Tiksi Hydrometeorological Observatory
Program of Research
First Year Projects and Installations
May 30, 2010
Version 1.0

Программа научных исследований на гидрометеорологической обсерватории в Тикси будет уточнятся. 15 мая 2010 года Научный комитет по программе исследований в Тикси обсудил и принял версию программы 1.0.

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The Science Program of Activities for the Tiksi Hydrometeorological Observatory is a developing document. On May 15th, 2009 Version 1.0_ 15.05.2009 document has been reviewed and accepted by the Tiksi Science team.

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1. Background

1.1 The Tiksi Hydrometeorological Observatory – A component of an International Arctic Hydrometeorological Observing System

In 2005 the Roshydromet Arctic and Antarctic Research Institute (AARI) submitted an Expression of Intent (EoI) to the International Polar Year (IPY) entitled “Developing the Atmospheric Observatory of Climatic Monitoring in Tiksi.” This EoI was integrated in the cluster Activity 196 “International Arctic Systems for Observing the Atmosphere” which coordinates monitoring activities between Observatories in the Arctic regions (www.IASOA.org). In 2006 (February 27th - March 3rd, Moscow) the U.S. National Oceanic and Atmospheric Administration of the Department of Commerce (NOAA) and the Russian Federal Service for Hydrometeorological Monitoring (Roshydromet) held the first official meeting to develop a memorandum of understanding (MOU) for Cooperation in the Areas of Meteorology, Hydrology and Oceanography. Project № 4.1 “ Establishing a Modern Weather Station and Research Observatory in Tiksi, Russia” was defined under this MOU and approved at the Second official meeting between delegates of NOAA and Roshydromet that took place on April 7-11th, 2008 in Silver Springs, Maryland. According to the work plan the objectives of the project are:

- Development of a Hydrometeorological Research Observatory in Tiksi, equipped by modern instruments of observations and communications, a power supply system, laboratory and office facilities suitable for supporting collection of quantitative data on atmospheric structure and processes as well as associated ocean and land parameters in order to further studies of weather and climate

- Integration of observatory measurements into International Networks, such as Global Atmosphere Watch (atmospheric gases and aerosols), Baseline Surface Radiation Network (atmospheric radiation), Climate Reference Network (climate-grade weather observations), Global Terrestrial Networks for Permafrost and Micropulse Lidar Networks (clouds and aerosols)

The Hydrometeorological Observatory activities will facilitate joint Roshydromet and NOAA missions to determine causes and effects of Arctic climate change. The emphasis will be on complex research directed towards understanding the interrelated components of the Arctic climatic system, including atmospheric and hydrological processes, atmospheric chemistry, permafrost degradation, coastal erosion, radiation balances, direct and indirect effects of clouds and aerosols on atmospheric radiation, and surface energy and gas flux balances/exchanges. It is expected that the US/Russian collaboration will provide the foundation for larger institutional and international participation as Tiksi becomes a major research facility in one of the most critical data-sparse regions of the Arctic. It is expected that there will be participation from Roshydromet, NOAA, the Russian Academy of Sciences (RAS), the U.S. National Science Foundation (NSF) and the scientific organizations of additional countries with research interests in the Tiksi region. The Finnish Meteorological Institute is an example of an early partner in this effort. The observatory in Tiksi will be an important component of a network of intensive Arctic atmospheric observatories including Barrow (Alaska, USA), Eureka and Alert (Canada), Summit

Station (Greenland), Ny-Ålesund (Norway), Pallas and Sodankylä (Finland) and Abisko (Sweden); these observatories will jointly provide monitoring over the circumpolar region. The following specific organizations will contribute to this activity:

ROSHYDROMET:
- Arctic and Antarctic Research Institute
- Centre for Environmental Chemistry (CEC) SPA “Typhoon”
- Voeikova Main Geophysical Observatory

The RUSSIAN ACADEMY OF SCIENCES:
- Obukhov Institute of Atmospheric Physics
- Shirshov Institute of Oceanography
- Institute of Physical, Chemical and Biological Soil Sciences
- Melnikov Institute of Permafrost

POLAR FOUNDATION (RUSSIA)

NOAA
- Earth System Research Laboratory
- National Climatic Data Center
- Air Resources Laboratory
- National Environmental Satellite, Data and Information Service

NATIONAL SCIENCE FOUNDATION

NATIONAL AERONAUTIC AND SPACE ADMINISTRATION
- Goddard Space Science Center

UNIVERSITY OF ALASKA

The Tiksi Hydrometeorological Observatory was identified by the International Polar Year Committee as a critical component of an international network of polar stations for monitoring long-term climate change in the Arctic. Creation of a program to organize a network of the Arctic observatories with coordinated strategies for long-term monitoring and study with standardized measurement protocols will be necessary to understand polar amplification of climate trends and the particular vulnerability of the Arctic ecosystems to anthropogenic influences.

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1.2 Science Drivers for the Tiksi Observatory

In addition to the well documented phenomenon of global warming, recent decades have observed fundamental changes in atmospheric composition not only in industrially developed countries, but also in remote regions of the globe, including the Arctic. In particular, for the last 7 years there has been an increase in the rate at which carbon cycle gases have been increasing (from about 1.4 ppm/year during 1990-1999 to 1.9 ppm/year during 2000-2007). These trends appear to be a result of both increased emissions of CO_2 in recent years as well as reduction of the uptake capacity of the ocean and biosphere. The role of the ice covered Arctic Ocean in this balance is presently less clear. Figure 1.1 shows the longitudinal distribution of air temperature anomalies from the instrumented record. Tiksi during the winter period can be seen to be one of the areas with the greatest positive temperature anomalies, especially between 1930 and 1940 which was a particularly warm decade for the entire Arctic region.

Concentrations of anthropogenic aerosols and airborne organic compounds have also increased and many are toxic, mutagen or carcinogenic with significant risks for adverse effects on human health and environments. Extensive experimental data indicate that the chemical processes that are initiated in the vicinity of urban areas and in oil-and-gas and industrial centers can lead to significant evolution of the chemical composition of air at great distances from the emission regions and with effects on remote ecological systems.

Tiksi is located in a boundary region at the confluence of Atlantic and Pacific influences on the Arctic atmosphere resulting in a wide variety of air masses with variable cloud and aerosol characteristics in the vicinity of the observatory. For instance, data from National Centers for Environmental Prediction (NCEP) reanalysis show that cloud cover variability is larger over Tiksi than over Barrow or Alert. This is particularly important in the context of cloud controls on atmospheric radiative fluxes, which are one of the possible reasons for climate change in this region. Observational data sets are presently insufficient to monitor these processes and verify modeled data. Consequently, new radiation data sets such as Baseline Surface Radiation Network and cloud measurements will be established in Tiksi to fill in this observational gap. These new measurements will be significantly more valuable in the context of the historical data of the Tiksi weather station.

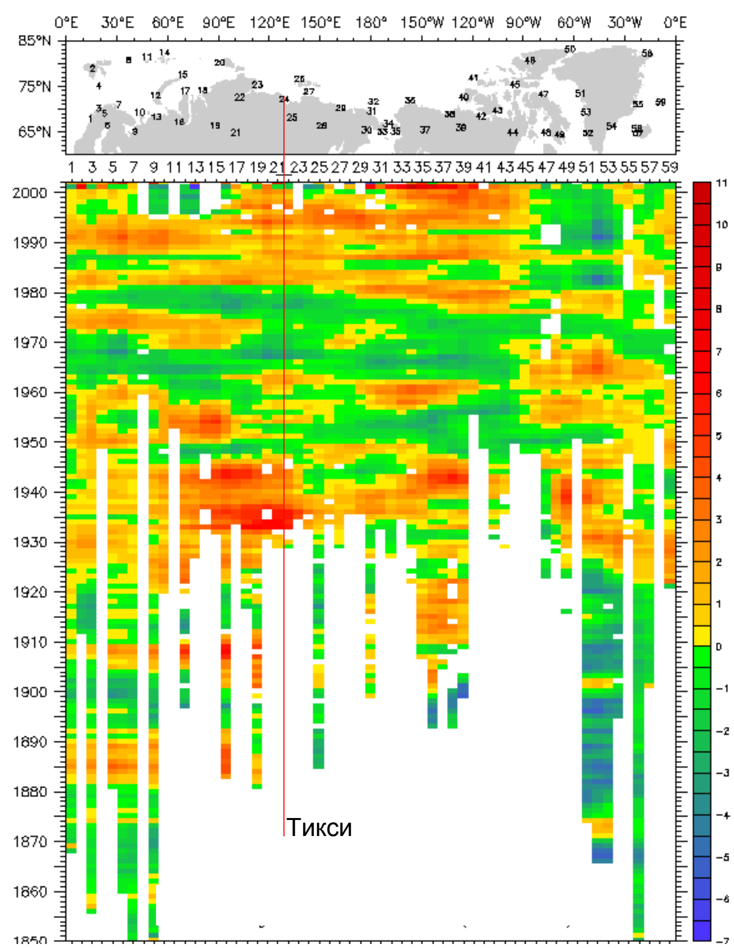


Figure 1.1 - Anomalies of February Surface Air Temperature for 59 Arctic stations (From Overland, 2004)

Tiksi is also in a region of particular interest for Arctic atmospheric pollution. The variable air mass sources create a natural laboratory to study the influence that the various source regions of Russia, Northern America, Europe and Central Asia have on regional air quality.

Tiksi is located at the mouth of the Lena River which is the second largest river draining into the Arctic Ocean; the 524 km^3/year of mean discharge is second only to the Yenisei (586 km^3/yr). The Lena is the only major Russian River for which most of the drainage basin is underlain by permafrost, making it hydrologically complex and particularly vulnerable to climatic warming. Tremendous stores of carbon are presently locked in the permafrost of this river basin, and the evolution of precipitation and evaporation patterns are very important for regional changes in the surface fluxes of CO_2 (increases to atmosphere with surface drying) and CH_4 (increases to atmosphere with increasing surface wetness). Monitoring of greenhouse gases will therefore be another critical program that will be established at the Tiksi Observatory.

The Laptev Sea is an area of such large ice production that it has been termed “the ice factory of the Arctic Ocean” and is the source of much of the sea ice that transits the Arctic Ocean and exits through the Fram Strait. This influences deep convection processes in the Greenland Sea, which is seen as a possible factor in long-term variability of the Earth climate.

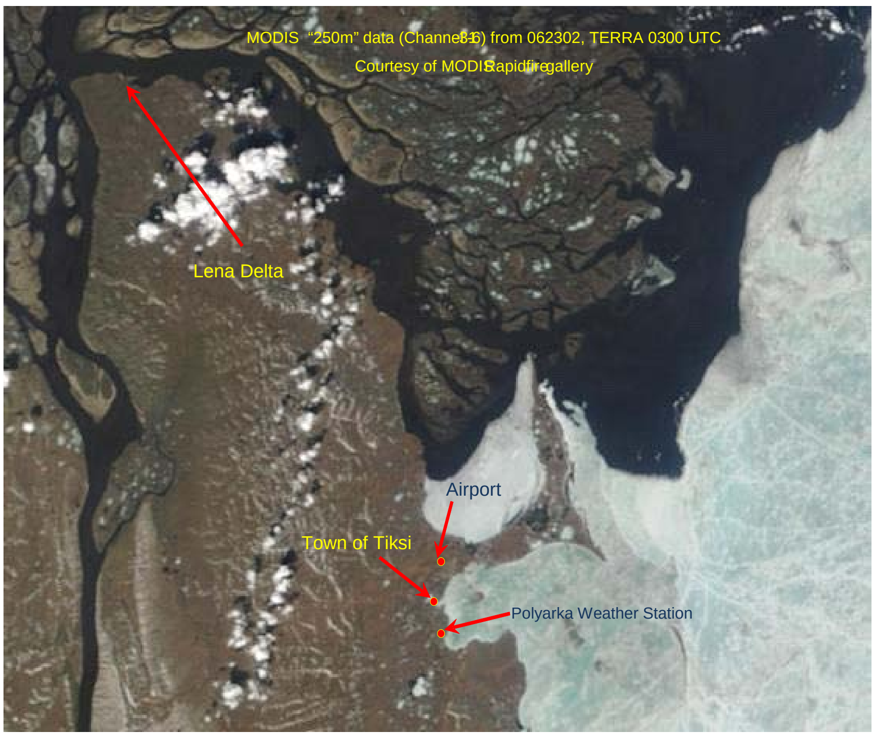


Figure 1.2 Site of the future Hydrometeorological observatory in the region of the existing weather station Polyarka (lowest red dot in figure)

The Laptev and East Siberian Seas show pronounced ice variability and loss during years of extreme ice retreat that are in part attributed to synoptic perturbations in that region. Having an observatory central to this region of high ice variability will allow better understanding of processes that lead to decreases in the perennial pack. Also, should this trend continue, Tiksi will be a strategic location along the Northern Sea Route to monitor conditions that influence ice concentrations, possibly with indicators that can be used for seasonal predictions.

