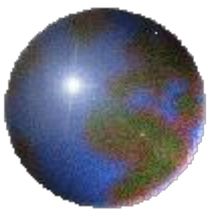
# Climate system change, from global to local: Lake Winnipeg Watershed




**By: Paul Beckwith**

Laboratory for Paleoclimatology and Climatology

Department of Geography, University of Ottawa


Laboratory for Paleoclimatology and Climatology

MANITOBA WILDLANDS©

SIERRA CLUB CANADA

uOttawa L'Université canadienne Canada's university

Lake Winnipeg Regulation; Manitoba Clean Environment Commission – April 9th, 2015

Graduate Studies in Geography It starts here.

NSERC CRSNG People. Discovery. Innovation.

# Lake Winnipeg Regulation (LWR) Hearings

How does one maintain control of water levels in Lake Winnipeg over this century (especially during extreme drought and flood intervals)?

Analyze climate history of last 100 years; climate models generate projections for the next 100 years.

How good are the models? Models work well for **linear** climate changes, where the weather statistics are invariant.

**This presentation** discusses how global climate system changes underway have changed the heat balance between the equator and the Arctic, thus changed atmospheric circulation patterns, ocean currents, and thus weather statistics. System is now **nonlinear**…

# Lake Winnipeg Basin – Five Watersheds


https://wpgwaterandwaste.files.wordpress.com/2015/02/lake_winnipeg.jpg

# Lake Winnipeg Regulation presentations

International Institute of Sustainable Development (IISD) presented "Strategic Large-Basin Management for Multiple Benefits" by Henry David Venema: emphasis on overall basin system components and interactions

Gregory McCullough presented "Climate in the Lake Winnipeg Watershed and the Level of Lake Winnipeg": examined previous century long climate patterns and inflow history to Lake Winnipeg; described climate pattern predictions for this century; related climate trends and variability to water levels

Manitoba Hydro (Water Resources Engineering Department, Power Planning Division) presented "Lake Winnipeg Watershed Hydroclimatic Study": quantified historic climate (temperature, precipitation, winds) to examine streamflow trends and variability; also used Global and Regional Climate models to make projections this century

# Outline: global climate system changes

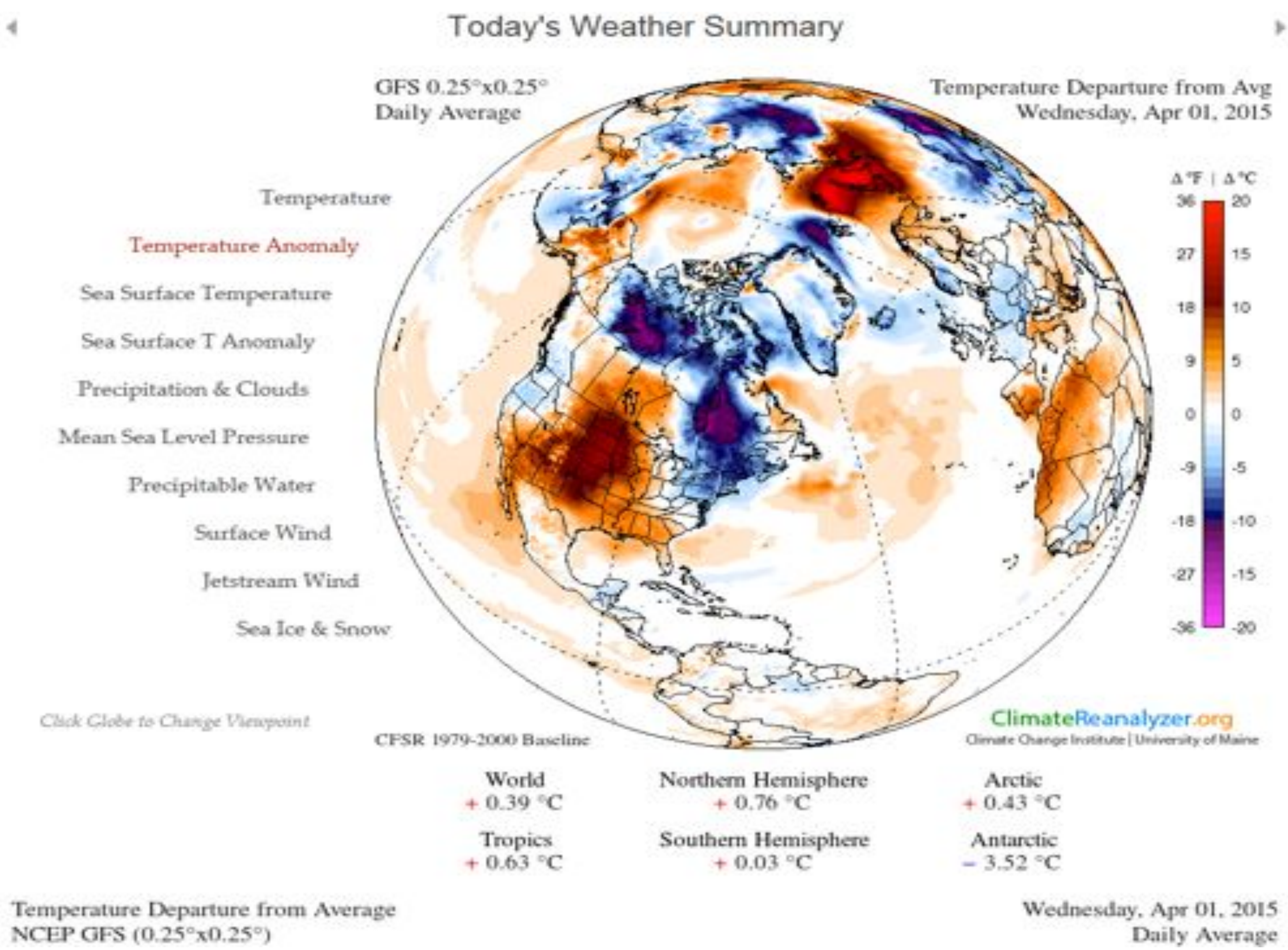
Increased human fossil fuel combustion and land use changes

→ atmospheric greenhouse gas concentrations up ($CO_2$, $CH_4$, $N_20$)

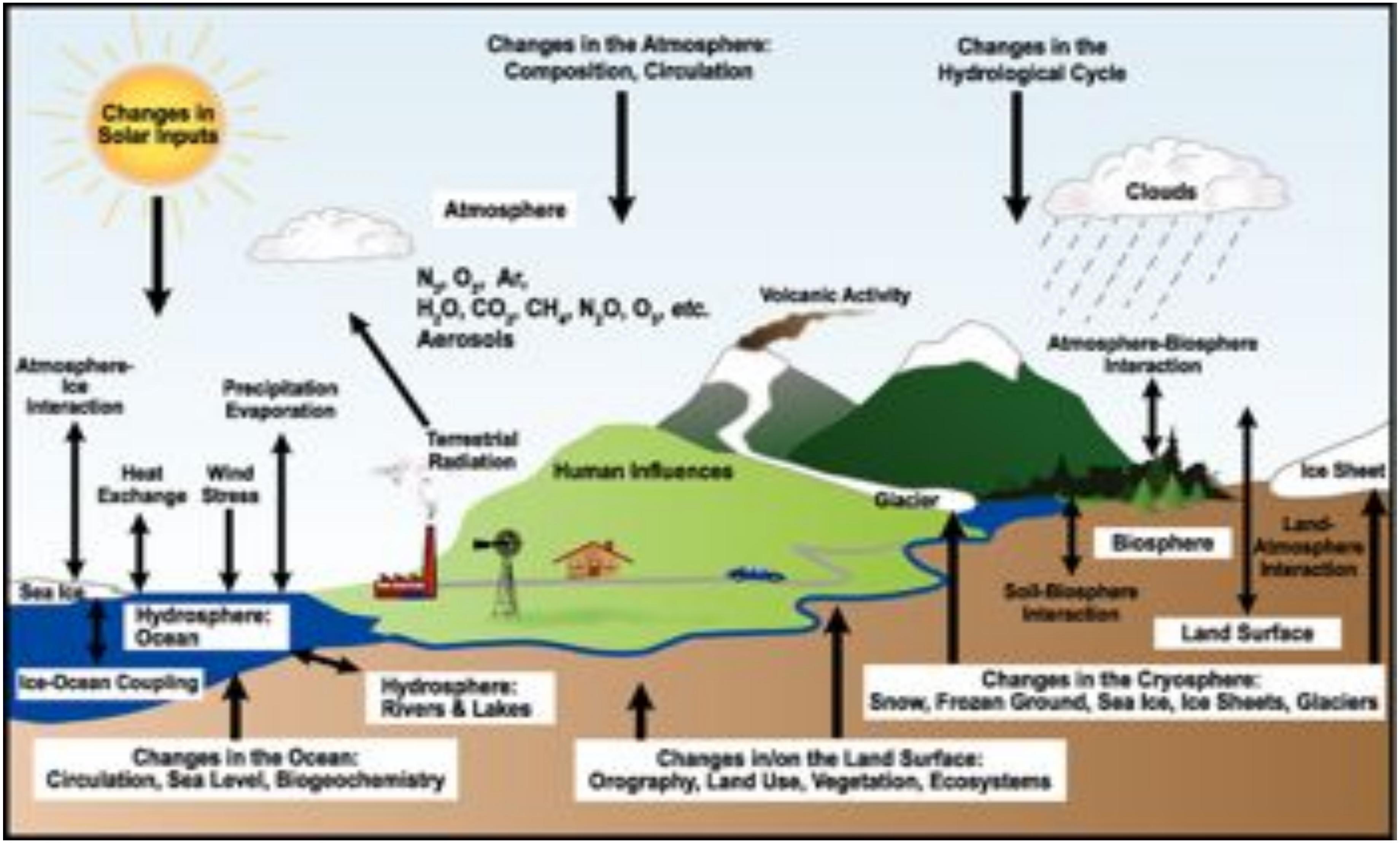
→Arctic temperature amplification of 5x to 8x global average due to darkening from declining sea ice, snow cover, Greenland melt

→ decreases equator-to-Arctic temperature difference

→causes less heat transfer from equator to pole in:
a)atmosphere: jet streams slow, become wavier and "persistent" → extreme weather events more frequent and intense, last longer
b)Oceans: currents such as Gulf Stream slow down, large sea level rise on US east coast

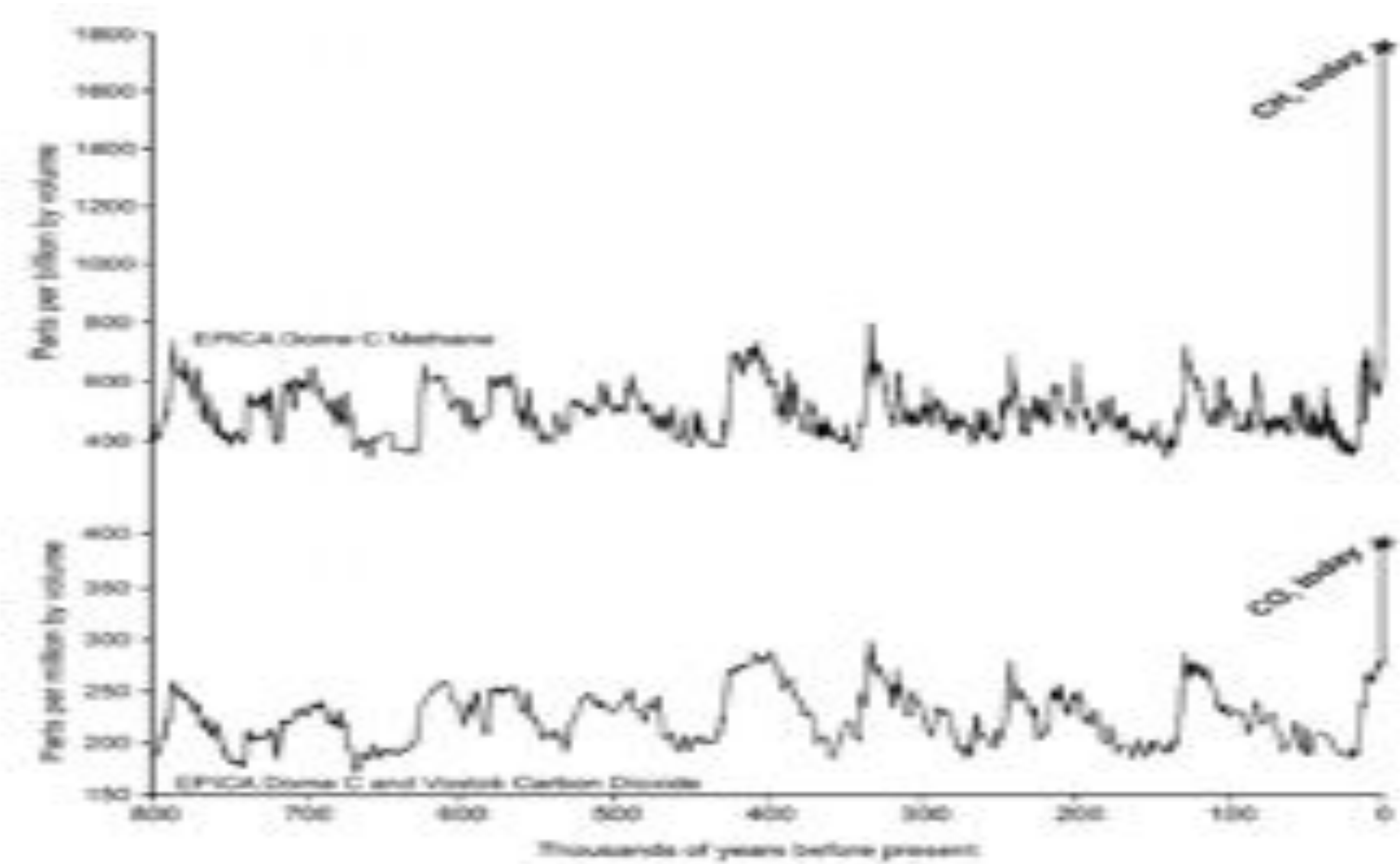

Today's Weather Summary
GFS 0.25°x0.25°
Daily Average
Temperature Departure from Avg
Wednesday, Apr 01, 2015
Temperature
Temperature Anomaly
Sea Surface Temperature
Sea Surface T Anomaly
Precipitation & Clouds
Mean Sea Level Pressure
Precipitable Water
Surface Wind
Jetstream Wind
Sea Ice & Snow
Click Globe to Change Viewpoint
Δ°F | Δ°C
36 20
27 15
18 10
9 5
0 0
-9 -5
-18 -10
-27 -15
-36 -20
CFSR 1979-2000 Baseline
ClimateReanalyzer.org
Climate Change Institute | University of Maine
World
+ 0.39 °C
Northern Hemisphere
+ 0.76 °C
Arctic
+ 0.43 °C
Tropics
+ 0.63 °C
Southern Hemisphere
+ 0.03 °C
Antarctic
− 3.52 °C
Temperature Departure from Average
NCEP GFS (0.25°x0.25°)
Wednesday, Apr 01, 2015
Daily Average

# Climate system of Earth (human timescales)




(IPCC:AR4, WG1, Ch. 1, 2007)

# Atmospheric methane and $CO_2$ concentrations




(Thompson, 2010)

