Boundary layer land surface as a coupled system

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- How to build and evaluate models, bottom-up / top-down
- Boundary layer climate equilibrium thinking
- Stable boundary layer land surface coupling as a budget problem

Bottom-up and top-down in land surface parametrization

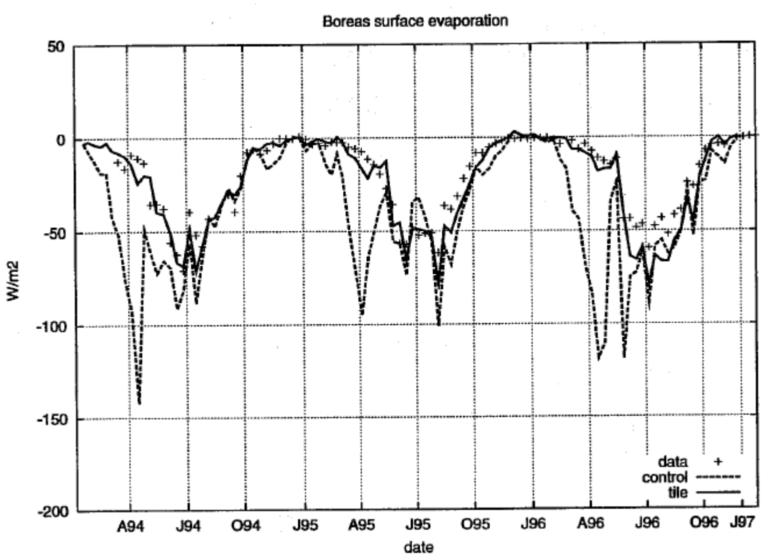
Bottom-up:

• Build land surface scheme from knowledge of vegetation and soil on local scale
•Derive land use data sets from satellite data
•Set parameters (soil, vegetation parameters)
•Test with local data and optimize parameters (no feedbacks)

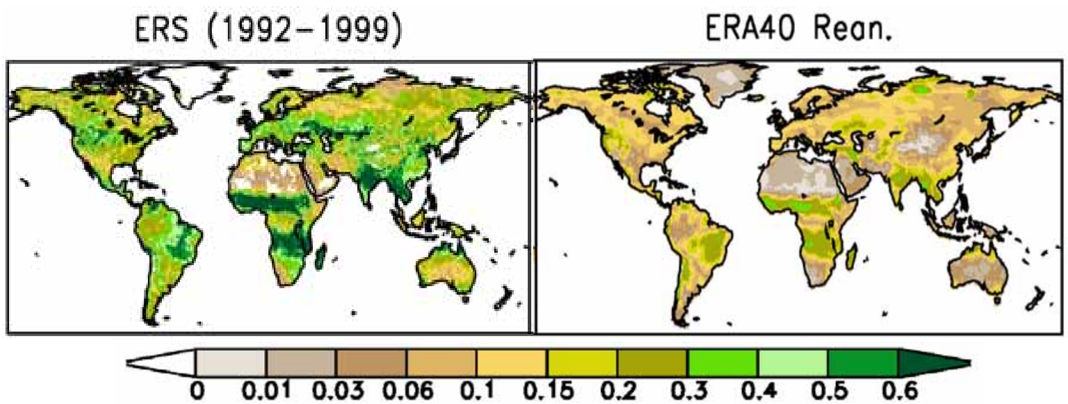
Top-down:

• Do long integrations in global model and assess large scale budgets (e.g. compare with precip and runoff data)
•Do data assimilation using boundary layer budgets of energy and moisture to infer surface fluxes (inverse modelling)
•Sensitivity experiments to optimize parameters (includes feedbacks)

Test of TESSEL in 1D for BOREAS (v.d. Hurk et al. 2000)



Mean annual range of soil water (Dirmeyer et al 1993)



ERA40 has smallest annual range of soil moisture of all products! Why? Possibly because: soil moisture reservoir too small? Rooting depth?

Alternative: Consider equilibrium climate of the coupled boundary layer / land surface system

Background references:

- Betts, A. K., 2004: Understanding Hydrometeorology using global models. *Bull. Amer. Meteorol. Soc*., **85**, 1673-1688.
- Betts, A. K and P. Viterbo, 2005: Land-surface, boundary layer and cloud-field coupling over the south-western Amazon in ERA-40. *J. Geophys. Res*., **110**, D14108, doi:10.1029/2004JD005702.
- ERA-40 Project Reports 6, 7, 22, 25
- *Betts, A.K., 2005: Radiative scaling of the nocturnal boundary layer. J. Geophys. Res., (submitted)*

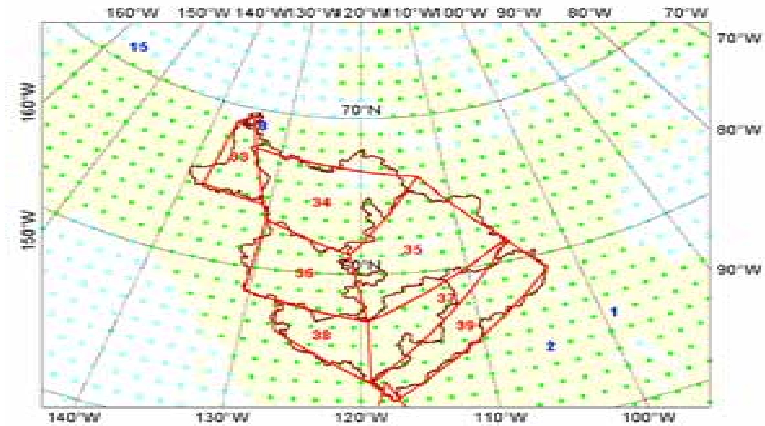
"Understanding hydrometeorology using global models" *[Betts, 2004]*

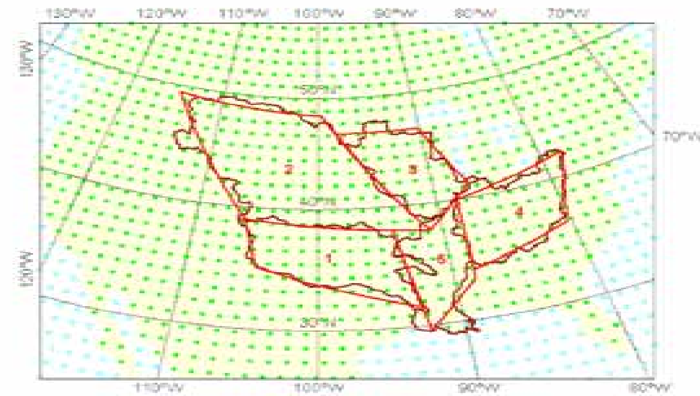
- Usually we rely on simple models to gain understanding, but hydrometeorology is too complex for that, and too important for us to be satisfied with rough approximations. The climate interactions of water [vapor, liquid and ice, and its phase change and radiation interactions] are central to understanding climate change [and they are closely coupled to the biosphere]

- A global model can show the structure of the links
- Useful if the model has been evaluated deeply

ERA40 river basin “*hydro-radiative climatology*”

- Hourly means over river basins
- Mackenzie, Mississippi,
  Amazon and LaPlata
- Soil, surface and atmospheric column
- Fluxes and state variables



