Groundwater Hydrology and Management
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Week - 12 Lecture 3
GRACE – SATELLITE DATA

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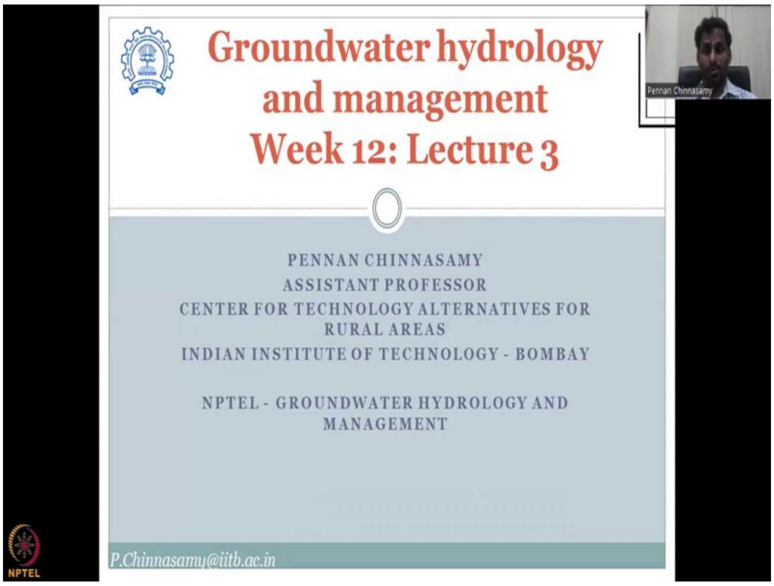

Hello everyone, welcome to NPTEL course on Groundwater Hydrology and Management. This is week 12, lecture 3, we are nearing the end of the entire NPTEL groundwater lecture wherein we have been focusing on different datasets to use in your groundwater studies models and research. Please understand that most of the data that I share has its own spatial and temporal limitations for which there is a need to use remote sensing data. So, I did not want to leave that overall contents.

So, what we are doing today is you will be focusing on the available remote sensing data which is free that you could use and understand the groundwater behavior. There are limitations on this site also as I said. So, you have to take your observed data and remote sensing data and try to mix it to a good new product to be focusing on something new.

Let me tell you how IMD works. So, IMD has, the Indian Meteorological Department has rainfall gauges to monitor rainfall. However, they felt that the spatial and temporal resolution may be limited and could be improved by augmenting with remote sensing data. So, they join hands with NRC and other external data products and NASA products and made a rainfall grid rather than a point data. They made a grid, how did they do it by merging the observation data and your satellite data to get good products like this, there are multiple other uses of satellite data. And it is good to see how that works for the groundwater system.

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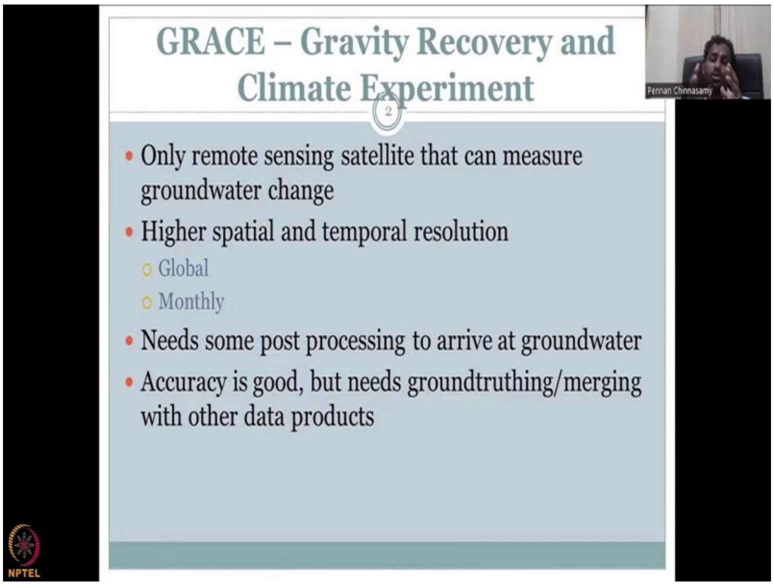

So, today, we will be looking at the most important groundwater instrument in the satellite that can monitor gravity, so gravity can be monitored and from gravity, you can estimate the groundwater hydrology, at least the change. So this mission very special mission is called GRACE, which stands for Gravity Recovery and Climate Experiment.

It is the only remote sensing satellite that can measure both terrestrial water and groundwater change, terrestrial is any water on top of the land, and including that and below the land, under the ground, also it can monitor and measure it was not made for that purpose. But the discoveries such that when they saw the gravity changes, and they understood that gravity cannot change within months, without a big, you know, a phenomena happening.

For example, if you have earthquake, then the mass has shifted to one place from here, the plates move, and maybe they get overland and so the masses changed. When mass changes or the weight, the mass changes, let gravity pull is more. We know this from physics, that as the mass changes the gravity pull on an object changes.

So knowing this, these smart, NASA and German space scientists, what they discovered is they made this GRACE satellite, which just monitors how the gravity changes across the globe. And those gravity changes along with other data can give you the ground water change. We will see how through some examples, and we will also see the website and how it works. Please understand this is not a standalone. Neither is the observation data. It is good to merge these two data together and make good products.

What are the benefits? The benefits are it produces higher spatial and temporal resolution, because your point data is only a well at a particular location. And it does not tell you the full picture of how the entire aquifer system changes and also the depth because as I said, you have drilling wells and you have shallow wells. Most of the monitoring is in the shallow wells, not the drilling wells. However, farmers are also using water from the drilling wells. So that is where GRACE data plays a very vital role.

