Space Apps is a NASA

incubator innovation program.

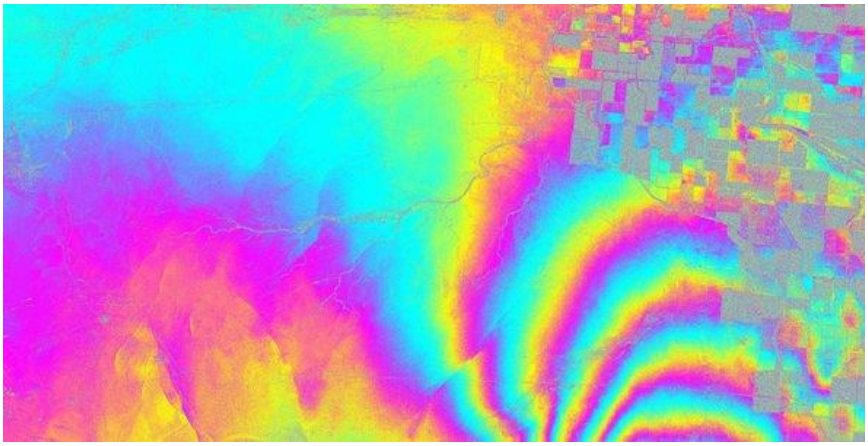
Dushanbe

TAJIKISTAN

«Stardust Crusaders»

Hackathon Project Report

"InSAR Change Detectives!"



Mahdi Samadov – Captain, aerospace engineer, PR manager.
Ilnar Khairullin – IT programmer, aerospace engineer.
Igor Shirobokov – Mathematician.
Evgeniy Mesherinov – engineer.

Tajikistan – 2022

Introduction

Scientists use repeat pass Synthetic Aperture Radar Interferometry (InSAR) to observe the relative motion of Earth's surface by measuring the time it takes for the electromagnetic signal to travel from a satellite to the ground and back. As the signal goes through the various layers of the atmosphere, it changes slightly. One of these changes takes place in the troposphere as the signal slows down when it interacts with water vapor. As the amount of total precipitable water vapor changes over time, the rate at which the signal slows changes as well. These changes can mask the actual surface deformation signal [1].

Many solutions to this problem have been developed over the years, including simple averaging, space-time adaptive filtering, and machine learning approaches. There are also other methods that use additional data to resolve the tropospheric signal.

Synthetic Aperture Radar (SAR) is a microwave imaging system. It has the ability to penetrate clouds because it uses microwaves. It works day and night because it is an active system. Finally, its "interferometric configuration", interferometric SAR or InSAR, allows accurate measurements of the path of radiation propagation, since it is coherent.

Measurements of variations in the trajectory of motion depending on the position of the satellite and the time of receipt allow you to create digital relief models (DEM) and measure centimeter deformations of the relief surface.

A digital SAR image can be viewed as a mosaic (i.e. a two-dimensional array formed by columns and rows) of small image elements (pixels). Each pixel is associated with a small area of the earth's surface (called a resolution cell). Each pixel gives a complex number that carries information about the amplitude and phase of the microwave field, backscattered by all the scatterers (rocks, vegetation, buildings, etc.) within the corresponding resolution cell projected onto the ground. Different rows of the image are associated with different azimuth locations, while different columns indicate different locations of the tilt range.

The location and size of the resolution cell in azimuth and slope range coordinates depend only on the characteristics of the SAR system. In the case of ERS, the SAR resolution cell size is about 5 meters in azimuth and about 9.5 meters in slope. The distance between adjacent cells is about 4 meters in azimuth and about 8 meters in slope. Thus, the SAR resolution cells overlap slightly in both azimuth and inclination.

Task

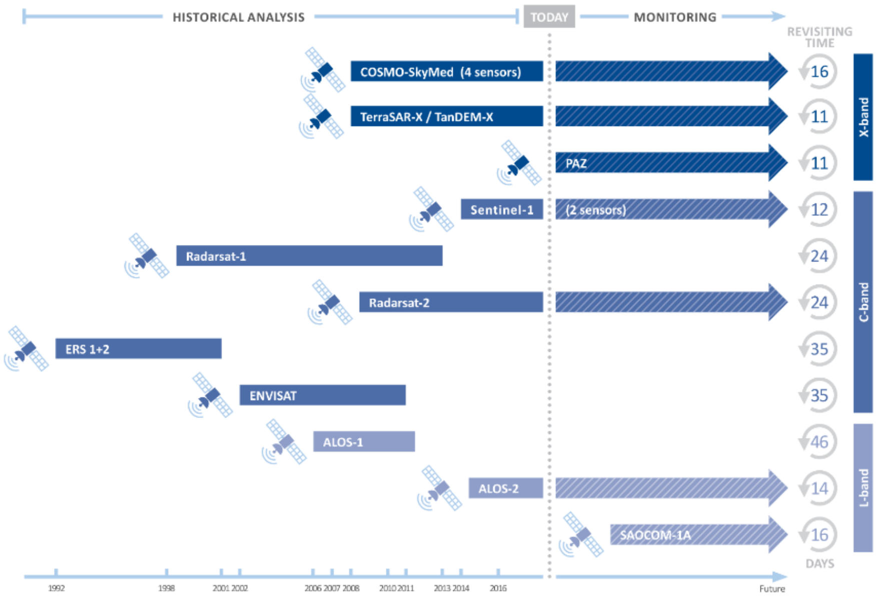
It is necessary to create a "notebook" containing both computer code and other elements (for example, text, images, links, drawings, etc.) that visualizes the original "noisy" InSAR data, applies and explains the algorithm used to remove the tropospheric signal, and presents the resulting "clean" data in an understandable form. [1]

Earth remote sensing satellites

Image Air-Quality-Transparent-Blue Remote sensing is the acquiring of information from a distance. NASA observes Earth and other planetary bodies via remote sensors on satellites and aircraft that detect and record reflected or emitted energy. Remote sensors, which provide a global perspective and a wealth of data about Earth systems, enable data-informed decision making based on the current and future state of our planet [2].

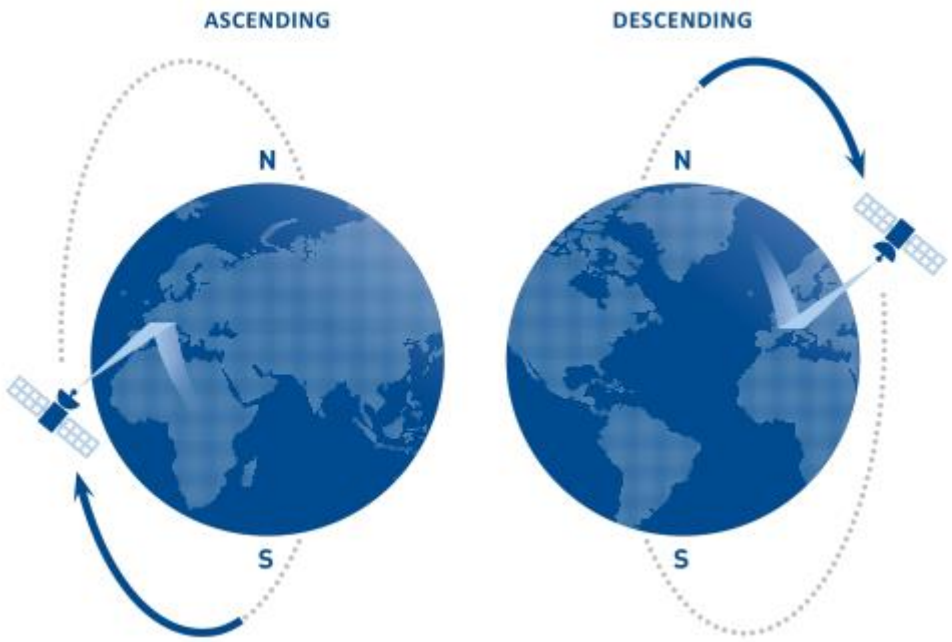
- Orbits
- Observing with the Electromagnetic Spectrum
- Sensors
- Resolution
- Data Processing, Interpretation, and Analysis
- Data Pathfinders

Synthetic Aperture Radar (SAR) satellites receive images of the Earth's surface by emitting radar signals and analyzing the reflected signal. As SAR satellites continuously travel around the globe, and over time it is possible to obtain several reliable images for the same area. By processing SAR data sets, the evolution of surface deformation can be extracted as useful for many applications [3].



