

Surface Energy Balance System and Evaporation/Transpiration

Z. (Bob) Su

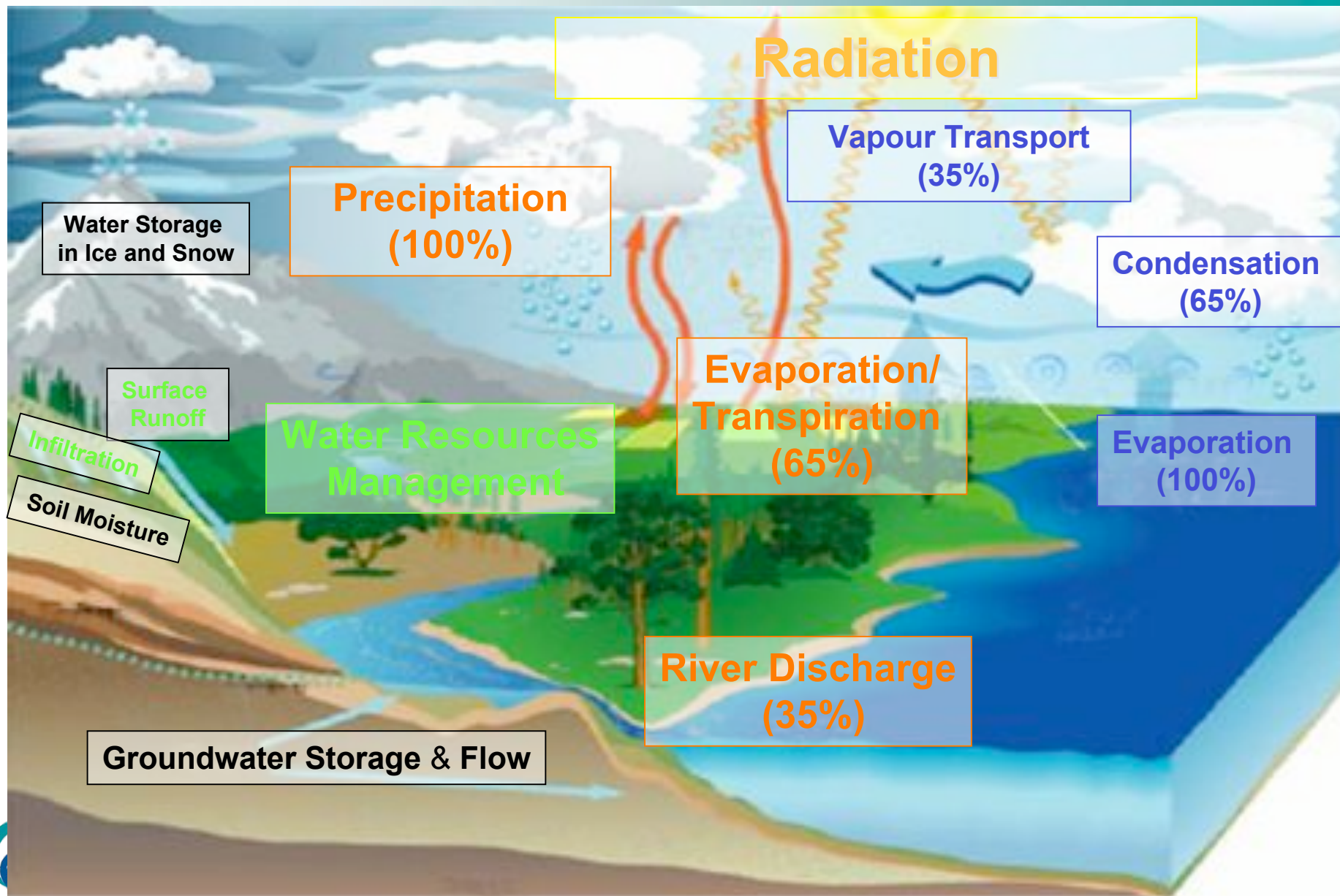
**International Institute for Geo-Information
Science and Earth Observation (ITC),
Enschede, The Netherlands**

B_SU@ITC.NL

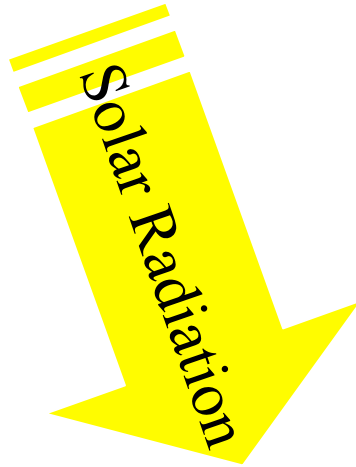
www.itc.nl



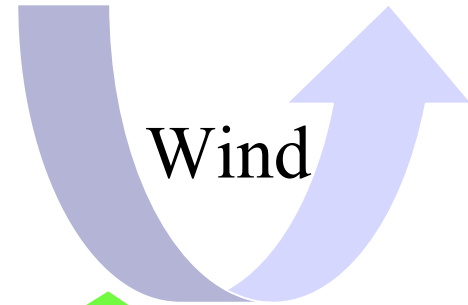
Earth Observation of Water Cycle



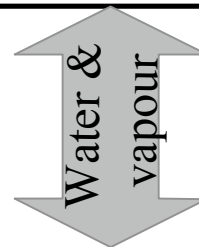
Land-Atmosphere Interactions - Terrestrial Water, Energy and Carbon Cycles



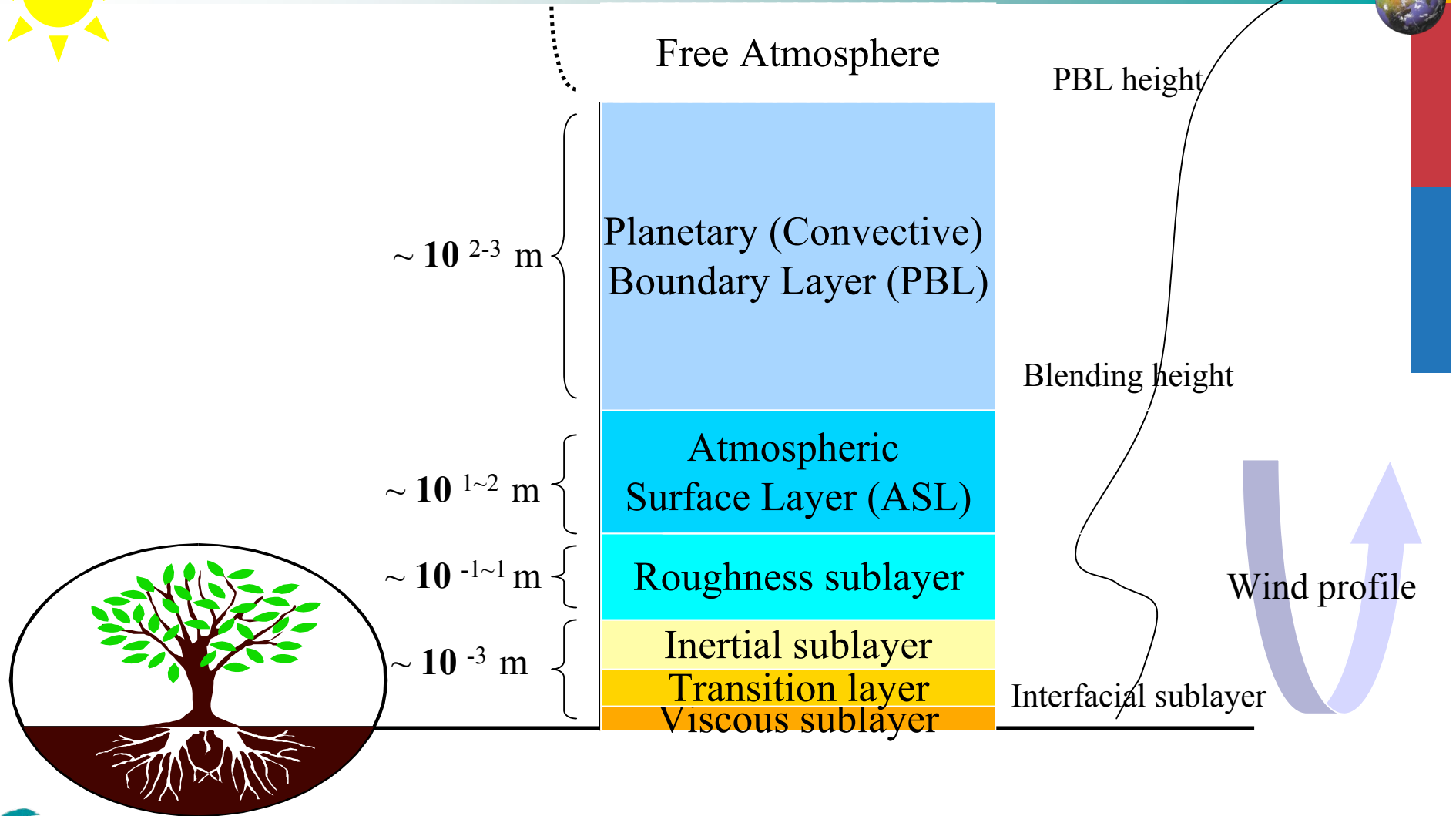
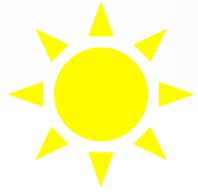
Precipitation



Biochemical Processes

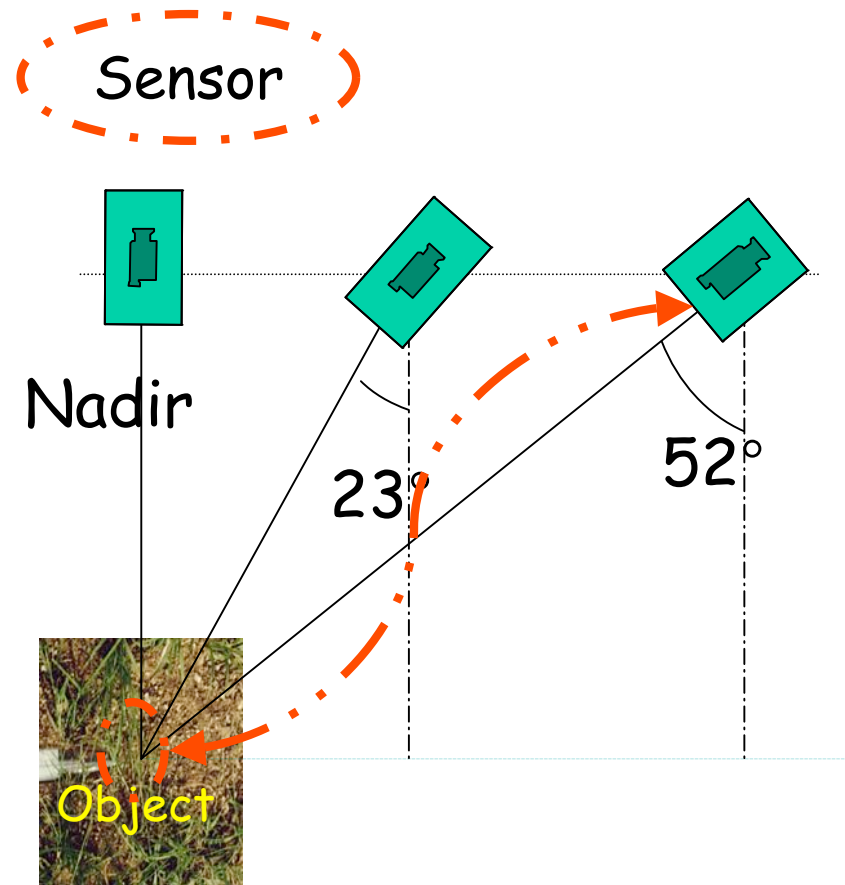


Structure of the atmospheric boundary layer considered in SEBS



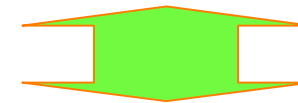
The Fundamental of Earth Observation

(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

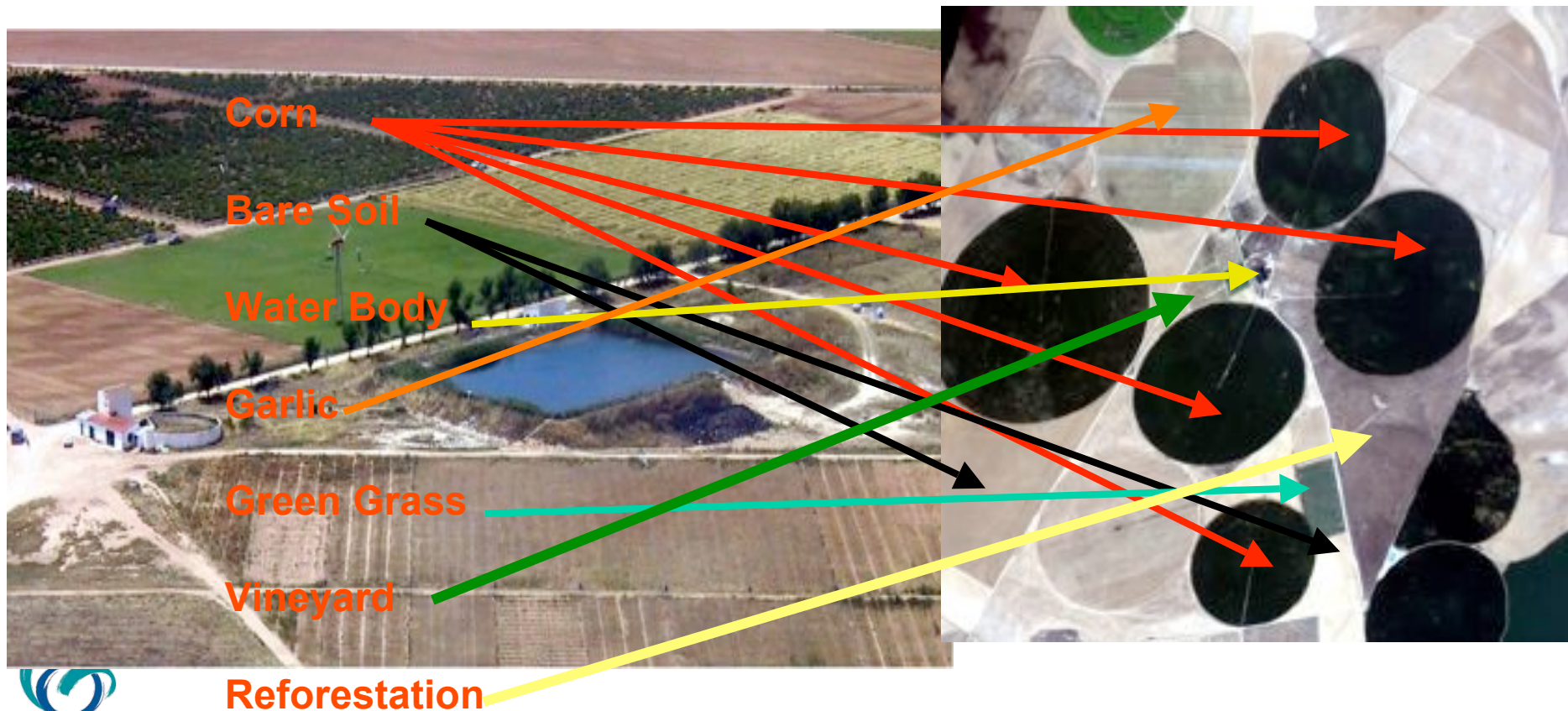
A: A Passive Sensor System
A+B: An Active Sensor System

