Climate Change and Vermont

Alan K. Betts
Atmospheric Research Research
Pittsford, VT
http://alanbetts.com

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Outline of this talk

• What is happening to
  – Global climate
  – Climate of Vermont

• Broader issues
  – System issues
  – Social issues
Fundamentals

- **Burning fossil fuels: transforming climate**
  - Many water cycle amplifying feedbacks
  - Heading for high CO$_2$ “Carboniferous era climate”
  - Oceans warming; Climate extremes increasing
  - Decadal to centennial - long timescales

- **Avoidance of responsibility for decades**
  - Climate change: *Incompatible with business-as-usual*
  - Soluble: using systems engineering
  - Create efficient society, based on renewable energy

- **Choices are value-based**
  - Science and economics need guidance
  - Market economy (mostly) maximizes current profit
Climate Drivers

• Burning fossil fuels increases CO₂ and CH₄
• Amplified 3 times by water vapor increase, also strong greenhouse gas
  – *Reduce cooling to space, while solar heating increases as snow and ice decrease*
• 93% of Earth’s warming is stored in oceans, giving stronger storms, with more precip.
  – Harvey, Irma, Maria, Florence, Michael
• Warming doubled in Arctic and winter by shrinking ice and snow
  – Changing mid-latitude weather; more stationary
Florence: N. Carolina Coast

Friday, 9/14/18
12:35pm EDT

Warm ocean
Rain >24in
Major flooding

New Bern: Saturday, 9/15
System Problem

• Human waste streams are transforming the Earth’s climate, and human and natural ecosystems
  – This affecting climate, weather, water supplies, food system and human health
  – Current financial interests vs Earth’s future
• New strategies and mindset needed to mitigate, adapt and build resilience
  – Is this an efficient way of doing this?
  – Can we manage our waste streams better?
  – Can we better manage our relation to the Earth?
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: jet-streams changing
Global Trend: 1880-2017

Land-Ocean: Global Means (J-D)

- No Smoothing
- Lowess Smoothing

Temperature Anomaly (C)

NASA GISS
• Arctic warming twice as fast as globe
• Half the Arctic Sea Ice Melted in 2012
• Open water gives warmer Fall in Northeast

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

http://nsidc.org/arcticseaicenews/
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http://nsidc.org/arcticseaicenews/
September Arctic Sea Ice Loss

Linear fit:
-3 m² sea ice / ton CO₂

150 sq.ft/car/year

350 Gt/decade
Transport: big CO$_2$ source

- High tech solution: convert all to electric cars
  - Means large investment in new infrastructure: good for economy!

- Cheap solution: plug-in hybrids, which reduce fossil fuels use by 80% with no compromises

- Annual auto fuel efficiency in Vermont: 25mpg
- Plug-in hybrid: 140 mpg: fixes problem, saves $
• 23000 miles; 50% electric, 50% hybrid: \textbf{140} mpg
  – 12000 miles/year: 88 gallons/year; 1400 KWh/year
  – Compare 25 mpg car: 480 gals, cost $1344
  – Saves: $1344 – (246+252) = $846 \text{ annual savings}
• Most efficient car on market \textit{(better than Tesla!)}
  – Running hybrid gets 68 mpg on VT roads at 50 mph
  – Long-trip: 2100 mile: avg 82 mpg (night plug-in)
• \textbf{So why doesn’t Toyota advertise them?}
Jan-2018

Warm Atlantic, Warm Arctic, west-NA; cold east-NA; warm Europe

Feb-2018

Warm Atlantic, Warm Arctic, east-NA; cold west-NA and Europe

March 2018: 4 Nor’Easter snowstorms
Snowfall and Snowmelt
Winter and Spring transitions

- Temperature falls/rises about 18°F with first snowfall/snowmelt
- **Snow reflects sunlight; shift to cold stable boundary layer**
  - *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

\[ \Delta T = T: \text{no-snow} - T: \text{snow} = -10.2(\pm 1.1)\degree C \]

Betts et al. (2016)
Winter is colder if more snow cover.
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”
Impact of Snow

- Distinct warm and cold season states
- Snow cover is the "climate switch"

With snow

- **Prairies**: Temperature falls 18°F
  - snow reflects 70%
- **Vermont**: Temperature falls 10°F
  - snow reflects 35% (because more forest)
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
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)
January 10 and 12, 2018

January 10, 2018
After cold snowy period
$T_{\text{min}}$ down to -10 to -20F

January 12, 2018
After $T_{\text{max}}$ up to 50F
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
Marker: Lake Freeze-up & Ice-out

Frozen Period Shrinking: variability huge

- Freeze-up later by +4 days / decade
- Ice-out earlier by -3 days / decade
- Lake frozen period trend -7 days/decade
- Interannual variability ≈ 50 yr trend
Very Heavy Precipitation Is Increasing

- Precipitation Extremes

- Most of the observed precipitation increase during the last 50 years has come from the increasing frequency & intensity of heavy downpours.