Pic. 1 – Historical Scale

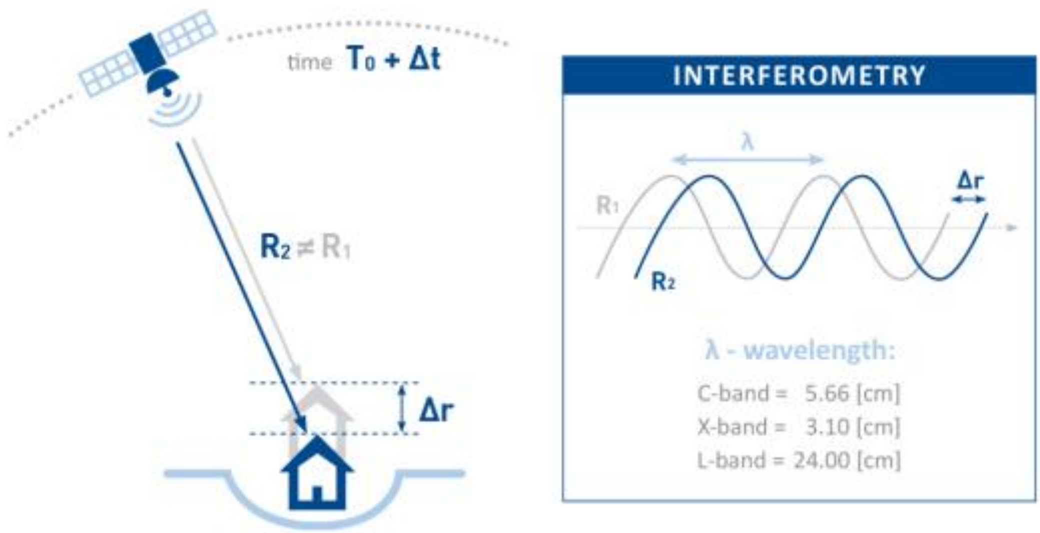
All satellites equipped with SAR sensors orbit the Earth on a near-polar orbit at an altitude ranging from 500 to 800 km above the Earth's surface. The time taken for a satellite to repass over the same area is called the 'revisiting time'. Since the launch of ERS satellites in 1992, numerous satellites have been orbiting the Earth, providing higher resolution images, faster repeat times and data redundancy for many parts of the world [3].



Pic.2 – Ascending and descending orbits

Interferometric Synthetic Aperture Radar (InSAR), or SAR Interferometry, is the measurement of signal phase change between two images acquired over the same area, at different time. When a point on the ground moves, the distance between the sensor and the point changes and so the phase value recorded by the sensor will be affected too. The change in signal phase ($\Delta\varphi$) is expressed by the equation below:

$$\Delta\varphi = \frac{4\pi}{\lambda}\Delta R + \alpha$$



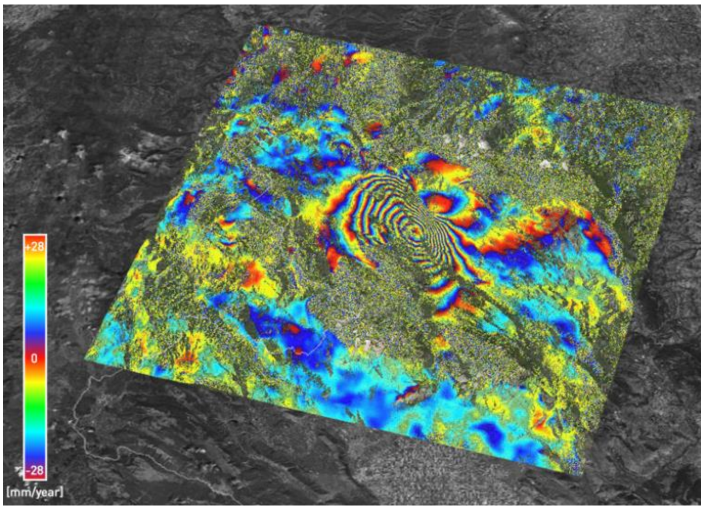
Pic.3 – InSAR: Interferometric synthetic aperture radar

Where λ is the wavelength, ΔR is the displacement in the Line Of Sight (LOS) and α is a phase shift due to different atmospheric conditions at the time of the two radar acquisitions.

Interferograms

An interferogram is the difference of the phase values corresponding to a certain area, i.e. it is a digital representation of a change in surface displacement. It corresponds to a matrix of numerical values ranging from $-\pi$ to $+\pi$ (phase variations) and it can be converted into a map

– the easiest way to observe whether motion has occurred over a certain area.



Pic.4 – An interferogram

Interferometric phase ($\Delta\varphi$) is impacted by four contributions: 1) topographic distortions arising from slightly different viewing angles of the two satellite passes (t), 2) atmospheric effects (α) arising from the wavelength distortions by the moisture-bearing layer, 3) any range displacement of the radar target (ΔR), 4) noise (decorrelation effects) [3].

These factors are given in the equation below:

$$\Delta\varphi = \frac{4\pi}{\lambda}\Delta R + \alpha + t + \textit{noise}$$

It is difficult to remove all the contributions to phase but the range displacement using a single SAR interferogram.

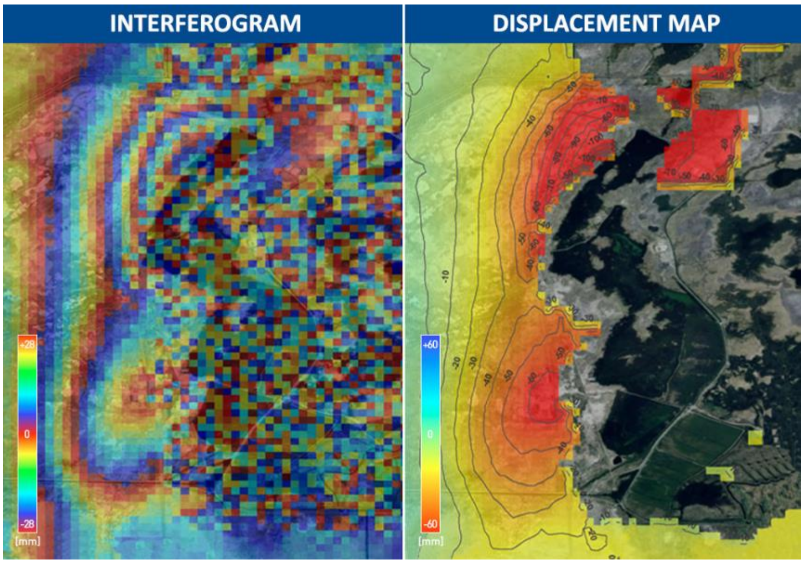
DInSAR (Differential InSAR) is not a tool for accurate displacement measurements, but it is useful in identifying footprints of progressing movement. Differential interferometry or DInSAR is interferometry itself. The only difference is that topographic effects are compensated by using a Digital Elevation Model (DEM) of the area of interest, creating what is referred to as a differential interferogram. This can be expressed as:

$$\Delta\varphi = \frac{4\pi}{\lambda}\Delta R + \alpha + \varepsilon + \textit{noise}$$

Where ε is the contribution to phase arising from possible errors in the DEM. Whenever noise levels are low (i.e. decorrelation effects are negligible) and the phase contribution due to the local topography is accurately compensated for (i.e. ε is also negligible), the interferometric phase $\Delta\varphi$ can be simplified as follows:

$$\Delta\varphi = \frac{4\pi}{\lambda}\Delta R + \alpha$$

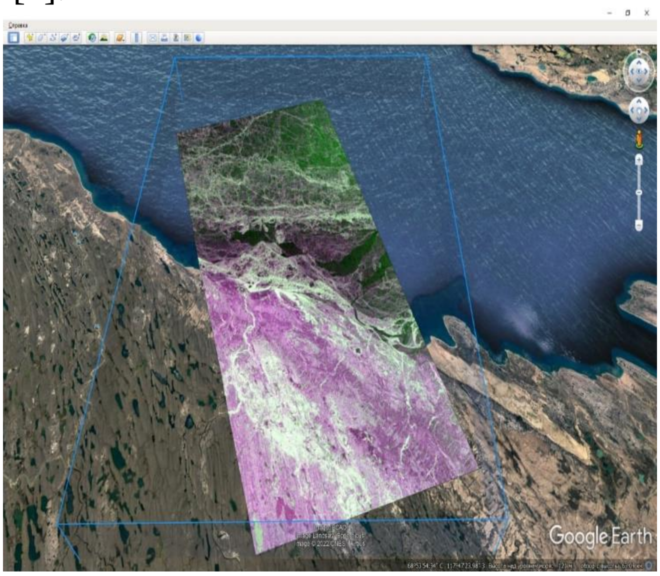
Where ΔR is any range displacement of the radar target and α is the atmospheric contribution to the phase shift. Once a differential interferogram has been prepared, a deformation map can be created for all areas that are coherent, as shown in the figure. Interferograms are very useful to monitor strong motion phenomena, such as earthquakes or volcanoes



Pic.5 – InSAR

Data processing. Individual Atmosphere Analysis Strategy.

