

SUSTAINABLE MINING AND GEOINFORMATION

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Lecture 07: Global Navigation Satellite System (GNSS)

Welcome Welcome to the course on sustainable mining and geoinformation. Today on the lecture number 7 we are going to discuss on GNSS which stands for Global Navigation Satellite Systems. Friends, all of us have been hearing the term GPS, Global Positioning System, which we have been traditionally saying it, but these days we have tried to rename it as GNSS, that stands for Global Navigation Satellite System. So, but in during this discussion we will be using both the terms in tandem, but the more appropriate term goes as GNSS that is Global Navigation Satellite System.



And the summary of the talk goes like this we will be covering the concepts broadly the GNSS. And we will discuss about GPS, the global positioning system. The traditional name came from the NAVSTAR series of satellites, constellation of satellites given by the United States of America, particularly by their Department of Defense. And further we have the Russian, the European systems, the GLONASS and Galileo and also we have our Indian system. There are also few regional systems like Chinese and Japanese.

CONCEPTS COVERED

- Introduction to GNSS (GPS, GLONASS, Galileo) for Mining Operations
- GPS for Mine Surveying, Equipment Tracking, and Precision Blasting
- Real-Time Kinematic (RTK) GNSS and Differential GNSS for High-Precision Applications in Mining




So, these we will try to understand and try to see how they are useful for mining operations. So, as I said GPS and GNSS we are more randomly using both the terms. So, GNSS utility for mining, surveying, equipment tracking and precision blasting we will discuss. And also we will try to understand the two terms particularly the RTK real time kinematics and the differential GNSS or traditionally we have been calling it as DGPS that is differential global positioning system. So these two modes are used for very high precise applications including the mining sector.

So, what is GNSS? As the expansion goes, Global Navigation Satellite System (GNSS) is a constellation of satellites—a group or constellation of all navigation systems and their augmentation. We will try to understand how they augment the signal and the responses under this topic. And thereby, it allows measuring the position. So, the moment we talk about position, we talk about x, y, and z in terms of the location. So, over the Earth's surface, we discuss it with respect to latitude, longitude, and elevation. So, we try to measure these—meaning the position—based on real-time data.

Global Navigation Satellite System (GNSS)



Group of all Satellite Navigation Systems (SNSs) and their Augmentations



Allows Measuring Positions in Real Time with an Accuracy of up to a Few Centimeters

←—————→

(Kumar et al., 2021)




So, at what point in time is the flight? Where is the cruise? We can measure and monitor with accuracy up to a few centimeters. So, that is the beauty. So, up to a few centimeters of accuracy, we are able to measure the position. So, very high positional accuracy. So, let us talk about different GNSS constellations by different countries.



So, traditionally, the first one—as you understand—GPS stands for Global Positioning System. It comes from the satellite constellation of NAVSTAR. NAVSTAR stands for Navigation Satellite Timing and Ranging. It is by the United States Department of Defense. It is owned by the US and has global coverage.

Later, in our next slides, we will discuss the number of satellites they have, including the numbers which are operational and those in reserve. So, let us talk about the second one: GLONASS. Its expansion is Global Navigation Satellite System. It is owned and operated by Russia with global coverage. The third one is BeiDou.

It is owned and operated by China but has global coverage. Galileo is by the European Union, and it also has global coverage. Now, let us see two important constellations of GNSS: one is QZSS, which has regional coverage and is owned and operated by Japan, and our own Indian one is called IRNSS or NavIC, which stands for Indian Regional Navigation Satellite System or Navigation Indian Constellation. Often, we understand it or hear it under the framework of GAGAN.

So, it is owned and operated by India. Both our Airport Authority and ISRO operate it and jointly own it. So, it has predominantly regional coverage. Let us see, as far as two important constellations, Galileo and GLONASS, are concerned. Galileo, this constellation, was initiated by the European Union and is a civilian-controlled navigation system.



So, it is not defense-oriented. So, it is designed to provide highly accurate and reliable global positioning. So, the Galileo constellation has 30 satellites, out of which 27 are operational and 3 are spares. Three are always kept or maintained as reserves, meaning that if one of the 27 operational satellites develops a malfunction, then one of these three spares will be diverted or replaced with the malfunctioning one.

