WEATHER AND CLIMATE PREDICTION

ATM S 380, Winter 2015
INSTRUCTOR

Daehyun Kim

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Born in 1980  B.S. 2003  Ph.D. 2010  2010-2013  2014-
CLASS MEETS

- MW 9:00-10:20am
  - ATG 310C for lectures
  - ATG 623 for lab
PURPOSE OF THE COURSE

To develop

1. Understanding of how numerical weather and climate predictions are made with an emphasis on the numerical weather and climate model

2. Ability to run the numerical models used in weather and climate prediction

3. Capability of analyzing various weather forecast and climate projection dataset.
YOU’LL HAVE ANSWERS TO THESE QUESTIONS AT THE END OF THE CLASS.

- Under what conditions the numerical weather and climate predictions are possible? In other words, how do they work?
- Why are those predictions inaccurate sometimes?
No textbook. Reading materials will be assigned when needed.
COURSE OUTLINE (SUBJECT TO CHANGE)

1. Numerical Weather Prediction (NWP): a brief history of NWP, atmospheric data assimilation, numerical model, parameterizations, ensemble forecast, predictability, uncertainty

2. Climate Prediction/Projection: El-Nino forecast, teleconnection, a brief introduction to Earth's climate system, energy balance model, earth system model, climate feedback processes
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**GRADING**

- Homework: 40%
- Participation: 10%
- Mid-term (written): 20%
- Final (written or term-project): 30%
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COURSE WEBSITE

http://www.atmos.washington.edu/~daehyun/class/380/home.html
IS NUMERICAL WEATHER PREDICTION ONE OF MANKIND'S GREATEST ACHIEVEMENTS? - CLIFF MASS (UW)
IS NUMERICAL WEATHER PREDICTION ONE OF MANKIND'S GREATEST ACHIEVEMENTS?

- Modern weather prediction is perhaps the most cooperative activity of our species.
- Modern weather prediction requires the ability to simulate atmospheric effects on a vast range of scales.
- Modern weather prediction uses the world's most powerful computers and the associated model software includes millions of lines of code.
- The number of lives saved and the economic value of weather prediction is beyond measure.
- The amount of data collected for operational numerical weather prediction is staggering.

http://cliffmass.blogspot.com/2014/12/is-numerical-weather-prediction-one-of.html
NEED FOR ACCURATE WEATHER AND CLIMATE PREDICTIONS

http://www.ncdc.noaa.gov/billions/overview
NEED FOR ACCURATE WEATHER AND CLIMATE PREDICTIONS

http://www.ncdc.noaa.gov/billions/overview
OPERATIONAL WEATHER AND CLIMATE PREDICTIONS

- National Weather Prediction center
  http://www.wpc.ncep.noaa.gov/
- National Climate Prediction center
  http://www.cpc.ncep.noaa.gov/
SUITE OF FORECAST PRODUCTS

Short Range Forecasts
Short range forecast products depicting pressure patterns, circulation centers and fronts, and types and extent of precipitation.
12 Hour | 24 Hour | 36 Hour | 48 Hour

Precipitation Amounts
Quantitative precipitation forecasts.
Day 1 | Day 2 | Day 3

Temperature
Maximum daytime or minimum overnight temperature in degrees Fahrenheit.

Wind Speed and Direction
Sustained wind speed (in knots) and expected wind direction (using 36 points of a compass) forecasts.

Precipitation Amount
Total amount of expected liquid precipitation.

Medium Range Forecasts
Medium range forecast products depicting pressure patterns and circulation centers and fronts
Day 3 | Day 4 | Day 5 | Day 6

Surface Analysis
Highs, lows, fronts, troughs, outflow boundaries, squall lines, drylines for much of North America, the Western Atlantic and Eastern Pacific oceans, and the Gulf of Mexico.
Standard Size | High Resolution

Predominant Weather
Expected weather (precipitating or non-precipitating) valid at the indicated hour. The weather element includes type, probability, and intensity information.

Chance of Precipitation
Likelihood, expressed as a percent, of a measurable precipitation event (1/100th of an inch).

