Surface Energy Balance System and Evaporation/Transpiration

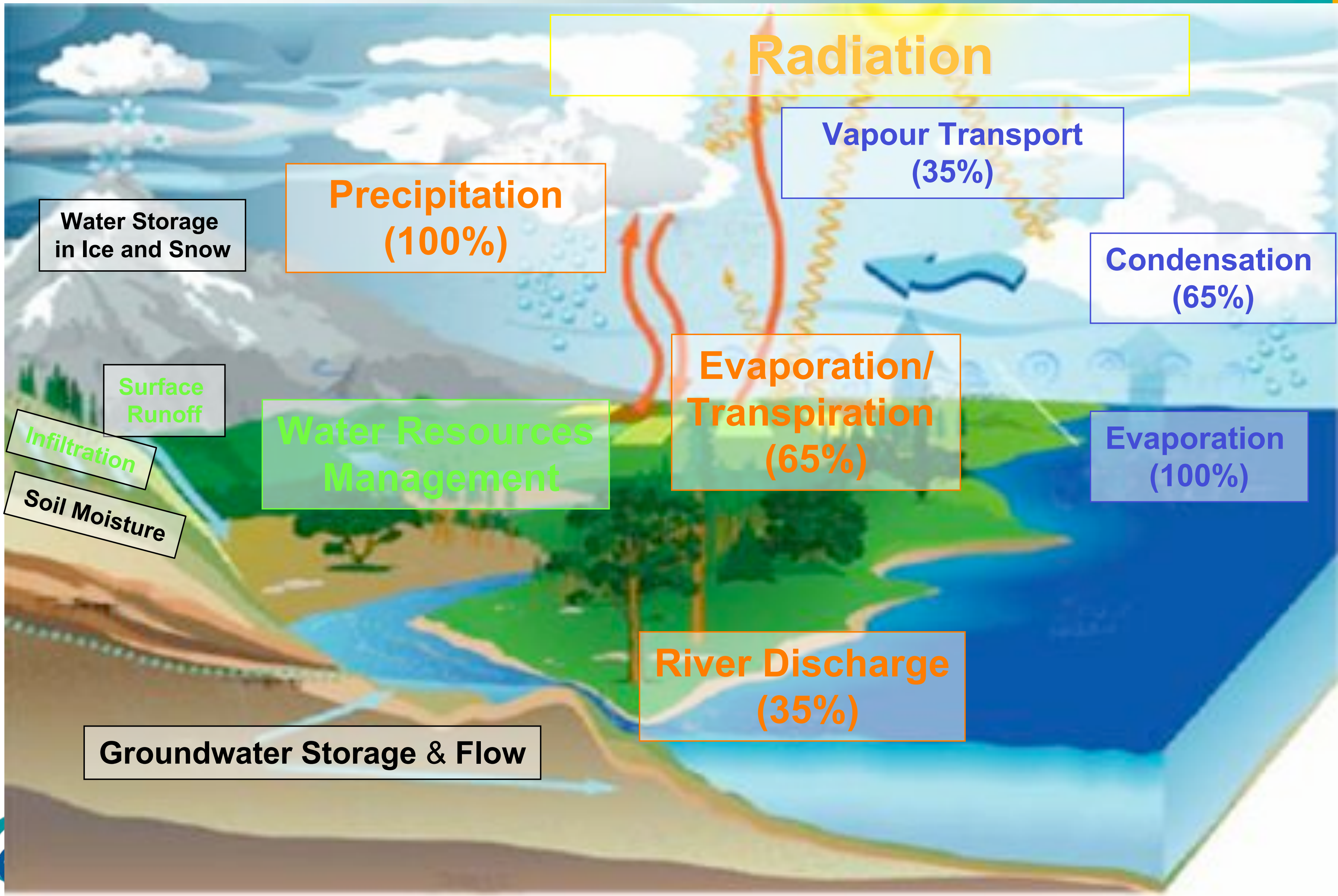
Z. (Bob) Su

International Institute for Geo-Information Science and Earth Observation (ITC), Enschede, The Netherlands

B_SU@ITC.NL

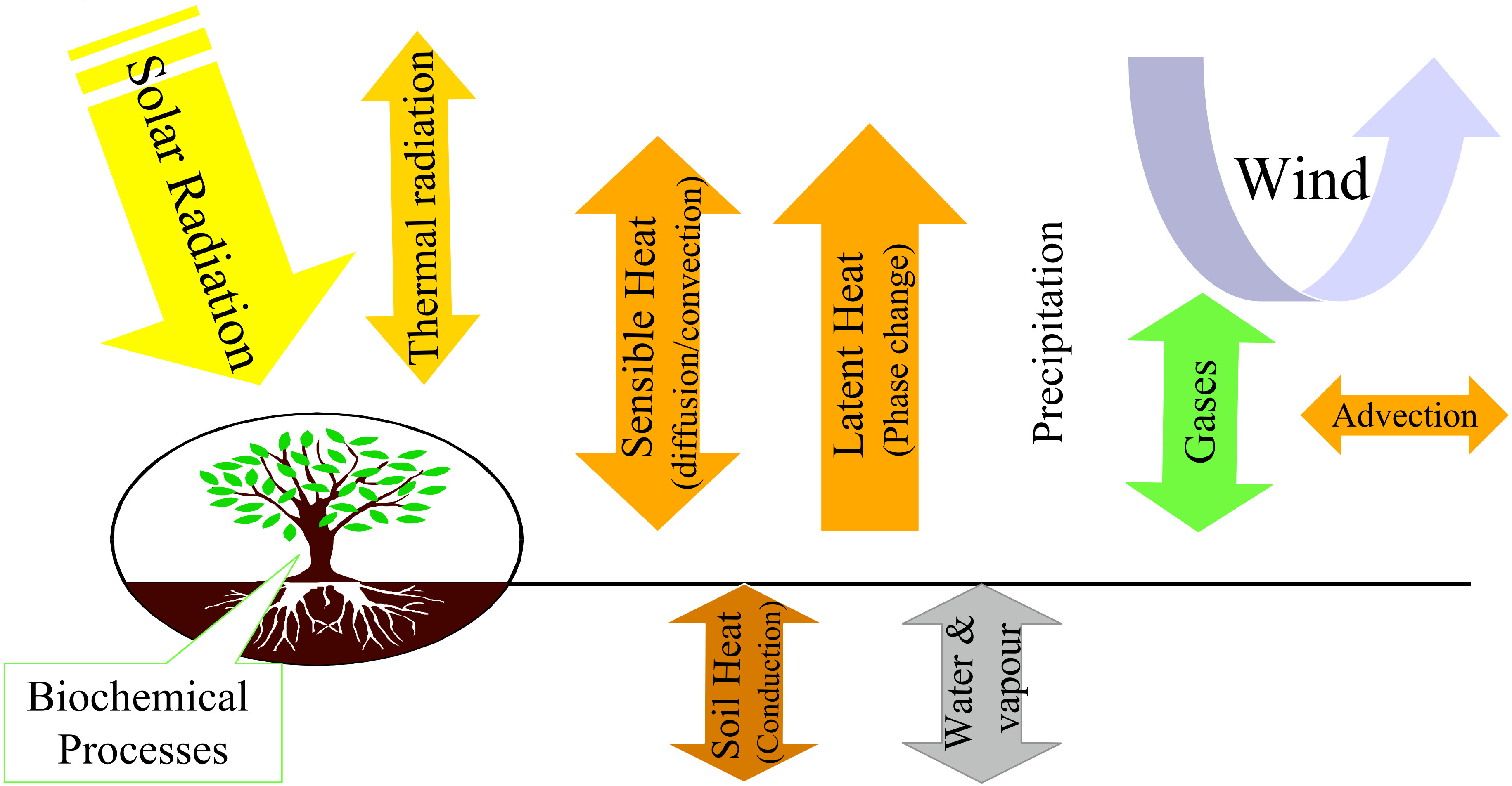
www.itc.nl

Earth Observation of Water Cycle

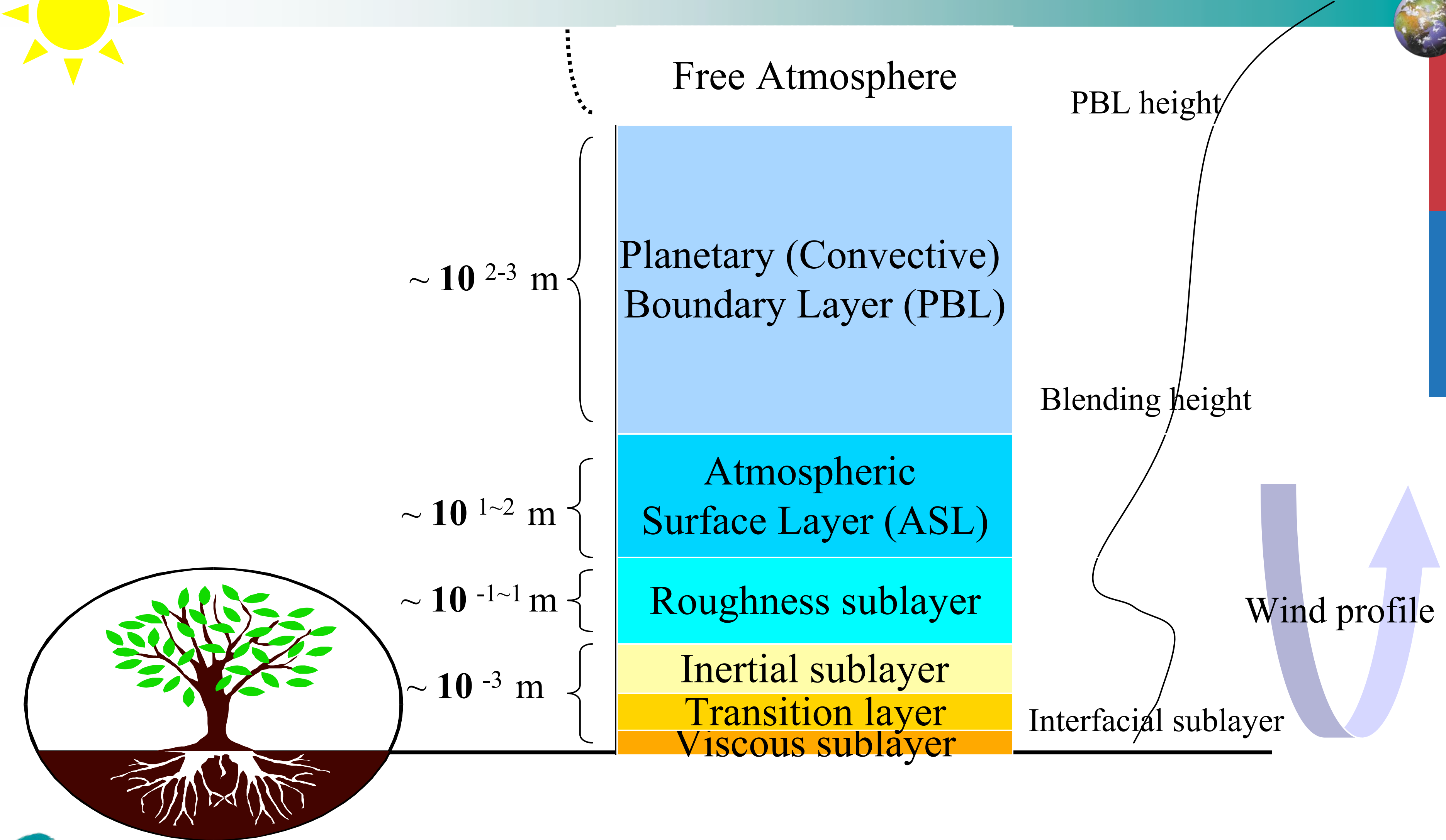


ITC

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

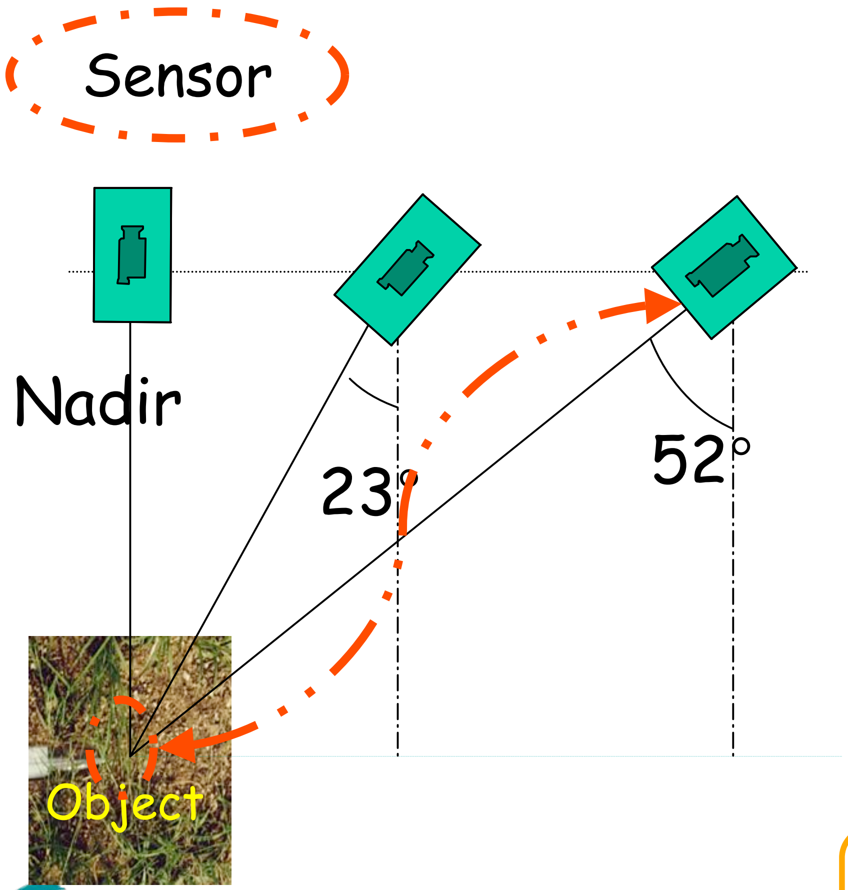


Structure of the atmospheric boundary layer considered in SEBS



The Fundamental of Earth Observation

(Sensor - Object Radiative Relationship)



Sensor Response

A. How much radiation is detected?
B. When does it arrive?

Object Properties:

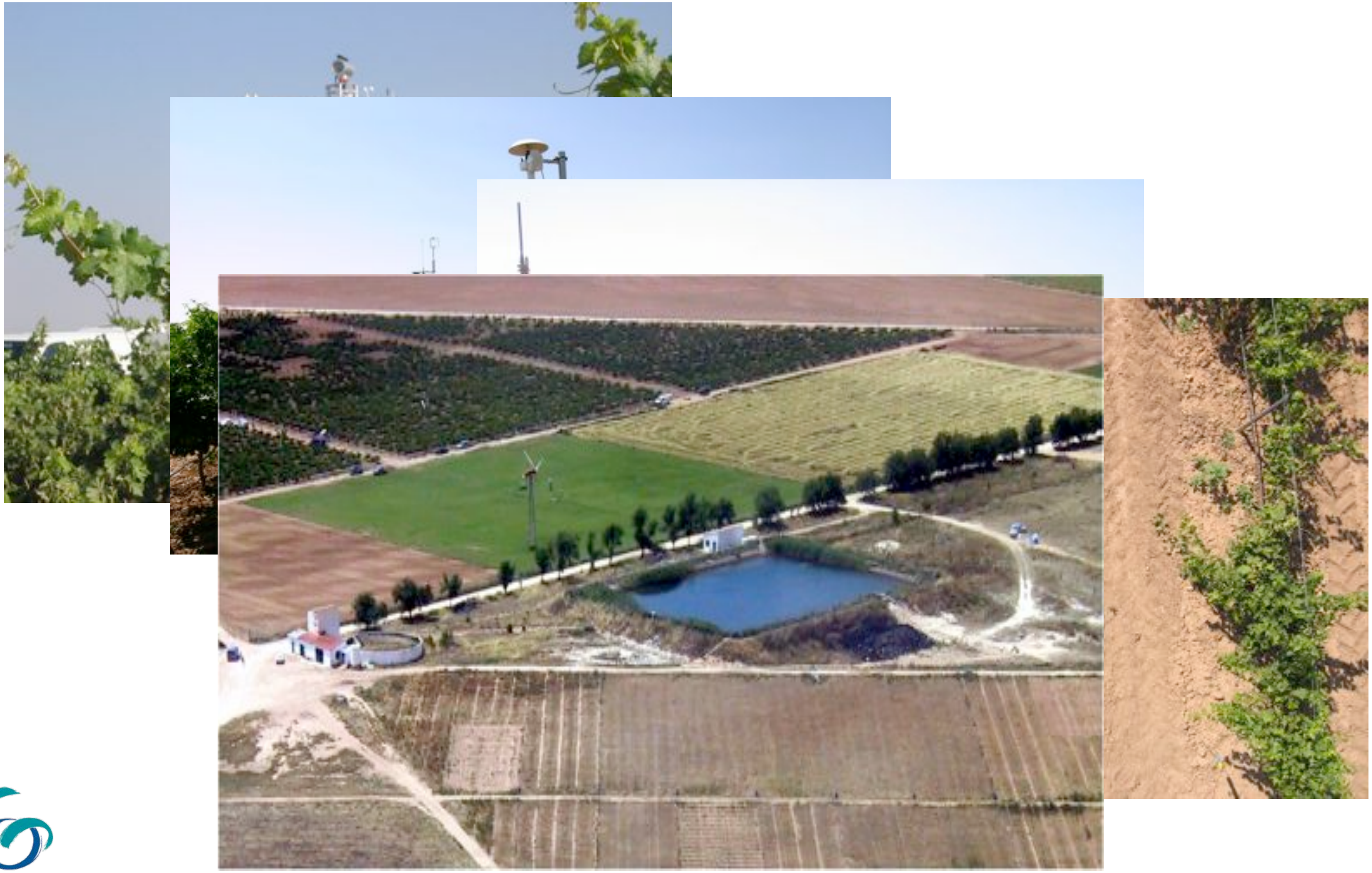
Its range, its combined temperature & Emissivity (or reflectivity) at different times, at different spatial resolution, at different wavelengths, at different direction, at different polarization

A: A Passive Sensor System
A+B: An Active Sensor System

BARRAX TEST SITE LOCATION

- Situated in the area of La Mancha, in the west of the province of Albacete, 28 km from the capital town
- Geographic coordinates: 39º 3’ N; 2º 6’ W
- Altitude (above sea level): 700 m

