Rapid Climate Change & Impacts:

From Global-to-Local (Manitoba)

Evidence for CEC MMTP hearings 2017

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Thursday May 25, 2017

Executive Summary

Whenever new infrastructure projects of significance are launched in Canada, there must be a federal Environmental Assessment (EA) performed to examine impacts of the project on the environment, and on the people living in that environment. In addition, there are various provincial, municipal and corporate assessment studies performed, including, for example the Environmental Impact Statement (EIS). Historically (and traditionally) these undertakings only examine the local (and sometimes regional) direct effects of the project on the environment during the construction phase, and perhaps extend to considerations over short-term time periods for the initial project operation. More recently, EA and EIS studies have been mandated to account for changes in climate, however up to now the scope of this climate change assessment has been woefully inadequate. To actually be realistic, meaningful and relevant, EA and EIS studies need to also consider the effect of the project both in the near- and long-terms on the overall global climate system. These studies must also ensure that all new projects are built strong enough and resilent enough to withstand the rapid global climate change effects that are quickly worsening.

Analysis and assessment of the carbon footprint of any project needs to consider:

1) Greenhouse gas (GHG) emissions for the construction process.
2) GHG emissions for the operation of the project over its expected lifetime.
3) Indirect GHG emissions that result from the operation of the project compared to no project existing.

Of course we do not want to double count GHGs (both at the mined source and upstream), but we do not want to miss any emissions either. The GHG accounting for the entire project life-cycle, from cradle-to-grave must be complete and accurate, with no unaccounted externalities.

In no EAs and EIS studies that I have seen for any project is there an acknowledgement that climate change is rapidly accelerating and is now a clear and present danger to our existing societies and our way of doing things. We live in a time in which increasingly severe impacts are occurring from our anthropogenic emissions that have changed both the chemistry of our atmosphere and our oceans. The Arctic region is rapidly darkening due to exponential rates of loss of both Arctic sea ice cover and terrestrial snow cover, and the darker surfaces (oceans and permafrost, respectively) are absorbing more solar energy leading to greatly increased warming of the entire northern region (Arctic temperature amplification, whereby the Arctic warming rate is many times faster than the global average). This warming imbalance with latitude, worsening year by year as snow and ice loss in the Arctic accelerates, is disrupting the global air circulation patterns (jet streams are slowing down, becoming much wavier and often getting “stuck” in persistant, long-duration patterns or modes) and the global ocean currents, both of which transfer heat around the planet (two-thirds in the atmosphere and one-third in the oceans).

Changing jet stream behavior means that weather statistics are also changing in our rapidly warming climate. For example, what used to be a one-in-a-hundred year event in our previously stable climate system (i.e. a rare flood or windstorm, with a 1% likelihood of occurring in any given year) may now actually occur every decade (or even every few years), in our new reality of a rapidly changing and unstable climate. Extreme weather events such as torrential rains leading to floods, and droughts in other areas are increasing in their frequency of occurrence, severity, and duration and they are occurring in regions that they never occurred before. This “weather weirding” or “weather whiplashing” is causing severe strain even today on global infrastructure, food and water supplies and thus to global economies. Our life sustaining systems on Earth are being severely threatened on all levels by these rapid changes in our atmosphere and oceans from fossil fuel emissions, and there is usually no mention of this new reality in our environmental impace studies and assessments, let alone acknowledgement of the great risks that humanity faces in this new rapidly changing climate system reality.

In this report I give an overview on the very latest climate change acceleration globally, continentally, and regionally (with emphasis to Manitoba). I provide clear and alarming scientific evidence that our climate system is undergoing abrupt changes that threathen our lifestyles in the near term. Given this reality, it is imperative that we consider the implications to and from abrupt climate change on all of our new infrastructure projects.

Climate Change and Impacts: Introduction

The aim of this report is to show the vital importance of being realistic about new large infrastructure projects in our existing reality of abrupt climate change. In order to do this, the report must first attempt to establish, using the very latest scientific observation of our climate that we are in a period of extremely rapid nonlinear change in our overall climate system. Specifically, I provide information on the latest alarming trends in global greenhouse gas atmospheric concentration levels, global average temperatures, Arctic climate with enormous temperature amplification, jet stream behaviour and the impact on extreme weather events, rising methane emissions from terrestrial permafrost and sea-floor sediment thawing, northern hemisphere versus southern hemisphere differences, and I make so simple trend-based projections of what we can expect to happen in the near future, over the next decade or so.

Once the idea that we are in abrupt climate change is presented, with the strongest case possible, I then discuss what these global changes mean for the specific region of Manitoba and attempt to give people the tools to examine how the climate will affect individual towns and locales where new project infrastructure is being proposed. The following sections, comprising the bulk of this report provide substantive scientific evidence, via observations and not models on how rapidly our climate system is changing, and the implications to society. Numerous diagrams are used, since they are easier to understand and provide unambiguous, undeniable evidence on the reality of our rapidly changing climate system.

Manitoba Hydro: Manitoba-Minnesota Transmission Project; Temperature Rise from Climate Change

The map in Figure 1 gives an overview of the lakes and rivers in Manitoba. The region of our focus is in the far south-eastern part of Manitoba, from Winnipeg down to the U.S. border at the state of Minnesota.

Figure 1: Map of Manitoba http://homer.ca/maps/manitoba.htm

The more detailed map in Figure 2 shows the Manitoba water basins and watershed boundaries. The Manitoba Hydro MMTP (Manitoba-Minnesota Transmission Project), which starts near Winnipeg, is located entirely in the Red River Basin. The final preferred route of the MMTP is shown in Figure 3.

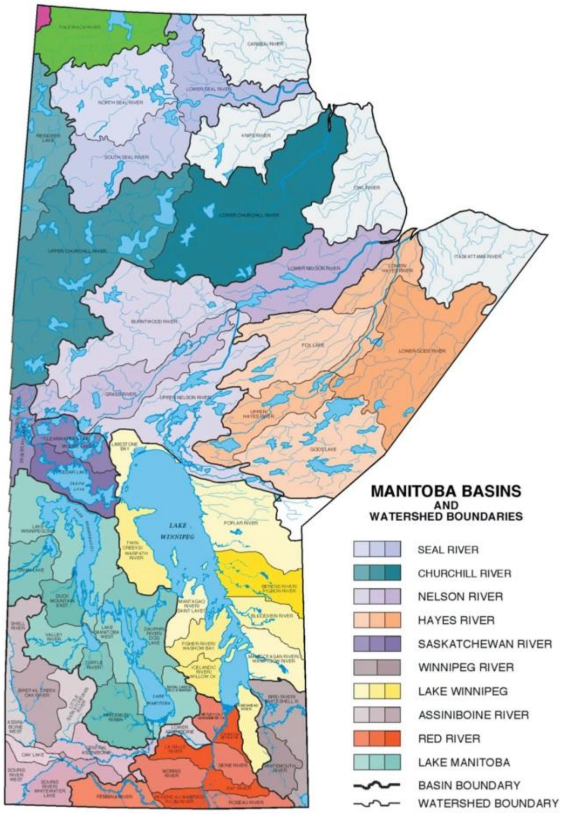


Figure 2: Manitoba Basins and Watershed Boundaries
https://www.gov.mb.ca/mit/floodinfo/floodoutlook/watersheds_data_maps.html

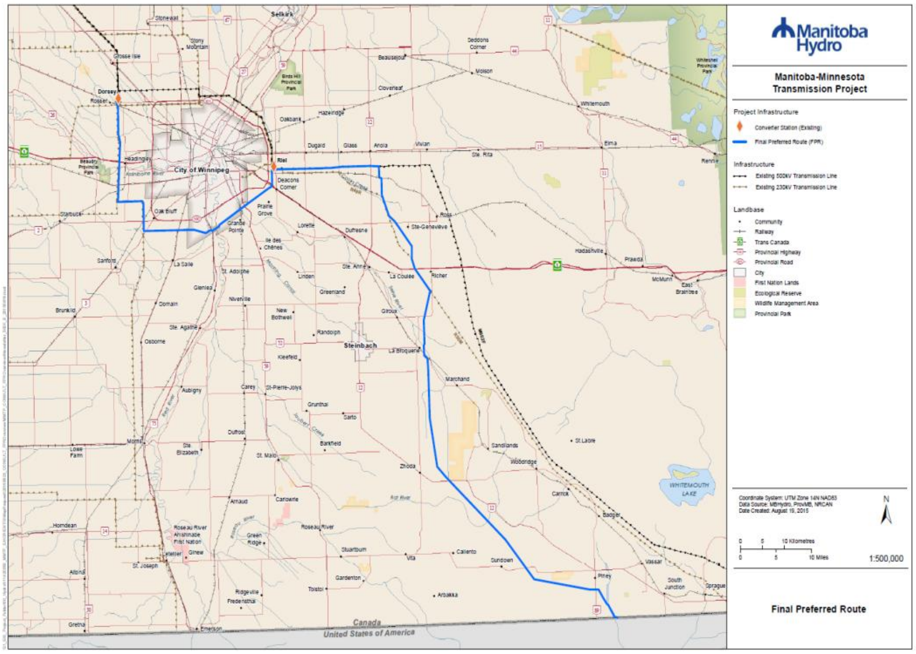


Figure 3: Final Preferred Route of Manitoba-Minnesota Transmission Project (MMTP)
https://www.hydro.mb.ca/projects/mb_mn_transmission/pdfs/mmtp_final_preferred_route_map_sept_2015.pdf

The plot in Figure 4 shows the average annual temperature in Manitoba from 1950 to 2015. Although there is quite a lot of variability, the clear trend indicates that the overall average annual temperature in Manitoba has increased by about 2.2°C over the past 65 years. The map in Figure 5 shows how global warming is expected to continue over various regions throughout Manitoba. Note that the region around in south-east Manitoba near Winnipeg is expected to warm by up to 10°C over the coming century.

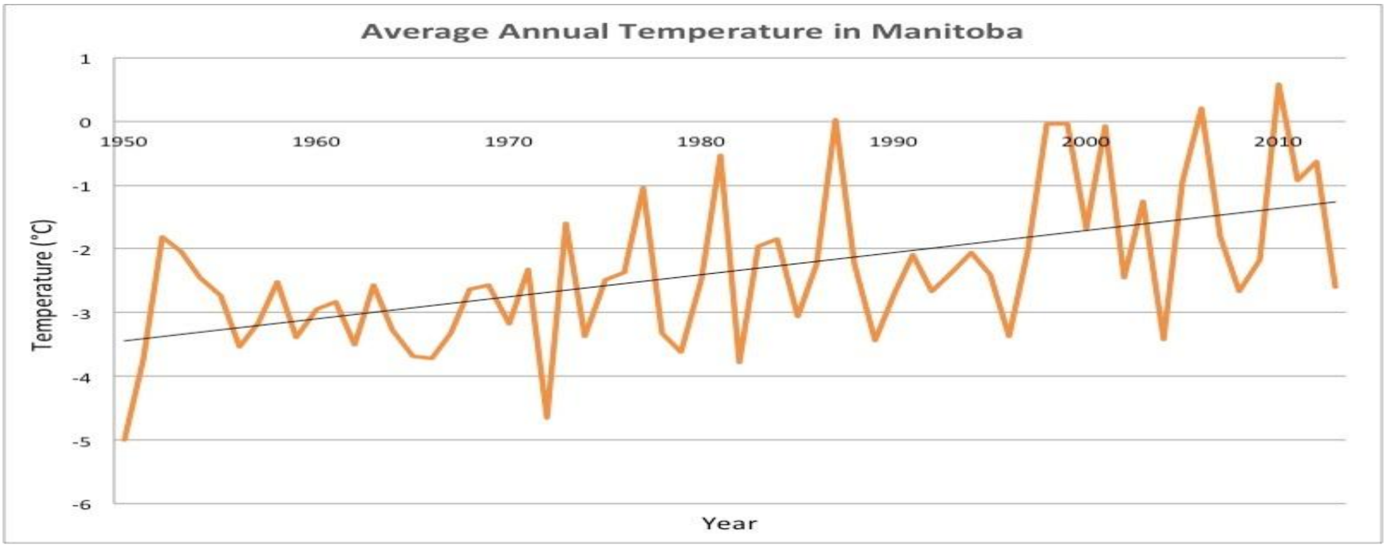


Figure 4: Average Annual Temperature in Manitoba from 1950 through 2013.
http://prairieclimatecentre.ca/2016/07/this-aint-your-grandparents-climate/

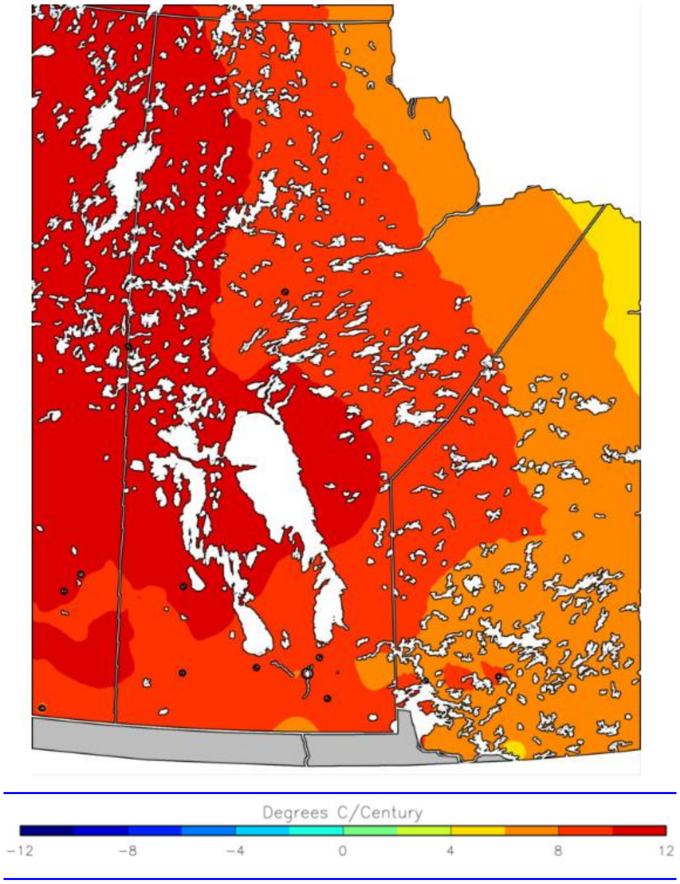


Figure 5: January Mean Temperature Trend from 1950 through 2013.
http://prairieclimatecentre.ca/2016/07/this-aint-your-grandparents-climate/

New Weather Statistics in our Rapidly Changing Climate System

Human emissions have changed the chemistry of our atmosphere and oceans, and we are now seeing enormous consequences from this. Since the Arctic temperature amplification (5 to 8 times greater than the global average in the high Arctic, due to darkening from exponential loss of sea-ice and terrestrial snow cover) has lowered the temperature gradiant to the equator, the jet stream behavior has been disrupted. Thus, the weather statistics have changed completely. Extreme weather events, such as torrential rains leading to floods in some regions, windstorms leading to infrastructure damage, heat waves and droughts in other regions) are now occuring: a) more often, and b) they are more severe and destructive, c) they are lasting longer, and d) they are often happening in new places (where they did not occur, i.e. large amounts of snow in the Atacama desert which is the driest place in the world).

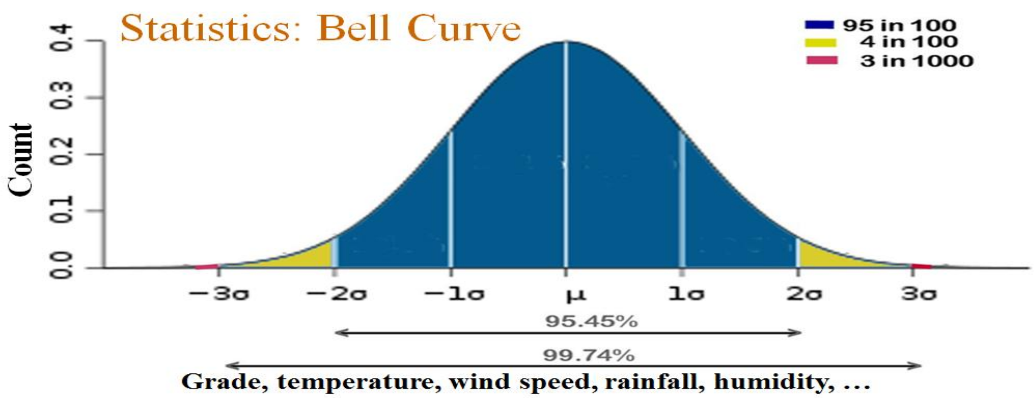


Figure 6: Bell Curve (also known as the Normal Distribution); fundamental to statistics. On the vertical axis there is Counts, or number of times something happens (frequency of occurrence). On the horizontal axis is the parameter that we are examining, for example school grade in a class, temperature, wind speed, rainfall amounts, humidity, etc.; namely any measurable weather parameter, in our case.

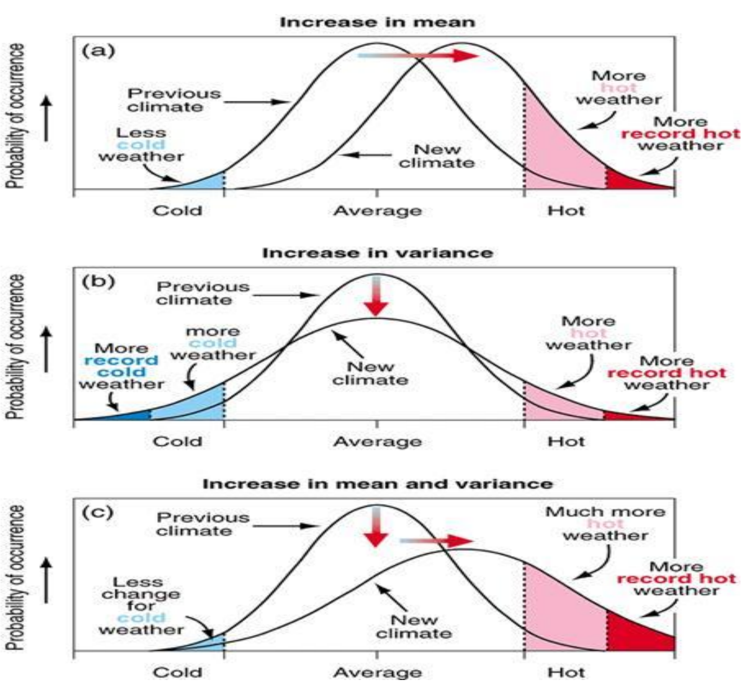


Figure 7: Bell curve changes from old stable climate ("previous climate") to "new climate". There can be changes in the a) mean, b) variance and c) both mean and variance. Note that the area under the curve determines the total number of events that occur for the given category (i.e. record hot weather).
http://esseacourses.strategies.org/module.php?module_id=181

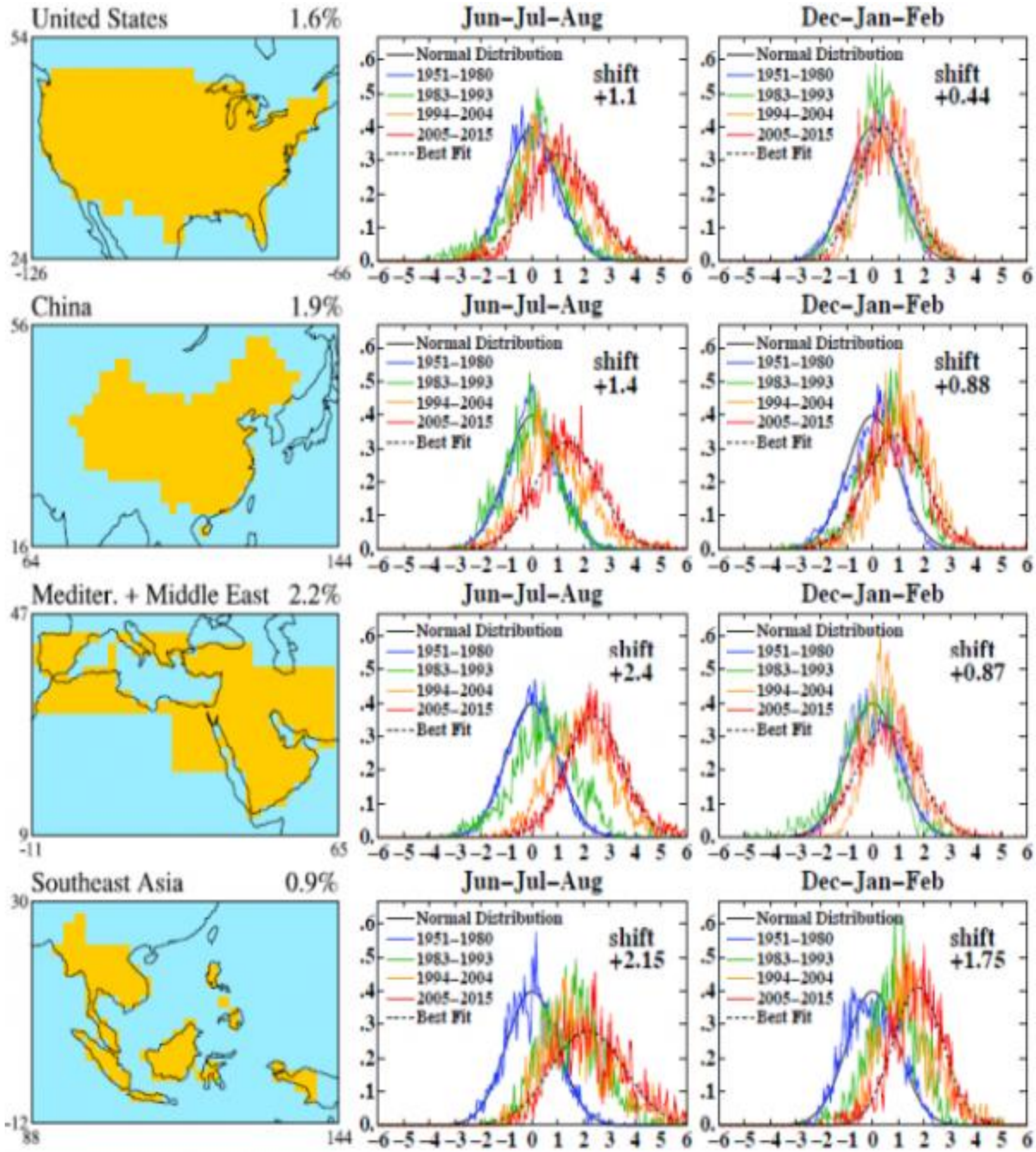


Figure 8: Shifting distribution of summer temperature anomalies (Jun-Jul-Aug) and winter temperature anomalies (Dec-Jan-Feb) for the United States, China, Mediterranean and Middle East, and for Southeast Asia over various decades since the 1970s. http://csas.ei.columbia.edu/2016/02/29/regional-climate-change-and-national-responsibilities/

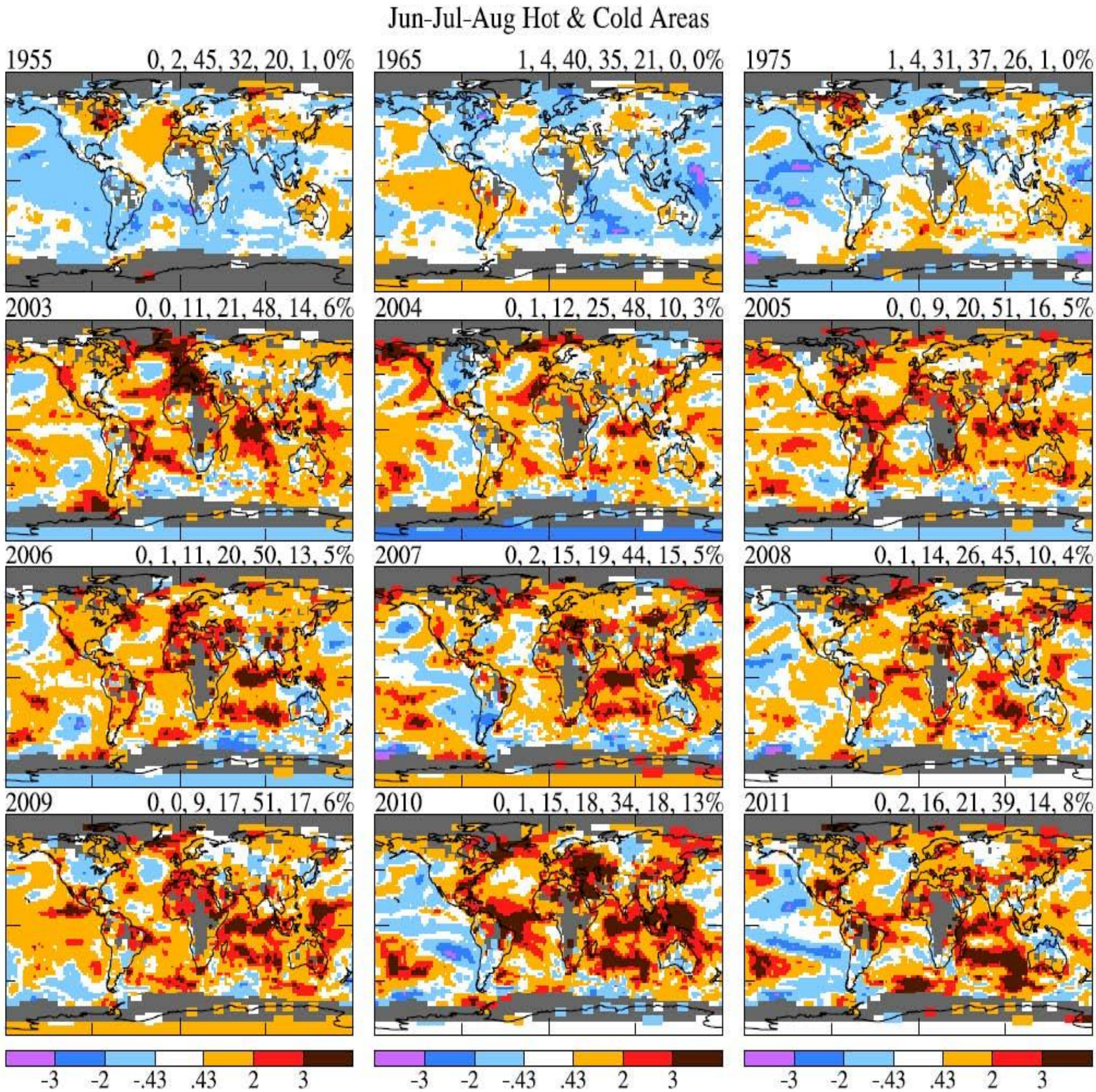


Figure 9: Jun-Jul-Aug *surface temperature* anomalies in 1955, 1965, 1975 and 2003-2011 relative to 1951-1980 mean temperature in units of the local standard deviation of temperature.
https://www.skepticalscience.com/Summary-of-Hansen-Nov-2011.html

Our Global Climate System: Joining-the-Dots

A combination of human fossil-fuel combustion increases and increased rates of land-use change (with urban and agricultural regions replacing forests) → (implies) atmospheric greenhouse gas concentrations or GHGs (mainly CO_2, CH_4, and N_2O) are quickly rising at ever increasing rates (basically exponentially) → Earth is rapidly warming → 7% increase in water vapor in the atmosphere per 1°C average temperature rise from greater surface water evaporation → even more warming → rapid decline in Arctic sea-ice and snow cover & faster Greenland ice-cap melting → Arctic surfaces become darker → more sunlight is absorbed → northern regions warm faster than the global average by 5x to 8x in high Arctic latitudes → decreased equator-to-Arctic temperature difference → less heat moves from the equator to the pole in the:

a) atmosphere: namely, the jet streams slow, become wavier and are often "stuck" → extreme weather events are a)more frequent, b)stronger, c)last longer and d)occur where they never used to occur.

b) oceans: stratification (layering from higher surface temperatures) and acidification kills off life throughout the entire marine food chain → reduces vertical mixing, thus nutrient upwelling as well as oxygenation → ocean currents such as the Gulf Stream slow down → large sea level rise floods coastlines, at faster rates on the east coast of North America, for example.

