Climate Change from the in situ data

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Typical daily temperature variance distribution in mid-latitudes

- ~80% - seasonal cycle
- ~15-20% - weather variability
- Residual – everything else (e.g., climate variability and change)
\[ Y = \Sigma X_i \]

\[ X_i \; [i=1,..k] >0; \; X_i \; [i=k+1,..n] <0 \]

- \( \Rightarrow \) \( E \; Y \) could be close to 0
- But, \( D \; Y \gg 0 \).

In real world: \( E \; Y \) is not 0; \( X_i \) interact among themselves, \( Y \) feedback to \( X_i \) variations
What this Presentation will try to cover:

1. Temperature and closely related measurements
   a. Direct observation
      i) Means
      ii) Extremes
      iii) Impact relevant
   b. Cryosphere
      i) Permafrost
      ii) Glaciers
      iii) Sea Ice Extent
         a. Spatial extent
         b. Seasonal duration
         c. Thickness
      iv) Snow cover (a separate talk)
      v) Lake and river ice

2. Circulation indices and temperature trends

3. Precipitation
   a. Means
   b. Extremes

4. Socially important variables
   6. i) Potential forest fire danger
   7. ii) Runoff
Global (NH) temperature estimates

- Köppen (1888)
- Callender (1940); Mitchell (1960s)
- Budyko (1972); Budyko & Vinnikov (1976)
- **1980s:** Major efforts
  - Jones et al. (UK); Bradley et al. (USA&UK)
  - Vinnikov et al. (USSR)
  - Hansen and Lebedeff (USA)
  - Folland et al. (UK); Raynolds et al. (USA)
- **1990s:** Intercomparison & adjustments
Global temperature
60S-90N

Annual time series. 1881-2005

Linear trend = 0.80K per 125 years
Jan-Feb Global Surface Mean Temp Anomalies
NCDC/NESDIS/NOAA (Smith and Reynolds, 2005)

- Land and Ocean
- Ocean
- Land
Northern Hemisphere surface air temperature

- **Summer**
  - Trends: 
    - winter = 1.2 K/125 yrs
    - annual = 0.9 K/125 yrs
    - summer = 0.6 K/125 yrs

- **Winter**

Reference period: 1951-1975

Annual time series 1881-2005
Linear trend = 0.88K per 125 years

Southern Hemisphere surface air temperature

- **Winter (DJF)**
  - Trends: 
    - winter = 0.6 K/125 yrs
    - annual = 0.7 K/125 yrs
    - summer = 0.9 K/125 yrs

- **Summer (JJA)**

Reference period: 1951-1975

Annual time series 1881-2005
Linear trend = 0.70K per 125 years

0 - 90N

0 - 60S
Northern Hemisphere temperature anomalies, 1881-2005
Arctic zonal temperature anomalies
(within 60º-90ºN latitudinal zone)

- Winter, summer, and annual anomalies, 1881-2005 period
- All linear trends significant at the 0.01 level
  - (available from CDIAC, Lugina et al. 2005).
Arctic temperature (60N - 90N)

Temperature anomalies, K

Years

1880 1905 1930 1955 1980 2005

2006
North Eurasian surface air temperature changes during the past 126 years

Continent north of 40°N and east of 15°E

Seasonal surface radiation budget over the Eastern Hemisphere (>40° N)

- July 1983 through October 1995 as determined by the GEWEX SRB project (Stackhouse et al. 2004).
Mean Winter Temperature Change
1956 to 2005 over the globe

• Data source: (Jones and Moberg 2003). Processed by the U.S. NOAA NCDC Global Climate at the Glance Mapping System
Mean Spring Temperature Change
1956 to 2005 over the globe

• Data source: (Jones and Moberg 2003). Processed by the U.S. NOAA NCDC Global Climate at the Glance Mapping System
Mean Summer Temperature Change 1956 to 2005 over the globe

- Data source: (Jones and Moberg 2003). Processed by the U.S. NOAA NCDC Global Climate at the Glance Mapping System
Some temperature derivatives in the boreal zone of the Northern Hemisphere
Length of the Frost-Free Period

Climatology

- Frost-free period has increased on average by 7% per 50 years
- Significant increases: Canada, Western Russia, Alaska
Statistically significant decrease (6%/50 yr) over the entire zone north of 50°N

Maximum absolute and relative reduction in heating degree days over Western Canada and Alaska (9%/50 yr. and 8%/50 yr.)

