South East European Virtual Climate Change Center

Surface representation in atmospheric models

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- *General remarks and short history*
- *The LISS*
- *The future LISS*

  + improved vegetation

  + very high resolution considerations
- *Dynamic vegetation*

A quote

- *“Much improved understanding of land-atmosphere interaction and far better measurements of land-surface properties, especially **soil moisture**, would constitute a major intellectual advancement and may hold the key to dramatic improvements in a number of forecasting problems, including the location and timing of deep convection over land, quantitative precipitation forecasting in general, and seasonal climate prediction.”*

- *US National Research Council, 1996*

- ***Modelling it***

Parameterization instead of direct implementation of physics (heat and water movements through soil) mainly due to the complexity of the horizontal and vertical structure of the soil and partly due to the complexity of the processes especialy when we wanta to include vegetation into conseiderations.

- ***Single layer + one bucket for the hydrology***
  Concerning the water movement one bucket model (Manabe 1969) assumes exchange only through top surfece

- ***w – tot. water stored in the column,***
- ***p – precip. ,***
- ***e – evap. ,***
- ***r – sfc runoff and drainage.***

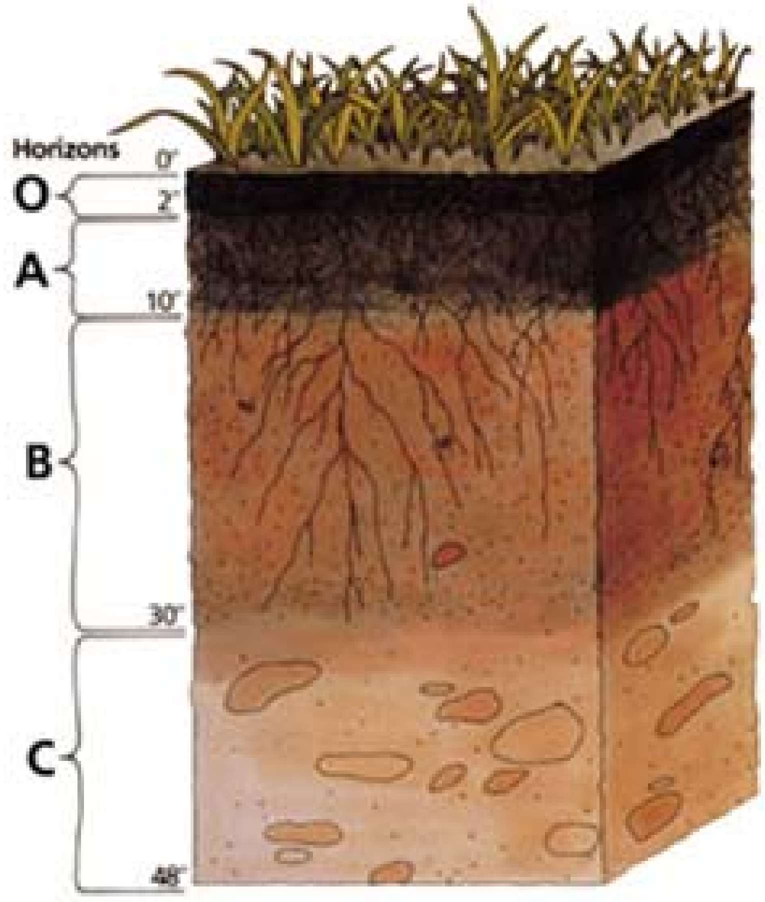
But that would be to svere asumption for the heat flux

- ***Solutions :***

1. ***The force-rstore approach originally proposed by Bhumralkar (1975) and Blackadar (1976) and later developed by Deardorff (1978), Lin (1980) and Dickinson (1988)***

2. ***The other one is Nickerson-Smiley (1975) approach where bottom flux is proportional to the net radiation.***

Schematic presentation of a soil column with different soil types and root structure



The L I S S

Land Ice/snow Sea Surface

Roll of the Land Surface Models (LSM) in Numerical Weather Prediction Models (NWPM)

in mathematical sense: Lower boundary condition for partial differential equations that describe processes in the atmosphere

in physical sense: LSM makes connection between atmosphere and land surface in exchanging energy, mass and momentum

<u>processes at the ground are smaller scale than spatial NWPM resolution</u>

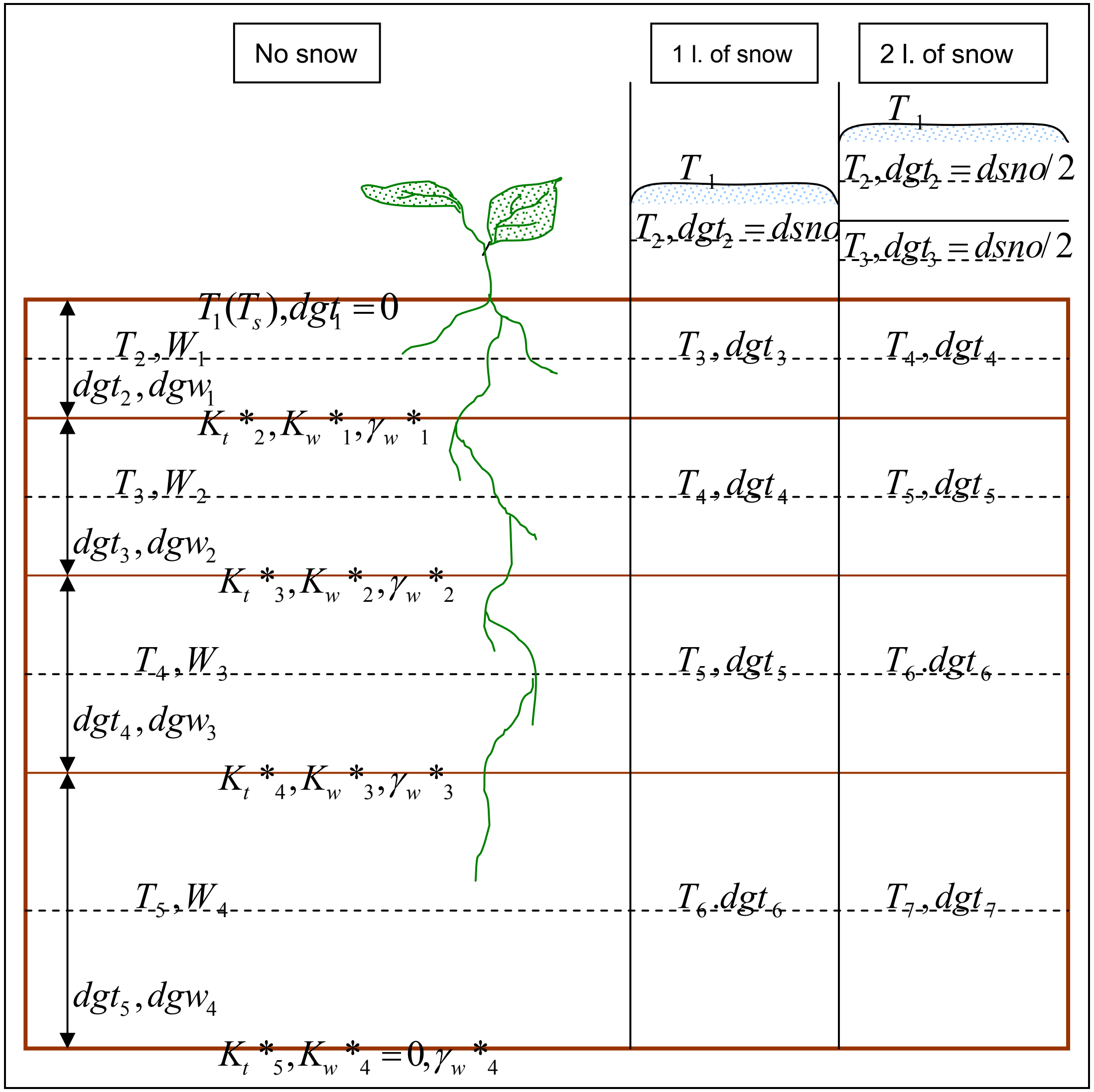
→ parameterization of the processes must be performed

complexity of the LSM: Compromise between needed and possible must be well made!

important!

Good forecast of the energy division between latent (moistening) and sensible (warming) heat The Bowen ratio

Vertical structure of LISS



LISS (Land, Ice, Sea Surface) Model

- part of the NWPM : NMM-B
- 1D model, with vertical coordinate
- multilayer in vertical, single layer for vegetation
- tested offline for two sites:
  - Caumont (France) and Bondville (USA)
  - bare soil + soya
  - results compared with:
    - measurements
      (soil temperature and moisture, surface fluxes)
    - results obtained with NOAH-LSM
      (model in operational use in most of the NWPM)

LISS description

- prognostic equations for:

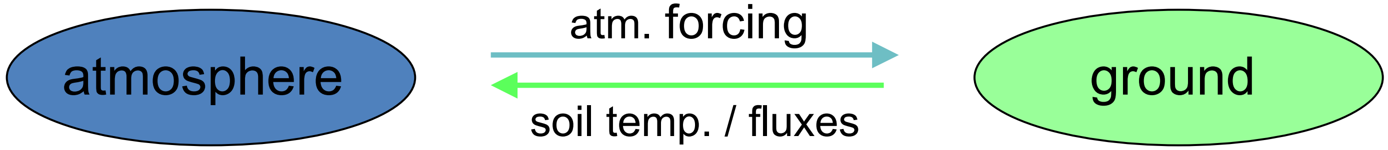
  soil temperature, soil moisture, melted snow amount,
  amount of water in the interception reservoir

- important dijagnostic vvariables:

  surface temperature, surface fluxes

- upper boundary condition:

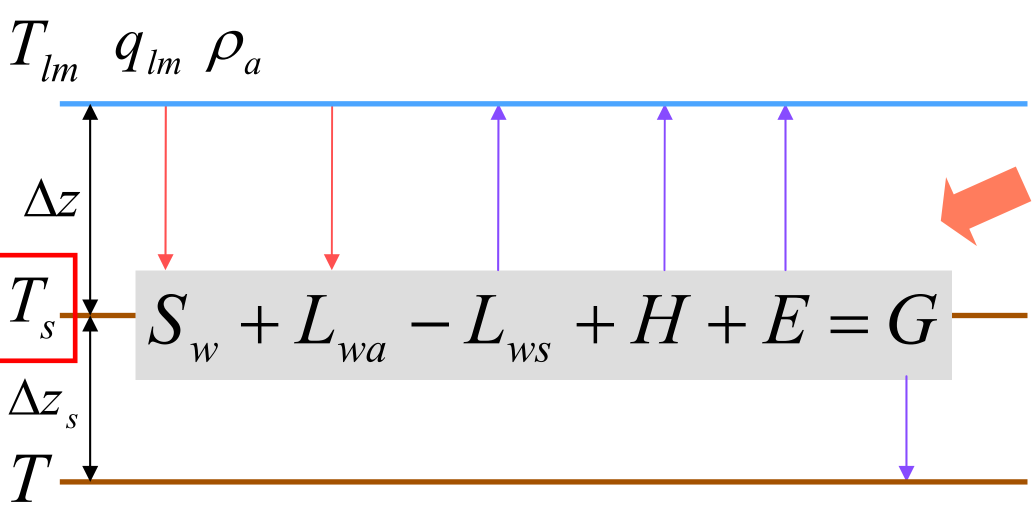
  atmospheric forcing
  (from the atmospheric part of the NWPM)



Soil temperature forecast

1. Soil surface temperature (skin temperature)

calculation from the
surface energy balance equation



$$S_w + L_{wa} - L_{ws} + H + E = G$$

$$S_w = (1 - alb) S_{w\,inc}$$

$$L_{ws} = \varepsilon \sigma T_s^4$$

$$H = \rho_a c_{pa} K_{hs} \frac{T_{lm} - T_s}{\Delta z}$$

$$E = \beta \rho_a L_v K_{hs} \frac{q_{lm} - q_{sat}(T_s)}{\Delta z}$$

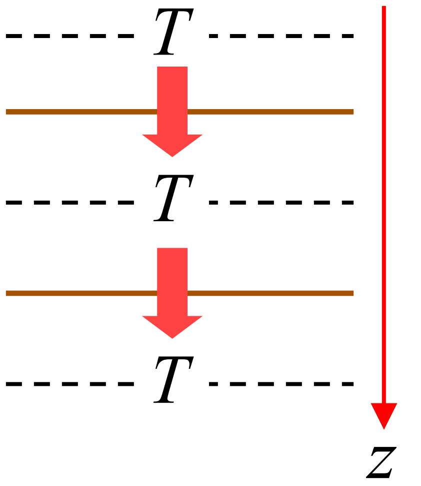
$$G = K_t \frac{(T_s - T)}{\Delta z_s}$$

linearization

Liner equation from which skin temperature can be explicitly calculated:

$$T_s = \ldots$$

2. Temperature of the soil layers



Fourier law of diffusion: $$(\rho c)\frac{\partial T}{\partial t} = \frac{\partial}{\partial z}\left(K_t \frac{\partial T}{\partial z}\right)$$

upper boundary condition: skin temperature

lower boundary condition:
- flux from last layer = 0 (if the last layer is deep enough)
- temperature below last layer = const

water phase change influence: latent heat → termic conductivity, transpiration

$$(\rho c)_{swi}\frac{\partial T}{\partial t} = \frac{\partial}{\partial z}\left(K_t \frac{\partial T}{\partial z}\right) + L_f \rho_w \frac{\partial W_i}{\partial t}$$

$$W_i = f_f(T)\,W$$

$$0 \le f_f \le 1$$

$$\Rightarrow \underbrace{\left[(\rho c)_{swi} - L_f \rho_w W \frac{\partial f_f}{\partial T}\right]}_{(\rho c)}\frac{\partial T}{\partial t} = \frac{\partial}{\partial z}\left(K_t \frac{\partial T}{\partial z}\right)$$

Snow

- model has ability to divide snow in multi layers, when height of the snow cover exceed some prescribed value

- temperature of the surface, snow layers and soil layers: same as in case without snow except that in the snow layers values for (ρc) and K_t are calculated for snow from its properties

- when snow melt exists: skin temperature = $0°C$

amount of melted snow:

from surface energy balance equation with term for latent heat of melting phase change

$$\rho_w L_f \frac{S_{melt}}{\Delta t} = S_w + L_{wa} - L_{ws} + H + E - G$$

evaporation parameterization $\longrightarrow$ β parameter

total latent heat flux is divided into : $E = E_{in} + E_{et} + E_{soil}$

1. evaporation from interception reservoir
2. evapo-transpiration
3. evaporation from bare soil

idea for parameterization: $E = (\ \beta_{in} + \beta_{et} + \beta_{soil}\ )\ E_p$

final expression for β parameter:

$$\beta = \underbrace{C_{liq}}_{1} + \underbrace{\left(1 - C_{liq}\right) C_{veg} \frac{1}{1 + r_c K_{hs} / \Delta z}}_{2} + \underbrace{\left(1 - C_{liq}\right)\left(1 - C_{veg}\right) \frac{1}{1 + r_{soil} K_{hs} / \Delta z}}_{3}$$

Soil moisture forecast

equation for volumetric liquid soil water content:

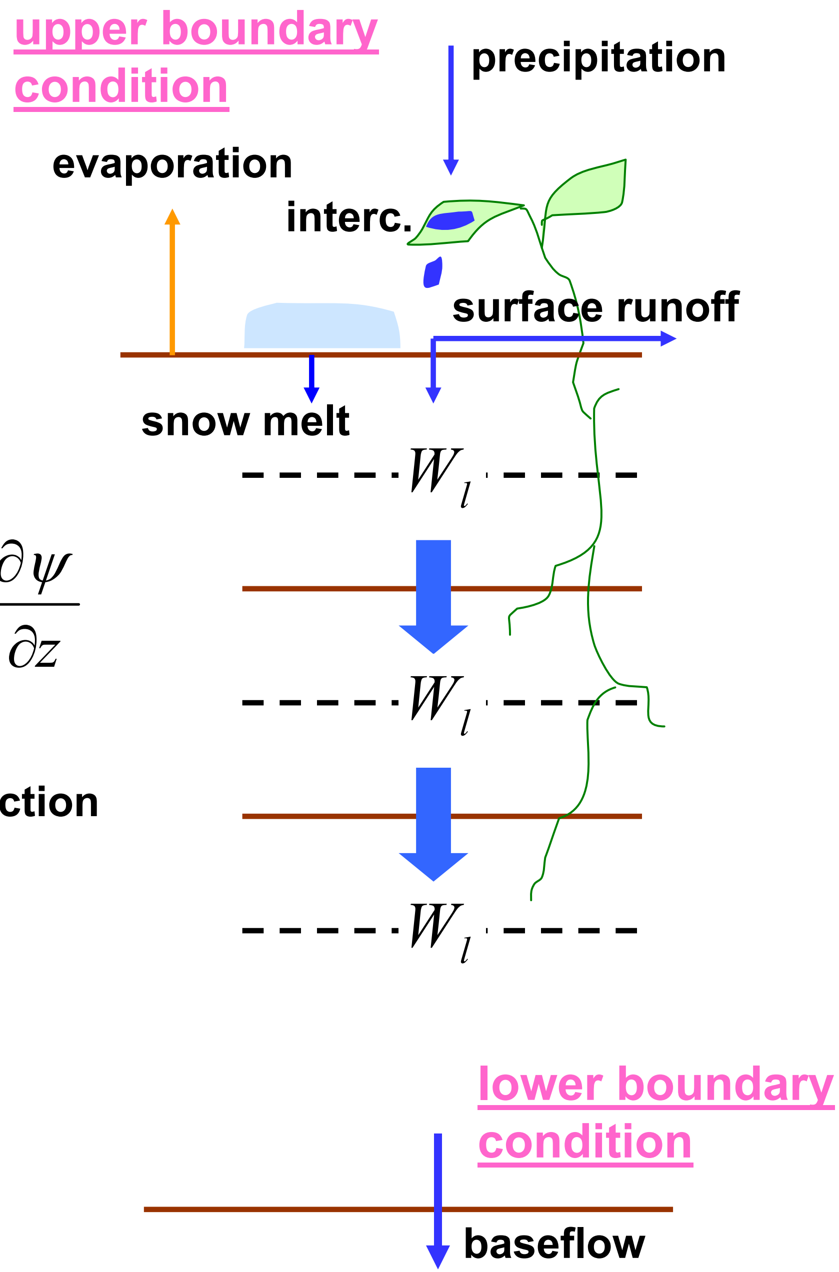
$$\rho_w \frac{\partial W_l}{\partial t} = -\frac{\partial F_w}{\partial z} + \rho_w R_{ex}$$

according to Darcy law: $F_w = -\rho_w \gamma_w \frac{\partial \psi}{\partial z}$

flux gradient — root extraction

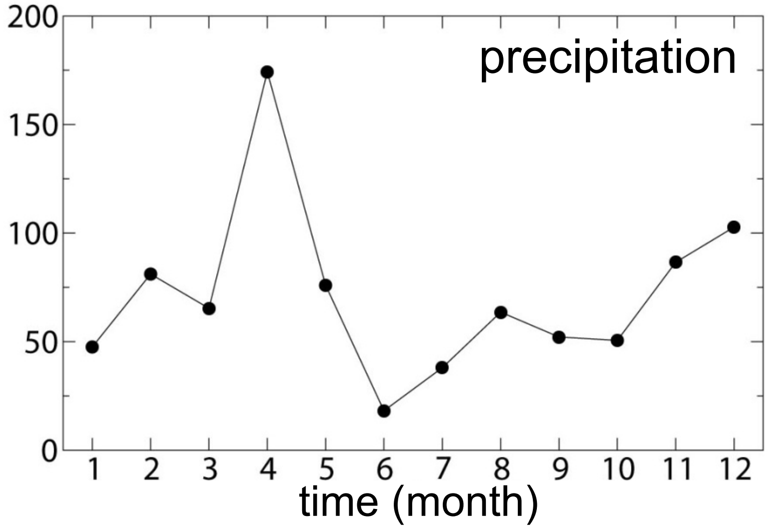
$$\frac{\partial W_l}{\partial t} = \frac{\partial}{\partial z}\left[K_w \frac{\partial W_l}{\partial z} + \gamma_w \right] + R_{ex}$$

