Dealing with Climate Change

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RACC High School Projects
VT EPSCoR
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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?

Discussion...
Earth sustains life

- Burning fossil fuels is increasing greenhouse gases and melting polar ice
- Climate is warming and extreme weather is increasing
- Water plays crucial role everywhere

January 2, 2012: NASA
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?
  - Is this an efficient way of doing this?
  - Can we manage our waste streams better?
  - Can I deepen my connection to the Earth?
Our Present Challenge

• How to reintegrate all that we know and understand
  – *given the deep interconnectedness of life & climate on Earth*
• 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

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**End of Nov. 2011**

**Hudson Bay was still nearly ice-free**

http://nsidc.org/arcticseaicenews/
June 2012 snow cover minimum

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

Steep fall since 2003
≈ 500,000 km²/yr
Snowfall and Snowmelt

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

Betts et al. 2014
More snow cover - Colder temperatures

Alberta, Canada
October to April

Freezing

Mean Temperature (°C)

Mean Temperature (°F)

Fraction of Days with Snow Cover

\[ T = 3.9 - 14.6 \times \text{FDS} \quad (R^2 = 0.79) \]
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
What Is Happening to 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
- Soil ice probably similar
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)
Heating Degree Days and Days below 0°F (Burlington)

- Heating degree days falling 290/decade
- $T_{\text{min}} < 0^\circ\text{F}$ falling 4 days/decade
Winter Hardiness Zones
– *winter cold extremes*

Change in 16 years

Minimum winter T
4: -30 to -20°F
5: -20 to -10°F
6: -10 to 0°F

© 2006 by The National Arbor Day Foundation®
Detailed Map (most recent)

- VT Hardiness Zone Map 1976-2005
  - mean 1990
  - South now zone 6

- Half-zone in 16 yrs = 3.1°F/decade
  - triple the rise-rate of winter mean $T$
  - 3 zones/century

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?
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 (4.5 days/°C)
Maples and Lilacs in spring

- Maple bud elongation mirrors lilac leaf
- Maple leaf-out mirrors lilac bloom
First and Last Frosts Changing

- Growing season for frost-sensitive plants increasing **3.7 days / decade**
- *Important for agriculture; local food supply*
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!
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
Jan. 1-24, 2014
850mb Temperature Anomaly

Extremes increasing across whole hemisphere: stationary patterns
Carbon Dioxide Is Increasing

Atmospheric CO₂ at Mauna Loa Observatory

Scripps Institution of Oceanography
NOAA Earth System Research Laboratory

Winter

Summer

Upward trend + 2ppm/year

YEAR


PARTS PER MILLION

320 340 360 380

January 2011
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 (H$_2$O, 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.
Increasing CO₂ is long-lived driver

Water: *Strong Feed-backs Amplify*

- GHGs up $\rightarrow$ Oceans, land warmer $\rightarrow$ Evaporation up

- **Water Vapor up**
  - WV infrared greenhouse up
    - Approx triples climate warming of planet
    - Locally reduces night-time cooling
      - Winter $T_{\text{min}}$ 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
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)
Vermont’s Future with High and Low GHG Emissions

What about VT forests?

Sub-tropical drought areas moving into southern US

Business as usual

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

(USGCRP, 2009)

• **Precipitation Extremes**

• 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**

• **Nine out of ten recent summers have been ‘wet’**

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.
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)*
- **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, or W. Pacific 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

- Record wet: OH to VT
- Record drought: TX & NM
- ‘Quasi-stationary’ pattern
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)
Jet Stream Patterns Slowing Down and Amplifying, Giving More Extreme Weather  
*(Francis and Vavrus, 2012)*
Blocking Pattern - Unique track

- 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 costs
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
Guidelines to Minimize Impacts

• *Planning a trajectory for sustainability*

• **Minimize waste streams**  
  – Especially those 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
Will Attitudes Change?

• Irene changed Vermont’s attitude

• Changing climate and extreme weather will raise awareness (sea level rise will be too slow)

• ‘Managing’ Lake Champlain basin is a microcosm for ‘managing’ the Earth
As Climate Changes….

- Everything is interconnected
- Human society and waste streams: people’s choices and actions
- Precipitation, seasons, streams, and forests; habitat and wildlife
- You have specific tasks in a large project
- But keep your eyes open to the big picture and draw connections
- Record more than the project lists/protocols
- Keep asking us for guidance
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