

Repetisjonsforelesning

GEF2200

Termodynamikk

TD. Førstehovedsetning.

$$dq = dw + du$$

Nyttige former:

$$dq = c_v \cdot dT + p d\alpha$$

$$dq = c_p \cdot dT - \alpha dp$$

Entalpi (h)

$$h = u + p\alpha \rightarrow dh = c_p \cdot dT \rightarrow v/\text{konstant trykk (dp=0)} \quad dq = dh$$

Adiabatiske prosesser: $dq = 0$

$$\rightarrow c_p \cdot dT - \alpha dp = 0 \rightarrow \dots \rightarrow \Theta = T \left[\frac{p_0}{p} \right]^{R/c_p}$$

Termodyn. (2)

Vanndamp i luft

- Mange måter å definere innholdet på

- Masseblandingsforhold $w = \frac{m_v}{m_d}$

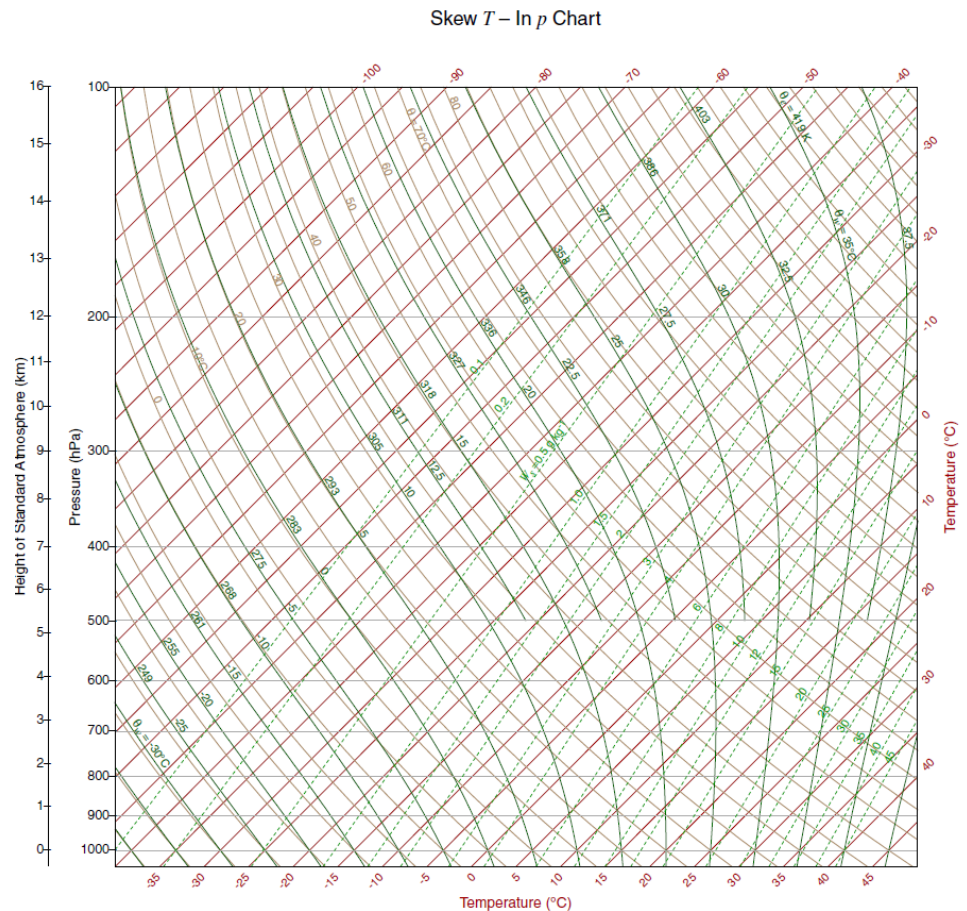
- Spesifikk fuktighet $q = \frac{m_v}{m_v + m_d}$

- Relativ fuktighet $RH = 100 \cdot \frac{w}{w_s} = 100 \cdot \frac{e}{e_s}$

TD 3.

Oppstigning → adiabatisk avkjøling →
metning (LCL) → kondensasjon →
frigjøring av latent varme → fuktig adiabat

Sondediagram:



TD 4. Ekvivalent potensiell temperatur

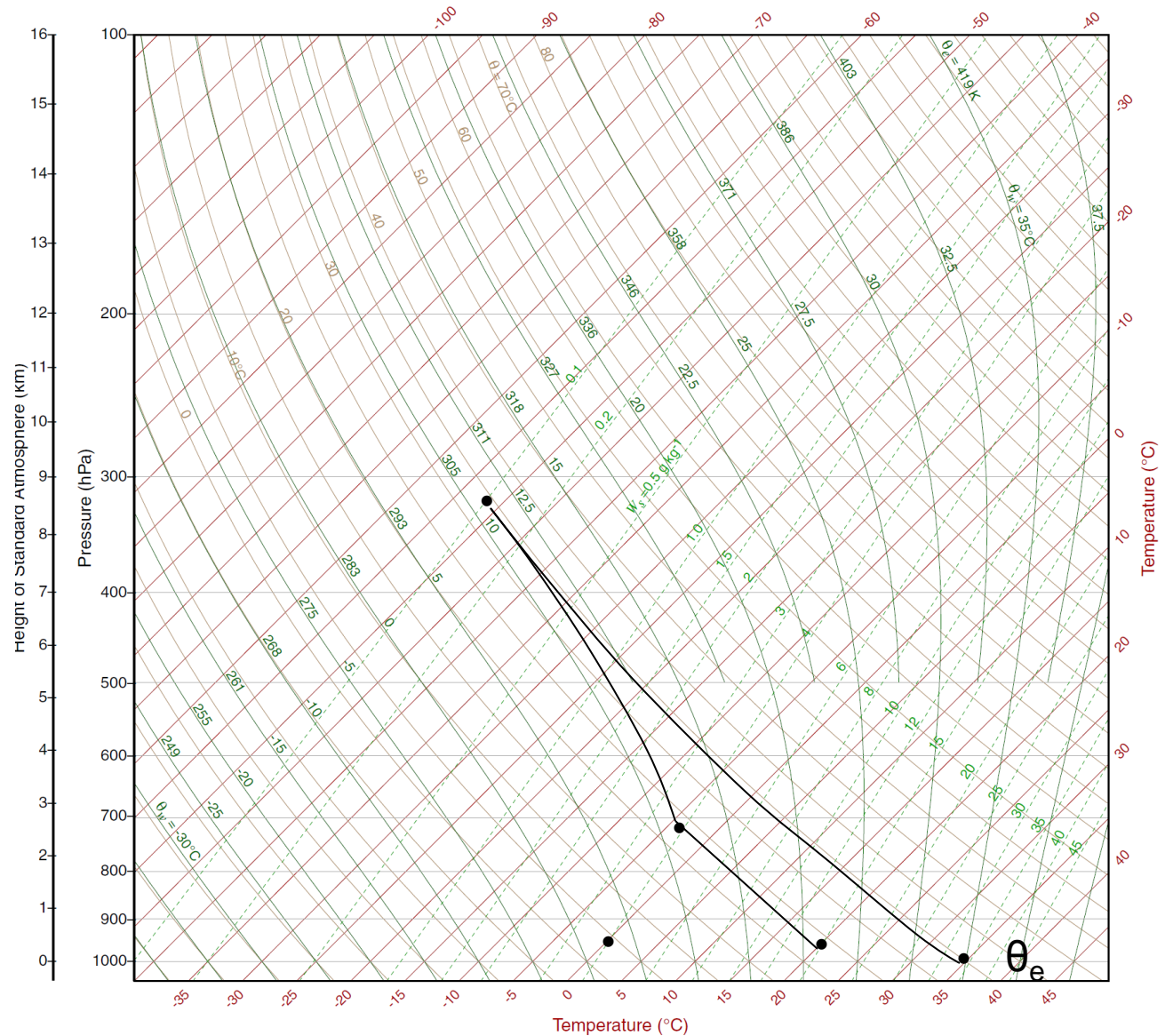
Skew $T - \ln p$ Chart

$T = 20^\circ\text{C}$

$P = 950 \text{ hPa}$

$w = 4 \text{ g/kg}$

Hva er θ_e ?



TD 6. Föhnvind

Oppstigning (fra T_0, p_0) → adiabatisk avkjøling →
metning (p_{LCL}) → kondensasjon →
frigjøring av latent varme →
Nedbør (reduisert vanninnhold) →
nedstigning → adiabatisk oppvarming → fordampning
→ undermetning ved $p < p_{LCL}$ → videre adiabatisk
oppvarming

Resultat: $T(p_0) > T_0$

TD 7. Statisk stabilitet

Tørr luft:

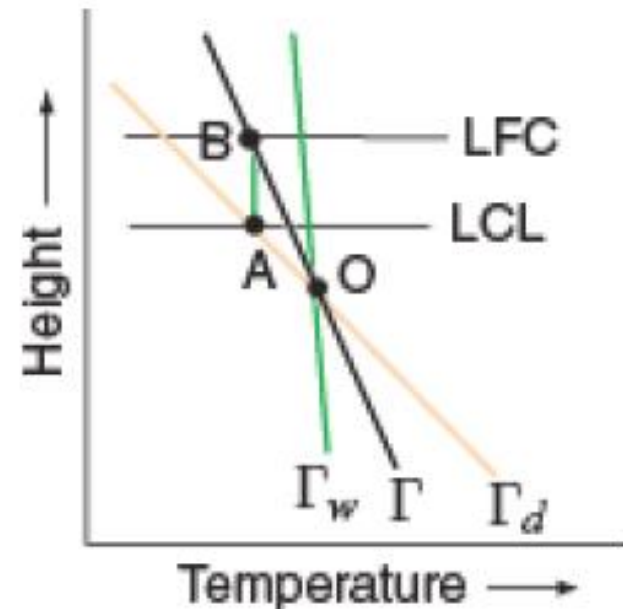
- Stabilt: $\frac{d\Theta}{dz} > 0 \quad \leftrightarrow \quad \Gamma < \Gamma_d$

- Nøytralt: $\frac{d\Theta}{dz} = 0 \quad \leftrightarrow \quad \Gamma = \Gamma_d$

- Instabilt: $\frac{d\Theta}{dz} < 0 \quad \leftrightarrow \quad \Gamma > \Gamma_d$

TD 7. Betinget instabilitet

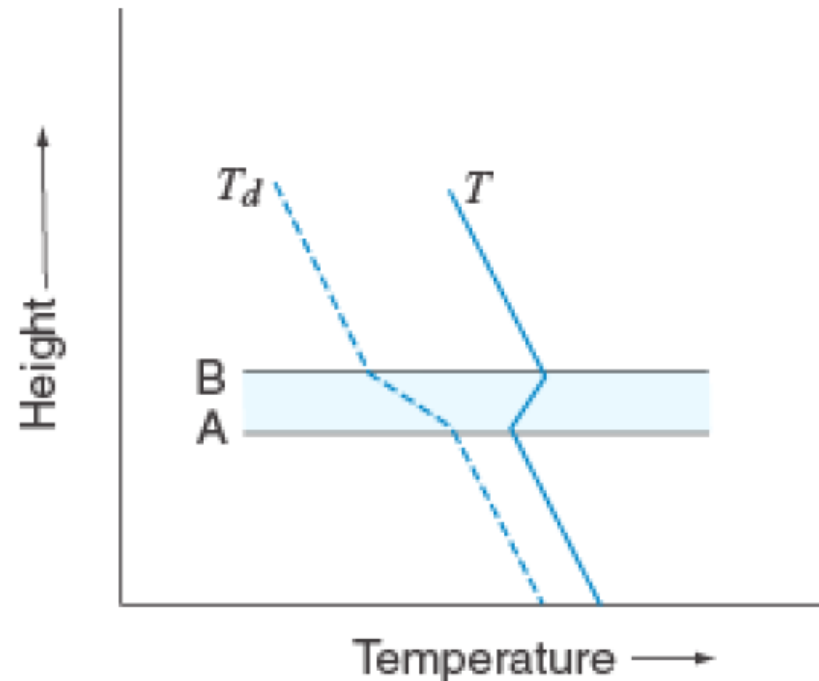
- Når $\Gamma_s < \Gamma < \Gamma_d$ har vi forhold som er betinget instabile.
- Betingelsen er at luftpakken når punkt B i figuren
- Mellom O og B er luftpakken tyngre enn ombivelsene



