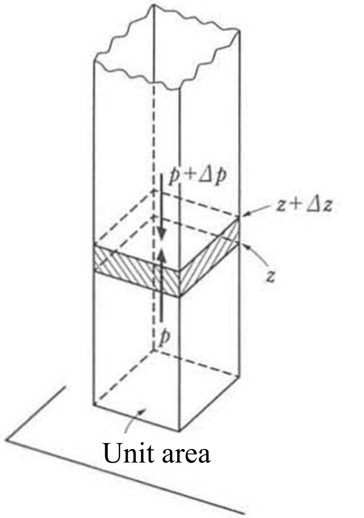
3. Atmospheric vertical structure

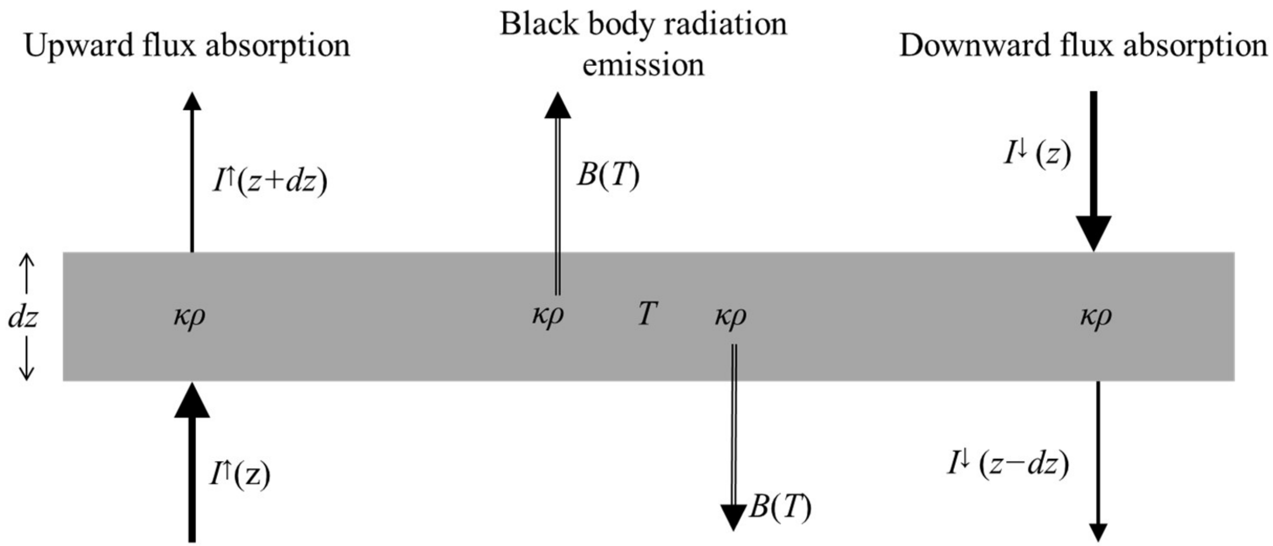
Heating	Radiation	Conduction	Convection
Heat transfer	Electromagnetic waves	Molecular motions	Fluid motions
Condition	Including vacuum	Continuum	Gravity
Governing law	Planck's law (Stefan-Boltzmann, Wien)	Molecular diffusion	Laminar advection Turbulent (eddy) diffusion
Temperature profile	dependent on optical depth (exponential)	exponential	isentropic (upward decreasing)
Constituents	–	Gravity separation	Homogenizing

Hydrostatic equilibrium



$$\Delta p = -g\rho\Delta z$$

"Two-Stream" Approximation for "gray" atmosphere



Vertical distribution of pressure

- Hydrostatic equation:

$$\frac{dp}{dz} = -g\rho$$

- Rewriting ρ by the ideal gas equation (Boyle-Charles law): $p = R\rho T$

$$\frac{dp}{dz} = -\frac{g}{RT}p \quad \rightarrow \quad \frac{1}{p}\frac{dp}{dz} - \frac{g}{RT} \equiv -\frac{1}{H}, \qquad H \approx \frac{287\ [\mathrm{J\ K^{-1}kg^{-1}}] \cdot 250\ [K]}{9.8\ [\mathrm{ms^{-2}}]} \approx 7[\mathrm{km}]$$

- Differentiation of logarithmic function:

$$\frac{1}{y}\frac{dy}{dx} = \frac{d \log_e y}{dx} = \frac{d \ln y}{dx} \quad \rightarrow \quad \frac{d \ln p}{dz} = -\frac{1}{H}$$

- Integration:

$$\ln p = -\frac{1}{H}z + \text{const.}$$

- Exponential function:

$$p = e^{-\frac{1}{H}z + \text{const.}} = e^{\text{const.}} \cdot e^{-\frac{1}{H}z} \equiv \text{const.}' \cdot e^{-\frac{z}{H}}$$

- Bottom boundary condition:

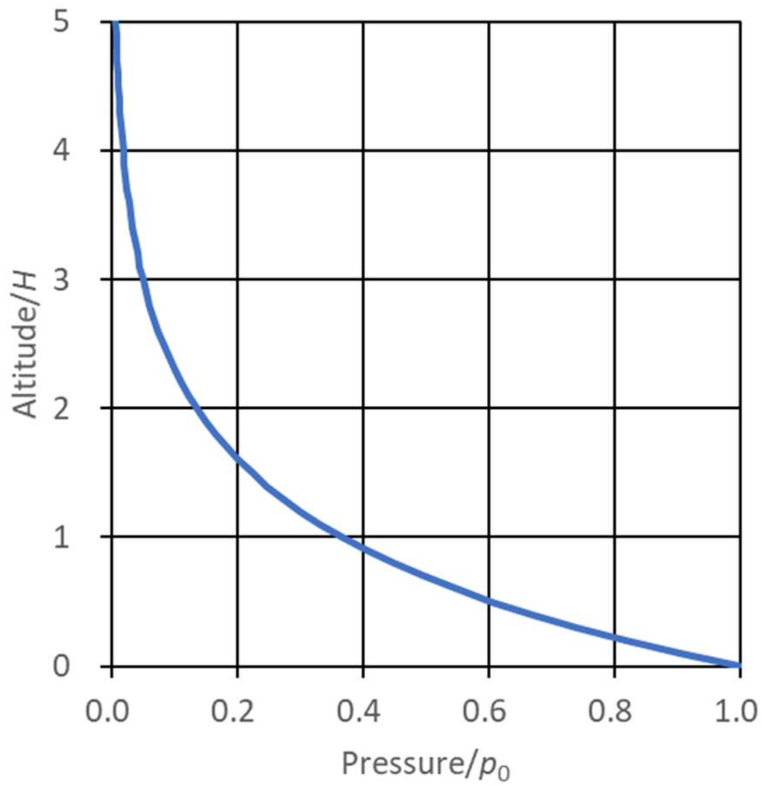
$$p = p_0 \quad \text{at} \quad z = 0 \quad \rightarrow \quad \text{const.}' = p_0$$

- Solution:

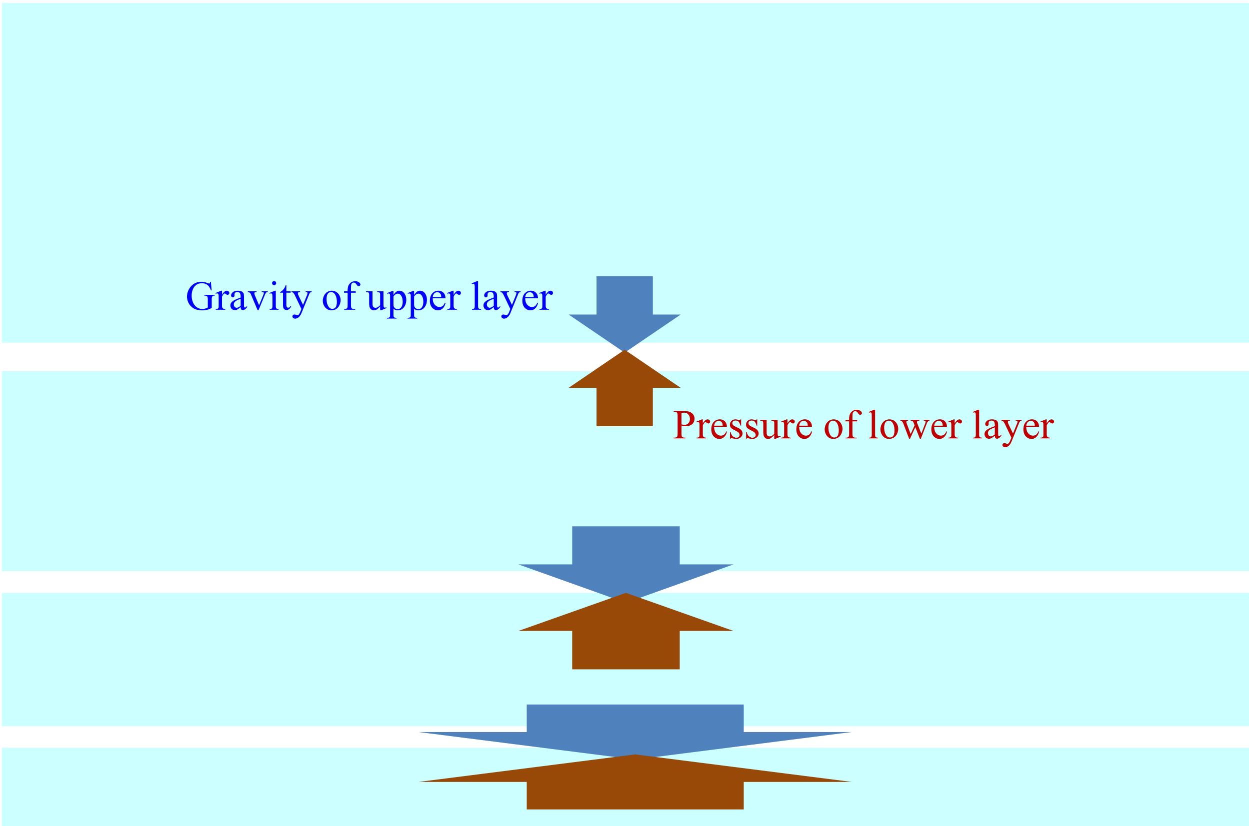
$$p = p_0 \cdot e^{-\frac{z}{H}}$$

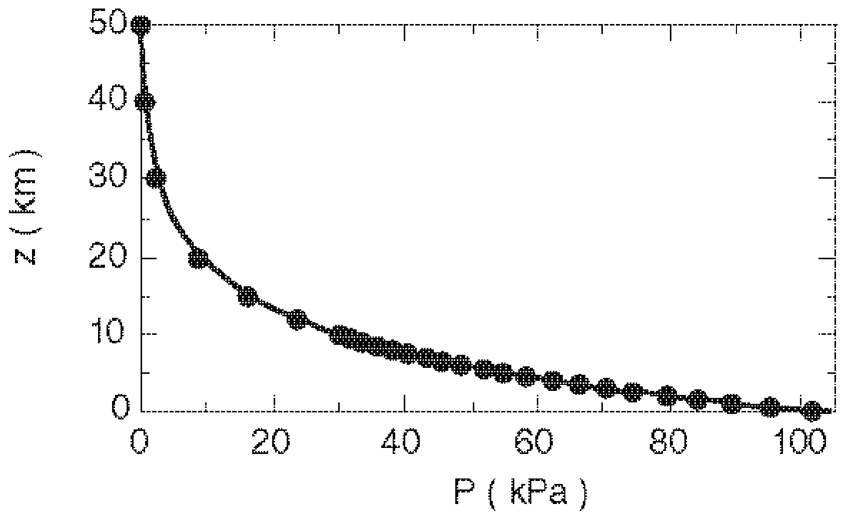
- Meaning of the "scale height" H:

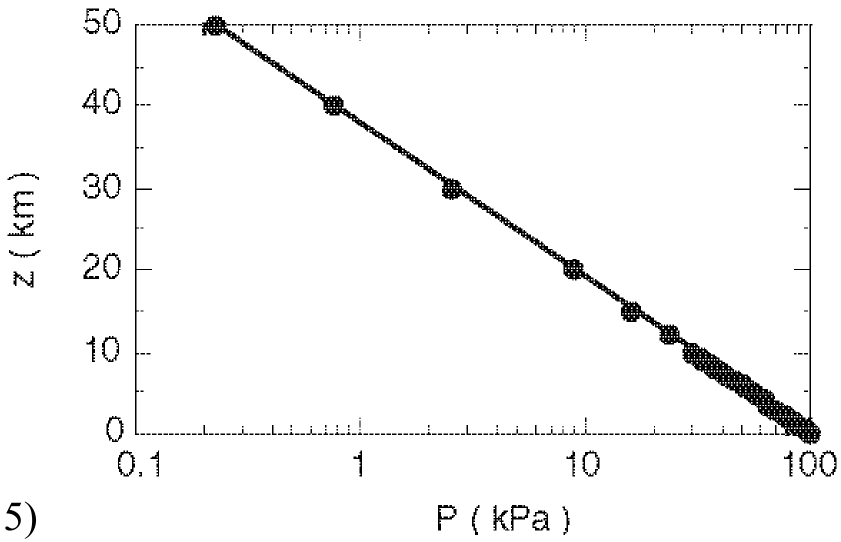
$$p = \frac{p_0}{e}, \frac{p_0}{e^2}, \cdots, \frac{p_0}{e^n}, \cdots \qquad \text{at} \quad z = H, 2H, \cdots, nH, \cdots$$



Pressure upward exponential decrease (Hydrostatic equilibrium)

