Thermodynamic energy eqn. (conservation of energy)

1. Energy conservation for air
2. Internal energy?
3. What is work?

From uspowerandlight.com

Q = ΔU + W

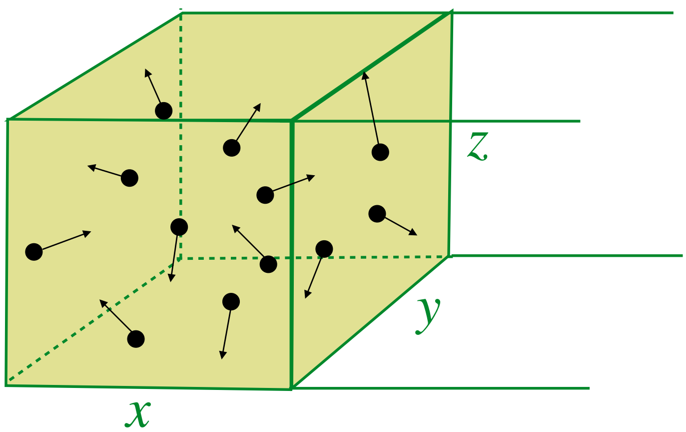
$$c_p \frac{DT}{Dt} - \alpha \frac{Dp}{Dt} = J$$

Conservation of energy

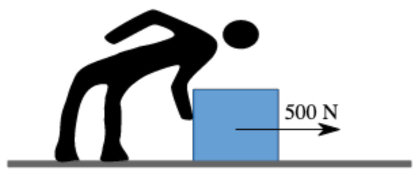
$$\frac{Q}{m} = \frac{\Delta U}{m} + \frac{W}{m}$$

$$c_v \Delta T + p\Delta\alpha = q \qquad (\alpha = V/m)$$

$$(c_v \Delta T + p\Delta v = q)$$



What is work?



From khan academy

$$W = F \cdot \Delta x$$

Conservation of energy

$$Q = \Delta U + W$$

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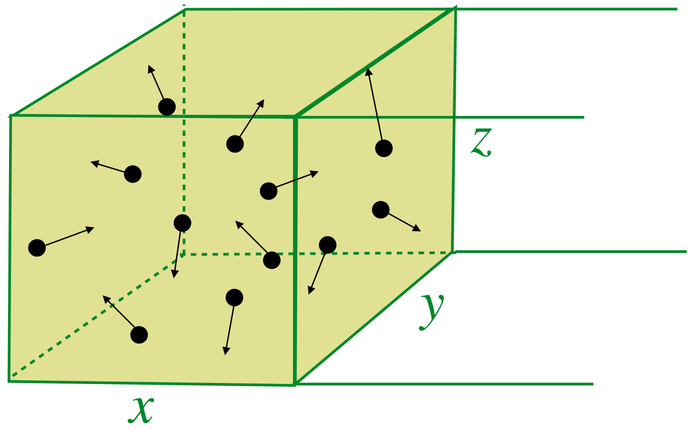
$$(c_v \Delta T + p\Delta v = q)$$



Conservation of energy

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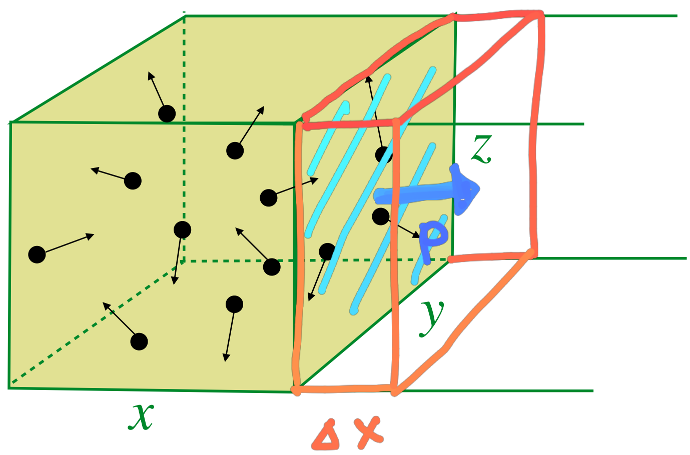

$$F = p \cdot \underbrace{y \cdot z}_{s}$$

$$F \cdot \Delta x = W$$

$$p \cdot \underbrace{y \cdot z \cdot \Delta x}_{\Delta V} = W$$

$$p \cdot \frac{\Delta V}{m} = \frac{W}{m}$$

$$p \cdot \Delta v = \frac{W}{m}$$

Conservation of energy

$$\frac{Q}{m} = \frac{\Delta U}{m} + \frac{W}{m}$$

* *Temperature is simply a measure of internal energy*

$$c_v \Delta T + p\Delta\alpha = q$$

$$(c_v \Delta T + p\Delta v = q)$$

c_v = 717.6 J K^{-1} kg^{-1}
(specific heat at constant volume)

