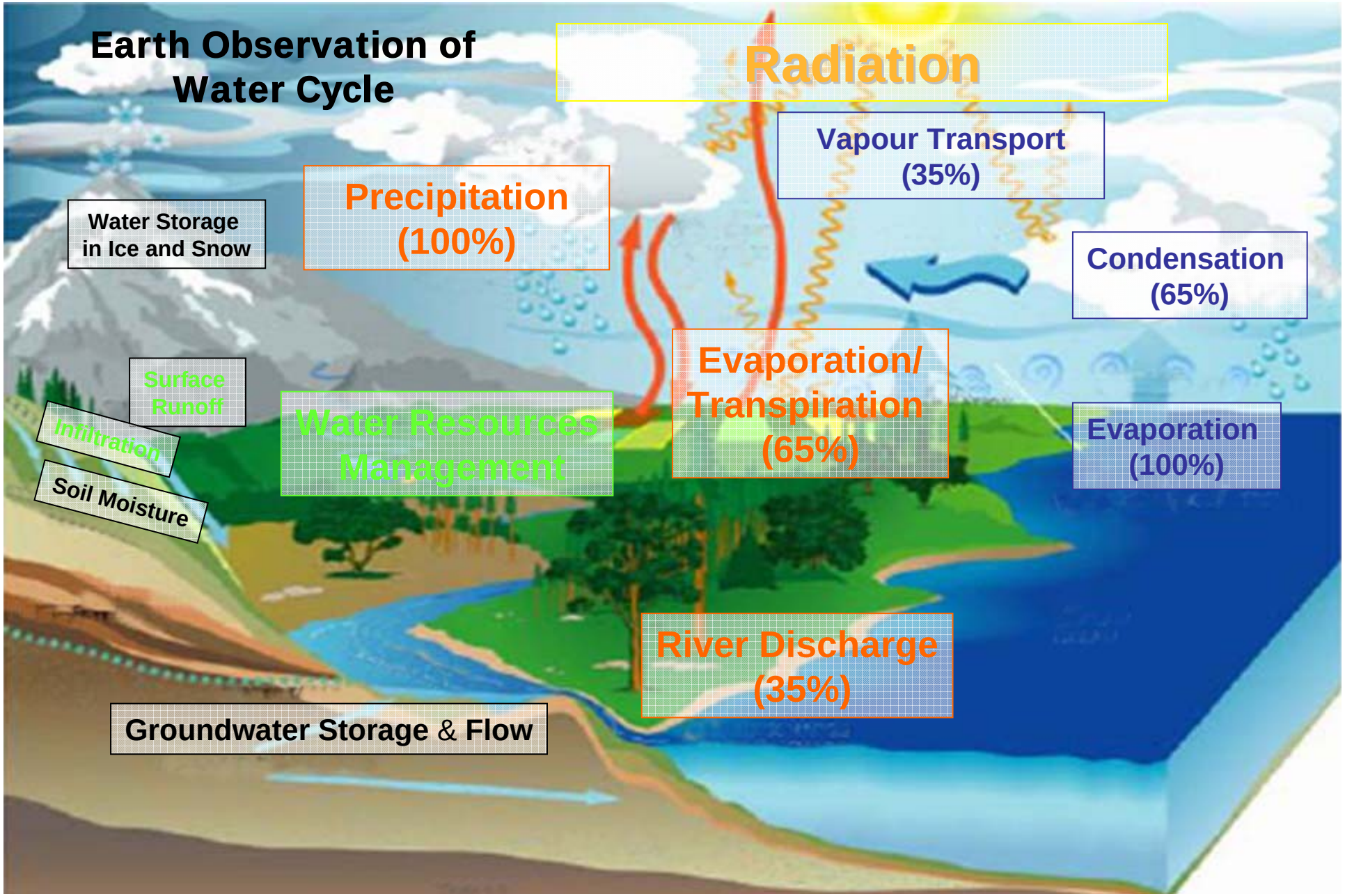
SEBS
Surface Energy Balance System for estimation of turbulent heat fluxes and evapotranspiration

Z. (Bob) Su
International Institute for Geo-Information Science and Earth Observation (ITC),
Enschede, The Netherlands
B_SU@ITC.NL, www.itc.nl/wrs

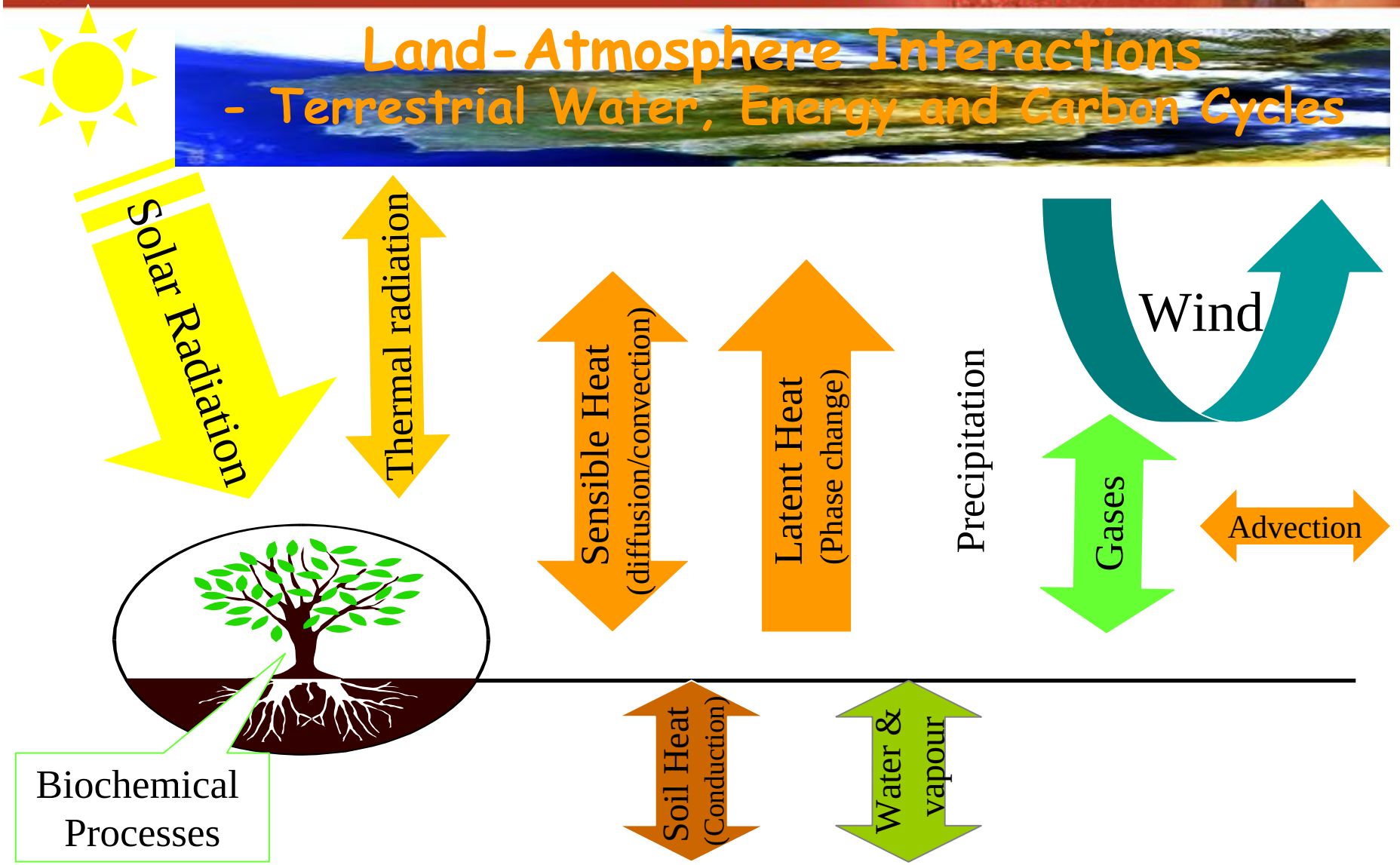
Monday 3 September 2007, Lecture D1La6


Earth Observation of Water Cycle
Radiation
Vapour Transport (35%)
Precipitation (100%)
Water Storage in Ice and Snow
Condensation (65%)
Surface Runoff
Infiltration
Soil Moisture
Water Resources Management
Evaporation/ Transpiration (65%)
Evaporation (100%)
River Discharge (35%)
Groundwater Storage & Flow

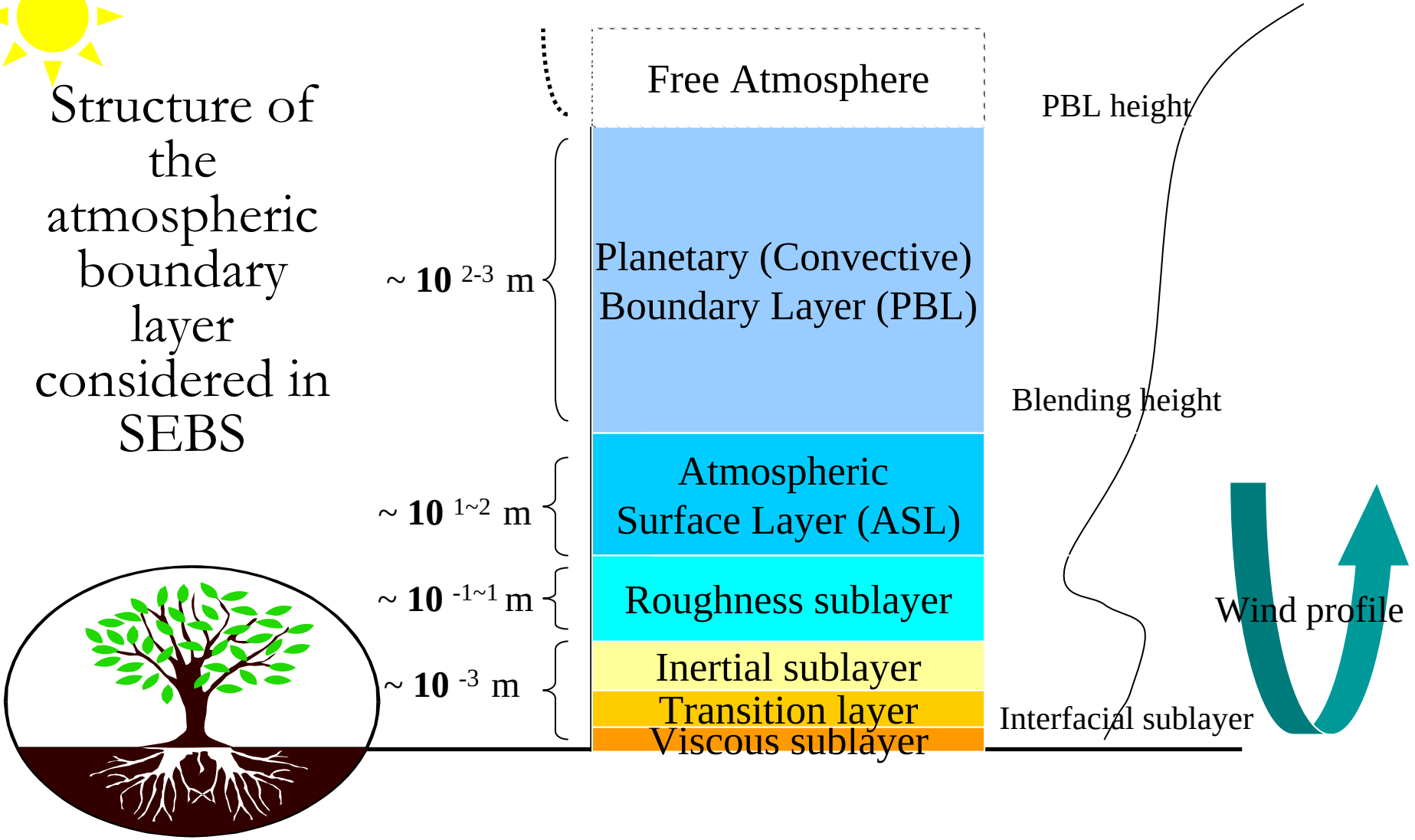
Learning Objectives

1. To understand basic ideas of the Surface Energy Balance System
2. To familiarize with the steps used in SEBS for the derivation of different flux terms
3. To understand the most critical processes in surface energy balance
4. To familiarize with the applications of SEBS