In summary, Tiksi is an ideal location for an intensive research facility to study interconnected components of the Arctic climatic system including atmospheric and hydrological processes, mechanisms of permafrost degradation and coastal erosion, and also processes of the continental shelf which plays a key role in the hydrology of Arctic Ocean.

1.3 Historical Data Records of Tiksi

In addition to these science-based considerations, the Polyarka weather station at Tiksi (71.6º N, 128.9º E) is an optimal location for a long-term climate observatory for a number of historical reasons. The existing meteorological station in Tiksi has one of the longest records of monitoring in the Arctic region. The Polyarka station was established on August 12th, 1932. From the onset, standard meteorological measurements of temperature, humidity, pressure and precipitation were augmented by additional measurements of snow depth, daily solar radiation, wind directions/speeds, and ground temperature. Visibility and cloud cover records were made, originally with just visual observations and then supported with additional instrumented observations starting in 1967. Beginning in January, 1966 there has been a schedule of 8 times/day intensive meteorological observations, and since January 1993 measurements have been made of atmospheric ozone. The Roshydromet Arctic and Antarctic Research Institute began a program of geomagnetic measurements in 1956.

Aerological (balloon) observations were initiated in 1935. Since 1946 there has been a standard 2 times/day launch program. A number of different systems have been utilized. Starting in 1935 Russian radiosondes R3-43 and sensor packages R3-049 designed by P.A. Molchanov were used, followed by the Malachite A-22 system between 1957 and 1975, the Meteorite-2 system with sensor package RKZ-5 from 1975 to 1988, and finally the AVK-1 system and sensor package MRZ-3 from 1988 to the present. The Tiksi Polyarka station is the location of one of the longest, nearly continuous records of upper air soundings in the entire Arctic region.

Oceanographic measurements have also been made at the Polyarka Station since its inception. These include regular measurements of sea surface temperature, salinity and sea surface level. Studies of the evolution of the morphological characteristics of fast ice and snow cover over space and time were initiated in 1932 and have continued to the present, comprising a long decadal historical record of annual variability of ice extent.

To support the Tiksi program, Roshydromet directed its Yakut branch, under the supervision of AARI, to develop a full digitized archive of conventional but critical hydrometeorological data that has been collected at the station for more than seventy years. This data set has been analyzed statistically and combined with mathematical modeling methods and has already enhanced scientific understanding of relationships between historical climate processes. It is also providing a foundation for guiding climate research program design into the future.

1.4 Tiksi Program Developments 2005 to 2009

Representatives of Roshydromet, NOAA, NSF, FMI, the Polar Foundation and the Alliance Group visited the Tiksi meteorological station on July, 2005 (figure 1.3). In addition to assessing the condition of the existing equipment and facilities, the group considered sites for the construction of a new Central Observatory and Weather Building building as well as an additional specialized facility intended to accommodate instruments measuring atmospheric chemistry, aerosols, gases and surface/atmospheric radiative fluxes; this second facility is referred to as the Clean Air Facility (CAF). The site for the Central Observatory and Weather Building was chosen to be in close

Figure 1.3 First expedition of the Tiksi of Observatory Planning Team

proximity to the existing station. The site for the Clean Air Facility was chosen to minimize influences from local sources of air pollution and for horizontal representativeness and uniformity of the underlying surface in a 1 km radius to support comparisons with satellite measurements. These considerations were balanced against logistical constraints such as access to power and operator access. A location was selected 1.5 km North West of the existing weather station for construction of the CAF. The surrounding surface in the vicinity of the CAF is reasonably homogeneous, is covered by a regionally typical mixture of wet and dry tundra vegetation, seasonal streams, rocky shale areas, with a mean altitude of 20-30 meters above sea level. The location is adjacent to an existing electrical line that runs from Tiksi to the weather station. The latitude/longitude of the Central Observatory and Weather Building and the new CAF site are shown in Table 1.1. The sites and relative location with respect to the town of Tiksi and the Geophysical Observatory of the Russian Academy are shown in Figures 1.2 and 1.4.

In August 2007, a second visit was made to the site by representatives of Roshydromet, NOAA, NSF and the Polar Foundation to tour the new Central Observatory and Weather Building building and the foundation work for the CAF. A formal site survey was also conducted to locate a site for a Climate Reference Network site; this site was selected in the immediate vicinity of the new Central Observatory and Weather Building in close proximity to the existing weather station measurements.

Table 1.1 Location of Meteorological station and CAF

	Latitude	Longitude
Meteorological station	71.586166 N	128.91883 E
Clean Air Facility	71.594528 N	128.88838 E

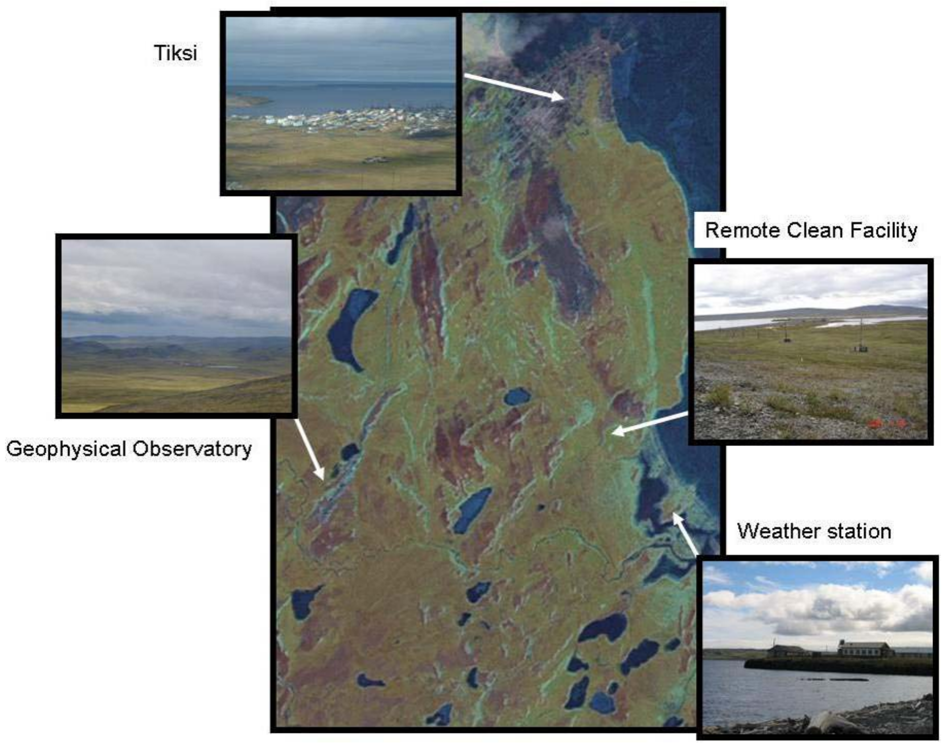


Figure 1.4 Vicinity of the Central Observatory and Weather Building and CAF sites

In September 2009, a team of Russian, U.S. and Finnish scientists arrived to make the first installations of radiation, UV and permafrost (AARI), CO_2 and methane fluxes, aerosol concentrations and size distributions (FMI and MGO), and BSRN, CRN, a turbulent flux tower, carbon cycle gases and black carbon samplers (NOAA). During this visit the science team noted substantial infrastructure improvements including power lines and roads between the town of Tiksi and the Polyarka station/CAF that were the result of support from the government of the Sakha Republic (Yakutia). The Polar Foundation arrived in Tiksi in October 2009 to complete construction work on the Central Observatory and Weather Building, the CAF and the site surrounding the CAF. The instrument installations and construction work were only partially completed due to problems resulting from delays in delivery of the equipment, customs, changes in work schedules and uncompleted building and site improvements.

In June 2010 the team will return to complete installations. In addition to year round standard meteorological and aerologic measurements, programs will be initiated for the climate reference network program (CRN), the Baseline Surface Radiation Network (BSRN), regular surface air samplings to study CO_2 and CH_4 concentrations, precipitation chemistry, monitoring of environmental pollutants, studies of Arctic environment influences on human health, and the surface/atmosphere energy exchanges. The data from these projects will contribute to a number of existing international networks for monitoring and predicting changes in the Arctic climate. These activities will build a scientific foundation for sound policies of environmental management to support maritime economic activities, navigation of Northern sea routes, human health, ecosystem management and Arctic/global climate challenges.

Table 1.2 Projects Scheduled for Tiksi.

Project	Objective
Standard Meteorological Measurements (AARI, ATDD, Yakutsk-Roshydromet)	Create an archive of calibrated meteorological observations. Support CRN program. Provide data to GTS WMO
Surface Radiation Balance (AARI, MGO, ESRL)	Create an archive of calibrated radiation observations. Support BSRN program.
Greenhouse Gases (MGO, FMI, ESRL)	Monitor greenhouse gases. Support WMO GAW program
Atmospheric Pollution (“Typhoon,” ATDD)	Monitor atmospheric pollution and POPs. Support AMAP and UNEP Programs.
Aerosol Studies (IO/RAS, AARI, FMI, MGO, ESRL, NASA)	Aerosol monitoring. Support GAW and AeRoNet Programs
Cloud Studies (MGO, ESRL,NESDIS)	Cloud microphysics and dynamics
Monitoring of UV radiation and total ozone content (AARI, MGO, Biospherical)	Monitor UV. Support UVnet.
Surface heat balance, turbulent heat and energy, CO_2/Methane Fluxes (IFA RAS, AARI, MGO, ESRL, ATDD,FMI)	Heat and energy atmosphere-surface exchanges studies
Precipitation Chemistry/Black Carbon (MGO, University of Washington)	Support COP-15 Black Carbon initiatives
Permafrost Studies (IGC/RAS, AARI, University of Alaska, ATDD)	Study of Permafrost structural evolution in multiple zones
Studies of environmental and climate changes on Human Health (AARI)	Human health in Arctic regions
Satellite Validation and Regional Studies (NESDIS, FMI)	Integration of remote and direct observational methods of the Arctic surface and atmosphere.

2.0 Projects Scheduled for 2010 Start

2.1 Meteorological Measurements

2.1.1 Surface Measurements

Standard meteorological monitoring at the Tiksi station Polyarka began in 1932 and has continued to the present with a consistent set of instruments which is a requirement for all Russian polar stations. These measurements form the basis for both operational prognostic forecasting and for fundamental research. The Tiksi data sets are a unique source of long-term, reliable data about the atmospheric surface layer in a particularly data sparse region of the globe. Despite developments over the last decade in remote methods for measuring fundamental meteorological parameters by a system of automated stations and satellites, the skilled observer remains the most reliable source of high quality detailed data records that includes many more variables than can possibly be collected by the other methods. This is due to the insufficient technologies to ensure reliable operation of instruments used on automatic meteorological stations in the Arctic. Unattended meteorological stations have problems with icing and biases resulting from heating and ventilation of sensors and only a subset of desirable measurements are presently recorded by modern automatic stations. Remote monitoring of basic meteorological parameters from satellites has a different set of issues resulting from the fundamental problem of having to retrieve parameters of interest from a limited number of passive channels as opposed to making direct measurements. Moreover, observer-based data sets of standard meteorological data remain one of the most valuable resources for validation of satellite retrievals.

Presently, the Tiksi station routinely measures atmospheric surface pressure, air temperatures and humidity, ground surface temperature, wind direction and speed, precipitation, snow depth, visibility, cloud base height, visual cloud fraction and type, and surface conditions and atmospheric phenomena. Table 2.1 presents the schedule of meteorological measurements of the Tiksi Station.

Table 2.1 – Timetable of meteorological observations at the Tiksi polar station (UTC)

Time of standard meteorological observations	Precipitation measurements	Snow Observations		
		Snow depth	Fractional coverage	Snow Morphology
0, 3, 6, 9, 12, 15, 18, 21	0,12	12	12	12

The extensive historical measurements are collected with instruments and with recording methods that require substantial updating from both the standpoint of antiquated instruments that can no longer be maintained and from the need for additional digital recording procedures to provide real-time internet dissemination. In 2010 the station will be equipped with an automated meteorological station (AMS) with the capability of measuring air temperature and humidity, surface temperature, wind speed and direction and atmospheric pressure. This is intended to supplement, not replace the regular observer observations. Table 2.2 lists the range and accuracy of measured variables that new modernized sensors will provide:

Table 2.2 - Characteristics of gauges for modernized standard meteorological observations

Parameter	**Instrument**
Air Temperature (T) and relative humidity (RH)	T measurement range: -50 °C to 50 °C, RH measurement range: 10 - 100 %, T error: at T >-30°C ±0,2 °C, at T < -30 °C ± 0,3 °C, RH error: ±2 %
Wind Speed	Measurement range. 0 – 75 m/s; threshold speed <0,5 m/s, : <30 m/s ± 0.3 m/c, at speed >30 m/s- 5 %
Wind direction	Measurement range: 0 - 360 °, resolution ± 2,8 °, threshold of sensitivity <1 m/s, error: ±3 °
Atmospheric pressure	Measurement range 600 – 1100 hPa, error: ±0,3 hPa
Ground temperature	Measurement range: -60°C to +60 °C, error: ± 0,3 °C.

