Climate Change
Observed and Projected

Jim Zandlo
State Climatology Office - DNR – EcoWaters

MN Forest Resources Council Meeting
March 23, 2011
Observable Climate Changes

Rates of changes in time have generally intensified since about 1980.

- Temperatures warming
- Precipitation increasing
  - Some precipitation conditions returning to conditions of about 100 years ago.
- Other conditions affected by changing climate
  - Lake ice dates and water temperature
  - Streamflow?
  - Other ‘natural resources’?

Caveats

- Over longer time periods not as ‘one-sided’.
- Non-climatic influences in the data
Some observed changes in the climate of Minnesota
Minnesota Average Annual Temperature

1.6°F/century

3.4°F/century
Temperature

• Increasing everywhere
  – more in north (top 1/3 of Minnesota)
  – more rapidly recently (since 1980)
  – more at night (Tminimum)
  – more in winter (Dec-Feb)

• Maps of observed warming of the last decade show warming everywhere. Some hint of extra warming around urbanizing locations.

• Water temperature of Lake Superior warming as well.
‘Non-climatic’ influences

- Local climate change
- Equipment bias
- Site bias
- Measurement contamination
- Observational errors
- Transcription error (data entry)
- Time-of-observation bias
- Global climate change
‘Non-climatic’ influences

• Local climate change
  – Land-use
    • Urbanization
    • Forest regrowth, conversion
    • Agricultural practice
      – No-till
      – Irrigation or not

http://duckwater.bu.edu/urban/sprawl.jpg
‘Non-climatic’ influences

• Site bias change
  – ‘minor’ station moves
  – 100 feet elevation, 5 miles allowed
  – ‘minor’ equipment moves ‘on-site’
• Site exposure
  • Tree growth
  • Buildings, roads, other infrastructure added
‘Non-climatic’ influences

• Site bias change
  – ‘minor’ station moves [H1 SL]
    • 100 feet elevation, 5 miles allowed
  – ‘minor’ equipment moves ‘on-site’
• Site exposure
  • Tree growth
  • Buildings, roads, other infrastructure added
‘Non-climatic’ influences

- Time-of-observation bias
Atmospheric Humidity

- Average dewpoint temperature is up slightly in summer, in winter dropping until about 1980 then recent rapid rise.
- Rising temperatures impacts may be amplified by rising air heat content due to humidity.
- Number of very humid days (Tdew>70) rising rapidly in last few decades but was as high in the 1940s.
- Summer dewpoints dropping off less at night.
Precipitation, Snow, Snow Depth

• Increasing since 1930s ‘dust bowl’ years.
  – ‘below normal’ year unusual since 1990.
• Number of heavy rain events increasing for decades but was as high a century ago.
• Snow fall generally increasing but recently decreasing in south.
Minnesota Annual Precipitation

(w/running 3-yr average)

2.7"/century

Inches

15 17 19 21 23 25 27 29 31 33 35

Lake Ice Out Dates

• Trend toward earlier dates has been increasing
• Pattern of ice out dates across the state is 3-4 days earlier now than it was about 35 years ago.
Lake Superior Buoy 45006 Temperature °F
one-year average departure from long-term average

© State Climatology Office, DNR Eco-Waters, Supt. 2010

9.0°/century
Some existing ‘future climate’ tools
<table>
<thead>
<tr>
<th>AR4 SRES</th>
<th>More economic focus</th>
<th>More environmental focus</th>
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The Modeled Future
some examples of tools and ‘data’

- IPCC reports http://www.ipcc.ch/
- Statistically downscaled monthly GCM *
  - The data http://gdo-dcp.ucrlnl.org/
  - Summary maps; Climate Wizard http://www.climatewizard.org/
- Dynamically downscaled GCM *
  - NARCCAP http://www.narccap.ucar.edu/
- All the GCM output *
  - PCMDI (info) http://www-pcmdi.llnl.gov/ipcc/about_ipcc.php
  - Model host specific websites
- SDSM Statistical DownScaling Model https://co-public.lboro.ac.uk/cocwd/SDSM/
- Panoply netCDF viewer * http://www.giss.nasa.gov/tools/panoply/
- ‘Climate Scenario at a Place’ [in Minnesota]

* All GCM, including downscaled, model time series data is distributed in netCDF format. Windows programs, s.a. Excel, don’t ‘know it’. A viewer or ability to write computer code is required for use. Some ESRI products may have ability to use netCDF. A single netCDF file is typically hundreds of Mb, commonly a Gb or more. There are hundreds of netCDF files available.
Pretty big picture projections …

Projected Change in Precipitation 1950-2000 to 2021-2040
(Percent of 1950–2000)

Average of 19 climate models.