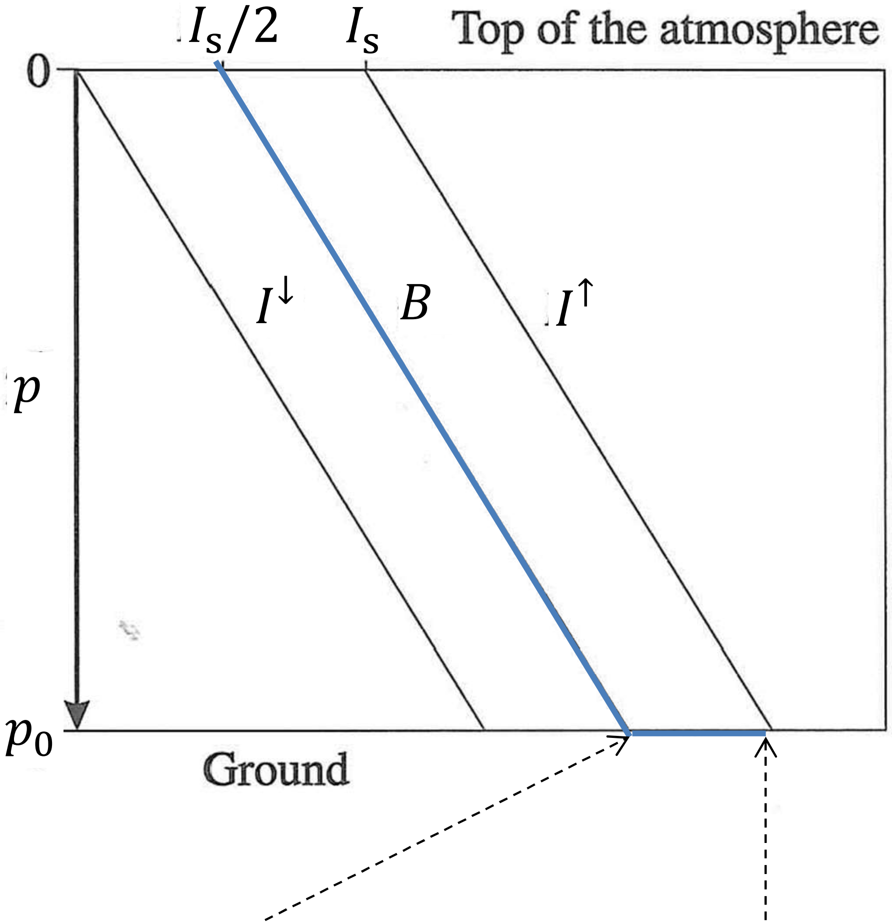






(Stull, 2015)

$$B(p) = \frac{I_s}{2}\left(\frac{\kappa}{g}p + 1\right) \longrightarrow T(p) = \left(\frac{B}{\sigma}\right)^{1/4} = \left[\frac{I_s}{2\sigma}\left(\frac{\kappa}{g}p + 1\right)\right]^{1/4}$$

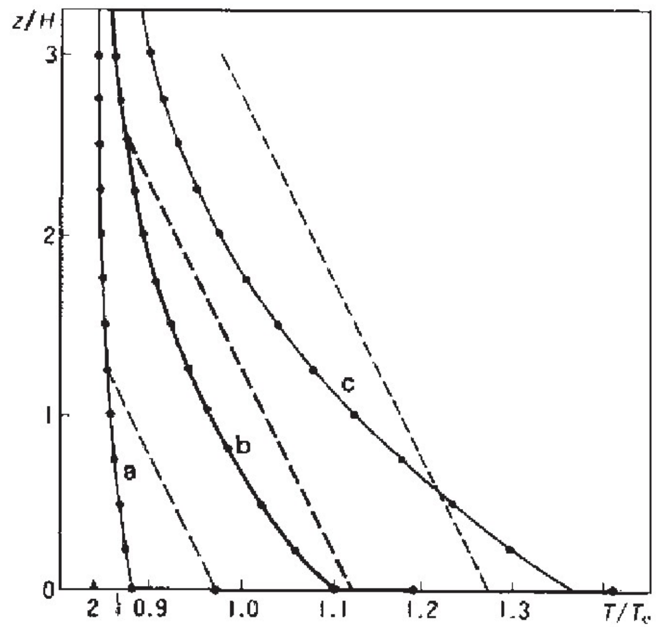


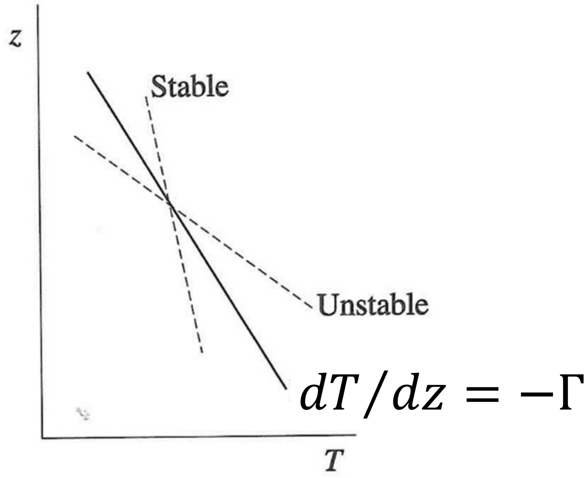
Atmos. Temp. at the bottom

$$\left[\frac{I_s}{2\sigma}\left(\frac{\kappa}{g}p_0 + 1\right)\right]^{1/4} = \left(\frac{B(p_0)}{\sigma}\right)^{1/4}$$

Ground temperature

$$T = \left(\frac{I^{\uparrow}(p_0)}{\sigma}\right)^{1/4} = \left(\frac{B(p_0) + I_s/2}{\sigma}\right)^{1/4}$$





1-dimensional climate: Radiative-convective equilibrium

- Radiative equilibrium

  $Q = \partial/\partial z\,[S + I^{\uparrow} - I^{\downarrow}] = 0$

  (S ∼ 0 for $z \neq 0$, ozone layer)

  ⇒ $\partial/\partial p\,[\sigma T^4] \sim S/p_1$

  ⇒ $-\partial T/\partial z$ increases downward

- Convective equilibrium (adjustment)

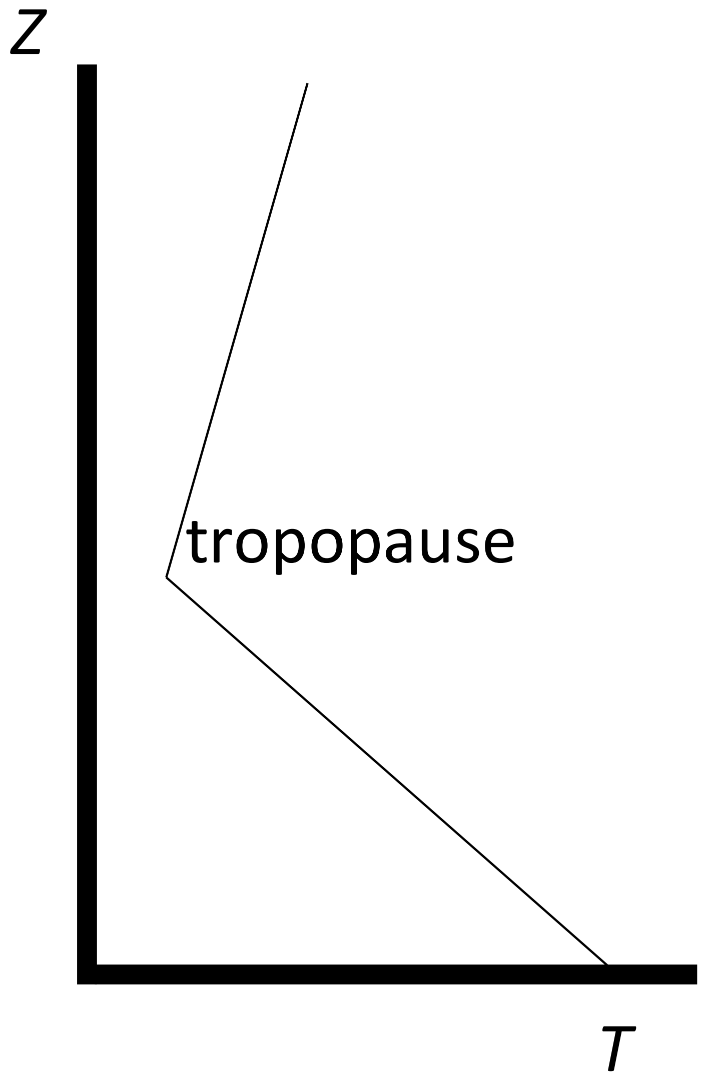
  $\partial \Theta/\partial z = 0$

  ⇒ (dry) adiabatic lapse rate:

  $-\partial T/\partial z = g/C_p \fallingdotseq 10$ K/km

- Separation of stratosphere (radiative)

  and troposphere (convective)



Balloons, vertical observations

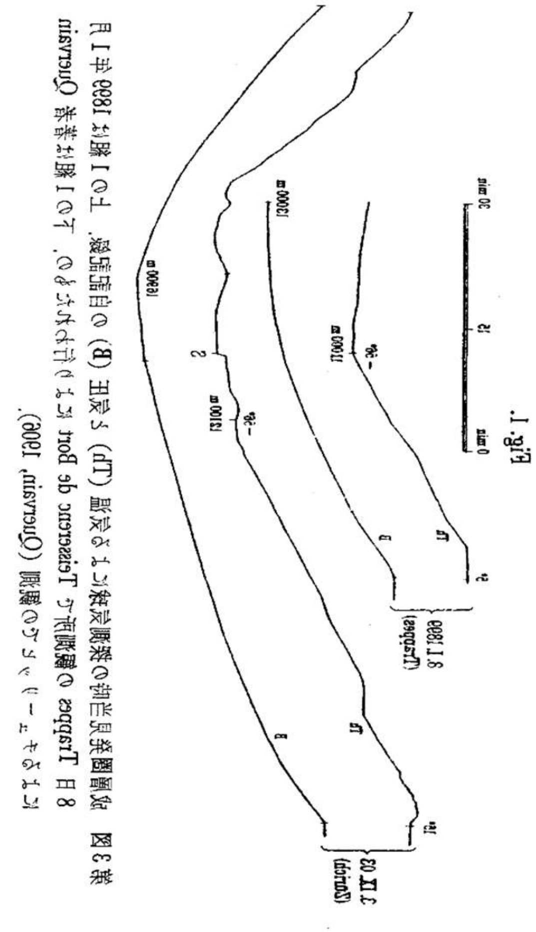
Joseph-Michel Montgolfier (1740 – 1810)
Jacques-Étienne Montgolfier (1745 – 1799)

Jacques Alexandre César Charles
(1746 – 1823)

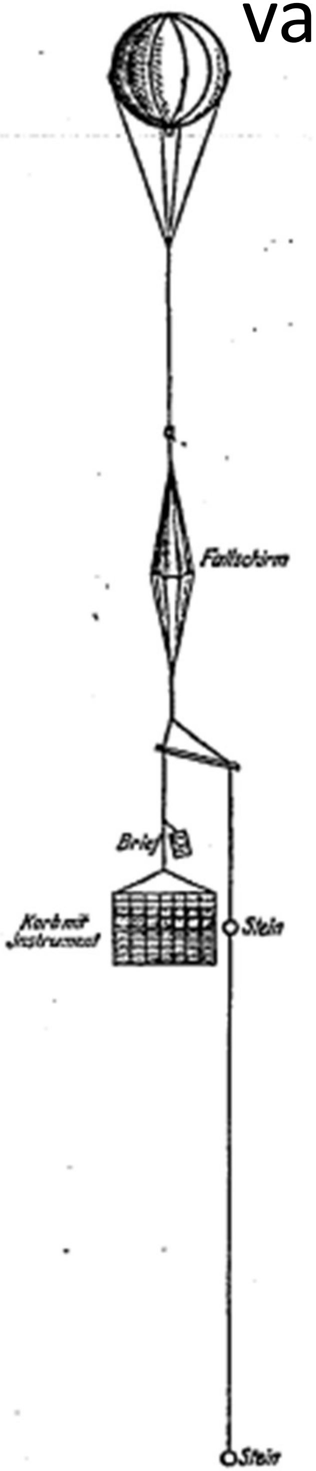
Leon Philippe Teisserenc de Bort
(1855 – 1913)

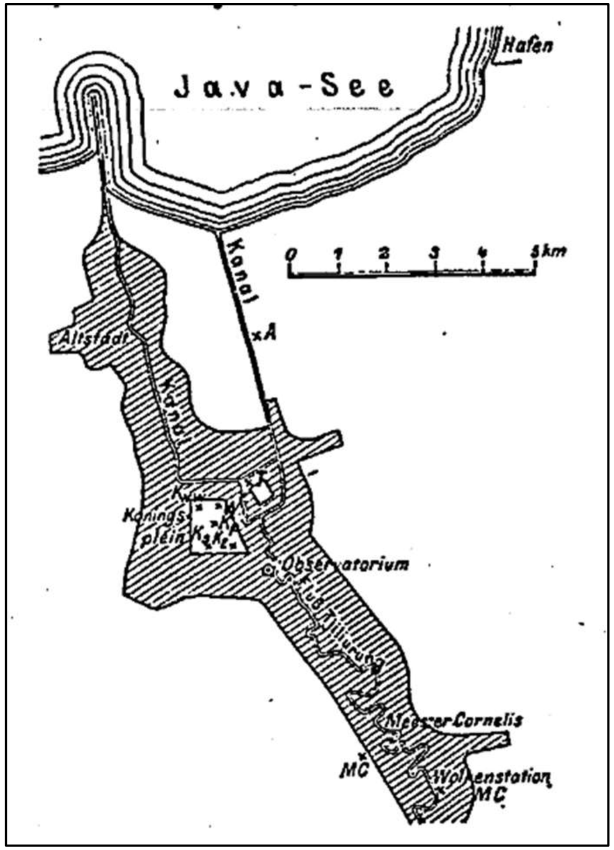
Montgolfière (hot air type) balloon
(at Annonay in June 4, 1783)

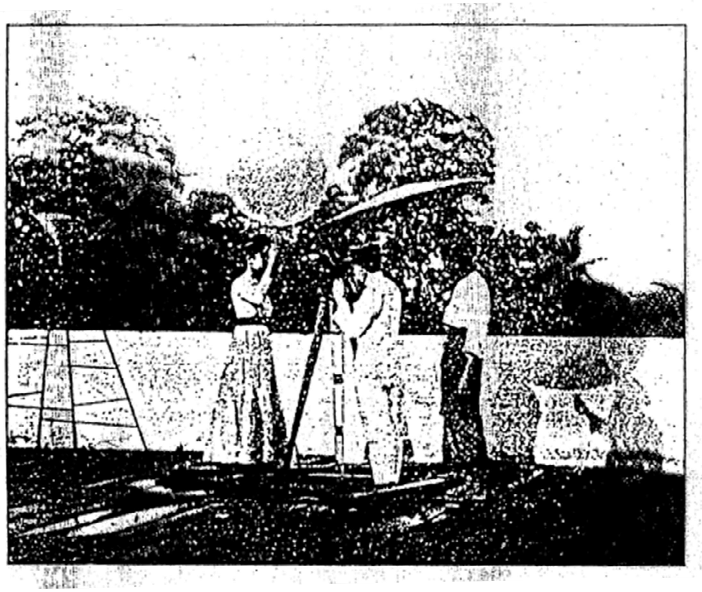
Charlière (light gas type) balloon
(at Paris in December 1, 1783)