# Recent atmospheric GHG concentration trends and rates

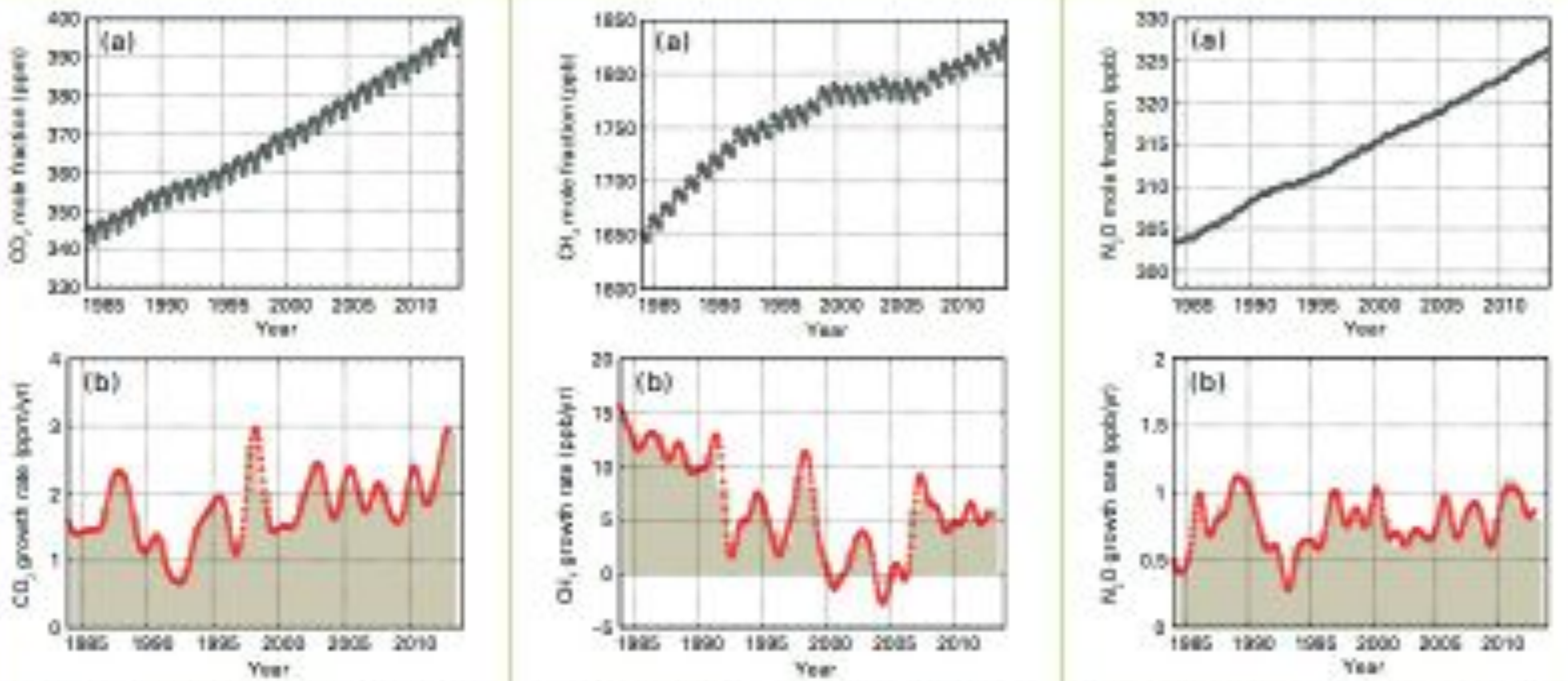



Figure 3. Globally averaged $CO_2$ mole fraction (a) and its growth rate (b) from 1984 to 2013. Differences in successive annual means are shown as shaded columns in (b).

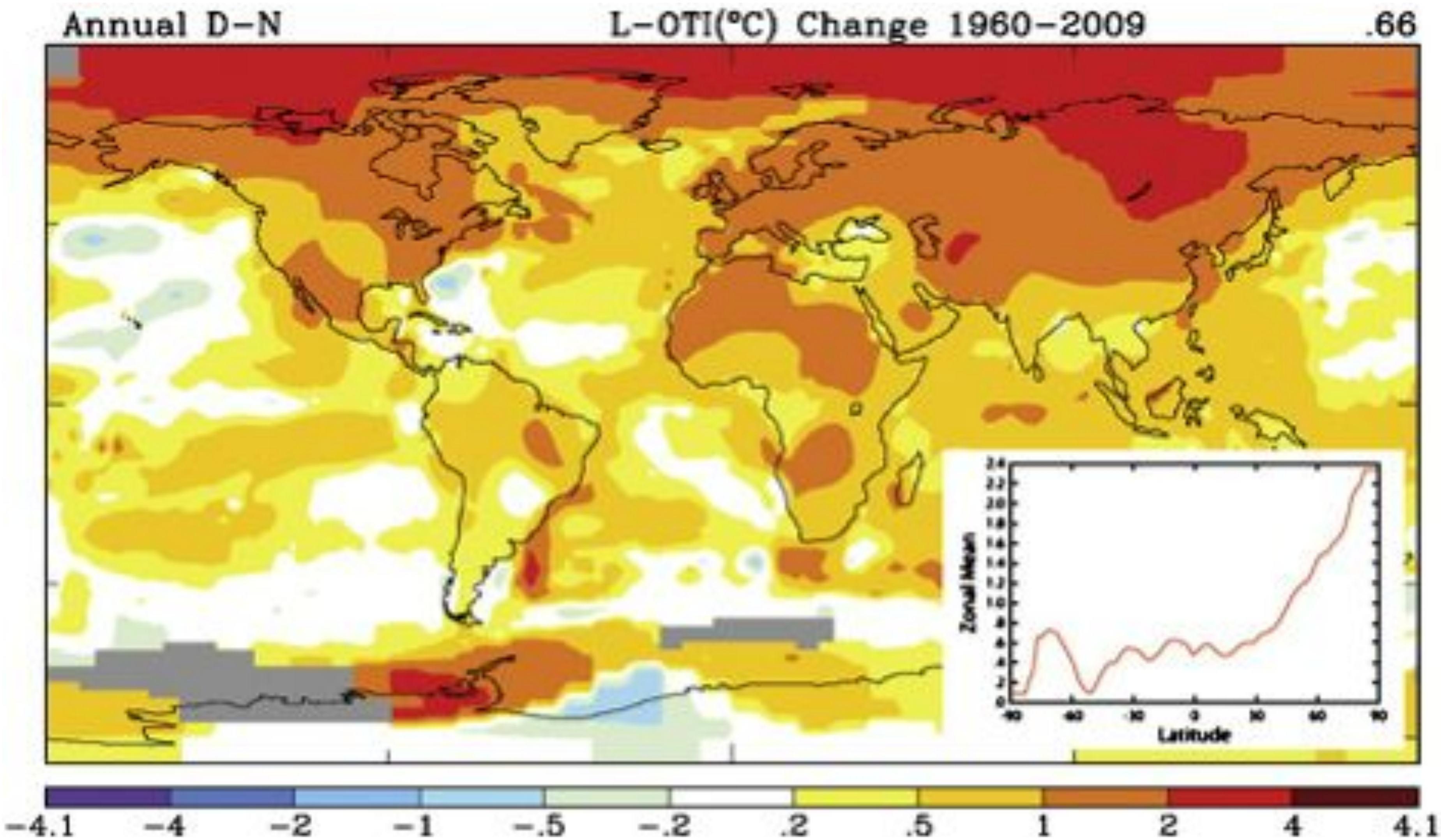
Figure 4. Globally averaged $CH_4$ mole fraction (a) and its growth rate (b) from 1984 to 2013. Differences in successive annual means are shown as shaded columns in (b).

Figure 5. Globally averaged $N_2O$ mole fraction (a) and its growth rate (b) from 1984 to 2013. Differences in successive annual means are shown as shaded columns in (b).

**Source: WMO Greenhouse Gas Bulletin, 9 September 2014.**

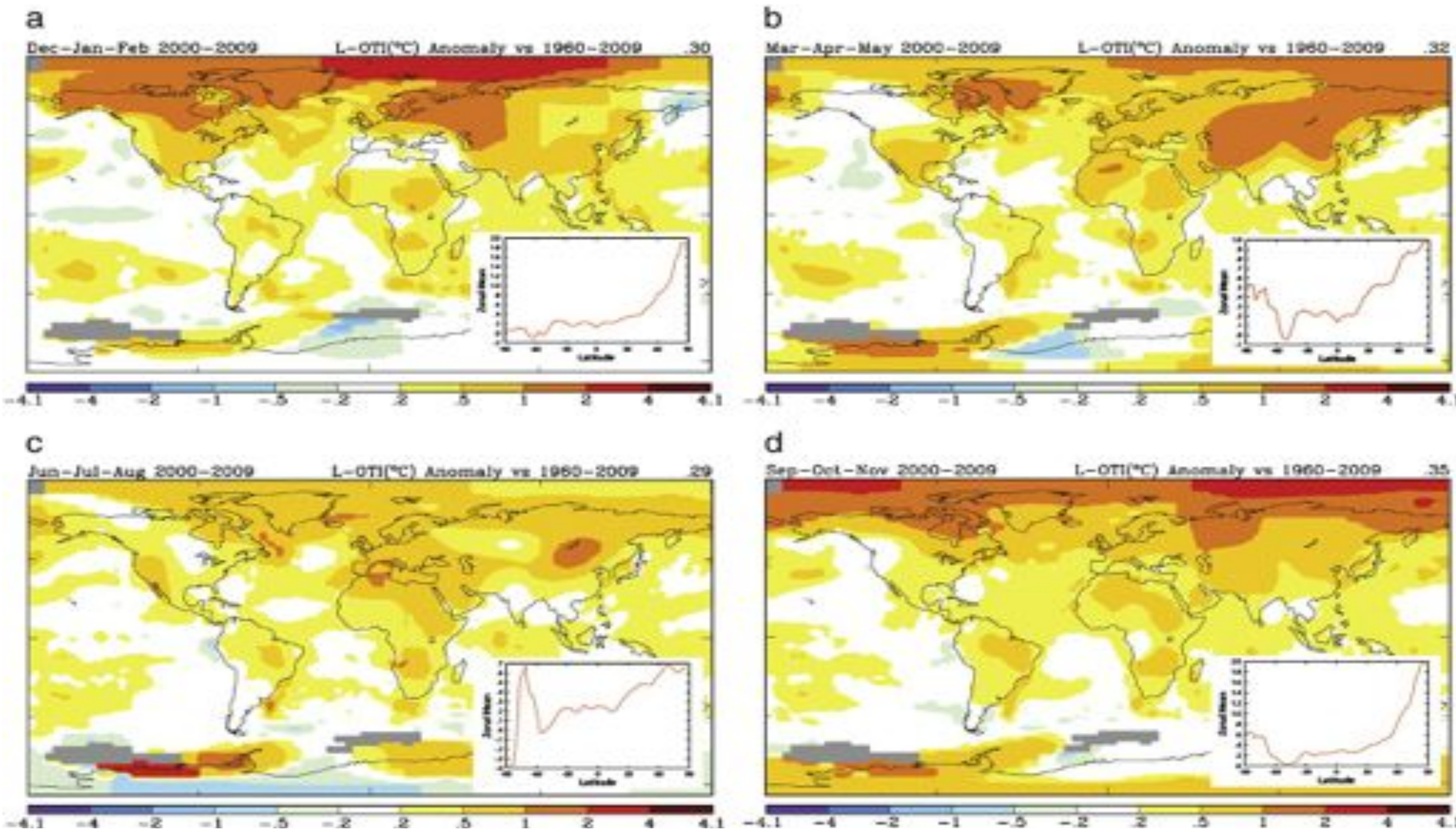
https://mogreenstats.files.wordpress.com/2015/01/ghg-levels-over-time.jpg

# Mean surface air temperature change ($^oC$)



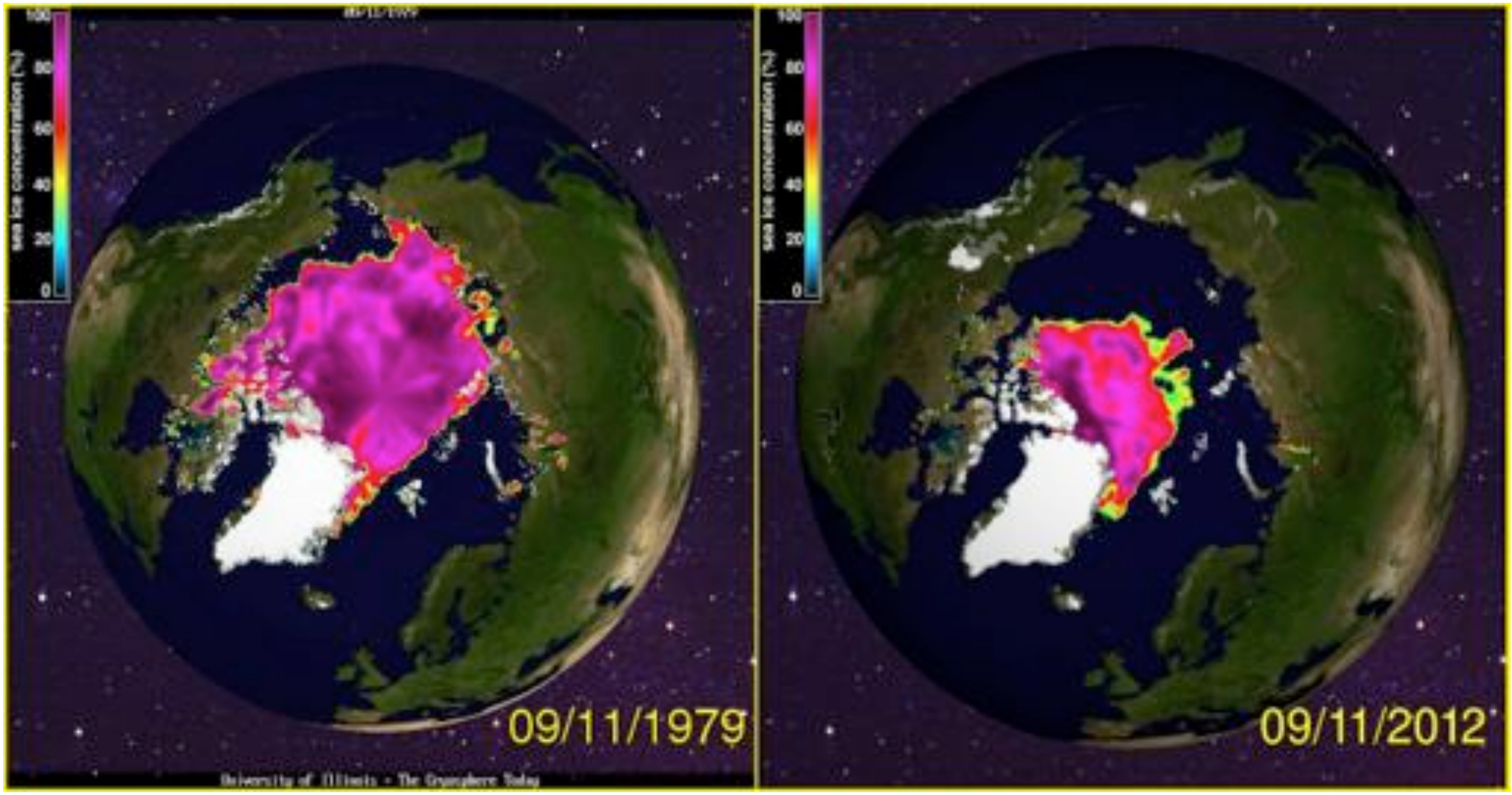

Serreze MC, Barry RG (2011) Processes and impacts of Arctic Amplification: A research synthesis. *Global and Planetary Change*, 77,85-96.

