

Interweaving Climate Research and Public Understanding

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Bert Bolin lecture
American Geophysical Union
San Francisco
December 14, 2016



Bert Bolin: 1925-2007

- **1946: BSc, Uppsala; MSc, 1949;
PhD, Meteorology, 1956, Stockholm**
- **1950: Princeton with Charney, von Neumann**
- **1961-1990: Professor, Meteorology, Stockholm**
- **1964-67: Chair, ICSU Committee on Atmos. Science**
- **1968-71: Chair, Global Atmospheric Research Program**
- **1984: AMS Rossby Medal “for his outstanding research enlarging our understanding of the atmosphere and oceans as a milieu, for valuable contributions to the understanding of global geochemical cycles, and for his international leadership in scientific planning of the Global Atmospheric Research Program (GARP)**
- **1988-97: IPCC Chair; First Assessment Report (1990),
Second Assessment Report (1995)**

Outline of this talk

- **Perspective**
- **Recent Research**
- **Public Outreach**
 - Framing of talks: local research
 - Articles and media
- **Central issues**
 - Responsibilities, strategies
 - Issues beyond ‘science’



Perspective

- **Tribute to my early teachers**
 - Ian Parker (Nottingham High School) - physics
 - *Sir Aaron Klug* and Peter Scheuer (Peterhouse, Cambridge) - physics
 - Frank Ludlam (Imperial College) - meteorology
- **Historic timeline**
 - VIMHEX, GATE-1974, Vermont (1978-present), FIFE, BOREAS, LBA, GEWEX; *ECMWF (1983-)*
- **Vermont Academy of Science and Engineering**
 - VASE President: 2005-2007
- **Ag-Canada (2012) asks for help: Prairie data**

Vermont Timeline

- *2005: VASE Presidential lecture: climate change*
- 2007: IPCC AR4 – flood of VT talk requests
- 2008: Rutland Herald and Times-Argus “Weekly Planet” environment section
- **2010:** <http://alanbetts.com>
- **Betts, 2011-12**
 - *Vermont Climate Change Indicators. WCAS*
 - *Communicating Climate Science. EOS, AGU*
 - *Climate Change in Vermont. Agency Natural Resources, Vermont*
 - *Seasonal Climate Transitions in New England. Weather*
 - *Environmental journalism revisited (Framing)*
- **2013-2016, Eight Prairie papers**

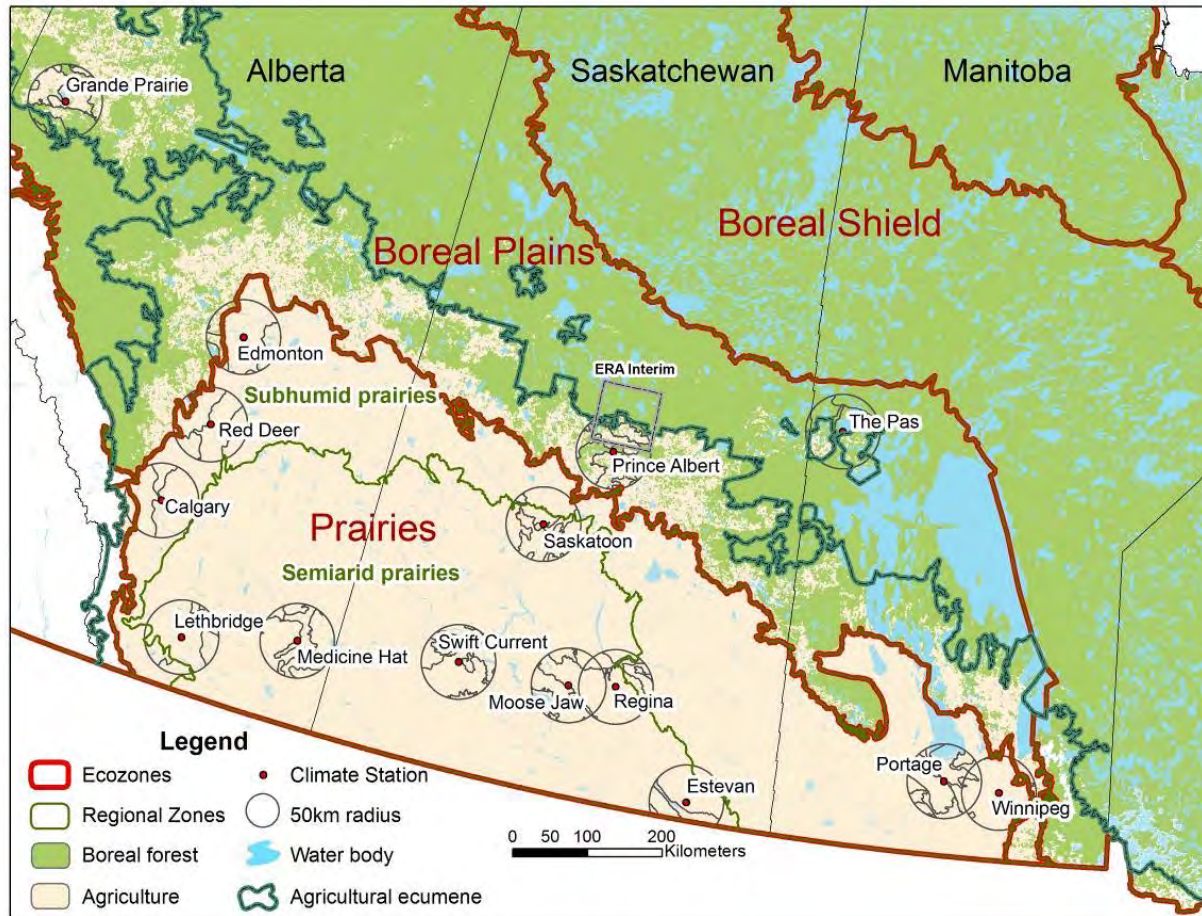
Fundamentals

- ***Burning fossil fuels: transforming climate***
 - *Many water cycle amplifying feedbacks*
 - *Heading for high CO₂ “Carboniferous era climate”*
 - *Climate extremes increasing*
 - *Decadal to centennial - long timescales*
- **Avoidance of responsibility for decades**
 - Politicians, professionals, public
 - Climate change: Incompatible with business-as-usual
- **Linked to unmanaged technology**
 - Soluble by changing system guidelines
 - Create efficient society, based on renewable energy
- **Choices are value based**
 - Not scientific or economic
 - Incompatible with exploitative model

Research: 2013-2016

- **Where is the data?**
 - *thanks to Ray Desjardins, Devon Worth*
- **Canadian Prairies: northern climate**
 - **Cold season hydrometeorology**
 - **Snow is a fast climate switch**
 - Two distinct “climates” - above and below 0°C
 - Separated by 10°C
 - Cold season temperature linear decrease with fraction days snow cover
 - Cloud coupling reverses with snow
 - April has 5-mo memory of cold season precipitation
 - **Warm season hydrometeorology**
 - **Cloud dominated**
 - **Summer memory of precipitation back to March**

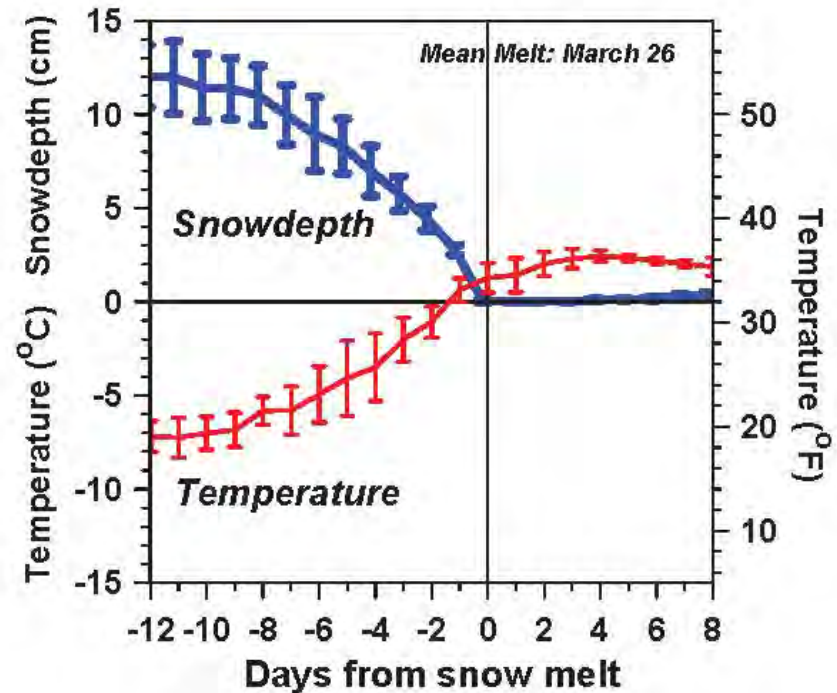
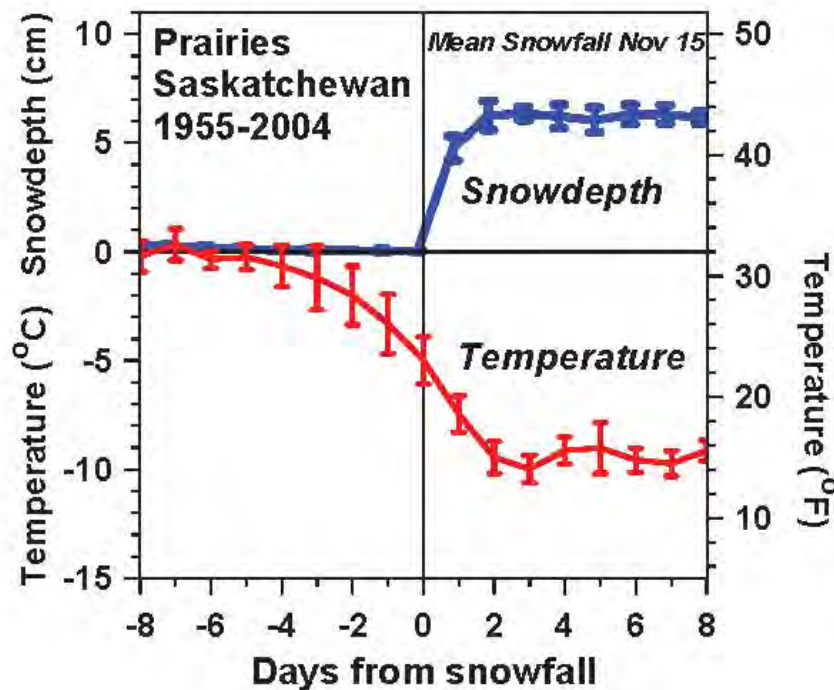
15 Prairie stations: 1953-2011



