Global navigation satellite system, basic principles, constellations, applications

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ITU Regional Seminar for CIS and Europe "Development of modern radiocommunication ecosystems"
St. Petersburg, Russian Federation, 6-8 June 2018

The addressed issues

1. Tasks and objectives of the global navigation satellite systems (GNSS)
2. GNSS frequency management
3. GNSS operation features
4. GNSS typical structure
5. GNSS characteristics
6. GNSS applications
7. International cooperation in GNSS

Tasks and objectives of the Global Navigation Satellite Systems

Objective : Providing guaranteed high-quality coordinate , time and navigation services to various users located at the Earth's surface or in near-Earth environment

Main tasks:

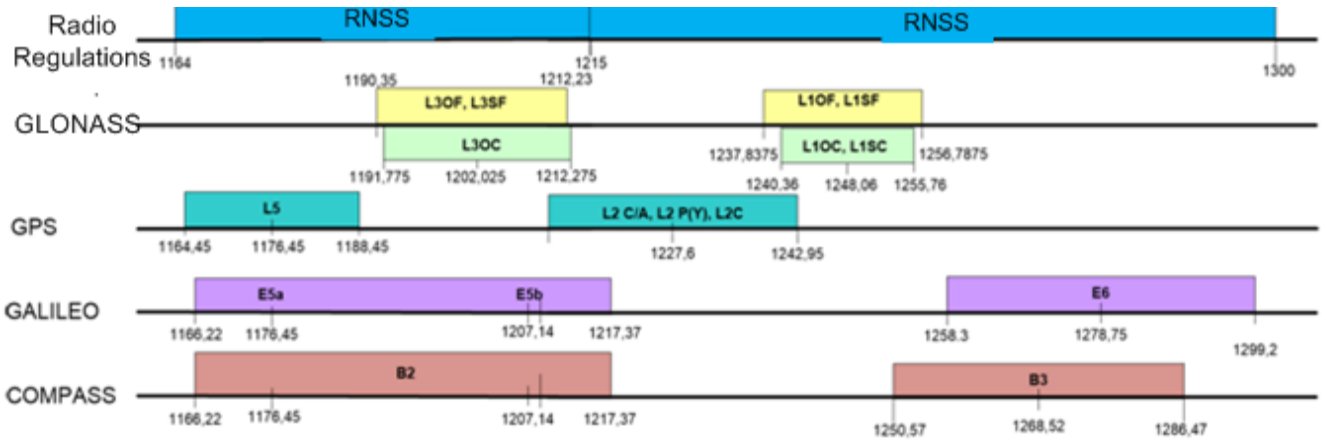
- ✓ Ephemerid data transmission of navigation satellites at a certain time;
- ✓ High accuracy time data transmission associated with UTC signals;
- ✓ Data transmission of integrity and accuracy of the ephemerid data and time.

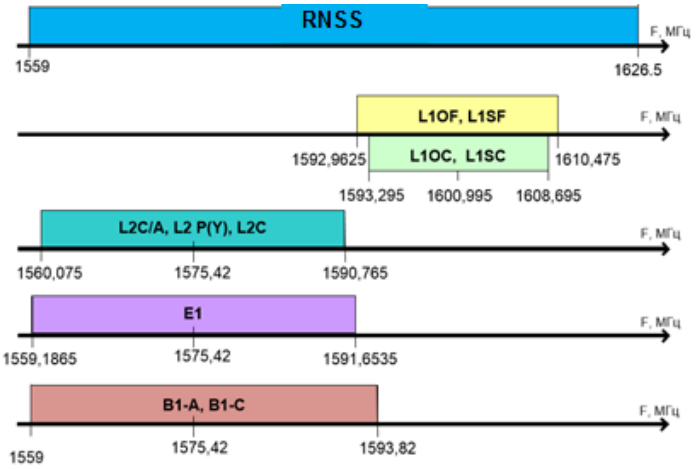
Frequency management for the Global navigation satellite systems

The Global navigation satellite services operate within the radionavigation-satellite service.

1.43 RR Radionavigation-satellite service: A radiodetermination-satellite service used for the purpose of radionavigation.

4.10 RR Member States recognize that the safety aspects of radionavigation and other safety services require special measures to ensure their freedom from harmful interference; it is necessary therefore to take this factor into account in the assignment and use of the frequencies.





Global navigation satellite systems in ITU-R Documents (1/2)

ITU-R Recommendations for RNSS systems

ITU-R M.1901 - Guidance on ITU-R Recommendations related to systems and networks in the radionavigation-satellite service operating in the frequency bands 1 164-1 215 MHz, 1 215-1 300 MHz, 1 559-1 610 MHz, 5 000-5 010 MHz and 5 010-5 030 MHz

ITU -R M.1787 - Description of systems and networks in the radionavigation-satellite service (space-to-Earth and space-to-space) and technical characteristics of transmitting space stations operating in the bands 1 164-1 215 MHz,1 215-1 300 MHz and 1 559-1 610 MHz

ITU -R M.1902 - Characteristics and protection criteria for receiving earth stations in the radionavigation-satellite service (space-to-Earth) operating in the band 1 215-1 300 MHz

ITU -R M.1903 - Characteristics and protection criteria for receiving earth stations in the radionavigation-satellite service (space-to-Earth) and receivers in the aeronautical radionavigation service operating in the band 1 559-1 610 MHz

ITU -R M.1904 - Characteristics, performance requirements and protection criteria for receiving stations of the radionavigation-satellite service (space-to-space) operating in the frequency bands 1 164-1 215 MHz, 1 215-1 300 MHz and 1 559-1 610 MHz

ITU -R M.1905 - Characteristics and protection criteria for receiving earth stations in the radionavigation-satellite service (space-to-Earth) operating in the band 1 164-1 215 MHz

Global navigation satellite systems in ITU-R Documents (2/2)

ITU-R Recommendations for RNSS systems

ITU -R M.1906 – Characteristics and protection criteria of receiving space stations and characteristics of transmitting earth stations in the radionavigation-satellite service (Earth-to-space) operating in the band 5 000-5 010 MHz

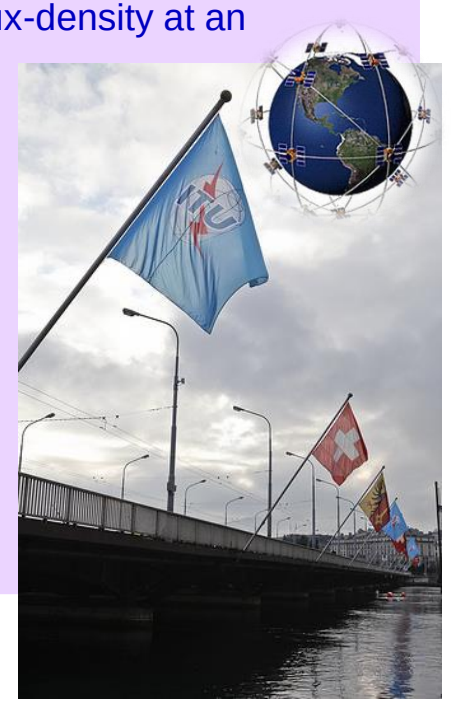
ITU -R M.2031 - Characteristics and protection criteria of receiving earth stations and characteristics of transmitting space stations in the radionavigation-satellite service (space-to-Earth) operating in the band 5 010-5 030 MHz

ITU -R M.1639-1 - Protection criterion for the aeronautical radionavigation service with respect to aggregate emissions from space stations in the radionavigation-satellite service in the band 1 164-1 215 MHz

ITU -R M.1642-2 - Methodology for assessing the maximum aggregate equivalent power flux-density at an aeronautical radionavigation service station from all radionavigation-satellite service systems operating in the 1 164-1 215 MHz band

ITU -R M.1831 - A coordination methodology for RNSS inter-system interference estimation

