Radiative control on the diurnal temperature range and the nocturnal boundary layer

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What causes global model climate biases?

- The interaction of the many parameterized processes

- Over land, these include

- sub-surface thermal and hydrologic
- Land-surface and boundary-layer
- Cloud and precipitation
- Shortwave and longwave cloud feedbacks

Can we keep trying plug-compatible sub-routines till some some combination 'works'?

- Unlikely to be satisfactory method since 8 or more components are involved
- **Need to understand how the coupled model system works**
- **Does coupling in model resemble reality?**
- *Probably not since 'land-surface coupling' differs widely in models (Koster et al., 2004)*

Consider the chain of processes involving water

(Yesterday's talk)

Precip $\longrightarrow$ SMI $\longrightarrow$ λE $\longrightarrow$ clouds $\longrightarrow$ Precip

vegetation *vegetation* *BL param* *dynamics*

soils *RH* *microphysics*

runoff *Cu param*

LW,SW radiation

R_{net} , H

SMI : soil moisture index

Consider the diurnal cycle of temperature

(It is an important climate parameter that has been changing)

- What determines the diurnal temperature range (DTR)?
- What determines the strength and depth of the night-time boundary layer (BL)?

- ???

Consider the diurnal cycle of temperature

- What determines the diurnal temperature range (DTR)?
- What determines the strength and depth of the night-time boundary layer (BL)?

Answer:

- *In ERA-40 they co-vary with net long-wave radiation (LW_{net})*

Reference

- *Betts, A.K., 2006: Radiative scaling of the nocturnal boundary layer and the diurnal temperature range. J. Geophys. Res., doi:10.1029/2005JD006560 (in press).*

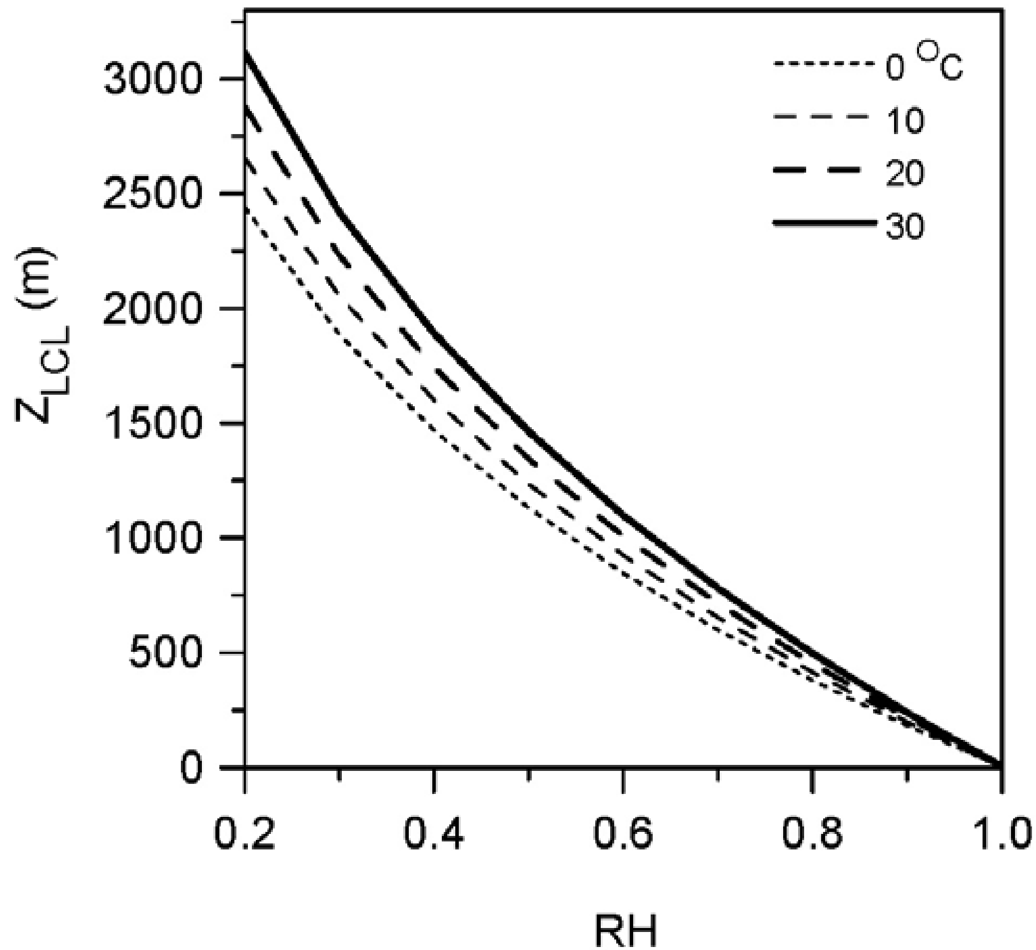
Model climate over land

- When does it cool a lot at night and form a very stable BL?
- When it is dry and there are no clouds.

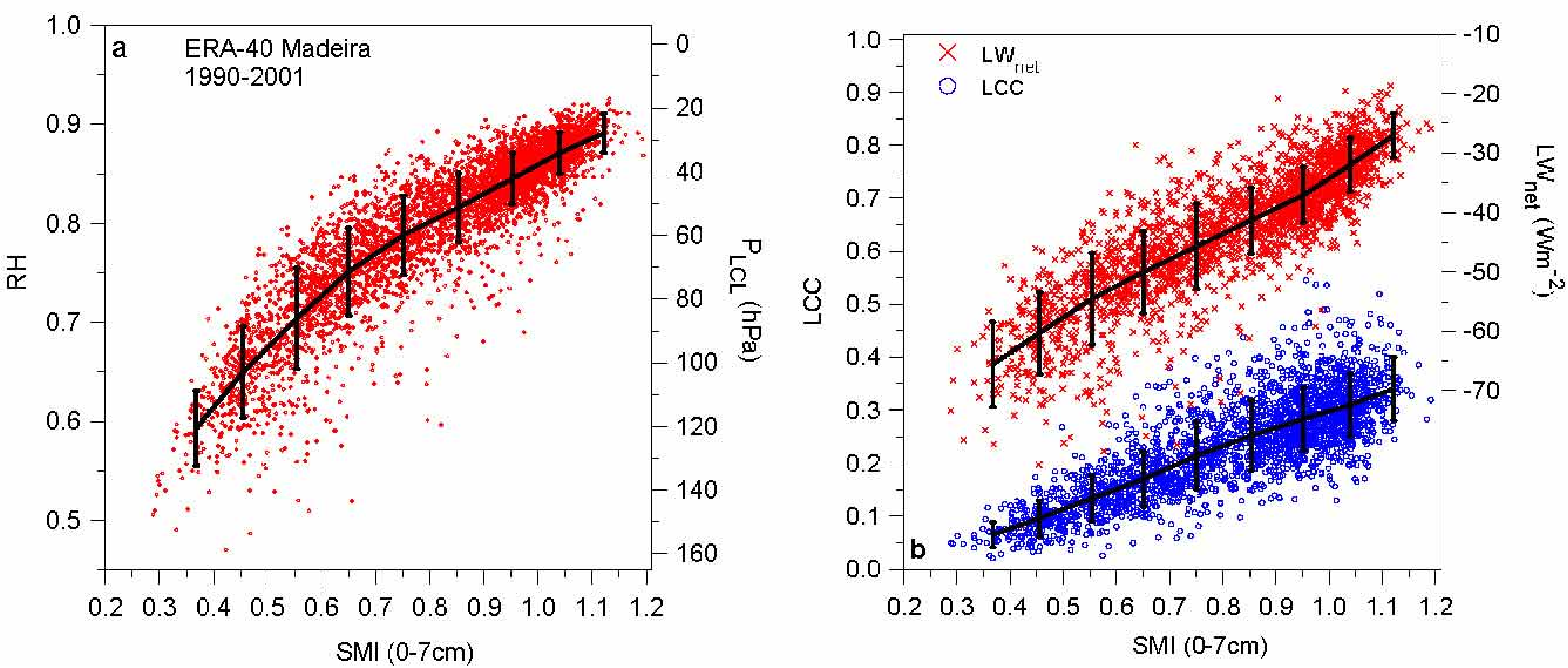
- *Then large diurnal temperature range*

