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

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REMOTE SENSING: CLIMATOLOGICAL APPLICATIONS

Good morning class and welcome to another lecture in climate dynamics monitoring and variability. Today we will go into our final section in the final week of our lecture series and that is shift from in-situ measurement techniques for climatology and meteorological applications to remote sensing and remote founding technology. that are usually done either through satellite systems or even ground based systems. So, the first thing I will try to do is to give you a general idea of where and why remote sensing and remote sounding technologies are used. what they are for and how they compare with in-situ techniques that we have been discussing so far either from ground in-situ measurements of temperature, humidity, pressure or upper atmosphere in-situ measurements to radio sonde methods. So, in this context we can define remote sensing and remote sounding application as those which measure meteorological and climatological properties from a distance.

That is the sensor system itself is not in direct contact with the entity that is whose properties it is measuring. So, if you look at a temperature sensor or pressure sensor that we looked at, the sensor is actually measuring the temperature, pressure, humidity values at the point that sensor is making contact with the air whose properties is being measured. Remote sensing is not like that. It is inferring this property from a location which is not close to where the proper, where the alien substance is whose properties are being measured.

Now how this is done? This is primarily done through the measurement and detection of electromagnetic radiation. Electromagnetic radiation is one of the few types of sensory information that is emitted by a substance and that can travel to empty space and can be detected far away from where the substance is. There are certain other signals also like audio signals that can also do that. But here for meteorological and climatological application, we will be focusing on electromagnetic radiation based detection property estimation systems. Now, this electromagnetic radiation can be emitted or reflected by land and sea surfaces or can be emitted scattered and transmitted by the atmosphere as well so we can measure the properties associated with surfaces land surface sea surface or surfaces of ice and to understand what type of surface that is what properties like temperature etc those surfaces have another option is measuring emitted scattered or transmitted radiation from the atmosphere to measure the properties of the atmosphere through which this radiation has been passing.

Now, all of these is usually done by orbiting instruments from space basically satellites, but can also be done from ground base stations And examples like that are radar stations or lidar stations which we will be discussing later this week. It can also be done through balloon and airplane which will contain this remote sensing system. So, what are the applications? The applications of remote sensing are quite large and not only are associated with climatological or meteorological properties. But a lot of other properties associated with getting geographic and location information in defense and intelligence gathering methods and in many other applications. Here though, we will primarily be looking at applications that are associated with meteorology and primitives.

So, if you are looking at some of the things that remote sensing and remote sounding systems can measure in the atmosphere, it can measure the temperature, the vertical profile of the temperature in the atmosphere, the vertical profile of pressure, the extent of precipitation, it can detect clouds and cloud types and their distribution. It can also measure wind velocity through tracking clouds. It can also detect concentrations of various gases, aerosols, etc. So, the entire set of properties usually you need for climatological modeling including atmospheric temperature, pressure profiles, precipitation amounts, cloud types, their distribution, wind velocity, gas concentration of various species. all of these can be detected by one or other type of remote sensing or sounding instrument when you are looking at land properties this can include things like topography so like the altitude of various land surfaces even sea levels which is quite important for climatological applications tectonic motion how land is moving due to the movement of plates.

It is extremely slow, but we can measure things like landslides, earthquakes, etc. Volcanic activity. Surface temperature, extremely important. Albedo of land. Soil moisture content, also very important to track and monitor to see if there is aridification caused by climate change.

Vegetation type. So, we can track how vegetation type is changing due to either human activity like deforestation etcetera, expansion of farm or through natural changes. Over ocean we can measure sea surface temperature, again extremely important, ocean is topography. Here what we are looking at is as we discussed earlier in some places ocean surface may be elevated and some places it may be depressed due to the action of wind systems, low pressure systems, high pressure systems that can be measured. Wave energy spectra, the strength of waves and the movement of waves and from this wave energy spectra we can actually infer the wind velocities over the ocean.

Ocean color which is important to look at to look at marine ecosystems and phytoplankton populations, plankton bloom that are also important indicators of various oceanic parameters and how they are changing. Finally the cryosphere which is the drone of ice which is the distribution and coverage of ice. movement of icebergs, movement of glaciers. So, this is this is extremely important when we are looking at changes in the ice cover, permanent ice cover in Antarctica, in Greenland, sea ice cover over Arctic, movement and retreat of glaciers in the mountainous regions etcetera. So, all of these aspects can be measured by remote sensing and remote sounding applications.

Now, we have been using two terms, remote sensing and remote sounding. What are these and what are the difference between them? So, let us look at the more common term which we often come across which is remote sensing. So we can define remote sensing in this way. Remote sensing seeks to receive electromagnetic radiation from an emitting or reflecting surface and hence seeks to infer properties associated with the object whose surface it is. So remote sensing is about detecting electromagnetic radiation coming from a surface either through emission or through reflection.

That surface may be a land surface, may be the surface of a cloud top, may be the surface of the ocean, may be the surface of ice. And using that emission, that radiation coming from that surface, we measure certain important properties associated with the surface. So, for example, in climatology, we can measure the radiation coming from the sea surface to measure the sea surface temperature. to the measurement of infrared radiation from the ocean surface. Or we can determine cloud distribution by detecting radiation reflected or emitted by the cloud top.