Sky Cover
Expected amount of opaque clouds (in percent) covering the sky.

http://www.weather.gov/forecastmaps
12-HOUR PROBABILITY FORECAST OF PRECIPITATION

http://www.weather.gov/forecastmaps
48-HOUR FORECAST MAP

http://www.weather.gov/forecastmaps
6-DAY FORECAST

http://www.weather.gov/forecastmaps
SEASONAL DROUGHT OUTLOOK

U.S. Seasonal Drought Outlook
Drought Tendency During the Valid Period
Valid for December 18, 2014 - March 31, 2015
Released December 18, 2014

KEY:
- Dark Brown: Drought persists or intensifies
- Tan: Drought remains but improves
- Green: Drought removal likely
- Yellow: Drought development likely

Author: Brad Pugh, Climate Prediction Center, NOAA

Depicts large-scale trends based on subjectively derived probabilities guided by short- and long-range statistical and dynamical forecasts. Short-term events — such as individual storms — cannot be accurately forecast more than a few days in advance. Use caution for applications — such as crops — that can be affected by such events. "Ongoing" drought areas are approximated from the Drought Monitor (D1 to D4 intensity). For weekly drought updates, see the latest U.S. Drought Monitor.

NOTE: The tan area areas imply at least a 1-category improvement in the Drought Monitor intensity levels by the end of the period although drought will remain.

The Green areas imply drought removal by the end of the period (D0 or none)

http://www.cpc.ncep.noaa.gov/
EL-NINO FORECAST

http://iri.columbia.edu/our-expertise/climate/forecasts/enso/current/
Based on current understanding (from observations, physical understanding and modelling), only the collapse of marine-based sectors of the Antarctic ice sheet, if initiated, could cause global mean sea level to rise substantially above the likely range during the 21st century. There is medium confidence that this additional contribution would not exceed several tenths of a meter of sea level rise during the 21st century.

Source: IPCC AR5
How do all these work?
Where are those predictions coming from?

How does this even possible?
law that governs the motion of the car

distance = speed x time

position of the car at initial time

position of the car in the future
Vilhelm Bjerkness (1862-1951): Norwegian physicist and meteorologist

His idea back in 1904:
“If it is true, as every scientist believes, that subsequent atmospheric states develop from the preceding ones according to physical law, then it is apparent that the necessary and sufficient conditions for the rational solution of forecast problems are the following:

1. A sufficiently accurate knowledge of the state of the atmosphere at the initial time

2. A sufficiently accurate knowledge of the laws according to which one state of the atmosphere develops from another.”
law that governs the motion of the car

\[
distance = speed \times time
\]

position of the car
at initial time

position of the car
in the future

law that governs

temperature of the air

temperature of the air
at initial time

temperature of the air
in the future
FIRST NUMERICAL WEATHER PREDICTION

- Lewis Fry Richardson (1881-1953): British mathematician, physicist, atmospheric scientist
- Made the first numerical weather prediction in 1922
- Did the calculations completely by hand! Took over 1000 hours for 6-hour forecast!
- Also had a dream of the future of weather prediction…

Source: Lynch (2006)
Whole story about Richardson’s first NWP experiment in this book. Check it out!
Goal: calculate the **surface pressure change at one point**, 6 hours in the future (initialized at 07UTC, 20 May 1910)

Initial state: obtained from sparse observation network

**Governing law** of atmospheric motion he used: primitive equations

**Numerical method**: Used finite differences to calculate changes in momentum, temperature, and pressure. Discretized in the horizontal and in the vertical.

Source: Lynch (2006)
“Imagine a large hall like a theatre, except that the circles and galleries go right round through the space usually occupied by the stage. The walls of this chamber are painted to form a map of the globe....A myriad computers are at work upon the weather of the part of the map where each sits, but each computer attends only to one equation or part of an equation.... Numerous little "night signs" display the instantaneous values so that neighbouring computers can read them.” in his book titled *Weather Prediction by Numerical Process*, 1922

Source: Lynch (2006)
RESULTS OF RICHARDSON

- Forecast change of surface pressure in 6-hour: 145mb!
- Why such a failure?
  - Initial condition?
  - Governing equation?
  - Numerical method?
- His governing equations represent the atmospheric gravity waves, which oscillate fast and have minor meteorological significance
- Solution: make time step short enough (computationally expensive), or remove the gravity wave from the system (requires theoretical development)

A simple schematic illustrating how extrapolating a noisy signal is dangerous…

Source: Lynch (2006)
## After Richardson’s Failure…

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>ISSUE</th>
<th>SOLUTIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Governing equation</td>
<td>Includes gravity waves</td>
<td>Better understanding of atmospheric dynamics (e.g. Jule Charney’s work)</td>
</tr>
<tr>
<td>Initial condition</td>
<td>Lack of observations</td>
<td>Radiosonde developed in late 1920s and widely used during WWII</td>
</tr>
<tr>
<td>Numerical method</td>
<td>Unstable</td>
<td>Understanding of the stability properties of numerical schemes</td>
</tr>
<tr>
<td>Amount of calculations</td>
<td>Too heavy</td>
<td>The first electronic computer (ENIAC) developed in 1945</td>
</tr>
</tbody>
</table>

Source: Lynch (2006)
The radiosonde is carried aloft by a balloon as part of a radiosonde operations suite of measurement technologies (measurements of temperature, humidity, and pressure as the balloon ascends from the land or ocean surface to heights up to about 30 km (a pressure altitude of about 11 hectopascals, hPa). When the device also measures winds, it is more properly called a rawinsonde, although the term radiosonde is often applied to both types.

