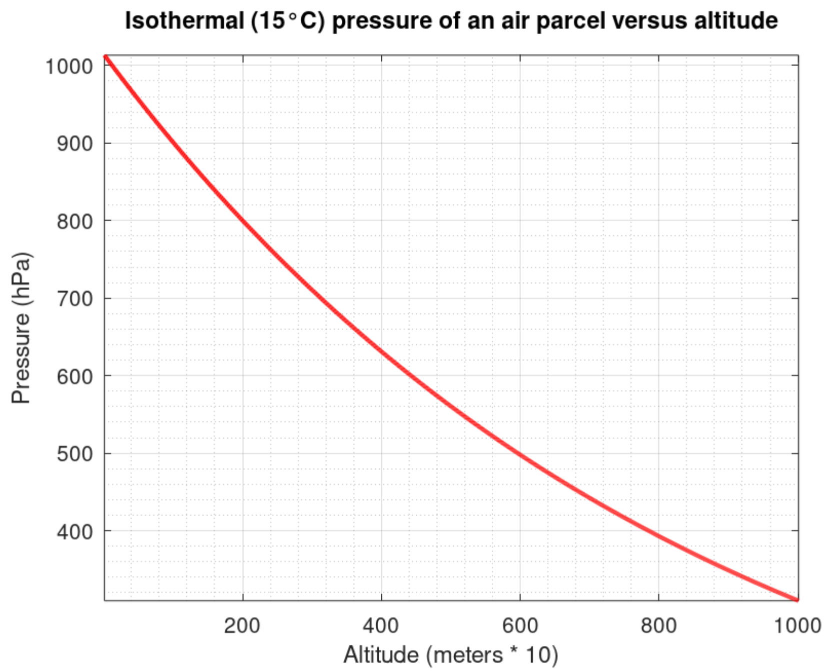
Octave simulation of an Air Parcel (10x10x10 m) rising up in the earth atmosphere from sea level.Three cases are considered : isothermal, adiabatic with dry air, adiabatic with wet air.