BARRAX TEST SITE LOCATION

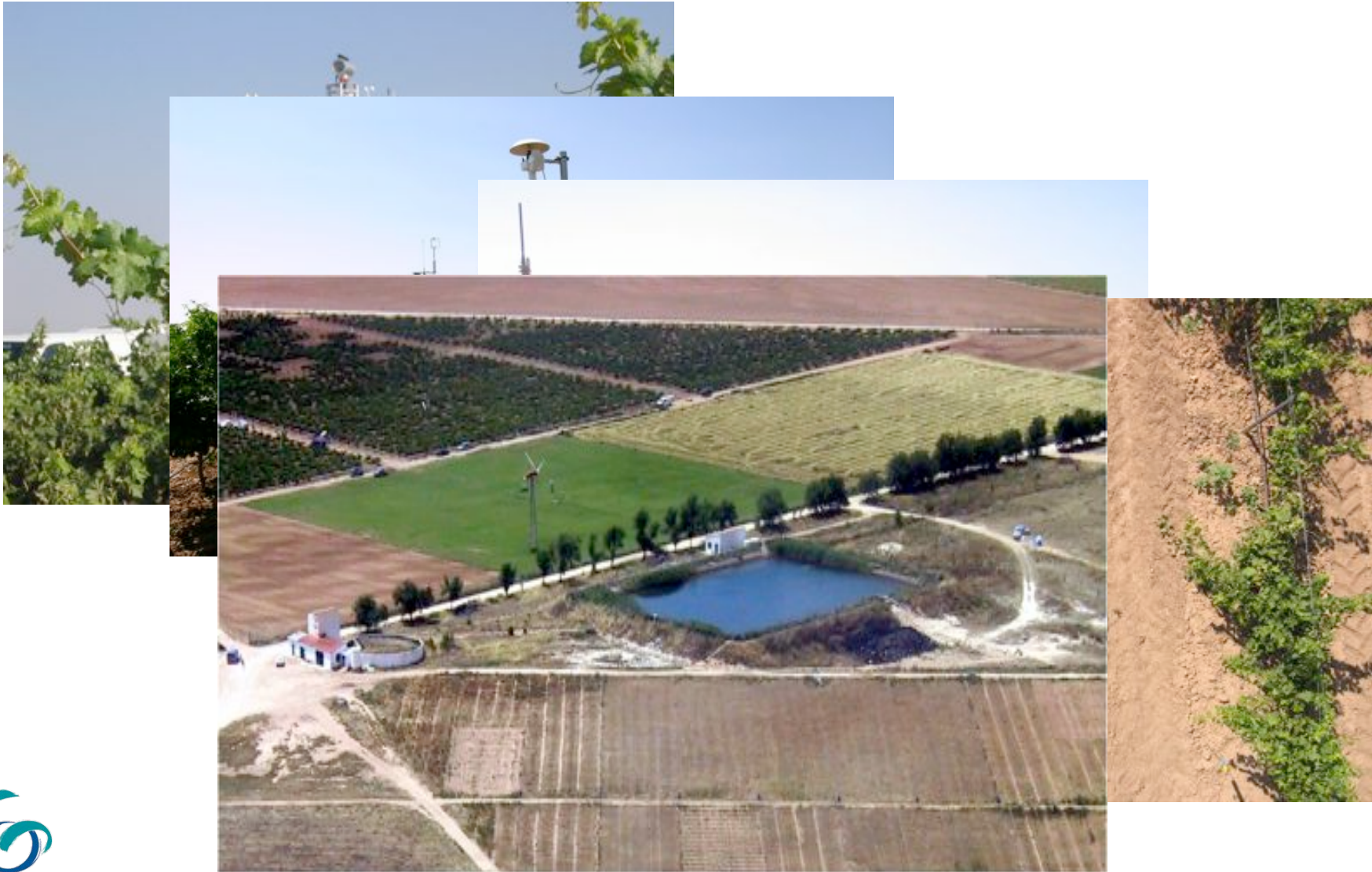
Study Area



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



The Canopy from Different Perspectives

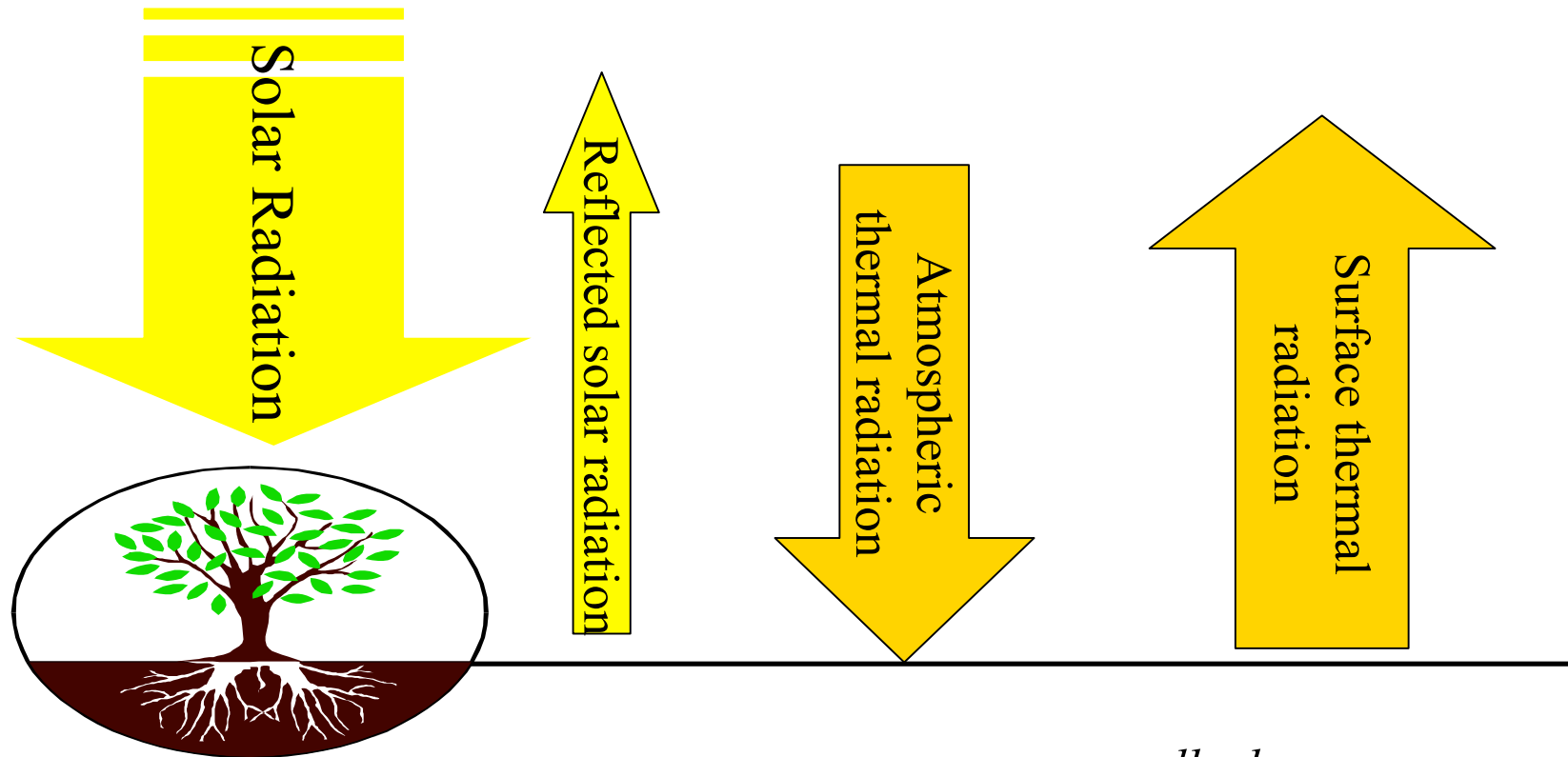


ITC Instrumentation SIN2FLEX Campaign 2005



- **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**

Surface Radiation Balance



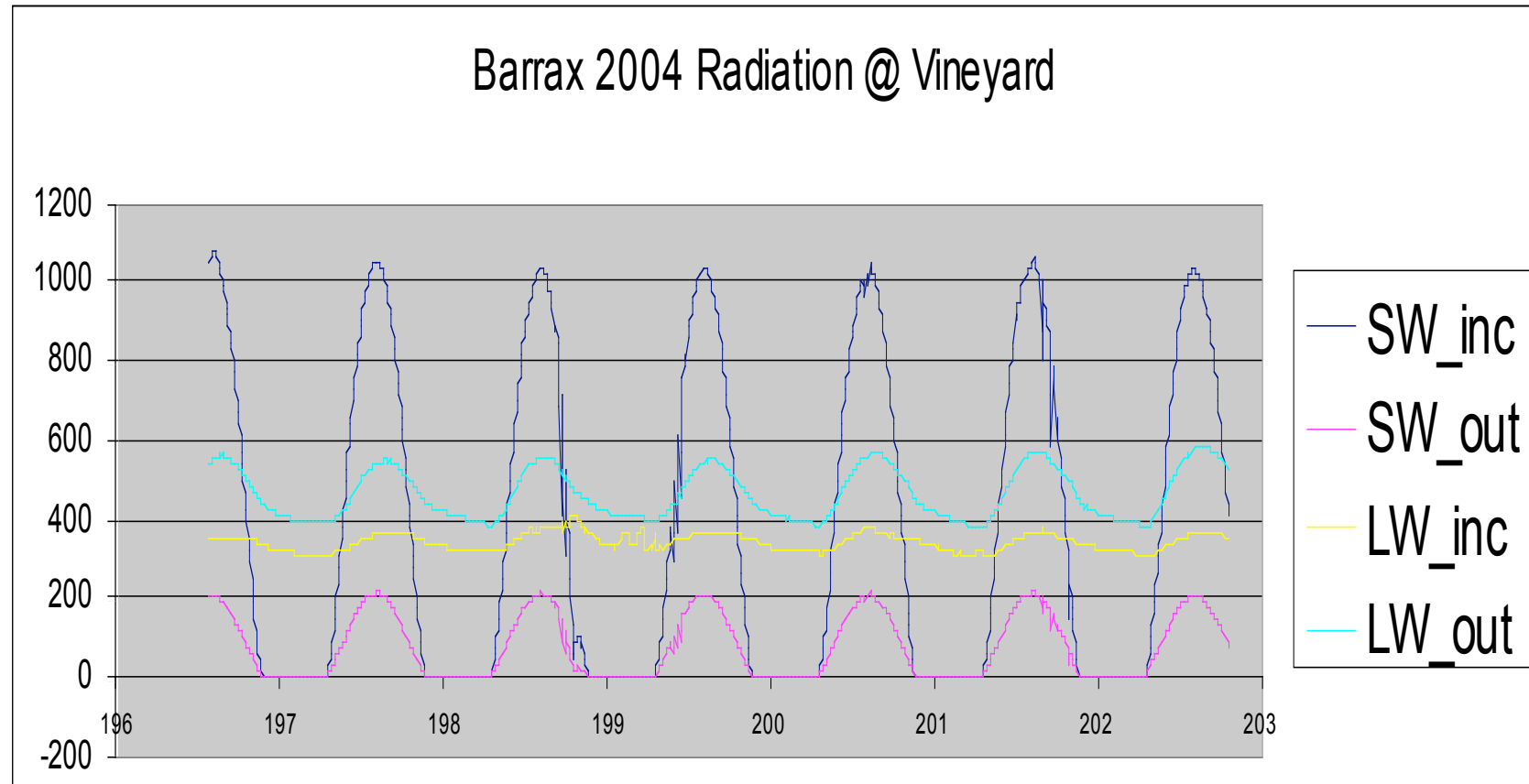
$$R_n = (1 - \alpha) \cdot R_{swd} + \varepsilon \cdot R_{lwd} - \varepsilon \cdot \sigma \cdot T_0^4$$

α : albedo

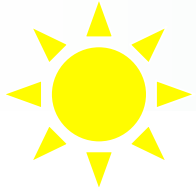
ε : emissivity

T_0 : Surface Temperature

Data from EAGLE/SPARC Campaign 2004, Barrax, Spain

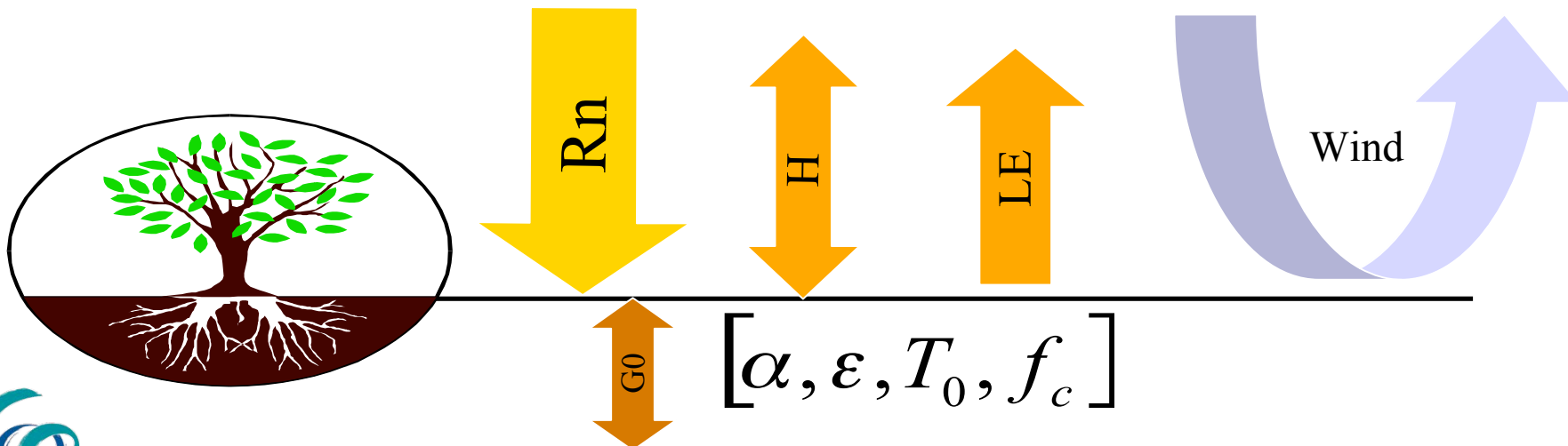


Surface Energy Balance Terms



$$R_n = G_0 + H + LE$$

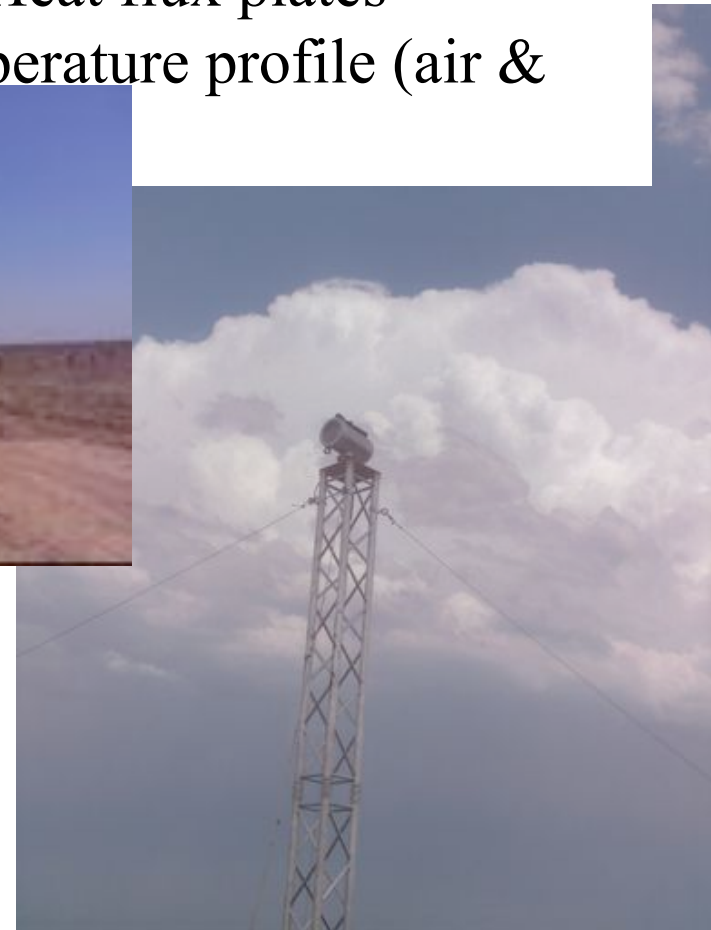
$$G_0 = R_n \cdot [\Gamma_c + (1 - f_c) \cdot (\Gamma_s - \Gamma_c)]$$



