REMOTE SENSING FOR NATURAL HAZARD STUDIES

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Lec 16a: Remote Sensing for Floods- I Part A

Hello everyone, today we will start Lecture 16 of Module 5, which is on Flood Studies. So, in this lecture, you will learn about remote sensing for floods. So, this is Part 1 of Lecture 16, and in this lecture, I will try to refer to some of the case studies and examples from the published literature, which will help you understand how remote sensing and GIS are used in flood studies. So, before we continue, let us go back and try to understand this flood. So, a flood is the inundation of a normally dry region caused by an increase in water in a river or stream. So, here you can see these examples: these are the real examples.

So, here, floods can be destructive and unpredictable, necessitating effective monitoring ranging from widespread river floods to localized flash floods. So, as I mentioned earlier, flood is a deadly natural disaster, but it has both aspects, negative and positive. Since it causes loss of lives and property, we try to focus on monitoring and prediction. So, climate

change and anthropogenic activities are increasing the frequency and intensity of flood events.

So, we all know that our human interventions are the main reason why these natural processes are getting disturbed, and because of that, we are experiencing more frequent floods. The growing impact of floods demand integrated and proactive risk management strategies. To save lives and property, we have to be proactive and utilize recent advancements in technology so that our predictions and modeling will be more accurate. Sudden events like flash floods provide little to no warning time because you cannot see if there is a breach of the dam, and it is due to some unforeseen causes. So, you will have no warning, you will not have any time to rescue.

So, in such conditions, eyewitness reports are often the only source for small-scale floods. So, many times in the isolated areas, only the eyewitness reports come from the people who live in the surroundings; they only report such cases, Limited stream gauze data in remote areas hinders real-time monitoring because to monitor or model the flood event, we need to have in-situ measurements; however, due to the scarcity of in-situ data, real-time monitoring is not possible, especially in isolated areas. So, because of this reason, satellite data bridge this gap, especially in inaccessible regions. So, remote sensing comes into the picture, and it can help to model, predict, or identify flood events. Here you can see that this is one example, So, this is before the flood, and this is after the flood.

So, remote sensing plays a crucial role in flood monitoring and management by providing frequent and synoptic observations of the Earth's surfaces, enabling flood mapping, inundation monitoring, and even damage assessment. Because here you can also go for the damage assessment, you will have pre- and post-event data sets. This is another example, so here you can see this is elevation, which is here, and here you can have the precipitation, and this is the time. So how is this precipitation happening in this particular region? Then you have annual rainfall, and this is the year; here it was month, here it is year. And this is, the blue color is showing the river, and this is the flood inventory, which is stars.

These are the reported flood datasets. So, with this information, you can also go for the comprehensive observation. So, it provides a broad view of the Earth's surface, monitoring large areas with frequent updates, because when you have the remote sensing data very frequently, we acquire the data and all the datasets that have been acquired will be stored in the archive. Crucial for understanding flood dynamics because, if you want to understand the flood dynamics, you need to have the historical data sets. So, one thing is the location of the event.

Then, how it occurred, what happened, and what the pre- and post-conditions were will be available to you through remote sensing datasets. When we talk about flood mapping and monitoring, satellite data identify the mapped flooded areas. Tracking the extent of

flooding over time helps in near-real-time disaster management. Here I am not writing in real-time; it is near real-time, So, please remember that with remote sensing data we can go for near-real-time, not real-time, because there will be a gap between the acquisition of your data, downloading, and then the usability of this data in your model. So, let us understand the importance of remote sensing.

So, here you can go for the flood prediction, which uses historical data and current conditions for the flood prediction. It helps to forecast potential floods and assess risk. It also helps to forecast potential floods and assess the risks. And the next is the damage assessment, where we evaluate the infrastructure damage after a flood event and assist in disaster response and recovery. So, here you can see this particular map; here you have different classes.

So, these classes have different color codes. And these color codes can be used to understand whether your area belongs to the very low, low, moderate, high, or very high category, So, this kind of flood prediction or flood modeling can be done with the help of remote sensing and in situ measurements. Spatiotemporal reconstruction of floods. Remote sensing allows for detailed mapping of flood evolution over time. So, because we have had the data set since, let us say, the 1980s, and we are in 2025.

