Radiation Heat Transfer
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Lecture - 31
Radiation Measurement

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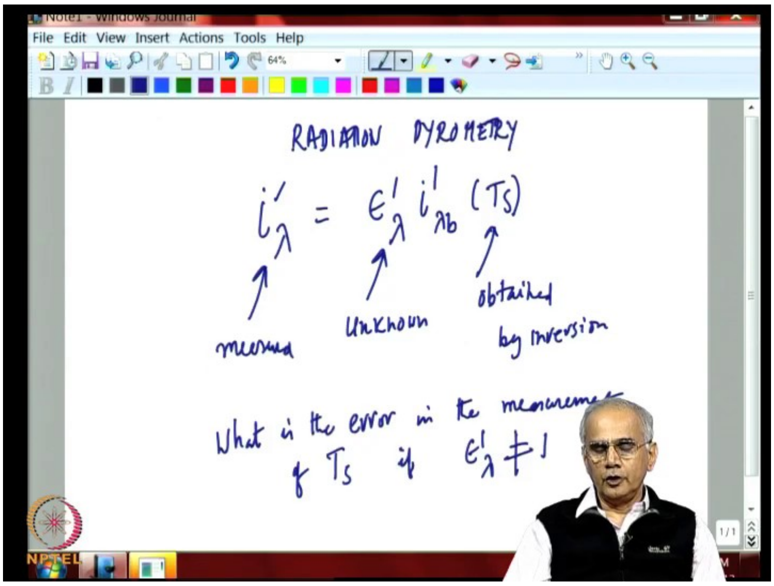

RADIATION PYROMETRY

$$i'_\lambda = \epsilon'_\lambda \, i'_{\lambda b}(T_S)$$

measured

unknown

obtained by inversion

What is the error in the measurement of T_s if $\epsilon'_\lambda \neq 1$

So far, we have discussed how to model radiation heat transfer from theoretical perspective. Today, we will look at how measurement of radiative flux can be used to measure temperature. This is called Radiation Pyrometry. One of the advantages of measuring temperature through the radiation emitted by the object is that the object can be quite far away. We do not have to physically disturb the object.

The measurement of temperature through radiative emission is one of the remote sensing techniques, which is very useful. But when we try to measure the temperature of an object by the radiation emitted by the object, we have to make some assumption about the properties of the surface, that is, what we are measuring is the intensity radiation coming from the object at a certain wave from certain angle. We know that that it is equal to the emissivity times the blackbody intensity at the surface temperature. We want to measure T_s, but this is very often unknown; this is measured; this is inferred from the measurement.

Now, if the surface whose temperature we are measuring is a black body, then of course is no problem. We can directly relate the measured directional emissive power to the black body emissive power and get the temperature by inversion. As far as so good, T s is obtained by inversion, provided you know the directional spectral emissivity. As we recall our discussion about the emissivity of various surfaces, they are extremely valuable. It depends on the state of the surface that is rough or smooth, whether there is an oxide layer or other impurities. It is very optimistic to expect that we will be know a priory, the directional spectral emissivity of any surface.

The next question we need to ask is, if you assume the surface to be a black body and find the temperature, what the error is. The question is what is the error in the measurement of T_s if epsilon prime lambda is not equal to one. That is the issue we need to address. We will see that there are various ways to get around this unknown that we are having in front of us.

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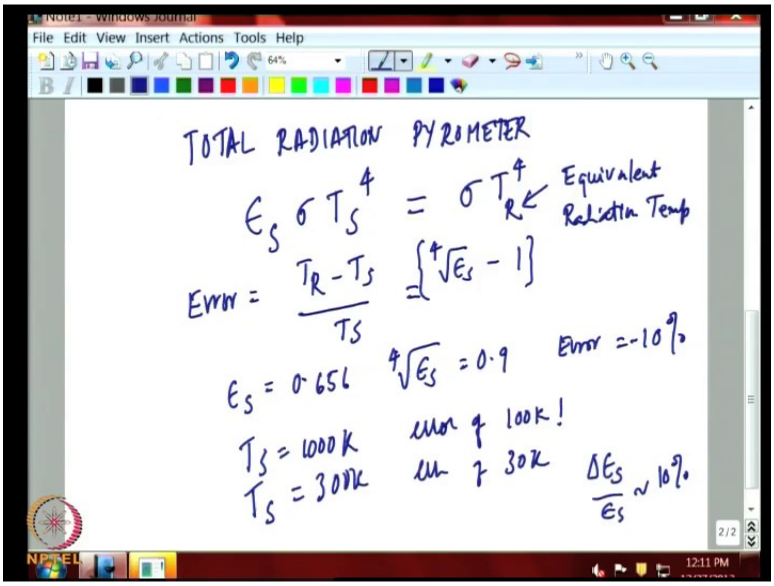

TOTAL RADIATION PYROMETER

$$\epsilon_s \sigma T_s^4 = \sigma T_R^4$$ ← Equivalent Radiation Temp

$$\text{Error} = \frac{T_R - T_s}{T_s} = \left\{ \sqrt[4]{\epsilon_s} - 1 \right\}$$

$\epsilon_s = 0.656$ $\sqrt[4]{\epsilon_s} = 0.9$ Error = -10%

$T_s = 1000\,K$ error of 100K!

$T_s = 300\,K$ err of 30K $\frac{\Delta\epsilon_s}{\epsilon_s} \sim 10\%$

First we look at the very simple instrument called the total radiation pyrometer. It measures the radiation from all wavelength from the given object and this is equal to what is known as the equivalent radiation temperature. We measure the radiation emitted by the object over all wavelength and assume that the surface is a black body then you get the equivalent radiation temperature.

Now, the error in measurement then is what you inferred that is T_R minus what is the actual surface temperature. This is the error. Now, we can estimate this very easily because this is nothing but, T_R from here is nothing but fourth root of epsilon minus one. We can now make estimation. Suppose for convenience, epsilon surface was around 0.656; taken for convenience. The fourth root of that will be 0.9. So, error will be ten percent.

The question is, if that error acceptable. Now, suppose we are measuring the temperature of a very hot object let us say thousand degree kelvin, then this will translate to error of 100 degrees Kelvin. That is the large. Now, whether that error is acceptable or not, depends on an application. There may be applications in the industry. Wherein, we need to know only temperature within hundred Kelvin, in which case you will accept this as reasonable. Or, if the emissivity of the, let say of a molten metal will not be normally as slow as 0.656. It may be higher. That will go down. Let us say error is five percent and so your error is 50 Kelvin.

