Upper Air Measurements
Upper Air Measurements

• Measurements above the surface become increasingly difficult with altitude
• Balloons, airplanes and rockets have all been used to carry instruments aloft to make ______ measurements
• Ground- and Satellite-based instruments can be used to make ______ measurements
• What portion of the atmosphere does upper air refer to in meteorology?
Methods for Measurement

• Measurements of temperature, pressure, humidity and wind can be made using in-situ instrument packages as well as remotely.

• Remote sensors can be classified as active sensors or passive sensors.
Active Remote Sensors

- Sensors emitting radiation/radio frequencies to measure a remote property are considered active sensors
- Radar, Lidar
Passive Remote Sensors

• Emit no radiation/radio frequencies. Receive only emitted signals
• Microwave radiometers, some satellite imagery
In-situ versus Remote

• Why use in-situ when remote is readily available?

• How good is remote coverage?
In-situ Platforms

- Aircraft
- Balloons
- Radiosondes
- Theodolites
Aircraft Measurements

- Take measurements along their flight path
- Commercial aircraft as well as research aircraft can be outfitted with equipment
- Research aircraft generally equipped with high-end instrumentation and can be manned or unmanned
- Commercial aircraft use simple packages to measure temperature, humidity and wind
- What is an obvious problem with commercial measurements?
Balloons

• Categorized according to size, color and extensibility
• Most balloons are the extensible type
• Inextensible balloons are also known as constant level balloons
• Color only matters if the balloon is to be observed visually (light preferred on clear days and dark on cloudy days)
Balloon Types

• Pilot balloons
  – used to track horizontal winds
  – Carry no payloads
  – Usually weigh between 10 and 100 grams

• Sounding balloons
  – Carry a payload to measure winds, temperature, humidity and pressure
  – Weigh 600 – 1800 grams
  – Larger balloons available for bigger payloads
Balloon Gases

• What gases are commonly used to fill the balloon?

• What are the advantages/disadvantages to each?
Balloon Flight

• How high do balloons get?

• What happens to radiosonde package?
Balloon Burst Height

![Graph showing the relationship between balloon mass and burst height and ascent speed. The graph indicates that as balloon mass increases, burst height also increases, while ascent speed decreases.]
Drag Force

• Why isn’t drag force shown on the prior plot?
Balloon Ascent Rate

• Function of lift, weight and payload
• Total lift force on a balloon

• Total lift mass
Balloon Ascent Rate

- Free Lift Force
- Free Lift Mass
Balloon Ascent Rate

• Balloon Drag

• Reynolds Number

• What is Dynamic Viscosity?
Dynamic Viscosity
Drag Coefficient

Fig. 12-1 Drag coefficients as a function of the Reynolds number for a disc and for a sphere.
Steady State Ascent

• When is steady state ascent achieved?
Balloon Ascent Rate

• If the balloons altitude is known, the density and dynamic viscosity can be calculated
• The Standard Atmosphere chart can also be used
Table 12-2 US Standard Atmosphere.

<table>
<thead>
<tr>
<th>z (km)</th>
<th>T (K)</th>
<th>p (hPa)</th>
<th>( \rho ) (kg m(^{-3}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>288.1</td>
<td>1013.25</td>
<td>1.2250</td>
</tr>
<tr>
<td>1.0</td>
<td>281.7</td>
<td>898.76</td>
<td>1.1117</td>
</tr>
<tr>
<td>2.0</td>
<td>275.2</td>
<td>795.01</td>
<td>1.0066</td>
</tr>
<tr>
<td>3.0</td>
<td>268.7</td>
<td>701.21</td>
<td>0.9093</td>
</tr>
<tr>
<td>4.0</td>
<td>262.2</td>
<td>616.60</td>
<td>0.8194</td>
</tr>
<tr>
<td>5.0</td>
<td>255.7</td>
<td>540.48</td>
<td>0.7364</td>
</tr>
<tr>
<td>6.0</td>
<td>249.2</td>
<td>472.17</td>
<td>0.6601</td>
</tr>
<tr>
<td>7.0</td>
<td>242.7</td>
<td>411.05</td>
<td>0.5900</td>
</tr>
<tr>
<td>8.0</td>
<td>236.2</td>
<td>356.51</td>
<td>0.5258</td>
</tr>
<tr>
<td>9.0</td>
<td>229.7</td>
<td>308.00</td>
<td>0.4671</td>
</tr>
<tr>
<td>10.0</td>
<td>223.3</td>
<td>264.99</td>
<td>0.4135</td>
</tr>
<tr>
<td>12.0</td>
<td>216.6</td>
<td>193.99</td>
<td>0.3119</td>
</tr>
<tr>
<td>14.0</td>
<td>216.6</td>
<td>141.70</td>
<td>0.2279</td>
</tr>
<tr>
<td>16.0</td>
<td>216.6</td>
<td>103.52</td>
<td>0.1665</td>
</tr>
<tr>
<td>18.0</td>
<td>216.6</td>
<td>75.65</td>
<td>0.1217</td>
</tr>
<tr>
<td>20.0</td>
<td>216.6</td>
<td>55.29</td>
<td>0.0889</td>
</tr>
<tr>
<td>22.0</td>
<td>218.6</td>
<td>40.47</td>
<td>0.0645</td>
</tr>
<tr>
<td>24.0</td>
<td>220.6</td>
<td>29.72</td>
<td>0.0469</td>
</tr>
<tr>
<td>26.0</td>
<td>222.5</td>
<td>21.88</td>
<td>0.0343</td>
</tr>
<tr>
<td>28.0</td>
<td>224.5</td>
<td>16.16</td>
<td>0.0251</td>
</tr>
<tr>
<td>30.0</td>
<td>226.5</td>
<td>11.97</td>
<td>0.0184</td>
</tr>
<tr>
<td>31.0</td>
<td>227.5</td>
<td>10.31</td>
<td>0.0158</td>
</tr>
<tr>
<td>32.0</td>
<td>228.5</td>
<td>8.89</td>
<td>0.0136</td>
</tr>
</tbody>
</table>
Balloon Ascent Rate