In this abrupt climate change scenario, we very quickly reach a world with no sea ice cover in the Arctic, initially at the end of the summer melt season and rapidly expanding in duration in the so-called "blue Arctic ocean" event. Methane emissions from the terrestrial permafrost and marine sediments increase, leading to a series of cascading feedbacks that further amplify the warming.

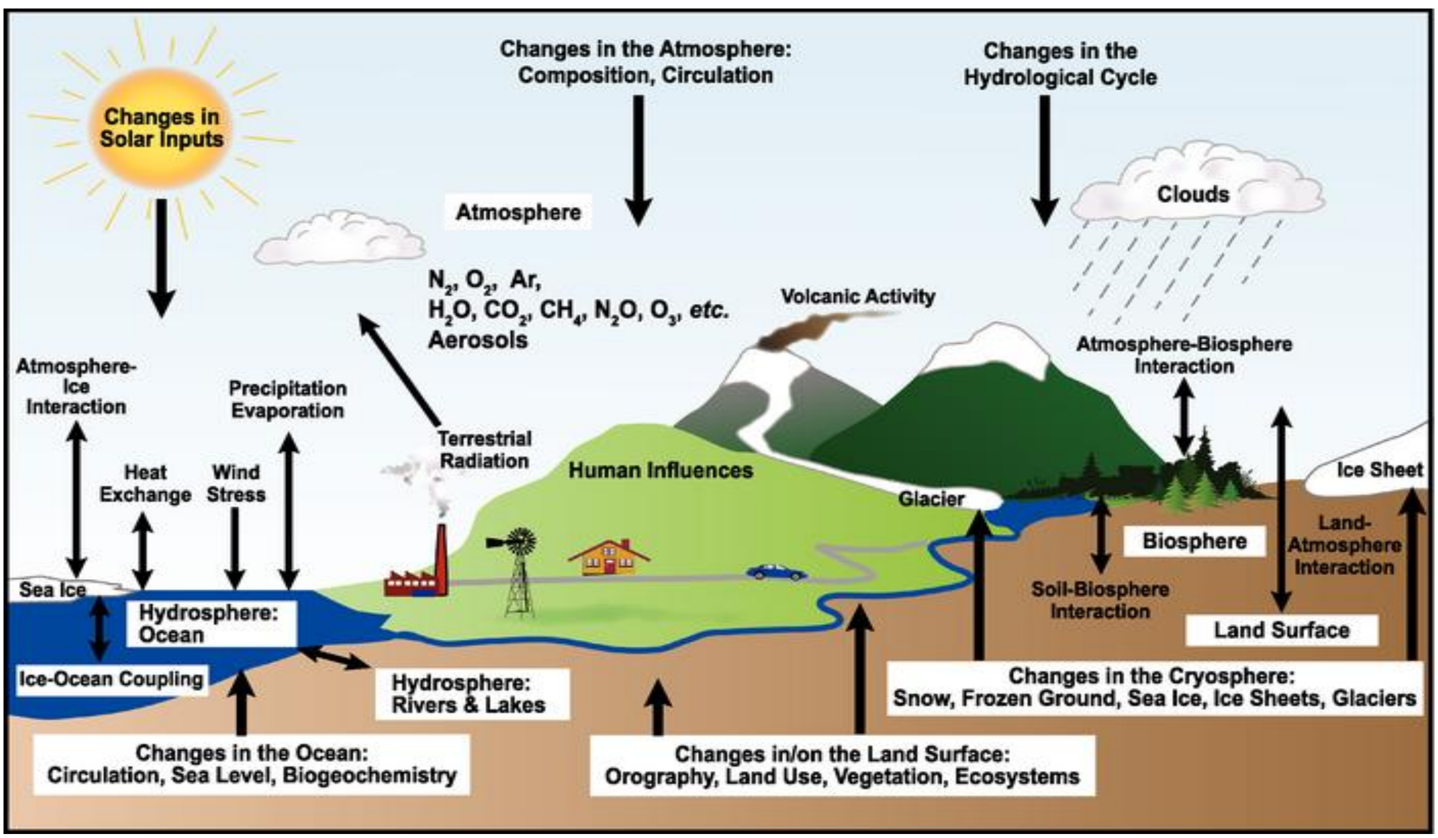


Figure 10: Earth Climate System Interconnections on Human Timescales.
Image source is the Intergovernmental Panel on Climate Change, Assessment Report 4, Working Group 1, Chapter 1 from 2007 (IPCC:AR4, WG1, Ch. 1, 2007)

Public Access to Near Real-time Climate and Weather Data

There is an enormous amount of climate and weather data available, in easy to understand and access formats. A large concern is that much of it is from the U.S. and in a Trump era we may lose access to this data, and would then be "flying blind" as the climate rapidly changes around us. Following are some key websites to access near real-time (from the day before, or even from the last few hours) climate and weather data:

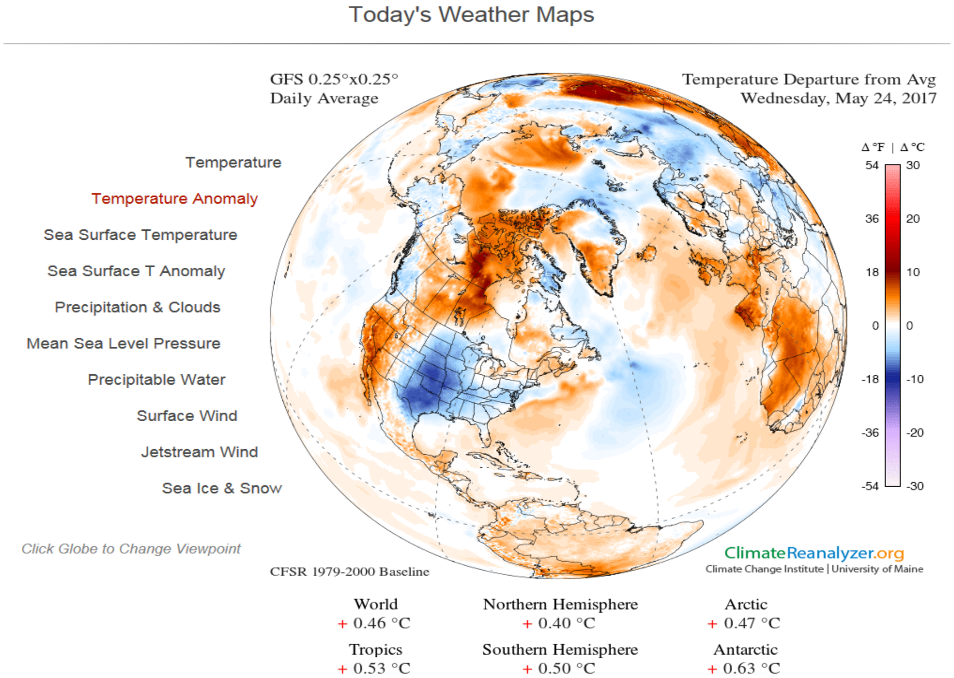


Figure 11: Temperature departure from the average (1979 to 2000 baseline) at all locations on the Earth. From Climate Reanalyzer, a University of Maine website http://www.cci-reanalyzer.org/

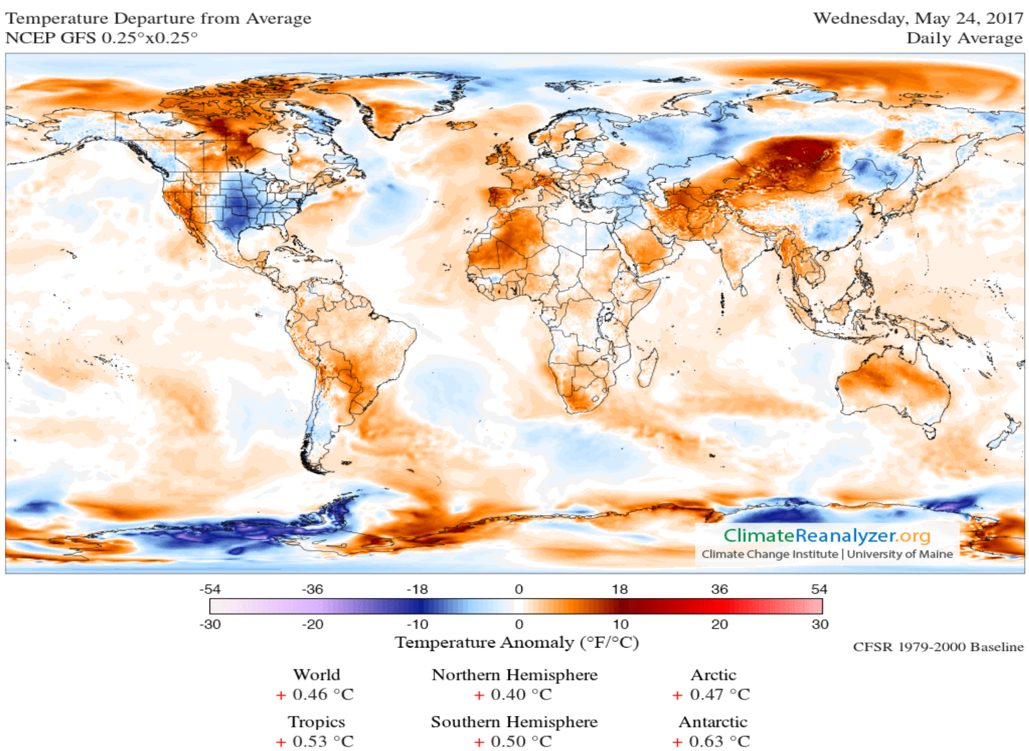


Figure 12: Temperature departure from the average (1979 to 2000 baseline) at all locations on the Earth. From Climate Reanalyzer, a University of Maine website http://www.cci-reanalyzer.org/

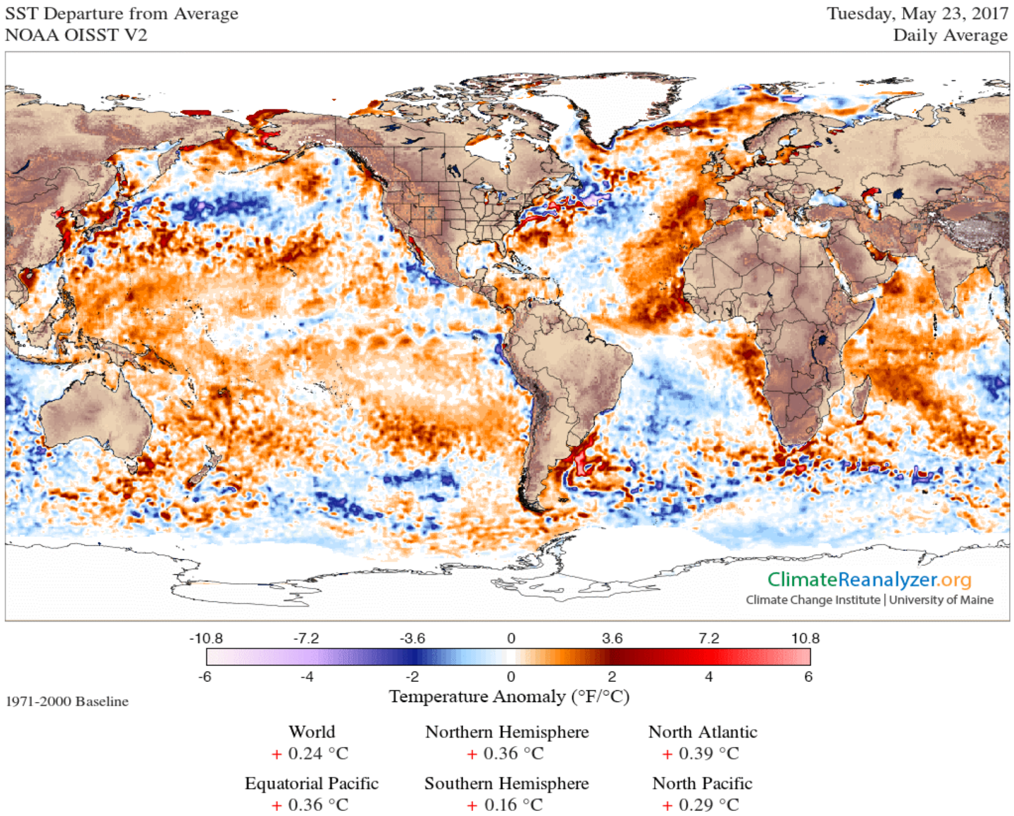


Figure 13: Sea-surface temperature (SST) departure from the average (1979 to 2000 baseline) at all locations on the oceans on Earth. From Climate Reanalyzer, a University of Maine website http://www.cci-reanalyzer.org/

The images on the above three figures (Figures 11 to 13) are from the Climate Reanalyzer University of Maine website. As rapid climate change proceeds, one can easily deduce that there are becoming more "clumpy" patterns in the images, with regions that are very warm in close proximity to areas that are very cold, as opposed to a more uniform situation.

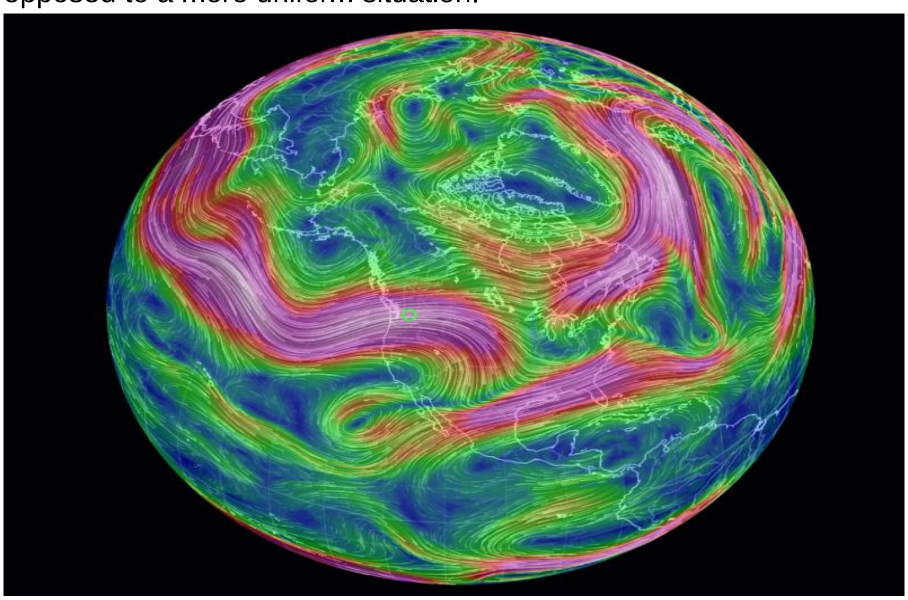


Figure 14: An image from Earth Nullschool showing the high altitude (atmospheric pressure is 250 mb) jet streams encircling the Earth (higher windspeeds are represented by the pink color). From the website you click on the text "Earth" on the lower left corner to access various menus to display any weather data that you want to examine. https://earth.nullschool.net//

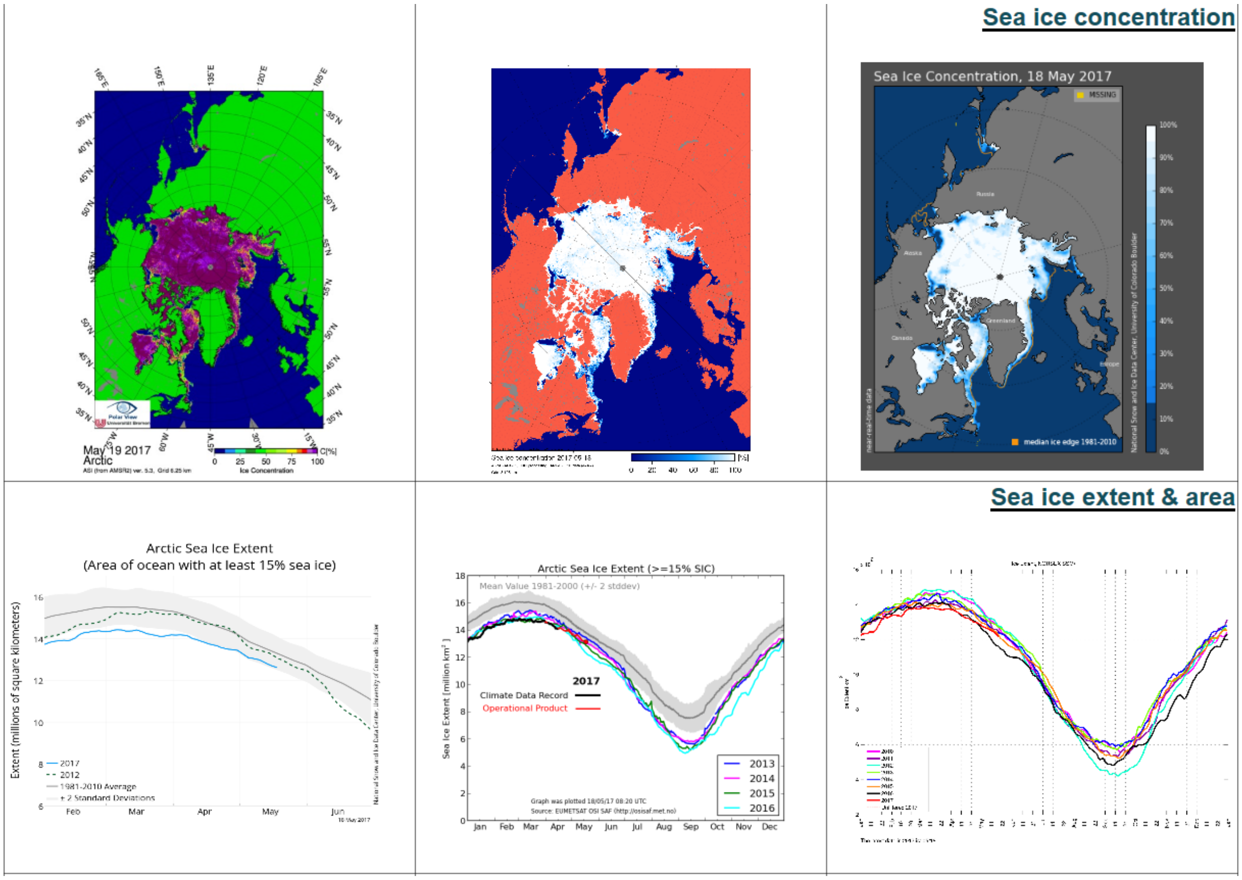


Figure 15: Near real-time satellite measured data from the Arctic region. The top three images display the Arctic sea ice concentration (100% means solid ice, 0% means no ice), while the plots on the bottom show the Arctic Sea Ice Extent (defined as the area with at least 15% sea ice) and the Arctic Sea Ice Area (defined as the area with 100% sea ice). All of these images can be obtained from the googling the Arctic sea ice graphs website: https://sites.google.com/site/arcticseaicegraphs/

Rate of Rise of Atmospheric Greenhouses Gases are Accelerating

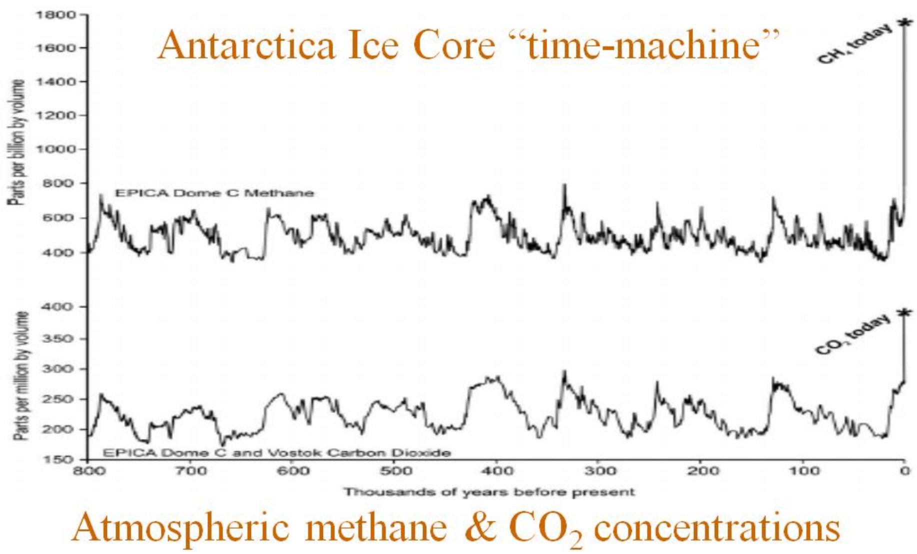


Figure 16: Atmospheric concentrations of methane (CH_4) and carbon dioxide (CO_2) for the last 800,000 years as determined by measurements of air bubbles in ice cores drilled through the thickest parts of the ice sheets in Antarctica.

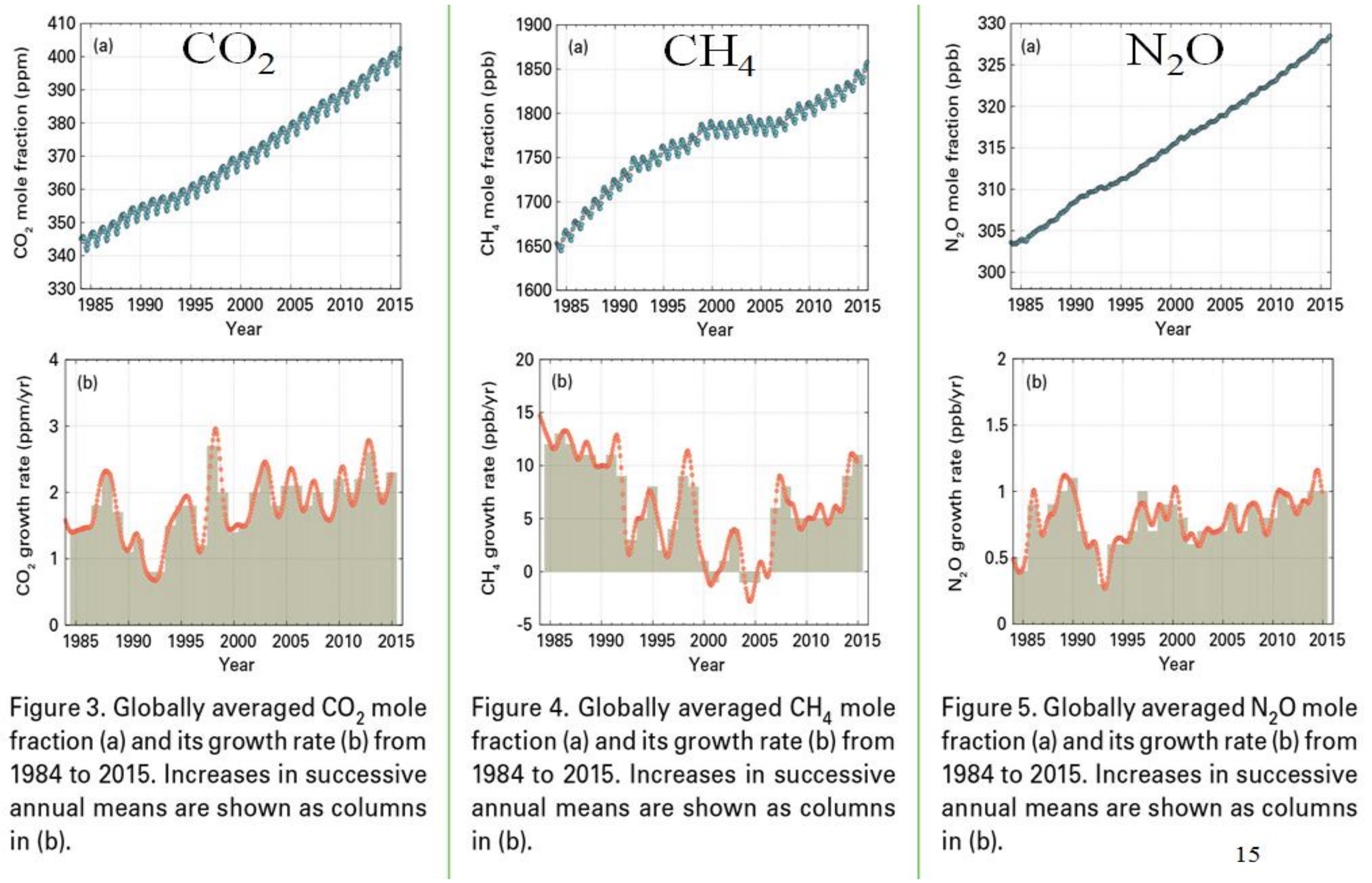


Figure 17: Atmospheric concentrations of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) from 1984 to 2015. The upper plots show the concentrations, while the lower plots show the yearly growth rate of the concentrations.

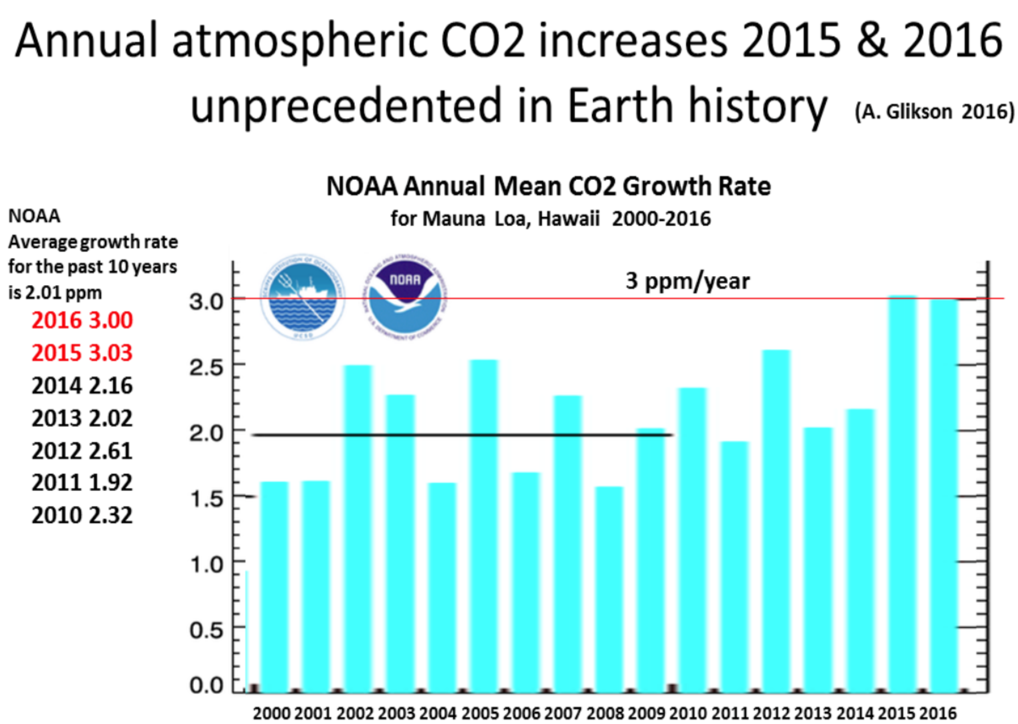


Figure 18: Growth rates of CO2 in the atmosphere since 2000. Note record levels of rise in the last two years.