For certain metallurgical application, if the requirement is you need to know the temperature of the molten metal only within fifty degree Kelvin, this method may actually work; provided the emissivity of the surface is about 0.7 or 0.8. This method is quite convenient; very simple method for measurement of temperature remotely. For example, suppose you are measuring an object very close to room temperature, then the error then the error is not very large. Error is lower. But, still it is quite large; ten percent.

This error can be of the order of thirty kelvin for ten percent error. Now, that may be unacceptable. Obviously, we do not have any real values of a temperature of an object, which is in room temperature at 300 Kelvin. So, obviously in this situation when you are trying to measure room temperature of a wall of a room, then you need to demand at least one percent accuracy, so that it can come down to around 3 degrees Kelvin. We know the emissivity of surface. Then, of course life is much easier. But, as we pointed out for most surfaces of engineering interest, it is not easy to get an accurate value of emissivity.

But, we can see that the errors that are measured here are actually the errors because you assume that the surface is a black body. Suppose we have a rough idea what the emissivity of surface is, then the error will not be such larger. Suppose, we know the emissivity of surface is somewhere between 0.7 and 0.8 with an inaccuracy of 0.1 which is typical for the surfaces, then the error is much lower because then we can put in that emissivity as a part of your program. Then, we can do an error analysis and find out on account of the error in emissivity of let us say of the order of ten percent, what is the impact on the temperature measurement.

So, measuring temperature with a total radiation pyrometer is quite convenient, if we have some knowledge of the accuracy, some knowledge about emissivity of the surface with an accuracy of ten percent. Then, our accuracy will be much larger. What we had in it is our assumption that emissivity is 1 and if the emissivity is not one, what is the other value that is coming in.

Now, total radiation pyrometer is widely used in the metallurgy industry because it is easily handled device we can easily use it without a power source, have a battery operated system. Since we are measuring the radiation emitted at all wavelengths, you are actually getting in a lot of radiation input into your detector The detector need not be a very sensitive detector, it can be a rugged one.

But, we can see that the accuracy of this device is very much dependent upon your knowledge about the emissivity of the surface. Some of the pyrometers have a place where we can enter what we know about the emissivity of surface and it will give you accordingly the temperature. But, if the emissivity of the surface is not accurate, this method is not going to work. The people have thought of other ways of measuring temperature. So, what we saw was a total radiation pyrometer.

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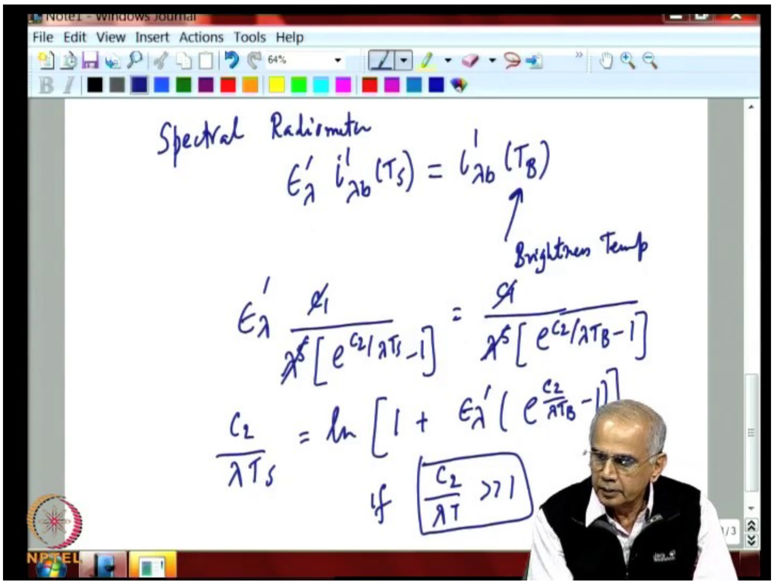

Spectral Radiometer

$$\epsilon'_\lambda \, i'_{\lambda b}(T_s) = i'_{\lambda b}(T_B)$$

Brightness Temp

$$\epsilon'_\lambda \frac{\cancel{C_1}}{\cancel{\lambda^5}\left[e^{C_2/\lambda T_s}-1\right]} = \frac{\cancel{C_1}}{\cancel{\lambda^5}\left[e^{C_2/\lambda T_B}-1\right]}$$

$$\frac{C_2}{\lambda T_s} = \ln\left[1 + \epsilon'_\lambda\left(e^{\frac{C_2}{\lambda T_B}}-1\right)\right]$$

if $\boxed{\frac{C_2}{\lambda T} >> 1}$

Now, we can now think of the next instrument; which is a spectral radiometer. The previous instrument the total pyrometer measures the total radiation at all wavelength; now, this spectral radiometer will only measure the radiation at a specific wavelength. The radiation will be equated to a black body and that is called the brightness temperature. So, brightness temperature is the temperature of a fictitious black body which emits the same amount of radiation as the real surface.

Now, if we write down what the actual emission from a black body is, if we know that; it will go as C_1 by lambda to the power of five into e to the power of C_2 by lambda T_s minus one. This of course, lambda to the power of five cancels out and C_1 also cancels out. We can write down the relation between the temperatures of the object as shown above. So, once you have measured the brightness temperature of the object we have some idea of the directional spectral emissivity of that surface, we can estimate the surface temperature.

Now, we might like to know what is the kind of error this introduces in comparison to the total radiation pyrometer. And, for that we will want to exploit one approximation, which we have used earlier. We saw that in many applications of relevance to Engineering, this quantity C_2lamda/T is much greater than one; not always, but in many cases.

