

SW01 - BASICS

No moisture in ISA RH=0%

ISA is a static model

prescribes p, ρ, T

ISA has highest absorption

Near surface: ISA is not used!!!

Constant traces:

Ne 18ppm

He 5ppm

Kr 1ppm

Xe 0.05ppm

H₂ 0.5ppm

Cold, Dry Day at Sea level: Low Density Altitude. AC: ↑

Hot, Humid Day at 5000ft: High Density Altitude. AC: →

Air cools down with height, because Air expands.

More bumping → more warmer

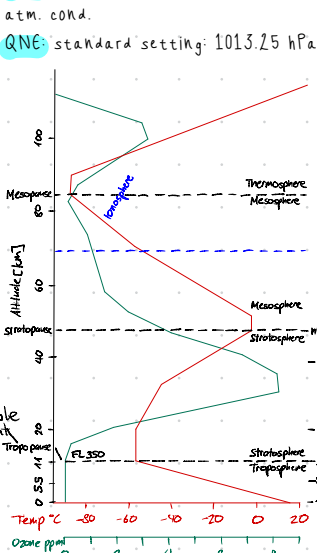
QFE: Air pressure measured at current location

QNH: QFE reduced to sealevel with ISA

QFF: QFE reduced to sealevel assuming actual

atm. cond.

QNE: standard setting: 1013.25 hPa



gas molecules are subjected to gravity. Molecules near surface experience gravity and pressure force from molecules above. Air near surface has higher pressure, which compresses it and increases density
Density Altitude: equivalent Alt. an object would be feeling at, if all environment condition like $T, p, \text{air humid.}$ are considered

- Pressure altitude: QNH deviation from Standard pressure: QNH < 1013 → +28 ft/hPa
QNH > 1013 → -28 ft/hPa

→ find $\Delta p = \text{QNH} - 1013$ → then $\cdot (\pm 28)$ → then + elevation (ft) → Height = z_2

- temp deviation ISA: 15°C at 0ft → -6.5 K/km or -2K/1000ft → 15 · (T - z_2) = TISA

→ T - TISA = deviation ΔT (°C) → $\Delta T \cdot 120 \text{ ft/K} \rightarrow \Delta z \rightarrow \Delta z + z_2 = \text{density Alt.}$

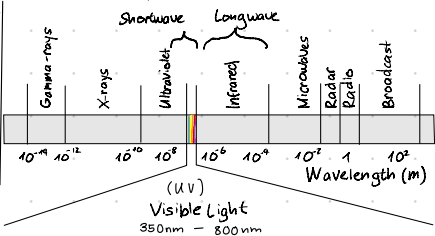
SW02 - RADIATION

Solar radiation is the main energy source for atm processes. spatial variations in (incoming and outgoing) radiation result in unequal distribution of energy weather is the atmosphere's thermodynamic response, constantly working to restore balance in energy distribution

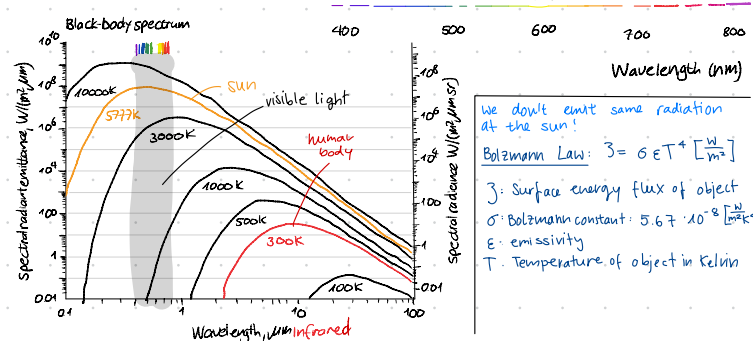
- Shortwave radiation: $200 \text{ nm} < \lambda < 4 \mu\text{m}$
- Longwave: $4 \mu\text{m} < \lambda < 100 \mu\text{m}$

- Black Body: perfect emitter/absorber ($\alpha = 0$) ($\epsilon = 1$)

△ reflectivity ≠ emissivity!



Terrestrial Radiation comes from the earth because of earth temperature



We don't emit same radiation at the sun!

Boltzmann Law: $3 = 6 \epsilon T^4 \left[\frac{\text{W}}{\text{m}^2} \right]$

ϵ : Surface energy flux of object

σ : Boltzmann constant: $5.67 \cdot 10^{-8} \left[\frac{\text{W}}{\text{m}^2 \cdot \text{K}^4} \right]$

ϵ : emissivity

T : Temperature of object in Kelvin

$$\text{Wien's Law: } J = \int_0^\infty \text{SFE}(T) d\lambda$$

$$\lambda_{\text{max}}(T) = \frac{2897.8}{T} \frac{\text{nm} \cdot \text{K}}{\text{K}}$$

SRE: Spectral radiant emittance

wavelength of max. intensity

rate of climb when:

↓ $p, \uparrow T, \uparrow \text{water vapor} \downarrow \rho$

Outgoing radiation_{sun} > Incoming-

radiation_{earth}

Solar constant:

incoming solar radiation at top of atmosphere

$$S_0 = \frac{\epsilon \epsilon_{\text{sun}} T_{\text{sun}}^4 \cdot 4 \pi R_{\text{sun}}^2}{4 \pi \text{AU}^2} = 1367.6 \frac{\text{W}}{\text{m}^2}$$

$T_{\text{sun}} = 5777 \text{ K}$

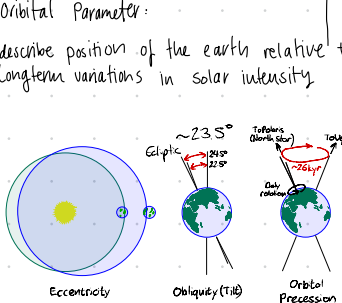
$R_{\text{sun}} = 696,390,000 \text{ m}$

$1 \text{ AU} = 1.496 \cdot 10^{11} \text{ m}$ (Astron. Unit)

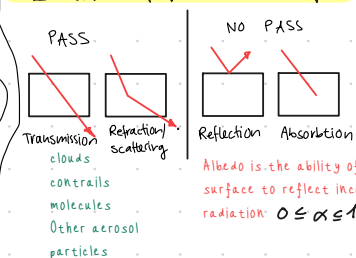
Orbital Parameter:

describe position of the earth relative to the sun

Longterm variations in solar intensity



- Interaction of radiation w. atmosphere



Albedo

↳ describes the fraction of (solar) radiation that a surface reflects.
↳ $\alpha = 0$: Black Body
↳ $\alpha = 1$: All radiation is reflected

Emissivity

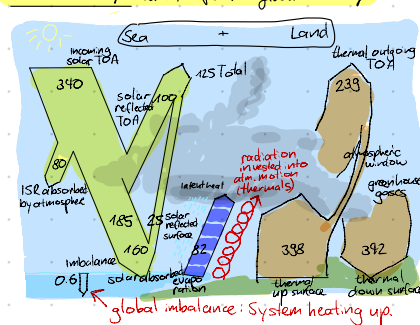
↳ describes the effectiveness of a surface in emitting as radiation
↳ $\epsilon = 0$: does not emit
↳ $\epsilon = 1$: Black Body

- Pyranometer: Measures short-wave radiation

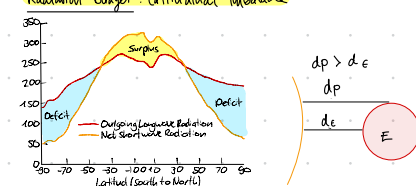
- Pyrgeometer: measures long-wave radiation

- Molecules only absorb specific wavelength. Absorbing particles get excited (Bending wiggling etc)

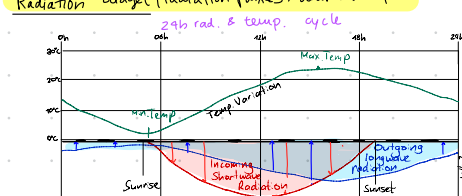
Radiation Budget: radiation fluxes global average



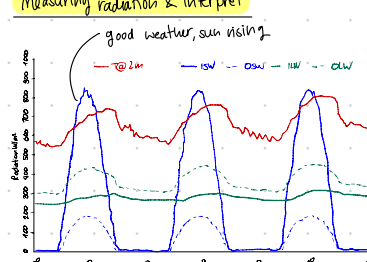
Radiation Budget: (latitudinal) imbalance