It was decided to process data from ALOS satellites (JAXA), since the data from these satellites contain more diverse images and signals that are well suited for research and for various projects [4].

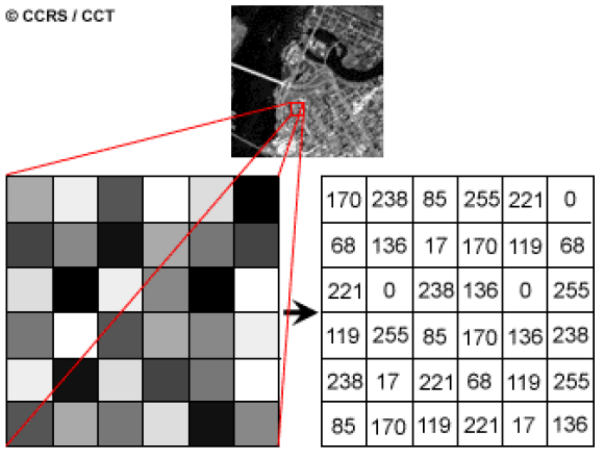


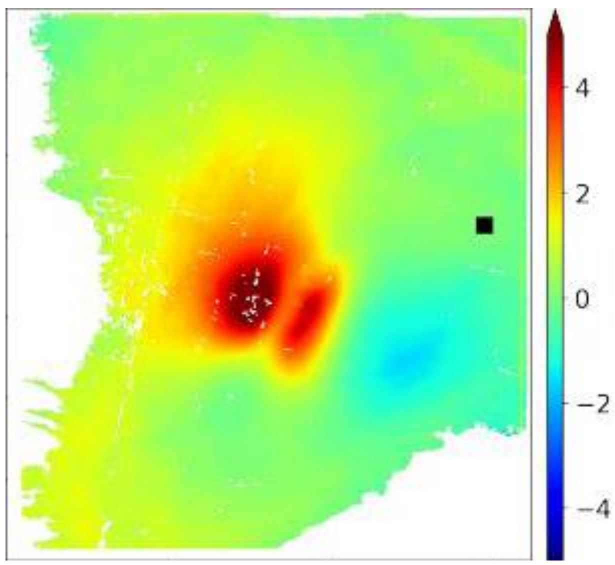
Pic.1 - Canada North-West territories (By: ALOS-3 satellite)

The high-resolution NWM output data combined with locally available observations make it possible to obtain a reliable representation of the non-isotropic distribution of water vapor during InSAR data collection. Such custom analysis can be used to obtain atmospheric correction products (phase screens) for InSAR interferograms. Adjusted InSAR interferograms allow better identification of the magmatic signal (inflation/deflation) of active volcanic areas. In the future operation mode, low-latency atmospheric correction products can be used for effective monitoring of hazardous volcanic areas for early warning of eruptions, earthquake response and landslide monitoring [5].

An interferogram was obtained in the form of a matrix of changes in the height of the surface (height, width)

$$Img_{w,h} = \Delta height$$





2) Pars of the data of the European weather model (it is the most accurate) ECMWF (European Center for Medium-term Weather Forecasts)

3) To correct the bias, it is necessary to use weight coefficients.

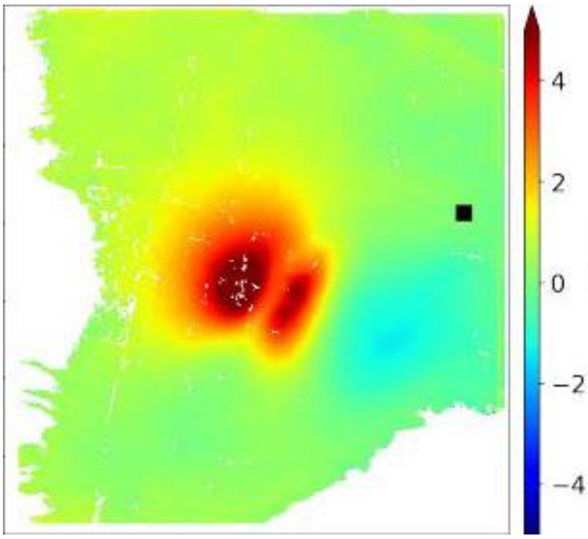
Surface Real Delay = Surface Total Delay – Surface Wet Delay

Use this formula

$$\Delta height = -\frac{4\pi}{\lambda} \cdot \frac{1}{10^6 \sin\theta} \int_{h=h_1}^{\infty} \left[\left(k_1 \frac{P}{T} \right) + \left(k_2 \frac{e}{T} + k_3 \frac{e}{T^2} \right) \right] dh$$

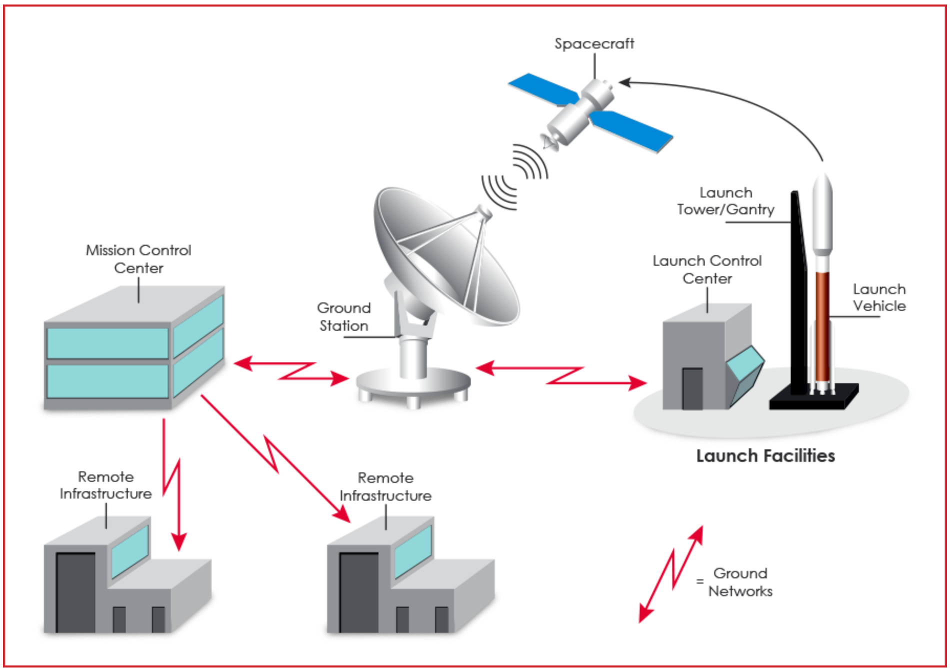
We make matrix corrections using the IDE MATLAB

And new values of altitude changes and corrections for atmospheric humidity were obtained.