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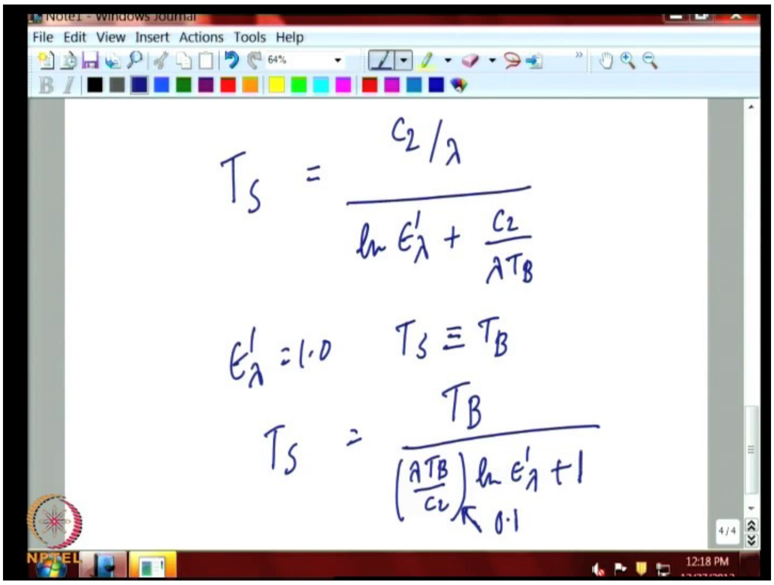

$$T_S = \frac{C_2/\lambda}{\ln \epsilon'_\lambda + \frac{C_2}{\lambda T_B}}$$

$$\epsilon'_\lambda = 1.0 \qquad T_S \equiv T_B$$

$$T_S = \frac{T_B}{\underset{\nwarrow\, 0.1}{\left(\frac{\lambda T_B}{C_2}\right)} \ln \epsilon'_\lambda + 1}$$

If that is the case, this approximation can be made, and then the previous result becomes somewhat simpler. We can then write T s as the equivalent to C two by lambda by log , as in the previous case if epsilon prime lambda is one, then of course T_S is identically equal to T_B. Otherwise, it is not.

Now, if we recall there are many many situations in the real world. Let me rewrite this equation in a slightly different form to bring this out. We can multiply by lambda T_B by C_2 both up and down, so T_S becomes as shown in the above equation. So, what we will really need is that the this quantity in the denominator should be small compared to one. Then, you are okay. Now, for example, this quantity lambda T B is typically is of the order of 0.1. This is of order point one, then even if epsilon by lambda let us say 0.9 or 0.8, it is not going to give a very large error; because it is a logarithmic term, this is multiplied by small quantity.

We can see that the accuracy that you will achieve by using a spectral radiometer is far superior to that you would get by using a total radiometer; that is, the pyrometer. That is the advantage of this instrument; is that because it measures the radiation emitted at a specific wavelength chosen by you. We can chose the wavelength, so that this quantity is much lesser than one of for the temperatures that you are dealing with; so that, the errors can be made quite small. We can have some control over the accuracy of the temperature measurement. However, you must remember that there is the penalty you have to pay in any of these situations.

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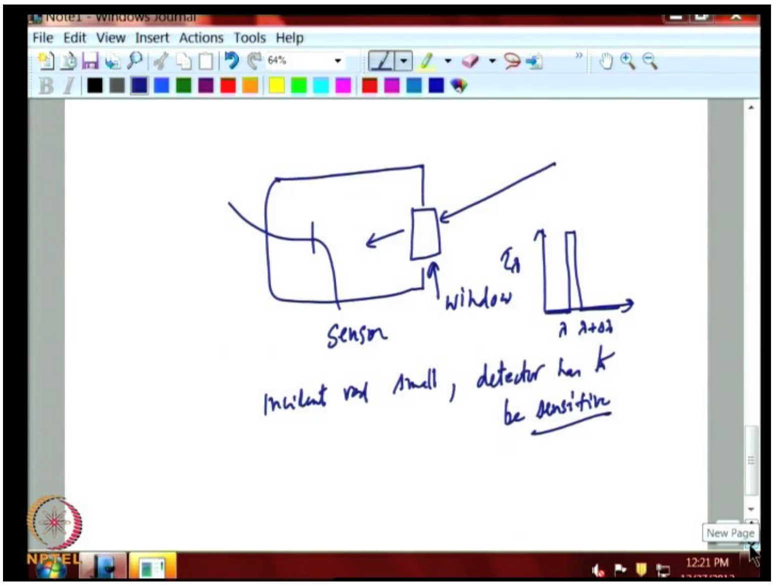

Incident rad small, detector has to be sensitive

The penalty in this case is that, since you are going to put a filter in front of the instrument; so, let us draw a big instrument looks like: that is the body of the instrument; that is the window and here is the sensor which measures, so the radiation coming in from this end and entering the sensor. Now, in the case of the spectral radiometer, this window will be; if you look at the transmissions of the window, it will be one, over a very narrow range of wavelengths of interest to you. They only admit radiations of small wavelength range, which you are going to choose depending on your application.

So, because we are completely blocking out radiation from all other wavelength, this signal, the incident radiation on the sensor will be small; because you are deliberately excluding any radiation outside the wavelengths of interest to you. The detector has to be very sensitive. That is the challenge now. Because we are using a spectral measurement technique not total as the signal then you are receiving a much smaller signal. Hence the detector we are using has to be much more sensitive and has to be able to respond to very small signals.

But, in return for this weakness, the strength of the method is that if an object has an emissivity less than one, 0.6 or 0.7, it will not have the same level of inaccuracy as the total radiation pyrometer because of the fact that we are going to choose the wavelength, so that this quantity is kept small. As long as this quantity is kept small, even emissivity 0.5 is not going to cause a very large problem.

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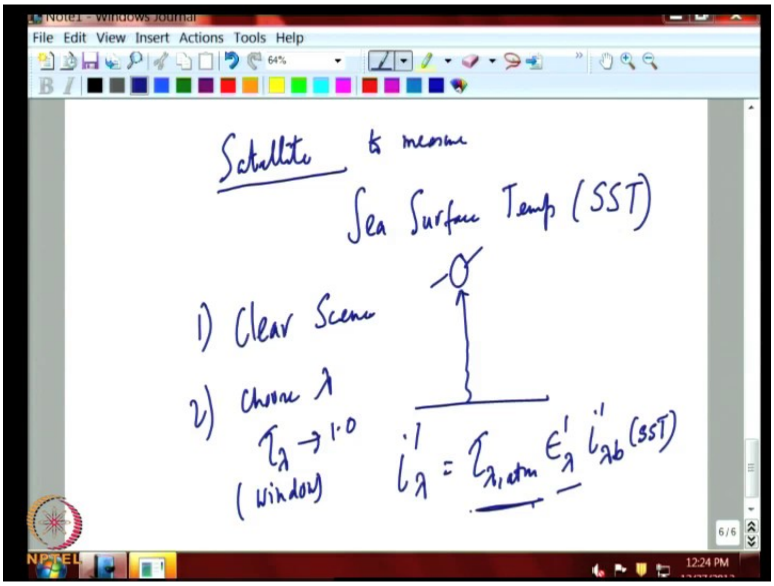

Satellite to measure

Sea Surface Temp (SST)

1) Clear Scene

2) Choose λ

$\tau_\lambda \to 1.0$

(window)

$$i'_\lambda = \underline{\tau_{\lambda,atm}}\, \underline{\epsilon'_\lambda}\, i'_{\lambda b}(SST)$$

That is the advantage of the spectral radiometer. Spectral radiometer is used widely. The most important application is in satellite. In satellite, spectral radiometer is used to measure sea surface temperature. To measure the sea surface temperature from the satellite; because as all of you realize as most of the earth is covered by oceans we need to know what the temperature of the ocean is.