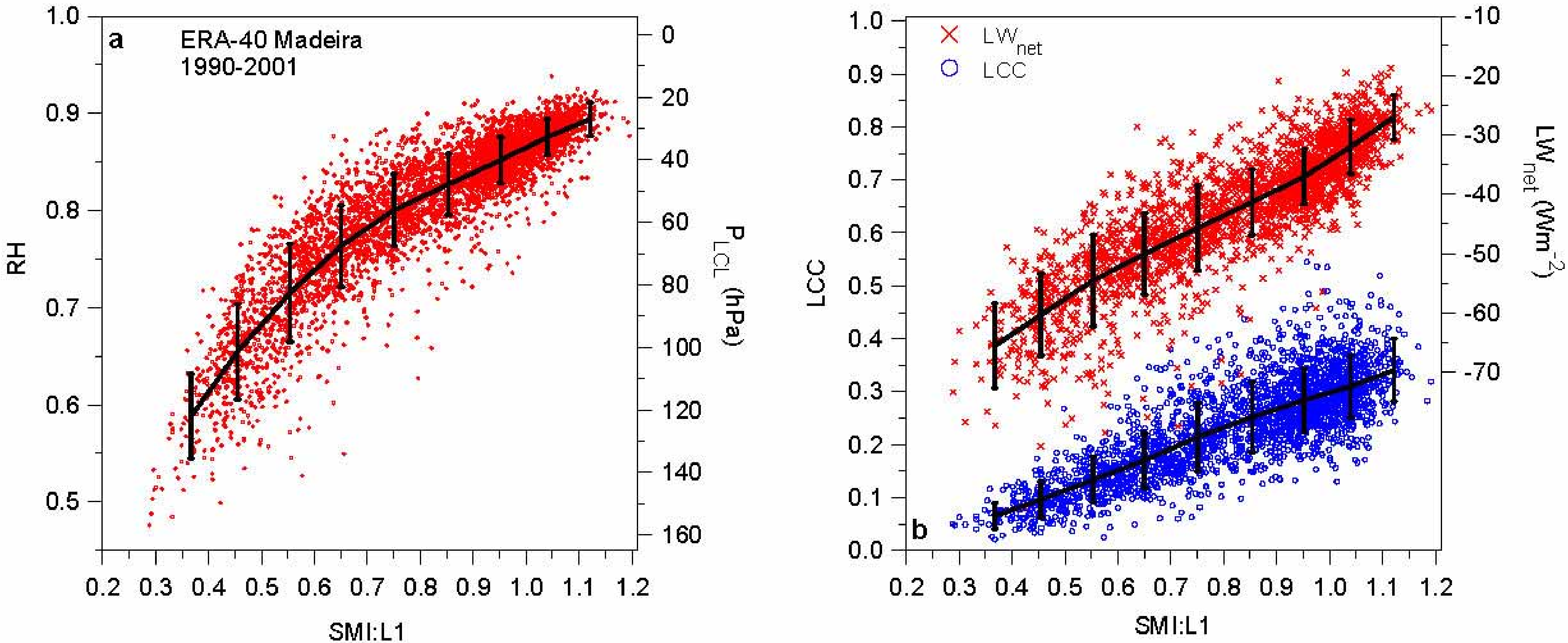


Model ‘climate state’ over land

- Map model climate state and links between processes using daily means
- Think of seasonal cycle as transition between daily mean states

  + synoptic noise
- Diurnal cycle determined by daily mean parameters

ERA40: Surface 'control'



- Madeira river, SW Amazon
- Soil water $\longrightarrow$ LCL, LCC and LW_{net}

[Betts and Viterbo, 2005]

Surface SW cloud forcing: SWCF

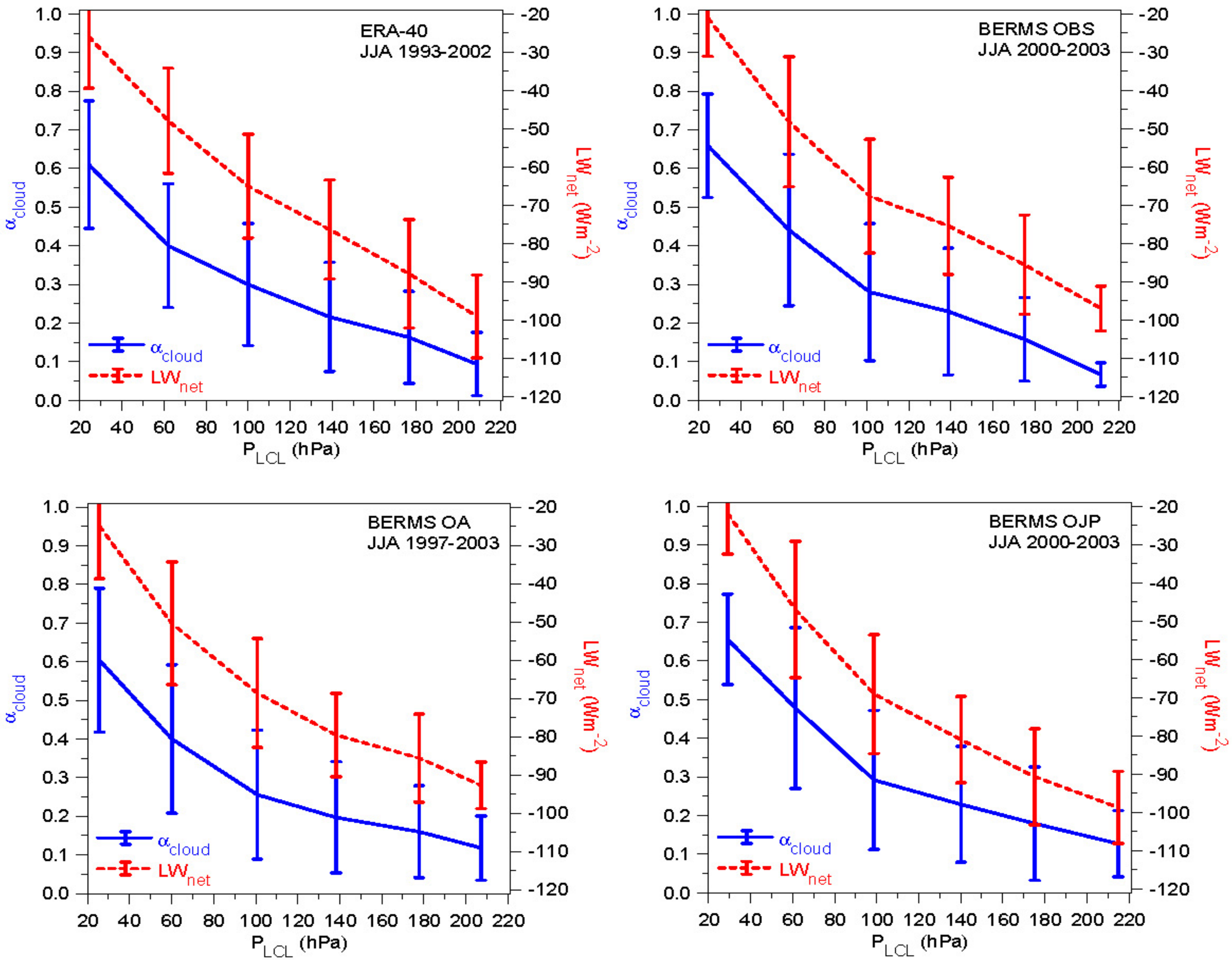
Define SURFACE 'cloud albedo'

α_{cloud} = 1-SW:SRF/SW:SRF(clear)

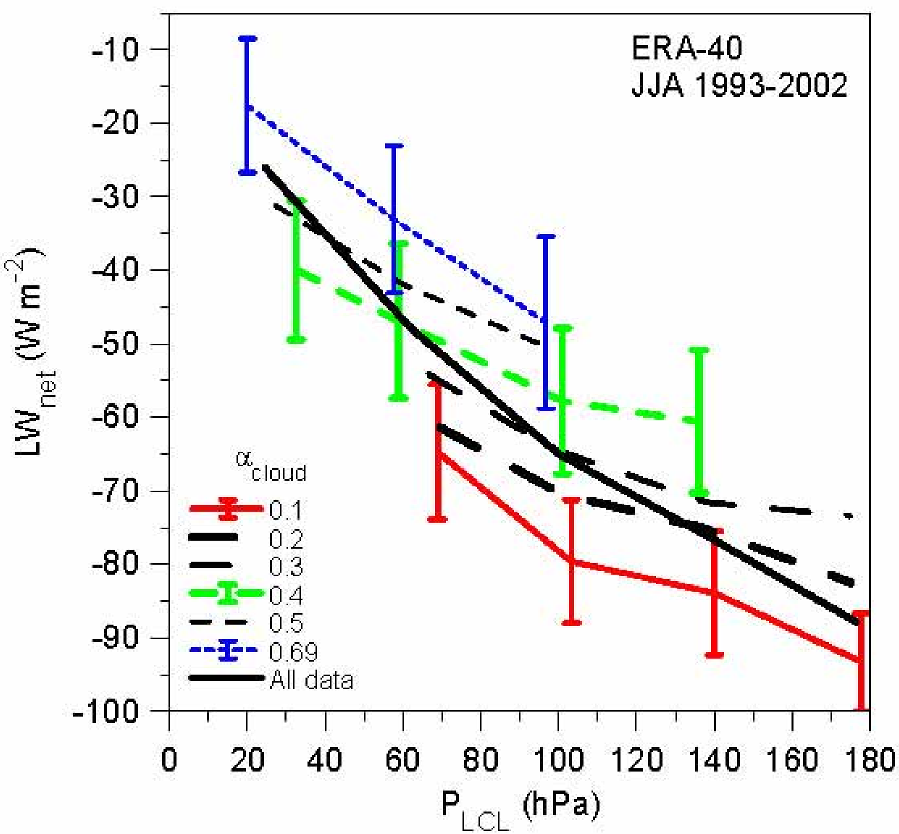
= -SWCF/SW:SRF(clear)

