Understanding the surface and BL coupling of water, CO_2 and clouds

Alan K. Betts

akbetts@aol.com

http://alanbetts.com

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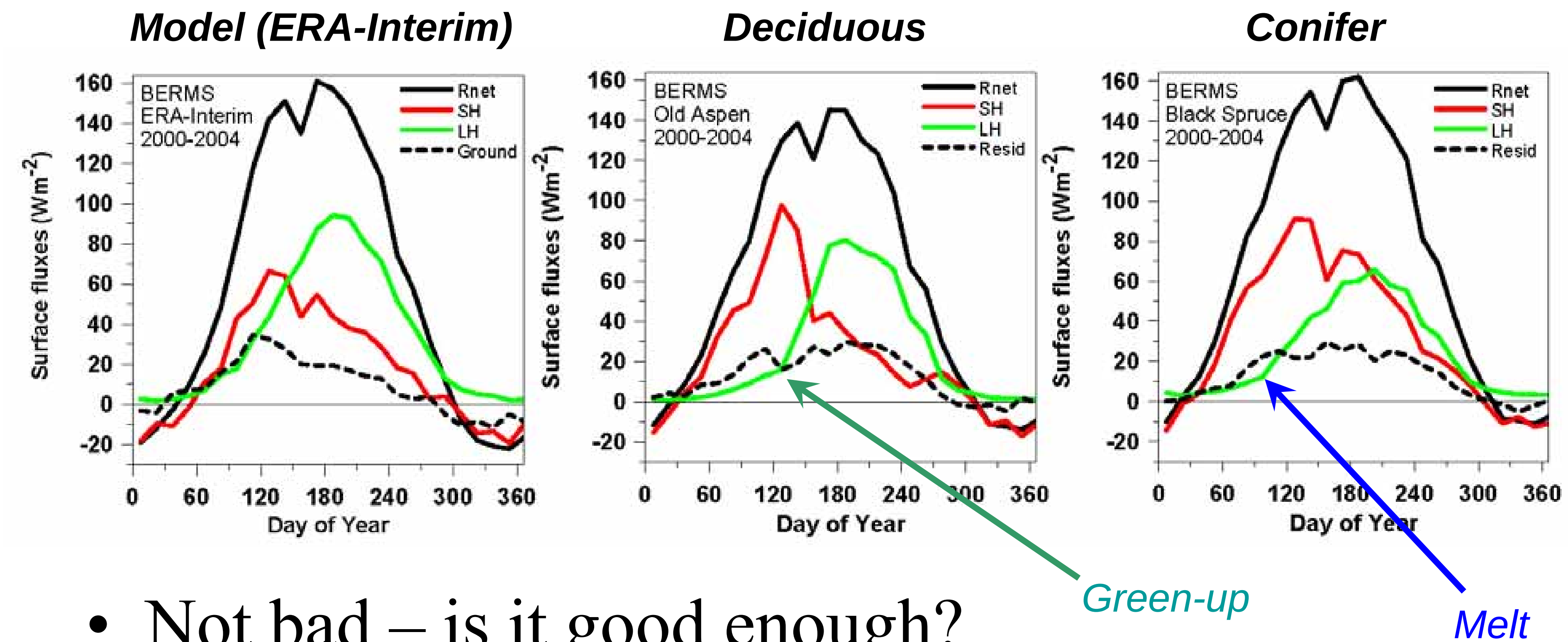
Outline

- ***"Beyond the Resemblance Test"***
- Evaluating models – key observables?
- Are coupled processes well represented?
- Are diurnal, seasonal and climate time-scales well represented?
- Coupling of energetics and CO_2 to the phase transitions of water – a holistic approach
- ***Can we make our models relevant to the real world?***

Seasonal Cycle: *BERMS 54N, 105W*



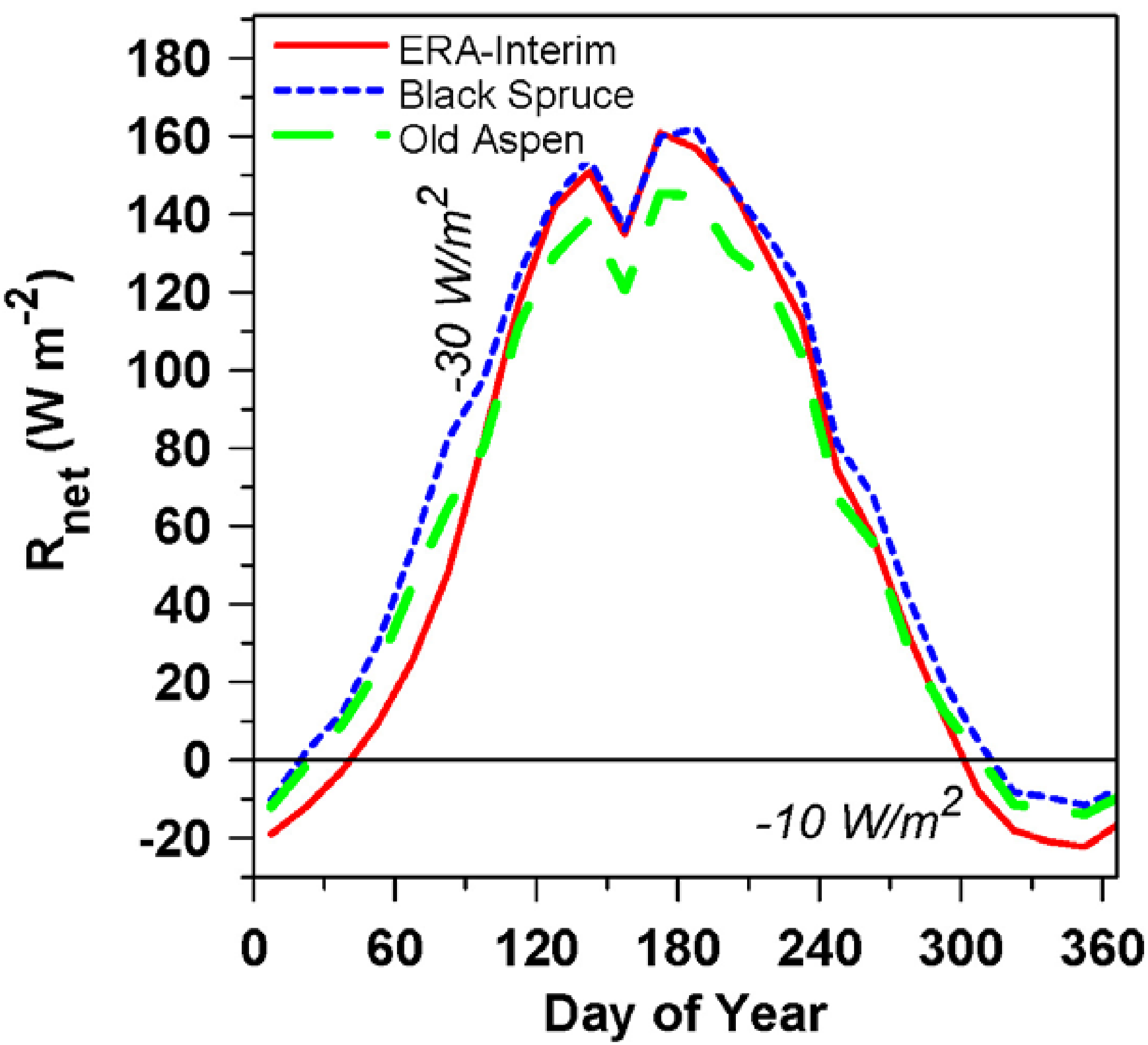
- Not bad – is it good enough?
- Model: SH too low; LH too high on May 1
- *No proper seasonal cycle of vegetation*
- Spring melt: large flux: 20-30 W/m²