2.1.2 Climate Reference Network

The U.S. contribution to meteorological measurements will consist of a Climate Reference Network (CRN) suite of instruments. The CRN will be installed in close proximity to the existing weather station sensors and is composed of triple redundant measurements of temperature and precipitation insuring continuity of a highly calibrated record. CRN stations are monitored and maintained to high standards, and are calibrated on an annual basis. In addition to temperature and precipitation, these stations also measure solar radiation, surface skin temperature, and surface winds, and are being expanded to include triplicate measurements of

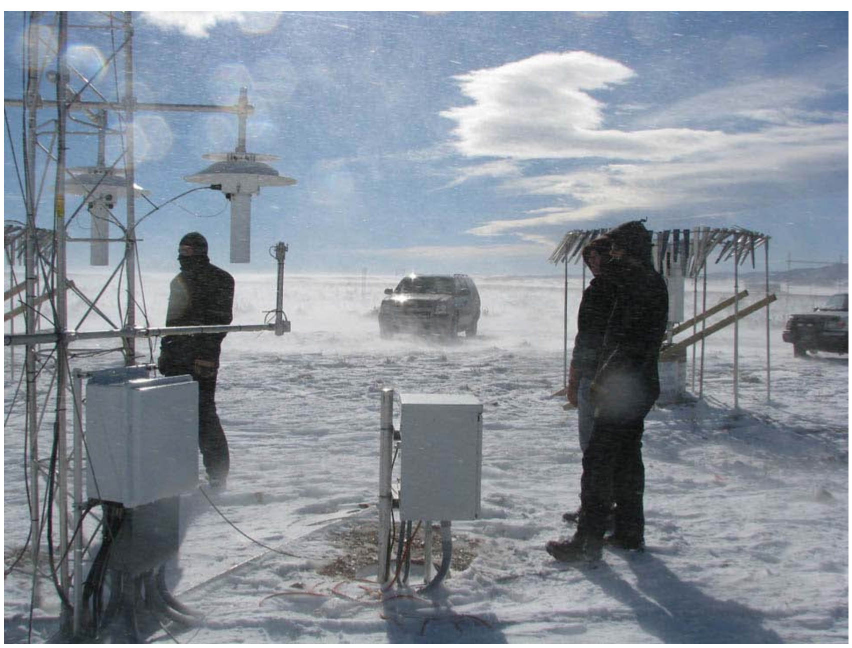


Figure 2.1 - The Standard CRN climate station

soil moisture and soil temperature at five depths, as well as atmospheric relative humidity. Experimental stations have been located in Alaska since 2002 and provide experience with special operational issues in Arctic regions. There are presently 112 stations in the continental U.S. and the 2 stations in Canada. The Tiksi station will be the 3rd station to be established outside of U.S. territories; a second Russian station is planned in the near future to be located in Yakutsk.

2.1.3 Upper Air Measurements

Current upper air measurements at the Tiksi Station include height (pressure), temperature and wind speed at 0 and 12 UTC; these are done with a tracking system that requires operator supervision for the duration of the launch. In 2010 the Tiksi Hydrometeorological observatory will be updated with the automated sounding system "VECTOR-M." The VECTOR-M radar-tracking system obtains atmospheric profiles of temperature, winds and humidity. The system performs preflight checks of a radiosonde instrument, automatic in-flight support, reception and processing of the coordinate-telemetric information, and processing and transfer of aerologic data transmissions through dedicated channels to an on-line archival system.

The automatic data processing system "VECTOR-M" is a class of digital radiosonde systems with an automatic tracking antenna and can be remotely controlled by an operator from a computer; automatic handling of the processed meteorological information and data transfer on meteorological bulletin channels and archiving routines. The system "VECTOR-M" is shown on figure 2.4 and its characteristics are listed in table 2.3.

Table 2.3 - " VECTOR-M " System Characteristics

Parameter	**Range and error of measurements**
Sounding range, km	20 - 250
Maximum Altitude, km	40
Frequency Range, MHz	1680 ±10
Air Temperature, °C	Measurement range -90 - +50, error ±0.15
Relative humidity, %	Measurement range 0 – 100; error ±0.5
Instantaneous and average wind speed, km/s	Measurement range 0 - 100; error ±0.7
Instantaneous and average wind direction, hail	Measurement range 0 - 360 °; error 1.5
Atmospheric pressure, hPa	Measurement range 2 – 1100; error ±2 hPa
Radiosondes types	MRZ-3A; MRZ-3AM; RZM-1-01; RZM-2-01; RZM-3-01; THE RUSSIAN FEDERATION-95
Operations Manuals	КН-04; ТАЭ-16М; ТАЭ-3; «СЛОЙ»; «ПРИЗЕМНЫЙ СЛОЙ»

a) b)

Figure 2.2 (a) Antenna and (b) receiving center for aerologic radar-tracking complex Vector-M

2.2 Measurements Supporting the Baseline Surface Radiation Network (BSRN) Program

The purpose of the Tiksi atmospheric radiation measurements will be improved information on the components of the surface radiation balance in a poorly observed geographical area. This will fill in a major gap in the Baseline Surface Radiation Network (BSRN) program (https://www.gewex.org/bsrn.html). The stated objectives of the BSRN program are to "provide a worldwide network to continuously measure radiative fluxes at the Earth's surface." The program began operations in 1992 and in 2008 had 43 stations providing data to the central archives in Bremerhaven, Germany. New stations are added regularly, and in 2004 BSRN was endorsed as the global surface radiation network for the Global Climate Observing System (GCOS). Activities include:

- Monitor the background shortwave and long-wave radiative components (least influenced by immediate human activities which are regionally concentrated) and their changes with the best methods currently available.
- Provide data for the calibration of satellite-based estimates of the surface radiative fluxes.
- Produce high quality observational data to be used for validating the theoretical computations of radiative fluxes by models

In Tiksi, the radiation measurements will be made with both standard Russian radiation sensors supplied by AARI and BSRN sensors supplied by NOAA. An important inter-comparison study of comparable measurements of direct, total and diffuse solar radiation will be made between the BSRN measurements and the standard actinometric measurements that are made at Russian radiation stations.

2.2.1 Russian Standard Radiation Measurements

The Russian instruments were installed in October 2009 (Figure 2.3). The characteristics of the Russian Standard Sensors are summarized in Table 2.4.

Table 2.4 – Characteristics of gauges for radiation measurements of Russian instruments

Direct solar radiation Actinometer AT-50	Spectral interval: 200 - 4000 nanometers, range: 0.01 - 1600 W/m^2, accuracy: <1.7%
Direct and diffused soar radiation Pyranometer M-80	Spectral interval: 200 - 4000 nanometers, range: 0.01 - 1600 W/м^2, accuracy: ±20 W/m2

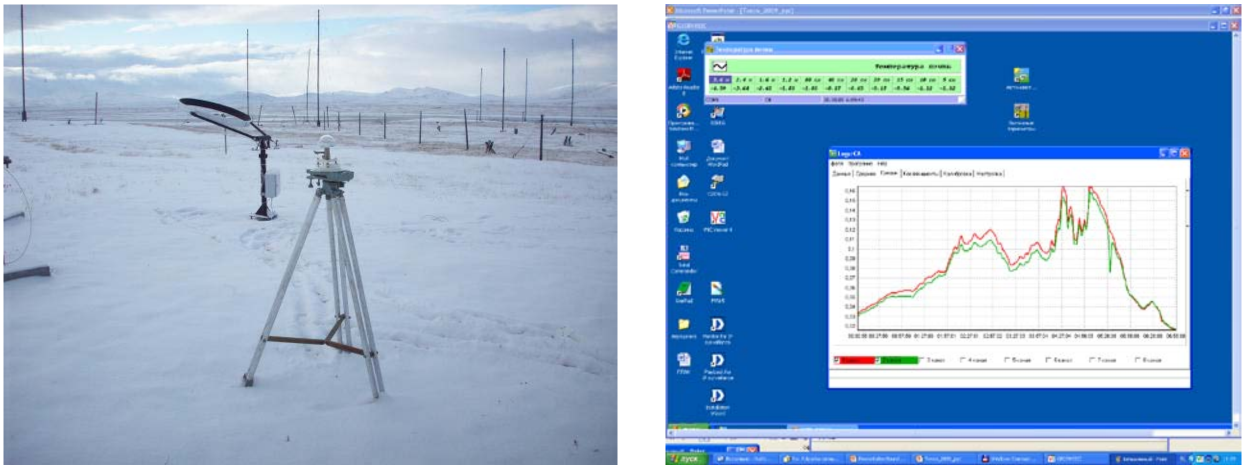


Figure 2.3: Russian sensors for measurement of total and diffused solar radiation, installed at the Hydrometeorological Observatory Tiksi (left) in October 2009 and an example of real-time data being received at the AARI Tiksi data center in St Petersburg, Russia (right).

2.2.2 BSRN Standard Radiation Measurements

The BSRN instruments (Figure 2.4) were shipped to Yakutsk in August 2009 and are scheduled for installation in May 2010. Examples of similar installations in Canada are shown in Figure 2.4. The characteristics of the BSRN sensors are summarized in Table 2.5.

Table 2.5 – Characteristics of gauges for radiation measurements of BSRN instruments

Variable/Instrument	**Range/accuracy**
Direct solar radiation Pyranometer CH1	Spectral interval: 200 - 4000 nanometers, range: 0 - 4000 W/m^2, accuracy: 2 % or ±3 W/m^2
Downward, diffuse and reflected solar radiation Pyranometer CM22	Spectral interval: 200 - 4000 nanometers, range: 0 - 4000 W/m^2, accuracy: ±9 W/m^2
Diffused solar radiation Pyranometer B&W 848	Spectral interval: 200 - 4000 nanometers, range: 0 - 1000 W/m^2, accuracy: ±5 W/m^2
Upward and downward long-wave radiation Radiometer PIR	Spectral interval: 5 - 42 microns, range: 0 - 4000 W/m^2, accuracy: ±10 W/m^2
Direct solar radiation on wavelengths 412, 500, 675, and 862 nm, Sun photometer SP-02	Optical thickness Resolution = .005 OT
Direct solar radiation on wavelengths 440, 670, 870, 936, and 1012 nm Sun photometer CE-318	Total water vapor, ozone and aerosol contents

a b

Figure 2.4: (a) BSRN Albedo rack with downward looking radiometers (b) BSRN upward looking radiometers and solar tracker

The data from the BSRN radiation suite and the Russian radiation sensors will be transferred via near real-time satellite to AARI where BSRN prescribed processing and quality checking will be performed. The data will then be submitted monthly to both the BSRN archives as well as the World Radiation Data Center (WRDC).

These continuous radiation data sets will be used to develop observation based records of surface forcing for climate research and development of improved parameterizations of radiative exchange between the surface and the atmosphere in climatic and prognostic models.

In addition to the instrumented measurements of radiation and albedo, the weather station observers will continue a long-term historical record of visual descriptions of the underlying surface and weather conditions including cloud characteristics, percentage sky overcast and visibility of the solar disk.

2.3 Measurements Supporting the Global Atmosphere Watch (GAW) Program

The Global Atmosphere Watch (GAW) Program addresses the need to understand and control the increasing influence of human activity on the global atmosphere. Among the grand challenges are:

- Stratospheric ozone depletion and the increase of ultraviolet (UV) radiation
- Changes in the weather and climate related to human influence on atmospheric composition, particularly, greenhouse gases, ozone and aerosols
- Risk reduction of air pollution on human health and issues involving long-range transport and deposition of air pollution

The focus of the GAW program is on global networks for monitoring GHGs, ozone, UV, aerosols, selected reactive gases, and precipitation chemistry. The stated objectives of the WMO/GAW program (http://www.wmo.int/pages/prog/arep/gaw/gaw_home_en.html) are a "partnership involving 80 countries, which provides reliable scientific data and information on the chemical composition of the atmosphere, its natural and anthropogenic change, and helps to improve the understanding of interactions between the atmosphere, the oceans and the biosphere."

