Insights from paleoclimate studies

- Is 20th century unprecedented in terms of recent global warming?
  - For past millennium, yes
- What is the natural behavior of the climate system?
  - Nonlinear! Abrupt transitions frequent
  - Mechanisms can be apparent, or not.
- Is 20th century representative of recent hydrologic (drought) variability?
  - No - natural variability is large!
- El Niño
  - Modern system summary
  - Is it changing? Will it? (big uncertainty)

"Multiproxy" temperature reconstructions

- Use annual (or nearly annual) resolution data
  - More and more efforts are including lower-resolution data to get back further in time, cover regions w/o annual data
- Combine them using a clever statistical method
- Calibrate to modern temperature
- Result is yearly history of temperature change
- Many authors have done this...

Global warming: natural cycle or unusual trend?

Global network of data

NH focus → NH reconstructions

Mann et al. 2008

Color = start date (year AD)
Was there a “Medieval warm period”?  
- Define - a period of global warmth in the Medieval interval (~800-1400 AD)  
- Often pops up in skeptic’s arguments against anthropogenic global warming (red herring)  
- Issues:  
  - Was it global?  
  - Was it warm relative to 20th century?  
- Answers - so far...  
  - Many records show warmth somewhere in this interval (800-1400)  
  - No century stands out as warm in most; it was not spatially coherent  
  - Definitely a period when more drought seen in SW  
  - Speculation that ocean temperatures involved (La Niña? Atlantic?)

How do past and future compare?  
- Use model driven by natural-only and natural + anthropogenic forcings  
- Natural+anthropogenic forcings match observed record best  
- Mismatch with only natural forcings

Causes of 20th century climate change
Take-away messages
• 20th century is warmer than any time in the past millennium.
• Strength of past century-scale variability is still debated, but 20th-century warmth is not.
• Anthropogenic forcings are required to explain recent temperature changes; they are not natural.

Another lesson from the paleo record:
Climate change can happen suddenly
• What is abrupt change? Why care?
• The ocean thermohaline example:
  – Processes
  – Records
  – Predictions
• Other kinds of abrupt change
  – Drought
  – Ecosystem

Nonlinear and threshold responses
• Contrast linear and nonlinear responses to forcing:
  - Forcing
    - Response
    - Forcing
    - Response
    - Forcing
  - One type of nonlinear response is a threshold response

The climate system shows all of these behaviors in various ways!

Characteristics of abrupt change
• Transition between states
• "Tipping points", thresholds
• More rapid than cause
  – (although cause often not fully known)
• Most critical: changes that are
  – Persistent
  – At least subcontinental in scale
  – Unexpected and/or for which adaptation (ecologic, economic...) is difficult

Nature, Sept. 4, 2009
Why be concerned?

• Abrupt changes are unpredictable, may be unprecedented
• Capacity to adapt will be key:
  – Economic resources
  – Ecological resilience
• Most economic studies of climate change focus on responding to gradual changes

Paleo evidence for abrupt change

• 11-13,000 yrs ago: Younger Dryas cooling
• Transitions in and out are fast! (Decadal or less)
• Such changes can be nearly global in scope
  – Tropical imprints here in trade wind strength, methane production
• Most likely mechanism is ocean circulation change

Meridional overturning circulation (MOC)

• Warm salty water from Gulf Stream moves north and cools
• Cold salty water is denser than surroundings and sinks
• Drives global pattern of 3-D ocean circulation
• North Atlantic salinity is the most important control on this overturning circulation

Meridional overturning circulation (MOC)

• This is a bit simplified, but gives a general picture...

http://www.whoi.edu/cms/images/oceanus/Thermohaline_S50_47168.jpg
Climate response to OC weakening

(Legrande et al. PNAS 2006)

- Climate model study of circulation shutdown
- Temperature
  - cooling in NH, especially N Atl
  - Warming in SH as northward heat transport weakened in NH
- Precipitation
  - Regionalized, zonal
  - Reduced over cold water
  - ITCZ weakened, move southward

Modern N. Atlantic:
- Salinity measured from many places (Dickson et al. 2002)
- Data in plot extend from 1965-2000
- North Atlantic is getting less salty
- Predicted to continue: increased precip and melting ice
- Warming will also help stabilize water column

Is MOC slowing?

- Measurements are ongoing (red lines are moorings)

Is the overturning circulation slowing?