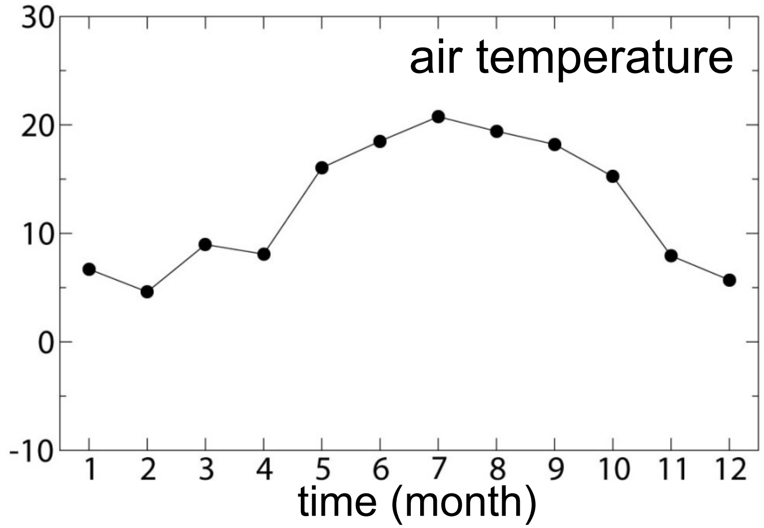
water diffusion — drainage (baseflow)



LISS verification :

experiment 1 – Caumont site (43°41'N and 0°06'W, altitude 113m)

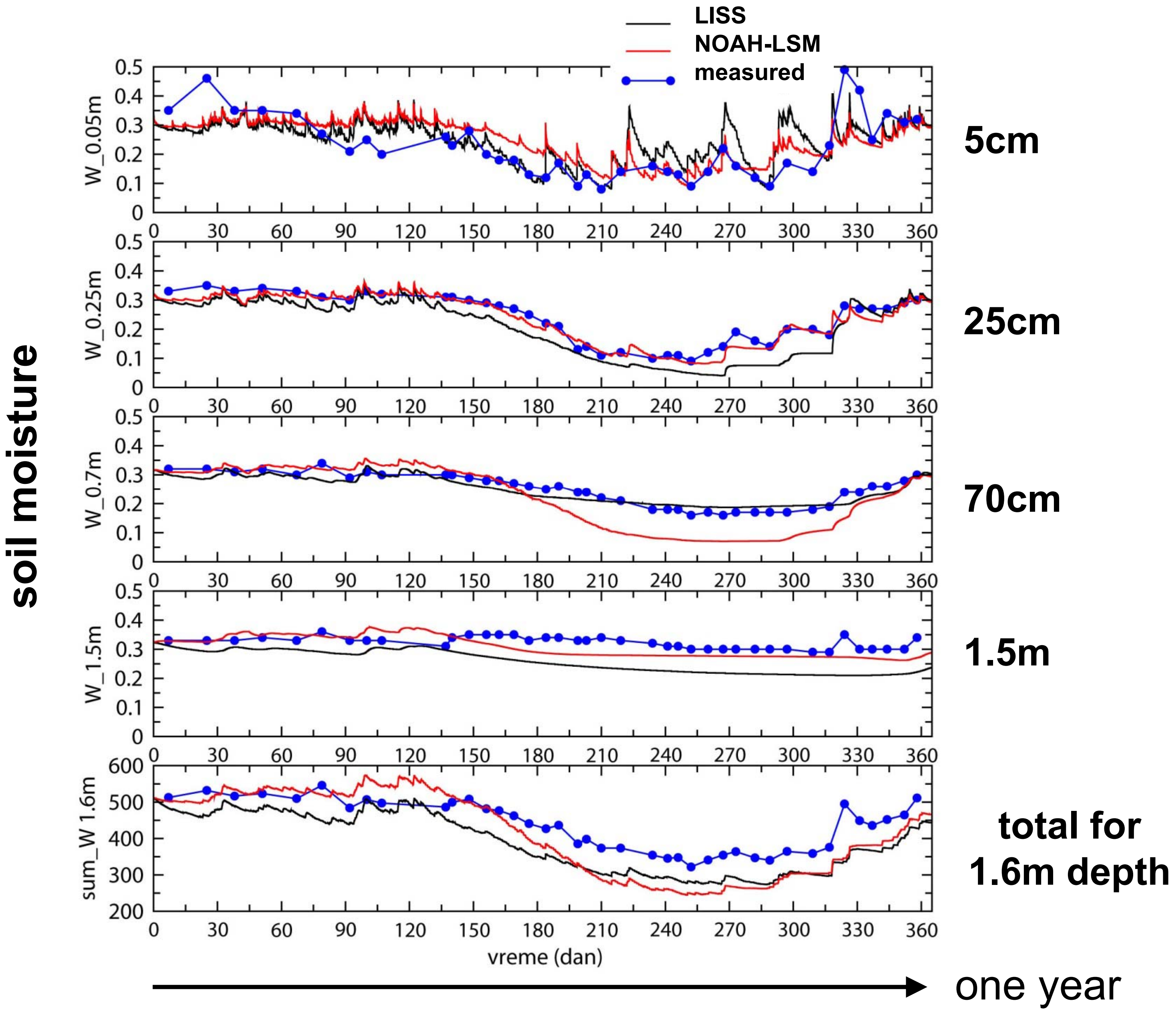




- soil type - loam ; vegetation type - soya (cropland)
- 1. – 120. day bare soil ; 121 - 273 vegetation ; 273 - 365 bare soil
- measurements: HAPEX-MOBILHY

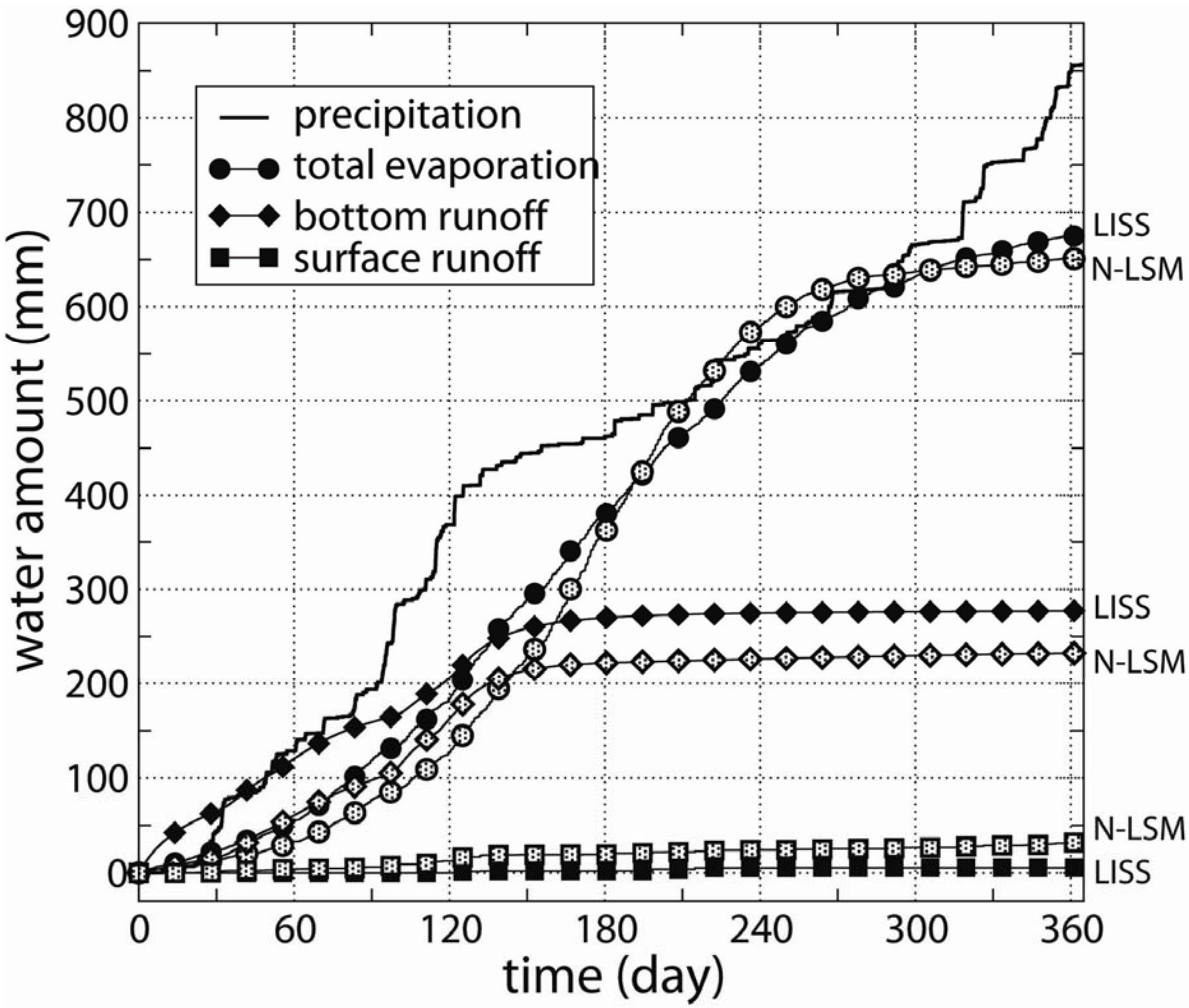
atmospheric forcing on 30min,
surface fluxes on 30min (147-182 days, IOP),
soil moisture on 10cm, to 1.6m depth, on 7 days