Conservation of energy

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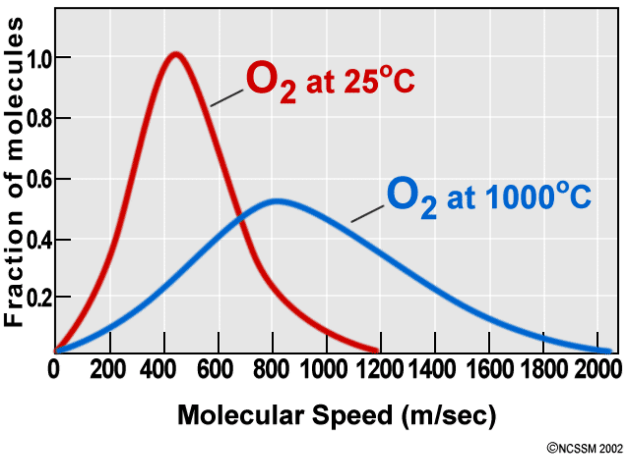
(specific heat at constant volume)

Internal energy

without rotation

$$N\left[\frac{1}{2}m'v^2\right]_{avg} = \frac{3}{2}nR^*T$$

N number of molecules
m' mass of molecule (kg)
n amount of molecules (in moles)
R^* gas constant (=8.314 J $K^{-1}mol^{-1}$)
($N/n = N_A$, Avogadro's number)



(from www.dlt.ncssm.edu)

Conservation of energy

$$\frac{Q}{m} = \frac{\Delta U}{m} + \frac{W}{m}$$

$$c_v \Delta T + p\Delta\alpha = q$$

$$(c_v \Delta T + p\Delta v = q)$$

c_v = 717.6 J K^{-1} kg^{-1}
(specific heat at constant volume)

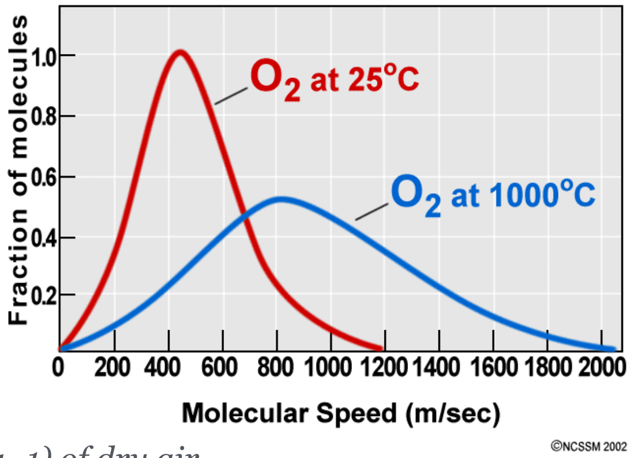
Internal energy

without rotation

$$\frac{[KE]_{avg}}{m} = \frac{3}{2}RT$$

N number of molecules
m' mass of molecule (kg)
n amount of molecules (in moles)
R^* gas constant (=8.314 J K^{-1}mol^{-1})
($N/n = N_A$, Avogadro's number)

R *specific gas constant (=287 J K−1 kg−1) of dry air*
(= R^*/M; M is moler mass of dry air)



(from www.dlt.ncssm.edu)

Conservation of energy

$$\frac{Q}{m} = \frac{\Delta U}{m} + \frac{W}{m}$$

$$c_v \Delta T + p\Delta\alpha = q$$

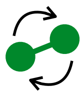
$$(c_v \Delta T + p\Delta v = q)$$

c_v = 717.6 J K^{-1} kg^{-1}
(specific heat at constant volume)