Now, for this time period at least, we have various datasets from various sources. So, those resources can be utilized to identify how a particular area is experiencing the flood over time and how the flood has behaved each time. So, those things can be assessed using the remote sensing dataset. Multi-temporal data capture flood spread and recession phases, helping to understand flood behavior in areas lacking historical records. Because, as I mentioned in the previous slide, if an area does not have the in-situ measurement unit, If there are no government officials involved in this measurement, then this will be based only on the local people who live in that area.

They will report that there was a flood event, but you will not have the data, except with the multi-temporal data set from the remote sensing sensors. This flood spread; how it has spread. If this is the active channel during the flood, what was the floodplain? How much time did it take to return to the normal phase, and how did it behave? So, those things can be assessed with the archived datasets. Time-series satellite images create a visual narrative of the flood event. Because many times what happens is that we try to utilize the satellite images with DEM, and then we try to proceed with the hydrodynamic modeling, allowing us to visualize what happened, how it occurred, which areas were flooded, how much water was there, and how people survived in that particular region.

Remote sensing detects erosion, sediment deposition, and debris flow, and reveals runoff generation patterns as indicators of flood strength and extent. So, here, remote sensing can help you identify the erosional places where a particular reach is experiencing erosion. So,

this particular reach was having the maximum bank erosion. Then, sediment deposition: what are the areas that received the sediment during this flood and got deposited, so you will easily identify them? Debris flow can also be monitored, and you can have a synoptic view of this particular area because of the spatio-temporal data set. These studies help to reconstruct ancient and undocumented floods, enabling estimation of historical flood magnitudes.

And the accurate paleo flirt, paleo flirt means the historical flirts. Records may help in modeling future flirt scenarios because, as you know, many of us are involved these days in artificial intelligence, machine learning, or deep learning methods, where we are utilizing all these data sets and trying to predict future events. So, in such cases, this historical data set will help you model it with high accuracy. accuracy. In this particular slide, this map is showing the flood risk, and here you can see that the green color indicates very low risk, yellow or maybe light green indicates low risk, orange indicates moderate risk, and red indicates high risk.

So, these areas nicely represent whether your area is in the low zone, high zone, or moderate zone. So, this is the flood risk map. So, there is a framework for the flood risk assessment. So, what we do for flood risk assessment is that we first identify the elements at risk; then we conduct the flood hazard assessment, and third is the vulnerability assessment. Once you have these three, you can go for the flood risk assessment.

Here you can see that the flood monitoring has different components. So, it has three stages: the first one is the forecast, the second one is the emergency monitoring, and the third one is the damage assessment, So, these stages occur before, during and after flood event, respectively. So, for a particular flood event, we have to see what the scenario is before, during, and after the flood event. So, despite the temporal divisions, all three are highly interconnected because forecasting, emergency monitoring, and damage assessment are all related to the same event. Improved forecasting leads to better emergency responses and more accurate damage assessments.

Spectral signatures of soil, vegetation, and water, and spectral bands of LANDSAT 7.
Source: Siegmund, Menz 2005 with modifications
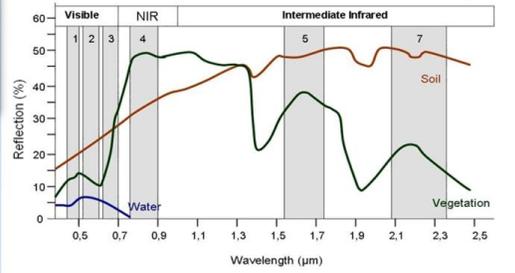
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Because the more accuracy you have in your predictions, the better you will be able to inform the people who are residing in that particular area well before the event, and then they will be able to save their lives and property. Then comes the forecasting, so here the forecast primarily relies on meteorological models and satellite data. So, we try to gather the information related to precipitation, wind speed, and cloud conditions, and the satellite data sets are involved in monitoring these events. Low to medium resolution optical data sets are often used for large scale weather and rainfall patterns. Because until now I have covered in several slides that remote sensing is one of the primary sources to generate these meteorological parameters, So, accurate forecasts and early warnings help to predict flood-prone areas in advance, which drastically reduce human and infrastructure losses.