Radiation Budget | radiation fluxes: diurnal cycle



Measuring radiation & interpret



SW03 - THERMO I

- adiabatic: no heat exchange between system & surroundings (many processes in atmosphere)

lapse rate: $\Gamma = \frac{dT}{dz}$; change of object when moving vertically

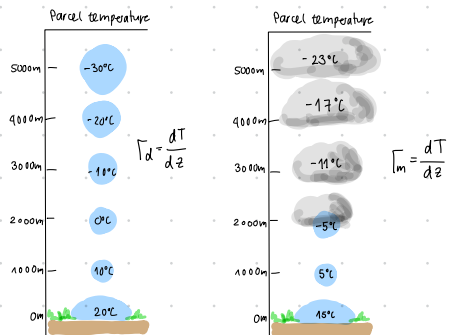
$\Delta U = Q + W$ "change in internal energy is equal to the heat added + work done on the system"

$dQ = dU - dW$; $dQ = mc_v dT + pdV$; (dry adiabatic) $= -9.8 \frac{K}{km}$ (moist) $\approx -3-9 \frac{K}{km}$

ISA environment: $\Gamma = -6.5 \frac{K}{km} \rightarrow$ lapse rate depends on day & rate of condense

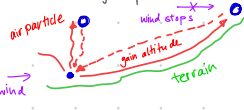
dry lapse rate

moist lapse rate



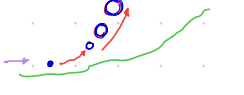
Atmospheric states

Stable: an air particle will always go back to its original position



Voraussetzung: air particle is always cooler than environment

unstable: an air particle will go out of balance after a tiny investment of energy



Voraussetzung: air particle is always warmer than environment

conditional (moist) state in between stable and unstable

- Dry bulb temperature: $RH = \frac{e}{e_s} \cdot 100 [\%]$ reg. temp measured by thermometer
- Wet bulb temperature: $RH = \frac{e_s(T_{wet})}{e_s(T)} \cdot 100 [\%]$ temp. reached through evaporation
- Dew point temperature: if cooled to this temp, moisture starts cond.
- Mixing ratio: relation between moisture & dry air $[\frac{g}{kg}]$ at 100% RH $= T_d = T_{wetbulb}$

$\rightarrow$ water vapor pressure e [Pa] partial pressure of water vap. in air [hPa]

$\rightarrow$ Saturation(water) vapor pressure e_s : saturated atmosph. = 100% RH $\rightarrow$ fog

Relative Humidity: $RH = \frac{e}{e_s}$

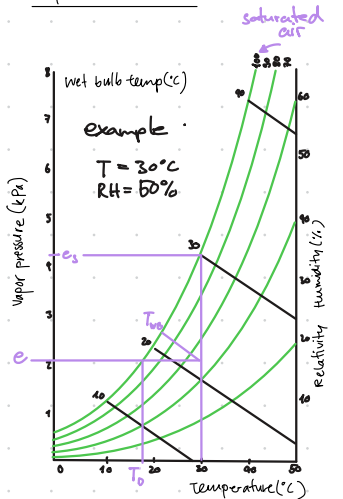
Quantification of humidity

- Dry bulb temperature $[T]$ $\rightarrow$ temperature of the air
- Wet bulb temperature $[T_{wb}]$ $\rightarrow$ temperature, which can be reached through evaporation cooling only
- Dew point temperature $[T_d]$ $\rightarrow$ temperature, when the moisture starts condensing: the lower the amount of moist, the lower T_p
- Mixing ratio $[\Gamma]$ in $\frac{g}{kg}$ $\rightarrow$ relates the mass of moisture in the air to the mass of dry air.
- Water vapor pressure $[e]$ in Pa
- Saturation water vapor pressure $[e_s]$ in Pa
- When the air can't absorb more moist (saturated air) $\rightarrow$ fog

$$e_s(T) = e_0 \exp \left[\frac{L}{R_v} \left(\frac{1}{T_0} - \frac{1}{T} \right) \right]$$

$\rightarrow$ warmer air holds exponentially more water vapor

Psychrometric chart



SW04 - THERMO II

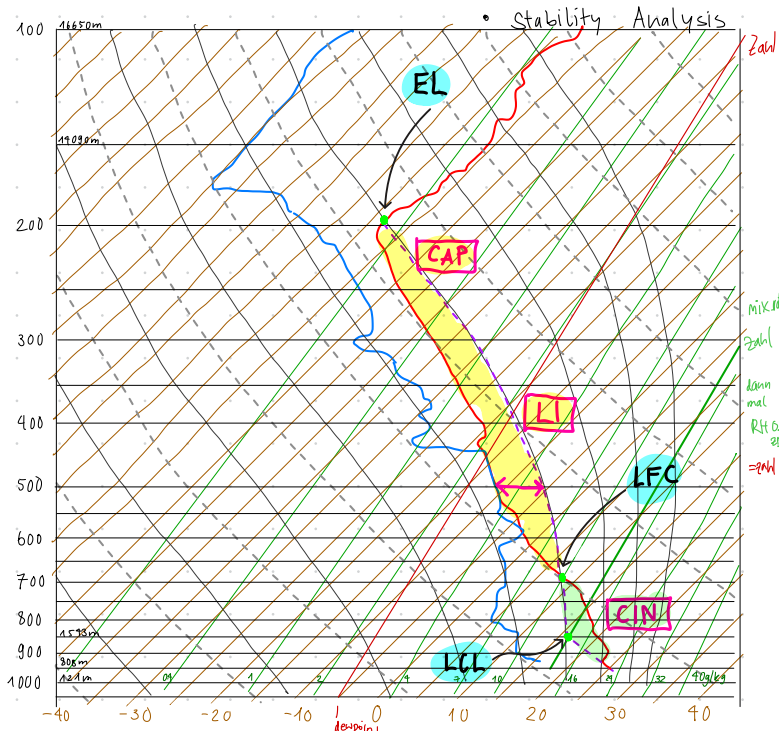
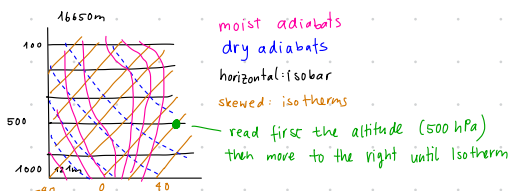
Cloud formation

"once the air temp reach the dew point the rel. humidity is 100%"

Recipe:

soot, pollen, sea sandal + water vapor + $T = 23.3^\circ C$ need air temp. approximately = to the dew point

Skew-T-log-p diagram: Main axes + Adiabats



When dew point = air temperature, condensation starts at the Lifting Condensation Level (LCL)

Above this, the parcel cools more slowly (moist adiabatic rate)

At the Level of Free Convection (LFC) (~ 700 hPa), its temperature equals the environment's. $\rightarrow$ where air starts rising freely

Lifted slightly higher, it rises freely until the Equilibrium Level (EL), where temperature and density match the surroundings again. $\rightarrow$ where ascent stops

The yellow area (CAPE) shows the energy an air parcel can gain while rising and condensing. $\rightarrow$ energy a rising parcel can gain $\rightarrow$ thunderstorm

High CAPE + low CIN $\rightarrow$ unstable atmosphere $\rightarrow$ strong thunderstorm potential

Low CAPE + high CIN $\rightarrow$ stable atmosphere: no convection or storm

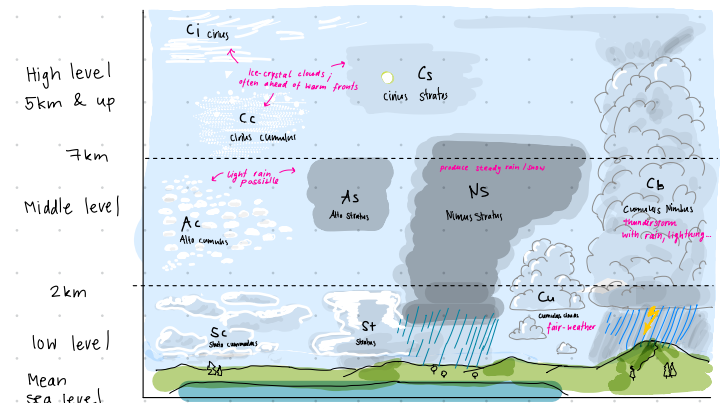
Lifted Index (LI) temperature difference between environment and air parcel at 500 hPa.

LI $> +1$ K: stable

LI < -5 K: very unstable $\rightarrow$ severe storm risk

CIN (Convective Inhibition): energy needed to lift a parcel to the LFC.

