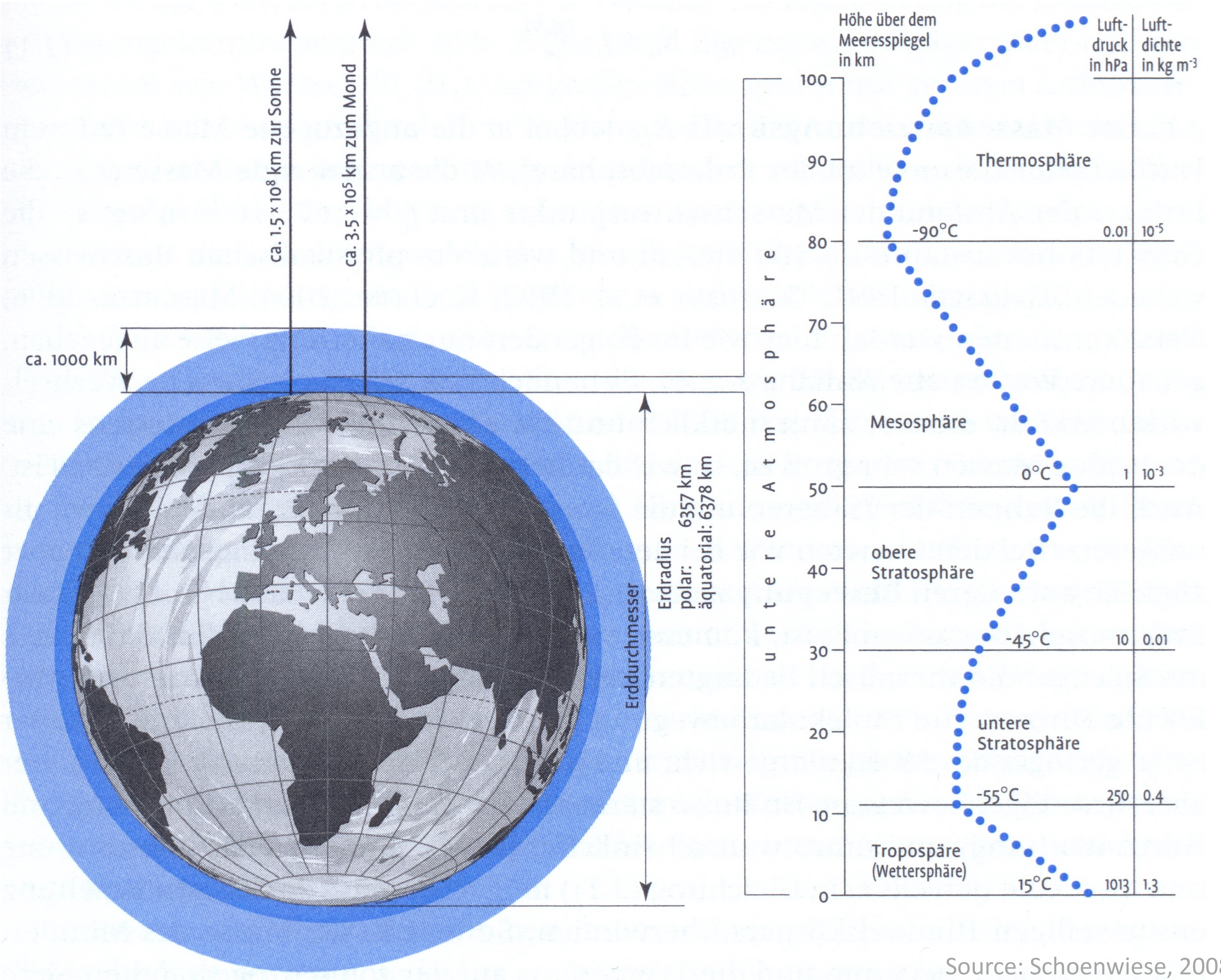
Field Observation in Climatology and Environmental Hydrology

Module: Weather Observations

Temperature, wind, radiation

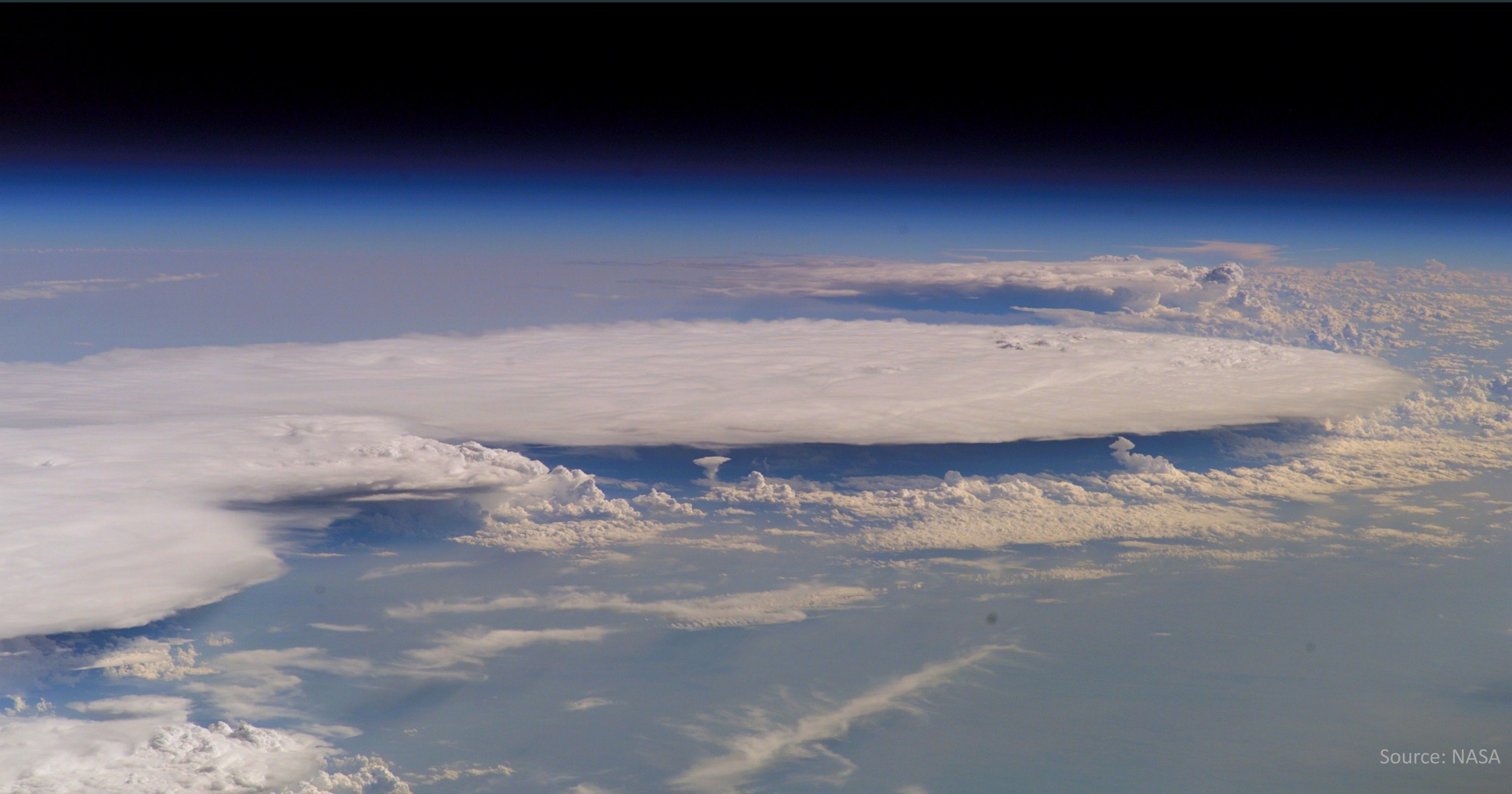
Prof. Dr. Tobias Sauter
Date 20.04.2023

Vertical structure of the atmosphere

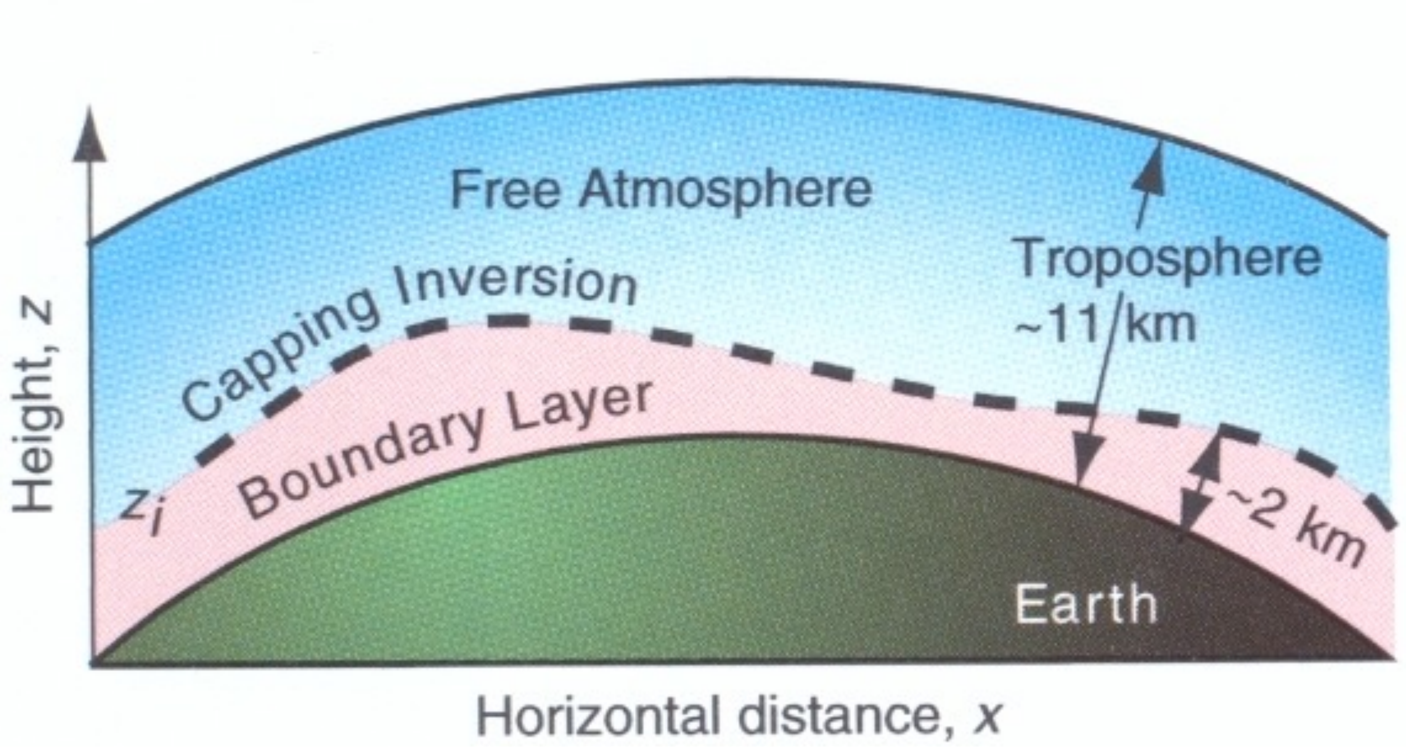


Source: Schoenwiese, 2008

Satellite image from NASA



Vertical structure of the troposphere



Vertical cross section of the Earth and troposphere showing the atmospheric boundary layer as the lowest portion of the troposphere