1- dry air at a constant temperature (15°C)




```
clc;clear all;format short;format compact;
% Air Composition in mol% : N2 78.084,O2 20.9476,Ar 0.9365,CO2 0.0319
% Universal Constants (S.I. Units) as follows
R  = 8.314472;  % Gas Constant
M  = 0.0289697; % Molar Mass of dry air , Kg/mol
g0  = 9.807;    % Gravity acceleration in m/s^2 on equatorial earth surface
Re = 6.38e06;   % Equatorial earth radius
T  = 273 + 15;  % start temperature of Air Parcel

% ----> Start Simulation : 1000 m^3 of air are considered as 'AIR PARCEL' 10 x 10 x 10 m <----

P = zeros(1000,1); P(1) = 101325;% start pressure @ sea level in Pa , 1 atm.
for h = 1:1000
  % the mass of 1000.0 m^3 of dry air is calculated according to pressure p(h); PV = nRT  ; mass = PVM/(RT)  [kg]
  m1 = 1000*P(h)*M/R/T;
  % the gravity acceleration decreases with altitude, a new is calculated
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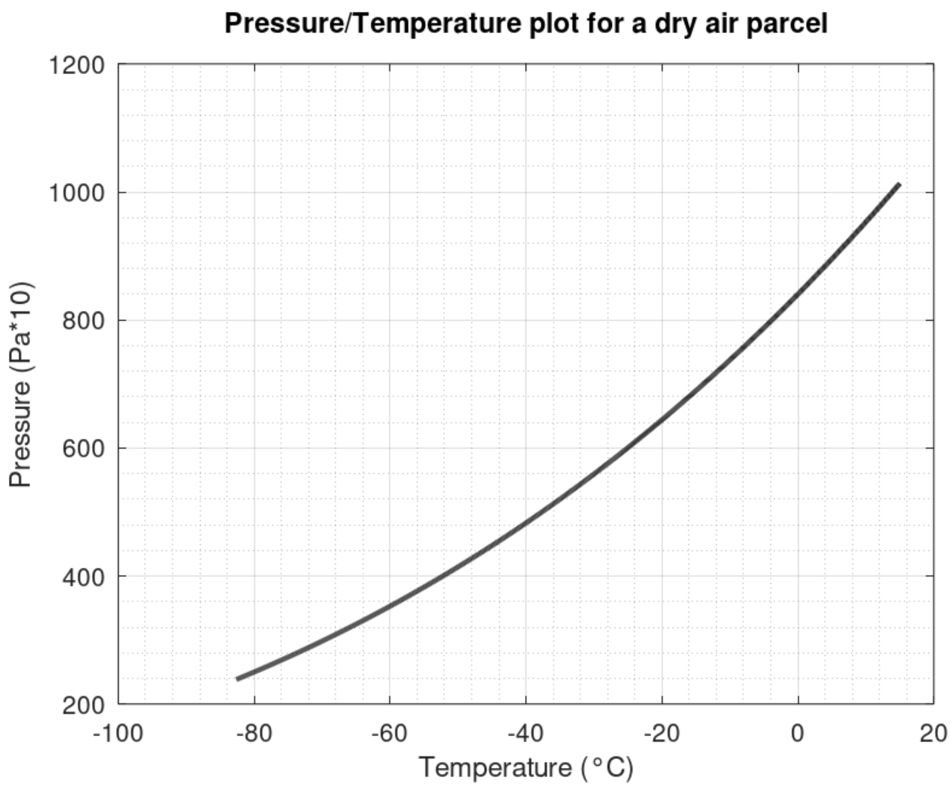
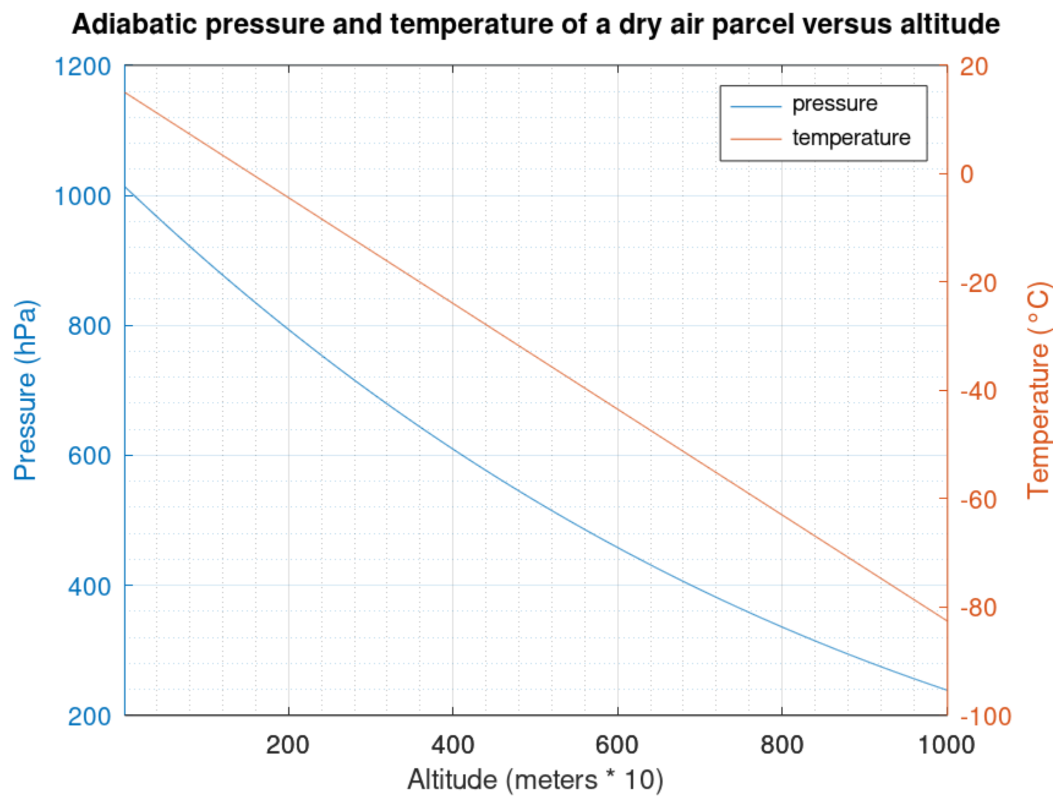
```
  g = g0*Re^2/(Re + 10*h)^2;
  % this mass is transformed in force acting on 1.00 m^2
  f1 = m1*g/100;
  % this force is detracted from the pressure, and a new one is calculated
  P(h+1) = P(h) - f1;
endfor