Significant reductions in heating degree-days are observed over Russia (~7%/50 yr.)
Thaw days. Winter Climatology
Frequency of days with thaw

Definition of thaw: SNOD > 0 & T > -2°C

Mean value = 17 days per season

Increase by 8 days per 50 years; $R^2 = 0.11$
Frequency of days with thaw over Alaska, Canada, and the fUSSR north of 50°N

A 20% (winter) to 40% (autumn) increase during the second half of the 20th century
Changes in derived-temperature characteristics over Northern Eurasia during the past 54 years (within the former USSR boundaries; period 1951-2004)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Trend estimates, %/54 yrs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Former USSR</td>
</tr>
<tr>
<td>Heating-degree days</td>
<td>-7</td>
</tr>
<tr>
<td>Degree-days below 0°C</td>
<td>-15</td>
</tr>
<tr>
<td>Degree-days above 15°C</td>
<td>11</td>
</tr>
<tr>
<td>Duration of the growing season</td>
<td></td>
</tr>
<tr>
<td>T&gt; 10°C</td>
<td>9</td>
</tr>
<tr>
<td>T&gt; 5 °C</td>
<td>8</td>
</tr>
<tr>
<td>Duration of the frost-free period</td>
<td>8</td>
</tr>
</tbody>
</table>

All trend estimates are statistically significant at 0.01 or higher levels.
Changes in temperature derivatives over northwestern quadrant of North America [north of 49ºN west of 95ºW] during the past 50 years

<table>
<thead>
<tr>
<th>Derivative</th>
<th>Trend, %/50 yrs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Alaska</td>
</tr>
<tr>
<td>Heating-degree days</td>
<td>-8</td>
</tr>
<tr>
<td>Degree-days below 0ºC</td>
<td>-17</td>
</tr>
<tr>
<td>Degree-days above 15ºC</td>
<td>31</td>
</tr>
<tr>
<td>Duration of the growing season (T&gt; 10ºC)</td>
<td>19</td>
</tr>
<tr>
<td>Frost-free period</td>
<td>6</td>
</tr>
</tbody>
</table>

* in eastern Canada similar changes are also statistically significant
Thus, there should be an additional water “demand” for evaporation and transpiration
Topics with temperature that are still under consideration

- Urbanization
- Screens
- Automation
- Land use changes
- Microwave Sounding Unit controversy
- Sea surface temperature estimates
- Paleoclimatic reconstructions
Cryosphere

Sea Ice
Glaciers
Permafrost
River and lake ice breakup
Snow cover (next week)
Sea Ice Extent Anomaly, Sept. 2002

Concentration anomaly (%) derived from DMSP SSM/I data relative to means for 1988-2000. (Fetterer et al. 2002)
Since 1980, perennial sea ice in the Arctic has declined at a rate of 9.8% per decade (Comiso 2006).

Courtesy of National Snow and Ice Data Center, http://nsidc.org/news/press/20050928_trendscontinue.html#fig1
Hemispheric Sea Ice Extent Anomalies

Northern Hemisphere Extent Anomalies Sep 2006

1979-2000 mean = 7.0 million sq km
slope = -8.6(+/-2.9) % per decade

http://nsidc.org/cgi-bin/wist/wist/wist_nt.pl
Northern Hemisphere Extent Anomalies May 2007

1979-2000 mean = 13.6 million sq km

slope = -2.8(+/-1.0) % per decade

Mean ice drafts at places where early cruises were (nearly) collocated with cruises in the 1990s.
- Decrease in sea ice thickness
- Sampling error issue not fully resolved
Meridional heat transfer

Ocean currents ~1/3 or ~ 0.5 x10^{15} W across 60°N
One of the first UCMO GCM sensitivity experiments with polar ice replaced by water at 273K

Changes in surface air temperature, K

Changes in glacier volume (km$^3$) since 1960

Source: http://www.nsidc.org
Impact on water supply…

When the millenium-old water storage will go, what to do?