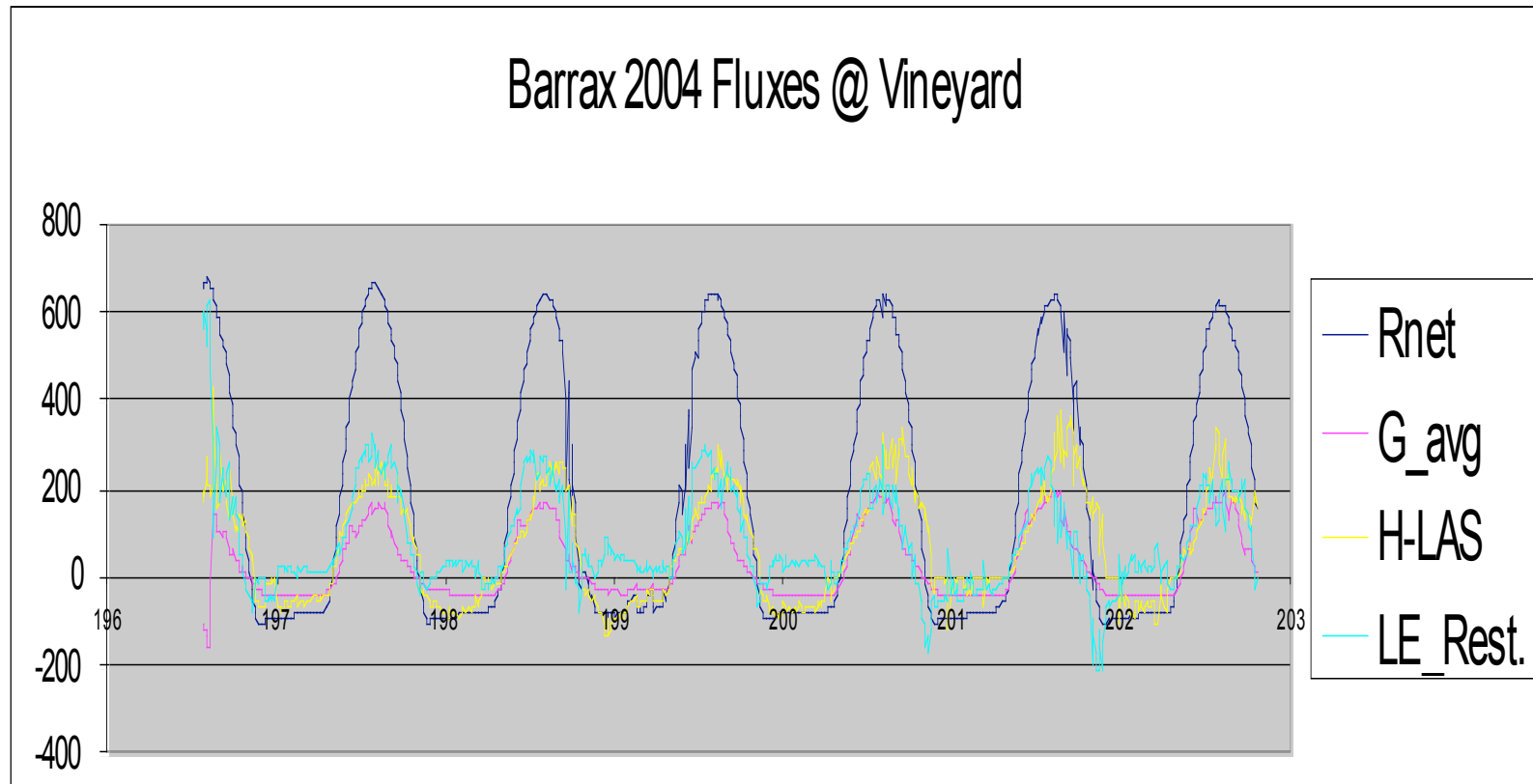
Instrumentation



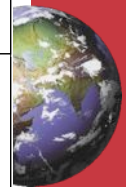
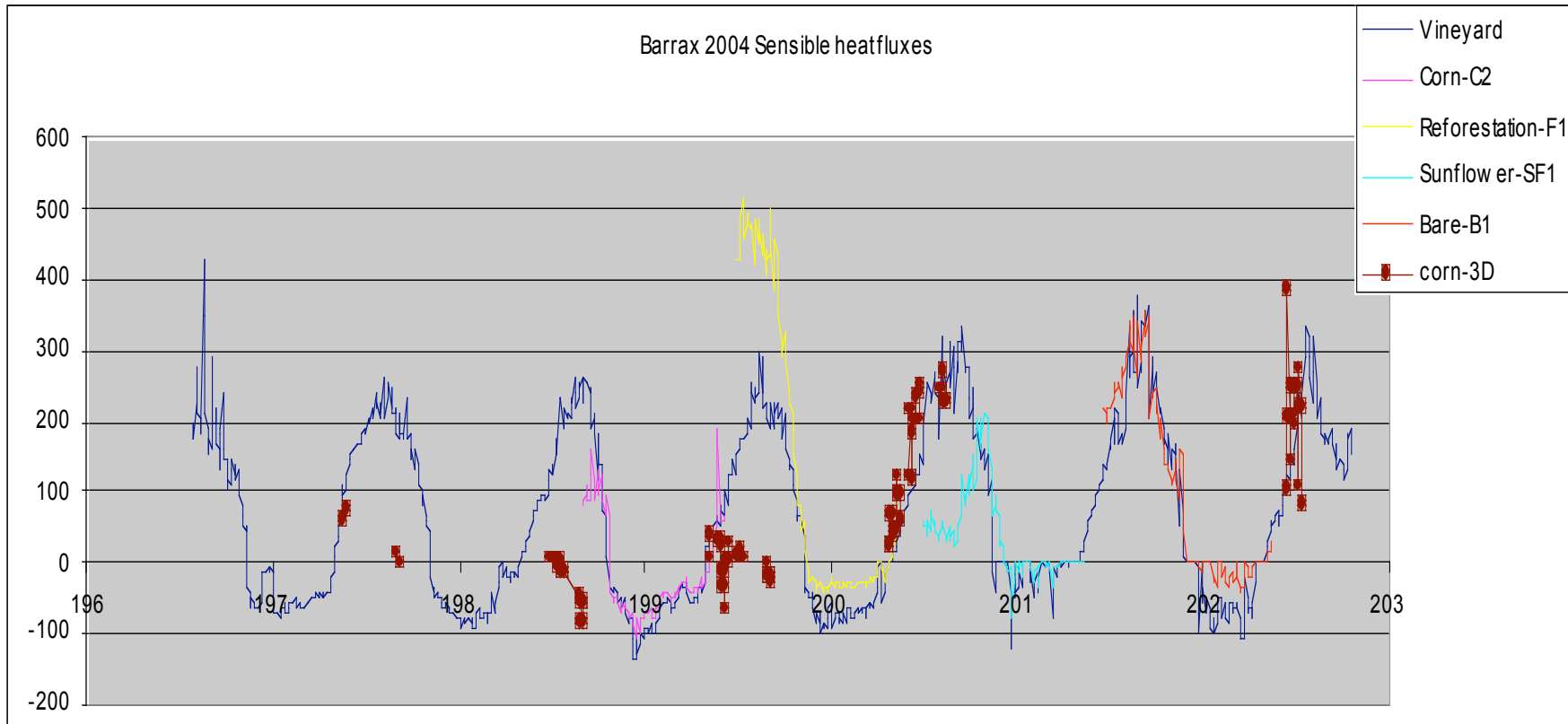
- **Scintillometer, 2 Sets**
- Radiation components
- Soil Heat flux plates
- Temperature profile (air &



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)

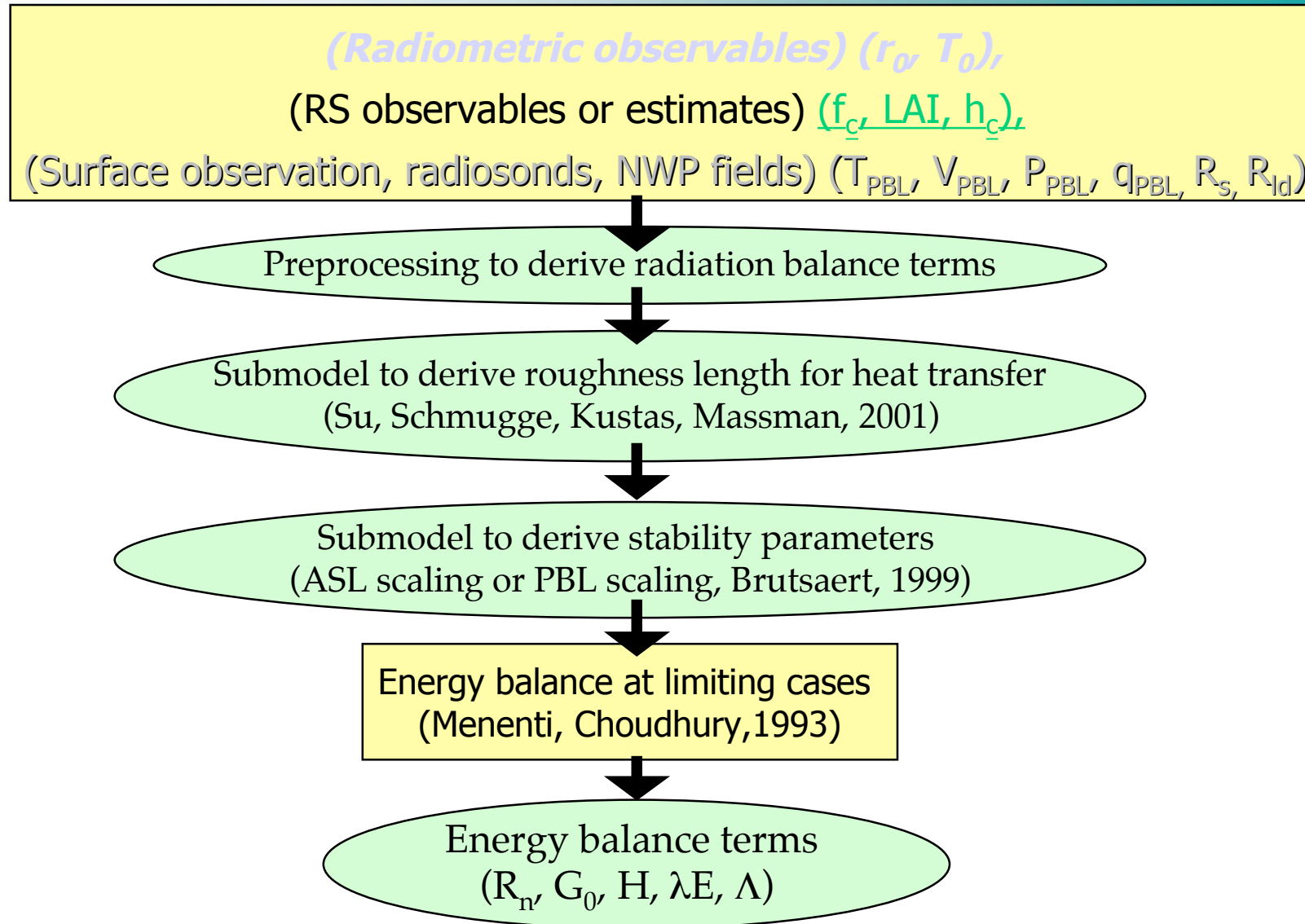
Nieuwenhuis et al., 1989
e.g. $E=a+b*T0$

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

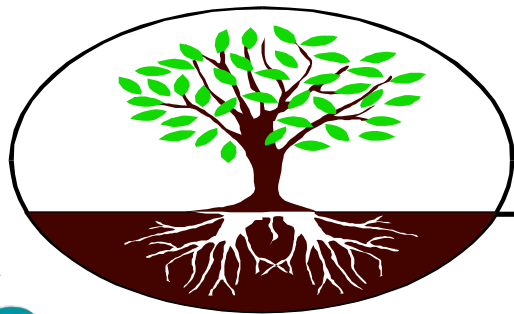
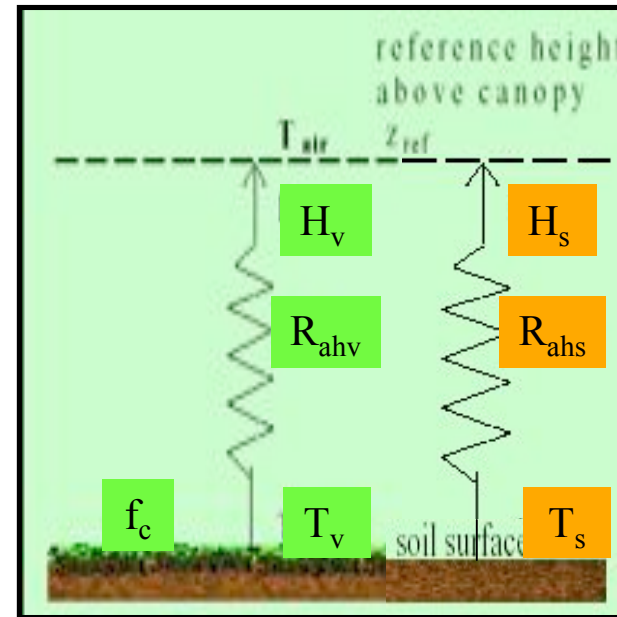
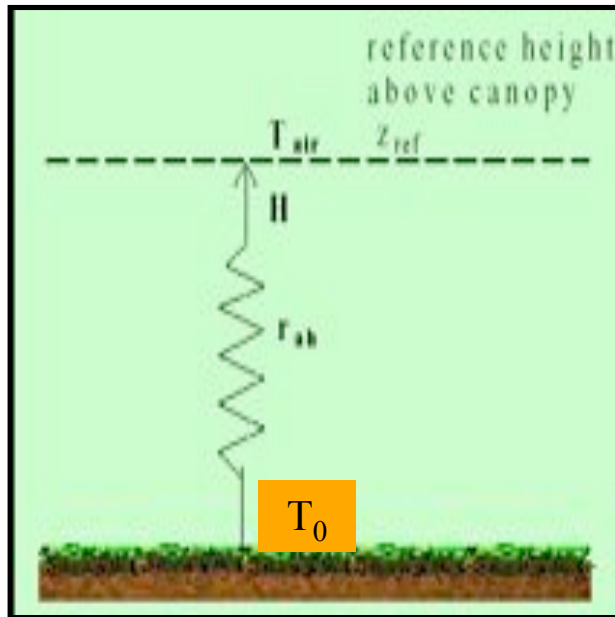
Roerink, Su, Menenti, 2000
Simplified Surface Energy Balance Index
(fitting dry and wet limiting cases in data)
(S-SEBI)

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



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

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

$$H_{dry} = R_n - G_0$$

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

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

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

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

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

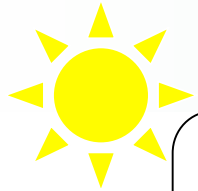
$$H = (1 - \Lambda) \cdot (R_n - G)$$

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

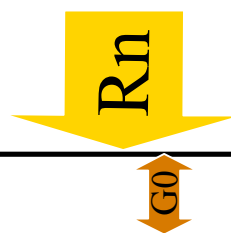
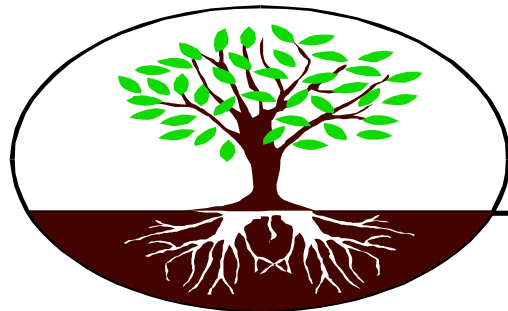
$$\Lambda = \frac{\lambda E}{R_n - G} = \frac{\Lambda_r \cdot \lambda E_{wet}}{R_n - G}$$