Net radiation

- Model R_{net} low in winter by $10W/m^2$
- Low in spring by $30W/m^2$

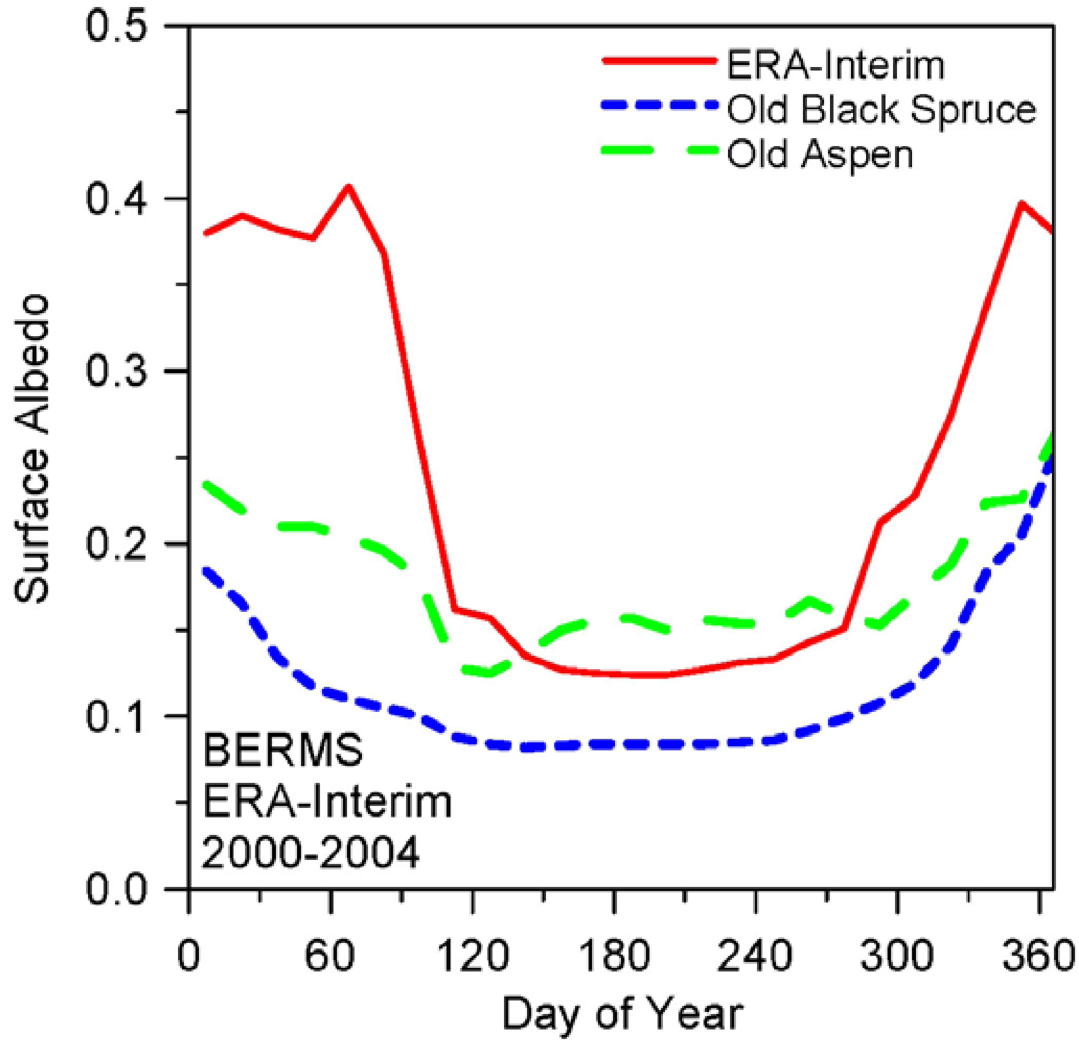
- *Why? Mostly surface albedo*

- **Errors are large for 'climate'**

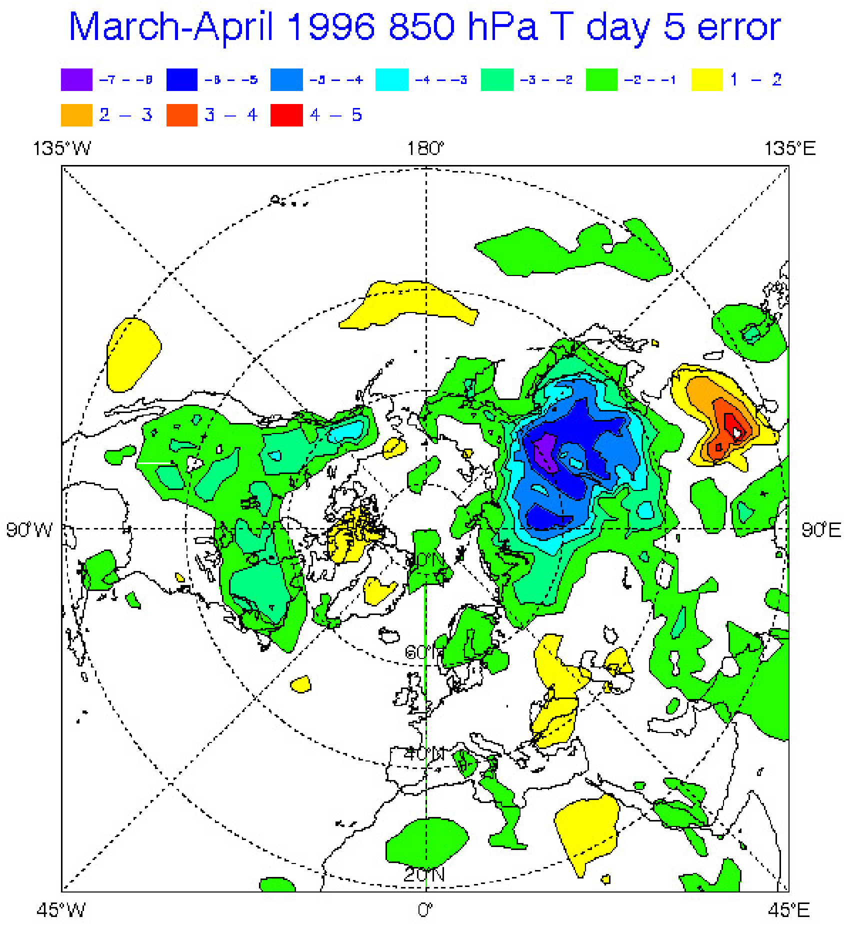


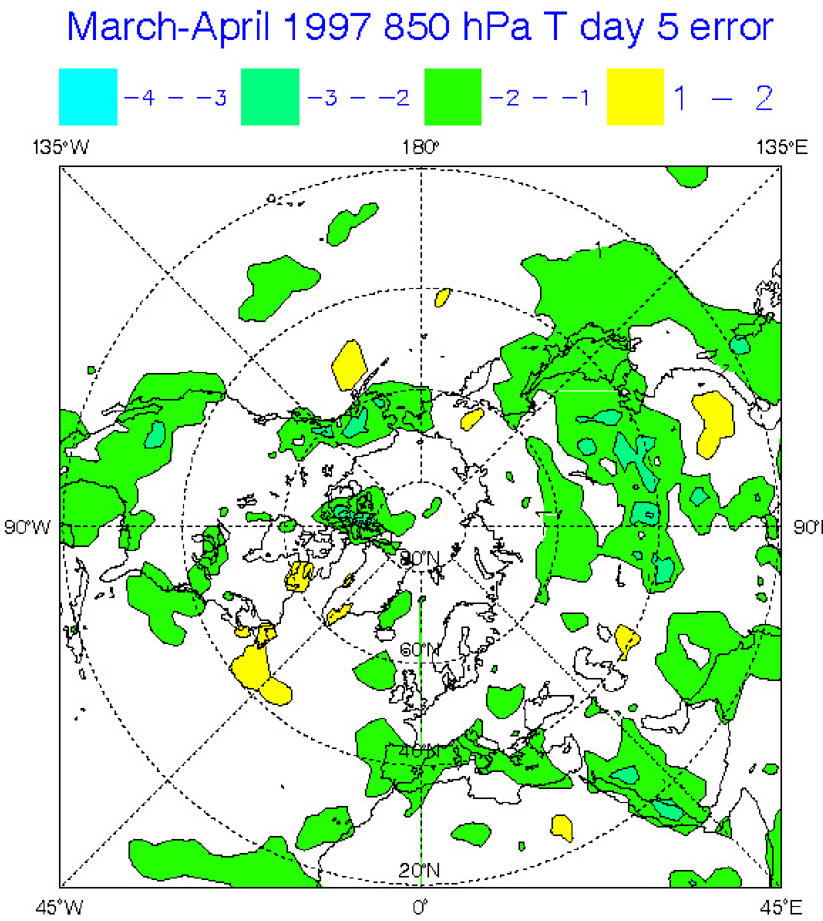
Surface albedo: *still critical*

- Dense forest canopies low even with snow
- Deciduous higher albedo – lower R_{net}
- *Mixed landscape with snow*
- 20% = 25 Wm^{-2} in spring



