United Nations / Austria / European Space Agency

*"Space Tools and Solutions for Monitoring the Atmosphere and Land Cover"*

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# "Concept of space system for global radio occultation monitoring of lower atmosphere and ionosphere based on super-small satellites with GLONASS/GPS navigation signal receivers"

# Authors of the concept

**FSUE "RISDE" (Russian Institute of Space Device Engineering):**

- Head organization for development of Russian satellite navigation system GLONASS
- Developer of the newest miniaturized onboard two-system (GPS/GLONASS) navigation receivers.
- Integrator of system "Radiomet"

**The Institute of radio engineering and electronics of the Russian academy of sciences (IRE RAS):**

- develops new radio holographic methods for studying circumterraneous space by means of a radio emission of satellites.
- participates in data processing of missions GPS/MET, CHAMP and other systems of radio holographic sounding of an atmosphere

# FSUE "RISDE"
## Key directions of space activity

- **SATELLITE NAVIGATION**
  Head organization for GLONASS design, development and usage

- **RESCUE SPACE SYSTEM**
  Head organization for development of the national segment of the COSPAS-SARSAT International search & rescue system

- **GROUND COMPLEX OF SATELLITE CONTROL**
  Head organization for the State integrated ground-based automated spacecraft control complex

- **SATELLITE COMMUNICATIONS AND DATA TRANSMISSION**
  Head organization for onboard relay complexes

- **MISSILE AND SATELLITE TELEMETRY**

# FSUE “RISDE”
# Key directions of space activity

•MONITORING OF HAZARDOUS OBJECTS AND CARGOES
Leading organization for Federal monitoring systems of critically important objects and hazardous cargoes

•RADIOENGINEERING PROVISION FOR SCIENTIFIC SPACE PROGRAMS
Medium and deep space exploration missions

•OPTOELECTRONIC SYSTEMS
Medium resolution optical scanners for meteorological satellites

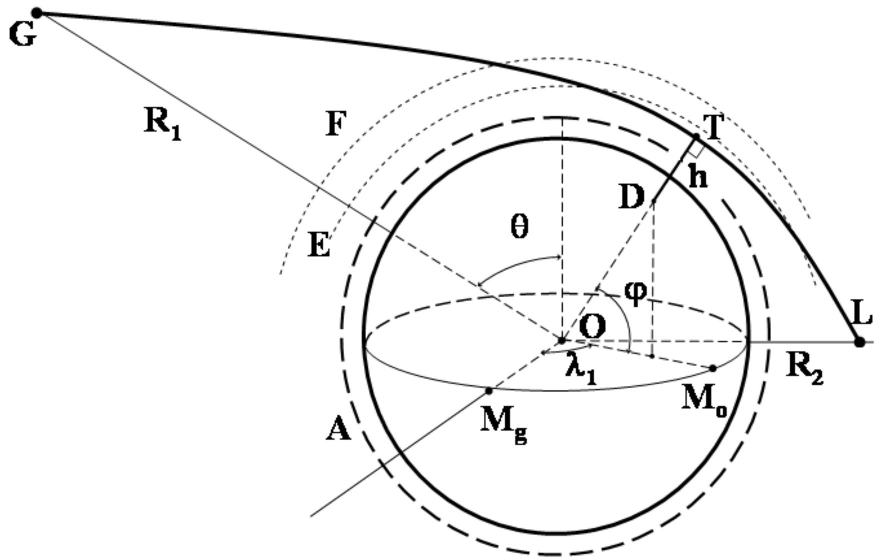
•EARTH REMOTE SENSING (ERS)
ERS information acquisition, processing and dissemination

•USER EQUIPMENT
Development of user equipment for the GLONASS/GPS, COSPAS, KURS and other systems

# Existing global satellite navigation systems

| | GPS | Glonass |
|---|---|---|
| Orbital planes | 24 satellites in 6 planes | 24 satellites in 3 planes |
| Orbit height | 26560 km | 25510 km |
| Inclination | 63° | 64,8° |
| Carrier frequencies | L1: 1575,42 MHz<br>L2: 1227,60 MHz | L1: 1602+0,5625*N L2: 1246+0,4375*N<br>N=1,2,…,24 |
| Codes | C/A and P(Y) | C/A and P |
| Signal access method | Code division multiply access (CDMA) | Frequency division multiply access (FDMA) |

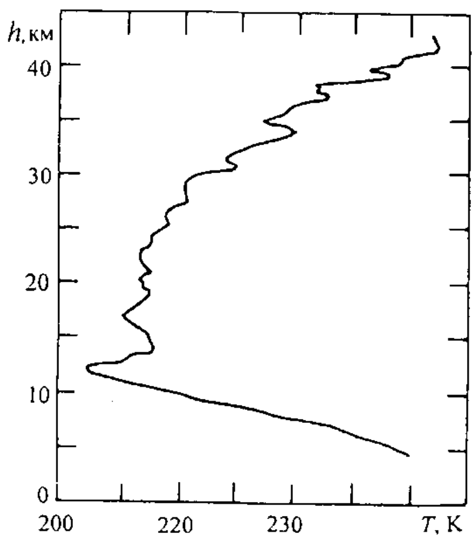
# Principle of radio occultation monitoring of the atmosphere and ionosphere

