Thermodynamic Aerological charts diagrams

UNIVERSITY OF WARSAW

- Thermodynamic charts are used to represent the vertical structure of the atmosphere, as well as major thermodynamic processes to which moist air can be subjected.
- Thermodynamic charts can be used to easily obtain different thermodynamic properties, e.g. θ (potential temperature) and moisture quantities (e.g., specific humidity), from a given radiosonde ascent.
- Even though today it is possible to compute many quantities directly, thermodynamic diagrams are still very useful and remain widely used.

- Each diagram has lines of constant:
  - p, pressure,
  - T, temperature,
  - θ, potential temperature,
  - q, saturation specific humidity, or r, saturation mixing ratio,
  - θ_e, saturation equivalent potential temperature (saturated adiabats).
- One difficulty with all diagrams is that they are two-dimensional, whereas the most compact description of the state of the atmosphere encompasses three dimensions, for instance, {T,p,q}.

The simplest and most common form of the aerological diagram has pressure as the ordinate and temperature as the abscissa.

- The temperature scale is linear.
- It is usually desirable to have the ordinate approximately representative of height above the surface. Thus the ordinate may be proportional to:
  - $-\ln p$ (the Emagram)
  - p^{R/c_p} (the Stüve diagram)

The Emagram has an advantage over the Stüve diagram in that the area enclosed by a process curve is proportional to energy.

$$dw = pdv = RdT - vdp$$

$$\oint dw = \oint RdT - \oint RT\frac{dp}{p} \longrightarrow \oint dw = -R\oint Td(\ln p)$$

RdT is an exact differential which integrates to zero

- A chart using T and $\ln p$ as coordinates acts as a true thermodynamic diagram, meaning that the enclosed area is proportional to energy.
- The logarithm of pressure is chosen for the vertical axis rather than pressure itself because, in an isothermal atmosphere, height varies linearly with $\ln p$. Consequently, for a realistic temperature profile, the ordinate is roughly proportional to height.