Internal energy

with rotation (two atom molecules)

$$\frac{[KE]_{avg}}{m} = \frac{5}{2}RT$$



N number of molecules
m' mass of molecule (kg)
n amount of molecules (in moles)
R^* gas constant (=8.314 J K^{-1}mol^{-1})
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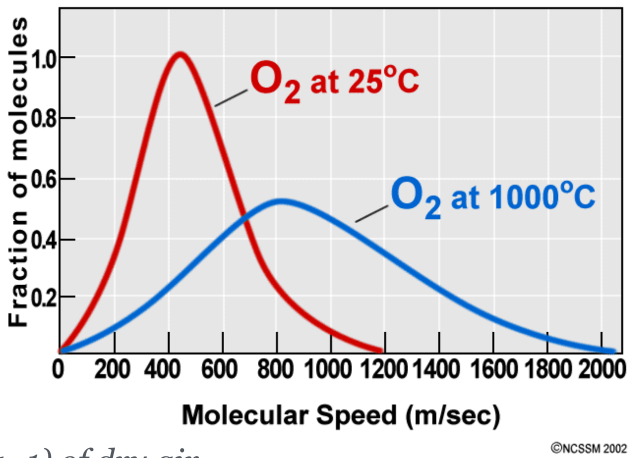


(from www.dlt.ncssm.edu)

Conservation of energy

First law of thermodynamics

For a closed system,

$\Delta U = Q - W$ (or $Q = \Delta U + W$)

Heat supplied from outside (Q) — *change in Internal energy* (ΔU) — *Work done by the system* (W)

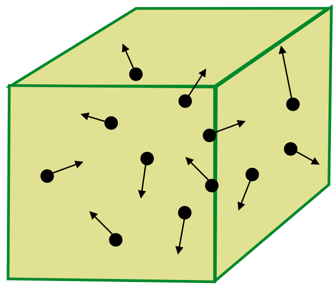
Atmospheric version (ideal gas, per unit mass)

$$c_v \Delta T + p\Delta\alpha = q$$

$$c_v \frac{DT}{Dt} + p\frac{D\alpha}{Dt} = J$$

$$c_p \frac{DT}{Dt} - \alpha\frac{Dp}{Dt} = J$$

popular form $(c_p \Delta T - \alpha\Delta p = q)$



$\Delta U/m = c_v T$
$= (5/2)\, RT$

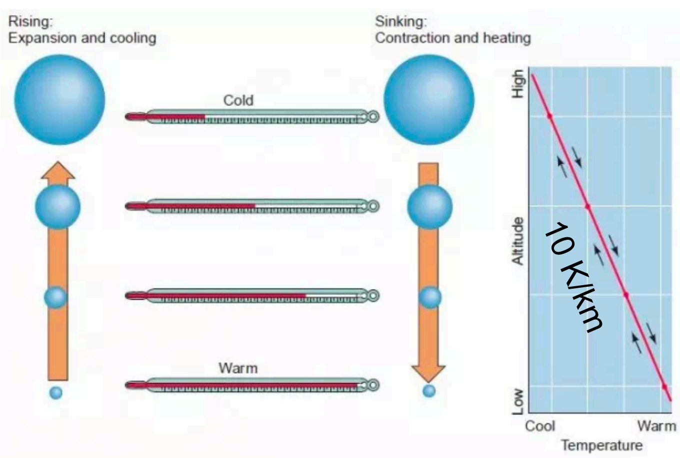
$c_v = 717\ \mathrm{J\ K^{-1}\ kg^{-1}}$
(specific heat at constant volume)

$c_p = 1004\ \mathrm{J\ K^{-1}\ kg^{-1}}$
(specific heat at constant pressure)

Dry adiabatic lapse rate (Γ_d)

For a rising air parcel, temperature decreases ~ 10 K/km

$$\Gamma_d = 10\ K/km$$



4.9 Adiabatic cooling and heating

When air is forced to rise, it expands and its temperature decreases. When air is forced to descend, its temperature increases.

