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

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Lecture 62

RADIATION AND PRECIPITATION MEASUREMENTS

Good morning class and welcome to our continuing lectures on climate dynamics, climate variability and climate monitoring. Today we will discuss the methods of measuring total radiation flux density or long wave radiation flux density. In order to measure the net radiation, the device that is typically used is called a peer radiometer. Here again, Here again the device is a thermopile only but of a different design. This system has both an upper and a lower sensing element and the key difference is it is not enclosed by any glass hemisphere so that the sensors absorb both long wave and short wave radiation. Because the glass initially eliminated the long wave radiation, now that we are not adding any glass hemisphere, it is absorbing both long wave and short wave radiation.

So, at the bottom, it is absorbing S upward plus L upward. At top, it is absorbing Sg plus Ld. Sensors are affected, however, by convective heat losses and hence, often a constant ventilation rate is desirable through a artificially flowing air flow to keep the instrument at a constant, desirable, repeatable behavior state. So the idea here is because it is not enclosed in a glass hemisphere, there will be heat losses due to natural convection, forced convection of wind flows, etc.

So instead, if we flow a breeze of air artificially over the sensor surface, then it ensures that the heat loss is a constant predictable amount which can be accounted for giving a more accurate analysis of the total radiation flux for the sensors. The total The net radiation flux becomes proportional to the difference in temperature between the upward upper sensor Tu and the bottom sensor Td, where C is a proportionality constant that depends on the conductivity of the material, the air flow velocity u as well as the cube of the bottom temperature, the temperature of the bottom sensor. So, this constant of proportionality itself is dependent on the temperature of the bottom sensor as well as material properties like conductivity k between these two sensors and the flow velocity that is being maintained for air at the top of these two sensors. So, this has to be evaluated through calibration process. So, this system is called a peer radiometer and this system helps us once we know the upper and the bottom temperature through a thermopile sensor, what the net heat flux is, which is the difference between the downward and the upward radiative heat flux.

$$S_g + L_d - \sigma T_o^4 = C(T_u - T_d)$$

Now, this is a standard design. In some designs, for better accuracy, we do not want to have this heat loss through natural or forced convection systems. So, in this case, instead of a glass dome, we can use polythene sheets. So, here is a peer radiometer top sensor, the bottom sensor is a symmetric bottom sensor at the bottom and this glass instead of this material is made up of glass, this material is made up of a polythene sheet which is inflated with nitrogen or air. The polythene allows entry of both short wave and long wave radiation.

So, the problem that glass domes have that is eliminated. And the shielding, because the polythene sheet creates a shield around the sensor, it reduces convective losses and hence corrections are not required.

The problem with this polythene covered sheet is this polythene is not a very rigid material. So, you need a pressurized nitrogen and air flow that needs to be replenished. So, this system requires a pump or a gas supply to keep the polythene dome inflated.

So, this is one of the restrictions that you need a local source of pressurized gas, pressurized air or pressurized nitrogen. So, it is somewhat difficult to deploy it on remote locations for indefinite periods of time without requiring some periodic maintenance for changing the gas cylinders. Peer radiometers are usually mounted 1 meter above the ground with the sensor surface parallel to the ground surface. This figure gives a specific type of a peer radiometer, a commercially available one, which can measure the net shortwave and longwave radiation range between 0.3 micrometers to 30 micrometers.

So, both the visible range, the ultraviolet range as well as the longwave range. Two black radiation absorbing plates act as sensors, one facing upward and one facing downward. Each transfers the energy absorbed to a separate 90 junction copper constant and thermopile. So, thermopile is again a series of thermocouples. So, it is a bimetallic bead made of copper constantion and there are 90 thermocouples in series to improve the sensitivity of this thermopile, ok.

And the specific type of material here is Lupolin, is a special type of polythene or like polycarbon based transparent material. Lupolin domes shield the thermopiles from wind and moisture and it is essentially transparent to radiation between 0.3 to 60 micrometers. For long term applications, as we have said, fittings permit attachment of a nitrogen source for continuous purging. So, that is the process used here.

So, we have looked at short wave radiation and net radiation evaluation. Now, we want to evaluate long wave radiation. And the sensor that is used for that is called a peer geometer, which is used for measuring long wave radiation. These are basically modified versions of field radiometers only. The only difference is it has two configurations because you have an upwelling longwave radiation and a downwelling longwave radiation.