Example. Central Asia. Example of a central Tien Shan glacier recession. Petrova Glacier in the Akshiyrak area, ASTER image, September 2002 (A), and instrumental topographic data (B) (Kuzmichonok et al. 2005)
Mass balance of mountain and subpolar glaciers with the aggregate area 785*10^3 km^2 and their contribution to the rise in sea level; observational results are weighted by sizes of individual glaciers (about 300 time series), primary systems (49 in the world) and by larger size systems (13); updated 10.10.04. Contribution increased in 1993-2002 decade from 0.40 to 0.73 mm/yr (M. Dyurgerov, 2004; results reported to NASA, NAG5-13691)

GLACIER CONTRIBUTION TO SEA LEVEL RISE

Dyurgerov 2004
Circumpolar permafrost extent

J. Brown, O. J. Ferrains, Jr., J. A. Heginbottom, and E. S. Melnikov (1997)
Two possible scenarios after the permafrost thaw:

- Wetlands
- Steppe
Changes in Permafrost Temperature in Barrow, Alaska Between 2001 and 1950

From Romanovsky (2002)
## Changes in Permafrost Temperature

<table>
<thead>
<tr>
<th>Country</th>
<th>Region</th>
<th>Permafrost Temperature Trends</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>Trans-Alaska pipeline route (20 m), 1983-2000</td>
<td>+0.6 to +1.5°C</td>
</tr>
<tr>
<td></td>
<td>Barrow Permafrost Observatory (15 m), 1950-2001</td>
<td>+1°C</td>
</tr>
<tr>
<td>Russia</td>
<td>East Siberia (1.6-3.2 m), 1960-1992</td>
<td>+0.03°C/year</td>
</tr>
<tr>
<td></td>
<td>North of West Siberia (10 m), 1980-1990</td>
<td>+0.3 to +0.7°C</td>
</tr>
<tr>
<td></td>
<td>European North of Russia, continuous permafrost zone (6 m), 1973-1992</td>
<td>+1.6 to +2.8°C</td>
</tr>
<tr>
<td></td>
<td>European North of Russia, discontinuous permafrost zone (6 m), 1970-1995</td>
<td>up to +1.2°C</td>
</tr>
<tr>
<td>Canada</td>
<td>Alert, Nunavut (15 m), 1995-2000</td>
<td>+0.15°C/year</td>
</tr>
<tr>
<td></td>
<td>Northern Mackenzie basin, NWT (28 m), 1990-2000</td>
<td>+0.1°C/year</td>
</tr>
<tr>
<td></td>
<td>Central Mackenzie basin, NWT (15 m), 1985-2000</td>
<td>+0.03°C/year</td>
</tr>
<tr>
<td></td>
<td>Northern Quebec (10 m), late 1980’s – mid 1990’s</td>
<td>-0.1°C/year</td>
</tr>
</tbody>
</table>

Source: Romanovsky (2002)
Earlier Ice Breakup
Late Lake and River Freeze Up

- ~2 week increase in length of ice-free season

Magnusson et al. (2000)
Atmospheric circulation
Seasonal mean patterns

Winter

Sea level pressure (hPa)

Surface air temperature (C)

Summer
Sea level pressure changes with the Northern Hemisphere SAT increase

Winter

Summer

4 hPa / 0.5K

-10 hPa; -8 lat. / 0.5K

-14 lon. / 0.5K

5 hPa / 0.5K

[+22 lon.; +5 lat.]/ 0.5K

[+7 lon.; -5 lat.]/ 0.5K

[-10 hPa; -8 lat. ]/ 0.5K
AO time series and its pattern

PDO time series and its pattern
✓ Note: Over past 10 years NAO and AO have been both strongly positive and negative
Seasonal changes in zonal temperature differences between tropics and mid-latitudes

- December-March
  - Zonal temperature gradients
    - Differences: T(0-30N) - T(30-60N)

- June-September

Gradient variations, Deg. C

Year: 1880 to 2020
Precipitation

Still in the research domain
Annual precipitation in high latitudes over the land

Data source: Global Daily Climatology Network (Gleason 2002)

- Additional water vapor influx from the tropics and Arctic ocean together with atmospheric warming intensified the water cycle
Statement of the problem

- No WMO standards for precipitation
- A sophisticated function of wind at the gauge orifice, weather type, gauge type, and observational practice is reported instead of “ground true” values
- Enormous need for the data
- Effects of climatic and practice changes
- Must make changes nationwide and secure homogeneity
A depiction of the systematic changes in the precipitation network over the former USSR (Groisman et al. 1991).