The Tiksi site will be particularly useful filling in a critical gap for the Global Atmosphere Watch Program (GAW) program due to both its remote location in a data sparse, pristine region and because of the enhanced warming that has been observed in the Russian Arctic sector. The Tiksi Observatory will complement high Arctic GAW stations presently operation at Alert (Canada), Ny-Alesund (Norway), and Barrow (USA).

2.3.1 Flask Sampling of Atmospheric Gases

The changing concentrations of greenhouse gases are recognized as one of the principal causes of climate change. The purpose of the flask program will be to take samples of air that will be analyzed for relevant carbon cycle gases. The primary greenhouse gases of interest are CO_2, CH_4, CO, H_2. Additionally, N_2O and SF_6 are of interest due their role in destruction of ozone, and the isotopes of carbon (C_{13}) and oxygen (O_{18}) can be used to provide information on air mass origins and atmospheric circulation. This project is a component the World Meteorological Organization (WMO) Atmosphere Watch (GAW) Program. The Russian Federation is a member of the WMO, and yet presently has only one official GAW station in Obninsk.

Redundant flask samples using a sampler (Figure 2.5) developed by the NOAA/GMD laboratories will be made on a regular weekly schedule, the samples will then be sent for analysis to NOAA/GMD in Boulder and Roshydromet/MGO in St. Petersburg. The NOAA/GMD Laboratory is the location of accepted air standards, and will analyze the flask samples for CO_2, CH_4, CO, H_2, N_2O, and SF_6 and the stable isotopes of CO_2 and CH_4 consistent with the Carbon Cycle Greenhouse Gas (CCGG) Cooperative Air Sampling Network Program. The Roshydromet/MGO laboratory will also perform analysis for a subset of these gases; CO_2, CH_4, H_2 and CO. The NOAA gas sampler is presently in Tiksi and the procedures for sample permits and regular of transportation of flasks between Tiksi and Boulder and St. Petersburg is in progress.

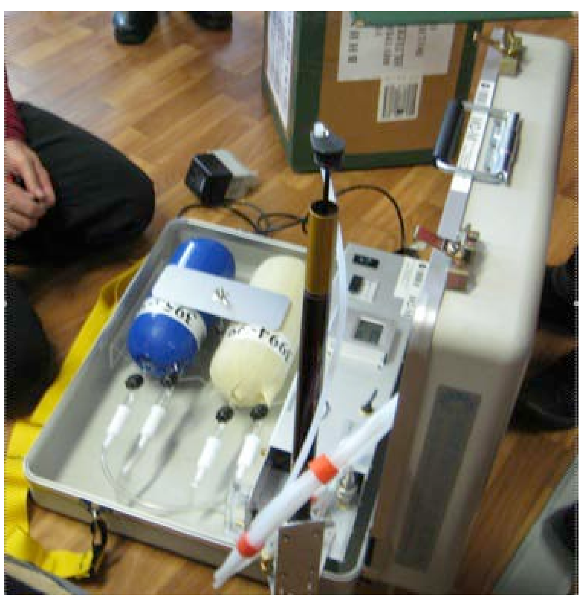


Fig. 2.5 NOAA Air Sampling Portable Device

2.3.2 *Black Carbon*

Black carbon (BC, sometimes referred to as soot) is a strong forcing agent for climate in general and the Arctic in particular. Unlike other aerosols, BC is expected to warm the atmosphere and, if deposited to the Arctic surface, increase the rate at which sea-ice and glaciers are disappearing. It may also have significant impacts on the water-ice balances of Arctic clouds and resulting radiative (energy balance) effects. Once emitted, BC has a short lifetime in the atmosphere (days to weeks); thus its reduction can be expected to provide rapid payback in reducing climate change. However, there are many key uncertainties about BC that preclude a confident estimation of its current contribution to Arctic climate and the potential gains to be made by emission abatement. This uncertainty is made even greater because the sources of BC to the Arctic are not well defined, the impacts of BC on Arctic climate and the melting of sea ice are not well understood, and the temporal trends in BC abundance, transport, and deposition over the past decades are poorly quantified. Uncertainties associated with modeling the transport of BC to the Arctic and the associated climate impacts are even larger.

The aethalometer® (figure 2.6) is an instrument that uses optical analysis to determine the mass concentration of particles collected from an air stream passing through a filter. These particles are directly emitted to the air during all combustion and are primarily associated with coal or diesel smoke. Aethalometers are used by air-quality monitoring programs. The AE31 Aethalometer measures optical absorption by suspended aerosol particles at seven wavelengths, (370, 450, 571, 615, 660, 880, and 950 nanometers). Real-time measurements of particle concentrations can be made with a time resolution of two minutes to one hour. Interpretation of the differences in optical response across the wavelength spectrum reveal information regarding aerosol size distribution, physical properties, and assist in identifying the primary components. A digital display/keypad combination interface is used to operate, monitor, calibrate, and service the instrument. The measurement data are stored within the instrument on removable media (compact flash or floppy disc drive options available). An analog channel outputs a signal for communicating the real-time mass concentration to an external data logger. This analog channel can also be programmed to communicate an instrument status condition. The NOAA aethelometer has been operating in Tiksi since September of 2009.

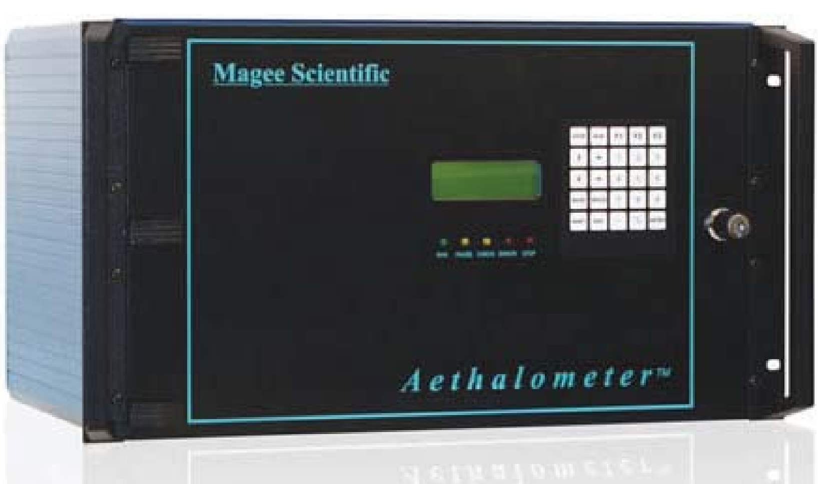


Figure 2.6 Magee Scientific AE31 Aethelometer

2.3.3 Carbon Dioxide, Methane and Water Vapor Concentrations

Another component of the greenhouse gas program is continuous measurement of carbon dioxide, methane and water vapor concentrations. This is important as information is lacking on the regional characteristics of these exchanges in the arctic and boreal regions which are main source or sink regions due to high biomass and soil carbon storage and extensive wetlands. In October 2009, the Finnish Meteorological Institute installed a system in the CAF that makes measurements of methane and carbon dioxide based on a laser spectroscopy (DLT-100) technology manufactured by Los Gatos Research, Inc. (figure 2.7). The instrument calibrates measurements of ambient outdoor air with gas standards from the World Meteorological Organization Calibration center at NOAA, in Boulder, Colorado U.S.A. The measurement system includes an air sample cryo-dryer from M&C Products TechGroup GmbH and a Nafion gas dryer by Perma Pure LLC.

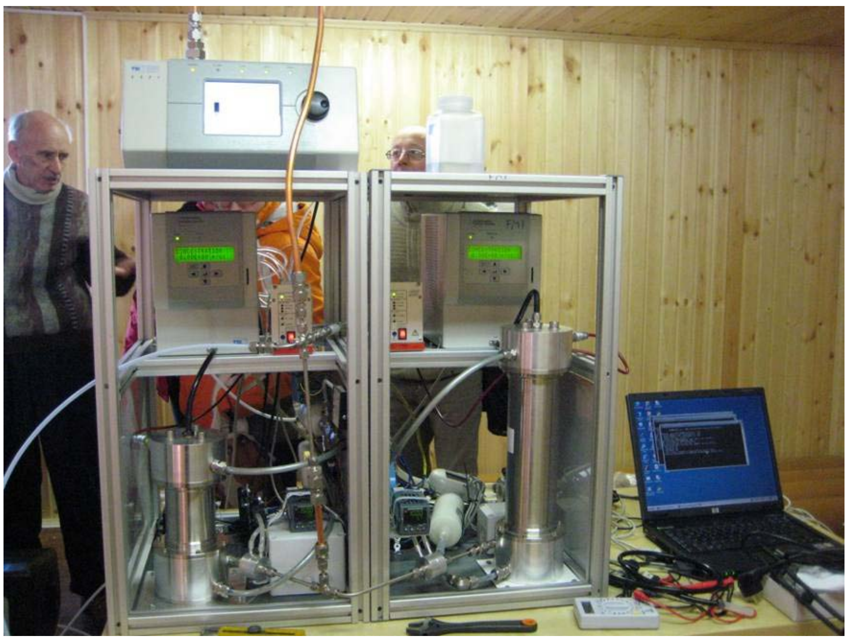


Fig. 2.7 CO2 and Methane measuring system installed by FMI in the CAF

A second program for measuring continuous concentrations of CO_2 will be established by AARI using a commercial device sold by the ОПТЭК (OPTEC) Company. The sampler will be installed in the CAF and 5 min samples will be averaged to 1 hour averages. Station operators will provide operations support including weekly calibration and periodic transfer of data from the sampler to media for transmission through the Tiksi communications system to the AARI Tiksi Data center in St Petersburg. Data will be further processed at MGO and AARI on a monthly basis that will account for wind direction so that data can be edited to represent concentrations of CO_2 and CH_4 for uncontaminated clean air sectors.

2.3.4 Aerosol Particle Measurements

Aerosol particles strongly affect the global climate by scattering and absorbing solar and terrestrial radiation and by changing the cloud properties. Aerosol effects depend on particle number, size and composition. Aerosol data in the Arctic and northern Siberia area are infrequent and long-term aerosol measurements in Tiksi are of major importance to quantify aerosol related climatic effects both regionally and globally. The Finnish Meteorological Institute (FMI) will measure the aerosol particle number size distributions in Tiksi with sizing instrumentation capable of high time and spectral resolutions and with a total particle size range from 7 nm to 10 µm diameters. The set-up consists of 2 separate instruments, the first is a DMPS (Differential Mobility Particle Sizer) instrument with a range of 7–500 nm, and the second is a TSI APS (Aerodynamic Particle Sizer) system with a range of 0.5 – 10 µm. The measurement principle of the DMPS is based on the particle electrical mobility which depends on the particle size whereas the APS classifies the particle sizes with a time-of-flight technique. The data is collected in-situ continuously and one aerosol particle size spectrum is obtained every 10 minutes.

2.3.5 Aerosol Optical Depth

Aerosol optical depth (AOD) is a quantitative measure of the extinction of solar radiation by aerosol scattering and absorption between the point of observation and the top of the atmosphere. It is one of the most important parameters determining the atmospheric impact on surface energy and radiation balances. NASA has contributed a CIMEL sun photometer (figure 2.8) to the Tiksi program to expand the AERONET (Aerosol Robotic NETwork) program that makes global measurements of AOD (http://aeronet.gsfc.nasa.gov/new_web/index.html). The measuring system consists of a photometer system with 9 filters (1020, 870, 675, 440, 500, 940, 380, 340 and 1640 nanometers) and will be installed by personnel from the NASA AERONET Program in June of 2010. The AERONET program supports a long-term, continuous and readily accessible public domain database of aerosol optical, microphysical and radiative properties for aerosol research and characterization, validation of satellite retrievals, and synergism with other databases. The network imposes standardization of instruments, calibration, processing and distribution.

Figure 2.8 CIMEL Sun photometer

2.3.6 Precipitation Chemistry

Monitoring of precipitation chemical composition consists of two phases: field sampling and laboratory analysis. The first phase involves collecting samples of precipitation (solid and liquid) in specialized sampler devices with precipitation amounts being recorded from standard gauges. Samples must be stored at the Central Observatory and Weather Building at sufficiently cold temperature while awaiting transport to the MGO analysis laboratory in St. Petersburg. The samples will be gathered in compliance with standardized GAW rules for selection of sampling sites, storage, and transport of samples to meet conditions that ensure the reliability of the resulting data on precipitation composition.

The second phase of the precipitation chemistry program will be carried out in the laboratory. In 2008 there were 12 regional precipitation chemistry laboratories operating within Roshydromet system. These laboratories have the capability to analyze precipitation samples and identify 9 main macro-components including ions of sulfates, chlorides, nitrates, hydrocarbons or acids, ammonium ions, sodium, potassium, calcium, magnesium and values of pH, conductivity and total salinity. In the MGO Laboratory, the analysis equipment includes an ANION- pH meter (conductivity and pH) and a PFA-378 flame photometer (potassium, sodium and calcium in aqueous solution). MGO will adhere to the standards of the WMO GAW program for all aspects of data quality control and standards in providing analysis of the samples.

