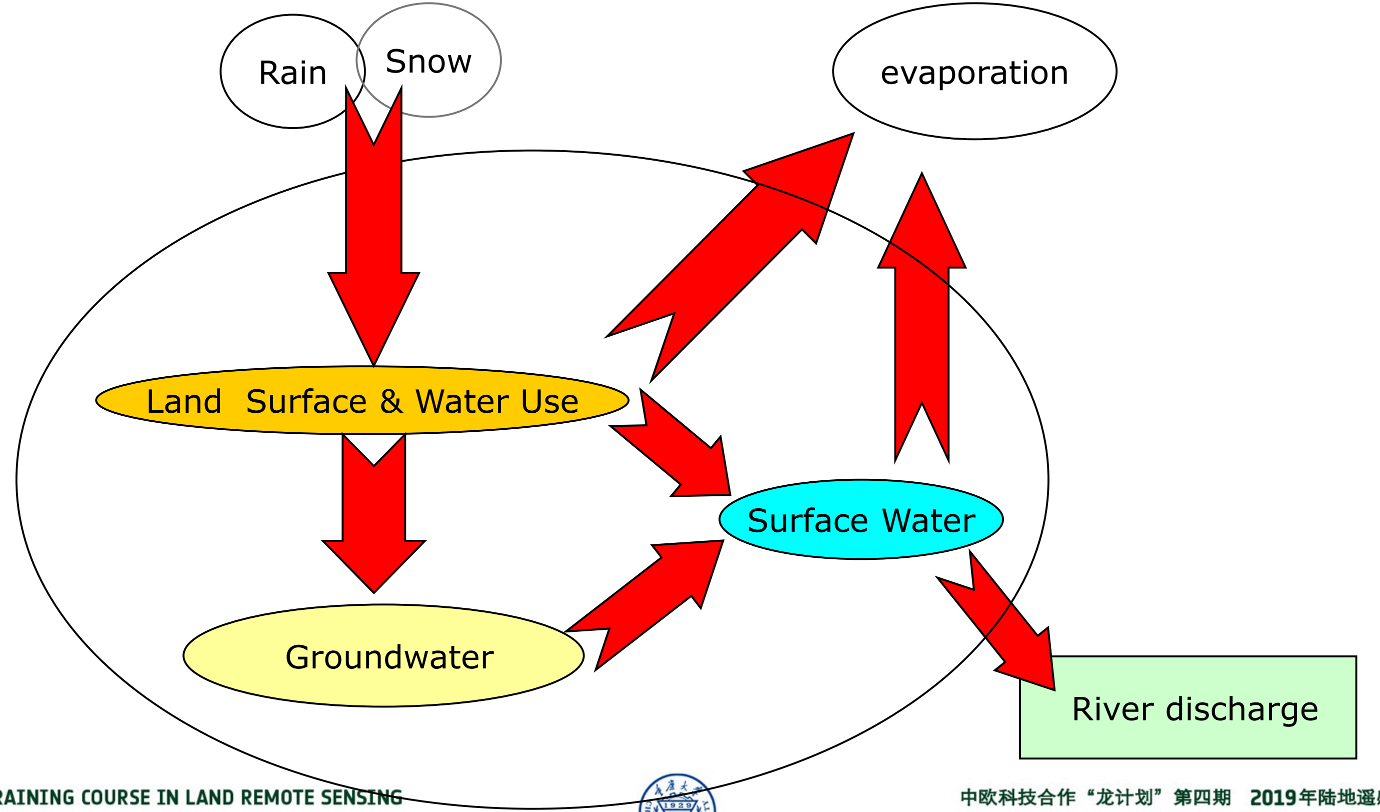
HOW CAN WE USE THIS INFORMATION FOR DROUGHT MONITORING AND PREDICTION?

WACMOS.org

wacmos

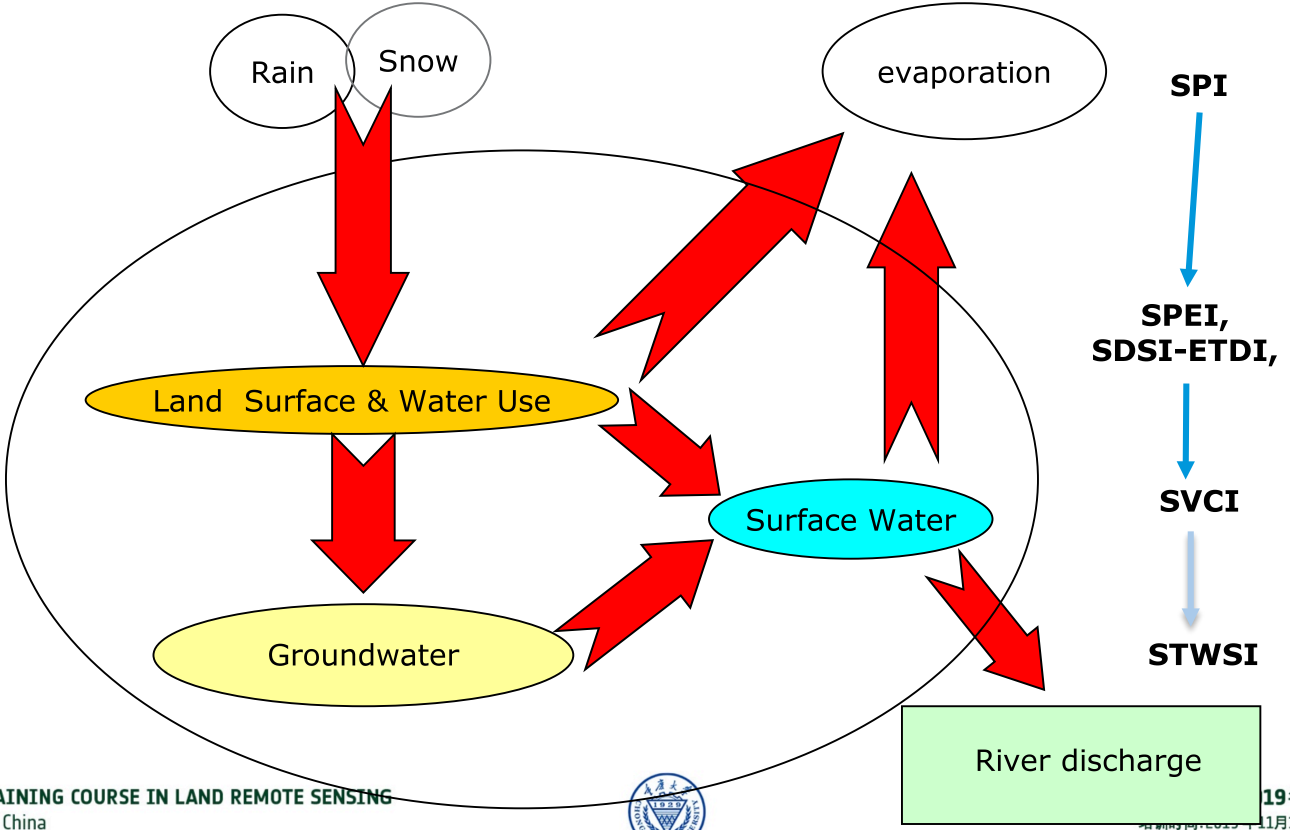
support to science element

Water Budget Closure



Q/A: how to put up a real time system?
How do we decide if there is a drought?

Water Budget Closure



Standardized Indices

SPI: Standardized Precipitation Index,

SPEI: Standardized Precipitation Evaporation Index,

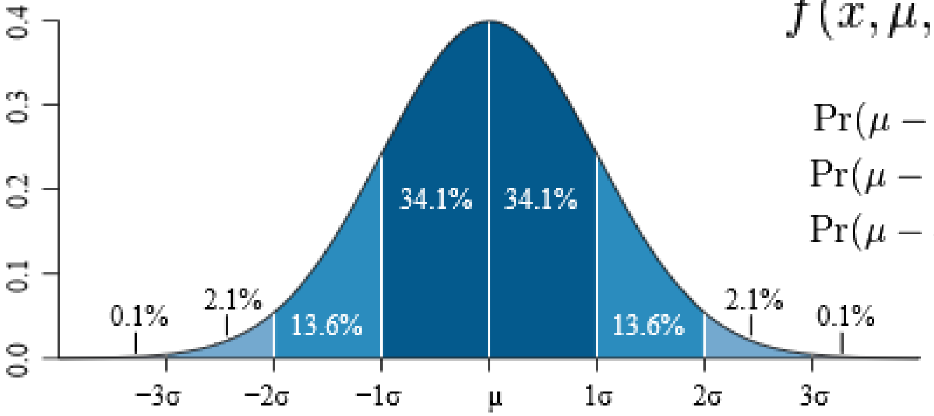
SDSI-ETDI: the Standardized Drought Severity Index-Evapotranspiration Deficit Index,

SVCI: Standardized Vegetation Condition Index,

STWSI: the Standardized Terrestrial Water Storage Index

- all calculated on weekly or monthly time interval from 1 to N time intervals (e.g. for 48 months) (i.e. as anomalies and cumulative anomalies)

How shall we define droughts?



$$f(x,\mu,\sigma) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$

$$\Pr(\mu - \sigma \le x \le \mu + \sigma) \approx 0.6827$$
$$\Pr(\mu - 2\sigma \le x \le \mu + 2\sigma) \approx 0.9545$$
$$\Pr(\mu - 3\sigma \le x \le \mu + 3\sigma) \approx 0.9973$$

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?