Energy Balance Residual Method - Turbulent Heat Fluxes



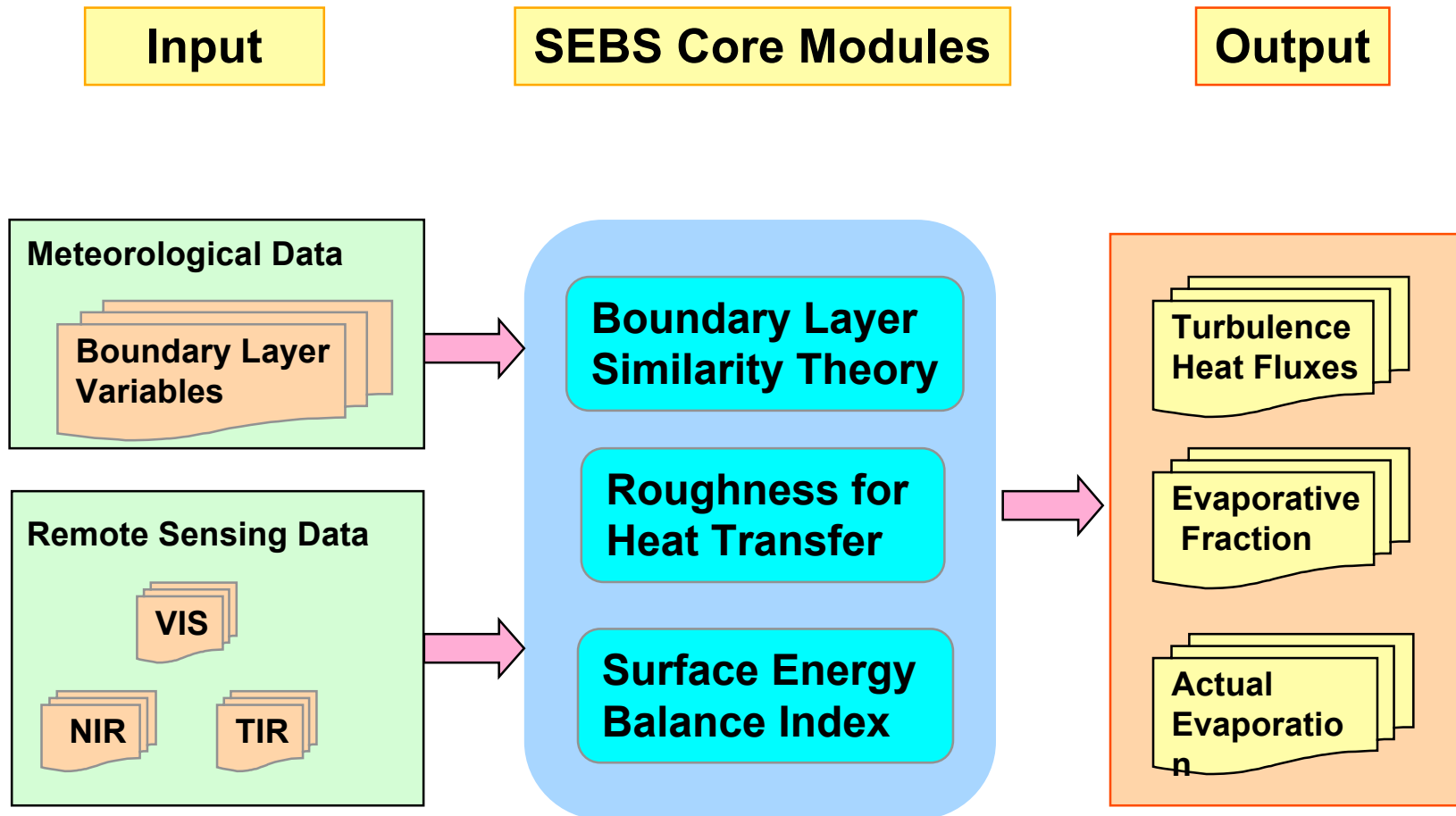
$$\left\{ \begin{aligned}
 u &= \frac{u_*}{k} \left[\ln \left(\frac{z - d_0}{z_{0m}} \right) - \Psi_m \left(\frac{z - d_0}{L} \right) + \Psi_m \left(\frac{z_{0m}}{L} \right) \right] \\
 L &= - \frac{\rho C_p u_*^3 \theta_v}{kgH} \\
 H &= ku_* \rho C_p (\theta_0 - \theta_a) \left[\ln \left(\frac{z - d_0}{z_{0h}}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



Wind, air temperature, humidity
(aerodynamic roughness,
thermal dynamic roughness)

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

SEBS - The Surface Energy Balance System





NOAA/AVHRR, LANDSAT, METEOSAT
(ENVISAT, ADEOS-II, MTPE)

RS

DEM

RS
(atmospheric sounding)

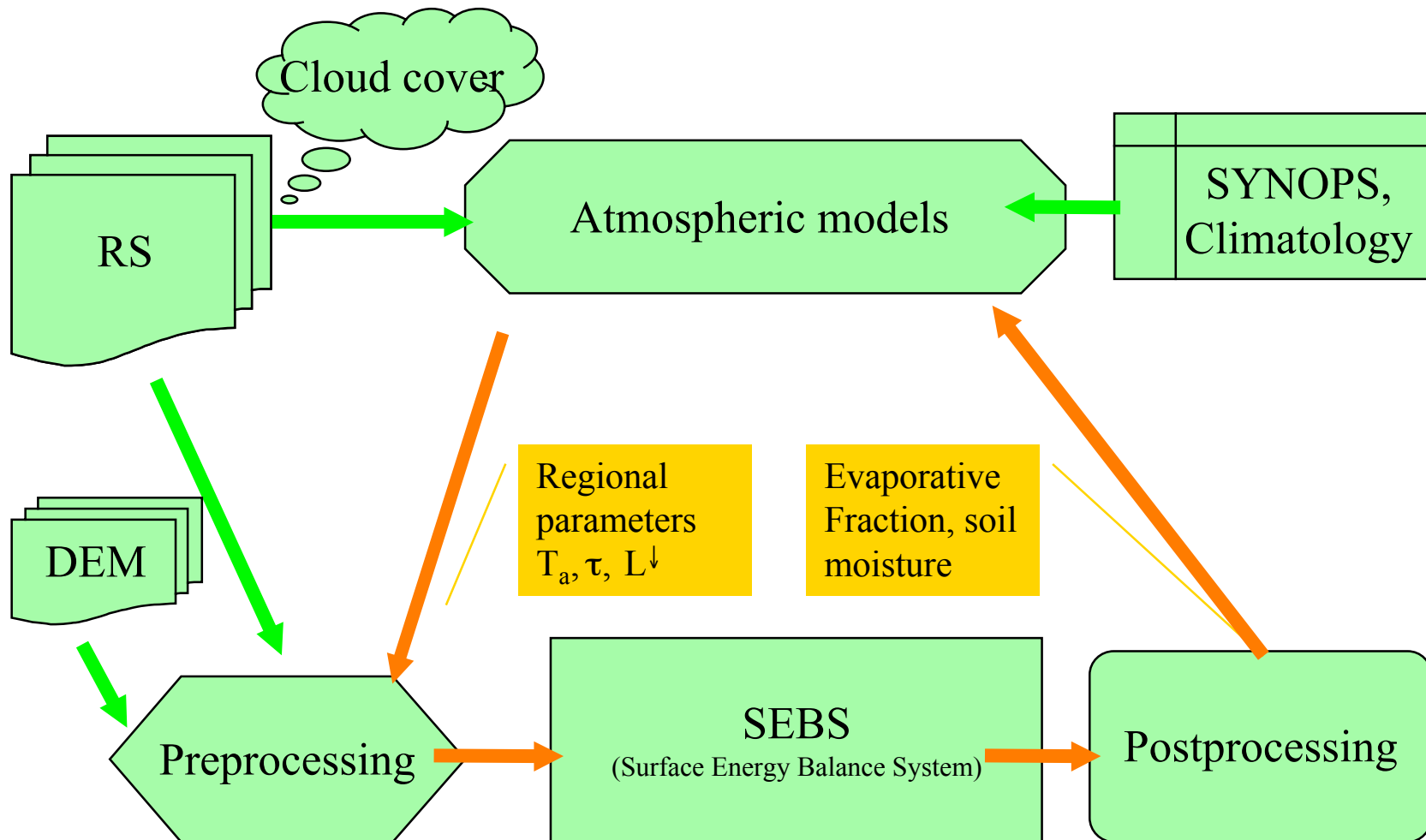
NWP

Regional Atmospheric State

Preprocessing



General Methodology



Step-by-Step SEBS Procedure

Satellite Active Archive

Make Selection Below

Enter as a New User

Enter as a Registered User

Product Data

Pre-processing

Customize map projection

Calibration

Geo-reference

Resize data

Split calibrated file

Geometry file

Geo-reference

Resize data

Split geometry file



Calculating Global Radiation

Calculating Surface Reflectance, Albedo and NDVI

Calculating Surface Emissivity

Calculating surface Emissivity

Emissivity of vegetation: 0.98

Emissivity of soil: 0.95

Mean correction factor: 0.002

Image sizes: 256 Rows 256 Columns

Input NDVI: ndvi.img

Output Emissivity: emis.img

File Input: surf.dg

Save as: surf.dg



Calculating Evaporative Fraction

PBL Depth (m): 820

PBL Potential Temperature (K): 312.15

PBL Wind Speed (m/s): 10.3

PBL Pressure (Pa): 83420

PBL Relative Humidity (ka/ka): 0.25

Surface Pressure (Pa): 90390

Image Sizes: 256 Lines 256 Samples

Input Directory: D:\

Global Radiation: globrad.img

Surface Albedo: albedo.img

NDVI: ndvi.img

Surface Emissivity: emis.img

Surface Temperature: temp.img

Output Directory: D:\

Net Radiation: netrad.img

Soil Heat Flux: soilht.img

Sensible Heat Flux: sensht.img

Latent Heat Flux: lateshl.img

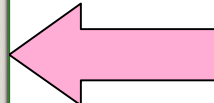
Evaporative Fraction: evaprec.img

Calculate

Current Directory: D:\

File Input: evap.cfg

Save As: evap.cfg



C:\SEBS_run\sensH_0710.img

C:\SEBS_run\lentH_0710.img

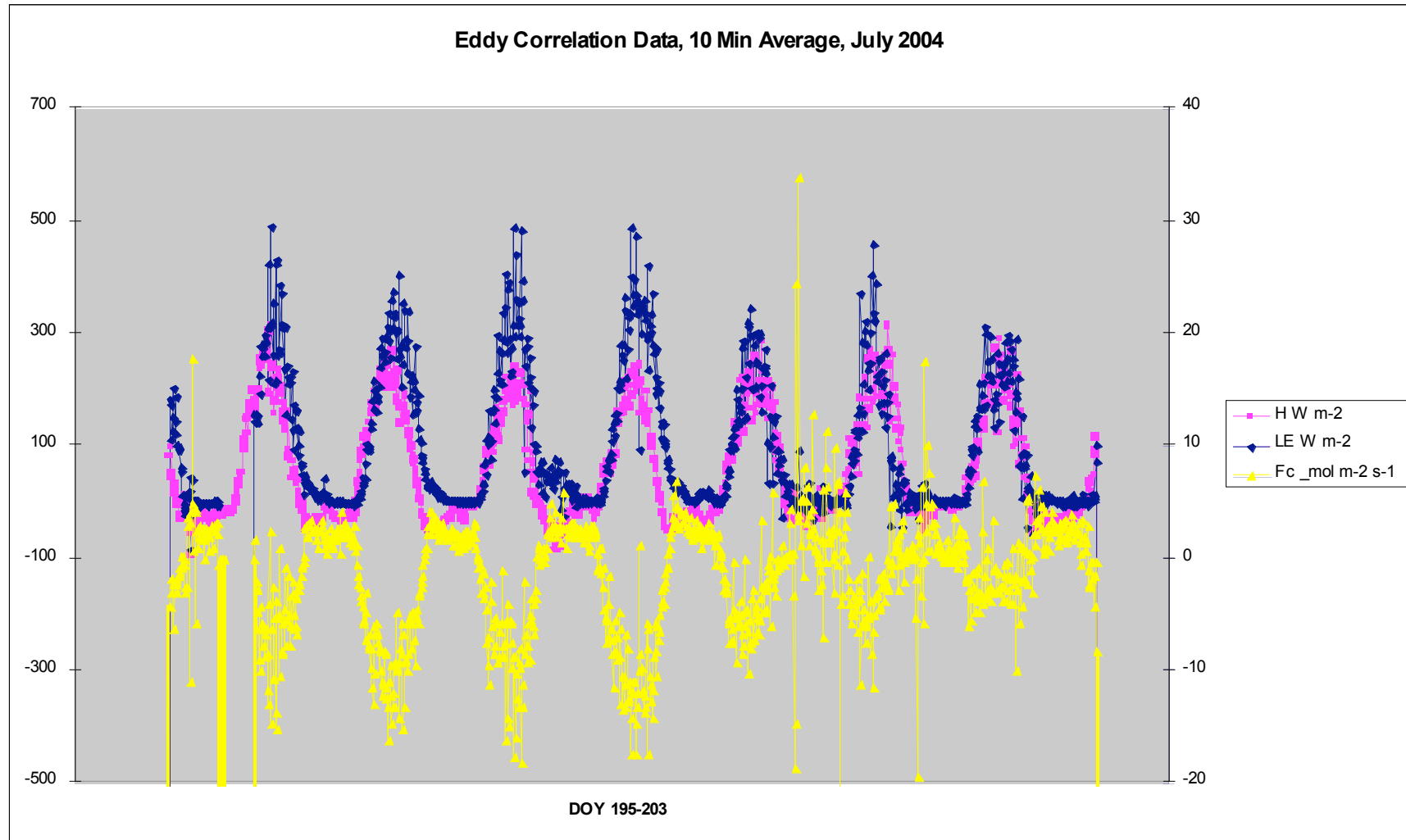
C:\SEBS_run\SEBS_ef_0710.img

rows: 133, columns: 181, value: 0.841126

close



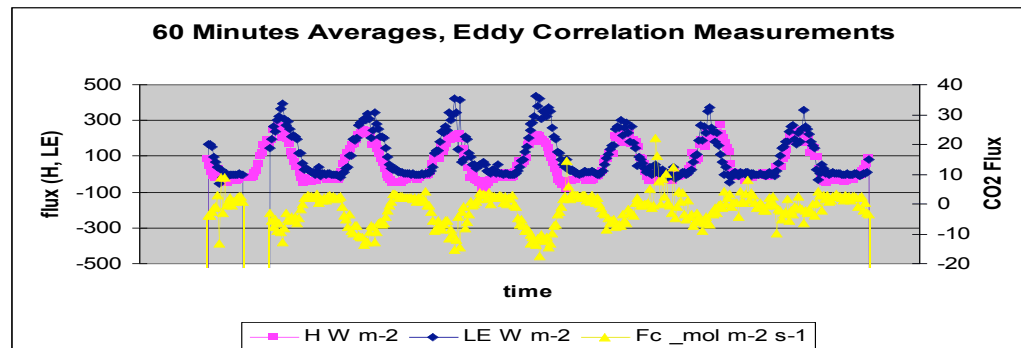
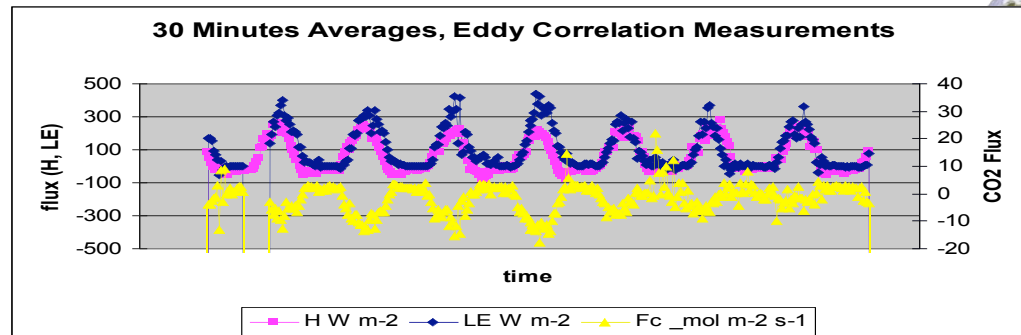
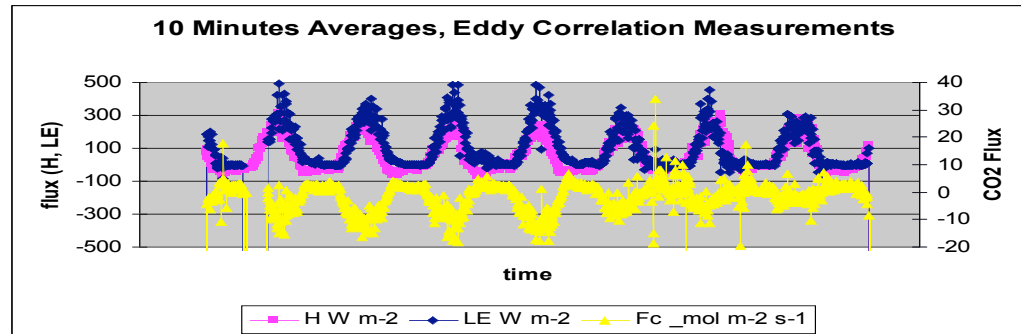
Flux data 2004 (Single set, height 3m)



