Thermodynamic Aerological charts diagrams

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- 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 obtain easily different thermodynamic properties, e.g. θ (potential temperature) and moisture quantities (such as the 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 videly used.

- Each diagram has lines of constant:
  - p, pressure,
  - T, temperature,
  - θ, potential temperature,
  - q, saturation specific humidity.
  - saturated adiabats.
- One difficulty of all diagrams is that they are two dimensional, and 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) or to p^{R/c_p} (the Stuve diagram).
- The Emagram has the advantage over the Stuve diagram in that area on the diagram is proportional to energy:

$$dw = pdv = RdT - vdp$$

$$\oint dw = \oint RdT - \oint RT\frac{dp}{p}$$

RdT is an exact differential which integrates to zero

$$\oint dw = -R\oint Td(\ln p)$$

- A chart with coordinates of T versus $\ln p$ has the property of a true thermodynamic diagram, i.e. the area is proportional to energy.
- The logarithm of pressure is chosen for the vertical coordinate rather than the pressure itself because in an isothermal atmosphere height varies with ln p, and hence for a realistic temperature profile the ordinate is roughly proportional to height.

CONSTRUCTION OF THE STUVE DIAGRAM

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

Simplicity of its construction

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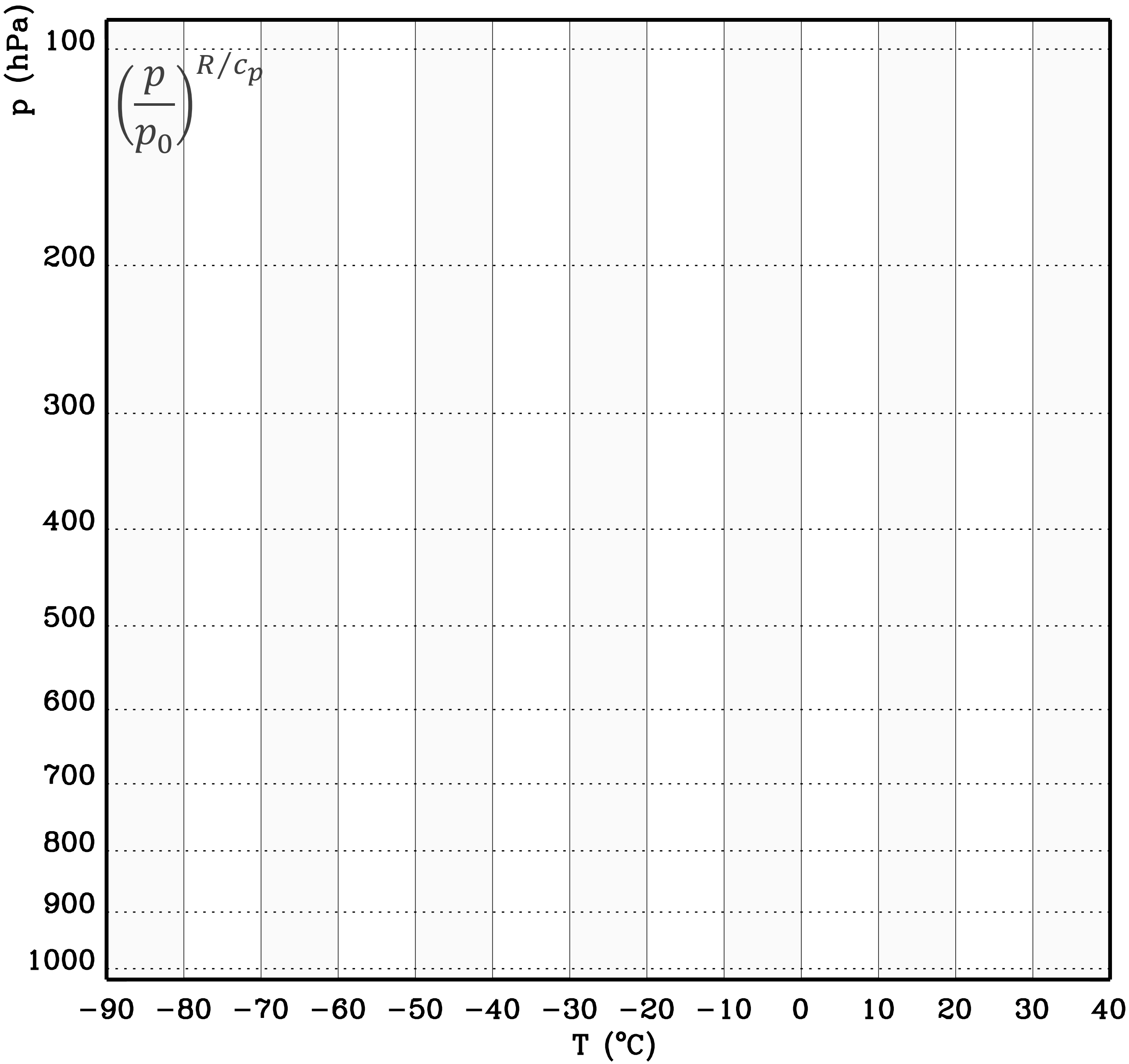
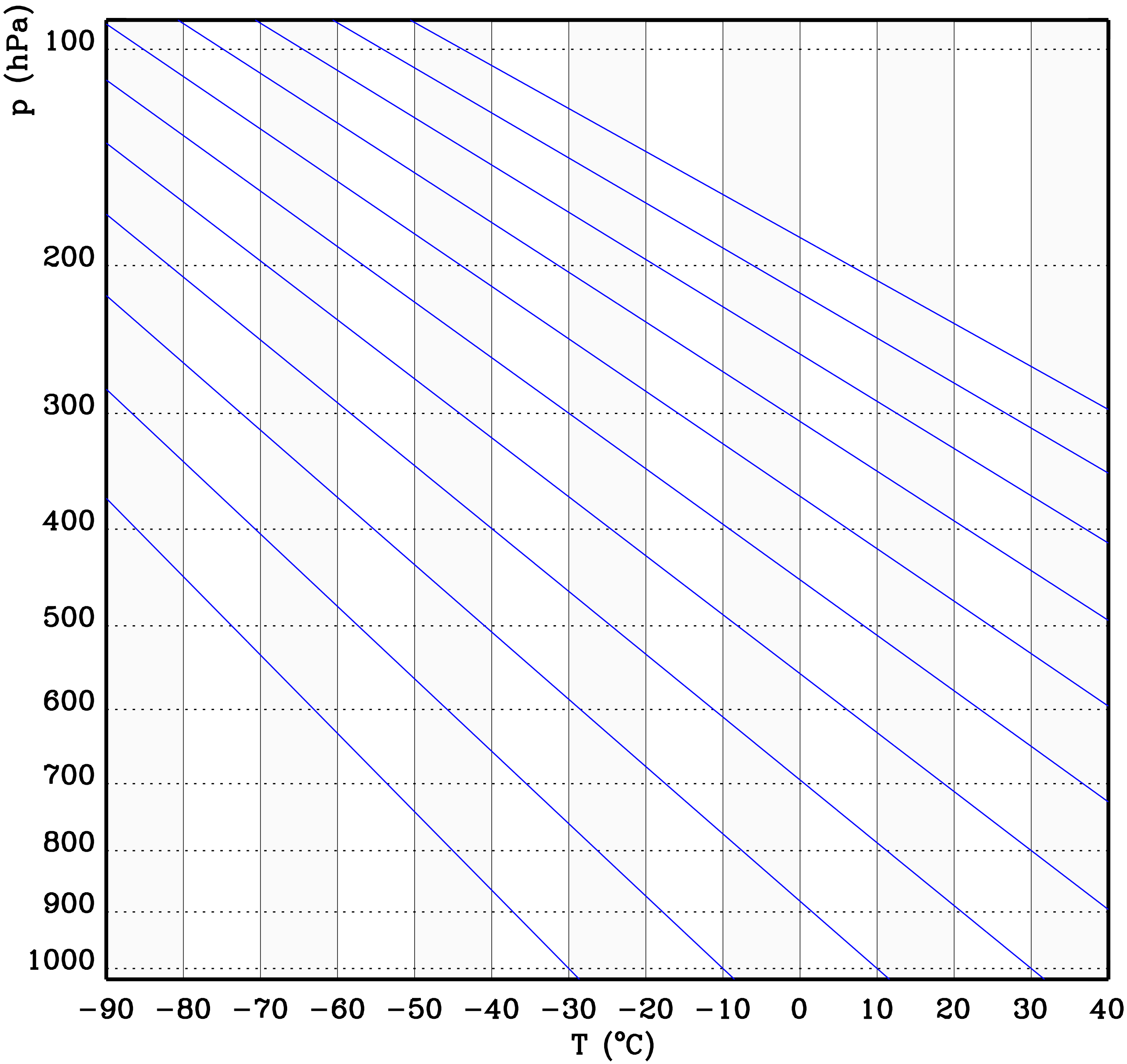
Stuve diagram

