Understanding Daily Climate at Northern Latitudes

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RACC
Research on Adaptation to Climate Change

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 amplifying role**

January 2, 2012: NASA

Earth's climate sustains life

Seasonal Climate

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

  - **Earth cools to space 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**
  - **Clouds: Water drops, ice crystals**
    - **Cools surface**
  - **Snow and Ice on surface**
    - **Cools surface**
- **Water vapor absorbs longwave**
  - **Primary "greenhouse gas"**
    - **Along with CO_2, CH_4, CFCs and many others**
    - **Re-radiation warms surface**

Winter Ice and Snow

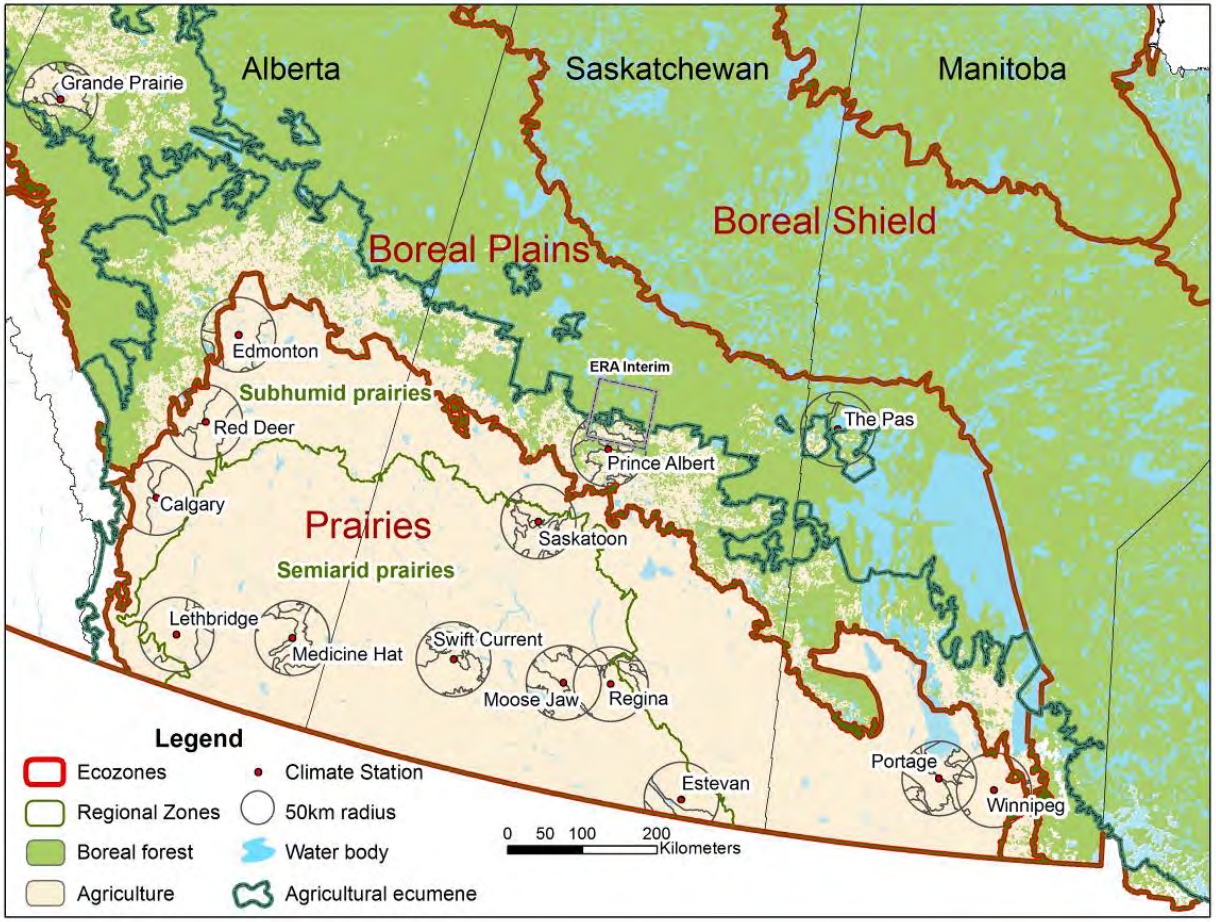
Vermont Winter 2006

- **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

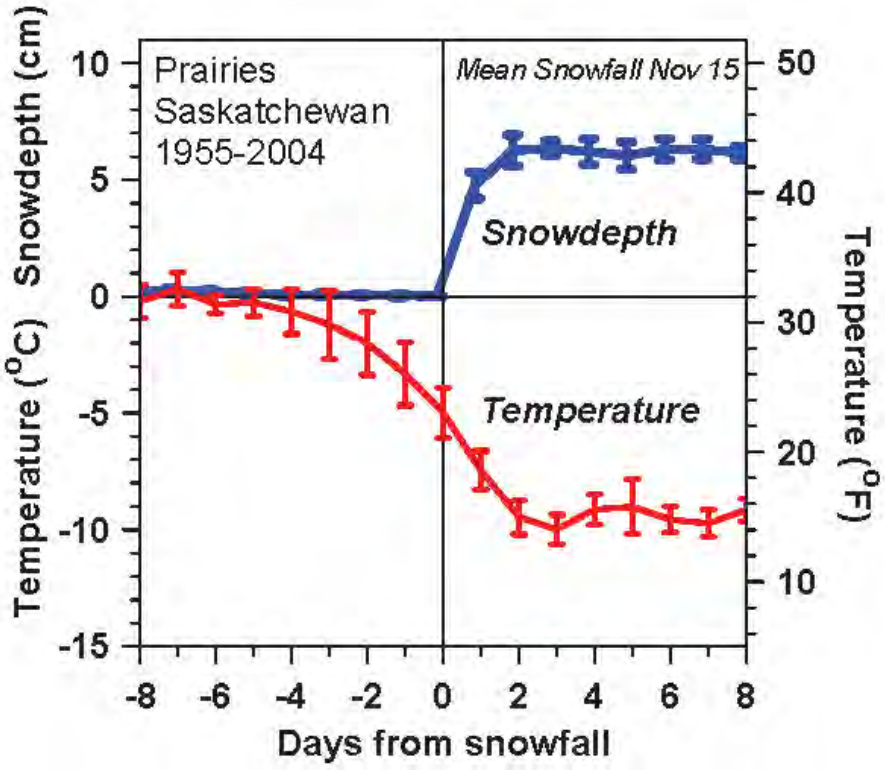
- **For years I have studied clouds and snow**
  - **And lectured on impacts *(with little data!)***
- **August 2012 – call from Agriculture-Canada**
  - **Please help us understand changing Prairie Climate**
    - **More intensive cropping, cooler summers**
    - **We have hourly data from 1953**
- **November, processed data arrives**
  - ***Amazing gift* 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**

