Module 4: Introduction in remote sensing

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Goal and objective of the session

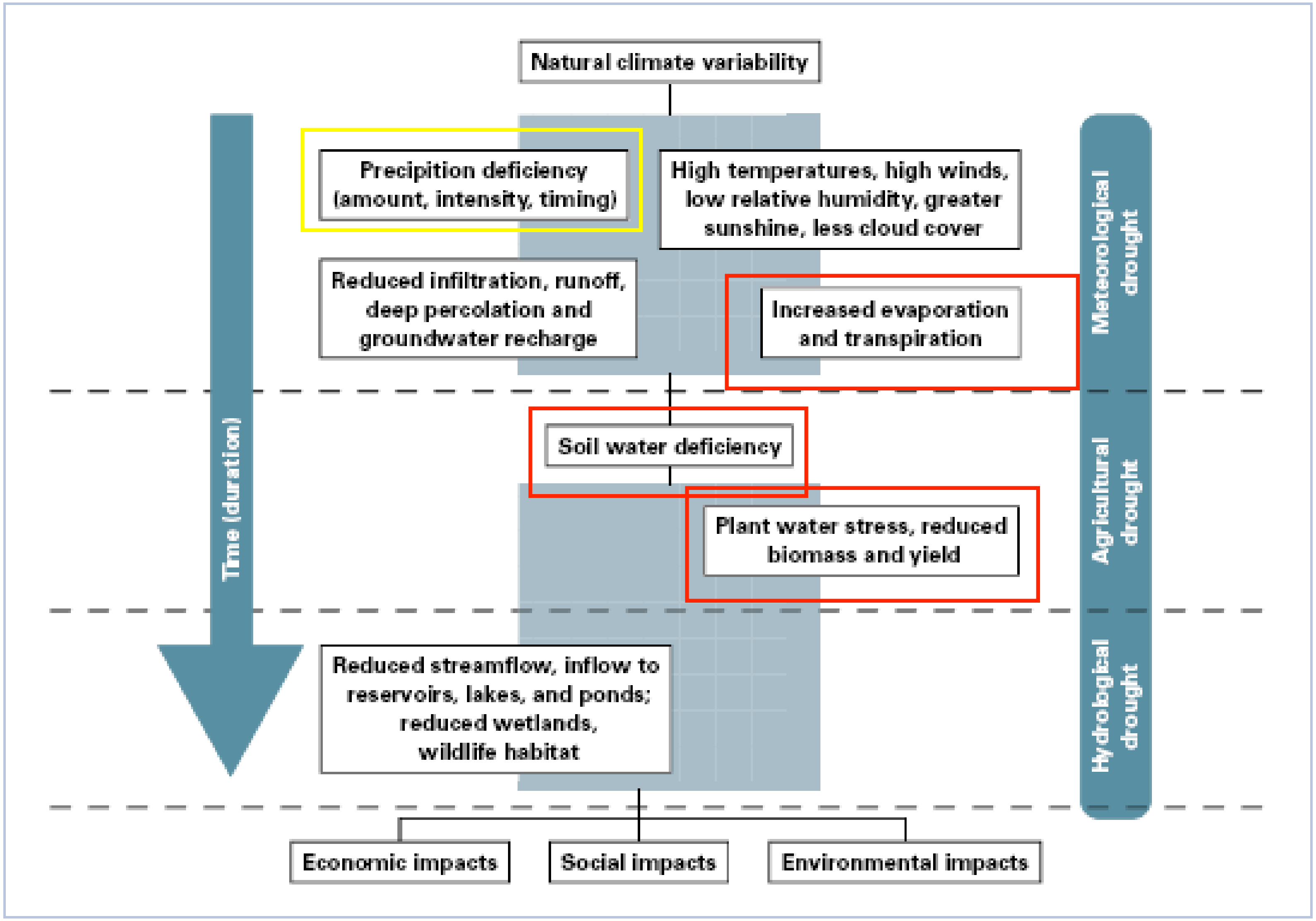
- At the end of the module participants should know
  - The Different kinds of droughts
  - To relate hydrological parameters to specific droughts
  - How remote sensing can be used to estimate these hydrological droughts
  - What the uncertainties in remote sensing data are?
  - How to deal with uncertainties (using indigeneous knowledge)
  - What drought severity indices are and how they can be estimated with remote sensing
  - How hazard can be identified by (synergies within) drought indices
  - What the risk of specific drought events is calculated.
  - How Risk can be minimized by forecasting drought and implementing a Drought Early Warning System.

Outline presentation

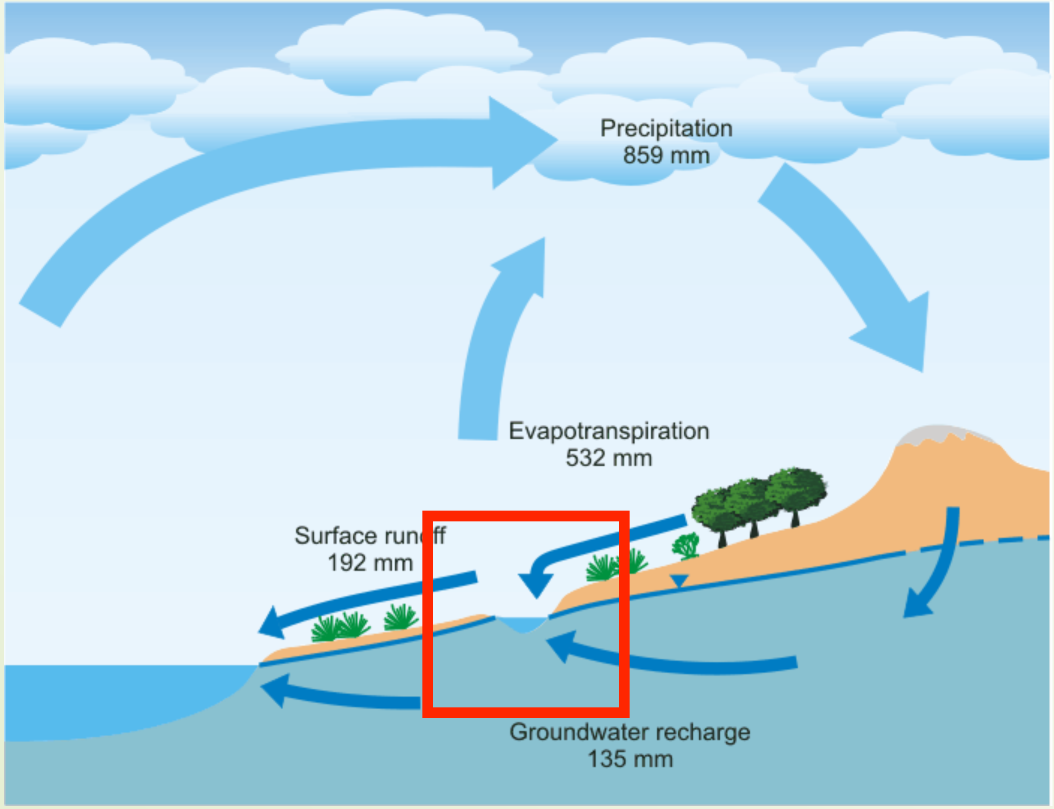
- Understanding the hydrology of drought
  - Water Balance
  - Temporal variation hydrological components
  - Data acquisition
- Remote sensing
  - Introduction
  - Observables
  - Processing chain
  - Uncertainty
- Drought indices
  - Requirements of a good indices
  - Advantage / disadvantages
  - Synergies
    - Standardized Precipitation Index, Soil moisture deficit index, Evapotranspiration deficit index
- Drought impact reduction
  - Risk analysis
  - Hazard identification
    - Past events
    - Current State observations
  - Forecasting
  - Early Warning System
- Indigeneous knowledge
  - Combining with remote sensing
- Acknowledgements

The Hydrology of Drought

Definition of Drought

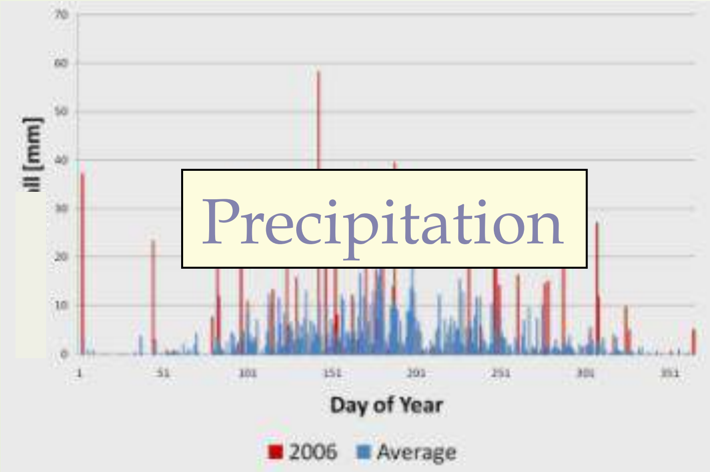


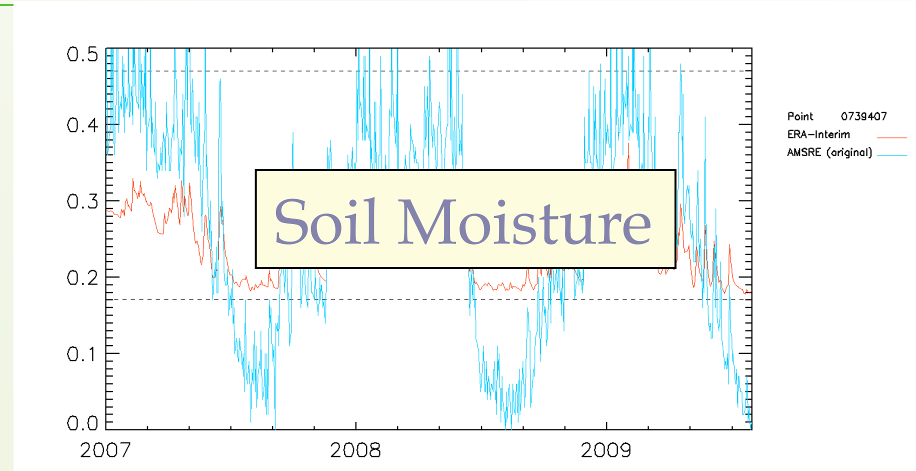
Water balance



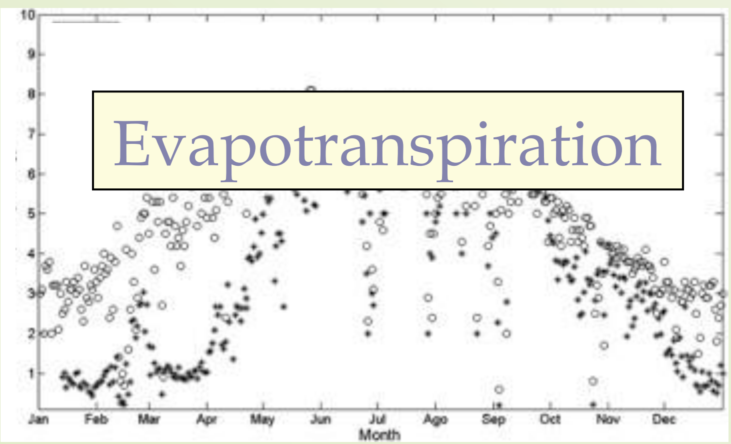
$$P + I = ET + R + \Delta S$$

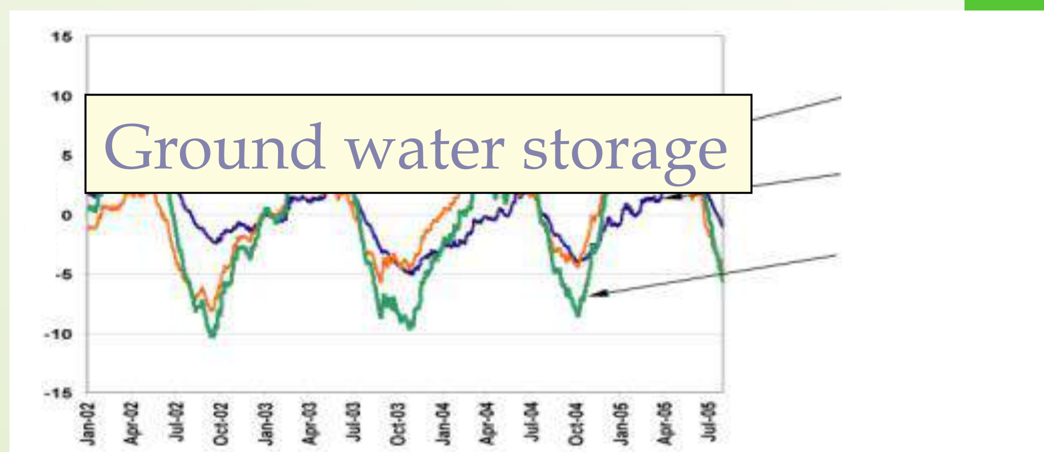
Temporal Variation Hydrological Components





Which plot contains, soil moisture, evaporation, precipitation and ground water storage???





Traditional Data acquisition

Precipitation

Ground water

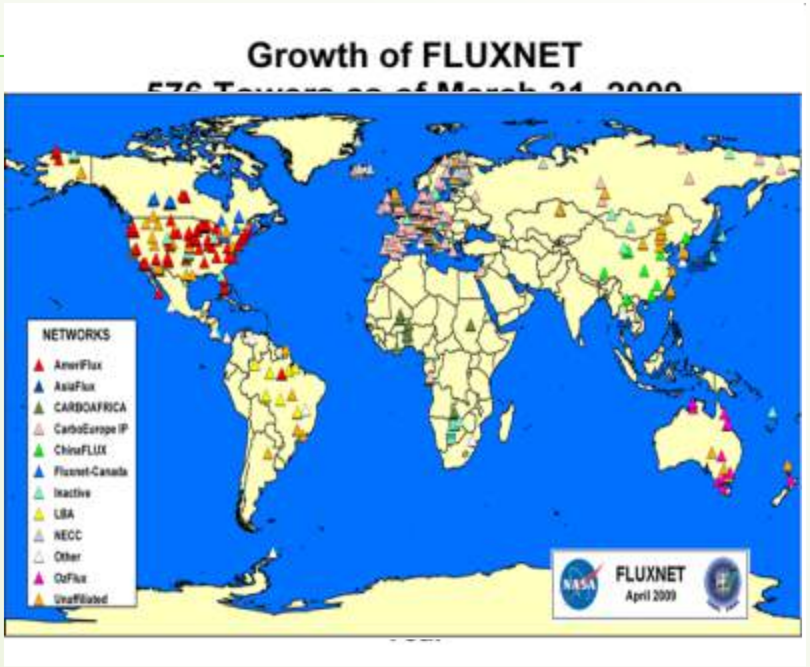
Soil Moisture

Evapotranspiration

Why Remote Sensing

- Field measurements
  - Different equipment
    - Eddy covariance
    - Scintillometry
    - Bowen Ratio
  - Number is increasing
    - CarboEurope, FLUXNET
  - Limited coverage

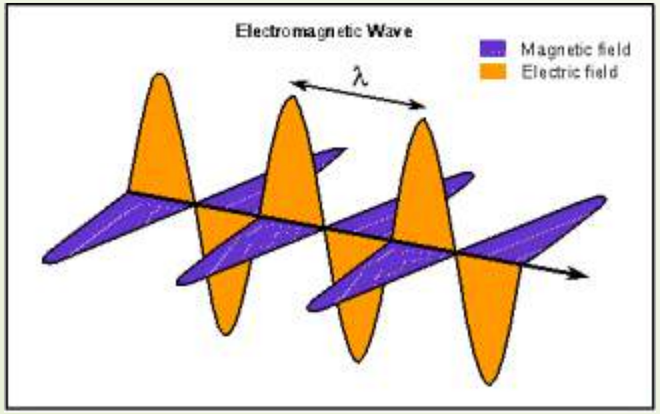
- Remote sensing
  - satellites
  - Global coverage



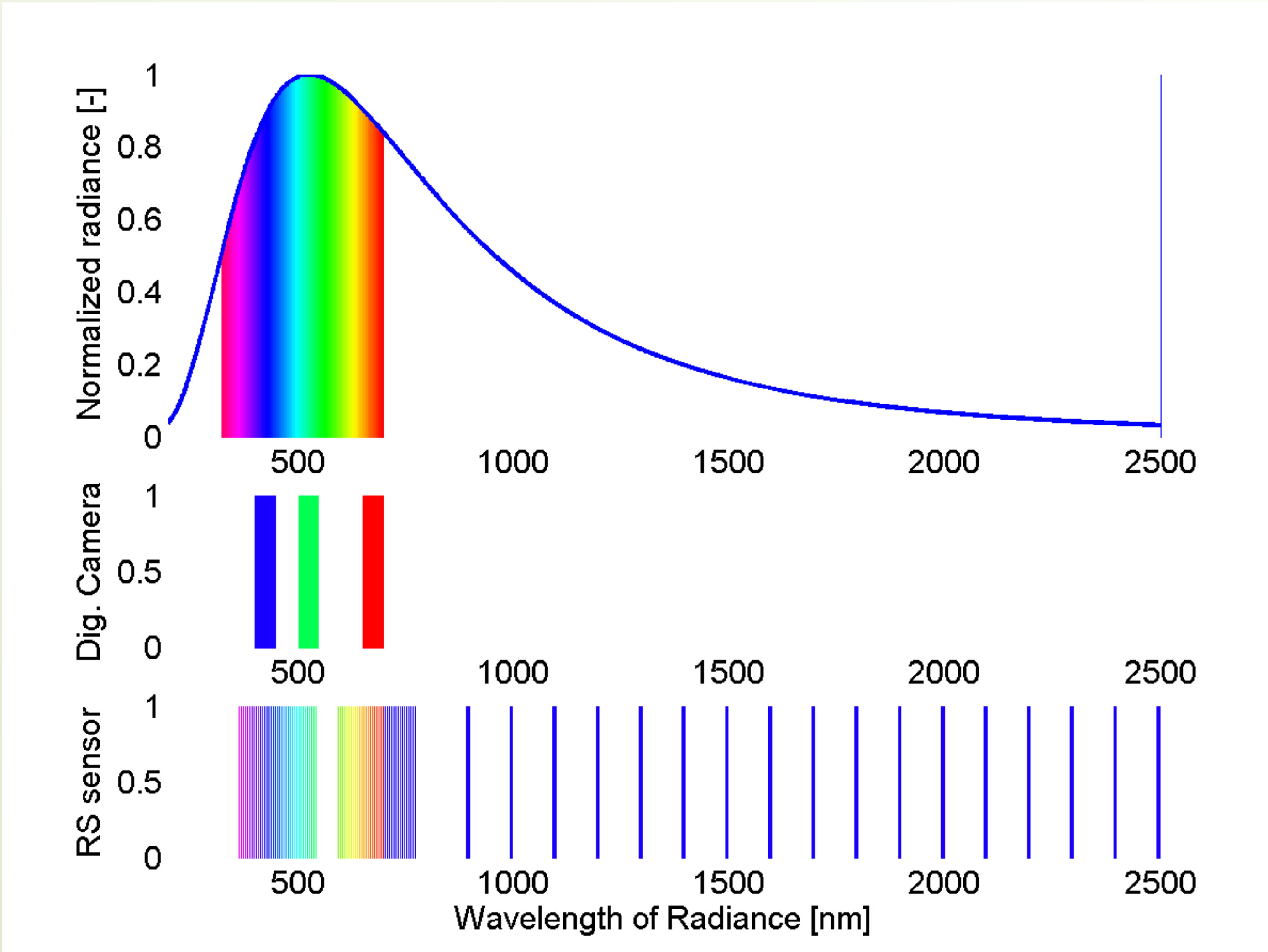
Remote sensing observations

Remote Sensing Principle

- Processes
  - Reflection
  - Footprint of processes
    - ✓ Evaporation
    - ✓ Transpiration
    - ✓ Rainfall
- Observations
  - radiation,
    - ✓ Optical
    - ✓ Thermal
    - ✓ microwave
  - Electromagnetic
    - ✓ Gravity



Satellite sensors

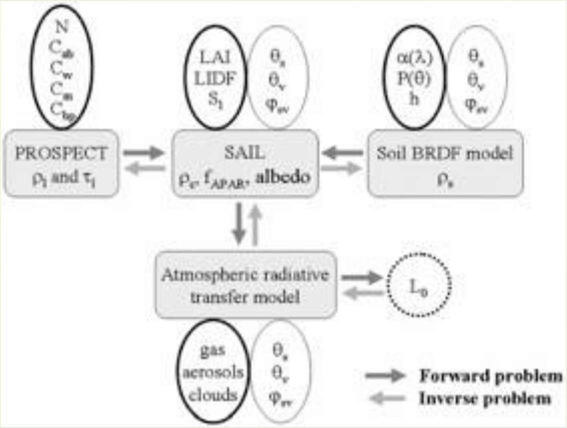


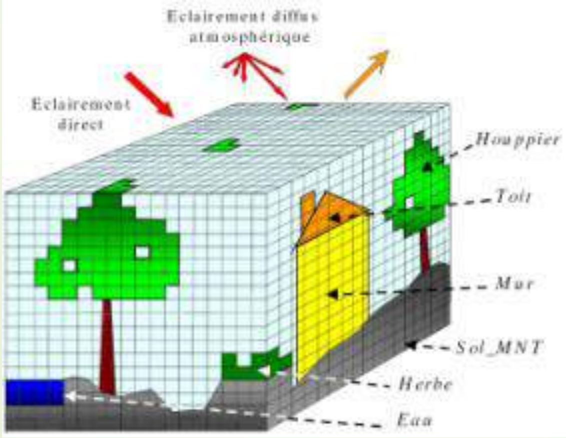
Remote sensing provides extra spectral information (!)