2.4 Measurements Supporting the Arctic Monitoring and Assessment Program (AMAP)

The Tiksi Observatory will support organization of measurements atmospheric pollutants such as Persistent Organic Pollutants (POPS) and heavy metals to support monitoring programs that are compliant with the Arctic Monitoring and Assessment Program (AMAP). The stated objective and priorities of AMAP (from www.amap.no) are:

“A coordinated monitoring program to:

- produce integrated assessment reports on the pollution status and trends of the conditions of Arctic ecosystems
- identify possible causes for changing conditions
- detect emerging problems, their possible causes, and the potential risk to Arctic ecosystems including indigenous peoples and other Arctic residents
- Recommend actions required to reduce risks to Arctic ecosystems

AMAP's priorities include the following contaminant groups and issues:

- Persistent organic contaminants (POPs)
- Heavy metals (in particular mercury, cadmium, and lead)
- Radioactivity
- Acidification and Arctic haze (in a sub-regional context)
- Petroleum hydrocarbon pollution (in a sub-regional context)
- Climate change (environmental consequences and biological effects in the Arctic resulting from global climate change)
- Stratospheric ozone depletion (biological effects due to increased UV-B, etc)
- Effects of pollution on the health of humans living in the Arctic (including effects of increased UV radiation as a result of ozone depletion, and climate change)

- Combined effects of pollutants and other stressors on both ecosystems and humans"

Tiksi is located at the mouth of the Lena River delta, which is recognized by AMAP as one of the 10 critical focus areas in the Arctic region.

2.4.1 Persistent Organic Pollutants

The project goal is to implement AMAP programs for measuring the concentration of persistent organic pollutants (POPs) and the monitoring of heavy metals and mercury, similar to the existing global network at GAW stations in Alert (Canada) Nu Alesund (Norway), Barrow (USA) and others (figure 2.9). To date, monitoring of surface-level Persistent Organic Pollutants (POPS) in the Russian Arctic has been episodic. The existing records are Dunay Island (1993-1994), Amderma (1999-2001), and Val'karkai in the Chukotka (2002-2003; 2008-2010). The only Russian Arctic station with a history of mercury measurements (since 2001) is Amderma. Tiksi is located in close proximity to Dunay Island; therefore there will be some opportunity for comparisons of new to historical measurements. In addition to quantifying local concentrations of pollutants, the Tiksi measurements will also facilitate the transport pathway and source studies when used in conjunction with other stations in the AMAP network.

Year-round monitoring of POPs will be established on the roof of the CAF through a hatch. POPs are sampled by pumping ambient air through a series of absorbent and aerosol filters; to capture ultralow concentrations of POPs, each filtering period involves pumping a volume of not less than 10,000 m^3 of air through filtration system. The system requires a high efficiency pumping system and shields to protect the filters from rain and snow (figure 2.10).

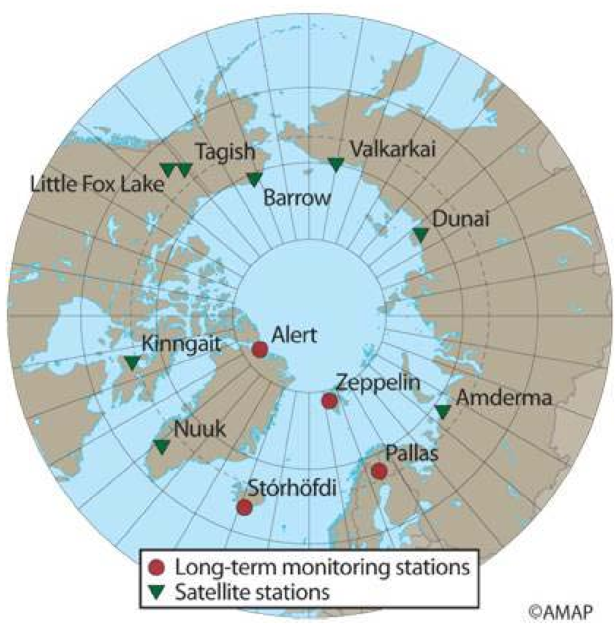


Figure 2.9 Location of Arctic POP stations

The filters and absorbents will be replaced weekly and sent to an analytical laboratory in Obninsk once every three months. The primary analysis method will be Gas Chromatography/Mass-Spectrometry to determine concentrations of 20 polycyclic aromatic hydrocarbons (PAHs) as well as the organo-halogen compounds including 60 congeners of polychlorinated biphenyls, 25 chlorinated pesticides, and the 7 isomers of toxaphene. Protocols for sampling and analysis will be consistent with the Arctic Air Toxics Network of the Canadian Northern Contaminants Research Program. This part of the Tiksi program is expected to contribute significantly to acquiring information for the Stockholm Convention on POPs.

Figure 2.10 Example of POPs sampling instruments

2.4.2 Heavy Metals

The objective of the studies on heavy metals, particularly mercury is to quantify the possible long-range transport and deposition of the semi-volatile species to the ‘Cold Pole’ of the northern hemisphere and eco-toxicological effects. Heavy metals are monitored with filter air sampling techniques similar those used for POPs. Air intakes will be installed on the roof of the CAF on the same platform that supports the POPs air intakes, and air will be pumped through a system of filters designed to capture heavy metals.

In view of the low concentrations of heavy metals in Arctic air, analysis utilizes atomic absorption spectroscopy (AAS) methods. Products of the analysis will include concentrations of ten elements including lead, cadmium, copper, nickel, barium, zinc, cobalt, chromium.

Airborne total gaseous elemental mercury will be monitored with an automated Tekran 2537A system that makes measurements continuously with the accuracy of parts of 1 ng/m3. The technique is based on highly selective gold adsorption of mercury vapor from the air. The analyzer is equipped with two gold cartridges (channels A and B). One cartridge is used to absorb mercury from the ambient air stream, the mercury in the second cartridge is thermally desorbed of mercury and total mercury mass is then determined using a cold water vapor atomic fluorescence spectrometer. The exposure time period for each cartridge is 30 min yielding a measurement resolution of 1/hr. These are further averaged to obtain daily concentrations.

2.4.3 Surface and Total Column Ozone

The NOAA Ozone and Water Vapor Group conducts research on the nature and causes of the depletion of the stratospheric ozone layer and the role of stratospheric and tropospheric ozone and water vapor in forcing climate change and in modifying the chemical cleansing capacity of the atmosphere. This mission is accomplished through long-term observations and intensive field programs that measure total column ozone, ozone vertical profiles (ozonesondes and umkehrs), ground level ozone, and water vapor vertical profiles in the upper troposphere and stratosphere and through transport modeling with isentropic trajectories. The NOAA contribution to the Tiksi Observatory Program is a Thermo Electronic 49i Sampler for the measurement of ground level ozone (Figure 2.11). Total column ozone is measured with a commercial Russian M-124 instrument (Figure 2.12).

Figure 2.11 Thermo Electron Corporation Model 49i Ozone Sampler

2.4.4 UV Radiation

The ozone program is designed to investigate the effects of UV radiation on humans, ocean ecosystems, and atmospheric chemistry as well as to provide validation for satellite-based UV observation programs. In October 2009, the Russian team installed a UV-radiation attachment to the existing M-128 ozonometer in Tiksi. The U.S. is currently identifying funding for an SUB150B instrument that would run side-by-side with the Russian instrument and would be compliant with the global international network for monitoring UV radiation. The SUB150B system is similar to existing observing systems at Barrow and Summit. The modified for UV radiation ozone sampler M-124 is compliant with the observational network standards for ultraviolet radiation in Russia. Data obtained using both devices will be a significant contribution to the WMO environmental UV monitoring reports that are updated regularly.

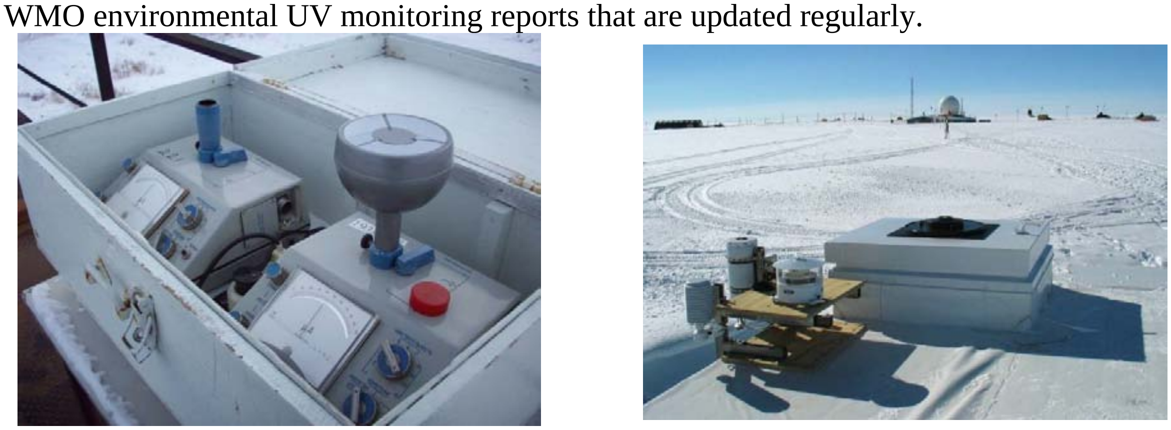


Figure 2.12 - Installations for observations of ultra-violet radiation: ozonometer M-124 with Larshe sphere in Tiksi (left) and device SUV-150B in the Summit, Greenland (proposed for Tiksi).

2.5 Turbulent Fluxes

Observational evidence suggests that atmospheric energy fluxes are a major contributor to the decrease of the Arctic pack ice, seasonal land snow cover and the warming of the surrounding land areas and permafrost layers. To understand the atmosphere-surface exchange mechanisms, improve models, and to diagnose climate variability in the Arctic, accurate measurements are required of all components of the net surface energy budget, the carbon dioxide cycle and important greenhouse gases for different regions of the Arctic during every season over many years. Although there is not a formal international Arctic flux network program, the need for such measurements has resulted in the development of flux tower installations around the Arctic, including the stations at Eureka, Ny-Alesund, Barrow, Pallas/Sodankylä, and Summit.

The Russian, U.S. and Finnish teams all have significant experience with measurement and analysis of turbulent and energy balance fluxes as well as fluxes of water vapor and carbon dioxide, and methane. Two separate installations for measuring fluxes over the tundra are being installed in Tiksi.

2.5.1 Methane and Carbon Dioxide Fluxes

The research teams from the Finnish Meteorological Institute and the Russian Main Geophysical Observatory partially installed instruments for measuring fluxes of carbon dioxide, methane and the components of the energy balance over a carefully chosen, representative tundra surface in the fall of 2009 (Figure 2.13). This installation when completed will utilize the micrometeorological eddy-covariance technique and measurements will be made at some distance from the Clean Air Facility. The instrumentation consists of three-axis sonic anemometer/thermometers, an NDIR analyzer for carbon dioxide and water vapor, and a high-flow TDL instrument. A limited set of meteorological observations, radiation, air and soil temperatures and humidity are measured to support flux measurements and data interpretation.

This information is expected to improve understanding of how permafrost tundra areas act as greenhouse gas source or sink in the present climate. The data will form a reference data set for the future conditions when the vegetation and soil processes may experience changes. Additionally, the local flux data will be used to accurately atmospheric concentrations of mercury and CO_2 to distinguish the relative effects of local source and large scale signals.

The micrometeorological studies in Tiksi will be the first year-round CO_2 and CH_4 flux measurements in high-Arctic areas. This will provide an opportunity to study spring and late autumn GHG emissions, which have been shown to be important in the permafrost areas. Plant growth and CO_2 and CH_4 exchanges will be studied in detail in relation to the high temporal resolution of flux observations. Remote sensing validation will be performed from areal averages of sensible/latent heat and CO_2 flux observations. Specific research objectives will be to:

- Estimate the seasonal cycle of CO_2 uptake by plants and respiration by soil and plants and to measure the annual carbon balance
- Quantify relationships between CO_2 uptake by plants and remote sensing vegetation indices
- Study how methane emissions from tundra ecosystem are related to soil thawing and freezing, environmental parameters and phrenology of vegetation

Figure 2.13 Micrometeorological eddy-covariance fluxes of carbon dioxide and methane will be measured on the tundra at a distance from the CAF (visible in background).