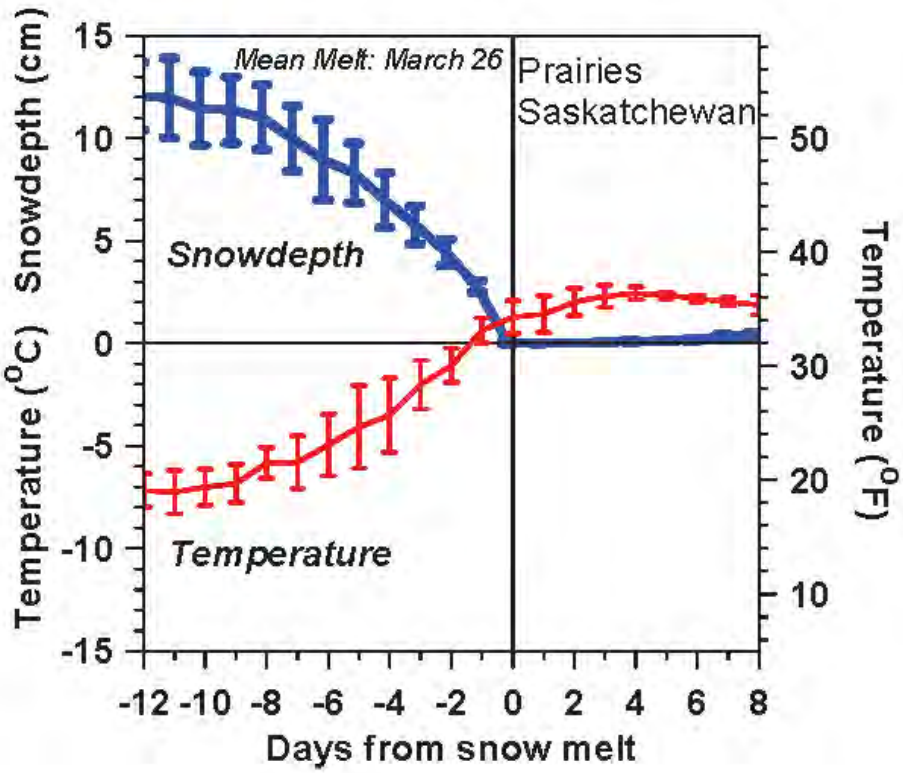
14 Prairie stations: 1953-2011



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

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***

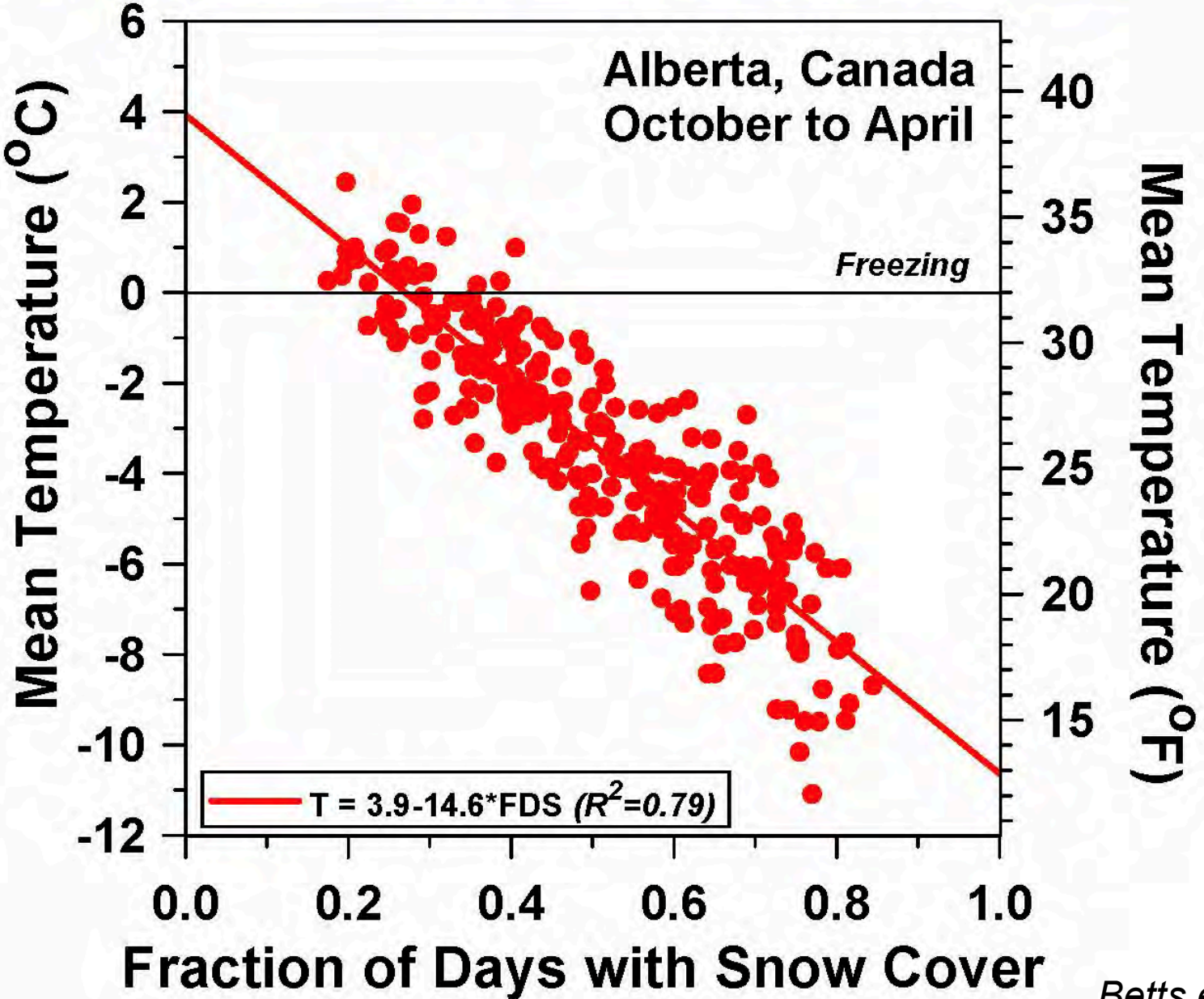
Surface Radiation Balance

- **Across snow transition**
  - **Surface albedo α_s increases: 0.2 to 0.73**
  - **LW_{dn} decreases**
  - **Opaque cloud increases**

- **SW_{net} falls 34 W/m^2**
- **LW_{dn} falls 15 W/m^2**
- **Total 49 W/m^2**

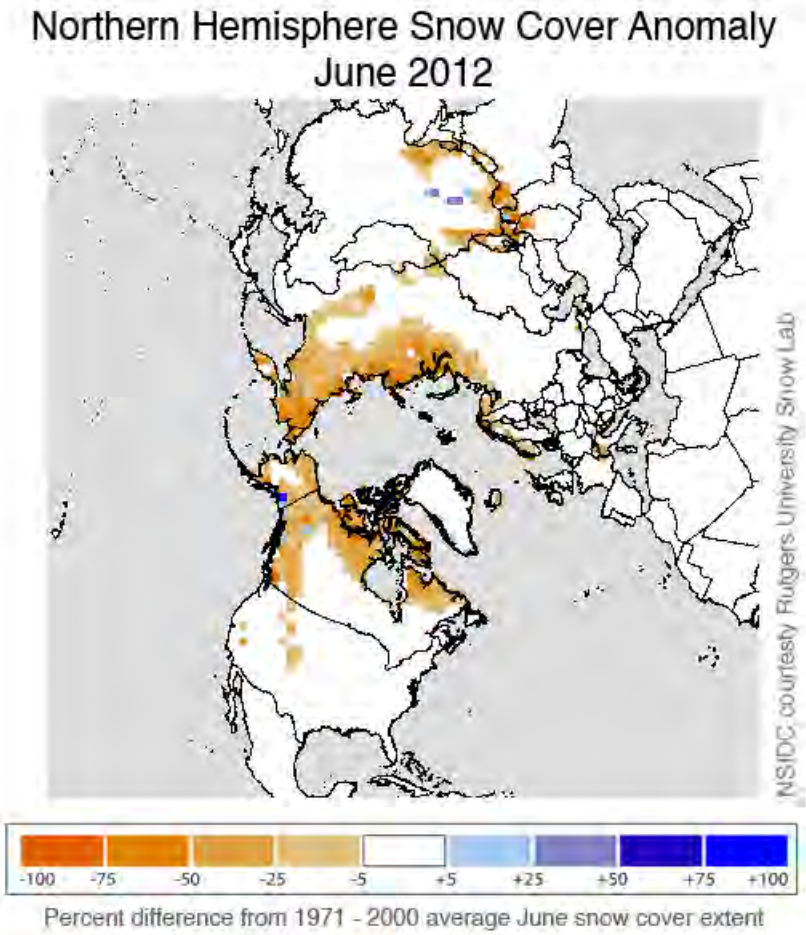
- **Surface skin T falls: ΔT = -11K to balance**
  (Stefan-Boltzman law: $\Delta(LW) = \Delta(\sigma T^4) = 4\sigma T^3 \Delta T$)