# Mean surface air temperature change ($^oC$)




Serreze MC, Barry RG (2011) Processes and impacts of Arctic Amplification: A research synthesis. *Global and Planetary Change*, 77,85-96.

## Arctic sea ice changes (end of summer melt)

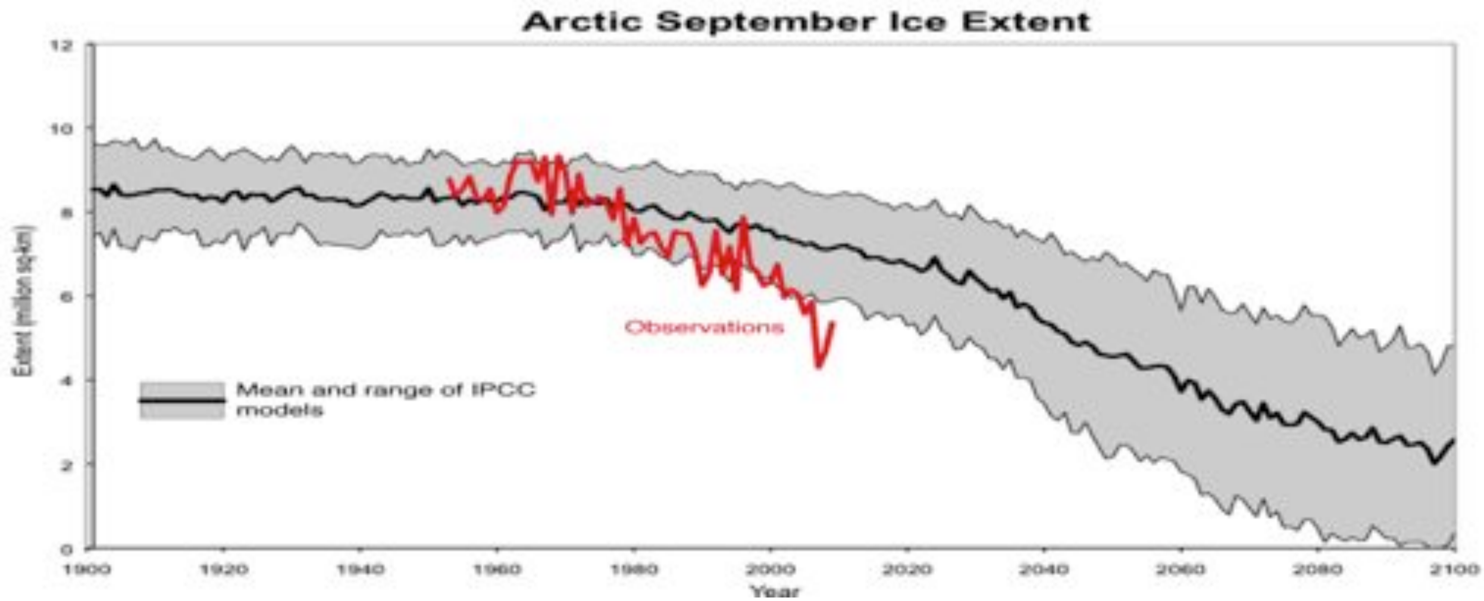



Movies: September sea ice minimums from 1979 to 2014

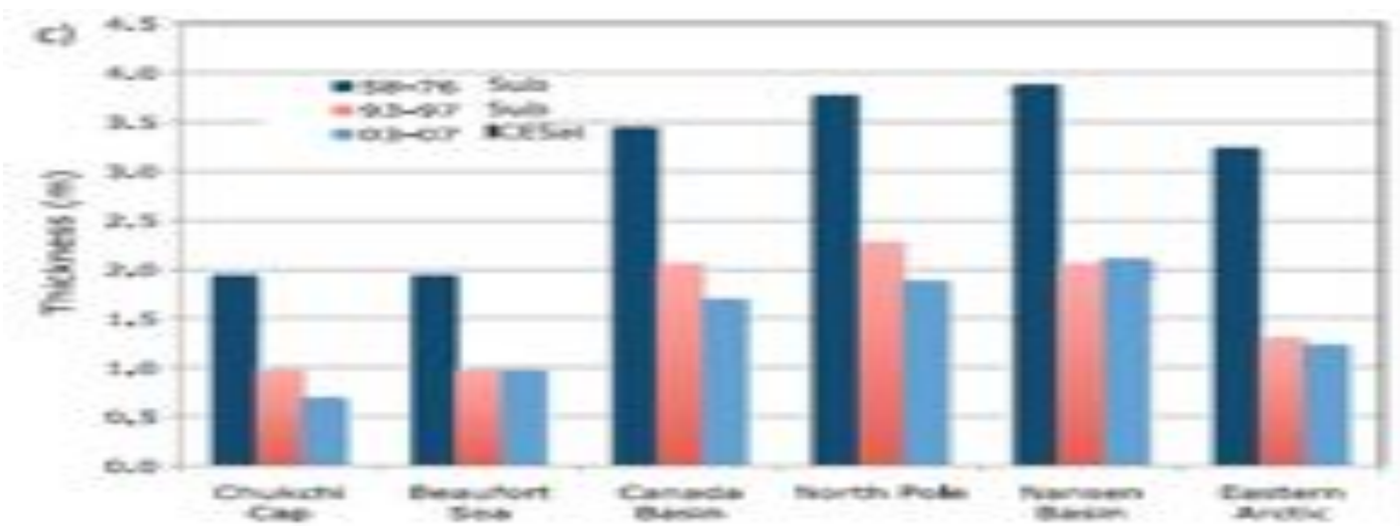
https://www.youtube.com/watch?v=nEOBwIopR9I

https://www.youtube.com/watch?v=AztEry44A9A

# Arctic sea ice changes

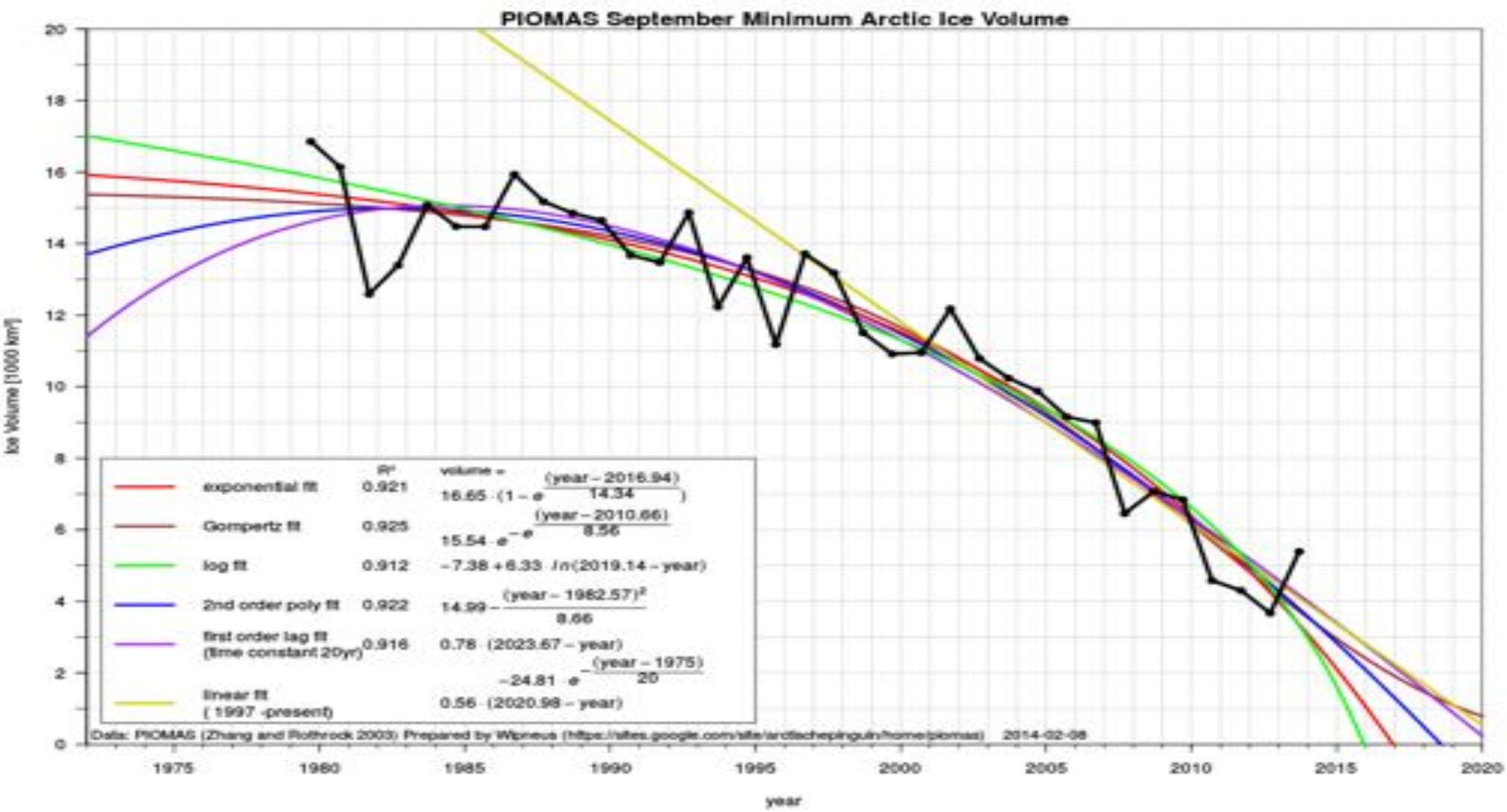



http://nsidc.org/icelights/files/2011/02/Decline_chart.png




Sea ice thickness (Kwok et. al., 2009)

# Arctic sea-ice yearly minimum volume (mid-September)

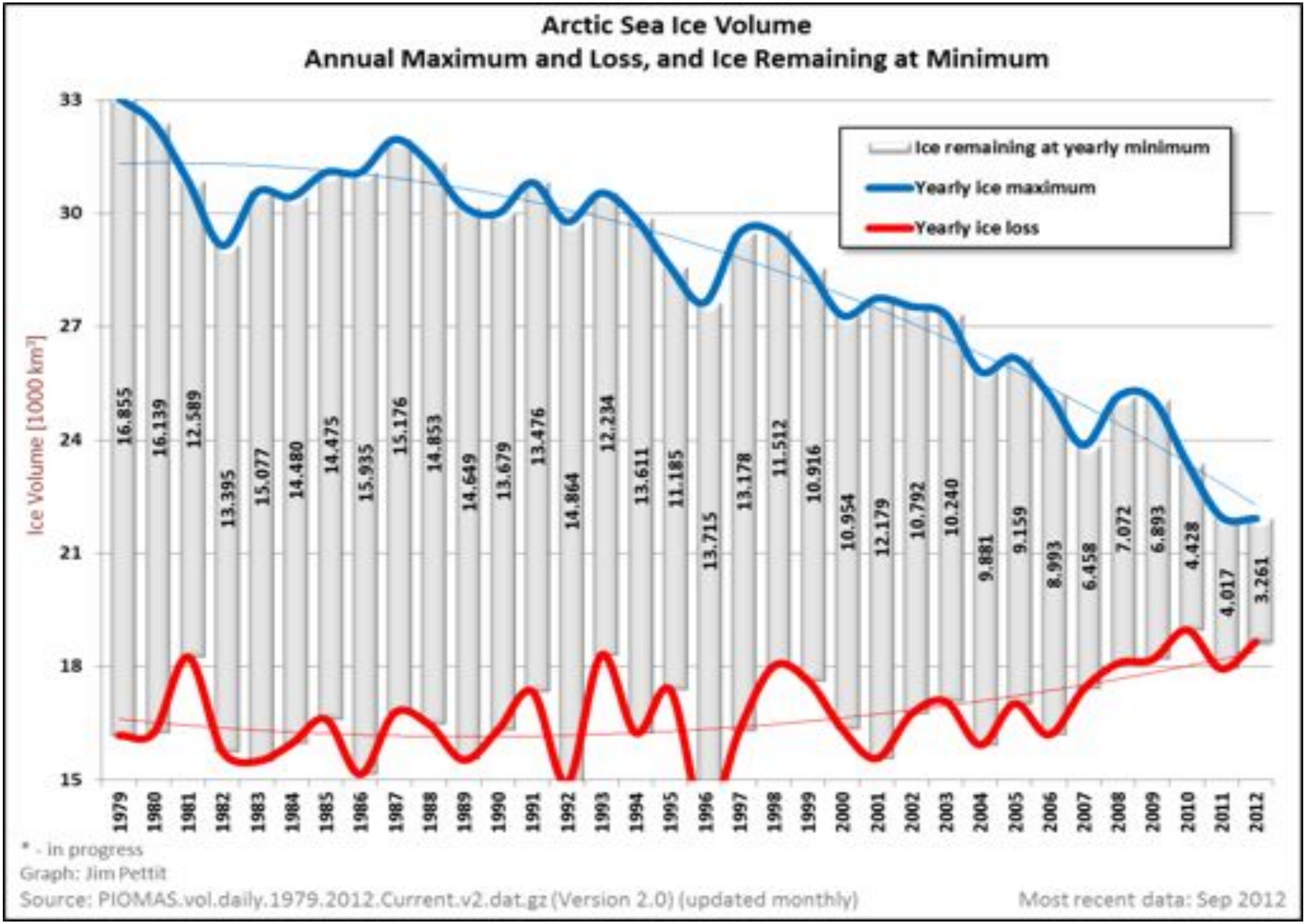


# Arctic sea-ice yearly minimum volume

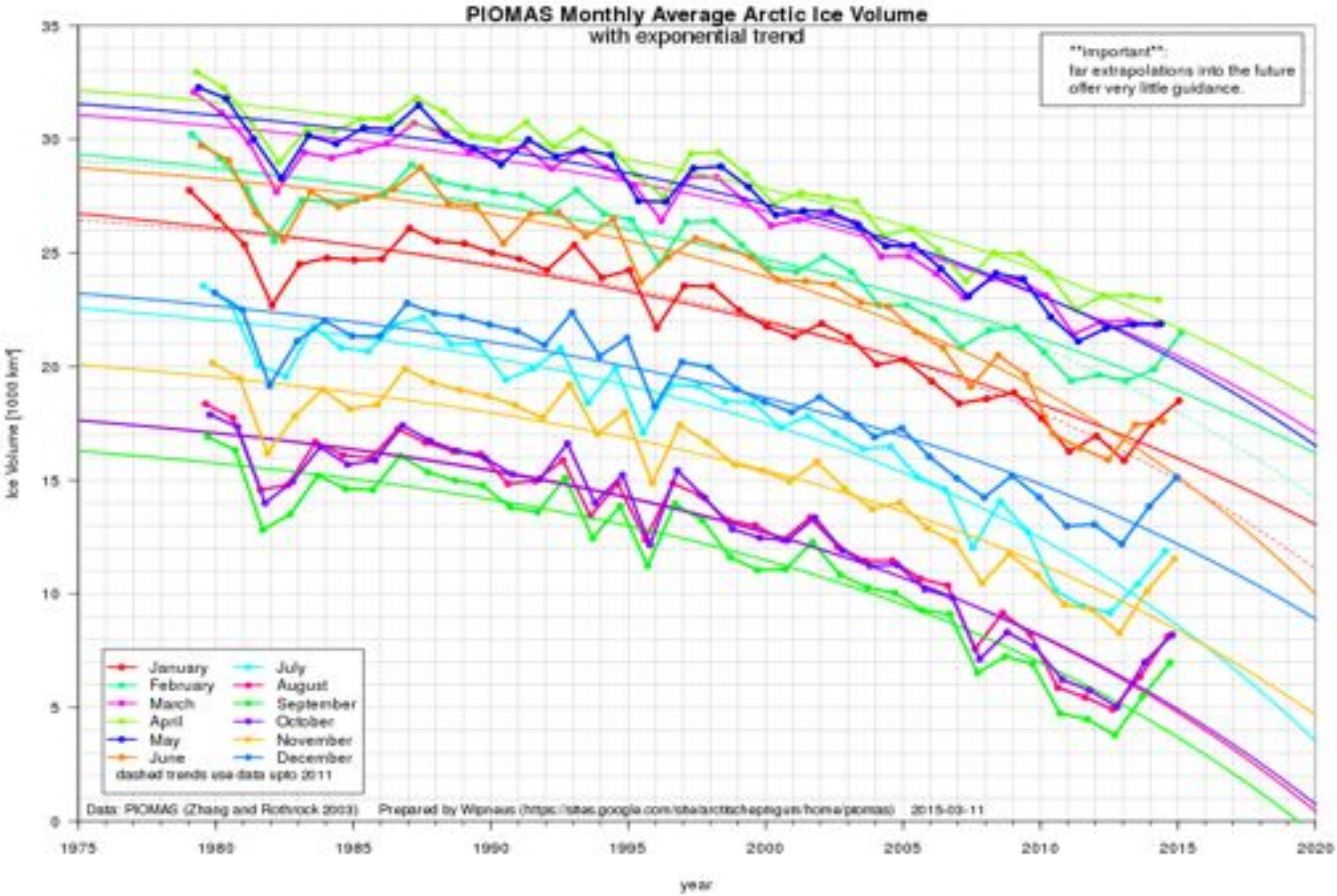
When will sea ice volume reach zero ("blue-ocean event)? Could downward trend reverse?

