Bulletin of the Geological Survey of Japan, vol. 52 (2/3), p. 83-88, 2001

Reviews

Aerogeophysics in Austria

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Klaus MOTSCHKA (2001) Aerogeophysics in Austria. *Bull. Geol. Surv. Japan*, vol. 52 (2/3), p. 83-88, 6 figs.

Abstract: This article gives a short summary of the airborne geophysical system used by the Geological Survey of Austria. It consists of a 4-frequency EM-Bird, a Cs-Magnetometer, 9 sodium-iodide crystals and some additional instruments like GPS, Radar- and Laser- altimeter. The EM-Bird is a newly developed, fully digital EM-system with a lot of advantages compared to the old analog systems. In the last years two infrared sensors and a passive microwave antenna for determining soil moisture have been added. Because of the newness of these instruments they are described in more detail.

1. Introduction

Since 1982 the Geological Survey of Austria (GBA) is performing aerogeophysical surveys in Austria. The instrumentation has been changed and improved several times which has resulted in considerable weight reductions and better accuracy. Today Austria's instrument configuration is one of the world's most modern and complex of its kind.

At present more than 10 % of the total area of Austria has been surveyed by detailed aerogeophysics (see Fig. 1). In line with the original goals as well as project changes made during the time of surveying, the different projects can be divided into three categories:

1. Projects related to base metal findings
2. Projects related to hydrogeological problems.
3. Projects for the examination of geogenic and anthropologically caused risk factors. These projects include the examination of major landslides and volcanic hazards, and applications of nuclear radiation protection (i.e. reactor accident in Tschernobyl) on the other hand.

Below is a brief depiction of aerogeophysical projects carried out by the GBA in foreign countries:

After initial test surveys in Hungary in 1987, aerogeophysical surveys were performed over a period of several years, mandated by our neighboring country. The purpose of these surveys on a scale of approx. 6000 profile kilometers was to support bauxite prospecting across larger areas. This resulted in the finding of at least two bauxite lenses.

In the spring of 1998 aerogeophysical surveys were performed within the scope of a European Union project in the Romanian as well as Ukrainian part of the Danube river delta. This project was to examine the natural production of greenhouse gases. The contribution of helicopter geophysics lies in the area of the examination of sediments in the delta as well as the determination of the boundary between fresh water and salt water in the coastal region.

Furthermore GBA was participating in a European Community project which involves aerogeophysical and ground geophysical surveys in the Vesuvios region.

2. Basic Survey Instruments

In Austria flying is performed by helicopter, model Agusta-Bell 212, of the Austrian Armed Forces. Fig. 2 provides a general summary of the survey instruments, which are used. In most cases an area is flown at a line spacing of 200 m. The helicopter flies at a constant altitude of 80 m above ground at a speed of approx. 100 km/h. Data is collected at a sampling-rate of 0.1 to 1 second, which corresponds to a survey sampling distance of 3 to 30 meters.

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Keywords: airborne geophysical system, 4-frequency EM-Bird, cesium magnetometer, sodium-iodide crystals, GPS, digital EM-system, infrared sensors, passive microwave antenna, soil moisture

