Climate Change in North America during the past half Century

I: Temperature/Humidity Trends in North America 1948-2010

II: Diurnal Temperature Range after Sept. 11, 2001

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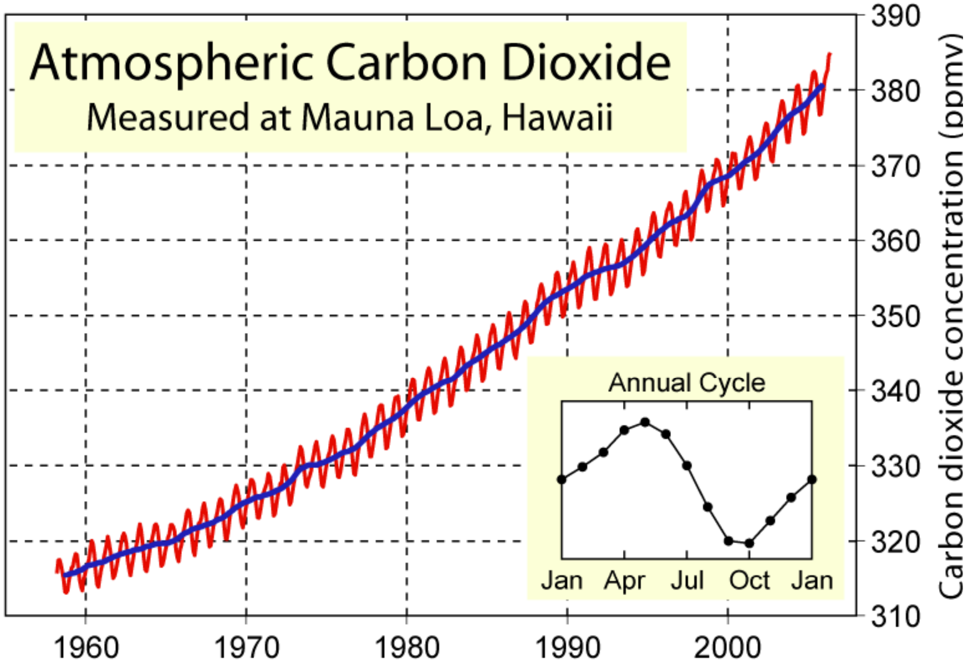
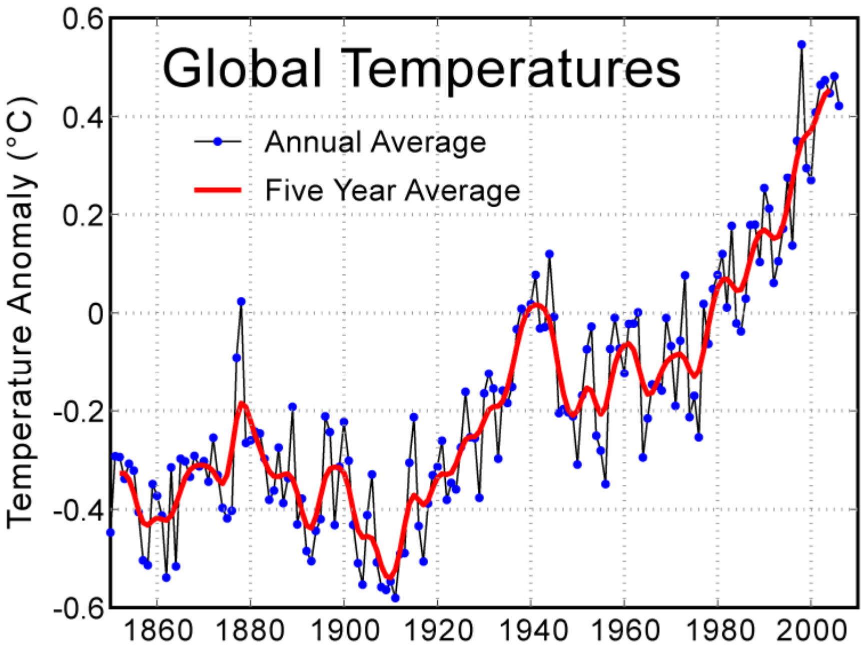
CAP Lecture Tour

2014

Greenhouse Effect

Gases in atmosphere such as water, carbon dioxide, methane, nitrous oxide act as blanket for Earth. Human activities such as burning fossil fuels have significantly increased greenhouse gases.





I: Motivation

- IPPC 2007 reports global average temperature increasing due to greenhouse gas emissions

- Clausius-Clapeyron shows exponential increasing saturation vapor pressure with temperature

- Assuming relative humidity remains constant, water vapor pressure P_w will increase

- Increased P_w predicted to amplify global warming, increase precipitation & intensify storms
  -Wentz et al, *Sci. Exp.* **317**, 233 (2007); Trenberth et al, *Clim. Dyn.* **24**, 741 (2005)
  -Allen & Sodden, *Sci.* **321**, 1481 (2008)

- P_w increased 6% per decade during 1975-2004 over Eurasia. Strong correlation with increasing temperature everywhere except for desert -Dai et al, *J. Clim.* **24**, 965 (2006)

Two studies attributed large increases in P_w to human influence

a) Global mean surface P_w increase of 0.11 hPa/decade during 1973-2003 .
   Willett et al, *Env. Res. Lett.* **5,** 025210 (2010)

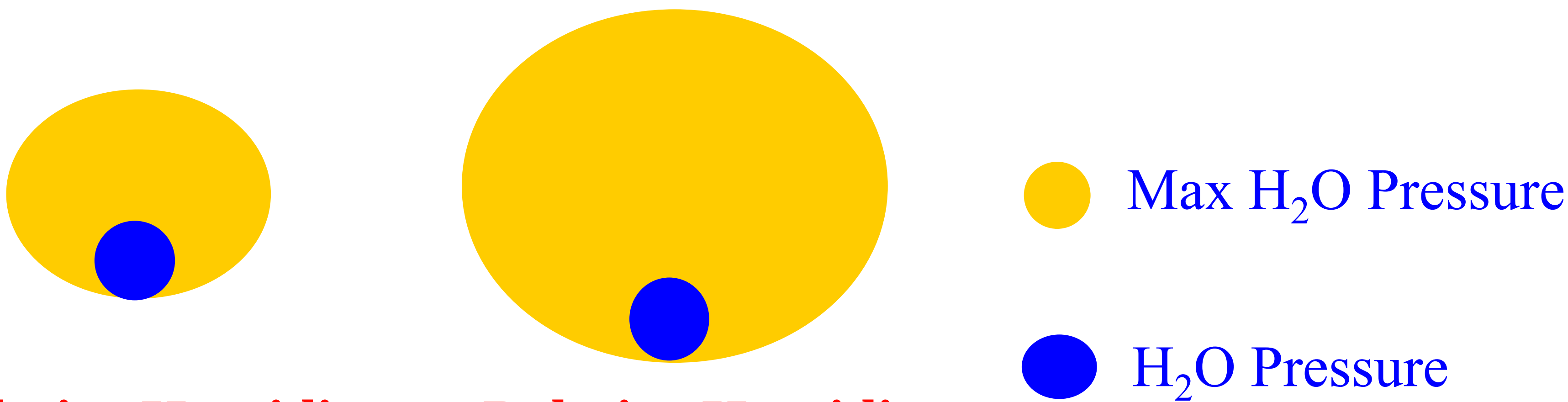
b) Microwave satellite imager P_{water} increase of 0.04 hPa/decade during 1988-2006
   -Santer et al, *Proc Nat Acad Sci* **104** 15248 (2007)

What is Relative Humidity?

$$\text{Relative Humidity} = 100 \times \frac{P(H_2O\ \text{Pressure})}{P(\text{Max } H_2O\ \text{pressure})}$$