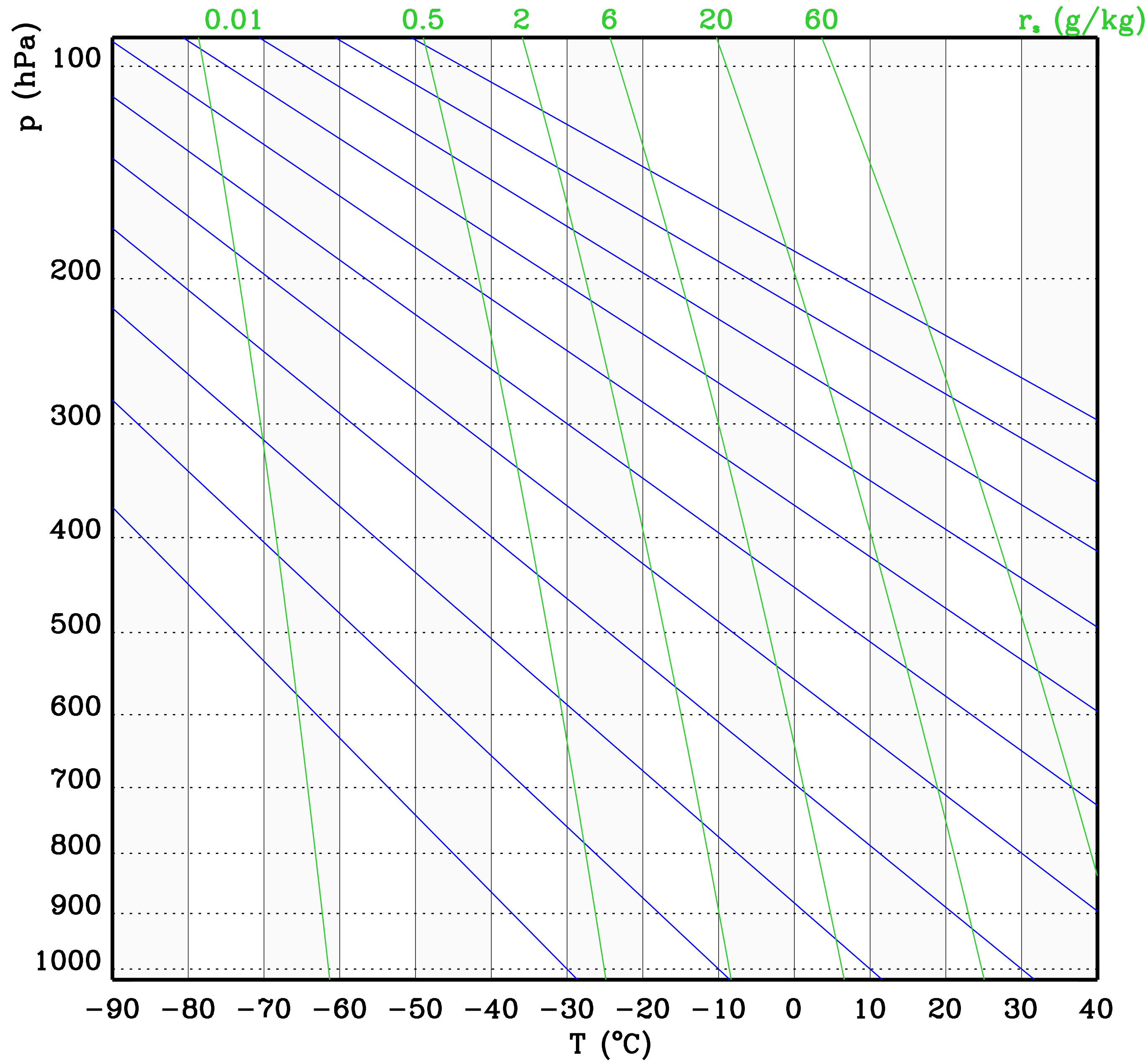


Stuve diagram



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

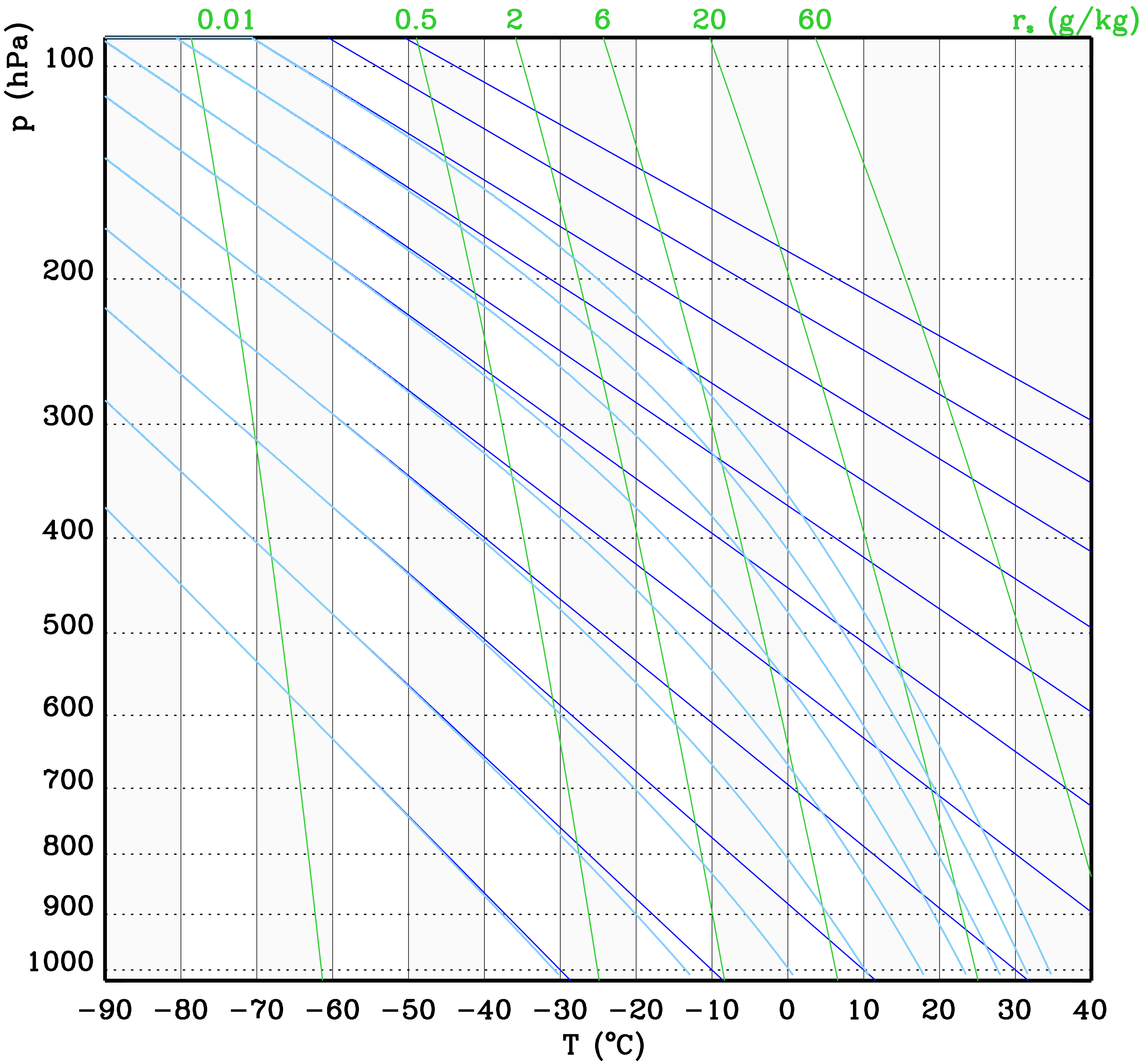
Stuve diagram



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

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

Stuve diagram

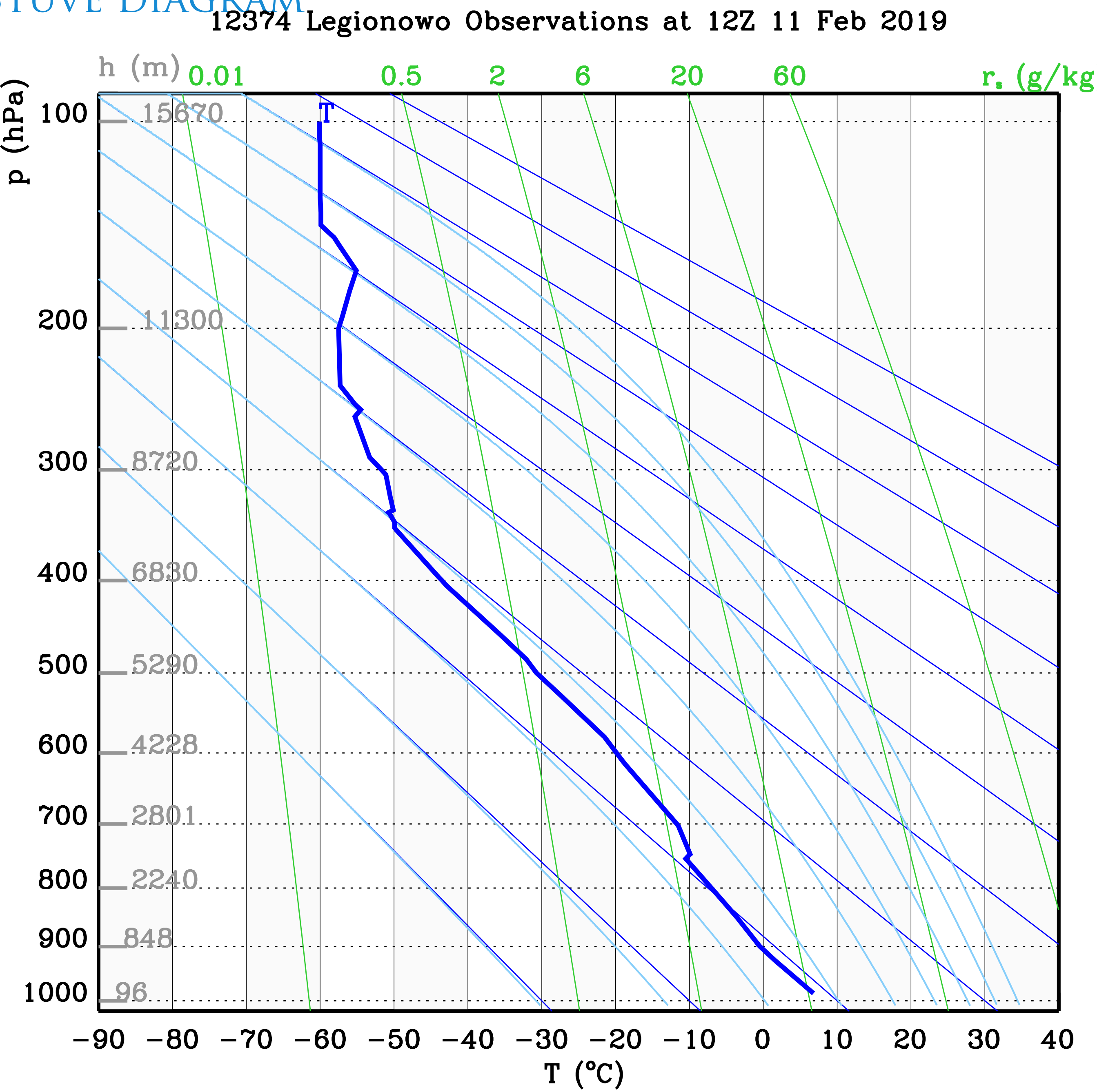


$$\theta = T\left(\frac{p_0}{p}\right)^{\kappa}$$

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

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

Stuve diagram



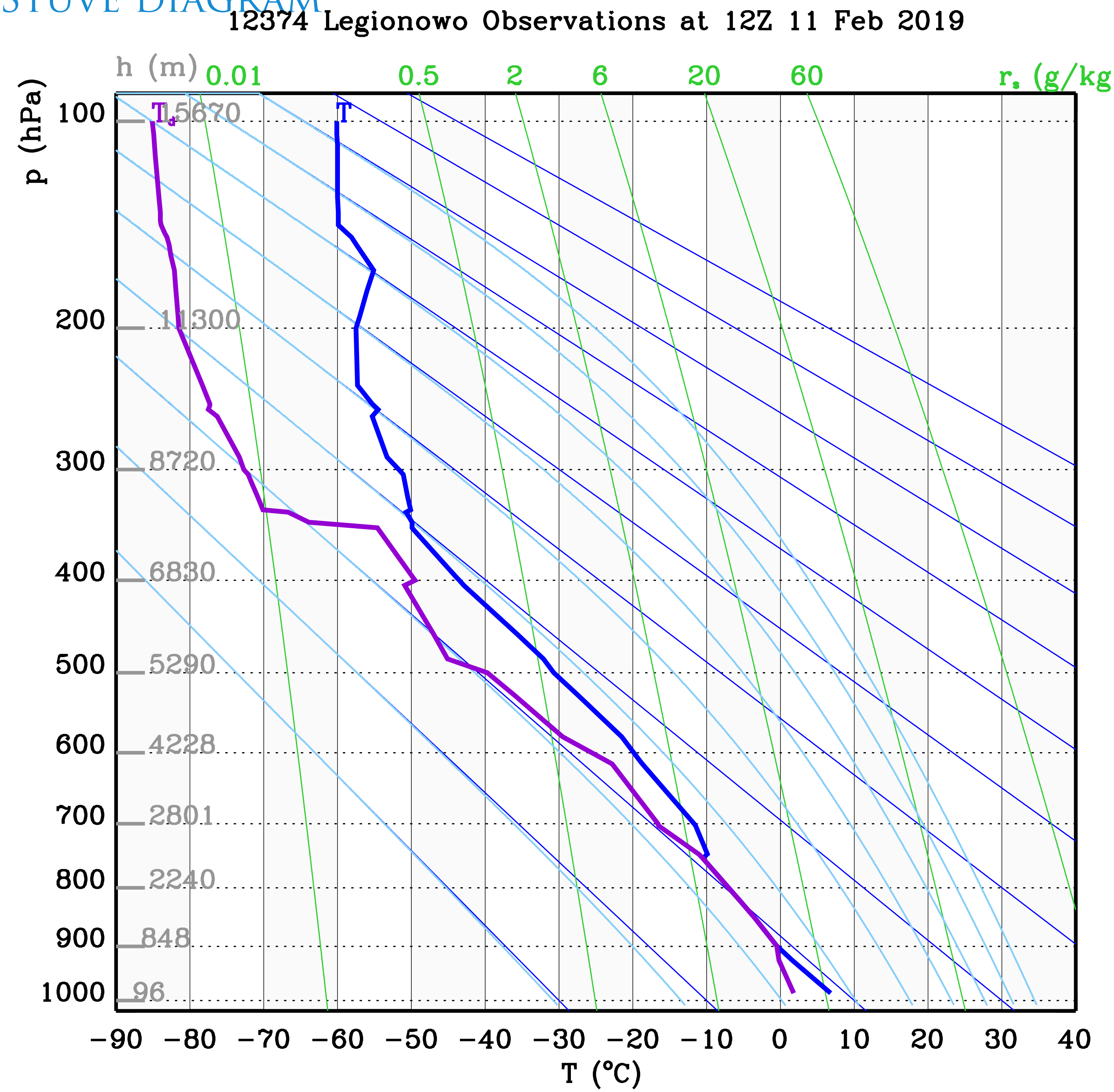
$$\theta = T\left(\frac{p_0}{p}\right)^{\kappa}$$

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

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

T

Stuve diagram



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

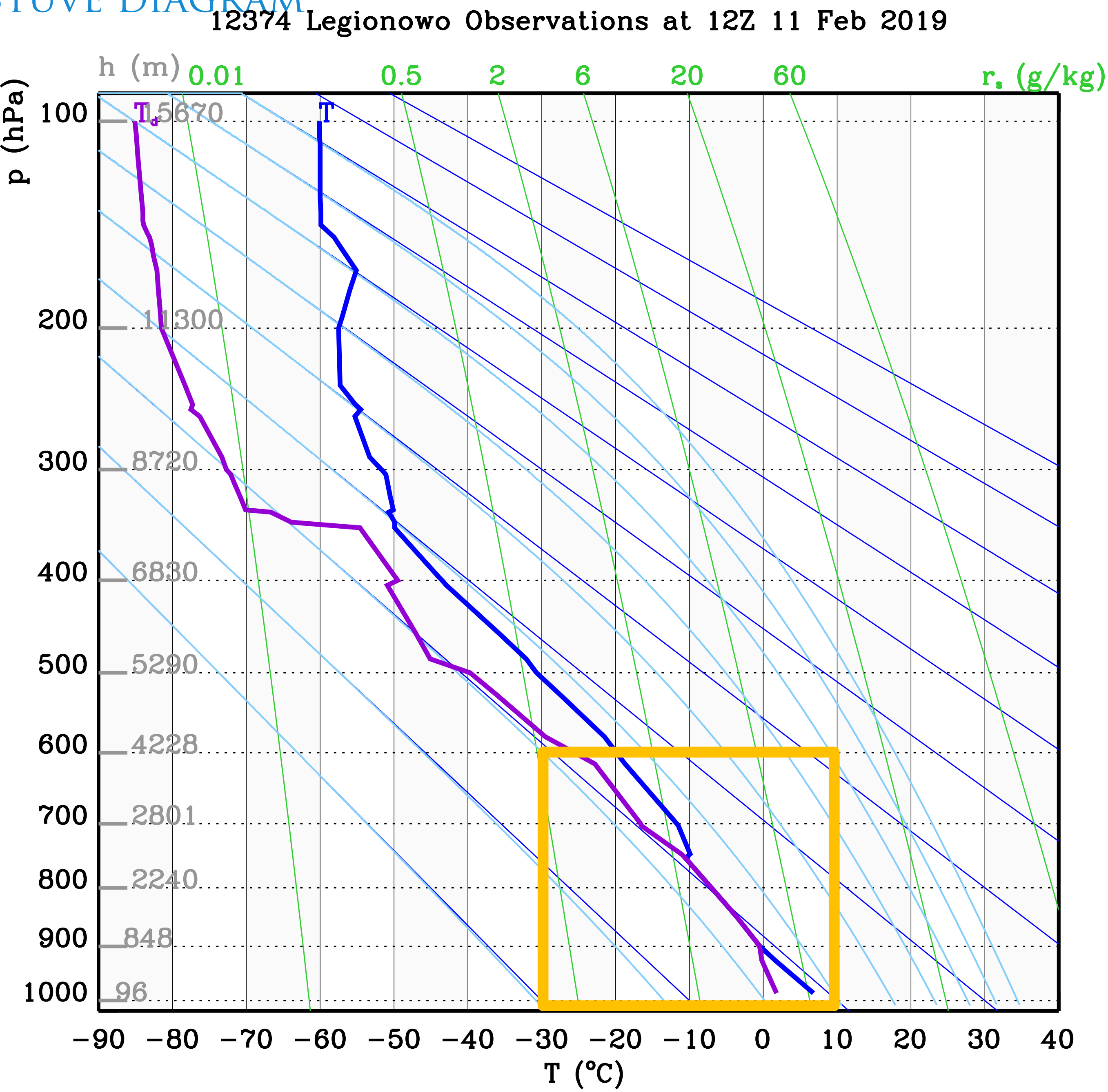
$$r_s = \varepsilon \frac{e_s(T)}{p - e_s(T)}$$

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

T

T_d

Stuve diagram



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

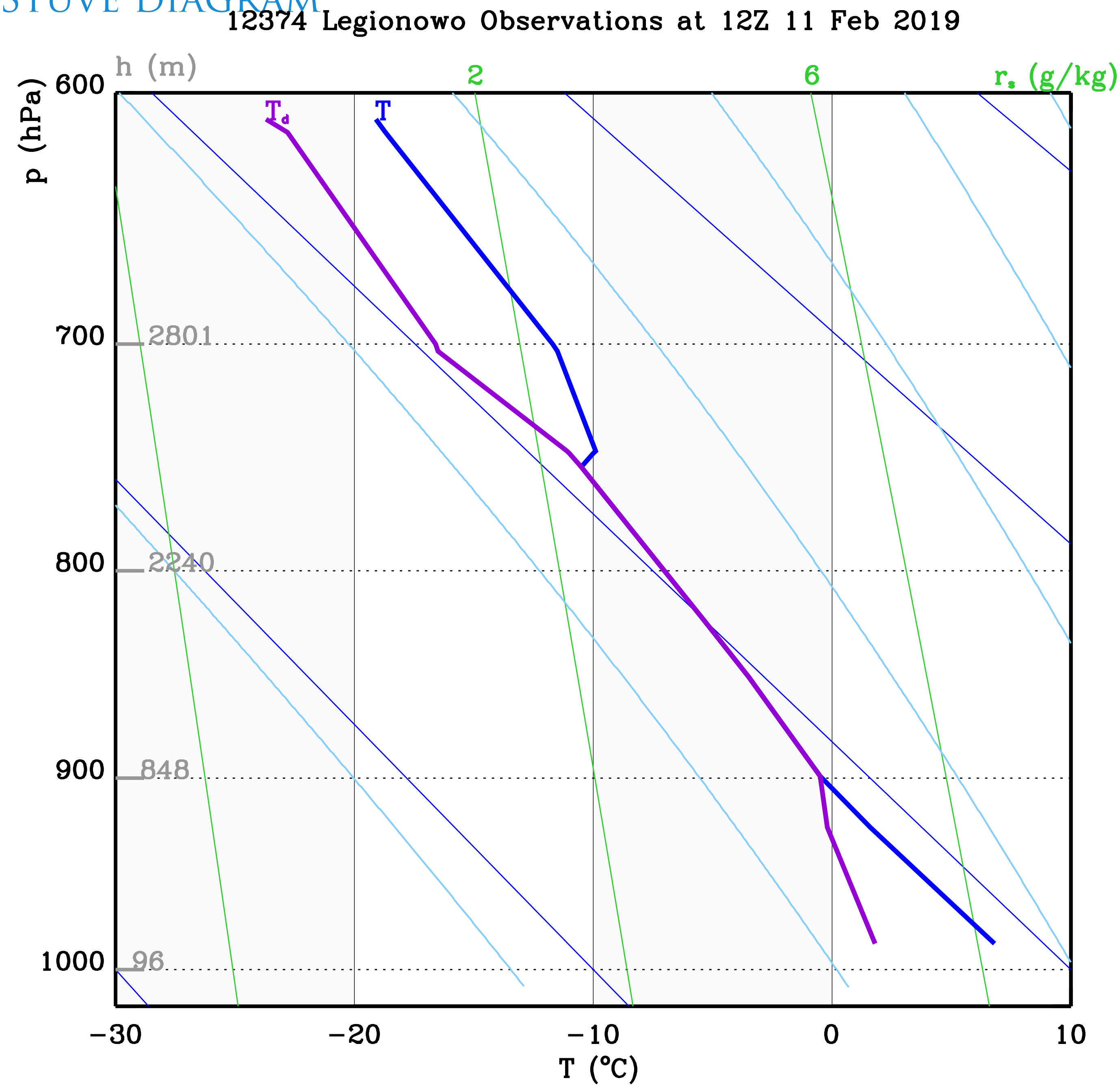
$$r_s = \varepsilon \frac{e_s(T)}{p - e_s(T)}$$

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

T

T_d

Stuve 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

Tephigram, literally the *T* φ *gram*, where φ was originally used to denote potential temperature.

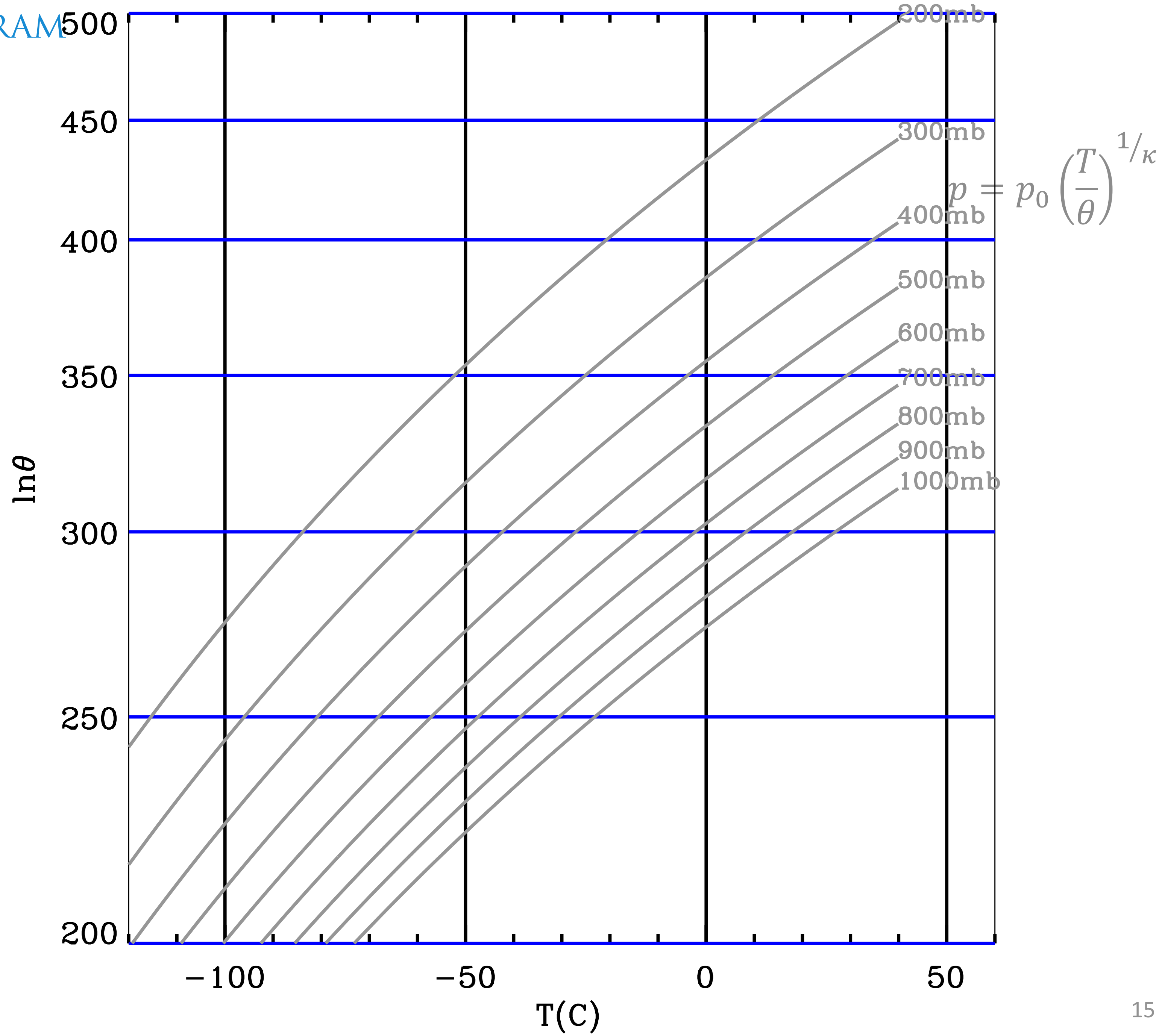
From the defining equation of entropy, it follows that the total heat added in a cyclic process is:

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

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

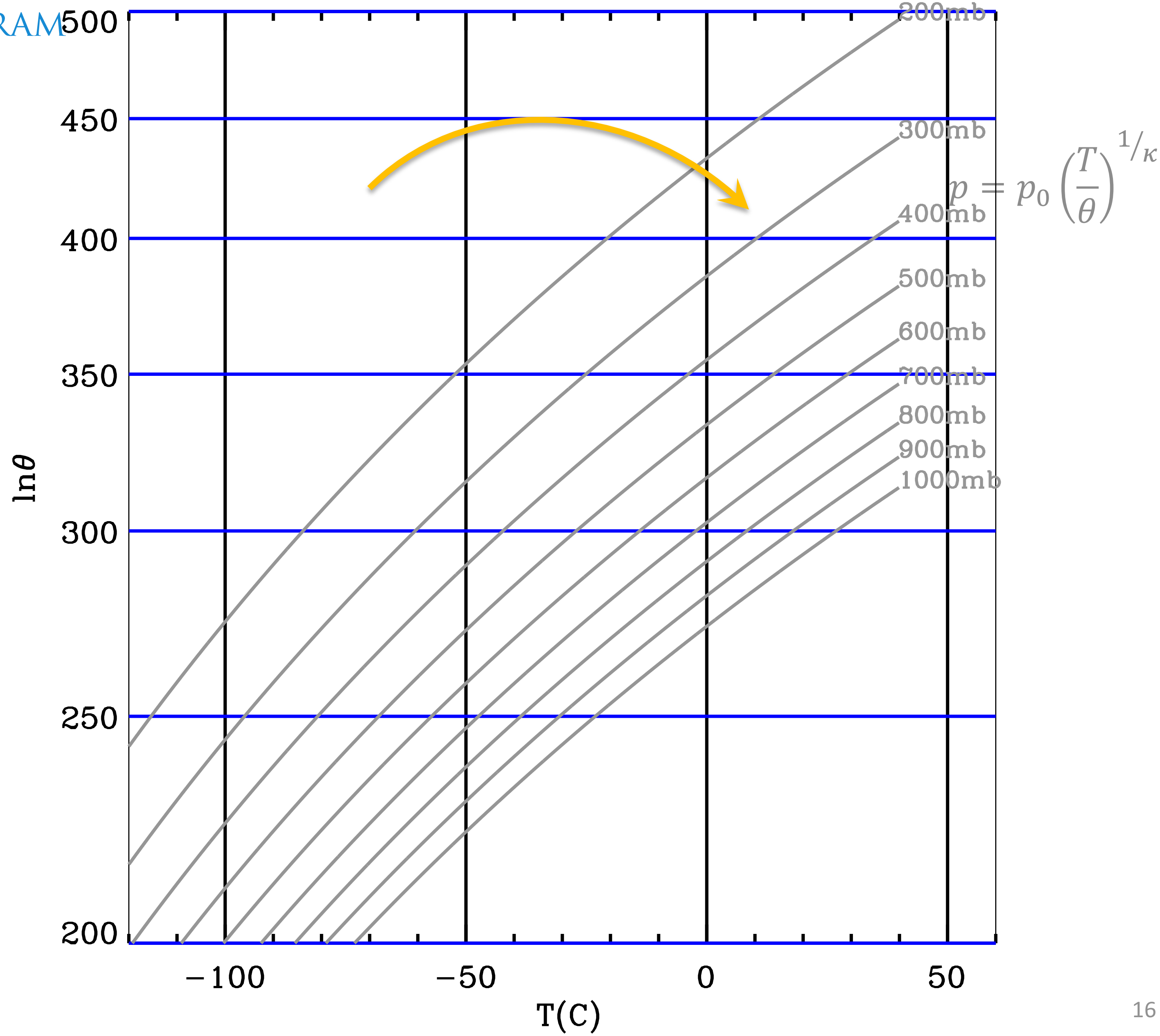
Usually Tephigrams are right-rotated so that the ordinate becomes roughly proportional to *ln p* and hence height.

Tephigram



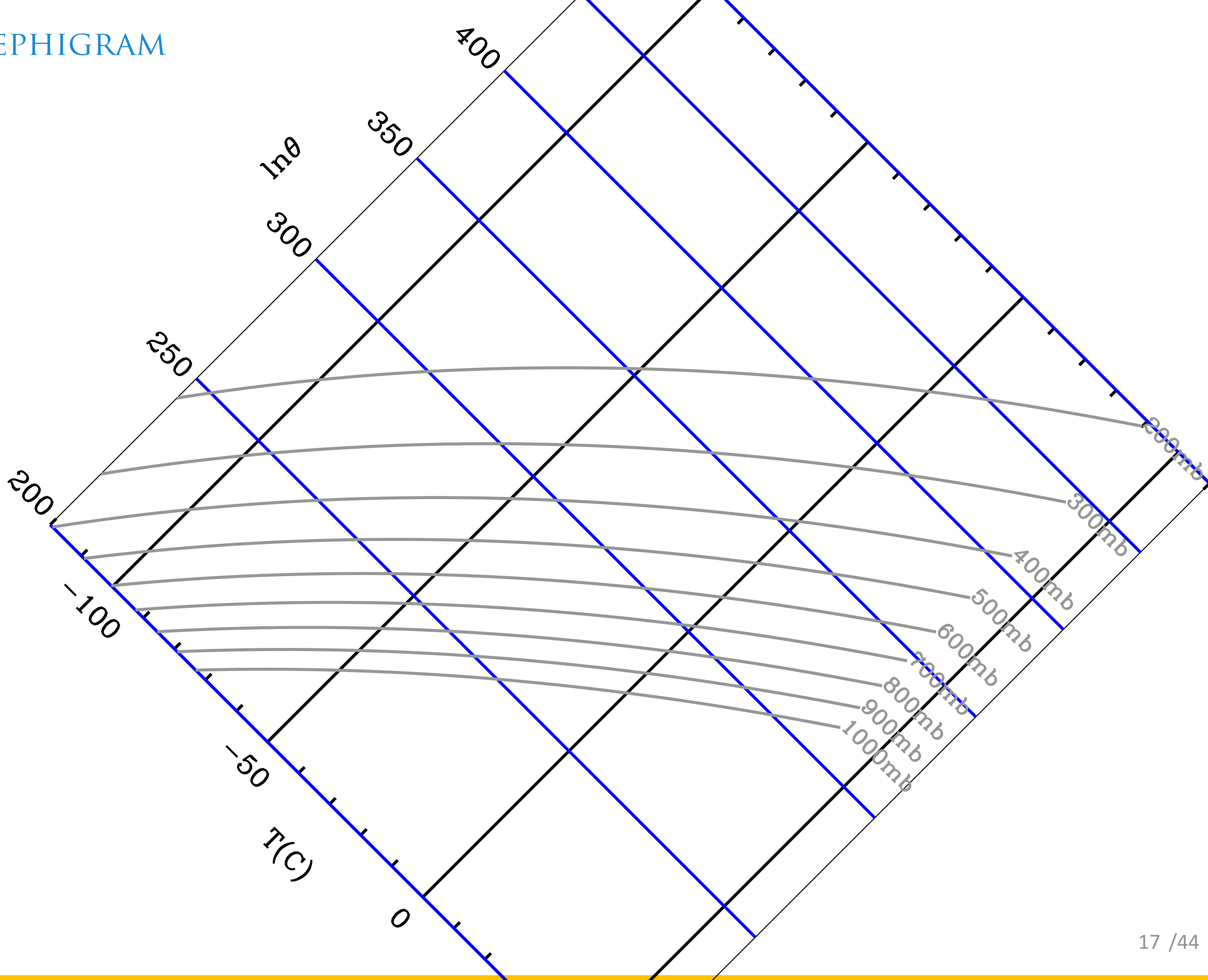
200mb
300mb
400mb
500mb
600mb
700mb
800mb
900mb
1000mb
$p = p_0 \left(\frac{T}{\theta}\right)^{1/\kappa}$
500
450
400
350
300
250
200
lnθ
−100
−50
0
50
T(C)

Tephigram



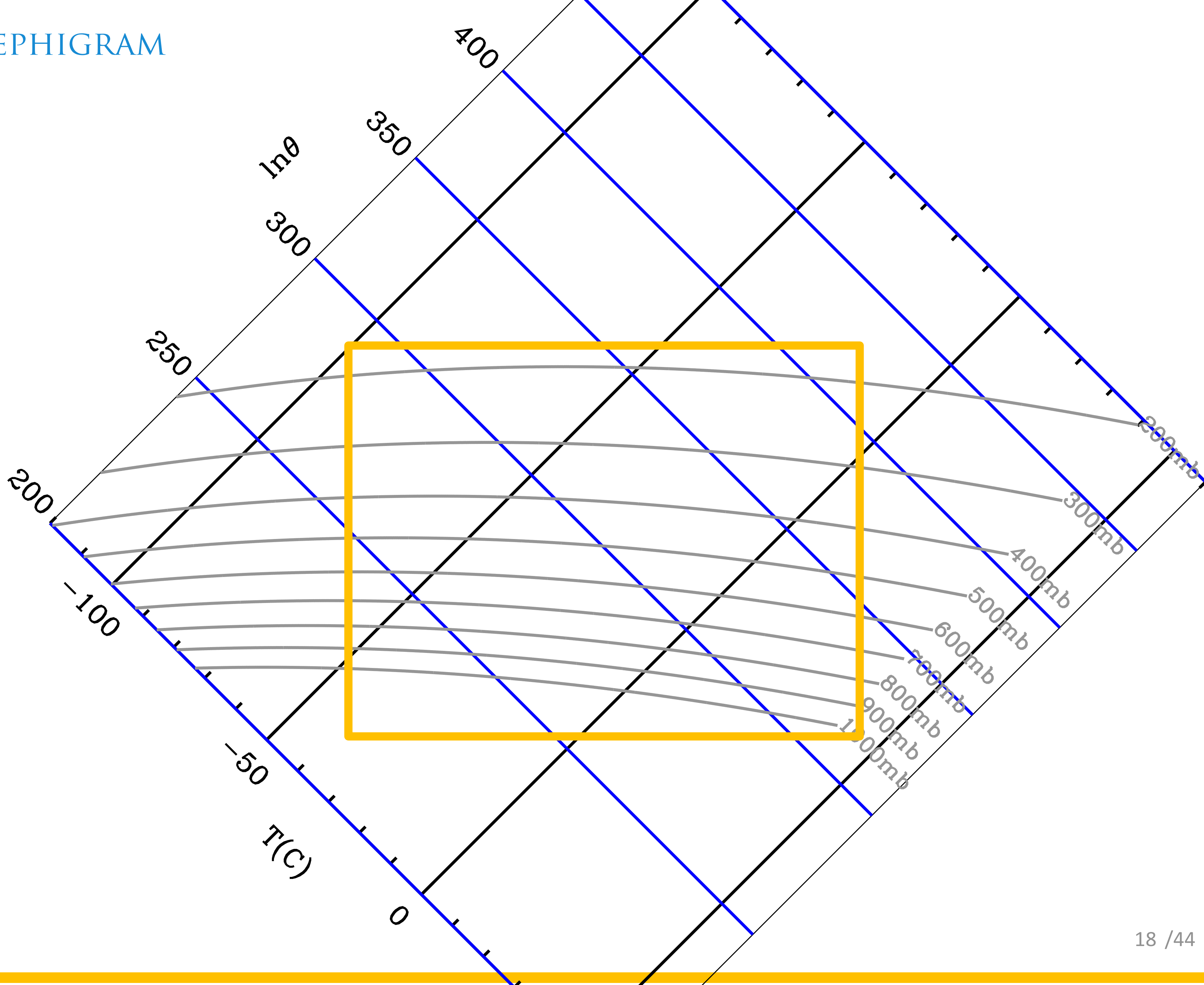
500
450
400
350
300
250
200
lnθ
−100
−50
0
50
T(C)
200mb
300mb
400mb
500mb
600mb
700mb
800mb
900mb
1000mb
$p = p_0 \left(\frac{T}{\theta}\right)^{1/\kappa}$

TEPHIGRAM



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

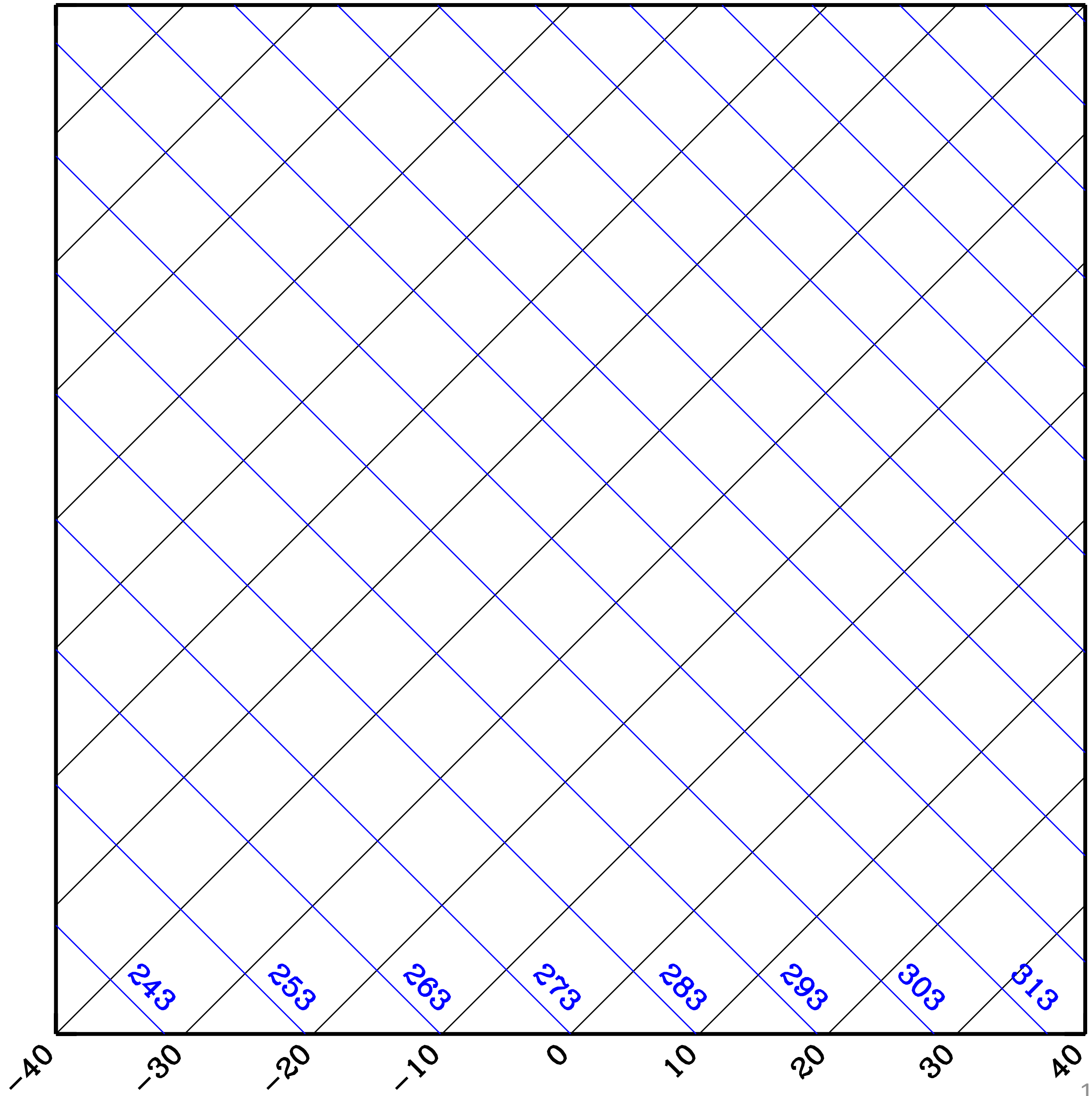
TEPHIGRAM



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

Tephigram

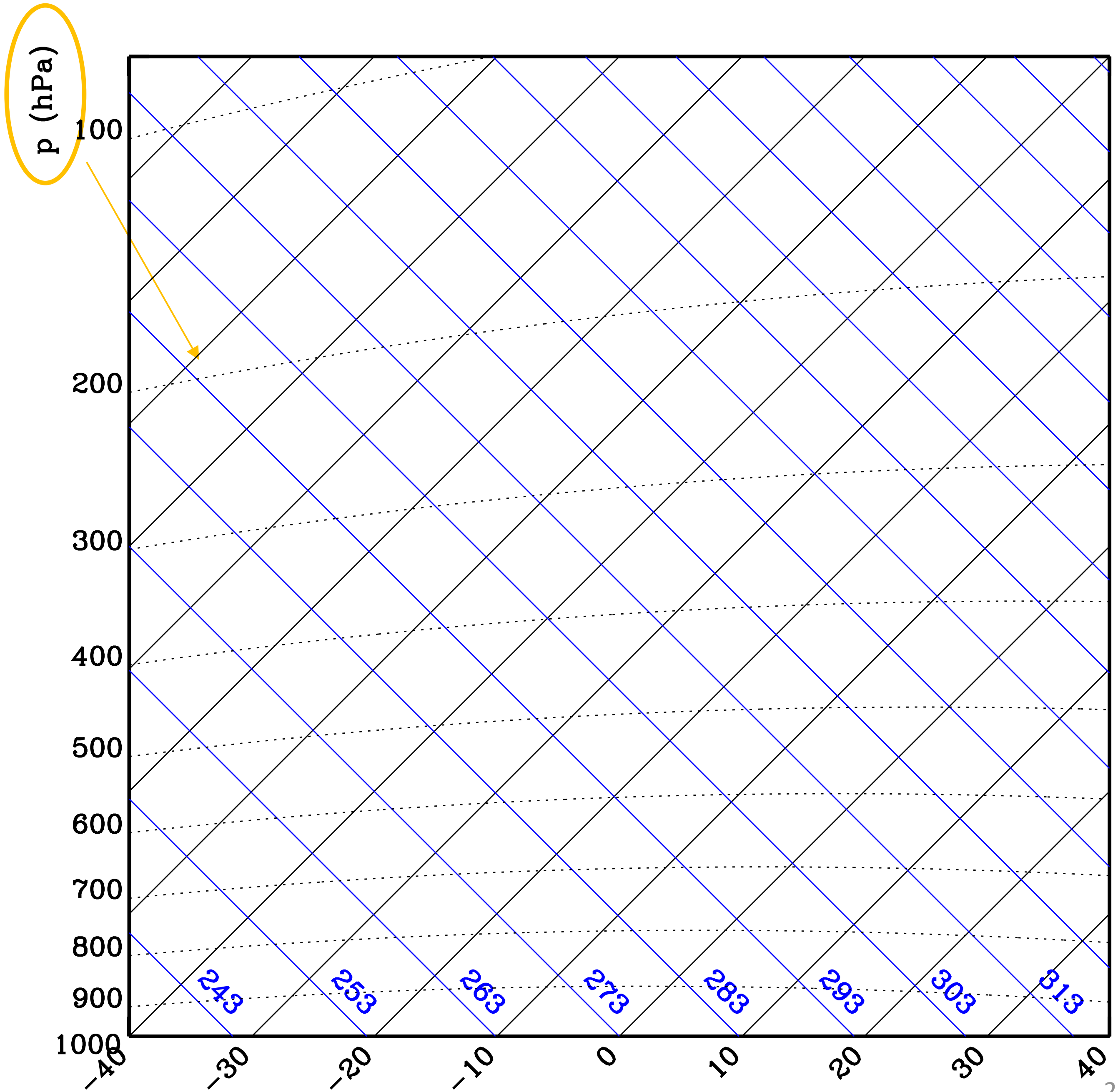
$$\theta = T\left(\frac{p_0}{p}\right)^{\kappa}$$