RH is related to height of LCL

- True over diurnal cycle and for daily mean
- Deep dry pm BL goes with large DTR and large outgoing LW_{net}

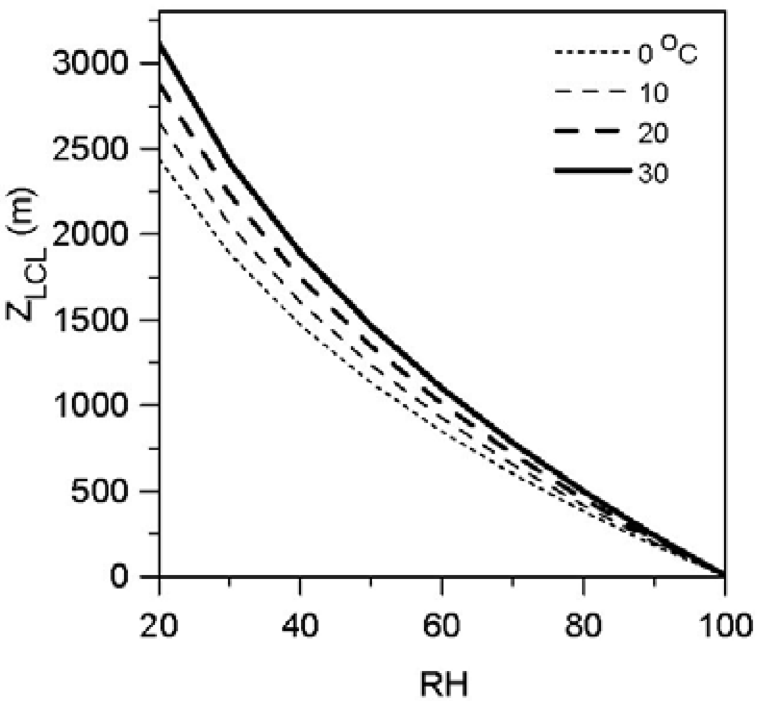


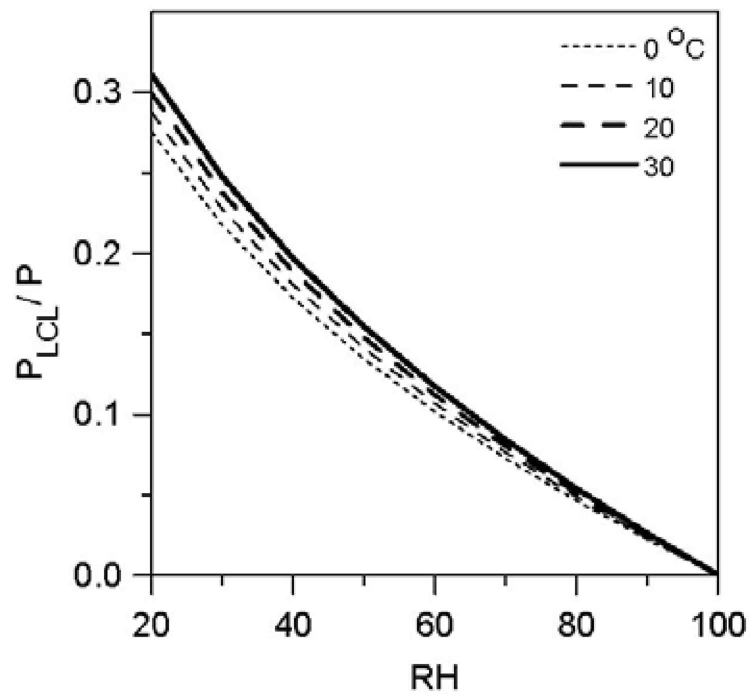
ERA40: Surface 'control'



- Madeira river, SW Amazon
- Soil water ⟶ LCL, LCC and LW_{net}

$SMI \longrightarrow R_{veg} \longrightarrow RH \longrightarrow LCL \longrightarrow LCC$





- RH gives LCL   [largely independent of T]
- Think of RH linked to availability of water

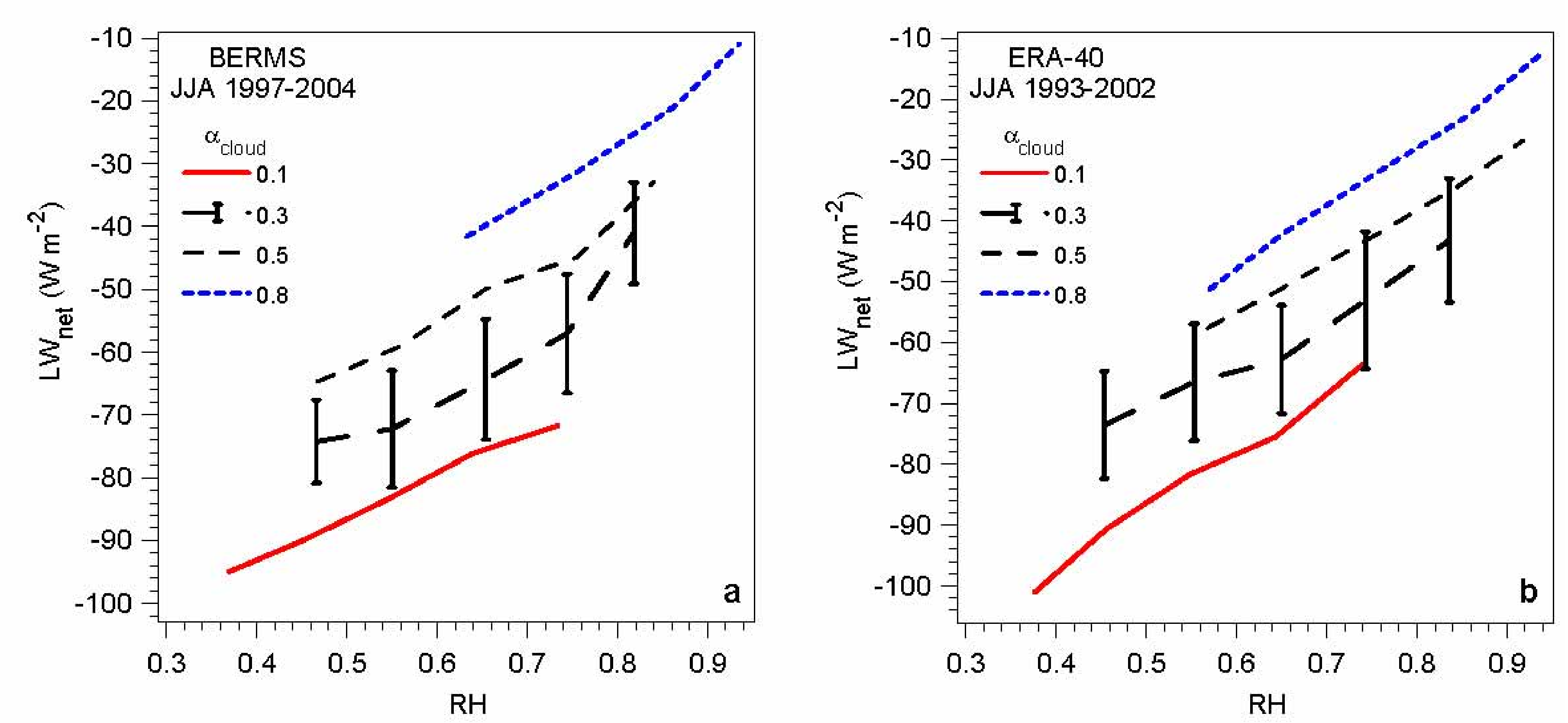
What controls daily mean RH anyway?