So, that way, it is 27 plus 3 in the Galileo constellation, and it is in medium Earth orbit (MEO) with enhanced signal clarity, even in high-latitude and urban areas. So, over high-latitude and urban areas, the signals are also very good. So, let us come to GLONASS, owned by the Russians. So, it stands for the Russian Global Navigation Satellite System, originally developed during the Cold War as a military alternative to GPS. GPS, as we know, is by the United States Department of Defense.

GLONASS was developed as an alternative during the Cold War—a military alternative to GPS. Unlike Galileo, GLONASS has a constellation of 24 satellites, of which 21 are operational and 3 are always kept in reserve. So, GLONASS satellites transmit on individual frequencies, with some sharing frequencies when positioned on opposite sides of the Earth to avoid signal overlap. So, these satellites transmit on individual frequencies, though there could be some overlapping or sharing based on positioning. So, this is about these two. Let us also have a look at our own, the GAGAN.

So, we have a system the GPS aided geo-augmented satellite navigation system. This is jointly developed by Airport Authority of India and Indian Space Research Organization. This is aimed at improving the accuracy, availability, integrity and continuity requirement of the GPS system. So, we say that it builds on the already existing GPS system by US DoD, but it also aimed at improving the accuracy and and wherever the availability is less

so it complements in terms of availability and also continuity in terms of requirement. So it helps mostly in civil aviation requirements

SBAS-GAGAN (GPS Aided Geo Augmented Satellite Navigation)

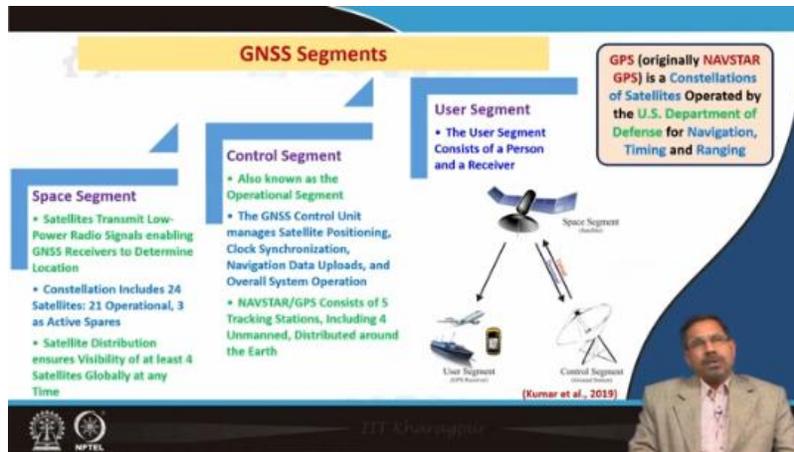
- Jointly Developed by AAI & ISRO
- Improve the Accuracy, Availability, Integrity and continuity requirements of the GPS System – Civil Aviation Requirements
- Enroute Navigation
 - High Position Accuracies with Integrity over a wide Geographical Area such as the Indian Airspace
 - Satellite based landing of Aircraft fitted with SBAS Receivers
 - To provide Fuel Efficient Air Corridors
 - Better Upper Air-Space Management over India

gaGan

AAI ISRO

and the second point is in terms of enroute navigation so this SBAS-GAGAN system it maintains high positional accuracy with integrity over a wide geographical region such as whole of the indian airspace and the satellite based landing of aircraft fitted with this satellite based augmented system abbreviated as SBAS receivers. So these are also aimed at providing fuel efficient air corridors and better upper air space management over India. So this is mostly to cater as the name terms as augmented. So it caters and augments the positional accuracy and gives us navigation and other positional accuracy related applications.

So, now let us go to the segments. So, broadly this GNSS has three segments. One is the space, second is the control, third is the user segment. So, in terms of the space segment, satellites transmit low power radio signals enabling GNSS receivers to determine the locations. So as far as GPS constellation is concerned, we have 24 satellites out of which 21 operational and 3 are remained as spares.



So, this satellite distribution ensures visibility of at least four satellites globally at any point in time. So, the constellation is such that at any point in time, over any place, there has to be availability or visibility of at least four satellites so that the positional accuracy in terms of X, Y, and Z is assured. Let us come to the second one, the control segment. It is also known as the operational segment. The GNSS control unit manages satellite positioning, clock synchronization, navigation data uploading, and overall system operations.