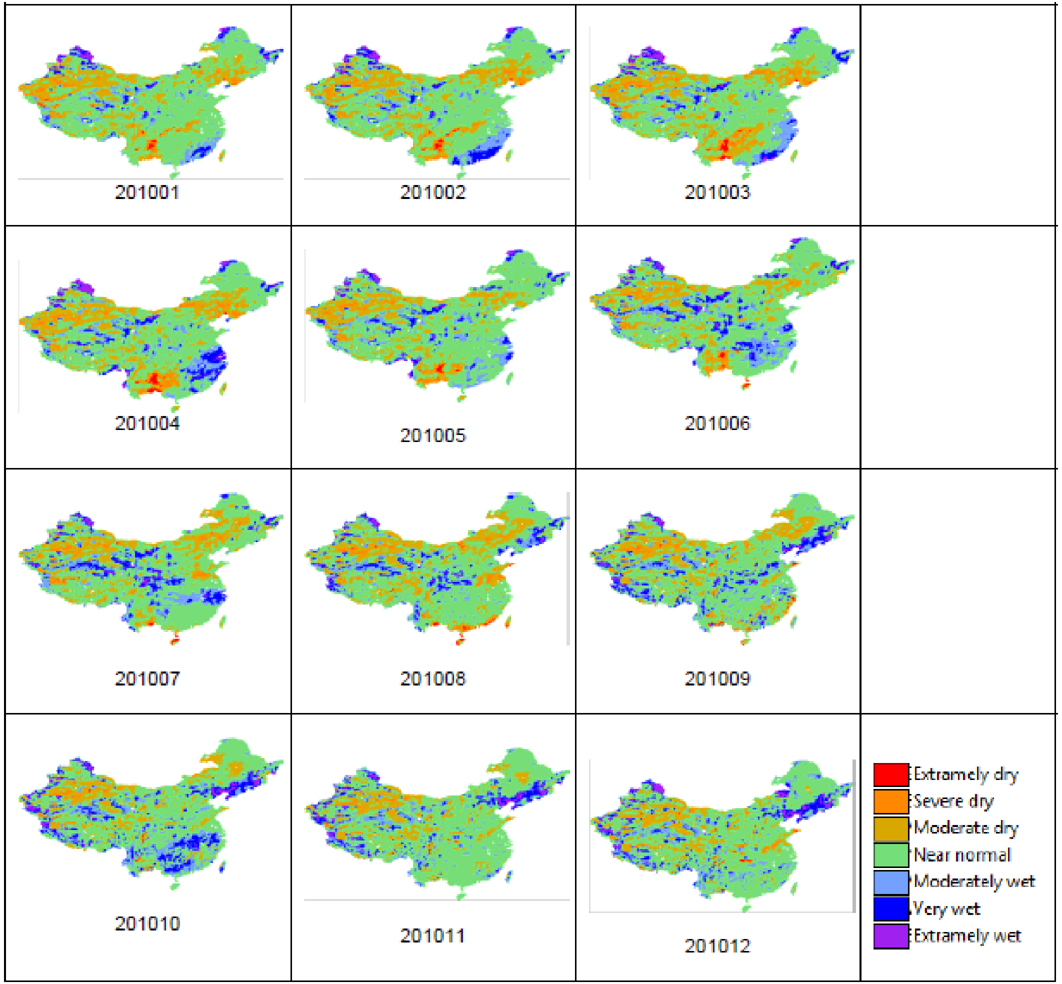
The probability that a normal deviate lies in the range $\mu - n\sigma$ and $\mu + n\sigma$ is,

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

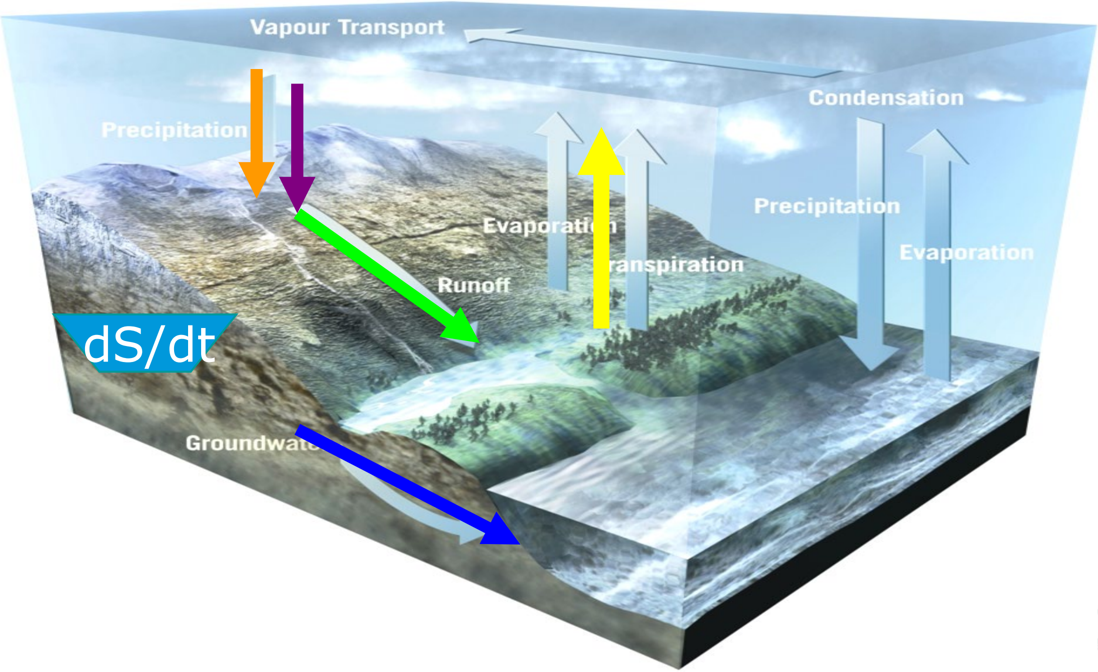
Value range	category
$\mu - 1\sigma$ < F > $\mu + 1\sigma$	Near normal
$\mu - 2\sigma$ < F <= μ-1σ	Moderately dry
$\mu - 3\sigma$ < F <= μ-2σ	Severely dry
F <= μ-3σ	Extremely dry
$\mu + 1\sigma$ <= F < $\mu + 2\sigma$	Moderately wet
$\mu + 2\sigma$ <= F < $\mu + 3\sigma$	Severely wet
$\mu + 3\sigma$ <= F	Extremely wet

i.e. 1 minus …	or 1 in …
0.317 310 507 863	3.151 487 187 53
0.045 500 263 896	21.977 894 5080
0.002 699 796 063	370.398 347 345
0.000 063 342 484	15 787.192 7673