So let's first discuss the upwelling longwave radiation. In this configuration, So, p-radiometer has two sensors, a top sensor and a bottom sensor. In this configuration, the bottom sensor is capped by an internally blackened aluminium cup, which is kept at a known reference temperature T0, so that the bottom sensor measures sigma T0 to the power 4 only. So, it is an internally blackened aluminum cup. So, it acts as a hemispherical black body which is kept at an isothermal temperature of T0.

So, whatever the sensor is measuring is the heat flux, radiative heat flux coming from this blackened aluminum hemispherical cup which will be sigma T0 to the power 4. the top sensor is a conventional P radiometer which measures Sg plus Ld. So, what we are getting therefore is that the downward short wave radiation and the downward long wave radiation Sg plus Ld minus the radiation emitted by this helisperical aluminum cup at the bottom minus sigma T0 power 4 is equals to the instrument constant into the difference in temperature T of the upper sensor and T of the bottom sensor. Now, C0 is known.

We are fixing it. So, this term is known. Tu and Td are being measured by the thermopipe anyways. C is known. So, the downward moving shortwave Sg plus downward moving longwave Ld, this total sum is known based on the upper and the lower sensor temperature readings. Now, along with this, if we have a pyranometer, a typical pyranometer that measures Sg, also present in the instrument set, that will measure Sg only.

So, this measures Sg plus Ld, this measures Sg. So, together the computer or the microchip can evaluate what the Ld, the downwelling long wave radiation is going to be. An alternate configuration is very similar, it will measure it here, the top sensor is capped and the bottom sensor is open and the pyrradiometer is located at the bottom. In that case then, when the bottom sensor is open, the top sensor is capped, you will measure Lu plus Su. And the bottom pyrradiometer, basically the albedo meter that we discussed, will measure the Su separately.

So, Lu can be evaluated. So, here is an example of this kind of a system made by this instrument on two days. So, it is day 44 of the year, day 45 of the year, day 46 of the year and day 47 of the year. And this is the net radiation Rn and this is the evaluated Rn value Sg minus Lu plus Ld minus Lu. They are more or less similar, there are still some differences between them, but you can see that they fall within the same lines.

All right. And these are being measured for multiple days. All right. So, for example, this one is a very clear day. This one was a cloudy day. So, the net flux was lower.

This one is more again a more clearer day. Okay. So, these fluctuations kind of give us the net radiation as well as the individual components. Now, let us change track a little bit and measure. So, that kind of covers all the radiation measuring instruments that we wanted to cover.

We were able to measure the shortwave radiation falling on the ground, the direct beam shortwave radiation, the reflected shortwave radiation based used on the albedo meter, the combined net radiation flux, the longwave downwelling and upwelling radiation. One of the last measuring system that we would want to talk about before we change track a little bit is measuring precipitation, which is of course a very important measure as well. So, the way to measure precipitation is rain gauges. So, a recording rain gauge helps maintain a continuous record of precipitation amount with duration in a given location. It requires a wide dynamic range since it must be able to remain dormant for long periods of time.

And this is one of the most challenging parts. Unlike the other things that we have been measuring, for example, pressure, temperature, radiation, intensity, etc. Rain is something that falls only in infrequent intervals and when it does fall, it may fall at very rapid rates. So, we must have an instrument that has the ability to remain dormant for long periods of time, but also can become quickly active and reliably operate over short periods when precipitation does occur.

That is one challenge. The second challenge is the rain collector because we are collecting the rainfall must be automatically emptied. and at a rapid rate at fixed collection level so that we can measure the volume of rain that is being that is being collected. But this emptying process should not be so slow that during that period rainfall measurement is getting affected. So, you should have a Emptying should happen at a fixed volume of rainfall collection. It should be fast so that it does not perturb the rainfall measurement for the bucket that follows after.

So, there are two types of rain gauges that are in common use. One common type of rain gauge is what is called the tilting siphon rain gauge. The figure of this tilting siphon rain gauge is shown. You have this bucket which is collecting rainwater and there is a pen which is connected to a float. A float is something that floats at the level of water.

