Climate Change and Vermont

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Rutland High School

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- Earth sustains life
- Weather changes fast
- Climate changes slowly
- Greenhouse gases keep Earth warm
- Burning fossil fuels – coal, oil and gas – is having a big effect on climate by increasing greenhouse gases: CO_2 and H_2O

January 2, 2012: NASA

Climate Change

- **One of the many great challenges for the 21st century - present path is unsustainable**
- **We are already decades late in taking action**

  Charney Report (1979): Carbon dioxide and Climate

  UN Framework Convention on Climate Change (1992) in Rio, Brasil

  - To stop "Dangerous Climate Change"

- **It is a global issue & a local issue**
  a societal issue & a personal issue

- **Clash between Earth science**
  and economic & social values

Outline

- **Science of climate change**
  - **Global scale: actual and future**
  - **What is happening to Vermont**

(Discussion)

- **The transition we face: 1:20pm**
  - **Managing the earth system**
  - **A question of attitude**

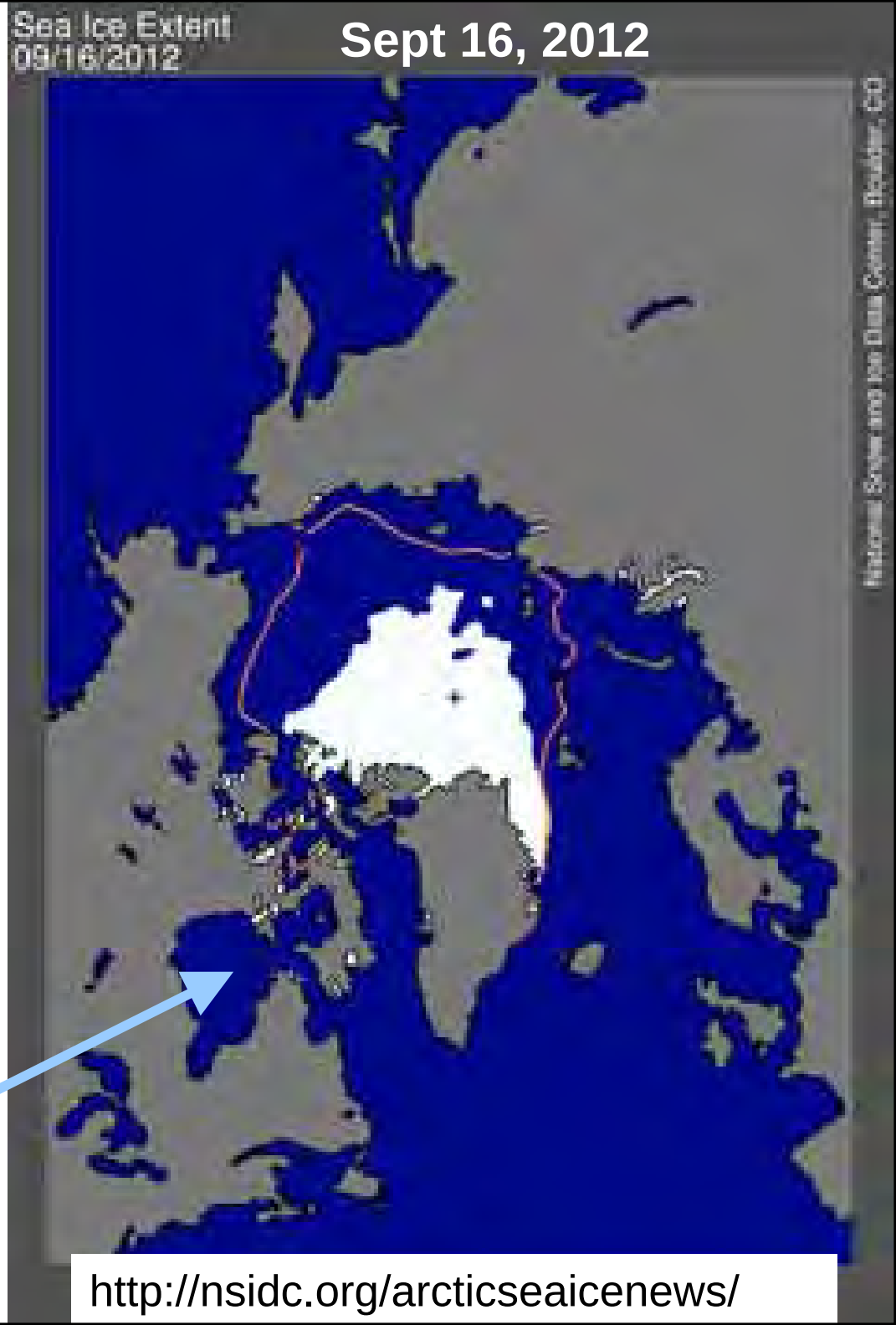
(Discussion)

- **Half the Arctic Sea Ice Melted in 2012**
  - *less 2013*

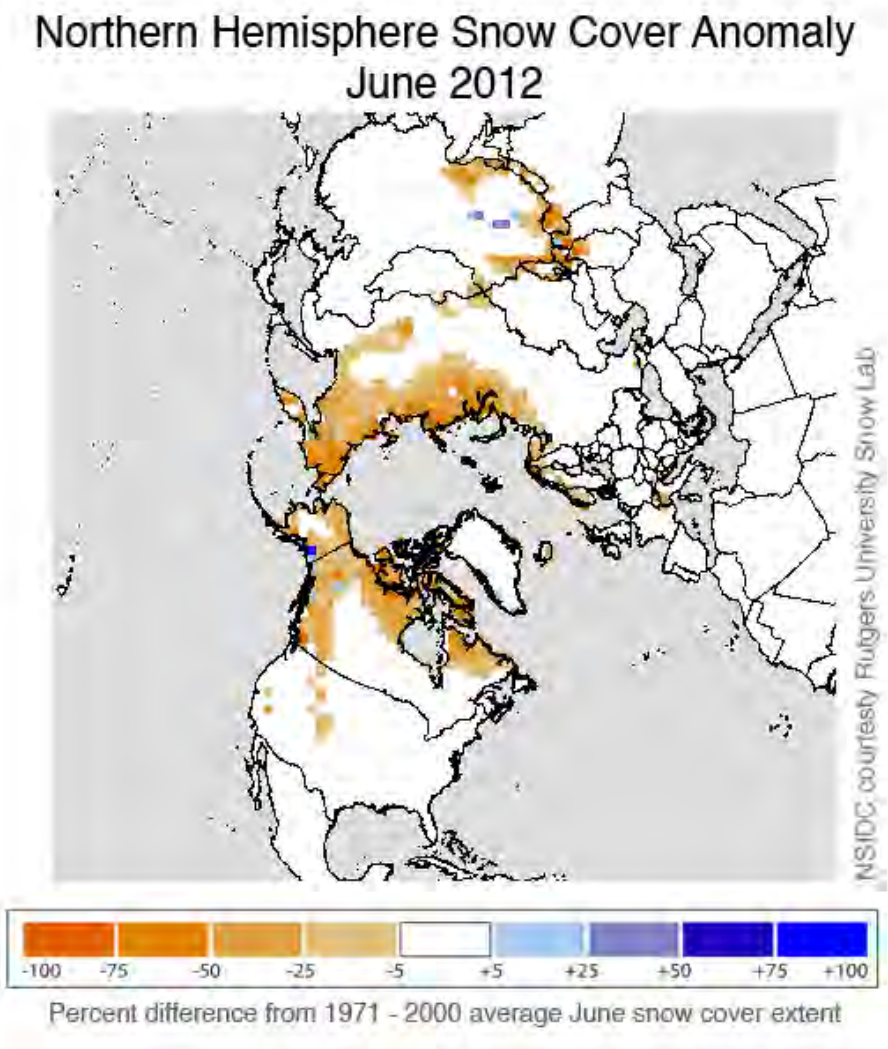
- ***Positive feedbacks:***
- ***Less ice, less reflection of sunlight***
- ***More evaporation, larger vapor greenhouse effect***
- ***Ice thin: most 1-yr-old***

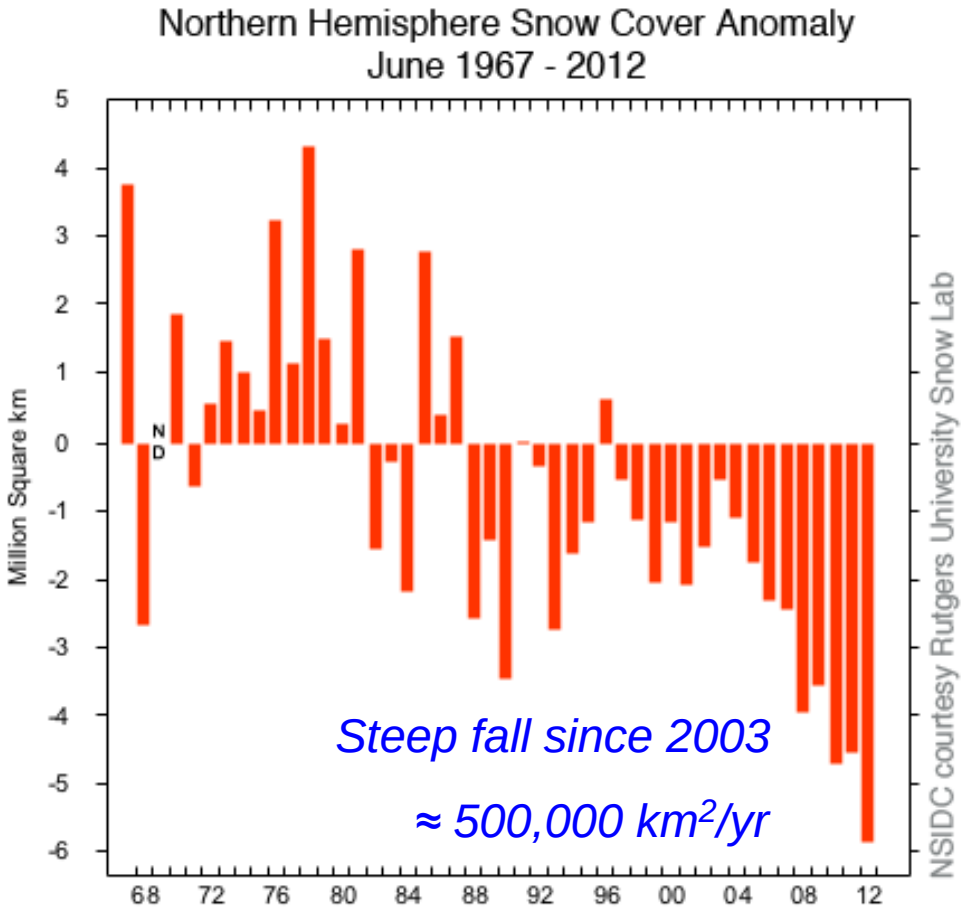
End of Nov. 2011 Hudson Bay was still nearly ice-free:

Open water in Oct. Nov. gives warmer Fall in Northeast



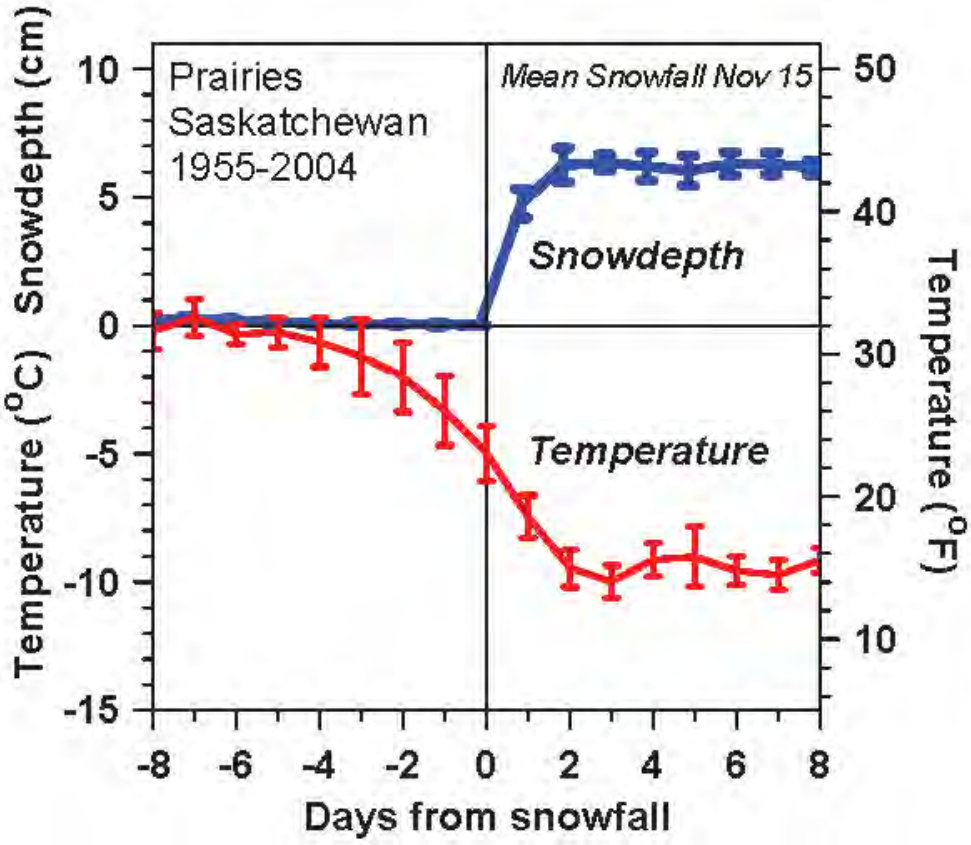
June 2012 snow cover minimum

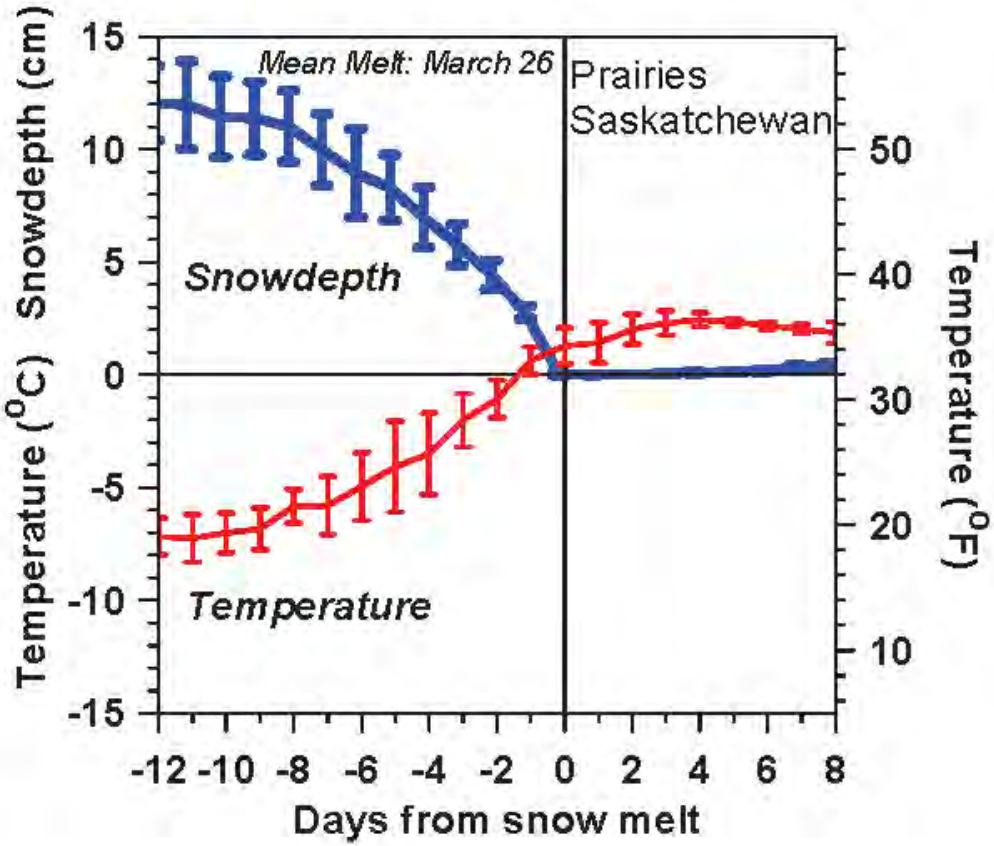




- **Arctic warming rapidly**
  - **Melting fast**
  - ***Much faster than IPCC models***
- **Northeast winters**
  - ***Same positive feedbacks***

Snowfall and Snowmelt

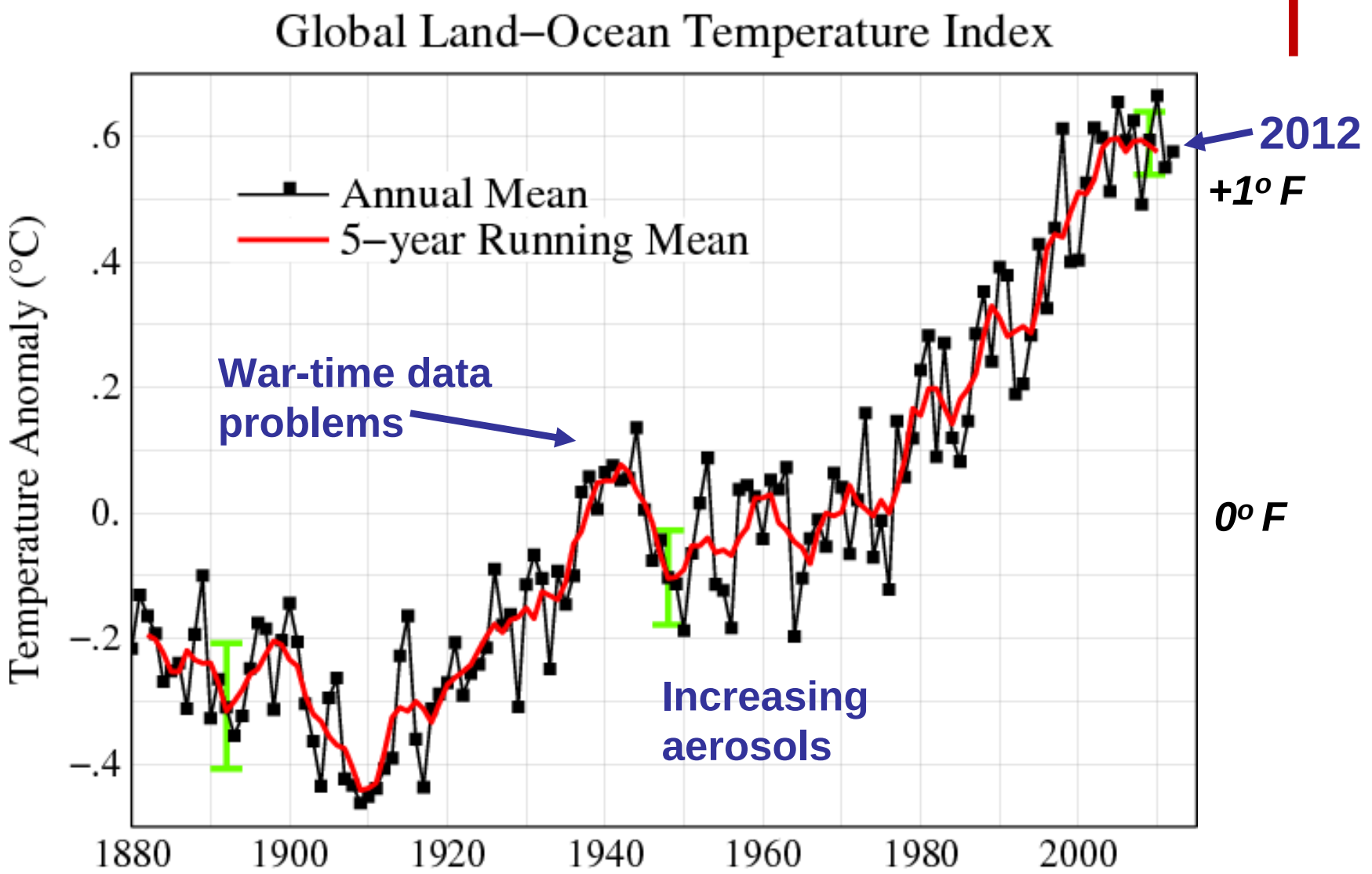




- **Temperature falls 18F (10C) with first snowfall**
- **Similar change with snowmelt**
- ***Snow reflects sunlight; reduces evaporation and water vapor greenhouse – changes 'local climate'***

