Current state and the probable future of Russian National hydrometeorological constellations.

Introduction

Creation and further development of space satellites meteorological constellations are based on the growing demand from governmental offices, various industrial branches and individual consumers in the global atmospheric processes data, climate changes monitoring, underlying surface images, emergencies tracking, and short- and longtime weather forecasts. Hydrometeorological satellites have several advantages over aerial survey systems. The main advantage is that despite lower than aerial survey resolution satellites have much greater coverage areas and can collect information of global processes on Earth in short time. Another great possibility is to track (in real-time also) dangerous weather phenomena such as storms, hurricanes, and tornados, which is almost impossible to do with an aircraft. All this makes satellite hydrometeorology unbeatable in global-scale weather and climate monitoring.
Nowadays satellite hydrometeorology is covering the following tasks:

1. Global scale cloudiness, snow and ice cover, dry land and sea surface images acquisition for:
    a. Wind speed and direction measurement;
    b. Precipitation and thunderstorm areas finding;
    c. Dangerous weather phenomena (tsunamis, tornados and hurricanes, storms, wildfires etc.) tracking and providing all the necessary information about it;
    d. Dry land, sea and ocean surface temperatures measurement.
2. Vertical temperature and humidity distribution data acquisition, which is necessary for numerical weather forecasts;
3. Solar activity, ionosphere perturbations data acquisition for emergency forecasting and prevention purposes.

For Russian Federation effectively solving of these problems is one of the most important efforts and due to its vast territory this can't be done with one or two satellites. The Russian Federal Space Program aimed to create several hydrometeorological satellites constellations:

- Electro-L
- Arctica-M
- Meteor-M (and Meteor-M oceanographic)

Accordin to this Program in 2015 Russia will have seven spacecrafts, which will form two full meteorological constellations (Electro-L and Meteor-M without Oceanographic spacecrafts) and one of two satellites from Arctica-M.

Electro-L and Arctica-M

Electro-L and Arctica-M are two high orbit constellations; Meteor-M and Meteor-M oceanographic forming one medium-height orbit satellite constellation. Electro-L is the geostationary orbit hydrometeorological satellites constellation that will consist of three spacecrafts with orbital positions on 76 degree of East longitude, 14 degree of West longitude and 166 degree of East longitude. Such configuration will allow to cover the most territory of the Earth but Arctic and Antarctic regions. The aims of the Electro-L constellation are to provide the hydrometeorological data and to act as retranslation system for the Federal Service for Hydrometeorology and Environmental Monitoring of Russia (Roshydromet). This covers the following tasks:

- Efficient cloudiness and underlying surface images delivery;
- Acquisition of the information on near-equatorial global atmospheric processes;
- Geophysical and heliophysical measurement;
- Hydrometeorological and auxiliary information collection and retranslation.

The information retranslation system will allow central office of the Roshydromet to achieve data from its far-away regional weather stations, low- and medium-height orbit hydrometeorological satellites and distribute processed data to the regional offices.
Each of three satellites will be equipped with the same set of instruments:

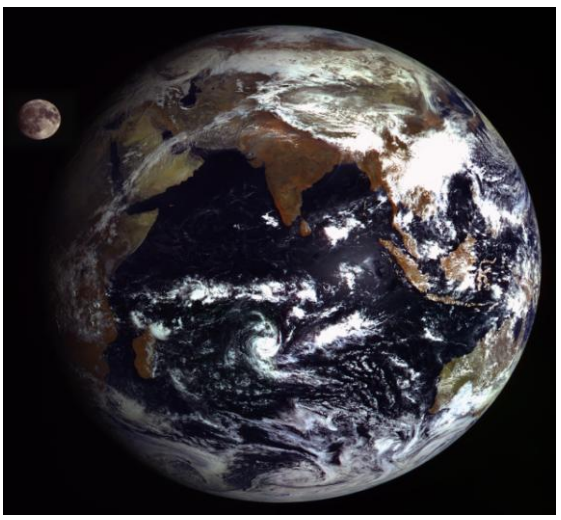
- MSU-GS: Multispectral scanning imager-radiometer (geostationary);
- GGAK-E: Module for Geophysical and heliophysical Measurements;
- BRTK: On board receiving, transmitting and retranslating unit.

Main parameters of Electro-L spacecrafts are shown in Table 1.