Canopy level Processes: Eddy Correlation Measurements

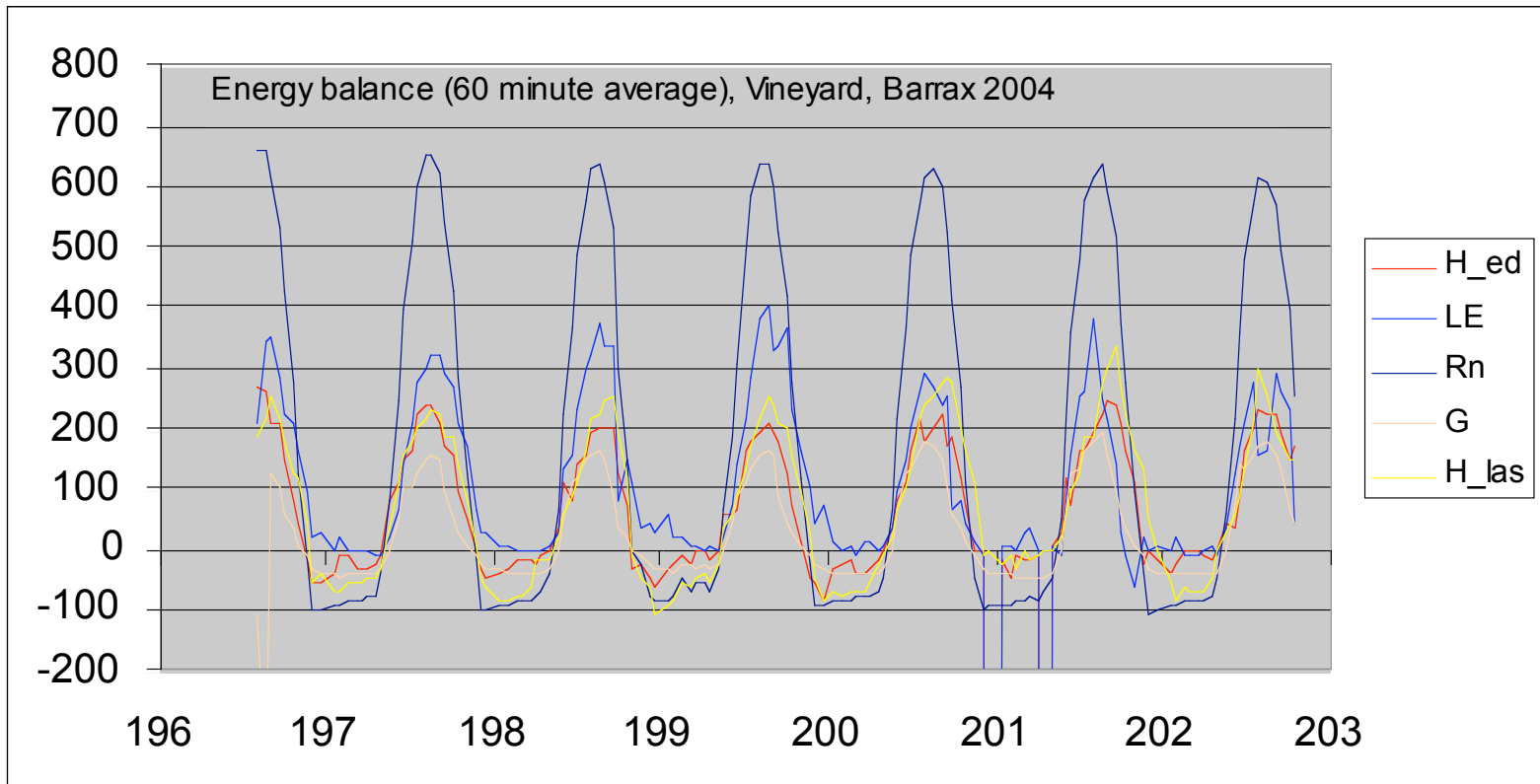


Canopy level:
Turbulence, H₂O, CO₂ fluxes and
CO₂ concentrations using an eddy
correlation system (Gill 3D sonic
+ closed path Licor gasanalyser:
CO₂ and H₂O + nitrogen reference gas
+ pneumatic mast + dataloggers)



Primary analysis: Energy balance components

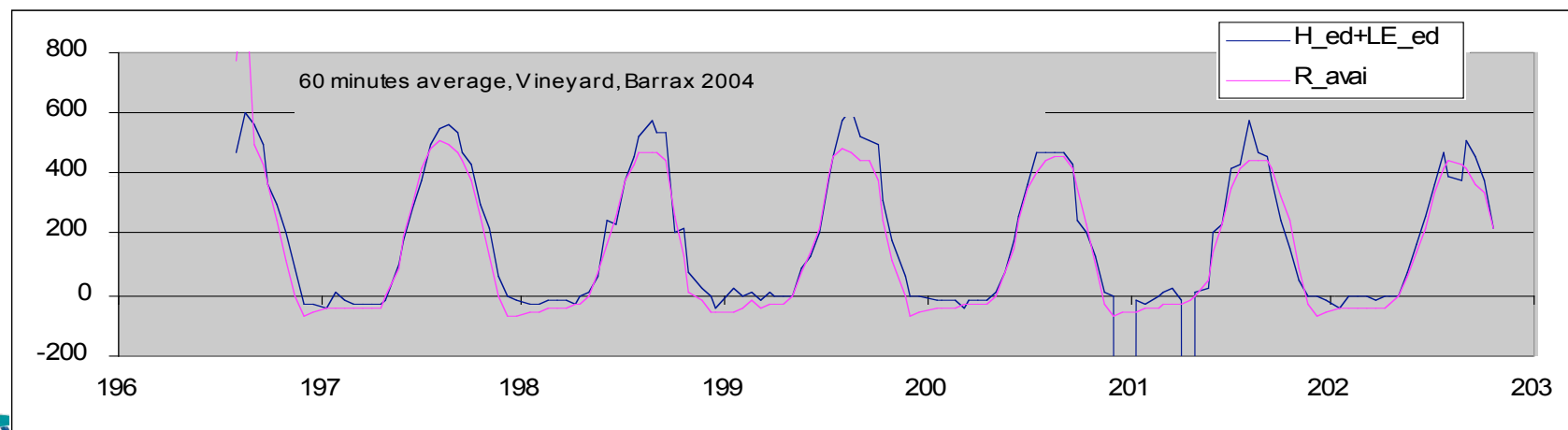
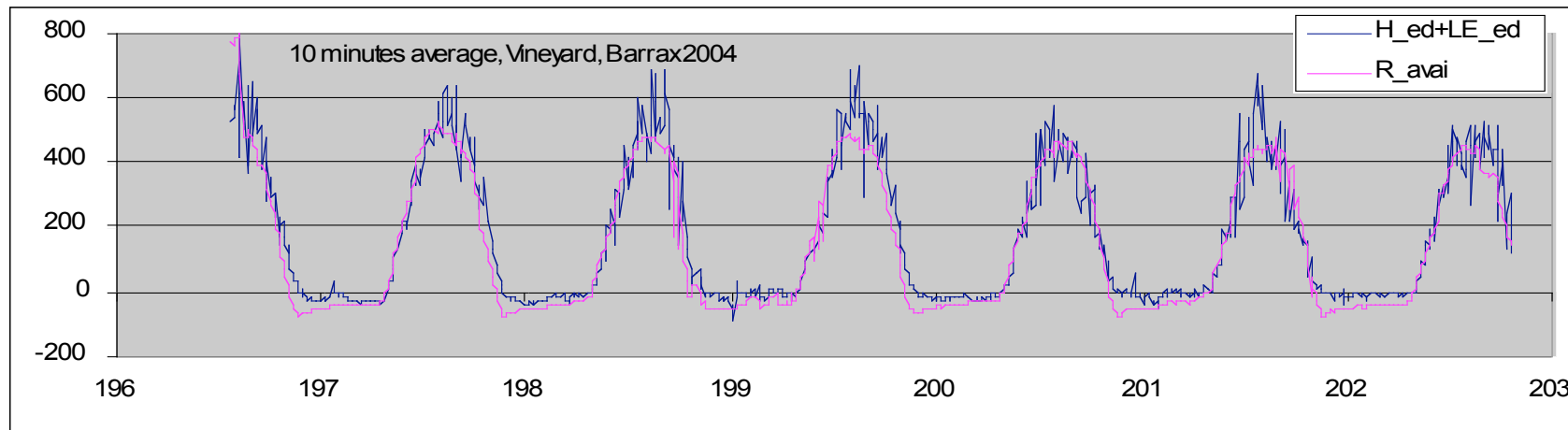
Energy balance



Primary analysis: Energy balance components

Energy balance closure ??

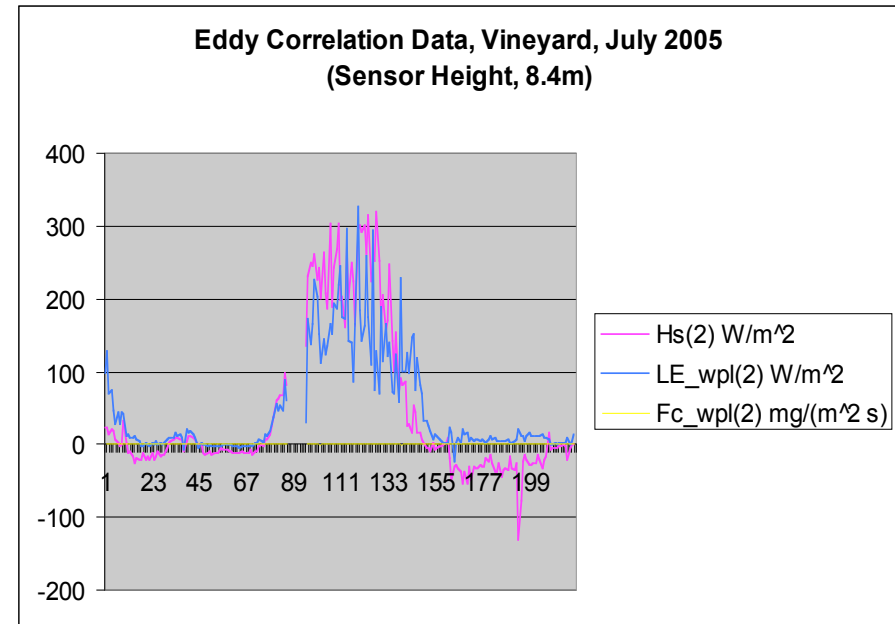
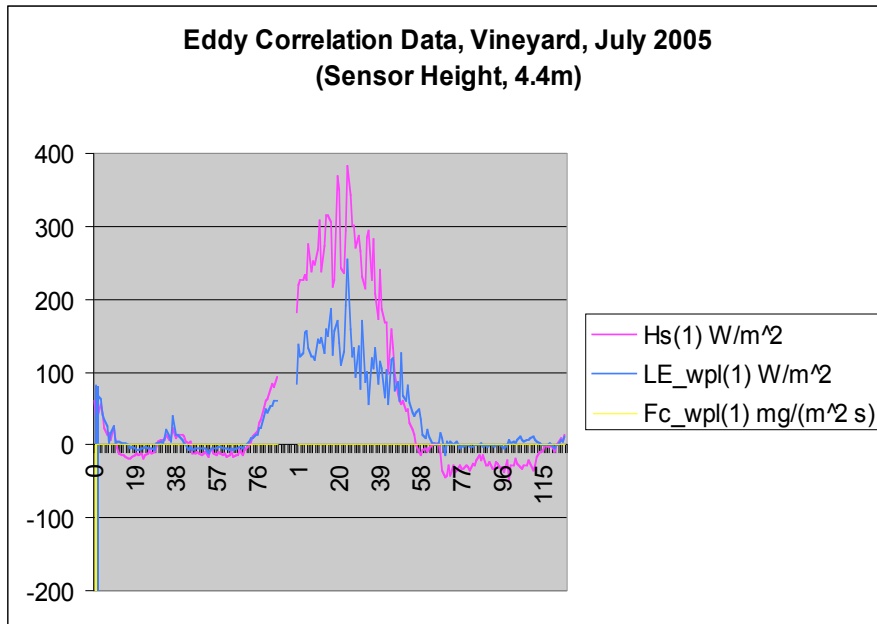
(Sum of H and LE exceeds the available energy)



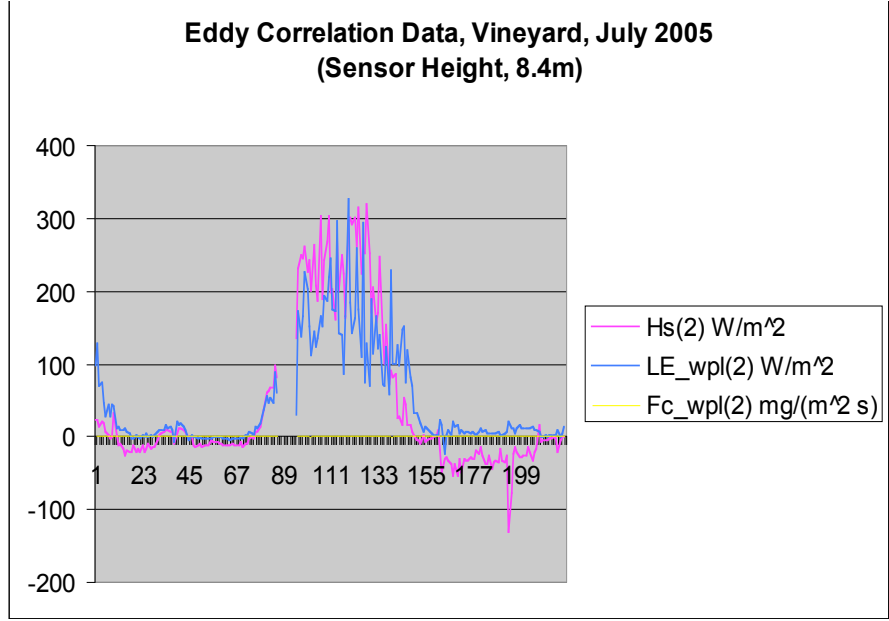
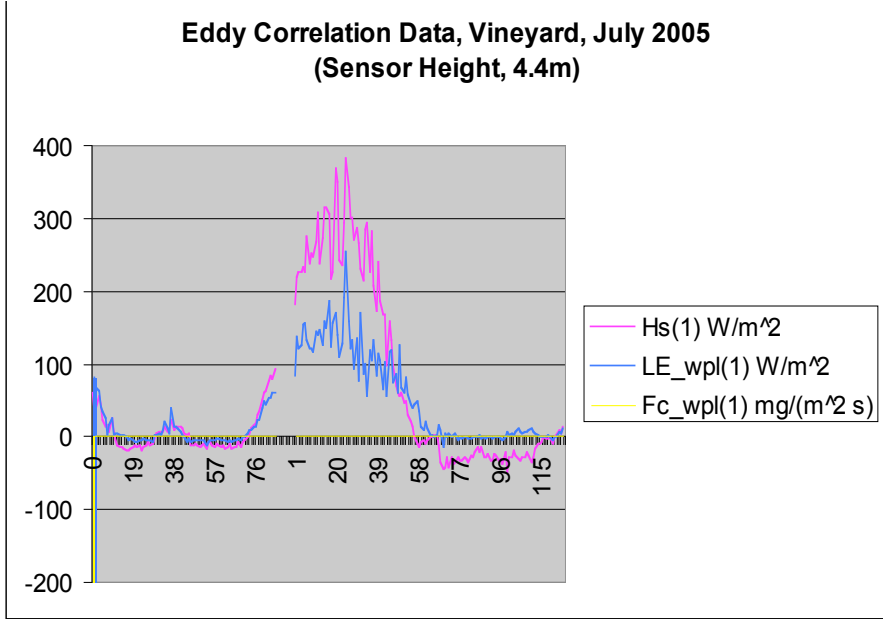
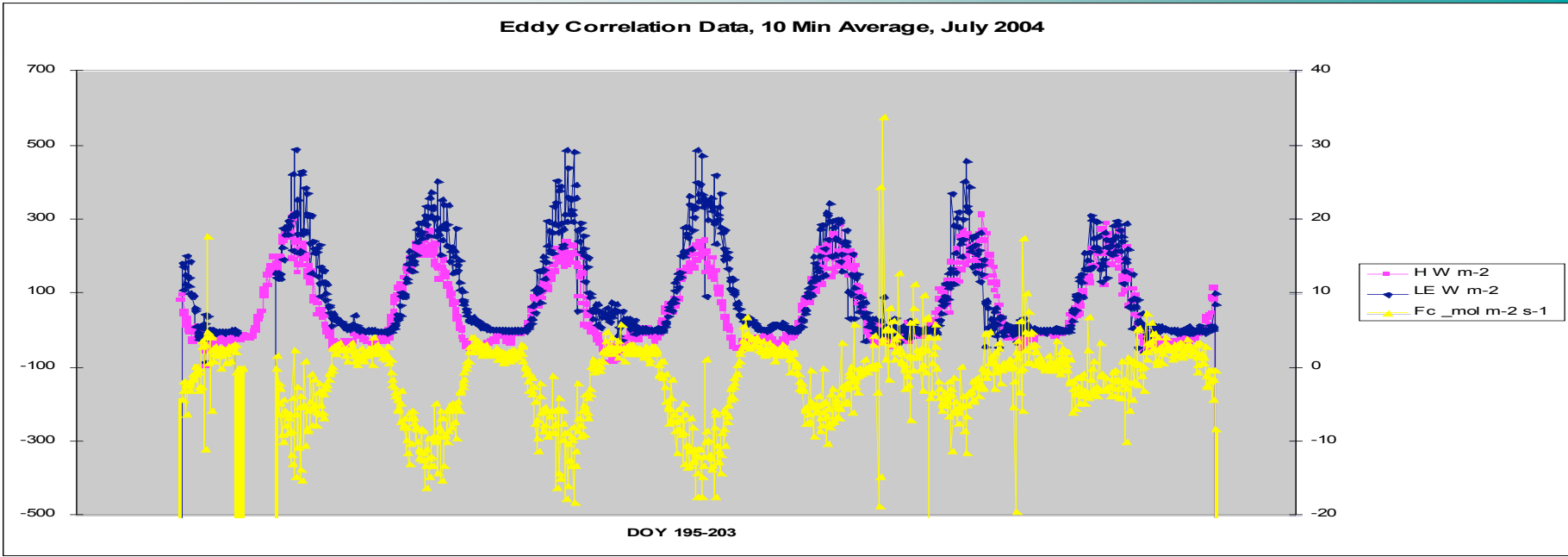
- **Eddy Correlation (CSAT 3, Li-COR 7500), 2 sets**



