Climate Science

“Finding message in the noise”

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There is a lot of noise...

Nothing is changing

Dishonest Science

IPCC Reports

Global Warming

Droughts

Climate Gate

Floods

Natural Disasters

Ice Ages

Conspiracy

Hockey Sticks

We're all going to die!

Lies

Himalayan Glaciers
Weather and climate are important

• Humanity has been intimately tied to weather right from the start... whenever that was

• In cities we are now often relatively detached from the weather

• We know rural communities and economies are tied to the weather

• But so is everyone, cities are just more buffered. In some ways cities are more vulnerable?
A philosophical side step

• Humanity is tied to the physical environment (weather, climate, earthquakes etc..)

• Human belief systems and faith systems are interwoven with the physical environment

• Science is supposedly detached from such “hinderences”.... though can it be?

• Faith and belief plays a large role in peoples actions and reactions:
  • In poorer communities and countries
    AND
  • In wealthy communities and countries
The earth is heated by the sun

• The climate is largely driven by radiation from the sun
• Different gases and particles reflect and absorb preferentially at different wavelengths
• High clouds and aerosols reflect shortwave radiation back to space
• So called “green house gases” (GHG) absorb outgoing long wave radiation and re-radiate it out to space and back to the earth's surface.
The earth is heated by the sun
The earth is heated by the sun

• Because of the spherical nature of the earth, strongest solar heating occurs at the equator and tropics.

• The poles receive very little heating, especially during winter months.

• Heating near the equator causes air to rise and cooler air to be drawn in from higher latitudes.

• Rising air spreads to higher latitudes at high altitudes, losing heat and eventually sinking around 20°-30° latitude to form the global high pressure systems and the Hadley circulation.

• Air at the surface moves away from these high pressure systems to even higher latitudes and interacts with cold air near the poles to form the polar front.
The earth is heated by the sun

• The continents interrupt the belts of high and low pressure and cause complex disturbances

• The mid-latitudes form a high energy zone where energy and heat is transferred through frontal systems that produce rainfall

• The tropics are areas of high rainfall due to strong heating and availability of moisture from ocean evaporation

• The sub-tropics are wet in summer and drier in winter as the tilt of the earth shifts the latitude of strongest heating

• The mid-latitudes also shift north and south during the seasons producing winter and summer conditions
The earth is heated by the sun

Various **orbital variations** produce long term variations in the amount of sunlight reaching the earth.

*Milankovitch* cycles described the variation in the orbit of the earth around the sun:

- **Eccentricity** describes changes in the shape of the earth's orbit around the sun from more circular to more elliptical.

- **Obliquity** describes the change in the tilt of the earth relative to the solar plane which impacts the magnitude of seasonal variations.

- **Axial precession** describes the change in tilt of the axis relative to the apex of the orbit which causes one hemisphere to have milder seasons than the other.
The climate has “Natural” variability

Various internal sources of variability have been identified that cause large scale variations in global and regional climate systems:

• El-Nino Southern Oscillation (ENSO)
• North Atlantic Oscillation (NAO)
• Southern Annular Mode (SAM)
• Quasi Bi-Annual Oscillation (QBO)
• And others...
So what about global warming?

• Water vapor is responsible for the greatest absorption followed by CO2 (carbon di-oxide) and CH4 (methane).

• Green house gases have different absorption properties, different concentrations and different timespans.

• CH4 is a more effective GHG than CO2 but it exists in smaller concentrations and is removed from the atmosphere faster.

• Gases are rated according to their “radiative forcing” which describes the equivalent increase in incoming solar radiation that would be required to produce the same warming.

• Complexities are added by the vertical and horizontal distribution of the gases and other interactions.

• The total estimated man induced radiation forcing is estimate (IPCC FAR) to be 0.6 – 2.4 W/m2 with a median estimate of 1.6 W/m2.
So what about global warming?
Is the planet warming?

- Observed records are very hard to work with...
Is the planet warming?

