Understanding the surface and BL coupling of water, CO$_2$ and clouds

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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 10 W/m$^2$
- Low in spring by 30 W/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 $R_{\text{net}}$
- *Mixed landscape with snow*
- $20\% = 25 \text{ Wm}^{-2}$ 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$^{\text{clear}}$
- Observations well defined ($80\text{km}$)
- 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 ($\alpha_{\text{cloud}}$)
- Quasilinear clear-sky and cloud greenhouse effects
- But typically model RH and cloud distributions biased
LW\textsubscript{net} and Diurnal Temperature Range – monthly mean data

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

\[ \Delta T_{rad} = \frac{LW_{net}}{4\sigma T^3} \ (^{\circ}C) \]

[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 $LW_{\text{net}}$ (reduced water vapor greenhouse)
- Snow uncouples ground
- Temperature falls

Note trees shade snow: low forest albedo
Rough energetics: snow-on-grass

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

- $SW_{\text{net}}$ impact = -80 Wm$^{-2}$ while snow lasts
When cold, adding 1mm water vapor to 30% RH atmosphere reduces outgoing LW$_{\text{net}}$ 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$_{\text{net}}$ 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

- Betts, A. K. (2010b), Vermont Climate Change Indicators. Submitted to *Weather, Climate and Society*. 