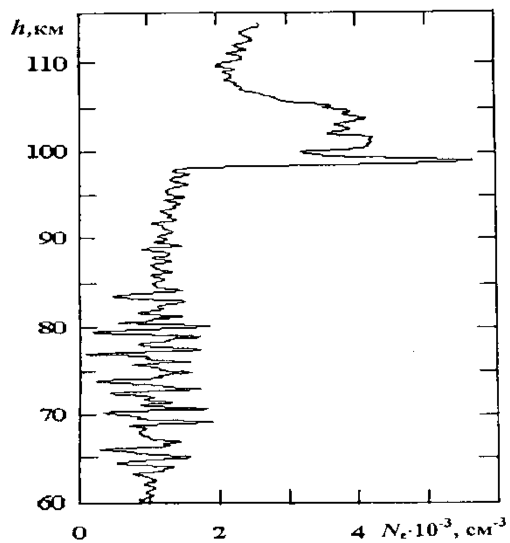


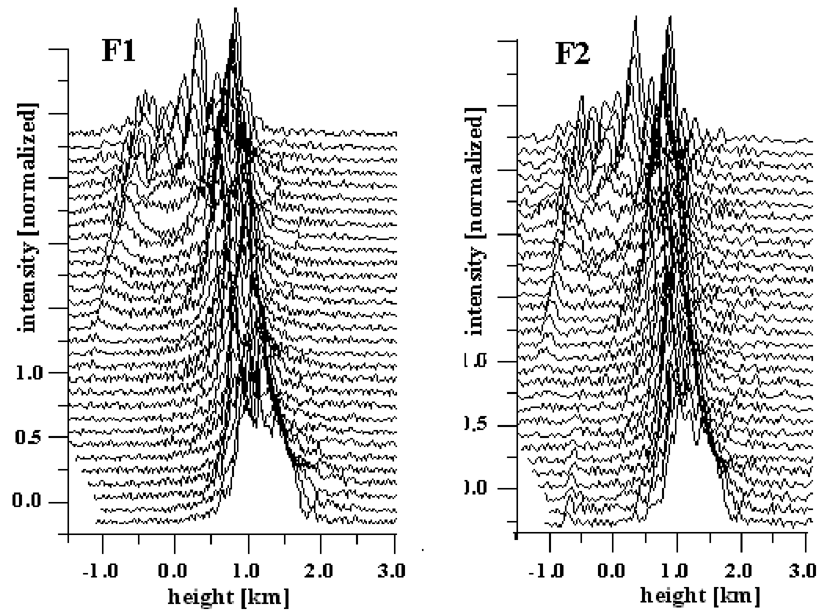

The emitting device (G) is located onboard GPS or GLONASS satellite. Receiver is installed onboard low-orbit satellite L of radio occultation space constellation. The altitude h of the investigated area is determined by geographical location of point T – perigee of radio ray GTL, where the distance TD from the Earth's surface is minimal.

Co-ordinates of the investigated area are determined by latitude $\varphi$ and longitude $\lambda$ of point D on the Earth's surface. Longitude $\lambda$ is measured from Greenwich meridian $M_g$. Designations F, E, A correspond to ionosphere layers F, E and atmosphere A. R1 and R2 – are the orbital radii of GPS satellite G and low-orbit satellite L of radio-occultation monitoring space system.

# Principle of radio occultation monitoring of the atmosphere and ionosphere



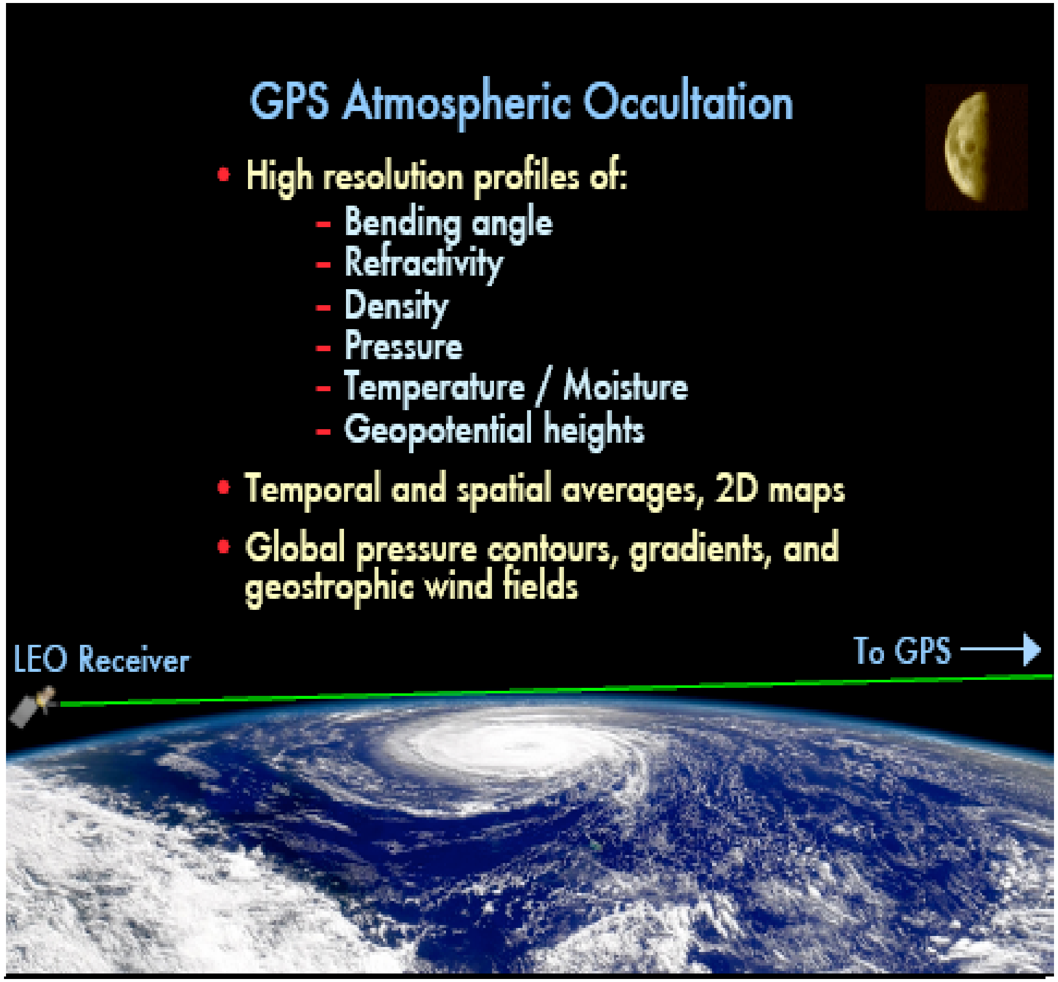

**Radio hologram from navigation satellite G, registered by LEO satellite L, contains information of the physical parameters:**

**- atmosphere - vertical gradients of refractivity, air density, pressure, temperature (*see the left pict.*), geopotential, humidity;**

**- ionosphere - electron density and its vertical gradient (*see pict. in the middle*);**

**- reflections from the Earth's surface (*see 1-D radio image of the atmosphere and surface*, *the right pict.*).**

In addition to traditional meteosatellites, space systems of radio occultation monitoring can provide <u>everyday and in global scale</u> the following objectives:




- monitoring of high-resolution vertical gradients of temperature and geopotential for improving weather forecast and investigation of climate changes;

-monitoring of vertical gradients of humidity in atmosphere for investigation of water circulation global processes and climatology;

- investigation of internal stratosphere waves and their role in energy exchange;

-monitoring of electron density for investigation the influence on ionosphere status from Solar activity, technogenic impact and other factors, etc.