Source: Wallace & Hobbs, 2006

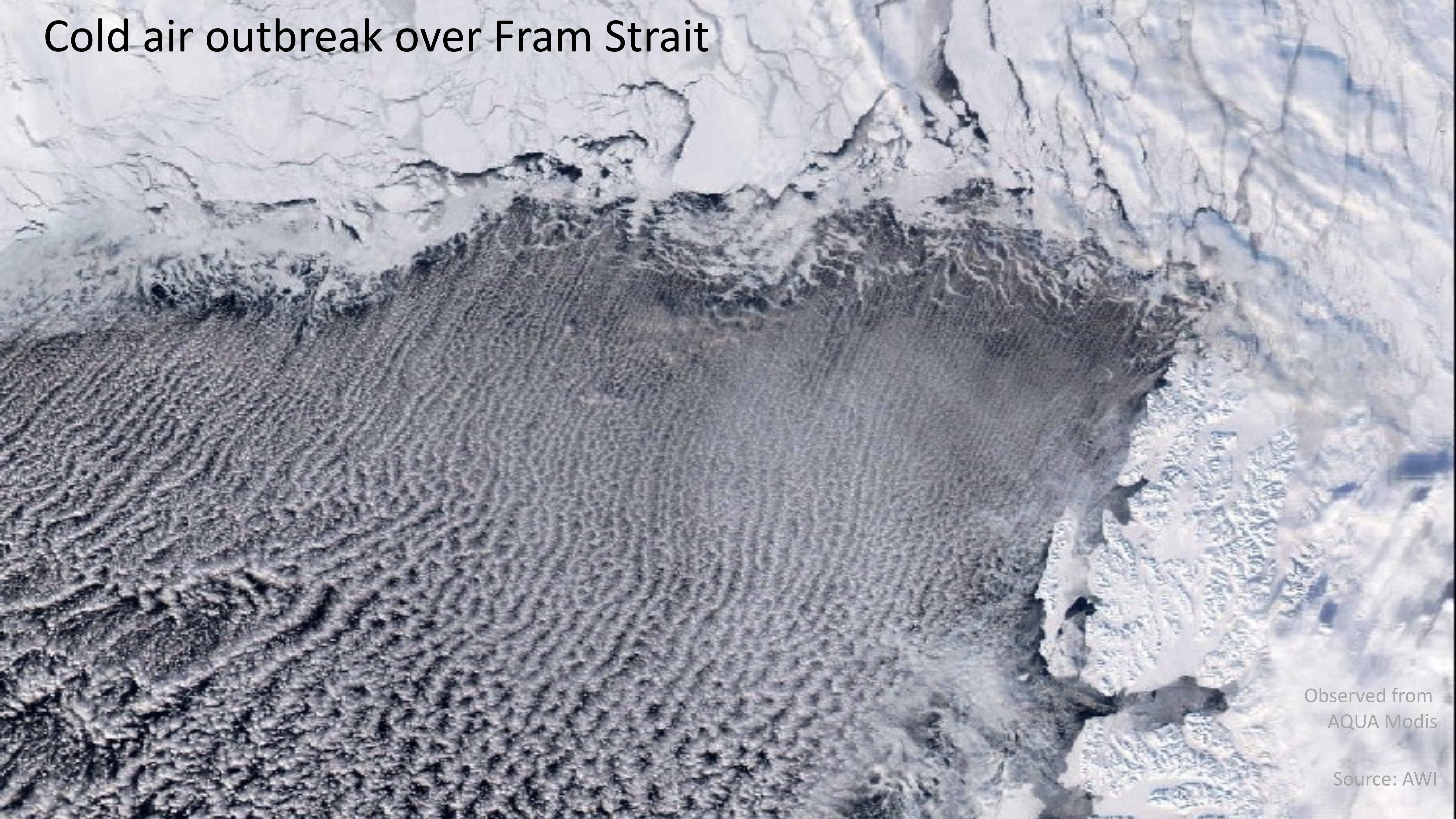
Inversion at the Böhmische Becken

Source:
wetterzentrale.de

Convection over a system of two leads (Fram Strait)

Source: AWI

Cold air outbreak over Fram Strait



Observed from AQUA Modis

Source: AWI

Smog in Los Angeles

Source: waow.com

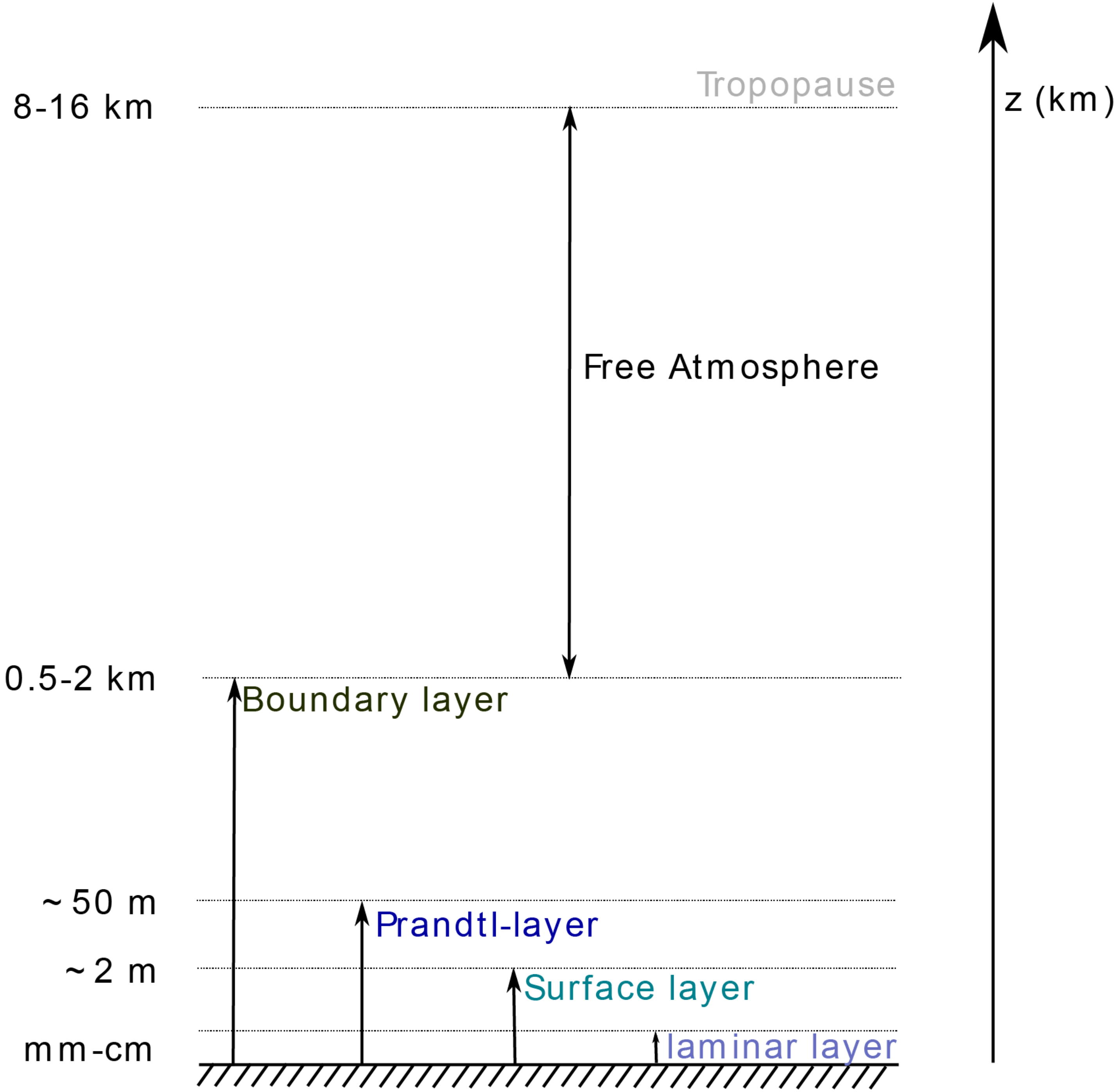
Boundary Layer

Definition

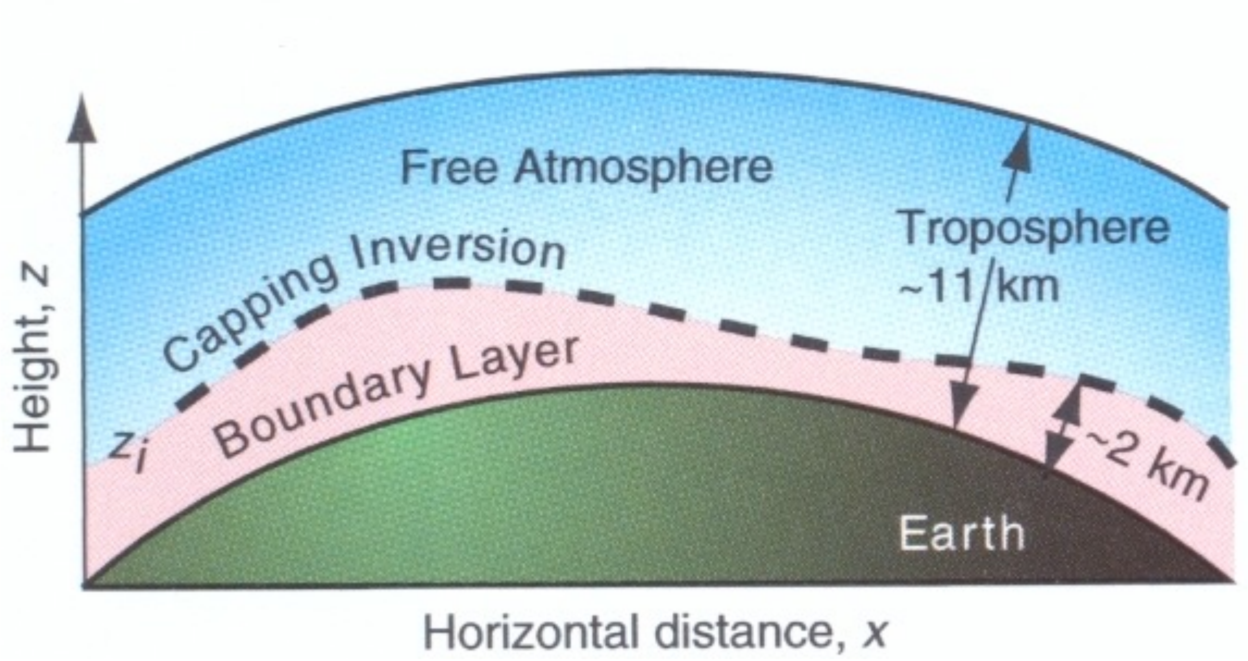
"The boundary layer is defined as the part of the troposphere that is directly influenced by the presence of the earth's surface, and responds to surface forcings with a timescale of about an hour or less."

Source: Stull, 2009

Vertical structure of the boundary layer



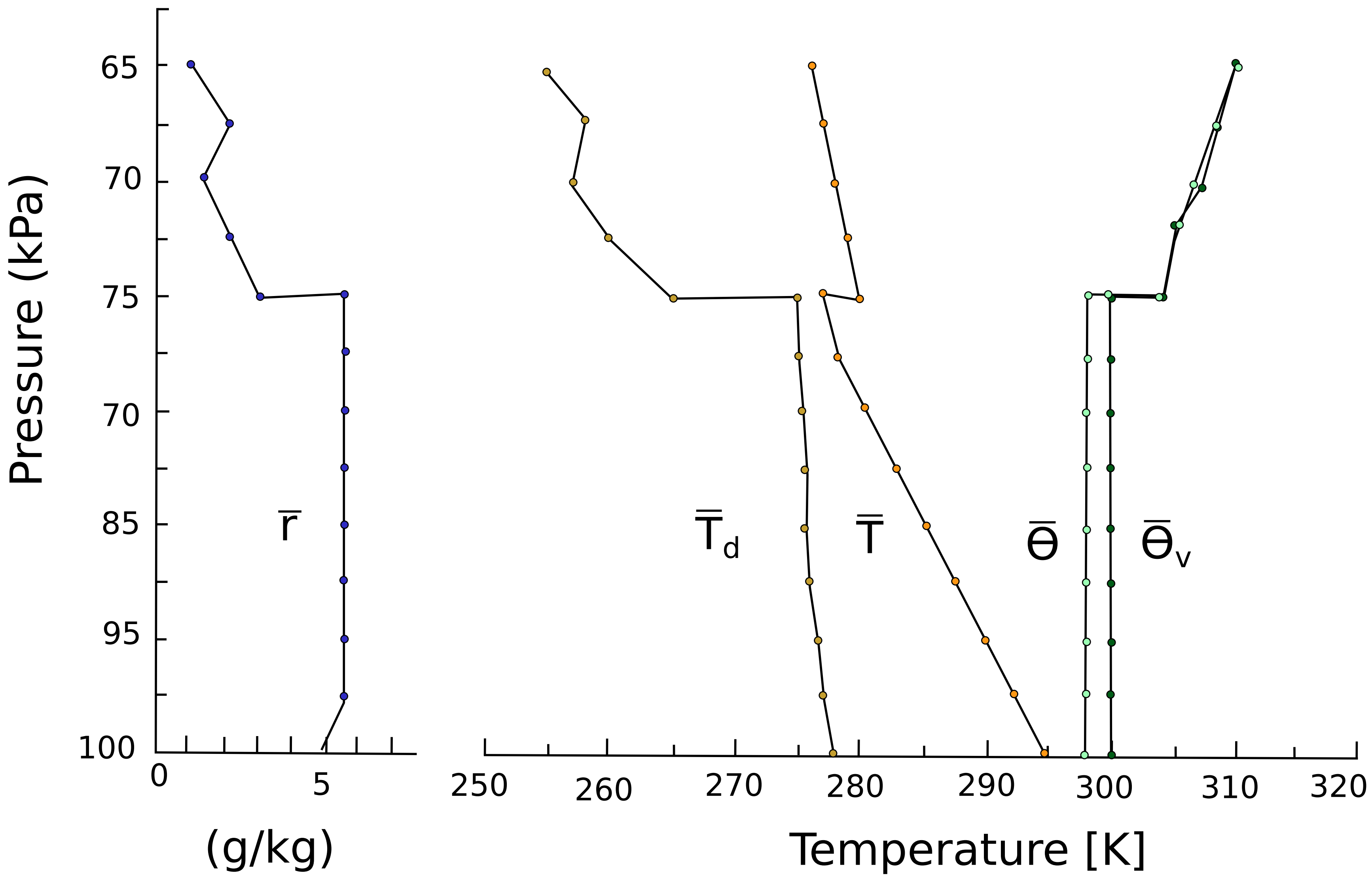
Characteristics of the boundary layer



Source: Wallace & Hobbs, 2006

- Wind velocity $U = 0$ at the surface
- Jump of physical properties at the surface
- Source/sink of energy and solid matter
- Characteristic vertical profiles of wind, humidity and temperature
- Profiles are coupled with fluxes
- Fluxes are mostly turbulent

