Remote Sensing: Principles and Applications
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Lecture-64
Application of RS in Water Resources Management-Part-1

Hello everyone, welcome to the next lecture in the course. Today we are going to discuss about application of remote sensing in water resources management. This is all together a different field. In the last lecture we discussed about land use, land cover classification and some applications of using the classified data and change deduction.

When we want to see the applications of remote sensing in water resource management then definitely it involves some sort of background knowledge in the field. In the introductory lectures I told that whenever you want to do some sort of applications then definitely the domain knowledge is needed for us to effectively apply remote sensing data sets. So, in this lecture we will try to get a very broad overview of water resource management and how different remote sensing data sets can be used in water resources management.

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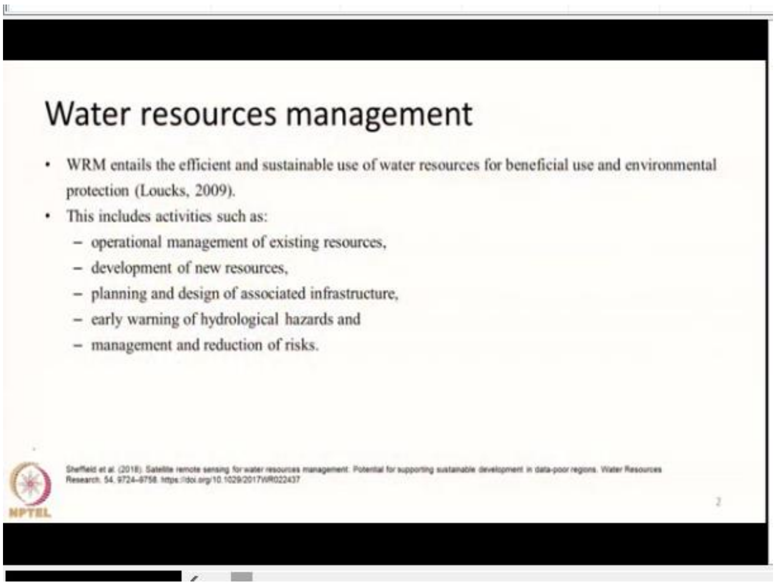

So, what water resource management is? To simply put water resource management is to deal with or is to develop a kind of procedures for efficient and sustainable use of water resources. That is we need water for many things; not only us, even the natural systems they need water for their own survival, even other living beings, plants and everything. So, there should be some sort of mutual agreemental use of water.

As humans we cannot take all the water available on the planet earth. We also need to spare something for the environment. So, water resource management is to deal with these kinds of problems for efficient management of water resources, so that it can be used sustainably for the beneficial use of humans as well as for environmental production. So, this is one of the definition.

There are different definitions available in various textbooks, but we try to cover in a broader sense. So, what are all the activities that will classify as water resources management. Water resource management will always deal with operational management of existing water resources, say we have a reservoir how to effectively operate it for sustainable water use. Development of new water sources, say exploration like construction of new dams, so that water can be provided for agriculture and drinking purposes for a region. Then planning and maintenance of associated infrastructure; water resource management people has to also deal with the infrastructure associated with it.

Say there is a reservoir, water has to be distributed to a nearby town means it will be distributed in form of pipe network. So, there will be specialized people dealing with those things, installing the infrastructure needed and maintaining it. Early warning on monitoring of natural hazards, say when drought occurs, then there will be lack of water, it may affect food production, it may affect all living beings. So, there should be some sort of activities going on for effectively monitoring such natural hazards or even to forecast it. Say flood is a natural hazard. So, when people predict region that is going to be flooded, the infrastructure dealing with water resource have to be prepared for it.

Say in a dam they can adjusts the water level so that the incoming water can be stored and released slowly. So, effectively monitoring as well as prediction of natural hazards comes under the purview of water resource management and reduction of risks, whenever something is done by human always, there will be some sort of risk associated with it. Say construction of a dam and maintaining a reservoir behind it. So, this involves some sort of risk, what if the dam breaks or if say flood occurs, how much people will suffer from the flood, how to mitigate the risk involved, how to mitigate the implications of hazards. So, water resource management is not like a small field, it encompasses several divisions and there is separate masters level program to teach the different aspects of water resource management. So, it will be almost impossible for us to cover it in one course rather than even in one lecture. So, let us see some of the important variables that we will be requiring for water resource management. For effectively managing the water resources, it will be beneficial if we have information about all components of water cycle and also how water is being utilized basically.