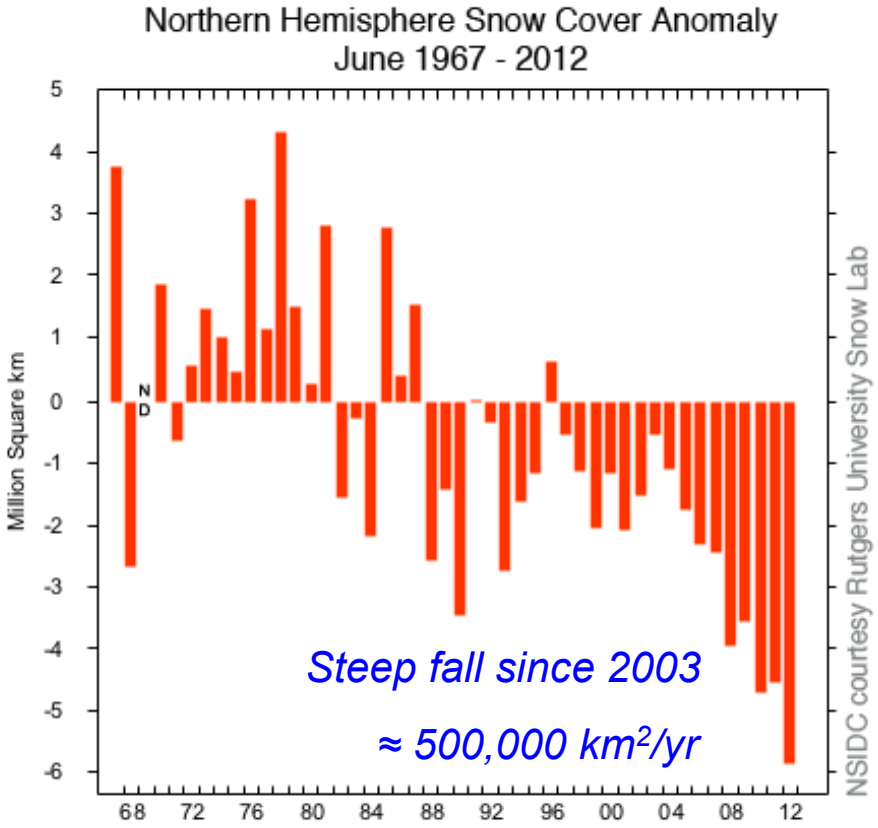
More snow cover - Colder temperatures



Betts et al. 2014

June 2012 snow cover minimum

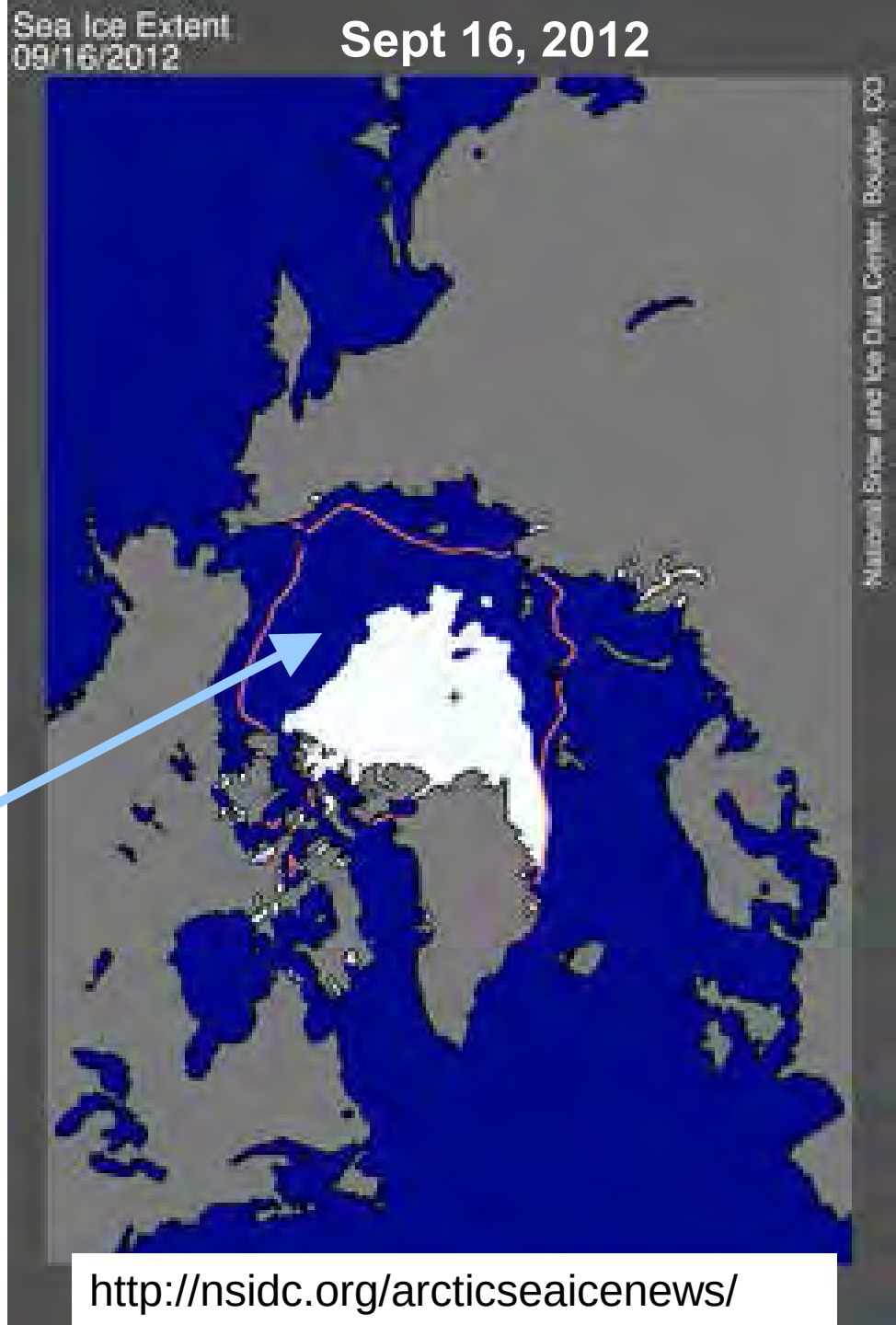




- **Arctic warming rapidly**
  - **Melting fast**
  - ***Much faster than IPCC models***
- **Northeast winters**
  - ***Same positive feedbacks***

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

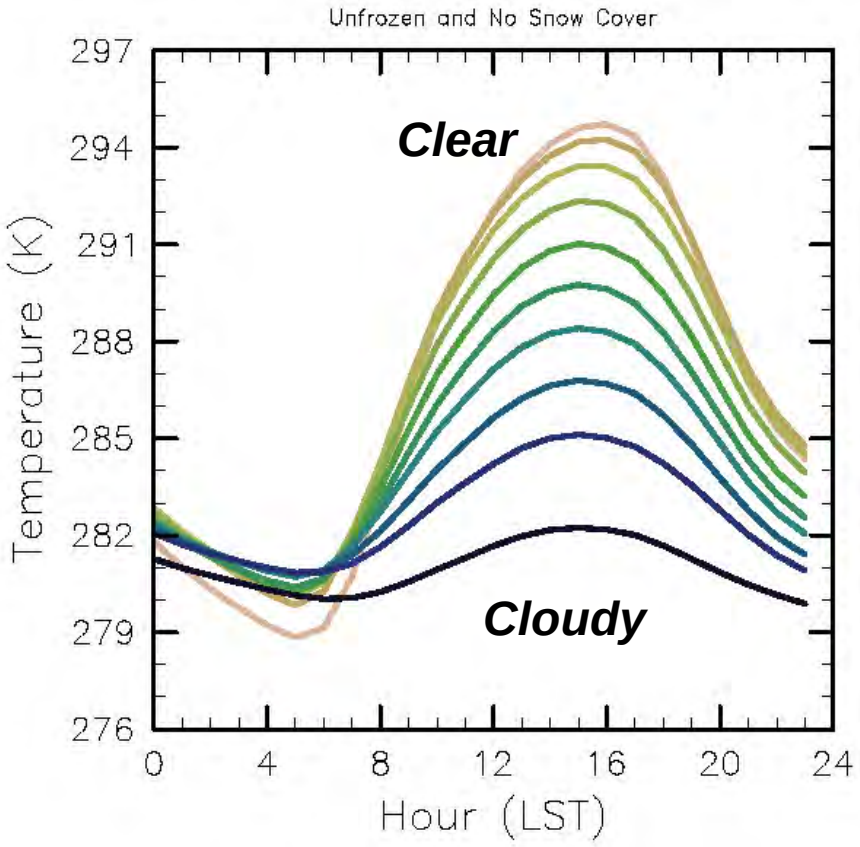
- ***Positive feedbacks:***
- ***Less ice, less reflection of sunlight***
- ***More evaporation, larger vapor greenhouse effect***
- ***Same feedbacks as in our winters***



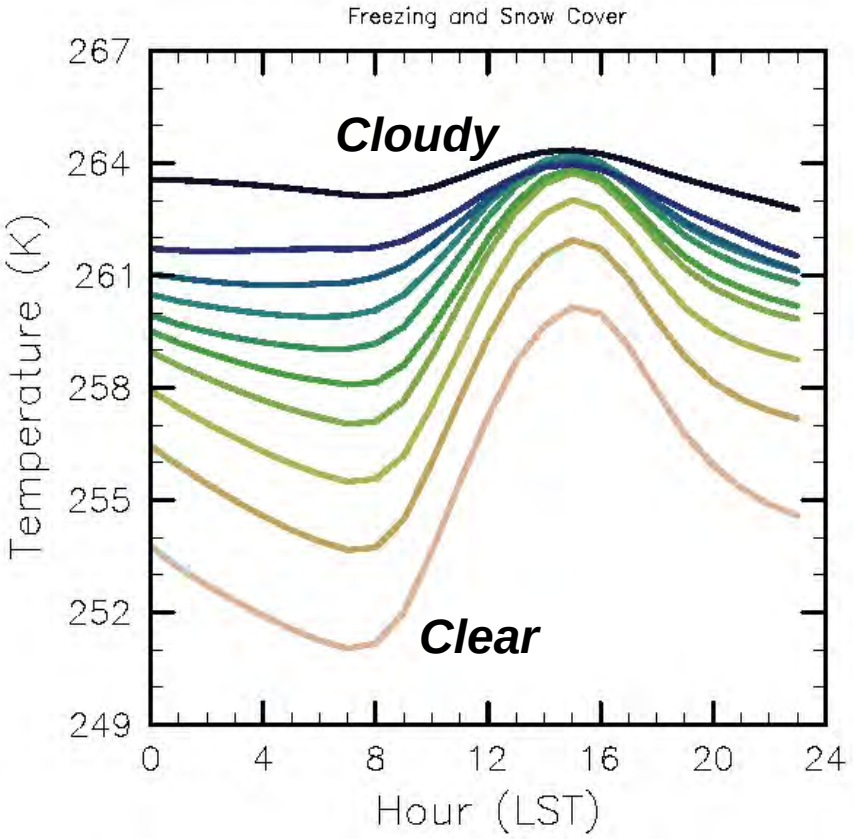
Winter Ice and Snow

Warm & Cold Climates: T><0°C

T_m >0°C: no snow: 150,000 days



T_m <0°C: snow: 75,000 days



- **Warm >0°C:** Clouds reflect sunlight
- **Cold <0°C:** Clouds are greenhouse & snow reflects sun

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: *79ºF 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**