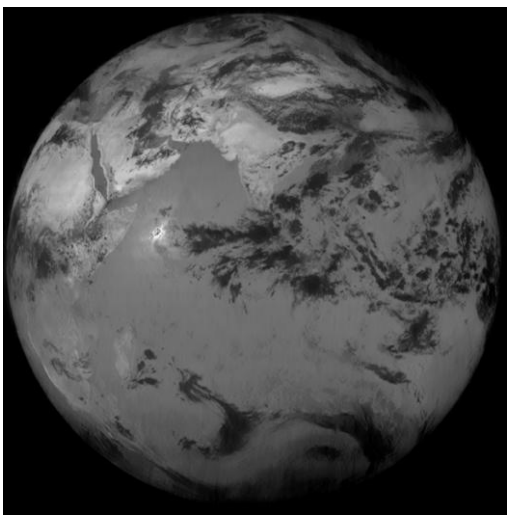
Table 1. Main parameters of the Electro-L spacecrafts

Parameter	Value
Orbit	Geostationary with accuracy of ± 0,5 degree on latitude and longitude
Number of channels	10
Waveband	0,5 – 12,5 mm
Resolution (nadir): - VIS and NIR - IR	 1 km 4 km
Period of observation: - normal mode(full Earth disc) - rapid mode (fragments)	 до 30 min до 15 min
Weight	About 1900 kg
Lifetime	10 years
Launch dates of No.1, No.2 and No.3	2011, 2013 and 2015

The first spacesraft of Electro-L constellation (named “Electro-L No.1”) was launched in 2011 and now operating in the test mode. Sample images acquired from the satellite are presented on Figures 1a and 1b. First one is showing the image of the full Earth disc which was obtained by MSU-GS imager-radiometer using visible spectral region channels 1-3 with the spatial resolution of 1 km. On Figure 1b the image of the full Earth disc in infra-red spectral region (channel 4, 3,5-4 μm) with spatial resolution of 4 km is shown.



a)



b)

Figure 1. Sample images taken by MSU-GS instrument on Electro-L No.1 spacecraft.

a) Channels 1-3, visible spectrum, wavebands: 0.50-0.65 μm, 0.65-0.80 μm and 0.8-0.9 μm
b) Channel 4, IR, waveband 3.5-4 mm, ΔT_{eqv} = 0,30 K

After flight tests the decision on instruments improvement was made. Improvement will mostly cover MSU-GS imager-radiometer and will be done for the Electro-L No.2 and No.3 satellites. The main goal of the upgrade is to acquire data from all 7 IR channels simultaneously. This will

be achieved by the optic system modification, changing the number of IR receivers and the transfer system data rate increase.
Arctica-M is another high orbit satellites constellation, which consist of two spacecrafts and will start to form from 2015. These spacecrafts will be operating on high-elliptical orbits with the apogee about 39 000 m (one can see specifications of the Arctica-M No.1 spacecraft in Table 2). The aim will be hydrometeorological monitoring and data retransmission on North latitudes more than 60 degree. Russia have the sea border about 19724,1 km in that region. The main use of this area is the North path for ships going from Pacific to Atlantic Oceans or to the northern parts of Russia and there are great reserves of oil and gas also. Launching of this constellation will make possible to cover the Arctic region, which is vital to Russian Federation because of its strategic significance.
The set of instruments of Arctica-M will include:

- MSU-GS: Multispectral scanning imager-radiometer;
- GGAK-E: Module for Geophysical and heliophysical Measurements;
- BRTK: On board receiving, transmitting and retranslating unit.

And will completely repeat the instruments set of Electro-L No.2 and No.3.

Table 2. Arctica-M No.1 spacecraft specifications

Parameter	Value
Orbit draconian period, sec	High-elliptical orbit, apogee 39000 m 43065 ± 1000
Number of channels	10
Waveband	0,5 – 12,5 mm
Resolution (nadir): - VIS and NIR - IR	 1 km 4 km
Observation period: - normal mode (full Earth disc) - rapid mode (fragments)	 30 min 15 min
Weight	About 1900 kg
Lifetime	7 years
Launch date of Arctica-M No.1	2015

Although the main purpose of Electro-L and Arctica-M satellites is to provide hydrometeorological data these spacecrafts will also be used as distress radiobeacons signal retranslators for the Cospas-Sarsat system. This will make possible to monitor and retranslate these signals from any part of the Earth.