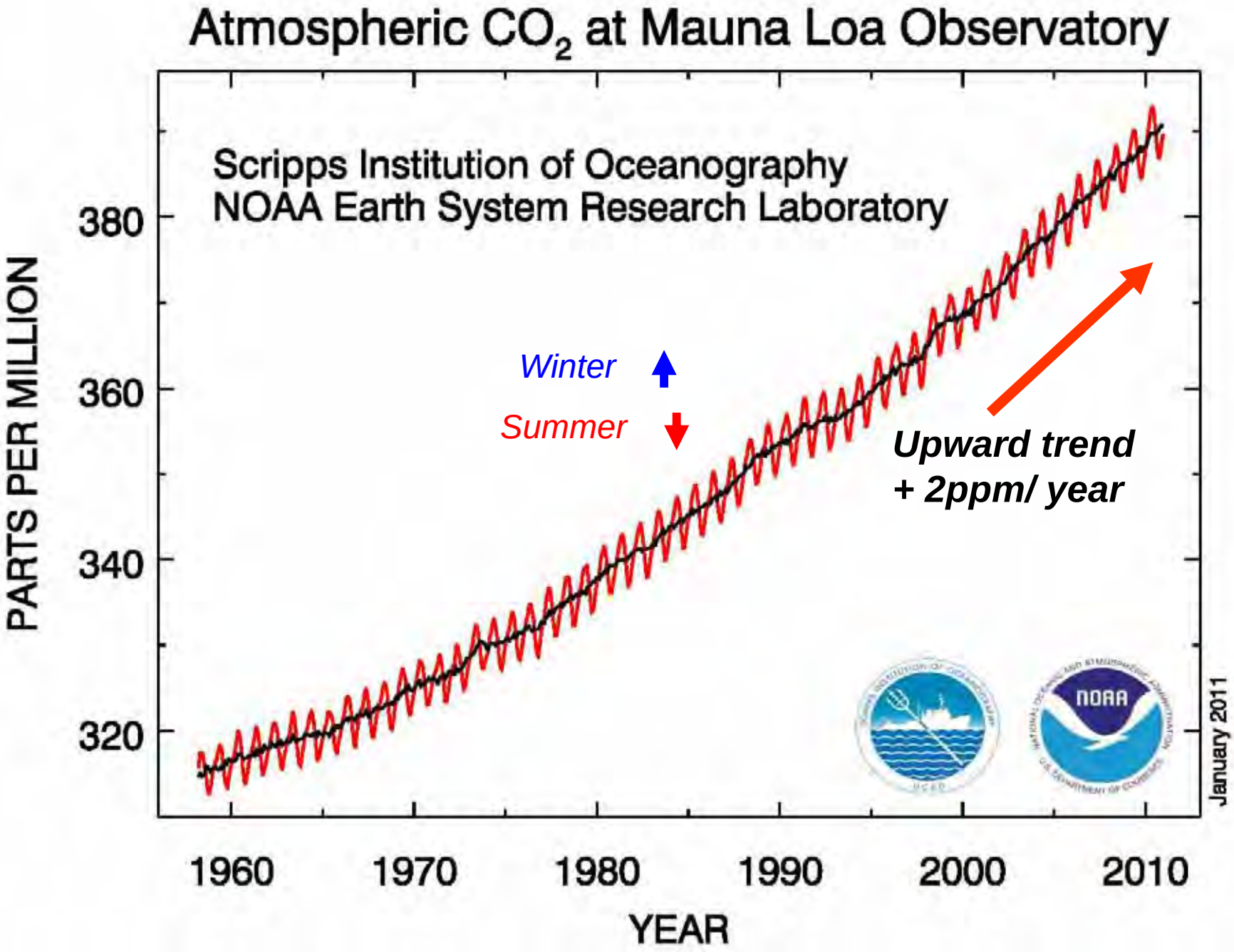
Betts et al. 2014

Global Temperature Rise
1880 – Present



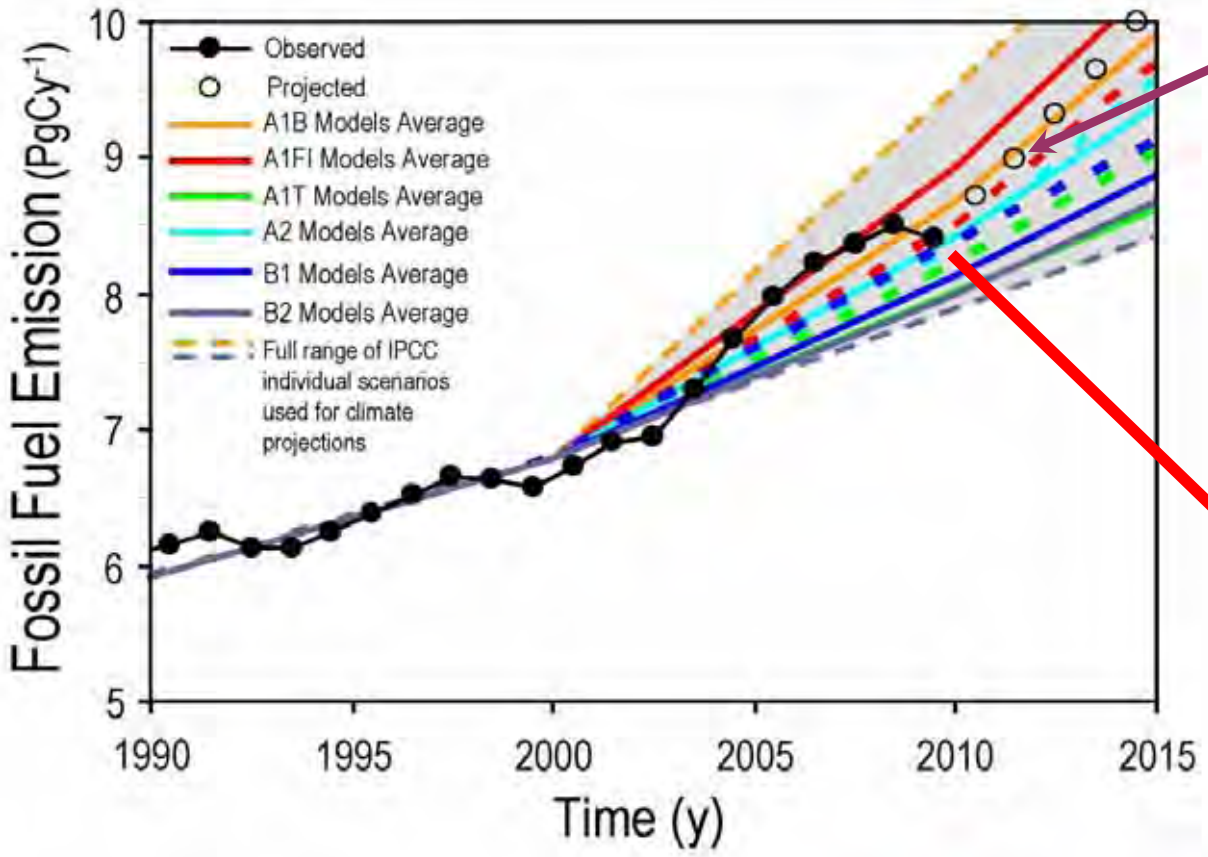
NASA-GISS, 2011

Carbon Dioxide Is Increasing



2009 Was "Good" for the Earth

Fossil Fuel Emissions: Actual vs. IPCC Scenarios



Back on growth: 2010, 2011

Emission Scenarios

- 4%/year

Updated from Raupach et al. 2007, PNAS; Data: Gregg Marland, Thomas Boden-CDIAC 2010; International Monetary Fund 2010

Why Is More Carbon Dioxide in the Air a Problem?

- **The air is transparent to sunlight, which warms the Earth**
- **But some gases in the air trap the Earth's heat , reradiate down, and keep the Earth warm (30^{o}C)**
- **These are "Greenhouse gases"- water vapor, carbon dioxide, ozone, methane (H_2O, CO_2, O_3, CH_4, CFCs..)**
- **CO_2 is rising fast: by itself only a small effect**

But as CO_2 Increases, Strong Water Cycle Feedbacks

- **Earth warms, and evaporation and water vapor in the air increases and this triples the warming**
- **As Earth warms, snow and ice decrease, so less sunlight is reflected, so winters and the Arctic are warming faster**
- **Doubling CO_2 will warm Earth about 5°F**
  - **Much more in the North, over land, in winter**
  - **Climate change we are seeing in Vermont will continue**

Sea-level Rise Will Eventually Flood Coastal Cities

- **Late 20th-century sea-level rise: 1 foot / century**
- **21st century: Likely to triple to 3 - 4 feet / century**
  - **And continue for centuries (accelerating for business as usual)**

- ***http://www.nature.com/news/us-northeast-coast-is-hotspot-for-rising-sea-levels-1.10880***

Changes in Vermont

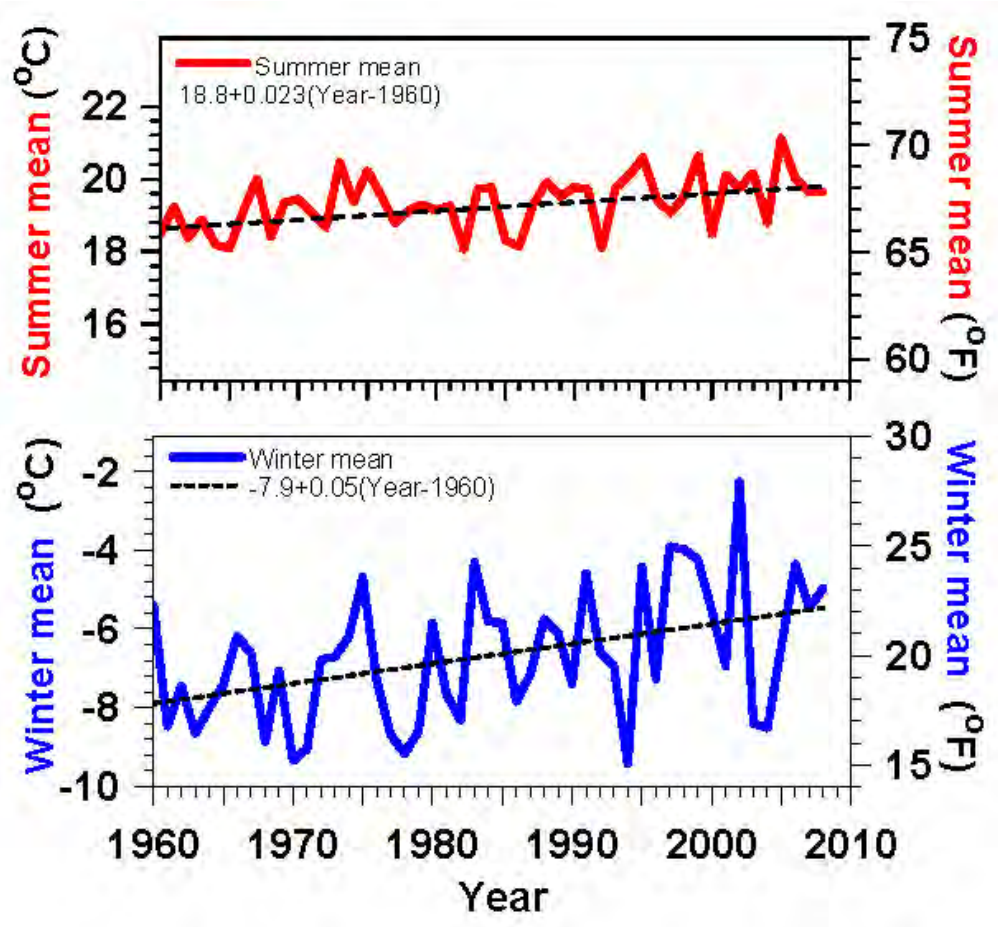
- **PAST 40/50 years** ***(global CO_2 forcing detectible)***
- **Warming twice as fast in winter than summer**
- **Winter minimums increasing even faster**
- **Lakes frozen less by 7 days / decade**
- **Growing season longer by 3-4 days / decade**
- **Spring coming earlier by 2-3 days / decade**

(Betts, 2011)

