Lecture 1: Fundamentals of Meteorology

Williams Ch. 1.1 – 2.7

Weather Analysis and Forecasting
Ch. 1.1 – 1.7, 2.1 – 2.6
Outline

• Introduction
• Classification of meteorology phenomenon
• Instrumentation at synoptic weather stations
• Upper air observations
• Satellite remote sensing
• Weather data and visualization
What is Synoptic Meteorology

• **Synoptic meteorology** refers to the analysis of large-scale atmospheric disturbances.
• Because only extratropical cyclones and fronts could be resolved on the early synoptic maps, synoptic ultimately became a term that referred to large-scale atmospheric disturbances.
• In this course, we will cover the behavior and evolution of
  – Surface fronts
  – Surface pressure systems
  – Upper-level troughs and ridges
  – Extratropical cyclones
  – Upper-level jets
Synoptic Meteorologists

• The study of weather phenomena on somewhat smaller spatial and temporal scales, mesoscale meteorology, includes the study of
  – convective storms
  – land-sea breezes
  – mountain waves

• Advances in observing and computing technology have blurred the boundary between synoptic and mesoscale meteorology as an increasing volume of high-resolution information has become available.

• Today's synoptic meteorologist benefits from in-depth knowledge of mesoscale processes and their interactions with synoptic-scale weather systems.
Synoptic Meteorologists

• The study of the physical laws which govern atmospheric motions and phenomena, along with the deductions from the laws, is known as **dynamic meteorology**.

• Thus, there are two basic approaches to studying atmospheric motions:
  – **Synoptic approach**: We can first observe a phenomenon and describe its characteristics, then analyze it to learn why it forms and why it behaves as it does, and ultimately to predict its behavior (i.e. the discovery of midlatitude cyclones)
  – **Dynamical approach**: We can predict a phenomenon’s existence based upon physical law, and then search for it in nature (i.e. the discovery of gravity waves).

• Today's synoptic meteorologist benefits from insights derived by physical laws (traditionally within the realm of dynamical meteorology) and the plethora of observational analysis based on our advances in observational technology and instrumentation.
The Task of an Atmospheric Scientist

- Atmospheric scientists today must have two essential skills
  - Knowledge of numerical modeling and modern observational systems
  - Solid classical physics foundation
- Atmospheric scientists who are able to synthesize theoretical concepts, observations, and conceptual and numerical models in their work are best able to contribute to scientific advance.
- Consider the following quote from C. -G. Rossby in 1934, a pioneer in the atmospheric sciences:
  - The principle task of any meteorological institution of education and research must be to bridge the gap between the mathematician and practical man, that is, to make the weather man realize the value of a modest theoretical education, and to induce the theoretical man to take an occasional glance at the weather map.
- This quote embodies the spirit of atmospheric science and this philosophy remains as relevant today as it was in 1934.
The Task of a Forecaster

• Weather forecasting necessitates understanding a wide range of processes and phenomena acting on a variety of spatial and temporal scales.
  – (1) Forecasting for a coastal location requires information concerning the near-shore water temperature, the potential for land–sea breeze circulations, and the strength and orientation of the prevailing synoptic-scale wind flow.
  – (2) The prediction of precipitation type can benefit from knowledge of atmospheric thermodynamics and cloud physics.

• In other words, the skill set necessary to become a proficient forecaster is the ability to synthesize information for a wide range of phenomena and to apply one's physics education to understand and predict atmospheric phenomena.
Classification of Meteorological Phenomena

- Synoptic meteorological phenomena occur over a temporal scale of days and spatial scale of 1000 km.
- The width of synoptic-scale features is much greater than its depth.
Time Zones

• Meteorological time is typically given by the global time standard called UTC (Coordinated Universal Time).
• This is also known as GMT (Greenwich Mean Time) or Z (Zulu) time.
• UTC/GMT time refers to the mean solar time at the Royal Observatory in Greenwich, London and is located on the Prime Meridian.
Time Zones

www.nist.time.gov

North America
South America
Europe
Africa
Asia
Australia/Oceania

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12am 12pm

midnight AM noon PM midnight
Time Zones

• Charleston is Eastern Standard Time (EST)
  – 5 hours behind UTC
• During summer, it’s Eastern Daylight Time (EDT)
  – 4 hours behind UTC
• Other US time zones
  – Central (CST → UTC -6)
  – Mountain (MST → UTC -7)
  – Pacific (PST → UTC -8)
Synoptic Surface Weather Stations
Synoptic Surface Weather Stations

- Synoptic weather stations have instruments which collect meteorological information at synoptic time 00 Z, 03 Z, 06 Z, 09 Z, 12 Z, 15 Z, 18 Z, 21 Z
- Typical weather stations have the following instruments:
  - Thermometers
  - Barometers
  - Psychrometers
  - Anenometers
  - Rain gauges
  - Ceilometer
Temperature

• Temperature is a measure of the motion (mean kinetic energy) of air molecules.
• The units of temperature are usually given in Fahrenheit, Celsius, or Kelvin
  \[
  (9/5 \times ^\circ C) + 32 = ^\circ F \\
  (^\circ F - 32) \times 5/9 = ^\circ C \\
  K = ^\circ C + 273.15
  \]
• All of the weather in the atmosphere occurs within the troposphere where the temperature generally decreases with height
Measuring Atmospheric Temperature

• Conventional thermometry
  – Mercury thermometers, bimetallic strips
• Electronic thermometers
  – Thermistors and thermocouples
• Remote sensing using radiation emitted by the air and surface
Atmospheric Pressure