Tephigram

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

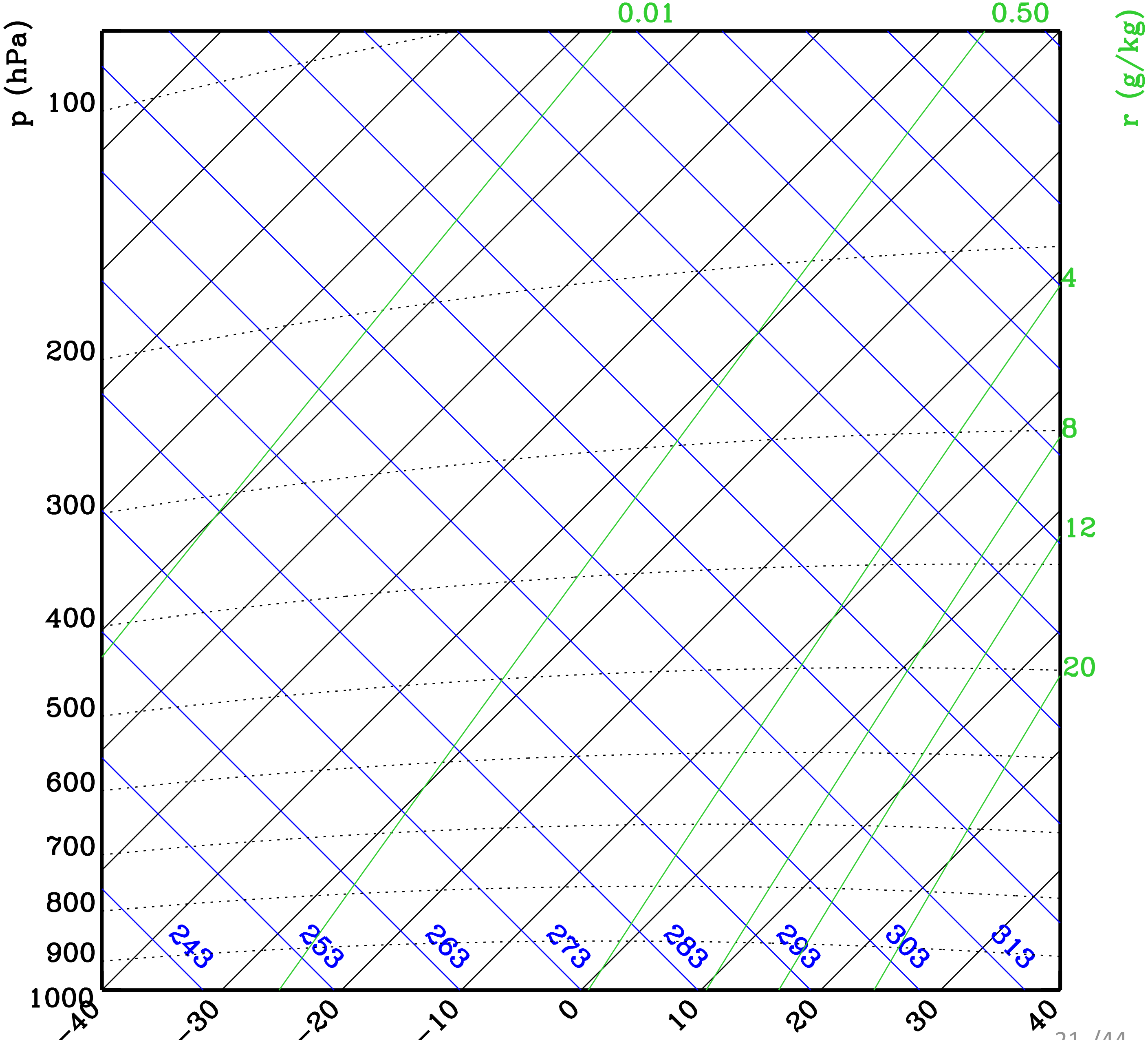
$$\theta = T \left(\frac{p_0}{p}\right)^{\kappa}$$



TEPHIGRAM

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

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

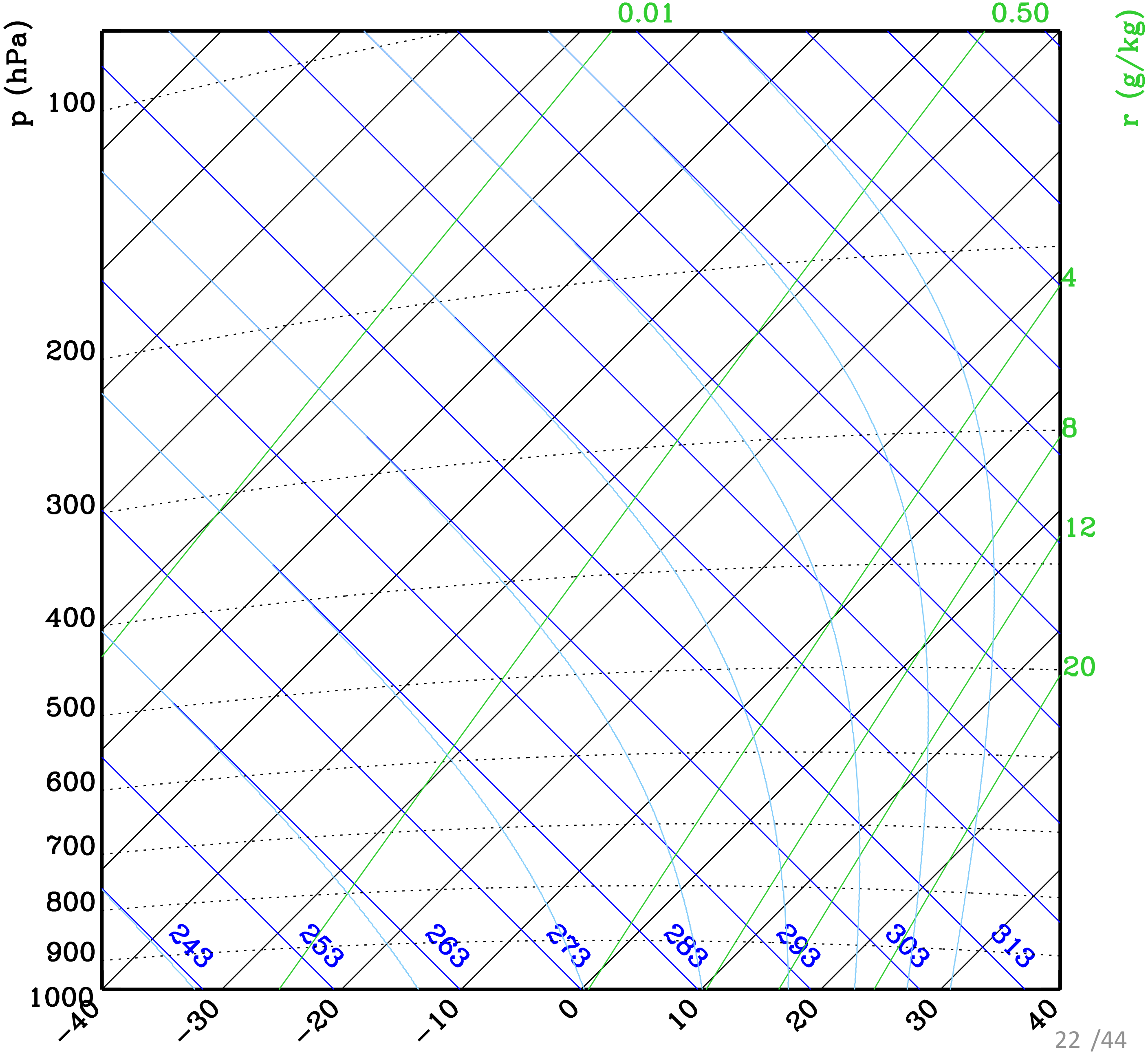


Tephigram

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

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

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



TEPHIGRAM

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

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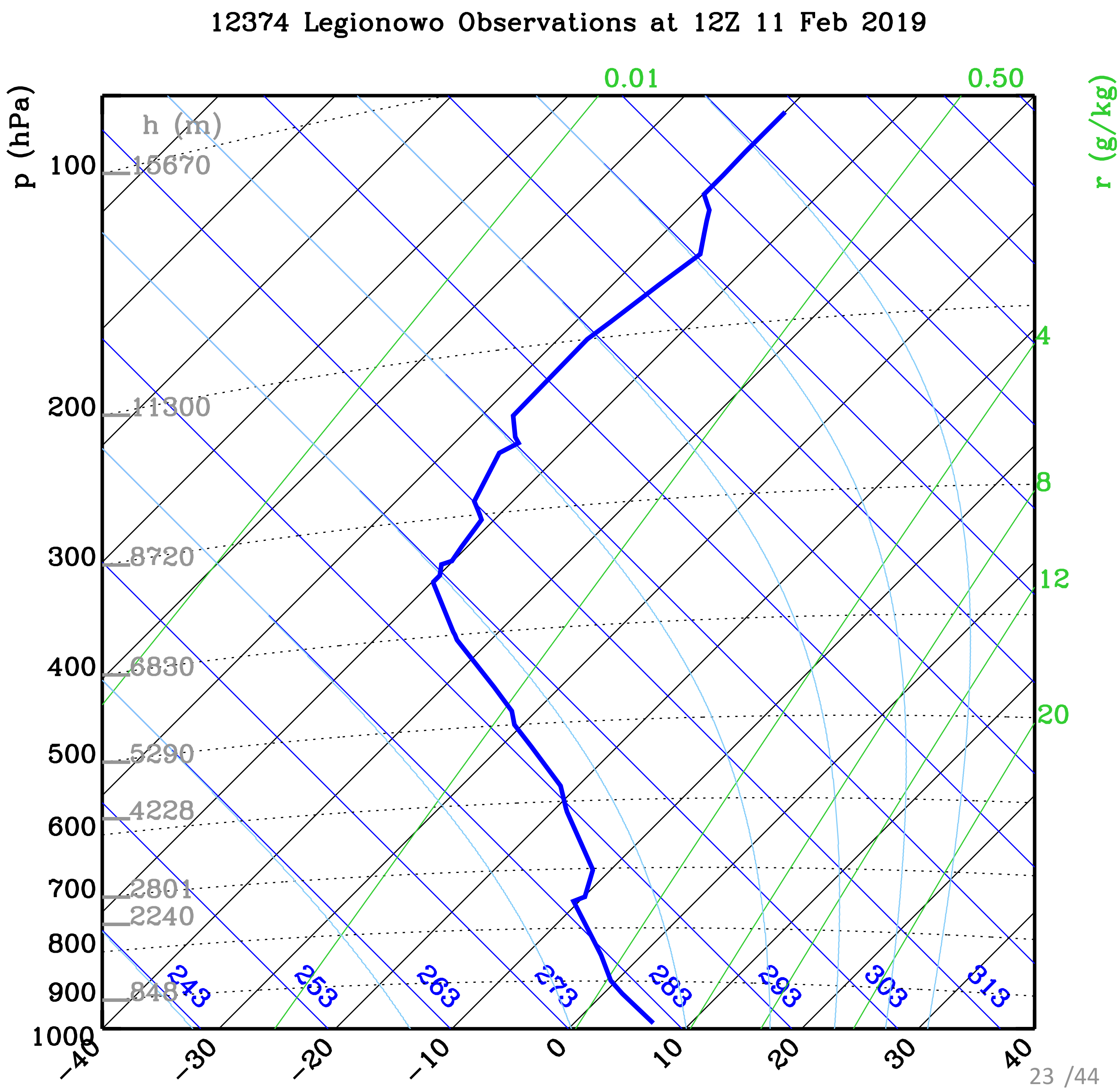
T



Tephigram

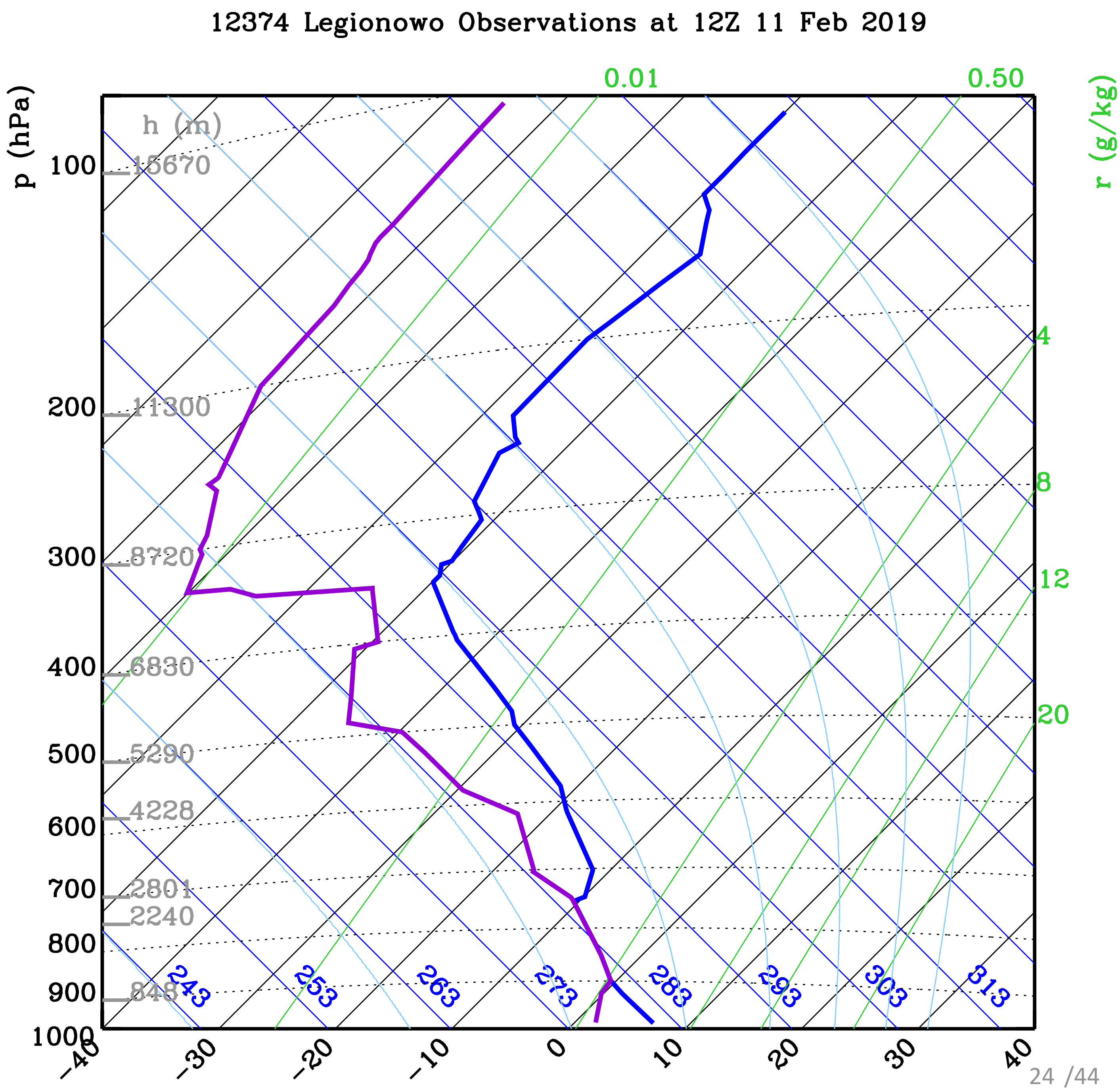
$$\theta = T\left(\frac{p_0}{p}\right)^{\kappa}$$

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

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

T

T_d



SKEW-T DIAGRAM

Skew_T adopts temperature, *T* and *lnp* as its thermodynamic coordinates.