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

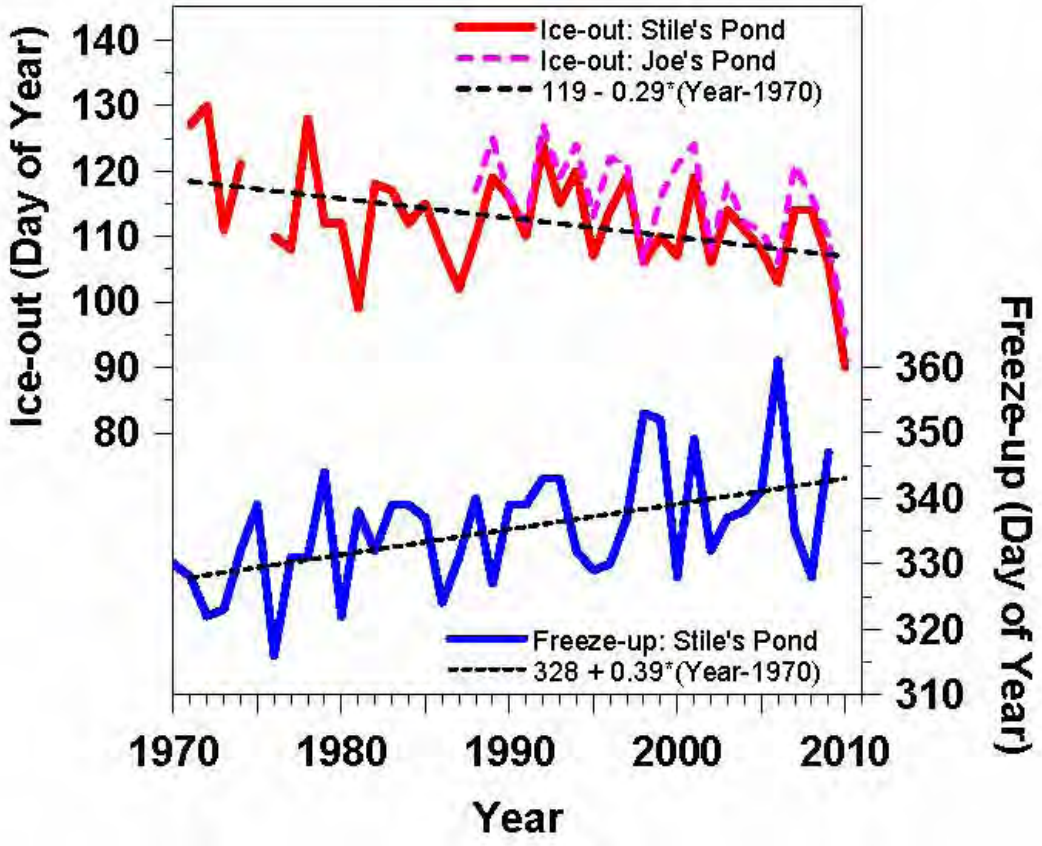
Vermont Temperature Trends
1961-2008

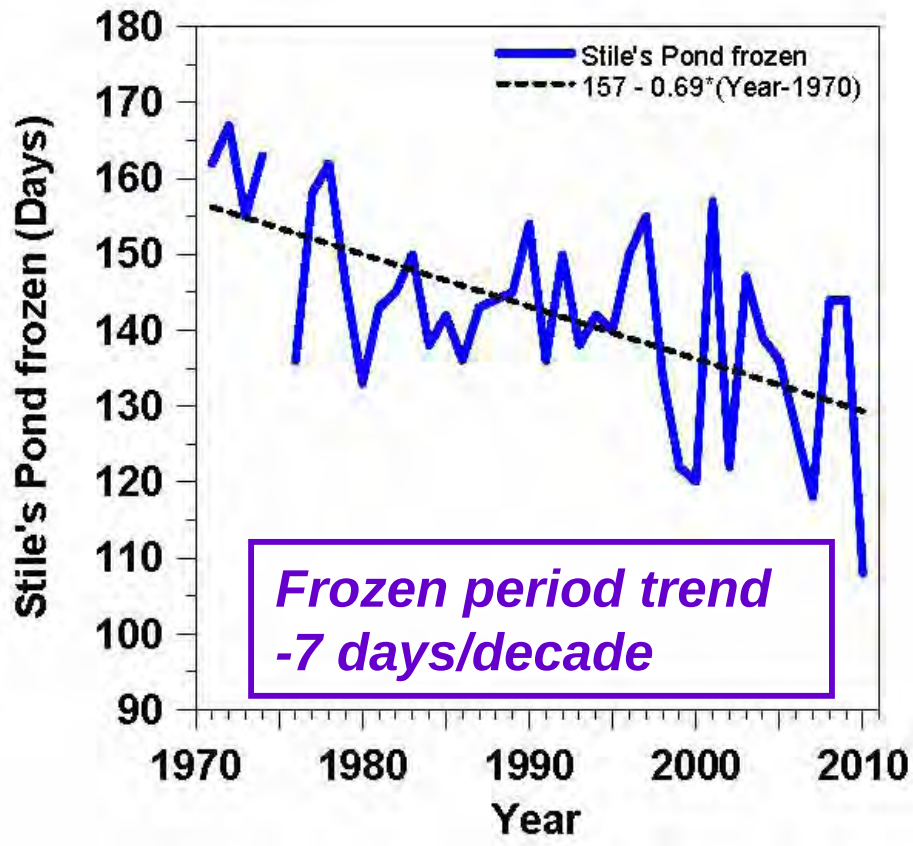
- **Summer +0.4°F / decade**
- **Winter +0.9°F / decade**
- **Larger variability, larger trend**
- ***Less snow (and increased water vapor) drive larger winter warming***



Lake Freeze-up & Ice-out Changing

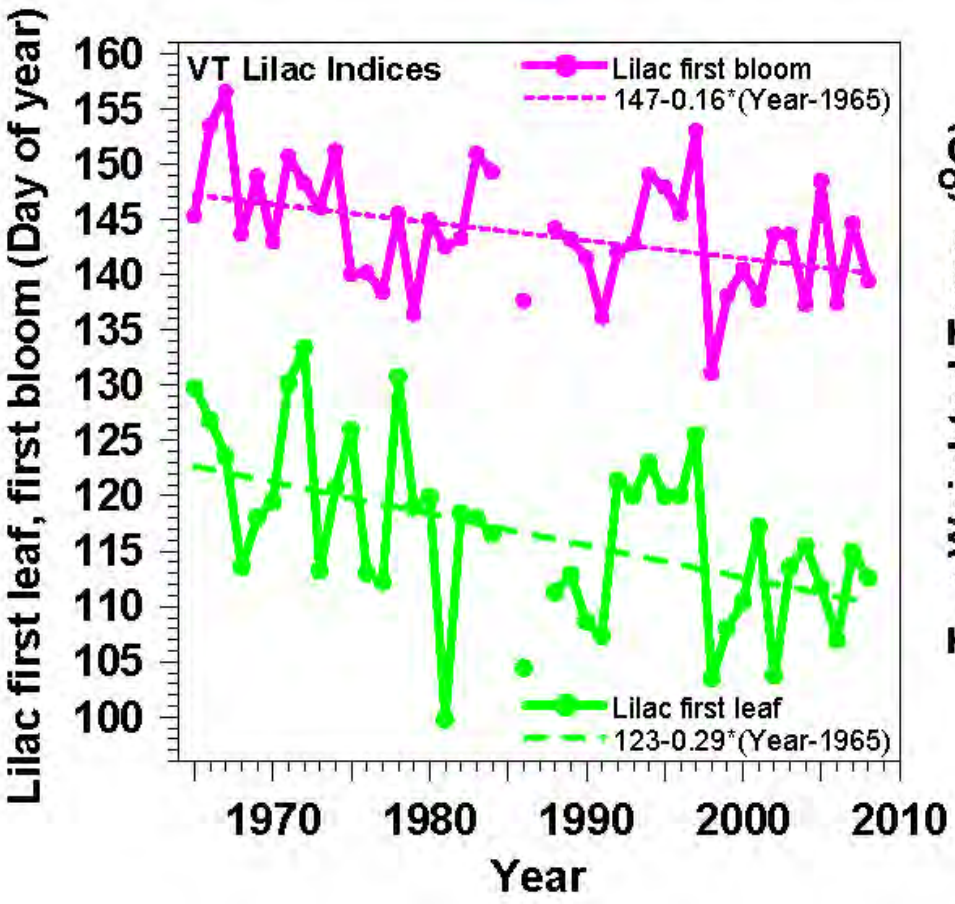
Frozen Period Shrinking Fast

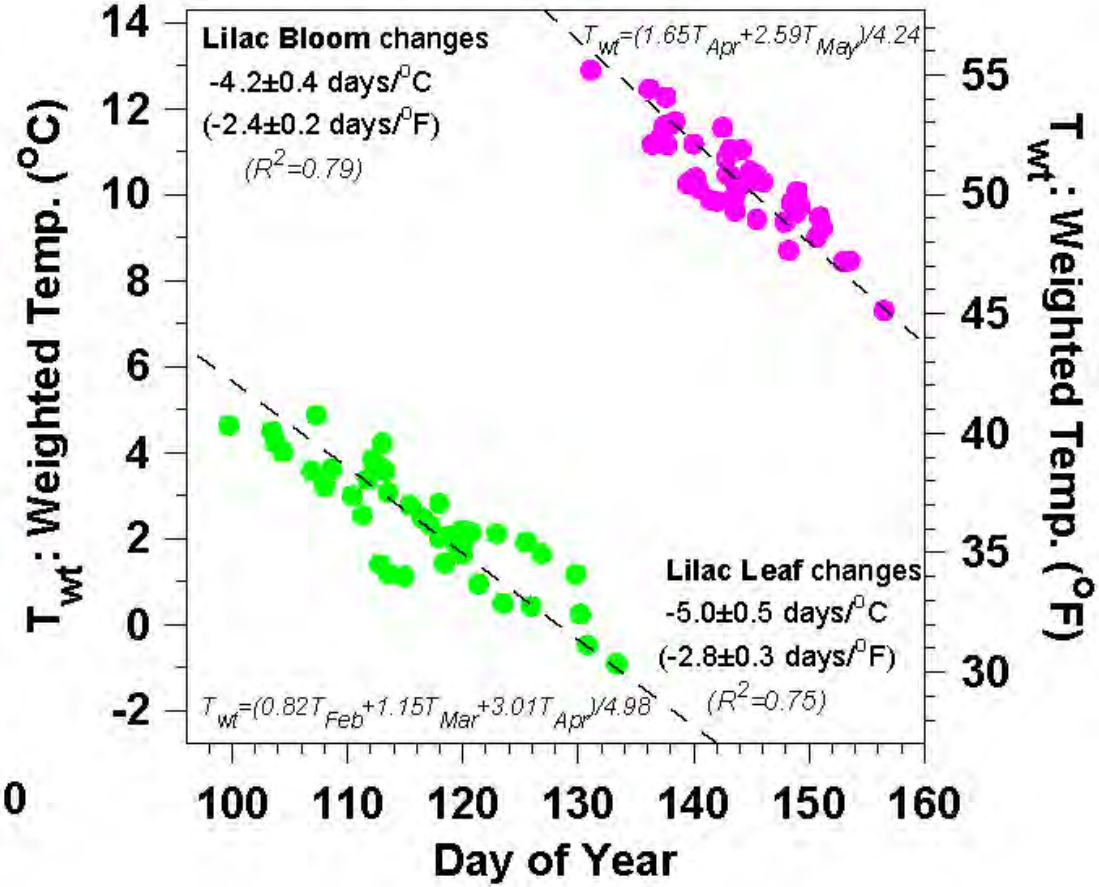




- Ice-out earlier **by 3 days / decade**
- Freeze-up later **by 4 days / decade**