Remote sensing types

- Ocean remote sensing
- Land remote sensing
- Atmosphere remote sensing

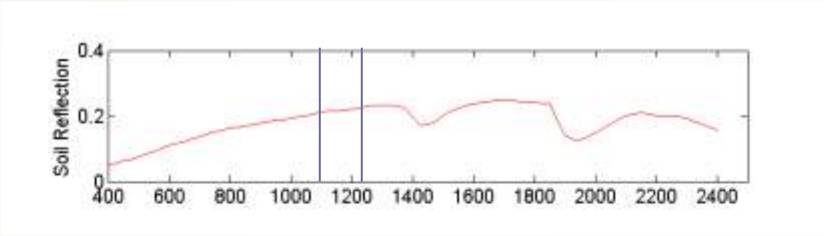
Retrieving Land Surface Parameters



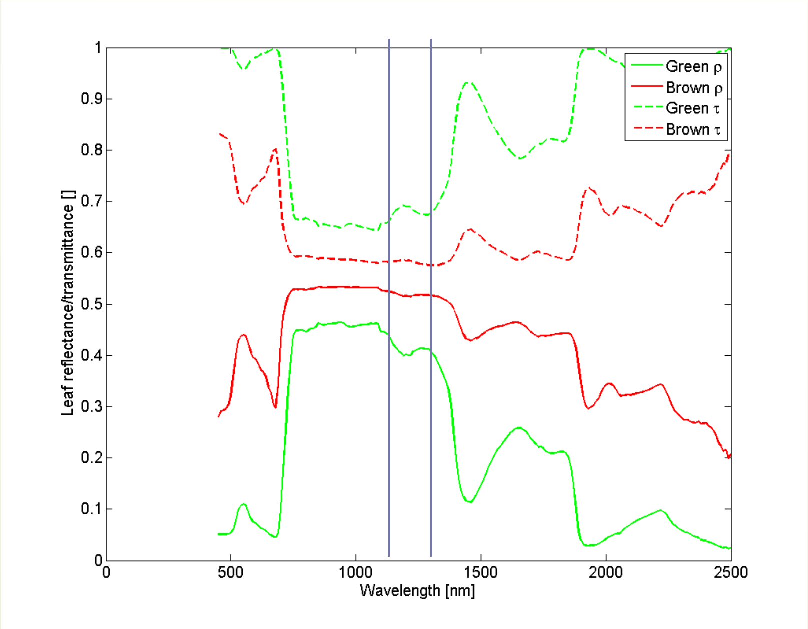


Empirical Techniques

- Using vegetation indices
  - 0.67 and 0.87 μm for ρ_{red} and ρ_{nir}



- Soil has ‘flat’ reflectance’
- Vegetation has large difference



$$NDVI = \frac{\rho_{red} - \rho_{nir}}{\rho_{red} + \rho_{nir}}$$

- Three different surface types: bare soil pixels (NDVI<0.2), mixed pixels (0.2<NDVI<0.5) and fully vegetation pixels (NDVI>0.5). (Sobrino and Raissouni, 2000).

Thresholds Method (NDVITHM)

- The final expressions obtained for this method are for bare soil pixels (NDVI < 0.2),
  $\varepsilon = 0.9825 - 0.051\ \rho_{red}$
  $\Delta\varepsilon = -0.0001 - 0.041\ \rho_{red}$

- for mixed pixels (0.2 NDVI 0.5),
  $\varepsilon = 0.971 + 0.018\ f_c$
  $\Delta\varepsilon = 0.006\ (1 - f_c)$

- and for vegetation pixels (NDVI > 0.5),
  $\varepsilon = 0.990$

- with f_c being the vegetation proportion, given by

$$f_c = \left(\frac{NDVI - NDVI_{\min}}{NDVI_{\max} - NDVI_{\min}} \right)^2$$

- where $NDVI_{min}$=0.2 and $NDVI_{max}$=0.5. The main constraint of this method is that it can not be used to extract water emissivity values because it is not possible to apply the NDVI and f_c equations for water pixels.

Inversions of Radiative Transfer Models

- SAIL Radiative transfer model
- Inversion of Model

Radiative transfer equation

- ‘Unsolvable equation’

$$\mu_o \frac{\mathrm{d}L_o}{\mathrm{d}z} = -\beta(\mu_o)L_o + \gamma'(\mu_s,\mu_o,\psi)E_s^o + \int_{4\pi} \gamma'(\mu_i,\mu_o,\varphi_i-\varphi_o)L_i \mathrm{d}\Omega_i$$

extinction

scattering of solar radiation

scattering of diffuse radiation

Fundamental physical quantities here are:

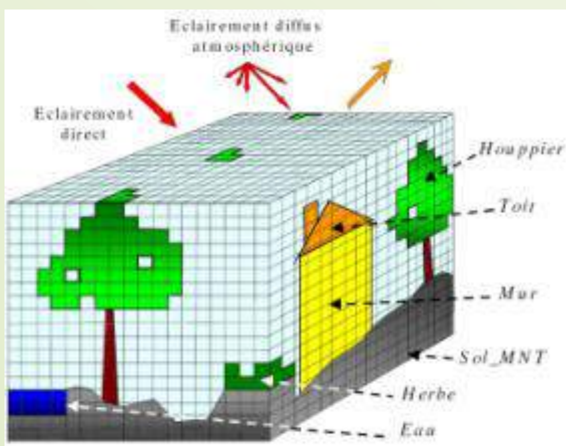
$\beta(\mu_o)$ = interception coefficient in direction *o*

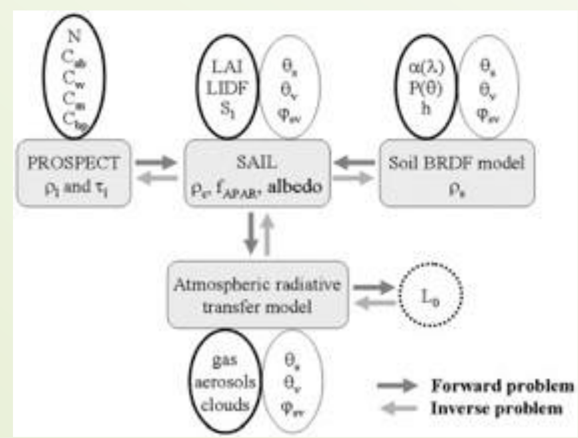
γ' = volume scattering phase function

Radiative transfer models

- Soil: modified
  - Hapke model
- Leaves:
  - PROSPECT model

- Canopy:
  - DART radiative transfer model
  - SAIL family of models,





Leaf Radiative transfer model

Leaf radiative transfer

- thin compact medium
- internal scattering
- selective absorption (pigments, water, dry matter)

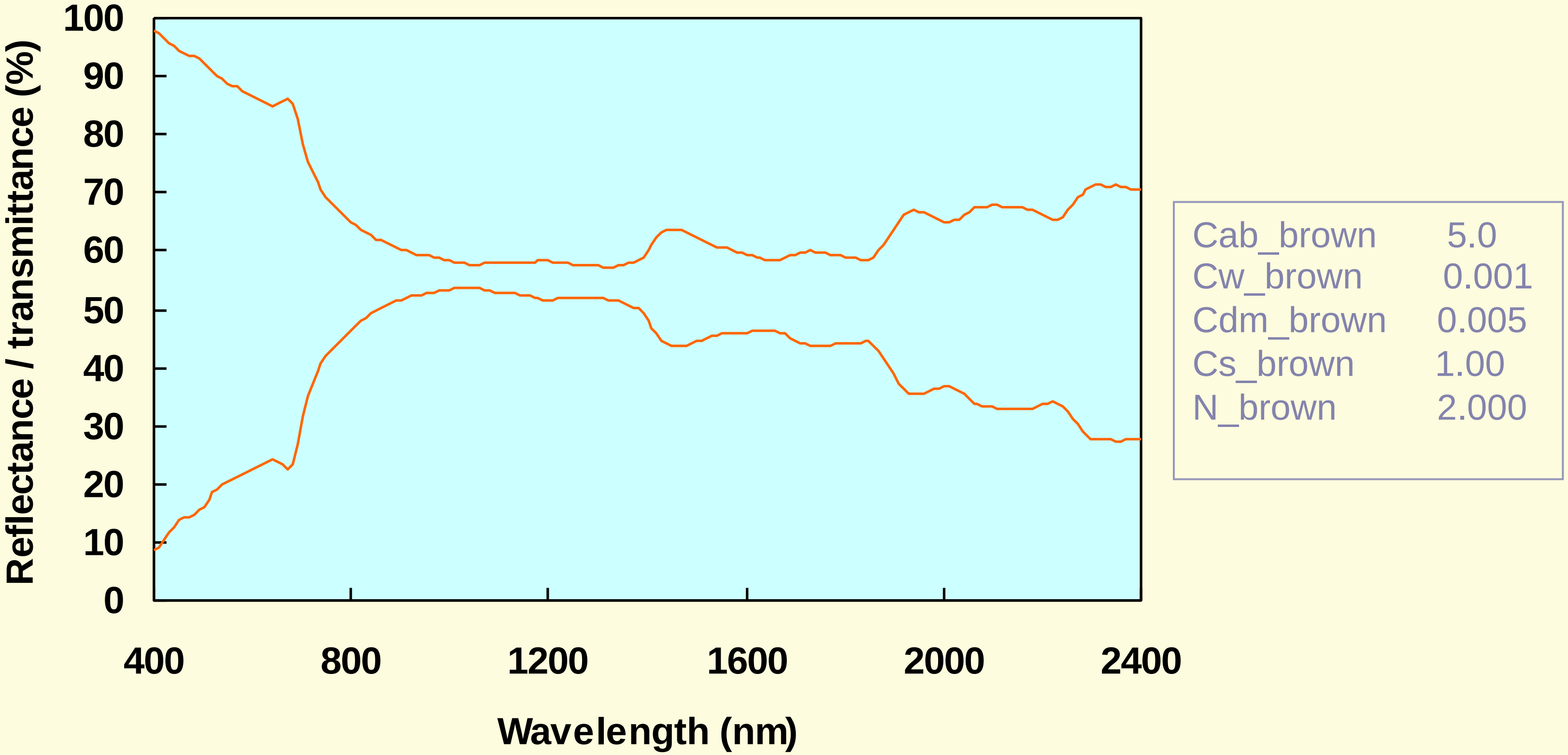
PROSPECT model (Jacquemoud & Baret, 1990)

- analogy to pile of glass plates to simulate internal scattering
- absorption spectra of chlorophyll, water, dry matter and brown pigments

modified version:

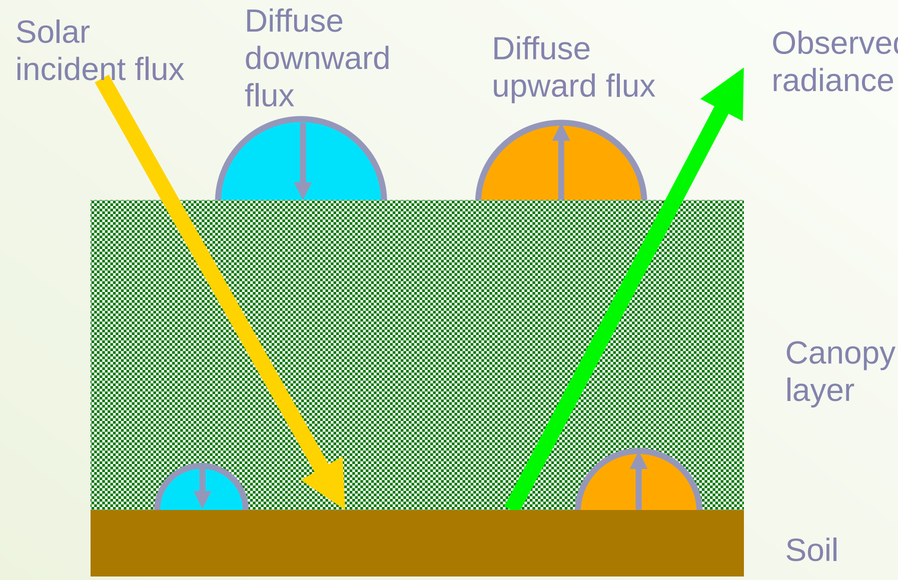
- also functions if no absorbers present

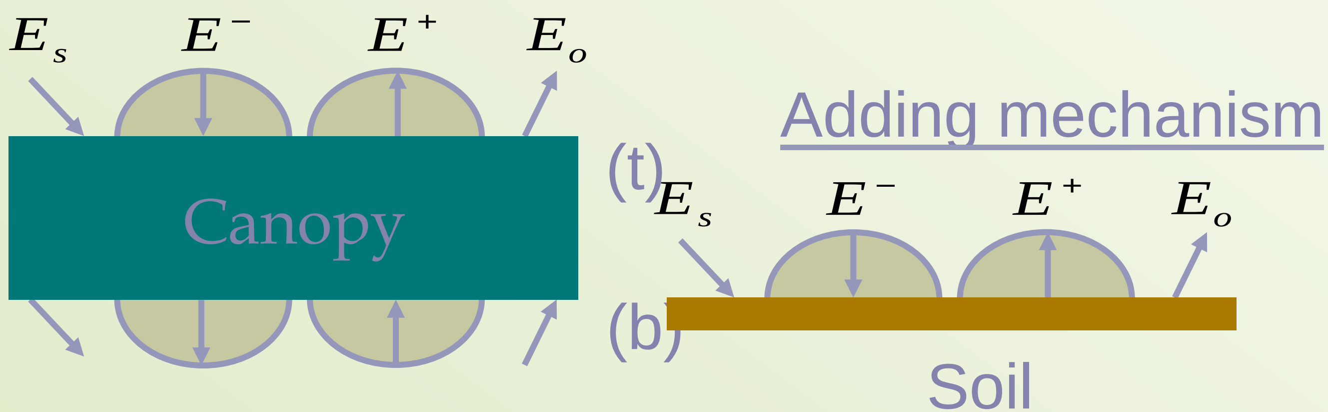
Prospect Examples



SAIL introduction

- Scattering *Arbitrary Inclined Leaves*
  - 4 stream
  - 1D radiative Transfer
  - Optical and Thermal



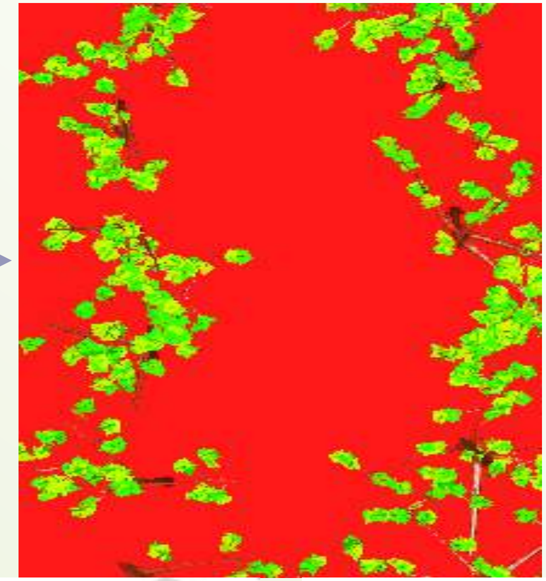


SAIL family

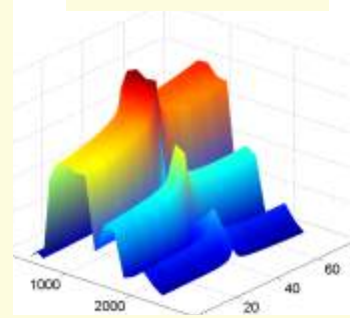
Property / Model	SAIL	SAILH	GeoSAIL	SAIL++	4SAIL	4SAIL2
year of development	1981	1989	1999	2000	2003	2003
type	turbid medium	hybrid	hybrid	hybrid	hybrid	hybrid
hot spot effect	no	yes	yes	yes	yes	yes
# of canopy layers	1	1	2	1	1	2
singularity removal	no	no	no	yes	yes	yes
numerical precision	single	single	single	double	double	single
speed optimisation	no	no	no	yes	yes	yes
# of diffuse streams	2	2	2	72	2	2
internal flux profiles supported	no	no	no	no	yes	no
thermal application supported	no	no	no	no	yes	no
non-Lambertian soil BRDF	no	no	no	no	no	yes
clumping effects	no	no	no	no	no	yes

Directionality

- Viewing angle
  - ✓ Looking downwards -> more soil
  - ✓ Looking Oblique -> Mostly vegetation
- Directionality signature
- Multiple (angular) observations ->extra Information
  - ✓ Hollywood
    - depth
  - ✓ Directional RS measurements
    - Different from hollywood
    - At present few ‘3D RS glasses’?



Reflection

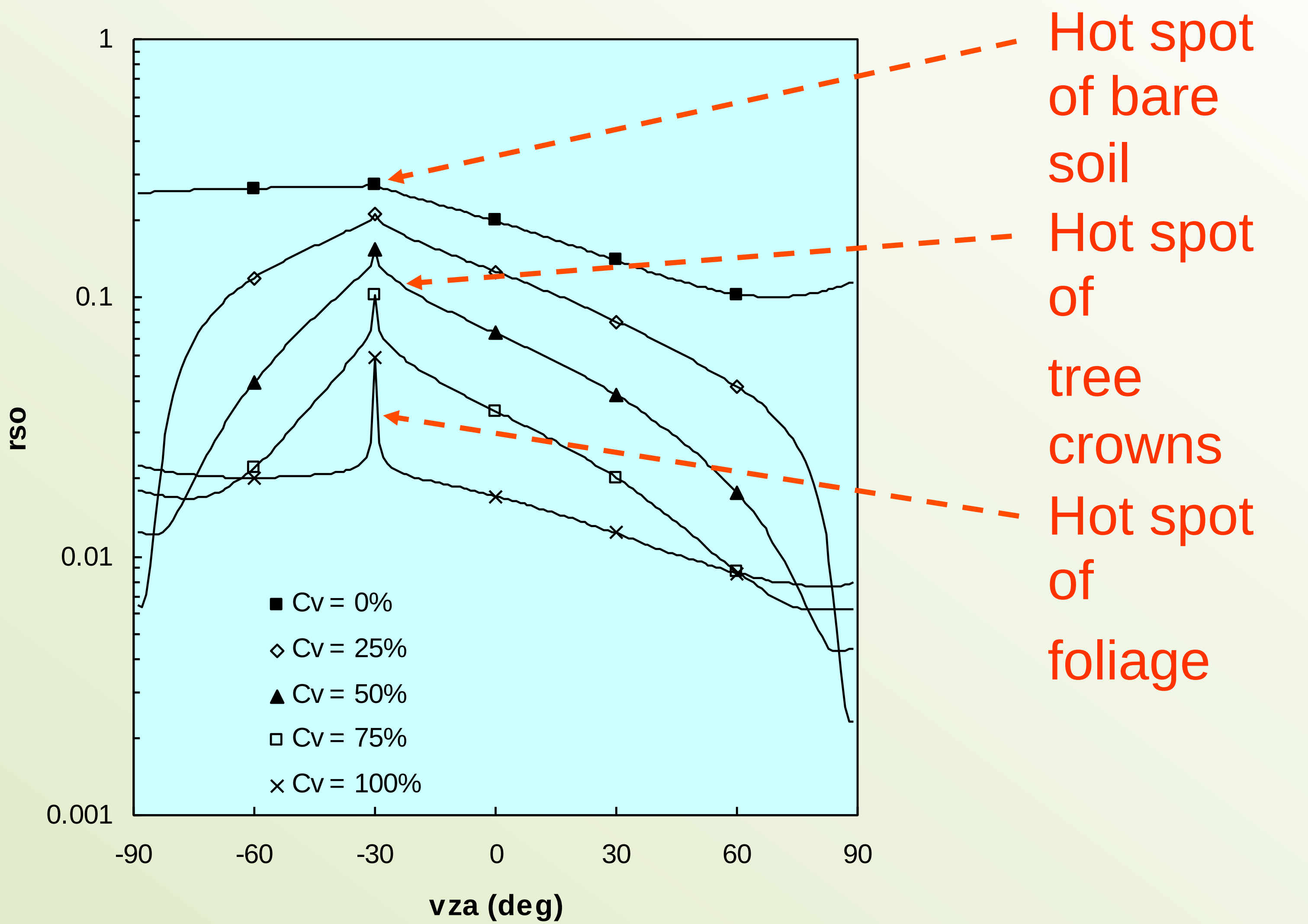


Brightness Temperature

But where to start?

