

REMOTE SENSING FOR NATURAL HAZARD STUDIES

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Lec 35b: Remote Sensing for Drought Assessment - Part B

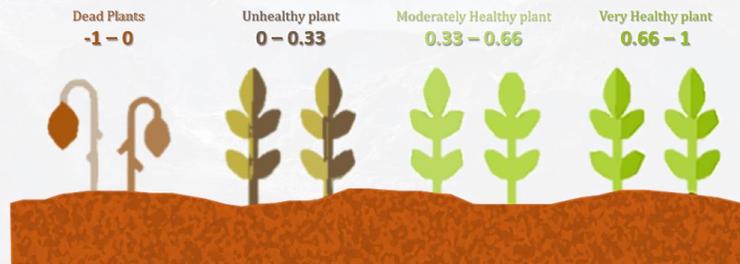
Hello everyone, welcome to Part 2 of Lecture 35. We will continue the discussion on the remote sensing applications in drought studies. So, in the previous part, we discussed a detailed introduction to the drought index, and then we also discussed the different indicators and how they differ from each other. So, with discussion, we come to the conclusion that remote sensing datasets are required to assess a larger area, whether it is under water stress or not. So, let us continue; first, we will try to learn how remote sensing is useful, and then subsequently, we will see the other details. So, satellite-based remote sensing provides high spatial and temporal resolution data that we know of.

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□ Normalized Difference Vegetation Index (NDVI):

- NDVI measures plant greenness, which declines during drought.
- Low NDVI values indicate stressed or dying vegetation due to water scarcity.
- Comparing NDVI trends over time helps identify drought onset, duration, & severity.



It captures atmospheric and land surface characteristics across a larger area. Remote sensing data offers continuous spectral measurement, improving drought assessment. So, what happens when we try to see the history of remote sensing? Initially, we had very coarse spatial and spectral resolution datasets. But with the advancement in technology, we have very high spatial and spectral resolution data. And when we are trying to capture the parameters, such as indicators like precipitation, temperature, wind, or humidity. When we

have the fine spatial resolution data set, we have more information, and even the high spectral resolution will help us identify all these parameters for a smaller pixel, and we will have the temporal variation of how it is changing over time. Several vegetation indices derived from satellite imagery help to monitor drought at a local to regional scale. So, depending on your study area, you can consider a small area or maybe a larger area. Hybrid drought indices integrate climate, satellite, and environmental data for a more accurate assessment.

Satellite remote sensing enables the estimation of key drought variables such as land surface temperature, evapotranspiration, soil moisture, and precipitation. So, this is the reason why I covered the basics of remote sensing at the beginning of this particular course, so that you will be able to perceive what the applications of remote sensing are in deriving different parameters in different natural disasters. So, if we talk about the land surface temperature, thermal remote sensing is used here. When we talk about evapotranspiration, you can use the optical data here. When we talk about the soil moisture here, both the optical and microwave datasets are used for the precipitation, while we are using the radar.

So that is why we learned about different types of remote sensing at the beginning of this course. Now you must be very clear about why and how we can calculate the land surface temperature using satellite data. How evapotranspiration is being calculated, what the application of remote sensing in soil moisture estimation is, and then precipitation estimation—everything we have covered. So, satellite-based microwave and radar instruments are increasingly used for soil moisture and precipitation estimation. Microwave sensors provide deeper soil moisture information, enhancing drought prediction models and offering better accuracy in detecting drought severity and duration.

□ Normalized Difference Vegetation Index (NDVI):

- NDVI is a ratio of Near-Infrared (NIR) and Red (Red) reflectance:

$$NDVI = \frac{\rho_{NIR} - \rho_{RED}}{\rho_{NIR} + \rho_{RED}}$$

ρ_{NIR} : Reflectance in the Near-Infrared band.

ρ_{RED} : Reflectance in the Red band.

- Higher NDVI values indicate healthy, dense vegetation, while lower values suggest stress or barren land.