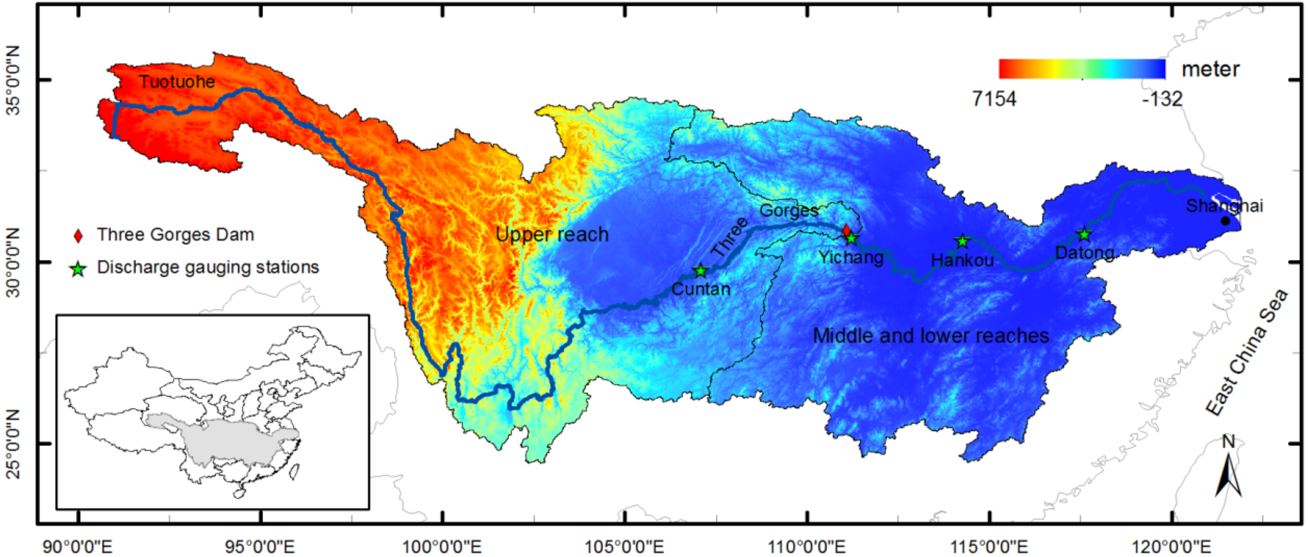
GLDAS derived Standardized total water storage index – drought situation



What is consistency among different physically interrelated variables (Spatial Water budget of the Yangtze River Basin)



Yangtze River Basin



- Upper Yangtze reach, from Tuotuohe, to Yichang.
- Middle reach from Yichang to Hukou.
- Lower reach extends from Hukou to the river mouth near Shanghai.
- Cuntan, Yichang, Hankou, and Datong are four gauging stations located along the mainstream of the Yangtze.

Closure of Water Cycle over a river basin

Total water Storage(TWS)

$$\frac{\partial S}{\partial t} = P_{GPCP} - E_{SEBS} - R_{Obs} * f(P_{i,j}, E_{i,j})$$

For this study we used the following datasets.

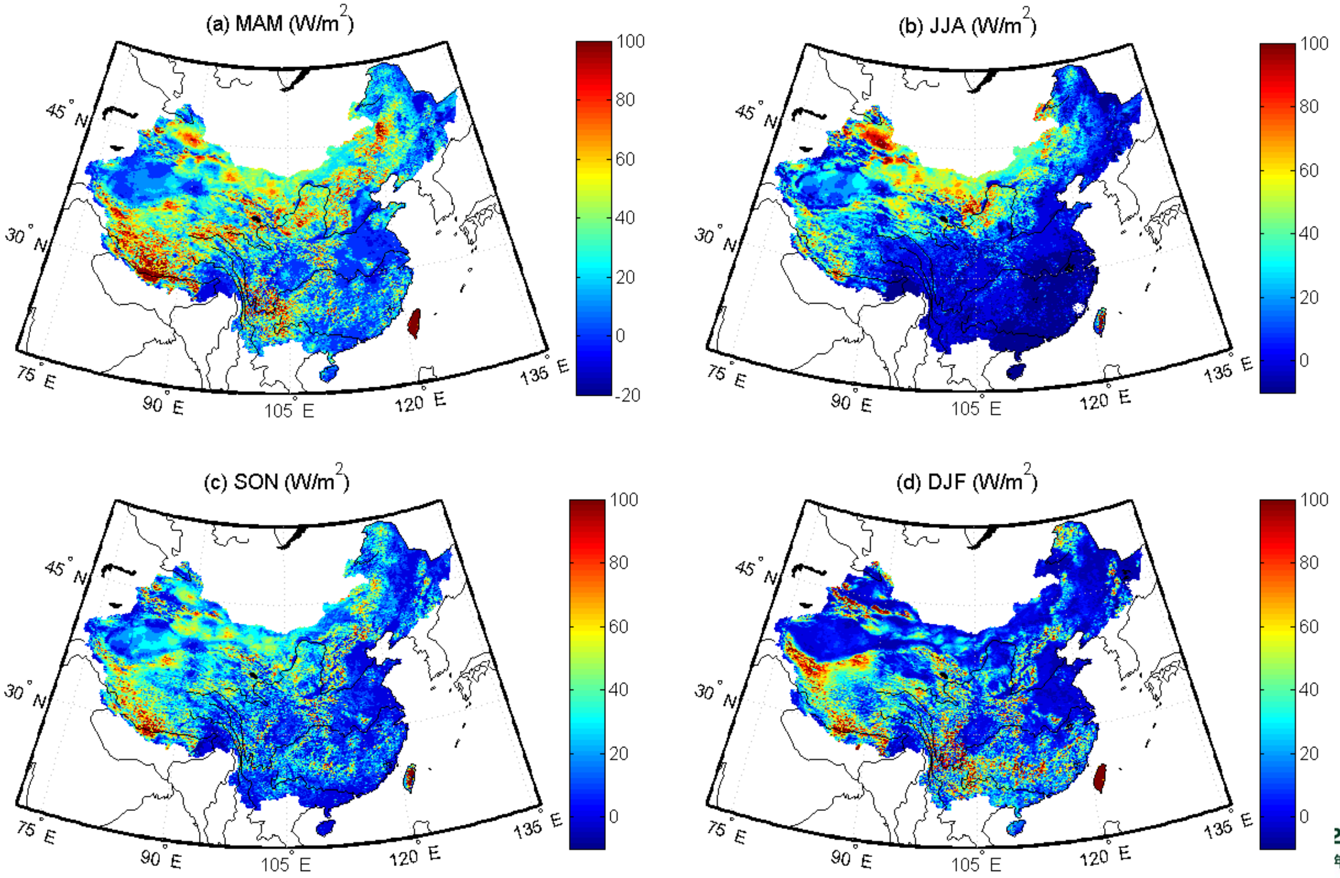
GPCP: Global Precipitation Climatology Project (P),
SEBS: SEBS derived land evaporation (E),
In-situ: River discharges (R),