Global Climate Change Impacts in the United States.
www.globalchange.gov/usimpacts
IPCC AR4 A1B projections from 21 models

<table>
<thead>
<tr>
<th>Region</th>
<th>Temperature Response (°C)</th>
<th>Precipitation Response (%)</th>
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<tbody>
<tr>
<td></td>
<td>Season</td>
<td>Min</td>
</tr>
<tr>
<td>CNA</td>
<td>DJF</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td>MAM</td>
<td>1.9</td>
</tr>
<tr>
<td></td>
<td>JJA</td>
<td>2.4</td>
</tr>
<tr>
<td></td>
<td>SON</td>
<td>2.4</td>
</tr>
<tr>
<td></td>
<td>Annual</td>
<td>2.3</td>
</tr>
<tr>
<td>30N,103W to 50N,85W</td>
<td>DJF</td>
<td>-4.0</td>
</tr>
<tr>
<td></td>
<td>MAM</td>
<td>-4.1</td>
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<td>JJA</td>
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<td></td>
<td>SON</td>
<td>-3.8</td>
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<tr>
<td></td>
<td>ANN</td>
<td>-3.2</td>
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‘Projections’ of past conditions
- missed temperature by -4.1 to 3.5
- missed precipitation by -37% to +84%
Regional climate change adaptation strategies for biodiversity conservation in a midcontinental region of North America
2009 Susan Galatowitsch, Lee Frelich, Laura Phillips-Mao
Geographic Analogies:
Places where the current climate resembles the climate projected for the future.

2009 Susan Galatowitsch, Lee Frelich, Laura Phillips-Mao
http://www.climatewizard.org
Climate Data for Climate Change Adaptation Analyses

Jim Zandlo
State Climatology Office – DNR Waters

DNR climate Change Adaptation Scoping Discussion
November 24, 2009
**Climate Impacts Science Primer:** How do scientists project future climates and their impact on resources in Washington State (WA) and the Pacific Northwest (PNW)?

1. Estimate future atmospheric greenhouse gas concentrations and other climate drivers.

   Q1 - What do scientists have to know before they can project future climate?

2. Use global climate models (CMs) to project future climate at a global scale.

3. Downscale CM results to project the future climate of WA and the PNW.

   Q6 - What factors control WA and PNW climate?
   Q7 - How do scientists “downscale” CM results to a region like WA?

4. Use regional hydrology models to project future snowpack, streamflow, and soil moisture.

   Q8 - How do scientists project climate change impacts on the water cycle?

5. Use resource management models or empirical relationships to understand implications for WA and PNW resources.

   Q9 - How do scientists project impacts on natural resources?

Prepared by Jennifer Kay, Joe Casola, Amy Snow, and the Climate Impacts Group (CIG) at the University of Washington for King County’s October 27, 2005 Climate Change Conference. This and other conference materials are available at: http://www.cses.washington.edu/cig/outreach/workshops/kc2005.shtml

Presented by Stickel, Portland 2009
The Modeled Future

• What’s needed for addressing adaptation issues?
  – summary of changes for some specific date or the trend over time relative to a base period.
  – time series used to emulate what’s affected

• General Circulation Models (GCMs)
  – used for *global climate* modeling
  – complicated
  – time series of future climatic conditions
The Modeled Future

• General Circulation Models (GCMs)
  – Time series use
    • ‘raw’
    • Downscaled
      – Statistical
      – Dynamic (regional climate models)
  – Statistics use
    • Trends and differences
    • derived time series
      – Analogy (past observations that look like modeled future)
      – Stochastic (weather generator)
What is needed from the ‘data’ for adaptation studies?

- Summary of changes for some specific date or the trend over time relative to a base period.
  - e.g. 5°F warmer in 2050 than 1970-2000
  - e.g. a graph (time series) of relative changes.