# Scientific space radio occultation satellite missions launched in 1995-2006

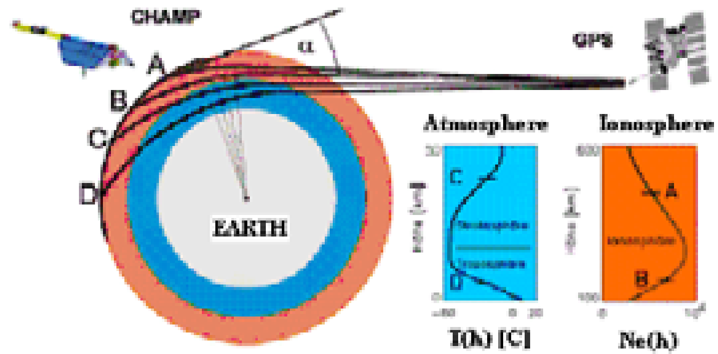
РОСКОСМОС

## GPS-Met, Micro-Lab-1, CHAMP, SAC-C, GRACE, METOP etc.

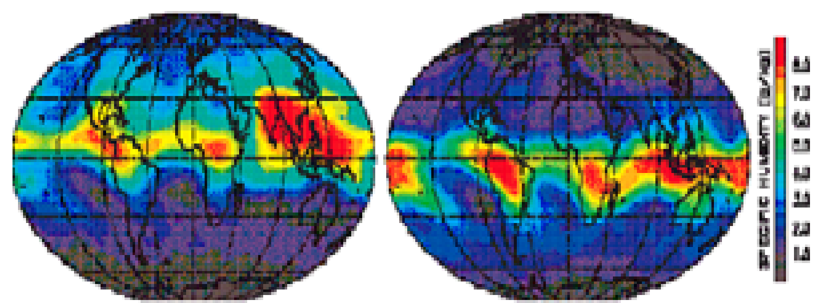
**These satellites (75-250 kg by mass) were equipped with special receivers for analyzing GPS-signals passed through atmospheric and ionosphere layers. The received data were delivered to ground stations and processed for calculating high-precision physical parameters of atmosphere and ionosphere.**

**These missions pursue <u>scientific purposes</u> (without regular monitoring of Earth atmosphere and ionosphere)**

CHAMP mission and first results. Wickert, 2002, PhD Dissertation (modified)

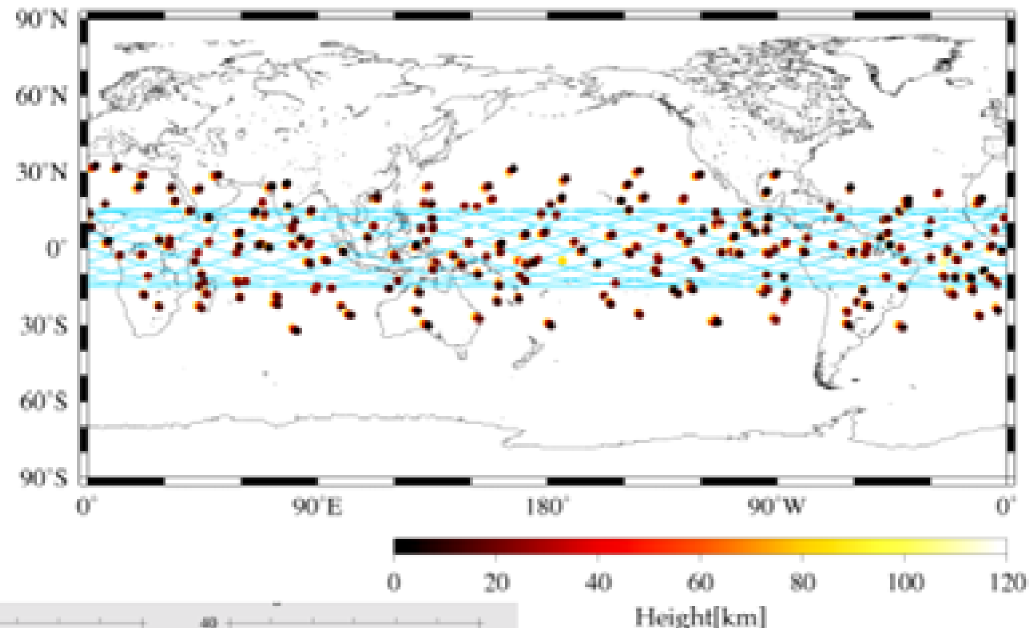



Humidity distribution in the atmosphere (CHAMP data). July 2003 (left), January 2003 (right). From Wickert 2006, FORMOSAT3 Workshop (modified).

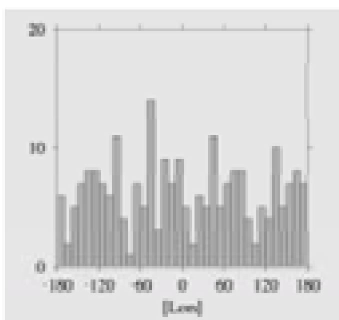


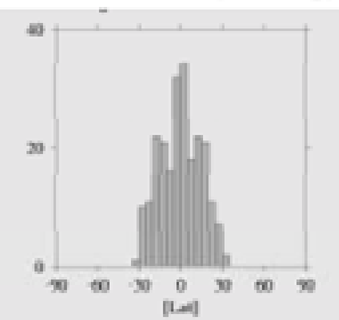
# Radio occultation project EQUARS
(INPE, Brasil)

