

Climate Change and Vermont



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- Earth is a complex system
- Its timescales are long
 - It runs well without us
 - but Earth's climate is unstable (Ice-ages)
- •Humanity big perturbation



Climate Change

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

J. S. Sawyer (1972): Man-made CO_2 and the "greenhouse" effect

- It is a global issue & a local issue a societal issue & a personal issue
- Clash of Earth science with social values

Outline

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

Discussion

My Background: Peterhouse, Cambridge - UK

- Founded 1284
- Medieval warm period;
 Vinland colony flourishes



My Background: Nottingham High School

- Founded 1513
- 1550: Heading into "Little Ice Age"
- 1620: Pilgrim fathers face bitter winters





- "Proxy" records from before the time of thermometers provide uncertain data, but they're all we have
- Black line is 150-yr instrument record

Global Temperature Rise 1880 – Present



NASA-GISS, 2011

2100: +5°F

Global Picture 2010

2010, warmest (tie) of 131 years $0.63 \,^{\circ}\text{C}$ (1.2°F)



- Record summer temps
 - Russia (100°F) Moscow fires
 - Pakistan (128°F) Extreme monsoon floods

Arctic Sea Ice Loss Has Accelerated



- Record ice loss in 2007
 - most ice now thin and only 1-2 years old
- Open water in October contributes to warmer Fall

Sea Ice Trends

- Sea ice is thinning rapidly
- Observed September decline appears to be faster than IPCC climate model projections





Carbon Dioxide Is Increasing





2009 Was "Good" for the Earth

Fossil Fuel Emissions: Actual vs. IPCC Scenarios



Key Diagnostic of the Carbon Cycle Evolution of the fraction of total emissions that remain in the atmosphere Total 10 CO_2 CO₂ Partitioning (PgC v⁻¹) emissions 8 Half to oceans & forests gC 6 Left in **Atmosphere** 2 Updated from Le Quéré et al. (2009). Nature Geoscience; Data: NOAA

It takes at least a century to remove CO₂ from the atmosphere, and many centuries to remove it from oceans

1990

2010

2010, CDIAC 2010

2000

1980

1970

1960

<u>Rising</u> Ocean Acidity Threatens Organisms

- From the Tropics to the Arctic, the seas are sucking up emissions of CO₂ from burned fossil fuels
- When CO₂ dissolves in water, carbonic acid is produced; the oceans are becoming more acidic













Why Is the Rise of Atmospheric CO₂ a Problem?

- The atmosphere is transparent to light from the sun, but not to infrared radiation from the earth
- Greenhouse gases: H₂O, CO₂, CH₄
 - trap the earth's heat, giving pleasant climate
- CO₂ rise alone has a small effect, BUT...

Why Is the Rise of Atmospheric CO₂ a Problem?

- As Earth warms, evaporation and water vapor increase and this amplifies warming a lot (3X)
- As Earth warms, snow and ice decrease and <u>this amplifies warming</u> in winter and northern latitudes, because less sunlight is reflected
- Doubling CO₂ will warm Earth about 5°F (3°C)
 - much more in the North and over land

Global Warming Is Unequivocal IPCC: Fourth Assessment, Feb., 2007

Since 1970, a rise in:

- Global surface temperature
- Lower atmosphere temperatures
- Global sea-surface temperatures
- Global sea level
- Ocean heat content
- Water vapor
- Rainfall intensity
- Extratropical precipitation
- Hurricane intensity
- Drought
- Extreme high temperatures
- Heat waves

(www.ipcc.ch)

Decrease in:

- NH snow extent
- Arctic sea ice
- Glaciers
- Ocean pH (increasing acidity)



Predicted Change in Temperature 2020-2029 and 2090-2099, relative to 1980-1999 (°C)

"Committed"

Still up to us!



(We did nothing for the last 20 years)

(We could halve this if we act now)



Climate Model Predictions



Mean Temperature Increase: (2080-2099) minus (1980-1999) for winter (DJF) and summer (JJA)

Mean of 23 climate models

For high CO₂ emission scenario (A1B)

Shading is points where increase is greater than standard deviation between models ('significant')

So imagine running many climate forecast models for 100 years and averaging the changes they show.

Polar regions in winter will warm more than +7.5C (13.5F)

Vermont +4C (7F) in summer



Climate Model Predictions



Climate Models Run for Different Scenarios for Global Emissions



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 accelerating for centuries
- Unless we drastically reduce burning of fossil fuels by 80% by 2050
- Sea-level rise will get our attention
 - But it will be too late!

