Monitoring the water cycle over land 1: Rainfall and surface energy balance

→ EARTH OBSERVATION SUMMER SCHOOL

Earth System Monitoring & Modelling

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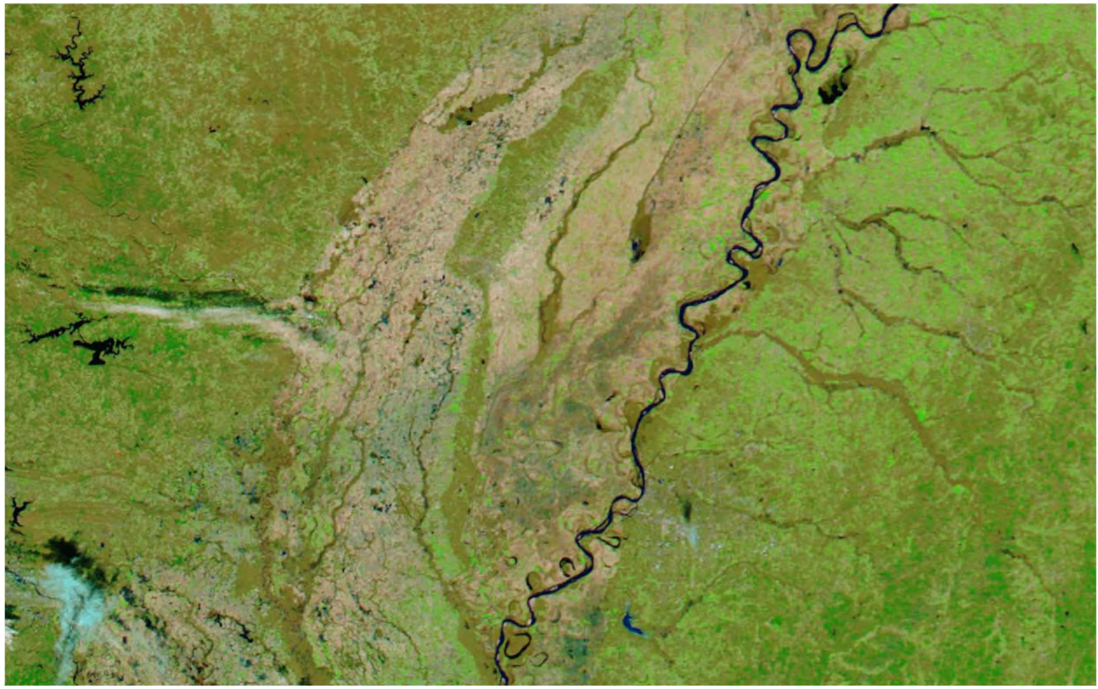
What shall we talk about?

- Some basic terms



Just to speak a common language

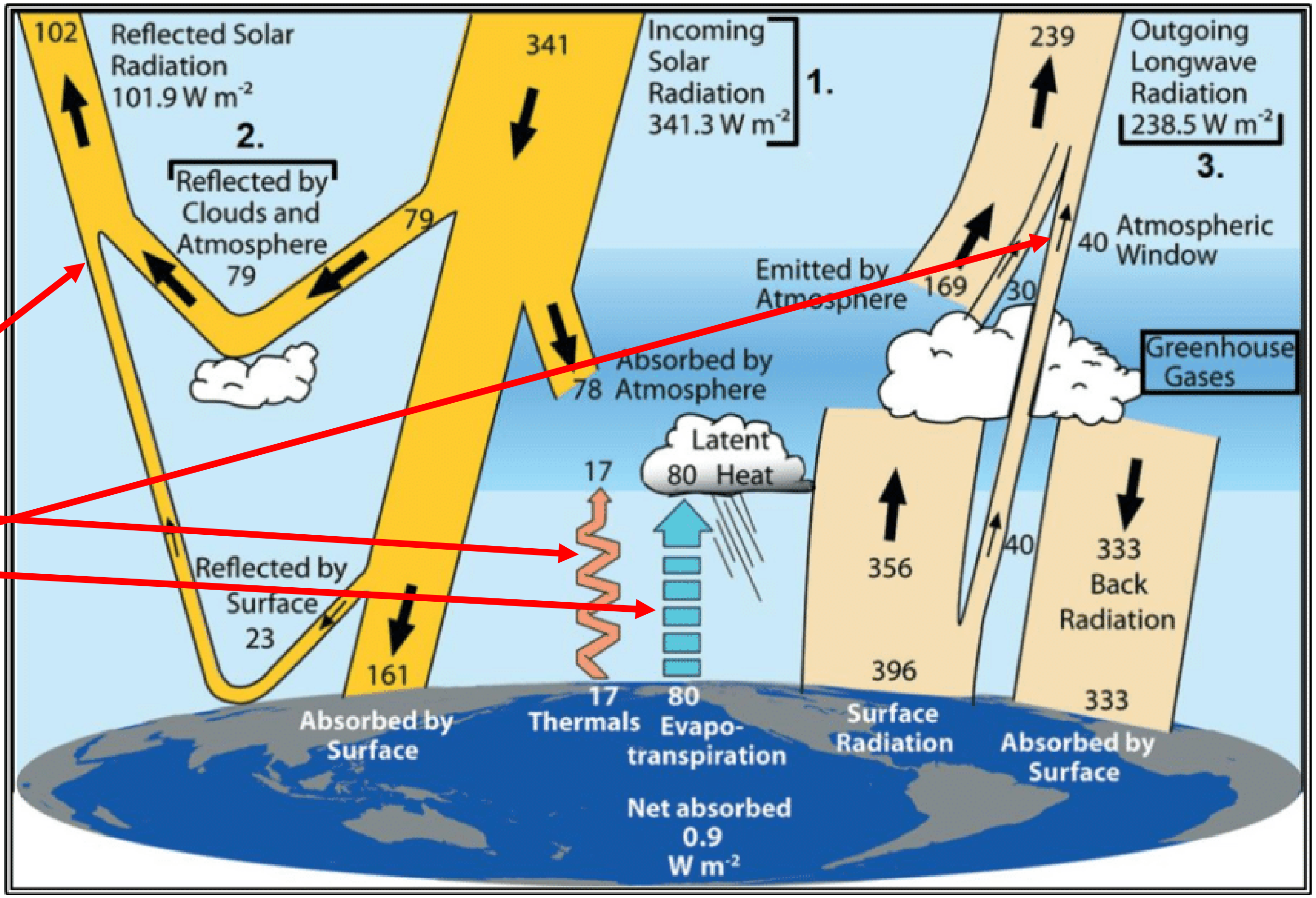
SOME BASIC TERMS

Earth Observation / Remote Sensing data collection

- My convention: Earth Observation (from satellites) ~ Remote Sensing (all platforms)
- EO / RS is a MEASUREMENT method using:
  - Electromagnetic energy
    - Intensity in one or a series of wavelength ranges (spectrometry)
    - Polarization (polarimetry)
    - Phase differences (interferometry)
    - Travel time, distance (altimetry)
  - Gravity field
    - Gravity or gravity gradient measurements with accelerometers on satellites (on board of the satellite(s))
    - Deduction of the gravity field from precise satellite orbit observations
    - Satellite-to-satellite tracking

Earth's global energy budget

- Numbers may slightly vary by different sources
- Role of atmosphere (greenhouse gases, atmospheric windows $f(\lambda)$)
- Three forms of flux leave the surface:
  - Convective
  - Latent
  - Radiant (this is what we measure with EO)



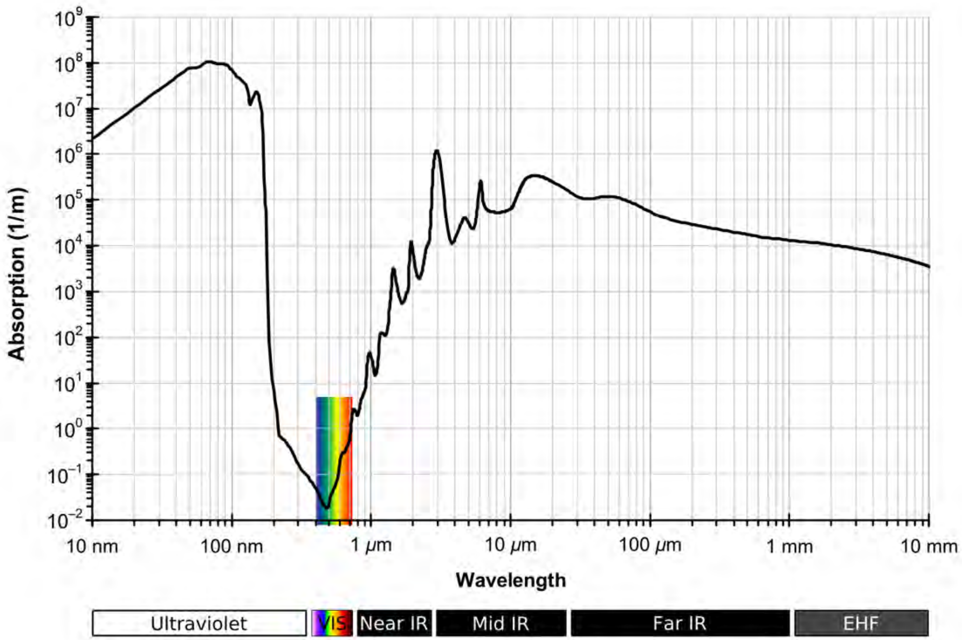
Source: Trenberth, Fasullo & Kiehl (2009)

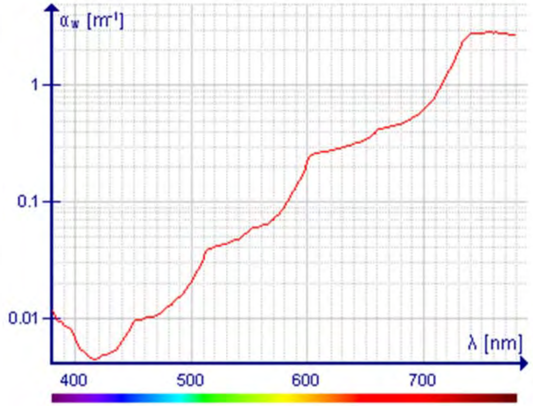
Earth Observation / Remote Sensing data analysis

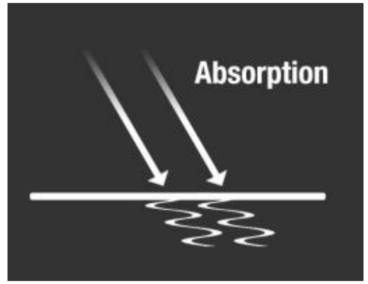
Deduction of data/information related to a selected field of interest (e.g., soil moisture) from the measured data (e.g., microwave intensity):

- Depends on the interaction between the analyzed object of interest (e.g., top layer of the soil) and the measured physical signal (e.g., microwave backscatter).
- Usually needs auxiliary data related to:
  - Geometry of the measurement;
  - Known distortions/noises
    - Atmospheric effects,
    - Measurement system noises, etc;
  - Additional data not measurable by RS (e.g., incident energy from external source, air temperature, wind).