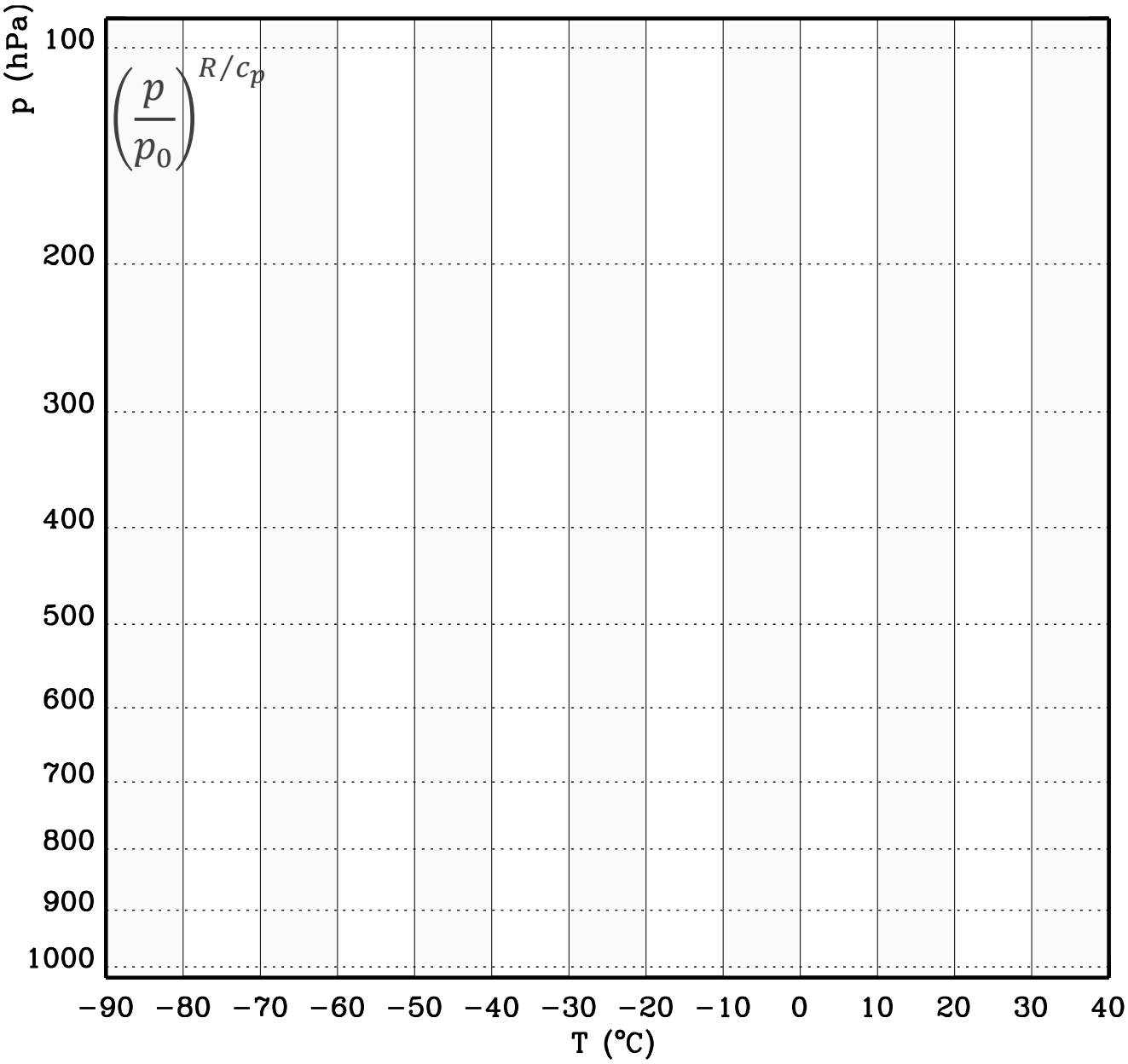
CONSTRUCTION OF THE STÜVE DIAGRAM

$T, \quad \left(\frac{p}{p_0}\right)^{R/c_p}$

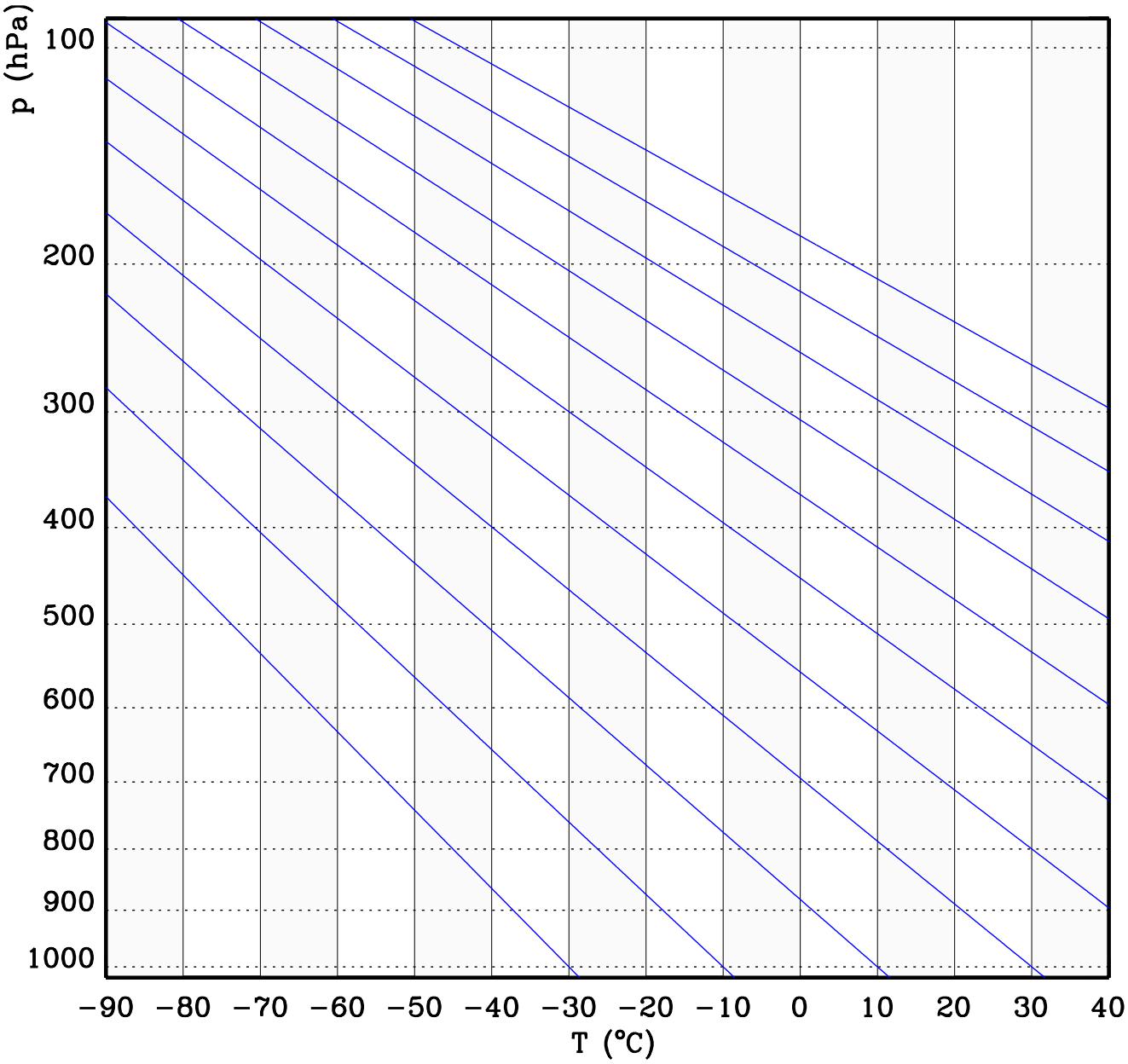
Simplicity of its construction

UNIVERSITY OF WARSAW

Stüve diagram

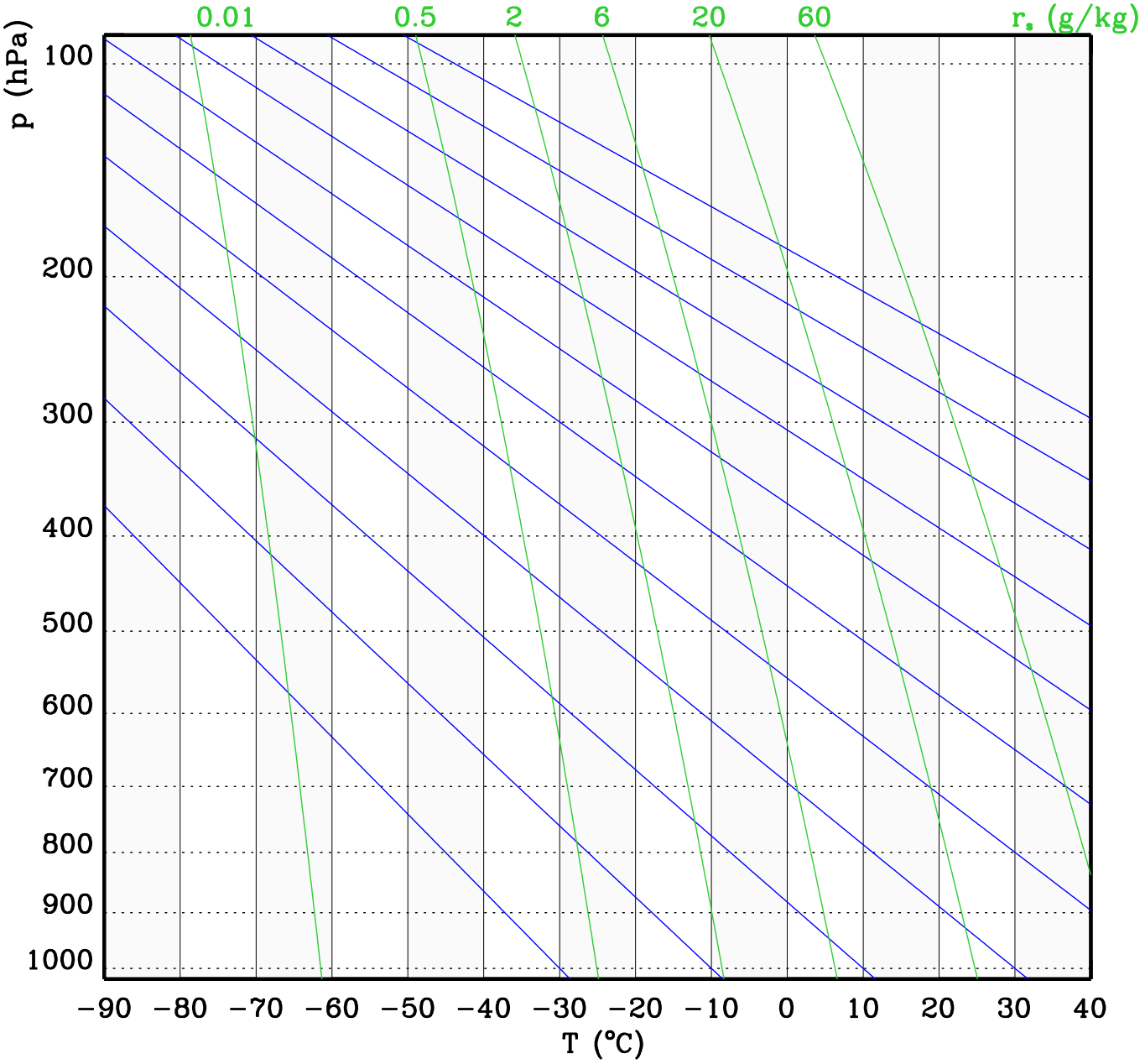


Stüve diagram



$$\theta = T\left(\frac{p_0}{p}\right)^{\kappa}$$

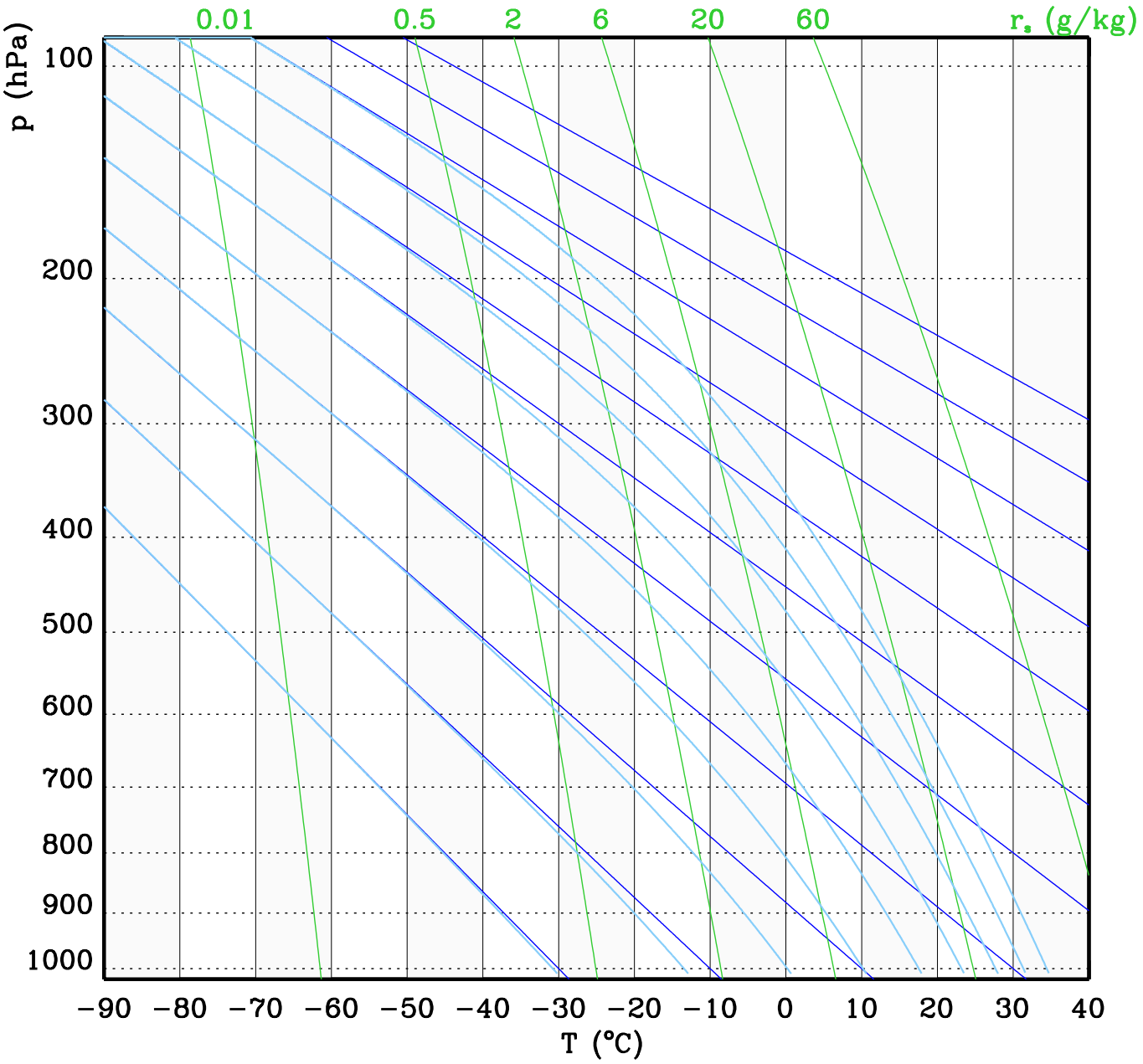
Stüve diagram



$$\theta = T\left(\frac{p_0}{p}\right)^{\kappa}$$

$$r_s = \varepsilon \frac{e_s(T)}{p - e_s(T)}$$

Stüve diagram

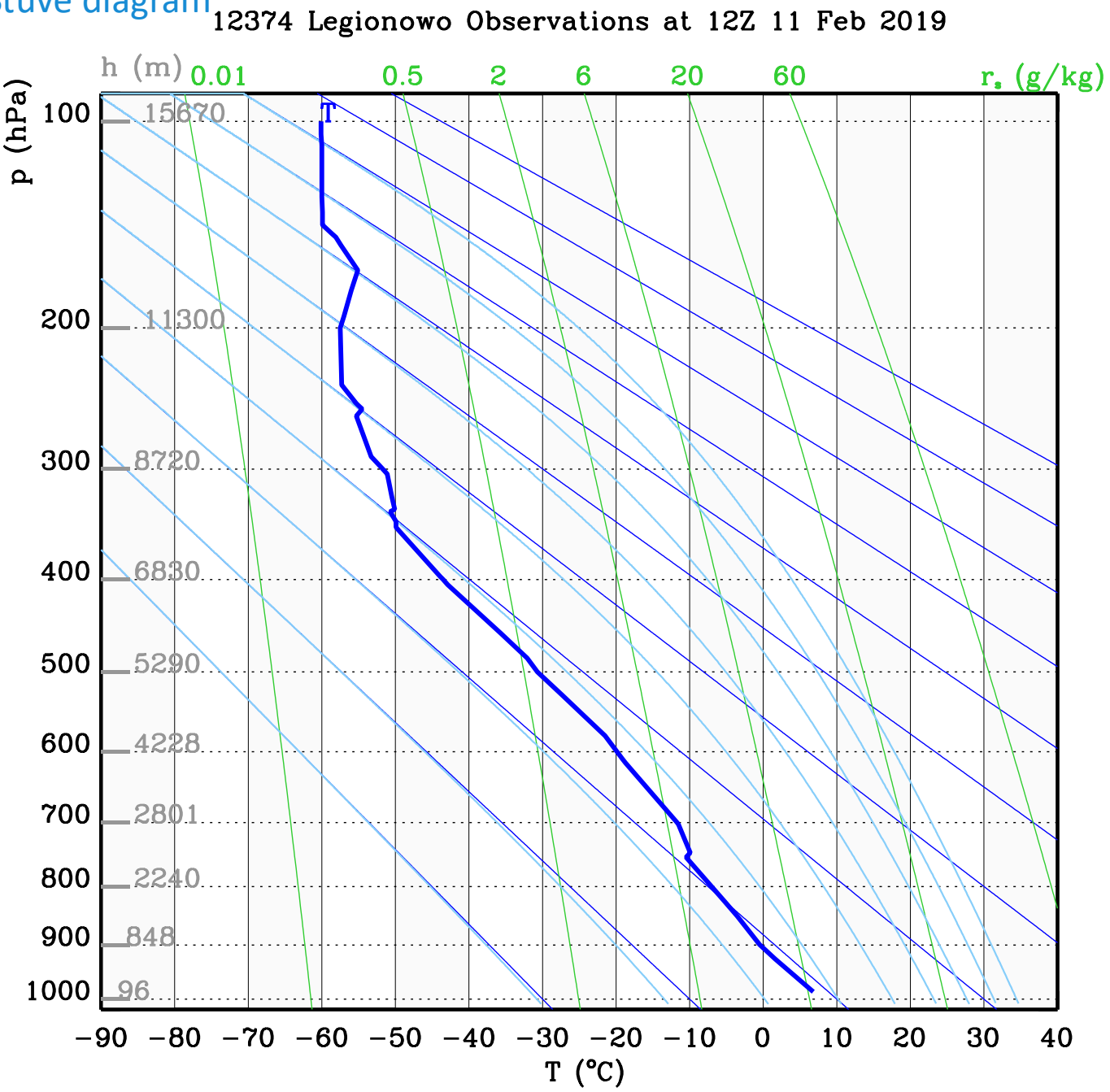


$$\theta = T\left(\frac{p_0}{p}\right)^{\kappa}$$

$$r_s = \varepsilon \frac{e_s(T)}{p - e_s(T)}$$

$$\theta_e = \theta \cdot exp\left(\frac{L_{lv} r_s}{c_p T}\right)$$

Stüve diagram



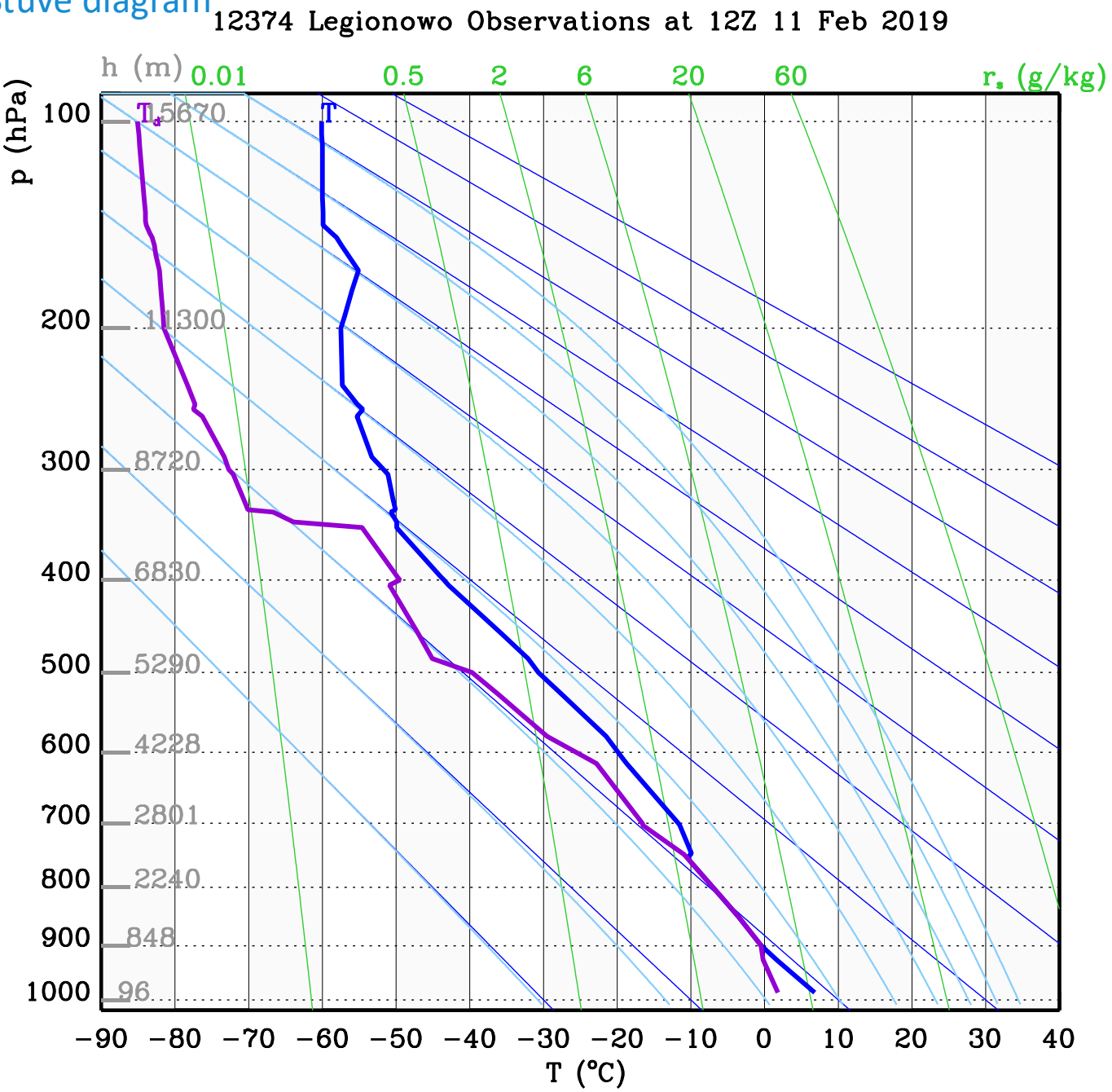
$$\theta = T\left(\frac{p_0}{p}\right)^{\kappa}$$

$$r_s = \varepsilon \frac{e_s(T)}{p - e_s(T)}$$

$$\theta_e = \theta \cdot exp\left(\frac{L_{lv} r_s}{c_p T}\right)$$

T

Stüve diagram



$$\theta = T\left(\frac{p_0}{p}\right)^{\kappa}$$

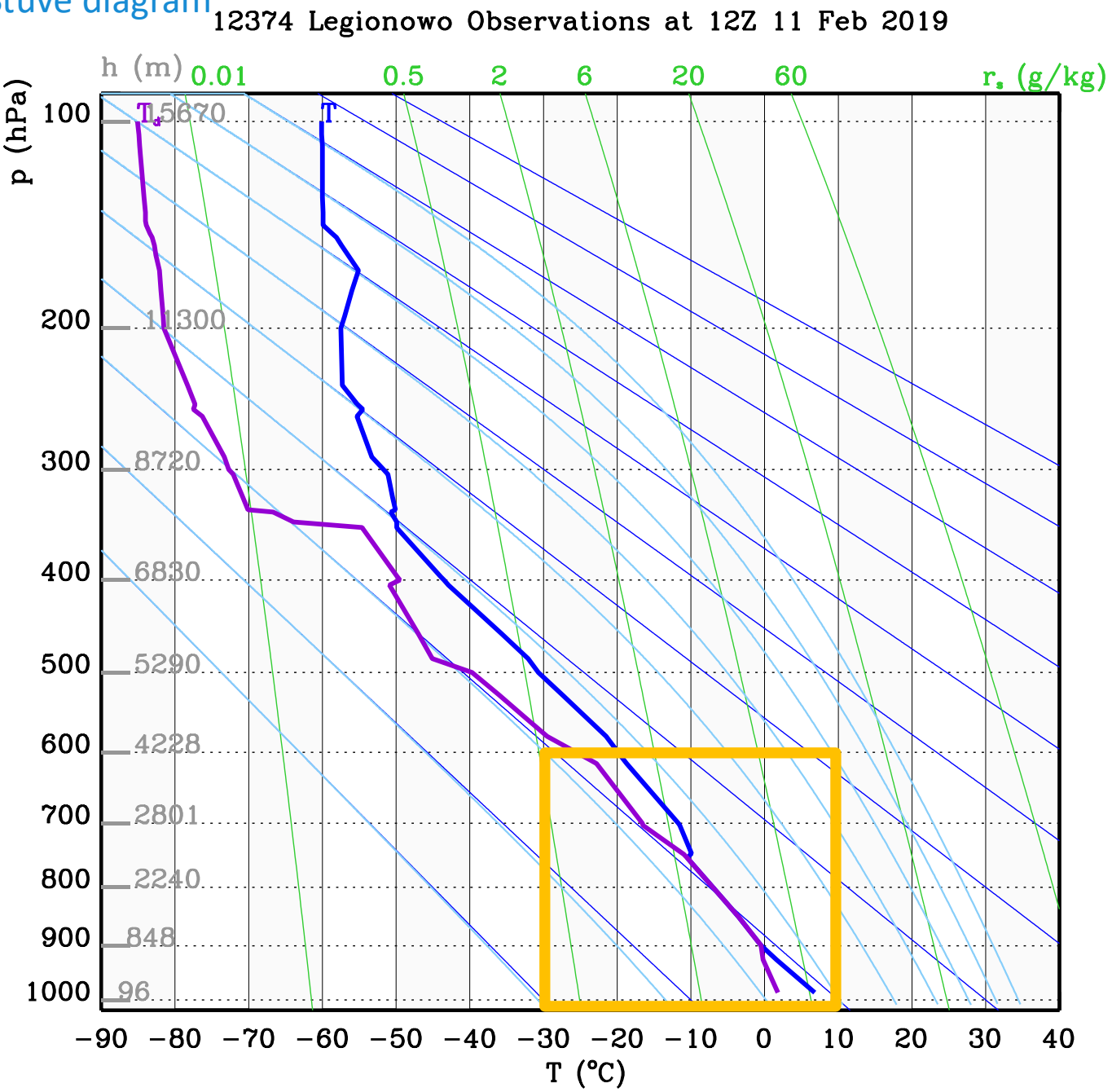
$$r_s = \varepsilon \frac{e_s(T)}{p - e_s(T)}$$

$$\theta_e = \theta \cdot exp\left(\frac{L_{lv} r_s}{c_p T}\right)$$

T

T_d

Stüve diagram



$$\theta = T\left(\frac{p_0}{p}\right)^{\kappa}$$

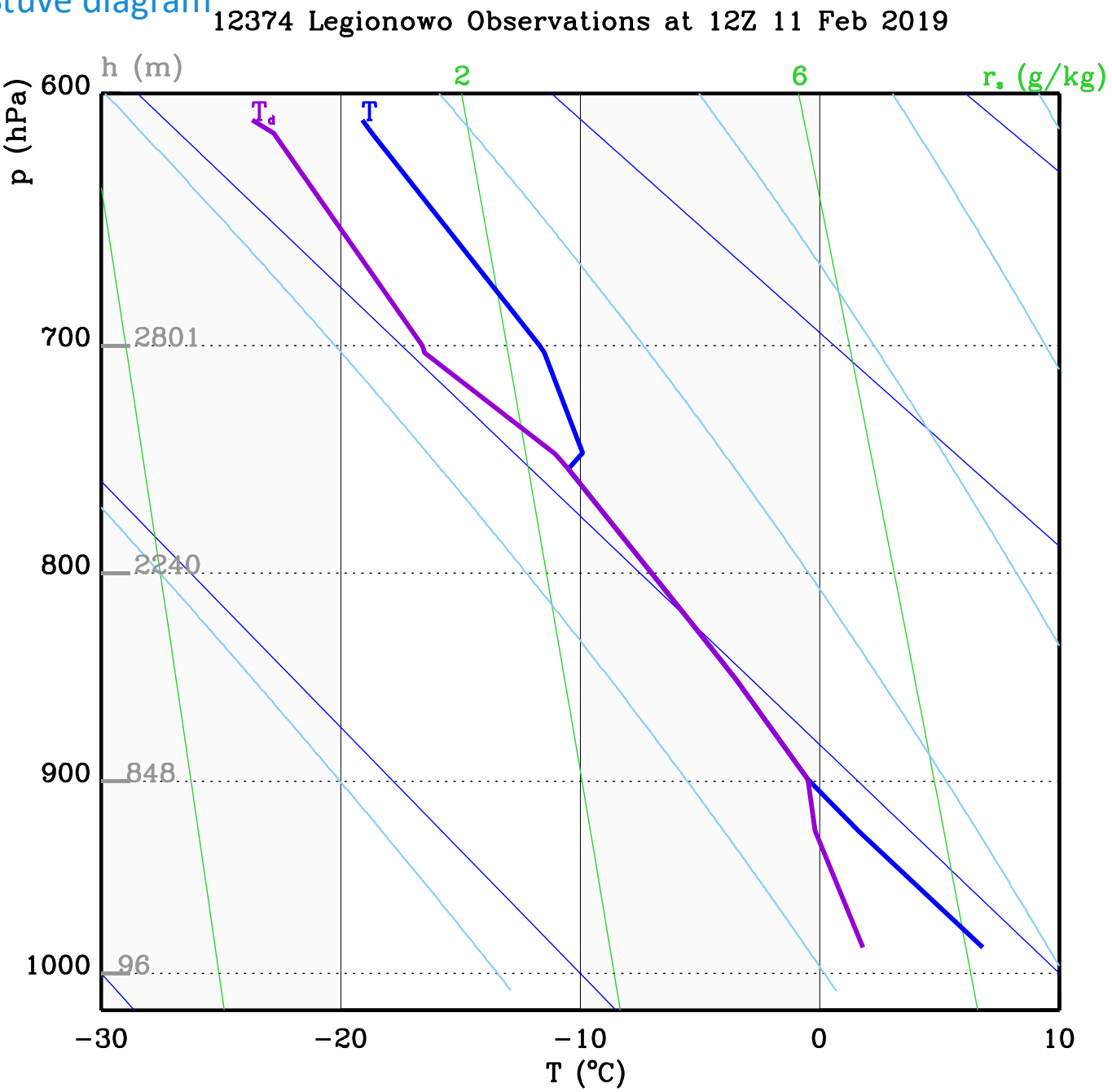
$$r_s = \varepsilon \frac{e_s(T)}{p - e_s(T)}$$

$$\theta_e = \theta \cdot exp\left(\frac{L_{lv} r_s}{c_p T}\right)$$

T

T_d

Stüve diagram



$$\theta = T\left(\frac{p_0}{p}\right)^{\kappa}$$

$$r_s = \varepsilon \frac{e_s(T)}{p - e_s(T)}$$

$$\theta_e = \theta \cdot exp\left(\frac{L_{lv} r_s}{c_p T}\right)$$

T

T_d

TEPHIGRAM

The name 'tephigram' literally stands for the $T - \varphi$ gram, where φ was originally used to denote potential temperature.

From the defining equation of entropy, it follows that the total heat added in a cyclic process is:

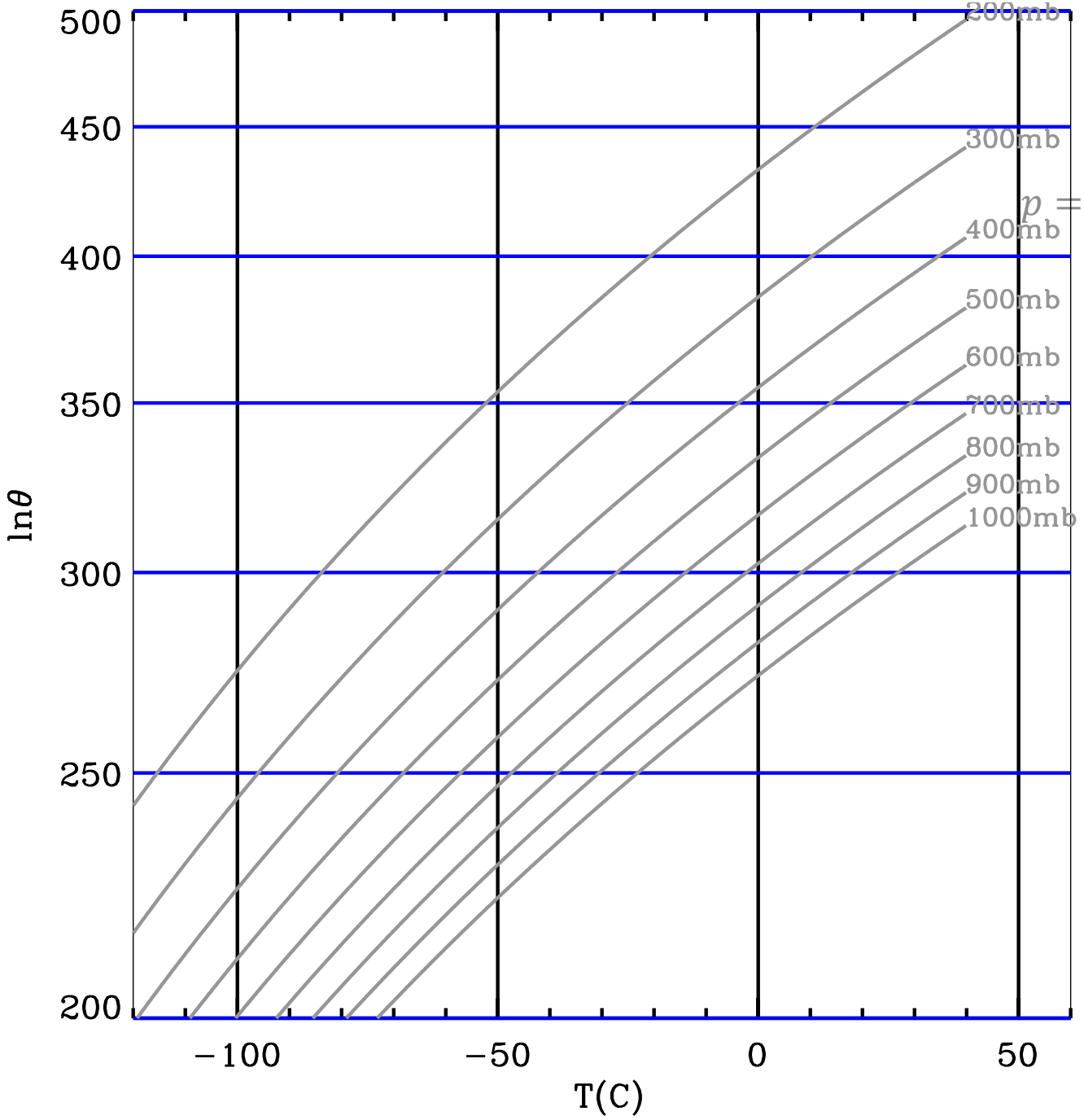
$$\oint dq = \oint T dS = c_p \oint T d(\ln \theta)$$

A chart with coordinates of T versus ln θ has the area-energy relation of a true thermodynamic diagram.

Usually, tephigrams are right-rotated clockwise so that the ordinate becomes roughly proportional to $\ln p$, and hence, height.