2.5.2 Surface Radiation and Energy Fluxes

The Tiksi Observatory facility will also include a 20 m flux tower to measure low level gradients of fluxes. Turbulent fluxes (momentum, sensible and latent heat) and meteorological data (wind speed and direction, air temperature and humidity) will be continuously measured and reported at three levels. Each level of the tower will be instrumented with identical Applied Technologies, Inc. (ATI) three-axis sonic anemometer/thermometers with heaters. A similar 10 m tower from Eureka, Canada is shown in figure 2.14. Licor-7500 fast-response infrared open-path gas analyzer (H_2O and CO_2 measurements) will be mounted on the second level. Turbulent data are sampled at a frequency of 10 Hz and the fluxes are based on the eddy-covariance technique. The ‘slow’ temperature and humidity Väisälä HMP probes will provide air temperature and relative-humidity measurements at three levels and will be used to evaluate the vertical temperature and humidity gradients. The mean wind speed and vertical wind speed gradient will be derived from the sonic anemometers. Instantaneous T/RH and other slow data (e.g., short-wave and long-wave radiation, surface temperature) will be collected by Campbell data loggers with 5-second sampling intervals. The Campbells will then average these raw values to 1-minute averages in real-time.

The Civilian Research and Development Foundation (CRDF and the Russian Fund for Basic research have approved funding for a joint science proposal for a team of scientists from the NOAA Physical Science Division, the Roshydromet Arctic and Antarctic Research Institute and the Russian Academy A.M. Obukhov Institute of Atmospheric Physics by to facilitate rapid ingest and understanding of the Tiksi tower data. Specific research objectives will include:

- What are the differences in Surface Energy Balance (SEB) and trace gases fluxes between these different Arctic sites? Barrow is in the Pacific sector, Eureka/Alert reside in the Atlantic sector, and Tiksi in the Siberian sector of the Arctic basin. What are the implications and interpretations in the context of climate change of such differences?
- How do the SEB and trace gases fluxes compare with previous analyses of Arctic sites? In particular, how do the SEB from these land-based sites compare with the analyses of measurements taken over the Arctic Sea ice?
- What are the contributions and implications of non-Monin-Obukhov (MO) turbulent fluxes on the SEB at each site? Global circulation and regional models represent the turbulent fluxes in a MO fashion. Due to terrain, mesoscale, and coastal influences, we anticipate a significant deviation from MO fluxes toward each site's SEB, and an assessment of these influences is of importance for accurate parameterization of the surface fluxes near these sites especially during periods of very stable boundary layer stratification.
- What are the contrast between the winter and summer SEB and trace gases fluxes, and which terms are seasonally the most important?

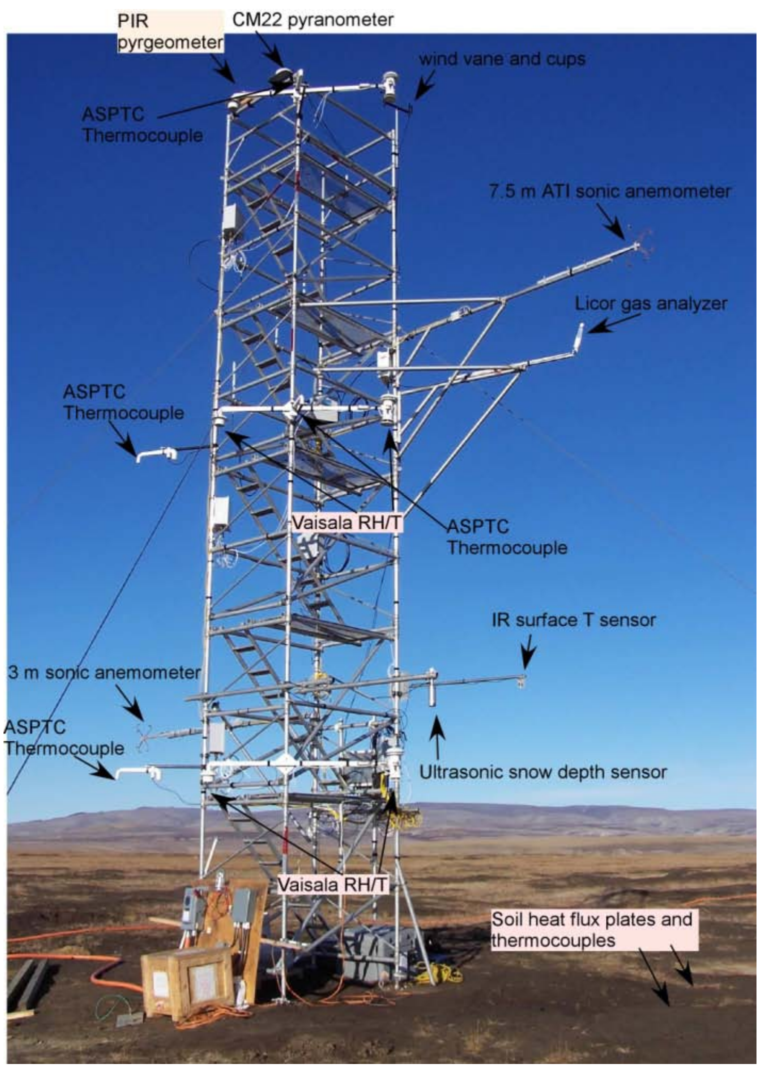


Figure 2.14 Example NOAA 10-meter tower in Eureka, Canada

2.6 Measurements supporting the International Permafrost Association (IPA).

Permafrost measurements are important in the context of widespread systematic changes in storage of greenhouse gases and organic carbon, effects on the infrastructure of human habitation in cold regions, and on ecological and land processes. It is essential that observational and analytical procedures to assess permafrost evolution continue over decadal periods to assess trends and detect cumulative, long-term changes in climate.

The parent organization that provides structure for permafrost programs is the International Permafrost Association (IPA). From the IPA site (http://ipa.arcticportal.org/index.php/About-the-IPA/) the stated mission is "to foster the dissemination of knowledge concerning permafrost and to promote cooperation among persons and national or international organizations engaged in scientific investigation and engineering work on permafrost". IPA originated the Global Terrestrial Network for Permafrost (GTN-P) "to organize and manage a global network of permafrost observatories for detecting, monitoring, and predicting climate change" (http://www.gtnp.org). This network, authorized under the Global Climate Observing System (GCOS) and its associated organizations, consists of two observational components: the active layer (the surface layer that freezes and thaws annually) and the thermal state of the underlying permafrost. The Circumpolar Active Layer Monitoring (CALM) program (http://www.udel.edu/Geography/calm/) in turn provides the coordination for the active and near surface permafrost changes in response to multi-decadal climate changes. The CALM network was established in 1990. The Tiksi Observatory active layer measurements will contribute directly to CALM. The existing deep permafrost measurements that have been conducted by the RAS Permafrost Institute (since the 1950s) and Institute of Physical-Chemical and Biological Problems of Soil Science (since 2001) in the Tiksi region will provide historical context for the Tiksi permafrost program.

2.6.1 Active Layer Measurements

The active layer permafrost studies in the immediate vicinity of the Central Observatory and Weather Building will be focused not just on recording how the permafrost temperature structure is evolving, but also on what mechanisms are driving the change. This requires detailed measurements of the exchange of heat and energy fluxes between the atmospheric surface layer and the tundra active layer. In September, 2009, the Russian team from AARI installed a unique complex for monitoring detailed profiles of permafrost temperatures in the vicinity of the Central Observatory and Weather Building (Figure 2.15 and 2.16). The AMT-5 thermometric system was developed by the Typhoon Hydrometeorological Instrumentation Design Office. The system utilizes thermally sensitive platinum resistors (thermisters) with a nominal resistance of 100 Ohms; each sensor is protected by a hermitically sealed, stainless steel housing. The sensors have a range of -60°C to 70°C ± 0.1 °C. Seven of the permafrost sensors are placed at levels between 0.05 and 3.6 m depth deployed in separate pipes which are cut to length corresponding to the depth of the desired measurement (3.2 m, 2.4 m, 1.6 m, 1.2 m, 0.8 m, 0.4 m and 0.2 m). Four additional sensors are deployed in the near surface layer (20cm 15 cm, 10 cm, 5 cm) supported on a metal frame. The data logging system communicates with a computer in the Central Observatory and Weather Building which is at a distance of 200 meters. Data is transmitted through satellite to the Tiksi Data Center in AARI in real time through the remotely accessible computer system.

(a) (b)

Figure 2.15 (a) Surface view of pipes housing sensors at 3.2 m, 2.4 m, 1.6 m, 1.2 m, 0.8 m, 0.4 m and 0.2 m depth. (b) Near surface sensors at 20cm 15 cm, 10 cm, and 5 cm depth

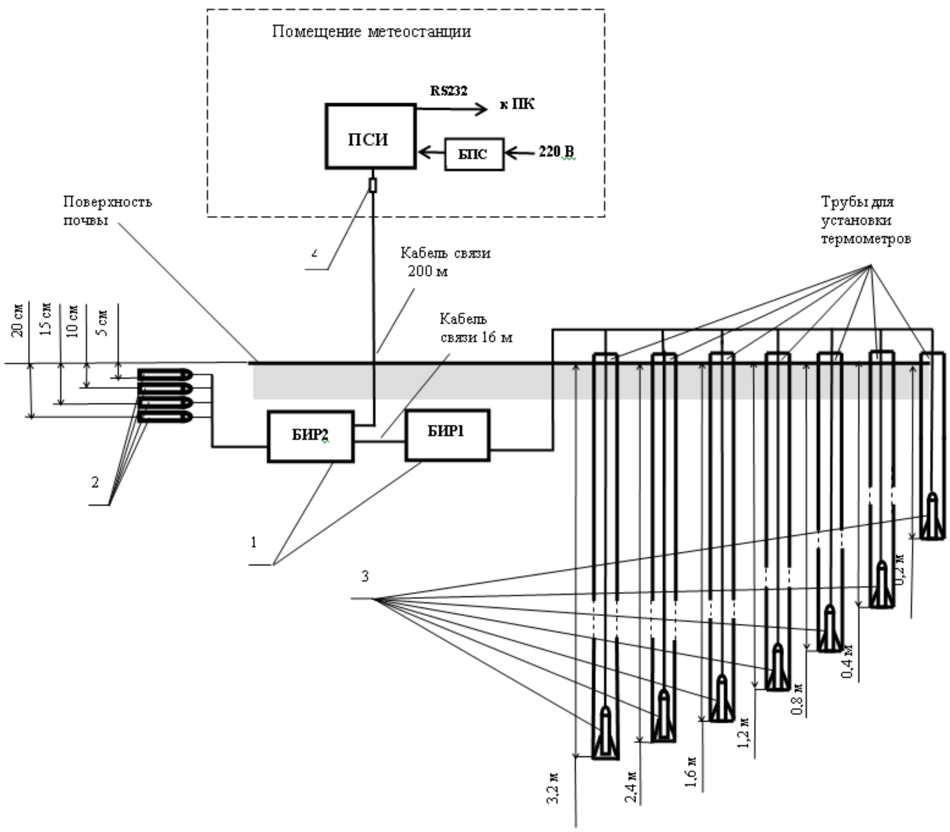


Figure 2.16 Schematic of permafrost active layer sensing complex

Preliminary results (Figure 2.17) show the temperature cross-section from day 270 to 340 after initial installation. In the layer between 3 to 3.5 m, temperatures were near constant at -6 °C. In the layer between 0 and 0.5 m, the temperatures changed from -6 °C to -14 °C as winter season progressed. The near surface active layer temperatures changed slowly in response to the air temperatures, lagging by 50 days before equilibrium was reached.

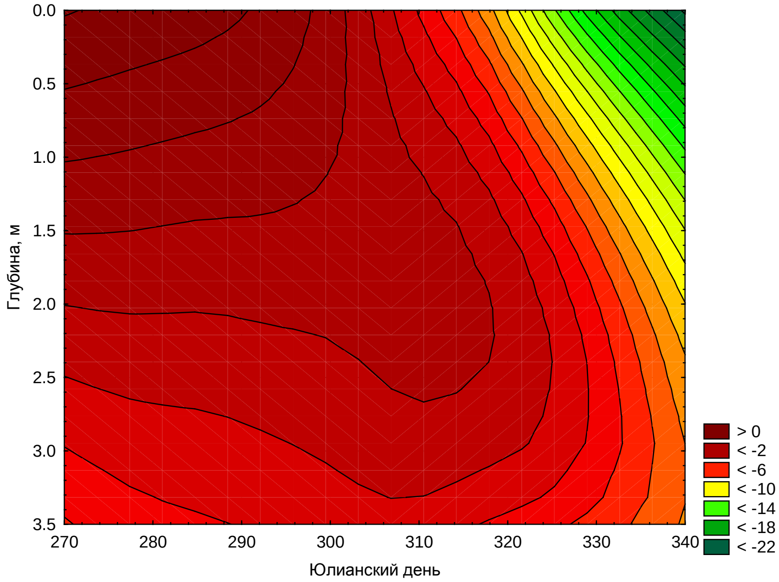


Figure 2.17 – First results showing temperature time-depth cross section from Julian Day 270 to 340

These measurements will be significantly enhanced in 2010 with installations of a turbulent flux tower (Section 2.5) and more sophisticated atmospheric radiation instruments (Section 2.2). These atmospheric measurements combined with the depth resolved measurements of the evolution of the active layer temperatures will contribute to the understanding and parameterization of the evolution of the permafrost characteristics for the Tiksi region.

