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

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RADIATION AND TEMPERATURE MEASUREMENTS - PART 1

Good morning class and welcome to our continuing lectures on climate dynamics, climate variability and climate monitoring. In the previous class, we finished our discussion of how to measure wind velocity. Now we will discuss a series of techniques that are used to measure a very important parameter, which is the total shortwave and longwave radiation that is passing through the atmosphere. The unit of this measurement is irradiance or radiation flux density which is watt per meter square. If you recall from our previous classes, this can be the total radiation flux density in the upper hemisphere. So, upward moving radiation flux or the radiation flux density in the lower hemisphere which corresponds to the downward moving radiation flux.

There are multiple types of radiation that are relevant and needs to be measured on their own right. These are explained here. L suffix U is the long wave radiation emitted upwards from the surface. So the upward moving long wave radiation we are calling as L suffix U.L suffix D is the long wave radiation emitted downwards towards the surface. So, this is the downwelling long wave radiation coming from the atmosphere towards the surface. STOA is the total incoming short wave radiation, basically the solar radiation at the top of the atmosphere. Total short wave radiation. Total incoming shortwave radiation is STOA, top of the atmosphere, so TOA.

SB is the direct solar beam radiation. That is, the radiation received directly from the sun measured normal to the beam direction. The solar beam comes directly here and suppose that it hits the ground at an angle 60 degrees. you take a surface which is normal to the 60 degree angle so that the solar beam hits that surface normally and the total radiation from this direct beam solar irradiance hitting normal to the surface is the S beam which is the direct beam solar radiation. SD is the diffuse shortwave radiation coming from all sides.

So the sky, because of the basically the scattering of dust particles, clouds, etc., if you see in the daytime, the sky is also quite bright. There is a lot of shortwave radiation coming down to the ground as diffuse radiation. Even on a clear day, especially on a foggy or a cloudy day, most of the radiation is diffused because the sun is hidden. So, this diffuse radiation that does not have a direction, it is coming from all over the sky is the diffuse component of shortwave radiation which we are calling S suffix D.

Then SG is the total scattered plus direct shortwave radiation falling on a horizontal surface. So, suppose you take a horizontal surface or surface which is flush with the horizontal which is the ground. And the total shortwave radiation, both the direct radiation as well as the diffuse radiation collected by this surface per meter square of its area is SG. Basically, the ground level shortwave radiation. Then SU is the upward reflected shortwave radiation.

Part of the radiation coming to the surface, solar radiation, gets reflected back up. Suppose it is a reflective material or even ice or even ordinary material, it is not a absorber of solar radiation. The part of the shortwave radiation that gets reflected back from the ground is moving upwards. So this is the upward moving or reflected shortwave radiation and this SU is alpha SG where alpha is the reflectivity of the surface. So downwelling, upwelling longwave radiation downwelling long wave radiation, total top of the atmosphere incoming short wave radiation, direct solar beam radiation normal to the direction of the beam, diffuse short wave radiation, total short wave radiation on the ground scattered and direct when it is flushed with the horizontal SG and SU the upward component of reflected short wave radiation.

The net radiation flux density at any location in the atmosphere is S at near the ground basically of if it is a horizontal location somewhere is the Total incoming shortwave radiation Sg minus the reflected shortwave radiation Su plus the downwelling longwave radiation Ld minus upwelling longwave radiation Le. Whatever shortwave radiation is coming down, whatever shortwave radiation is going up, whatever longwave radiation is coming down, whatever longwave radiation is going up. These all together is the net radiation flux density Rn at a location. in watt per meter square so what we will show in the next few classes is how do we measure this alright so the basic instrument of measurement is called a radiometer it is an instrument that measures radiation nothing to do with radios so remember that the working principle at its core is a thermopile Now what is a thermopile? The basic idea is it is converting electromagnetic energy into thermal energy of an exposed absorbing surface. So, you have an absorbing surface.

This surface absorbs the long wave and the short wave radiation depending on what is being used, what is being measured and converts this radiation energy into thermal energy of the surface. So, just to remind you because this is often a mistake. The radiation energy itself is not thermal energy or heat energy. It is electromagnetic energy. When it is absorbed by a surface, it gets converted into thermal energy.

So, there is an energy conversion process that happens before it becomes heat energy. So, it converts electromagnetic energy into thermal energy of an exposed absorbing surface. The temperature difference between the heated absorbing surface and an unexposed surface is used to measure the radiation energy flux. So, suppose you have a surface which is absorbing the shortwave radiation at the top, at the bottom is a shaded surface which does not absorb any of the shortwave radiation. Clearly, because of the absorbed shortwave radiation flux here, this surface will get heated, and its temperature will rise above the bottom surface.

Then the temperature gradient between these two surfaces gives us an ability to measure the radiation energy flux when thermal equilibrium is reached. Those who have taken heat transfer classes will understand that have a hot plate and a cold plate and there is suppose a certain conductive solid material between them. If there is a flux coming at the top surface, this flux will transmit down to the bottom surface through a temperature gradient. And knowing the temperature gradient and knowing the conductivity of the material, we can find this radiation flux at the top that is being absorbed. So what we need to measure is the temperature difference between the top surface which is absorbing and the bottom surface which is shaded.