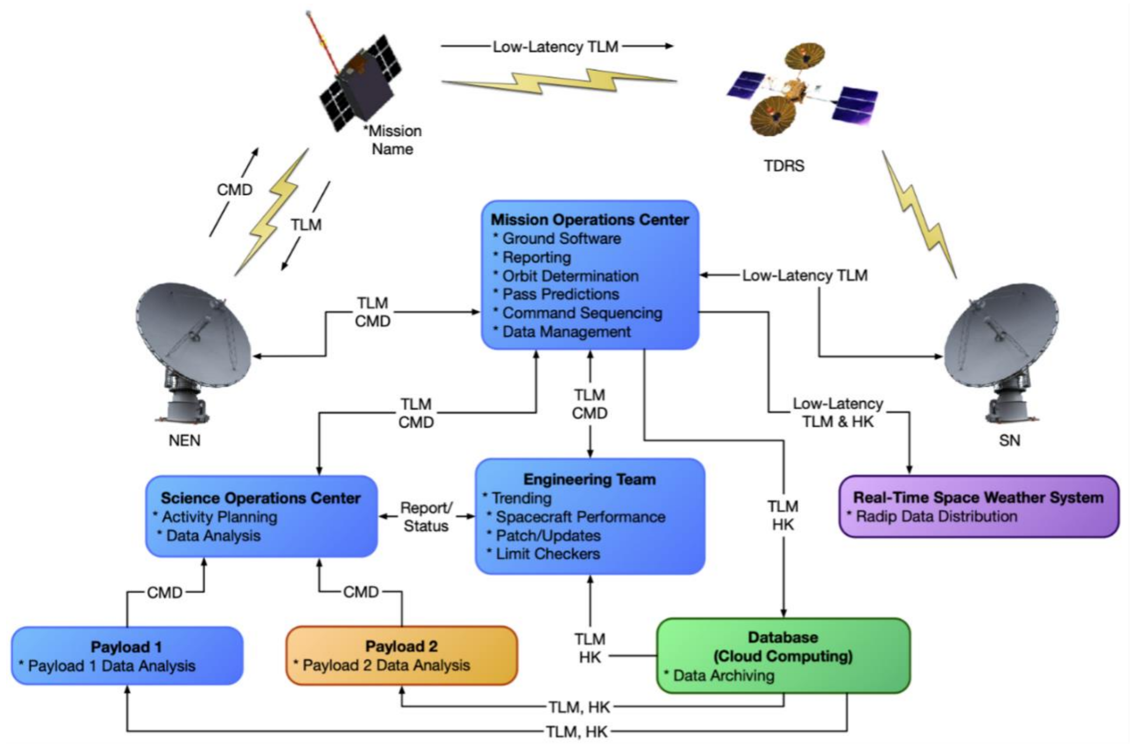
Mission Control Center

The Mission Control Center is a center from where data from satellites and the ISS are monitored and received. Pic.6 shows Space Ground Systems.



Pic.6 – Space Ground Systems.

Picture 7 shows a detailed description of the Mission Control Center.



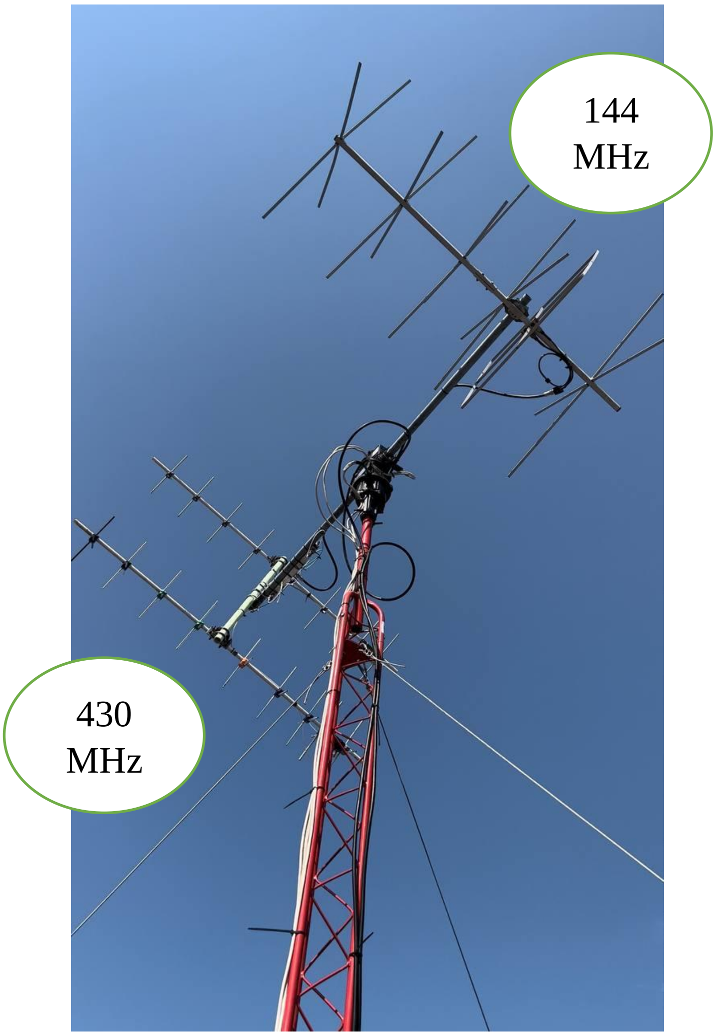
Pic.7 – Mission Control Center

In the Mission Control Center, you can find devices such as a receiver, an antenna control device, SDR, a computer and a noise filter.

Pic.8 – An antenna control device **YAESU G-5500**

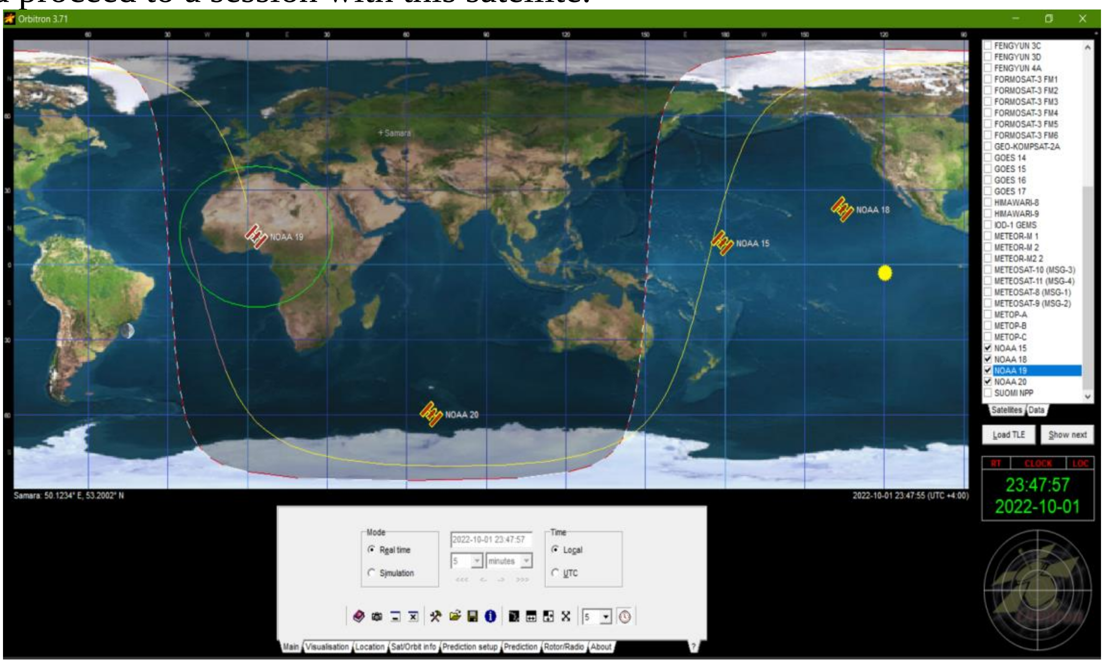
Pic.9 – **ICOM IC-910H** Transceiver

The **ICOM IC-910H** transceiver is a basic radio station designed to work in amateur bands: 2 m (144 MHz), 70 cm (430 MHz) and 23 cm (1200 MHz when installing the UX-910 module).