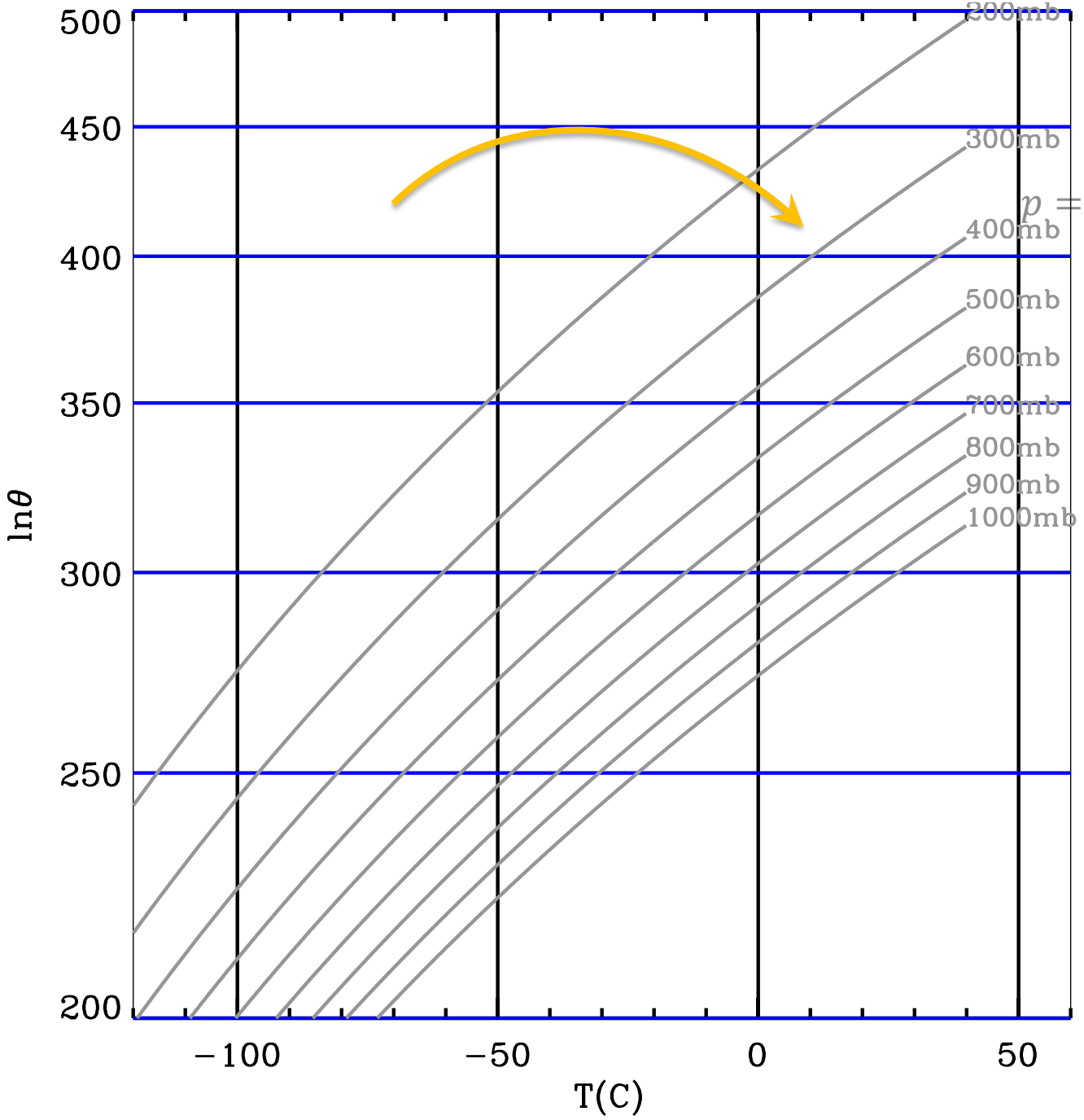
UNIVERSITY OF WARSAW

Tephigram



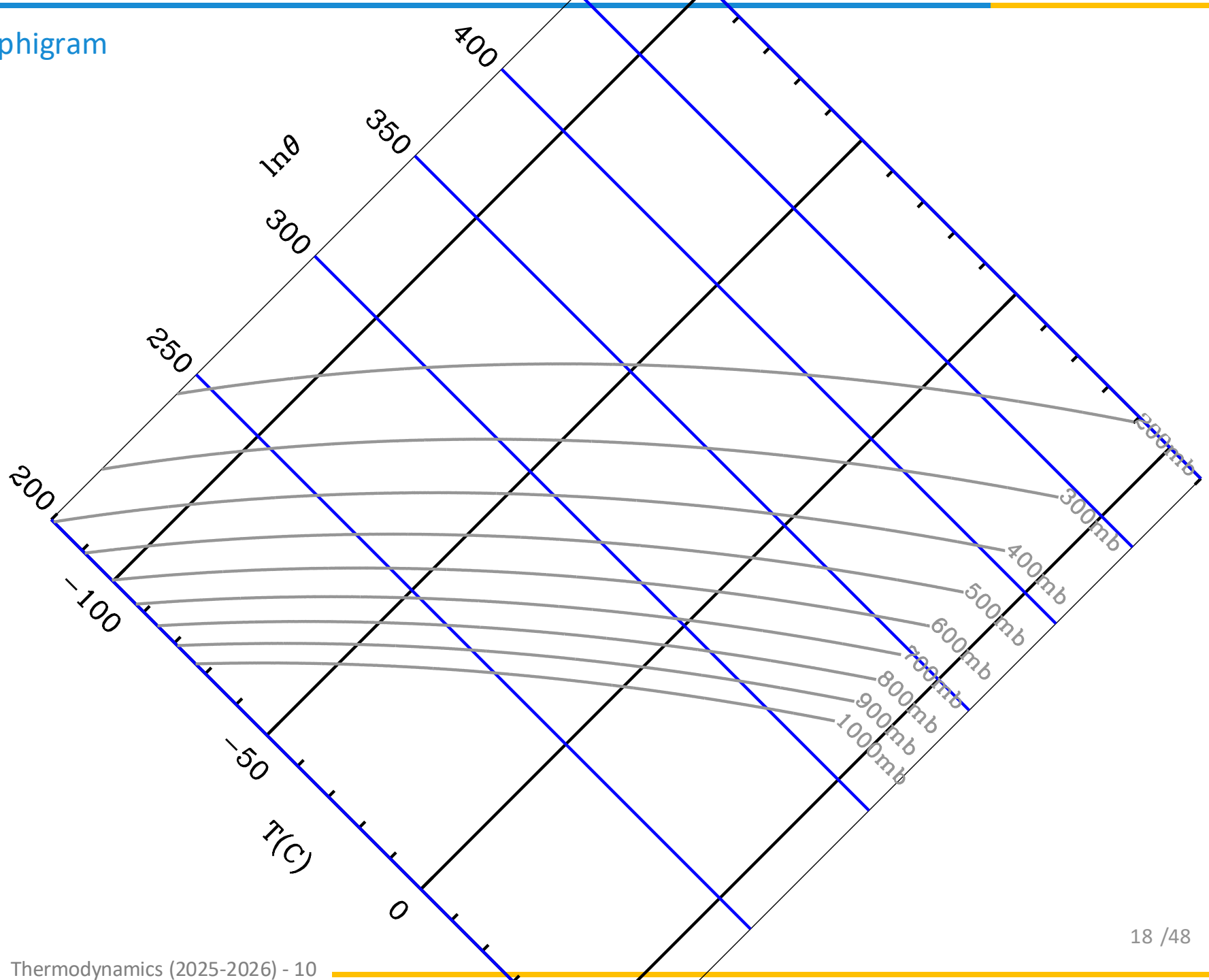
$$p = p_0 \left(\frac{T}{\theta}\right)^{1/\kappa}$$

Tephigram

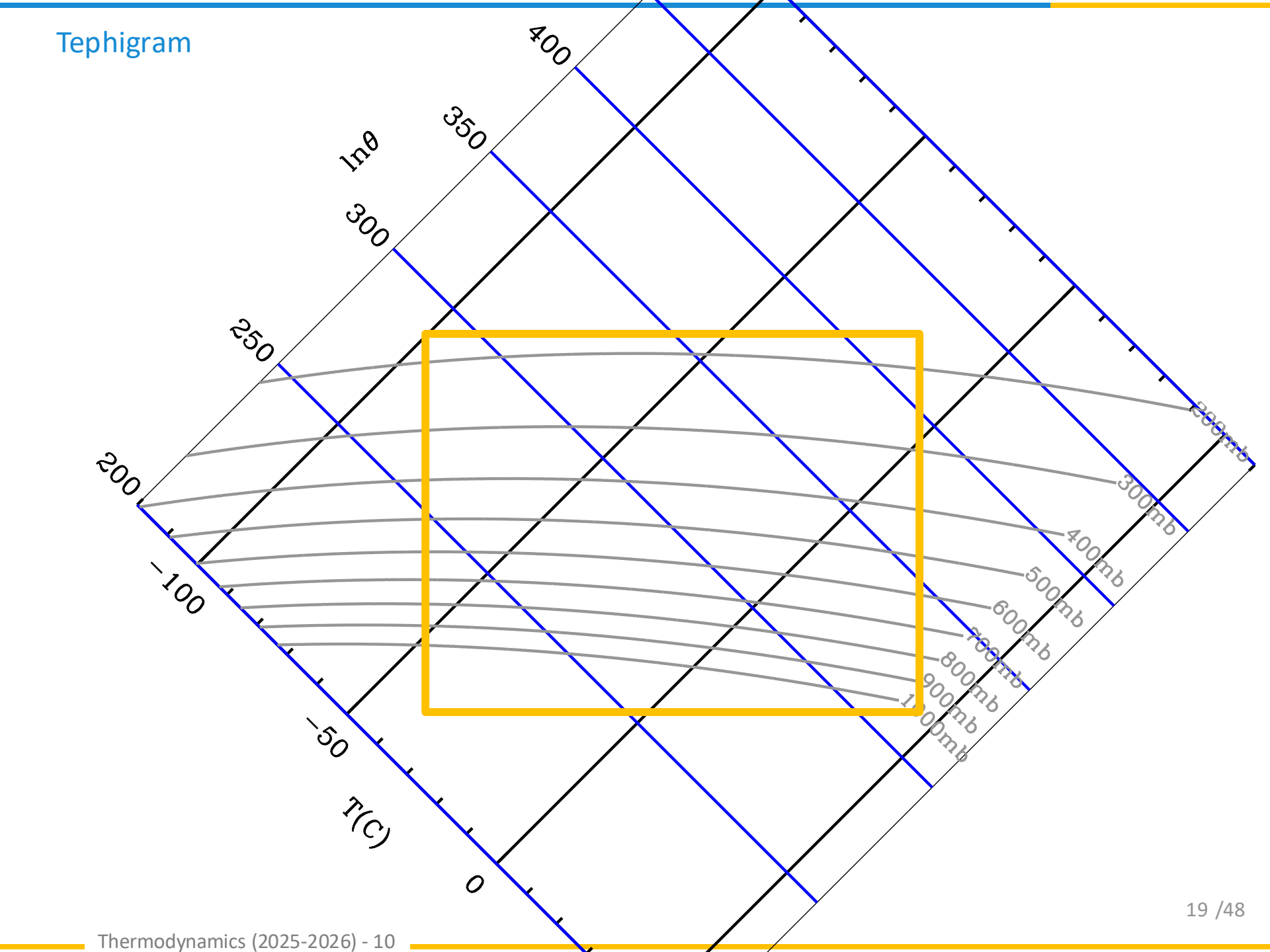


$$p = p_0 \left(\frac{T}{\theta}\right)^{1/\kappa}$$

Tephigram

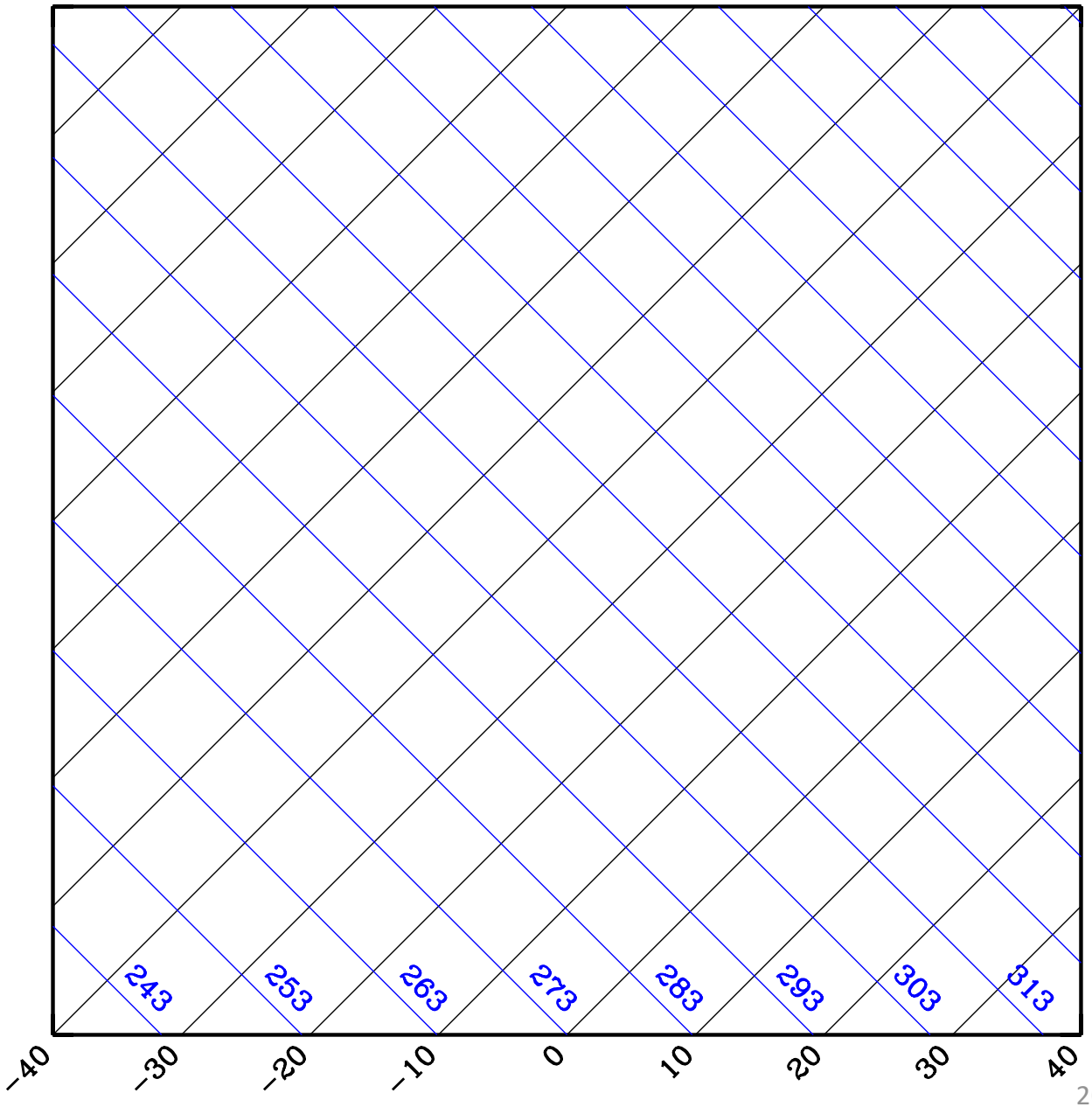

400
350
lnθ
300
250
200
−100
−50
T(C)
0
200mb
300mb
400mb
500mb
600mb
700mb
800mb
900mb
1000mb

Tephigram


400
350
lnθ
300
250
200
−100
−50
T(C)
0
200mb
300mb
400mb
500mb
600mb
700mb
800mb
900mb
1000mb

Tephigram

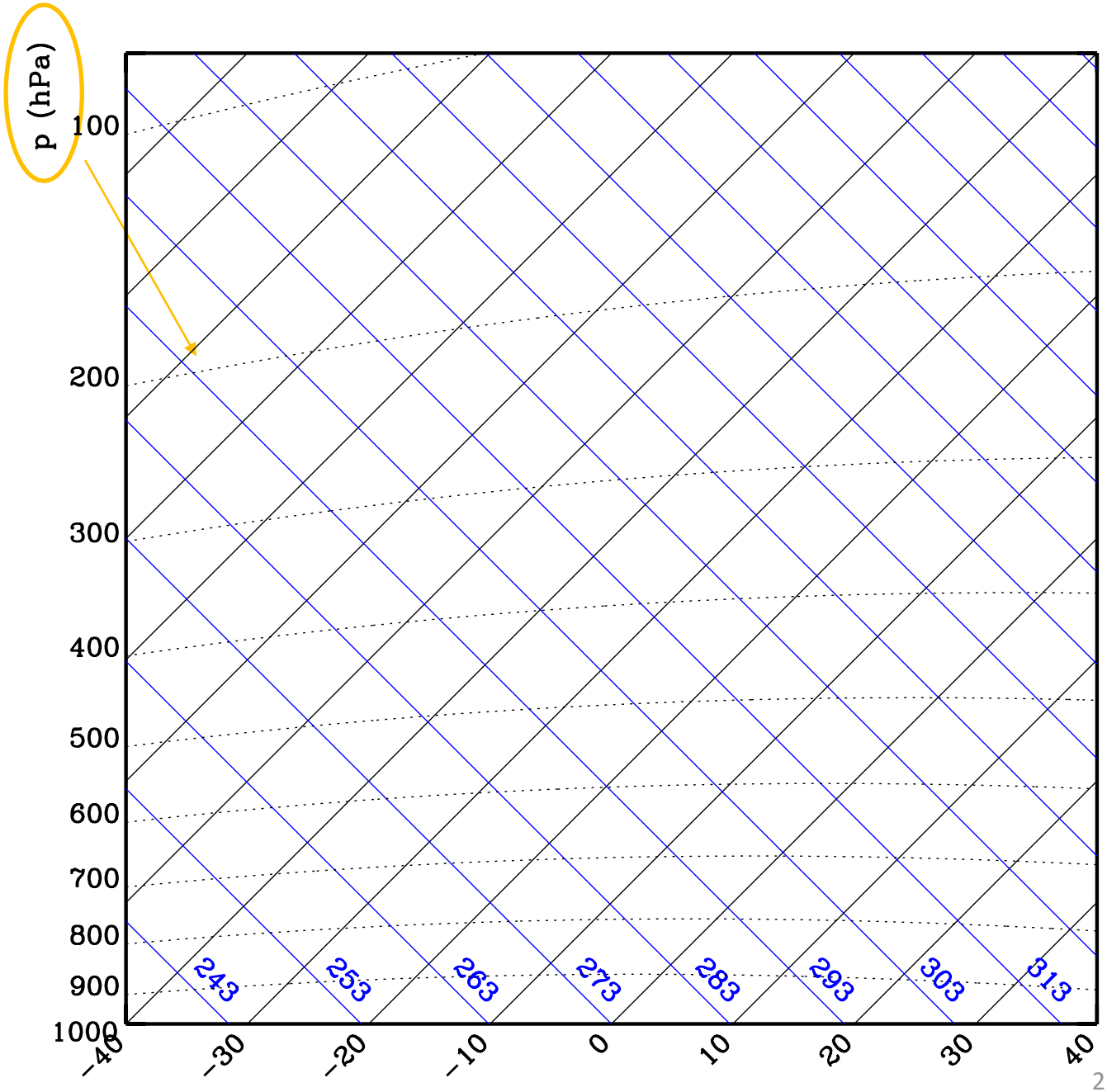
$$\theta = T\left(\frac{p_0}{p}\right)^{\kappa}$$



Tephigram

$$p = p_0 \left(\frac{T}{\theta}\right)^{1/\kappa}$$

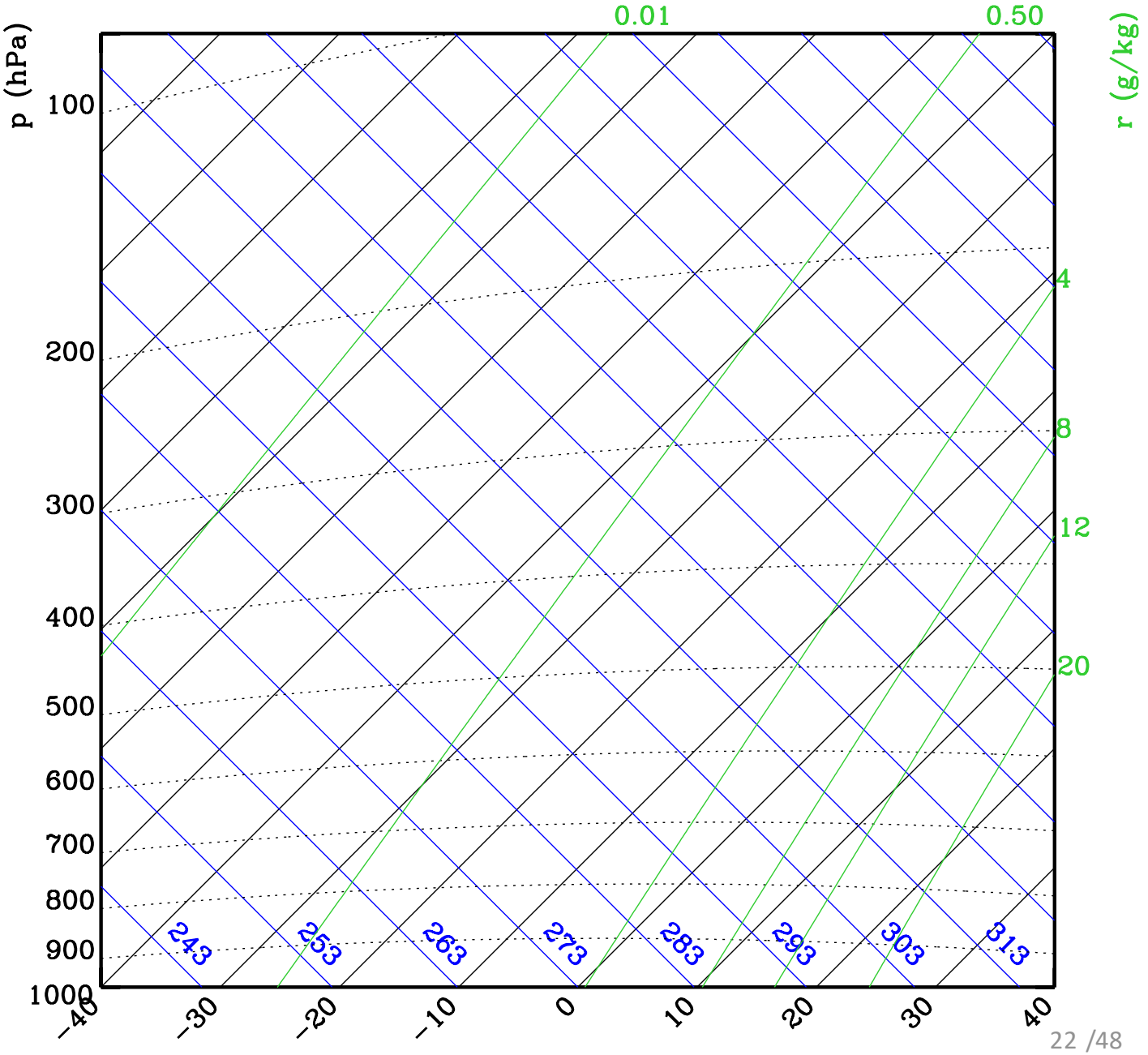
$$\theta = T \left(\frac{p_0}{p}\right)^{\kappa}$$