Then you have higher spatial, spatial and temporal resolution, the groundwater data is monitored once every quarter, which is once in four months. However, the satellite data, GRACE is monitored every month. And they are also thinking about by monthly data. So this high resolution would eventually be very, very helpful for monitoring groundwater change. So we have global scale.

Now, globally, we can monitor because some of the aquifers are too big, like example the Ganges flame, aquifers, and then monthly, you need to see the changes because suddenly there is a big pumping happening. And we may miss it if we do not look at it at once. However, this data since it is a very specific specialized satellite data, it needs some post processing and cleaning to arrive at a tangible data for groundwater. So that is one limitations.

There are some calculations that you will need to do based on the water balance calculations to arrive at groundwater, what you get is a gravity change. How do you change the gravity anomaly? Anomaly is the change per unit time. How do you change the anomaly to a monthly reading or a groundwater? It is the question. That we will show in a very simple water balance equation. Accuracy is good.

For a millimeter, also, we will get accuracy, but it needs a tremendous amount of groundtruthing. So this is the catch. I am saying that you can use this where you do not have data. So but now on the other hand, I am saying you do have data that can validate the GRACE mission.

So how do you do this? Basically, you should be able to merge the both the datasets where the locations are known and the groundwater observations are available, then we could actually merge these products and make predictions for groundwater anomaly groundwater storage change across other regions.

Basically, what you get here is a net groundwater thickness or volume change between months. And so, if you have a long time period, and you know that the post monsoon season the groundwater change is positive, and then from the post monsoon, groundwater is going to be depleted either by base load or by pumping and then it comes to the groundwater least level or point before the summer or during summer we call it pre monsoon season, here post monsoon and pre monsoon.

So, post monsoon have the highest groundwater level whereas the pre monsoon will have the least, let us take Maharashtra case you have good groundwater levels post monsoon for example, July August, because monsoon starts in June and then you have very low levels in March April, May, May is really low.

So, that is where you need water to irrigate for crops and people use a tremendous amount of water the evaporation is high, transportation is bad. So therefore, we do need good observation data for groundtruthing. So the good part here is it is not going to compete with observation data it is going to lie is or you get united unison with observation data to produce good groundwater storage change values.

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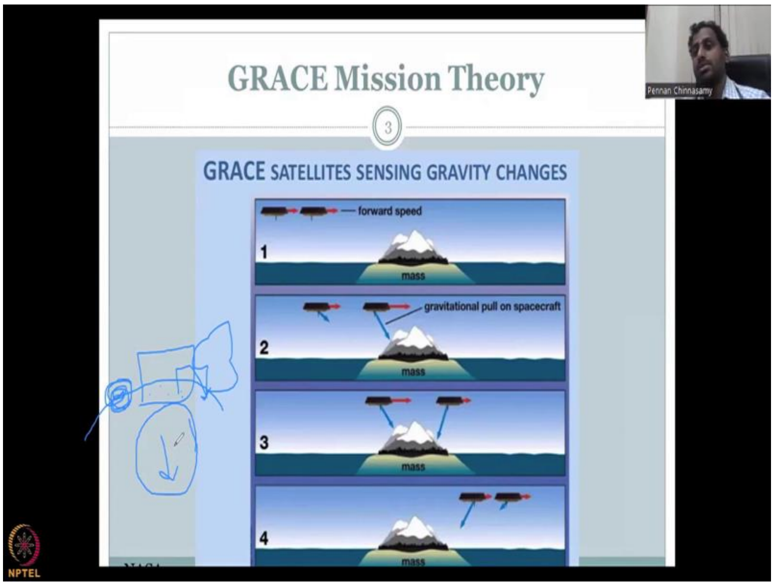

I will show you the mission how it works. So satellites are normally called missions. So this GRACE mission theory is given by a NASA. So, what you see here is the GRACE mission on and how it works. So, this GRACE mission is launched by a combined effort of NASA and the German JPLNJ GMC. So you will see all these different partners come together and work on a common satellite which is good for the planet. It is one of a very unique system but let us talk about the satellite and how it measures.

So you have a mass, the mass, in this first case it is two satellites, this is the only few missions where the satellite is launched in pairs, you have two satellites and as the name suggests, one is called Tom and the other is called Jerry. So, basically Tom runs and Jerry catches, Tom is the cat, so Tom is the mouse. Is it Tom? Yes. So, you have Tom and Jerry story Tom is the cat and Jerry is the mouse.

So, Jerry runs and Tom catches. So, here Jerry is running first and then when the satellite goes on top of the Earth, it gets pulled by the mass. So, when the satellite sees a bigger mass, then the satellite moves faster. So, this satellite is not recording anything only it is moving around the planet and it speeds up and slows down depending on the mass.

So, the next satellite which is your Tom is catching with Jerry and whenever the first step it goes fast it records how fast it goes, then when it slows down it records how slow it goes this changing accelerometer because it accelerates and then de-accelerates, so basically it is not pulled by the body but mostly pulled by the attraction towards the first satellite.

So, now what happens is you have the satellite going in, the first satellite going around the earth and when it goes faster, the second satellite goes faster and then when it goes slower, this goes closer this change in speed is measured and the speed is then converted to a gravity change because the gravity changed the speed changes. So, this is how the GRACE system works in a very simplistic manner. There is much more physics in it, but I have just explained it simplistic manner.

So, the first forward speed is there and then the gravitational pull is acting on the first satellite. So, it goes faster, then, when it goes faster the second satellite does not know that this guy is going too fast. So it catches up it catches up by the attraction towards here and also the gravity mass and then goes on so this change in speed is recorded and it is taken as a change in gravity that is it. There is no other force that can influence the speed of a satellite it is purely gravity. So here, why does not other satellites do it? Because they do not carry a very sensitive accelerometer.