% ----> End of simulation and graphics <----

plot (P/100,'r','LineWidth',2);grid on;grid minor on;axis("tight");
xlabel('Altitude (meters * 10)');ylabel('Pressure (hPa)');
title('Isothermal (15°C) pressure of an air parcel versus altitude');
```

2 - dry air parcel adiabatic expansion





```
clc;clear all;format short;format compact;
% Air Composition in mol% : N2 78.084,O2 20.9476,Ar 0.9365,CO2 0.0319
% Universal Constants (S.I. Units) as follows
R  = 8.314472;  % Gas Constant
M  = 0.0289697; % Molar Mass of dry air , Kg/mol
g0 = 9.807;     % Gravity acceleration in m/s^2 on equatorial earth surface
Re = 6.38e06;   % Equatorial earth radius
T  = 273 + 15;  % start temperature of Air Parcel
% NASA thermodynamic coefficient for dry air
dry_air = [ 1.009950160e+04,-1.968275610e+02,5.009155110,-5.761013730e-03,1.066859930e-05,...
           -7.940297970e-09,2.185231910e-12,-1.767967310e+02,-3.921504225e+00];

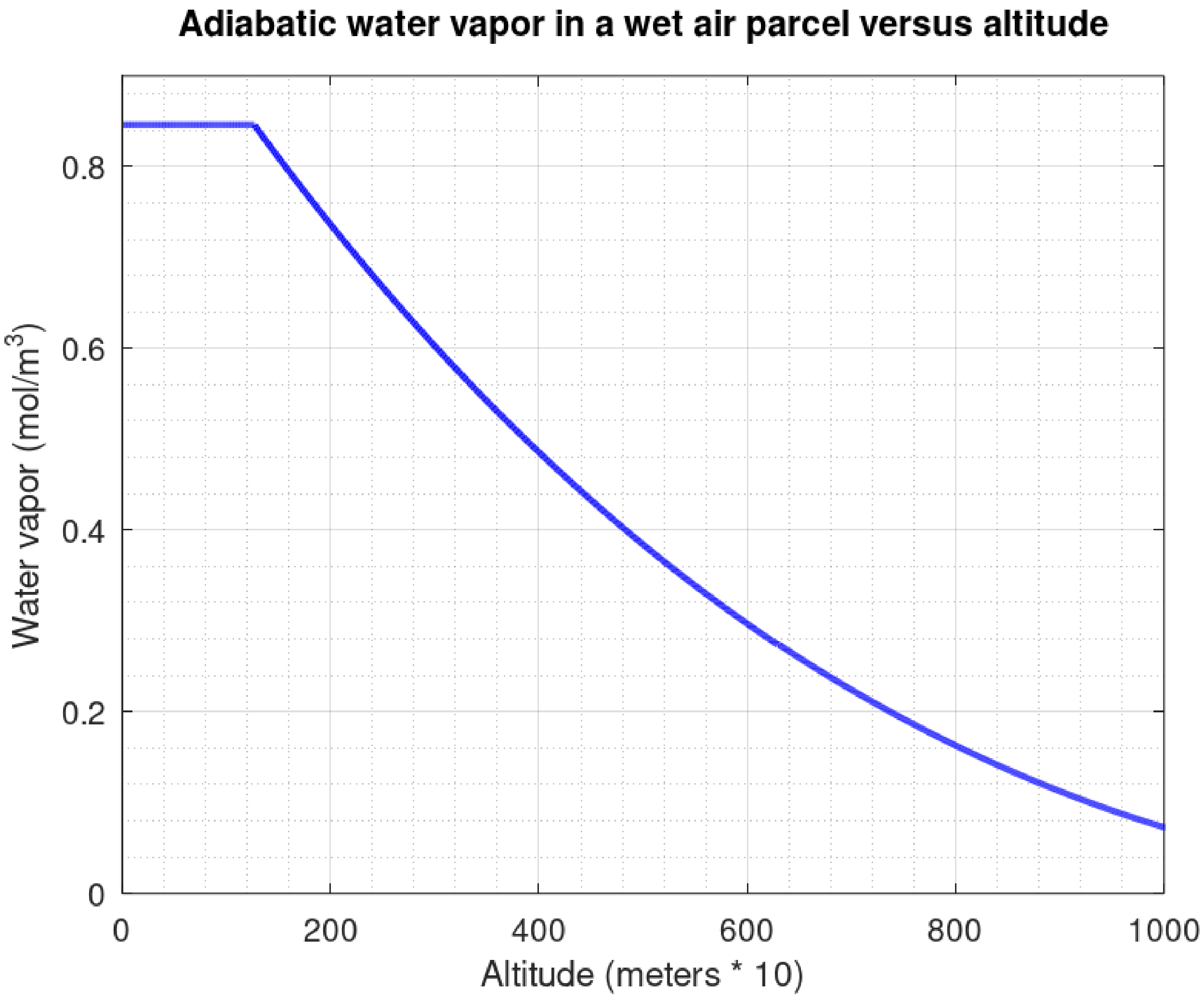
% ----> Start Simulation : 1000 m^3 of air are considered as 'AIR PARCEL' 10 x 10 x 10 m <----

