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НОВЫЕ МЕТОДЫ И РЕЗУЛЬТАТЫ ИССЛЕДОВАНИЙ ЛАНДШАФТОВ В ЕВРОПЕ, ЦЕНТРАЛЬНОЙ АЗИИ И СИБИРИ

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Монография содержит информацию о самых современных методологиях и результатах в ландшафтных исследованиях. Она может быть использована в качестве руководства для исследователей, преподавателей, студентов и всех, кого интересует тема ландшафтной науки и смежных дисциплин. Монография является особо ценной информационной базой для лиц, принимающих решения на различных уровнях, от местных до международных органов по принятию решений. Приведенная в монографии информация представляет собой современный уровень ландшафтной науки в очень краткой форме.

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This monograph shall inform you about up to date methodologies and recent results in landscape research. It is intended as a guide for researchers, teachers, students, decision makers, stakeholders interested in the topic of landscape science and related disciplines. It provides information basis for decision makers at various levels, from local up to international decision bodies, representing the top level of landscape science in a very short form.

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Chapter III/39: FAST RESPONSE ANEMOMETERS AND ITS APPLICATION FROM THE VOLGA STEPPE REGION TO EASTERN SIBERIA

Глава III/39: Быстродействующие анемометры и их применение на территории от приволжских степей до Восточной Сибири

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ABSTRACT. The eddy-covariance method is a tool that uses the high-frequency turbulent fluctuations within the atmosphere to determine energy and matter turbulent fluxes of different substances between the atmosphere and the underlying surface. The most important device is the sonic anemometer to measure the fluctuations of the three component wind vectors, with the first instruments developed in the 1960s in Moscow and tested in the Volga steppe region. This paper presents a general overview on ground-based sonic anemometers and Pitot tube meters for aircrafts with high response times. In this context, we evaluate methane fluxes in the Siberian permafrost area and aircraft measurements in the Lena region. Our approaches allow a spatial-frequency analysis of turbulent structures from the smallest scales to the mesoscale.

Резюме. Метод вихревой ковариации основывается на высокочастотных измерениях турбулентных пульсаций в атмосфере и применяется для изучения энергетики и природы турбулентных потоков различных субстанций между атмосферой и ниже лежащей поверхностью. Одним из наиболее важных инструментов для измерения пульсаций трех компонент вектора ветра является ультразвуковой анемометр, разработанный в 1960-х годах в Москве и испытанный в степях Волжского региона. Настоящая статья посвящена общему обзору высокочастотных звуковых анемометров для наземных измерений и быстродействующих авиационных измерителей, основанных на трубке Пито. В качестве примера представлены потоки метана, в зоне вечной мерзлоты Сибири и авиационных наблюдений в районе реки Лена. Наши подходы позволяют проводить пространственно-частотный анализ турбулентных структур от наименьших масштабов до мезомасштабов.

KEYWORDS: eddy-covariance method, sonic anemometer, methane fluxes, aircraft measurements, Volga steppe region, Chersky, Lena River

Ключевые слова: вихревой ковариационный метод, ультразвуковой анемометр, потоки метана, авиационные наблюдения, приволжский степной регион, Черский, река Лена

INTRODUCTION

The eddy covariance method [1] is nowadays a widely used observational approach for determining fluxes of energy and matter between the surface and atmosphere, with applications not only in meteorology but also in ecology and applied sciences. The first instrumentation devices that facilitated a practical realization of eddy-covariance were developed in Moscow and tested in the Volga steppe region. The presented paper gives an overview of the development of the fast response wind measurements from its early stages nearly 60 years ago to the present. The fluctuation of the vertical and horizontal wind components, together with the fluctuations of the temperature and trace gases, must be measured with a frequency of 10-20 Hz. These high sampling frequencies and the associated storage of the large amount of data were a major obstacle in the early years of application, but due to advances in the development of electronic components even higher measurement frequencies can now be realized.