- Time series used to emulate what’s affected
  - annual, monthly, daily, even sub-daily available
  - GCM model ‘data’ generally has biases
  - Use in ‘applied’ model; e.g. fish survival
The Modeled Future

• Many General Circulation Models (GCMs) which are used for *global climate* modeling.
  – Many institutions have their own models
  – Many scenarios of the future conditions that we ‘control’
  – Many starting points (‘initial conditions’) for calculations
### Special Report on Emissions Scenarios (SRES) of Fourth Assessment Report (AR4) vs. projected global average surface warming until 2100

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## Data Availability Summary (as of 27 February 2008)

shaded area indicates that at least some but not necessarily all fields are available for data type indicated

<table>
<thead>
<tr>
<th></th>
<th>time-independent land surface</th>
<th>monthly-mean atmosphere</th>
<th>daily-mean atmosphere</th>
<th>3-hourly atmosphere</th>
<th>time-independent ocean</th>
<th>monthly-mean ocean</th>
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<td>WCRP CMIP3</td>
<td><a href="http://www-pcmdi.llnl.gov/ipcc/about_ipcc.php">http://www-pcmdi.llnl.gov/ipcc/about_ipcc.php</a></td>
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‘World Climate Research Programme – Coupled Model Intercomparison Project’
Chain of Uncertainty

Impact is added in each layer of models and assumptions...
The Modeled Future: Uncertainty

• ‘Que sera, sera’ — things will change, we’re just not sure how

• Model differences: unresolved science

• Intrinsic (initial conditions)

Presented by Ben Santer, Portland 2009
Example of initial condition uncertainty

Simulated and observed regional sea-surface temperatures

courtesy Ben Santer
Computer models can perform the “control experiment” that we can’t do in the real world.

The Modeled Future (past)

• GCMs are judged by how well their calculations of the climate of some recent period (e.g. 1970-2000) compare to what was measured.
  – Trends: match well
  – Absolute values and (?) statistical distribution: ‘not so much’
Typical biases of precipitation

PowerPointPDF - A method of correction of regional climate model data for hydrological modelling, Juris Sennikovs, Uldis Bathers
What is Downscaling?

Something you do to a 20\textsuperscript{th}-Century climate model simulation to reproduce the observed climate.

Will also give the projected regional climate change when applied to a future climate model simulation.

From Salathe, Portland 2009
An Example: hydrology models

Need runoff (RO)

- Daily or even sub-daily required
  - Highly non-linear response
    - RO zero or very small unless a precip threshold is reached
    - Heavy RO only occurs for largest precip events

- GCM models
  - Precip is average over a large area. But, averages over large areas, of course, are always no bigger and generally much smaller than amounts that fell at any given point within the area.
  - Readily available ‘downscaled’ GCM data currently only on a monthly time scale (same sort of problem as with areal averages; i.e. what happened over a smaller slice of time such as a day?).

That is, the GCM estimates of future conditions cannot be used ‘as is’ by someone using long-standing existing hydrologic modeling techniques.
In a 1°x2° GCM grid cell (thousands of square miles) a single value for precipitation is calculated.
Rainfall Totals for Southeastern Minnesota
August 18-20, 2007

In a 1°x2° GCM grid cell (thousands of square miles) a single value for precipitation is calculated.

An intense storm can have precipitation changes of as much as one inch per mile.
In a 1° x 2° GCM grid cell (thousands of square miles) a single value for precipitation is calculated.

An intense storm can have precipitation changes of as much as one inch per mile.

6 inches of rain is readily handled by a ‘100 year design’ culvert but 16 inches will wash it away.
Hokah ann max daily PRCP vs. RP

precipitation, inches

return period (years)

GEV(3): Generalized Extreme Value distribution parameters: 2.15849 0.92974 0.08075
Hokah ann max daily PRCP vs. RP

August 18-19, 2007 15.10 inches ➔

GEV(3): Generalized Extreme Value distribution parameters: 2.05556, 0.86992, -0.32709
‘1000-yr (approx) events’ in Southern Minnesota in the last decade
Changes in areas of Heavy Precipitation in Minnesota

- areas of heavy (multi-inch) rains per year are rising

- counts of heavy rains as a fraction of all rains are rising
  (but also note high count early in last century)
What is Downscaling?

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From Salathe, Portland 2009
Challenge: Climate Model Forecast Use

1) Climate Model Scale - Biased

bias-correcting...

then downscaling...

