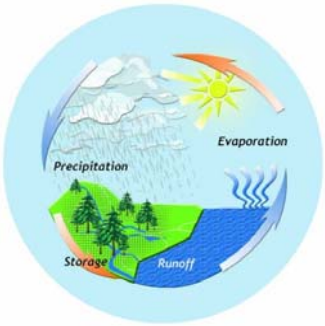


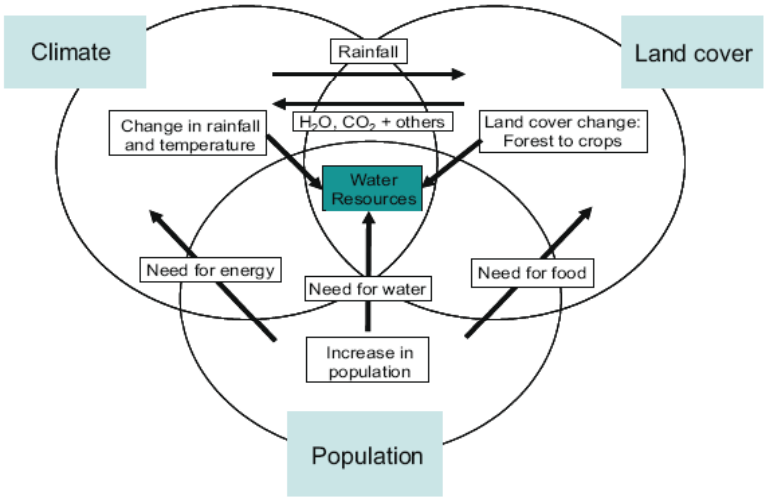
Water Cycle and Global Change: how RS data can help ?

Gilles Boulet, CESBIO

Outline

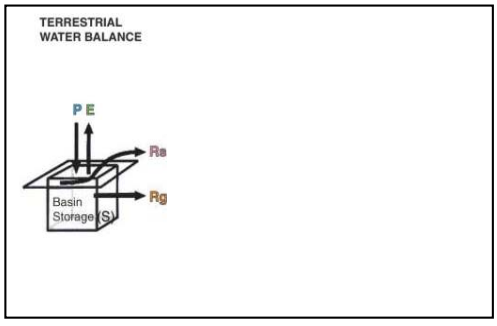
- What do we know about Global Change and the water cycle ?
- What is the expected impact of Global Change on the water cycle ?
- What are the existing tools to assess the components of the water cycle at regional and global scales ?
- What new Remote Sensing data and products can offer to understand the water cycle ?

Global Change



(R. Harding)

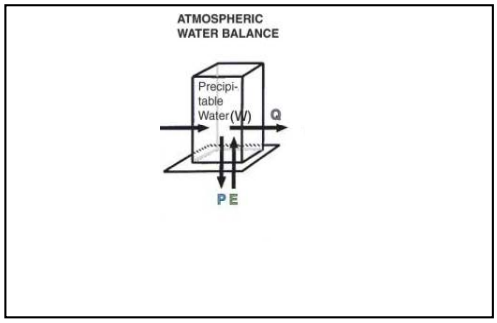
Atmospheric-Terrestrial Water Balance



- Terrestrial water balance: $\frac{\partial S}{\partial t} = (P - E) - R_s - R_g$

(S. Seneviratne)

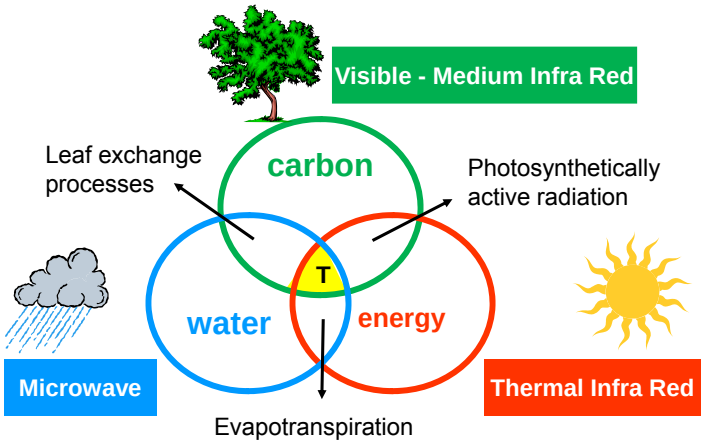
Atmospheric-Terrestrial Water Balance



- Terrestrial water balance: $\frac{\partial S}{\partial t} = (P - E) - R_s - R_g$
- Atmospheric water balance: $\frac{\partial W}{\partial t} = -\nabla_H \vec{Q} - (P - E)$

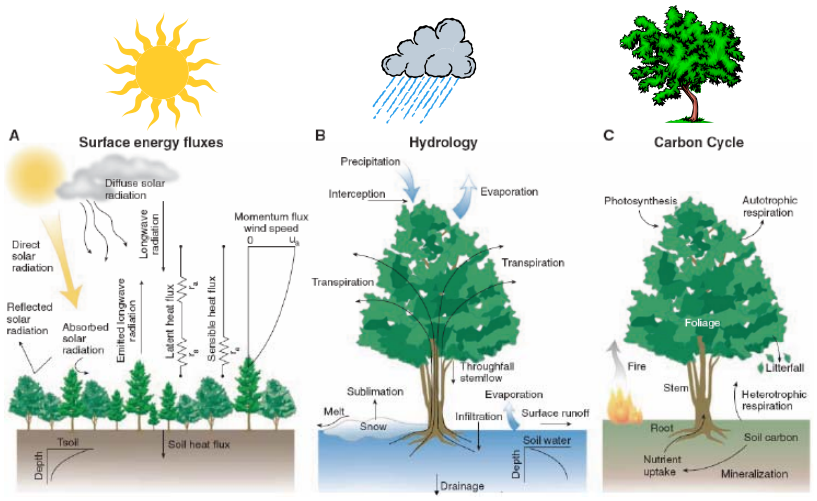
(S. Seneviratne)

coupled biogeochemical cycles



land surface monitoring

coupled biogeochemical cycles

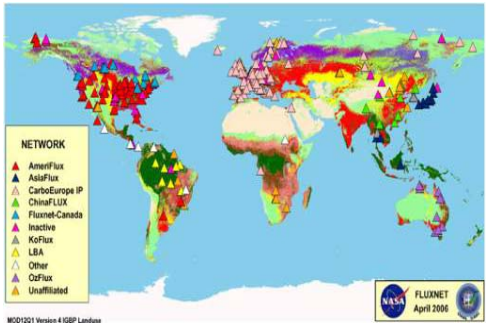


(Bonan, Science 2008)

Observations: FLUXNET

- Worldwide CO_2, water and energy flux measurements (integrating several projects such as AMERIFLUX, CARBOEUROPE, …)

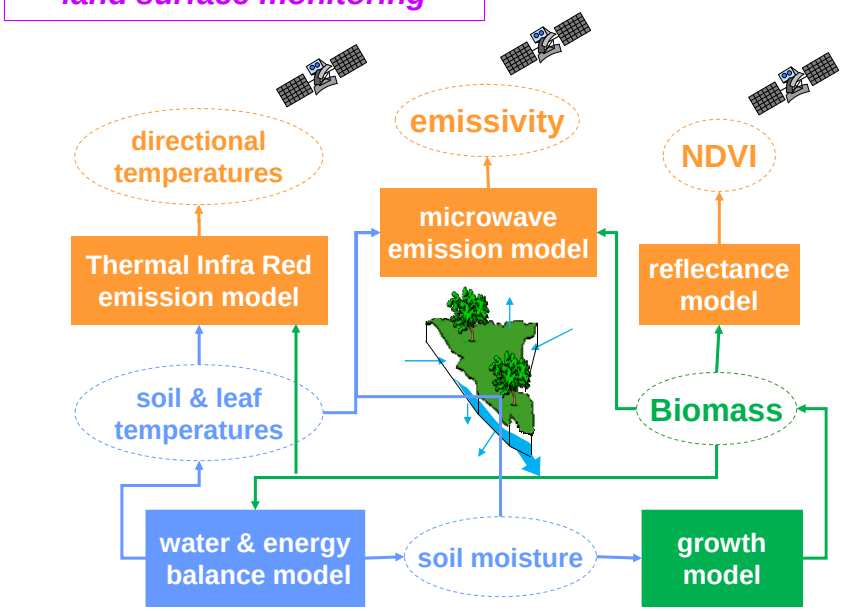
- At present, about 200 tower sites
  - however, still some serious limitations in temporal availability (in Europe, most measurements available after 1995 only)
  - only few sites with soil moisture measurements