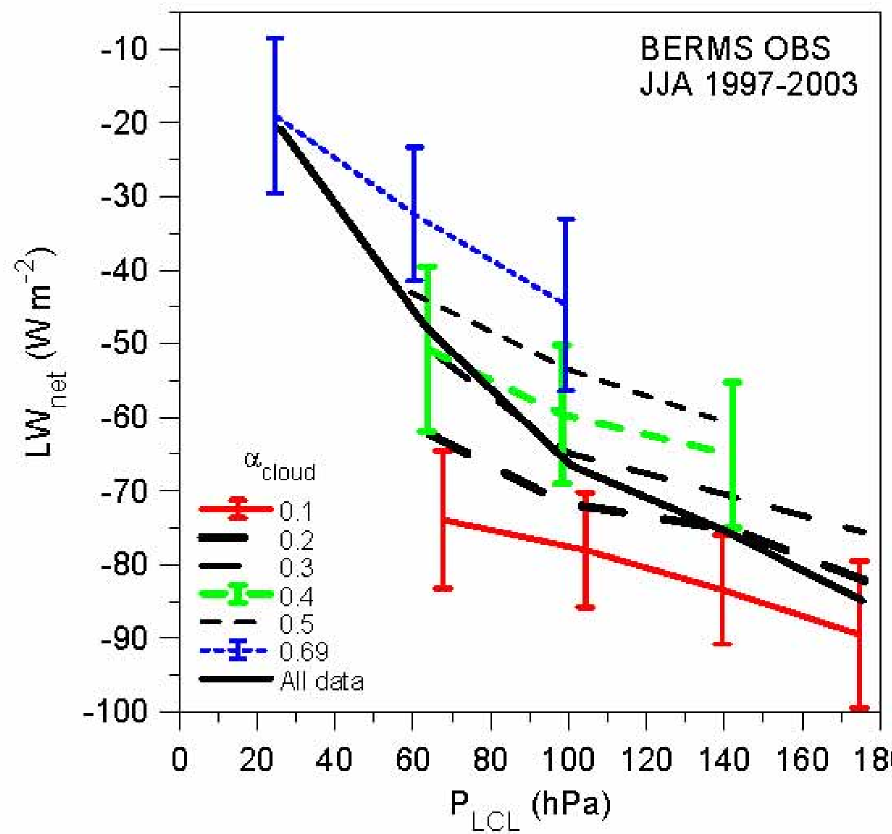
[fraction reflected or absorbed by cloud field]

$P_{LCL} \rightarrow \alpha_{cloud}$ and LW_{net}



Controls on LW_{net}



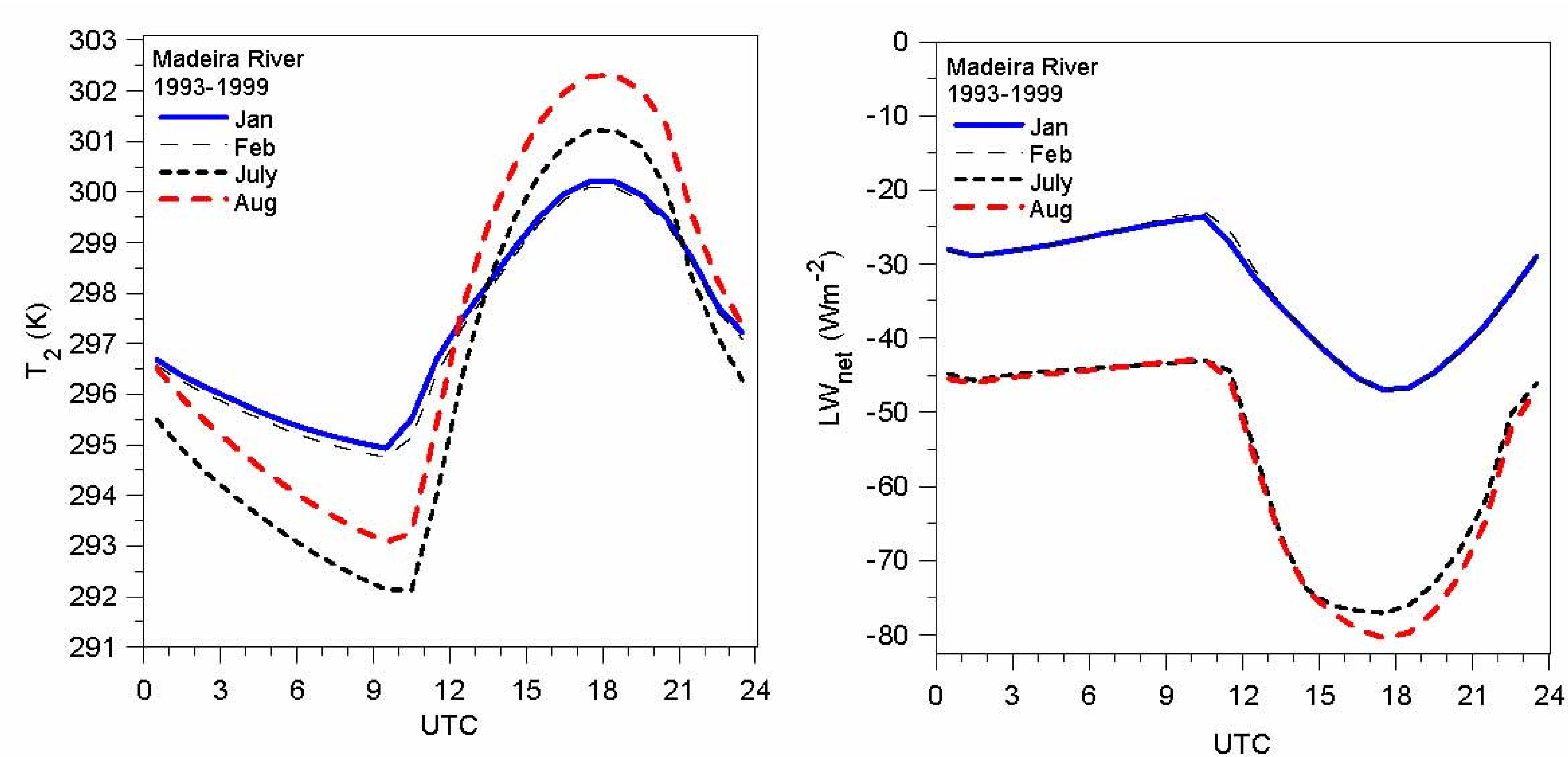


- Same for BERMS and ERA-40
- Depends on P_{LCL} [mean RH, & depth of ML]
- Depends on cloud cover

What controls diurnal cycle?

- Is it daytime process?
- Nighttime processes?
- Or both?
- Use of global model [e.g. ERA-40] as diagnostic tool for studying coupled land-atmosphere
- LWnet and the radiative scaling of nocturnal BL
- Conclusions/Lessons

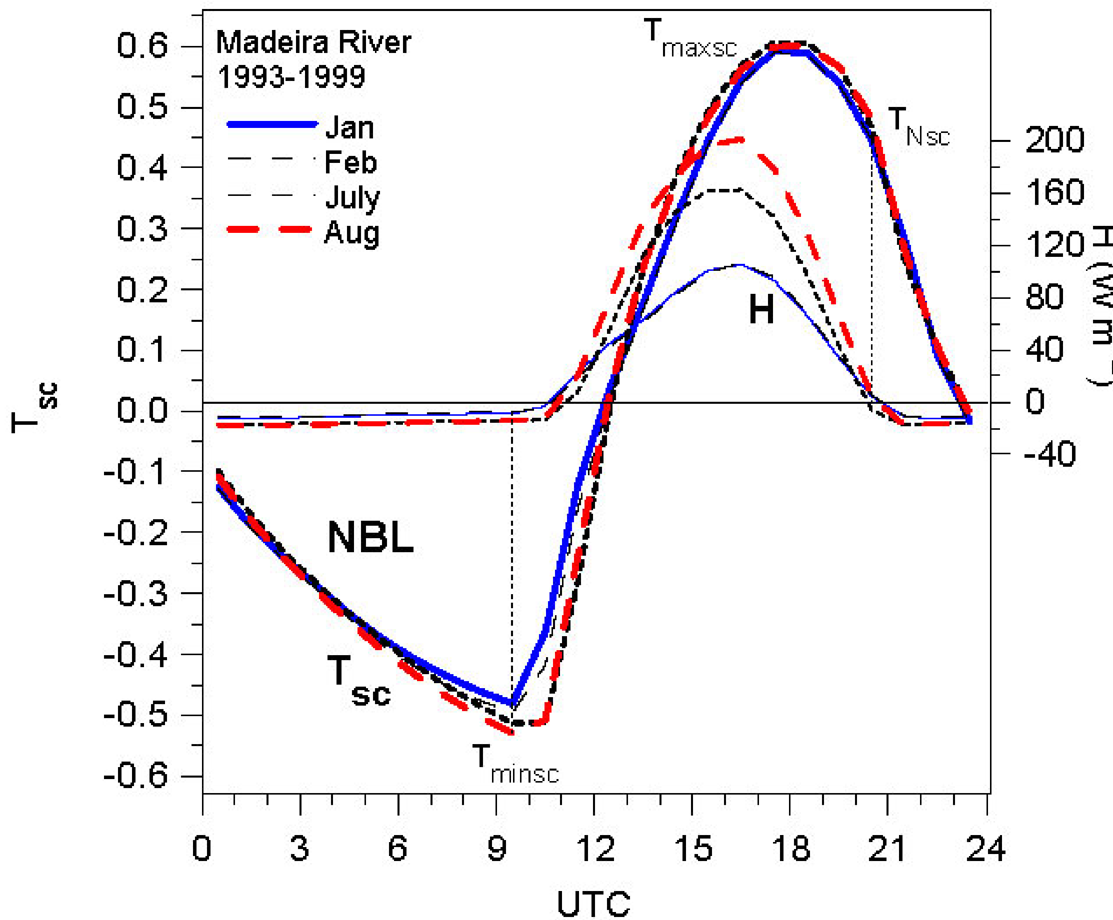
LW_{net} linked to diurnal cycle and nocturnal BL strength