Observation Angles

Output



Cap-Net SCaN ITC REMERH WaterCap UNEP-DHI CENTRE

Inversion

Finding the input parameters of the forward radiative transrfer model that make the error between observed radiation and simulated radiation the smallest

Radiative transfer Inversion techniques

- Indices
- Model-based multiple regression
  - statistics
- Look-up tables
- Neural networks
- Model inversion by fitting / optimisation

Look-up tables

- Observing Radiation with particular sensor setup
  - Sensor sensitivity
  - Viewing angle
- Creation of large datasets with different scenarios
  - Combination of variations
    - LAI, fc, Cab.. Etc
  - 'Forward' Radiative Simulation of each scenario
  - Adaptation of sensor sensitivity
- Calculation of cost function
  - (Weighted) Root mean square error

$P_O(\lambda)$

$a^j, b^j, \ldots$

↓

RTM

↓

$P_s(\lambda)(a^j, b^j, \ldots)$

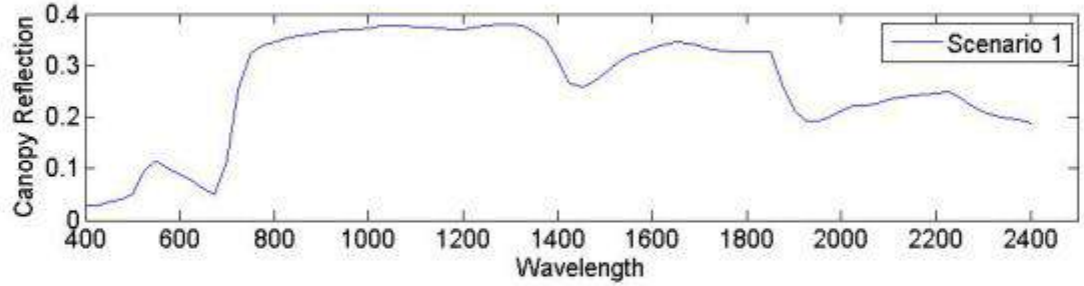
$$RMSE_j = \sqrt{\sum_\lambda w(\lambda)\left(P_o(\lambda) - P_{aj}(\lambda)\right)^2}, rMSE_j = \sqrt{\sum_\lambda w(\lambda)\left(\frac{P_o(\lambda) - P_{aj}(\lambda)}{P_o(\lambda)}\right)^2}$$

- Find minimum

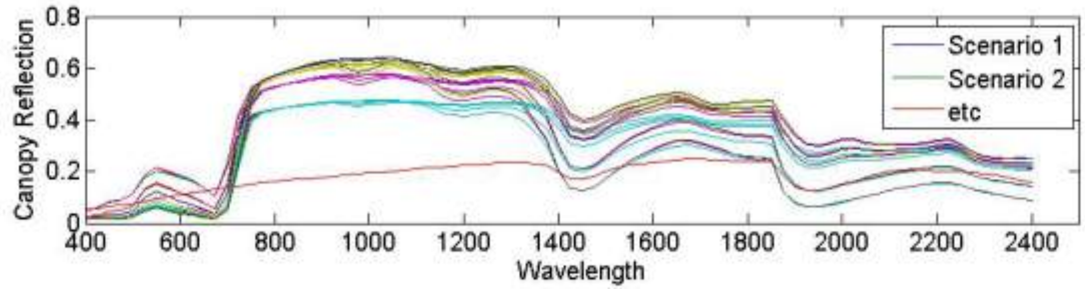
$$j_{BestFit} = \min(RMSE(j)) \longrightarrow a, b, \ldots (i_{bestfit})$$

Example

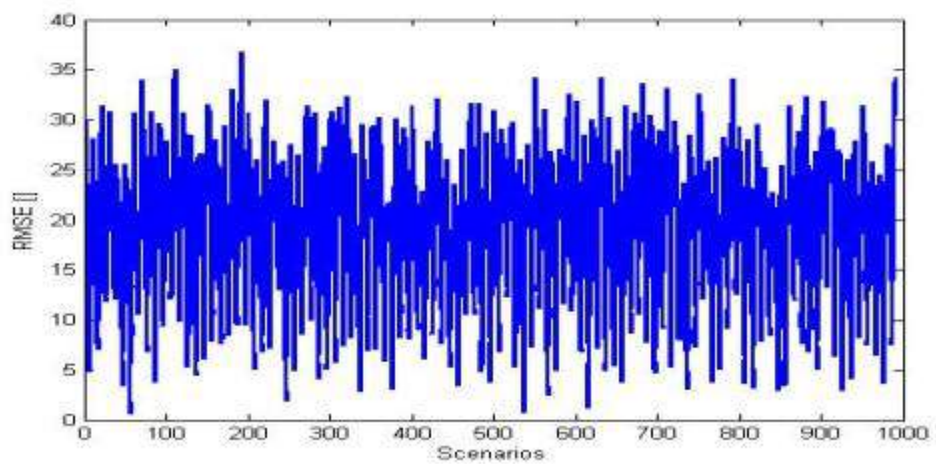
- Observation



- LUT



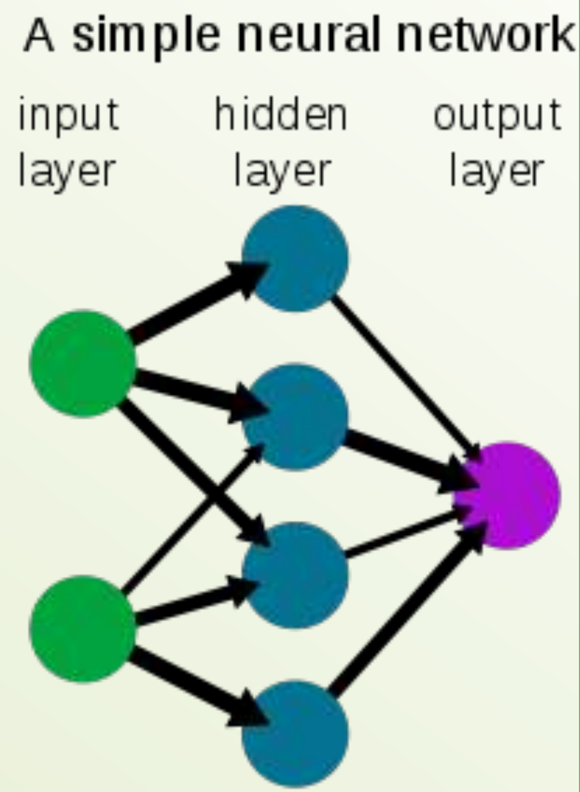
- RMSE



Neural Netwerk

- A blackbox is trained with simulated values of observed model
  - Similar to LUT
  - Is able to interpolate between set values
  - Created before inversion

- BEAM MERIS Vegetation Processor
  - SAIL training



Optimization techniques

- Observing Radiation with particular sensor setup $P_O(\lambda)$
- Calculate initial
  - Guess parameters
  - 'Forward' Radiative Simulation of initial
- Calculation of difference
- Calculate Jacobian
  - Local Sensitivity
- Invert Jacobian
- Update parameters

a^i,bi,…

↓

RTM

↓

$P_i(\lambda)$

$$\frac{dP_i}{da_i}, \frac{dP_i}{db_i}$$

$$\frac{da_i}{dP_i}, \frac{db_i}{dP_i}$$

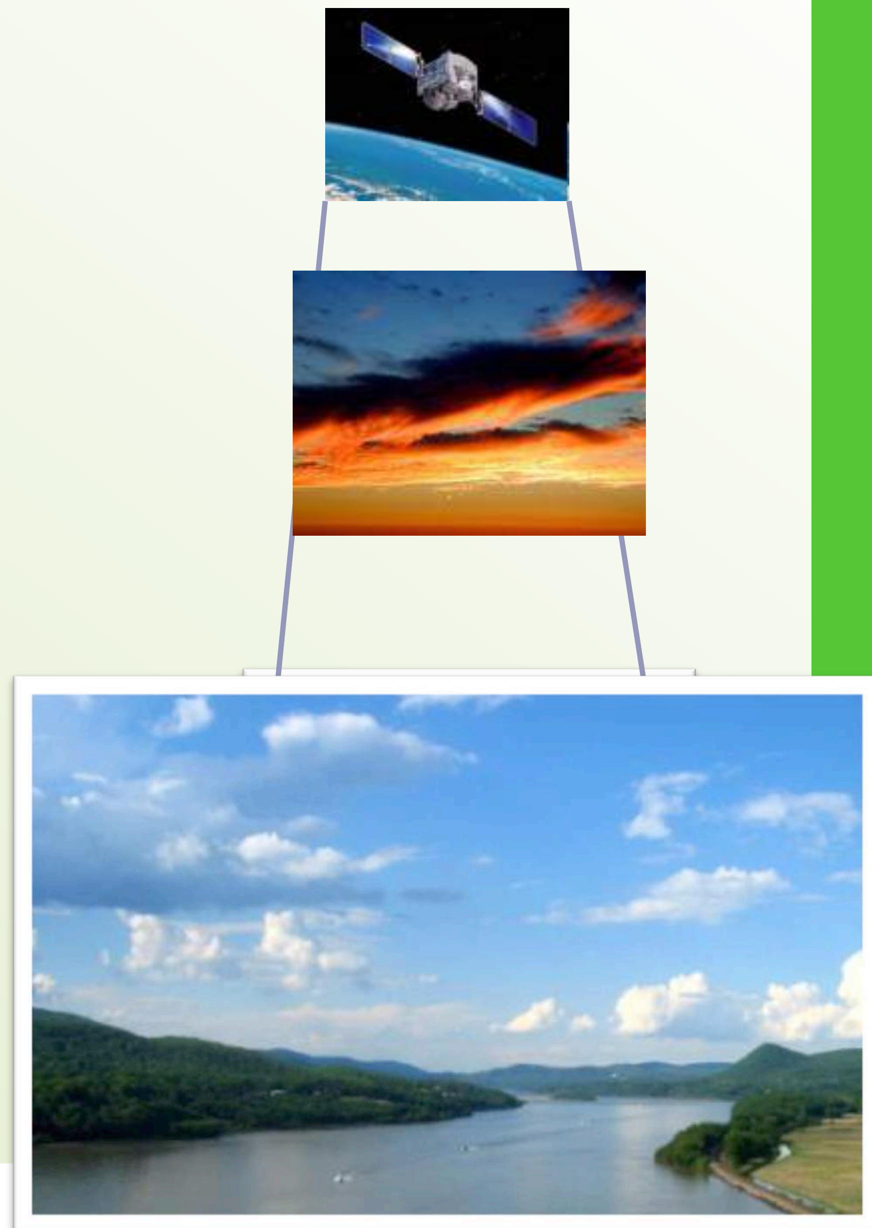
$$a_{i+1} = \frac{da_i}{dP_i}\left(P_o - P_i\right), b_{i+1} = \frac{db_i}{dP_i}\left(P_o - P_i\right)$$

Variables:

- Desired variables
  - Precipitation
    - ✓ Resolution 3 km
  - Soil moisture
    - ✓ 12.5 km to 50km resolution
  - ET cannot directly be measured:
    - ✓ Vegetation cover, LST, Vegetation
    - ✓ density, reflectance,..
    - ✓ Meteorological conditions
    - ✓ 90 m -3km resolution
  - Ground water
    - ✓ > 100km
  - Runoff, Inflow
    - ✓ Not yet (SWOT)
      - http://swot.jpl.nasa.gov/

Processing steps

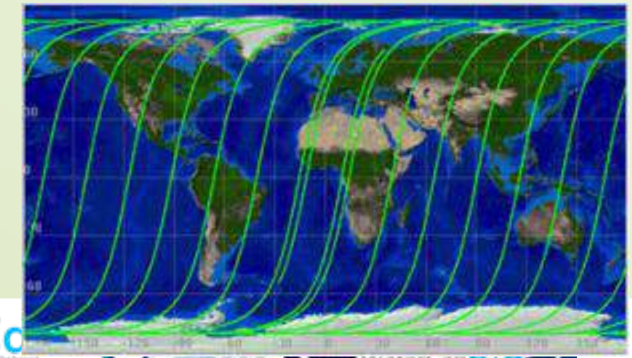
- In remote sensing output products are given a status level
  - L1a, raw radiances, uncorrected for geometry, and atmosphere
  - L1b, toa radiances, corrected for geometery, uncorrected for atmosphere
  - L2, boa reflectances, corrected for geometry and atmosphere
  - L3, biophysical parameters (LAI), gaps due to cloudcover/ sensor malfunction
  - L4, biophysical parameters, gapfilled (by model)
  - L5, combined products ->
    - ✓ Evapotranspiration, Soil Moisture



Satellite types

- Geostationary satellites
  - 35.786 kilometers
  - Lower resolution
  - Meteo Satellites (Meteosat, MSG, GOES)
  - Disk Observation

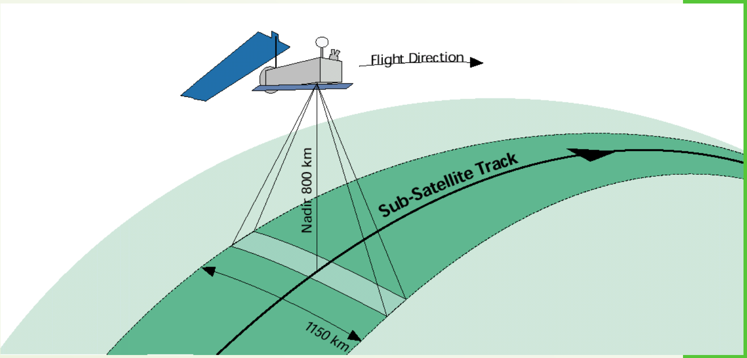
- Orbiting satellites
  - Sun Synchronous
  - 600 – 800km
  - Higher resolution
  - Swath observation



Example of Geostationary Satellite

Orbiting Satellites

- Resolution
  - Dependent on sensor type
    - ✓ Optical (0.6 w/m2/nm)
    - ✓ Thermal (0.028 w/m2/nm)
    - ✓ microwave
- Swath
  - Width of the image
  - Determined by resolution and data transfer
- Time cycles
  - Revisit time ~1-7 days
  - Repeat cycle, 1-35 days
- Examples
  - AVHRR (1km, 2400 km, 1DAY REVISIT)
  - AMSRE (10km, 1445 km, 2-7days)
  - MODIS (300m-1km, 1.5 days)
  - AATSR (1km, 512KM, 3 days)
  - Landsat (30m-60m, 185km, 16 days)
  - CHRIS PROBA (15m, 14km, 16days)



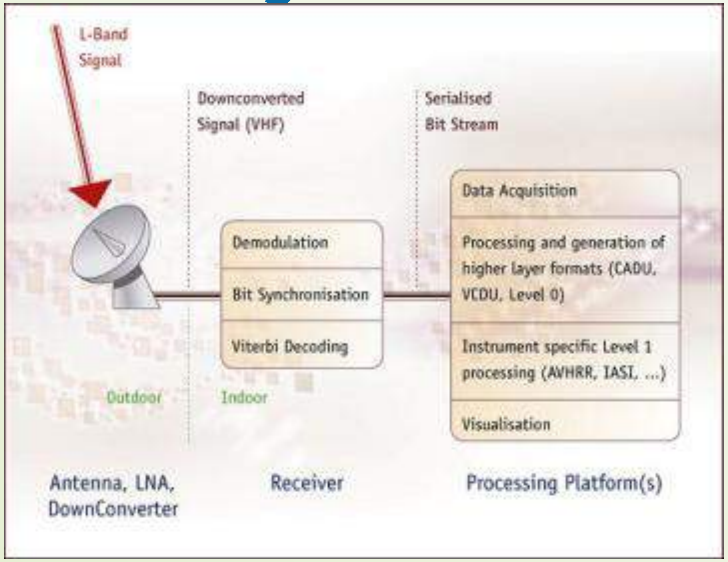
future satellites

- Thermal bands
  - preferably 2 bands

- Sentinel-3
  - Continuation of AATSR/MERIS sensors
  - Operation-time: 2012-….
- HYSPIRI
  - Continuation mission of ASTER
  - Operation-time: 2015-2017.
- LDCM
  - Landsat Data Continuation Mission
  - Operation-time: 2015-2017.
  - uncertain if thermal band is going to be present
- Sentinel-4
  - Based on Meteosat 2nd Generation sensor
  - Operation-time
- Meteosat Third Generation
  - Continuation of Meteosat 3rd Generation sensor
  - Operation time: 2015-2025
- GOES-R
  - Continuation mission of GOES
  - increased number of spectral bands
  - Operation-time: 2015-….

Data transfer

- Data transmitted to ground stations
- microwave (L-band)
- Some Processing



End of part 1

Module 4: Interpretation of RS data

Evapotranspiration from space

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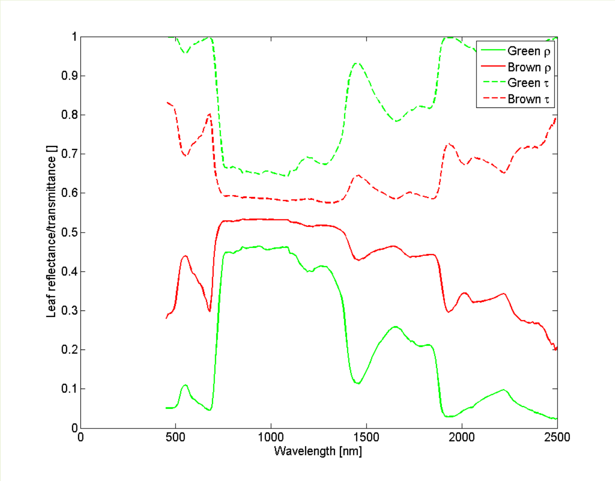
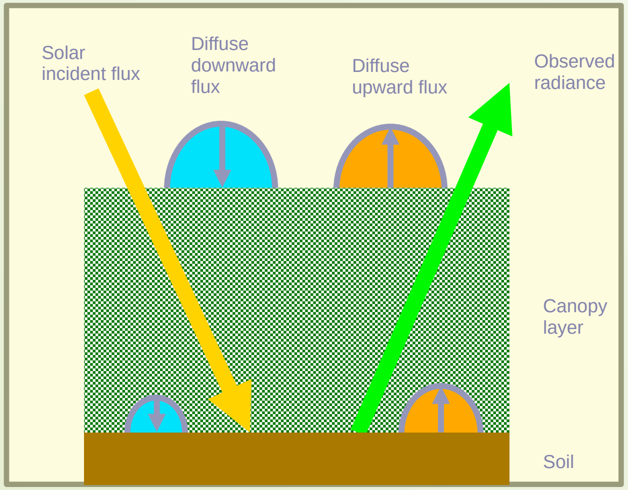
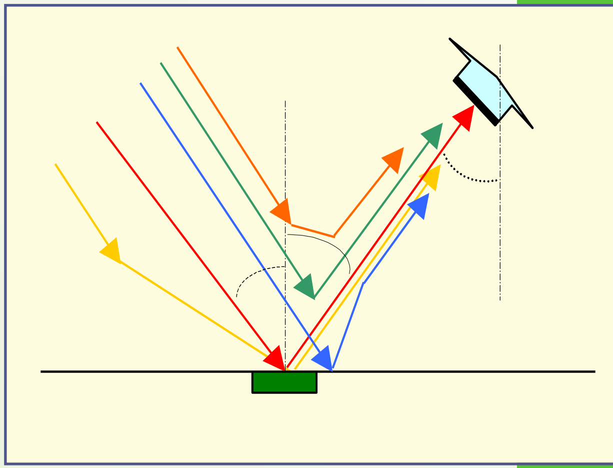
Recap

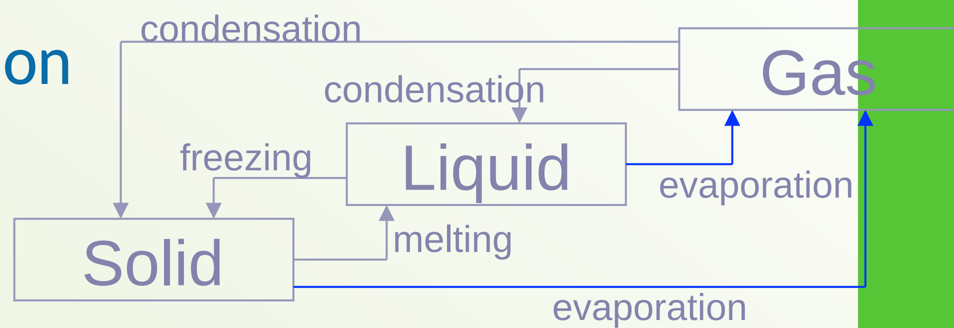

Green ρ
Brown ρ
Green τ
Brown τ
Leaf reflectance/transmittance []
Wavelength [nm]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
500
1000
1500
2000
2500

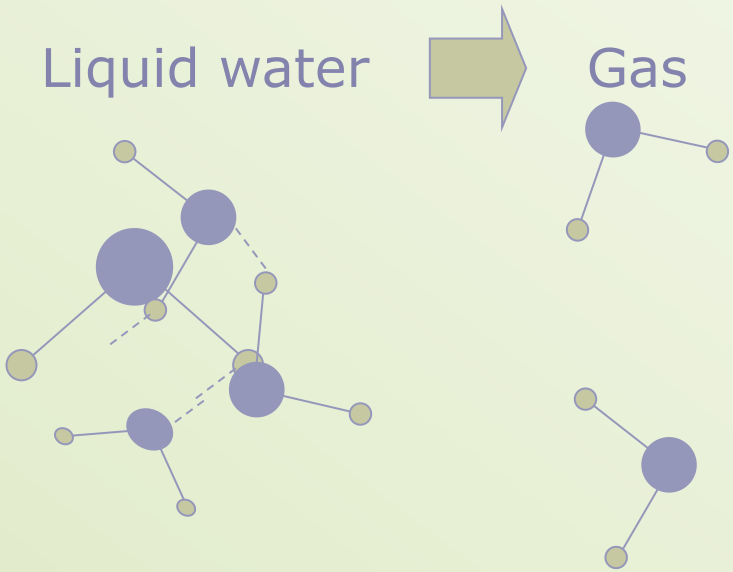

Solar incident flux
Diffuse downward flux
Diffuse upward flux
Observed radiance
Canopy layer
Soil



Evapotranspiration definition

- Evapotranspiration
  - Evaporation + transpiration
  - to convert into vapour
  - costs Energy

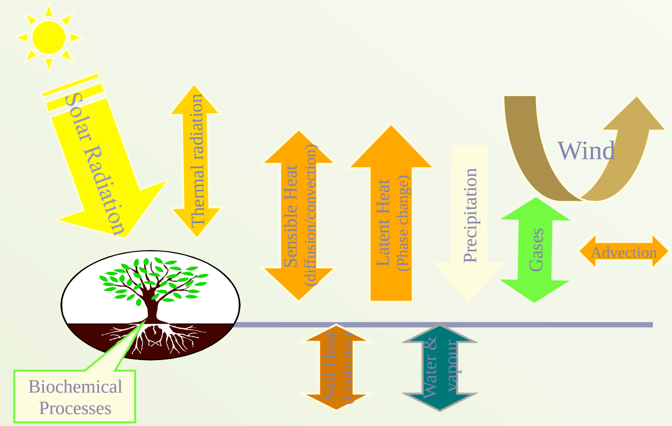




The energy for ET is extracted from the environment. The energy thus ‘stored’ in the water vapour is called ‘latent heat’