How do we know?

$$c_p \Delta T - \alpha\Delta p = q$$

$$c_p \Delta T = \alpha \Delta p$$

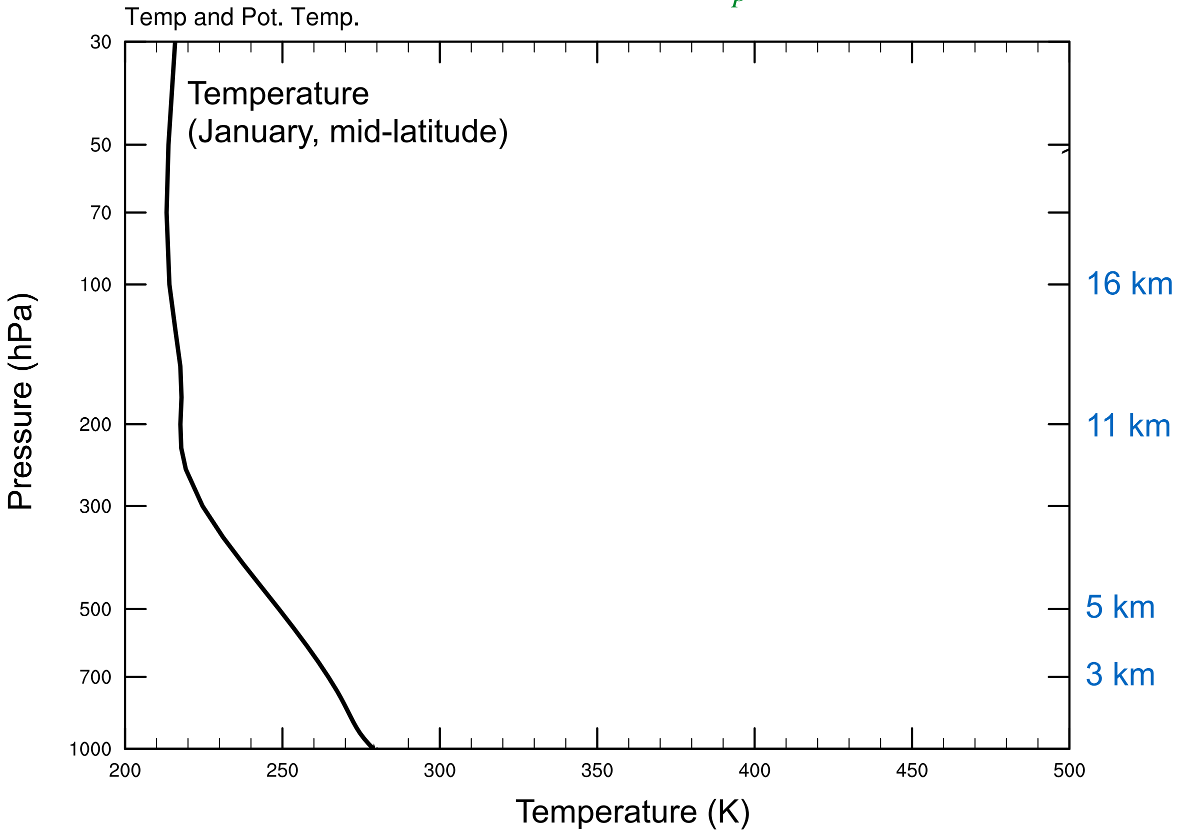
$$= -g\Delta z$$

$$\frac{\Delta T}{\Delta z} = -\frac{g}{c_p}$$

$$\frac{-10\ m/s^2}{1004\ J/kg\cdot K}$$

Potential temperature (θ)

