“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
- Pressure
- Wind
- Rainfall
- Observation network

Non-station-based Measurements

2

- Weather radar
- Weather satellites
- Argo floats

Reanalysis

3

- What is reanalysis?
- Why doe we need it?
- A few examples

Paleoclimate proxy records

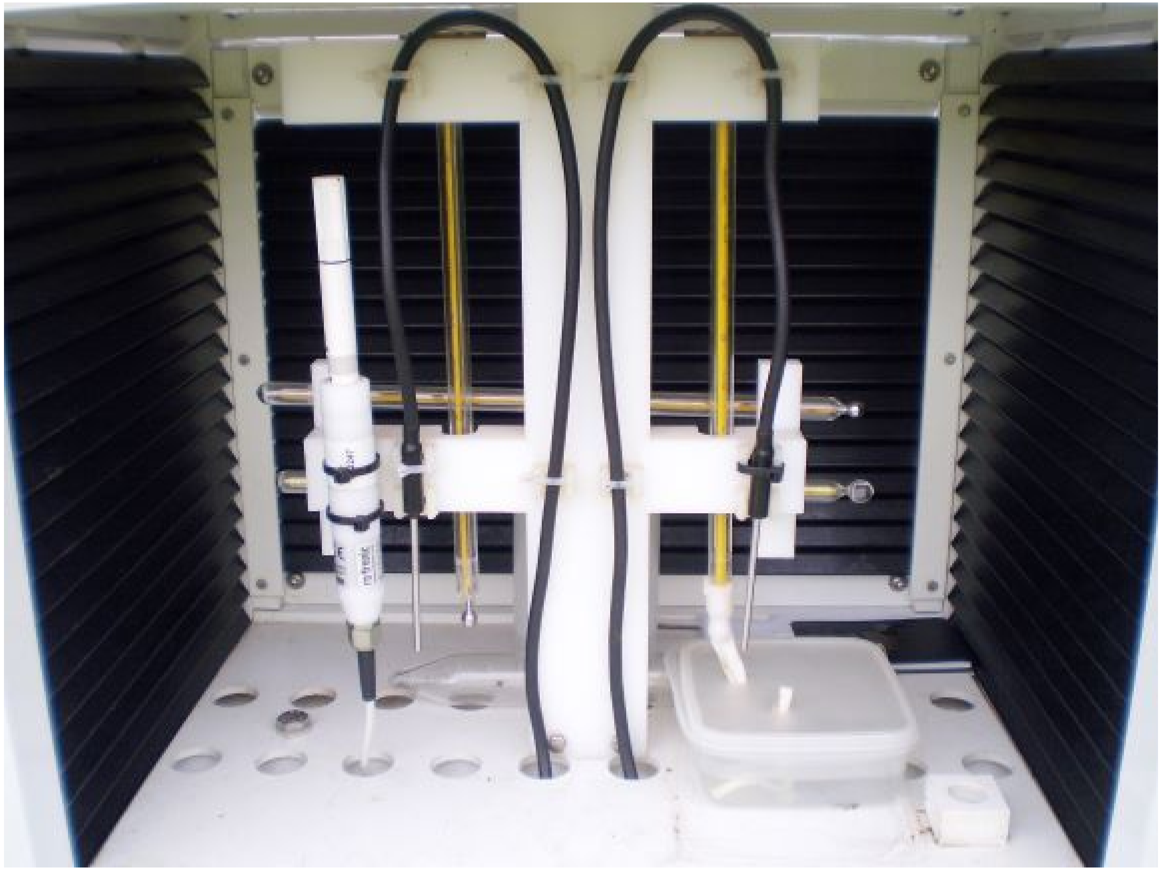
4

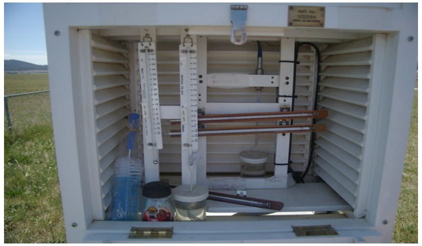
- The fundamental paradigm
- Dealing with uncertainty
- A few examples

https://www.flickr.com/photos/87591849@N00/6301186281

https://www.flickr.com/photos/87591849@N00/6301188055

1. Station-based measurements → Temperature: Stevenson screen





1. Station-based measurements → Temperature: PRT

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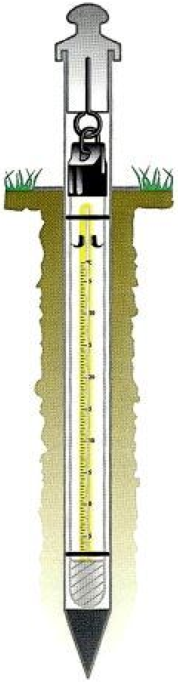
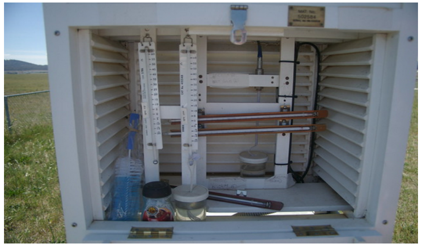
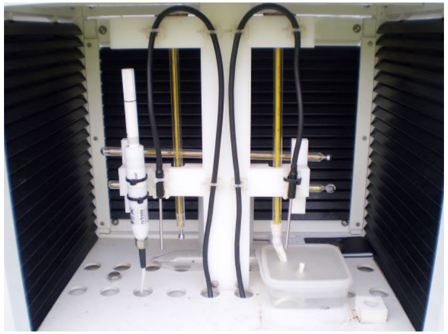
https://www.metoffice.gov.uk/weather/guides/observations/how-we-measure-temperature



