Understanding Daily Climate at Northern Latitudes

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Lyndon State

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RACC
Research on Adaptation to Climate Change

Vermont EPSCoR
CWDD
Center for Workforce Development & Diversity

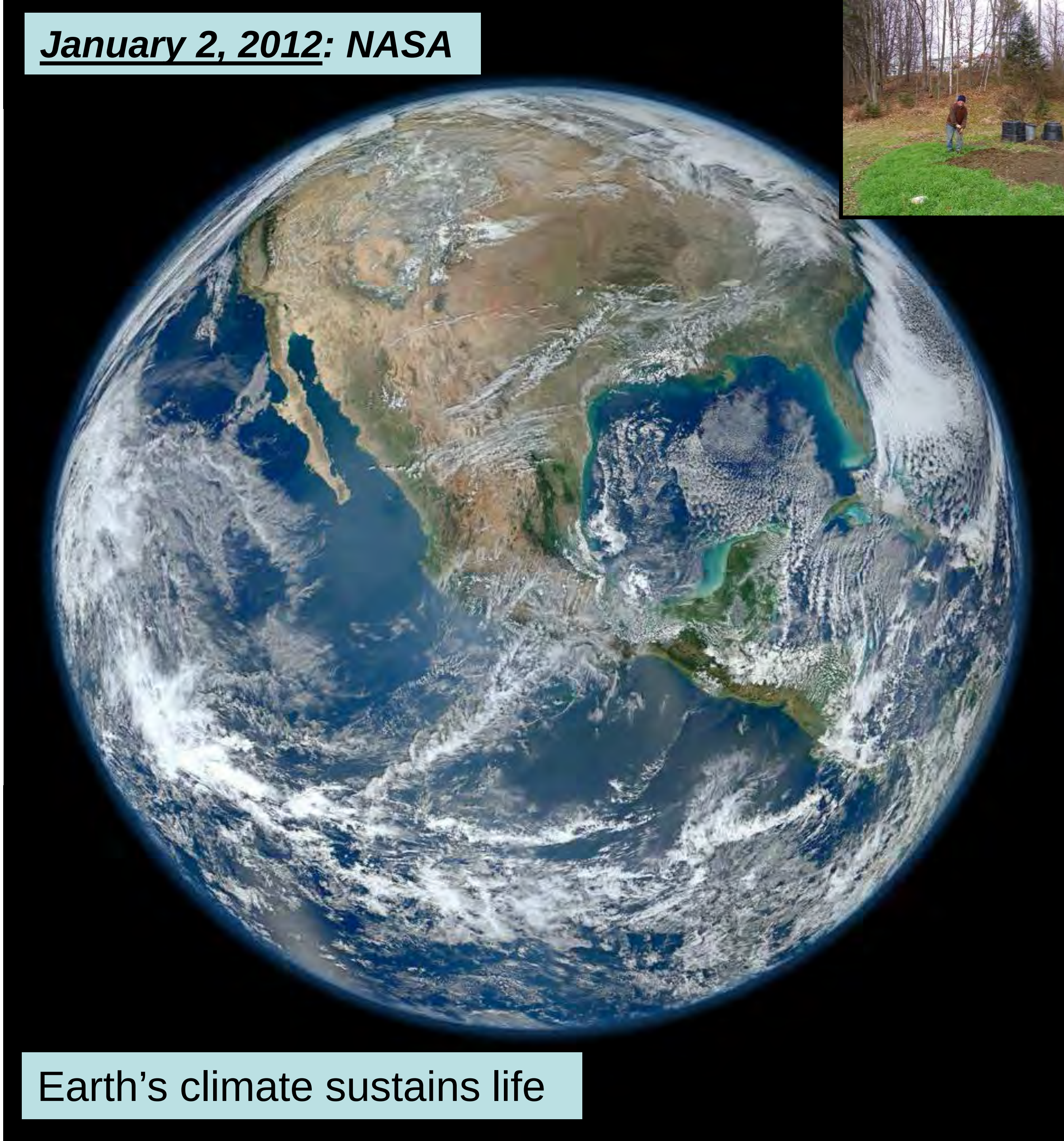
Outline

- **Northern latitude climate**
  - **Large seasonal cycle**
  - **Water, water everywhere**
  - **Cold winters with snow**
  - **Important seasonal transitions**

- **Climate changing**
  - **Arctic warming twice as fast as tropics**
  - **Vermont winters as well**
  - **Seasons changing**

Discussion…

- **Burning fossil fuels is increasing greenhouse gases**
- **Climate is warming: ice is melting, extreme weather is increasing**
- **Water plays crucial <u>amplifying role</u>**



Seasonal Climate

- ***Leave daily weather aside for moment***
- **What determines seasonal climate?**
  - **<u>Sun heats the earth</u>**
  - **Clear sky: shortwave mostly transmitted**
  - **Reflected by clouds and snow**
  - **Sun elevation is low in winter**

  - **<u>Earth cools to space</u> in longwave/IR**
  - **Trapped by atmosphere and clouds**
  - **Reradiated down to surface**

Water, Water Everywhere-1

- Three phases: ice, liquid, vapor
- Latent energy of phase change
  - Freezing-melting: 0.3 MJ/kg
    - Stabilizes soil temperatures in winter
    - Energizes thunderstorms
  - Condensation-evaporation: 2.5 MJ/kg
    - Cools ocean, land, transpiring plants
    - Energizes weather: cyclones, hurricanes

Water, Water Everywhere-2

- Reflection of sunlight (SW)
  - Clouds: Water drops, ice crystals
    - Cools surface
  - Snow and ice on surface
    - Cools surface

- Water vapor absorbs longwave (LW)
  - Primary "greenhouse gas"
    - Along with CO_2, CH_4, CFCs and many others
    - Re-radiation down warms surface

Hurricane Sandy

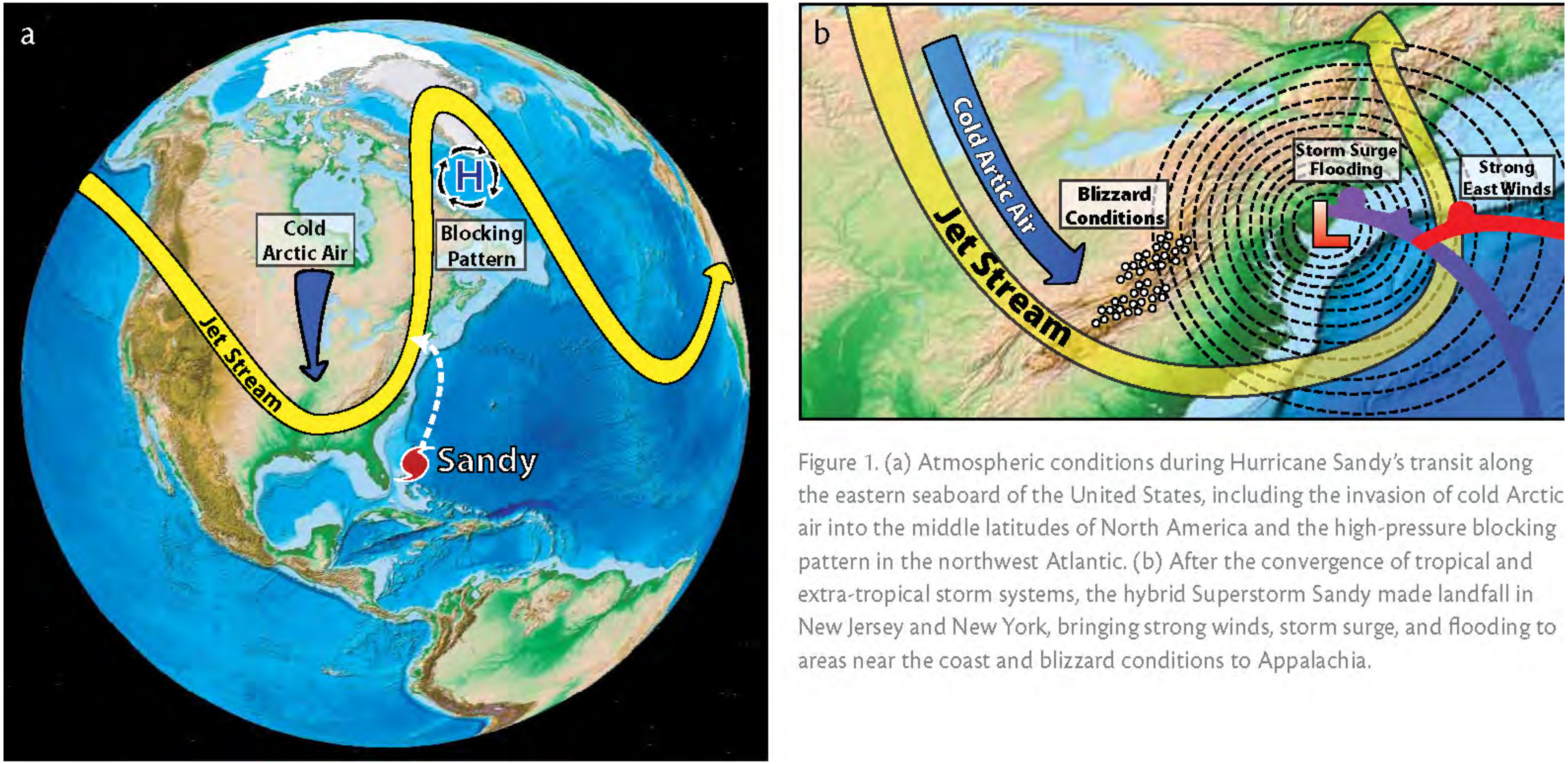


Figure 1. (a) Atmospheric conditions during Hurricane Sandy's transit along the eastern seaboard of the United States, including the invasion of cold Arctic air into the middle latitudes of North America and the high-pressure blocking pattern in the northwest Atlantic. (b) After the convergence of tropical and extra-tropical storm systems, the hybrid Superstorm Sandy made landfall in New Jersey and New York, bringing strong winds, storm surge, and flooding to areas near the coast and blizzard conditions to Appalachia.

- **High amplitude jet-stream + blocking pattern + strong cyclone + hurricane winds/warm ocean + full moon high tide = record storm surge**

[Greene et al., Oceanography, 2013]

Winter Ice and Snow

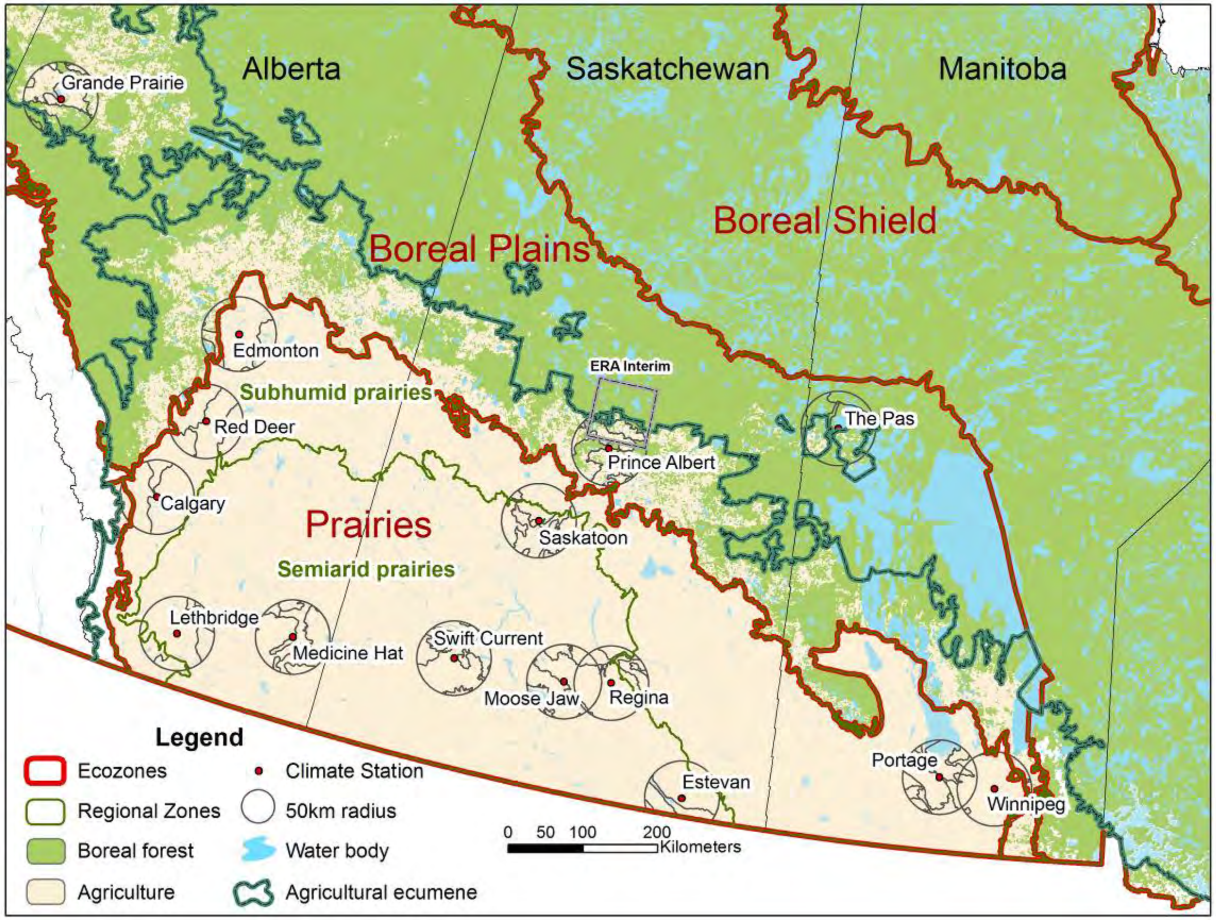
Vermont Winter 2006

- **Snow reflects sunlight, except where trees shadow**
- **Cold; little evaporation, clear sky; earth cools to space**
- ***2011-12 warm winter, snow melts → positive feedback***
- ***2014, 15 more snow and colder***