Here this satellite has no fancy things it is only the only fancy because there is no camera and nothing the only fancy thing is this accelerometer and it is very very sensitive which means a very highly accurate accelerometer and that can be changed to a gravity pull. Now, the other theory. So, let us see what would change between months. So, this is the first month the mass is there the, the satellites go past and it goes past this 1 2 3 4 is done the satellites are gone.

Then, the next month again the satellite comes every month once the satellite comes to the same location. Now if the mass has changed, why would the mass change here because you have snow on the top maybe the snow melts down and when the snow melts down there is less mass on the earth on that point. So, it the pool is different, the pool is not the same. So, there is less mass, less pull and less speed.

So, now this difference between months is accounted for this moment. So think about a region where there is no surface water and there is no change in mass, no snow, no nothing that melts between months what changes is the water under the ground. So, we draw it just as an example.

So, we have this as the Earth and this has some water bodies that like a lake and then there is trees, etcetera, etcetera. So, when the satellite goes on this part and the lake value changes between months, then it is influenced by the lake also because gravity everything on top of the earth and under the earth influence the gravity on this satellite, what about in a place like this where in a picture like this, there is no change in surface water because there is no surface water, all it is soil moisture, and groundwater.

And if there is a pump, which is pumping groundwater into the aquifer, from the aquifer into the agricultural fields, then a mass is lost, you are losing groundwater mass when you pull water out the weight of water is lost and this can be accurately estimated by GRACE. So, now you think that water which you take out is a level which is depleted and that level is also equal to a mass it has a mass 1000 liters is equal to the calculations for a weight depending on the density of water.

So, you have this as one as thick to measure and monitor the groundwater change using the change in mass of groundwater, which has been extracted and put outside. So now the extracted water can be covered with evapotranspiration or taken away to cities for drinking water, etcetera. But now it has been caught as a mass change.

So, when the satellite flew flies on that particular location, and there is no change in lakes, there is no change in trees because trees are standing and also there is a building the building does not change suddenly within a month 2, 4, 5 floors, extra added then the pure change is due to soil moisture and groundwater change. Now, we should just remove the soil moisture, I will come to that part when I discuss the equation.

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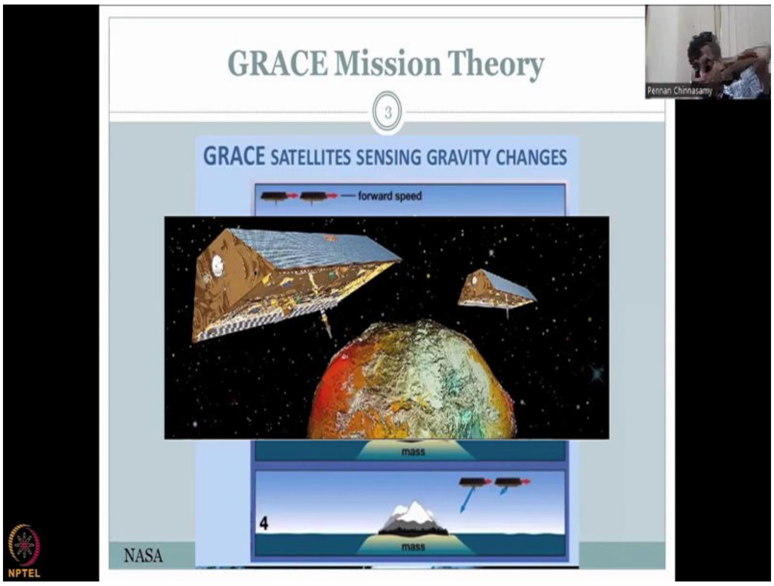

So, this is how the satellite looks at the planet, it does not have an optical sensor, where like other data we saw it is taking hyperspectral, hyperspectral images, different band bands coming in for assessing the properties of land properties of leaves, color, etc. Here it is purely the gravity. So, now, you see how the GRACE looks at it is not a smooth sphere, because it is having differences in masses, suddenly you have the Himalayas has a high mass and then it goes around the Himalayas and then it dips down into the oceans and lakes and other areas.

So, it is not a common surface. So, what you see here is a changing surface of the earth and most of the changes are attributed to soil moisture and groundwater change unless and otherwise it is a big change in the season, you have snow fall or snow melt and then those masses have been accounted for.

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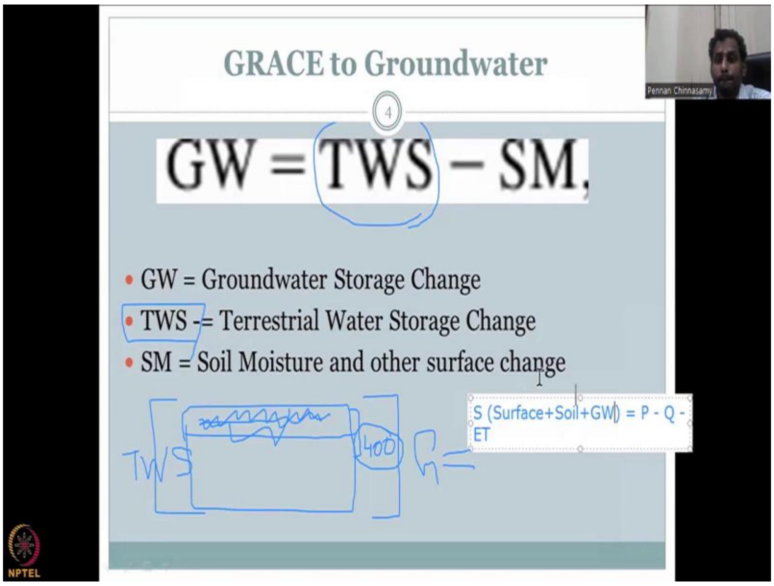