- *Hourly* p, T, RH, WS, WD, Opaque Cloud (SW_{dn} , LW_{dn})
- *Daily* precipitation and snowdepth
- Ecodistrict crop data since 1955; BSRN data
- Albedo data (MODIS/CCRS: 250m)

Snowfall and Snowmelt

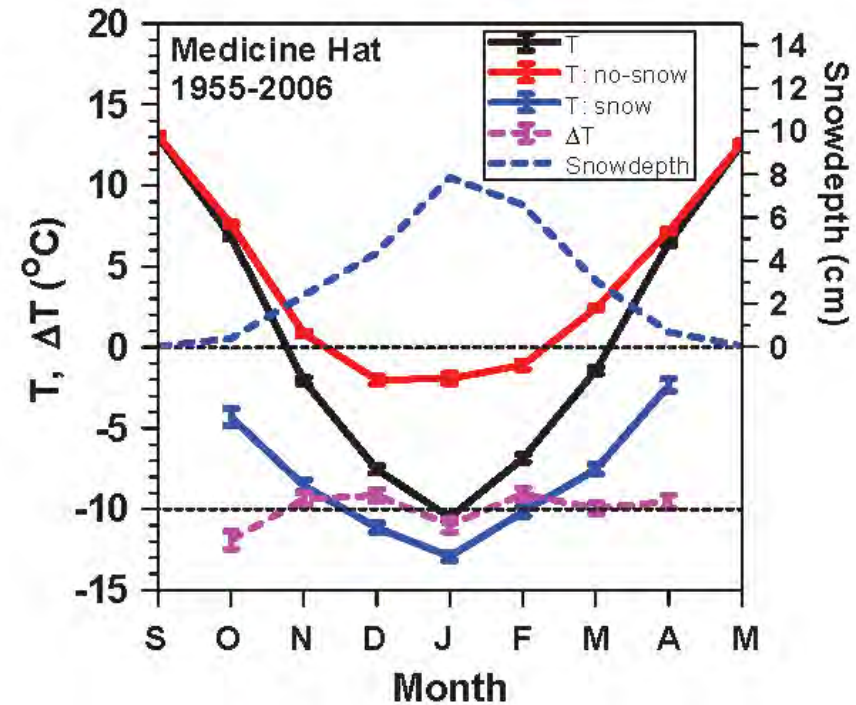
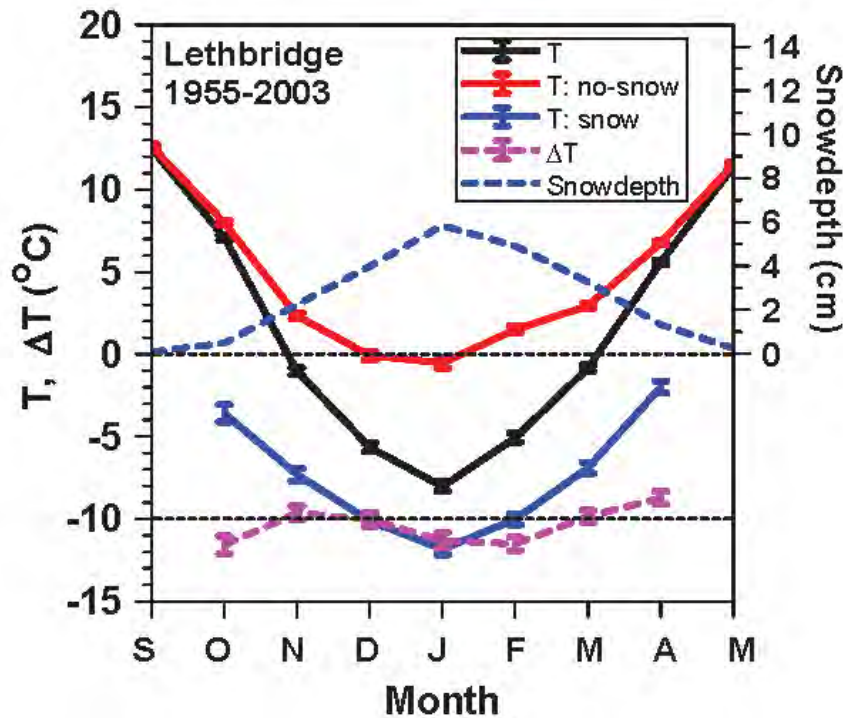
Winter and Spring transitions



- Temperature falls/rises about 10K with first snowfall/snowmelt
- ***Snow reflects sunlight; shift to cold stable BL***
 - Local climate switch between warm and cold seasons
 - *Winter comes fast with snow*

(Betts et al. 2014a)

Impact of Snow on Climate



Separate mean climatology into days
with no-snow and Snowdepth >0

$$\Delta T = T:\text{no-snow} - T:\text{snow} = -10.2(\pm 1.1)^{\circ}\text{C}$$

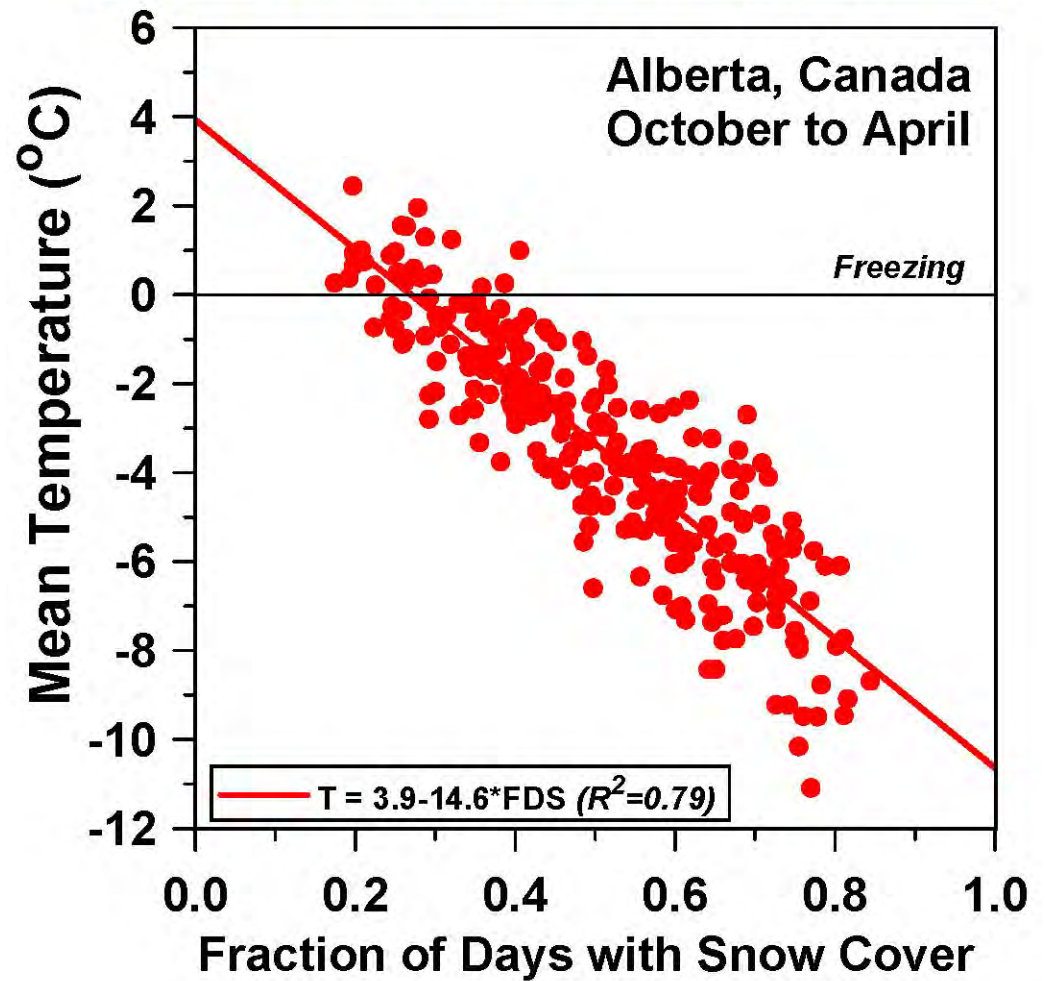
Betts et al. (2016)