Stability Scale:
 > 6 : very stable $6-1$: Stable $1-2$: Slightly unstable
 -2 to -6 : Unstable -6 to -9 : Very unstable > -9 : Extremely unstable



clouds are visible tiny water droplets and/or ice crystals suspended in air

(cooling + moisture = cloud formation)

convection: surface heating causes local rising $\rightarrow$ cumulus

orographic lift: air forced up over mountains $\rightarrow$ Altostratus, Cumulonimbus

frontal lift: warm air rises over denser cold air $\rightarrow$ Nimbostratus, Cirrostratus along a front

convergence: Air flows together & must rise $\rightarrow$ cumulonimbus (low-pressure zone)

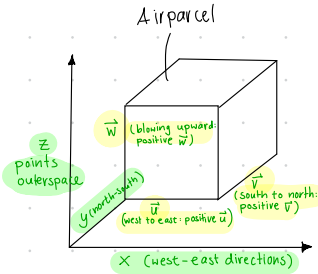
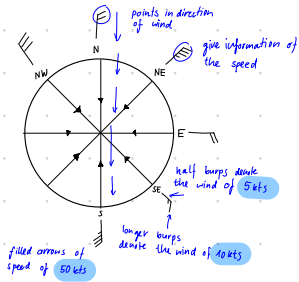
zusatz info (latin)
 • cirro = high / icy • strato = layered
 • alto = mid-level • cumulo = heaped / vertical
 • nimbus = rain-bearing

SW05 - WIND I

Wind Basics

(winds are named from where they come from)

isobars always points to the area with lower pressure



Forces acting on Air parcels (Horizontal motion)

along x-axis: Coriolis force Centrifugal force

$$\frac{du}{dt} = -\frac{1}{\rho} \frac{dp}{dx} + f_c \cdot v = C_p u \cdot U + s \cdot v \cdot \frac{U}{R}$$

along y-axis:

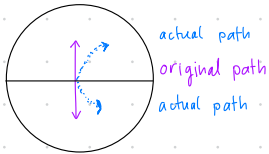
$$\frac{dv}{dt} = -\frac{1}{\rho} \frac{dp}{dy} = f_c \cdot u = C_p v \cdot U = s \cdot u \cdot \frac{U}{R}$$

only valid for northern hemisphere!

Coriolis force: $f = 2 \Omega \sin \varphi$; $\Omega = 7.292 \cdot 10^{-5} \text{ s}^{-1}$

- zero at the equator ($\varphi = 0^\circ$), maximum at poles ($\varphi = \pm 90^\circ$)
- deflects motion to the right in NH, to the left in SH
- Acts perpendicular to motion; it changes direction but not speed

Geostrophic Wind - straight isobars, No friction (Air flows parallel to isobars)



$$\frac{d\mathbf{v}}{dt} = -\frac{1}{\rho} \frac{dp}{dx} + f_c \cdot v$$

derivative of wind gradient in U direction

Coriolis acceleration, with $f = 2 \Omega \sin(\text{latitude})$

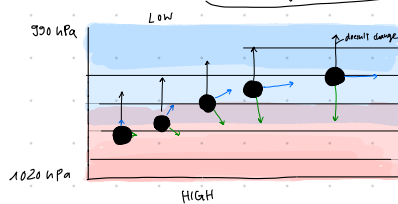
X-Axis Y-Axis

pressure gradient in x-direction

(valid only above friction layer, not near equator)

stronger gradient $\rightarrow$ faster wind

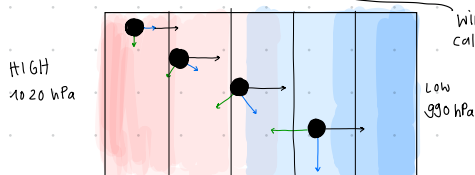
- Geostrophic Wind with North-South pressure gradient



to the east, called "westerlies"

Coriolis force pressure gradient force (doesn't change) wind vector

- Geostrophic Wind with a west-East pressure gradient

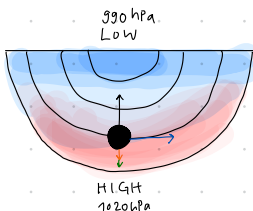


geostrophic formula on a constant-p surface: $U_{tot} = \frac{g}{f_c} \cdot \frac{dz}{ds}$

Gradient Wind - curved isobars

$$\frac{du}{dt} = -\frac{1}{\rho} \frac{dp}{dx} + f_c \cdot v + s \cdot v \cdot \frac{U}{R}$$

adds centrifugal force because it's now curved



wind vector Coriolis force centrifugal force

opposite the gradient force, perpendicular

assuming steady state:

$$0 = -\frac{1}{\rho} \frac{dp}{ds} + f_c \cdot U_{tot} + \frac{s}{R} U_{tot}^2$$

U_{tot} mit Mitternachtsformel:

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

Explicit Gradient Wind formula

High-Pressure System $U_{gr} = \frac{fR}{2} = \sqrt{\frac{fR}{2}} \cdot \frac{dp}{dr} \frac{R}{f}$

Low-Pressure System $U_{gr} = -\frac{fR}{2} + \sqrt{\frac{fR}{2}} \cdot \frac{dp}{dr} \frac{R}{f}$

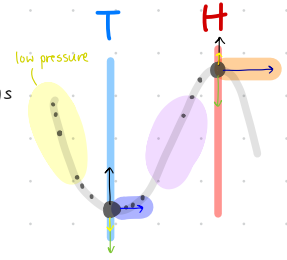
Assuming the geopotential gradient:

winds around a low pressure system will always be slower than a high pressure system.

• We call winds along low pressure system

subgeostrophic because they blow at the lower speed

• high pressure: supergeostrophic



Near surface wind - effect of Friction

Friction reduces speed $\rightarrow$ weaker Coriolis $\rightarrow$ flow turns toward low pressure.

Air crosses isobars instead of following them exactly.

Over land: deflection $\approx 45^\circ$

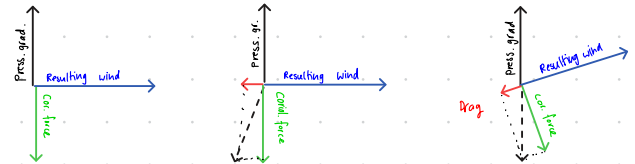
Over sea: $\approx 15-30^\circ$

• If the Airparcel experiences friction an additional force will act on the parcel

Consequences:

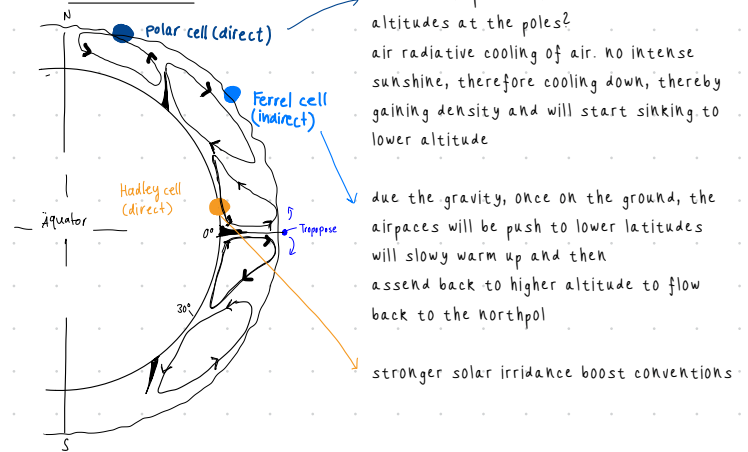
Toward low $\rightarrow$ convergence, rising air, clouds/rain.

From high $\rightarrow$ divergence, sinking air, clear weather.



SW06 - WIND II

Global circulation:



Mechanisms:

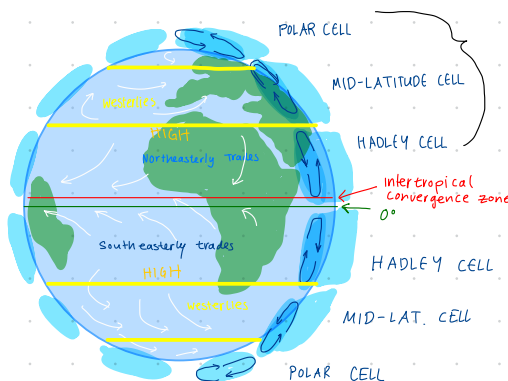
- Air sinks at poles due radiative cooling (high density, descends)

- Air rises near equator due intense solar heating & convection

on the northern hemisphere the hadley cell will lead to higher altitude South westerlies winds which convert to north easterlies trailwind when the air mass flow back to equator at lower altitude

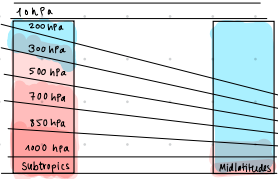
Wind patterns

- Easterlies: near equator
- Westerlies at mid-latitude
- Polar easterlies: near poles



Thermal Wind:

- Relates vertical wind shear to horizontal temperature gradients.
- Stronger thermal wind where temperature difference between air masses is large.
- Leads to jet stream formation.

