Goals for today: Begin Part II – Water in the Atmosphere 5 Oct., 2011

• what does "relative humidity" mean? Why do we speak of the "dewpoint" of air, as well? How are these related? How do these relate to the mass of water per cubic meter, i.e. "absolute humidity"? We'll cover the most useful humidity variables, their inter-relationship, how to calculate one from another

- what is the difference between "saturated" air and "supersaturated air"?
- how can cloud droplets be liquid, yet have a temperature far below 0°C?

Tory web camera, 08:30 MDT	Edmonton Past 24 H	Int'l Airport our Conditions				
Tues 4 Oct. 2011	Imperial Units					
	Date / Time (MDT)	Conditions	Temp (°C)	Humidity (%)	Dew Point (°C)	
	4 October 2011					
	8:00	Fog	5	100	5	
	7:00	Fog	4	100	4	
The second se	6:00	Fog	4	100	4	
	5:00	Fog	3	100	3	
and the second sec	4:00	Fog	3	99	3	
	3:00	Cloudy	5	99	4	
	2:00	Cloudy	3	97	2	

71119 WSE Edmonton Stony Plain Observations at 12Z 04 Oct 2011

71119 WSE Edn PRES HGHT TEMP DWPT RELH MIXR DRCT SKNT THTA THTA THTV 100 1000.0 2 925.0 671 4.4 4.4 100 5.77 260 2 you'll be able to check 200 1000.0 893 7.2 7.2 100 7.13 299 7 200 1000.0 893 7.2 7.2 100 7.13 299 7 300 894.0 948 9.0 8.0 93 7.58 308 7 300 828.0 1373 14.4 -1.6 33 4.02 245 10 300 848.0 1393 14.4 -1.6 33 4.02 245 10 400 775.9 213 11.2 -11.4 19 2.07 200 25 500 5620 1829 13.8 -59 -21.0 26 21.3 210 26 600 726.9 2743 5.9 -12.0														
100 HPa m C C % g/kg deg knot K <	71119	WSE Edn	PRES	HGHT	TEMP	DWPT	RELH	MIXR	DRCT	SKNT	THTA	THTE	THTV	
200 1000.0 2 995.0 671 914.0 766 909.0 811 4.0 3.9 909.0 811 4.0 3.9 909.0 811 4.0 3.9 909.0 811 4.0 3.9 909.0 811 909.0 817.2 7.2 100 897.7 914 900.8 80 897.7 914 897.7 914 897.7 914 900.8 80 897.7 914 900.8 80.0 800.7 1219 1249 124 805.0 1373 14.4 -1.6 33 4.02 245 10 MIXR from TEMP, 0 1524 14.7 -5.8 242 298 210 100 1229 13.8 -11.1 17 2.04 102 26 100 285.0 <t< th=""><th>100</th><th>16260 m</th><th>hPa</th><th>m</th><th>С</th><th>С</th><th>0/0</th><th>g/kg</th><th>deg</th><th>knot</th><th>К</th><th>К</th><th>К</th><th></th></t<>	100	16260 m	hPa	m	С	С	0/0	g/kg	deg	knot	К	К	К	
200 1000.0 2 9925. 671 990.0 811 4.6 3.9 99 5.60 274 4 900.0 893 7.2 7.2 100 7.13 299 7 897.7 914 7.9 7.5 97 7.30 305 8 897.7 914 7.9 7.5 97 7.30 305 8 897.7 914 7.9 7.5 97 7.30 305 8 800 865.7 1219 12.4 1.9 49 5.09 335 1 800 865.7 1219 12.4 1.16 33 4.02 245 10 800 1373 14.4 -1.6 33 4.02 245 10 MIXR from TEMP, DWPT 400 2260 m 834.9 1524 14.7 -5.8 24 2.83 11 DWPT 400 2260 m 729.9 2743 5.9 -12.0 26 2.13 210 24 <td< th=""><th></th><th>NN4</th><th>1000 0</th><th>·</th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th></td<>		NN4	1000 0	·										
