

Global and Local Climate and our Future



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ENVS 151, *UVM April 21, 2015*





Outline

- Science of climate change
 - Global and local
 - What is happening to Vermont?
 - Why is extreme weather increasing?
- The transition we face
 - Can we stabilize the climate?
 - Why is it difficult?
 - What are scientists' responsibilities?

Discussion

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
 <u>amplifying role</u>



"The difficulty is that with the rise of the modern sciences we began to think of the universe as a collection of objects rather than a communion of subjects"

> The Great Work: Our Way into the Future Thomas Berry, 1999

Chilly Winter Here - Look at the Rest of the Northern Hemisphere!



Extremes Larger in February - Pattern stationary



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

March similar Pattern stationary for 3 months



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
- 2013-14 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
 - <u>Please help us</u> understand changing Prairie Climate
 - We have hourly data from 1953
- Nov. 2012: data arrives amazing gift that answers questions I have had for years
 – With cloud data and snow data.

Clouds and Climate



- Above freezing: Clouds reflect sunlight
 - Less cloud, much warmer in afternoon
- Below freezing: Clouds are greenhouse (snow reflects sun)
 - Less cloud, temperatures fall at night, very cold at sunrise

Snowfall and Snowmelt



- Temperature falls 18F (10C) with first snowfall
- Reverse change 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

- 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
 - <u>Same feedbacks as in</u> <u>our winters</u>



http://nsidc.org/arcticseaicenews/

Rise of Greenhouse Gases (GHG) Shift Energy Balance of Planet

- The atmosphere is transparent to light from the sun, but not to infrared radiation from the earth
- GHG: H₂O, CO₂, CH₄, O₃, CFCs trap the infrared from the surface, giving climate suitable for life by warming planet 60°F
- Rise of CO₂ alone has only a small warming effect

BUT...



Water, Snow & Ice Give Positive Radiative Feedbacks

- As Earth warms, evaporation and water vapor increase and this is 3X amplifier on CO₂ rise
- As Earth warms, snow & ice decrease and reduced solar reflection <u>amplifies warming</u> in Arctic in summer and mid-latitudes in winter
- Doubling CO₂ will warm globe about 5°F (3°C)
 - Much more in the cold regions and over land, which responds faster than oceans
 - Shift climate into new states

What Is Happening to Vermont?

- 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
- Soil ice probably similar

Winter Hardiness Zones

- winter cold extremes



Lilac Leaf and Bloom



- Leaf-out -2.9 days/decade; Bloom -1.6 days/decade
- Large year-to-year variation related to temperature: 2 to 3 days/ °F

First and Last Frosts Changing



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



January 2, <u>2012</u>

March 11, <u>2012</u>



October 2011– March 2012

- Warmest 6 months on record
- My garden frozen only 67 days
- January 15, <u>2013</u>
- but 2014, 2015 frozen!



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

2012 Exceptionally Warm



2011-2012 Winter in Canada



°C

7.5 6.5

5.5

4.5

3.5

2.5

1.5

0.5

-0.5

-1.5

-2.5

-3.5

-4.5

-5.5

-6.5

Little snow in Vermont winter 2011-12 – very warm Record temperatures Jan-Aug 2012 Record Arctic ice melt

http://www.ncdc.noaa.gov/temp-and-precip/maps.php

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

Spring transition-2 5/15/2010

• Weather

Cooler, humid, cloudy week

Climate

- <u>After leaf-out,</u> large evaporation
- Temp. falls 3-5°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



Summer dry-down

- Wet in spring
- Soil moisture falls: summer dry-down
- Low humidity & little rain
- Can lock-in drought in central US: as 2012



Many Wet Summers in Vermont – in last decade



- 2004, 2006, 2008, 2009, (2010), 2011, 2013, (2014) wet
- Direct fast evaporation off wet canopies
 - Evaporation-precipitation feedback increases rain

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!

Later frost: Growing season getting longer



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

Global Climate Change

- One of the many great challenges for the 21st century - present path is unsustainable
- Known about it for 35 years:

- First National Academy of Science Report in 1979

- Earth science conflicts with political values (and vested interests in fossil fuel economy)
- It is a global issue, a local issue and a moral issue

Vermont's Future with High and Low GHG Emissions

What about VT forests?

Sub-tropical drought areas moving into southern US



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

2011 Classic VT Flood Situations

- Spring flood: heavy rain and warm weather, melting large snowpack from 2010-11 winter
 - 70F (4/11) and 80F(5/27) + heavy rain
 - record April, May rainfall: 3X at Burlington
 - Severe Winooski flood
 - Lake Champlain record flood stage of 103ft
- Irene flood: tropical storm moved up east of Green Mountains
 - 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)

2011 Floods: VT and NY

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

March-August 2011 Statewide Ranks

National Climatic Data Center/NESDIS/NOAA



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]

Can We Stop "Dangerous Climate Change"?