So, water cycle means how water keeps on transforming itself from one phase to another or from one place to another, it goes through several parts, say from the land or oceans it may evaporate and go to the atmosphere, a part of it may come back as rain. So, whatever comes back as rain it will be flowing along the hills and land and it will be reaching the rivers. The rivers will flow to the oceans; a good fraction of it will go to the ground water system and so on.

So, this is a simple explanation of water cycle. But if we can quantify all these different components of the water cycle it will be really beneficial or helpful for us to effectively manage them. So, if we know there is a severe ground water shortage in one particular region then the government over the region may not permit development of more ground water extraction zones or bore wells, etc,. So, there can be some sort of policy restrictions or if we are able to predict the rainfall is going to be very poor in the next season, then people will be prepared for it. So they will be trying to maintain the water they have in the reservoirs and reduce the consumption.

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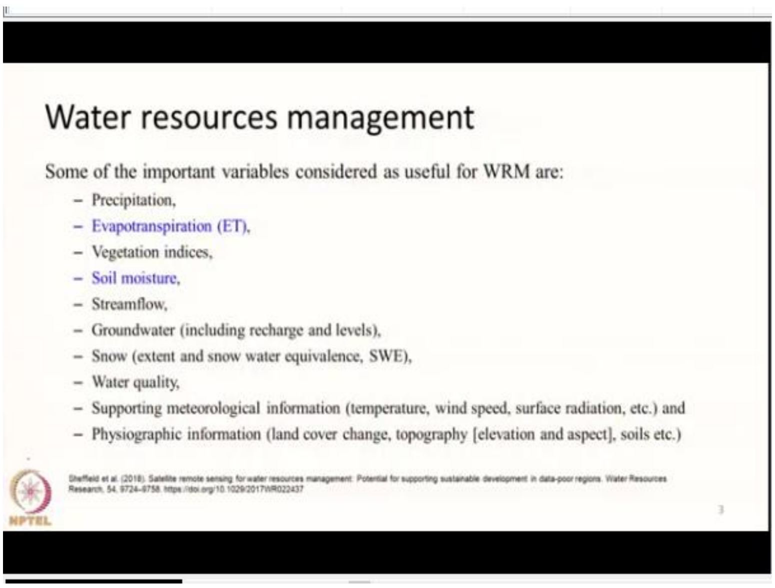

If we have information about the different components of water, it will be definitely of great use in management. Precipitation or rainfall, evapotranspiration, soil moisture, stream flow, ground water level and in some places rivers are fed by snow. So, the snow extent and snow water equivalence, water quality all these things are some of the important variables that will be required by people working in the domain of water resource management. In addition to this experts in the field will also require information about meteorological variables.

Temperature, humidity, pressure, etc are the meteorological variables that people will try to combine with remote sensing data sets and some sort of models. In addition to that physiographic information such as land use, land cover maps, topography, that is elevation. Again these can be obtained from remote sensing land use, land cover we just saw in the last lecture, topography that is DEM we can obtain from optical remote sensing or from stereophotogrammetry or radar remote sensing or even Lidar. So, basically several variables have been listed as needed in water resource management. In this lecture we will not be able to cover everything but we will quickly see how remote sensing is helpful in retrieving two variables.

One is evapotranspiration and another thing is soil moisture. First we will see how to model or estimate evapotranspiration from remote sensing?