The logarithm of pressure is chosen for the vertical coordinate rather than the pressure itself because in an isothermal atmosphere height varies with *lnp*, and hence for a realistic temperature profile the ordinate is roughly proportional to height.

Isotherms are skewed at an angle of about 45° from the vertical. The exact angle of skewness is chosen so that adiabats and isotherms are orthogonal at 1000 hPa and 0°C.

A chart with coordinates of *T* versus *ln p* has the property of a true thermodynamic diagram, i.e. the area is proportional to energy.

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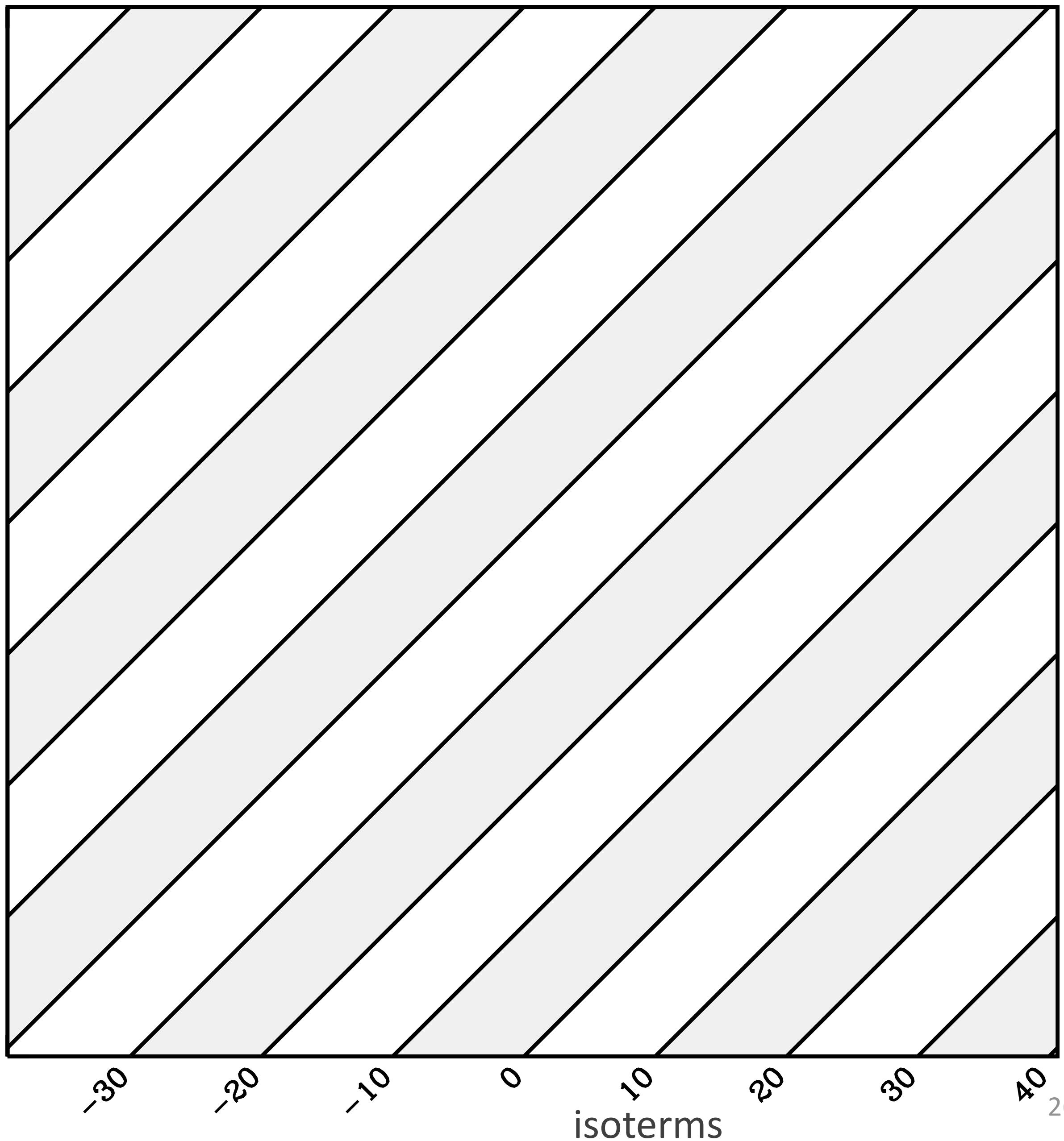
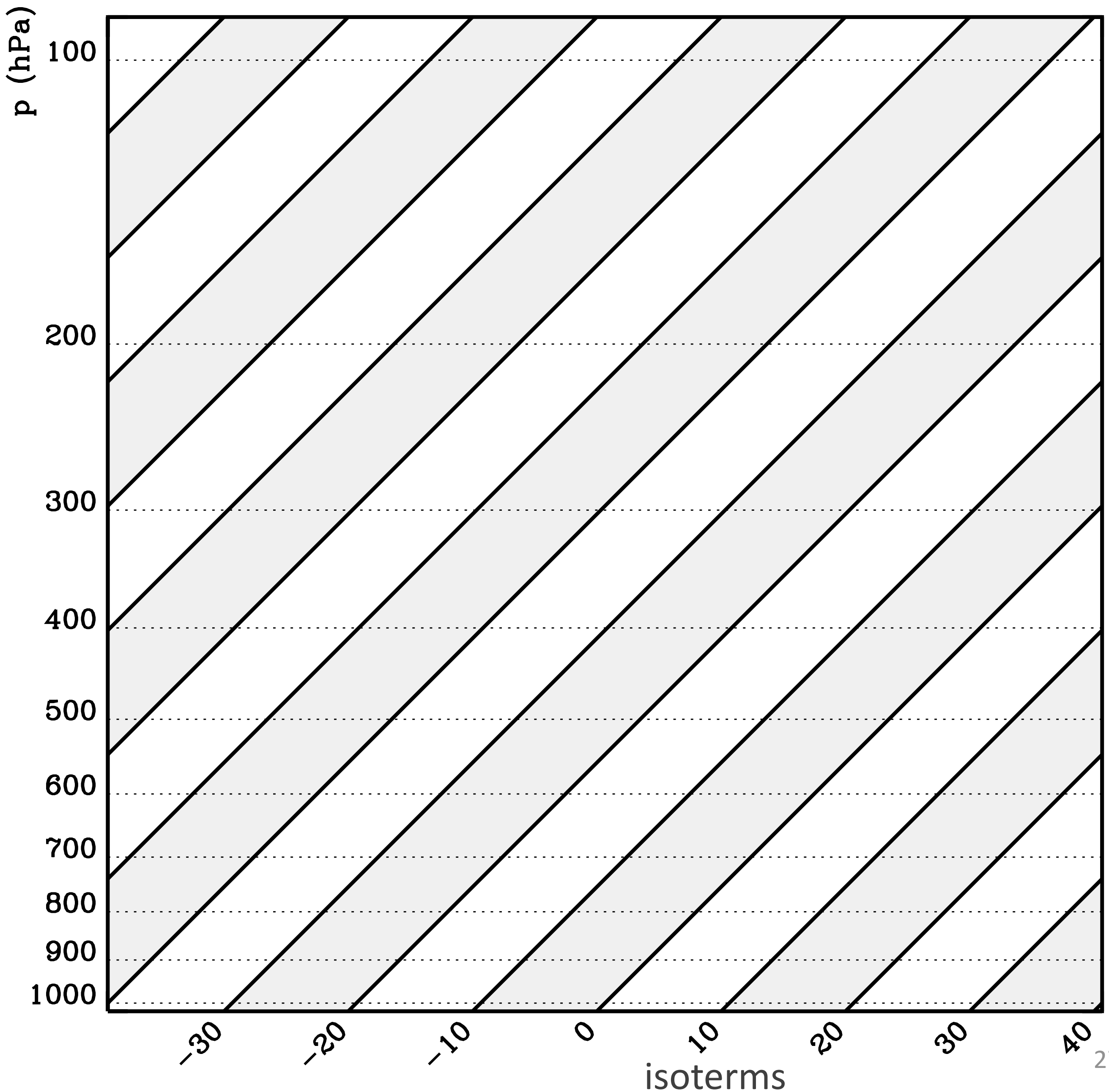


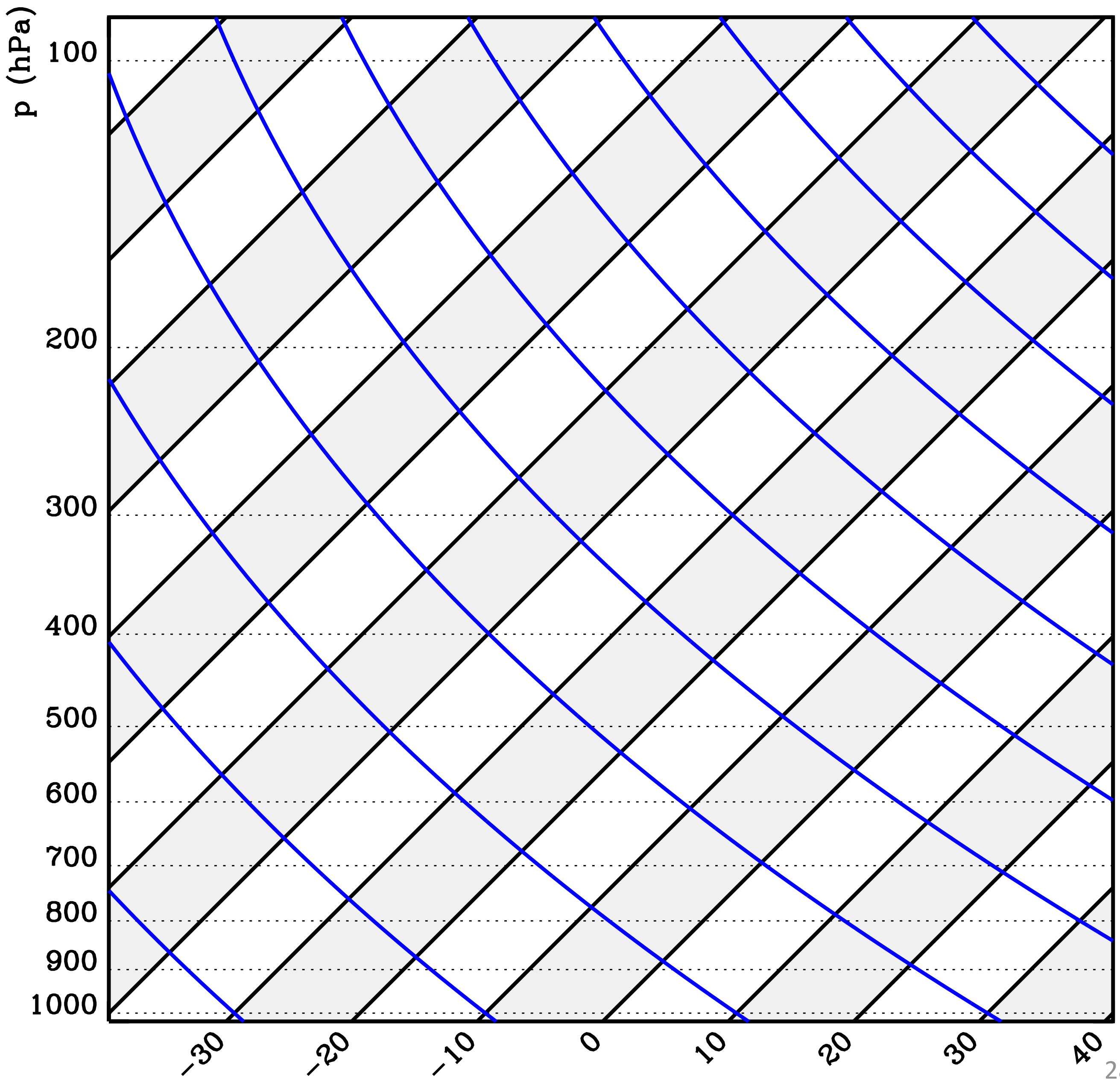
−30
−20
−10
0
10
20
30
40
isoterms

Skew-T diagram



Skew-T diagram

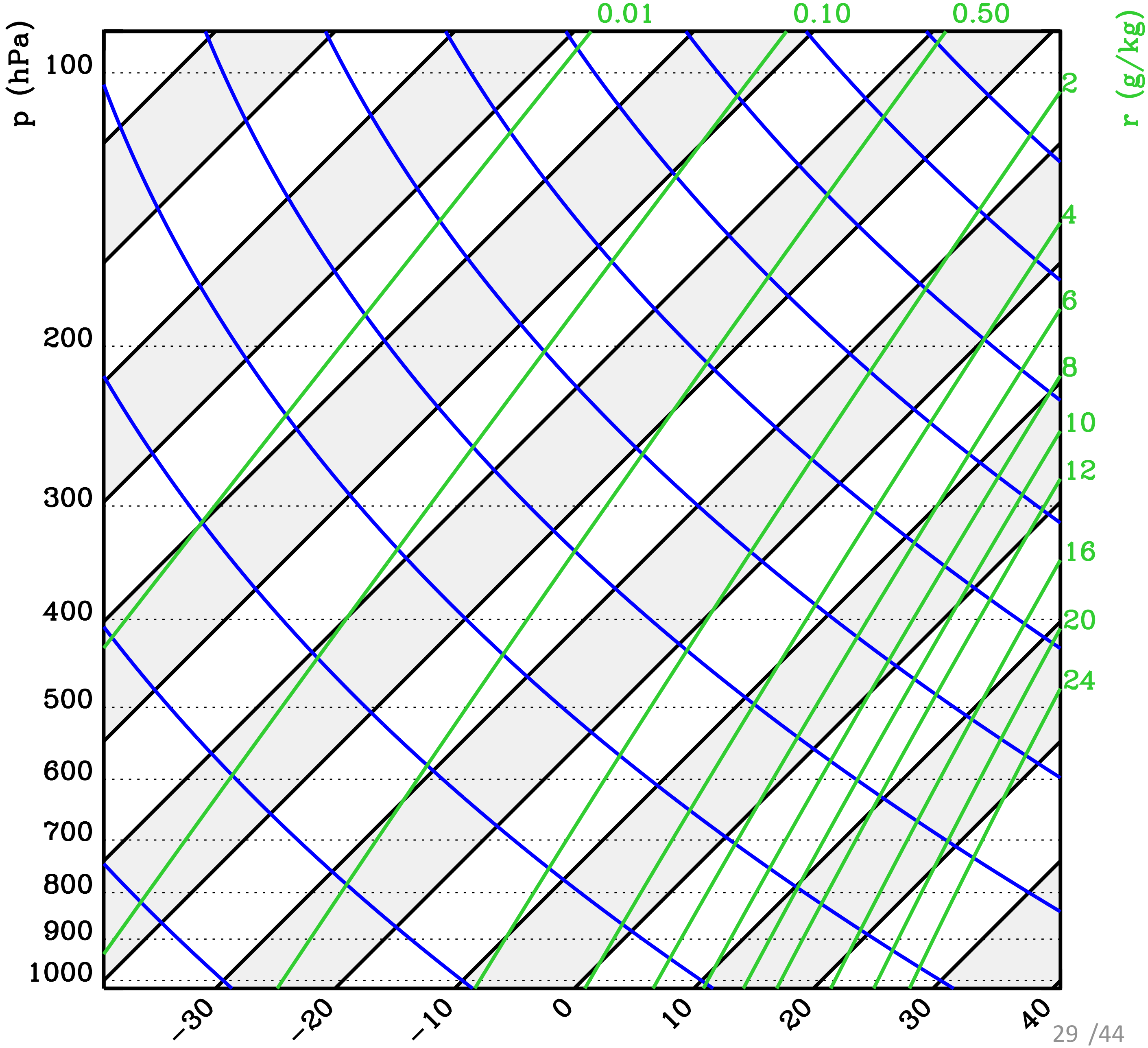
$$\theta = T\left(\frac{p_0}{p}\right)^{\kappa}$$