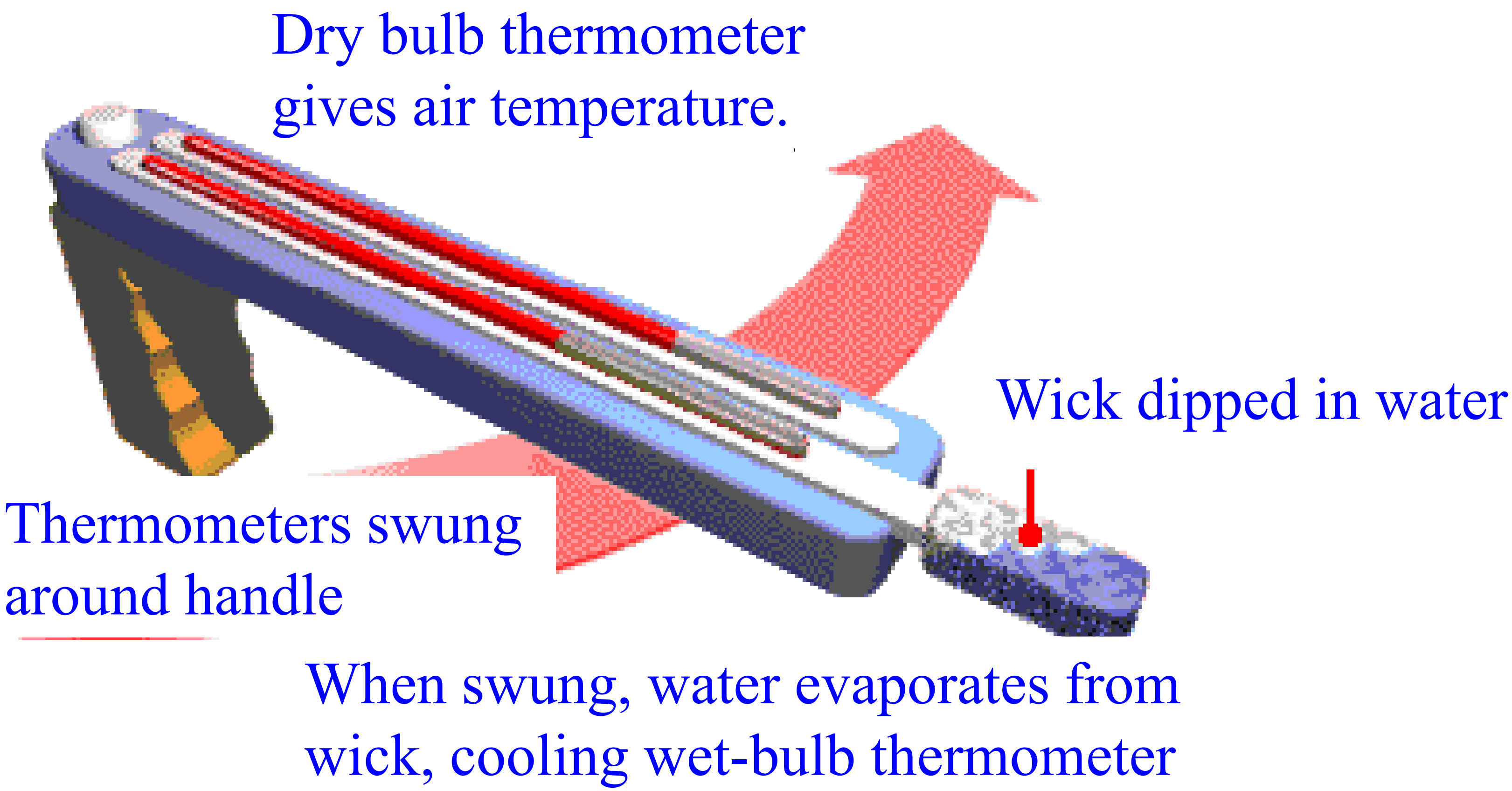
- ability of air to hold water
- depends on amount of water vapour and temperature.