ECMWF reduced boreal forest surface albedo: 0.8 to 0.2 with snow

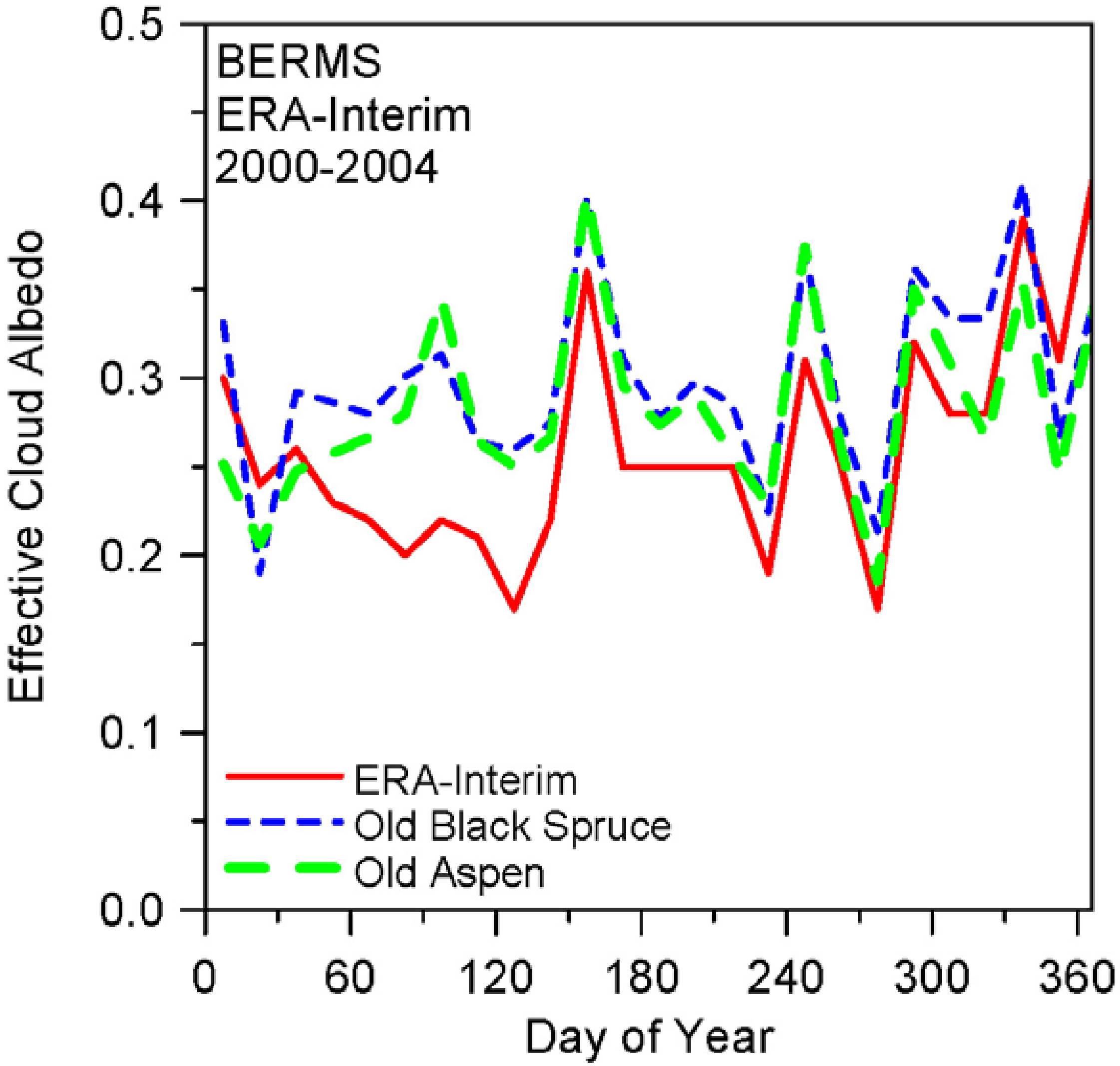




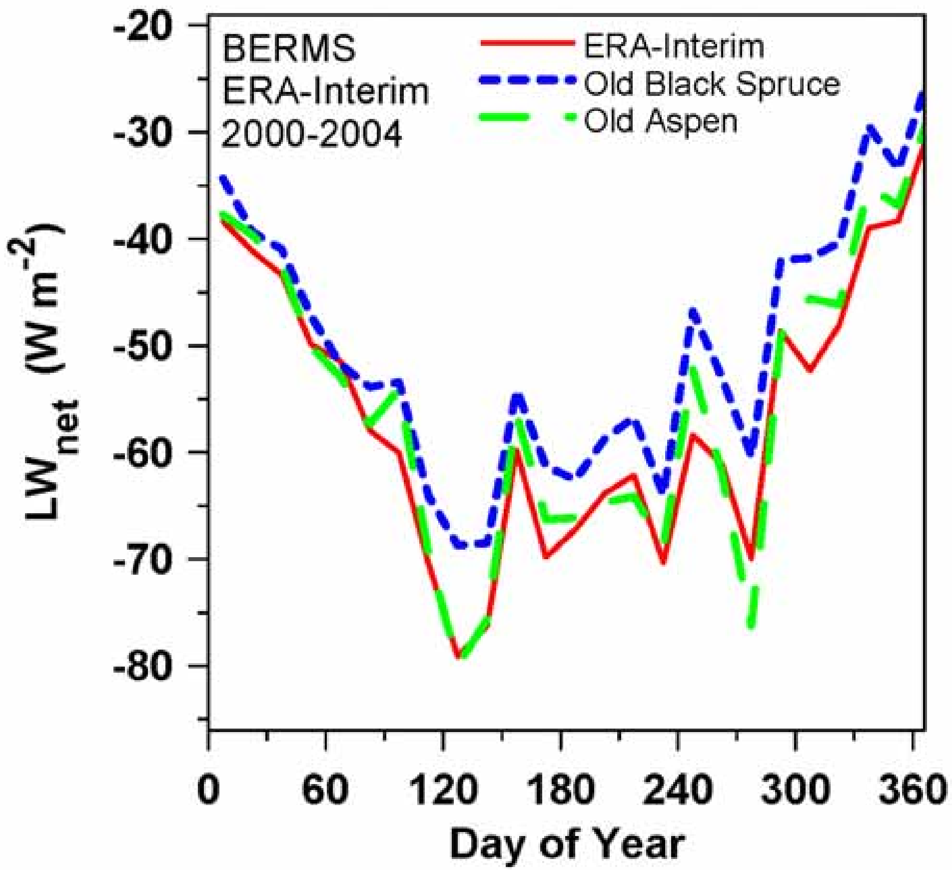
- Large systematic bias reduction; ***snow/ice-albedo feedback***
- NH 850 hPa T forecast skill improved Feb. to mid-May