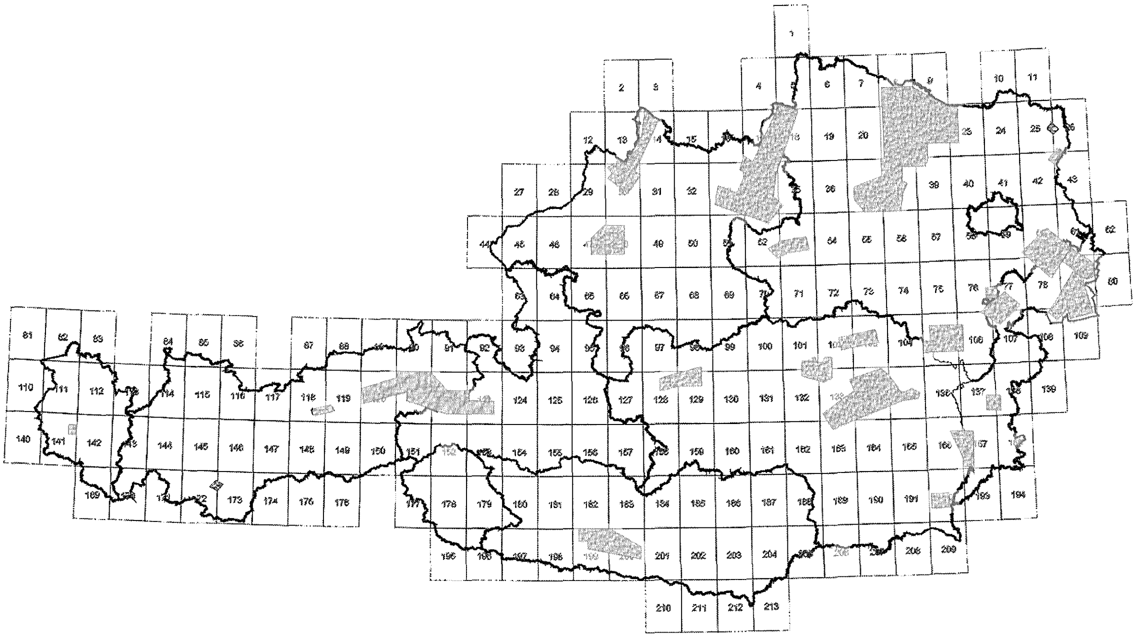

Fig. 1 Areas of aerogeophysical flying over Austria (till 31. 12. 1999).