So, this is the core as far as the segment is concerned, that is, the control segment. So, this NavStar or GPS consists of five tracking stations as an example, out of which four are unmanned and distributed around the Earth's surface or over the globe. On the right-hand side, you can see a depiction where all three segments, starting from the space, the control, and the user segment, have been demonstrated. So, as far as the user segment is concerned, the user segment consists of a person and a receiver on the ground, on the Earth's surface. So, broadly, these are the three segments as far as the GNSS is concerned, as far as the GPS and other GNSS are concerned.

So, let us see the four or five broad functions of the GNSS, the points. First, GNSS determines precise location on Earth by calculating the distance between the satellites and the GPS receiver. So, what exactly does it calculate? The precise location on the Earth's surface by calculating the distance between the satellite and the GPS, or you say, GNSS receiver. Using a network of orbiting satellites, GNSS receivers, or you say, the GNSS receivers, they receive or gather two types of satellite data. One is in terms of almanac information that gives us the position, and the second one is important as the ephemeris information, which gives the precise orbital data.

GNSS Functioning

- GNSS Determines Precise Locations on Earth by Calculating Distances between Satellites and a GPS Receiver
- Using a Network of Orbiting Satellites, GNSS Receivers Gather Two Types of Satellite Data: **Almanac Information (approximate Positions)** and **Ephemeris Information (Precise Orbital data)**
- By Measuring **Signal Delays** and Applying the Speed of Light, the Receiver calculates distances from multiple Satellites, which allows for Accurate **Triangulation**
- Triangulation:** The GPS Receiver Needs Signals from at least 3- Satellites to Determine a **2D-Position (Latitude and Longitude)**
- When a Fourth Satellite is Available, the Receiver can Calculate a **3D Position (Latitude, Longitude and Altitude)**, which Removes Ambiguity, providing **Precise Positioning**

(Kumar et al., 2019)

So, by measuring the signal delays and applying the speed of light the receiver on earth surface it calculates the distance from multiple satellites because as you know minimum of 4 satellites are needed to get a good triangulation in terms of positional accuracy. So, the triangulation, in terms of triangulation, the GPS receiver needs signals from at least three satellites to determine a two-dimensional position. That means lat-long to give you the x and y in terms of the position, it needs a minimum of three. Whereas to give the z or the third dimension the elevation or the altitude it needs a minimum of four satellites to calculate based on the triangulation network. So when a four satellite is available the receiver can calculate a 3D position that is latitude, longitude and altitude which removes ambiguity providing precise positioning.

So, components of a GNSS signal are the fundamental frequency which is generated on board the atomic clock mounted at 10.23 MHz. So friends, all of us know this GNSS, they give us four unknowns, x, y and z in terms of position and the fourth one, x, y and z are the three unknown variables in terms of position or the location and the fourth one is the time. very precise time we get from the atomic clock which is mounted on board that operates at 10.23 megahertz. And coming to the carrier frequencies we have L1 and L2 at 1575.42 megahertz and 1227.6 megahertz. So, L1 operates at 19 centimeter wavelength and dominantly for civilian and military use.

Components of a GNSS Signal

- Fundamental Frequency**
 - Generated by onboard Atomic Clocks at 10.23 MHz
- Carrier Frequencies**
 - L1: 1575.42 MHz (19 cm wavelength) – Civilian and Military use
 - L2: 1227.60 MHz (24 cm wavelength) – Primarily Military
- Modulated Data**
 - L1: C/A code, P code, Y code, Navigation Message
 - L2: P code, Y code, Navigation Message
- Pseudo Random Noise (PRN) Code**
 - Unique to each Satellite for Signal Differentiation and Alignment
- Codes**
 - C/A Code (Civilian): Provides accuracy of 10-20 m
 - P Code (Precision): Higher accuracy, used for both Civilian and Military; enhanced via Dual-Frequency Processing
 - Y Code (Protected): Encrypted for Military, ensuring High Security
- Navigation Message**
 - Contains Satellite Orbit, Clock Corrections, Ionospheric Delay Model, and System Status

Whereas the L2 operates at 24 centimeter wavelength, but it is primarily for defense or military use. Coming to the data modulation. In terms of L1, we have the course acquisition, CA code, precision code, P code and the Y code apart from the navigation based messaging system. The L2 data modulation do not have the coarse acquisition code, but it has the rest 3 what the L1 has. They are the P code, precision code, Y code and the navigation messaging system.

