How will Climate Change Affect Vermont?

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January 23, 2017

Outline of this talk

- Fundamentals
- Research on “winter”
- What is happening to
  - Global climate
  - Climate of Vermont
- Broader issues
  - Strategies, Responsibilities
  - Issues beyond science

Fundamentals

- ***Burning fossil fuels: transforming climate***
  - ***Many water cycle amplifying feedbacks***
  - ***Heading for high CO_2 "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**
  - **Solutions incompatible with exploitative model**

System Issues

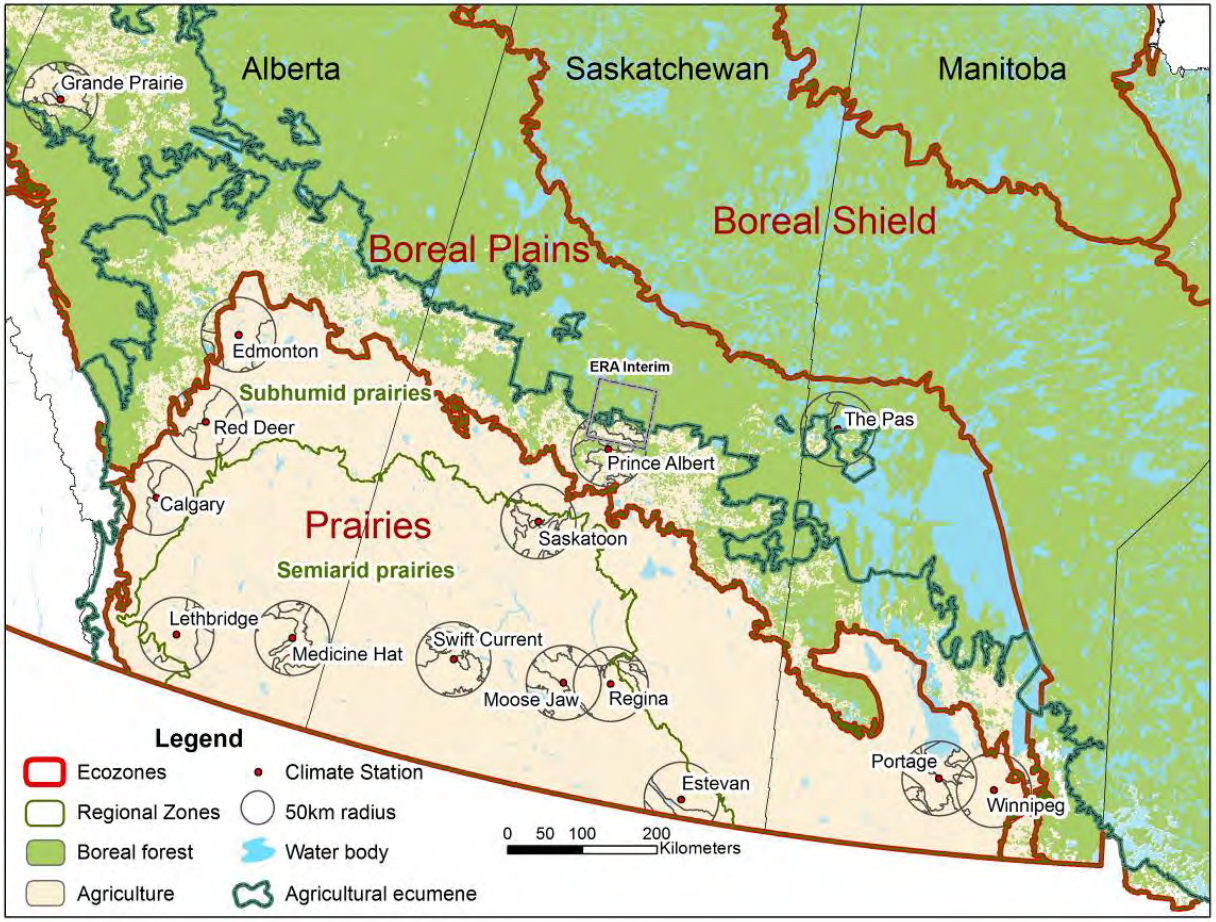
- **Human waste streams are transforming the Earth's climate, and human and natural ecosystems**
- **How will this affect landscape, water supplies, food system and human health?**
- **What strategies and mindset are needed to mitigate, adapt and build resilience in Vermont?**
  - **Can we better manage our relation to the Earth?**
  - **Is this an efficient way of doing this?**
  - **Can we manage our waste streams better?**
  - **How can we adapt?**

Our Present Challenge

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

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

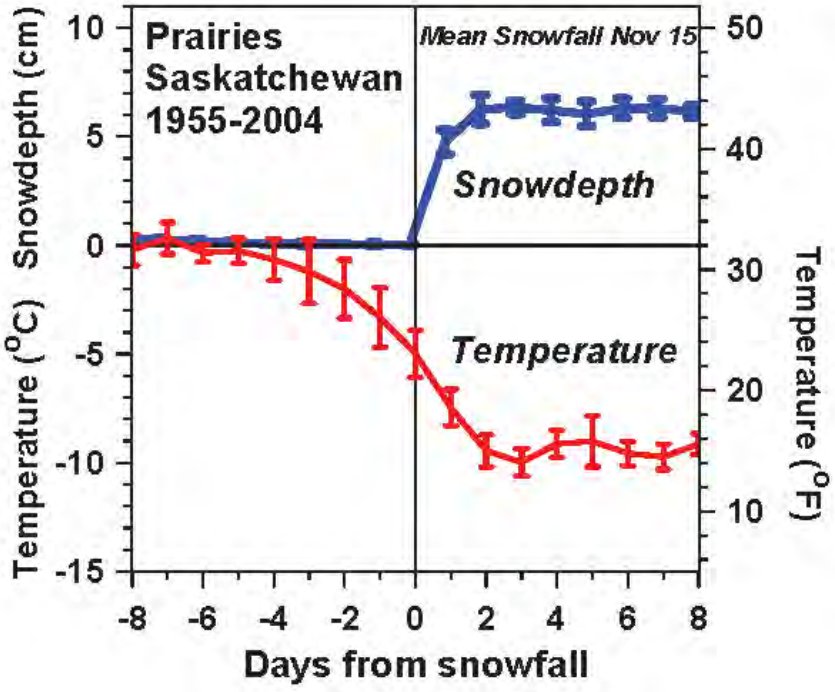
15 Prairie stations: 1953-2011

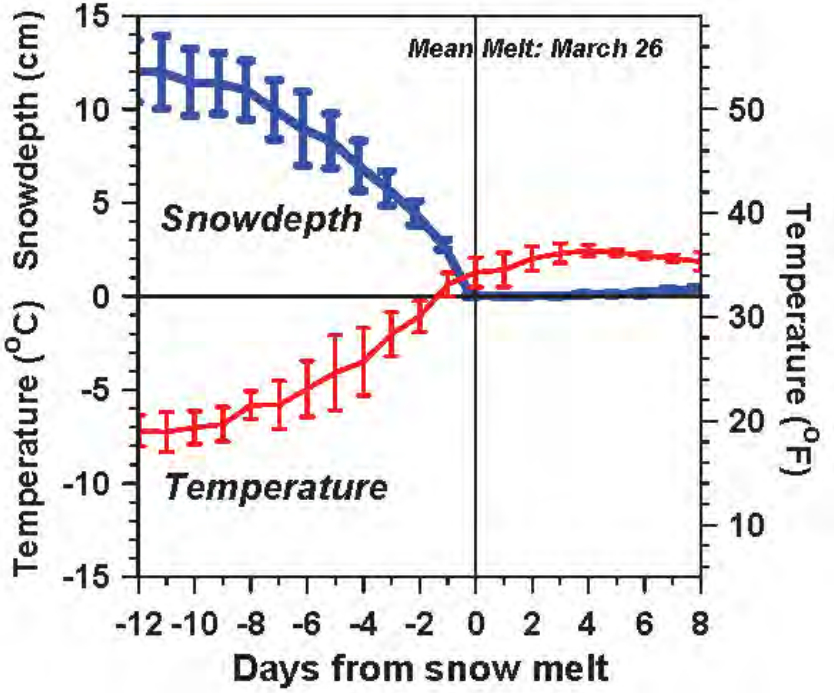


- ***Hourly*** **p, T, RH, WS, WD, Opaque Cloud (SW_{dn}, LW_{dn})**
- ***Daily*** **precipitation and snowdepth**
- **Ecodistrict crop data since 1955**
- **Albedo data since 2000**