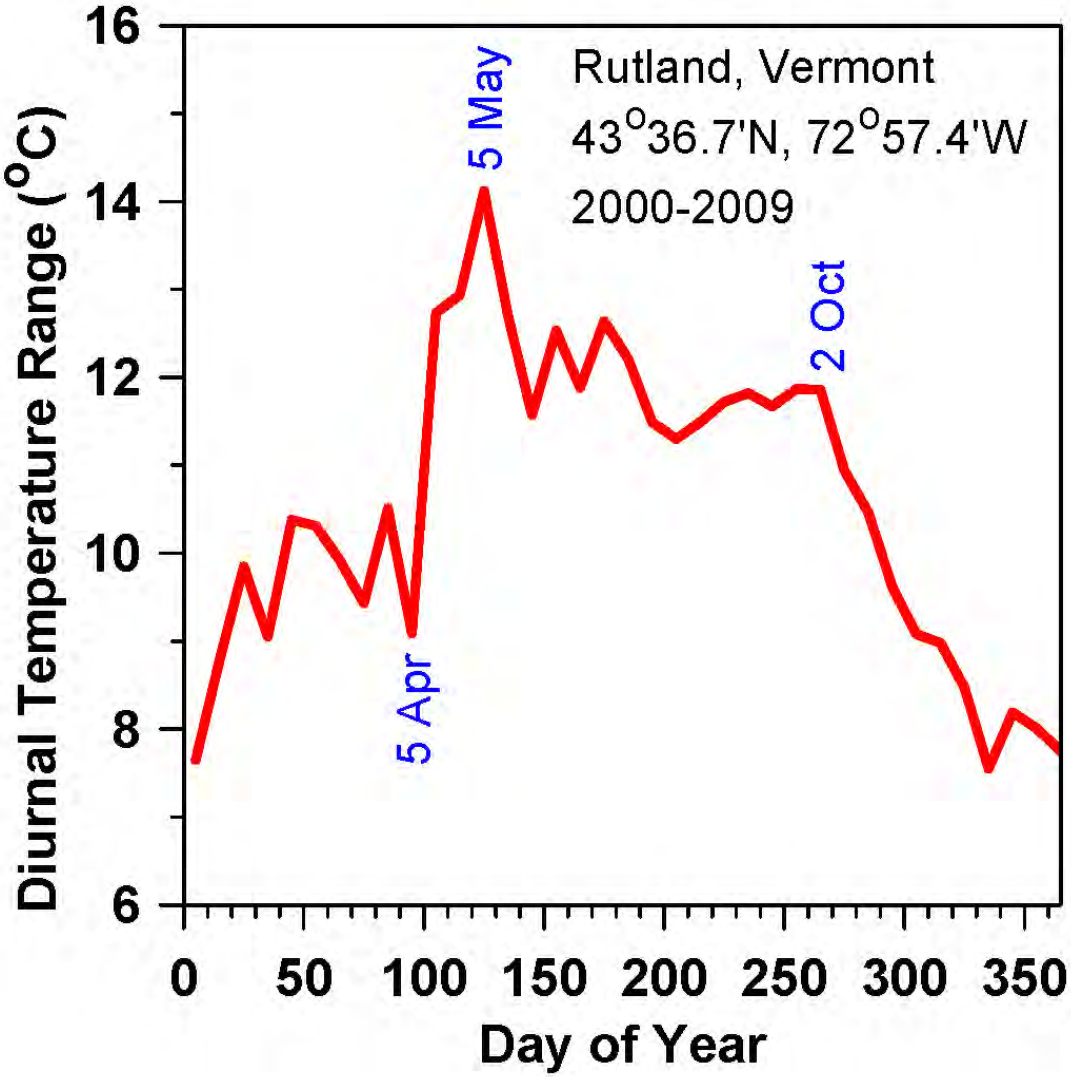
- ***Trend earlier***

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

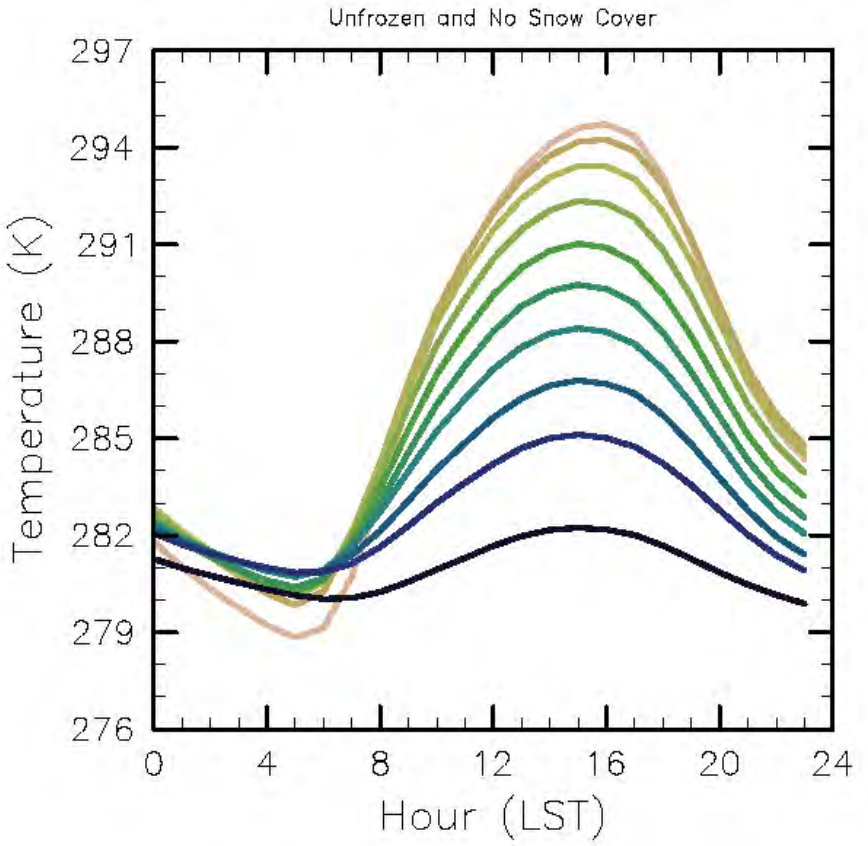
March 11, 2012

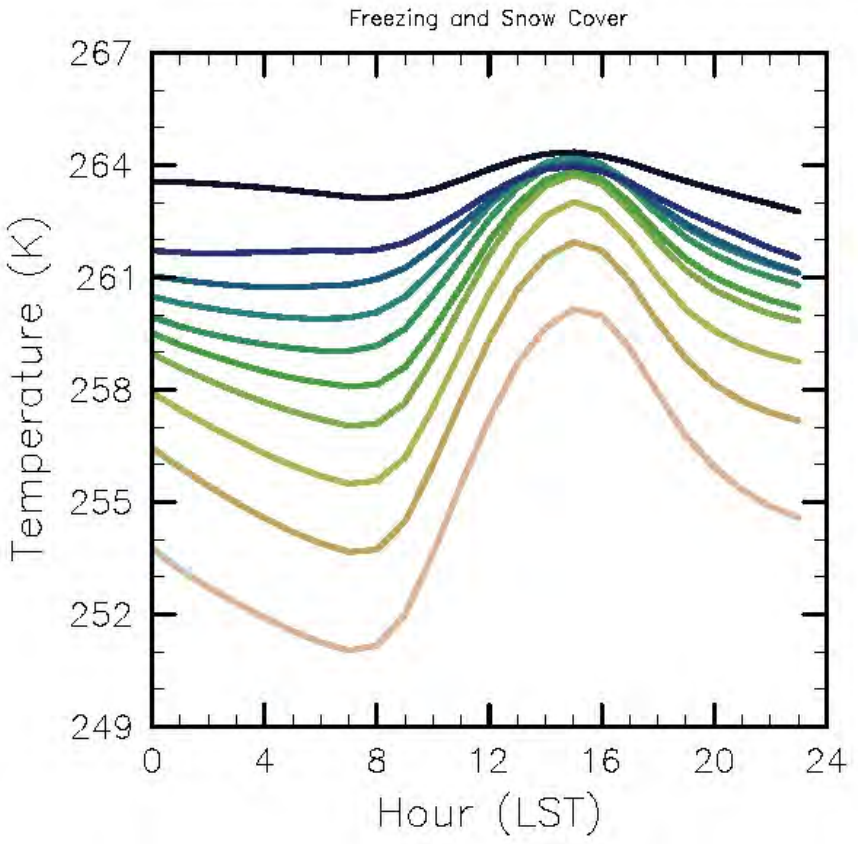
October 2011– March 2012

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

- **January 15, 2013**

Clouds: Warm & Cold Climates





- **Freezing point of water changes everything!**
- **Warm >0°C: No Snow: Surface solar heating, clouds reflect**
  - **unstable boundary layer**
- **Cold <0°C: Snow: Surface cools radiatively, clouds 'blanket'**
  - **stable boundary layer**

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)

- **Extreme weather increasing**
- ***Evaporation increases with T***
- ***More 'quasi-stationary weather patterns'***