TD 8. Konvektiv instabilitet

- Konvektiv instabilitet kan vi når et fuktig lag ligger under et tørt lag, og begge heves.
- Fuktig lag: Frigjøring av LH → sakte reduksjon av temperaturen
- Tørt lag: Tørr adiabatisk
→ raskere temperaturreduksjon

→ Instabilt etter hvert



TD 9. Carnotsykel med vann/vanndamp

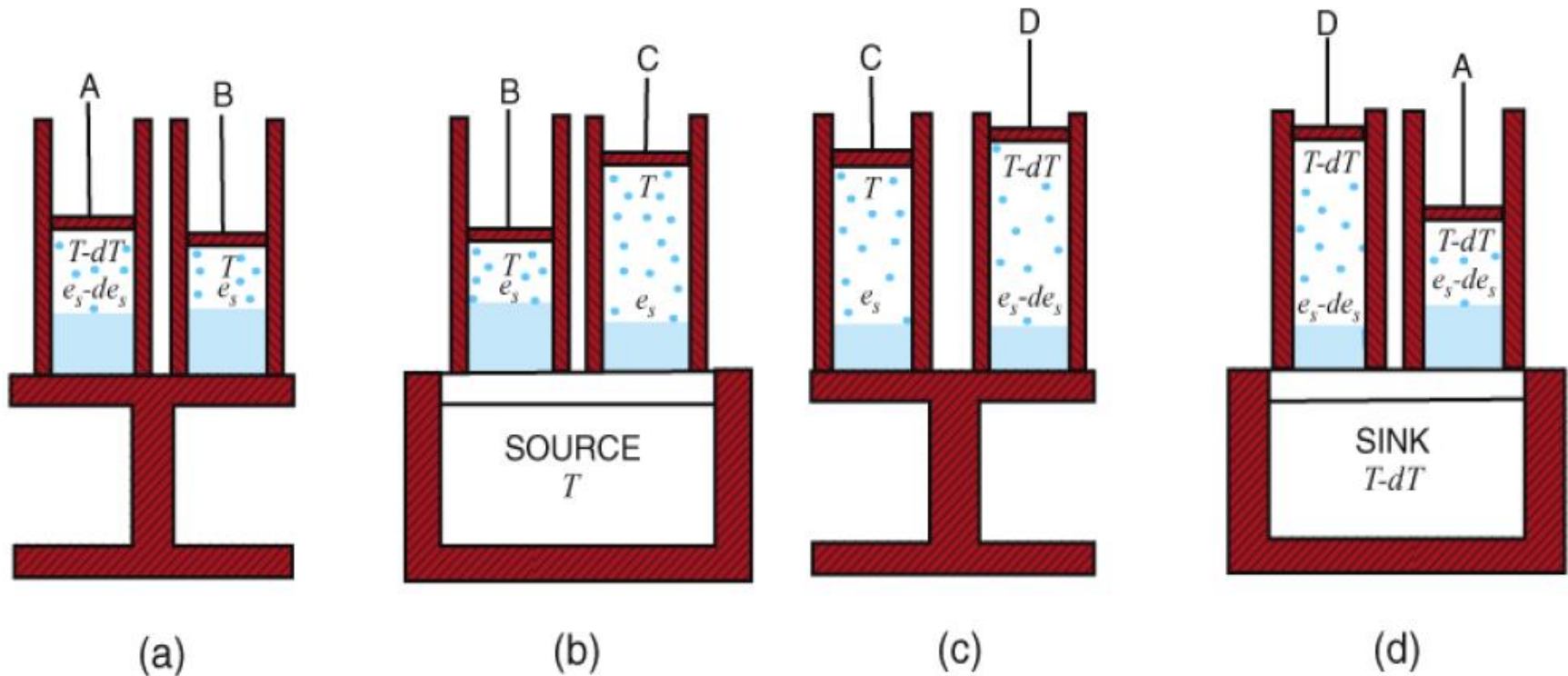


Figure 3.24 Transformations of a liquid (solid blue) and its saturated vapor (blue dots) in a Carnot cycle. The letters A, B, C, D indicate the states of the mixture shown in Fig. 3.23. The red shaded areas are thermally insulating materials.

TD 10. Clausius-Clapeyrons likning

C.-C. likning forteller oss hvordan metningstrykket til vanndamp varierer med temperaturen

$$\frac{de_s}{dT} = \frac{L_v}{T(\alpha_2 - \alpha_1)}$$

Kan integreres \rightarrow
$$\ln \frac{e_s (hPa)}{6.11} = \frac{L_v M_w}{1000 \cdot R^*} \left[\frac{1}{273} - \frac{1}{T} \right]$$

Skyfysikk

Kondensasjon av dråper

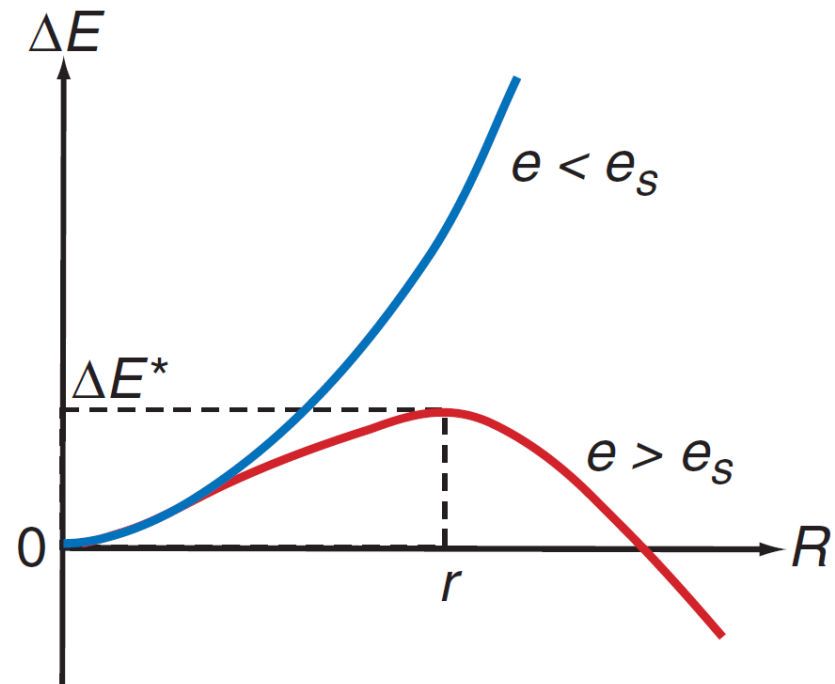
- Balanse mellom overflatespenning (A) og indre energi ved faseovergangen (V)
- V/A øker når radiusen øker
→ større dråper er mer stabile