Snowfall and Snowmelt

Winter and Spring transitions

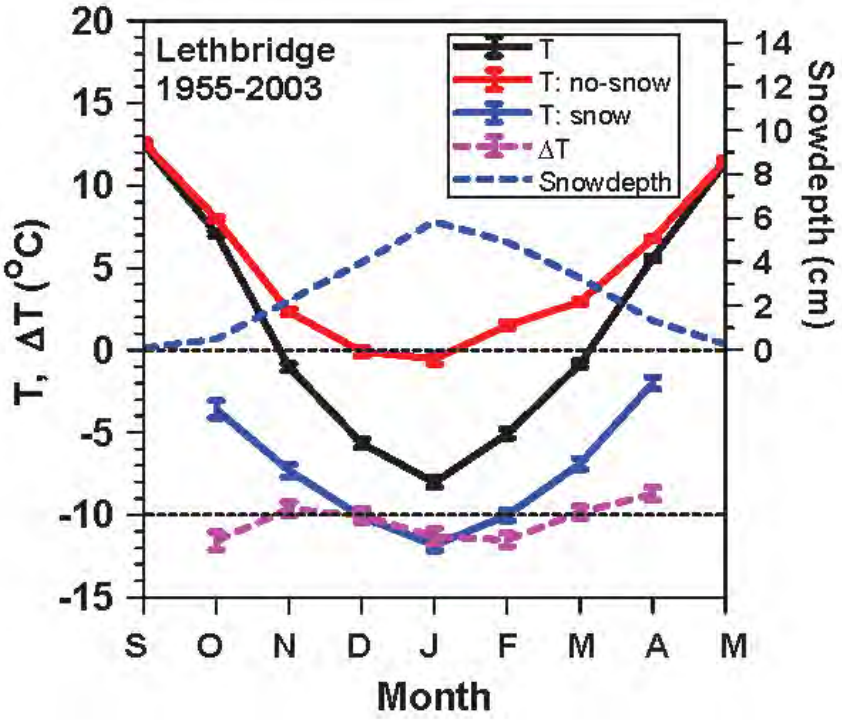


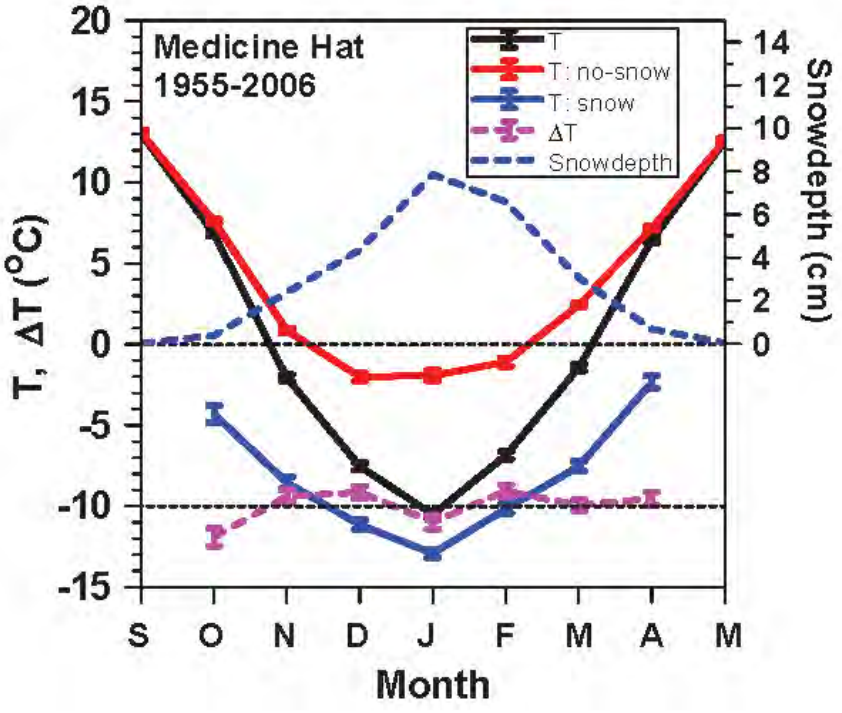


- **Temperature falls/rises about 10K with first snowfall/snowmelt**
- ***Snow reflects sunlight; shift to cold stable BL***
  - ***Local climate switch between warm and cold seasons***
  - ***Winter comes fast with snow***

(Betts et al. 2014a)

Impact of Snow on Climate





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

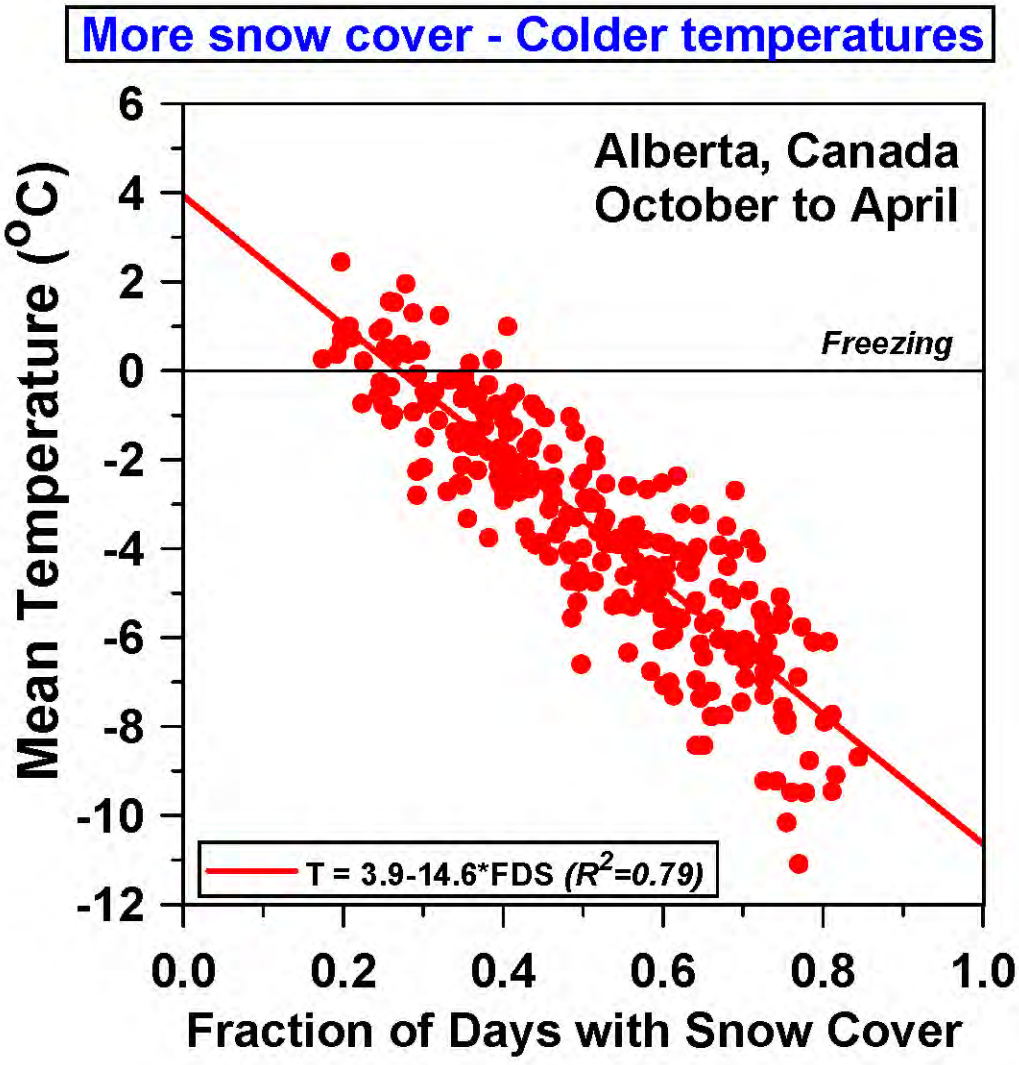
ΔT = T:no-snow –T:snow = -10.2(±1.1)°C

Betts et al. (2016)