In the pre satellite era, most of the data was obtained from the ships. But, these data are limited to certain regions of the world where there is a lot of shipping. We did not have true information about sea surface temperature over all parts of the world. We got lot of data where certain shipping routes, where lots of ships plied; let us say between Singapore and Chennai. But in other places, in the remote places of the world where ships do not ply that often we had known no data.

In order to estimate the global mean temperature, we need data over all oceans of the world. So, satellite provides the only opportunity to measure the temperature of the ocean over all parts of the world. The technique that is used is you choose a clear sea scene, so there are no clouds. And, so what those satellites measures this emission from the sea. Choose lambda such that tau lambda is tends to one; it is called the window of the atmosphere because if the emission from the whole surface is absorbed on the way, then we have to account for it. So, what the satellite is measuring in this case is what is transmitted by the atmosphere, times what is emitted by the ocean surface.

In comparison to what we have discussed for measurements in the industry, where the radiometer is close to the surface, so that this term is one, now we are contained with this problem. We will choose a wavelength where this is close to one. We hope that this quantity is also close to one. Fortunately, for us the spectral emissivity of the ocean is very close to one; 0.98, 0.99; because the water is a good absorber in the infrared also emits very well.

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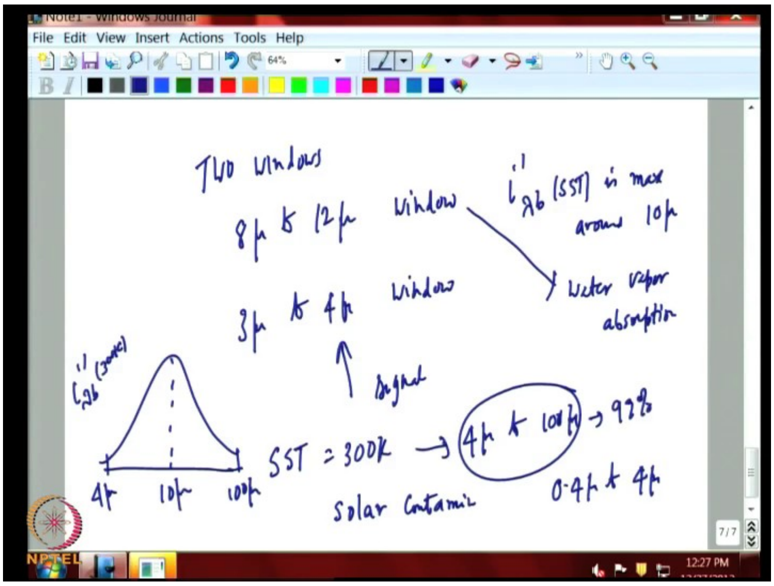

This does not pose a serious problem as this. Now, generally what is done for satellite measurement is, they choose; there are two windows which are of interest. One is the 8 to 12 micron window the other is 3 micron to 4 micron window. Now, the 8 to 12 micron window is very popular because i prime lambda b at the typical temperature of the ocean is maximum around 10 micron. So because of that, this 8 to 12 micron window is preferred because signal is stronger in the satellite. But, in this window there is also some water vapor absorption, so that this poses some problem in reality. Especially, in the tropics where the water vapor content is large, this can cause a large error. We will discuss later how this can be tackled.

The other window is 3 to 4 micron. It is quite transparent. But, signal here is weak; because all of you recall that for a SST around 300 K, radiation is lying between 4 micron to 100 micron; so, ninety nine percent of radiation lies in this range. If you are going to look at 3 to 4 micron, it will be less than one percent of the radiation in that tail of the spectrum.

If we look at the typical i prime lambda b of 300 k, the maxima will be around 10 micron. By 4 micron and here 100 micron, here signal is going to be extremely weak. But, still this is looked at because the transmittance of the atmosphere is very high. There is no absorption band of water vapor in this region.

The other problem is faced in this 3 to 4 micron window is the solar contamination. If we recall, solar radiation lies between 0.4 micron to 4 micron. In 3 to 4 micron, there is some radiation.

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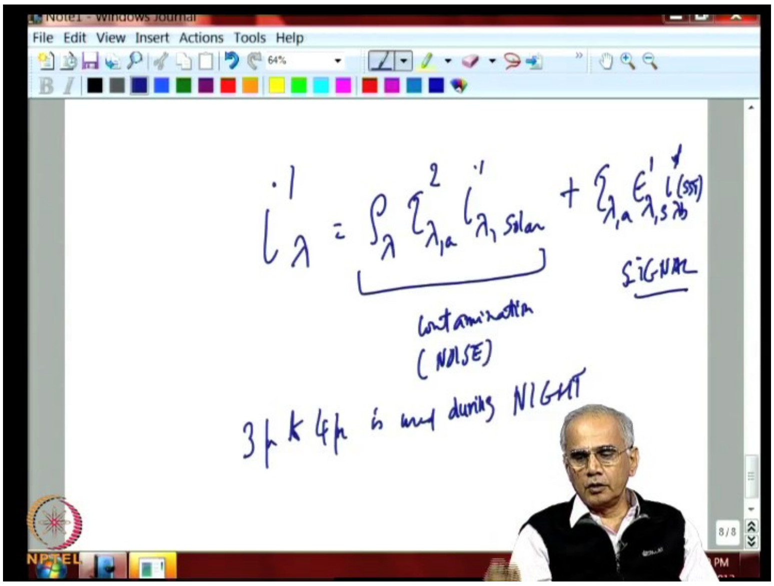

$$i'_\lambda = \underbrace{\rho_\lambda \tau^2_{\lambda,a} i'_{\lambda,solar}}_{\substack{\text{contamination} \\ \text{(NOISE)}}} + \tau_{\lambda,a} \epsilon'_{\lambda,s} i'_{b}(SST)$$

SIGNAL

3μ & 4μ is used during NIGHT

So, what we are measuring in the satellite is the reflectivity of the surface times the transmitted atmosphere device of i prime lambda solar plus tau lambda atmosphere, epsilon prime lambda of the surface and i prime lambda b of S S T. This is the contamination. We do not want this because we are trying to measure the sea surface temperature. This is the signal we want, while this is the noise as far as you are concerned. We can do nothing about it.