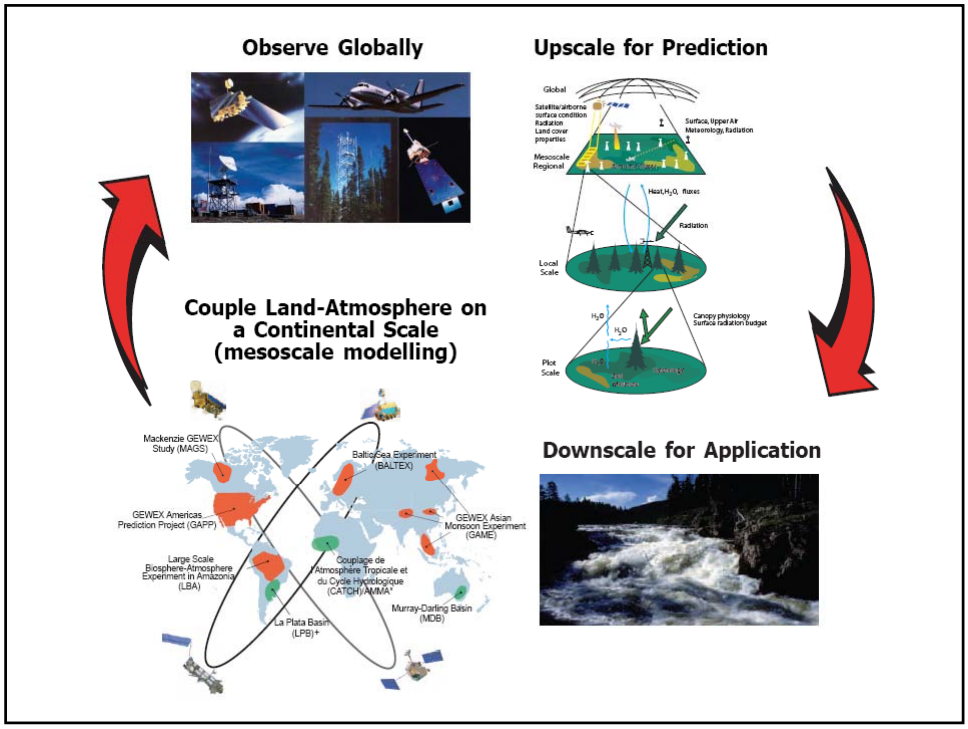


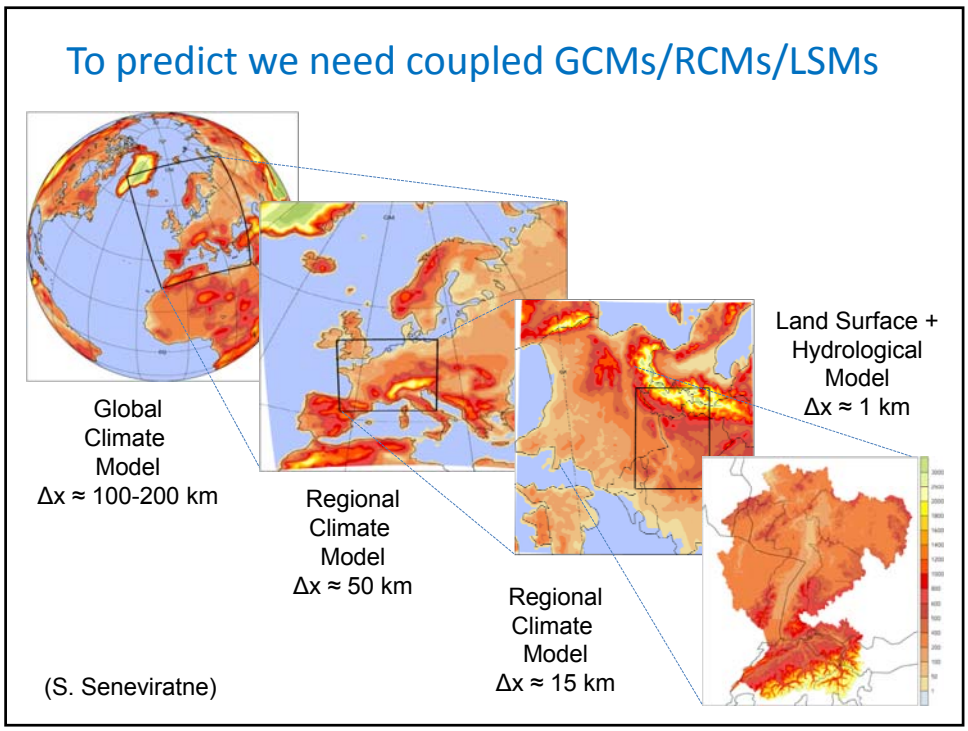
http://www-eosdis.ornl.gov/FLUXNET/

Rationale

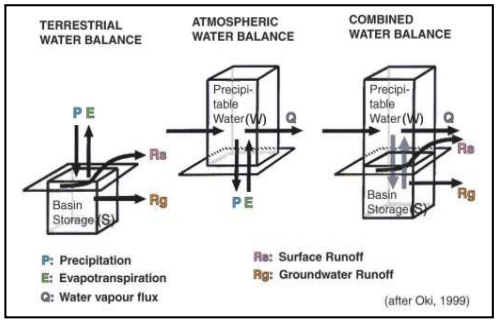
- Mix of in situ obs / RS obs / models
  - Insitu obs: point scale mostly, except streamflow = integrating variable; some are very old
  - RS obs: at many scales but indirect estimates, mostly recent data
  - Models: at many scales but uncertain; good prospective tools
- Beforehand = separate use or forcing; now = joint use of all obs and models




Observe Globally
Upscale for Prediction
Couple Land-Atmosphere on a Continental Scale (mesoscale modelling)
Downscale for Application
Mackenzie GEWEX Study (MAGS)
Baltic Sea Experiment (BALTEX)
GEWEX Americas Prediction Project (GAPP)
GEWEX Asian Monsoon Experiment (GAME)
Large Scale Biosphere-Atmosphere Experiment in Amazonia (LBA)
Couplage de l'Atmosphère Tropicale et du Cycle Hydrologique (CATCH/AMMA)
Murray-Darling Basin (MDB)
La Plata Basin (LPB)+


To predict we need coupled GCMs/RCMs/LSMs
Global Climate Model Δx ≈ 100-200 km
Regional Climate Model Δx ≈ 50 km
Regional Climate Model Δx ≈ 15 km
Land Surface + Hydrological Model Δx ≈ 1 km
(S. Seneviratne)

Atmospheric-Terrestrial Water Balance



The water-balance estimates depend only on observed or assimilated variables (≠ P,E)

Main limitation: valid only for domains > 10^5-10^6 km² (Rasmusson 1968, Yeh et al. 1998)

- Terrestrial water balance: $\frac{\partial S}{\partial t} = (P-E) - R_s - R_g$

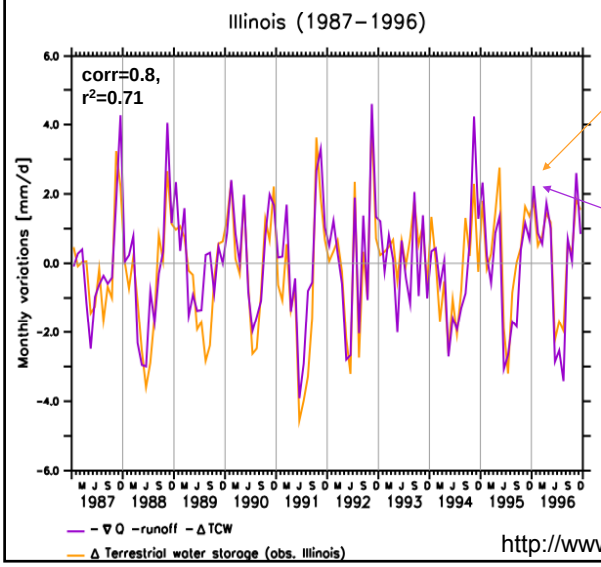
reanalysis data (ERA-40)

- Atmospheric water balance: $\frac{\partial W}{\partial t} = -\nabla_H \vec{Q} - (P-E)$
- Combined water balance: $\frac{\partial S}{\partial t} = -\nabla_H \vec{Q} - \frac{\partial W}{\partial t} - R$

measured streamflow (R_s+R_g)

Case Study: Mississippi & Illinois

Seneviratne et al. 2004, J. Climate, 17 (11), 2039-2057



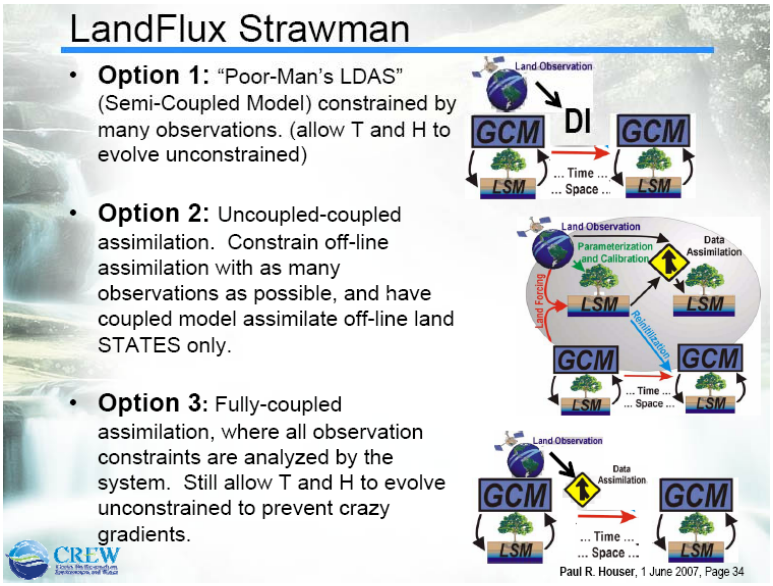
Water-balance Estimates

$$\frac{\partial S}{\partial t} = -\nabla_H \vec{Q} - \frac{\partial W}{\partial t} - R$$

Observations (soil moisture + Groundwater + snow)

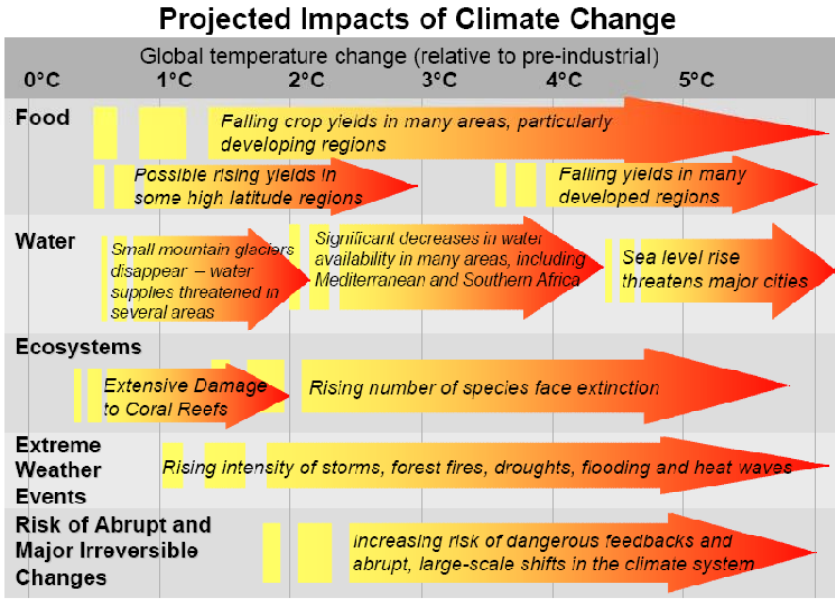
http://www.iac.ethz.ch/data/water balance/