Interannual variability of T coupled to Snow Cover

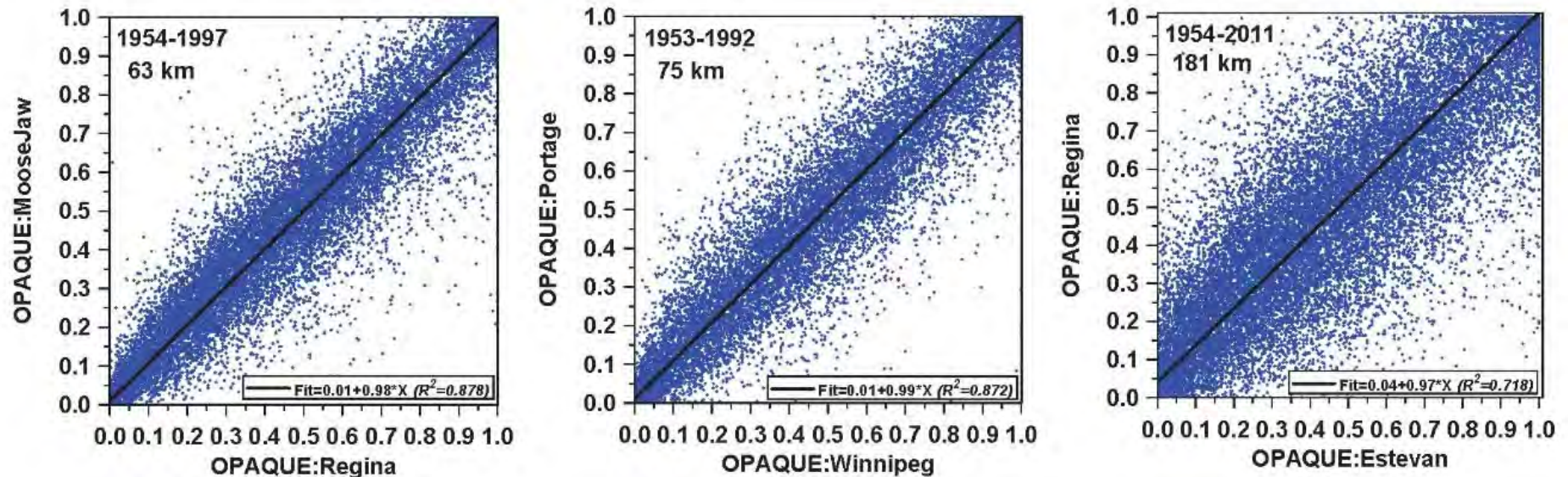
- Alberta: 79% of variance
- Slope T_m $-14.7 (\pm 0.6)$ K

10% fewer snow days
= 1.5K warmer
on Prairies

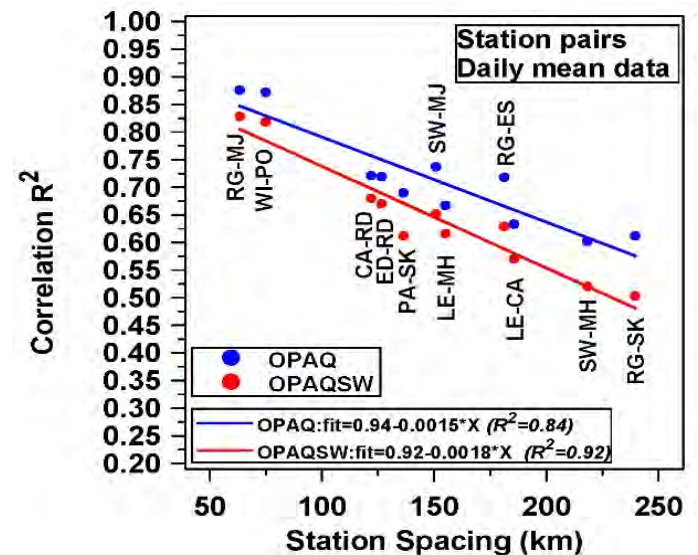
More snow cover - Colder temperatures



Opaque Cloud (Observers)



- Daily means unbiased
- Correlation falls with distance
- **Good data!**



Diurnal cycle: Clouds & Snow

Canadian Prairies 660 station-years of data

Winter climatology

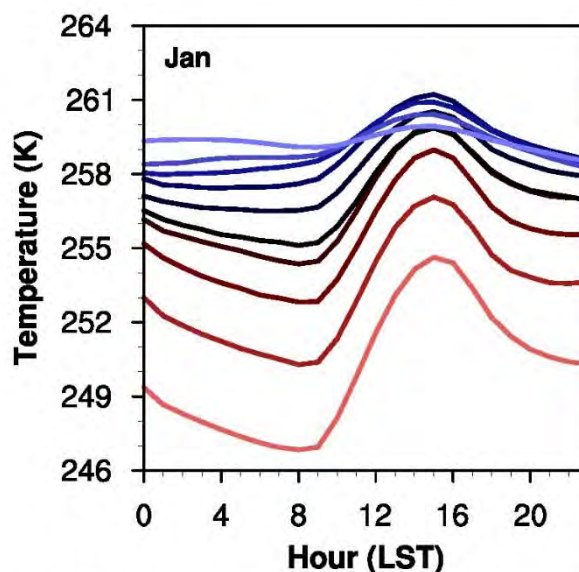
- Colder when clear
- LWCF dominant with snow
- Stable BL

Summer climatology

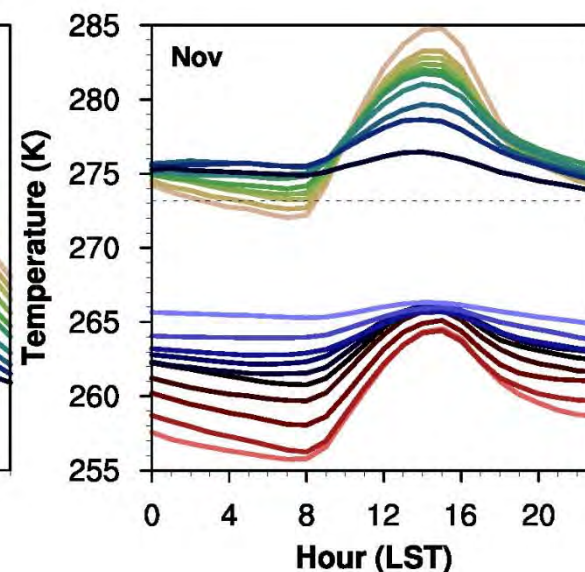
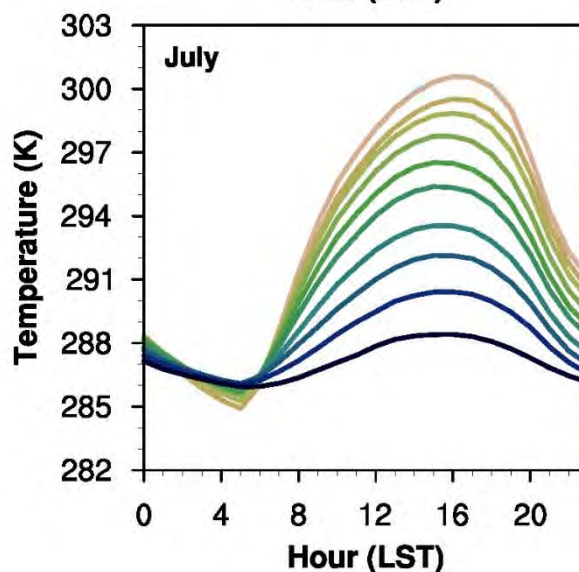
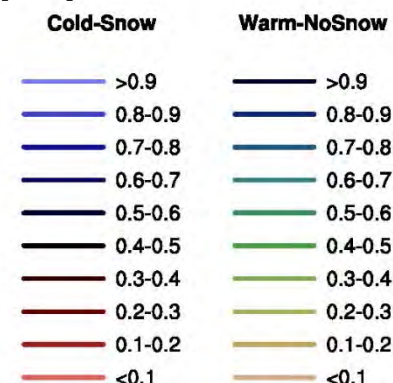
- Warmer when clear
- SWCF dominant: no snow
- Unstable daytime BL

Transition months:

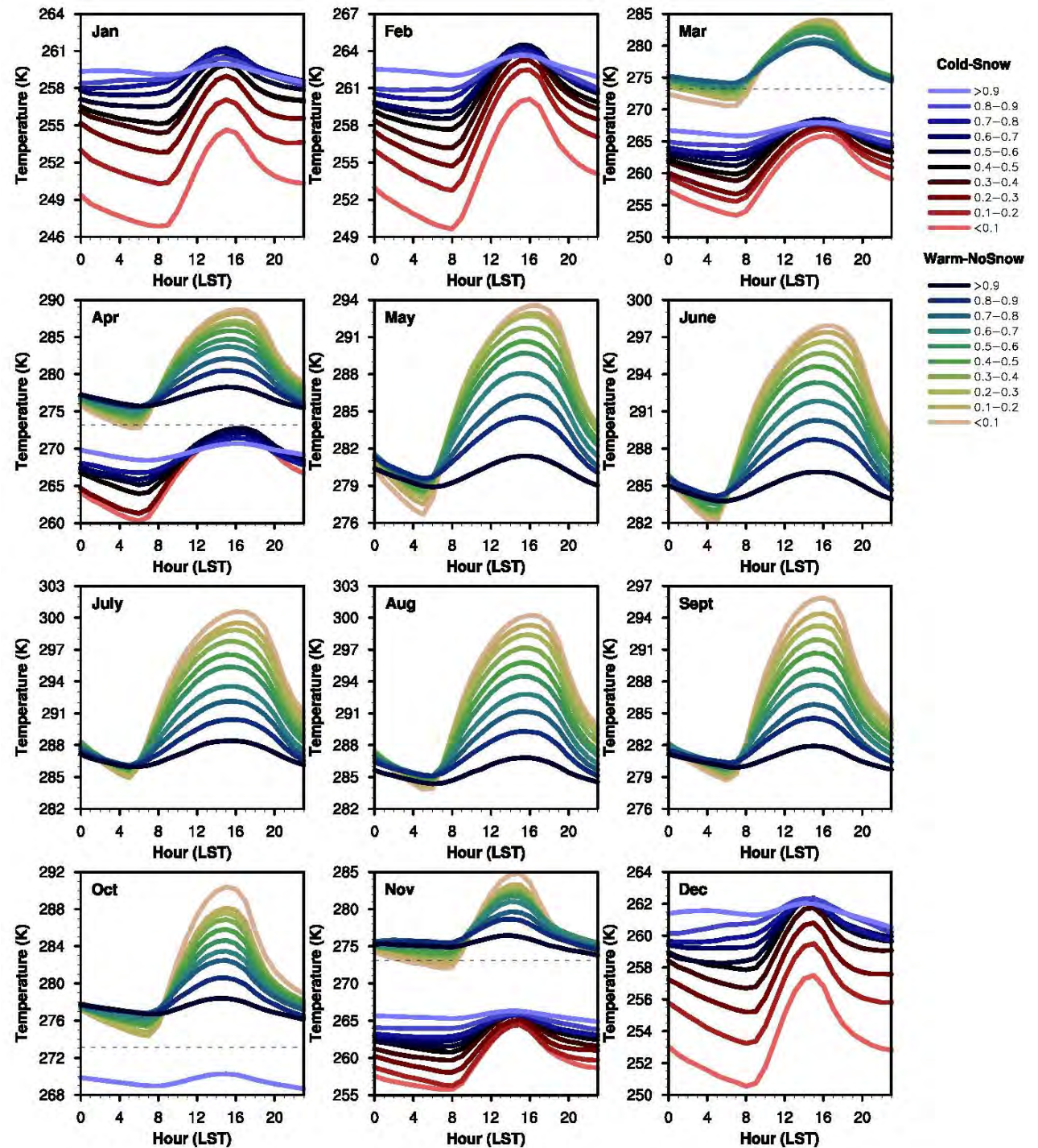
- Show both climatologies
- With 11K separation
- Fast transitions with snow
- Snow is “Climate switch”



Opaque cloud fraction



Monthly diurnal climatology (by snow and cloud)



Impact of Snow

- **Distinct warm and cold season states**
- **Snow cover is the “climate switch”**
- **Prairies: $\Delta T = -10^{\circ}\text{C}$ (winter albedo = 0.7)**
- **Vermont: $\Delta T = -6^{\circ}\text{C}$ (winter albedo 0.3 to 0.4)**
- **Snow transforms BL-cloud coupling**
 - **No-snow ‘Warm when clear’ - convective BL**
 - **Snow ‘Cold when clear’ - stable BL**

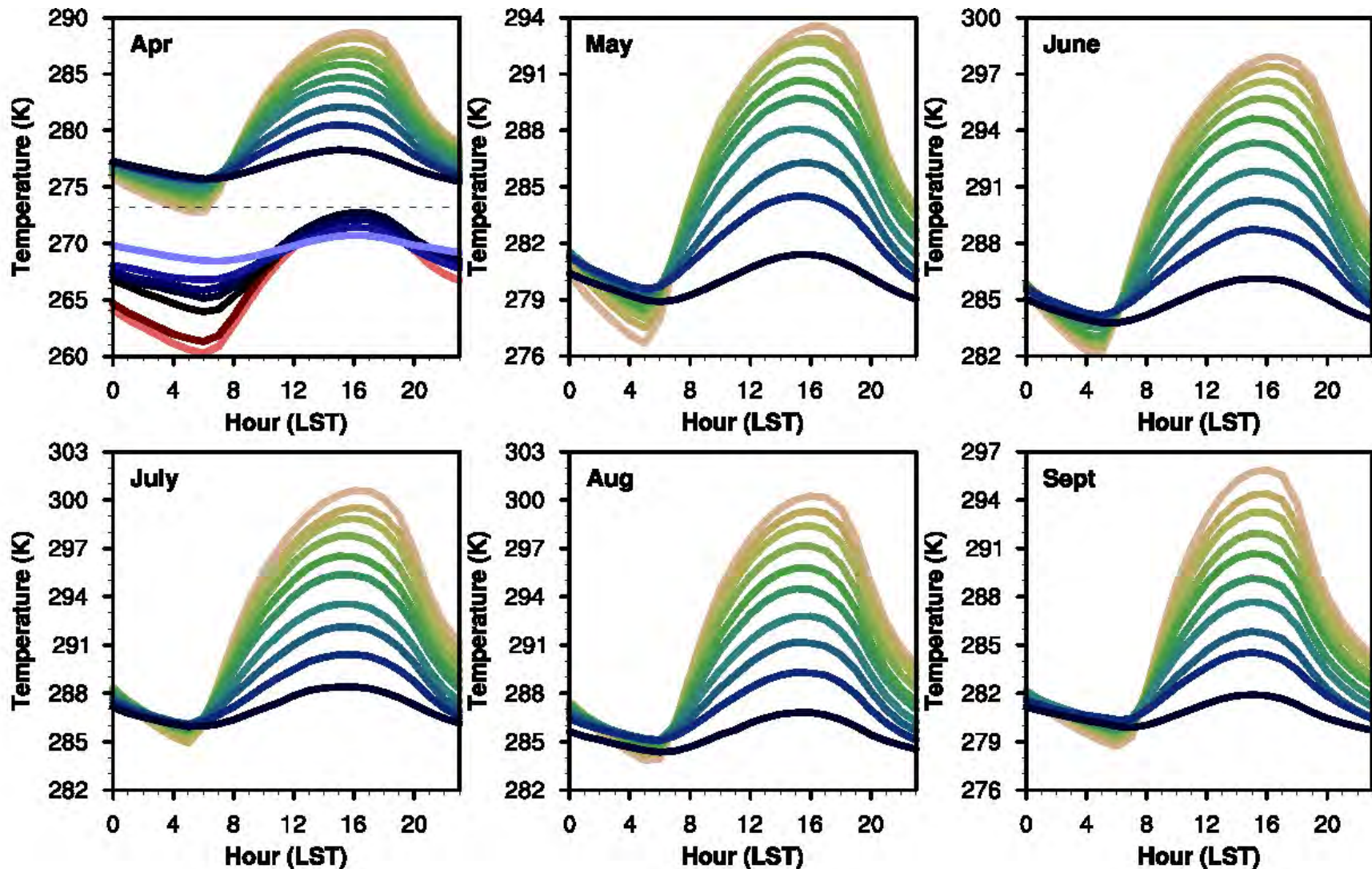
Warm Season Climate

(April – October with no snow)

- *Hydrometeorology*
 - with Precipitation and Radiation/clouds
 - Diurnal cycle of T , RH , θ_E , LCL
 - Cannot do coupling with just T & $Precip$!
- *Daily timescale primarily radiation driven*
 - Night LW_n ; day SW_n (and EF)

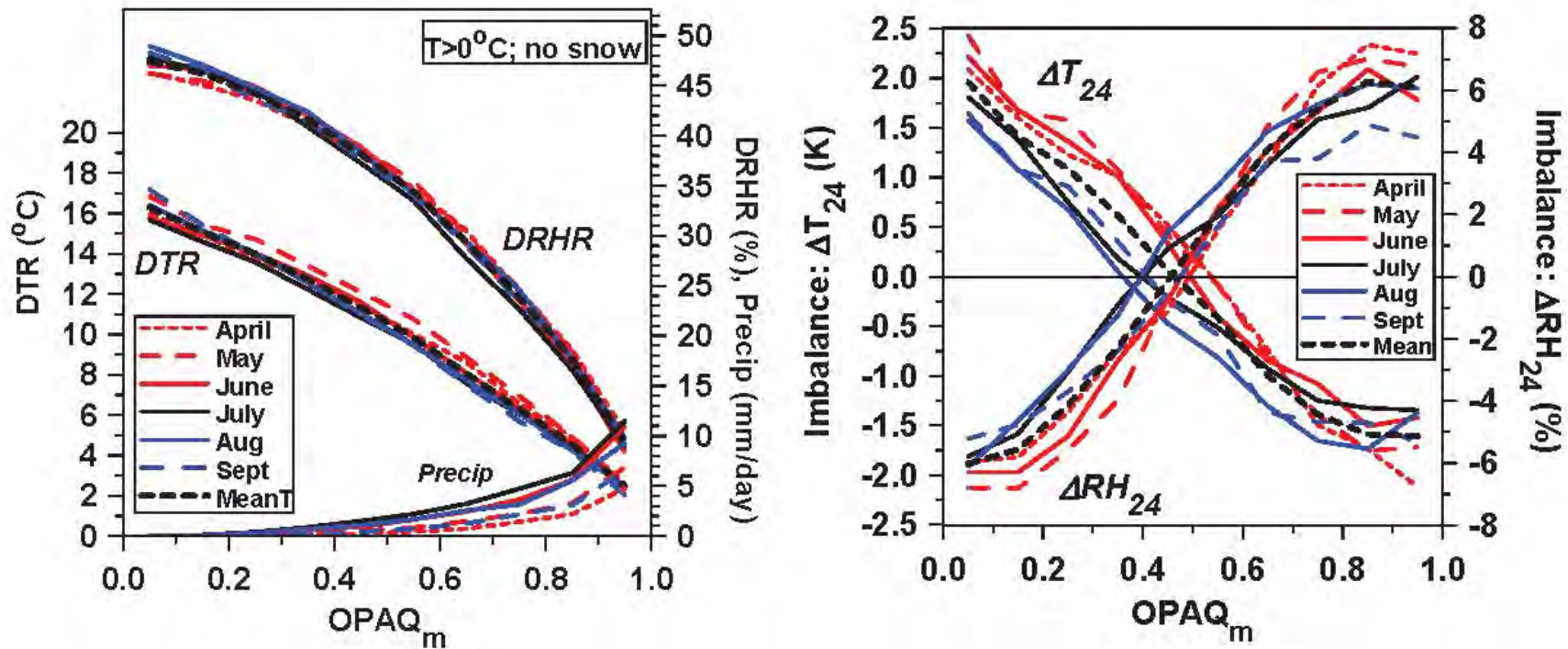
*Betts et al. 2014b; 2016
Betts and Tawfik 2016)*