From Figure 16 to 18 we can see that greenhouse gases in the atmosphere are rising very rapidly. Specifically, CO_2 and CH_4 are undergoing record rates of rise; in fact CO_2 rose an unprecedented 3.05 ppm in 2015 (off the graph) and although expected “a priori” to rise as much as 3.5 ppm in 2016 based on the beginning of that year, the yearly 2016 rise ended up at 3.0 ppm. Oxygen isotopes in the frozen water of the ice cores allow us to determine global air temperatures at the time the ice was formed, while counting the ice layers allows us to determine dating intervals back 800,000 years from the thickest ice sheets in Antarctica

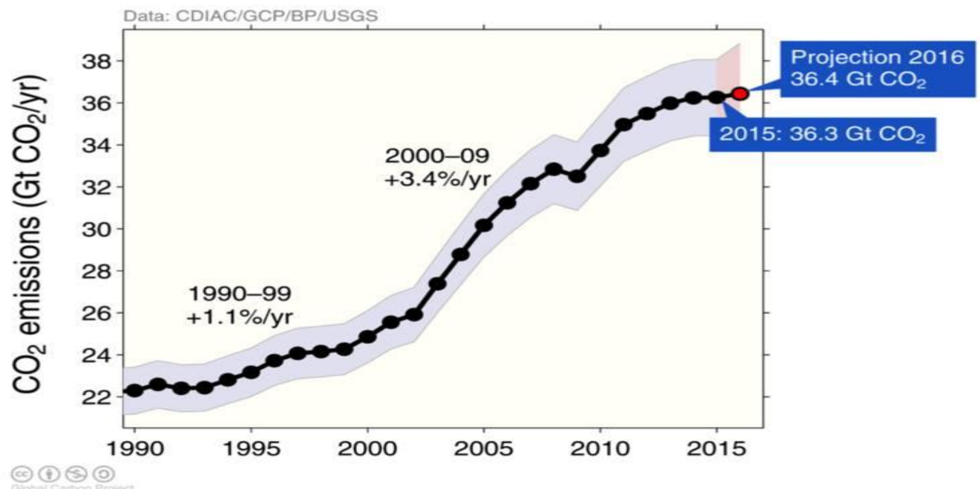


Figure 19: Global CO_2 emissions each year from 1990 onward, from human (anthropogenic) sources only.

Referring to Figure 19, we can note that the yearly CO_2 emission level rise from humans (anthropogenic) has levelled off over the last 3 to 4 years. Although this is very good news on the surface, it makes the record-breaking rises being measured in the atmosphere (as discussed previously for Figure 18) even worse news, since the implication is that our vast and natural global sinks of carbon, such as the terrestrial vegetation (notably rain forests, northern boreal forests), and ocean dissolution, and phytoplankton levels are absorbing less carbon, and becoming smaller sinks. Clearly, this means that if we do not urgently slash fossil fuel emissions fast enough, there is an enormous risk that the release of carbon from our reservoirs concurrently with the reduction of the Earth’s natural carbon sinks will overwhelm our meagre efforts to halt abrupt climate change.

Global Mean Surface Temperatures are Accelerating Upward

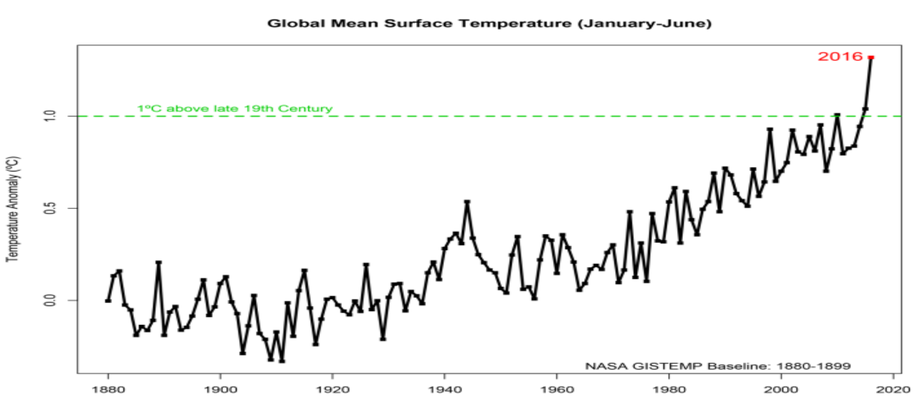


Figure 20: Global mean surface temperature anomaly from 1880 to June 2016. The baseline (0.0 on the vertical axis is the average temperature between 1880 and 1899.

Note this very important and mostly overlooked point on temperatures:
The Paris climate conference (COP21) temperature targets that are widely disseminated and cited are for maintaining global average temperatures below 2°C (with an aspiration to stay below 1.5°C) **relative** to baseline temperatures in 1750 (considered as the pre-industrial era). Thus, in order to compare temperatures in Figure 20 to the temperatures widely cited from COP21, one must **ADD** 0.15°C to the late 19th century values in order to get the temperature rise **relative** to pre-industrial 1750. We must compare apples-to-apples when we discuss temperature rise that is an upper limit for humanity. In Figure 21 and Figure 22 the annual mean surface temperatures are given relative to the 1951-1980 average, which necesitates the use of another correction factor to **ADD**, since this average is higher than the late 19th century average by 0.3°C (see figure captions on these plots).

Also note that for northern countries, such as Canada the temperature increases are higher than those increases in global average temperature. For example, if global average temperature rise was 1°C above pre-industrial, then the temperature rise in much of Canada (including Manitoba) is at least 2°C (i.e. at least double the global average). Northern Manitoba will warm faster than southern Manitoba, in general.

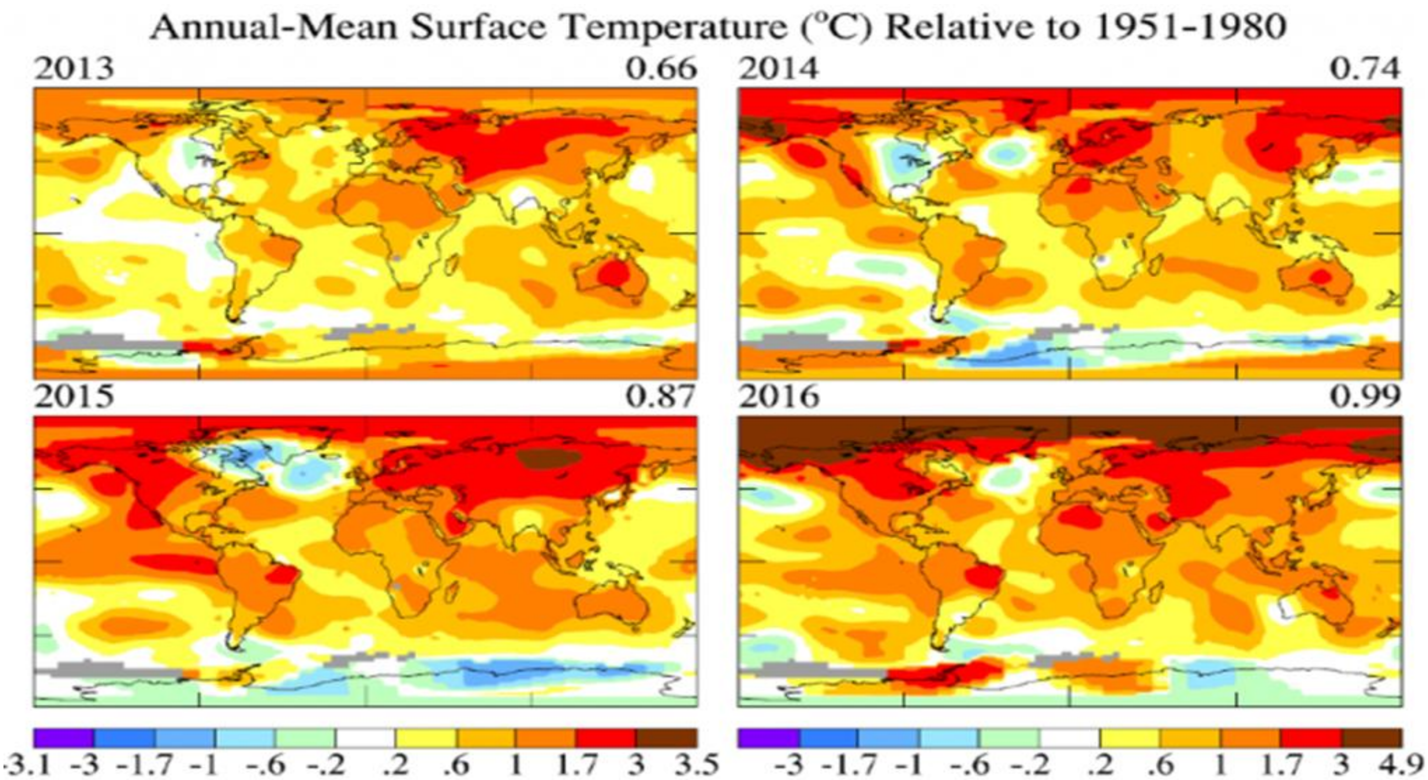


Figure 21: Maps for four different years show the annual mean surface temperature (°C) across the Earth relative to the baseline (1951 to 1980 average temperature). The number on the top right of each map shows the global average in the given year relative to the baseline; for example the 2016 average global temperature was higher than the baseline (1951-1980 average temperature) by 0.99°C. Note that the 1951-1980 average temperature is higher than the 1880-1910 average temperature by 0.3°C; and the baseline 1880-1910 average temperature is higher than the pre-industrial (1750) temperature by 0.15°C.

In conclusion we calculate that last year (2016) the global average temperature was higher than the pre-industrial (1750) temperature by 0.99 + 0.30 + 0.15 = 1.44°C, which is fast approaching the 1.5°C aspirational temperature from the Paris COP21 climate conference.

It is also very important to note that Canada (like all other northern countries) is warming much faster than global averages; the higher in latitude you go in Manitoba, the faster the warming rate that occurs.

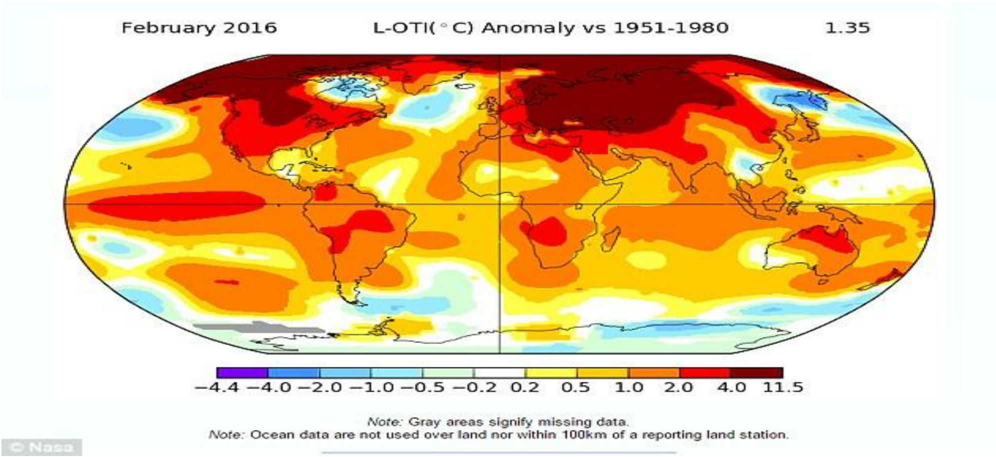


Figure 22: The mean surface temperature (°C) across the Earth for the month of February 2016 relative to the baseline 1951-1980 average temperature. The number on the top right of the map is the global average in the given month of February 2016 relative to the baseline 1951-1980 average temperature, in this case warmer by 1.35°C. Since the 1951-1980 average temperature is higher than the baseline 1880-1910 average temperature by 0.3°C, and the baseline 1880-1910 average temperature is higher than the pre-industrial (1750) temperature by 0.15°C; we can calculate that the average February 2016 global temperature was higher than the pre-industrial (1750) temperature by 1.35 + 0.30 + 0.15 = 1.8°C. This is frighteningly above the COP21 aspiration of 1.5°C and is fast approaching the 2.0°C safe temperature limit.

The plot in Figure 20 shows that the global mean surface temperature of our planet spiked to record high levels in the first 6 months of 2016, and is showing unprecedented increases. The Figure 21 plot showed that the average temperature for 2016 was 1.44°C above pre-industrial, while the entire month of February 2016 was 1.8°C above pre-industrial. In fact, in February 2016 there were clusters of a few days where the global average temperature was higher than the 1951-1980 average by 1.50°C, and when corrected gives a value higher than pre-industrial by 1.95°C. Startling since Paris has a 2°C safe target, with aspiration to be below 1.5°C. An emergency situation, in fact…

Arctic Temperature Feedbacks Cause Exponential Decline in Arctic Sea-Ice

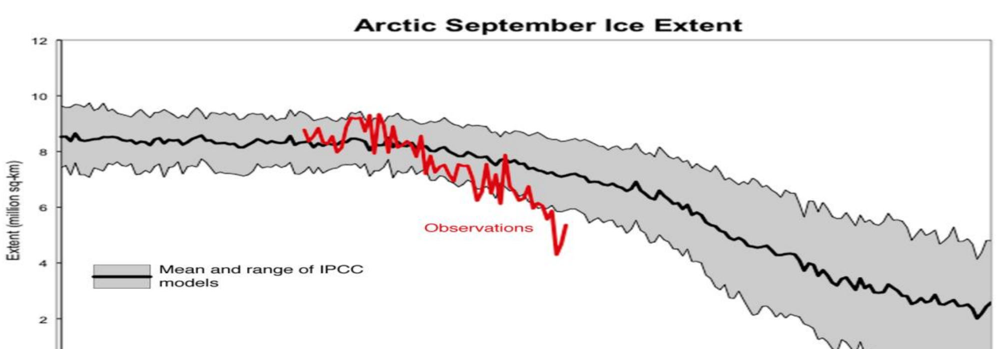


Figure 23: September sea-ice extent in the Arctic. The observed sea-ice decline (red line) is occurring much more rapidly than the computer modelled declines (mean (black line) and range (grey region)) for the ensemble of all of the IPCC (Intergovernmental Panel on Climate Change) climate models. This plot is from the Copenhagen Diagnosis Report (2012).

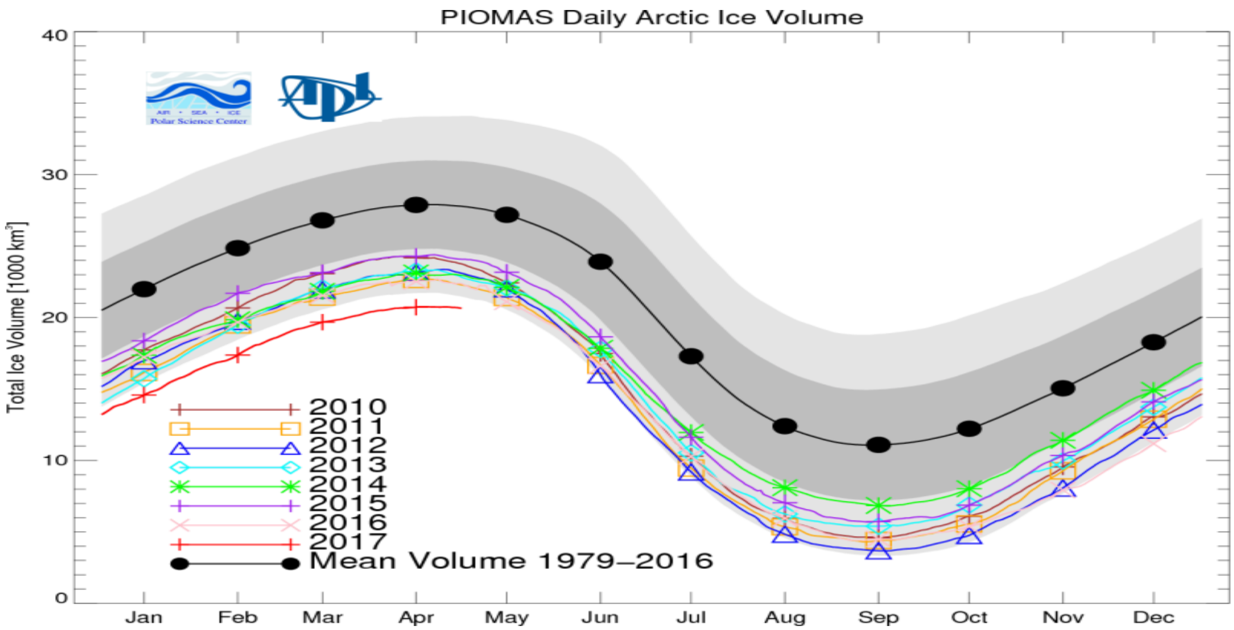


Figure 24: Daily Arctic sea-ice volume plotted on an annual basis for selected years, as determined from a hybrid satellite data (for area) and thickness model (PIOMAS). Note that ice volume = area x thickness. Note how the ice volume for 2017 is much lower than that in any other year. Plots are easily found by Googling "Arctic Sea Ice Graphs", as mentioned previously.

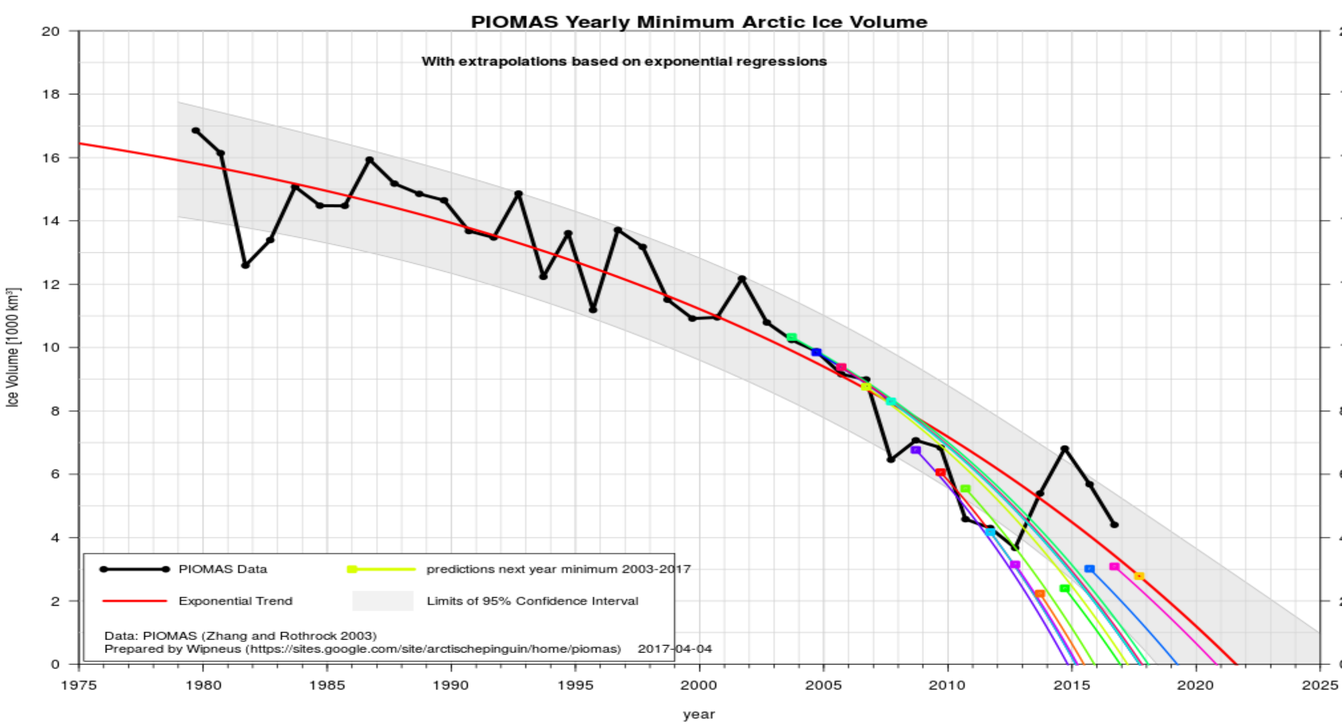


Figure 25: Yearly minimum Arctic sea-ice volume plotted from 1975 to present. Notice the strong downward trend in ice volume, matching quite well to the exponential trend line (black). The colored lines are exponentially declining trend lines taken from a given starting point. For example, an exponential best fit line over all the years shown predicts that the Arctic sea-ice would completely vanish by the summer of 2021 (red line). If a trend line was taken after the sharp decline in volume in 2012, then the prediction for complete loss of sea ice at the minimum is for summer (September) this year (2017).

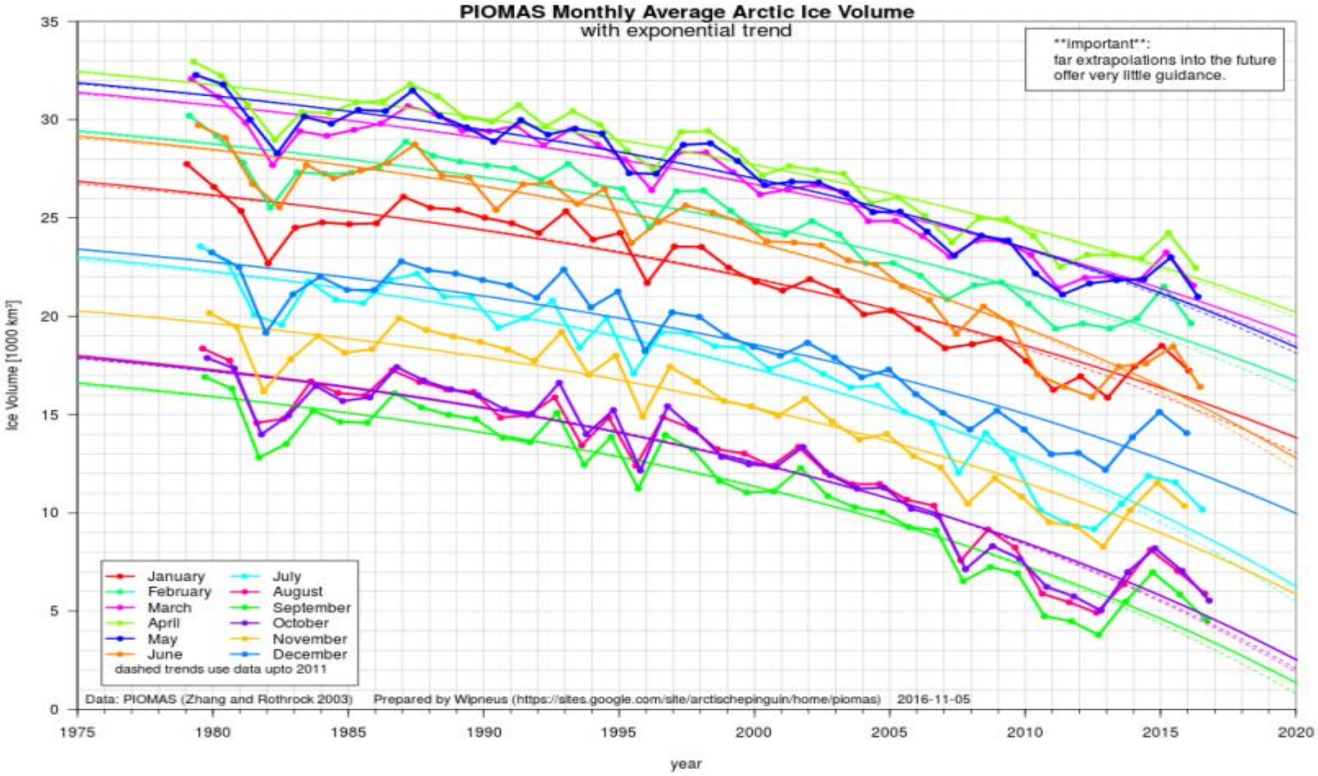


Figure 26: Annual, monthly average ice volumes with fitted exponential trend lines for each month of the year. Notice that the lowest green line is for the month of September, and matches the black line in Figure 25.

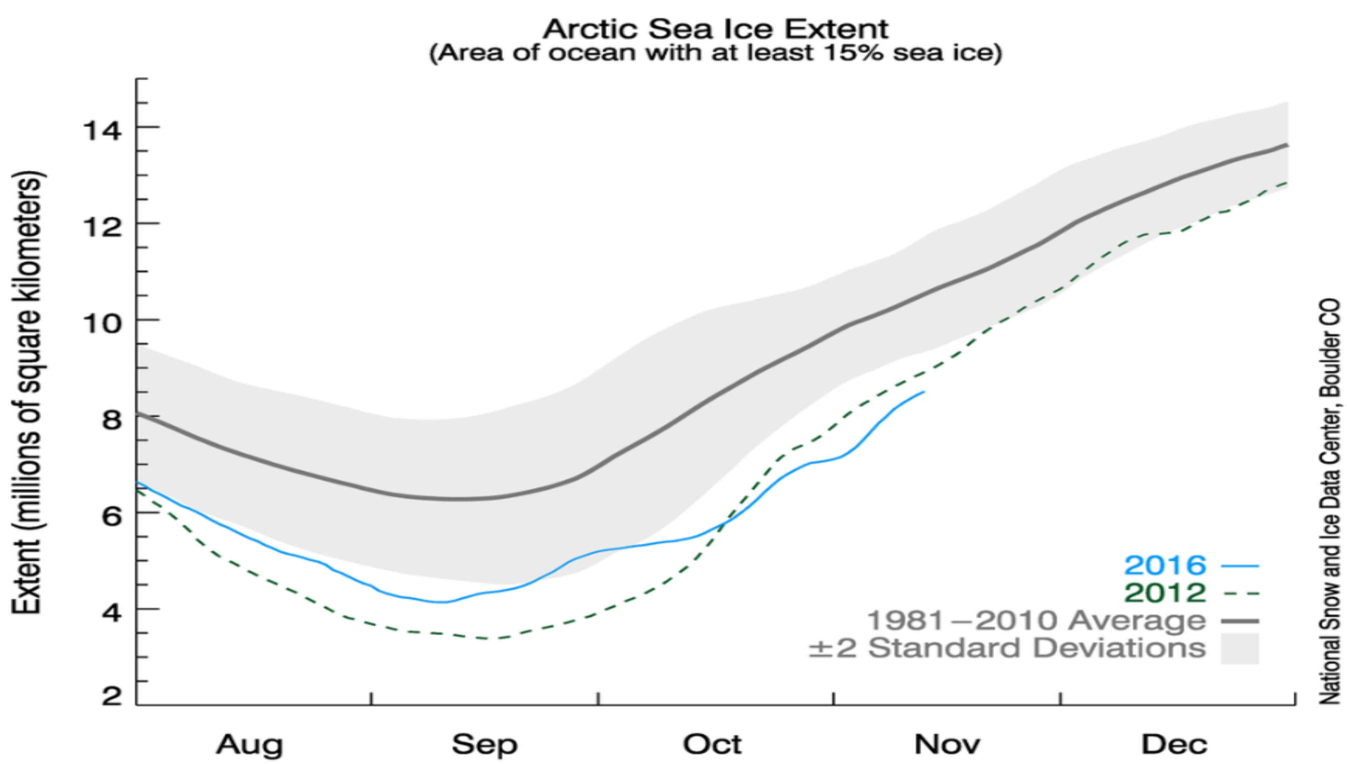


Figure 27: Arctic sea-ice extent from the NSIDC (National Snow and Ice Data Center), updated in near real-time and easily accessed from the one-stop-shopping "Arctic sea-ice graphs" website.

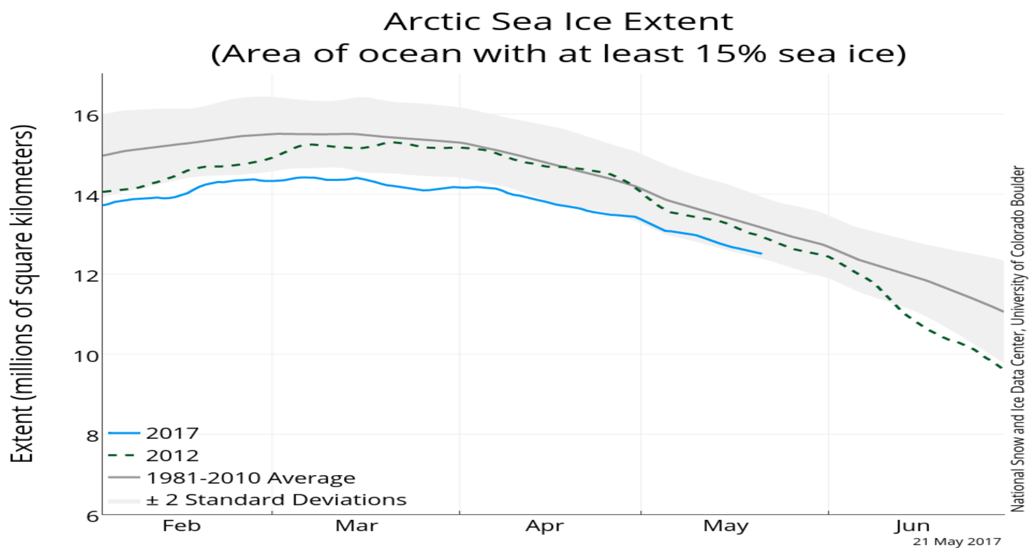


Figure 28: Arctic sea-ice extent from the NSIDC (National Snow and Ice Data Center), updated in near real-time and easily accessed from the one-stop-shopping "Arctic sea-ice graphs" website.