200 999.0 811 4.0 3.9 99 5.60 274 4 200 999.0 811 4.0 3.9 99 5.60 274 4 807.7 914.7 7.5 97 7.30 305 8 90.0 833 7.2 7.2 100 7.13 299 7 300 897.7 914 7.9 7.5 97 7.30 305 8 7 humidity figures – by 300 820.0 1373 14.4 -1.6 33 4.02 245 10 computing RELH & 300 820.0 1373 14.4 -1.6 33 4.03 243 10 400 7260.m 884.0 1393 14.4 -1.6 33 4.03 243 10 400 7260.m 759 2134 11.2 11.4 19 2.07 200 25 500 5620.m 720.9 238 1.5 2.10 210 24 . nocturnal radiation inversion <			925 0	ے 671							A ()			
200 900.0 811 4.0 3.9 90 5.60 274 4 you'll be able to check consistency of cited humidity figures – by consistency of cited humidity figures – by computing RELH & NMIXR from TEMP, 12.4 300 884.0 933 12.4 1.9 49 5.60 235 10 400 885.7 1219 12.4 1.9 49 5.09 335 10 400 8850.0 1373 14.4 -1.6 33 4.02 245 10 computing RELH & MIXR from TEMP, DWPT 400 848.0 1393 14.4 -1.6 33 4.02 245 10 MIXR from TEMP, DWPT 400 7220 m 843.9 1529 13.8 -11.1 17 2.04 195 300 500 5620 m 775.9 2134 11.7 23 210 26 -10 30 600 700.9 2987 3.8 -12.0 26 2.13 210 26 -10 30 -10 -10 14 19 207 200 -10 -10 24 <th></th> <th>13680 0 1</th> <th>914 0</th> <th>766</th> <th>4 4</th> <th>4 4</th> <th>100</th> <th>5 77</th> <th>260</th> <th>2</th> <th></th> <th>r toda</th> <th>y's class</th> <th></th>		13680 0 1	914 0	766	4 4	4 4	100	5 77	260	2		r toda	y's class	
200 900.0 893 7.2 7.2 100 7.13 299 7 consistency of cited humidity figures – by computing RELH & some computing RELH & midity figures – by computing RELH & midity figures – by computing RELH & MIXR from TEMP, DWPT 300 8280 1373 14.4 -1.6 33 4.02 245 10 MIXR from TEMP, DWPT 400 8280 1393 14.4 -1.6 33 4.02 245 10 400 8280 1393 14.4 -1.6 33 4.03 243 10 831.9 1524 14.7 -5.8 24 2.98 230 11 400 7260 m 805.0 1829 13.8 -11.1 17 2.04 195 30 500 5620 m 702.0 2134 11.2 -11.4 19 2.07 200 25 600 700.0 2987 3.8 -12.0 26 2.13 210 26 600 620 m 700.0 2987 3.8 -12.2 30 2.15 210 30 <td< th=""><th></th><th></th><th>909.0</th><th>811</th><th>4.0</th><th>3.9</th><th>99</th><th>5.60</th><th>274</th><th>4</th><th>vou'l</th><th>ll be a</th><th>ble to chec</th><th>:k</th></td<>			909.0	811	4.0	3.9	99	5.60	274	4	vou'l	ll be a	ble to chec	:k
200 187 mm 897.7 914 7.9 7.5 97 7.30 305 8 consistency of cited humidity figures – by computing RELH & humidity figures – by computing RELH & MIXR from TEMP, B36.0 300 8280 m 848.0 1393 14.4 -1.6 33 4.02 245 10 computing RELH & MIXR from TEMP, DWPT 400 834.9 1524 14.7 -5.8 24 2.98 230 11 400 7260 m 805.0 1373 14.4 -1.6 33 4.02 245 10 MIXR from TEMP, DWPT 400 7260 m 805.0 1829 13.8 -11.1 17 2.04 195 30 500 5620 m 720.9 2743 5.9 -12.0 26 2.13 210 24 600 700 2987 3.8 -12.2 30 2.15 210 26 - - nocturnal radiation inversion 700 2987 m 3.8 -12.2 30 2.15 210 26 - - shallow saturated layer	~~~		900.0	893	7.2	7.2	100	7.13	299	7	, , , , , , , , , , , , , , , , , , ,			
300 894.0 948 9.0 8.0 93 7.58 308 7 humidity figures – by computing RELH & humidity fi	200	1987 m	897.7	914	7.9	7.5	97	7.30	305	8	cons	sisten	cy of cited	