Generally the 3 to 4 micron channel is used for measurement at night. We want to use during night, so when there is no solar contamination. It is pretty accurate. And in most parts of the world, the temperature of the ocean between day and night is not very different. The day measurement is given up.

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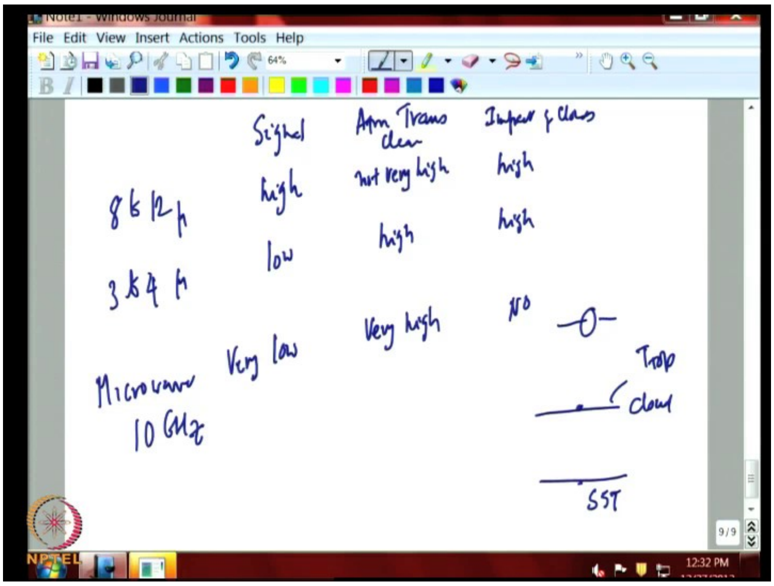

	Signal	Atm Trans clear	Impact of clouds
8 & 12 μ	high	not very high	high
3 & 4 μ	low	high	high
Microwave 10 GHz	Very low	Very high	No

But, remember that the major weakness of these two channel; let us now putdown the three channels; 8 to 12, 3 to 4 and we will very soon now discuss the microwave. Now, the advantage of this channel is signal is high; if we chose this channel, the signal is low; we got the microwave which will discuss now, it will also be low.

If we look at the atmospheric transmittance, here this is not very high because of what we have. This is high and this is very high in the microwave. If we look at impact of clouds is high, clouds completely blocked the surface. This is high; no impact.

We can see that both 8 to 12 micron wavelength has 3 to 4 micron are both useful for clear sky only. If there are clouds, we cannot use the infrared channels at all because clouds are strong absorbers of infrared they will block the emission of the ocean surface. We will not be measuring the ocean surface temperature, but the cloud top temperature. These are the ocean at temperature we have cloud, we have cloud top temperature and we have satellite to only measure this temperature, not this temperature; because cloud is pretty opaque to IR. If we want to measure temperature in cloudy condition like during the monsoon, then we have to go to microwave. In microwave the typical channel uses around ten giga hertz.

The signal is very weak as we can imagine because the tail of the spectrum of the black body spectrum shows that the radiation emitted in the microwave at 300 degrees Kelvin is probably one-millionth of the radiation emitted at as the ten micron. So, from the point of view of signal, we would actually put very low here. In spite of that, this channel is very important because it can give the ocean temperature during the monsoon. Otherwise, during the four months of the monsoon June to September, we will get no data over the ocean.

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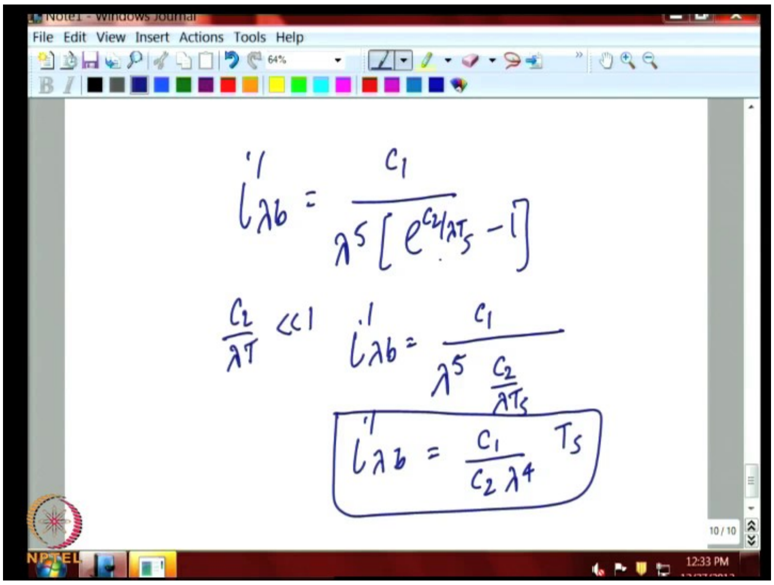

$$i'_{\lambda b} = \frac{C_1}{\lambda^5\left[e^{C_2/\lambda T_s} - 1\right]}$$

$$\frac{C_2}{\lambda T} << 1 \qquad i'_{\lambda b} = \frac{C_1}{\lambda^5 \frac{C_2}{\lambda T_s}}$$

$$\boxed{i'_{\lambda b} = \frac{C_1}{C_2 \lambda^4} T_s}$$

Now, let us look at the microwave advantages. We write i prime lambda b; you know that it is C one by lambda to the power of five e to power of C two by lambda T minus one. Since, we are talking about C two by lambda T being very small; because lambda is very large. We can expand this; so, i prime lambda b will be C 1 by lambda to the power of five C two by lambda T one plus, and one will cancel out. We go this way. So, i prime lambda b will come out as C one by C two lambda to the power of four into T s. This is huge advantage for us. Because the intensity we are measuring is proportional to the surface temperature, so we do not have the nonlinearity that is there in the original equation.