We can detect what type of cloud it is to and what is the distribution of various cloud types over the globe by looking at cloud top surface emission properties. Remote sensing requires that the medium between the surface and the receiver which is usually in the satellite be non participatory. So, we want the data that is coming from the surface unmodified by any of the intervening medium between the surface and the detector. So remote sensing usually focuses on those electromagnetic spectrum ranges where which are transparent to atmospheric attenuation or emission. Because if atmosphere is participating then we cannot get the proper surface emission data.

So that is remote sensing about surfaces and estimating properties of the surface. So that kind of gives us an idea of what remote sounding is. Now we are no longer interested in the surface. We are interested in the properties of the intervening medium itself, the layers of the atmosphere. So, here we are focusing on how the intervening layers of the atmosphere are changing the incoming radiation that is being detected and using that change to infer properties of this intervening medium between the surface and the detector.

Hence, in remote sounding, depending on requirement, electromagnetic wavelengths are chosen where there is considerable atmospheric emission, absorption or backscatter. Emission means the atmosphere is actively emitting the EM radiation wavelength that it is detecting. Absorption means the atmosphere is actively absorbing, if not emitting, the electromagnetic radiation wavelength that is being detected. scattering is basically it is reflecting in a diffuse way the electromagnetic radiation that is passing through that medium. Each of these systems can be used to infer various properties of the atmosphere like temperature profile, species profile, amount of aerosols, rain or snow in the atmosphere in through which this radiation is being transmitted.

So, vertical profiles of atmospheric temperature, density or absorbing slash scattering species like CO2, O3, aerosols etcetera are measured through remote sounding applications and here we require frequencies which are participatory, okay. And because of this remote sounding can span over a wide range of frequencies depending on what substance we are interested in. So, if we are interested in ozone concentration for example, we would be looking at the UV range. If we are interested in say CO2 concentration, we would be looking at the infrared range, right. So, the difference, so depending on which gas we are interested in, we will have very different wavelength for remote sound.

A second terminology that will also you will also come across in remote sensing and remote sounding applications is active versus passive systems. So passive systems measure radiation emitted by natural sources like shortwave radiation emitted by the sun or reflected by the grounds or the clouds or longwave radiation emitted by the ground or the sea. So naturally occurring electromagnetic radiation, radiation of the solar radiation or reflected shortwave radiation from the ground, cloud, aerosols, etc. These can be measured or long wave thermal radiation emitted by the ground or the sea or even the atmosphere. If these are being detected, the detection system is called a passive wave.

Active systems differ from passive systems in that they generate their own electromagnetic source. So active systems have a transmitter that emits radiation at certain frequency and the receiver that detects and analyzes the part of this radiation that is reflected back from the ground or aerosols or inhomogeneities of the atmosphere. Active systems can include satellites as well as ground based systems where what we are doing is we are choosing a set of frequency bands and actively emitted electromagnetic, emitting electromagnetic radiation from these frequency bands to the surface or to the participating medium we are interested in and looking at the scattered or reflected radiation coming back from the surface or the participating medium to gather information about that surface or the medium. And common application includes radar and radar technologies which we will discuss later in, later this week. So, that is active versus passive.

The third terminology depends, is based on the type of frequency bands a detector is sensing. The first type of frequency band we will be discussing is called the VNIR band which is visible and near infrared region. So, this is the region of short wave radiation being emitted by the sun or reflected by the ground, cloud, ice or ocean surface. And this is the range spanning from 0.3 to 3 micrometers. So, UV range to near infrared range including the visible range, ok. This can be used for aerial photography in visible spectrum and by electro-optical system which includes both visible and infrared vision. In this class we will not discuss aerial photography per se, we will be discussing the electro-optical DNIR system very near visible near infrared vision. reflection or scattering of solar radiation by surfaces is the primary signal that is being detected by these DNIR receivers. So, this is primarily talking about reflected radiation or scattered solar radiation.

And usually only remote sensing applications are done in DNIR because in the visible and the near infrared region there is very little active absorption and emission by the atmosphere. But scattering of course is possible, so scattering based remote sounding applications are there and this we will be discussing later in the class. But mostly DNIR systems work on remote sensing applications. The second part type of system is CIR, thermal infrared region. So, this is the far infrared region and here imaging is done between 3 to 15 micrometer.

So, 3 micrometer to 15 micrometer, so this is the thermal radiation range if you remember The 3 to 100 is the earth's total radiation spectrum micrometers and 15 is where the earth's radiation more or less peaks. And the detection range for our case that we look for TIR imaging is 3 to 15 micrometers because beyond 15 micrometers the water vapor signal is too strong for it to be of mass use, okay. And this basically is used to detect thermal radiation received from terrestrial surfaces TIR application can involve both remote sensing and remote sounding. So, when you are going for TIR application there are two there are basically two different possibilities. You can do a remote sensing where you still measure the thermal infrared emission from surfaces sea surface, ground surface, cloud surface etcetera or you can do remote sounding You are basically looking at how atmospheric emission and attenuation is altering the emitted, the radiation that is being detected for a given range and based on that incurring atmospheric properties.