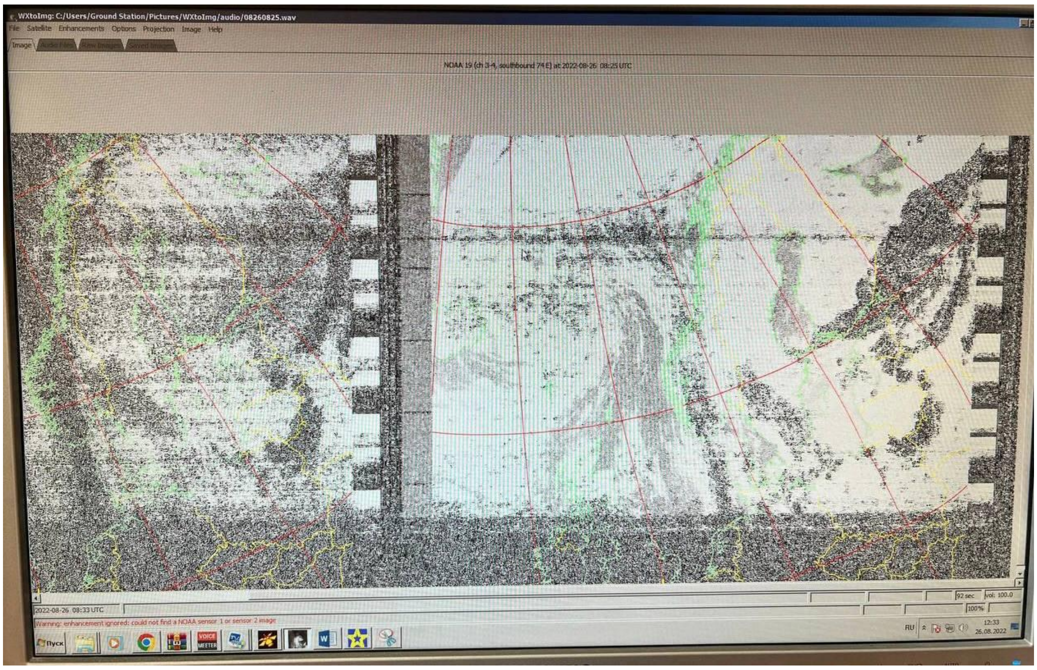
Pic.10 – Antenna.

The Orbitron program can calculate the flight of the Earth remote sensing satellite in advance and proceed to a session with this satellite.



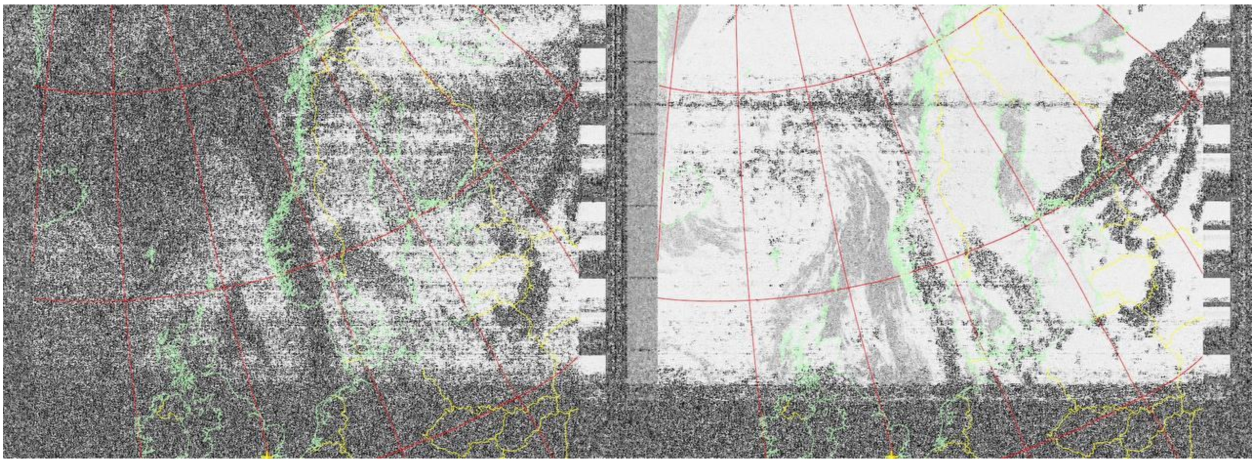
Pic.11 – Orbitron

The WXtoImg program is needed in the Mission Control Center.



Pic.12 – WXtoImg program

After the passage of the remote sensing satellite, such a meteorological map was obtained.



Pic. 13 – Received data from satellite NOAA

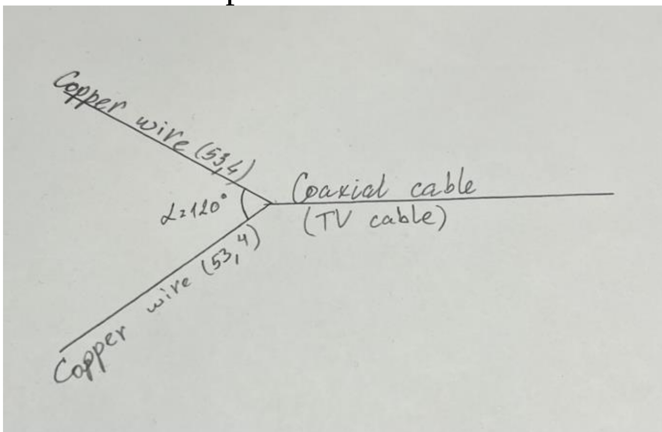
The data was obtained from NOAA remote sensing satellites at the Nanosatellite Mission Control Center of Samara State Aerospace University.

Portable flight control center.

Usually, mission control centers are located in the city, and this has a bad effect on the signals received from spacecraft, so it is desirable to create a portable control center that allows scientists and engineers to work far outside the city. This method allows you to reduce the noise from the city and receive clean signals from remote sensing satellites.

The portable control center requires devices: 2 aluminum wires, a TV tuner (RTL2832U), a computer, plywood, coaxial cable and a battery pack.

A simple antenna is enough to receive a satellite signal. The most disposable, but effective option is two 53.4 cm long copper wires connected in the shape of the letter V at an angle of 120 degrees. This antenna is ideal for operating at 137 MHz. The base of the antenna is plywood. Pic.14 shows the shape of the antenna.

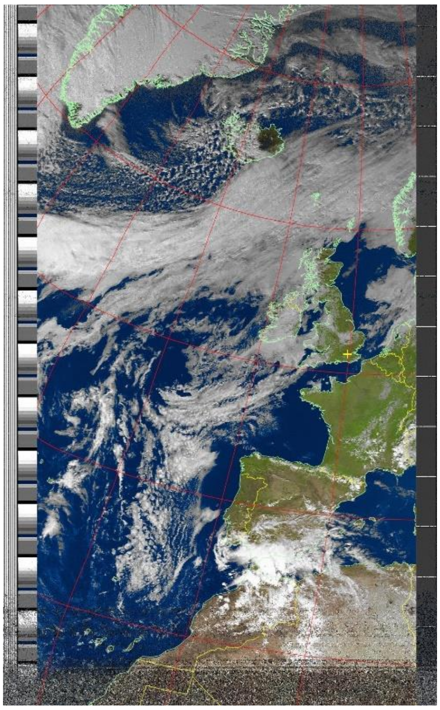


Pic.14 – The shape of the antenna

When the satellite is above us, open the SDR software, set the frequency to 137 MHz and set the receiver parameters as follows:

- FM modulation
- band: 44 kHz

In addition to photos from a meteorological satellite, with the help of such equipment, you can truly become the ruler of the radio airwaves. All the content on the air is available to you, including negotiations on the police wave, the exchange of information between aircraft pilots and airport dispatchers. In a word, the whole globe and even space. Including signals from the ISS.