Zero is essentially when sea ice extent is less than one million $km^2$ at end of the melt season (usually in mid-September). Year to year variability is large.

Based on plot trend lines there is a high probability that the first "blue-ocean event" will occur on or before September in 2020



Arctic Sea Ice Volume
Annual Maximum and Loss, and Ice Remaining at Minimum
Ice remaining at yearly minimum
Yearly ice maximum
Yearly ice loss
Ice Volume [1000 km³]
33
30
27
24
21
18
15
16.855
16.139
12.589
13.395
15.077
14.480
14.475
15.935
15.176
14.853
14.649
13.679
13.476
14.864
12.234
13.611
11.185
13.715
13.178
11.512
10.916
10.954
12.179
10.792
10.240
9.881
9.159
8.993
6.458
7.072
6.893
4.428
4.017
3.261
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
* - in progress
Graph: Jim Pettit
Source: PIOMAS.vol.daily.1979.2012.Current.v2.dat.gz (Version 2.0) (updated monthly)
Most recent data: Sep 2012




https://sites.google.com/site/arctischepinguin/home/piomas/grf/piomas-trnd2.png

# Arctic sea-ice monthly average volume

Suppose the first "blue ocean" event occurs in 2020
Ice-free duration likely less than 1 month in September

Ice-free duration extended to 3 months within 2 years (by 2022)

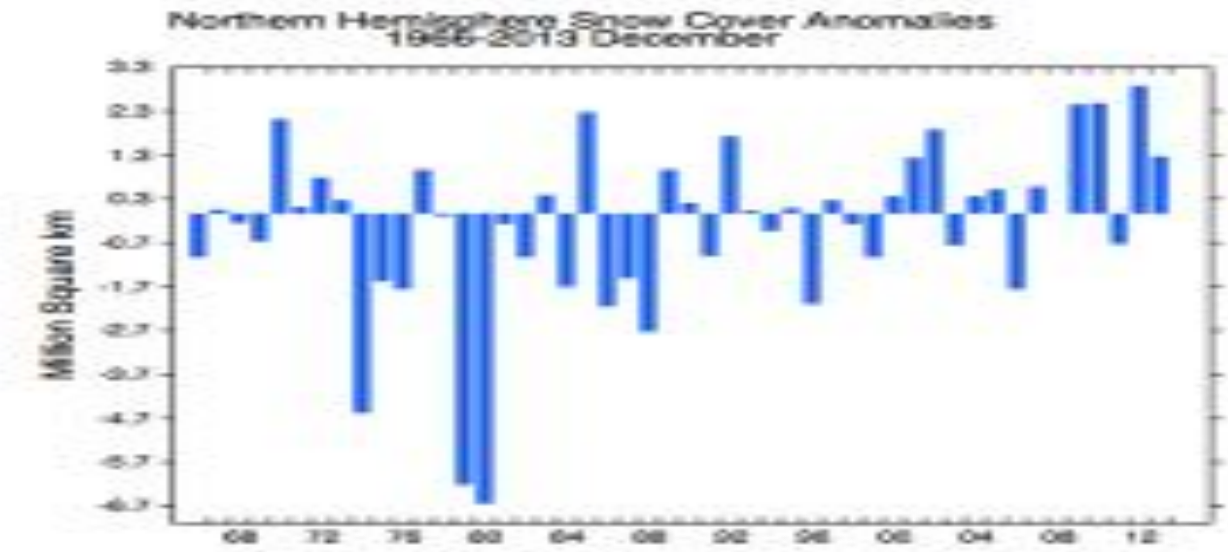
Ice-free duration extended to 5 months within 2 more years (by 2024)

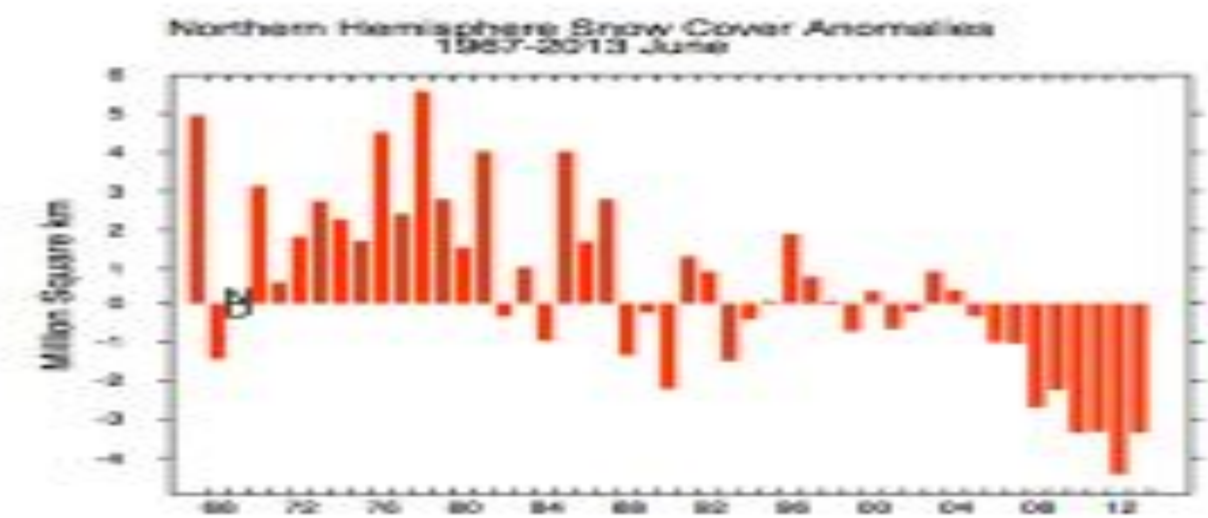
Ice-free duration all year within roughly 6 more years (by 2030)

Huge feedbacks:
a)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 temperature (via sensible heat) of that 1 kg of water to 80 $^{o}$C.
b)darkening region absorbs much more solar energy

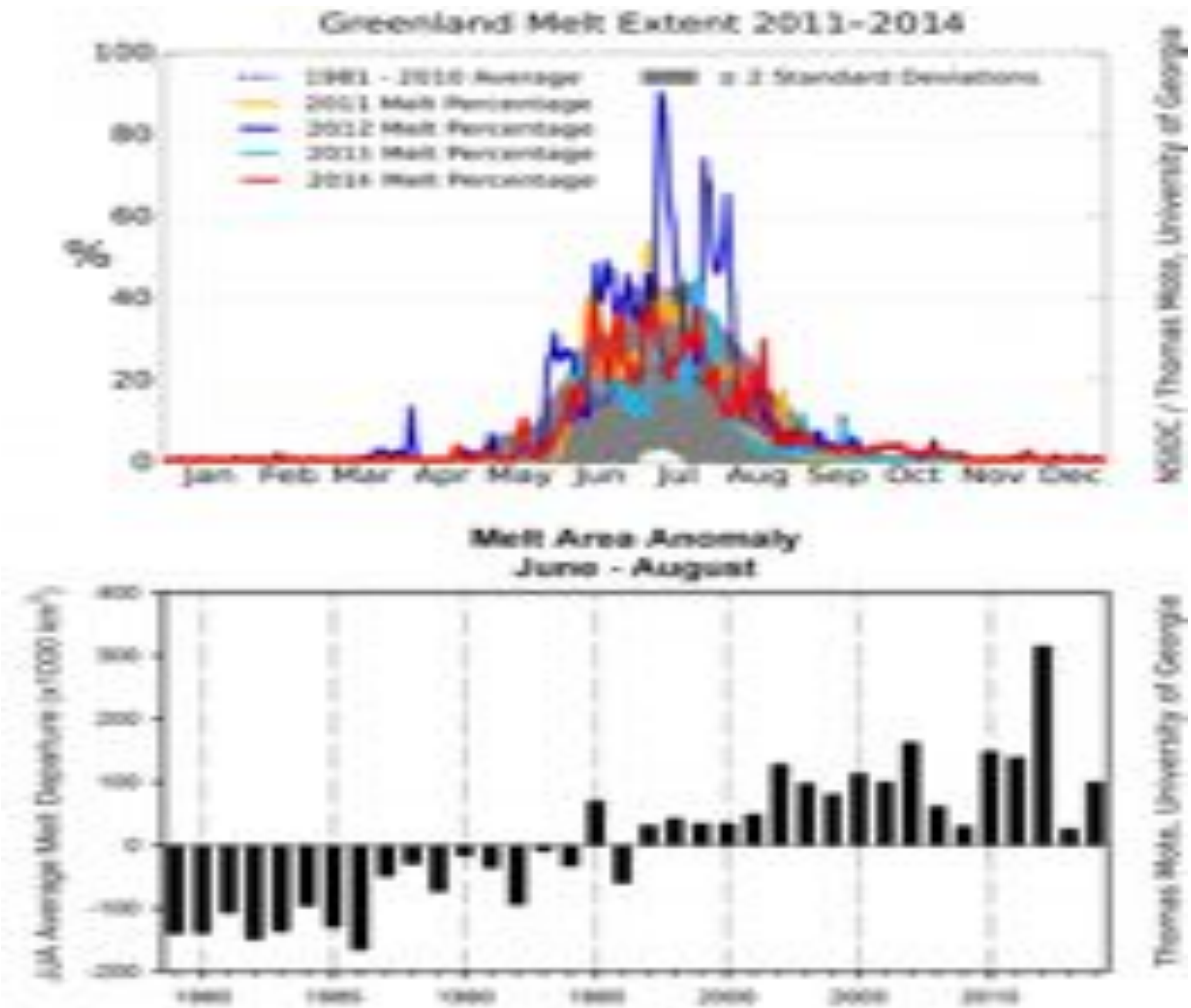
December and June Northern Hemisphere snow cover anomalies

Much less snow cover in spring → darker surface → more solar energy absorption → more heating → more snow melt



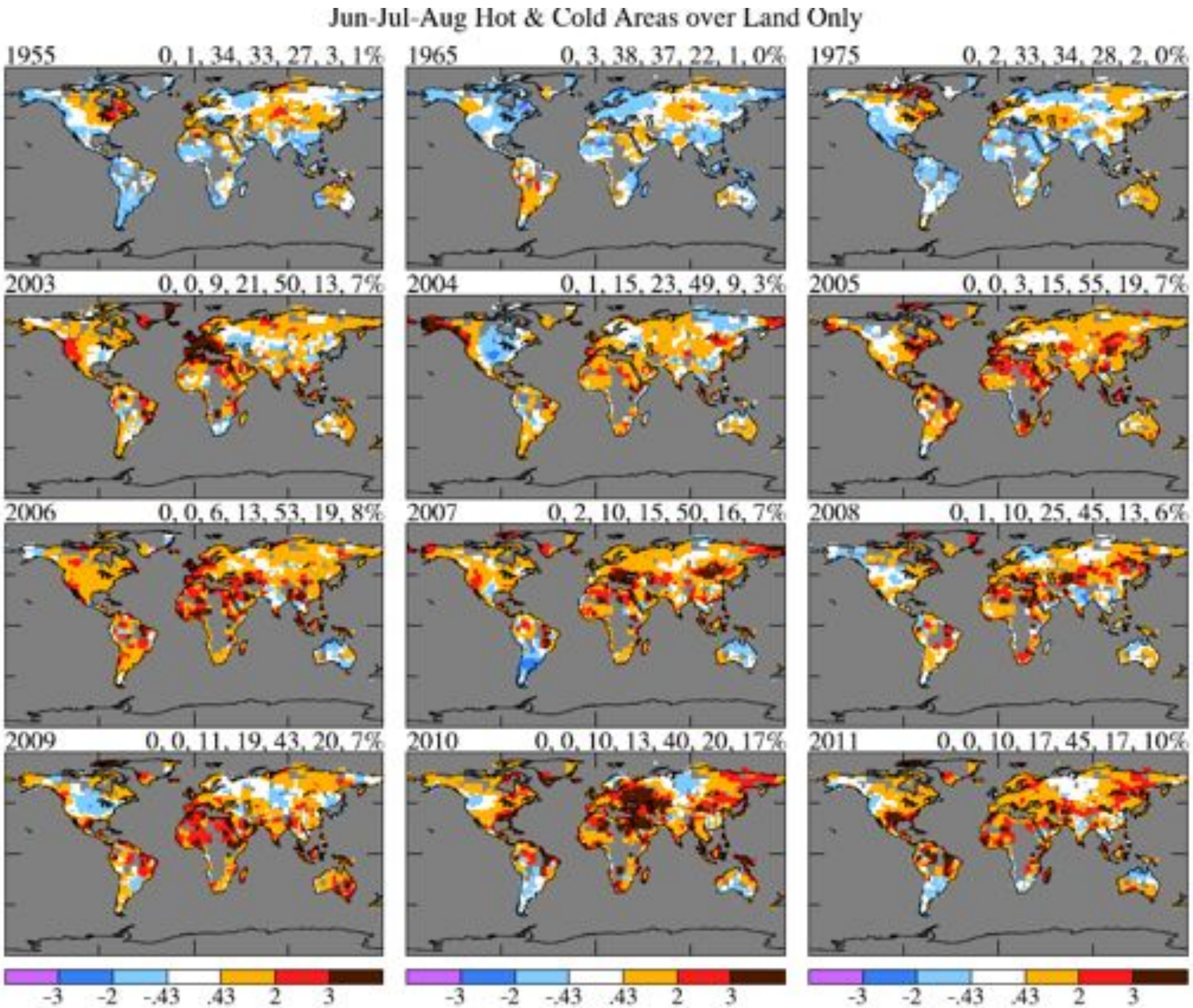




https://www2.ucar.edu/atmosnews/perspective/11278/spring-snow-goes-downhill




Fraction of ice sheet surface on Greenland subject to melting (albedo is lower in these regions → darker)

http://www.arctic.noaa.gov/reportcard/images-essays/fig3.1d-tedesco.png



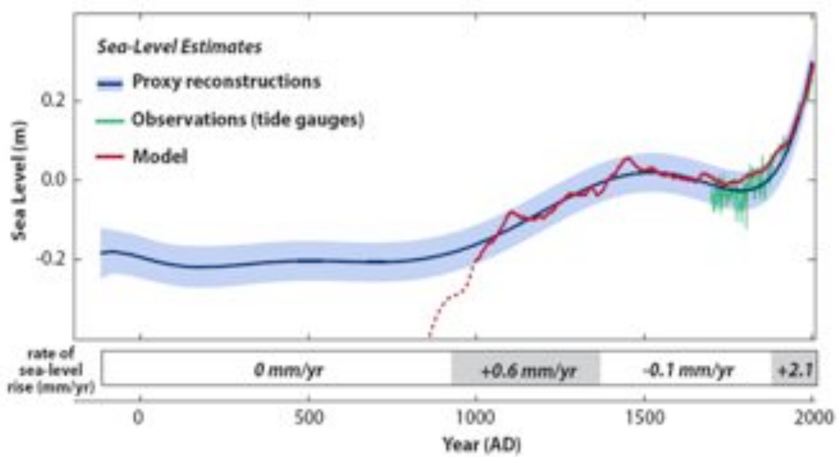

Jun-Jul-Aug surface temperature anomalies over land relative to 1951-1980 mean temperature

