Course Name: An Introduction to Climate Dynamics, Variability and Monitoring

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HUMIDITY MEASUREMENTS AND PRESSURE MEASUREMENTS

Class and welcome to another lecture in Climatic Dynamics, Climate Variability and Climate Monitoring. In the previous class, we were discussing methods by which humidity of air can be measured. The measurement process is called hygrometry and humidity measuring instruments are called hygrometers in general. We discussed mechanical hydropower hygrometers which uses things like hair to measure the relative humidity as well as electronic hygrometers which include hygristors where the relative humidity is correlated with changes in electrical resistance of the material and humicaps where which respond to relative humidity changes by changes in capacitance. There is another method to measure humidity and this method uses temperature and such humidity measuring instruments are called psychrometers. So psychrometers measure humidity from temperature differences between dry bulb and wet bulb air temperature.

Now what is dry bulb temperature and what is wet bulb temperature? Dry bulb thermometer is a typical air thermometer of any type which as you recall we ensure that the temperature sensor or the temperature bulb is not in contact with any moisture or rainfall. Wet bulb thermometer sensors are opposite. Their sensor bulb is covered by a wetted cotton or a muslin cloth As the water evaporates from the cloth, it extracts heat from thermometer bulb thereby reducing the measured temperature. So, the rate of heat extraction is dependent on the rate of evaporation of water from this wetted cotton fabric, which in turn depends on the relative humidity of air.

The relative humidity of air is high, the evaporation rate will slow. So, the heat extraction will also slow down and the wet bulb temperature will approach that of the dry bulb temperature. Whereas, if the air is dry with low relative humidity, you will have significant evaporation rates and hence the wet bulb temperature will be significantly lower than the dry bulb temperature. Hence, the difference between the dry bulk and the wet bulk temperature is proportional to the inverse of relative humidity. In general, we can arrive at a correlation that correlates the vapor pressure of air at the given temperature T being equal to the saturation vapor pressure at the measured wet bulk temperature value So, the wet bulb thermometer will measure a certain air temperature.

The saturation vapor pressure at that wet bulb temperature using the Clausius Clapeyron relation which we discussed much earlier when we were discussing humidity and humidity measures in class, that value minus a factor A into the air pressure into the difference between dry bulb and wet bulb temperature.

$$e(T) = e_{sat}(T_{wb}) - Ap(T_{db} - T_{wb})$$

So, the actual vapor pressure equal to saturation vapor pressure at the wet bulb temperature value minus a factor A into the ambient pressure into the difference between the dry bulb and wet bulb temperature. This A into p can be correlated, this A value we can correlate for different types of dry bulb temperature measurement. Usually, Stevenson's screen thermometers also have a wet bulb thermometer inside of them. For them, A into p is given by 0.8 P by 1000, where p is measured in hectopascals and A is measured in Kelvin units. So, if pressure is measured in hectopascals, then the value of A is 0.8 into 24 minus 3. for Stevenson screen thermometer instruments. For force ventilated psychrometers, a common example is the Assmann psychrometer we will see in the next slide.

$$Ap = \frac{0.8p}{1000} \quad p\ in\ hPa, A\ in\ K^{-1}$$

Here we have a forced ventilation system. The A is 0.667 into 10 to the power minus 3. So, different wet bulb thermometer types will have different air factors, but using that we can evaluate the vapor pressure of air at the measured dry bulb temperature value. So one common type of psychrometer that is used is called the Assmann psychrometer.

$$Ap = \frac{0.667\ p}{1000}$$

A picture has been shown here. This uses polished metal shields to protect the thermometers from radiation. We have two thermometers here, a wet bulb and a dry bulb thermometer. and applies a forced ventilation by a clockwork motor. There is a clockwork motor working here which allows air circulation inside to reduce the radiation correction.

And this is an example of the inside of a Stevenson screen thermometer which contains a dry bulb thermometer and a wet bulb thermometer acting together. There are other thermometer measurements also which shows kind of the vertical variation of temperature with the inside of the screen. So, using such systems we can evaluate the measurements of dry and wet bulb temperature for various relative humidity values. So, for a given air temperature T, suppose the air temperature T is 20 degree centigrade, then at a relative humidity value of 15 percent, which is quite dry air, you see that the difference between the dry bulb temperature and the wet bulb temperature is around 12 degree centigrade, 11 to 12 degree centigrade. Whereas, if the relative humidity is 70 percent, then the difference is around 4 degree centigrade and 20 degree centigrade.