The Canopy from Different Perspectives

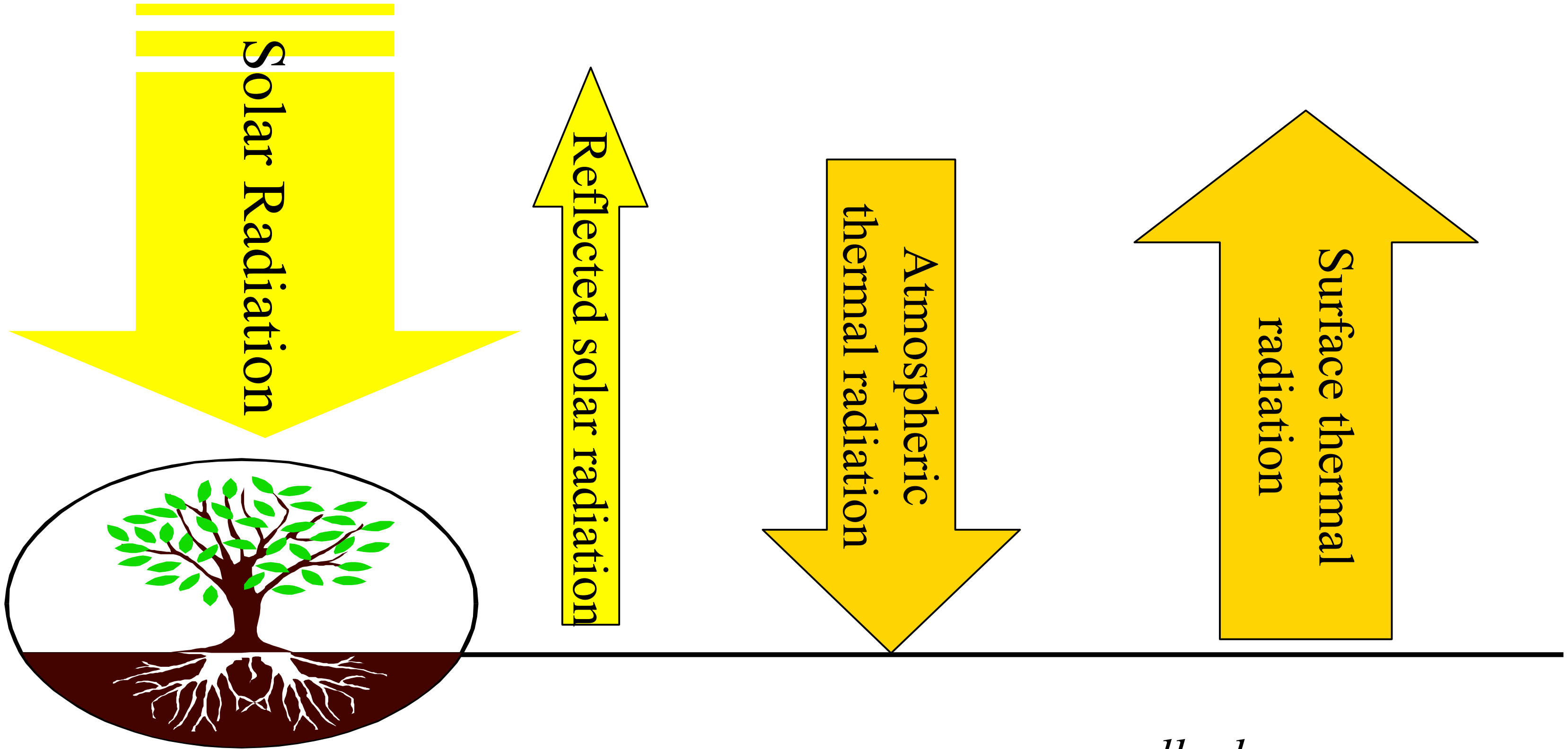


ITC Instrumentation SIN2FLEX Campaign 2005

- **Eddy Correlation (CSAT 3, Li-COR 7500), 2 sets**
- **Scintillometer, 2 Sets**
- Radiation components
- Soil Heat flux plates
- Temperature profile (air & soil)
- **Goniometer**
- Thermal camera, Everest thermal radiometer
- ASD spectrometer,
- Digital camera
- Li-COR LAI2000
- (Thermal couples) Component temperatures
- **ITC MSG-1 facility**

ITC

Surface Radiation Balance



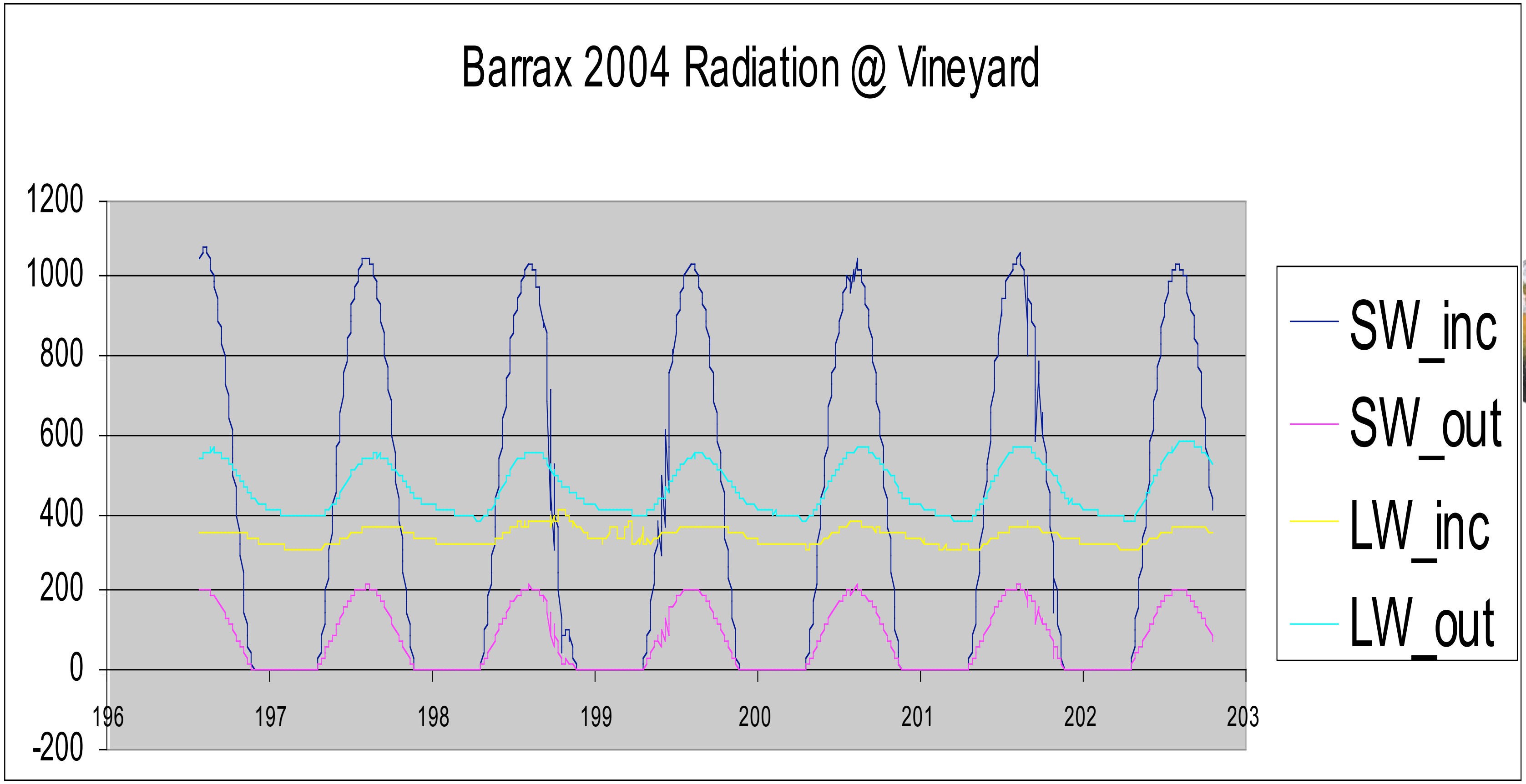
$$R_n = (1 - \alpha) \cdot R_{swd} + \varepsilon \cdot R_{lwd} - \varepsilon \cdot \sigma \cdot T_0^4$$

α : *albedo*

ε : *emissivity*

T_0 : *Surface Temperature*

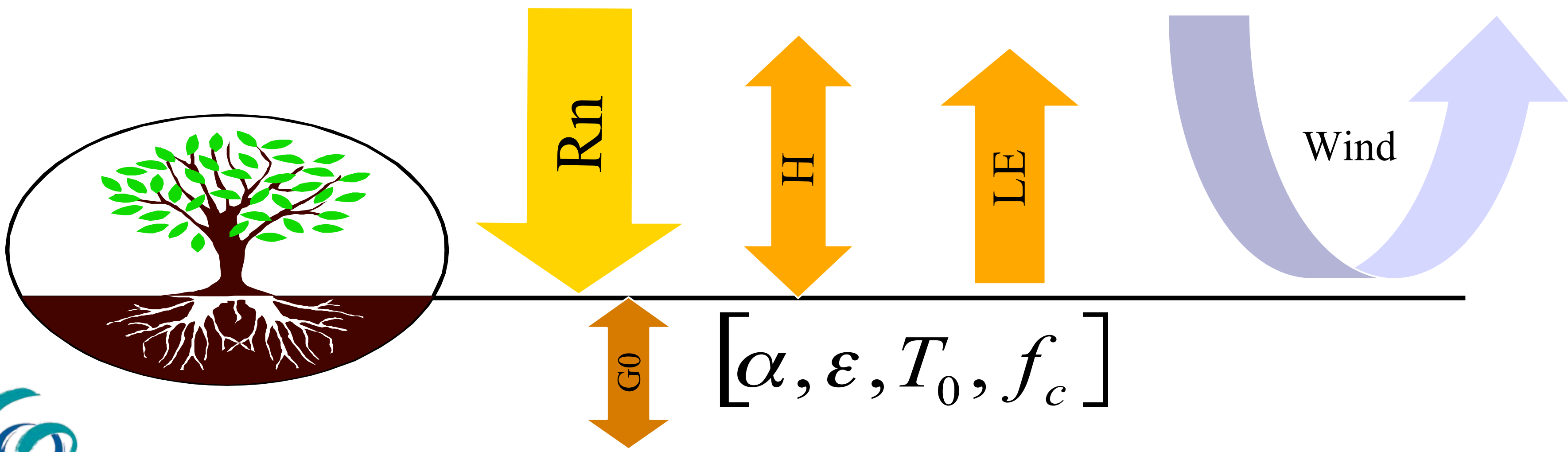
Data from EAGLE/SPARC Campaign 2004, Barrax, Spain



Surface Energy Balance Terms

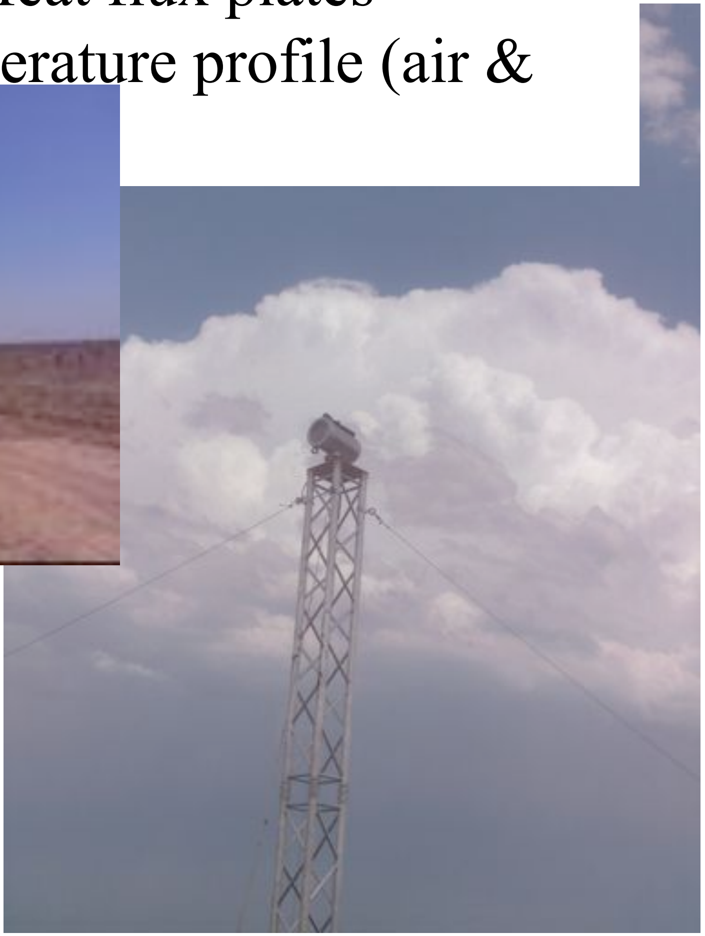
$$R_n = G_0 + H + LE$$

$$G_0 = R_n \cdot \left[\Gamma_c + (1 - f_c) \cdot (\Gamma_s - \Gamma_c) \right]$$

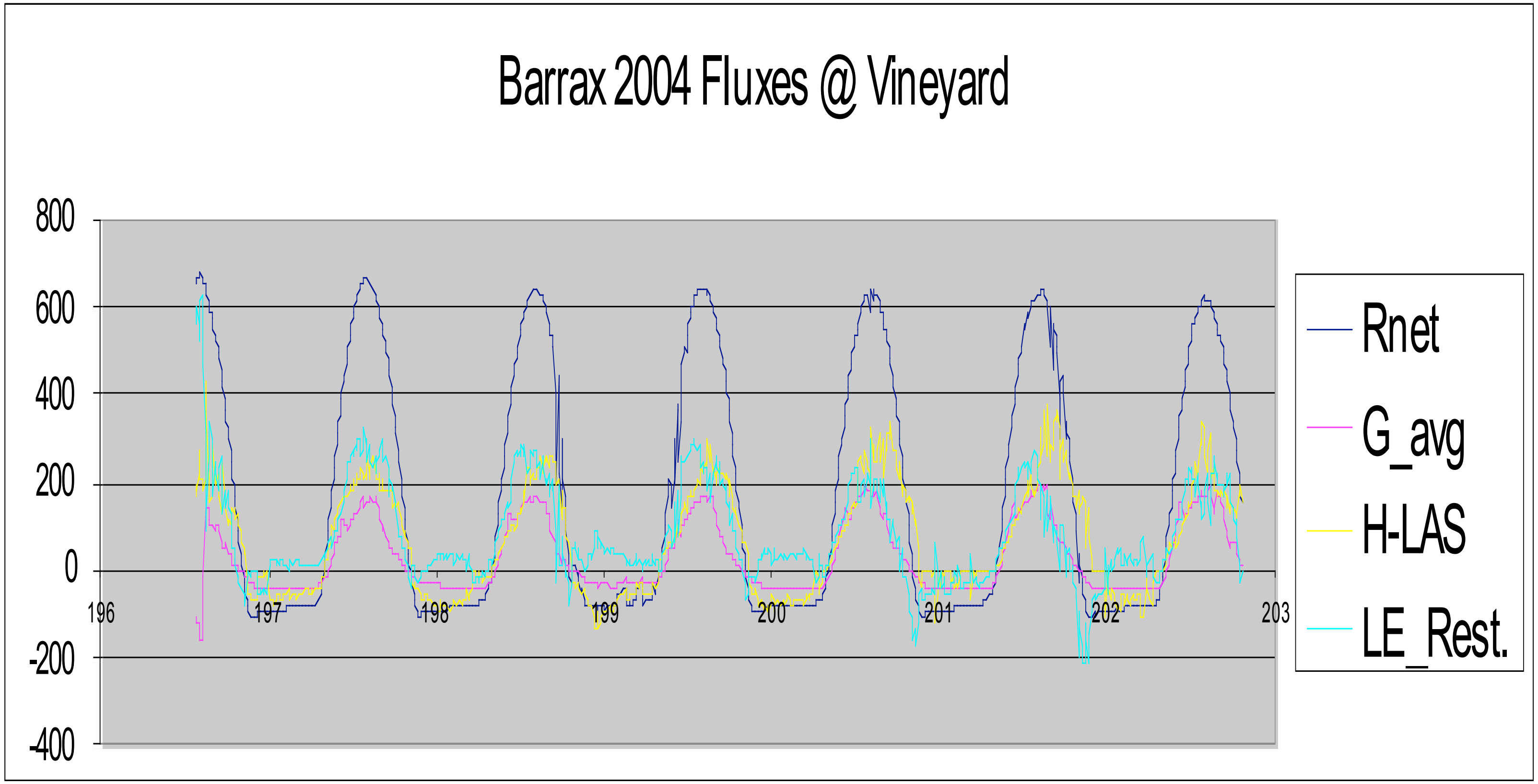


Instrumentation

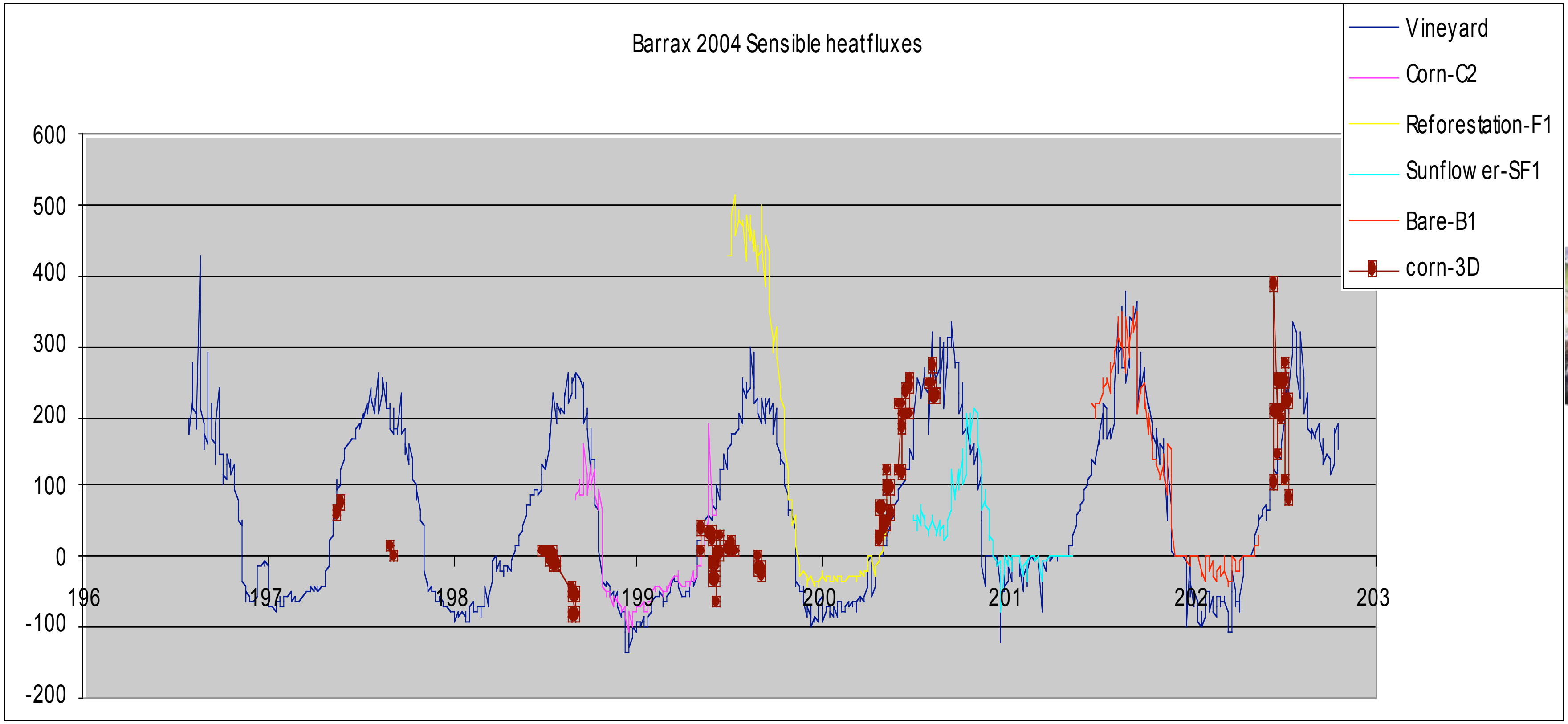
- **Scintillometer, 2 Sets**
- Radiation components
- Soil Heat flux plates
- Temperature profile (air &