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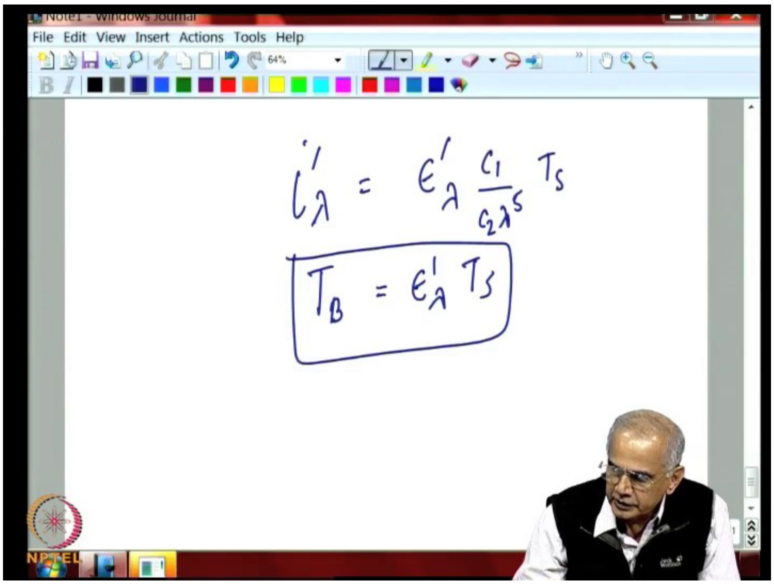

$$L'_\lambda = \epsilon'_\lambda \frac{C_1}{C_2\lambda^5} T_s$$

$$\boxed{T_B = \epsilon'_\lambda T_s}$$

In microwave we can easily write that the surface temperature measured by this one is equal to epsilon prime lambda times C one by C two lambda to the power of five into T s. If we write in terms of brightness temperature, we can see that the brightness temperature is equal to epsilon prime lambda in to T s.

When we measure the microwave radiation and estimate the brightness temperature, we are measuring actual temperature if the emissivity is one; otherwise, it goes down linearly with emissivity. This is very linear equation. It has tremendous advantages in terms of processing the data.

But because of the signal from the ocean surface in microwave is very very low, we need extremely special electronic amplifiers; which will amplify the signal by million times accurately for it to be able to measure. But, today this is the preferred way of measuring the sea surface temperature in the tropics under cloudy conditions; because it is able to measure temperature, even when there are clouds. It cannot give you a good data when there is rainfall; because the liquid droplets or ice particle interfere with the emission from the ocean surface. But, otherwise this method is very valuable method for measuring temperature under cloudy conditions.

So, all the challenges due to low signal in the microwave have been overcome by designing a large antenna and in demonstrating that the high gain amplifier can be utilized. We see that the spectral radiometer approach, where we measure the radiation from the surface at a given wavelength is a very useful technique because it enables you to reduce the inaccuracies caused by the emissivity being different from one.

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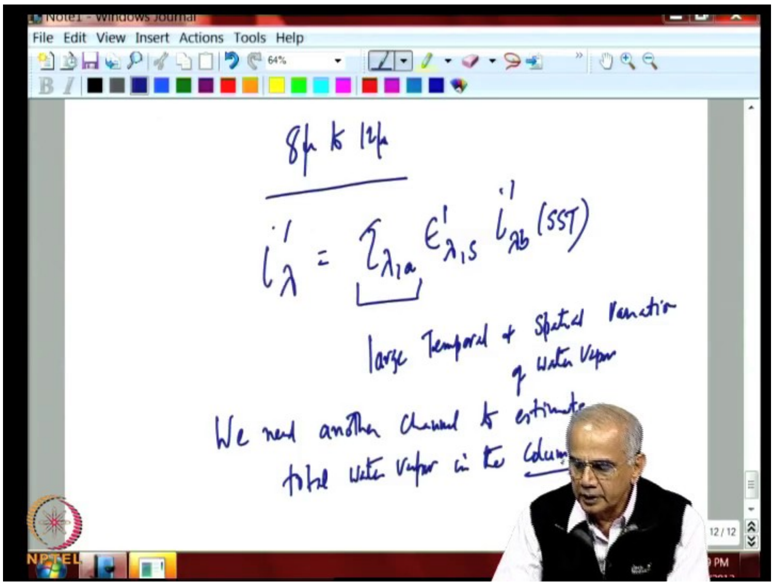

8μ to 12μ

$$i'_\lambda = \underbrace{\tau_{\lambda,a}}\, \epsilon'_{\lambda,s}\, i'_{\lambda b}(SST)$$

large Temporal + Spatial Variation of water Vapor

We need another channel to estimat
total water vapor in the colum

Now, let us come back to our problem in the 8 to 12 micron channel, which is the most popular channel still. We saw that what we are measuring here is what is transmitted by the atmosphere times what is emitted by the surface. Now, this is an issue. If this is varying a lot, the major reason why it is transmitted below one in the 8 to 12 micron band is because of water vapor. The water vapor varies a lot; both spatially and temporal, so that this will introduce noise.

Due to large temporal and spatial variation of water vapor, there will be large uncertainty in the estimate of i prime lambda. Now, this is a fairly serious issue in the tropics, where an accurate estimate of sea surface is very important. Because it has been shown that the sea surface temperature controls where deep clouds form, where the major tropical rainfall systems occur.

We need accuracy in estimation of sea temperature. But, we are throttled partly because not because of emissivity is less than one. That is not an issue at all; which is very close to one. It is because the transmittance is highly variable in space and time due to high variability of water vapor. T he way to get around this is to get an estimate of water vapor. If we get estimation of water vapor by an independent mean, then we can estimate the tau lambda with some accuracy, some error. So, essentially we need another channel to estimate total water vapor in the column. This is absolutely essential for you to able to estimate tau lambda a.

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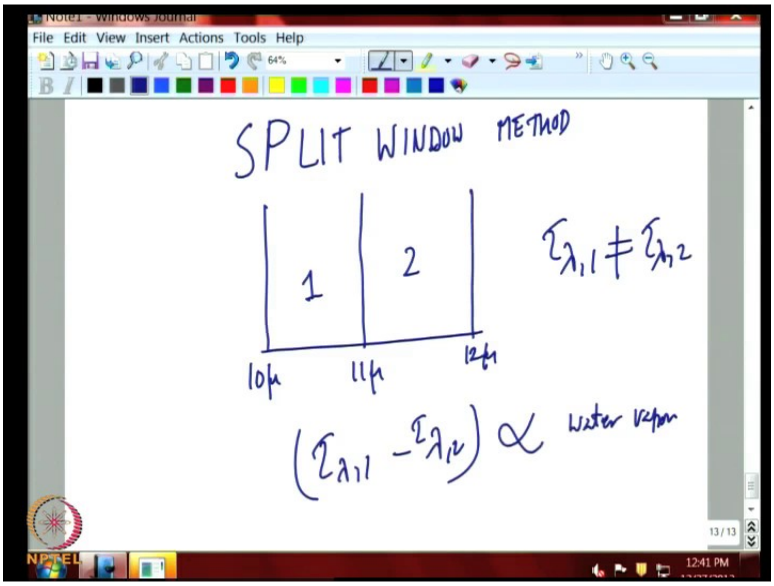

It is done essentially by using two wavelengths. It is called the split window method. This split window method essentially takes this region between 10 micron and 12 micron and splits the window into two parts. This is the channel one and this is the channel two. The water vapor impact on these channels is not the same. Hence there is slight difference in the transmittance. The transmittance in region one is not equal to transmittance in region two. The difference in the transmission is an indicator of how much water vapor is there. The difference in the transmittance is proportional to water vapor in the column. So, by measuring the brightest temperature in the two different channels, we can partly account for the impact of the water vapor. Now, the way that is done is by the concept of what is known as color temperature.