Monthly Diurnal Climatology



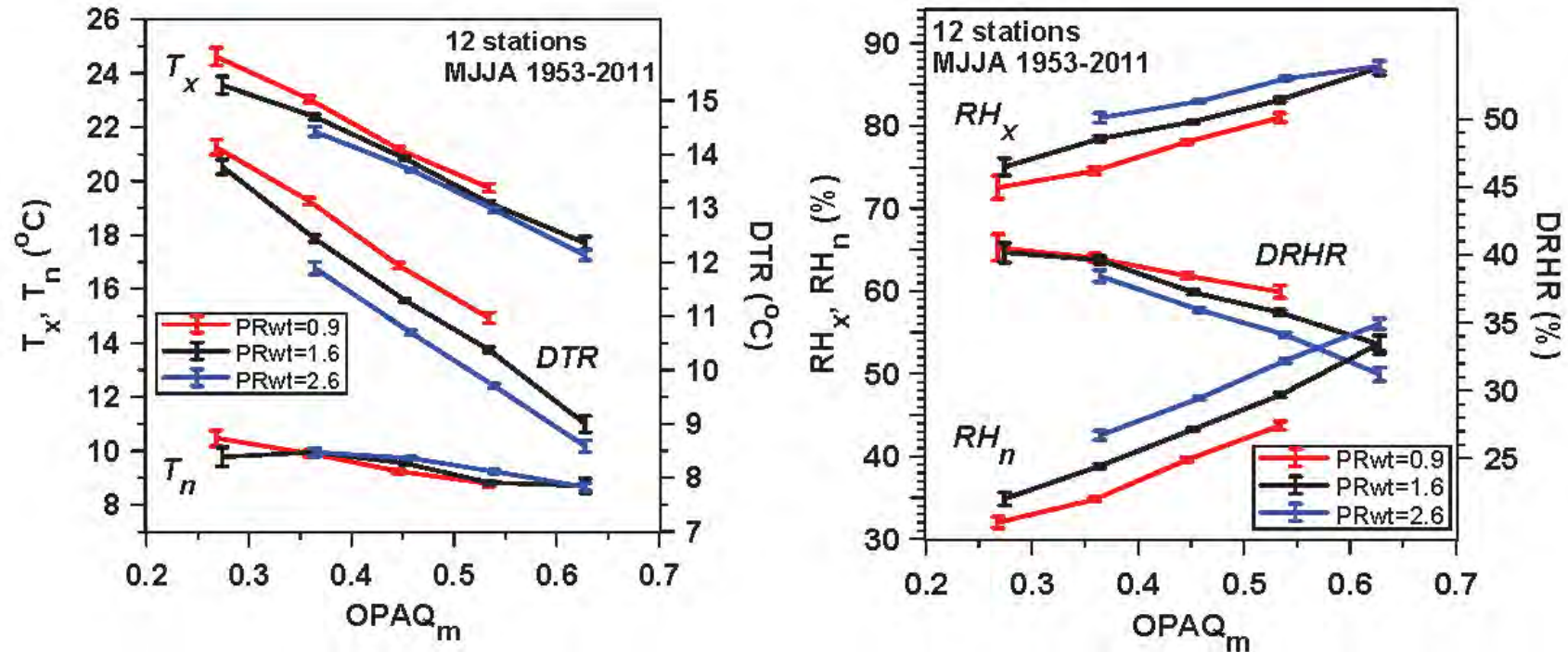
Q: How much warmer is it at the end of a clear day?

Diurnal Ranges & Imbalances



- April to Sept: same coupled structure
- Q: Clear-sky: warmer (+2°C), drier (-6%)

Monthly Coupling to Cloud and Precipitation



- Merge May to August: monthly anomalies
- Diurnal ranges larger when drier

(Betts et al. 2016)

Warm Season Climate

- *Monthly Hydrometeorology*
 - *Fully coupled*
 - *Precipitation, cloud, T , RH , θ_E , LCL , Q*
 - *Use regression to couple anomalies*

(Betts et al. 2014b; 2016)

Monthly Regression on Cloud and lagged Precip. anomalies

- **Monthly anomalies (normalized by STD of means)**
 - opaque cloud (CLD)
 - precip. (PR-0, PR-1, PR-2): current, lagged 2 to 5 months

e.g.

$$\delta \underline{\text{DTR}} = A * \delta \text{CLD} + B * \delta \text{PR-0} + C * \delta \text{PR-1} + D * \delta \text{PR-2} \dots$$

(Month) (Month) (Month-1) (Month-2)

Soil moisture memory

*April: memory of entire cold season (snow, soil ice)
back to November freeze*

June, July, Aug: memory of precip. back to March

April: Precip Memory back to November

1953-2010: 12 stations (620 months)

Variable	δDTR	δT_x	δRH_n	$\delta\text{P}_{\text{LCLx}}$
$\text{R}^2 =$	0.67	0.47	0.65	0.66
Cloud-Apr	-0.52±0.02	-0.78±0.04	0.76±0.03	-0.93±0.04
PR-Apr	-0.06±0.02	(0.01±0.04)	0.20±0.03	-0.19±0.04
PR-Mar	-0.12±0.02	-0.22±0.04	0.23±0.03	-0.27±0.03
PR-Feb	-0.07±0.02	-0.12±0.04	0.16±0.03	-0.19±0.03
PR-Jan	-0.09±0.02	-0.19±0.04	0.17±0.03	-0.21±0.03
PR-Dec	-0.06±0.02	(-0.06±0.04)	0.16±0.03	-0.19±0.03
PR-Nov	-0.08±0.02	-0.13±0.04	0.07±0.03	-0.11±0.03

April remembers precip. back to freeze-up

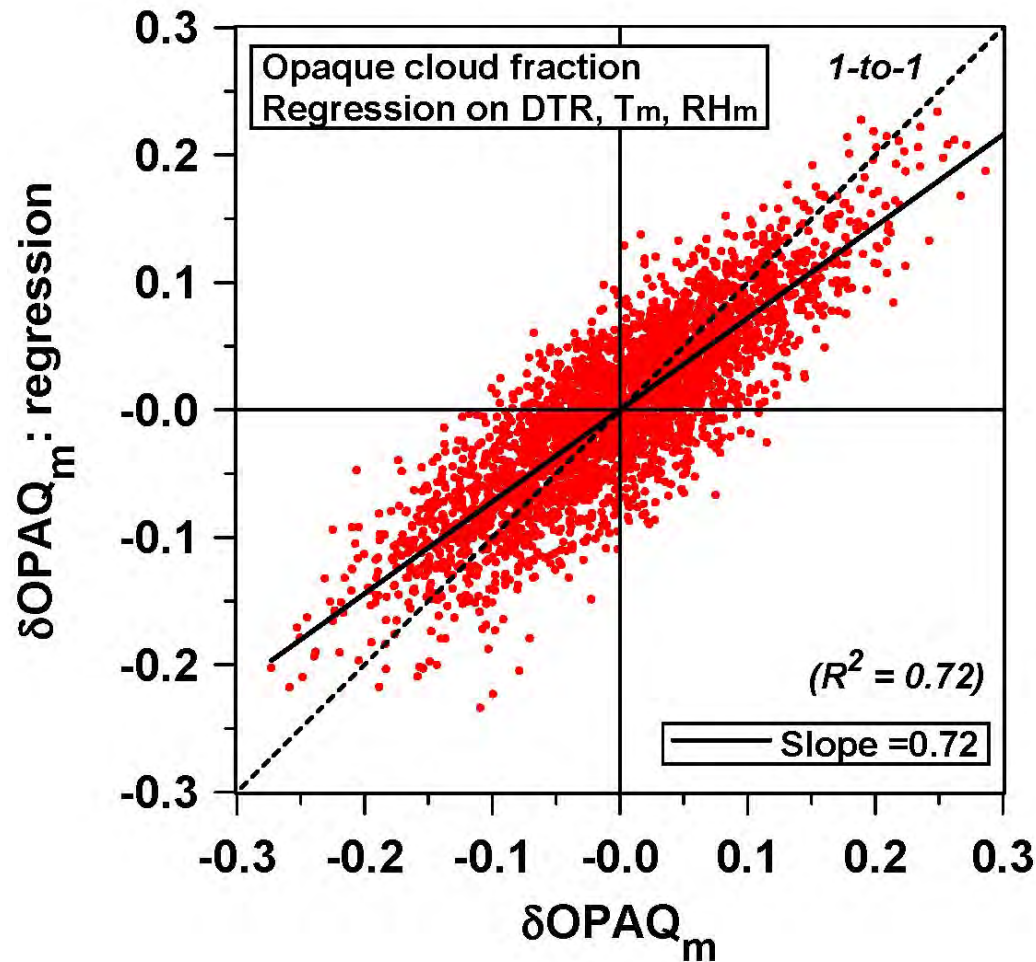
Summer Precip Memory back to March

JULY 1953-2010: 12 stations (614 months)

