“climate is what you expect, but weather is what you get”
LECTURE 3:
Measurement of weather and climate

ML-4430: Machine learning approaches in climate science

5 May 2021
Station-based Measurements

1. Temperature
2. Pressure
3. Wind
4. Rainfall
5. Observation network

Non-station-based Measurements

1. Weather radar
2. Weather satellites
3. Argo floats

Reanalysis

3. What is reanalysis?
4. Why do we need it?
5. A few examples

Paleoclimate proxy records

4. The fundamental paradigm
5. Dealing with uncertainty
6. A few examples
1. Station-based measurements → Temperature: Stevenson screen
1. Station-based measurements → Temperature: PRT

https://www.metoffice.gov.uk/weather/guides/observations/how-we-measure-temperature
1. Station-based measurements → Temperature: PRT

https://www.metoffice.gov.uk/weather/guides/observations/how-we-measure-temperature
**Measuring temperature**

- Stevenson screens used to shield thermometers from direct radiation
  - Set a high of 1.25 m or 2 m

- Dry bulb temperature and wet bulb temperature
  - Used to calculate humidity

- Mercury thermometers replaced by platinum resistance thermometers (PRTs)

- Soil temperatures measured with in-glass alcohol thermometers
1. Station-based measurements → Pressure: Deployment *in situ*
1. Station-based measurements → Pressure: Capacitive pressure sensor

1. Station-based measurements → Pressure: Mean sea level pressure

\[ p_0 = p_s \exp \left( \frac{g}{R} \frac{H_p}{T_s + \frac{a H_p}{2} + e_s C_h} \right) \]
Measuring pressure:

- Sensor has to be shielded from wind
- Multiple sensors to ensure consistency and identify abnormal measurements
- Typically, a (silicon) capacitive pressure sensor is used
- Knowing the height (above sea level) of the sensor and the temperature, mean sea level pressure can be obtained

\[
p_0 = p_s \exp \left( \frac{g H_p}{R} \left( T_s + \frac{a H_p}{2} + e_s C_h \right) \right)
\]
1. Station-based measurements → Wind: Cup Anemometer

https://www.metoffice.gov.uk/weather/guides/observations/how-we-measure-wind
1. Station-based measurements → Wind: (Ultra) Sonic Anemometer

https://www.metoffice.gov.uk/weather/guides/observations/how-we-measure-wind
1. Station-based measurements → Wind: Gusts

https://www.metoffice.gov.uk/weatherguides/observations/how-we-measure-wind
Measuring wind:

- Cup anemometer
  - Rotation of cups proportional to wind strength
  - Position of wind vane gives direction

- (Ultra) Sonic anemometer
  - Extreme conditions
  - Speed of acoustic signals give wind speed and direction

- Regular calibrations in wind tunnels

- Gusts → maximum three second average wind speed

1. Station-based measurements → Wind: Gusts
1. Station-based measurements → Rain

https://www.metoffice.gov.uk/weather/guides/observations/how-we-measure-wind
Measuring rain:

- Storage rain gauge
  - *Manual* → an observer has to pour the rain water in the tube and read the amount

- Tipping bucket rain gauge
  - *Automatic* → the tipping action triggers a count of 0.2 mm in a circuit
  - Count can also be transmitted wirelessly

- For daily readings, standard time for measurement is at 09:00

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1. Station-based measurements → Rain
1. Station-based measurements → Observation network
Outline

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2. Non-station-based measurements → Weather radar: Structure

https://www.dwd.de/EN/research/observing_atmosphere/weather_radar/weather_radar_node.html
2. Non-station-based measurements → Weather radar: Scan strategy
2. Non-station-based measurements → Weather radar: Output

https://www.dwd.de/EN/research/observing_atmosphere/weather_radar/weather_radar_node.html
$R = \left( \frac{10^{\text{dBZ}} - 10}{200} \right)^{5/8}$

### Reflectivity in dBZ versus Rainrate

<table>
<thead>
<tr>
<th>L_Z (dBZ)</th>
<th>R (mm/h)</th>
<th>R (in/h)</th>
<th>Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>0.07</td>
<td>&lt; 0.01</td>
<td>Hardly noticeable</td>
</tr>
<tr>
<td>10</td>
<td>0.15</td>
<td>&lt; 0.01</td>
<td>Light mist</td>
</tr>
<tr>
<td>15</td>
<td>0.3</td>
<td>0.01</td>
<td>Mist</td>
</tr>
<tr>
<td>20</td>
<td>0.6</td>
<td>0.02</td>
<td>Very light</td>
</tr>
<tr>
<td>25</td>
<td>1.3</td>
<td>0.05</td>
<td>Light</td>
</tr>
<tr>
<td>30</td>
<td>2.7</td>
<td>0.10</td>
<td>Light to moderate</td>
</tr>
<tr>
<td>35</td>
<td>5.6</td>
<td>0.22</td>
<td>Moderate rain</td>
</tr>
<tr>
<td>40</td>
<td>11.53</td>
<td>0.45</td>
<td>Moderate rain</td>
</tr>
<tr>
<td>45</td>
<td>23.7</td>
<td>0.92</td>
<td>Moderate to heavy</td>
</tr>
<tr>
<td>50</td>
<td>48.6</td>
<td>1.90</td>
<td>Heavy</td>
</tr>
<tr>
<td>55</td>
<td>100</td>
<td>4</td>
<td>Very heavy/small hail</td>
</tr>
<tr>
<td>60</td>
<td>205</td>
<td>8</td>
<td>Extreme/moderate hail</td>
</tr>
<tr>
<td>65</td>
<td>421</td>
<td>16.6</td>
<td>Extreme/large hail</td>
</tr>
</tbody>
</table>