10480 m 865.7 1219 12.4 1.9 49 5.09 335 1 computing RELH & 300 9220 m 848.0 1393 14.4 -1.6 33 4.02 245 10 MIXR from TEMP, 834.9 1524 14.7 -5.8 24 2.98 230 11 DWPT 400 7260 m 805.0 1829 13.8 -11.1 17 2.04 195 30 500 775.9 2134 11.2 -11.4 19 2.07 200 25 500 5620 m 770.9 2743 5.9 -12.0 26 2.13 210 24 600 720.9 2743 5.9 -12.0 26 2.13 210 24 - nocturnal radiation inversion 700 2987 m 70.9 2743 5.9 -12.0 26 2.13 210 24 - nocturnal radiation inversion 1000 1373 m -0 0 0 0 0 0 0 - nottu			894.0	948	9.0	8.0	93	7.58	308	7	hum	iditv f	iaures — bv	
300 850.0 1373 14.4 -1.6 33 4.02 245 10 Computing RELFIX 300 848.0 1393 14.4 -1.6 33 4.03 243 10 400 834.9 1524 14.7 -5.8 24 2.98 230 11 400 7260 m 865.0 1829 13.8 -11.1 17 2.04 195 30 500 5620 m 775.9 2134 11.2 -11.4 19 2.07 200 25 500 5620 m 7720.9 2743 5.9 -12.0 26 2.13 210 26 600 700.0 2987 3.8 -12.2 30 2.15 210 26 .0 <td< th=""><th></th><th>18488</th><th>865.7</th><th>1219</th><th>12.4</th><th>1.9</th><th>49</th><th>5.09</th><th>335</th><th>1</th><th>000</th><th>nuting</th><th></th><th></th></td<>		18488	865.7	1219	12.4	1.9	49	5.09	335	1	000	nuting		
300 8280 m 848.0 1393 14.4 -1.6 33 4.03 243 10 MIXR from TEMP, 400 834.9 1524 14.7 -5.8 24 2.98 230 11 400 805.0 1687 15.0 -11.0 16 2.03 212 21 DWPT 400 7260 m 775.9 2134 11.2 -11.4 19 2.07 200 25 500 5620 m 720.9 2743 5.9 -12.0 26 2.13 210 24 600 720.9 2743 5.9 -12.0 26 2.13 210 24 700 2987 m 3.8 -12.2 30 2.15 210 26 - nocturnal radiation inversion 700 9987 m 9987 m 9987 m 9987 m - - - shallow saturated layer 900 671 m - 0 0 10 20 30 40 - - -80 -70 - 60 -50 - 40 - 30 - 20 - 10 0		$\nabla X \nabla$	850.0	1373	14.4	-1.6	33	4.02	245	10	COIII	puing	JRELNA	
400 834.9 1524 14.7 -5.8 24 2.98 230 11 400 819.0 1687 15.0 -11.0 16 2.03 212 21 DWPT 400 7260 m 805.0 1829 13.8 -11.1 17 2.04 195 30 500 748.0 2438 8.5 -11.7 23 2.10 210 30 500 5620 m 720.9 2743 5.9 -12.0 26 2.13 210 24 600 700.0 2987 3.8 -12.2 30 2.15 210 26 - nocturnal radiation inversion 700 2987 m 3.8 -12.2 30 2.15 210 26 - shallow saturated layer 900 1373 m - - - - - - - 1373 m - - - 0 10 20 30 40 - - - - 10 0 10 20 30 40 <th>300</th> <th>8280 m</th> <th>848.0</th> <th>1393</th> <th>14.4</th> <th>-1.6</th> <th>33</th> <th>4.03</th> <th>243</th> <th>10</th> <th>MIXI</th> <th>R fron</th> <th>n TEMP,</th> <th></th>	300	8280 m	848.0	1393	14.4	-1.6	33	4.03	243	10	MIXI	R fron	n TEMP,	
400 7260 m 775.9 2134 11.2 -11.4 19 2.07 200 25 748.0 2438 8.5 -11.7 23 2.10 210 30 500 5620 m 700.0 2987 3.8 -12.2 30 2.15 210 26 600			834.9	1524	14.7	-5.8	24	2.98	230	11		эт		
400 775.9 2134 11.2 -11.4 19 2.07 200 25 748.0 2438 8.5 -11.7 23 2.10 210 30 500 720.9 2743 5.9 -12.0 26 2.13 210 24 700.0 2987 3.8 -12.2 30 2.15 210 26 600		$\nabla \nabla X$	819.0	1687	15.0	-11.0	16 17	2.03	212	21				
500 748.0 2438 8.5 -11.7 23 2.10 210 30 500 748.0 2438 8.5 -11.7 23 2.10 210 30 600 700.0 2987 3.8 -12.2 30 2.15 210 26 600 700.0 2987 3.8 -12.2 30 2.15 210 26 700 2987 m - - - - - - nocturnal radiation inversion 700 2987 -	400	7260 m	805.0 775 Q	2134	15.0	-11.1 -11 /	10	2.04	200	30 25				