Interannual variability of T coupled to Snow Cover

- Alberta: 79% of variance
- Slope T_m -14.7 (± 0.6) K

10% fewer days with snow cover = 1.5°C (2.6F) warmer on Prairies



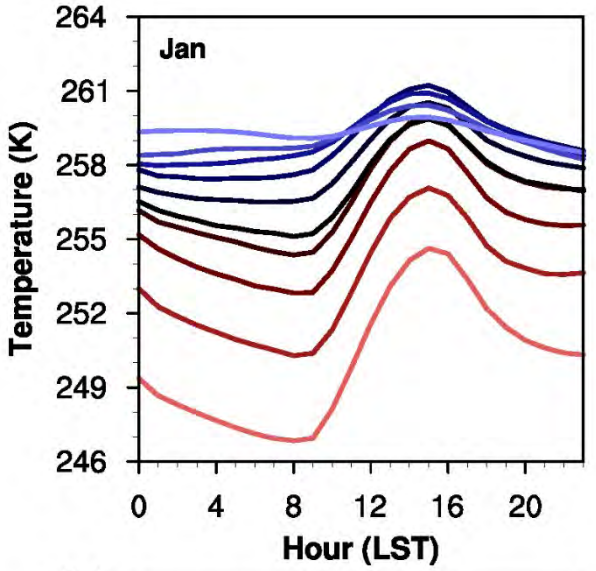
Diurnal cycle: Clouds & Snow

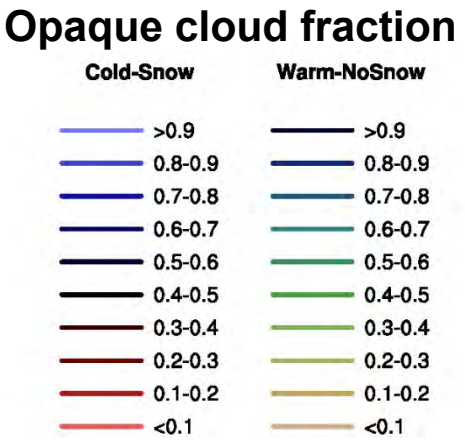
Canadian Prairies
660 station-years of data

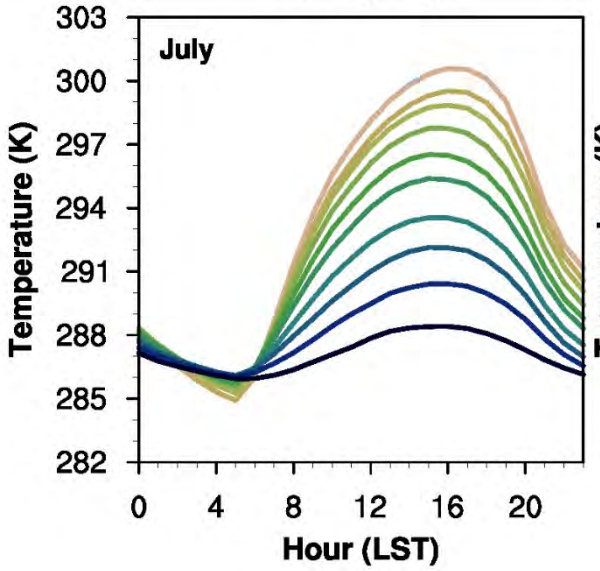
Winter climatology
- Colder when clear
- LWCF dominant with snow
- Stable BL

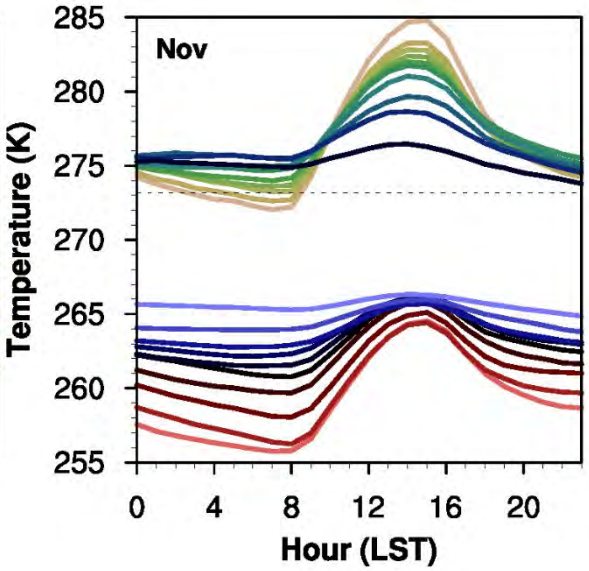
Summer climatology
- Warmer when clear
- SWCF dominant: no snow
- Unstable daytime BL

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









Warm and Cold Seasons

- **Clouds - reflect sunlight**
- **Less cloud - Warm in afternoon**

- **Snow - reflects sunlight**
- **Clouds: reduce cooling at night**
- **Less cloud: very cold at sunrise**

Impact of Snow

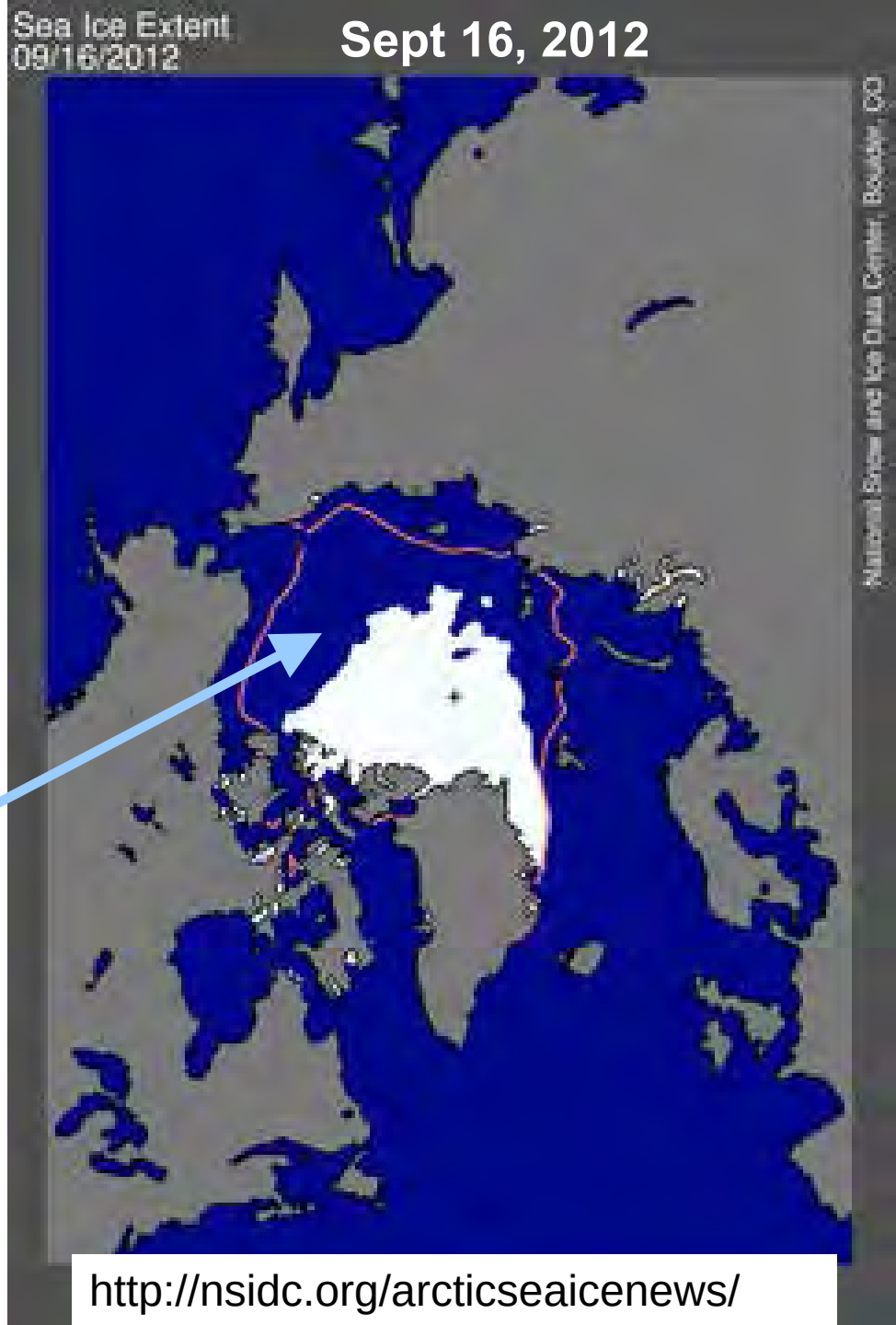
- **Distinct warm and cold season states**
- **Snow cover is the "climate switch"**
- **Prairies: ΔT = -10°C (18°F)**
  - **(winter albedo = 0.7)**
- **Vermont: ΔT = -6°C (11°F)**
  - **(winter albedo 0.3 to 0.4)**
- **Snow transforms surface-cloud coupling**
  - **No-snow 'Warm when clear' - convective**
  - **Snow 'Cold when clear' - stable**