Example: Temperature variation



Evolution of temperatures based on radiosonde launches

modified after Stull, 2009

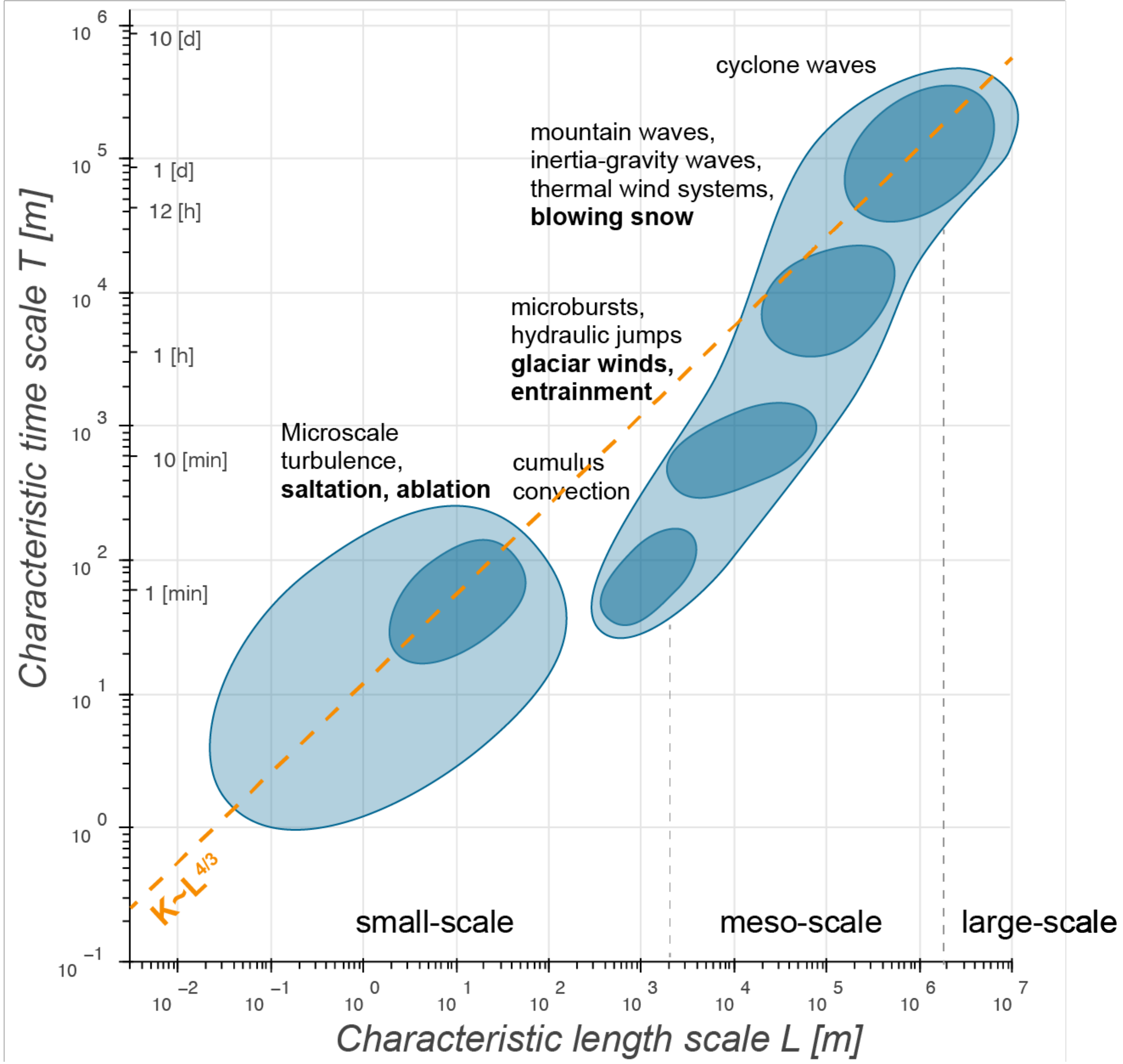
Boundary Layer

Definition

“The boundary layer is defined as the part of the troposphere that is directly influenced by the presence of the earth’s surface, and responds to surface forcings with a timescale of about an hour or less.”

Source: Stull, 2009

Atmospheric scales



Types of clouds in the BL: Fair weather clouds

Cumulus humilis

Cumulus humilis

Source: www.wolkenatlas.de

Types of clouds in the BL: Stratocumulus

Stratocumulus stratiformus opacus

Stratocumulus stratiformus translucidus

Source: www.wolkenatlas.de

Why studying boundary layer (BL)?

Baloon launch

Source: NOAA

Why studying BL?

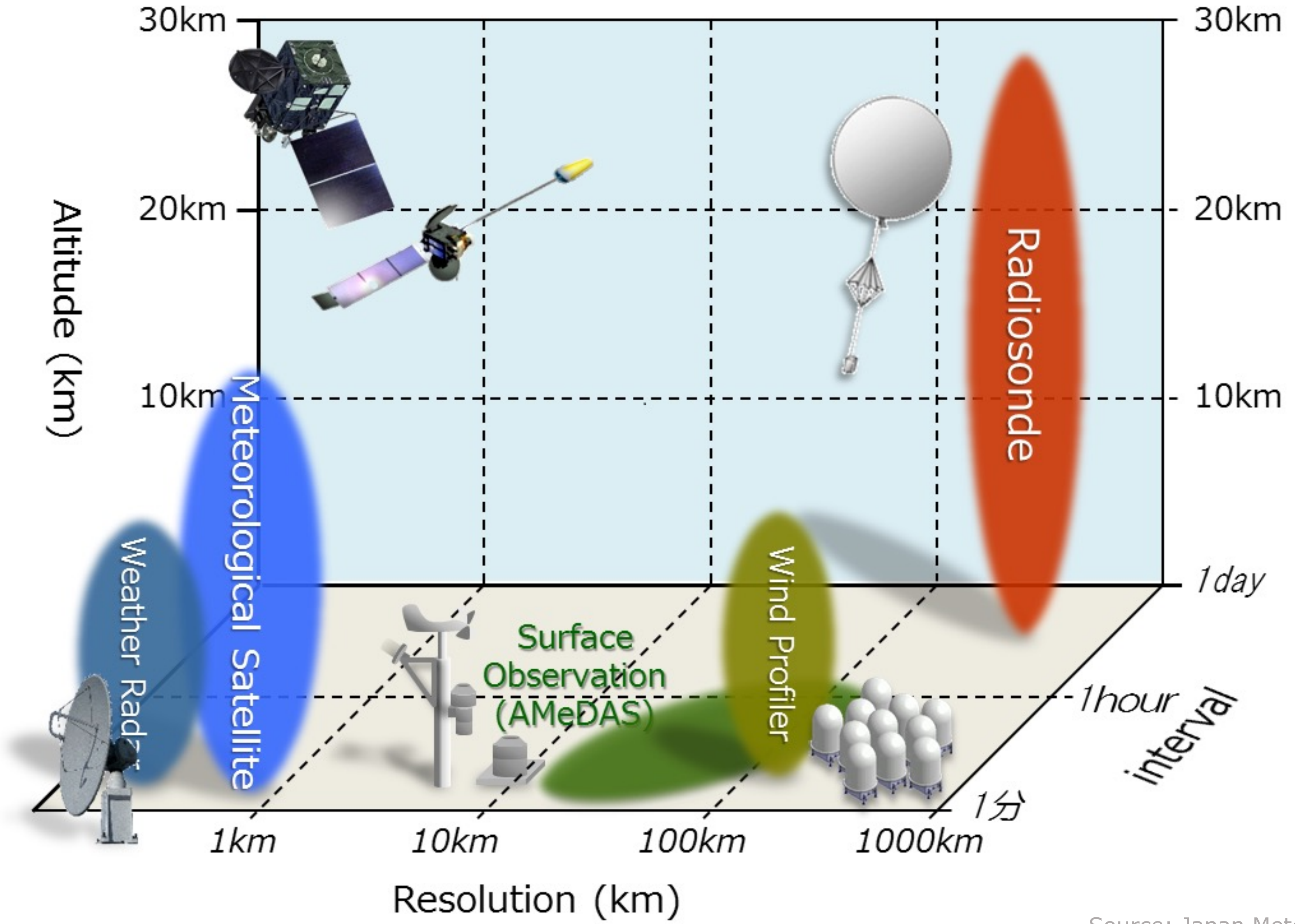
- We live our lives within the boundary layer
- Weather forecast (dew, frost, etc.)
- Baroclinity is generated
- Air quality and pollution
- Energy exchange at atmosphere-surface interface
- Cloud nuclei transported by BL processes
- Dissipation of kinetic energy (50% of atmosphere)
- Unsolved problems of classical physics, e.g. turbulence
- Turbulence
- Exciting processes and phenomena