Tephigram

$$\theta = T\left(\frac{p_0}{p}\right)^{\kappa}$$

$$r_s = \varepsilon \frac{e_s(T)}{p - e_s(T)}$$

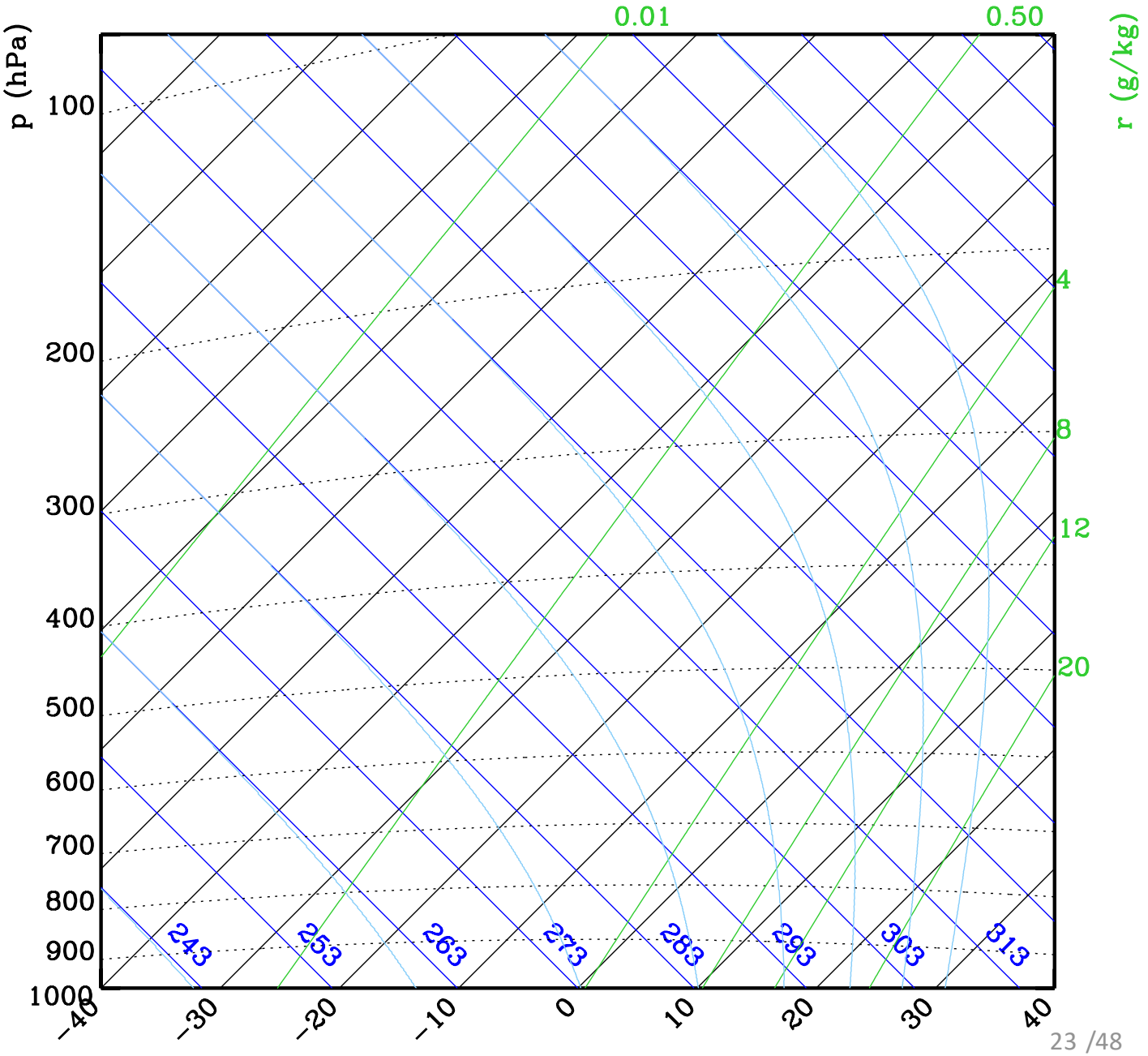


Tephigram

$$\theta = T\left(\frac{p_0}{p}\right)^{\kappa}$$

$$r_s = \varepsilon \frac{e_s(T)}{p - e_s(T)}$$

$$\theta_e = \theta \cdot exp\left(\frac{L_{lv} r_s}{c_p T}\right)$$



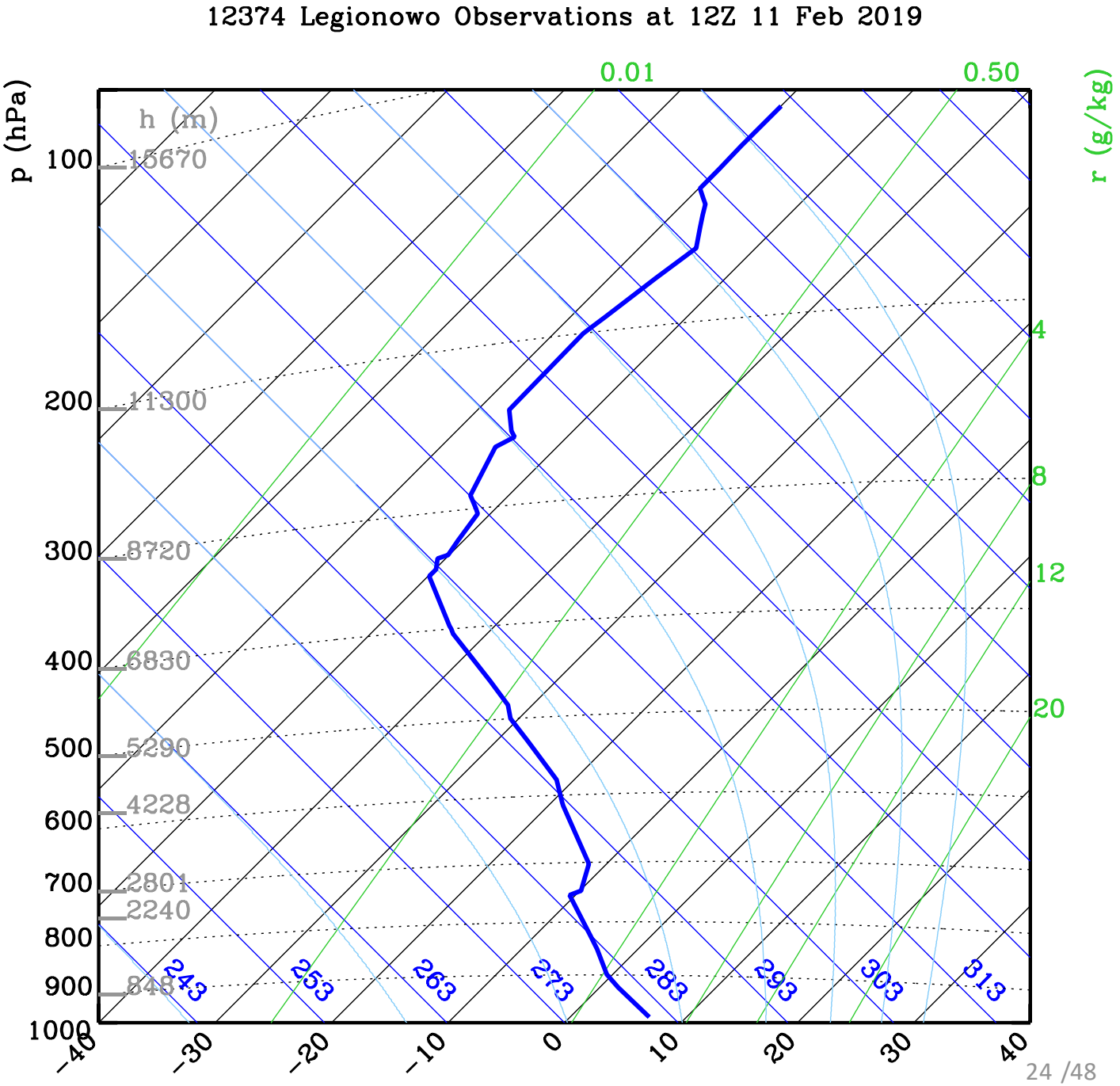
Tephigram

$$\theta = T\left(\frac{p_0}{p}\right)^{\kappa}$$

$$r_s = \varepsilon \frac{e_s(T)}{p - e_s(T)}$$

$$\theta_e = \theta \cdot exp\left(\frac{L_{lv} r_s}{c_p T}\right)$$

T



Tephigram

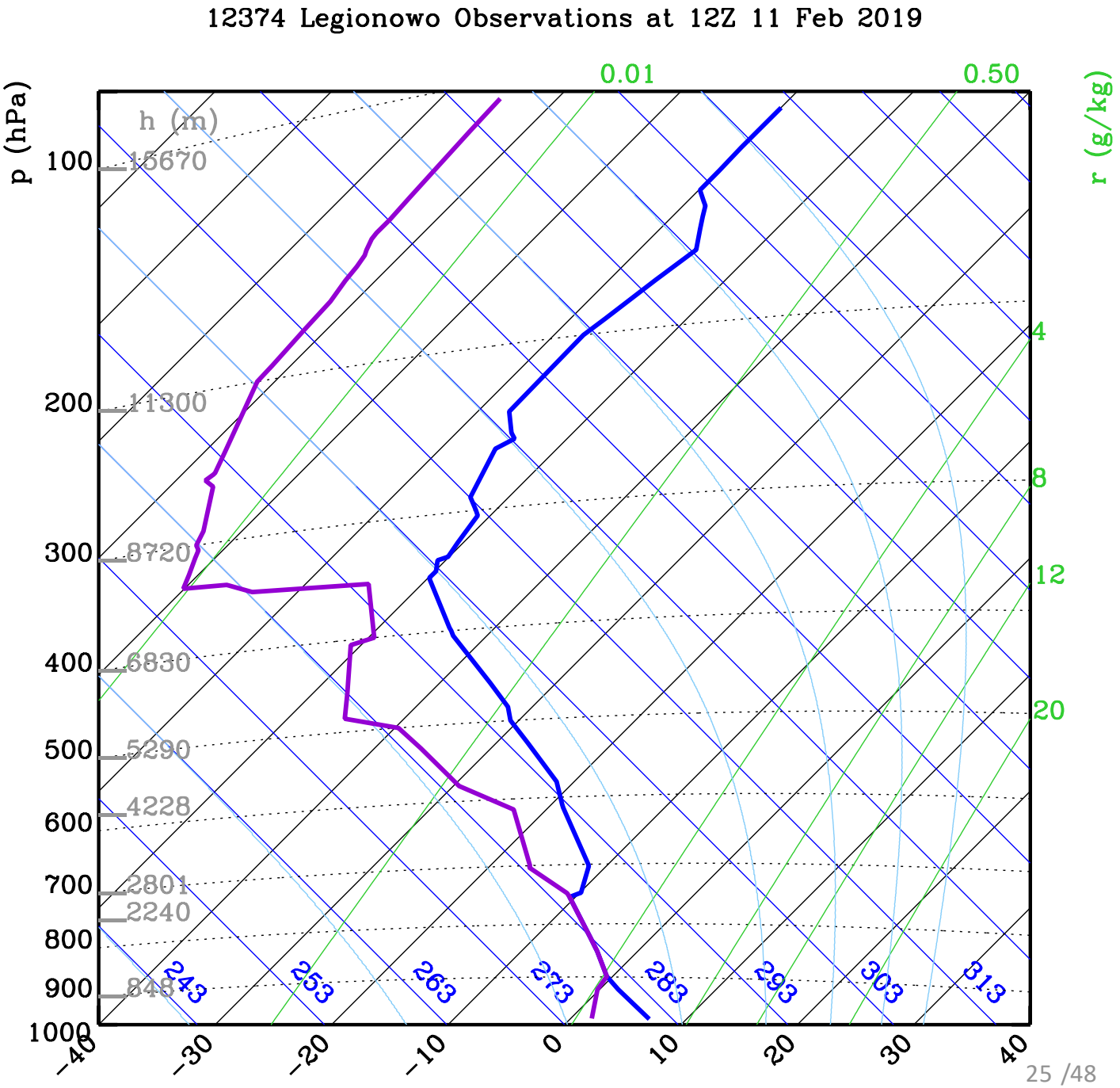
$$\theta = T\left(\frac{p_0}{p}\right)^{\kappa}$$

$$r_s = \varepsilon \frac{e_s(T)}{p - e_s(T)}$$

$$\theta_e = \theta \cdot exp\left(\frac{L_{lv} r_s}{c_p T}\right)$$

T

T_d



SKEW-T DIAGRAM

The Skew-T diagram uses temperature (T) and $\ln p$ as its thermodynamic coordinates.

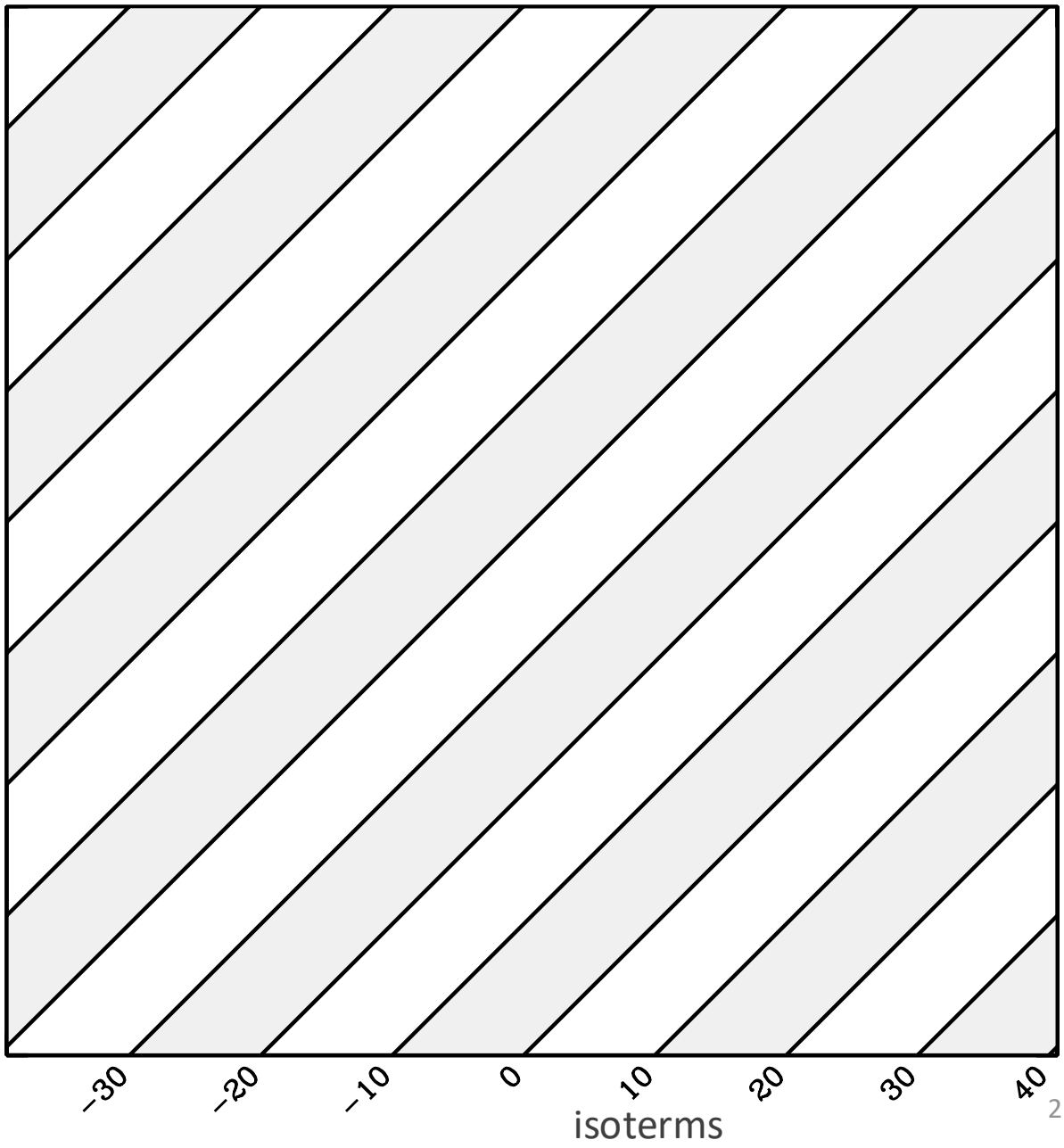
The logarithm of pressure is chosen for the vertical axis instead of pressure itself because height varies linearly with $\ln p$ in an isothermal atmosphere. Consequently, for a realistic temperature profile, the vertical coordinate is roughly proportional to height.

Isotherms are skewed at an angle of approximately 45° to the vertical. The specific angle of skewness is chosen so that dry adiabats and isotherms are orthogonal at 1000 hPa and 0°C.

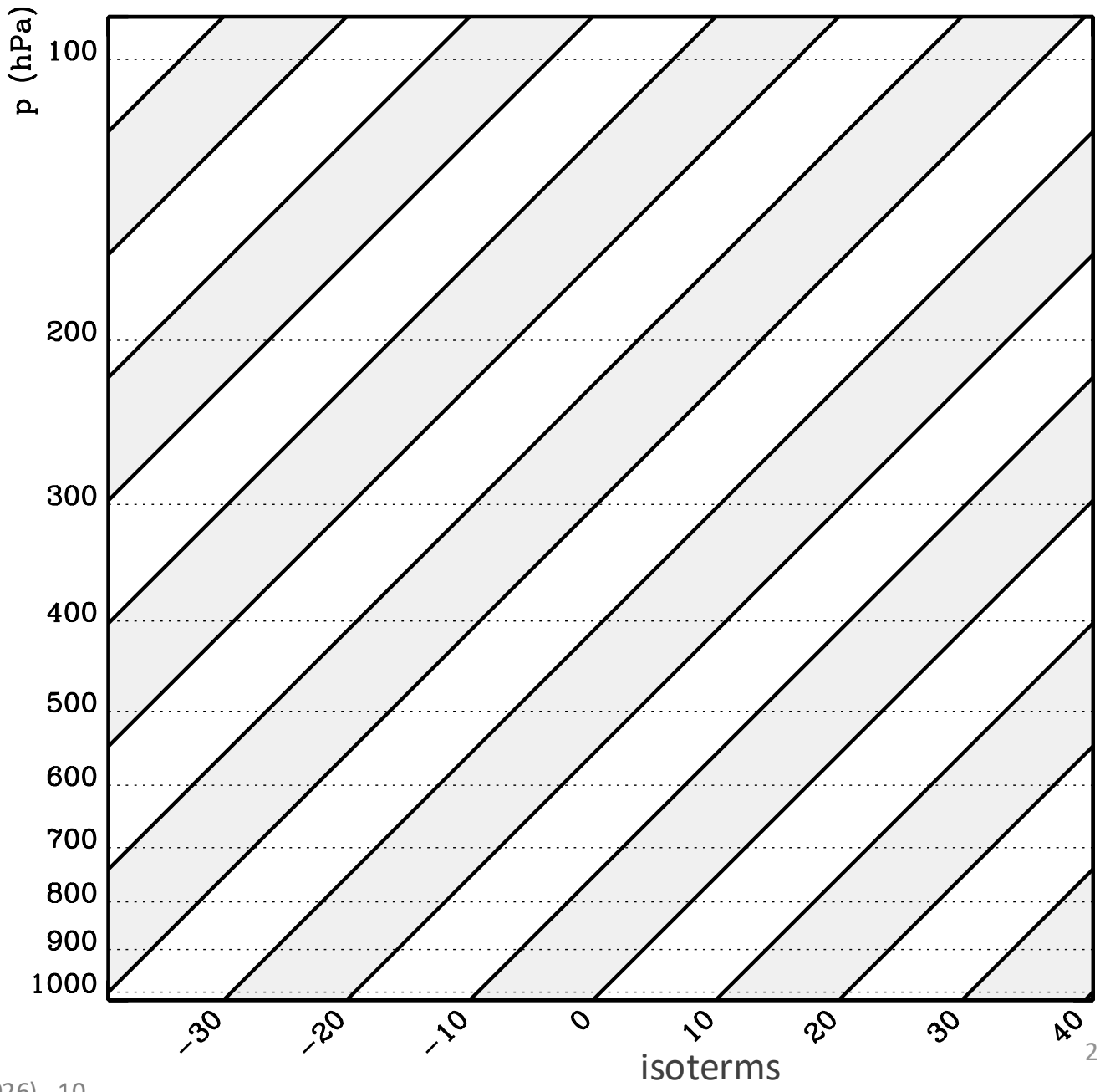
As with any chart using T and $\ln p$ as coordinates, the Skew-T acts as a true thermodynamic diagram, meaning that the enclosed area is proportional to energy.