<u>JULY</u>	δDTR	δRH_n	$\delta\text{P}_{\text{LCLx}}$	$\delta\text{Q}_{\text{Tx}}$
R^2	0.68	0.61	0.62	0.26
Cloud-July	-0.56±0.03	0.50±0.03	-0.63±0.04	(0.03±0.04)
PR-July	-0.31±0.02	0.37±0.03	-0.45±0.04	0.34±0.04
PR-June	-0.22±0.02	0.34±0.03	-0.44±0.04	0.38±0.04
PR-May	-0.12±0.02	0.11±0.03	-0.16±0.04	0.16±0.04
PR-Apr	-0.04±0.02	0.06±0.03	-0.06±0.03	0.12±0.04
PR-Mar		0.06±0.03	-0.07±0.03	0.10±0.04

June, July, Aug have precip memory back to March

Cloud anomalies from Climate anomalies



δOPAQ_m to ± 0.04

- $\delta\text{OPAQ}_m : \text{reg} = -0.64 * \delta\text{DTR} - 0.23 * \delta T_m + 0.11 * \delta\text{RH}_m$

Monthly and daily bins

- **Daily binning shows dependence of climate on cloud (radiation) and wind-speed**
- **Monthly anomaly analysis adds the lagged precipitation (soil moisture) dependence**
 - RH, Q: precip. memory as long as 5 months
- Asymmetric response to dry/wet precipitation anomalies
- Observed coupling coefficients can be compared with model representations

Science questions?

(Papers: alanbetts.com)

Vermont Talks

- Schools and colleges
- Professional groups
- Citizens groups
- State agencies/government
- ***230+ talks: 2006-2016***
- ***TV and radio interviews***

(alanbetts.com/talks)

Climate Processes

- *Solar seasonal cycle*
- *Temp., RH, Cloud, Precip. coupled*
- **Reflection of SW**
 - Clouds: Water drops, ice crystals
 - Cools surface
 - Snow and ice on surface
 - Cools surface
- **Water vapor/clouds trap LW**
 - Re-radiation down warms surface

Warm and Cold Seasons



- **Unstable BL: SWCF -**
- **Clouds at LCL**
 - reflect sunlight

- **Stable BL: LWCF +**
- **Cloud reduce LW loss**
- **Snow - reflects sunlight**

January 2, 2012: NASA

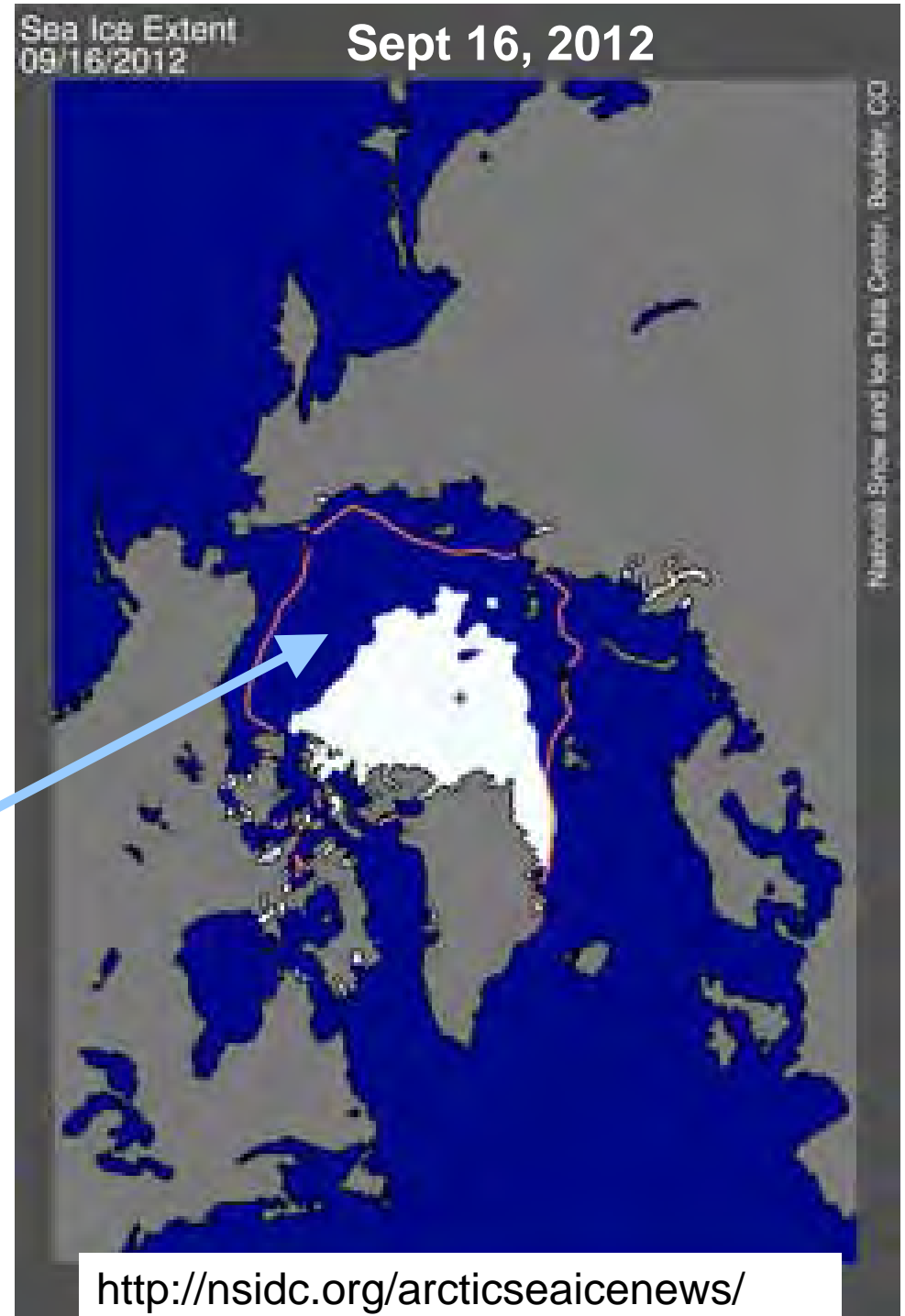
Earth's climate sustains life

- Burning fossil fuels is increasing greenhouse gases
- **Climate is warming: ice is melting, extreme weather is increasing**
- Water plays crucial amplifying role
- Planetary modes crucial



- **Half the Arctic Sea Ice Melted in 2012**
- **Open water in Oct. Nov. gives warmer Fall in Northeast**

- Positive feedbacks:
- *Less ice, less reflection of sunlight*
- *More evaporation, larger vapor greenhouse effect*
- Same feedbacks as in our winters





January 2, 2012



March 11, 2012



October 2011– March 2012

- **Warmest 6 months on record**
- **My garden frozen only 67 days**

• **January 15, 2013**



February 5, 2016

(Digging in Feb. first time ever)

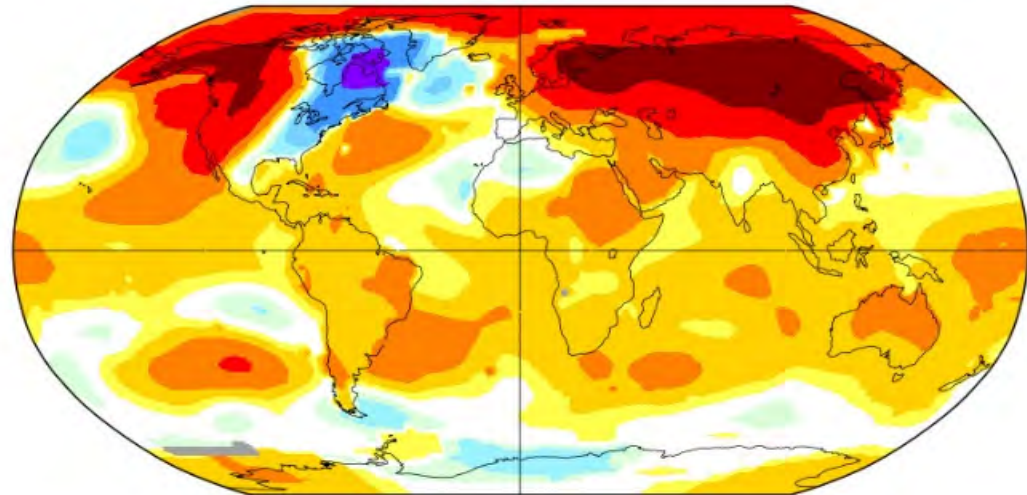


***Jan-Feb-Mar
2015***

Jan-Mar 2015

L-OTI(°C) Anomaly vs 1951-1980

0.86



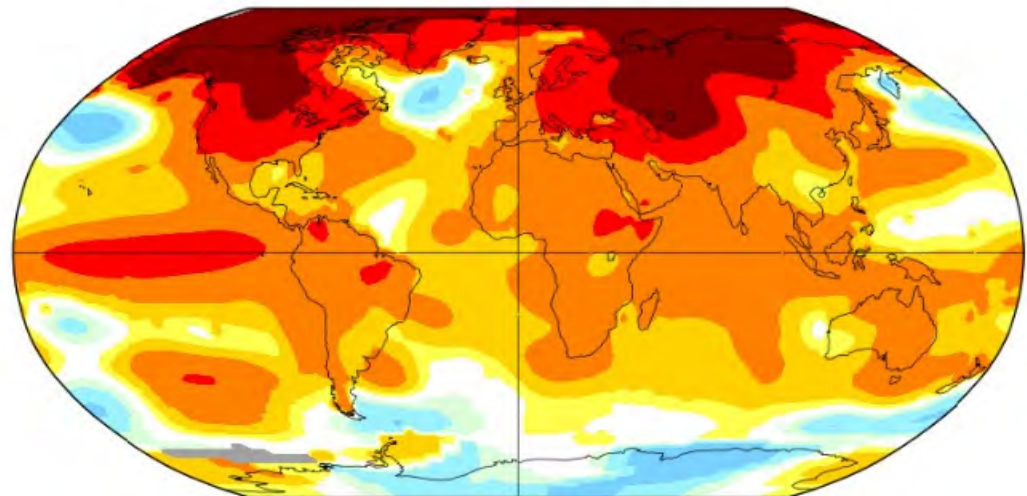
-5.0 -4.0 -2.0 -1.0 -0.5 -0.2 0.2 0.5 1.0 2.0 4.0 6.4