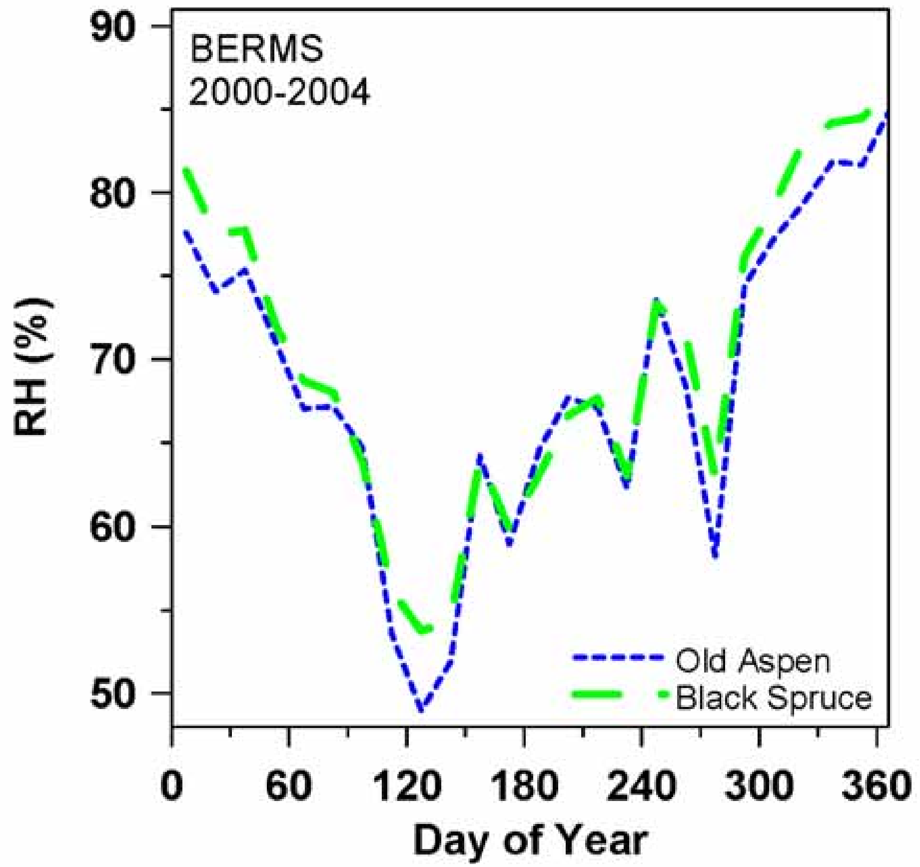
Effective cloud albedo

- SWCF/SW_{clear}
- Observations well defined *(80km)*
- Model shows correlation, except in spring
- Good enough?
- 5% = 15 Wm^{-2} in summer
- *(Tuesday: A21I, 8am)*