Skew-T diagram

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

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

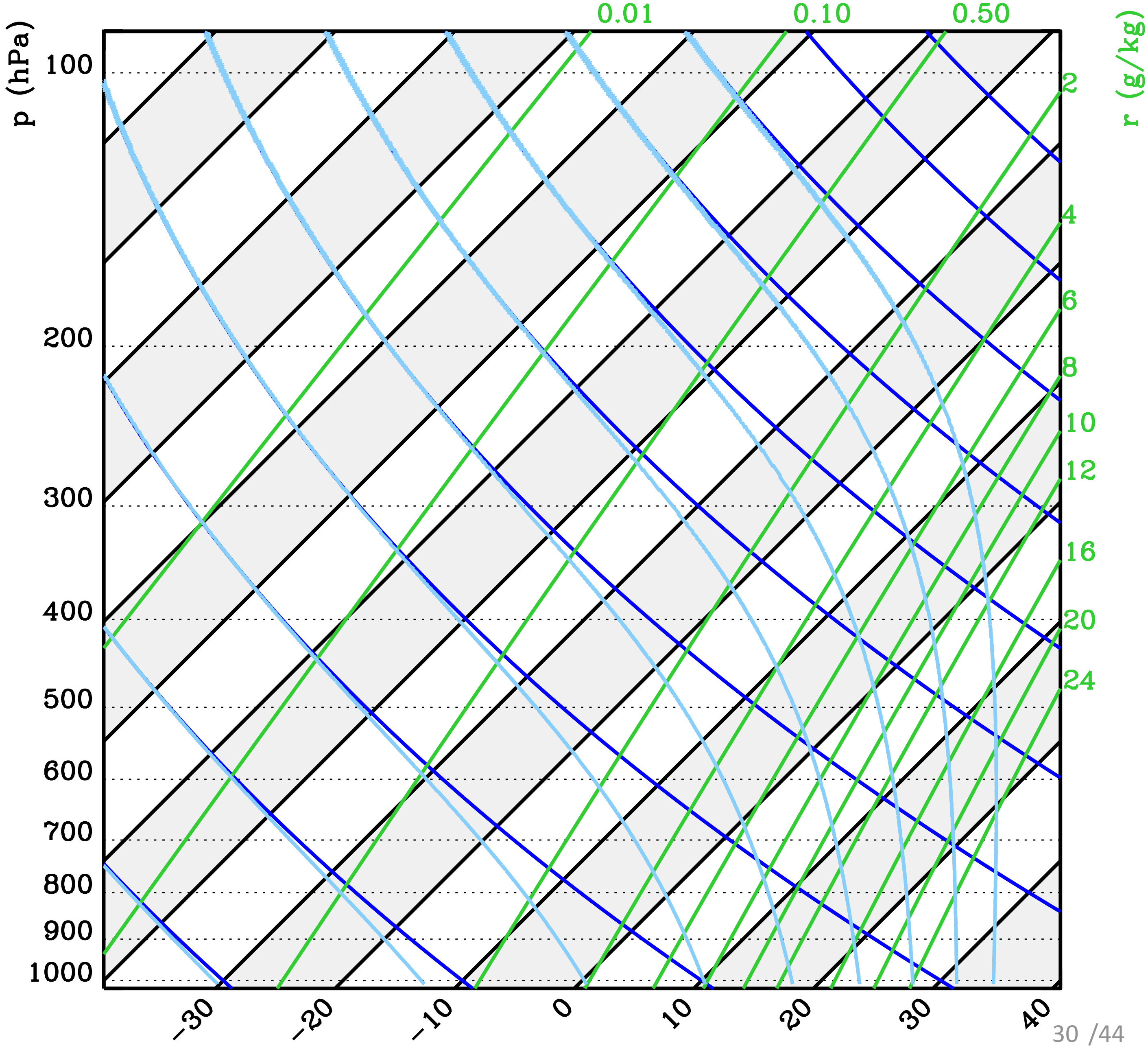


Skew-T diagram

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

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

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



Skew-T diagram

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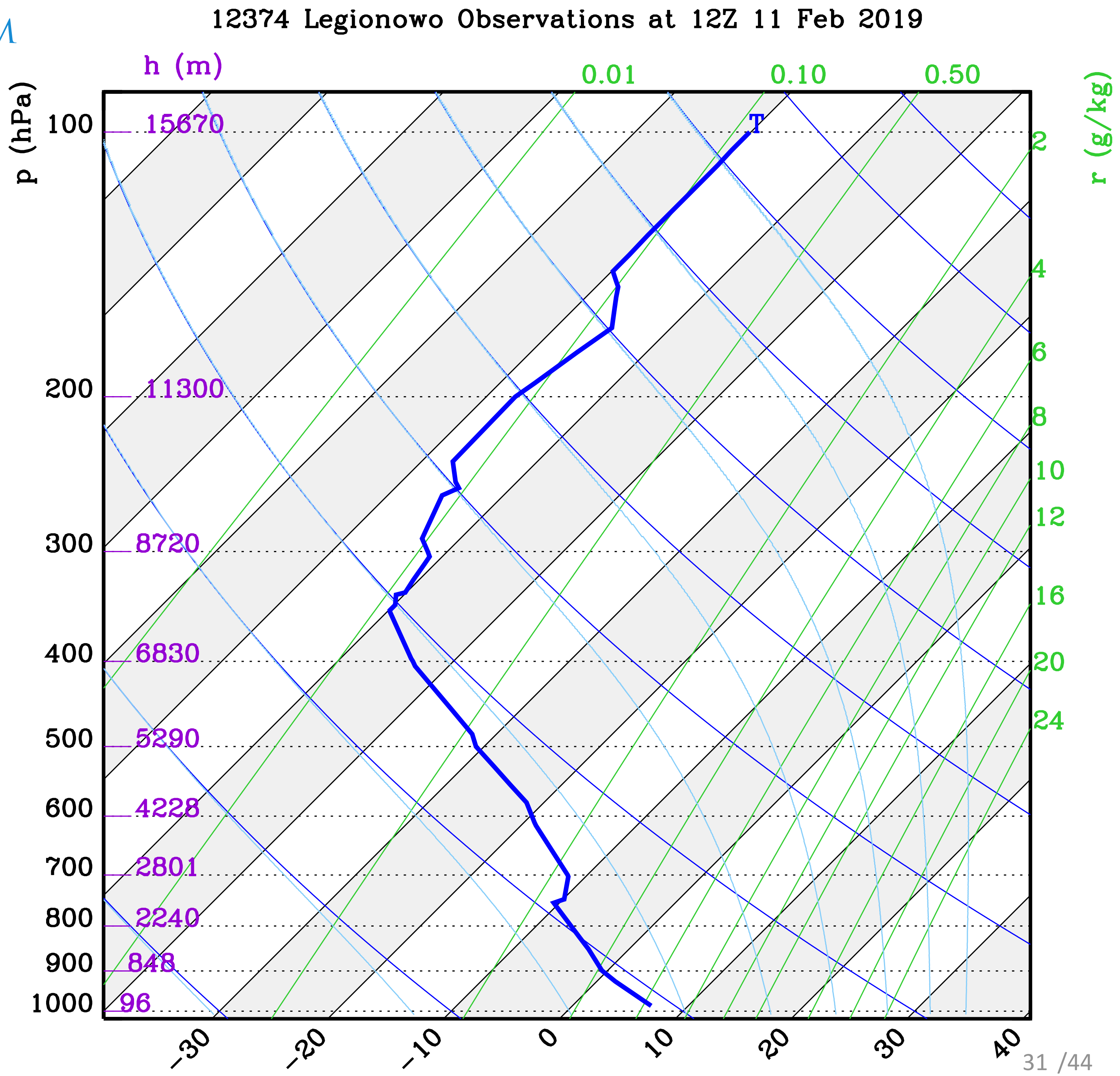
$$\theta_e = \theta \cdot exp\left(\frac{L_{lv} r_s}{c_p T}\right)$$

T



Skew-T diagram

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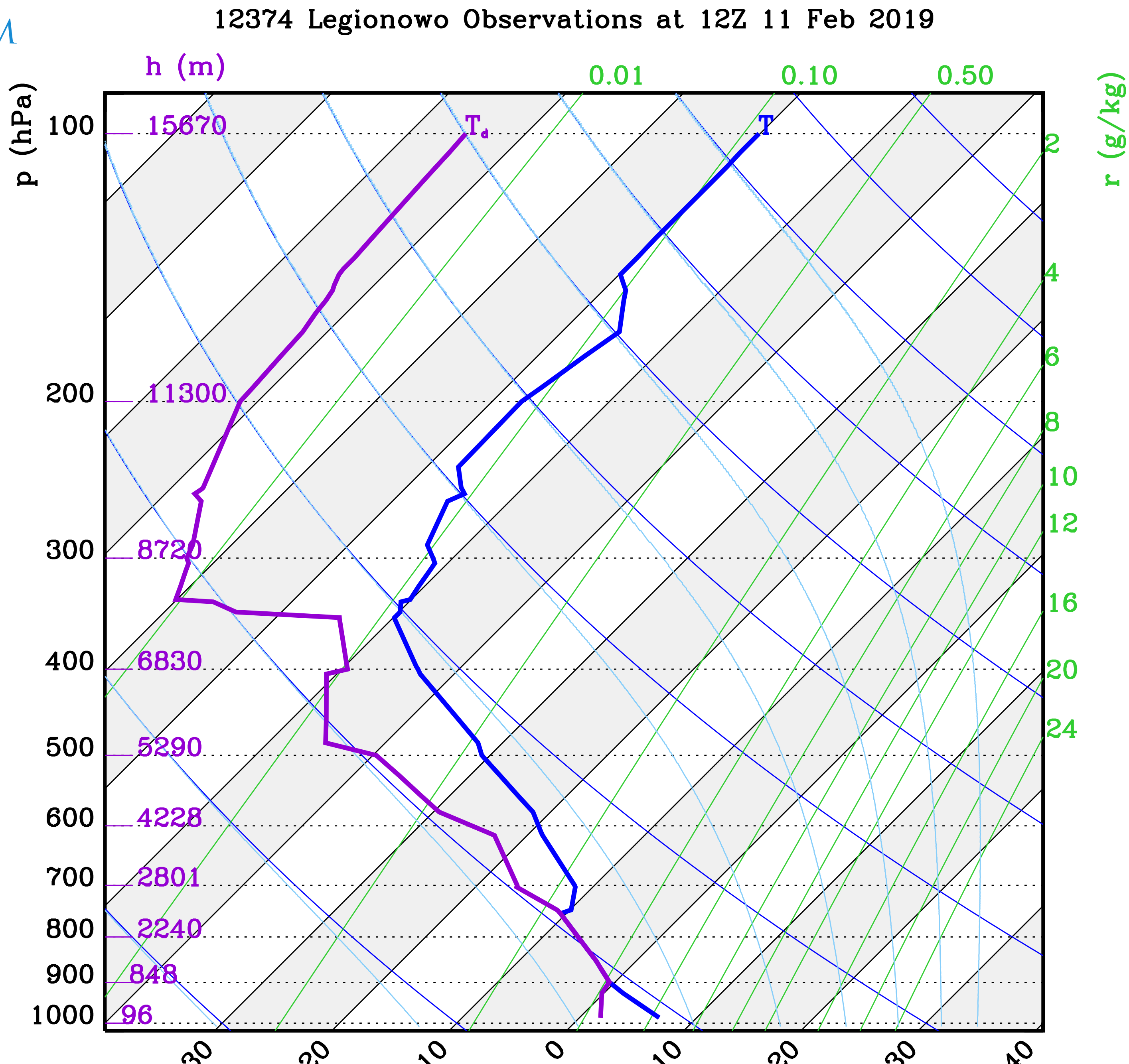
$$r_s = \varepsilon \frac{e_s(T)}{p - e_s(T)}$$

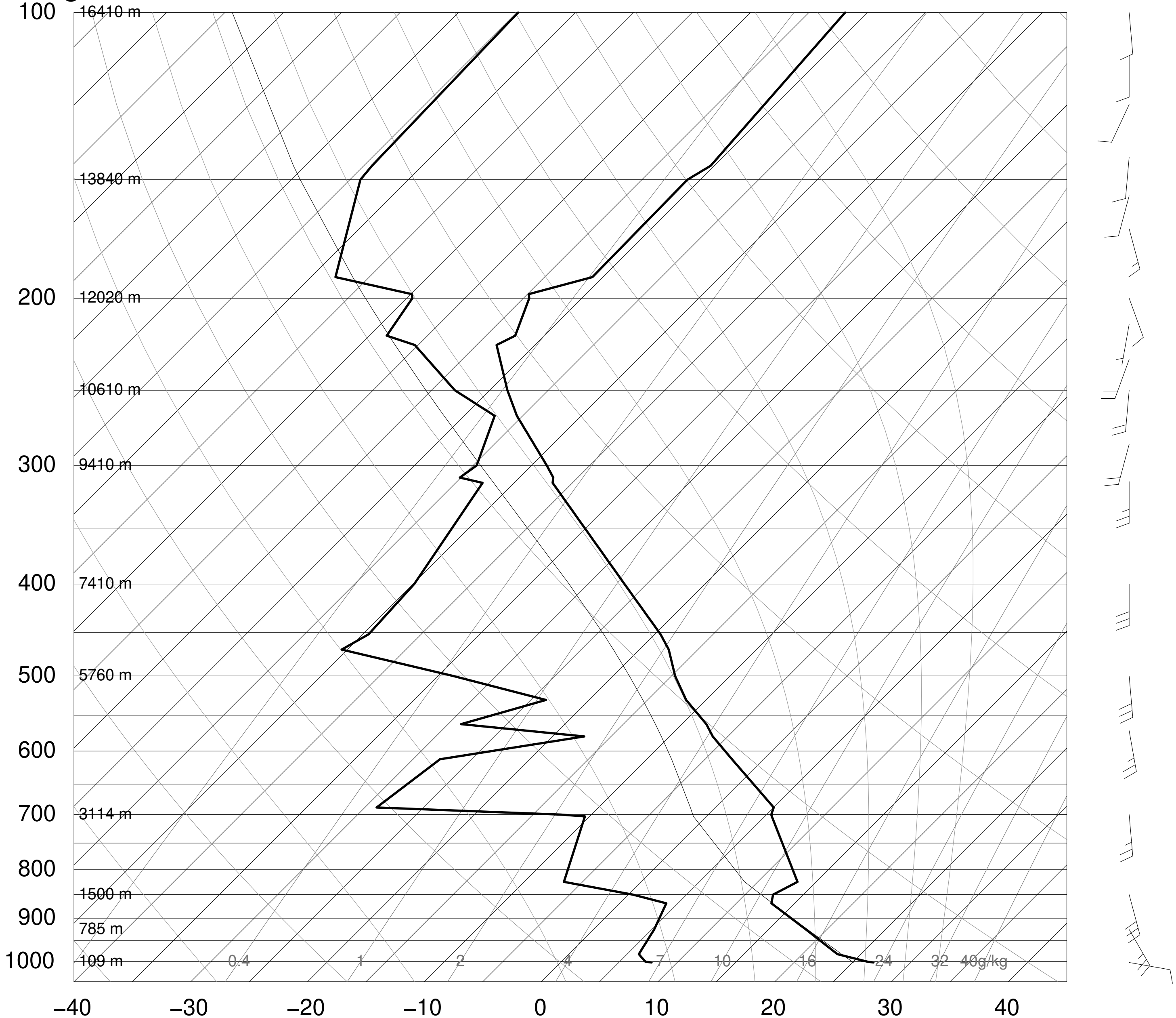
$$\theta_e = \theta \cdot exp\left(\frac{L_{lv} r_s}{c_p T}\right)$$