(units: local standard deviation of temperature)

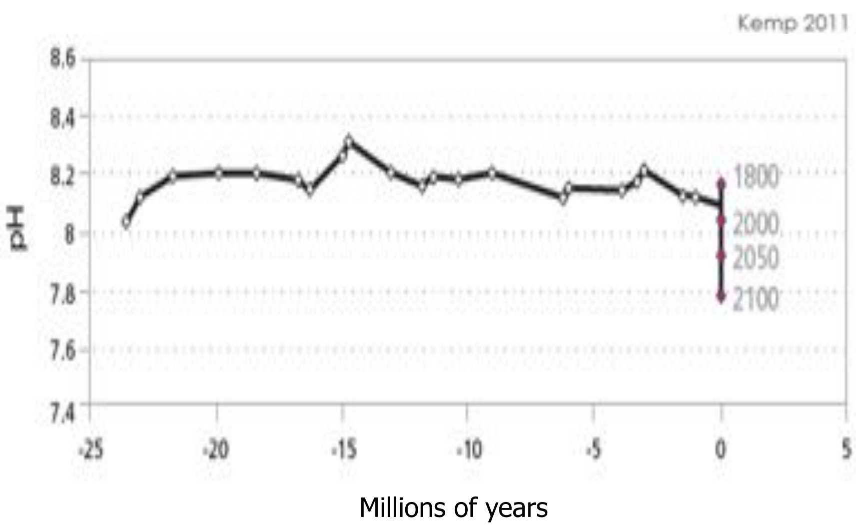
Numbers above maps are percentages of areas in specific legend respectively (7 bins)

(Hansen, 2011 report) http://www.columbia.edu/~jeh1/mailings/2011/20111110_NewClimateDice.pdf

# Sea-level increase, ocean pH decrease, ice cap melting

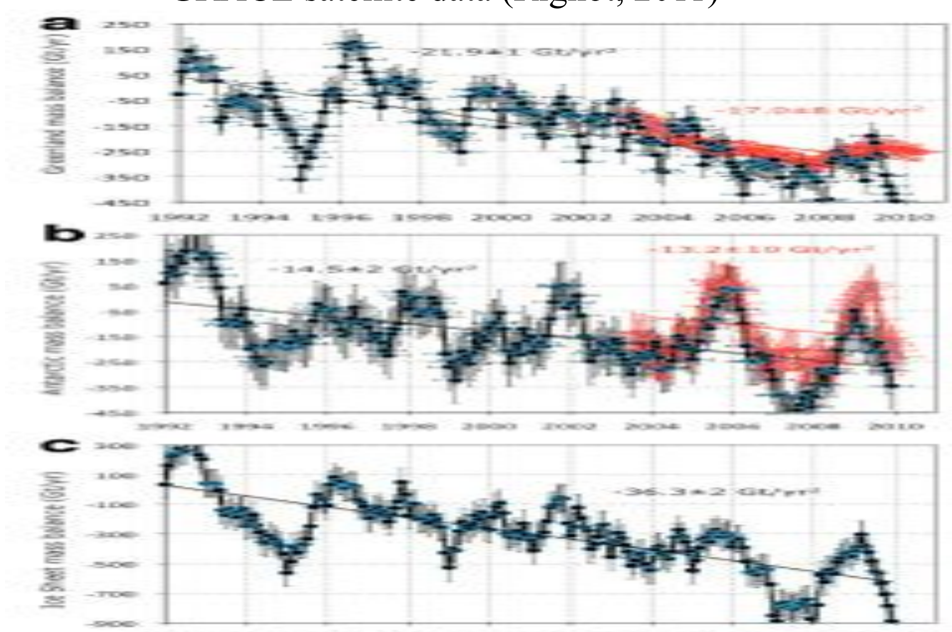



1) Expansion of water; 2) mountain glacier melt; 3) ice caps; 4) Greenland and Antarctic ice sheet melt
Present rate of rise 3.4 mm/year; projected rise of 1 foot by 2050, up to 2 meters by 2100; Hansen says 5 meters
Paleorecords: 121 kyr ago (Eemian); rise 50 cm/decade for 5 straight decades (Blanchon et. al., 2009)




$CO_2$ in air + water vapor → carbonic acid → rain drops → fall into ocean (Synthesis Report, 2009)

a)Greenland ice cap loss; b) Antarctica ice cap loss
c) Total ice cap loss
GRACE satellite data (Rignot, 2011)



# *Feedback in the Arctic*

- Albedo flipping as sea-ice melts; present sea-ice forcing 0.1 $W/m^2$; sea-ice gone for one month 0.3 $W/m^2$; eventual disappearance 0.7 $W/m^2$
- Rate of warming in Arctic now about 2 $^oC$/decade (~6x global rate); rate will increase with ice vanishing

- Methane sources

Terrestrial permafrost 1700 Gtons C; ESAS permafrost 1750 Gtons; 50 Gtons in precarious state, liable to sudden release

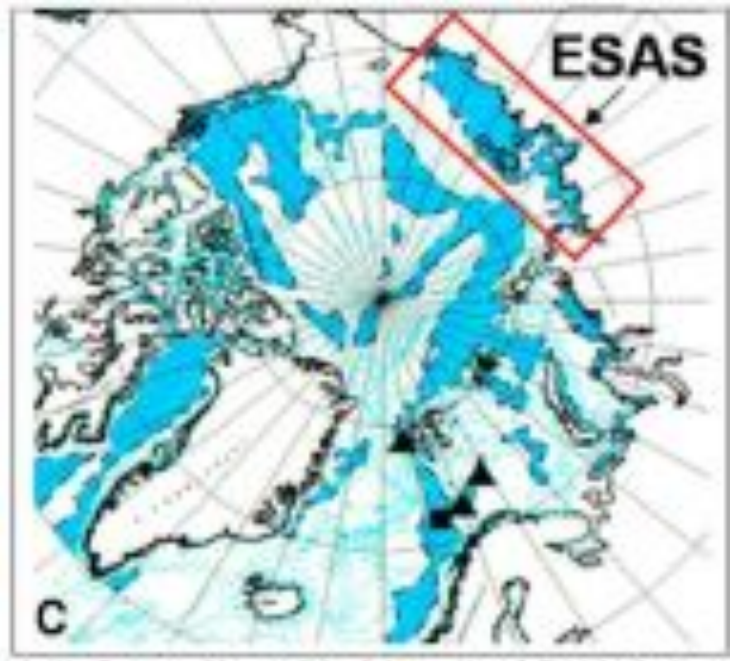
→ surge in atmospheric methane level by 11x

→ catastrophic feedback loop

→ warming spiraling up

→ world food production spiraling down;

release of only 15 Gtons over 10 years would dominate $CO_2$ forcing (no chance at 2$^o$C stabilization)



Arctic Ocean with predicted deposits of CH4 hydrates shown in blue [Semiletov, 2012]

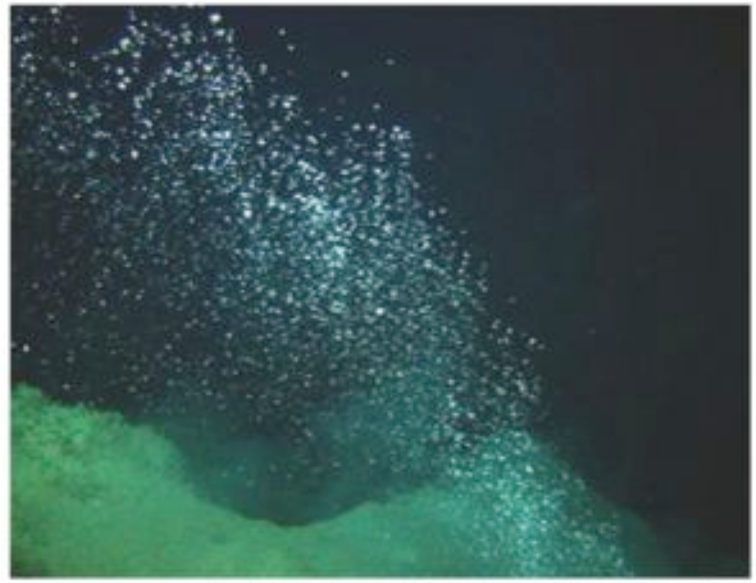
# *Methane in the Arctic*

- Up to now methane emissions in Arctic are estimated to be quite small (10-20 Mtons carbon)

- Very recent escalation of emissions (within last few year)

Apparent from Eastern Siberia Arctic Shelf (hundreds of plumes tens of meters in diameter a few years ago; now hundreds of plumes as large as 1 km in diameter in study area)

Dozens of Siberian methane craters appearing on land (largest is 1 km in diameter)