Distribution of Occultation Events with EQUARS in 24 hours
(Geograph




**RO-satellite with low inclination (less then 20°) increases periodicity of observations for near-equatorial zones**



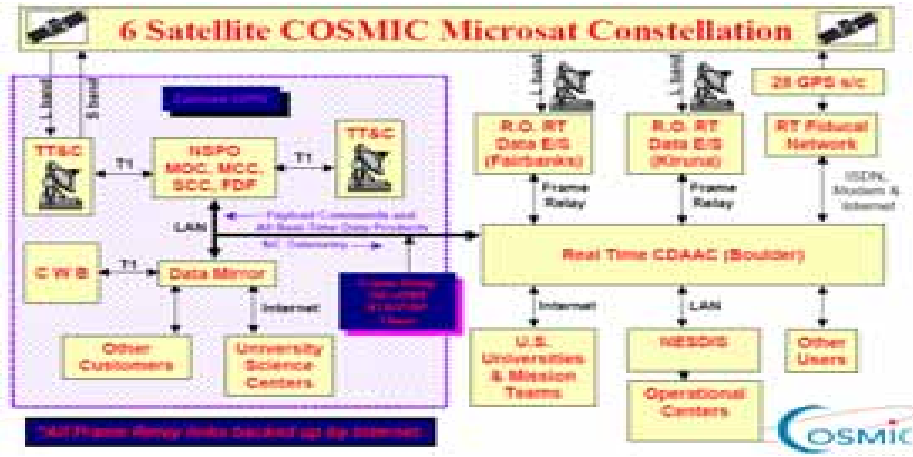

Longitude

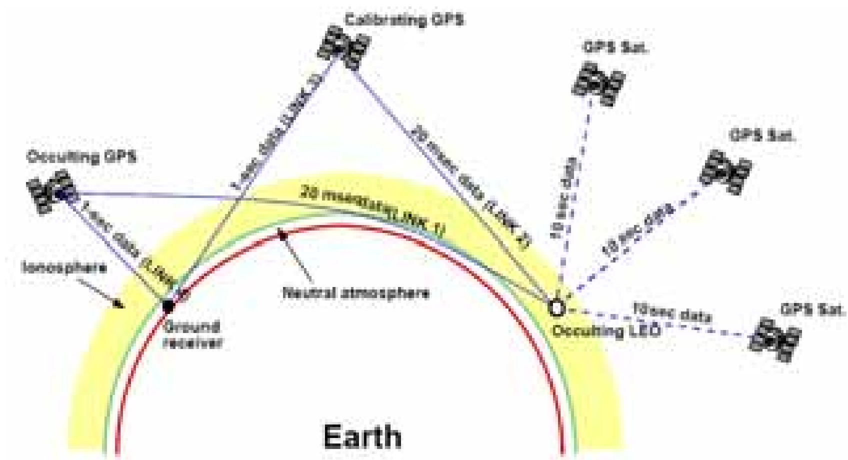
30 0 30
Latitude

| | |
|---|---|
| Orbit altitude: | 700km |
| Inclination : | 15.0 deg |
| Eccentricity : | 0.0 |
| Right ascension: | 0.0 |
| Argument of perigee : | 0.0 |
| Number of occultation : | 228 |
| Range of lat : | -30.261/30.824 |

# Space system "Formosat-3" (COSMIC) for regular radio occultation monitoring of the Earth atmosphere and ionosphere

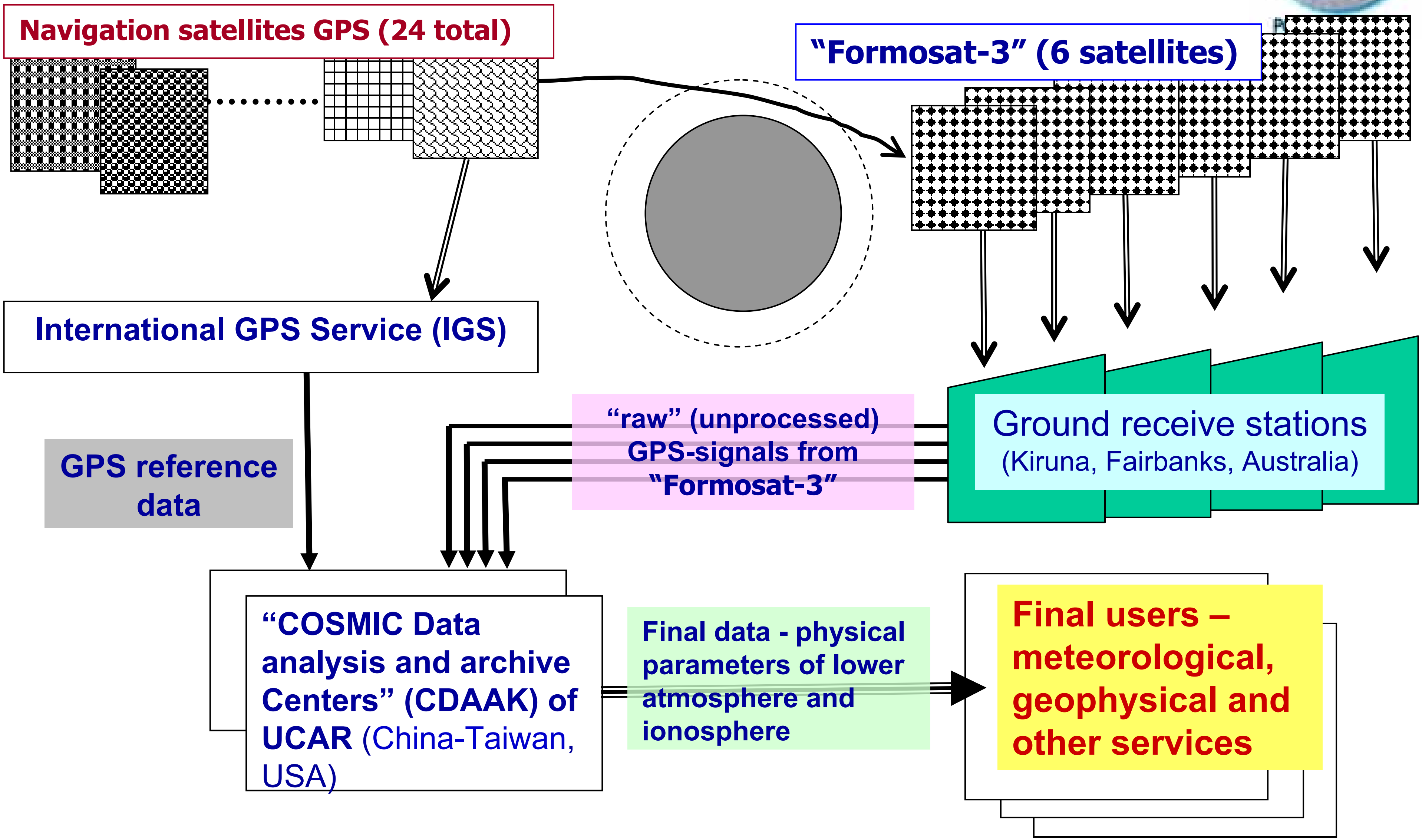
"Formosat-3" structure. C.Rockin, 2000, TAO (modified)