- Amazon dry season
  - larger diurnal cycle and outgoing LW_{net}

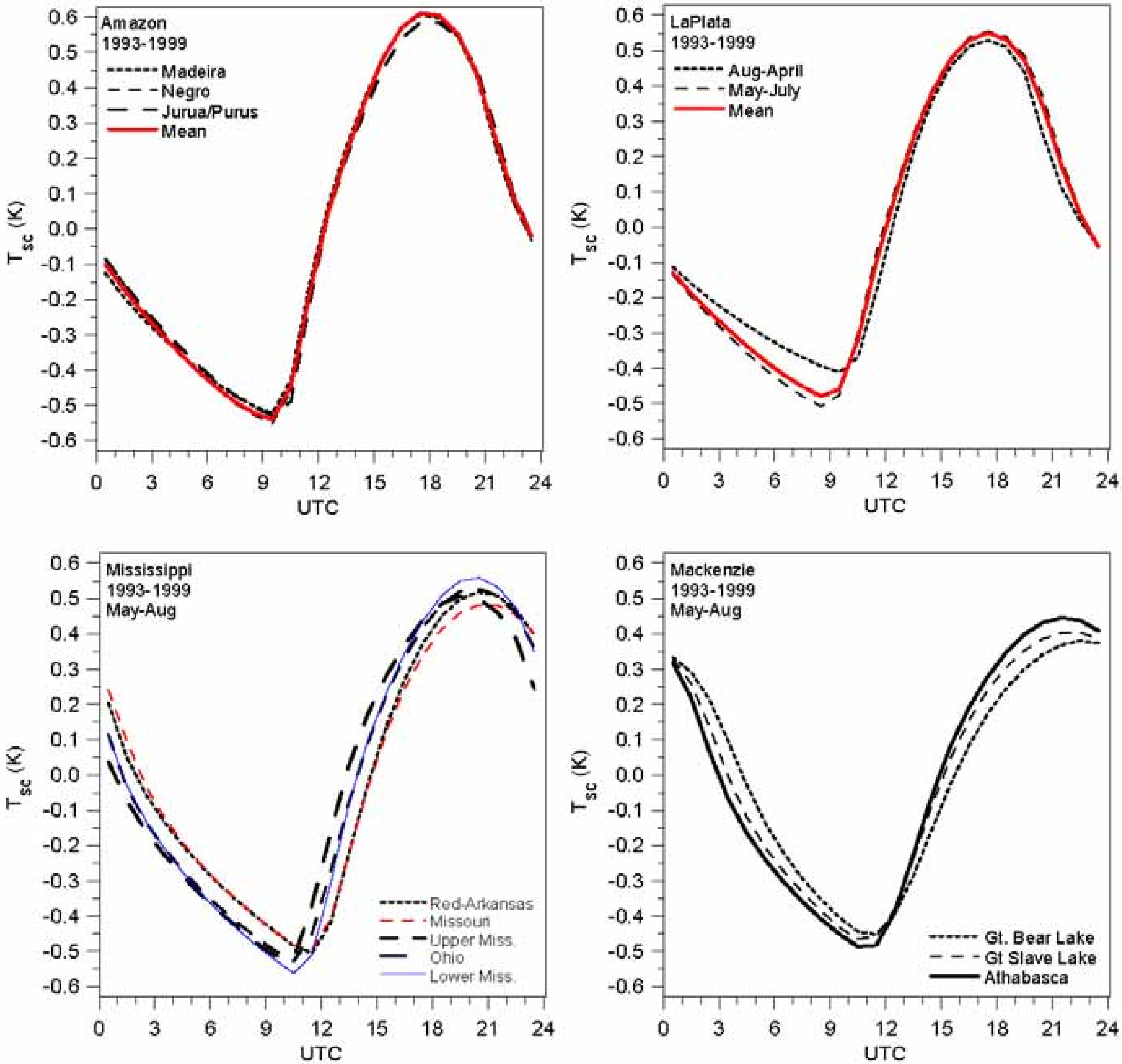
Radiative scaling of NBL

- Radiative temperature scale
- $\Delta T_R = -\lambda_0\, LW_{netN}$
- $\lambda_0 = 1/(4\sigma T^3)$
  $= 0.175\ K/(Wm^{-2})$
  at T=293K
- $T_{sc} = T_2 / \Delta T_R$