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

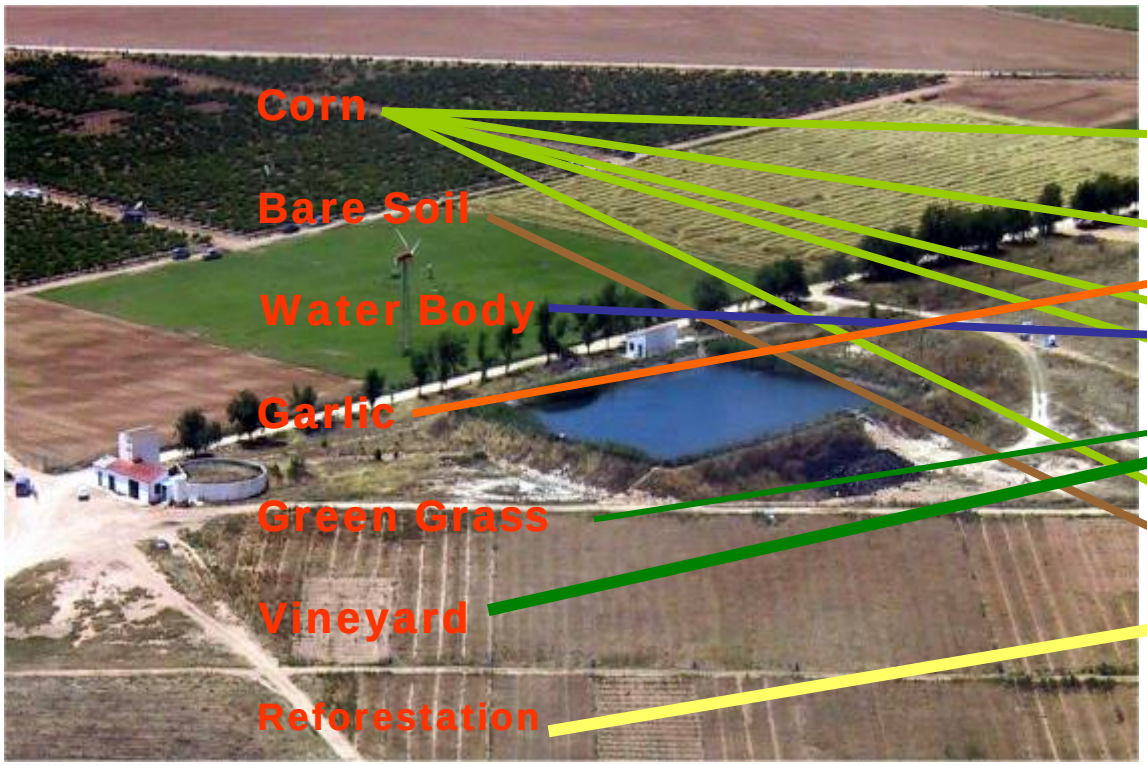


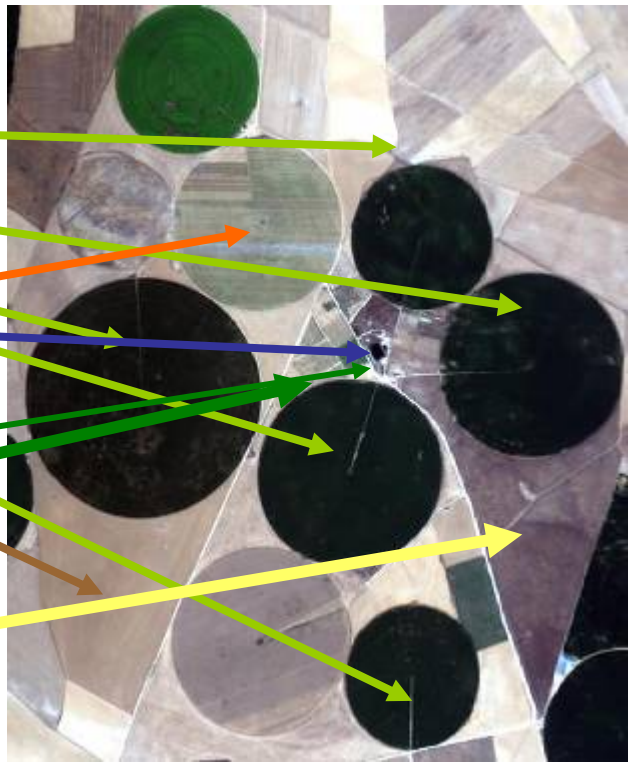
Structure of the atmospheric boundary layer considered in SEBS



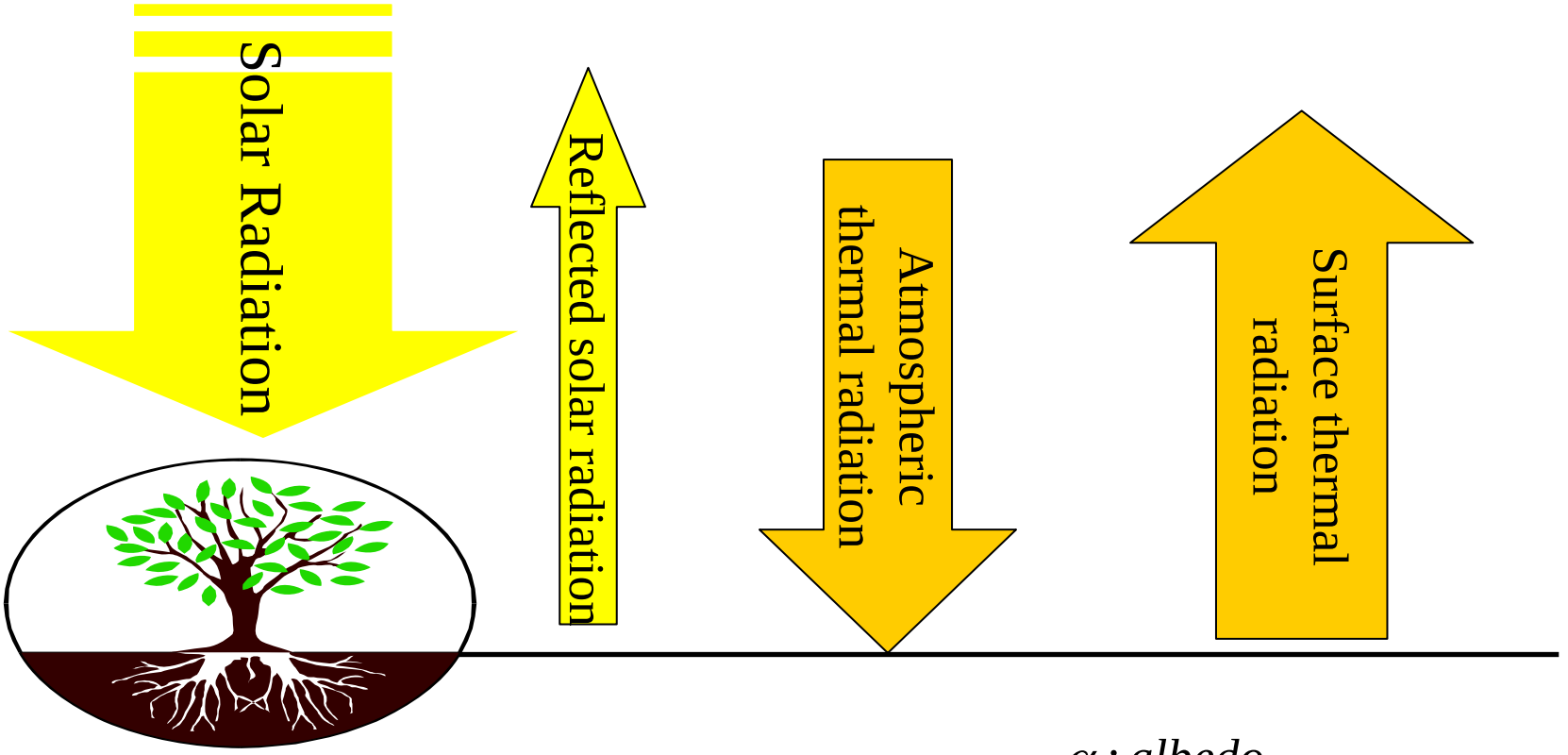
Barrax Test Site, Spain

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





Surface Radiation Balance



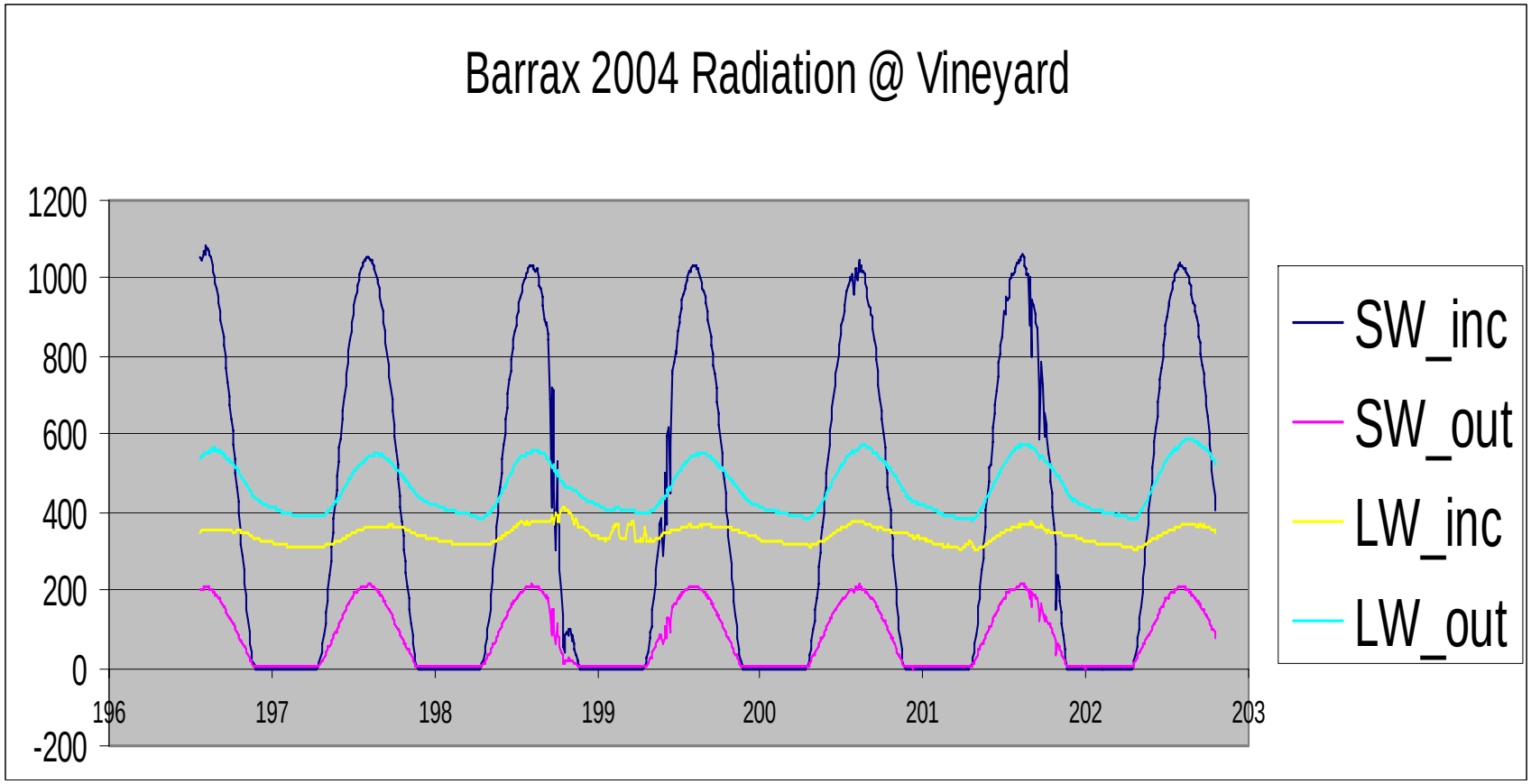
$$R_n = (1-\alpha)\cdot R_{swd} + \varepsilon \cdot R_{lwd} - \varepsilon \cdot \sigma \cdot T_0^4$$

α : *albedo*

ε : *emissivity*

T_0 : *Surface Temperature*

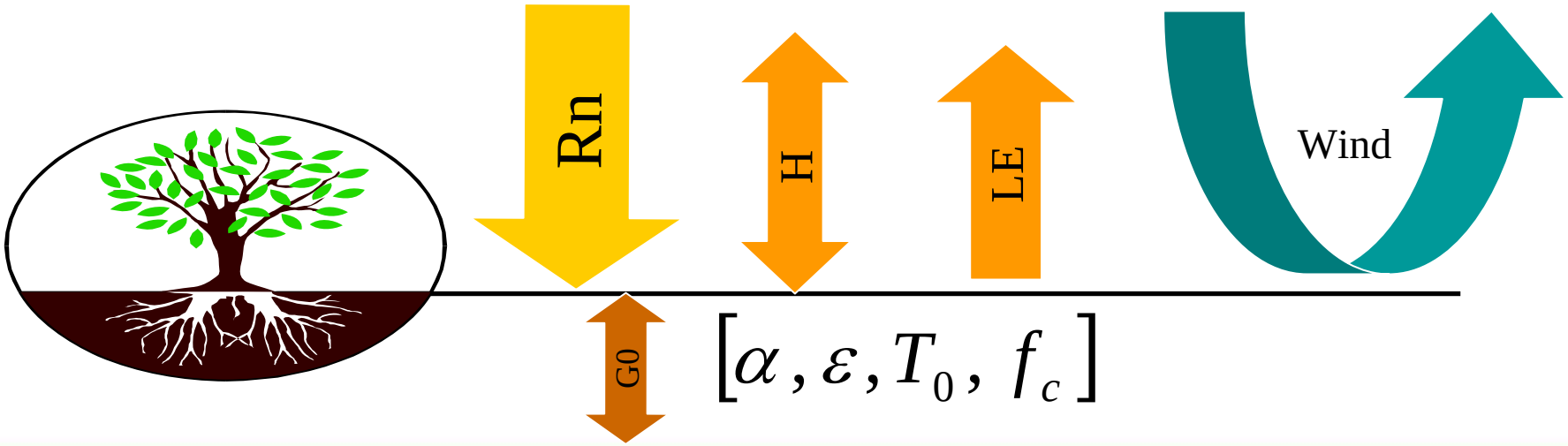
Data from EAGLE/SPARC Campaign 2004, Barrax, Spain