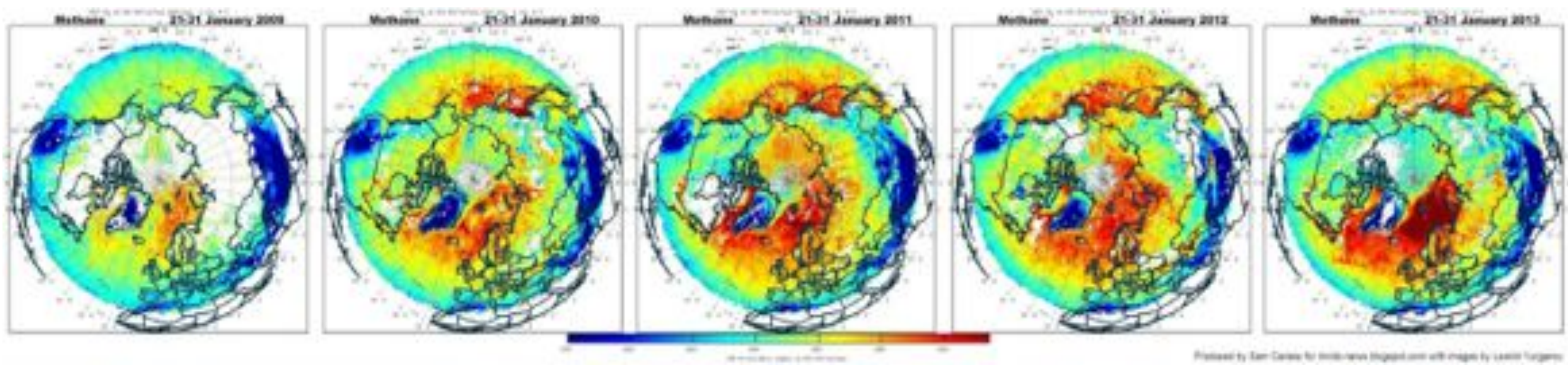


A methane plume being released from the sea bed

# Methane in the Arctic atmosphere

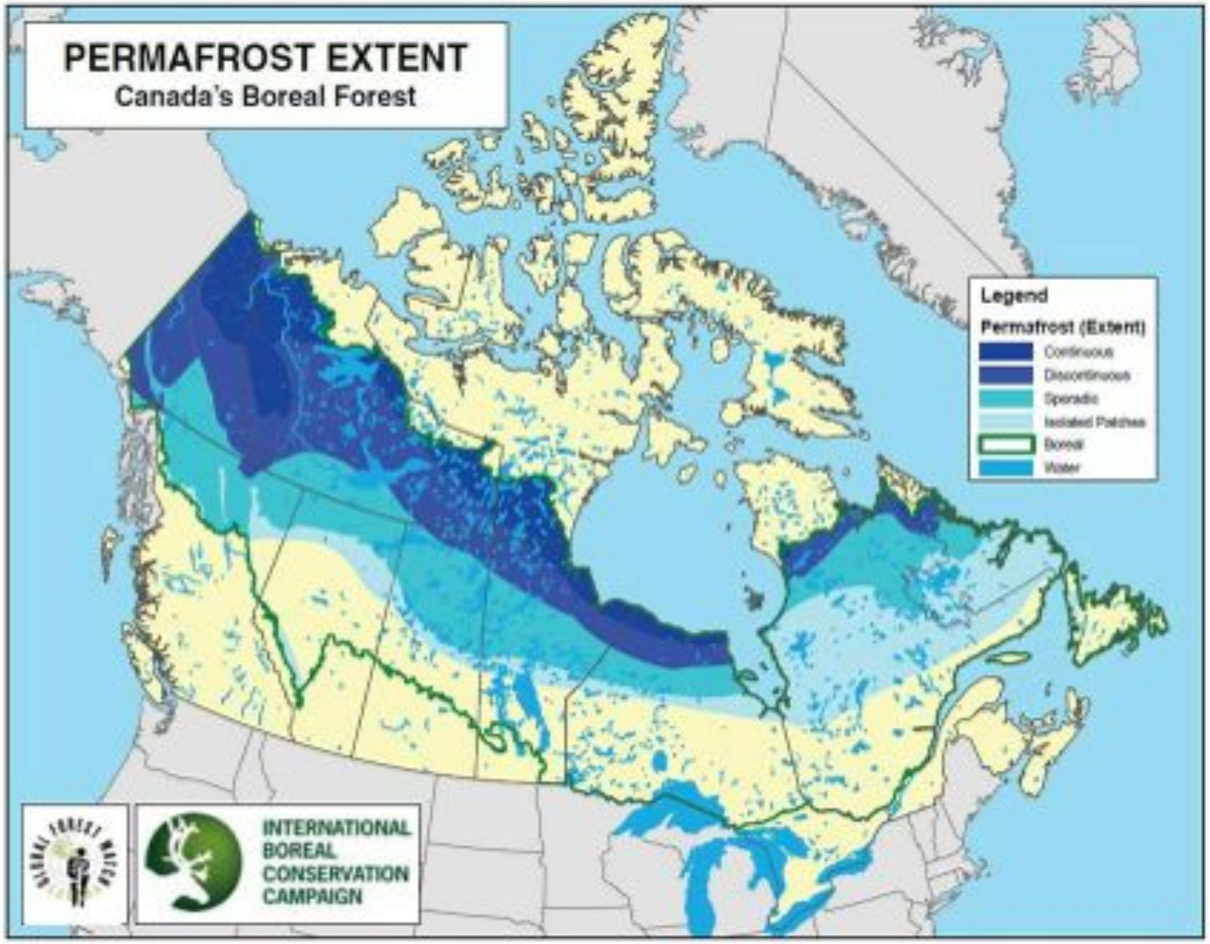
January 21st to 31st

2009 2010 2011 2012 2013



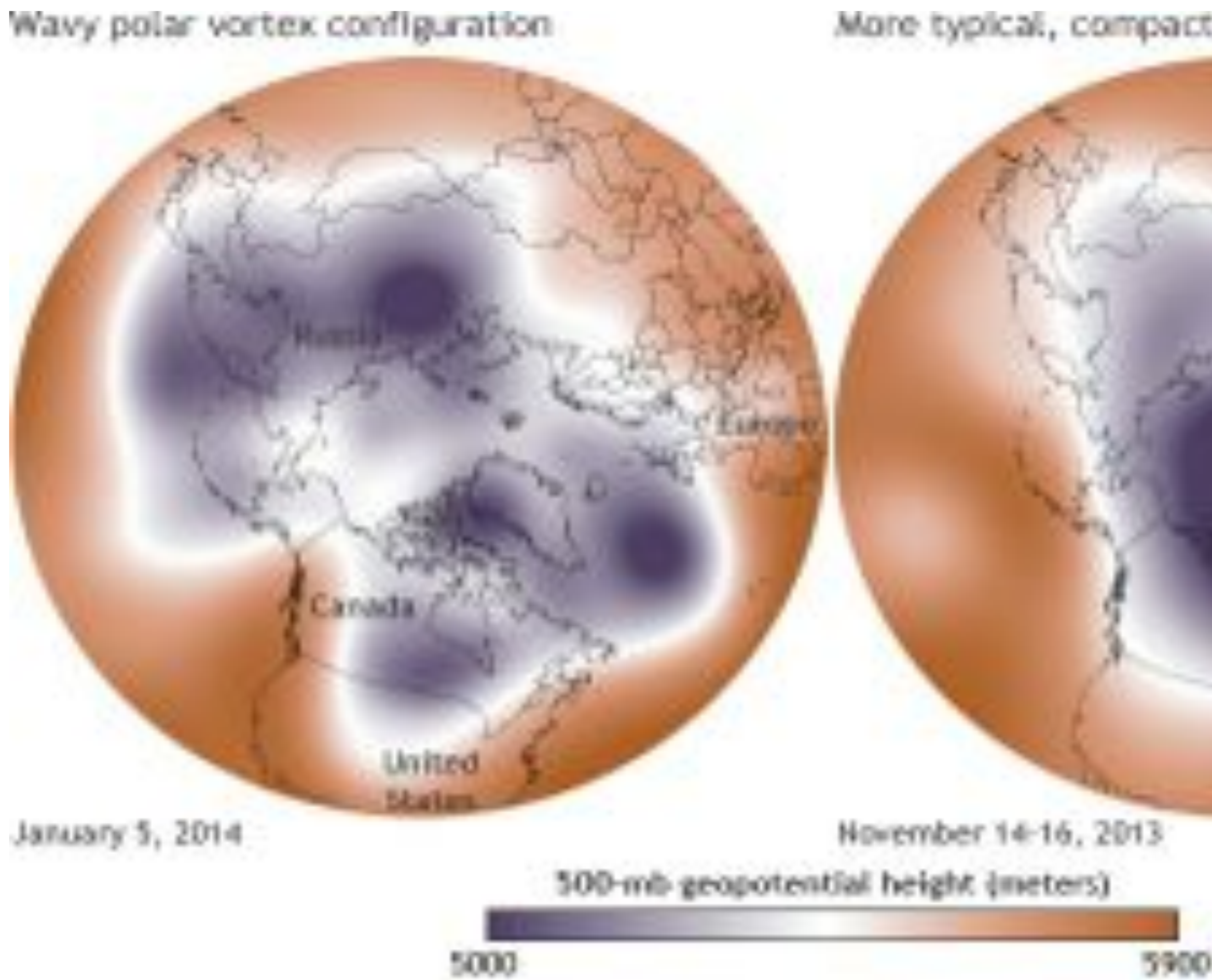
Methane levels over 5 years in the Arctic showing a large increase in open water regions near the sea ice (red → higher concentrations)

https://robertscribbler.files.wordpress.com/2015/03/methane-jan21-31.jpg



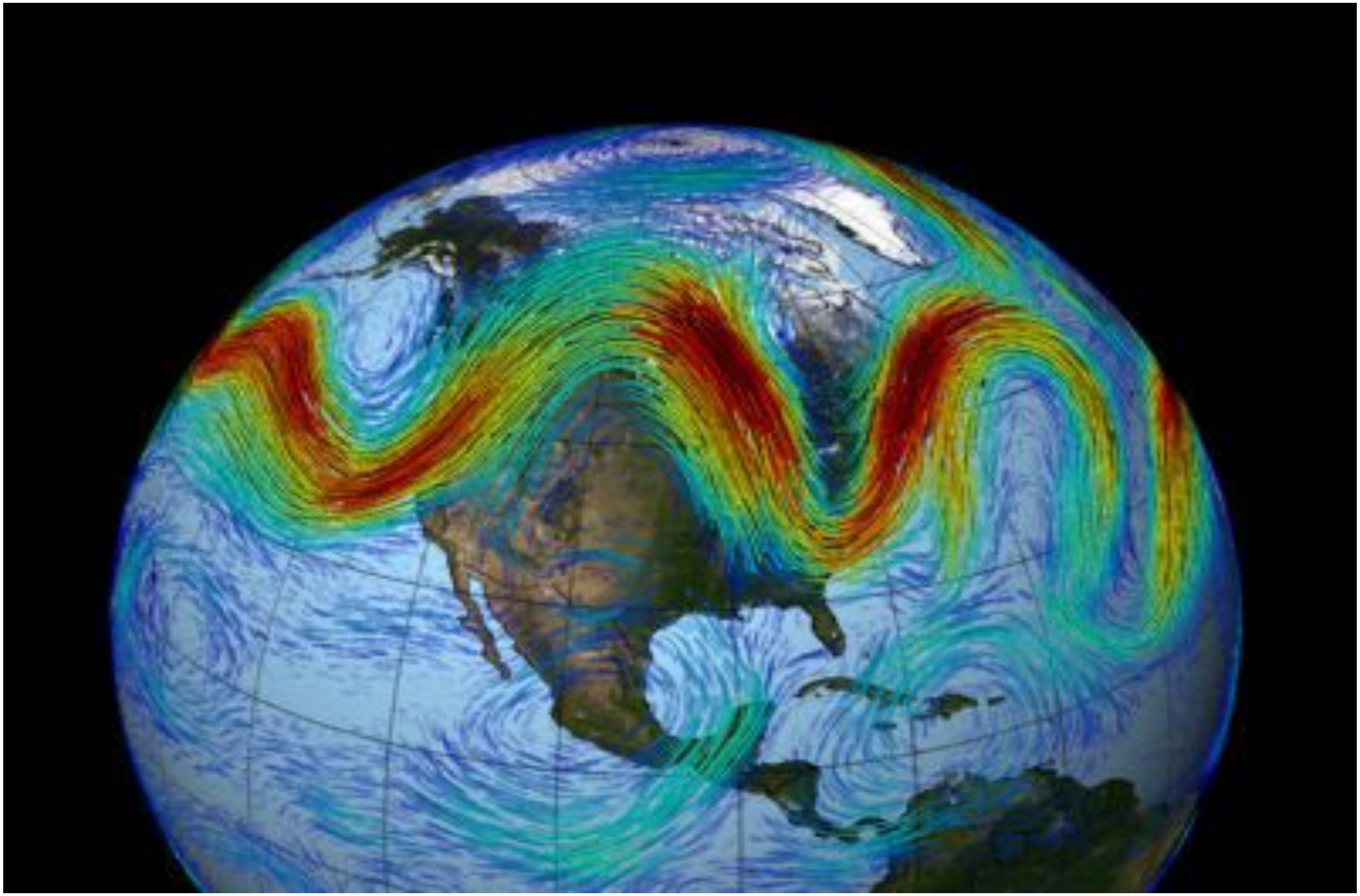

Permafrost map of Canada, showing "isolated patches of permafrost" extending down to northern Lake Winnipeg.

http://www.bing.com/images/search?q=canada+permafrost+map&id=BE72DD192108BF622FC43DCE8C362A44A42F68A0&FORM=IQFRBA#view=detail&id=6DF87AC241B6F514638D35789563E2007F1C9BE8&selectedIndex=14



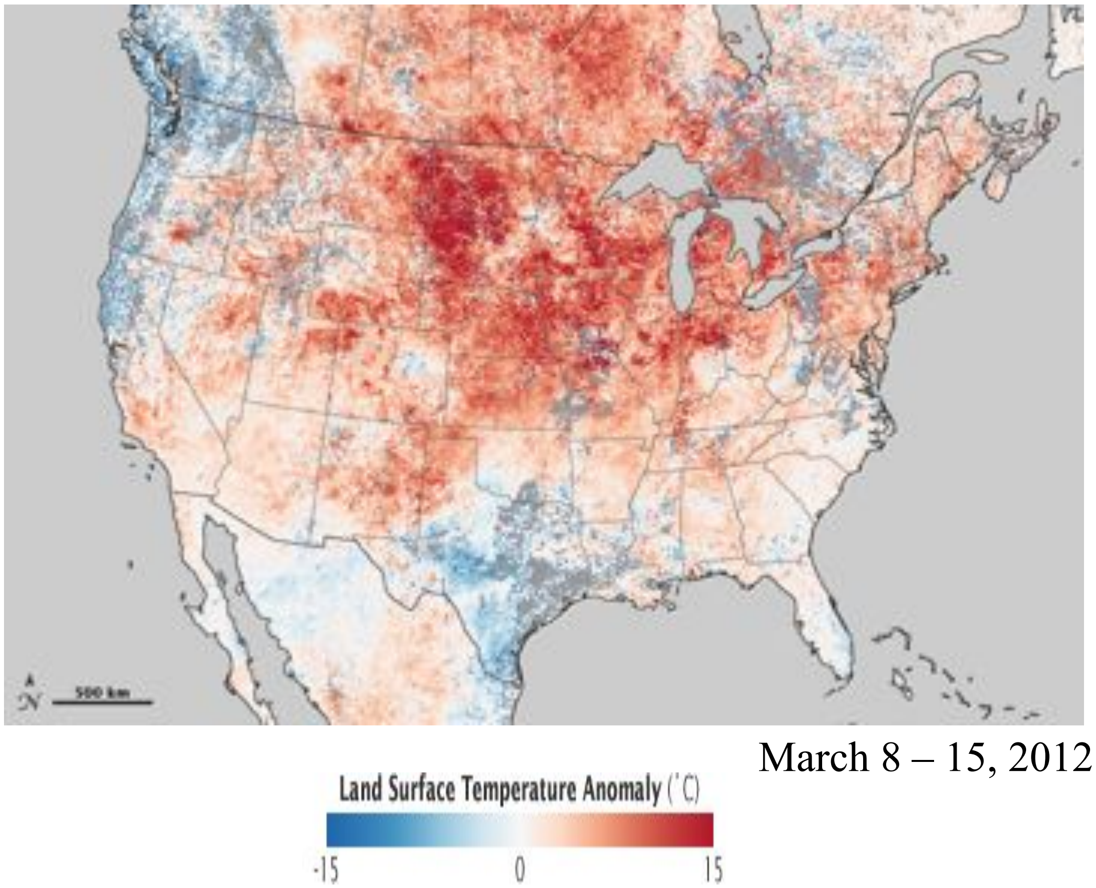

Downward looking Arctic view: shows "normal" and "wavy" jet stream configurations. Purple areas are cold and brown areas are warmer. Jet streams are white border lines between the cold and warm air masses.

http://www.climate.gov/sites/default/files/styles/inline_all/public/Jan5_Nov14-16_500mb_geopotentialheight_mean_620.jpg?itok=zdAE3xoi



Side view of exceptionally wavy jet stream.
https://eos.org/wp-content/uploads/2015/02/GL060764_Hassanzadeh_cropped_web-800x600.jpg

# *Extreme weather events in 2012*




March 8 – 15, 2012

(NASA Earth Observatory
http://earthobservatory.nasa.gov/IOTD/view.php?id=77465&src=share

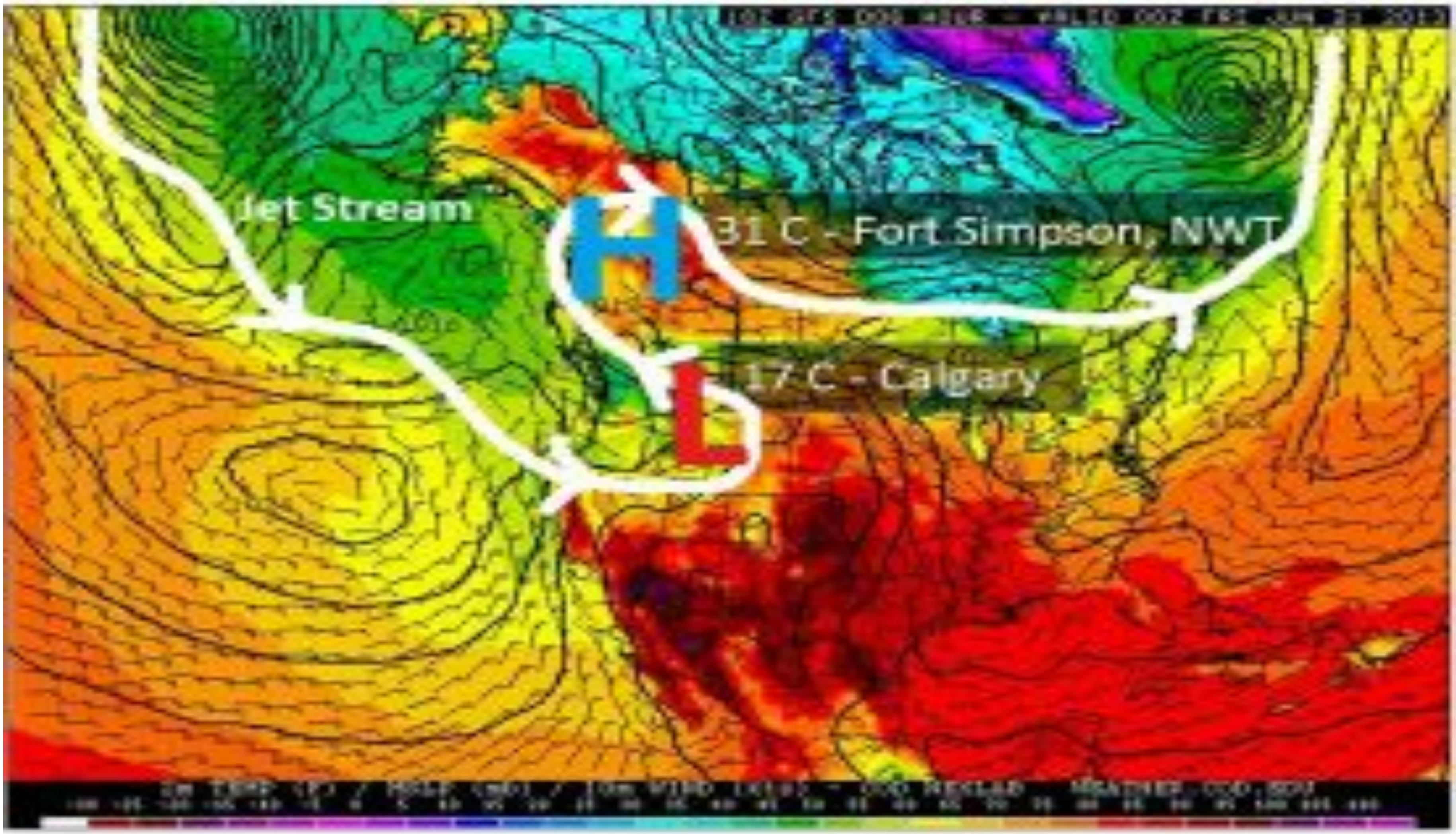

*"The duration, areal size, and intensity of the "Summer in March", 2012 heat wave are simply off-scale, and the event ranks as one of North America's most extraordinary weather events in recorded history."*