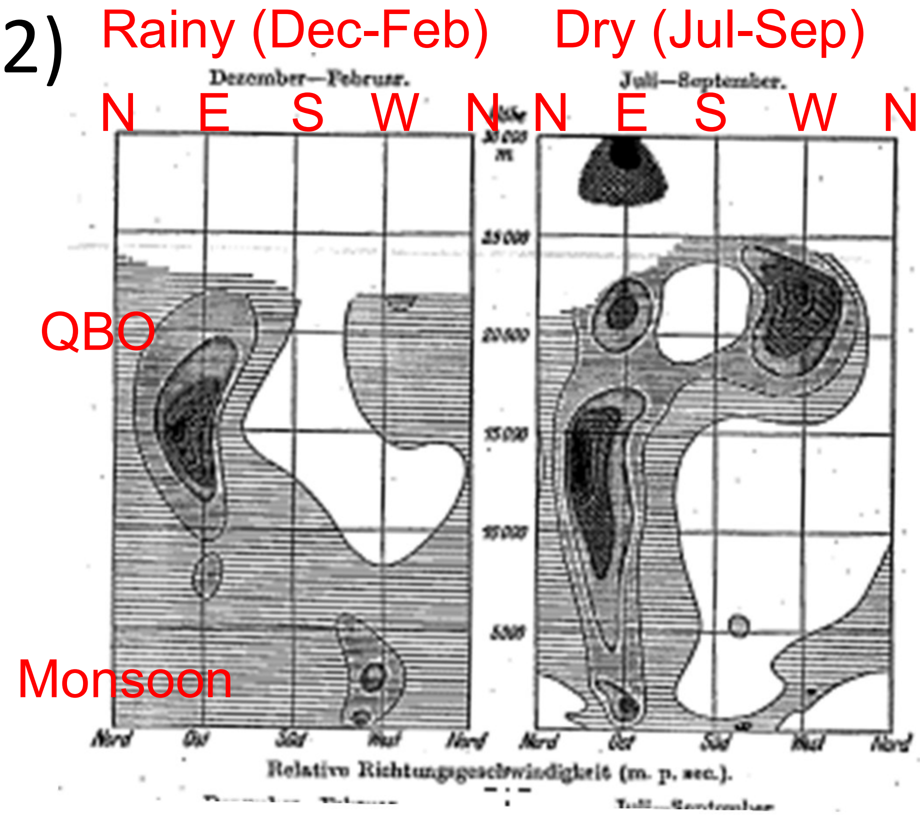
van Bemmelen (1913, 1922)

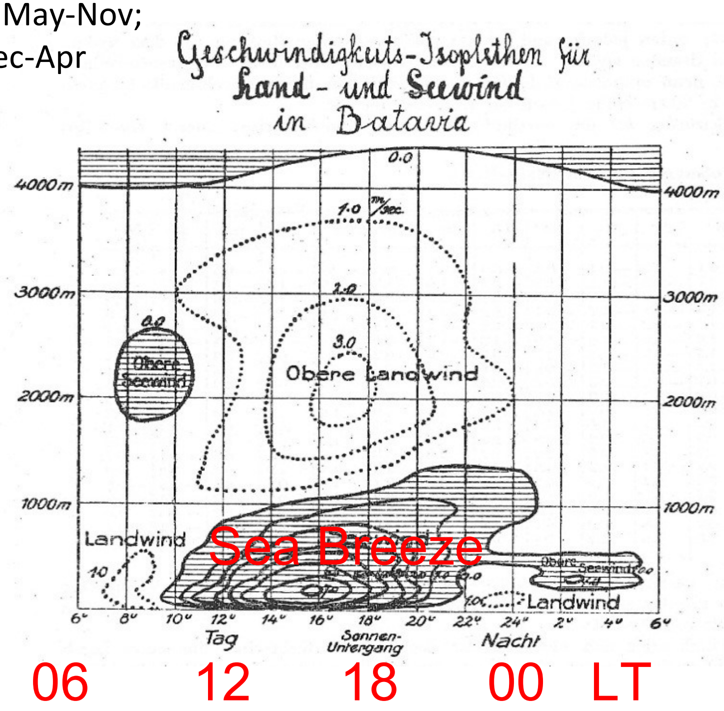




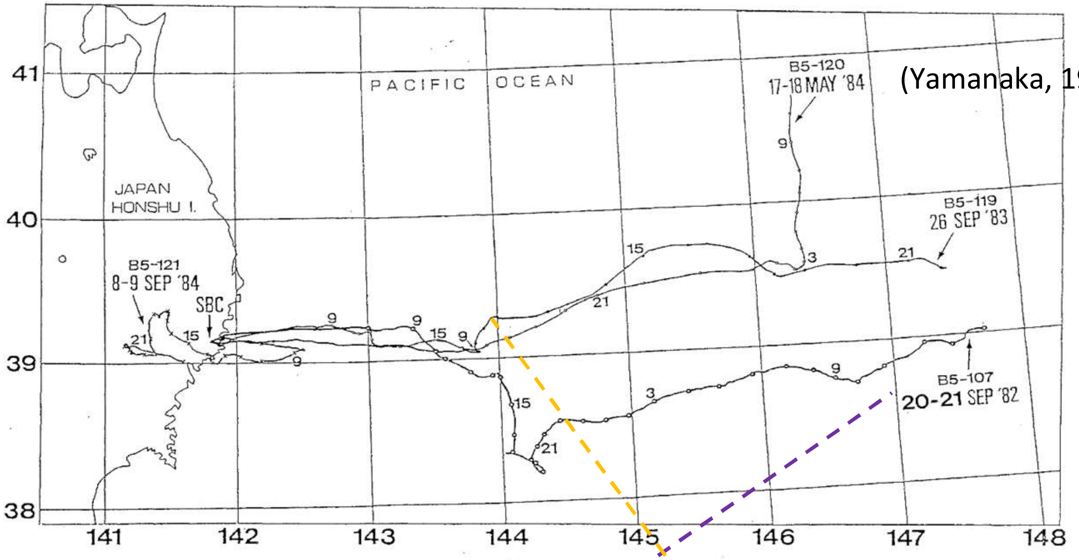


06-24 LT hourly for May-Nov;
08, 14, 19 LT for Dec-Apr
during 1905-15

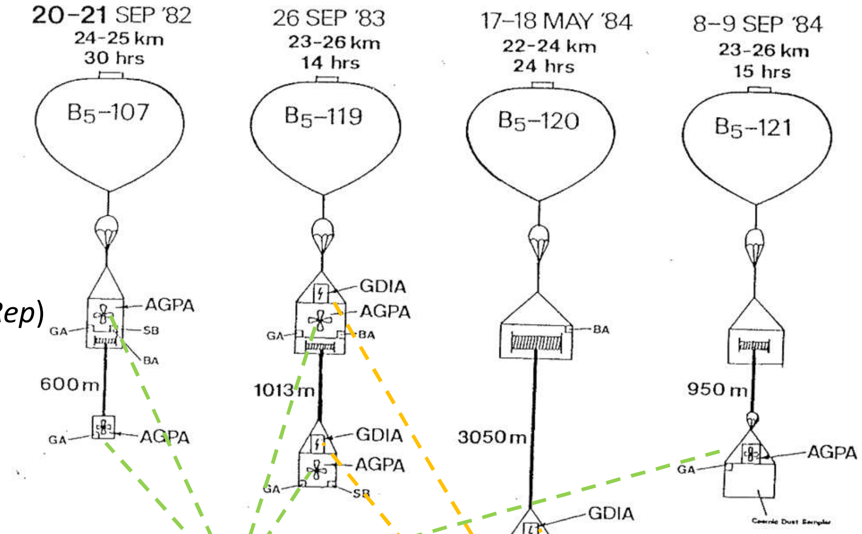




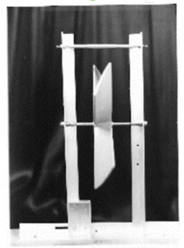
Anemometer, reel d/u & balloon trajectory for stratospheric gravity waves/turbulence (1980 – 4; WRI-Nagoya U + ISAS / MAP)



(Yamanaka, 1985, *ISAS Rep*)