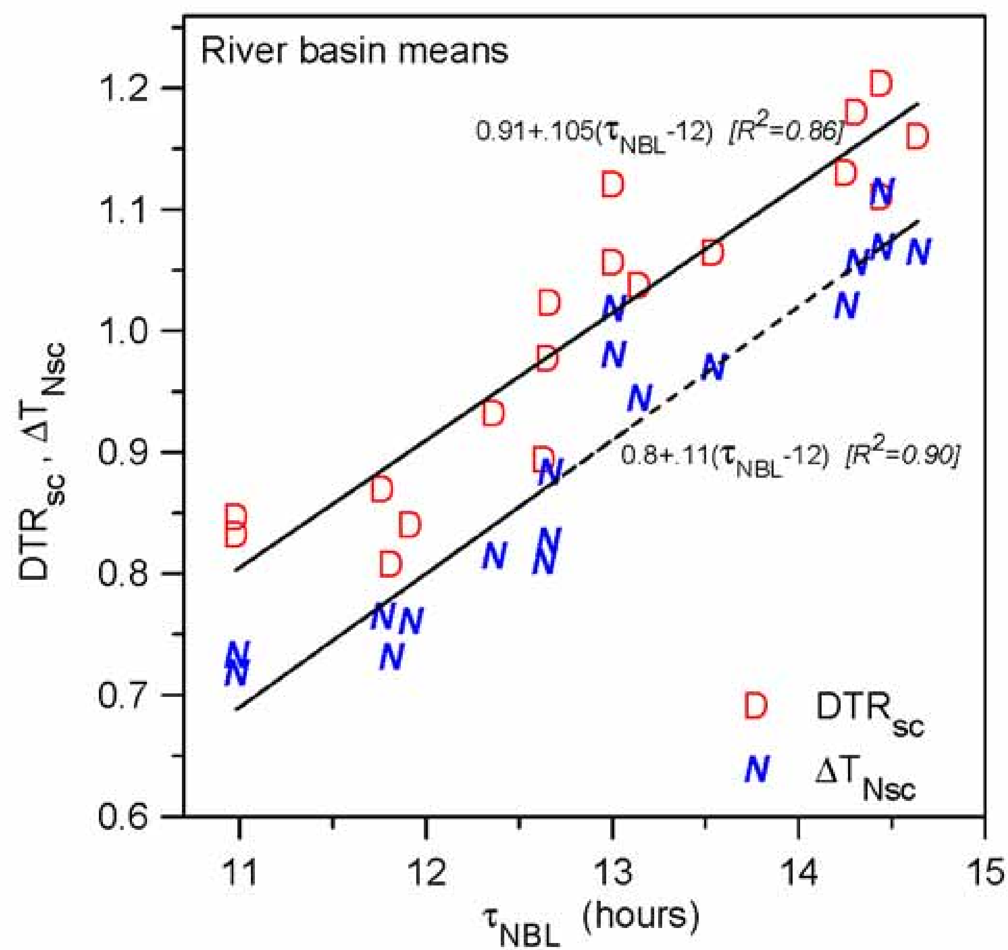
Scaling across basins

- Amplitude decreases with increasing latitude

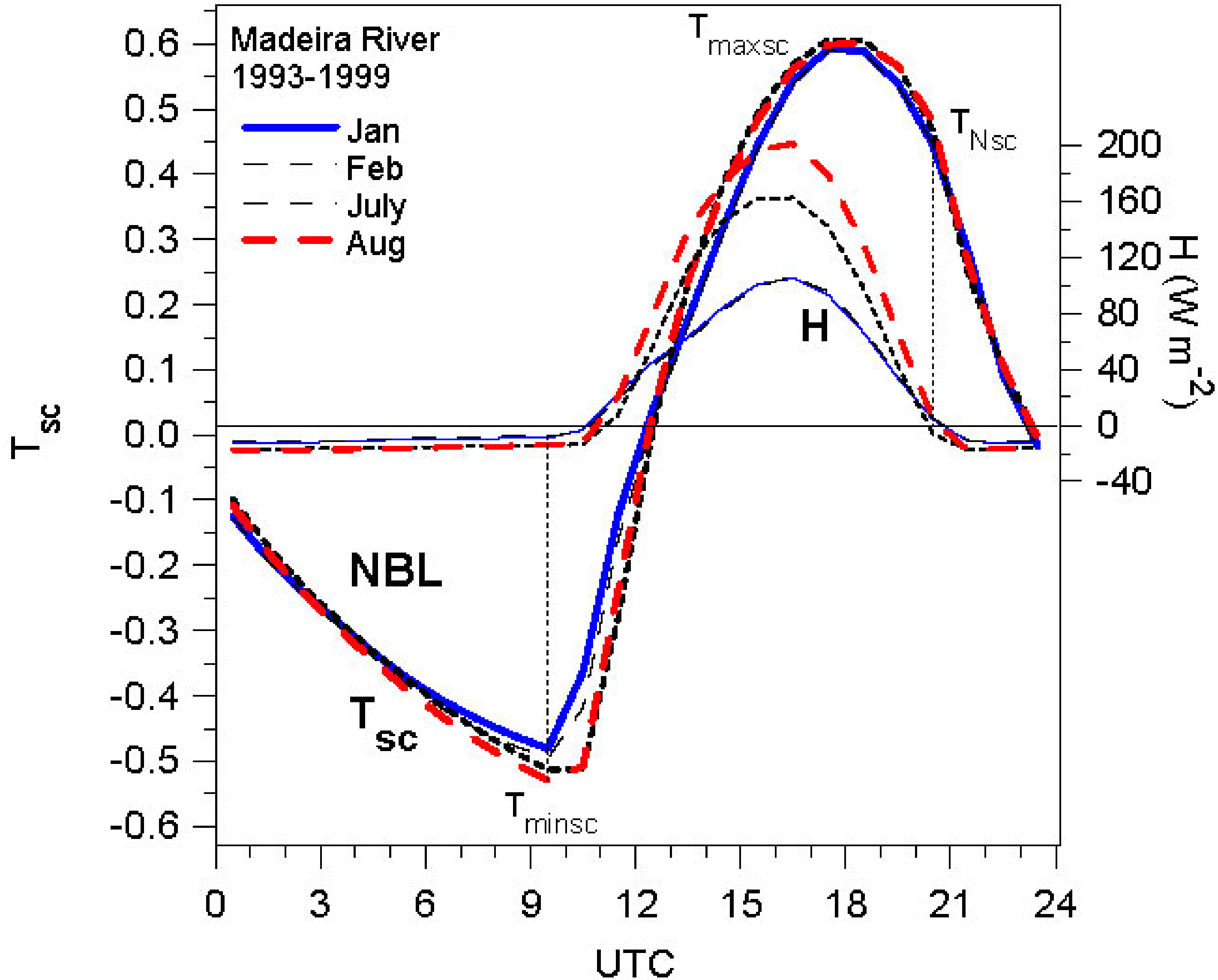


Scaled amplitude increases with 'night-length' (H<0)