Two additional CALM sites are located in the tundra landscape at the Bykovsky peninsula 30 km from the Tiksi. Comparison of active layer parameters between these three sites will be important to understand spatial variability of the exchange of heat and energy fluxes between the atmospheric surface layer and the tundra active layer at the region.

2.6.2 Underlying Permafrost Measurements in Tiksi Region

The Russian (formally Soviet) Academy of Science Melnikov Permafrost Institute (MPI) and more recently the Institute of Physical-Chemical and Biological Problems of Soil Science (IPhCnBPS) in collaboration with the University of Alaska, Fairbanks support permafrost measurements in the Tiksi region. First measurements were made in the 1950s and continue to the present although with interruptions in the 1970s and 1980s. Boreholes were drilled the foothills of the Primorsky Range, on Lyalkina Mountain in 1992 (by the MPI) and at 6 representative tundra areas of the Bykovsky peninsula between 2001 and 2004 (by the IPhCnBPS). In these regions, the deep permafrost is continuous and historically has maintained temperatures between –9 to –11°C with active layers that typically do not exceed 0.6 m. The boreholes are 30 m and instrumented with a thermister chains with sensors at 0, 1, 2, 3, 5, 10, 20 and 30 m depths (Figure 2.18). The boreholes have been supplemented since 2001 with measurements of temperature in the active layer in support of the Circumpolar Active Layer Monitoring program (CALM). The Bykovsky peninsula boreholes are distributed in different

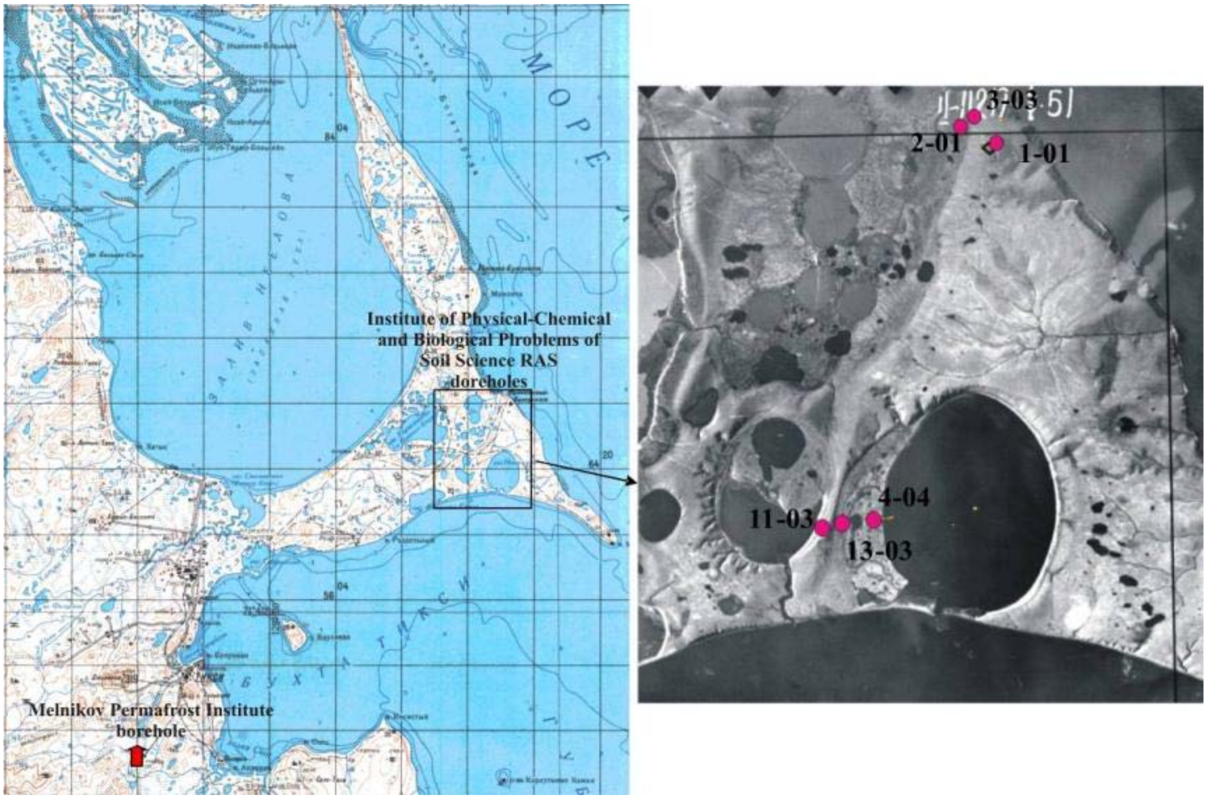
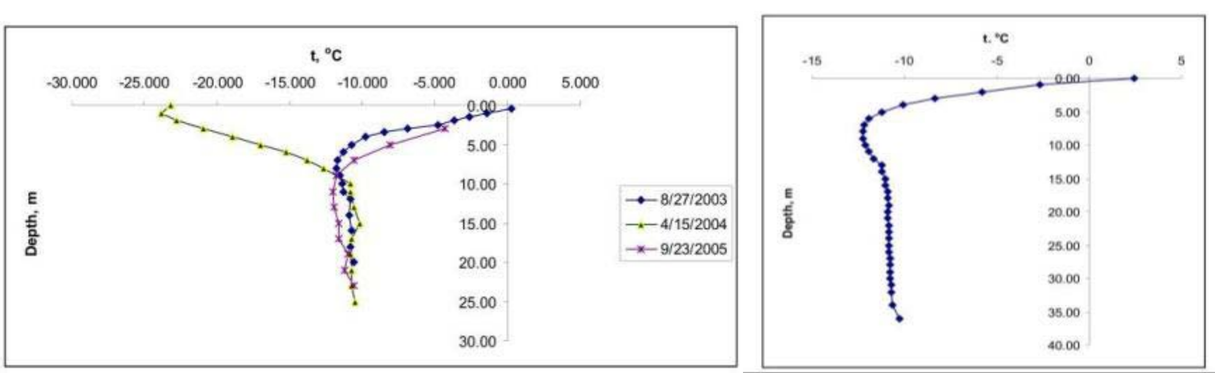


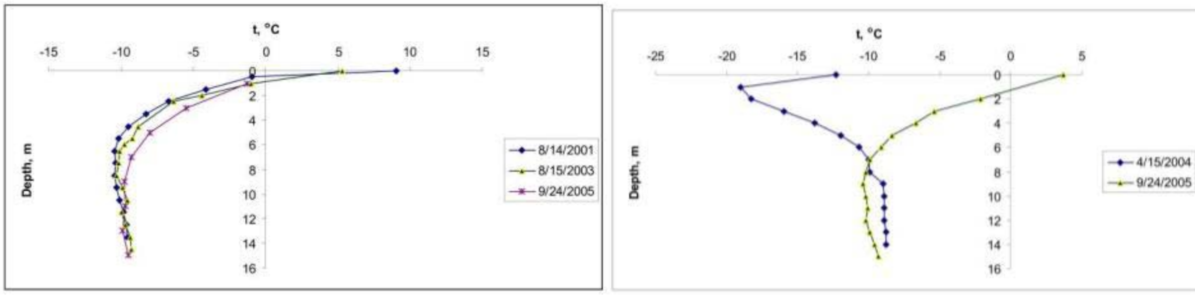
Figure 2.18 Melnikov Permafrost Institute and Institute of Physical-Chemical and Biological Problems of Soil Science /UAF borehole sites relative to Tiksi.

regimes including areas representative the late Pleistocene accumulative plane (yedoma) and thermokarst depressions. Within "yedoma" areas mean annual ground temperature (MAGT i.e. the temperature at the depth where there is penetration of an effect from annual air temperature variations), is –10.9°C; and in thermokarst depressions the MAGT is -9°C (Figure 2.19).

Observations at these sites were originally episodic, but since 2006, two boreholes (one yedoma site and one thermokarst depression site) were instrumented by 4-channel HOBO U12 data loggers with TMC-HD thermisters (resolution 0.03°C) at 3, 5, 10 and 15 m depth. Additional 2-channel loggers were installed for monitoring of the active layer temperature at one of the yedoma sites (2008) and thermokarst depression (2009.



(a) **(b)**



(c) **(d)**

Figure 2.19 Temperature profiles from boreholes in yedoma areas (a) and (b) and thermokarst areas (c) and (d)

To support the Tiksi Hydrometeorological Observatory, it is expected that the existing observations will be maintained on a continuous basis and the network will be expanded with additional infrastructure including new sites, active layer instrument complexes to complement the deep bore holes, and additional continuous data loggers. In addition, instrumentation will be installed for continuous observations of unfrozen water contents and single measurements of thermal conductivity of the active layer soils and underlying frozen quaternary deposits. It will be highly desirable to have a borehole in the immediate vicinity of the Central Observatory and Weather Building to complement the AARI active layer measurements and other Observatory installations. This

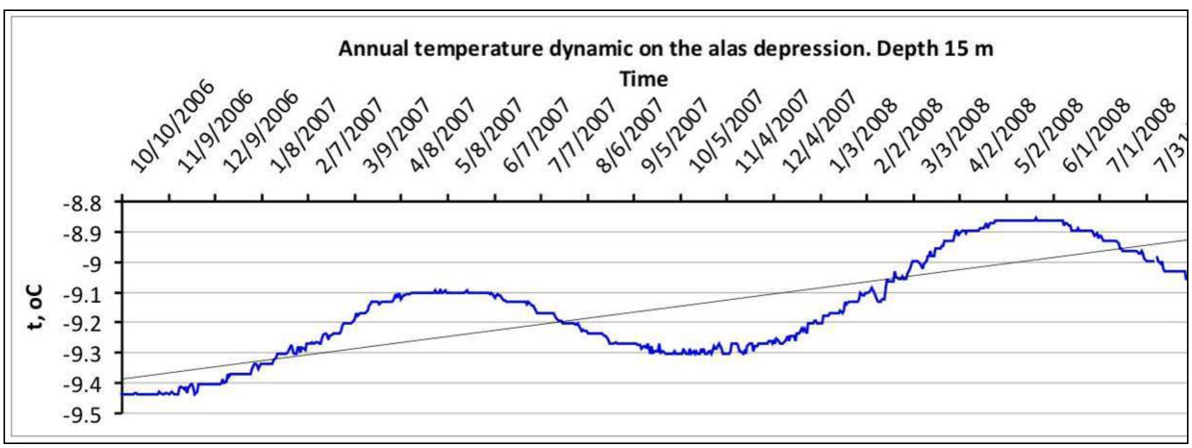


Figure 2.20 – Annual temperature cycle at 15 m depth showing a 0.2 °C increase in temperature between the mean maximum for 2007 and 2009

program offers an opportunity for shared logistical resources for routine and annual maintenance and technical support between organizations (AARI, NOAA, RAS, and UAF).

The combination of high-resolution permafrost temperature monitoring and atmospheric observations in Tiksi will provide an opportunity to quantify estimate permafrost response to climatic change, including (for various temporal scales) the relationships between the permafrost temperature structure at different depths, atmospheric air temperature, precipitation, volumetric water (ice) and organic carbon content of the frozen ground. It is expected that the information will significantly improve parameterizations of surface-atmosphere exchanges for regional and global climate models as well as providing initialization and validation data sets.

3.0 Projects Scheduled for 2011 and Beyond

The Tiksi Observatory will have adequate facilities for a significant number of additional projects. It is expected that in the near future that there will be interest on the part of many international organizations in adding to the complement of instruments that are scheduled for installation in 2010. These additional programs will be structured around 4 major objectives;

- Enhancing atmospheric observations
- Ancillary measurements in the areas of biological, terrestrial and oceanographic sciences that will support Arctic system science
- Integration of the Tiksi Observatory into globally distributed observing systems such as supported by the Environmental satellites
- Application of the Tiksi observations towards impacts studies on humans and societies

3.1 Cloud-Aerosol Studies

Clouds remain the most poorly understood and least well-modeled component of the climate system. Polar clouds in particular have unique properties have a substantial role in governing surface radiative fluxes and atmospheric heating rate profiles. Clouds also have a significant impact on satellite retrievals of surface temperature, ice motion, ice concentration, aerosols properties, snow extent, and surface albedo; therefore, a major objective at the Tiksi Observatory will be to use the surface measurements of clouds to calibrate and correct satellite measurements.