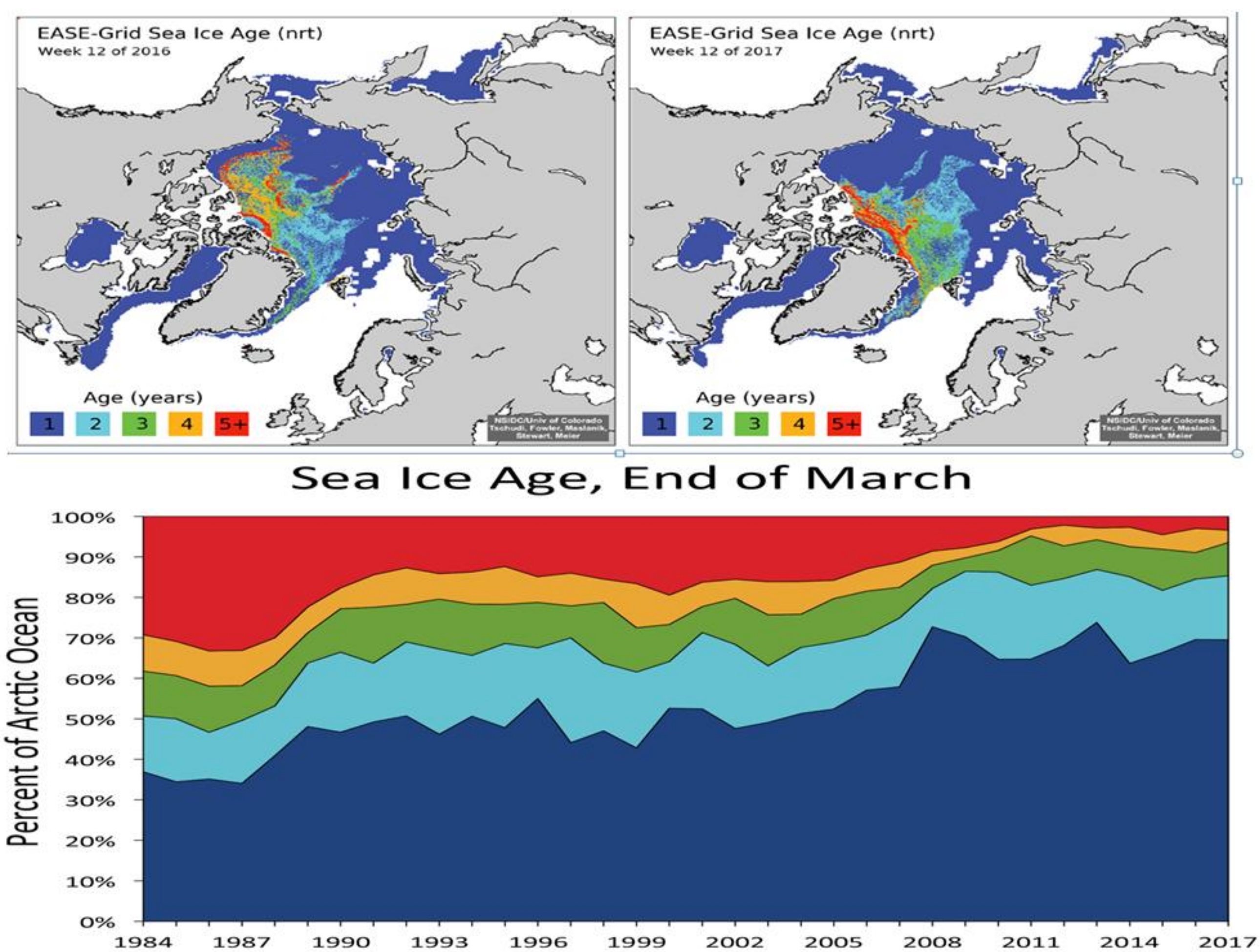


Figure 29: Arctic sea-ice age declines. Age of the sea ice in years is color-coded. The top-left map is for week 12 of 2016, while the top-right is for week 12 of 2017. The lower plot shows the rapid decline of old ice in the Arctic. Accessed from the one-stop-shopping "Arctic sea-ice graphs" website.

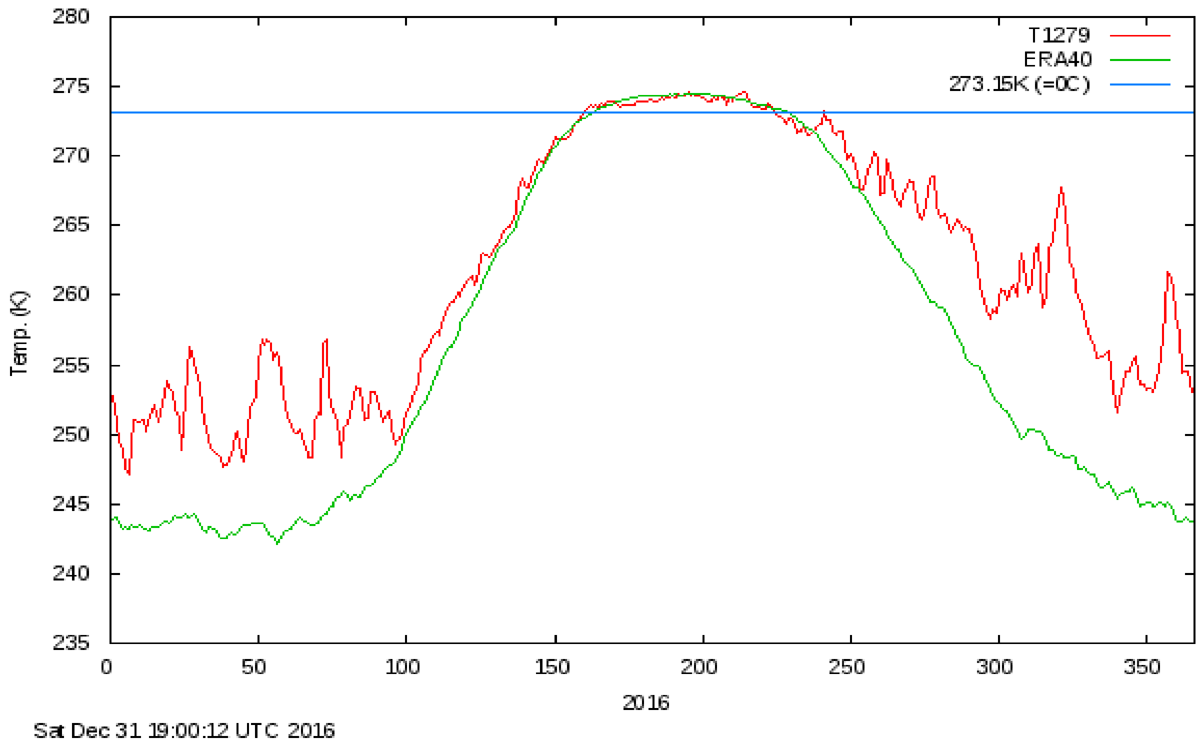


Figure 30: Arctic region temperature (in Kelvin) above latitude 80°N for 2016 (Julian Days are on the horizontal axis; 1 is January 1st and 365 is December 31st) as compared to the long-term average (green line). The temperature peaked at over 20°C above average in November 2016, meaning that it was still "essentially summer" in the Arctic at that time last year. Data is from the website http://ocean.dmi.dk/arctic/meant80n.uk.php

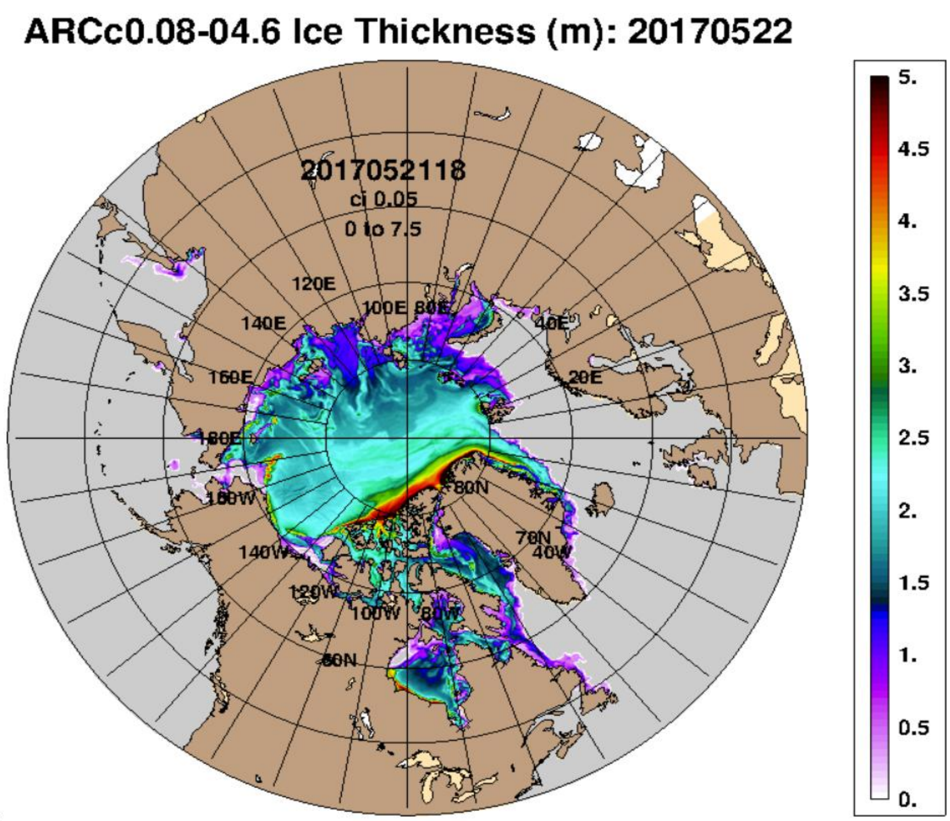


Figure 31: Up-to-date daily information on Arctic sea ice thickness from the U.S. Navy: https://www7320.nrlssc.navy.mil/hycomARC/arctic.html

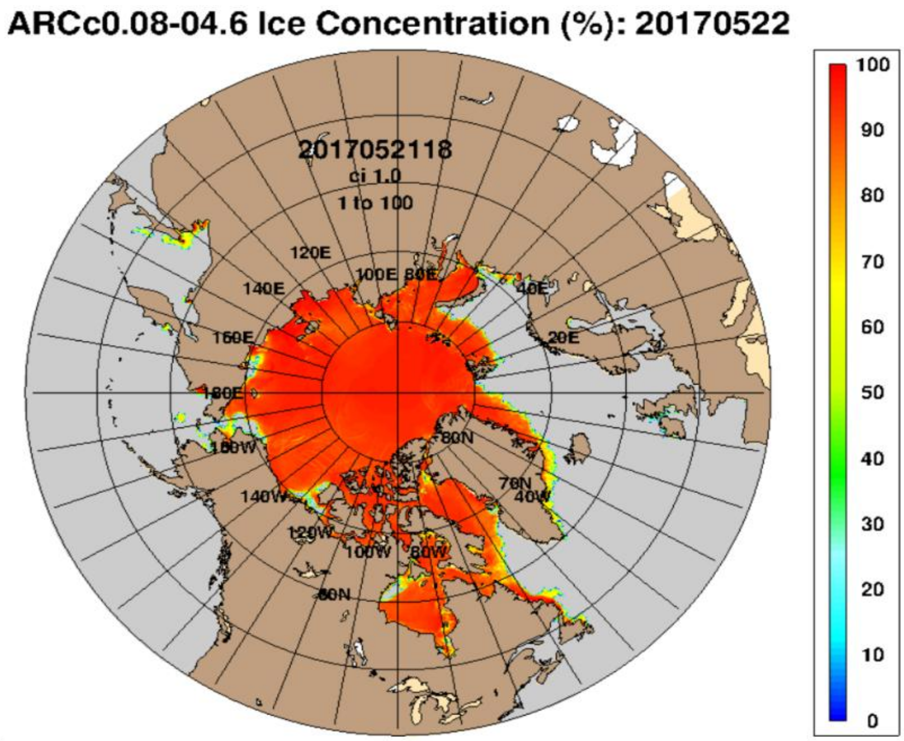


Figure 32: Up-to-date daily information on Arctic sea ice concentration from U.S. Navy: https://www7320.nrlssc.navy.mil/hycomARC/arctic.html

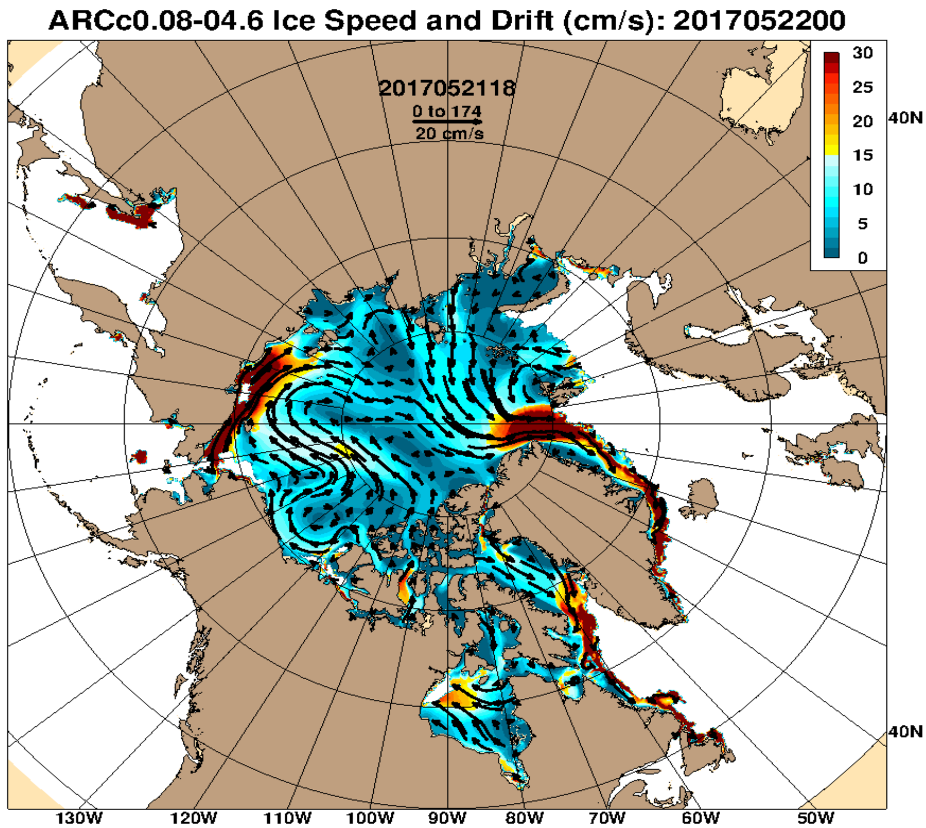


Figure 33: Up-to-date daily information on Arctic sea ice speed and drift from U.S. Navy (also available: concentration, thickness & ice motion, sea-surface height (SSH), sea-surface temperature (SST), sea-surface salinity (SSS), etc. https://www7320.nrlssc.navy.mil/hycomARC/arctic.html

Antarctic Sea-ice is also at Record Lows; thus Global sea-ice is incredibly low

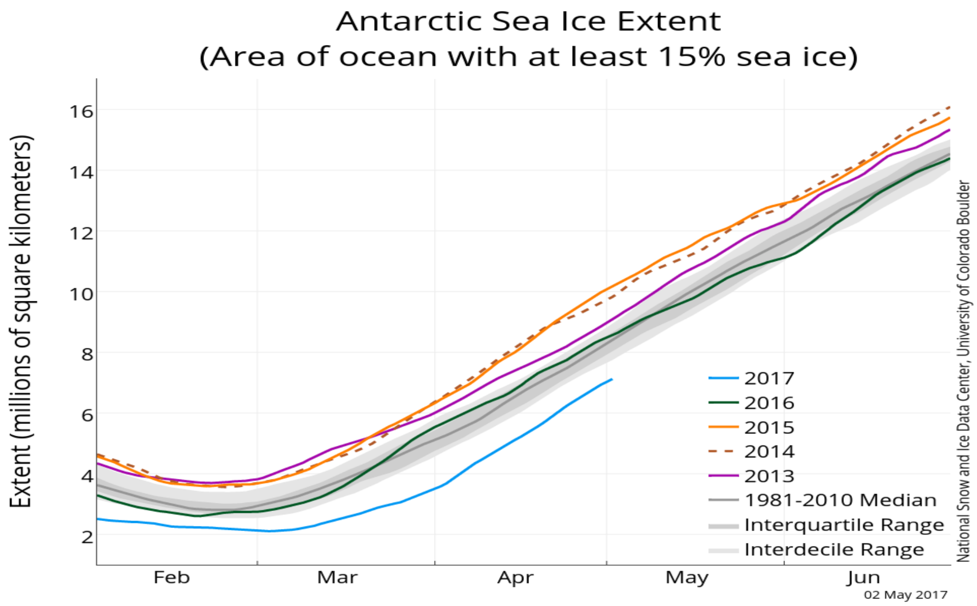


Figure 34: Antarctic sea-ice extent from the NSIDC (National Snow and Ice Data Center), updated in near real-time and easily accessed from the one-stop-shopping "Arctic sea-ice graphs" website. Similarly to Arctic sea-ice, the Antarctic is setting record lows in 2017, far below anything previously observed.

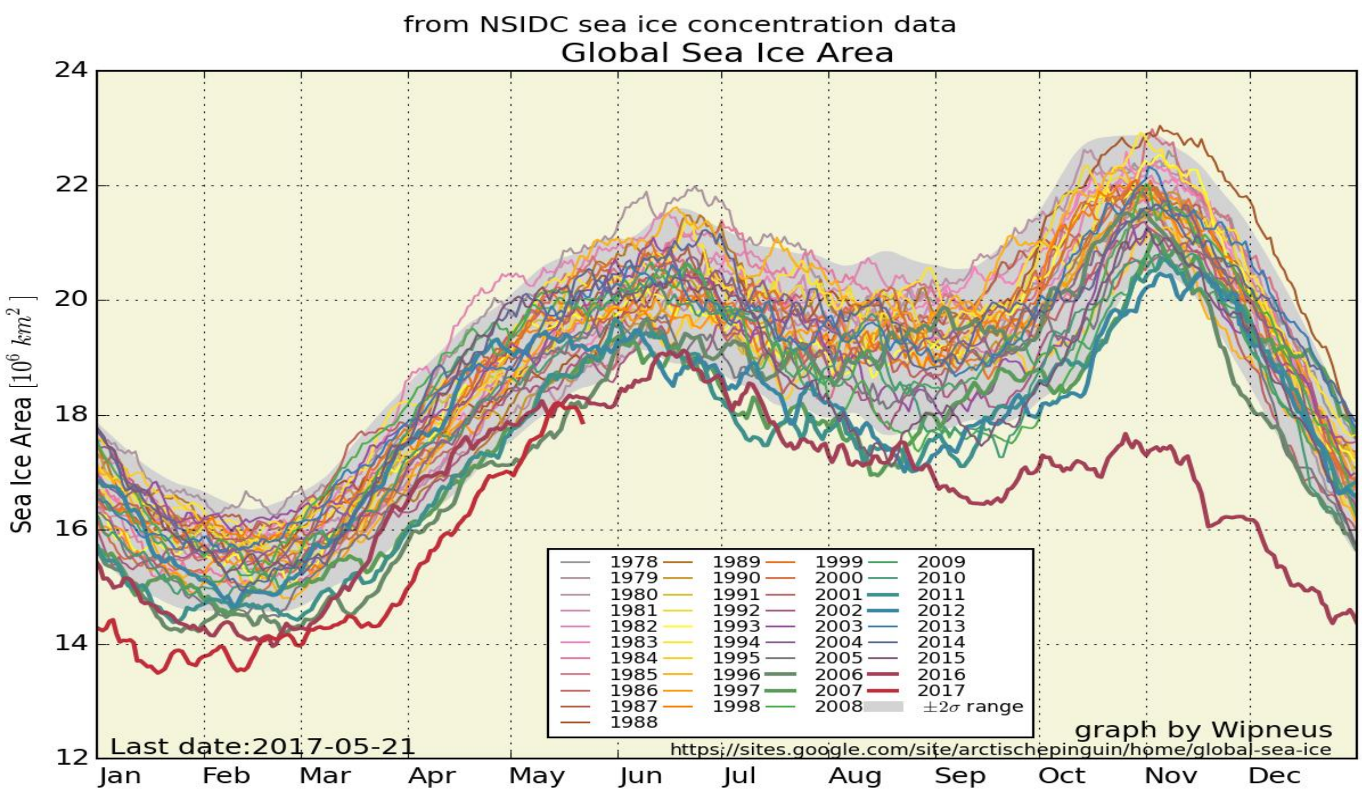


Figure 35: Global sea-ice area, obtained by adding the Arctic sea-ice area to the Antarctic sea-ice area. Calculated from NSIDC (National Snow and Ice Data Center) sea ice concentration data by Wipneus, updated in near real-time and easily accessed from the one-stop-shopping "Arctic sea-ice graphs" website. Since both the Arctic sea-ice, the Antarctic sea-ice are setting record lows in 2017, the sum of the two is even lower.

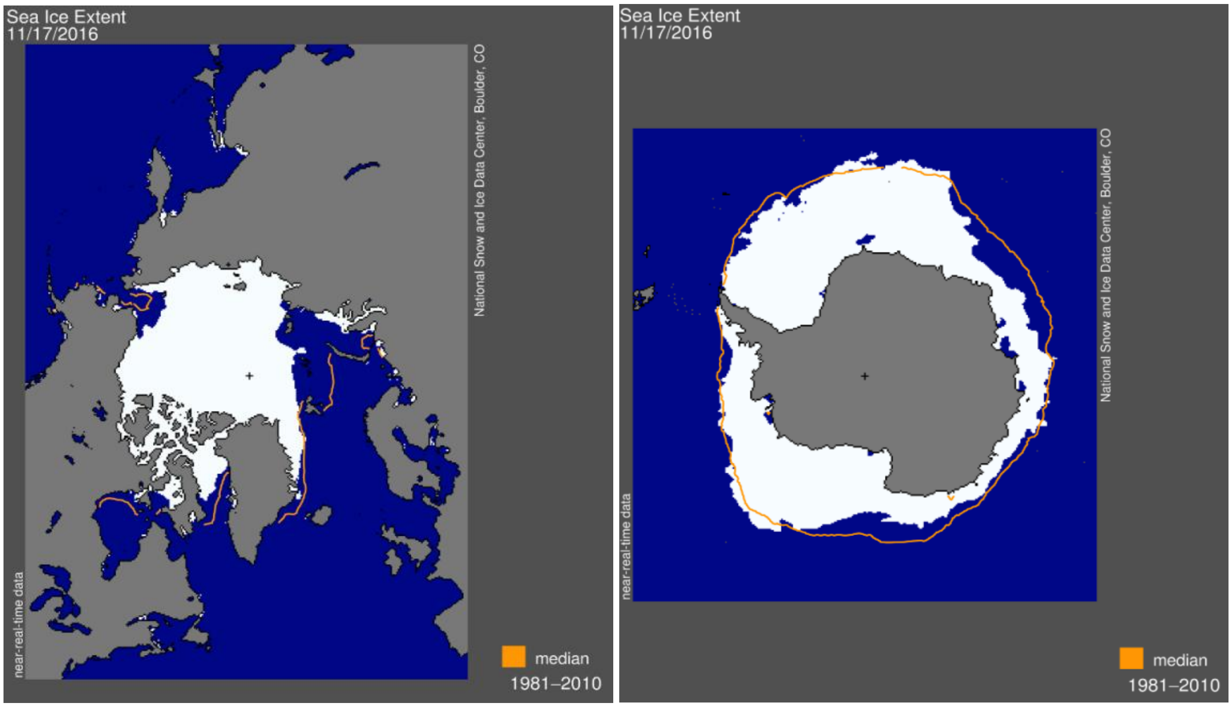


Figure 36: Arctic and Antarctic sea-ice extents showing the large decline from the long term average between 1981 and 2010. The white areas in each image show the sea ice extent in both the Arctic and Antarctic, respectively, on November 17th, 2016 as measured by satellite sensors. The orange line on each map shows the median November 17th extent of the sea ice between the years 1981 to 2010. Clearly, the extent for 2016 is much lower than the longer term median extent. These images are from the NSIDC (National Snow and Ice Data Center).

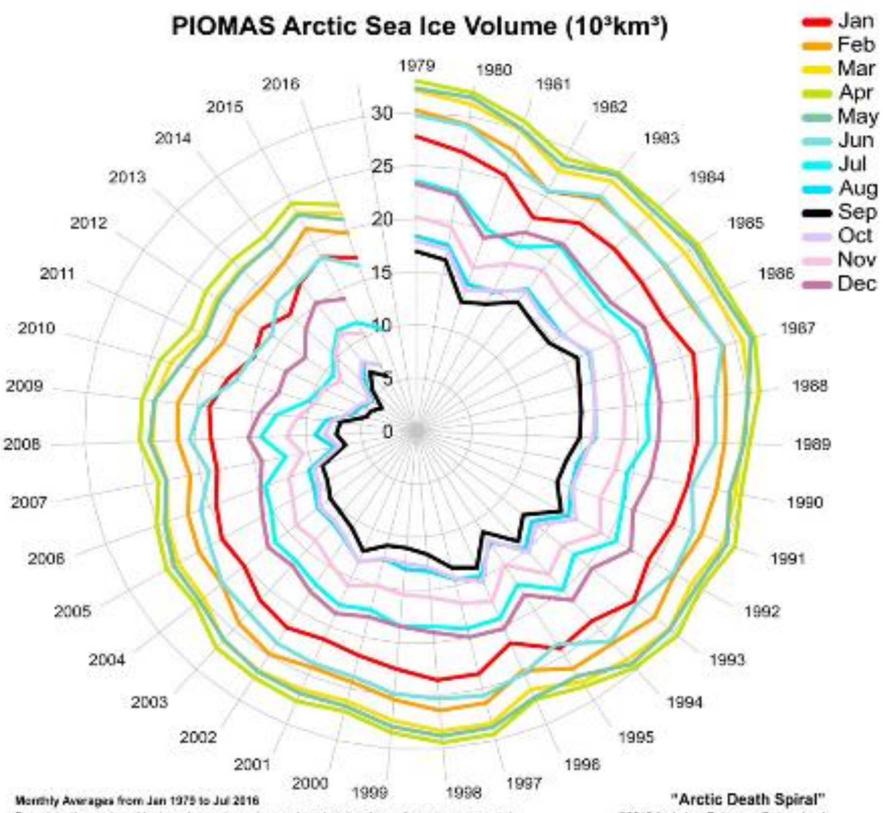


Figure 37: Polar plot clearly showing the so-called "Arctic Death Spiral" created by Andy Lee Robinson with NSIDC data.

Arctic Sea-Ice is Rapidly Trending Downward to Zero ("Blue-ocean event")

***Near future scenario*:**

Overall downward trend in sea-ice extent continues → high probability exists that the first "Arctic blue ocean" event (time t = 0) will occur by 2020 or sooner (ice-free duration would likely be less than 1 month in September) → ice-free duration extends to 3 months (no Arctic ocean sea-ice occurs for August, September and October) by t + 1 or 2 years (2021 to 2022) → ice-free duration extends to 5 months (no Arctic Ocean sea ice for July, August, September, October, and November by t + 3 years or so (2023) → ice-free duration occurs ALL YEAR by t + 10 years (by 2030 or so).

Huge feedbacks are occurring due to a) darkening Arctic as ice vanishes, and b) latent heat feedbacks: The quantity of heat (latent heat) sufficient to melt 1 kg of ice at just below freezing to 1 kg of water at just above freezing would raise the temperature (sensible heat) of that 1 kg of water to 80 ^{o}C. Net result: as the Arctic loses sea ice the water temperature will skyrocket.