- Far north basins have short NBL duration in summer



NBL duration $\tau_{NBL} > \tau_N$ NBL growth time

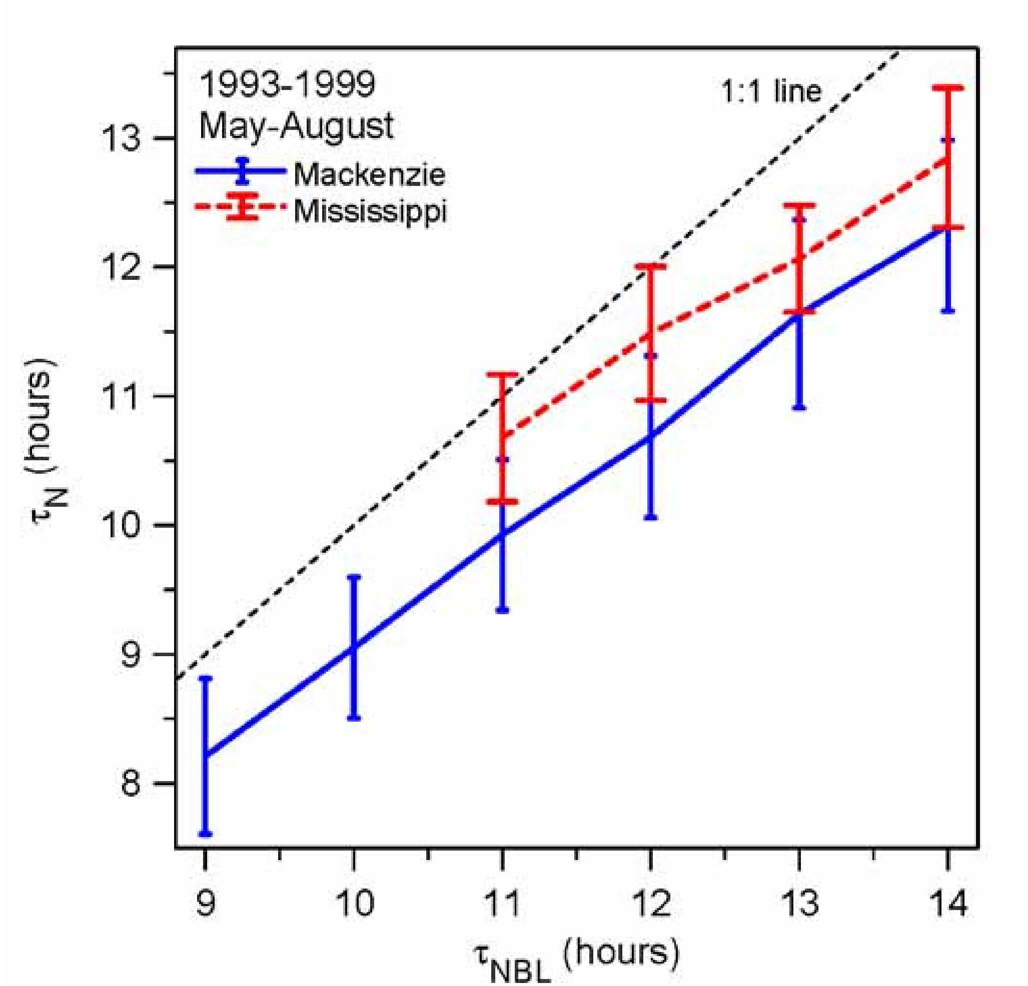


NBL duration: daily data

NBL duration

$$\tau_{NBL} > \tau_N$$

NBL growth time



Dependence of ΔT_{Nsc} and H_{sc} on NBL growth time

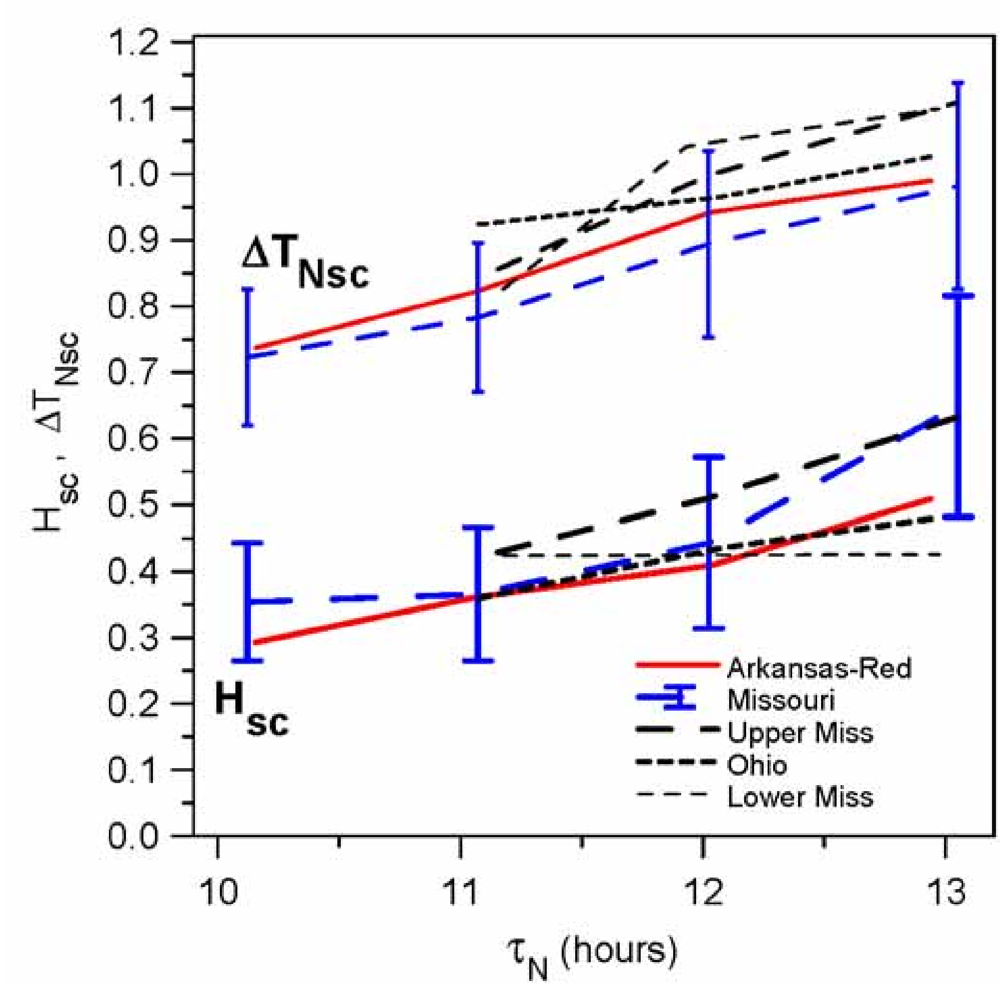
Daily data:

Strength of NBL

$\Delta T_{Nsc} = \Delta T_N / \Delta T_R$

Scaled heat flux

$H_{sc} = H_N / (-LW_{netN})$

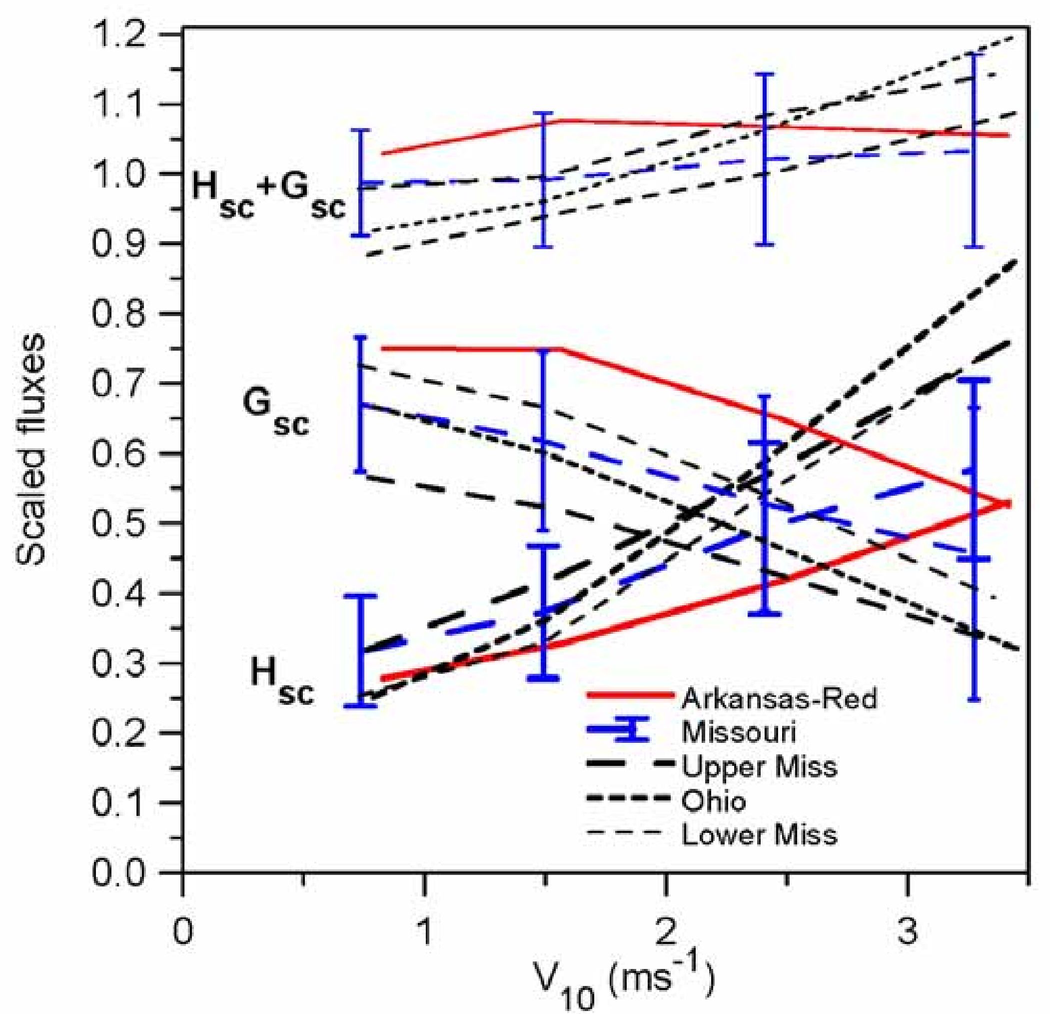


Dependence of scaled energy budget on windspeed

For NBL:

$H_{sc} + G_{sc} \approx 1$

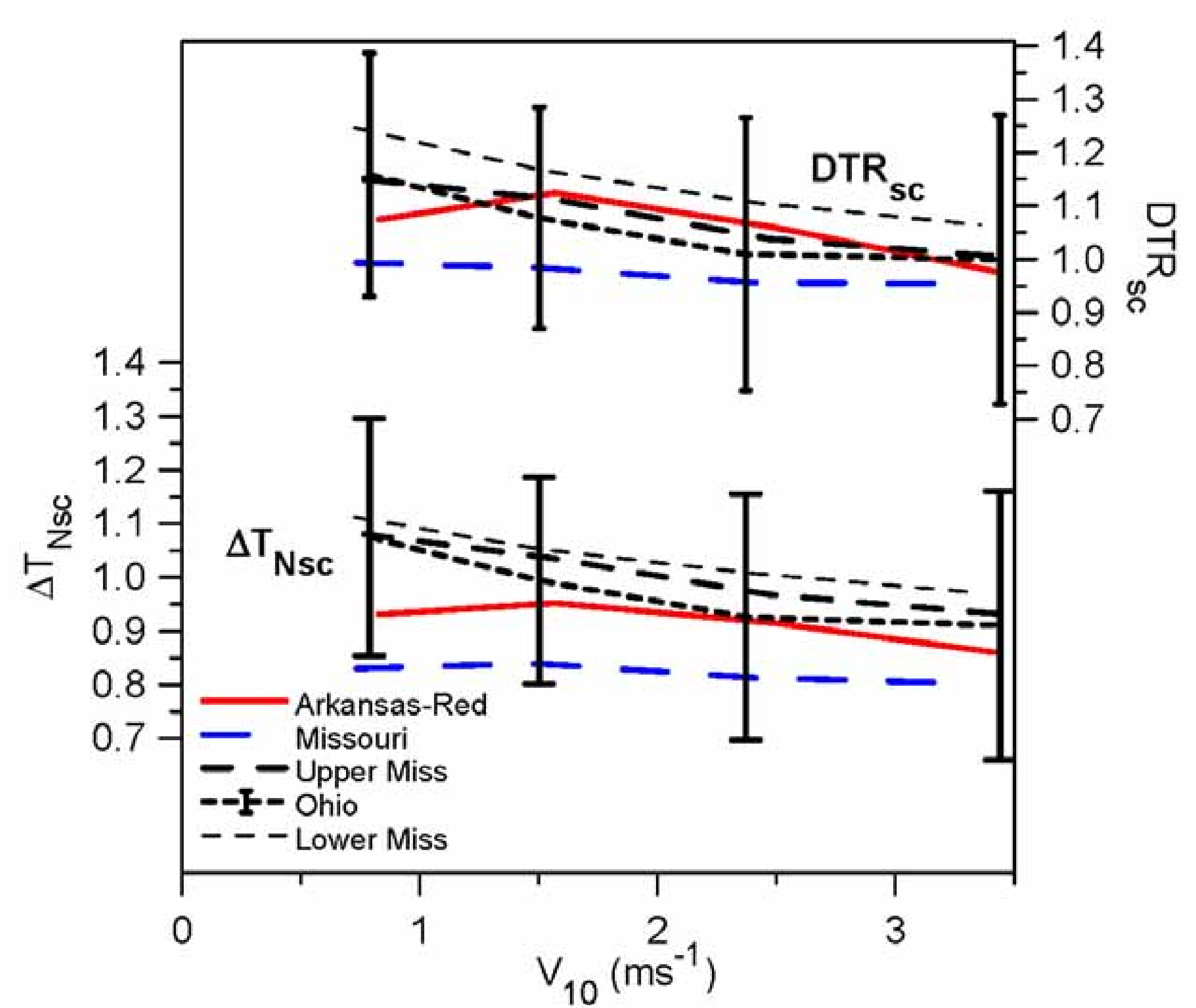
Partition changes with wind speed, but basins differ in slope