Land Data Assimilation System

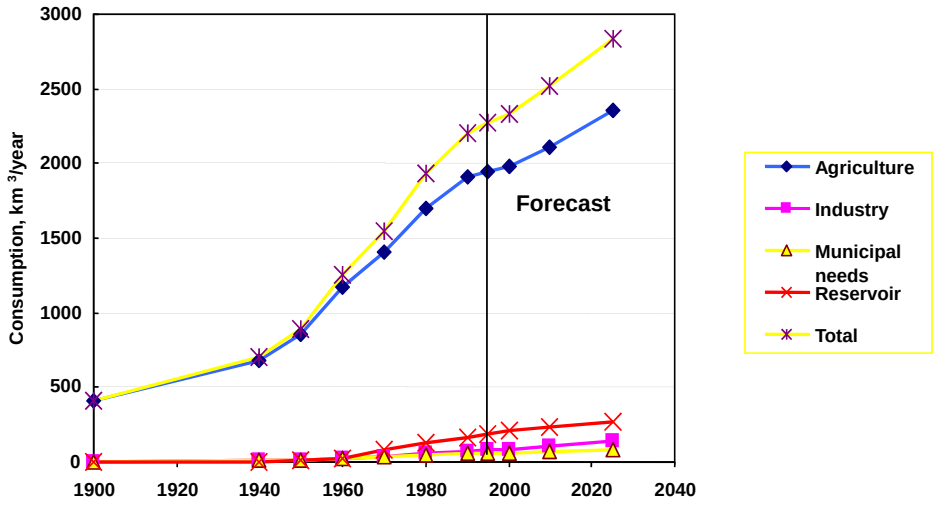


Drivers of Global Change:

- Increasing population
- Increasing water consumption
- Land cover/use change
- Increasing greenhouse gases

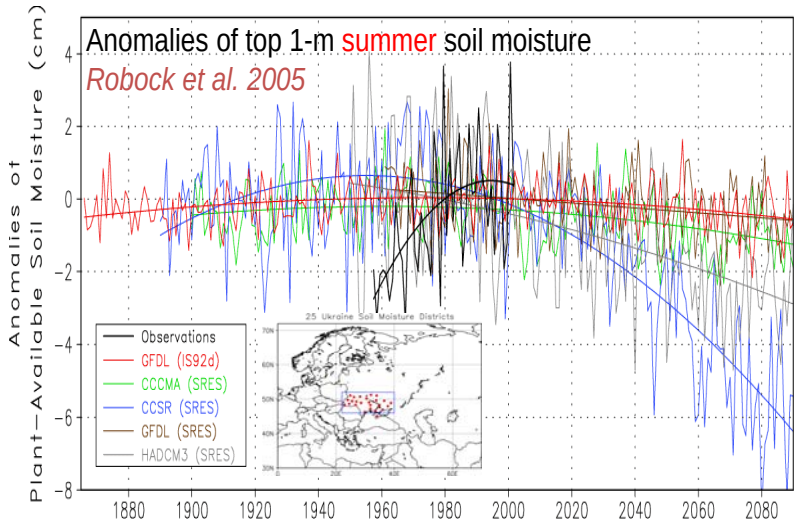


Stern Review (2006)



Water Consumption (*Shiklomanov 2000)*

SOIL MOISTURE

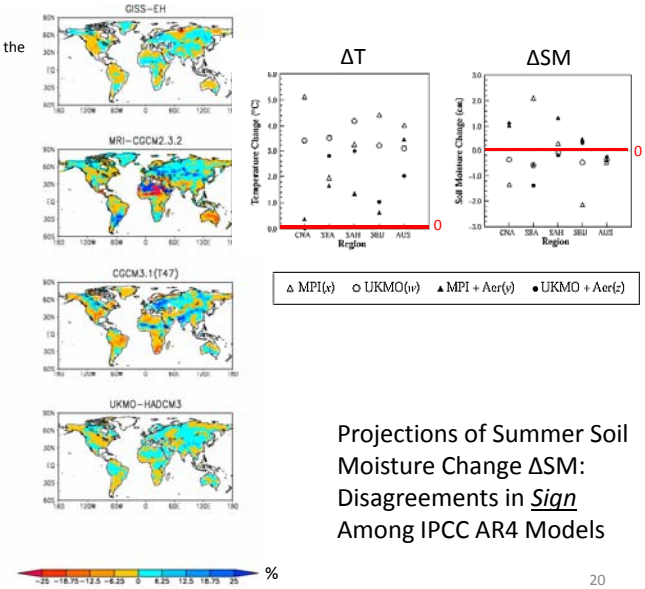


ISSI International Team – LDAS
BERN

YHK Jan 2010

Imperative for Climate Change Science

Li et al., (2007): Evaluation of IPCC AR4 soil moisture simulations for the second half of the twentieth century, *Journal of Geophysical Research*, 112.



Projections of Summer Soil Moisture Change ΔSM: Disagreements in ***Sign*** Among IPCC AR4 Models

Massachusetts Institute of Technology

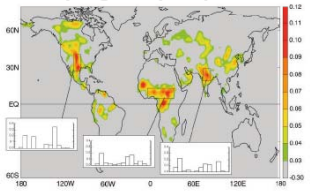
20

Multi-Model Consensus of Regions Where Soil Moisture Impacts Seasonal Precipitation

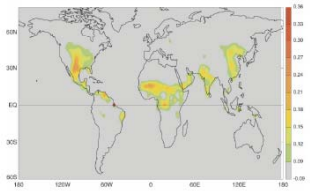
Impact of soil moisture on precipitation and temperature

(Global Land-Atmosphere Coupling Experiment / GLACE, 12 global climate models, summer 1994)

Coupling with precipitation



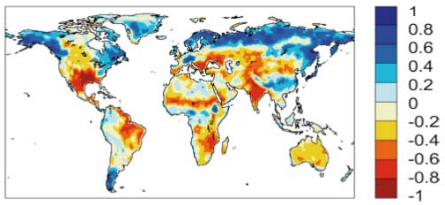
Coupling with temperature



(Koster et al., 2004, Science; Koster et al. 2006, JHM)

(IPCC simulations: ECHAM5, GFDL, HadGEM1; summers 1970-1989)

Correlation (temperature, evapotranspiration)



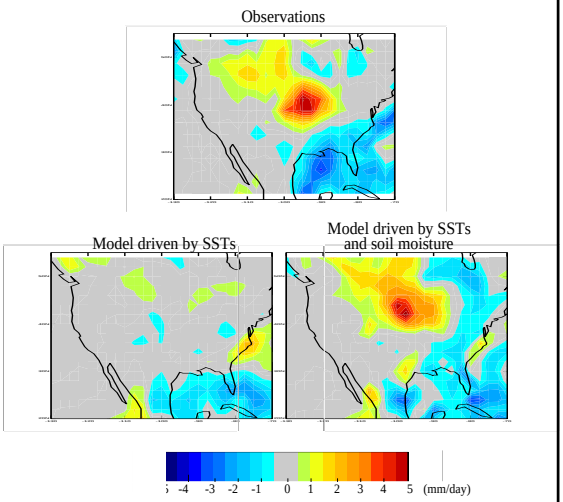
(Seneviratne et al. 2006, Nature)

Strong coupling in transitional zones between dry and wet climates

(S. Seneviratne)

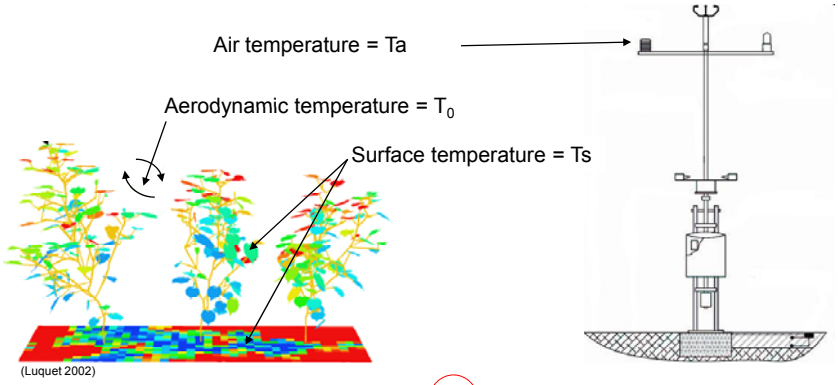
- relevant for climate variability and extreme events (droughts, heatwaves, heavy precipitations events, floods, ...)
- relevant for numerical weather prediction, seasonal forecasting, climate change projections ...
- important source of uncertainty for our understanding of the climate system due to lack of observations and complexity (feedbacks, heterogeneity)

SUMMER 1993 RAINFALL MINUS SUMMER 1988 RAINFALL



(courtesy S. Seneviratne + Y. Kerr)