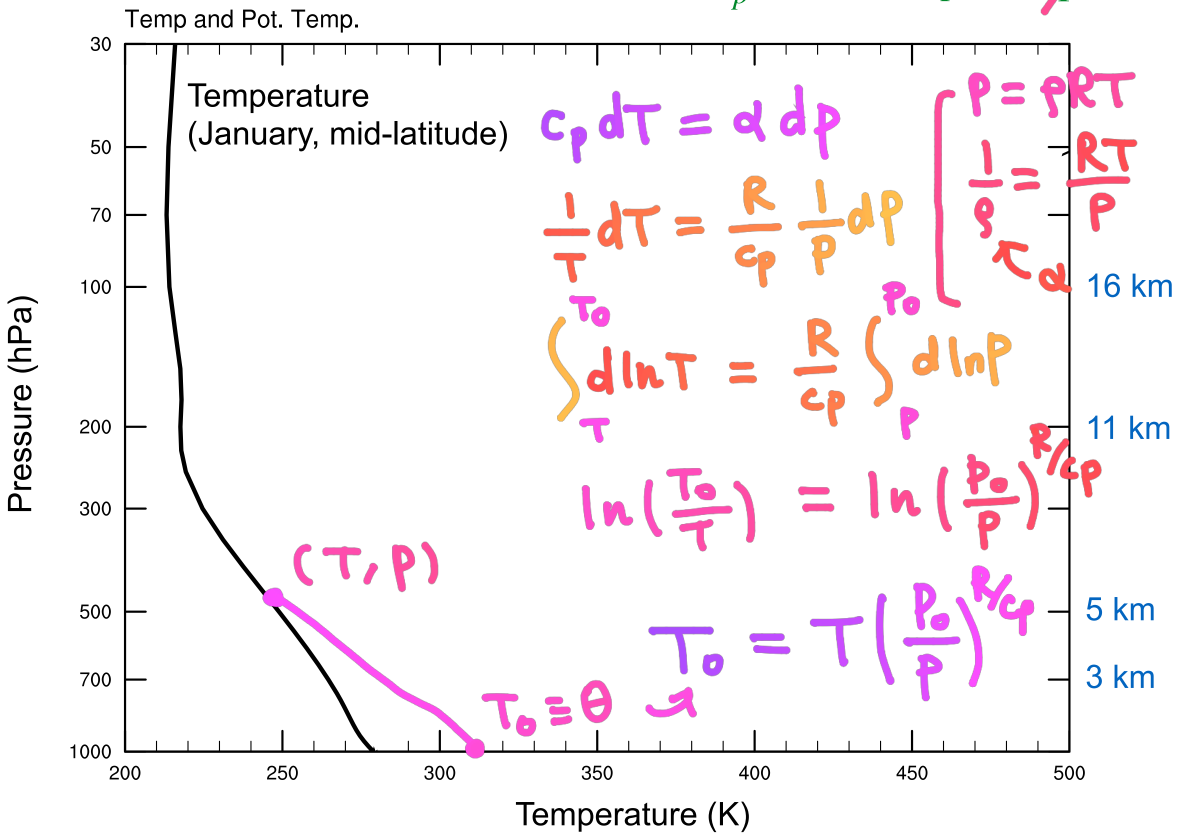
$$c_p \Delta T \; - \; \alpha \Delta p \; = \; q$$



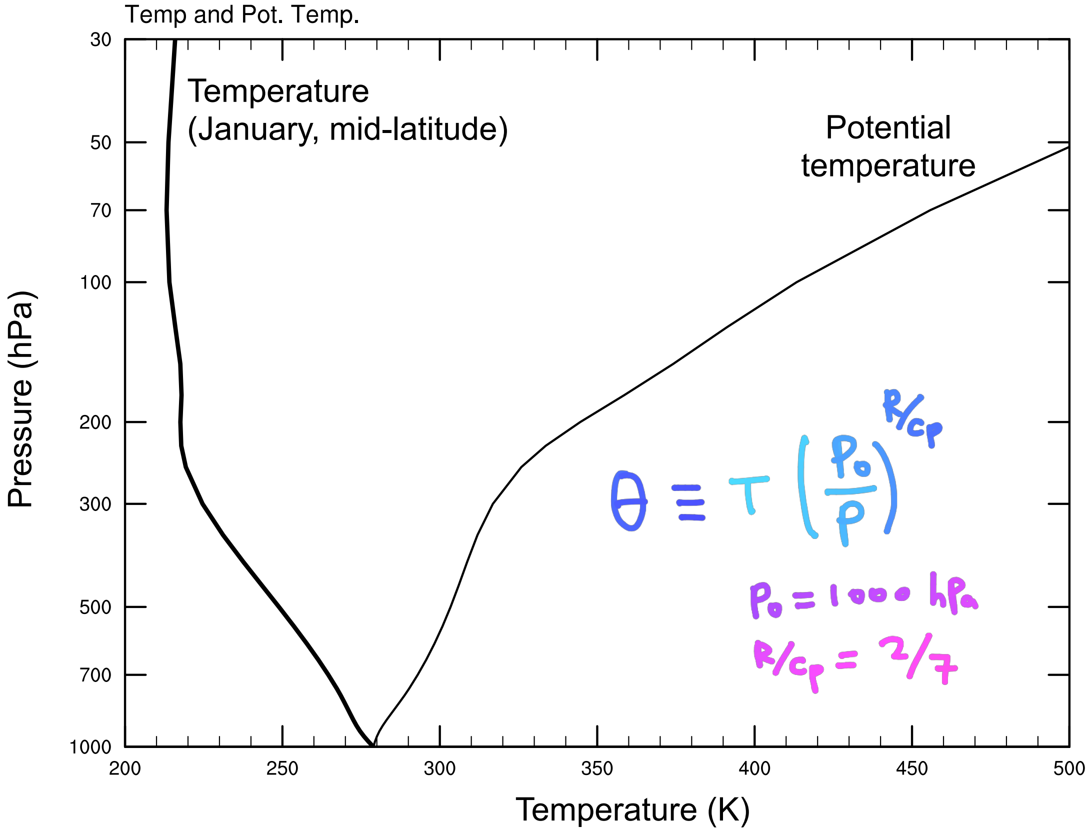
Potential temperature (θ)