Dependence of DTR_{sc} and ΔT_{Nsc} on windspeed

Weak decrease with windspeed

$\Delta T_{Nsc}/DTR_{sc} \approx 0.9$



Radiative velocity scale gives NBL depth **h**

NBL energy balance gives

h = $(H_{sc}/\beta\Delta T_{Nsc})$ $\mathbf{W_R}$ tau_N

$\approx$ $\mathbf{W_R}$ tau_N

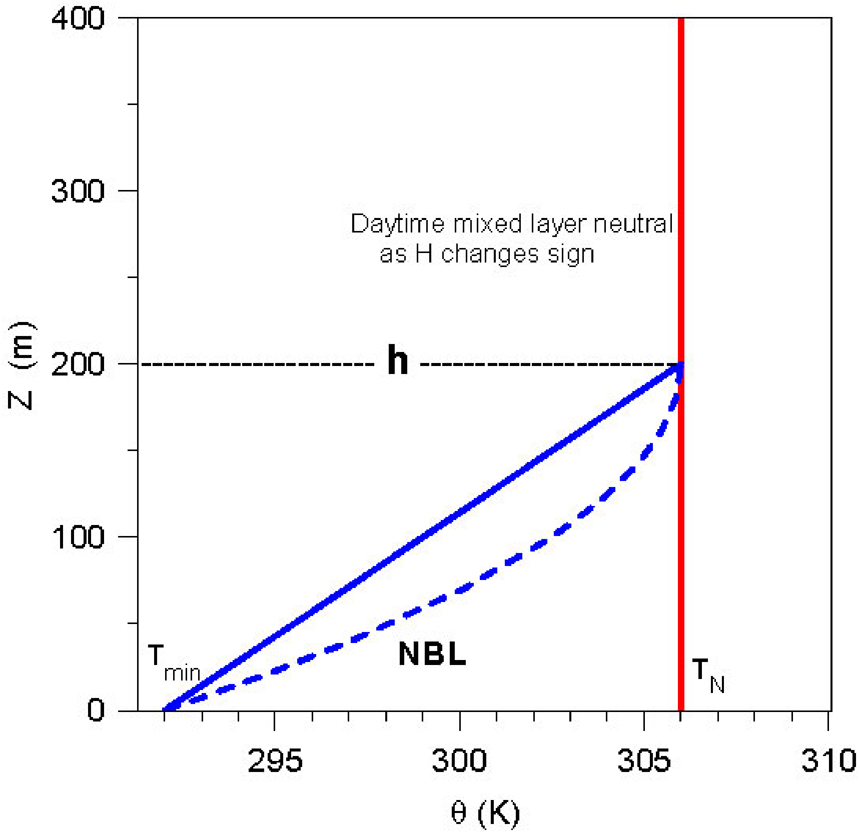
[Linear profile: β=0.5
Quadratic profile: β=0.33]

Radiative velocity scale

- $\mathbf{W_R} = 1/(\rho\ C_p\ \lambda_0)$

  $\approx 0.0048\text{m s}^{-1}$ [40hPa day^{-1}]

- **h** $\approx$ 200m for tau_N =12h



Regression on daily summer data
[non-tropical basins: 10700 days]