Scintillometer Data from EAGLE/SPARC Campaign 2004, Barrax, Spain



Scintillometer Data 2004



Remote sensing of heat fluxes and evaporation
- a brief history of the developments in the Netherlands

Analytical vs (semi-)empirical approach

Menenti, 1980, Menenti, 1984,
(two-layer combination eq.
for a drying soil)

Menenti, 1993
(personal note doubting the success
of pure analytical approach)

Menenti & Choudhury, 1993
extended Jackson et al., 1981, 1988's
Crop Water Stress Index (surface scaling)
to Surface Energy Balance Index
(PBL scaling with kB_1=2.3, Bw=2.9)
(->applications Aral sea, Menenti et al. 2001)

Su, 2001, 2002 extended SEBI concept with
the kB_1 model of Su, Schmugge, Kustas & Massman, 2001
and BAS of Brutsaert, 1999 (Surface and PBL scaling)
Surface Energy Balance System (SEBS)

(->coupling to NWP fields: Jia et al. 2001, ATSR data
->extension to parallel-source: Su & Rauwerda 2001, ATSR data
->estimation of daily, monthly, annual evaporation: Li et al. 2001
->drought monitoring: Su et al. 2001, 2003)

Nieuwenhuis et al., 1989
e.g. E=a+b*T0

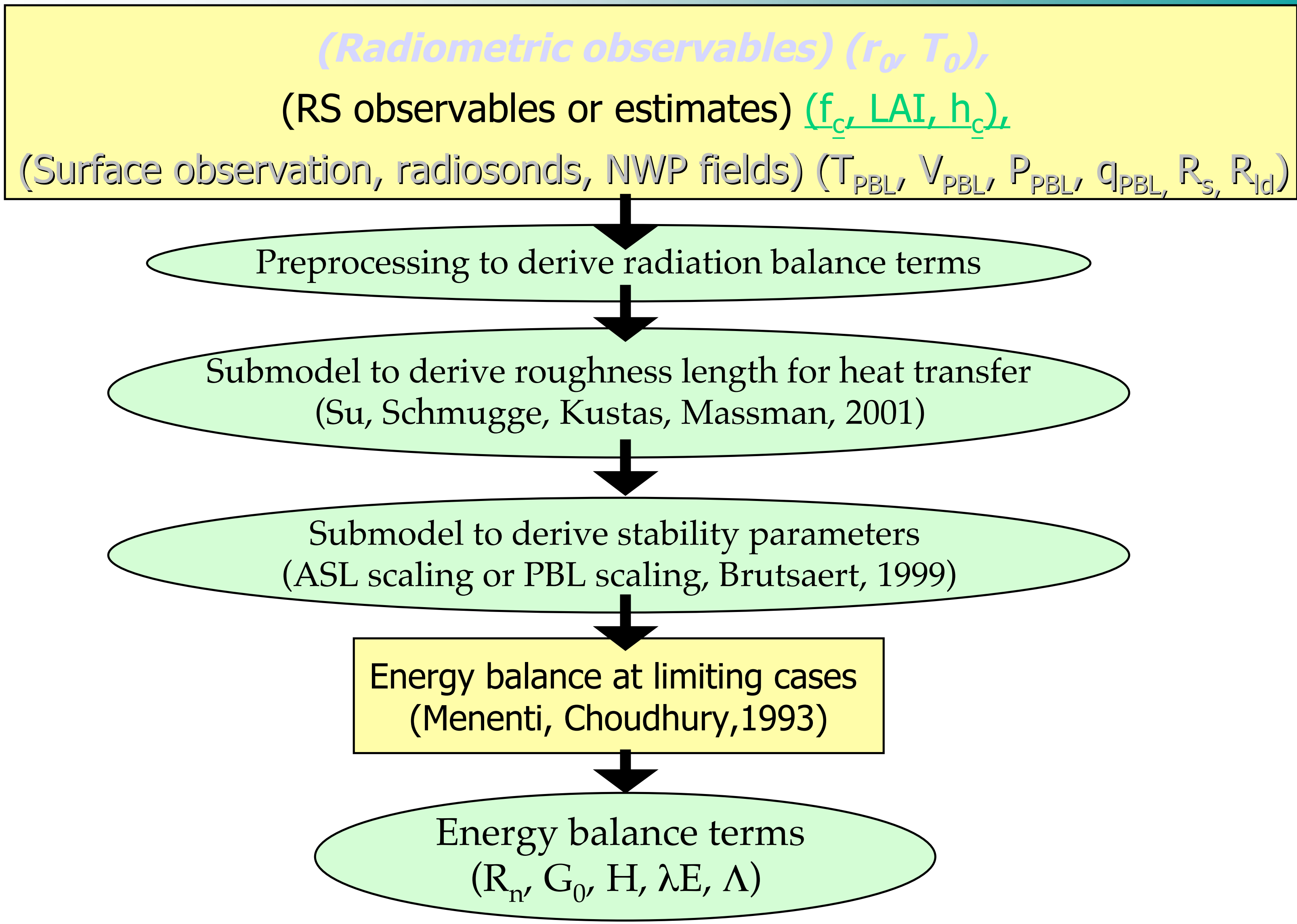
Bastiaassen, 1995
Surface Energy Balance Algorithm for Land (SEBAL)
(require simultaneous presence of
absolute dry and absolute wet pixels
-> applications in irrigation management

Su, Pelgrum, Menenti, 1999
correction in SEBAL for a theoretical problem and
extension to include NWP fields with a up-scaling,
down-scaling scheme

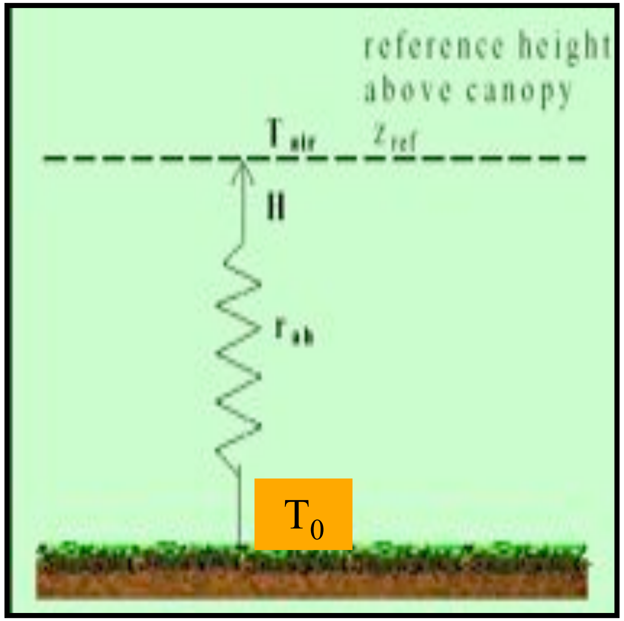
Roerink, Su, Menenti, 2000
Simplified Surface Energy Balance Index
(fitting dry and wet limiting cases in data)
(S-SEBI)

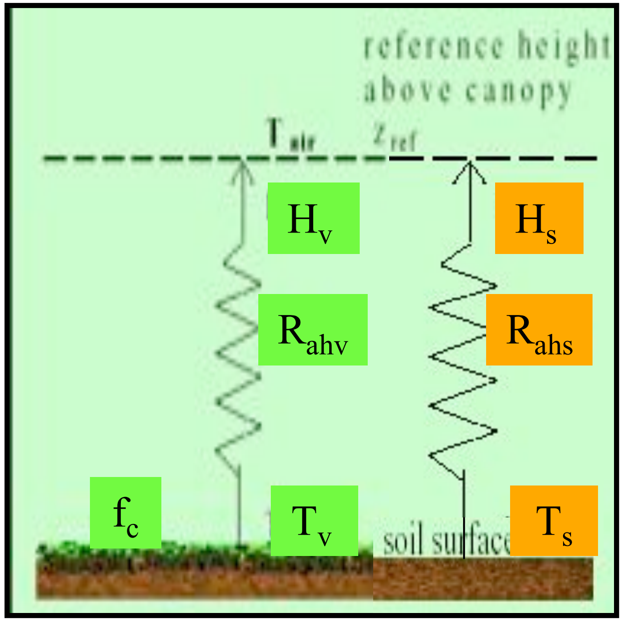
ITC

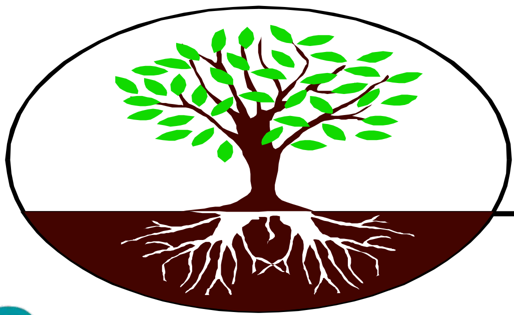
Schematic representation of SEBS



Remote sensing of heat fluxes and evaporation - SEBS Single source, SEBS Parallel-source







SEBS Basic Equations

Su, 2002, HESS, 6(1),85-99

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

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

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

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

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

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

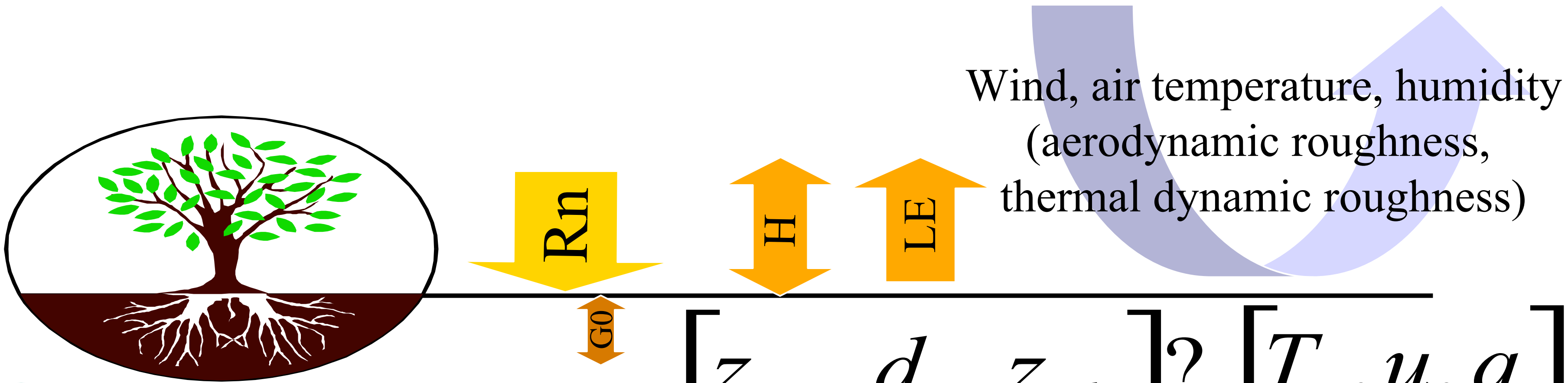
$$\Lambda = \frac{\lambda E}{R_n - G} = \frac{\Lambda_r \cdot \lambda E_{wet}}{R_n - G}$$

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

ITC

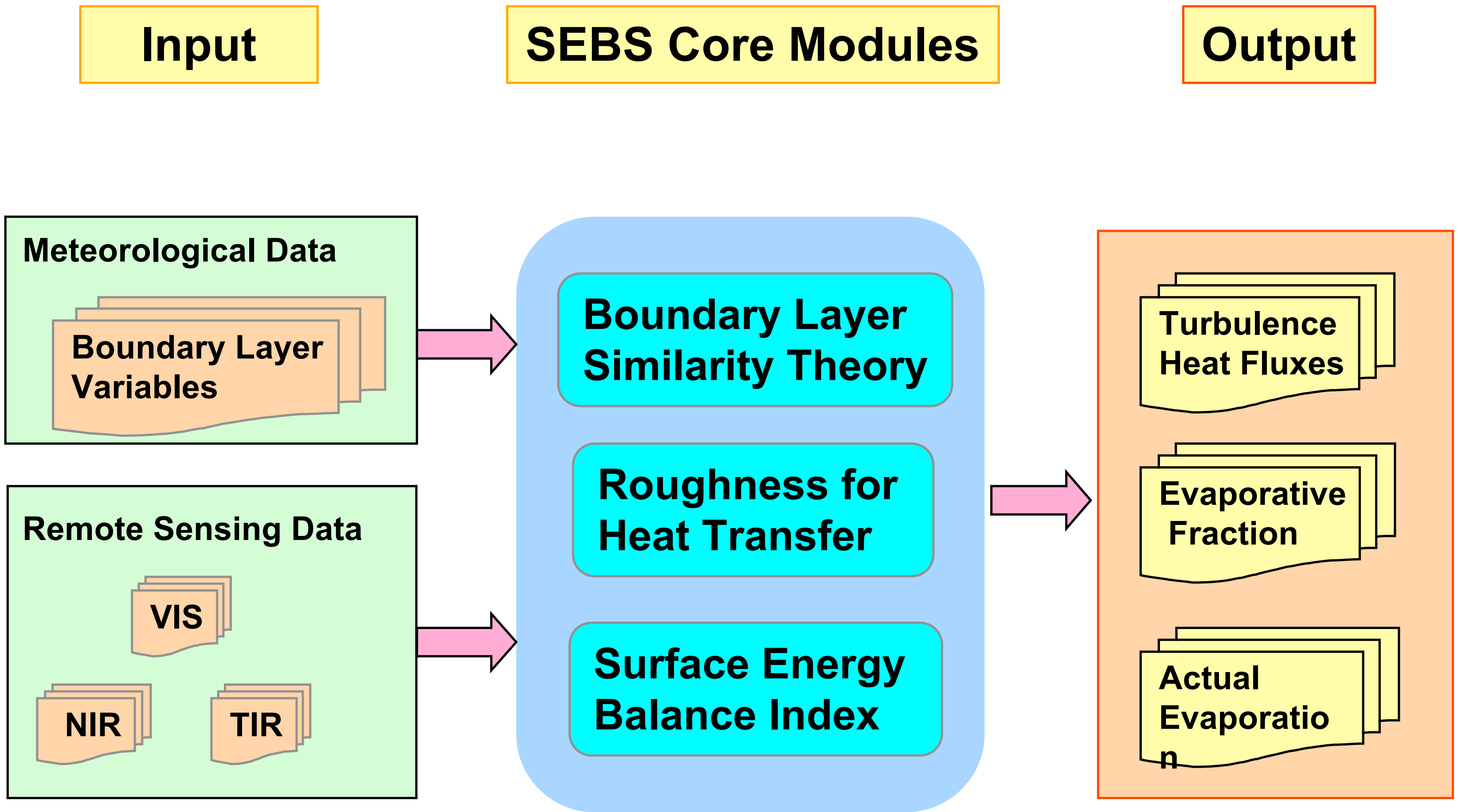
Energy Balance Residual Method - Turbulent Heat Fluxes

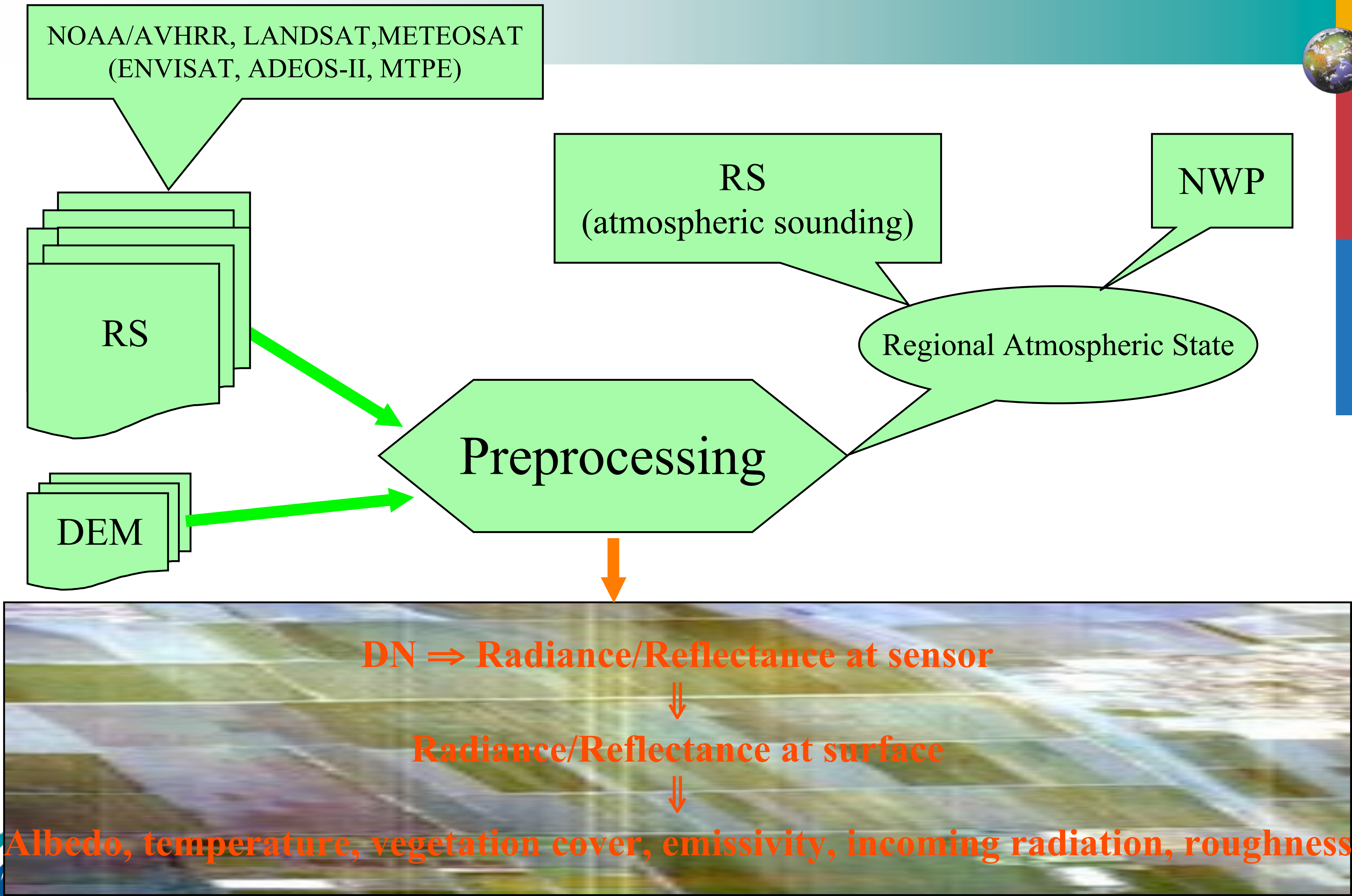
$$\begin{cases} u = \dfrac{u_*}{k}\left[\ln\left(\dfrac{z-d_0}{z_{0m}}\right) - \Psi_m\left(\dfrac{z-d_0}{L}\right) + \Psi_m\left(\dfrac{z_{0m}}{L}\right)\right] \\ L = -\dfrac{\rho C_p u_*^3 \theta_v}{kgH} \\ H = k u_* \rho C_p \left(\theta_0 - \theta_a\right)\left[\ln\left(\dfrac{z-d_0}{z_{0h}}\right) - \Psi_h\left(\dfrac{z-d_0}{L}\right) + \Psi_h\left(\dfrac{z_{0h}}{L}\right)\right]^{-1} \end{cases}$$