$$c_p \Delta T \; - \; \alpha \Delta p \; = \; q$$

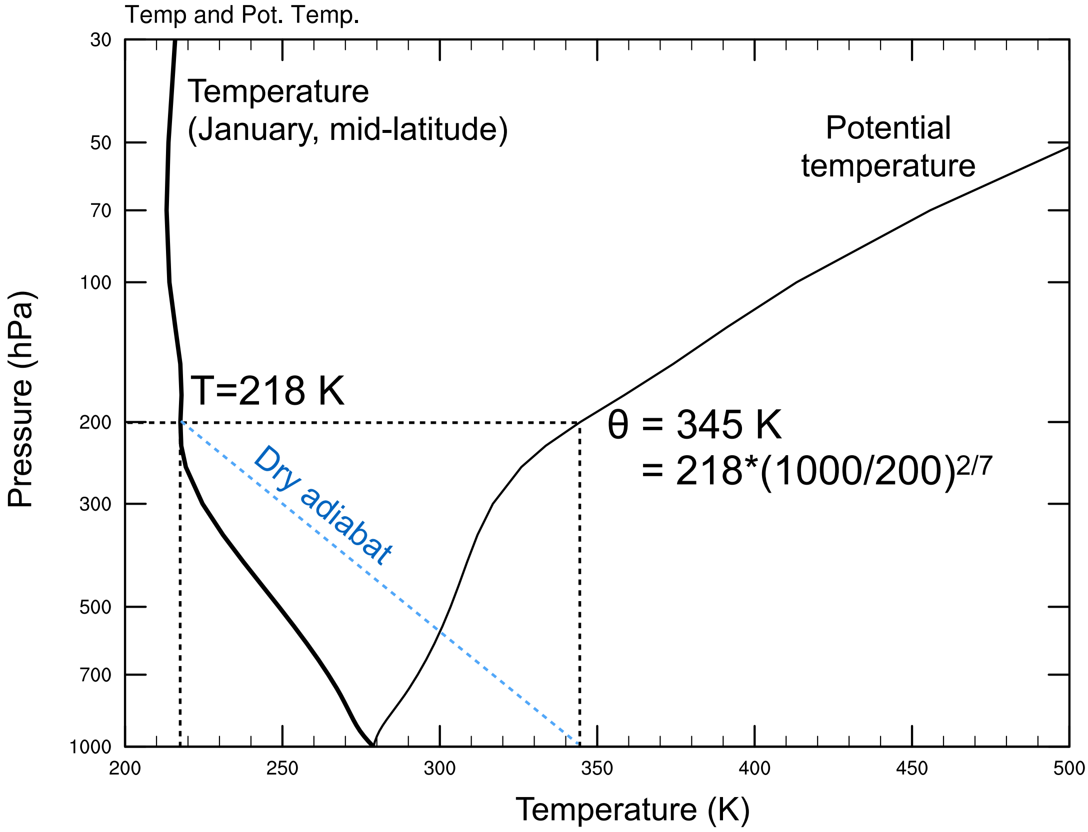
adiabatic



Temperature (T), potential temperature (θ)



Temperature (T), potential temperature (θ)