Diurnal temp range

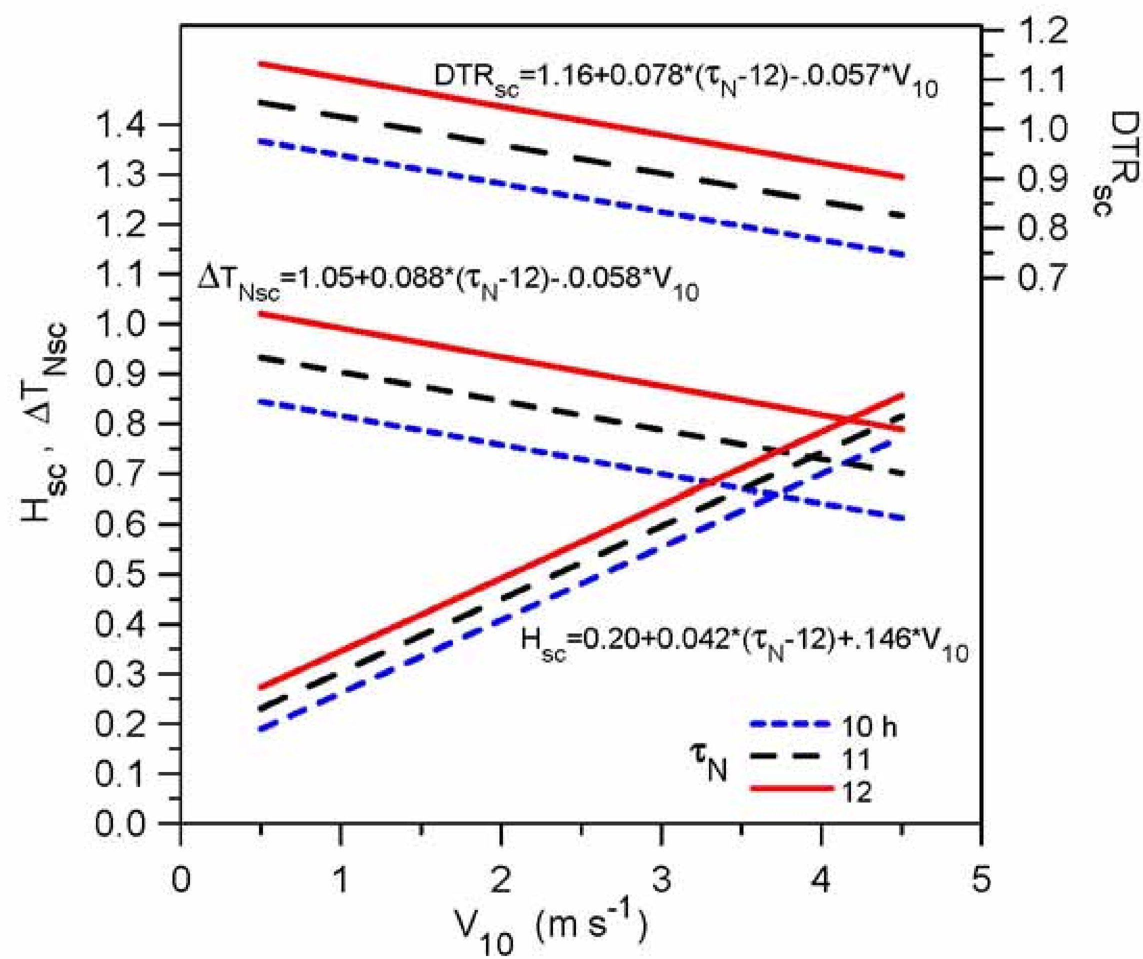
$DTR_{sc} = DTR/\Delta T_R$

Strength of NBL

$\Delta T_{Nsc} = \Delta T_N/\Delta T_R$

Scaled heat flux

$H_{sc} = H_N/(-LW_{netN})$



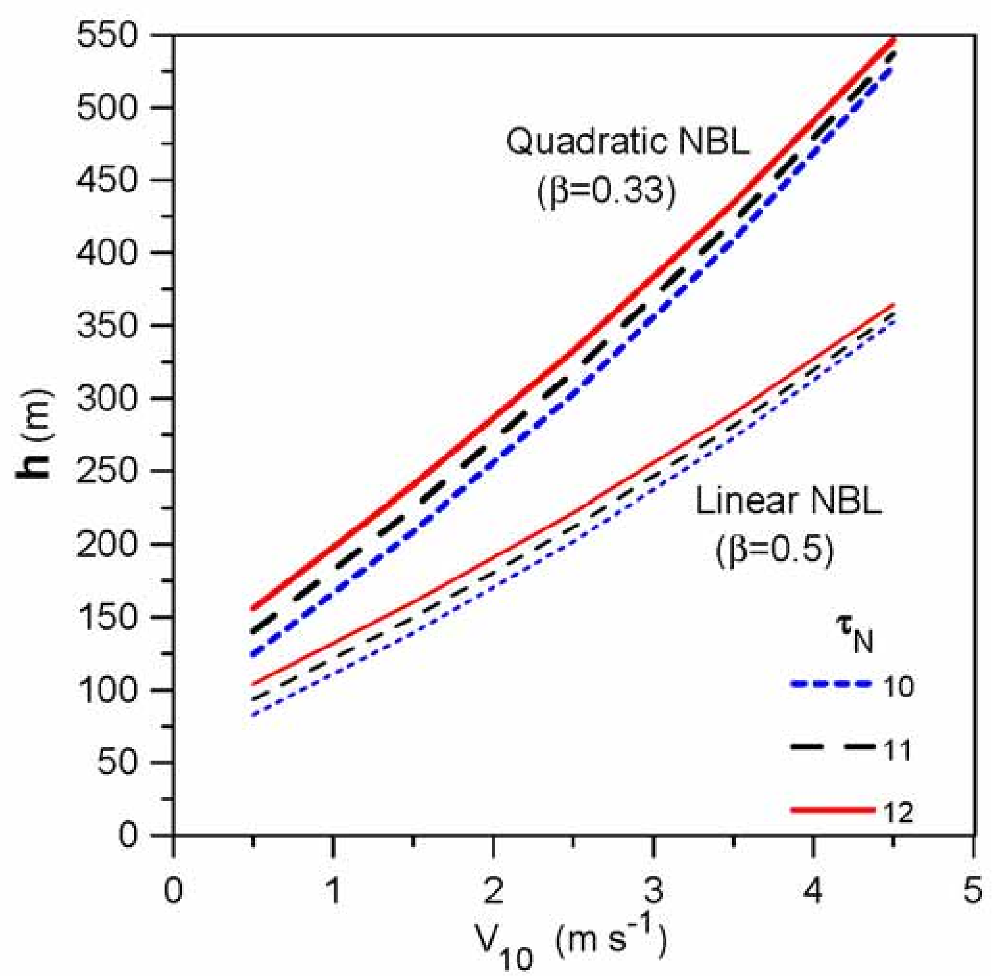
NBL depth: **h**

Using regression fits in

h = $(H_{sc}/\beta\Delta T_{Nsc})$ $\mathbf{W_R}$ tau_N

Linear profile: β=0.5

Quadratic profile: β=0.33

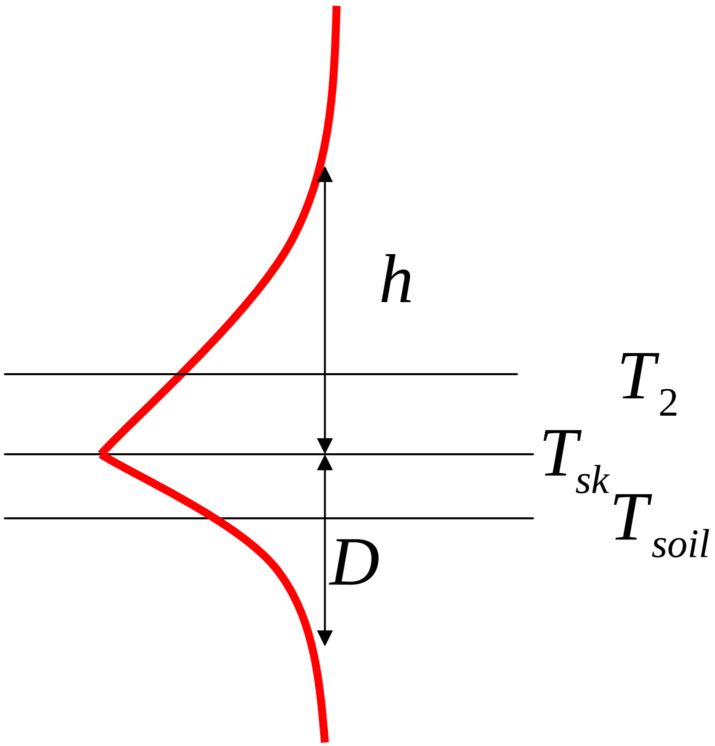


How to verify model behavior ?

Use budget approach with night time averaged fluxes

Major issues:

- How to distribute the long wave cooling realistically over sensible heat flux and soil heat flux
- How to distribute heat fluxes realistically over vertical in atmosphere and soil



Uncertain parameters:

- Boundary layer height (depends on wind speed and stability functions)
- Coupling coefficients between skin layer and soil
- Coupling between skin layer and 2m level (depends on roughness lengths and wind speed)
- Soil properties

Observations:

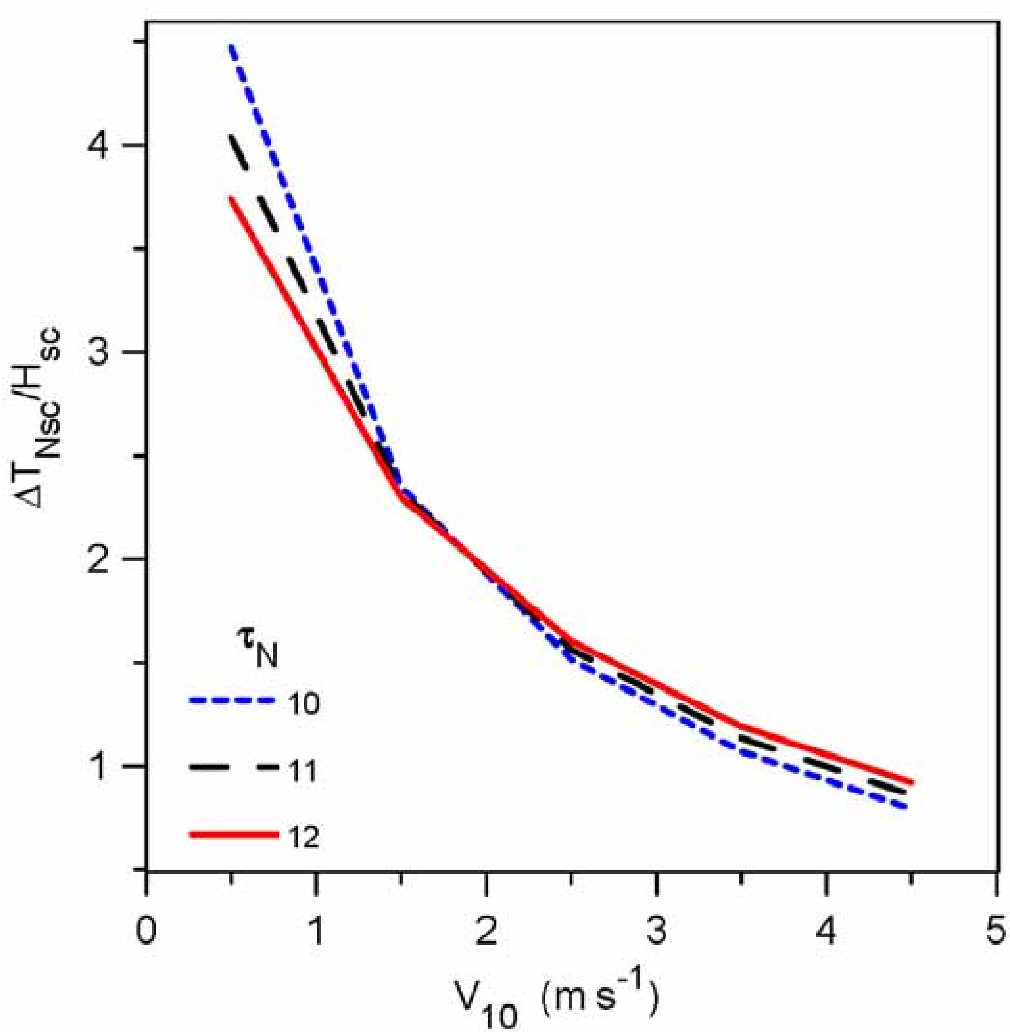
- Amplitude of diurnal cycle
- Long wave flux
- Sensible heat flux
- Soil heat flux

NBL CO_2 storage 'amplifier'

- $\Delta CO_{2N} = (R/\mathbf{W_R})(\Delta T_{Nsc}/ H_{sc})$

- where R is respiration rate
- $\Delta T_{Nsc}/ H_{sc}$ is amplifier
- β cancels, if same for CO_2

- $R/\mathbf{W_R} \approx 0.2/0.0048$
  ≈ 42 ppm CO_2



Conclusions

- For climate and seasonal forecasts, accuracy of daily mean state and diurnal cycle is key
- Are observables coupled correctly in a model?
- Key observables:
  - BL quantities: RH, LCL, DTR, (NBL) ΔT_N, ΔCO_{2N}
  - α_{cloud} : Cloud impact on surface SW
  - LW_{net}: linked to diurnal cycle; NBL

Lessons for the future?

- **Radiation, clouds, and surface climate are a tightly coupled system**
- True but still largely ignored
- Global models are powerful tools for understanding the coupling of complex processes involving clouds & radiation
- Links in the coupled system need careful evaluation against observables