Key questions

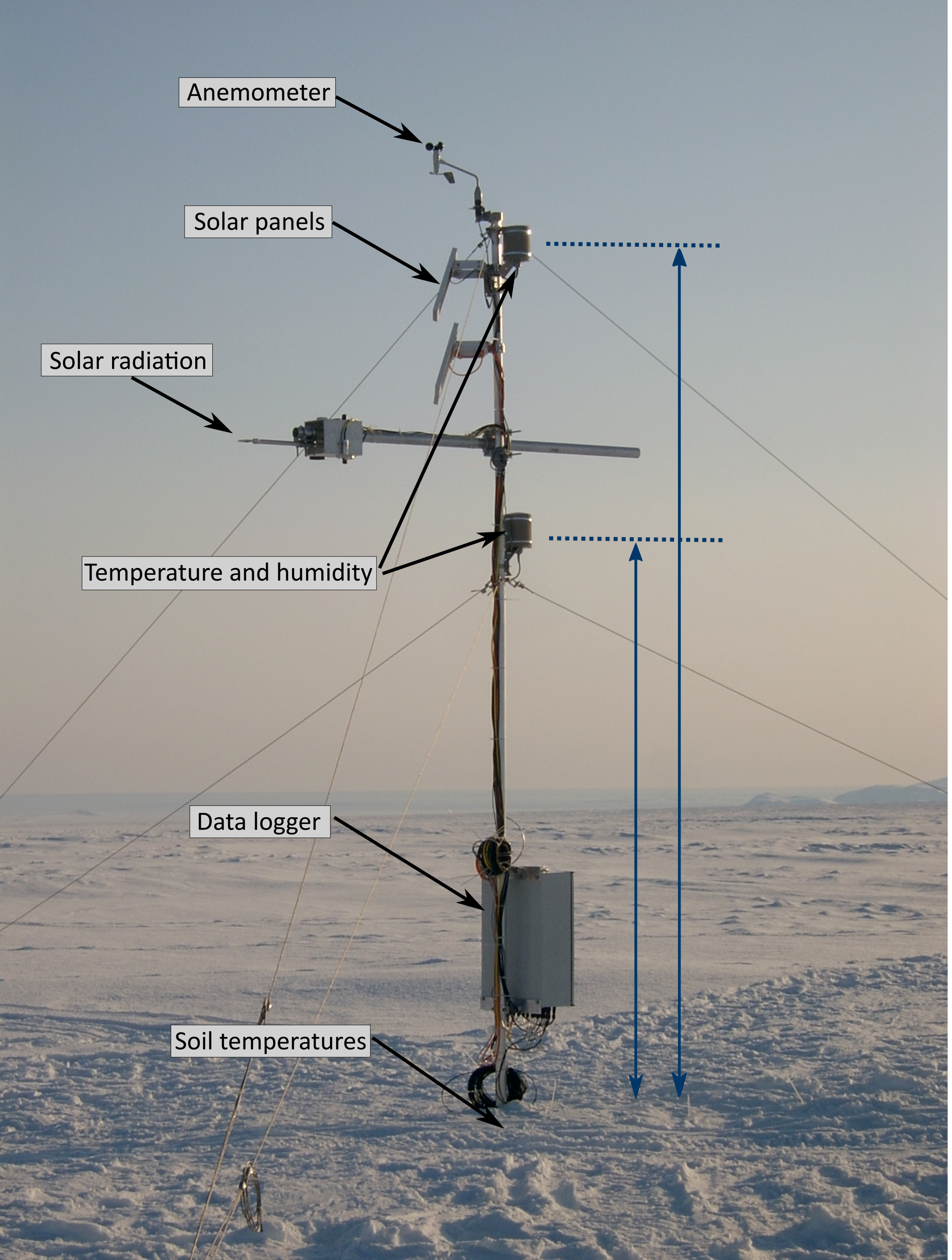
- How is the planetary boundary layer (PBL) vertically structured?
- How can the PBL be physically be described?
- What determines the exchange of energy and mass between the atmosphere and the Earth’s surface?
- How much water, energy and other properties are available at the surface?

How can we measure meteorological quantities?

Weather observation



Source: Japan Meteorological Agency (JMA)



Automatic weather stations (AWS) are equipped with sensors that can measure a variety of meteorological quantities.

- Temperature: thermistor or thermocouple
- Relative humidity: capacitive or resistive sensor
- Barometric pressure: piezoresistive or capacitive sensor
- Wind speed and direction: anemometer and wind vane
- Precipitation: tipping-bucket or weighing-bucket gauge
- Solar radiation: pyranometer or solar radiation sensor
- Atmospheric radiation: pyrgeometer
- Soil temperature and moisture: temperature and moisture sensors

Logger-file

```
TIMESTAMP_START,TIMESTAMP_END,TA_F,TA_F_QC,SW_IN_POT,SW_IN_F,SW_IN_F_QC,LW_IN_F,LW_IN_F_QC,VPD_F,VPD_F_QC,PA_F,PA_F_QC,P_F,P_F_QC,WS_F,WS_F_QC,WD,USTAR,RH,NETRAD,PPFD_IN,SW_OUT,LW_OUT,CO2_F_MDS,CO2_F_MDS_QC,TS_F_MDS_1,TS_F_MDS_2,TS_F_MDS_3,TS_F_MDS_1_QC,TS_F_MDS_2_QC,TS_F_MDS_3_QC,SWC_F_MDS_1,SWC_F_MDS_2,SWC_F_MDS_3,SWC_F_MDS_1_QC,SWC_F_MDS_2_QC,SWC_F_MDS_3_QC,G_F_MDS,G_F_MDS_QC,LE_F_MDS,LE_F_MDS_QC,LE_CORR,LE_CORR_25,LE_CORR_75,LE_RANDUNC,H_F_MDS,H_F_MDS_QC,H_CORR,H_CORR_25,H_CORR_75,H_RANDUNC,NIGHT,NEE_VUT_REF,NEE_VUT_REF_QC,NEE_VUT_REF_RANDUNC,NEE_VUT_25,NEE_VUT_50,NEE_VUT_75,NEE_VUT_25_QC,NEE_VUT_50_QC,NEE_VUT_75_QC,RECO_NT_VUT_REF,RECO_NT_VUT_25,RECO_NT_VUT_50,RECO_NT_VUT_75,GPP_NT_VUT_REF,GPP_NT_VUT_25,GPP_NT_VUT_50,GPP_NT_VUT_75,RECO_DT_VUT_REF,RECO_DT_VUT_25,RECO_DT_VUT_50,RECO_DT_VUT_75,GPP_DT_VUT_REF,GPP_DT_VUT_25,GPP_DT_VUT_50,GPP_DT_VUT_75,RECO_SR,RECO_SR_N
199701010000,199701010030,-5.493,0,0.0,0.0,0,237.296,2,0.594,0,82.3,0,0.0,0,1.05,0,167.031,0.0618,85.3667,-0.98,-9999,-9999,-9999,361.763,0,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-0.26254,3.0,1.02657,0,1.97293,-9999,-9999,2.91982,-11.9127,0,-22.893,-9999,-9999,16.4153,1,-1.25987,2,1.85492,0.12365,2.22009,2.99135,1,1,1,1.22137,0.776866,1.58852,1.70841,2.68474,-1.26096,-0.682262,0.683538,0.749269,0.525548,0.714577,0.79154,0.0,0.0,0.0,0.0,-9999,-9999
199701010030,199701010100,-5.167,0,0.0,0.0,0,237.296,2,0.6,0,82.3,0,0.0,0,1.39,0,170.768,0.123,85.5667,-1.97,-9999,-9999,-9999,361.001,0,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-0.63874,3.0,3.52141,0,6.76452,-9999,-9999,2.12977,-10.3506,0,-19.8815,-9999,-9999,28.1156,1,-0.753289,2,1.76764,0.716147,0.820267,2.9814,1,2,1,1.25153,0.786515,1.64,1.76439,2.20844,-1.06483,0.240244,0.881249,0.810669,0.568614,0.745767,0.810669,0.0,0.0,0.0,0.0,-9999,-9999
199701010100,199701010130,-5.297,0,0.0,0.0,0,234.602,2,0.582,0,82.3,0,0.0,0,1.07,0,171.602,0.212,85.8667,-0.76,-9999,-9999,-9999,362.157,0,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-1.0802,3.0,-0.696116,0,-1.33572,-9999,-9999,2.64714,12.7497,0,24.4622,-9999,-9999,27.8184,1,-1.25987,2,1.85492,0.48255,2.22009,2.99135,1,1,1,1.23947,0.782672,1.61562,1.74196,2.70293,-1.22142,-0.656377,0.376184,0.785722,0.551116,0.742044,0.801874,0.0,0.0,0.0,0.0,-9999,-9999
199701010130,199701010200,-5.33,0,0.0,0.0,0,234.602,2,0.433,0,82.3,0,0.0,0,0.57,0,182.835,0.0649,89.4667,-0.81,-9999,-9999,-9999,361.137,0,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-1.53866,3.0,6.05088,0,11.6033,-9999,-9999,2.76928,2.85576,0,5.4754,-9999,-9999,25.967,1,-1.25987,2,1.85492,0.581905,2.22009,2.99135,1,1,1,1.23642,0.781695,1.61249,1.73629,2.69986,-1.22812,-0.660743,0.198632,0.779487,0.546743,0.741306,0.800587,0.0,0.0,0.0,0.0,-9999,-9999
199701010200,199701010230,-5.688,0,0.0,0.0,0,234.602,2,0.289,0,82.3,0,0.1,0,0.63,0,194.535,0.0888,92.7667,-0.36,-9999,-9999,-9999,363.244,0,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-1.92758,3.0,0.688845,0,1.31993,-9999,-9999,3.28199,-8.82101,0,-16.8997,-9999,-9999,11.0534,1,1.80132,1,2.07126,0.131897,2.22009,2.99135,1,1,1,1.20344,0.771078,1.54762,1.67535,-0.394485,-1.29979,-0.7079,0.639181,0.714354,0.501058,0.681278,0.784258,0.0,0.0,0.0,0.0,-9999,-9999
199701010230,199701010300,-5.134,0,0.0,0.0,0,234.602,2,0.186,0,82.3,0,0.2,0,1.04,0,177.585,0.1172,95.5333,-0.46,-9999,-9999,-9999,356.845,0,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-2.19766,3.0,9.37122,0,17.9487,-9999,-9999,2.95552,18.9034,0,36.1974,-9999,-9999,19.3479,1,-0.753289,2,1.76764,0.820267,0.820267,2.9814,2,2,1,1.2546,0.78749,1.64722,1.77011,2.21151,-1.05813,0.101594,0.888309,0.817101,0.573126,0.746626,0.817101,0.0,0.0,0.0,0.0,-9999,-9999
199701010300,199701010330,-5.656,0,0.0,0.0,0,234.602,2,0.132,0,82.3,0,0.0,0,1.15,0,173.256,0.282,96.7,-0.73,-9999,-9999,-9999,358.033,0,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-2.36326,3.0,-3.74961,0,-7.17823,-9999,-9999,3.21406,-19.7737,0,-37.8439,-9999,-9999,16.7304,1,1.80132,1,2.07126,0.48255,2.51023,2.99135,1,1,1,1.20638,0.772029,1.55428,1.68075,-0.391528,-1.39387,-0.763802,0.610709,0.719993,0.505013,0.686657,0.785029,0.0,0.0,0.0,0.0,-9999,-9999
199701010330,199701010400,-5.721,0,0.0,0.0,0,234.602,2,0.096,0,82.3,0,0.0,0,0.89,0,165.347,0.207,97.6,-1.84,-9999,-9999,-9999,360.944,0,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-2.4762,3.0,-2.82474,0,-5.40802,-9999,-9999,4.60756,-10.5448,0,-20.181,-9999,-9999,17.7426,1,1.80132,1,2.07126,2.51023,2.99135,6.32275,1,1,0,1.20042,0.770097,1.54076,1.66979,-0.397532,-5.55265,-1.30756,-0.732786,0.708576,0.497005,0.675768,0.783462,0.0,0.0,0.0,0.0,-9999,-9999
199701010400,199701010430,-5.297,0,0.0,0.0,0,245.024,2,0.119,0,82.217,0,0.0,0,1.01,0,169.904,0.2334,97.1,-0.72,-9999,-9999,-9999,357.585,0,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-2.55554,3.0,0.308907,0,0.591408,-9999,-9999,4.43042,-9.28634,0,-17.7725,-9999,-9999,18.6348,1,-1.25987,2,1.85492,-5.17451,2.22009,2.99135,0,1,1,1.23947,0.782672,1.61562,1.74196,2.70293,-1.22142,-0.656377,5.55317,0.785722,0.551116,0.742044,0.801874,0.0,0.0,0.0,0.0,-9999,-9999
199701010430,199701010500,-5.721,0,0.0,0.0,0,245.024,2,0.113,0,82.2,0,0.0,0,0.8,0,176.457,0.253,97.1667,-0.41,-9999,-9999,-9999,368.105,0,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-2.64022,3.0,6.63813,0,12.7088,-9999,-9999,4.33663,36.0712,0,69.0343,-9999,-9999,16.6881,1,1.80132,1,2.07126,0.131897,2.22009,2.99135,1,1,1,1.20042,0.770097,1.54076,1.66979,-0.397532,-1.30631,-0.712227,0.6382,0.708576,0.497005,0.675768,0.783462,0.0,0.0,0.0,0.0,-9999,-9999
199701010500,199701010530,-5.59,0,0.0,0.0,0,245.024,2,0.083,0,82.2,0,0.0,0,0.42,0,166.635,0.3317,97.9333,-1.2,-9999,-9999,-9999,363.898,0,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-2.74522,3.0,-4.35856,0,-8.34454,-9999,-9999,4.42917,-14.5308,0,-27.8095,-9999,-9999,18.2888,1,-1.53533,2,1.85492,-2.58751,2.22009,2.99135,0,1,1,1.21244,0.773988,1.56809,1.69192,2.95122,-1.28034,-0.695029,3.32358,0.731735,0.513249,0.697855,0.786618,0.0,0.0,0.0,0.0,-9999,-9999
199701010530,199701010600,-5.004,0,0.0,0.0,0,245.024,2,0.129,0,82.2,0,0.0,0,0.48,0,178.796,0.0586,96.9333,-0.87,-9999,-9999,-9999,359.661,0,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-2.84922,3.0,2.60142,0,4.98047,-9999,-9999,5.06417,-4.14367,0,-7.9303,-9999,-9999,16.161,1,-0.195464,2,1.81128,0.511539,1.06147,1.40844,1,2,2,1.26671,0.791326,1.6759,1.79273,1.66581,-0.269106,0.375233,0.680767,0.842834,0.591176,0.749579,0.842834,0.0,0.0,0.0,0.0,-9999,-9999
199701010600,199701010630,-4.645,0,0.0,0.0,0,245.024,2,0.172,0,82.217,0,0.0,0,0.3,0,198.917,0.2442,96.0333,-0.07,-9999,-9999,-9999,356.997,0,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-9999,-2.92622,3.0,7.34776,0,14.0674,-9999,-9999,3.99565,-4.78778,0,-9.16302,-9999,-9999,16.797,1,-0.195464,2,1.81128,-0.103363,1.00968,1.40844,1,2,2,1.30035,0.801891,1.73579,1.85592,1.69941,0.
```