$$\left[z_{0m}, d_0, z_{0h}\right]? \left[T_a, u, q\right]?$$

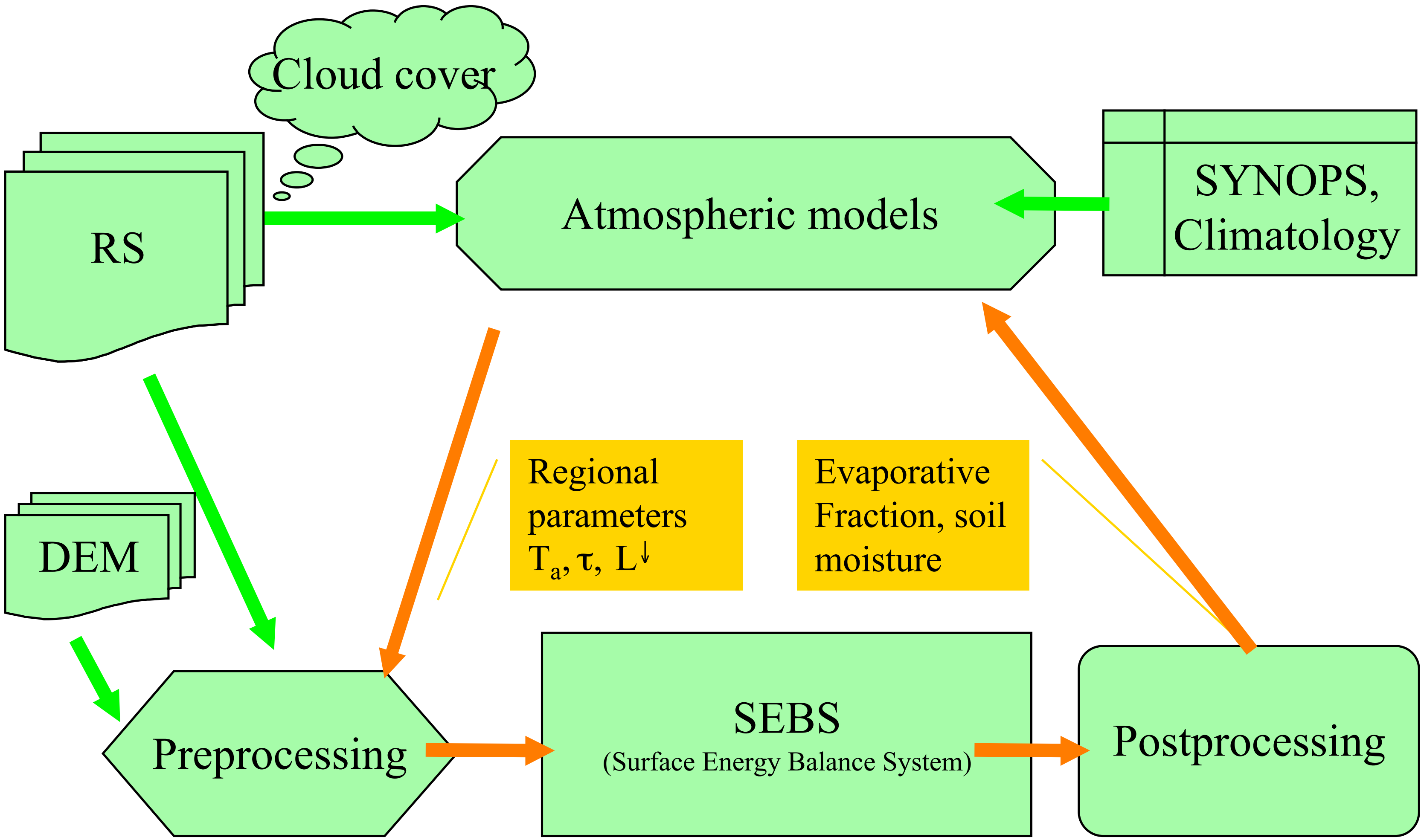
SEBS - The Surface Energy Balance System



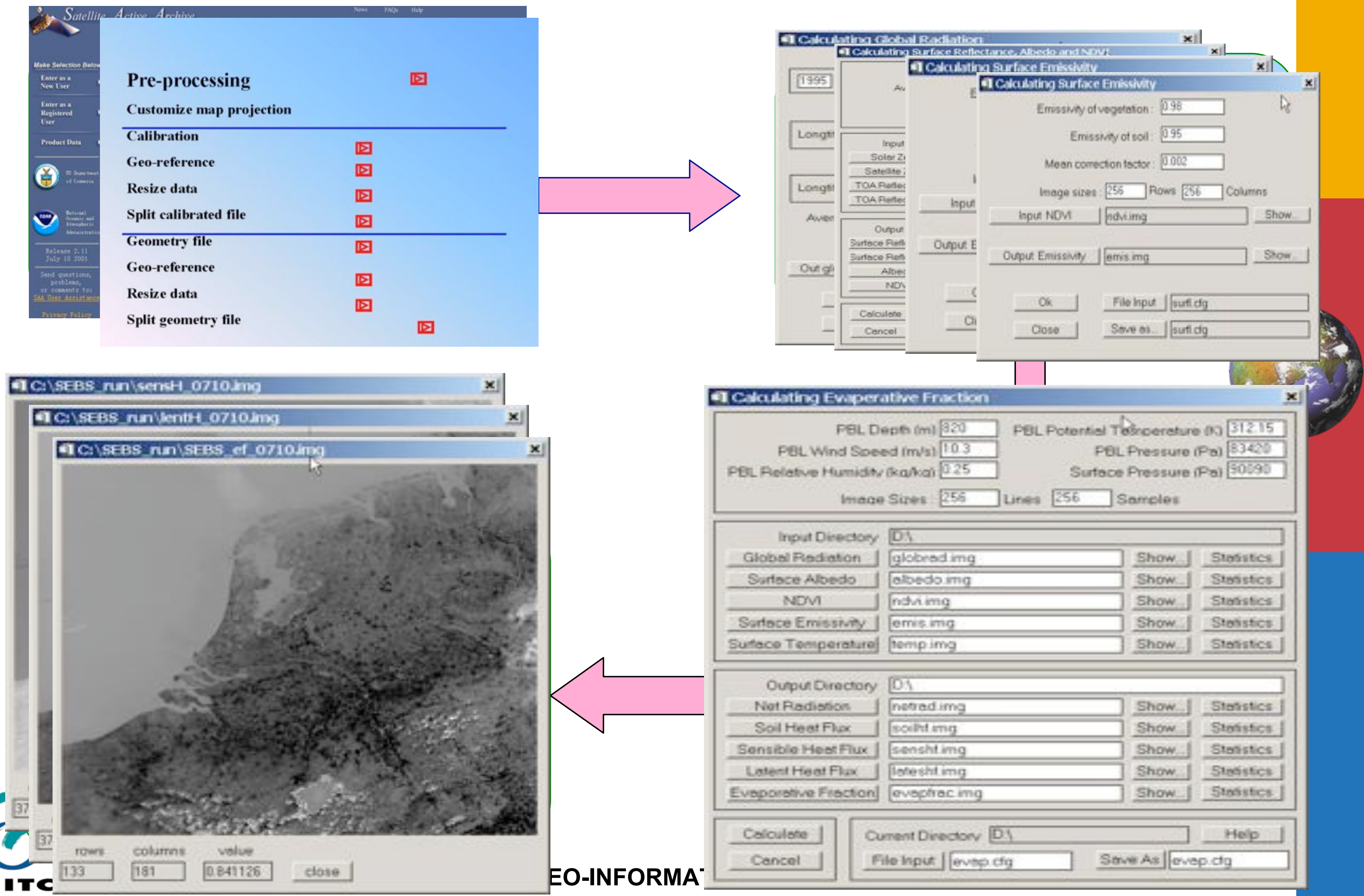

NOAA/AVHRR, LANDSAT,METEOSAT
(ENVISAT, ADEOS-II, MTPE)
RS
(atmospheric sounding)
NWP
RS
Regional Atmospheric State
Preprocessing
DEM
DN ⇒ Radiance/Reflectance at sensor
⇓
Radiance/Reflectance at surface
⇓
Albedo, temperature, vegetation cover, emissivity, incoming radiation, roughness

ITC

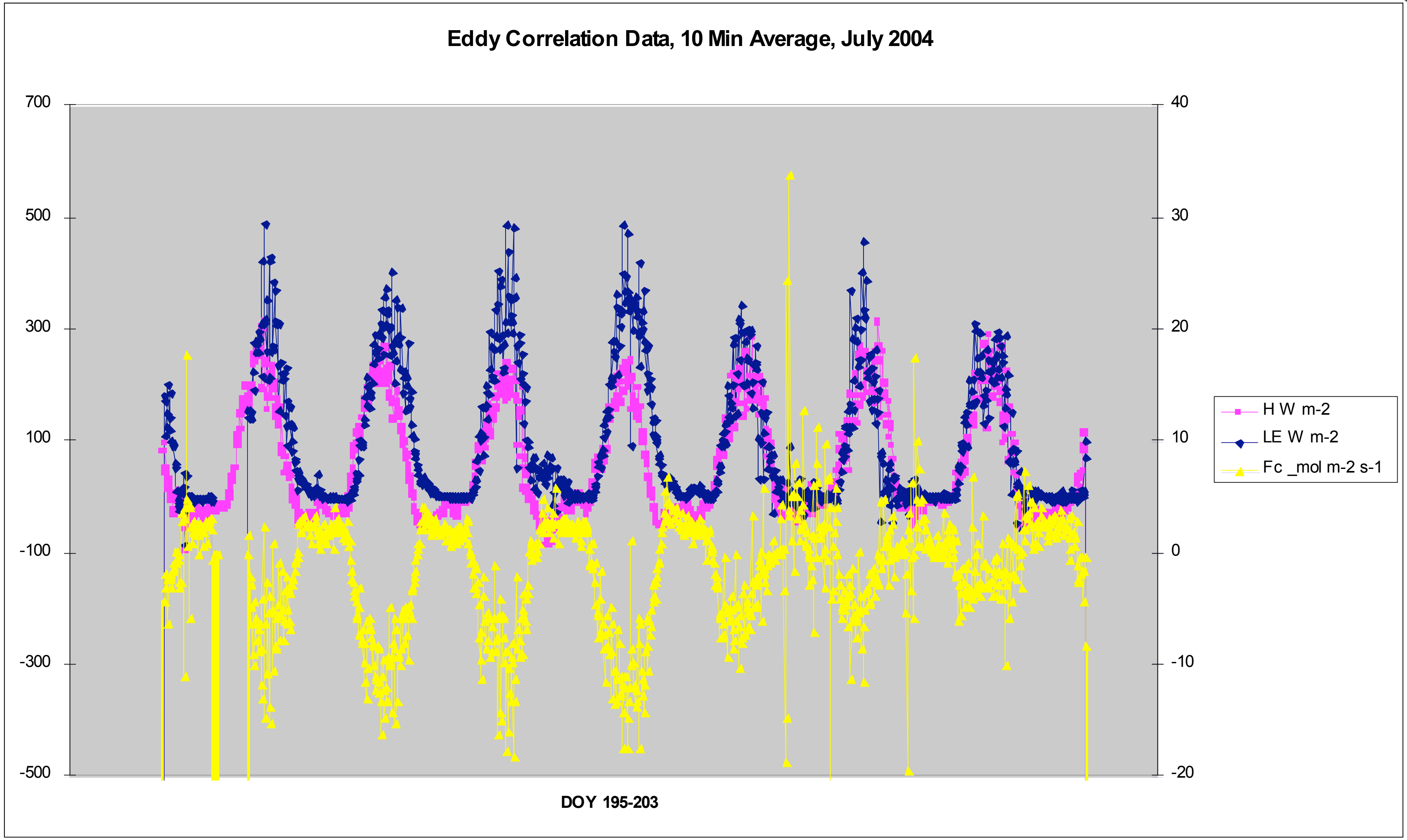
General Methodology



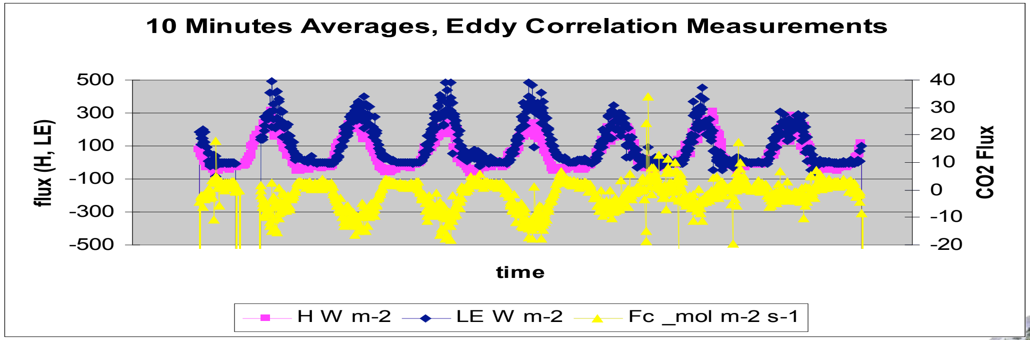
Step-by-Step SEBS Procedure

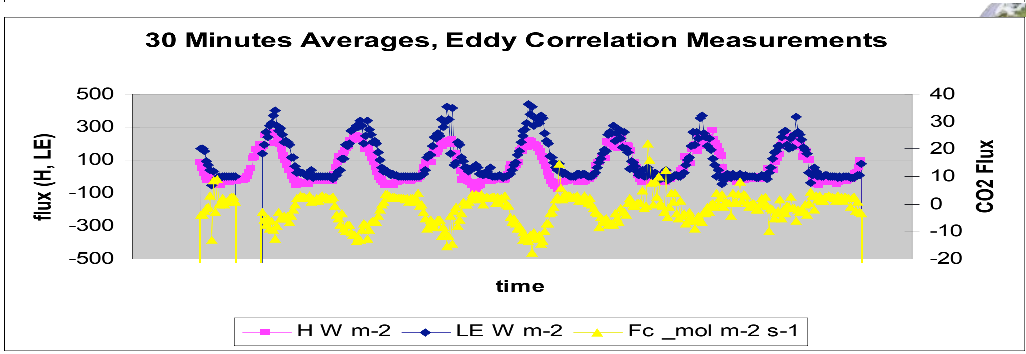


Flux data 2004 (Single set, height 3m)

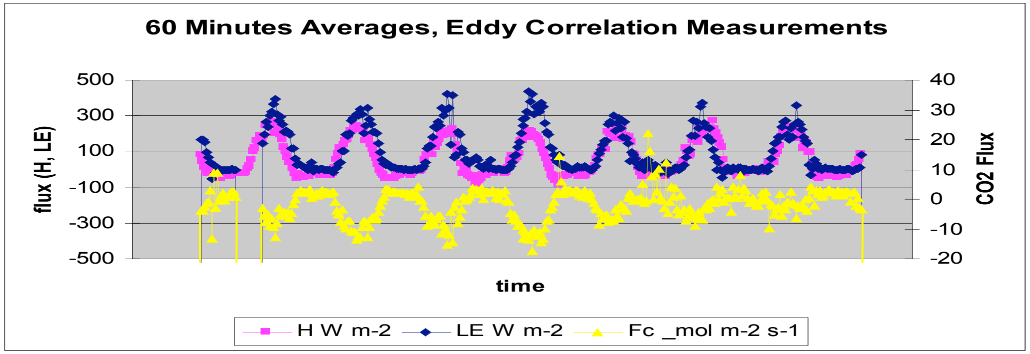


Canopy level Processes: Eddy Correlation Measurements

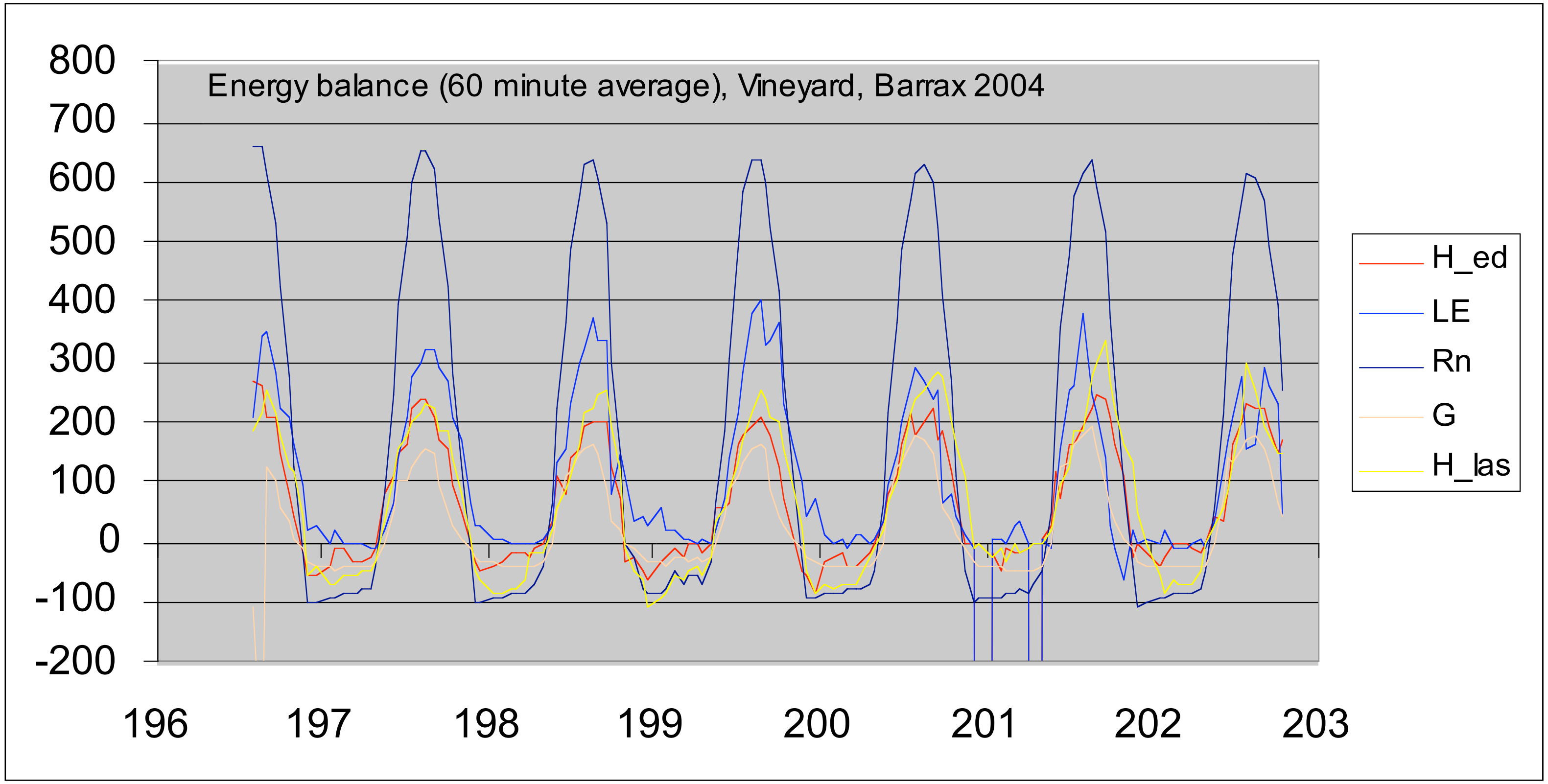




Canopy level:
Turbulence, H_2O, CO_2 fluxes and CO_2 concentrations using an eddy correlation system (Gill 3D sonic + closed path Licor gasanalyser: CO_2 and H_2O + nitrogen reference gas + pneumatic mast + dataloggers)