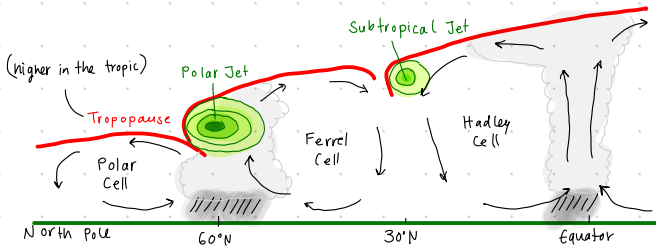


altitude at
subtropics ≠ midlatitude!
→ because density:
warmer air = lower density
air pressure decrease more slowly in
warm air than cold air

Jet Streams:

- Fast, narrow bands of wind near the tropopause.
- Found in subtropical and polar regions.
- Average speed 60 kt.
- Pilots use jet streams for fuel efficiency (eastward) or avoid them (westward).
- The core lies just below the tropopause.
- Jet meandering → caused by Rossby waves.

Jetstream always located between tropopause at border between south



Rossby-Waves

- Large-scale waves in westerly flow.
- Created by conservation of absolute vorticity and mountain/temperature influences.
- Regions of troughs (cold air southward) and ridges (warm air northward).

circulation at midlatitudes:

describe a tendency of an object to rotate

$$\text{Vorticity} = \zeta = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}$$

$$\zeta = 0$$

no rotation

$$\zeta > 0$$

counterclockwise rotation

$$\zeta < 0$$

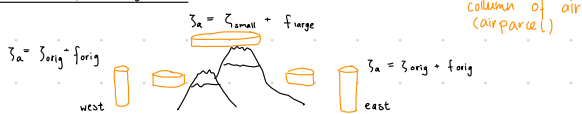
clockwise rotation

$$\zeta_a = \zeta + f \quad \text{Coriolis parameter}$$

"abs. vorticity" = "relative vorticity" + object own the vorticity
regionally conserved!! $\zeta + f = \text{const.}$

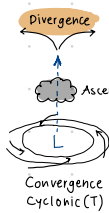
- compensate for the decrease in relative vorticity → increase Coriolis parameter
- increase parameter "f" → by going northwards

Rossby wave propagation:

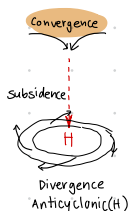


- colder air-masses into warm → trough (low pressure)
- warmer air-masses into cold → ridge (high pressure)

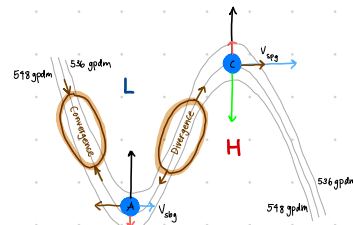
Ageostrophic flow



Near the surface, friction slows the wind, disturbing geostrophic balance and causing air to spiral inward → convergence.
Since it can't move downward, the air rises → ascent.
While rising, it expands and cools, leading to condensation, cloud formation, and precipitation.
Result: Low pressure systems bring cloudy, rainy, stormy weather.



near the surface: Air moves outward from the center of high pressure → divergence: air parcels move apart.
vertically: To replace the air that diverges at the surface, air from above must sink downward → called subsidence.
during sinking: sinking air is compressed by higher pressure below → it warms up. Warm air can hold more moisture → any clouds evaporate.
Result: High pressure systems are clear, dry, and stable



vectors:

Black: indicate vertical motion induced by divergence/convergence (total wind)

Brown: ageostrophic wind component, difference between the total wind & geost. wind

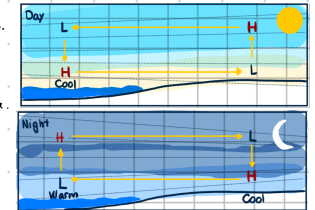
Blue: geostrophic wind, flow parallel to height contour (balanced by Coriolis & press. gradient)
Green: downward motion (subsidence), near H or convergence aloft
Red: upward motion (ascent), near L or divergence aloft

SWOT - LOCAL WIND I WIND III

wind system: local winds are caused by different heating of surfaces. Warm air is lighter rises & creates low pressure near ground. Cooler air flows towards this low pressure. These winds are near the surface, follow a daily cycle, & are weaker than large scale winds.

Sea breeze:

During day, land heats up faster than the sea. A low-pressure area forms over land & a high pressure area over the sea. Wind therefore blows from the sea toward the land. This is called a sea breeze. At higher altitude, the air flows back from land to sea.

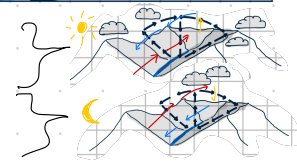


Land breeze:

During night, land cools down faster than sea. High pressure forms over land and low pressure over sea. Wind then blows towards the sea. → "land breeze"

Valley breeze & Mountain breeze

- During day, mountain slopes are heated by the sun.
- Air rises along the slopes, producing an upslope "valley breeze"
- Convergence & descending air in the valley centre
- During night the slope cools rapidly. Cool dense air flows down slope into the valley "mountain breeze" & leads to divergence in the valley



Alpine Pumping:

During the day, strong heating of the Alps causes air to rise over the mountains. As a result, air flows near the surface from the Swiss Plateau towards the Alps. At night, this circulation reverses. Alpine pumping explains daily wind direction changes in Switzerland and can occur without a synoptic-scale weather system.

WIND SYSTEM & THEIR MECHANISM

SIROCCO

Forms when a low pressure system is located over the Mediterranean Sea. Strong southerly winds transport warm air and dust towards Europe sometimes causing Saharan dust events

BISE

High pressure over northeastern Europe and low pressure over the Mediterranean produce cold, dry northeasterly winds across the Swiss Plateau, accelerated between Jura and Alps (Venturi effect)

MISTRAL

Forms when high pressure is located over France and low pressure over the Mediterranean. Air is channeled through the Rhone Valley, strongly accelerated, and produces cold, gusty winds

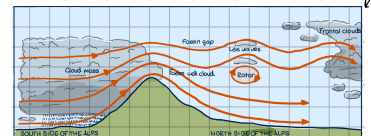
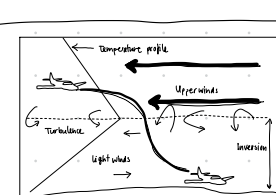
BORA

A very strong, cold downslope wind along the Adriatic coast, driven by dense cold air flowing over mountains

SÜDFÖHN

Higher pressure south of the Alps than north causes air to rise and cool on the windward side and sink and warm on the leeward side. Winds are warm, dry, gusty, and often turbulent

"AUSTRIAN FÖHN" (SHADDER FÖHN) is a Bora-like downslope wind on the eastern side of the Alps, primarily driven by cold, dense air flowing over and down the terrain, rather than by classical Föhn warming.



FÖHN HAZARDS

Hazards:

Turbulence at an inversion, types of wind shear, mountain waves & rotors

TURBULENCE

Air flow from laminar to turbulence → non directional movement on the air. Turbulence is transporting: • momentum (=friction) • heat • water vapor • other trace gases • aerosols (dust) in all direction

EDR (Eddy Dissipation Rate): a metric to measure the intensity of atmospheric turbulence
→ Rate at which energy dissipates into heat → unit: $[m^3 s^{-1}]$

The higher EDR, the stronger the turbulence

- Large eddies: Laminar air turns to eddy movement
- Kolmogorov eddies: Gets separated & broke down
- dissipation in to heat: Turn into energy & dissip. into heat

Main reason: Wind shear (wind going on different direction/speed), near ground in the boundary layer, jetstream, in & around thunderstorms, aircraft wake turbulence, during föhn convection over mountain

typical instability: • Kelvin-Helmholtz

side effect: exchange between air layer, mixing molecule

Formulary

Magnitude of geostrophic wind: $\frac{dv}{dt} = g \cdot \frac{dz}{dy} + f \cdot u \Rightarrow U = \frac{g}{f} \cdot \frac{dz}{dy}$

Logarithmic wind profile

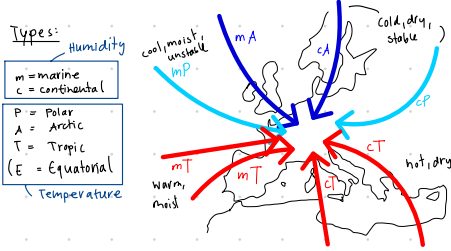
describes how wind speed increases with height above the ground in the atmospheric surface layer. It means that wind speed does not increase linearly with height, but logarithmically: the increase is very steep close to the ground and becomes gradually weaker with height.

$$u(z) = \frac{u_*}{K} \ln \left(\frac{z}{z_0} \right)$$

friction velocity
height above ground
surface roughness length
K von Kármán constant

SW08 - AIRMASSSES & FRONTS

- Air mass:** in meteorology, large body of air having nearly uniform conditions of temperature and humidity at any given level of altitude. forms whenever the atmosphere remains in contact with a large, relatively uniform land or sea surface for a time sufficiently long to acquire the temperature and moisture properties of that surface.



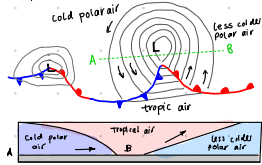
as airmasses move they are modified by the surfaces they pass over (heat, cooling, adding/removing moisture)

- Fronts:** a transition zone where two airmasses of different temp. & humidity meet.