Interaction of liquid water and VIS – IR - TIR





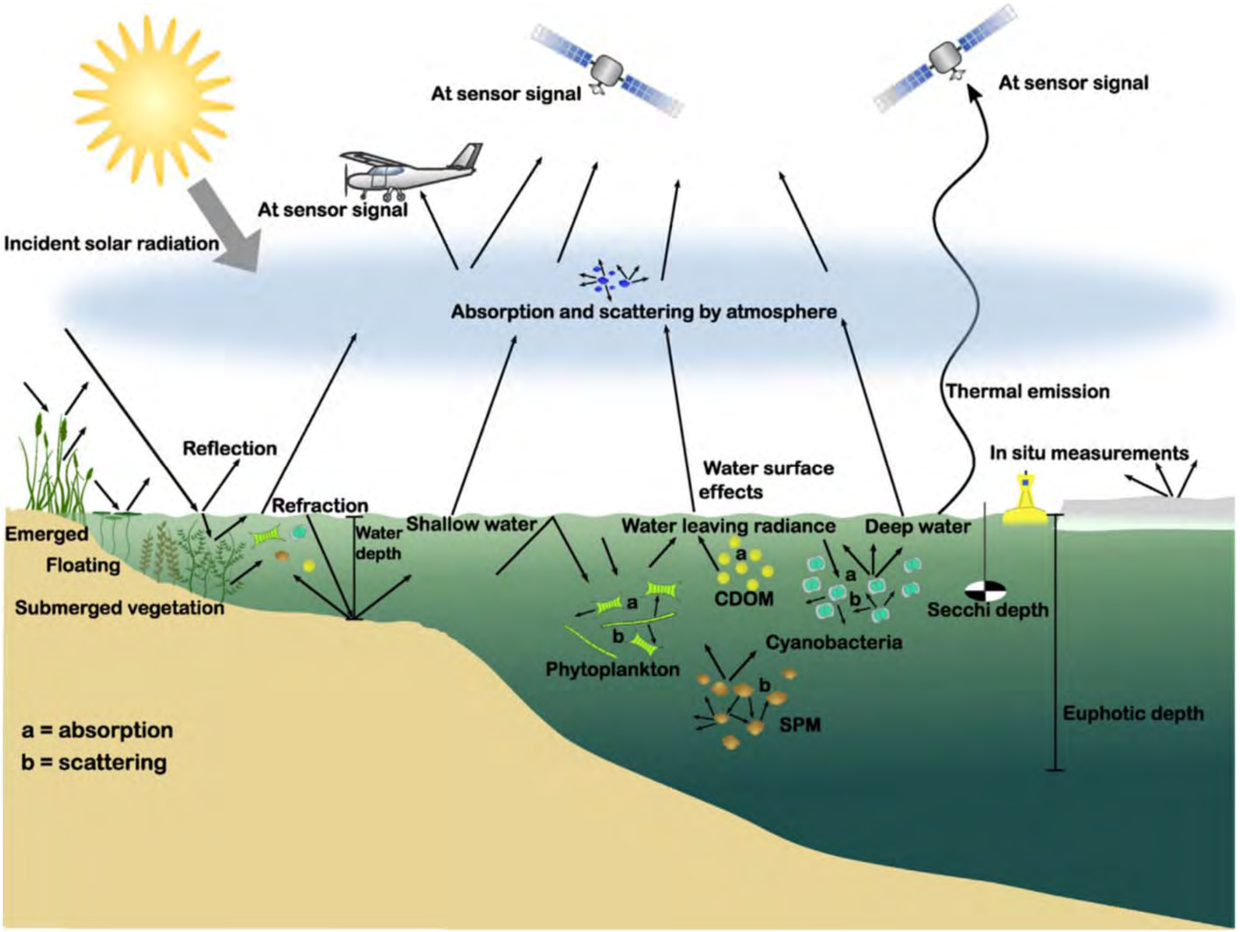


Absorption

- Low at the shorter λ in VIS
- Quickly increased from blue to TIR

Sources:
Kebes at English Wikipedia
NASA (2010)

Interaction of real water bodies and VIS



Complex interactions:

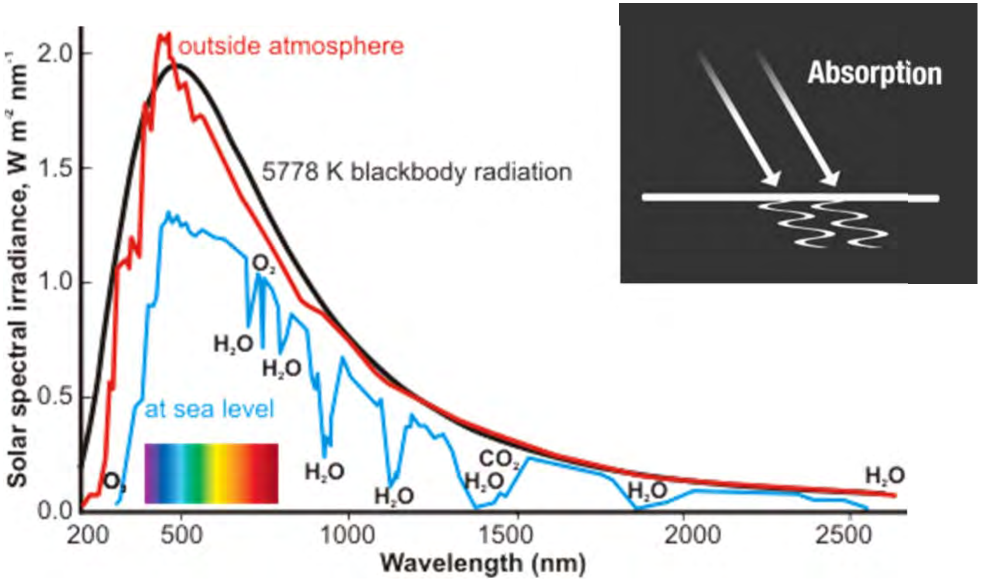
Reflection and refraction at the surface

Absorption by water and other dissolved and suspended/floating constituents

Scattering (backscatter) by suspended/floating constituents

Source: Dörnhöfer & Oppelt (2016)

Interaction of water in the atmosphere and VIS - IR



Source: Chaplin (2018)

Absorption by vapour (gas), scattering by droplets (liquid and ice)

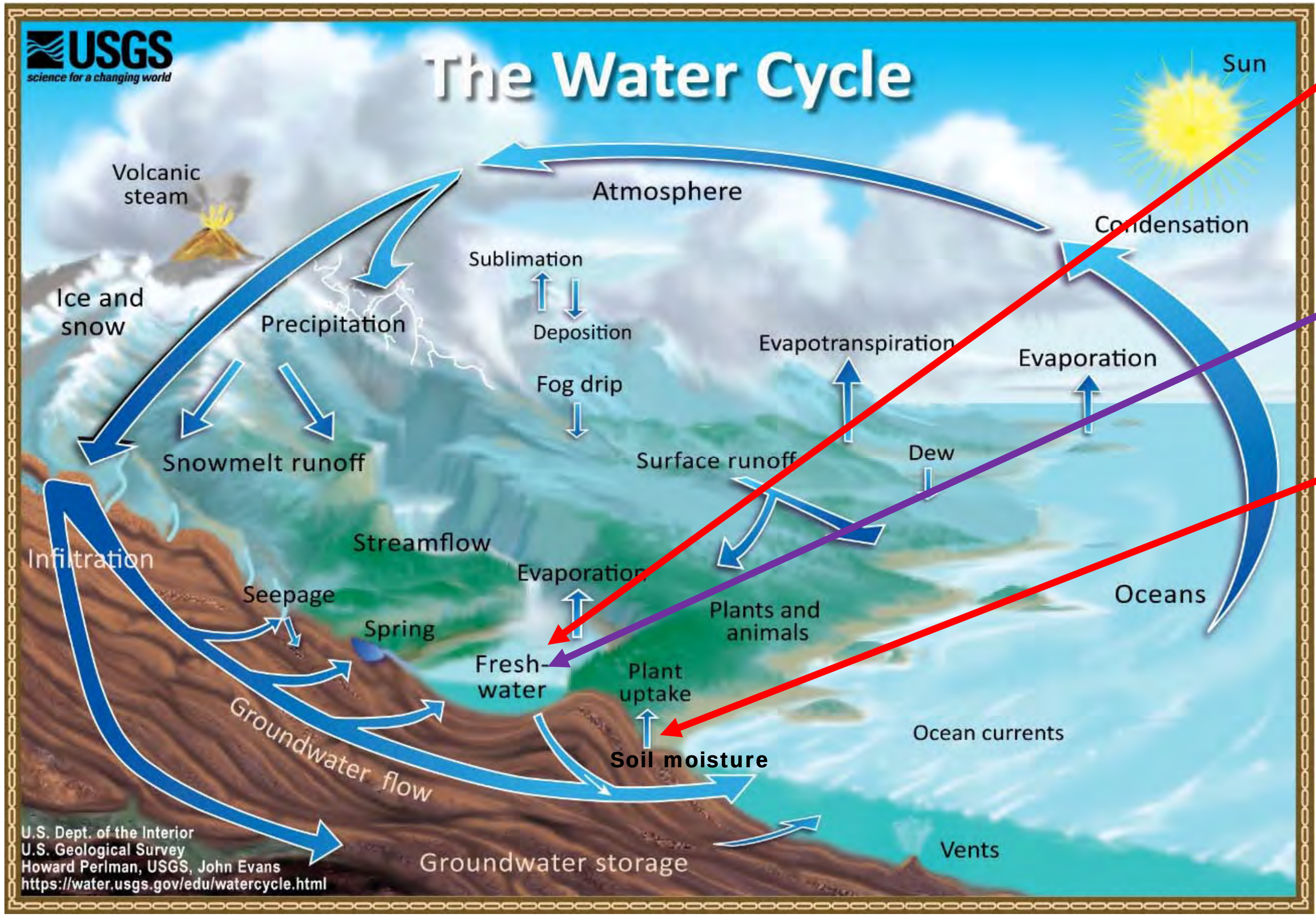
Source: www.wikiwand.com

Water and microwave

- H_2O is a dipol molecule
- Effects microwave emission/backscatter
- The dielectric constant of water (~80) is very different from other natural materials of the surface (e.g. soil particles ~4)

- Problem: besides the dielectric properties, geometry of the surface (surface rougness) and scattering geometries effect the signal.