LISS vs. NOAH-LSM and measurements: soil moisture

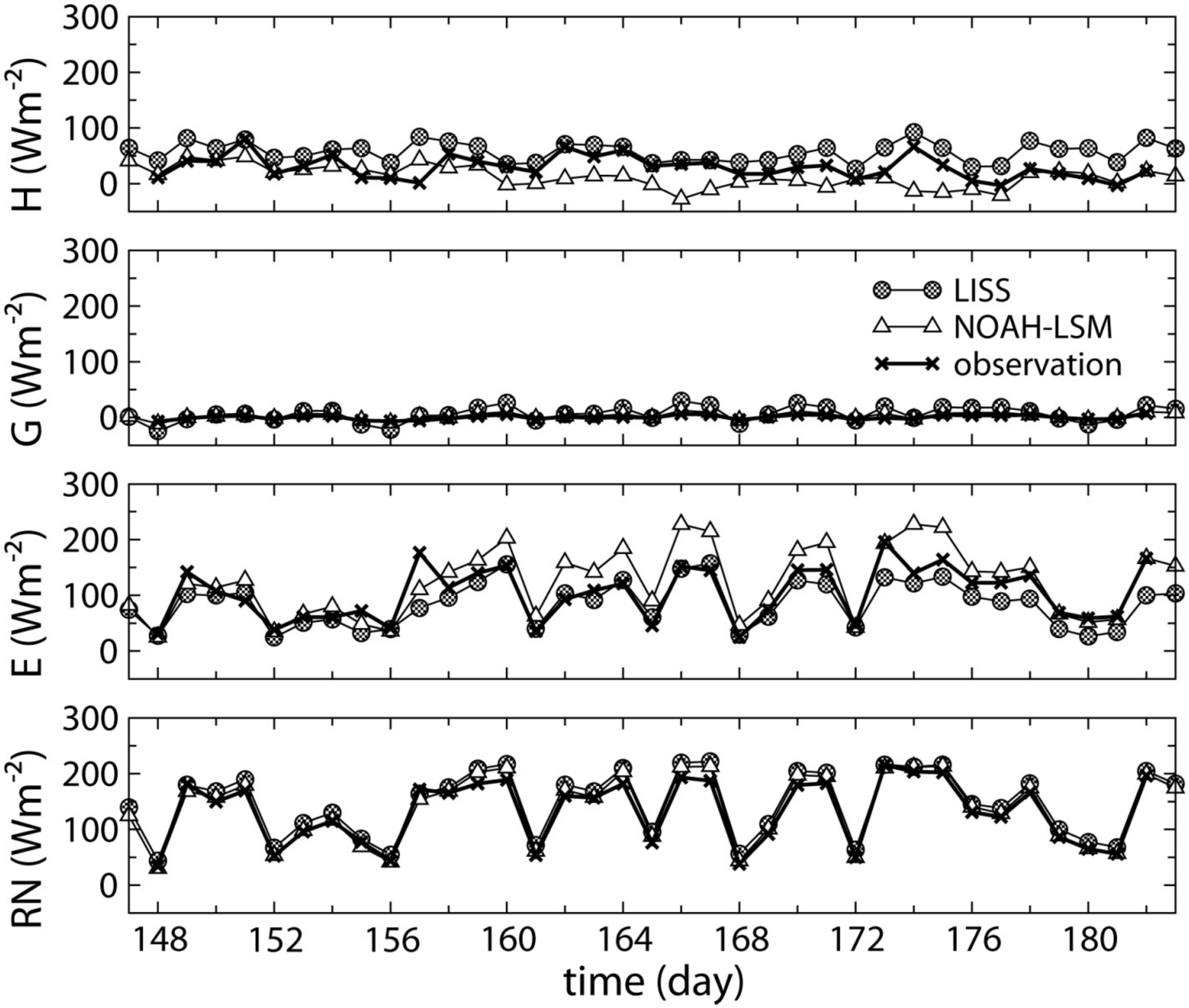


LISS vs. NOAH-LSM : water budget

$$W(t) - W(0) = \int_0^t \left(precipitation - evaporation - runoff \right) dt$$

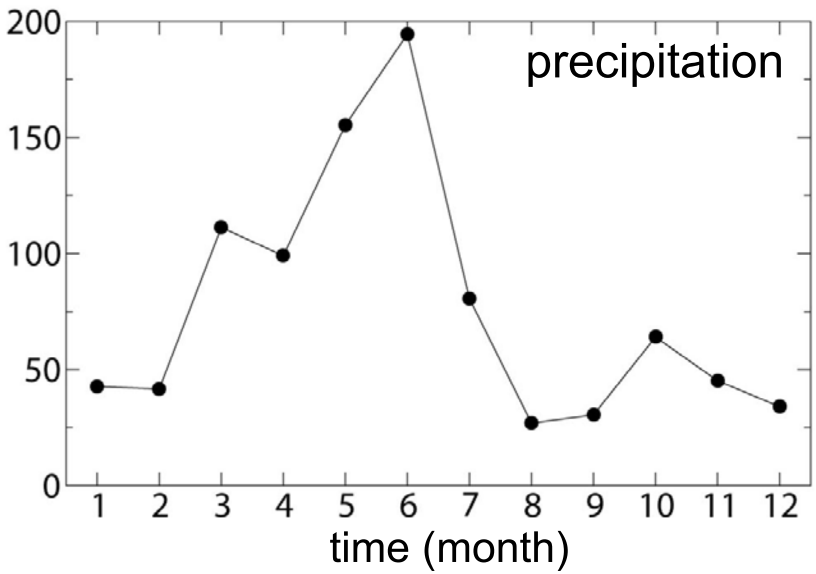


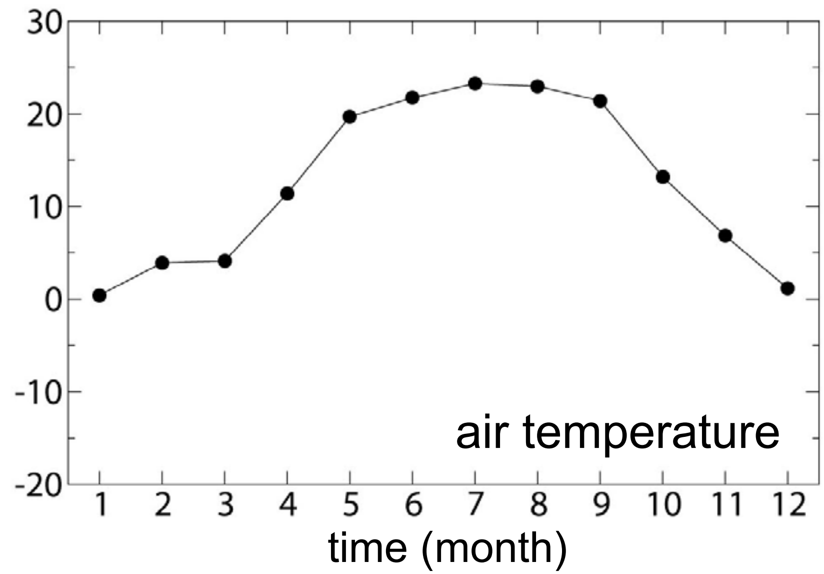
LISS vs. NOAH-LSM and measurements : surface fluxes



RMSE	H	E
LISS / NOAH	64.6 / 61.4	119.6 / 124.1

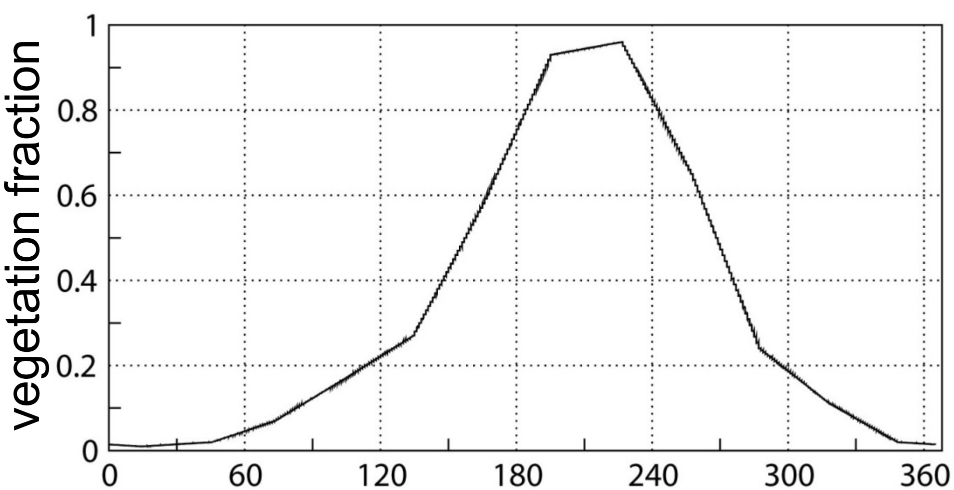
LISS verification :
experiment 2 – Bondville site (40.01N i 88.37W, altitude 219m)