Northern Hemisphere snow cover in spring is dropping 2x faster than sea-ice

Everybody talks about the exponential decline in the Arctic sea-ice, BUT almost nobody considers the Arctic spring snow cover decline that is twice as fast as the sea-ice decline. Less snow cover over the northern land regions → dark tundra exposed → more solar radiation absorption → more heating of the Arctic → even less snow cover. The rapidly darkening Arctic (from snow cover decline and sea ice decline) is leading the the large observed Arctic temperature amplification.

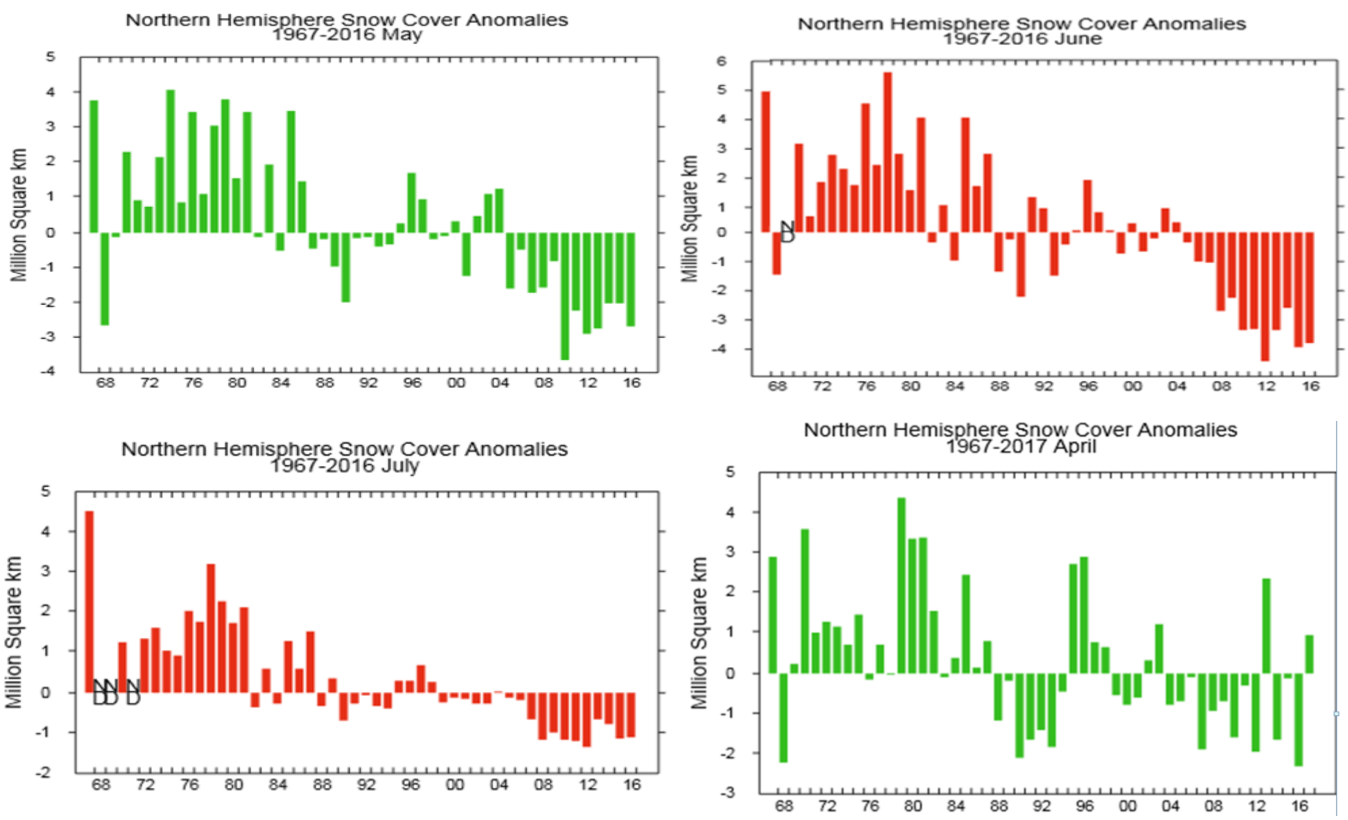
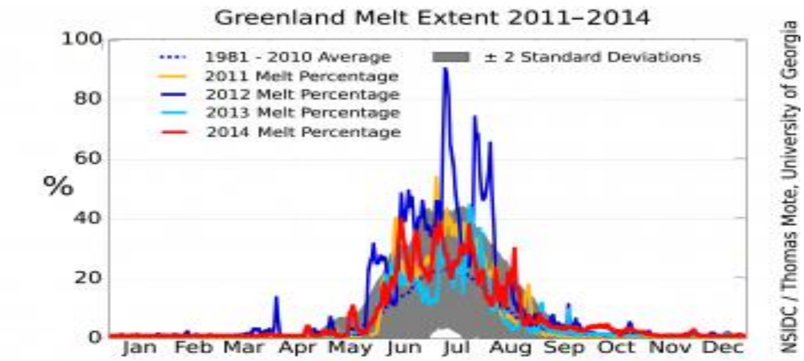


Figure 38: Northern Hemisphere Snow Cover Anomalies, in millions of square kilometers from 1968 through to now. The two top plots, and the lower left plot are from May, June, and July 2016, respectively. The lower right plot is from April 2017. These plots are all generated using data and tools online at the Rutgers Snow and Ice data center: http://climate.rutgers.edu/snowcover/

Sea-level Rise; Ocean Acidification; Greenland and Antarctica Ice Cap Melt



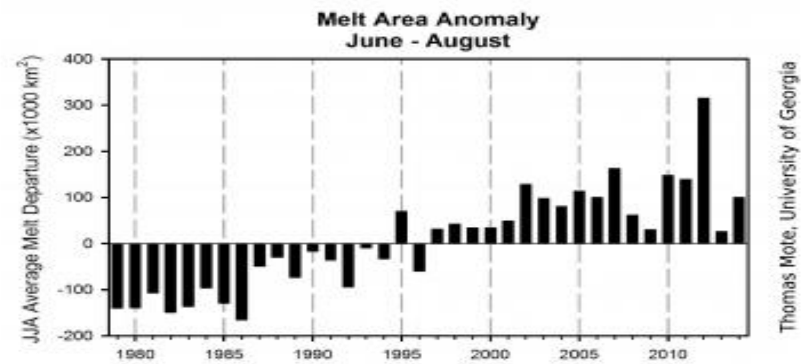


Figure 39: Percentage of the overall Greenland ice sheet surface extent that was subject to melting in recent years (0% is no melt on the ice surface, 100% would be melting across the entire ice surface). The lower plot shows the departure, or anomaly from the normal case. Note that the surface albedo (reflectance) is greatly lowered (ice is darker) in these melt regions due to low reflectivity surface meltwater ponds, exposed dust and dirt in the ice, and ash settling on the ice from northern boreal forest fires.
http://www.arctic.noaa.gov/reportcard/images-essays/fig3.1d-tedesco.png

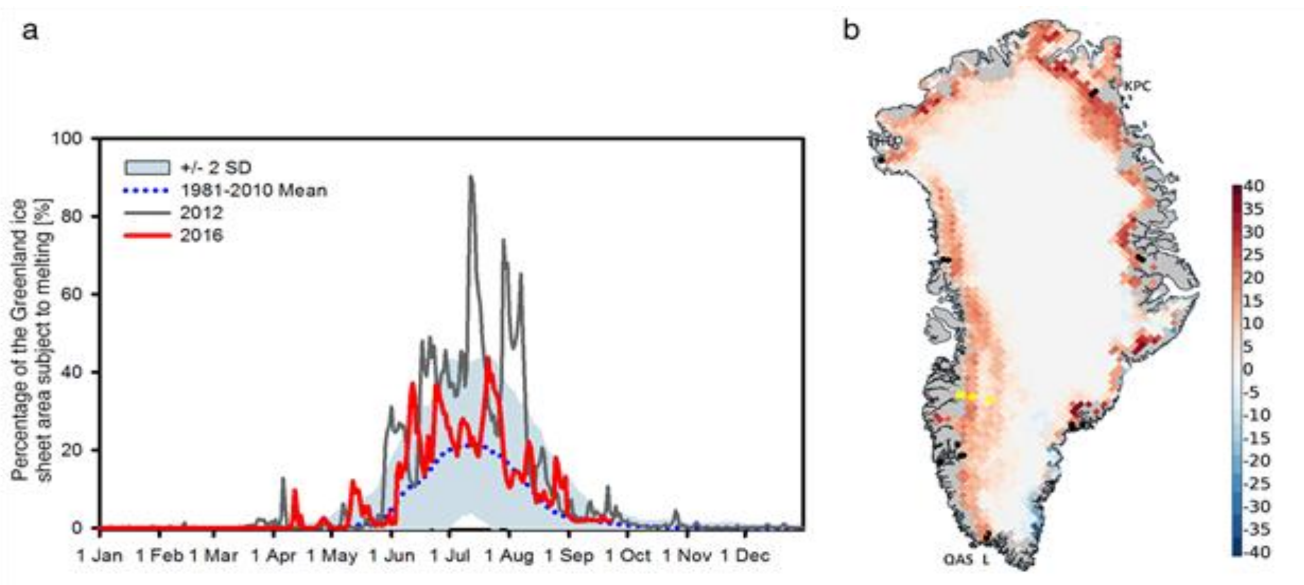


Figure 40: a) Percentage of Greenland ice sheet with surface melting in 2016 (red) and in the highest melt year 2012 (grey). Also shown is the baseline 1981-2010 average melt percentage (dashed blue line), and the spread in the melt data, based on variation of ±2 standard deviations from the mean (shaded). b) Change in number of melting days for 2016 relative to 1981-2010 mean.
http://www.arctic.noaa.gov/Report-Card/Report-Card-2016/ArtMID/5022/ArticleID/277/Greenland-Ice-Sheet

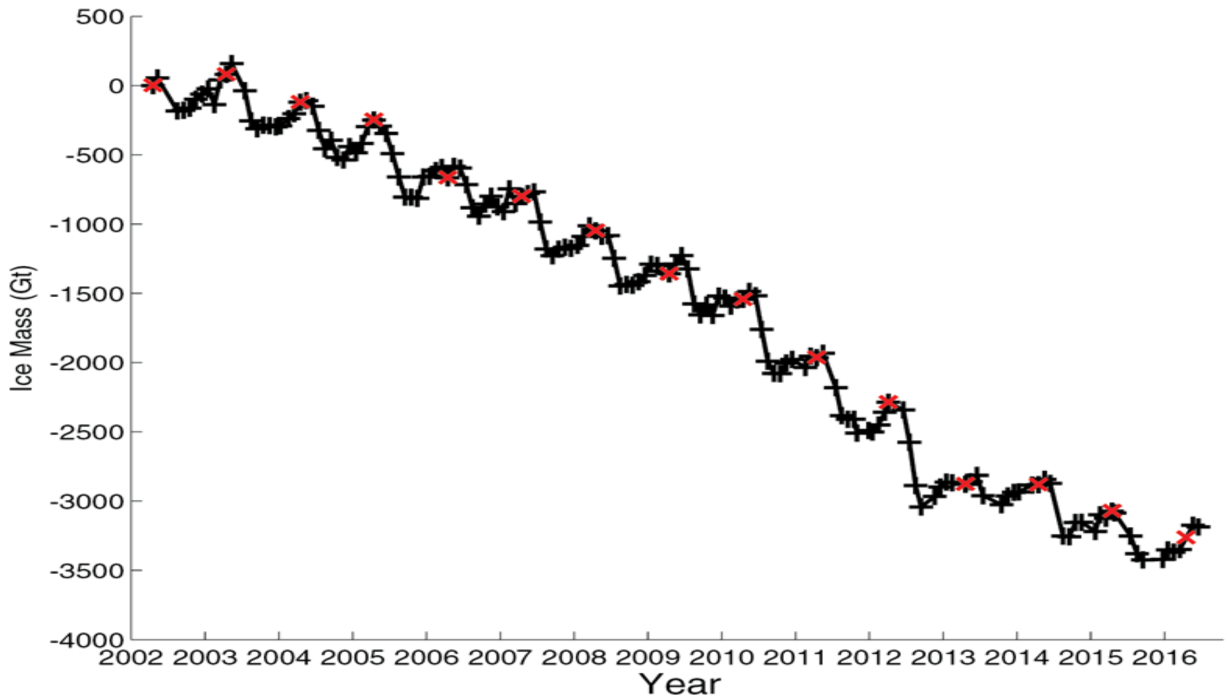


Figure 41: Monthly change in the total ice mass (in Gigatonnes: GT) for the Greenland ice sheet between 2002 and 2016, as estimated from GRACE satellite sensor data. The red crosses denote the values for the month of April in each year.

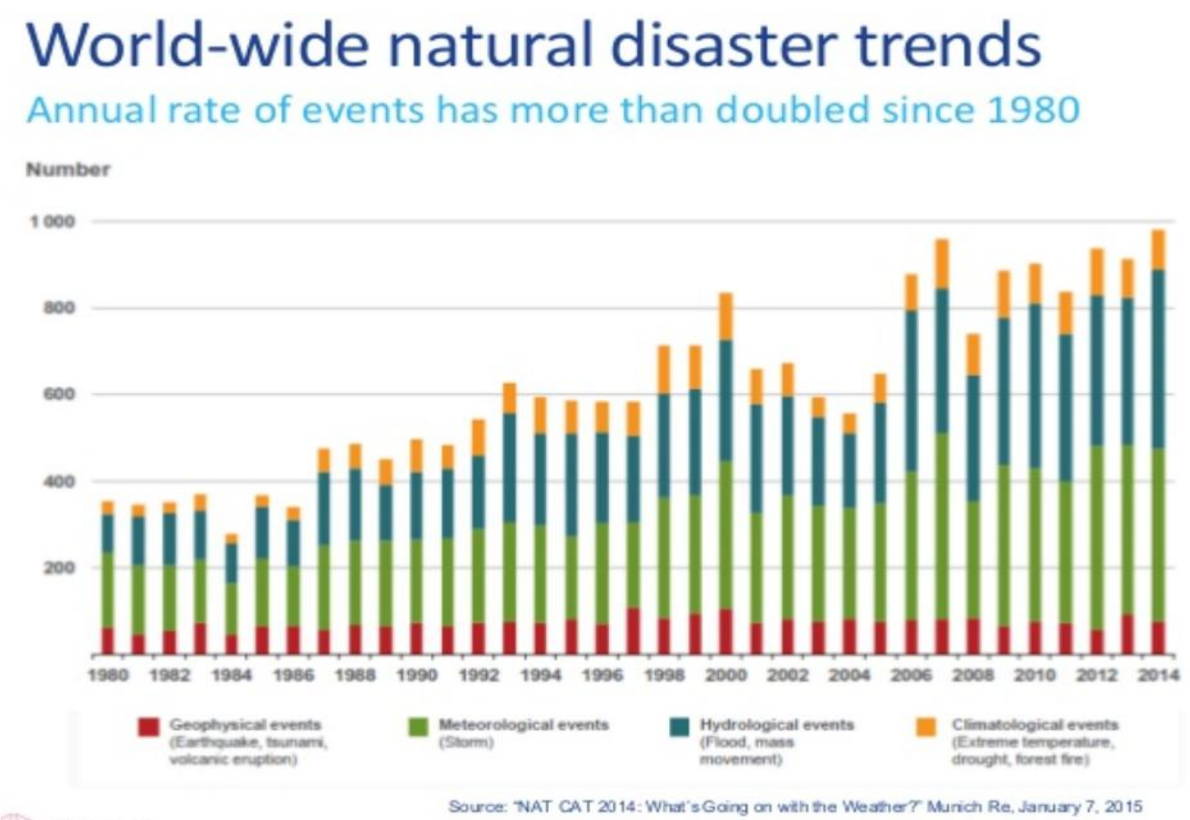
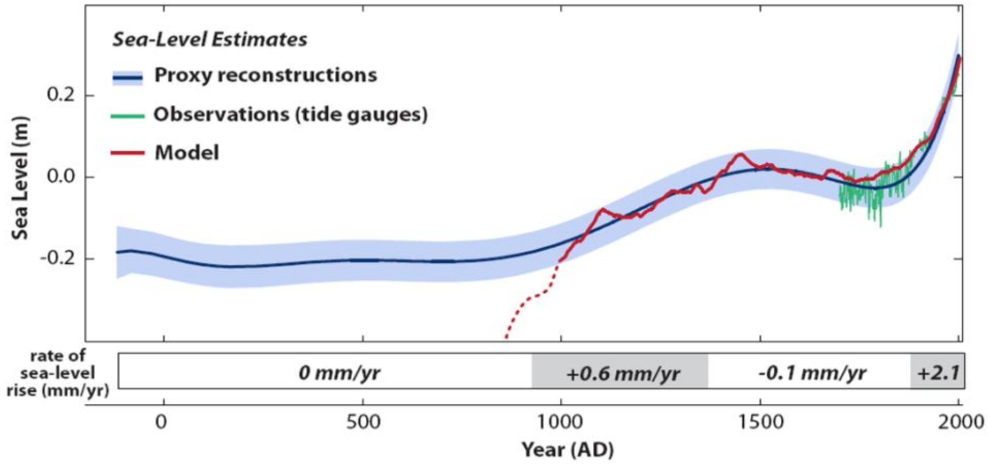


Figure 42: World-wide Natural Disaster Trends from Munich Re. Meteorological events (storms), hydrological events (floods and mass movements like landslides and sinkholes), and climatological events (extreme temperatures, droughts and forest fires) are all trending up quite rapidly.



Kemp 2011

Figure 43: Sea-level estimates for the last 2000 years. We are experiencing a rapidly accelerating rise in global sea levels due to: 1) Expansion of water; 2) mountain glacier melt; 3) ice caps melt (Greenland and Antarctic).

The present rate of sea level rise today is about 3.4 mm/year, and the total expected rise is 0.3 meters (about 1 foot) by 2050, and up to 2 meters by 2100. Just before the U.S. election in 2016, a report out of California projected a sea level rise approaching 1 to 1.5 meters by 2050. The famous climate scientist James Hansen predicted a rise of 5 meters by 2100. When I take a doubling period of 7 years for melt rates from Greenland and Antarctica (rate observed over last 3 doubling periods, or about last 21 years of data) then I come up with a number of roughly 7 meters of sea level rise by 2070 (this simply assumes that the 7 year doubling period continues until then). Paleorecord data from 121 kyr ago indicates that sea level rose about 5 cm (2 inches) per year for over 50 years (Blanchon et. al., 2009), for a total of 2.5 meter rise in 50 years.

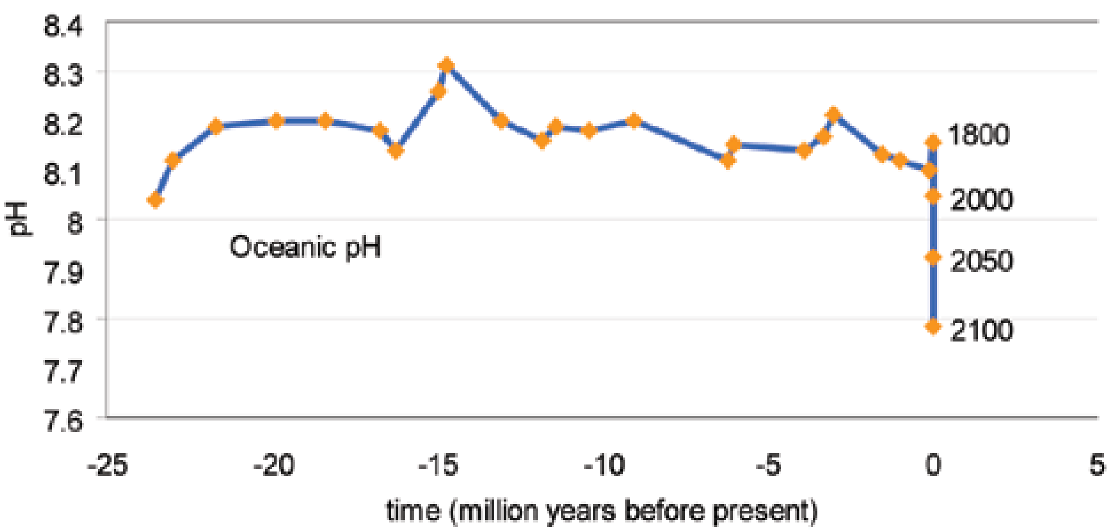


Figure 44: Ocean pH levels are plotted over the last 25 million years. Lower ocean pH corresponds with higher ocean acidification. pH levels of the open ocean surface have dropped from about 8.2 to 8.05 in the last 3 or 4 decades, meaning that ocean acidity is 30% larger (pH scale is logarithmic). Higher CO_2 levels in the atmosphere gets absorbed into raindrops generating carbonic acid, which subsequently precipitates into the ocean causing ocean acidification, especially in the near-surface water (before vertical mixing).

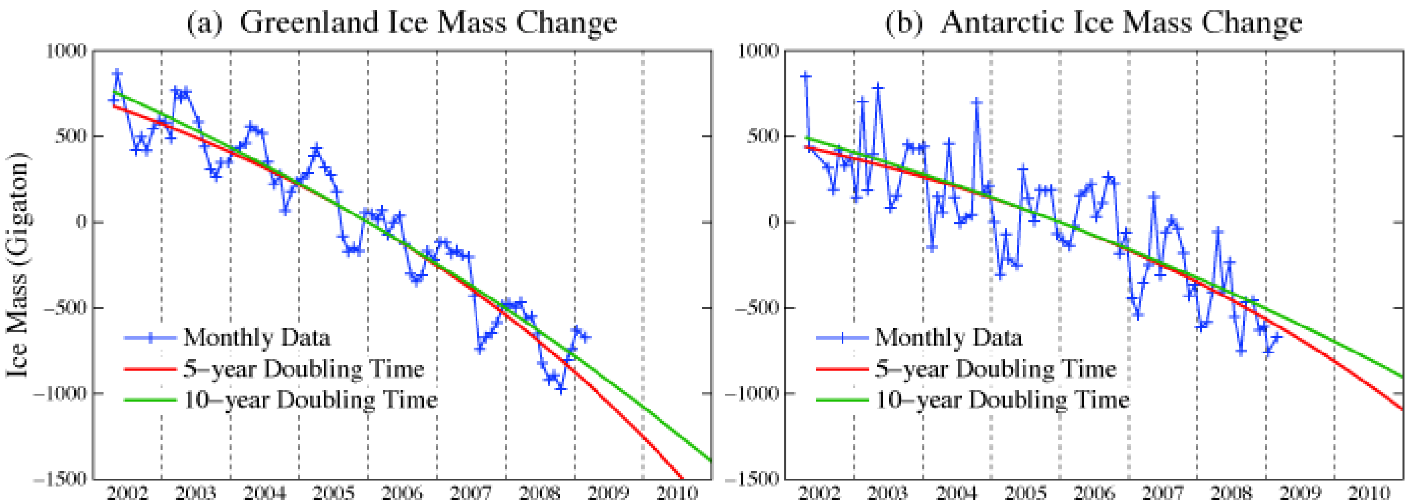


Figure 45: Both Greenland and Antarctic ice cap melt rates are doubling roughly every 7 years, from observations over the last 20 years or so (shown back to 2002 in these plots). If this doubling trend and period continues, we can easily project into the future an enormous sea level rise; namely 7 meters of sea level rise by about 2070.

Methane Feedbacks in the Arctic are an Enormous Risk to Society

Methane levels in the atmosphere have been rapidly rising since 2007. Human sources include fracking leakage, livestock, industrial processes, and natural gas flaring, while natural sources include wetlands, permafrost thawing, and hydrates. The main sink (removal from atmosphere) is reaction of the methane molecule with hydroxyl ions (OH^-), and the atmospheric lifetime is about 12 years on average (much higher in the high Arctic where there is very little water vapor, and much lower near the equator where it is very humid). The Global Warming Potential (GWP) for methane is 34x, 86x and >150x averaged over 100 years, 20 years and a few years, respectively. When methane is released in the high Arctic, it causes tremendous localized warming there until it diffuses to the rest of the atmosphere.

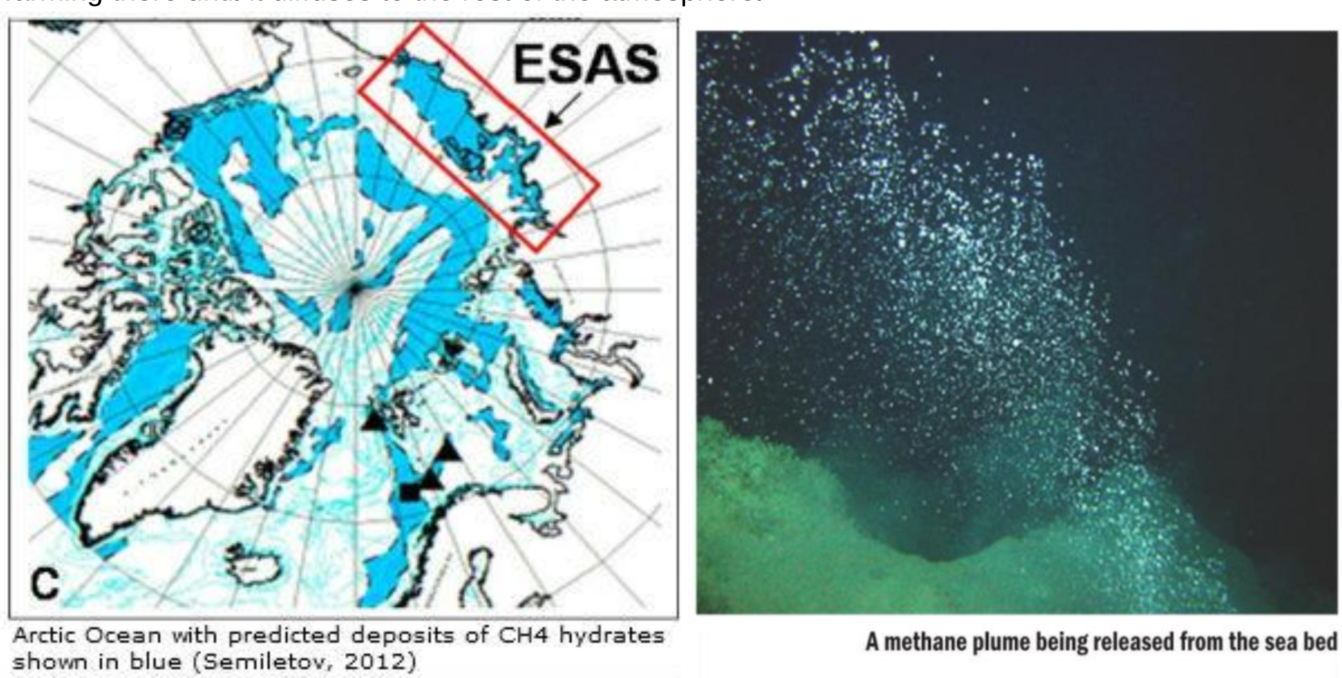


Figure 46: Polar map, with a top-down view of the Arctic region showing the predicted locations of methane hydrates. The image on the right shows methane bubbles being released from hydrates on the sea floor.