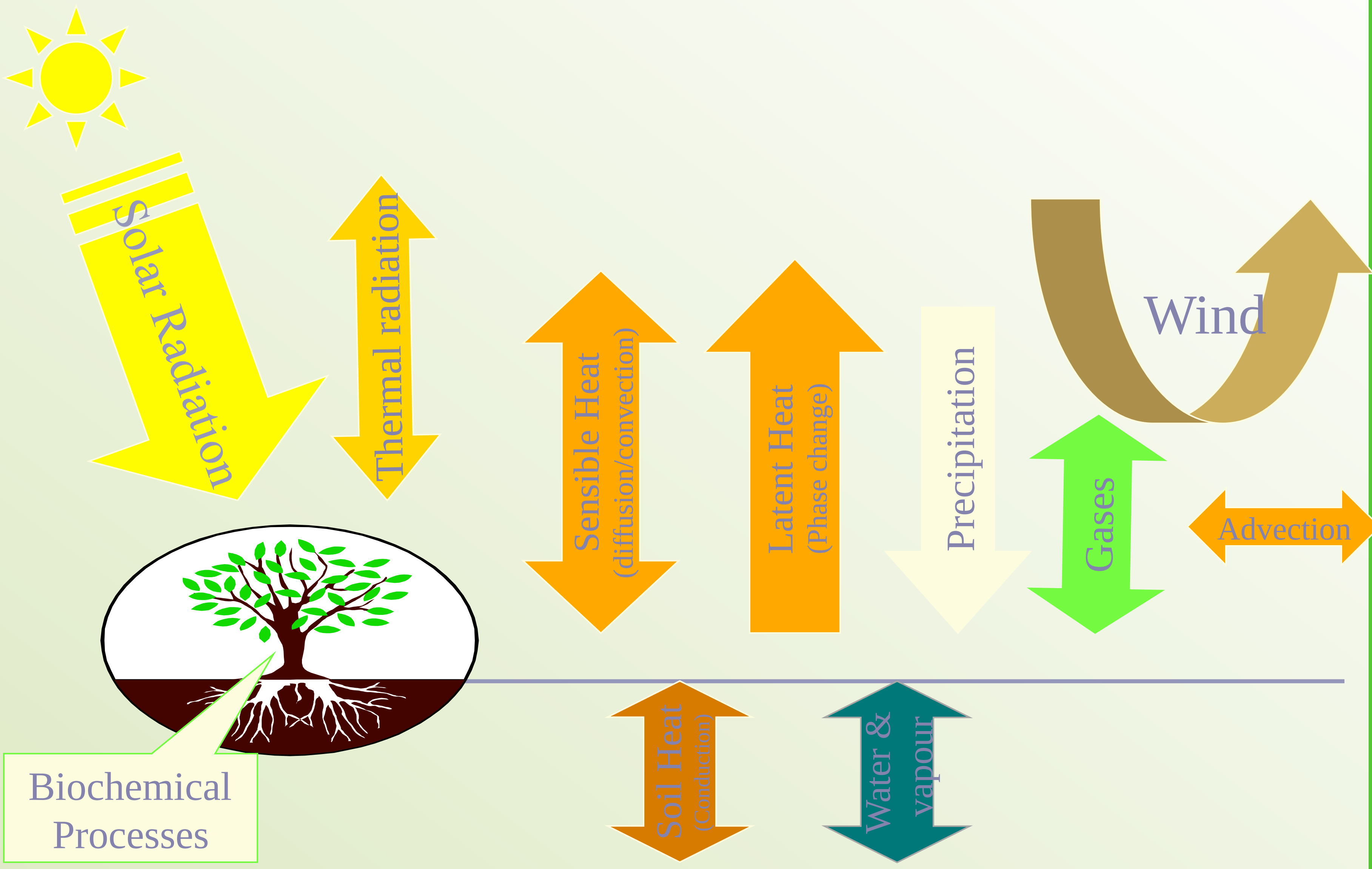
Why Evapotranspiration – Relevance

- Evapotranspiration (ET) refers to evaporation (from water or soil surfaces) and biospheric transpiration
  - Remote Sensing scales are too large to separate the two
- ET is often considered plays a central role in the water, energy and carbon cycles, and is common to all three cycles:



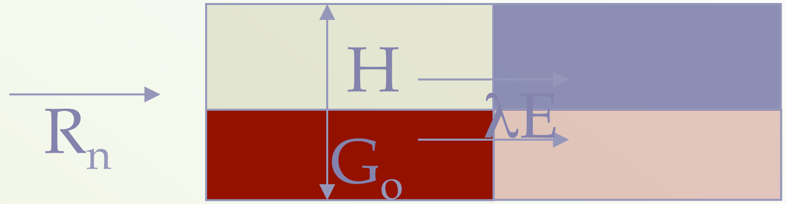
- Quantification of terrestrial ET helps determine the biological environment and its water use efficiency
- ET is of primary interest to water resources management in practice because many end users need ET to estimate the loss of useable water from the soil column and to help determine plant water stress for
  - drought assessment,
  - agricultural irrigation management,
  - forest fire susceptibility.
- Knowledge of surface ET helps in understanding the formation of summertime convective precipitation patterns.

Land-Atmosphere Interactions - schematic



Surface Energy Balance

- Energy Balance



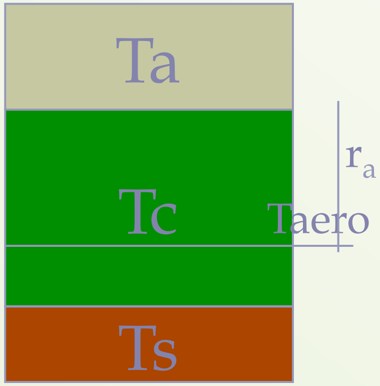
$$\lambda E = R_n - G_o - H$$

$$R_n = \left[(1-\alpha)\cdot R_{swd}\right] + \left[\varepsilon \cdot \varepsilon_a \sigma T_a^4 - \varepsilon \cdot \sigma \cdot T_0^4\right]$$

$$G_0 = R_n \cdot C \exp(-\beta LAI)$$

- The difference in the Surface Energy Balance methods is the way that they calculate the Sensible Heat
- Single Source parameterization
  - ✓ SEBAL, SEBI
  - ✓ Problem
    - r_a and T_{aero} can not be measured from space (yet).

$$H = \rho_a C_p \frac{(T_{aero} - T_a)}{r_a}$$



- Two source models
  - ✓ (TSEB, TSTIM, ALEXI)
  - ✓ Problem
    - model is too complex for implementation for global coverage

$$H = \rho_a C_p \left[\frac{(T_c - T_a)}{r_{ac}} - \frac{(T_s - T_a)}{r_{ac} + r_{as}}\right]$$

Sensible heat: Energy Cascade

- The sensible h
influenced by
atmosphere.
  - Energy casca
    - Richardsor
      - *"big wh*
have le

$$\frac{\partial \rho}{\partial t} + \frac{\partial \rho u}{\partial x} + \frac{\partial \rho v}{\partial y} + \frac{\partial \rho w}{\partial z} = 0 \quad (1)$$

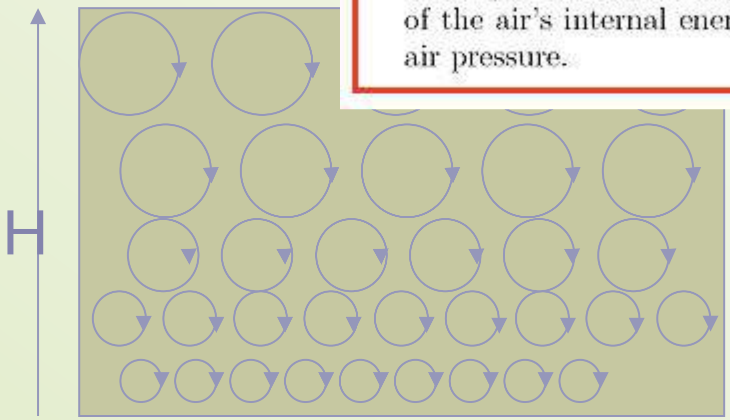
$$\frac{\partial \rho u}{\partial t} + \frac{\partial (\rho u^2)}{\partial x} + \frac{\partial (\rho u v)}{\partial y} + \frac{\partial (\rho u w)}{\partial z} = -\frac{\partial p}{\partial x} + \nu \left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2} \right) \quad (2)$$

$$\frac{\partial \rho v}{\partial t} + \frac{\partial (\rho u v)}{\partial x} + \frac{\partial (\rho v^2)}{\partial y} + \frac{\partial (\rho v w)}{\partial z} = -\frac{\partial p}{\partial y} + \nu \left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} + \frac{\partial^2 v}{\partial z^2} \right) \quad (3)$$

$$\frac{\partial \rho w}{\partial t} + \frac{\partial (\rho u w)}{\partial x} + \frac{\partial (\rho v w)}{\partial y} + \frac{\partial (\rho w^2)}{\partial z} = -\frac{\partial p}{\partial z} + \nu \left(\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial z^2} \right) \quad (4)$$

$$\frac{\partial \rho E}{\partial t} + \frac{\partial (\rho u E)}{\partial x} + \frac{\partial (\rho v E)}{\partial y} + \frac{\partial (\rho w E)}{\partial z} = -\frac{\partial p u}{\partial x} - \frac{\partial p v}{\partial y} - \frac{\partial p w}{\partial z} + S \quad (5)$$

where ρ is the air density, u, v, w are the components of the air's velocity, E is measure of the air's internal energy (which allows us to compute its temperature) and p is the air pressure.



- State of atmosphere needs to be taken into account

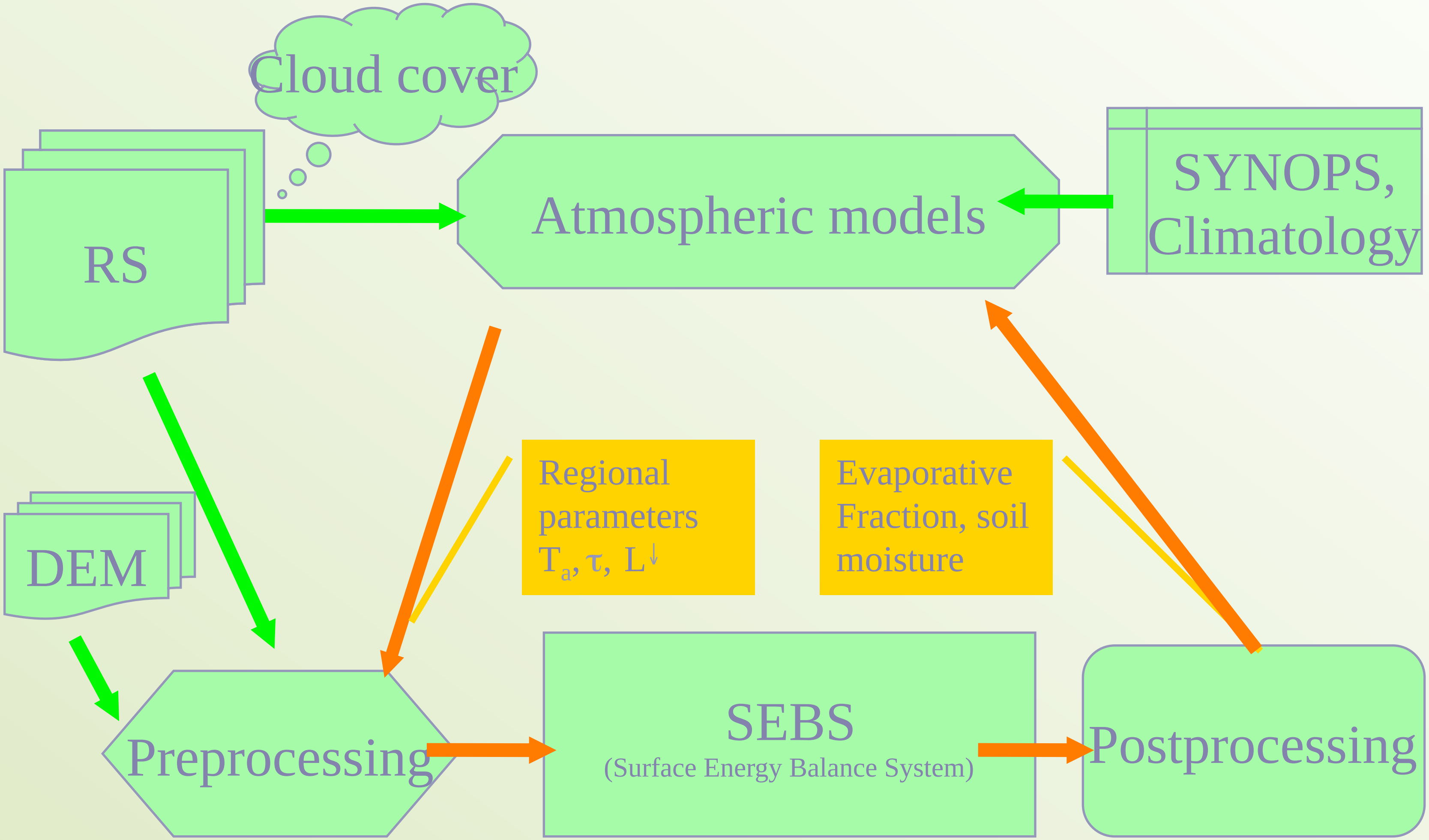
Energy Balance Models

- One source models (SEBAL, S-SEBI).
  - use the variation within the image of surface temperature
    - ✓ SEBAL and S-SEBI. (Bastiaanssen 2000; Bastiaanssen et al, 2005; French et al. 2005; Timmermans et al., 2007)
- Two source models (TSEB, TSTIM, ALEXI):
  - Partitioning sensible heat between the vegetated canopy and the soil
    - ✓ the 'virtual' sink/source height of these variables is replaced by the physical vegetation height and the soil height, which are physically measurable quantities. (Norman et al, 2005; Kustas and Norman,1999)
    - ✓ Difficult for large scale estimations
- One source Physical Model (SEBS)
  - calculates the sensible heat by iteration over a set of equations. These equations characterize the physical relationships between the mean wind speed, the mean temperature and the Obukhov length. (Su, 2002, Jia et al, 2003, Su et al., 2005, McCabe and Wood, 2006).
    - ✓ Incorporates physical parameterization of roughness heights and is therefore applicable at large scales

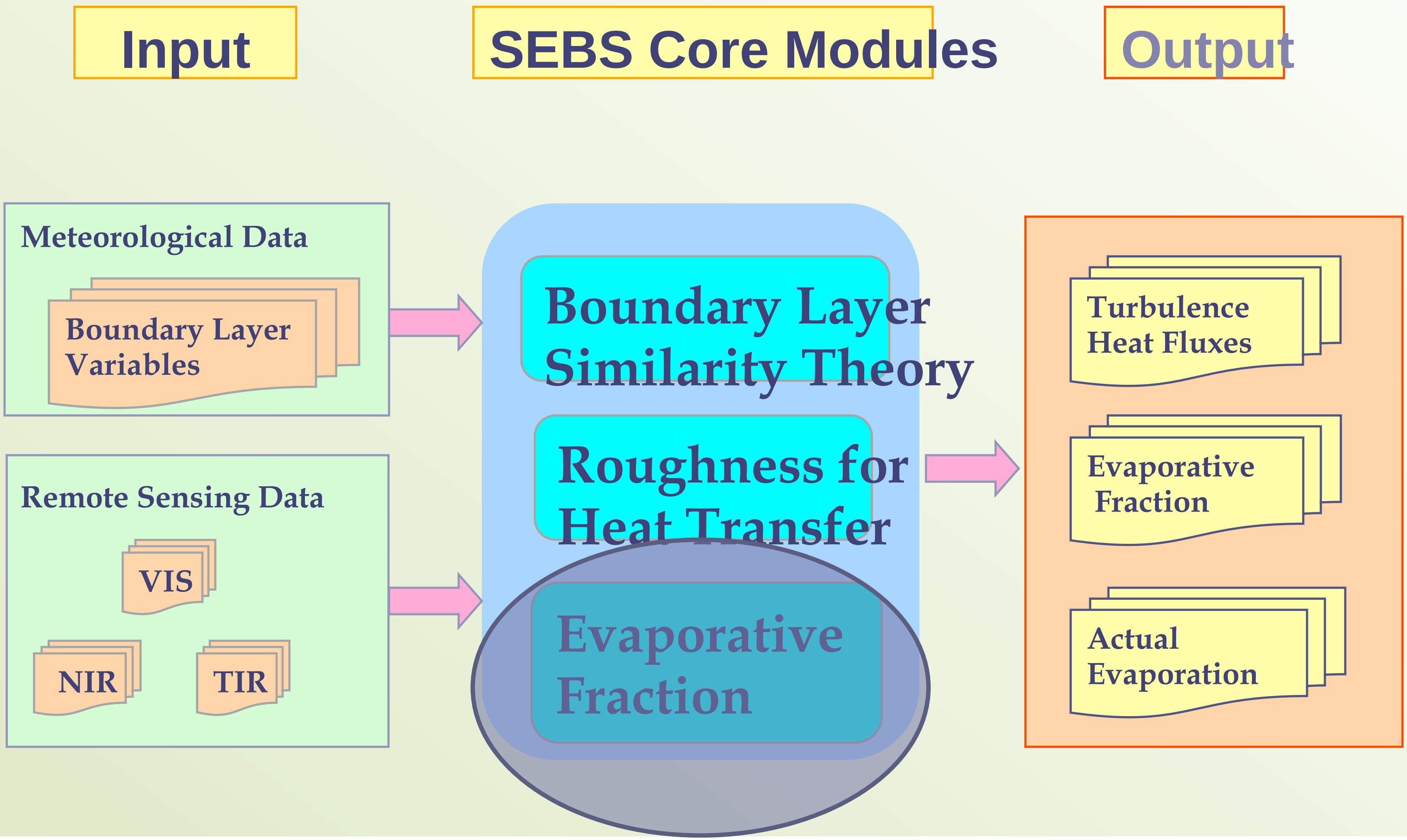
SEBS advantages

- SEBS advantages
  - physical based calculation of the aerodynamic resistances
    - ✓ Iteration through coupled set of equations representing physical processes.
    - ✓ Local and regional scales
      - Monin Obukhov Similarity (MOS) theory
      - Bulk Atmospheric Similarity (BAS) theory
  - incorporation of surface state in calculation of daily evapotranspiration
    - ✓ calculation of theoretical limits of evapotranspiration
      - wet pixel (Penman Monteith), dry pixel (0)
    - ✓ the evaporative fraction
  - validated in several studies

General Methodology

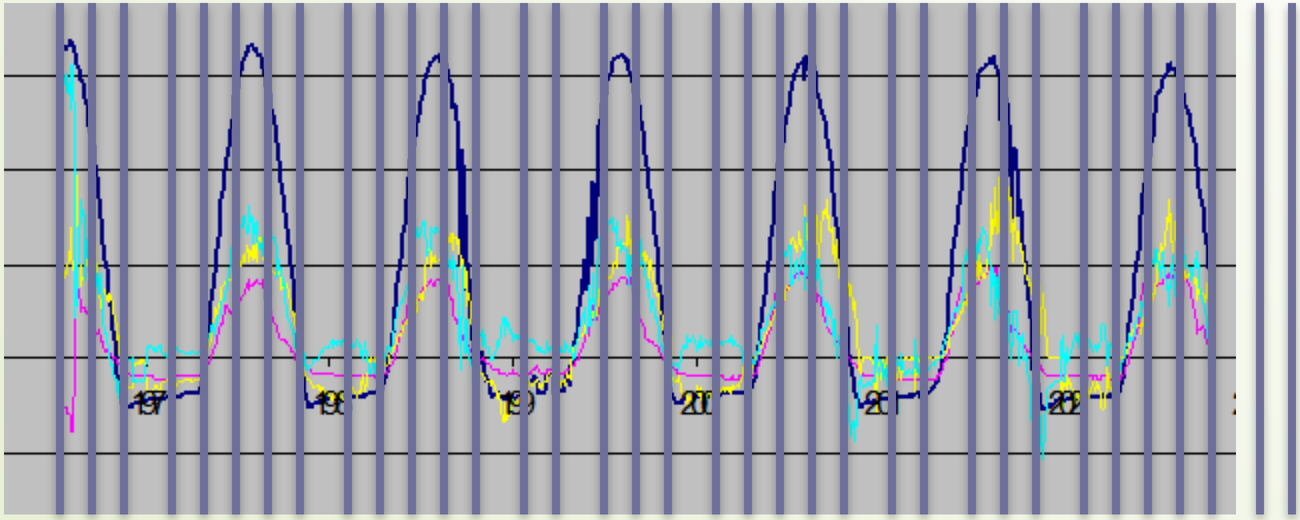


SEBS - The Surface Energy Balance System



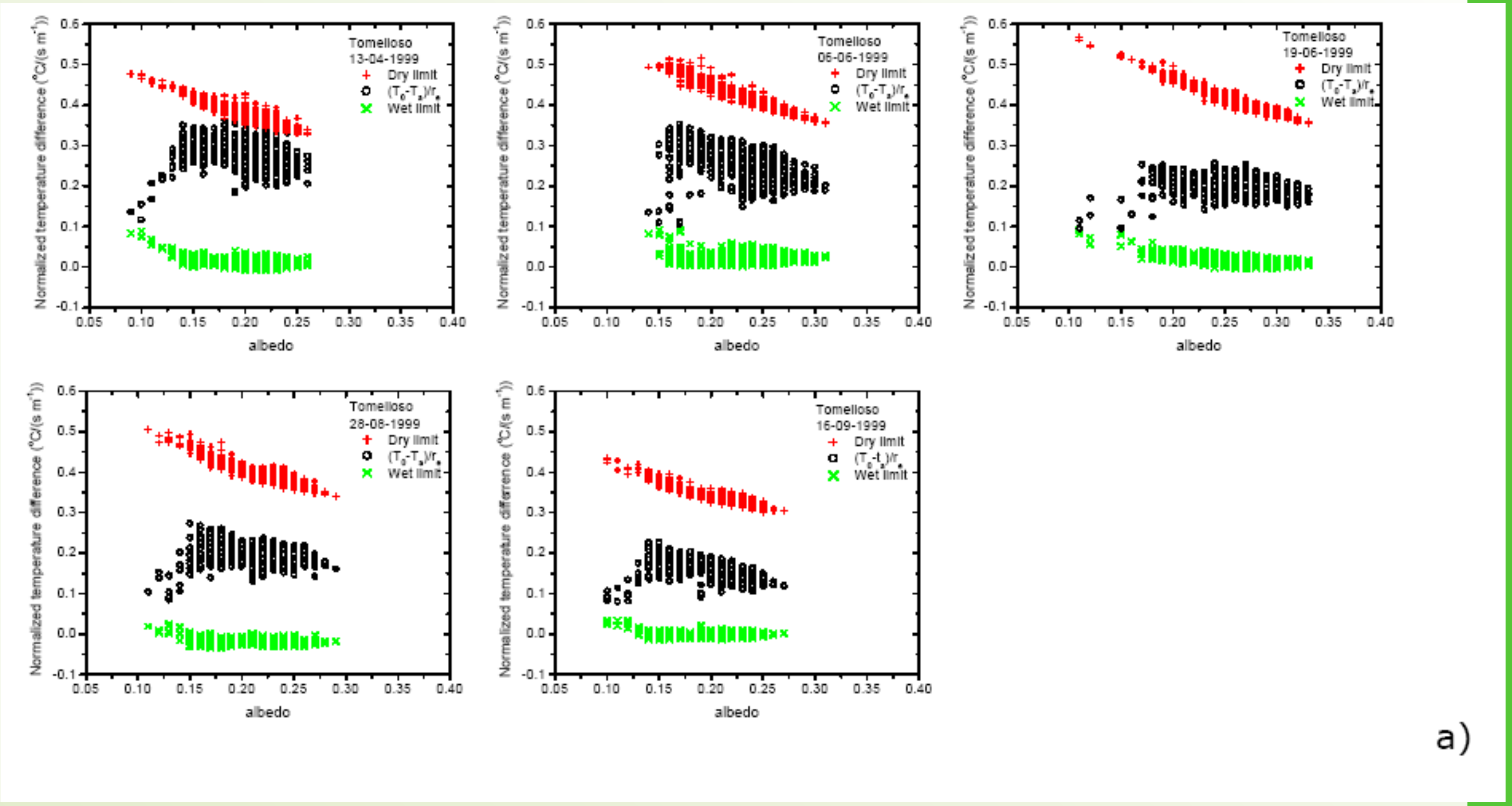
Surface

- Satellite Overpasses



- Measurements of Rn,G0, H and LE are instantaneous values!