ITU -R M.2030 - Evaluation method for pulsed interference from relevant radio sources other than in the radionavigation-satellite service to the radionavigation-satellite service systems and networks operating in the 1 164-1 215 MHz, 1 215-1 300 MHz and 1 559-1 610 MHz frequency bands



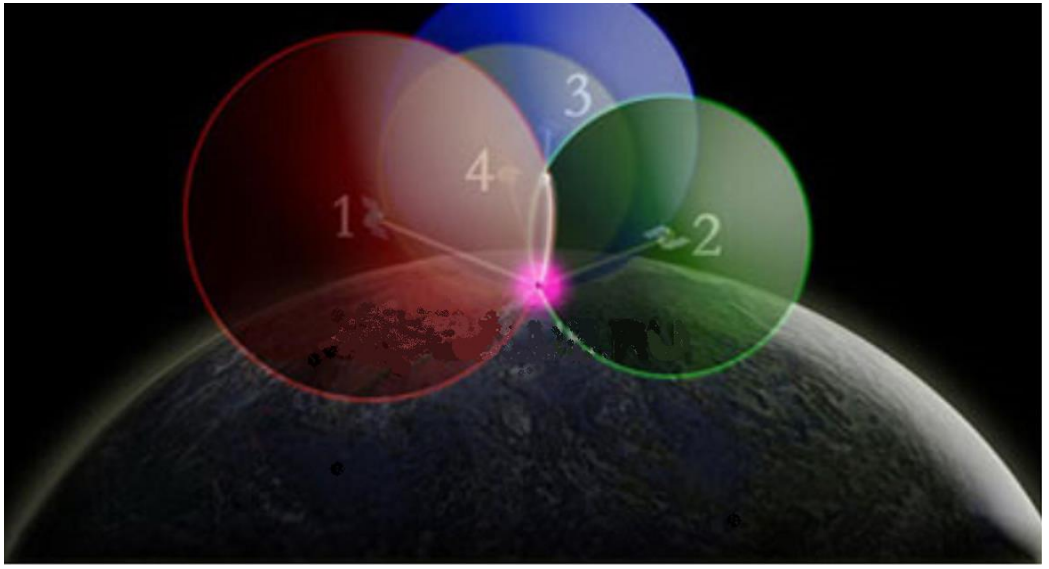
Operation principles of global navigation satellite systems

Input data:

- Satellite coordinates (determined based on ephemerid data);
- Distance from satellite to the Earth,
- Reference time.

Output data:

- Signal propagation time,
- Distance from the user to minimum 4 satellites,
- User location.



GNSS typical structure

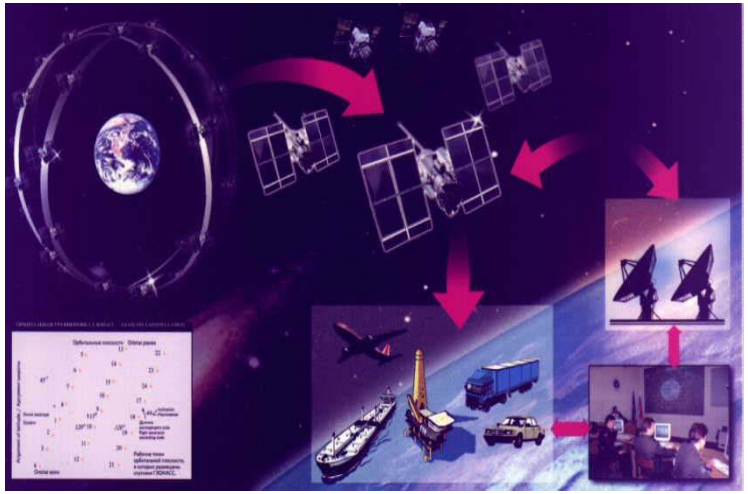
Global navigation satellite system

Space complex

- Orbital constellation
- Space-rocket complex
- Ground-based control and management segment

System of a posteriori high-precision determination of ephemerides and time corrections

Equipment of navigation and time users



Techniques

- Techniques for defining and predicting of the Earth rotation
- Techniques for setting time scale
- Techniques for specification of astronomical and geodetic parameters

Supplements

- Wide-area Differential Correction and Monitoring system
- Regional differential systems
- Local differential systems

Operating global and regional navigation satellite systems and their augmentation systems

Global navigation satellite systems (GNSS)

➢ GLONASS (Russian Federation)	24+ sat. (GNSS)
➢ GPS (USA)	30-36 sat. (GNSS)
➢ GALILEO (EU)	26 sat. (GNSS)
➢ COMPASS-M (China)	27 sat. (GNSS)

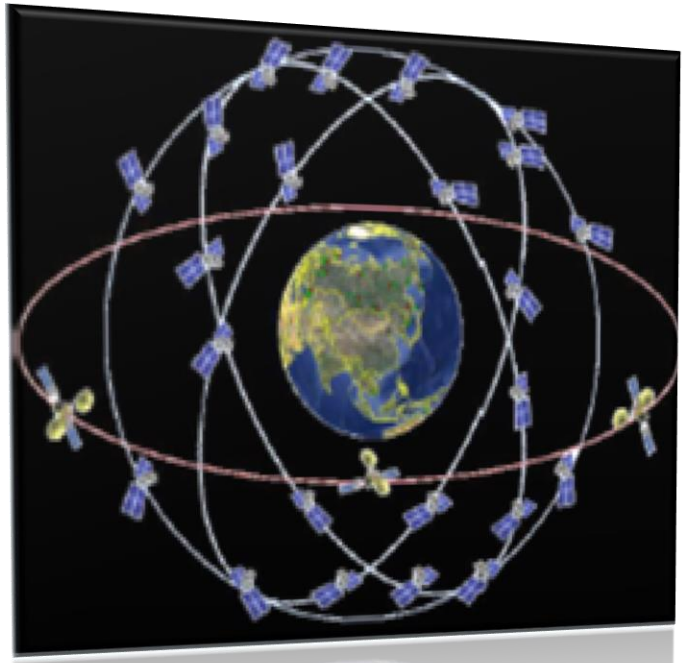
Regional navigation satellite systems (GNSS)

➢ IRNSS (India)	7 sat. (GNSS)
➢ QZSS (Japan)	3 sat. (GNSS)
➢ COMPASS-I, G (China)	10 sat. (GNSS)