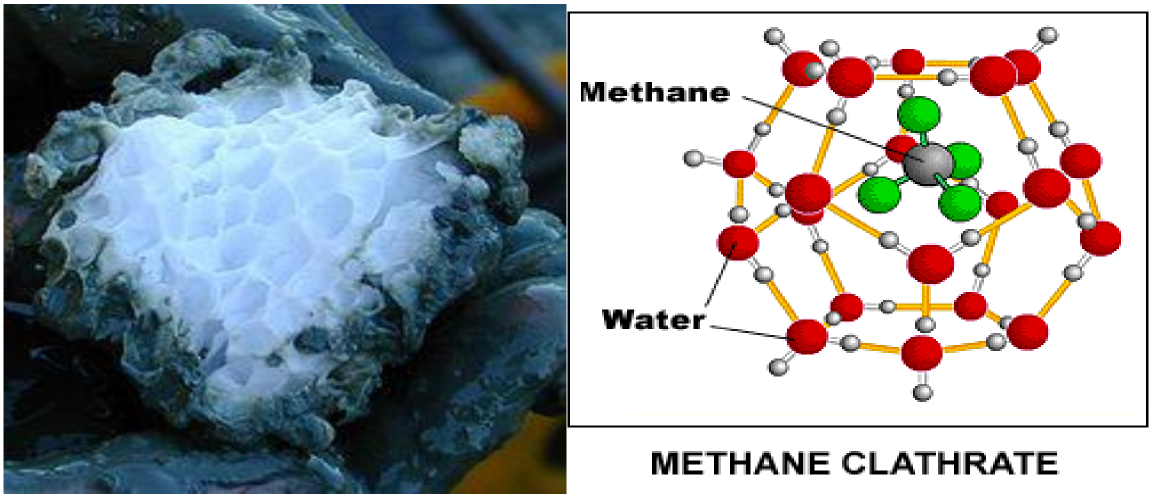


Figure 47: Left image shows methane clathrate obtained from drilling into the sediments on the ocean floor. The right image shows the physical structure of methane clathrates, which is basically a methane molecule confined within a 3-D lattice of frozen water molecules (ice). When the clathrate thaws, the methane is released and there is a volume expansion (frozen clathrate to gaseous methane) of about 160 times. The large craters in Siberia (numbering in the thousands, at last count) are believed to be "blown out" soils from the large pressures generated within the ground from thawing methane clathrates.

Up to now methane emissions in the Arctic are estimated to be quite small (10-20 Mtons of carbon). A very recent escalation of emissions in the last few years has occurred. The most unstable region to watch is the Eastern Siberian Arctic Shelf (ESAS). The hundred of methane plumes bubbling up, that were tens of meters in diameter only a few years ago have changed to hundreds of plumes with sizes as large as 1 km in diameter for the Russian scientific study area. Note that this implies an enormous emission increase of 2500 times (from a simple area ratio $(1000\ m/20\ m)^2 = 2500x$).

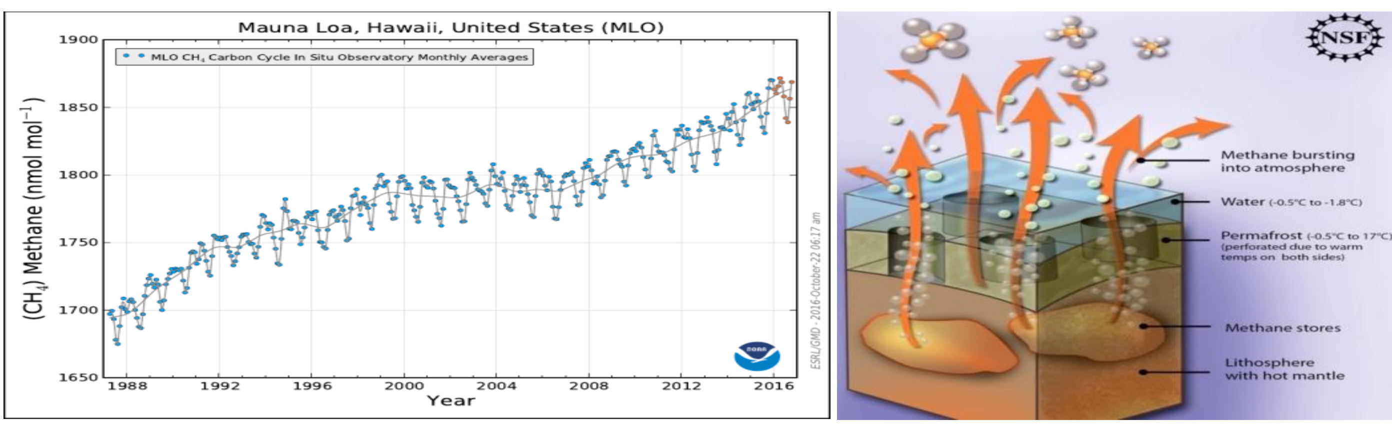


Figure 48: Methane concentrations in the atmosphere, as measured since 1987 at the famous monitoring station in Hawaii. The graphic on the right shows how methane enters the atmosphere from permafrost on continental shelves in the Arctic, for example.

The rate of warming in the Arctic is now about 2°C/decade (~6x global average rate), and this rate will increase as the sea-ice vanishes, due to **cascading feedbacks** from the darkening Arctic. The Arctic albedo (more commonly called reflectance) decreases as the sea-ice melts; present sea-ice forcing → 0.1 W/m^2; with sea-ice gone for one month → 0.3 W/m^2; with eventual disappearance year round → 0.7 W/m^2). Methane emission rises in the Arctic from land-based permafrost and sea-floor sediments if an extremely powerful accelerating feedback. **Methane sources** include terrestrial permafrost containing 1700 Gtons of carbon; ESAS permafrost on the ocean continental shelf with an estimated 1750 Gtons; of which 50 Gtons is thought to be in a precarious state, liable to sudden release. Note that with only 5 Gtons in the atmosphere **TODAY**, a 50 Gton release would lead to almost instant temperature spikes with the following effects:

- → surge in atmospheric methane levels by 11x
- → catastrophic feedback loops
- → warming spirals up
- → world food production spirals down

A release of only 15 Gtons over 10 years would dominate our human CO_2 forcing (leaving absolutely no chance at obtaining the Paris COP21 safe-temperature target of 2°C stabilization, let alone the aspirational target of 1.5°C.

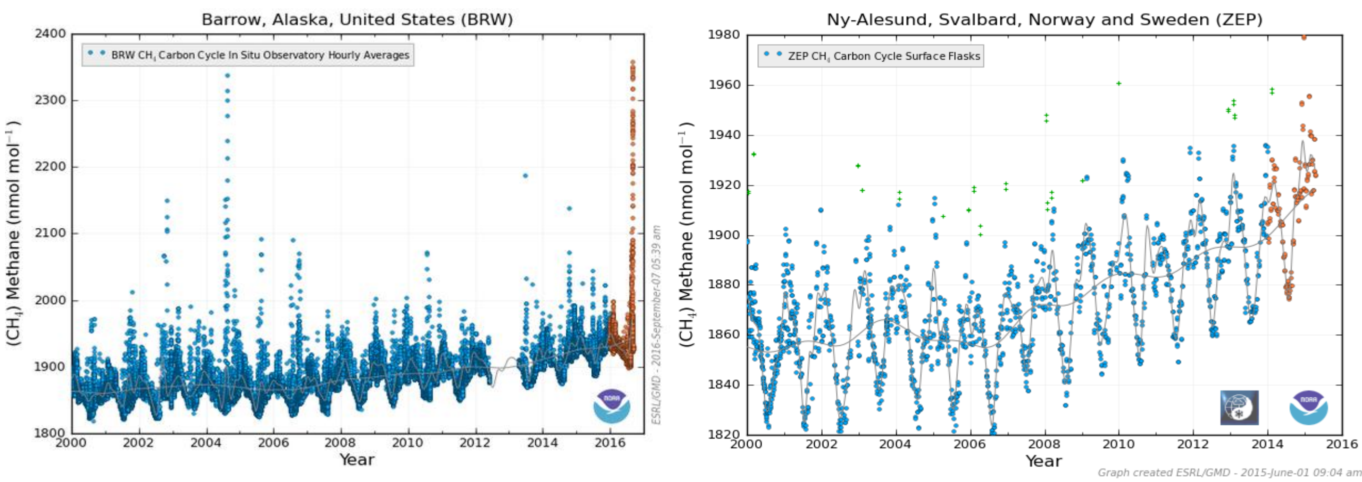


Figure 49: Surface flask measurements of atmospheric methane gas concentrations measured at opposite sides of the Arctic; namely in Alaska and Svalbard. Both show rapid rises, and many spikes.

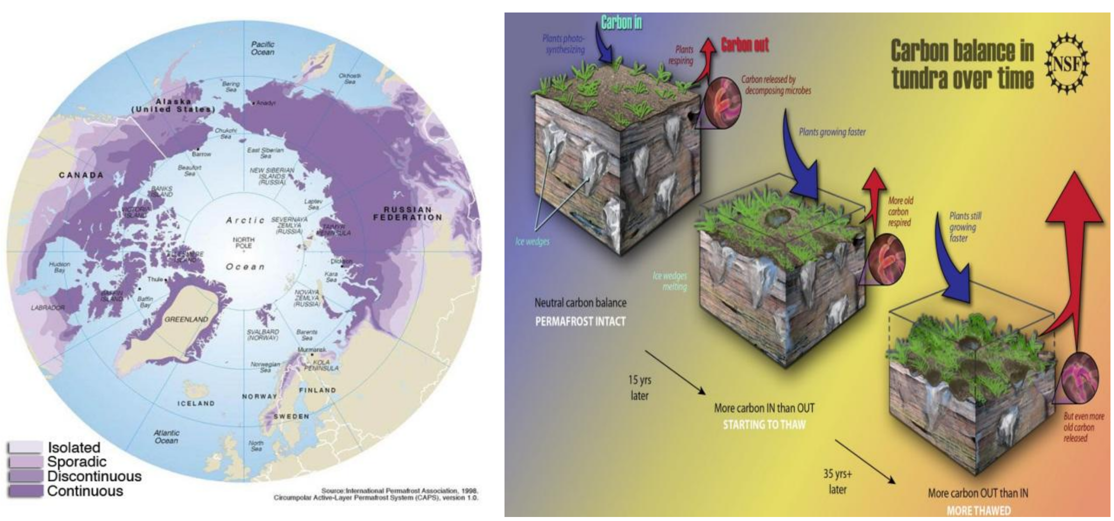


Figure 50: Polar map view looking down over the North Pole, showing the location of the different categories of permafrost. Schematic diagram on the right shows the process for methane release from thawing terrestrial tundra permafrost.

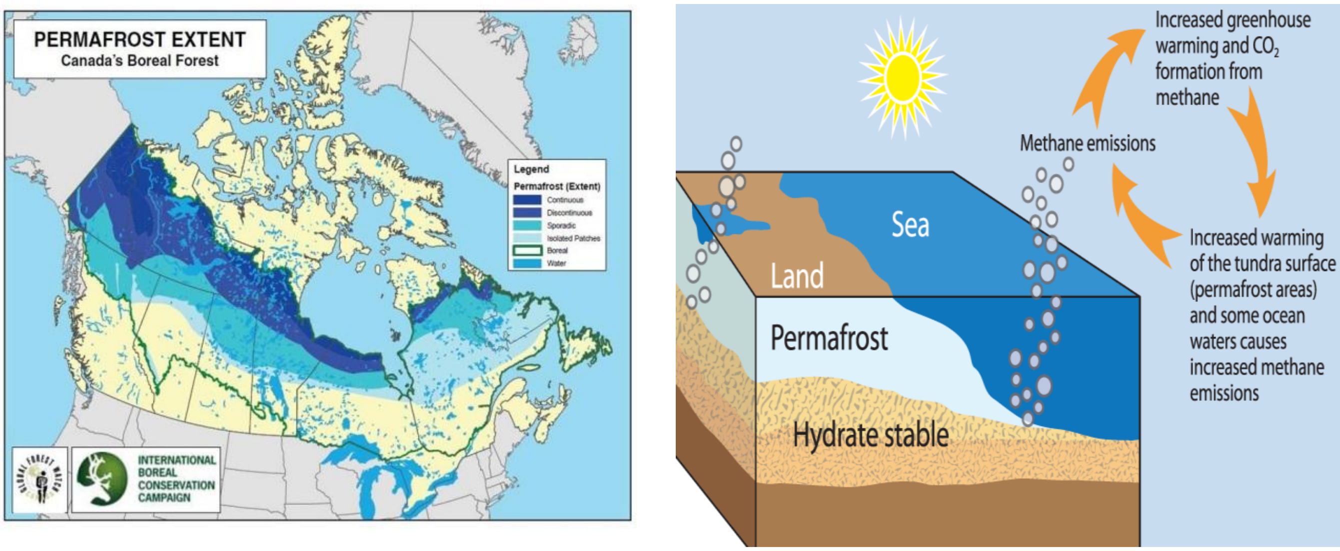


Figure 51: Map showing the permafrost extent in Canada's boreal region (note extent in northern half of Manitoba). The schematic diagram on the right shows how methane is released from clathrates (hydrates) on the ocean floor. Warming ocean temperatures lead to higher emissions over relatively shallow Arctic continental shelves, such as the ESAS.

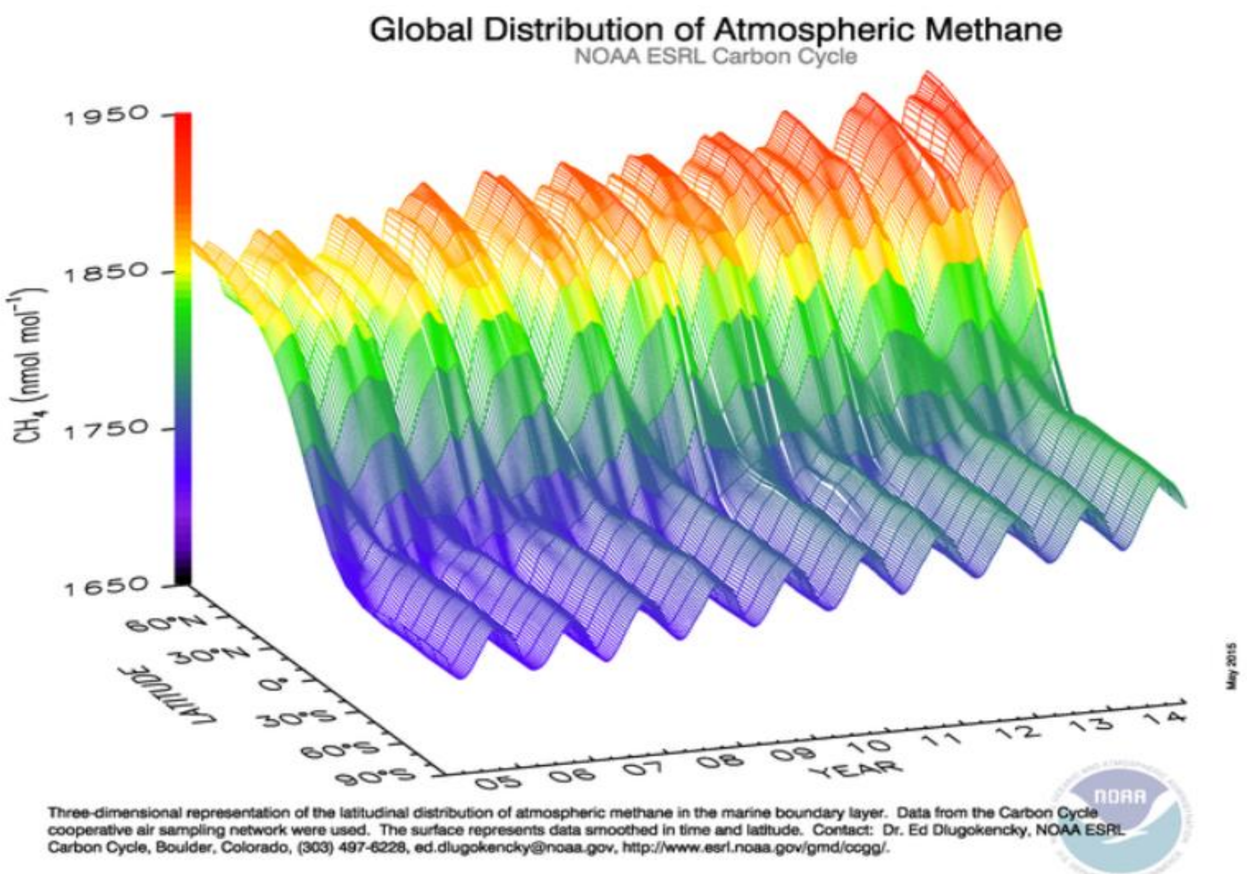


Figure 52: Global Distribution of Atmospheric Methane versus latitude from 2005 to 2014. Note how methane is increasing over time (mostly since 2007) and how the methane concentration is much greater in the Arctic region than anywhere else (most sources are in the Arctic, methane lasts longer in the Arctic since the air is very dry, and thus there is a dearth of hydroxide ions).

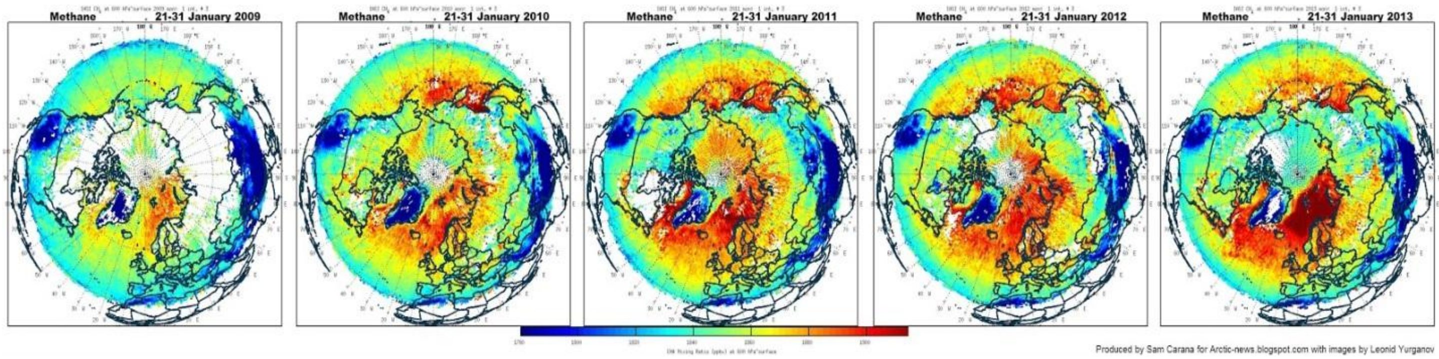


Figure 53: Methane level variations in the Arctic atmosphere over a 5 year time period (namely, 2009 through 2013; methane levels are averaged at each location over the last 10 days of January for each of these years and is shown in the 5 maps). Over this time period, the maps show a large increase (red), especially over the vast open water regions that have been recently opened up by sharply declining sea ice.
https://robertscribbler.files.wordpress.com/2015/03/methane-jan21-31.jpg

Jet Stream Winds are Slowing, Becoming Wavier and More Persistent

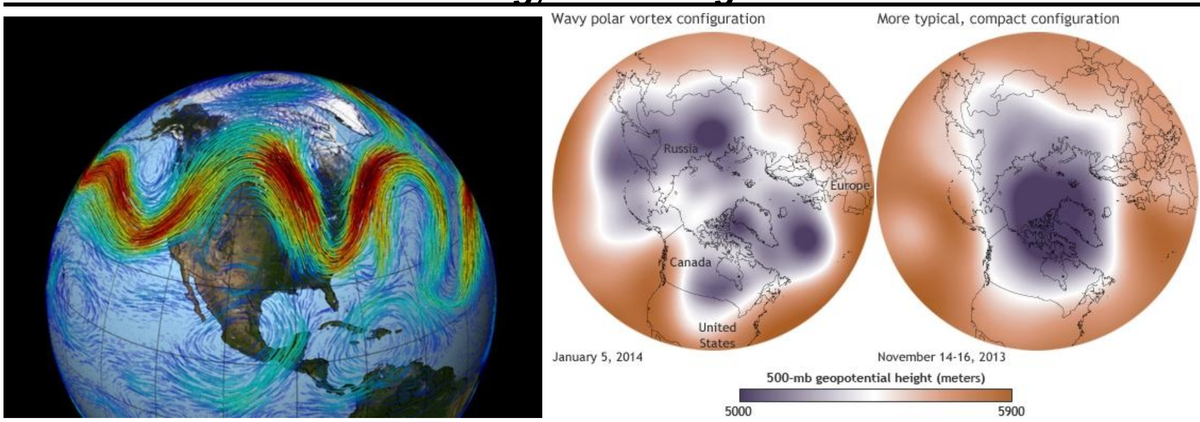


Figure 54: Left image is a side view of an exceptionally wavy jet stream (large north-south wave amplitude).
https://eos.org/wp-content/uploads/2015/02/GL060764_Hassanzadeh_cropped_web-800x600.jpg
Maps on the right are a downward looking Arctic view, showing both "normal" (on the left) and "wavy" (on the right) jet stream behavior: purple areas are cold; brown areas are warmer. Jet streams are the white border lines between the cold and warm air masses.
http://www.climate.gov/sites/default/files/styles/inline_all/public/Jan5_Nov14-16_500mb_geopotentialheight_mean_620.jpg?itok=zdAE3xoi

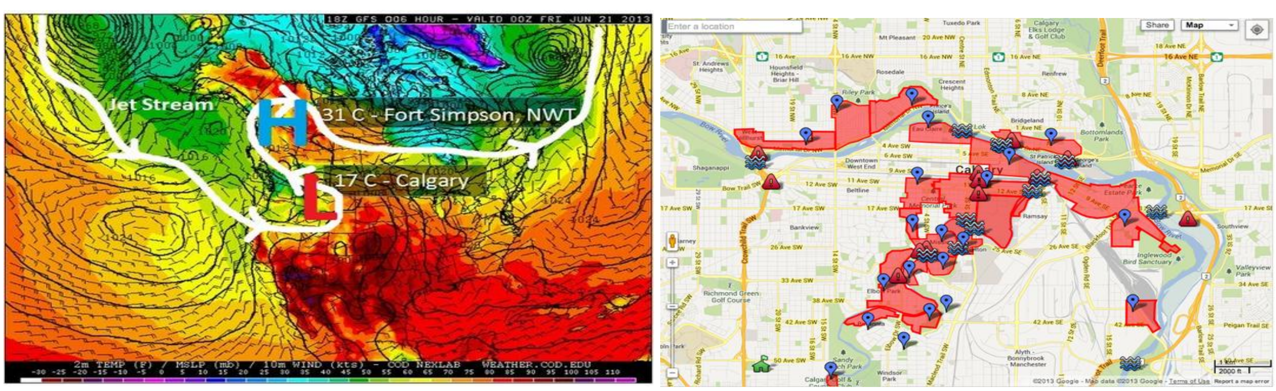


Figure 55: The map on the left shows the unusual, highly folded jet stream configuration (white line) near Calgary during the record flooding event in June, 2013 with insured damages exceeding $6 billion; http://media.twnmm.com/storage/11698939/15. The map on the right shows the flooded sections of downtown Calgary during this flood. http://media.twnmm.com/storage/11698939/15

For every 1°C rise in temperature, the air can hold 7% more water vapor → as air rises and cools the water vapor within condenses into water droplets, forming clouds and releasing vast amounts of energy to fuel more intense storms.

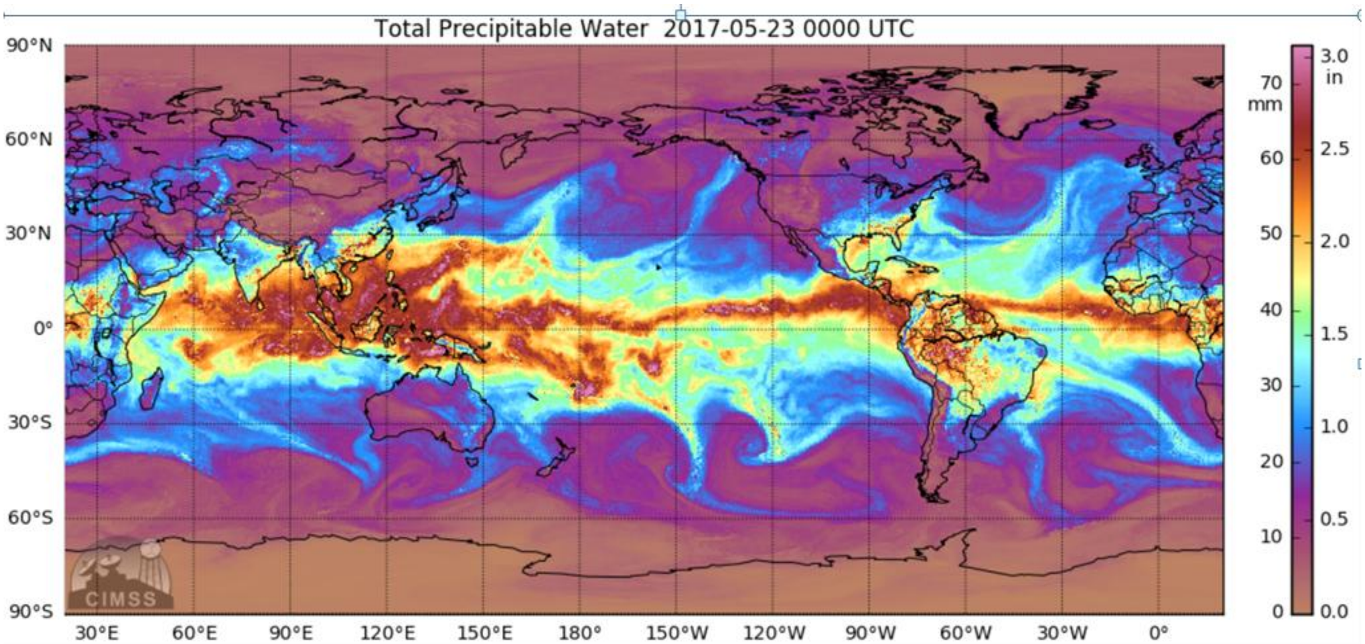


Figure 56: Real-time data on total precipitable water. Notice "fingers" stretching upwards to higher latitudes. http://tropic.ssec.wisc.edu/real-time/mtpw2/product.php?color_type=tpw_nrl_colors&prod=global2&timespan=72hrs&anim=html5

Global Extreme Weather Events: More Frequent, Stronger, and Last Longer

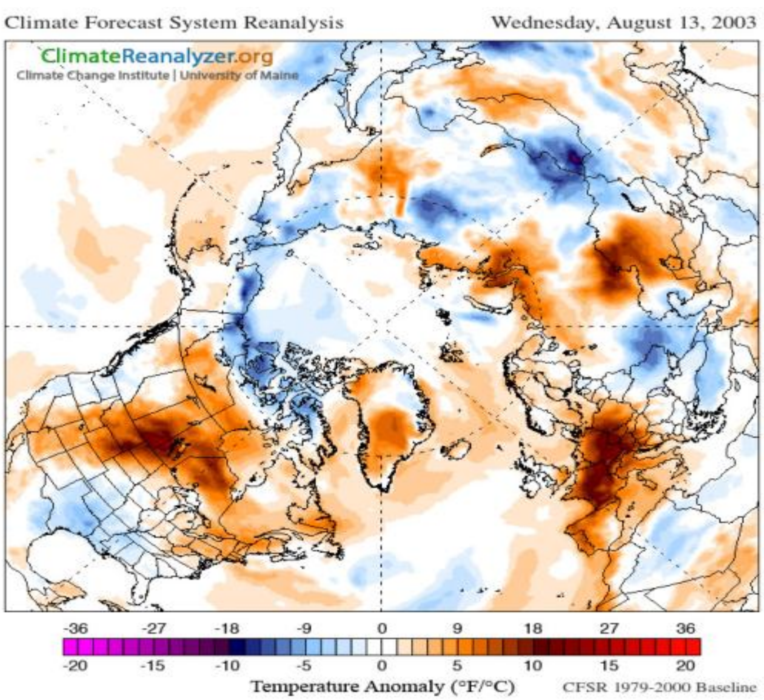


Figure 57: Polar looking map showing the temperature anomalies on Aug. 13, 2003; one of the worst days in the extensive, long-duration European heatwave that killed >70,000 people. The root cause was a very wavy and stuck, persistant jet stream ridge. At that time, as indicated on the map, most of Manitoba & Saskatchewan also endured a lengthy heatwave.

Record Rainfall in April and early May, 2017 → Record Water Levels & Flooding in Quebec, Ontario & B.C.

