Global Climate Change and Vermont

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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: CO₂ and H₂O



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

J. S. Sawyer (1972): Man-made CO₂ and the "greenhouse" effect
 Charney Report (1979): Carbon dioxide and Climate
 UN Framework Convention on Climate Change (1992) in Rio, Brazil
 - 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
- The transition we face
 - Managing the earth system
 - How to deal with it

Discussion

- 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
 - Ice thin: most 1-yr-old

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



http://nsidc.org/arcticseaicenews/

Sea Ice Trends

- Sea ice is thinning rapidly
- Observed September decline appears to be faster than IPCC-AR4 climate model projections
- [AR5 projections should be faster]





June 2012 snow cover minimum



Northern Hemisphere Snow Cover Anomaly June 1967 - 2012 SIDC courtesv Rutgers University Snow Lab 2 Million Square km 0 -1 -3 Steep fall since 2003 -5 ≈ 500,000 km²/yr -6 68 08 12

- Arctic warming rapidly
 - Melting fast
 - Much faster than IPCC models
 - Northeast winters
 - <u>Same positive feedbacks</u>

Snowfall and Snowmelt



- Temperature falls about 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

Carbon Dioxide Is Increasing





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°C)
- These are "Greenhouse gases"- water vapor, carbon dioxide, ozone, methane (H₂O, CO₂, O₃, CH₄, CFCs..)
- CO₂ is rising fast: <u>by itself only a small effect</u>

But as CO₂ 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 <u>warming faster</u>
- Doubling CO₂ will warm Earth about 5°F
 - Much more in the North, over land, in winter
 - Climate change we are seeing in Vermont will continue

Only Half of Total CO₂ Emissions Remain in the Atmosphere



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

<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













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

What Is Happening to Vermont?

- **PAST 40/50 years** (global CO₂ 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
- Soil ice probably similar

Heating Degree Days and Days below 0°F (Burlington)

Winter Hardiness Zones

- winter cold extremes

Detailed Map (most recent)

- VT Hardiness Zone Map 1976-2005
 - <u>mean 1990</u>
 - South now zone 6
- Half-zone in 16 yrs = 3.1°F/ decade
 - <u>triple the rise-rate</u>
 <u>of winter mean T</u>
 - 3 zones/century
- <u>http://planthardiness.ars.usda.g</u> <u>ov/PHZMWeb/</u> (Krakauer, Adv. Meteor. 2012)

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

- Hardy peaches: 2012
- More pests survive winter
- What is this?

Bennington & Brattleboro are becoming zone 6

- Hardy peaches: 2012
- More pests survive winter
- What is this?
- Avocado
 - Didn't survive frost
 - 2100 survive in CT
 - Our forests?

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

Maples and Lilacs in spring

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

January 2, <u>2012</u>

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 Mountains
- Contrast snowy winter 2010-11

Across the border: Canada

- Winter 2011-12: Far above "normal"
 - Canada's winters also warming 0.9°F/decade
- Climate doesn't see the border!

2012 Exceptionally Warm

- Burlington Area Extremes
- Highest Average
 Temperature degrees F
- Days: 9/1/2011 8/31/2012
- Length of period: 365 days
- Years: 1850-2012
- Rank Value Ending Date
- 1 50.4 8/31/2012
- 2 48.4 8/31/2002, 8/31/1949
- 4 48.2 8/31/2010
- 5 48.0 8/31/1999
- 6 47.9 8/31/2006
- 7 47.8 8/31/1991, 8/31/1995
- 9 47.6 8/31/1899, 8/31/1903

(Scott Whittier: NWS-BTV)

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

Increasing Positive Temperature Extremes is "Global Warming"

(a) Probability Distribution of Northern Hemisphere Land Summer Temperature Anomalies

⁽Hansen, 2012)

- Frequency of occurrence (vertical axis) of local June-July-August temperature anomalies for Northern Hemisphere land in units of local standard deviation (horizontal axis). The normal (gaussian) distribution bell curve is shown in green.
- Large increase in anomalies > +3σ is global warming
 Baseline 0.15% has increased to 10% in 45 years

December 21, <u>2012</u>

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
- Important for agriculture; local food supply

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

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

Very Heavy Precipitation Is Increasing

- Precipitation Extremes
- Most of the observed increase in precipitation during the <u>last 50 years</u> has come from the increasing frequency and intensity of heavy downpours.
- 67% increase in Northeast

(USGCRP, 2009)

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.

Summer "stormflow" increasing

Most >50%

Lent (2010) USGS, Me

Figure 4. Geographic distribution of summer storm fow trends, 1950-2006.

Hydrology Sensitive to Climate

Lent (2010), USGS, Me

- Peak spring runoff
- Earlier in northern New England in recent years
 ≈ 3 days/decade
- Timing related to air temperatures in Spring

(Hodgkins and others, 2003)

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%/°F)
- <u>Quasi-stationary</u> large-scale flow means longer rain events in low-pressure convergent regions, and longer droughts in high-pressure divergent regions
- As climate changes, <u>quasi-stationary</u> largescale 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 Statewide Ranks

National Climatic Data Center/NESDIS/NOAA

As Arctic warms, jet stream patterns are slowing down and amplifying, giving more extreme weather

(Francis and Vavrus, 2012)

Image - NASA

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

(Francis and Vavrus, 2012)

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)

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]

Increasing Extreme Weather

- The answer to the oft-asked question of whether an (extreme) event is caused by climate change is that <u>it is the wrong</u> <u>question.</u>
- <u>All weather events are affected by climate</u> <u>change</u> because the environment in which they occur is warmer and moister than it used to be. (Trenberth: Climatic Change 2012)
- .. and global weather patterns are changing

Increasing CO₂ is long-lived driver Water: *Amplifying Feed-backs*

- Water Vapor up
 - WV infrared greenhouse up
 - Approx triples climate warming of planet
 - Locally reduces night-time cooling
 - Winter T_{min} increase: less severe winters
 - Longer growing season between frosts
 - Latent heat release in storms up
 - Increases precipitation rates
 - Increases precipitation extremes
 - Increases wind-speeds and storm damage
 - Increases snowfall from coastal storms in winter
- Snow and ice down, less sunlight reflected
 - Warmer Arctic in summer
 - Warmer northern winters
 - Less ice-cover: more evaporation
 - More lake-effect snowstorms

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

Background papers:

http://alanbetts.com/

- Vermont Climate Change Indicators
- Seasonal Climate Transitions in New England
- Extreme Weather and Climate Change

http://www.anr.state.vt.us/anr/climatechange/Adaptation.html

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

2009 Was "Good" for the Earth

Fossil Fuel Emissions: Actual vs. IPCC Scenarios

Our Present Challenge

 How to reintegrate all that we know and understand

given the deep interconnectedness
 of life & climate on Earth

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

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 CO₂ to 1,000 ppm—and in time melt icecaps
 - Can we "sequester" CO₂ (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 CO₂ is an "unfair cost" to the "free market"
 - Yet we are still subsidizing fossil fuels
- 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

Can't Avoid the Big Issues!

 Regulation is needed – 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

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?

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

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