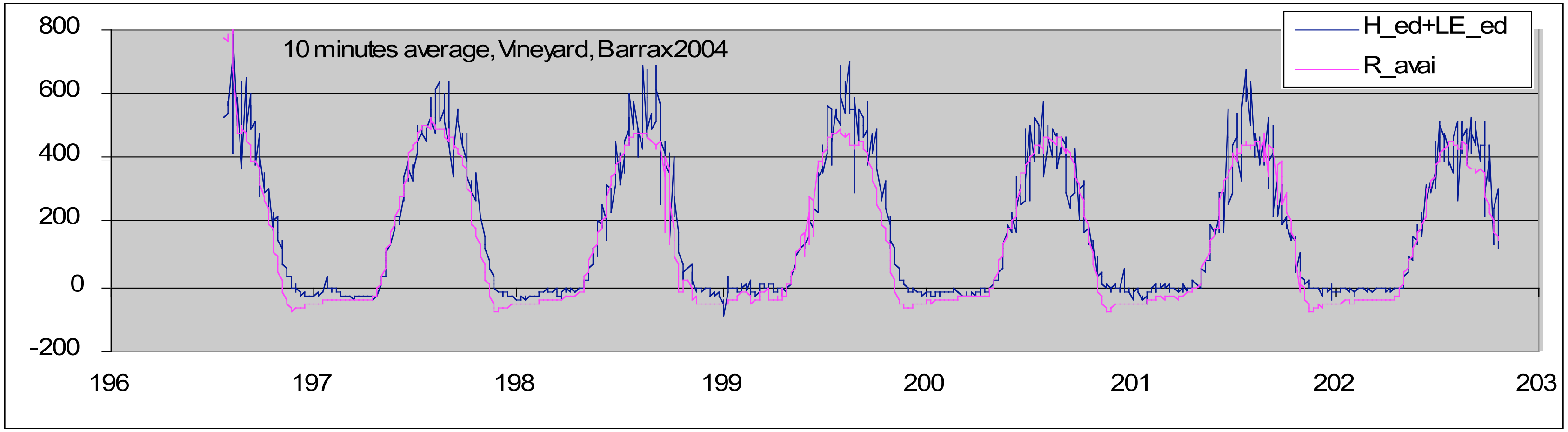


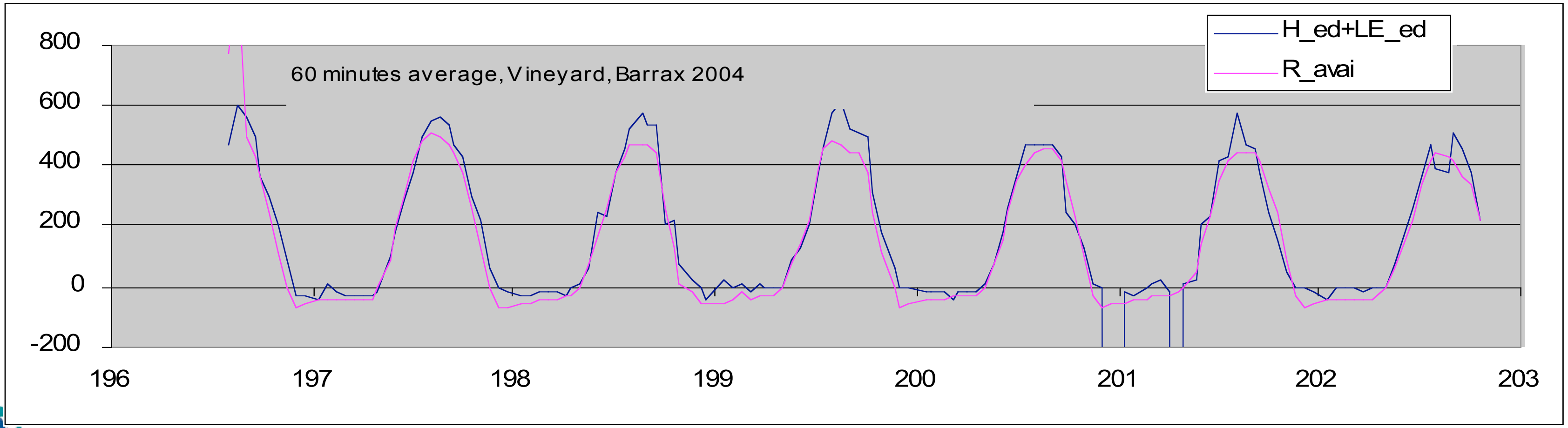
Energy balance



Energy balance closure ??

(Sum of H and LE exceeds the available energy)



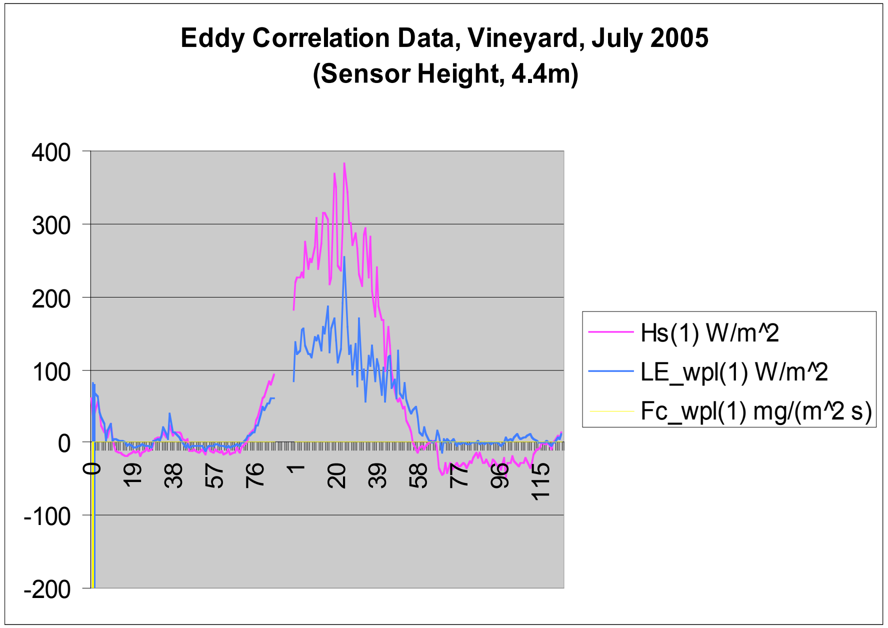


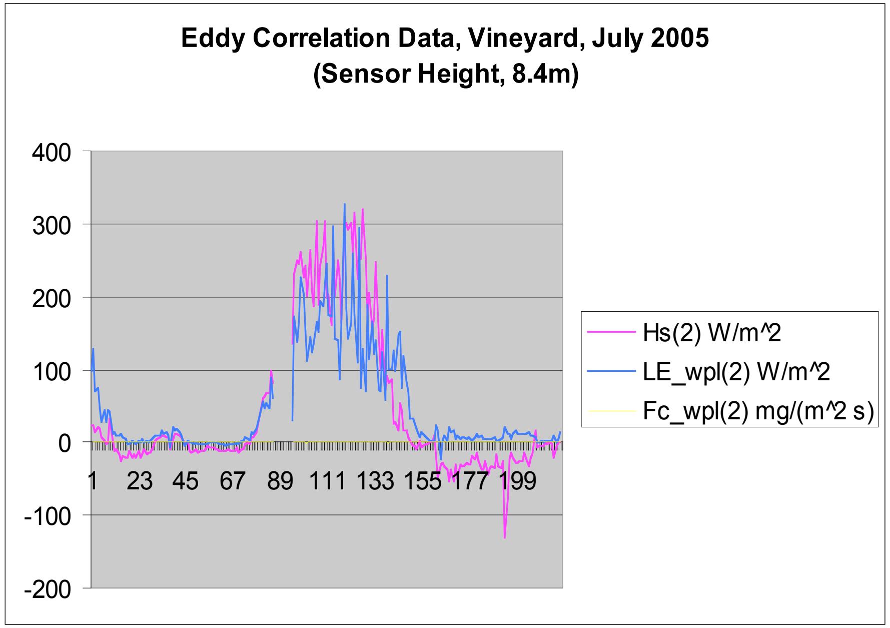
ITC

• **Eddy Correlation (CSAT 3, Li-COR 7500), 2 sets**

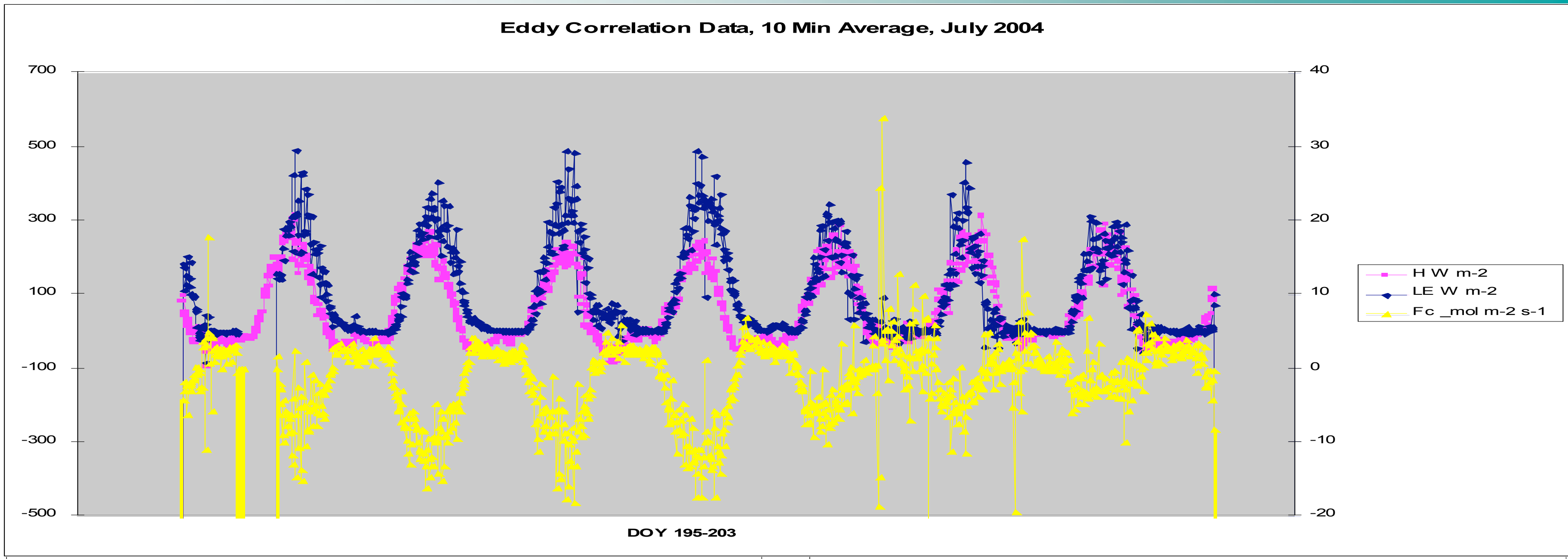
ITC

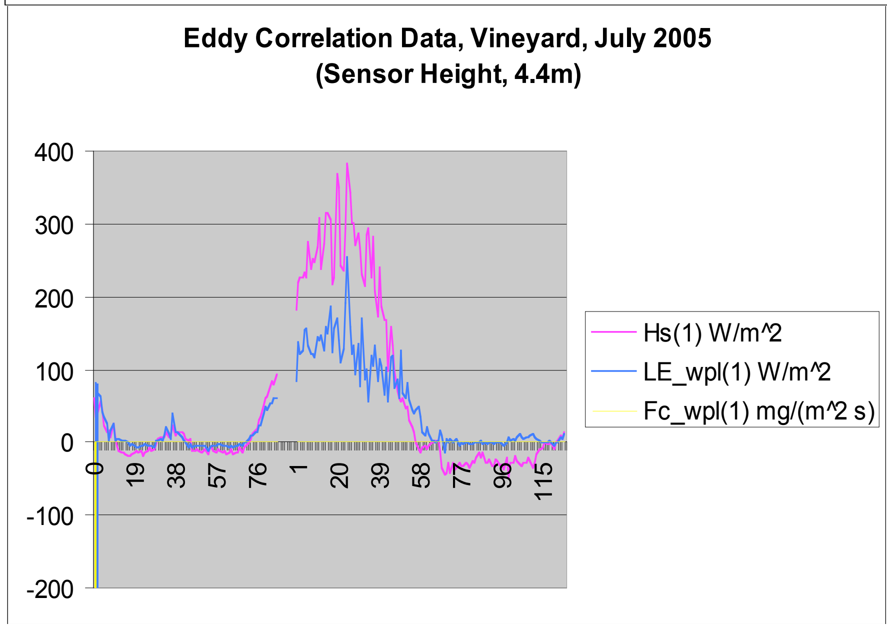
Flux data 2005 (Double set)