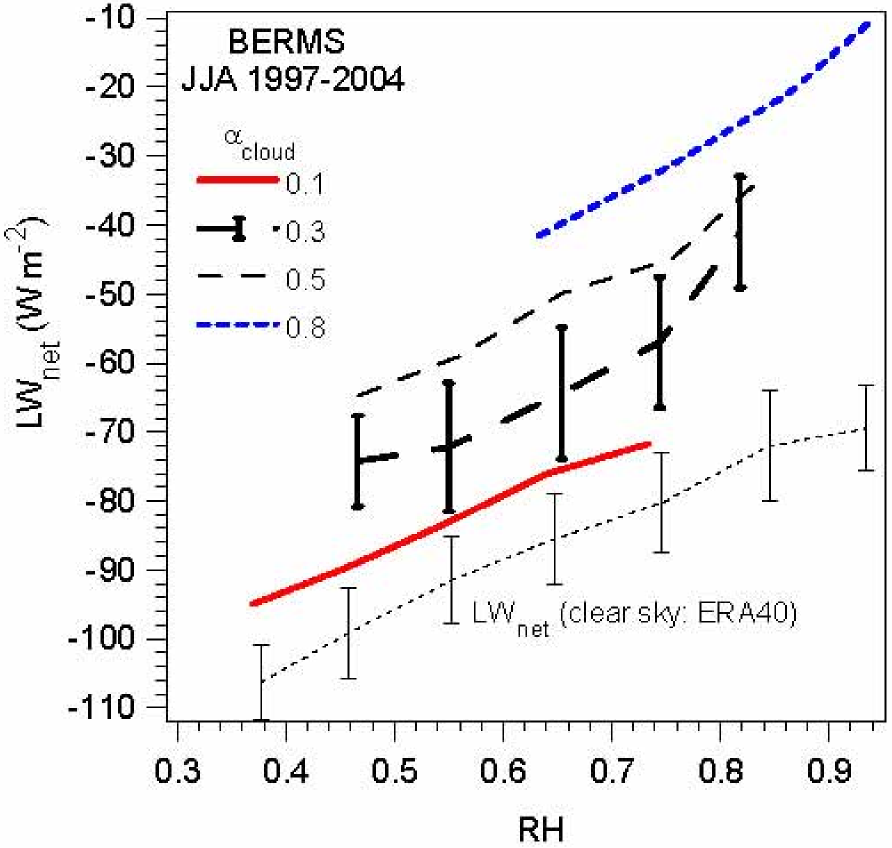
Net surface LW

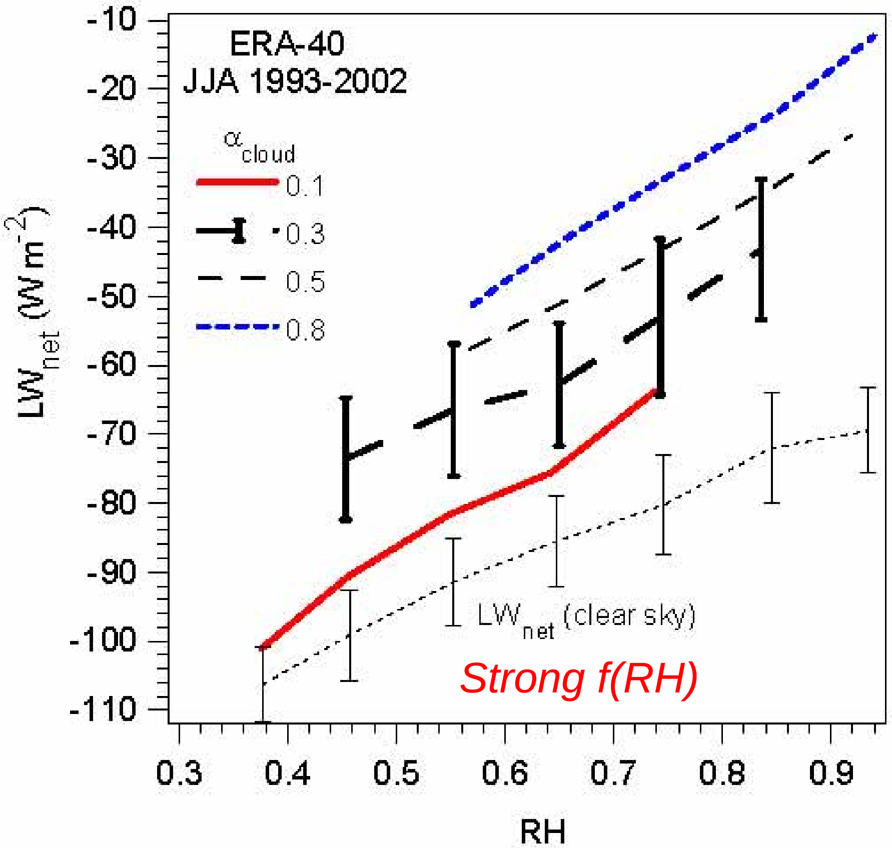




- Not bad – peaks when dry in spring
- Structure reflects RH and cloud changes

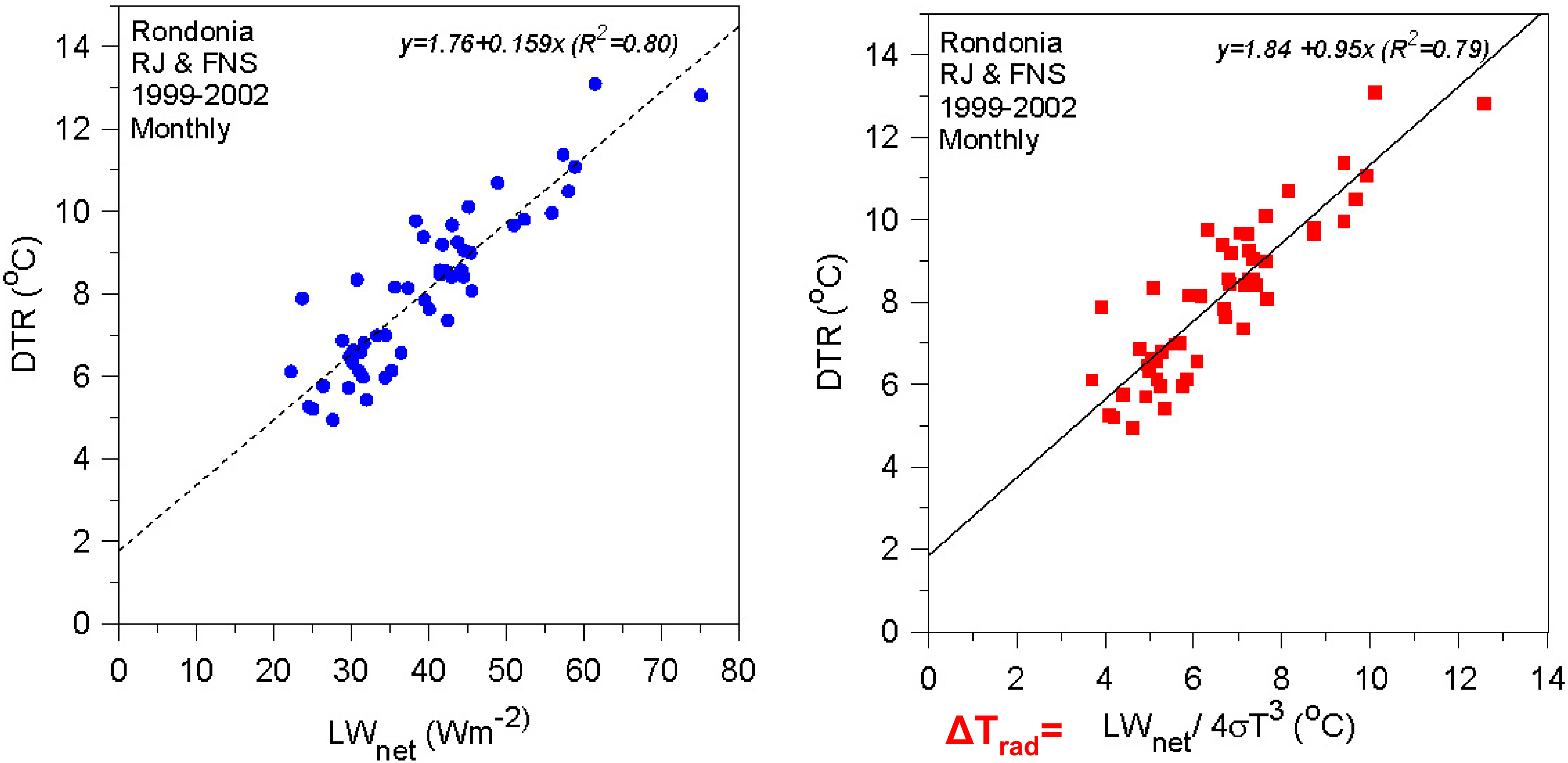
Net surface LW





- Point comparison: stratified by RH (LCL) & ECA (α_{cloud})
- Quasilinear **clear-sky and cloud greenhouse effects**
- But typically model RH and cloud distributions biased

LW_{net} and Diurnal Temperature Range – monthly mean data

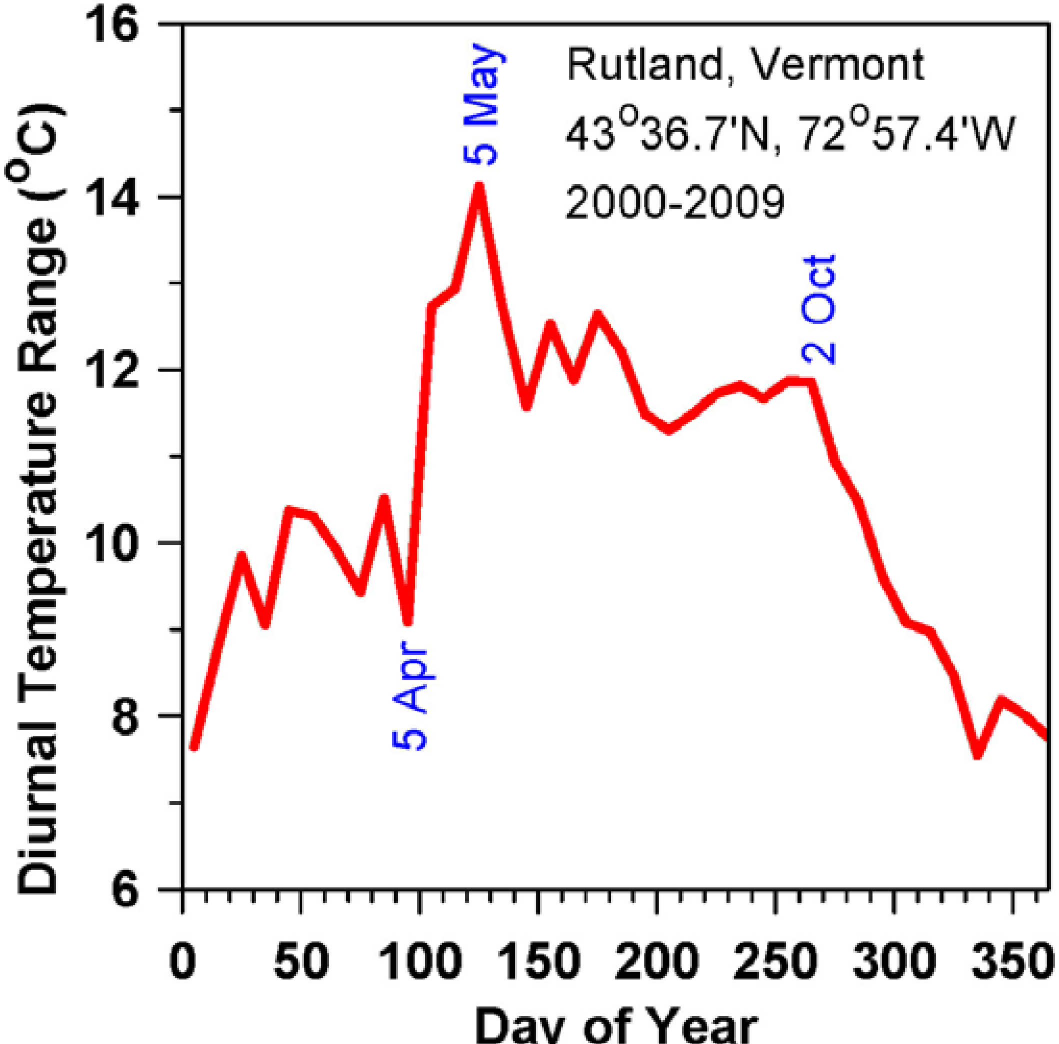


- Mean LW_{net}, DTR (and NBL) correlated – how good is your model?