Pic.15 – Data from NOAA satellite

Budget

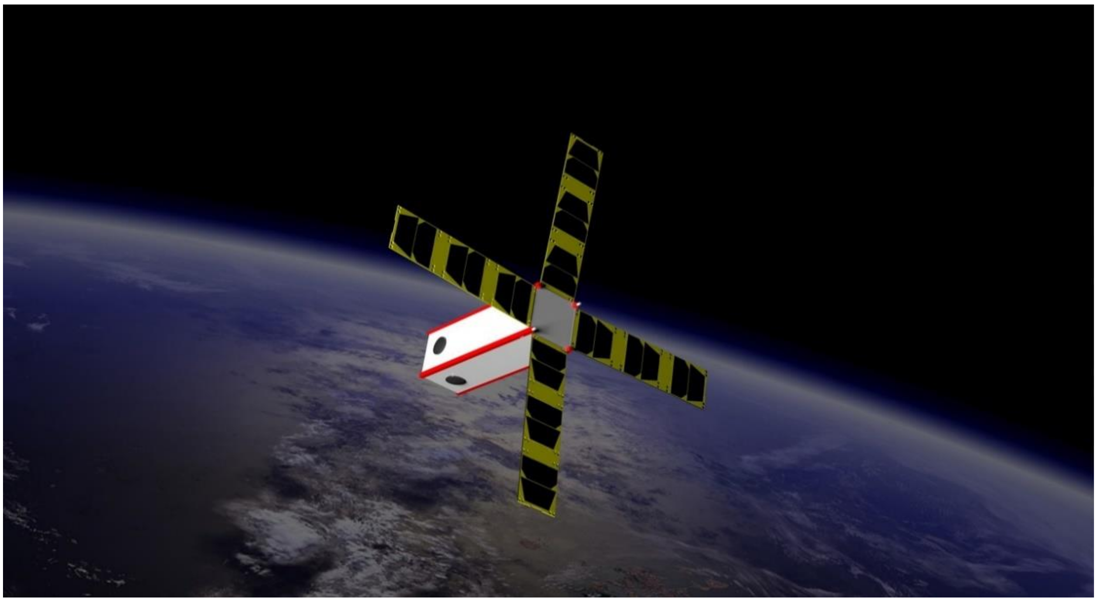
A market analysis was carried out to purchase the necessary elements for the implementation of the project and data processing.

Devices	Prices $
Antenna	650
Mast	300
Cable (20 m)	150
Tuner RTL2832U	50
An antenna control device YAESU G-5500	1500
RS-918 Plus 15W HF SDR Transceiver	420
Total	3070

Remote sensing satellite of the earth in Cubesat format.

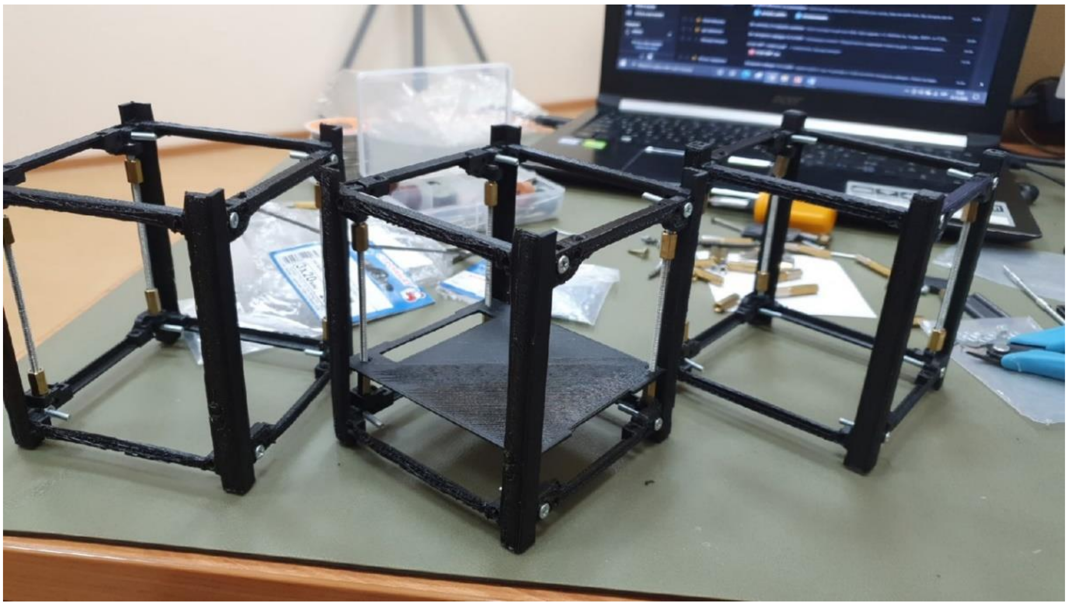
One of the promising areas is remote sensing nanosatellites, which can perform the same tasks as large remote sensing satellites, but at a lower cost.

The idea of developing a nanosatellite with a VR camera and the possibility of a remote connection to it, thereby anyone will be able to observe the planet Earth from a height of 550 km and fully immerse themselves in space. And also the thermal imager is able to detect foci of forest fires [6].

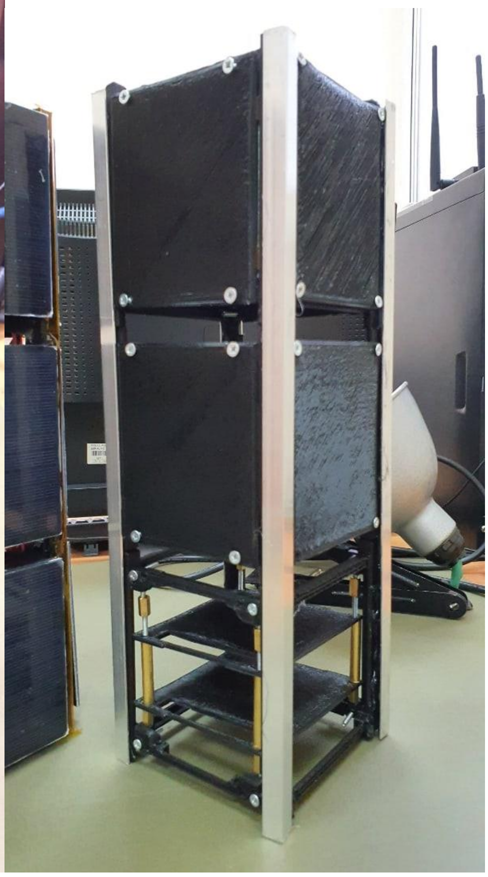


The initial appearance of the satellite was complex in design and it was decided to optimize the design. The classical scheme of CubeSats for 3U was chosen.

In the first stage, CubeSat is made of PLA material and printed on a 3D printer.



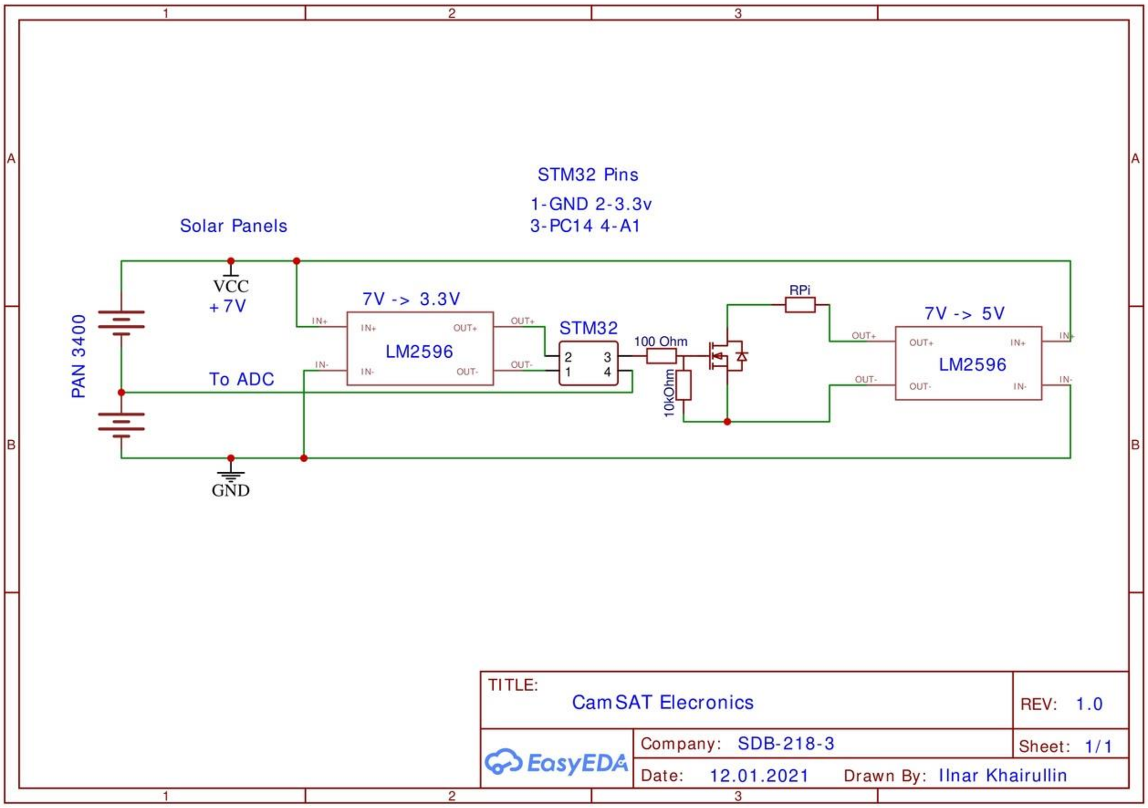
Then these units were assembled



Imitation solar panels are attached to the case.

