Regional Impacts of Climate Change

Antonio J Busalacchi
Outline

• Weather Extremes the New Normal
• Observed Changes in the Climate System
• Projections of Future Climate Change
• Grand Challenges for Climate Research on Regional Scales
  – Sea Level
  – Cryosphere
  – Hydrology
  – Extremes
Weather Extremes are the New Normal
Interruptions to Electric Grid Increasing
Loss events worldwide 2014
Geographical overview

Winter damage
USA, Canada, 5–8 Jan

Flash floods
USA, 11–13 Aug

Floods
United Kingdom, Dec 2013–Feb 2014

Floods
Bosnia and Herzegovina, Serbia, Croatia, Romania, 13–30 May

Typhoon Rammasun
China, Philippines, Vietnam, 11–22 Jul

Winter damage
Japan, 7–16 Feb

Typhoon Kalmaegi
China, Philippines, Vietnam, 12–20 Sep

Drought
USA, 2014

Severe storms
USA, 18–23 May

Severe storms
USA, 2–4 Apr

Severe storms
USA, 3–5 Jun

Drought
France, Belgium, Germany, 7–10 Jun

Severe storms
USA, 27 Apr–1 May

Hurricane Odile
Mexico, 11–17 Sep

Severe storms
India, Pakistan, 3–15 Sep

Cyclone Hudhud
India, 11–13 Oct

Floods
India, Pakistan, 3–15 Sep

Earthquake
China, 3 Aug

Severe storms
USA, 18–23 May

Geophysical events
(Earthquake, tsunami, volcanic eruption)

Meteorological events
(Tropical storm, extratropical storm, convective storm, local storm)

Hydrological events
(Flood, mass movement)

Climatological events
(Extreme temperature, drought, wildfire)

Loss events

Selection of Catastrophes
Overall losses ≥ US$ 1,500m

Source: Munich Re, NatCatSERVICE, 2015
Loss events in the US 1980 – 2014

Number of events

2014 Total: 119 Events

Source: Geo Risks Research, NatCatSERVICE
US Natural Catastrophe Update

Convective loss events in the US
Overall and insured losses 1980 – 2014

Analysis contains:
severe storm, tornado,
hail, flash flood and
lightning

Overall losses
(in 2014 values)*

Insured losses
(in 2014 values)*

*Losses adjusted
to inflation based
on country CPI

Source: Geo Risks Research, NatCatSERVICE

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NatCatSERVICE

Loss events worldwide 1980 – 2014
Number of events

Source: Munich Re, NatCatSERVICE

- Geophysical events (Earthquake, tsunami, volcanic activity)
- Meteorological events (Tropical storm, extratropical storm, convective storm, local storm)
- Hydrological events (Flood, mass movement)
- Climatological events (Extreme temperature, drought, forest fire)

Source: Geo Risks Research, NatCatSERVICE – As at January 2015

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The Physical Climate System
Climate change research has been around over 100 years.

- S Arrhenius 1859-1927
Projections of climate change

Svante Arrhenius, “Verldamas Utveckling”, 1906

... any doubling of the percentage of carbon dioxide in the air would raise the temperature of the Earth’s surface by 4°C.

... the percentage of carbonic acid in the atmosphere may, by the advances of industry, be changed to a noticeable degree in the course of centuries.

Intergovernmental Panel on Climate Change 2007

... the best estimate of climate sensitivity to a CO₂ doubling is a warming of 3°C, with a likely range of 2 to 4.5°C.

... “business as usual” scenarios lead to CO₂ doubling over pre-industrial levels between 2050 and 2100.
The IPCC WG1 Sequence……

IPCC (1990)  Broad overview of climate change science, discussion of uncertainties and evidence for warming.


IPCC (2001) “Most of the warming of the past 50 years is likely (>66%) to be attributable to human activities.”

IPCC (2007) “Warming is unequivocal, and most of the warming of the past 50 years is very likely (90%) due to increases in greenhouse gases.”

IPCC (2013) “Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased.”
Observed Changes in the Climate System

Atmosphere

Each of the last three decades has been successively warmer at the Earth’s surface than any preceding decade since 1850. In the Northern Hemisphere, 1983–2012 was likely the warmest 30-year period of the last 1400 years (medium confidence).