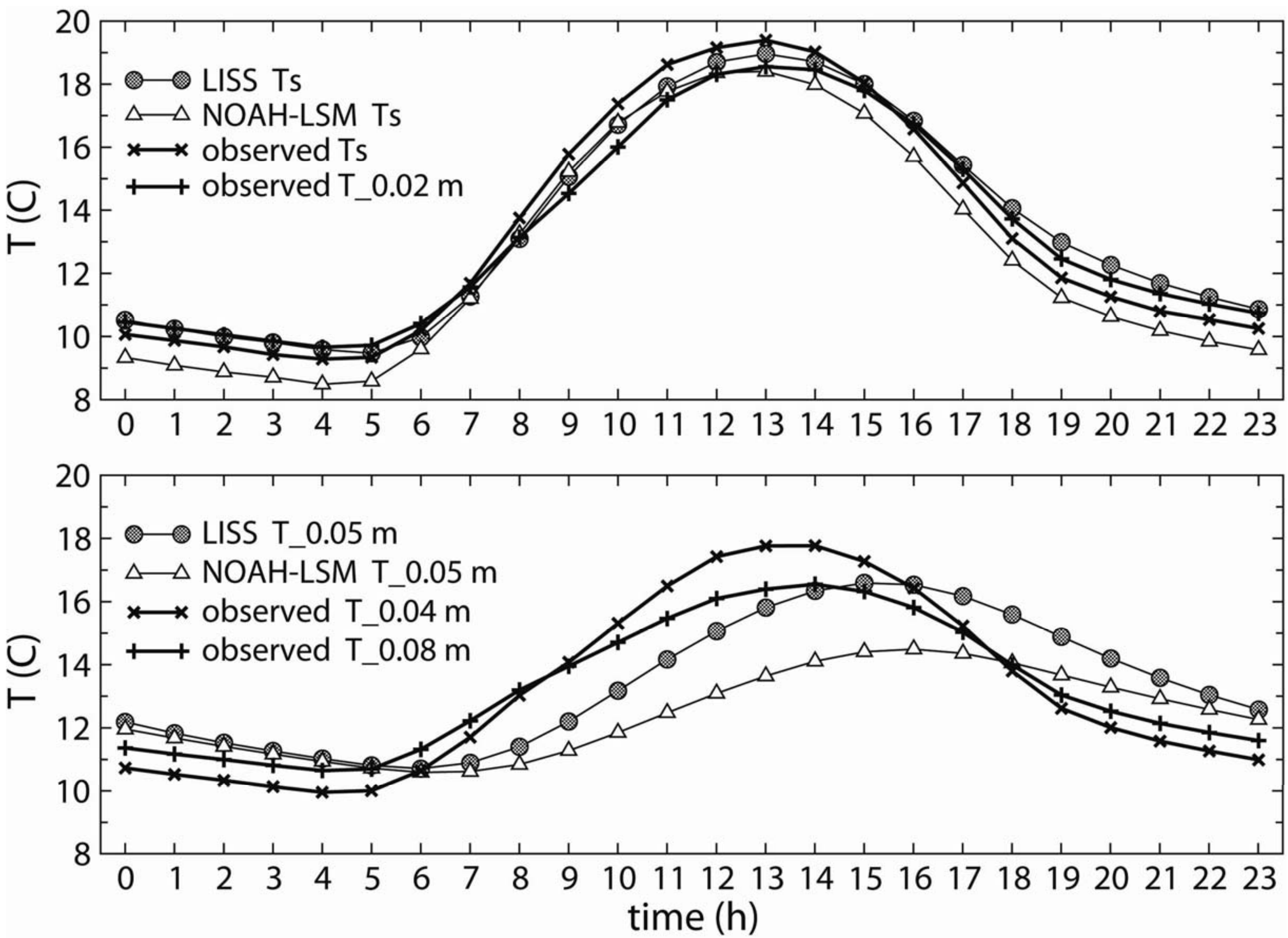


- soil type – silty clay loam
  vegetation – soya (cropland)
- measurements:

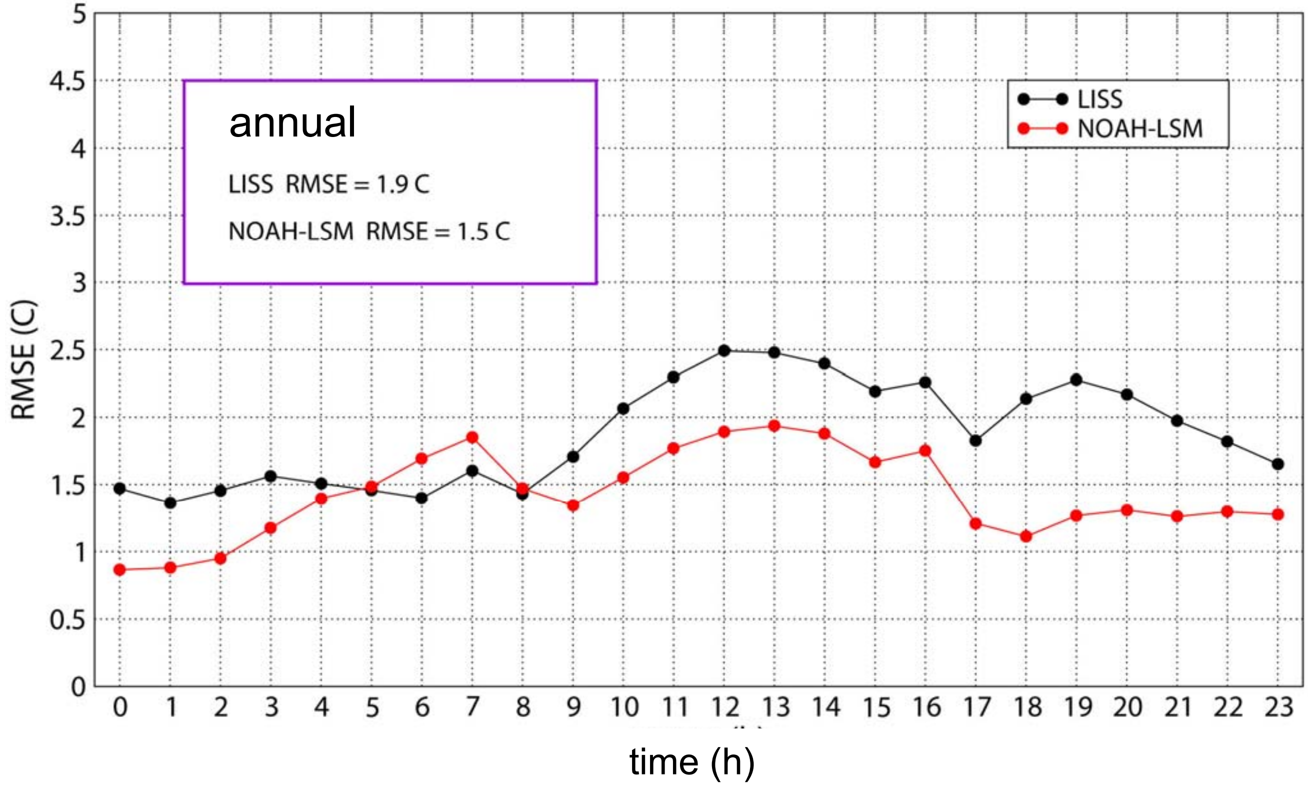
  on 30min, for one year
  - atmospheric forcing
  - soil temperature
  - surface fluxes



LISS vs. NOAH-LSM and measurements:
mean annual diurnal change of the skin and near surface temperature