Both possibilities are open in this range for usage. The third section is the microwave region. Here both passive microwave radiometer, so microwave is 4 millimeter to 4 meter wavelength and active systems like weather radar usually operate. So, weather radar are active systems that emit microwave radiation and this is reflected back by clouds, the rain droplets and snow droplets and the amount of reflection kind of gives us the extent of precipitation that is happening in a region, ok. So, here both remote sensing and remote sounding methods are done. So here you can see the range of wavelengths starting from 0.1 micrometers to around 0.1 meters.

So you can see 0.3 is the VNIR region. So 0.3 is somewhere here. You can see from here you get a lot of regions which are atmospherically transparent. The dark regions are where atmosphere absorbs a lot of radiation. And the wider regions are where atmosphere is transparent to radiation

So, between 0.3 which is somewhere here to 3 micrometers which is again somewhere here, you have a lot of transparent bands where remote sensing is possible. There are certain opaque bands where remote sounding is possible and transparent bands where TIR based remote sensing is possible. So, both are used. Then you go to microwave region which is 4 millimeter. So, here again the atmosphere becomes transparent.

So, here again we are looking at either remote sensing imaging through micro system or remote sounding by active scatter of snow and rain particles okay because atmospheric gases no longer participate that scattering becomes clearer in the microwave region so we can measure the amount of rainfall that is happening to microwave based radar okay Now remote sounding applications of course use a wide range of wavelength over this entire system and beyond actually because remote sounding can use radio waves as well and we will discuss remote radar that use radio waves to detect various properties of atmosphere later in this video. So, remote sounding applications use a wide range of wavelengths as the need is to detect absorption or scattering profiles in the atmosphere caused by variations of various property variables. So, this is temperature density absorbing species aerosol systems. So, they range from ultraviolet to radio waves, the entire span of EM radiation relevant to Earth. Finally, we can discuss some of the main differences within in-situ versus remote sensing and sounding system.

So, in-situ measurement that we have been discussing in the last week and a half. are able to provide very accurate point data near the surface and in the troposphere or lower stratosphere region through ground based and radiosonde sensors. So, you are getting good quality location specific point data which are extremely accurate. remote measurements are less resolved. So, we will see that the spatial resolution is quite coarse in many types of remote measurement techniques.

Those are spatially average data in many cases. So, you are getting temperature at a specific location at a specific time for in-situ measurement. while remote sensing and remote sounding will give you temperature averaged over a certain region of space, may be 100 meters or even 1 kilometer over a certain amount of time. So, it is giving you an average data rather than point to point data. However, the advantage is remote sensing and remote sounding can get a lot of data from a large spatially distributed region at once. So, the quantity of interest can be measured rapidly and repeatedly over large spans covering hundreds of kilometers.

So, a satellite can measure the sea surface temperature over the entire Pacific for example, very quickly and repeatedly. in situ measurements to boils floating over the ocean surface, you will get certain point data in different locations, but not the entire continuous temperature information that can be obtained from a satellite. Similarly, a radio sound can measure point to point altitude based temperature data over a certain location in the world. Whereas the atmospheric sounding technique can get the vertical profile of the temperature over a large region of the planet very quickly and repeatedly. So, that is one of the advantages of remote sounding measure, remote measurement that the entire global picture of a certain property can be easily obtained over the entire globe, over an entire nation, over an entire continent, over an entire ocean, those information can be easily obtained.

So, that is the point that we are looking at the second case, it provides less coverage and data can only be obtained from specific locations, correct. Remote measurements especially on satellite systems provide global coverage and there are certain things that are very difficult to cover by in-situ techniques. So, for example extent of forest fire, amount of deforestation, the seasonal and yearly decrease of an entire glacier. You have to go to extremely remote locations continuously and repeatedly if you are going to do this by in-situ method whereas remote sensing can do this very easily and safely from space because these regions are often remote and often politically also dangerous or inaccessible. However, in-situ systems are generally inexpensive to install and maintain.

Remote sensing systems are expensive to launch and maintain. You have to have sophisticated satellite systems, satellite launchers that are launching a system in space and you have to have a dedicated team of scientists and engineers maintaining the satellite trajectory and maintaining all its instruments remotely from a ground station, right. So, the entire launching and maintenance of a satellite over a say a decade of its operation is quite costly. Of course, with the advent of commercial less costly satellite systems in the recent decades that cost is decreasing very rapidly and this is one of the places where there is a lot of innovation happening in satellite technology to decrease the cost of these satellite systems. So, in that way remote sensing is becoming more common and more ubiquitous as the costs are decreasing, alright.

So, today we will stop here. I hope I gave a brief introduction of the various what remote sensing and remote sound is, its types and advantages and disadvantages. We will continue this discussion in the next class. Thank you for listening and see you in the next class.