CubeSat-3U

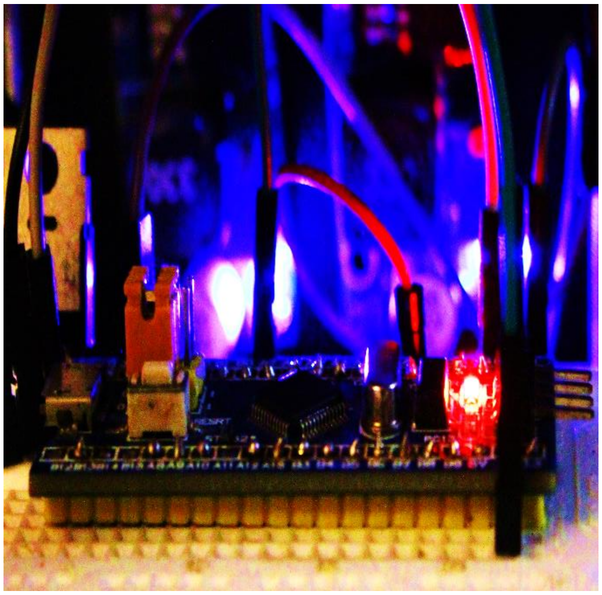
Simulation of spacecraft power supply.



The STM32 microcontroller controls the power supply of the system and does not allow the Raspberry Pi to discharge the batteries. Also in the future, it is planned to set active stabilization using coils and inertial flywheels.

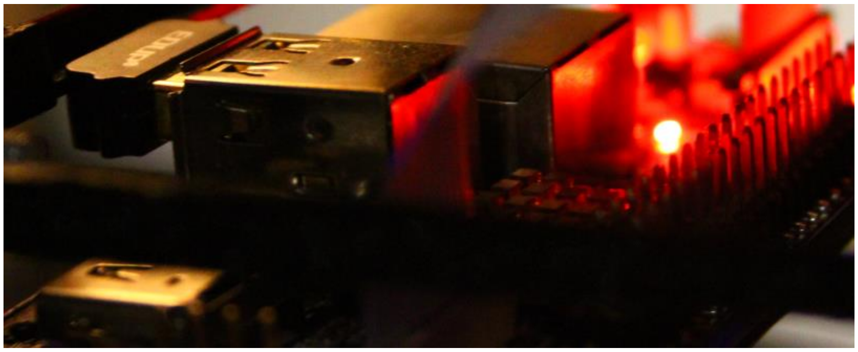
```
HAL_ADCEx_Calibration_Start(&hadc1);

while (1)
{

    HAL_ADC_Start(&hadc1);
            HAL_ADCEx_InjectedPollForConversion(&hadc1, 100);
            adc_val = HAL_ADC_GetValue(&hadc1);
            HAL_ADC_Stop(&hadc1);
           // HAL_Delay(100);
            voltage = adc_val * (3.3/4095);
            if (voltage >= 3.2 )
                HAL_GPIO_WritePin(KEY_GPIO_Port, KEY_Pin, 1);
          if (voltage <= 2.7 )
              HAL_GPIO_WritePin(KEY_GPIO_Port, KEY_Pin, 0);

}
```

Part of the program for the STM32 microcontroller.

