Hydroclimate Issues: Water, Energy and Carbon

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TRACE Discussion Workshop

Silver Spring

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Major Scientific Question

- **How does climate change and climate variability affect the hydrological cycle on a sub-regional to continental scale and to what extent is it predictable?**

- ***Broad 'motherhood' statement***
  - ***But is it close enough to real needs?***

Since 1992 the GEWEX community has ..

- Improved its models
  - but has it paid enough attention to the real world?
- Talked about making predictions but
  - model biases and simplifications limit credibility
  - Earth system too complex to be ‘predictable’
- Talked about
  - making products that are useful for stakeholders
  - collaborating across federal agencies

- How can TRACE avoid ‘business as usual”

Questions

- **How well are we modeling the regional climate system?**

- **Where is our understanding critically lacking**?

- **What do regional stakeholders need for planning?**

More Questions

- Climate instabilities limit predictability
  - Robust retrospective 50 yr analyses
  - What are robust trends?
  - What is driving trends in extremes?

  - What are critical modes of variability in regional climate?
  - What are critical observables?

Modeling Issues

"Beyond the Resemblance Test"

- **Evaluating models – key observables?**
- **Are coupled processes well represented?**
- **Are diurnal, seasonal and climate time-scales well represented?**
- **Are the energetics, the phase transitions of water and the CO_2 fluxes properly coupled?**

- ***Are our models relevant to the real world?***
- ***Is the Spring and Fall phenology accurate?***

Winter/Spring Transitions

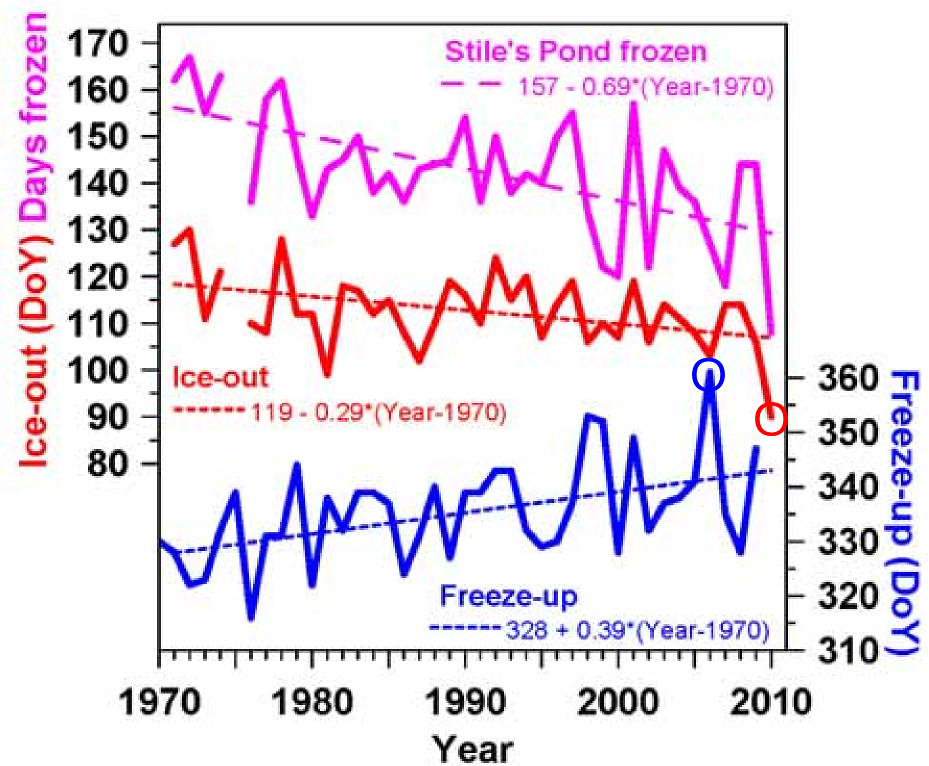
- **Snow**: over-grass and under-forest albedo
- **Melt**: soil phase change energetics and water storage
- **Pre-forest leaf-out**: low EF; large DTR; low WV greenhouse
- **Post-leaf-out**: high EF; low DTR and high WV and cloud greenhouse

- **Coupling of phase changes-phenology-C/H_2O budgets-cloud albedo-LW**

What are key observables?