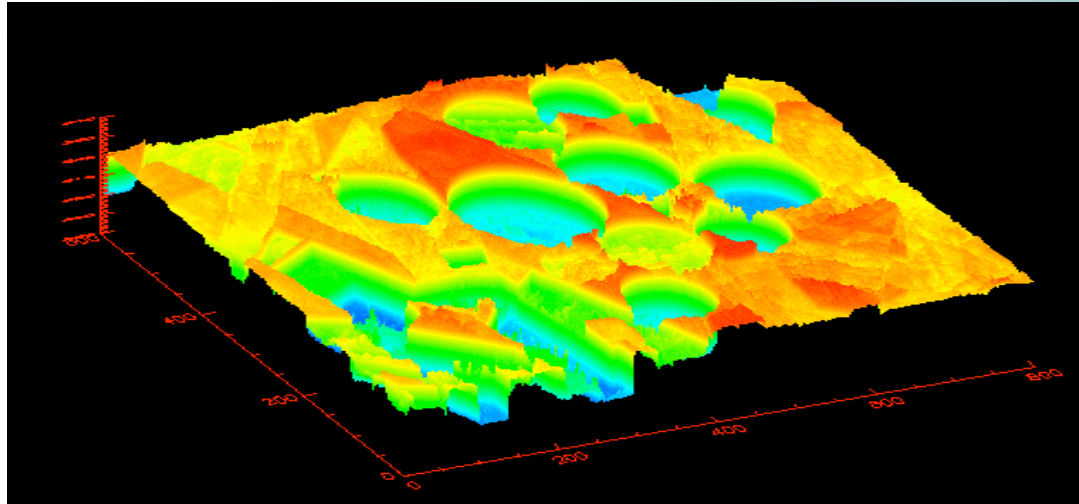
Flux data 2005 (Double set)



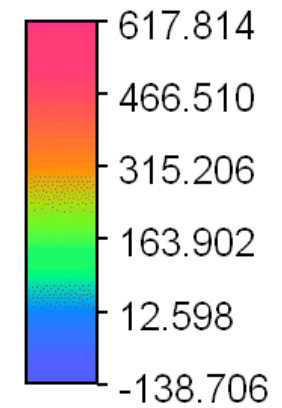
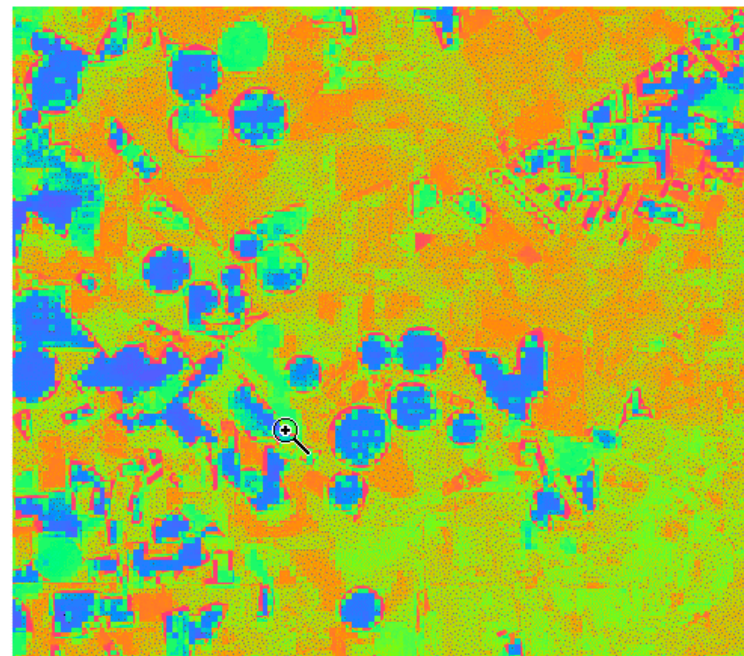
Flux data 2004 vs flux data 2005



Results from SEBS



Sensible Heat
AHS 15 July 2004
(A. Gieske)



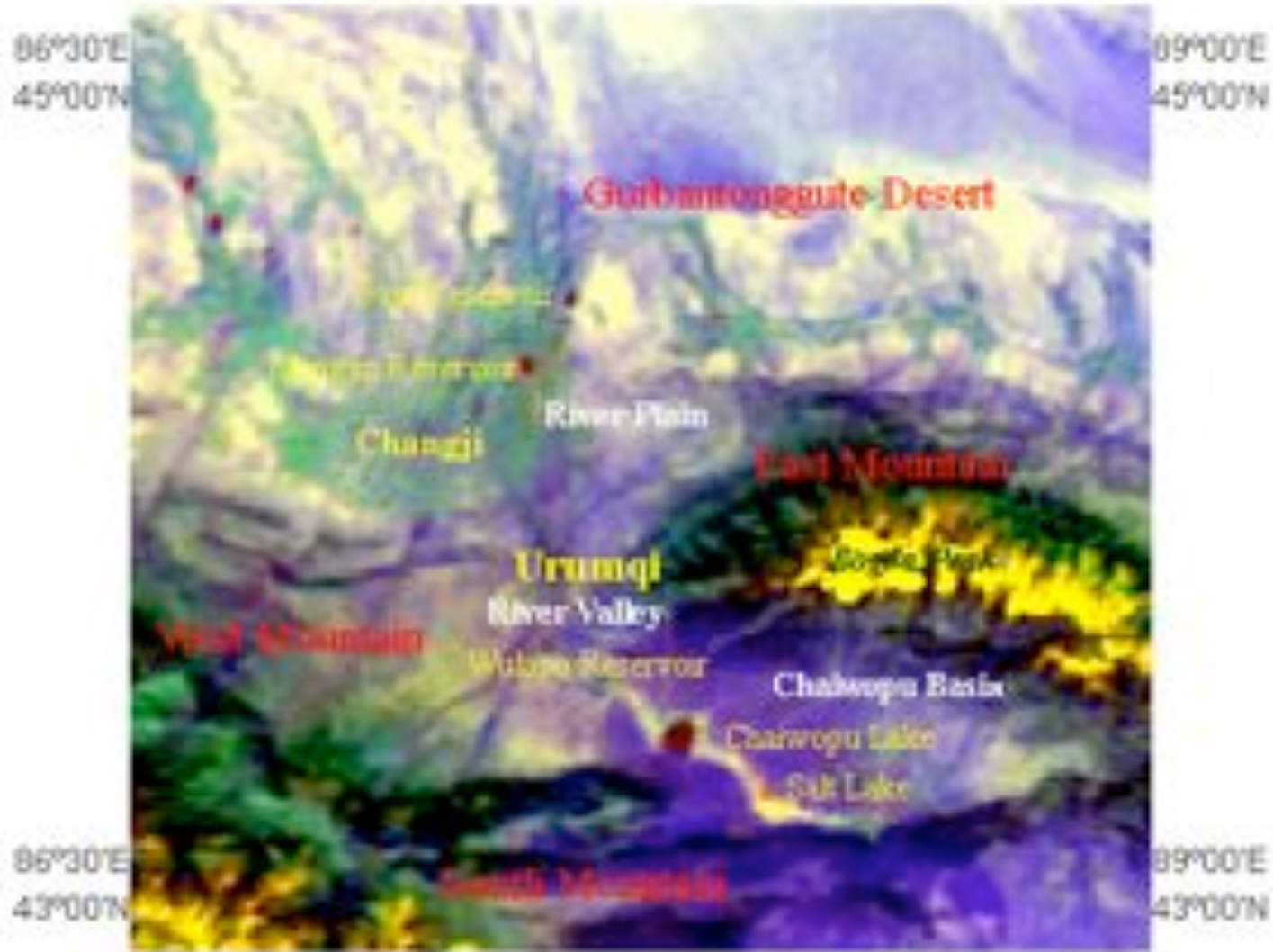
WM⁻²

Sensible Heat
ASTER 18 July 2004

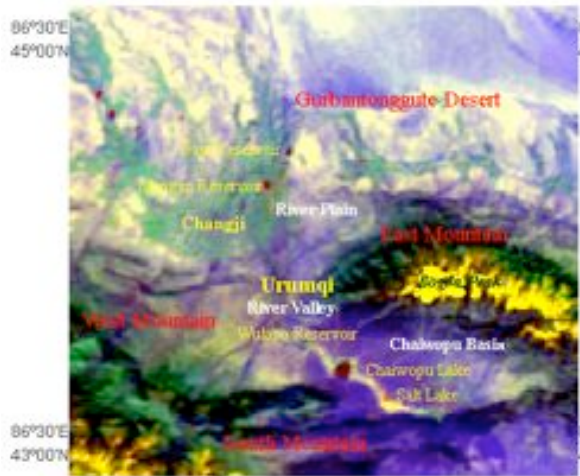
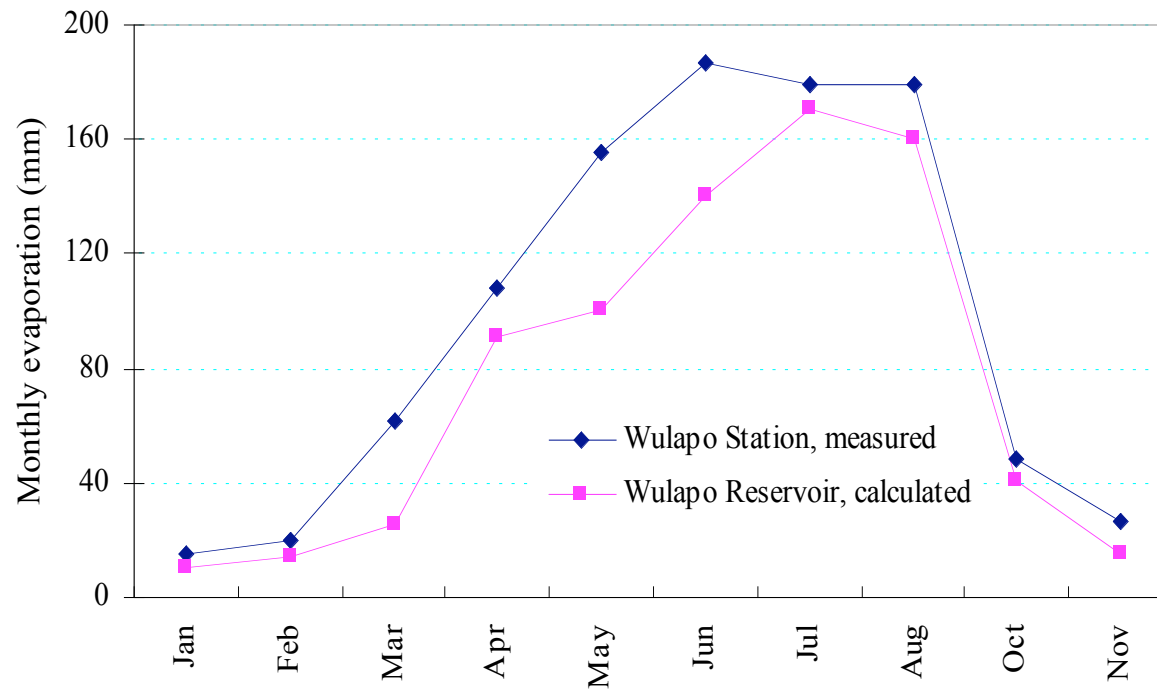
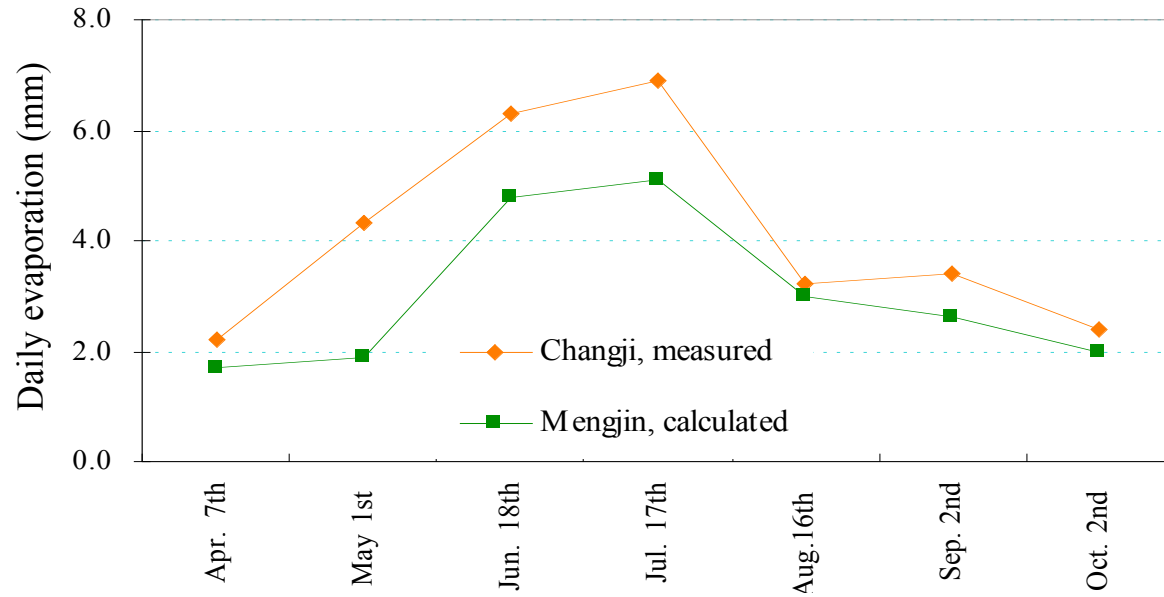
Some applications

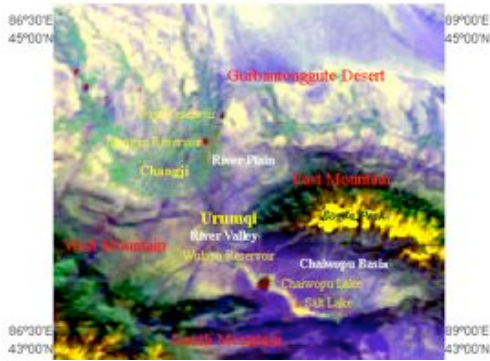


Application to the Urumqi River Basin, NW China



Comparison to measurements (water surfaces)