Serendipity in Science

- **For years I have studied clouds and snow**
  - **And lectured on impacts *(with little data!)***
- **August 2012 – call from Agriculture-Canada**
  - **Please help us understand changing Prairie Climate**
    - **More intensive cropping, cooler summers**
    - **We have hourly data from 1953**
- **November 2012, processed data arrives**
  - ***Amazing data* answers questions I have had for years**
  - **With reflective cloud data I didn't know existed!**
    - **Clouds: daily cycle of temperature and humidity**
    - **Crops and summer climate**
    - **Winter climate transitions with snow**
    - **Climate, rain and clouds in growing season**

15 Prairie stations: 1953-2011



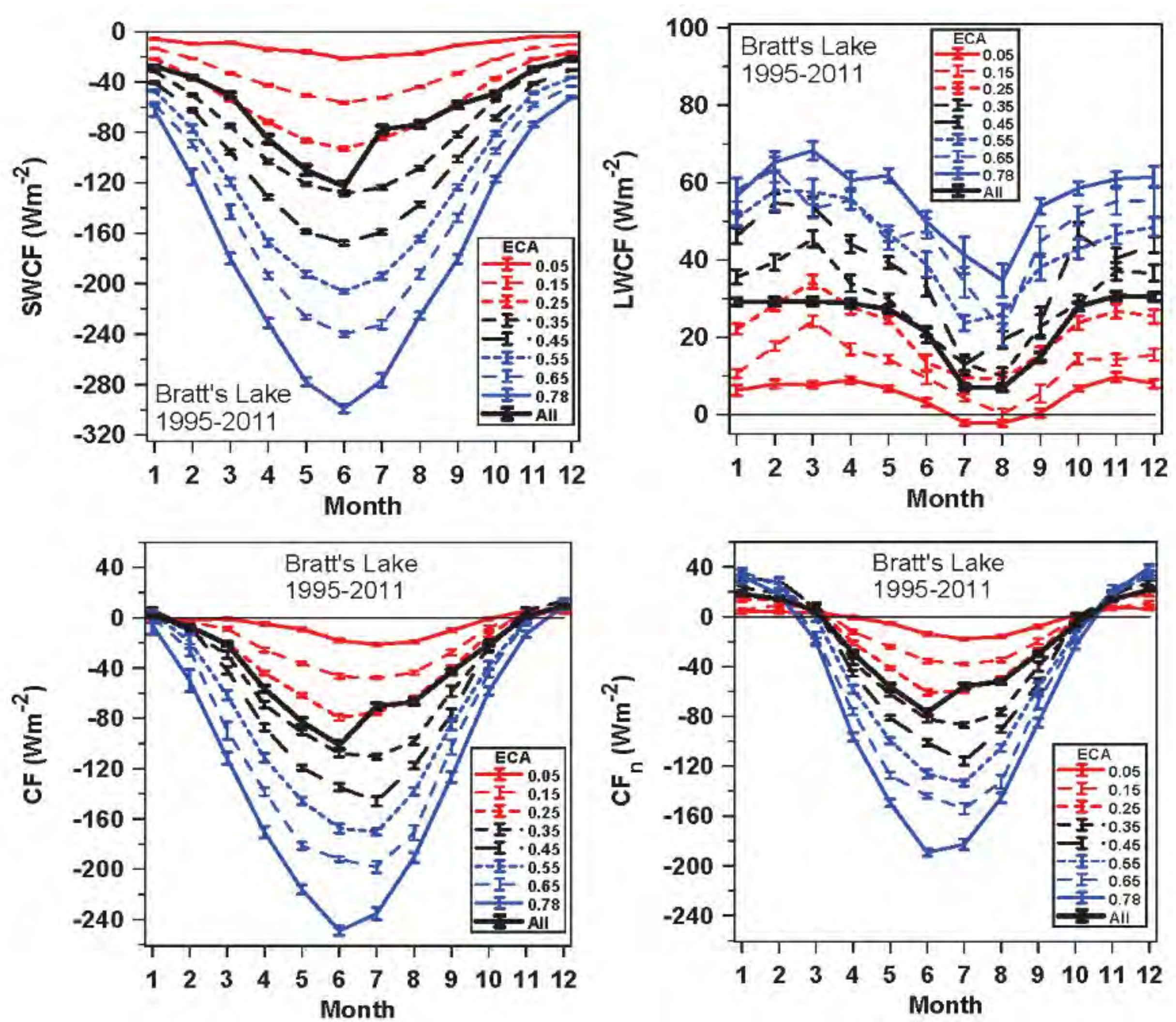
- *Hourly* **p, T, RH, WS, WD, Opaque Cloud**
- *Daily* **precipitation and snowdepth**

References

- **Betts, A. K. (2009), Land-surface-atmosphere coupling in observations and models. *J. Adv. Model Earth Syst., Vol. 1, Art. #4,* 18 pp., doi: 10.3894/JAMES.2009.1.4**
- **Betts, A.K., R. Desjardins and D. Worth (2013a), Cloud radiative forcing of the diurnal cycle climate of the Canadian Prairies. *J. Geophys. Res. Atmos., 118,* 1–19, doi:10.1002/jgrd.50593**
- **Betts, A.K., R. Desjardins, D. Worth and D. Cerkowniak (2013b), Impact of land-use change on the diurnal cycle climate of the Canadian Prairies. *J. Geophys. Res. Atmos*., 118, 11,996–12,011, doi:10.1002/2013JD020717**
- **Betts, A.K., R. Desjardins, D. Worth, S. Wang and J. Li (2014a), Coupling of winter climate transitions to snow and clouds over the Prairies. *J. Geophys. Res. Atmos*., 119, doi:10.1002/2013JD021168.**
- **Betts, A.K., R. Desjardins, D. Worth and B. Beckage (2014b), Climate coupling between temperature, humidity, precipitation and cloud cover over the Canadian Prairies. *J. Geophys. Res. Atmos*. 119, 13305-13326, doi:10.1002/2014JD022511**
- **Betts, A.K., R. Desjardins, A.C.M. Beljaars and A. Tawfik (2015), Observational study of land-surface-cloud-atmosphere coupling on daily timescales. *Frontiers in Earth Science*, accepted.**

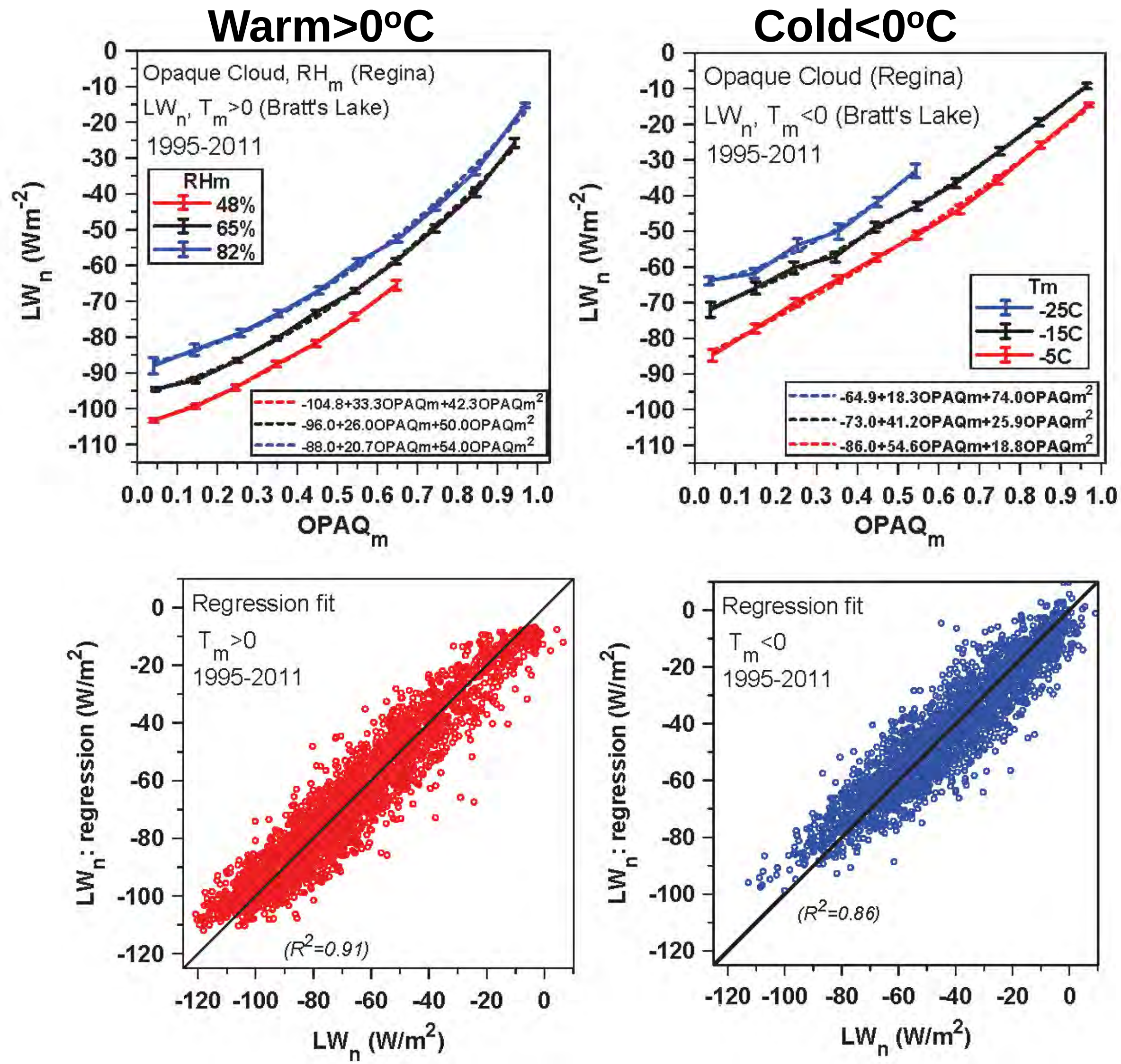
Clouds affect SW and LW Radiation Fluxes

- **“Cloud Forcing”**
  - ***Change from clear-sky***
- **Clouds reflect SW**
  - ***SWCF***
  - ***Cool***
- ***Clouds trap LW***
  - ***LWCF***
  - ***Warms***
- ***Sum is CF***
- ***Surface albedo reduces SW***
  - ***Net is CF_n***
  - ***Add reflective snow, and CF_n goes +ve***