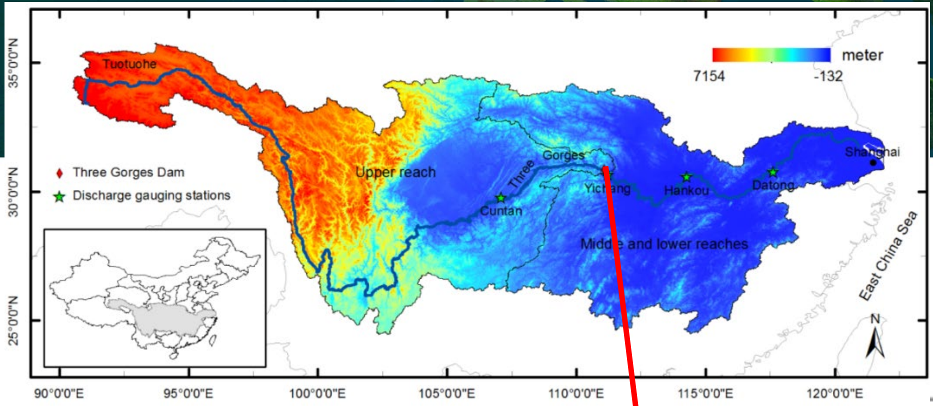
In-situ & satellite Observations

REA-Interim: ECMWF reanalysis (P, E, R), → **Reanalysis**

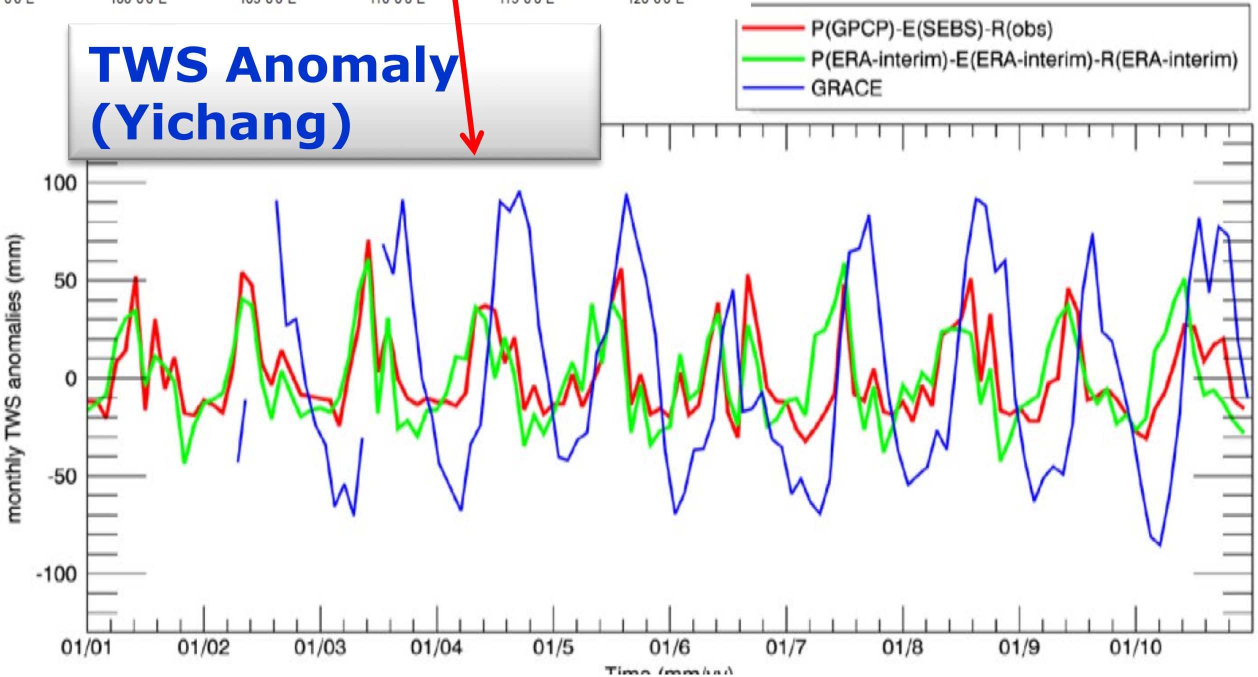
Storage change: The Gravity Recovery and Climate Experiment (GRACE) observations (dS/dt). → **Satellite Observations**

Seasonal average maps of sensible heat flux (H)
(a) Mar-May, (b) Jun-Aug,(c) Sep-Nov, (d) Dec-Feb

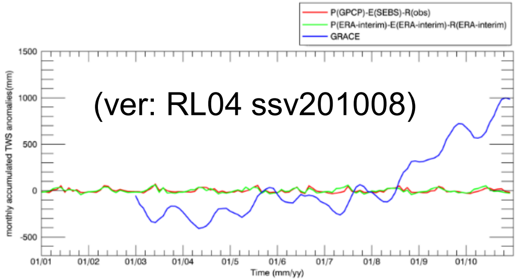


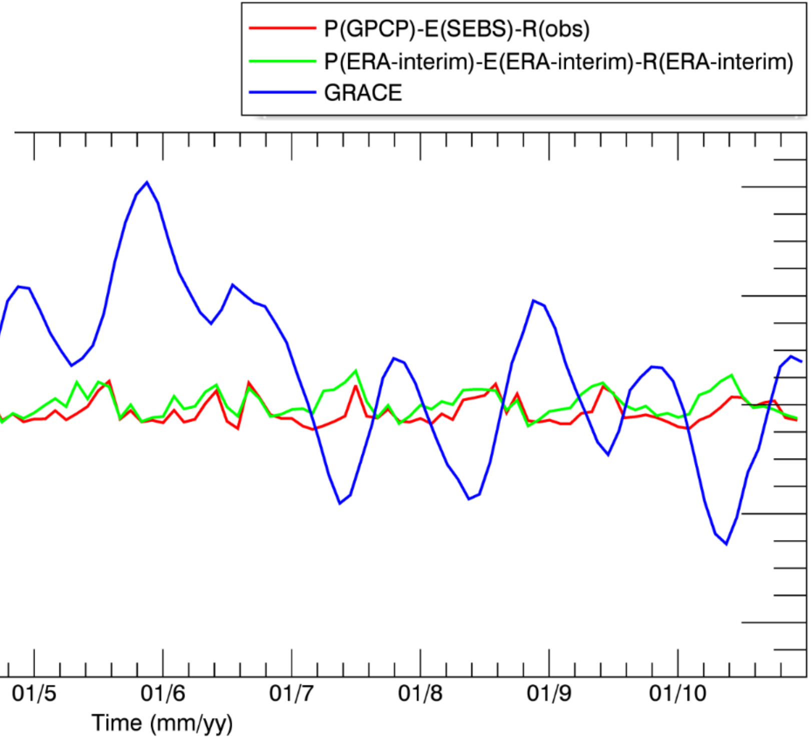


TWS Anomaly (Yichang)



Cumulative TWS anomaly at Upper Reach (Yichang station)





GRACE data
(ver: RL05.DSTvSCS1401)

UNIVERSITY OF TWENTE.

MSc Thesis

Drought Monitoring And Assessment Using Remote Sensing

By: Peter Muiruri

WREM 2017/18

ITC FACULTY OF GEO-INFORMATION SCIENCE AND EARTH OBSERVATION

THE STANDARDIZED INDICES FRAMEWORK

SPI (McKee et al., 1993)

- Precipitation (P) is the only input, (+30yrs rainfall ideal)
- Multiscalar: staggered from 1-48months scale
- Precipitation record normalized using the Gamma PDF before transformation to a Gaussian multivariate

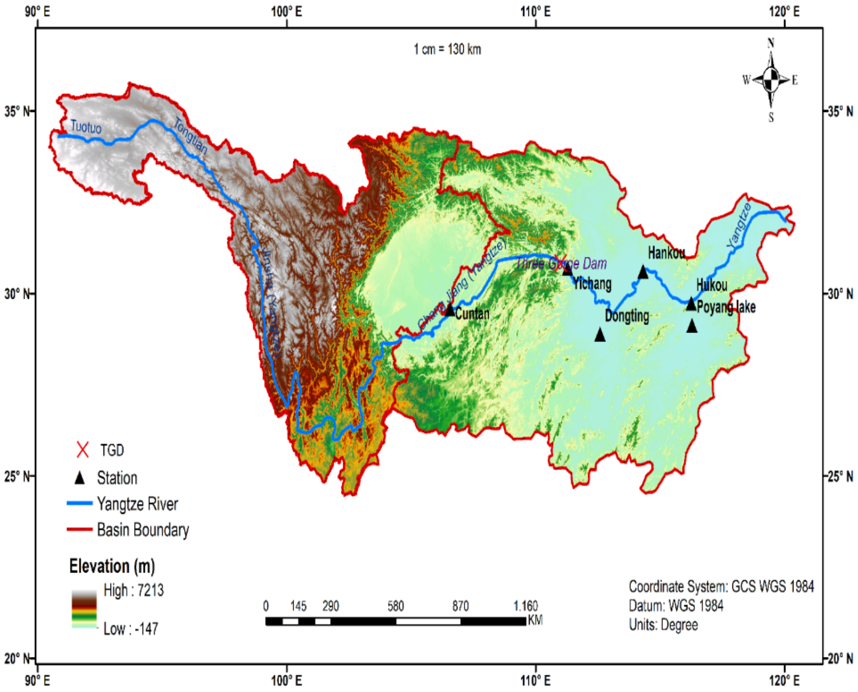
- **SPAEI (Homdee et al., 2016); substituted SPEI (Vincente-Serrano et al., 2010)**
  - Combines P and ETa; >Multiscalar
  - Normalized using the GEV PDF
- **SVI (Peters, 2002)**
  - NDVI values are standardized :

$$NDVI_{ijk} = \frac{NDVI_{ijk} - \overline{NDVI}_{ij}}{\sigma(ij)}$$

- **STWSI**
  - TWS standardized similarly as the SVI >Multiscalar

Sustained negative values show drought.