Earth's climate sustains life

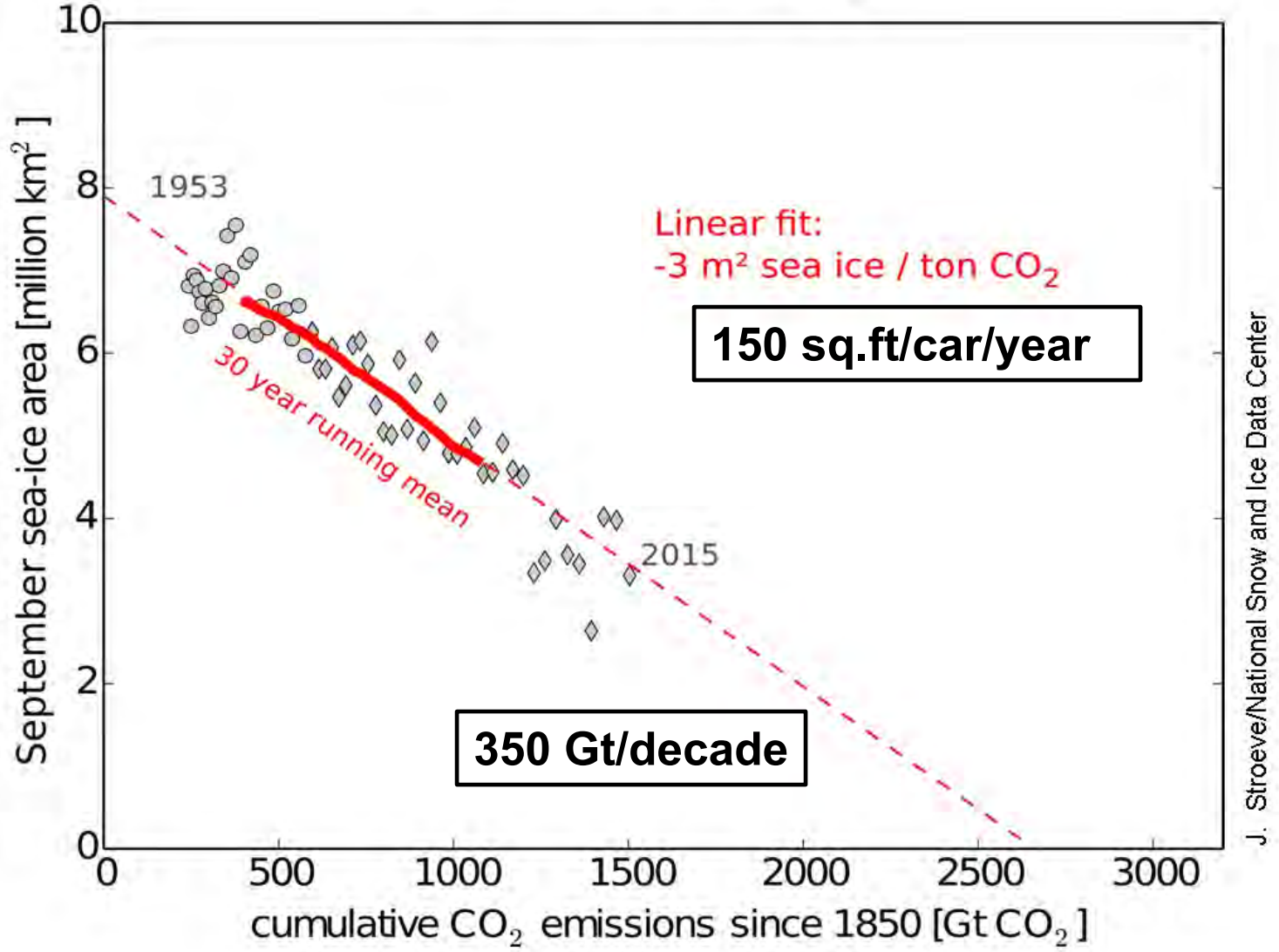
- Burning fossil fuels is increasing greenhouse gases
- Climate is warming: ice is melting, extreme weather is increasing
- Water plays crucial amplifying role
- Planetary modes crucial

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

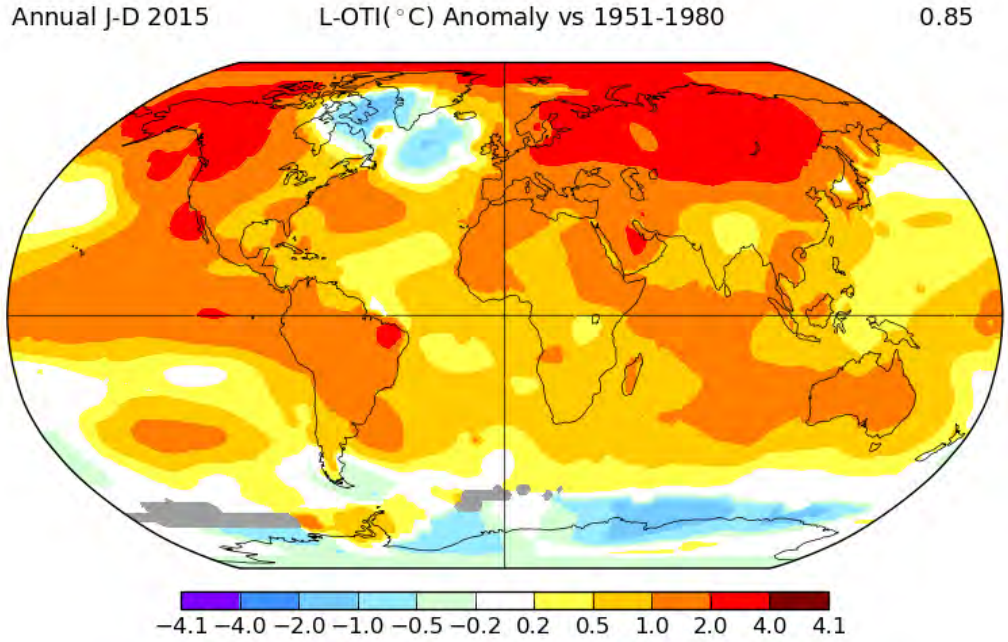
- ***Positive feedbacks:***
- ***Less ice, less reflection of sunlight***
- ***More evaporation, larger vapor greenhouse effect***
- ***Same feedbacks as in our winters***