500 500 720.9 2743 5.9 -12.0 26 2.13 210 26 600 700 2987 3.8 -12.2 30 2.15 210 26 .nocturnal radiation inversion 700 2987 3.8 -12.2 30 2.15 210 26 .nocturnal radiation inversion 700 2987 .nocturnal radiation inversion .shallow saturated layer .shallow saturated layer 900 1373 m .noctor -50 - 40 - 30 - 20 - 10 0 10 20 30 40 .input to the set of the			748 0	2134	85	-11.4	23	2.07	200	20				
500 700.0 2987 3.8 -12.2 30 2.15 210 26 • nocturnal radiation inversion 600 2987 3.8 -12.2 30 2.15 210 26 • nocturnal radiation inversion 700 2987 m -<	500	5 BOOM	720.9	2743	5.9	-12.0	26	2.13	210	24				
600 700 2987 m inversion 800 1373 m 600 • shallow saturated layer 900 671 m • light wind -80 - 70 - 60 - 50 - 40 - 30 - 20 - 10 0 10 20 30 40	500		700.0	2987	3.8	-12.2	30	2.15	210	26	• no	cturn	al radiation	
600 Inversion 700 2987 m 800 1373 m 900 1373 m 671 m 0 2 m 0 600 - 50 - 40 - 30 - 20 - 10 0 10 0 10 -80 - 70 - 60 - 50 - 40 - 30 - 20 - 10 0 10 0 10 -80 - 70 - 60 - 50 - 40 - 30 - 20 - 10 0 10 0 10 20 - 70 - 60 - 50 - 40 - 30 - 20 - 10 0 10 0 10 20 - 70 - 60 - 50 - 40 - 30 - 20 - 10 0 20 - 70 - 60 - 50 - 40 - 30 - 20 - 10 0 20 - 70 - 60 - 50 - 40 - 30 - 20 - 10 0 20 - 70 - 60 - 50 - 40 - 30 - 20 - 10 0 20 - 70 - 60 - 50 - 40 - 30 - 20 - 10 0 20 - 70 - 60 - 50 - 40 - 30 - 20 - 10 0 20 - 70 - 60 - 50 - 40 - 30 - 20 - 10 0 20 - 70 - 60 - 50 - 40 - 30 - 20 - 10 0 20 - 70 - 60 - 50 - 40 - 30 - 20 - 10 0 20 - 70 - 60 - 50 - 40 - 30 - 20 - 10 0 20 - 70 - 60 - 50 - 40 - 30 - 20 - 10 0 20 - 70 - 60 - 50 - 40 - 30 - 20 - 10 0 20 - 70 - 60 -	~ ~ ~		NX		NN	N X	1 / IN/	IN		Æ		·		
700 2987 m	600					Th th	MY/	\Box		7/	inve	ersion		
700 2987/m • shallow saturated layer 800 1373/m • shallow saturated layer 900 671 m • light wind -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 • light wind	700				1 1		$\frac{1}{2}$		\rightarrow	\checkmark				
800 900 1000 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40	700	538X1m /			\mathbf{X}		N//			21	• ob	مالصير	acturated	
900 1373 m 1000 2 m -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40	000				\mathcal{A}			11/1/		¥٧-	• Sh	allow	saturated	
900 1000 	800	1373 m					1100	AU I			laye	er		
1000 2m 01 04 04 04 04 04 04 04 04 04 04 04 04 04	900	071	H_{-}	$-\mathbf{k}$	Δh	$\square A$		V M I		£				
-80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40	1000	0/11					A.V.							
-80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40	1000	2 m 1			17	ľ К	11.14	1777 8	अ/स् ध्		• lig	ht win	d	
-80-70-60-50-40-30-20-10 0 10 20 30 40	00 70 00 50 40 00 10 0 10 00 00 40													
	-80-70-60-50-40-30-20-10 0 10 20 30 40													
122 04 Oct 2011 University of Wyoming	12Z 04	Oct 2011			Univ	versitv	∕of₩	/yomi	ng					