STUDY AREA- YANGTZE RIVER BASIN, CHINA

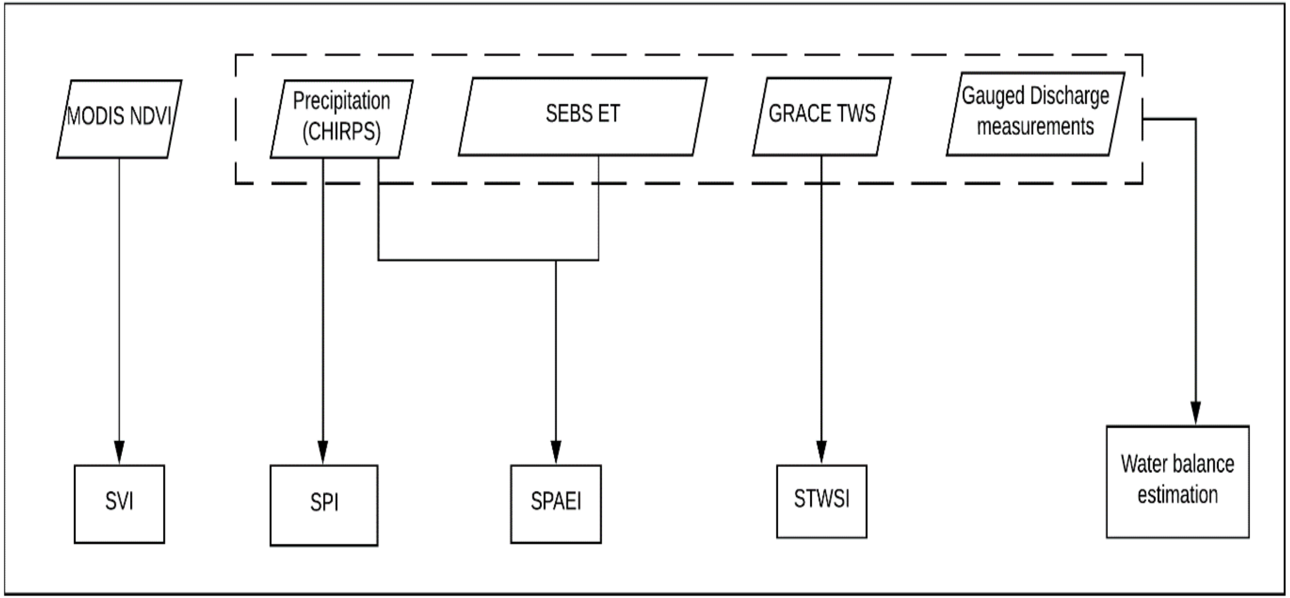


- River Yangtze sourced in the Qinghai-Tibetan Plateau.
- Flows 6300km eastwards to the sea.
- Cuntan forms the entrance to the 600km long Three Gorges Dam

DATA

	Product	Source	Period	Temporal	Spatial extent
1	Precipitation (P, mm)	CHIRPS	Jan 1981 –Aug 2017	Monthly	0.05°x 0.05°
2	Actual Evapotranspiration (ETa, mm)	SEBS	April 2000-July 2017	Monthly	0.05°x 0.05°
3	Gauged discharge measurements (m^3/s)	Yangtze River: Cuntan station	Jan 2005-Dec 2010	Monthly	Point data
4	Terrestrial water storage (TWS, mm)	GRACE Satellite	Apr 2002 – Dec 2017	Monthly	1°x 1°
5	Modis NDVI (MOD13C2.005)	USGS (LP DAAC) dataset discovery portal	Feb 2000-Aug 2017	Monthly	0.05°x 0.05°

METHODOLOGY

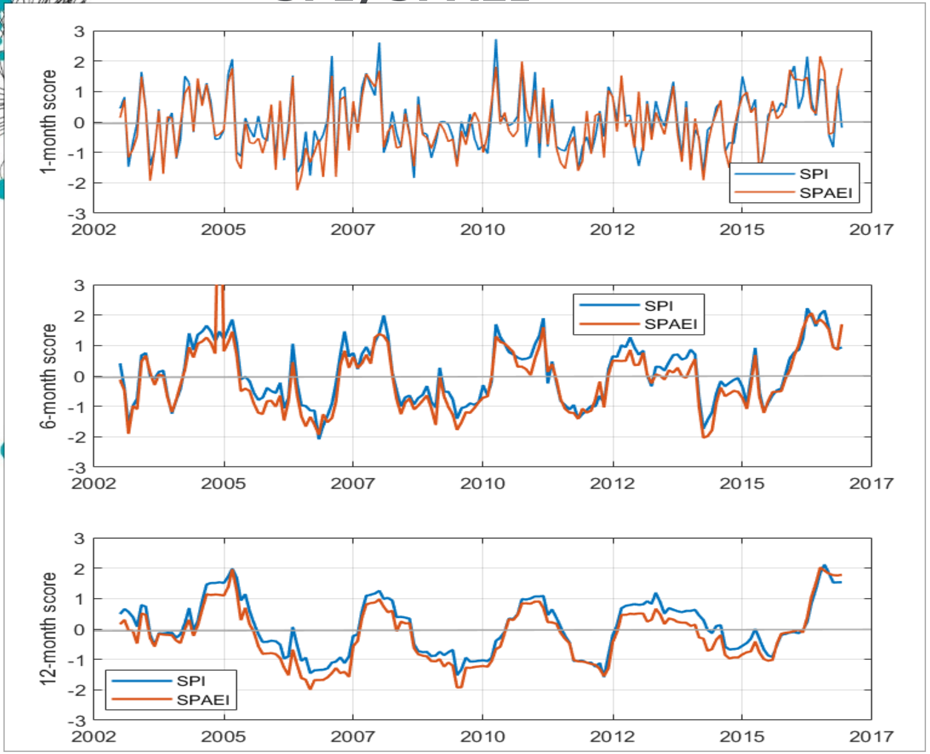


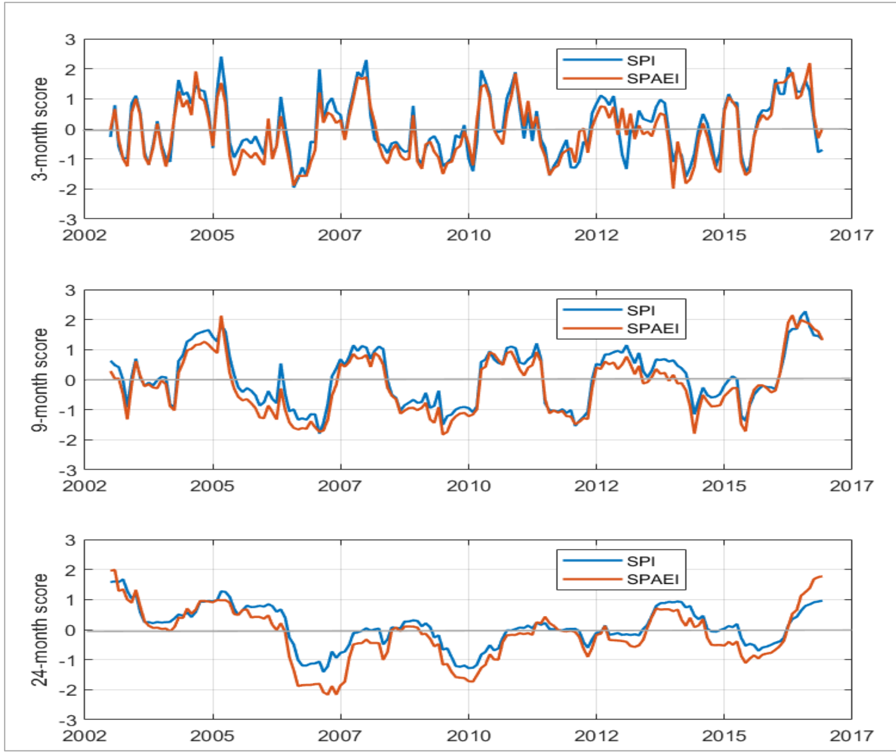
Calculate the SDI and estimate WB agreement