Many Challenges Face Us

- Extreme weather: Floods, fires, & drought
 - 32 weather disasters >\$1B in 2011
- Melting Arctic and permafrost methane release is positive feedback
- Ecosystem collapse, including perhaps forest and ocean ecosystems
- Collapse of unsustainable human population

Local Example: What Is Happening to Vermont?

- Local climate change indicators
- Easier to grasp than global view
- Warming twice as fast in winter than summer
- Winter severity decreasing
- Lakes frozen less by 7 days / decade
- Growing season longer by 3.7 days / decade
- Spring coming earlier by 2-3 days / decade

Vermont Temperature Trends

- Summer mean (°C 22 70 20 Summer +0.4°F / decade 18 65 16 60 30 ίς Ο nter 25 Winter mean Winter +0.9°F / decade -6 20 -8 -10 1960 1970 1980 1990 2000 2010 Year
- Less snow drives 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)

Lilac Leaf-out and Ice-out Coupled



- Lilac leaf and lake ice-out both depend on Feb. Mar. and April temperatures
- Trends indicate earlier spring

Maples and Lilacs in spring



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

Vermont Winter 2006



- Sun is low; and snow reflects sunlight, except where there are trees!
- Sunlight reflected, stays cold; little evaporation, clear sky; earth cools to space

USDA Hardiness Zones - Northeast



Gardening in Pittsford, Vermont in January





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

December 20, 2011



January 2, 2012



December 2011 Statewide Ranks

National Climatic Data Center/NESDIS/NOAA



Freeze-up was January 3

December 2011:

6th Warmest on record

First and Last Frosts Changing



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

Spring Climate Transition

Before leaf-out

Little evaporation → Dry atmosphere, low humidity

- → Low water vapor greenhouse
- \rightarrow Large cooling at night
- → Large diurnal temp. range
 - giving warm days, cool nights and frost

• After leaf-out

Large evaporation → Wet atmosphere, low cloudbase

- \rightarrow 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!

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

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

Very Heavy Precipitation Is Increasing

- Most of the observed increase in precipitation during the last 50 years has come from the increasing frequency and intensity of heavy downpours.
- 67% increase in Northeast
- Little change or a decrease in the frequency of light and moderate precipitation
- Vermont streamflow is increasing



The map shows percent increases in the amount falling in very heavy precipitation events (defined as the heaviest 1 percent of all daily events) from 1958 to 2007 for each region. There are clear trends toward more very heavy precipitation for the nation as a whole, and particularly in the Northeast and Midwest.

Projected Precip. Increase by 2090

- For Vermont
- 15% in winter,
- 10% in spring
- 5% in fall
- No change, summer
- Heavier rain and more drought

Projected Change in North American Precipitation by 2080-2099



The maps show projected future changes in precipitation relative to the recent past as simulated by 15 climate models. The simulations are for late this century, under a higher emissions scenario." For example, in the spring, climate models agree that northern areas are likely to get wetter, and southern areas drier. There is less confidence in exactly where the transition between wetter and drier areas will occur. Confidence in the projected changes is highest in the hatched areas.

2011 Vermont Floods

113

Record

Warmest

107

116

116

115

102

116

Above

Normal

Much

Above

Normal

- Record spring flood on Lake Champlain
- Record floods following TS Irene
- Record wet in NE March-August, 2011 (but TX, NM record drought)



Discussion

- http://alanbetts.com
 - this talk http://alanbetts.com/talks
 - articles at http://alanbetts.com/writings
 - papers at http://alanbetts.com/research
- Vermont Climate Change Indicators
- Seasonal Climate Transitions in New England

Other Resources

 Sunday Environment page in Rutland Herald/Montpelier Times Argus: 2008-2012 – 43 articles

http://alanbetts.com/writings

• Yearly summary articles

CO₂ is the Primary Control Knob in the Climate System



- Falls 5°C in 1 year; 35°C in 50 years
- Water vapor falls 90%; cloud-cover goes to 75%; sea-ice to 50%

What Will This Mean For You?

- Society needs to rethink its relationship to the natural environment and its ecosystems in less than one generation
- Our <u>'lifestyle</u>' is disconnected from what the earth can sustain and the large inertia of the earth system is masking the extent of the crisis we face
- Individual can rethink priorities but societal changes are needed: from towns to global
- Ask
 - Is this an efficient and sustainable way of doing this?
 - Do I have a deep understanding and connection to Earth?

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

Broad Guidelines or Rules to Minimize Impacts

- Minimize the lifetime of human waste 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