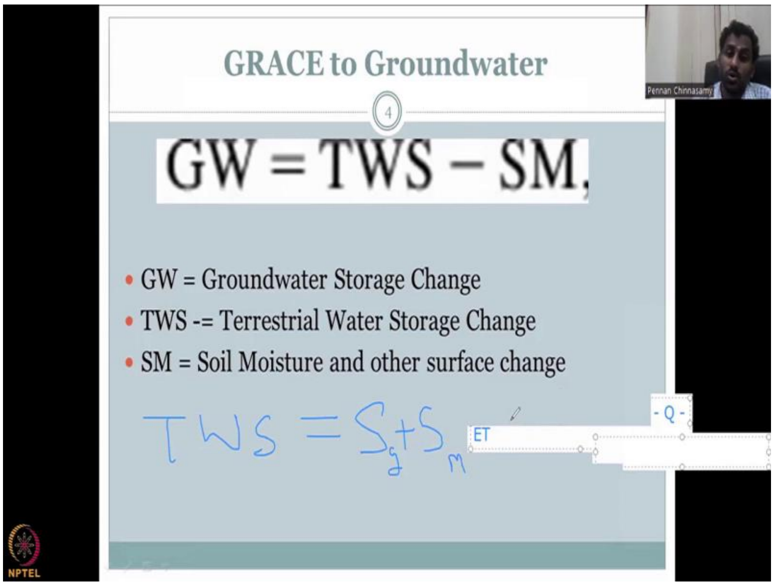

So, here is the equation that we use groundwater change, groundwater storage as a volume change, I will draw it also for explaining purpose. So, think about this compartment, which the GRACE is getting pulled every month, once a month. So, now, what you get is a total gravity change because from here a total gravity change, which is now equated to a groundwater by this formula, they give you the gravity change is converted to terrestrial water storage.

So, what you get from GRACE is this output terrestrial water storage change which is any water on the top surface and ground also the atmospheric cloud precipitation does not come it is purely the earth under the earth whatever storage is there and on the surface of the earth what is we have so, what we have here is the gravity is converter normally changes converter to terrestrial water storage change, which is this just the GRACE real output. Now, to get groundwater out, so, I am going to say what is TWS, so, this whole change is TWS.

So, this data is TWS, now we know that soil moisture is up to 0 to 400 centimeters maybe. So, 400 centimeters, we have soil moisture data below that it is shallow aquifer and deep aquifers. So, now, what happens is, I will subtract the soil moisture change, change not the exact soil moisture, I will subtract the soil moisture change.

So, now, what happens is the TWS change and soil moisture change is taken out the remaining is only the groundwater change. It is a very simple hydrological balance that you have, because when you have the hydrological balance, let me type it here just so that we can quickly look at it. We had storage change is equals to precipitation minus Q which is the runoff minus ET and then plus the groundwater net or you can say plus groundwater net.

So, the storage can also be taken to the other side which is your surface plus soil plus groundwater is equivalent to the precipitation minus the runoff minus the ET here we have in this particular example here what we have is this part estimate all this is estimated now, because precipitation minus Q minus ET is that the terrestrial water storage, the water storage S.

So, now this part is taken to be as TWS because the storage change includes the top surface and then the ground also. So, that is the net storage that is becoming TWS as per the satellites definition, let me see if I could clear it. So, what has happened is we have seen that TWS we write it again TWS is equal to your groundwater storage. All storages together, just the storage change the total storage change.

And now just to get groundwater you subtracted with your surface is the storage plus the total storage, it is your groundwater storage plus your soil moisture storage, and then your surface water storage. However, surface water we said it is not happening. It is only yourself soil and groundwater. So now you can reduce it to just the groundwater.

So, the theory is now clear, I hope you take the terrestrial water storage from GRACE change, it is all change, they will not give you the raw data monthly data, they will run it across 5 years and then remove the average. So, what do you see is an anomaly, not the actual data. So, for some particular reason, they do not give you the monthly actual data, they give you the anomaly data.

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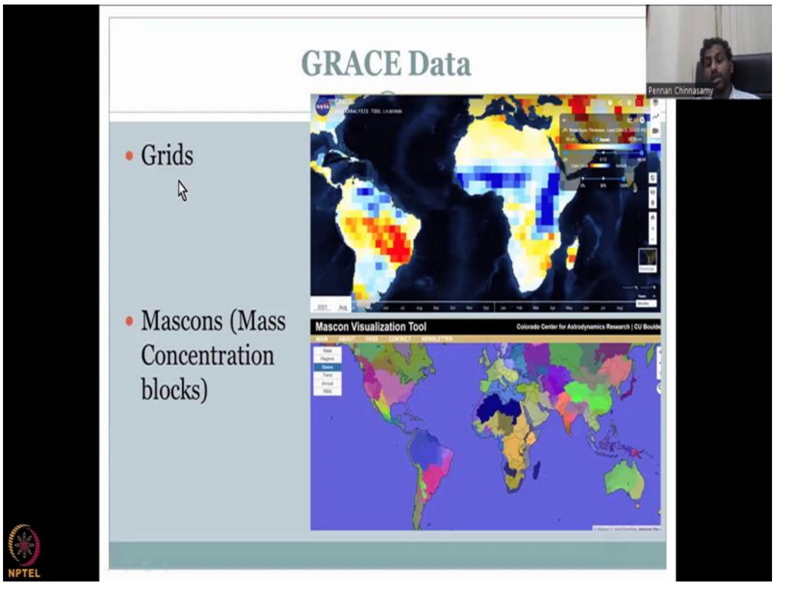

So moving on, let us see how the data comes. The data comes as grids from which you can take a point and then say this is the value of water groundwater storage in that space. How do you compare it with an observation well? You can take an observation well, you can know the thickness of the aquifer by different data.