- RH is balance of subsidence velocity and surface conductance
- Subsidence is radiatively driven [40 hPa/day]
  + dynamical ‘noise’
- Surface conductance

$$G_s = G_a G_{veg} / (G_a + G_{veg})$$

[30 hPa/day for $G_a = 10^{-2}$; $G_{veg} = 5.10^{-3}$ m/s]

When it is dry and there are no clouds: -LW_{net} is large



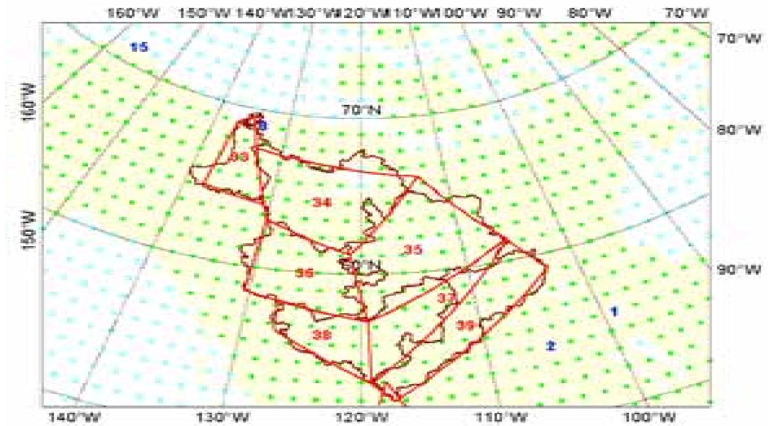
Boreal forest data

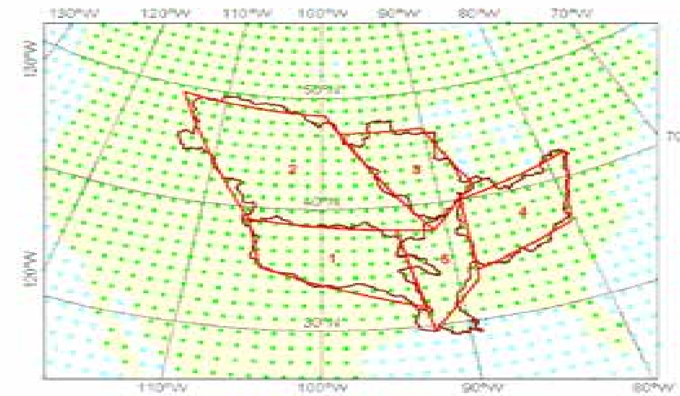
ERA-40 data

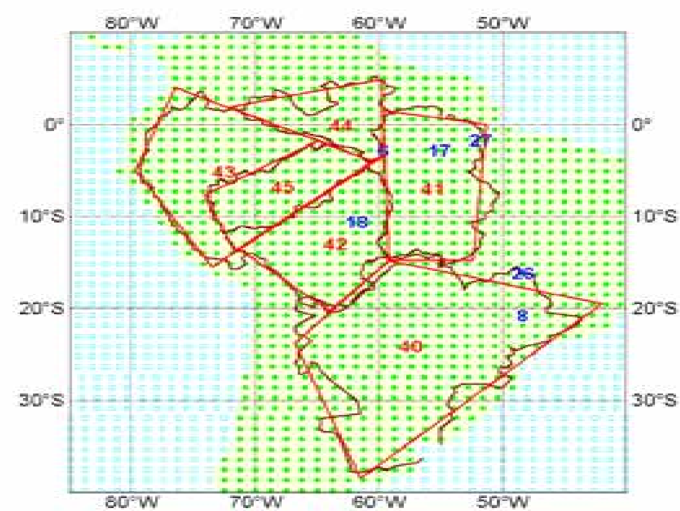
- LW_{net} is large when mean RH and cloud cover are low [here given by cloud albedo: α_{cloud}]

Use ERA40 model data for river basins

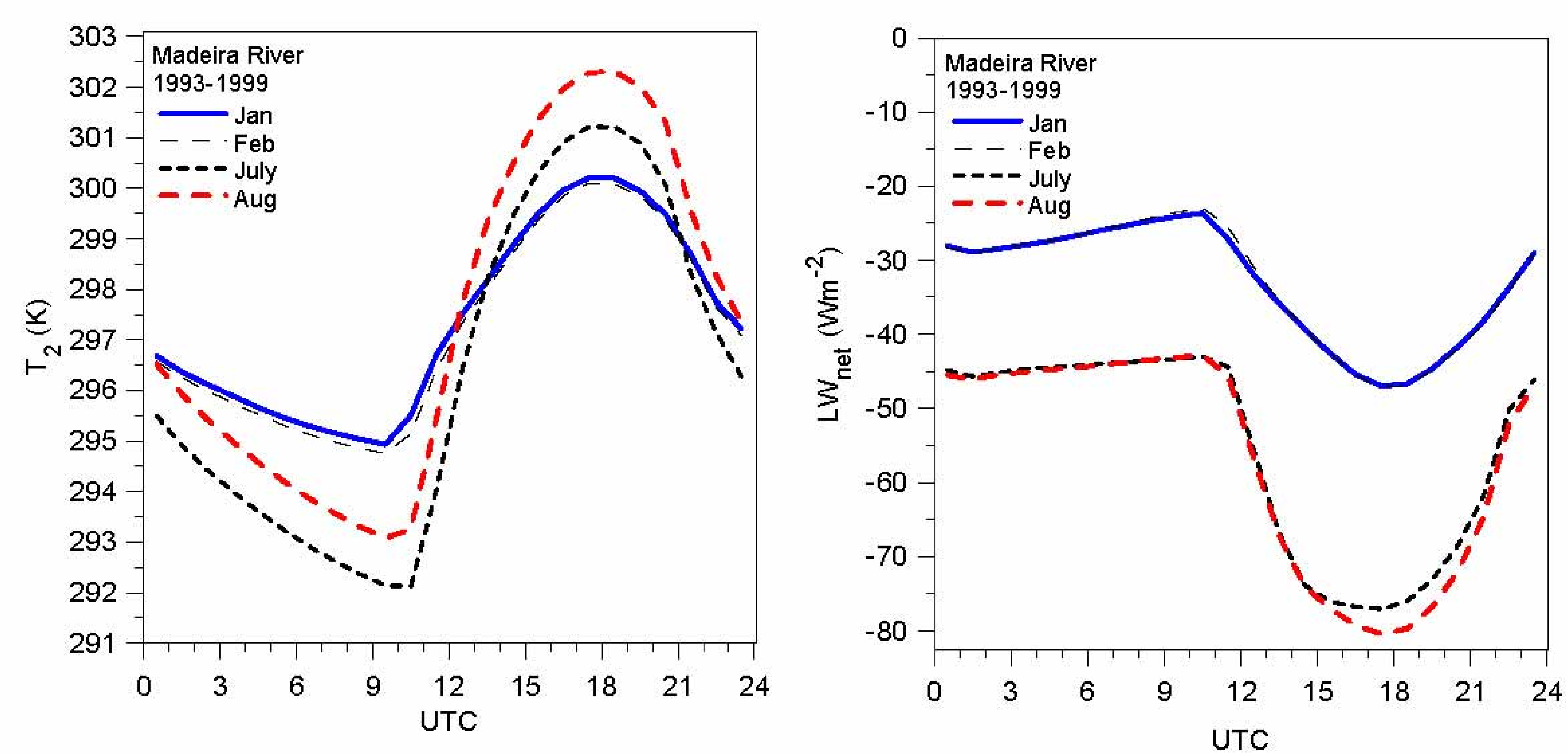
- Hourly means over river basins
- Mackenzie, Mississippi,
  Amazon and LaPlata
- Soil, surface and atmospheric
  column
- Fluxes and state variables