After 1991, a new development in the NIS countries.
A depiction of the systematic changes in the precipitation network over North America (Groisman and Easterling 1994).

Switch from inches to mm and to direct gauge measurements.
What biases can do with precipitation measurements?

Figure 1 from Karl et al. 1993:

Some important precipitation measurement discontinuities over the last 100 years at many primary observing stations within various mid- and high latitude Northern Hemisphere countries.
Mean number of days with non-zero very light daily precipitation over the conterminous United States

![Graph showing the mean number of days with non-zero very light daily precipitation over the conterminous United States from 1900 to 2020. The graph includes two sets of data points: one for days with 1 mm > P > 0.5 mm (dark diamonds) and the other for days with 0.5 mm > P > 0 (pink circles). The data shows an increasing trend over time.]
Difference between precipitation totals over the Russian permafrost-free zone estimated using 2 archives
Major permafrost-free zone of the Russian Federation and its precipitation changes

Groisman and Rankova 2001
Comprehensive routines

\[ P = K \times (P'' + _P - P_{f1} - P_{f2}) \]

- \( K = 1 + A(U_h \mu)^2 \); or
- \( \mu \) is a conversion to air density at 1013hPa
- \( U_h \) is a wind speed at the gauge orifice when \( P \)
- \( A \) is a function of gauge and precipitation types
- \( P'' \) is the measured precipitation
- \( _P \) is wetting/evaporation correction
- \( P_{f1} \) and \( P_{f2} \) are adjustments for flurry and blow-in

Golubev et al. 1995, 1997; Bogdanova et al. 2002a,b
Increase (%) in mean annual precipitation throughout the former USSR during the 1961-1990 period compared to P" (measured).
Seasonal cycle of monthly precipitation

Russian Arctic (north of 70N; west of 110E)
Regionally averaged January precipitation time series prior and after bias correction. East Siberia

Monthly precipitation, mm

$y = 0.0625x - 108.17$

$R^2 = 0.1245$
Annual precipitation in Fairbanks, Alaska
Annual precipitation in Canada
Mean scale factor = 1.35; [1.12 to 1.50].

Cambridge Bay, NWT
Extremes

For empirical research dense networks with daily time resolution are needed.

For theoretical conclusions reliable models are needed.
Alaska, Canada, Fennoscandia, and the former USSR

- Statistically significant increase of warmest nights
- Statistically significant decrease of coldest nights
Regions in North America, where changes of specific extreme events have been recently documented (or projected by global climate models) and thus require more thorough assessments.
Changes in the surface water cycle listed below have been statistically significant in the 20\textsuperscript{th} century:

Regions with more humid conditions (blue), regions where potential forest fire danger has increased in the 20\textsuperscript{th} century (red), and the region where agricultural droughts have increased (circled).

Mescherskaya & Blazhevich (1997), Dai et al. (2004), Zhai et al. (2005), Groisman et al. (2005)
Changes in rainfall intensity

Why do we expect changes?
- Climatology
- Models
- Models + Observations

Higher temperatures => increase in precipitation intensity

Projected changes in “very heavy” precipitation with the CO₂ doubling

Regions with disproportional increase (+) and decrease (-) in heavy precipitation

Groisman et al. 2005, J. Climate

What have we already observed?
Regions with statistically significant annual increases in “very heavy” precipitation over the United States

Why are changes in the rainfall intensity not so visible in changes in flood events?