Surface energy balance

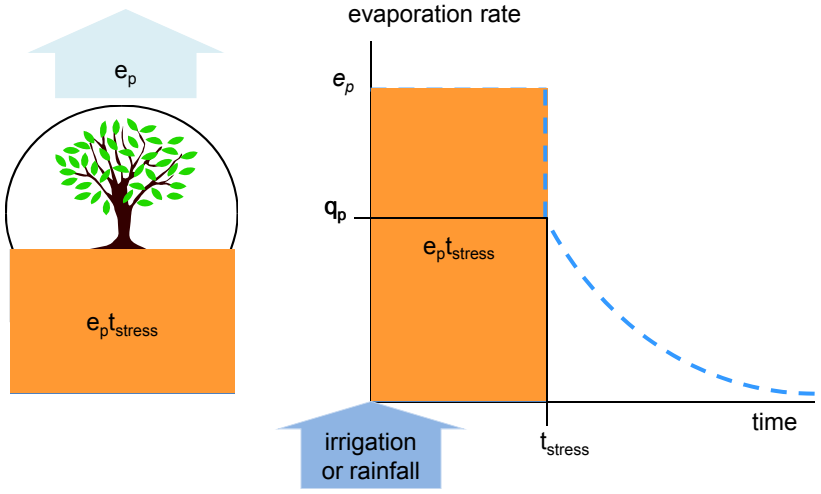


$$Rn(Ts)-G(\sim Ts)=H(T_0)+\lambda e(T_0)$$

Link between the energy and the water balance = surface resistance to evaporation

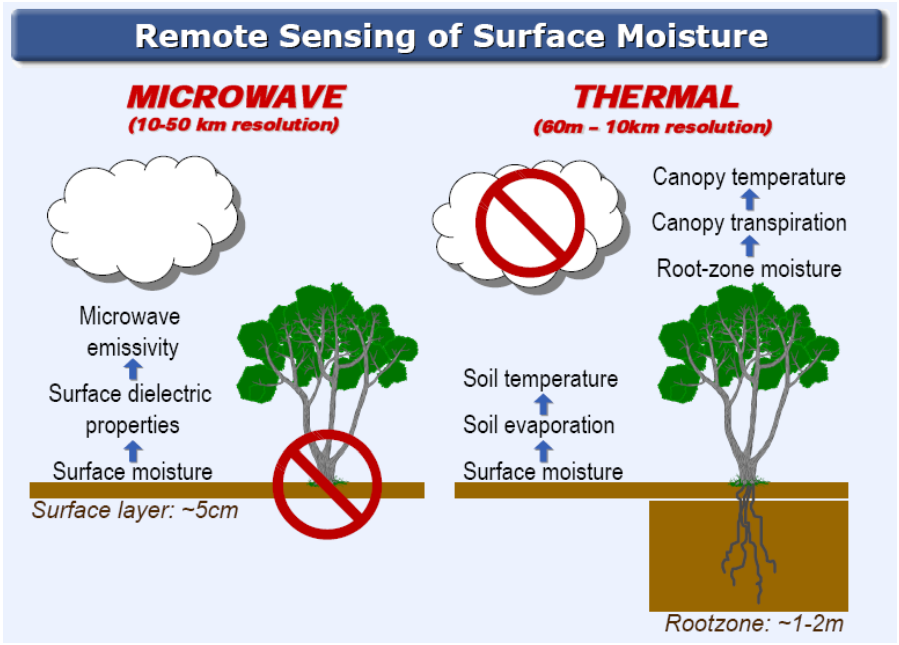
23

Two-stage transpiration description

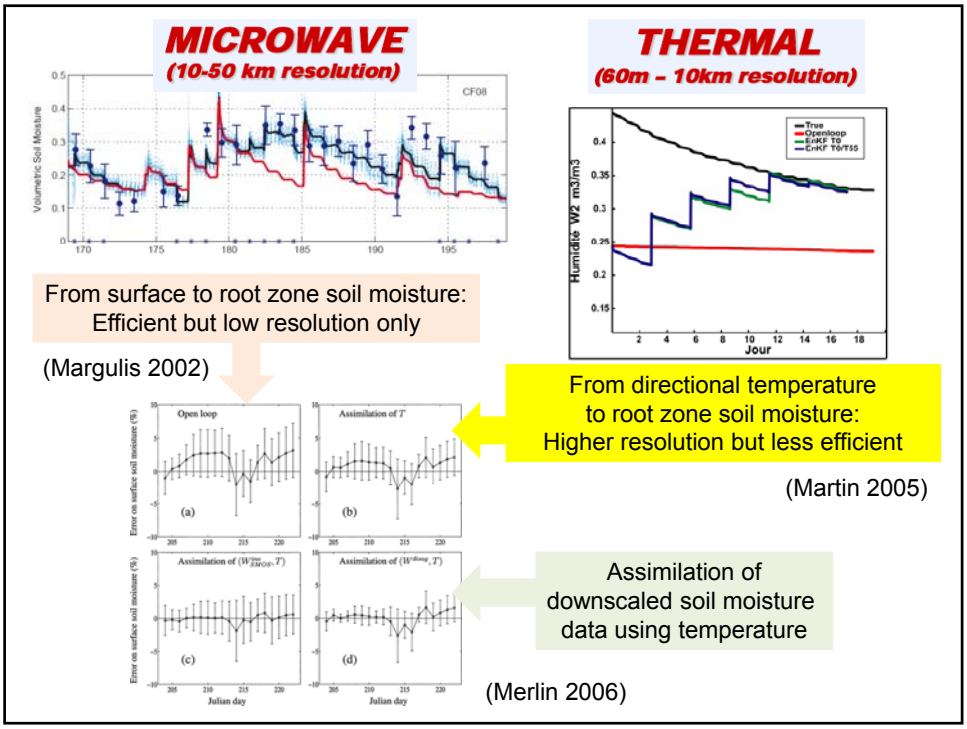


(see Levine and Salvucci, Water Resour. Res 1999)

24



(From Martha Anderson)

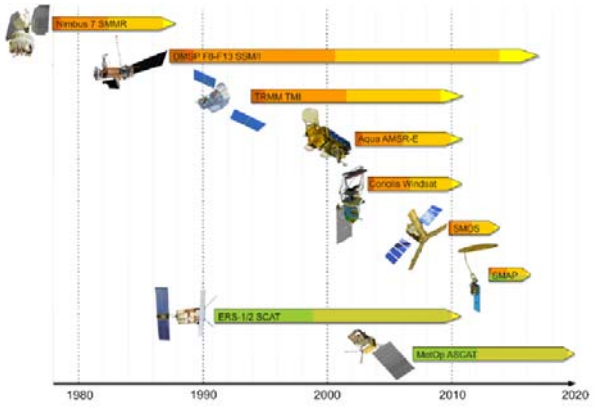


wacmos
support to science element

WACMOS: Soil Moisture

esa

Goal: Produce first global, multi decadal (30+ years), consistent soil moisture data set from existing datasets

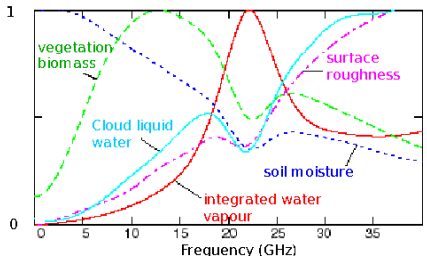


How?

SMOS

Several passive microwaves sensors
- Sensitivity to soil moisture variations is optimal on L-band
- Soil moisture products are provided based on these sensors

Comparison of TB from SMOS to ones from other passive microwaves sensors
- AMSR-E at 6.9 GHz
- TMI at 10.7 GHz

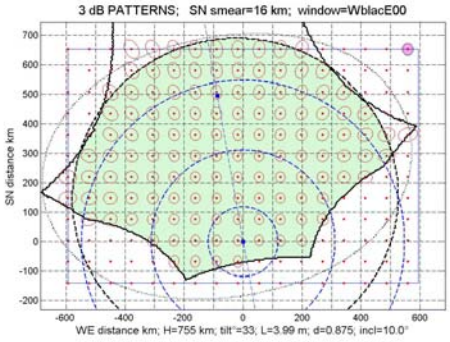


	Band	Repere	Angle	Spatial resol.	Acqu. time	Product used
SMOS	L / 1.4	XY	multi	43km	6:30	L1C
AMSR-E	C / 6.9	HV	55°	56km	1:30	L3 V06
TMI	X / 10.7	HV	52.8°	50km	flex	1B11

Principle of operations

SMOS FOV; 755 km, 3x6, 33°, 0.875l,

- 3 arms / interferometry
- Each integration time (2.4 s) a full scene is acquired (dual or full pol)
- Average resolution is 43 km, with a global coverage
- Each point of the surface seen with several angles
- Maximum revisit (equator) is 3 days (good for hydrology)



P. Waldteufel, 2003

SMOS soil moisture retrieval

LAI	Land cover	Soil Texture	Temperatures…
↓ MODIS	↓ ECOCLIMAP	↓ FAO	↓ ECMWF

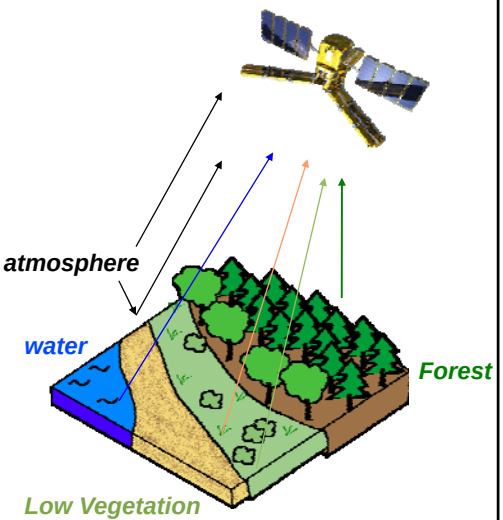
Vegetation Layer

Radiative transfer model : L-Meb model
(L band Microwave Emission of the Biosphere)
Wigneron et al.