Now you merge the thickness of aquifer data with the level data to get a volume. And that is what GRACE data gives you the end, it is an increase or a decrease in volume and how much for it. So you can get it as grids or mascons, mass concentration blocks, 5 to 10 years ago, it was very detailed work you need to do to get this data out.

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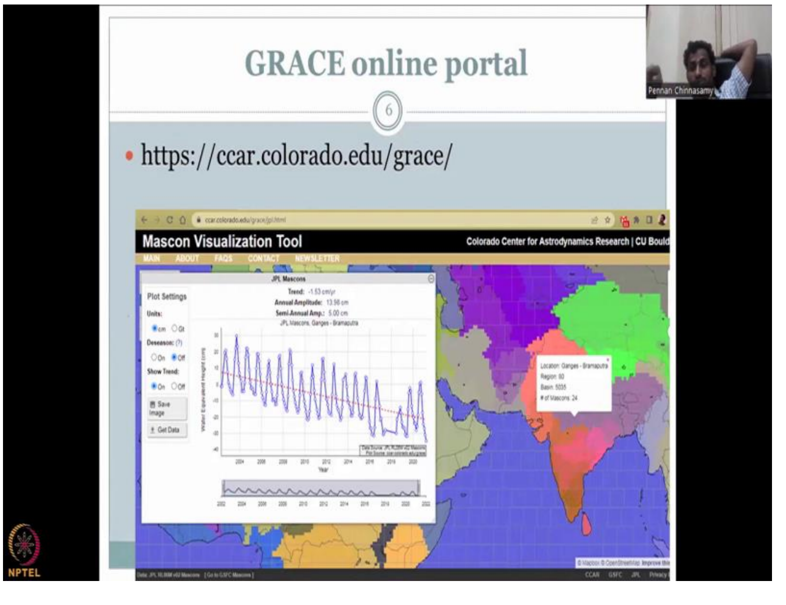

But now they have given you a visualizer from which you can easily download the data and use it. If you do not want to fully download the data. At least you can take these kinds of estimates from which you can clearly understand what the trend of terrestrial water storage is. And from terrestrial if you know the soil moisture, you can actually get a groundwater.

So, your soil moisture also follows your seasonal pattern. And that data is also available in Google Earth Engine and NASA websites. You can take it and use it even the other datasets that I have shown move and so you can use those datasets to take soil moisture, subtract that from terrestrial waters change and then you will get the net water availability.

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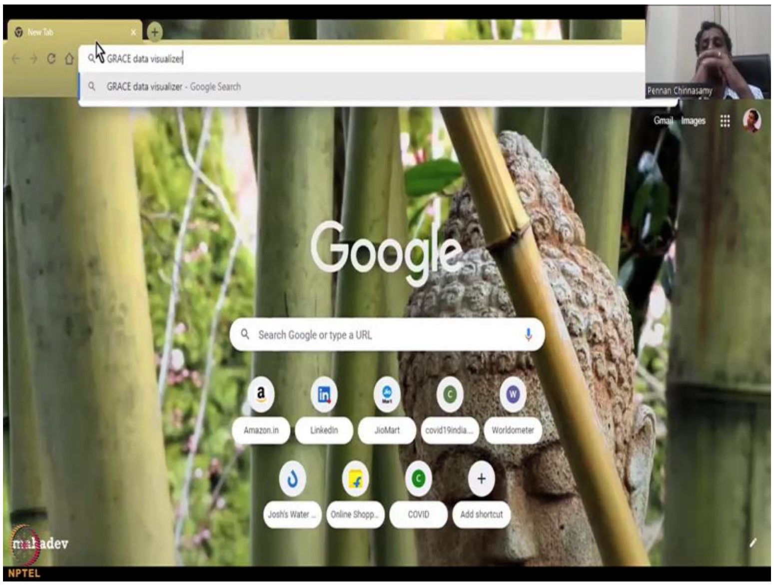