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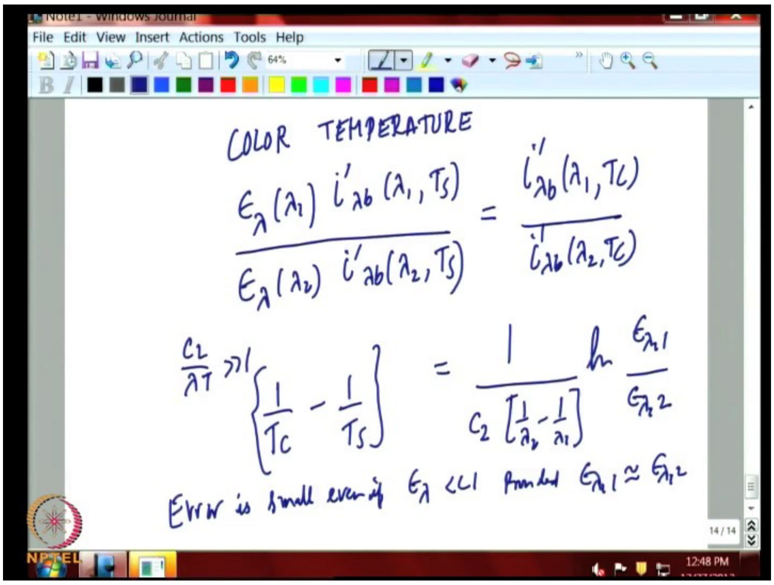

COLOR TEMPERATURE

$$\frac{\epsilon_\lambda(\lambda_1)\, i'_{\lambda b}(\lambda_1, T_S)}{\epsilon_\lambda(\lambda_2)\, i'_{\lambda b}(\lambda_2, T_S)} = \frac{i'_{\lambda b}(\lambda_1, T_C)}{i'_{\lambda b}(\lambda_2, T_C)}$$

$$\frac{C_2}{\lambda T} \gg 1 \quad \left\{\frac{1}{T_C} - \frac{1}{T_S}\right\} = \frac{1}{C_2\left[\frac{1}{\lambda_2} - \frac{1}{\lambda_1}\right]} \ln \frac{\epsilon_{\lambda 1}}{\epsilon_{\lambda 2}}$$

Error is small even if $\epsilon_\lambda \ll 1$ provided $\epsilon_{\lambda 1} \approx \epsilon_{\lambda 2}$

Now let me talk about the last radiometer called color temperature. The color temperature in which you use two adjacent wavelengths; lambda one, lambda two and look at the intensities as the ratio and ask yourself what temperature of a black body will give the same ratio. Here what we are doing is really using two adjacent channels. The emissivity will not be same in these two wavelengths.

We define color temperature as that temperature of black body whose ratio of intensities in the two channels is same as what is there in the real surface. Now, if we once more utilize a fact that C two by lambda T is much greater than one, we can simplify the equation further as shown in the above figure. Now what is the advantage of this method, the color temperature method? Color temperature will be same as surface temperature if the emissivity in the two channels is same.

Even though the emissivity of this surface may be very small, may be 0.1 or may be 0.05, as long as it does not vary in the adjacent channel, then error will be small. The error is small, provided the two emissivities are very close. They can be low value, but they have to be very close. Now, we can see the challenge. In order for us to ensure that the emissivity in the two channels close to each other, we want to keep lambda one, lambda two, where you look very close to each other. But, we make it too close that denominator will go to zero and become larger. There is a judicious choice required, so that the two wavelengths are sufficiently separated; so that, this quantity is not too small.

But, at the same time it is not too far apart that these two differ a lot. This requires some experimentation and some judgment in choosing the two channels that you will use to measure color temperature. But, we can see clearly that the color temperature approach will provide you accuracies much better than either that total radiation pyrometer or the spectral radiation pyrometer because the error does not depend on the actual value of emissivity. The error depends on how much emissivity differs in the two channels.

If we choose a wavelength range, where the spectral emissivity of the object is not changing much, then you will get a very accurate answer. But, one must also recognize that this technique is more sophisticated and more complicated; because you have to measure the radiation between two channels, take a ratio then find the temperature. It requires some software. It is not as simple as the total radiation pyrometer in which very simple techniques will give you the surface temperature. In the case of the color temperature you need a ratio comparison we need to do an iteration to find T c, which gives you the same ratio as the actual surface.

But, we can see that by using two adjacent channels having very similar emissivities, you are able to measure the temperature of surfaces; whose emissivity is unknown and quite small. The same logic applies in the atmosphere by choosing two adjacent channels. We are; in the case of the atmospheric application, this concept is used slightly differently because wherein, we are exploiting the difference in the transmittance of the atmosphere of the two channels to get an estimation of the transmittance. There by we get an accurate temperature.

In the case of the measurement of the ocean surface temperature, it is not the problem of emissivity; emissivity is close to one. It is the problem of the atmospheric transmittance. So, where there you are using the split-window in an attempt to get an idea of what is the departure of the transmittance atmosphere from one, on account of the water vapor; how much water vapor is there. There by estimate the amount of water vapor. In the case of the Engineering application, the surface temperature measurement is influenced strongly by emissivity of the surface; while measurement of the ocean surface temperature, the issue is not the emissivity of the surface, but that transmittance of the atmosphere.

So, using of two channels in the case of engineering application is to minimize the impact of surface emissivity. In the case of ocean surface temperature measurement, emissivity is close to one. The major problem is the variation of transmittance in the atmosphere.