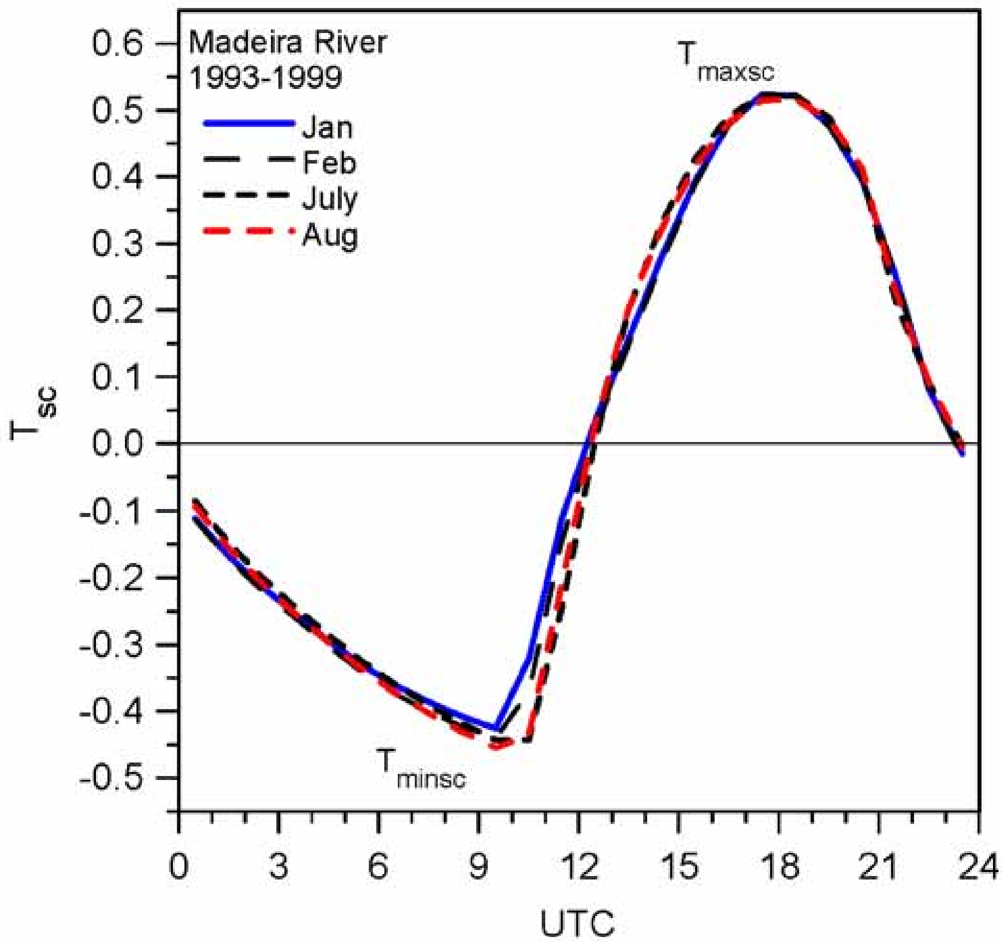
LW_{net} linked to diurnal cycle



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

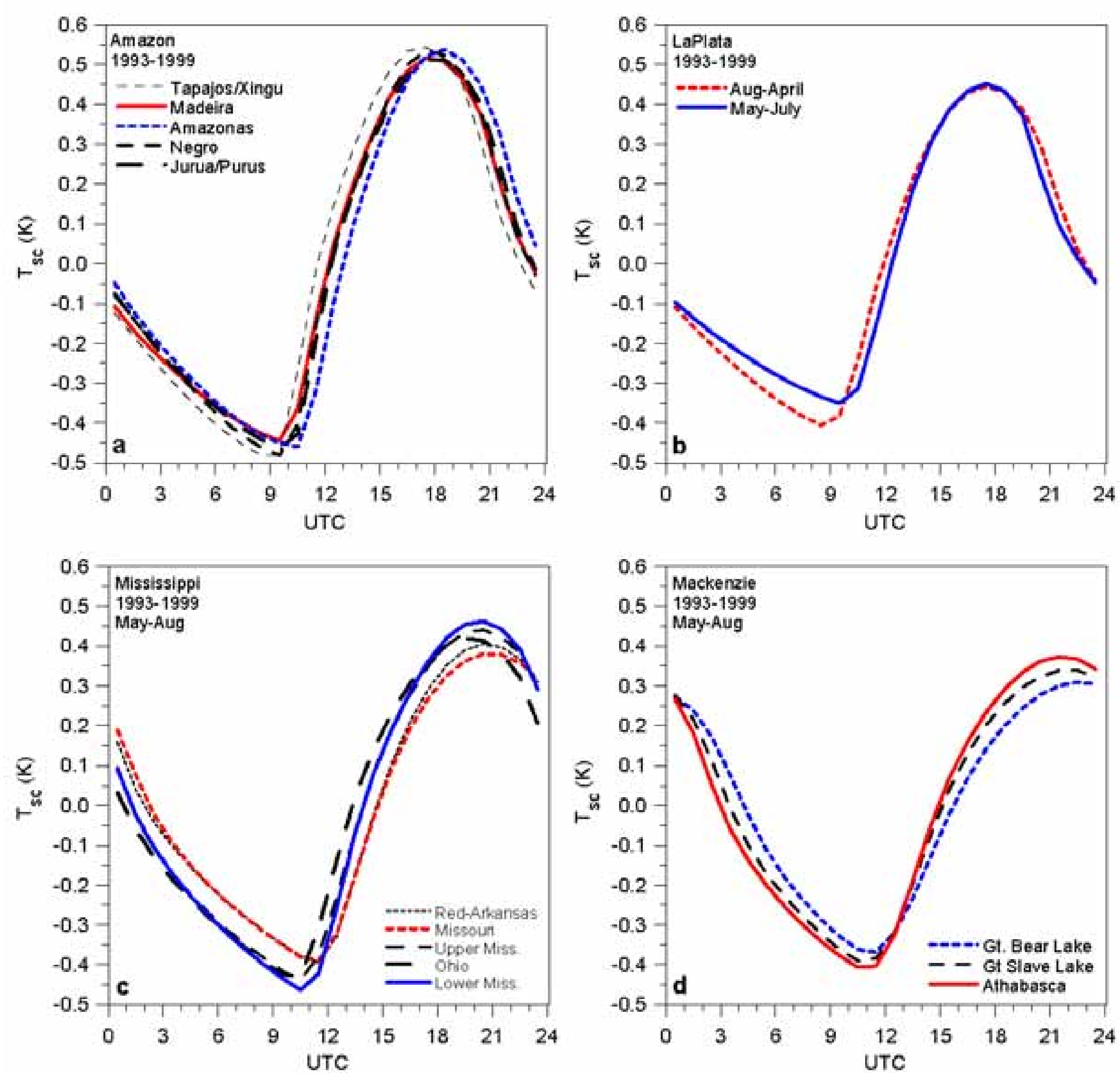
Define radiative temperature scale from 24-h mean LW_{net}