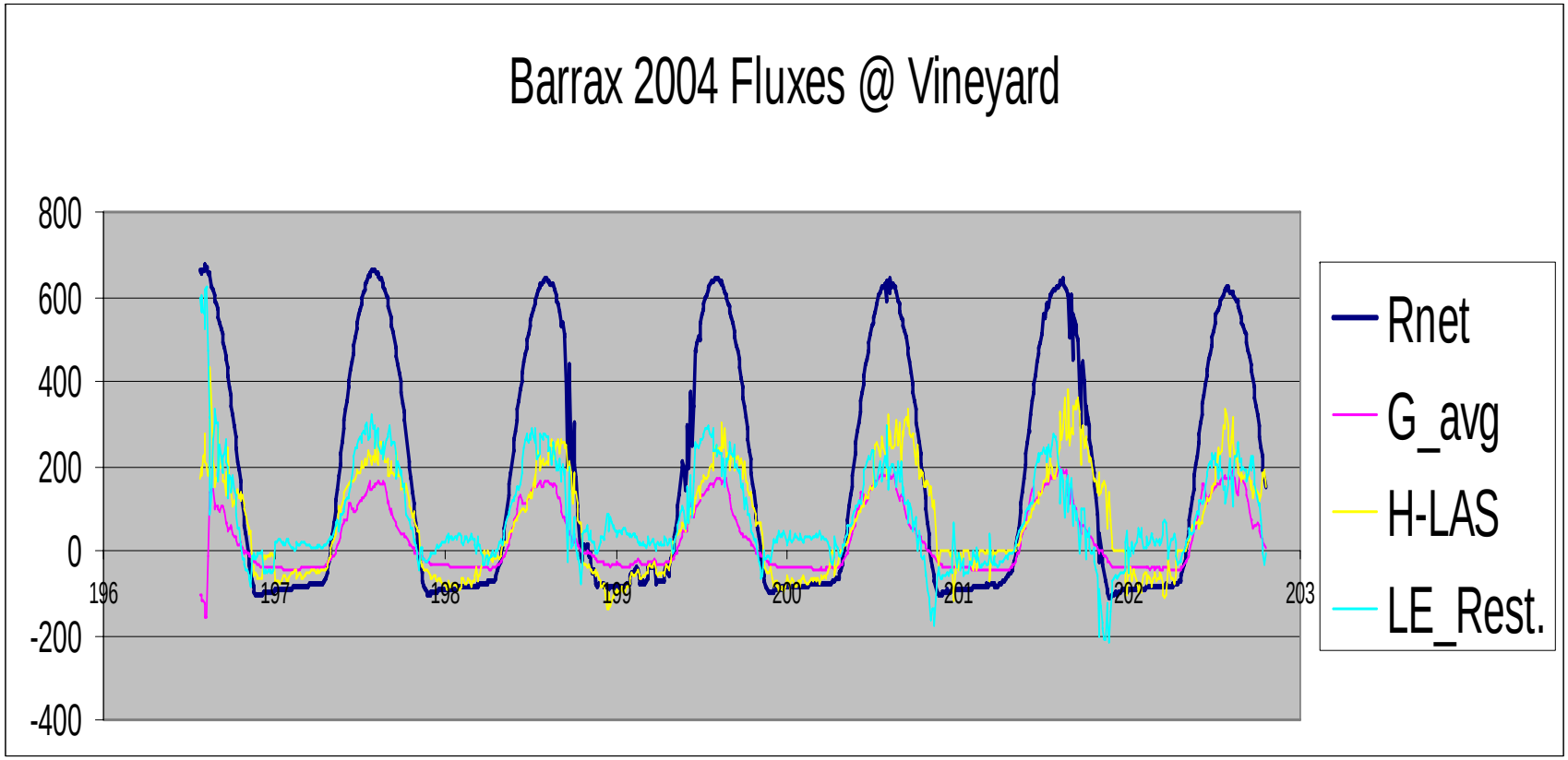
Surface Energy Balance Terms

$$R_n = G_0 + H + LE$$

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



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



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)

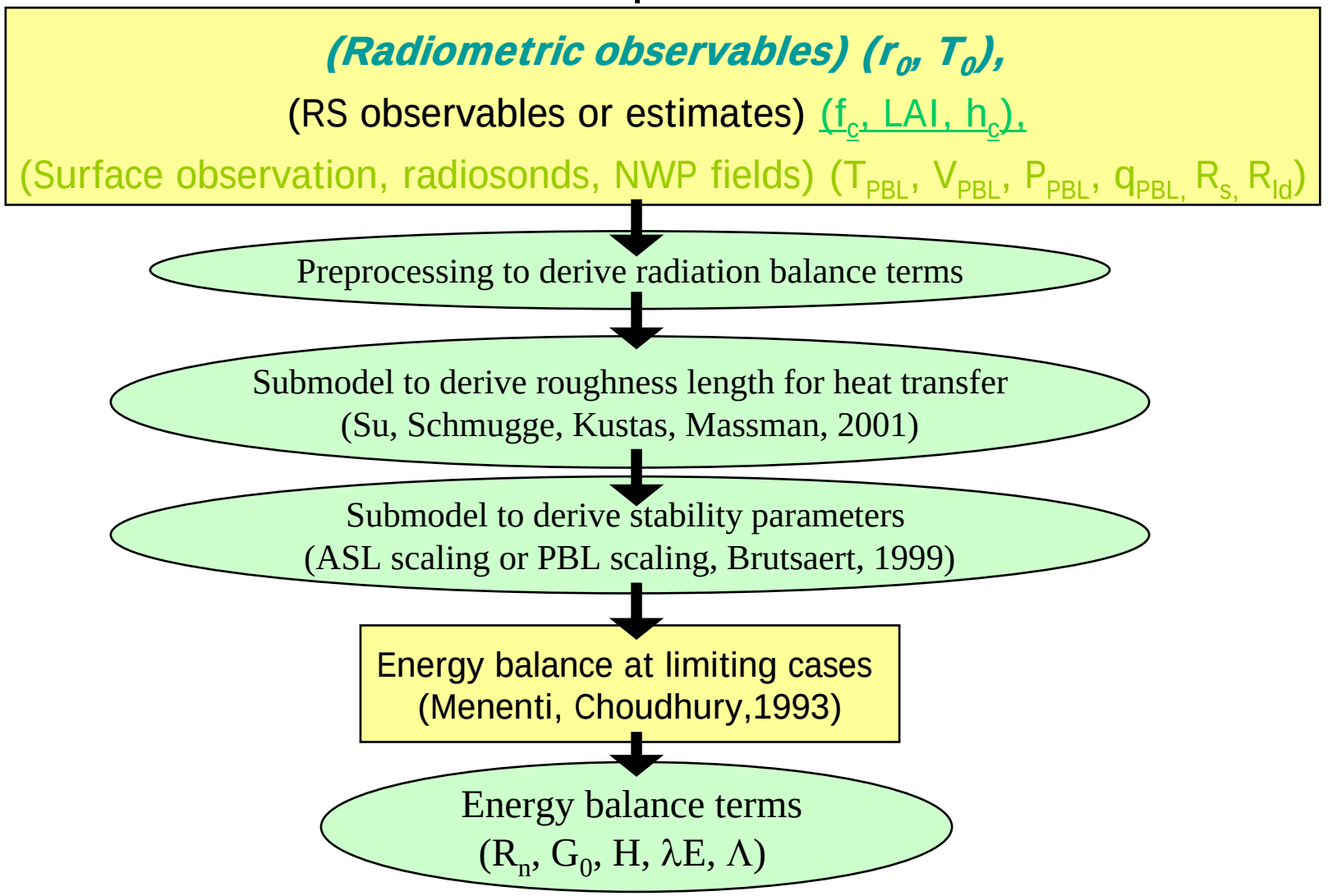
Nieuwenhuis et al., 1989
e.g. E=a+b*T0

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

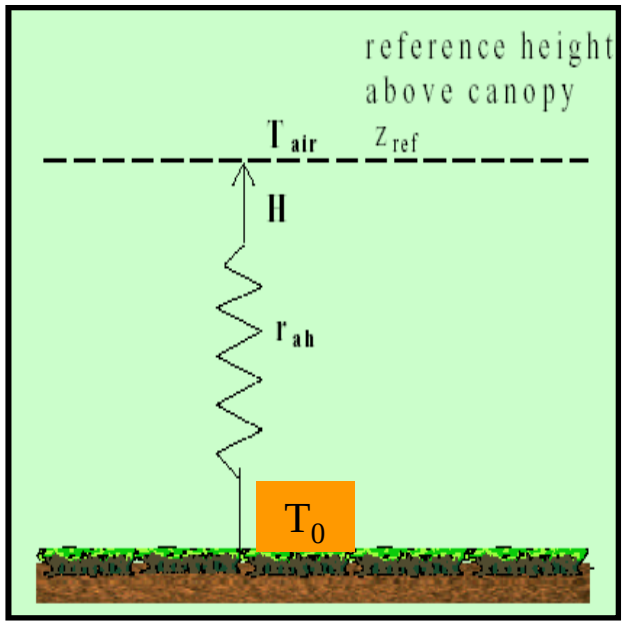
Su, Pelgrum, Menenti, 1999
correction in SEBAL for a theoretical problem and
extension to include NWP fields with a up-scaling,
down-scaling scheme

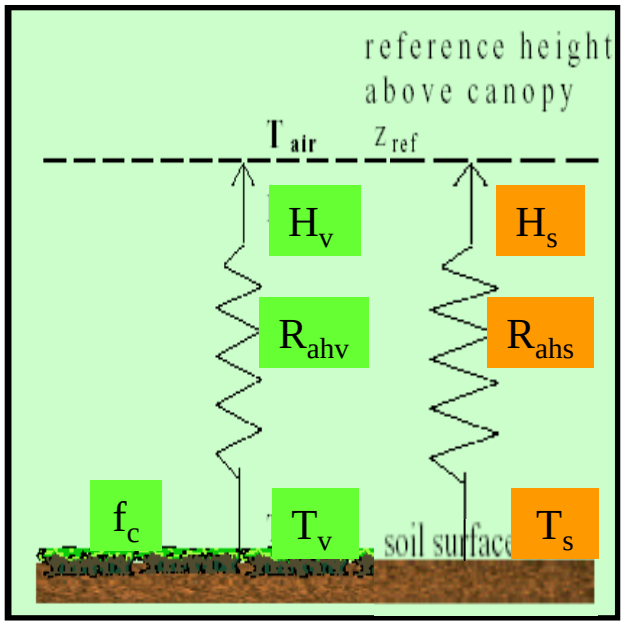
Roerink, Su, Menenti, 2000
Simplified Surface Energy Balance Index
(fitting dry and wet limiting cases in data)
(S-SEBI)