- Historical records of atmospheric CO2 concentrations show a very steady increase during the observed record.
- Isotope analysis allows separation of fossil fuel derived CO2 versus other sources.
Is the planet warming?

- Historical records of surface temperatures show generally increasing temperatures throughout the last half of the 20th Century with more rapid increases in the last 20 years.

- Observations of stratospheric temperature show decreases which concurs with an increase in GHGs in the troposphere.

- The occurrence of volcanic eruptions (Pinatuba and El Chichon) can be seen in the stratospheric temperature records due to increases in particles which absorb sunlight.

- Observed surface temperature increases show nearly double the rate of increase in high latitudes compared to the tropics.

NOTE: The need for ongoing, accurate historical records is of great importance!
Is the planet warming?

• Climate Projections are very difficult to validate because we can't wait that long!
• BUT... The first projections were started between 15 and 20 years ago
• Those projections were considered alarmist
• Those early projections (in the IPCC TAR) have been shown to underestimate recent warming
Historical records [ precipitation ]

• Historical records of precipitation are more complex with large regional differences.

• Generally, increased temperatures result in increased atmospheric moisture content which, given suitable synoptic drivers can result in increased precipitation.

• However complex circulation changes and spatial shifts can produce different results in different areas as well as different seasons.
What South Africa?

• The local picture is never that “simple”

• Different months show different trends → Seasonal shifts

• Lack of observations and different observation periods causes major problems
0021778_W: Climatology of median total precipitation (1961-2000)
What about sea level rise?

• Global mean sea level driven by 2 processes
  • Thermal expansion
  • Melting of glacial ice

• Regional sea levels driven by global sea levels as well as:
  • Land masses rising or falling (glacial isostatic adjustment)
  • Ocean circulation changes
  • Atmospheric pressure changes
Can humans really change the climate?

• A valid question!
• Could it not be solar variations?
  • Estimates of GHG forcing are between 0.6W/m² and 2.4W/m²
  • Solar forcing variations are between 0.06W/m² and 0.3W/m²
  • Solar forcing cannot explain recent warming (rather the opposite)
  • We know of no other natural source of variability that could change temperatures as fast
Climate Modeling Basics

Global Climate Models or General Circulation Models (GCMs)

• Provide a means of understanding past changes and variability

• Provide a tool for generating future projections of climate

• Range in complexity, spatial resolution and ability to simulate current climate
Climate Modeling Basics

Basic principles:

• Divide the atmosphere into a number of rectangular grid cells and vertical layers

• Each cell in each layer is considered homogeneous

• The flow of air, moisture and energy from cell to cell is calculated based on known equations of motion

• These calculations are performed for discrete time steps (around 15 minutes)

• Many processes occur at scales smaller than the grid box scale:
  • Boundary layer mixing
  • Convection
  • Clouds
  • Precipitation

• These processes are “parameterised” by sub-models

• Much of the differences between models is a result of parameterisations, particularly of cloud processes
The World in Global Climate Models

Mid-1970s

- CO₂
- Rain

Mid-1980s

- Clouds
- Land Surface
- Prescribed Ice

FAR

- Volcanic Activity
- Sulphates
- "Swamp" Ocean

SAR

- Ocean

TAR

- Carbon Cycle
- Aerosols
- Rivers
- Overturning Circulation

AR4

- Chemistry
- Interactive Vegetation
Climate Modeling

Strengths:

- Able to simulate the large scale observed climate systems such as
  - Major pressure systems
  - Mid-latitude disturbances
  - Most large scale tropical processes (ITCZ)
  - Some models able to simulate Monsoonal systems
  - Respond to changes in GHG concentrations to match observed trends in temperature
Climate Modeling Basics

Weaknesses

- Grid scale diagnostic variables (precipitation) have strong biases
- Inter-annual variability typically smaller than observations
- Not all models capture certain regions well (monsoons)
- Inability to accurately simulate some important processes such as tropical cyclones
Seasonal forecasting

Two main methods

- Correlation based methods
  - Warm oceans over there means wet summer here

- Model based methods
  - Similar to climate models but driven by prescribed sea surface temperatures
  - Try to capture climate response to different SST changes

- Statistical methods to combine all of the above and get a more accurate answer

What are they so bad?