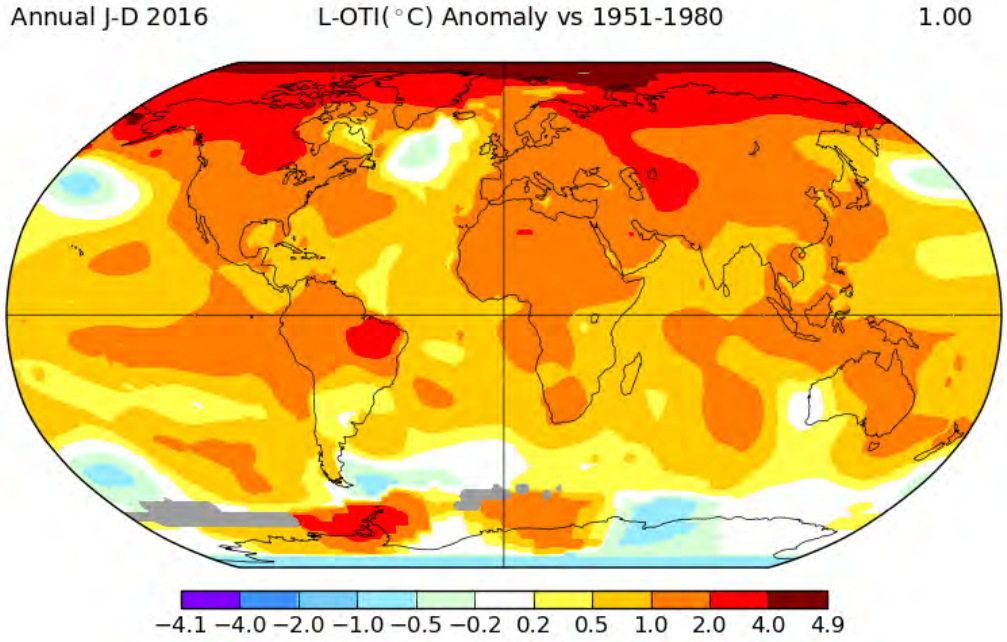
September Arctic Sea Ice Loss



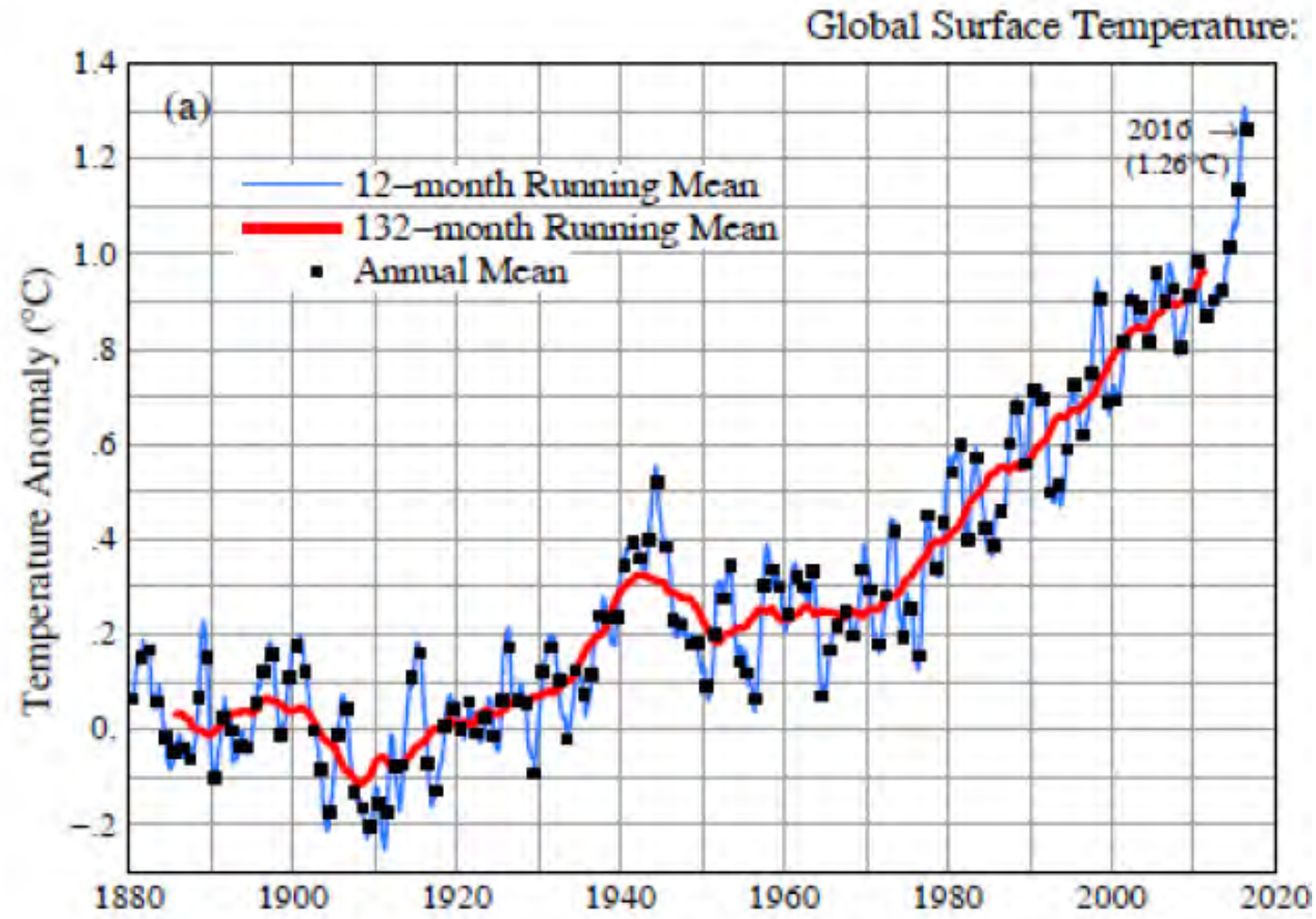
2015


Annual J-D 2015
L-OTI(°C) Anomaly vs 1951-1980
0.85
−4.1 −4.0 −2.0 −1.0 −0.5 −0.2 0.2 0.5 1.0 2.0 4.0 4.1

2016


Annual J-D 2016
L-OTI(°C) Anomaly vs 1951-1980
1.00
−4.1 −4.0 −2.0 −1.0 −0.5 −0.2 0.2 0.5 1.0 2.0 4.0 4.9

Long-term Global Mean Trend 1880-2016



Gardening in Pittsford, Vermont in January

January 7, 2007

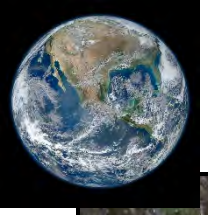
December 2006:

- **Warmest on record**

January 10, 2008

Warm Fall:

- **Record Arctic sea-ice melt**
- **Snow cover in December, ground unfrozen**



January 2, 2012

March 11, 2012

October 2011– March 2012

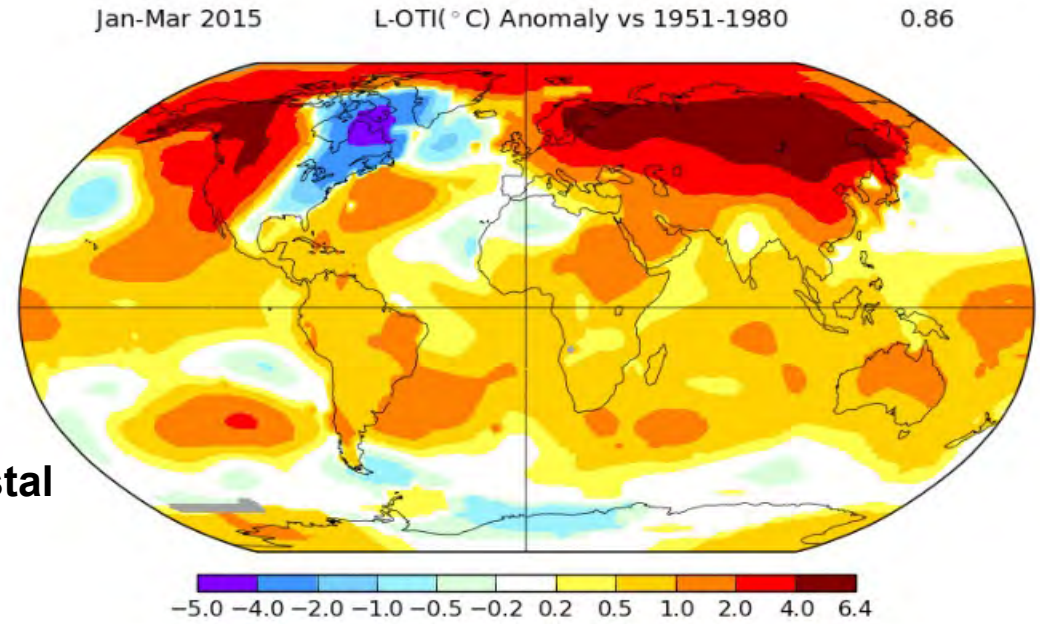
- **Warmest 6 months on record**
- **My garden frozen only 67 days**

•January 15, 2013

February 5, 2016
(Digging in Feb. first time ever)