<u>Low Temperature</u> **<u>High Temperature</u>**

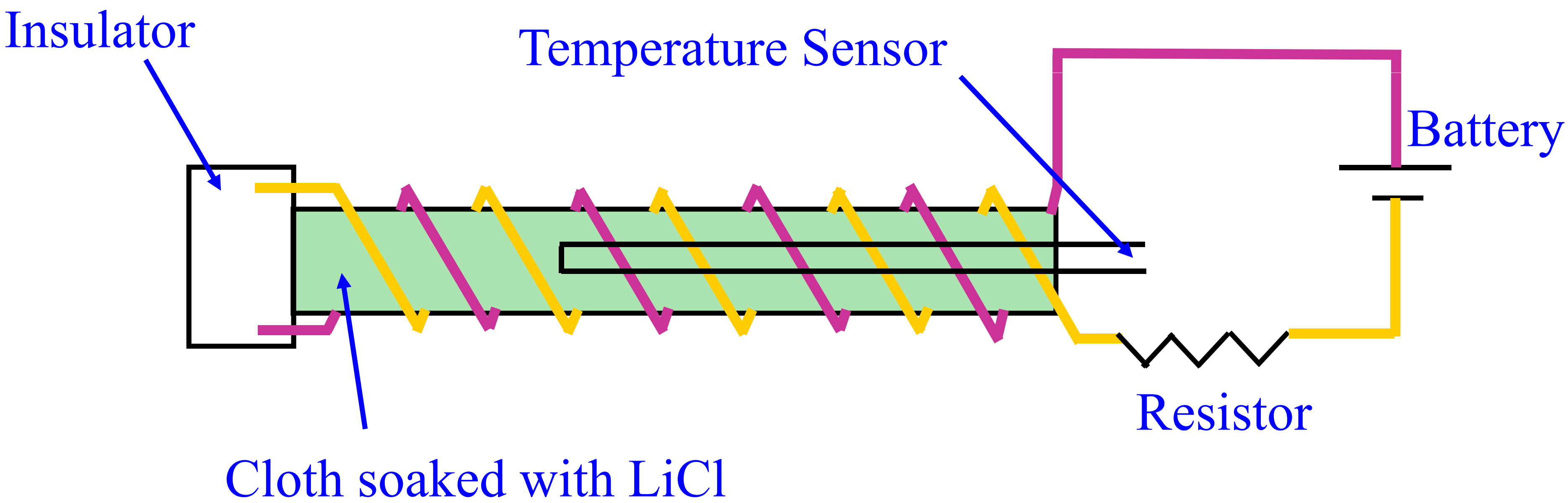


Relative Humidity$_1$ > Relative Humidity$_2$

Psychrometer



Dew Cell



Operation

1. LiCl very hygroscopic, becomes conductive when it absorbs H_2O

2. Electric current is proportional to relative humidity

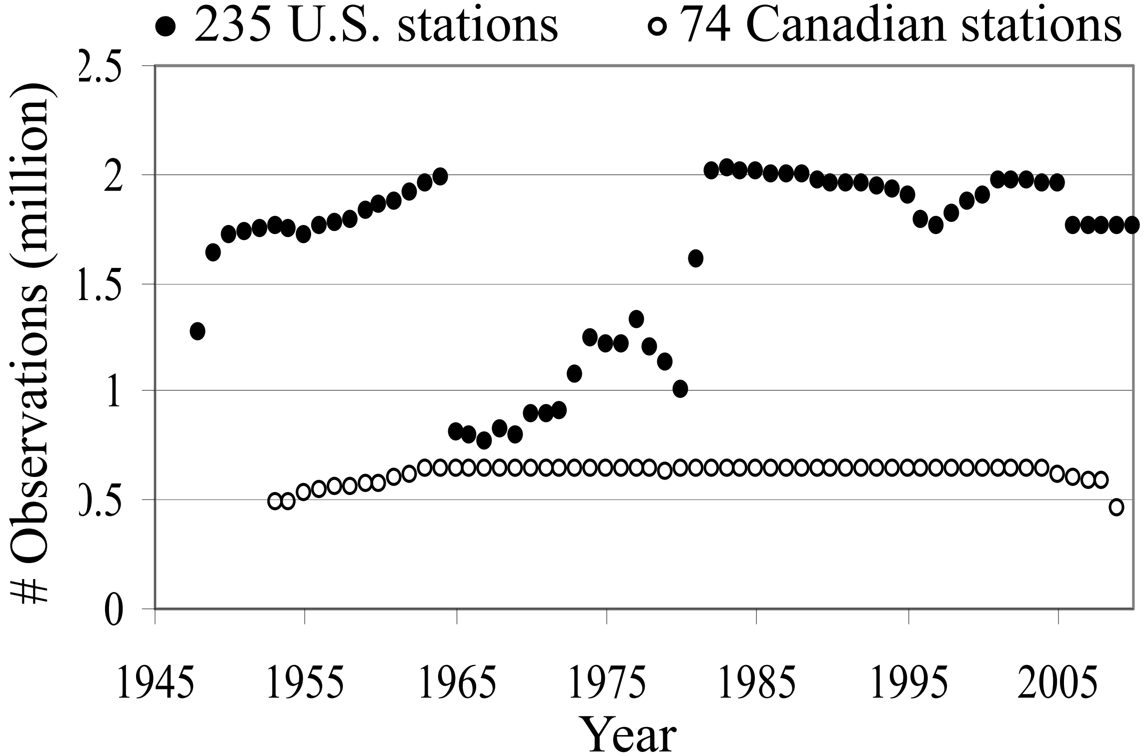
Temperature/Relative Humidity Dataset

> ¼ billion hourly temperature & relative humidity observations available from:

• Environment Canada: Airport stations after 1953, Arctic stations open in late 1950s.

• University Corporation for Atmospheric Research: U.S. hourly data for 1948-2005. Data taken every 3 hours during 1965-1980.

• U.S. Data for 2005-2010 purchased from Speedwell Weather



Fraction of hourly data present averaged 95% (80%) at Canadian (U.S.) stations.

Methodology

- Criteria for station selection was that data be present for > 50% of all hours
- Data investigated for crazy values. Eg. 13 stations had identical temperature recorded every hour for several weeks in 1996.
- Water vapor pressure P_w found from relative humidity (RH) & temperature (T)

$$P_w = RH * P_{sat}$$

Saturation water vapour pressure P_{sat} measured in hPa given by

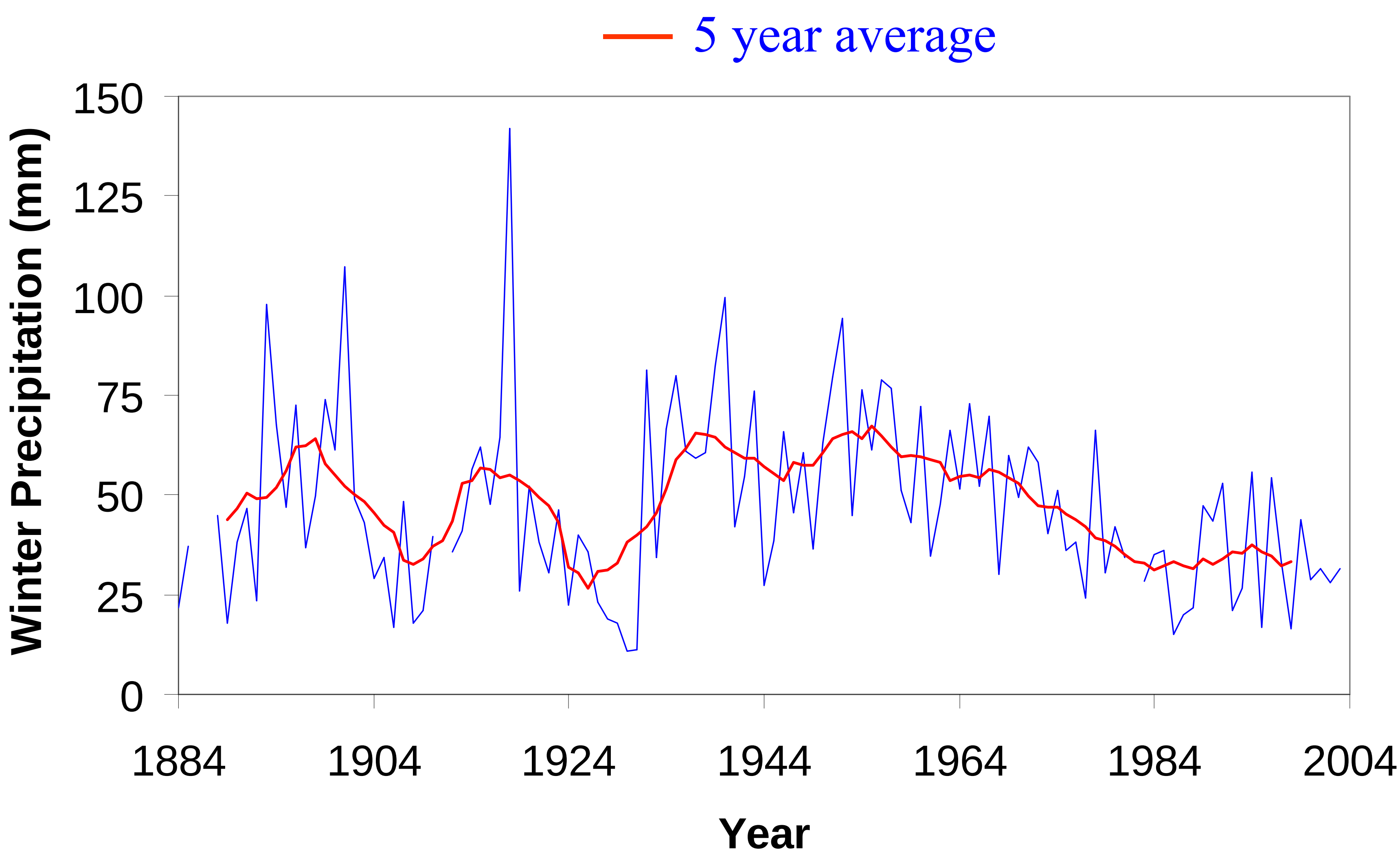
$$P_{sat}(T) = 6.112\ e^{17.62\ T / (243.12+T)}$$

- For each station, seasonal average found if:
  1) observations exist for > 30% of all hours

  2) observations exist for >25% of all hours in each 4 hour period. This is important because sometimes stations only open during day.
- Seasons: Winter(Dec.-Feb.), Spring(March-May), Summer (June-Aug.), Fall (Sept.-Nov.)