Surface dielectric Model

Dobson model (Dobson et al. 1985)
Nominal wet soil
Pure Water
Saline Water

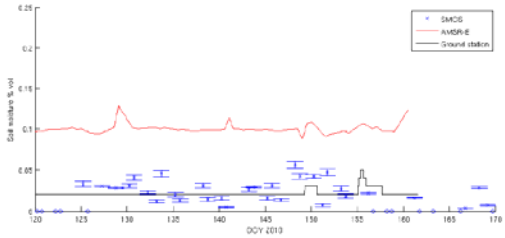
Simple empirical relationship
Frozen soil
Ice
Barren rocks
Urban
snow

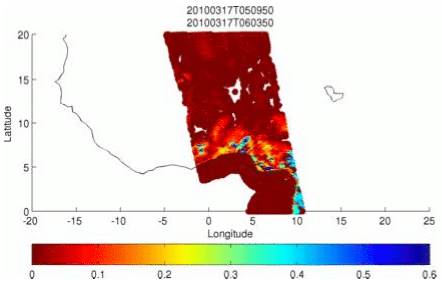


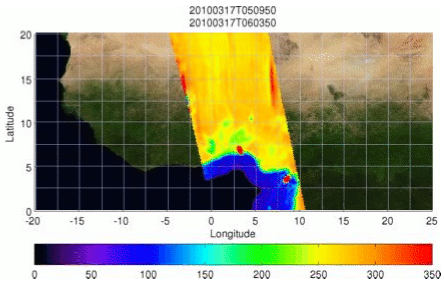
Sahel L1 (Tb) and L2 (SM) products

Ground measurements and soil moisture products

- SMOS: L2SM
- AMSR-E: NSIDC V06
- Ground station: Niger
- Temporal periode: May – June

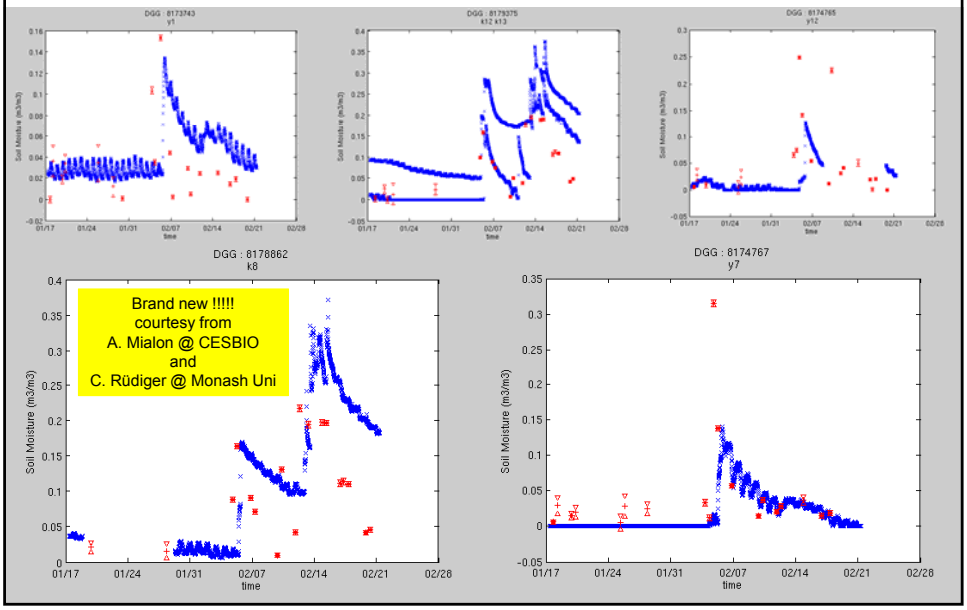






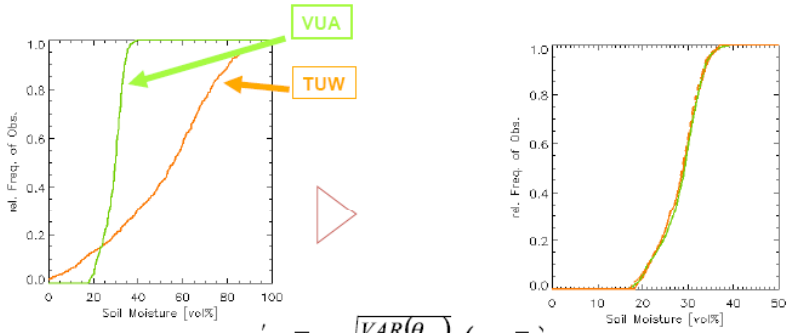
(C. Gruhier 2010)

Evaluation: AACESS experiment in Australia



Data set merging – current status

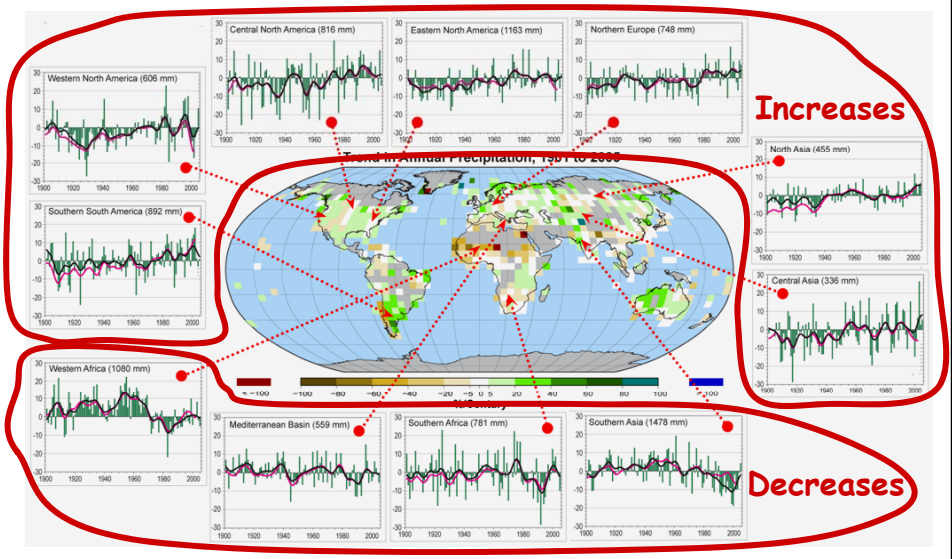
- Match the two datasets e.g. with Cumulative Distribution Function (CDF) matching
  - **Problems**: data gaps and changes in frequency (SSM/I)



$$\theta_S' = \overline{\theta}_M + \sqrt{\frac{VAR(\theta_M)}{VAR(\theta_S)}} \cdot (\theta_S - \overline{\theta}_S)$$

(WACMOS, VU Amsterdam+TUWien)

Precipitations



Smoothed annual anomalies for precipitation (%) over land from 1900 to 2005; other regions are dominated by variability (from R. Harding based on IPCC 2007 report).

TABLE 1. Summary of the high-resolution precipitation products used in this study with input data types and a summary of the combination method. Geo-IR stands for geosynchronous infrared.

Product name	Input data	Combination method
3B42	Geo-IR, microwave from SSM/I, TRMM, AMSU, AMSR, and gauges	Merged microwave and microwave-calibrated IR calibrated to global gauge network
CMORPH	Geo-IR, microwave from SSM/I, TRMM, AMSU, and AMSR	PMW rain rates advected and evolved according to IR imagery
Hydro-Estimator	Geo-IR and NWP	Brightness temperature in geo-IR, modulated by cloud evolution, stability, total precipitable water, etc.
NRL blended	Geo-IR, microwave from SSM/I, TRMM, AMSU, and AMSR	Histogram-matching calibration of geo-IR to merged microwave; weighted combination
PERSIANN	Geo-IR and TRMM microwave	Adaptive neural network calibration of geo-IR to PMW

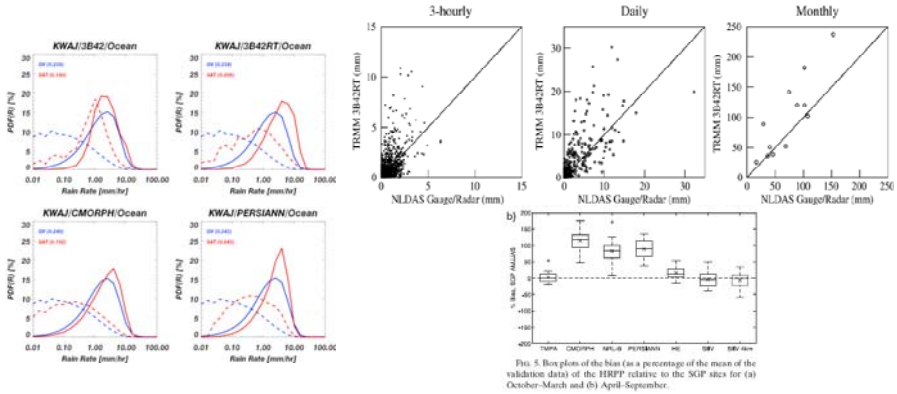
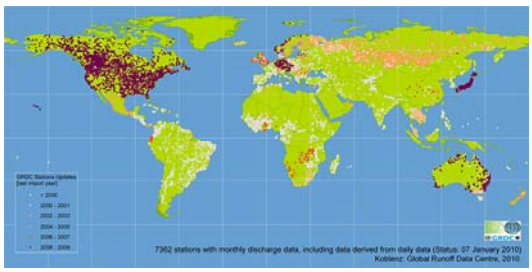
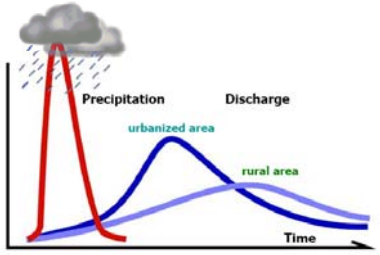


FIG. 5. Box plots of the bias (as a percentage of the mean of the validation data) of the HRPP relative to the SGP sites for (a) October–March and (b) April–September.