- 71% increase in Northeast

(Walsh et al., 2014)
Wilmington, J. Cantore

Brattleboro, M. Reston

Brattleboro, VT. Courtesy of Caleb Clark, CNN

Wilmington, J. Cantore
TS Irene

Roads in valleys

Massive damage

Some roads took months to repair

*Rte 131, Cavendish
Sept, 2011*
Value of Flood Plains

- Otter Creek after Irene on August 30, 2011
  - River rose ten feet: flood plain saved Middlebury
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**
2011 Floods: VT and NY

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

March-August 2011 Statewide Ranks

March-August, 2011

- Record wet: OH to VT
- Record drought: TX & NM

Pattern nearly stationary
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.
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: $trillions at stake
Growth of CO₂ Emissions
Flat for 3 years

China shifts to renewables

2000–09
+3.4%/yr

China burns coal

1990–99
+1.1%/yr

CO₂ rise

Data: CDiac/GCP/BP/USGS

Projection 2016
36.4 Gt CO₂

2015: 36.3 Gt CO₂

- 3%/year

Need 80%
drop by 2050

Global Carbon Project
What can we “safely” burn?

• Only 750 Gt more for an even chance of keeping warming below 2°C [3.8°F]
• Requires leaving 2/3 of remaining fossil fuels in ground
• Only 21 years left at 36 Gt/year
• Rapid phase-down extends period
Efficiency Comes First

- We need to double or triple our energy efficiency because...
  - We cannot replace current fossil fuel use with biofuels & renewable energy
  - Fossil fuel reserves are enough to push CO$_2$ to 1,000 ppm
    - Radically change climate/wipe out many species
    - Flood coastal cities as icecaps melt: and over centuries raise sea-level >100ft
2015 was Transition Year

• Climate meeting in Paris in December
  – 188 Nations made ‘national commitments’

• Pope Francis encyclical on the environment, climate change and our responsibilities to the Earth
  – Exploitation of the Earth and the poor are inseparable
  – Short-term profit as primary motive is immoral

• 2017: US wants to avoid the commitments it made; China and Europe have to take lead
IPCC Special report (SR15) Oct. 2018

• Paris agreement won’t give 2°C warming
  – So promised to try: “study 1.5 ºC”

• SR15: keeping warming below 1.5 ºC has huge benefits to Earth

• But means massive effort before 2030
  – Reduce emissions by 45% below 2010

• Or consequences large by 2040-2050
Powerful interests are threatened

• Fossil fuels reserves are worth $20-30T
  – Big money: ‘of course we will burn them’
  – Regulating or taxing emissions of CO₂ is an ‘unfair cost to the free market’
  – *(Too bad if the Earth’s ecosystems are destroyed: our kids can pay the price)*

• Our politics are facing collapse: fantasy disconnected from real world
  – *We are all deeply embedded in system*
Step back from dark side

• Practical Local Solutions

• Vermont: some progress (< promised)
  – Large solar development
  – Battery storage coming
    • California installing 100MWh storage units
  – Energy efficiency for homes and businesses underway
  – Need net-zero building codes
  – Need transportation shift
Social and moral shift

• **The Future Is Not Our Past**
  – *an economic, technological and financial system driven primarily by short-term profit*

• **Collectively, we create the future**
  – *Plan for a transition to a sustainable society*
  – *Put community values and systems thinking above short-term profit*
  – *Reconnect with the natural world*

• **Will we turn the ship around?!**
Outreach as scientists

• We face many environmental catastrophes in your lifetime
  – You need awareness, knowledge, vision, skills, resilience, community, grounding in the Earth
  – You will be expected to guide in desperate times, so prepare with an open heart
  – Realize the depth of our interconnections
Traditional Solutions…

• More Science, more solid ‘predictions’
• Better communication of Science
• Hope that policy will catch up
  – But total mismatch of timescales, trends
  – In US, overt corruption increasing

• Earth scientists have a responsibility for the Earth
  (Betts, BAMS 1976)
  – Accept this moral responsibility as a global community of scientists
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 and globally
  – Priceless to societies lost in corruption & deceit

• Challenge is that humanity is embedded in a deeply interconnected living Earth system
  – That cannot be separated and objectified
  – In fact the incompatibility of our social frames with the Earth system is driving climate change
  – Earth system limits need adaptive co-operative global governance that values the future
• 50 years of research papers
• 10 years of newspaper articles
  – Written so a scientist will see them as accurate; transparent to public (art-form)
• 10 years of talks to VT
  – Schools, citizen & business groups
  – I say “Yes” when asked
• I rely on ‘serendipity’
Discussion

alanbetts.com

(Research, talks & articles)