[Betts: JGR, 2006; Betts and Silva Dias, 2010]

Annual cycle of Diurnal Temperature Range (DTR)

- DTR increases sharply after 5 April, peaking at the time of forest leaf-out in the first week of May, and then falling as transpiration rapidly increases



Betts, 2010a

Are spring transitions correct?

- 15 April after melt
- Low transpiration
- Dry atmosphere
- Larger DTR

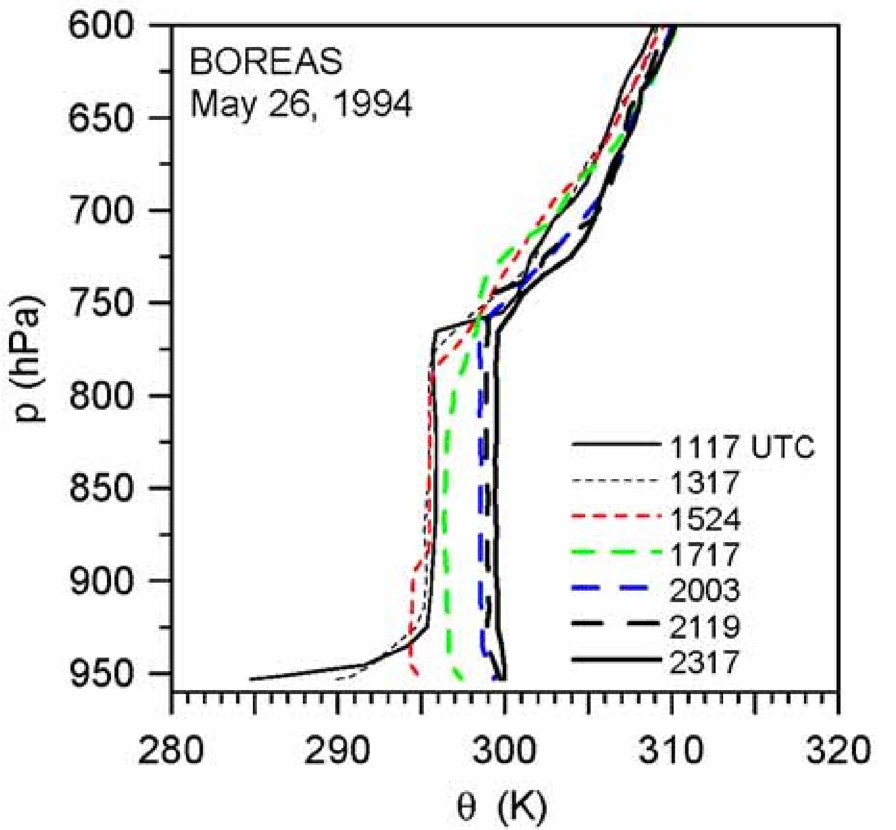
15 May after leafout
Large transpiration
Moist atmos., clouds
DTR reduced

More extreme at boreal latitudes

- Mid-May: frozen roots, conifer canopy at 23°C
- Surface pools everywhere but no evaporation and afternoon RH = 27%
- Cloud-base 2000m
- A ‘green desert’

– too cold to evaporate

- Longer seasonal lag than New England



Energetics of ground & snow melt

- 1 meter frozen soil = 300mm water
- 1 meter snow = 100mm water
- 25 Wm^{-2} melts 6.5 mm/day
- Soil phase change gives 'sink' of 25 Wm^{-2} for 45 days in spring and smaller 'source' over longer time period in fall
- As climate warms, frozen period shrinks at mid- and high latitudes – *Model must be accurate as freezing point matters!*

Winter transition: T falls sharply

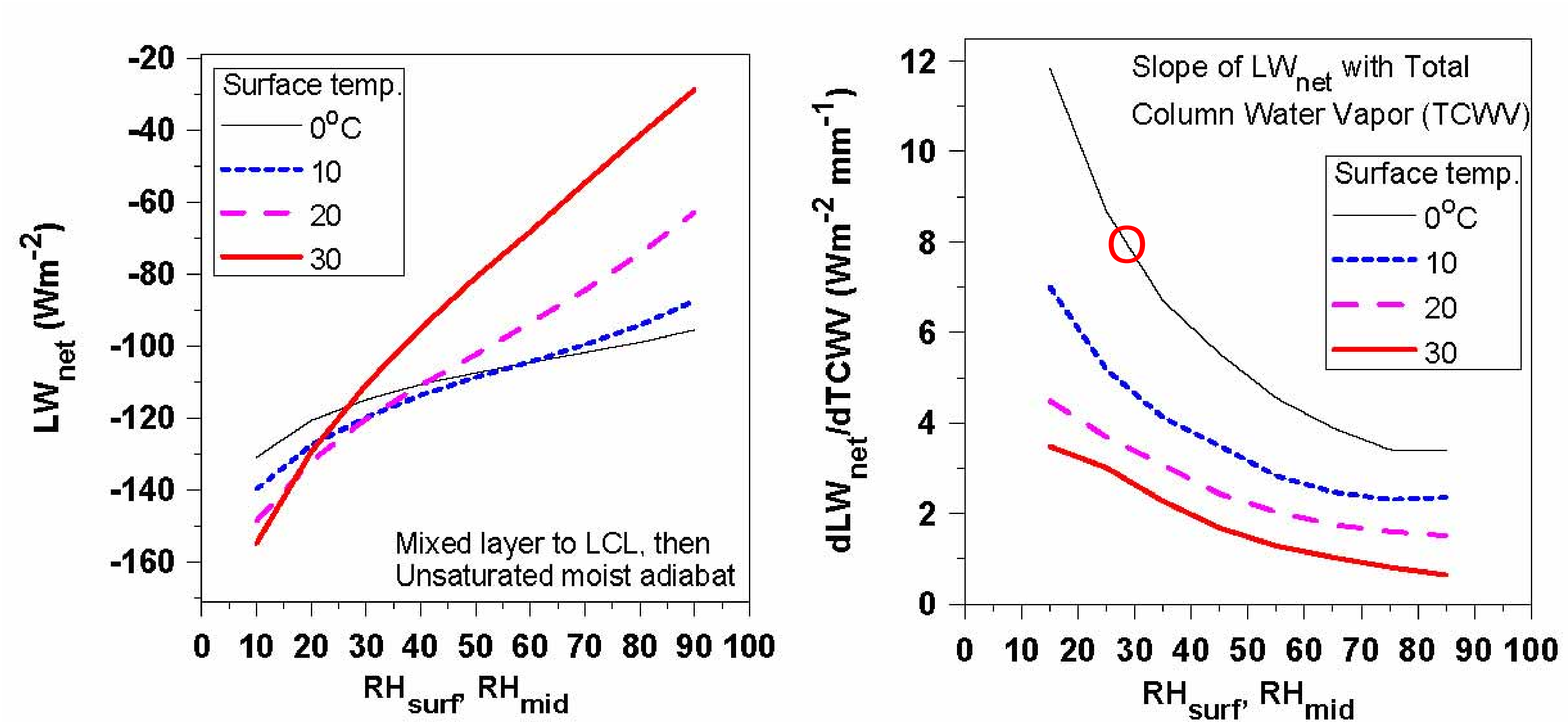
- Snow reflects sunlight
- Sublimation low
- Dry atmosphere
- Large outgoing LW_{net} (*reduced water vapor greenhouse*)
- Snow uncouples ground
- Temperature falls

Note trees shade snow: low forest albedo

Rough energetics: snow-on-grass

- Winter SW_{down}(clear) ≈ 130 Wm^{-2} (Vermont in Feb.)
- 10cm fresh snow changes albedo from 0.15 to 0.75 & drops SW_{net} from 110 to 30 Wm^{-2}
- Residual 30 Wm^{-2} sublimes 1cm snow/day [1mm ice]
- Snow loss increases as snow ages
  – snow lasts ≈ 5 days,
  – reducing solar heating to ≈ zero
- SW_{net} impact = -80 Wm^{-2} while snow lasts