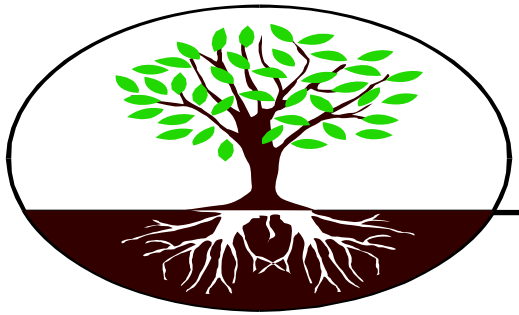
Schematic representation of SEBS



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







Wind

SEBS Basic Equations

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

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

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

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

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

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

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

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

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

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

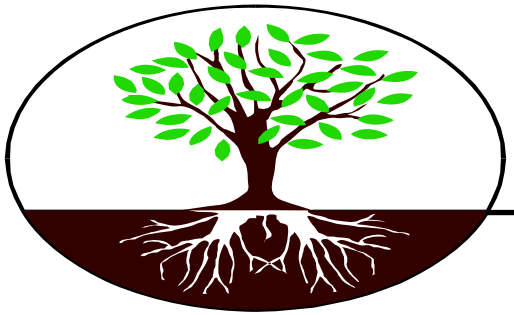
$$H = (1 - \Lambda) \cdot (R_n - G)$$

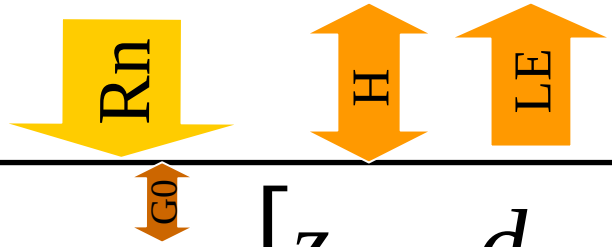
$$\lambda E = \Lambda \cdot (R_n - G)$$

Energy Balance Residual Method - Turbulent Heat Fluxes

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

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





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

The scalar roughness height for heat transfer

$$z_{0h} = z_{0m} / \exp\left(kB^{-1}\right)$$

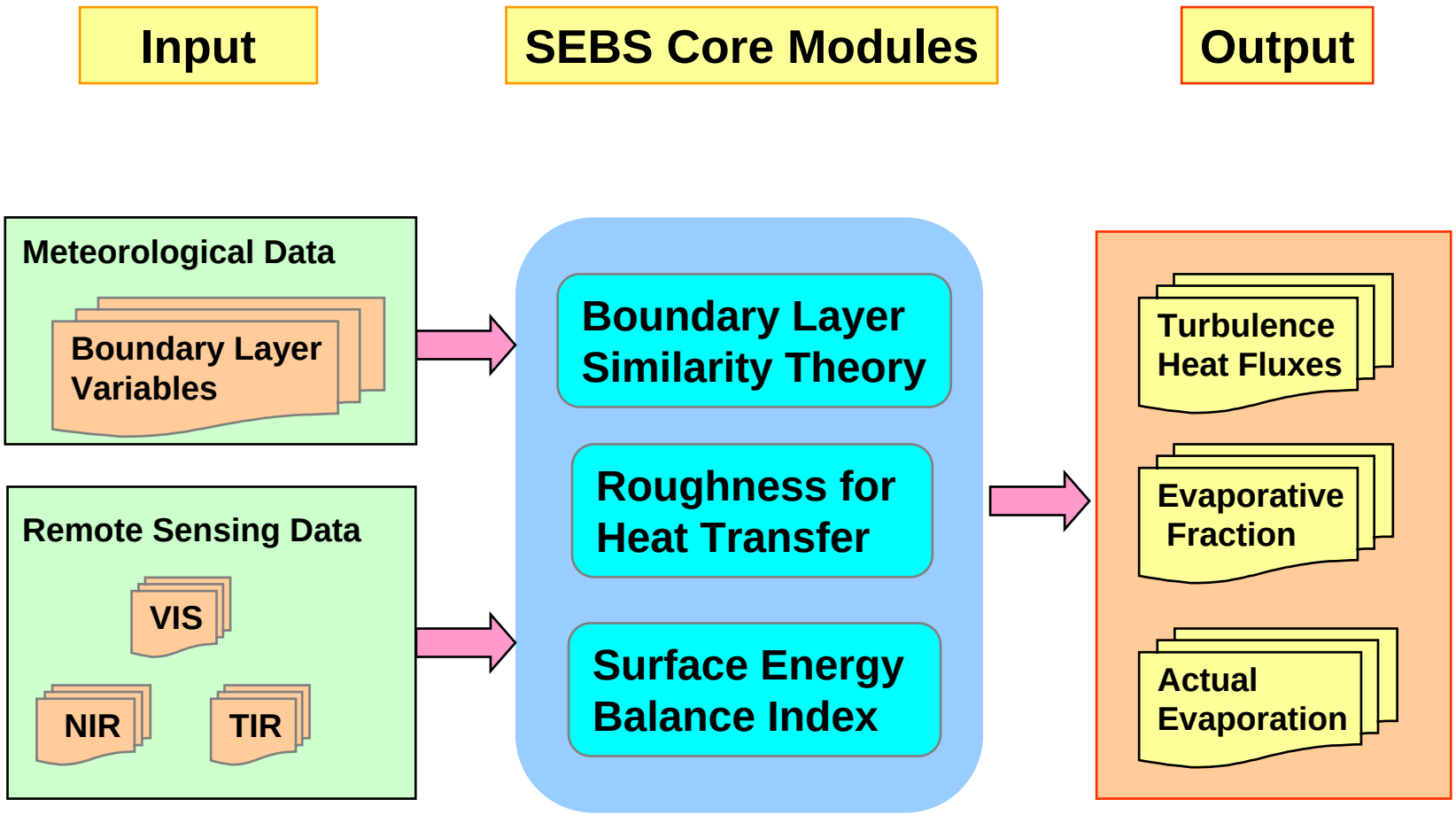
The within-canopy wind speed profile extinction coefficient,

$$n_{ec} = \frac{C_d \cdot LAI}{2u_*^2 / u(h)^2}$$

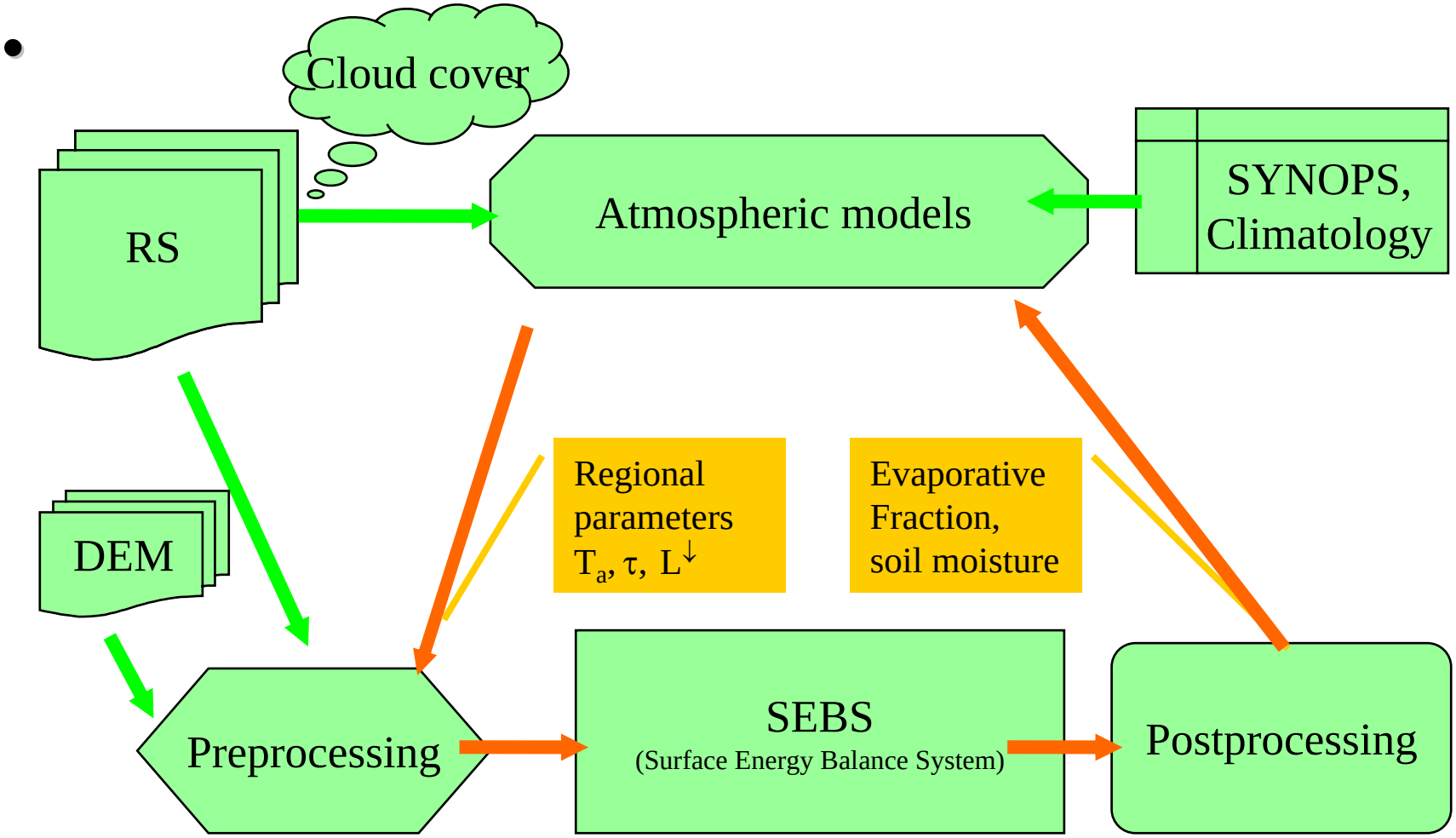
$$kB^{-1} = \frac{kC_d}{4C_t \frac{u_*}{u(h)}\left(1 - e^{-n_{ec}/2}\right)} f_c^2 + 2 f_c f_s \frac{k \cdot u_* / u(h) \cdot z_{0m} / h}{C_t^*} + kB_s^{-1} f_s^2$$

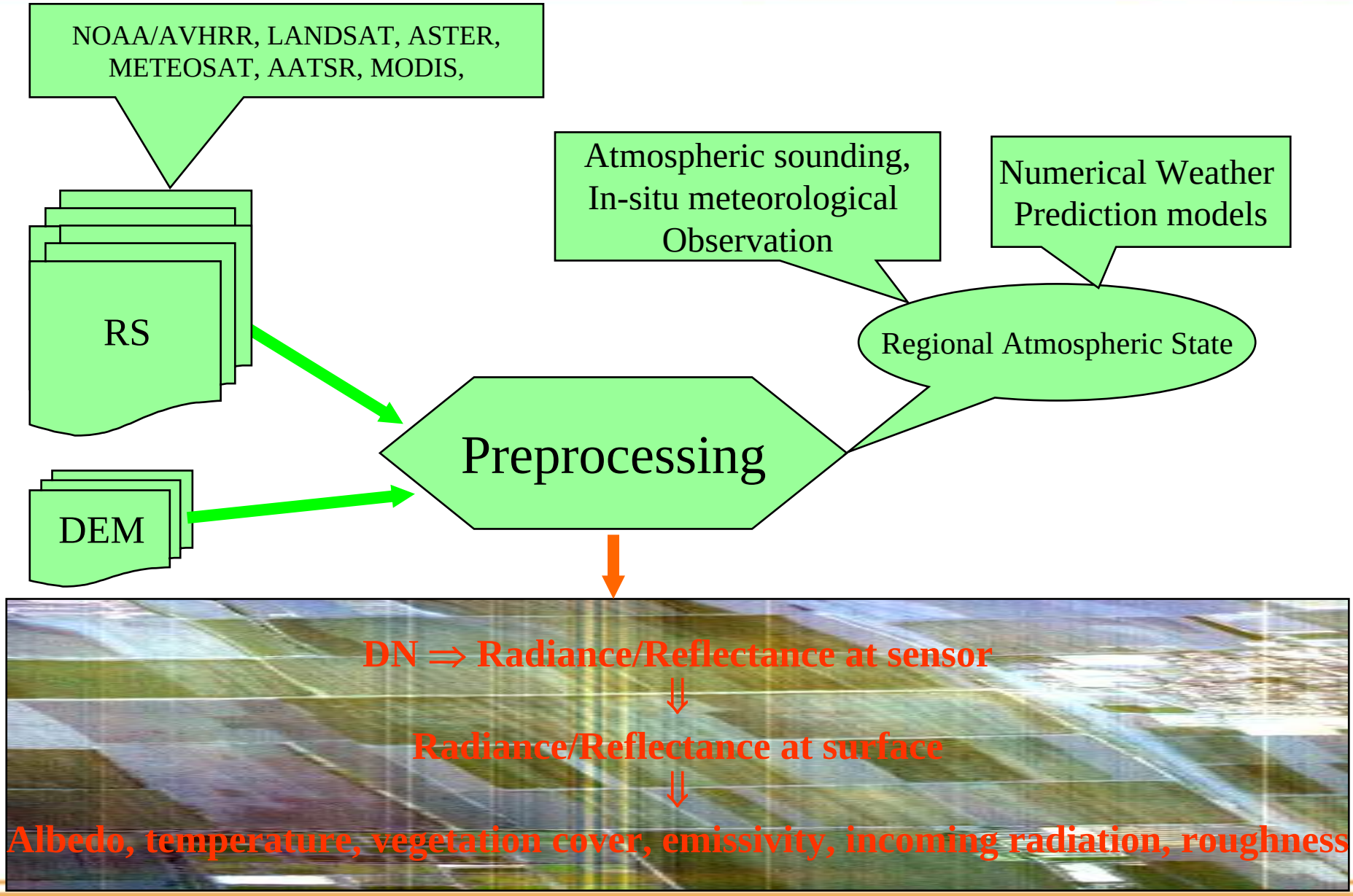
$$kB_s^{-1} = 2.46\left(\mathrm{Re}_*\right)^{1/4} - \ln[7.4]$$