Lilac Leaf and Bloom in Spring





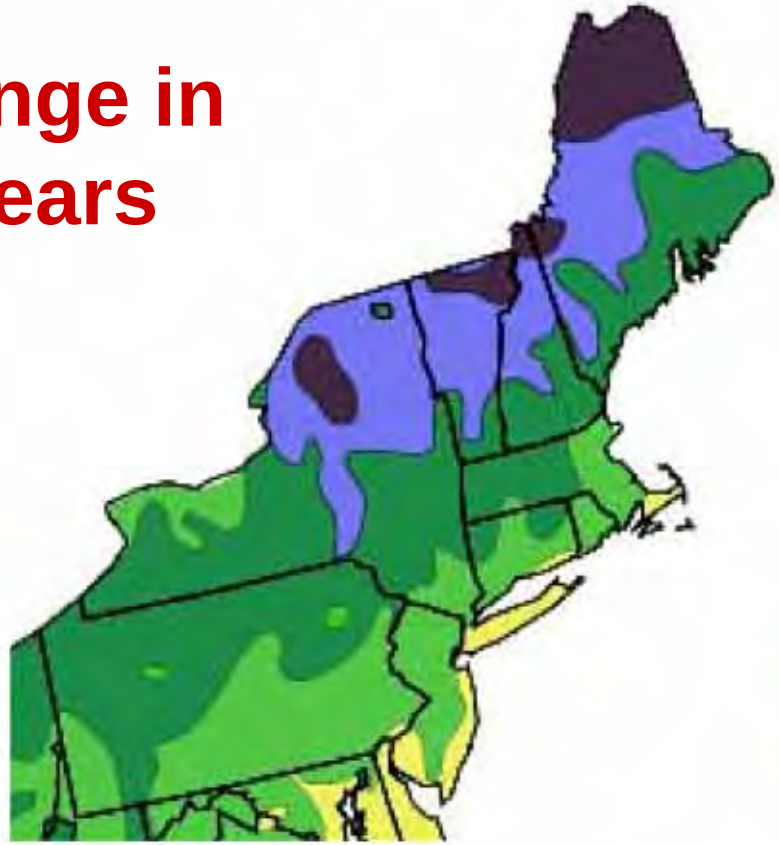
- **Leaf-out earlier by 3 days/decade (tracks ice-out)**
- **Bloom earlier by 1.5 days/decade**
- **Leaf & bloom change 2.5 days/°F (4.5 days/°C)**

Vermont Winter 2006

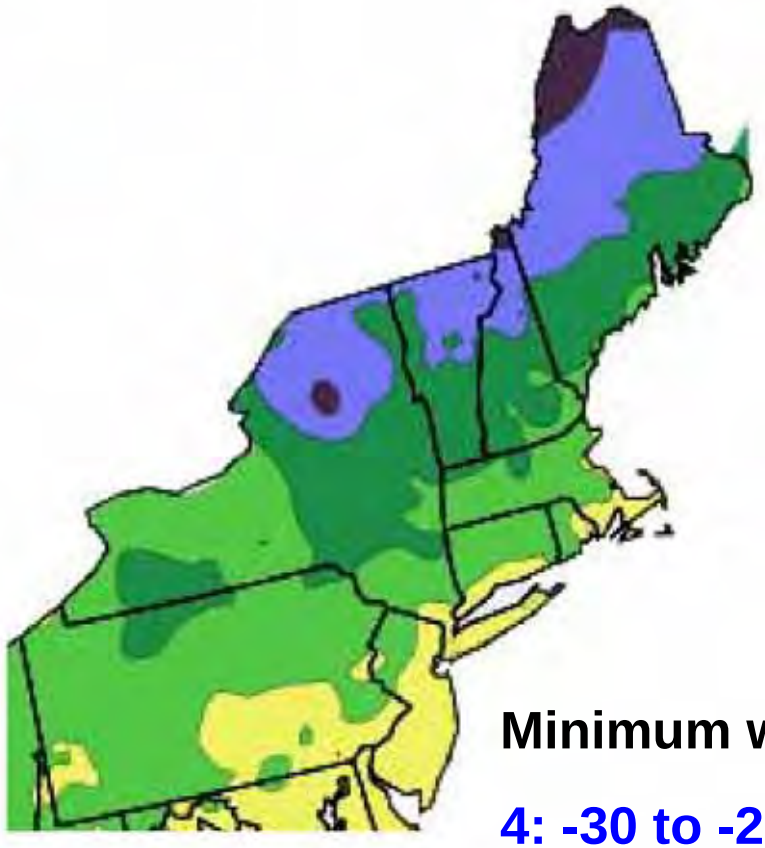
- **Snow reflects sunlight, except where trees shadow**
- **Cold; little evaporation, clear sky; earth cools to space**
- ***2011-12 warm winter, snow melts → positive feedback***
- ***2013-14 more snow and colder***

Winter Hardiness Zones - Northeast

Change in 16 years



1990



2006

Zone

USDA Hardiness Zones

Minimum winter T

4: -30 to -20°F

5: -20 to -10°F

6: -10 to 0°F

Bennington & Brattleboro are becoming zone 6 *(T_{min} > -10F)*

- **Hardy peaches: 2012**
- **More pests survive winter**

- **What is this?**
  - **Oct 1, 2012**

Bennington & Brattleboro are becoming zone 6

- Hardy peaches: 2012
- More pests survive winter

- What is this?
  - Oct 1 2012

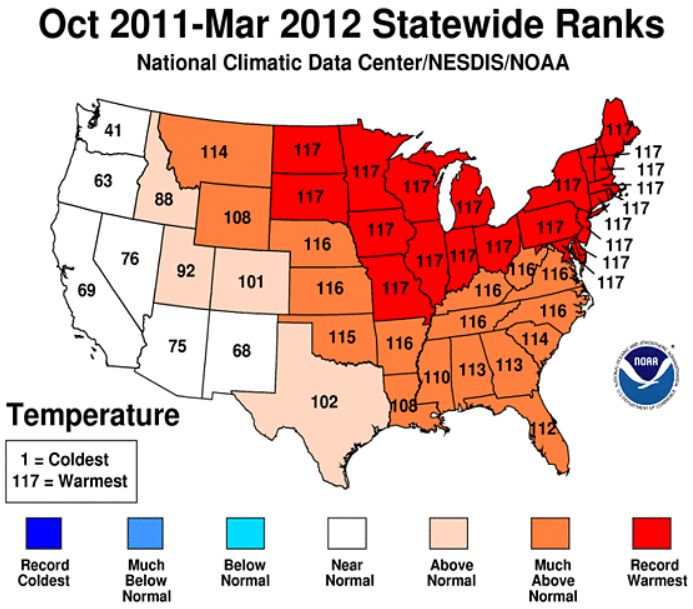
- **Avocado**
  - Didn't survive frost
  - 2100 survive in CT
  - Our forests?

January 2, 2012

March 11, 2012

October 2011– March 2012

- **Warmest 6 months on record**
- **My garden frozen only 67 days**
- **No permanent snow cover west of Green Mntns**
- **Contrast snowy winter 2010-11**