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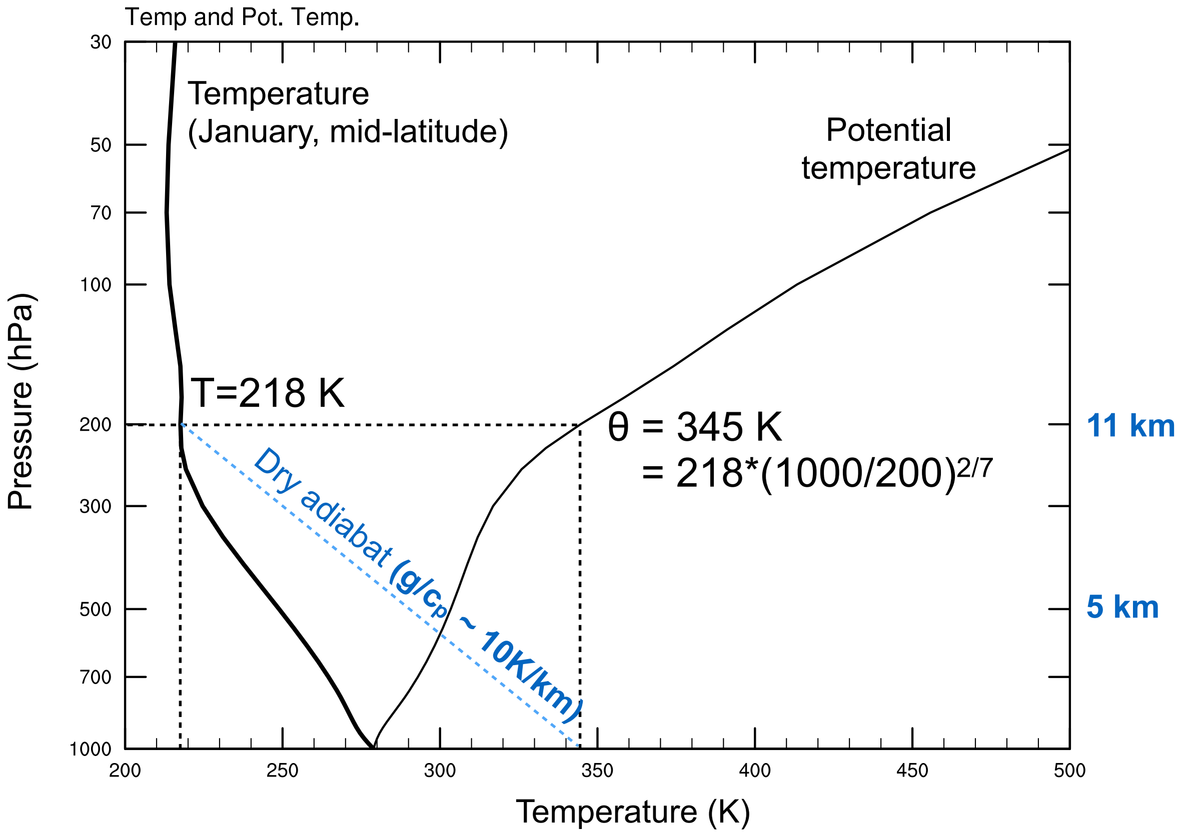
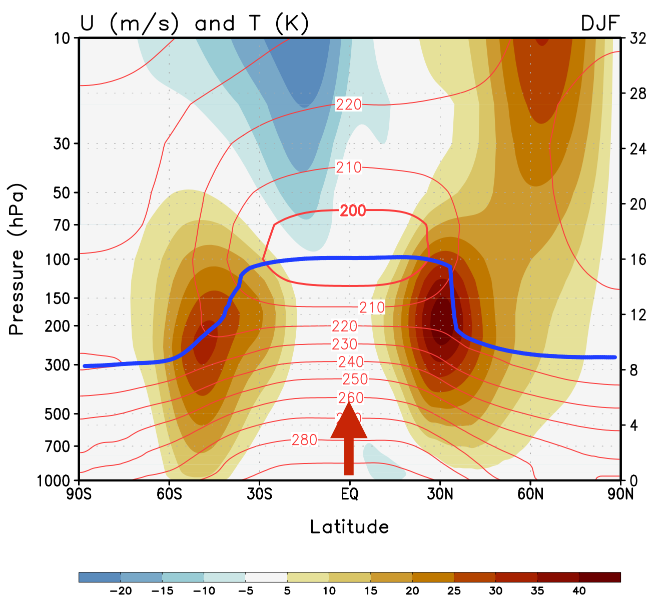
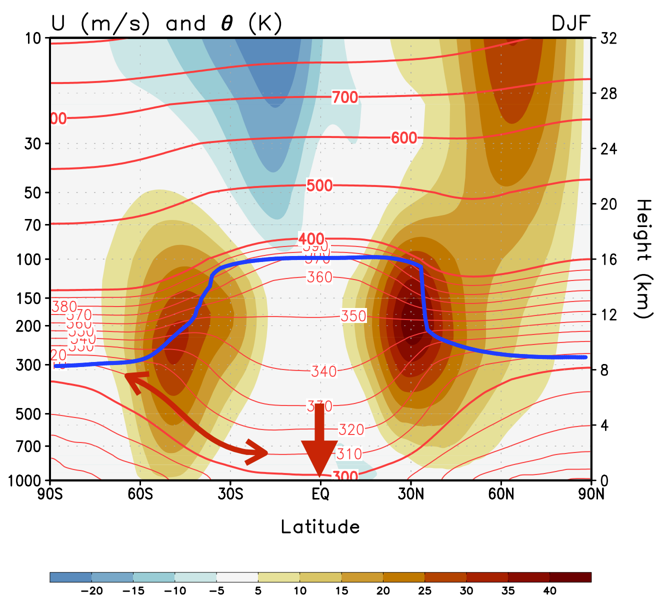


