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

**Professor Name: Dr. Sayak Banerjee**

**Department Name: Climate Change Department**

**Institute Name: Indian Institute of Technology Hyderabad (IITH)**

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# RADIATION AND TEMPERATURE MEASUREMENTS - PART 2

Good morning class and welcome to our continuing lectures in climate dynamics, climate variability and climate monitoring. In the previous class, we started discussing radiometers which are radiation measuring instruments. We discussed one type of radiometer, pyranometer, which measures the shortwave radiation that is hitting the ground for a horizontal surface and is giving the value $S_g$ over the upward hemispherical field. Now, we will discuss what are called thermopile based pyre heliometers. If you remember, pyre heliometers are radiometers that measure the direct beam solar radiation. That is the radiation that is directly incident on a surface which is kept normal to the direction of solar incidence.

And it is the direct beam that is it eliminates all the diffuse radiation coming from all over the sky and is only looking at the radiation coming directly from the sun. Basically if you look at the sun, The amount of radiation coming into your eye, though I will not recommend that for obvious safety reasons, is the direct beam solar radiation. How do we measure this? The basic principle is thermopile for all of them. Alright, so we have a sensing surface, we have a base surface which is not exposed to radiation and the temperature difference gives the flux to thermocouples.

However, in this case, the blackened thermopile sensor is put inside a long internally blackened tube. So, you have this long tube and the sensor is at the base of this tube. So, now why is this tube used? So, if you see, this is end point of the sensor, this is another end point of the sensor. If you take a straight line and go to the opposite side at the top of the tube at the exit, you get this line. Similarly, here if you draw a line from this, the opposite end point and to the opposite top of the tube, you get this line.

The angle between these two lines is 5 degrees. Okay. So, anything within this 5 degree cone angle is the only part that is hitting this sensor. And you can make this cone angle small enough so that it only covers the cone angle that is subtended by the sun on a surface that is oriented directly towards the sun. Because the sun looks like a disc, right? So, it subtends a cone angle.

And you can make this cone angle so that it is directly is equal to the solar, the cone angle subtended by the solar disk. Then you ensure that the rest of the sky and the associated diffuse radiation is not incident on this sensor surface. And now if this tube is attached to a solar tracking apparatus. Which ensures that the axis of this tube is always normal to the direction in which the axis of this tube is parallel to the center line between the solar disk and this surface midpoint. So, this line is always tracking the sun.

So, wherever the sun is in the sky, the solar tracking apparatus moves both in a 360-degree fashion through the sky to always be oriented so that the cylinder's midline axis falls on the center of the solar disk as seen on the sky. The pair heliometer is mounted on a solar tracker that tracks the sun through the sky, hence the cylinder axis is always pointing towards the sun. Since the sensor is always normal to the sun, $S_b$ can be greater than $S_g$. Remember, $S_g$ is the horizontal surface like this.

Okay. So, if you have a direct solar beam which is at an angle say 60 degrees from the normal, then the radiation flux is basically $S_b\cos\theta$. Okay. which will be lower. So, if the theta angle goes to 90 degrees, cos theta goes to 0. When theta is 0, that is directly normal at noontime in the equator, then SG equals to $S_b$, at least the direct part of the beam.

But there will also be diffuse radiation coming from the rest of the sky. So, depending on the angle of incidence of the sun with respect to the ground, the $S_g$ can be greater or less than SB. Because the fraction of the direct beam solar radiation it is, $S_g$ has is basically $S_b$ cos theta plus $S_d$. And $S_b\cos\theta$, if it is small enough, then $S_b\cos\theta + S_d$, the diffuse, can be lower than $S_b$. Correct? If Z is the zenith angle, so theta here is Z, the angle sun makes with the ground normal, then $S_g$ is basically $S_b\cos Z + S_d$. So, this expression is always satisfied. All right. So, here you can see in this plot the three components. solar radiation at the top of the atmosphere. This is the direct solar radiation at the top of the atmosphere.