Chapter 5 "Atmospheric Moisture" introduces the water vapour variables

- absolute humidity ρ_v [kg m⁻³]
- vapour pressure (partial pressure of water vapour) e [Pa]

• specific humidity $q = \frac{m_v}{m_v + m_d} = \frac{\rho_v}{\rho} \approx \left(r = \frac{m_v}{m_d}\right)$

Mixing ratio

q, r do not change when parcel of air expands or contracts without condensation/evaporation; nor do they change if parcel warms/cools

How are these inter-related – and why do we need so many?

Ideal gas law for water vapor

$$e = \rho_v R_v T$$

- e , vapor pressure [Pa]
- $ho_{
 m v}$, absolute humidity [kg m⁻³]
- $R_v = 462 [J \text{ kg}^{-1} \text{ K}^{-1}]$, specific gas const. for water vapor
- *T*, temperature [K]

Form is identical to the ideal gas law giving relationship between total pressure, total density, and temperature:

$$p = \rho R T$$

Concept of "equilibrium" (or "saturation") vapour pressure

- A thought experiment... container and contents held at fixed temperature T
- The unique equilibrium value e_s depends only on T, so we write $e = e_s(T)$
- And $e_s(T)$ serves as a "benchmark" against which we may compare the actual vapour pressure of any sample of air





(a)

Nature of the "equilibrium"

• The warmer the "system" the higher the average kinetic energy of the molecules in the liquid layer and the more likely their ability to "bust the bonds" (of electrical attraction – water being a polar molecule) retaining them in the liquid layer

 Mechanism of evaporation? A near surface molecule gets "bumped" by another and escapes – evaporation systematically removes molecules having more energy than average, which is why energy must be supplied to maintain the evaporating surface at constant temperature

• At a higher system temperature *T* there is a greater flux of escaping molecules – and to balance the escape flux we need an increased return flux, which is achieved by having more molecules of vapour above the liquid surface. More (and more energetic) molecules of vapour in the gas volume results in a higher vapour pressure *e*