Water cycle – how RS can see the state variables 1



Water surface:

- Radar backscattering
- Optical / thermal

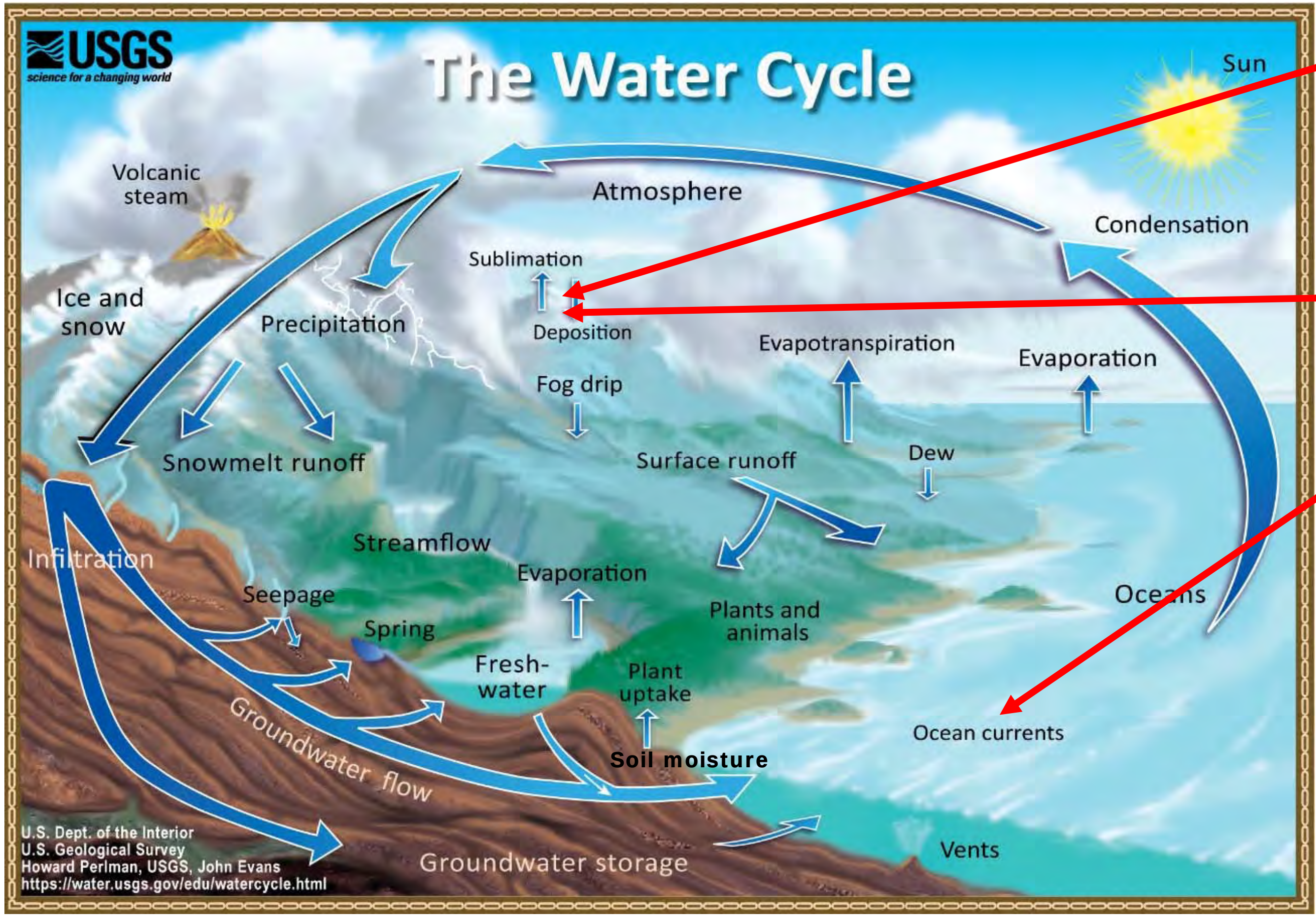
Water body volume:

- Proxy (water surface)

Soil moisture:

- Microwave active/passive

Water cycle – how RS can see the state variables 2



Ice/snow cover:

- Optical / thermal
- Microwave a/p

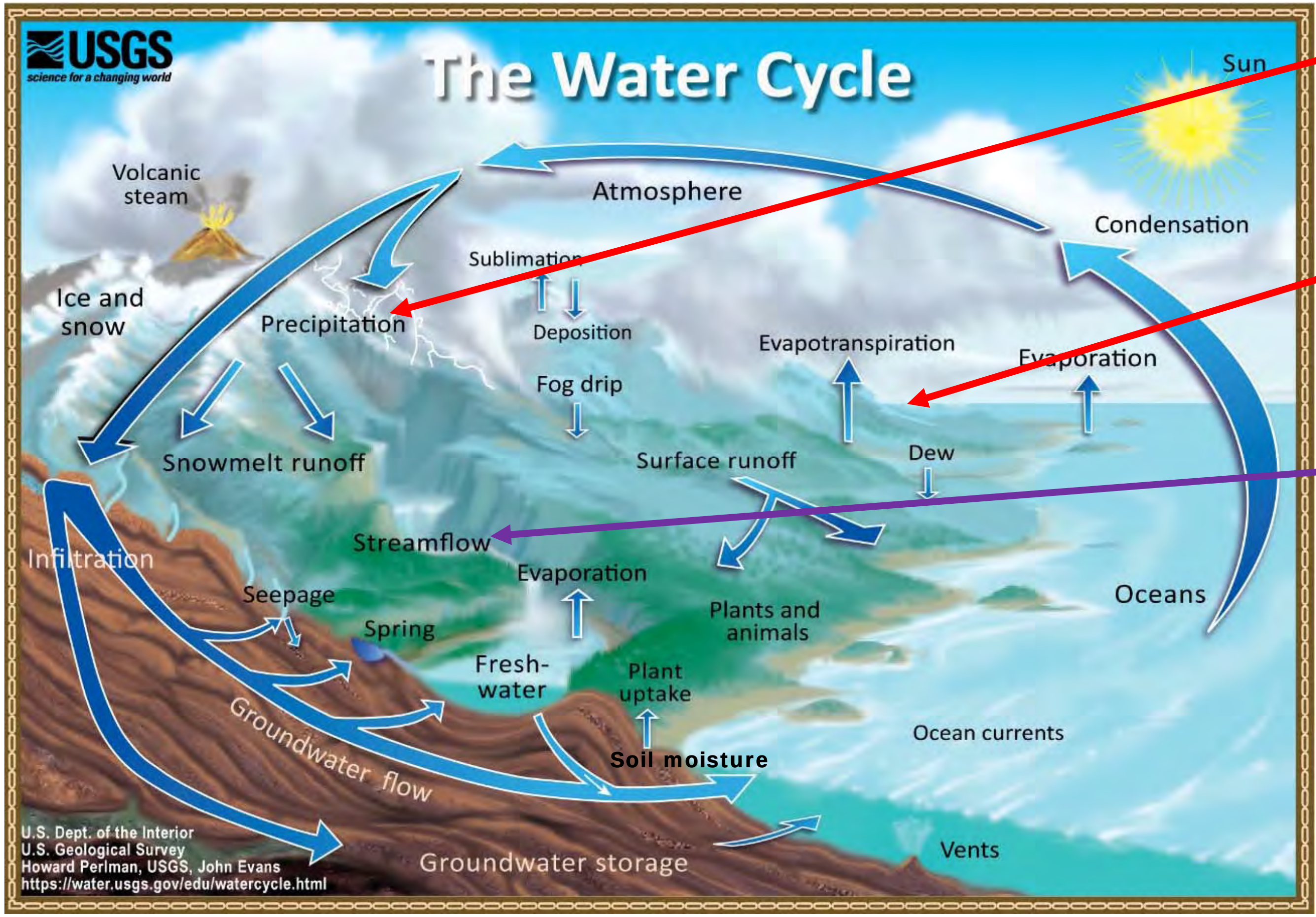
Snow water equivalent:

- Microwave a/p

Water quality:

- Optical / thermal

Water cycle – how RS can see the fluxes 1



Precipitation:

- Radar
- Cloud properties (T)

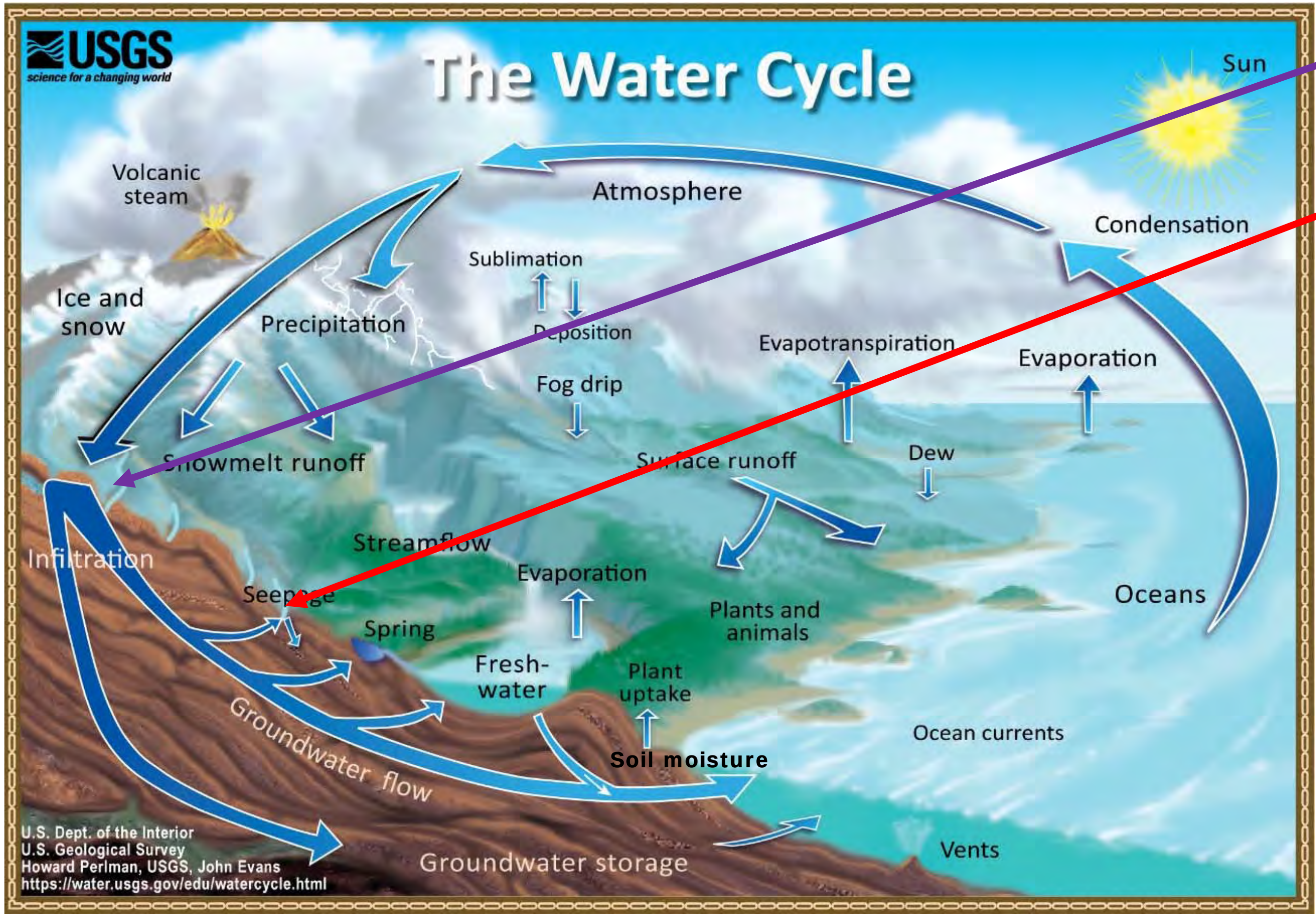
Evapo(transpi)ration:

- Estimation via land cover
- Surface energy balance

Streamflow (surface runoff):

- Proxy (water stage)

Water cycle – how RS can see the fluxes 2



Infiltration:

- Regional water balance

Seepage:

- Thermal
- Proxies (vegetation)

In general: simple and complex fluxes:

- Integration of RS & models

PRECIPITATION

Precipitation mechanisms

Related to uplift of moist air

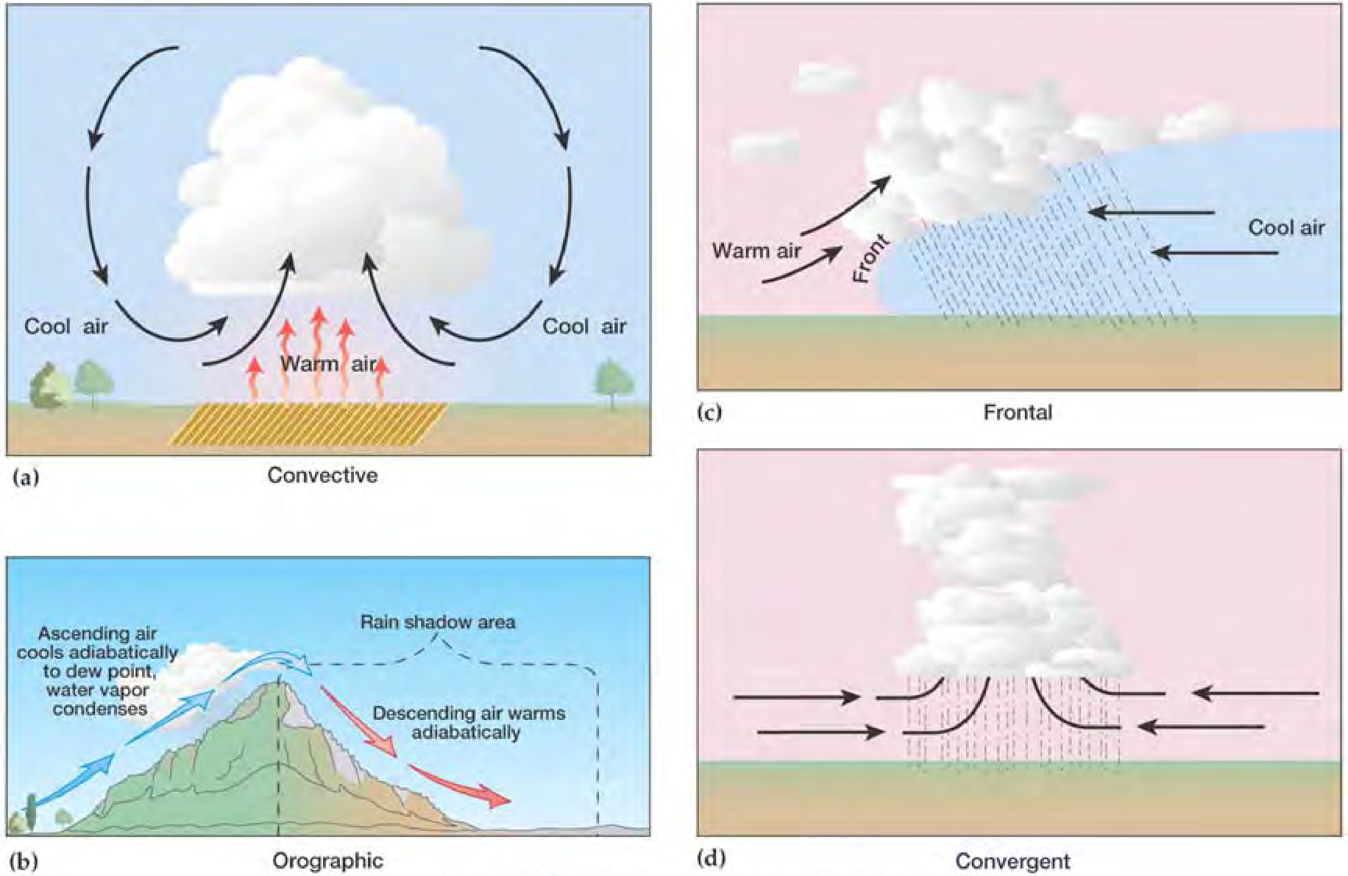
a) Convective uplift (e.g., summer storms)

b) Orographic

c) Frontal (cold, warm and occluded)

d) Convergent (cyclonic)

Various meteorological circumstances result in different forms of precipitation, e.g., drizzle, rain (liquid); snow, hale (solid).



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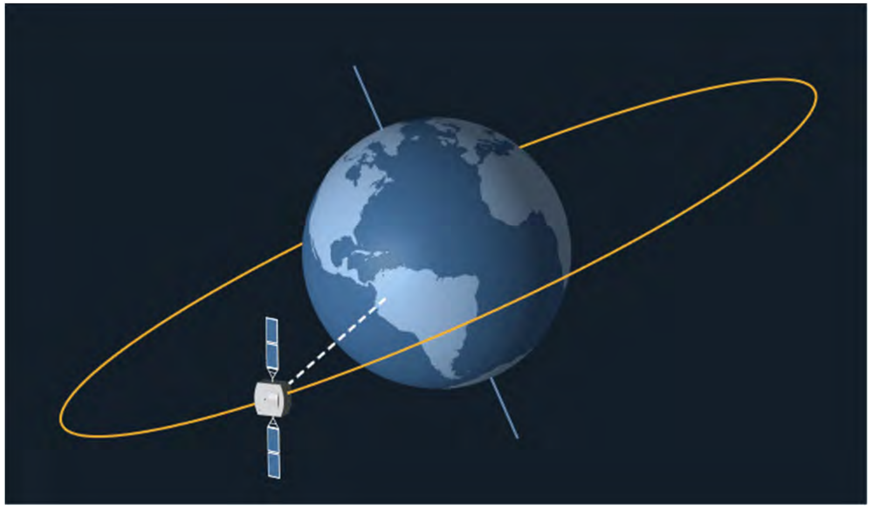
Source: http://web.gccaz.edu/...

Satellite remote sensing of precipitation: orbits

Geostationary orbit:

- 36,000 km above the Equator
- 1-10 km spatial resolution
- 15-30 minutes temporal resolution
- Increasing geometric distortion towards the poles due to Earth curvature

Source: http://www.seos-project.eu/...



(Quasi)polar orbit:

- 200-1000 km above surface
- 1-1000 m spatial resolution
- 1-14 days temporal resolution (depending on constellation & geographic location)
- Less geometric distortion in an image due to Earth curvature

Source:https://dlmultimedia.esa.int/...

Precipitation – VIS / IR techniques

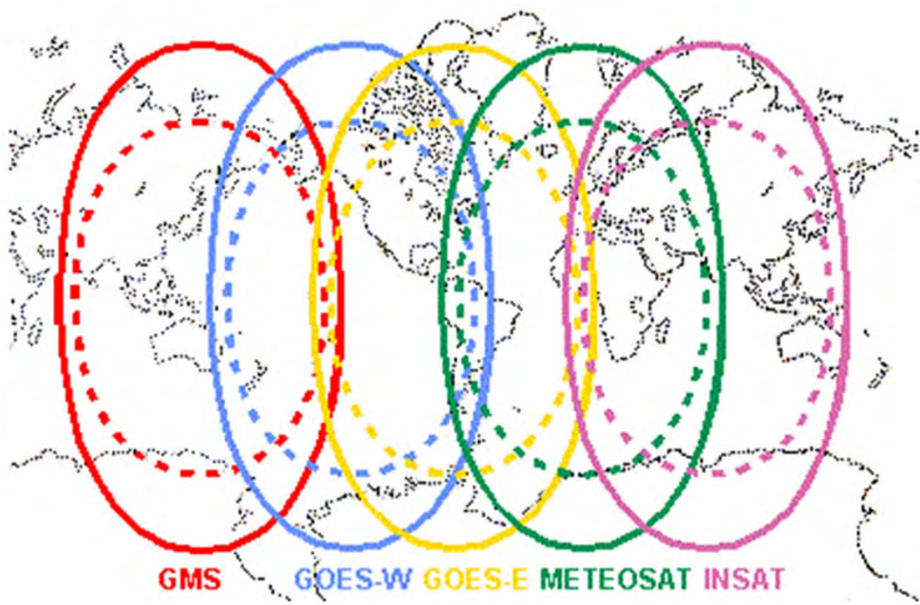
Based on outgoing long-wave radiation (OLR)

- Basis: Precipitation leading to outgoing longwave radiation different from normal background
- Empirical relationship: P~OLR
- Example: IR bands of AVHRR or NOAA-series satellites for OLR, explained 40% of the areal average rainfall variability.