In this Summary for Policymakers, the following terms have been used to indicate the assessed likelihood of an outcome or a result: virtually certain 99–100% probability, very likely 90–100%, likely 66–100%, about as likely as not 33–66%, unlikely 0–33%, very unlikely 0–10%, exceptionally unlikely 0–1%. Additional terms (extremely likely: 95–100%, more likely than not >50–100%, and extremely unlikely 0–5%) may also be used when appropriate.
Observed globally averaged combined land and ocean surface temperature anomaly 1850-2012
Map of the observed surface temperature change from 1901 to 2012 derived from temperature trends determined by linear regression. Trends have been calculated where data availability permits a robust estimate (i.e., only for grid boxes with greater than 70% complete records and more than 20% data availability in the first and last 10% of the time period). Other areas are white. Grid boxes where the trend is significant at the 10% level are indicated by a + sign.
The World in Global Climate Models

- **Mid-1970s**: Carbon dioxide ($CO_2$) emissions, rain, and land surface.
- **Mid-1980s**: Clouds, volcanic activity, sulphates, and prescribed ice.
- **FAR**: Swamp ocean, carbon cycle, aerosols, and rivers.
- **SAR**: Ocean, interactive vegetation, atmospheric chemistry, and oceans.
- **TAR**: Overturning circulation.
Geographic resolution characteristic of the generations of global climate models used in the IPCC Assessment Reports:

- FAR (1990): ~500 km (T21)
- SAR (1996): ~250 km (T42)
- TAR (2001): ~180 km (T63)
- AR4 (2007): ~110 km (T106)
Comparison of observed and simulated climate change based on three large-scale indicators in the atmosphere, the cryosphere and the ocean: change in continental land surface air temperatures (yellow panels), Arctic and Antarctic September sea ice extent (white panels), and upper ocean heat content in the major ocean basins (blue panels). All time-series are decadal averages, plotted at the centre of the decade. For temperature panels, observations are dashed lines if the spatial coverage of areas being examined is below 50%. For ocean heat content and sea ice panels the solid line is where the coverage of data is good and higher in quality, and the dashed line is where the data coverage is only adequate, and thus, uncertainty is larger. Model results shown are Coupled Model Intercomparison Project Phase 5 (CMIP5) multi-model ensemble ranges, with shaded bands indicating the 5 to 95% confidence intervals.
CMIP5 multi-model simulated time series from 1950 to 2100 for change in global annual mean surface temperature relative to 1986–2005,
Maps of CMIP5 multi-model mean results for the scenarios RCP2.6 and RCP8.5 in 2081–2100 of (a) annual mean surface temperature change, (b) average percent change in annual mean precipitation. The number of CMIP5 models used to calculate the multi-model mean is indicated in the upper right corner of each panel. Hatching indicates regions where the multi-model mean is small compared to natural internal variability (i.e., less than one standard deviation of natural internal variability in 20-year means). Stippling indicates regions where the multi-model mean is large compared to natural internal variability (i.e., greater than two standard deviations of natural internal variability in 20-year means) and where at least 90% of models agree on the sign of change.
WCRP Future Directions: Actionable Science

Defined as: data, analysis, and forecasts that are sufficiently predictive, accepted and understandable to support decision-making, including capital investment decision-making.

World Climate Conference-3, OceanObs ‘09, ICSU Review and Visioning, acknowledge WCRP past contributions and identify future challenges and opportunities.

Need for more flexibility/agility to respond to expanding users needs, that includes information:

- At regional scale
- For key sectors of global economy
- For adaptation, mitigation and risk management
WCRP Grand Challenges

• Regional Climate Information

• Regional Sea-Level Rise

• Cryosphere in a Changing Climate

• Clouds, Circulation, and Climate Sensitivity

• Changes in Water Availability

• Science Underpinning the Prediction and Attribution of Extreme Events
Grand Challenge on Regional Climate Information

Question:
Can we provide skillful, regional climate information at seasonal to decadal time scales plus credible and useful long-term regional climate change projections?

Science Topics
• Intraseasonal to interannual variability & predictability
• Monsoon systems
• Decadal variability & predictability
Natural factors that affect climate/water extremes

- Risk of an extremely heavy precipitation event in North America is influenced by El Nino and La Nina

Estimated risk of occurrence of a 20-year event

- **increased**
- **reduced**

during an El Nino event.