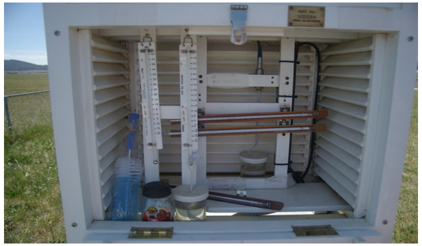


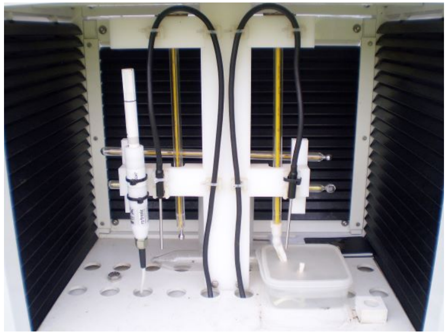


1. Station-based measurements → Temperature: PRT

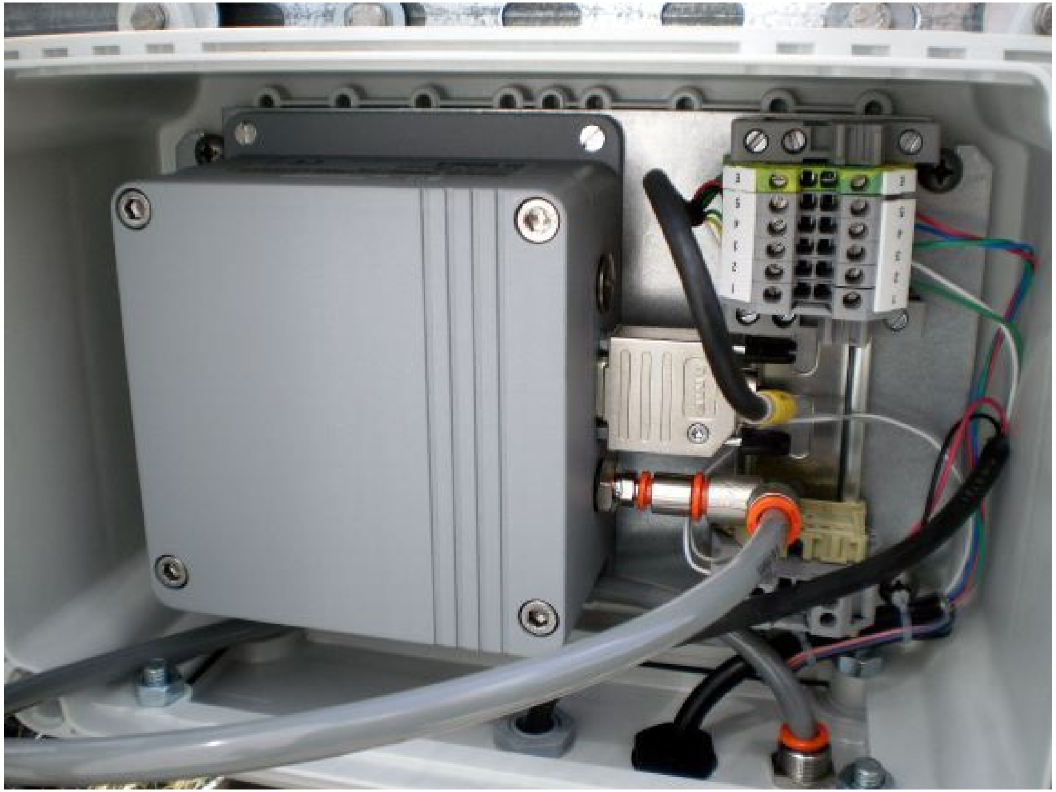
Measuring temperature

- 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

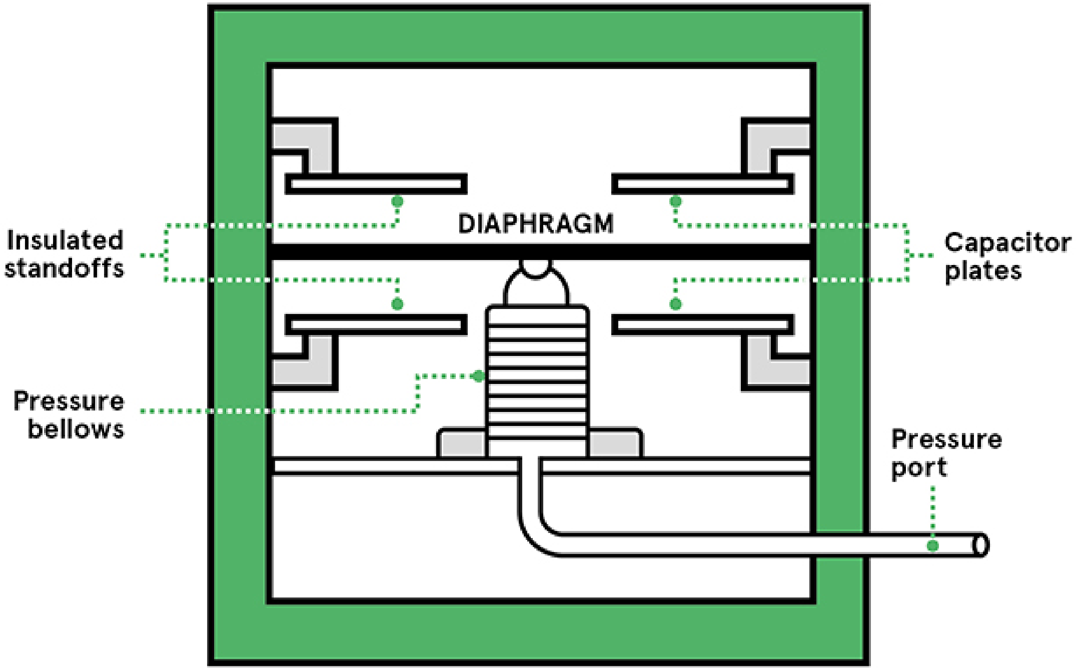


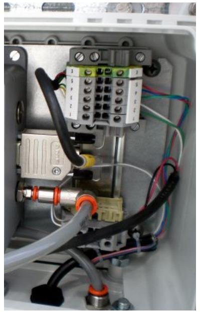


https://www.metoffice.gov.uk/weather/guides/observations/how-we-measure-atmospheric-pressure



1. Station-based measurements → Pressure: Deployment *in situ*


Insulated standoffs
DIAPHRAGM
Capacitor plates
Pressure bellows
Pressure port



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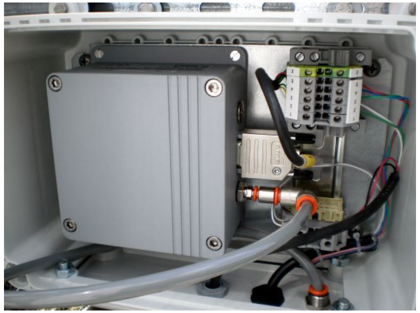
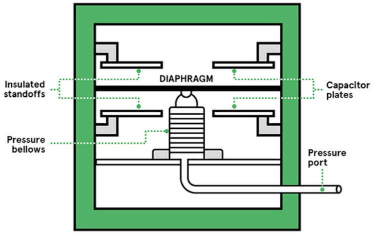
https://www.wmo.int/pages/prog/www/IMOP/meetings/SI/ET-Stand-1/Doc-10_Pressure-red.pdf

$$p_0 = p_s \exp\left(\frac{\frac{g}{R} H_p}{T_s + \frac{a H_p}{2} + e_s C_h} \right)$$





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

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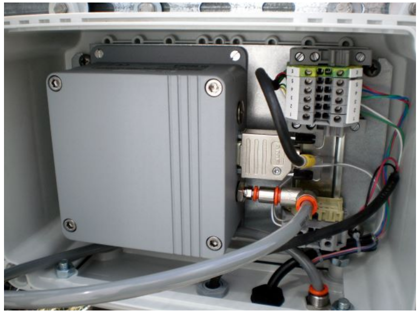
Measuring pressure:

- 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



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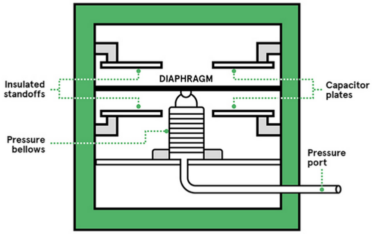


1. Station-based measurements → Wind: Cup Anemometer

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

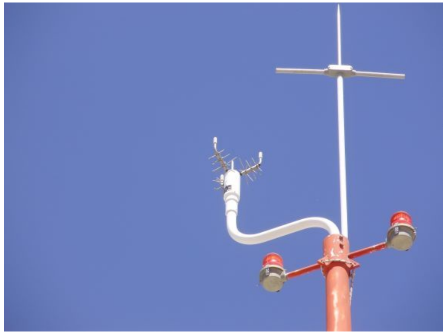
1. Station-based measurements → Wind: (Ultra) Sonic Anemometer

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

1. Station-based measurements → Wind: Gusts

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

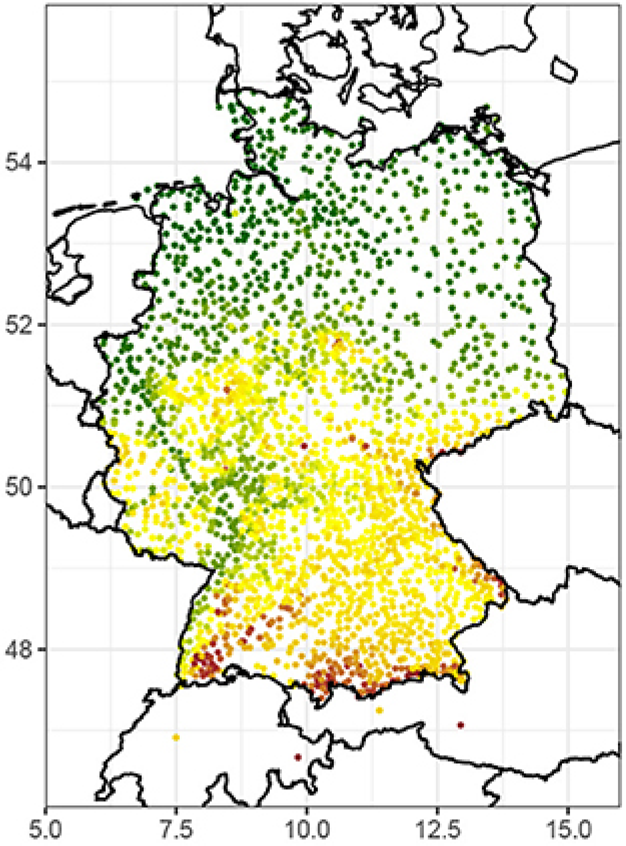


1. Station-based measurements → Rain

Measuring rain:

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

https://www.metoffice.gov.uk/weather/guides/observations/uk-observations-network
https://www.frontiersin.org/articles/10.3389/fenvs.2019.00143/full



1. Station-based measurements → Observation network

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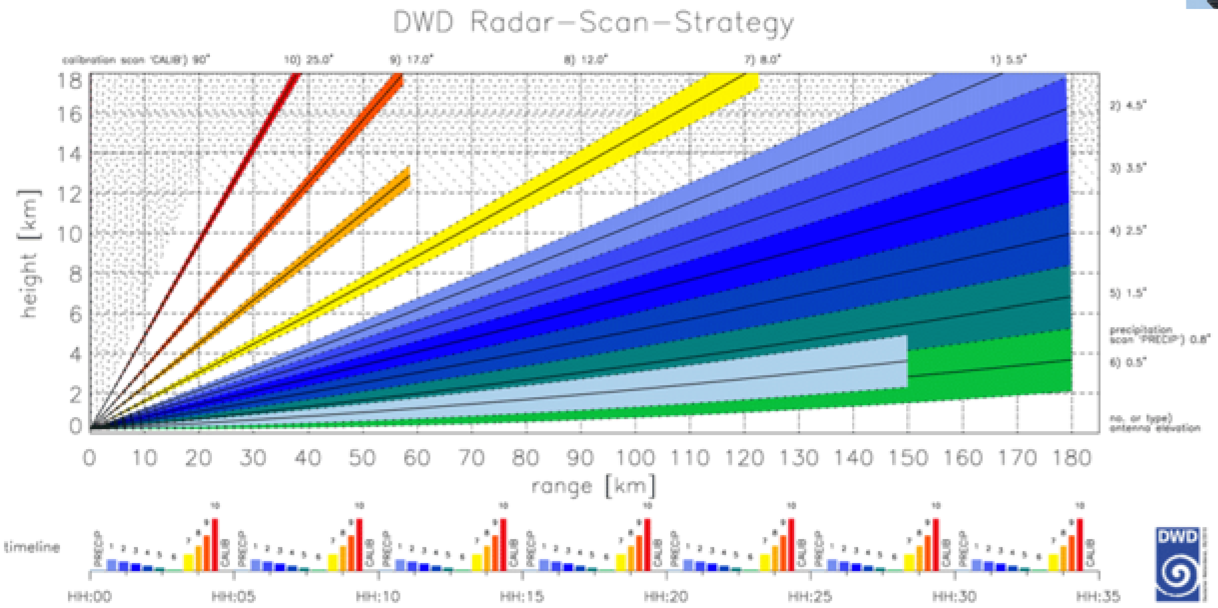
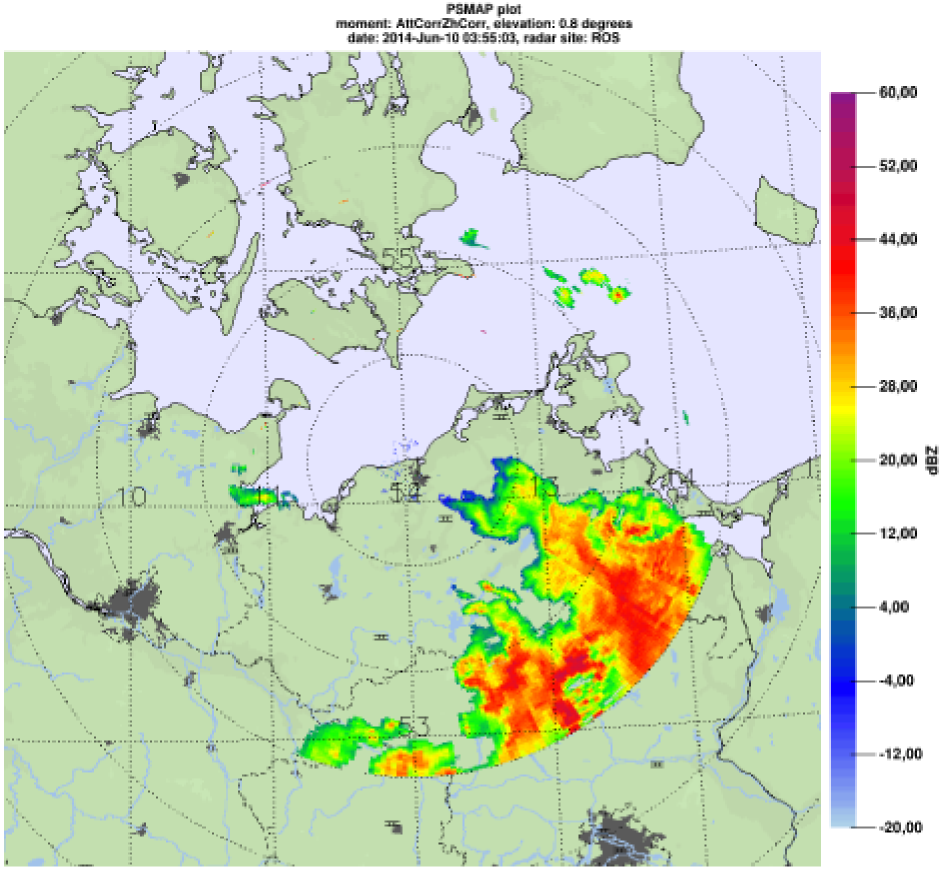
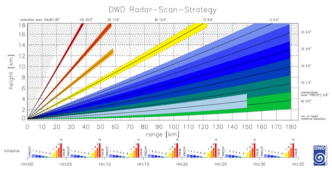
2. Non-station-based measurements → Weather radar: Structure