Coming to the pseudo-random noise, abbreviated as PRN code, it is unique to each satellite for signal differentiation and alignment. This is very important because it has to be unique as far as each satellite is concerned in that GNSS constellation. So that the individual signal will be captured characteristically and aligned as far as the triangulation and other calculations go. And as far as the course is concerned, the civilian code, dominantly the course acquisition code, provides accuracy. At the range of 10 to 20 meters, whereas the precision code has a higher accuracy but is used both for civilian and military applications, enhanced via dual-frequency processing, whereas the Y code is a much more protected and encrypted one, which is used for military or defense purposes.

So it has to have very high accuracy and encryption. The navigation message contains satellite orbit, clock correction-based information, the ionospheric delay models, and the system status. Coming to the different sources of errors, friends, based on the triangulation, the receiver on the ground calculates the position in terms of x, y, and z. So, a lot of errors could be there in this calculation as far as the GNSS is concerned. So, errors related to GNSS satellites—we could have errors in the clock itself. So, that is called the clock error.

Sources of Errors in GNSS

Errors Related To GNSS Satellite

- Satellite Clock Error
- Satellite Geometry Error
- Satellite Orbit Error
- Ephemeris Error

Errors Related to Transmission of Signal Through the Atmosphere

- Ionospheric Delay
- Tropospheric Delay
- Multipath Error

Errors Related to GNSS Receiver

- Receiver Clock Error

Other Errors

- Selective Availability (SA)

The diagram illustrates the signal path from a satellite to a receiver. A satellite in orbit sends a signal that passes through the ionosphere and troposphere before reaching the receiver. Various error sources are labeled: Orbit Error, Clock Error, Epsilon (SA), Other (SA) at the satellite; Ionospheric Refraction and Tropospheric Refraction in the atmosphere; Multipath at the receiver; and Receiver Noise at the receiver itself.

NPTEL

It could be with the geometry of the satellites, called the satellite geometry error. It could be with the orbits of the satellites, regarded as satellite orbit error or with the ephemeris. So, the errors related to the transmission of signals through the atmosphere—when it comes through the atmosphere, we sometimes, in this sense, call it an interfering or disturbance layer as far as the atmosphere is concerned. So, we say there could be some delay as far as the ionosphere or the troposphere is concerned. So, we put them under tropospheric delay or ionospheric delay. So, on the right-hand side, we have a depiction: orbit error, clock error, epsilon error, and other errors like dither and others.

Ionospheric refraction and tropospheric refraction. When you have a density variation in the layers, at the edge you expect a kind of delay, which we can describe as refraction-induced delay. And then you can also have multipath. So that is also categorized under multipath error. So errors related to GNSS receivers could also come from clock errors.

Other errors include selective availability. When considering selective availability, some errors are also induced. Now let us discuss these two forms: one is real-time kinematics for high-precision positioning technology, and the second is differential GPS, sometimes called DGPS or differential GNSS. RTK (real-time kinematic GPS) is a high-precision positioning technology used in many sectors, including mining. This positioning technology enhances the accuracy of standard GNSS signals by employing a reference system.



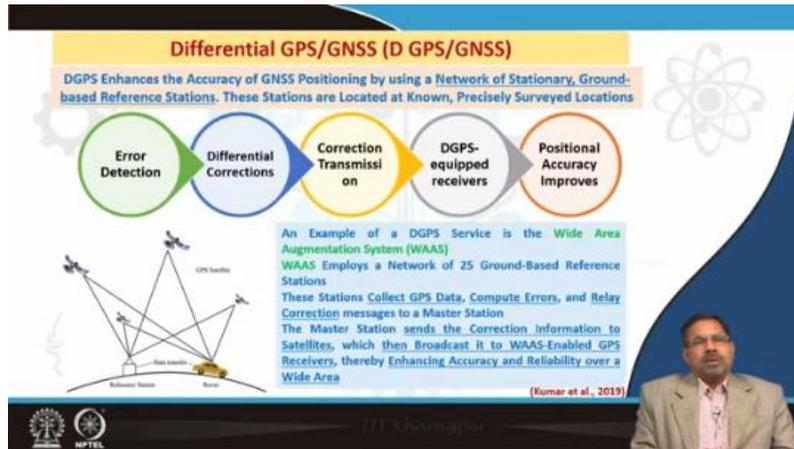
This reference system helps provide real-time corrections to any mobile receiver. The reference station transmits corrections to the mobile receiver, sometimes called a rover, under line-of-sight conditions. So what happens with the reference station? It is a fixed reference station placed at a known and accurately measured location. A reference system must be placed at a known and accurately measured location.