Surface water



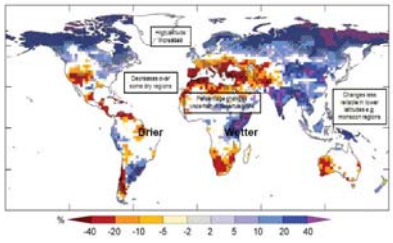
Precipitation to runoff



(R. Harding)

21st Century Water Availability (Runoff) Changes

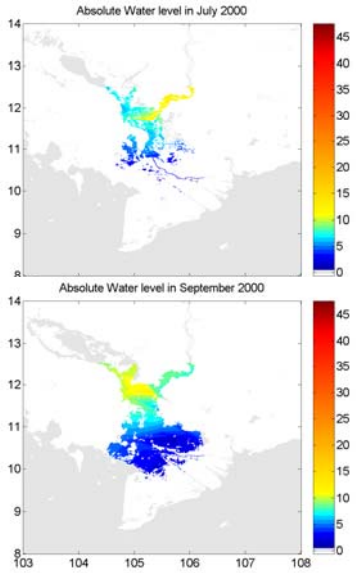
(A1B; Annually averaged)

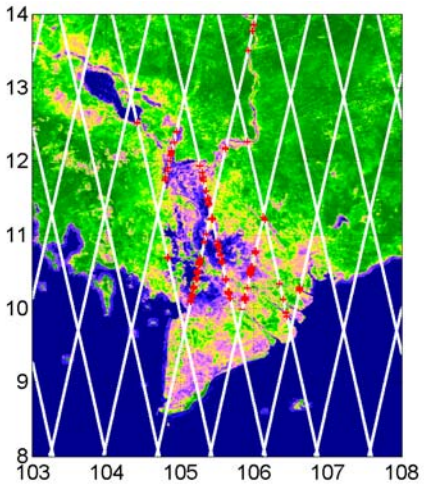


(GRDC group)

Seasonal flood monitoring in the Mekong Basin

ERS/ENVISAT altimetry + SPOT/VGT imagery





Frappart et al., 2006

Dynamic of surface water extent at global scale

1) Global surface water extent from multi-satellite method

Merging of satellite data with different wavelengths (surface classification, NN, vegetation)

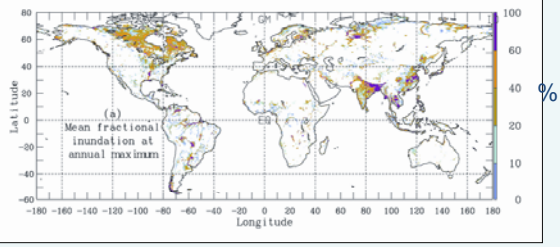
Passive microwave
SSM/I emissivities at 19, 37 GHz, H and V polarizations

Active microwave
ERS scatterometer backscattering coefficient at 5.25 GHz

Visible and near infrared
AVHRR NDVI (visible and near-infrared reflectances)

[Prigent et al, 2001; Prigent et al, 2007
Papa et al., 2006, 2007,2008]

Mean fractional surface water extent at annual maximum



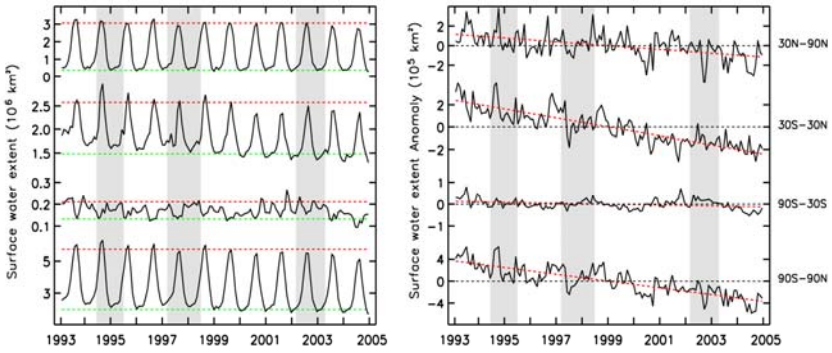
- Data mapped on equal-area grid with 0.25°x0.25° resolution at equator (773 km²)
- Monthly resolution for 1993-2004

and at least extended to 2012 and longer

(Papa 2007)

Dynamic of surface water extent at global scale

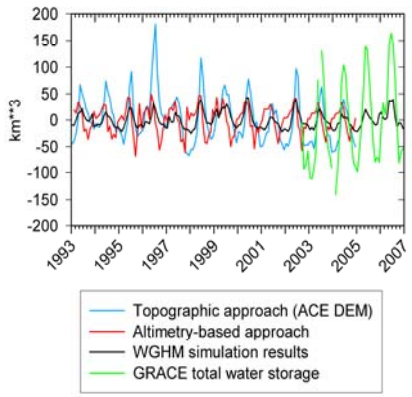
Global and zonal temporal variations of inundated surfaces extent



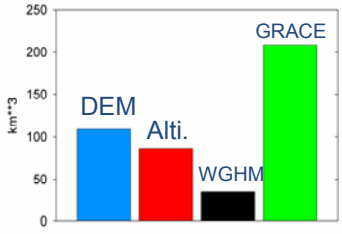
Global results: maximum extent: ~6.7 million km², strong seasonal cycle and inter-annual variability

Need of validation, comparison, evaluation of these results

Surface water storage change: Rio Negro basin case study

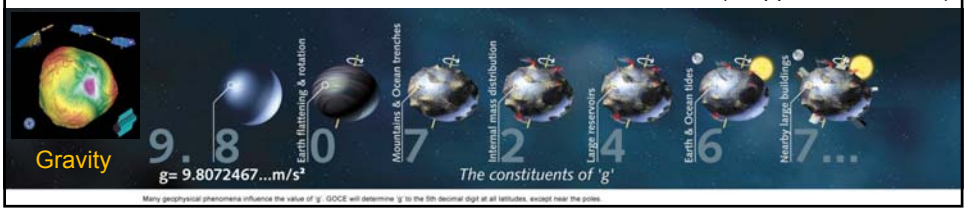


Mean seasonal amplitude of water storage change

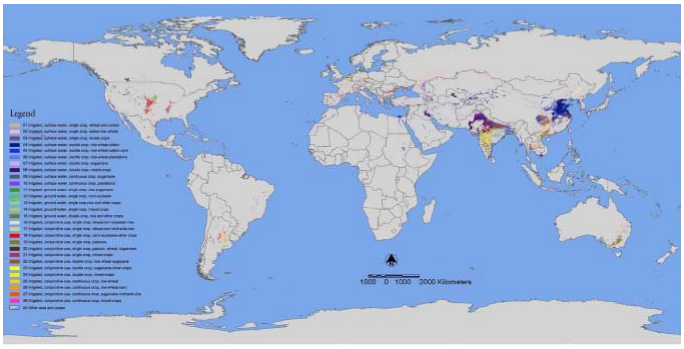


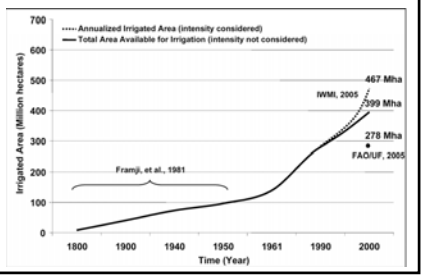
Surface water volume change from multi-sat/alti is ~ 38% of Grace total storage

(Frappart et al., 2008)



Groundwater





Source: IWMI

$\Delta S_{GW} = \Delta S_{Total} - \Delta S_{SW} - \Delta S_{SM} - \Delta S_{SNOW} - \Delta S_{AtmVap}$ → GCM + vap product

GRACE

Multisat. Inundation + radar altimetry

LSM + SMOS, SMAP

Model + passive microwave (SSM/I, AMSR)

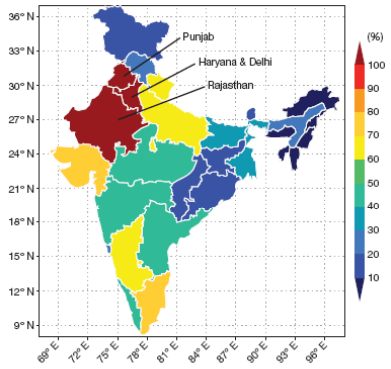


Figure 1 | Groundwater withdrawals as a percentage of recharge. The map is based on state-level estimates of annual withdrawals and recharge reported by the Indian Ministry of Water Resources[5]. The three states studied here are labelled.

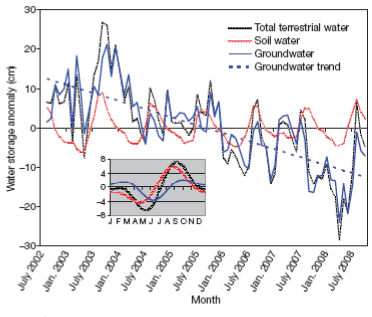
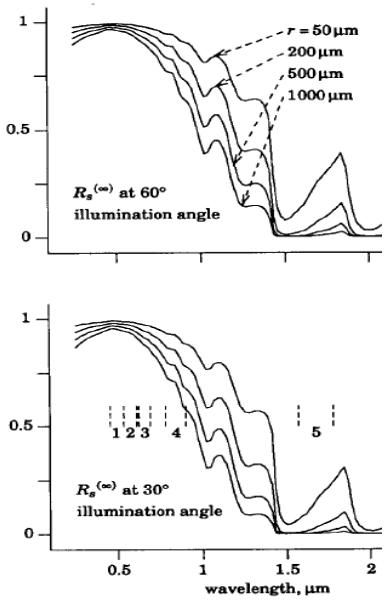


Figure 3 | Monthly time series of water storage anomalies in northwestern India. Monthly time series of anomalies of GRACE-derived total TWS, modelled soil-water storage and estimated groundwater storage, averaged over Rajasthan, Punjab and Haryana, plotted as equivalent heights of water in centimetres. Also shown is the best-fit linear groundwater trend. Inset, mean seasonal cycle of each variable.