2. Non-station-based measurements → Weather radar: Scan strategy

https://www.dwd.de/EN/research/observing_atmosphere/weather_radar/weather_radar_node.html





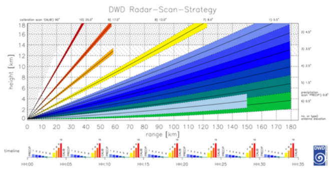
2. Non-station-based measurements → Weather radar: Output

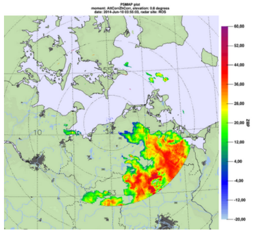
https://en.wikipedia.org/wiki/DBZ_(meteorology)

$$R = \left(\frac{10^{\frac{dBZ}{10}}}{200} \right)^{\frac{5}{8}}$$

Reflectivity in dBZ versus Rainrate

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





ML-4430 Lecture 3: Measurement of Weather and Climate

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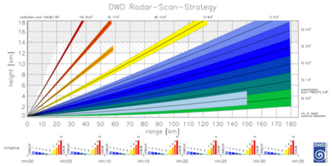
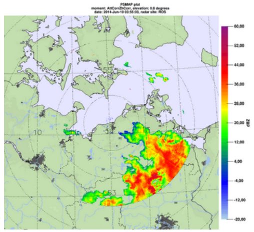
Weather radar:

- 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 relesed as rainfall data





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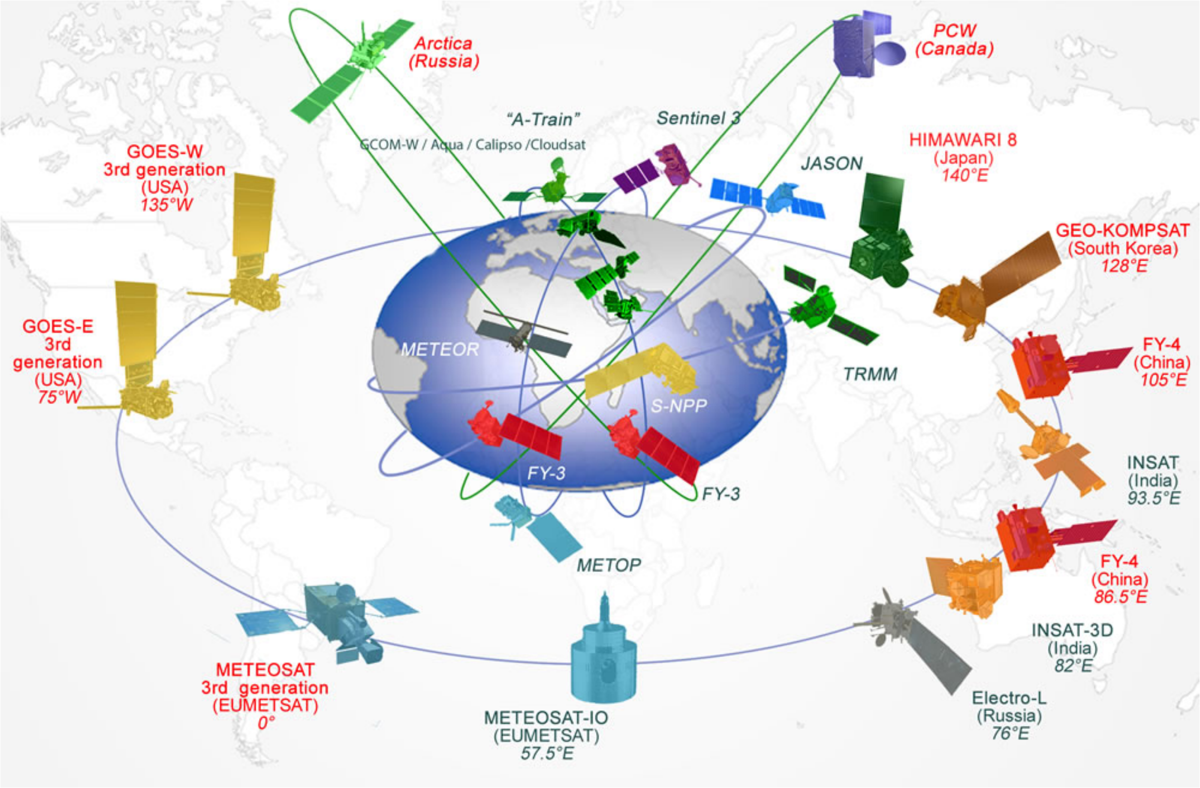
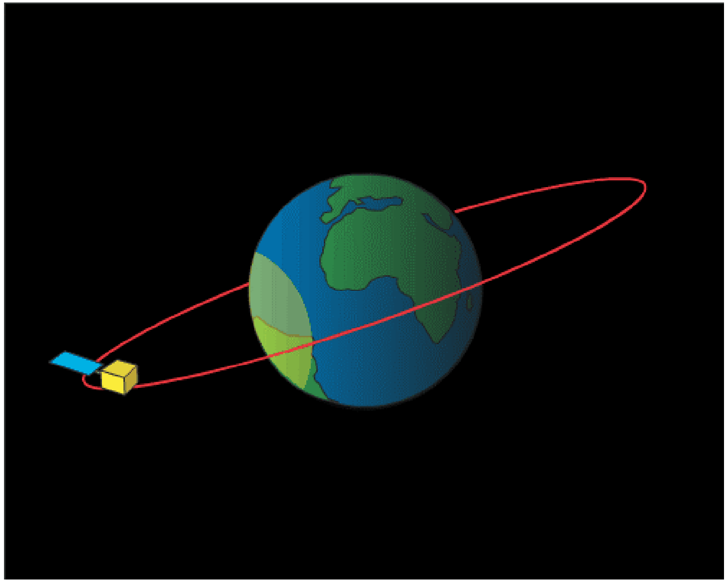
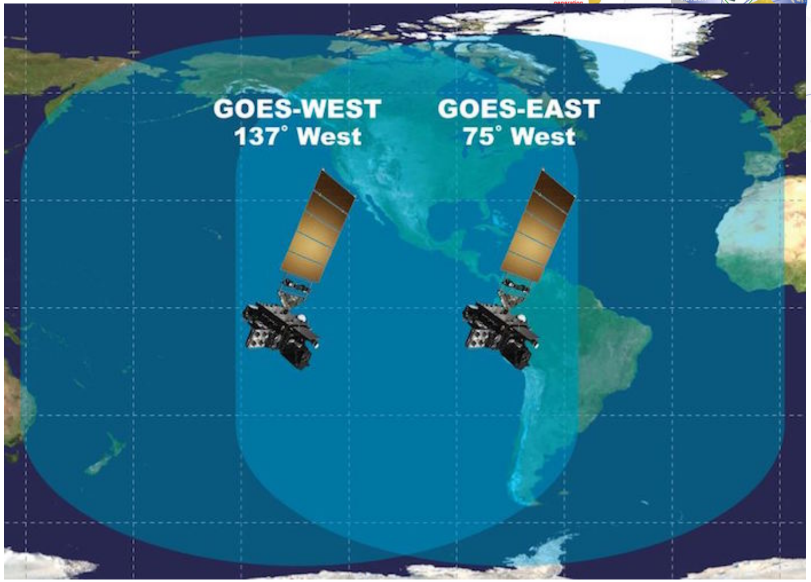
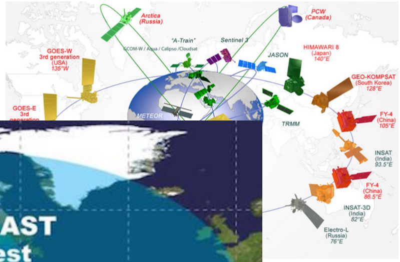