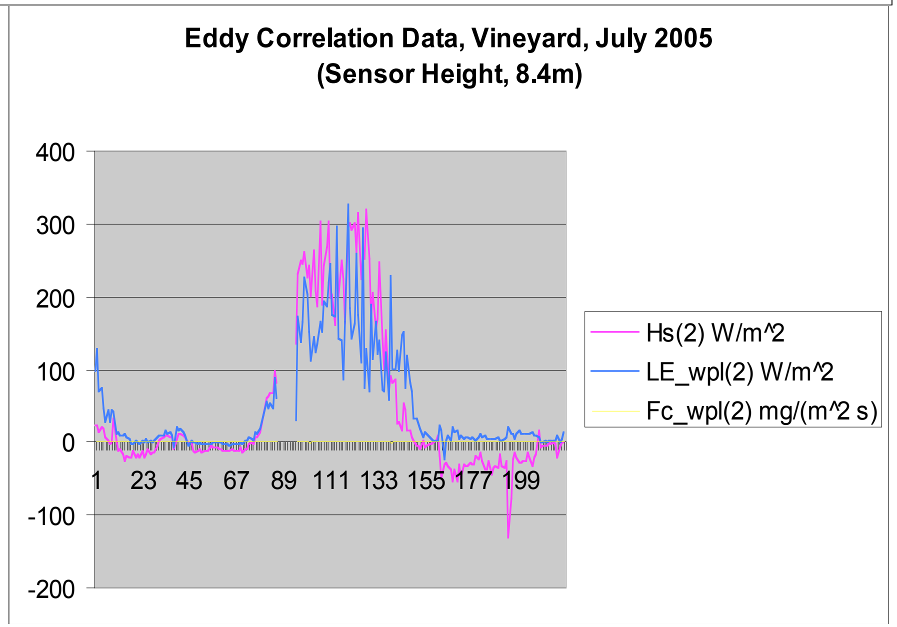




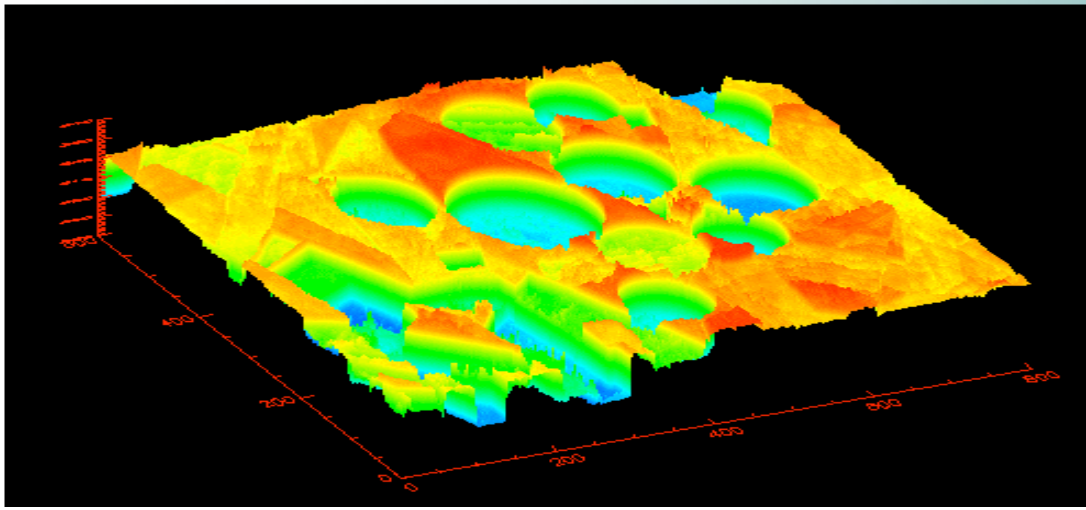
Flux data 2004 vs flux data 2005



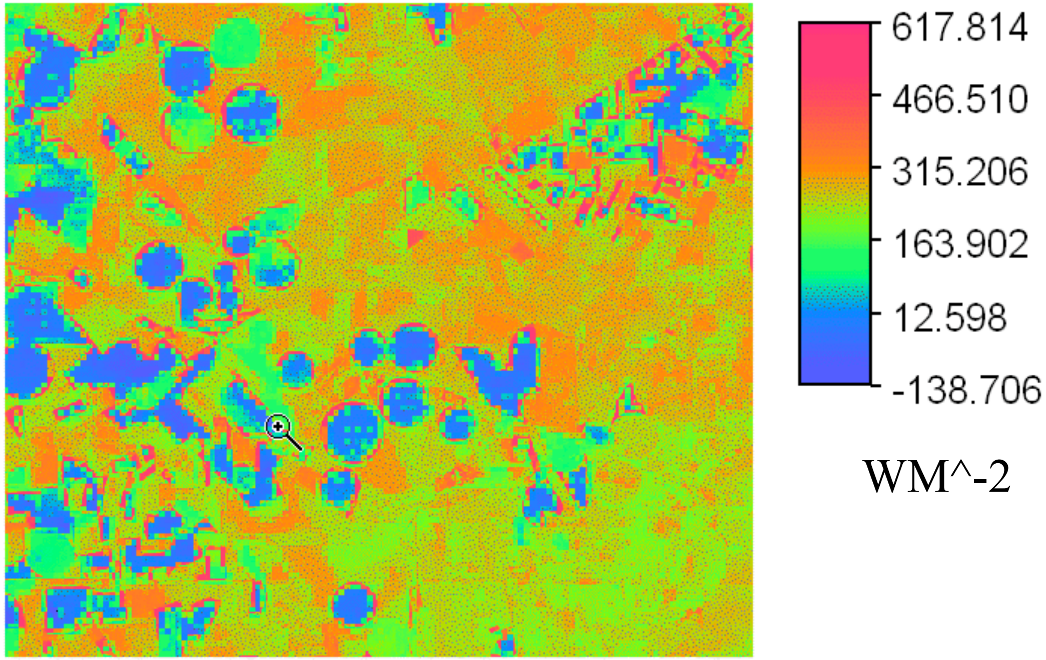




Results from SEBS



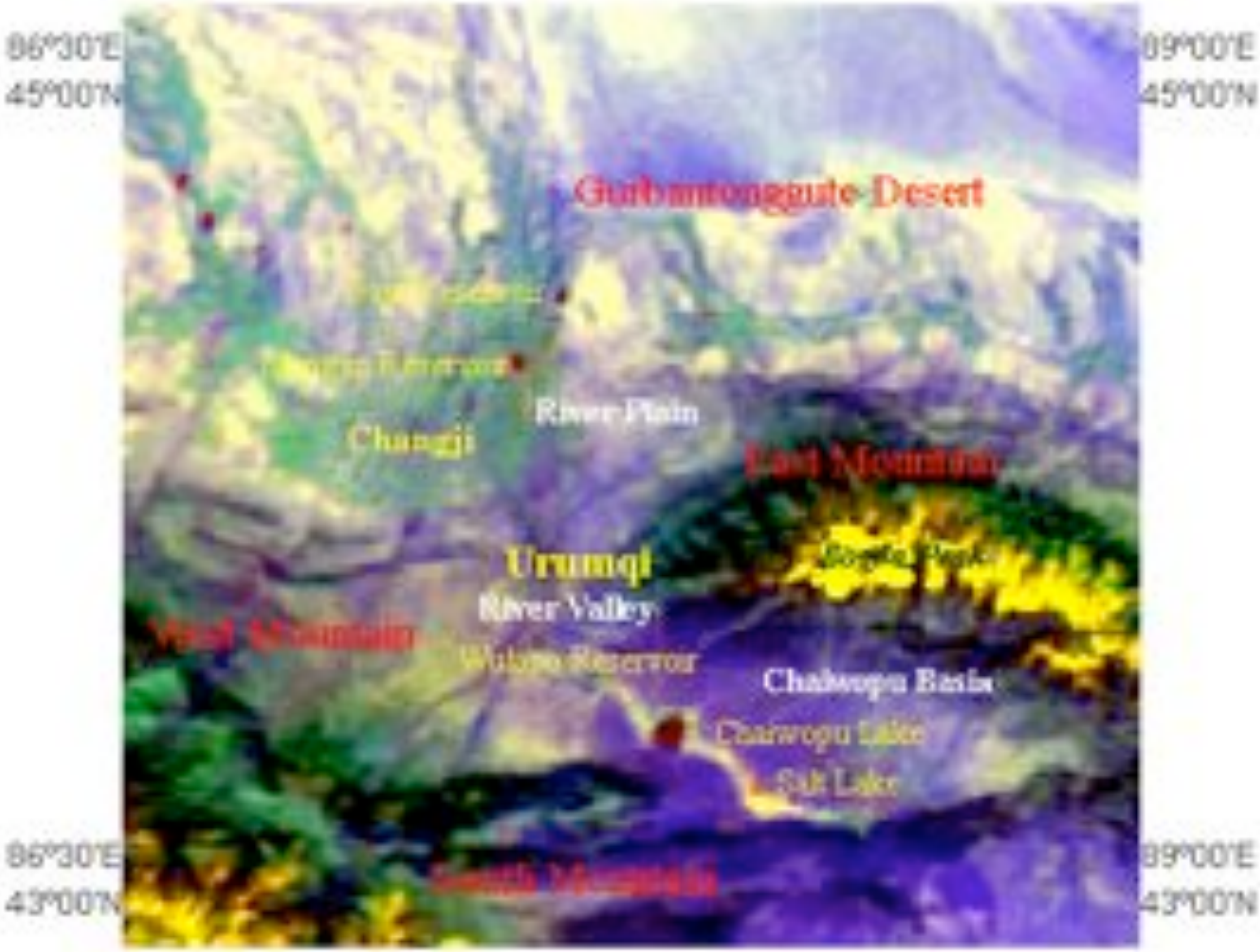
Sensible Heat
AHS 15 July 2004
(A. Gieske)



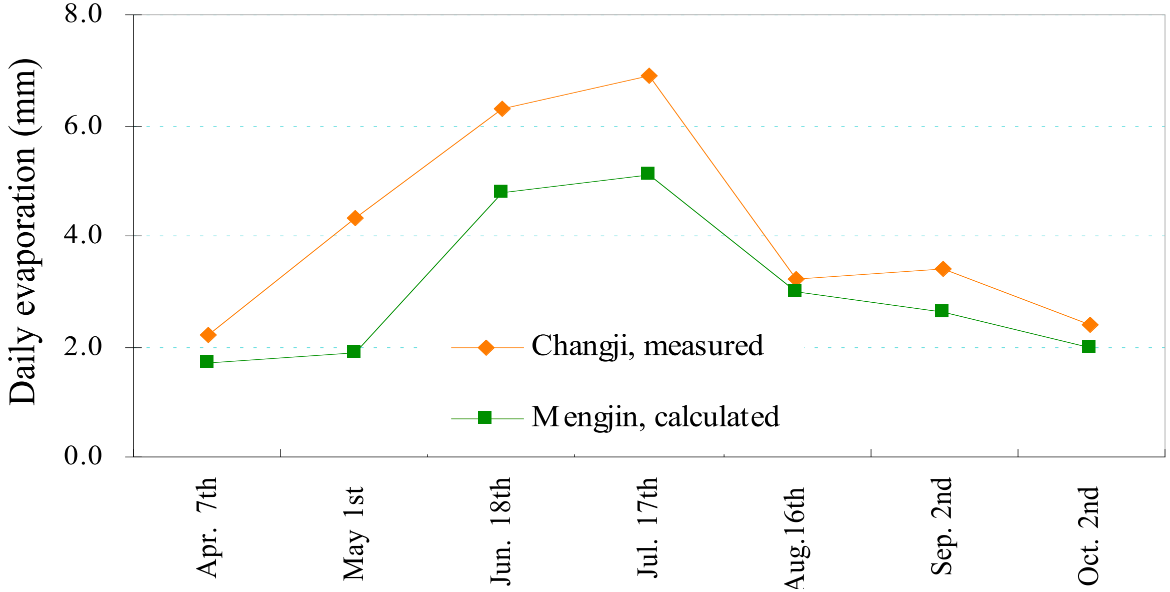
Sensible Heat
ASTER 18 July 2004

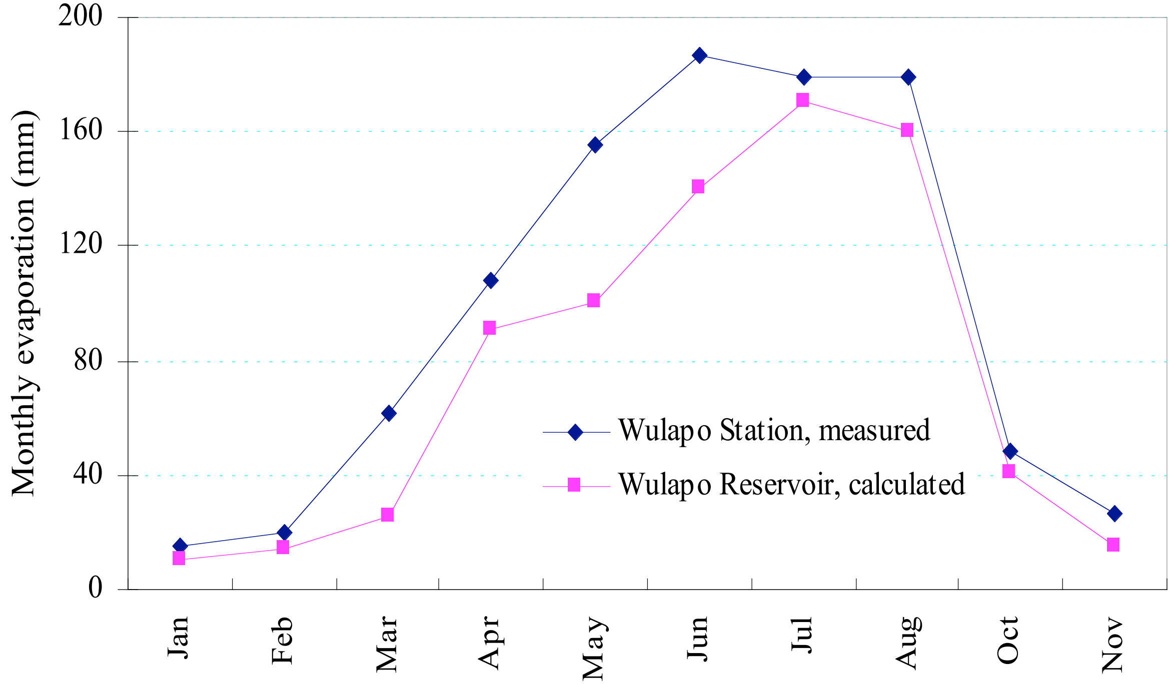
Some applications

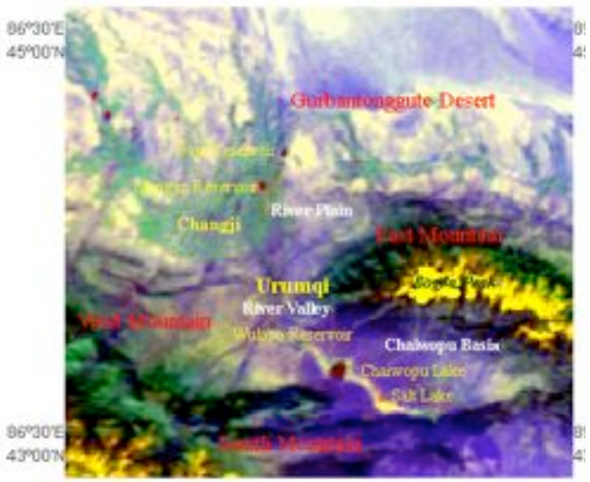
Application to the Urumqi River Basin, NW China

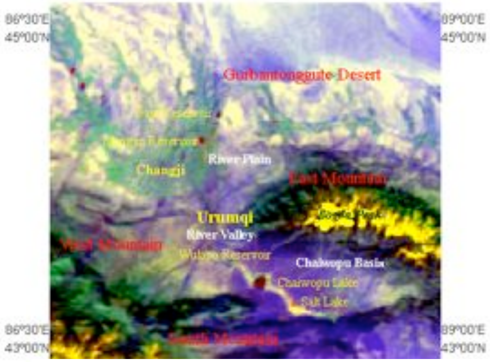


Comparison to measurements (water surfaces)

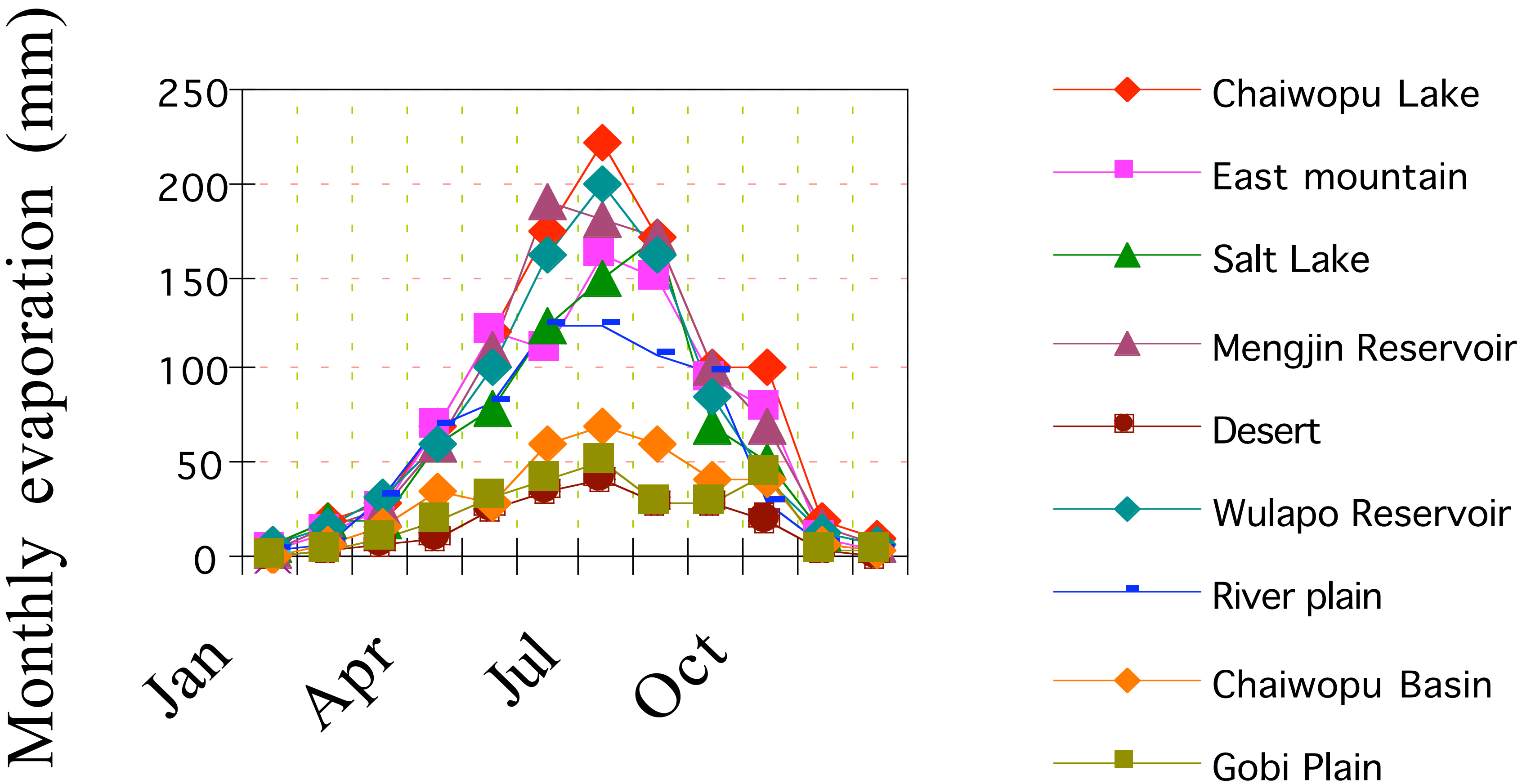




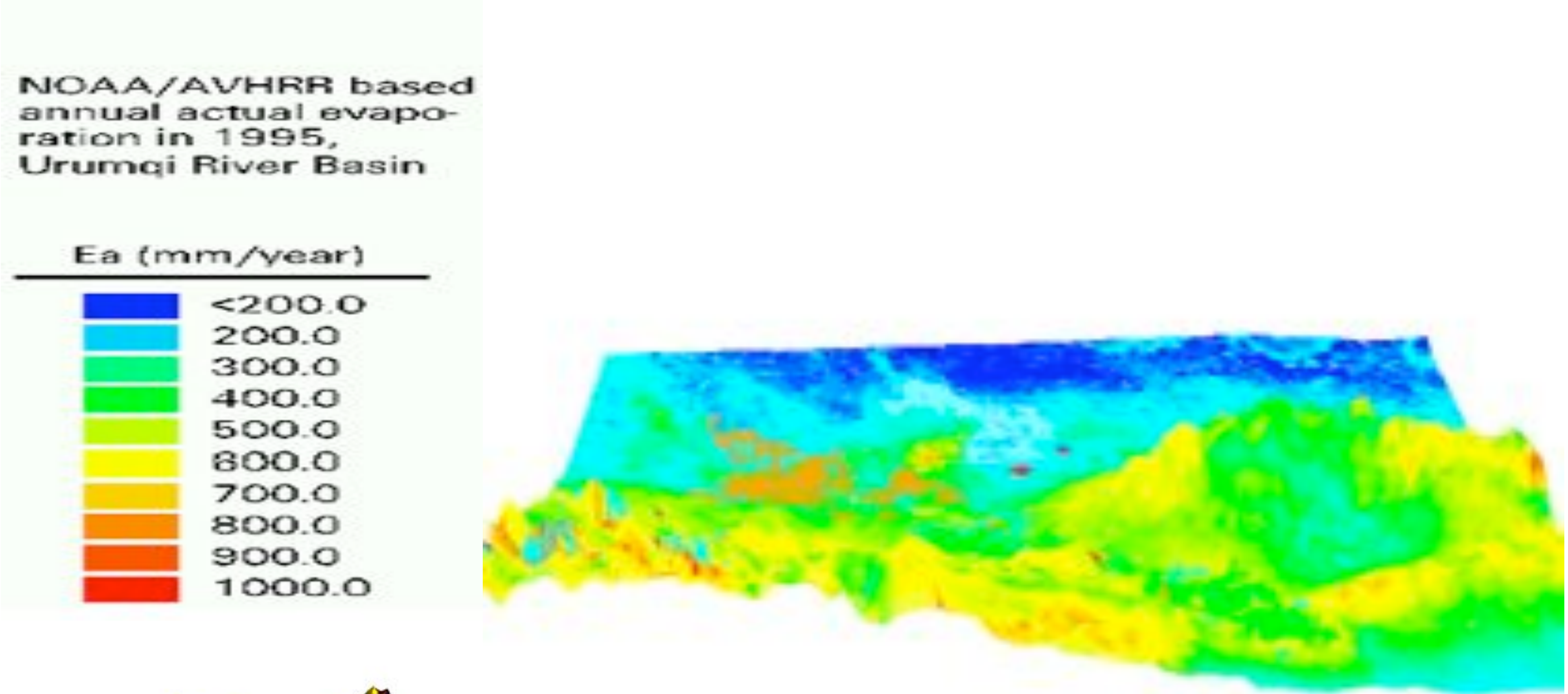


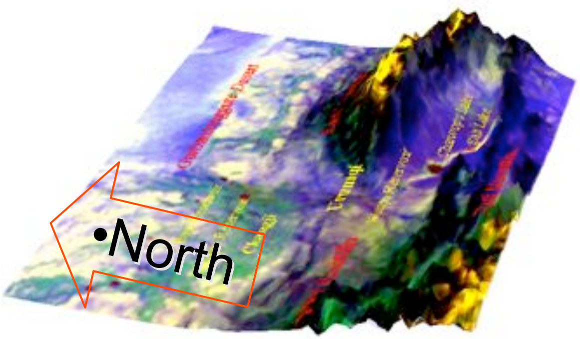


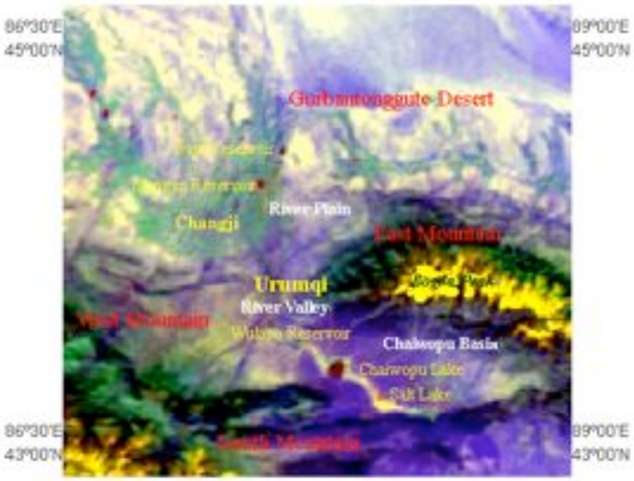
Monthly evaporation from different surfaces in the Urumqi River Basin