- Atmospheric pressure is the force per unit area of a column of air above you.
- Atmospheric pressure arises from gravity acting on a column of air.
- Pressure is the weight of the air above you.
- The units of pressure are given in hPa or millibars.
  - 1 hPa = 1 mb = 100 Pa
  - 1 inch of mercury = 33.86 mb
Measuring Atmospheric Pressure

- Fluid column barometer
- Aneroid barometer
Humidity

- Humidity is a measure of the amount of water vapor in the air.
- Because of its important in determining the distribution of precipitation and atmospheric stability, several different measurements for moisture are commonly used:
  - **Mixing ratio**: The mixing ratio \( q \) (units: g/kg) is simply the ratio of the mass of water vapor to the mass of dry air in a given volume.
  - **Relative humidity**: Relative humidity is the ratio of the mass of water vapor in the air to the mass of water vapor needed to saturate the air at that temperature. High relative humidity occurs when the temperature is close to the dew point.
Measuring Humidity

- Psychrometer
- Hygrometers
- Remote sensing from radiation emitted by water vapor molecules
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Wind

- Wind is air’s response to pressure differences
- Wind speed can be measured in miles per hour (mph), knots (kt), or meters per second (m/s)
  - 1 knot = 1.15 mph = 0.514 m/s
- Wind direction tells us FROM WHERE the wind is blowing
- Wind direction is measured in degrees (like a compass, not like the degrees in math).
Measuring Wind

- Anemometers
  - Cup/vane
  - Vane/propeller
- Remote sensing
  - Radar
- Tracer techniques
  - Tracking balloons
  - Chemical tracers
  - Clouds
Rain Gages

- Conventional rain gauge
- Tipping bucket rain gauge
- Remote Sensing
  - radars
  - passive satellite retrievals
- Snow is difficult to measure because wind
  - creates non-uniform depth
  - affects collection
Cloud Cover

• Visual observations
• Aircraft
• Remote Sensing
  – Ceilometers: lasers bouncing light off the clouds from below
  – Satellites: measuring radiation reflected and emitted by clouds
Upper Air Observations

• The primary instrument used in upper air observations is the radiosonde.
• Radiosondes measure temperature, relative humidity, pressure, and wind as a function of height.
• Radiosondes are launched twice a day: 00Z and 12Z.
Upper Air Observation Stations
Satellite Remote Sensing

• Remote sensors can obtain information about properties of an object or volume without coming into physical contact with that object

• The advantages include
  – Fully automated, thus require only an occasional technician
  – Excellent coverage (horizontally) even over oceans

• The disadvantages include
  – Does not measure state variables directly – must be inferred or retrieved
  – Satellites have poor vertical resolution
  – Expensive
Brief Overview of Remote Sensing

\[ \nu = \frac{c}{\lambda} \]

- \( \nu \) is frequency (s\(^{-1}\))
- \( c \) is the speed of light (m.s\(^{-1}\))
- \( \lambda \) is wavelength (m)

### Table: BAND, Typical \( \lambda \) (cm), Primary Application

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Brief Overview of Remote Sensing

• The amount of radiation emitted by a blackbody is uniquely determined by its temperature.
• Furthermore, as wavelength increases, penetration generally increases.
• Thus, remote sensing in the atmosphere usually exist within the microwave range of the EM spectrum.
Satellites

• The most common remote sensor used are satellites.
• There are two types of satellites: polar orbiting and geostationary.
Satellites

- Latest generation of GOES weather satellites (GOES-8,9,10) all carry 5 imaging sensors in the following portions of the EM spectrum:
  - Channel 1: Visible (0.6 microns)
  - Channel 2: Shortwave IR (3.9 microns)
  - Channel 3: Water vapor (6.7 microns)
  - Channel 4: IR (11 microns)
  - Channel 5: IR (12 microns)
Visual Channel

• The visual channel displays albedo or reflectance as a percentage
• The images appear much like how the human eye sees it
• Clouds and snow appear bright white while oceans and vegetation are dimmer
Infrared (IR) Channels

• In general, the warmer an object the more IR energy it emits.
• The satellite measures this energy, calibrates it to temperature and the output is shaded to represent colder and warmer temperatures.
• Where clouds exist the temperature shown is at cloud top.
• Where clouds do not exist the temperature shown is that of the ground.
• High clouds are relatively cold, low clouds are warmer and the land is typically even warmer.
Water Vapor Channel

- Images correlate to the quantity of water vapor in the upper portions of the atmosphere (25,000 ft and higher in general)
- Red indicates very dry upper atmospheric regions and may indicate clear skies
- Blue and green shades are indicative of high-level moisture and potential cloudiness
Observational Weather Data

• Raw surface data can be found
  – NOAA’s Aviation Weather Center
  – Center Weather Service Unit
  – Ogimet

• Upper-air radiosonde data can be found
  – NOAA/ESRL Radiosonde Database
  – RAOB Data Retriever
  – Integrated Global Radiosonde Archive
Real-Time Weather Data Visualization

• There are many meteorology departments that visualize real-time observational weather data
  – Oklahoma Weather Lab
  – College of DuPage Weather Lab
  – Plymouth State Weather Center
  – Penn State Electronic Map Wall

• Government labs and agencies also provide websites to visualize real-time weather data
  – NCAR Real-Time Weather Data
  – NWS Weather Prediction Center
Archive Weather Maps

• Government labs and agencies also provide archived weather maps from 1990s
  – NCAR Real-Time Weather Data (from 1996)
  – NWS Weather Map Archive (from 1990)
  – Weather Prediction Center Surface Analysis Archive (from 2006)

• Some universities and private companies also provide archived weather maps
  – Plymouth State Weather Center (from 1998)
  – Unisys Weather Image and Map Archive (from 2004)
  – Radar and Satellite Archives (from 2005)