CRB domain, June precip

2) Climate Model Scale - Unbiased

Experimental seasonal hydrologic forecasting for the Western U.S., Lettenmaier, 2004

3) Hydrology Model Scale - Unbiased
BCSD Method – “BC”

- At each grid cell for “training” period, develop monthly CDFs of P, T for
  - GCM
  - Observations (aggregated to GCM scale)
  - *Obs are from Maurer et al. [2002]*

- Use quantile mapping to ensure monthly statistics (at GCM scale) match

- Apply same quantile mapping to “projected” period

As presented by Maurer (Santa Clara U), Portland 2009
Constructed Analogues

Library of previously observed anomaly patterns:

Given daily GCM anomaly

Coarse resolution analogue:

Analogue is linear combination of best 30 observed

Apply analogue to fine-resolution climatology
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See Climate Impacts Science Questions for answers to Q1-Q9

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http://climate.umn.edu/doc/CC1103.ppt
Glossary - acronyms

- **BC** Bias Correction
- **CA** Constructed Analogues
- **CDF** Cumulative Distribution Function
- **CF** Climate and Forecast (metadata conventions)
- **CMIP** Coupled Model Intercomparison Project
- **ESG** Earth System Grid
- **GCM** General Circulation Model, global climate model
- **IPCC** Intergovernmental Panel on Climate Change
- **NARCCAP** North America Regional Climate Change Assessment Project
- **NCAR** National Center for Atmospheric Research
- **NCDC** National Climatic Data Center
- **netCDF** network Common Data Form (ALL GCM data in this format)
- **PCDMI** Program for Climate Model Diagnosis and Intercomparison
- **SD/SDS** Statistical Downscaling
- **SRES** Special Report on Emissions Scenarios (IPCC)
  » A/B: ‘business-as usual’ (growth)/’green’, 1/2: ‘one world’/’to each his own’
- **WCRP** World Climate Research Program
Glossary

**ensemble** for a given scenario, a collection of the output from more than one model or set of initial conditions

**forcing** representation of physical environment of the system to be calculated; e.g. CO2 changes through time

**scenario** a set of prescribed ‘forcings’ that will be used when calculating the climate; e.g. CO2 rising through time to double
## GCM acronyms

- **BCC** Beijing Climate Center, China
- **BCCR** Bjerknes Centre for Climate Research, Norway
- **CCSM3** Community Climate System Model, NCAR, USA
- **CGCM** Coupled General Circulation Model, Canada
- **CNRM** Centre National de Recherches Météorologiques, France
- **CSIRO** Commonwealth Sci. & Industrial Research Org., Australia
- **ECHAM** European Center (Forcasts) - Hamburg, Germany
- **ECHO-G** ECHAM+HOPE-G (Hamburg Ocean Primitive Equation), Germany / Korea
- **FGOALS** ???, China
- **GFDL** Geophysical Fluid Dynamics Laboratory, USA
- **GISS** Goddard Institute for Space Studies, USA
- **INGV** Instituto Nazionale di Geofisica e Vulcanologia, Italy
- **INM** Institute for Numerical Mathematics, Russia
- **IPSL** Institut Pierre Simon Laplace, France
- **MIROC** Model for Interdisciplinary Research on Climate, Japan
- **MRI** Meteorological Research Institute, Japan
- **PCM** Parallel Climate Model (NCAR), USA
- **UKMO** UK Meteorological Office (Hadley Center), UK

GCM run scenarios

- Picntrl: pre-industrial control
- PDcntrl: present-day control
- 20C3M: climate of the 20th century
- Commit: committed climate change
- SRESA2: IPCC SRES A2
- SRESA1B: IPCC SRES A1B
- SRESB1: IPCC SRES B1
- 1%to2x: 1%/year until CO2 doubled
- 1%to4x: 1%/year until CO2 quadrupled
- Slab cntl: slab ocean control
- 2xCO2: 2xCO2 equilibrium
- AMIP: Atmospheric Model Intercomparison Project

http://www-pcmdi.llnl.gov/ipcc/standard_output.html#Experiments
Bias Correction (BC)

Varying degree of bias geographically, between models, between scenarios, etc.

Figures by Andy Wood, U Wash.
The Modeled Future

• Analogy
  – Constructed Analogues
    • Past geographical patterns used to ‘recognize’ GMC generated patterns
  – Local
    • e.g. ‘Climate Scenario at a Place’ [for Minnesota]

• Stochastic
  – Use ‘weather generator’ with observed distribution functions changed by the amount of change predicted by GCMs