$$\Delta E = 4\pi R^2 \sigma - \frac{4}{3} \pi R^3 nkT \ln \frac{e}{e_s}$$

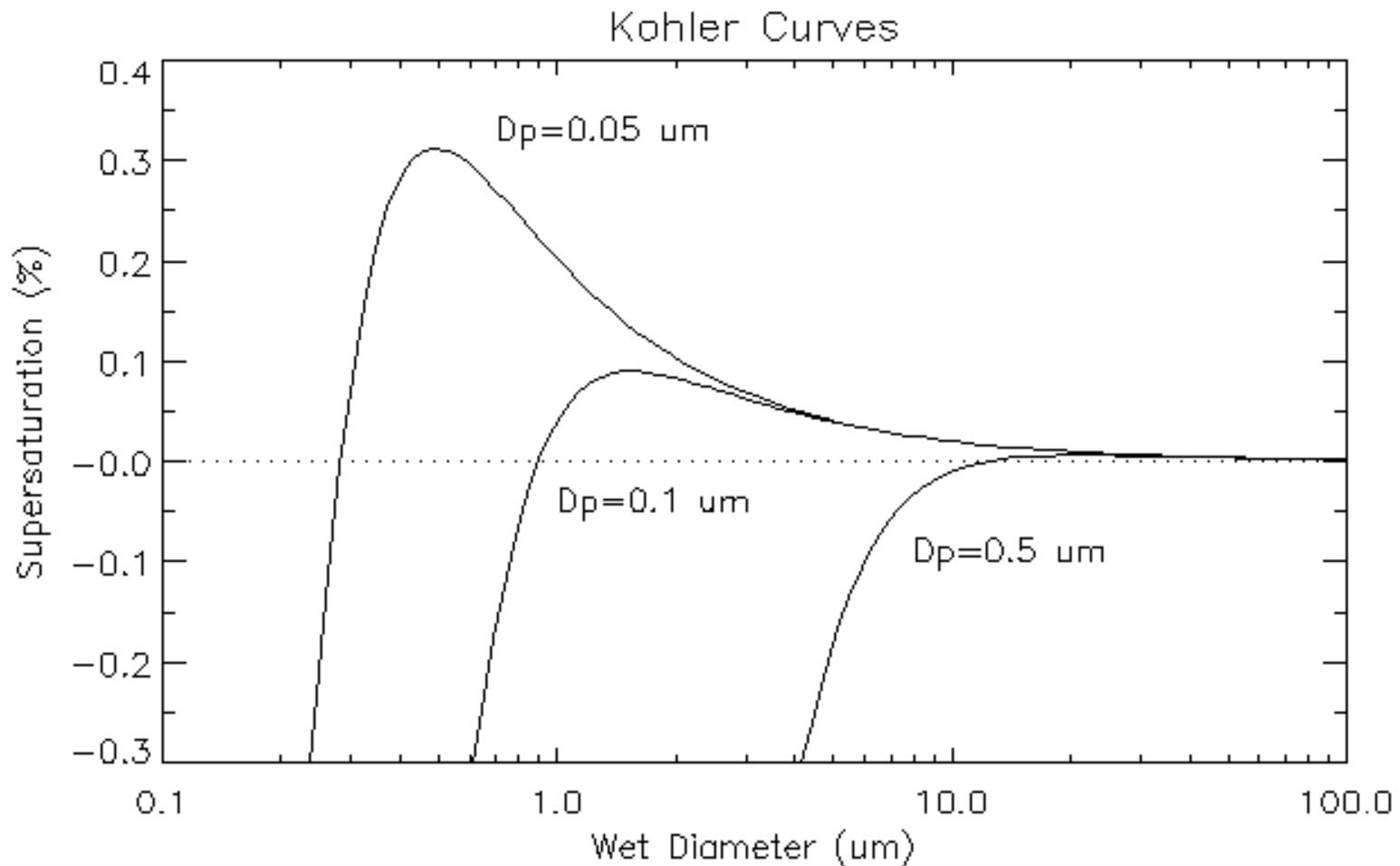
Homogen nukleasjon

Krever meget høy overmetning

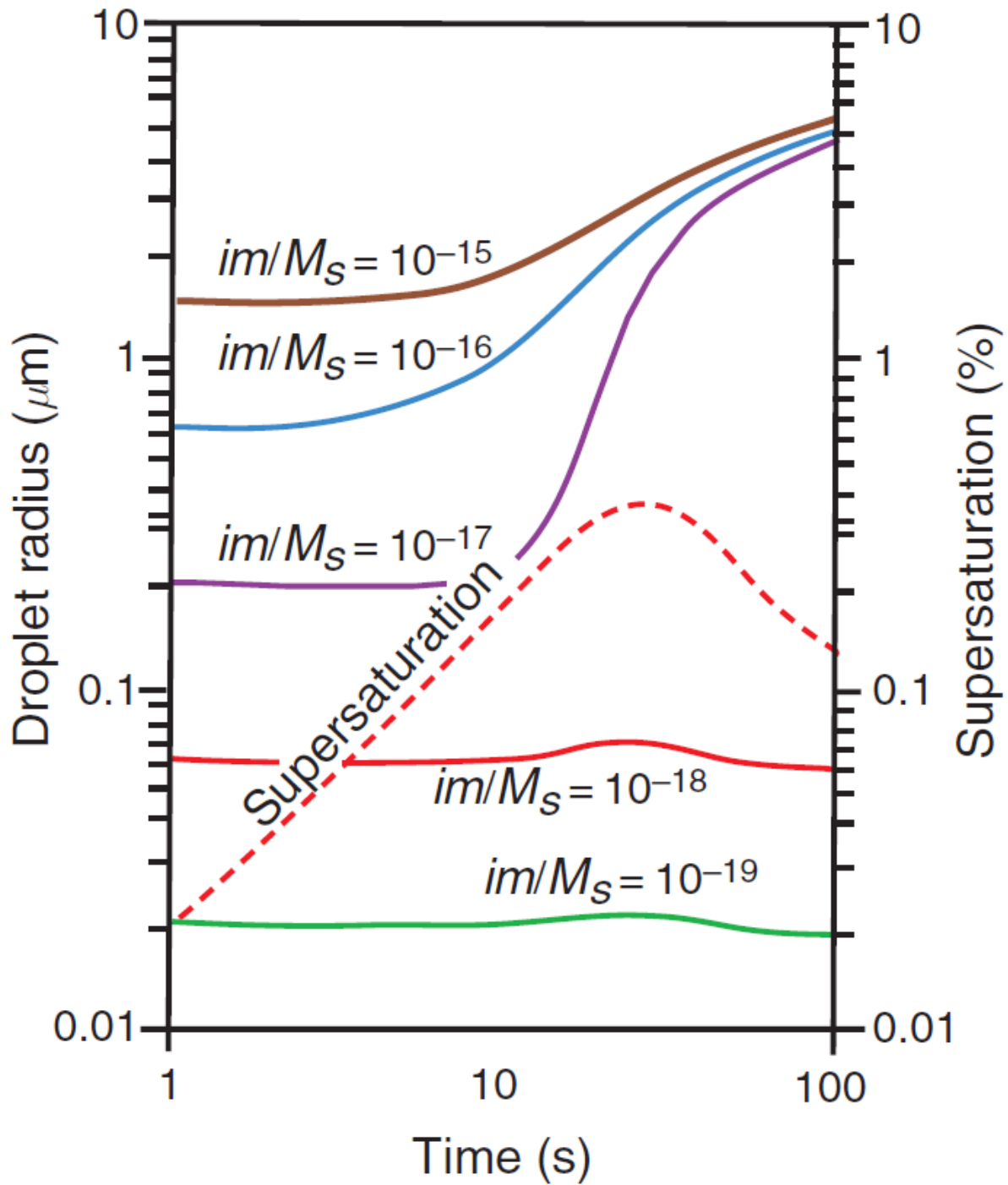
$$r = \frac{2\sigma}{nkT \ln \frac{e}{e_s}}$$



SF2. Het. nukleasjon

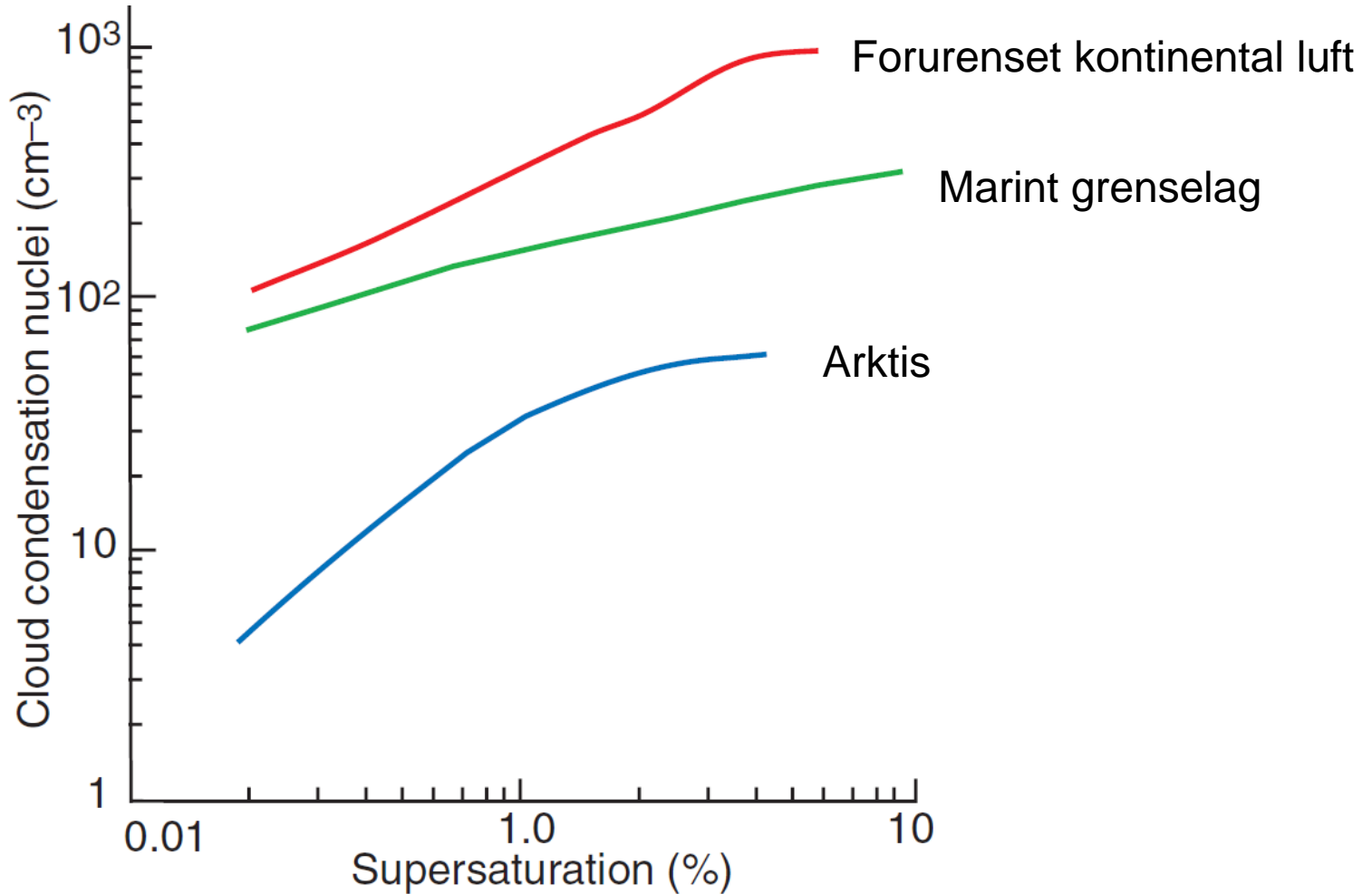


Kohler kurver for kuleformede NaCl partikler



SF3. Stort antall CCN tilgjengelig

Antall CCN aktivert øker med økende S



Conventional
borderline
between cloud
droplets and
raindrops

$$r = 100$$
$$v = 70$$



CCN

$$r = 0.1 \quad n = 10^6$$
$$v = 0.0001$$

Large cloud
droplet

$$r = 50 \quad n = 10^3$$
$$v = 27$$



Typical cloud droplet

$$r = 10 \quad n = 10^6 \quad v = 1$$

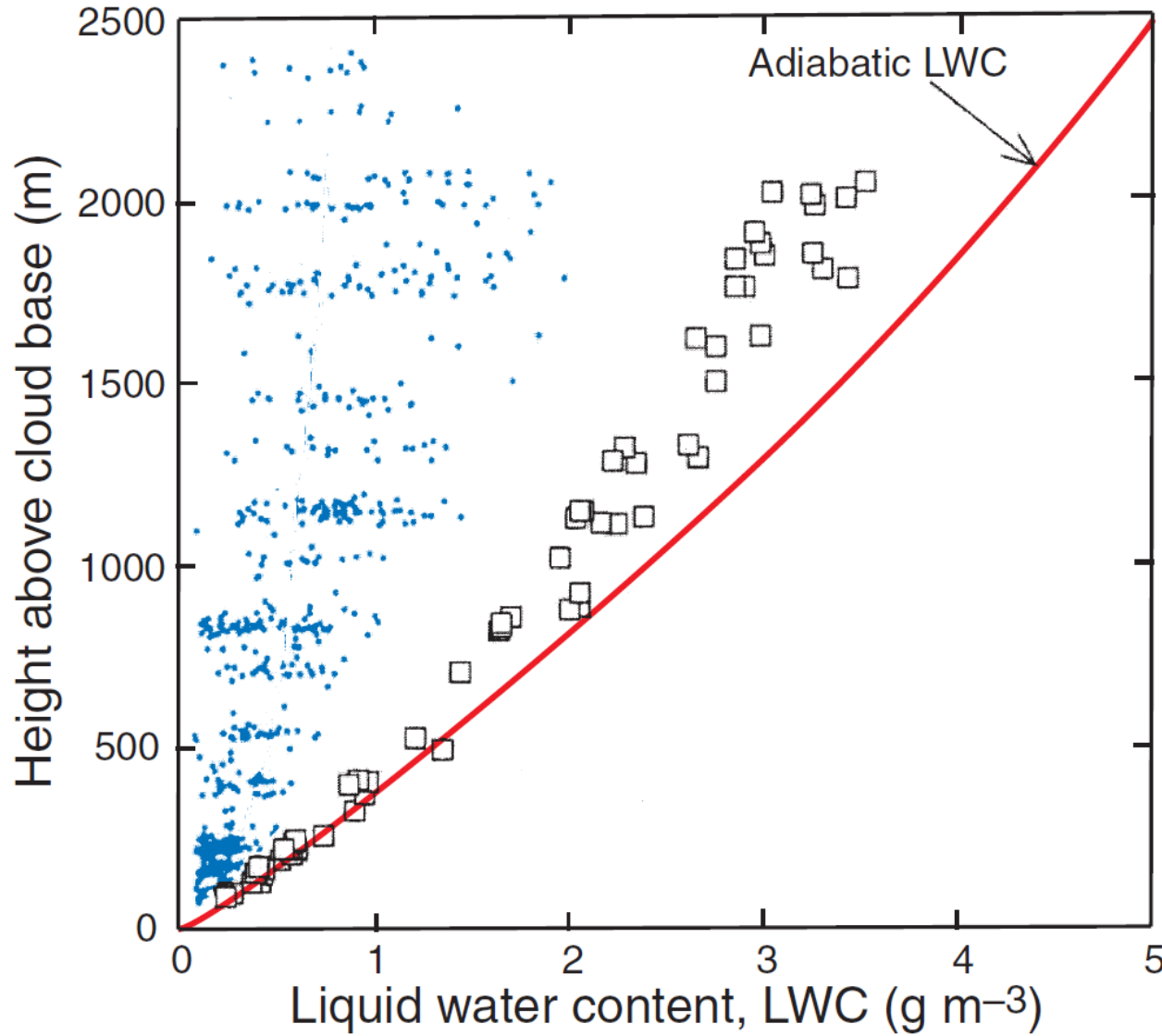
n: Antall pr. liter luft
r: Radius i μm
v: Fallhast. cm/s