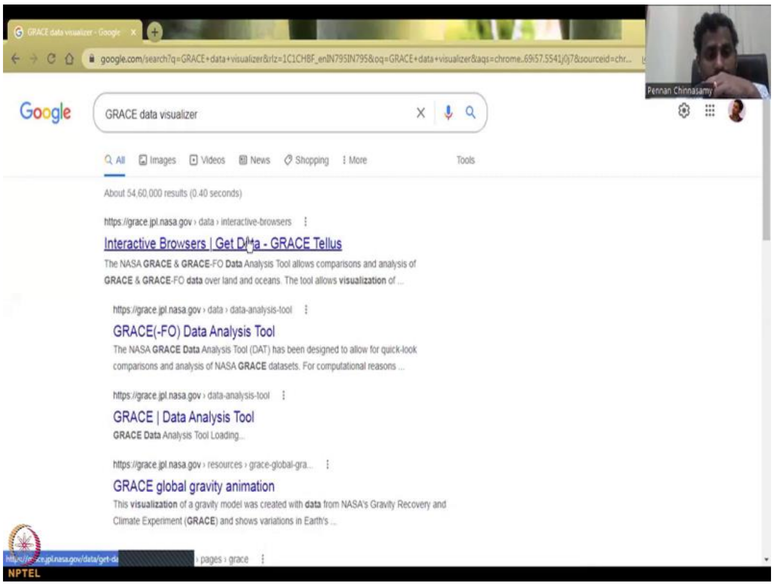

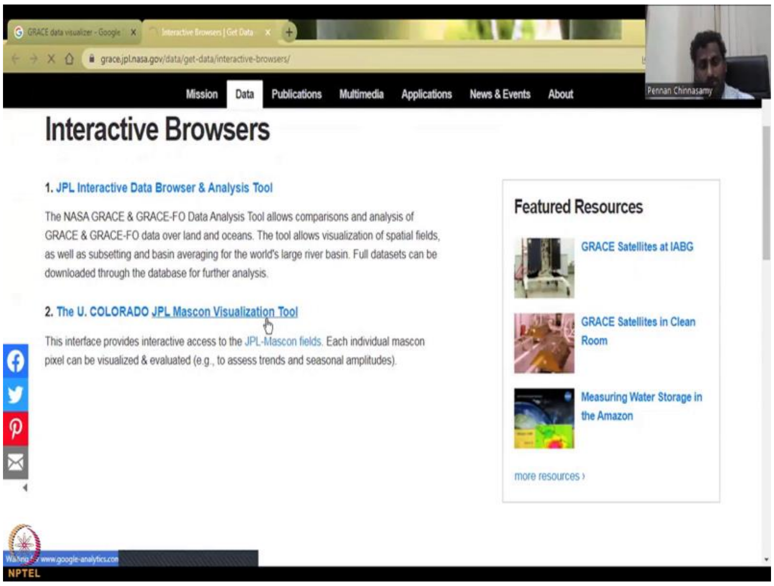

I am going to show you the website now. Let us start by a Google page on seeing how this works. So, I have opened a new Google page and all I am going to type is GRACE data visualizer. I have given the link in the slide, so you can also look at it. So, the first one is GRACE interactive browsers is there, you can click it to view the different datasets that are available. There are two solutions for the data. There is a JPL interactive and U.COLORADO, or the mascon is a recent one. So, I am going to click the mascon.

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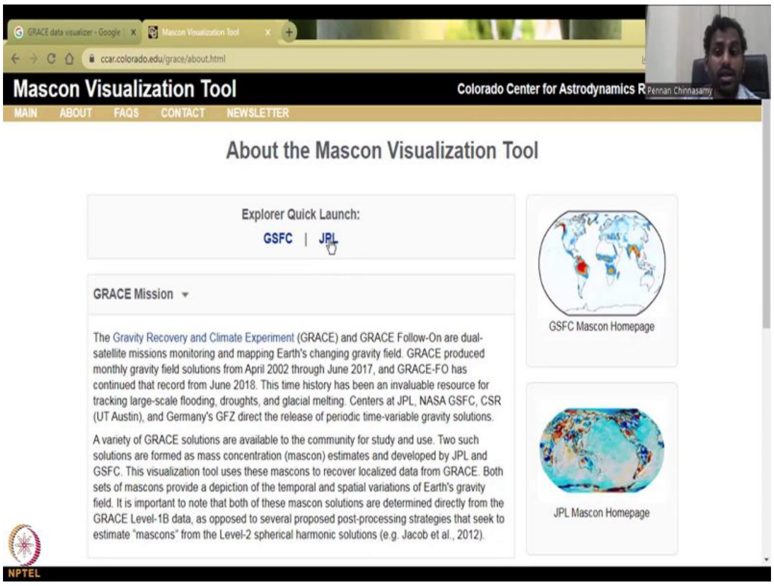

And you have two links. As I said, the GSFC, which is a different center that actually gives the solutions or JPL. Most of the Indian data is based on the JPL, so I am just clicking the JPL.

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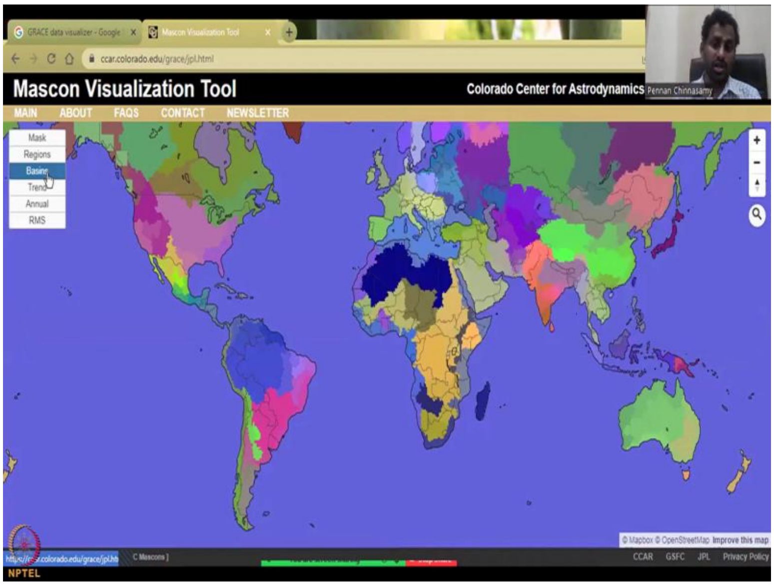