Early Spring: Daffodils, Forsythia

79ºF on March 22, 2012

Pittsford Vermont

3/22/12

Pittsford Vermont

3/24/12

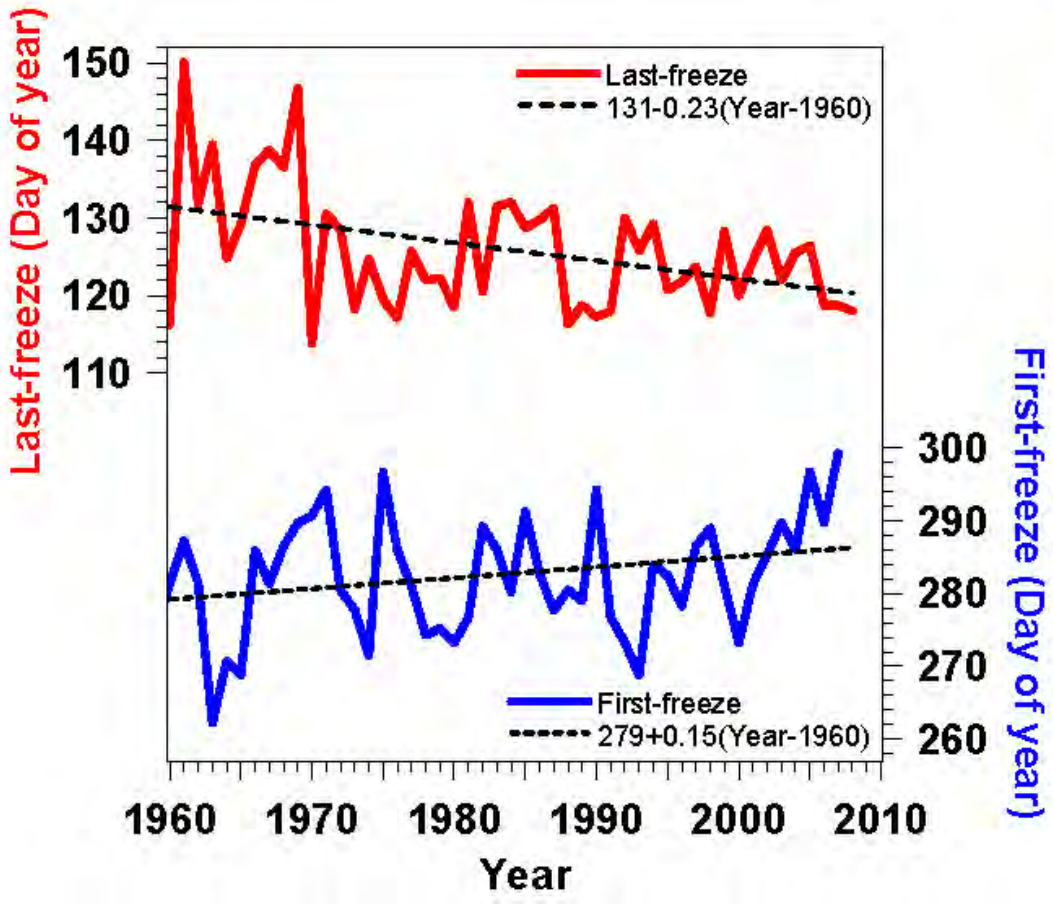
December 21, 2012

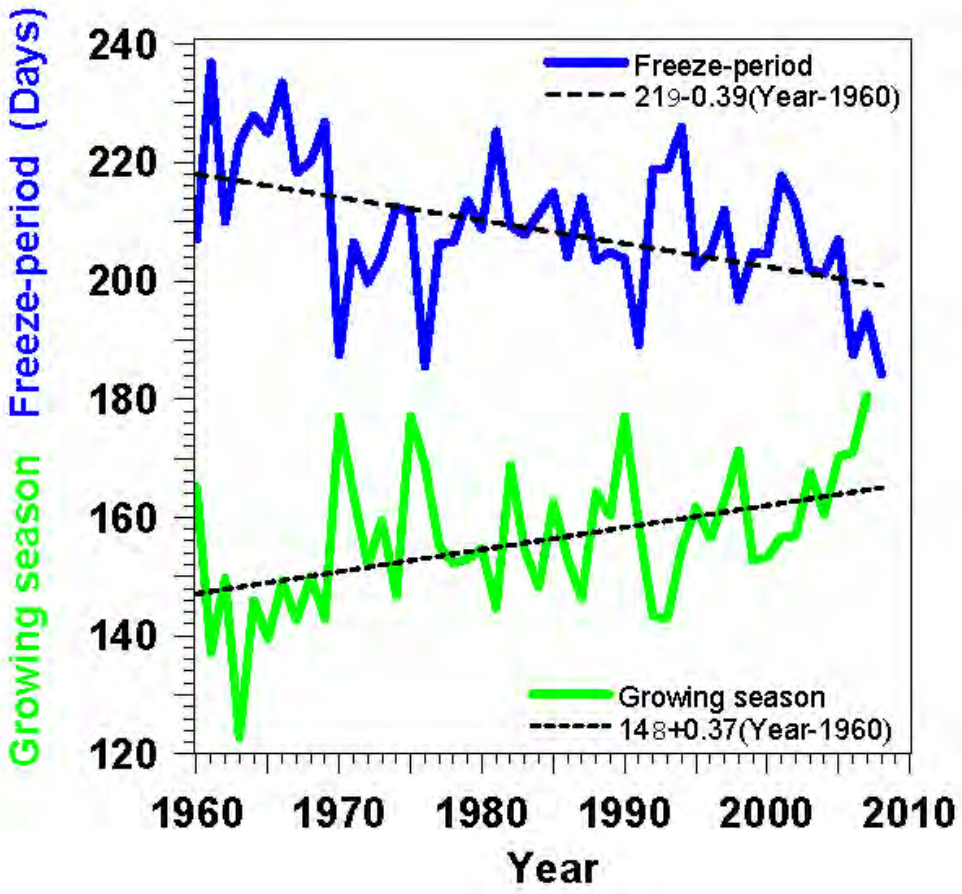
January 15, 2013

Past Winter

- **Dec 25:** Ground froze hard
- **Dec 27-28:** Foot of snow
  - Air temperatures plunged but ground thawed under snow
- **Jan 12-14:** **45-50F:** Snow melted
- **Jan 15:** Time to dig again..
- Followed by freeze-up.. Melt
- **Final Melt - March 11**

First and Last Frosts Changing



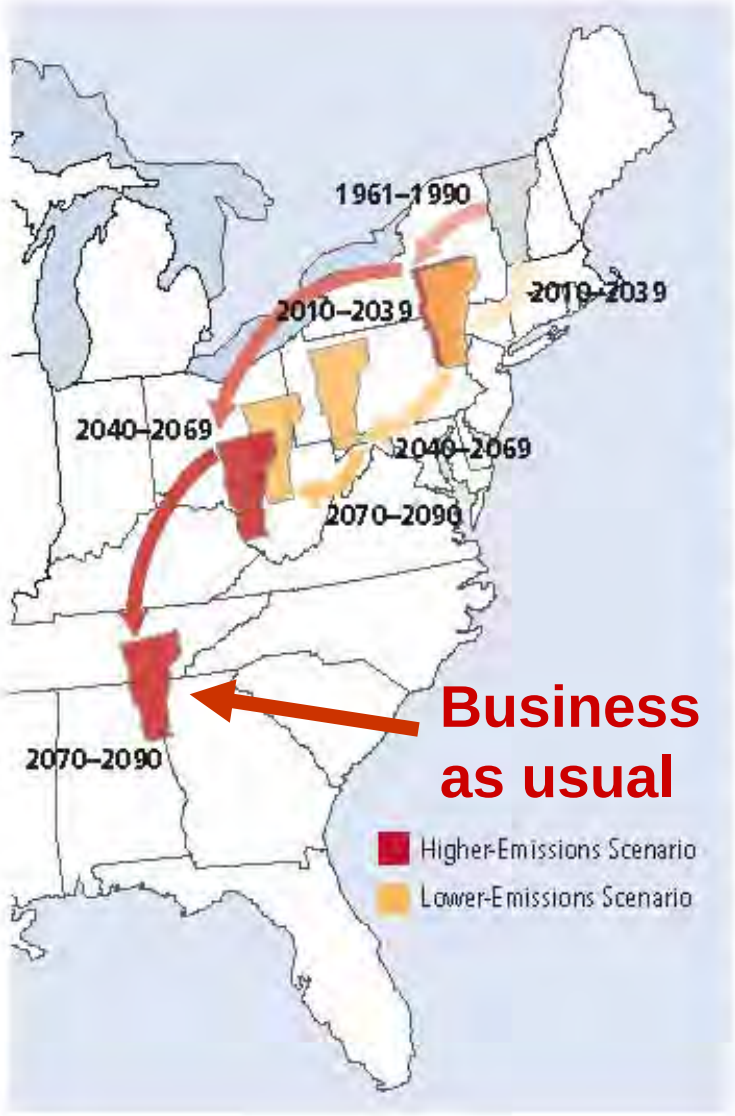


- **Growing season for frost-sensitive plants increasing 3.7 days / decade**
- **A help for growing “local food”**

Vermont's Future with High and Low GHG Emissions

What about skiing?

What about tropics?



Migrating State Climate

Changes in average summer heat index—a measure of how hot it actually feels, given temperature and humidity—could strongly affect quality of life in the future for residents of Vermont. Red arrows track what summers in Vermont could feel like over the course of the century under the higher-emissions scenario. Yellow arrows track what summers in the state could feel like under the lower-emissions scenario.

NECIA, 2007

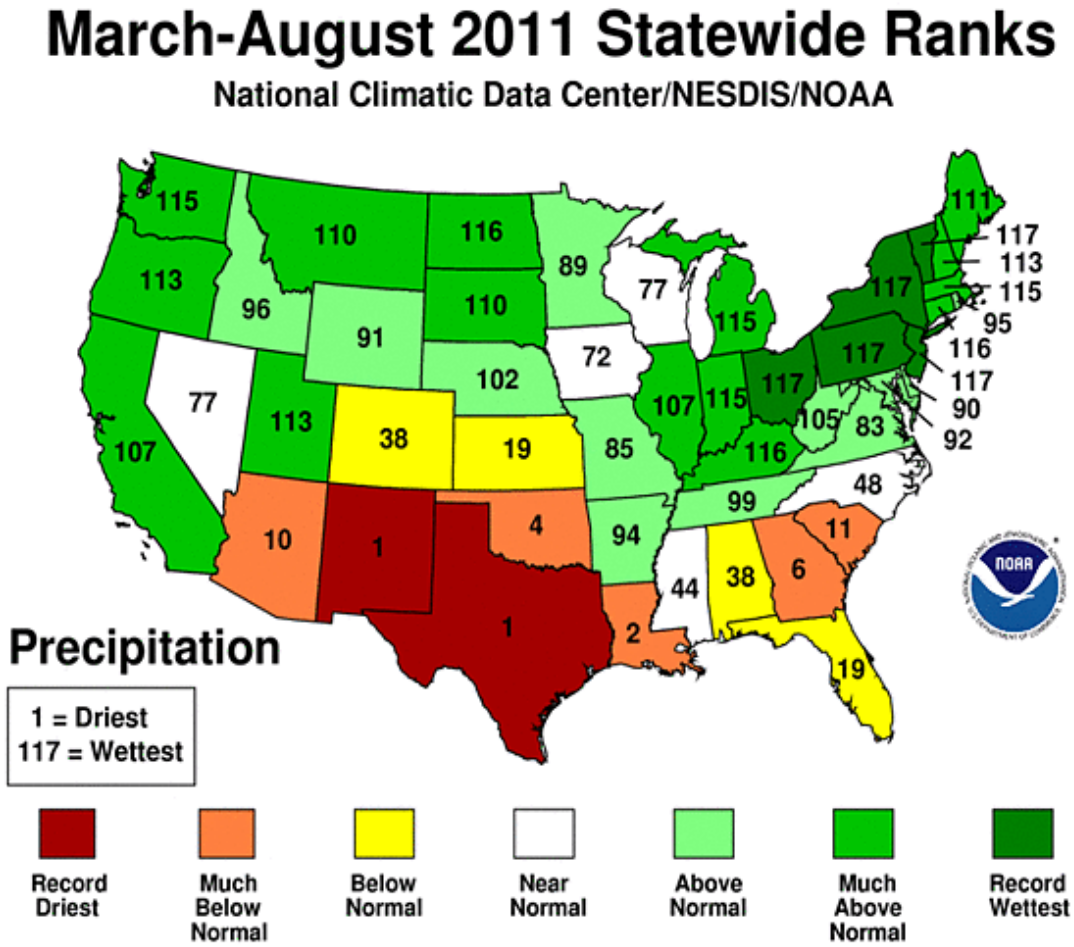
Extreme Weather (precip.)

- **Precip. is condensation of atmospheric water vapor - larger latent heat release drives storms**
- ***Saturation vapor pressure at cloud-base increases steeply with temperature (4%/^{o}F)***

- **Quasi-stationary large-scale flow means longer rain events in low-pressure convergent regions, and longer droughts in high-pressure divergent regions**
- ***As climate changes, quasi-stationary large-scale modes appear to be more frequent***
  - ***Cause may be Arctic warming: needs more study***

2011 Floods: VT and NY

- **Record spring flood: Lake Champlain**
- **Record flood with tropical storm Irene**