SEBS - The Surface Energy Balance System

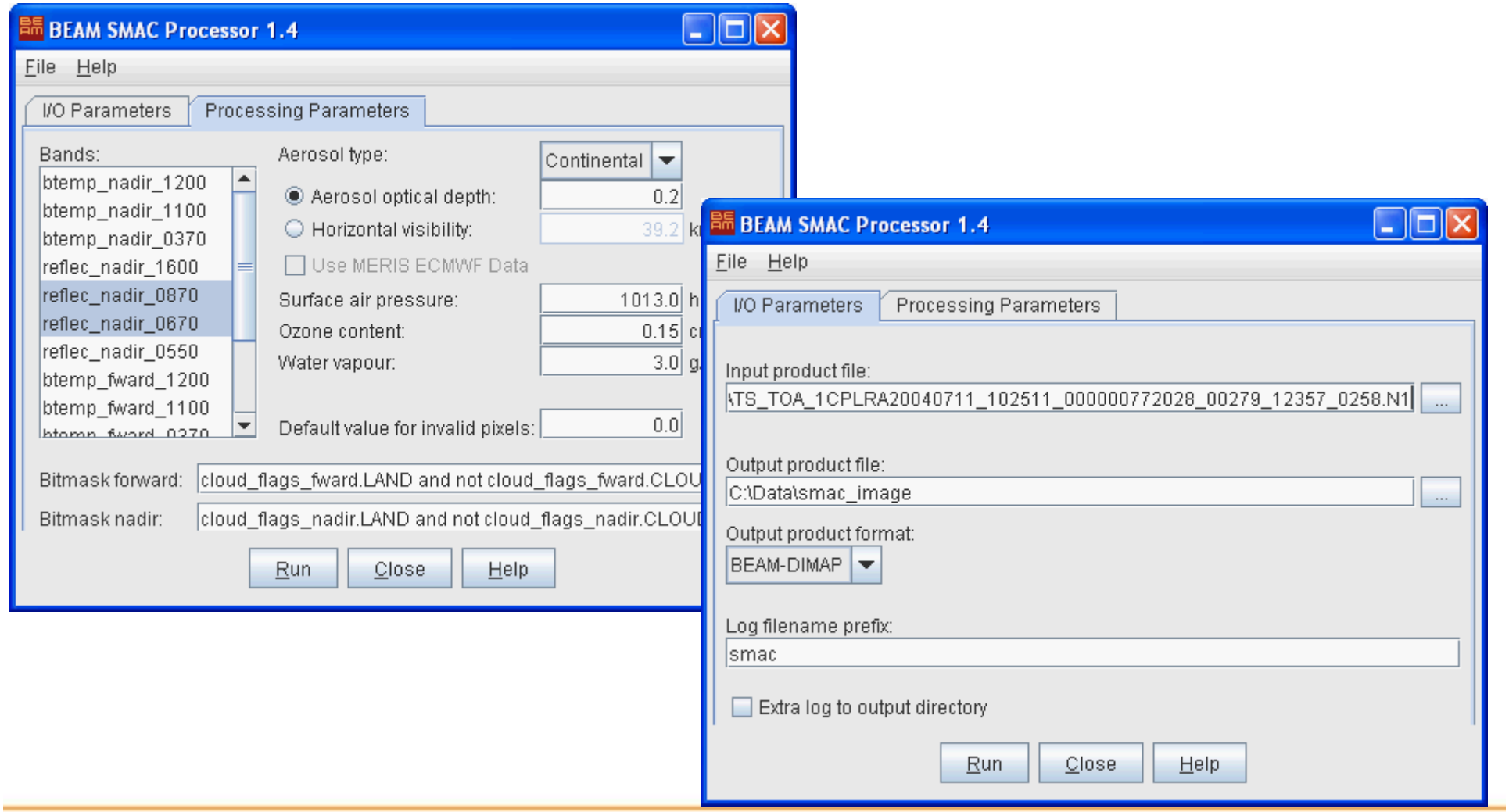


General Methodology

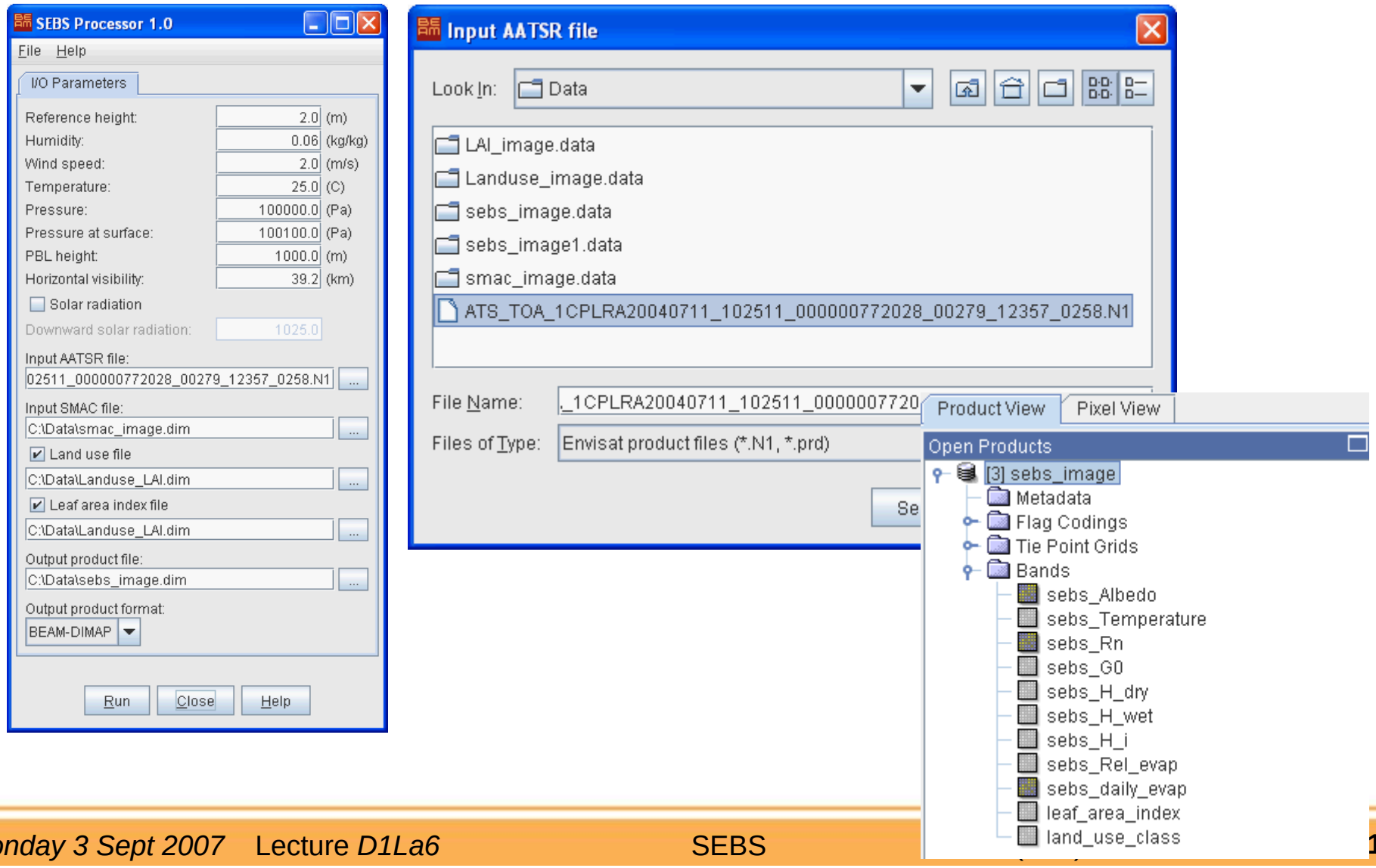



NOAA/AVHRR, LANDSAT, ASTER, METEOSAT, AATSR, MODIS,
RS
DEM
Atmospheric sounding, In-situ meteorological Observation
Numerical Weather Prediction models
Regional Atmospheric State
Preprocessing
DN ⇒ Radiance/Reflectance at sensor
⇓
Radiance/Reflectance at surface
⇓
Albedo, temperature, vegetation cover, emissivity, incoming radiation, roughness

SEBS plug-in in BEAM



SEBS plug-in in BEAM

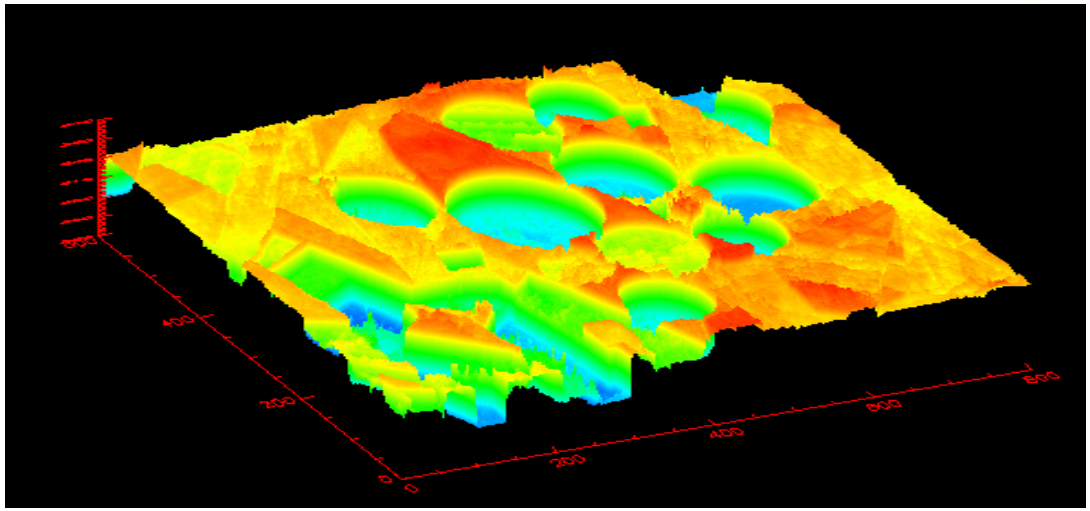


SEBS plug-in in BEAM - Roughness height for momentum transfer

Land-use classes and associated roughness height Z0m values

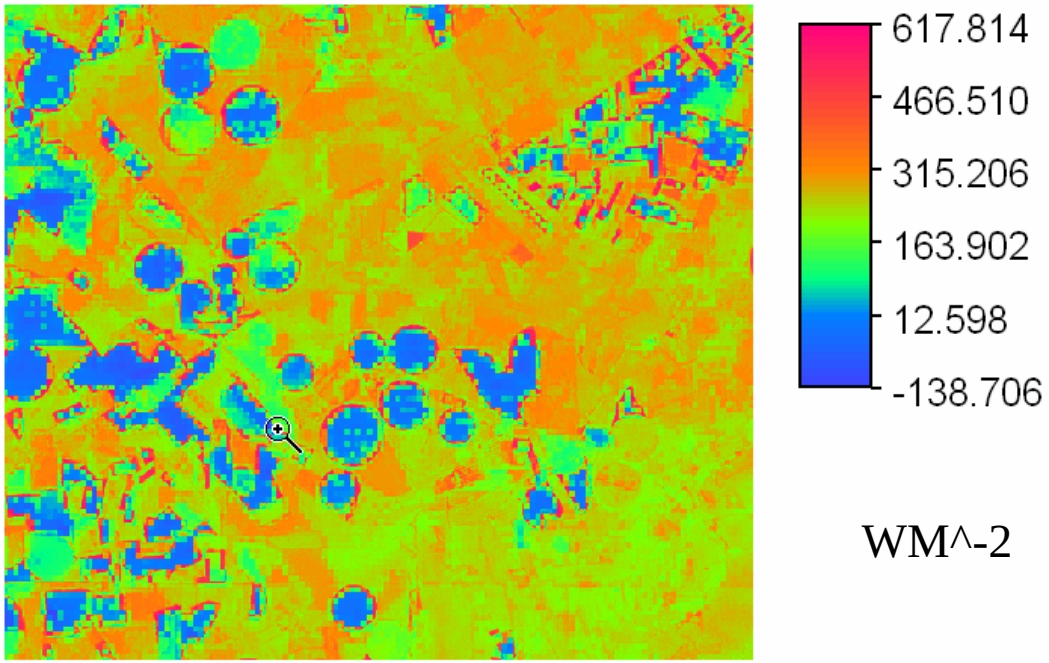
ClassCode	Z0m (m)	Land-use class
End_of_head	==========	
code 1	0.0340	Grass
code 2	0.1300	Maize
code 3	0.0639	Potatoes
code 4	0.0639	Beets
code 5	0.1300	Cereals
code 6	0.0639	Other_crops
code 7	0.4066	Greenhouses
code 8	0.6065	Orchards
code 9	0.0639	Bulbs0.0639
code 10	1.2214	Deciduous_forest
code 11	1.2214	Coniferous_forest
code 12	0.0408	Heather
code 13	0.0408	Other_open_spaces_in_natual_areas
code 14	0.0012	Bare_soil_in_natural_area
code 15	0.0002	Freshwater
code 16	0.0002	Salt_water
code 17	1.1052	Continuous_urban_area
code 18	0.5488	Build_up_area_in_rural_area
code 19	1.2214	Deciduous_forest_in_urban_area
code 20	1.2214	Confiferous_forest_in_urban_area
code 21	1.2214	Build_up_area_with_dense_forest
code 22	0.0334	Grass_in_build_up_area
code 23	0.0012	Bare_soil_in_build_up_area
code 24	0.0035	Main_roads_and_railways
code 25	0.5488	Buildings_in_rural_areas

These are default values and need to be adjusted according to actual phenological stage.