Rainfall VIS / IR

GOES Precipitation Index (GPI)

- Basis: cold cloud-top temperature proportional to precipitation
- For pixels of cloud-top temperature (CCTs) less than 235 K are classified as raining pixel, and assigned a rainfall rate of 3 mm/hr
- Reproduce climate-scale precipitation patterns for tropics and sub-tropics
- But problematic for orographic and high-latitude precipitation



Passive microwave techniques

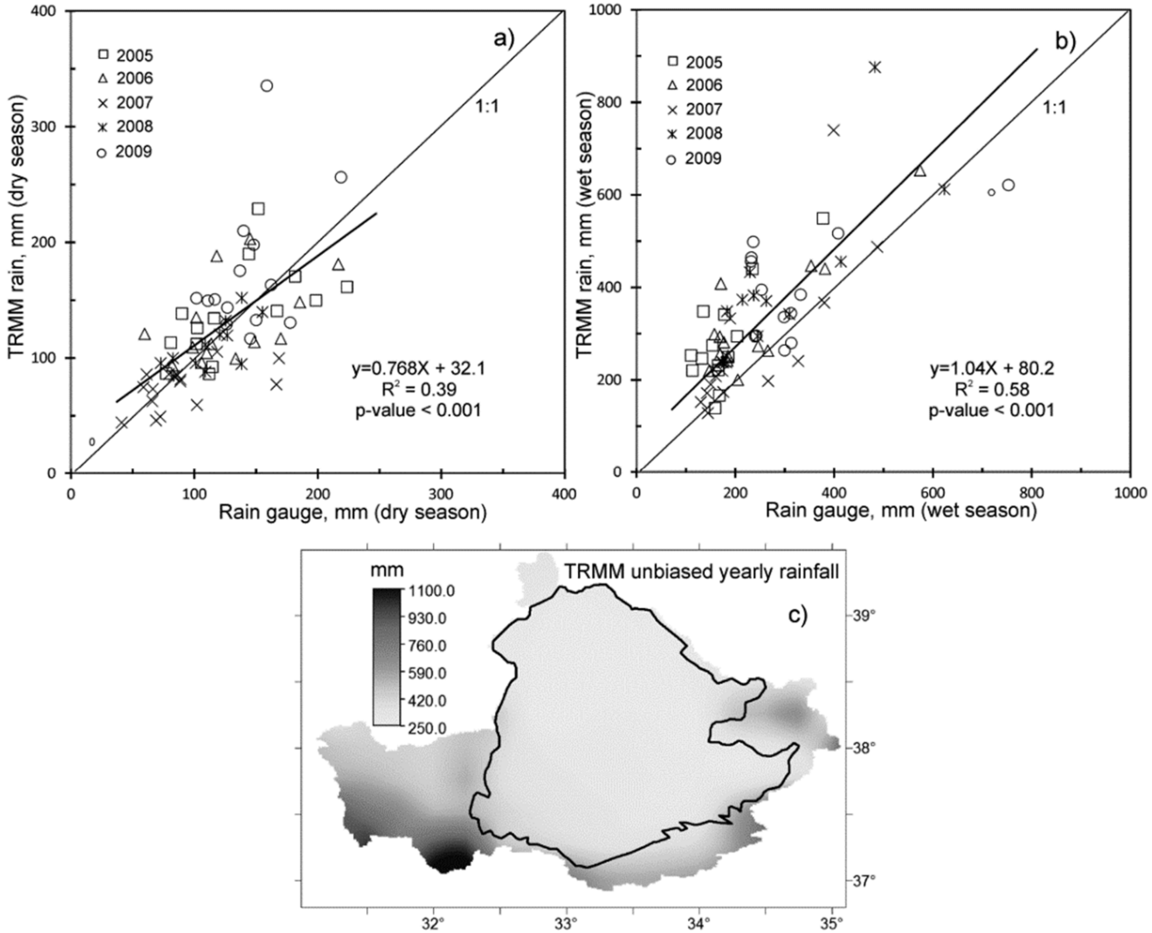
- Rain droplets scatter microwave

1.) Over ocean clouds emit additional energy to the bacground, i.e., are „warmer" than the background

2.) Over land the signal emitted by te surface is attenuated in the rain baring clouds

- The signal represents the whole air column, not only the rain at the surface.
- Coarse resolution (10-50 km)

Tropical Rainfall Measuring Mission data vs. raingauge



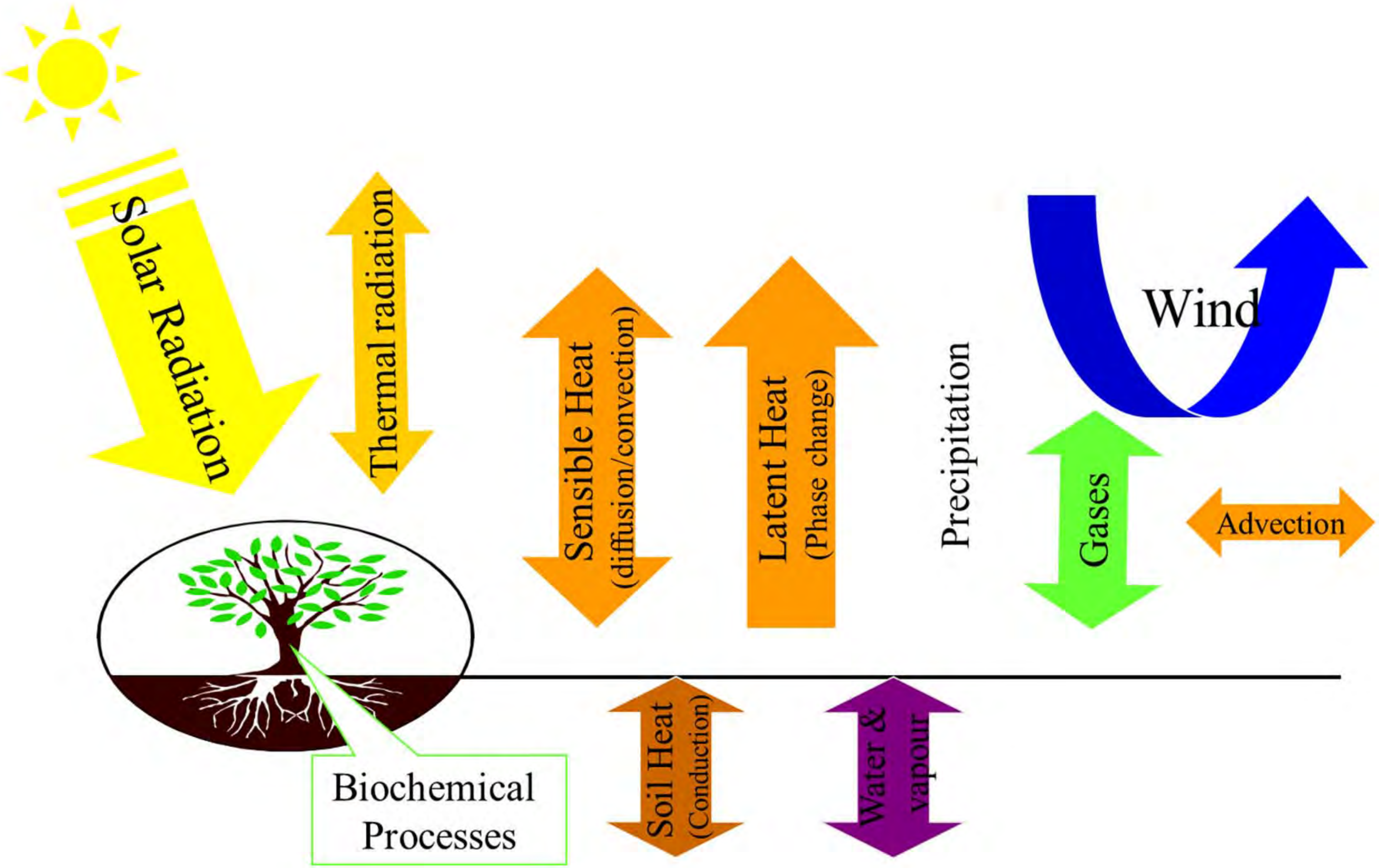
- TRMM PR (precipitation radar) - First rainfall radar
- 3 hourly and 7 day accumulated data
- Longer accumulation (>1 month) improves correlation with in situ gauge data
- Example: Konya basin, Turkey

Source: Gokmen et al. (2013)