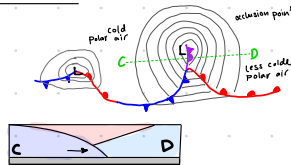
- brings clouds in a distinctive sequence → depends on type of fronts & type of airmasses
- Strong horizontal **temperature**, **moisture**, **wind** gradient } front characteristics
- Strong vertical shear of the horizontal wind
- High vorticity ("curvature" of flow)
- Clouds and precipitation

- cold fronts is faster!** → more dense than warm air → "pushes" away precipitation cooling (by evaporation): accelerates the cold front, decelerates the warm front

simple model



occlusion



- vertical crosssection (model): cold front faster than warm

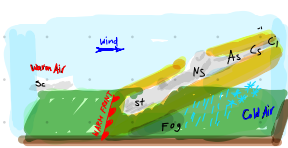


- cloud formation

Warm front: cirrus → cirrostratus → altostratus → nimbostratus → stratus

Cold front: cumulus → cumulonimbus → possible clear sky after passage

Occluded front: mix of both patterns, often widespread precipitation



Frontogenesis: Cyclogenesis

→ Frontogenesis: Front entsteht oder wind stärker (Fronten werden im Tiefdruckgebiet verstärkt)

→ Cyclogenesis: Tiefdruckgebiet entsteht oder wind stärker

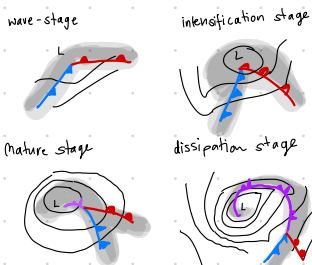
→ Warm and cold fronts are "twins": both are zones with lifting on the warm side, and subsidence on the cold side (circulation)

Trough over Low = Cyclolysis, Trough East to Low = Cyclogenesis (Divergence)

Norwegian - Cyclone Model

cold front overholes warm front → occlusion

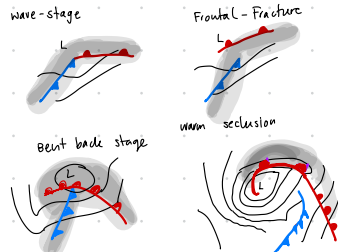
- front driven
- early occlusion
- cyclosis start early
- symmetric structure



Shapiro - Keyser Cyclone Model

Fronts break apart & separate from each other (frontal fracture), cold front brakes back, so there's only a "warm-seclusion", a warm front in the center of the low pressure system.

- jet-driven
- frontal fracture
- cyclosis starts late
- asymmetric structure



SW09 - WEATHER OBSERVATION

Weather Satellites

Types of orbits

Geostationary: 35,800 km altitude, fixed view of one region, e.g. Europe

→ Good for continuous monitoring, but lower resolution near poles.

Polar orbiting: 600 to 1200 km altitude, global coverage every 12 h, higher spatial resolution.

In orbit: $F_g = F_{ce}$ Balanced orbiting satellite:

$$\frac{G \cdot M_{earth}}{r} = V^2$$

sun-synchronous orbit (or quasi-polar orbit) (Landsat)

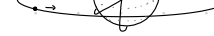
ca. 35° 800 km asl

T = 24h

Between 600-1200 km asl

T = 400 min

Orbital Orbit: (ISS, space shuttle, etc.)



Geostationary Orbit (or geo-synchronous orbit) (meteosat)

RESOLUTION

- Resolution decreases poleward for geostationary satellites

- Low orbits allow a higher resolution

- Technical advancement allows a higher resolution

e.g. Meteosat Third Gen:

spatial resolution ≈ 1 km, temporal resolution ≈ 150s

Spectral channels, 3 wavelength:

Visible VIS: detects reflected sunlight, shows clouds, surface features daytime only 600nm, cant distinguish clouds vs. snow

Infrared IR: detects emitted thermal radiation, works day and night, gives cloud top temp

10.8 μm, the hotter the surface, the shorter the wavelength & the more intensive the radiation

- works at night
- shows cloud height
- only top layer visible



6.2 μm

Water vapour WV: shows upperlevel moisture and air motion patterns.

Cloud-top-temperature CTT

CTT < -30°C = Risk of thunderstorm activity

CTT < -50°C = Risk of large thunderstorms with heavy lightning activity

CTT < -60°C = Risk of devastating thunderstorms with significant hail precipitation

Remote sensing: measurement of atmospheric / surface properties without direct contact; uses electromagnetic radiation

i) **Weather Radars: (active)**

It best measures objects with size similar to the emitted wavelength, 3 to 10 cm for Weather Radar

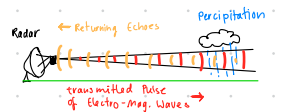
• strong echo strength → storm, thunder, ...

• Doppler → detects motion (radial velocity) → wind shear, storm rotation

• Dual-Polarisation → shape (type) of object → distinguishes rain/snow/hail

CAUTION: Radars (λ = 3.10 cm) can only see objects of comparable size, therefore:

Rain drops, hail, large snow flakes: ✓ Clouds, ice crystals, Drizzle, Haze: ✗



ii) **Satellites (passive remote sensing)**

Sensor does not emit radiation, measures naturally emitted / reflected electromagnetic radiation

• VIS → reflected sunlight (daytime only)

• IR → emitted thermal radiation (day & night)

• WV → radiation from water vapour (mid-upper troposphere)

CAUTION:

cannot directly detect precipitation, limited vertical resolution, reduced accuracy near surface

In-Situ Sensing

Direct measurement with sensor in contact with the atmosphere, Measures variables directly, no electromagnetic radiation

• There's strict guidelines for proper measurements

• Sensors are delicate and there are various factors that can distort measurements

• Measurement devices therefore must be designed well to prevent distortion

• Regular maintenance is mandatory

- **Thermometer**

Material property changes with temperature

Must be shielded from solar radiation

Sensor must be well ventilated and in contact with air

- **Anemometer**

Wind causes rotation (cup) or transit-time difference (ultrasonic)

Measures wind speed, and direction with wind vane

- **Pluviometer, (rain gauge)**

Collects precipitation in a funnel

Measures precipitation amount, (tipping bucket or weighing)

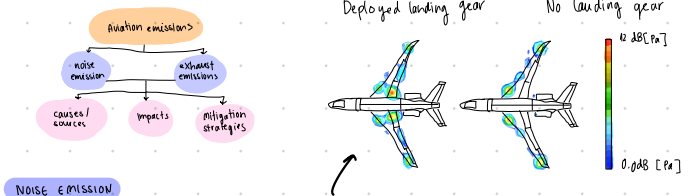
- **Barometer**

Air pressure causes mechanical deformation

Converted to pressure value

SW10 - AV EMISSION / IMPACT / MITIGATION

SW11- NUMERICAL MODELS



NOISE EMISSION

Causes / Sources: Air frame + landing gear / Engine fan / Exhaust Jet / Flaps

Impact on people: annoyance, sleep disturbance, impaired cognitive development in children, impaired learning, impact health, hypertension, increased mortality

Mitigation

- Noise regulation & standards in aviation $\Rightarrow$ EU.
- Technology for noise reduction: Using counter frequencies, ultra high bypass engines, chevron nozzle, low noise augmentation system

EXHAUST EMISSION

causes: Combustion process (Suck-Squeeze-Bang-Blow)
Fuel:

Jet A1 (kerosene)

- Made of hydrocarbons, molecules made of carbon (C) and hydrogen (H)
- C8 - C13 $\rightarrow$ molecules with 8 to 13 atoms
- Art of hydrocarbons in there: Naphthalen aromatics, alkanes, alkenes $\Rightarrow$ Fuel molecules which burns goods
- sulfur (up to 10 ppm), not wanted (increases emission) but unavoidable
- Additive = *Zusatzstoffe* $\Rightarrow$ corrosion protection

MOGAS / AVGAS

- mainly C5-C9 hydrocarbons $\rightarrow$ smaller molecules than kerosene
- More volatile, perfect for piston engine combustion
- Lead (Pb) up to 0,8g/L $\Rightarrow$ increases knock resistance
- Scavenger $\rightarrow$ substances that help to remove the lead from the engine after combustion, so it doesn't accumulate in the engine
- sulfur max 550 ppm
- combustion process: Burning of hydrocarbons

stoichiometric: helps to estimate: amount needed oxygen, amount of CO₂ & water production, how clean an efficient the combustion is

Combustion of jet fuel process:

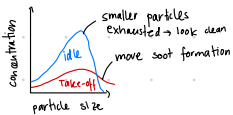
CO₂ $\Rightarrow$ 3,1 kg per kg fuel H₂O $\Rightarrow$ 1,1 kg per kg fuel SO₂/H₂SO₄ $\Rightarrow$ if sulfur in fuel