**"Formosat-3"** (NSPO, China-Taiwan)**:**
**6 microsatellites (m=69 kg).**
**Orbits: H=800 km, i=72 °**
**Monitoring of vertical gradients of physical parameters:**
**- in lower atmosphere: range of heights – 1…35 km, resolution - 200 m**
**- in ionosphere: range of heights – 90…400 km, resolution – 800 m**
**Launched April 2006)**

# Radio occultation space system “Formosat-3”



# Coverage of measurements: for meteorological sounders and for space missions (“Formosat-3” + EQUARS)

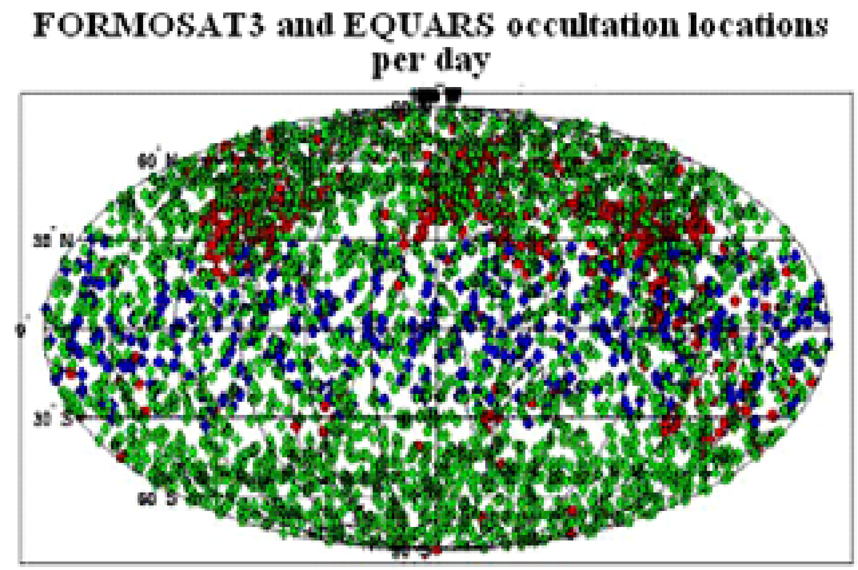



Figure from Tsuda et al., 2006, FORMOSAT3 Workshop (modified)

**Traditional meteorological sounders:** 4 soundings/day/sounder over some areas of the land. Heights: 0…30 km (atmosphere), 250…350 km (ionosphere). No global coverage

**Space-based sounders “Formosat-3” (green) + EQUARS (blue): up to 2500 soundings/day at the heights: 1…35 km (atmosphere), 90…400 km (ionosphere) in global scale – including hardly accessible regions (over oceans and poles of the Earth )**

# Possible restrictions of "Formosat-3" efficiency

**•Number of everyday observations is limited because only GPS-signals are registered by «Formosat-3» satellites (neither Glonass nor Galileo signals)**

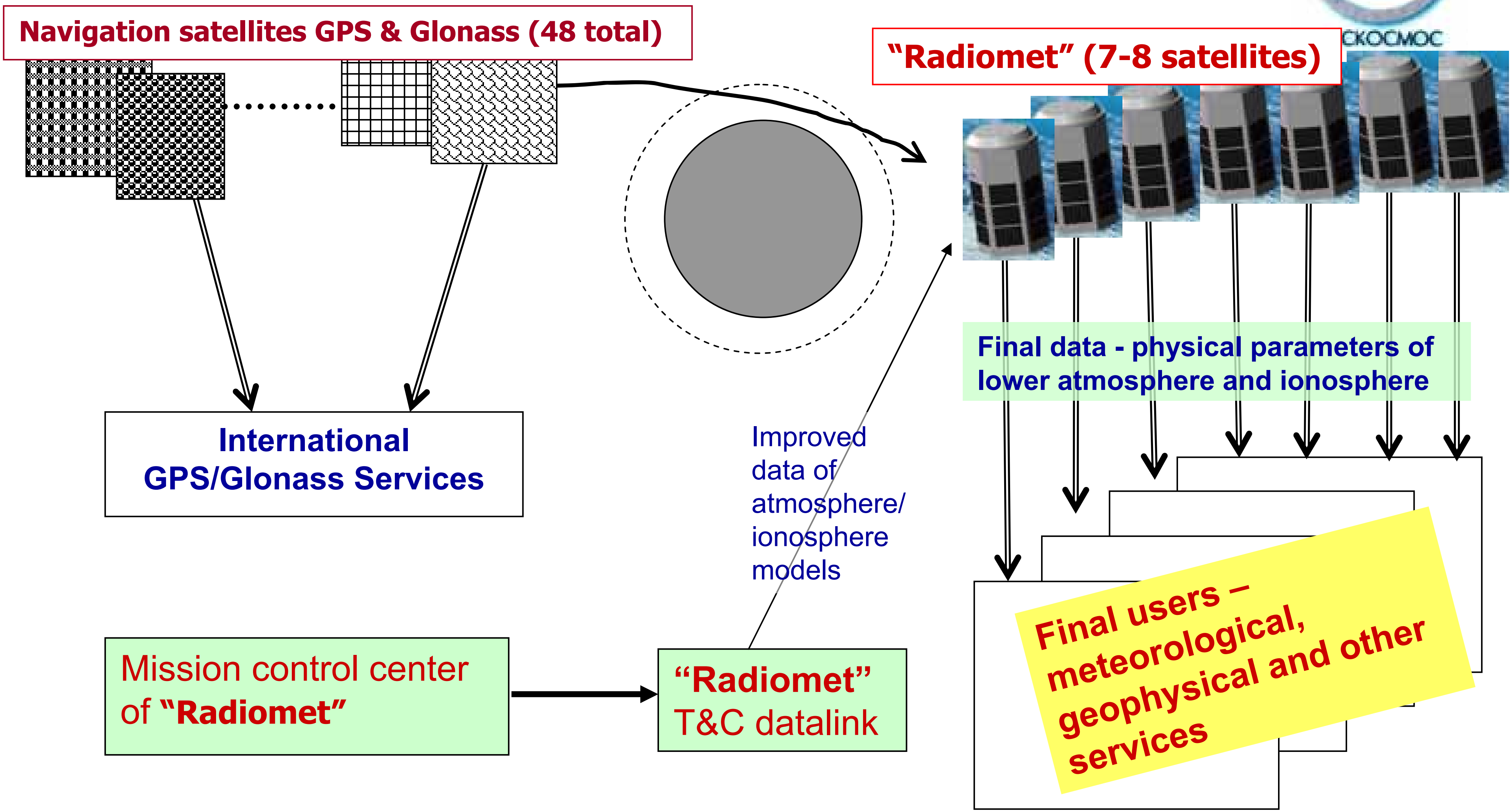
**-Periodicity of observation in not sufficient in case of rapid atmospheric process monitoring (especially for near-equatorial areas of the Earth)**