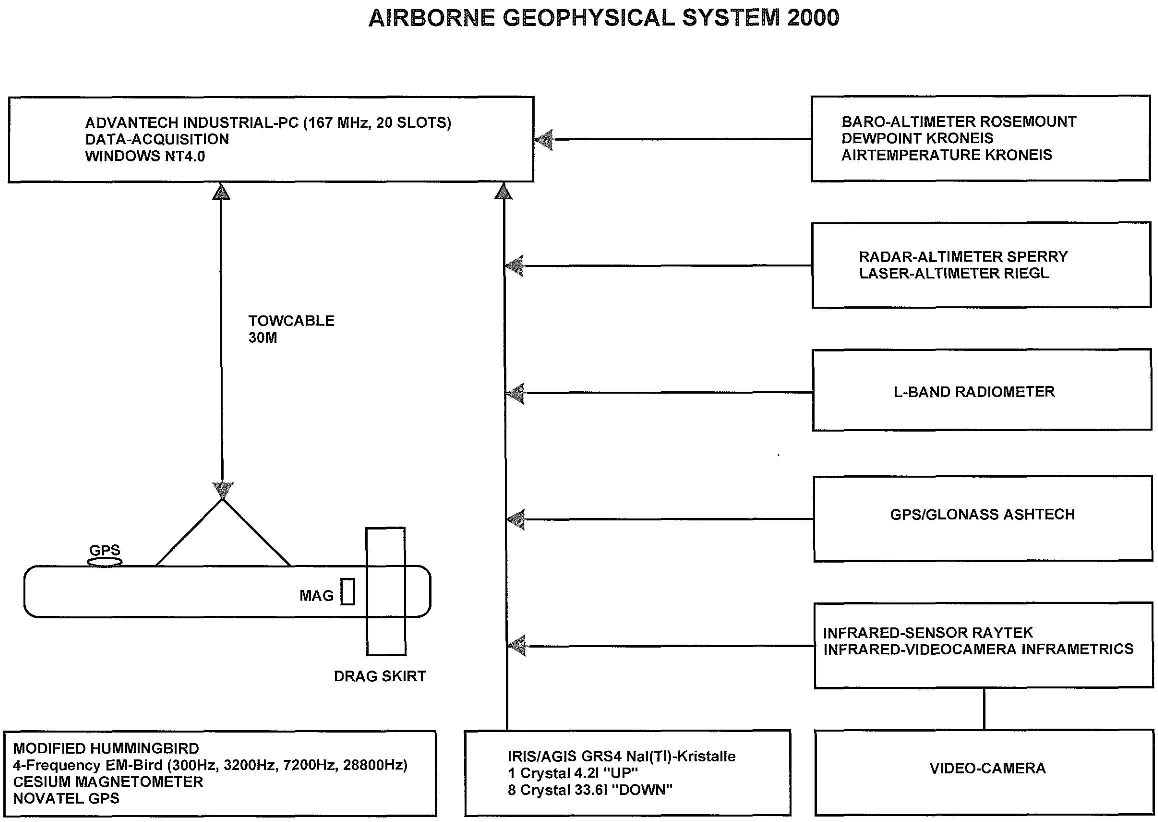

Fig. 2 Airborne geophysical system of the Geological Survey of Austria.

Below is a general summary on the survey instruments that are used.

a. Electromagnetic probe ("Bird") (10 samples/second)

At the beginning of aerogeophysical survey flights a probe of 10 m length and 250 kg weight was used (DIGHEM II: 900 Hz and 3,600 Hz, DIGHEM IV: 900 Hz (2x), 7,200 Hz, and 32,000 Hz). During the summer of 1995 these were replaced by a GEOTECH-"Bird" of 5.6 m length and 140 kg weight. Just as its forerunners, it is transported along by a tow cable 30 m below the helicopter.

The electromagnetic measuring probe is constantly being upgraded in collaboration with Canadian companies. For example, presently a wide-band sensor has been developed which will not only register survey signals of the 4-frequency probe, but also other anthropologically (16 2/3 Hz, 50 Hz; VLF: 15-30 kHz) or geogenic (AFMAG: 100-500 Hz) caused alternating fields. This is to improve the range of application of aeroelectromagnetics (i.e. larger penetration depths).

Inside this new probe there are four transmitting coils as well as four receiving coils in different geometric arrangements (co-axial, co-planar). The transmitting coils transmit an electromagnetic alternating field with frequencies of 300 Hz, 3,200 Hz, 7,200 Hz and 28,800 Hz. To a certain degree frequencies can be chosen freely. The receiver and the transmitter circuit are fully digital, this means that no analog signals are used for signal processing. The main advantages are less noise, better drift control, spectrum analyzer on all receiver channels, cross coil measurements, digital filtering, switchable 50/60 Hz filter, switchable transmitter frequency (1 Hz to 200 kHz), multiple frequencies on one transmitter coil using modulation techniques and digital communication between the Bird and the helicopter.

b. Gamma-ray spectrometer (1 sample/second)

This instrument (installed inside the helicopter) assists in the determination of natural and artificial radioactivity. Essentially, it consists of 9 sodium-iodide crystals, which convert gamma radiation into flashes of light. Appropriate survey instruments determine their energies. This covers the energy spectrum of 0.2 to 6.0 MeV in 256 channels. Natural gamma radiation is essentially derived from three sources: the radioactive elements thorium (energy peak: 2.62 MeV), uranium (energy peak: 1.76 MeV) and potassium (energy peak: 1.46 MeV). These elements occur in different rocks and soils at various concentration levels.

Since the air layer between helicopter and ground is absorbing gamma radiation (depending on the physical condition of the air), the exact flight altitude, air pressure, air temperature as well as air moisture (see section d.) have to be taken into consideration when correcting survey data.

c. Cs-Magnetometer (10 samples/second)

The Cs-Magnetometer is integrated into the above-mentioned EM survey probe and measures the total intensity of the earth's magnetic field.

d. Additional instruments

(1) GPS and navigation (5 samples/second)

In order to fly as accurately as possible over a given survey area a precise determination of position during flight is required. This task is carried out by an ASHTECH-GPS/GLONASS-receiver. By means of American (GPS) and Russian (GLONASS) satellite reception a precision of 10 m, without need of further correction, can be obtained (subsequent correction by means of a base station, a precision up to decimeter level can be achieved). The pilot is able to compare the previously determined survey profiles with the actual positions flown by means of a flight-direction indicator and, therefore, navigate with precision.