Meteor-M and Meteor-M Oceanographic

Meteor-M is the medium-height orbit satellites constellation. This constellation will consist of three Meteor-M spacecrafts and two Meteor-M Oceanographic spacecrafts.
The goal of the "Meteor-M" satellite constellation is to provide the real-time hydrometeorological data for The Federal Service for Hydrometeorology and Environmental Monitoring Of Russia (Rosgydromet). This constellation covers following tasks:

- Global scale meteorological data acquiring for weather forecasts
- Hazardous weather phenomena info providing
- Climatic factors monitoring and global climate changes monitoring
- Radiation and solar activity monitoring in near-Earth space.

All this will improve the flight and marine navigation safety, radio channels stability and human health. Most interesting specifications of Meteor-M No.1 spacecraft one can see in Table 3.
The satellite No.1 was launched by the "Souz-2" rocket launcher and the "Fregat" acceleration module in 2009 and now is operating on the 830 km height orbit with inclination about 98.72

degrees. Other three spacecrafts (No.2, No.2-1 and No.2-2) will be launched in the years of 2013, 2014 and 2015 respectively. The first oceanographic spacecraft will be launched in 2015.

Table 3. Meteor-M No.1 specifications

Parameter	Value
Orbit Height Inclination	Medium-height orbit, 830km 98,72 degree
Orientation accuracy	0,1 degree
Weight	About 2900 kg
Lifetime	5 years
Launch dates of No.1, No.2, No.2-1 and No.2-2, No.3	2009, 2013, 2014 and 2015

Each spacepcraft will have the same set of the instruments which is presented in Table 4.

Table 4. Meteor-M instruments set.

Instrument	**Purpose**	**Wavebands**	**Swat width, km**	**Resolution, km**
MSU-MR: Multispectral scanning imager-radiometer (low resolution)	Cloudiness maps	0,5 – 12,5 μm (6 channels)	3000	1 x 1
MTVZA-GYA: Scanning microwave imager-sounder	Temperature, humidity profiles and near-water winds measurements	10,6-183,3 GHz (26 chanels)	2600	12 – 75
IKFS-2: IR Fourier spectrometer (starting from Meteor-M No.2)	atmosphere temperature and humidity profile measurements	5-15 μm	2000	35
BRLK: Synthetic Aperture Radar	Ice tracking	9500-9700 MHz	600	0,4 x 0,5
GGAK-M: Module for Geophysical and heliophysical measurements	Heliophysical and geophysical measurements			

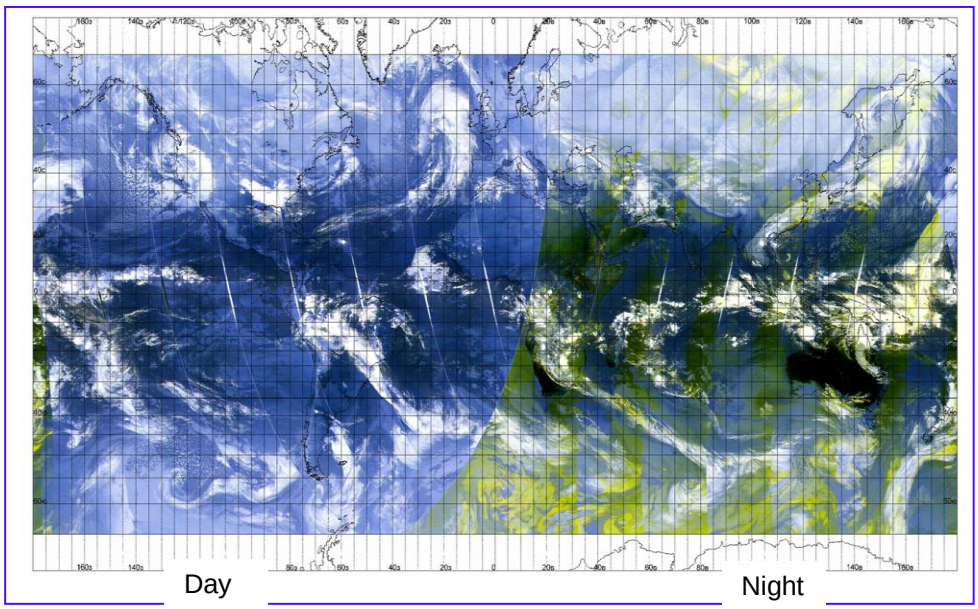


Figure 2. Daily cloudiness map, tropics 20–21.01.2010. Acquired by MSU-MR, Meteor-M No.1 spacecraft. IR channels 4-6, Wavebands: 3,5 - 4,1 mm; 10,5 - 11,5 mm; 11,5 - 12,5 mm