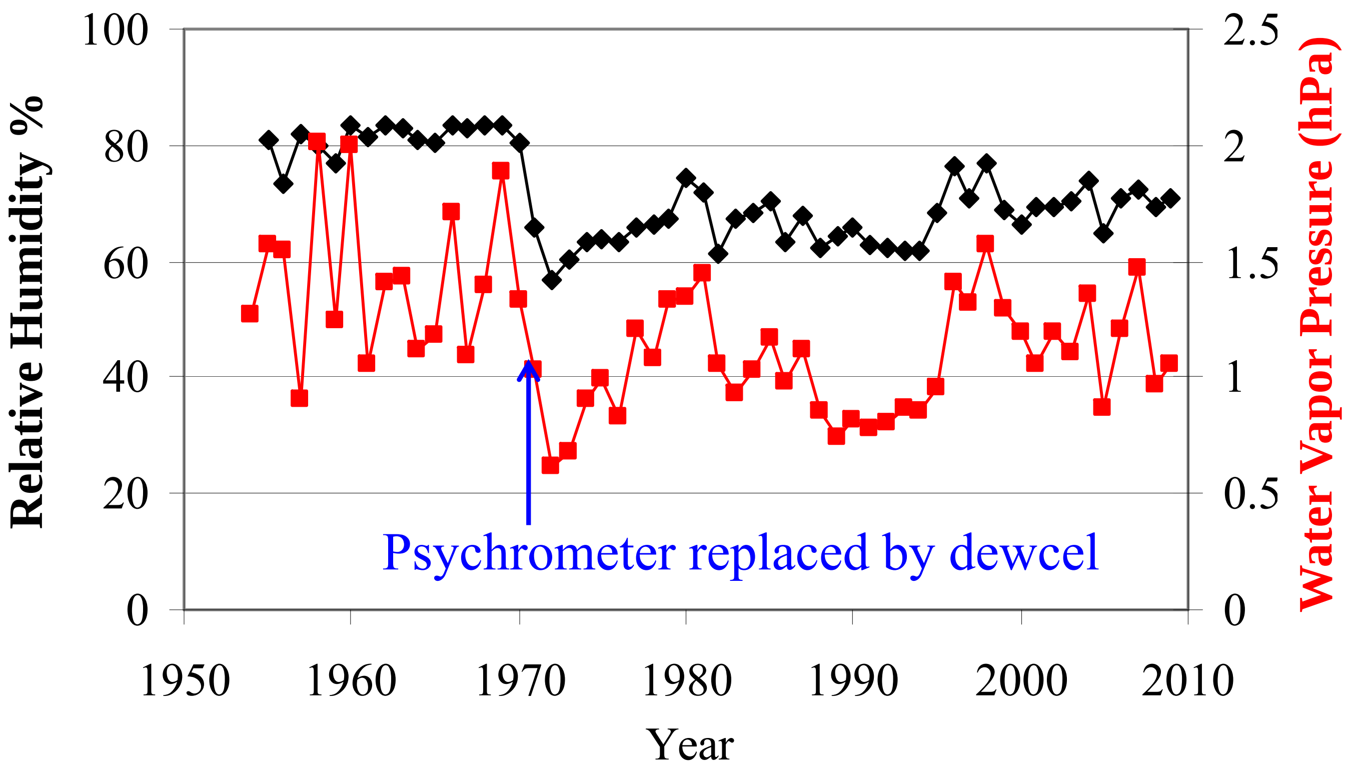
Caution I: Decadal Variation of Climate

Winter Precipitation, Medicine Hat, Alta.



Caution 2: Examination for Inhomogeneities

W. van Wijngaarden & L. Vincent, *J. Geophys. Res.*, **110**, D22102 (2005)



Each time series (t_i , y_i) i=1,2,3 … n fitted by:

1) Model 1: $\mathbf{y_i = a_1 + b_1 t_i + e_i}$ T test assessed trend at 5% significance level.

2) Model 2: $\mathbf{y_i = a_2 + b_2 t_i + c_2 I + e_i}$ Linear trend + Step I occurring at year t_s

3) F test determined which model better fitted data at 95% level

Correcting Inhomogeneities

L. A. Vincent & W. A. van Wijngaarden, *J. Climate* **20**, 5100 (2007)

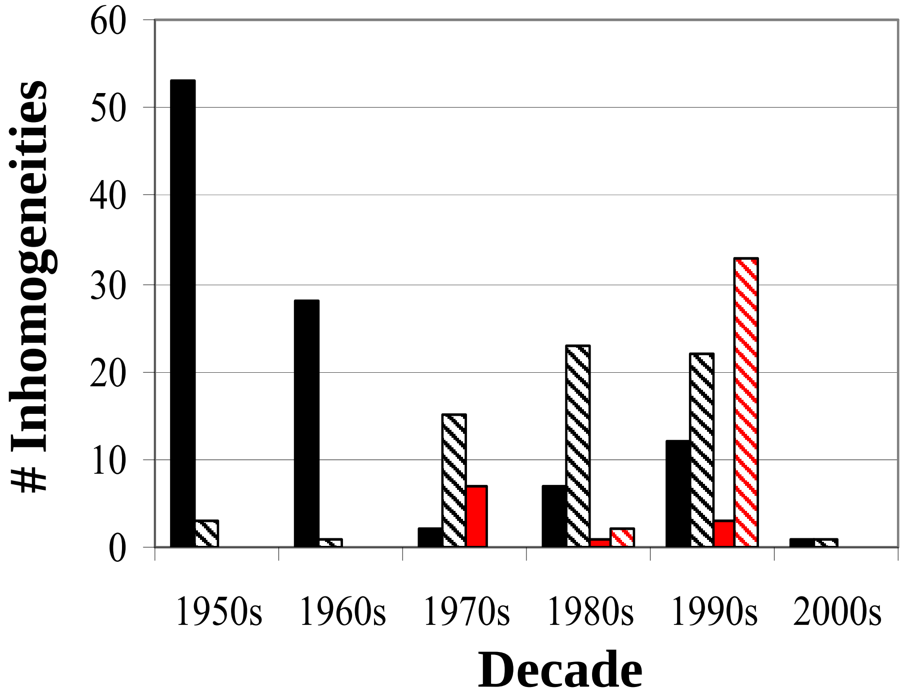
- Ideally, data corrected by understanding instrument change/malfunction
- If correction not possible, time series having inhomogeneity can be compared to time series of neighbouring stations that do not exhibit inhomogeneities
  - Nearest neighbouring stations in Canada may be 1,000 kilometers away & experience a very different climate
  - Difficult when systemic change occurs eg. replacement of psychrometer by dewcel in Canada in early 1970s
- Is the resulting inhomogeneity correction made sufficiently accurately to give a meaningful trend result?
- Better option may be to throw out time series having inhomogeneity although this is difficult when dataset is small

Inhomogeneity Temporal Distribution

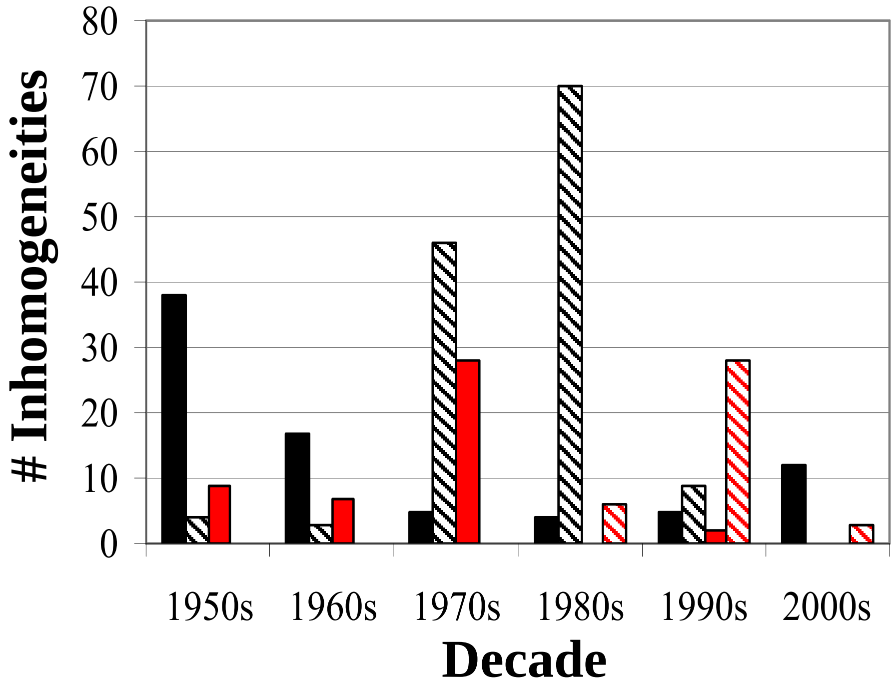
Solid (Cross hatched) Bar = Negative (Positive) Step