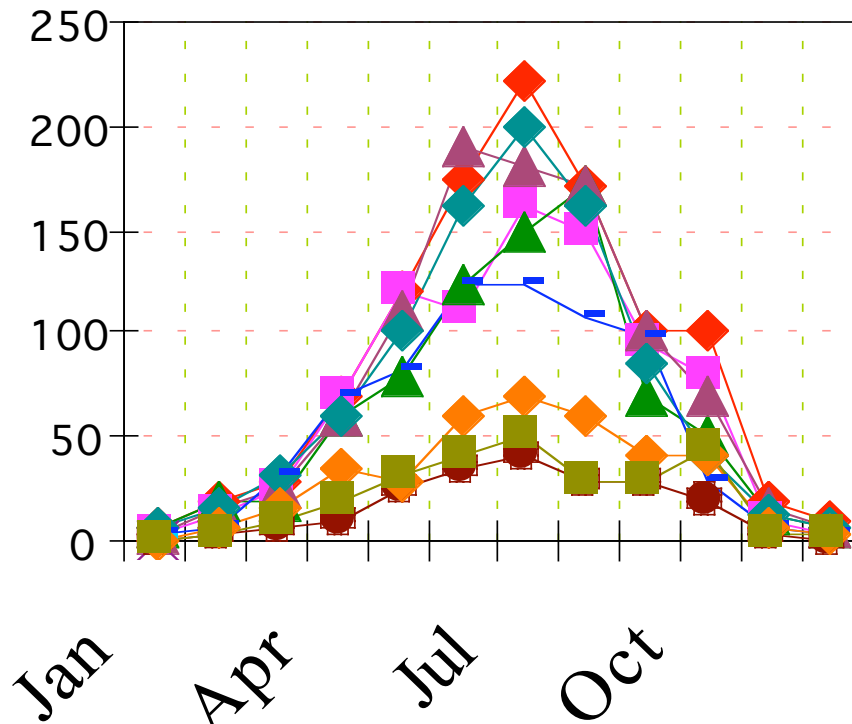




Monthly evaporation from different surfaces in the Urumqi River Basin



Monthly evaporation (mm)

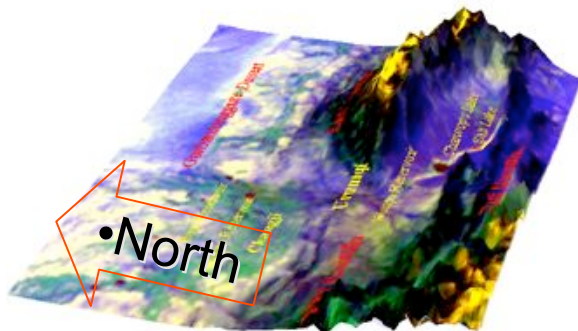
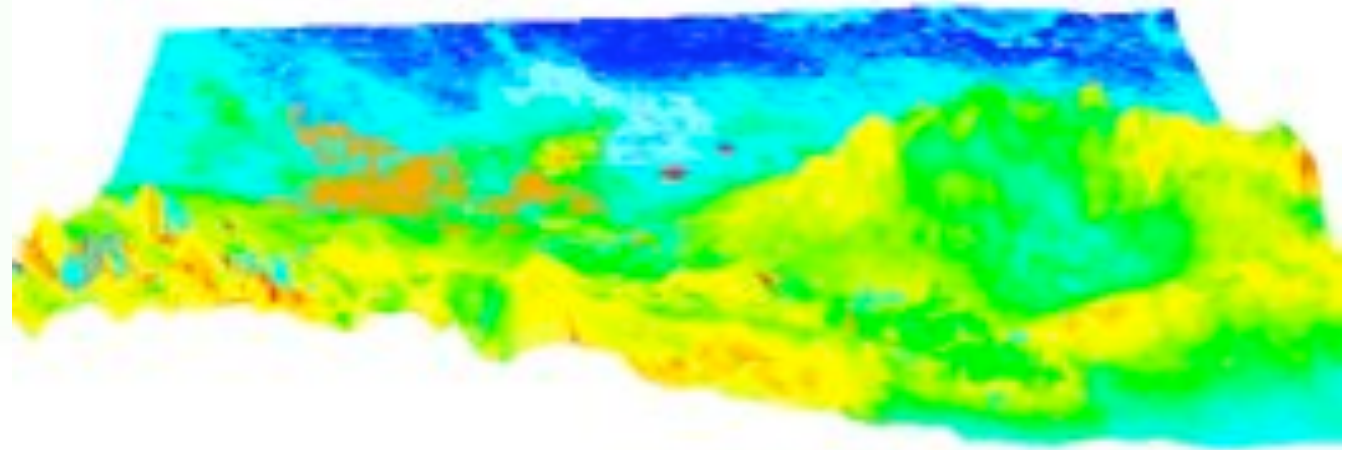


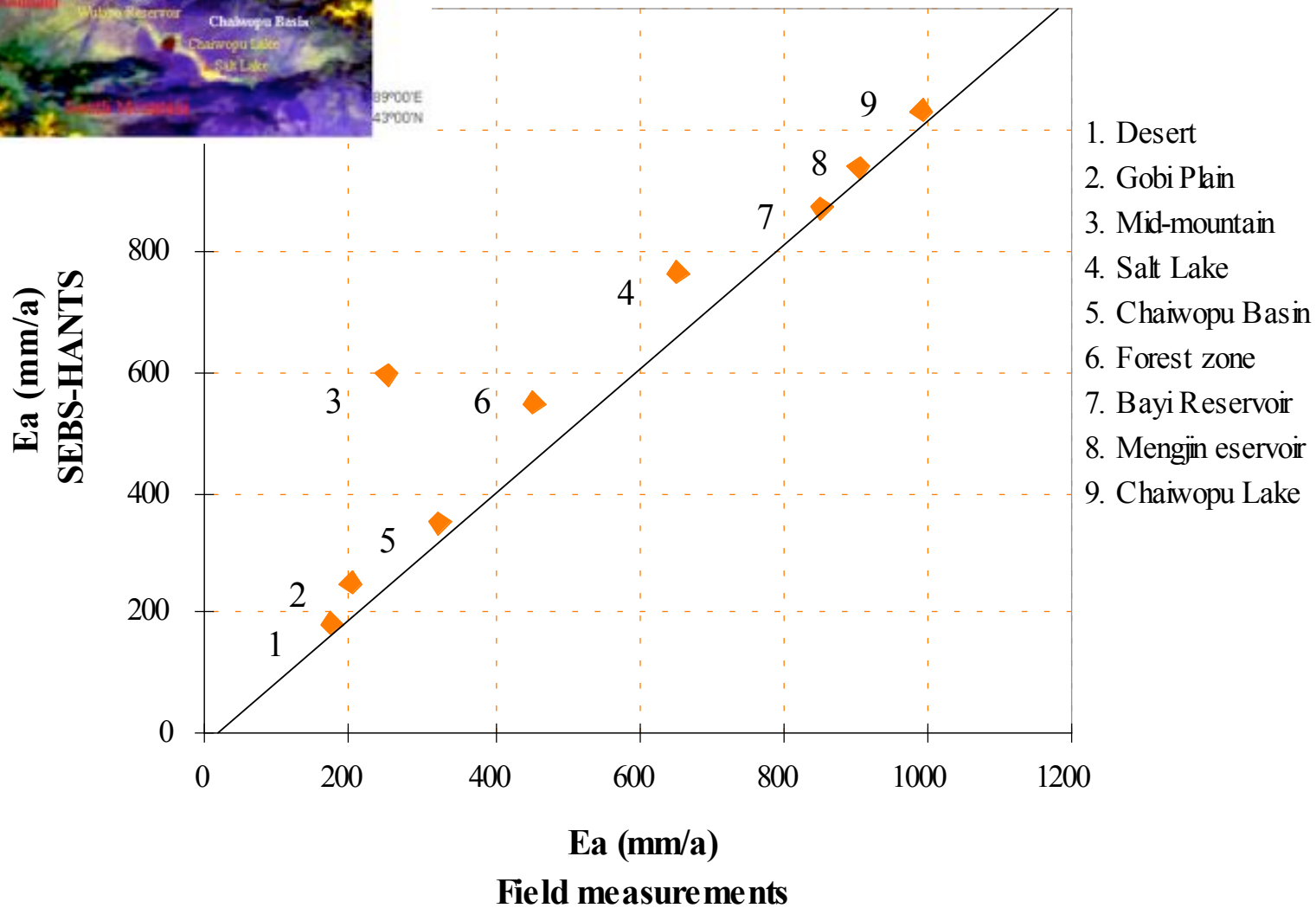
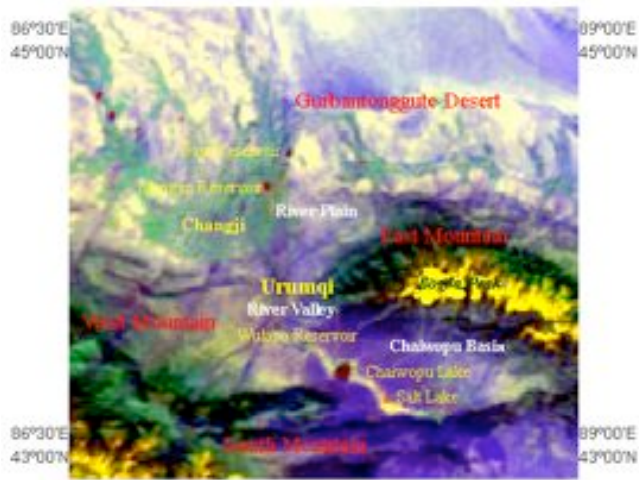
- ◆ Chaiwopu Lake
- East mountain
- ▲ Salt Lake
- ▲ Mengjin Reservoir
- Desert
- ◆ Wulapo Reservoir
- River plain
- ◆ Chaiwopu Basin
- Gobi Plain

Spatial Distribution of Annual Evaporation over the Urumqi River Basin

NOAA/AVHRR based
annual actual evaporation in 1995,
Urumqi River Basin

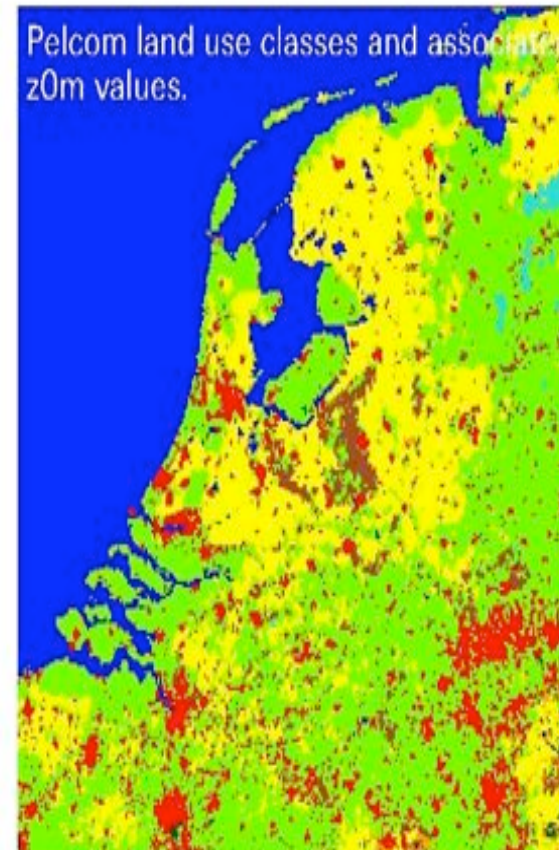
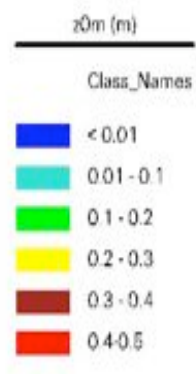
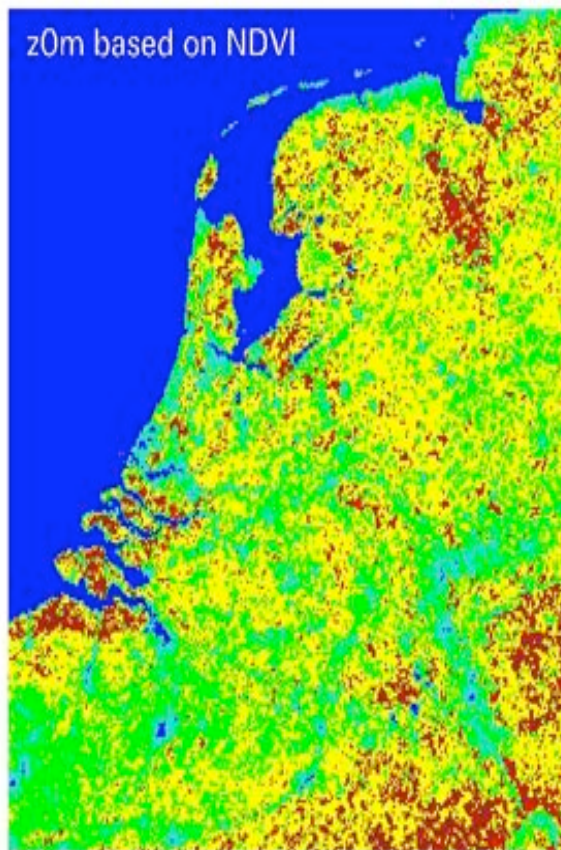
Ea (mm/year)





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

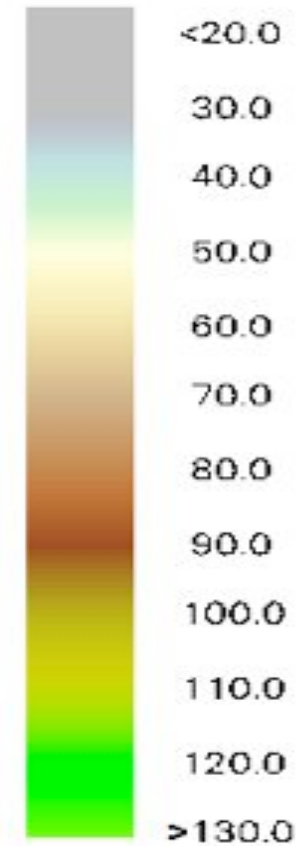
Applications to the Netherlands (Methods to determine z0m)



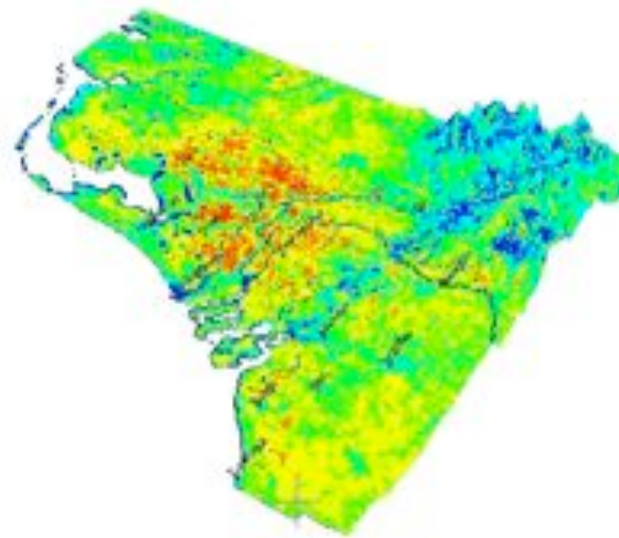
Monthly evaporation during 1995



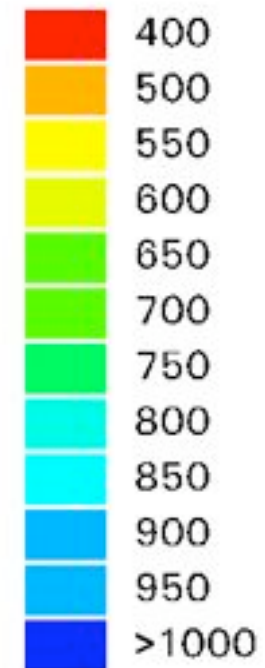
Monthly EV(mm)