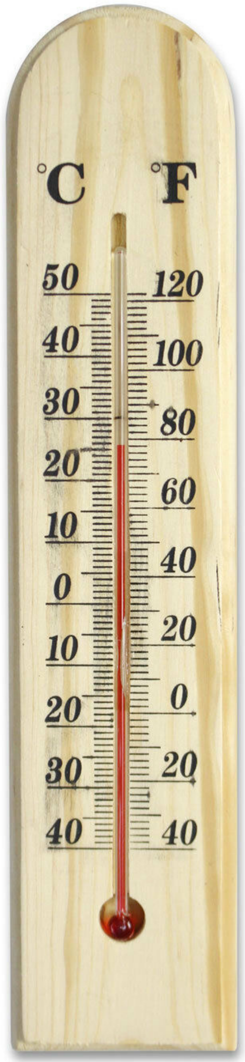
Climate elements

Quantity	Units
Air temperature	ºC, ºF, Kelvin
Air pressure	hPa, mbar, mmHg, Torr (historisch)
Humidity	g/m^3, g/kg, %
Precipitation	mm, l/m^2
Evaporation	mm, l/m^2
Wind	m/s, knt, Bft
Wind direction	Degrees north
Radiation	W/m^2

Air temperature

Measurement principle:

$$\text{Volume } (V) \propto T$$



- **Units**
  ºC, ºF, Kelvin

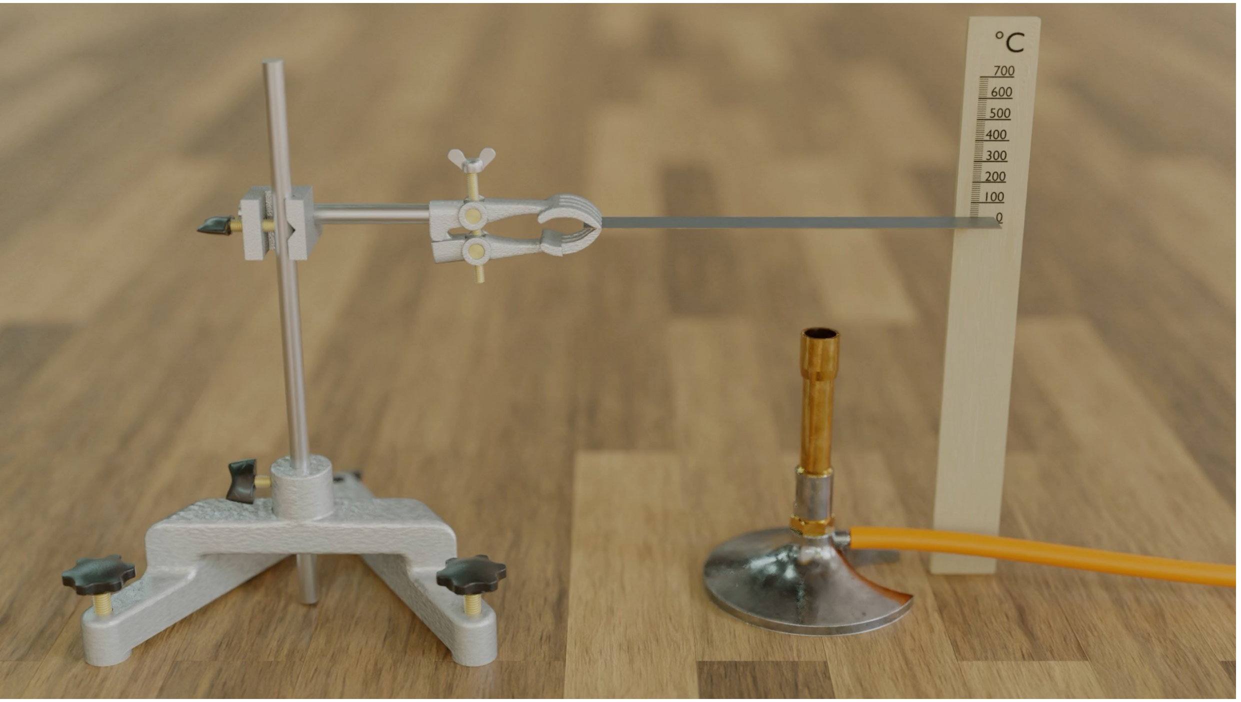
- **Physical principle**
  Temperature of a substance is related to the average kinetic energy of the particles of that substance.

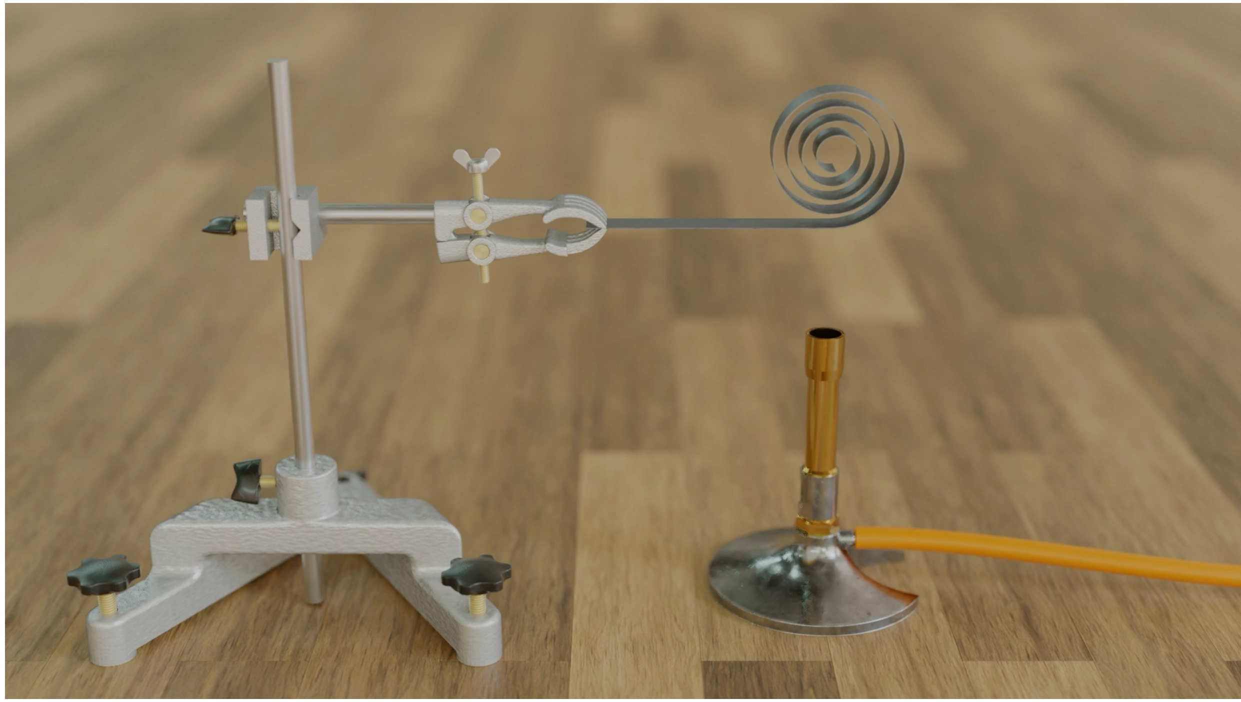
- **Physical properties**
  Volume, electrical resistance, radiation emission

Air temperature– Bimetal thermometer

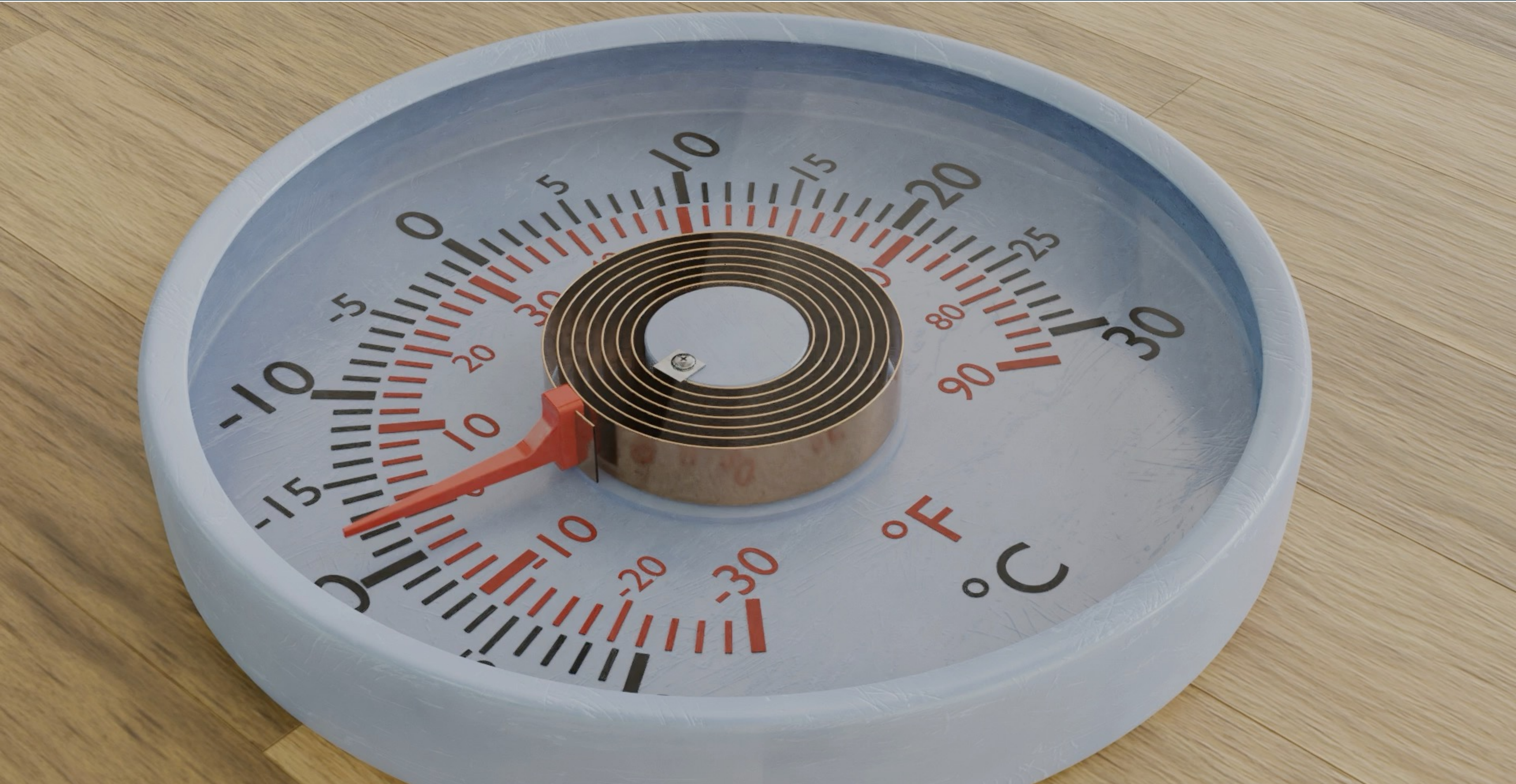
Measurement principle:

$$\text{Volume } (V) \propto T$$





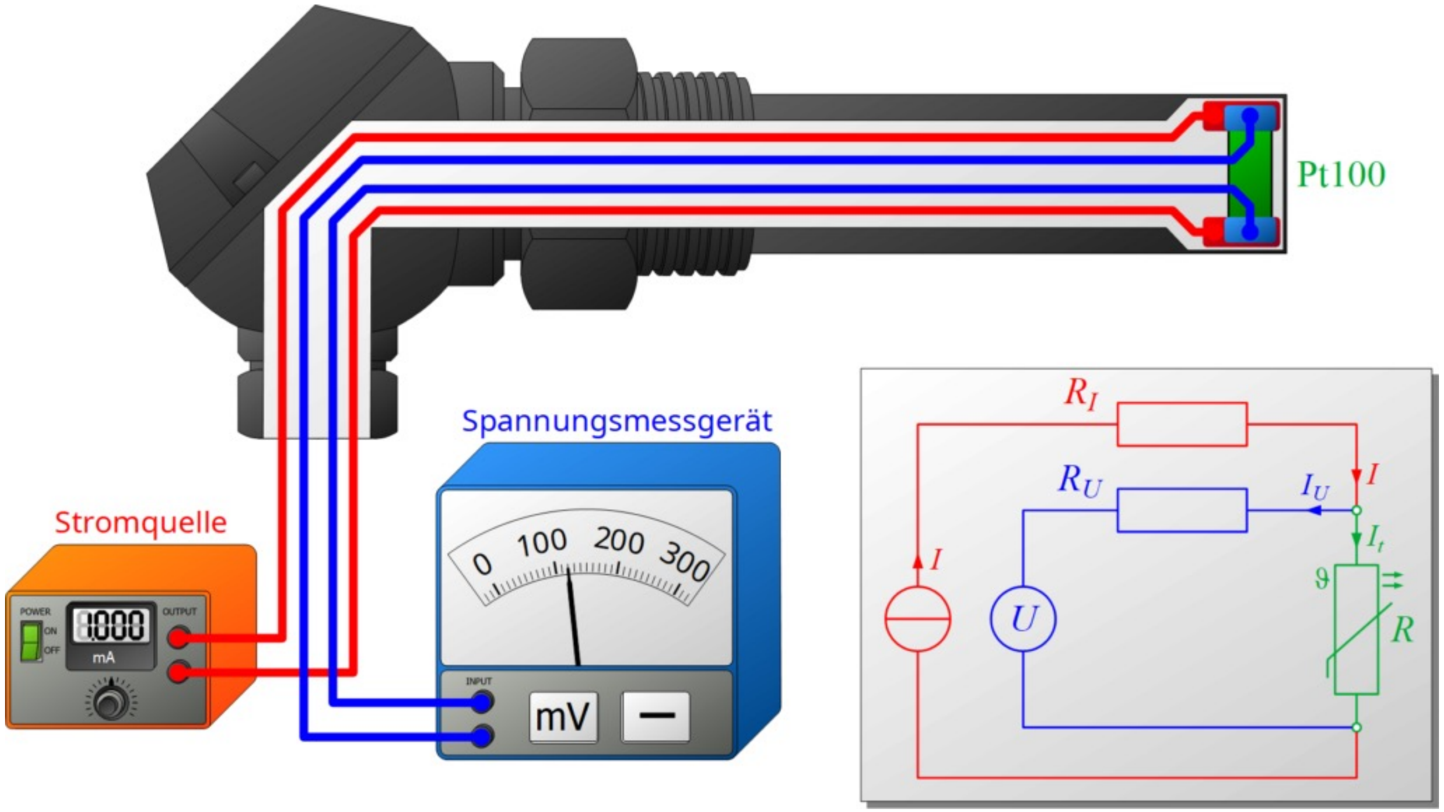
Air temperature– Bimetal thermometer



Air temperature

Measurement principle:

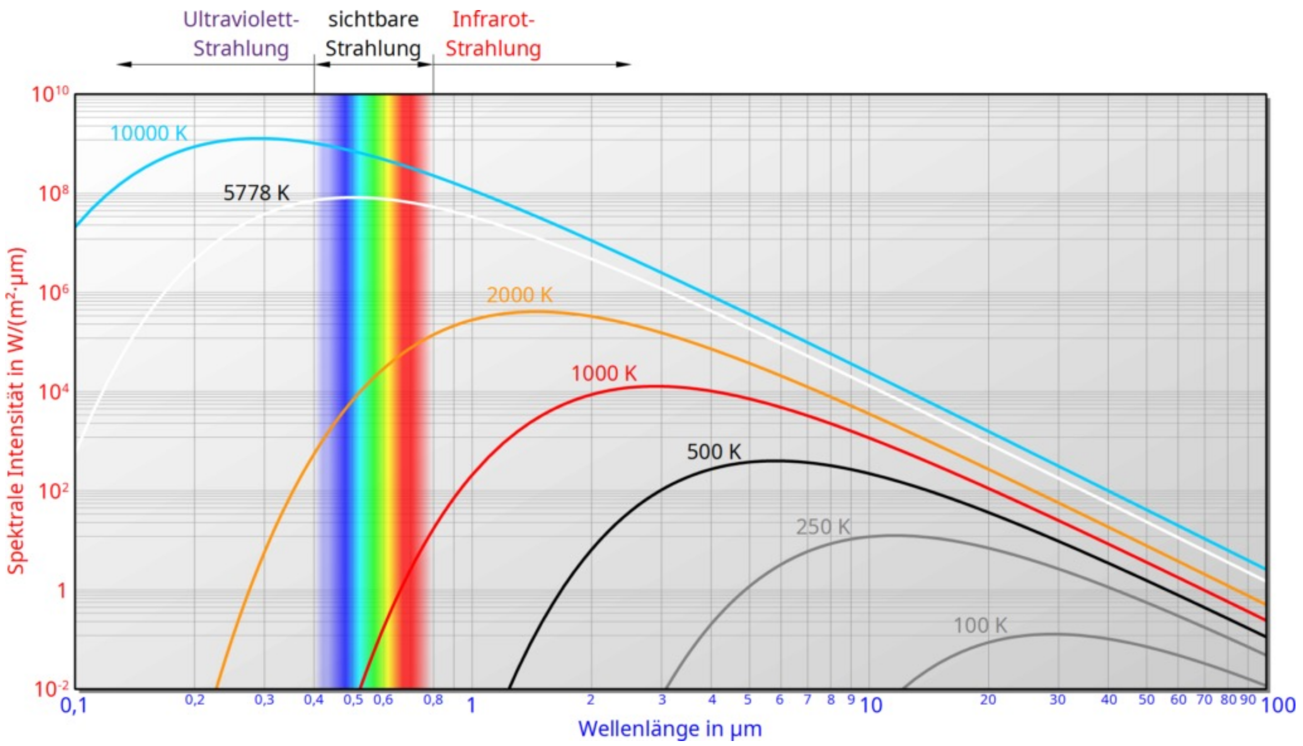
$$\text{elektrical resistance } (R) \propto T; U = R \cdot I$$



Air temperature

Measurement principle:

$$\text{Emission } P = \epsilon\sigma T^4$$



Water vapor

Measure	Units
Absolut humidity	g/m^3
Specific humidity	g/kg
Water vapor pressure	hPa
Saturation water vapor pressure	hPa
Relative humidity	%
Dew point temperature	ºC
Saturation mixing ratio	g/kg

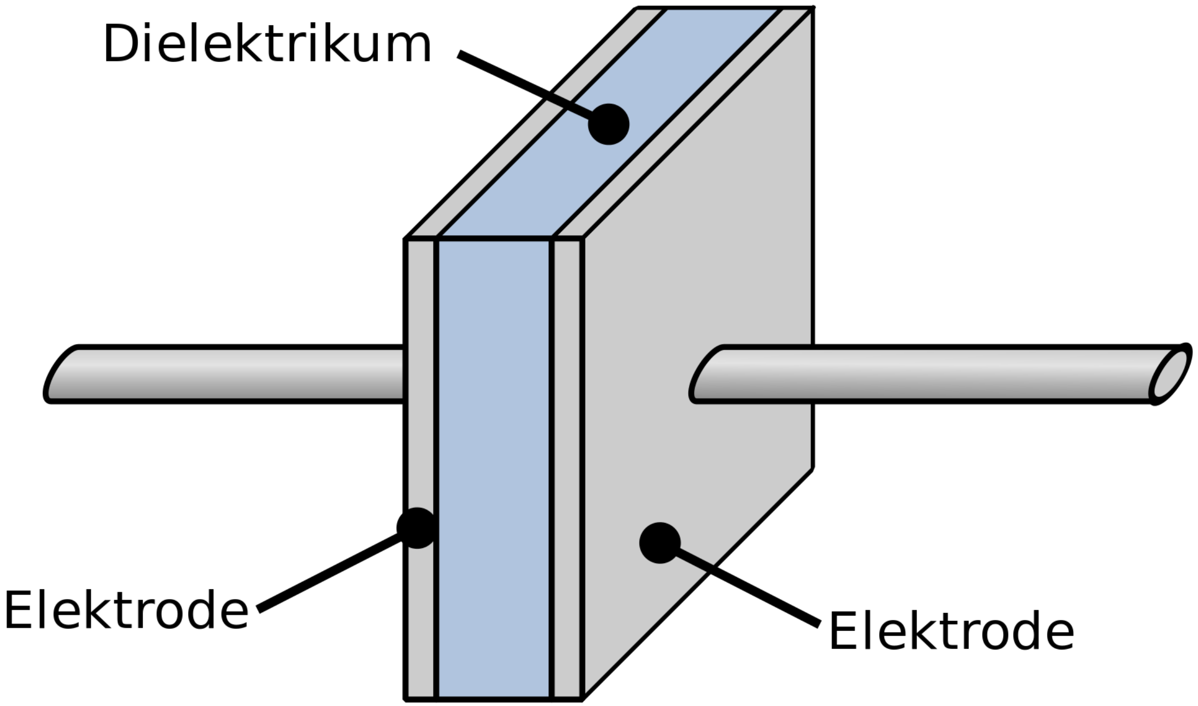
Water vapor

Measurement principle:

Length and volume change due to embedding of water molecules in solid bodies → Hair hygrometer

Measurement principle:

Absorption hygrometer: Change in the capacitance of capacitors



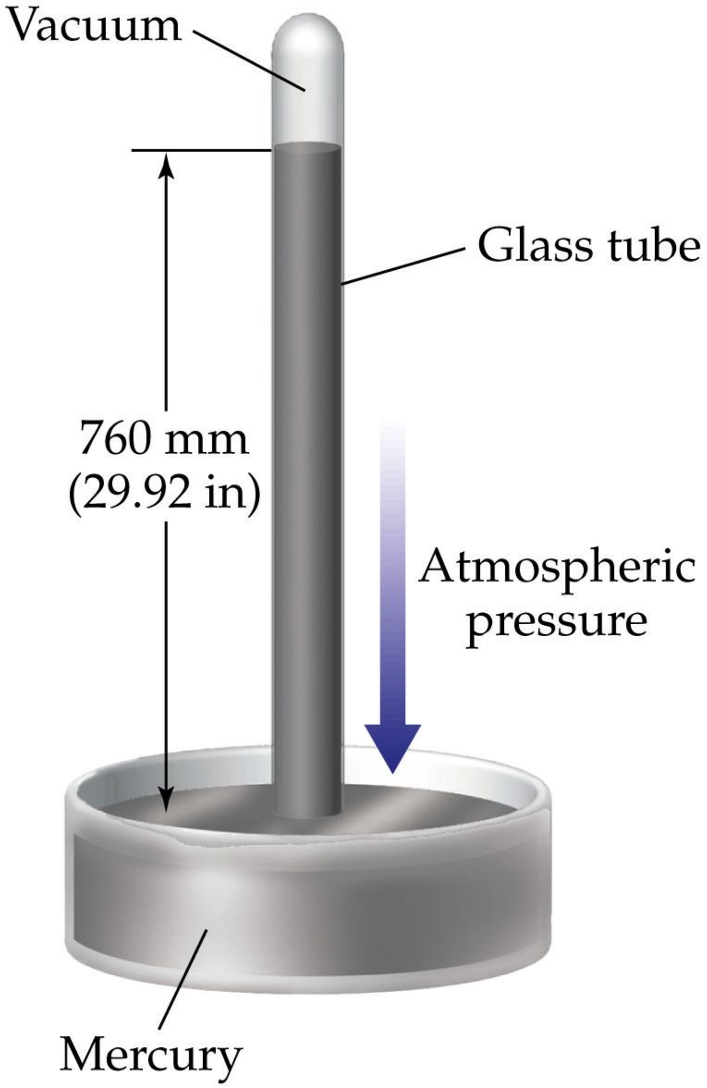
Air pressure

Experiment of Torriccelli

$$p = \rho \cdot g \cdot h \rightarrow h = \frac{p}{\rho \cdot g}$$

$$= \frac{101300\ Pa}{13550\ kg\ m^3 \cdot 9.81\ m\ s^2} = 0.76\ m$$

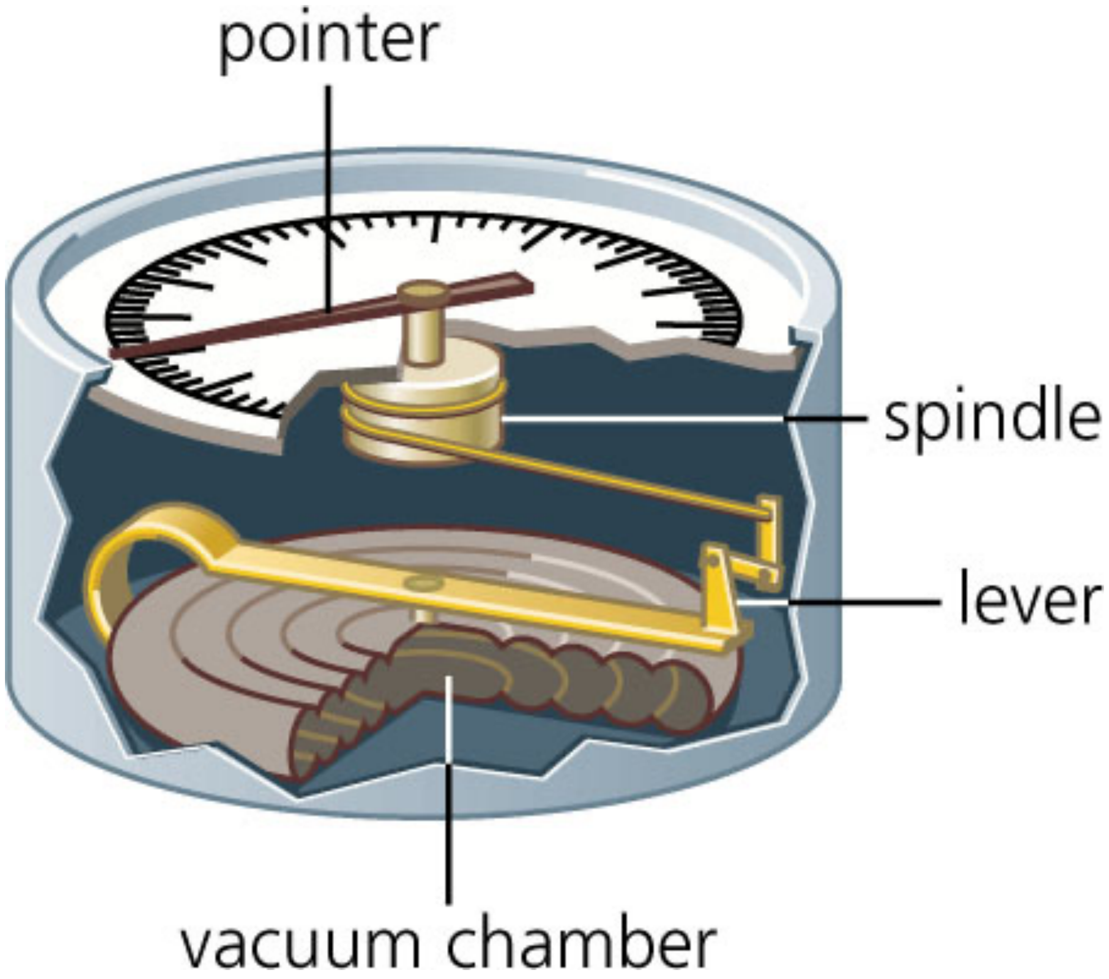
$$1013\ hPa \equiv 760\ mm\ Hg\ (\text{Torr})$$



Source: https://atmos.uw.edu/~hakim/101/pressure/

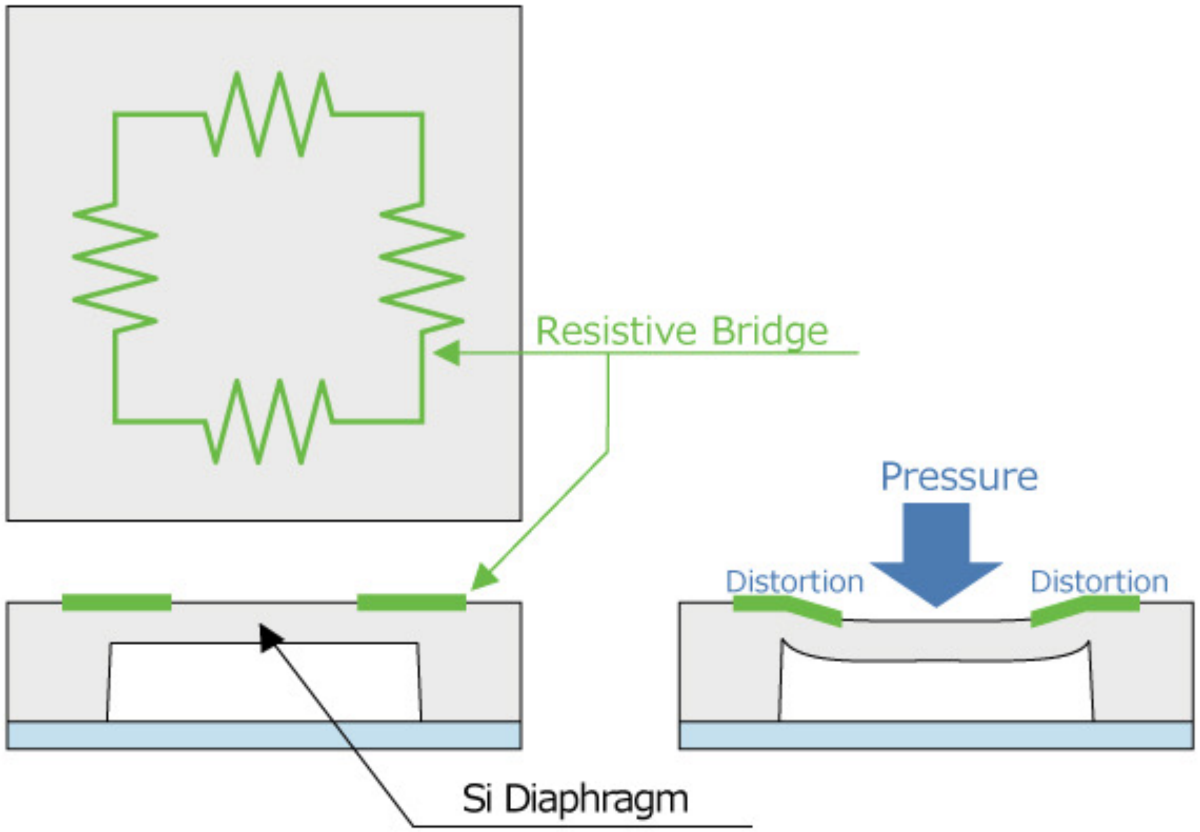
Air pressure

Aneroid barometer. The chamber contains a partial vacuum that expands and contracts for small pressure changes. The linear motion of the chamber is converted into radial motion for display on a dial.



Air pressure

Electronic barometer. Operate according to the piezoresistive effect, in which the deformation of the semiconductor diaphragm changes the internal resistance.



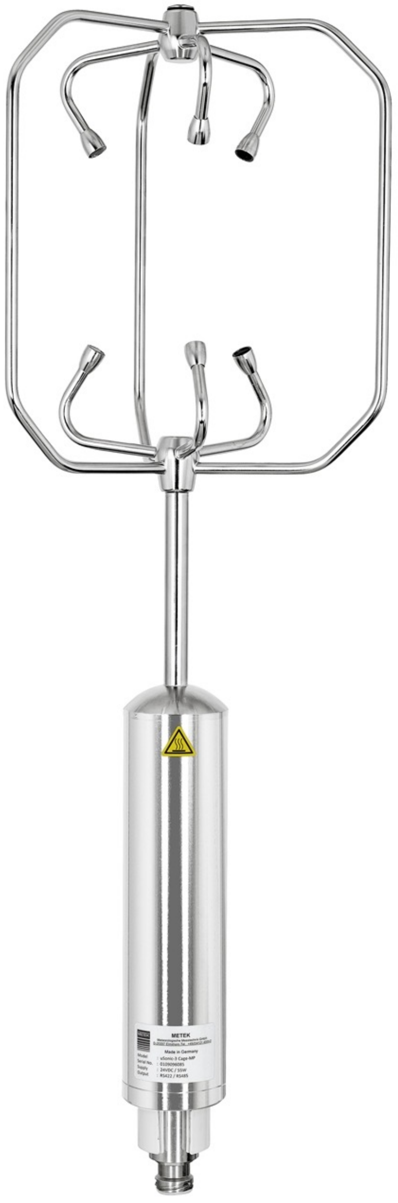
Wind velocity

Anemometer. A pulse counter is used for the wind speed (coil+magnet). The wind direction is measured using a resistor.

Source: Campbell Scientific

Wind velocity

Ultrasonic Anemometer. Sonic anemometers work on the principle that the travel time of sound waves through air is affected by the wind speed component parallel with the direction of travel. The basic element of a sonic anemometer consists of an ultrasonic sound emitter and receiver at opposite ends of a sampling volume.



Source: Metek

Precipitation

Remember.

- Precipitation intensity: mm/h
- Precipitation type
- Precipitation amount
  water column in mm, water quantity in l/m^2
  Note: 1 mm $\equiv$ 1 l/m^2

Source: Metek

Precipitation

Laser Disdrometer. Optical laser-based disdrometers use laser beams to measure the number, size and velocity of raindrops

Source: https://webshop.ats-net.com

Source: https://www.biral.com

Precipitation

Acoustic sensors. Rain measurement is based on acoustic detection of each individual rain drop as it impacts the sensor cover. Larger drops create a larger acoustic signal than smaller drops. The piezoelectric detector converts the acoustic signals into voltages.

Source: https://Vaisala.com

Radiation

Source: https://www.hukseflux.com

Pyranometer. A pyranometer has a sensor that is coated to absorb **solar radiation** and is usually made of silicon, germanium, or a thermopile. The absorbed heat is conducted to a thermocouple or thermopile, which generates a voltage proportional to the temperature difference.

Pyrgeometer. The pyrgeometer is coated with a material that is transparent to **longwave radiation**. The absorbed heat is conducted to a thermocouple or thermopile, which generates a voltage proportional to the temperature difference.