Meteor-M No.1 passed all flight tests and already working more than 26000 hours on the orbit. This spacecraft was used in solving several hydrometeorological tasks.
The first one is the global scale cloudiness map in tropics region which is quite significant for the Earth weather and climate monitoring. The full picture of the daily cloudiness can be seen on the Figure 2. As soon as this map was made with IR channels 4-6 (3,5 - 4,0 μm; 10,5 - 11,5 μm; 11,5 - 12,5 μm) of MSU-MR it can be done 24 hours a day.

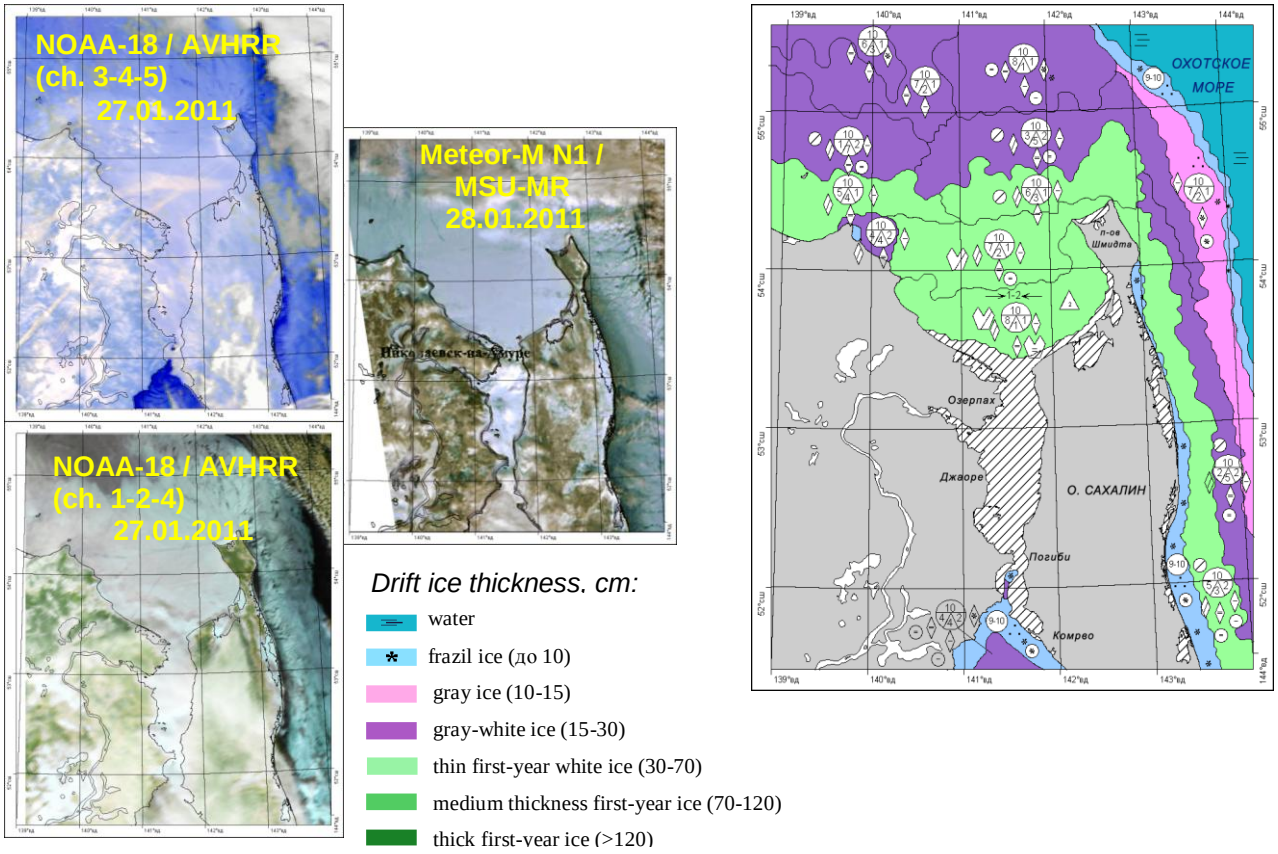


Figure 3. Okhotsk Sea ice situation map. Map was made from Meteor-M No. 1 (MSU-MR) spacecraft and NOAA-18 (AVHRR) spacecraft images (raw data is shown on the left), 27-28.01.2011