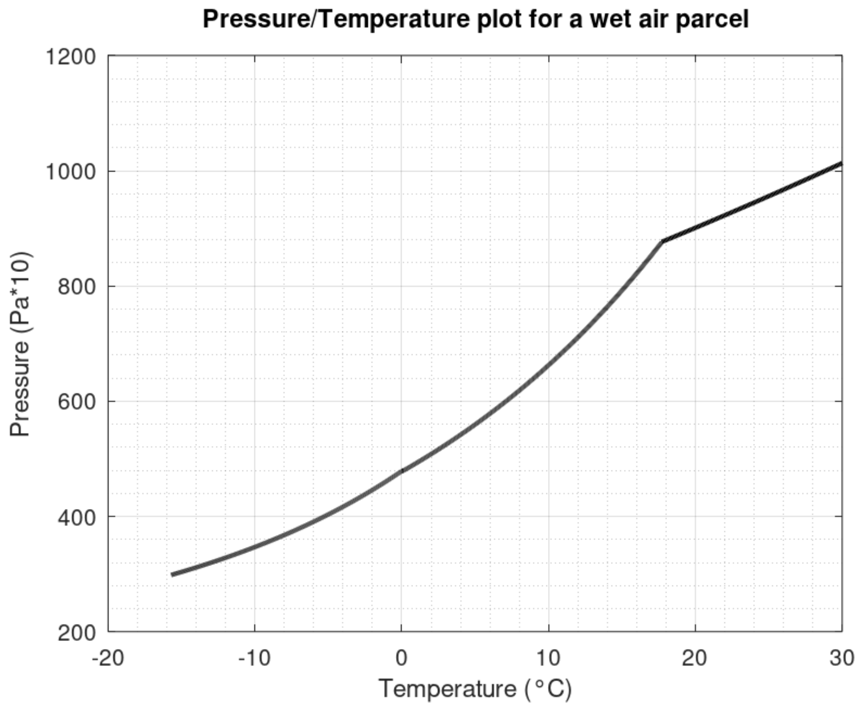
p = zeros(1001,1); P(1) = 101325;% start pressure @ sea level in Pa , 1 atm.
T = zeros(1001,1); T(1) = 288; % start temperature 15°C
for h = 1:1000
  % the mass m1 and moles of 1000.0 m^3 of dry air is calculated according to pressure p(h); PV = nRT  ; mass = n*M
[kg]
  n1 = 1000*P(h)/R/T(h); m1 = n1*M ; % n1 is the number of moles in the air parcel
  % the gravity acceleration decreases with altitude, a new is calculated
  g = g0*Re^2/(Re + 10*h)^2;
  % this mass is transformed in force acting on 1.00 m^2
  f1 = m1*g/100;
  % this force is detracted from the pressure, and a new one is calculated
  P(h+1) = P(h) - f1;
  % Cp is calculated and dT due to expansion adiabatic work is calculated
  Tx = [T(h)^-2,T(h)^-1,1,T(h),T(h)^2,T(h)^3,T(h)^4];
  Cp = R*sum(Tx.*dry_air(1:7));
  deltaT = 1000*(P(h) - P(h+1))/Cp/n1;
  T(h+1) = T(h) - deltaT;
endfor