- **Polar areas are not observed due to «Formosat-3» orbit inclination (72°)**

**-Time delay of data delivery to final users is rather long (3 hours and more). It is connected with the procedure of data processing which is not "real-time".**

Received by «Formosat-3» satellites "raw" (unprocessed) GPS-signals are transmitted to ground stations of meteorological network and further to **"COSMIC Data analysis and archive Centers"** of UCAR. Raw data are then thematically processed together with GPS reference data from **International GPS Service (IGS).** After that the final data of atmosphere and ionosphere (vertical gradients of the electron density, humidity, pressure, etc.) are delivered to final users – meteorological, geophysical and other services.

# Radio occultation space system “Radiomet”



# Radio Occultation Space System “Radiomet”

## Basic features

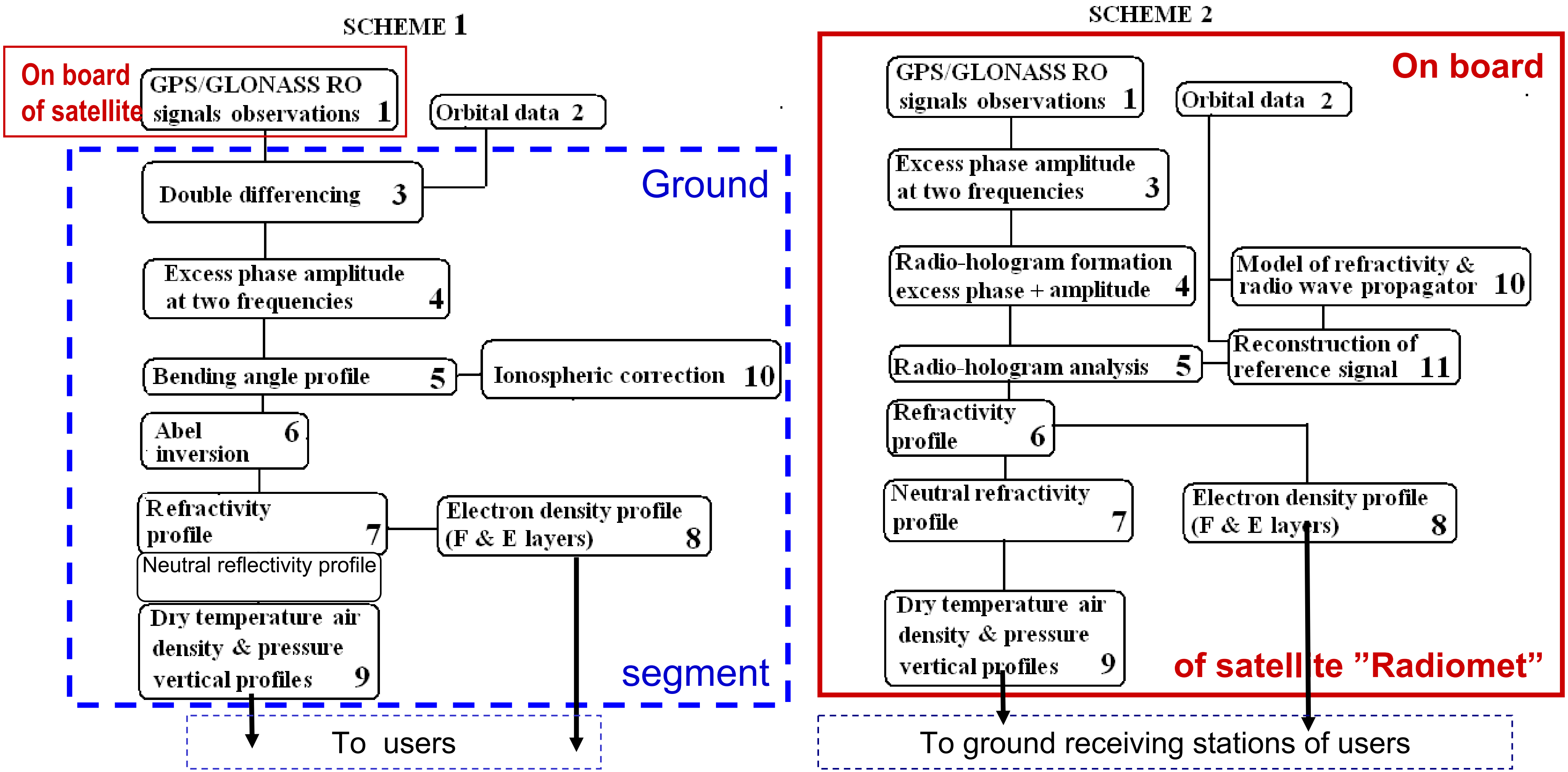
- <u>Multy-system receivers</u>. Low-orbit “Radiomet” satellites to be equipped with multy-system receivers in order to register signals from both GPS and Glonass (also from Galileo - in future). That should increase up to 2…3 times the Number of everyday observations of atmosphere and ionosphere

- <u>Optimization of orbits.</u> Periodicity of observations to be increased for any area of the Earth (including near-equatorial and polar zones) due to optimization of the constellation orbit parameters (polar-orbit satellites to be added)

- <u>Real-time on-board data processing</u>. Delay of data delivery to final users to be crucially minimized (up to real-time). GPS/Glonass signals will be thematically processed on board of “Radiomet” satellites. New Radio holographic methods of navigation signal processing (developed by IRE RAS) will be applied. Final data of vertical gradients of the electron density, humidity, pressure, temperature etc. can be transmitted from satellites to users’ local stations

- <u>Miniaturization of satellites.</u> “Radiomet” system incorporates supersmall (less than 20 kg by mass) satellites based of nano- and microtechnologies. That would ensure significant cost savings of the satellite development and launch.

# Radio Occultation Data Analysis: in CHAMP, Cosmic, etc. systems (1); on "Radiomet" satellite (2)




**Scheme 2: Radio holographic Focused Synthetic Aperture (RFSA) method** (A.G. Pavelyev, K. Igarashi, K. Hocke). Patent of Japan P2001 – 18248. Int. Cl. G 0 1 S 13/89 5/14 G 03 H 5/00 (P2003 - 4844), 2003.