- **Surface and effective cloud albedos (SW)**
- **Frozen ground, snow cover, frozen lakes**
  - **total frozen water, SW reflection, 0^{o}C transitions**
  - **assimilate NCRS SCAN data?**
- **Surface RH and LCL**
  - **availability of water, vegetative resistance, CO_2**
- **Diurnal temp. range**
  - **surface LW_{net}, WV and cloud greenhouse (LW)**
- **Seasonal transitions**
  - **integrated markers of climate system: ice and vegetation**

Lake frozen period shrinking fast



Interannual Variability of Ice-out is

4.2 ±0.5 days per °C

O Record Dec T

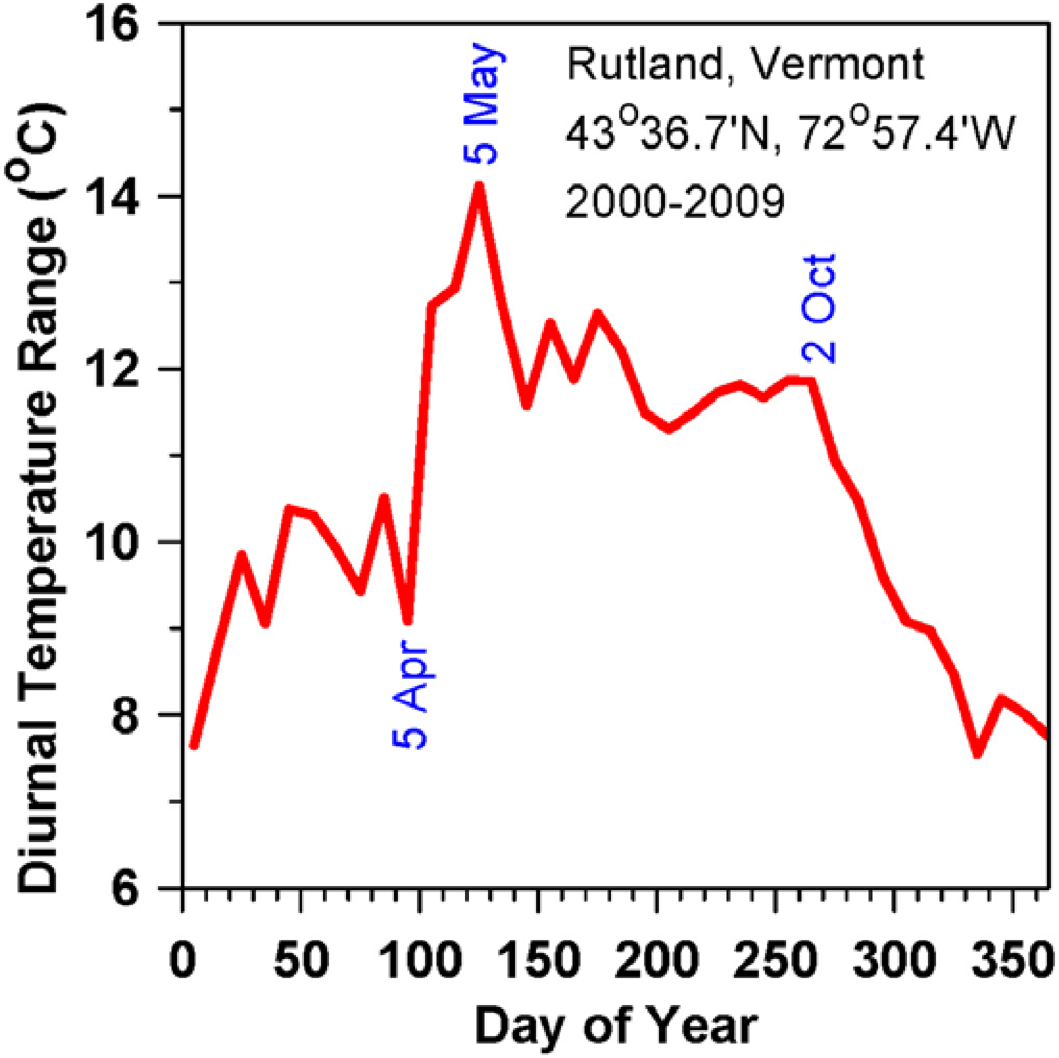
O Record spring T

- **Frozen lakes are regional climate indicator**
  - **Ice-out earlier -3 days/decade**
  - **Freeze-up later +4 days/decade**
  - **Frozen period -7 days/decade**

(Betts, WCAS 2011)

Annual cycle of Diurnal Temperature Range

- **Ice-out: 5 April**
- **Leaf-out: 5 May**
- **Summer transpiration**
- **Fall frost: 2 Oct**



(Betts, Weather 2011)

Where is our understanding critically lacking?

- **Precipitation**

- **BL coupling of ET, CO_2 uptake, cloud cover and WV greenhouse as pCO_2 increases**
  - **See on-line materials**

Critical Precipitation Issues

- **Precipitation intensity: understanding historic changes; and future climate. Not just q_s(LCL)**
  - **Critical for climate change adaptation and planning**
- **Summer precipitation-evaporation feedback**
  - **Adaptation to changing flood-drought frequency**
- **Coupling between local climate & large-scale circulation modes**
  - **sensitivity to climate change**
- **Coupling of aerosols, clouds, radiation and precipitation**

What do regional stakeholders need for planning?