So, as the level of water in the bucket increases, the float also moves upward and the pen is connected to the float and this pen is also moving upward vertically. So, as rainfall happens, the float moves upward vertically and during this period it is inscribing a line. This line is a, so this is the graph. So, it is rotating, it is wrapped around a slowly rotating cylinder. As the pen moves upward vertically and the cylinder slowly rotates around it, the line it inscribes, this pen inscribes is kind of a monotonically increasing line with a fixed slope, with a certain slope.

And the slope of this monotonically increasing line gives a measure of the rate at which water level is increasing. So, for example, if this is for example, movement of a cylinder by 30 degrees, this has moved up to this point. However, if the rainfall is much more gradual, then the movement may be like this. And if the rainfall is very rapid, the movement can go like this.

Very quickly it will move. So, the cylinder will not have a sufficient chance to move, make a same angular sweep. Okay. Now, once the chamber is sufficiently full, the chamber tilts, allowing a siphon to drain the water out of the chamber. So, once the chamber is sufficiently full, the chamber is kind of balanced. Once it has gone beyond a certain threshold weight, the cylinder tilts, which allows the siphon to drain out the water very quickly.

And the water level falls very quickly. The pen also drops very quickly down. So, under typical operation, we have this kind of a sawtooth curve. The slope may not be constant because the rainfall rate may be different. So, here we have a constant slope sawtooth, but that need not be the case. But we have this sawtooth curve and every time it moves down, one bucket has been filled and it is getting empty.

So, this way we can evaluate the total amount of rainfall as well as the rainfall rate. The next type of measuring system is called the tipping bucket rain gauge. So tipping bucket rain gauge is an interesting design. Basically it has a seesaw mechanism with two buckets at the two arms of your seesaw.

So here is the two small crevices. So these are small recesses where water can accumulate and this is the seesaw system. At a standard configuration, one of the arms is up and the other arm is down, alright. And this funnel which is collecting rainwater, this funnel kind of directs the rain, rainwater to the upper arm of the seesaw bucket, the bucket which is present in the upward arm of your seesaw, ok. As the bucket fills up, the weight increases and eventually a pivot happens. As soon as the pivot happens, this moves quickly to the top and the funnel starts directing rainwater to this bucket, which was initially at the downward position.

And this bucket moves downward here and drains the water into the drainage system. Again, when this bucket fills to a certain level, the weight causes a pivot and the system repeats itself cyclically. Each pivot action generates a pulse via magnetic or optical switch. You can see it here. The accumulated number of pulses is proportional to the rainfall amount and the frequency of pulses is proportional to the rainfall rate.

So, the total number of pulses because each pulse happens after a certain standard volume has been collected in the bucket and the pivot has happened. So, the total number of pulses gives you the rainfall amount and the number of pulses per unit time, say there are 50 pulses per minute that will give you the rainfall rate because suppose each per each bucket may get say 4 millimeters of millimeter cube of water, ok. 50 * 4. So, 200 millimeter cube of water has fallen over a 1 minute interval, something like that. Of course, that is a very high rate, what I am saying.

It can be a quite sensitive instrument as each pivot can happen for rainfall depth of as low as 0.1 millimeter. So, very low amounts of rainfall can also be measured by this system. So, if B 0.1 millimeter is the depth at which the pivot occurs and if N be the total number of tips and if t1, t2, ti, tn be the times at which the tips, the pivots have occurred, so the time also is recorded as the pulse comes.

Then total rainfall depth is N into B. N is the total number of pivots. B is the depth per pivot. Average rainfall rate is this total rainfall depth by the total time tn minus t1. And instantaneous rainfall rate around a certain time ti is the pivot depth B by the time interval between the two successive pivots at that instant of time. So, you can get instantaneous rate, total average rainfall rate, total rainfall, all of those using this tipping bucket range.

Total Rainfall depth:

$$P = N \cdot B$$

Average rainfall rate:

$$R_{\text{avg}} = \frac{P}{t_n - t_1}$$

Instantaneous rainfall at time t_i is:

$$R_i = \frac{B}{t_{i+1} - t_i}$$

Okay, so we will stop here today. We have covered a set of instruments that are primarily ground-based in-situ measuring instruments for measuring the various meteorological and climatological characteristics in the ground. In the next lecture, we will look at upper air measurements also called radiosondes. Okay, thank you for listening and see you in the next class.