So, deeper soil means that when we are using the microwave, the depth of penetration is greater compared to the optical data. Advanced remote sensing techniques are improving vegetation stress analysis, groundwater flux, and precipitation forecasting. The integration of sophisticated analysis, modeling, and basic research is crucial for an enhanced early warning system. So, this is NDVI, and we also learned about NDVI in the previous few lectures. NDVI is a widely used vegetation index derived from satellite remote sensing to monitor vegetation health and coverage. NDVI measures chlorophyll activity and plant productivity. It helps to assess the vegetation health, stress, and cover changes due to drought conditions widely used for drought monitoring. So, here you can see the values. It ranges from 0 to 1. So, this is 0.18, and here you have 0.93. So, this is the range for this particular data set. So, how do we calculate the NDVI? NDVI measures plant greenness, which declines during drought because there is less water. Available for these plants, and here you can see their chlorophyll content will be reduced.

So, low NDVI values indicate stressed or dying vegetation due to water scarcity. Comparing NDVI trends over time helps identify drought onset duration and severity. So, how severe is it so you can identify the crop status, whether our crop will be average, below average, or normal? So, NDVI is a ratio of near-infrared and red reflectance. Here we use this equation, and the reflectance in both the NIR band and the red band is used. So, higher NDVI values indicate healthy dense vegetation while lower values suggest stress or barren land.

Now, the next index is the Enhanced Vegetation Index (EVI). So, EVI and NDVI utilize similar technique. However, EVI is derived from data collected by MODIS-based satellites. So, this is MODIS data. Both indices are computed using the MODIS platform and evaluated in comparison to AVHRR-based measurements. EVI demonstrates greater

sensitivity to variation in canopy structure, type, and plant morphology. EVI can indicate vegetation stress and changes associated with drought conditions. So, here are the strengths and weaknesses listed. So, here you can see that the high resolution and broad spatial coverage across different terrain is the strength. Effective for large-scale drought monitoring and early warning systems, the weaknesses are that plant canopy stress may result from factors other than drought, making the interpretation difficult.

□ Temperature Condition Index (TCI):

- Land surface temperature was calculated by using following formula (*wang et al. 2001*):

$$LST = T_4 + 3.63(T_4 - T_5) + 0.87$$

where LST denotes land surface temperature.

T_4 is the brightness temperature of AVHRR channel 4.

T_5 is the brightness temperature of AVHRR channel 5.

Limited historical satellite data makes long-term climatic study challenging. Now we have the TCI (Temperature Condition Index). It is developed by Kangen with the National Oceanic and Atmospheric Administration (NOAA) in the United States, and it uses the AVHRR thermal bands to assess vegetation stress due to temperature and excessive wetness. It estimates conditions related to maximum and minimum temperatures adjusted to account for different vegetation responses to temperature change. Land surface temperature was calculated using the following formula from Wong et al. (2001), and you can see that the land surface temperature can be calculated using band number 4. And band number 5, where LST is the land surface temperature, and T_4 is the brightness temperature of AVHRR channel 4, is the brightness temperature of channel 5 of AVHRR. So, remember that whenever you have some numbers, they are specific to a particular sensor. And if you want to use some other data, you have to translate this number with respect to its wavelength to the other sensors. The TCI is a remote sensing-based thermal stress indicator to evaluate the water stress on vegetation due to higher soil surface temperatures.

□ Temperature Condition Index (TCI):

- The TCI is a Remote Sensing-based thermal stress indicator to evaluate the water stress on vegetation due to higher soil surface temperatures.

$$TCI_i = \frac{LST_{max} - LST_i}{LST_{max} - LST_{min}} \times 100$$

- Where the LST_i is the smoothed 8-day land surface temperature,
- LST_{max} and LST_{min} are defined as the maximum and minimum LST_i value in multiyear, and i is based on the monthly scales.

And this is how we calculate LST, which is the smoothed 8-day land surface temperature, and LST max and minimum are defined as the maximum and minimum values of LST, based on multi-year data and the monthly scale. And here you can see again the strengths and weaknesses are listed. So, it is used alongside NDVI and the vegetation condition index for drought impact assessment. So, these three, NDVI, VCI, and TCI, are used together to evaluate the actual situation of the area with respect to water stress. Now, we have the VCI; the VCI is utilized for the evaluation of vegetation in drought conditions affecting agriculture. VCI utilizes AVHRR thermal bands; it helps to detect drought conditions and pinpoint their onset, particularly in regions where drought events are localized and less distinct. It also assesses the impact of drought on vegetation by tracking changes over time and comparing them with historic data, providing insight into the onset, duration, and severity of the different drought episodes. So, VCI can be calculated using this equation. And here, more than 16 days of NDVI is used. So, this is the 16-day NDVI, and minimum and maximum are used here.