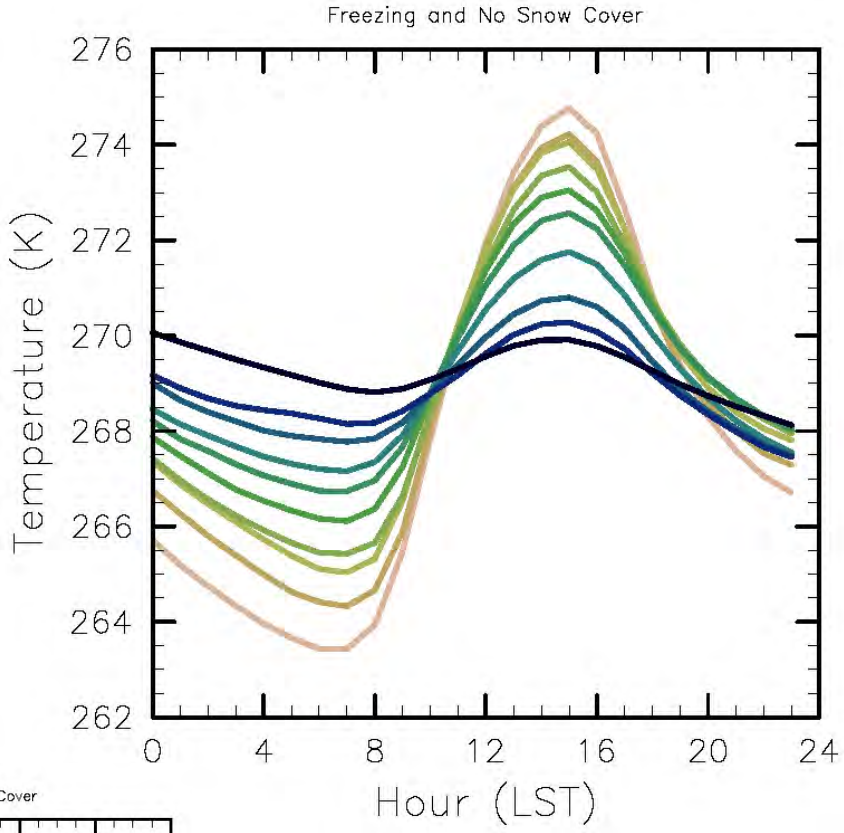
Discussion

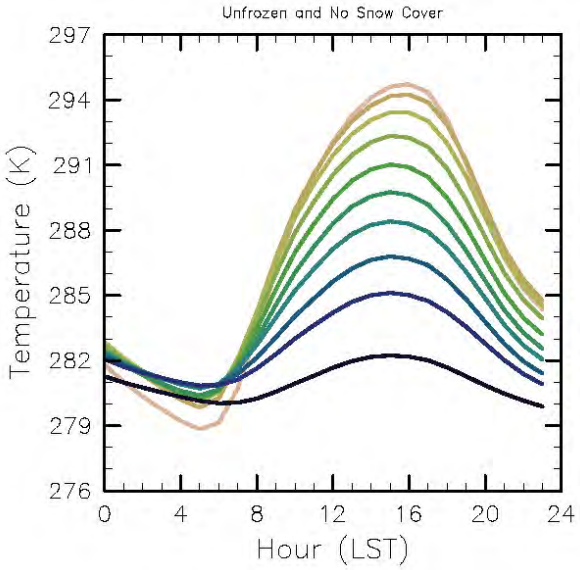
Background papers:

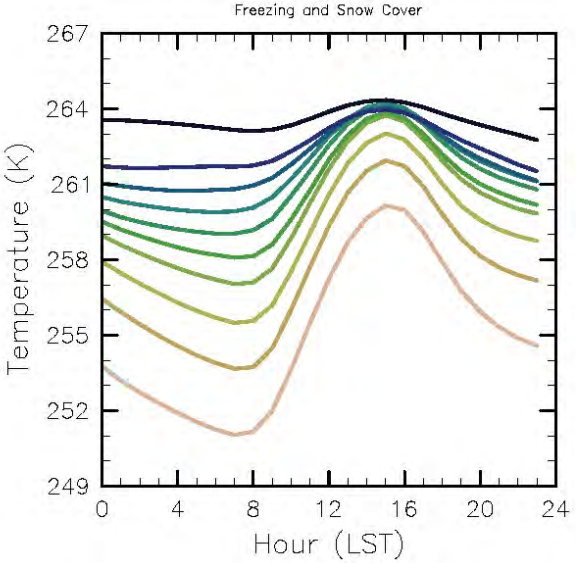
http://alanbetts.com/

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

Freezing but no snow cover

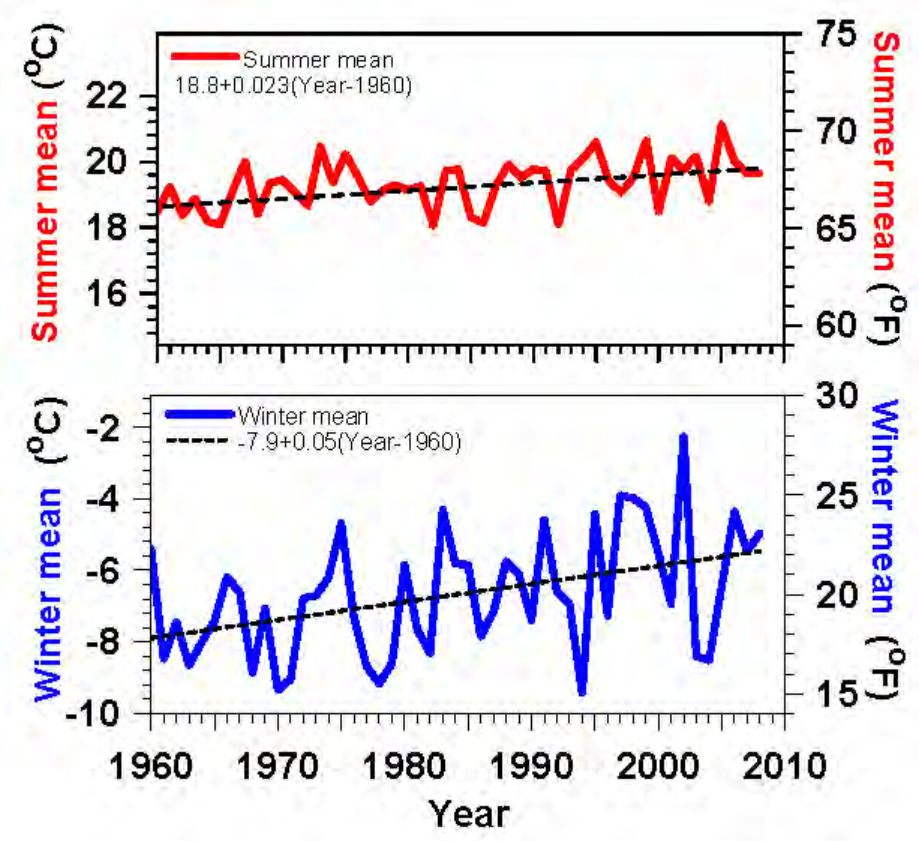






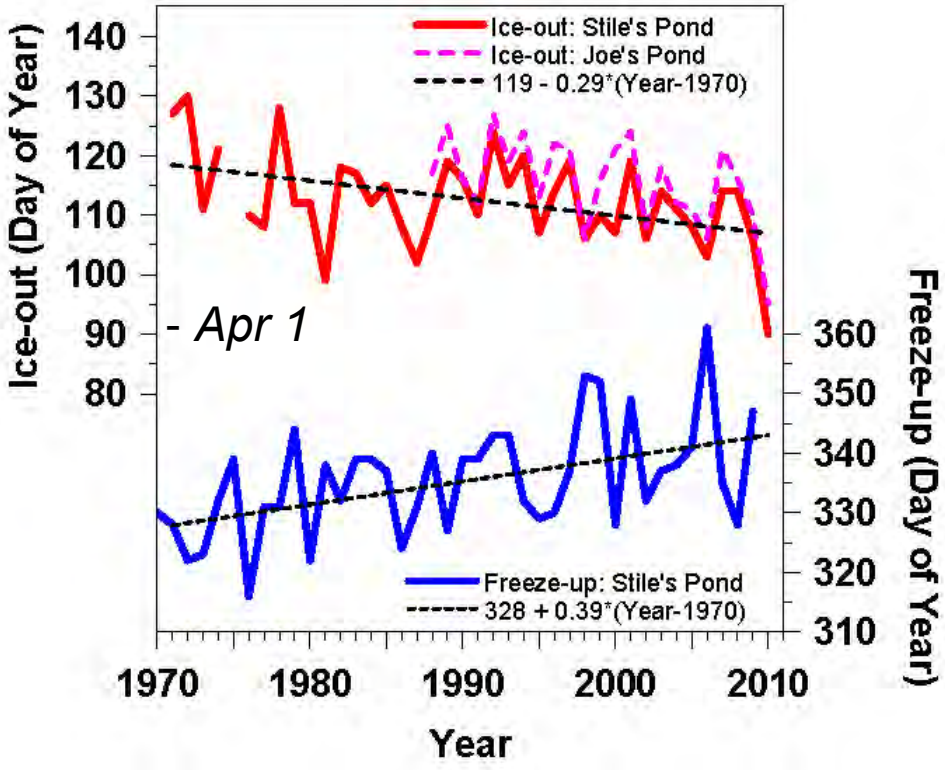
Vermont Temperature Trends 1961-2008

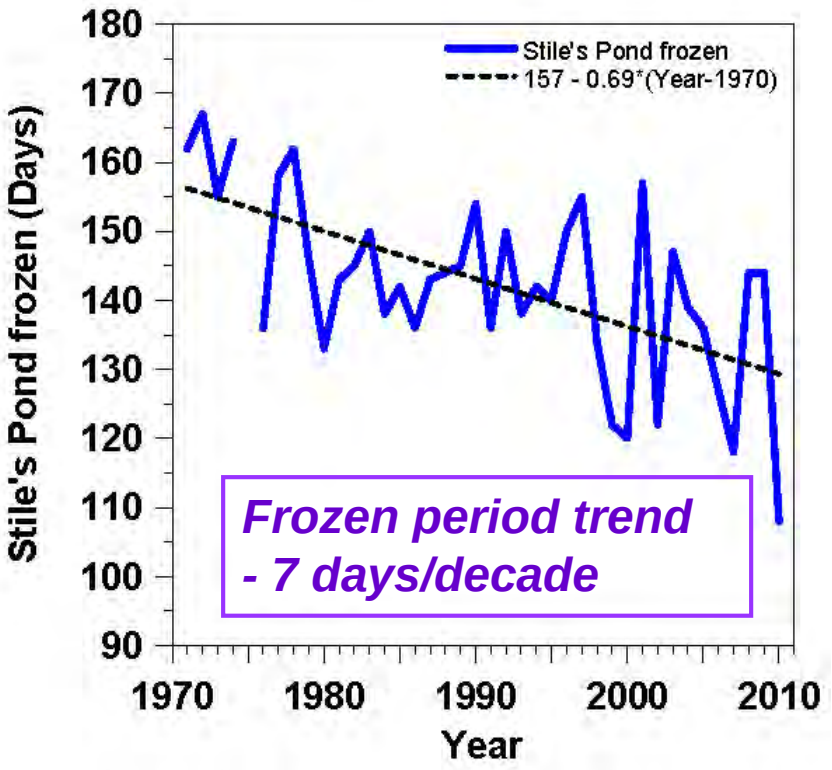
- **Summer +0.4°F / decade**
- **Winter +0.9°F / decade**
- **Larger variability, larger trend**
- ***Less snow (and increased water vapor) drive larger winter warming***