THE SONIC ANEMOMETER

The most important instrument for the eddy-covariance method is the sonic anemometer. Still, after the presentation of the theoretical foundations, more than ten years of research were required until the first design of today's anemometers was finalized by Bovscheverov and Voronov [2], and only some years

later similar instruments were developed in the USA [3] and Japan. A crucial step towards the general applicability of these new instruments was the organization of sonic anemometer inter-comparison experiments, with one of the first being performed in the Volga steppe region near Tsymlyansk[4].
The first sonic anemometers used the phase shift method [2,3, Figure 1]. In this method, the ultrasonic signal emitted by the transmitter is received at several points, and wind velocities can be derived as a function of the phase difference between the transmitted and received signals. Modern sonic anemometers use the travel time principle and a direct time determination [5]. In this method, a sonic signal is transmitted from both sides of a measurement path and received on the opposite sides. Since the propagation of these signals is influenced by the wind velocity, one signal is faster than the other. The exact travel times of the sonic signals are subsequently used for the determination of the wind velocity:

$$t_{1,2} = \frac{\sqrt{c^2 - u_n^2} \pm u_d}{c^2 - u^2} d \qquad (1)$$

where d is the path length, u_d is the wind component along the path, u_n is the normal component of the wind, and c is the sound velocity.
The difference of the reciprocal travel times gives the wind velocity, and the sum of the reciprocal travel times can be used to derive the sound velocity:

$$\frac{1}{t_1} - \frac{1}{t_2} = \frac{2}{d} u_d \qquad (2)$$

$$\frac{1}{t_1} + \frac{1}{t_2} = \frac{2}{d} c \sqrt{1 - \frac{u_n^2}{c^2}} \approx \frac{2}{d} c \qquad (3)$$

The sound velocity is a function of temperature and moisture

$$c^2 = 403 T \left(1 + 0.32 \, {}^{e}\!/_{p}\right) \qquad (4)$$

using the partial pressure of water vapor e and the air pressure p. The product of the temperature T and the moisture dependent term is called the sonic temperature and the flux that can be calculated based on the sonic temperature is the buoyancy flux, which can be transformed with the moisture flux into the sensible heat flux.

MEASUREMENT OF METHANE FLUXES OVER THE SIBIRIAN PERMAFROST REGION: PITOT-TUBE ANEMOMETER ON AIRCRAFTS

Aircraft measurements allow the application of the eddy covariance method, but instead of a sonic anemometer a multi-channel Pitot-tube and a hot-wire thermometer are used, and instead of a time series a spatial series is measured. The Russian ILYUSHIN-18D (IL-18D) is an aircraft-laboratory [7] carrying special instruments designed to measure atmospheric variables at a very high frequency during field campaigns. A gust-probe system measured the wind speed, wind direction and air temperature (see Figure 2). Turbulence measurements included horizontal (longitudinal with respect to flight direction) wind speed fluctuations, vertical wind speed fluctuations, air temperature fluctuations, and absolute air humidity fluctuations.
A high-response pressure sensor, connected to a Pitot pressure probe and static pressure holes, measured dynamic pressure. A barometer, connected to the static pressure holes of the aircraft pressure system, measured static pressure. A fast-response platinum wire thermometer, specifically designed for aircraft conditions, measured the temperature. The angle of attack was based on measured pressure differences in the holes of a spherical probe. Gyros measured variations in pitch angle, and a stable accelerometer measured variations in aircraft vertical acceleration. Doppler radar measured the horizontal components of the aircraft's ground speed; and the vertical component of the aircraft's ground speed fluctuations were calculated using the well-known gas-dynamics and dynamics equations [8]. As an example, the aircraft laboratory was deployed to conduct flux measurements along flight paths over non-homogeneous terrain in the vicinity of Yakutsk in eastern Siberia.

Figure 1 – Russian phase shift anemometer during the experiment ITCE-81 [6] at the Tsymlyansk research area (left) together with the Japanese Kaijo-Denki sonic anemometer PAT 300, working with the travel time principle (Photograph: Foken)

SURFACE FLUXES

Permafrost soils in northern high latitudes are characterized by enormous carbon stocks that are estimated to contain about 50 percent of the global below-ground carbon reservoir. With about two thirds of the Arctic being classified as wetlands, the prevalence of inundated conditions also implies that permafrost regions hold the potential to become substantial future sources of methane. This very complex region is therefore the subject of many scientific investigations. The example presented in this chapter is focused on the Chersky region in North-East Siberia [10]. In the study area, two eddy-covariance measuring complexes were installed with a sonic anemometer and a closed path gas analyzer to measure water, methane, and carbon dioxide fluxes (Figure 3).