-growing season started 5 weeks early

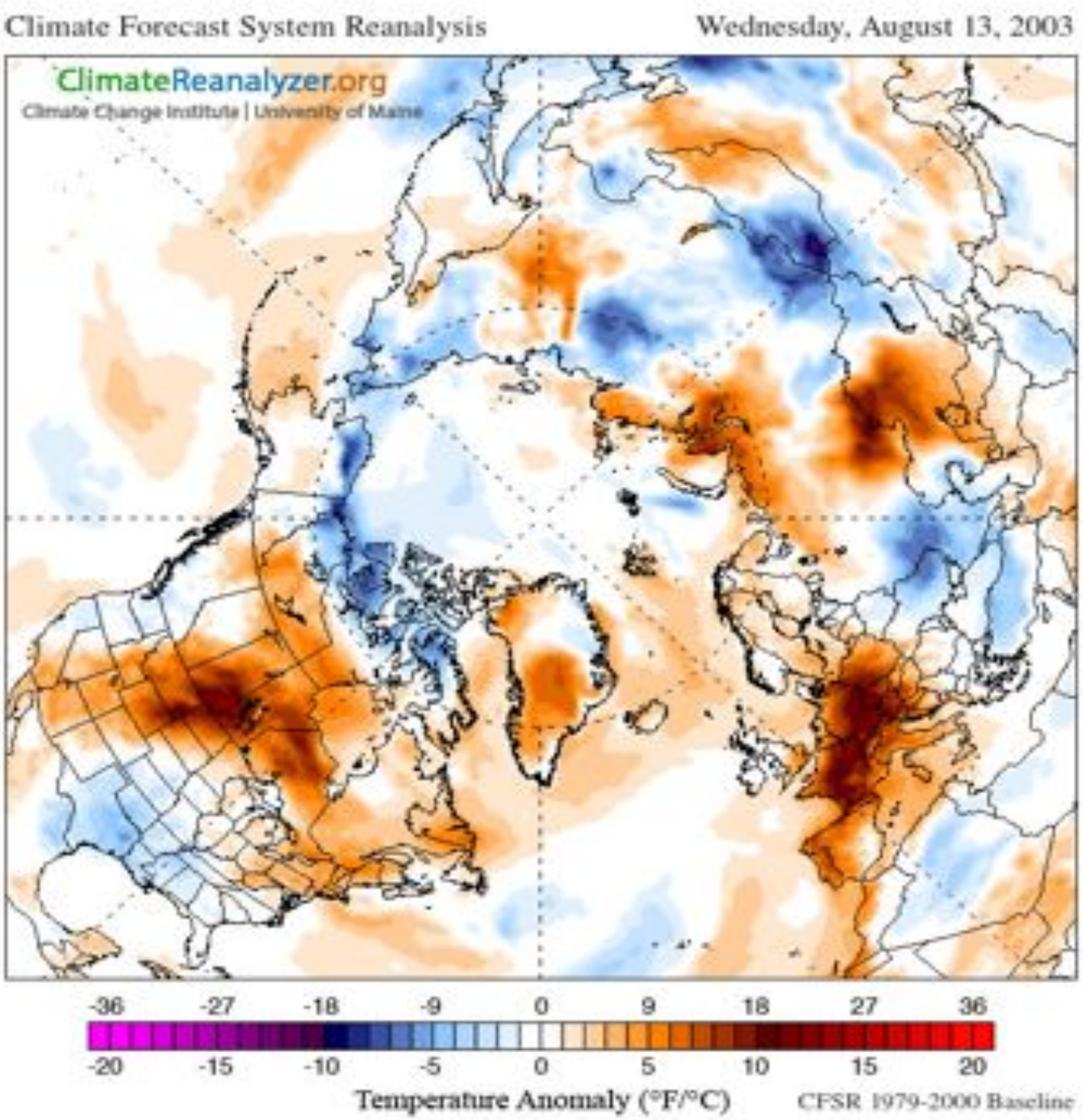
-early snowpack loss will cause low river flows in summer

-sets stage for summer heat and drought

(Wunderground, 2012)

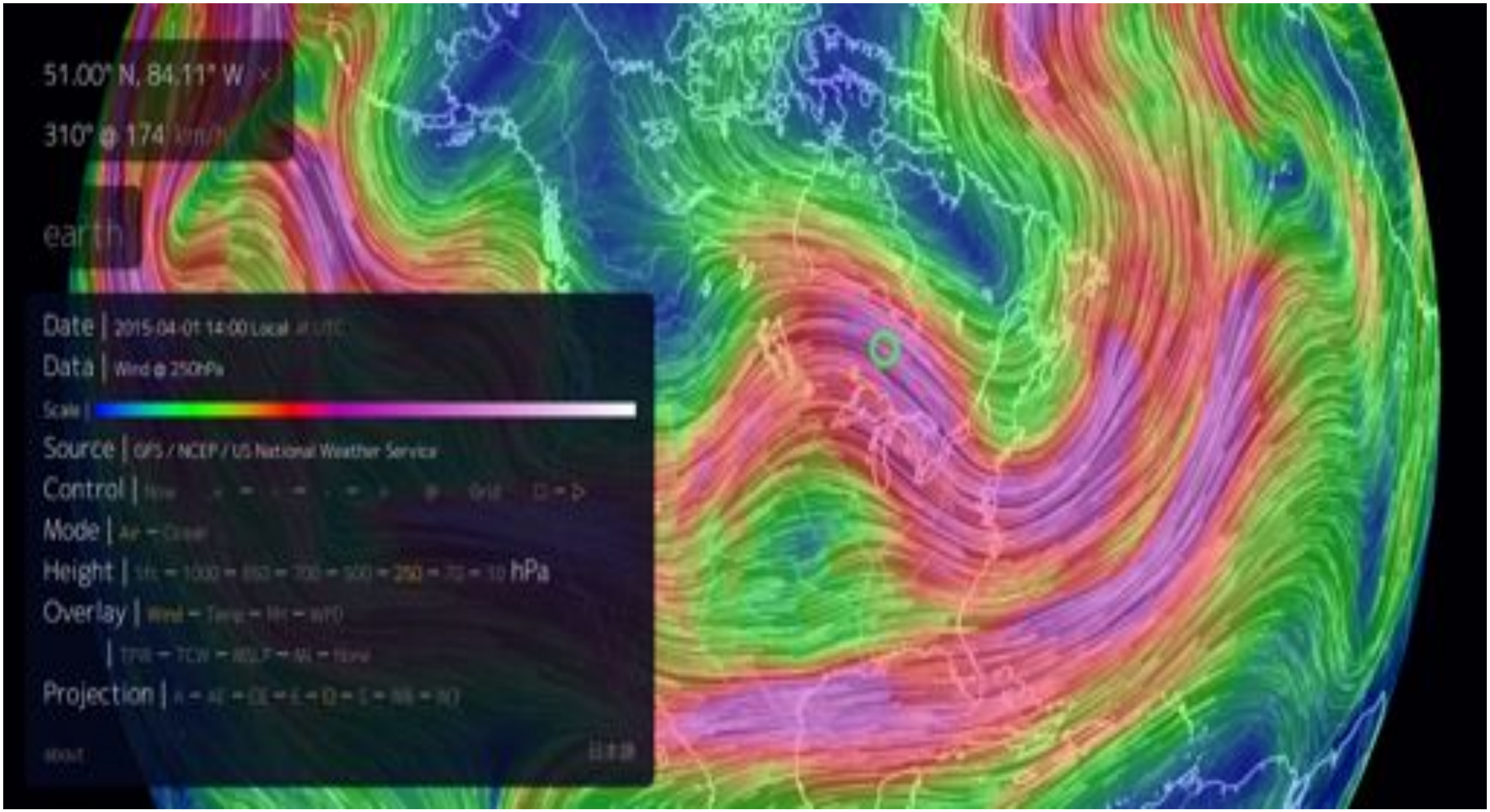



Jet stream configuration near Calgary during record flood of June, 2013 with insured costs exceeding $6 Billion; http://media.twnmm.com/storage/11698939/15



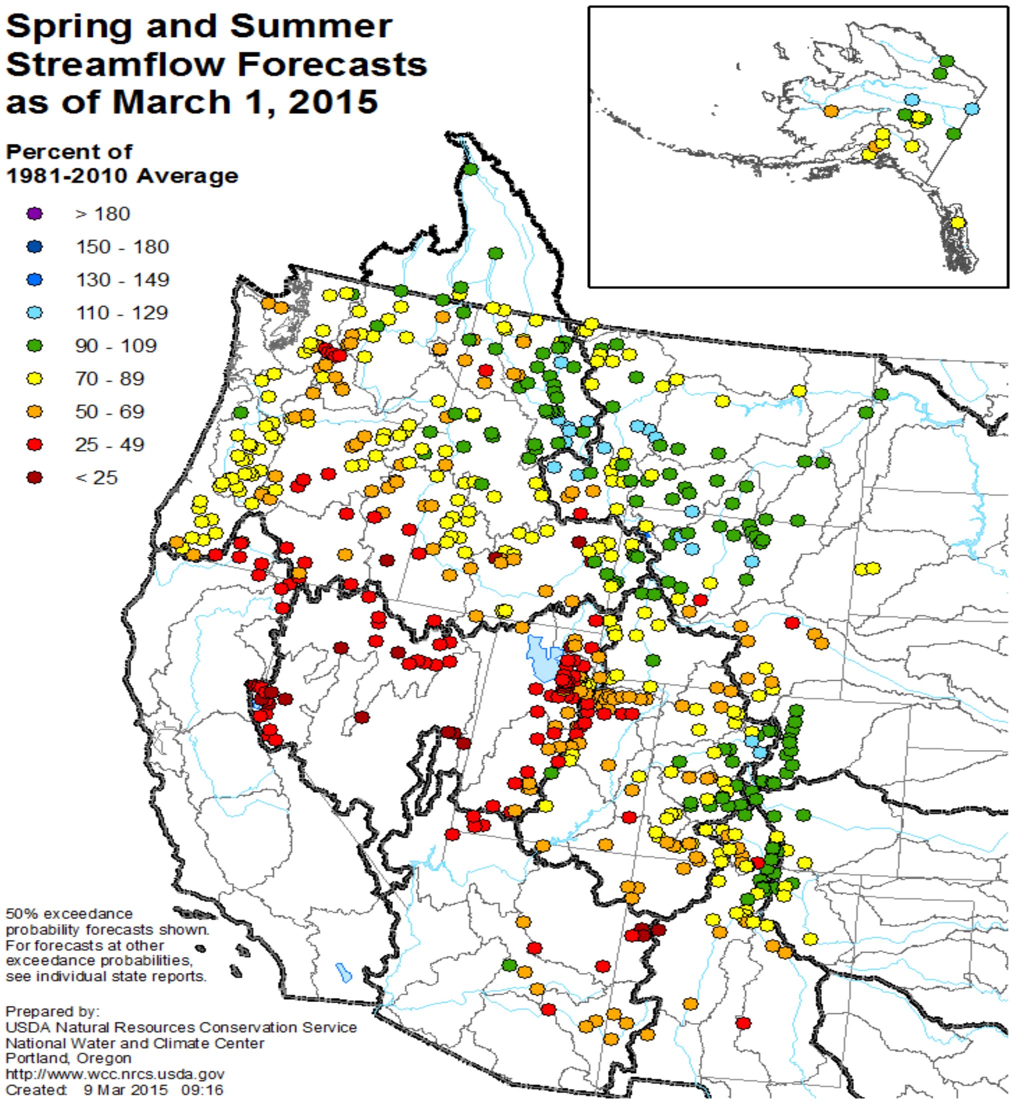

Temperature anomalies on Aug. 13, 2003, one of worst days in extensive, long-duration European heatwave that killed >70,000 people. From Climate Reanalyzer (see Links section). Root cause was wavy and stuck (persistent) jet stream ridge.


Blue-green algal bloom in 2014 that shut down Toledo water supply for many days.
http://voices.nationalgeographic.com/files/2013/04/Slide3.j




Example from Earth Nullschool (see links section) of Lake Winnipeg region, showing jet stream winds (at 250 mbar pressure level) from April 1, 2015. The coordinates/windspeed and direction on the top left is data at the location of the green circle. Jet stream variation affects Lake Winnipeg region.