In addition, the position of the "Bird" can be registered with a second GPS-receiver.

(2) Flight altitude and determination of flight course (10 samples/second)

Flight altitude is very important for calculating electrical resistivity of the surveyed ground (see Section a.) as well as radioactivity (see Section b.). Three different simultaneously used systems are available for this purpose:

Laser altimeter: 10 cm accuracy
Radar altimeter: 2 m accuracy
Barometric altimeter

Due to its short wave lengths the laser altimeter, in contrast to the radar altimeter, is able to penetrate through leafy canopy thereby making the estimation of tree heights possible.

During the entire time of flying a VHS video camera is recording flight path on tape. Using a topographic map permits the subsequent control of GPS/GLONASS coordinates as well as subsequent determination of position, in the event of missing satellite signals.

(3) PC with LCD-Monitor, Video-recorder

An industrial PC, a video-recorder as well as a LCD-monitor is on board the helicopter for recording and constant control of survey data.

(4) Air and Dew Point Sensor (1 sample/second)

As mentioned in Section b., information on air temperature and air humidity is required for correcting radiometric data. These sensors are installed in a special housing attached sideways to the helicopter.

(5) VLF Instrument

The so-called VLF method (VLF=Very Low Frequency) is used as a supplement to the electromagnetic methods. The VLF method applies high capacity transmitters that are being used in various countries for communicating with submarines in a frequency range of 15–30 kHz. The passive receiver coils contained in the small bird are pulled along, 20 m below the helicopter. These tools are used for the discovery of electrical conductive bodies.

(6) Gradiometer

Another procedure useful for the VLF method as well as the magnetic field survey, is the "Gradiometer" arrangement. In this procedure two sensors are towed along at a vertical distance of 2 to 3 m, thereby increasing the resolution capacity, as well as the accuracy of the survey procedure.

(7) Ground Equipment

The ground equipment consists of a workshop bus where GPS reference data and the daily variations of the earth magnetic field are registered during survey flights, as well as a trailer for transporting the "Bird". The latter is equipped with solar cells and guarantees the power supply, independent of the public electric network system.

3. Infrared and Soil Moisture Surveys

Since 1994 the Department of Geophysics of the GBA has been using a L-Band-radiometer for its aerogeophysical surveys as well as an infrared sensor for the assessment of soil moisture. In 1997, an infrared video camera was added to the survey system.

Due to the newness of these survey instruments and the uniqueness worldwide of this survey procedure performed by helicopter, more detailed information will be given below.

The content of soil water is of great importance for many hydrological, agro-meteorological, ecological, as well as biological processes. Although the total volume of soil moisture is minimal, water content close to the surface controls the energy exchange between soil and atmosphere. The link between soil moisture, evaporation and transpiration is of utmost importance for predicting reciprocal influence of ground surface on climate and weather. These survey systems are mainly used in the following areas:

* determining water movements near ground surface
* estimating the spread of precipitation over large areas
* employing artificial irrigation.

3.1 Special Survey Instruments

Functioning modes and first results of these instruments are explained below.

a. Infrared Sensors (1 sample/second)

At the beginning of the non-contact temperature surveys an infrared thermometer made by EVEREST INTERSCIENCE Inc. was used. This instrument, however, which was developed for use in the field of agriculture, could not withstand the constant vibrations of the helicopter. After approx. one and a half years it was, therefore, replaced by a sensor made by RAYTEK (Fig. 3). This instrument, which is attached sideways to the helicopter, operates in a spectral range of 8 to 14 μm and possesses a relative accuracy of 0.1 ℃ in a temperature range of −18 ℃ to 500 ℃. Temperature values are read once every second via a serial connection. The diameter of surveyed area is approx. 3 m, at a flight altitude of 80 m.