- $\Delta T_R = -\lambda_0 \, LW_{net24}$
  where $\lambda_0 = 1/(4\sigma T^3)$
  [from slope of Stefan-Boltzmann σT^4]
- $T_{sc} = (T_2 - T_{24}) / \Delta T_R$
- Collapses diurnal cycles to one curve

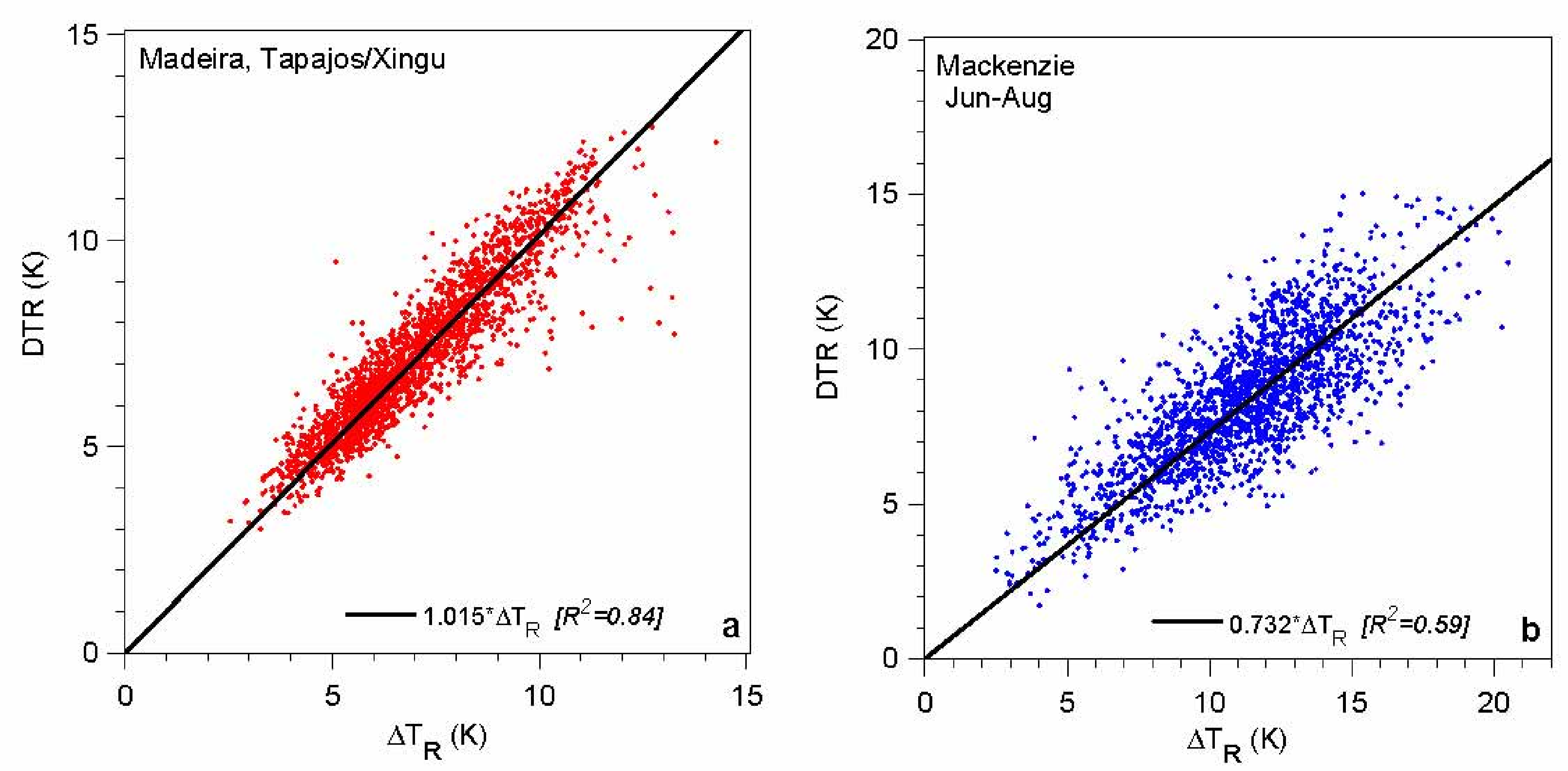


Apply across all river basins

- DTR_{sc} amplitude decreases with increasing latitude



Plot daily DTR against ΔT_R



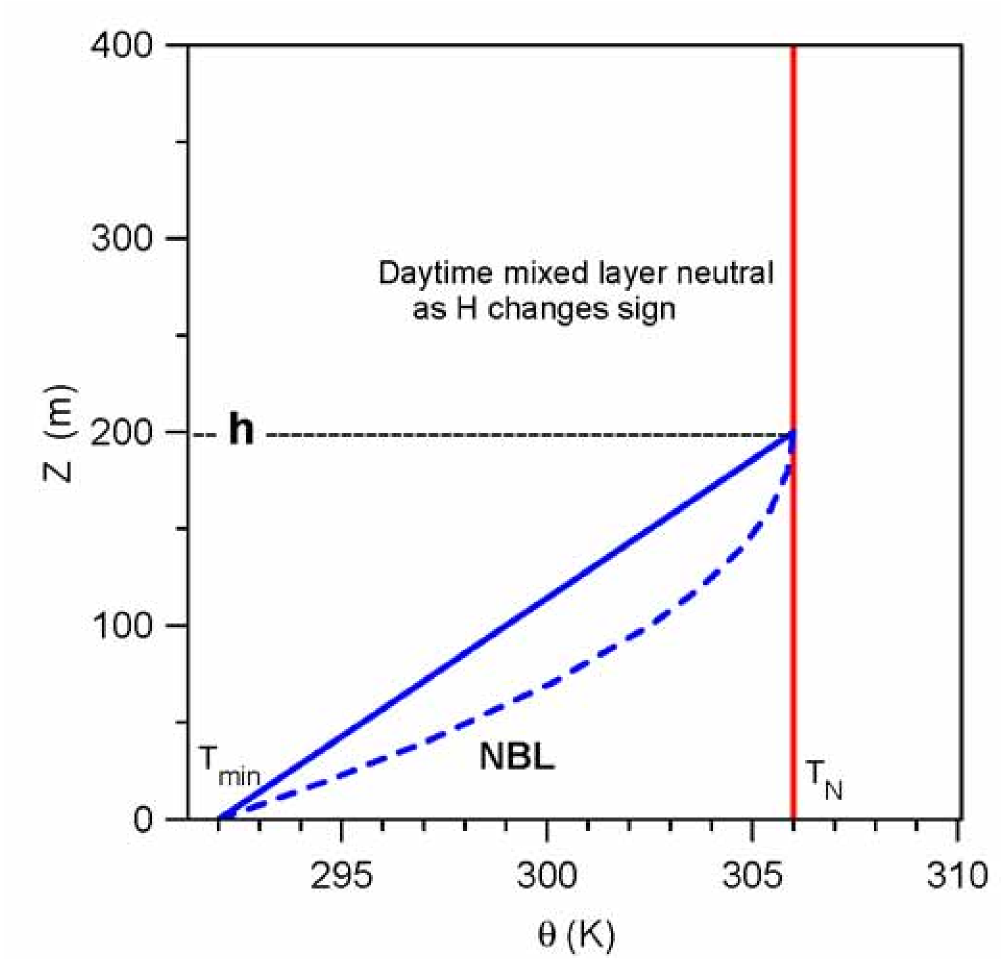
Amazon

Mackenzie

Define strength of Night-time BL

At dawn (T_{min}) define strength of NBL as

$\Delta T_N = T_N - T_{min}$

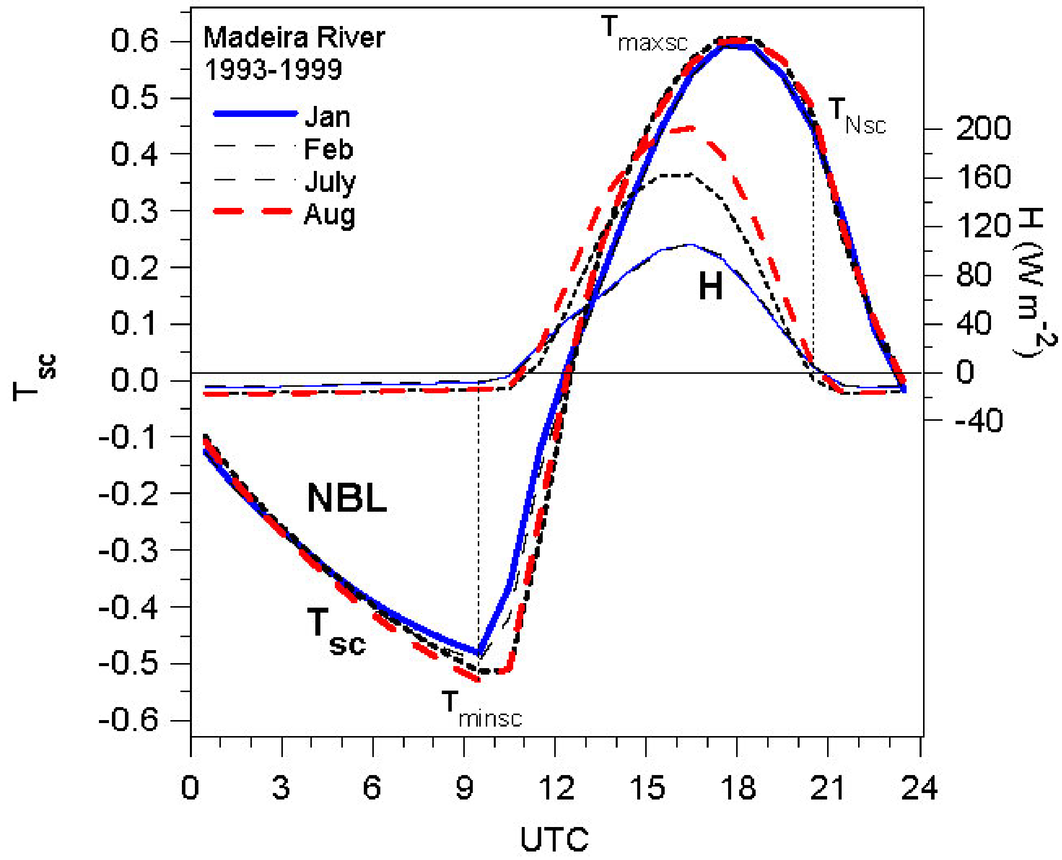