Evaporative fraction



SEBS Basic Equations

$$R_n = G_0 + H + \lambda E$$

$$\lambda E_{dry} = R_n - G_0 - H_{dry} \equiv 0, \quad or$$
$$H_{dry} = R_n - G_0$$

$$\lambda E_{wet} = R_n - G_0 - H_{wet}, \quad or$$
$$H_{wet} = R_n - G_0 - \lambda E_{wet}$$

$$H_{wet} = \left((R_n - G_0) - \frac{\rho C_p}{r_{ew}} \cdot \frac{e_s - e}{\gamma} \right) \Big/ \left(1 + \frac{\Delta}{\gamma} \right)$$

$$\Lambda_r = \frac{\lambda E}{\lambda E_{wet}} = 1 - \frac{\lambda E_{wet} - \lambda E}{\lambda E_{wet}}$$

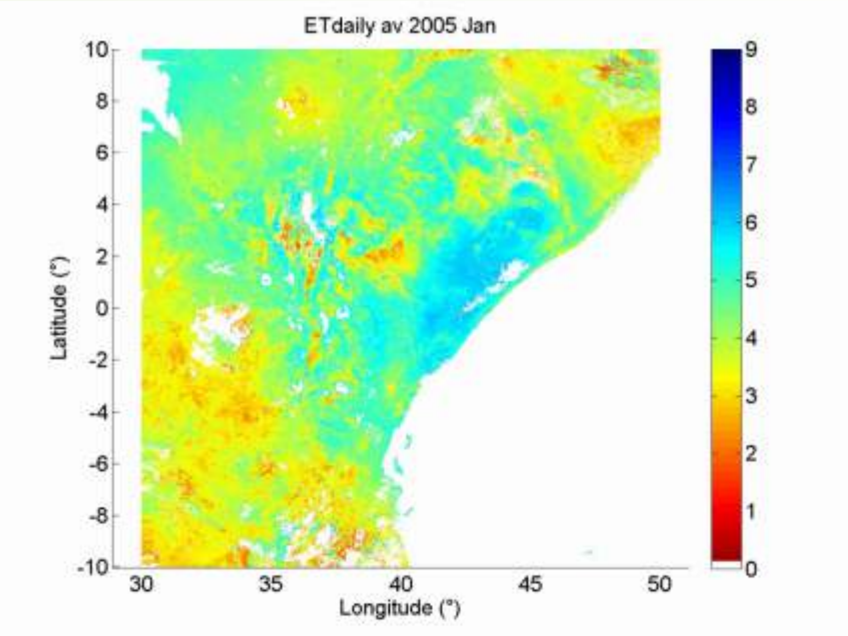
$$\Lambda_r = 1 - \frac{H - H_{wet}}{H_{dry} - H_{wet}}$$

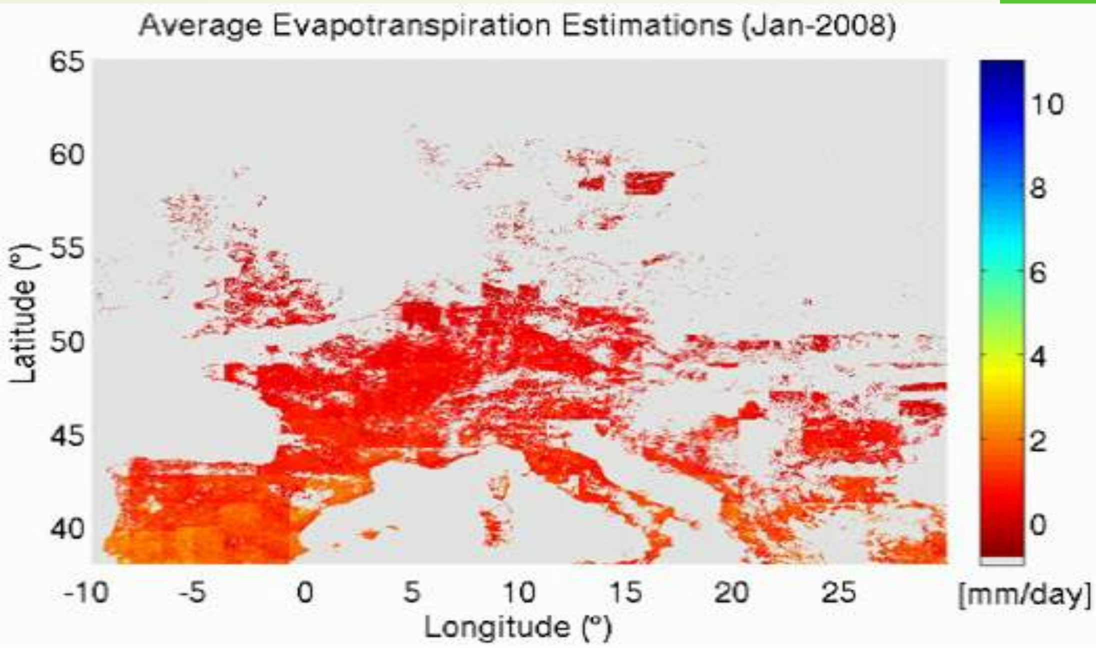
$$\Lambda = \frac{\lambda E}{R_n - G} = \frac{\Lambda_r \cdot \lambda E_{wet}}{R_n - G}$$

$$H = (1 - \Lambda) \cdot (R_n - G)$$
$$\lambda E = \Lambda \cdot (R_n - G)$$

Evapotranspiration

- ET from WACMOS
  - W.ET
  - Synergistic use
    - ✓ AATSR/MERIS
    - ✓ MODIS
  - Period: 2003-2010
- Areas
  - Horn of Africa
  - Europe
  - China (upcoming)



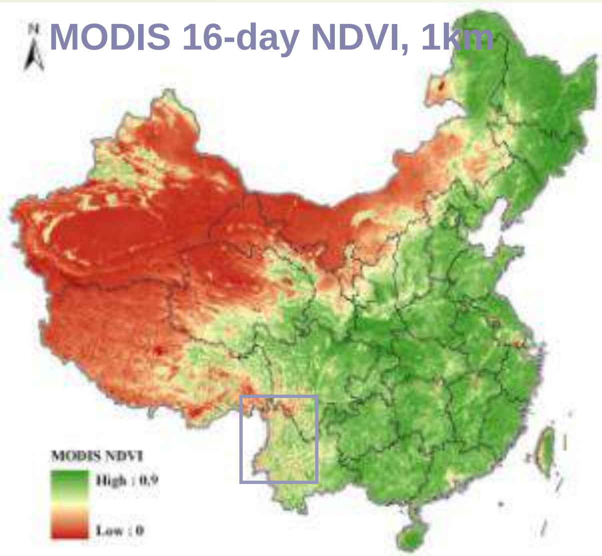


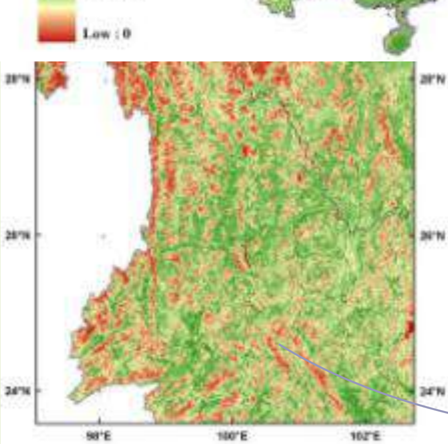
Uncertainty of such products

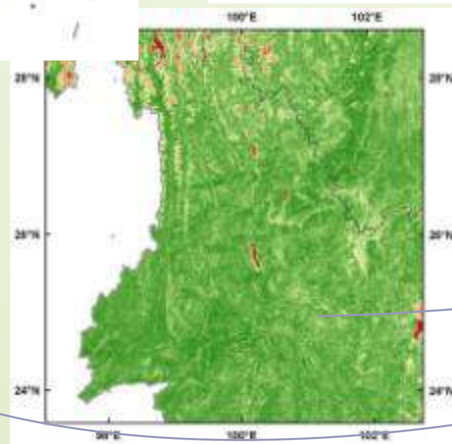
- What is worse:
  - A false prediction of sunshine?
  - A false prediction of rain?
- What the better prediction is better?
  - One with high uncertainty that turns out to be wrong
  - One with low uncertainty that turns out to be true
- Uncertainty in each of the processing steps
  - Sensor noise
  - Atmospheric correction error
  - Sensitivity model
  - Model error
  - Calculation error

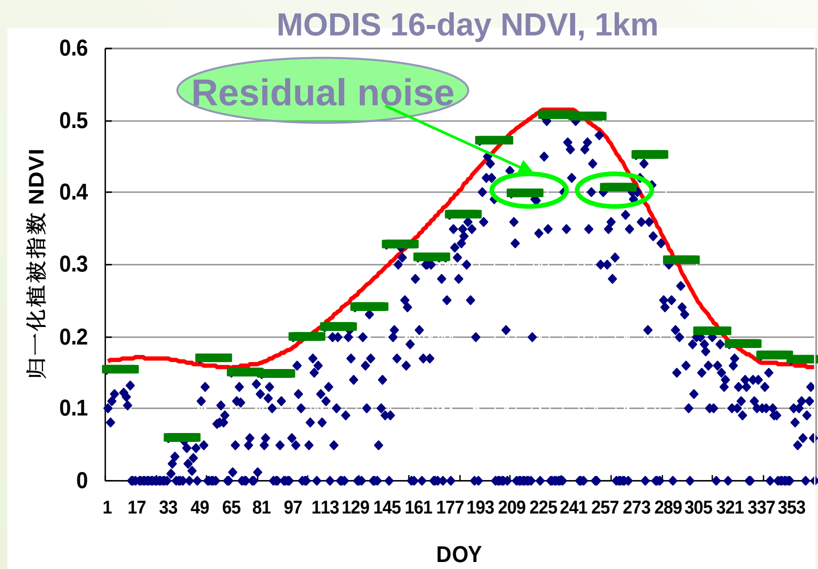
Data quality

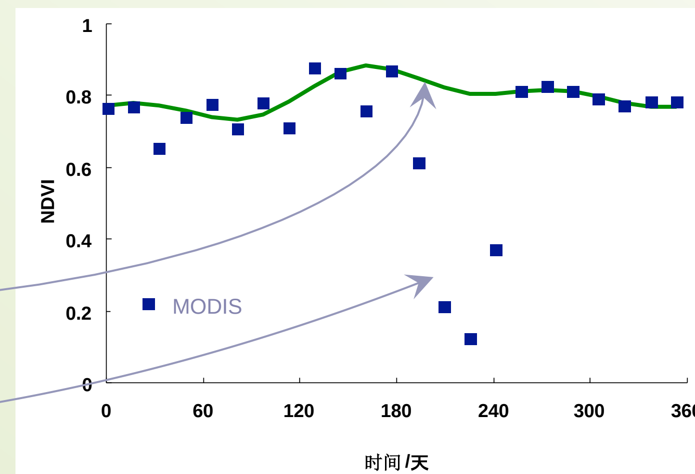
Noise in NDVI products







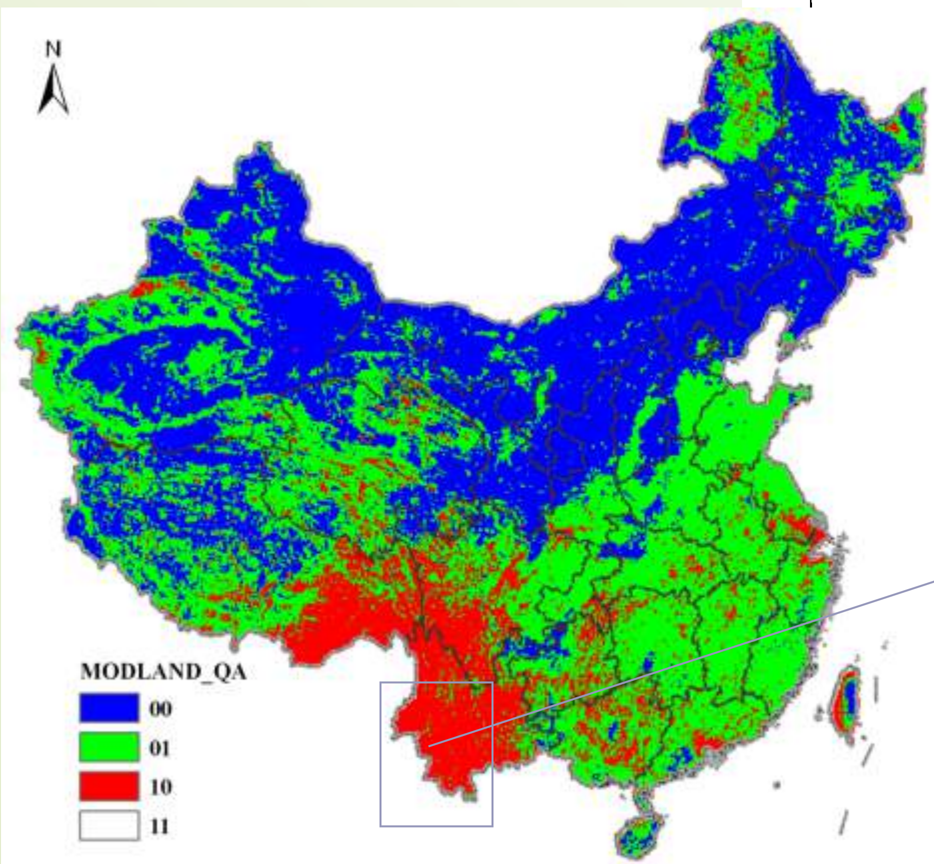


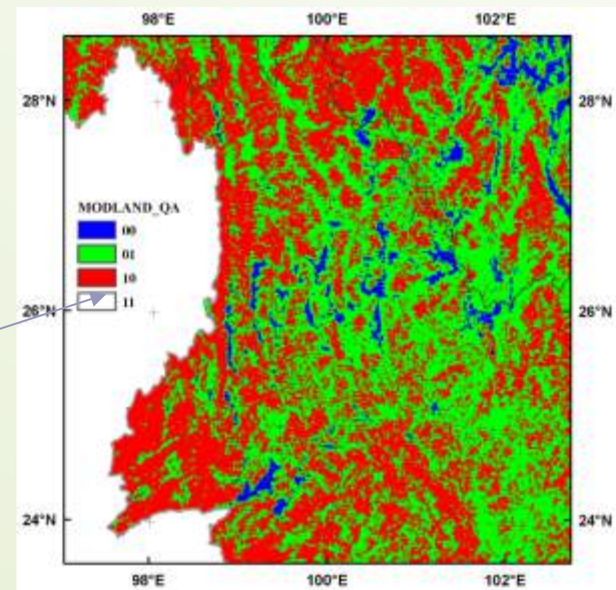


Data flagging

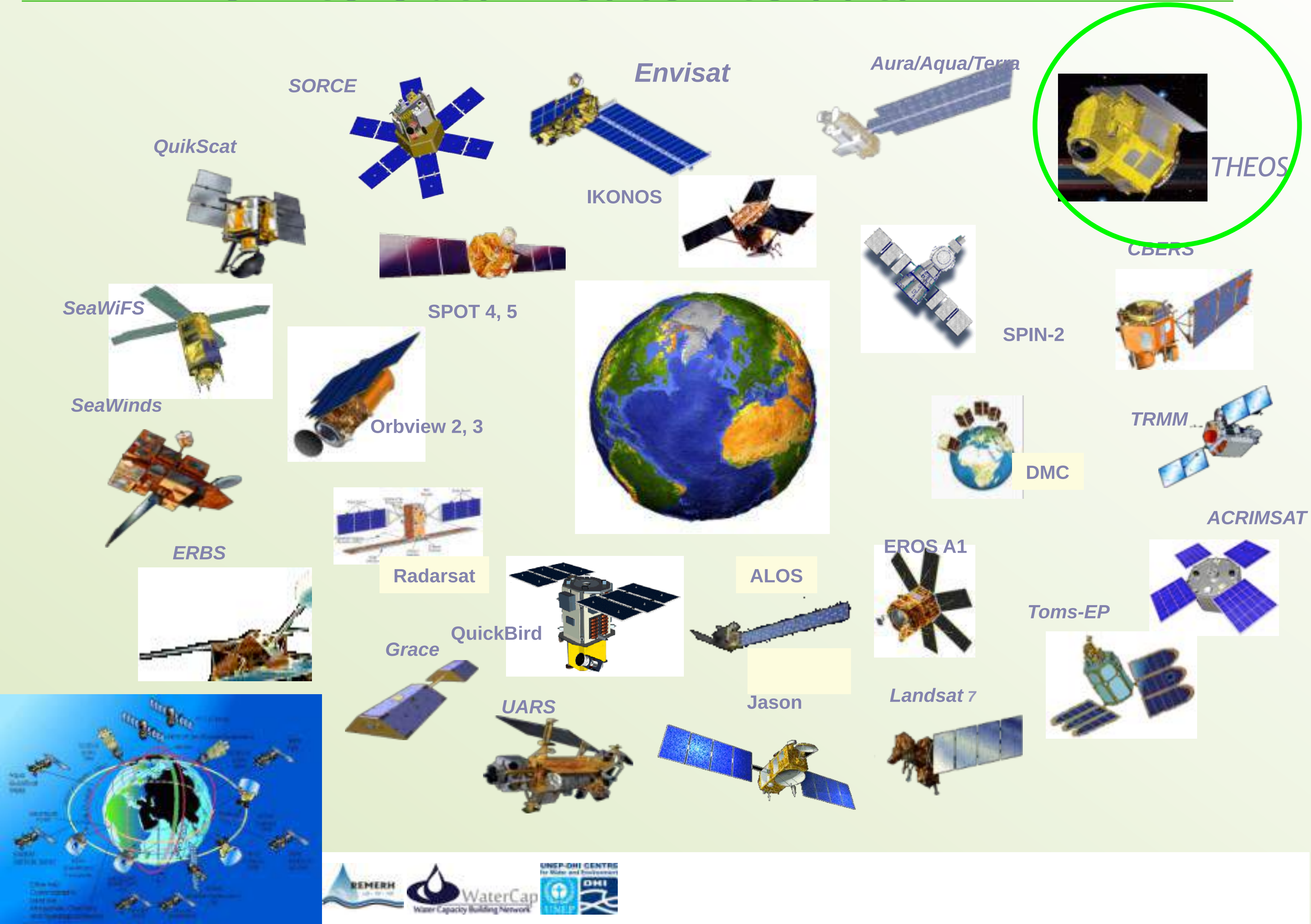
MODIS data quality layer

bit	Long Name	Value	Key
0–1	MODLAND_QA	00	VI produced, good quality
		01	VI produced, but check other QA
		10	Pixel produced, but most probably cloudy
		11	Pixel not produced due to other reasons than clouds





How to obtain satellite data?