The radiosonde itself is an expendable, balloon-borne device that measures the vertical profile of meteorological variables occurring from the surface to stratospheric levels. It is used for in situ observations that are made from ground-based radio-receiving stations, and its data are available to all nations using the Global radiosonde station network.

Since 1957 all stations have made their soundings at 0600 and 1800 Coordinated Universal Time (UTC), except for those maintaining the special tropical sounding system, which sends soundings at 0000 and 1200 UTC. Other uses of radiosonde data were the single most important factor in a 20% increase in hurricane forecast accuracy over the decade of the 1990s. Other uses included climate studies, air pollution investigations, and specialized uses of atmospheric soundings: to analyze and describe current weather conditions (mostly those occurring in the boundary layer) and to assess significant changes in meteorological conditions at various standard or so-called mandatory (pressure) levels as well as at pressure levels at which pre-specified changes in meteorological conditions occur.

Typical radiosonde flight train
- Balloon
- Parachute
- Hanger board
- Unwinder
- 60 m string
- Radiosonde

Global radiosonde station network from Dabberdt et al. (2003)

My small contribution to a recent field campaign (DYNAMO) *note that apparently a helmet is not actually required for modelers to launch radiosondes
ENIAC: THE FIRST COMPUTER

- ENIAC: The Electronic Numerical Integrator and Computer
- Used for the first “successful” numerical weather forecast in 1950
THE FIRST “SUCCESSFUL” NWP EXPERIMENT

- Jule Charney, Ragnar Fjortoft, John von Neumann (1950)
- Research proposal proposed three uses for NWP:
  - Weather prediction
  - Planning where to take observations
  - Weather modification!
- Used barotropic model (no gravity waves, no problems with imbalanced initial conditions)

Visitors and some participants in the 1950 ENIAC computations. (© MIT Museum).
FIRST FORECAST

Initial conditions of 500-hPa height field

Observed height 24 hrs later

Observed and computed change in height

Forecast height 24 hrs later
SECOND FORECAST

Initial conditions

Observed height 24 hrs later

Observed and computed change in height

Forecast height 24 hrs later
WHAT HAS HELPED THE CONTINUOUS INCREASE OF OUR ABILITY TO FORECAST WEATHER?

Source: ECMWF
MORE OBSERVATIONS

Source: ECMWF

Source: IPCC wiki
MORE OBSERVATIONS
# BETTER NUMERICAL MODELS

<table>
<thead>
<tr>
<th></th>
<th>1950 NWP</th>
<th>CURRENT (NCEP GFS)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Coverage</strong></td>
<td>Around North America</td>
<td>Global</td>
</tr>
<tr>
<td><strong>Horizontal grid spacing</strong></td>
<td>~ 700 km</td>
<td>~ 25 km</td>
</tr>
<tr>
<td><strong># of vertical levels</strong></td>
<td>1</td>
<td>64</td>
</tr>
</tbody>
</table>
Modeling our climate

Brown Science Center
AR = “assessment report”
FAR = “first” AR, etc
FAR: 1990, SAR: 1995
AR5: 2014
MORE AND MORE SOPHISTICATED PROCESSES IN THE MODEL

Source: ECMWF

Source: wikipedia.org
INCREASING COMPUTING POWER

FLOPS = Floating-point Operations Per Second

- exaFLOPS $10^{18}$ (Quintillion)
- petaFLOPS $10^{15}$ (Quadrillion)
- teraFLOPS $10^{12}$ (Trillion)
- gigaFLOPS $10^9$ (Billion)

Source: www.top500.org
MOST IMPORTANT ONES: PEOPLE THOSE

- who make observations
- who build numerical models
- who study atmospheric dynamics and physics to deepen our understanding of the atmospheric processes
HOMEWORK 1

- http://www.atmos.washington.edu/~daehyun/class/380/HW/HW1.html

- Watch the video (link below, a plenary talk given by Dr. Alan Thorpe at the World Weather Open Science Conference last August) and write a summary about it (at least 1/2-page with 12-pt, single-spaced). Bring your questions to the class on Monday, January 12.

- *Link to the talk (it is on the left and on third row from top, Dr. Thorpe's talk begins around 40’30'”): Advances in global numerical weather prediction and future prospects (Alan Thorpe, ECMWF)