So it kind of goes like this. So this solar radiation at the top of the atmosphere is ground horizontal. This is your $S_g$ that we evaluated earlier. And this is the direct beam solar radiation. And you can see that for a clear sky situation, except near noon time, Where the theta angle is quite small, your $S_b$ can be greater than STO and $S_g$ because of this cosZ function that is there. Alright. So, this is important to know. So, this way we can measure the direct beam solar radiation. The main constraint here is you have to have a solar tracking apparatus which is reasonably costly. So, it is not a passive device like a pyranometer. You need a solar tracking apparatus to evaluate $S_b$.

There is no getting around to that fact. Alright. Now, we will discuss how do we measure just the diffuse radiation. So we have to go back. We have not shown how diffuse radiation is measured because a specific type of pyranometer is able to measure the diffuse radiation only. And these are called shade ring pyranometer. The idea is the solar disk, if you see in the sky, moves at a certain circular arc on the sky. So, if you have a shade ring which is oriented such that it blocks this circular arc region, then throughout that day and most of the time throughout one or two weeks around that day, the pyranometer which is installed will not be seeing any direct solar beam falling on it. So this shade ring is periodically adjusted after say one or two weeks to adjust for the change in the locus of the solar disc with seasons. So how the solar disc moves in winter is different from how the solar disc moves in summer.

So you have to move it periodically to get it properly oriented, but if properly oriented, this shade ring ensures throughout the day the pyranometer does not receive any direct solar beam at all. Then what does it receive? Only the diffuse radiation coming from the rest of the sky. So, that way it can measure $S_d^{path}$. The problem is it also obstructs a part of sky. See, it's a solar, it's a disc, it's a circular arc that is being shaded.

The sun is somewhere in that arc, but the rest of the arc at a certain point of the day is sky. The sun is not there, right? So that part of the sky is being blocked as well. So, a part of the diffuse radiation is also not coming because part of the sky where the sun is not there at that moment is also being blocked by this shade ring. So, usually a multiplying factor k which is less than 1 is used to correct for this sorry, which is greater than 1 is used to correct for this loss of diffuse radiation from the shaded parts of the sky. So, $S_d^{corr}$ is $S_d^{meas}$ into this k, where k is $\frac{1}{1-qf}$, where qf is a positive term which is less than 1, ensuring that k is a factor which is greater than 1. Okay. Here f is a solar terrestrial geometry factor. This one is kind of fixed and can be easily determined though the expression is complicated based on the day of the year, the latitude value of that location, the specific time of day, etc. So, if you input these values, this f factor which is a solar terrestrial geometry factor basically tells you how much of the sky is being obscured. that part this F term takes care of. The q term is the anisotropy factor which basically tells you that the part of the sky that is being blocked is not equally bright.

So, this is a very important point. Suppose you take a clear sky day, you will see that closer to the sun, the sky is far brighter than towards the parts of the sky which is far away from the sun. There the blue is much darker whereas closer to the sun the blue is much lighter and much brighter. Because basically the diffuse radiation is coming from the solar beam being diffracted and reflected by the dust particles, snow particles etc. on the atmosphere. And most of this is happening first along the direction in which the sunbeams are coming and from there further reflection is spreading throughout the rest of the sky. Clearly therefore, the sky closer to the sun has more diffuse reflection and hence is brighter than the sun sky further away. And this is an anisotropic factor that kind of is also dependent on the How much dark particles are there in the sky in the first place, if there is fog, etc., etc. So, that has to be evaluated semi-empirically.

So, these two factors, if it is known, you will give the k and you will give the corrected diffuse radiation value of a shade ring pyrannometer. All right? So, now you can see you have a shade ring pyranometer which gives you $S_d$ and a regular pyranometer which gives you $S_g$ which is basically $S_d\cos\theta$ direct solar radiation part and the diffuse radiation. The horizontal component of direct beam solar radiation can be evaluated using these two together by removing the diffuse part that is obtained from here. All right. So, that is another way to get the value of $S_b$.