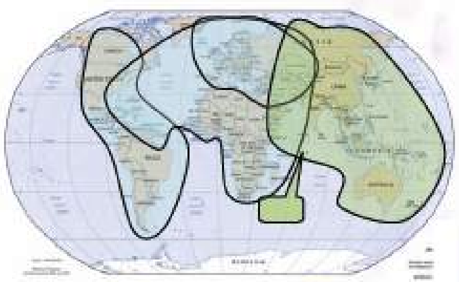
Available Remote sensing Data :

- Precipitation
  - TRMM rainfall (5km, 3hourly)
    - ✓ ftp:/disc2.nascom.nasa.gov/data/s4pa/TRMM_L3/TRMM_3B42_daily
  - MSG rainfall (3km, 30 minutes)
    - ✓ GEONETCAST
  - CMORPH rainfall (8km, 30 minutes)
    - ✓ ftp://ftp.cpc.ncep.noaa.gov/precip/global_CMORPH/daily_025deg/
- Evapotranspiration
  - MODIS
    - ✓ **ftp://ftp.ntsg.umt.edu/pub/MODIS/Mirror/MOD16/**
  - WACMOS
    - ✓ Wacmos.org
    - ✓ (registration needed)
  - LANDSAF
    - ✓ http://landsaf.meteo.pt/
    - ✓ (registration needed)
- Soil Moisture
  - AMSR-E
  - WACMOS
    - ✓ http://www.esa-soilmoisture-cci.org/

Group on Earth Observations

GEONETCast

- **A near real-time system to disseminate space-based, air-borne and in situ data, metadata and products through satellites**
- **The vision is to provide easy access to as much data and as many people as possible**



Infrastructure and Data Provider

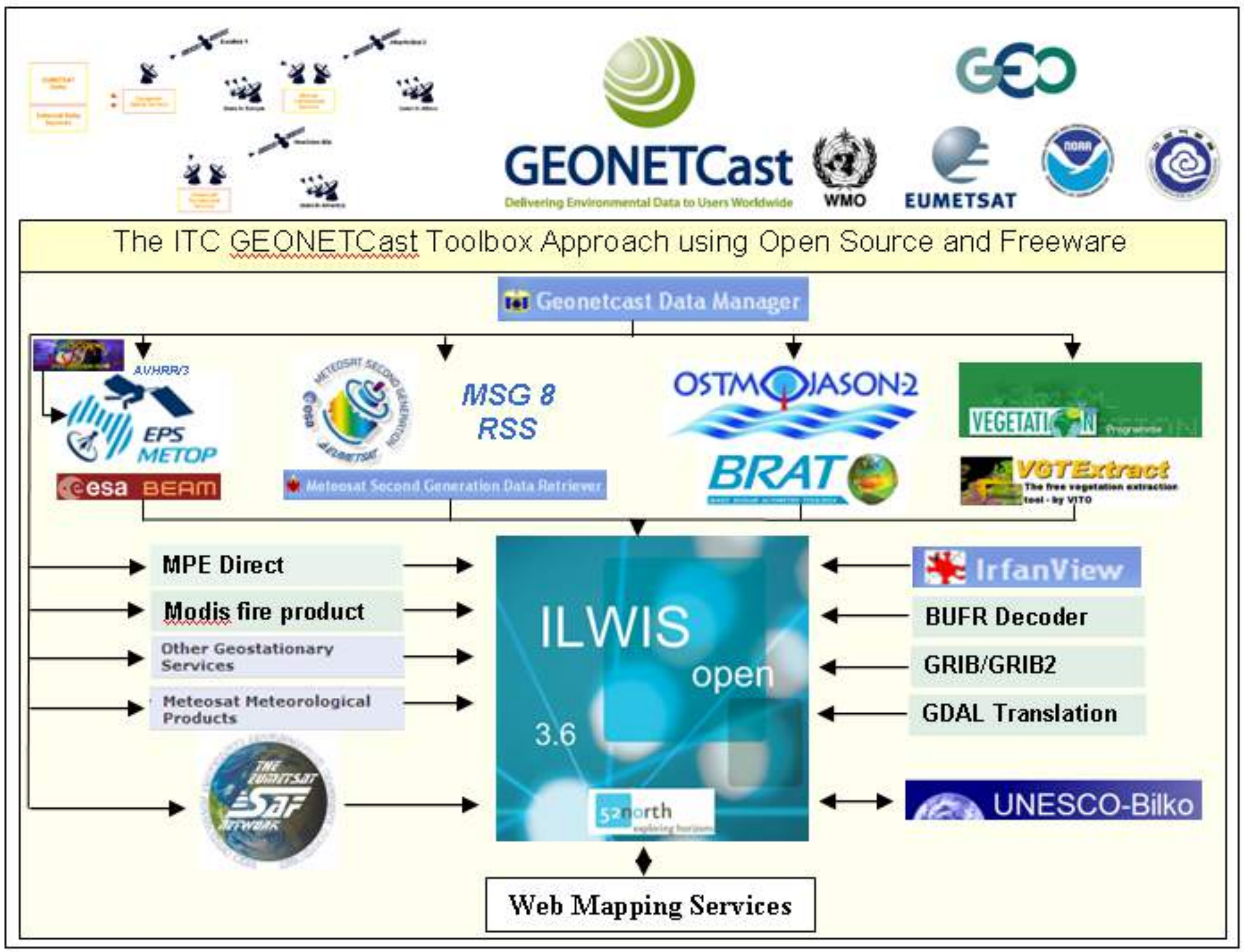
Data Dissemination is One of Key Components

User Capacity Building

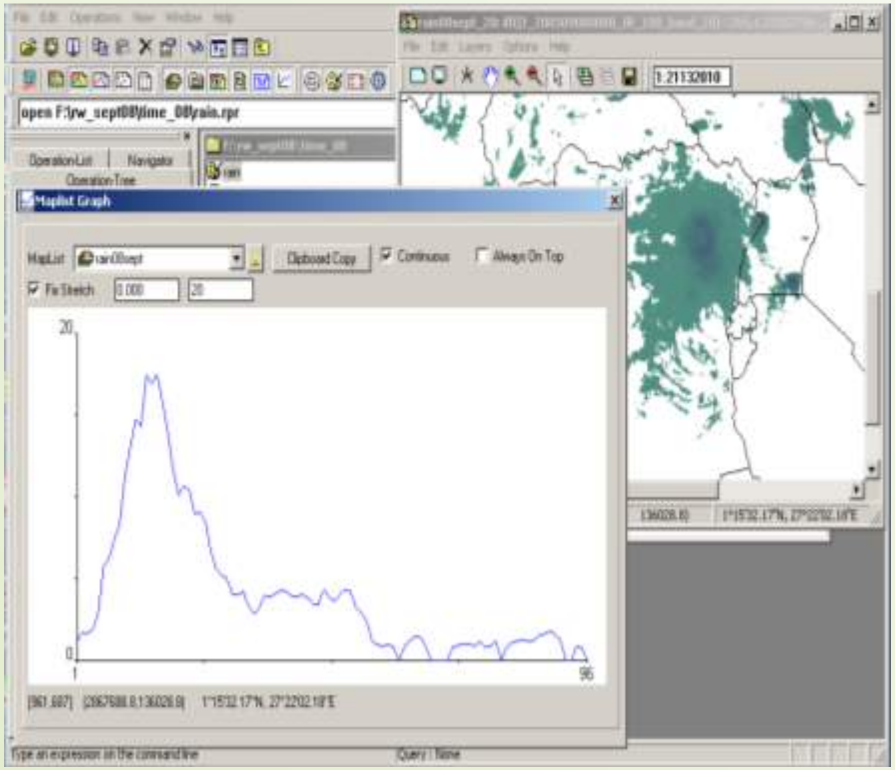
Data Policy | **User Requirement** | **Technical Specifications**

ITC GEONETCast Toolbox approach

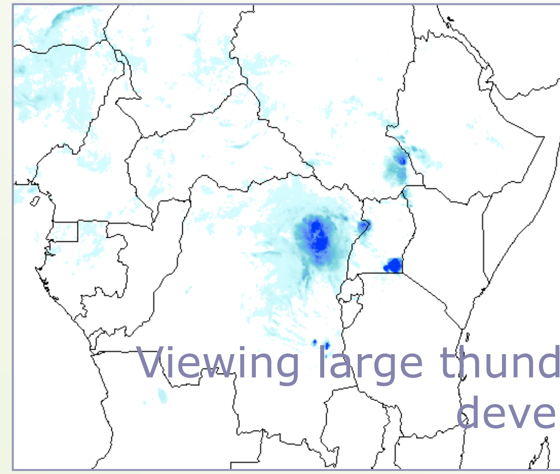
Rationale: Develop an easy to operate, open system for rapid data retrieval, processing and dissemination (via web-based services)



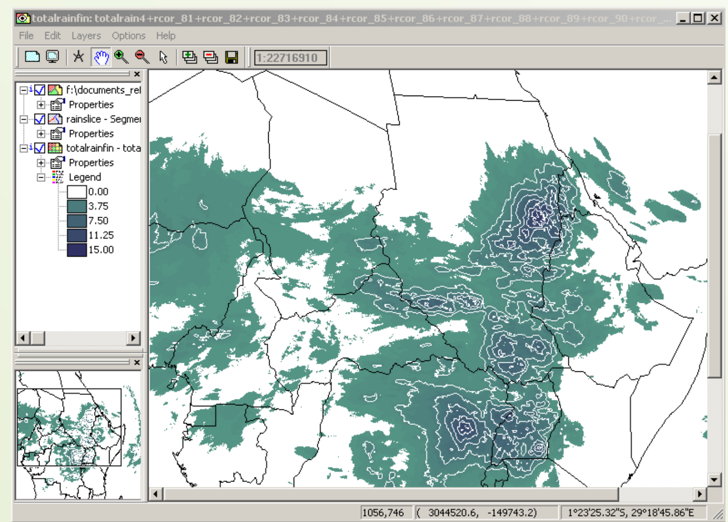
Precipitation from GEONETCAST



15-minute interval evaluation of
Rain intensity (4*24=96)
Using ILWIS MAPLIST command
ILWIS graphic analysis output



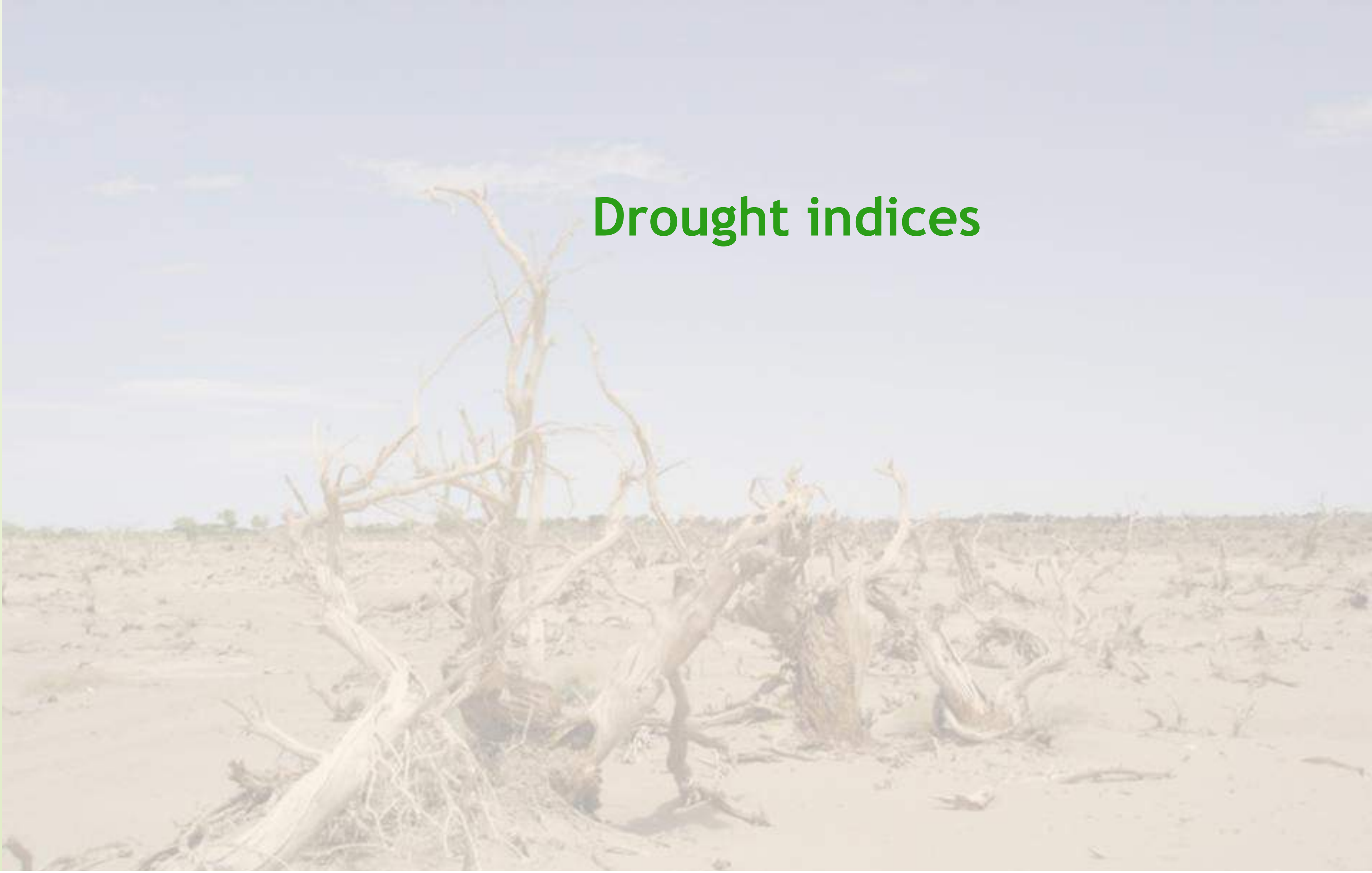
Viewing large thunderstorm development



Daily rainfall mapping using aggregation techniques

End of part 2

Drought indices



Drought Definitions

- Which kind of droughts are there?
  - Meteorological drought
    - ✓ lack of precipitation over a region for a period of time. Precipitation has been commonly used for meteorological drought analysis
  - Agricultural drought
    - ✓ Declining soil moisture and consequent crop failure without any reference to surface water resources
  - Hydrological drought
    - ✓ Inadequate surface and subsurface water resources for established water uses of a given water resources management system.
  - Socio-economic drought
    - ✓ failure of water resources systems to meet water demands and thus associating droughts with supply of and demand for an economic good (water)

Drought monitoring requirements

- Several drought indices have been derived in recent decades.
- Commonly, a drought index is a prime variable for assessing the effect of a drought and defining different drought parameters, which include intensity, duration, severity and spatial extent.
- A required characteristics of a drought index
  - The index must be able to reflect developing short-term dry conditions
  - Index should not have any seasonality
    - (irrespective of summer/winter)
  - Index should be spatially comparable
    - (irrespective of humid/arid)
- It should be noted that a drought variable should be able to quantify the drought for different time scales for which a long time series is essential.

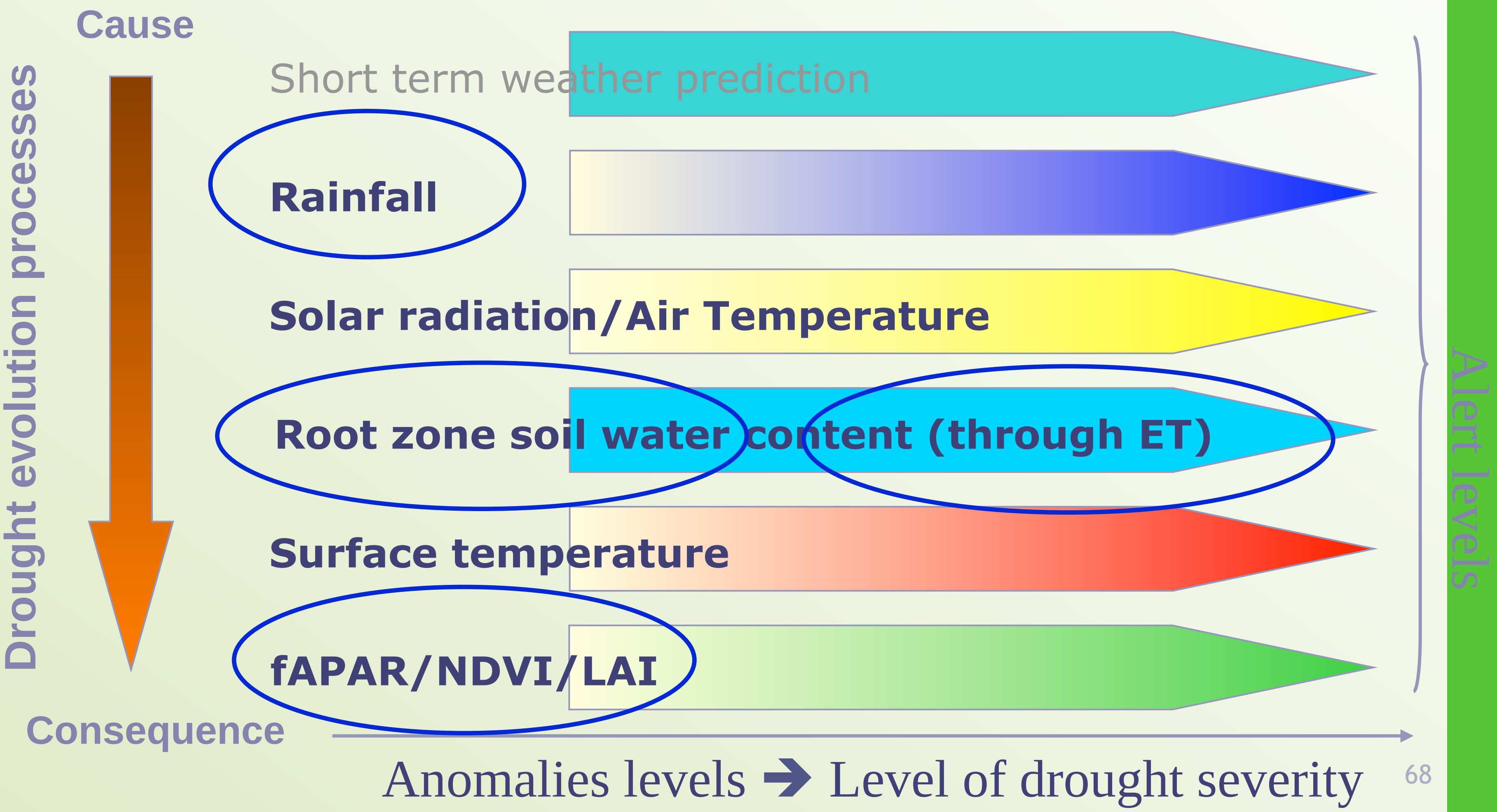
Drought indices

- Palmer
  - Palmer Drought Severity Index(PDSI), 1964(!)
    - Widely used and able to estimate agricultural drought, but lags several months behind of the drought. Also will not work properly in case of frozen ground
- Palmer Hydrological Drought index
  - Is developed on basis of PDSI, to quantify long term impact of drought. Uses precipitation, outflow and storage and is consequently very slow
- Percent of Normal
  - Effective in one region, but cannot identify specific impact or Inhibitation factor for drought risk mitigation management
- Crop Moisture Index (CMI)
  - Is faster than PDSI and PHDI
- Standardized Precipitation Index (SPI)
  - Can provide an early warning system.
- Evapotranspiration Deficit Index
- Water Requirement Satisfaction Index
- Soil Moisture Anomalies
- Soil Moisture Deficit Index
- NDVI

- …..

Drought indicators by Remote Sensing

Towards alert levels



Rain : Precipitation anomaly

Drought occurs due to shortage of water at land surface which is mainly from precipitation

- **Precipitation anomaly**

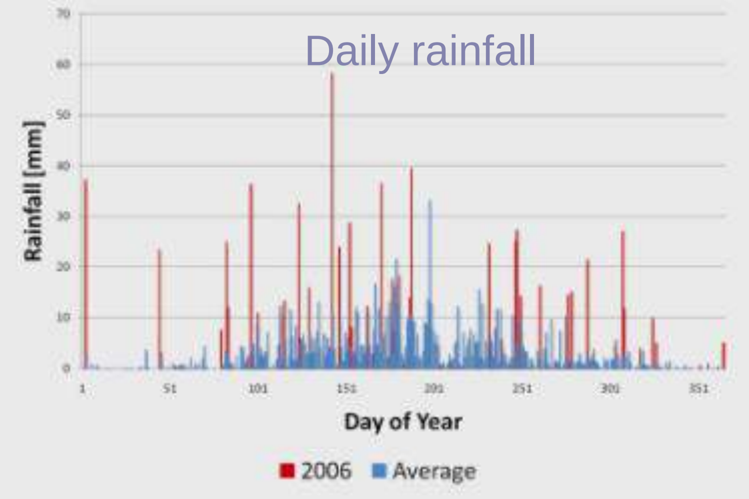
  $\Delta P = P - P(mean)$

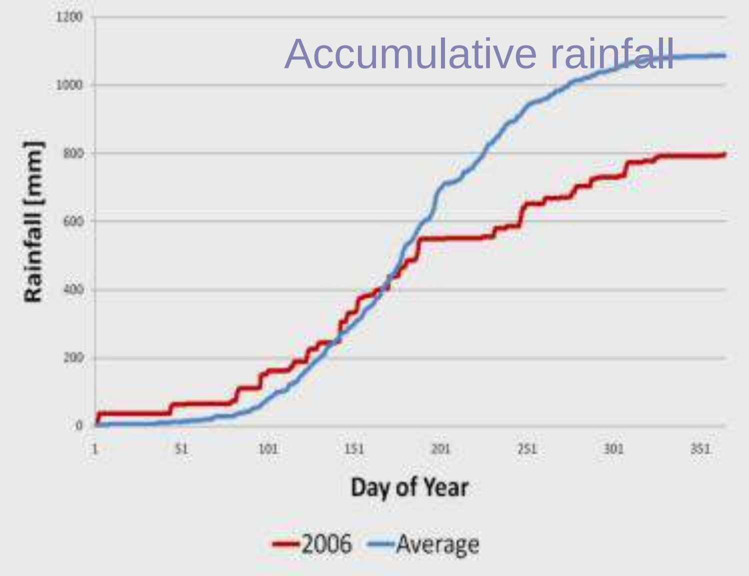
- **Accumulative precipitation anomaly**

  $\Delta Pacc = Pj - Pj\ (mean)$ (j = a specific period, week, month, year, etc)

- Long lasted (accumulative) negative rainfall anomaly leads to severe drought.