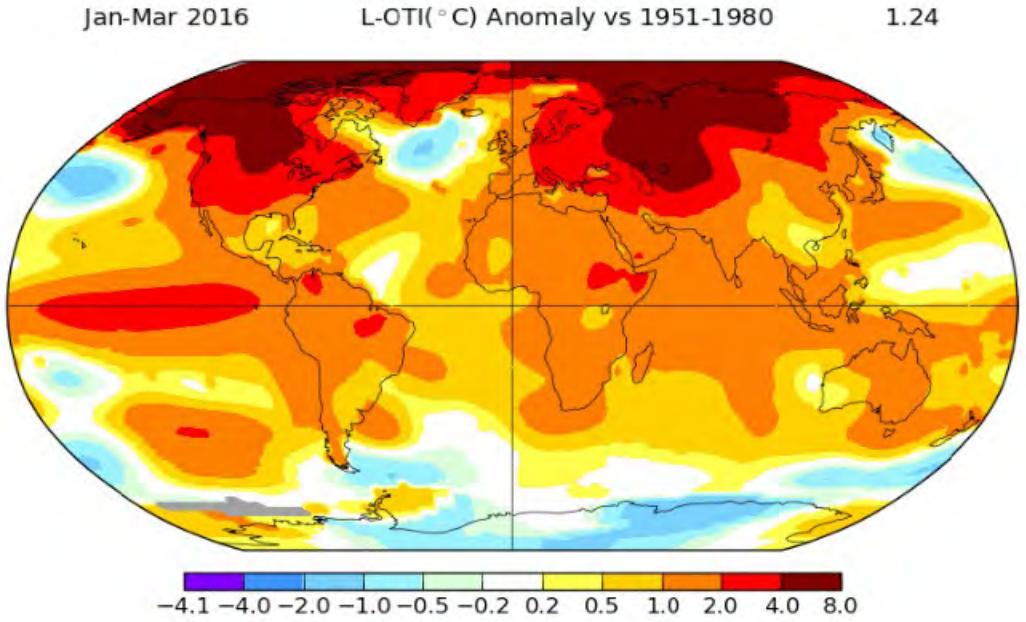
Jan-Feb-Mar 2015

Warm Atlantic, cold NE, strong coastal storms - Boston record snow



Jan-Feb-Mar 2016

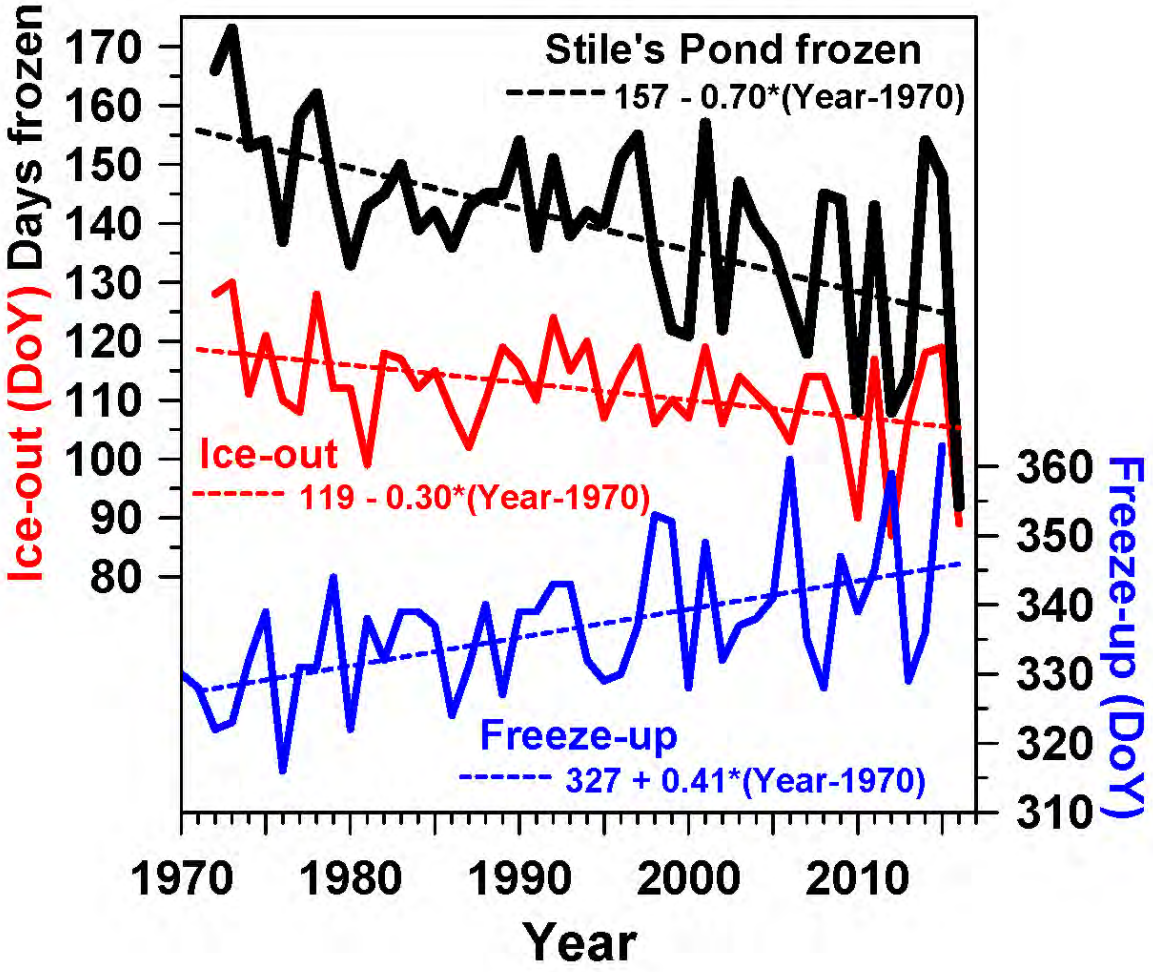
Warm Atlantic, warm NE, little snow, warm Arctic



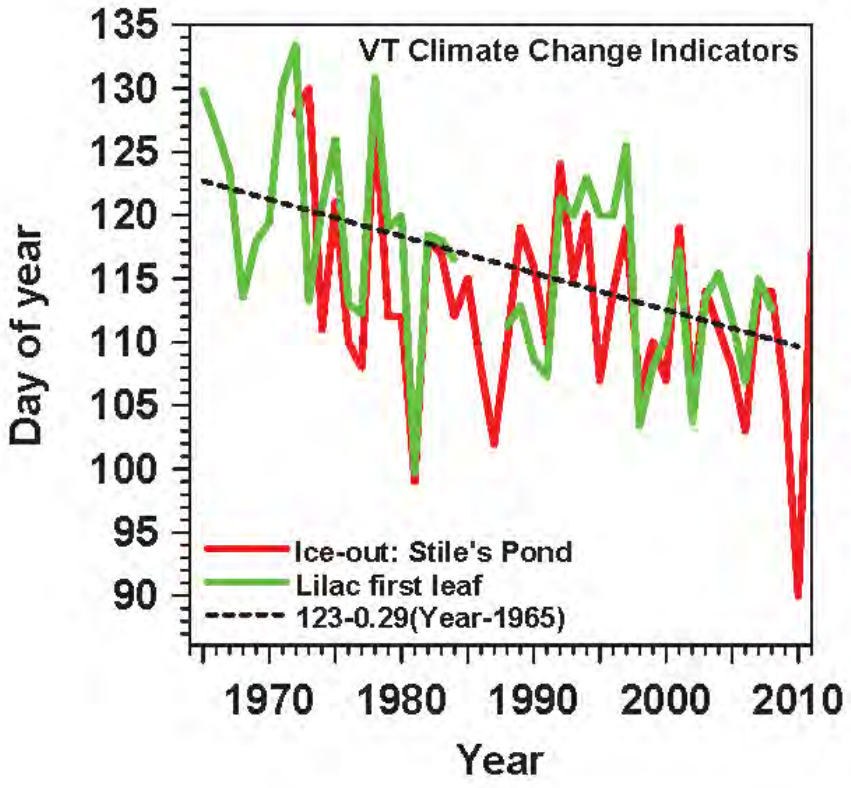
Lake Freeze-up & Ice-out Changing

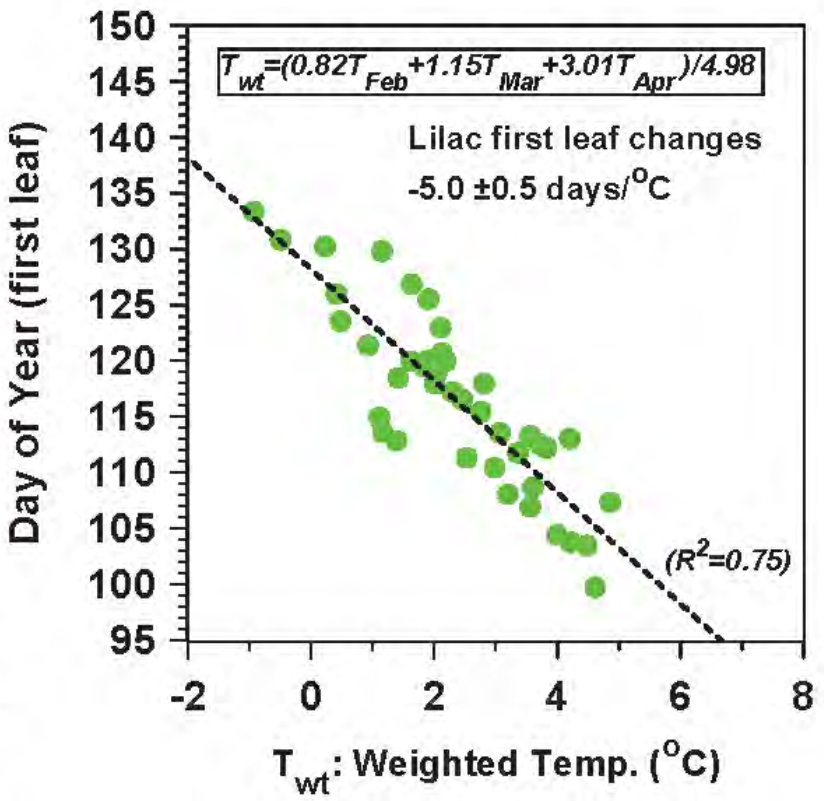
Frozen Period Shrinking: variability huge

