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

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AUTOMATIC WEATHER STATIONS, TEMPERATURE MEASUREMENTS AND HUMIDITY MEASUREMENTS

Good morning class and welcome to our continuing lectures on climate dynamics, climate monitoring and climate variability. In the last class, we looked into the different parts of a data acquisition system that is used to acquire data and store it from the various sensors that are part of the meteorological package. One of the important aspects of a meteorological package is what is called the automatic weather stations, which are commonly used in many places to simultaneously acquire multiple types of meteorological and climatological data. So it's an integrated data logging system supplied with a power supply and a series of sensors specifically intended for meteorological monitoring. They sense and store frequent measurements of temperature, rainfall, wind, pressure and solar radiation. This temperature data, rainfall data, wind data, pressure data and solar radiation data.

These devices operate using multi-channel data logger with multiple sensors. So, for example, here we have such a data logger which is on a tripod stand. This is your data logger with a strong weatherproof enclosure. This is the solar panel which is giving it with power. This is the air temperature and relative humidity sensor. This is our rain gauge, how much rain is falling. This is our solar radiation sensor. This is wind speed and wind direction sensor. This is our cup anemometer. This is our wind vane. This is solar radiation sensor. This is temperature and humidity. And this is our data acquisition system taking data and recording it. May be battery operated with solar panels that help recharge the battery, so external power supply is not needed, which makes it very convenient. May have Wi-Fi or satellite connection to directly transmit data to the research station. So these are often put into the field in various places. They are connected by Wi-Fi to a centralized research station and from that different climatological and meteorological data can be obtained. So, now that we have looked into the principles of instrumentation and the principles of data acquisition, let us look at the sensors that we used for measuring the various meteorological and climatological variables. The first climatic parameter that we will measure is temperature, which is of course the most important.

Here, we will basically talk about air temperature. Of course, there are other sensors that measure sea temperature at the surface or with depths or the land temperature. We will not go into those. We will just look at the air temperature measurement systems. The challenge in air temperature measurement is thermal conductivity of air is quite low. Heat transfer from the air to your sensor does not happen very quickly. The second problem is the impact of solar radiation heating up a thermometer. If there is solar radiation, say either direct sunlight or diffuse sunlight, that will heat up your thermometer and hence give readings which are higher than if it was just measuring the air temperature. Remember air is transparent solar radiation, it does not heat up. So what are the requirements? One key requirement is good thermometer exposure to air.

So, proper shading to shield thermometer from solar radiation is also important. Good exposure to air so that heat can be conducted into your sensor. Protection from precipitation, the thermometer should not get wet, this is important because when water evaporates, it absorbs heat from your sensor. So, the sensor cools down compared to and hence it is showing lower temperature. This principle will be used in a different context when you are measuring humidity using wet path thermometers. But for measuring air temperature, the thermometer should be shielded from both the solar radiation and from rain. It also needs to have a proper ventilation. There should be good air flow around the thermometer. This is needed so the thermometer can lose heat it gains from absorbing diffused solar radiation. We will discuss the role of proper ventilation in this class in the later section.

So good exposure to air, proper shading to shield thermometer from both solar radiation and production from precipitation and proper ventilation or air flow around the thermometer. Now, what types of thermometers are there? There is of course our famous mercury thermometers. We will not discuss them because these are rarely used nowadays. A type of thermometer that is used is called a thermistor. What is a thermistor? A thermistor is a temperature measurement device that is made up of a semiconductor device specifically fabricated so that its electrical resistance varies markedly with temperature. So, the electrical resistance of the semiconductor device is extremely sensitive to changes in its temperature. So, the electrical resistance becomes the variable that which is the output from the thermistor and because it is temperature dependent, it gives us temperature, the temperature data. where you should have a negative temperature coefficient, that is resistance decreases with increasing temperature. So resistance, this is electrical resistance mind you, as a function of temperature is like a exponential b by T.

So as temperature tends to infinity, this term goes to 0. So, it just becomes a and at lower temperatures, it is higher. So, as the temperature increases, the resistance falls. So, the resistance varies exponentially, rapidly due to exponential temperature dependence. As temperature increases, here usually the temperature is in kelvins, the corresponding B values are given. So, is given for a given thermistor. So, as temperature decreases, 1 by T increases, so this exponential term increases, so resistance increases. The resistance varies rapidly due to exponential dependence. Thermistors have high resistance, hence errors due to extraneous resistances of connectors are small. So you can see even at high temperatures, the resistances are of 1000 ohms and it can go up to 5000 ohms at lower temperatures. Usually, other resistances added to it due to the various connectors, wires, leads, etc. contribute very little and so it has very good error. So, it is a very accurate type of a temperature sensor. It can be made very small and compact. So you can see this bead type and disc type thermistors.