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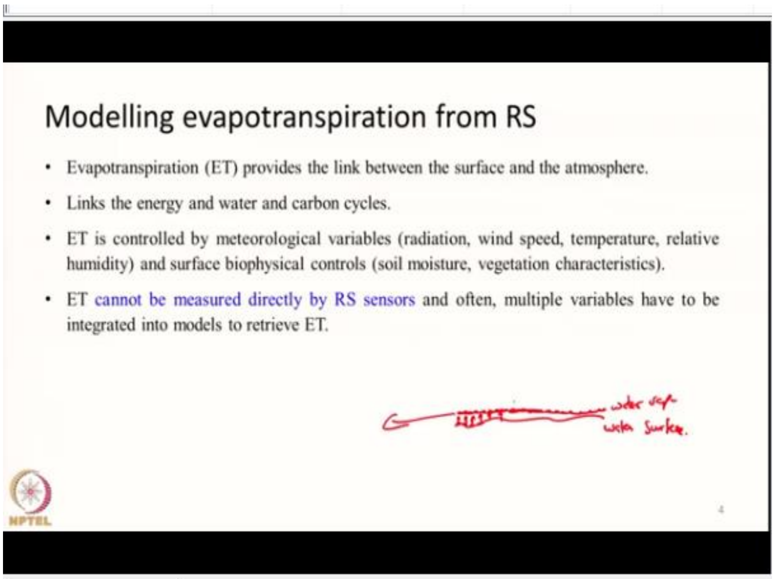

Evapotranspiration is the transfer of water from liquid phase or solid phase to vapour phase and getting removed from the surface to the atmosphere. Say you have a bucket full of water, if you keep it open for some time then, the level of water in the bucket would have gone down.

So the water has escaped from it, the liquid water has transformed itself into vapour phase and got mixed with atmosphere. Similarly this process is a continuous process, it happens everywhere and all the time. Evapotranspiration is actually a driving cycle or a driving force of the water cycle that connects the land and the atmosphere, because water has to move from land to the atmosphere and evapotranspiration actually provides a pathway.

And also it connects energy and water cycles like the earth as a planet and as a system has so many cycles within it water cycle, energy cycle, carbon cycle or other nutrient cycle and so on. So, there is always some sort of interconnection between these different cycles for the globe to function as a system. So, this evapotranspiration provides a link between the energy cycle and the water cycle.

Because when evapotranspiration occurs, only water will get transferred from land or ocean to the atmosphere then only it can again come back. If evapotranspiration stops, then the cycle is cut off, not only water is getting directly transferred, plants will also transpire water, when you pour water to plants, it takes it for its functioning and a large fraction of water goes back to the atmosphere in form of transpiration. Plants will open their stomata like tiny holes in the leaves which will allow the water to escape. So, it provides cooling to the leaves and it also the part of the way in which vegetation functions. So, this is closely connected again with carbon cycle, because plants store carbon, it is the primary producer. So, it is kind of a complex system in which evapotranspiration is actually a finding place.

So, monitoring this evapotranspiration is one of the crucial elements for understanding earth as a system and also for various applications in water resources, agricultural purposes and so on. So, evapotranspiration is basically controlled by meteorological factors, that is for evapotranspiration to occur first thing you need is a source of water, there should be some water present maybe like on the land surface, it may be wet or there can be healthy vegetation or there can be a water body anything, any source of water must be present, then some atmospheric forcing.

Atmospheric forcing means there should be some input energy to the system. So, that this water can gain energy and move away, because it needs some amount of energy for the water to get transferred from liquid form to vapour form and escape. So, that energy has to be provided and when water transfers phase, the water molecules on the surface will get transferred as vapour.

Let us say the entire air parcels closer to some water body is now saturated with water. Now it has to be moved away, unless there is a gradient say there should be continuous transport of this water vapour away from the source which is done by wind. Similarly like temperature humidity all these things play a major role. So, evapotranspiration is controlled by surface controls like surface parameters. Say if there is a vegetation, vegetation will not let all the water from it to escape, there will be some sort of controlled mechanism through which vegetation will transpire water.

So, evapotranspiration is controlled by meteorological variables and also by surface biophysical controls. So, effectively in remote sensing we will try to monitor these different controls and try to use it for estimating evapotranspiration, because evapotranspiration cannot be measured directly by remote sensing sensors. We can only measure few variables that will provide us clues related to remote sensing.

Say vegetation parameters, surface temperature and all these things. These are some of the variables which are closely connected with the process of evapotranspiration and using these variables we have to estimate evapotranspiration. So, the remote sensing based models for estimating evapotranspiration can be broadly classified into 2 categories.