True vapour pressure *e* and dewpoint T_{d} are in 1:1 relationship



True vapour pressure *e* and dewpoint T_{d} are in 1:1 relationship



the dewpoint

 $T=15^{\circ}C, T_{d}=10^{\circ}C$

T =15°C, *e* =1227 Pa

Same information

$$e = e_s(T_d)$$

RH =
$$\frac{e}{e_s(T)}$$
 = $\frac{12.27}{17.04}$ = 0.72 or 72%

T [°C]	e _s (T) [hPa]
0	6.11
5	8.72
10	12.27
15	17.04
20	23.37

Why call the equilibrium** vapour pressure a "benchmark"?...

- air does not "have" saturation vapour pressure, but has an ACTUAL vapour pressure *e*
- normally e is less than or equal to the "holding capacity at equilibrium" or "benchmark," e_s

Analogy: your bank account allows an overdraft of \$1000. Designate that overdraft limit by the symbol "OL." Different people, or the same person at different times, have different numerical values for the variable whose symbol is OL.

You carry a certain amount of cash ("c", [\$]). Perhaps at noon you have c=1.5 and since you wish to buy a book, you go to an ATM and withdraw \$20, so now c=21.5, until you buy the book. You do not "have" or "carry about" an amount of money OL. OL is, as far as your every day behaviour is concerned, only an idea. The reality in your pocket is the actual amount of cash, c. And OL is only relevant to c in as much as, potentially, you can augment c by drawing on your account, until such time as your account is overdrawn by amount OL.

** The term "equilibrium" v.p. is clearer than "saturation" v.p.

Suppose the surface analysis for 12Z (0600 MDT) indicates that $(T, T_d) = (8, 4) \circ C$. What was the relative humidity outside?

- If outside air was drawn into your house and mixed well inside without addition of water vapour, and if inside temperature was +21 °C, what was the relative humidity inside your house?
- What was the vapour density (ie. absolute humidity, ρ_v) of this inside air?

First, establish the "benchmark" outside, $e_s(T)=e_s(8)=10.72$ hPa Now, establish the actual vapour pressure outside, $e=e_s(4)=8.13$ hPa Then, RH outside was RH=100 e / benchmark = 100 8.13/10.72 = 76%

Inside, the benchmark is $e_s(T)=e_s(21)=24.5$ hPa.

But the actual vapour pressure is just that of the outside air, e=8.13 hPa. So, the RH of the air in the house is RH = 100 8.13/24.86 = 33%

And, the absolute humidity, from the Gas Law, is:

 $\rho_v = e / R_v T = 813 / (462^*(273+21)) = 6.0 \times 10^{-3} \text{ kg m}^{-3} = 6 \text{ g m}^{-3}$

 T °C
 e_s(T)
[hPa]

 4
 8.13

 8
 10.72

 21
 24.86



Humidity calculations

Suppose the surface analysis for 12Z (0600 MDT) indicates that $(T, T_d) = (8, 4) \circ C$. What was the relative humidity outside?

- If outside air was drawn into your house and mixed well inside without addition of water vapour, and if inside temperature was +21 °C, what was the relative humidity inside your house?
- What was the vapour density (ie. absolute humidity, ρ_v) of this inside air?

T ∘C	e _s (T) [hPa]
4	8.13
8	10.72
21	24.86

First, establish the "benchmark" outside, $e_s(T)=e_s(8)=10.72$ hPa Now, establish the actual vapour pressure outside, $e=e_s(4)=8.13$ hPa Then, RH outside was RH=100 e / benchmark = 100 8.13/10.72 = 76%

Inside, the benchmark is $e_s(T)=e_s(21) = 24.5$ hPa.