- Short-term shortage of precipitation is not necessary to result in drought.

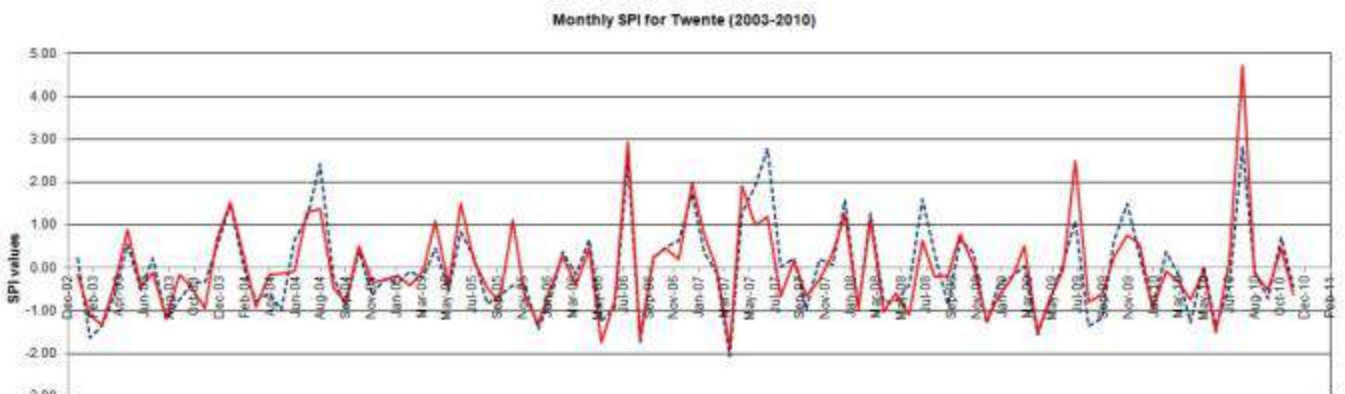




Rain: Standardized Precipitation Index

- Standard in meteorological world
- Easily adaptable
- 3/6/9 Monthly Moving average
  - where, is the monthly precipitation observation, is the mean monthly precipitation, and is the standard deviation.

$$SPI = \frac{\left(x_i - \bar{x}\right)}{\sigma}$$



Classification of SPI (Edward and McKee 1996)

+ 2 .00	Extremely wet
+1.50 to +1.99	Very wet
+1.00 to +1.49	Moderately wet
-0.99 to +0.99	Normal
-1.00 to -1.49	Moderately dry
-1.50 to -1.99	Severely dry
<-2.00	Extremely dry

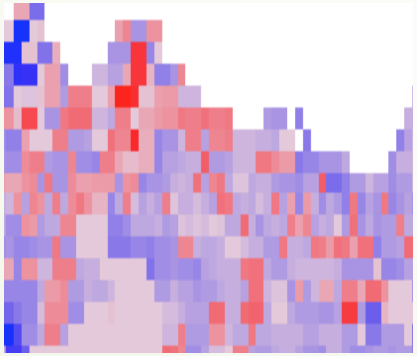
Water Requirement Satisfaction Index (WRSI)

- Water satisfaction requirement
  - an operational monitoring which indicates performance of a crop based on the availability of water during a growing season (Allen et al., 1998)

$$WRSI_j = \frac{AET}{WR} * 100$$

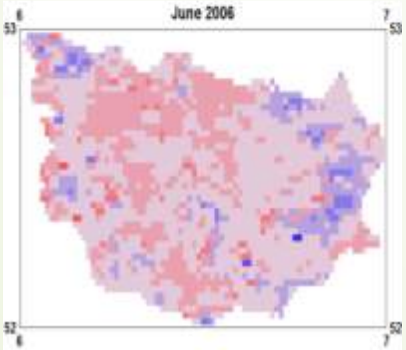
AET : seasonal actual crop evapotranspiration (mm d-1)
WR: seasonal water req. (mm d-1) (WR = PET*kc)

Evapotranspiration Drought Index (ETDI)



Lower evapotranspiration values are indicators of plant moisture stress. ETa in combination ETref is a good indicator for moisture stress detection in crops and precedes the onset of drought.

ET has a very "short memory" of land surface property that responds very quickly to changes and anomalies in climate forcing. \ an excellent early warning indicator and could provide a hint of an impending drought.



- **Weekly/Monthly Water Stress**

  WS = (ETref-AET)/Etref

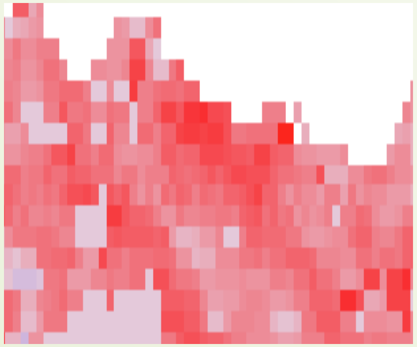
- **Water Stress Anomoly**

  WSA = (MWSj-WSij)/ (MWSj-minWSj)x100 if WS=MSW

  WSA = (MWSj-WSij)/ (maxWSj-MWSj)x100 if WS>MSW

- Evapotranspiration Deficit Index

$$ETDI_j = 0.5 ETDI_{j-1} + \frac{WSA_j}{50}$$



ETDI will range from -4 (very dry) to 4 (very wet), and can be calculated for different depths of soil moisture. ETDI-2, ETDI-4, ETDI-6, resp top 2,4,6 feet.

Soil Moisture as a drought indicator

Drought occurs due to shortage of water at land surface. The primary source of water for the plants is soil moisture (though some plants have roots that go to depths as much as 60 meters)

- **Soil Moisture Deficit**

  SD = (SWij-MSWj)/ (MSWj -minWj)x100 if SW=MSW

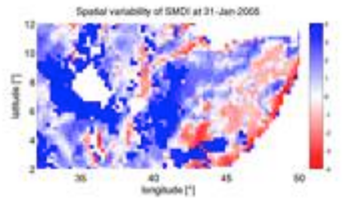
  SD = (SWij-MSWj)/ (maxSWj -MWj) x100 if SW>MSW

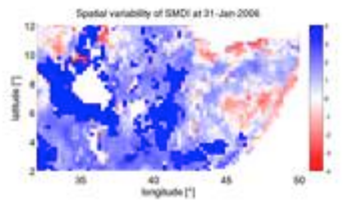
  SW = soil water at month j and year I, MSW = longterm mean soil water at month j, minSW = longterm minimum soil water at month j, maxSW = longterm maximum soil water at month j

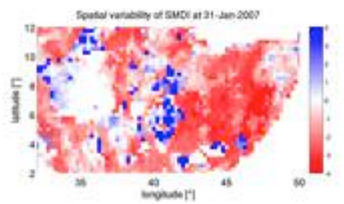
- **Soil Moisture Deficit Index**

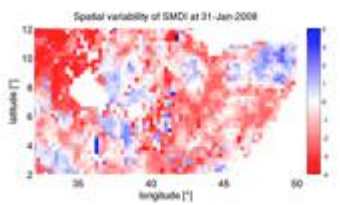
  SMDIj = 0.5*SMDIj +SDj / (50)

SMDI will range from -4 (very dry) to 4 (very wet), and can be calculated for different depths of soil moisture. SMDI-2, SMDI-4, SMDI-6, resp top 2,4,6 feet.









Drought indicators by Remote Sensing

- **Indirect Indicators**

Drought are naturally associated with land surface condition through:

- vegetation state and cover through various vegetation indices (VIs) commonly measured by visible red (R), near infrared (NIR) bands of satellite sensors;

- soil water content status through near-surface soil moisture observations from microwave bands, and land surface temperature from thermal infrared bands (TIR).

LST as a drought indicator

Higher than expected canopy temperatures are indicators of plant moisture stress ➔ LST is a good indicator for moisture stress detection in crops and precedes the onset of drought.

LST is a very "short memory" of land surface property that responds very quickly to changes and anomalies in climate forcing. ➔ an excellent early warning indicator and could provide a hint of an impending drought.

LST anomaly:

$$\Delta LST = LST - LST_{mean}$$

Temperature Condition Index (TCI) (Kogan, 1995, 2002):

$$(LST - LST_{min}) / (LST_{max} - LST_{min})$$

0 ← cold extreme
1 ← warm extreme

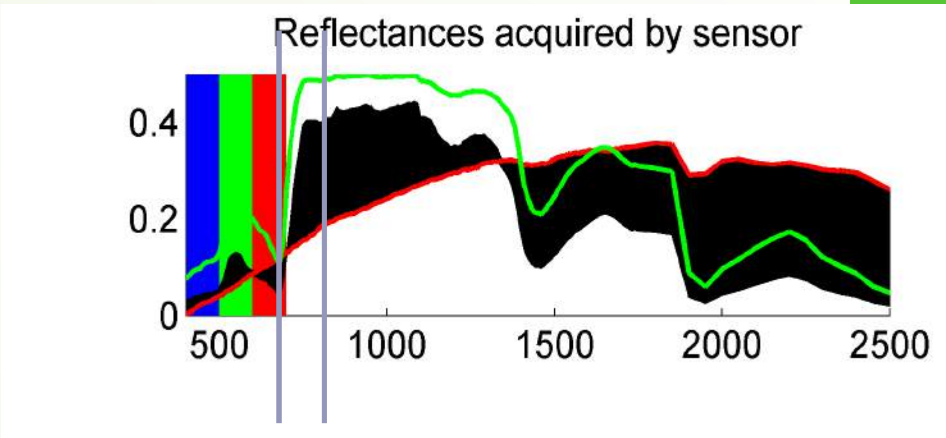
- LST_{mean}: historical mean temperature
- LST_{min}: historical minimum LST in a pixel
- LST_{max}: historical maximum LST in a pixel

Temperature Anomaly Index (TAI) (Jia et al. 2011, manuscript)**:**

$$N\_\Delta LST = \Delta LST / (LST_{max} - LST_{min})$$

-1 ~ 0 : negative anomaly corresponding to cooler than normal condition
0 ~ 1: positive anomaly corresponding to warmer than normal condition

NDVI as a drought indicator



- Drought affects vegetation state and cover, which can be observed through various vegetation indices (VIs) commonly measured by visible red (R), near infrared (NIR) bands of satellite sensors

- **NDVI anomaly:**

  Δ NDVI = NDVI – NDVImean

- **Vegetation Condition Index** (**VCI**) (Kogan, 1995, 2002):

  (NDVI - NDVImin) / (NDVImax - NDVImin)

  0 : bad vegetation condition
  1: good vegetation condition

- **Vegetation Anomaly Index (VAI)** (Jia et al. 2011, manuscript)**:**

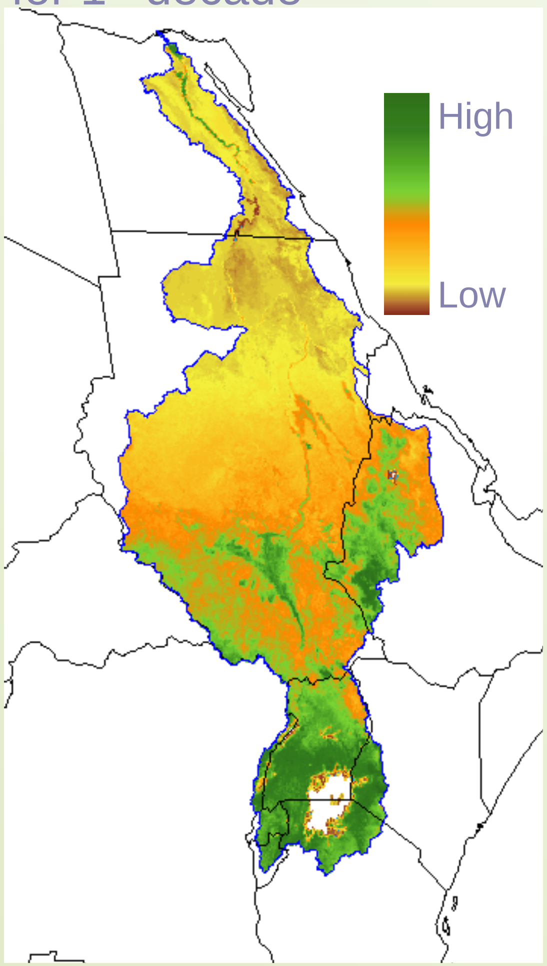
  N_ΔNDVI = Δ NDVI / (NDVImax - NDVImin)

  -1 ~ 0 : negative anomaly corresponding to decreased vegetation condition

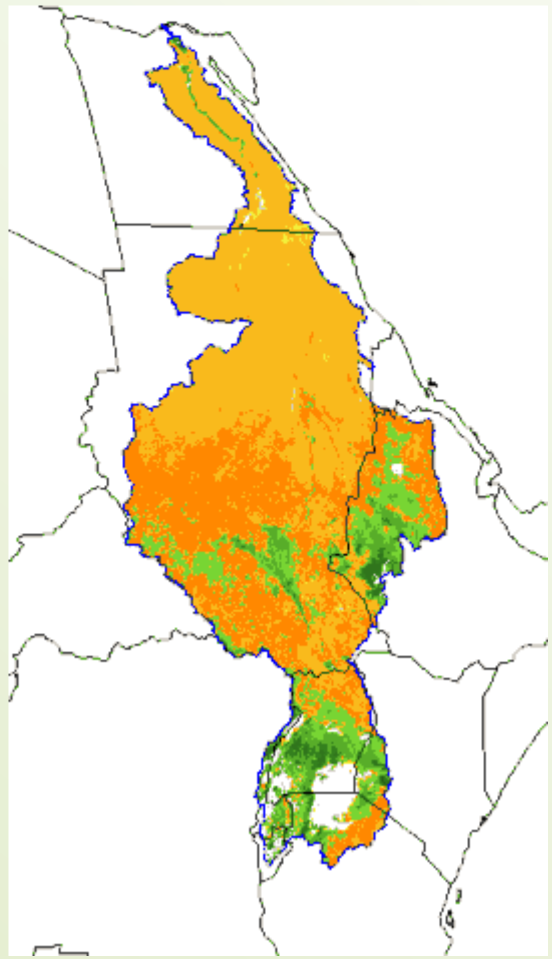
  0 ~ 1: positive anomaly corresponding to increased vegetation condition

NDVI as a drought indicator

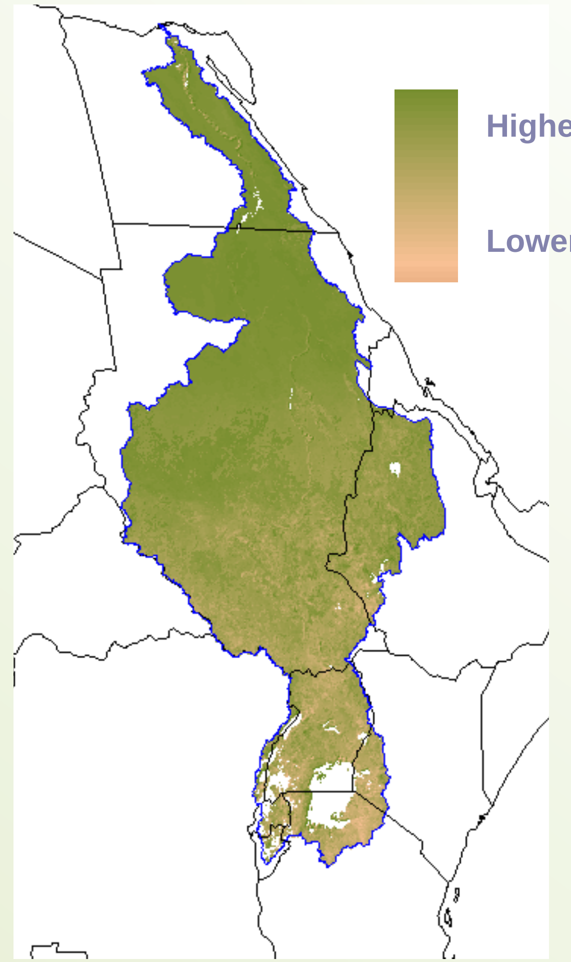
10 day Long Term Mean NDVI for 1st decade



10 day Actual NDVI of 01 to 10 /01/2006



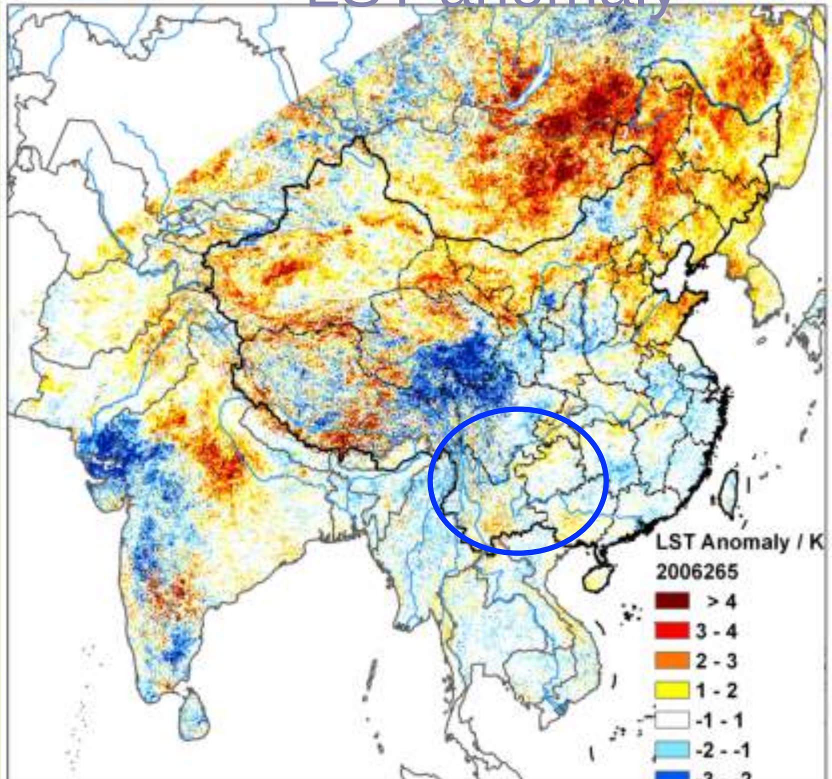
Drought Severity Index: Actual NDVI – Mean NDVI



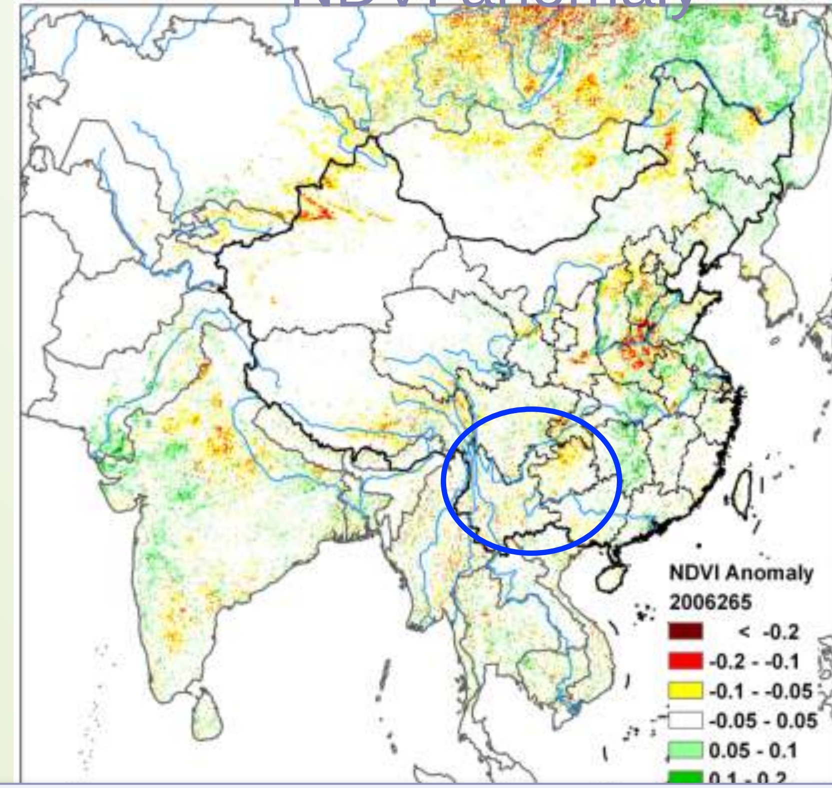
Drought Monitoring Applications

Sichuan-Chongqing 2006 Summer drought

LST anomaly



NDVI anomaly



Time lag of response to drought between LST and NDVI is 4 – 5 weeks.
LST anomaly appeared as early as around mid of June (DOY177), while NDVI anomaly occurred around beginning of August (DOY217).