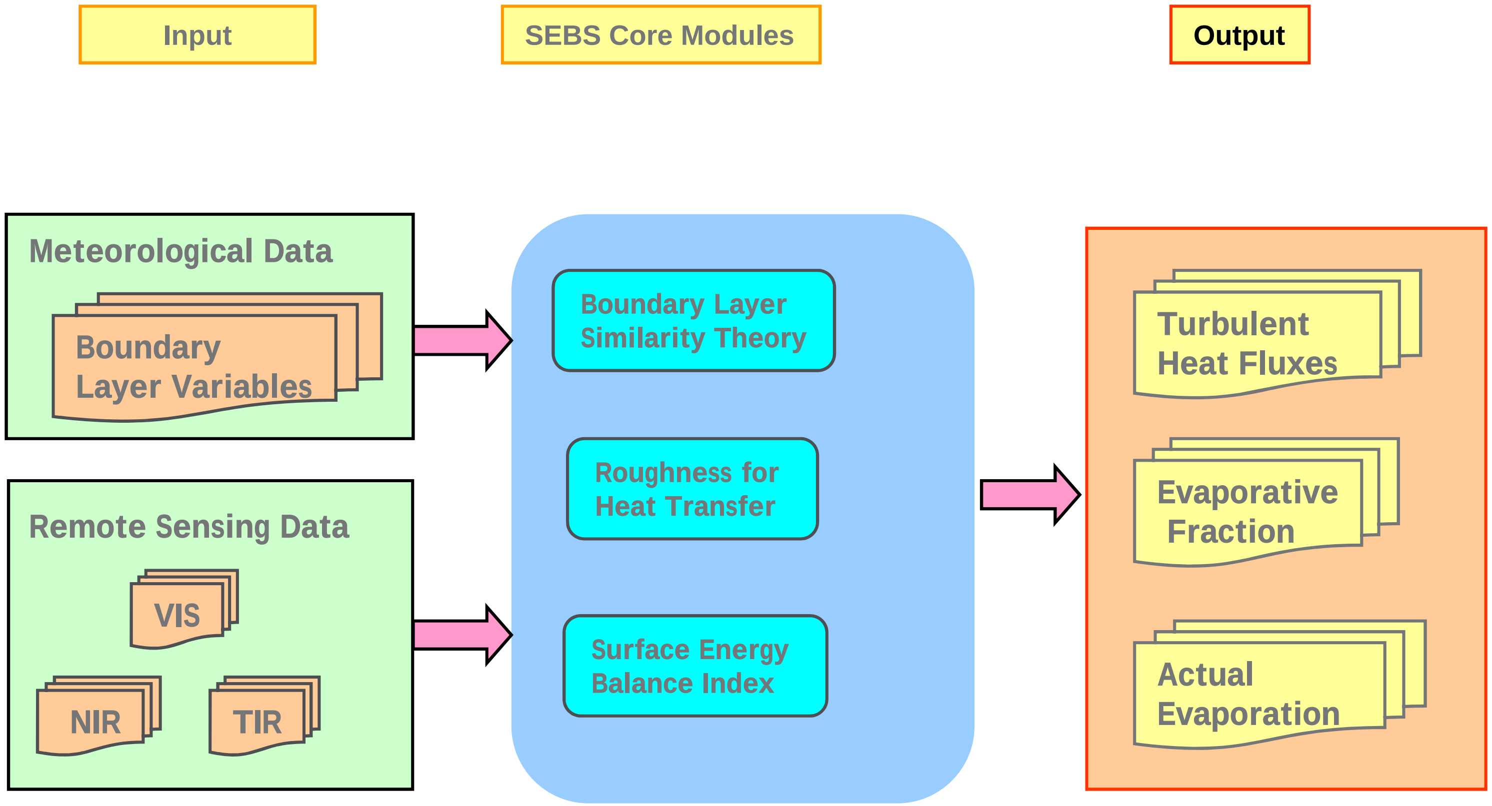
A quick look at

SURFACE ENERGY BALANCE - EVAPORATION

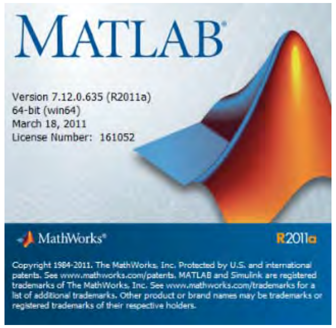
Schematization of fluxes



SEBS – Surface Energy Balance System



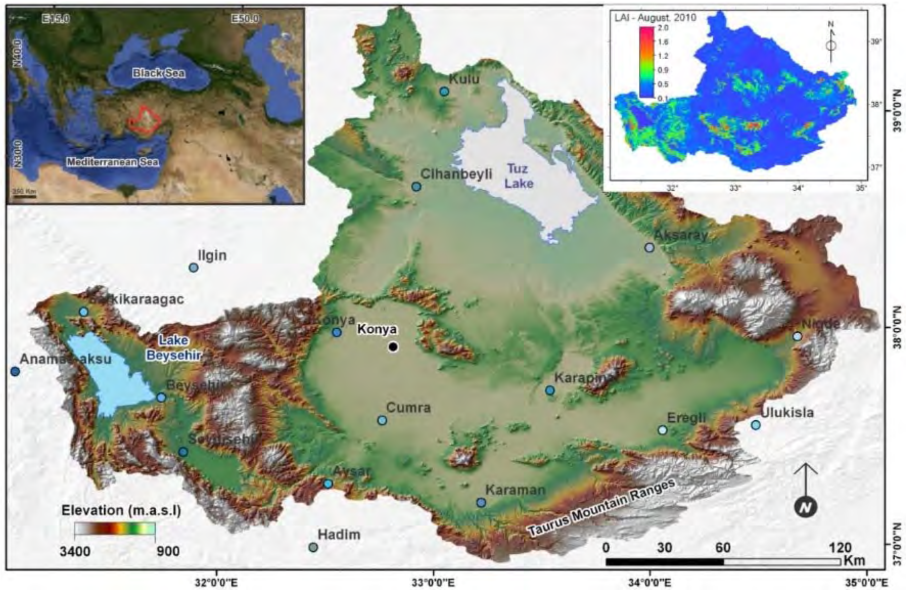
SEBS implementation in software packages



Case study: Konya Basin, Turkey

CALCULATING WATER BALANCE OF A CATCHMENT

The Konya closed basin, Turkey



Location, DEM and LAI of the Konya closed basin (KCB). Locations of 18 meteorological stations are shown on the map.

Elevation: 900 – 3.534 m.a.s.l.

Surface area: 54.000 km^2

Climate: Arid to semi-arid

P ≈ 350 mm/year

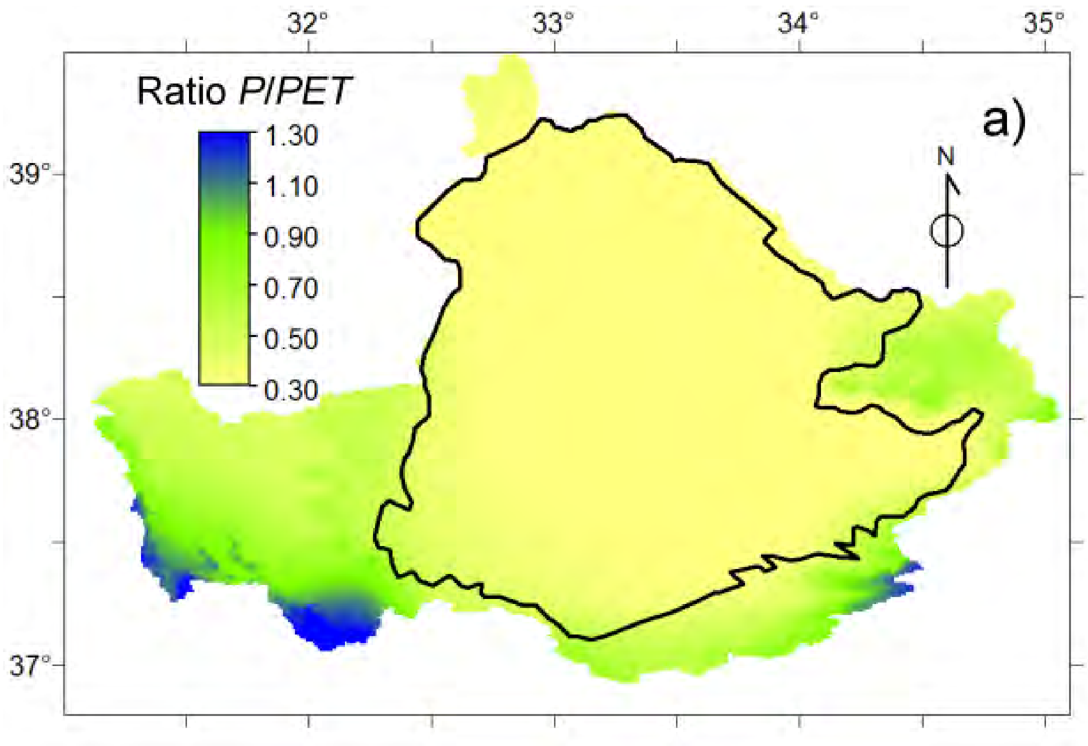
PET ≈ 1400 mm/year

Land cover: shows a strong contrast b/w intensively irrigated agricultural lands and the sparse steppe areas.

Water resources:

Groundwater (GW) is the main source for irrigation. The surface water is comparably limited and managed through man-made reservoirs for supplying additional irrigation (15-20%)

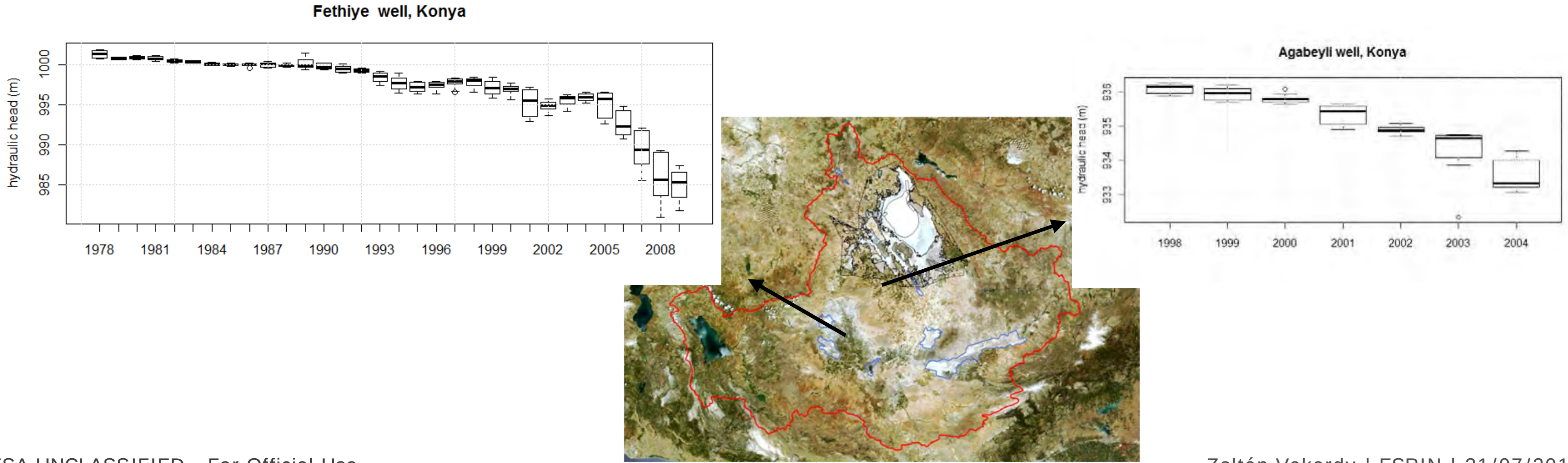
Problem: water limited region with very few in situ measurements



Parsons and Abrahams (1994): water limtited region is, where P-PET<0.75

Groundwater resources under strong anthropogenic influence:

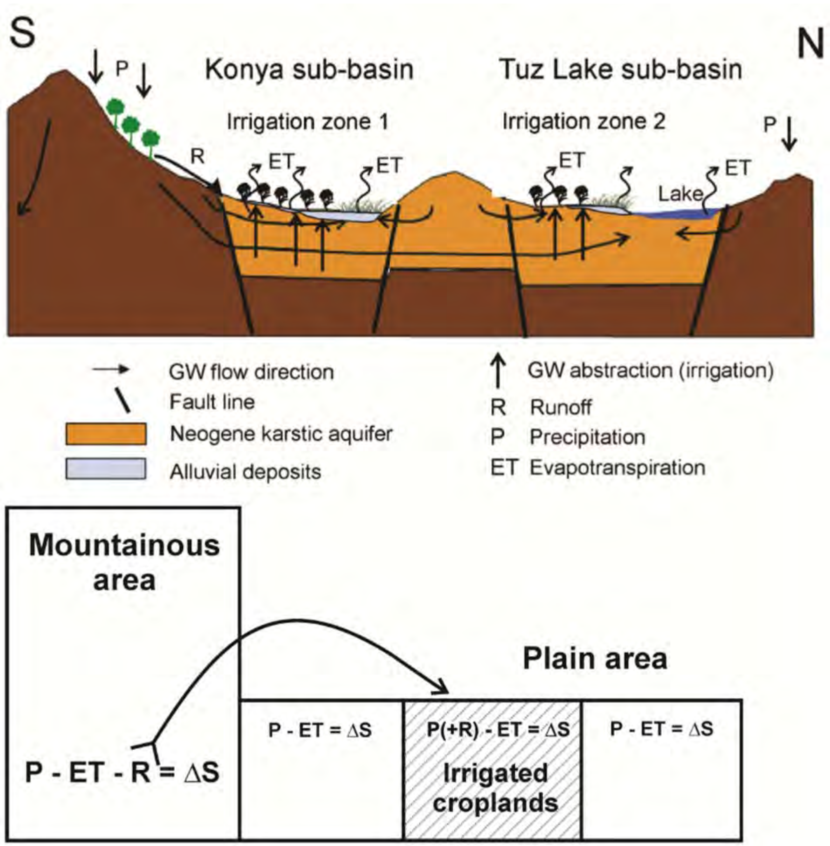
Groundwater abstraction for irrigation, approximately 1 m year^{-1} groundwater head decline over the last few decades (Bayari et al., 2009).