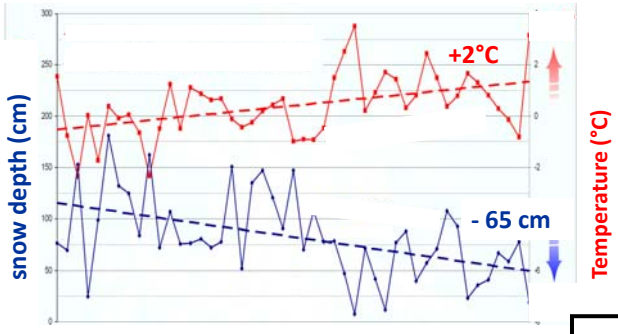
(Rodell 2008)

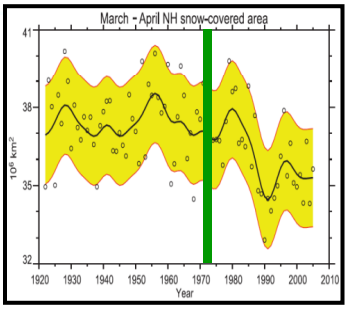
Snow



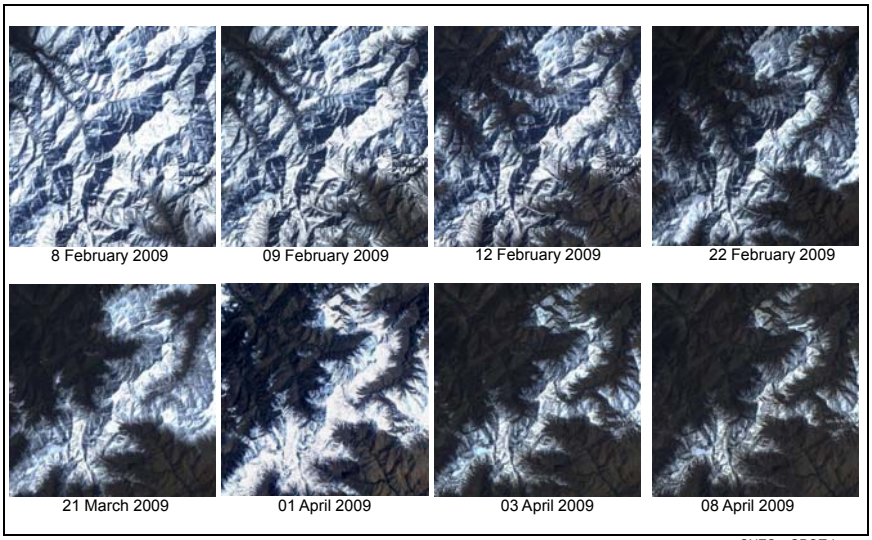
- Good signature of CC, esp. in remote areas where direct anthropogenic perdutbations are minimum
- Snowmelt sustains summer lowflows in many semiarid mountains
- Snowfall, snowmelt, sublimation rates will be modified

"col de porte", French Alps, elevation 1300m
(December-April average)





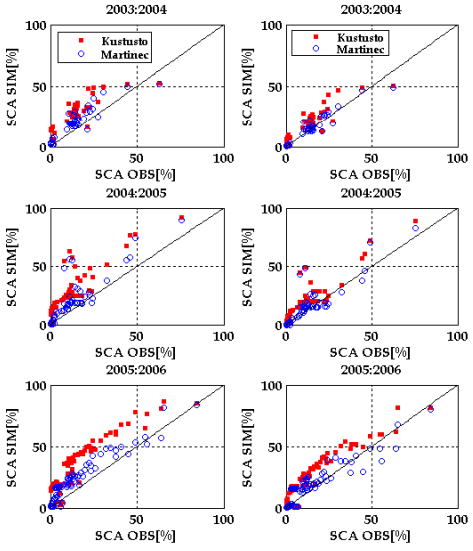
METEO FRANCE
Centre d'Etude de la Neige



CNES – SPOT-Image

Sample of the 2008/09 time series of FORMOSAT2 images @ 8 m resolution

Without Sublimation **With Sublimation**



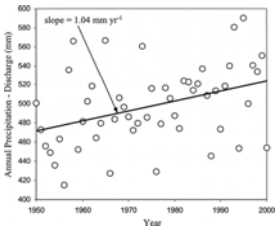
		Martinec	
		Without subl.	With sublimation
2003/2004	*RMSE (%)*	7,70	**3,93**
	BIAIS (%)	5,40	**0,68**
2004/2005	*RMSE (%)*	12,75	**8,80**
	BIAIS (%)	7,59	**2,64**
2005/2006	*RMSE (%)*	9,54	**7,43**
	BIAIS (%)	7,65	**3,20**

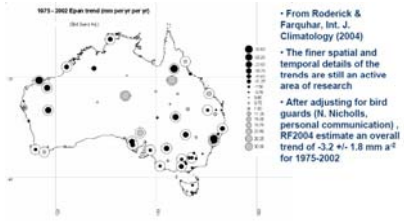
		Kustusto	
		Without subl.	Avec sublimation
2003/2004	**RMSE (%)**	14,98	**8,66**
	BIAIS (%)	13,18	**6,32**
2004/2005	**RMSE (%)**	19,51	**11,46**
	BIAIS (%)	16,43	**8,33**
2005/2006	**RMSE (%)**	19,50	**12,17**
	BIAIS (%)	17,61	**10,40**

EVAPORATION

www.bom.gov.au

P-R



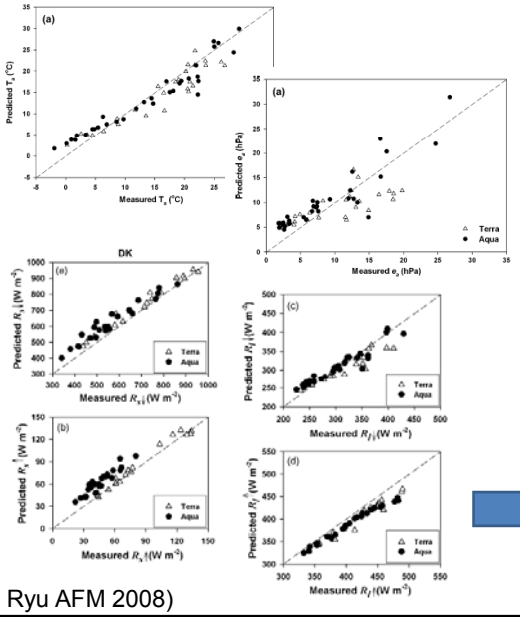


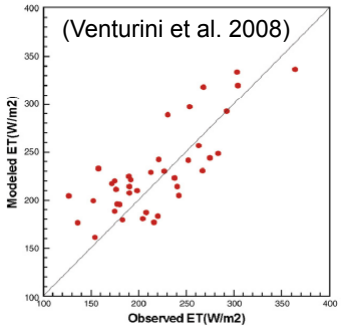
Walter, M. T., D. S. Wilks, J.-Y. Parlange, and R. L. Schneider. 2004. Increasing Evapotranspiration from the Conterminous United States. *Journal of Hydrometeorology* 5: 405-08.

The Class A Pan controversy

What about an increase in groundwater uptake ? (Pan A location ?)

Evaporation from RS data only





	Time	Space
MOD3 (Geolocation)	5 min	1 Km
MOD4 (Aerosol)	5 min	10 Km
MOD5 (Total Precipitable Water)	5 min	5 Km
MOD7 (Atmospheric Profiles)	5 min	5 Km
MOD11A1 (LST/Emissivity)	6 min	1 Km
MOD43B3 (BRDF/Albedo)	16 day	1 Km

(Y. Ryu AFM 2008)

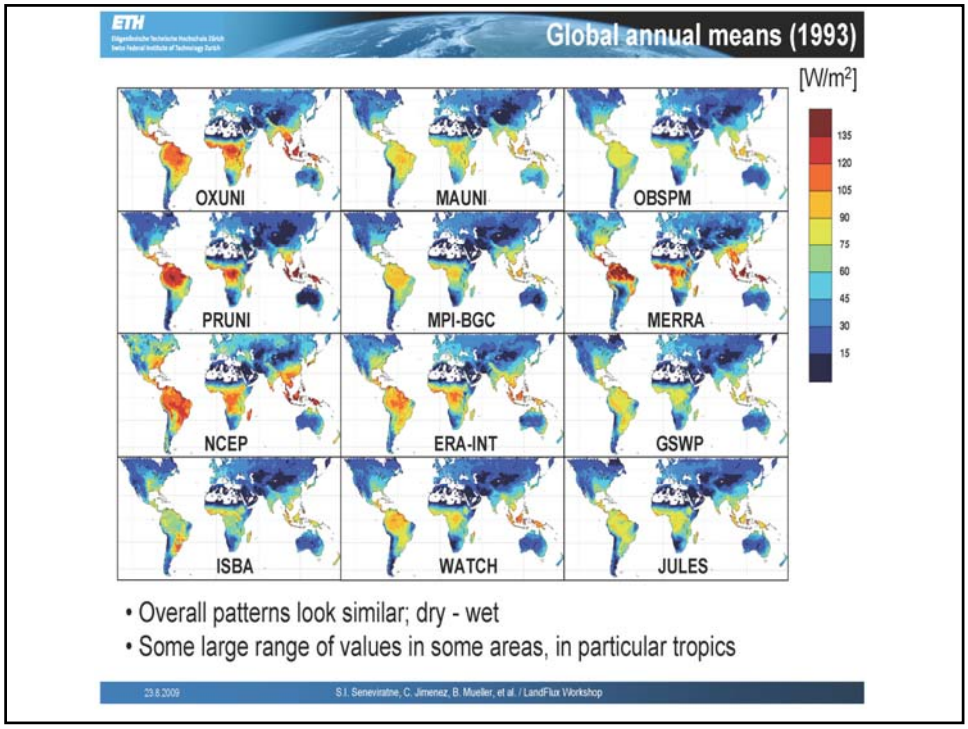
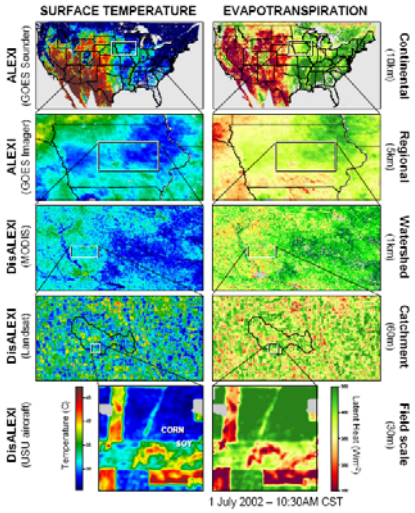
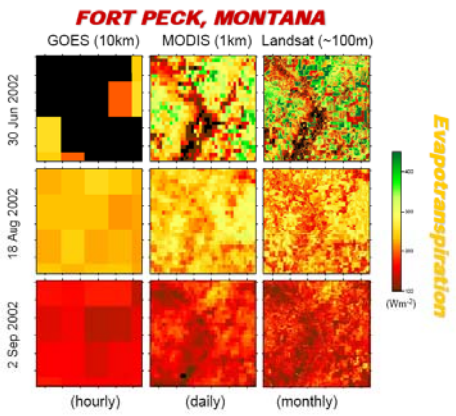


Table 1
Classification of some methods to assess water stress from TIR data.