LW impact of water vapor



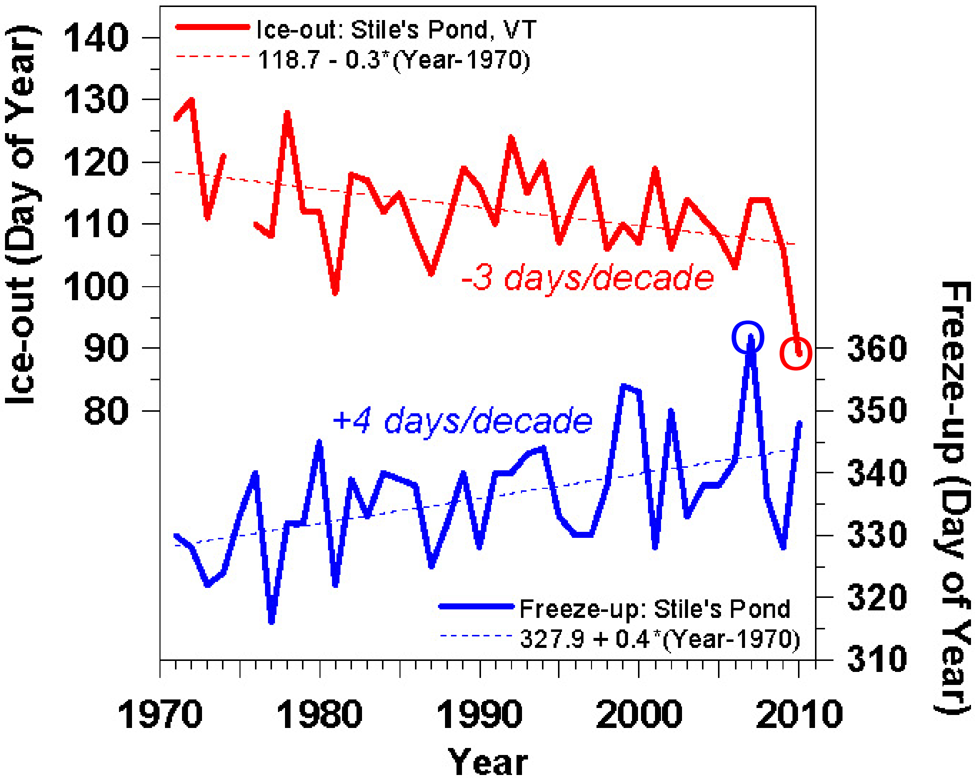
- When cold, adding 1mm water vapor to 30% RH atmosphere reduces outgoing LW_{net} by 8 Wm^{-2}

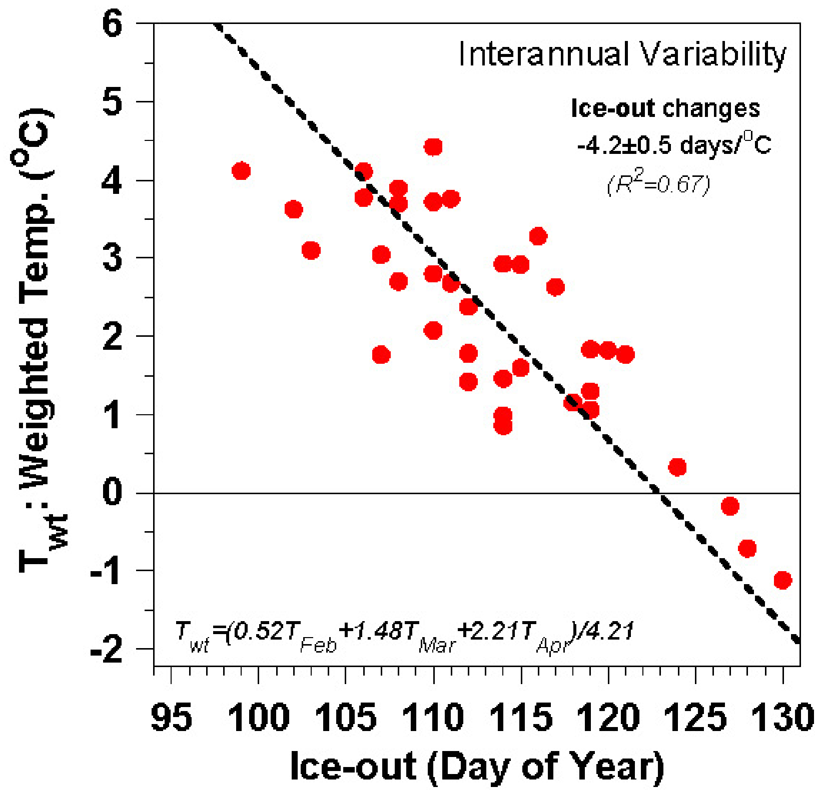
Betts & Chiu, 2010, unpublished

What are key observables?

- Surface albedo, effective cloud albedo
- **Frozen** ground, snow cover, frozen lakes
  - total frozen water and SW reflection
- Seasonal transitions are good integrated markers of climate system: **ice and vegetation**
- Surface RH and LCL: linked to availability of water and vegetation
- DTR coupled to surface LW_{net} coupled to WV and cloud greenhouse effect

Small Lakes: frozen period change





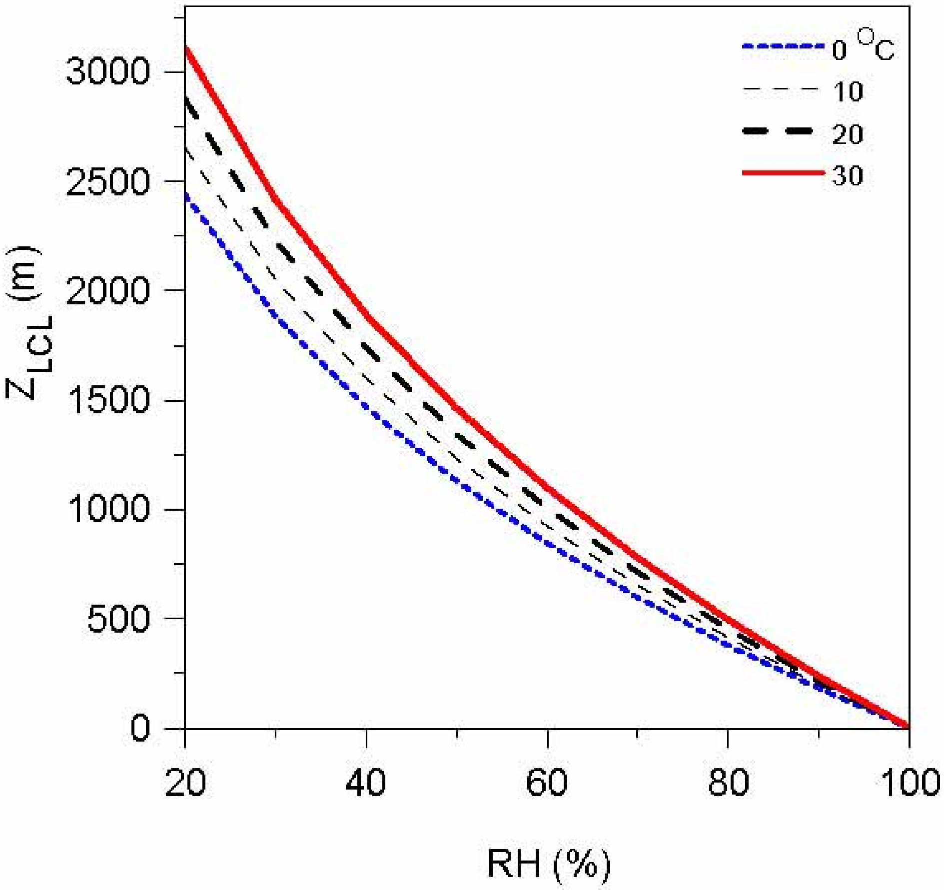
- Frozen period shrinking 7 days/decade
- Monitor frozen lakes as regional climate signal