Augmentation systems

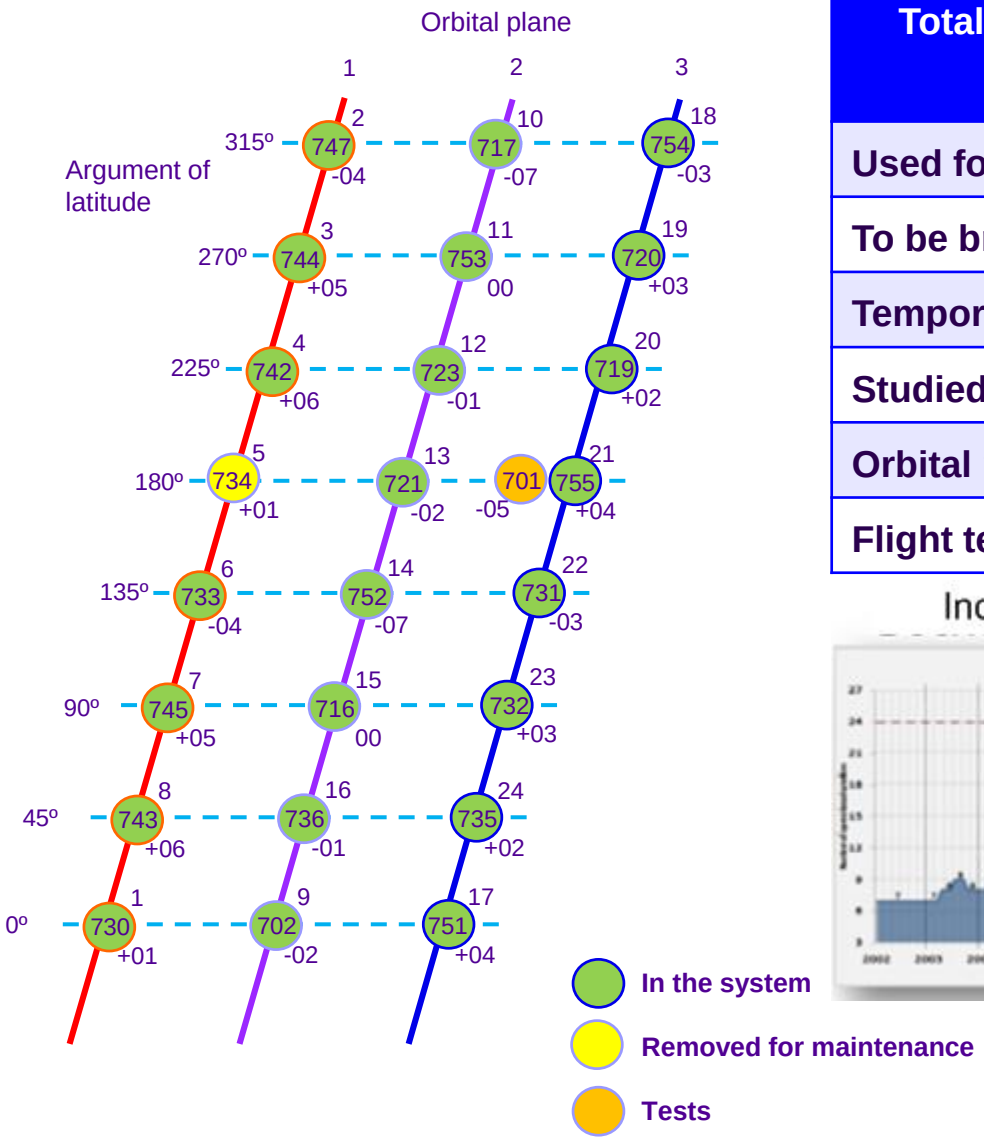
- ➢ SDCM (Russian Federation)
- ➢ WAAS (USA)
- ➢ EGNOS (EU)
- ➢ MSAS (Japan)
- ➢ GAGAN (India)

GLONASS system (1/3)
Basic characteristics



Basic characteristics	
Number of satellites	24 and more
Number of planes	3
Number of satellites in a plane	8
Orbit altitude	19100 km
Inclination	64 deg.
Rotation period	11 h 15 min
Operational frequency bands	L1, L2, L3

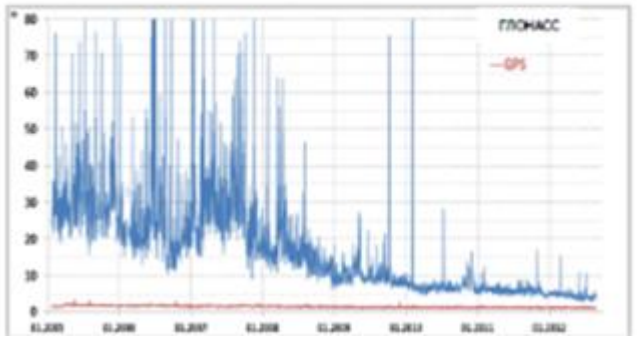
GLONASS system (2/3)
Current status



Total number of satellites in GLONASS orbital constellation on 04.05.2018	25 sat.
Used for missions	23 sat.
To be brought into use	-
Temporarily removed for maintenance	1 sat.
Studied by the Chief designer	-
Orbital reserve	-
Flight tests	1 sat.

Increase of GLONASS OC

Increase of GLONASS accuracy



GLONASS system (3/3)
System development *

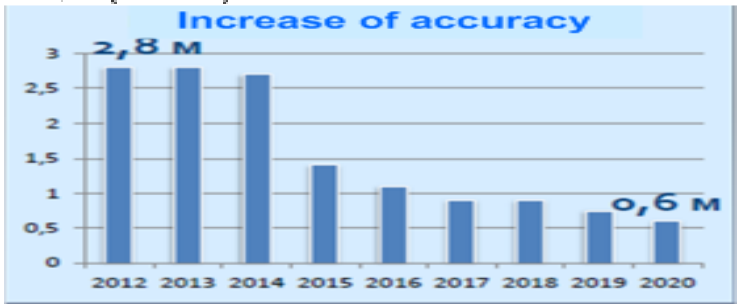
1982 — 2009 — 2011 — 2017...

Glonass

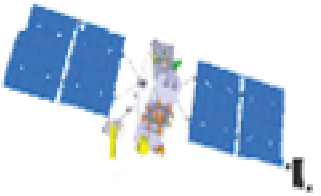
- 3 year guaranteed design life
- Instability of onboard control system 5×10^{-13}
- Signals L1SF,L2SF, L1OF (FDMA)

Glonass-M

- 7 year guaranteed design life
- Instability of onboard control system 1×10^{-13}
- Signals "Glonass"+ L2OF (FDMA)

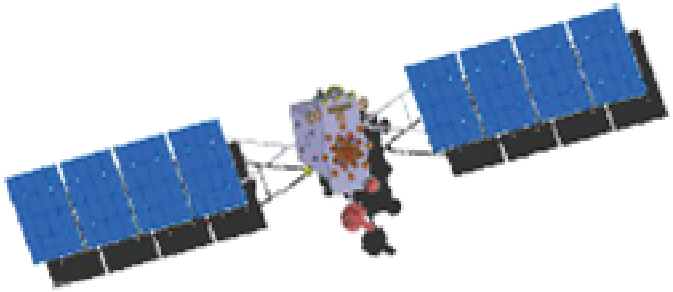


Glonass-K



- 10 year guaranteed design life
- Leaky body
- Expected Instability of onboard control system ~10...5×10^{-14}
- Signals "Glonass-M"+ L3OC (CDMA)-test
- Search and rescue signals

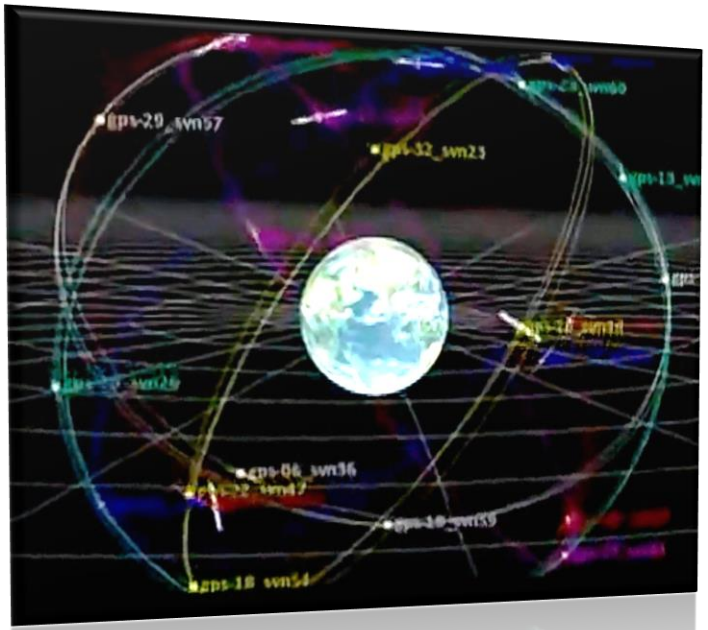
Glonass-K 2

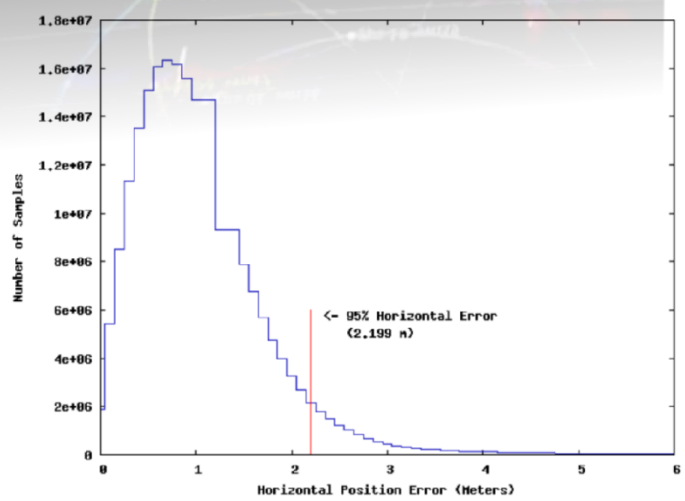


- 10 year guaranteed design life
- Leaky body
- Expected Instability of onboard control system ~5...1×10^{-14}
- Signals "Glonass-M"+ L1OC, L3OC,L2SC (CDMA)
- Search and rescue signals