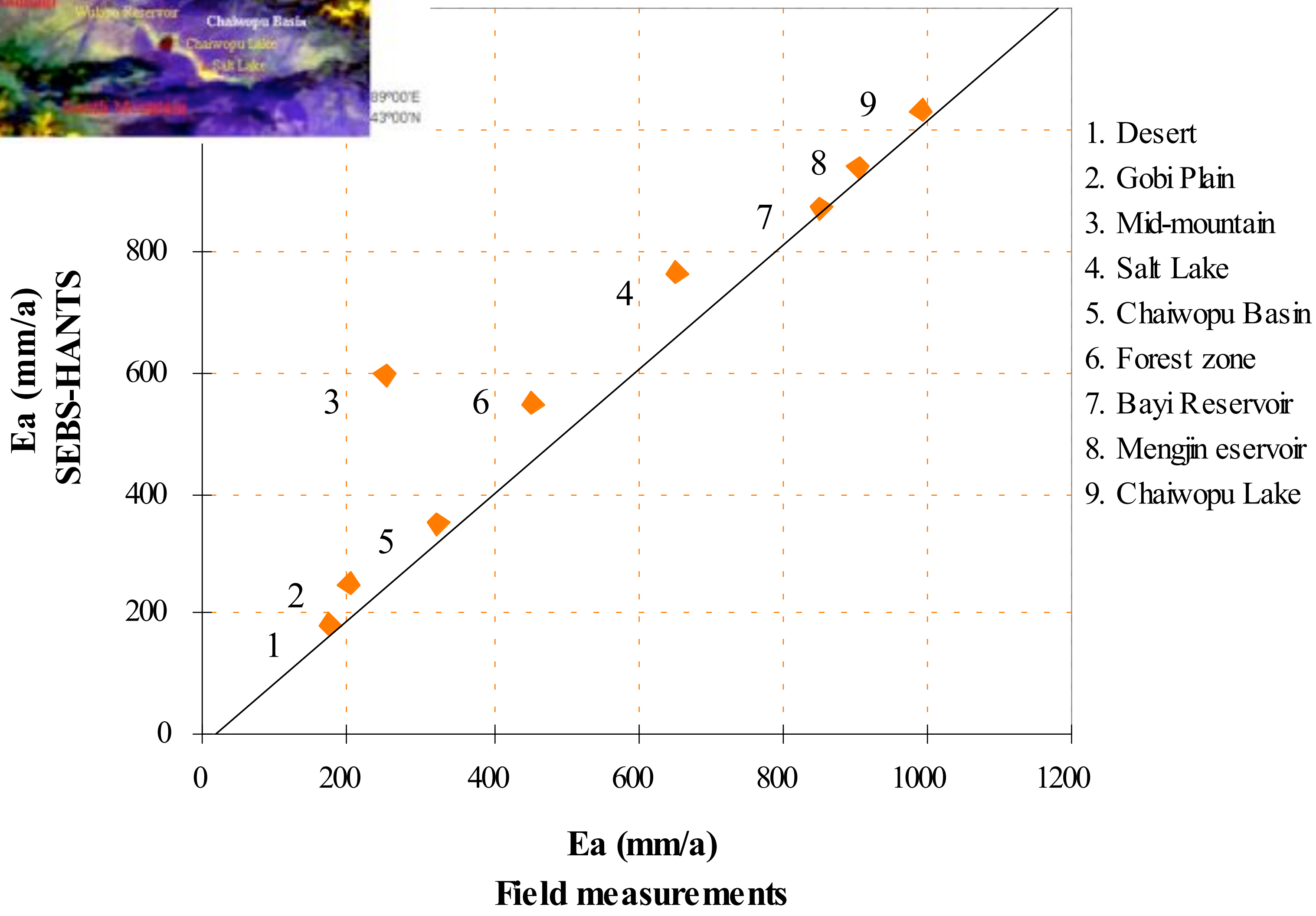


Spatial Distribution of Annual Evaporation over the Urumqi River Basin

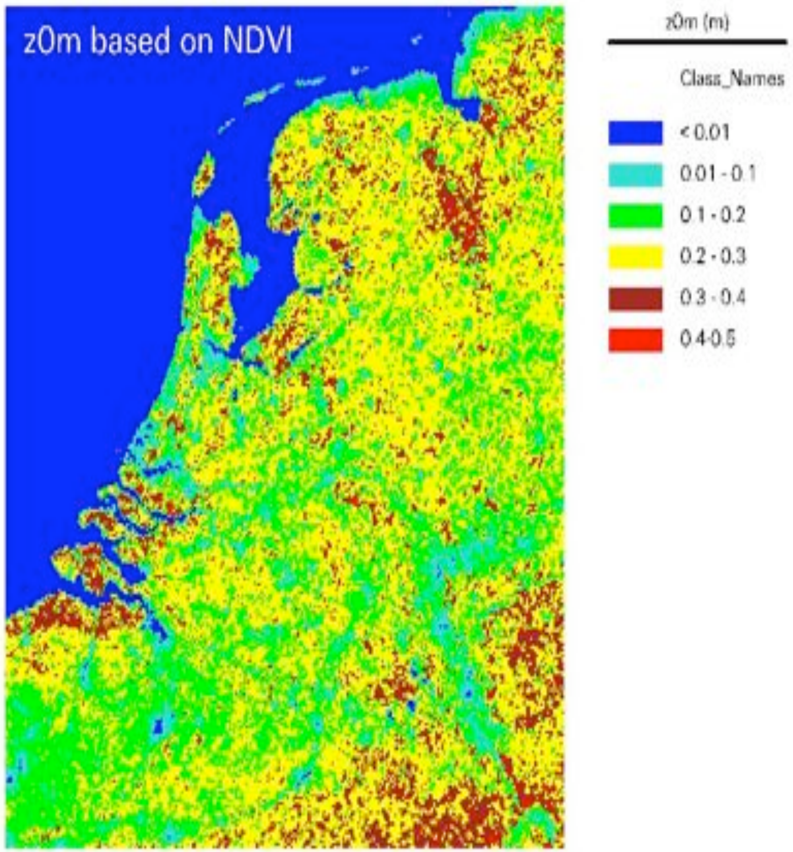


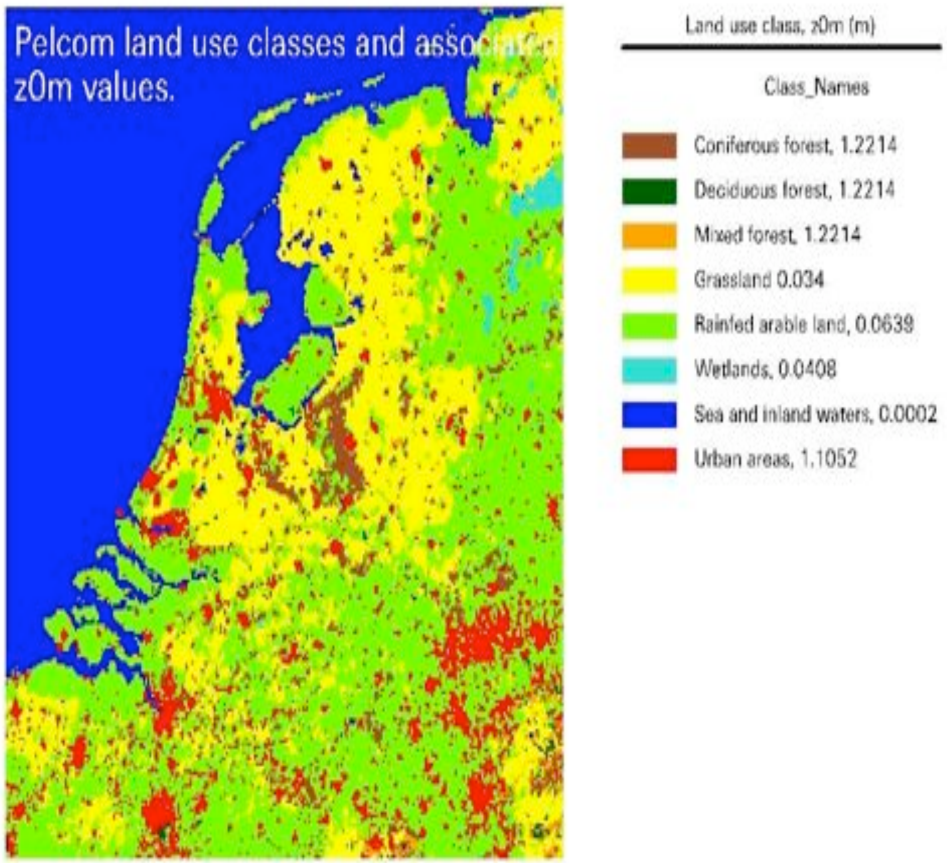



86°30'E 45°00'N
89°00'E 45°00'N
Gurbantonggute Desert
Changji
River Plain
East Mountain
Urumqi
River Valley
Chaiwopu Basin
Chaiwopu Lake
Salt Lake
86°30'E 43°00'N
89°00'E 43°00'N

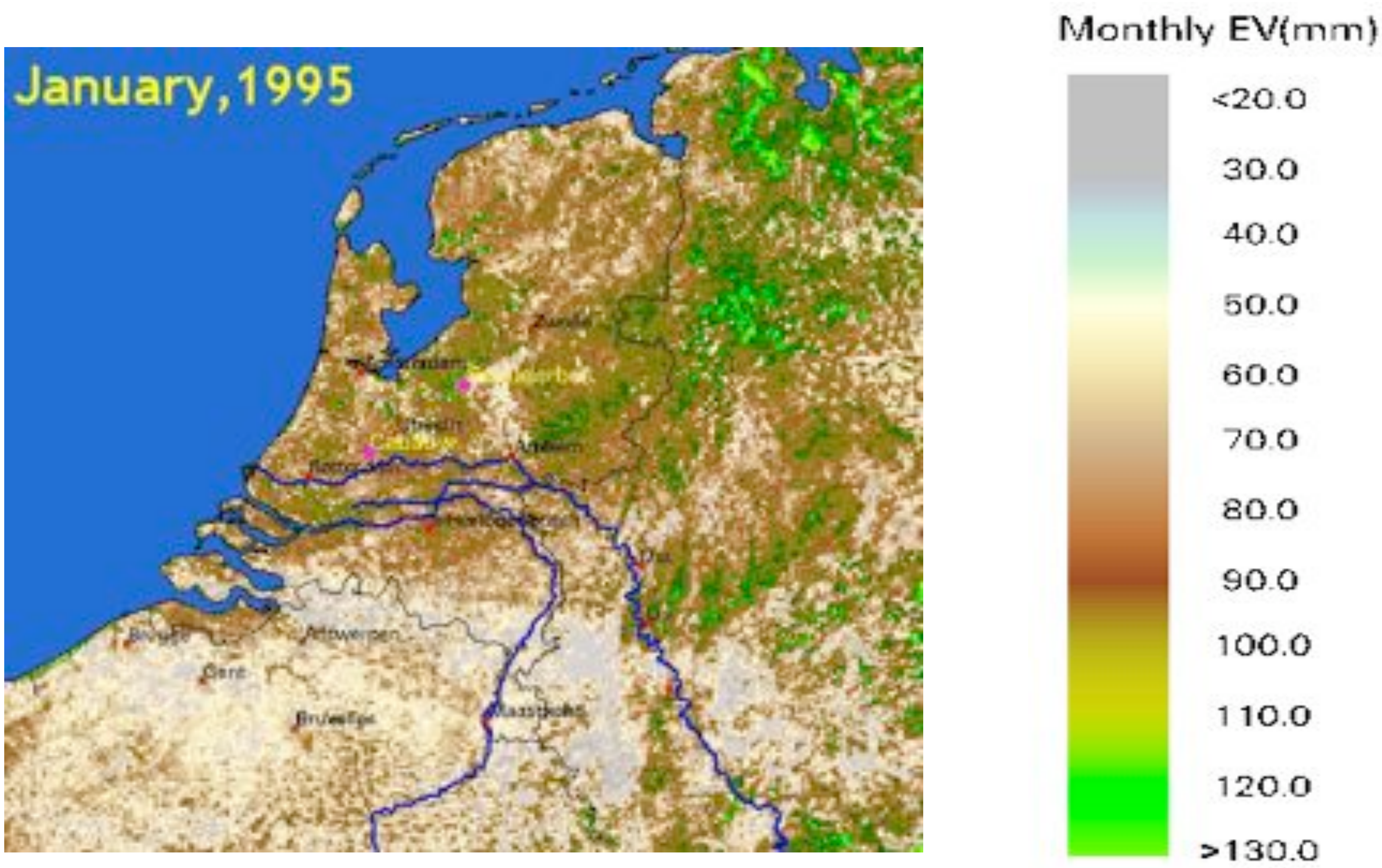

Ea (mm/a)
SEBS-HANTS
0
200
400
600
800
1000
1200
Ea (mm/a)
Field measurements
1
2
3
4
5
6
7
8
9
1. Desert
2. Gobi Plain
3. Mid-mountain
4. Salt Lake
5. Chaiwopu Basin
6. Forest zone
7. Bayi Reservoir
8. Mengjin eservoir
9. Chaiwopu Lake

Applications to the Netherlands
(Methods to determine z0m)