- Balloon vertical speed
Calculation Errors

- Balloon materials are not completely elastic, thus balloon volume is not inversely proportional to atmospheric density as assumed
- Gas inside the balloon will leak through the balloon
- As balloon ascends into cooler air, thermal lag may cause internal gas to be warmer than external gas
Calculation Errors

• Balloon shape is not always spherical
• Vertical wind components can aid or deter buoyant effects
• Drag coefficient is not constant and changes with density, diameter and ascent speed of balloon
Average Ascent Rate

• Typical ascent rate is ________ m/s and is usually nearly constant with altitude
Wind Measurement

• Horizontal wind speed can be determined by visually tracking a balloon (pilot balloon)
• Tracking capabilities include theodolites, double theodolites and radars
• Use of an instrument package can include tracking using GPS
• Balloons follow the mean flow because of their large surface area and small mass
Wind Force

• Force exerted on a balloon by the wind force

• If we assume the balloon speed is approximately equal to wind speed, we can simplify
Theodolites

• Measures the azimuth of the balloon (relative to true north) and the elevation angle usually at 1-minute intervals

• If the ascent rate is known, the position of the balloon can be determined and wind velocity inferred from successive positions

• Two theodolites increase tracking accuracy

• Limited to visual range

• Works poorly with cloud cover
Balloon Tracking Calculations
Radiosonde Tracking

• Transmits measured data to ground via radio transmitter
• Position can be determined using a radio theodolite or radio direction finder
• Combine pressure from radiosonde with tracking information and complete position can be computed
• Radio theodolites work best with high-frequency radiowave sondes (typically ______ Mhz)
Radar Tracking

• Balloons carrying corner reflectors can be tracked by radar
• Determines slant range to the balloon as well as azimuth and elevation angles
• Measures angles to within 0.1 degrees and to within 30 meters.
• Balloon height can be corrected for curvature of the earth
Navigation Aids

• Some radiosondes carry special radio receivers that detect navigational signals
• Data is relayed to a ground station where position is then calculated
• Requires more expensive sonde, but less expensive ground station (neither radar nor radio direction finder is needed)
• Ideal for portable ground stations
• Navigational aids available are LORAN C, OMEGA, and GPS
LORAN C

• LORAN – LOng Range Aid to Navigation
• High Accuracy, medium-range navigational aid operating at frequencies around 200 kHz
• Primary use is marine navigation
OMEGA

• Network of eight atomic-clock-controlled transmitters operating in the very-low-frequency band
• Designed to provide global coverage
• Each station transmits sequentially for 0.9 to 1.2 seconds on three assigned frequencies (10.2, 11.3, 13.6 kHz)
• No two stations transmit at the same time on one frequency
• No individual station transmits on more than one frequency at a time
• Cycle is repeated every 10 seconds
• At the three frequencies, the earth’s surface and the ionosphere act as waveguides
• Transmitters excite various modes of propagation whose amplitudes and phase velocities vary with the height of the ionosphere, direction of propagation and range from transmitter
GPS

• Array of 24 satellites orbiting at 20200 km above the earth’s surface
• Orbital period 12 hours and the orbital plane is inclined at 55 degrees with respect to the equatorial plane
• Each satellite is equipped with an atomic clock and transmits signals at precise intervals on two frequencies (1.226 GHz and 1.575 GHz)
GPS

• If a receiver can ‘hear’ four satellites at once, the position of the receiver can be determined to within 100 m (worst case)
• Works anywhere on the earth’s surface
• Sonde transmits the received GPS signals to its ground station which also receives GPS signals
• Ground station computes the position of the sonde and of itself and obtains the sonde position relative to the ground station
GPS

• This procedure (called differential GPS) compensates for many of the system errors
Navigational Aid Errors