# Radio occultation space systems “Radiomet” and «Formosat-3» can complement each other

| Radio occultation space system | “Formosat-3” (COSMIC) | “Radiomet” + “Formosat-3” |
|---|---|---|
| Registered navigation satellite signals | GPS only | GPS, “Glonass”, Galileo |
| Number of everyday observations | from 1500 to 2500 | Up to 10 000 |
| Medium period of observations for each area | ~ once per day | 3…4 times per day |
| Polar zones observation | No | Yes |
| Final parameters of atmosphere and ionosphere are formed: | On the ground segment | On board of satellites |
| Time delay of data delivery to final users | ≥ 3 hours | Up to real -time |

# Miniaturization of satellites

| | |
|---|---|
| **SMALL SATELLITES** | **500 – 1000 kg** |
| **MINISATELLITES** | **100 – 500 kg** |

***«SUPER-SMALL» SATELLITES:***

| | |
|---|---|
| **MICROSATELLITES** | **10 – 100 kg** |
| **NANOSATELLITES** | **1 – 10 kg** |
| **PICOSATELLITES** | **< 1 kg** |

**Super-small satellites:**

- ***are simpler and cheaper than a "full-scale" operational spacecrafts***
- ***require very short time for their production and flight testing***
- ***open the shorter way to substitute traditional "large" spacecrafts by super-small satellite constellations, reducing development costs***

# Miniaturization of satellites
## FSUE "RISDE"s program of nanosatellite technology demonstrators "TNS"

**The main objective of the Program is to test in space the following miniaturized instruments and equipment:**

- new satellite control technology via space communication systems;
- active magnetic systems for attitude control;
- instruments for remote sensing, data storage and data delivery channels based on COTS ("Commercial-Off-The-Shelf")-components;
- new types of Sun sensors, accelerometers, magnetometers, solar batteries, micropropulsion units and other miniaturized components for super-small satellites;
- various instruments for investigation of Earth, atmosphere, ionosphere, magnetosphere.

# FSUE "RISDE"s program of nanosatellite technology demonstrators "TNS"

РОСКОСМОС

| Nanosatellite | Objectives of satellite missions |
|---|---|
| TNS-0 №№1,2 | Testing of new satellite control technology – via space communication system |
| *TNS-0 №№3,4,5* | •Investigation of disasters' impacts on atmosphere and ionosphere<br>•Testing of nanosatellites for the AIS-system space segment (in cooperation with ESA-ESTEC & LUXSPACE Sarl)<br>•Testing of micro- and nanotechnological units and elements |
| TNS-1 | Testing of  perspective instruments for Earth remote sensing |
| *TNS-2 №№ 1,2* | •Investigation of various satellite control methods and active magnetic attitude control systems<br>•Radiometeorological sounding of atmosphere and ionosphere by GLONASS/GPS signals |
| TNS-2 №3 | Testing of satellite micropropulsion units |

# 1st Technological Nanosatellite TNS-0 №1

**TNS-0 №1 DESIGNED FOR SHORT-TIME FLIGHT TESTING:**

- a new nanosatellite platform
- a new flight control method using GLOBALSTAR space communication system
- serviceability monitoring method using COSPAS-SARSAT space system
- new miniaturized devices (power supply, Sun and horizon sensors, controller units, etc.)


| | |
|---|---|
| ORBIT | Low (360 km, 51,8° ) |
| ATTITUDE CONTROL SYSTEM | Passive, magnetic |
| POWER SUPPLY | Lithium battery, 10 A·h |
| TEMPERATURE CONTROL SYSTEM | Passive magnetic |
| TOTAL MASS (except launching device) | 4.5 kg |
| LIFETIME ON THE ORBIT | 5 months |
| CONTROL & TELEMETRY | through GLOBALSTAR system |
| SERVICEABILITY MONITORING | through COSPAS-SARSAT system |

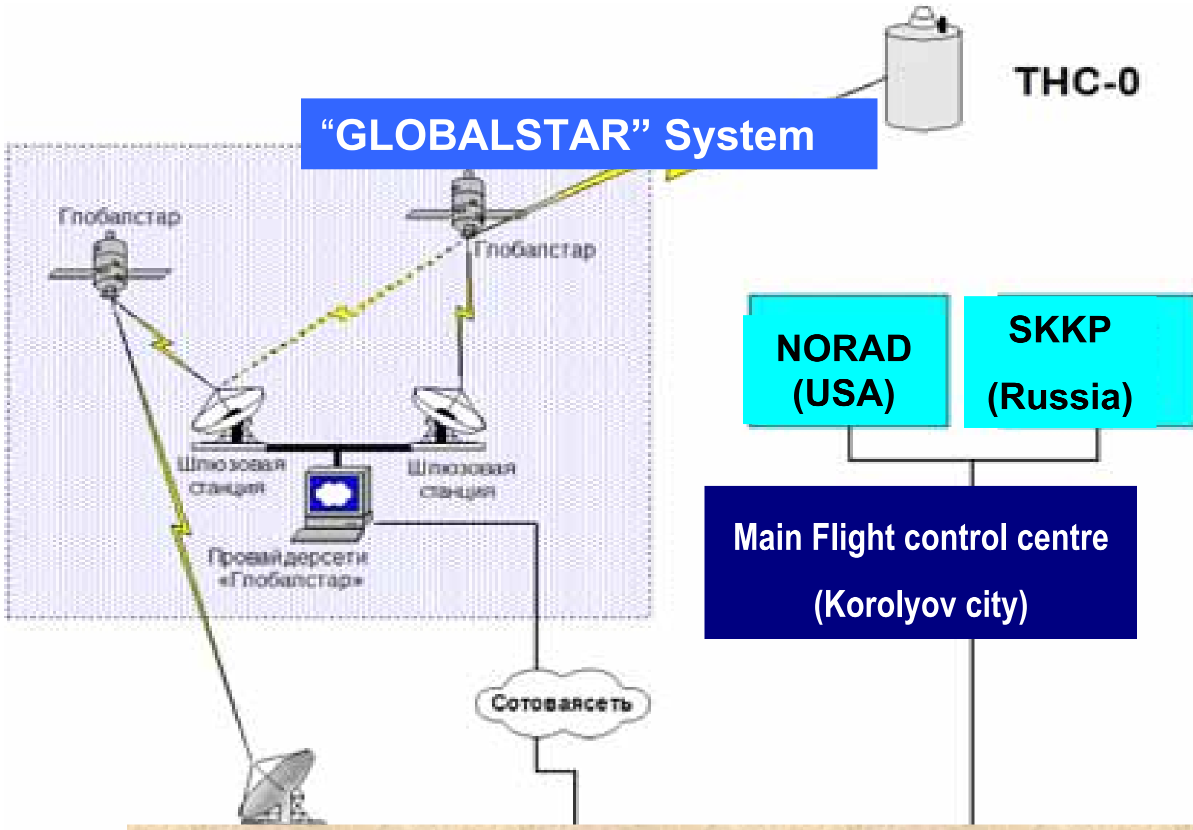
# Launch of “TNS-0” from ISS
## 28 March 2005