$$\frac{\Delta S}{\Delta t} = P - ET - R$$

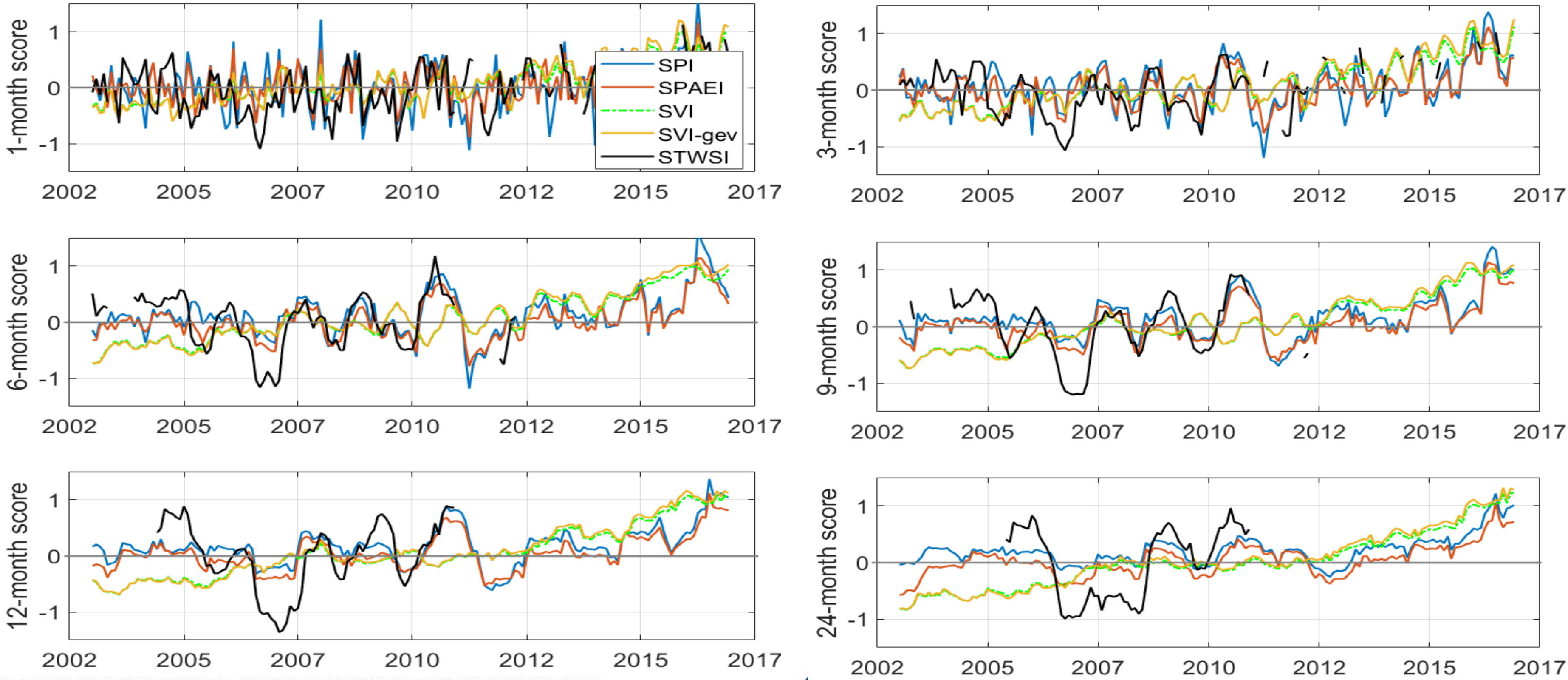
CONT.... CUNTAN AREA TIME SERIES

SPI/SPAEI

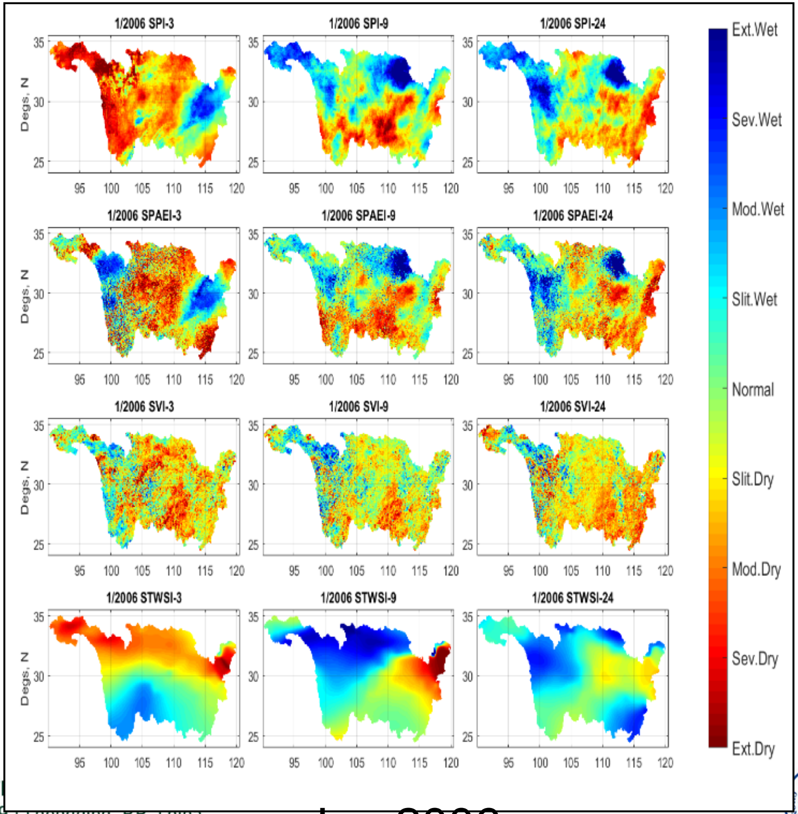




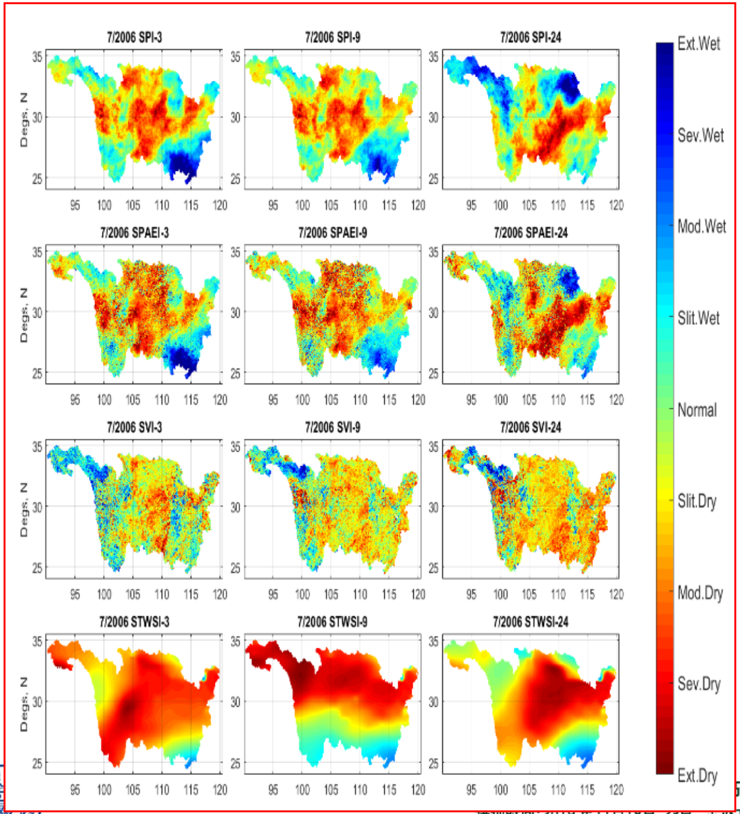
RESULTS BASIN MEAN TIME SERIES



TEMPORAL DROUGHT EVOLUTION IN 2006 & 2010

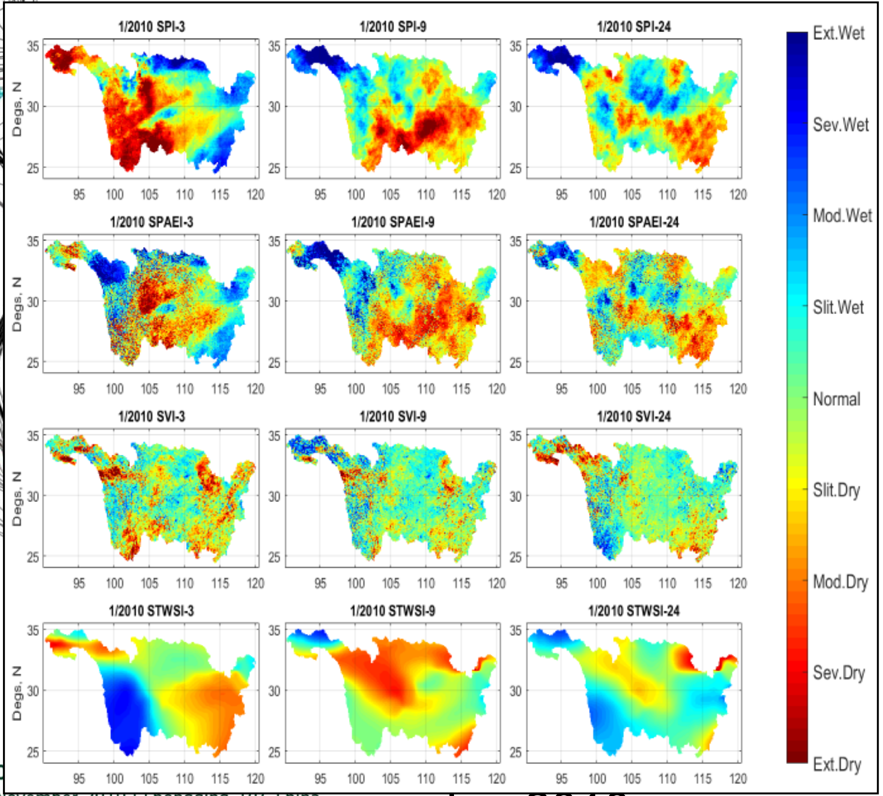


Jan 2006

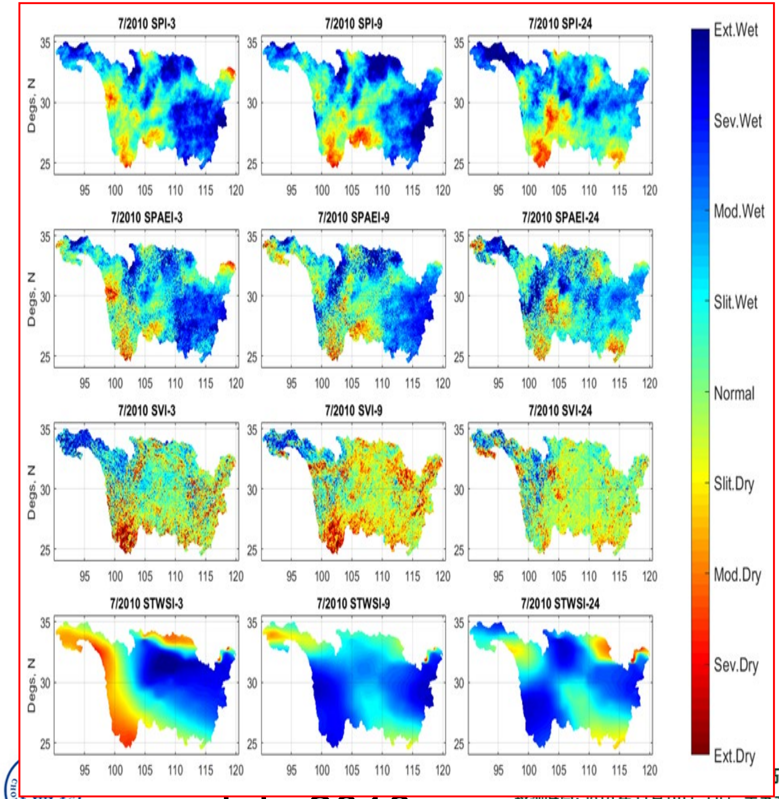


July 2006

TEMPORAL DROUGHT EVOLUTION IN 2006 & 2010

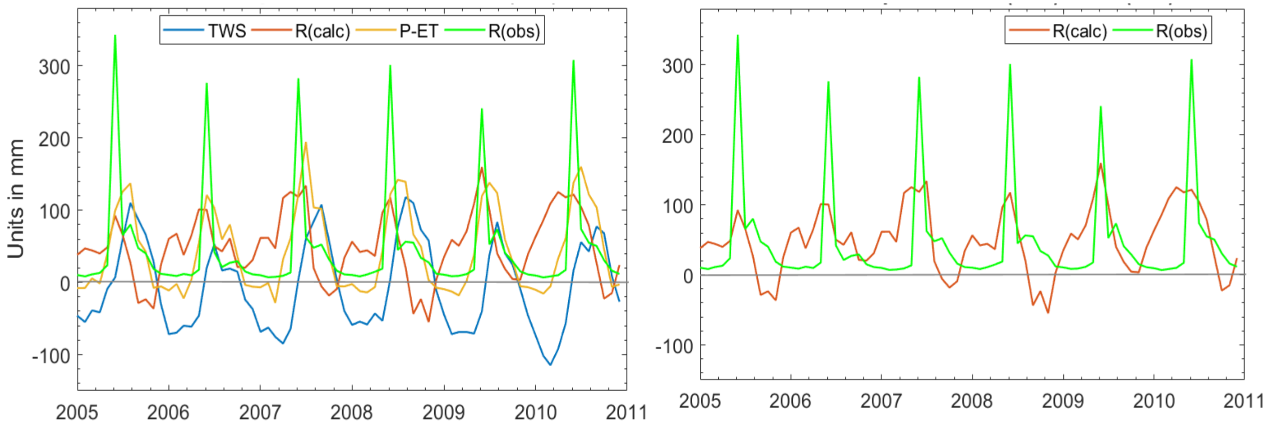


Jan 2010



July 2010

CONT.... WATER BALANCE



Good agreement and consistency:- adequate capture of surface water fluxes dynamics