Typical raindrop

$$r = 1000 \quad n = 1 \quad v = 650$$

Innblanding av tørr luft i skyen

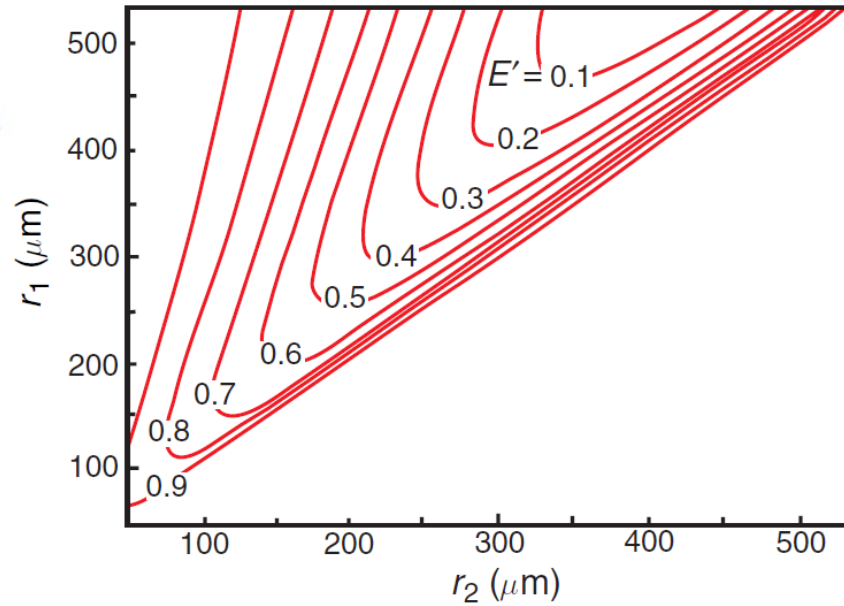
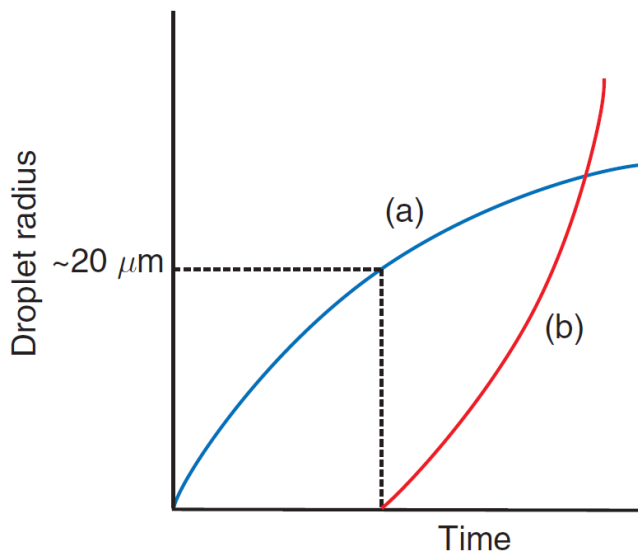
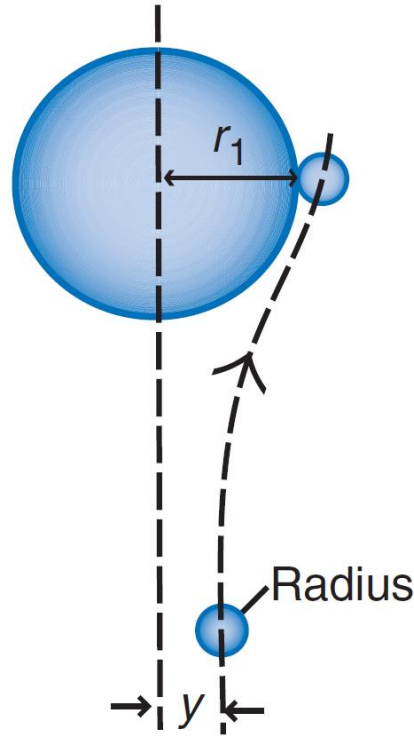
➔ Reduksjon i vanninnhold



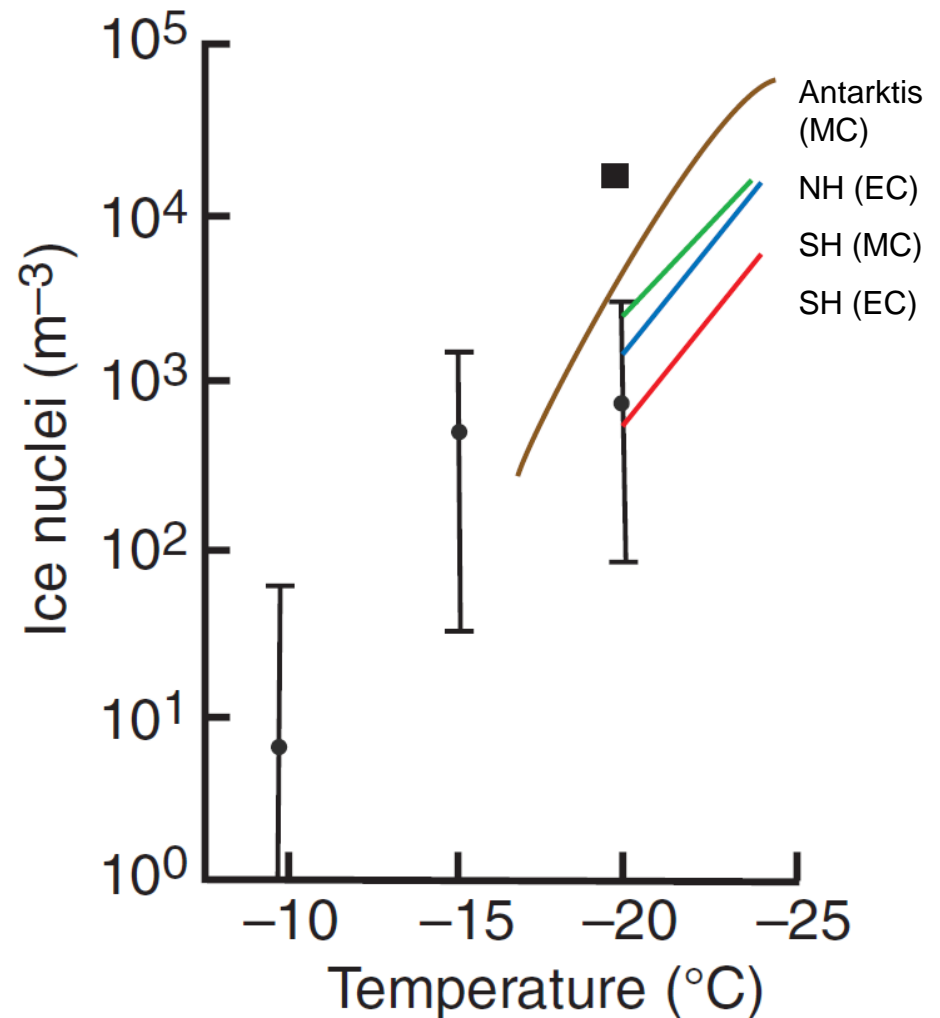
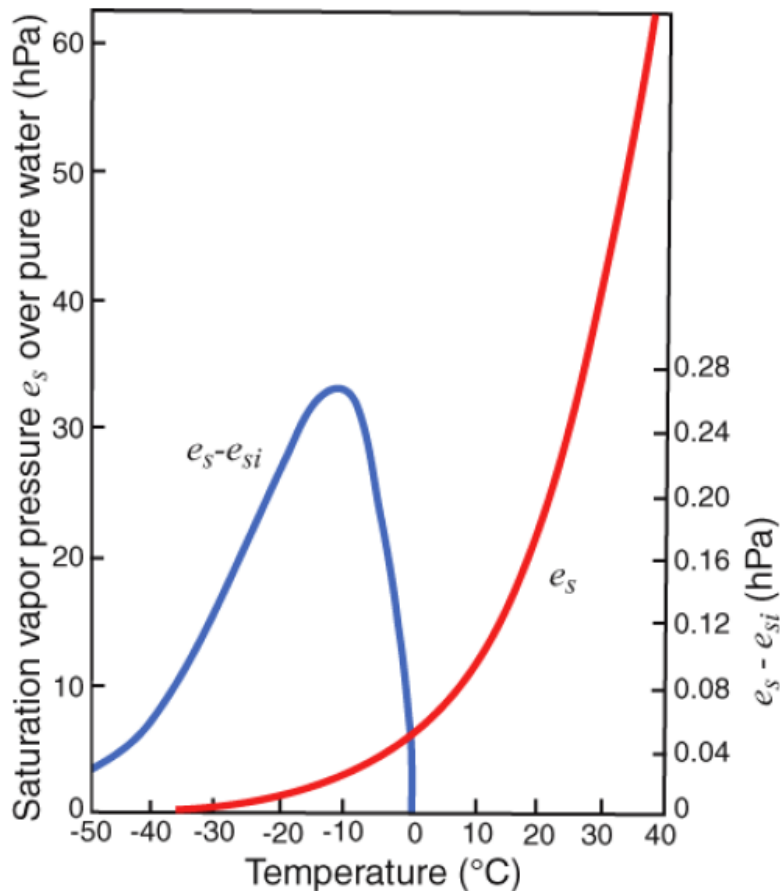
SF 4. Dråpevekst ved kondensasjon og koalesens

$$r \frac{dr}{dt} = G_l S$$

$$G_l = \frac{D \rho_v(\infty)}{\rho_l}$$



SF 5. Kalde skyer ($T < 0^\circ\text{C}$)