- Regional climate is not well understood
- ENSO is a strong driver but not all the time
- The climate is messy?
Climate Modeling [ scenarios ]

Simulation of future climate requires specification of future GHG concentrations

The IPCC Special Report on Emissions Scenarios (SRES) produced a range of future social/economic scenarios and associated GHG emission rates:

A range of future projections (SRES A2, B1, B2)

- A1 = Rapid growth, technological development and regional development
  - A1F1 is a fossil fuel intensive version
  - A1T is alternative energy version
  - A1B is a balance between fossil and alternative

- A2 = Slower, more heterogeneous growth

- B1 = Similar to A1 but with move towards service and information economy and clean industry

- B2 = Focussed on local and regional development with orientation towards environmental concerns
Climate Modeling [ CMIP 3 archive ]

Couple Model Inter comparison Project (CMIP)

• An archive of 24 GCMs from about 14 different modeling groups
• 20\textsuperscript{th} century control simulations
• A future projection per SRES Scenario
• Hundreds of Terrabytes of data!

CMIP archive: http://cmip-pcmdi.llnl.gov/
Climate Modeling [ downscaling ]
Climate Modeling [ downscaling ]

Global Models not good at the grid scale for precipitation and temperature

The local scale climate is a function of large scale climate and local drivers:
  • Topography
  • Land use
  • Land ocean interactions

**Downscaling** attempts to determine the local scale response to large scale climate state
  • Dynamical downscaling uses limited area dynamic model (like GCM) to simulate the physical processes at the regional scale
  • Statistical or Empirical downscaling uses statistically derived relationships that describe the local scale response to the large scale climate state
Climate Modeling [ downscaling ]

**Dynamical Downscaling** (Regional Climate Models) – **Advantages:**

- A dynamical response that captures physical processes
- Can include land surface interactions and other feedbacks
- Not subject to problems of stationarity in the regional climate

**Dynamical Downscaling** – **Disadvantages:**

- Expensive to run, computational and skills
- Model bias as for GCMs
- Difficult to validate
Climate Modeling [ downscaling ]

Empirical Downscaling – Advantages

- Cheap to run, computationally
- Robust results that resemble observations
- Easier to validate against observations
- No inherent bias, except in extremes

Empirical Downscaling – Disadvantages

- No dynamical process or regional feedbacks
- Possible stationarity issues
- Difficulty in capturing extremes
Application [ regional climate analysis ]

A number of steps are important in evaluating a regional climate in the context of Climate Change

• What aspects of climate are important for your region and sector?
  • Important to identify high level characteristics such as seasonality or droughts

• Understanding current and past climate variability
  • What are the dominant weather systems that drive your regional climate?
  • What drives the climate variability in your region (ENSO, NAO, SAM?)
  • What variability has the region experienced in the past and what impact has that had?

• Understanding past changes (trends)
  • How have the aspects of climate that are important changed over the last 30 or more years?
  • What changes has society/infrastructure already adapted to?
A number of steps are important in evaluating a regional climate in the context of Climate Change

• Using GCM projections
  • Use of multiple models
  • Model agreement or disagreement and what do do?

• Using downscaled projections
  • Empirical or Dynamic? (or both?)

• Use of appropriate metrics and statistics
  • Annual total precipitation is not always useful
  • Dry spell duration
  • 90% percentile daily totals
  • Days exceeding temperature threshold
  • Degree cooling days
  • Etc...

• What happens if your observed trends disagree with future projections

• What about the next 10-20 years?
Example: Dar es Salaam
Example: Dar es Salaam
Example: Dar es Salaam
Example: Dar es Salaam
The End....