2. Non-station-based measurements → Weather satellites

https://www.weather.gov/about/satellites

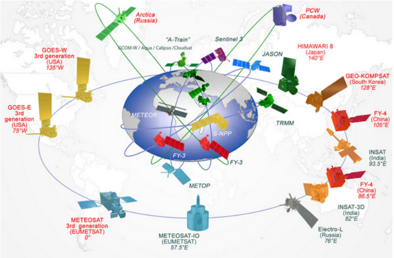


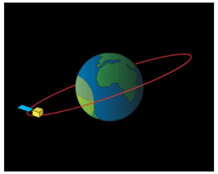


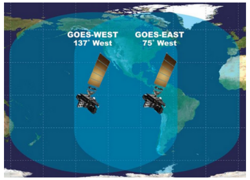


2. Non-station-based measurements → Weather satellites: Geostationary orbit

https://www.youtube.com/watch?v=y_jM_BxQGvE&t=1s







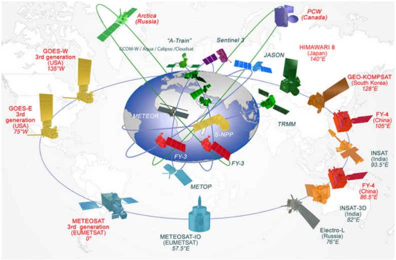
2. Non-station-based measurements → Weather satellites: Polar orbit

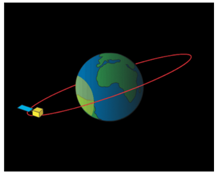
Weather satellites

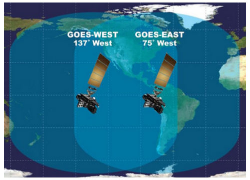
- High resolution data
  - Even for remote locations like oceans, deserts, mountains, and poles
  - Weather forecast and monitoring

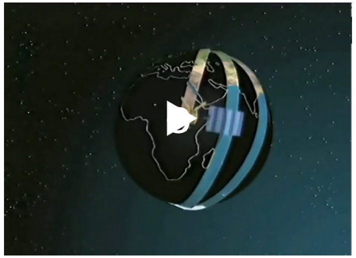
- Geostationary satellites
  - Fixed location with respect to earth
  - 35000 km above earth

- Polar satellites
  - Revolves around the earth on a polar axis
  - 800 – 900 km above the earth
  - Every 102 minutes approx.

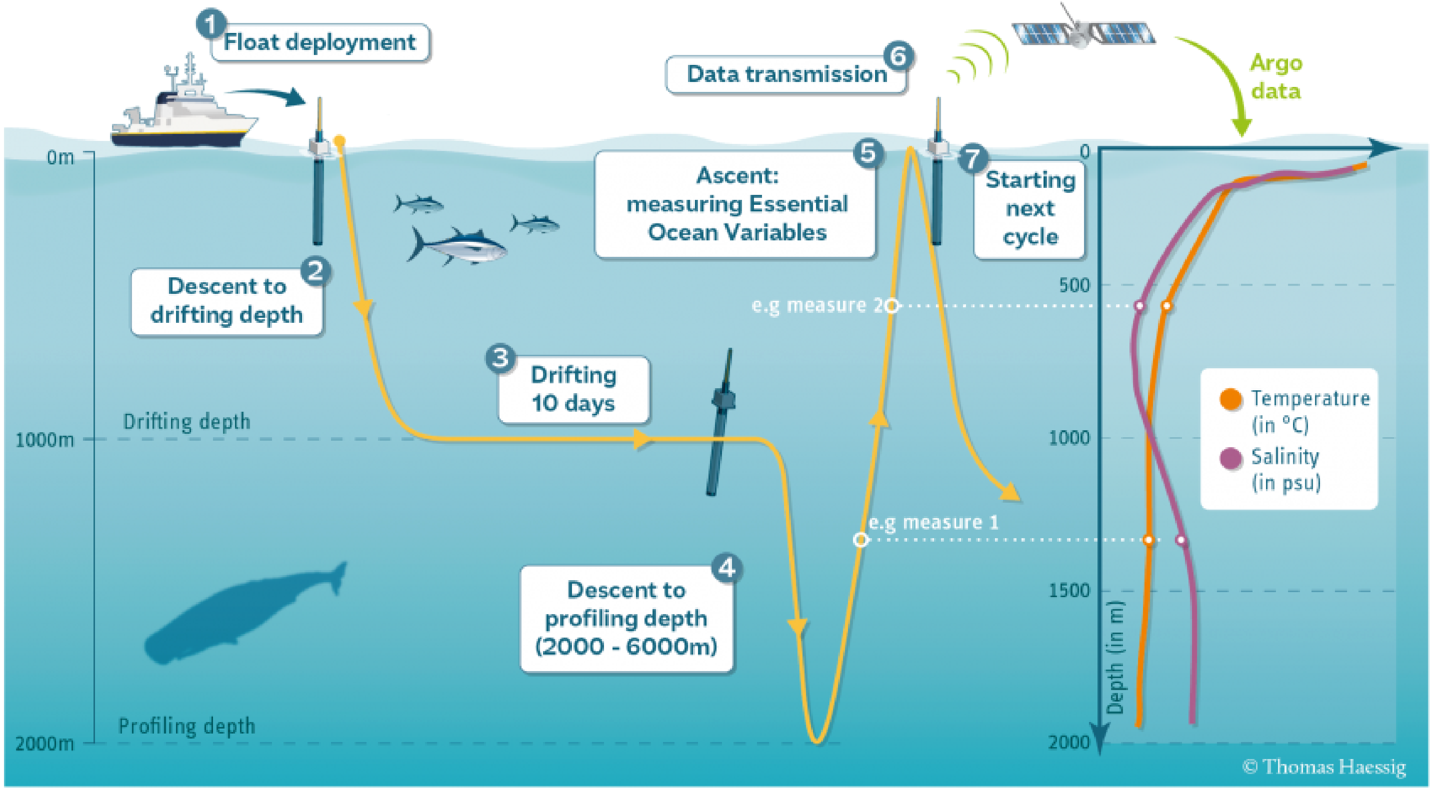






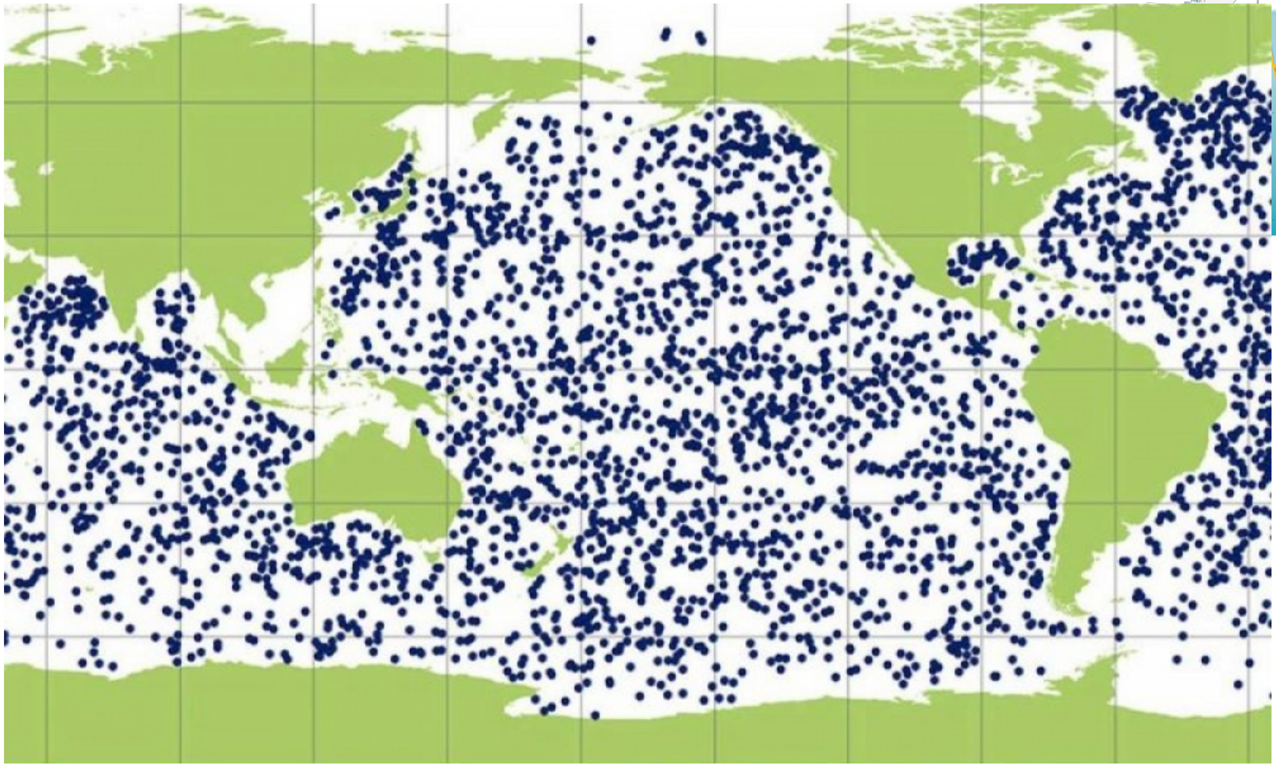


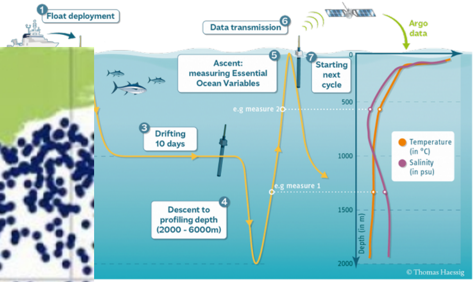
https://argo.ucsd.edu/how-do-floats-work/