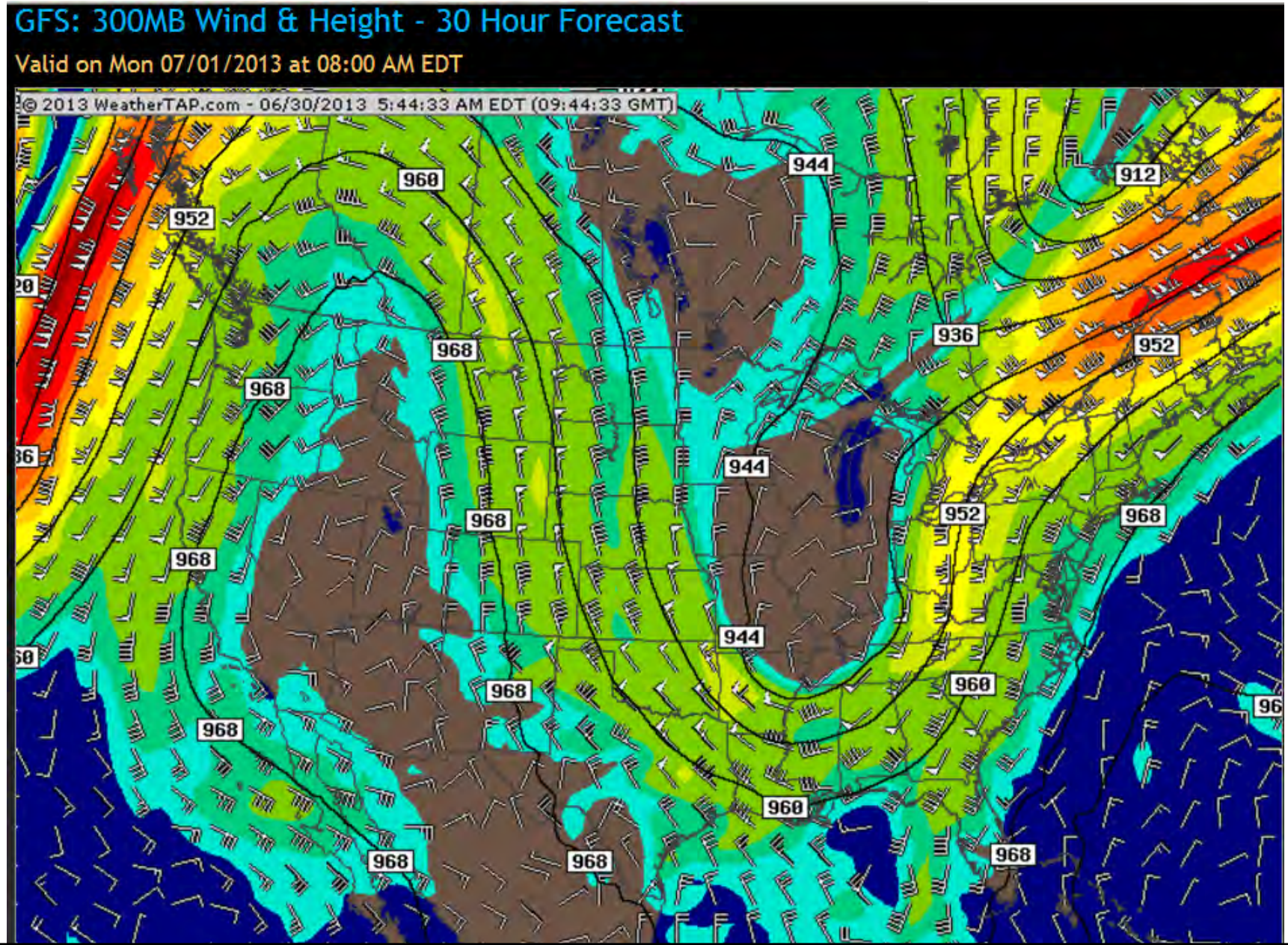


March-August, 2011

- **Record wet : OH to VT**
- **Record drought: TX & NM**
- **'Quasi-stationary' pattern**

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

(Francis and Vavrus, 2012)



Blocking Pattern - Unique track

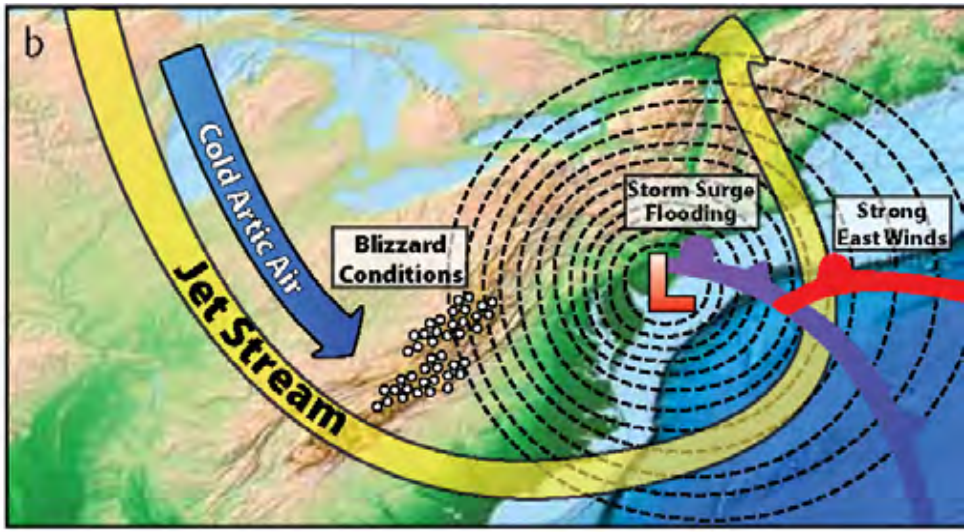


Figure 1. (a) Atmospheric conditions during Hurricane Sandy's transit along the eastern seaboard of the United States, including the invasion of cold Arctic air into the middle latitudes of North America and the high-pressure blocking pattern in the northwest Atlantic. (b) After the convergence of tropical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

What Lies Ahead?

- **Accelerating change, increasing extremes**
- **Increasing adaptation and rebuilding costs**
- **Environmental damage that will transform or destroy ecosystems- locally and globally**
- **Freely dumping waste streams from society into atmosphere, streams, lakes and oceans is unsustainable – long term costs now exceed $1000 trillion**
- ***Will need fossil carbon tax (a "waste" tax) to incentivize mitigation and pay for the long-term adaptation and health costs***

Discussion

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Climate Change: a Question of Attitude

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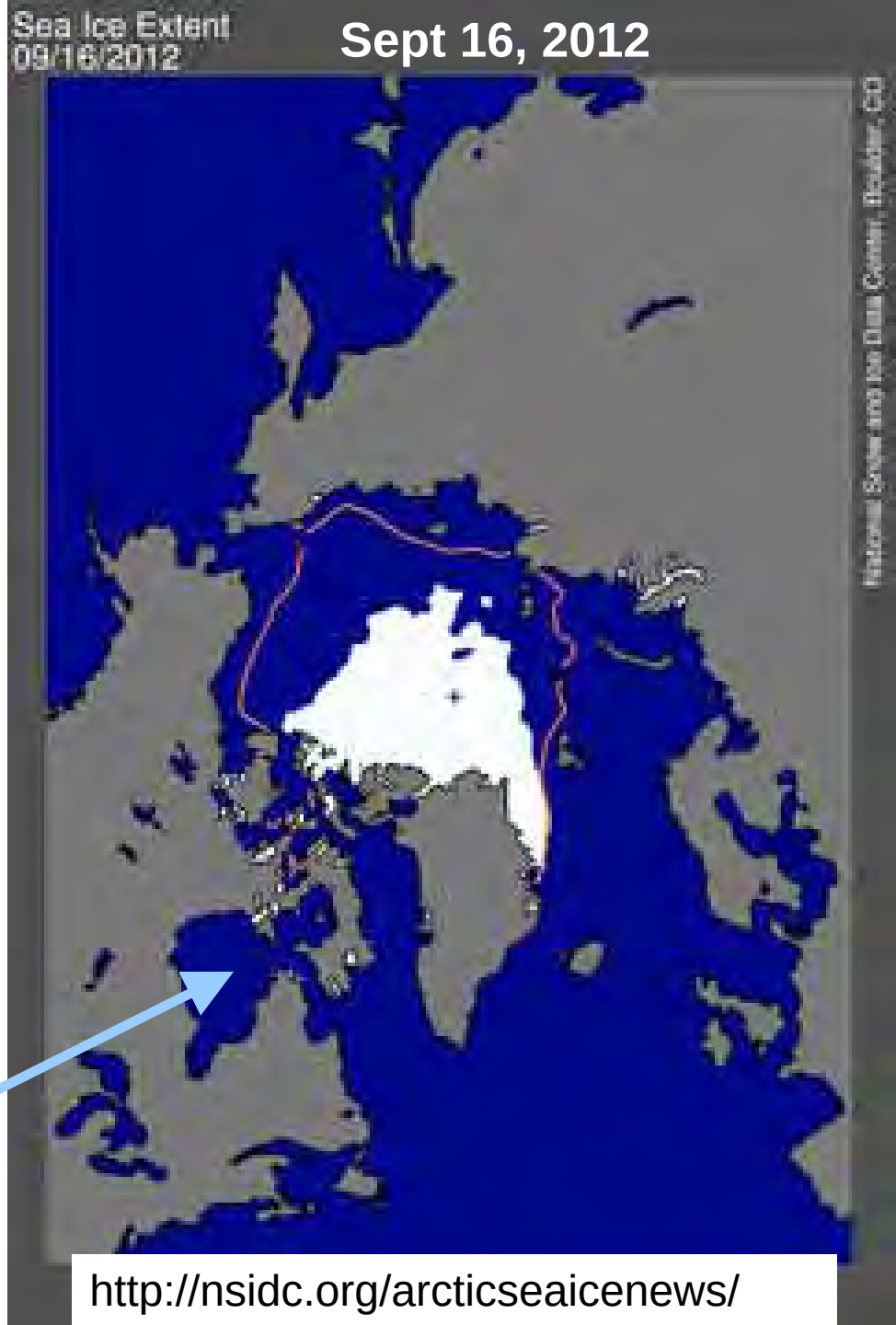

http://nsidc.org/arcticseaicenews/

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Our Present Challenge

- **How to reintegrate**
  all that we know and understand

  – *given the deep interconnectedness*
  of life & climate on Earth

Can We Stop "Dangerous Climate Change"?

(UNFCCC 1992)

- **Yes: Quickly stabilize atmospheric CO_2**
- **This means an 80% drop in CO_2 emissions!**
- **This is very difficult**
  - **Fossil fuels have driven our industrial growth and population growth for 200 years**
  - **Our "lifestyle" has become dependent on fossil fuels**

Managing Our Relation to the Earth System

- **Our technology and our waste-streams are having large local and global impacts on the natural world and must be carefully managed — *because we are dependent on the natural ecosystems***

How Do We Manage the Earth?
(When there is so much we don't know)

- **Need a long time horizon:**
  - **Generational to century *(Forest timescale)***
- **We need some new rules / guidelines**
  - **Our numbers are so great**
  - **Our industrial impact is too large**
  - **Maximizing profit as a guiding rule has failed us**
- **Re-localize to regain control / responsibility and minimize transport**

A Path Towards ‘Sustainability’

- ***Necessary to:***
- **Minimize the lifetime of human waste products in the Earth system and eliminate waste with critical biosphere interactions**
- **Maximize recycling and re-manufacturing to minimize waste-streams and the use of non-renewable raw materials**
- **Maximize the efficiency with which our society uses energy (and fresh water)**
- **Maximize the use of renewable resources**

Examples of Long-Lived ‘Waste’

- **CFCs – refrigerants – very stable – lifetime centuries - broken down by sunlight in stratosphere – catalyze ozone destruction, which protects earth from UV**
- **CO_2 from fossil fuels – lifetime centuries – a greenhouse gas that traps earth’s heat radiation – pushing earth to warmer climate**
- **Nuclear waste – plutonium-239: half-life 24000 years – nuclear weapons**

Efficiency Comes First

- **We need to double or triple our energy efficiency because…**
  - **We cannot replace current fossil fuel use with biofuels & renewable energy**
  - **Oil and gas reserves are limited, but coal & oil shale reserves are sufficient to push CO_2 to 1,000 ppm—and in time melt icecaps**
    - **Can we "sequester" CO_2 (put it back in the earth)?**

Why Is It Difficult for Us?

- **The "American dream" is crumbling**
  - **"Economic growth" based on fossil fuels, debt, and consumerism is unsustainable — and a disaster for the planet!**
- **Individual "rights" and the needs of humanity must be balanced against the needs of the earth's ecosystem**
- **We don't know how to guide and manage technology —so the result is tremendous successes and catastrophic failures**

Why Is It Difficult for Us?

- **Fossil fuels reserves are worth $20-30T**
  - **Regulating emissions of CO_2 is an "unfair cost" to the "free market"**
- **Politics lost in fantasy**
  - **Ignoring Earth system and climate issues**
  - **Ignoring future costs**
    - **Manhattan within 1-ft of flooding with Irene**
    - **Did they put waterproof doors on tunnels? No**

Surely Technology Can Save Us?

- **Critical for transition but real issue is**

- **Our world of technology is having a global impact on the natural world, which is alive, complex and beyond our 'control'**
- **So technology must be carefully managed — particularly our waste-streams — because we are dependent on the natural world**
  - **But this is challenging with our ideology**

Technology can be Useful

Trucks or lightweight Trikes!