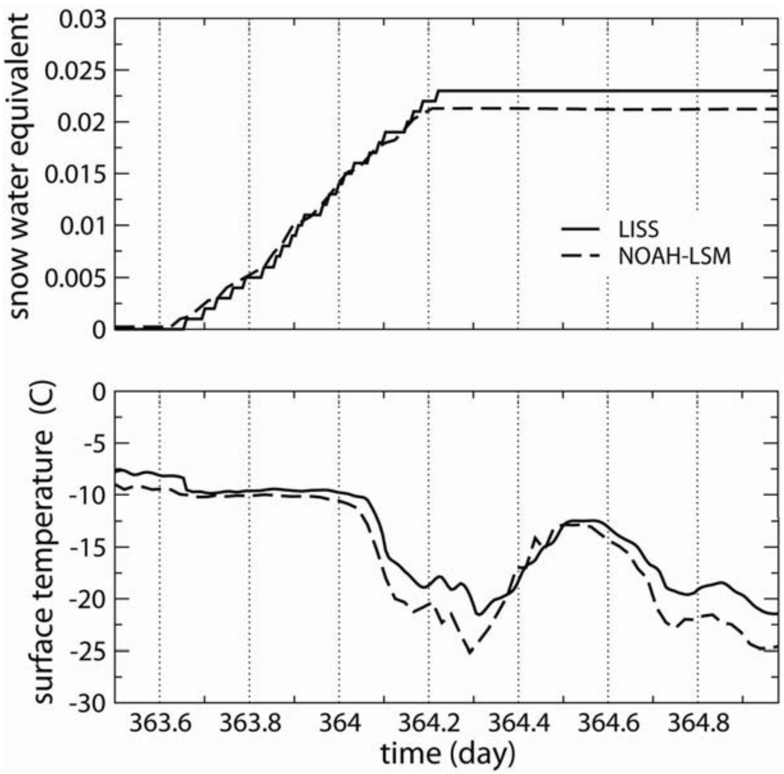


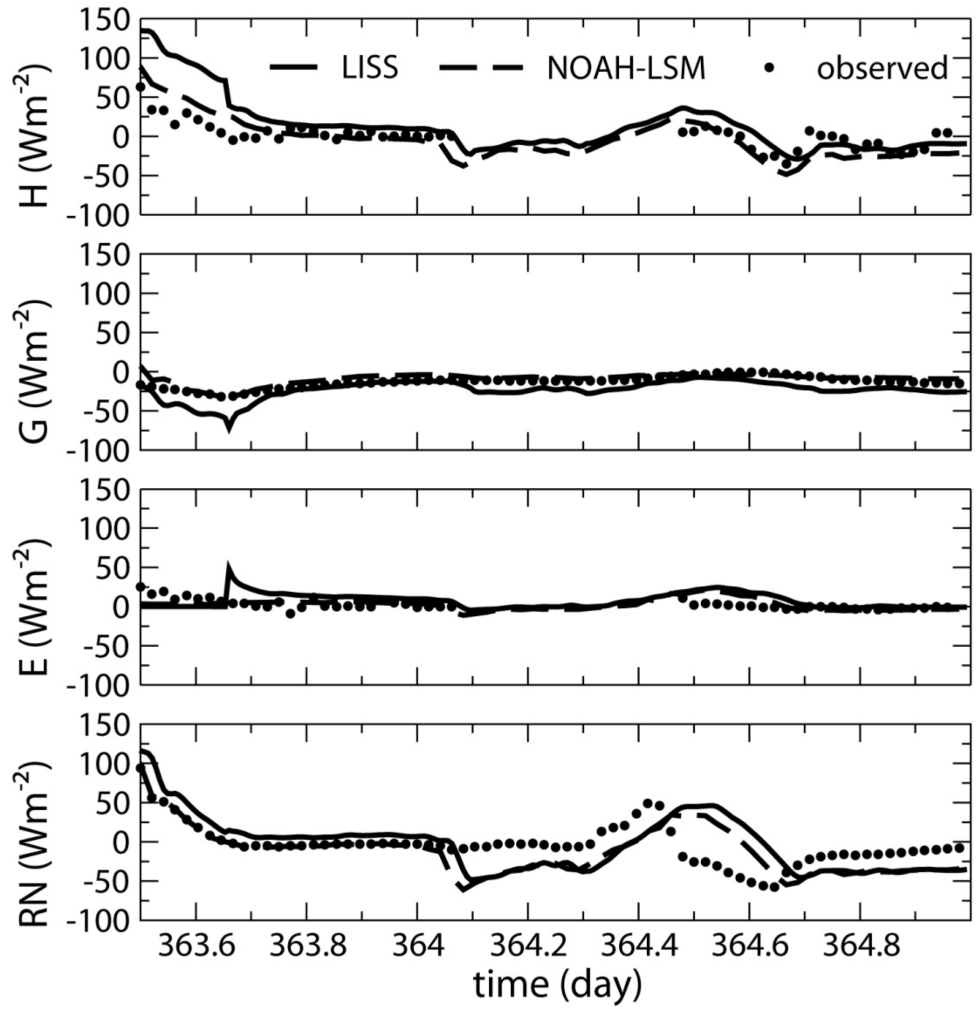
LISS vs. NOAH-LSM and measurements: skin temperature RMSE



LISS vs. NOAH-LSM and measurements: snow

snow appeared at the end of the year, in the last 3 days





Summary

● ***LISS model needs only information about soil and vegetation type for simulation, therefore it is prepared for operational use in NWPM.***

● ***Basic tests for verification of mass and energy conservation are performed and model has shown that it is numerically correct.***

● ***Soil moisture forecast is very good in each model layer ; distribution of water in model between processes that are components of water balance are similar as in reference model NOAH-LSM.***

● ***Parameterization of surface fluxes in LISS performed very well and it is able to simulate rapid and intense diurnal changes.***

● ***Skin temperature depends on surface fluxes and therefore LISS also showed that it is able to catch rapid and intense temperature change.***

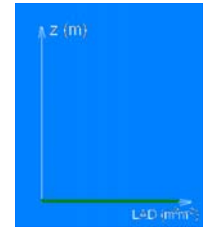
● ***For mean annual values LISS gave excellent results, which is important for long range simulations.***

● ***LISS verification for snow case could not be fully performed because data were not available, but for presented three-day period LISS showed promising results.***

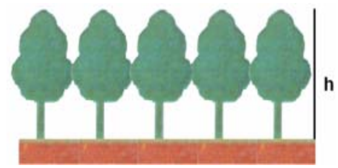
Vegetation present on the surface

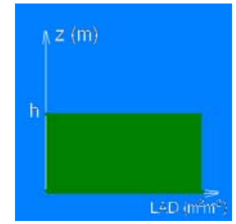
- *Evapo-transpiration from canopy*
- *Rain interception and re-evaporation*
- *Extraction of water from different soil layers through the root system*
- *Modeling*

- ***The big leaf***

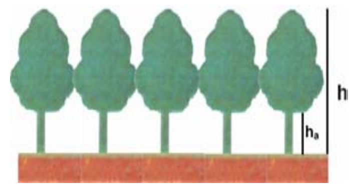


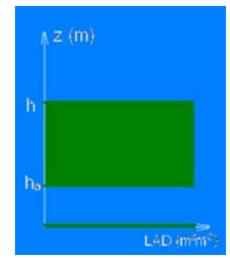
- ***Single layer***



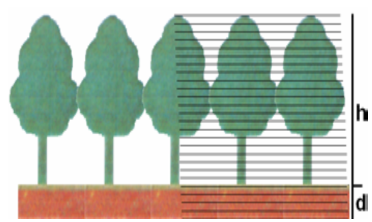


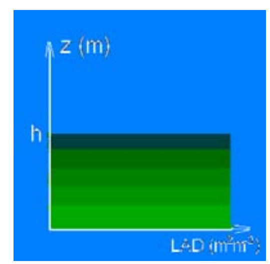
- ***Sandwich***





- ***Multi layer***





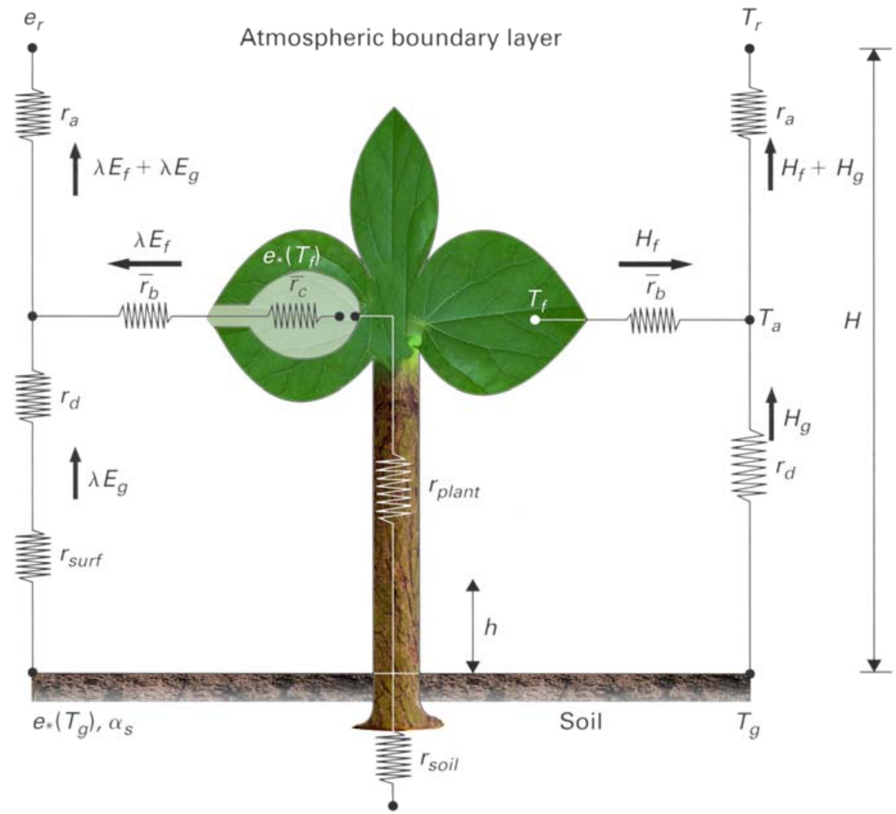
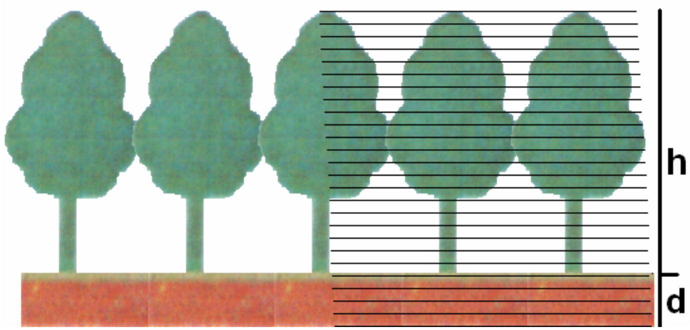
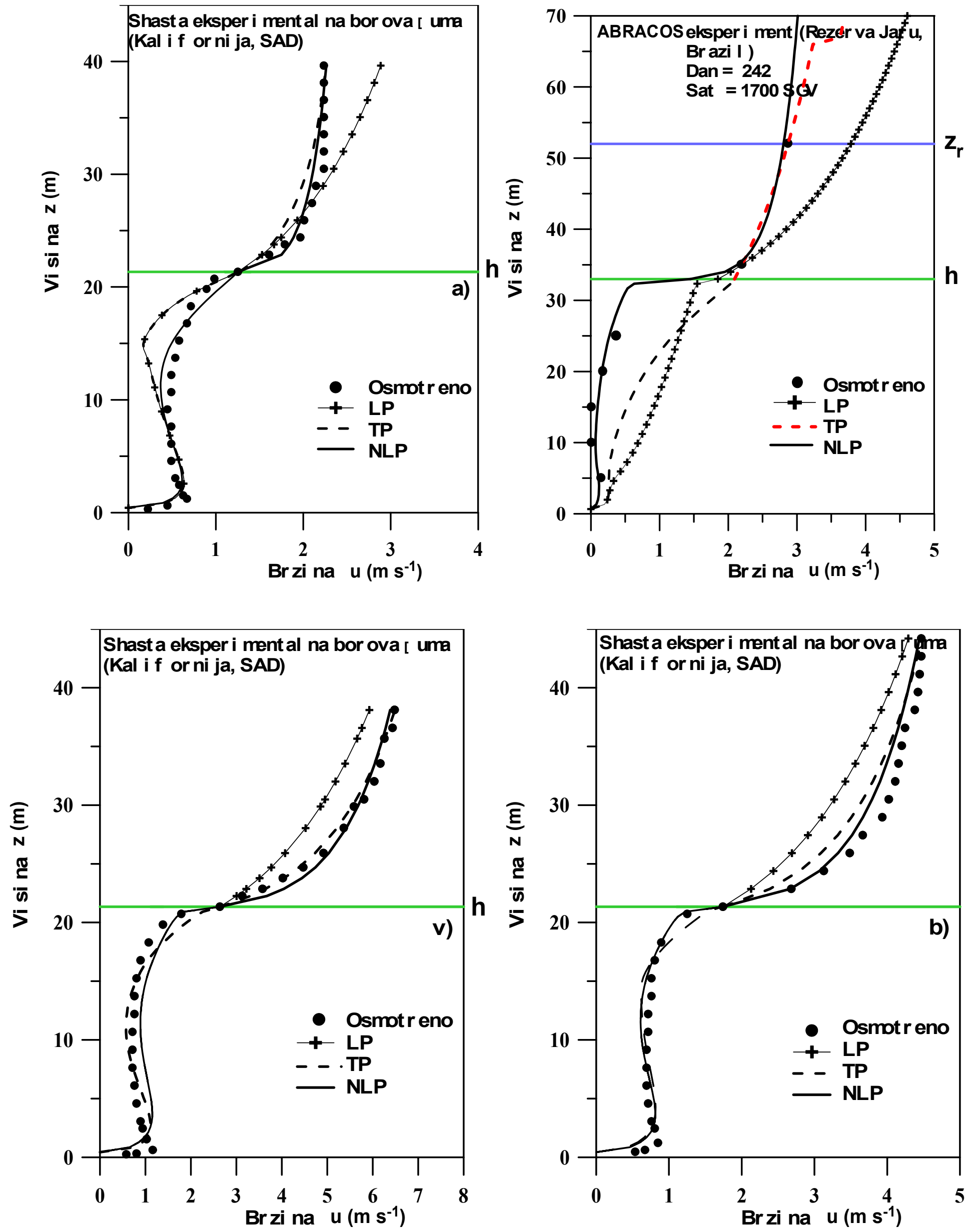