- 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 linked to temperature:**
- **-5 days/ °C or -3 days/ °F**
  - **(No-snow – Snow) winter = 6*5 ≈ -30 days earlier leaf-out**

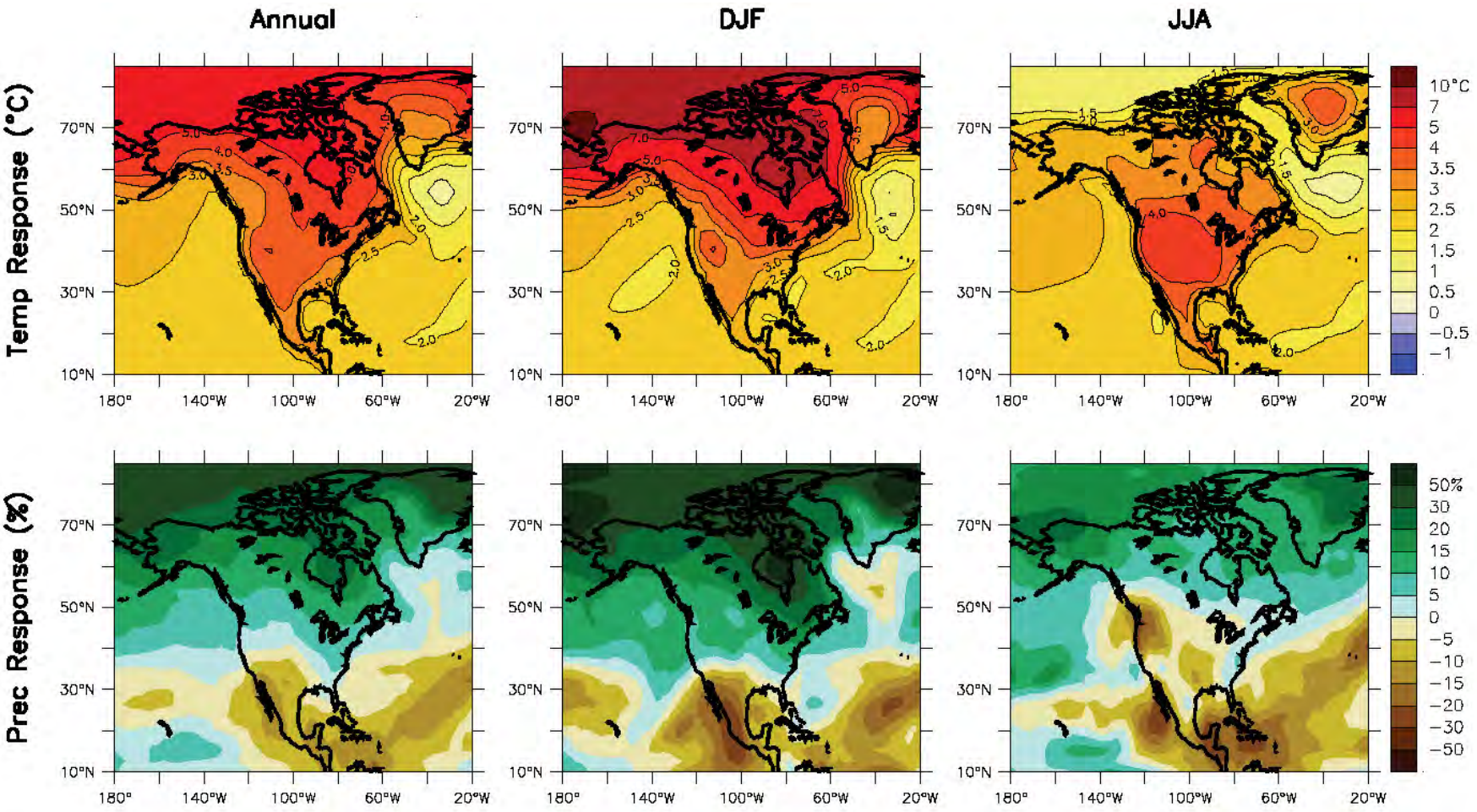
Fall Climate Transition

- **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

T, Precip. Changes (2090-1990)

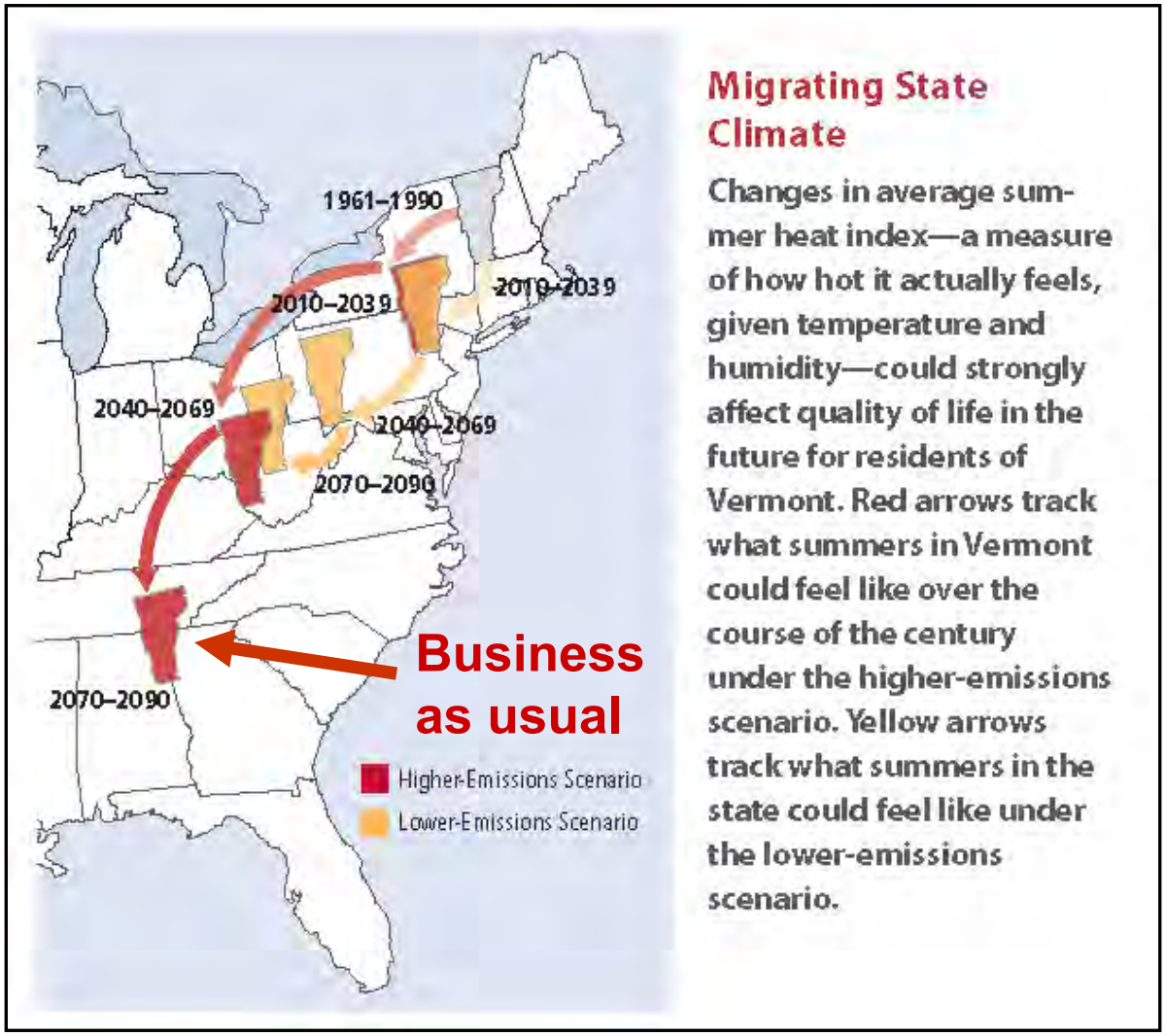


- Temperature and precipitation changes over North America from an average of 21 AOGCM projections for A1B **high emission scenarios**.
- Top row: Annual mean, winter (DJF) and summer (JJA) temperature change between 1980 to 1999 and 2080 to 2099. **[NE winter: +4.5C, +8F]**
- Bottom row: for fractional change in precipitation. **[NE winter: +25%]**

Vermont's Future with High and Low GHG Emissions

What about VT forests?