It can be made very small and compact. And even with shields and ventilator arrangements, the total thermistor system will be quite small. So it's quite portable and can be used in many places. Response times are 1 to 10 seconds and resolution of up to 0. 02 degree centigrade. So, response time we have already discussed in the previous class. What response time means? It is around 1 to 10 seconds depending on how small the thermistor is. Smaller the thermistor, lower the response time, faster responses. And resolution is also quite good. It is 0.02 degree centigrade. For continuous logging, resistance values are converted to voltage values. Remember your DAS, DAS, data acquisition systems usually prefer voltage value. These are more easily convertible. So, there is a resistance to voltage converter. Then these voltage values are used to store the data. Since thermistors have a nonlinear response to resistance, if you convert it to voltage just directly, you will have a very nonlinear kind of a curve which is not very good. So, you have a kind of a electronic circuit which does linearization of the voltage signal. The linearization of the signal is typically done using a non-linear resistance measuring circuit. We will not discuss how that circuit is made, but you have a non-linear resistance measuring circuit which creates a linear voltage response to the non-linear resistance input. If the resistance is going like this, you see the voltage is increasing more or less in a linear fashion. So, that is for a thermistor is it is very useful, widely used, good resolution, good response, everything is and low errors. So, like what you call So, next we will discuss another type of thermometry which also is related to resistance changes with temperature. But instead of a semiconductor, we use a metal, specifically platinum. These are called metal resistance thermometry.

These use metals whose electrical resistance increases with temperature. So, notice the difference. In semiconductor, the electrical resistance decreases with temperature. In metal, specifically platinum in this case, the electrical resistance is increasing with temperature. And the common type is platinum resistance thermometric, which is called PRT. And it is used because it has a linear resistance relationship. So, while semiconductors have an exponentially decaying relationship of resistance with temperature, platinum has a linearly increasing relationship of resistance with temperature. And the value of platinum resistance, thermometry resistance is R0 into 1 plus alpha T minus T0. where for a commercial platinum resistance thermometry, we have something called the Pt-100 standard, is a common standard for all of these platinum PRT devices where R0 is 100 ohms at T0 0 degree centigrade and alpha is 0.00385 Kelvin inverse. So, this is the alpha value. So, the slope of this curve is 0.00385 per Kelvin and the R0 value is 100 ohms and T0 is 0 degree centigrade. This is ET100 standard. Note two things. Firstly, the resistance is quite small. So, just at 0 degree centigrade, for example, this term drops out. So, R is equal to R0. So, it is 100 ohms. Whereas, for a semiconductor at 0 degree centigrade, it is like 2500 ohms.

So, platinum resistance thermometry resistance values are often quite small. This is a problem because then extraneous resistance additions can create a non-random error okay so what we call here if you remember systemic uncertainty. The addition of extra leads, resistance wires, etc. can add to the resistance and create a systemic uncertainty that has to be calibrated for in these kinds of systems. However, the advantage is it is a linear system and platinum resistance thermometry retains its linear values over a large range of temperatures. So, this expression is valid over a large temperature range Hence, it is a popular system, you can directly get the resistance temperature from the resistance very quickly. The other issue is that its alpha value is quite low. So, the slope is 0.00385 Kelvin inverse. R0 is 100 ohms. So, for 1 degree change in temperature, 100 into this, you get 0.385 increase in resistance, 0.385 ohms only. So the response is quite small.

The resistance change response is quite small. So you have to have a good amplifier to amplify that response properly without inaccuracies. The response time is also quite low, response times are around 120 seconds. So, it takes more than 2 minutes and remember response times is 3 tau. So, a step change in temperature will take 2 into 3, 6 minutes to get fully recorded. Resolution is reasonably good, 0.05 to 0.2 degree centigrade. For air temperature measurements, a cylindrical PRT, as you can see here, so the platinum wire is wound inside the cylinder, used with an enclosing radiation shield. You have a radiation sheet around. Chain resistance for unit change in temperature are fairly small. So, PRTs are prone to error due to resistance contributions from connecting wires, self-heating effects, etc. a voltage amplifier is needed to amplify the voltage signal, because again the signal is quite small. So, now let us go back to the original point that you have the impact of both direct and diffuse solar radiation that can heat up your thermometer and give you temperature values higher than what the air temperature truly is. These are called radiation errors. So, solar radiation falling on a thermometer will cause its temperature to be greater than the air temperature. The corresponding radiation error can be approximated as and we are not again deriving the expression The radiation error delta T rad is the measured temperature minus the actual air temperature.

This is proportional to S. S is the incident radiation flux in watt per meter square. Root over D, D is the sensor diameter and U is the air speed past the sensor. So, if we decrease the radiation flux. decrease the diameter of the sensor and if we increase the wind speed by providing ventilation, then this radiation error can be minimized. So, usually all air temperature measurement devices are shielded, that is they are put in a box, a ventilated box within which air is flowing through this outer kind of screens.

So, air can go past freely through, but because of these shields around, direct solar radiation cannot enter. So, you also saw a smaller variant of this in our automatic weather station, this one. Again you see this kind of, if you remember windows of old buildings have these kinds of slatted screens. So, that is specifically what is being done here. So, the air can enter, but sunlight does not. So traditional double louvered radiation screen by Thomas Stevenson. These are often called Stevenson screen type thermometers. Thermometers are inside and this is the outer Stevenson screen. This is called a Stevenson screen type thermometer. These are widely used in many meteorological devices and it's one of the most widely used meteorological temperature measurement systems well established for many many decades now.