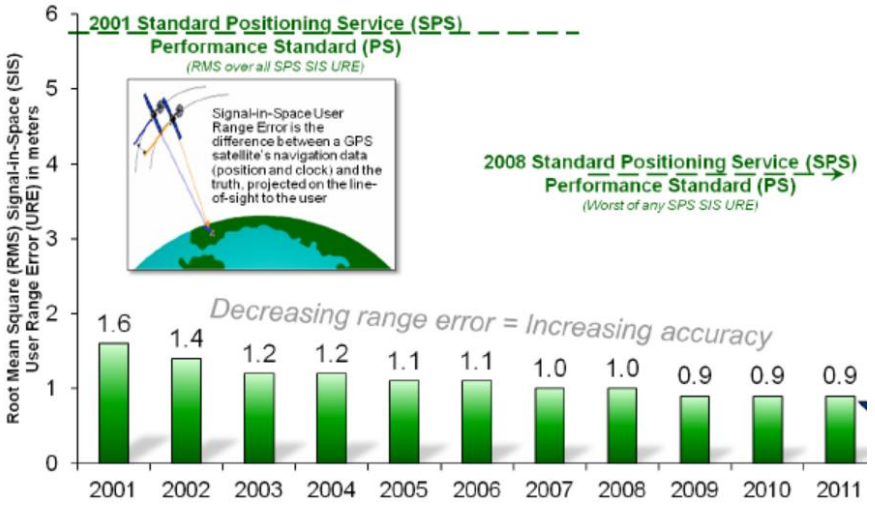
*) According to "XII International navigation forum ", 24-25 April 2018, Moscow (Russian Federation)

GPS system (1/3)
Basic characteristics

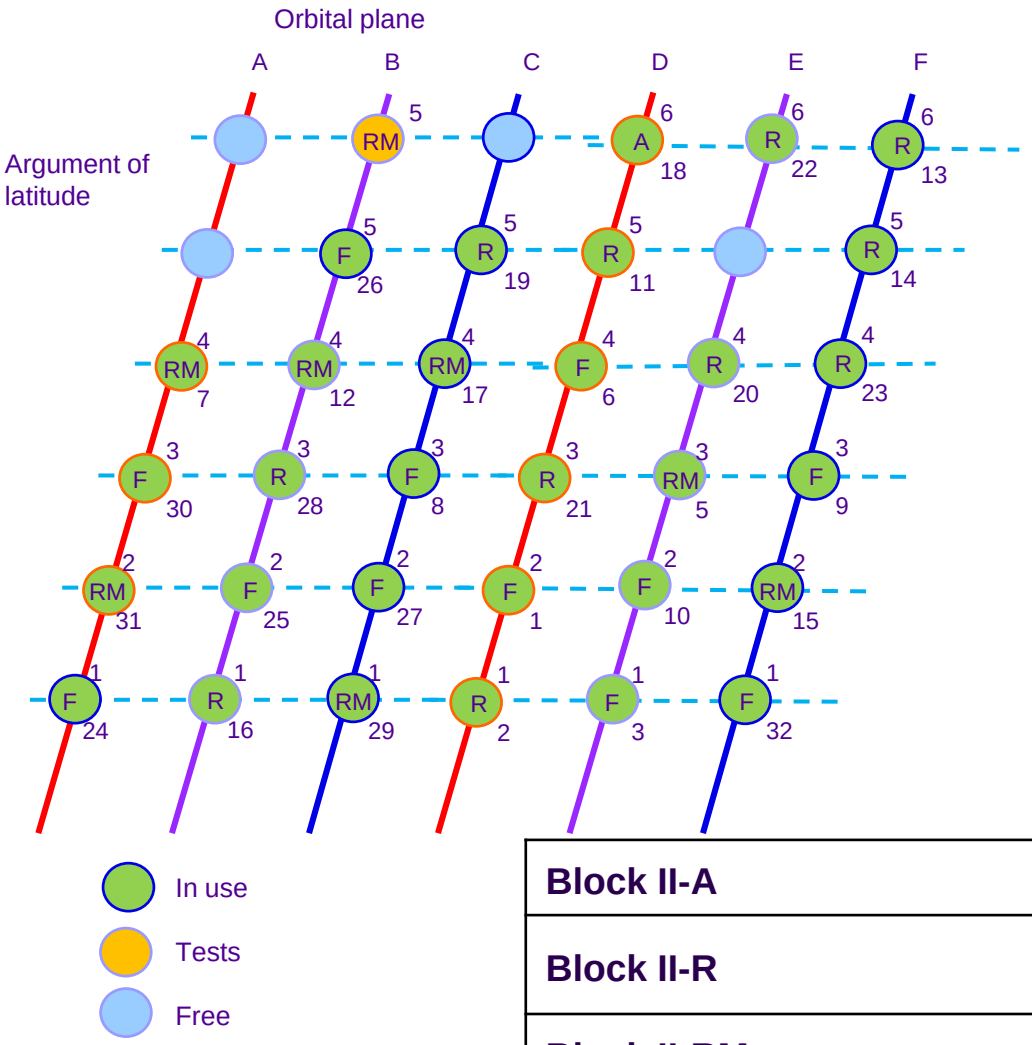




Basic characteristics	
Number of satellites	30 - 36
Number of planes	6
Number of satellites per plane	5…6
Orbit altitude	20181.6 km
Inclination	55 deg.
Rotation period	11 h 58 min
Operational frequency bands	L1, L2, L5

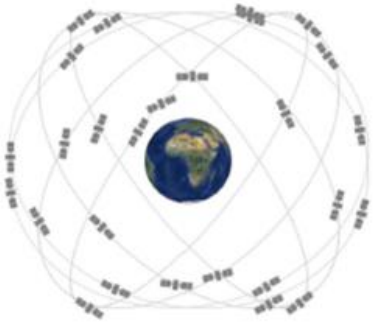


GPS system (2/3)
Current status

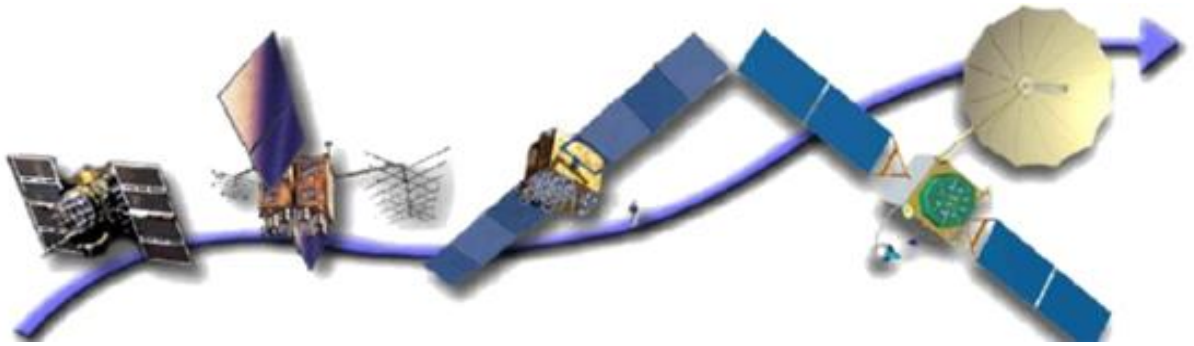


Total number of satellites in GPS OC on 14.05.2018	32 sat.
Used for missions	31 sat.
To be brought into use	-
Temporarily removed for maintenance	1 sat.
To be removed from the system	-
Orbital reserve	-
Flight tests	-

Block II-A	1 sat.
Block II-R	11 sat.
Block II-RM	8 sat.
Block II-F	12 sat.