UNIVERSITY OF WARSAW

Skew-T diagram

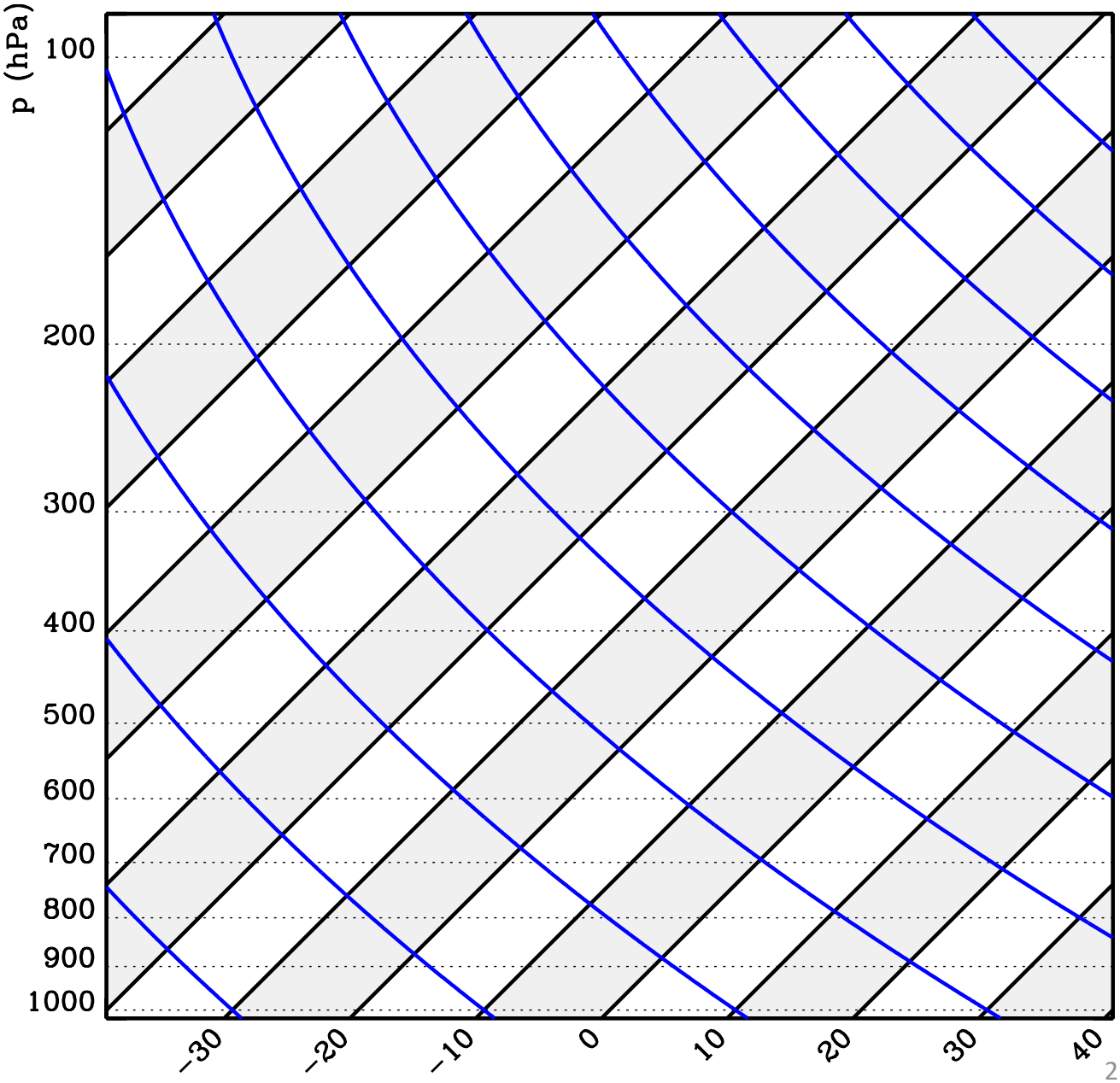


Skew-T diagram



Skew-T diagram

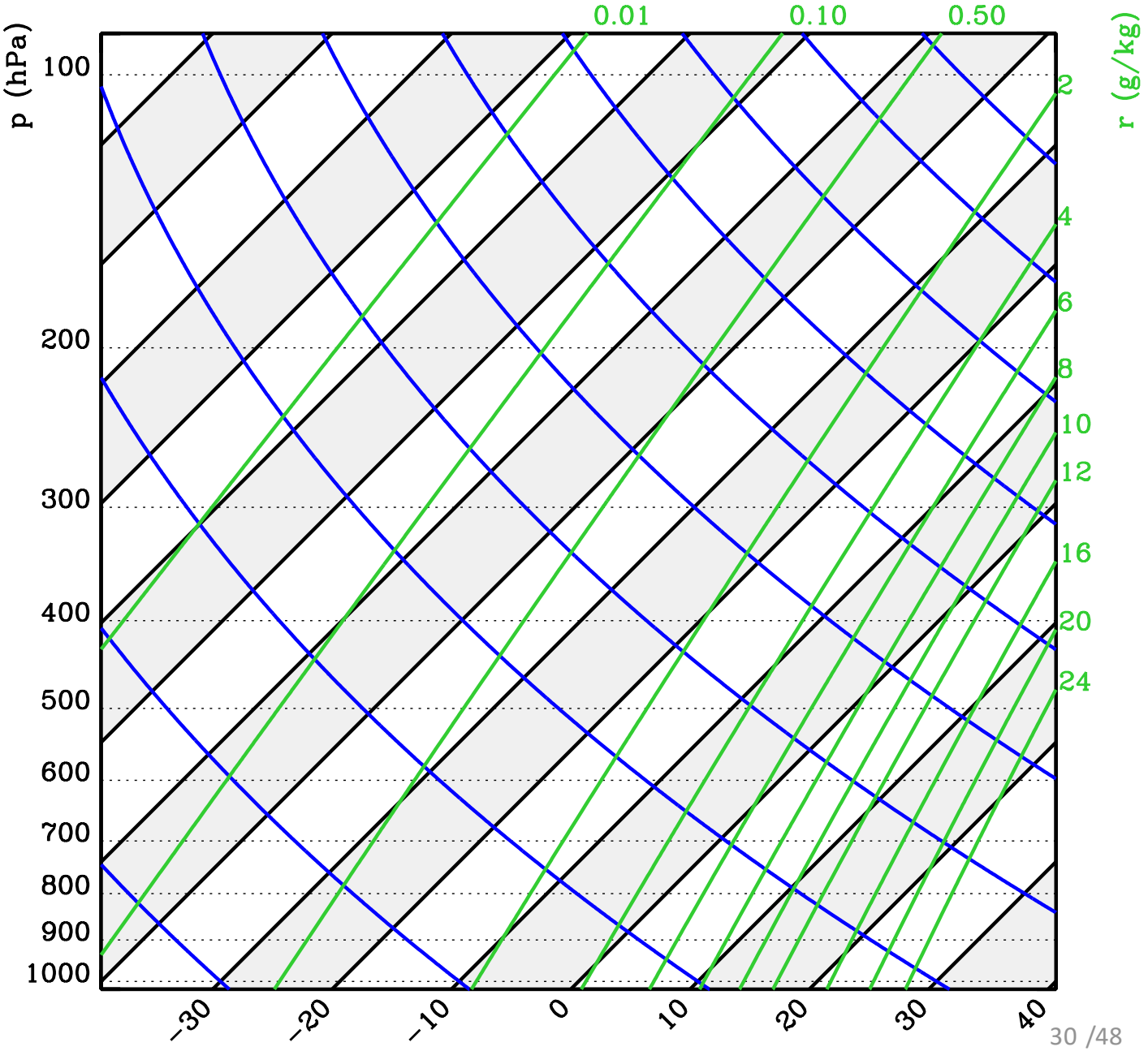
$$\theta = T\left(\frac{p_0}{p}\right)^{\kappa}$$



Skew-T diagram

$$\theta = T\left(\frac{p_0}{p}\right)^{\kappa}$$

$$r_s = \varepsilon \frac{e_s(T)}{p - e_s(T)}$$

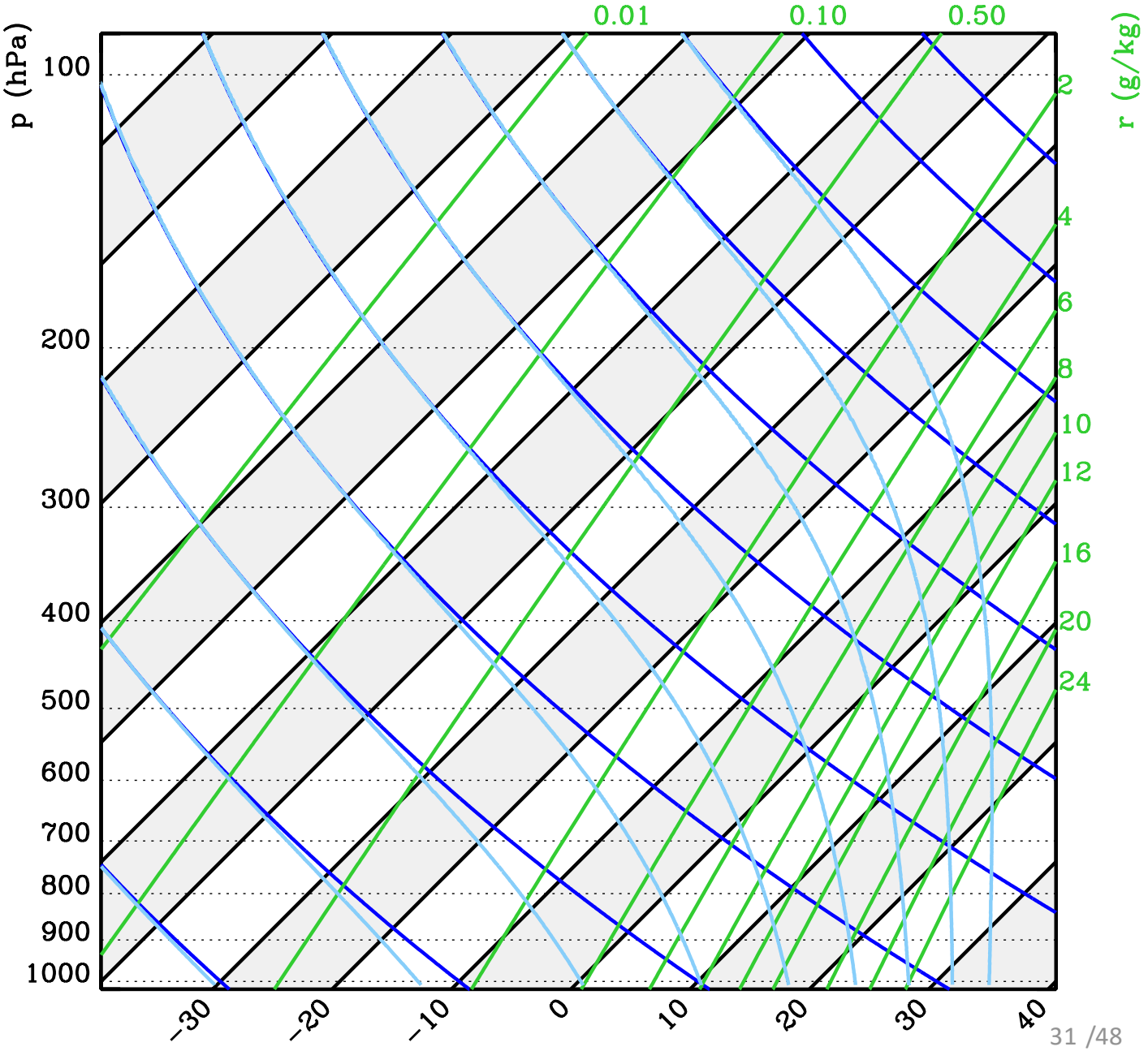


Skew-T diagram

$$\theta = T\left(\frac{p_0}{p}\right)^{\kappa}$$

$$r_s = \varepsilon \frac{e_s(T)}{p - e_s(T)}$$

$$\theta_e = \theta \cdot exp\left(\frac{L_{lv} r_s}{c_p T}\right)$$

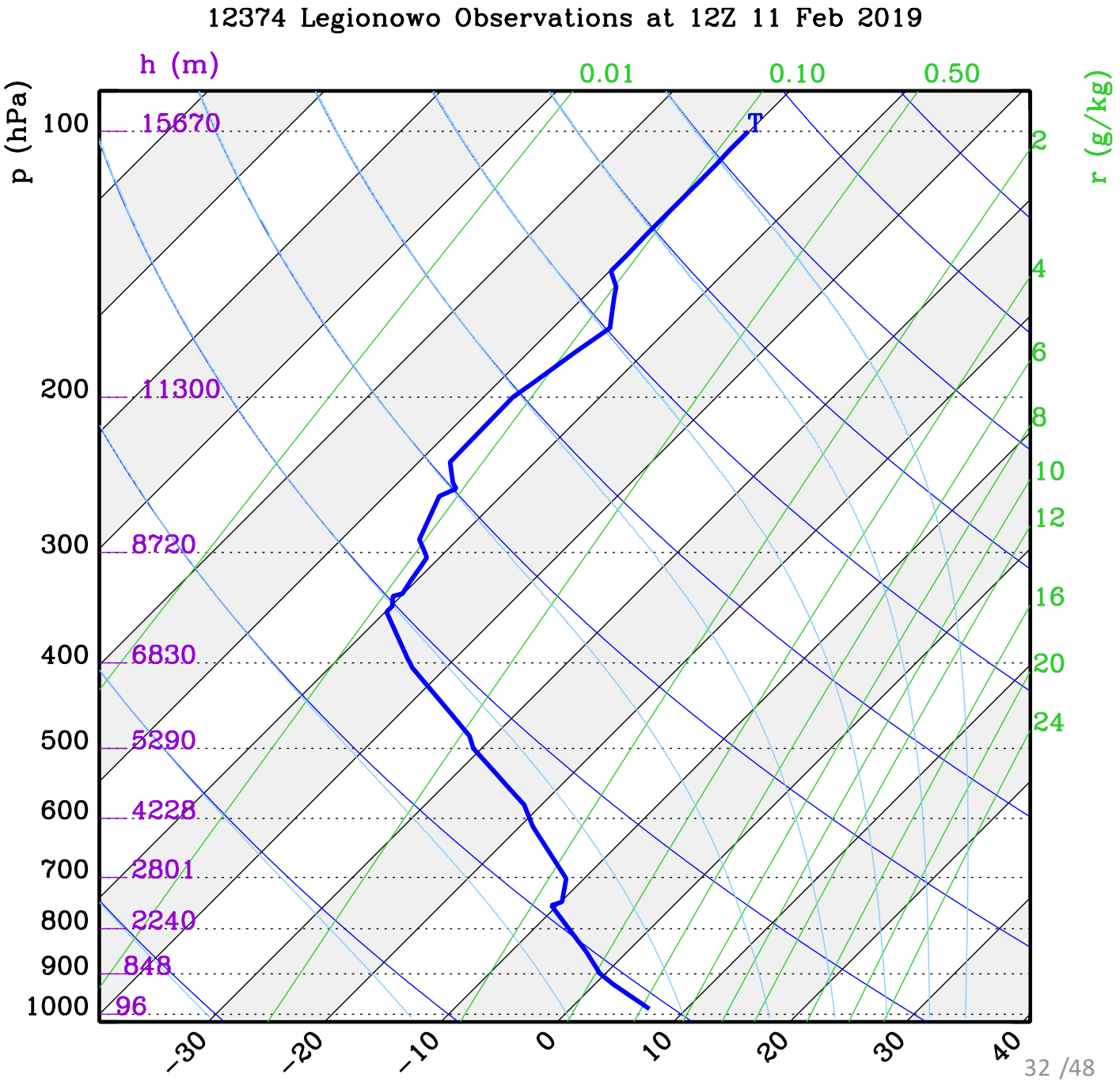


$$\theta = T\left(\frac{p_0}{p}\right)^{\kappa}$$

$$r_s = \varepsilon \frac{e_s(T)}{p - e_s(T)}$$

$$\theta_e = \theta \cdot exp\left(\frac{L_{lv} r_s}{c_p T}\right)$$

T



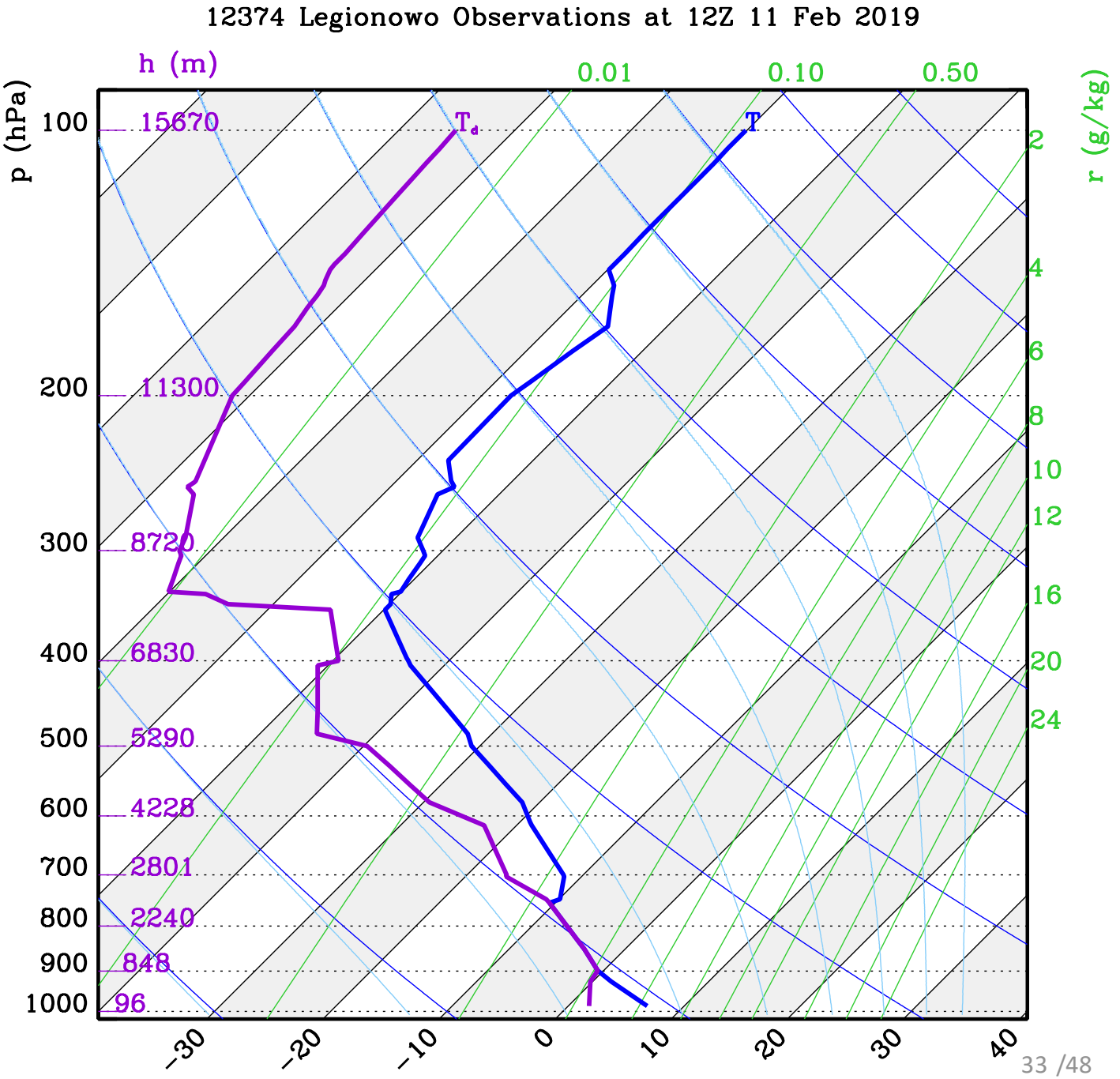
$$\theta = T\left(\frac{p_0}{p}\right)^{\kappa}$$