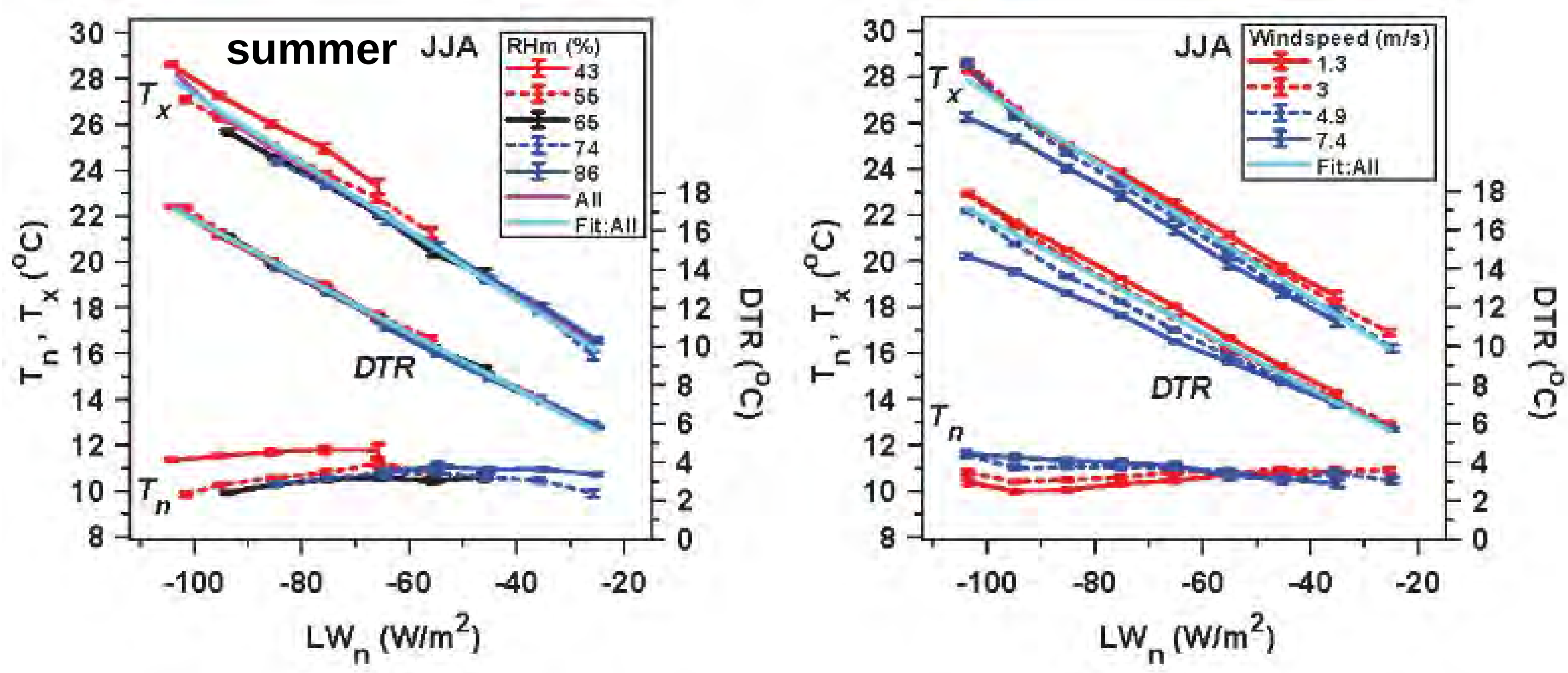


Use Baseline Surface Radiation Network to "calibrate" Opaque Cloud

- **Daily mean opaque cloud $OPAQ_m$**
- ***LW cools but clouds reduce cooling***
- **Net LW: LW_n**
  - *T>0: depends on RH as well*
  - *T<0: depends on T*
- ***Regression gives LW_n to ± 8W/m² if T_m>0 (R^2=0.91)***



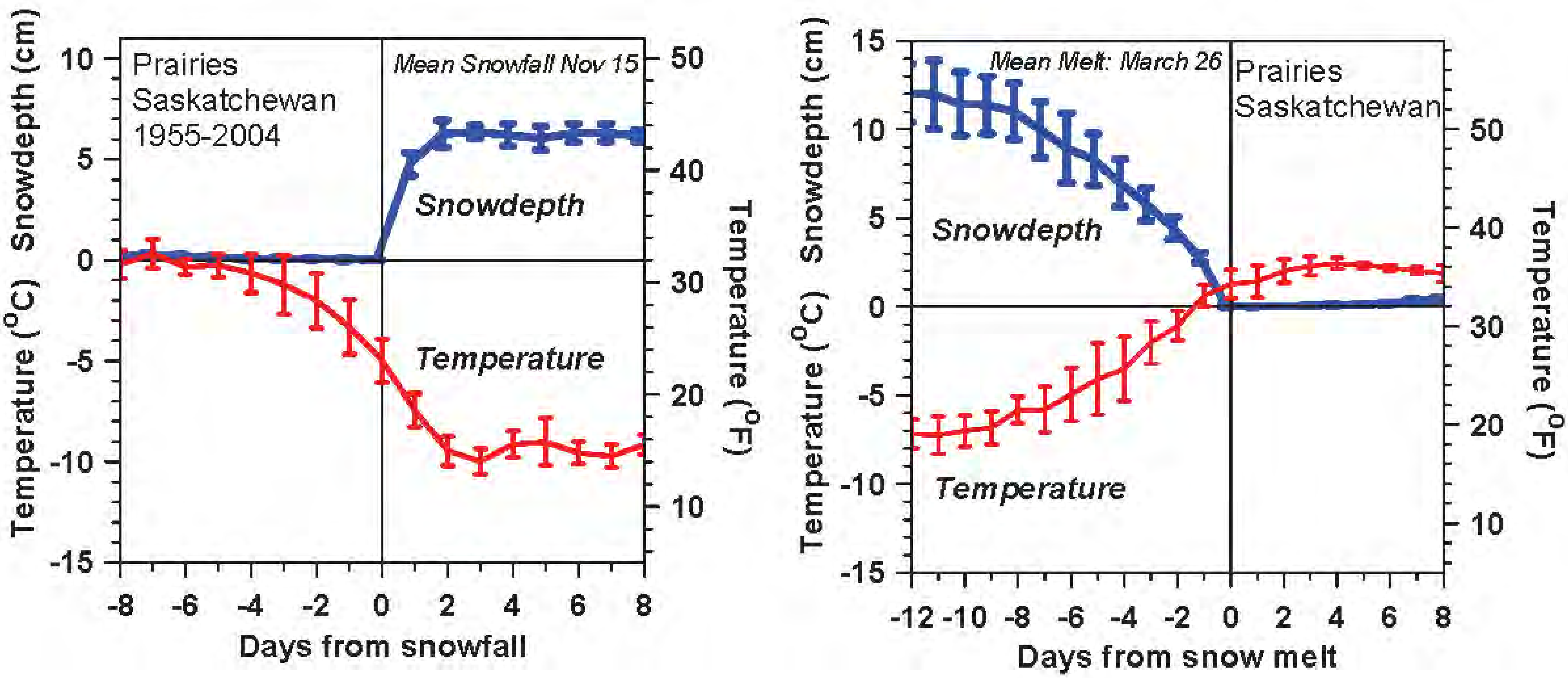
Diurnal Temperature Range (DTR) proportional to LW_n



- *Cloud reduces LW_n cooling*
- ***DTR depends <u>linearly</u> on LW_n***
  - ***cooling from afternoon T_{max} to sunrise T_{min} (T_x to T_n)***
- ***Wind reduces DTR***

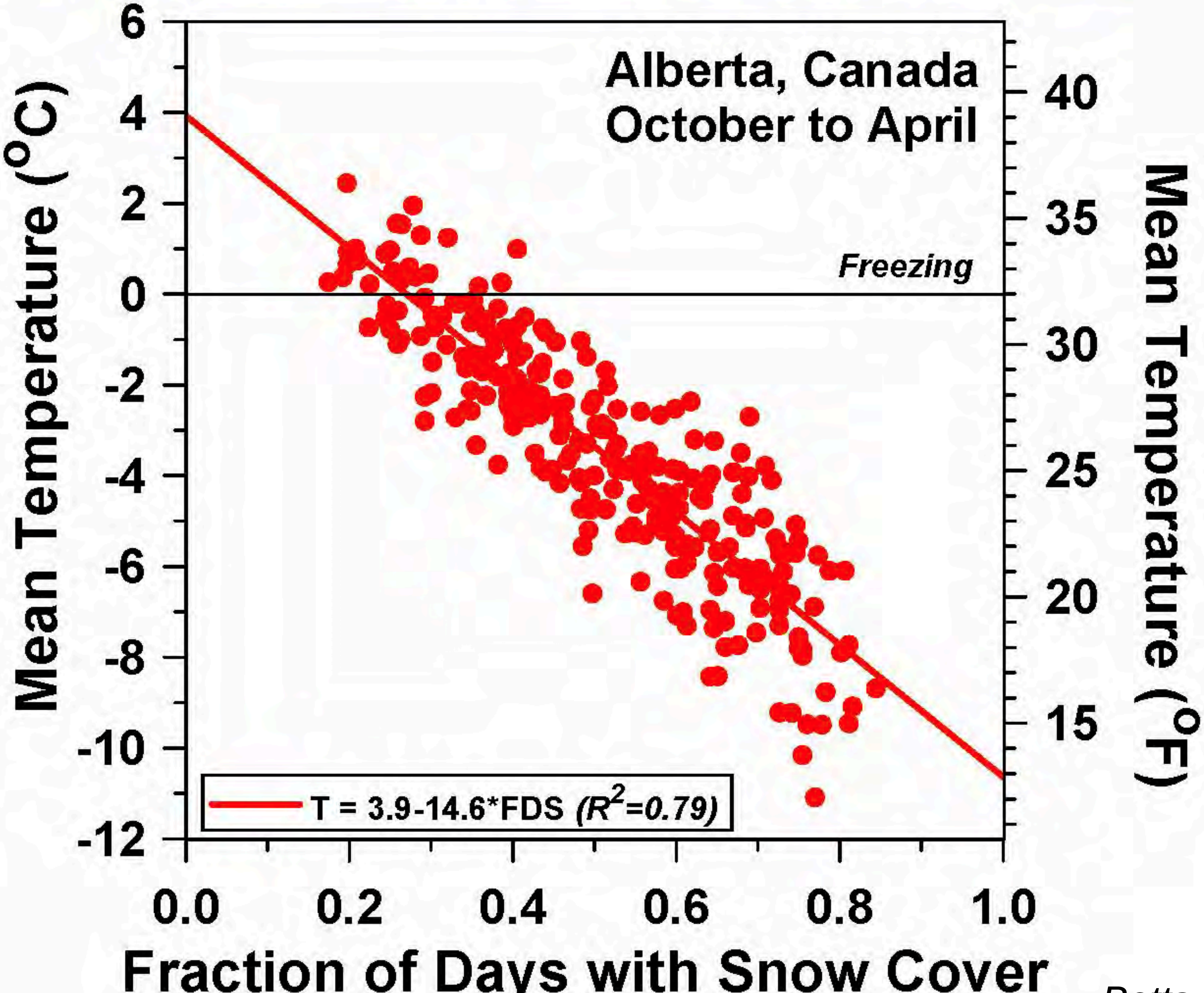
Why are Cold and Warm Seasons Different? Snow/ice!