In India, the Central Water Commission (CWC) provides a 5-day advanced flood forecast for 20 major rivers. I have also given a detailed introduction to the CWC in the previous lectures. So, I hope you will remember and recall all the concepts, and you will be able to understand how CWC is involved in predicting these events. Forecasts are generated using data from GFS, which is the Global Forecast System, and WRF, which stands for Weather Research and Forecasting methods. The in-house developed model system is automatically updated every 3 hours for all stations during the monsoon season.
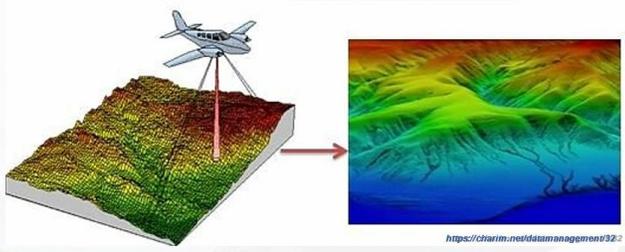
So, all the in-situ measurements are connected to the base station; also, the satellite datasets are accessed, and these models are updated every 3 hours, forecast models integrate real-time rainfall data to provide actionable flood alerts, aiding early warning and mitigation efforts. Many times, you might receive a message that there will be a strong thunderstorm or rainfall. So, do not walk or leave your houses; something like that you might have received. So, that is the communication, Because of this prediction, it is being communicated to the people who are residing in that particular area. Additionally, a near-

real-time inundation forecast is being developed for the Ganga Basin under the National Hydrology Project (NHP), utilizing high-resolution DEM from NRSC, Survey of India, and other state government offices.

So, we are in the process of developing this kind of system for the Ganga Basin, and hopefully we will be able to save lives and property more effectively. Then comes the emergency flood monitoring high-resolution data set. When I say high-resolution data set, I mean high spatial resolution data set, because the width of the river is not so high everywhere. So, we have to have a high spatial resolution data set. So, high-resolution data from optical and radar sensors during floods provide fast and reliable monitoring for disaster response.

So, here you can see the example: this is from Germany, this is from China, and this is from Peru. This shows how the optical remote sensing datasets are used. Here you have Landsat, Landsat, and Sentinel-2, and here you can see that the black color in these images represents the invalid data, which is cloud or shadow, and this light blue is flood water, and this dark blue is permanent water. Optical sensors may face limitations due to clouds and poor lighting because we all know that optical remote sensing has its own limitations. Therefore, the use of synthetic aperture radar is ideal due to its cloud penetration and day-night observation capabilities.

We all know that synthetic aperture radar uses the microwave wavelength, which is a high wavelength. So, in the high wavelength region, this cloud coverage is not a problem, as scattering can be minimized, and also, we are talking about the active SAR. So, day-night observation is possible. So, during a flood event, what happens is that it generally occurs in the monsoon period when there are cloudy skies and the illumination conditions are not

so good. So, optical remote sensing has its own limitations in such cases; microwave remote sensing can be of great help.

Let us talk about the damage assessment after the flood. So, remote sensing provides spatial data aiding the assessment of the extent of damage in affected areas, erosion, and the infrastructure post-flood, Multitemporal analysis helps track changes over time, facilitating recovery strategies and future risk reduction. So, here is one example; you can see this particular boundary. So, this is the pre-event, and this is the post-event. Now, here you can see that visually it is very clear that after this flood, this particular area has changed drastically.

So, this is what I meant: pre- and post-event data sets are available from the space that will help you analyze the changes. So, the integration of monitoring stages is essential. So, we have monitoring, then assessment, and then we have a forecast. So, we start with monitoring, then we go for the assessment, and then we go for the forecast. So, the forecast guides emergency teams to high-risk zones, the emergency monitoring data helps to validate and refine the forecast, and the damage data feeds back into the model to improve prediction accuracy.

So, this continuous cycle enhances long-term flood preparedness. So, if this has been developed for a particular location or a particular section of the river, then over time this model can be retrained and the accuracy can be increased. So, let us talk about the optical remote sensing applications. So, the optical remote sensing captures reflected radiation across the visible to infrared bands. I hope you remember that when we talk about optical remote sensing, we refer to the reflected and emitted domains. So, when we talk about the reflected domain, it is from 0.4 micrometer to 2.5 micrometer, and here basically we get this surface reflection, which will give you this surface information; it will not give you the subsurface information, remember that. So, it performs well in rural and natural areas under clear sky conditions because we are talking about the relatively shorter wavelengths that are greatly affected by scattering and absorption, and also because of the presence of clouds. Water appears dark due to low reflectance, which aids flood detection. So, if this data is fortunately available without any cloud cover or with very limited cloud cover, the water will appear blue or dark. So, that will help you identify the flooded zones.