T

T_d



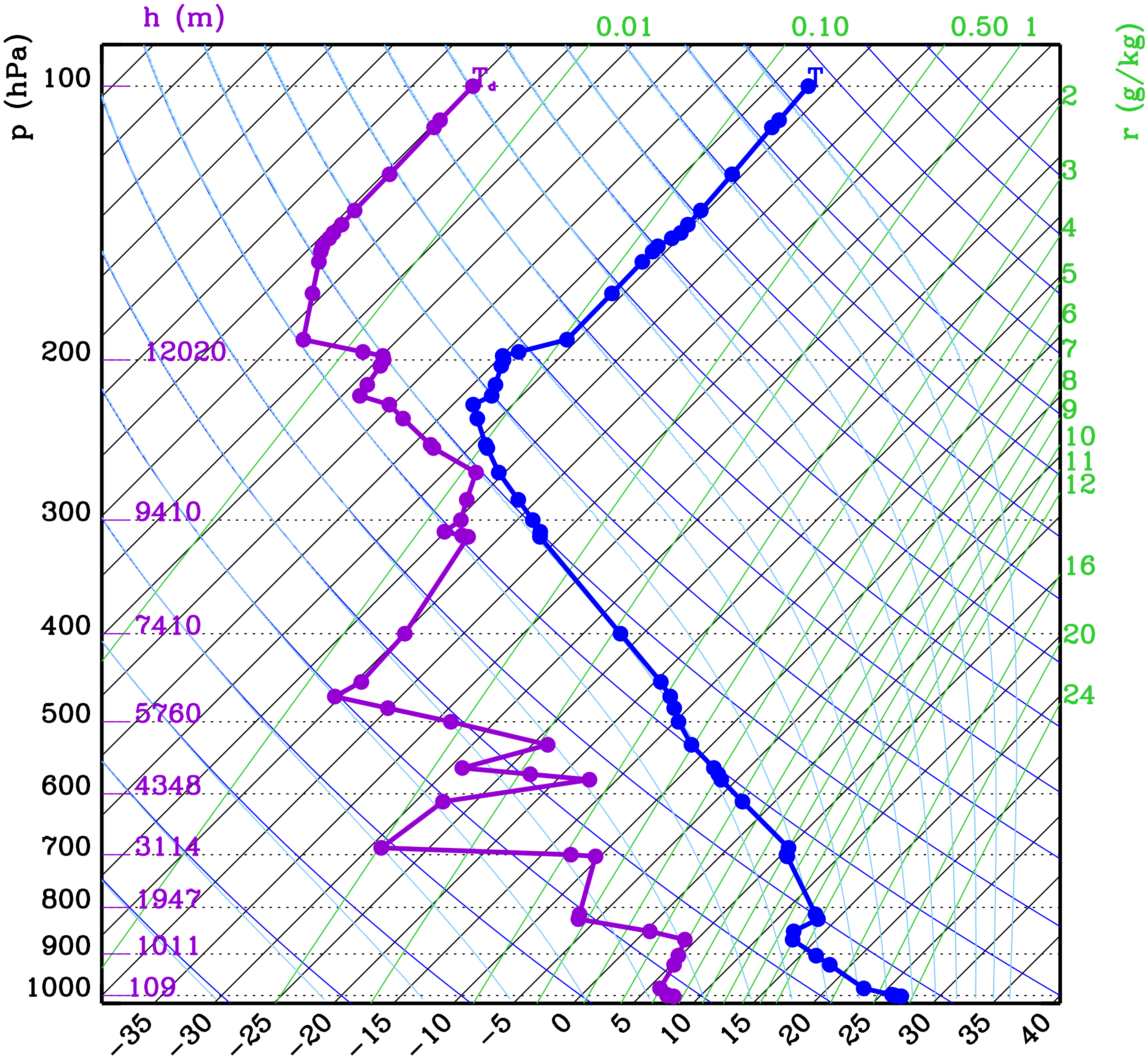
12374 Legionowo

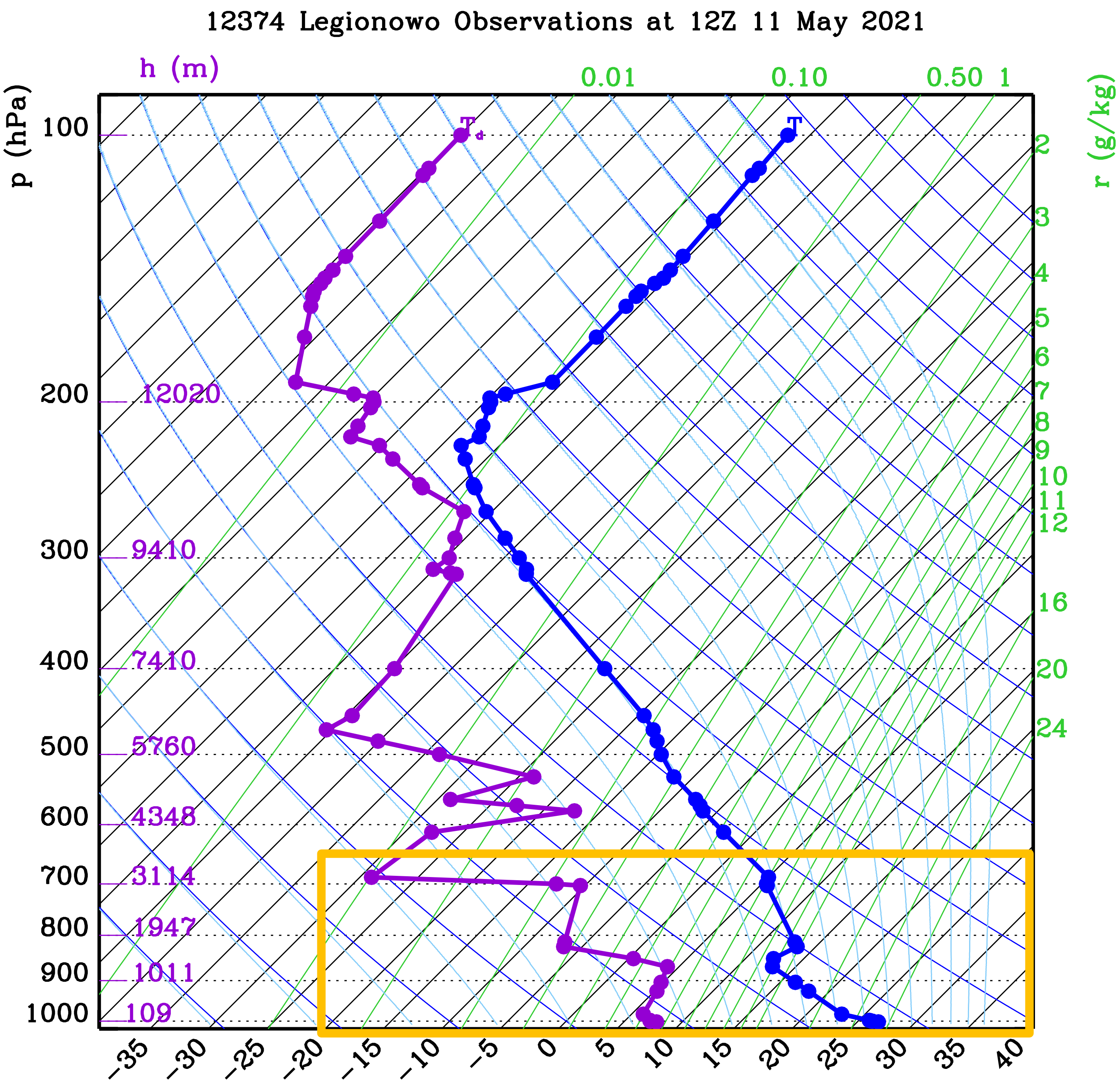


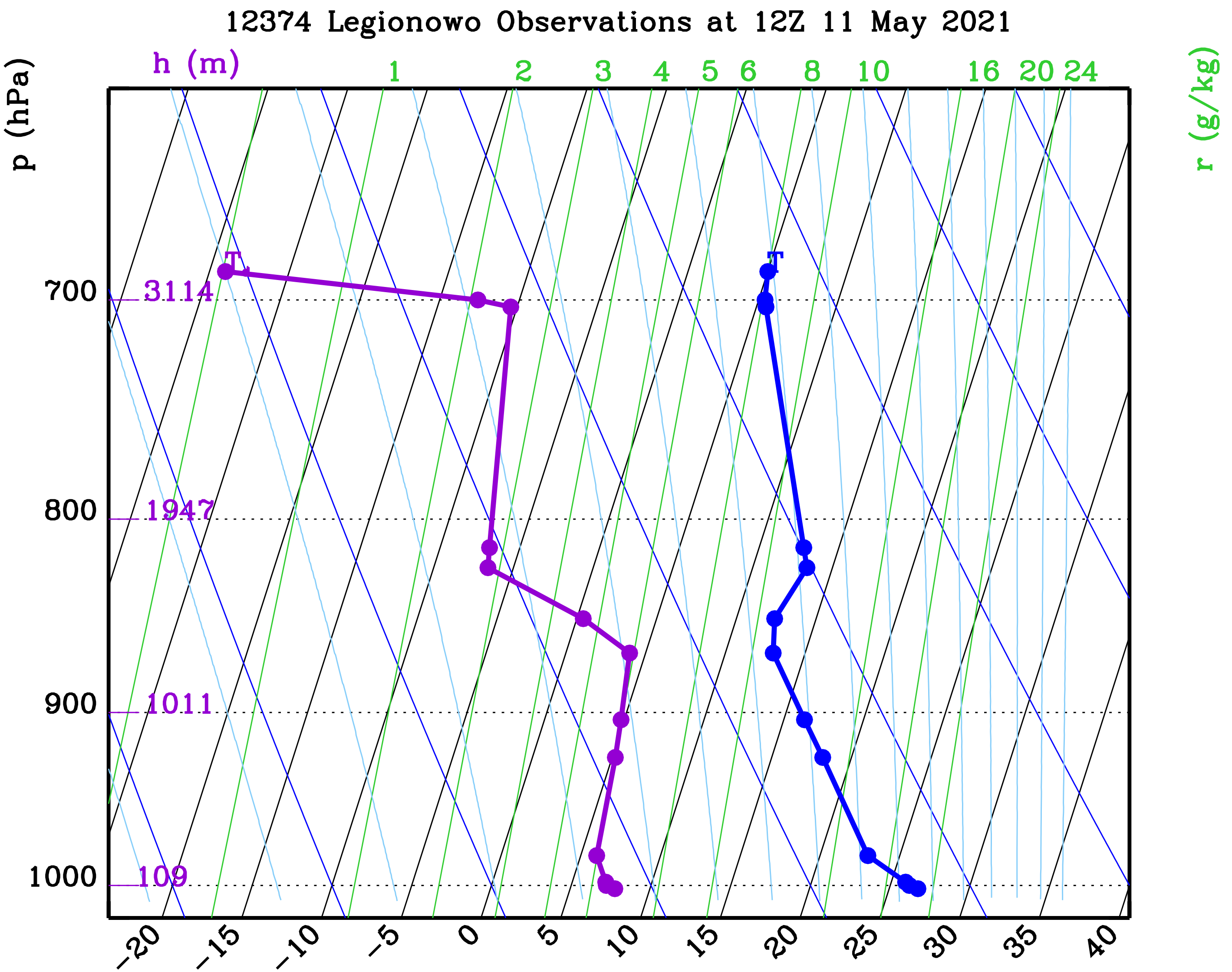
SLAT	52.40
SLON	20.96
SELV	96.00
SHOW	5.64
LIFT	3.87
LFTV	3.66
SWET	92.21
KINX	9.50
CTOT	15.10
VTOT	27.10
TOTL	42.20
CAPE	0.00
CAPV	0.00
CINS	0.00
CINV	0.00
EQLV	−9999
EQTV	−9999
LFCT	−9999
LFCV	−9999
BRCH	0.00
BRCV	0.00
LCLT	275.7
LCLP	761.1
LCLE	316.2
MLTH	298.0
MLMR	6.09
THCK	5651.
PWAT	15.71

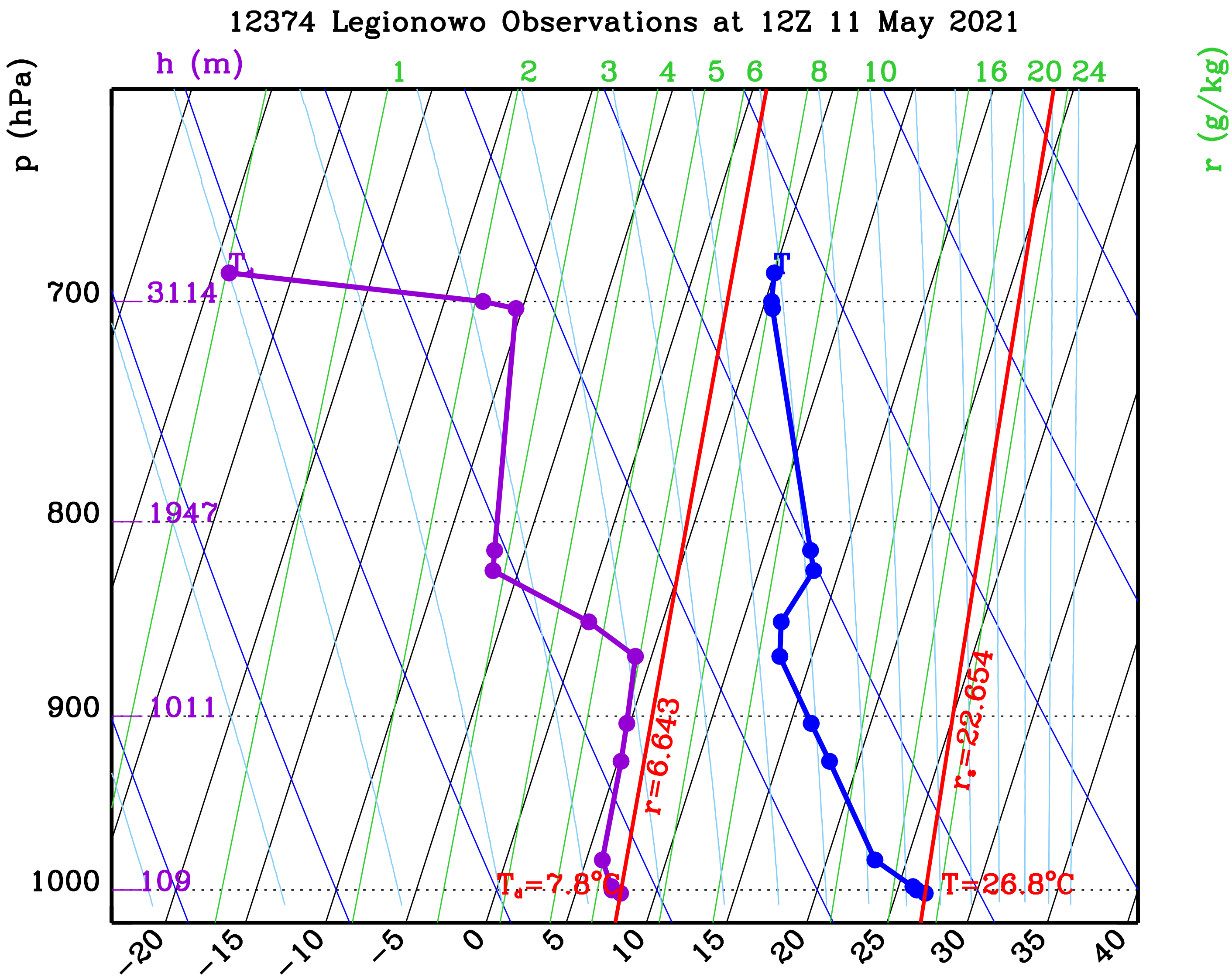
12Z 11 May 2021 **University of Wyoming**

12374 Legionowo Observations at 12Z 11 May 2021




12374 Legionowo Observations at 12Z 11 May 2021
h (m)
p (hPa)
r (g/kg)
0.01
0.10
0.50 1
100
200
300
400
500
600
700
800
900
1000
12020
9410
7410
5760
4348
3114
1947
1011
109
Td
T
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


12374 Legionowo Observations at 12Z 11 May 2021
h (m)
p (hPa)
r (g/kg)
1
2
3
4
5
6
8
10
16
20
24
700
3114
800
1947
900
1011
1000
109
T
T
−20
−15
−10
−5
0
5
10
15
20
25
30
35
40