Snowfall and Snowmelt



- **Temperature falls 10C (18F) with first snowfall**
- **And rises again with snowmelt**
- ***Fast transitions in 'local climate'***
  - ***Snow reflects sunlight***
  - ***Reduces evaporation and water vapor greenhouse***

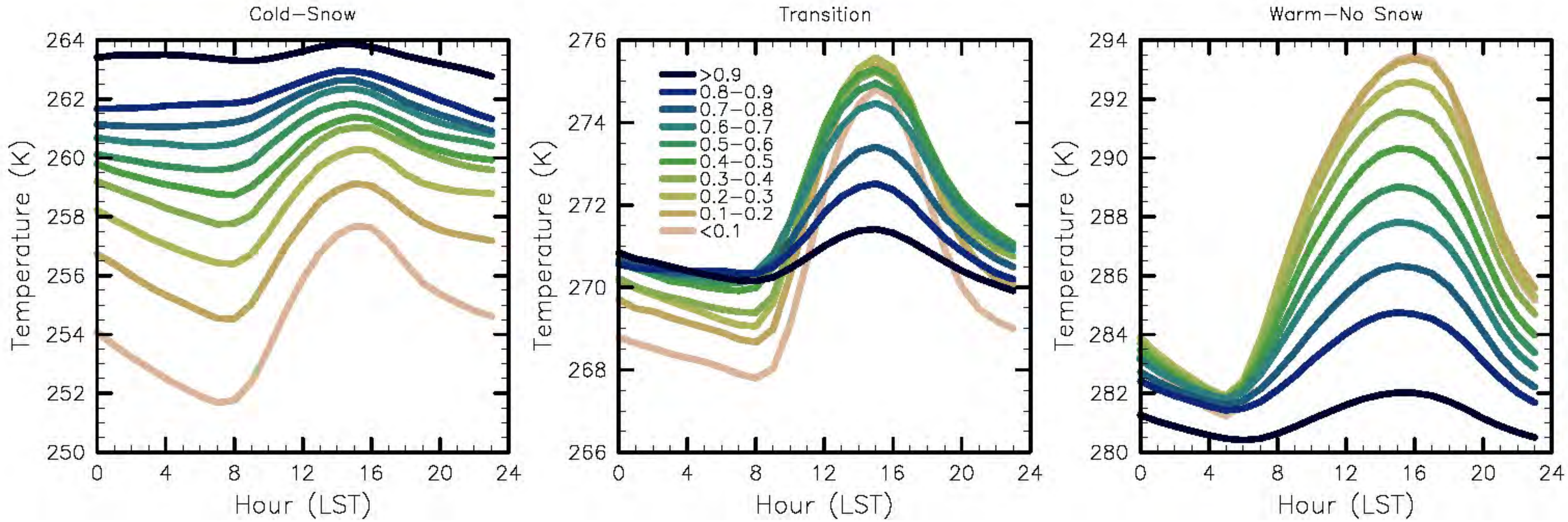
More snow cover - Colder temperatures



Betts et al. 2014

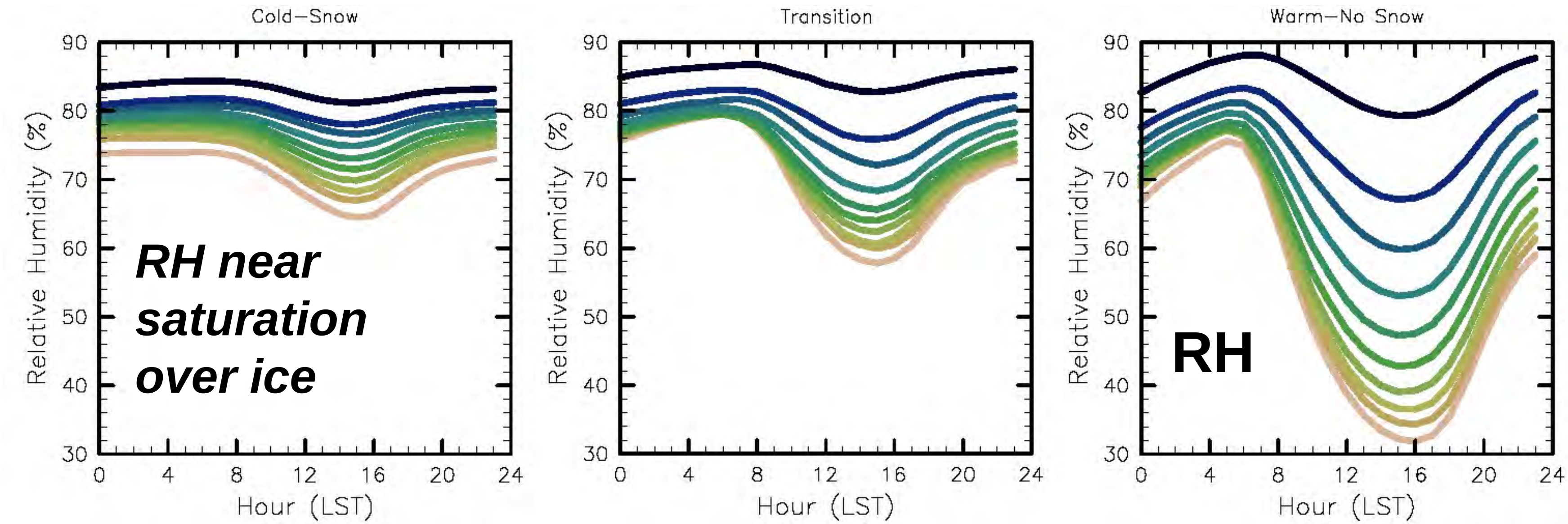
Clouds: Warm & Cold Climates

Cold-snow <0°C | **Transition** | **Warm-snow >0°C**

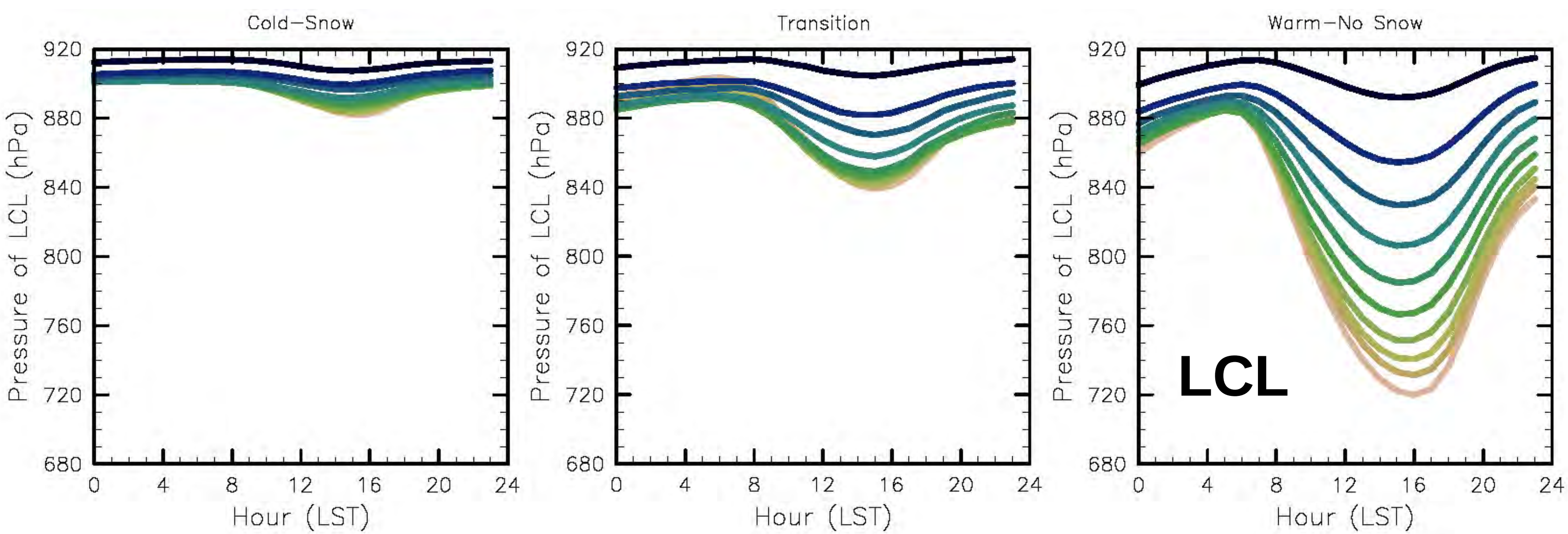


- ***240,000 days (650 station-years)***
- **<u>Freezing point of water changes everything</u>!**
- **Cold <0°C: Snow: Surface cools radiatively, clouds ‘blanket’**
  - **stable boundary layer**
- **Transition: >0°C: Snow; <0°C: No Snow: near freezing**
- **Warm >0°C: No Snow: Surface solar heating, clouds reflect**
  - **unstable boundary layer**

Freezing point of water changes everything



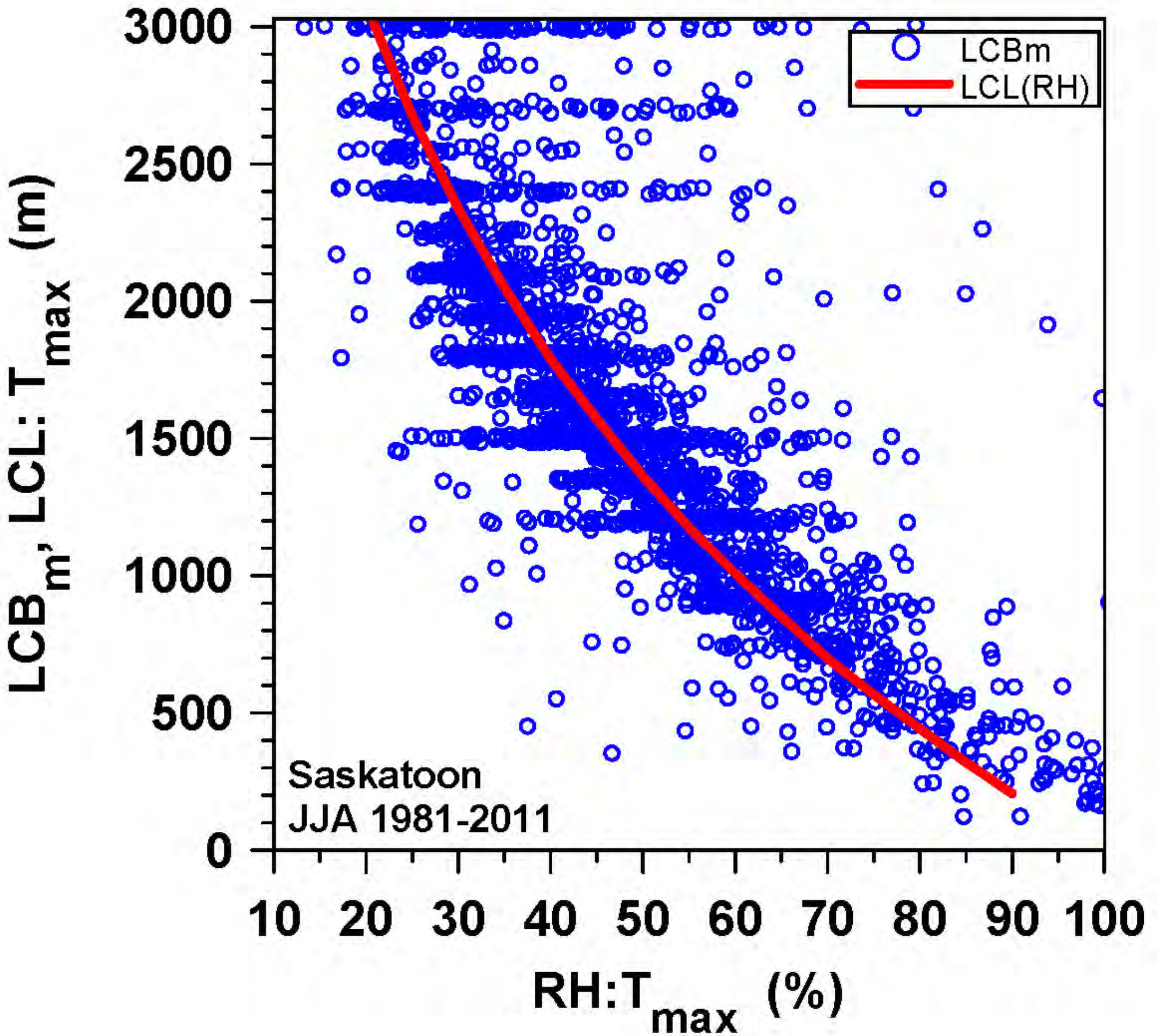
- Cold <0°C: Snow Transition Warm >0°C: No Snow:



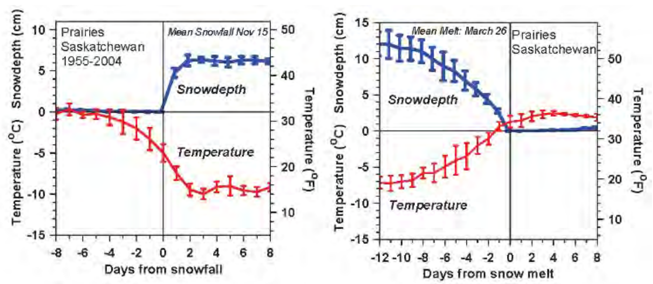
Afternoon LCL is Cloud-base

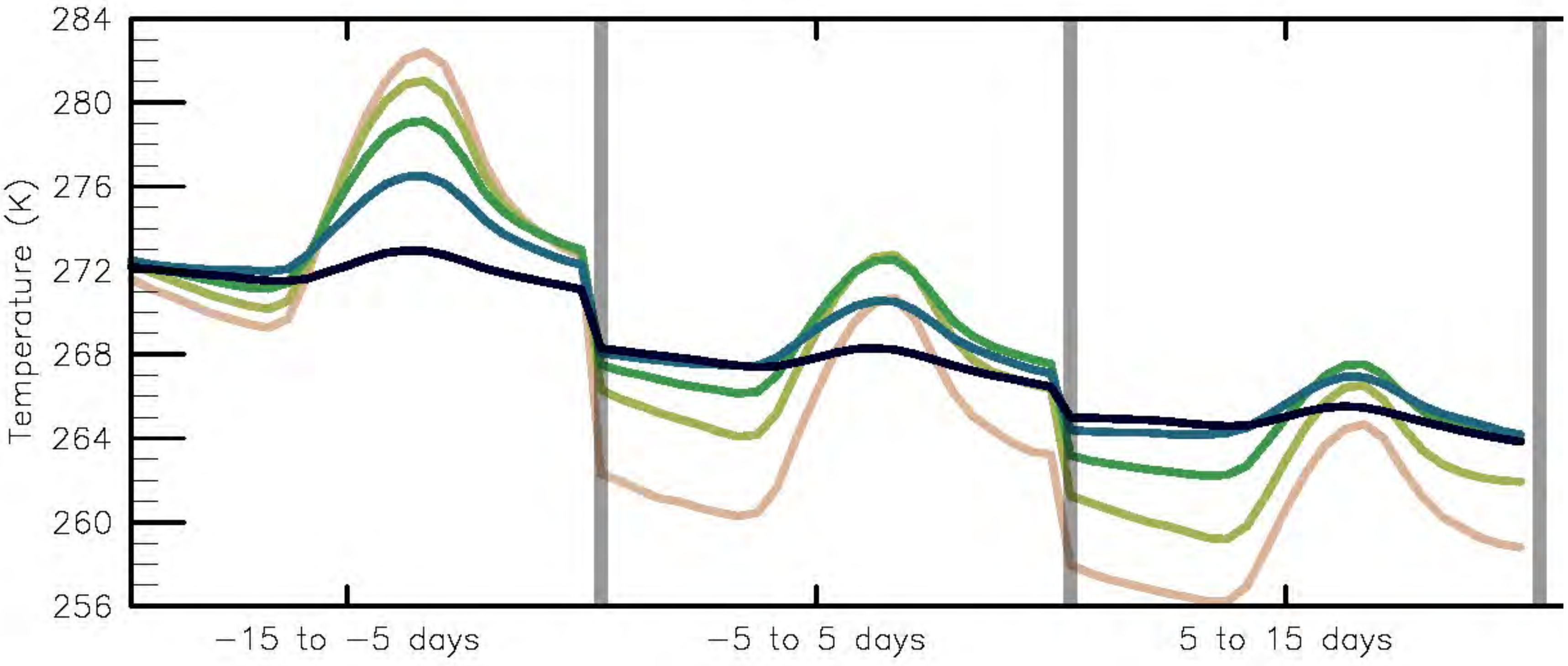
- At T_{max}
- Lowest cloud-base *(ceilometer)*
- LCL (surface)

- ***Coupled convective boundary layer (CBL)***



Snow transitions

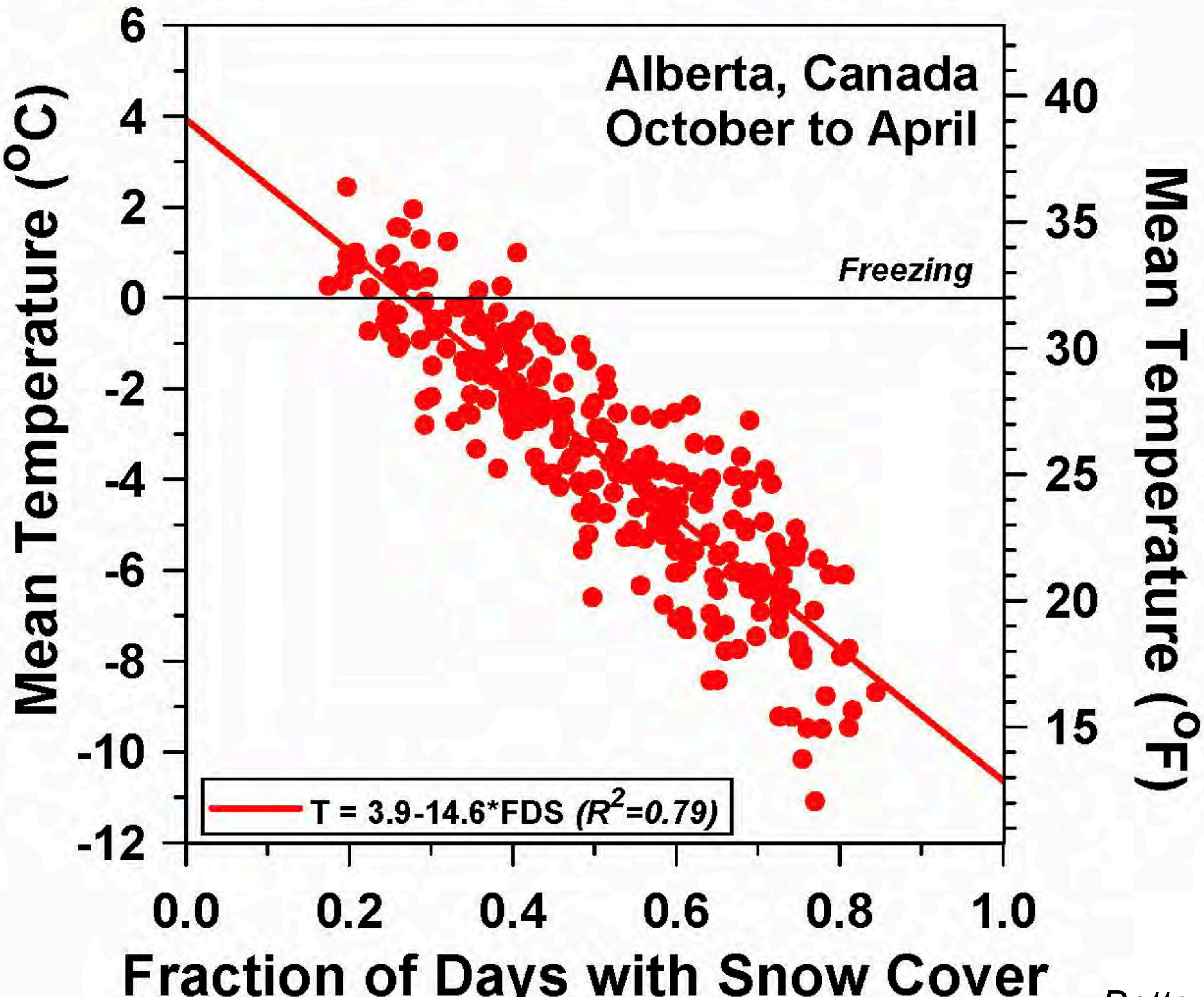




- Ahead of snow — Transition — After Snow
- Warm >0^{o}C: No Snow — Transition — Cold <0^{o}C: Snow
- Time sequence shows same three regimes

Winter Ice and Snow

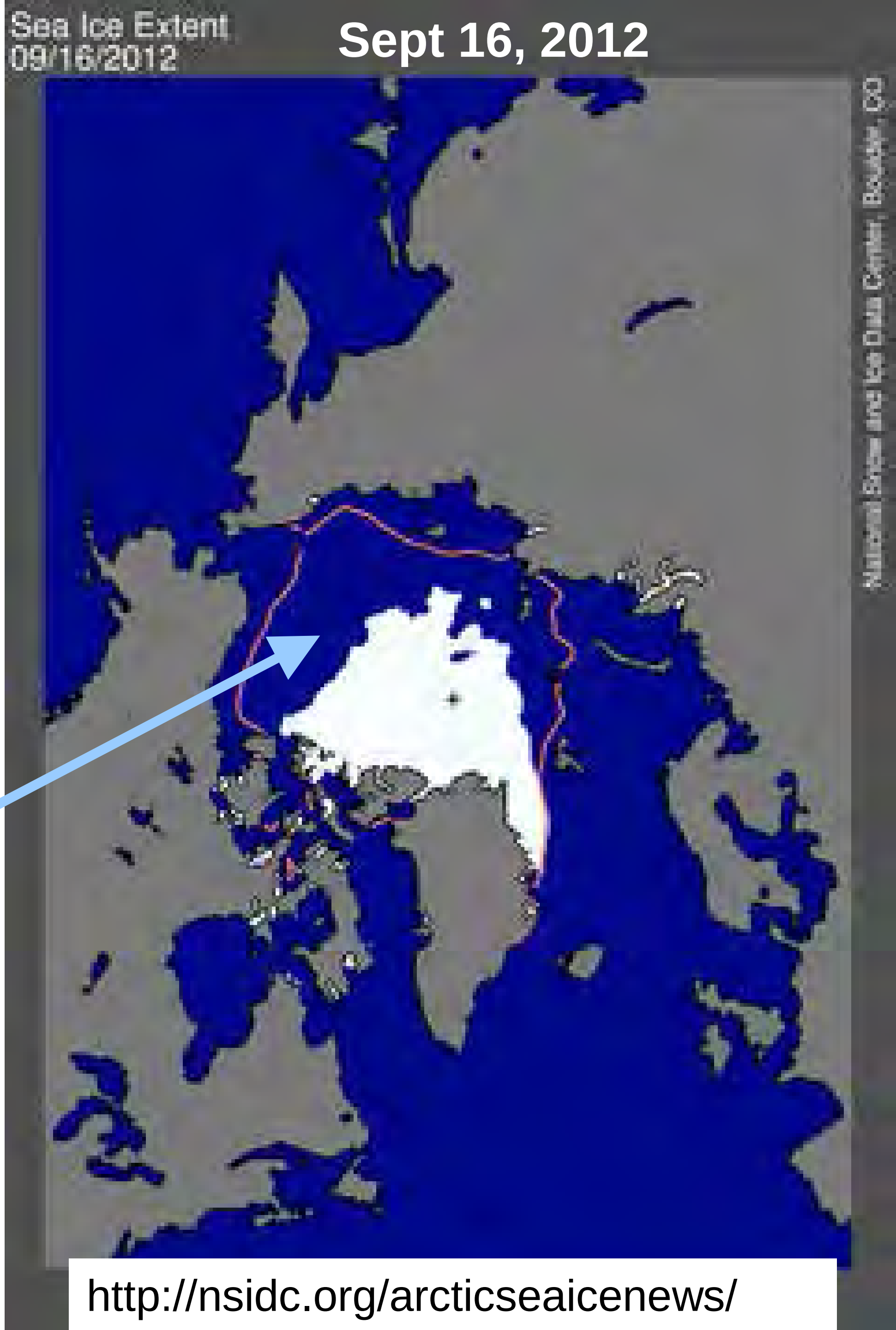
More snow cover - Colder temperatures



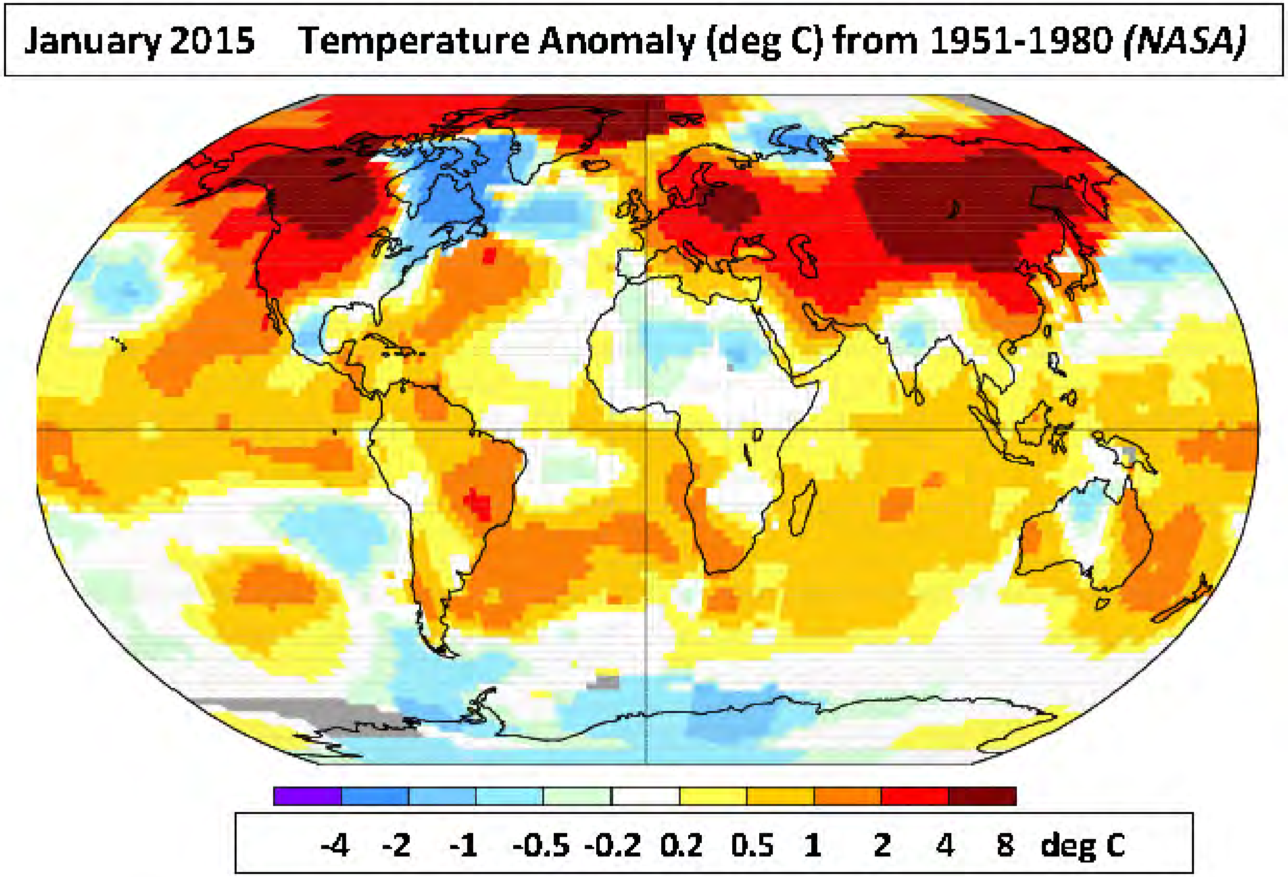
Betts et al. 2014

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

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



What happened this winter?