- Yes: Quickly stabilize atmospheric CO₂
- This means an 80% drop in CO₂ 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

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, shale-gas & shale-oil reserves are sufficient to push CO₂ to 1,000 ppm—and in time melt icecaps
 - Need to leave 1/3 oil; 1/2 gas; 4/5 coal in ground

Why Is It Difficult for Us?

- Fossil fuels reserves are worth \$20-30T
 - Regulating emissions of CO₂ is an "unfair cost" to the "free market"
 - Carbon tax needed to change economics
- Politics lost in fantasy and deceipt
 - 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

What Lies Ahead?

- Humanity's impact is now global
- Climate extremes increasing
- Environmental damage that will transform or destroy ecosystems
- Dumping waste streams into atmosphere, streams, lakes and oceans is unsustainable – long term costs likely to <u>exceed \$1000 trillion</u>
- Will need <u>fossil carbon tax</u> to incentivize mitigation and pay for the long-term costs

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?
 - How do we pay for the damage we are doing?
- Moral Issue
 - We need to care for and co-operate with the Earth
 - Shift in understanding and mind-set needed

What are the Responsibilities of Environmental Scientists?

- Just do research?
- Publish in the usual jargon in copyrighted journals not available to the public?
- Avoid public discussion and politics?
 - Many places (Canada and some states) 'govt' scientists are banned from public comment on climate change
- What happens to science with political censorship?

What are the Responsibilities of Environmental Scientists?

- Just do research?
- Publish in the usual jargon in copyrighted journals not available to the public?
- Avoid public discussion and politics?
- Or accept that with understanding comes responsibility
 - To society
 - To the Earth
 - To the future

What can be Done?

- Environment page in Rutland Herald and Barre-Montpelier Times-Argus since 2008
 - Betts and Gibson (2012), Environmental journalism revisited
- Help state government
 - Adaptation docs for Agency of Natural Resources
 - Testimony to VT House/Senate committees
- Public talks and radio/TV interviews
 - Far reaching beyond the 'science'
 - Les Eglises Vertes (de Canada)

What can be Done? (2)

- All research, talks and writings available on my web-site creative commons license
 - Papers have 'plain English' abstract
- Research data freely available (Envir-Canada)
- Newspaper articles are technically accurate to a scientist, but complexity is transparent to the public
- I accept that I am responsible to society for what I understand
- I share my informed opinion over the entire range of social issues, including the economic, political and spiritual

How could I do this?

- I opted out of the 'academic system' and the consumer society: built house in Vermont
- NSF funded me as an individual on 5-year grants for more than 30 years

– I am 'unfair competition' (overhead = zero)

- As well as science, I paid attention to both global issues and spiritual issues
- I write explicitly on ethical issues, so I have a reputation for 'scientific integrity'

- Betts, A. K. (2011), Communicating Climate Science. EOS.

• Supported by society, I am responsible to communicate to society

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 powerful economic and financial system driven by short-term profit
- Needs deep community discussion
 - New values that respect the Earth
 - Understanding to work with the Earth

2015 is Transition Year

- Climate meeting in Paris in December
 - Nations making commitments
 - 33 countries have submitted plans so far
- Pope Francis will issue the first Papal Encyclical on the environment, climate change and our responsibilities to the Earth
 - Will shift the position of the Catholic church
 - Protestant traditions will follow his lead
 - Shift from short-term profit as primary motive
- New values that respect the Earth

Discussion

- This talk <u>http://alanbetts.com/talks</u>
- Rutland Herald articles at

http://alanbetts.com/writings

Interesting papers at

http://alanbetts.com/research

- Vermont Climate Change Indicators
- Seasonal Climate Transitions in New England

What Do We Need To Do?

- The transition to a sustainable society will take decades and a community effort
- 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

Agricultural planning

- Frozen ground and lakes: -7d/decade
- Earlier melt, earlier spring leaf-out: 3d/decade
- Frost-free growing season: +4d/decade
 - Greenhouse, row cover seasonal extenders
- Winter extremes increasing with variable snow
 - T_{min} extremes increasing +2-3°F/decade
- More winter precipitation
 - Wetter snow; more mixed phase; more frequent melt
- Variable summer precipitation
 - Heavier rain-rates, longer storms, longer droughts
 - Maximize soil water infiltration; water storage
 - Manage to reduce soil erosion
 - Design infrastructure to handle larger runoff
 - Increase soil organic matter

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 guide has failed us
- We must manage our society better!

Broad Guidelines or Rules to Minimize Impacts

- Minimize the lifetime of waste products in the Earth system and eliminate waste with critical 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

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 limits
 - That accept our moral responsibilities

- 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



NASA-GISS, 2015

Carbon Dioxide Is Increasing



Growth of CO₂ Emissions Continues



2014 emissions flat – shift from coal in China

Shrinking Winter: Pittsford, VT (Freeze-up used to be mid-November)





January 7, <u>2007</u> December 2006: • Warmest on record

January 10, <u>2008</u>

Warm Fall:

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