So, these curves can help you evaluate the relative humidity value given the measurement of the dry bulb and the wet bulb temperature. So, suppose you say that your dry bulb temperature is 10 and the difference between dry bulb and wet bulb temperature is say around 3. So, 3 and 10 it is around 60 percent relative humidity. So, that is how these curves can be used to evaluate the relative humidity concentration of air. Finally, we give you a table where the different humidity sensors are compared with each other.

A few we have not covered like chemical absorption based relative humidity sensor and dew point meters. Other types of hygrometers and psychrometers we have covered. First of all, psychrometers, the accuracy is around plus minus 5% RH. So, again here, the values are somewhat inaccurate. But its time response is very good, around 1 meter.

So, the various time responses and the various accuracy percentages are shown in this table. Next up, we will discuss how to measure pressure. So as you know, pressure is a very important atmospheric variable. The main challenge in measuring pressure is accuracy and resolution. So, atmospheric pressure varies exponentially with altitude, as you all know, starting from around 10 to the power 5 hectopascals and decreasing up to 3 orders of magnitude to nearly 100 hectopascals towards the top of the stratosphere.

So, if you are actually looking at altitude based pressure measurement, which is very important to evaluate the various pressure charts that we have seen in the climatological classes that we have done before, you need a pressure sensor which can give accurate results over a range spanning three orders of magnitude, which is a challenging task. Furthermore, the required measurement accuracy must be of the order of 0.1 hectopascals as small changes in pressure have a large impact on weather front development. So, not only do we have to measure pressure from 10 to the power 5 hectopascals to 100 hectopascals, the accuracy should be less than 0.1 hectopascal which is quite a tall order.

The pressure measuring devices are called barometers. They are of two types, a liquid, usually a mercury barometer, and a non-liquid, usually called an aneroid barometer. So, barometer is a pressure measuring device made up of two types, liquid barometer and aneroid barometer. And we have something called the barograph which is an instrument that can continuously measure and record pressure in readouts and charts. So, first we will look into the liquid barometer or a mercury barometer.

In a mercury barometer is a liquid barometer that measures pressure by determining the height of the liquid column in a sealed and evacuated feed. So, we have here as you can see a sealed and evacuated tube which is dipped inside a container containing the liquid of choice, usually mercury. The atmospheric pressure acts on the free surface of this mercury liquid and since there is no atmospheric pressure inside the tube, the mercury column rises till the weight of the mercury column is balancing the pressure force acting on the free surface of the mercury outside of the tube. Hence, the absolute pressure of atmosphere Pa is equals to the height of this mercury column into the density of this mercury column into the gravitational acceleration g. This is, as you can see, is a relatively simple principle by which absolute pressure of atmosphere can be determined at any given altitude.

One of the concerns here is the pressure measurement here is a multiplication of three individual measurements. The height that you are measuring by either a manually or through a readout, the density of mercury which you should know very well and the gravitational acceleration at that altitude. Remember, g will change with altitude. that change in g will also have to be factored in. Density of mercury will change with temperature, so the local temperature will have to be well, also have to be measured to evaluate the density of mercury at that specific temperature and the height also has to be accurately measured.

Of pressure measured this way, del P by p, the relative accuracy is the square root of the sum of the squares. So, it is a root mean square of the relative error or height, density and gravitational constant. And remember del P by p has to be less than 10 to the power minus 4. So del H by H, del rho by rho and del g by g also have to be accurate to less than 10 to the power minus 4 to get the desired level of accuracy which is quite challenging. Here mercury has certain advantages.

$$\frac{\delta P}{P} = \sqrt{\left(\frac{\delta h}{h}\right)^2 + \left(\frac{\delta \rho}{\rho}\right)^2 + \left(\frac{\delta g}{g}\right)^2}$$

Mercury is a dense liquid and hence the liquid column height remains reasonable. It has low vapour pressure and hence can maintain a very good vacuum. which makes the height based correlation here correct. If it had a very high vapor pressure, then this evacuated space would have the vapors of that liquid which would have added additional pressure force at the top of this liquid column which would be hard to properly account for. Also, mercury is easily cleaned, does not wet glass and is easily readable.