Changes in particular cloud properties (for example optical depth) are expected to be indicators of atmospheric climate change since seasonally and annually averaged cloud properties represent the integrated influence of changing storm tracks, atmospheric temperatures, aerosol characteristics, and moisture sources. At present, studies of Arctic long-term cloud variability primarily focus on cloud fraction without distinction of cloud type or composition. Recent case studies indicate that specific cloud properties such as water content or cloud base temperature are likely to have much stronger linkages both statistically and mechanistically to climate change variables than simple cloud fraction.

Aerosols have bearing not only on the radiation budget through direct radiative forcing but also indirectly through their influence on cloud microphysical properties that affect cloud distributions and optical properties. The IPCC report "Climate Change 2007 recommends systematic observations focused on aerosol-cloud interactions. Instruments that can be deployed in Tiksi to further quantify cloud properties include All-Sky Imagers (hemispheric photography), Microwave Radiometers (integrated liquid water path and integrated vapor water path) and ceilometers (laser measurement of cloud base height), cloud-profiling radars and cloud-aerosol profiling lidars.

Studies with this combination of sophisticated sensors that will quantify cloud microphysical and macrophysical properties are expected to significantly enhance the long qualitative record of human based observer cloud records that currently exists for Tiksi.

3.2 Human Studies

Measurements at the Tiksi Observatory will allow detailed studies of the impacts of the Arctic environment, including weather and solar ephemeris cycles, on the general health of Arctic residents. The Russian Arctic and Antarctic Research Institute was a center for Polar Medicine studies between 1976 on 1991. The center was engaged in the study of both environmental impacts on the human organism as well as human adaptation to the Arctic environment. In 1992 this research was interrupted, however, it is recognized that the subject has not lost urgency, especially in a view of modern climate warming in the Arctic regions. Specific research topics that will be reinstated and/or initiated include:

- Studies of how meteorological and polar solar cycles impact human functionality. This study will be conducted through daily check-ups of volunteers from among the employees of the Tiksi Observatory. Monitors will include automated and semi-automated diagnostic systems recording cardiograms, blood pressure, encephalograms, and chrono reflectometry techniques to monitor reflexes. These data, collected over a full year are expected to quantitatively document changes in human physiological well-being as temperatures and sunlight availability vary through the extremes of the Arctic annual cycle.
- Studies of how meteorological and polar solar cycles impact disease rates and for peoples of the Bulun Ulus (region). Specifically, daily meteorological and solar ephemeris observations will be correlated with daily morbidity rates.
- Studies will be conducted of possible impacts of Arctic climate change on human health by retrospective comparison of the Tiksi meteorological data and solar ephemeris observations to morbidity rates for the past sixty years.
- Tele-medical communication system will be installed between the Tiksi observatory and the Tiksi Data Center/AARI that are designed to support medical consultations, both in real-time or retrospectively that can guide the delivery of the medical assistance, if necessary, to the Observatory's personnel.

3.3 Satellite Studies

A number of weather/environmental satellites are operated by NOAA's National Environmental Satellite, Data, and Information Service and the Russian Federation launched the METEOR-M weather satellite in (September 2009). These systems provide pan-Arctic coverage and in the recent decade there has been significant effort in developing Arctic specific environmental products. For example, new satellite sounders provide high vertical resolution of certain atmosphere properties, robust spectral information for cloud property retrievals and the estimation of atmospheric chemical constituents including ozone, sulfur dioxide, and carbon monoxide and satellite altimeters and active microwave sensors provide new opportunities to characterize sea ice and ice sheets. The satellite measurements will be particularly important to integrate the Tiksi Observatory measurements into a larger view of the Arctic that will contribute significantly to the WMO Global Cryosphere Watch (GCW) program.

The availability of the detailed surface-based observations at Tiksi will add to the constellation of the IASOA surface stations that greatly aid in development, calibration and validation of satellite products. In turn the satellite sensors will provide a horizontally distributed context in which to interpret the single point measurements at the observatories.

4.0 Existing Facilities as of spring 2010

The Hydrometeorological Observatory of Tiksi includes the new Central Observatory and Weather Building (with research space and infrastructure), a Clean Air Facility (CAF), and various surrounding racks, towers and instrument cabins that will be accessible on boardwalks that will be installed in summer of 2010. There have been significant power line and road improvements between the town of Tiksi and the Observatory site that were funded through the Yakutia Regional governance.

4.1 Central Observatory and Weather Building

As of spring 2010 the Central Observatory and Weather Building is largely completed and occupied by the Roshydromet Tiksi weather station staff (Figure 4.1). Internet through satellite connections is available. The Central Observatory and Weather Building is spacious, comfortable and furnished with two furnished bedrooms, a kitchen and good office space and accessible roof space where some science projects are have been installed in addition to some weather station instruments. A list of final items for construction completion has been submitted, including plumbing and water, additional insulation, drainage, additional weatherization, and noise abatement issues during high wind periods. There is storage, and adequate additional space inside as well as on the roof for science projects without interference with the routine weather station activities. A diesel generator backup system is on site. The Central Observatory and Weather Building is adjacent to the original weather station which is still in use. The Central Observatory and Weather Building will be the location of choice for projects that will benefit from daily operator supervision and which do not require a remote, pristine location. The primary facility has staff on site 24 hours/day who commute on shifts from the town of Tiksi.

Figure 4.1 Exterior of Central Observatory and Weather Building

4.2 Interior of primary facility

4.2 Clean Air Facility (CAF)

The CAF was designed accommodate specialized requirements particularly for air sampling projects that require pristine environmental conditions. Some of the specialized aspects include masts to support intake towers, pump rooms and usage of special building materials that do not outgas compounds that would contaminate air samples. The full details of the building specifications were developed in 2007 by a joint team of U.S., Russian, Finnish, Norwegian, and Japanese scientists; the resulting document is the Tiksi Clean Air Facility (TCAF) Requirements Document.

As of fall of 2009 the CAF building had been constructed on the foundation and the electrical system and interior finish work was in progress. A Russian, U.S and Finnish science team reviewed progress and made extensive notes on completion details. The projected location of outside towers, racks, connecting walkways and power/communication lines were resurveyed and documented. The Polar Foundation was on site in October of 2009 and made progress on these requests. The final completion work is scheduled for May-June of 2010.


Figure 4.3 Exterior of new Central Observatory and Weather Building in September 2009


Figure 4.4 Interior of the Clean Air Facility in September 2009

4.3 Communications.

To ensure communication, data transfers and personnel access to internet-based information resources, a satellite connection Russia utilizing VSAT technology has been established between the Central Observatory and Weather Building in Tiksi and the Roshydromet Arctic and Antarctic Research Institute (AARI) in St. Petersburg. Russia. Data is transmitted via a Yamal-200 satellite channel in the Ku-band with rates of 512 Kbytes /sec. The Central Observatory and Weather Building and the CAF are connected through wireless. VoIP providing telephone connectivity is installed. The Satellite system transfers between the AARI and Tiksi Hydrometeorological Observatory systems are through VPN protocols. The satellite receiving dish and interior work stations have been in Tiksi since spring of 2008 (Figure 4.6).

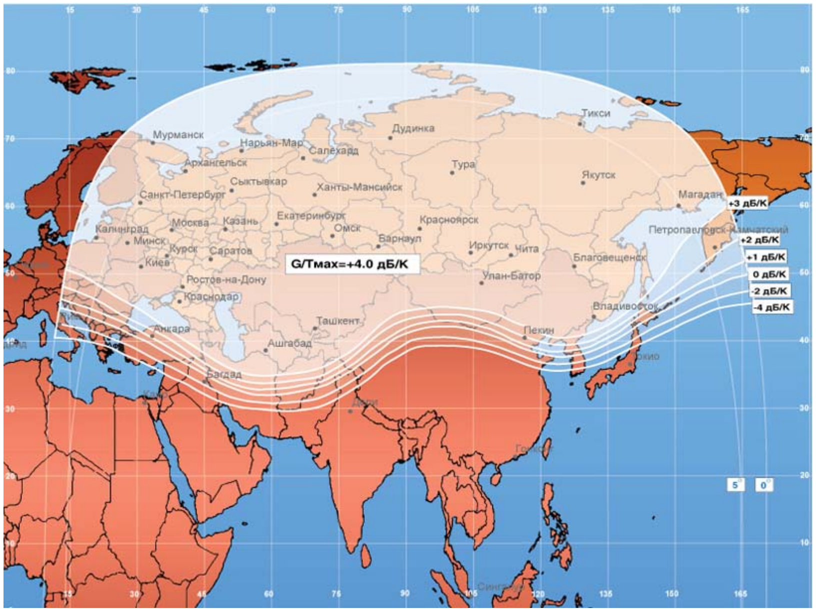


Figure 4.5 Yamal Ku-band coverage

All data will be transmitted from Tiksi Observatory to the Tiksi Data Center (TDC) in AARI. The AARI Tiksi Data Center has a IBM Blade Server HS21 server for receiving and collecting the data transmitted from the Tiksi measurement systems. The server is configured with FTP and other web and mail services to facilitate transfer of data from the TDC to the outside world. The Tiksi Data Center will follow the data protocols of the World Meteorological Organization (WMO) Global Telecommunication System (GTS).
http://www.wmo.int/pages/prog/www/TEM/GTS/index_en.html

Figure 4.6 Tiksi on site communication systems

5.0 Appendices

5.1 Tiksi Science Team

For the Russian Federal Service for Hydrometeorological and Environmental Monitoring	For the U.S. National Oceanic and Atmospheric Administration
Alexander Danilov Arctic and Antarctic Research Institute	Taneil Uttal Earth Systems Research Laboratory
Alexander Makshtas Arctic and Antarctic Research Institute	Russell C. Schnell Earth Systems Research Laboratory
Alexander Reshetnikov Voeikova Main Geophysical Observatory	Jeffrey Key NOAA Satellite and Information Service
Alexei Konoplev Typhoon Institute for Environmental Chemistry	Vladimir Romanofsky University of Alaska
For the Finnish Meteorological Institute	
Tuomas Laurila Finnish Meteorological Institute	

5.2 Table of Acronyms

AARI	Арктический и антарктический научно-исследовательский институт Arctic and Antarctic Research institute
AeRoNet	Сеть автоматизированных аэрозольных наблюдений НАСА Aerosol Robotic Network, NASA
AMAP	Программа исследований загрязнений Арктики Arctic Monitoring, Assessment Program
AMF	АРМ передвижной комплекс ARM Mobile Facility
ARM	Атмосферные радиационные измерения Atmospheric Radiation Measurement
BSRN	Сеть базовых радиационных наблюдений Baseline Surface Radiation Network
CALM	Циркумполярный мониторинг активного слоя Circumpolar Active Layer Monitoring
CASN	Сеть согласованного отбора проб воздуха Cooperative Air Sampling Network
CEC	Научно-производственное объединение «Тайфун» Center for Environmental Chemistry - Typhoon
CRN	Базовая сеть наблюдений за климатом Climate Reference Network
DoE	Департамент энергетики Department of Energy)
FMI	Финский метеорологический Институт Finnish Meteorological Institute
GAW	Глобальное наблюдение за атмосферой Global Atmosphere Watch
GCOS	Сеть глобального слежения за климатом Global Climate Observing Network
GMD	Подразделение глобального мониторинга НОАА Global Monitoring Division, NOAA
GSFC	Годдаровский центр космических полетов Goddard Space Flight Center
GTN-P	Глобальная наземная сеть – вечная мерзлота Global Terrestrial Network- Permafrost
IPA	Международная ассоциация по исследованиям вечной мерзлоты International Permafrost Association
JPL	Лаборатория реактивного движения Jet Propulsion Laboratory
MGO	Главная Геофизическая Обсерватория им. Воейкова Main Geophysical Observatory
MPLNET	Сеть лидарных наблюдений НАСА Micro-Pulse Lidar Network, NASA
NSF/OPP	ННФ Офис полярных программ National Science Foundation Office of Polar Programs
OCO	Спутниковая орбитальная углеродная обсерватория Orbiting Carbon Observatory
POPs	Устойчивые органические загрязнения persistent organic pollutants

PSD	Подразделение физических наук НОАА Physical Sciences Division, NOAA
RAS	Россиская Академия Наук Russian Academy of Sciences
Roshydromet	Федеральной службы по гидрометеорологии и мониторингу окружающей среды Российской Федерации Russian Federal Service for Hydrometeorological Monitoring
UVMN	Сеть мониторинга ультрафиолетового излучения UV Monitoring Network, NSF/BSI

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