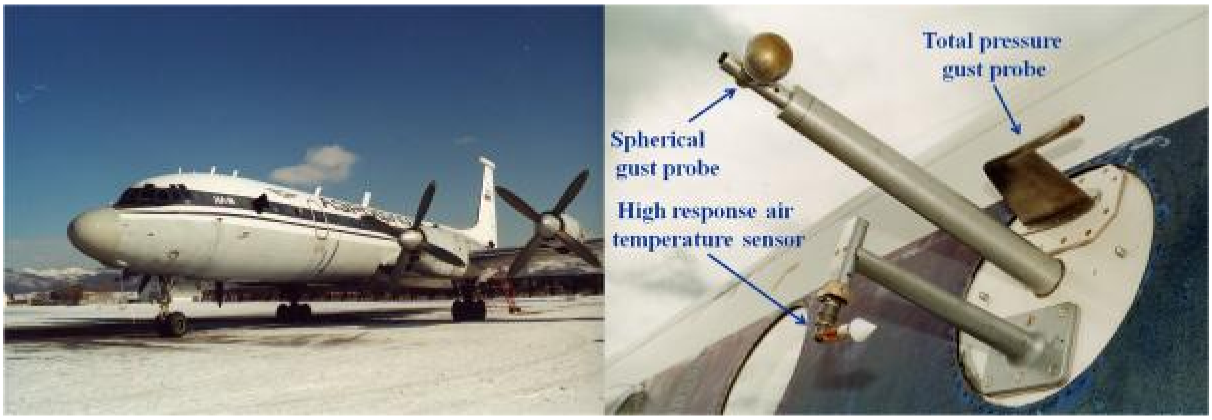

Figure 2 – Aircraft-laboratory Il-18D (left) and aircraft sensors (right) used for eddy-covariance measurements [9]

Figure 3 – Eddy-covariance towers at the Chersky research site (Photograph: Göckede). The system consists of a heated sonic anemometer (METEK USA1), an open-path gas analyzer for CO_2/H_2O (LiCor 7500, only right picture), and the inlet line for a closed-path gas analyzer for CH_4/CO_2/H_2O (Los Gatos FGGA).

CONCLUSIONS

1. Following the development of the modern sonic anemometer in Russia, since the 1960s it has facilitated the determination of direct observations of energy and matter exchange processes between surface and atmosphere, being the core instrument for the so-called eddy-covariance method.
2. The development of sonic and Pitot-type anemometers was essential for the application of the method for surface and aircraft based measurements. As shown in our examples, such measurements may significantly contribute to determine methane fluxes in the Siberian permafrost region and therefore the reduction of uncertainties regarding the role of these systems in the context of global climate change.
3. The application for aircraft measurements allows a spatial-frequency analysis of turbulent structures from the smallest scales to the mesoscale.

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Chapter III/40: SOIL MAPPING WITH *GEOPHILUS ELECTRICUS*
Глава III/40: Картирование почв с помощью *GEOPHILUS ELECTRICUS*

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ABSTRACT. Near-surface geophysical techniques such as the developed *Geophilus Electricus* system have the potential to map important soil parameters. The Geophilus sensor uses an equatorial dipole-dipole array of rolling electrodes and allows for measuring the apparent electrical resistivity at five depth levels. Therefore, in addition to conductivity maps illustrating lateral variations of apparent conductivity, sounding curves are available at each measurement point. These contain information about vertical changes in electrical conductivity up to a depth of about 1.5 m. Using an appropriate inversion procedure, allows us to transform the measured data into resistivity-depth-functions. However, due to the complex parameter relationships usually observed between electrical conductivity and different soil properties, we typically can not translate our geophysical result into a single soil attribute like soil moisture or clay content. To overcome some of such limitations in interpretation, we combine our electrical data with measurements of the natural gamma radiation, which may be a good indicator for soil clay content.

Резюме. Приповерхностные геофизические методы, такие как разработанная система Geophilus Electricus, могут отображать важные параметры почвы. Датчик *Geophilus* использует экваториальную диполь-дипольную решетку прокатных электродов и позволяет измерять кажущееся электрическое сопротивление на пяти уровнях глубины. Поэтому в дополнение к картам проводимости, иллюстрирующим боковые вариации кажущейся проводимости, кривые зондирования доступны в каждой точке измерения. Они содержат информацию о вертикальных изменениях электропроводности на глубине около 1,5 м. Используя соответствующую процедуру инверсии, мы можем преобразовать измеренные данные в функции глубины удельного сопротивления. Однако из-за сложных отношений параметров, которые обычно наблюдаются между электропроводностью и различными свойствами почвы, мы, как правило, не можем перевести наш геофизический результат в единую почвенную характеристику, такую как влажность почвы или содержание глины. Чтобы преодолеть некоторые из таких ограничений в интерпретации, мы объединяем наши электрические данные с измерениями естественного гамма-излучения, что может быть хорошим показателем содержания глины в почве.