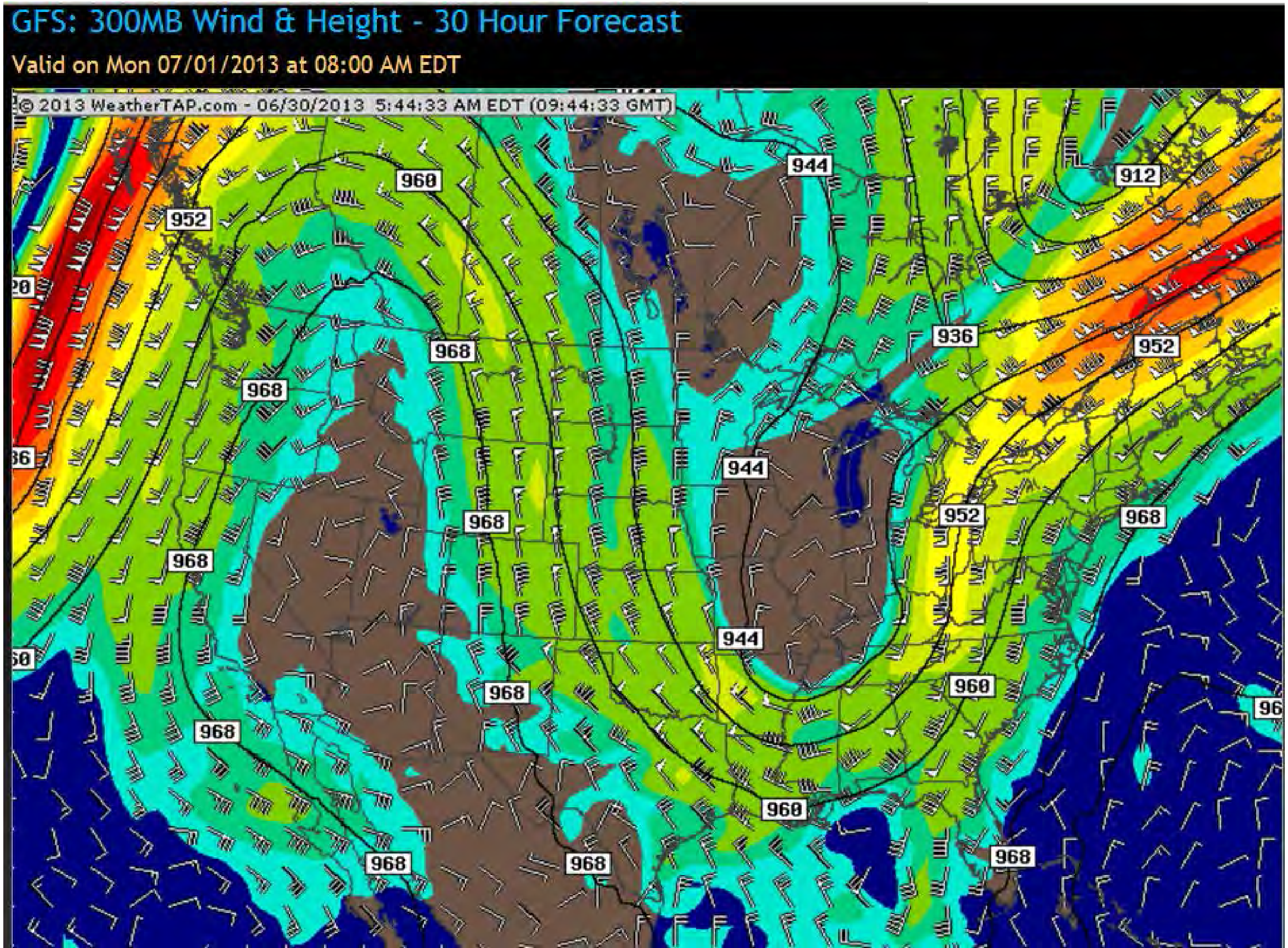


Cold in eastern US and Canada

Record temperatures across Western NA and Eurasia

Jet Stream Patterns Slowing Down and Amplifying, Giving More Extreme Weather

(Francis and Vavrus, 2012)



Move on to Spring

- Why is it still cold?
  - Sun is 2 days past equinox!
  - Yet colder than 19 September

Move on to Spring

- Why is it still cold?
  - Sun is past equinox!
- Takes energy to melt snow but snow reflect sun!
- Then takes energy to melt ground
  - Goes faster after snow melts
- No transpiration till soil melts/warms
  - So sun's energy first goes to heating

Spring transition-1 4/15/2008

- ***Weather***

  Sunny, dry week

- ***Climate***
  - After snowmelt **before leaf-out**
  - Little evaporation
  - Warm & dry
  - Large daily temp. range
  - **Frost likely**

- ***Trend earlier***

Pittsford, Vermont

Warm winter with little snow
Early Spring: *79°F on March 22, 2012*

Pittsford Vermont

3/22/12

Pittsford Vermont

3/24/12

Daffodils, Forsythia in bloom

Spring transition-2 5/15/2010

- ***Weather***

  Cooler, humid, cloudy week

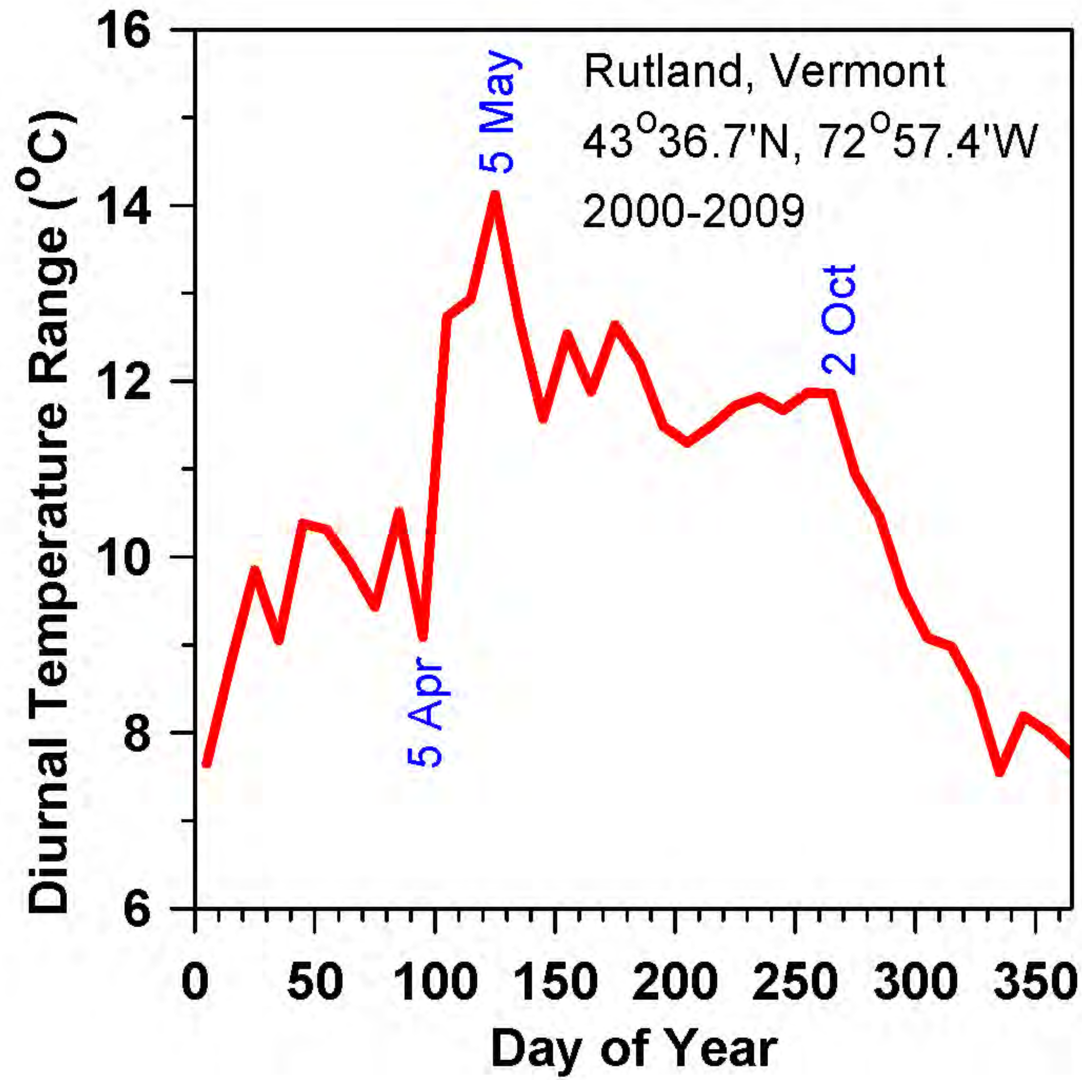
- ***Climate***
  - **After leaf-out,** large evaporation
  - Temp. falls 3-5^{o}C
  - Low cloud-base
  - Smaller daily temp. range
  - **Frost unlikely**

- ***Trend earlier***

Pittsford, Vermont

Daily Temperature Range (DTR)

- DTR = T_{max} - T_{min}
- April 5: snow melted but little transpiration
- Sun getting higher, warm and dry
- May 5: DTR peaks
- Forests leaf out, transpiration soars, DTR drops
- Oct 1: frost ends transpiration
- Sun sinking; heading for winter



Forecasts: Can we model these spring transitions correctly?

- **Snowmelt, soilmelt**
- **Low transpiration**
- **Dry atmosphere, few clouds**

Forest leaf-out
Large transpiration
Moist cloudy atmos.

Summer transitions

- Summer dry-down; soil moisture, evaporation, precipitation fall
- May lock into a dry spell, a ‘drought’ till upset by strong weather system
  - Planetary waves/jet-streams
- But it can go either way …
- Many wet summers in past decade

Summer dry-down

- **Wet in spring**
- **Soil moisture falls: summer dry-down**
- **Low humidity, no clouds or rain**
- **Hay dries fast!**

Wet summers

- Many wet summers in past decade
- Fast evaporation off wet canopies
- Feedback: evaporation → precipitation

Fall Climate Transition

- **Vegetation postpones first killing frost**
- **Deciduous trees still evaporating: moist 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 shuts down, leaves turn, 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

January 2, 2012

March 11, 2012

October 2011– March 2012

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

- **January 15, 2013**

Discussion

Background papers:

http://alanbetts.com/

- *Five "Prairie" papers*
- *Seasonal Climate Transitions in New England*
- *Vermont Climate Change Indicators*
- *Extreme Weather and Climate Change*
- *"Environmental journalism revisited"*

What Is Happening to Vermont?