Its position has to be known with certainty. This station continuously monitors the signals received from the GPS satellites and calculates the positioning errors. Since this monitors the signals received from the satellites, it calculates the errors. Now, once this is done, the transmission of the corrections begins. The reference station transmits these errors, which are in terms of positioning errors.

These errors are transmitted to the RTK rover, or the mobile receiver, by a communication method such as UHF or VHF radio, GSM, or an internet link. So, through any of these media—VHF, UHF, GSM, or internet link—the positional errors are transmitted to the RTK rover or the mobile receiver. Now, once it is transmitted, the mobile receiver mounted on equipment or handheld uses the correction data from the reference station to improve the accuracy of its own GNSS system. The rover then determines its position with centimeter-level precision. So, the precision improves.

So, what happens in terms of application? RTK GPS typically requires an unobstructed line of sight between the reference station and the rover. There must be no obstruction between the reference station and the rover. The distance between the two is also a factor, as the accuracy of corrections decreases over larger distances. So, if it is placed at a larger distance, the accuracy of the correction will decrease.

Whereas, if it is around 10 to 20 kilometer, then generally the performance is very good. So, now let us see about the differential GPS or differential GNSS. So, this DGPS or the differential GPS enhances the accuracy of GNSS positioning by using a network of stationary ground-based reference system. So, unlike in RTK, Here there are a network of stationary and ground based reference systems.



These stations are located at known and precisely surveyed locations. So what happens? They help in error detection, then it goes in terms of differential corrections, helps in differential correction, then the correction is transmitted and the DGPS equipped with receivers helps in improving the positional accuracy. So, an example of DGPA service is the WAAS, sometimes called WAAS, Wide Area Augmented System, which employs a network of 25 ground-based reference stations. These stations collect GPS data, compute errors and relay messages to a master station.

So if you have a number of about 25 ground-based reference system, we can understand that the errors are well calculated, then it is used for correction and in turn improving the positional accuracy. So, the master station sends the correction information to satellites which then broadcast it to WAAS enabled GPS receivers thereby enhancing accuracy and reliability over a wide area. So let us see the difference between these two in terms of accuracy DGPS gives much DGPS accuracy is 0.5 to 5 meter whereas RTK gives you 1 to 2 centimeter. The correction methods code phase correction is applied in terms of differential GPS or differential GNSS. Whereas in terms of RTK it is a carrier phase correction and the applications as far as DGPS is concerned general navigation and agriculture whereas for RTK it is mostly used for surveying construction including application in the mining sector.

Differential GPS (DGPS) and Real-Time Kinematic (RTK) GPS are both advanced methods used to enhance the accuracy of positioning systems by correcting errors in standard GPS signals

Feature	DGPS	RTK GPS
Accuracy	0.5 to 5 m	1 to 2 cm
Correction Method	Code Phase Corrections	Carrier Phase Corrections
Latency	Higher latency, with slower Updates	Low latency, Real-time Updates
Range	Effective over larger Distances	Limited to 10–20 km from Base
Applications	General Navigation, Agriculture	Surveying, Construction, Mining

Latency: The Time between the measurement of Velocity



So, the GNSS applications in the mining sector are, as we mentioned, it could be in surveying, it could be in equipment tracking and control, in precision blasting, and also additional applications of GNSS in mining are Safety enhancement, automation, and fleet management. Let us see in terms of the application in surveying. High-precision terrain mapping and enhanced satellite visibility with GLONASS are used for mining surveying. In terms of precision blasting, mapping and aligning blast patterns, monitoring the blasting outcomes using UAVs, Unmanned Aerial Vehicles.



As far as equipment tracking and control is concerned, real-time tracking of mining equipment, and also improvement in terms of accuracy with a dual system, GPS plus GLONASS. So, look at this: the dual system GPS, the signals received from two or more GNSS systems like GPS from the NAVSTAR constellation, GLONASS from the Russian constellation—if we integrate them, we come out with a dual system. So, the equipment tracking and control and many other applications in mining get benefits when we use dual-system tracking.