Relation to diurnal cycle

NBL forms when sensible heat flux H goes negative

Define NBL strength at dawn (scaled)

$\Delta T_{Nsc} = T_{Nsc} - T_{minsc}$



Define scaled DTR, ΔT_N

- Diurnal temp range

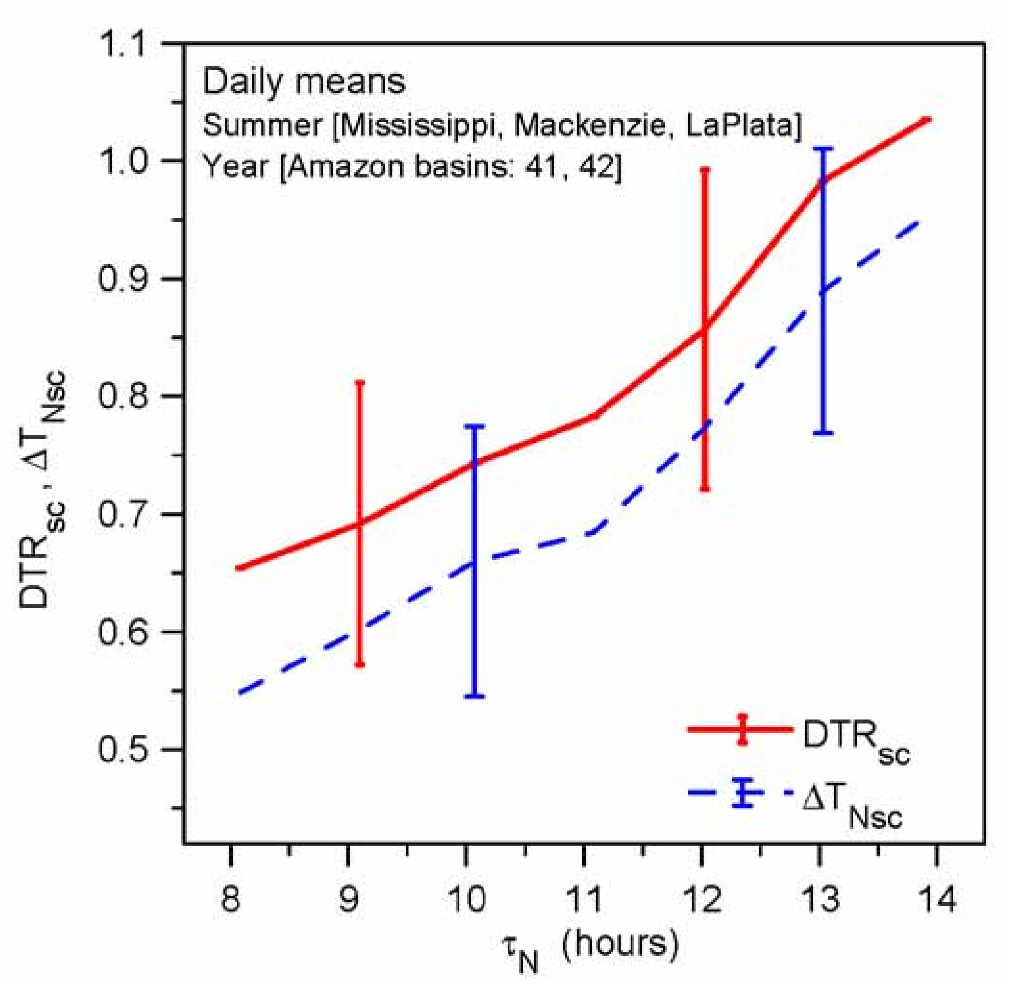
  $DTR_{sc} = DTR/\Delta T_R$

- Strength of NBL

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

Scaled amplitudes increase with growth-time of NBL (τ_N)

- In summer northern basins have shorter NBL growth-time and smaller DTR_{sc} and ΔT_{Nsc}
- $\Delta T_{Nsc} / DTR_{sc} \approx 0.9$