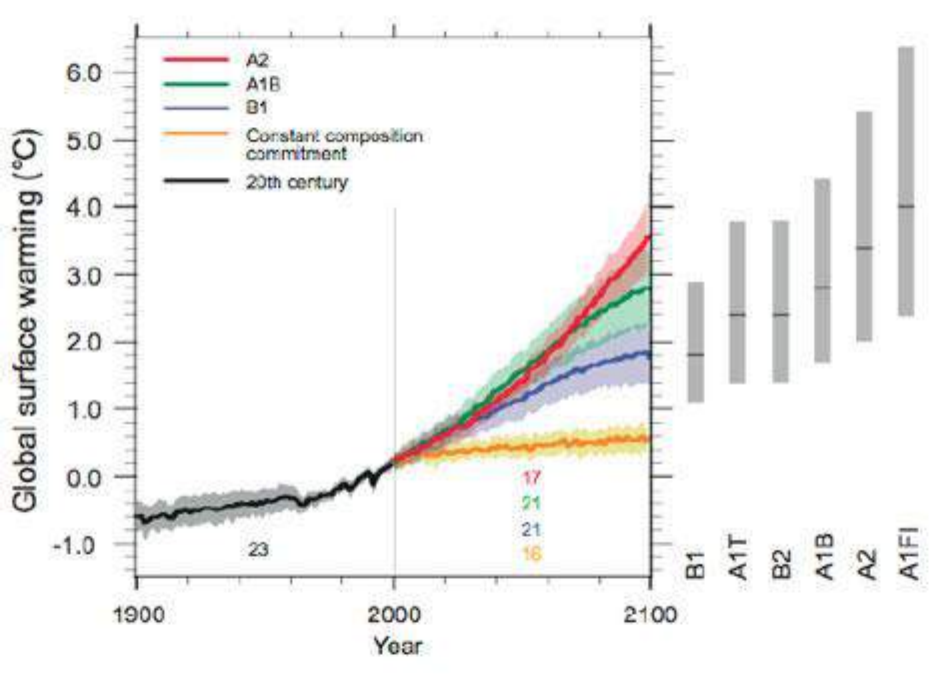
Which drought index is best suited to predict a Hazard?

Not one(!),

Instead combine indices and use synergies between them!

Climate change predictions

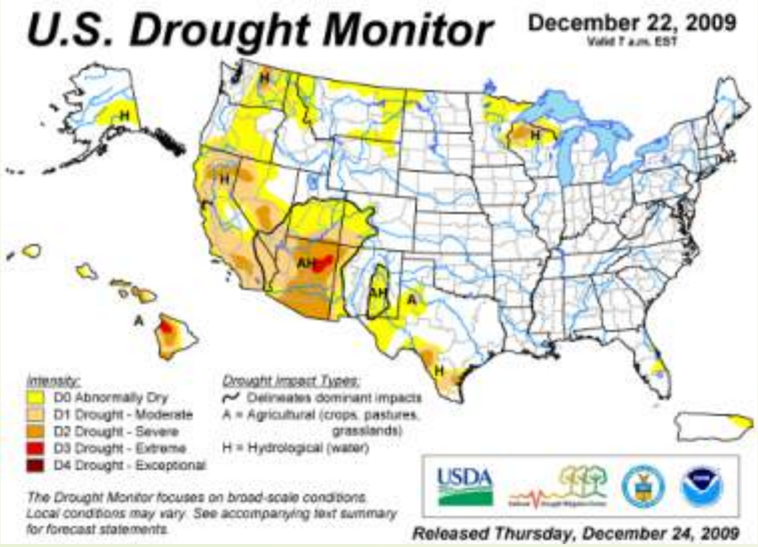
- IPCC:
  - Climate change predictions
    - ✓ Several models, several scenarios,

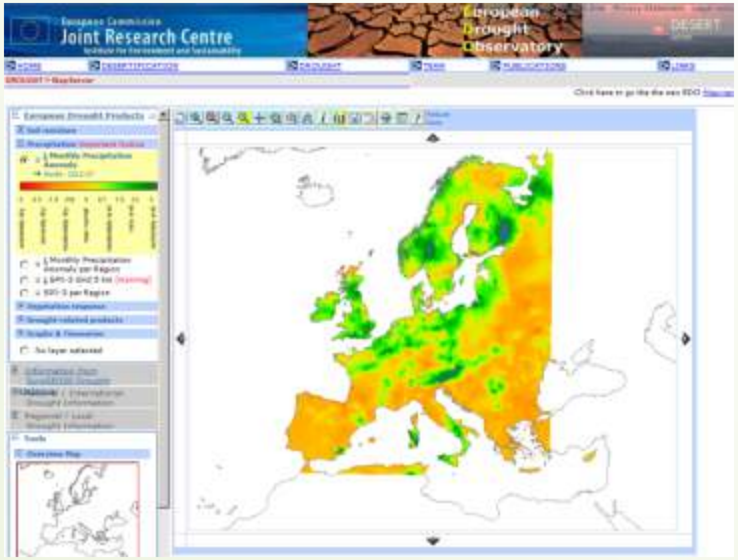


  - Assurance in predictions through quantification of overlap between models in particular scenarios:

Examples of Drought monitors

Drought monitors

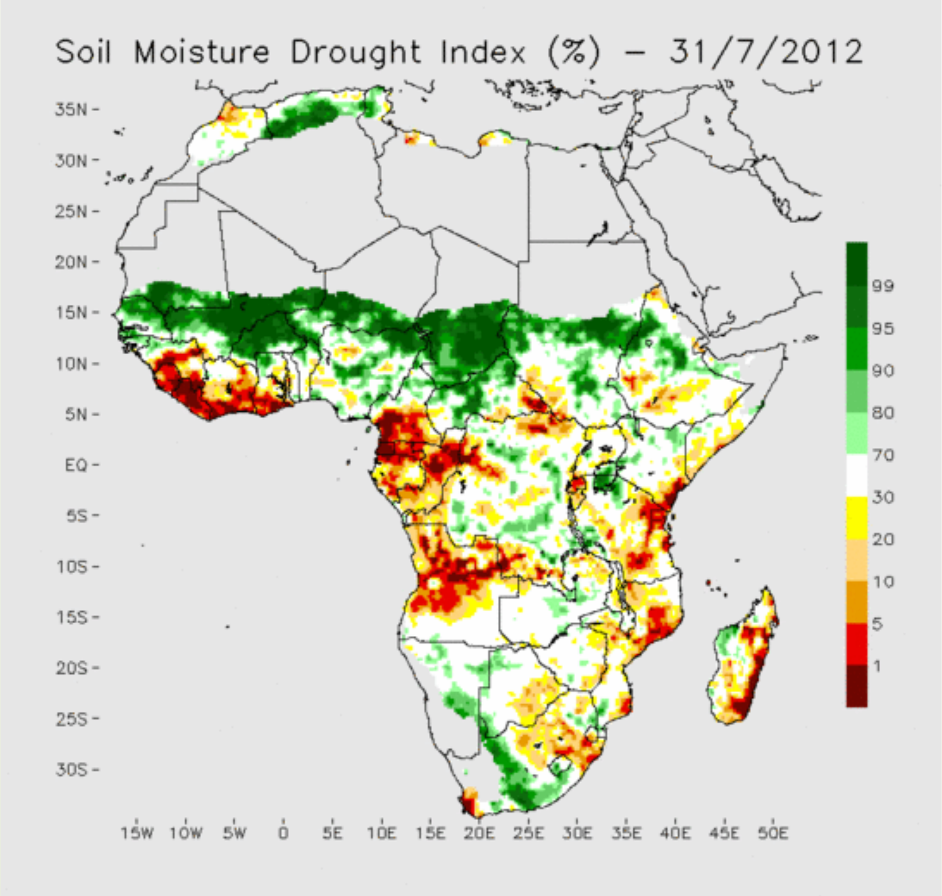




- (US) National drought information monitor
  - http://droughtmonitor.unl.edu/
- European Drought observatory
  - http://desert.jrc.ec.europa.eu/action/php/index.php?action=view&id=201
- Global Drought information System (GDIS)
  - www.clivar.org/organization/extremes/activities/GDIS-workshop

African Drought Monitor

- Princeton university
- VIC model
  - Variable infiltration model



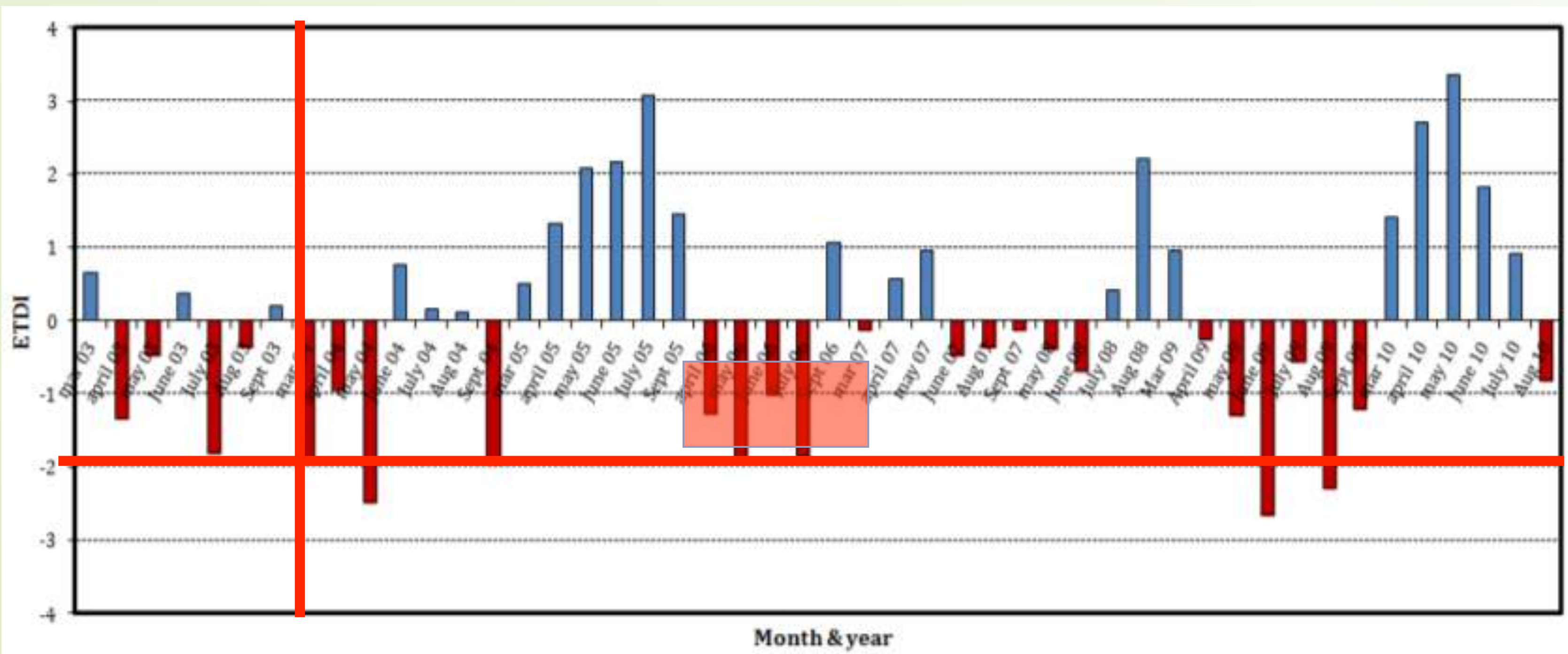
http://hydrology.princeton.edu/~nchaney/Africa_Drought_Monitor_Webpage/GMinterface.php

Drought impact reduction

Hazard

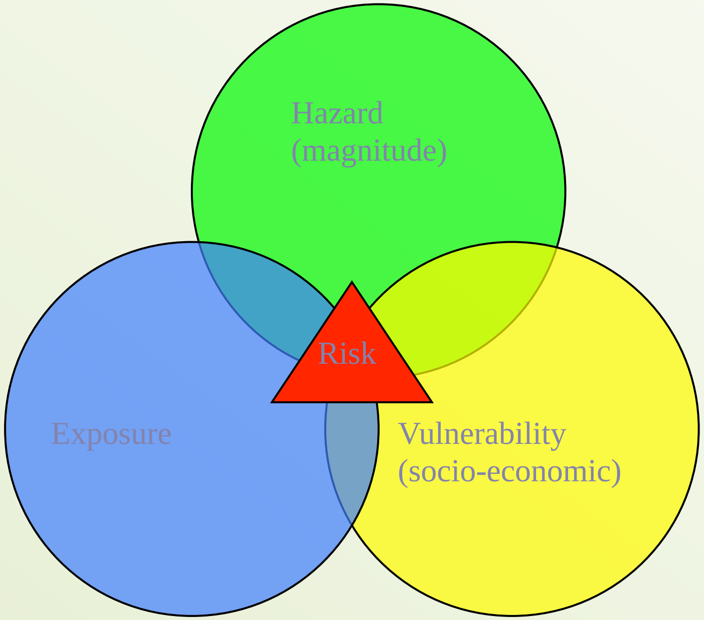
- Threshold
  - Intensity
  - Onset
    - ✓ Food production
  - Duration/ frequency
    - ✓ Depletion of water supply

Historically driven thresholds



Risk Identification

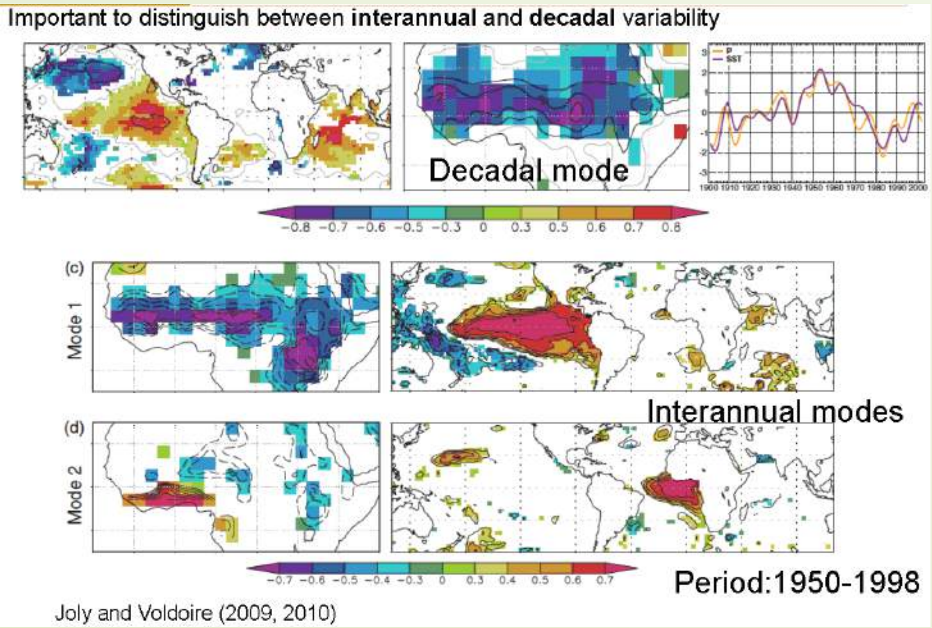
- Past events
- Current State observations

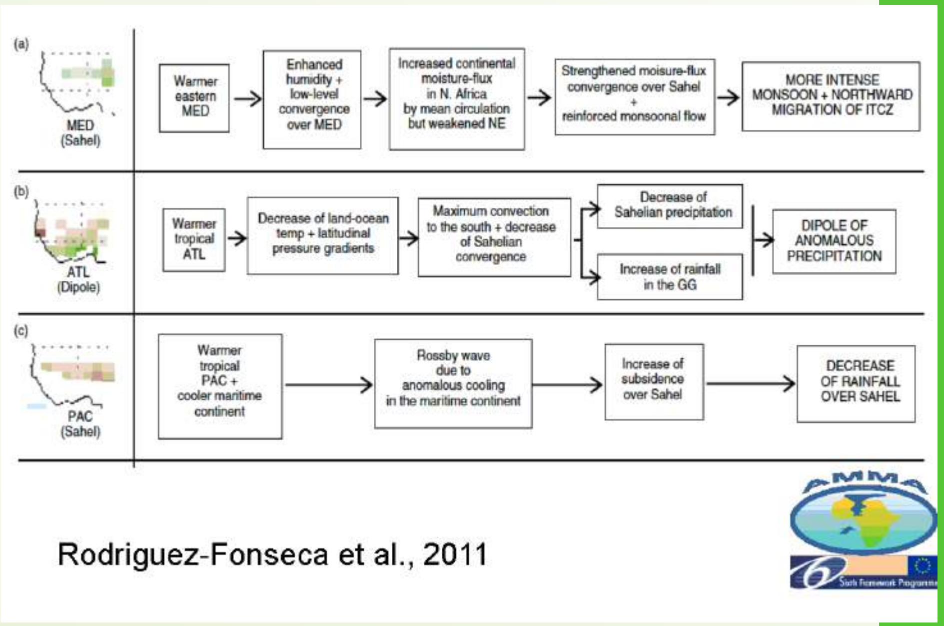


- RISK = Hazard x Vulnarability / Resilience
- Resilience => forecasting + management

Drought Forecasting

- Short term prediction
  - Seasonal Weather Forecast, ECMWF
- Long term prediction
  - SST dependence, IPCC reports

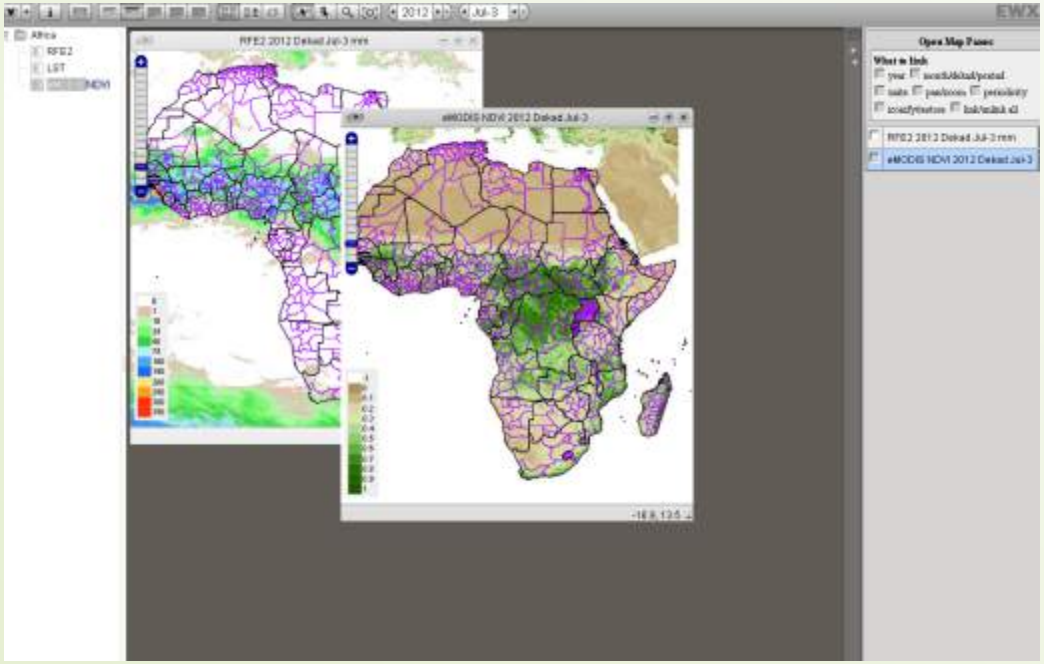




Roberto Mechoso et al, 2012, From African Drought, the SST influence on West African Rainfall, Frascati

Drought Early Warning system

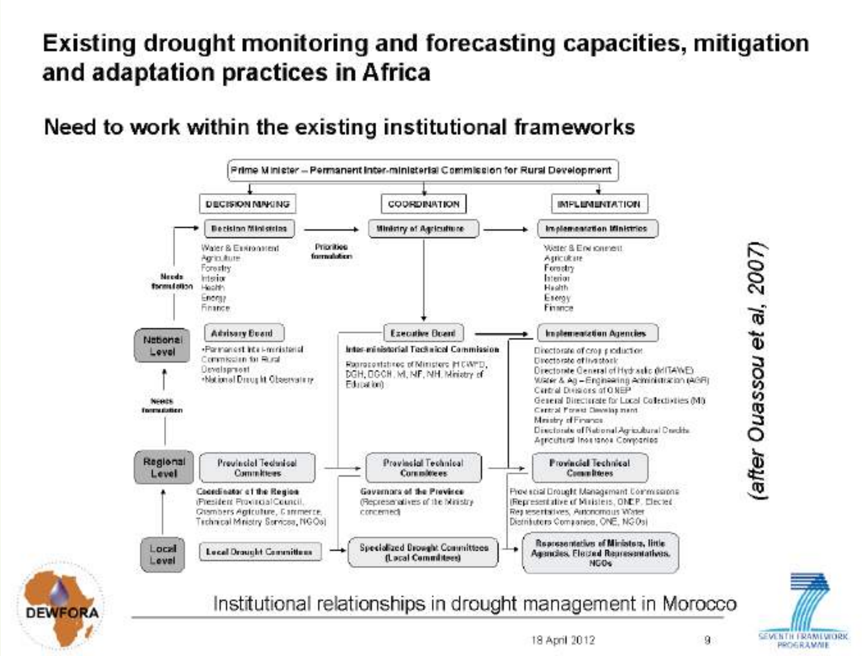
- Early Warning Explorer
  - http://earlywarning.usgs.gov:8080/EWX/index.html



- DEWFORA (Drought early warning FORecasting in Africa)
- ✓ http://www.Dewfora.net

Indigenous knowledge

- What do you do in Great Britain when they predict sun?
  - Bring an umbrella!
- Integrate indigeneous knowledge into your drought information system
  - Experts at each level
- Incorporate a priori knowledge into the algorithms:



$$\Delta p = V\left(S^2 + I\right)^{-1}\left[SU^T\Delta\left(r_a - r\right) + V^T\Delta\left(\rho_a - p\right)\right]$$

Conclusion

- Remote sensing only observes radiation
- Radiative transfer model is needed to retrieve land surface parameters
- Evapotranspiration is important in drought monitoring, but cannot be directly measured from space
- Evapotranspiration can be calculated using SEBS
  - Large scale products are currently available over africa, for example W.ET

Conclusions 2

- Drought can be quantified by looking at different land surface variables
- Merging several drought indices (like SPI, ETDI and SMDI) increases the accuracy of predicting drought
- Drought Risk can be calculated on basis of the vulnerability, the exposure, and the hazard level.
- Several drought monitors are currently available.

Questions?