Now, coming to the other applications, we have mine surveys, very high-precision surveys, machine control, and automation. So, automated equipment, blast-hole drilling—we also use it for precise drill placements. Sometimes, environmental monitoring and land reclamation, we use monitoring deformation and subsidence by taking a lot of the positional data points as far as the area is concerned. Also, the pit and quarry monitoring, slope stability, and safety analysis can also be done using this RTK-based GNSS, the data points, or positional data points. So, infrastructure development construction such as roads or dams, safety enhancements including proximity warning systems—we have a lot of applications as far as the RTK GNSS is concerned in the mining industry.



So, coming to an example, yes, the Raniganj coal field in West Bengal—this coal field, which is very renowned as far as coal production is concerned—experiences substantial ground subsidence. A lot of events have happened. Ground subsidence occurs due to extensive underground mining and coal bed methane extraction. And also, what has happened in this case study by Ghosh et al. in 2024 is that they have integrated DGPS with InSAR techniques, and it was pivotal. They found that it is very effective in monitoring and managing these ground subsidence-based deformations. So, the surface deformation monitoring using DGPS survey was conducted using a base-rover setup, deploying multiple stations across the coal field by Ghosh et al.

DGPS in Mining

1. Raniganj Coalfield, West Bengal, India
It experiences substantial Ground Subsidence due to Extensive Underground Mining and Coal Bed CH₄ Extraction
Integration of DGPS with InSAR Techniques, has been Pivotal in Monitoring and Managing these Deformations

- **Surface Deformation Monitoring:** The DGPS survey was conducted using a Base-Rover Setup, Deploying Multiple Stations across the Coalfield
- **Integration with InSAR Data:** DGPS data are used to validate InSAR-derived Deformation maps, which are generated using Persistent Scatterer InSAR (PS-InSAR) and Small Baseline Subset InSAR (SBAS-InSAR) Methodologies
- **Field Observations and Hazard Management:** The Integration of DGPS and InSAR enables the Identification and Mitigation of Geological Hazards, offering Valuable Insights for Regional Planning and Disaster Management Strategies

(Ghosh et al., 2024)



And they have also integrated this information with the InSAR data. Friends, we have already discussed SAR interferometry. So, this DGPS data were used to validate the InSAR-derived deformation maps, which are generated using persistent scatter InSAR and small baseline techniques. And then, as far as field observation and hazard management are concerned, the integration of DGPS and InSAR data finally enabled the identification and mitigation of geological hazards, thereby offering valuable insights for regional planning and disaster management strategies. So, the integrated use of data points from DGPS along with InSAR has provided a good deformation study or subsidence study.

Now, let us conclude. The points we discussed broadly are GNSS technology. We introduced GPS, the Global Positioning System; GLONASS, the Russian system; and Galileo, the European system. All of them have implications in the mining industry, including the enhancement of mining safety, efficiency, and precision. GPS, or GNSS in general, aids in surveying, equipment tracking, and precision blasting. RTK GPS provides centimeter-level accuracy for automation and machine control, whereas DGPS supports very high-level subsurface deformation monitoring.

CONCLUSION

- GNSS Technologies (GPS, GLONASS, Galileo) Enhance Mining Safety, Efficiency, and Precision
- GPS aids in Surveying, Equipment Tracking, and Precision Blasting
- RTK GPS Provides Centimeter-level Accuracy for Automation and Machine control
- DGPS supports Surface Deformation Monitoring
- Integrated GNSS Systems Ensure Reliable Data in Complex Terrains
- GNSS Transforms Mining with Precise, Real-Time Positioning & Monitoring



Integration of GNSS systems ensures reliable data in complex terrains. GNSS transforms mining with precise real-time positioning and monitoring. So, to conclude, we discussed the GNSS Global Navigation Satellite System. Traditionally, we have been studying it as GPS, the Global Positioning System, which originated from the NAVSTAR constellation of satellites by the United States Department of Defense. But as we discussed and now understand, GNSS is a generic term that accounts for all these navigation constellation systems owned by the US, European Union, and Russia.

Now we can see for regional applications also Chinese, Japanese, and ours, the Indian system, GAGAN. So, thank you very much.