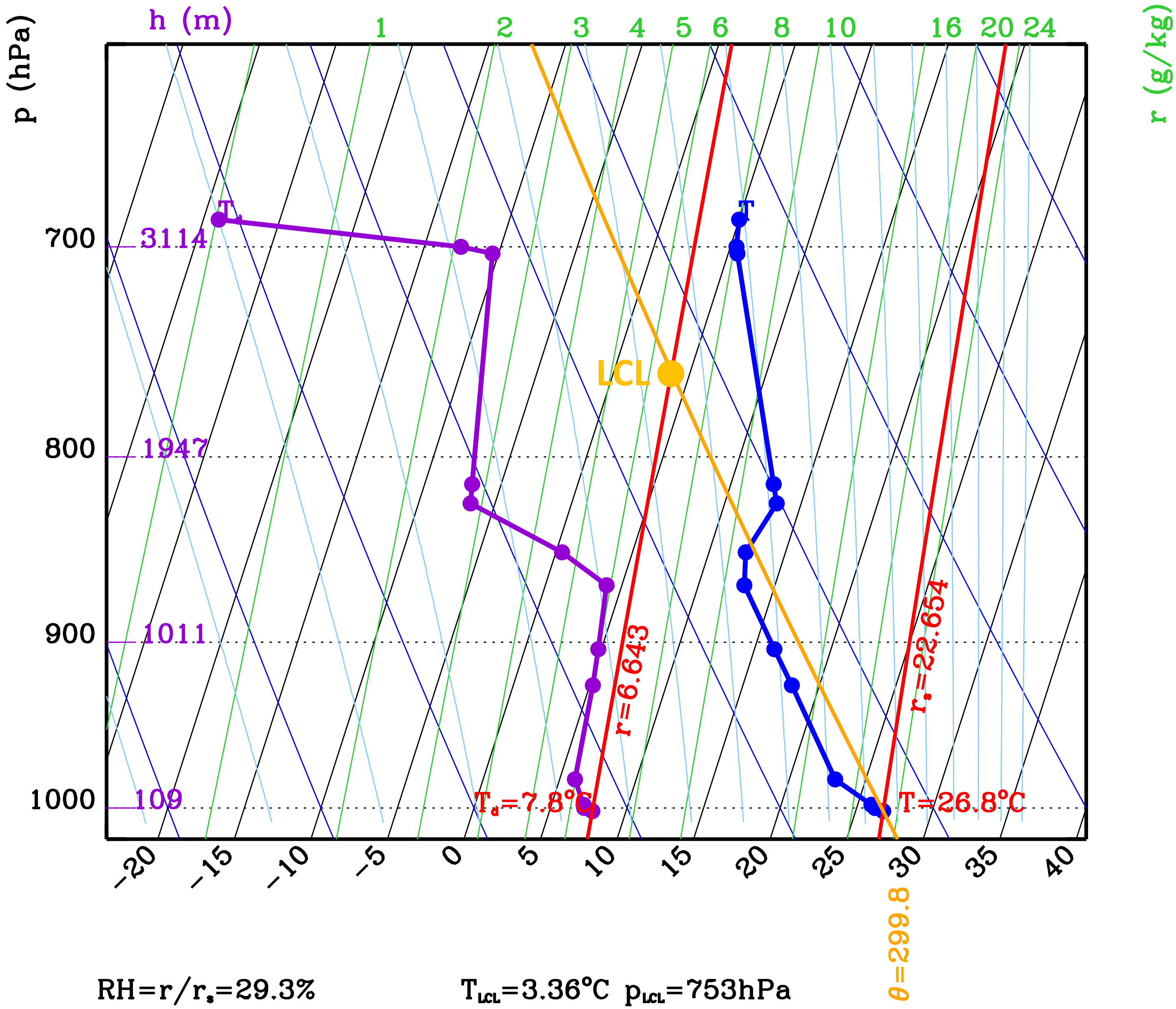


RH=r/r_s=29.3%

RH=q/q_s=29.8%

RH=e/e_s=30.1%

12374 Legionowo Observations at 12Z 11 May 2021

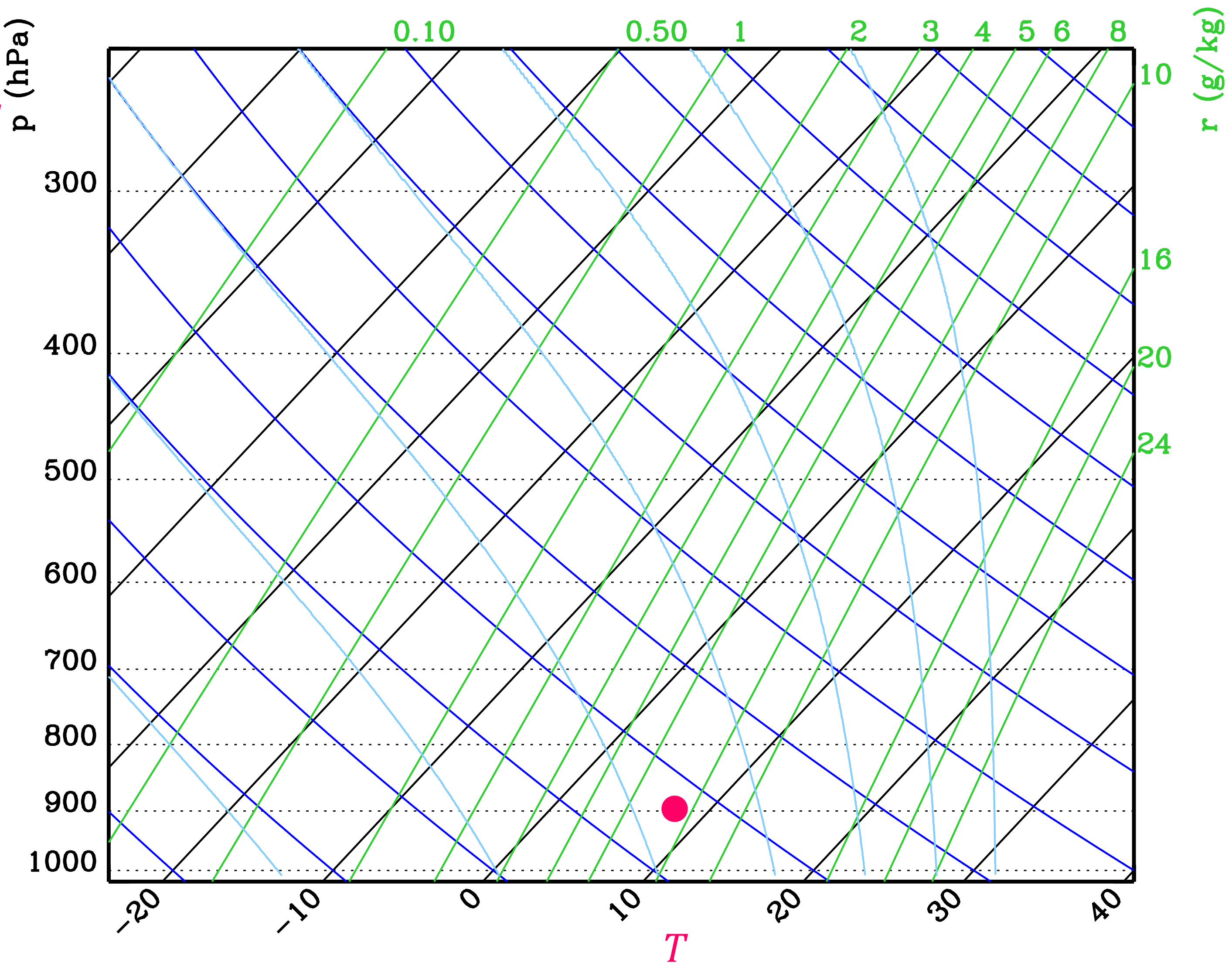


RH=r/r_s=29.3% T_{LCL}=3.36°C p_{LCL}=753hPa

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

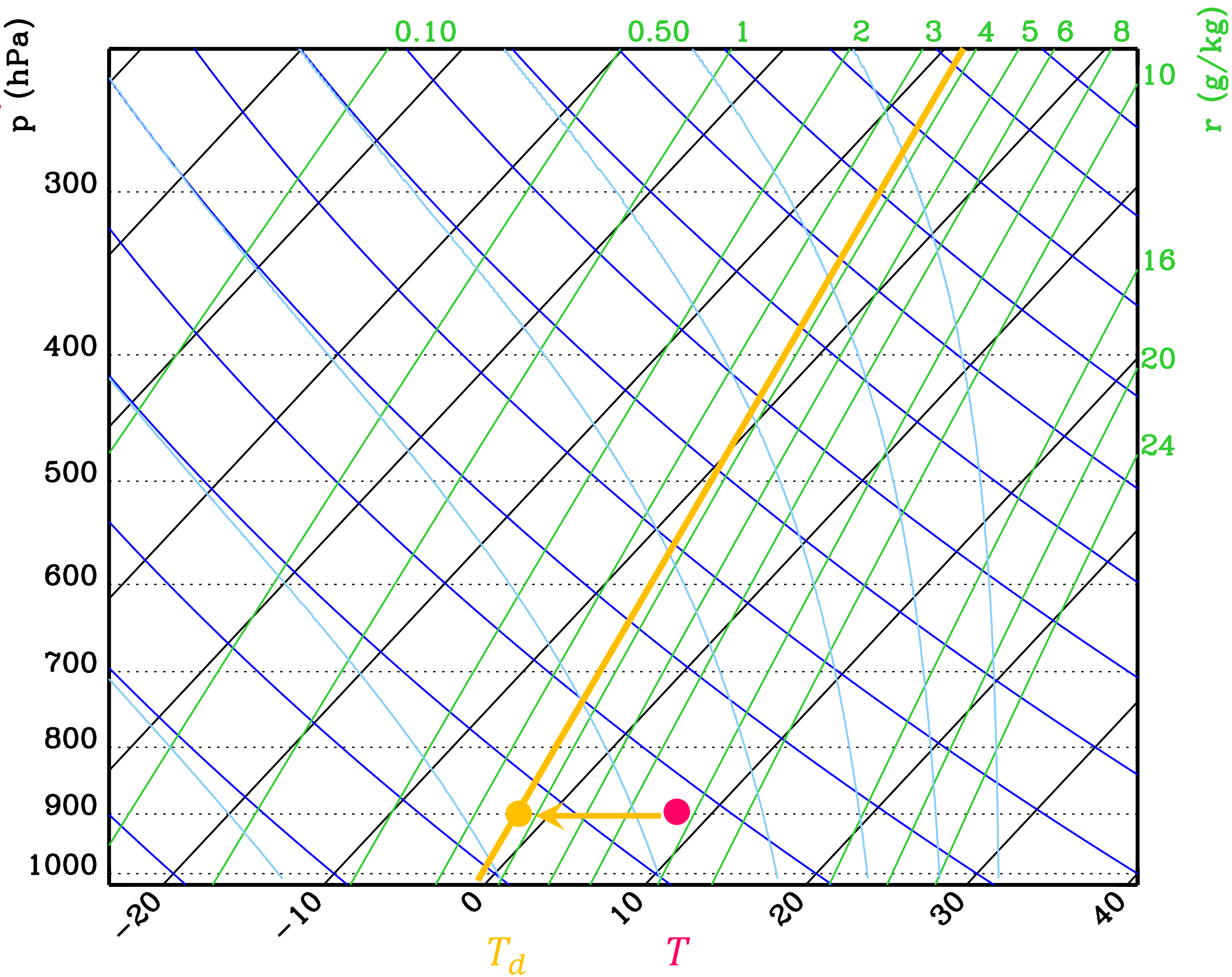
RH=e/e_s=30.1% T_{LCL}=3.80°C p_{LCL}=757hPa

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



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

$T_d \approx -2°C$

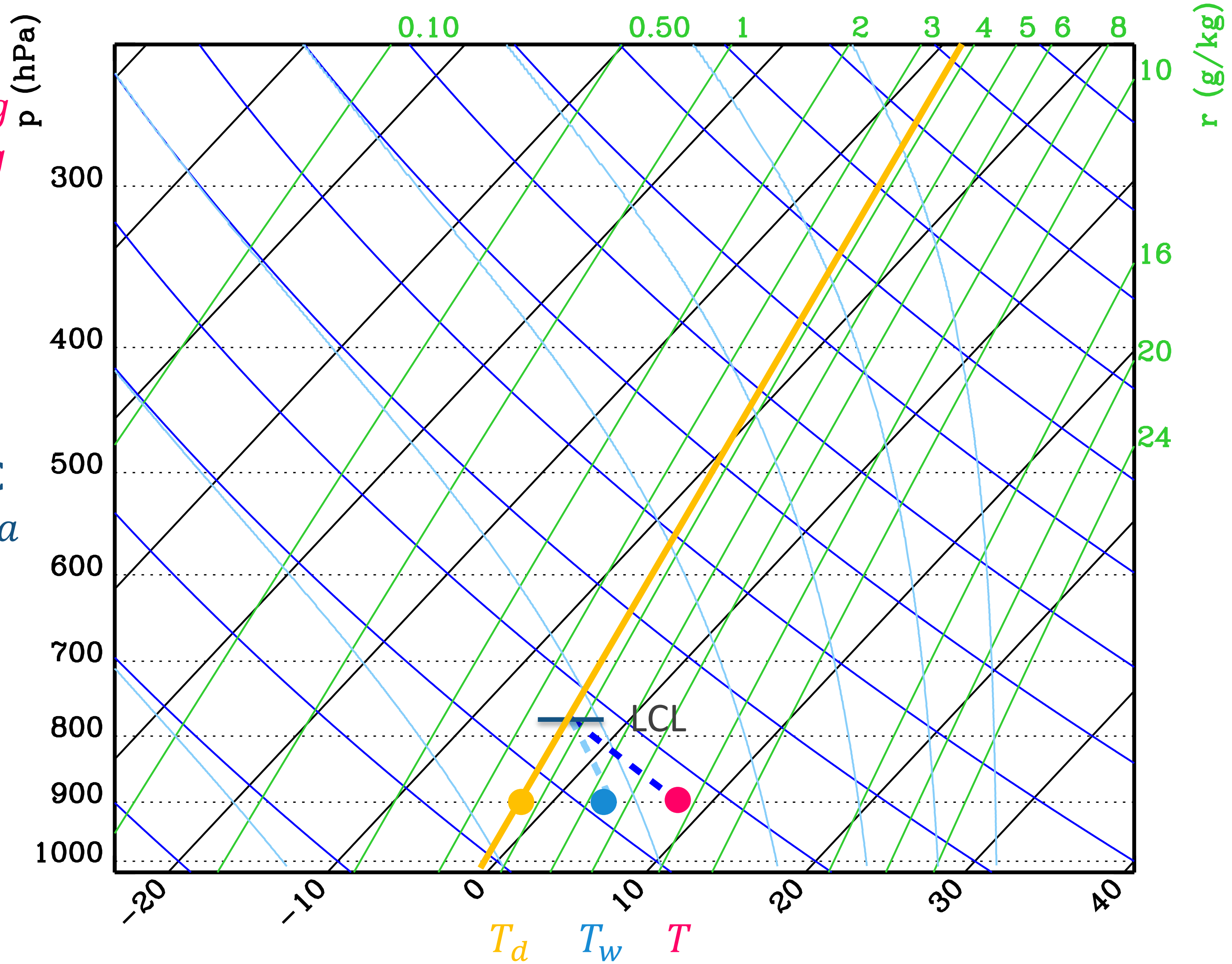


$T_o = 8°C$
$p_o = 900$ hPa
$r_o = 3.75\ g/kg$
$r_{s0} = 7.5\ g/kg$
$f_o = 50\%$

$T_d \approx -2°C$

$T_w \approx 3°C$

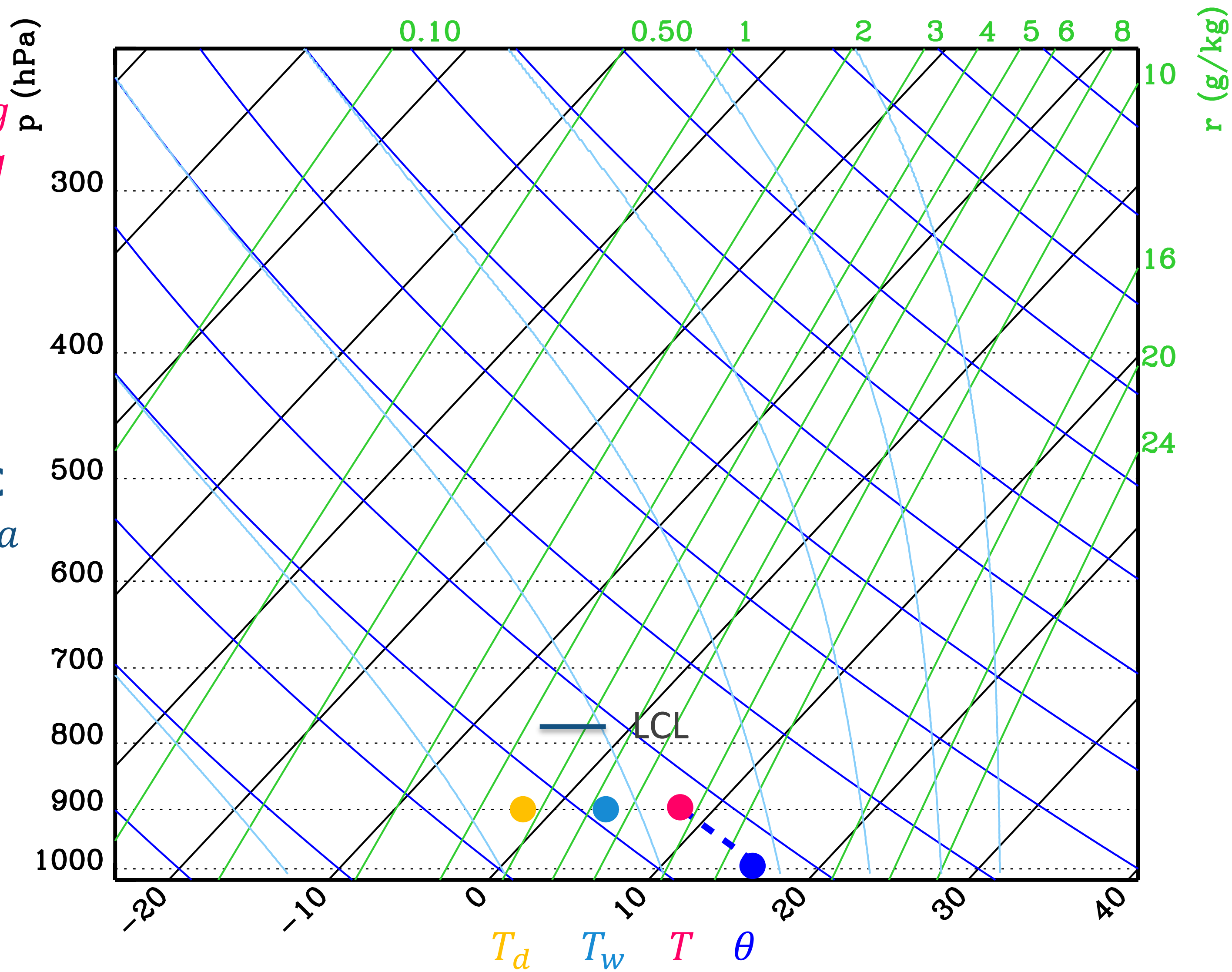
$T_{LCL} \approx -3.8°C$
$p_{LCL} \cong 774\ hPa$



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

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

- $\theta \approx 16.6°C$



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

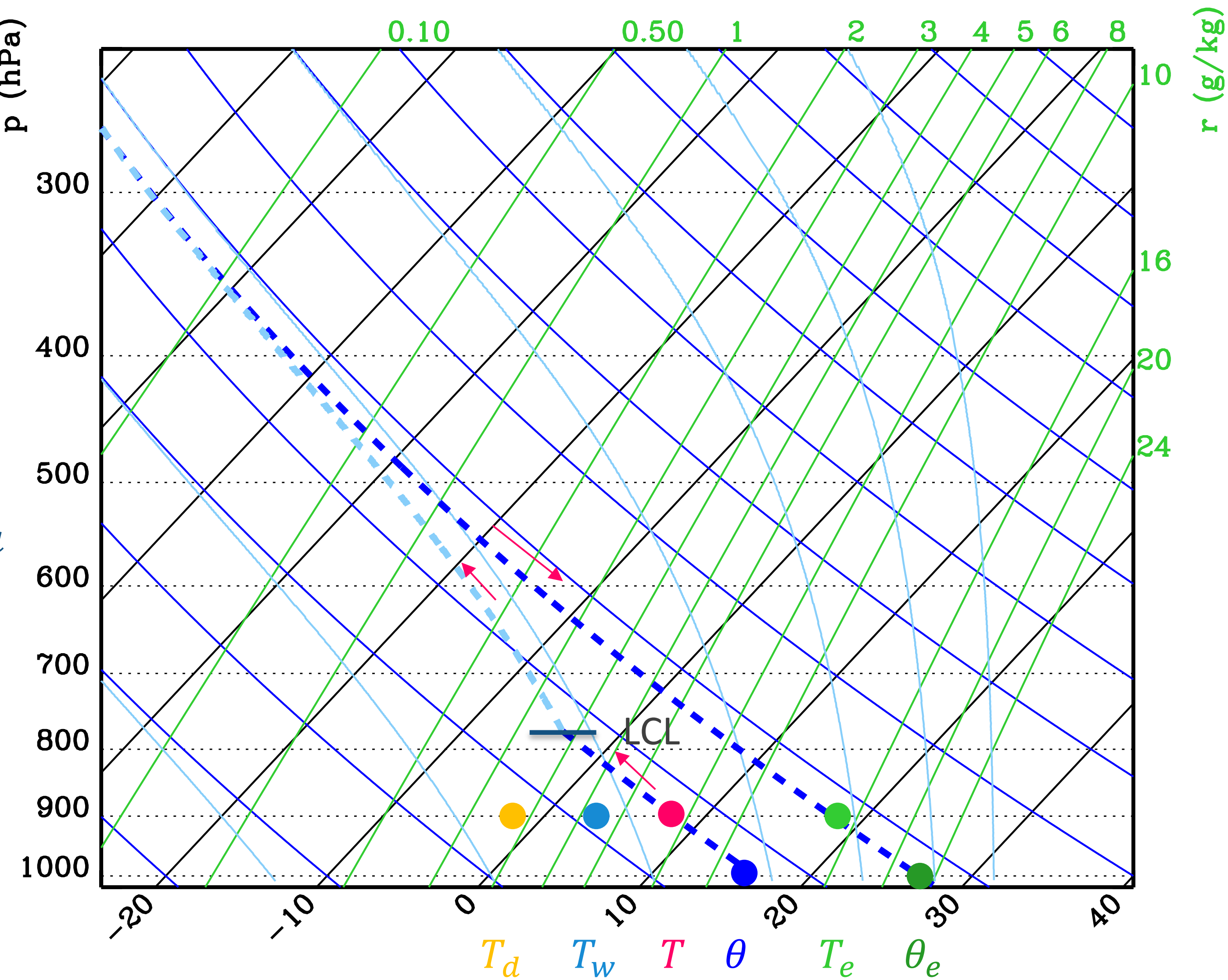
$T_d \approx -2°C$

$T_w \approx -3°C$

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

$\theta \approx 16.6°C$

$T_e \approx 18°C$
$\theta_e \approx 28°C$



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

$T_d \approx -2°C$

$T_w \approx 3°C$

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

$\theta \approx 16.6°C$

$T_e \approx 18°C$
$\theta_e \approx 28°C$

$T_{se} \approx 26°C$
$\theta_{se} \approx 36°C$