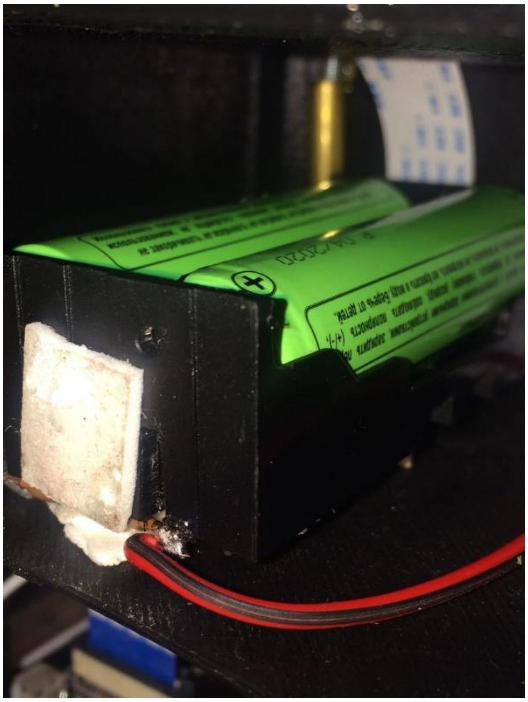


STM32 Microcontroller

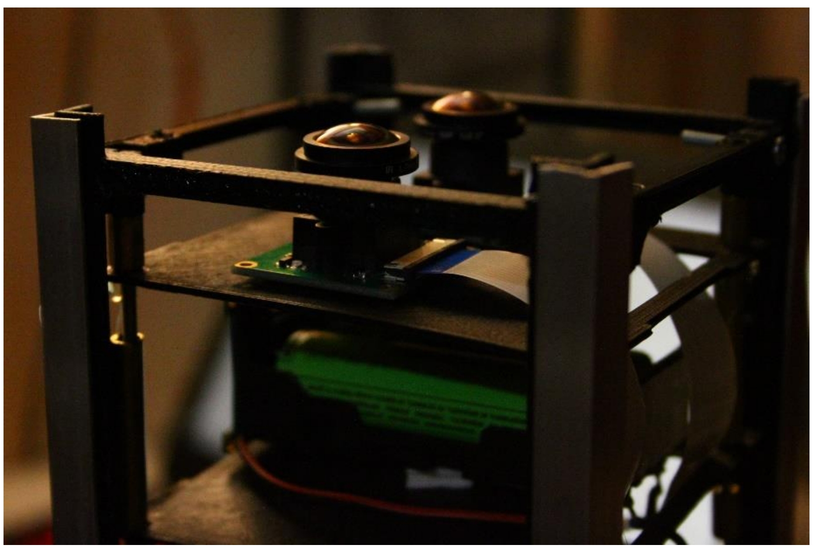
Raspberry Pi & Stereo Pi



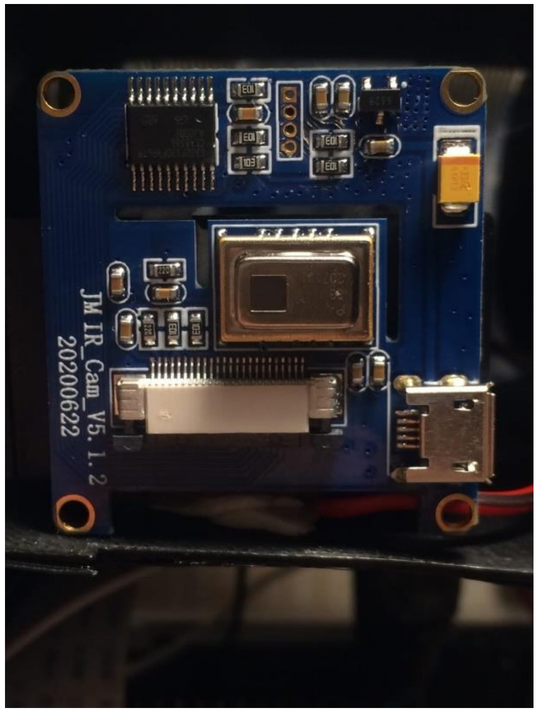
USB Adapter WI-FI for Rpi



Batteries

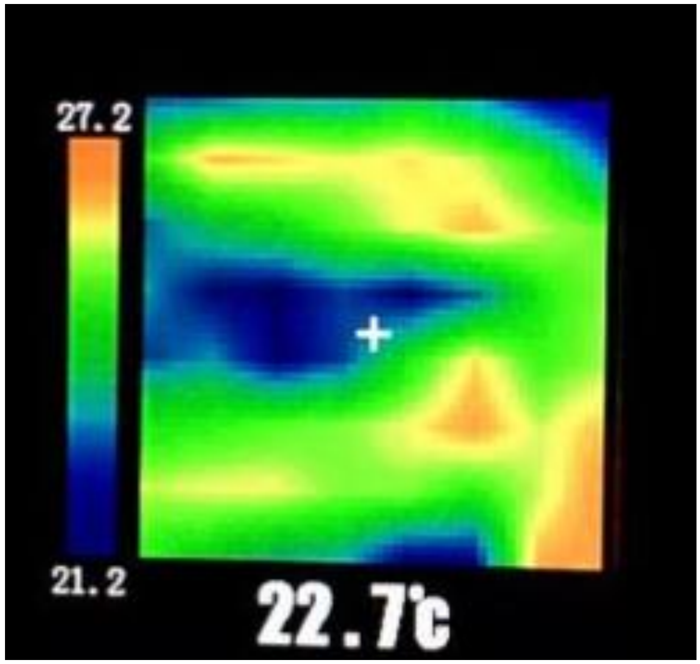


Cameras with a viewing angle of 175 degrees for VR.



Thermal imager

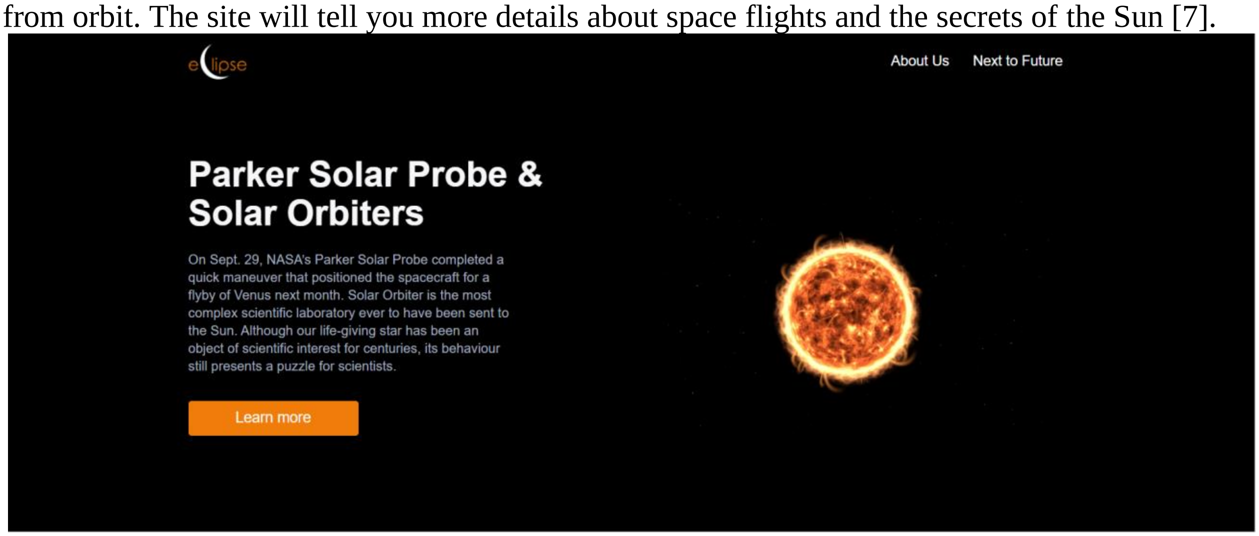
Photos taken from the satellite "CubeSat – 3U"



Photos taken from the thermal imager

A website «Eclipse»

On the website you can get acquainted with orbiting spacecraft, receive daily space forecasts and photos from orbit. The site will tell you more details about space flights and the secrets of the Sun [7].



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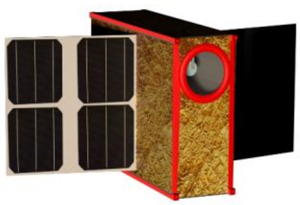
American Space Dushanbe



As part of the NASA 2050 program

The project focuses on current heliophysical missions, such as the Parker Solar Probe and the Solar Orbiter, while encouraging users to think about future solar energy exploration, for example, we plan to launch an orbital solar nanotelescope that studies the Sun.

Learn more

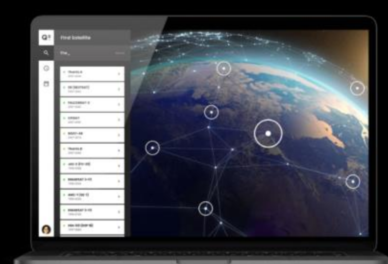
eclipse

About Us Next to Future

Getting photo from telescope remotely

The Observing with NASA website of the Harvard-Smithsonian Center for Astrophysics provides an opportunity to conduct free observations and photographing of spacecraft using a network of micro-observational robotic telescopes. In order to organize the observation process, it is necessary to send an e-mail request to receive an image of the space object of interest from the list posted on the website.

Learn More



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Changeable weather

The weather is the background on which a person develops. He studies, works, communicates with people around him, laughs, feels both in summer and in winter. A person cannot feel joy exclusively in summer, and be in a state of sadness and loneliness all autumn. This happens if a person has set himself up for it. And the weather influence on mood.

Learn more

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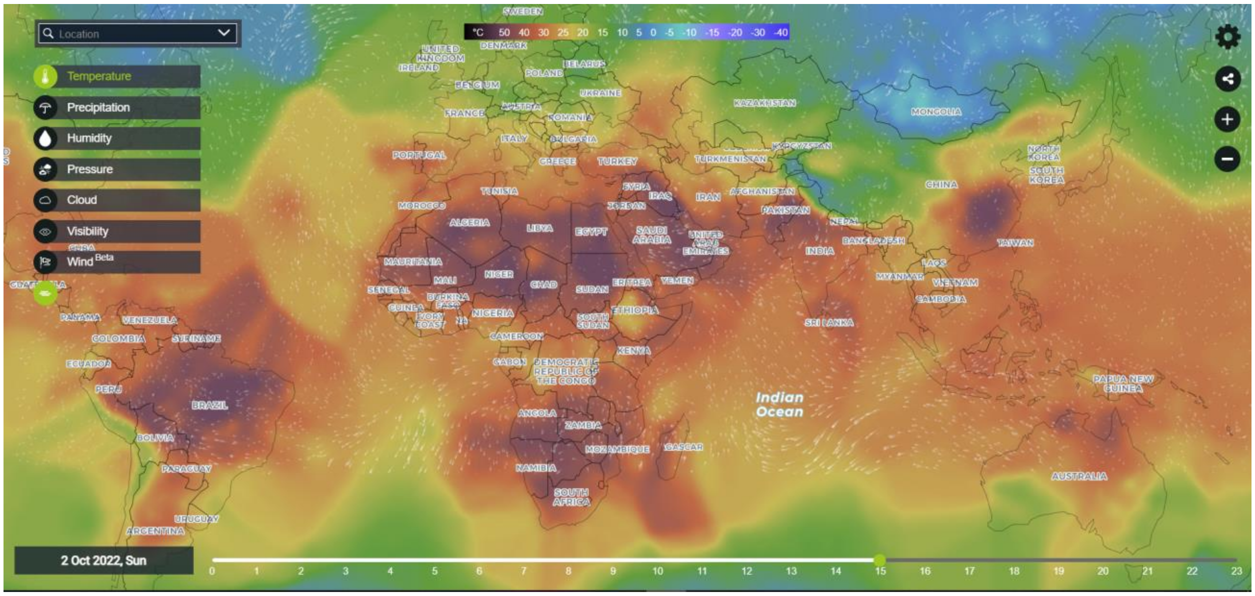

This map allows you to consider noise conditions during data processing when sending data from remote sensing satellites.

Sources

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