Figure 8.1. Schematic diagram of the Land–Air Parameterization Scheme (LAPS). The transfer pathways for latent sensible heat fluxes are shown on the left- and right-hand sides of the diagram respectively.

2 layer model



Lalic, B., Mihailovic, D.T., 2008: Turbulence and wind above and within the forest canopy, In: Fluid Mechanics of Environmental Interfaces, Eds.: C. Gualtieri and D.T. Mihailovic, Taylor & Francis Ltd., 221-240



Some additional comments/questions about soil /vegetation

- ***Horizontal movement of water ?***

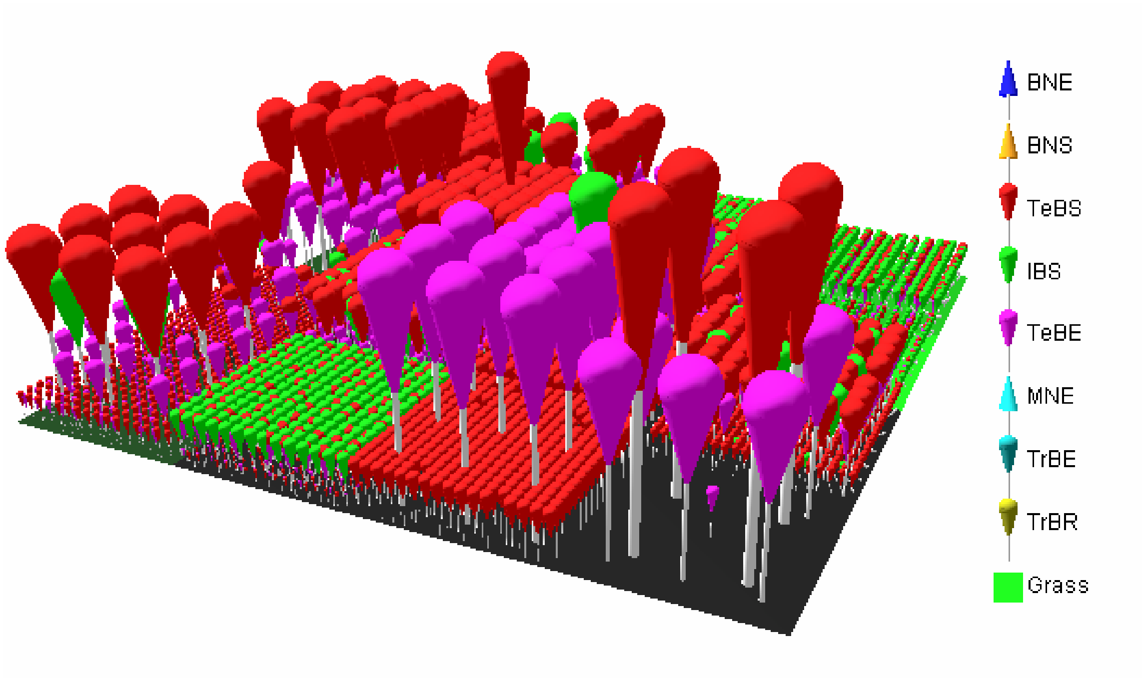
Depending on the lead-time. Up to 10 days probably not important,

monthly probably yeas,

seasonal and longer definitely yeas.

More on the subject in the hydrology talk.

Spatial variations of the parameters that describing soil movement of water and heat conduction is very variable even on the smallest imaginable scales say few tens/hundreds of meters. This led in some cases to very high resolution in the size of the grid cells on land. This raises the question of the fluxes entering grid cell in the atmospheric model. We can have simple spatial averaging or more sophisticated, physically based aggregation. This influences the surface layer calculations, length scale, friction height etc.



An example of possible complexity of vegetation within the single grid cell

(Belgrade area, The LPJ-GUESS data for fractional types)

Dynamic vegetation

- ***Biosphere plays an active role in maintaining the global environment. Vegetation influences atmosphere through the state of the soil, evapo-transpiration and greenhouse gas exchange, while the atmosphere vegetation through radiation, precipitation and wind.***

A dynamic vegetation model simulates vegetation life cycle. It is capable of differentiating between vegetation types depending on the external conditions.

Of course, such complex topic has generated variety of models with different complexity.

A model like that can be either coupled to GCM or can be run alone with prescribed meteorological and soil data.

Typical structure of a dynamical vegetation model combines biogeochemistry, biogeography, and several other sub-models for wildfires, forest/land management decisions, wind-throw, insect damage, ozone damage etc

very different time scales are involved

Time scales

- ***short timescales (i.e., seconds to hours), :rapid biophysical and biogeochemical processes that exchange energy, water, carbon dioxide, and momentum between the atmosphere and the land surface.***

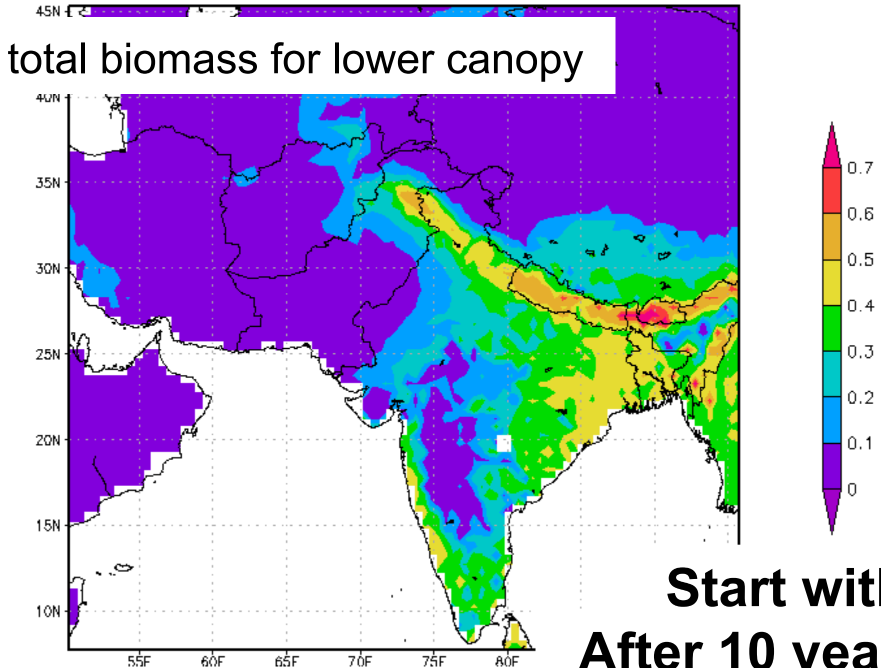
- ***Intermediate-timescale (i.e., days to months) processes include changes in the store of soil moisture, changes in carbon allocation, and vegetation phenology (e.g., budburst, leaf-out, senescence, dormancy).***

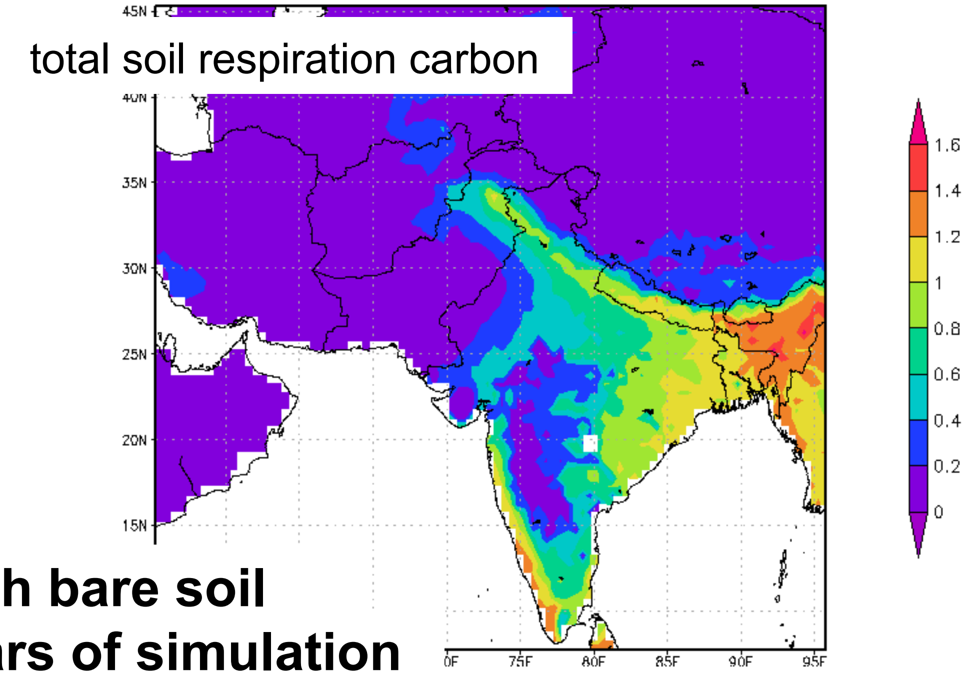
On longer timescales (i.e., seasons, years, and decades), there can be fundamental changes in the vegetation structure itself (disturbance, land use, stand growth).