- **PAST 50 years** ***(global CO_2 forcing detectible)***

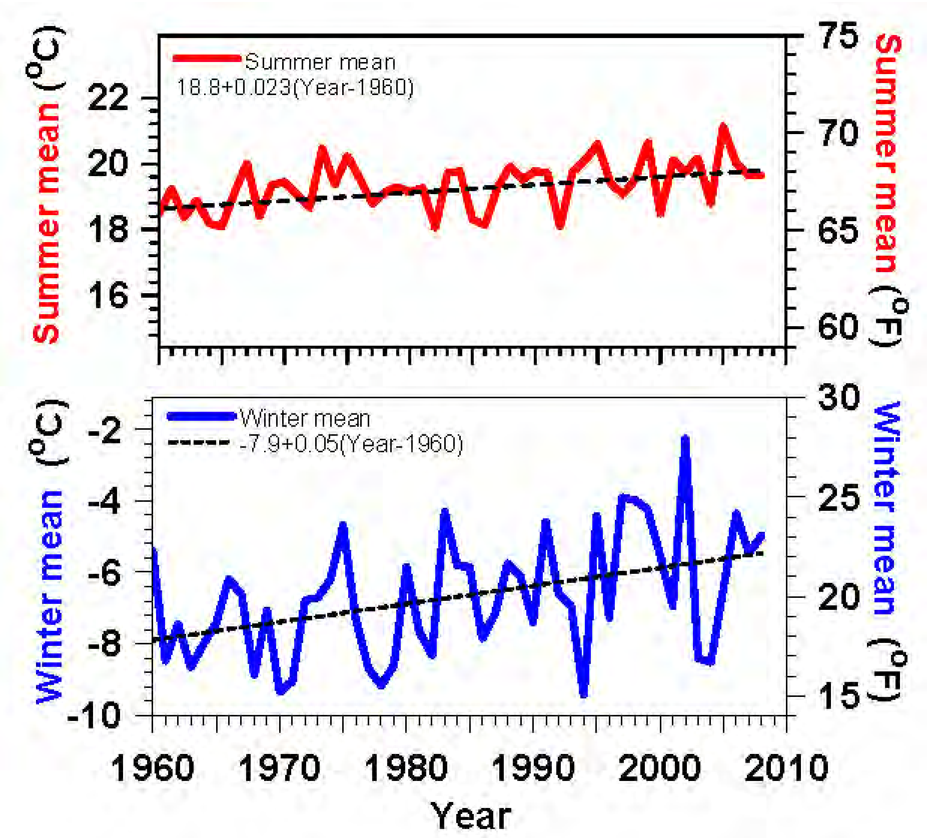
- **Warming twice as fast in winter than summer**
- **Winter minimums increasing even faster**
- **Lakes frozen less by 7 days / decade**
- **Spring coming earlier by 2-3 days / decade**
- **Growing season longer by 3-4 days / decade**

(Betts, 2011)

- **<u>Extreme weather increasing</u>**
- ***Evaporation increases with T***
- ***More 'quasi-stationary weather patterns'***

Vermont Temperature Trends 1961-2008

- **Summer +0.4°F / decade**

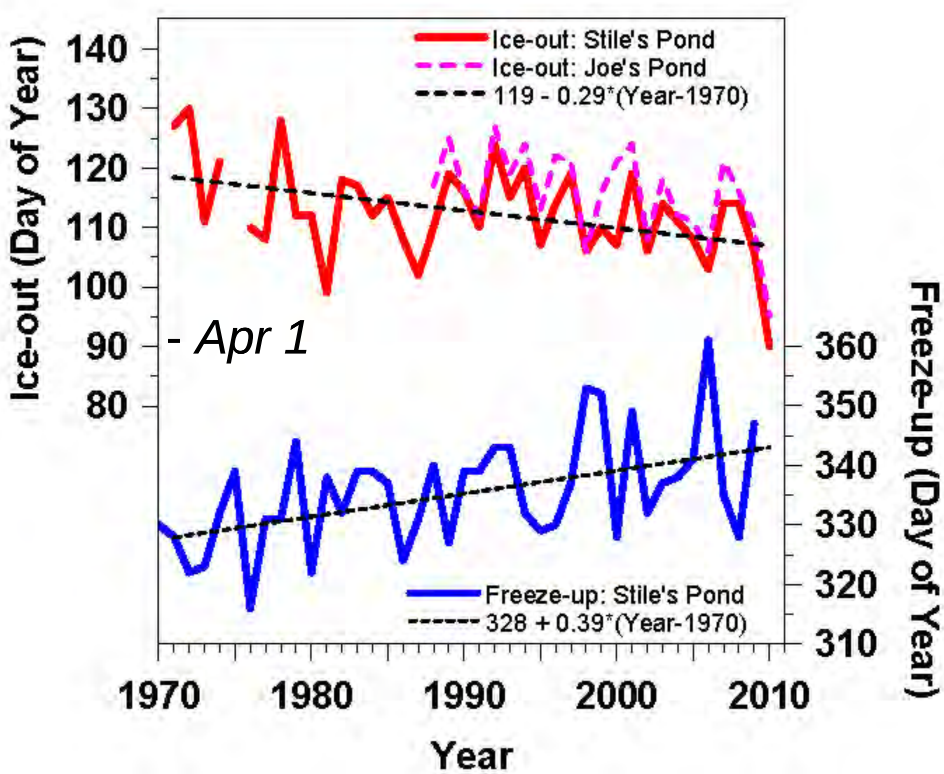


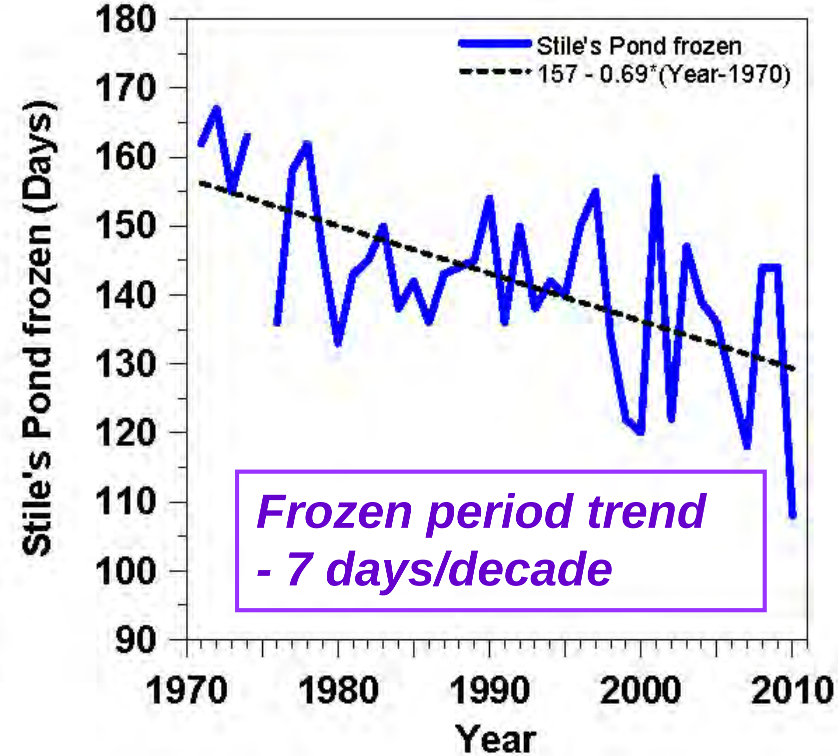
- **Winter +0.9°F / decade**
- **Larger variability, larger trend**

- ***Less snow (and increased water vapor) drive larger winter warming***

Lake Freeze-up & Ice-out Changing

Frozen Period Shrinking Fast



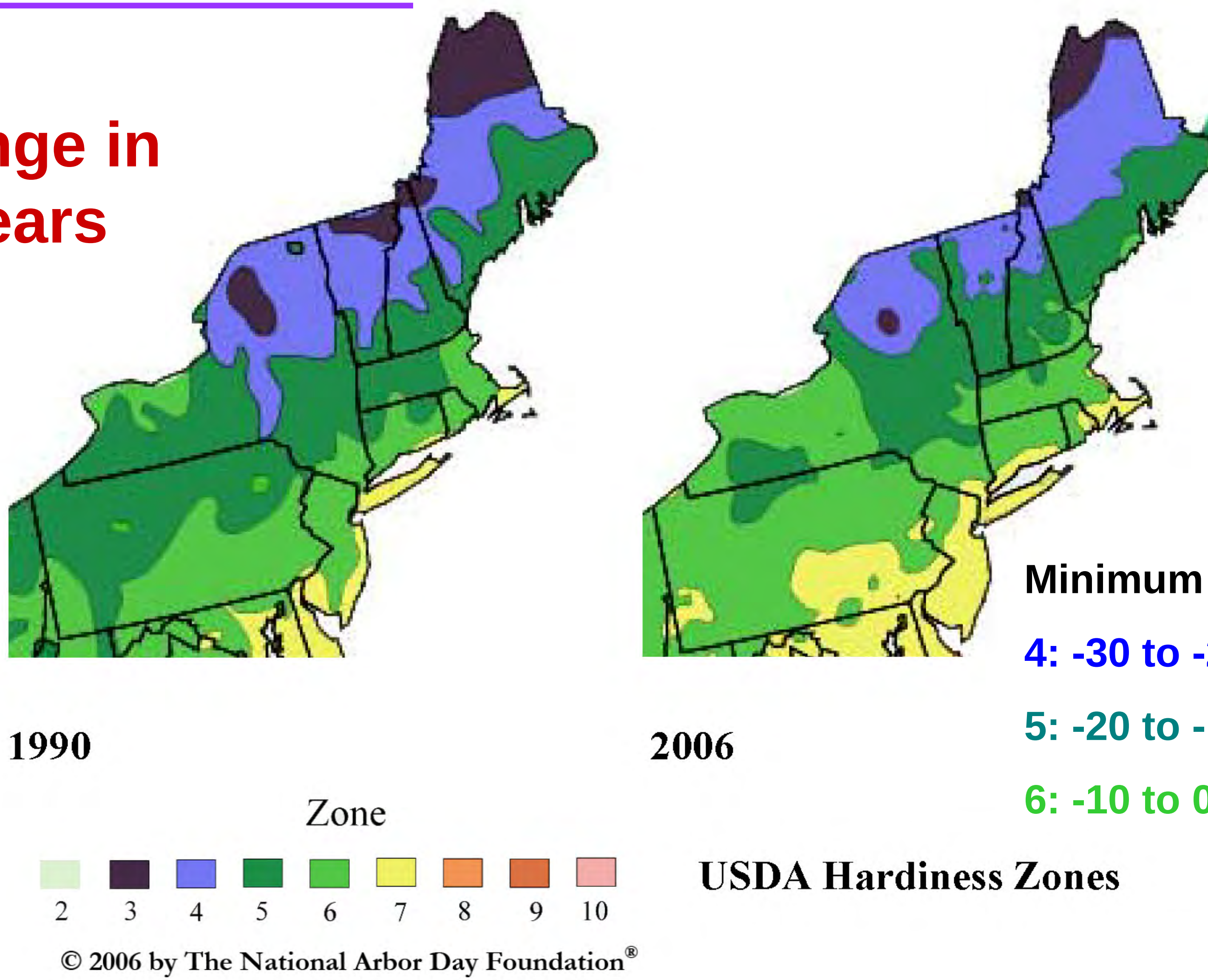


- **Ice-out earlier by 3 days / decade**
- **Freeze-up later by 4 days / decade**
- ***Soil ice probably similar***