- **Adaptation planning**
  - **Built infrastructure (future hydrologic indices)**
  - **Forest ecosystem management**
    - **Changes in carbon-water-albedo-radiation balance with tree species as climate changes**
    - **Winter pest survival**
  - W**ildlife management: as ecosystems change**
  - **Agriculture: food and biofuels**
- **Renewable energy**
  - **cloud cover and wind trends**
- **Sustainability and resilience from global economic shocks**

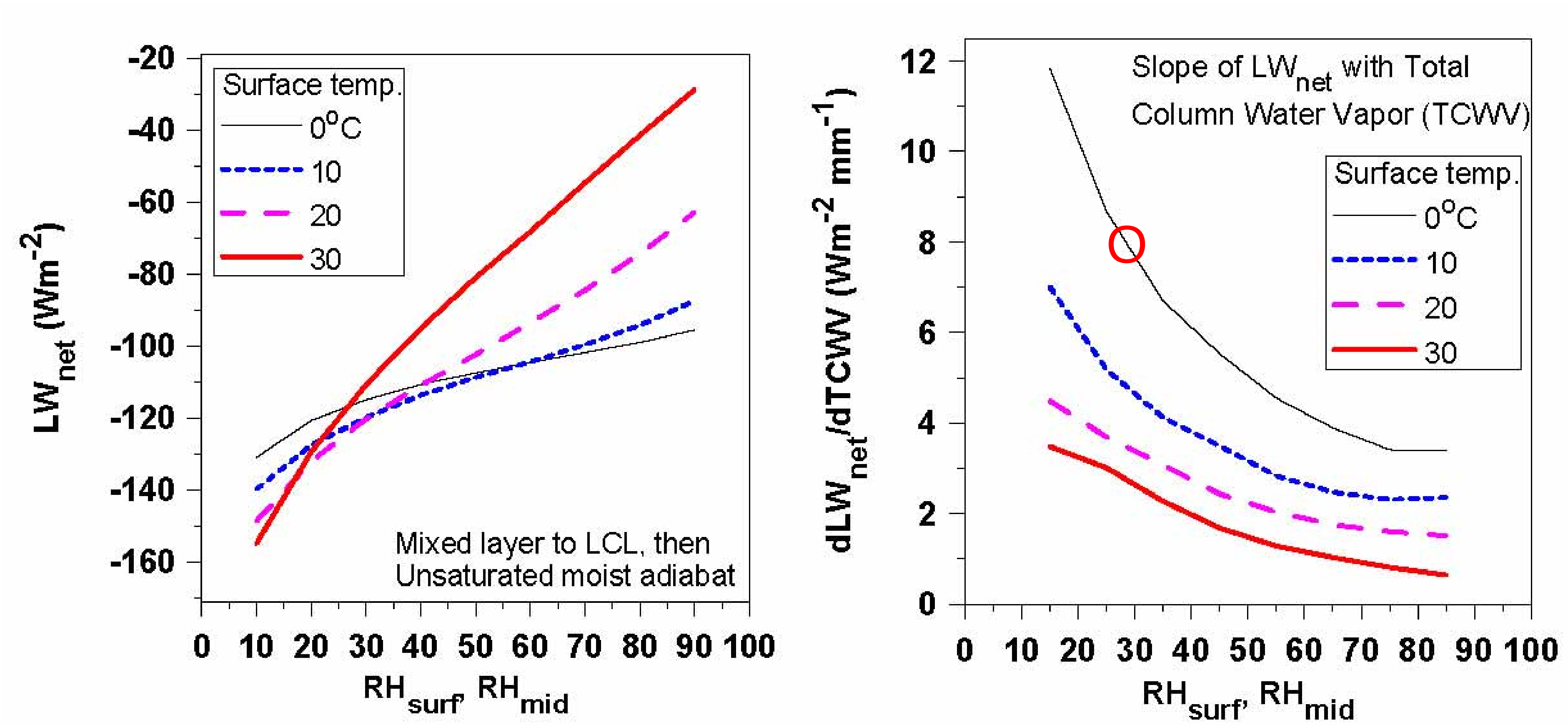
References and this talk (more slides) available at http://alanbetts.com/research

- Betts, A. K. (2009), Land-surface-atmosphere coupling in observations and models. *J. Adv. Model Earth Syst., 1(4),* 18 pp., doi: 10.3894/JAMES.2009.1.4 http://adv-model-earth-syst.org/index.php/JAMES/article/view/v1n4/JAMES.2009.1.4
- Betts, A. K. and J. C. Chiu (2010), Idealized model for changes in equilibrium temperature, mixed layer depth and boundary layer cloud over land in a doubled CO_2 climate. *J. Geophys. Res.,115*, D19108, 2009JD012888.
- Betts, A. K. (2011), Vermont Climate Change Indicators. *Weather, Climate and Society* (in press)
- Betts, A. K. (2011), Seasonal Climate Transitions in New England. *Weather* (in press)