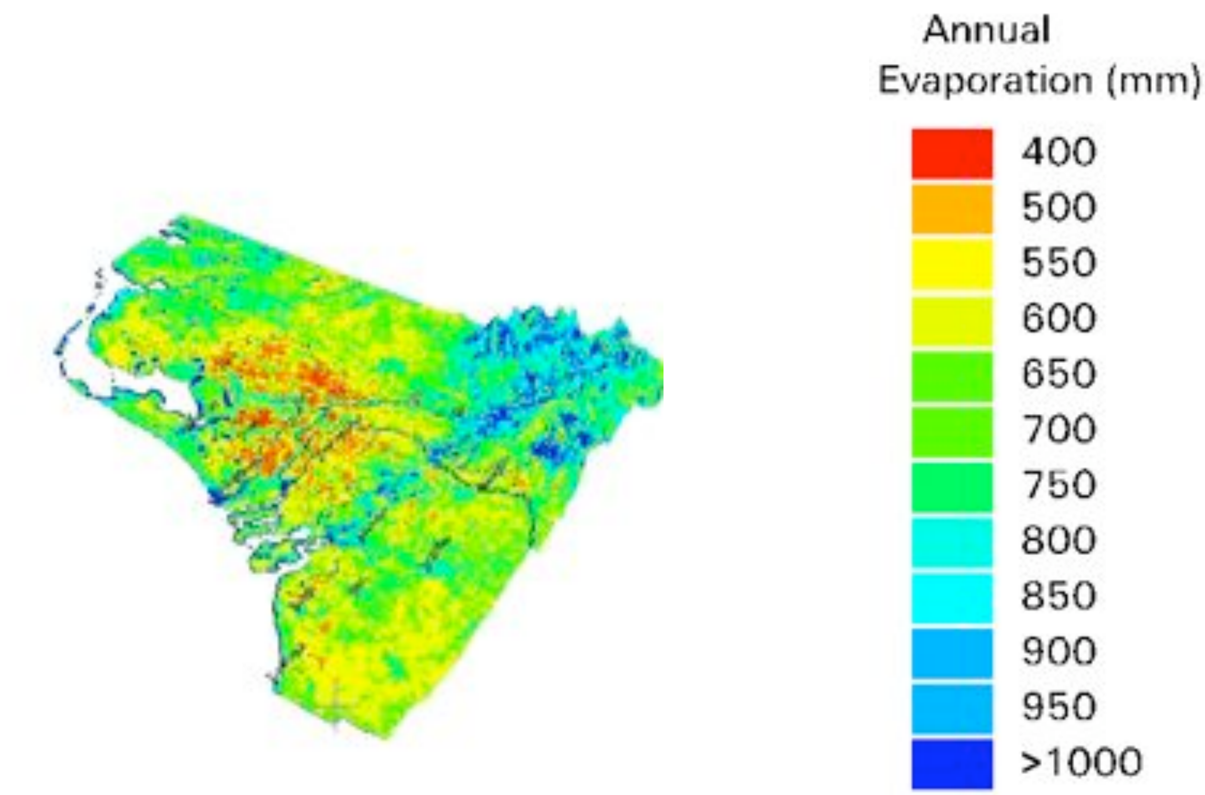




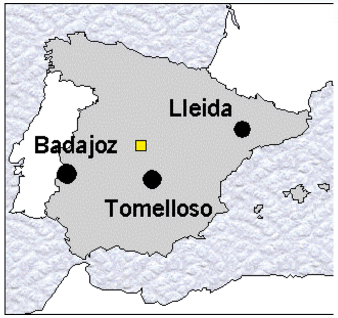
Monthly evaporation during 1995

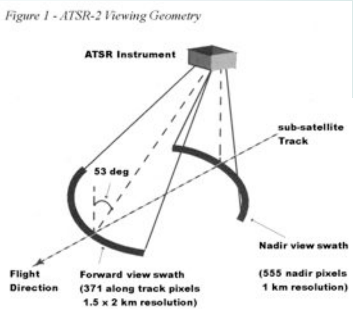


Annual evaporation in 1995

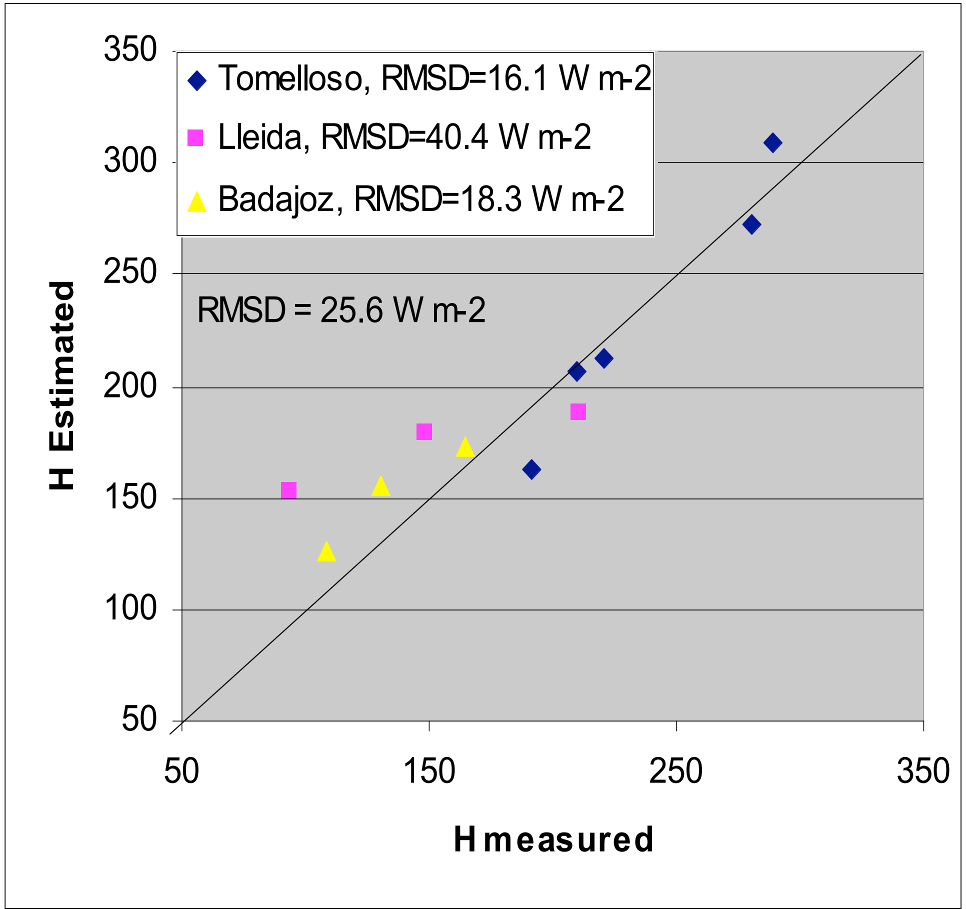


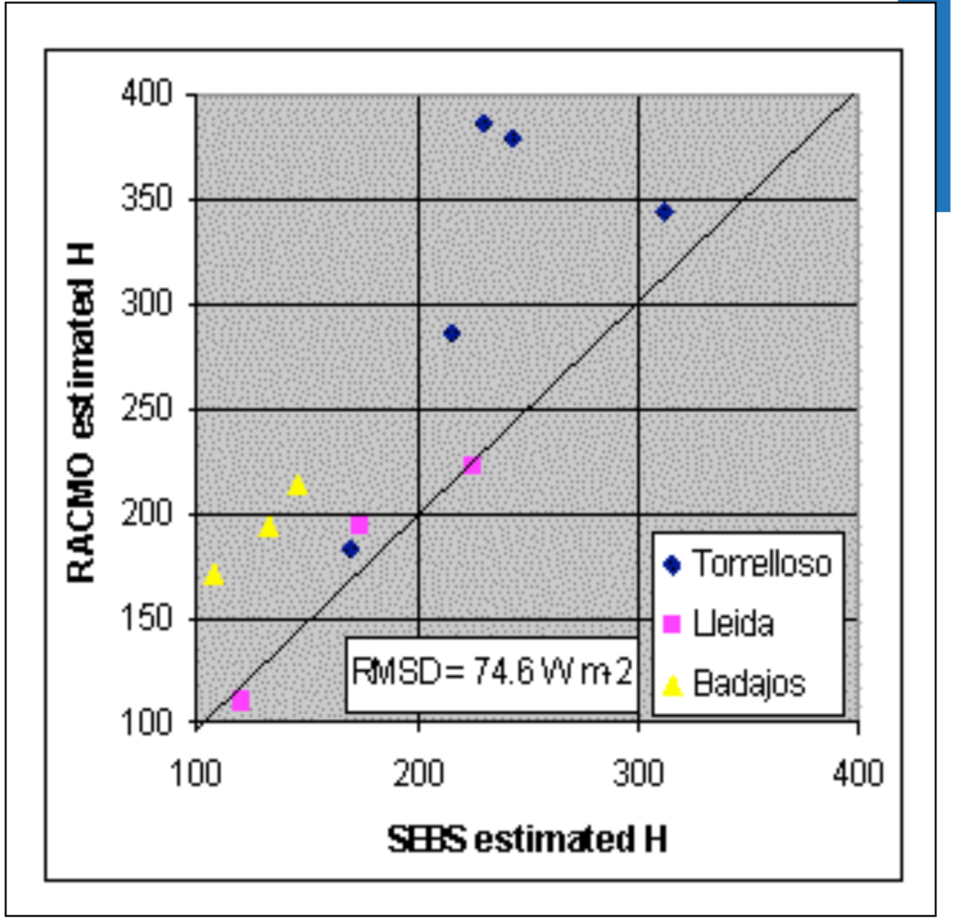
Validation of Atmospheric Models at Regional Scales





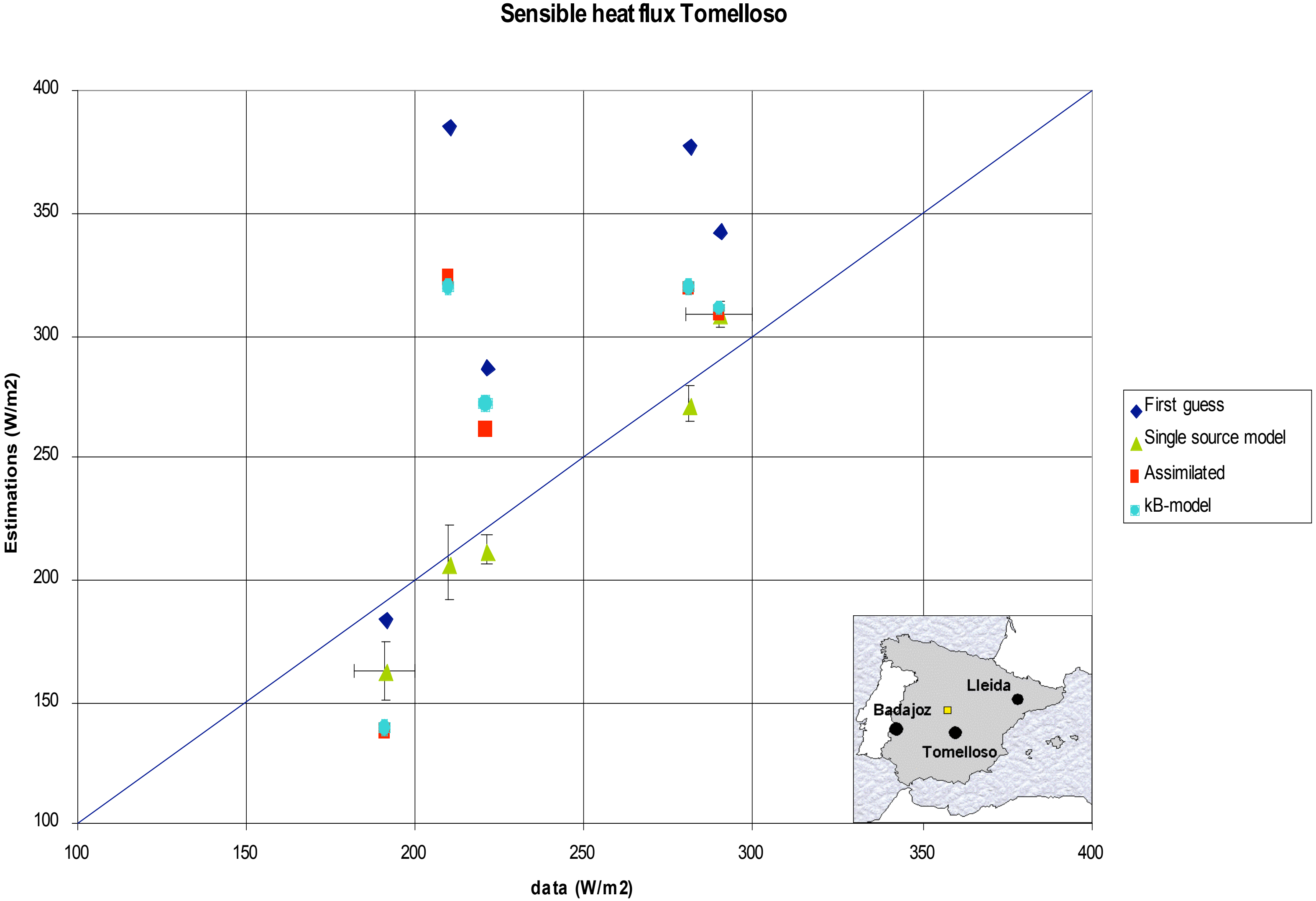
Scintillometer measurements, retrievals by SEBS using ATSR data and RACMO PBL fields, and simulation by RACMO (Jia, Su, vd Hurk, Moene, Menenti, de Briun, 2002),



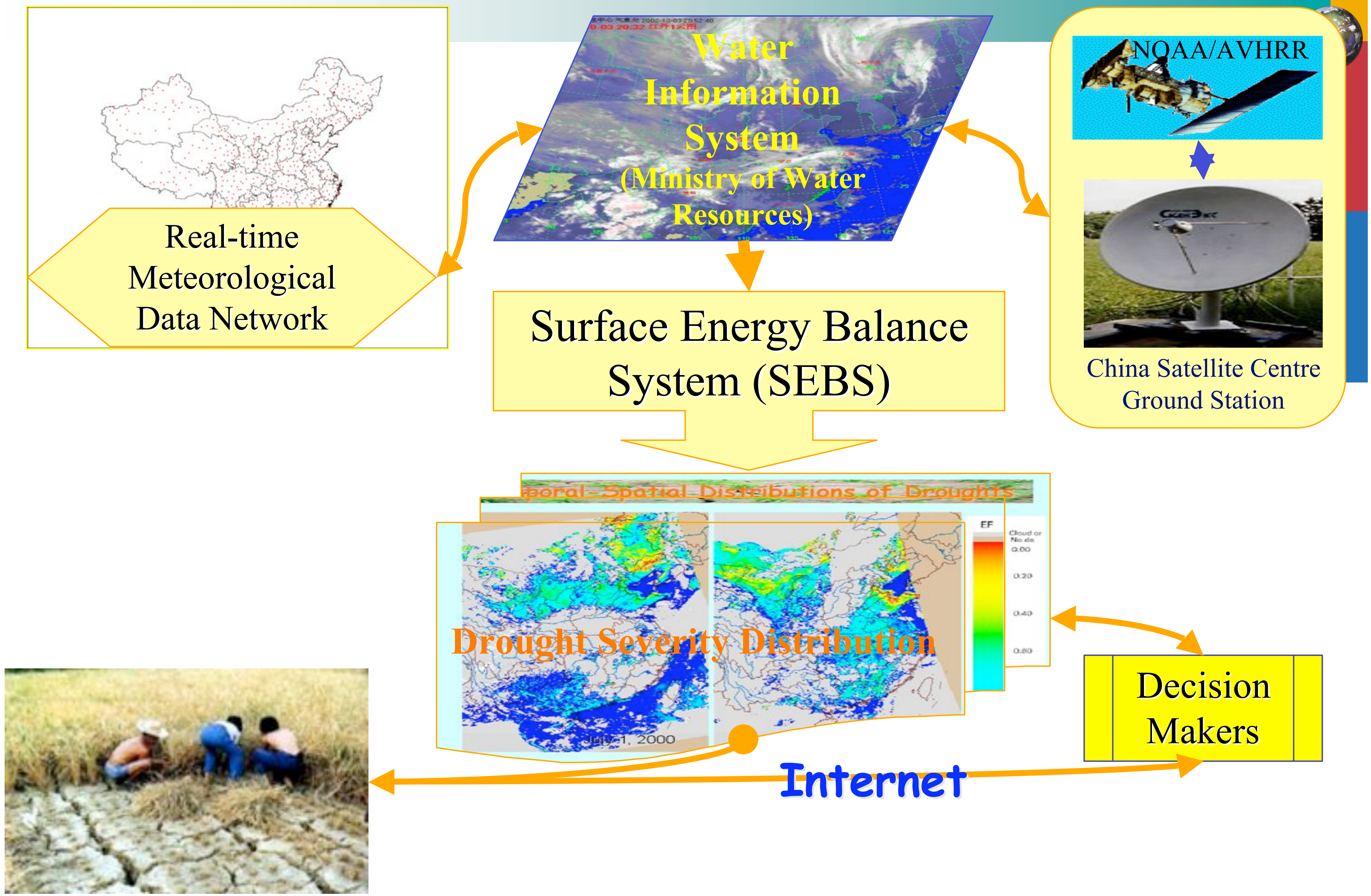


Data Assimilation in Atmospheric Models

RACMO run without data assimilation ("first guess"), SEBS retrievals (the single source), RACMO run (assimilated), and a RACMO run with the kB-model by Su et al (2001) (vd Hurk, Su, Verhoef, Reorink, Jia, 2001)

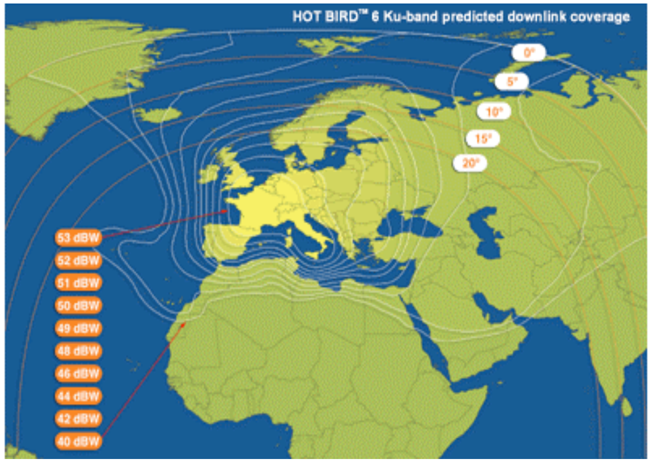


A Real-time Drought Monitoring System



ITC MSG-1 Facility

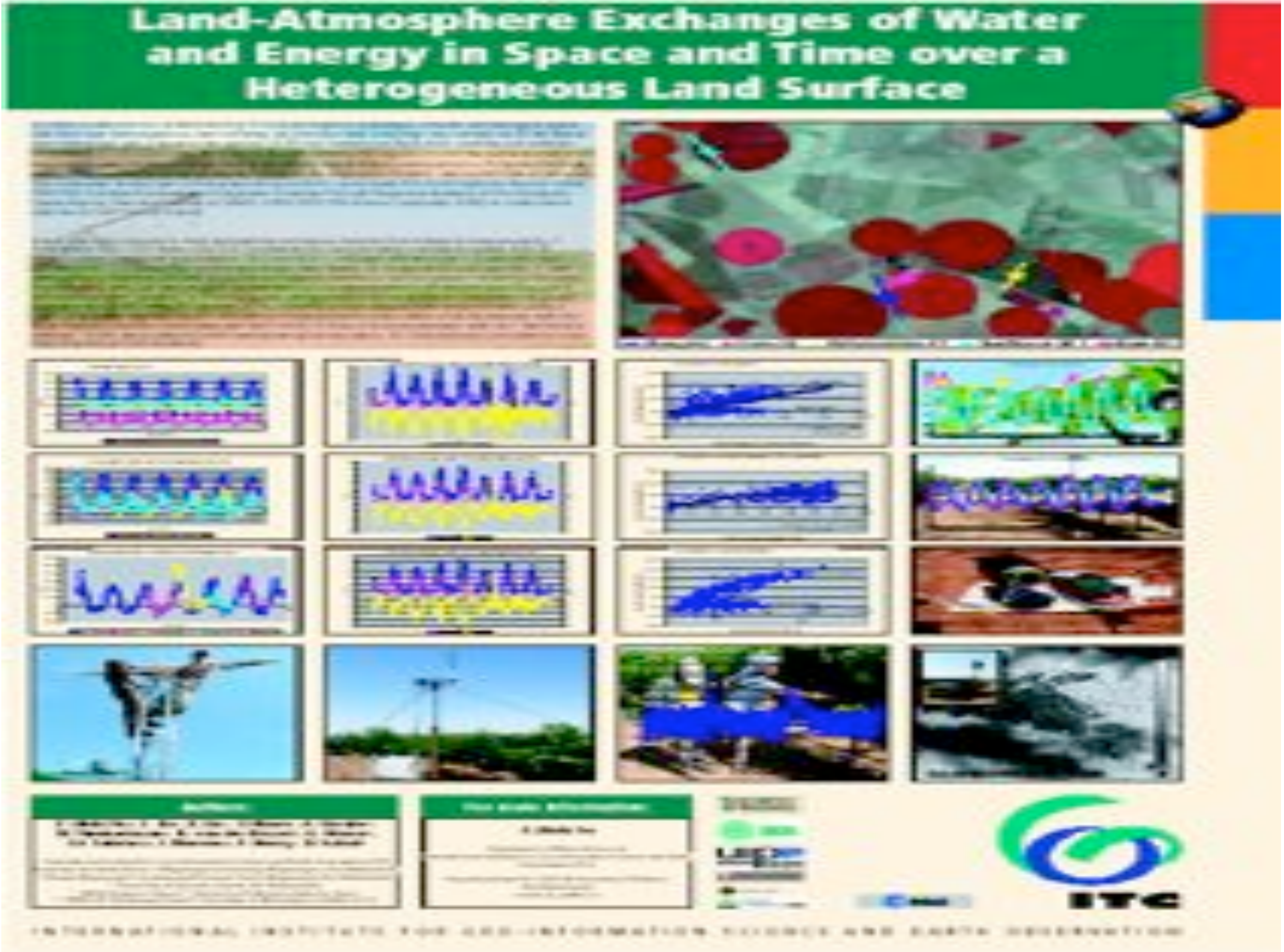
- Hotbird 6 broadcast
- 88 cm satellite dish



Conclusions

- The Surface Energy Balance System (SEBS) is briefly introduced.
- SEBS is scale invariant, so that it can be applied easily to different scales. Data of high or low spatial resolution from all sensors in the visible, near-infrared and thermal infrared frequency ranges can be used in the system.
- Based on a set of case studies, SEBS has proven to be capable to estimate turbulent heat fluxes and evaporation from point to continental scale with acceptable accuracy for low vegetation.
- Big uncertainty exists in estimation of Z0m, LIDAR measurements will be very helpful.
- Applicability to forests needs to be investigated further.
- The results demonstrate that SEBS algorithm can be used for spatial-temporal estimation of actual evaporation with an acceptable accuracy.

ITC


Land-Atmosphere Exchanges of Water
and Energy in Space and Time over a
Heterogeneous Land Surface
ITC

EAGLE2006

(8 June – 2 July 2006)

EAGLE Netherlands Multi-purpose, Multi-Angle and Multi-sensor,
In-situ, Airborne and Space Borne Campaigns over Grassland and Forest