30 mph Danish electric tricycle:

with 150 mile range

- **Strengths of science:**

  - integrity, honesty and communication

  - *particularly valuable in a society lost in ignorance and deceit*

- **Limits of science:**

  - tangible, measurable and communicable

  - *hard to deal with the complexity and interconnectedness of the living natural world*

What Do We Need?

- **So we need honest, truthful, smart pathways forward**
  - **That will not frighten people into paralysis**
  - **That will spread hope, not anger or despair**
  - **That sidestep ideological barriers with new language**
  - **That develop adaptive governance**
    - **The US Constitution gives no rights to the Earth**
  - **That respect Earth system processes & limits**

The Future Is Not Our Past

- **Collectively, we create the future, so we need to plan for a transition to a sustainable society**
- **Face the future with an attitude of**

“Bold Humility”

(Frances Moore Lappé: RAFFL, Rutland, 2007)

- **Efficient society with renewable technologies**
- **Balance community solutions and government interventions**
- **Ask**
  - **Is this an efficient and sustainable way of doing this?**
  - **Do I have a deep understanding and connection to Earth?**

Community-Transition

- **The transition to a sustainable society will take decades and a community effort**
  - **www.transitionnetwork.org**

- **Food: local agriculture & gardens**
- **Energy: Double energy efficiency ….**
  - home heating – district heating + cogen
  - renewable electricity mix
  - efficient transportation system
  - careful forest management
- **Finance: relocalization in real world**

We have the technical knowledge but not the right attitude!

- ***You all know the importance of 'attitude'!***

- ***The Future is not our Past***
  - **We have to create the future**
  - **Older generation is lost in the past; and afraid to face change**
  - **You are not as tied to the past**
  - **Learn from the past and ask what we can do better – together as a community**

  - **OK: easy to say – but what if you don't know what to do!**

Attitude!

- **Where do you start?**
- **First: *hope is essential***
  - **Why? It opens doors, it connects you to others and to the natural world.**
  - **Hope is not an optimistic assessment of what could happen: it is an *attitude* that opens doors to the world, to each other and to your own creativity**
  - ***[despair closes doors]***

Attitude!

- ***Even when you don't know what to do, sometimes you have to make choices***
  - **Usually you know what is foolish.**
  - **Often you don't know what is best**
  - **Don't feel paralyzed: make a choice.**
  - ***Choice aligns you, your will and everything changes***
  - **Develops your ability to respond; your sense of commitment to yourself and others**
  - *[If you make a bad choice, change direction at once: you are free to do this]*

Attitude!

- ***Patience and stillness***
  - **Sometimes you have to go into the woods and sit down with the earth in the stillness**
  - **Open yourself to the wider world beyond your limited experience and still narrow world view**
  - **Yes, this takes patience**
  - **You think you know everything, but sometime in the next 10 years you will realize that though you have learnt so much - what you don't know, what is still waiting to be discovered is immeasurably greater**
  - **That is comforting – you may think you are stuck, but tap into a wider world and things will change in amazing ways**

Attitude!

- ***Community***
  - **You did not create the Earth's problems**
  - **You cannot solve them by yourself**
  - **You need a supportive community**
  - **Not just a community of your peers, but the older and sometimes wiser as well**
  - ***Listen to all voices*** **– we have to create a new world – and we are all part of this**

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Can’t Avoid the Big Issues!

- **Regulation is good – Reagan, G.H. Bush and Riley (EPA) pushed through the Montreal Protocol and the Clean Air Act Amendments over business opposition**
  - **saved the Earth from an ozone catastrophe**
- **Technology must be managed to minimize human impacts on the Earth**
- **Impacts have to be <u>fully</u> costed**
- **People need a vote, so they need to be informed**

Simple Suggestions

- **Reeducation of society and its 'systems'**
  - **The transition we face is huge**
  - **What will raise awareness/change paradigm?**
  - **Reduce human stress…**
- **Examine food system waste-streams**
  - **Compost all organic waste**
  - **Aim to recycle everything**
  - **Limit phosphorus loads on streams/lakes**
  - **Fresh water not critical in VT, but is elsewhere**
- **Reconnect with natural world**
  - **Fundamental if we are to accept transition**
  - **Grow food inside in winter?**

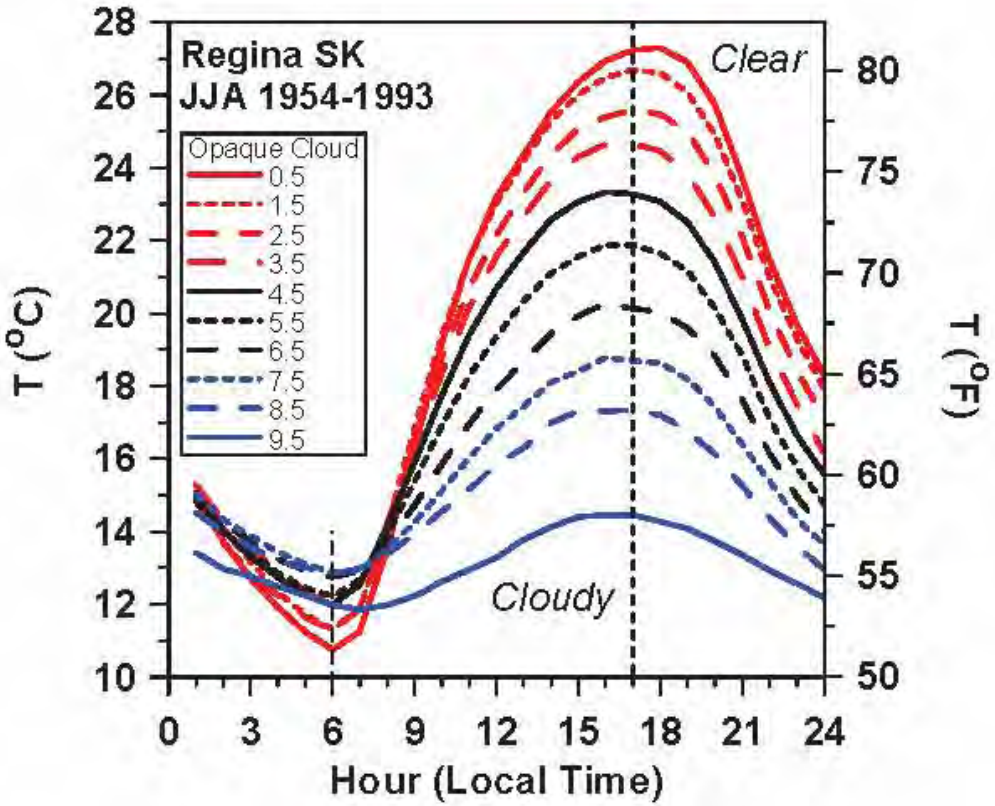
What are Key Issues in Vermont for Sustainability and Resilience?

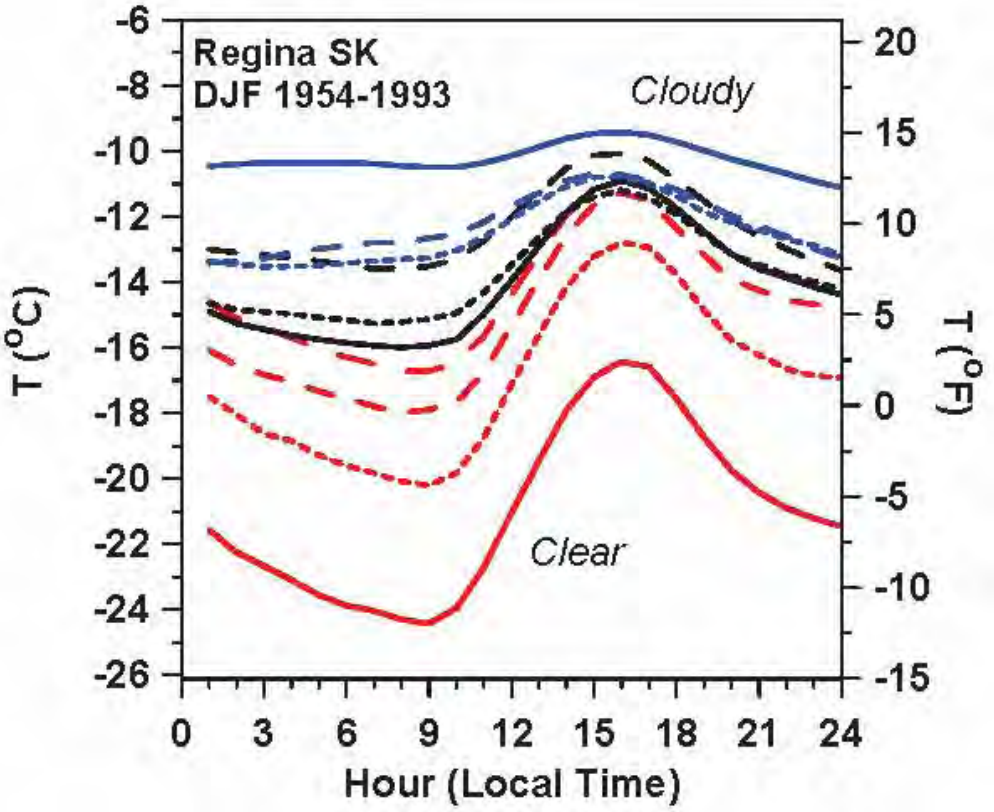
- **Energy efficient housing**
  - **Passive solar, net-zero, (geothermal)**
  - **Efficient lights, appliances**
  - **End-to-end recycling/remanufacturing**
- **Landscape management of water and waste-streams**
  - **Flood/drought extremes, runoff**
- **Community gardens and composting**
  - **Local food and waste management**
- **Renewable energy supplies/microgrids**
- **Efficient transportation/transit**

2011 Classic Flood Situations

- **Spring flood: heavy rain and warm weather, melting large snowpack from 2010 winter**
  - **70F (4/11) and 80F(5/27) + heavy rain**
  - **record April, May rainfall: 3X at BTV**
  - **Severe floods on Winooski and Adirondack rivers**
  - **Lake Champlain record flood stage of 103ft**
- **Irene flood: tropical storm moved up east of Green Mountains and Catskills**
  - **dumped 6-8 ins rain on wet soils**
  - **Extreme flooding**
  - **(Floyd on 9/17/1999 had similar rain - but with dry soils there was less flooding)**

Clouds: Summer & Winter Climate





- **Summer:** **Clouds reflect sunlight (soil absorbs sun)**
  - **no cloud, hot days; only slightly cooler at night**
- **Winter:** **Clouds are greenhouse (snow reflects sun)**
  - **clear & dry sky, cold days and very cold nights**

Betts et al. 2013

Spring Climate Transition

- **Before leaf-out**

Little evaporation → **Dry atmosphere, low humidity**
→ **Low water vapor greenhouse**
→ **Large cooling at night**
→ **Large diurnal temp. range**
giving warm days, cool nights and frost

- **After leaf-out**

Large evaporation → **Wet atmosphere, low cloudbase**
→ **Small cooling at night**
→ **Reduced maximum temperature**
→ **Reduced chance of frost**

- ***Spring is coming earlier***

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