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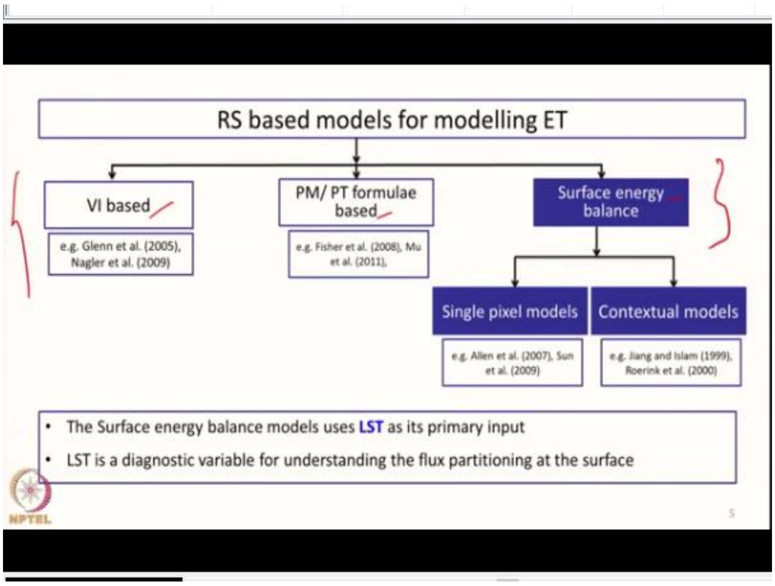

The models are vegetation index based models, Penman Monteith or Priestley-Taylor formula based models and then surface energy balance based models. There are other different classes and many classes are coming, but these are some of the classical 3 classes of models. Nowadays even machine learning models are being used to very large extent.

But the 3 models we are listing here are the classical ones. So, the vegetation index base models, is applicable over vegetated surfaces basically and this is kind of an upscaling strategy.

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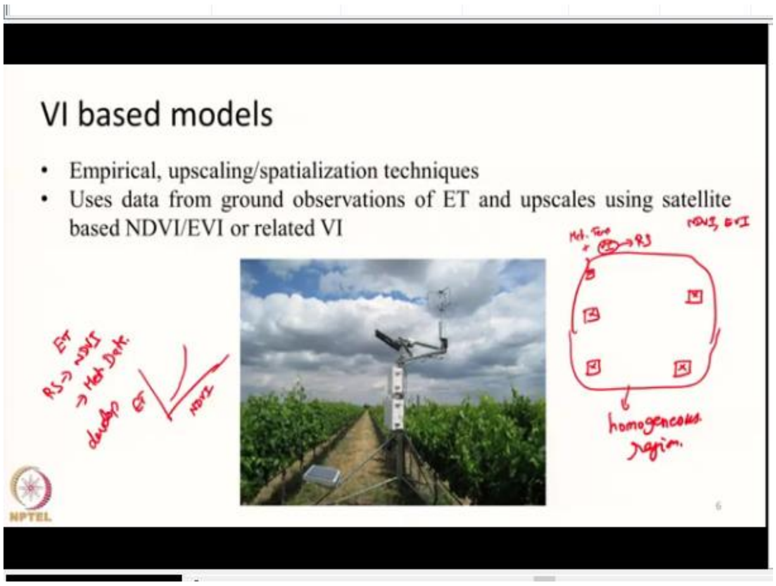

Upscaling strategy means you have a large region, over large region let us assume, it is homogeneous in terms of vegetation and water availability. Let us say you have some ground measurements of evapotranspiration distributed across this region, some 4, 5 ground based measurements you have. Along with this ground based measurements let us say we are measuring meteorological variables such as temperature, humidity and we are measuring some sort of vegetation indices using remote sensing.

Say I am measuring NDVI or EVI. So, at this particular small field or one pixel in a image I have a collective information of the actual evapotranspiration that is occurring from remote sensing dataset. I will get NDVI and the meteorological information from any other source either from ground measurement or even from remote sensing. So, using this data for the 5 stations we can develop a relationship between ET and any of these auxiliary variables. Let us say NDVI or EVI. Some people have related ET only with vegetation index, some people have related evapotranspiration with vegetation index and meteorological variables and so on.

So, effectively we are developing a relationship between evapotranspiration and this vegetation index. We have it over those 4, 5 points in our region where we have ground measurements.