□ Vegetation Condition Index (VCI):

- The VCI_i compares the $NDVI_i$ data for a given period with the highest and lowest values of the NDVI data for the whole period.

$$VCI_i = \frac{NDVI_{max} - NDVI_i}{NDVI_{max} - NDVI_{min}} \times 100$$

- The $NDVI_i$ is the smoothed 16-day $NDVI_i$,
- $NDVI_{min}$ and $NDVI_{max}$ defined as minimum and maximum values of $NDVI_i$ for all pixels and periods, respectively, and i is based on the monthly scales.

This is again the strengths and weaknesses of the VCI vegetation condition index. Now comes the VHI; the Vegetation Health Index is a widely recognized drought index derived from remote sensing data, and it is followed by many researchers. You can see that the list is here. It is formulated as a linear combination of two key components. The first one is the VCI, and the second one is the TCI. The VHI is based on two primary assumptions. So, here the first one is that vegetation health deteriorates when NDVI values are low and LST values are high. So, if NDVI is low, it could have many other reasons why a particular vegetation is under stress. But at the same time, we are analyzing the LST, and the temperature is also high, which confirms that the stress is due to the temperature and water scarcity. Since the relative influence of vegetation and temperature on overall vegetation health is uncertain, VHI is commonly calculated as the average of VCI and TCI.

□ Vegetation Health Index (VHI):

- The Vegetation Health Index (VHI) is given by :

$$VHI = \alpha VCI + (1 - \alpha)TCI$$

Where, α is a weight parameter that is usually set as $\alpha = 0.45$ (Kogan, 1997, 2001).

- The Vegetation Health Index (VHI) and its two components are analyzed in correlation with the Standardized Precipitation Evapotranspiration Index (SPEI) at various timescales.
- This approach seeks to enhance the understanding of vegetation responses to drought events across different conditions.

So, the Vegetation Health Index is given by this equation. So, here the VHI is equal to αVci plus $(1 - \alpha) Tci$, and α is the weight parameter that is usually set as 0.45. It is based on different experiments which are done by many researchers. So, you can see the Kagen 1997 and 2001; they have come to the conclusion that it is generally 0.45. The vegetation health index (VHI) and its two components are analyzed in correlation with the standardized precipitation evapotranspiration index (SPEI) at various time scales. This approach seeks to enhance the understanding of vegetation responses to drought events across different conditions.

□ Soil Adjusted Vegetation Index (SAVI):

- SAVI is an enhanced version of NDVI designed to reduce the impact of soil background interference on vegetation indices.

$$SAVI = \frac{(NR - RED)}{(NR + RE + L)} \times (1 + L)$$

Where L is a soil brightness correction factor, typically set to 0.5 but adjustable based on local conditions.

- SAVI is particularly effective in areas with sparse vegetation, where soil influence can significantly affect vegetation index values.
- NDVI is a widely used index for assessing plant health, while SAVI is a modified version that minimizes soil background effects in regions with low vegetation cover.

Then we have the SAVI; this is the Soil Adjusted Vegetation Index. SAVI is an enhanced

version of NDVI designed to reduce the impact of soil background interference on the vegetation index. So, this SAVI is $(NIR - Red) / (NIR + Red + L)$ that is multiplied by $1 / (1 + L)$, L is the soil brightness correction factor typically set to 0.5 but adjustable based on local conditions. So, SAVI is particularly effective in areas with sparse vegetation where soil influence can significantly affect vegetation index values. NDVI is a widely used index for assessing plant health, while SAVI is a modified version that minimizes soil background effects in regions with low vegetation cover. So, this is one of the indexes that is widely used.