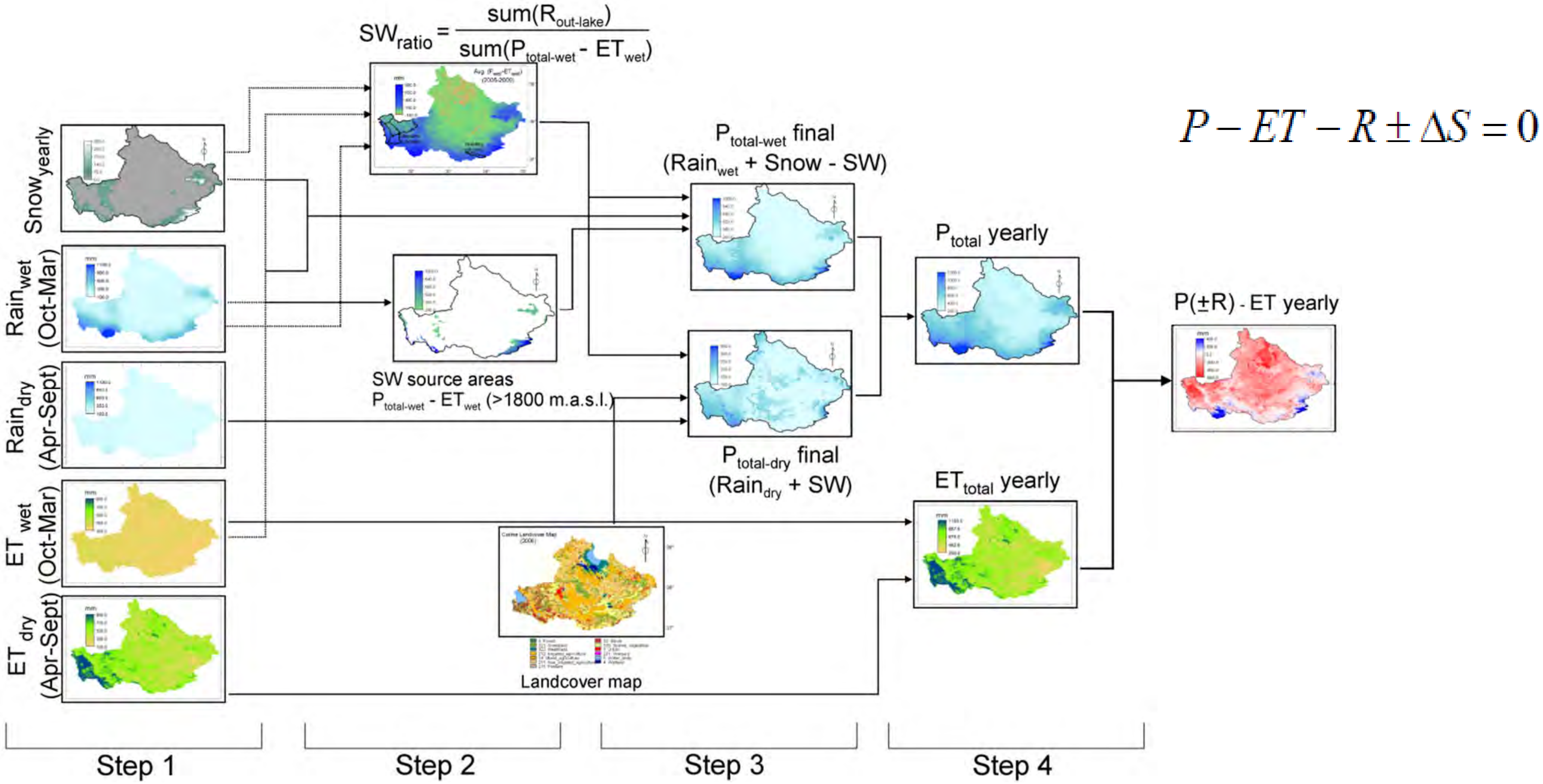
Earth observation supported regional water balance calculations

WATER BALANCE CALCULATION METHODS

Conceptual model for the water balance calculations



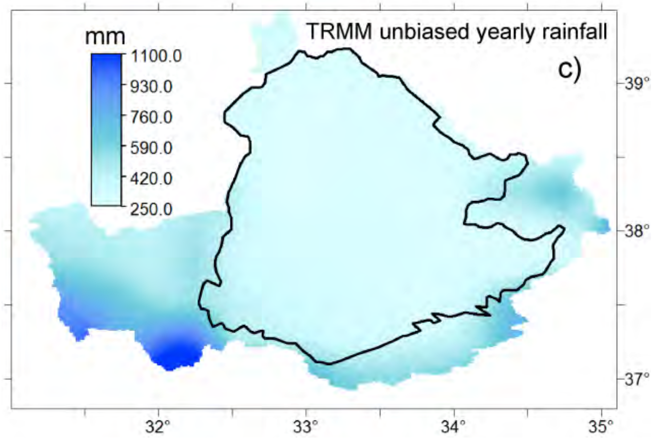
Spatially distributed water balance calculations

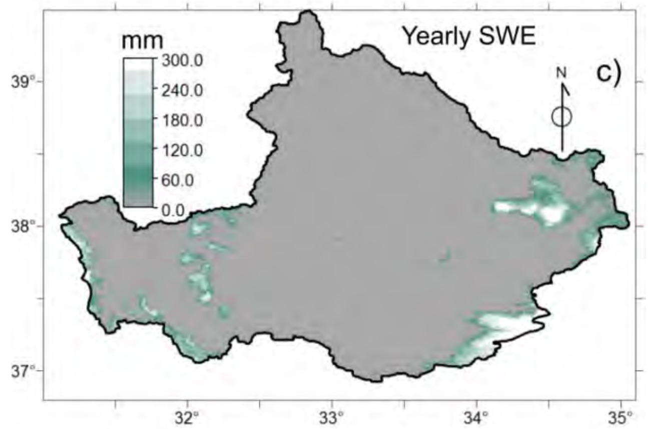


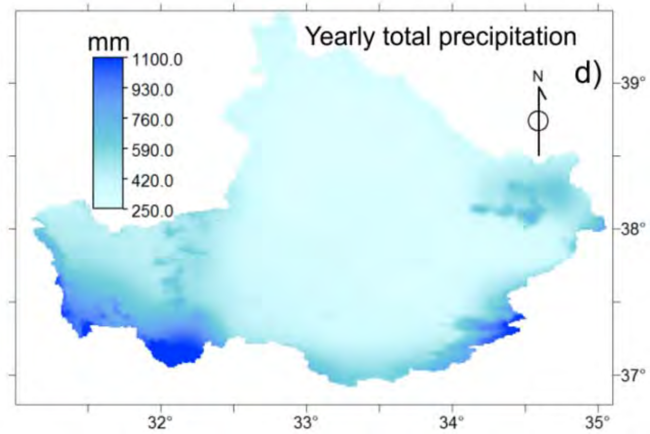
Earth observation supported regional water balance calculations

WATER BALANCE RESULTS

Spatial distribution of precipitation

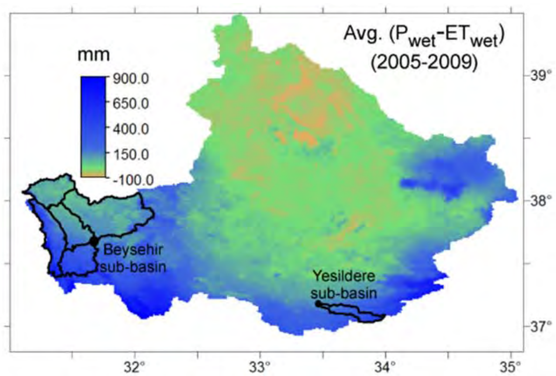


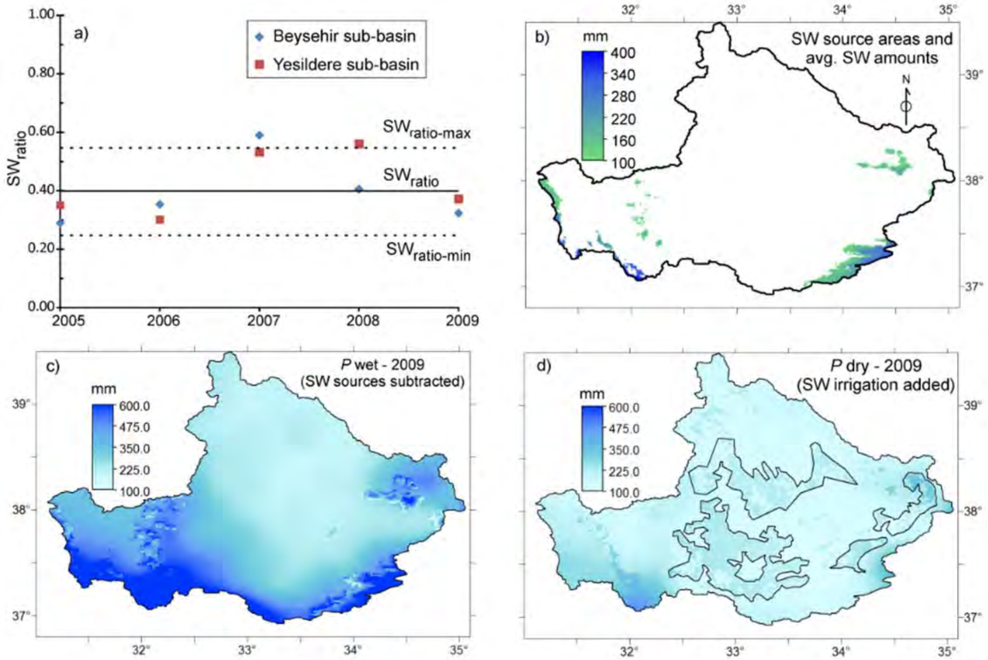


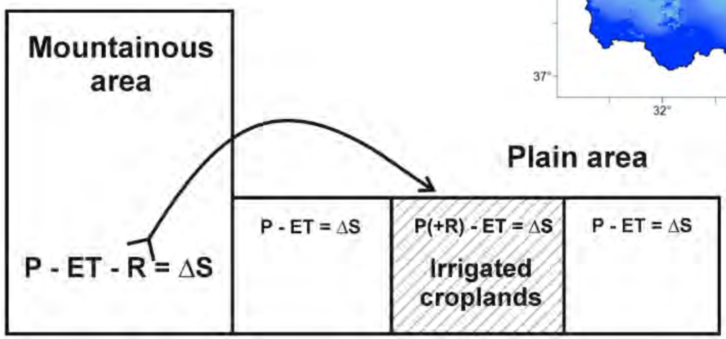


- TRMM is not sensitive to snowfall
- Snow can be observed in the visible bands
- In situ SWE was used for characterizing snow