Then we get satellite data. So, in satellite data we will have vegetation index for all the pixels. So, we will apply this relationship to the other pixels for which we do not have ground measurements.

Say you have one equation ET is equal to some equation in terms of NDVI or EVI and you get this EVI information from remote sensing. Just apply it in this equation and get it. So, this is a very simplified explanation of vegetation index based models that is why it is called as upscaling method. Upscaling means you have few ground measurements that can be applied to the data acquired over the few ground points to the entire region. So, this is one of the simplest methods that was developed, but these sort of methods are applicable only over homogeneous regions. If the characteristics of the region changes then the equation that you developed from the ground stations will not be valid.

The next class of models is Penman Monteith or Priestley-Taylor based models. So, the Penman Monteith or Priestley-Taylor equation are some of the classical equations in hydrology to estimate evapotranspiration. So, they were defined to estimate a maximum evapotranspiration that can occur. People call it as potential evapotranspiration or in some sense people will also call it as reference evapotranspiration. So, these are different aspects and these 2 equations are effectively the classical equations.

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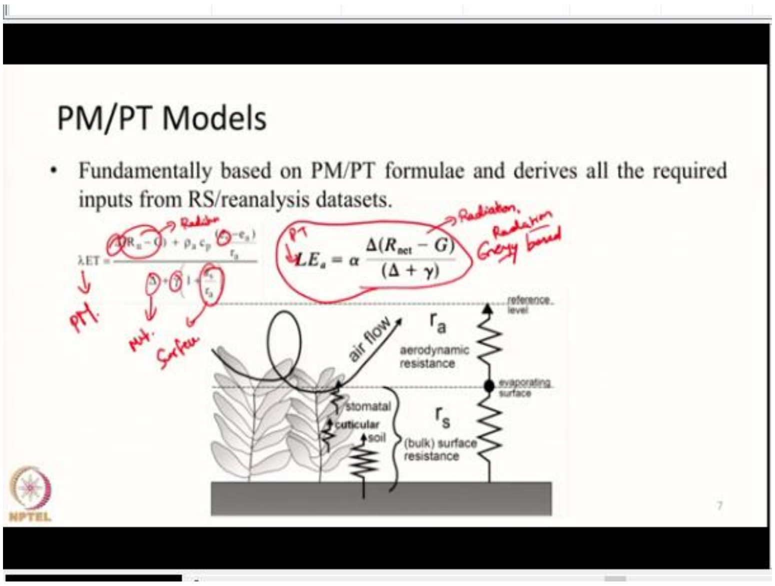

So, the Priestley-Taylor which is given here basically tells that, it is kind of a simple model which will help us to calculate evapotranspiration as a function of radiation. I already told you some sort of energy is required to transfer this water to vapour form and based on this solar radiation which is one of the major variables, there are other form of radiation that will occur. We will see in the later slides. So, how much radiation is available or conceptually how much energy is available and what fraction of the energy goes to the atmosphere as ET. So, it is kind of a simplified model or we can also call it as energy based equation or radiation based equation. Because the primary connecting factor is energy or radiation. On the other hand the Penman-Monteith equation is kind of a full fledge equation that relates the energy terms, meteorological variables and also the surface control.

So, this R_s/R_a is the surface controls on evapotranspiration , these variables (e_s-e_a), Δ, γ, these are all meteorological variables R_n - G is the radiation control. So, it combines all factors that influence evapotranspiration. The Priestley–Taylor equation is a simplified representation of Penman-Monteith equation. The Penman-Monteith is the expanded way. Priestley–Taylor is shortened or simplified version of Penman-Monteith. So, these equations are effectively developed and tested across different sites in the globe and normally people will run these equations with ground observed data. But later after year 2000 and all, there were lot of studies which investigated the potential of remote sensing data sets for getting the variables required for these equations. Say if we somehow get all the variables required by these equations through remote sensing or some sort of atmospheric reanalysis product, then we will calculate evapotranspiration. So, this is the basic concept behind this Penman-Monteith or Priestley–Taylor based equation.