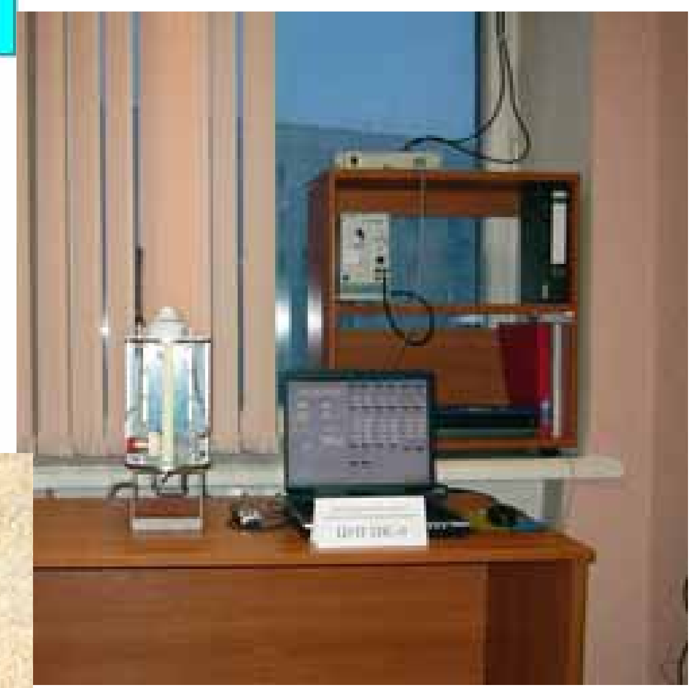

**Russian Space Researcher Salizhan SHARIPOV:**

**(left) checking “TNS-0” before its flight**

**(right) pushing away the nanosatellite off the ISS**

# *Flight Control Center*
# *for* “TNS-0” nanosatellite



**Flight control centre “FCC-TNS”**

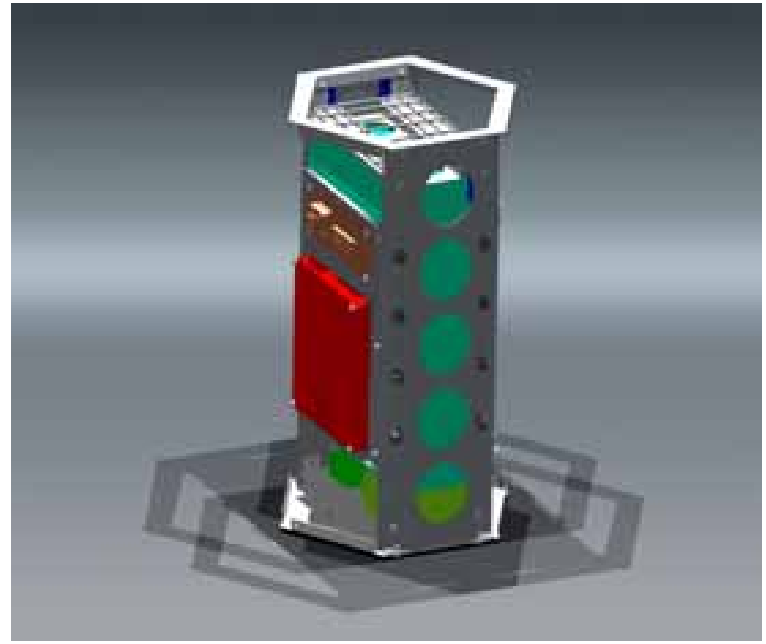
**in *FSUE “RISDE”***

# Geography of “TNS-0 №1” successful contacts via GLOBALSTAR System

# Nanosatellite TNS-2
## for multifunctional flight testing

### Basic equipment

- **3-axis active magnetic attitude control system**
- **GaAs Solar Batteries**
- **satellite control - through satellite communication systems GLOBALSTAR and/or ORBCOMM**
- **micropropulsion units for orbit correction**
- **special GLONASS/GPS-receiver for atmosphere and ionosphere radiometeorological sounding**



**Main co-developers:**

- *ZARM laboratory (Bremen, Germany) (satellite control system via ORBCOMM )*
- *Institute of Applied Mathematics, Russian Academy of Science (magnetic attitude control system)*
- *Institute of Radioengineering & Electronics, Russian Academy of Science (radiometeorological sounding experiments)*

# CONCLUSIONS

**Space systems of radio occultation (RO) monitoring using navigation satellite signals open unique new possibilities for atmosphere/ionosphere meteorological monitoring which are inaccessible both for traditional meteorological sounders and for conventional meteo satellites with on-board optical or microwave sensors.**

- **Space systems of RO monitoring by GPS signals - such as Space system "Formosat-3"(COSMIC) can obtain daily and in global scale high-resolution data of:**
  - **vertical gradients of atmospheric temperature, pressure, humidity and other factors for investigation of climate changes and improving weather forecast;**
  - **vertical gradients of ionosphere electron density for investigation the influence of Solar activity, technogenic impact and natural catastrophe prognosis.**
- **New proposal of Russian Institute of Space Device Engineering and RAS Institute of Radio engineering & Electronics enables to further improve RO-space systems capabilities. New RO-space system "Radiomet" which uses both GPS and GLONASS signals and minimizes delay of data delivery due on-board data processing will provide effective radiomonitoring 3…4 times/day all over the globe.**
  - **We are hoping to put "Radiomet" RO-system in action within the nearest years and invite other countries' organizations to joint development of this project**

**The Presenter - cand.sci., leading researcher**
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**<u>On the Photo</u>:**
**In the Russian Flight Control Centre of ISS, 28 March 2005**