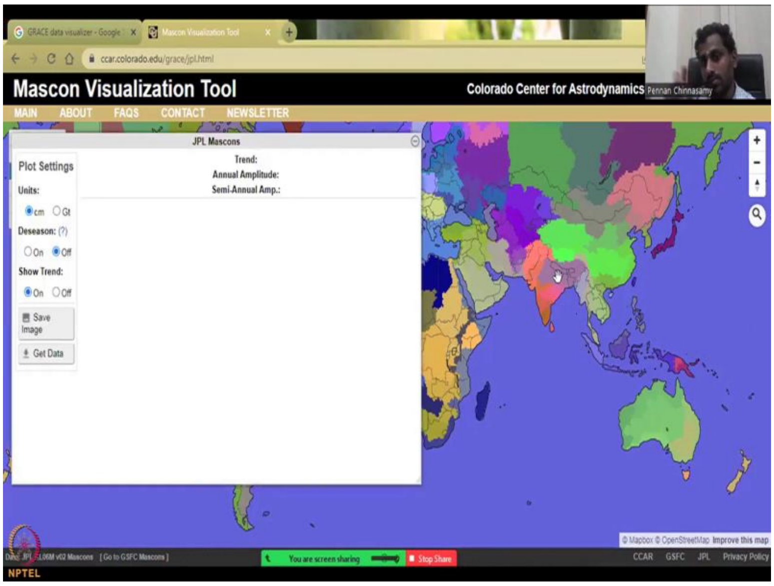

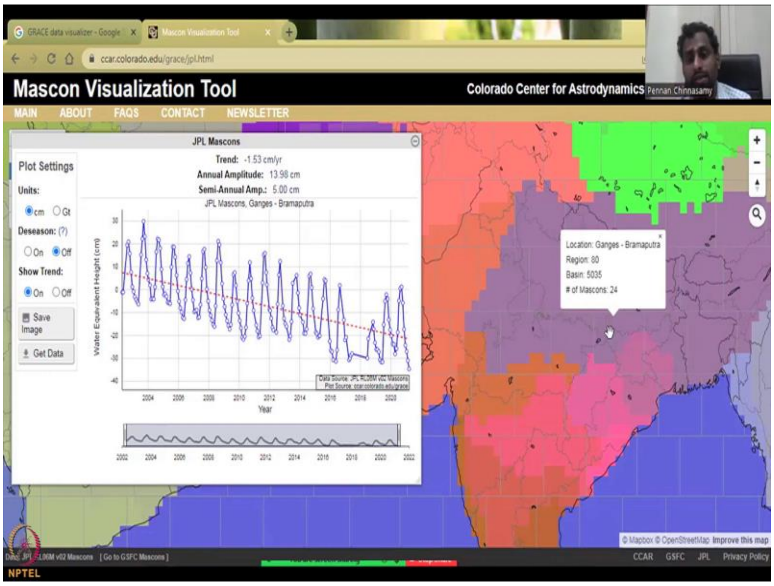

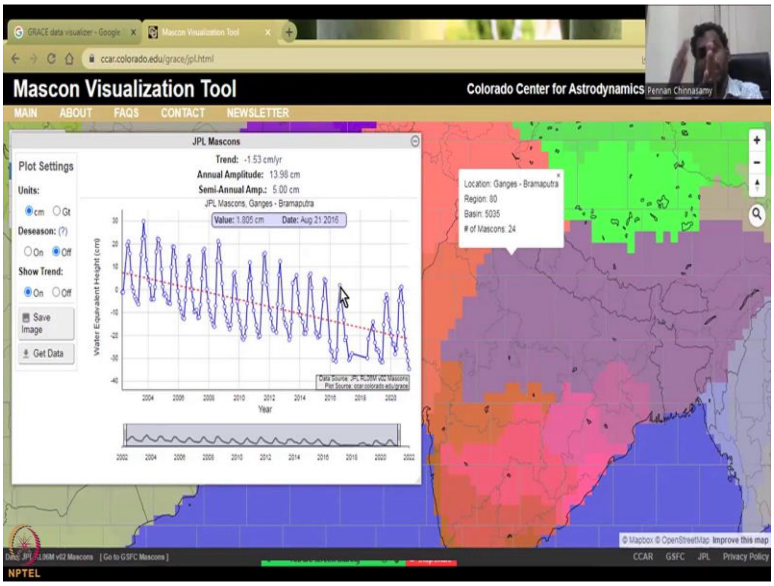

For you to understand you can take any solution. So, so basically, you have the satellite data, and the satellite data is converted to a solution to a value and that value, a lot of multiple centers work on it, each center has their own algorithm. So, the JPL is what a lot of Indian which has used. So we are using that in our study now. So, what you see here is the India and all the other countries of the world, it is you can measure it as regions and now the regions are Asia, Europe, Middle East, Africa, Australia basins, regions, you can do it as basins, because basins would be make more sense.

As I earlier mentioned, the GRACE works on large scale, so you need to have large scale area to monitor the groundwater change and anomaly, so, you see here you have the basin as the Ganges basin. I am just going to click the Ganges basin, mouse you just click there, and it picks the mascon that particular grid. So, I hope you could see the grid. So, this is what the satellite each time it measures one value for the entire grid.

So, that is where you can see that it is not a very small scale district or a block level analysis, it is a massive analysis and from there you can try to understand what is happening in the district but not accurately. So, that is one limitation of GRACE. But as I said, for large scale basins and Ganges studies, Kaveri basin studies, this data has worked, and I am going to show you the Ganges basin here.

So, within the Ganges basin, there are multiple grids, so, this grid might have a different trendline but all of the all of it since we are using it as the basin, the basin value is given. So, JPL mascon Ganges, Brahmaputra basin is the name the trend is minus 1.53 centimeters per year, the terrestrial water storage change is going negative. So this includes the Ganges and Brahmaputra people who think that there is so much water in that basin, why is the dataset of water going down the flow is not coming down.

So, what else should come down the groundwater there has been extensive pumping in this region. So, if you multiply this by the area of the basin, you will get how much water we are taking out and that could equate well to your 265 Kilometer cube per year analysis much more than that for the entire India. So, you could have this trend, you can see how the water terrestrial water storage changes as I said it is an average so above the average or below the average is what is going to show so and in the net it increases slightly about goes down. So this seasonality is because of a monsoon.

Whenever you have the monsoon rainfall and goes up and down when there is a big drought here you do not see a big push in the upper direction, but with the seasonality if the level comes down, then it is a pumping scenario because the seasons going like this, you have summer you have summer in the water and then you have rainfall summer, rainfall summer. But if the overall trend is depleting, that means that your groundwater and other water resources there is depleting because the rainfall is actually trying to push it back, but it is not getting enough strength.