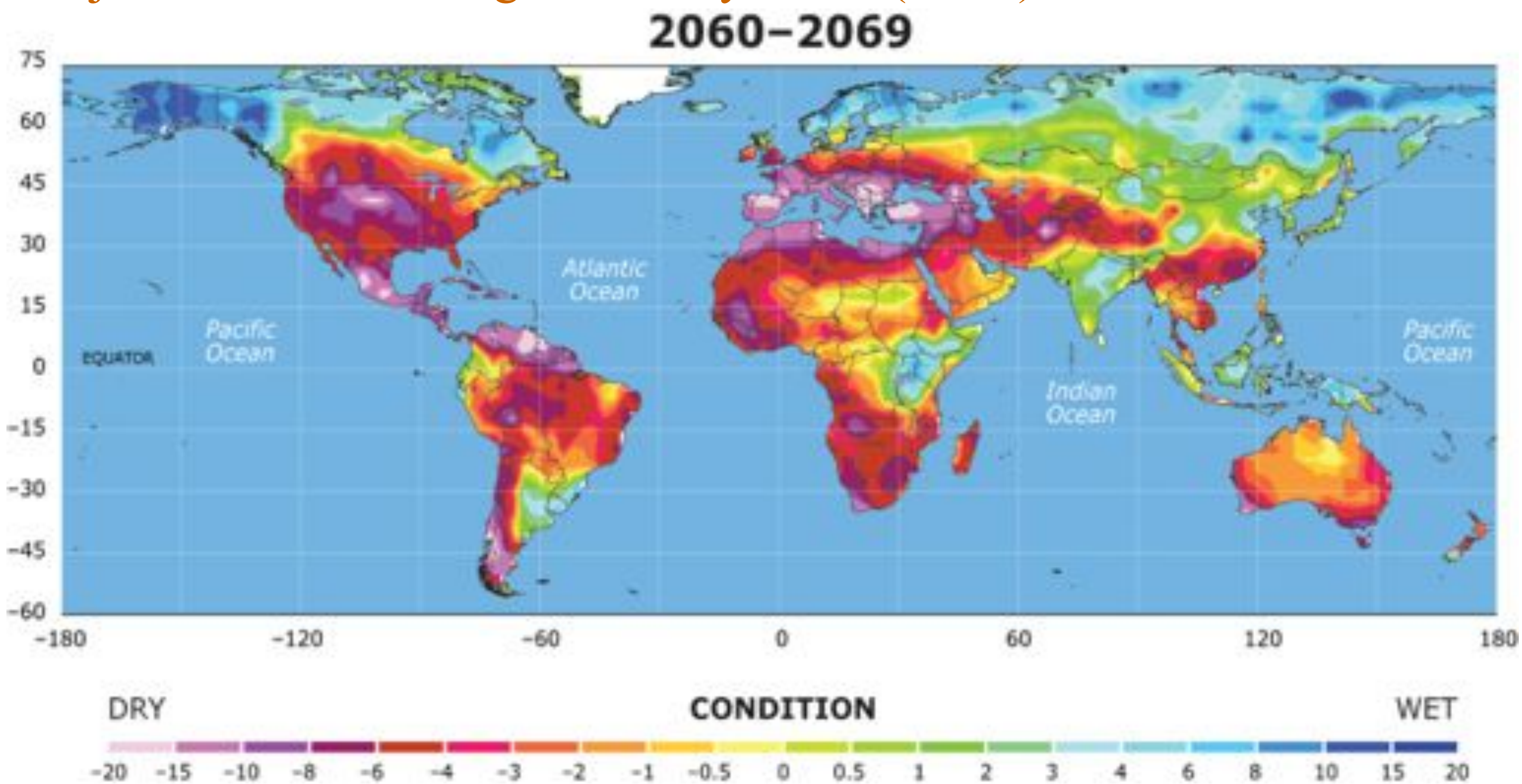

Example from Earth Nullschool (see links section) of Lake Winnipeg region, showing jet stream winds (at 250 mbar pressure level) from April 1, 2015. The coordinates/windspeed and direction on the top left is data at the location of the green circle.



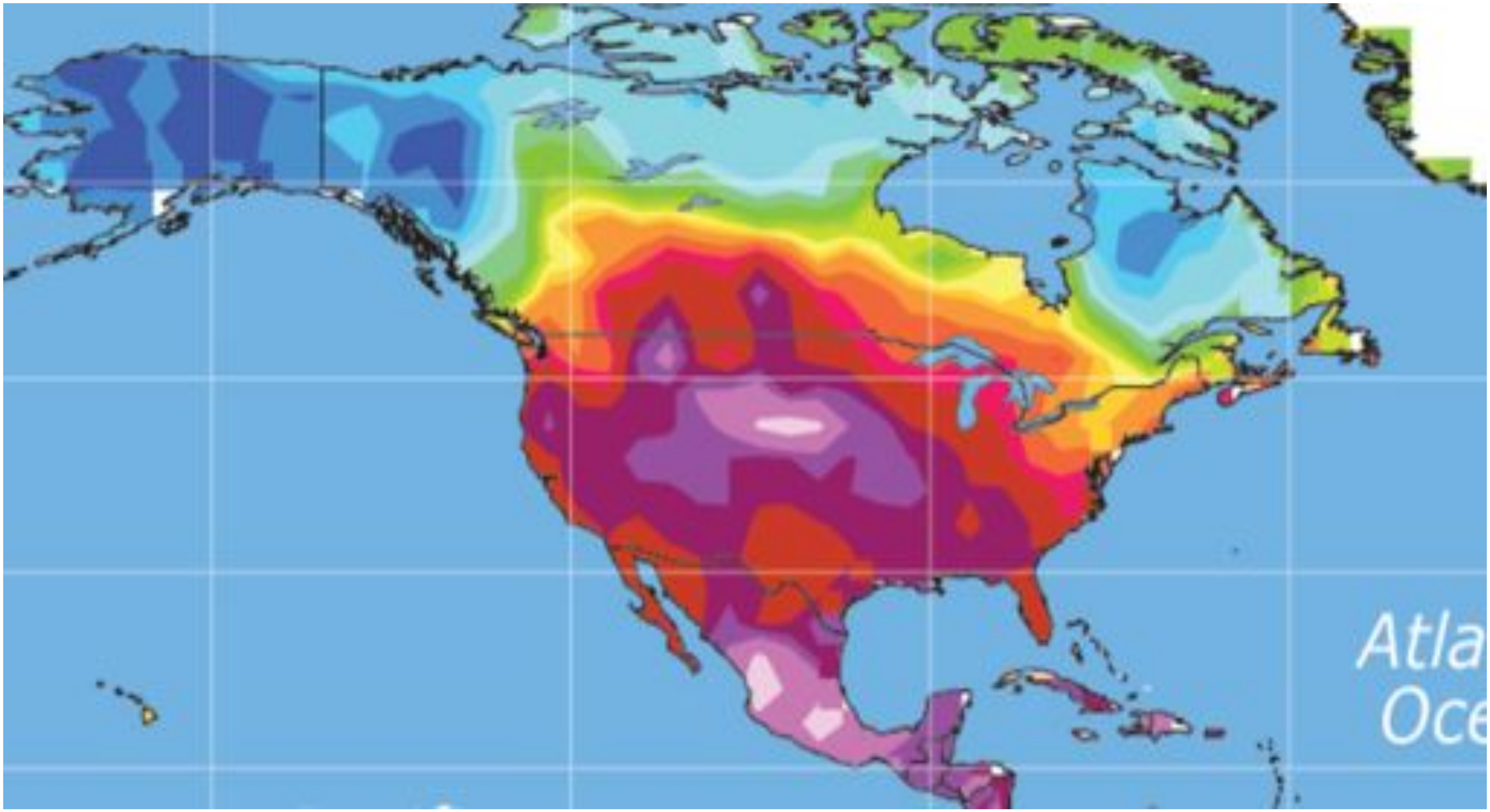

Sierra Nevada has the lowest snowpack ever recorded in California history.

Projected streamflows shown on map

# Projected Palmer Drought Severity Index (PDSI)




Projection of global spatial variability of wet/dry conditions from NCAR analysis (Dai, 2011) shows that many regions of the globe are expected to get much drier. The Winnipeg Lake Basin primarily straddles the light and dark orange regions (-1 to -3) and lower, reaching -6 to -8 as you move westward to central Canada.



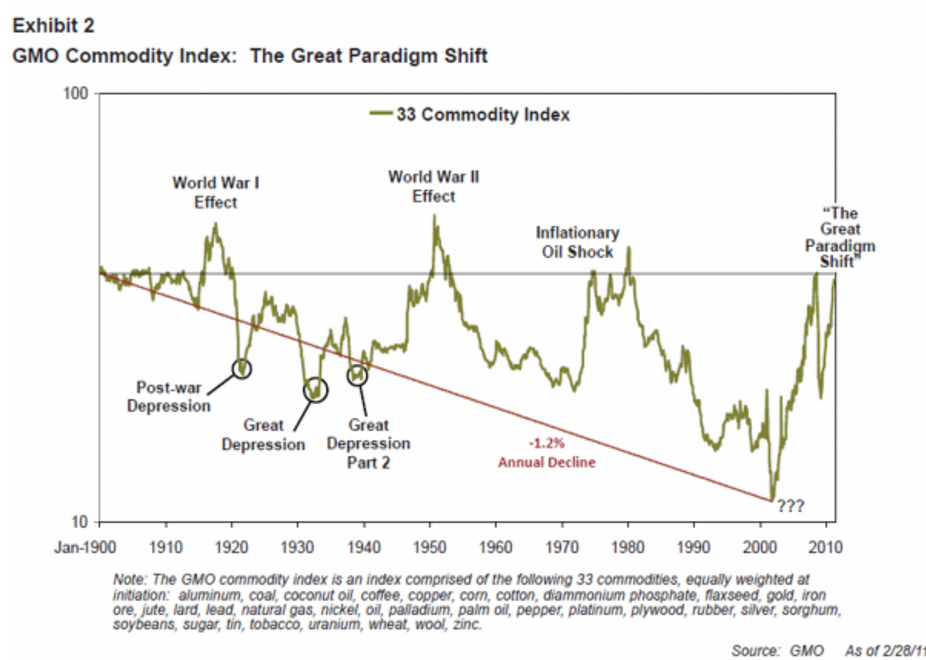

Expansion of previous map over North America.
Since about 1950, the global percentage of dry areas on the planet has increased by about 1.74% of global land area per decade

# Procrastination to action: climate Pearl Harbor(s)?

Drivers of serious government action: "bad things must happen to regular people in rich countries right now"; media must report them as being a result of climate change; requires a change in "world view"

1)ice-free Arctic this decade
2)extremely rapid warming
3)methane surges
4)mega-drought hitting US southwest
5)more Katrina like superstorms
6)heat waves hitting US breadbasket
7)accelerating sea-level rise, visible ice shelf collapses
8)Amazon rainforest collapse

More comprehensive presentation at:
http://www.cmos.ca/Ottawa/SpeakersSlides/PaulBeckwith_19Jan2012.pdf




*"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, British House of Commons

# Summary: global climate system changes

Increased human fossil fuel combustion and land use changes

→ atmospheric greenhouse gas concentrations up ($CO_2$, $CH_4$, $N_20$)

→Arctic temperature amplification of 5x to 8x global average due to darkening from declining sea ice, snow cover, Greenland melt

→ decreases equator-to-Arctic temperature difference

→causes less heat transfer from equator to pole in:
a)atmosphere: jet streams slow, become wavier and "persistent" → extreme weather events more frequent and intense, last longer
b)Oceans: currents such as Gulf Stream slow down, large sea level rise on US east coast

# Key web links (1)

Arctic sea ice graphs: Real-time time series plots on sea ice extent, area, thickness, motion; maps on ice locations, meteorology, ocean temperatures and conditions, ocean buoy data, all updated daily:

https://sites.google.com/site/arcticseaicegraphs/

Climate Reanalyzer: Real-time information on atmospheric weather and ocean conditions, displayed in a different format to Earth nullschool; great for examining global temperature anomalies (difference between present day and climate normal): http://www.cci-reanalyzer.org/

# Key web links (2)

Earth nullschool: Real-time Earth sphere projections for atmospheric weather (temperatures, precipitation, winds at pressure levels up to top of troposphere (lower atmosphere where weather occurs); also data on oceans (temperatures, currents, etc.); click on text “earth” in bottom left corner to access variables, drag to rotate view, use slider to zoom, click on location for local (point) measurement: http://earth.nullschool.net/

Lima, Peru COP20 presentation that I gave at a press conference on the present state of the climate system: https://www.youtube.com/watch?v=QQkNxuQ0DoI
Climate system disruption video that I created March 24, 2015: https://www.youtube.com/watch?v=GR2RDwhBFh4
Many other climate system videos on my YouTube channel, linked on Twitter and Facebook

# Global-to-Local Scale: Local Lake Winnipeg Effects

1) **Climate history** (temperature, precipitation) over last century in Lake Winnipeg basin (normals and trends) used as basis to extrapolate future changes. Justified if climate system is stable, however not when global climate system changes alter the statistics of climate and weather events (i.e. a 1 in one hundred year flood no longer occurs, statistically once in a hundred years)

2) **Variability** has increased across most timescales (daily, weekly, monthly, seasonal, yearly, multi-decadal). “Weather Whiplashing” often occurs. Over span of 3 years, Mississippi River in U.S. experienced record flood levels, record low water levels, and then record flood levels. Over a few weeks, a city can experience record high temperatures, record low temperatures, and then swing back to record high temperatures. “Whiplashing” frequency depends on location relative to jet streams.

# Global-to-Local Scale: Local Lake Winnipeg Effects

3) **Regional climate projections** based on “downscaling” Global Circulation Models; works well when GCM projections are for a slowly varying, linear climate system. However, risky relying on models when we are experiencing rapid changes in overall climate system. Models project averages, but it is the extreme peaks/valleys that have the largest detrimental effects.

4) **Hydroclimate studies** assess lake levels, streamflows and water temperatures based on historical data and projections from regional models and/or downscaled models. With much greater variability from global climate system changes, these studies are expected to be much less accurate.

5) **Climate statistics** have changed (globally and locally), probabilities based on a historically stable climate (eg. risks of “one-in-a-hundred” or “one-in-a-thousand” event) need to be reevaluated since they may no longer be valid. For example, higher weighting on recent behaviour (nearest decade) may lead to better risk assessments.

## Global-to-Local Scale: Local Lake Winnipeg Effects

6) **Lake temperature** will become very important during heat waves with extended droughts. Annual evaporation will remove much more than 20% of the inflow, the lake volume will decrease and there will be much greater risk of eutrophication and blue-green algae blooms.

7) It is difficult to know if the **annual mean inflows** increase in the watershed of 58% from 1924 to 2003 will maintain this trend. Given the recent abrupt changes in the global climate system it is very important to examine and weight more recent data higher.

# Global-to-Local Scale: Local Lake Winnipeg Effects

8) **Decrease in mean discharge** of Saskatchewan River will continue. Many glacially fed rivers are drying up due to rapidly declining mountain snowpacks. The Sierra Nevada snowpack (California) is only at 6% normal capacity (April, 2015). Steadily rising temperature trends at mountain elevations cause rapid glacial decline; 20% decline in spring snow cover throughout U.S. Rockies since 1980 (Pederson et al., 2013). Peyto glacier which helps feed Mistaya and North Saskatchewan Rivers has lost 70% of ice mass. Rocky Mountain glaciers supply majority of stream flow in Alberta, Saskatchewan, and Manitoba. Runoff from snowpack supplies 60% to 80% of annual water supplies to 70 million people in the American West (USGS article: http://e360.yale.edu/feature/loss_of_snowpack_and_glaciers_in_rockies_poses_water_threat/2785/ )

# Global-to-Local Scale: Local Lake Winnipeg Effects

8) (continued):

**Glacier covered regions** in South and North Saskatchewan River Basins in Alberta declined in area by 37% and 22% respectively since 1975 (Pomeroy, 2014). In the short term glacially sourced water flows can temporarily increase during "last gasp" of glacier. Water access rights for one unit of water input into the Saskatchewan River in Alberta allow Alberta 50%, Saskatchewan 50% of the remainder (25% of input), and Manitoba the remainder (25% of input)). These ratios were determined under drought conditions and usage may need to be re-evaluated. This reduction of high elevation glacier water storage is a risk to people around the planet.

# Global-to-Local Scale: Local Lake Winnipeg Effects

9) **Climate "normals"** from thirty year period 1981 to 2010 are used in analysis of climatic characteristics of the Lake Winnipeg basin. Since most of rapid changes in global climate system have occurred from 2000 to present, thus it makes sense to also analyze climate based on older 1971 to 2000 climate "normals".

10) Lake Winnipeg Watershed has had a **"wet cycle"** for last 15 years or so. There is no expectation this will continue as global climate system changes accelerate. Many climate models (noted previously to underestimate the rate of change) project increased global aridity in the 21$^{st}$ century over much of the planet (most of Africa, the Americas, Australia, Southeast Asia, southern Europe and the Middle East). It seems clear that variability between exceptional drought and severe flooding will increase in many regions.

# Lake Winnipeg Basin


http://www.iisd.org/wic/lake_wpg_basin.asp