Peaks spikier in R(obs) than in R(calc) due to dam water-release in June

In winter, TWS decreases as water leaves the catchment (water release as groundwater or as surface runoff) and R increases, P replenishes TWS flux outflow in summer.

Distinct pattern in WB deficits appearing to occur/coincide with reported drought event

CONCLUSION

The proposed SDI framework is feasible

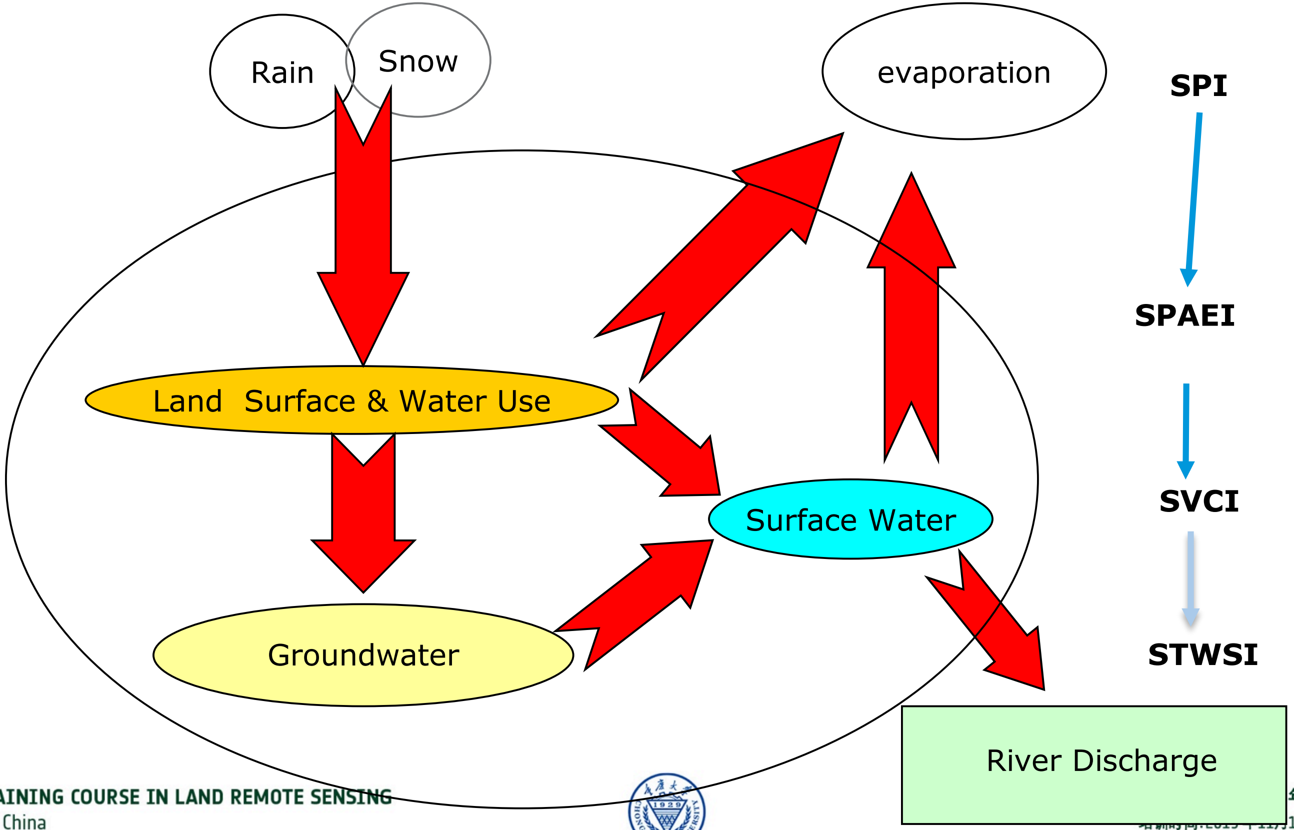
SPAEI show higher severity and longer drought durations compared to SPI, probably because the SPAEI incorporates ETa.