It is not having enough data. So, there is a loss. So, and every month when you move this mouse on the data point, you can see that this is September 13 2015, August 21. So, the peak monsoon seasons are captured, eventually and the value was given and how much it is given, you can change the units, you can have some other trends on and off if you want. And also you can take a different point in the location if you want. It imposes and take another trend.

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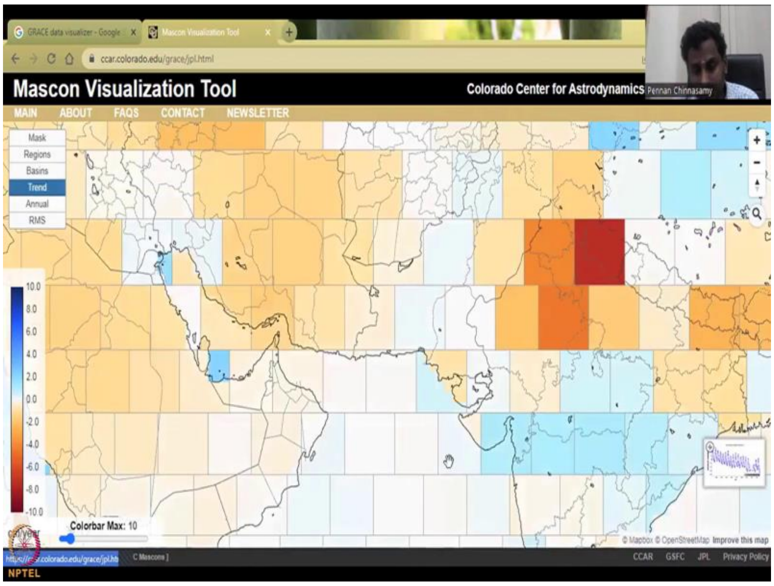

So, this trend is by pixel. So, the pixel is big as you can see, and you can just click that pixel and you can see for example, here, this mascon, this whole grid, which is covering right in the center of Rajasthan is declared declining. So, the recording has started again, so the recording of data is going down.

So then, what we can see is, we also noted that some were the groundwater is going up, so let us take this pixel, for example. So, you can see it is going up. So, this actually relates very closely to the CG web data that we saw. But what is the difference here? The difference here is, it is monthly, and it covers the entire whole area in one go.

And it also includes deep and shallow aquifers because it is terrestrial and down anything that down that changes is going to impact your GRACE, have to record. So you can also save the data as an image, you can take this as an image for your studies, or you can also get the data as a CSV file and then we can change it.

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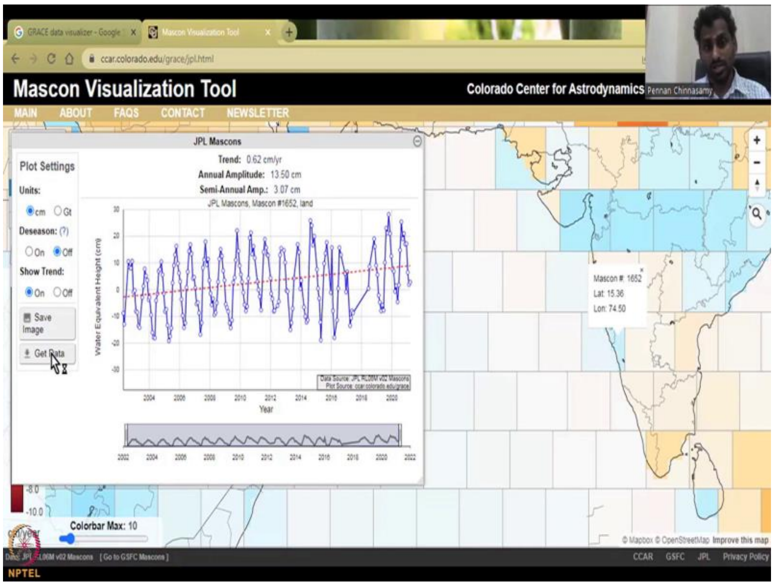

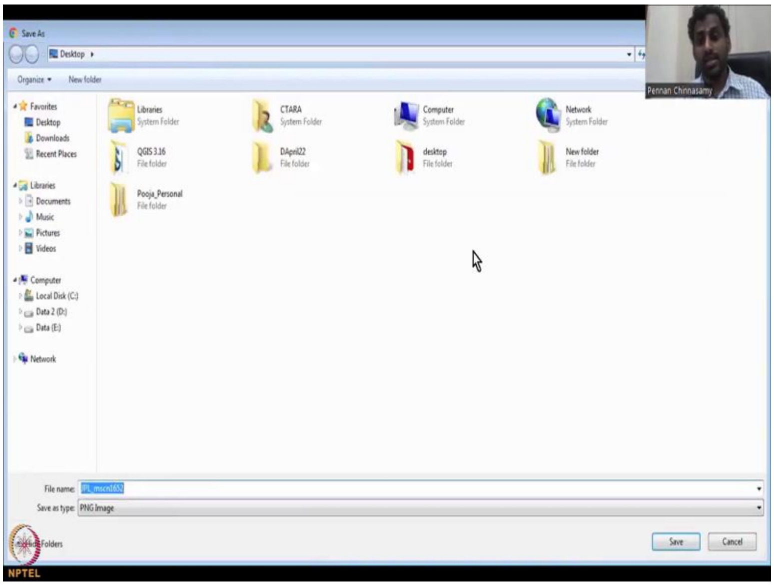

So as I said, you could easily get the data and then subtract the soil moisture to get the groundwater. This course this particular lecture is to introduce this topic. There are a lot of literature, a lot of tutorials on this on YouTube and free open source platforms. Please go there.

And if you are interested in GRACE, have a look at it. I have introduced the topic, you can learn more they give you a step by step how to do these calculations. With this I will start today's lecture. Thank you.