Groisman et al. 2005, J. Climate
Regions in the Central U.S. where statistically significant annual increases in very heavy precipitation were first reported and counts of the upper 0.3% of daily rain events (with return period of 4 years)

Linear trends (1893-2006 and 1967-2006) are 22%/114yrs and 27%/40yrs respectively

Update of Groisman et al. 2005
Heavy and very heavy precipitation: Northwestern coast of North America

**British Columbia, south of 55N**

- Increase [%/50 yrs]
  - Mean P: 7
  - Upper 5%: 16
  - Upper 0.3%: 19

**Alaska, south of 62N**

- Mean P: 10
- Upper 5%: 18
- Upper 0.3%: 37
Precipitation and “very heavy” precipitation in Fennoscandia

All increases in the second half of the 20th century have occurred in the past 25 yrs
Annual number of days with “heavy” precipitation events over Northern Eurasia

“Heavy” = \{ > 2 \times \sigma \} of the events with P > 0.5 mm

A circumpolar increase of 12%/50yrs north of 50°N (mostly from Eurasia where spring and summer increase in convective clouds is observed)
Summer frequency of wet days and days with heavy rains

Asian part of Russia. Summer

Sun and Groisman 2000
Seasonal frequency of occurrence of daytime *Cumulonimbus* and *Cumulus*

Summer Dryness. Theoretical expectations


Everything else will be empirical evidence
Eastern Siberia.
Regionally averaged January and July precipitation prior and after bias correction
Thus, in high latitudes we have:

• Up to two-digit (%) increase in temperature derivatives $\Rightarrow$ evapotranspiration may $\uparrow$;

• Earlier snowmelt & more frequent thaws $\Rightarrow$ more cold season precipitation become unavailable in the warm season;

• Only moderate increase in precipitation but increase in thunderstorm activity $\Rightarrow$ more warm season precipitation goes into runoff;

• All the above $\Rightarrow$ possibility of drier summer conditions $\Rightarrow$ increase in forest fire danger.
Dynamic of Forest Fires in Russia

Fire numbers (top) and the area covered by fire (bottom) during the 1965-2001 period (Korovin and Zukkert 2003)
Three Indices were used to assess the potential forest fire danger.

- **Keetch-Byram Drought Index (KBDI)** (This index uses daily data on maximum temperature and precipitation).
  
  **Index is developed and used in the United States**

- **Modified Nesterov and Zhdanko Indices**
  (These indices use synoptic daytime data on temperature and humidity and daily precipitation and snow on the ground)

  **Indices are developed and used in Russia**

Implementation of all these indices gave similar results for Alaska.
Frequency of high KBDI values in Central (between 62°N & 66.7°N) and Southern Alaska in spring (MAM) and summer (JJA) seasons.

- Since 1944 (in Central) and 1937 (in Southern Alaska), we have a sufficient number of stations.
- After the fire outbreak in 1957/1958, a steady increase in frequency of spring and summer days with high KBDI was documented up to 2003. In 2004 and 2005, there were another fire outbreaks.
Example: Russian Far East south of 55°N

- Spring: Increase = 25%/100 yrs
- Summer: Increase = 70%/100 yrs
Southeastern Canada, fraction of strings of dry days longer than 20 days

Red dashed line: linear trend (1.3% per 40 years)
Regions where dry episode frequency is increasing during the past 40 years

30 and above days in dry episodes (20 for SE Canada)

60 and above days in dry episodes
Dry episodes over North America

During the past four decades over the contiguous US:

- the duration of prolonged dry episodes has significantly increased over the Eastern and Southwestern United States; in particular, the return period of 1-month-long dry episodes over the Eastern U.S. is reduced more than twofold from 15 to 6-7 years.

- For the same period, the increase in the frequency of prolonged dry episodes has expanded to neighboring regions of Mexico and Canada

- The changes are a new phenomenon, are observed on the background of the relatively “wet” period, and corroborate the notable change in rainfall rate distribution.
Changes in streamflow (%)

Winter

Annual

Runoff deviations for the 1978-2000 period compared to the long-term mean for ~ previous 55 years.

Georgievsky et al. (2003)
May-July drought index for the major cereal-producing region of western Siberia and northern Kazakhstan

- Updated from Mestcherskaya and Blazhevich (1997)
- Linear trend is 16%/100yrs