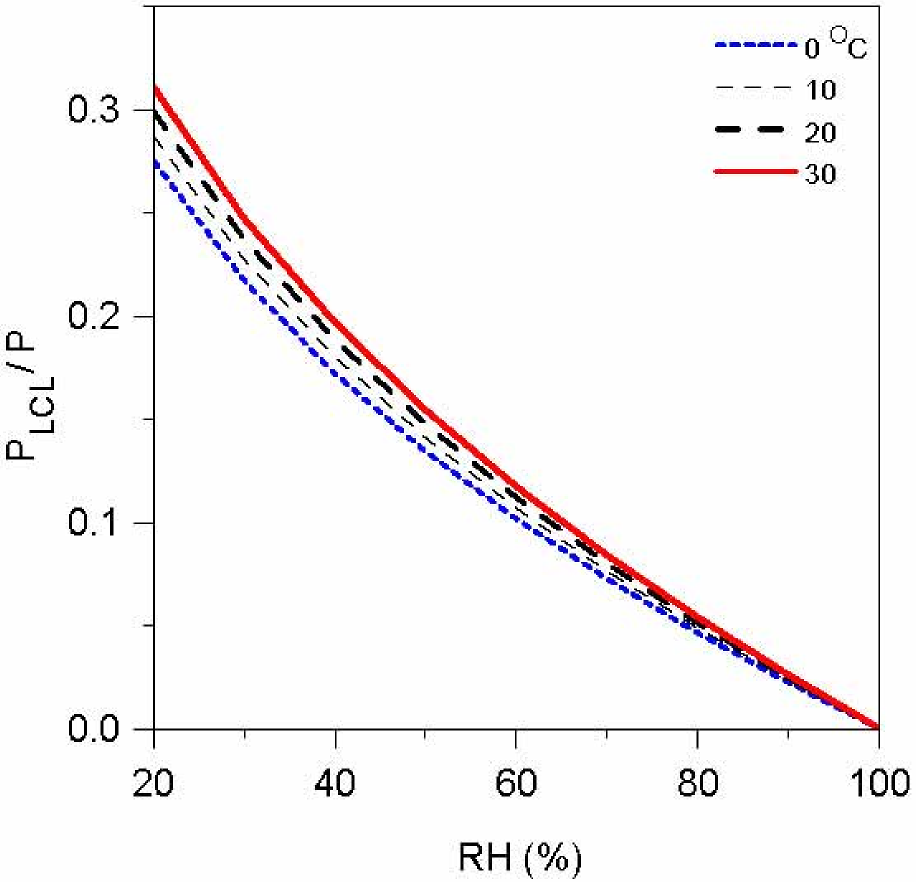
Betts, 2010b

CO_2 and the water cycle

- RH and LCL **over land** linked to stomatal conductance during growing season
- Ratio of transpiration/CO_2 uptake falls as atmospheric CO_2 increases
- Potentially this lowers RH, increasing LCL/cloud-base and amplifies T_{surf} rise
- How does this impact cloud cover?
- *Can we monitor this coupling on regional scales? Reflects both vegetation adaptation and changing water cycle!*

Aside: Relation of RH to LCL



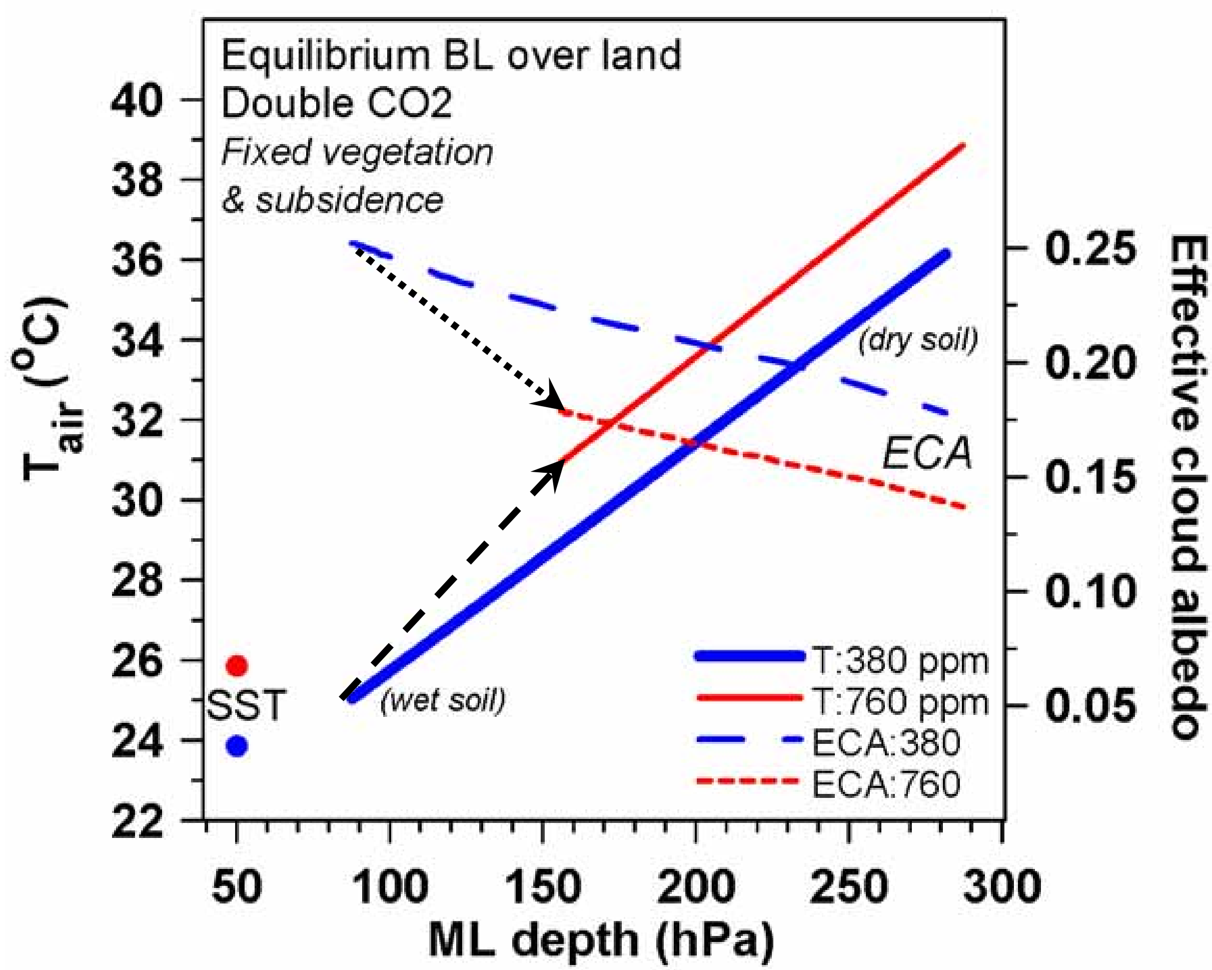


- Z_{LCL} is fn(T) but not p

P_{LCL}/p is weak fn(T)

Idealized BL model: doubled CO_2

- Reduced stomatal conductance gives warmer temps, higher cloud-base lower RH
- Less cloud comes from warmer temp. not CO_2 rise
- *(Idealized summer model has too large an impact)*
- ***Is this observable with rising CO_2?***



Betts and Chiu, JGR 2010

What are my messages?

- Move away from analyzing single variables & ask: “*How well are coupled processes represented in model?*”
- Analyze the links between the seasonal cycle, vegetation and the water cycle - *critical for climate change & for human society*
- Ask if model is *relevant* to the earth system, its ecosystems and human society?

References available at http://alanbetts.com

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