Circulation measured in Sverdrups (Sv) - 10^6 cubic m/sec
Red line is strength of overturning circulation, calculated as sum of relevant transports - see papers for details if you want more

- 2005 studies found significant slowing since 1950 (Bryden et al., Nature) - by 30%
- New data show large intra-annual variations - 30% change is not significant (Cunningham et al. 2007 Nature)
- Red curve is strength of overturning circulation (April 2004-March 2005): 18.7 ± 5.6 Sv, with range of 4-35 Sv
20th-century abrupt change - rainfall

- Dark red = more abrupt during 20th century
- Semiarid regions most susceptible to abrupt changes in precip.

Abrupt veg change, New Mexico 2002-2004

Drought: 20th century in context (western US)

Does the 20th century represent typical drought variability? (length, frequency, intensity)

- 20th century: 2 major decade-scale droughts, 1930s and 1950s
- Previous 400 yrs: about 2 decade-scale droughts per century
- Previous millennium: several multi-decadal droughts (e.g. 1550-1600; 1300’s; 1100’s)
- Before 1000 yrs BP - major shift to very dry conditions
- How does the current drought stack up?

Drought from tree-ring reconstructions

- Episodically dry in “medieval” epoch (here 900-1300 AD)
- Early 20th century wet

Cook et al. 2004, Science
Medieval drought

- Drought increased throughout western US
- “Medieval dry period”?
- Mechanism: some have argued for La Niña; others say not so simple...

What causes drought?

- SST patterns, which steer air masses to different places (initiate) – e.g. La Niña
- Land surface and vegetation interactions, which help determine moisture availability and create positive feedbacks (amplify/persist)

SST and precip correlations (McCabe et al. 2004, PNAS)

- Warm north and tropical Pacific: wet southwest (El Niño)
- Warm north Atlantic: dry southwest

Other “megadroughts”

- Lots of variability but patterns regional
- Natural variations dwarf what we have seen in 20th century
- Causes??

Overpeck, Cole and Bartlein, 2004
El Niño, La Niña, and the Southern Oscillation

**ENSO** = El Niño/Southern Oscillation system

El Niño is the interannual warming of the eastern and central Pacific

La Niña indicates cooling in the same area.

Southern Oscillation is the inverse relationship between atmospheric pressure in the E and W tropical Pacific


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**Walker circulation**

- east-west atmospheric circulation over the Pacific
- (easterly trade winds, rising in W, sinking in E, westerly up high)
- Note thermocline position: shallow in E, deep in W

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**La Niña Conditions**

- Convective Loop
- Thermocline:
  - Shallow in E, deep in W

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**El Niño Conditions**

- Increased Convection
- Thermocline:
  - Shallow in E, rises in W

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**El Niño:**

- Walker circulation breaks down; SST gradient relaxes as east warms
- Thermocline drops in E, rises in W

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[http://www.rebertus.com/AZFlow.htm](http://www.rebertus.com/AZFlow.htm)

[http://www.na8on.co.ke/](http://www.na8on.co.ke/)
Index of ENSO 1950-present

- Interannual variations
- Shift in 1976 to warmer state
  - fewer/weaker La Niñas
  - more/stronger El Niños

http://www.cdc.noaa.gov/ENSO/enso.mei_index.html

Local rainfall anomalies

- Tucson’s winter rain often originates in the tropical Pacific
- Storms develop over warm Pacific waters and move large amounts of moisture and energy into the southwest US and northern Mexico.
- This satellite image shows an example of a storm moving from the tropical Pacific into southern Arizona.

What about La Niña...?

- La Niña events may be worse for the US than El Niño’s...
  - Drought
  - Fire
  - Atlantic hurricanes
  - Locally (Tucson): dry winters
Tropical forests and El Niño

• During El Niño years, more tropical fires
  - Amazon, Indonesia are drier
• Usually manmade fires that get out of control more easily
• A major source of CO₂ to atmosphere!
• Health effects
  - Particulates, ash
  - CO₂ from forest fires in 1997-8 was 30% higher than from vehicles and ff burning!

Is El Niño changing?

• 20th century: trends not obvious?
• LOTS of internal variability

What are some key lessons from paleo records?

1. Greenhouse gases are higher than they have been in 800,000 or more years, and the rates of change are faster than in the past (see last weeks lecture).
2. Temperatures are warmer now than they have been in the past 1000+ years
3. Past changes have happened fast, indicating that climate change has nonlinear aspects
4. Natural variability in key parts of the climate system (e.g. El Niño, regional droughts) is large and we do not fully understand it.