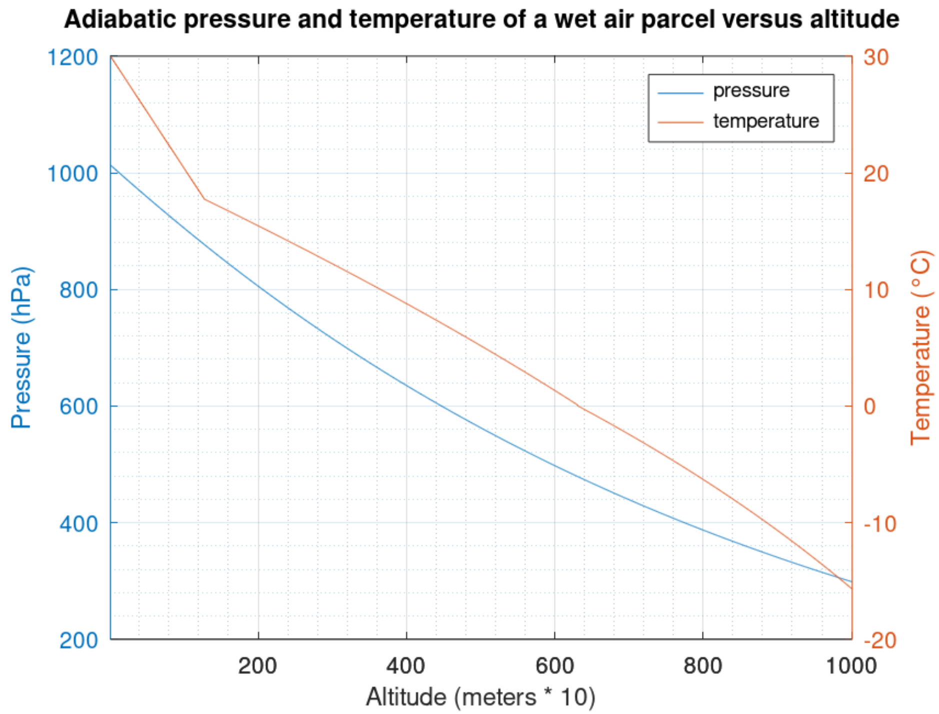
% ----> End of simulation ; graphics <----
x = linspace(1,1001,1001);
ax = plotyy (x,P/100,x,T-273);grid on;grid minor on;
xlabel("Altitude (meters * 10)");
ylabel (ax(1), "Pressure (hPa)");
ylabel (ax(2), "Temperature (°C)");
title("Adiabatic pressure and temperature of a dry air parcel versus altitude");
legend("pressure","temperature");
figure
plot(T-273,P/100,'k','LineWidth',2);grid on;grid minor on;
```