Winter Hardiness Zones

– *winter cold extremes*

Change in 16 years



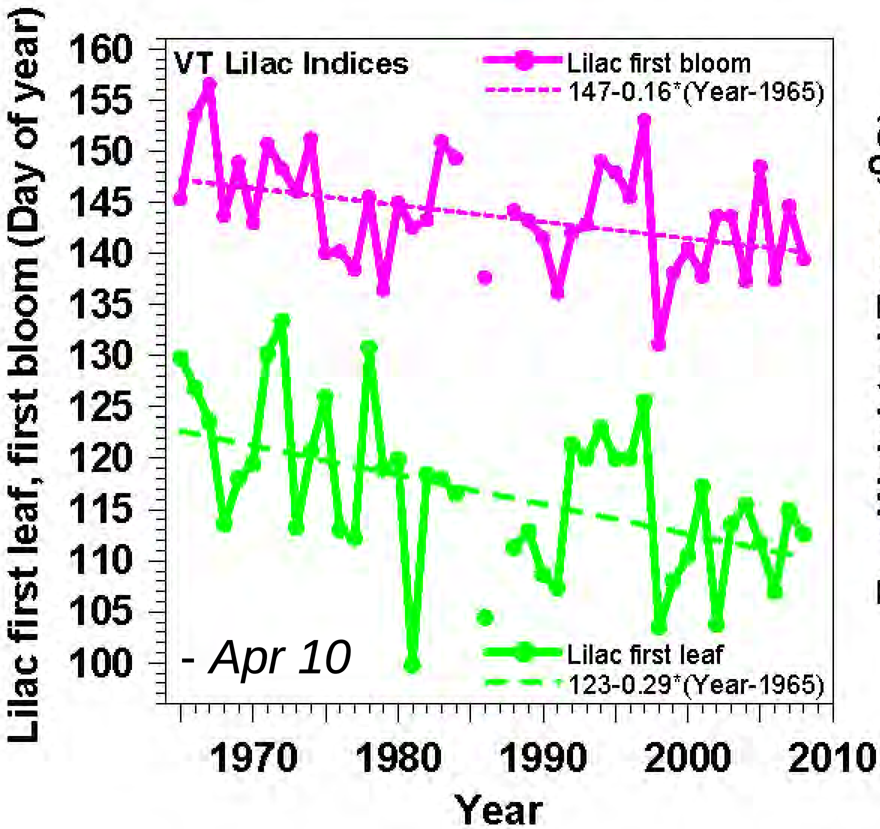
Minimum winter T

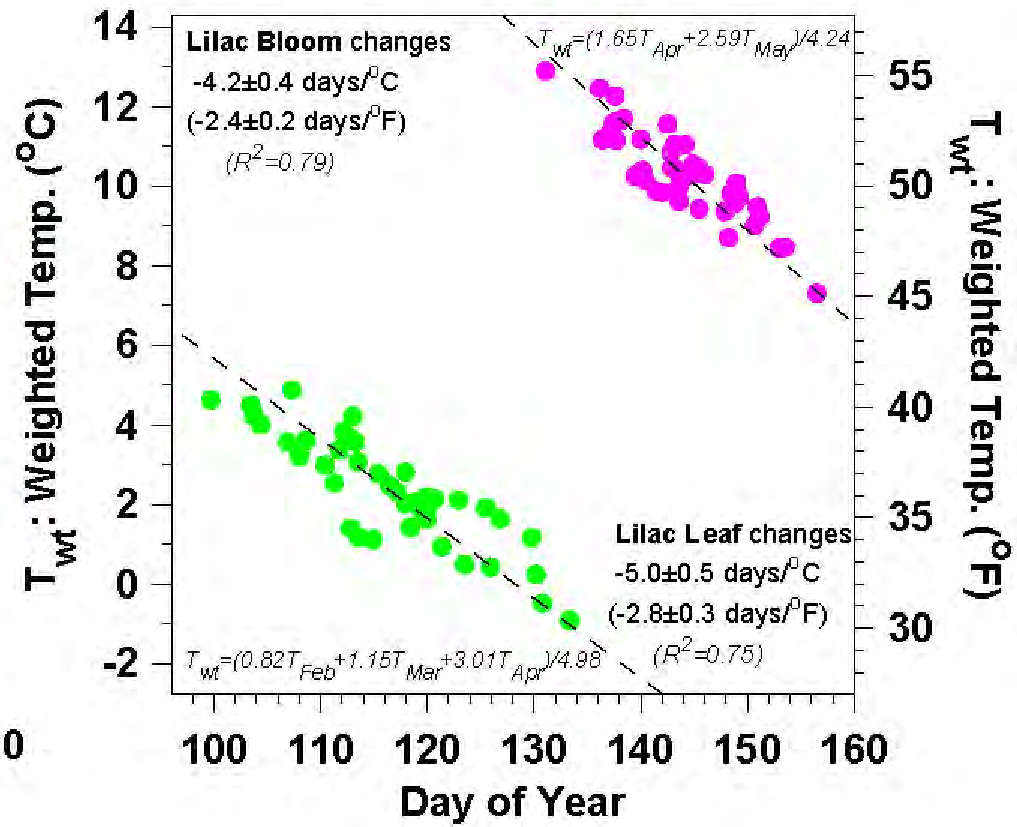
4: -30 to -20ºF

5: -20 to -10ºF

6: -10 to 0ºF

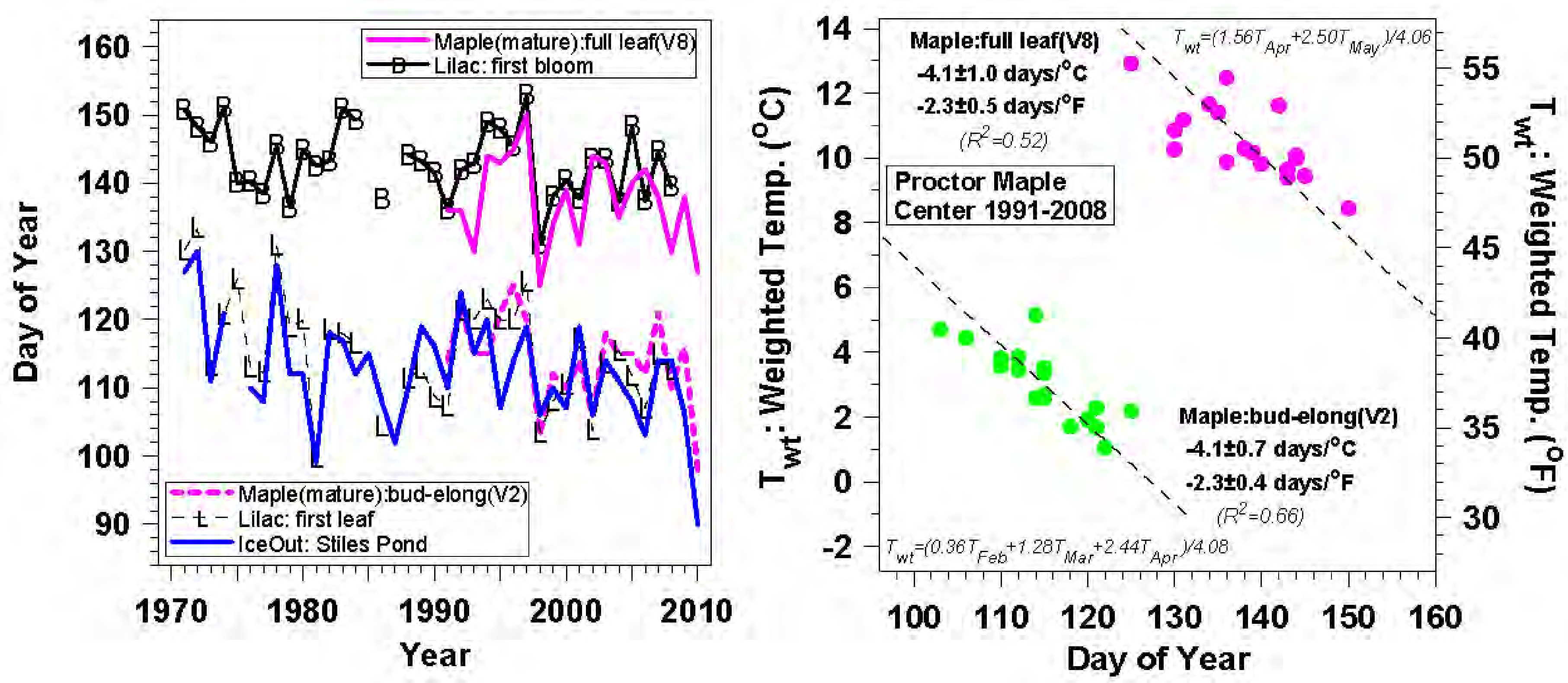
Lilac Leaf and Bloom





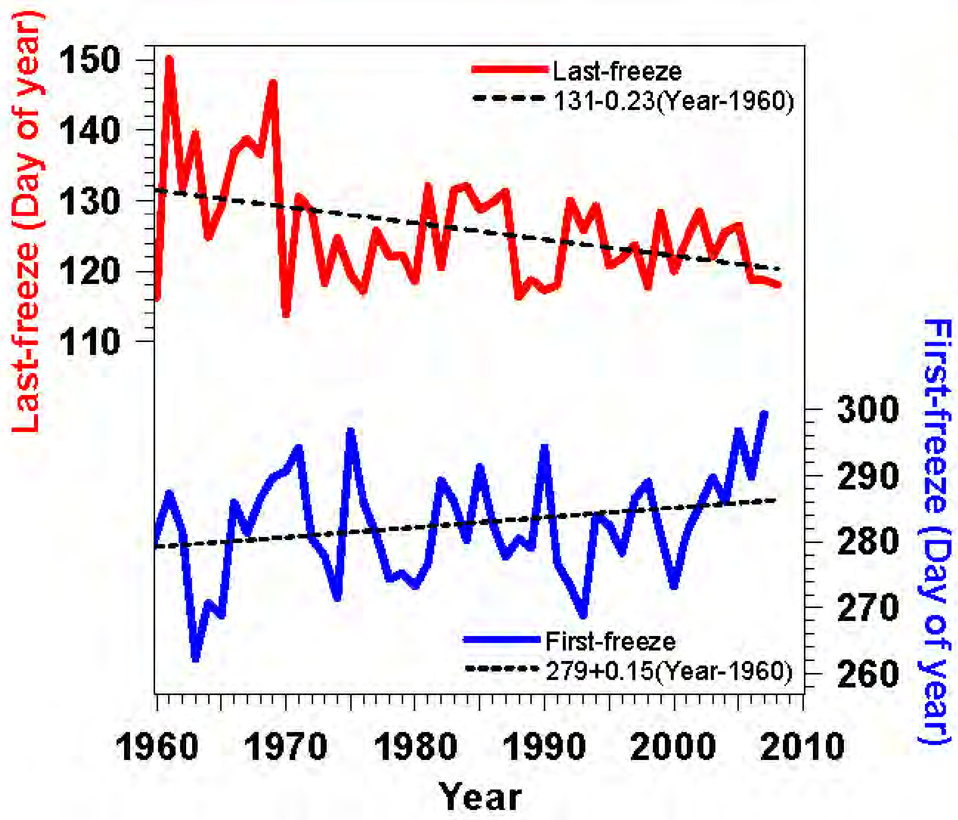
- **Leaf-out -2.9 days/decade; Bloom -1.6 days/decade**
- ***Large year-to-year variation related to temperature: 2.5 days/ °F (4.5 days/°C)***

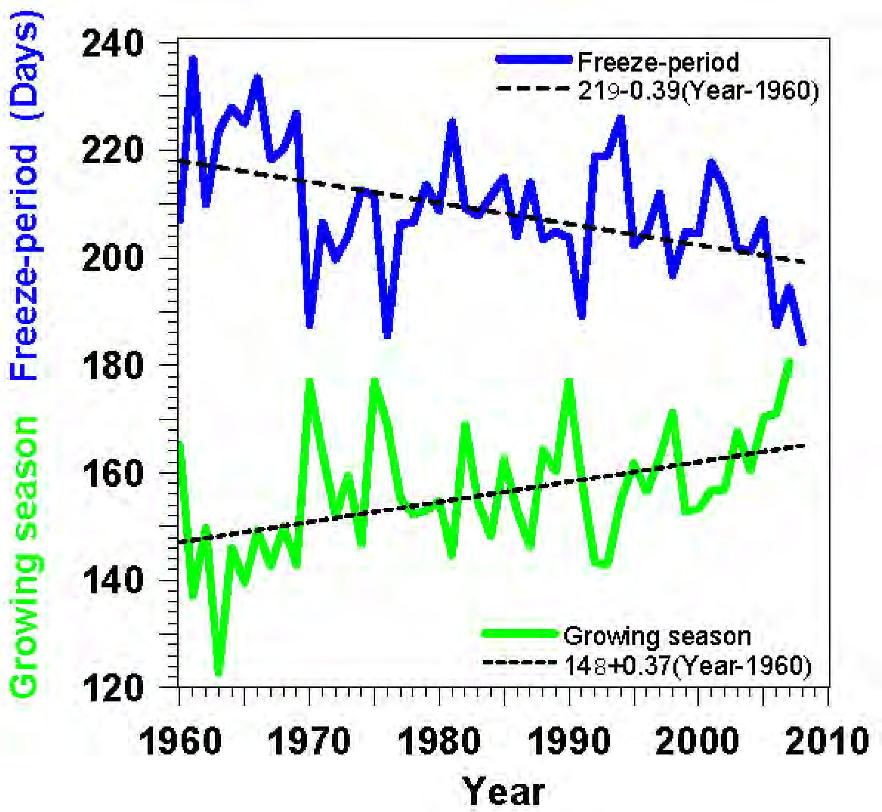
Maples and Lilacs in spring



- Maple bud elongation mirrors lilac leaf
- Maple leaf-out mirrors lilac bloom

First and Last Frosts Changing





- **Growing season for frost-sensitive plants increasing 3.7 days / decade**
- ***Important for agriculture; local food supply***