But the actual vapour pressure is just that of the outside air, e=8.13 hPa. So, the RH of the air in the house is RH = 100 8.13/24.86 = 33% And, the absolute humidity, from the Gas Law, is:

 $\rho_v = e / R_v T = 813 / (462*(273+21)) = 6.0 \times 10^{-3} \text{ kg m}^{-3} = 6 \text{ g m}^{-3}$



Humidity calculations

Suppose the surface analysis for 12Z (0600 MDT) indicates that $(T, T_d) = (8, 4) \circ C$. What was the relative humidity outside?

- If outside air was drawn into your house and mixed well inside without addition of water vapour, and if inside temperature was +21 °C, what was the relative humidity inside your house?
- What was the vapour density (ie. absolute humidity, $\rho_{_{\! v}})$ of this inside air?

T ∘C	e _s (T) [hPa]
4	8.13
8	10.72
21	24.86

First, establish the "benchmark" outside, $e_s(T)=e_s(8)=10.72$ hPa Now, establish the actual vapour pressure outside, $e=e_s(4)=8.13$ hPa Then, RH outside was RH=100 e / benchmark = 100 8.13/10.72 = 76%

Inside, the benchmark is $e_s(T)=e_s(21) = 24.5$ hPa. But the actual vapour pressure is just that of the outside air, e=8.13 hPa. So, the RH of the air in the house is RH = 100 8.13/24.86 = 33% And, the absolute humidity, from the Gas Law, is:

 $\rho_v = e / R_v T = 813 / (462*(273+21)) = 6.0 \times 10^{-3} \text{ kg m}^{-3} = 6 \text{ g m}^{-3}$



Our common measures of humidity...

1) RH = 100
$$\frac{e}{e_s(T)}$$

- 2) Vapour pressure deficit (V.P.D.) $e_s(T) e_s(T)$
- 3) Temperature-dewpoint spread $T T_d$

... all relate back to this "benchmark," whose definition appeals to a plane surface of liquid water. But in the atmosphere, where is this plane surface of free water?... Absent!

Condensation in the atmosphere does not necessarily occur at RH=100%

Condensation may commence at RH < 100% onto tiny "hygroscopic" (waterseeking) particles, e.g. sea-salt ("condensation nuclei")

... or, condensation in a very clean atmosphere might not commence until RH > 100% ("supersaturation")

Necessary relative humidity of air to cause formation of liquid water droplets in atmos - the curvature effect



Assume a pure droplet of radius *R* which is at same temperature *T* as air around it. What is the numerical value of the vapour pressure *e* around the droplet necessary to ensure equilibrium? Is it equal to $e_s(T)$?

No.

Equilibrium can only occur if $e > e_s(T)$, a condition called "supersaturation". The smaller the drop radius, the larger the supersaturation necessary to ensure equilibrium (Fig 5-12).

"If the atmosphere were devoid of aerosols, condensation would occur only by *homogeneous nucleation*, in which droplets form by chance collision" - such droplets are initially small, and so only possible with a high level of supersaturation (p147)

Necessary relative humidity of air to cause formation of liquid water droplets in atmos - the curvature effect



Explanation? The surface area $(4\pi R^2)$ to volume $(4/3 \pi R^3)$ ratio of a spherical particle is 3/R and so goes to infinity as radius R becomes small... so very easy for liquid water to escape from small droplets

Necessary relative humidity of air to cause formation of liquid water droplets in atmos - the solute effect

Now assume an impure droplet of sufficiently large radius R that the curvature effect can be neglected. Again, let it be at same temperature T as air around it.

What is the numerical value of the vapour pressure **e** around the droplet necessary to ensure equilibrium?

Equilibrium occurs at $e < e_s(T)$. Solutions require less vapour above the surface to maintain equilibrium.

Explanation? The solute molecules substitute for water molecules, so there are fewer water molecules adjacent to the surface and able to escape.





"under most circumstances" (p147-8) the solute effect and curvature effect approximately cancel, and condensation *normally* occurs at RH slightly below 100%