Results from SEBS

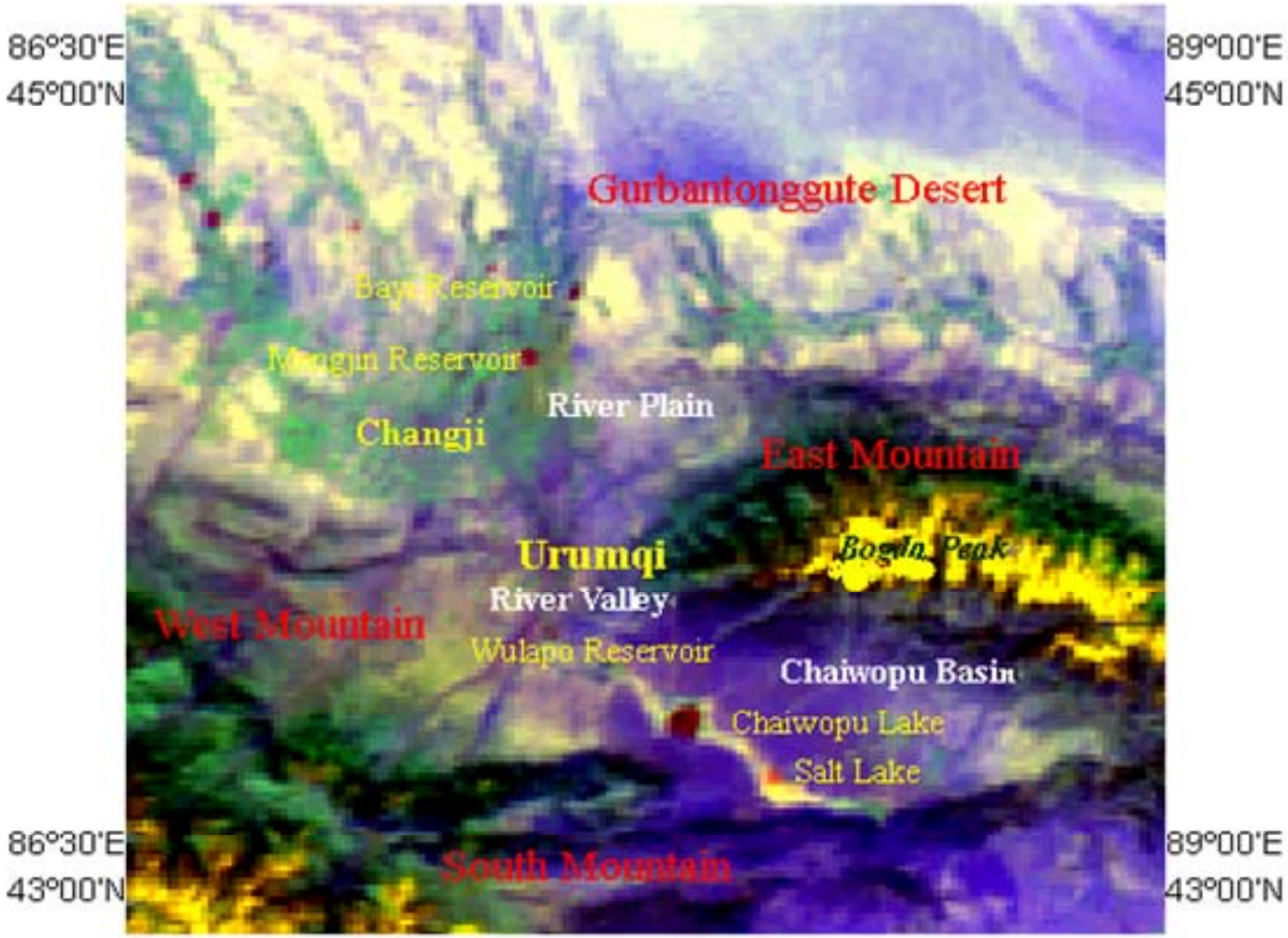
Sensible Heat
AHS 15 July 2004
(A. Gieske)



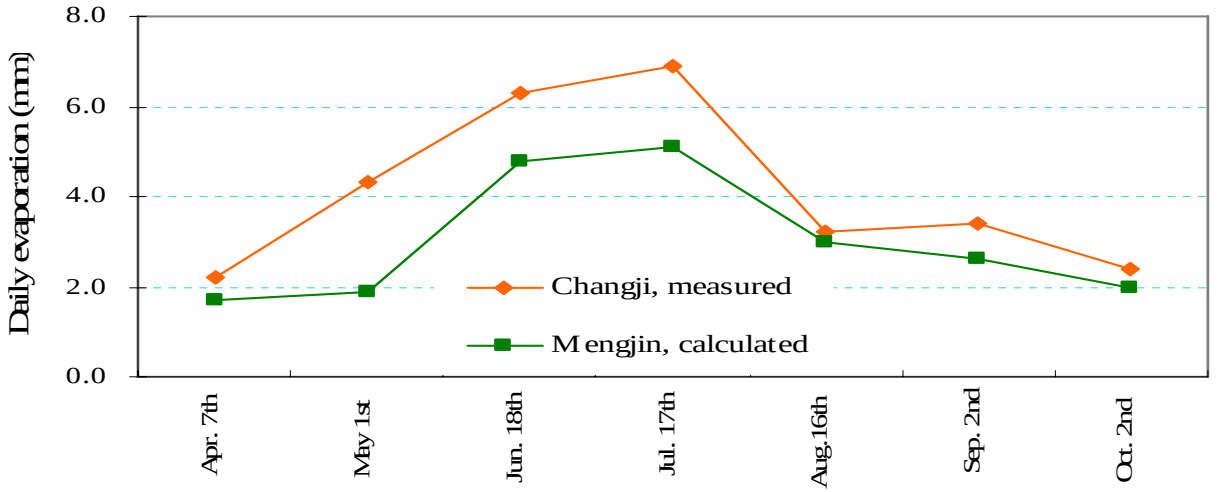
Sensible Heat
ASTER 18 July 2004

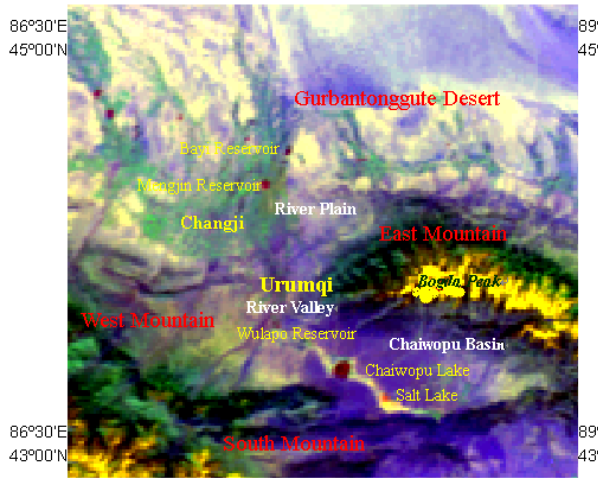
Some applications

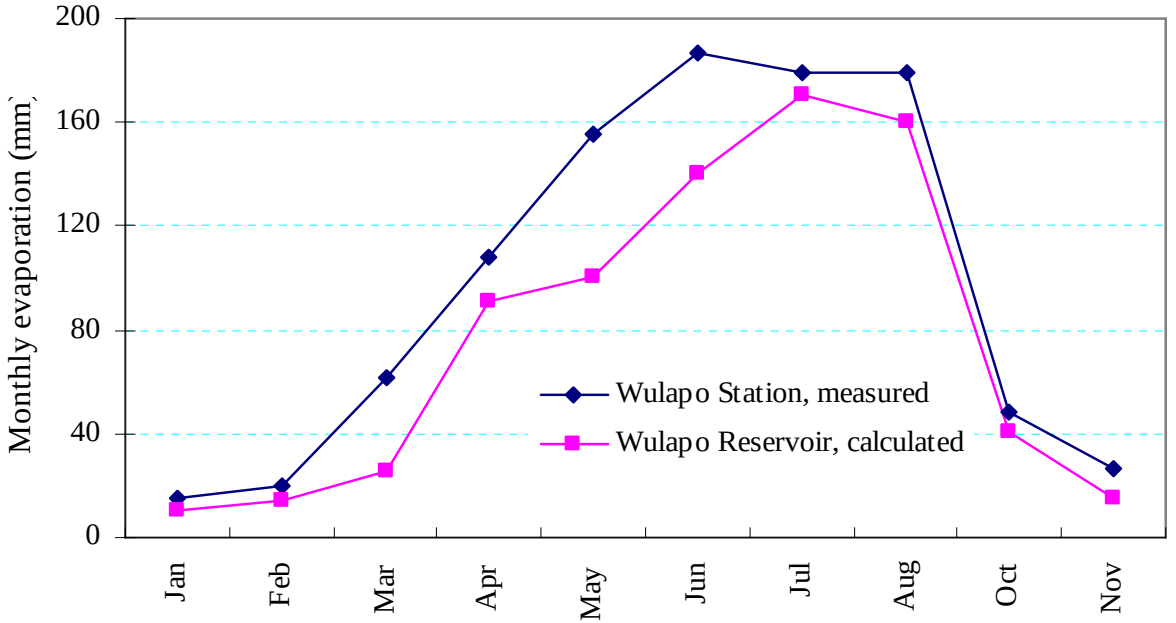
Application to the Urumqi River Basin, NW China

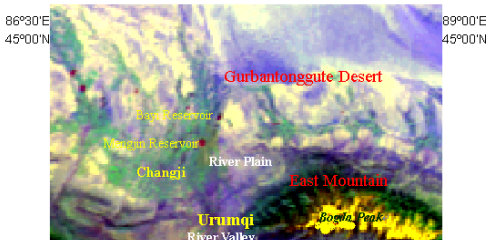


Comparison to measurements (water surfaces)