2. Non-station-based measurements → Argo floats: How does it work

https://argo.ucsd.edu/





2. Non-station-based measurements → Argo floats: Network

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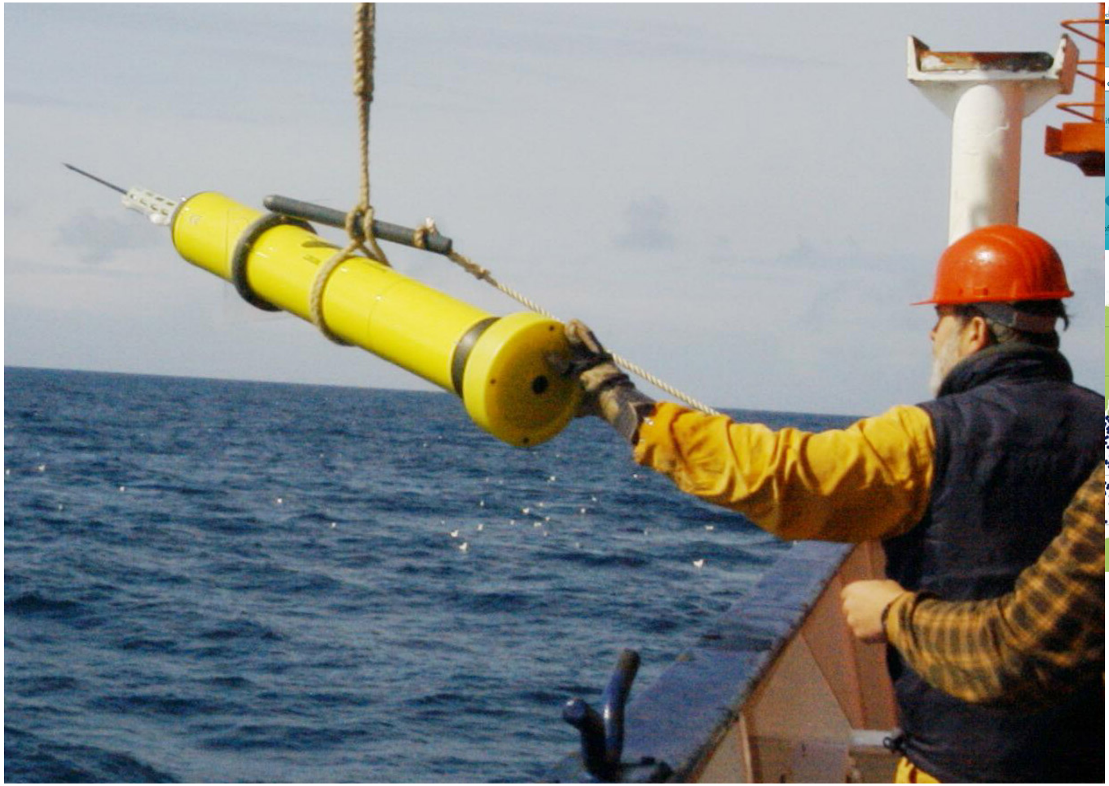
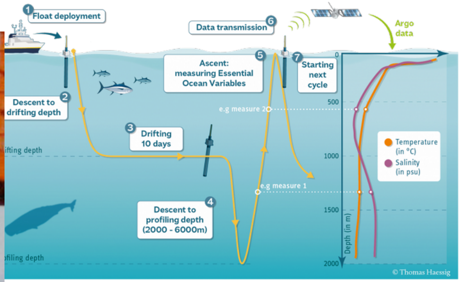
https://argo.ucsd.edu/outreach/multimedia-resources/photos/

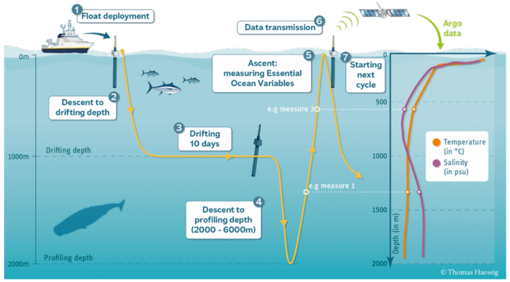


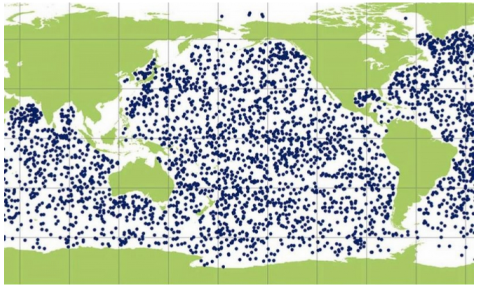


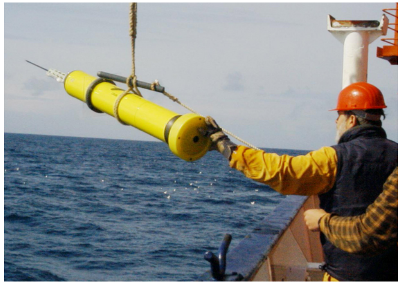
2. Non-station-based measurements → Argo floats: Network

Argo floats

- More than 3500 floats worldwide
- Managed by a large international coopertaion 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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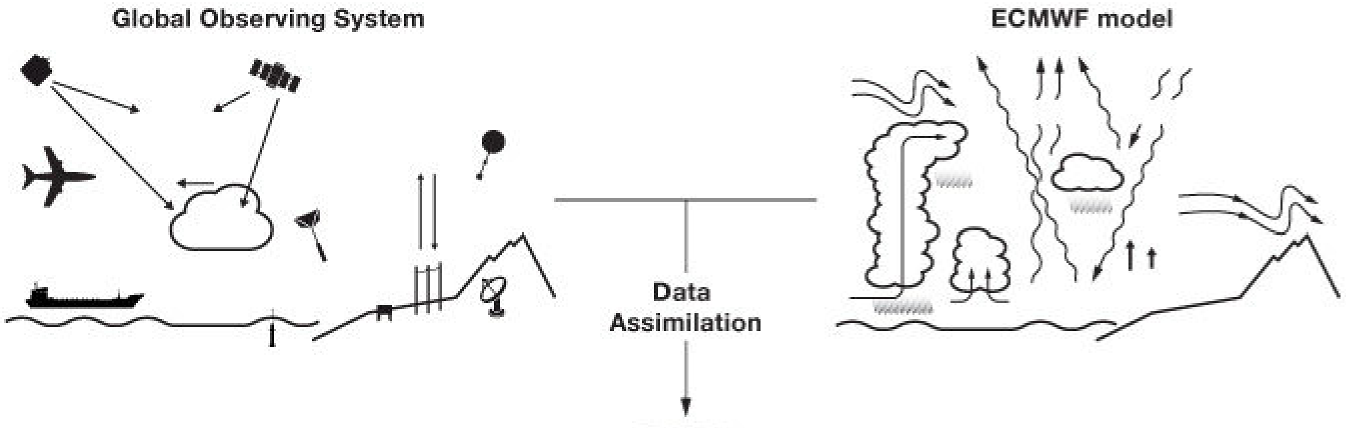
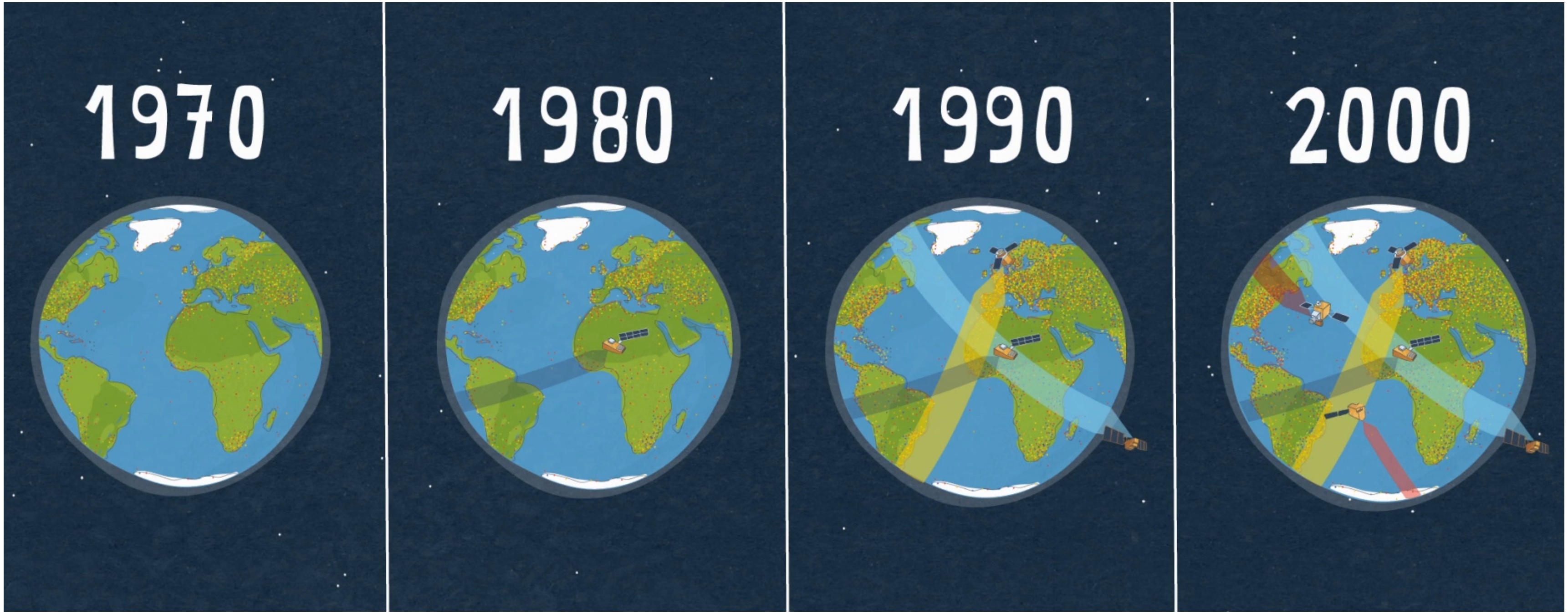
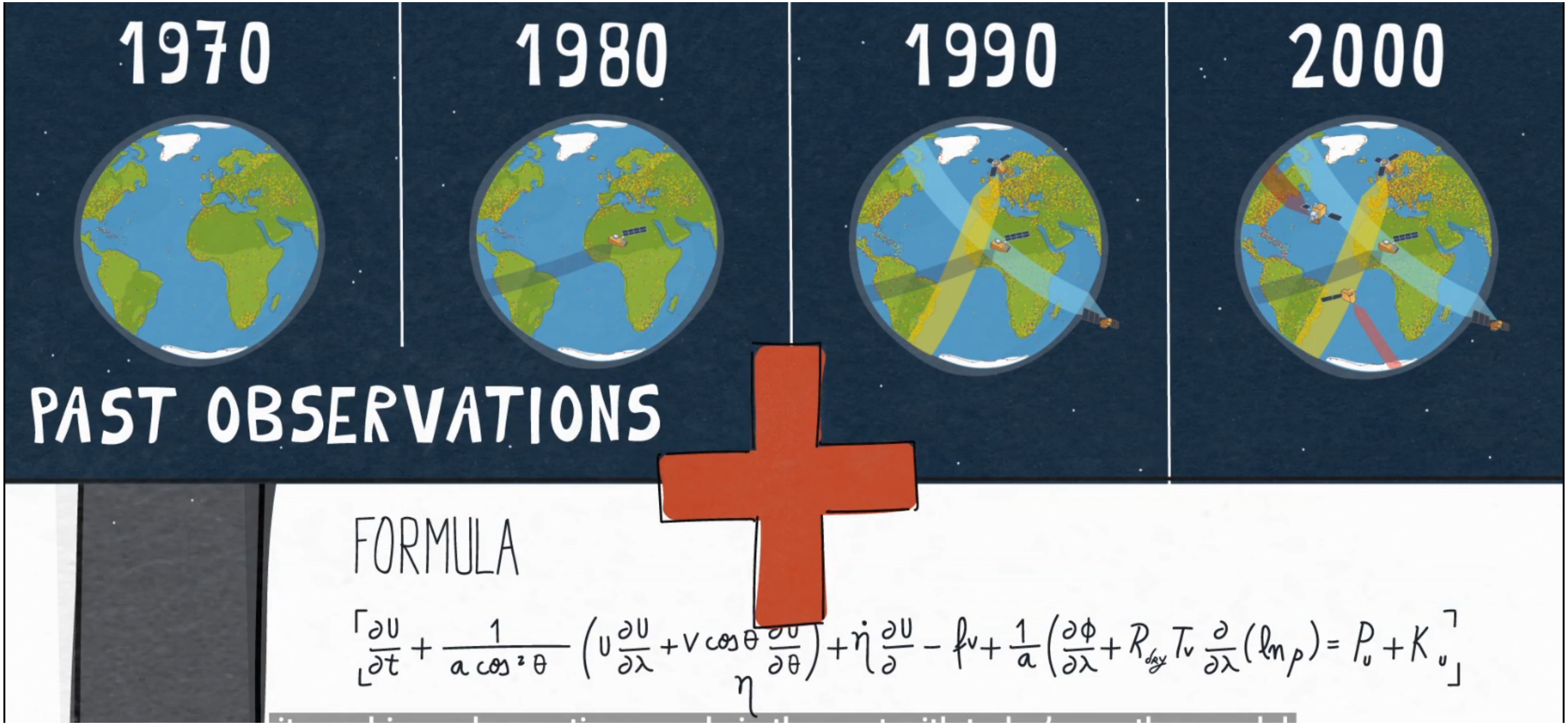