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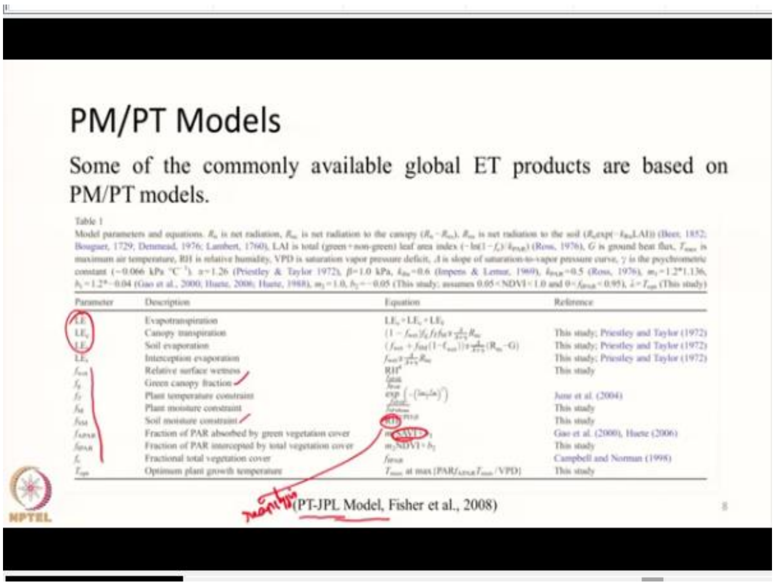

So, this slide gives us some basic example for this model. Here we have listed one model called PT-JPL Priestley–Taylor jet propulsion laboratory model which is one of the very famous model based on the Priestley–Taylor equation. So, essentially this calculates evapotranspiration using several variables that can be retrieved from remote sensing. That is say green canopy fraction, soil moisture, vegetation indices, temperature data, humidity data, all these things comes from reanalysis product and so on. So, effectively this model tells us these are all the different remote sensing data sets if we combine them together in a certain fashion we will be getting evapotranspiration.

So, there are again plenty of different models available, say Penman-Monteith model is the basis for development of ET by MODIS product. MODIS has its own land product evapotranspiration level 3 which is based on Penman-Monteith equation. So, there are several different models available where each author may improve upon the equations used how to relate the remotely sensed variables with those various parameters within the Penman-Monteith equation or Priestley–Taylor equation. So, that itself is kind of a huge class of models available within it. The next class of model is the surface energy balance based models. So, these class of models is the one that we can actually feel the connection between evapotranspiration, the water cycle and the energy cycle. So, we will see what surface energy balance in a brief manner.

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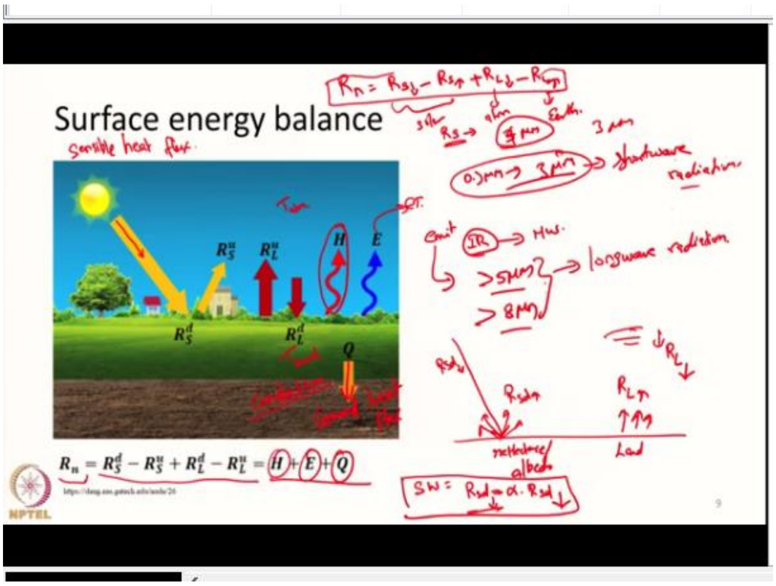