And this is measured using what is called a thermopile which is a set of thermocouples connected in series. So a thermocouple is a temperature measuring instrument. We will discuss it in the next slide because we did not discuss this earlier. In radiation measuring it is specifically thermocouples are widely used as a temperature measuring instrument because it is excellent at measuring temperature differences between two points rather than it can measure absolute temperatures also, but it is excellent at measuring temperature differences between two points which is what we need here. So, the temperature signal is converted to a voltage signal, thermocouple does that automatically.

The Moll thermopile sensor is an example that uses a series connection of constant manganese thermocouple. We will discuss types of thermocouple later. So in the next slide, this will become clear to measure the temperature response. One advantage is thermopiles are broadband radiation sensors and can absorb radiation over a wide range of wavelengths, which is what we need. What we need Here is the entire range of short-wave radiation on one hand and the entire range of long-wave radiation on the other hand.

We do not want a sensor which absorbs a certain frequency and does not absorb other frequencies. That is something that the thermopile can do well. It's a broadband absorber and hence this is usually the instrument of choice that is used in radiometers. One disadvantage is a voltage output is small 5 to 10 millivolts and hence a voltage amplifier is necessary for the signal to be recorded in a data logger and corresponding errors of amplification have to be minimized. So, now what is a thermocouple? Something that we did not explain during the various types of temperature sensors we discussed about.

So, here in a thermocouple two different metals are welded, twisted or soldered together. So this is one metal, the blue one, and this red one is another metal. And this is either welded, twisted or soldered together at a junction. And this is called the thermocouple junction or a bead. Usually it is a form of a small spherical bead where the two metals are welded or soldered together.

And this is called a thermocouple junction. If you have two such junctions, this is one junction, there is another junction here where the two metals are connected electrically together. If there are two such thermocouple junctions that are electrically connected in series as you can see here, a small emf is generated. So, these two junctions, this is one junction, this is another junction, these are connected in series by these wires, right. If this is done and there is a temperature difference between this junction and this junction, suppose this is the hot junction at the sensor which is being heated and this is the shaded or the cold junction and there is a temperature difference between these two junction.

we get a electromotive force between is generated between these two junctions which is proportional to the temperate. The emf is proportional to the temperature difference between these two junctions. This is called the C-back effect. We will not discuss this, why it happens, etc. But it is sufficient to know that if you have this type of two junctions, which are with two different metals and if you make them, if the temperature between these two points are different, an EMF is generated which generates a voltage signal, small voltage signal of around 40 micro volts per Kelvin.

So, these are the lead wires which is connected to the voltmeter which measures the amount of voltage signal that these junctions are generating. Alright. So, if you know the voltage signal and if you know the calibration between the temperature difference between these two junctions and the expected voltage signal, then you can evaluate the temperature difference between these two junctions from there. So, it is ideally suited to measure temperature differences and hence widely used for such applications and heat flux measurements. And in thermopile, That is what we want.

We want to find the heat flux, the radiation heat flux. Correct. So that is why thermocouples are widely used in radiometers. If a single temperature is to be measured, as is often the case in other types of applications, then the second junction is kept at a fixed reference temperature, say 0 degree centigrade. Suppose a small ice bath or something is being used, where the second junction is kept at a fixed temperature, so that knowing that this cold junction is at a certain temperature, absolute temperature of the hot junction can be evaluated.

In modern instruments an electronic reference junction is used which gives a fixed voltage. So, instead of dipping the cold junction in a ice bath a fixed electronic reference junction is used and in that case the change from this reference voltage becomes the emf and that way a single temperature can be measured. But in our case we are measuring the temperature between the exposed surface and the shaded surface.

Response times are 0.5 to 5 seconds. So it's a quick response system. The temperature voltage characteristic is however non-linear. So different metal junctions are used for different temperature range of indices. Because over a large range the temperature response is non-linear. Different metal junctions are more sensitive in different temperature ranges.

So, depending on the temperature range you are interested in, the two metal identity has to change. Typical junctions are like type K, chromel, alumen, type J, iron, constantan, type T, copper, constantan. It can be a metal or a metal alloy as well. And in our case, this thermopile uses a constantan, manganese.

These are again alloys. Alright. So you can see here, usually the wire is not exposed to the bare area. It is embedded within, say, the sensor surface. So this is the external shield. This is the measuring junction. And this is the surface that is exposed to the radiation, for example.

So, there are many types of radiometers depending on the type of radiation that we are measuring. So, we have shortwave radiation. We have four types of measuring radiometer for shortwave radiation measurement. First is the pier heliometer. Pier heliometer or pier heliometer is the measurement of direct beam solar radiation, the normal to the solar beam.