2. Non-station-based measurements → Weather radar: Conversion to rainfall in mm
Weather radar:

- Ground based monitoring
  - Rain, snow, hail → storms
- High resolution in space and time
- Measures radar reflectance of ‘hydrometeors’ i.e. droplets of water in the atmosphere
- Raw data processed by national weather services to be released as rainfall data
2. Non-station-based measurements → Weather satellites

https://www.dwd.de/EN/research/observing_atmosphere/satellites/weather_satellites_node.html
2. Non-station-based measurements → Weather satellites: Geostationary orbit
2. Non-station-based measurements → Weather satellites: Polar orbit
Weather satellites

- High resolution data
  - Even for remote locations like oceans, deserts, mountains, and poles
  - Weather forecast and monitoring

- Geostationary satellites
  - Fixed location with respect to earth
  - 35000 km above earth

- Polar satellites
  - Revolves around the earth on a polar axis
  - 800 – 900 km above the earth
  - Every 102 minutes approx.
2. Non-station-based measurements → Argo floats: How does it work

https://argo.ucsd.edu/how-do-floats-work/
2. Non-station-based measurements → Argo floats: Network

https://argo.ucsd.edu/
2. Non-station-based measurements → Argo floats: Network
Argo floats

- More than 3500 floats worldwide
- Managed by a large international cooperation network
- Data from the surface of the ocean and up to a depth of 2 km
  - Temperature and salinity profiles
  - Velocity and currents
  - Pressure
  - Mixed layer depth
- First attempt at global subsurface measurements
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Paleoclimate proxy records

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5. Dealing with uncertainty
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3. Reanalysis → What is reanalysis?

https://www.ecmwf.int/en/about/media-centre/focus/2020/fact-sheet-reanalysis
3. Reanalysis → Why do we need reanalysis?

https://www.youtube.com/watch?v=FAGobvUGI24&t
3. Reanalysis → Why do we need reanalysis?

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FORMULA

\[
\frac{\partial \Psi}{\partial t} + \frac{1}{a \cos \theta} \left( u \frac{\partial \Psi}{\partial x} + v \cos \theta \frac{\partial \Psi}{\partial \theta} \right) + \eta \frac{\partial \Psi}{\partial \eta} - f v + \frac{1}{\alpha} \left( \frac{\partial \phi}{\partial \lambda} + R v \frac{\partial}{\partial \lambda} \left( \ln \rho \right) \right) = P_u + K_u
\]
3. Reanalysis → A few examples
3. Reanalysis → A few examples

Surface air temperature anomaly for January 2020 relative to 1981-2010
Reanalysis

➢ Combine weather data from heterogeneous sources with a SOTA weather forecast model
  ➢ Regularly gridded long-term climate data

➢ Necessary because:
  ➢ Data sources are thing as we go back in time
  ➢ Data sources are spatially irregular
  ➢ Data is distributed over different sources

➢ NCEP R2 and ERA5 are popular reanalysis products
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4. Paleoclimate proxy records
   - The fundamental paradigm
   - Dealing with uncertainty
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4. Paleoclimate proxy records → The fundamental paradigm
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4. Paleoclimate proxy records → Dealing with uncertainty
4. Paleoclimate proxy records → Dealing with uncertainty

(a) No error quantification

(b) $p(t|z) \sim \mathcal{N}$ (independent errors)

(c) $p(t|z) \sim \mathcal{N}$ (dependent errors)

(d) $p(t|z) \sim \mathcal{U}$ (dependent errors)
4. Paleoclimate proxy records → A few examples
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Paleoclimate proxy records

➢ Obtained from sedimentary archives
  ➢ Tree rings, stalagmites, ice cores, marine sediment cores, ...

➢ Geochemical and physical measurements such as oxygen / carbon isotopes, ring widths, pollen grains, dust particle size, ... record the climate of the past

➢ Age measurements from radiocarbon dating, U/Th dating, layer counting introduce uncertainty in timing of signal

➢ Provides spatially sparse, temporally uncertain, but nevertheless invaluable information about the earth’s past climate