***Jan-Feb-Mar
2016***

Jan-Mar 2016

L-OTI(°C) Anomaly vs 1951-1980

1.24



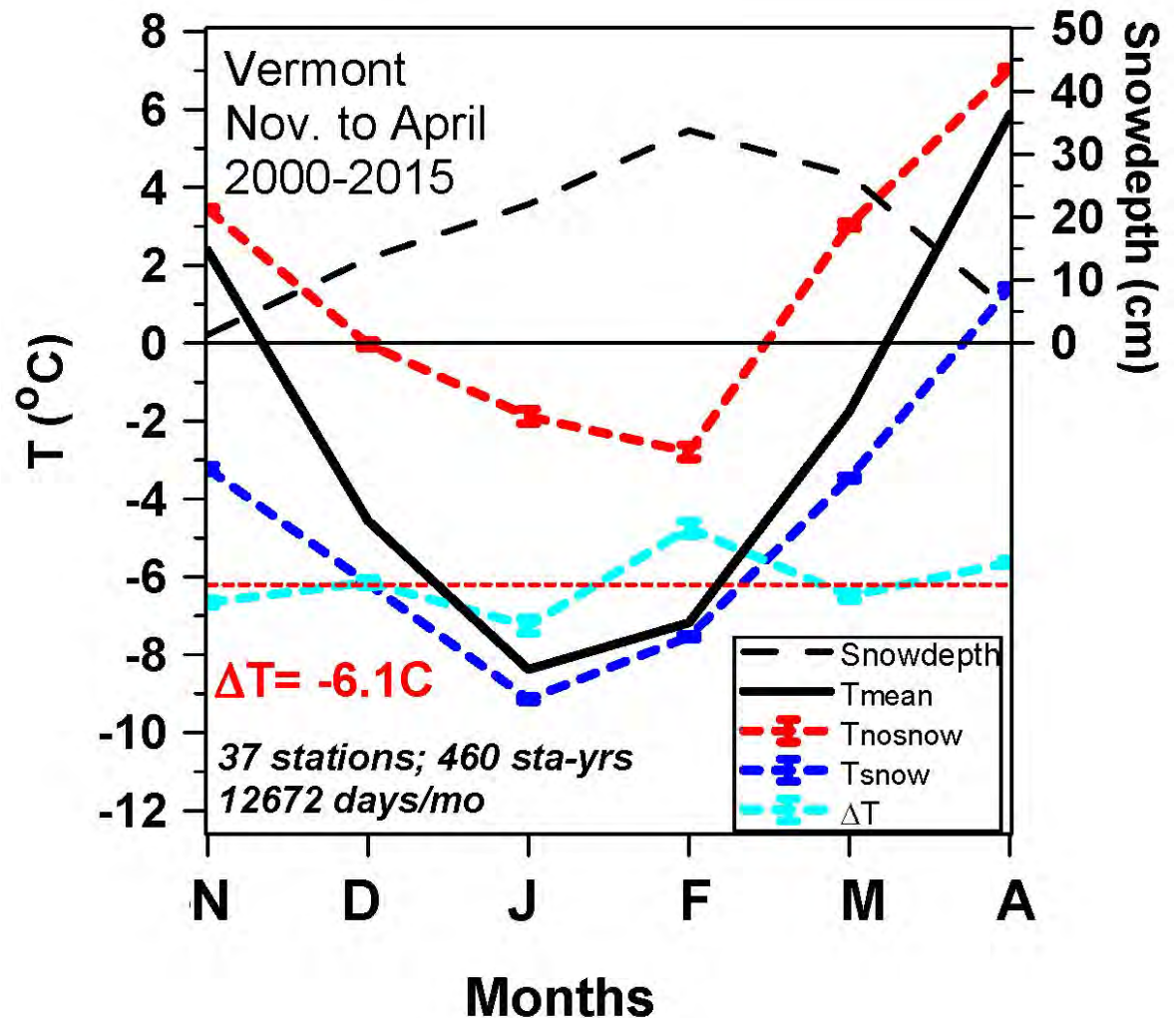
-4.1 -4.0 -2.0 -1.0 -0.5 -0.2 0.2 0.5 1.0 2.0 4.0 8.0

Climatological Impact of Snow: Vermont

Separate mean climatology into days with no-snow and with snow

Difference $\Delta T = -6.1(\pm 0.7)^{\circ}\text{C}$

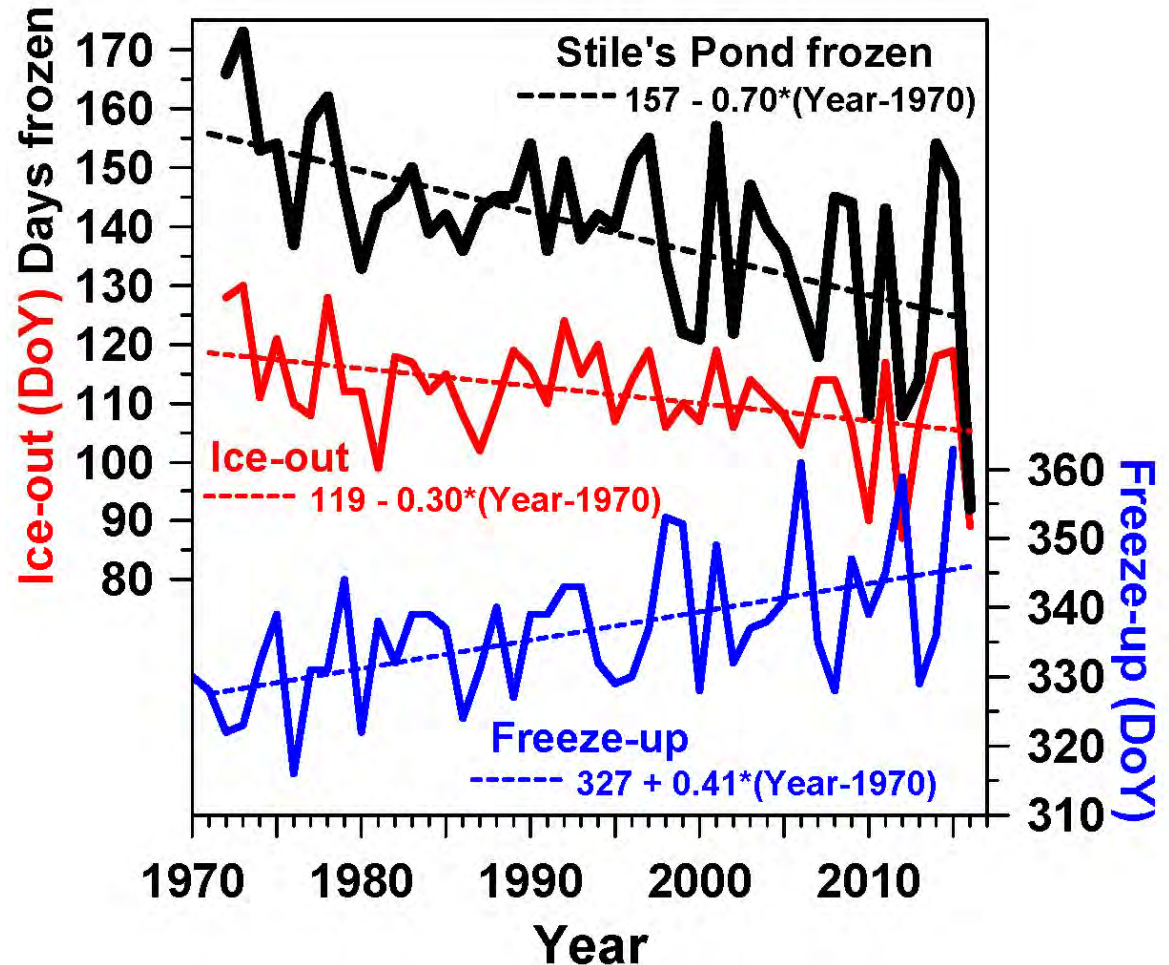
Snow-free winters: warmer than snowy winters: $+6^{\circ}\text{C}$