Sub-tropical drought areas moving into southern US



NECIA, 2007

System Issues

- **Human waste streams are transforming the Earth's climate, and human and natural ecosystems**
- **How will this affect landscape, water supplies, food system and human health?**
- **What strategies and mindset are needed to mitigate, adapt and build resilience in Vermont?**
  - **Can we better manage our relation to the Earth?**
  - **Is this an efficient way of doing this?**
  - **Can we manage our waste streams better?**
  - **How can we adapt?**

What Lies Ahead?

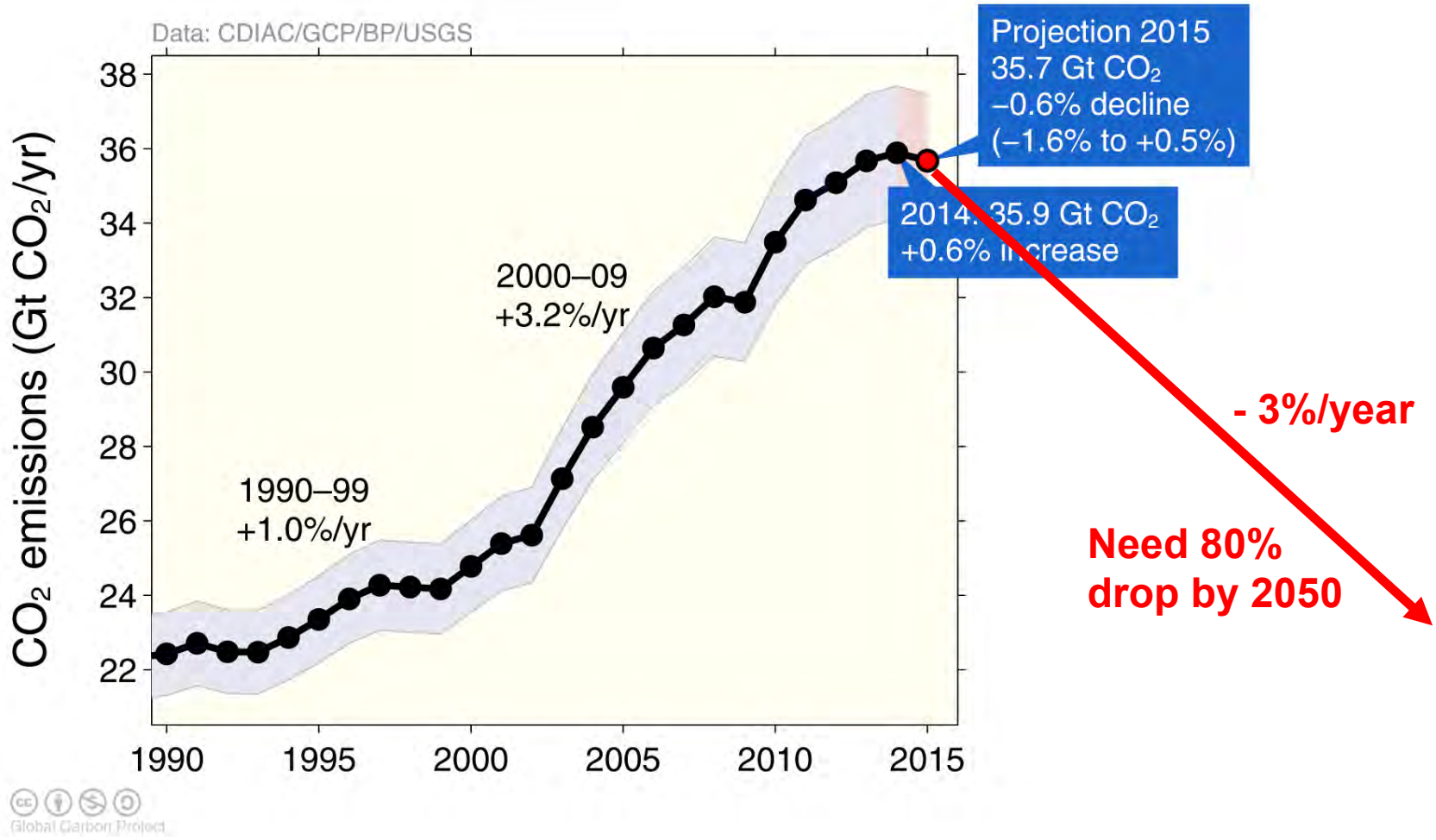
- **Accelerating change, increasing extremes**
- **Increasing adaptation and rebuilding costs**
- **Environmental damage that will transform or destroy ecosystems- locally and globally**
- **Freely dumping waste streams from society into atmosphere, streams, lakes and oceans is unsustainable – long-term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

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 possible but very difficult**
  - **Fossil fuels have driven our industrial growth and population growth for 200 years**
  - **"Lifestyle" has become dependent on fossil fuels**
  - **Powerful vested interests**

Growth of CO_2 Emissions Slowing?



‘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***
- **We need new ‘rules’ because**
  - **Our numbers and industrial output are so large**
  - **Maximizing consumption and profit have led to present predicament**

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**

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 enough to push CO_2 to 1,000 ppm**
    - **in time melt icecaps, raise sea-level 150ft**
    - **Can we "sequester" CO_2 (put it back in the earth)?**

Simple Suggestions

- **Reeducation of society and its 'systems'**
  - The transition we face is huge
  - What will raise awareness/change paradigm?
  - How can we better manage our relation to Earth?
- **Understand water and landscape**
  - Limit phosphorus loads on streams/lakes
  - Fresh water supply not critical in VT, but is elsewhere
- **Examine all waste-streams**
  - Aim to recycle/remanufacture everything
  - Fully cost all waste streams
- **Relocalize food system**
  - Compost all organic waste
- **Default energy use should be 'OFF'**
  - Maximize energy efficiency: housing, transport, power
  - Add and monitor renewable power
- **Reconnect with natural world**
  - Fundamental if we are to accept transition

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"**

- **Real Earth system issues being ignored**
- ***Our politics are facing collapse – becoming a fantasy disconnected from the real world***

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 <u>alone</u>**
  - **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 or despair)***
- ***You need grounding***
  - ***in yourself, as a group and with the Earth***

Ethical issues

- **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?**
- **Fundamental 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

Will Attitudes Change?

- Irene changed Vermont's attitude

- State moving in right direction
- Local community solutions essential

- Federal government now out-to-lunch

As Climate Changes….

- **Everything is interconnected**

- **Human society and waste streams: people's choices and actions**
- **Precipitation, seasons, streams, and forests; habitat and wildlife**

- **Keep your eyes open to the big picture and draw connections**
- **Talk to your neighbors and ask what you can do**
- **Stay connected to Vermont's natural environment**

How do we plan/adapt?

- **Futures needs creative approaches**
  - **Community support**
  - **People reconnected to landscape**
  - **Efficient transport: cooperative**
  - **Separate ‘electric bike’ roads**
- **We need to work with the Earth**
  - **Manage water on landscape**
  - **Manage forest diversity for a warmer climate**
  - **Manage diversified year-round agriculture**
  - **Manage energy crops and solar farms**

Discussion

alanbetts.com

(articles and talks)

Technology can be Useful

Trucks or lightweight Trikes!

30 mph Danish electric tricycle:

with 150 mile range

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**