Lake Freeze-up & Ice-out Changing

Frozen Period Shrinking Fast



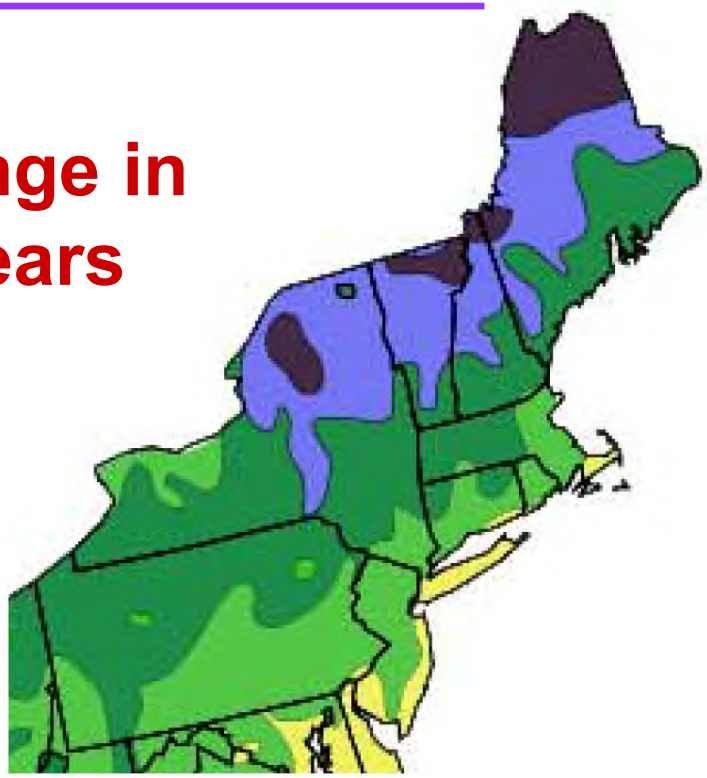


- **Ice-out earlier by 3 days / decade**
- **Freeze-up later by 4 days / decade**
- ***Soil ice probably similar***