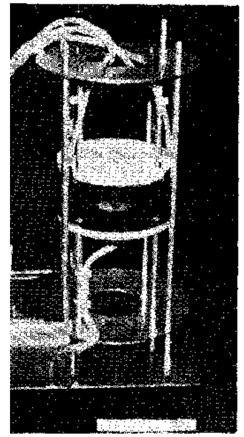


Adapted Gill-type propeller anemometer

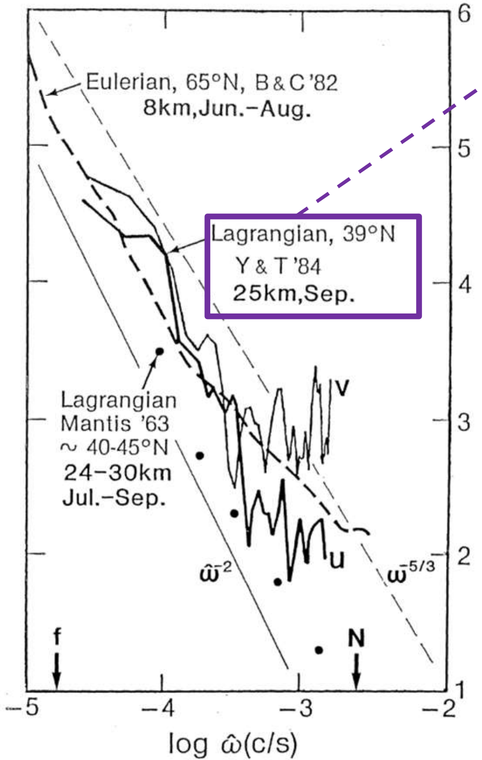


(Yamanaka et al, 1985, *JAOT*)

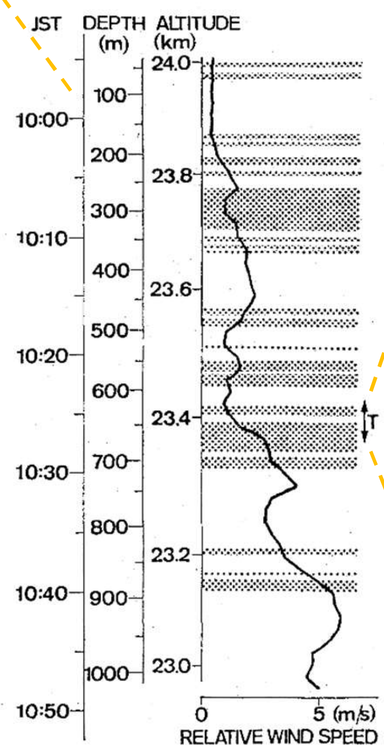
Glow discharge ionic anemometer

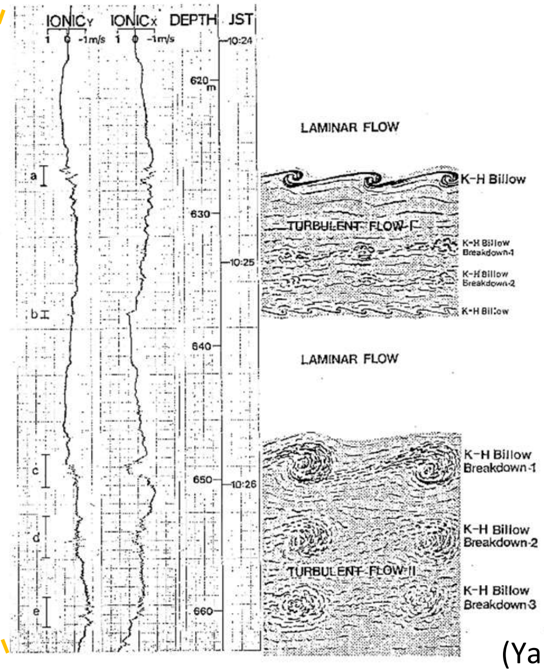


(Yamanaka et al, 1985, *RSI*)

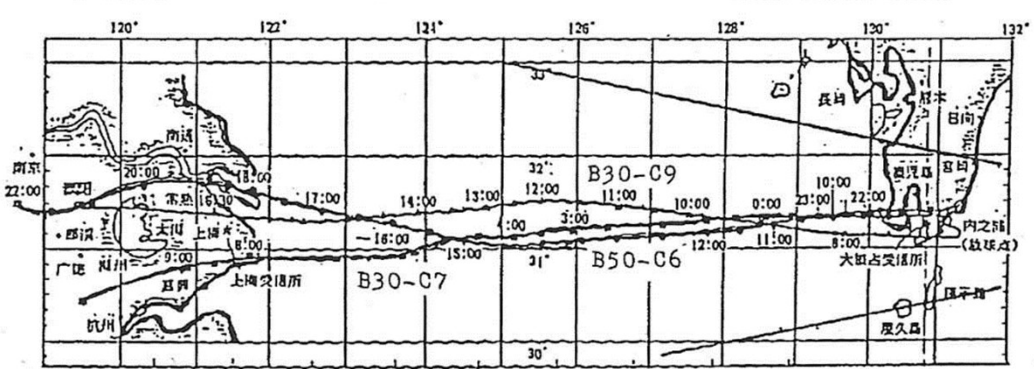


(VanZandt, 1985, *MSTRWS*)

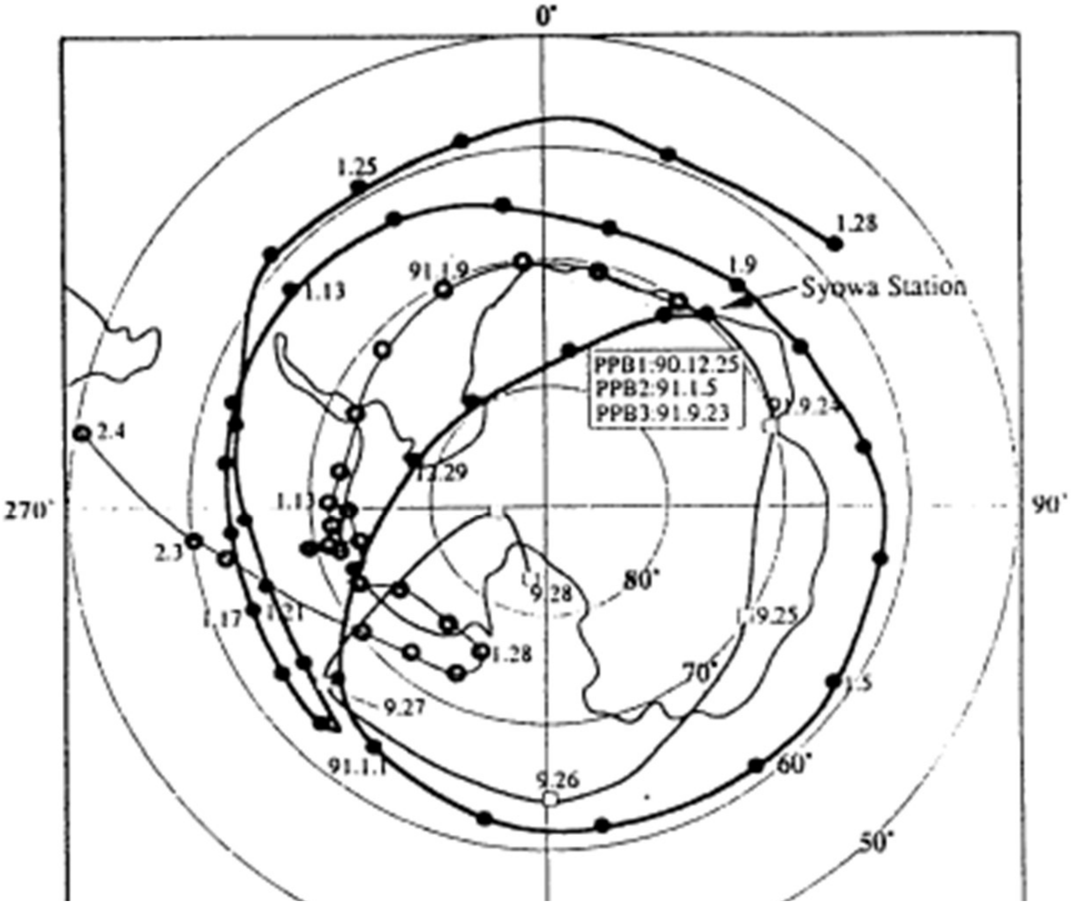




(Yamanaka et al, 1985, *JMSJ*)