Define scaled DTR, ΔT_N and H

- Diurnal temp range

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

- Strength of NBL

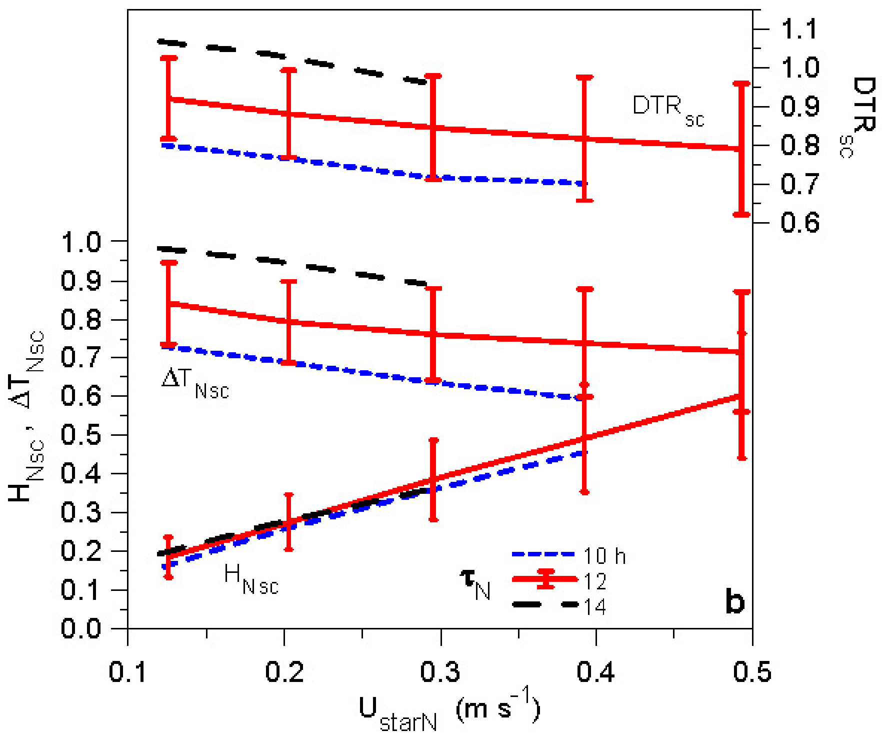
  $\Delta T_{Nsc} = \Delta T_N/\Delta T_R$

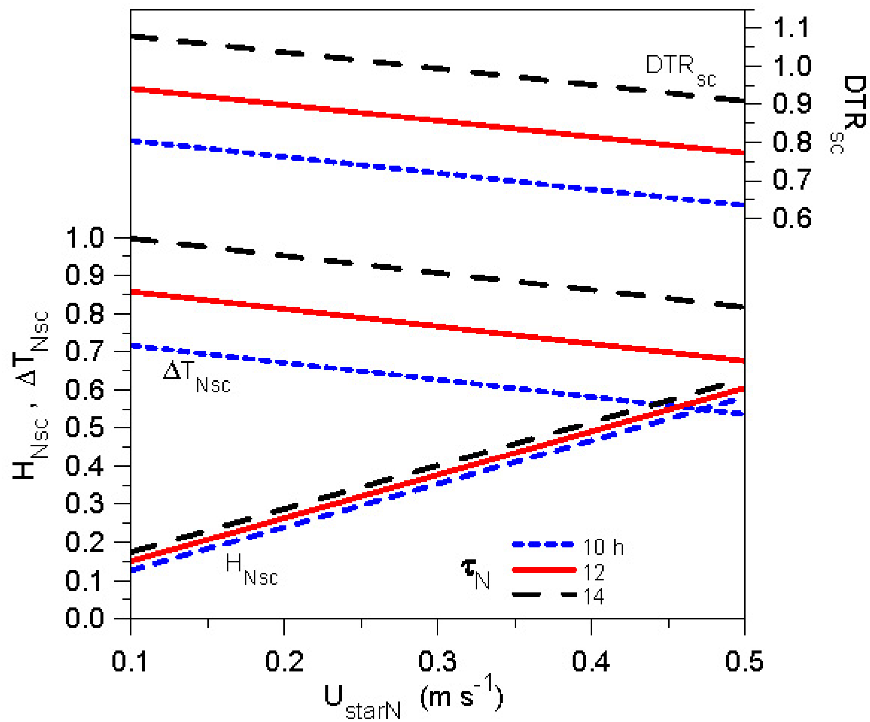
- Scaled heat flux

  $H_{sc} = H_N/(-LW_{net24})$

Binned data and regression

[summer daily data: 10700 days]





Binned data

Regression fit

DTR_{sc} ; ΔT_{Nsc}; H_{sc} as function of τ_N and friction vel. U_{starN}

In ERA-40…

- Scaled diurnal temperature range and NBL strength increase with length of night and decrease weakly with friction velocity

- Scaled night-time heat flux increases with friction vel. and weakly with length of night

Radiative velocity scale gives NBL depth **h**

NBL energy balance gives

$$\mathbf{h} = \mathbf{W_R}\, \mathbf{J}_N / \beta \mathbf{R}$$

where $\mathbf{R} = (\Delta T_{Nsc} / H_{sc})$

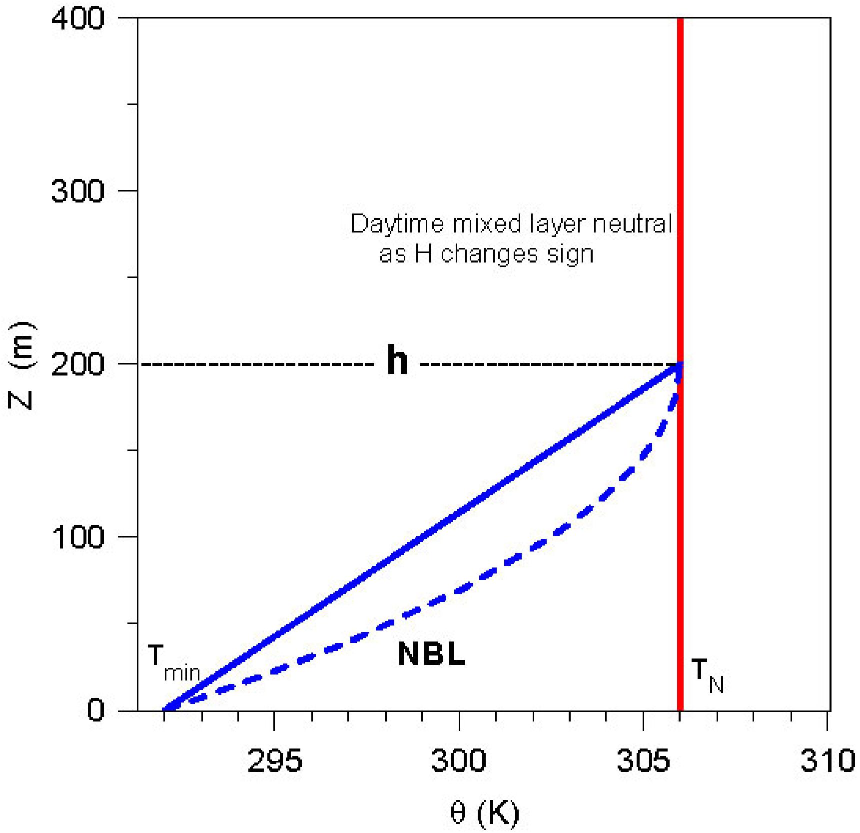
[β=0.5, linear profile; 0.33, quadratic]