GPS system (3/3)
System development*



Block IIA/IIR

Basic GPS
- Standard accuracy
  - Signal frequency (L1)
  - (C/A - Code)
- High accuracy
- - Y-Code (L1Y & L2Y)
  - navigation Y-Code

Block IIR-M, IIF

IIR-M: Basic GPS capabilities plus
- **Second civilian signal (L2C)**
- **M-Code (L1M & L2M)**

IIF: IIR-M capabilities plus
- **Third civil signal (L5)**
- 2 rubidium + 1 cesium (clock)
- 12 year design life

Block III

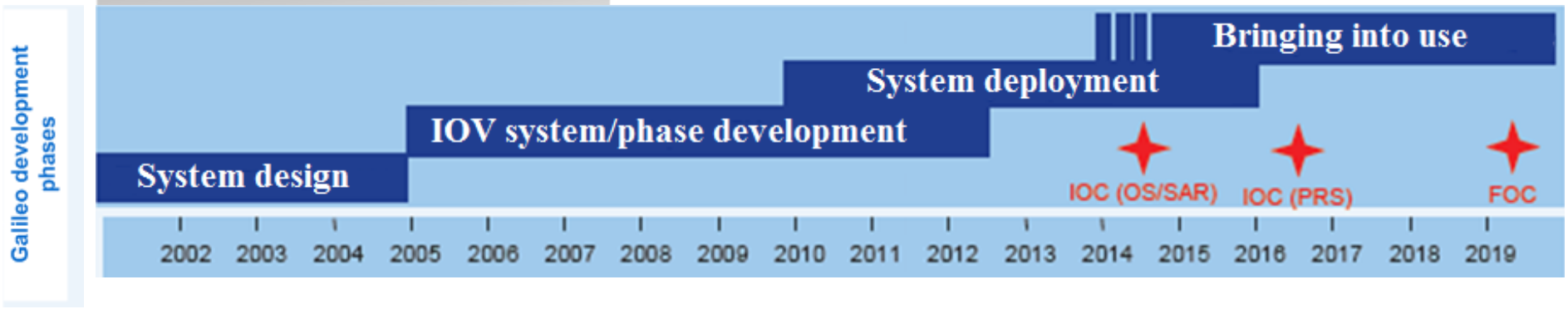
- Backward compatibility
- **Fourth civil signal (L1C)**
- 4x improvement of range error in comparison with IIF
- Increased availability
- Increased integrity
- 15 year design life

Signal	Advantages	Available	Will be available on 24 satellites
L2C	Meet the commercial requirements for ionospheric correction, increased effective power, etc.	On 10 sat.	~2018
L5	Meet the safety requirements; 3-frequency positioning technique	On 3 sat.	~2021
L1C	GNSS interoperability ; Increased quality in difficult conditions	The first satellite in 2015	~2026

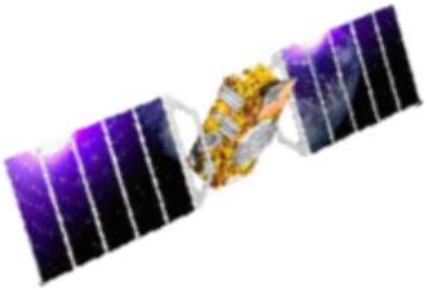
*) According to 12 meeting of International Committee on Global Navigation Satellite Systems, December 2017, Kyoto (Japan)

GALILEO system (1/2)
Basic characteristics

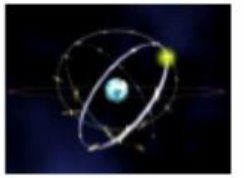
Basic characteristics	
Number of satellites	30
Number of planes	3
Number of satellites per plane	10
Orbit altitude	23222 km
Inclination	56 deg.
Rotation period	14 h 4 min
Operational frequency bands	L1, E5, E6



GALILEO system(2/2)
System development*

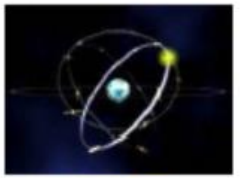


Full Operational Capability
24+2 operational satellites and complete ground infrastructure



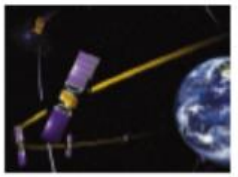
2020

Initial operational capability
15 operational satellites and operational ground infrastructure