The next part is how do we measure the reflected shortwave radiation? And here what we use is what is called an albedo meter. Okay. Here, a pair of pyranometers are used, one facing up and another facing down. You can see here, this one is facing up and this one is facing down. The one facing down measures the amount of reflected radiation $S_u$. All right. Okay. So, this is the, it is one facing down. So, it is getting all the reflected shortwave radiation, which is entirely diffuse, of course. And the albedo is determined as alpha equal to $S_u/S_g$. Albedo is the fraction of the solar radiation hitting the ground that is being reflected, right? So, this is the $S_u/S_g$ value. Now, the albedo value will depend a lot on the time of day because at sunset, near the sunset, the solar angle is much larger.

So, you will get much more reflection, okay? So, albedo in general physically albedo is dependent on the time of day very strongly. However, the traditional albedo measurement is giving the albedo at noon time. So, it is a kind of a surface property and we are defining this property using the albedo values at noon time. So, near noon time, this ratio gives you the albedo value for that specific surface, whether it is a snow covered surface or a grass surface or a sand surface. Of course, the albedo will be different in sunset and sunrise. But albedo at noon at a given time of day is the albedo value for that day in that year for that sun. Alright, that is how the traditional convention. Okay. So, we have looked at the various types of shortwave radiations. We have said that we have to calibrate them as well. So, how do we calibrate these shortwave radiometer instruments? The primary calibration standard is called a cavity radiometer. So, a cavity radiometer uses a blackened cavity. So, in some ways the cavity radiometer looks very much like your period heliometer. It contains a blackened cavity which in turn contains a blackened metal cone.

You see this metal cone here. This is the blackened cavity. And inside you have this blackened metal cone which absorbs the shortwave radiation. So, the cavity is given such that the entire shortwave radiation falls on this metal cone surface. So, you have this metal cone and the cavity and everything that is coming is directed into this metal cone. All right. So, this cone as a result gets heated up and base of this cone is connected to a thermal resistance creating a temperature difference between the instrument body and the cone base. So base of this cone gets heated up because of this blackened cavity. So why are we using a cavity? A black cavity, a black cone shaped cavity is certain to absorb all radiation that is incident on it. And we can evaluate how much radiation is incident on it by this angle of the cone and angle of the aperture at the top.

So it absorbs all the shortwave radiation. It acts like a perfect black body for the shortwave radiation. And then the temperature difference between the cone base and the instrument body is measured and is proportional to the heat flux from the cone to the instrument. That's number one. Alright. Now what we can do, this cone has an aperture, is basically a disc. You can now move this aperture to block that entire cone so that it does not get any radiation. So, you can think of like a camera or the top of a telescope and you are basically using a cover to cover the telescope's top surface so that no light can enter the telescope anymore. Alright. Then what you do? Of course, the cone will start to cool. Correct. Then what you do? You turn on a compensatory resistive electrical heat flux. So, this cone is kind of surrounded by electrical resistance heater. And you give a certain flux to this resistance heater till the cone reaches the same temperature it would have reached by absorbing all the shortwave radiation that was incident on it. Then, just by looking at the  electrical flux, electrical wattage that this heater is consuming and by knowing the cone area in which the absorption is taking place, you can find the heat flux that this cone was absorbing, alright. You are no longer measuring temperature, you are no longer using any resistance model to measure the proportionality constant into temperature difference.

What you are doing is you are just measuring the temperature of the cone and the temperature of the instrument base through a thermocouple or a thermopile system. Then you are trying to keep the same temperature when the cone is not getting any radiation using an electrical flux and that wattage is the wattage watt per meter square needed that is being absorbed by the cone in the first place. So, this way any uncertainties associated with the resistance model proportionality constant is eliminated and you get a primary calibration standard that gives from first principle  the exact amount of shortwave radiation that is being absorbed by this cavity radiometer. Now, you can compare this cavity radiometers measured watt per meter square of the of solar radiation SG and compare this solar radiation and compare this with a pyrheliometer or a value or something else with the same kind of aperture. All right. Based on that you can calibrate the other instruments as well. So, this way you can develop a primary calibration standard to calibrate the rest of your radiometers.

Okay, so I will stop here today. The next part we will go in shift from short wave radiation to long wave radiation measurements. Alright, so we will see how long wave radiation gets measured using P radiometers. Okay, thank you for listening and see you in the next one.