• LORAN C
  – Wind speed errors: 0.7 m/s
  – Vertical position: 150 m

• OMEGA
  – Wind speed errors: 1.5 m/s
  – Vertical position: 300 m

• GPS
  – Wind speed errors: 0.1 m/s
  – Vertical position: 30 m
Radiosondes

- Carry sounding payloads to heights of 30 km or higher
- Typically measure pressure, temperature and humidity and sends data to a ground station via radio transmitter
- Special payloads have been designed to measure radiation (solar and terrestrial), ozone concentration, electrical potential gradient, air conductivity, and radioactivity
Radiosonde Requirements

• Generally designed to be used only once
• Must be designed for mass production at low cost
• Must be capable of operating on an internal battery for ~ 3 hours
• Must be able to transmit radio signal at least 200 km
• Mass density must be low enough not to damage jet engines or windshields
Radiosonde Requirements

• Have a short service life, but need to have a long shelf life before use
• Drift must be carefully controlled or sensors must be calibrated quickly before flight
• To obtain readings representative of layers ~100 meters thick, a reading from each sensor must be completed every 15-20 seconds for a 5 m/s ascent rate
Pressure Sensor

• Usually a single metallic diaphragm aneroid or silicon diaphragm sensor
• Designed to respond to the logarithm or pressure rather than linearly with pressure to enhance high-altitude performance
• Metallic diaphragm sensors lose sensitivity at low pressure (<_____ hPa) so they are sometimes augmented with hypsometers (why?)
Temperature Sensors

• Small-rod thermistors or temperature-sensitive capacitors

• Thermal lag must be small (because of constant changing pressures and densities)

• Typical time constant for a rod thermistor 1.27 mm in diameter is 4.5 seconds at 1000 hPa, 10.6 seconds at 100 hPa, and 30 seconds at 10 hPa
Temperature Sensors

- Radiation error is a major concern
- Sensor is ventilated by 5 m/s ascent of sonde, but must not be exposed to direct sun
- Radiation “shield” is part of sensor itself and consists of highly reflective coating
- Doesn’t use typical shield like the sensors on the ground
Humidity Sensors

• _______ sensors are the typical humidity sensors used in radiosondes
• Psychrometric sensors have been used on some and chilled-mirror hygrometers have been used for research projects
• Response time increases as temperature decreases because of the lower amounts of water vapor present at colder temperatures
Dropsondes

• Created by scientists and engineers at NCAR
• Designed to be dropped from an aircraft at altitude to more accurately measure (and therefore track) tropical storm conditions as the device falls to the ground
• The dropsonde contains a GPS receiver, along with pressure, temperature, and humidity (PTH) sensors to capture atmospheric profiles and thermodynamic data
Dropsondes

• The device's descent is usually slowed by a parachute, allowing for more readings to be taken before it reaches the water beneath
• Dropsondes are commonly used by Hurricane Hunters to obtain data on hurricanes, and these data are then fed into supercomputers for numerical weather prediction
Dropsondes

• The dropsonde is released when the plane reaches the eye of the hurricane, normally at around 10,000 feet (approx. 3,000 meters)
Drifsonde

• A drifsonde is a high altitude, durable weather balloon holding a transmitter and a bank (35 in the first models) of miniature dropsonde capsules

• These water-bottle-sized transmitters have enough power to send information on their parachuted fall to the balloon, and then the balloon holds a transmitter powerful enough to relay readings to a satellite
Driftsondes

• The sensor packages are relatively inexpensive ($400 each)

• After being introduced in April 2007, around a thousand a year are expected to be used to track winds in hurricane breeding grounds off of West Africa, which are too far for practical operation of Hurricane Hunter planes
Driftsondes
Tethersondes

- Uses a balloon tethered to the ground
- Regular intervals along the length of the tether are instrumented to provide measurements of temperature, humidity, pressure and winds
Tethersondes
Radiosonde Exposure Errors

• Accentuated by extreme variations in temperature, pressure, air density, solar radiation, electric field gradients, environmental shock in handling, wetting and icing by cloud drops, etc

• Generally best to make sensors as small as possible to counteract problems

• Sonde package swings below balloon and the pendulum motion can be detected by some systems which need to be filtered out
Barometer Errors

- Small size means smaller temperature gradients across the sensor and faster response to temperature changes
- Silicon integrated circuit a few mm in thickness and diameter can be used
Temperature Sensor Errors

• Small size needed to reduce radiation heating and dynamic lag
• Vaisala RS-90 sonde uses an unshielded capacitive sensor 0.1 mm in diameter
• Radiation heating is approximately 0.5 K at 10 hPa which can be corrected down to 0.1 K
Humidity Sensor Errors

• Capacitive sorption sensors in some sondes are designed to eliminate condensation in supercooled clouds

• Other sondes use dual sensors to measure RH; one is heated to remove condensate while the other is measured

• Heating is then switched to the other and measurements are taken on the first one after cooling

• Heating cycle is ~ 40 seconds
Temperature and RH Sensor Errors

• Both are located on an arm protruding from the sonde to isolate them from heat from the sonde and provide better atmospheric exposure