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**
  - ***Freezing point accuracy matters in models!***
  - ***Assimilate NCRS SCAN data?***

LW impact of water vapor

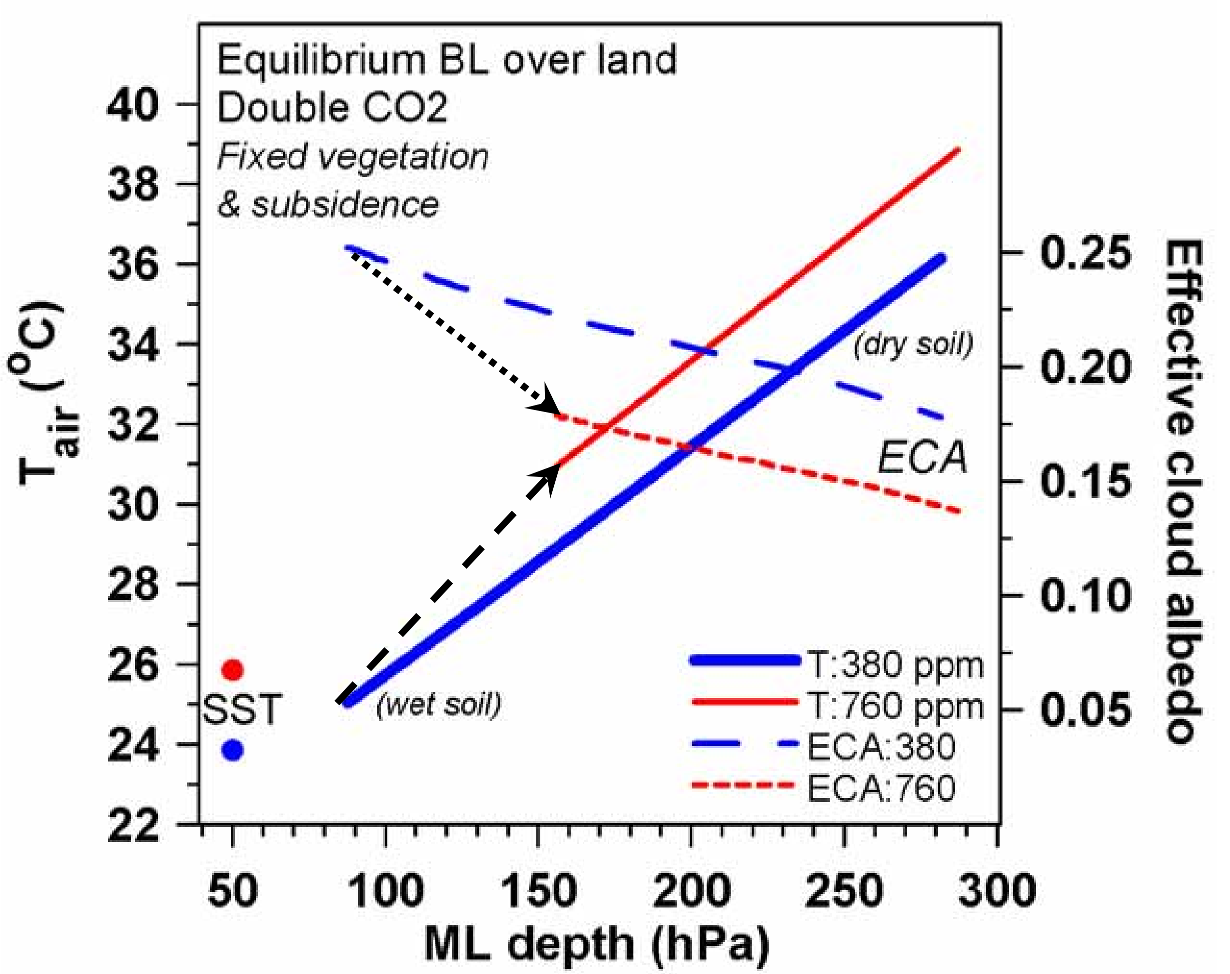


- **Sensitivity increases with decreasing RH and T**
  - **Adding 1mm column water vapor reduces outgoing LW_{net} by 8 Wm^{-2} at 0°C and 30% RH**

Betts & Chiu, 2010, unpublished

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]

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!***

Framework for a Hydrologic Climate-Response Program in New England

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http://pubs.usgs.gov/of/2009/1115/

Climate Research in the USGS Maine Water Science Center

- Since 2001 the USGS MeWSC has evaluated the impact of climate change on long-term hydrologic records in New England
- Primary work demonstrated strong relationships between climate and some hydrologic variables
- Hydrologic variables displayed consistent temporal and geographic trends