Effect of La Nina roughly opposite

*Zhang, et al 2005*
Role of the ocean: long-term drought

US Dustbowl Era 1930's

Very dry

Warm SST

Cold SST

Ocean temperatures conditioning the atmosphere

1998-2002 SST Anomaly

Model precipitation anomaly 1998-2002

Dry

Observed precipitation anomaly 1998-2002

Dry

Wet

Downscaling for Philippines Reservoir Inflow

Sea Surface Temperatures

Historical Angat Inflow Observations

Global Climate Model

Statistical Model

B. Lyon (IRI)
A. Lucero (PAGASA)
Soil moisture in southern Africa in mid-April 2014. The image on the left is based on rain gauge data only. It shows that data gaps and lack of spatial variability limit the information that can be provided in large areas of Africa to monitor plant health. The more detailed image on the right includes soil moisture data from ESA’s SMOS mission, which are assimilated into the United States Department of Agriculture’s Foreign Agricultural Service forecasting system. This adds significant information in large areas of southern Africa.
Grand Challenge on Sea Level Rise

Challenges:
• Scenario uncertainty/global mean sea level
• Inter-model spread
• Strong internal variability

Research Activities
• Past changes in regional sea level
• Present sea level changes and processes
• Future projections
• Ocean-Coastal and Human Interaction
Observed indicators of a changing global climate

Global mean sea level relative to the 1900–1905 mean of the longest running dataset, and with all datasets aligned to have the same value in 1993, the first year of satellite altimetry data. All time-series (coloured lines indicating different data sets) show annual values, and where assessed, uncertainties are indicated by coloured shading.
Projections of global mean sea level rise over the 21st century relative to 1986–2005 from the combination of the CMIP5 ensemble with process-based models, for RCP2.6 and RCP8.5. The assessed likely range is shown as a shaded band. The assessed likely ranges for the mean over the period 2081–2100 for all RCP scenarios are given as coloured vertical bars, with the corresponding median value given as a horizontal line.
World Cities Exceeding 5 Million Residents

Source: U.N. Population Division
Sea level fall along the U.S. west coast and rise in the western tropical Pacific Ocean since early 1990s appears to result from the phase change of the Inter-basin Pacific Decadal & multi-decadal Variability (Weiqing Han et al., University Colorado, 2011)
The light blue area depicts today’s FEMA 100-year flood zone for the city (the area of the city that is expected to be flooded once every 100 years).

With rising sea levels, a 100-year flood at the end of this century (not mapped here) is projected to inundate a far larger area of New York City. (NCA, 2009)
Grand Challenge on Cryospheric Changes

Science Topics

• A coordinated focus on seasonal, interannual and longer-term predictions and projections of polar climate and the role of cryosphere in climate predictability

• A focused effort on improving the representation of permafrost and high-latitude land surface, including wetlands, in climate models, with specific emphasis on their role in the global carbon cycle

• A focused effort on developing ice sheet models, with specific emphasis on the role of ice sheet dynamics on the rate of the SLR
Total Greenland ice sheet melt area increased 65% since 1979 over the 30 year record; on average 2%/year.

The increasing trend in the total area of melting bare ice is at 13% per year.

Courtesy of K. Steffen

Model projections of sea ice thickness when the Arctic is nearly ice free in September, within 30 years. Units for sea ice thickness are meters. Figure from Wang and Overland.
Grand Challenge on Water Availability

Science Questions:

• How can we better understand and predict variations and changes in precipitation?
• How do changes in the land surface and hydrology influence past and future changes in water availability and security?
• How can we use the current “water” observations and products in assessing climate change?
• How can better models lead to improvements in water management?
Water and Population

Water is not everywhere!

Approximate percentage of global water supply

Approximate percentage of global population

15% 8%
26% 6%
36% 60%
11% 13%
8% 13%
5% 1%
Water Availability

Territory size shows the proportion of all worldwide freshwater resources found there
The water cycle describes the continuous movement of water through the climate system in its liquid, solid and vapor forms, and storage in the reservoirs of ocean, cryosphere, land surface and atmosphere.
Climate Change is Water Change

Spruce Beetle Kill, San Juan Mountains, 2012

* Heat Drives the Water Cycle - 1000 km³ evaporates daily from the oceans
* The Water Cycle mixes heat from areas of too much to too little
* As the Atmosphere Warms it Holds More Moisture: ~5°F warming is 20% increase
* Heating Up the Earth (and uneven heating) results in Water Cycle changes
  * More Evaporation, More Precipitation, More Moisture
  * Changes in weather patterns
  * Wet Wetter, Dry Drier Standard Rule
  * More Intense Floods and Droughts
* All Kinds of Water Changes Already Noted
  * More rain/less snow, Earlier Runoff, Higher Water Temps, More Intense Rain
* Many of the most critical impacts of climate change will arise through water cycle changes driven by higher temps, not simply rising temperatures
April 2013 “showers” in Argentina