Black = U.S. **Red = Canada**

a) Temperature



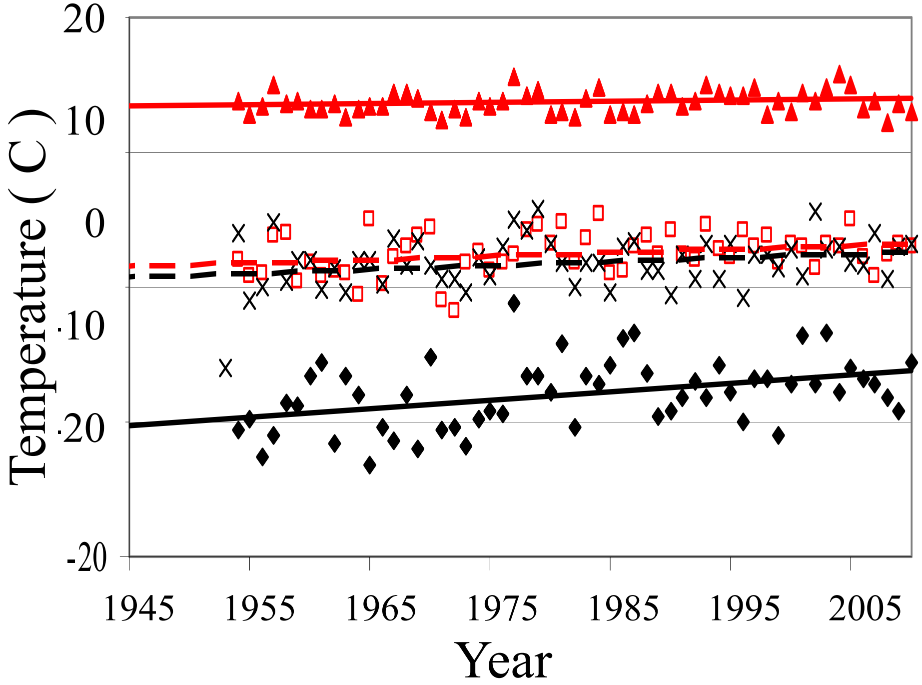
b) Water Vapor Pressure



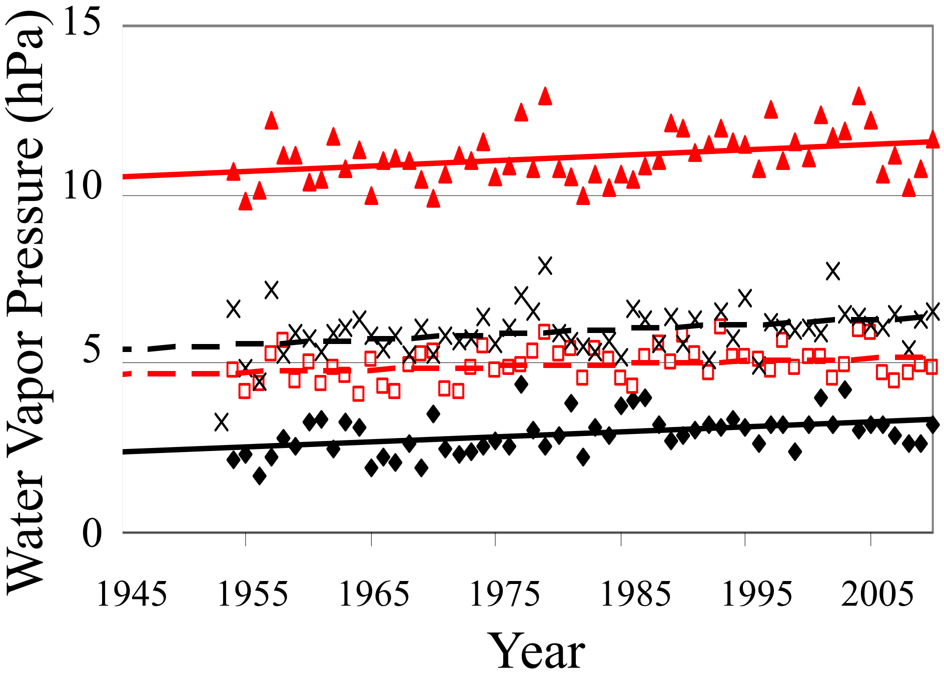
Trends for Anchorage, Alaska

Winter — Spring — Summer — Fall

a) Temperature



b) Water Vapor Pressure



Focus on the Arctic

Climate Change predicts Arctic warms most rapidly. Is it happening?

<u>Dire Consequences</u>

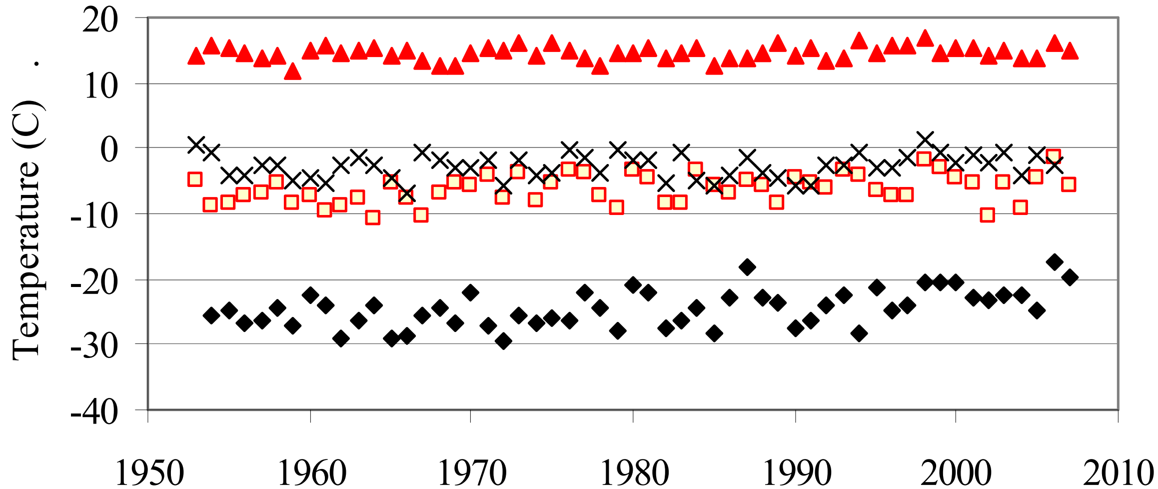
- Navigable Northwest Passage – loss of Canadian sovereignty, oil spills
- Starving polar bears
- Destruction of Inuit way of life