$$r_s = \varepsilon \frac{e_s(T)}{p - e_s(T)}$$

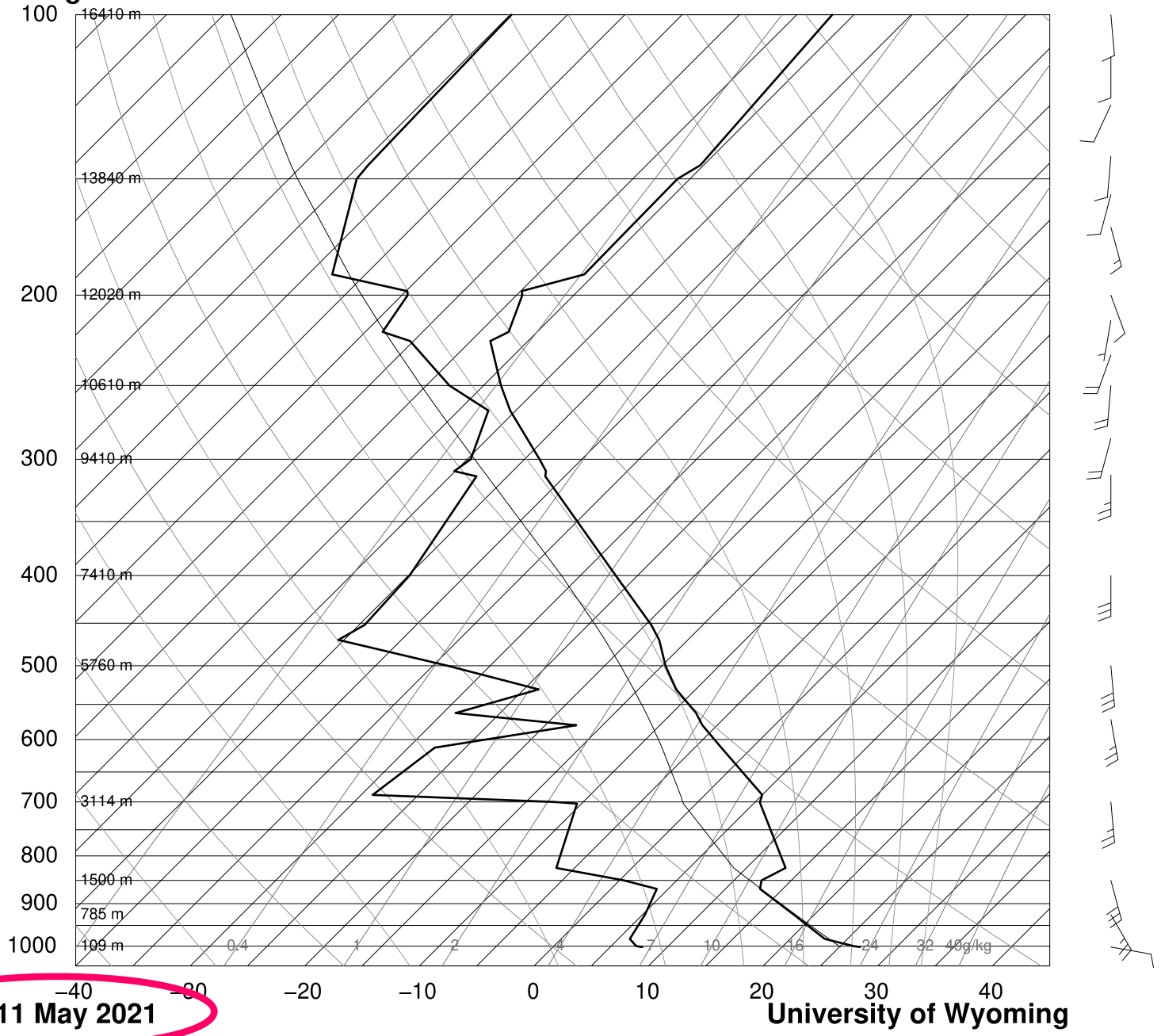
$$\theta_e = \theta \cdot exp\left(\frac{L_{lv} r_s}{c_p T}\right)$$

T

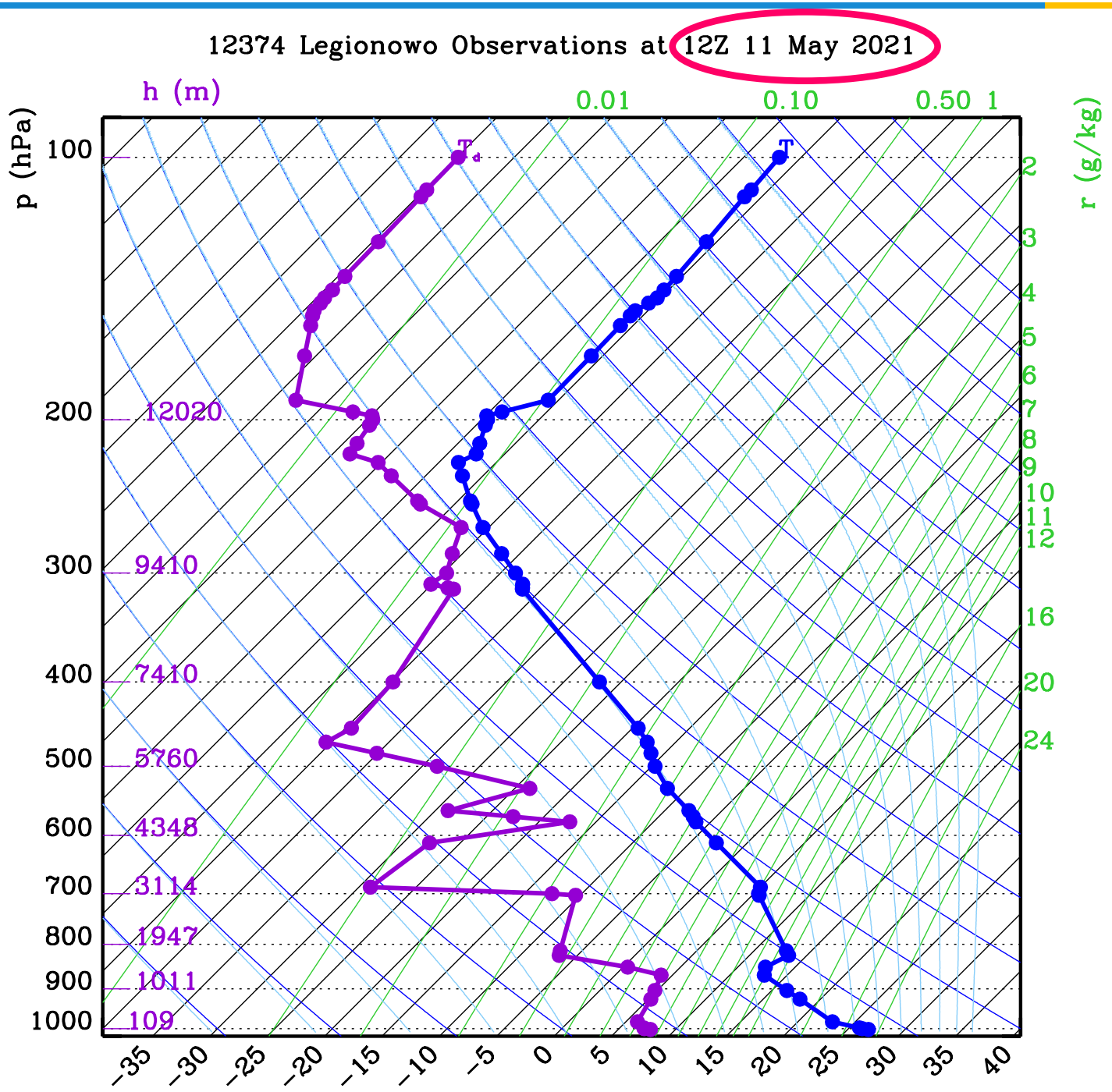
T_d



https://www.weather.uwyo.edu/upperair/sounding_legacy.html



SLAT	52.40
SLON	20.96
SELV	96.00
SHOW	5.64
LIFT	3.87
LFTV	3.66
SWET	92.21
KINX	9.50
CTOT	15.10
VTOT	27.10
TOTL	42.20
CAPE	0.00
CAPV	0.00
CINS	0.00
CINV	0.00
EQLV	−9999
EQTV	−9999
LFCT	−9999
LFCV	−9999
BRCH	0.00
BRCV	0.00
LCLT	275.7
LCLP	761.1
LCLE	316.2
MLTH	298.0
MLMR	6.09
THCK	5651.
PWAT	15.71

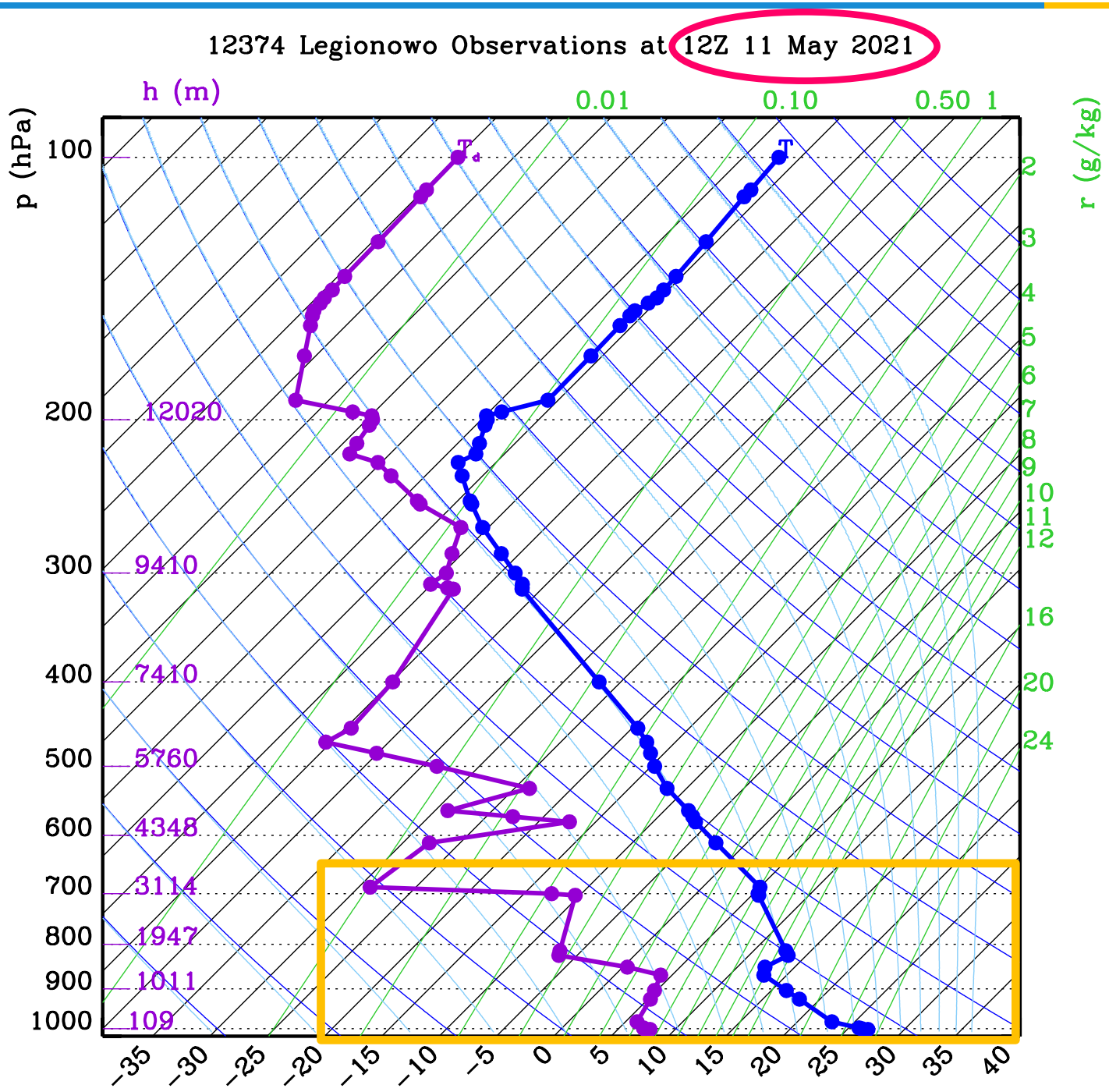


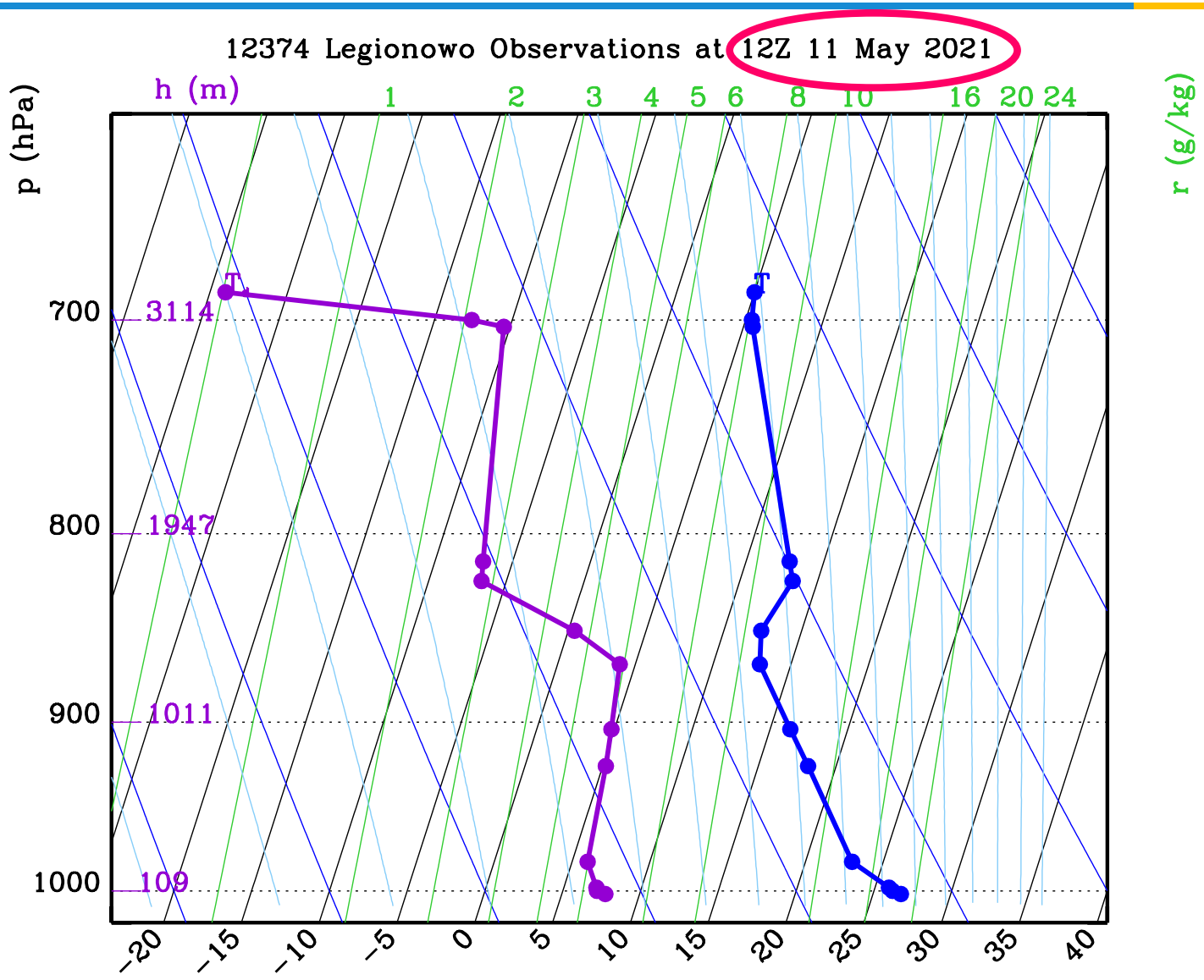
T

θ

r_s

θ_e


12374 Legionowo Observations at 12Z 11 May 2021
h (m)
0.01
0.10
0.50
1
p (hPa)
r (g/kg)
100
200
300
400
500
600
700
800
900
1000
12020
9410
7410
5760
4348
3114
1947
1011
109
2
3
4
5
6
7
8
9
10
11
12
16
20
24
−35
−30
−25
−20
−15
−10
−5
0
5
10
15
20
25
30
35
40
T
T
T
θ
r_s
θ_e