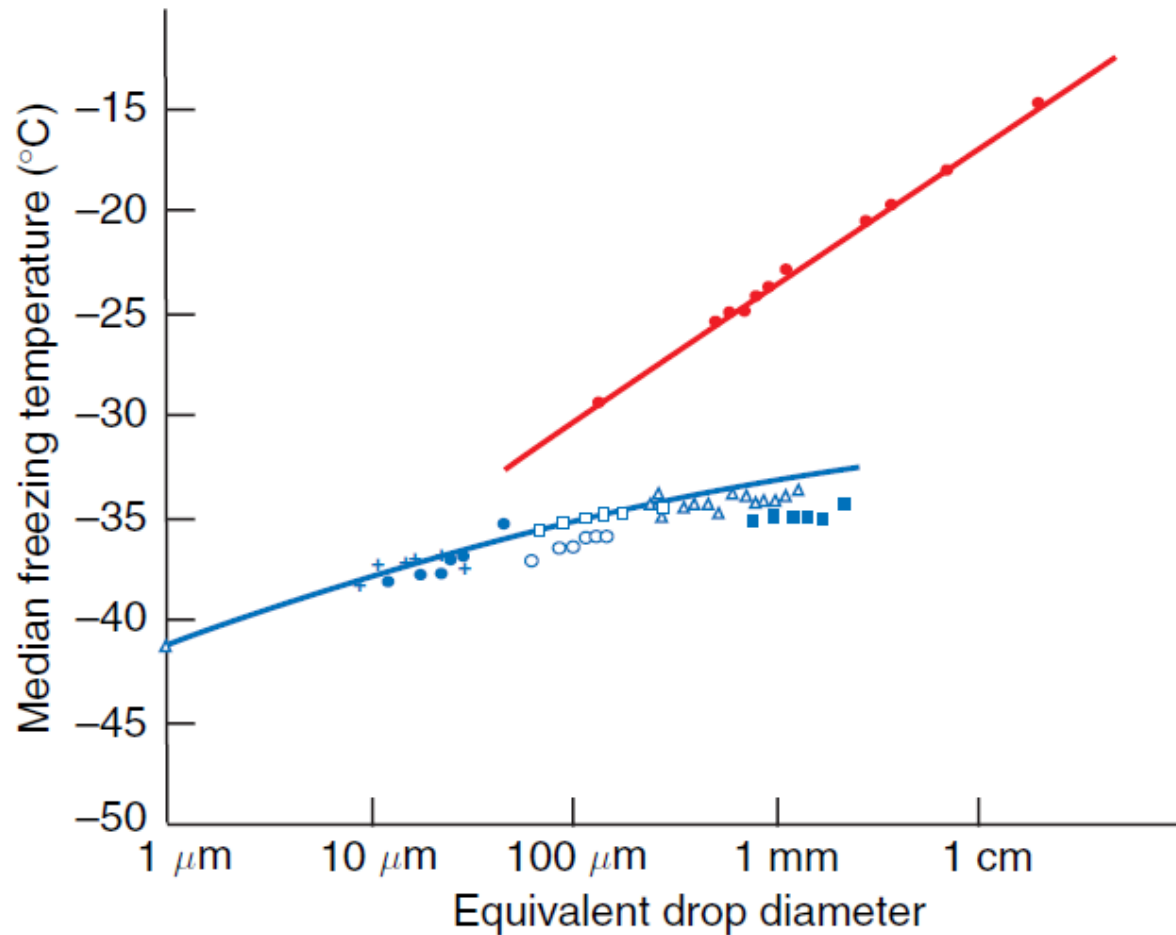
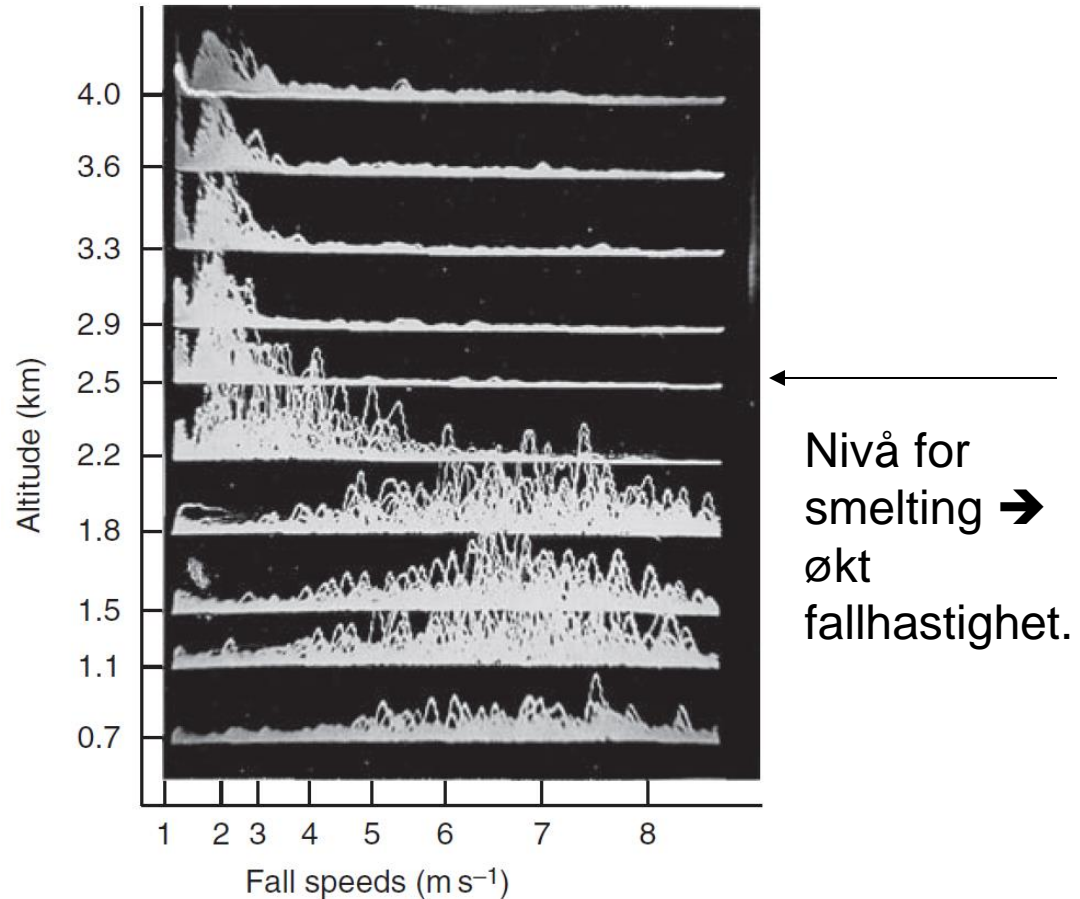


Fig. 6.29 Median freezing temperatures of water samples as a function of their equivalent drop diameter. The different symbols are results from different workers. The red symbols and red line represent heterogeneous freezing, and the blue symbols and line represent homogeneous freezing. [Adapted

SF 6. Nedbørutløsning

- Vekst av iskrystaller
(overmeting i forhold til is)
- Fordampning av skydråper
(undermetning i forhold til flytende vann)
- Bergeron-Findeisen prosessen



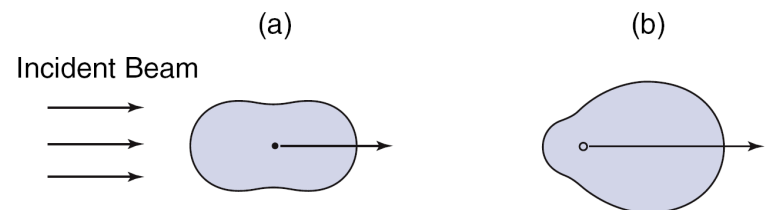
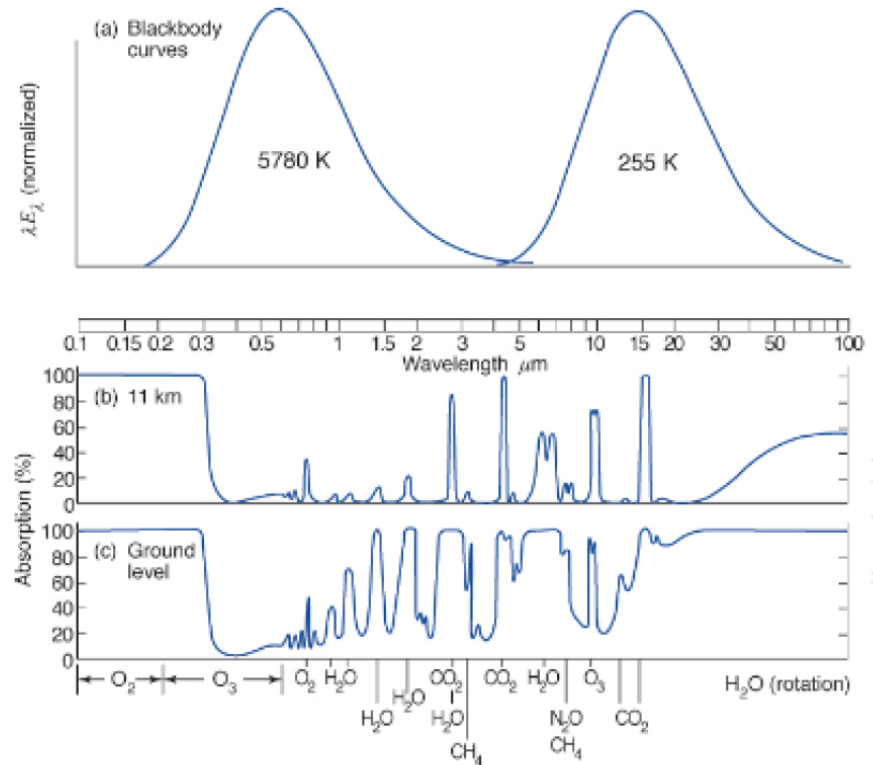
Stråling

Sentrale begreper/sammenhenger

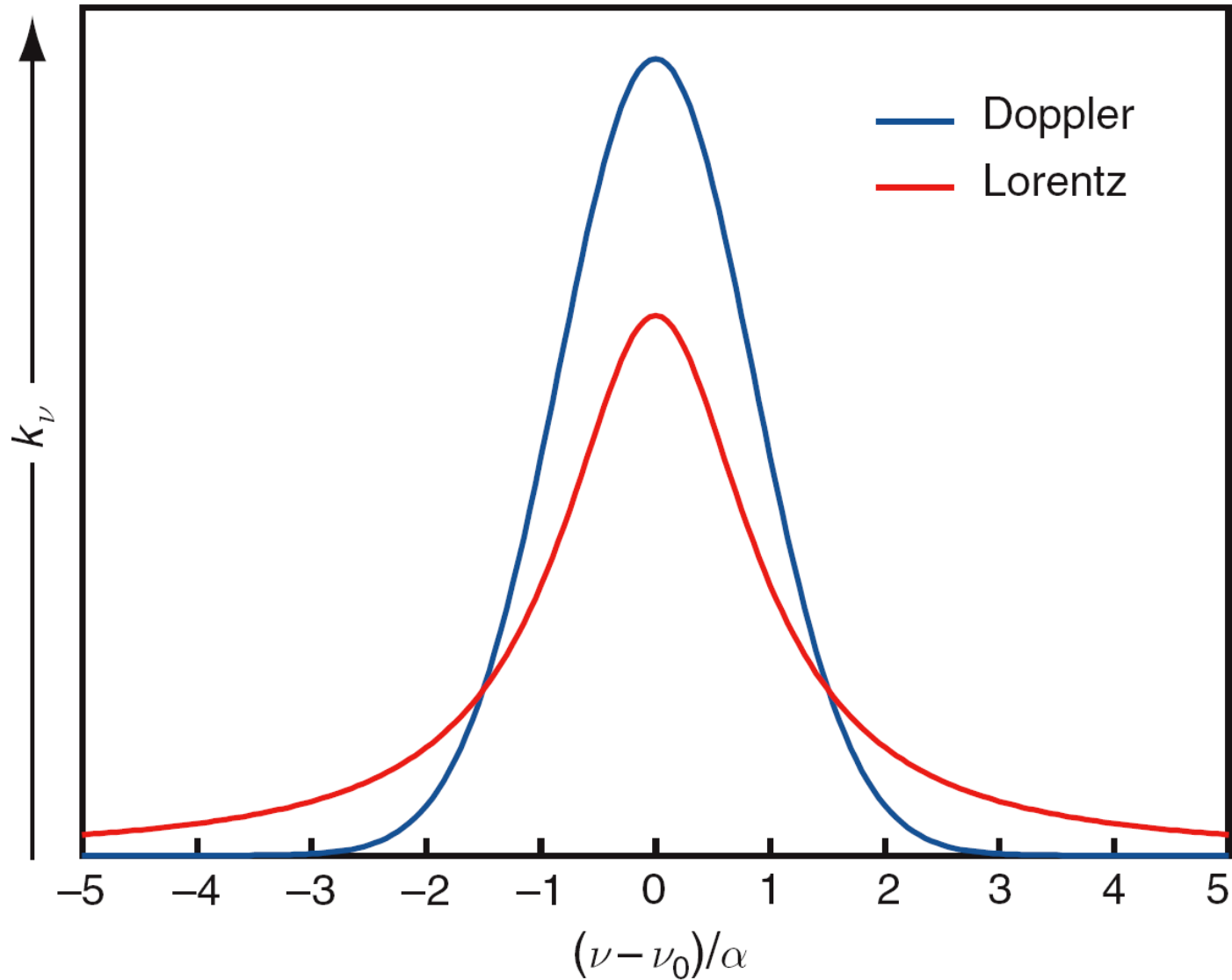
- Intensitet/strålingsfluks
- Svartlegemsstråling – Planck / S.-B. lov
- Kortbølget vs. langbølget stråling
- Spredning vs. Absorpsjon, Ekstinksjon=spredning+absorpsjon

$$dI_{\lambda} = -I_{\lambda} \cdot \rho \cdot r \cdot k_{\lambda} \cdot ds$$

- Drivhuseffekt, absorpsjon etterfulgt av re-emisjon
- Kirchhoffs lov



Stråling 2. Absorpsjonslinjer



Stråling 3.