At temperature > 1600° nitrogen and oxygen molecules start to dissociate & forms NO_x
NO_x: *Sticksstoff*

Mitigation

Jet engine exhaust: SO₂ NO_x CO UHC PM Lead

- Particulate Matter (PM) = Tiny solid particles that appear in the exhaust plume.
- Soot = *Russ* $\Rightarrow$ They don't evaporate anymore
depends on: aromatic (they easily become carbon structure) and hydrogen content (more of it = cleaner combustion)



VPM = volatile particulate matter (>10nm)
Hot exhaust gases meet moisture and therefore forms particles
Measurement: engine exit: only soot, very few vpm
15m downstream: 15m behind nozzle (*duz*) $\Rightarrow$ a lot of new small vpm (section <10-20nm)

Air-fuel ratio (AFR)

How much air we have relative to what's needed for complete combustion.

$$\lambda = \text{AFR} / \text{AFR}_{\text{stoch}}$$

$\lambda > 1$: Rich = too little air

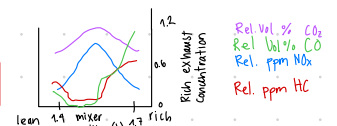
$\lambda < 1$: Lean = too much air

$\lambda = 1$: Stoichiometric, amount of air matching required volume

rich mixture: unburned HC (UHC) $\rightarrow$ Unburned hydrocarbons remain and CO instead of CO₂ gets formed, particulate matter

stoichiometric mixture: CO₂ & H₂O, and burn temperature rises & NO_x formation increases

Lean mixture: Low to no HC or CO, generally low NO_x



Why are pollutants here?

- Fuel composition: Sulfur, aromatics, fuel hydrogen content, lead (Pb) $\rightarrow$ key component driving emissions
- Ambient condition
- Cooler days $\rightarrow$ lower combustor inlet temperature $\rightarrow$ less efficient combustion
 - higher UHC, CO, PM emissions (low thrust)
 - lower NO_x (high thrust)
- Hot days $\rightarrow$ higher combustor inlet temperature $\rightarrow$ higher exhaust temperature
 - higher NO_x emissions, pronounced at high thrusts

Pollutant analysis:
Pollutant: NO_x, CO, SO₂
UHC, PM
Non-Pollut: but Greenhouse gases:
CO₂, H₂O

Δ (NO_x & CO has also GHG)

Impacts

Air quality impacts:

- Ecosystem damage (Acid rain, Soil & Water deterioration): SO₂, NO_x, UHC, Lead
- Ecosystem damage (ozone chemistry & smog, plant health): SO₂, NO_x, CO, UHC, PM
- Human health (respiratory irritant, impacts on cardiovascular health): SO₂, NO_x, UHC, PM, Lead
- Poison: CO, Lead

Climate impacts:

- Greenhouse gases: H₂O, CO₂, NO_x, UHC
- ozone chemistry at ground & altitude: CO, NO_x, UHC
- aerosol (formation) (controls aerosol-cloud interaction): H₂O, UHC, SO₂, PM

Extra

Emission per engines [g]:

- Fuel Flow / Time = fuel flow $\cdot$ time in mode $\cdot$ 60

Emission per engines = EI $\cdot$ Fuel flow / time

Emission per day in kg:

Emissions per engine $\cdot$ Traffic $\cdot$ engines
1000

"weather of today is the weather of tomorrow" called **Persistence:**

GOOD

- regions with low variability
- during stable weather cond.
- in short time

BAD

- in regions with high variability
- during frontal passages
- in regions with complex terrain and dynamics

Numerical weather prediction uses computers to solve the physical equations governing the atmosphere. The atmosphere is represented by discretization into grid boxes and time steps, within which momentum, mass, and energy are calculated.

BASIC EQUATIONS driving a weather model

Conservation of momentum, energy, mass and moisture:

"Why is this used?"
Change of velocity with time:
$$\frac{\partial \vec{v}}{\partial t} = -(\vec{v} \cdot \nabla) \vec{v} - \frac{1}{\rho} \nabla p - \vec{g} - 2\vec{\Omega} \times \vec{v} + \nabla \cdot (\kappa_a \nabla \vec{v}) - \vec{F}_d$$

advection of momentum, change in pressure, vertical acceleration (only for w-comp), Coriolis force, "diffusion" of momentum, friction

"Why don't we get colder/warmer?"
Change of temperature with time:
$$\rho c_p \frac{\partial T}{\partial t} = -\rho c_p (\vec{v} \cdot \nabla) T - \nabla \cdot \vec{R} + \nabla \cdot (\kappa_r \nabla T) + C + S$$

Change of temp, divergence of radiation, "diffusion" of temperature, heating through convection, radiating through convection

"Why is there a flow of mass to a place where I take air 'empty'?"
"And what about moisture?"

$$\frac{\partial \rho}{\partial t} = -(\vec{v} \cdot \nabla) \rho - \rho (\nabla \cdot \vec{v})$$

continuity (mass conservation) eq.

$$\frac{\partial q}{\partial t} = -(\vec{v} \cdot \nabla) q + \nabla \cdot (\kappa_q \nabla q) + S_q + E$$

moisture eq.

$$p = \rho R T$$

equation of state

$\vec{v}$ = velocity
 T = temperature
 p = pressure
 ρ = density
 q = specific humidity
 g = gravity
 $\vec{\Omega}$ = rotation of Earth
 $\vec{F}_d$ = drag force of Earth
 $\vec{R}$ = radiation vector
 C = conductive heating
 c_p = heat capacity, constant p
 E = evaporation
 S = latent heating
 S_q = phase change source
 κ = diffusion coefficients
 R_d = dry air gas constant

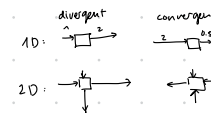
Numerical model languages:

- Python, NumPy, Matlab, gfortran, Fortran, Java
- Fortran still in use because: its fast, easier code manipulation
But increasing demand for models in higher level languages, Python mostly
- Advection: Transport by large scale resolved wind (move an air parcel somewhere else)
- Resolved: Larger or bigger than your box
- Diffusion: Transport by small scale wind unresolved $\rightarrow$ Not necessary molecular diffusion

Vector Calculus

$\nabla =$ "Nabla" = divergence

(does more come out of a box than in- or vice versa)



divergence:
"what comes out > what goes in"

convergence:
"what goes in > what comes out"

Differences

Weather model: simulates the time evolution of the atmosphere over short periods (hours per day)

Climate model: descr. statistical properties of climate system (mean, variability) over long timescale (years/centuries)

Numerical weather model

Discretization and model types

- Continuous atmosphere $\rightarrow$ finite grid points + time steps
- Global models: GFS, IFS, GEM, ICON
- Regional models: HIRLAM, WRF, AROME
- Complex topography requires smaller grid boxes but increases uncertainty

Why not high resolution worldwide?

- Too many grid boxes to compute
- More boxes $\rightarrow$ longer computation time
- Models must run several times per day
- Data exchange (I/O, MPI) becomes the limiting factor at high CPU counts
- Extremely high electricity demand for global high-resolution models

Parameterization

Processes smaller than the grid resolution cannot be resolved explicitly and are described using simplified empirical relationships:

Convection, Cloud microphysics, Turbulence and diffusion, Radiation, Orographic effects, Surface processes

Data assimilation

Data assimilation combines observations with model forecasts to produce the most realistic and physically consistent initial state.

Observation sources: Synop stations and ships, Buoys, Aircraft, Radiosondes, Satellites

you are able to explain how models are "started" and how they generate usable data

1) **Initial condition:** The analyzed atmospheric state at the start of a model simulation.

2) **Boundary condition:** Prescribed atmospheric or surface values at the edges of the model domain.

Modeling Perspective

- Eulerian: observing changes at a fixed location
- Lagrangian: Following air parcel along its path $\rightarrow$ especially useful for volcanic ash & pollutants

What if we lose all satellites?

- S.H: Prediction quality sinks quickly $\rightarrow$ At day 5: Prediction is worse by 3 days
- N.H: Prediction quality sinks but less than in S.H $\rightarrow$ At day 5: 3/4 loss at day 5 $\rightarrow$ because of synop and airplane observations

Improvements in weather modeling

- better parametrization, increase in resolution, improvement in topography information, increase in the number of assimilated data, improvements of the advection scheme

SW12- AVIATION HAZARDS

• Accident statistics from NTSB ("US-SUST") → icing, turbulence, wind shear, thunder storm...