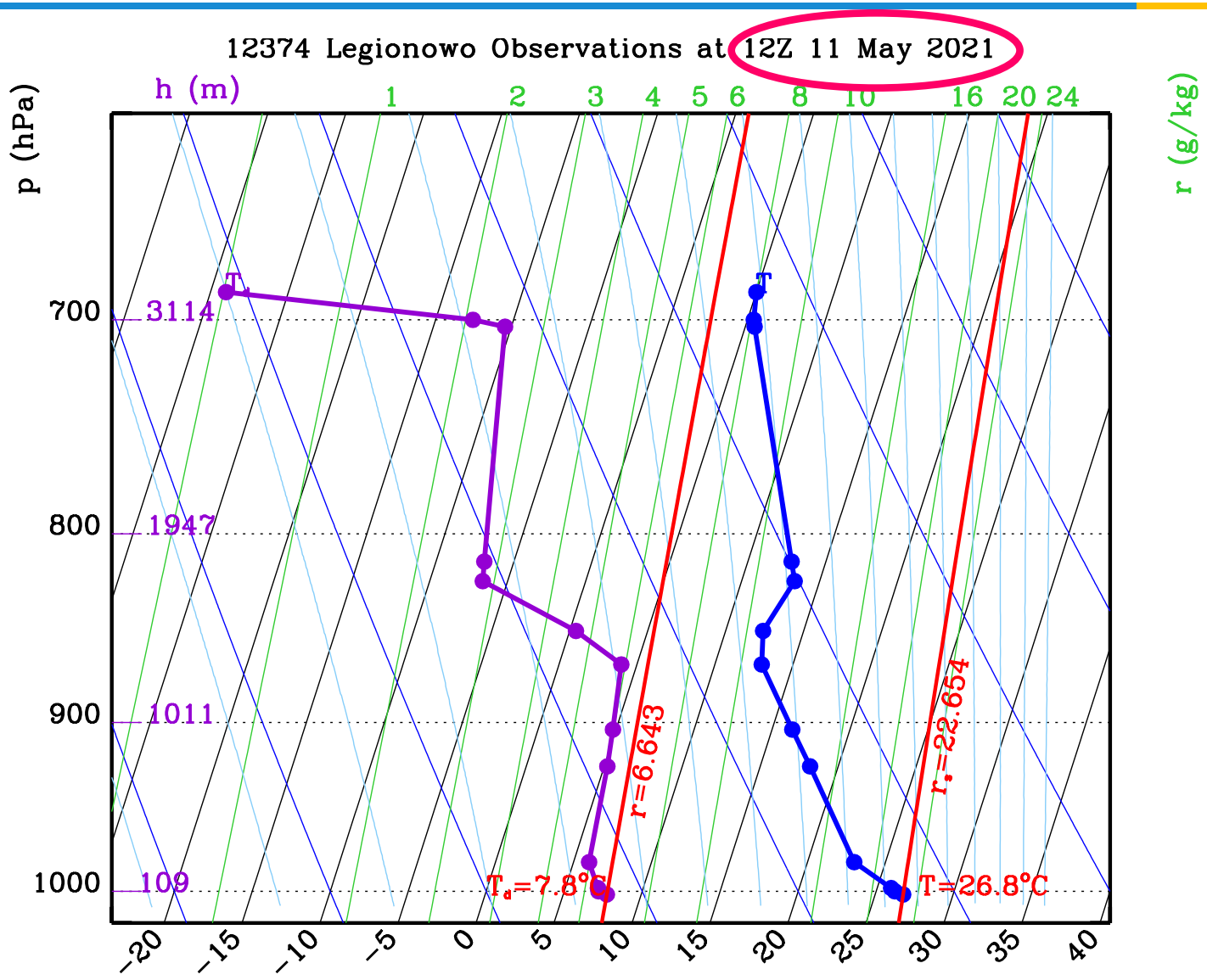


T

θ

r_s

θ_e



T

θ

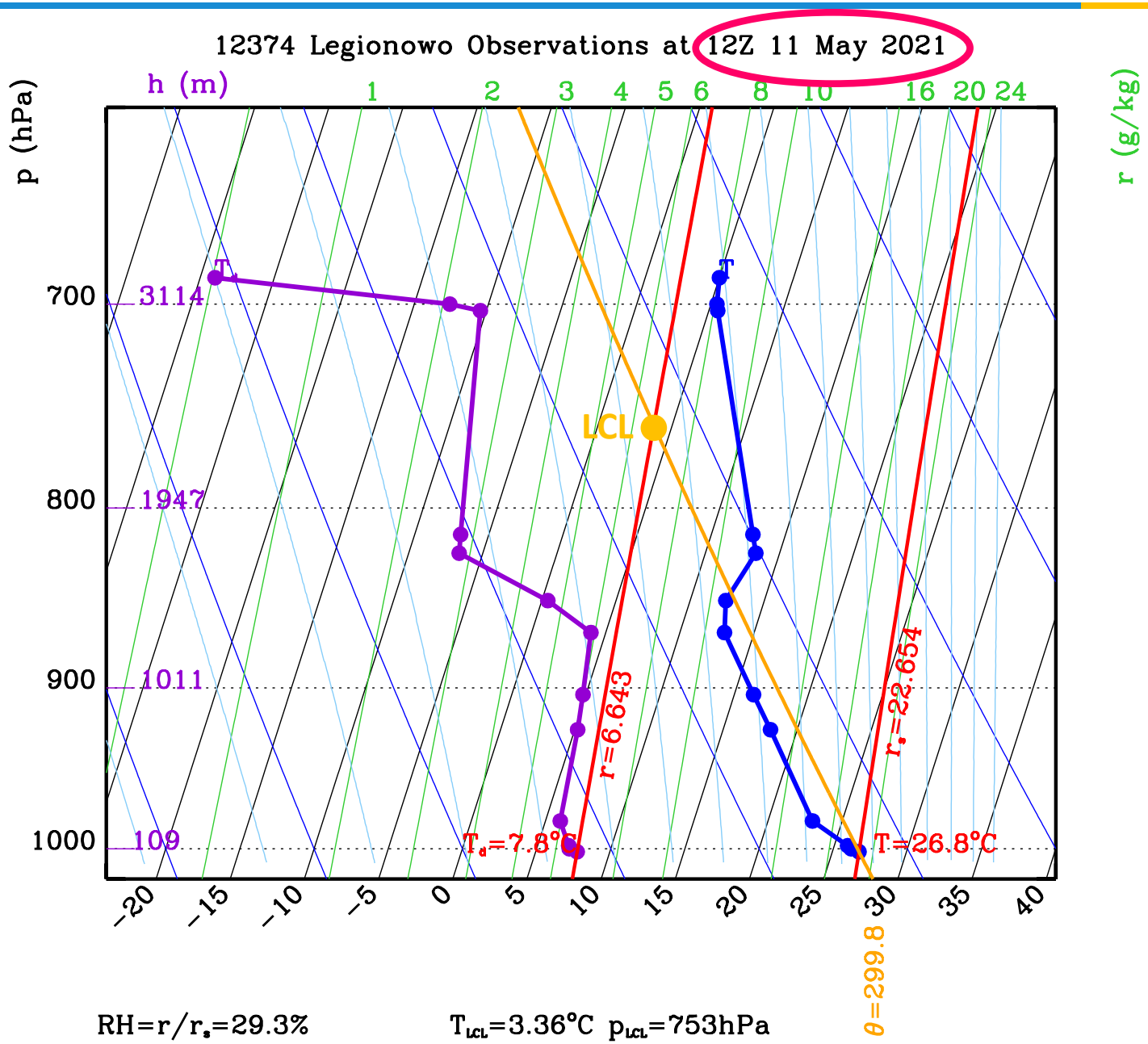
r_s

θ_e

RH=r/r$_s$=29.3%

RH=q/q$_s$=29.8%

RH=e/e$_s$=30.1%



T

θ

r_s

θ_e

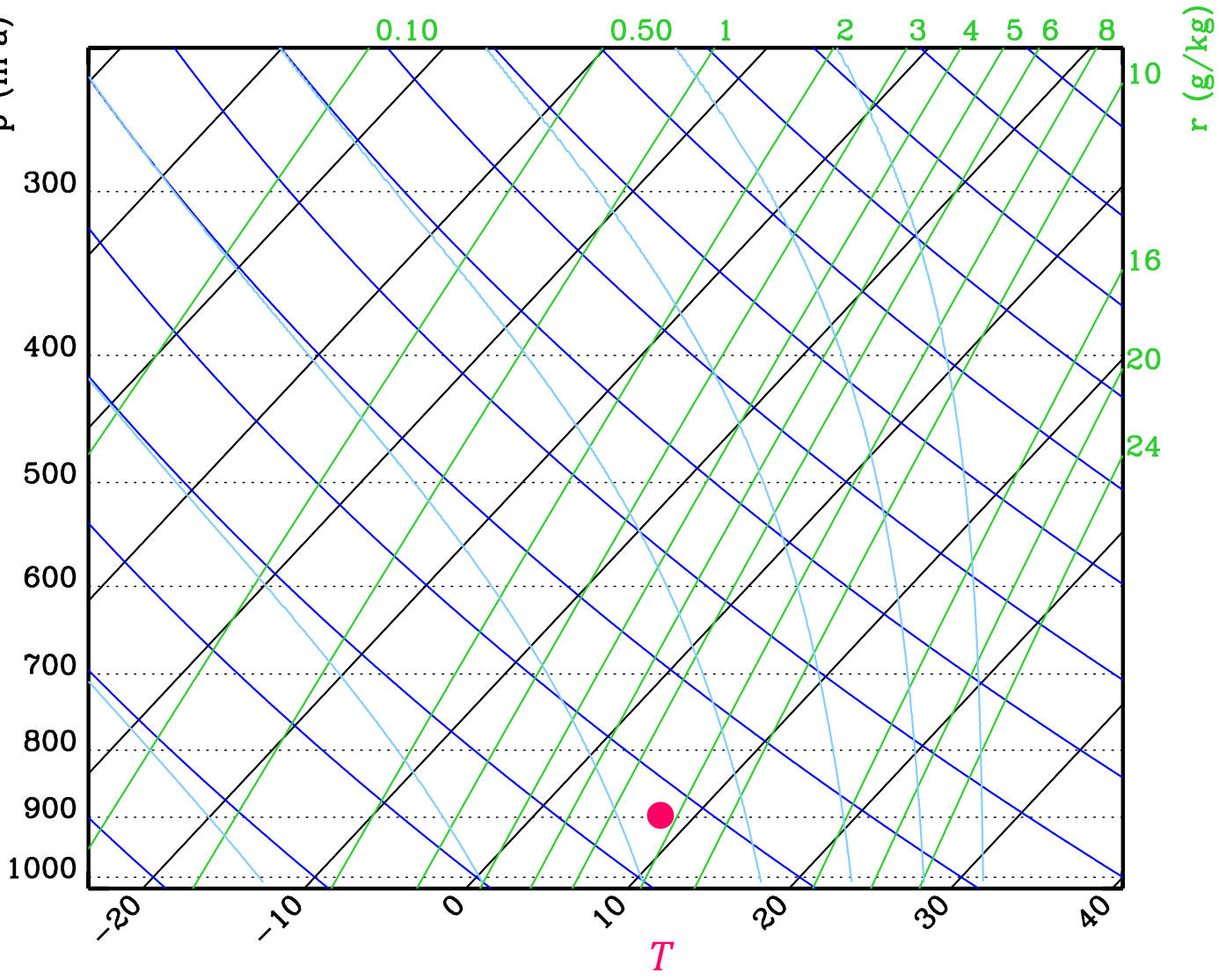
RH=r/r$_s$=29.3% T_{LCL}=3.36°C p_{LCL}=753hPa

RH=q/q$_s$=29.8% T_{LCL}=3.63°C p_{LCL}=756hPa

RH=e/e$_s$=30.1% T_{LCL}=3.80°C p_{LCL}=757hPa

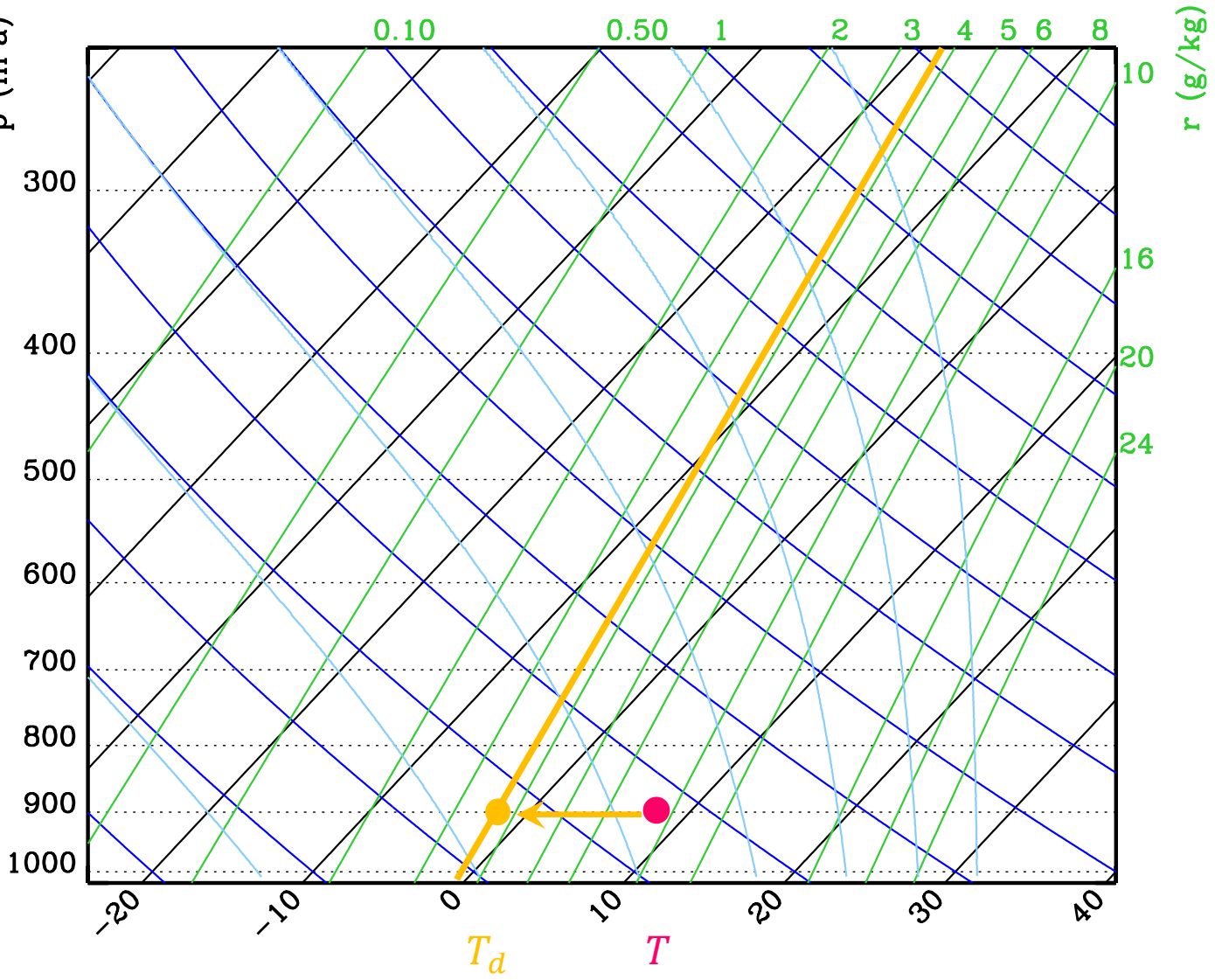
T θ r_s θ_e

- $T_o = 8°C$
  $p_o = 900\ \text{hPa}$
  $r_o = 3.75\ g/kg$
  $r_{s0} = 7.5\ g/kg$
  $f_o = 50\%$



T θ r_s θ_e

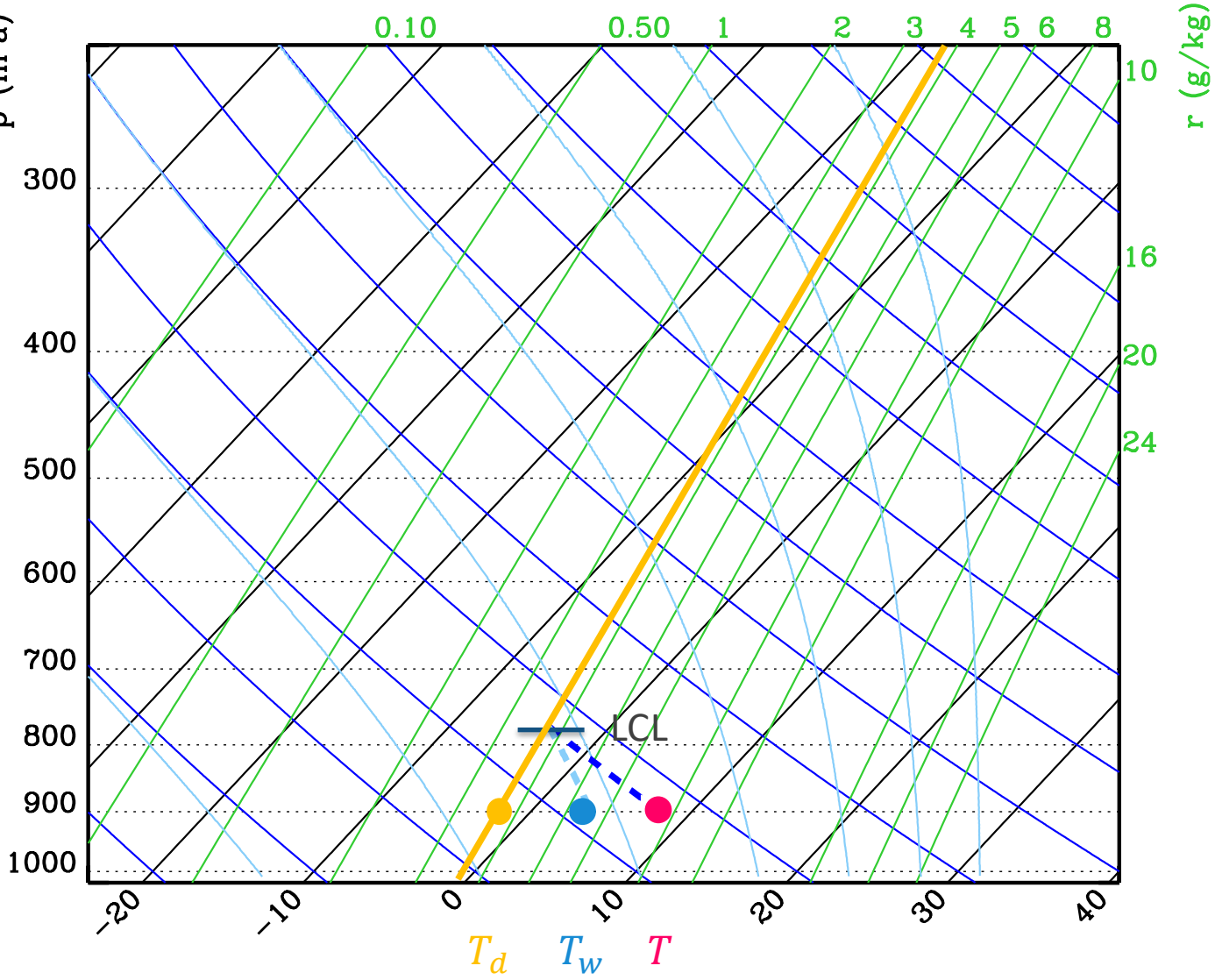
- $T_o = 8°C$
  $p_o = 900\ \text{hPa}$
  $r_o = 3.75\ g/kg$
  $r_{s0} = 7.5\ g/kg$
  $f_o = 50\%$
- $T_d \approx -2°C$



T θ r_s θ_e

- $T_o = 8°C$
  $p_o = 900\ \text{hPa}$
  $r_o = 3.75\ g/kg$
  $r_{s0} = 7.5\ g/kg$
  $f_o = 50\%$
- $T_d \approx -2°C$
- $T_w \approx 3°C$

$T_{LCL} \approx -3.8°C$
$p_{LCL} \cong 774\ hPa$

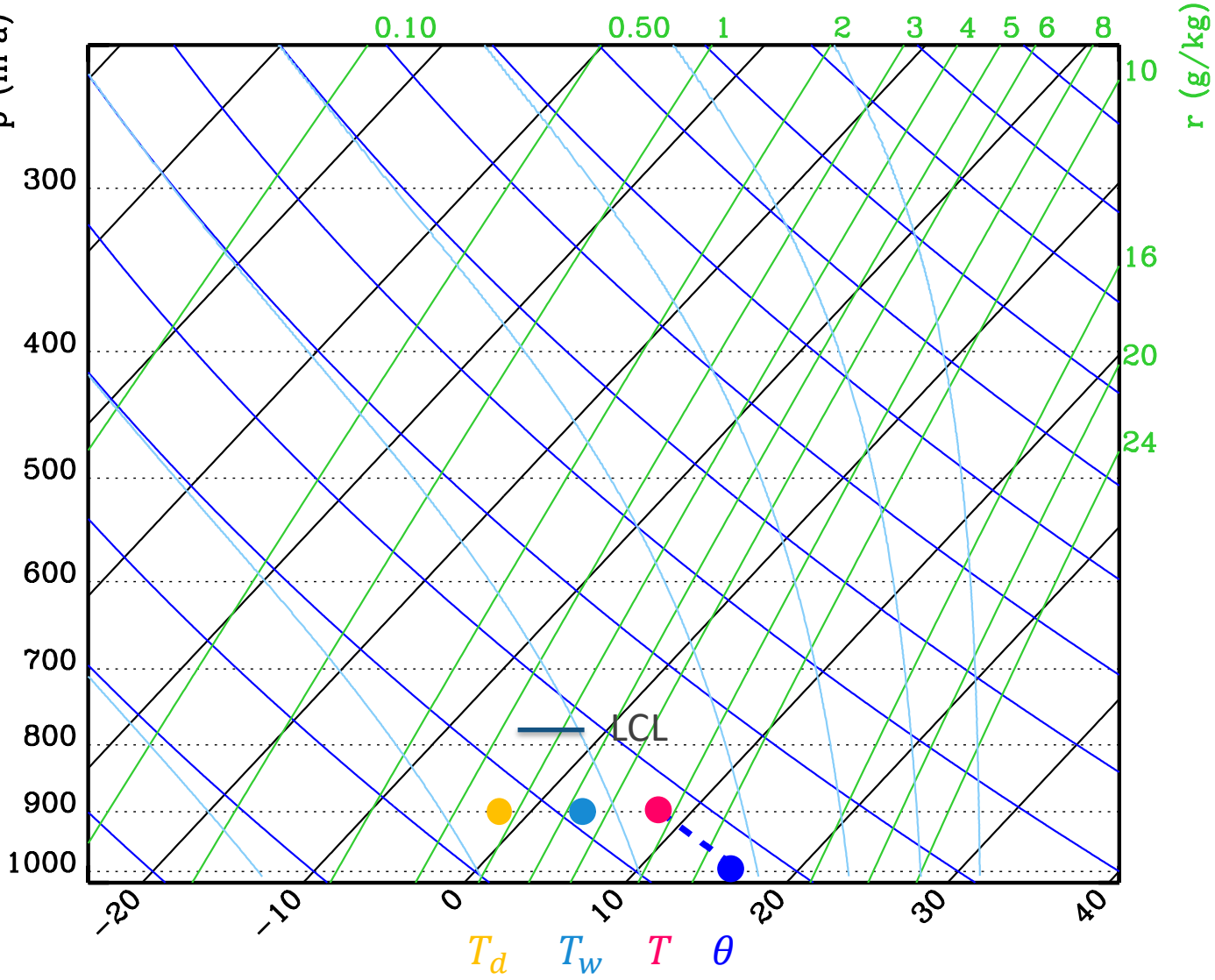


T θ r_s θ_e

- $T_o = 8℃$
  $p_o = 900\ \text{hPa}$
  $r_o = 3.75\ g/kg$
  $r_{s0} = 7.5\ g/kg$
  $f_o = 50\%$
- $T_d \approx -2℃$
- $T_w \approx 3℃$