1 April 2013: Torrential rain Buenos Aires. Over night, rainfall records broken, >6 inches in less than two hours; flooding, killing eight people and leaving hundreds displaced. Buenos Aires Central Observatory

3 April 2013: Next storm 11 to 16 inches in some spots in La Plata Basin. Damage: >$500Million

“Since the early ‘80s, the frequency of extreme weather events dumping over 100 millimeters of water has tripled,” Canziani
The record is especially noteworthy since before Sept. 9, Boulder, along with much of eastern Colorado, was still mired in long-term drought conditions. As of Sept. 17, Boulder’s monthly rainfall during September stood at 17.18 inches, all but 0.02 inches of which fell during the preceding week. The previous all-time monthly record was 9.59 inches in May of 1995.
The Palmer Drought Severity Index (PDSI) uses readily available temperature and precipitation data to estimate relative dryness. The PDSI is a standardized measure, ranging from about -10 (dry) to +10 (wet) with values below -3 representing severe to extreme drought. Dai, Aiguo & National Center for Atmospheric Research Staff (Eds)
Many dry areas are getting drier.

Observed sea surface temperature (SST) and links to the pattern of rain in Africa SSTs and Sahelian rainfall have varied in the past.

Some studies suggest links to widespread ocean SST trends and global warming. *Physical understanding of regional changes worldwide (snowpack? evaporation?) is needed for projections/attribution…..*
Drought: Tools and Resources

U.S. Drought Monitor

April 14, 2015
(Released Thursday, Apr. 16, 2015)
Valid 7 a.m. EST

Drought Impact Types:
- ~ Delineates dominant impacts
- S = Short-Term, typically less than 6 months (e.g. agriculture, grasslands)
- L = Long-Term, typically greater than 6 months (e.g. hydrology, ecology)

Intensity:
- D0 Abnormally Dry
- D1 Moderate Drought
- D2 Severe Drought
- D3 Extreme Drought
- D4 Exceptional Drought

The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. See accompanying text summary for forecast statements.

Author:
Michael Brewer
NCEI/NOAA

http://droughtmonitor.unl.edu/
Grand Challenge on Climate Extremes

• There is a general consensus emerging from climate research that any change in the mean climate is likely to feature even larger changes in the frequency and severity of extreme climate events.

• Research foci for the WCRP include:
  – Detecting significant trends, changes in extreme events and abrupt changes in global and regional climate.
  – Improvement in climate change projections not just for the mean climate, but for changes in extreme events.
Extreme Events over the Past Decade

- Heat waves / Extreme high temperatures
- Severe or prolonged droughts
- Cold waves / Extreme low temperatures / Snow storms
- Tropical cyclones, hurricanes and typhoons
- Intense storms / Flooding / Heavy rainfall
Changes in temperature extremes, 1951-2003

• Over 70% of land area sampled shows significant change in minimum temperature extremes (days/decade)

• Warm nights (cold nights) have increased (decreased) by about 25 days since 1951

• Warm days (cold days) have increased (decreased) by about 15 days

Alexander et al. 2006
Indices of precipitation “extremes”

- Tendency is consistent with model results and physical understanding

Groisman, et al 2005
Soil moisture variability found to be a main driver for projected changes in temperature variability in Europe

Standard deviation of summer temperature, CHRM model


SCEN (2080-2099)

CTL$_{UNCOUPLLED}$

SCEN$_{UNCOUPLLED}$

Simulations with soil moisture set to climatology ("uncoupled")

(Schär et al. 2004, Nature)

(Seneviratne et al. 2006, Nature)
Late 21st Century Climate Warming Projection-- Average of 18 CMIP3 Models

Modeled Category 4 & 5 Hurricane Tracks

Present Climate

The Cat 4-5 increase is not projected for all of the 18 individual models:

Warmed Climate

(27 Simulated Hurricane Seasons)  Source: Bender et al., Science, 2010
Summary

• “Whacky” weather is here to stay
• More extreme events; i.e., more intense storms and more widespread drought
• Wetter regions getting wetter, drier getting drier
• Sea level will inexorably continue to rise, but regional impacts (from storm surge, changes in ocean circulation, wind set up, tidal amplitudes, subsidence) may be order 10 times global mean