Beers lov for ekstinksjon av kortbølget stråling

$$I_{\lambda} = I_{\lambda, \infty} \cdot e^{-\tau_{\lambda} \sec \theta} \qquad \tau_{\lambda} = \int_z^{\infty} k_{\lambda} \cdot \rho \cdot r \cdot dz$$

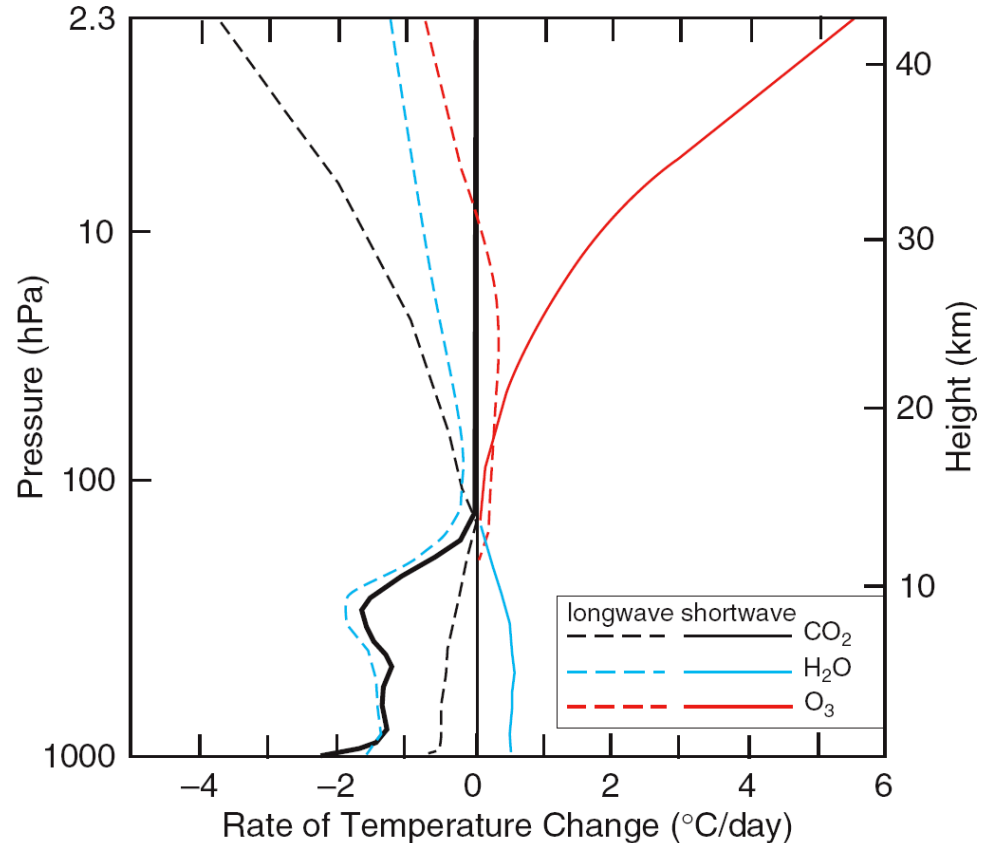
Schwarzschilds likning, Absorpsjon og emisjon av langbølget stråling

$$dI_{\lambda} = -(I_{\lambda} - B_{\lambda}(T)) \cdot \rho \cdot r \cdot k_{\lambda} \cdot ds$$

Stråling 4. Oppvarming pga. flukskonvergens av stråling vertikalt

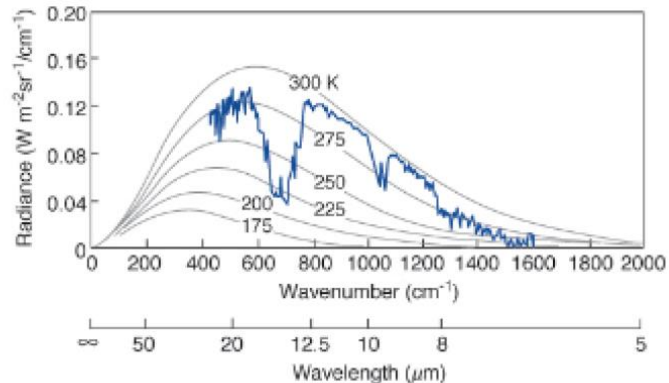
Nettoabsorpsjon av strålingsenergi → oppvarming

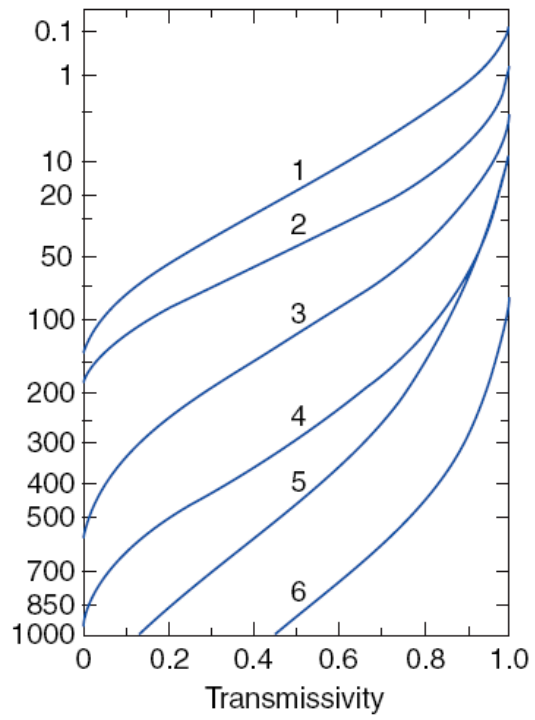
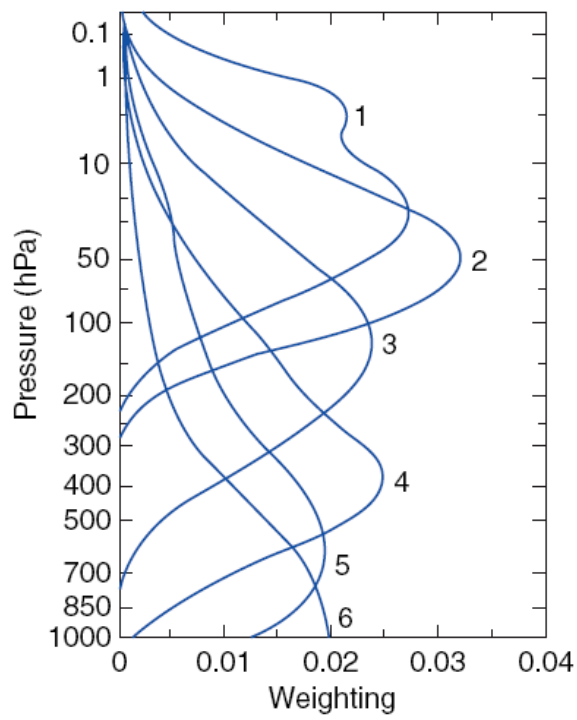
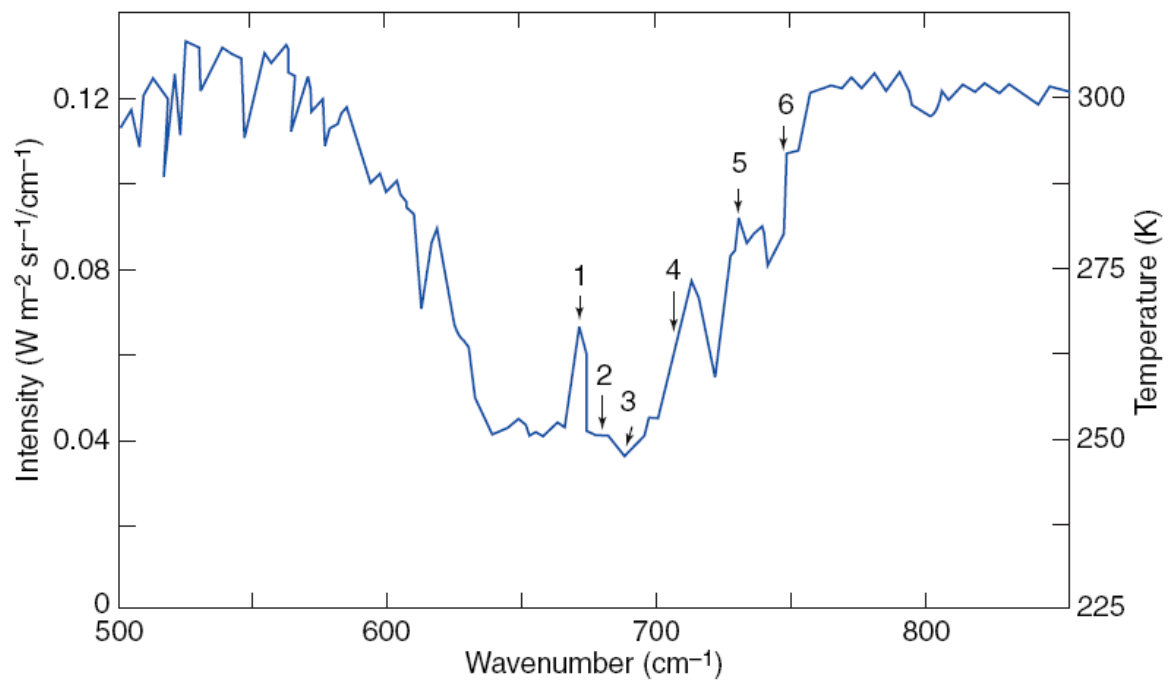
$$\rho \cdot c_p \frac{dT}{dt} = - \frac{dF(z)}{dz}$$