2015

In-orbit testing
4 operational satellites and initial ground infrastructure



2011

Galileo system Testbed v2
GIOVE-A and -B Satellites and ground operations

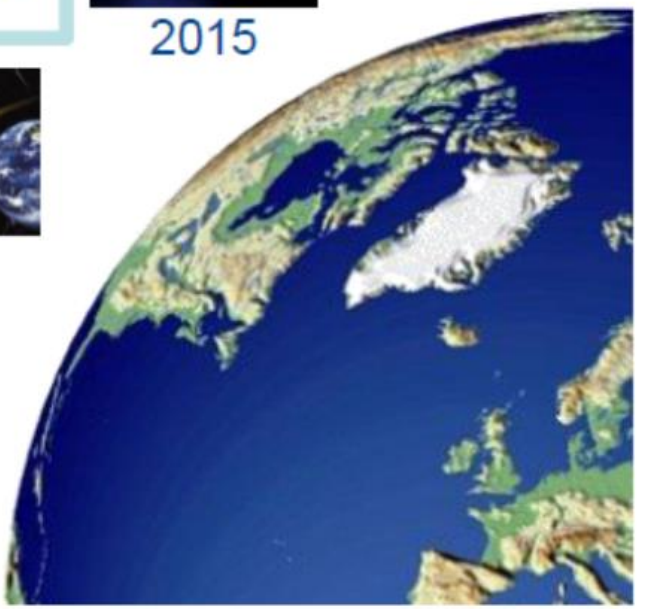
GALILEO GIOVE

2005

System TB v1
Algorithms validation

GALILEO GSTB-V1

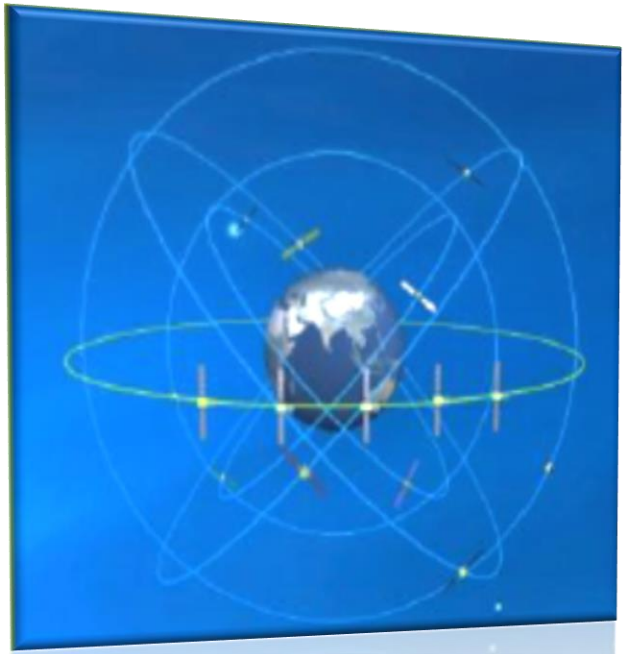
2002

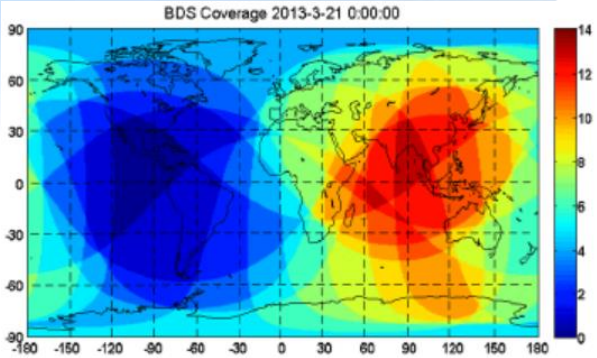


GALILEO EGNOS

*) According to 12 meeting of International Committee on Global Navigation Satellite Systems, December 2017, Kyoto (Japan)

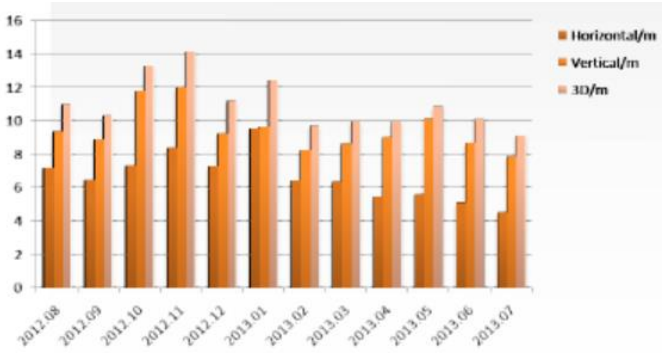
BeiDou system(1/2)
Basic characteristics





BeiDou System Coverage

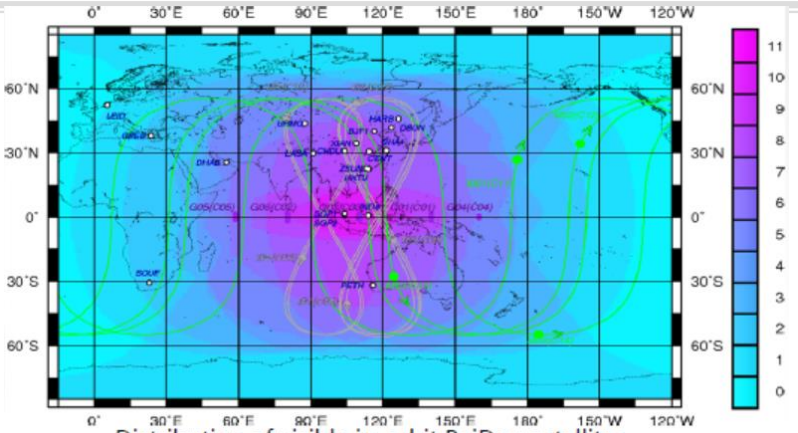
Basic characteristics	
Number of satellites	27 MEO + 5 GSO, 3 IGSO
Number of planes	3
Number of satellites per plane	9
Orbit altitude	21528 km
Inclination	55 deg.
Rotation period	12 h 53 min
Operational frequency bands	B1, B2, B3



Positioning accuracy (95%)

BeiDou system (2/2)
System development*

Total number of satellites in BeiDou OC	28 sat.
Geo-stationary orbit	6 sat.
Geosynchronous inclined orbit (i=55 deg.)	8 sat.
MEO	14 sat.

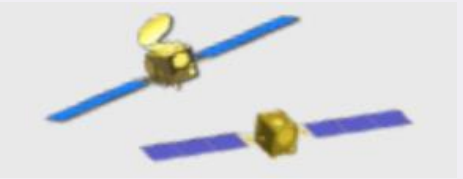


Distribution of visible in-orbit BeiDou satellites

Plans for 2020

Space segment

- 3 satellites on GSO
- 27 satellites on non-GSO (3 satellites on IGSO and 24 satellites on MEO)
- Global coverage



Ground control segment

- Operation and Control Center
- Data Centers
- Uplink Stations
- Monitoring stations

User segment

- Creation and introduction of BeiDou user terminals
- Compatibility of BeiDou terminals with GNSS systems

*) According to “XII International navigation forum ", 24-25 April 2018, Moscow (Russian Federation)

Interconnection of navigation satellite systems with users of navigation services

Users

User requirements

System requirements

GNSS systems development

New technologies, services

New possibilities

Global navigation satellite systems

- GLONASS (Russian Federation)
- GPS (USA)
- Galileo (EU)
- Compass (M) (PRC)

Regional navigation satellite systems

- IRNSS (India)
- QZSS (Japan)
- Compass(G) (PRC)
- Compass (I) (PRC)

Augmentation systems

SDCM (RF) WAAS (USA) EGNOS (EU) MSAS (Japan) GAGAN (India)

Application of the global navigation satellite systems (1/16)













- Transport
- Communication and broadcasting systems
- Agriculture
- Building
- Land management and cadaster
- Mapping and geodesy
- Geological exploration and mining operations
- Scientific researches, astronautics
- Logistics и commerce
- Search and rescue operations
- Power engineering
- Forestry
- Fishing
- Health care and other.

GNSS Applications (2/16)
Satellite navigation systems in aviation

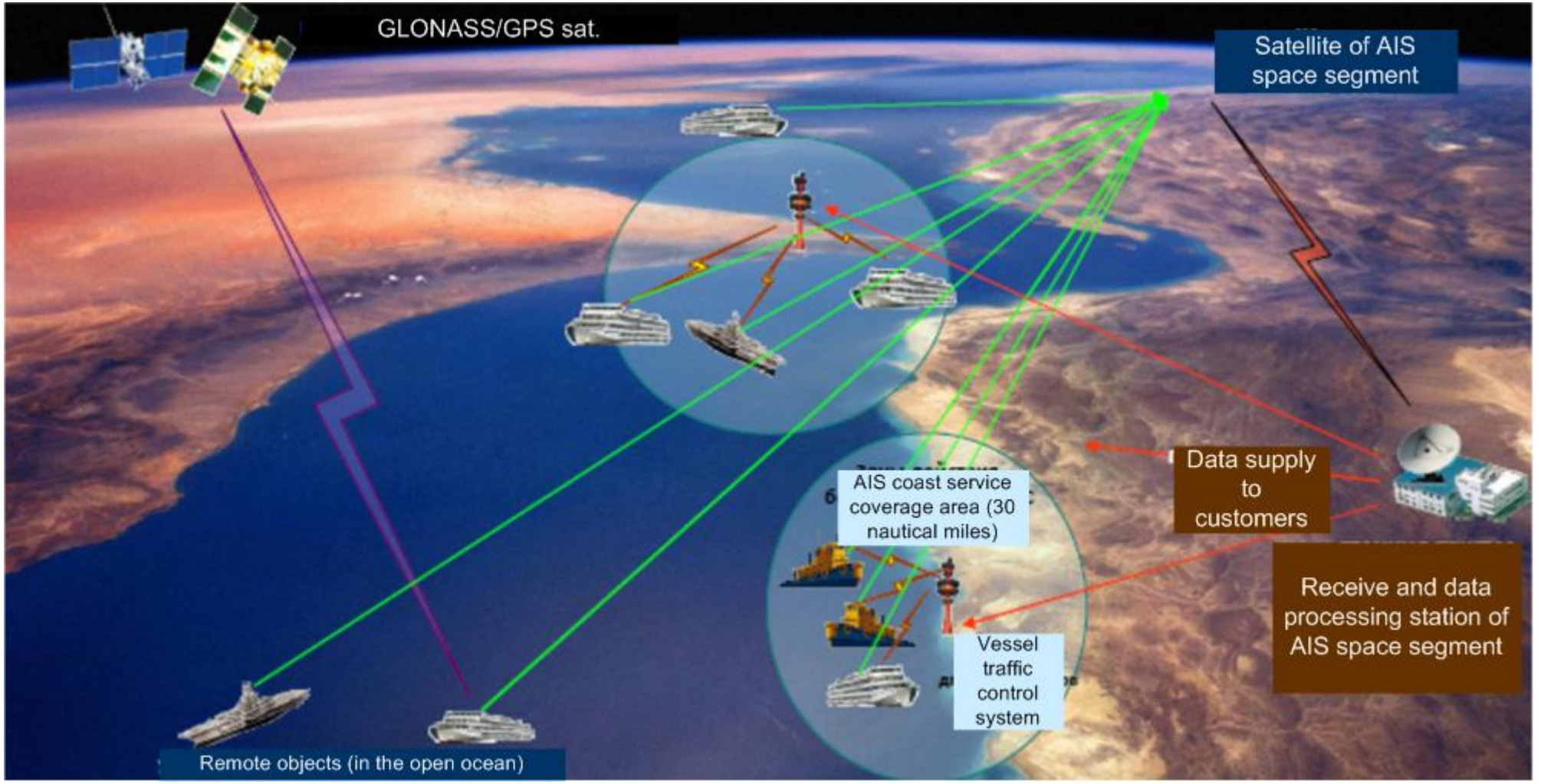
- Aeronautical navigation systems:
  - en-route;
  - approach;
  - landing.
- Automatic Dependent Surveillance and collision avoidance systems