However, one of the main problems with a mercury-based barometer system or any liquid barometer system in general is it has low portability. Of course, it is made of liquid which makes it not very large rugged. Mercury also has appreciable thermal expansion and hence needs a constant temperature environment in which to measure the pressure. If the temperature changes too much, you need to have the exact correlation of temperature with density and exact measurement of temperature as well. Considerable liquid volume is needed and mercury is a toxic liquid.

A common type of mercury barometer used is a Q pattern barometer which has been shown here. And this is a kind of the vernier dial that has been shown here. It contains a mercury storage system, a vernier scale to get the height more accurately and a thermometer is inbuilt into this barometer for temperature measurement and the corresponding correction of the mercury expansion factor. Next, we discuss aneroid barometer that is barometer that do not use a liquid column to measure pressure. Aneroid barometers usually use a thin metal chamber or diaphragm with a membrane which deforms under pressure differences.

So, it is made up of a thin metal chamber or diaphragm containing a membrane which deforms under pressure differences. The deformation can be measured mechanically or electronically. The metal capsule or diaphragm is evacuated and that is how the pressure differential can be measured. If both sides have the same pressure, then there would not have been a differential force that is deforming that membrane. But because one side is evacuated, it feels the pressure from the other side which deforms the membrane and the elastic modulus of the material allows it to be distorted by the atmospheric pressure changes by a repeatable amount.

Because the material is elastic within a certain band, it can go back to its original configuration once the pressure is removed. Measurements of deformation can be measured electrically through changes in capacitance and inductance. So, once again the deformation can be transported into a signal in capacitance or inductance or mechanically via pointer displacements. So, this is the idea here. This is the pressure and this causes a vertical deformation.

If there is a capacitance inside this aneroid capsule, then the distance between the capacitance plates are changing due to the change in pressure, which is causing a change in capacitance. Similarly, an inductance band system is by displacing a permeable core within a coil of wire, creating a change in the inductance. So, here you have a wire coil and there is a core and that core is changing in dimension and hence the inductance is also changing which becomes the signal in an inductance based aneroid barometer. In a barograph, multiple aneroid capsules are connected in series to increase the sensitivity of pressure changes. So, you have multiple aneroid capsules one after another.

You can see here, you have each of these are individual. aneroid capsules which are placed in series to increase the sensitivity to pressure changes. Barographs are not very accurate, plus minus 1 hectopascals is its accuracy, but they can be used to maintain a continuous pressure record at a given location. Even if they are not very accurate, because barographs can automatically measure and record pressure, it can be used to have a continuous pressure record in a given location. Aneroid sensors can be made very cheaply and hence are widely used in domestic wall barometers, in pressure altimeters and barograms.

Some other types of aneroid barometer include the flexible diaphragm sensor. which is a variant of the aneroid barometer, detects the flexing of a thin silicon diaphragm, there is a thin silicon diaphragm inside, and associated change in capacitance caused by separation of the diaphragm and the metal plate distance. This is basically this system here. Small and light sensors used in radiosondes, which are used for upper air measurements, those things have flexible diaphragm sensors for measuring pressure with altitude, because these are small and light and cheap. Finally, we have vibrating cylinder barometer which is a highly accurate type of pressure measuring barometer.

These sense pressures based on change in natural frequency of oscillation for a thin walled cylinder whose insides are open to the atmosphere. So, this is the cylinder. It is a thin walled cylinder. The inside is open to the atmosphere and the outside is enclosed within a vacuum.

So, there is a pressure differential. Now, this thin walled cylinder is vibrating in its natural oscillation frequency. You know resonance frequency, that is the natural oscillation frequency. These cylinders will have it. That is vibrating in its natural oscillation frequency. And these oscillations are excited by magnetic forces coming from electromagnetic coils around the cylinder.

So, the cylinder is wrapped with electromagnetic coils and magnetic forces generated by this coil give the force necessary to have the cylinder vibrating in its own natural frequency. However, as the pressure inside the cylinder changes, the natural frequency also changes and hence the vibration frequency changes. So, we can get a relationship between the vibration frequency and the pressure inside the cylinder. High resolution of 0.01 hectopascals and high accuracy of plus minus 0.05 hectopascals can be obtained by the vibrating cylinder barometer system. So, we will stop this week here. We will continue our discussion with wind measurements and wind measurements of both magnitude and direction in the next class. Thank you for listening and see you again in the next class.