The second task is the sea ice situation monitoring with MSU-MR instrument. This is raver important for marine navigation in the North regions of Russian Federation. The sample map of Okhotsk Sea ice situation near the Sakhalin Island is shown on the Figure 3. This ice map was made with the data from Meteor-M No.1 (MSU-MR instrument) and NOAA-18 (AVHRR instrument). Source images from Meteor-M No.1 and NOAA-18 are on the left.
The third task is the dangerous weather phenomena tracking. Meteor-M No.1 was used in the wildfires monitoring with MSU-MR instrument. Wildfires caused by the abnormal heat of summer 2010 in Central Russia region are presented on the Figure 4. One could see large areas of burning peat fields in the Moscow and Nizhniy Novgorod areas.

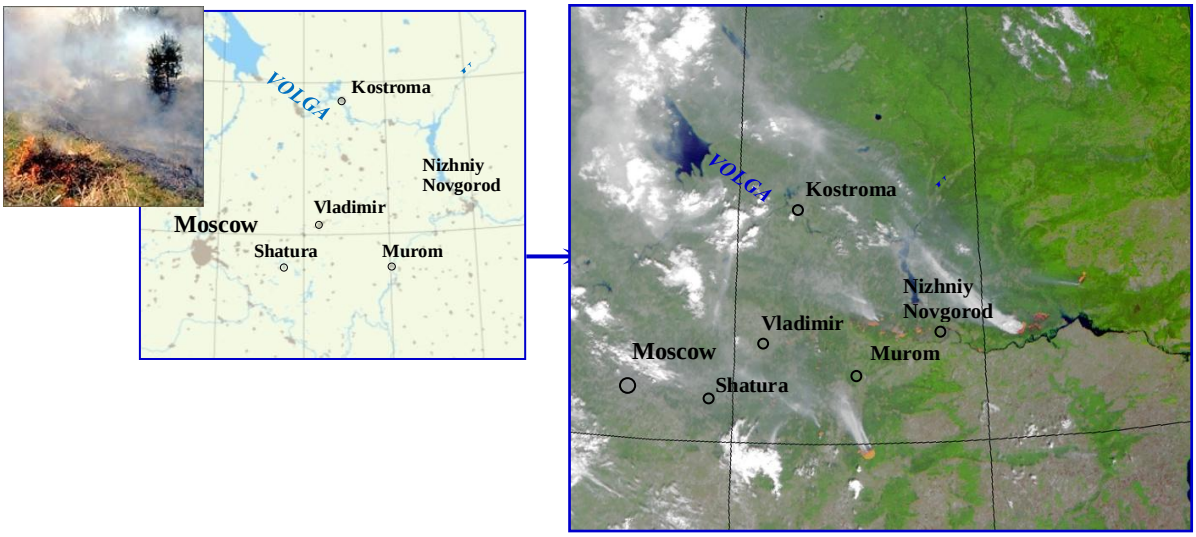


Figure 4. Wildfires tracking with Meteor-M No.1, MSU-MR instrument. Central Russia region, 26.07.2010.

Other areas of use are Arctic and Antarctic radiolocation maps creation with BRLK instrument, ocean streams monitoring and humidity and temperature profiles acquisition with MTVZA-GYA. So even one satellite from the Meteor-M system can be used in various situations such as global scale cloudiness monitoring, ocean and sea navigation, wildfires and flood tracking and many others. With increase of the number of spacecrafts better efficiency and coverage area enlargement will be achieved.

Conclusion

Even first two satellites from Meteor-M and Electro-L constellations can solve various meteorological problems such as:

- Daily global scale cloudiness maps creation
- Sea Ice maps creation
- Emergencies such as Wildfires, floods, oil slicks etc. monitoring
- Hazardous nature phenomena investigation (storms, tsunamis etc.)
- VIS images of the Earth disk acquiring (soil and vegetation)

Electro-L N1 also provide the possibility to retranslate hydrometeorological information and emergency signals from Cospas-Sarsat radiobeacons.

Increase in number of spaececrafts up to 7 in 2015 will allow to solve vast spectrum of hydrometeorological problems with the coverage of all the Earth surface but Antarctic region. This will lead to higher flight and sea navigation safety, more accurate weather forecasting, more accurate important climate factors monitoring and emergencies (such as thunderstorms, wildfires etc) tracking.