So, pier heliometer or I do not exactly know the pronunciation here. It measures the direct beam solar radiation. So, if you go back here, you will find SB. So, peer heliometers are for measuring the direct beam solar radiation. Pyranometers are measuring the global solar radiation over a hemispheric field of view are measuring SG, the total solar radiation scattered and direct. Then you have the photometer which we will not discuss a lot here. It measures light in the visible part of the spectrum only. This is a little bit of difficulty because shortwave radiation does not only mean visible spectrum. the near infrared region which is between 700 micrometers to say, from 700 micrometer wavelength to, sorry, 700 nanometer to around 3 micrometer.

That region is the near infrared region which is also counted as a part of the shortwave radiation because solar energy is coming at those infrared regions as well. But photometers measure light in the visible spectrum only either as energy or number of quanta. This is sometimes used when we are only looking at visible spectrum. Then you have the albedometer which measures the upward reflected shortwave radiation. So, pure heliometers, direct beam, pyranometers total at ground, albedometers upward reflected shortwave radiation, photometer only the visible spectrum.

Then you have instruments that measure longwave radiation only or the total longwave and shortwave radiation. So, pier radiometers, this one, measures the net radiative flux of short wave and long wave radiation both together. Pier geometer measures, so this is S plus L, both together. Usually, either the upper side or the lower side.

A single instrument cannot measure both. You will have two measuring the upward downwelling short wave and long wave radiation and the upwelling short wave and long wave radiation. Then you have peer geometer. So, this is basically measuring the terrestrial radiation usually over hemisphere upward or downward. We will discuss this as well. This is and then an infrared thermometer or pyrometer measuring long wave radiation emitted from an object from which object's temperature is derived.

So, peer geometer usually gives the long wave radiation, peer radiometer is both long wave and short wave. And this pyrometer is usually used to measure temperature of the ground for example. Spectroradiometer, we will not discuss measurement of radiative energy in a specific part of the spectrum at a given spectral radiation. These are more specialist instruments, these are we will not discuss in this class. Okay, so let me just quickly look at a pyranometer and then we will stop this class.

So, remember what a pyranometer is? It is measuring the global cellular radiation, basically SG. So, how does it look like? Basically, if you can see in this figure, there is a black circular disc. which is enclosed in a glass half-hemispherical dome. There will be two of them, one of them, it kind of depends. The reason for using the glass dome is it blocks the far infrared region of the solar spectra and allows the near infrared and visible region to enter.

So, by putting the glass dome, we ensure that we are only measuring the short wave radiation part. Two glass domes are used in general to avoid losses due to convection, etc. So, remember the surface is getting heated due to radiation flux. If the surface is getting cooled due to movement of air through convective heat losses, then the total heating will be under estimated. That is why you often have multiple layers of glasses to stop wind flow and natural convection and forced convection from playing a major part.

In general, radiation is already stopped because the glass is opaque to long wave radiation. So, it detects the temperature difference between a blackened sensing surface which is this TB black and the cold instrument body TW. The instrument body is below this sensing surface and the temperature of this colder instrument body is measured which is not receiving radiation and hence it is at a lower temperature. And this temperature difference is being measured by your thermopile pyranometer. The shortwave radiation SG is proportional to a proportionality constant C into the difference between the sensing surface temperature and the instrument body temperature, where C is an instrument constant found through calibration.

Even though it is called a constant, it is a somewhat weak function of temperature. And hence, more accurate pyranometers do have a correcting compensation factor built in to take care of this instrument, this variability of C with temperature. But in general, this is the equation. And so, it is a very simple. So, once you know the constant to get proper calibration, this can be used to find the temperature difference between the, so the temperature differences are measured using your thermopile, using basically thermocouples.

Once you know this, once you know C, you can find the shortwave radiation in watt per meter square. Blackened multi-element thermopile, multi-element mills, there are multiple thermocouples in series housed within a glass hemisphere facing upwards. So, here the reason why we are having thermocouples in series, it increases the sensitivity of the thermocouple itself. So, if you have multiple series connected metal junctions between your final and the initial temperature that you want to change, the voltage signal for small differences in temperature gets magnified which helps to detect small changes as well. This is very useful because we do not expect the temperature difference to be much. The heated surface may get heated up to say 40-50 degree centigrade while the unheated surface is like 10-20 degrees, 10 degrees maximum. So, the difference is not that large. So, you need that series connected thermocouple. So, glass blocks wavelengths in the long infrared region greater than 3 micrometers and prevents convective losses.

So, here is the measurements from a pyranometer in a relatively clear day. So, where there is very little cloud, if there is cloud, of course, this changes a lot because the direct beam solar radiation is blocked. All right. And this is the incoming solar radiation at the top of the atmosphere. So, you can see a very nice parabolic proportional profile is coming because there are no clouds etc.

And the difference is basically the solar energy that is being absorbed by the atmosphere or reflected back by dust particles, cloud, etc. So, this is a reasonable data that shows that our pyranometer is performing reliably. So, today we will stop here. We will continue our discussion of the radiation measurement techniques in the next class as well. Thank you for listening and see you in the next class.