- Air traffic control systems
- Search and rescue systems
- Airport equipment monitoring and control systems

GNSS Applications (3/16)
Satellite navigation systems in maritime/river transport

- Onboard electron mapping, navigation systems and equipment
- Vessel traffic control system on coast
- High-accuracy navigation systems in ports and channels
- Safety systems, search and rescue systems

GNSS Applications (4/16)
Satellite navigation systems in search and rescue systems



Integration of the existing AIS systems with the global navigation satellite systems

GNSS Applications (5/16)
Satellite navigation systems in vehicles

Navigation services for cars

Emergency services: The Ministry of Emergency situations, the Ministry of Internal Affairs, ambulance

Toll road system

Monitoring systems

Public transport

Commercial vehicles

Special vehicles: public housing, forestry, hazardous cargo, highway engineering

Intelligent transport systems of cities and highways

GNSS Applications (6/16)
Satellite navigation systems in emergency communication systems in vehicles

Examples of state projects of GNSS application in vehicles			
NG 9-1-1 USA		Mobile phone coordinates and other devices including vehicle navigation communication terminals are automatically determined by GPS and transmitted to controller 911 by manual or automated **dial 911**	since 2011
SAMVAR **Brasil**		Cars are equipped with navigation communication terminals GPS which automatically transfer the information related to car theft and with additional equipment for engine block system for search operations and traffic monitoring.	since 2012
ERA-GLONASS Russia		New cars are equipped with navigation communication terminals ERA-GLONASS which automatically transfer their coordinates in case of car incident to **emergency operators (system 112).**	since 2013
eCall EU		Cars are equipped with navigation communication terminals GALILEO/GPS which automatically transfer their coordinates in case of incident to emergency operators.	since 2014
EDR USA		New cars are equipped with “black box” EDR (Event Data Recorder) which records the information related to car accident, engine operation parameters and other car elements.	since 2015

GNSS Applications (7/16)
Satellite navigation systems in vehicle monitoring systems


Public transport control system


School bus tracking and control system


Public utilities vehicles control system


Mobile units control system


Ambulance units control system


Dangerous goods transfer safety system

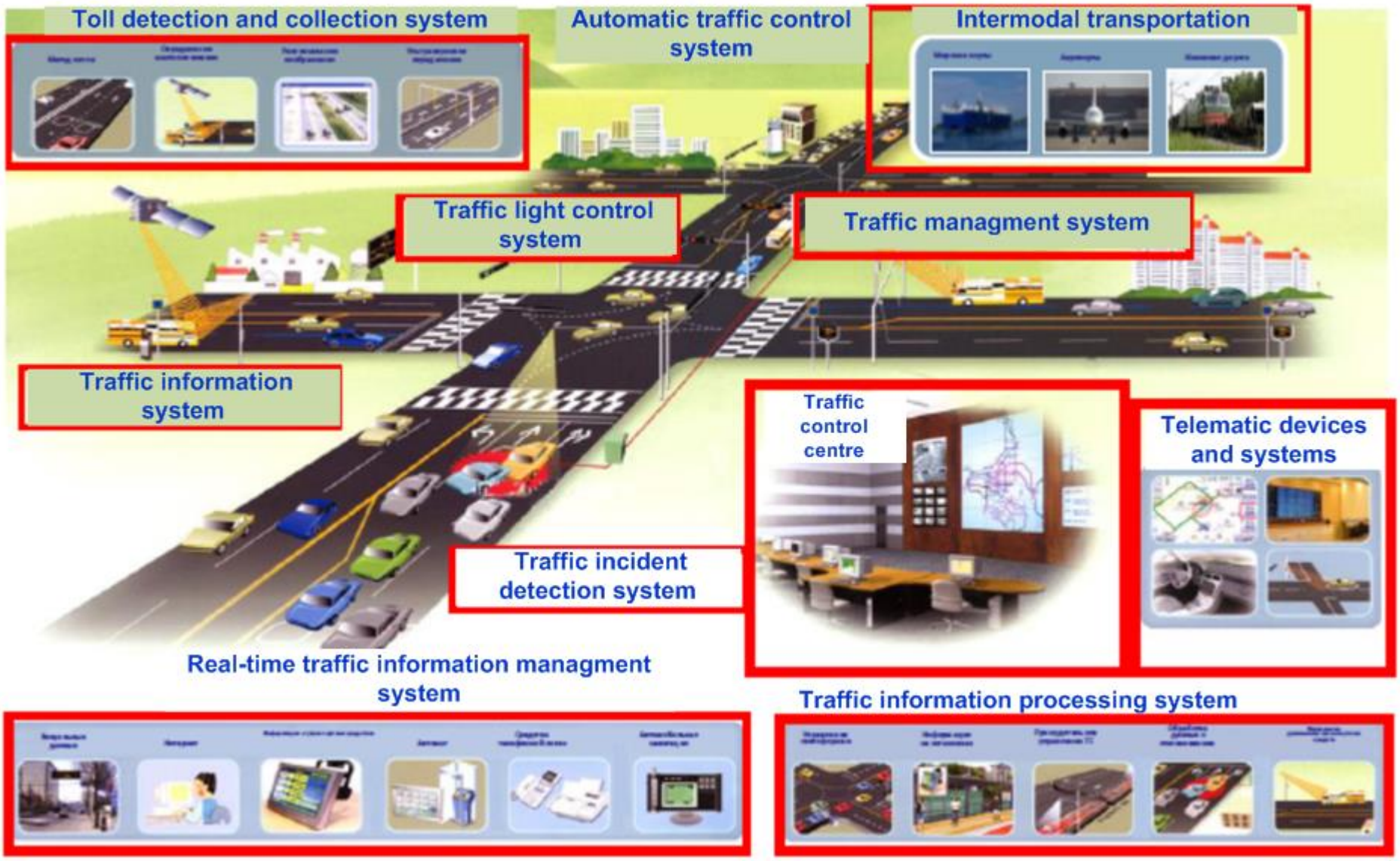

Agricultural vehicles monitoring system


Logging and timber transporation monitoring system

- **Reduced cost for goods transportation by 17-20%**
- **Reduced fuel consumption by 12-30%.**