Snowmelt distribution via reservoirs







$$SWratio = \frac{\sum R_{outflow}}{\sum P_{wet} - \sum ET_{wet}}$$

ET estimate with improved SEBS

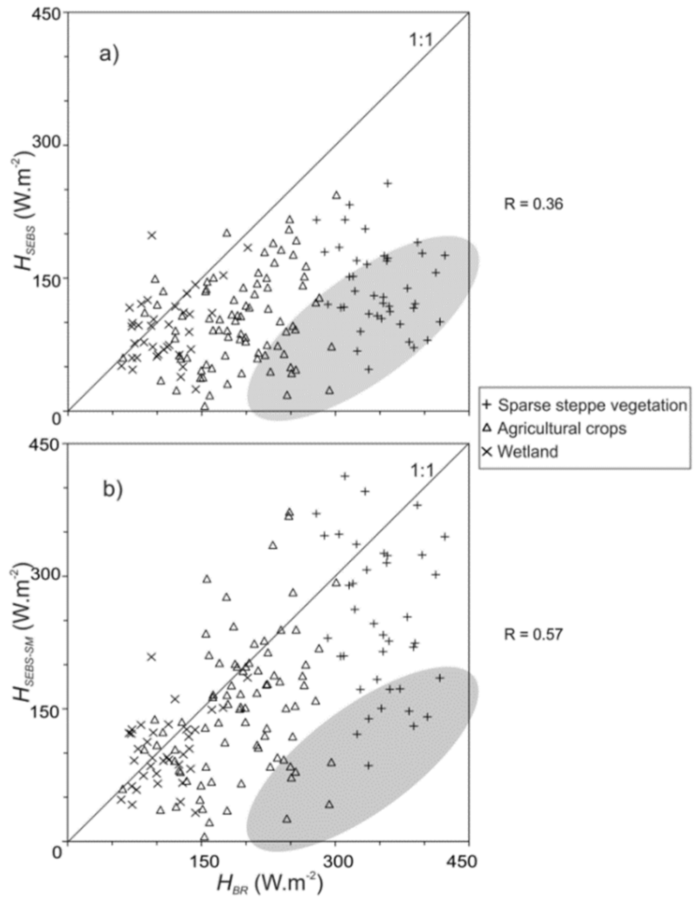
SEBS overestimates ET in water stress areas

New approach proposed (Gokmen et al., 2013):

$$kB^{-1} = SF \times kB^{-1}_{SEBS}$$

$$SF = a + \frac{1}{1 + \exp(b - c \times SM_{rel})}$$

SM_{rel} from microwave RS

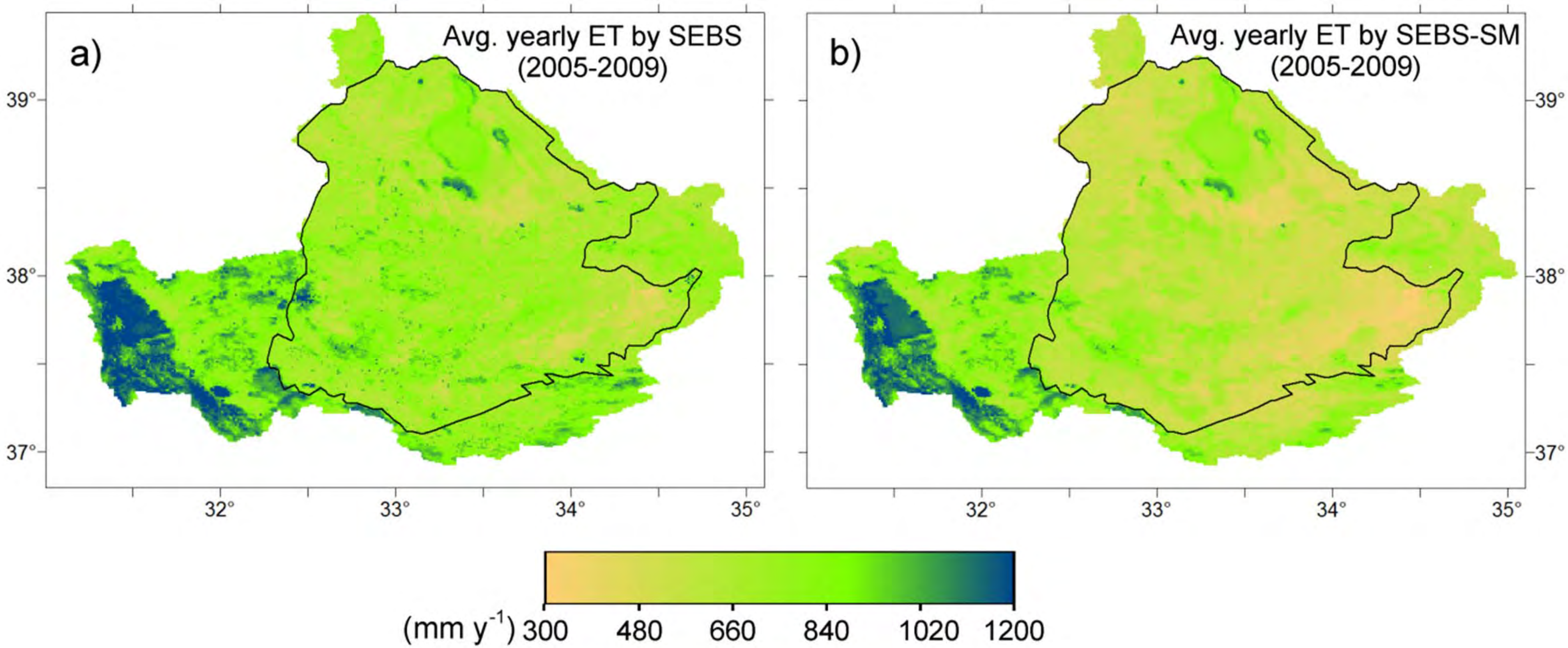


Improvement of ET estimate

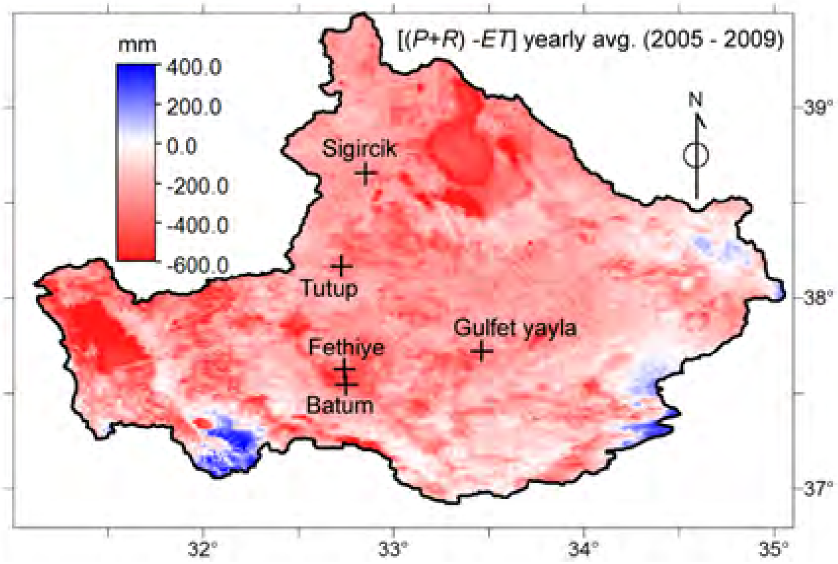
Sensible heat flux errors based on Bowen ratio station measurements

Land cover	n	$RMSE_{SEBS}$ [W m^{-2}]	$rRMSE_{SEBS}$	$RMSE_{SEBS\_SM}$ [W m^{-2}]	$rRMSE_{SEBS\_SM}$
Sparse steppe	42	226.1	129.7	153.8	88.2
Crops	83	113.0	47.2	90.7	37.9
Wetland	36	44.1	31.1	42.1	29.7
Overall	161	142.7	36.3	103.9	26.4

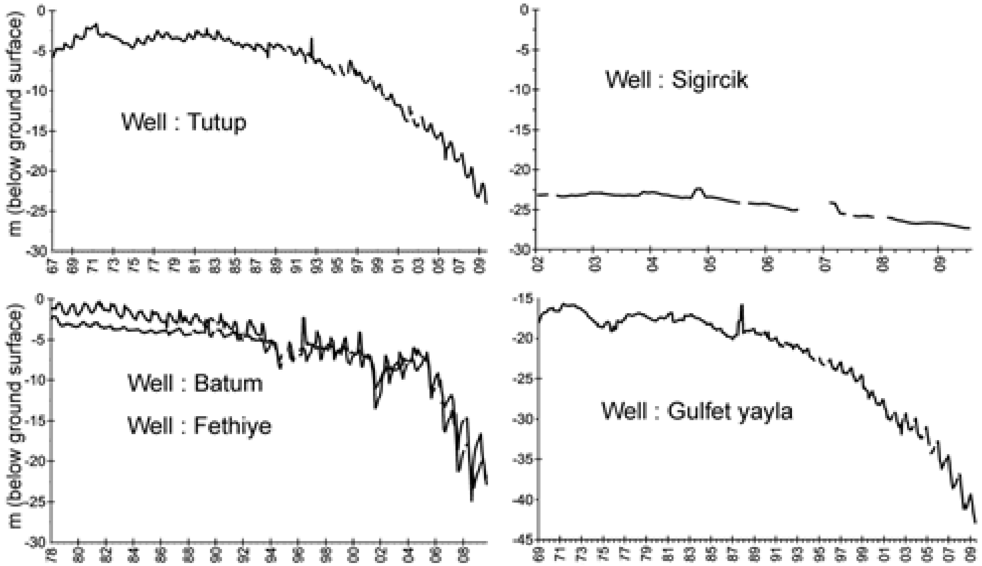
Spatial distribution of ET



Spatially distributed water balance



$$P - ET - R \pm \Delta S = 0$$



ΔS_{RS} versus ΔS_{GW}

Grey areas show ranges estimated from porosity/specific yield uncertainties