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□ Normalized Difference Water Index (NDWI):

- NDWI is derived by calculating the normalized difference between reflectance values in the Green and NIR bands, leveraging their unique spectral properties to detect water bodies.

$$NDWI = \frac{G - NIR}{G + NIR}$$

- While NIR wavelengths are strongly absorbed by water, Green is only partially absorbed, enabling NDWI to effectively measure changes in water content.
- Its high precision in identifying water features and minimal sensitivity to atmospheric influences make NDWI a reliable tool for water assessment and monitoring in remote sensing applications

Now, here you can see the details of the papers that we have used in the previous slides; we are also using some of the inputs in the next few slides. Now, we have the NDWI; this is for the water. So, NDWI is derived by calculating the normalized difference between reflectance values in the green. NIR bands leverage their unique spectral properties to detect water bodies.

So, here is the normalized one. So, that is why we have G minus NIR divided by G plus NIR. While NIR wavelengths are strongly absorbed by water, green is only partially absorbed, enabling the NDWI to effectively measure changes in water content. The high precision in identifying water features and minimal sensitivity to atmospheric influence make NDWI a reliable tool for water assessment and monitoring in remote sensing applications. Then we have this LSWI. So NDWI is less effective in early crop seasons due to its insensitivity to monitor foliage variation, which is masked by soil background, ? This is what we also discussed in the previous slides. Since agricultural drought results from soil moisture deficit and vegetation water stress, NDVI should be used along with the water index for better early-season drought detection. The SWIR optical domain is. It is ideal for detecting leaf liquid water, which makes up 70 to 90 percent of the leaf weight. The 2130-

nanometer band is less affected by ozone, Rayleigh scattering, water vapor, and aerosol. So, studies indicate that this particular wavelength is more useful for assessing vegetation water status, drought detection, and water sustainability than the 1,640-nanometer band.

□ Land Surface Water Index (LSWI):

- The Land Surface Water Index (LSWI) is computed as:

$$LSWI = \frac{\rho_{858} - \rho_{2130}}{\rho_{858} + \rho_{2130}}$$

ρ_{858} nm: reflectance at 858 nm.

ρ_{2130} nm: reflectance at 2130 nm.

- LSWI quantifies liquid water in vegetation canopies, interacting with solar radiation, and is effective in assessing soil and vegetation water content post-monsoon.

So, this LSWI can be calculated using this method. So, here we are using 2 bands: 858 nanometers and 2130 nanometers. and this can be mapped to any satellite data that you intend to use. LSWI quantifies liquid water in the vegetation canopy interacting with solar radiation and is effective in assessing soil and vegetation water content post-monsoon. So, NDWI for agricultural drought monitoring is used for detecting stress in vegetation affected by drought.

□ Normalized Difference Drought Index (NDDI):

- The NDDI is a key tool for drought monitoring, combining the Normalized Difference Vegetation Index (NDVI) and the Normalized Difference Water Index (NDWI).

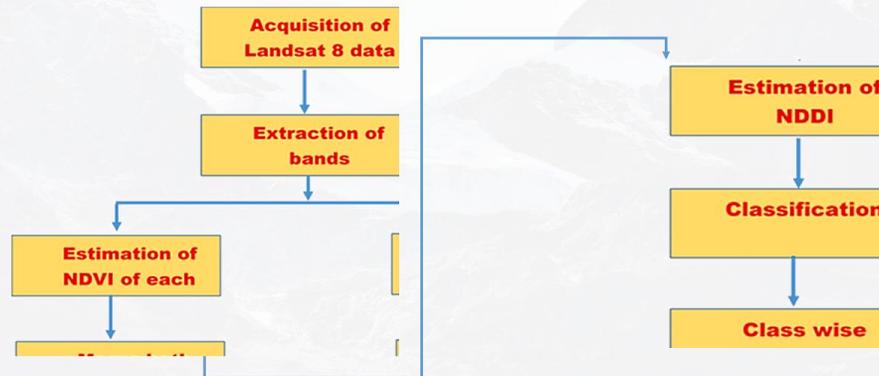
$$NDDI = \frac{(NDVI - NDWI)}{(NDVI + NDWI)}$$

- NDDI is a more sensitive drought indicator than NDVI and NDWI individually.
- A high NDDI value signals drought conditions, where both NDVI and NDWI are low, indicating reduced vegetation health and water availability.
- Conversely, a low NDDI value suggests no drought or minimal water scarcity, as NDVI and NDWI values rise, reflecting lush vegetation with adequate moisture.