3. Reanalysis → What is reanalysis?



3. Reanalysis → Why do we need reanalysis?



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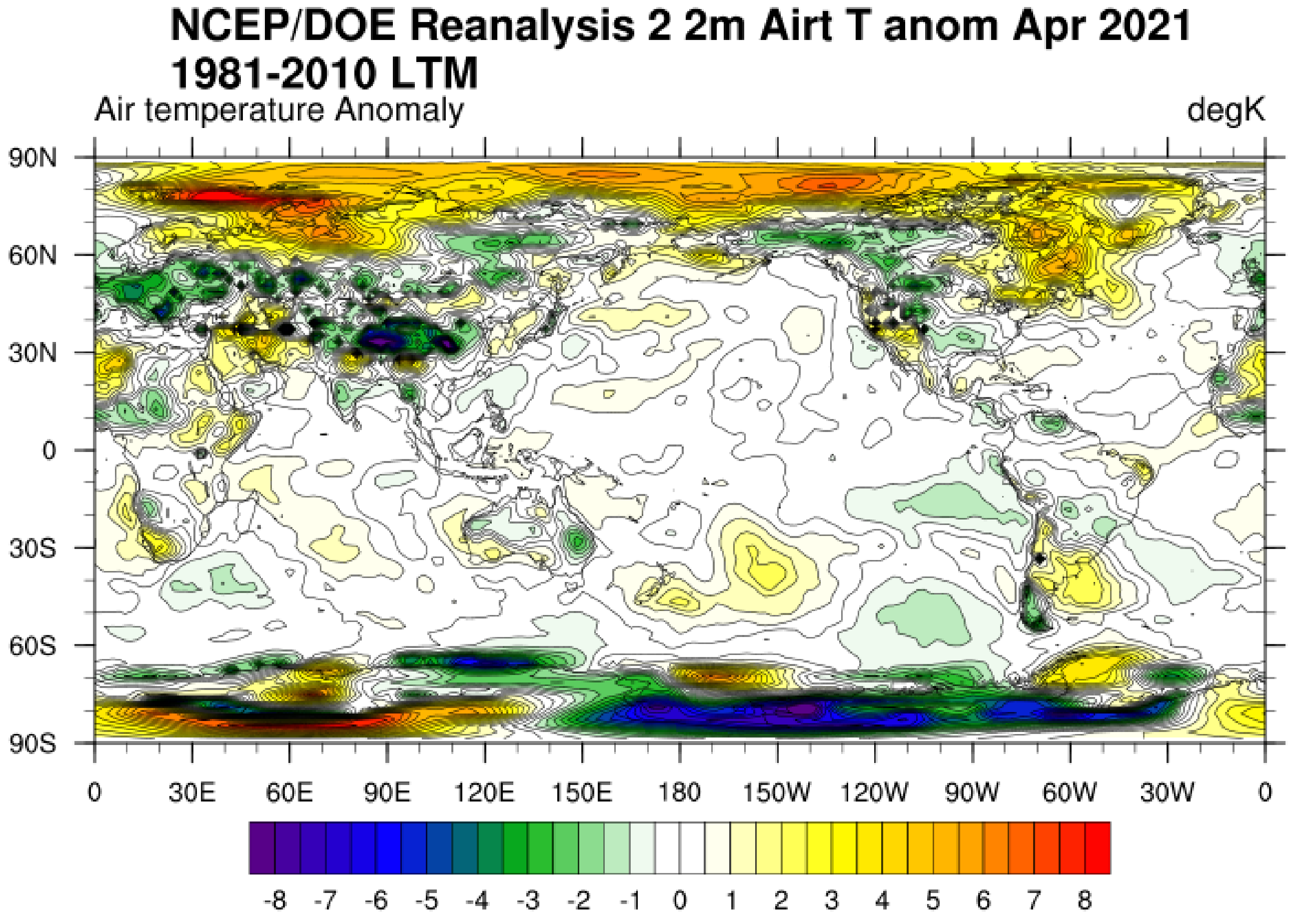
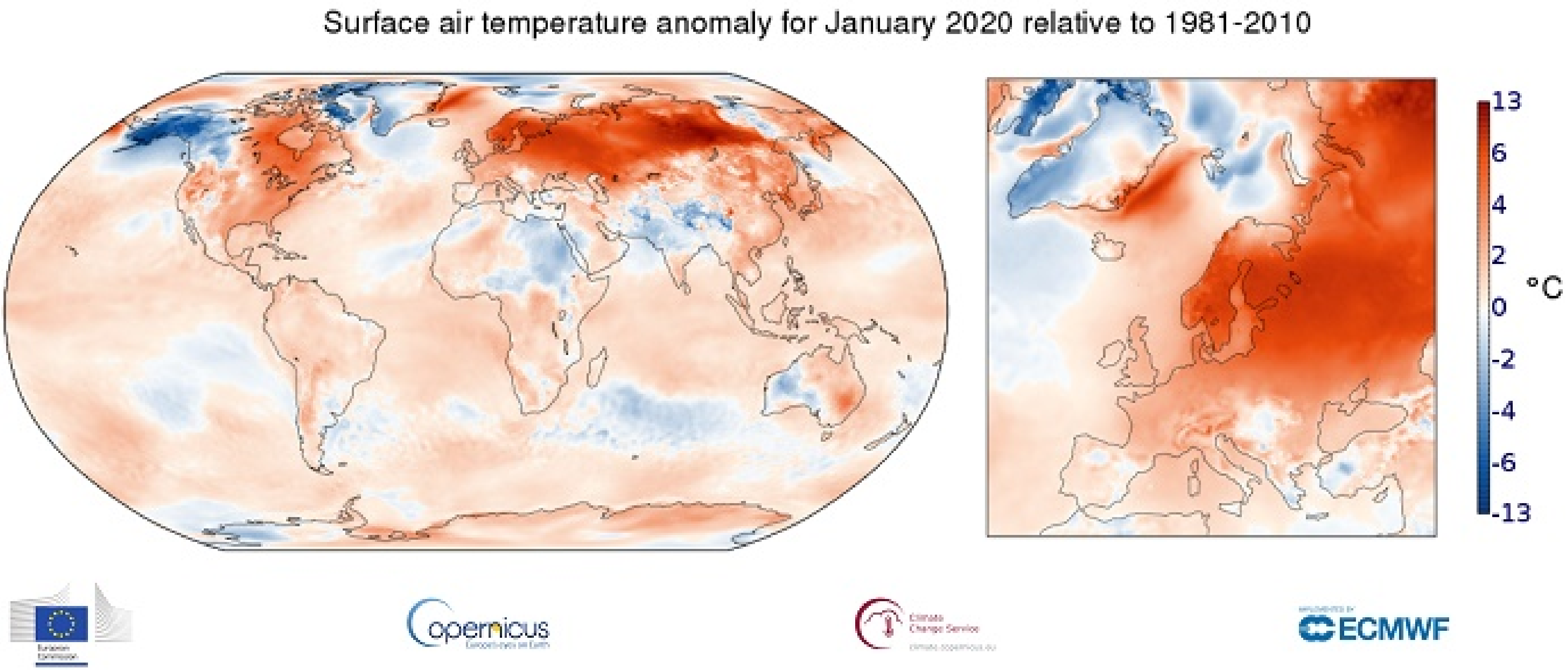