However, traditional Stevenson screen type thermometers may have poor ventilation if natural wind speeds are low. Of course, wind will not be blowing throughout the day. So, if there is no wind, then there is no effective wind velocity inside the screens. So, you can still have appreciable radiation error at low wind speeds. And this is what is seen here. This is the temperature of such a thermometer minus the temperature of a properly aspirated thermometer, which is close to the actual temperature. So, this is the calibration standard. And you see at wind speeds lower than 2 degree, 2 meter per second, you have errors of around 0.2 to 0.5 degree centigrade over estimations. Median errors are around less than 0.2. One of the calibration standards for the Stevenson screen tap thermometers is an aspirated resistance based thermometer with a sun tracking shedding. So you have the screen thermometer and this is our calibration standard. It has a shedding that tracks the sun so that the thermometer is never being directly heated by the sunlight.

And here we have the thermometer. Here is a thermometer and the thermometer has an internal fan or a motor kind of a thing. It is artificially blowing air over its sensor. As a result, it is artificially aspirated. So, you have high air speeds and that reduces the error. So, this can be used as a reference to measure the radiation error of students and screen thermometers. And this has been done. done in the previous plot. Now, the other problem with Stevenson screen thermometers is because of these enclosures, the response time for such thermometers is large. If the air temperature changes, the effect takes a long time to percolate into your screen enclosed thermometer. Response times are 5 to 30 minutes. So, again if you do a 30 into 3, it may take one and a half hours for the air temperature to resist fully for plus step change.

So, that needs to be taken into account as well. The response time in this case is given as A by u to the power n. where a is 8.2 and n is 0.5 for a Stevenson's beam thermometer, where u is the beam velocity. So, if again if the beam velocity is high, then there is less problem. So, this you can see here as well. This is the lag time versus the velocity. So, for velocity is greater than 1.5, the lag times are less than a few minutes. However, at very low velocities, you can get 15-20 minutes of lag. It is an exponential thing. We will start our discussion of hygrometry today as well. So, hygrometry is measuring of humidity. So, these are called hygrometers.

The most classical type of hygrometers are mechanical hygrometers. This uses hygroscopic substances like hair, which increases in length by about 2 percent when relative humidity increases from 0 percent to 10 percent. You can see this human hair or any type horse hair, different types of hairs are used. This is put out between two points. Now, as the air becomes more humid, the hair length increases and the tension in the hair decreases and this less tension is impacting a point through a series of connectors. They, however, have low accuracy. So, plus minus 5% RH. So, whatever your RH value is, plus minus 5% of that is the accuracy of the system and poor stability. So, requires frequent calibrations with a calibration standard. Often, a set of linkages are connected to the hair element to amplify the change signal because the signal change is quite small and linearize the response to the signal. So, here we are showing one such case where the linearization has been done.

DCE is the horse hair or the hair element. It is a hook is stretching it and making it bent. So, there is a hook here which is attached to this hair element and is pulling it in this way. That is why it has a wedge shape. The angle of this wedge is this theta, half angle of this wedge. This hook is connected to your pointer as you can see through a kind of a skew Z type connector. And the angle between this skew that is connecting the pointer with this hook is alpha via hook which is free to pivot around B. So, B is a free pivot. This yields a non-linear response of the pointer proportional to the product of the cosines of the stretching angle theta and the pivoting angle alpha. So, the pointer response is proportional to cos theta cos alpha.

At high communities cos alpha is greater than cos theta. High humidity length is bigger and you get cos alpha greater than cos theta. This approximately compensates for the reduction in the hair sensitivity with increasing RH. So, what we are doing is because the hair sensitivity is the change in the length is decreasing as humidity is increasing for say suppose humidity is changing from 80 percent to 90 percent the length change is much smaller than humidity increasing from 30 percent to 40 percent. The theta term is being altered also because the total length has increased. So, cos alpha is becoming greater than cos theta. So, the change in cos alpha kind of compensates for the decrease change in the cos theta value. So, you get an approximately linear response and linear sensitivity. This is the counter balance. However, there are better ways to measure humidity electronically as well.

And two of them are hygristors and humicaps. These are electronic hygrometers. So, hygristors, you look at this hygristor like this. responds to relative humidity changes by changes in resistance. So, here again you have a change in the resistance due to change in relative humidity of air. Hygristors are made of carbon particles with a hygroscopic film.

So, carbon particles with a hygroscopic film are used to generate these hygristors. The resistance increases rapidly as the film absorbs water at high RH conditions. So, this carbon particles are coated with this hydroscopic film and as this absorbs water, the hygristor resistance increases rapidly. And this response is calibrated to evaluate the relative humidity of air. Response is highly non-linear with very reduced response at low RH value.