Temperature Trends at 2 Arctic Stations

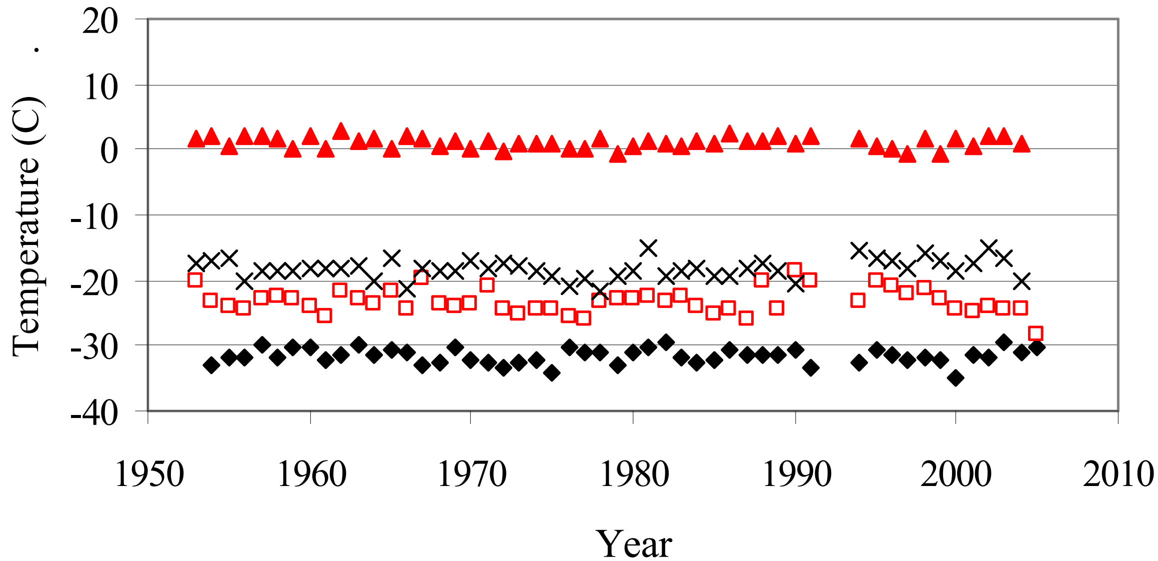
◆ Winter, □ Spring, ▲ Summer, x Fall

W. A. van Wijngaarden, Pacific & Arctic Oceans: *New Ocean. Res.*, Nova Science (2008)

a) Yellowknife,NWT

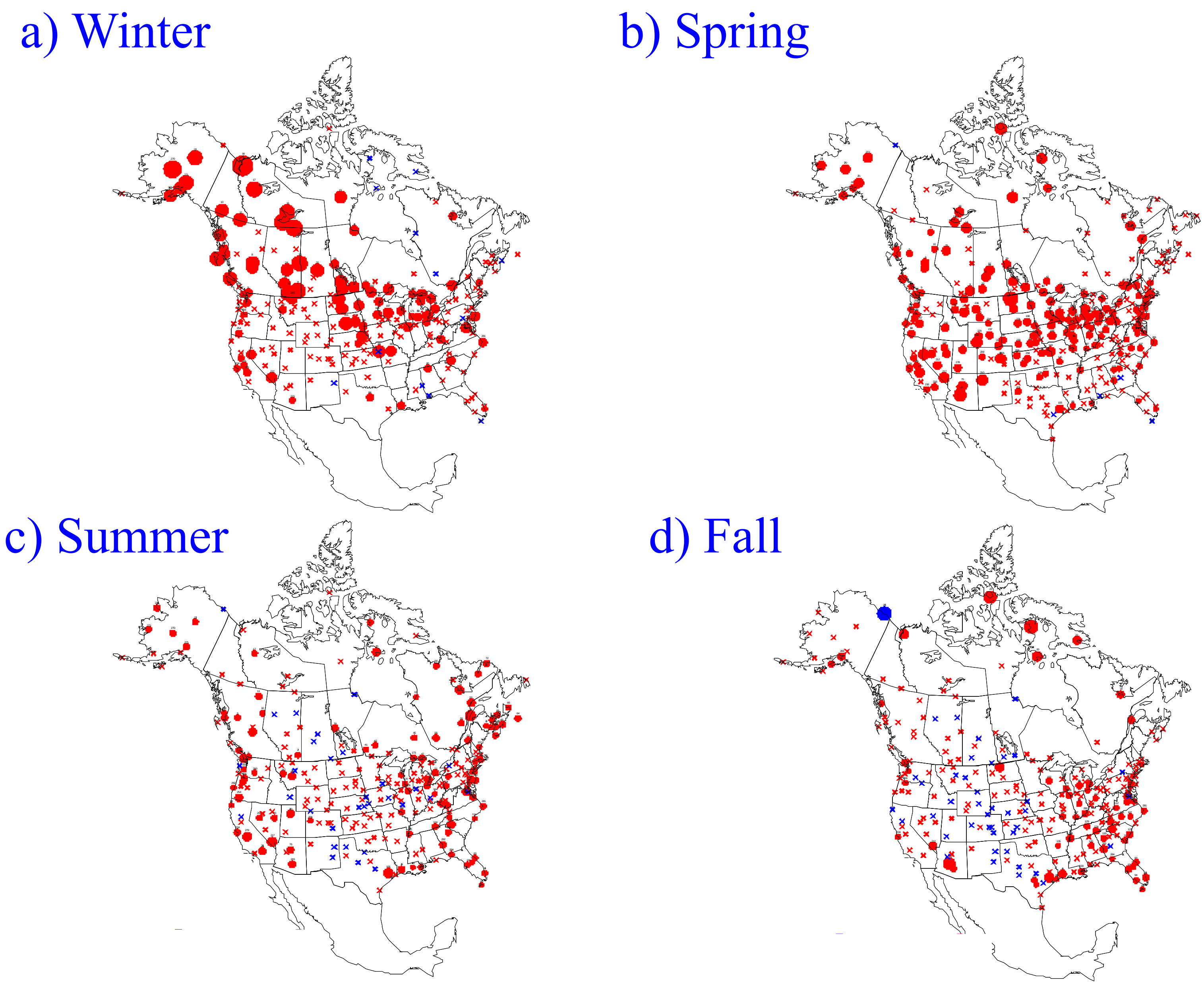


b) Alert, Nunavut



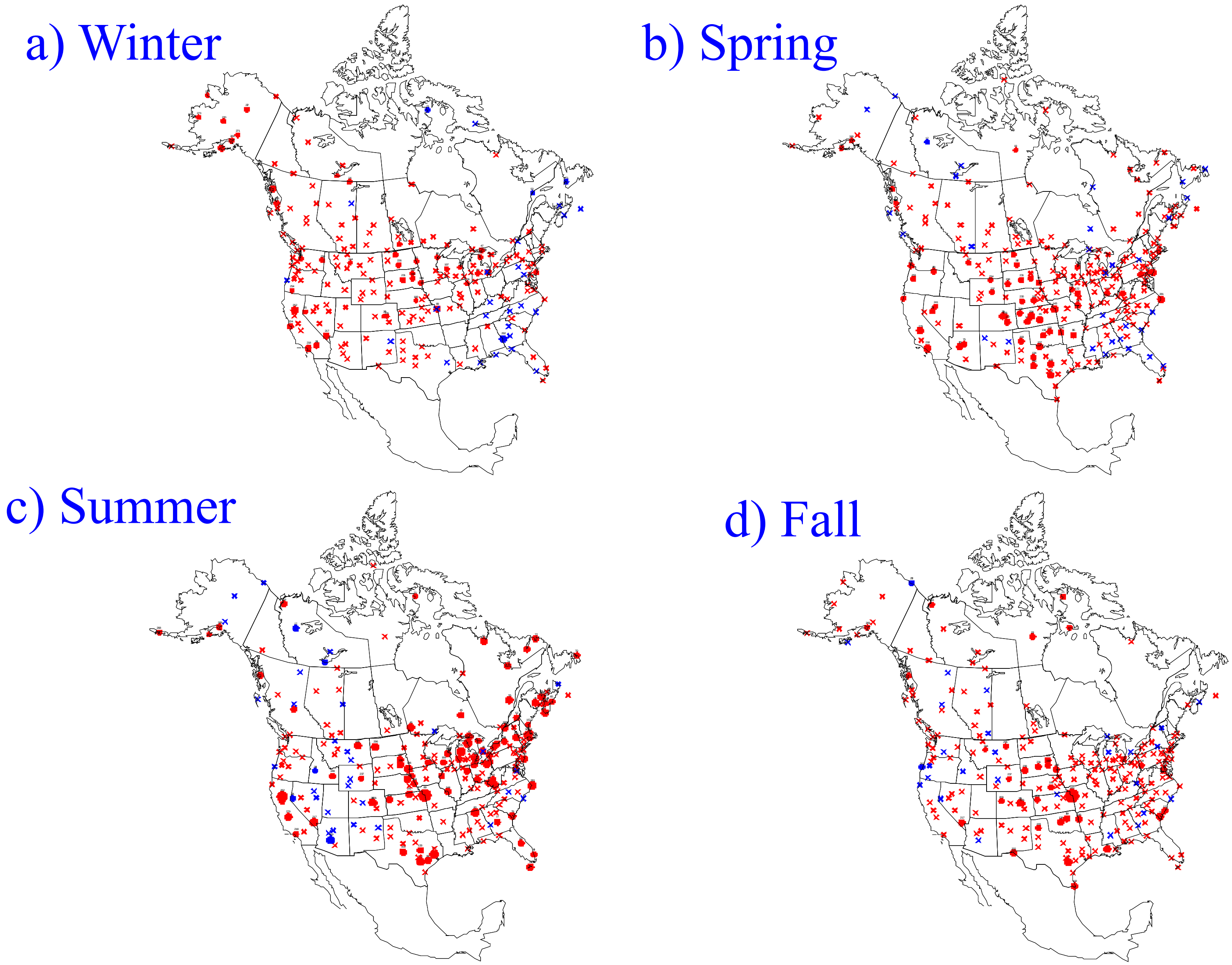
Temperature Trends 1948-2010

x = statistically insignificant trend ● -5 ºC ● +5 ºC



Water Vapor Trends 1948-2010

x = statistically insignificant trend • -2.5 hPa • +2.5 hPa



North America Trend Summary 1948-2010

Only considering data without inhomogeneities

V. Isaac & W. A. van Wijngaarden, *J. Climate* **25**, No. 10, 3599 (2012)

	Temperature Trend °C/decade	Water Vapor Trend	
		hPa/decade	%/decade
Winter	0.30	0.04	0.8
Spring	0.24	0.06	0.7
Summer	0.13	0.11	0.7
Autumn	0.11	0.07	0.7
Average	**0.20**	**0.07**	**0.7**

Assuming constant relative humidity, T=15 °C, ΔT=0.20 °C/decade, gives $\Delta P_{water}/P_{water}$ = 1.3%/decade, about double observed.

Part I Conclusions

Inhomogeneities

Decreasing steps in temperature & water vapor pressure more prevalent in 1950s & 60s while sudden increases occurred primarily in later decades.

Temperature Trends

Increases of 0.30 & 0.24 ^{o}C per decade in winter & spring much larger than summer & autumn trends. Greatest warming in Western Arctic, Canadian prairies & American Midwest.