The strengths and weaknesses are listed here. So, you can go through it; NDDI is the normalized difference drought index. So, NDDI is a key tool for drought monitoring, combining the normalized difference vegetation index and the normalized difference water index (NDWI). So, if we are calculating this NDDI, you need to have the NDVI and NDWI together, and then you can calculate the normalized difference drought index. NDDI is a more sensitive drought indicator than either NDVI or NDWI individually.

A high NDDI value signals drought conditions where both NDVI and NDWI are low. Indicating reduced vegetation health and water availability. Conversely, a low NDDI value suggests no drought or minimal water scarcity as NDVI and NDWI values rise. Reflecting less vegetation with adequate moisture conditions. Let us see some of the case studies, explorations, and advancements of NDDI leveraging NDVI and NDWI in the Indian semi-arid region.

□ METHODOLOGY (Patil et al. 2024) :



This is a remote sensing-based study. So, the study integrates remote sensing data with the Indian Meteorological Department. Rainfall and dry spell records confirm the effectiveness of vegetation indices as independent drought indicators complementing traditional methods. Because whatever we have discussed as the drought indices in the previous few slides, those are conventional methods. Now, when we are talking about the remote sensing-based indices, these are contemporary, and we are trying to utilize remote sensing as an important tool in drought studies; that is why we are trying to replace the conventional techniques or conventional methods with remote sensing-based indices. Because we all know that we have limitations in collecting data in the field. So, that is why remote sensing plays an important role in providing you with all the information from space, and that will be more helpful. So, this particular study is from Maharashtra; it is from Patil et al. 2024, and here you can see this particular graph. You can see the monsoon period, summer period, and winter period rainfall. It is measured in mm, and this is the average rainfall. And this is the post-monsoon. So, if you have this kind of information from satellites or from the IMD data, then you can easily calculate this, or you can derive this conclusion. So, here you can see the positive and negative rainfall, that you can calculate using the previous information.

So, Patil et al. (2024) have used this methodology to identify whether a particular area is under water stress or not. So, here you can see that the x-axis represents the month and the y-axis represents rainfall; here you have the average rainfall. Then this is the average rainfall in millimeters, this is 2022, and this is a dry spell. So, Similarly, they have interpreted the data in different ways, and you can easily see how useful it is when you are utilizing or integrating the remote sensing-based data set in your study. Then they calculated the NDVI, and here you can see the NDVI values. This is NDWI, and then they

have used this NDDI to identify whether a particular area is under stress or not. So, the classification rule followed by Patil et al. (2024) states that NDVI from minus 1 to minus 0.3 indicates severe drought, while from minus 0.3 to 0 indicates moderate drought. 0 to 0.3 is a mild drought, and 0.3 to 1 is no drought. Similarly, for NDWI and NDDI, they have used a different classification scheme, and then they have come to the conclusion that this is 0.5 to 1, which indicates extreme drought conditions. Drought detection and declaration in India is from Bhardwaj and Mishra 2021. So, the declaration of drought marking the beginning of the state's response to a district drought situation is guided by the provisions outlined in the Manual for Drought Management 2016. Drought is declared in a district if the drought indicator specified in the policy meets the condition of the drought declaration framework. So, this is available, and if you are interested, you can go through it. So, state agencies monitor drought and declare them at the district level based on a two-triggering system.

This drought declaration follows ground-truthing and assessment of crop losses. Trigger 1: mandatory indicator that is the Kharif rainfall deviation SPI and dry spell. Then Rabi, that is, rainfall deviation, SPI, dry spell, reservoir storage index, and groundwater drought index. For Rabi crops, indicators are adjusted for rain-fed, surface or groundwater-irrigated, and northeast monsoon-dependent areas. Trigger 2 impact indicators; it is activated only if trigger 1 is set off. The indicators used here are remote sensing NDVI vegetation condition index, soil moisture percentage, available soil moisture, and moisture adequacy index. In the hydrology part, there is a stream flow index, reservoir storage index, and a standardized groundwater index. So you can see the real-time drought monitoring that is available, and here you have different codes, and you can see whether a particular area is under stress or not. For drought detection, the SIF indicator outperforms NDVI as used in existing policy. Detected and declared drought shows a higher probability of detection in central India.