Hence, one will estimate of what is the mean transmittance of the atmosphere. That is obtained indirectly by two adjacent wavelengths. They both are split-window techniques. In one case, you are splitting the window in order to get an idea of the transmittance between two windows. In the other case you use a split-window in order to eliminate the impact of low surface emissivity. In the rest of the lecture we will give brief account of the kinds of detectors that are used in radiation measurement.

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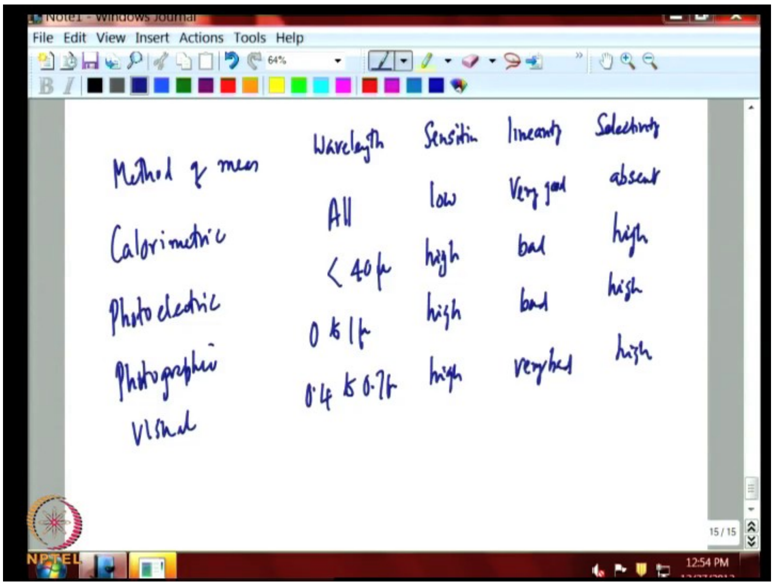

Method of meas	Wavelength	Sensitivity	linearity	Selectivity
Calorimetric	All	low	Very good	absent
Photoelectric	< 40μ	high	bad	high
Photographic	0 to 1μ	high	bad	high
Visual	0.4 to 0.7μ	high	very bad	high

So, let us look at the method of measurement and what the wavelength radiation can measure, what is the sensitivity, what is the is it linear response and selectivity. Now, the most popular method is calorimetric, which is oldest method used in the radiation transfer. It looks at all wavelength essentially, but sensitivity is low; because we are measuring the radiation of all wavelength, you are letting detector temperature to go up we are measuring the change in temperature. The sensitivity is not very high. It is very linear because the temperature is proportional to the incoming in There is no selectivity. It does not choose any one wavelength; choose the wavelength.

The next method which was used was photo electric. Essentially, the one in which as the photons impinging on the surface increases, enables more electrons to be released. It can be used only on certain range of wavelengths. Typically it can go from zero microns to less than forty micron; because we have got very high wavelength; the frequency is very low. When less than forty micron, it works quite well. But, we can imagine the wavelength is too high, the frequency is very low. That is not enough energy in the photon to induce a photoelectric effect.

This method has high sensitivity because we can use amplifiers; once the electron is released, we can use various techniques of amplification to get a very high signal. But, it is not linear because it responds only for the certain wavelength and but selectivity is very high. It selects certain wavelength and it is not sensitive to other wavelengths.

The third technique is, which all of us have heard is photographic; which we can use traditionally in Metallurgical industries, where we look at the color of the object there by decide what the temperature is. This only works in the range from zero to one micron because you need visible light for this kind of method. The sensitivity is quite high, but linearity is poor and selectivity is also high; this is very similar to visual method, which is used by metallurgists in the field. This is 0.4 to 0.7 micron. Our own eye that we are using, it is very sensitive. We all know sensitivity is high, but of course linearity is not good and selectivity is high.

We have the broad picture of the different techniques that are being used today. We can see calorimetric method is ideally used in total radiation pyrometer where all the radiation of the object comes into the pyrometer, hits the detector we detect the temperature change, and from that you infer the radiation. The other methods are spectrally selective. Hence they do not measure the total radiation; they are only measured in certain wavelength. But, they have much higher sensitivity than the calorimetric method.

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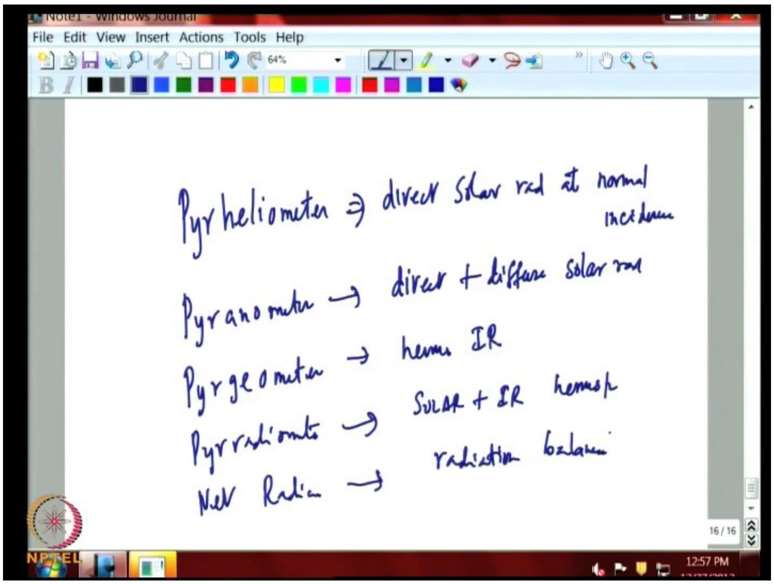

Pyrheliometer → direct Solar rad at normal incidence

Pyranometer → direct + diffuse solar rad

Pyrgeometer → hemis IR

Pyrradiometer → SOLAR + IR hemisph

Net Radion → radiation balance

Now, in those sensors in which temperature measurement is used, of course you have to have detecting the temperature change; it can be done by thermo couple or other devices. But, let me just give you few names today of the kind for readymade use. One is called the pyrheliometer. This one measures direct solar radiation at normal incidence; which is now getting very important, if we want to utilize the solar radiation using concentrators you need this information.

On the other hand, if we want the radiation both direct and diffuse, we can use pyranometer which measures both direct plus diffused solar radiation. This also is used all over the word. If we want to measure in the infrared, use pyrgeometer. Pyrgeometer measures hemispherical infrared radiation. If we measure both, it is called a total radiometer; which measures both solar plus I R hemispherical values. A net radiometer uses two radiometers up and down and it measures the net radiation. These are the common instruments routinely used in the field for measuring solar radiation, I R radiation and net radiation.

So, thank you.