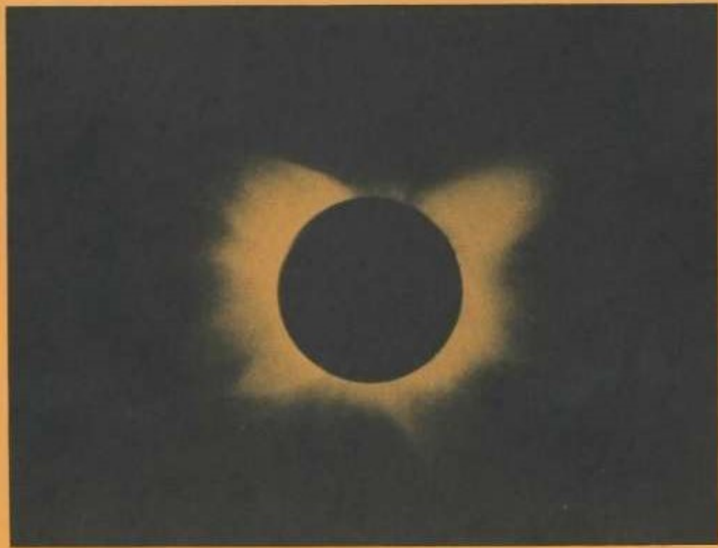


East China Sea transoceanic flights (1986～88; ISAS, CAS-IAP)
(Nishimura et al., 1982, 1988, 1990)



Polar Patrol Balloons (PPB) (1990 – 91; ISAS, NIPR, NASA)
(Nagata et al. 1985; Nishimura et al. 1985; Yamanaka et al. 1988; Hirasawa et al. 1990; Ejiri et al. 1993; ….)

インドネシア日食気球観測と惑星間塵
——太陽ダストリングの観測をめぐって——
(1983/6/11; ISAS, NAO, LAPAN)



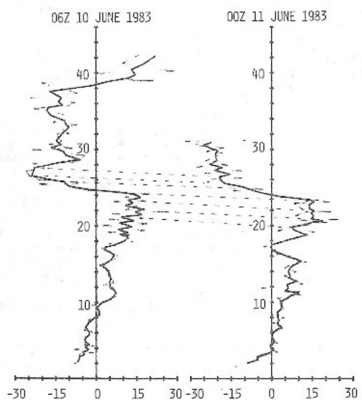
108 (Yamanaka et al., Oct 1983; MSJ)

QBO東西風交替期の赤道成層圏風系の鉛直微細構造

山中大学*・秋山弘光・狛 豊・岡部選司・西村 純（宇宙研）
J. Soegijo・T. S. Tatang (LAPAN, Indonesia)

1983年6月11日のインドネシア皆既日食の際に太陽コロナの大気球観測が行なわれ,** これに先立ち気球航跡予測のための成層圏風系の観測が宇宙研とLAPAN（インドネシア航空宇宙局）によってゴム気球・大気球・気象ロケットを用いて行なわれた。これらの解析結果を紹介する。

下図に示したものは日食前日および当日の東西風鉛直プロフィルである。赤道成層圏における風系の鉛直微細構造の解析としては以前に Cadet & Teitelbaum (1979, JAS, 36, 892) によりGATEの資料についてなされているが，それは1974年7月の東風フェイズのものである。今回の場合，中部成層圏25km高度付近はちょうどQBOの西風から東風への交替期に当っており，中層大気大循環に及ぼす波動の効果を考える上で非常に貴重な資料であると言える。下図にはCadetらの示したような位相の下方伝播が認められ鉛直位相速度は約400m/dayとなるが，これはこの期間の東西風速0の高度の降下速度とよく一致している。また特に東西風速0の高度直下5km程度の層内に細かくかつ激しい変動が著しい。QBO西風領域の卓越上伝波は混合Rossby重力波のはずであるが，水平方向の資料が足りないためそれと同定できる波の検出は理論的に導出される波の構造を与えてやる必要がある。会場では東西風速0の高度周辺の微細構造について重点的に報告する。