On the other hand, a lower POD was found in regions of high drought susceptibility, like Rajasthan, Andhra Pradesh, and Karnataka. Large differences between the detected and declared droughts were identified in the irrigated areas of Punjab and the Gangetic Plain. The difference in detected or declared droughts can be attributed to ground truthing and crop-cutting experiments, irrigation uncertainty in data and indicators, and several other socio-political factors. In the other one, we have this assessment of meteorological and agricultural drought using remote sensing and its impact on groundwater in an agriculturally productive part of Northwest India. The study examines meteorological and agricultural drought using SPI, VHI, and NVSWI during the wheat growing season, which is Rabi.

It analyzed drought patterns and investigated the correlation between these indices and the gross primary productivity, which is GPP, while also assessing groundwater trends. So, here this is a combination of different parameters, and together they evaluated what the

situation is. Drought assessment and its impact on groundwater is from Kaur et al. 2022. Climate change has increased the frequency of droughts affecting agriculture and groundwater.

This study aims to identify meteorological drought event duration and intensity, monitor agricultural drought between 2001 and 2002, and 2019 to 2020 using drought indices. Investigate the relationship between drought indices and groundwater levels, and how these two are related. So, the study area was Punjab and Haryana, and here you can see the average annual rainfall in the agroclimatic zone that is less than 300 mm; for the second zone, you have 500 to 700, and in the third, it is 750 to 1000. Topography consists mostly of flat terrain with some undulating areas in the north and south. So, here you can see what data set they have used: IMD graded data set, MODIS 13 Q1, then MODIS 11 A2, and then MODIS 17 A2 SGF.

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INDICES EMPLOYED	Vegetation Condition Index (VCI)	$VCI_t = \frac{NDVI_{max} - NDVI_t}{NDVI_{max} - NDVI_{min}} \times 100$
	Temperature Condition Index (TCI)	$TCI_t = \frac{LST_{max} - LST_t}{LST_{max} - LST_{min}} \times 100$
	Vegetation Health Index (VHI)	$VHI = \alpha VCI + (1 - \alpha) TCI$
	Vegetation Supply Water Index (VSWI)	$VSWI = \frac{NDVI}{LST}$
	Normalized Vegetation Supply Water Index (NVSWI)	$NVSWI = \frac{VSWI - VSWI_{min}}{VSWI_{max} - VSWI_{min}} \times 100$

So, this is the GPP, gross primary productivity, LST, TCI, NDVI, VCI, and the rainfall data that is being used here. So, here the spatial resolution, temporal resolution, and the time period are also given. So, the drought parameters were determined using run theory, and their statistical characteristics include run length. Run sum and intensity were analyzed. The correlation between seasonal NV SWI and drought indicators like SPI, VHI, GPP, and groundwater level was analyzed.

Seasonal SPI 12, which is from December to March, was used to assess drought severity and its impact on vegetation and agricultural productivity. The trend analysis of NVSWI and groundwater levels was conducted, and different estimators were used. Now, if you see the VCI, TCI, VHI, VSWI, and NVSWI, all the equations are given here. Now, all of them can be calculated using the remote sensing data, provided that your study area has

been captured by the satellite. So, the drought duration, drought severity, and drought intensity can be analyzed, and they have analyzed this.

You can see here the duration of the drought, right here, and this is the period where we have sufficient or more than sufficient rainfall. The spatial-temporal distribution of parameters for the years 2016 to 2017, and all these parameters are given here: A, B, C, D, E, F, G, and here the maps are provided, and the legend can be used to read this particular map. Agriculture drought assessment from NVSWI is provided here and here; you can see the value. That is how they are using greater than 20 for severe drought, 20 to 40 for moderate drought, 40 to 60 for minor drought, 60 to 80 for normal, and greater than 80 for wet.

Now the value greater than 80 is in green. So, you can analyze these images with this legend here; you can see the groundwater level and NVSWI relationship between this 2-year gap. So, here you can see that for Punjab and Haryana, they have analyzed the reasons behind showing these examples or case studies. To tell you that remote sensing has the potential to be used in drought studies, you should learn the basics and use the appropriate datasets. So, whatever references or books that I have referred to are listed in the next few slides. So, you can just go through them if you want; you can Google it, get more details, download the papers, and read them. So, you can see this is the next slide of suggested readings; then we have this. So, with this, I will end this lecture.

Thank you very much.