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

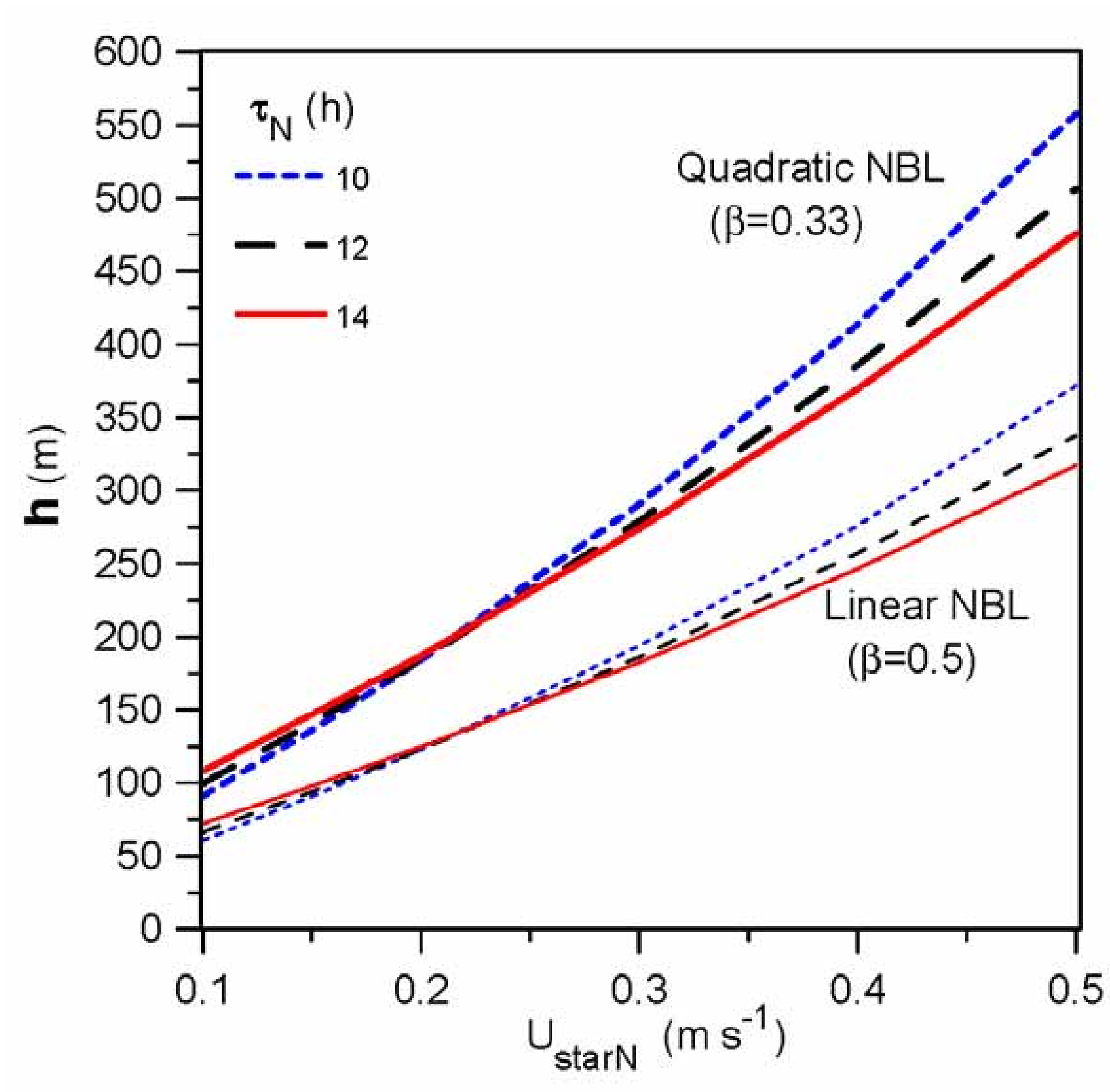
is a radiative velocity scale

[≈ 0.0048m s^{-1} or 40hPa day^{-1}]

Gives h ≈ 20hPa for $\mathbf{J}_N$ =12h



NBL depth: $h = W_R J_N / \beta R$



h increases with friction velocity

R is an 'amplifier' for NBL CO_2 storage

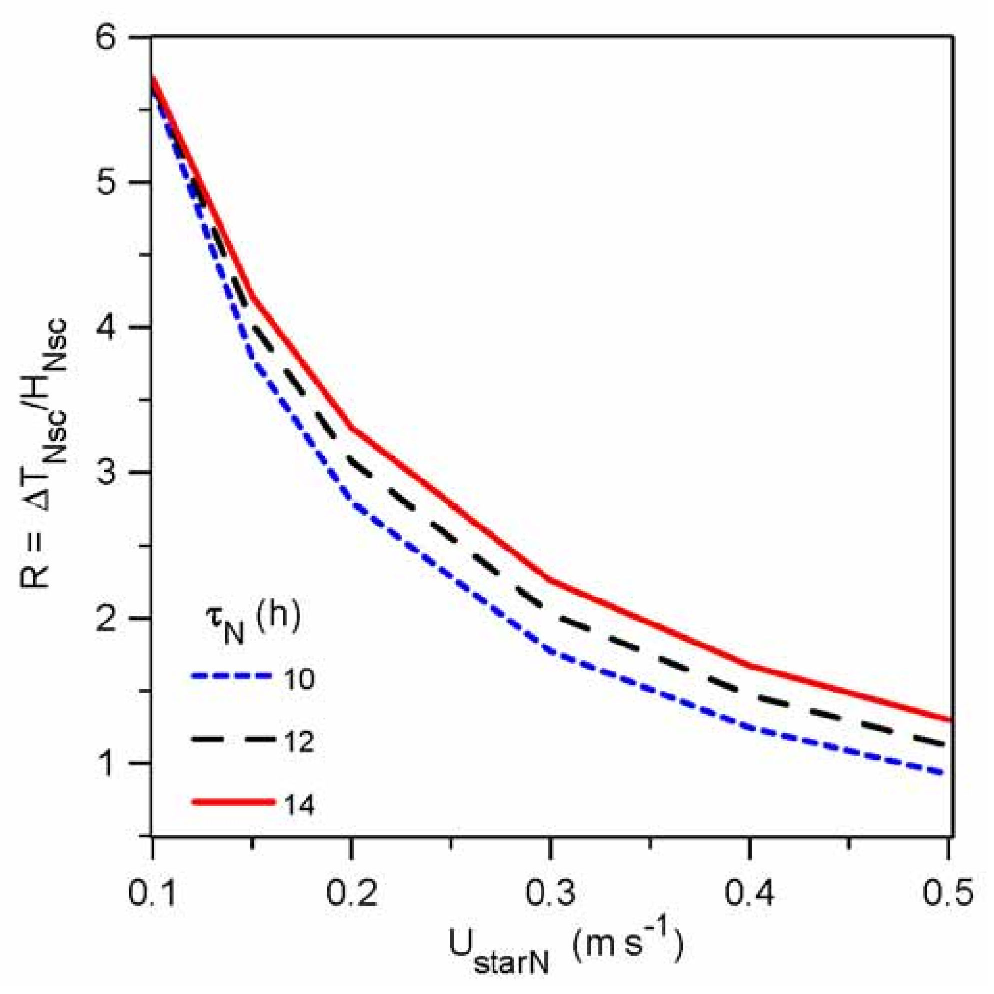
ΔCO_{2N} = **R** (Resp/$\mathbf{W_R}$)

where Resp is respiration rate

Resp/$\mathbf{W_R}$ ≈ 0.2/0.0048

≈ 42 ppm CO_2

Night-time rise is 42**R**



Conclusions

- LW_{net} depends on RH and cloud cover
- Amplitude of diurnal temperature range depends mostly on LW_{net} and night-length, and decreases a little with wind-speed
- Strength of NBL at dawn is related (90%)
- NBL depth increases steeply with friction velocity (and depends on vertical profile)

Lessons for the future?

- Radiation, clouds, and daily surface climate are a tightly coupled system

- Models can help us understand the coupling of complex processes involving clouds & radiation

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