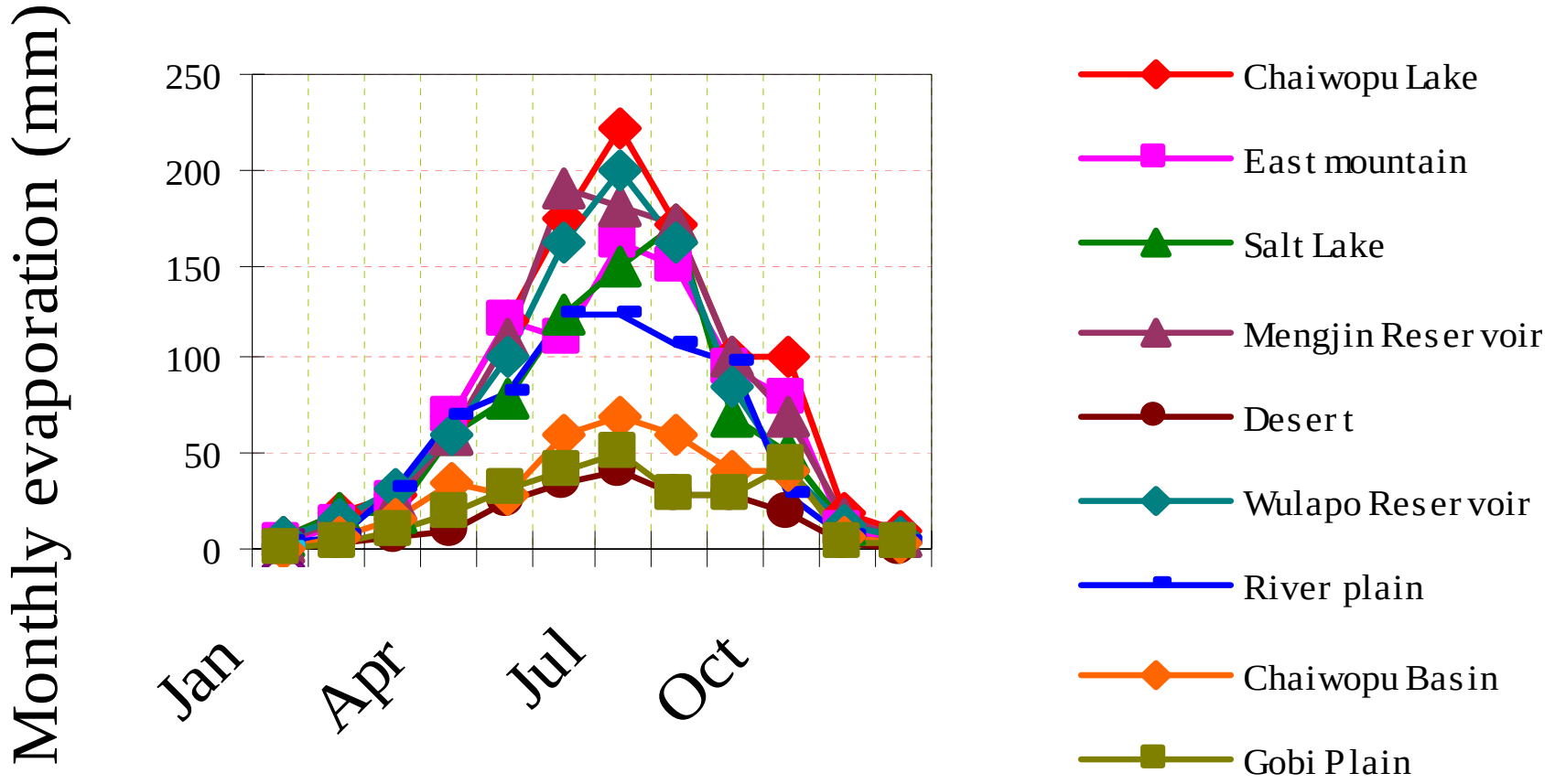








Monthly evaporation from different surfaces in the Urumqi River Basin

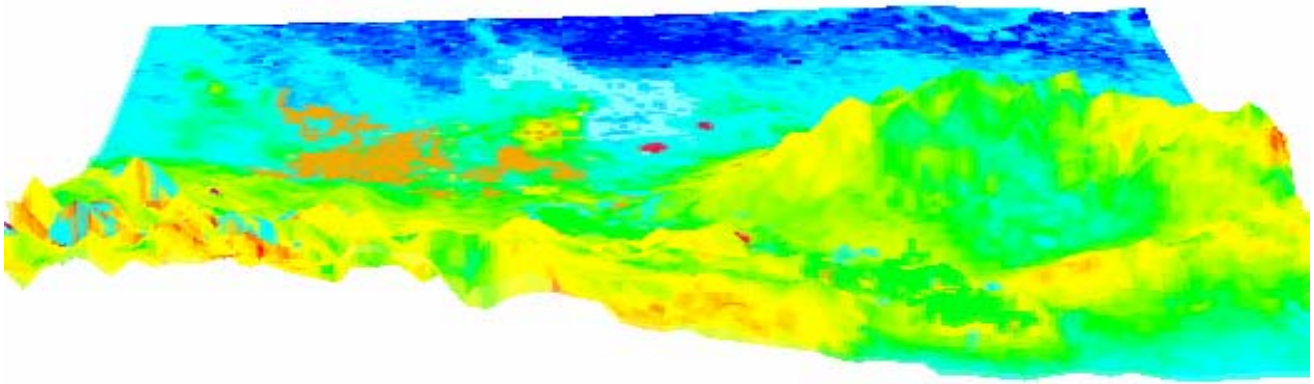


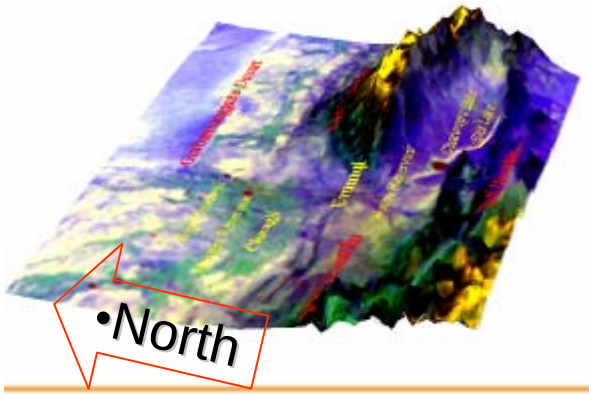
Spatial Distribution of Annual Evaporation over the Urumqi River Basin

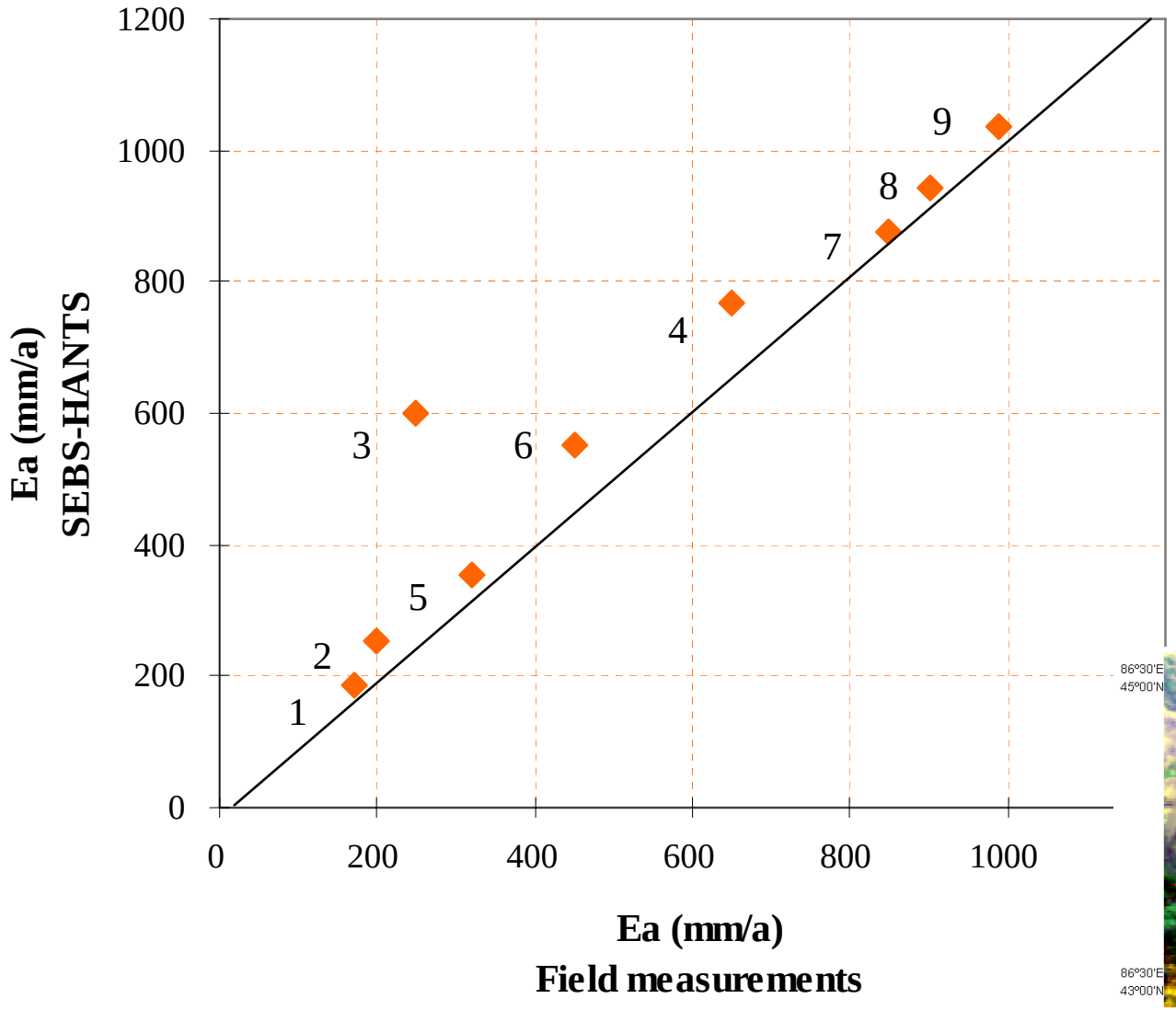
NOAA/AVHRR based annual actual evaporation in 1995, Urumqi River Basin

Ea (mm/year)

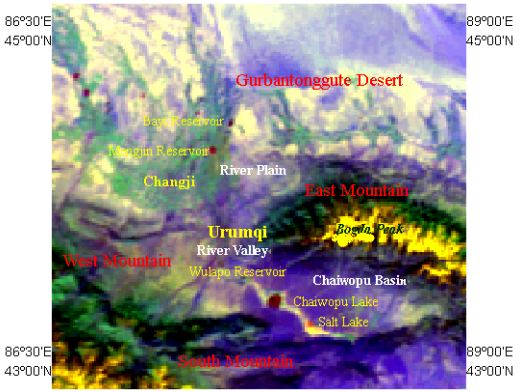
- <200.0
- 200.0
- 300.0
- 400.0
- 500.0
- 600.0
- 700.0
- 800.0



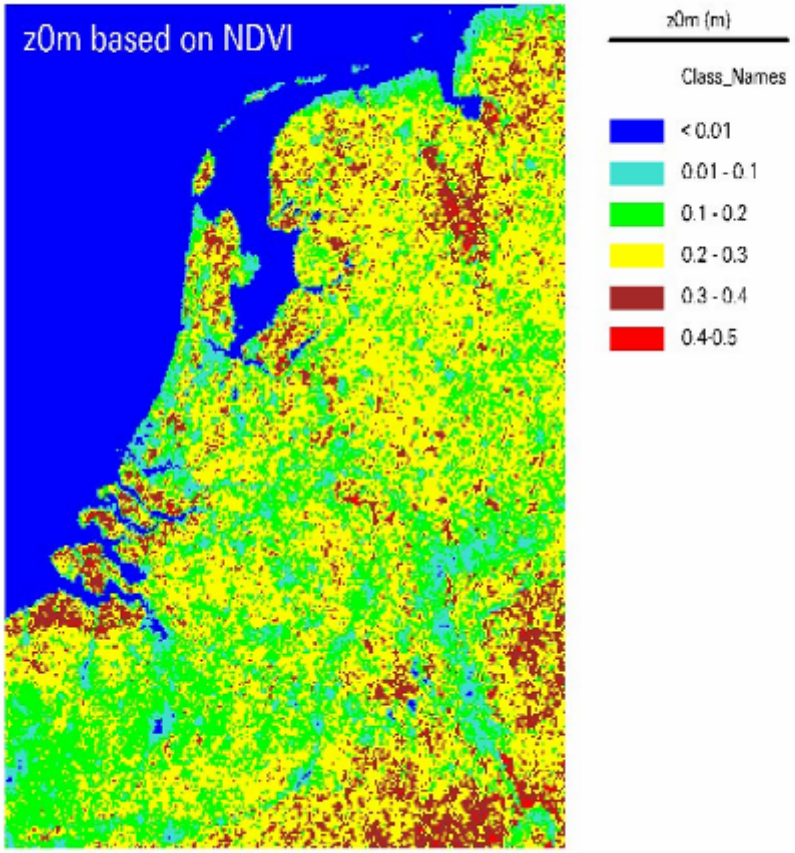


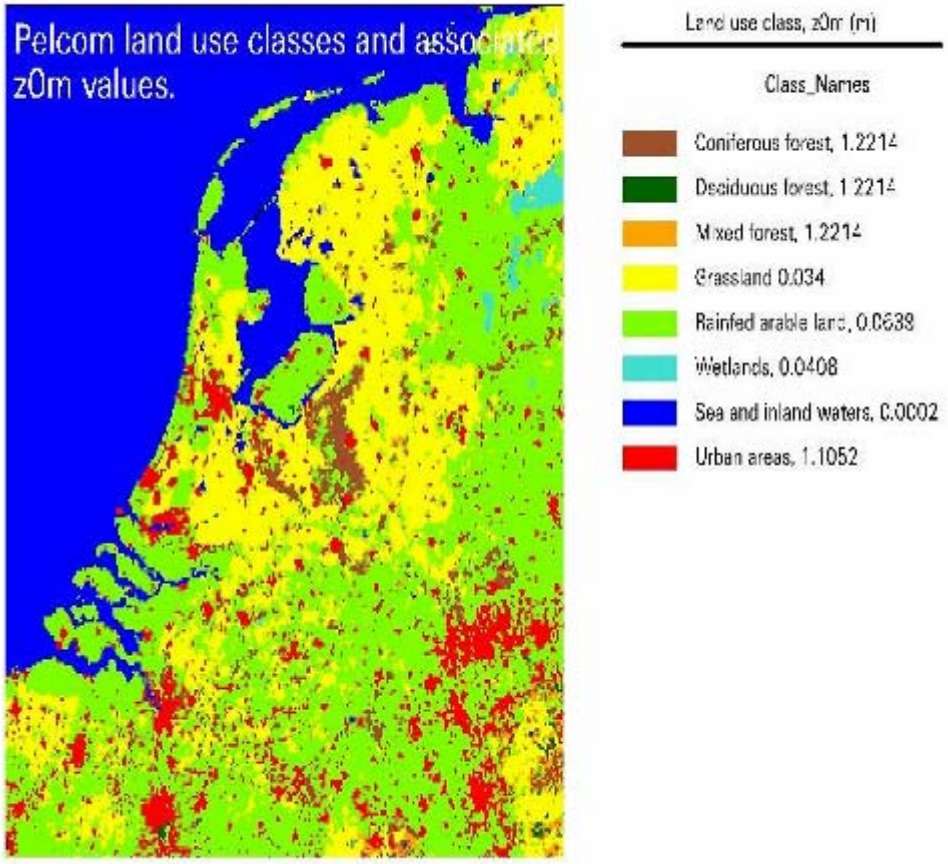


1. Desert
2. Gobi Plain
3. Mid-mountain
4. Salt Lake
5. Chaiwopu Basin
6. Forest zone
7. Bayi Reservoir
8. Mengjin eservoir
9. Chaiwopu Lake