ICING

• "Recipe" = water + cold temp + little to no ice-phase (no activated ice nuclei)

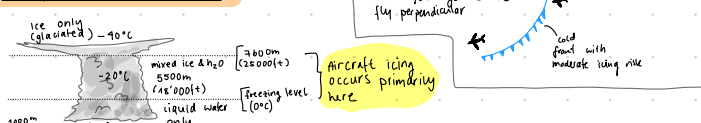
(but not too cold: more than 50% of icing events occur between -4°C & -14°C)

→ that range contains the highest concentration of super. droplets

• 50% of all icing occurs between 4'000ft & 12'000ft (FL040-FL120)

→ where SLW concentration is the highest → below -14°C : less to no liquid droplets

water, temperature, altitude



Bergeson-Findeisen-process:

If ice crystals are present in a supercooled cloud:

• Water vapor prefers to deposit on ice rather than stay as droplets, lower saturation vapor pressure over ice

• Ice crystals grow, droplets shrink

• → SLW decreases

• → Structural icing risk drops significantly

Meaning: mixed phase clouds can quickly become glaciated, reducing icing risk.

Ice type: CLEAR ICING



• large droplets in cumulonimbus clouds, freezing rain, or terrain effects

RIME ICING



• small supercooled droplets in stratiform clouds

MIXED ICING



• large & small droplets coexist
• liquid & frozen particles coexist
• wet snow

classification: (rate of accretion)

Light (no change of course or altitude is necessary/no loss of airspeed, 0.6 to 2.5 cm/hr)
• Moderate (airspeed loss, 2.5 to 7.5 cm/hr)
• Severe (anti-ice/ice-icing can't cope with icing anymore, imminent diversion necessary)

countermeasures:

• Avoid areas w/ icing risk! → on ground: deicing!

• Air: deicing boots / system, heating wings, viscous

• carburetor icing

Effects: • increase weight • reduce lift • decrease thrust (w/ prop-icing / carb-icing) • increase drag

TURBULENCE

Why a problem? when it encounter turbulence? optimal AOA & wind disturb → stall (worst case)

• "recipe": wind shear!

• Can be due:

- any TAS > 0.1x of the aircraft
- wind flow
- disturbance within the wind flow triggered by thermals, mechanic stress, etc
- flying near ground
- other aircraft

classification: ⇒ Eddie dissipation rate:

- Nil (peak EDR < 0,1)
- Light ($0,1 \leq \text{peak EDR} < 0,2$)
- Moderate ($0,2 \leq \text{peak EDR} < 0,45$)
- Severe ($0,45 \leq \text{peak EDR}$)

TYPES

- Wake turbulences: due vortices spread lateral from the rear of the aircraft. Up to 5 miles back & 500-300 feet downwards.
- Turbulence due mechanical stress: occurs when wind encounters obstacles (building, trees, mountains) and is thereby swirled

clear-air-Turbulence: created in free atmosphere by unstable flows, such as breaking gravity waves and is particularly dangerous for pilot because it's invisible

Turbulence due to thermals: caused by raising warm air over heated ground & strongest over land during day

Countermeasures: - Look at Sigmet/Pireps

THUNDERSTORM

Hazards: Strong updrafts, downdrafts, wind shear (horizontal/vertical), icing, turbulence, hail, Dynamics

Microbursts are short-lived, extremely strong downdrafts from thunderstorms that are particularly dangerous during take-off and landing due to massive wind shear

Countermeasures: • TS difficult to forecast (can be very local)

• Use onboard radar

• Inquire windspeeds from TWS if VECT

• TAF with Tempo PROB 40TS should be considered carefully not ignored!

Virga downdrafts: caused by evaporation of precipitation below the cloud, cooling the air and can cause strong downdrafts & wind shear often as precursor to microburst.

Density altitude: - High temperatures
- Low QNH
- High humidity } Danger!

SW13- CLIMATE CHANGE

WEATHER: describe the short-term state of the atmosphere (hours to days), such as temp, precipitation, wind, or cloud cover at a specific place & time

CLIMATE: is a statistical description of weather, typically averaged over a long period, can be described as: change of tendencies of (regional) weather patterns • change in probability of certain (extreme) weather events • consequence: global warming

• How today's global warming differs from past climate variations

• Past climate variation were mainly driven by: natural forcing, "Minkavitch cycles" (orbital changes), volcanic activity, solar variability, acting over 1000 years

• Today characterized by: • very rapid temp. increase • clear correlation with anthropogenic greenhouse gas emission (CO_2 , CH_4) • warming rate far exceeding natural variability observed in paleoclimatic records

ICE: last Glacial maximum 24'000 years ago → "the more older ice, the denser the ice" increasing pressure & recrystallization

Information from ice cores → DIRECT: isotopes; composition of ice & gas bubble

Information from ice cores → INDIRECT: isotopes (age, temp); composition of ice & gas bubble (• CH_4 concentration)

ISOTOPES OF HYDROGEN: are atoms of the same element with same number of protons, but a different nr. of neutron all hydrogen isotopes have 1 proton.



Molecular weight of water (H_2O) depends on hydrogen & oxygen isotopes!

• lighter water evaporates more easily

• leaving heavier water/ice back

• composition of ice is temperature dependent!

• Arctic amplification (AA): Arctic warms about 2-3 times faster than the global mean:

Key drivers include:

• ice albedo feedback: melting ice reduces surface reflectivity, increasing solar absorption.

• Water vapour and cloud feedbacks: warmer air holds more moisture, enhancing longwave trapping.

• Arctic greening: vegetation changes lower albedo.

Enthalpy effects: reduced energy required for phase changes, less ice to melt.

These interacting positive feedbacks strongly amplify warming in the Arctic

• "feedback" & apply this conceptual model each other:

A feedback is a process in which an initial temperature change triggers secondary effects that feed back onto the temperature, either amplifying it (positive feedback) or damping it (negative feedback)

• climate scenario

Climate scenarios are model based projections of future climate under different socio-economic and emission pathways.

Modern scenarios include SSPs / RCPs, ranging from strong mitigation to high emission futures They project:

- continued global warming,
- stronger warming over land and the Arctic,
- changes in precipitation patterns, including more extremes;
- region specific impacts, e.g. wetter winters and drier summers in Switzerland

Scenarios are not predictions but plausible futures based on assumptions

• different (aviation) climate mitigation: CO_2 reduction, improved ATM, System-level approaches...

pparts per mio. volume

1 ppmv = 10^{-6}

Emission per engines [g]:

- Fuel Flow / Time = fuel flow • time in mode • 60

Emission per engines = EI • Fuel flow / time

Emission per day in kg:

Emissions Per engine • Traffic • engines
1000

AFR - Air-Fuel-Ratio:

1) $\lambda = \frac{\text{AFR}_{\text{real}}}{\text{AFR}_{\text{stoich}}} \text{ AFR} = \frac{m_{\text{air}}}{m_{\text{fuel}}}$

$\lambda > 1$: Rich = too little air

$\lambda < 1$: Lean = too much air

$\lambda = 1$: Stoichiometric, amount of air matching required volume

CO_2 Konzentration in ppmv

1) Erdoberfläche berechnen: $A = 4\pi R_{\oplus}^2 = P_{\oplus} A$

2) Gesamtmasse der Atmosphäre $m_{\text{air}} = \frac{P_{\oplus} A}{g}$

3) ppmv in Massenmischungsverhältnis umrechnen:

$$w = \text{ppmv} \cdot 10^{-6} \cdot \frac{M_{\text{CO}_2} \rightarrow 44 \text{ g/mol}}{M_{\text{air}} \rightarrow 28.96 \text{ g/mol}} \\ \uparrow 426.5 \text{ ppmv} = 126.5 \cdot 10^{-6} \text{ (7.5)}$$

4) CO_2 - Masse berechnen: $M_{\text{CO}_2} = w \cdot m_{\text{air}}$

5) Prozentualer Beitrag Anteil [%]: $\frac{M_{\text{aviation}}}{M_{\text{global}}} \cdot 100$

Volumen (oder Stoffmenge) eines Gases
 $\text{ppmv} = \frac{\text{Gesamtmenge (oder Gesamtstoffmenge)}}{\text{Gesamtmenge (oder Gesamtstoffmenge)}} \cdot 10^6$

TAF

Tempo 2602/2606 MIFG
→ 26. von 02:00 - 06:00 shallow fog

METAR: A3028 = 30.28mHg (Altimetersetting) 1inHg = 33.86hPa

1hPa = 0.0295293inHg 1gdp = 10m 1ft = 0.3048m

SW02 Atmosphere

$$P = \frac{F}{A} \quad S = \frac{m}{V}$$

Druck in einer Höhe z / Höhe z aus einem P(z)

$$P(z) = P_0 \cdot \left(1 - \frac{0.0065 \cdot z}{T_0}\right)^{5.255}$$

$$z = \frac{T_0}{L} \left[1 - \left(\frac{P}{P_0}\right)^{1/5.255}\right]$$

wie schwer die Luft an einer Fläche die Luft ist an

QFE; Stationsdruck: $\downarrow$ in Pa!