Water Vapor Pressure Trends

Fewer stations exhibit increase in water vapor pressure compared to temperature. Stations experiencing largest increasing water vapor pressure trends evident in summer mainly in eastern U.S.

Results differ from previous studies in that water vapor trends are smaller & strong correlation between temperature & water vapor pressure trends not found. Other work examined less data for shorter periods of time than ¼ billion observations during 1948-2010 analyzed by our work.

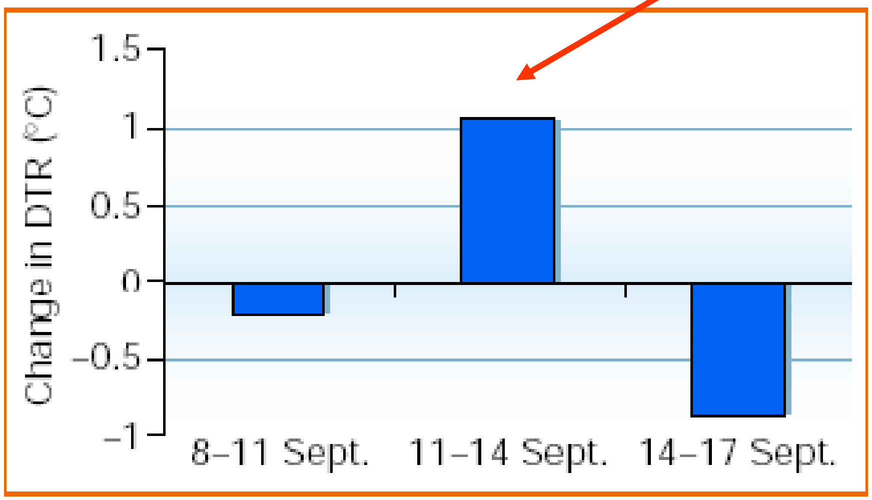
Easy access to archival climate records that precede satellite measurements by decades critical to improve quantitative estimate of anthropogenic climate change.

II: Change in U.S. DTR after Sept. 11, 2001

D. Travis et al, *Nature* **418**, 601 (2002) & *J. Climate*, **17**, 1123 (2004)

Diurnal Temperature Range (DTR) = Max Day Temp – Min Night Temp

Flight Ban in US

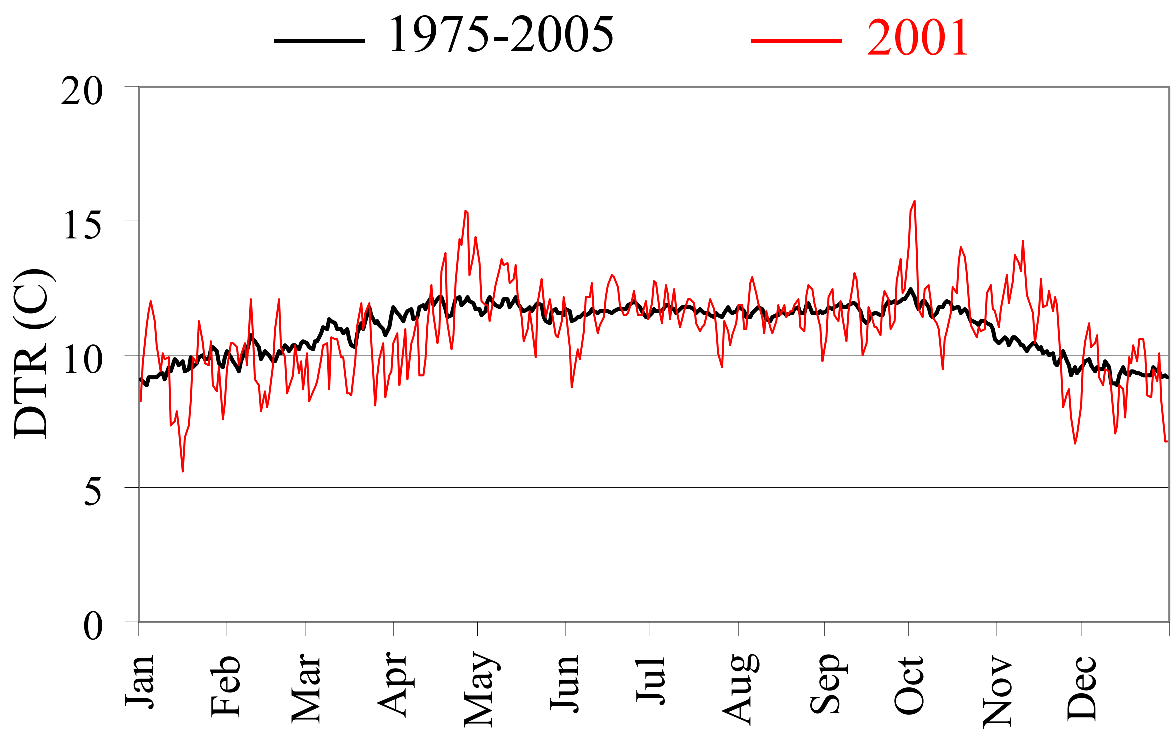


- Increase in DTR during flight ban due to no jet contrails
- Contrails act as clouds, block sunlight during day & trap radiation at night
- DTR change of 1.5 °C over entire continental U.S. within hours of shutting off a few thousand jet engines comparable to global warming by millions of smokestacks/cars operating for over a century!