b. Infrared video camera

Since 1997, the infrared video camera ThermaCAM made by INFRAMETRICS has been in use (Fig. 4). This camera operates with a FPA (Focal Plane Array) detector which converts infrared radiation into electrical signals through an arrangement of 256×256 (=65,536) platinum-silica (Pt-Si) sensors. This is obtained by a frequency of 50 Hz (PAL system). Each Pt-Si detector element reduces its electrical resistance when infrared radiation incidences with the appropriate wavelength (3.4–5 μm) which results in

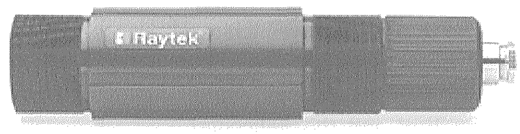

Fig. 3 Infrared sensor by RAYTEK.

Fig. 4 ThermaCAM infrared video camera by INFRAMETRICS.

the electrical current rising. The degree to which the current rises is proportional to the amount of radiation received. Sensitivity is in the range of 0.1 ℃. The detector is cooled by a Stirling micro-cooler. This cooler, which operates on the basis of the Stirling circular process (isothermal compression and expansion), cools the detector within minutes to −196 ℃.

Measured temperatures range between −20 ℃ and 450 ℃. At starting point a VHS (S-VHS) signal in black and white or color is used. The option of a digital starting point (digital depth 12 bit) is also possible. This has the advantage that the loss of quality, which is unavoidable during analog recording on videocassettes, is avoided. Its disadvantage is the enormous amount of data produced during the data storage, which can only be done on special media (i.e. digital videocassette, CD-ROM).

In the spring of 1998 a standard 16-degree lens which came with the camera was replaced with a 32-degree fish-eye lens. At 80 m flight altitude this facilitates a view of field of 44.7 m diameter.

For the evaluation of videotapes, the "ThermaGRAM for Windows" program package is available. It consists of an ISA picture processing card as well as a software program, running under MS-Windows. This facilitates, for example, depicting pictures from the visible spectrum area along with infrared pictures. However, analog recording (see above) will result in an equivalent loss of quality.

c. L-Band-Radiometer (1 sample/second)

This passive antenna, which was developed by the "Space Research Group" of the Technical University of Budapest, is employed for estimating soil moisture in water content percentage and is attached to the bottom of the helicopter (Fig. 5). The antenna measures the radiation from the ground, reflected in the L-Band (1,400 to 1,427 MHz, (λ =21 cm). The intensity of this radiation correlates to the water content in the soil and is influenced by the surface temperature, surface roughness as well as vegetation. The "penetration" depth of this method is 5-10 cm. The radiometer has a sensitivity of 0.3 ℃ and is equipped with an aperture angle of 19°. At a flight altitude of 80 m this results in a survey diameter of 26.8 m. Data is read and recorded, once per second, via a serial connection.

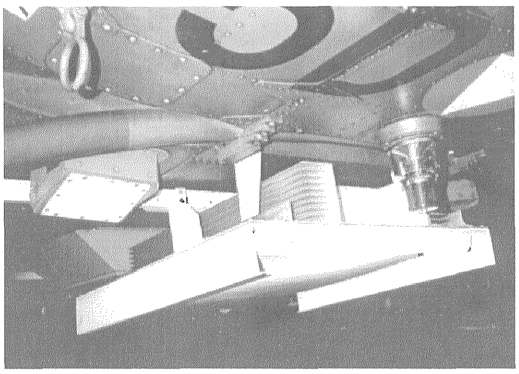

Fig. 5 L-Band-Radiometer.

In order to avoid any influences of temperature, the antenna is equipped with a heater, as well as a cooler and can be constantly operated at 49.9 ℃.

d. TDR Probe

A TDR probe (Time Domain Reflectometer) made by UMS was purchased for the purpose of calibration before start-up of the helicopter (Fig. 6). Time Domain Reflectometry is a fast, exact and indirect method for surveying volumetric moisture content in the field. Moisture content is determined in order to ascertain dielectric constancy of the ground by means of an electromagnetic impulse.