3. Reanalysis → A few examples



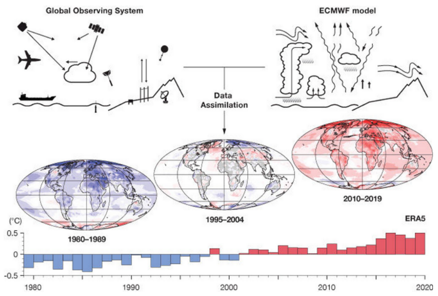
3. Reanalysis → A few examples

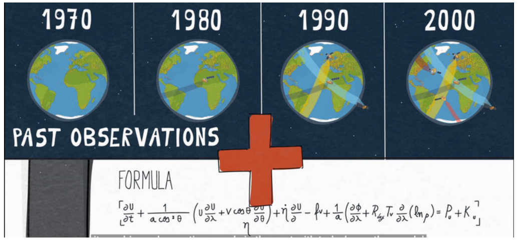
Reanalysis

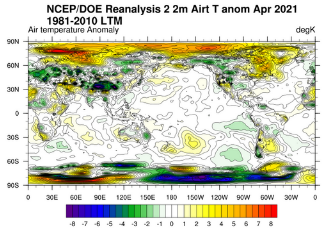
- Combine weather data from heterogeneous sources with a SOTA weather forecast model
  - Regularly gridded long-term cliamte data

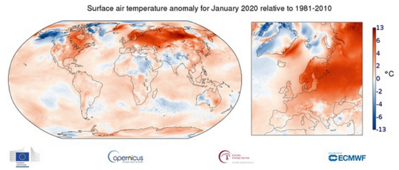
- Necessary because:
  - Data sources are thing as we go back in time
  - Data sources are spatially irregular
  - Data is distrbiuted over different sources

- NCEP R2 and ERA5 are popular reanalysis products









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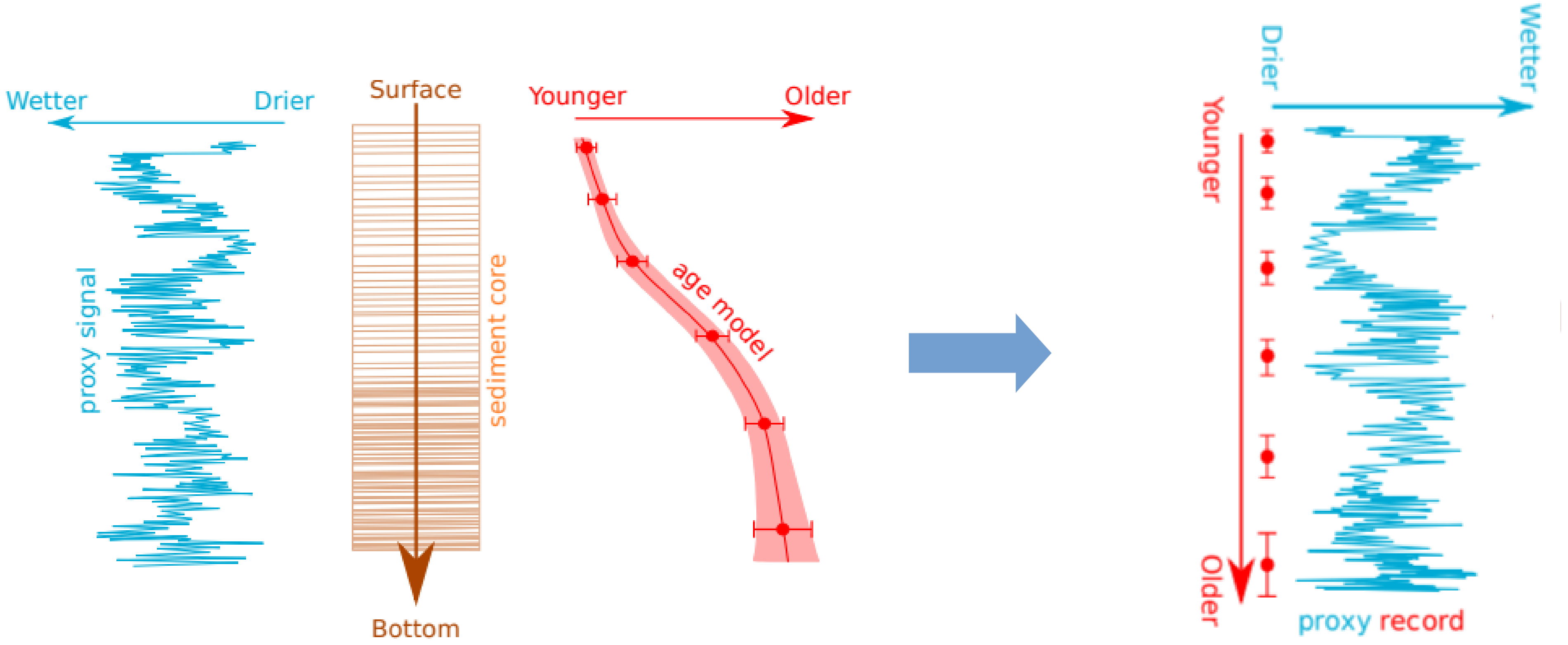
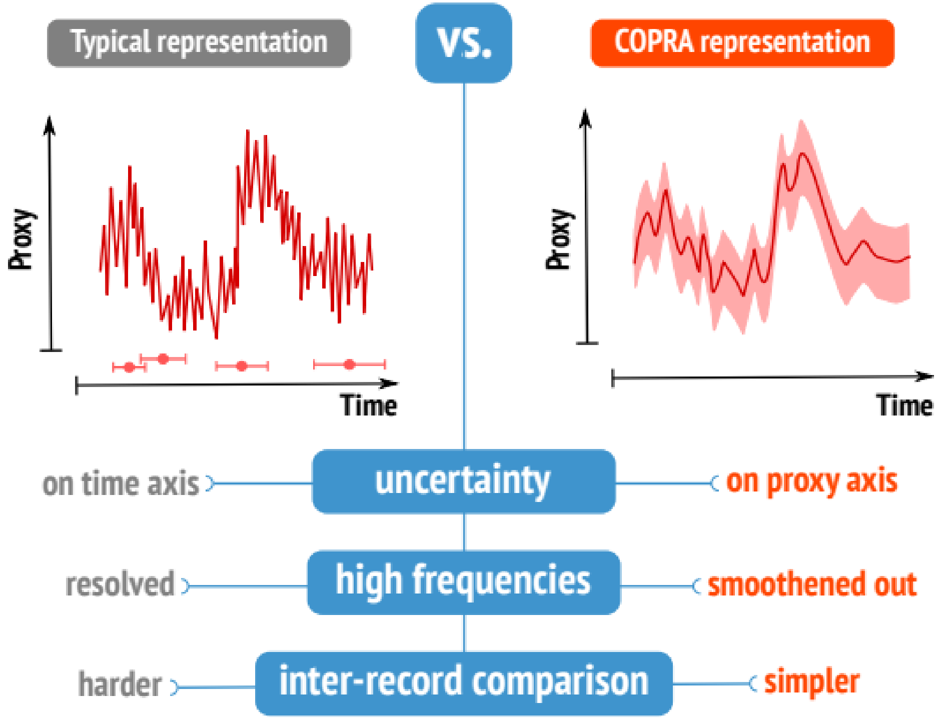
Surface
sediment core
Bottom