Temperature (T), potential temperature (θ)

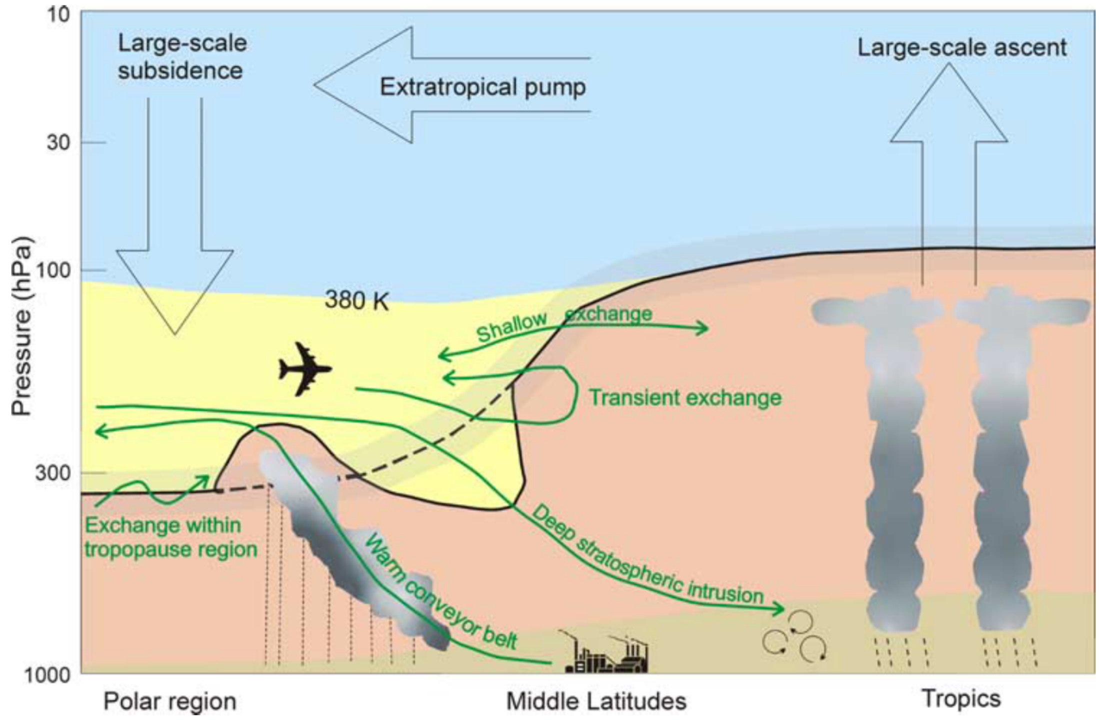




Shading: zonal wind (m/s)
Contour: temperature (K)
Thick line: tropopause

Global transport processes

(stratosphere-troposphere exchange process; STE)



(Stohl et al. 2003)

Transport along **isentrope**
(constant potential temperature surface)