- ***Several DGVMs have been developed by various research groups around the world i.e. HRBM, IBIS, LPJ, SEIB and TEM among others. Currently we are using IBIS model and have done preliminary runs for several regions of the world i.e. Europe and India subcontinent using observed climate forcing.***

- ***Our plans are coupling of IBIS with our regional climate model. In the first phase regional climate model will provide forcing for the vegetation module.***

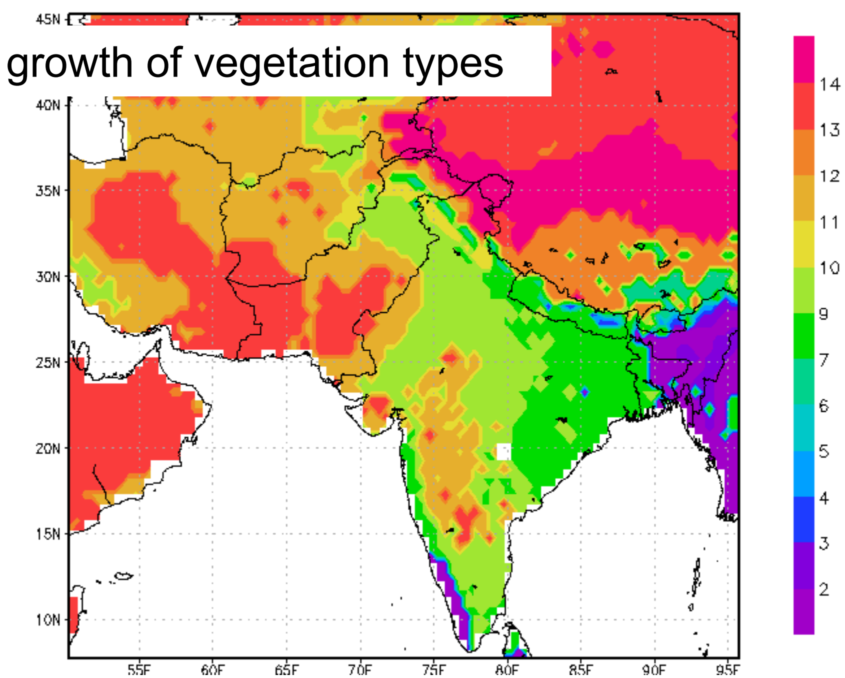
- ***The last step will be full coupling between atmospheric and vegetation components over very long (climate) time scales. We will also consider combination of afore mentioned models and finally try to improve certain aspects of the vegetation model.***





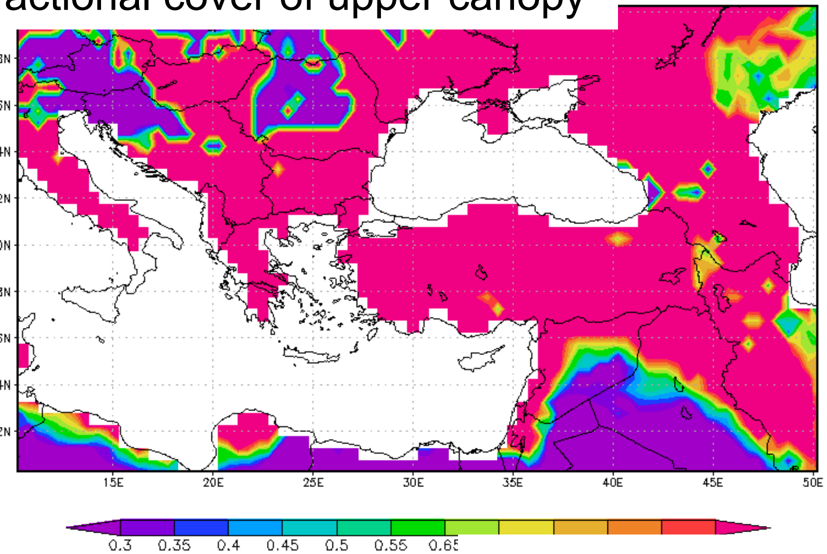
Start with bare soil

After 10 years of simulation

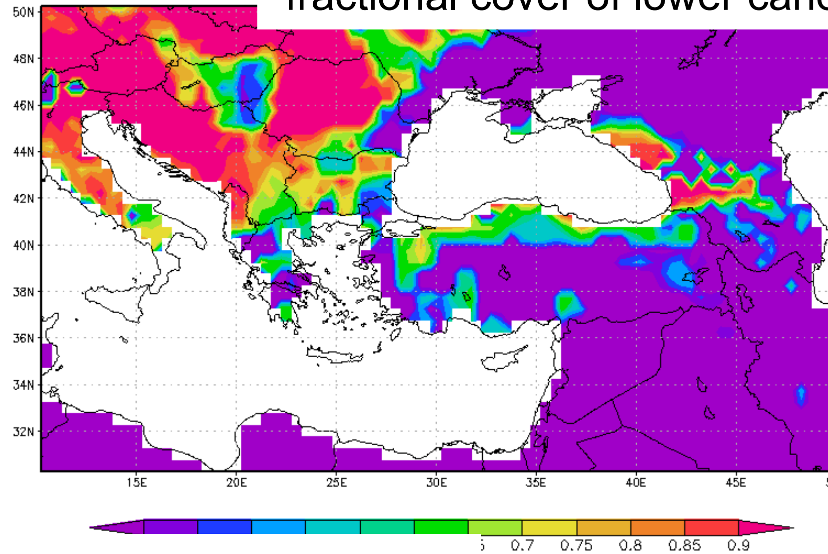


Vegetation type classifications
1: tropical evergreen forest / woodland
2: tropical deciduous forest / woodland
3: temperate evergreen broadleaf forest / woodland
4: temperate evergreen conifer forest / woodland
5: temperate deciduous forest / woodland
6: boreal evergreen forest / woodland
7: boreal deciduous forest / woodland
8: mixed forest / woodland
9: savanna
10: grassland / steppe
11: dense shrubland
12: open shrubland
13: tundra
14: desert
15: polar desert / rock / ice

fractional cover of upper canopy

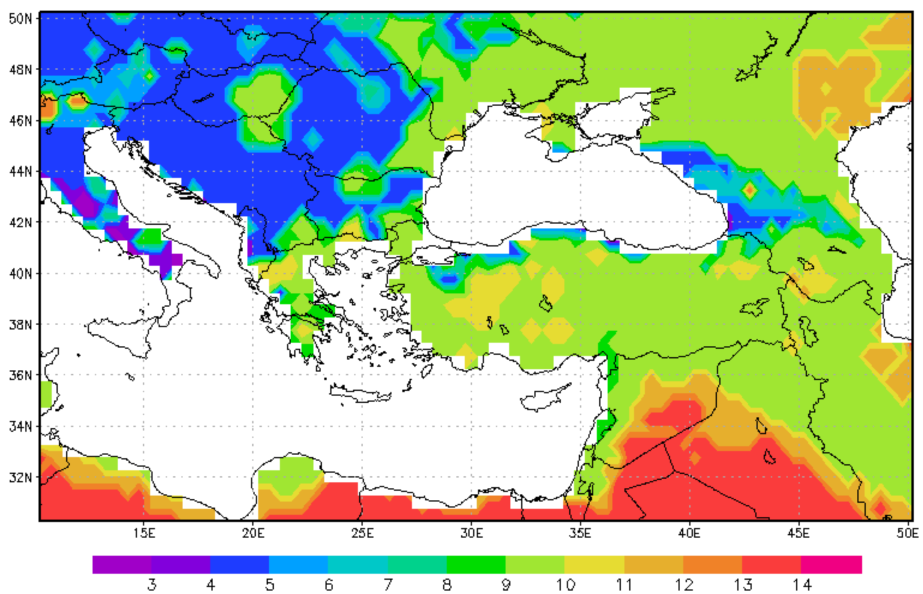


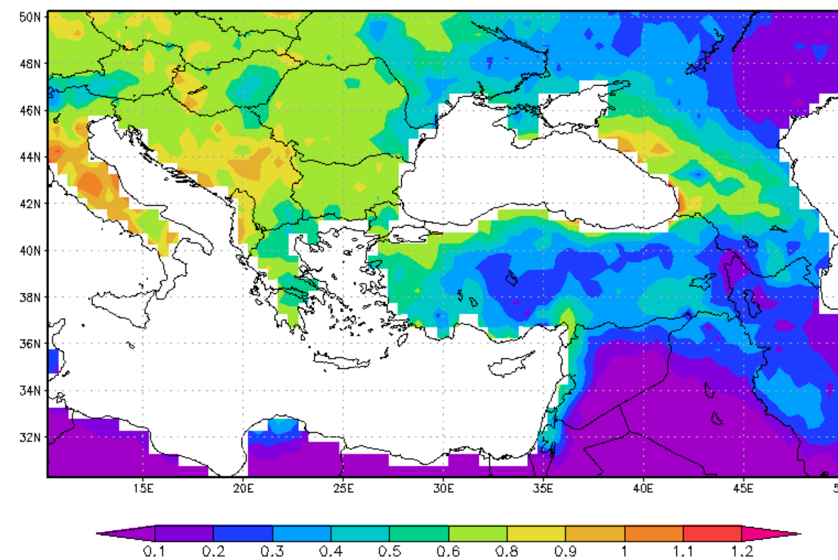
fractional cover of lower canopy



Start with observed vegetation
After 10 years of simulation

growth of vegetation types





total net primary production