```
xlabel("Temperature (°C)");
ylabel("Pressure (Pa*10)");
title('Pressure/Temperature plot for a dry air parcel');
```

3 – wet air parcel adiabatic expansion (with water condensation)








```
clc;clear all;format short;format compact;
% Universal Constants (S.I. Units) as follows
R  = 8.314472;  % Gas Constant
Ma = 0.0289697; % Molar Mass of dry air , Kg/mol
Mw = 0.018016;  % Molar mass of water , Kg/mol
g0 = 9.807;     % Gravity acceleration in m/s^2 on equatorial earth surface
Re = 6.38e06;   % Equatorial earth radius

load -binary 'interp.bin' m;
P = zeros(1001,1);P(1) = 101325;    % start pressure in Pa
T = zeros(1001,1);T(1) = 273 + 30;  % start temperature
H2O = zeros(1001,1);                % mol H2O(vap) in Air Parcel
Pvap = exp(polyval(m(:,4),T(1)));   % water vapor partial pressure in Pa at T(1), supposed T>273
StartH2O = 50;                      % start relative humidity
H2O(1) = StartH2O/100*1000*Pvap/R/T(1); % mole water at T(1) in the whole Air Parcel
```

```
% <---- Start simulation ---->

for h = 1:1000
  % saturated water pressure Pvap and heat of condensation dH are calculated
  if T(h) <= 273.15                            % SOLID ICE <--> VAPOR
    Pvap = exp(polyval(m(:,2),T(h)));
    dH = polyval(m(:,1),T(h));
  else                                         % LIQUID WATER <--> VAPOR
    Pvap = exp(polyval(m(:,4),T(h)));
    dH = polyval(m(:,3),T(h));
  end
  % number of water moles at saturation
  H2Osat = 1000*Pvap/R/T(h);
  %..does water vapor condense ?
  if H2Osat < H2O(h)        % water vapor condenses, however 50% of due, in a single step (kinetics)
    nC = (H2O(h) - H2Osat)*0.5 % nC is the number of water moles condensing
    H2O(h) = H2O(h) - nC;   % refresh of water vapor
  else
    nC = 0;                 % water doesn't condense
  endif
  H2O(h+1) = H2O(h);
  % the total moles nT of 1000.0 m^3 of wet air is calculated according to pressure P(h); PV = nRT
  nT = 1000*P(h)/R/T(h);
  % the mass of the Air Parcel is calculated
  m1 = Mw*H2O(h) + Ma*(nT - H2O(h));
  % the gravity acceleration decreases with altitude, a new one is calculated
  g = g0*Re^2/(Re + 10*h)^2;
  % this mass is transformed in force acting on 1.00 m^2
  f1 = m1*g/100;
  % this force is detracted from the pressure, and a new one is calculated
  P(h+1) = P(h) - f1;
  % Cp is calculated and dT due to expansion adiabatic work
  Cp = polyval(m(:,5),T(h));
  deltaT = (1000*(P(h) - P(h+1)) - nC*dH)/Cp/nT;% by now Cp refers to dry air
  T(h+1) = T(h) - deltaT;
endfor

% ----> End of simulation ; graphics <----

x = linspace(1,1001,1001);
ax = plotyy (x,P/100,x,T-273);grid on;grid minor on;
xlabel("Altitude (meters * 10)");
```

```
ylabel (ax(1), "Pressure (hPa)");
ylabel (ax(2), "Temperature (°C)");
title('Adiabatic pressure and temperature of a wet air parcel versus altitude');
legend('pressure','temperature');
figure
plot(x,H2O/1000,'b',"LineWidth",2);grid on;grid minor on;axis([0,1000,0,0.900]);
xlabel("Altitude (meters * 10)");
ylabel("Water vapor (mol/m^3)");
title('Adiabatic water vapor in a wet air parcel versus altitude');
figure
plot(T-273,P/100,'k',"LineWidth",2);grid on;grid minor on;
xlabel("Temperature (°C)");
ylabel("Pressure (Pa*10)");
title('Pressure/Temperature plot for a wet air parcel');
```

File **interp.bin** interpolates themodynamic data from NASA-CEA database with a third order polynomial