Very recently, in April and early May 2017, Ottawa (and much of Ontario and Quebec) received >150 mm of rain in April (more than double the monthly normal amount), and an additional 117 mm in the first week of May. Normal rainfalls for April and May (64.8 mm and 76.8 mm, respectively; see Figure 58) were greatly exceeded. River systems were inundated and floods exceeding 1-in-100 year recurrence intervals in many places were reached, peaking in the case of the City of Ottawa on Saturday May 6th 2017. Record water levels in Lake Ontario and the St. Lawrence River are presently ongoing.

Natural disasters always have a natural & human component, and in Ottawa's case the human control of the Ottawa River northern watershed reservoir levels and the large reservoir water dumping that occurred is a very significant factor that made the flooding much worse.

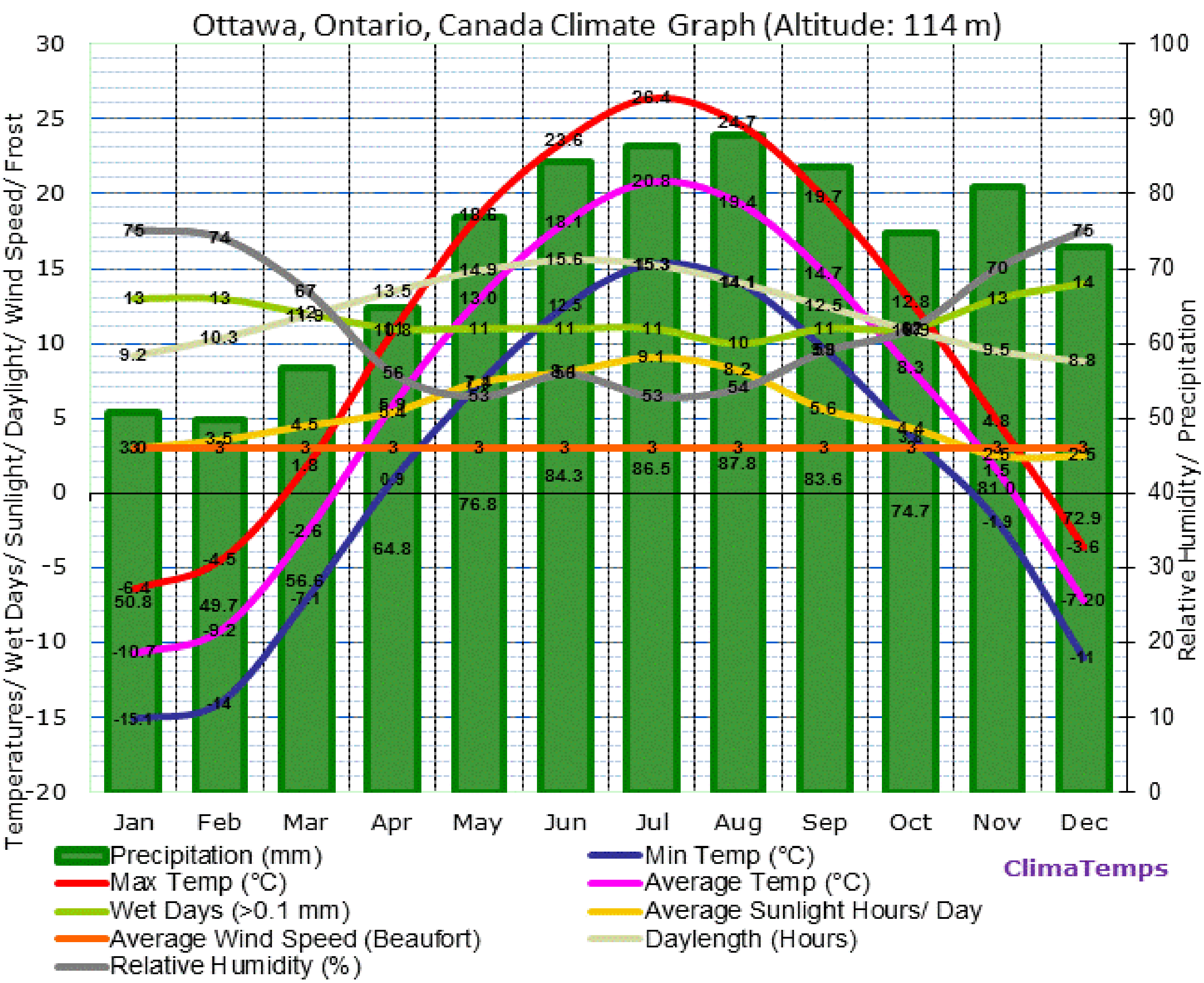


Figure 58: Climograph of Ottawa, Ontario showing many weather variables including monthly average precipitation levels and temperatures. Notice that the average precipitation in April and May are 64.8 mm and 76.8 mm respectively. In contrast, in this year (2017) the April rainfall was 150 mm (over two times higher), and the rainfall in the first week of May was 117 mm (normally it would be one-quarter of 76.8 mm or about 20 mm per week, so almost six times higher in one week), explaining why there has been so much flooding this year.

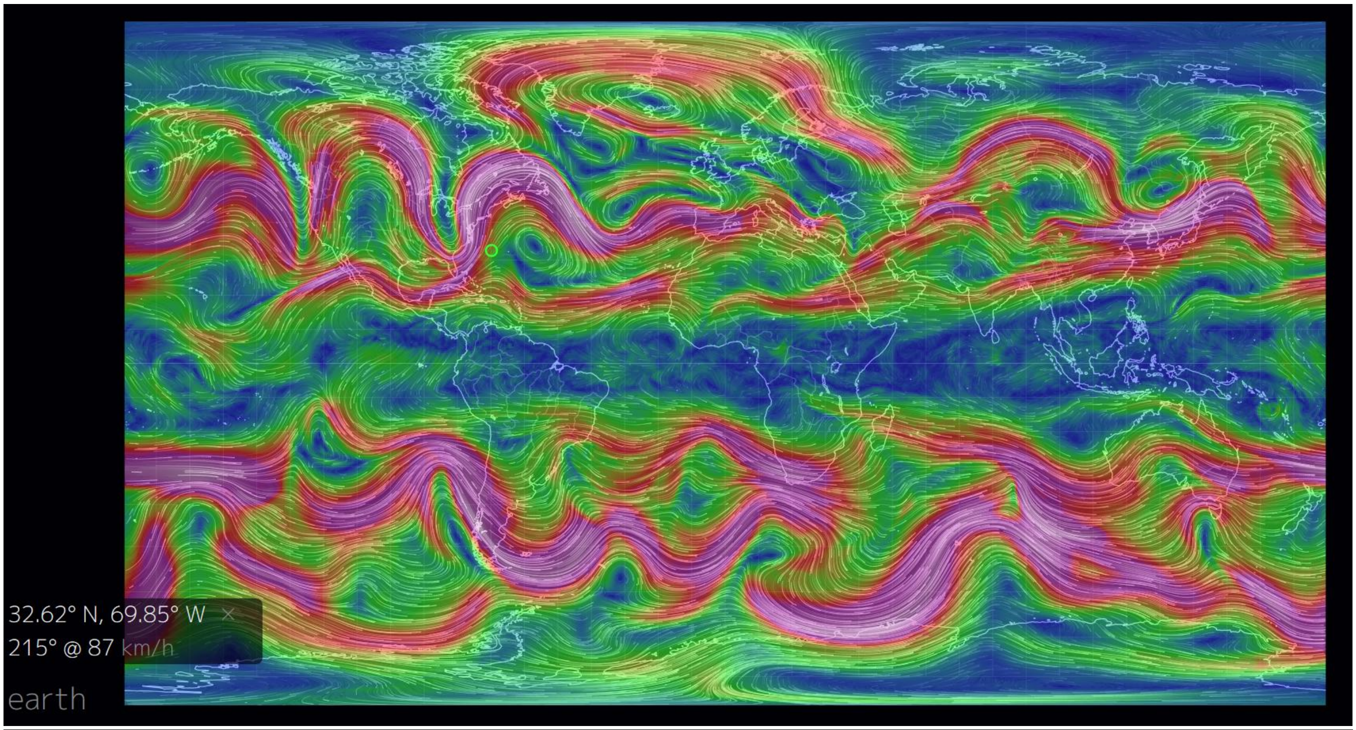


Figure 59: Flooding Disaster: Jet-stream winds at the 250 mb pressure level on May 6th, 2017. The pattern over North America is a classic stuck pattern ("omega" block: with low pressure over the east and west coasts; and a high pressure over the central region). This pattern resulted in 3 days of torrential rains in the Ottawa River watershed, leading to severe flooding along this river in the cities of Ottawa and Gatineau.
https://earth.nullschool.net/#2017/05/06/0600Z/wind/surface/level/patterson/loc=-69.850,32.617

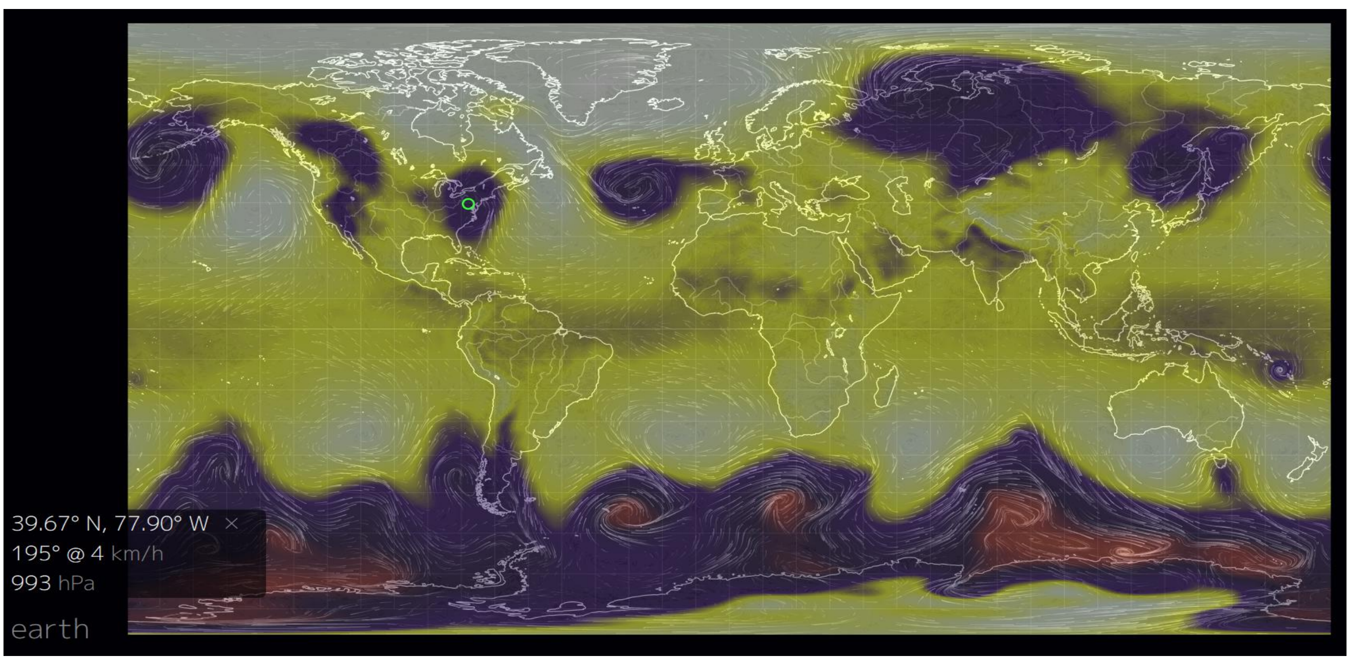


Figure 60: Flooding Disaster: Mean Sea-Level Pressure (MSLP) on May 6th, 2017. The dark purple regions are low pressure (thus stormy areas) while the whitish regions are high pressure regions (warm and dry). The pattern over North America is a classic "omega" block (low pressure over east and west coasts; high pressure over central region). The rainfall from this stuck pattern over three days contributed to large flooding along the rivers in Ottawa and Gatineau.
https://earth.nullschool.net/#2017/05/06/0600Z/wind/surface/level/patterson/loc=-69.850,32.617

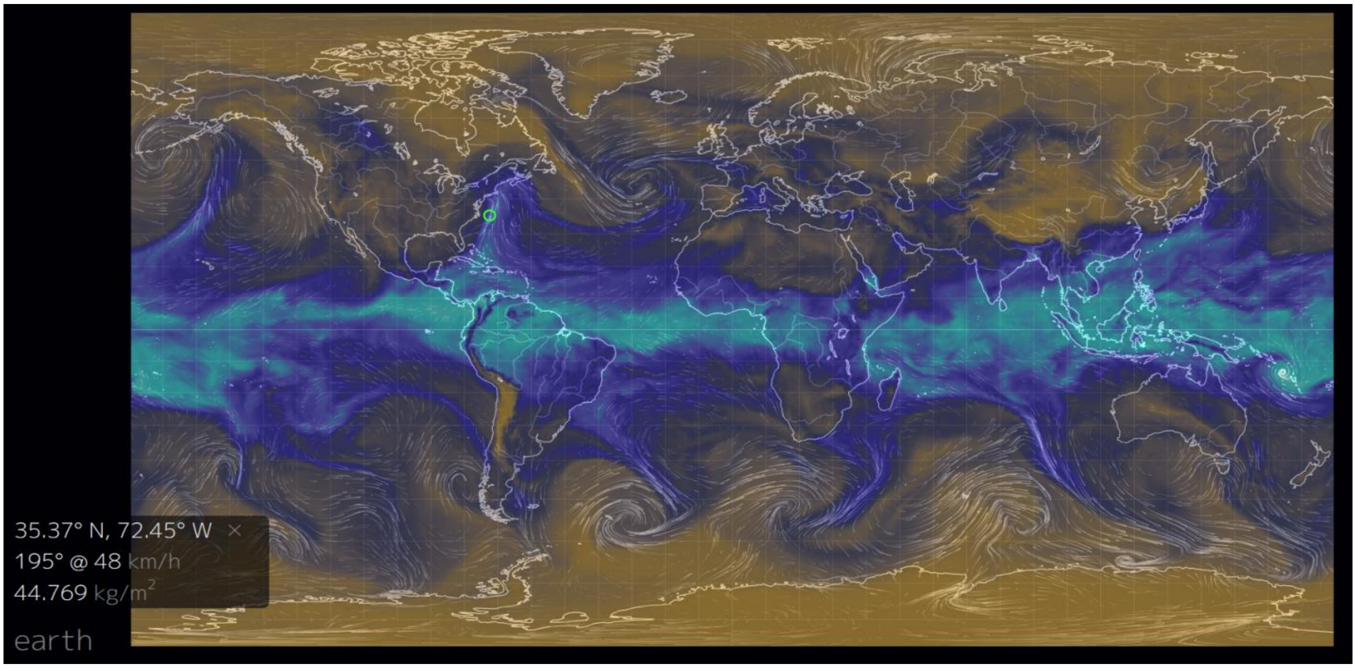


Figure 61: Flooding Disaster: Wind & Total Precipitable Water (TPW) on May 6th, 2017. Large amounts of water are being carried north over the extremely warm waters of the Gulf Stream, and dumped on the eastward regions of North America, including Quebec and Ontario.
https://earth.nullschool.net/#2017/05/06/0600Z/wind/surface/level/patterson/loc=-69.850,32.617

New Brunswick island cut off from mainland due to thunderstorm – CBC News – Friday May 19th, 2017

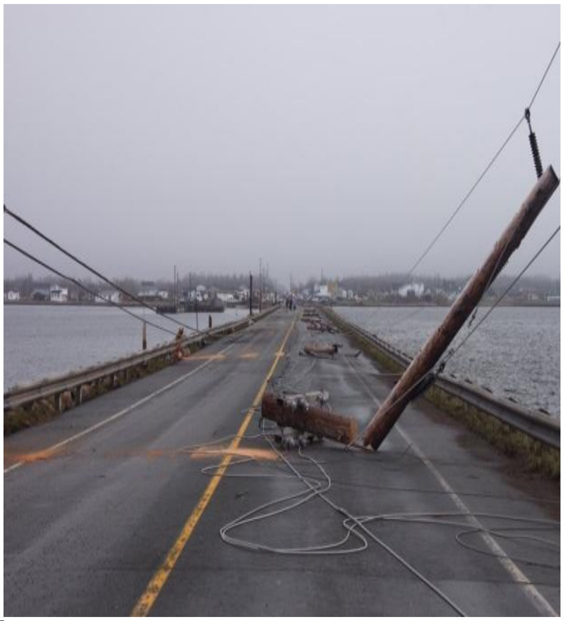


Figure 62: Heavy winds split power poles in half and tore roofing tiles off buildings, with damage observed over a wide geographical area (not characteristic of tornadoes). Damage is more indicative of straight-line winds that are not associated with atmospheric rotation. Based on the extent of the damage, it appears that wind gusts may have reached 190 km/hr. Up to 20 power poles fell during the storm (12 on the causeway between the island and the mainland; these were encased in the cement on the bridge).
http://www.cbc.ca/news/canada/new-brunswick/lameque-power-outages-storm-1.4123039

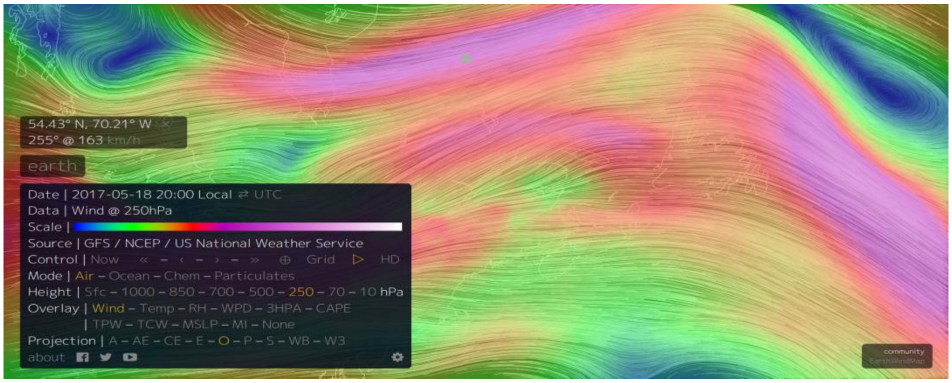


Figure 63: New Brunswick Storm: Earth Nullschool showing jet stream winds on the night of May 18th, 2017. The pink streaks are the regions of the upper atmosphere with the strongest winds. Local near-surface wind gusts up to 190 km/hr were reported on Lameque Island, causing the significant infrastructure damage to transmission line poles and building roofs.
https://earth.nullschool.net/#2017/05/19/0000Z/wind/isobaric/1000hPa/orthographic=-69.55,47.93,3000/loc=-55.501,39.751

Blue-Green Algae in Lake Winnipeg as an indication of climate change already in Manitoba

Heat waves in recent years over relative shallow bodies of water including Lake Erie and Lake Winnipeg have led to an increasing incidence of extensive blue-green algal blooms. When these blooms occur they make life miserable for people using the lake for recreational purposes like fishing and swimming, and noxious algae mats wash up onto shorelines posing a health risk to people living along the shorelines. Also, these blooms can choke off city water supplies, as happened a few years ago on the western shorelines of Lake Erie. There are many causes of these blooms, including an overabundance of nitrogen and phosphorus runoff. However, with our rapidly changing climate system the associated increase in the frequency, intensity and duration of extreme weather events such as heat waves (leading to much higher water temperatures), and also more torrential rain events lead to large runoff pulses from agricultural lands into rivers and then into these shallow lakes. Thus, it seems that the increasing prevalence of blue-green cyanobacterial algae blooms in Lake Winnipeg is an essential indicator of climate change impacts that are already impacting livelihoods in Manitoba. Not only that, but these algal blooms are occurring further and further north, into regions up near Hudsons Bay where they did not occur previously.

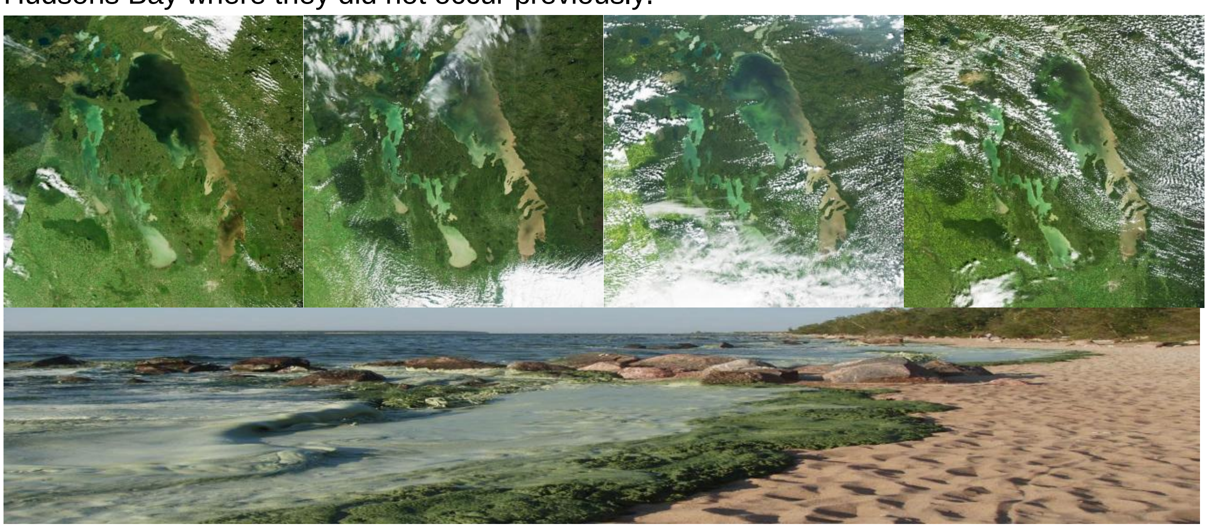


Figure 64: Top: Four satellite images of Lake Winnipeg on June 21, June 30, July 16th and July 22nd, respectively. The green color of the lake water is indicative of blue-green algae blooms. http://lakewinnipegresearch.org/blog/?page_id=1385 Lower image: Washed up algae on a shoreline in Lake Winnipeg. http://pfc.ca/wp-content/uploads/2009-conference-a2-bmartin-oct29am-en.pdf

Drought Map for Earth in about 50 years

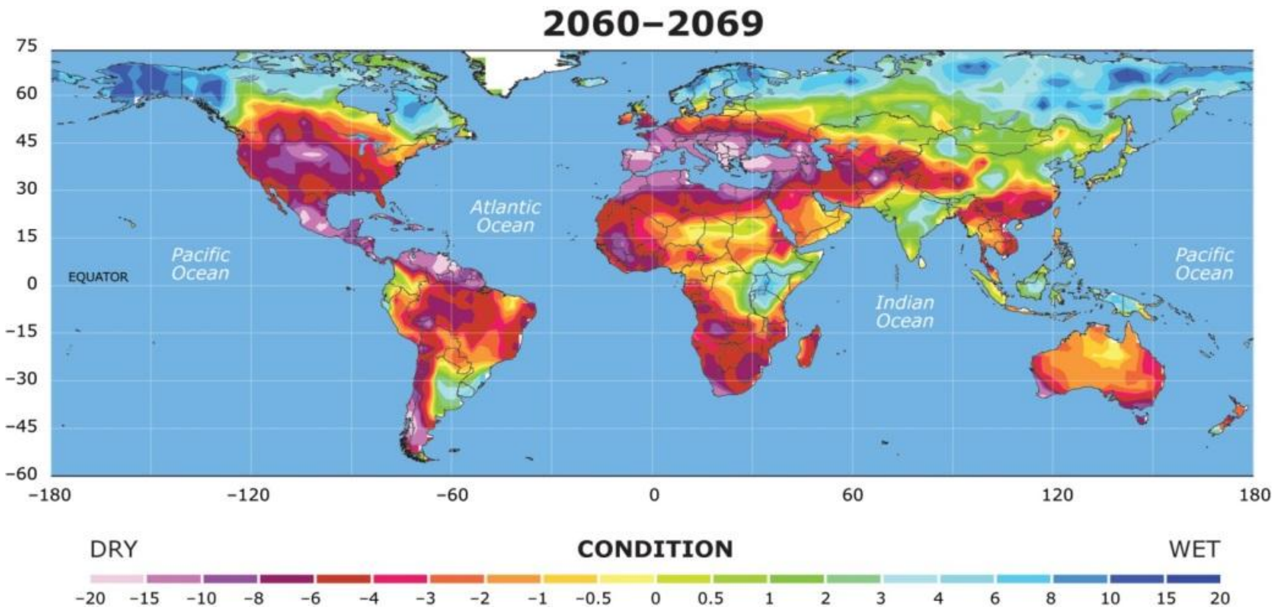


Figure 65: Projections of global wet & dry conditions (Dai, 2011) → many farming regions are expected to get much drier. Southern Manitoba straddles the pink & red regions (-3 to -6), reaching -6 to -8 as you move westward.

Global Food Supply Risk from Rapid Climate Change

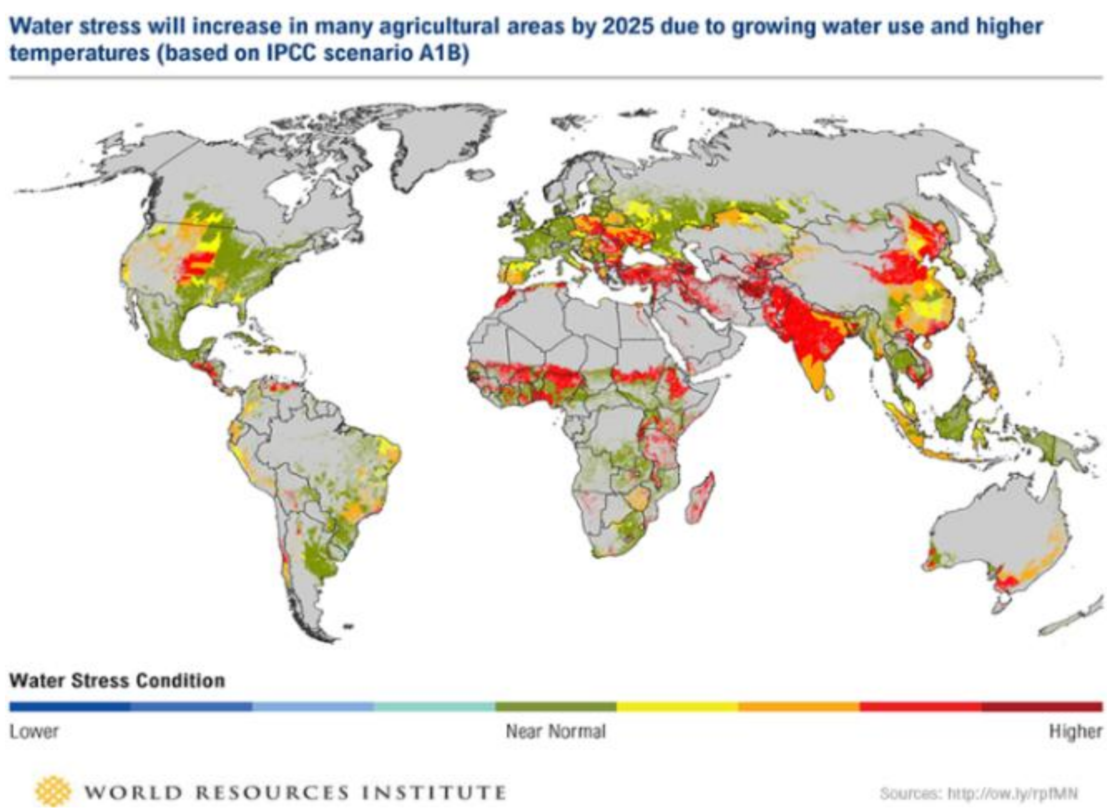


Figure 66: Water stress levels in agricultural regions around the planet are very uneven. With growing water demand and shifting rainfall patterns (from rapid climate change) it is likely to worsen.