Stråling 5. Fjernmåling av temperaturprofilen i atmosfæren

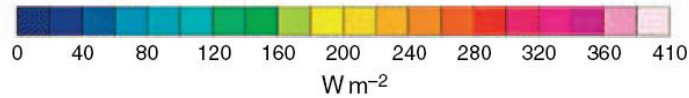
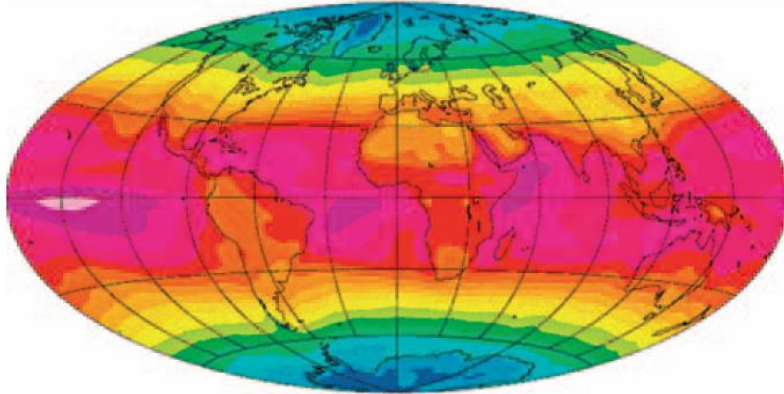
- Har diskutert: Maks utstråling (på toppen av atm) fra det laget der $\tau=1$ (opt. dybde)
- Høyden på dette nivået avhenger av bølgelengden pga. abs. fra drivhusgasser



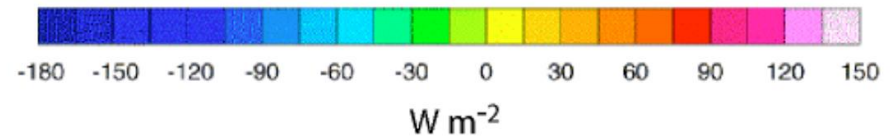
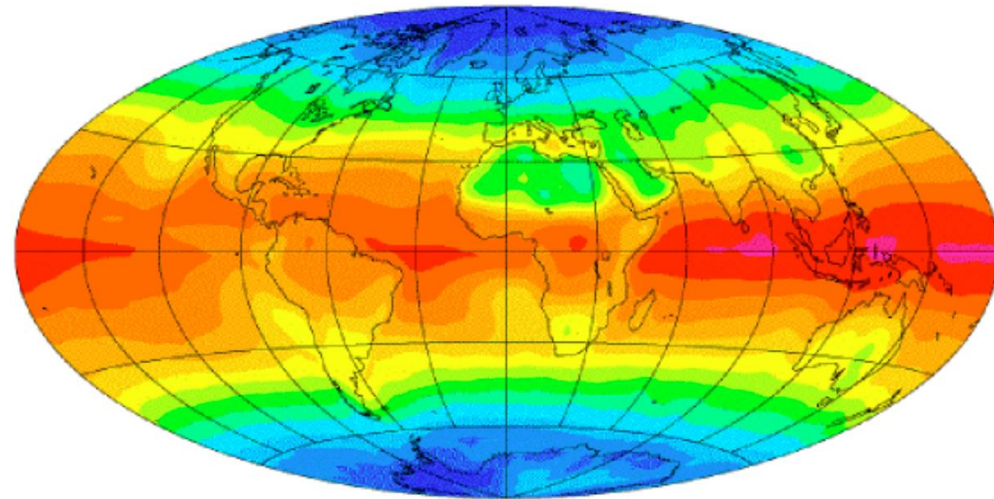


Stråling 6. Energibalansen

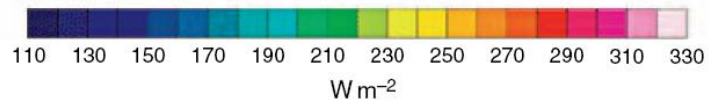
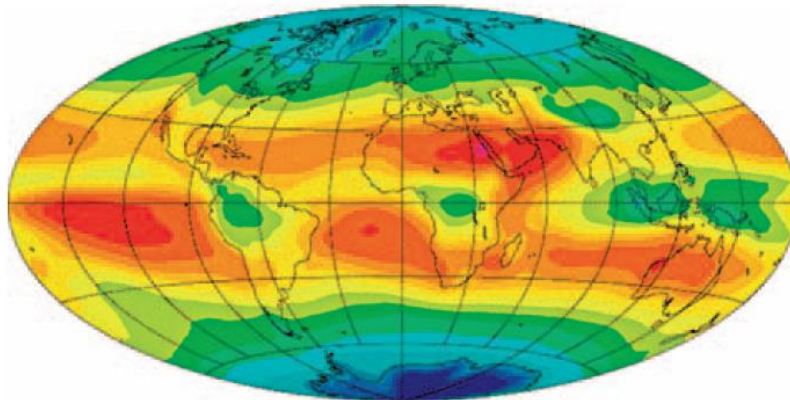
Absorbed Solar Radiation



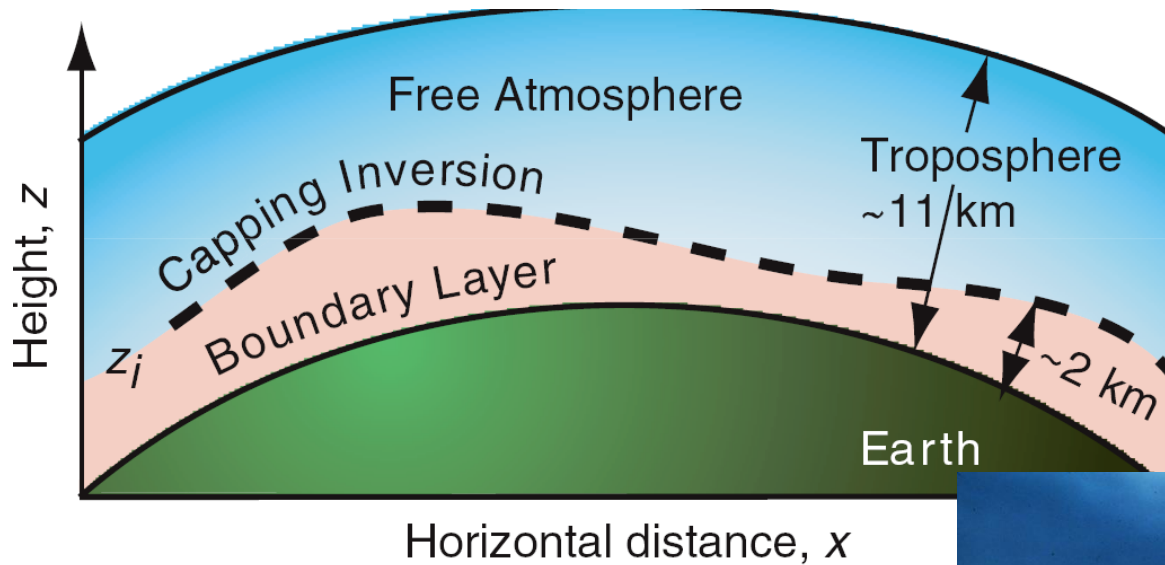
Net Radiation



Outgoing Longwave Radiation



Grenselaget



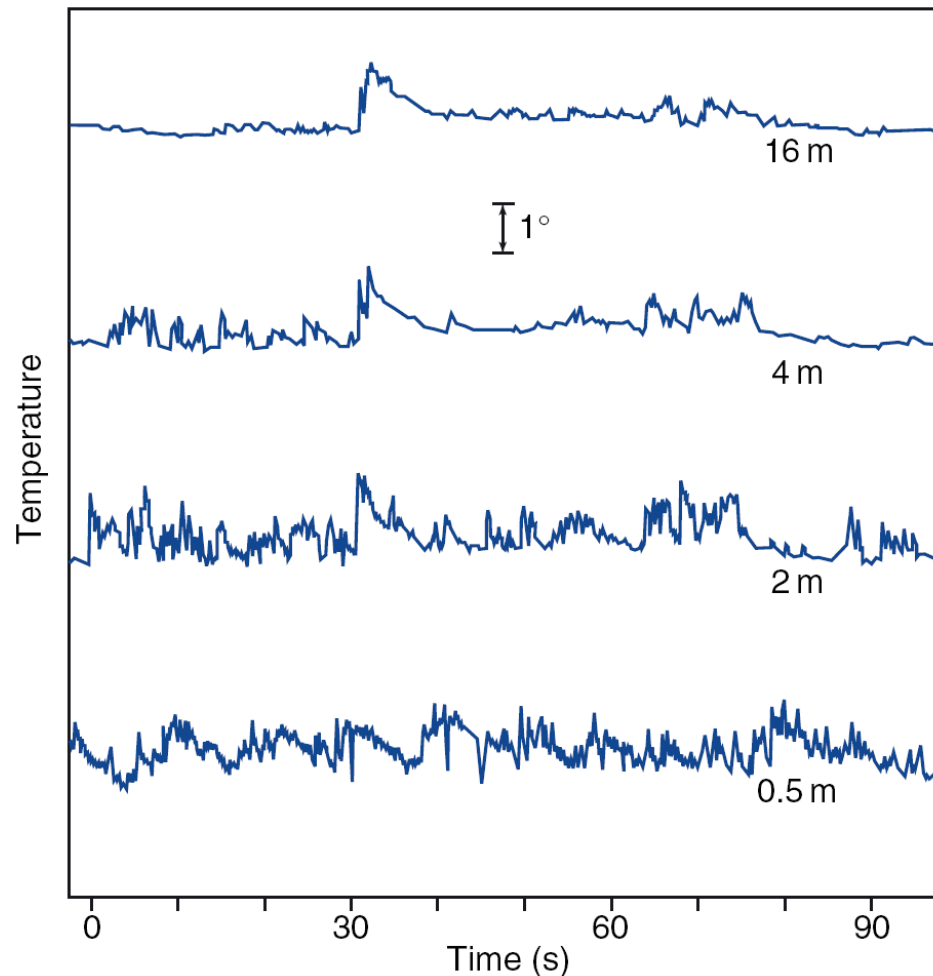
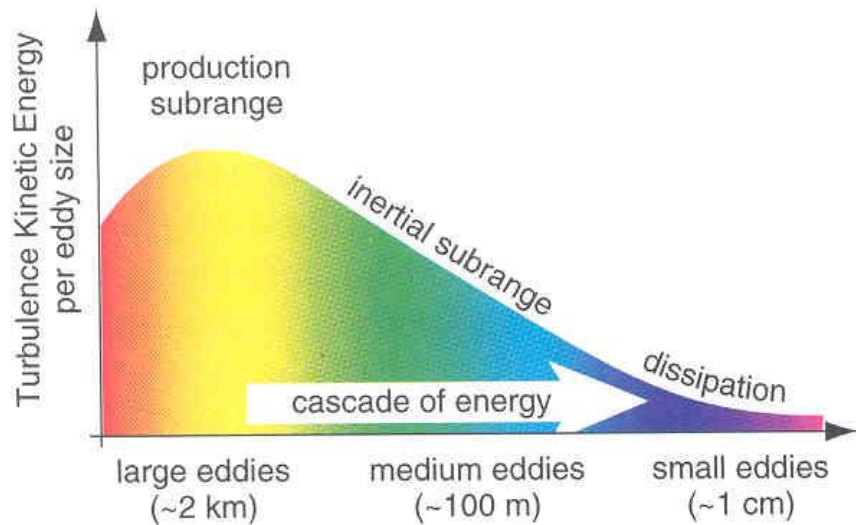
Adapted from *Meteorology for Scientists and Engineers*
Companion Book to C. Donald Ahrens' *Meteorology Today*,
Stull, p. 65. Copyright 2000. Reprinted with permission
of Thomson Learning, a division of Thomson Learning: www.thomsonri.com
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Stratus cloud deck

Grenselaget 2.