Practical recommendations

Idea and Creativity

Preparation and scientific concept

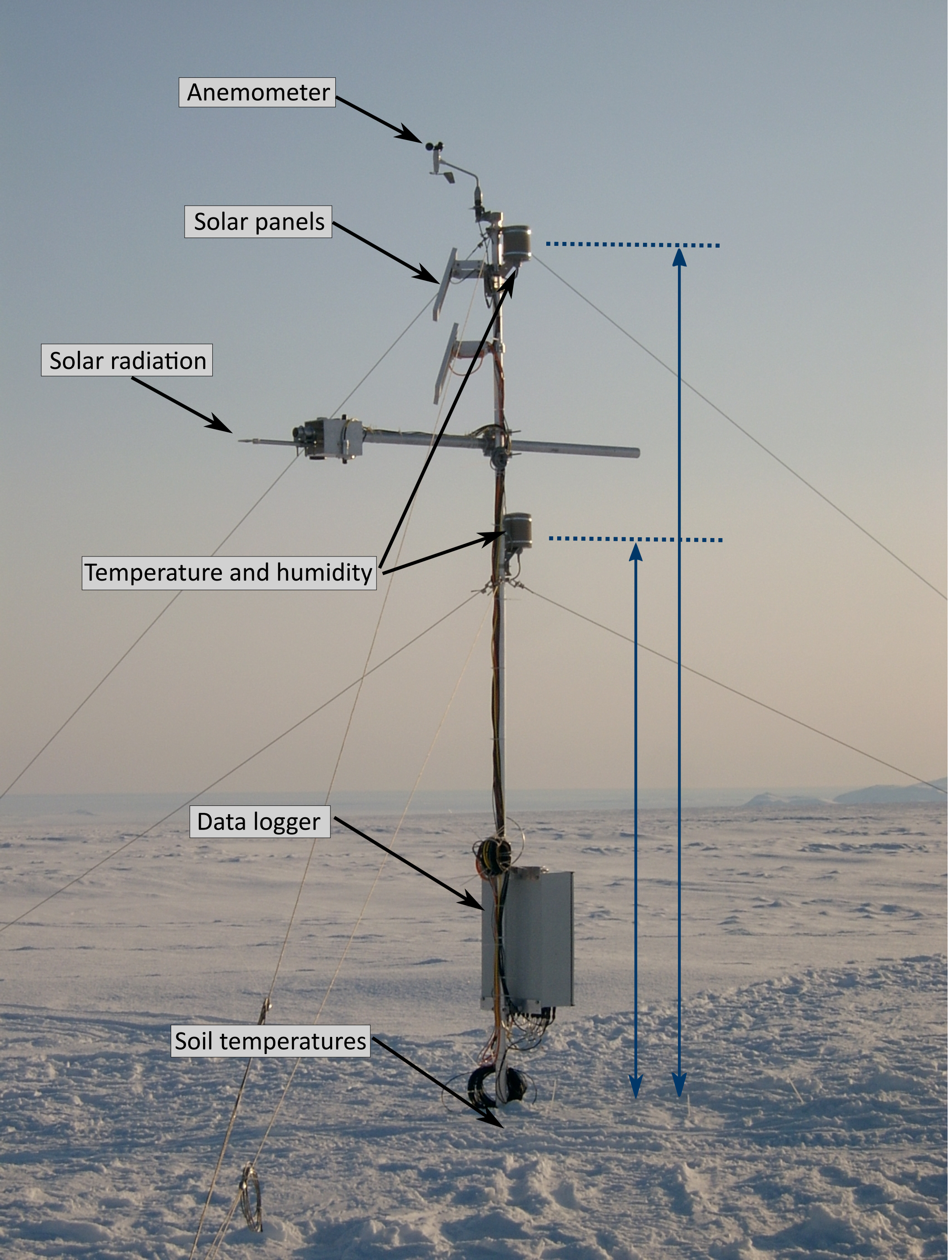
- What are the open research questions, knowledge gaps, and hypothesis?
- Which processes are involved?
- How can superimposed processes be disentangled?
- What measurement strategy is needed?

What exciting hypotheses and questions can we raise in this field course?

Practical issues

Strategy

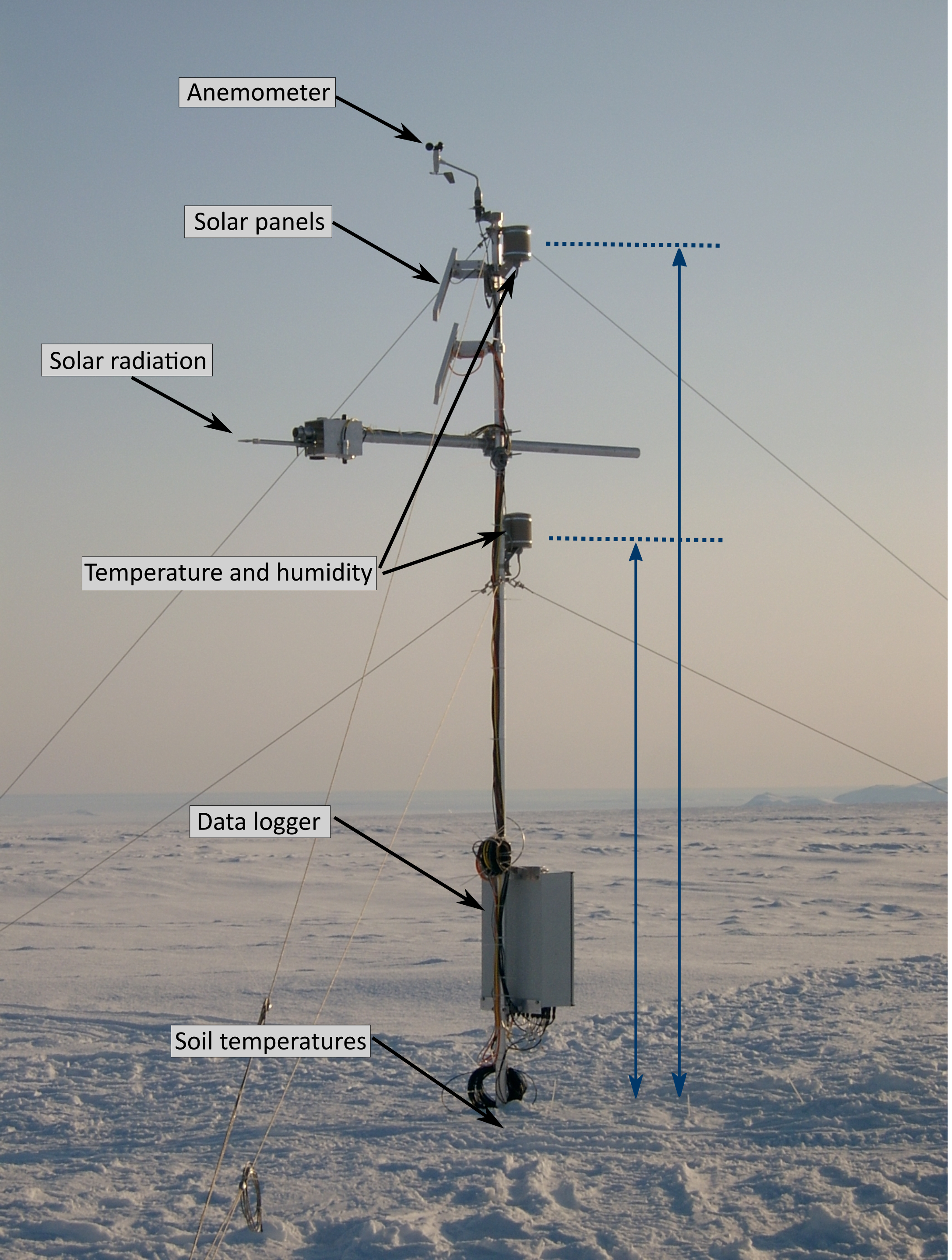
- What should be measured where and when?
- Local characteristics, e.g. wind fields, radiation etc.
- Logistical problems, e.g. long approaches
- Homogeneous surface
- Detailed documentation, e.g. sensor heights, weather conditions etc.



Choice of Sensors

- Spatial and temporal resolution
- Accuracy
- Availability of data
- Which parameters are needed?
- Which sensors are needed
- Location of measurements

Practical issues - Logistics



Documentation

- Date and time
- Height and direction of all sensors
- Name of person who installed and checked the sensor
- Who checked the sensor, and when? What was modified?
- Does the station work?

Documentation

Wetterbeobachtung

Datum: .... Beobachter: .... Uhrzeit: ....

Bedeckungsgrad [1/8]: .... Wolkenart: ....

Wolkenzugrichtung: .... Luftdruck: ....

Lufttemperatur (trocken): .... Lufttemperatur (feucht): ....

Windrichtung: .... Windgeschw.: ....

Bemerkungen: .... Regenmenge: ....seit: ....

Wetterbeobachtung

Datum: .... Beobachter: .... Uhrzeit: ....

Bedeckungsgrad [1/8]: .... Wolkenart: ....

Wolkenzugrichtung: .... Luftdruck: ....

Lufttemperatur (trocken): .... Lufttemperatur (feucht): ....

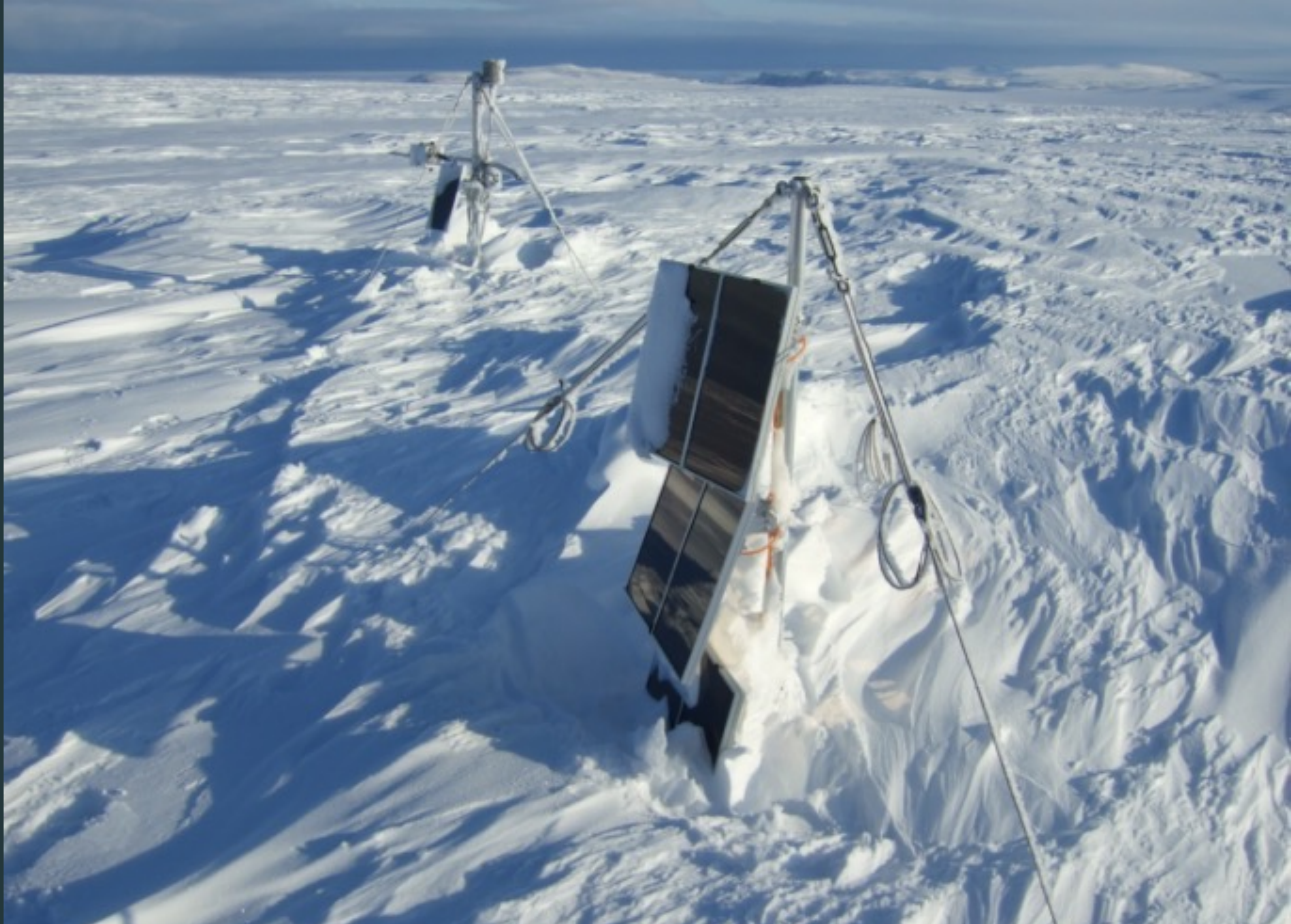
Windrichtung: .... Windgeschw.: ....

Bemerkungen: .... Regenmenge: ....seit: ....

Wetterbeobachtung

Datum: .... Beobachter: .... Uhrzeit: ....

Quality assessment



Quality assessment

Quality assessment

Quality control

- Data quality check
- Check for outliers and obvious wrong measurements (statistical test)
- Data correction
- Data sample within the measurement range?
- Temporal resolution sufficient for further evaluation
- Identification of unwanted meteorological influences (time series analysis, e.g. standard deviation)
- Stationarity test

Real-world exercises