$T_{LCL} \approx -3.8℃$
$p_{LCL} \cong 774\ hPa$

- $\theta \approx 16.6℃$

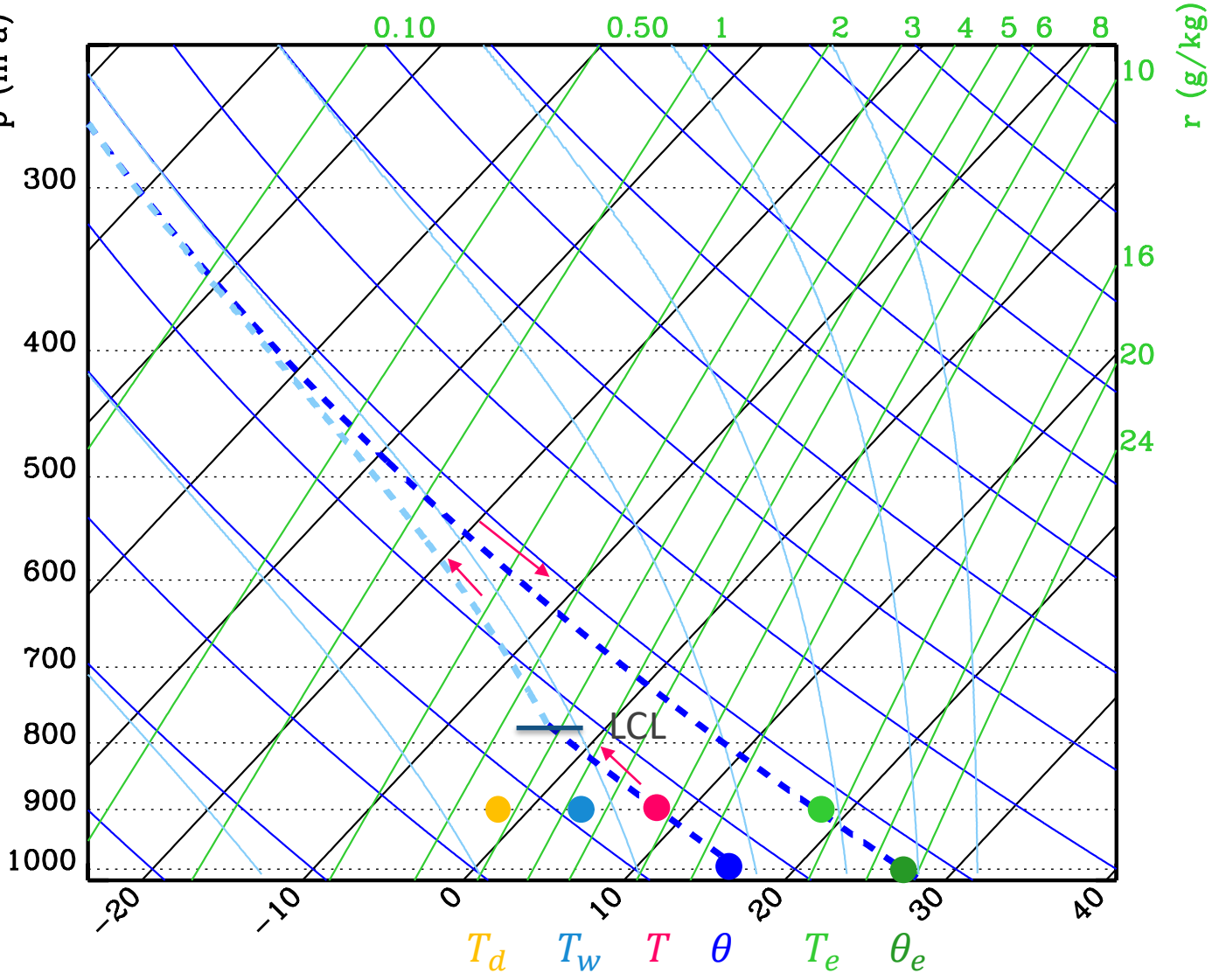


T θ r_s θ_e

- $T_o = 8°C$
  $p_o = 900\ \text{hPa}$
  $r_o = 3.75\ g/kg$
  $r_{s0} = 7.5\ g/kg$
  $f_o = 50\%$
- $T_d \approx -2°C$
- $T_w \approx -3°C$

$T_{LCL} \approx -3.8°C$
$p_{LCL} \cong 774\ hPa$

- $\theta \approx 16.6°C$
- $T_e \approx 18°C$
- $\theta_e \approx 28°C$

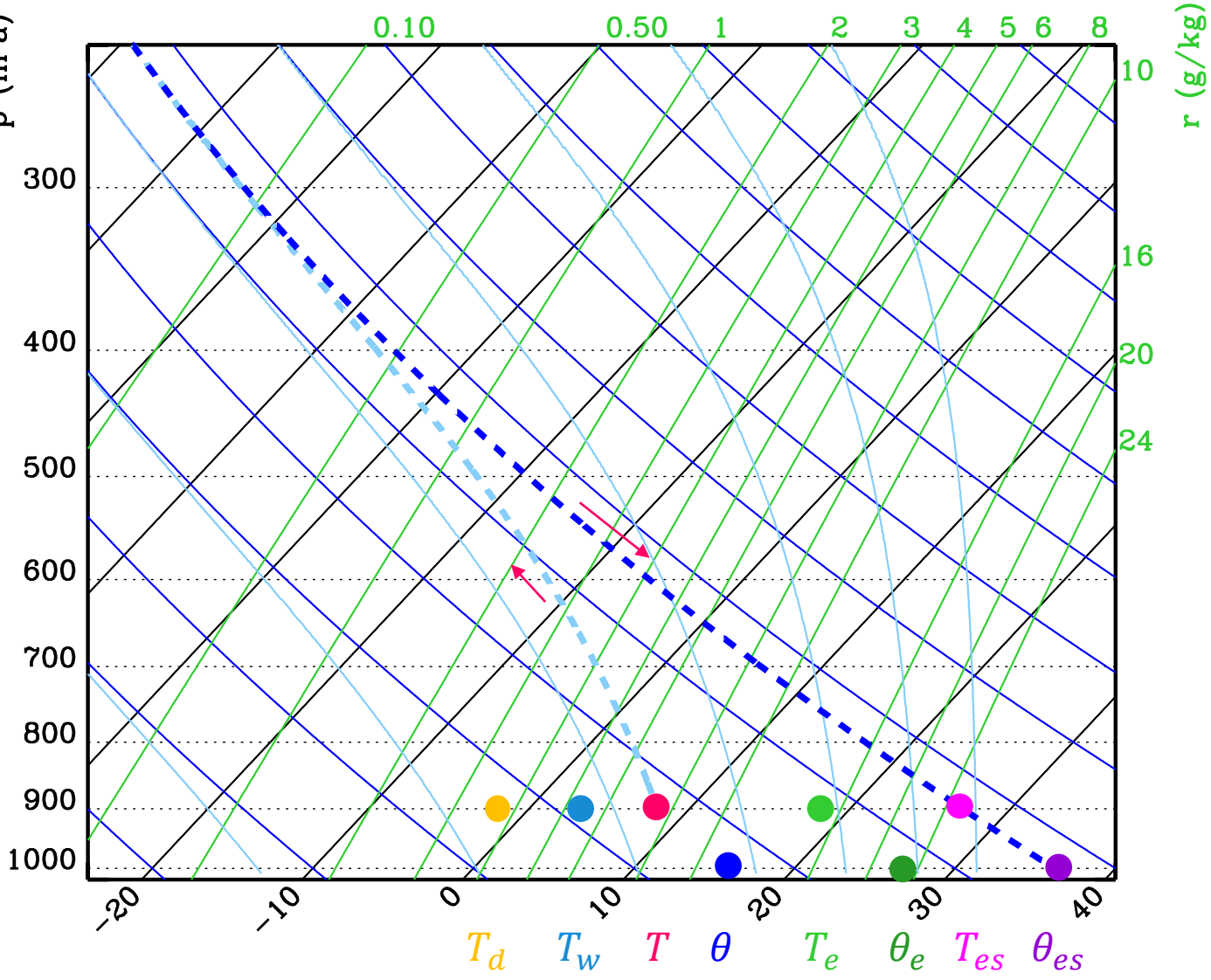


T θ r_s θ_e

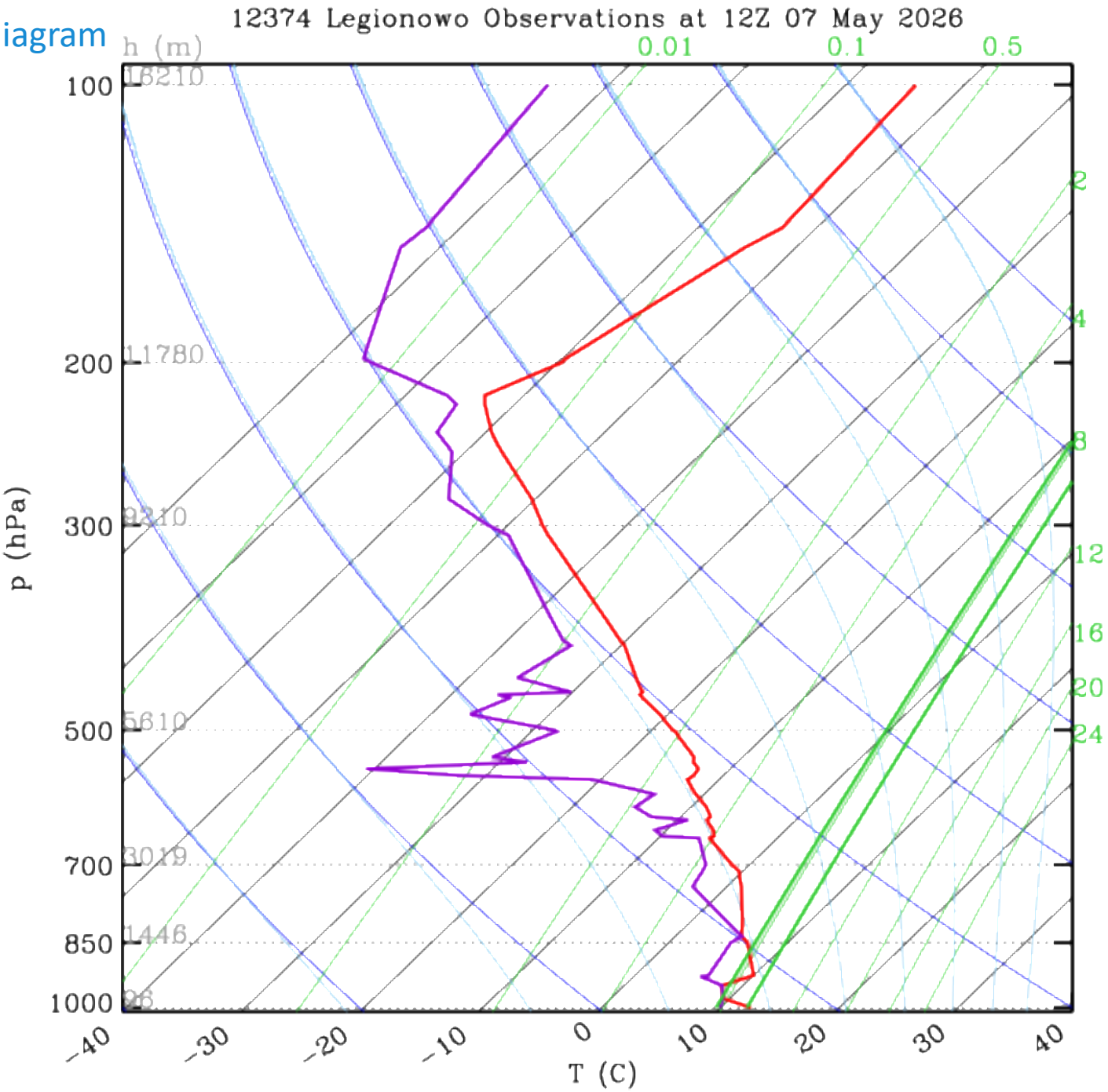
- $T_o = 8℃$
  $p_o = 900\ \text{hPa}$
  $r_o = 3.75\ g/kg$
  $r_{s0} = 7.5\ g/kg$
  $f_o = 50\%$
- $T_d \approx -2℃$
- $T_w \approx 3℃$

$T_{LCL} \approx -3.8℃$
$p_{LCL} \cong 774\ hPa$

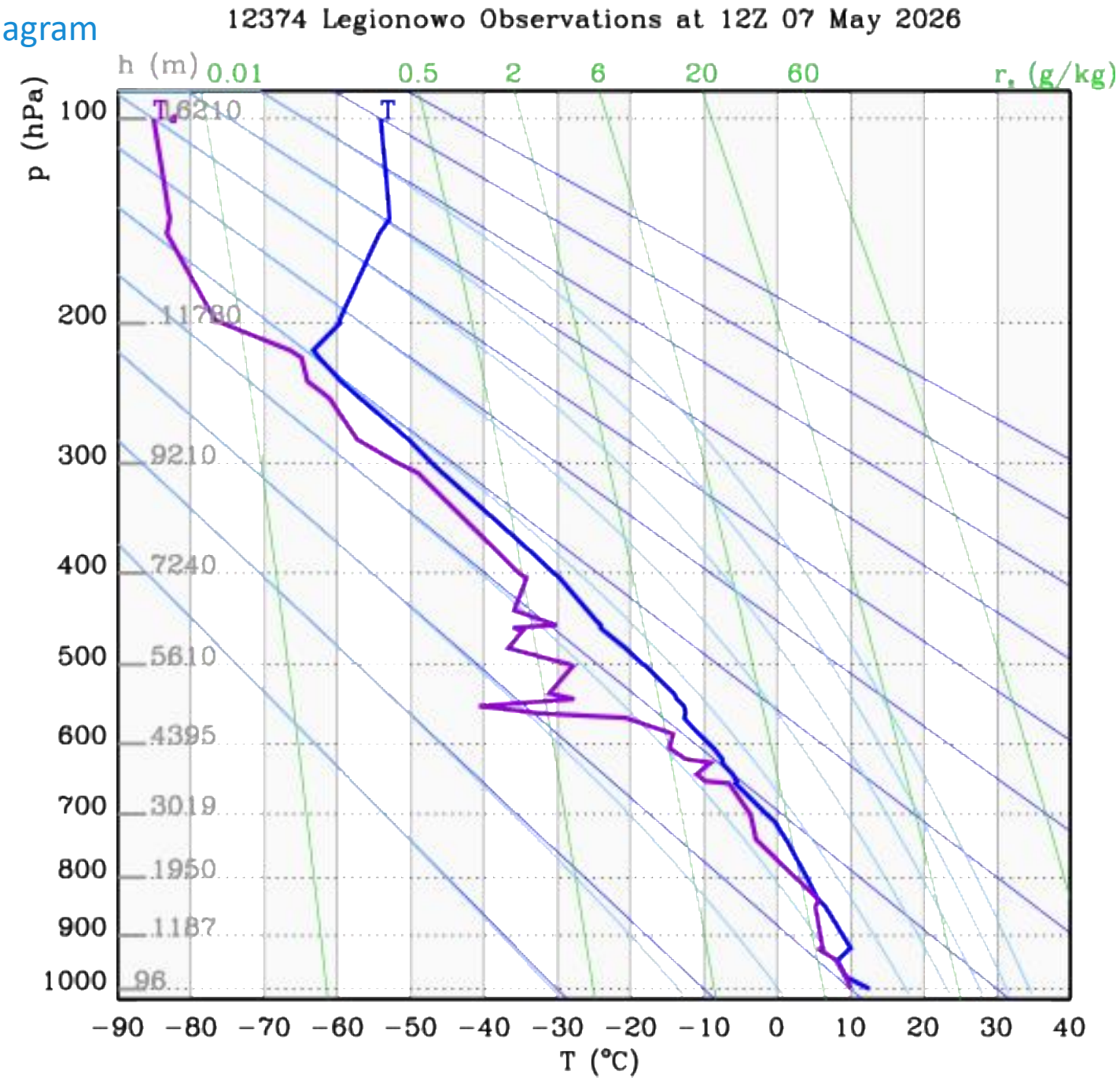
- $\theta \approx 16.6℃$
- $T_e \approx 18℃$
- $\theta_e \approx 28℃$
- $T_{se} \approx 26℃$
- $\theta_{se} \approx 36℃$



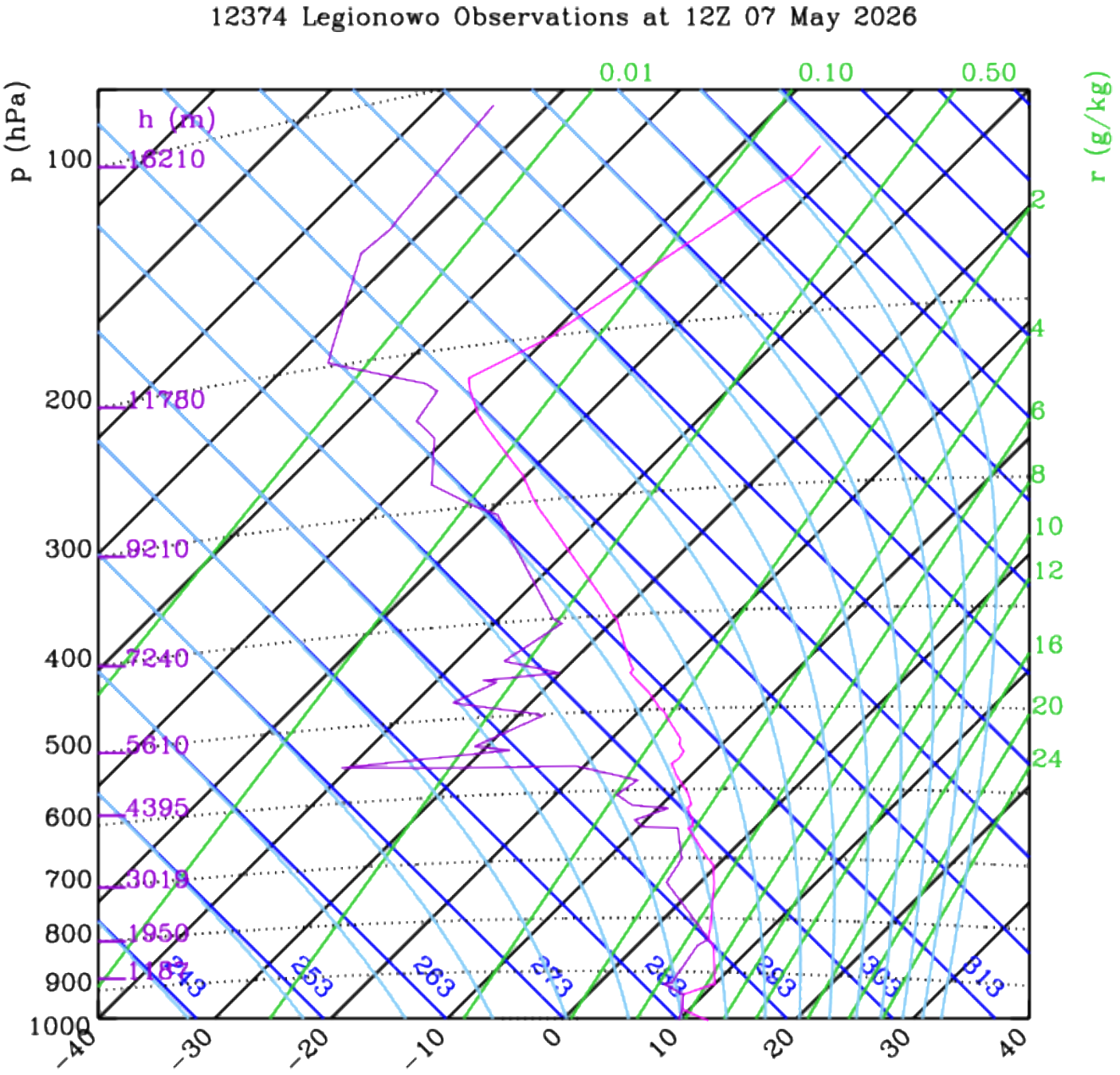
Skew-T diagram



Stüve diagram



Tephigram


12374 Legionowo Observations at 12Z 07 May 2026
p (hPa)
h (m)
16210
11780
9210
7240
5610
4395
3019
1950
1167
0.01
0.10
0.50
r (g/kg)
2
4
6
8
10
12
16
20
24
100
200
300
400
500
600
700
800
900
1000
-40
-30
-20
-10
0
10
20
30
40