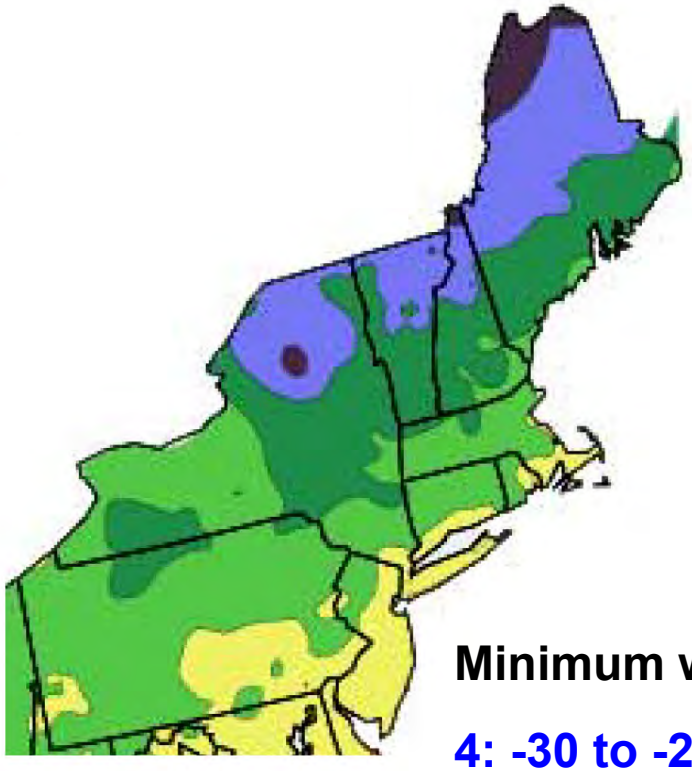
Winter Hardiness Zones

– *winter cold extremes*

Change in 16 years



1990



2006

Minimum winter T

4: -30 to -20°F

5: -20 to -10°F

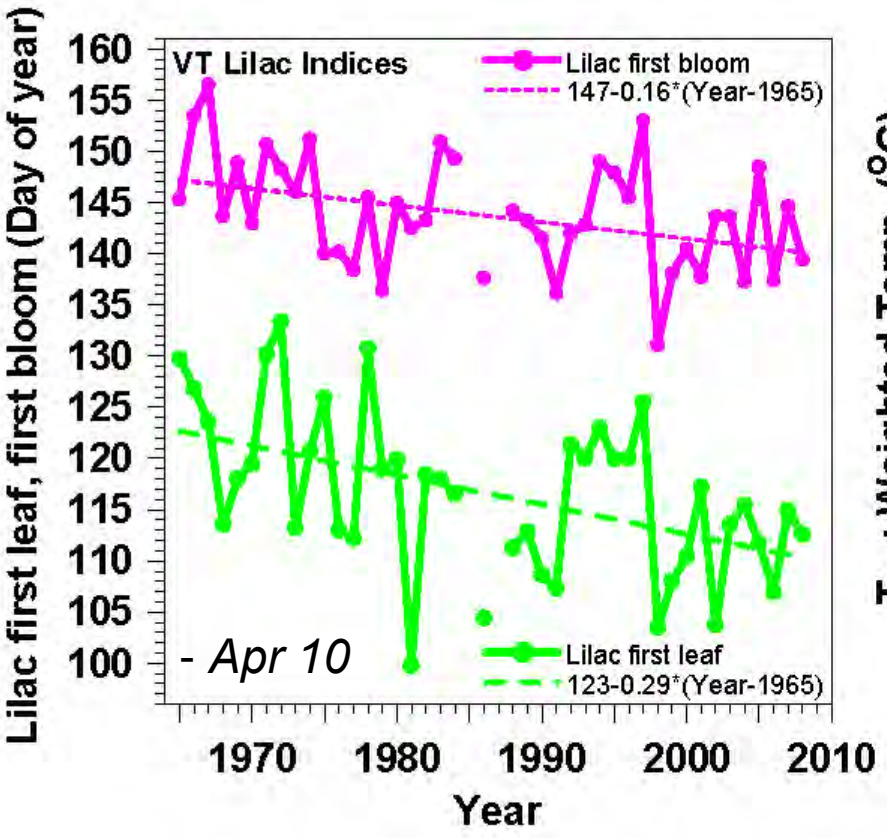
6: -10 to 0°F

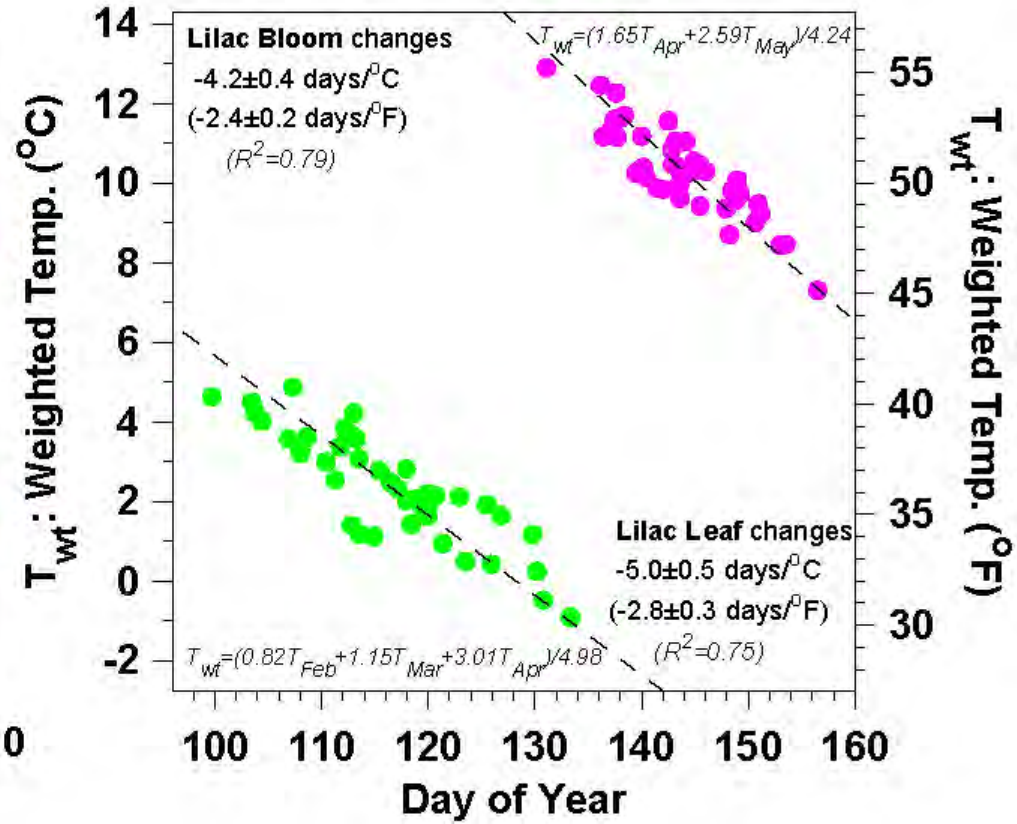
Zone

2 3 4 5 6 7 8 9 10

USDA Hardiness Zones

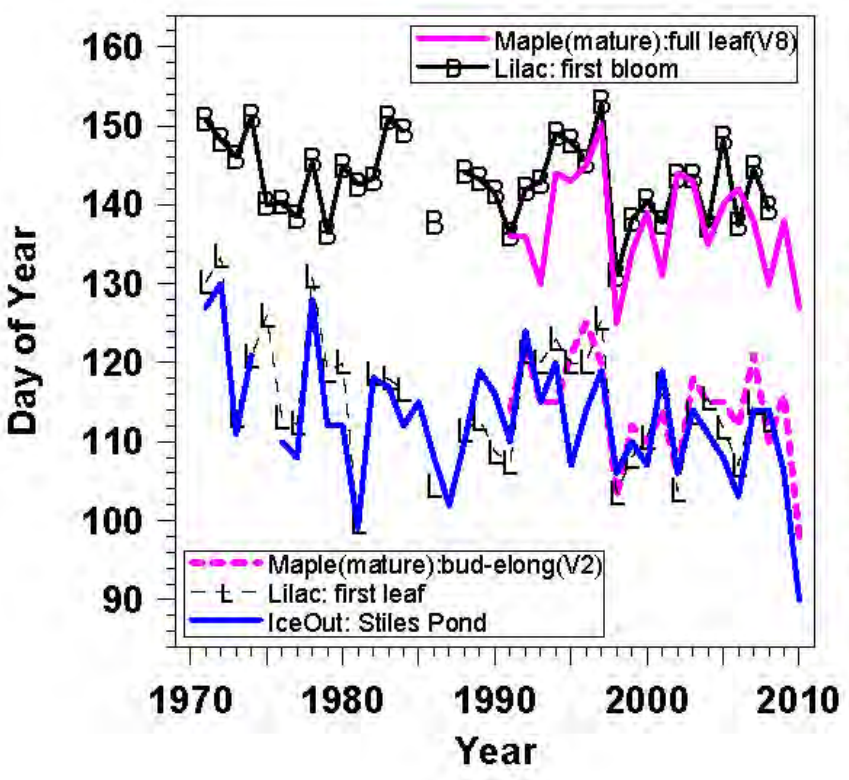
Lilac Leaf and Bloom

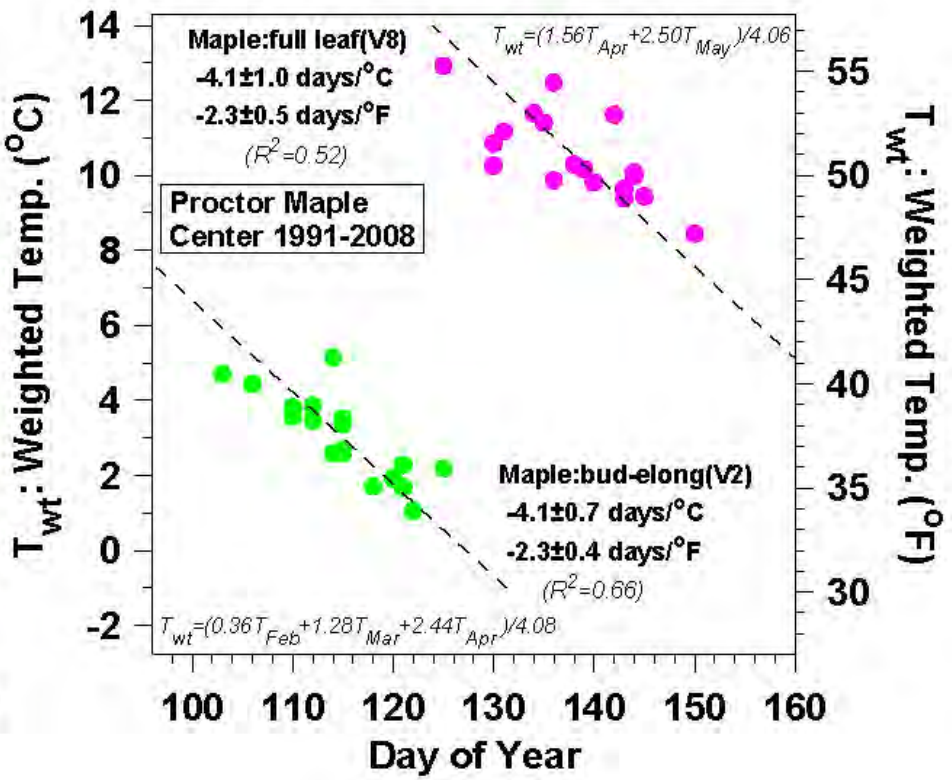




- **Leaf-out -2.9 days/decade; Bloom -1.6 days/decade**
- ***Large year-to-year variation related to temperature:***
  2.5 days/ °F (4.5 days/°C)

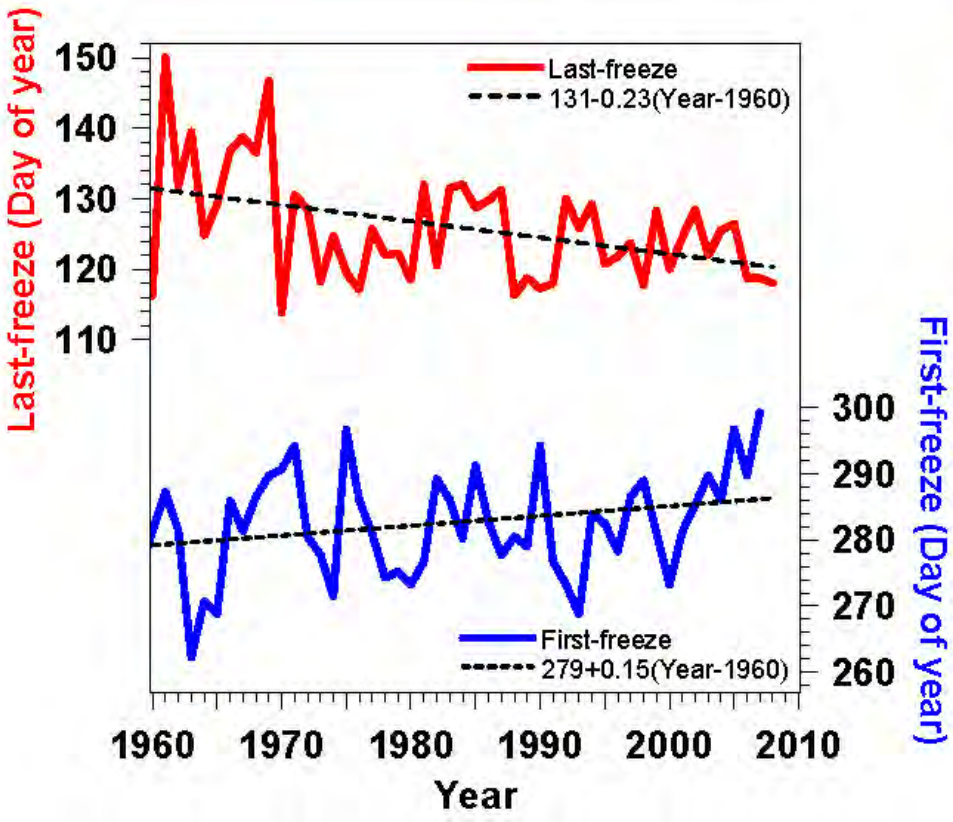
Maples and Lilacs in spring

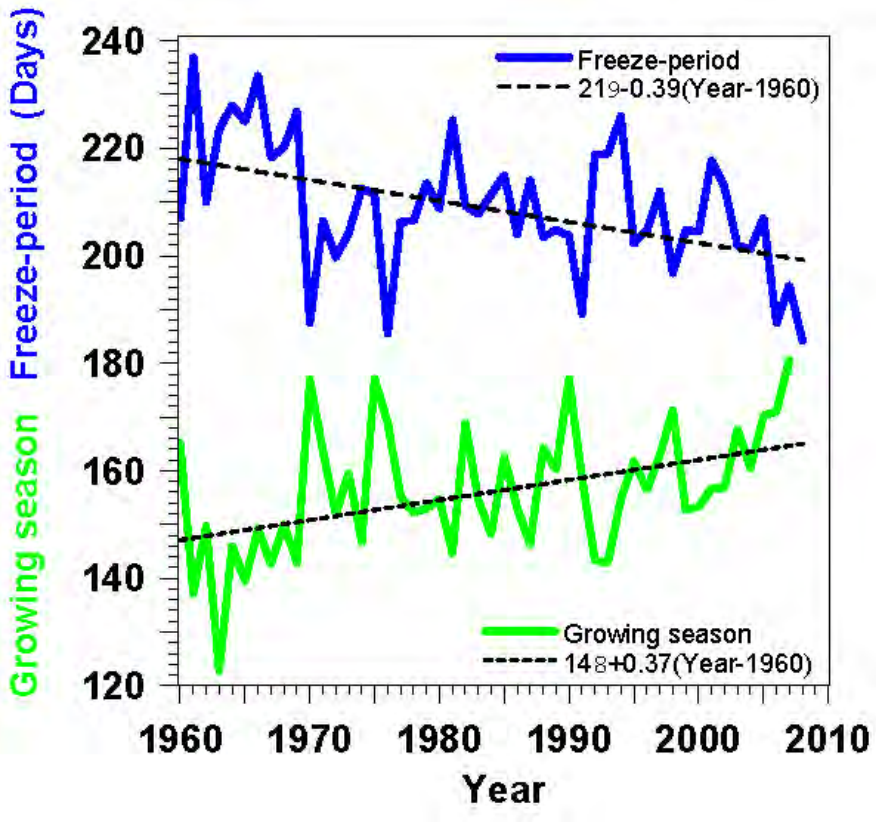




- **Maple bud elongation mirrors lilac leaf**
- **Maple leaf-out mirrors lilac bloom**