*) according to the "Conference of Operators and Users of the Satellite Communications and Broadcasting Network of the Russian Federation"

GNSS Applications (8/16)
Intelligent Transport systems



GNSS Applications (9/16)
Satellite navigation systems in mining industry*

- Increase of transportation >12%
- Reduction of fuel consumption by 8%
- Reduction of demurrage by 50%

*) according to the "Conference of Operators and Users of the Satellite Communications and Broadcasting Network of the Russian Federation"

GNSS Applications (10/16)
Satellite navigation systems in agriculture*

Agriculture with GNSS in:

- Increase of revenue by **10%** annually
- Reduction of costs on oil and fuel by **52%**
- Reduction of costs on labor force by **67%**

*) according to the "Conference of Operators and Users of the Satellite Communications and Broadcasting Network of the Russian Federation"

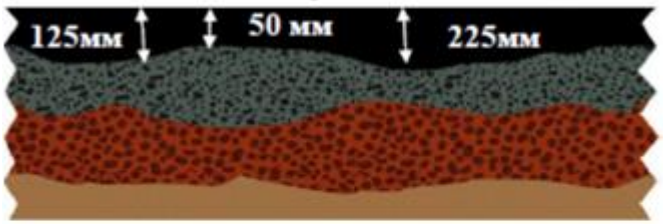
GNSS Applications (11/16)
Satellite navigation systems in
Land management and cadaster, mapping and geodesy

- ✓ **Reduction of land measuring operations period 2-3 times**
- ✓ **Reduction of costs for cadastral operations 2 times**

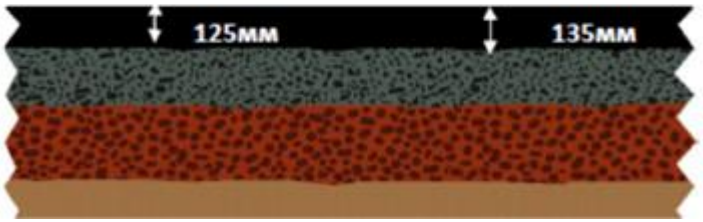
*) according to the "Conference of Operators and Users of the Satellite Communications and Broadcasting Network of the Russian Federation"

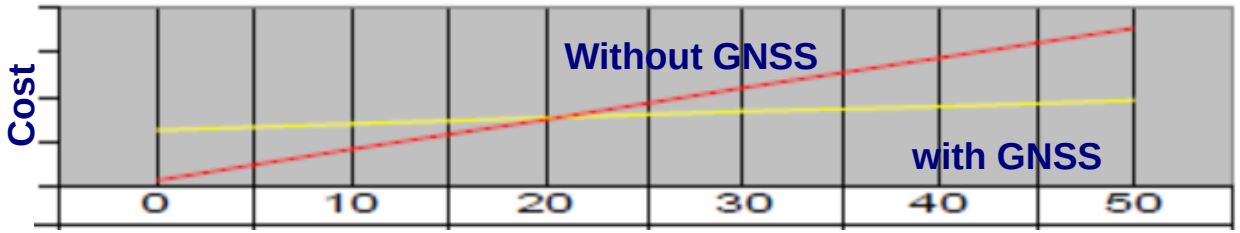
GNSS Applications (12/16)
Engineering operations and road construction

Using standard motor grader
usual planning accuracy ±50 mm



Using navigation techniques
planning accuracy ±5 mm





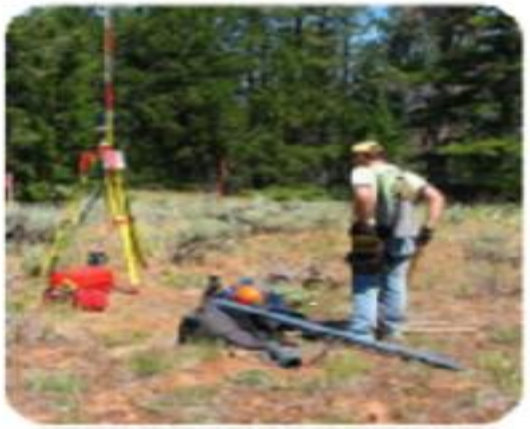
Dependence of costs on the length of the constructed route

*) according to the "Conference of Operators and Users of the Satellite Communications and Broadcasting Network of the Russian Federation"

GNSS Applications (13/16)
Forest conservation and forestry

Detection of weak, medium and serious danger to forest areas

Forest fire monitoring and control

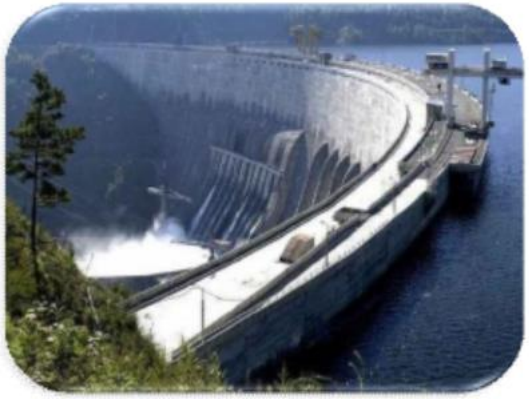


Forest law violation monitoring

GNSS Applications (14/16)
Building and construction monitoring systems

Purpose : continuous control of displacements and vibrations of bridge elements, dams, towers and other constructions in order to:

- early diagnostics of construction integrity;
- Prompt revealing of construction stability loss

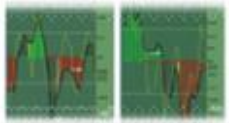


Under control:

- Spectrum characteristics of vibrations in the range from 0.1-10 Hz with 1 mm error;
- Displacement on each space axis with 3-5 mm error

GNSS Applications (15/16)
Seismic activity and landslide control

- Remote monitoring of seismic activity and landslide process
- Prompt transmission of the data related to seismic area state and slopes to control center
- Analysis and processing of the received data
- Prompt warning in case of dangerous seismic activity or landslides

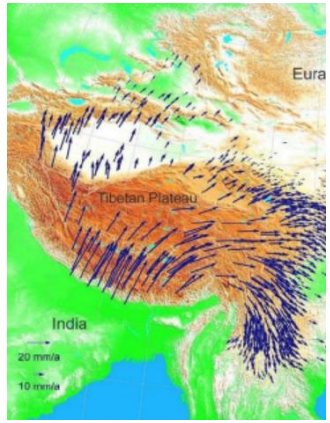


Detailed schedule of displacement: measured and averaged values

Operator management center

Displacement vectors on satellite photo

Messages on exceeding the permissible displacement threshold



GNSS Applications (16/16)
Timing system

- Synchronization of communication and broadcasting networks
- Pointing and tracking of satellite antennas and radioastronomical stations;
- Power system
- Telecommunication systems and other.

International cooperation in GNSS

International Committee on GNSS (ICG) – international forum to solve compatibility issues, interoperability and and global usage of GNSS systems

Committee members: more than 20 countries and international organizations

ICG International Committee on Global Navigation Satellite Systems

Committee meetings:

1-st meeting: 2006, Vienna (Austria)
2-nd meeting: 2007, Bangalore (India)
3-d meeting: 2008, Pasadena (USA)
4-th meeting: 2009, Saint-Petersburg (Russia)
5-th meeting: 2010, Turin (Italy)
6-th meeting: 2011, Tokyo (Japan)
7-th meeting: 2012, Beijing (China)
8-th meeting: 2013, Dubai (UAE)
9-th meeting: 2014, Prague (Czech Republic)
10-th meeting: 2015, Colorado **(USA)**
11-th meeting: 2016, Sochi **(Russia)**
12-th meeting: 2017, Kyoto (Japan)
13-th meeting is planned to held in 2018 in Xian (China)

Any questions?

Thanks for attention!

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