Diurnal Temperature Range during 2001

W. A. van Wijngaarden, *Theoretical & Applied Climatology* **109**, 1 (2012)

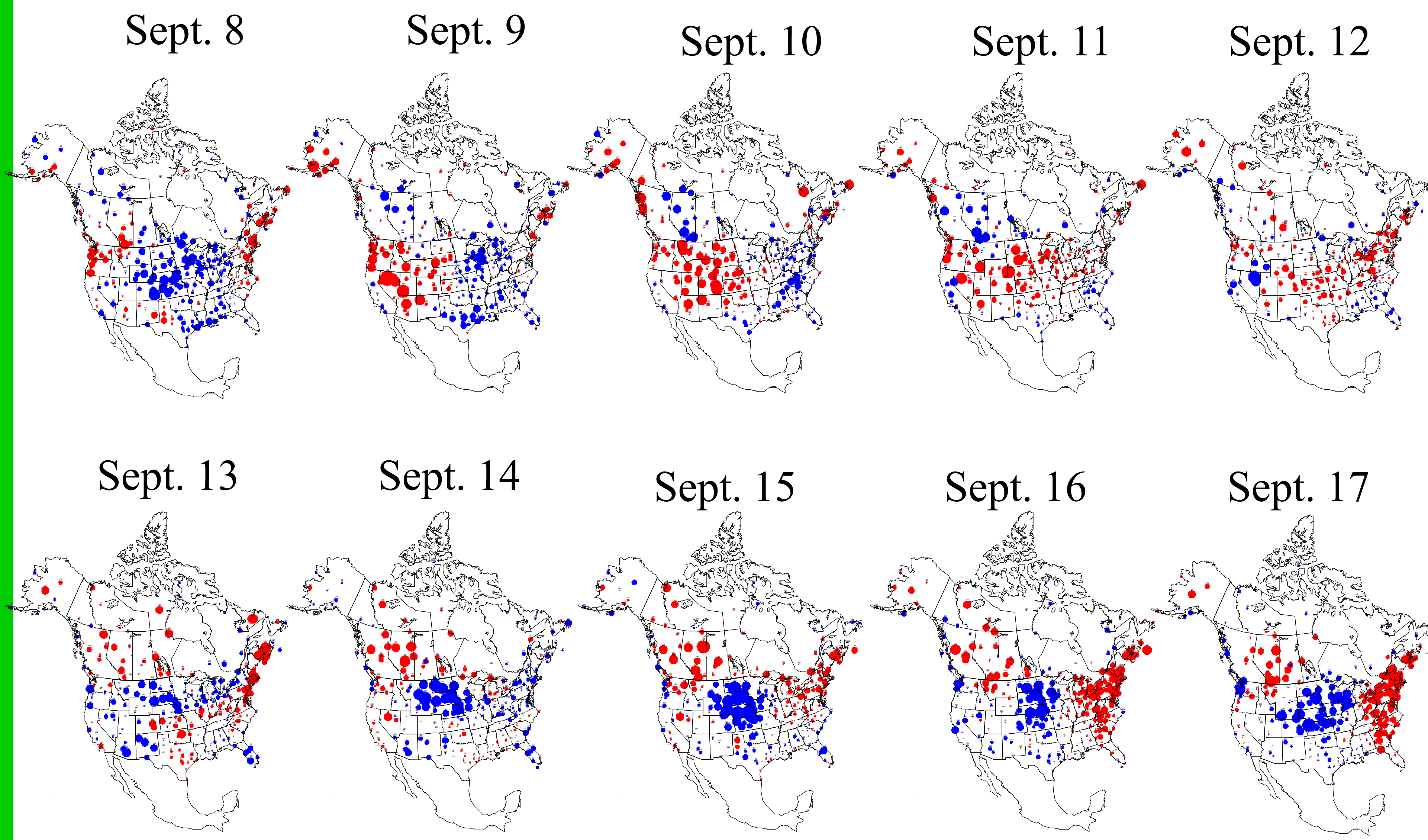
Average DTR experienced by continental U.S. stations excluding Alaska.



- DTR Change during Sept. 2001 smaller than evident in May or Oct., 2001
- No significant perturbation evident in temperature, relative humidity near 9/11
- 2001 data fluctuates about 1975-2005 average with time constant of several days comparable to time for weather system to move across North America.

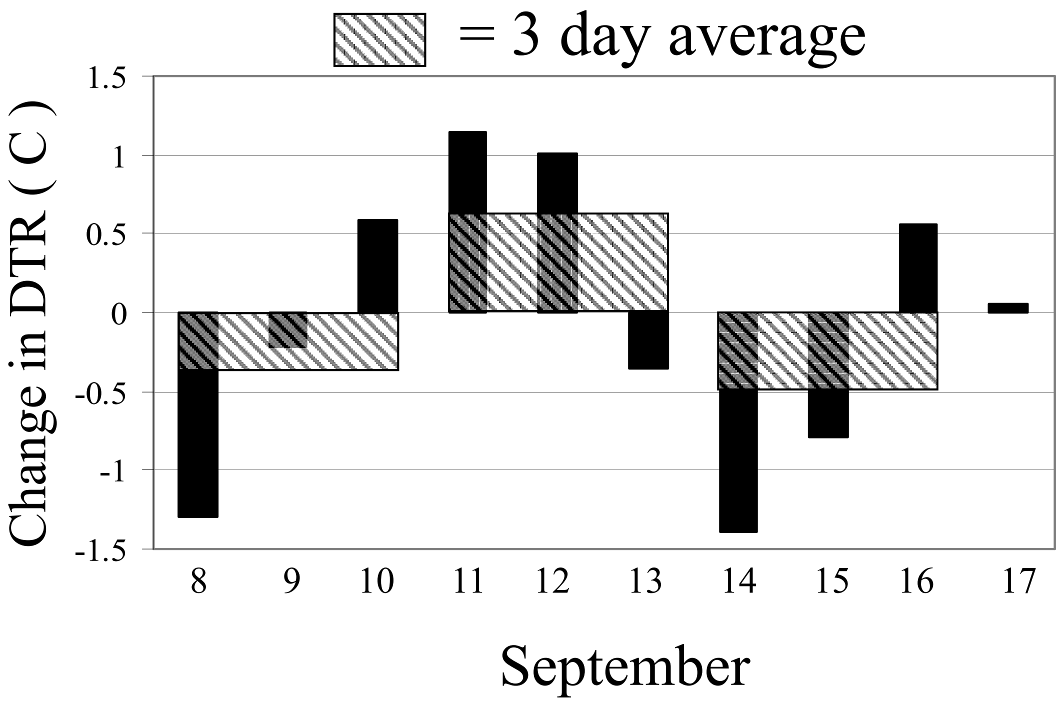
DTR Sept. 8-17, 2001 – 1975-2005 Average

● -10 ºC ● +10 ºC



Change in U.S. DTR during Sept. 8-17, 2001

V. Isaac & W. A. van Wijngaarden, *J. Climate* **25**, No. 10, 3599 (2012)



• DTR change begins before flight ban & begins to taper off before flight ban ends

• Maps show DTR change during Sept. 8-17, indicate North America had predominantly clear skies during flight ban. Other work found reduction of cloudiness. A. Kalstein et al, *Clim. Res.* **26**, 1(2004); G. Hong et al, *Geophys. Res. Lett.* **35**, L23815(2008)

Caution warranted when claiming dramatic climate change occurred on very short time scales & concluding it is due primarily to anthropogenic effects.