First and Last Frosts Changing

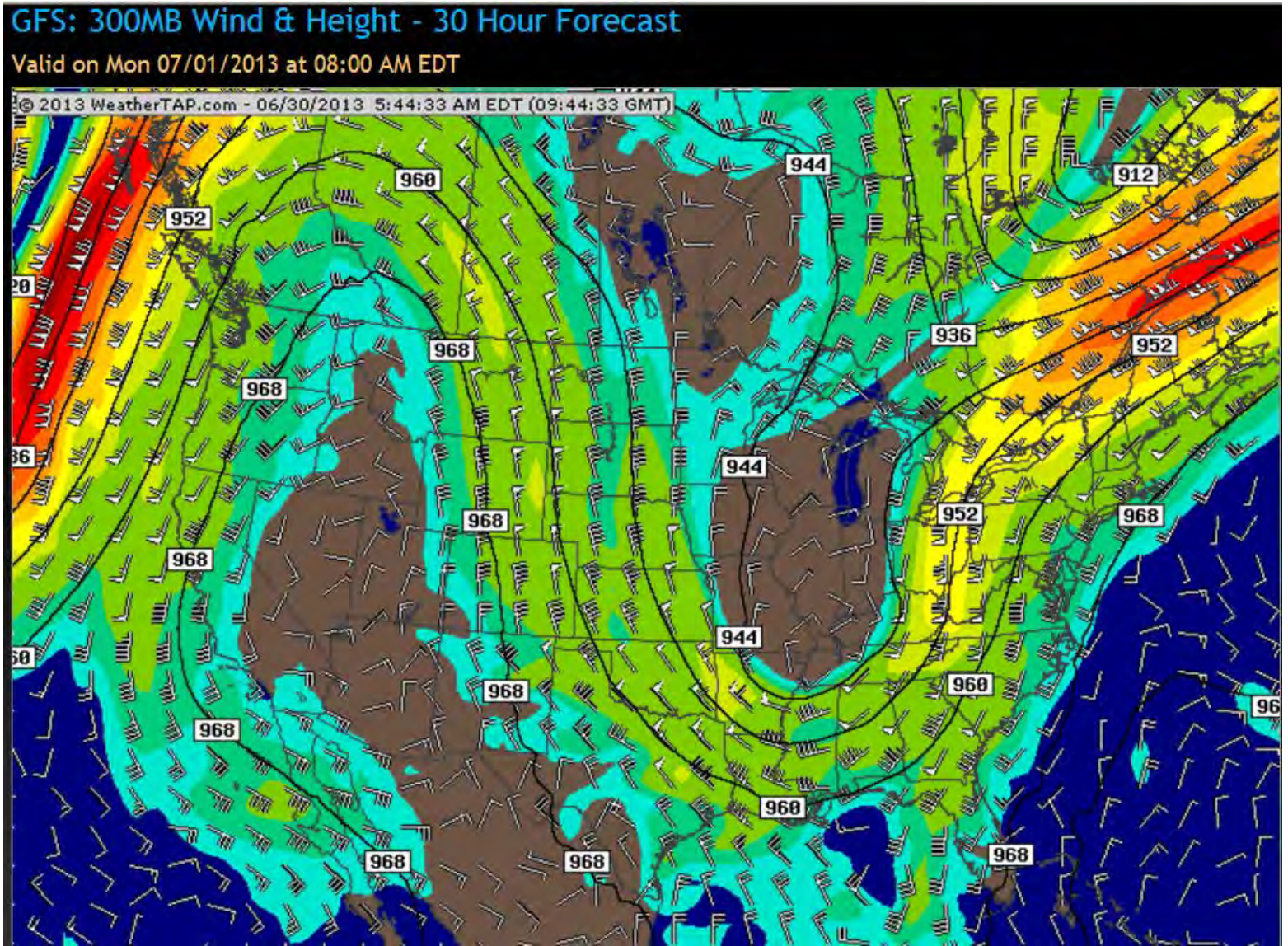




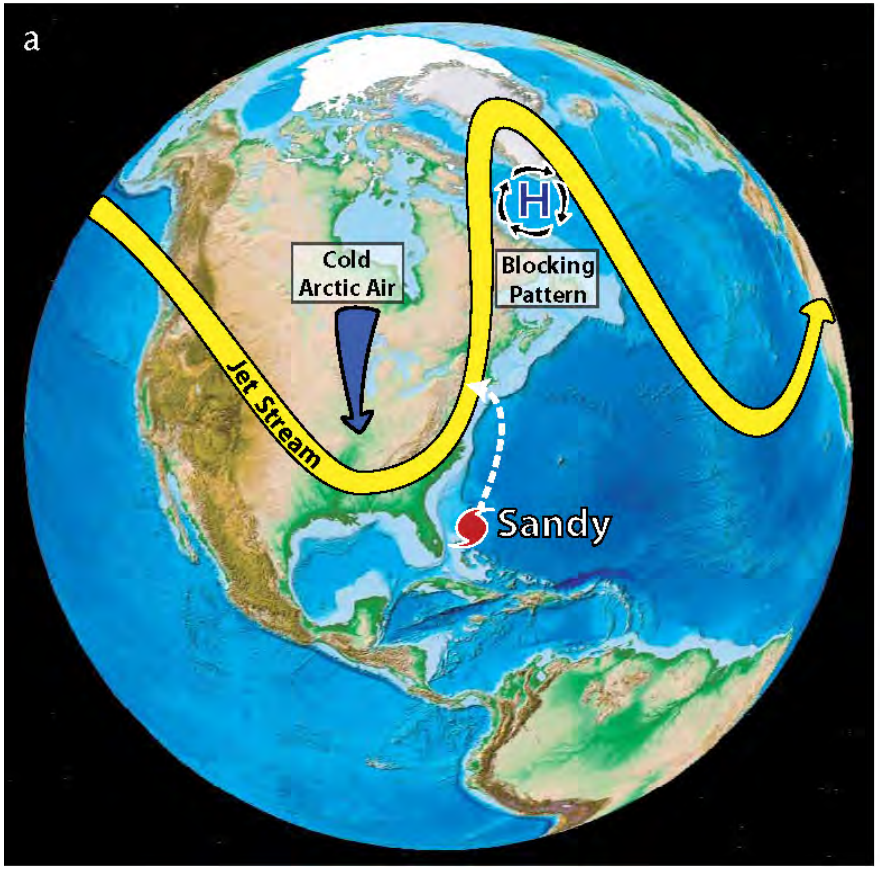
- **Growing season for frost-sensitive plants increasing 3.7 days / decade**
- ***Important for agriculture; local food supply***

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

(Francis and Vavrus, 2012)



Blocking Pattern - Unique track



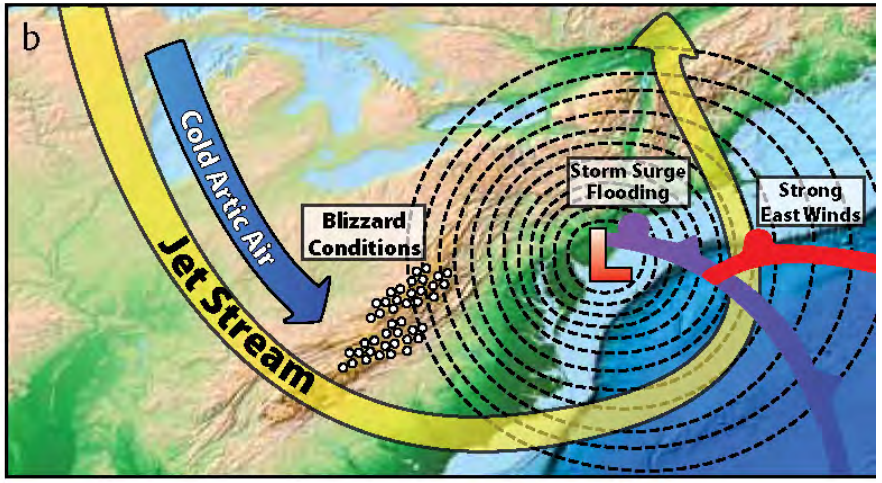


Figure 1. (a) Atmospheric conditions during Hurricane Sandy's transit along the eastern seaboard of the United States, including the invasion of cold Arctic air into the middle latitudes of North America and the high-pressure blocking pattern in the northwest Atlantic. (b) After the convergence of tropical 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 + full moon high tide = record storm surge + disaster**

[Greene et al., Oceanography, 2013]