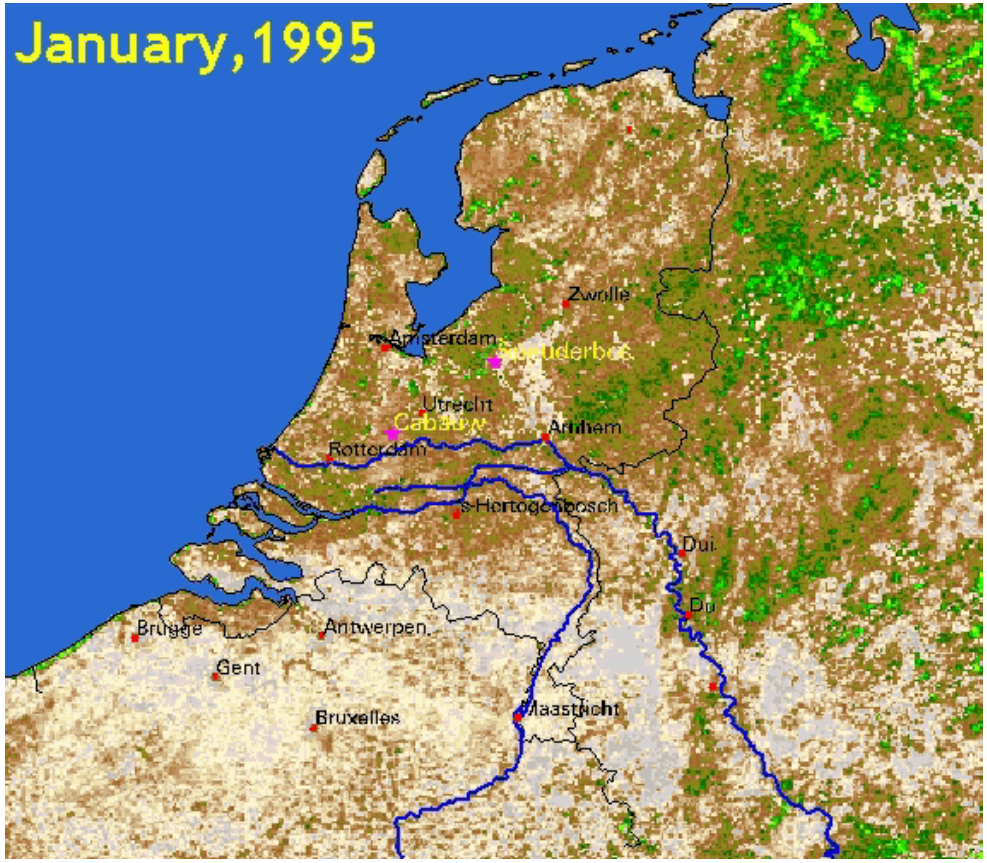


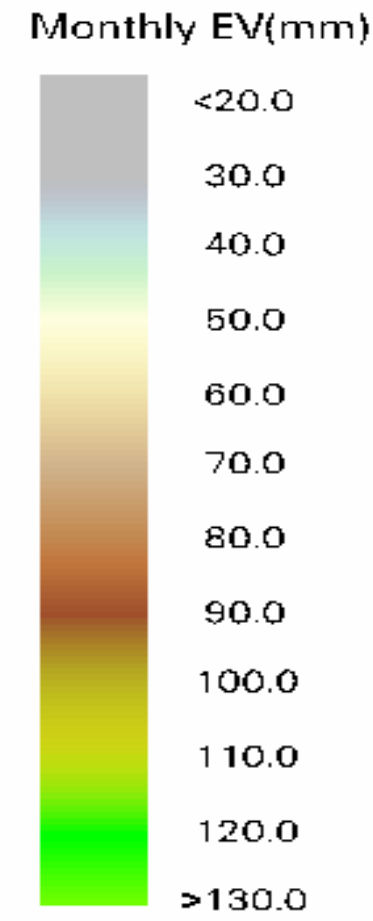
Applications to the Netherlands (Methods to determine z0m)



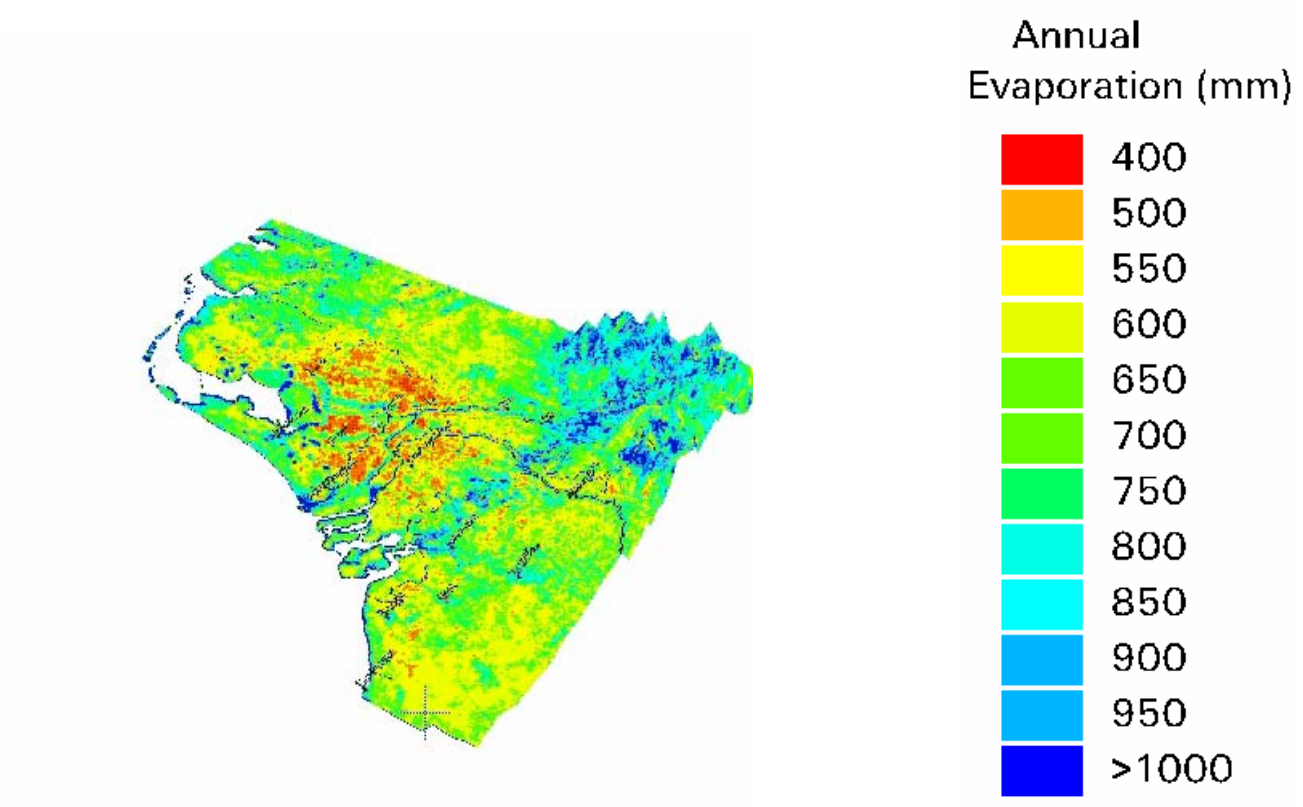


Monthly evaporation during 1995

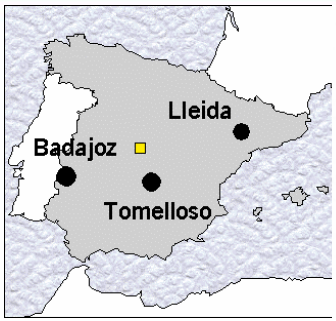


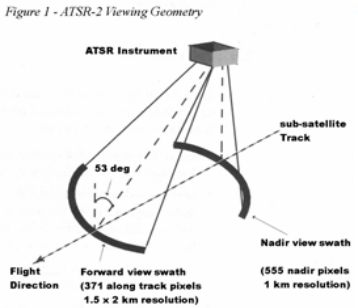


Annual evaporation in 1995

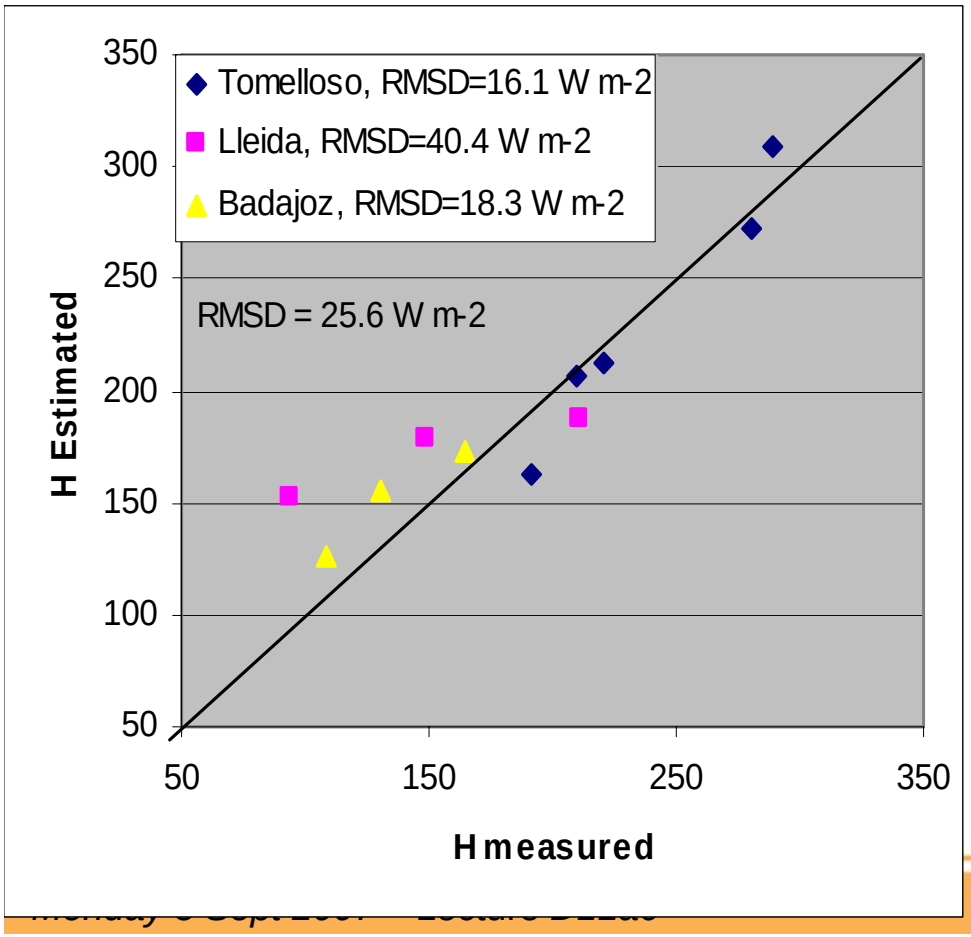


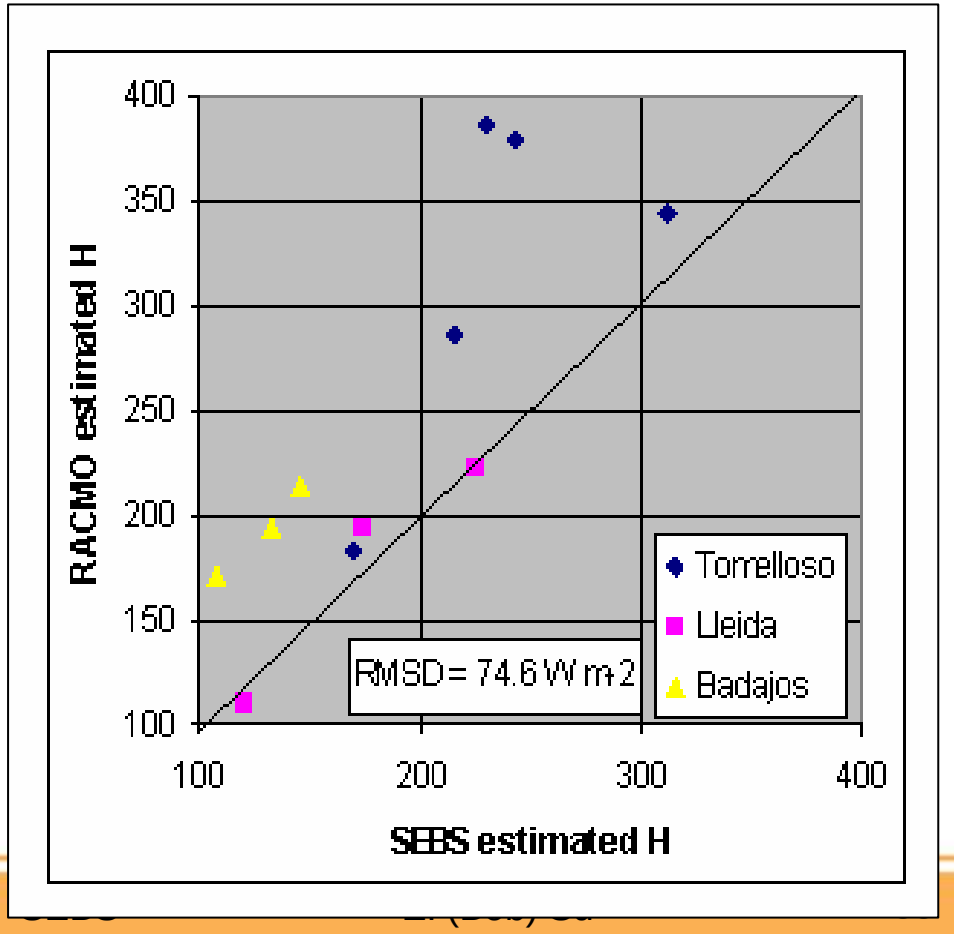
Validation of Atmospheric Models at Regional Scales





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),





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.
- The results demonstrate that SEBS algorithm can be used for spatial-temporal estimation of actual evaporation with an acceptable accuracy.

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