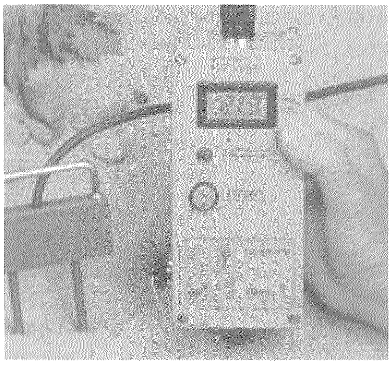

Fig. 6 TDR Probe by UMS.

3.2 Determining Soil Moisture

The characteristic of the antenna is first calibrated by flying over closed-in water surfaces and so-called ECCOSORB-mats. It determines 100 and 0 % of the soil moisture content. Calibration should be performed several times for each surveyed area. Infrared sensor and L-Band-Radiometer data, which is available, once every second, supply the input for a software package for evaluating soil moisture. The result, which is obtained, represents the brightness temperature of the ground surface. It corresponds to the temperature of a black body that emits radiation with the same energy and the same wavelength. Subsequently, with the aid of theoretical models the soil moisture is calculated. At the same time it is possible to include corrections for roughness and vegetation on the ground surface. However, due to the minimal effect of this correction (~1-3 % soil moisture) as well as the extremely elaborate determination of these correction values, it has been decided to forego this procedure at the present time.

4. Conclusions

Since the end of the 1980's the application spectrum of aerogeophysics has progressed from pure base metal projects to research projects which have tested, and are currently testing, hydrogeological problems and geogenic caused risks. The increased contamination of the natural environment (in the largest sense) is resulting in increased contamination conflicts. Geosciences, including helicopter geophysics, are able to make a substantial contribution to solving this problem. Listed below are some of the problem areas:

Hydrogeology
Determining the thickness of the overburden and its transmissibility. Intensive agricultural exploitation is resulting in increased nitrate contamination of groundwater. By means of helicopter geophysics (electromagnetics, radiometrics, soil moisture) large areas can be surveyed within a short period of time. This provides, on a purely qualitative basis, the distinction between upper layers of higher clay content (with lower transmissibility) and coarsely clastic sediments (with higher transmissibility).

Mass raw materials
Since many mass raw materials such as gravel, sand and clay differ mostly in their petrophysical properties, aerogeophysical surveys can be effective for the separation of mass raw materials.

Soil Science
Due to the installation of a soil moisture survey instrument as well as an infrared sensor in the helicopter in addition to gamma ray spectrometry it may become possible to derive geology-relevant parameters from aerogeophysical surveys. In the coming years new instrument developments in this field (infrared spectrometry) may provide us with the possibility of performing mineral differentiation directly from aircraft. These developments are as significant for general geology as they are for practical purposes.

Geogenic and anthropologically caused risks
Applying aerogeophysical surveys on mass movements should be intensified since difficult areas too can be surveyed by helicopter. Important additional information related to the condition of landslides can be obtained because of recently available infrared and soil moisture survey instruments.

Received June 30, 2000
Accepted January 10, 2001

オーストリア地質調査所における空中物理探査システム

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要　旨

本論では，オーストリア地質調査所が所有する空中物理探査システムについて簡単に紹介する．探査システムは，4 周波数の EM（空中電磁）装置，セシウム空中磁力計，9 個の NaI 結晶からなるシンチュレーションカウンタ（γ 線測定装置）に加えて，GPS，レーダー及びレーザー高度計等からなる．EM 装置は全く新規に開発されたもので，完全にディジタル化されたシステムで従来のアナログシステムに比べ多くの利点を有する．最近，赤外線センサーと受動型マイクロ波アンテナが土壌の水分を調査するためにシステムに加えられた．本論では，最近追加されたシステムについて特に詳細に記述する．
（要旨翻訳：大熊茂雄（地殻物理部））