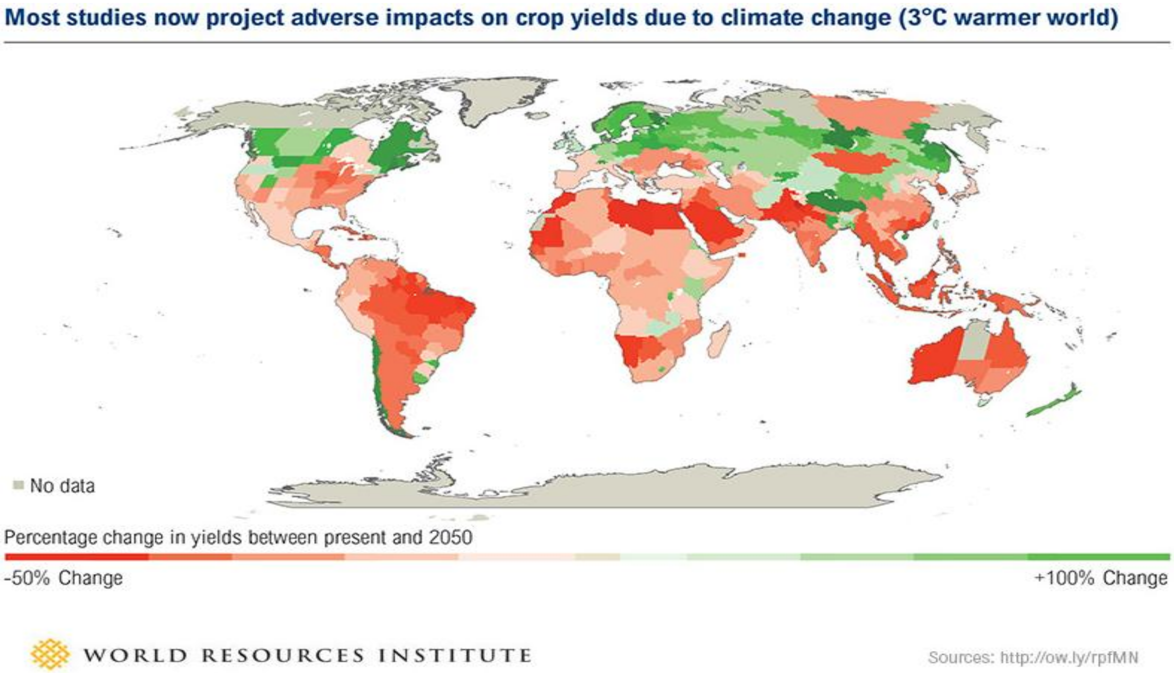


Figure 67: Projected impacts on crop yield percentages from an increase in global average temperatures by 3^{o}C from climate change.

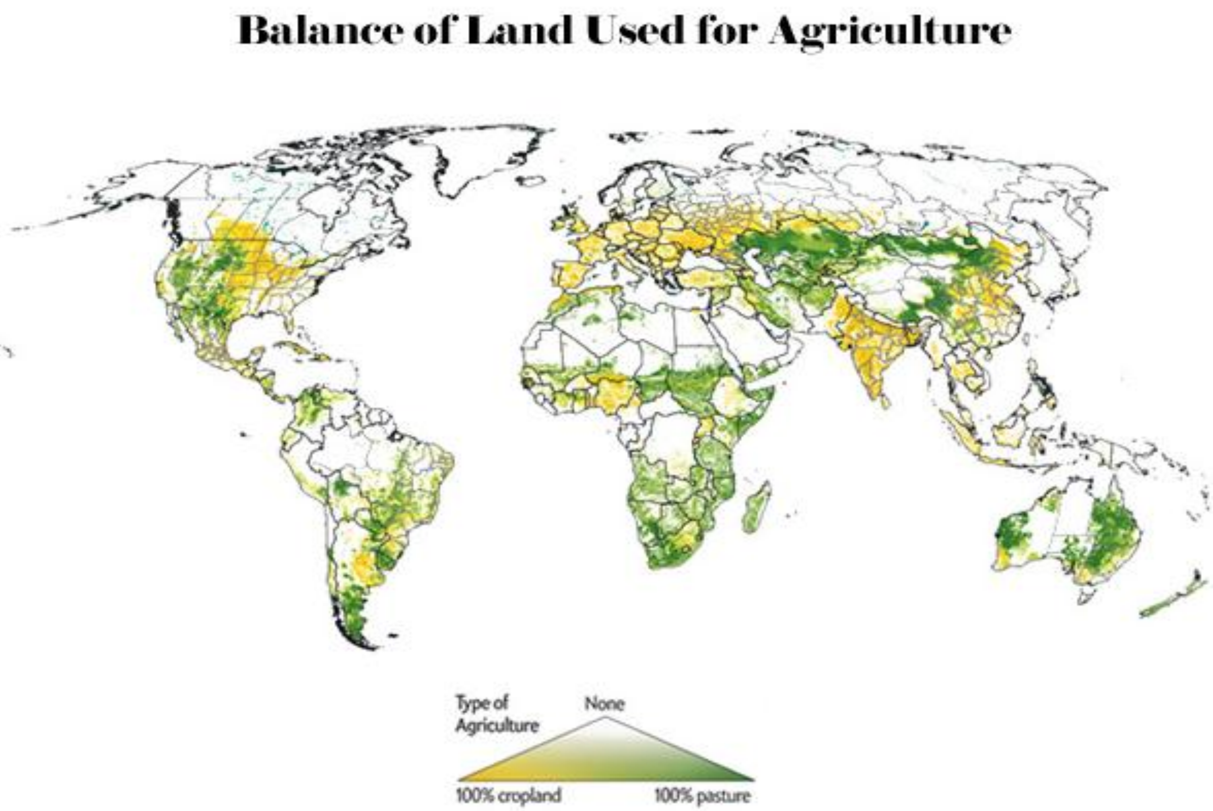


Figure 68: Balance of land use in agriculture between cropland (direct food crops) and pasture land (for livestock grazing).

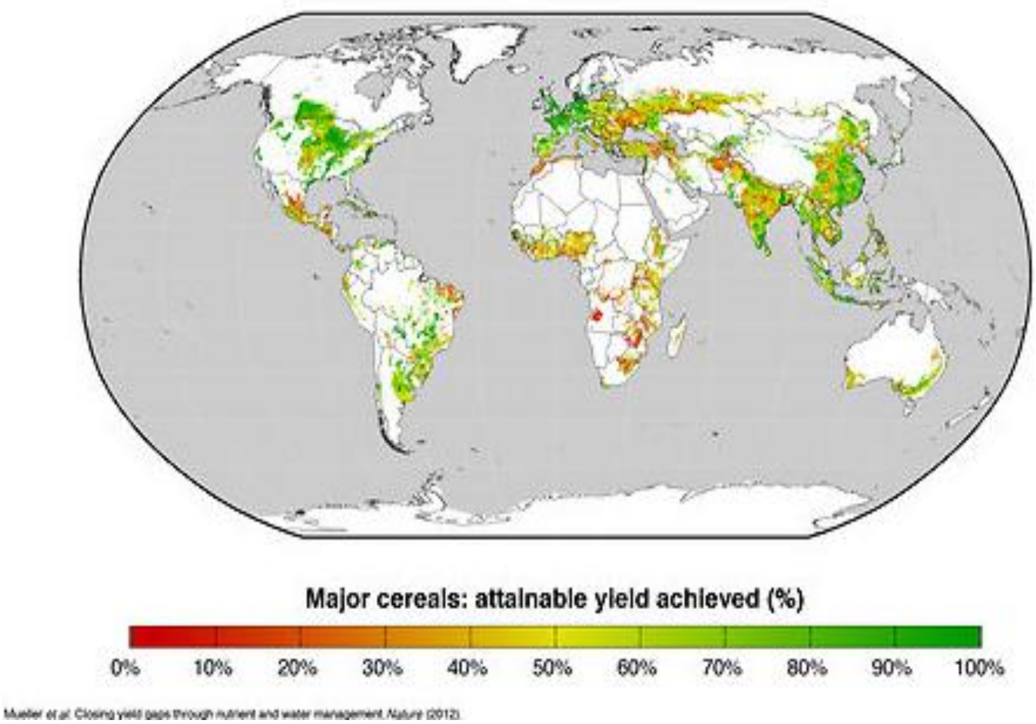


Figure 69: Attainable crop yields achieved for major cereals grown around the planet.

Our global food supply is the Achilles Heel of our civilization, and is very likely to be severely strained soon from rapid climate system changes that are presently underway. Agricultural regions around the planet are increasing enduring water stress, and associated crop yield reductions (especially in major cereal yields) due to these ongoing rapid climate system changes, most notably from extreme weather events like flooding and severe, long duration droughts (i.e. the five year California droughts, followed by torrential rains and flooding). The only realistic common-sense conclusion is that humanity is undergoing a global climate change emergency. The sooner society recognizes this, the better the prognosis.

Cascading Feedbacks Have Created a Global Climate System Emergency

Cascading feedbacks are when one feedback changes the system enough such that another feedback kicks in and moves the system even more, and so on, analogous to the situation of toppling dominos. For example, large melting of ice on Greenland will raise sea levels, likely enough to lift up Antarctic sea ice shelves and thereby accelerate their melting which raises sea level even more, and so on.

It seems that for the general public to mobilize and demand serious government action on climate change, that “bad things must happen to regular people in rich countries right now”; and the media must report the cause of these “bad things” to be rapid climate change. Essentially, this requires a change in “world view”. Here is what society can expect in the near term:

1) ice-free Arctic in September likely this decade
2) extremely rapid warming acceleration
3) permafrost thaw (land & marine) methane surges
4) mega-drought hits U.S. southwest & Great Plains

5) more Katrina like superstorms
6) heat waves hitting U.S. & Canadian breadbaskets
7) accelerating sea-level rise, ice shelf collapses
8) Amazon rainforest collapse
9) Huge rise in extinction rates of plants and animals
10) Enormous geopolitical problems, as nations build borders and compete for dwindling resources including food and fresh water

A more comprehensive presentation is at: http://www.cmos.ca/Ottawa/SpeakersSlides/PaulBeckwith_19Jan2012.pdf and on my website http://paulbeckwith.net and in my >200 YouTube videos (google my YouTube channel).

The following quote, from Sir Winston Churchill to the British Parliament prior to the start of the Second World War seems to apply to humanity now in the face of rapidly accelerating abrupt climate system change…

> *"Owing to past neglect, in the face of the plainest warnings, we have entered upon a period of danger. The era of procrastination, of half measures, of soothing and baffling expedience of delays, is coming to its close. In its place we are entering a period of consequences. We cannot avoid this period, we are in it now…"* **Winston Churchill, Nov. 12, 1936, speaking to the British House of Commons**

Climate Change Survival: Three-Legged-Barstool

Step a) General Public, Policy Makers, Governments, Military, and Scientists (or basically, everyone on the planet) must "get-with-the-program" and recognize our worsening Climate Change EMERGENCY
Step b) Governments around the planet MUST declare a Global Climate Change Emergency
Step c) Deploy "Three-Legged-Barstool" technologies to have a decent chance to survive the wrenching changes that we cannot avoid.

Figure 67: Three-legged-barstool metaphor for approach to address our global climate change emergency.

Three-legged-barstool approach:

Leg 1: Slash fossil-fuel emissions to zero as quickly as possible.

Leg 2: Deploy Carbon Dioxide Removal (CDR) technology to lower atmospheric concentrations to < 350 ppm, and methane removal technology.
Leg 3: Deploy Solar Radiation Management (SRM) technology to cool the Arctic.

Global-to-Local Scale: Manitoba and Environmental Assessments: Key Points and Recommendations

1) Climate history (temperature & precipitation) over the last century in Manitoba (historical averages & trends) are often used as a basis for expected future changes. This method is prone to large errors & uncertainties since rapid global climate changes discussed have essentially changed the statistics of climate & thus weather events & recurrence intervals (i.e. 1-in-100 year flood).

2) Variability has increased across most timescales (decadal, year-to-year & even seasonal, monthly & weekly timescales). The term “weather whiplashing” applies. A particular city or region can experience record high temperatures one week, record low temperatures the next week, & swing back to record high temperatures the subsequent week. The risk of “weather wilding” is dependent on the location relative to the jet stream waves. For example; the “Summer in March”, 2012 heat wave in North America; 1st week of March had normal cold temperatures; 2nd week was up to 15^{o}C warmer than normal; followed by a killing frost causing $100 million damage to Ontario’s apple crops.

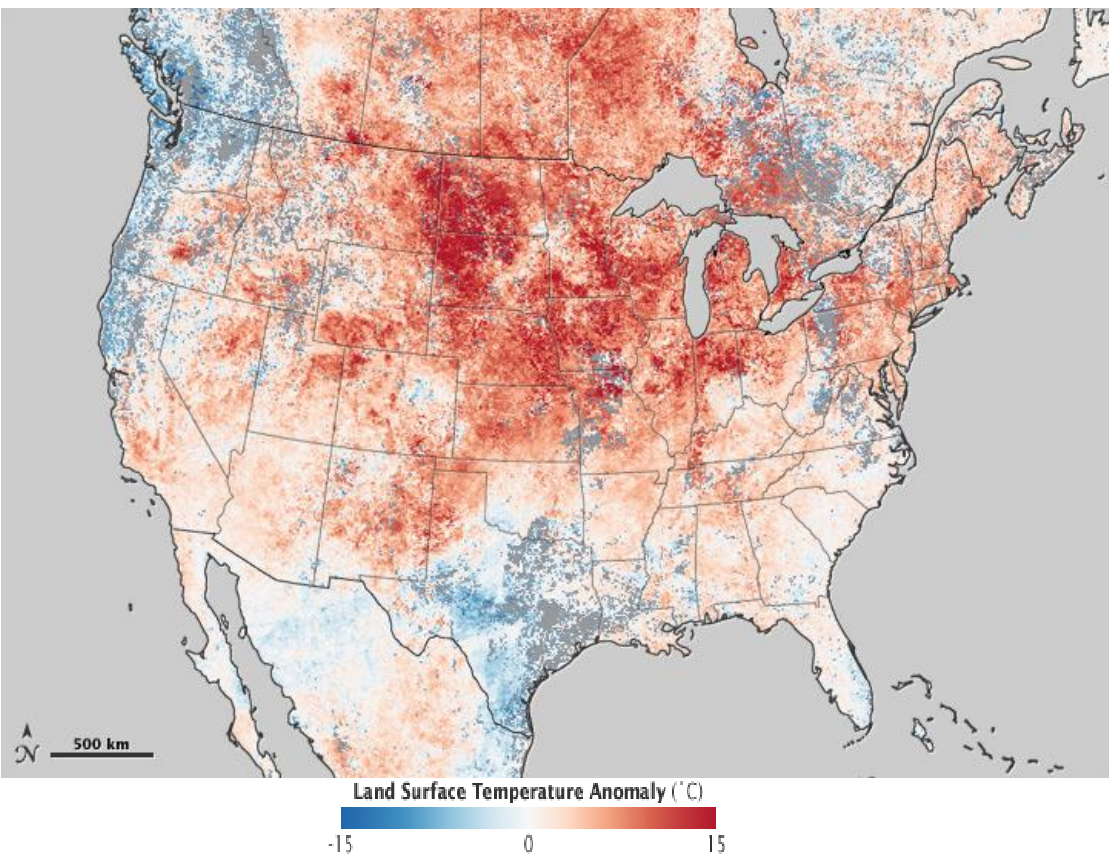


Figure 68*:* North American Heat Wave: March 8 – 15, 2012

"The duration, areal size, & intensity of the "Summer in March", 2012 heat wave are simply off-scale, & the event ranks as one of North America's most extraordinary weather events in recorded history." (Wunderground, 2012)

In 2012, the growing season started 5 weeks early; early snowpack loss caused low river flows in summer, and the stage was set for summer heat & droughts. NASA Earth Observatory
http://earthobservatory.nasa.gov/IOTD/view.php?id=77465&src=share
3) Climate projections for Manitoba are based on "downscaling" the Global Circulation Climate Models (GCMs) to the specific region. This makes sense when the GCMs closely mirror a slowly varying, linear climate system (which is NOT the case). However it can be very risky to rely on these models when we are experiencing extremely rapid changes in the climate system that the GCMs are not capturing.

4) Manitoba climate/hydroclimate studies assess atmosphere & water conditions (including lake levels, streamflows & water temperatures) based on data from the last century as well as projections from the regional models. With much greater variability due to global climate system changes, these studies are expected to be less reliable.

5) Since climate statistics have changed, probabilities that are based on a stable climate, namely the risks of "one-in-a-hundred" or "one-in-a-thousand" events need to be carefully evaluated since they are highly likely to no longer be valid. In this case, more weighting on recent behaviour over the nearest decade will be expected to lead to better modelling and risk assessments.

6) Lake Winnipeg water temperature is very important during heat waves with extended droughts. Annual evaporation will remove much more than 20% of the inflow, the lake volume will decrease & there will be much greater risk of eutrophication & blue-green algae blooms, similar to what occurred on the west shore of Lake Erie in the summer of 2014. Less lake volume will reduce hydro-electric power generation and perhaps reduce electricity supply for the MMTP grids.

7) Decreases in mean discharge of the Saskatchewan River need to be studied carefully since many glacially fed rivers are drying up due to rapidly declining snowpacks in the mountains. Steadily rising temperature trends at mountain elevations are causing rapid glacier declines, as well as a 20% decline in spring snow cover throughout the Rockies in the U.S. since 1980 (Pederson et al., 2013). The Peyto glacier which helps feed the Mistaya & North Saskatchewan Rivers has lost about 70% of ice mass. Glaciers in the Rocky Mountains supply the majority of the stream flow used in Alberta, Manitoba & Saskatchewan. Also, runoff from snowpack supplies between 60 - 80% of annual water supplies to 70 million people in the American West. Water flow is vital for generation of the power production supplying the MMTP grid.
http://e360.yale.edu/feature/loss_of_snowpack_and_glaciers_in_rockies_poses_water_threat/2785/
The glacier covered regions in the South & North Saskatchewan River Basins in Alberta have declined in area by 37% & 22% respectively since 1975 (Pomeroy, 2014). In the short term, glacially sourced water flows can temporaily increase during a "last gasp" of the glacier.

The Prairie Provinces Water Management Agreement dictates the split in water use from Alberta to Manitoba. Water access rights in this agreement mean that for one unit of water input in Alberta into the Saskatchewan River the division is as follows: Alberta 50%, Saskatchewan 50% of the remainder (25% of input), and Manitoba the remainder (25% of input). These ratios were determined under drought conditions & useage may need to be reevaluated. The agreement also means that Manitoba is at the end of the pipe when there is excess water, like in 2011 and 2014. Also, the Lake of the Prairies on the border of Manitoba and Saskatchewan is a reservoir to hold water when there is too much or when there is a drought. These 1950s arrangements in no way anticipate glaciers melting down, rivers drying up, and other effects that are occurring in our rapidly changing climate system. Thus, this agreement will need to be re-negotiated by the prairie provinces.

Thus, it is clear that any climate change caused reduction of high elevation glacier water storage is a large risk to people around the planet, not just in Manitoba but also, notably to people relying on water storage in the Himilayas, Andes & Rockies Mountains.

8) Climate normals from the thirty year period 1981 to 2010 are usually used in the analysis of climatic characteristics in Manitoba, including in the SE region of the MMTP. Since most of the rapid changes in the global climate system have occurred in the time period from 2000 to present, it makes sense to also analyze climate based on the older 1971 to 2000 climate normals. Using the more recent climate normals is actually hiding climate change that has happened in the previous decades. This point needs to be given careful consideration in any and all climate change studies for MMTP and for any other infrastructure projects undertaken by Manitoba Hydro and other companies, and assessed by the CEC and any regulatory bodies.

9) The Lake Winnipeg Basin has been experiencing a "wet cycle" for the last 15 years or so. There is no expectation that this will continue as rapid global climate system changes accelerate. Many climate models (noted previously to underestimate the rate of change) project an increased global aridity in the 21st century over much of the planet (most of Africa, the Americas, Australia, Southeast Asia, southern Europe & the Middle East). It seems clear that large variability between exceptional drought & severe flooding (called weather whiplashing, or weather wilding) will increase in many regions.

10) There are many ways in which the MMTP grid can be severely tested by extreme weather events. Converter stations & substations spread over a large region can become inundated by flood waters from widespread torrential rain events that greatly exceed rainfall rates and amounts in short periods of time (i.e. five months of rainfall in a few days, as experienced by Calgary & Toronto events in 2013, and large regions of Ontario, Quebec & British Columbia in April & May, 2017.

11) When surface air temperatures in the summer over Lake Winnipeg are very high, in combination with warm surface water temperatures, there are very high evaporation rates and thus lots of warm humid air is created over the lake. With temperatures of 30^{o}C and 100% humidity levels, there are large convective storms occurring that often generate tornadoes. We clearly need decent observational records on the number of these tornadoes, and on how many have occurred IN the MMTP region over the last few decades. It seems that this data is somewhat lacking.

Tornadoes are always a risk to power line infrastructure. It is important to accurately quantify the risks based on the existing statistics of storms that generate tornadoes, and try to determine how these statistics are changing with ongoing abrupt climate change. One major concern is that the existing region in the central U.S. known as "tornado alley" migrates northward over the border to Canada. The location is the region where there is a large and frequent clash of air masses, namely the warm humid air moving northward from the Gulf of Mexico collides with the cool dry air masses moving southward from the Arctic. With a warming climate, it is very possible that the collision region shifts northward, perhaps as far north as southern Manitoba?

12) Derechos are straight-line winds lacking the rotation leading to tornadoes, but with winds strong enough to damage transmission line towers & thus power grids. They are mostly a phenomena caused by a rapidly

moving frontal system and can extend over a large region (hundreds of km long, by 30 km wide); i.e. the New Brunswick storm on May 19th, 2017 toppled 20 power poles.

13)Ice storms (freezing rain) are generally very rare events since the conditions that generate them are extremely rare due to extremely tight temperature ranges (when it is slightly colder then the precipitation falls as snow, and when it is slightly warmer then you get rain instead of freezing rain). Also, the meteorological conditions for ice-storms need to stay in this tight range for a long period of time, for example days as in the widespread Quebec/Ontario ice storm of 1998. These rare conditions may become more frequent as rapid climate change accelerates due to the increased humidity in the air, and the shift from cold temperatures to warmer temperatures near freezing. In addition, the locations for freezing rain events may shift as the climate warms, more quickly at higher latitudes than lower latitudes.

14) The increased frequency of heat waves & associated droughts with rapid climate change may become problematic to the MMTP grid. Heat waves cause power lines to expand & sag, potentially increasing the risk of fires if the lines sag into tall vegetation. The conductivity of the conductors in the lines decreases as temperature increases, and there is a feedback to even higher temperatures from increased resistive heating of the lines. Risks of fire greatly increased as vegetation dries and is stressed, and fires can shut down the grid. It is also important to note that with a warmer, more humid and energetic atmosphere from rapid climate change there will likely be more lightning generated from storms. This lightning, when combined with heat waves and stressed trees will increase the number and size of fires that will pose increased risk to many parts of the MMTP infrastructure, including transmissions lines, towers, stations and substations. Systems to detect lightning strikes, and ignition of vegetation would allow more rapid firefighting response before fires get out of control.

15) Manitoba Hydro and many other companies, and the CEC and many other regulatory bodies consistently have an over-reliance on IPCC (Intergovernmental Panel of Climate Change) climate models. There is a lot of money invested in large scale GCMs (Global Climate Models), and these models are used to make projections on how climate change will play out in the near-term to far-term. Unfortunately, these models are unable to project what is happening now on the ground.

16) The Prairie Climate Atlas uses data from 12 downscaled global climate models (GCMs) to make projections on climate conditions for the prairies, including Manitoba. This capability is extremely useful, but since the GCMs do not account for the extremely rapid changes that are occurring in the Arctic such as the complete loss of sea ice within a few years as opposed to the modeled 30 years or so, any results from these projections is likely to be on the conservative side. It is important to incorporate all of the Arctic feedbacks effects into these models, such that they more closely resemble the observations. Clearly, if there is a discrepancy between the model and the observations, then the model is simply wrong. Observations are reality.

17) The increasing prevalence of extreme weather events, namely of intense wind storms, including derechos (straight line frontal winds), downbursts and tornadoes requires a re-examination of the traditional lattice stand-alone towers, versus guyed towers, versus the newer streamlined pole towers used in many places in Europe (these newer design pole towers are shorter, so the wind stress is lower; also the tower cross section is much smaller so they are more durable, with less sway in strong windstorms as compared to the traditional lattice towers).

Do a simple Google search on the phrase “climate change faster than expected” and you get enormous numbers of hits, and then do a search on “climate change slower than expected” and you get next-to-nothing. Clearly, what mainstream science (including the IPCC) expect to happen is completely biased on the conservative side, with expectations of slow linear changes in climate. Thus, whenever some new abrupt episodic observation comes along then it is undoubtedly “faster than expected”. This means that science, policy makers, and report writers need to pay less attention to models and much more attention to climate observations to get a better understanding of the reality of abrupt climate system change. A great example is on when Arctic sea ice will vanish in September for the first time. Models will still be claiming that this will happen in 2040 or so even as the ice completely disappears from the Arctic Ocean by 2020 or earlier. This would be laughable if the consequencies of these errors were not so severe to humanity.

Overall Summary: Rapid Climate Change and Impacts (Manitoba)

It is important that people in all walks of life, whatever their background and skill sets, educate themselves about the reality of how GHG emissions are rapidly changing our climate. It is important for the public and decision makers to really understand that these seemingly endless and accelerating rises in atmospheric GHG concentrations are not just numbers in a spreadsheet, but actually have clear and present risks to the well-being of every human being, plant and animal within Earth’s ecosystems.

Clearly, people need to separate themselves from the status quo, business-as-usual, growth at all costs paradigns prevelant throughout our present society and get a realistic and clear, unambiguous, truthful picture of the rapidity of abrupt climate change, and understand how it threatens our entire civilization and ability to thrive (or even survive) on this planet. At present there does not seem to be any sense of urgency (and thus true understanding) of these grave risks. This lack of a sense of urgency is very noticible even at international climate change policy conferences like the yearly COPs (Conference of Parties), and as a scientist and a citizen I find this extremely disturbing and question how this can be our present state of awareness. Surely we can do better than this, for the

In short, there is absolutely no recognition of the enormous existential risks that humanity faces NOW from our rapid destabilization of our global climate systems and weather patterns, and the huge threats to our global food and water supplies. None whatsoever...

Building any new fossil-fuel infrastructure in our carbon-constrained world is like throwing money at the horse and buggy industry while your competition is mass-producing cars; in other words it is economically insane.
The economic downside risks to Canada from building any new fossil-fuel infrastructure are enormous, and it is abundantly clear that huge price swings in global oil markets take Canada’s economy on wild oscillations; when the USD oil price was about $140 per barrel the Canadian dollar was nearly worth $1.10 U.S., and when oil prices dropped to less than U.S. $30 the Canadian dollar plummeted to about $0.65 U.S.; and staying low almost completely hollowed out Canadian manufacturing and killed far more jobs in Canada than the oil industry ever provided.

Climate change cares only about absolute concentrations of GHGs like CO_2, methane and nitrous oxide in the atmosphere, and not on intensities per GDP or per capita. – recently, a huge acceleration in global temperatures has been occurring; in fact annual average temperature in 2016 was 1.44^{o}C above the pre-industrial (1750) global average temperature; very rapidly nearing both Paris targets of 2^{o}C and 1.5^{o}C (actual and aspirational, respectively). The atmospheric CO_2 concentration rise in both 2015 and 2016 was at the level of 3.0 parts per million (ppm); these are frightening rises in light of IEA claims that global emissions from humans actually flattened out in 2014 and 2015, and in light of the fact that annual rises averaged only 2 ppm in recent previous decades, and more like 1 ppm in decades prior to that. This represents a truly frightening spiralling up of rates of atmospheric concentration rise.

In our present, severely “carbon-constrained” world, all emissions from any project must be assessed, including embedded emissions from equipment, grid electricity and fuels to run the project. Environmental Assessments and Environmental Impact Statements must examine not only how a project affects, but also how it is affected by global climate system changes. It would be helpful to see a complete life cycle analysis (LCA) of ALL the GHGs in relation to planning, construction, and operating the proposed MMTP for a timeframe of 50 years. This type of LCA should be a requirement in any EA or EIS review.