FIELD TECHNIQUES FOR ATMOSPHERIC SYSTEMS

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Contents

Summary

The article illustrates the requirements for field techniques currently used in atmospheric science. The necessity of field campaigns is highlighted to explore the complex structure of interconnected processes. A few conceptual aspects of field campaigns and techniques are considered. Special attention is focused on quality assurance of the various techniques and instruments used in field campaigns. Among the various platforms used to carry instruments for atmospheric measurements in the field, aircraft, satellites, balloons, ships and buoys are emphasized.

The large field of sampling techniques for chemical measurements is a major issue of this article. Special techniques and combinations of instruments are used to directly measure atmospheric flux. The article also lists a few intensive field studies and long-term monitoring programs that are of interest for a large community of researchers in environmental questions.

1. Introduction

Knowledge about the structure of meteorological relations and weather systems formation came up in the beginning of the 20th century after establishing a worldwide network of meteorological observation stations. In consecutive field studies this concept of a measuring network turned out to be the only way of retrieving knowledge about atmospheric relations and the complex interaction of competitive feedback processes.

Clearly, the concept of field measurements must be adapted to the temporal and spatial scale under consideration.

As shown elsewhere (see *Measurement Tools for Atmospheric Systems*), many instruments are suited for field measurements. The reader is recommended to read that article in advance. The issues of this article are some general remarks on field techniques and field campaigns, the synergetic effect of using a suitable combination of instruments, the diverse platforms available for mounting instruments and sampling techniques for aerosols and gases to bring air into an instrument, or, into the laboratory. With respect to long-term monitoring for a climatology of trace gases or reconstruction of climate parameters, the analysis of archives is outlined. Additionally, tracer experiments as special arrangements for determining pollution dispersion are briefly discussed. Further, the measurement of various fluxes is presented. These measurements often make use of a combination of instruments. Finally, a few selected international field campaigns and long-term monitoring programs, which demonstrate the power of a coordinated effort, are listed.

2. Conceptual Aspects of Field Campaigns and Techniques

The first question to be answered in the context of atmospheric studies is always the scale of the processes involved. With respect to temporal resolution, two approaches are to be distinguished: Episodic measurements, such as case studies or intensive field campaigns, and monitoring networks, mainly addressing climatological questions and long-term trends. The use of high-tech instruments is restricted to intensive field campaigns, whereas simple, proved and easy-to-handle instruments must be used for continuous monitoring often maintained at remote locations. The concept of intensive field campaigns should take care of the three-dimensional extension of the atmosphere. Therefore, measurement tools such as remote sensing, balloon, aircraft and satellite-borne instruments should be involved. Best results are obtained when the instruments are set up for the highest representativity of measurements. Most remote systems for exploring the vertical distribution of various atmospheric parameters are also found mounted on the platforms described below. As far as instruments are considered, remote sensing systems are described elsewhere (see *Measurement Tools for Atmospheric Systems*).

With respect to *quality assurance* of the measurements, a few points are mandatory to be considered. Measurements in the field are always more difficult than laboratory analyses. The instruments may be exposed to unfavorable weather conditions, they are transported to remote locations or mounted on unstable platforms. The instruments must be tested under similar conditions prior to be used in the field. Because of often uncertain power supply at remote locations, the instrument must be constructed to withstand power supply instabilities. The most crucial issue on quality assurance is calibration. The interval of calibration must correspond to the long-term stability of the technique. A few instruments, mainly for chemical species, have built in self-calibration units. Periodic intercomparison events during field campaigns must be planned before starting the campaign. Instead of intercomparison, a mobile calibration unit is often used for continuous checks and calibrations of ground stations. Considering the rough environmental conditions of outdoor measurements, a cleaning strategy for the sensitive instruments is recommended. Although these recommendations are commonplace, they are sometimes not considered during planning, or not enough time is given to fulfill the requirements.

3. Platforms

Moving platforms are very popular with atmospheric measurements, because they allow for fast cruising over large areas, even in the vertical dimension. But also ground-fixed platforms, such as towers, are used for mounting instruments to get representative measurements. In addition, ships and buoys are used to complete the use of instruments for measuring atmospheric properties over the oceans.

3.1. Aircraft

The advantage of aircraft as platforms for airborne instruments is their mobility and the inclusion of the vertical dimension. Light aircraft can carry pay loads of up to 100 kg, reach a height of up to 6 km and cruise at 250 km/h. The advantage of this type of aircraft is the maneuverability, so that it is suited even in complex topography within narrow valleys. Turbo-prop machines can carry a few hundred kilograms up to a height of 7 km with a range of a few thousand kilometers. Large turbo-props can carry payloads up to a few tons. Jet aircraft range from small to large airliners, they can carry different payloads up to a few tons and can reach heights up to 12 km. Special aircraft are developed to reach heights up to 20 km. These machines are suited for exploring the upper troposphere and the lower stratosphere. For special applications in a local context, remotely controlled model aircraft or drones are used with small payloads, but with very high maneuverability and low costs.