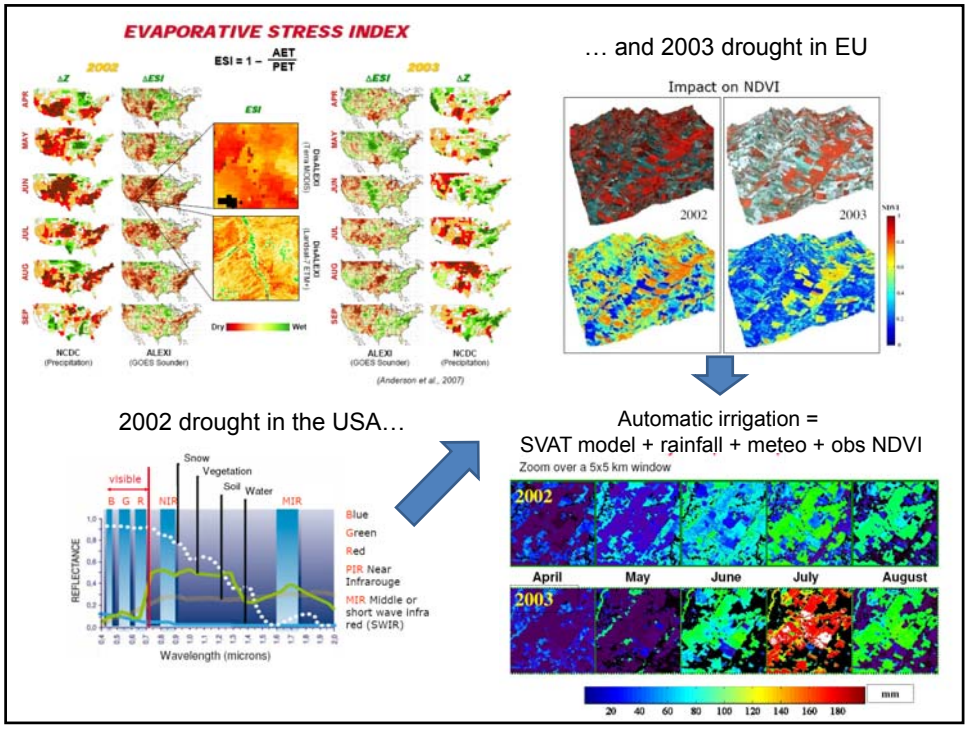
	With an energy balance model	Without energy balance model
Instantaneous retrieval	SEBAL, ALARM, SEBS, etc.	TVI, TVDI, etc.
Time series analysis	CWSI, SEBI, WDI, etc.	Albedo, $T_s - T_a$, $(T_s - T_a)/R_n$, etc.
Data assimilation in a state-space model	Simple (thermal inertia only, no water balance involved) or complex (SVAT, water balance involved)	Assimilation of time to stress in water balance models (e.g. SVATsimple)

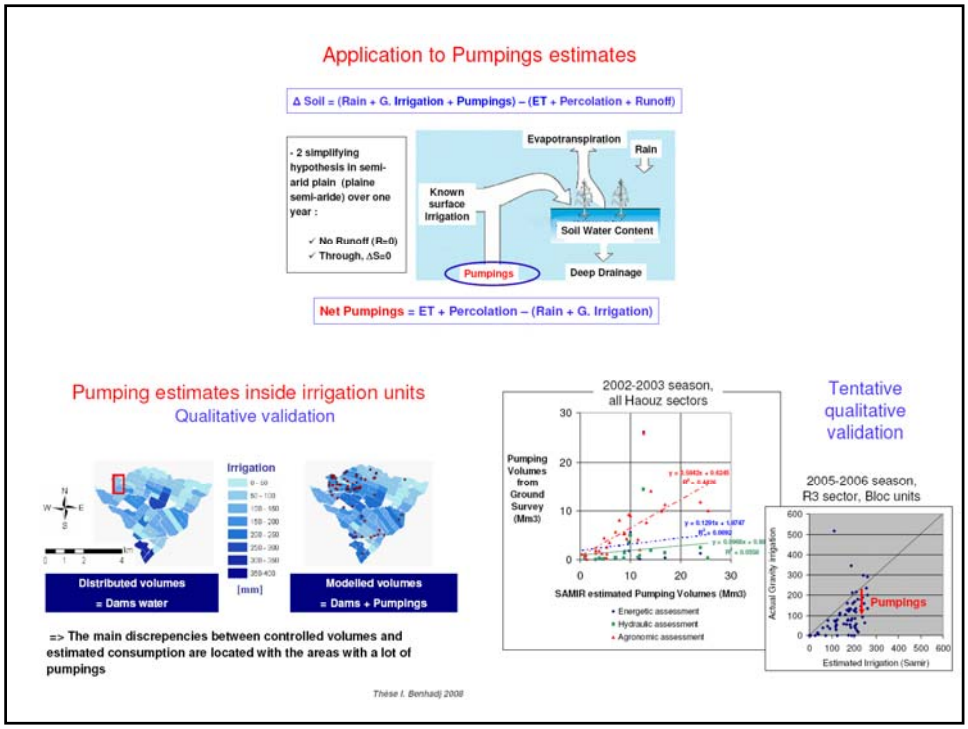
(Boulet 2007)





(Anderson 2007)


EVAPORATIVE STRESS INDEX
ESI = 1 – AET/PET
2002
2003
ESI
Dry
Wet
NCDC (Precipitation)
ALEXI (GOES Sounder)
(Anderson et al., 2007)
… and 2003 drought in EU
Impact on NDVI
2002
2003
2002 drought in the USA…
Snow
Vegetation
Soil
Water
visible
B G R
NIR
MIR
REFLECTANCE
Wavelength (microns)
Blue
Green
Red
PIR Near Infrarouge
MIR Middle or short wave infra red (SWIR)
Automatic irrigation =
SVAT model + rainfall + meteo + obs NDVI
Zoom over a 5x5 km window
2002
2003
April
May
June
July
August
mm
20 40 60 80 100 120 140 160 180

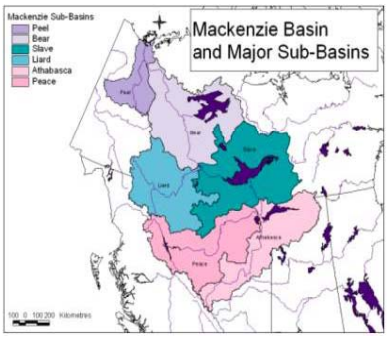

Application to Pumpings estimates
Δ Soil = (Rain + G. Irrigation + Pumpings) – (ET + Percolation + Runoff)
- 2 simplifying hypothesis in semi-arid plain (plaine semi-aride) over one year :
✓ No Runoff (R=0)
✓ Through, ΔS=0
Evapotranspiration
Rain
Known surface Irrigation
Soil Water Content
Pumpings
Deep Drainage
Net Pumpings = ET + Percolation – (Rain + G. Irrigation)
Pumping estimates inside irrigation units
Qualitative validation
Irrigation
[mm]
Distributed volumes = Dams water
Modelled volumes = Dams + Pumpings
=> The main discrepencies between controlled volumes and estimated consumption are located with the areas with a lot of pumpings
Thèse I. Benhadj 2008
2002-2003 season, all Haouz sectors
Pumping Volumes from Ground Survey (Mm3)
SAMIR estimated Pumping Volumes (Mm3)
Energetic assessment
Hydraulic assessment
Agronomic assessment
Tentative qualitative validation
2005-2006 season, R3 sector, Bloc units
Actual Gravity irrigation
Pumpings
Estimated Irrigation (Samir)

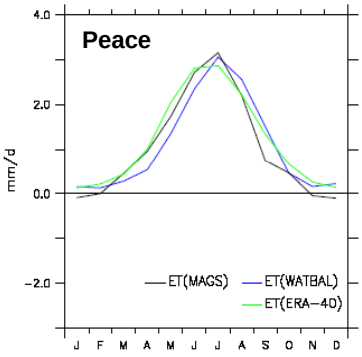
Estimation of large-scale ET

Atmospheric water balance:

$$\frac{\partial W}{\partial t} = -\nabla_H \vec{Q} - (P - E) \quad \Rightarrow \quad E = \frac{\partial W}{\partial t} + \nabla_H \vec{Q} + P$$

Mackenzie GEWEX Study (MAGS)





Louie et al. 2002

Conclusion

- In situ observations show usually the longest historical records for most water cycle components, but it is hard to infer continental and global trends, and some components are poorly observed (e.g. evaporation)
- RS data have little historical records > pb of continuity, but they do provide integrated information at many scales
- RS data at present are mostly used to evaluate and improve the chain of GCM/RCM/LSM models