```
clc;clear all;format short;format compact;
% Universal Constants (S.I. Units) as follows
R  = 8.314472;  % Gas Constant
M  = 0.0289697; % Molar Mass of dry air , Kg/mol
% NASA thermodynamic coefficients
% solid H2O, valid 200 to 273.15 K
H2O_cr = [-4.026777480e+05,2.747887946e+03,5.738336630e+01,-8.267915240e-01,4.413087980e-03,...
          -1.054251164e-05,9.694495970e-09,-5.530314990e+04,-1.902572063e+02];
% liquid H2O, valid 273.15 to 373.15 K
H2O_liq = [1.326371304e+09,-2.448295388e+07,1.879428776e+05,-7.678995050e+02,1.761556813,...
          -2.151167128e-03,1.092570813e-06,1.101760476e+08,-9.779700970e+05];
% H2O gas, valid 200 to 600 K
H2O_gas = [-3.947960830e+04,5.755731020e+02,9.317826530e-01,7.222712860e-03,-7.342557370e-06,...
            4.955043490e-09,-1.336933246e-12,-3.303974310e+04,1.724205775e+01];
% dry air
dry_air = [ 1.009950160e+04,-1.968275610e+02,5.009155110,-5.761013730e-03,1.066859930e-05,...
           -7.940297970e-09,2.185231910e-12,-1.767967310e+02,-3.921504225e+00];
Rx1 = H2O_gas - H2O_cr; % H2O(solid) <==> H2O(gas) 200 --> 273.15
Rx2 = H2O_gas - H2O_liq;% H2O(liquid) <==> H2O(gas) 273.15 --> 373.15

i = 0;
for T=180:273
  TxH = [-1/T,log(T),T,T^2/2,T^3/3,T^4/4,T^5/5,1,0];
```

```
  TxS = [-1/T^2/2,-1/T,log(T),T,T^2/2,T^3/3,T^4/4,0,1];
  % SOLID ICE <--> VAPOR
  DeltaH = R*sum(TxH.*Rx1);DeltaS = R*sum(TxS.*Rx1);DeltaG = DeltaH - T*DeltaS;
  Pvap = 101325*exp(-DeltaG/R/T); % Pvap is the H2O vapor pressure in Pa!!
  ++i;x1(i) = T;y1(i) = DeltaH;y2(i) = log(Pvap);
endfor

i = 0;
for T=273:330
  TxH = [-1/T,log(T),T,T^2/2,T^3/3,T^4/4,T^5/5,1,0];
  TxS = [-1/T^2/2,-1/T,log(T),T,T^2/2,T^3/3,T^4/4,0,1];
  % LIQUID WATER <--> VAPOR
  DeltaH = R*sum(TxH.*Rx2);DeltaS = R*sum(TxS.*Rx2);DeltaG = DeltaH - T*DeltaS;
  Pvap = 101325*exp(-DeltaG/R/T); % Pvap is the H2O vapor pressure in Pa !!
  ++i;x2(i) = T;y3(i) = DeltaH;y4(i) = log(Pvap);
endfor

i = 0;
for T=210:330
  % Cp is calculated (specific molar heat for dry air)
  Tx = [T^-2,T^-1,1,T,T^2,T^3,T^4];
  Cp = R*sum(Tx.*dry_air(1:7));
  ++i;x3(i) = T;y5(i) = Cp;
endfor
m = zeros(4,5);
m(:,1) = polyfit(x1,y1,3);
m(:,2) = polyfit(x1,y2,3);
m(:,3) = polyfit(x2,y3,3);
m(:,4) = polyfit(x2,y4,3);
m(:,5) = polyfit(x3,y5,3);
save -binary 'interp.bin' m
```