https://publishup.uni-potsdam.de/opus4-ubp/frontdoor/index/index/docId/7831



4. Paleoclimate proxy records → The fundamental paradigm



4. Paleoclimate proxy records → Dealing with uncertainty

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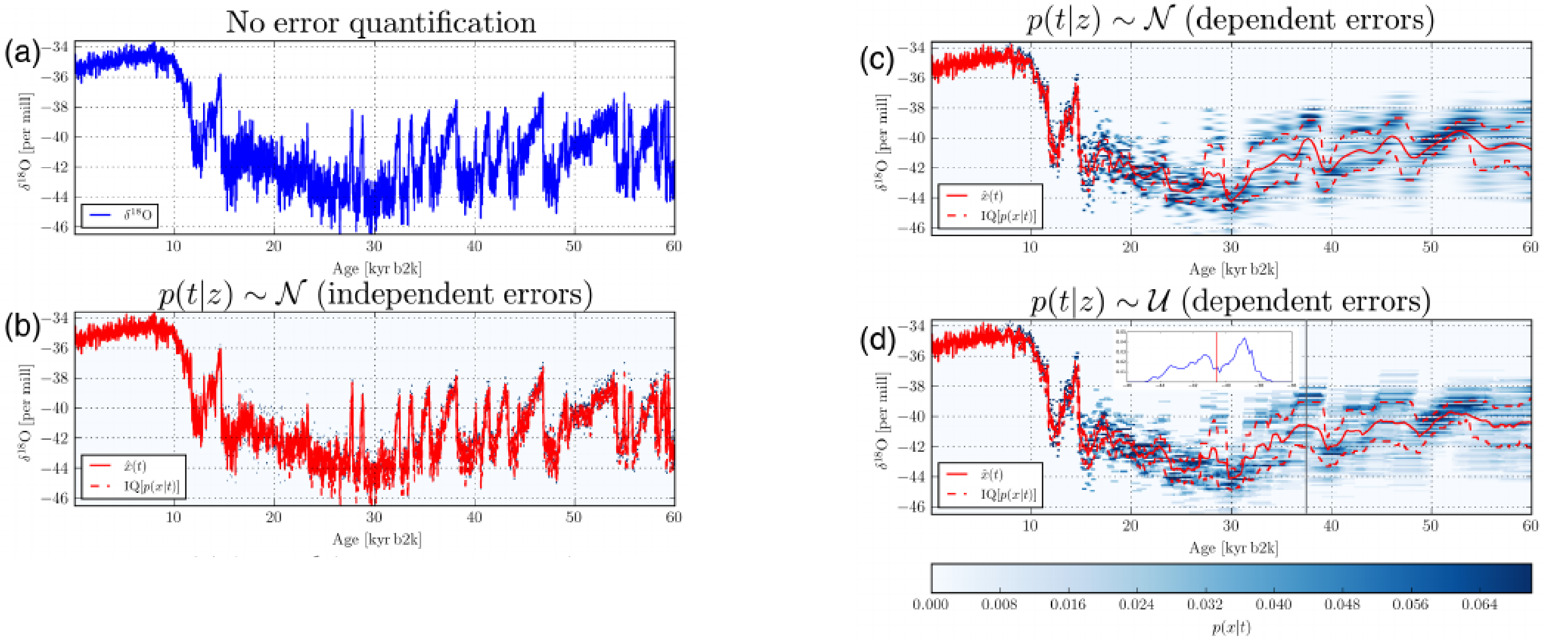
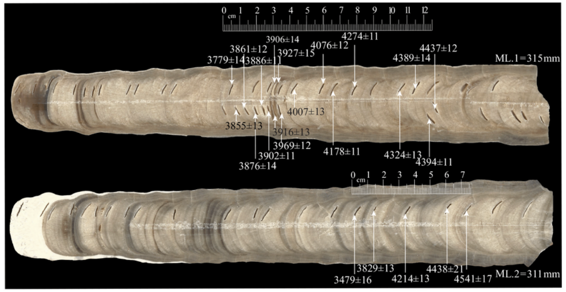
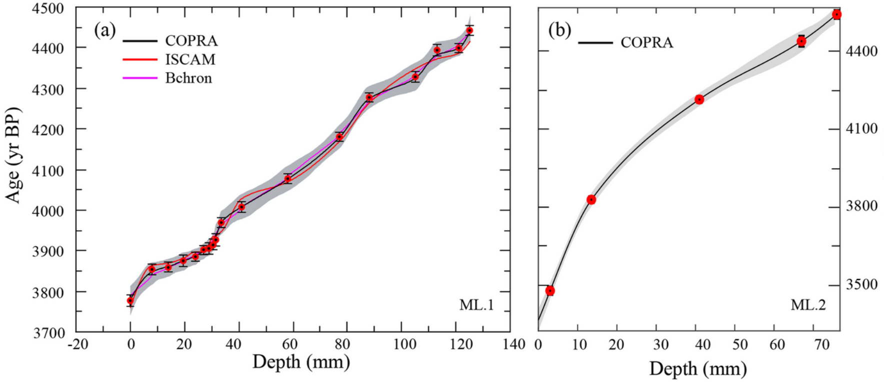
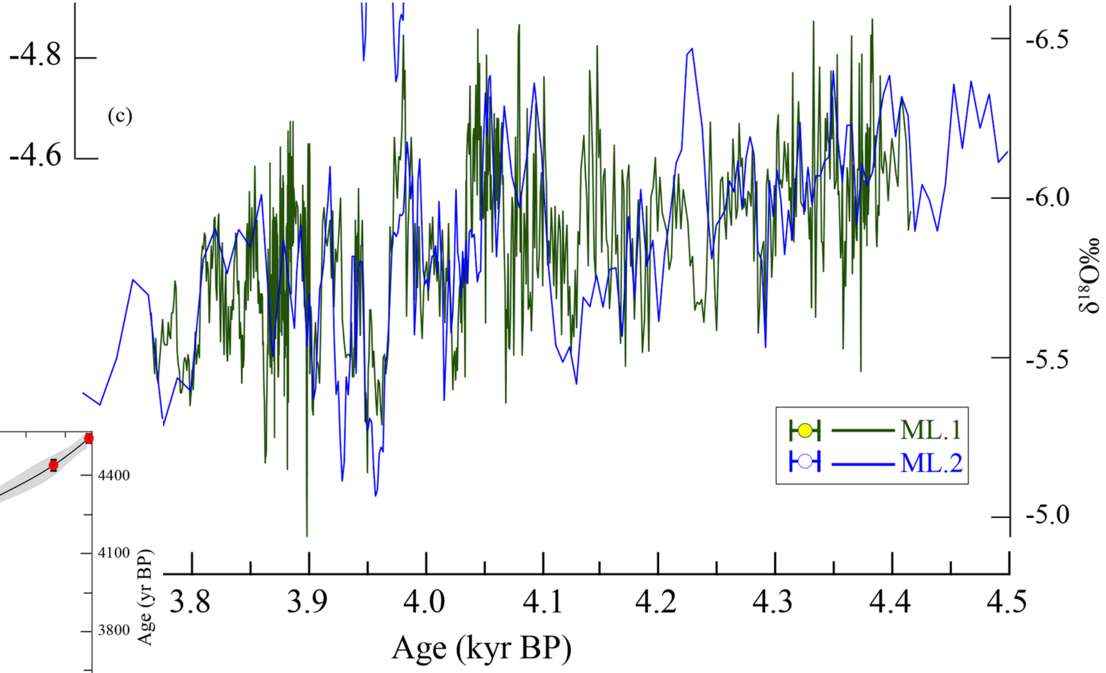


4. Paleoclimate proxy records → Dealing with uncertainty

https://cp.copernicus.org/articles/14/1869/2018/







4. Paleoclimate proxy records → A few examples

https://doi.org/10.1016/j.quascirev.2006.08.002

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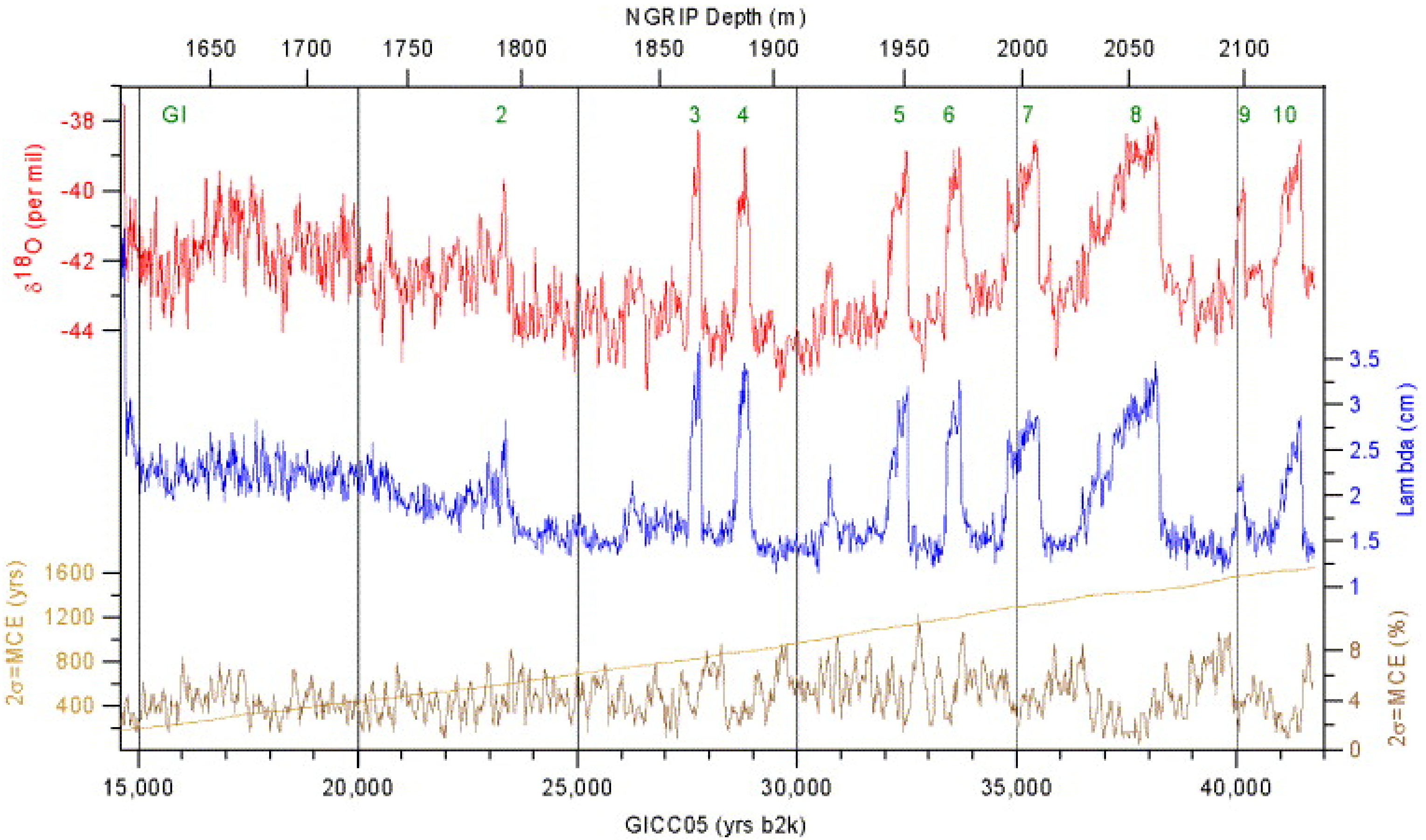

4. Paleoclimate proxy records → A few examples

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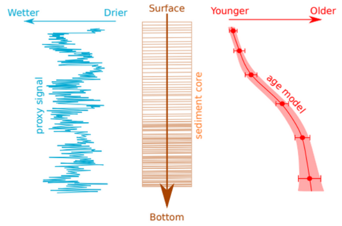
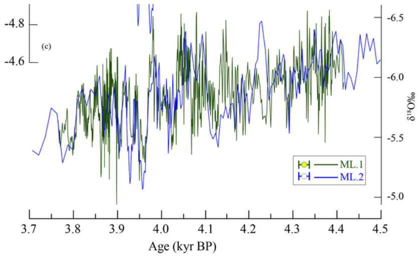
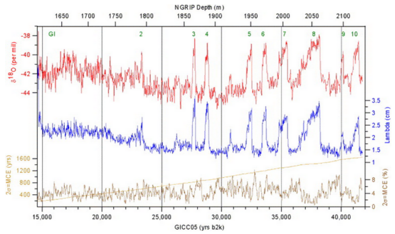
Paleoclimate proxy records

- 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







Q&A