Let us say we have a land surface basically. So, solar radiation is the primary driving force, it provides most of the energy to us, we all know that the incoming solar radiation primarily composed of energy within say 4 micrometers or 3 micrometers. So, most of the energy that is coming from the sun is coming in the wavelength less than 3 micrometers. We call this as short wave radiation. This comes in form of radiation and we call this wavelength as short wave radiation. Then atmosphere and land surface both by virtue of their own temperature will emit energy which we have seen in thermal infrared remote sensing. So, land surface has a certain temperature T_{atm} due to which they will have their own emission. So, that emission will occur in infrared wavelengths. So, essentially the wavelength of emission due to land surface will typically be greater than 5 micrometer in most of the cases or it will be more primarily greater than 8 micrometer. But effectively this has a wavelength longer than incoming solar radiation. So, we call this emitted radiation as long wave radiation. So, these are effectively the driving forces of energy on the surface. In addition to this the surface has some sort of reflectance or albedo (because we are going to measure it in a hemispherical sense). Due to the surface albedo a fraction of it will be reflected back. So, this is R_{sd} incoming, this is R_{sd} outgoing, that is incoming energy is from the sun, outgoing energy is what is being reflected by the surface. We have seen almost all surfaces have some sort of reflectance.

So, some energy will be reflected back what is coming in from the sun. So, this will look something like the radiation that came in minus albedo times the radiation that goes out. Say albedo of a surface is 0.2, that means the surface will reflect 20% of incoming energy. So, remaining 80% will be there at the surface, 20% is reflected back. So, this is with respect to short wave radiation. Similarly, land surface due to its own temperature will be keep on emitting energy. So, we call this as R_L upward, this will be going upwards from the surface to atmosphere. Atmosphere will be emitting energy on its own due to its temperature.

That will be R_L downwards. So, all these things are the radiation components. So, effectively the net radiation available at the surface is given by ($Rs_{incoming}$ - $Rs_{outgoing}$) + ($R_{Lincoming}$ - $R_{Loutgoing}$). So, this is the net energy available from radiation at the surface and this is due to solar radiation. $R_{Lincoming}$ is due to atmospheric emission, $R_{Loutgoing}$ is due to earth surface emission. Now all this radiation will drive many processes but for our discussions we will talk only about two processes, what we call it as turbulent exchange of energy. Let us say land surface is now being heated up. During day time solar radiation will be more, it will be heating up the land surface to a very good extent.

So, the temperature of the land surface has to go up somewhere. The land surface will now heat up the air molecules near the surface, air molecules will go lesser in density and will go up. New air molecules will come down, colder air molecules will again get heated up and they will move up. So, this is kind of a heat transfer through convection, that is air molecules getting repeatedly heated by the land surface; they move up and they come down. So, it is a cycle, it goes on as a convective process. This way of energy transfer from the land surface to the atmosphere is called as sensible heat flux, we can sense the heat transfer that is why it is called as sensible heat flux.

If there is water present on the land surface, say it is not a dry surface some sort of water is present then, this radiation terms whatever is remaining on the earth surface will be used to remove some part of water to the atmosphere as ET. Because water needs energy for itself to get transferred from liquid to vapour form. So, whatever is the radiation that is present, a fraction of the energy will be used by the water to get transferred to vapour form. So, it uses some energy on its own, that is called latent heat flux or otherwise in terms of hydrological sense we call it as evapotranspiration.

Latent means hidden, the energy used by water will not be known to us, because when there is a phase change from liquid form to vapour form the temperature of the water body will not change, the energy will be used up by the water for this phase transfer. So, the temperature will not raise, we may not even know that a phase change is happening and energy is being used. So, this is like the broad explanation of surface energy balance equation. Say the net energy or the net radiation of the surface comprises of 4 quantities that will be equal to these 3 H + E + Q. H is the sensible heat flux, E is the average transportation and Q is ground heat flux, that is transfer of heat from the surface to the underground through conduction process.

So, in the introductory lecture to thermal remote sensing I told about different processes, different ways of heat transfer conduction, convection, radiation. All these things are happening here on the surface. Incoming energy is primarily through radiation, the transfer of energy happens through convective process, again under the ground the heat gets transferred through conduction, all these things comes.

So, if you think all the radiation terms is coming to the surface effectively will be equal it out by these 3 terms H + E + Q. If we can calculate this energy terms, we can easily calculate the E out of it. So, that is the basic principle of surface energy balance based equation. So, this is how we will calculate. So, in the next lecture we will quickly see how remote sensing is helpful for getting ET from this surface energy balance equation.

Thank you very much.