So, optical remote sensing is limited by cloud cover, especially during flood events, because at that time we mostly have this cloud coverage and the lighting conditions will not be good. So, conditions like turbidity, sun glint, and wind can also affect the detection accuracy because they will hinder this measurement. So, because of that, optical remote sensing has limited application in flood studies. However, if the data set is available, it can be used correctly. Then comes thermal remote sensing, which is also optical remote sensing.

So, here you can see that the water has low reflectance in the thermal and infrared ranges. So, that can be used to identify the water from other dark areas because shadows will also be present in optical remote sensing. So, this can be used to distinguish water from other dark surfaces, like shadows. It is useful in detecting shallow or turbid water that is not easily visible otherwise. It also enhances reliability in high reflectance environments like cities.

Because here we are talking about the emission and the wavelength is from 2.5 micrometers to 16 micrometer, but generally we refer to 3 to 16 micrometer because 2.5 to 3 micrometer is the overlapping region between reflectance and emittance, So, because of this reason, we use this 3 to 16 micrometer. But in some of the books, you may find 2.5 to 16 micrometers, so both are correct. Then comes the surface temperature, so the object is above 0 degrees Kelvin. So, when we talk about thermal remote sensing, the surface temperature is key. So, the object above 0 degrees Kelvin emits radiation; why? Because we have to maintain equilibrium with the surroundings. So, whatever energy we have gained through solar radiation or from any other external temperature. That will be released to maintain our temperature with the surroundings, and in this case, what happens is that the emission will occur, and the emitted energy will be measured by your sensor.

So, in thermal remote sensing, we measure the radiant energy, The digital elevation model, which is another very important source of information when we talk about flood studies, provides information about the topography. So, here this is available along with the latitude and longitude that will accurately provide you with the information about the elevation of that particular point. Digital elevation models represent the Earth's surface elevation, which is vital for geospatial analysis and is generated using remote sensing technologies. So, various methods for DEM generation are the conversion of contour lines, photogrammetry, satellite stereo pairs dataset, radar interferometry, and laser altimetry. Topographic and hydrological information extracted from this DEM are very common.

In addition, its products, such as slope, aspect, and basin information, are widely used in many applications. It is not only in the water resources and flood studies that this application of this information is very important or crucial in many other hazard studies. So, this is one example. So, this is a satellite image captured from a satellite, and this is the DEM generated from, let us consider, any source you have for the digital elevation model. So, once you see them separately, you will have the information that this point and this point are the same.

So, you have to refer to both images one by one to know what the land use and land cover are and what the elevation is. But in GIS, we can integrate them together, and then we can find that this particular location has this elevation. So, this is the 3D modeling of that particular area, and here you can proceed with the hydrodynamic modeling, and then you

will precisely know if you have one glass of water, whether it will flow in this direction or that direction, because you know the slope. as well as the right aspect.

So, this is the application of the remote sensing dataset. Now, the optical stereo-based DEMs. So, these are the optical stereo-based DEMs: Aster, Cartosat, Allos Pulsar, and Spot DEM. There are various sources for this digital elevation model, including InSAR-based DEMs. SRTM, TanDEM-X, then Copernicus DEM these are available. Airborne and Lidar-derived DEMs are mentioned here, indicating that these DEMs are derived from lidar, and the resolution is also included.

So, when we talk about watershed modeling, this digital elevation model, the stream network, and the satellite images play a crucial role, and then you can have the 3D modeling of this particular watershed. So, large rivers with several tributaries are typically called river basins, whereas watersheds are used for tributaries or small streams. So, once we have all these data sets for the entire drainage system, we can proceed with the watershed modeling. So, there are different flood controlling factors. So, here you can see the rainfall, geomorphology, and other hazards; then soil elevation, slope, curvature, flow direction, stream density, distance from the river and road, land use, land cover, NDWI, NDVI, and TWI. So, these are very important in flood studies. So, with this, I will finish part 1 of this lecture, and we will continue this in the next part. Thank you. Thank you very much.