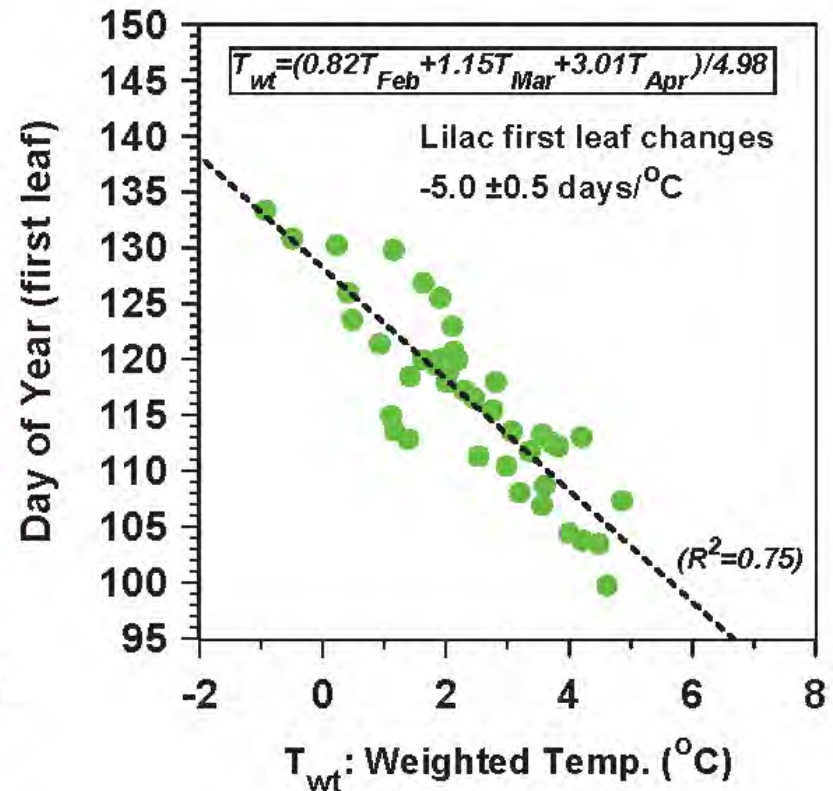
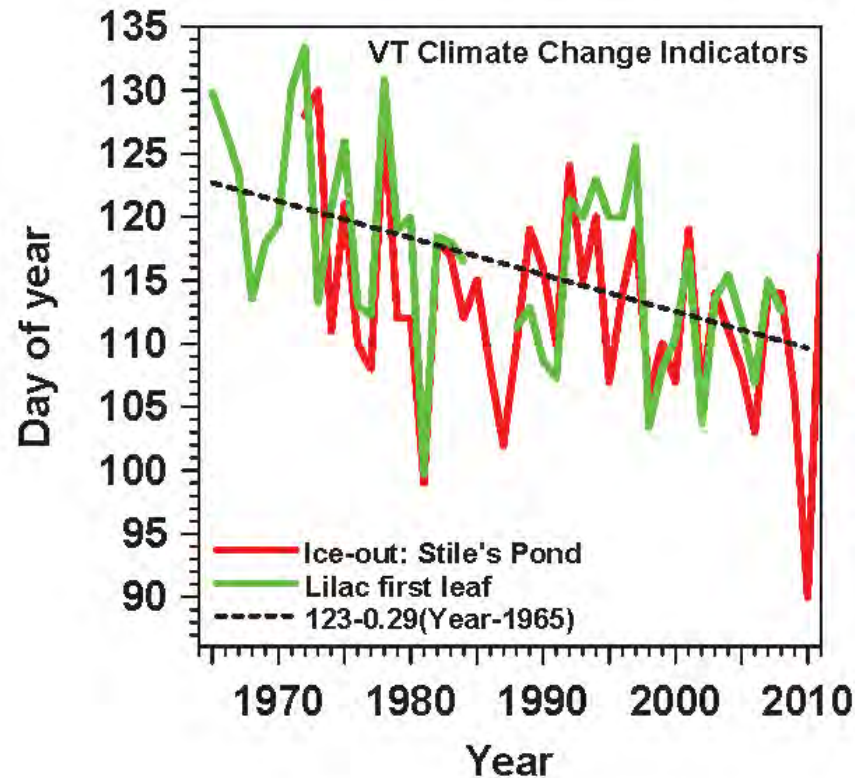
Lake Freeze-up & Ice-out Changing

Frozen Period Shrinking: variability huge

- Ice-out earlier
 - by -3 days / decade
- Freeze-up later
 - by +4 days / decade
- Lake frozen trend
 - - 7 days/decade



Lilac First Leaf Earlier



- First leaf and ice-out changing: -3 days/decade
- Large variability coupled to temperature: -5 days/ $^{\circ}\text{C}$
 - (No-snow – Snow) winter = $6 \times 5 \approx -30$ days

Fall Climate Transition

- **Vegetation delays first killing frost**
- While deciduous trees still evaporating: moister air with clouds
- Water vapor & cloud greenhouse reduces cooling at night and prevents frost
- Till one night, dry air advection from north gives first hard frost.
- Vegetation dies, skies become clearer and frosts become frequent
- *The opposite of what happens in Spring with leaf-out!*



Clear dry blue sky after frost. Forest evaporation has ended; water vapor greenhouse is reduced, so Earth cools fast to space at night

Later frost: Growing season getting longer

Role as Writer

- I am a scientist, a writer & public speaker
 - I speak and write about what I know
 - Connect local issues to global issues
 - Science matters – *but issues far beyond 'science'*
 - Clash between *Earth system reality* and political and economic ideologies
 - *"Earth wins hands-down"*
 - Many difficult ethical and moral choices
- The transition we face is huge: *must be faced*
 - Can we stabilize the climate?
 - Can we build a sustainable future?
 - Why we need community

Vermont Newspaper Columns

Environmental journalism revisited (Betts and Gibson 2012)

2008-2016: 90 articles: “They blend science with a systems perspective, and encourage the reader to explore alternative and hopeful paths for themselves, their families and society”

(Rutland Herald and the Barre-Montpelier Times Argus)

Today’s communities must understand the connections between energy use, climate and food to make the transition to an efficient, resilient and sustainable society.

(alanbetts.com/writings)

Column Philosophy

- **These columns go through the seasons**
 - dealing with weather, climate, climate change, energy and policy issues
- **They blend science with a systems perspective**
 - encouraging the reader to explore alternative and hopeful paths for themselves and society
- **They are written so that a scientist will perceive them as accurate (even if simplified)**
 - While the public can relate their tangible experience of weather and climate to the much less tangible issues of climate change, energy policy and strategies for living sustainably with the Earth system

But Society is Deeply Polarized

Ideology has become more important than evidence

- Follows the 'big lie' principle

Sen. Sheldon Whitehouse, 10/11/2015

“In recent weeks the right-wing attack machine has been up in arms regarding a letter sent by a group of 20 climate scientists to President Obama, Attorney General Lynch, and White House science adviser John Holdren requesting that the Department of Justice (DOJ) investigate fossil-fuel companies that appear to have lied about the effects of their products on our world's climate.

This week, the [Wall Street Journal joined the fray](#), writing that "advocates of climate regulation are urging the Obama Administration to investigate people who don't share their views... they want the feds to use a law created to prosecute the mafia against lawful businesses and scientists.”

Funded by Cabal of Libertarian Billionaires

- **Aim: *purchase control of the Republican Party***
 - US Congress and many state legislatures
- **Doctrine: *limited role for government***
 - protect wealth, property and the rule of law
- **Freedom to exploit the earth:**
 - Shall not be limited by environmental regulation
- **Leading to** *(Dark Money, Jane Mayer, 2016)*
 - *Climate science is a (fictitious) conspiracy*
 - *Doctrine in direct conflict with Earth's ecosystem*

What is Needed?

Honesty, Accuracy, Clarity!

- **Honesty and integrity**
 - *Moral values: rooted in the Earth and spirit*
- **Accuracy needs understanding/fact-checking**
 - *Collaboration with professionals/scientists*
- **Clarity needs plain English, not jargon**

The Future Is Not Our Past

- *Collectively, we create the future, so we need to plan for a transition to a sustainable society*
- In the face of a economic, technological and financial system driven by short-term profit
 - *Put systems-thinking above profit!*
- Needs deep community discussion
 - *New values that respect the Earth*

Community is Central

- You cannot deal with environmental issues alone
 - They were created by the community over time
 - You need a community to weigh the evidence, search for creative solutions, and tell the truth
 - For moral support: *to face resistance or opposition with hope, not fear, despair or gloom*
- *You need grounding*
 - *in yourself, as a group and with the Earth*

Systems Engineering Guidelines for a Sustainable Society

- **Minimize the lifetime of human waste products** in the Earth system and eliminate waste with critical climate/biosphere interactions
- Minimize the use of non-renewable raw materials, and
- Maximize recycling and re-manufacturing
- **Maximize the efficiency** with which our society uses energy and fresh water, and
- Maximize the use of renewable resources

Change of Attitude Needed?

- **Do we just exploit the Earth's wealth**
 - For greater 'economic growth'
 - For a wealthy few
 - What will be left for our children?
 - What happens to the ecosystems we depend on?
- **Moral Issue**
 - Don't we need to co-operate with the Earth?
 - *Shift in understanding and mind-set needed*

- *“Many things have to change course, but it is we human beings above all who need to change. We lack an awareness of our common origin, of our mutual belonging, and of a future to be shared with everyone.”*

Pope Francis, Encyclical 2015

What is our role as Scientists?

- **Honesty, accuracy, clarity, and depth**
 - “**Bold humility**” *(Francis Moore Lappé)*
 - **Earth scientists should consciously accept responsibility for the Earth**
 - *As the political and economic system will not*
 - **Speak clearly to society: creative hope not despair**
 - **Search for language that sidesteps ideology**
 - *Realize that Earth system limits will need adaptive global governance*
 - *and a paradigm shift in science*

(alanbetts.com)

Paradigm shift for science?

- **Great value of science is its honesty, integrity and its cooperative global vision**
 - It deals with the measurable world
 - It communicates openly
 - Priceless to a society lost in corruption & deceit
- **Greatest challenge is that humanity is embedded in a deeply interconnected living Earth's system**
 - That cannot be separated and objectified
 - In fact the separation of our social frames from the Earth's ecosystem is driving climate change