1) Formel: $m = \frac{P \cdot A}{g}$ ← geg. oder assume

Different Charts Modell

Significant Weather Chart

environmental Temp at tropopause → -39 / 320 = minimum Tropopause at FL320

maximum tropopause nicht einfach ablesbar

"xxx" → wenn Basis unterhalb FL100 oder oberhalb FL450 with

850hPa = 1500m
800hPa = 2000m
700hPa = 3000m
500hPa = 5500m

ISA RH = 0%

P = 1013hPa

Lapse Rate = -2°C/1000ft

↔ -6.5K/km

QFE = QNH - dp

Tatsächlicher Druck am Platz

QNH = METAR/TAF (Druck auf MSL reduziert)

sonst: $= QFE + \frac{(\text{elevation}) \cdot ft}{28}$

QNE = 1013.25hPa / 29.92inHg Standarddruck

QFF = Pressure reduced to sealevel (Formel Psi)

Psi = Pressure red. to sealevel (QFF) in dPa (= 0.01hPa)
P = Actual measured Pres. (QFE) in dPa (= 0.1hPa)
T = Air Temp
Nb = Altitude in m

$$QFF = P_{sl} = P \exp\left(\frac{h_b}{30.8} \cdot \frac{10.5152}{(x + T + 273.15) + \frac{h_b}{30.8}}\right)$$

$$x = \frac{(T + 273.15)}{P} \exp\left(\frac{(T + 273.15) \cdot \frac{h_b}{30.8}}{T + 273.15 + \frac{h_b}{30.8} - 1060}\right)$$

① Pressure altitude:

1) druck differenz

ISA = 1013.25 $\Delta P = 7.75hPa$
QNH = 1021
(aus METAR 10)

2) umrechnung in Höhenkorrektur

$$\Delta h = 7.75hPa \cdot 28ft = 217ft$$

$\Delta P \cdot 28ft$

3) PA ausrechnen:

pressure is higher than ISA:

• wenn QNH > ISA $\Rightarrow PA = \text{Airport alt} + \Delta h$

$$\text{Airport alt. (5600ft)} - 217ft = 5383ft$$

• wenn QNH < ISA $\Rightarrow PA = \text{Airport alt.} + |\Delta h|$

② Density altitude

1) PA berechnen

2) OAT (outs. Temp) am Platz nehmen

3) TISA auf dieser Höhe bestimmen

ISA nimmt um 2°C pro 1000ft ab

$$T_{ISA} = 15^\circ C - \frac{2^\circ C}{1000ft} \cdot 5383 = 15 - 10.766 = 4.24^\circ C$$

4) Temperaturdifferenz

$$\Delta T = OAT - T_{ISA} = 25 - 4.24 = 20.76^\circ C$$

5) DA-Korrektur (Faustregel 120ft pro °C)

$$\Delta h = 120ft/K \cdot 20.76^\circ C = 2490ft$$

$$6) DA = PA + DA\text{-korrektur} = 5383ft + 2490ft = 7873ft$$

SW02 Radiation

Energie benötigt zum Abkühlen

1) Temp.änderung: $\Delta T = T_{\text{anfang}} - T_{\text{zieltemp}}$

2) Volumen der betrachtete Schicht: $V = A \cdot d$

3) Masse: $m = \rho V$

4) Energie, die weg muss $Q = mc \Delta T$

Netto-Strahlungsleistung bestimmen:

$$1) \text{ mittlere Temp: } T_{mid} = \frac{T_{out} + T_{inlet}}{2} \quad [in K]$$

2) Ausgehende LW-Strahl: $L_{\uparrow} = \epsilon \sigma T_{mid}^4$

3) Netto-Verlust (pos. = Energieverlust): $L_{net} = L_{\uparrow} - L_{\downarrow}$

4) Leistung: $P = L_{net} A$

$$\text{Zeit bis zum Gefrierbeginn: } t = \frac{Q}{P} \quad [in \text{ sek.}]$$

SW03+04 Thermo dynamik

• local saturation vapor pressure e_s / water vapor (saturated) pressure

WMO CIMO!

$$e_s(T) = 6.112hPa \cdot \exp\left[\frac{17.62 \cdot \frac{T[K]}{292.15K - 30.03} - 7.812 \cdot \frac{903}{T[K]}}{1}\right] = 21.92hPa$$

• actual vapor pressure e / saturation pressure at the dewpoint $e = e_s(T_d)$

$$e = e_s(-9^\circ C) = 6.112hPa \cdot \exp\left[\frac{17.62 \cdot \frac{264.15K}{292.15K - 30.03} - 7.812 \cdot \frac{903}{264.15K}}{1}\right] = 310.5Pa$$

$$RH = \frac{e}{e_s(T)} \cdot 100\% = \frac{e_s(T_d)}{e_s(T)} \cdot 100\%$$

• mixing ratio % = $r = \frac{\epsilon \cdot e}{p - e}$
or $r = \frac{m_{\text{water vapor}}}{m_{\text{dry air}}}$

• dewpoint T_d with WMO CIMO equation

$$T_d = \left[\frac{4842.903 - 3003 \cdot \ln\left(\frac{e}{e_s}\right)}{17.62 - \ln\left(\frac{e}{e_s}\right)} \right] \quad [K]$$

Gleichgewichtstemperatur

Reflexion berücksichtigen (albedo)

$$P_{in} = \pi r^2 \cdot S_0 \cdot (1 - \alpha) = 4\pi r^2 \epsilon \sigma T_e^4$$

1) Abgestrahlte Leistung bestimmen: $P_{out} = \epsilon \sigma T_e^4 \cdot A$

$$2) \text{ Strahlungsgleichgewicht ansetzen } P_{in} = P_{out} \Rightarrow T_e = \left(\frac{S_0 (1 - \alpha)}{4 \epsilon \sigma} \right)^{1/4}$$

$$3) \text{ dann in } ^\circ C \rightarrow T_e = T - 273.15$$

• time calculation until something cools down:

$$1. \Delta T = T_{\text{was dem gekühlt sein muss}} - T_{\text{start temp}}$$

$$2. Q = c \cdot m \cdot \Delta T \Rightarrow m = \frac{P \cdot V}{c}$$

$$3. J_{out} = 5.6 \cdot 10^{-8} \cdot \left(\frac{T_{start} + T_{ende}}{2} \right)$$

$$4. L_{diff} = L_{in} - J_{out}$$

$$5. t = \frac{Q}{L_{diff}}$$

Isobaric chart / surface pressure chart



• Pressure gradient $\frac{\partial P}{\partial y} = \frac{\Delta P}{\Delta y}$

1) zwei Isobaren wählen $\pm B$ • innere $P_1 = 980hPa$ • äußere $P_2 = 1005hPa$ $\Delta P = P_2 - P_1$

2) Strecke zwischen 2 Isobaren wählen: $\Delta y \approx 640km = 640000m$

$$\text{geostrophic wind } U_g \quad \frac{dv}{dt} = -\frac{1}{f} \frac{\partial P}{\partial y} + f u$$

in equilibrium condition: $\frac{dv}{dt} = 0$ (wind speed doesn't change anymore)

$$0 = -\frac{1}{f} \frac{\partial P}{\partial y} + f u \Rightarrow U_g = \frac{1}{f} \frac{\partial P}{\partial y} \approx 26 [ms^{-1}] (\approx B)$$

• Gradient wind U_{gr} High-Pressure System $U_{gr} = \frac{U_g}{2} + \sqrt{\left(\frac{U_g}{2}\right)^2 + \frac{R}{f} \frac{\partial P}{\partial y}}$
Low-Pressure System $U_{gr} = \frac{U_g}{2} - \sqrt{\left(\frac{U_g}{2}\right)^2 + \frac{R}{f} \frac{\partial P}{\partial y}}$
Einheit $[ms^{-1}]$! $\approx B \approx 20.6ms^{-1}$
Miss den Abstand vom Referenzpunkt zur betrachteten Isobare

Unterschied Geostr. & Grad. Wind

$$\Delta U = U_g - U_{gr} = 5.2ms^{-1} \approx 19kmh^{-1}$$

"Gradientwind ist hier ca. 20km/h langsamer als geostrophisch"

500hPa Geopotential chart / Isohypsenkarte



Geostroph. Wind aus 500hPa Isohypsen

• geopot.-height-gradient

• Δz : Höhenunterschied zwischen zwei Isohypsen. $548 - 510 = 38gpm = 80m$

$$\nabla z = \frac{\partial z}{\partial y}$$

• ∂y : gemessen, senkrecht zu den Isohypsen

Geostrophische Gleichung

$$V_g = \frac{g}{f} |\nabla z|$$

Coriolis parameter = $2 \Omega \sin \phi$

• Gradient Wind V_{gr}

R = Krümmungsradius der Isohypsen

nur für 500hPa Druckflächen, Nordhalbkugel

$$V_{gr} = \frac{fR}{2} + \sqrt{\left(\frac{fR}{2}\right)^2 + gR \left(\frac{\partial z}{\partial y}\right)}$$