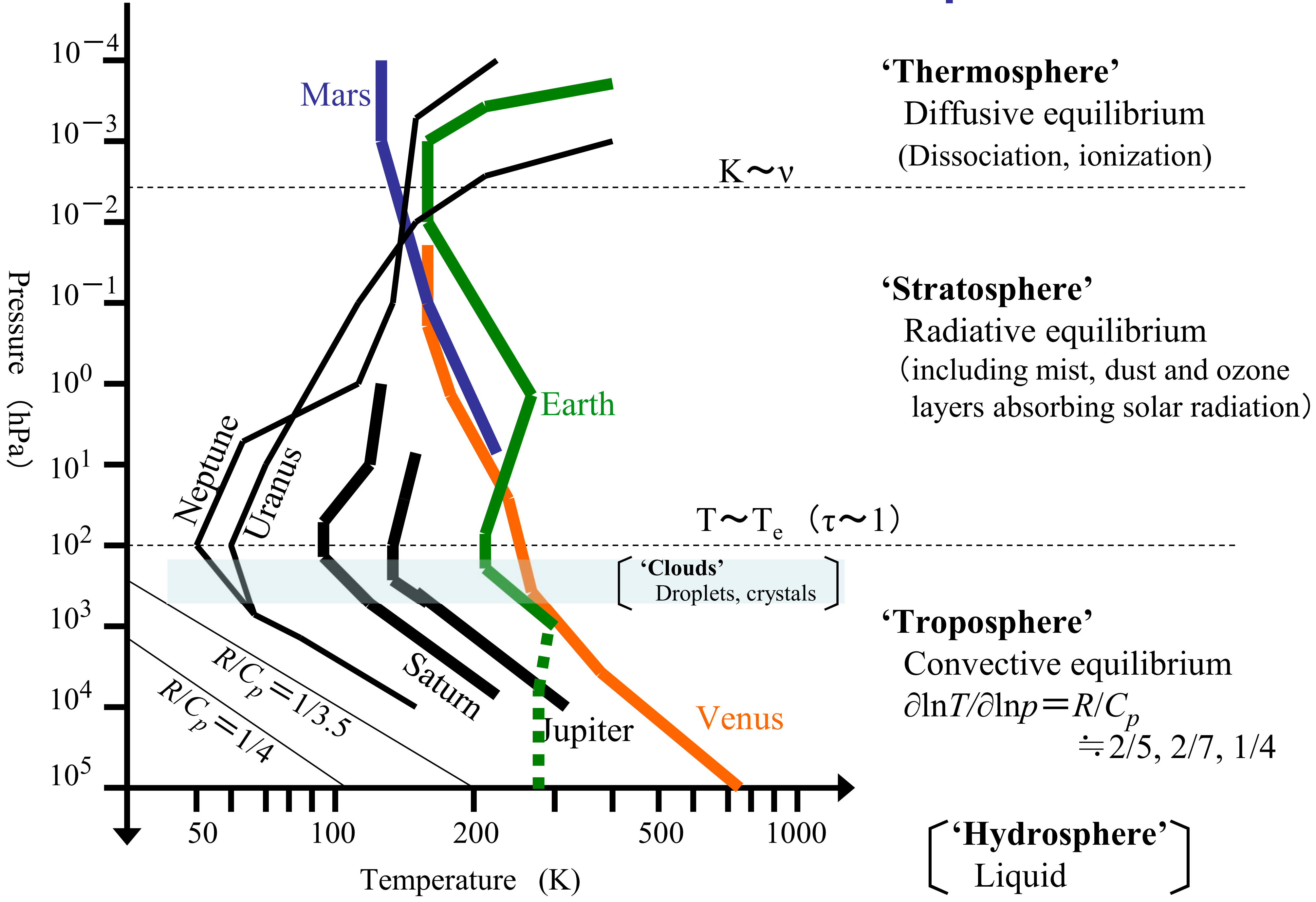


［謝辞］赤道成層圏の最近の資料の入手については気象庁高層課の方々の御厚意を得た。また気象研丸山健人博士にはQBOに関する未発表の解析結果を送って頂き，気象庁予報課高瀬邦夫氏にはルーチンデータ閲覧の便宜をはかって頂いた。

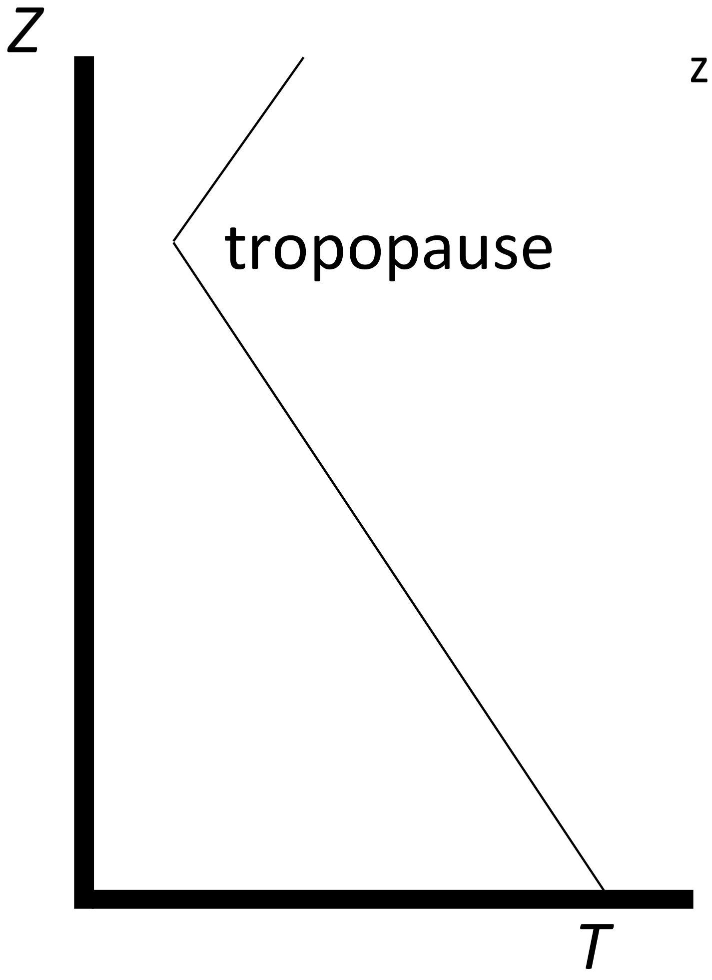
←図．インドネシア東部ジャワのWatukosek (112°40′E, 7°36′S) における東西風鉛直プロフィル．縦軸は高度(km)，横軸は東西風速(m/s)．太線は3分移動平均値，細線は1分毎の値をプロットしたもの．風速の極値を比較して破線でむすんである．風速値の精度および鉛直分解能は±1m/s，200m程度．

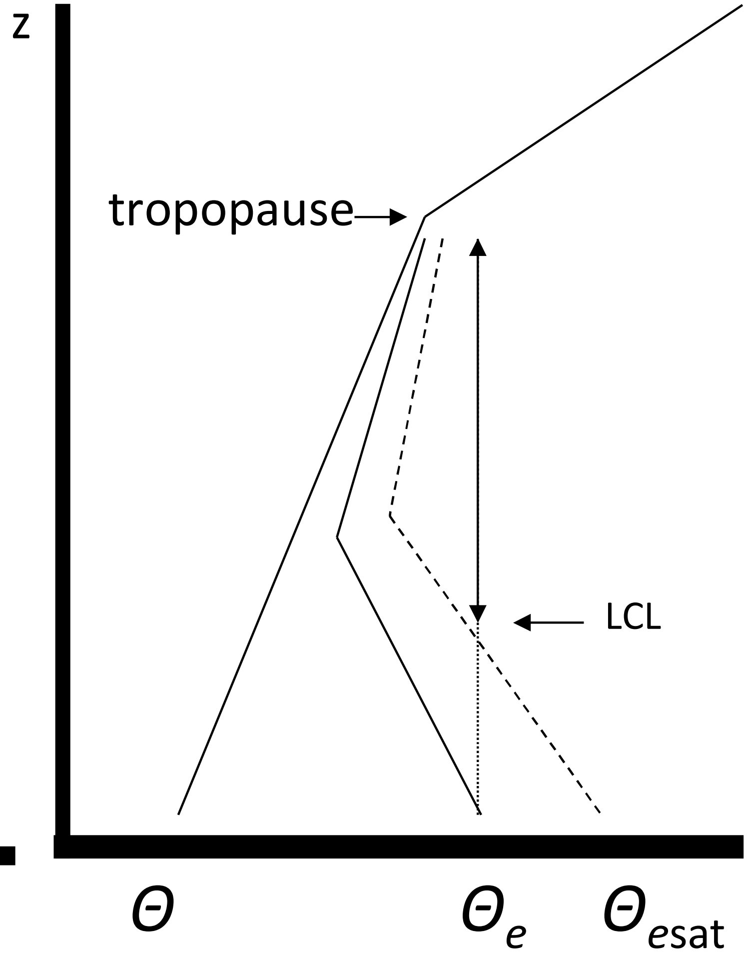
* 名大院理学研究科の委託による宇宙研受託学生．
** 隊長田鍋浩義東京天文台助教授以下東京天文台・京大理学部・宇宙研・LAPANの研究者・技術者が参加．

Vertical structure of atmosphere



Equivalent potential temperature





(Dry) Adiabatic process:
Thermodynamic equation (5)

$C_p \frac{D\theta}{Dt} = 0 \rightarrow$

$$\theta = T \cdot \left(\frac{p_{00}}{p}\right)^{R/C_p}$$

Moist(Pseudo-)adiabatic process:
(5) and moisture eq. (6):

$C_p \frac{D\theta_e}{Dt} = LS/T \rightarrow$

$$\theta_e = \theta \cdot \exp\left(\frac{Lr_s}{C_p T}\right)$$

"Paradox" of conditional instability:
- Convection generated spontaneously only when cloud appears.
- Cloud becomes most active when convection is developed.

$\Rightarrow$ *Forced motions (waves, circulations), or CISK*