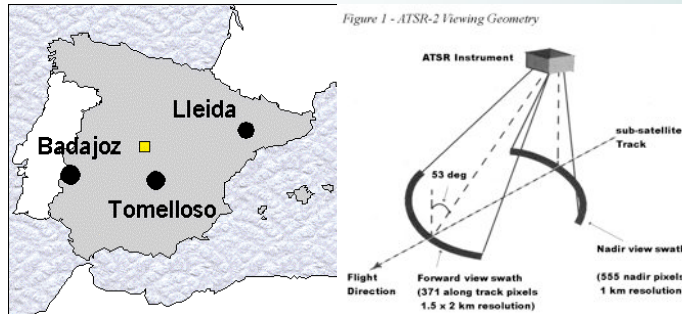
Annual evaporation in 1995



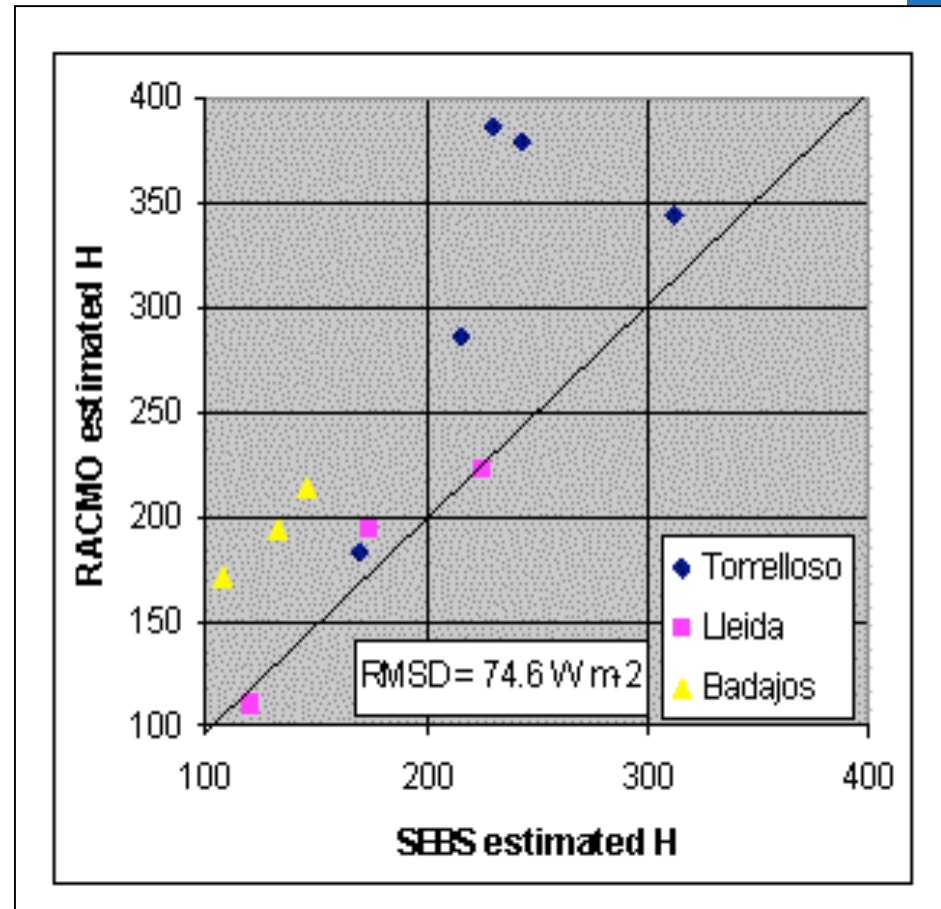
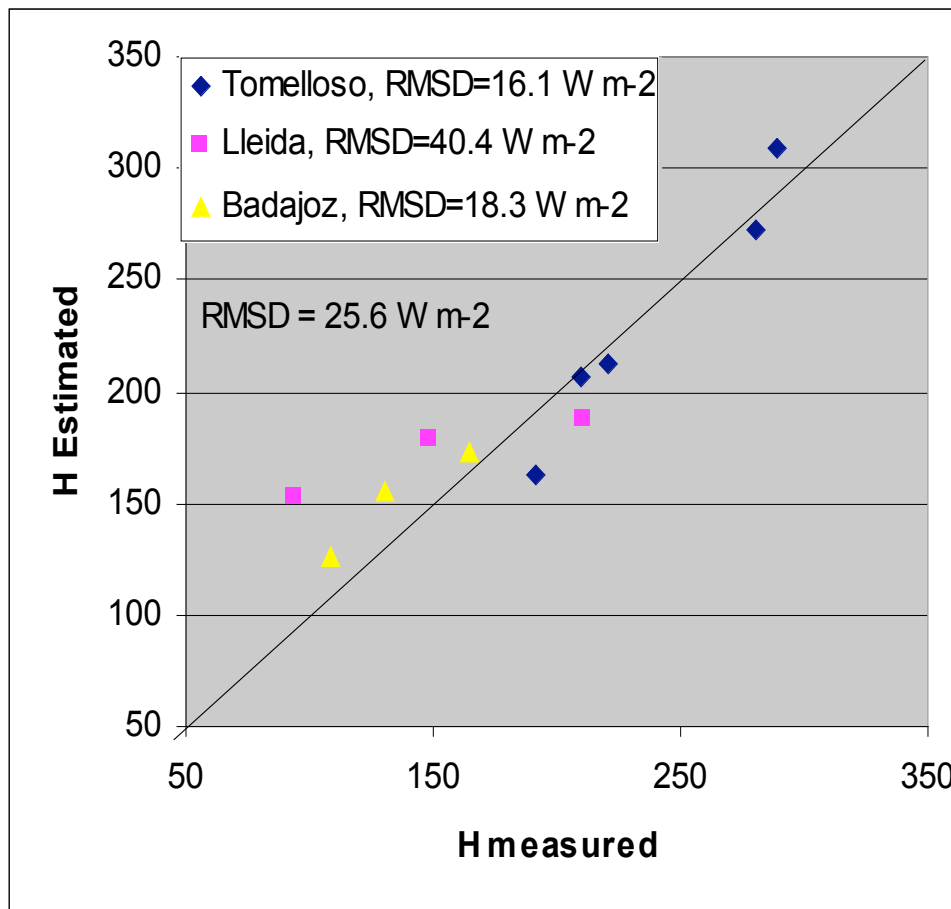
Annual
Evaporation (mm)



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),

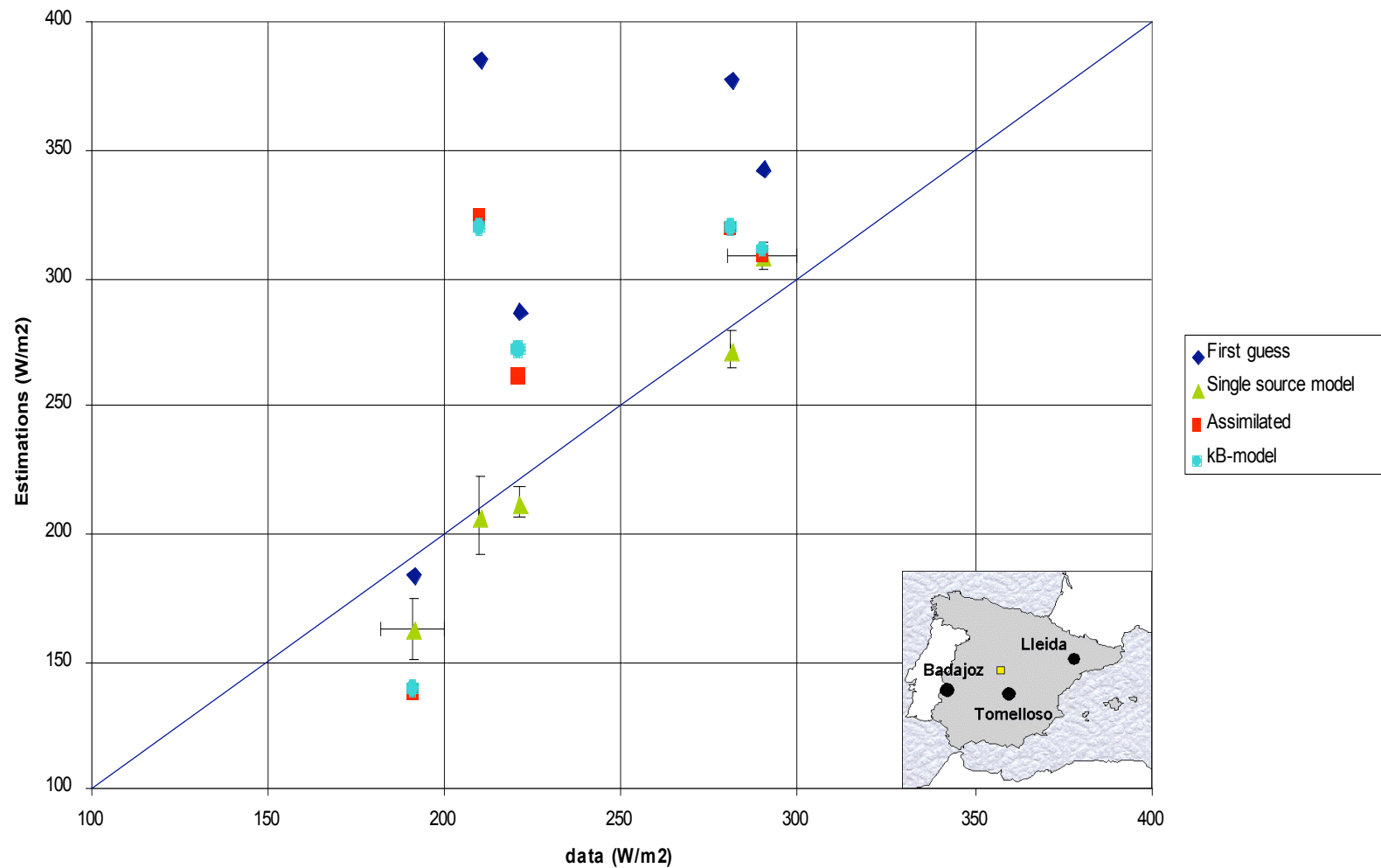


Data Assimilation in Atmospheric Models

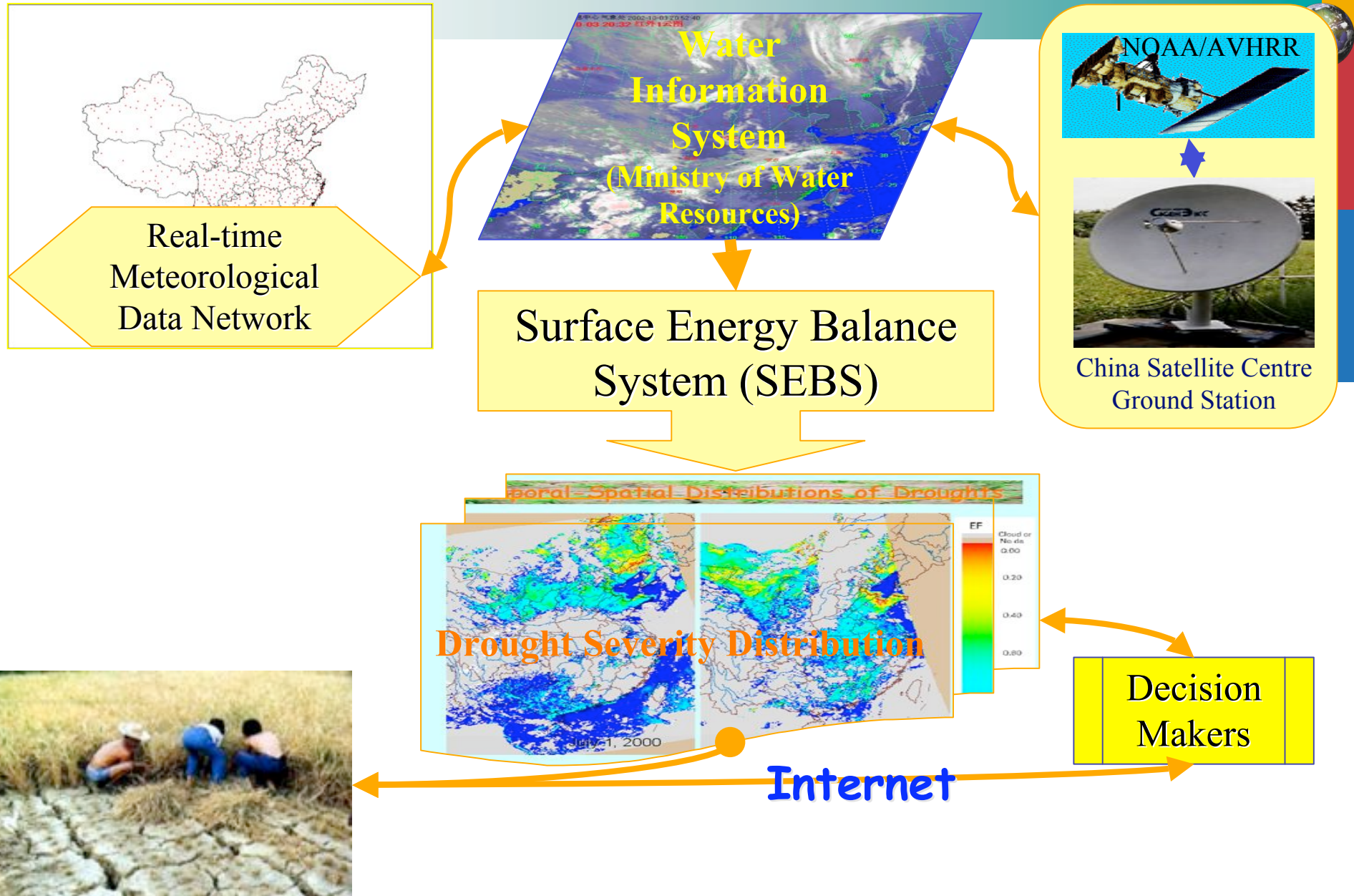
RACMO run without data assimilation (“first guess”), SEBS retrievals (the single source), RACMO run (assimilated), and a RACMO run with the kB-model by Su et al (2001) (vd Hurk, Su, Verhoef, Reorink, Jia, 2001)



Sensible heat flux Tomelloso

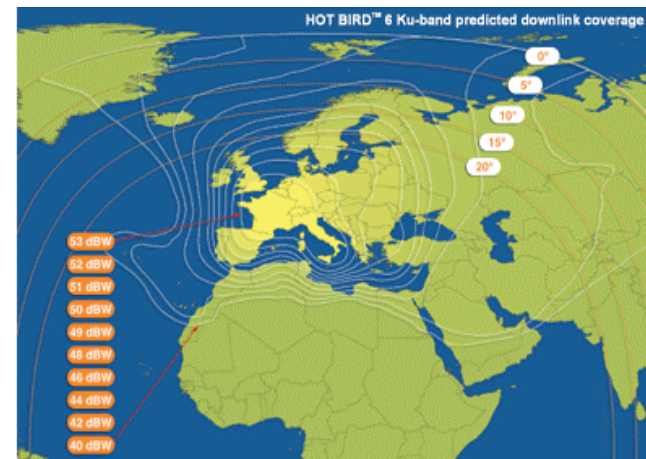


A Real-time Drought Monitoring System



ITC MSG-1 Facility

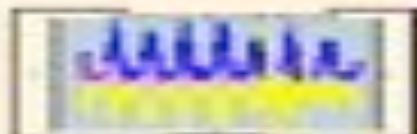
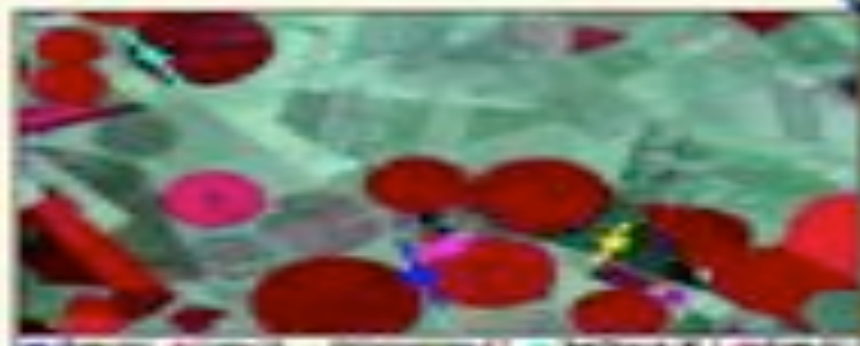
- Hotbird 6 broadcast
- 88 cm satellite dish



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 Z_0 , 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.

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



Authors:
 L. M. Thompson, J. A. S. Gochis, J. R. Kiniry, J. A. Carter, M. S. Timlin, J. A. Jensen, & J. A. M. Baker
 Department of Agricultural and Biosystems Engineering, Texas A&M University, TAMU-2131, TAMU, TX 77724-2131, USA
 Email: lthompson@aggri.tamu.edu, jgochis@aggri.tamu.edu, jkiniry@aggri.tamu.edu, jcarte@aggri.tamu.edu, ms.timlin@aggri.tamu.edu, jmjensen@aggri.tamu.edu, jaker@aggri.tamu.edu

Host Institution:
 Texas A&M University
 Department of Agricultural and Biosystems Engineering
 TAMU-2131, TAMU, TX 77724-2131, USA
 Email: lthompson@aggri.tamu.edu





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

EAGLE2006

Speulderbos Tower

Cabauw Tower

Loobos Tower

ITC

ESA, Italy
ITC, The Netherlands
University of Valencia, Spain
INTA, Spain
ITRES, Canada
DLR, Germany
WUR / ALTERRA, The Netherlands
CSIT, France
NLR, The Netherlands
KNMI, The Netherlands
WUR / Meteorology Group, The Netherlands
RIVM, The Netherlands
WH Stichtse Rijnlanden, The Netherlands
MIRAMAP, The Netherlands
University of Washington, USA
University of South Carolina, USA
ISAFOM, Italy
Utrecht University, The Netherlands
Streekbeheer, The Netherlands
Egros, The Netherlands