SPI and SPAEI infer changes occurring at shallow depth and on surface, good for meteorological drought. STWSI infer deep-water horizons and TWS. STWSI and SPAEI can compliment each other in monitoring hydrological drought. SVI is limited as is affected by phenology and influenced by meteorological forcing

R(calc) overestimates runoff in winter through summer except for June where the observed runoff is twice the calculated runoff due to the dam-water release

No WB closure. PBIAS in accumulated annual averages is small (8.85%). Distinct pattern in WB deficits appearing to occur/coincide with reported drought event

Water Budget Closure

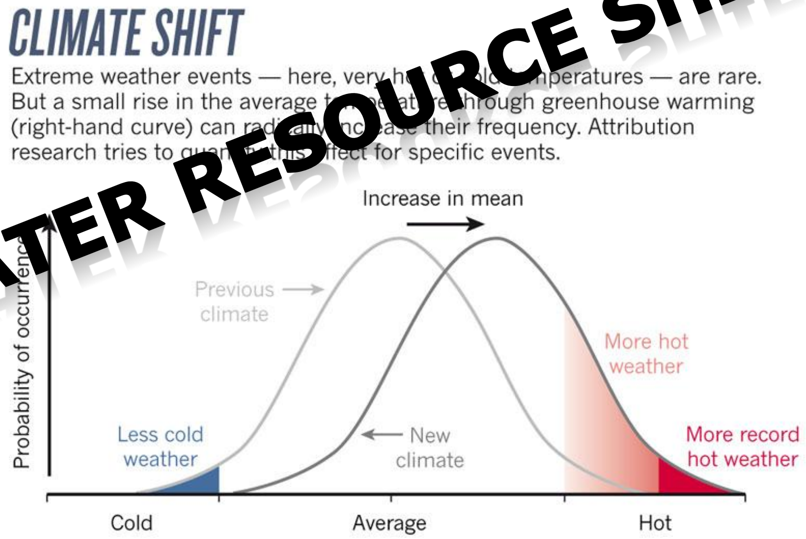


Q1: What are observed impacts to water resources in Yangtze due to climate and human changes ?

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 ?

WATER RESOURCE SHIFT?



Referances/Further Readings

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Chapter 8
Drought Monitoring and Assessment Using Remote Sensing

Z. Su, Y. He, X. Dong, and L. Wang

8.1 Introduction

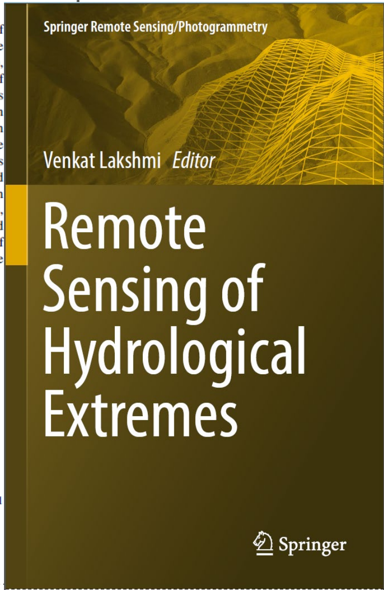
Drought has wreaked havoc to human societies throughout history. Impacts of drought include devastated crops, famine and conflicts and wars. Serious and severe droughts have occurred on every continent throughout history (Heffernan 2013), including the global mega drought of 4200 years ago that is linked to demise of Akkadian Empire (Kerr 1998) and civilisations in Greece, Egypt and the Indus Valley of Pakistan, the great famine in 1876–1878 which resulted in more than 5 million deaths in India and 30 million in total, the federation drought in 1901 in Australian, the US dust bowl in the 1930s, the central European drought in the 1940s and the Sahel drought in 1970s and 1980s when famine led to 600,000 deaths in 1972–1975, and again in 1984–1985. These droughts have all been associated with climatic shifts that caused low rainfall and as such climate change is now an accepted powerful causal agent in the evolution of civilisation. In many regions, climate change is expected to increase the amount of land at risk from drought and heat and will threaten more arable areas. Timely assessment and monitoring of drought will increase the drought preparedness, relief and mitigation and reduce the damage of drought impacts to the environment, economy and society.

Z. Su, Ph.D. (✉) • L. Wang, M.Sc.
Faculty of Geo-Information Science and Earth Observation (ITC), University of Twente, Hengelosestraat 99, P.O. Box 217, Enschede 7500 AE, The Netherlands
e-mail: z.su@utwente.nl; l.wang-3@utwente.nl

Y. He, Ph.D.
National Meteorological Center, University Road No. 8, Beijing 100081, P.R. China
e-mail: yanbohe@cma.gov.cn

X. Dong, Ph.D.
China Three Gorges University, University Road No. 8, Yichang 443002, Hubei, P.R. China
e-mail: xhdong24@hotmail.com

V. Lakshmi (ed.), *Remote Sensing of Hydrological Extremes*, Springer Remote Sensing/Photogrammetry, DOI 10.1007/978-3-319-43744-6_8



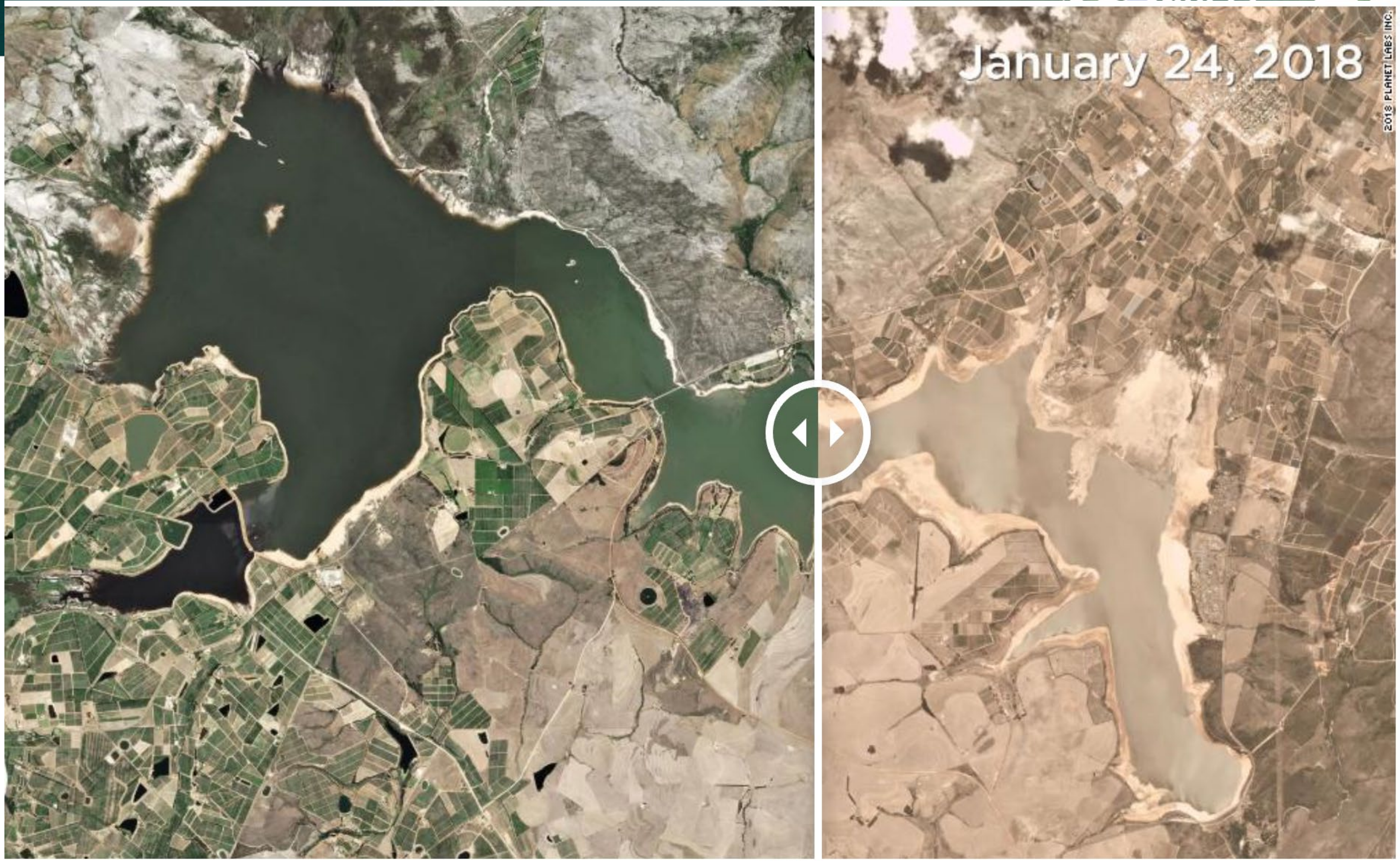
Yes, it is water availability!

Final Q/A,
How important is all this fuss?

How acute is it to deal with drought ?

Editor's Note: *Cape Town is enduring the worst water crisis to face a modern city, and its officials project it may run out of water next year, if not sooner. This is the first installment in Cape Town*

Too little water: In my city of Cape Town, there is only one topic of conversation: water
http://www.cnn.com/2018/02/01/opinions/cape-town-water-crisis-opinion-joseph/index.html


January 24, 2018
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Thank you very much for your attention!