Statistisk beskrivelse



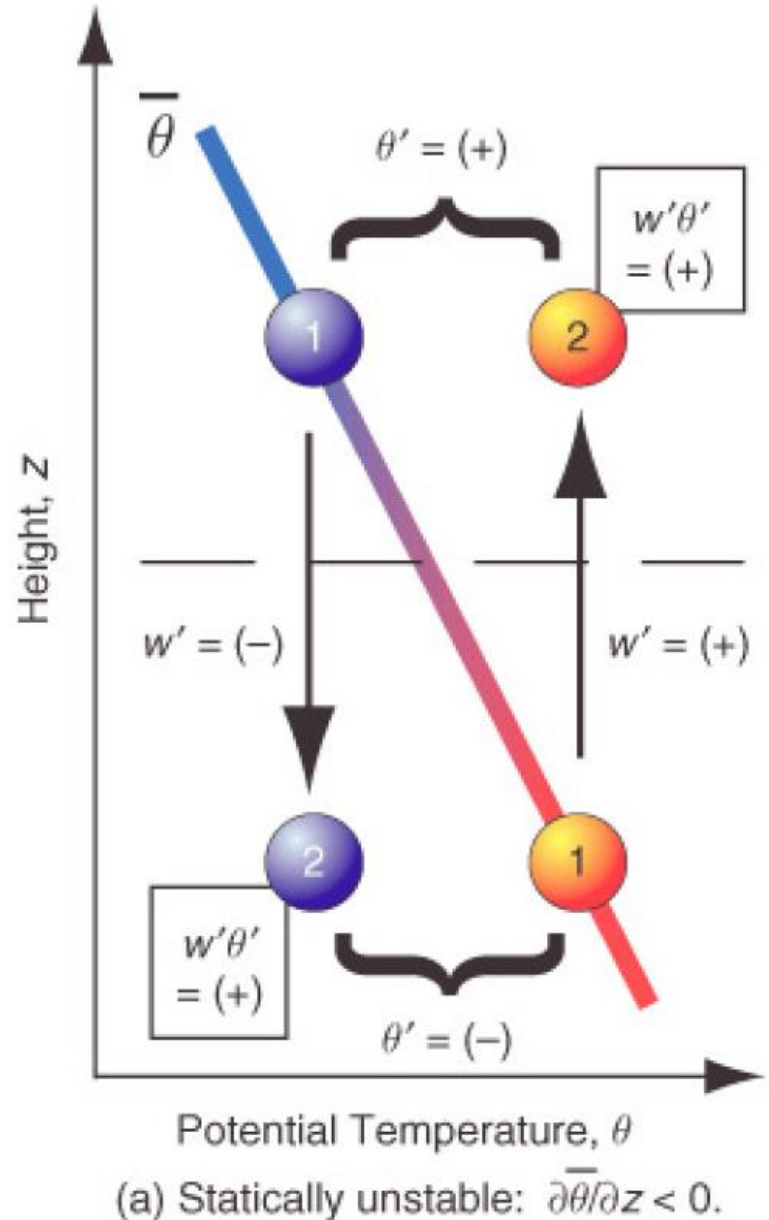
Kilder for turbulens:

1. Mekanisk turbulens
2. Termisk turbulens
3. Inertielt (fra større virvler)

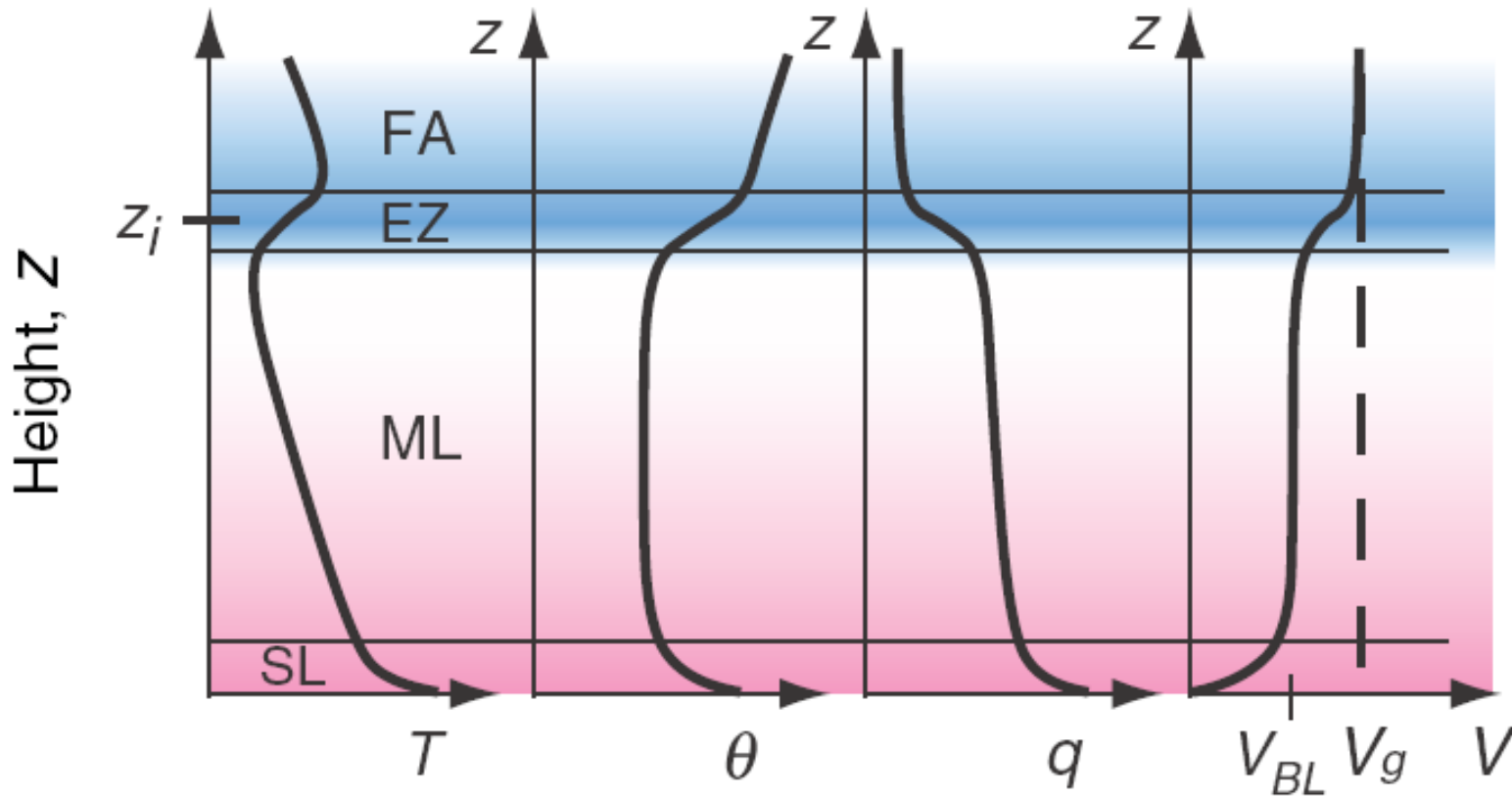
GL 3. Turbulente flukser

- Turbulente flukser beskrives ved kovariansledd

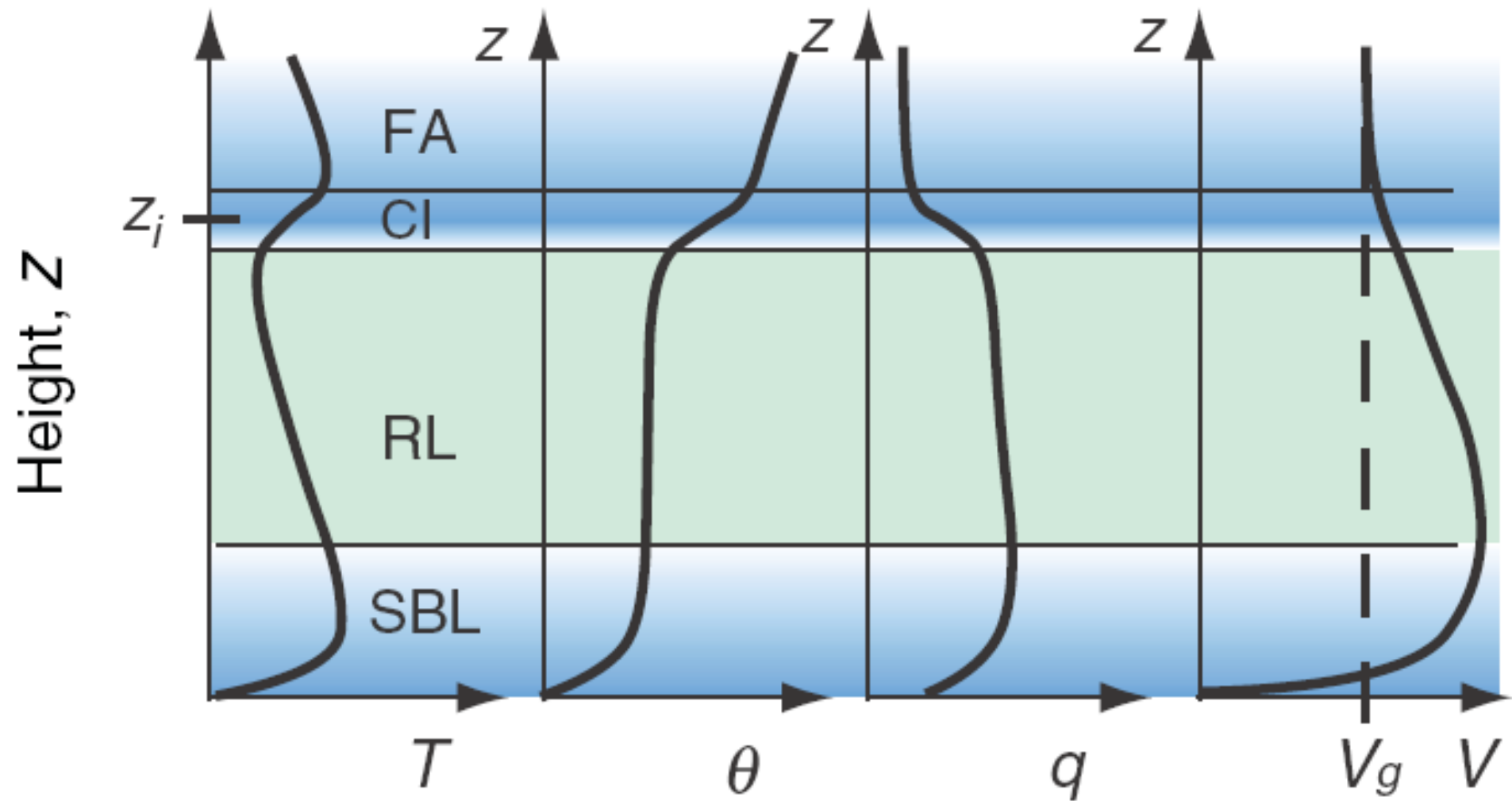
$$\text{kov}(w, \theta) = \frac{1}{N} \sum_{i=1}^N [(w_i - \bar{w})(\theta_i - \bar{\theta})] = \overline{w'_i \theta'_i}$$



GL 4. Døgnlig variasjon i PBL



(a) DAY



(b) NIGHT

GL 6. Flukser mellom bakken og atmosfæren

- Kan parameteriseres ved såkalte "Bulk formler"
- Følbar varme: $F_{HS} = C_H |V| (T_S - T_{air})$
- Fuktighet (latent varme)

$$F_{vann} = C_E |V| (q_{Sat(T_s)} - q_{air})$$