3.2. Satellites

Satellite measurements attracted attention for a large range of applications. A worldwide coverage of data became available by using satellites as platforms for almost all radiation instruments. The instruments on satellites are placed to look along different directions into the atmosphere. The limb view is a nearly horizontal view tangential to the Earth’s surface, so that the absorption path for gas concentration measurements is as long as possible. The limb view is also suited to realize vertical profile measurements. The nadir looking instrument has a downward viewing path and is best suited for measuring long wave radiation emitted by the earth’s surface. An occultation viewing instrument looks into the Sun during sunset or sunrise and is used for absorption measurements to get gas concentrations. The satellite-borne instruments make use of a wide part of the electromagnetic spectrum from microwave to infrared, visible and ultraviolet wavelengths. The radiation observed from satellites is either emitted from the earth’s surface or from the sun, and scattered within the atmosphere.

Satellites for meteorological parameters are in use since the first Meteosat TIROS-1 started its activity in 1960. The main goal of the early satellites was to improve the weather prediction with the aid of a visualization of the water vapor distribution. During the last years, the development of instruments tends to increase the resolution in time, space and wavelength. Today’s satellites realize spatial resolutions down to a few meters and spectral resolutions up to 200 channels. Clearly, with increasing spatial resolution the temporal resolution tends to decrease. The combination of data from different satellites is often used to get the benefit from both extremes. A higher aggregation of knowledge is achieved by including the information of ground stations and meteorological profiles. This information is widely used in the routine runs of weather prediction models. It is therefore recommended to combine these model results with satellite data to get high temporal and spatial resolutions.

Satellites for meteorological measurements mainly observe wind, temperature and humidity. Over the oceans, the surface wind sensing is realized with scanning the sea surface and calculating the *wind* from the observed water waves. The HRDI (high resolution Doppler imager) on UARS (upper atmosphere research satellite, measurements from 1992 to 1997) measured winds in the stratosphere. Oxygen lines are used in the spectrum of scattered sunlight, and their Doppler shift is analyzed with very high accuracy. Tropospheric wind over the continents are derived by tracking cloud, fog or aerosol movement. *Temperature* is measured by the spectrometrical determination of the width of molecular absorption lines. The CLAES (cryogenic limb array etalon spectrometer) measured temperature besides some trace gases. The *radiation budget* of the lowest atmosphere is a topic of primary interest for the *energy budget* of the air close to the surface. The mixing processes and air mass exchange between emission sources close to the ground and the troposphere are controlled by this energy budget. From nadir looking instruments, such as AVHRR (advanced very high resolution radiometer) on NOAA and HRV (high resolution visible) sensor on SPOT, the surface temperature and, with the aid of models, the latent and sensible heat fluxes can be determined.

A variety of instruments have been developed to measure *chemical constituents* of the atmosphere. The reader is referred to additional literature given in the bibliography. Only a few instruments will be shortly presented in the subsequent paragraphs.

The *MAPS* (measurement of air pollution from satellite) sensor on space shuttle missions measured tropospheric CO and N_2O in the spectral range from 4.5 to 4.8 μm with a gas filter correlation radiometer. This nadir-looking radiometer consists of an electro-optical sensor measuring the absorption lines of the two gases. In this arrangement, the incoming beam is split into three beams: two passing a CO and a N_2O containing cell, one falling directly onto a detector. The observed signal differences are used for CO and N_2O determination in the altitude range from 0 to 18 km.

TOMS (total ozone mapping spectrometer) sensed the total atmospheric ozone column, using spectroscopy in the wavelength range from 331 to 380 nm where other molecules show no strong absorptions. This solar ultraviolet radiation is strongly backscattered from the atmosphere. By combining scattering and absorption, the ozone amount can be determined. An external scan mirror scans the 3° field of view across the satellite ground track to build up a global picture of the entire illuminated atmosphere. TOMS was on duty from 1979 to 1992 and revealed excellent data on the development of the ozone hole. The TOMS sensor was mounted on the NIMBUS-7 mission. In the future, the TOMS missions will be continued with TOMS-EP (Earth Probes), a free-flying spacecraft with a nadir pointing sensor. The TOMS-EP provides a contiguous survey of the earth every day.

The *SCIAMACHY* (scanning imaging absorption spectrometer for atmospheric cartography) is a passive spectrometer for the measurement of trace gases in the troposphere and stratosphere, operating by DOAS of solar and lunar radiation in the spectral region from 240 nm to 2400 nm. The instrument looks in three different modes: occultation (Sun/Moon), nadir and limb scattering. The pixel size in nadir-viewing mode is 32 km along track and 16 km across track. The swath width is 1000 km, the scan period 4 s in forward and 1 s in backward motion. The limb mode provides trace gases (O_3, NO, NO_2, HCHO, SO_2, OClO, NO_3, CO N_2O and H_2O) and aerosol profiles with 3 km vertical resolution from ground to 90 km.

The Radarsat, started in 1995, is an observation satellite with a SAR equipment. A special scanning technique is used for extended observation coverage on command. Extended-range coverage is obtained by using a set of contiguous beams, enabling images to swath widths of up to 500 km with a corresponding decrease of spatial resolution. The principle of changing swath widths is shown in Figure 1.

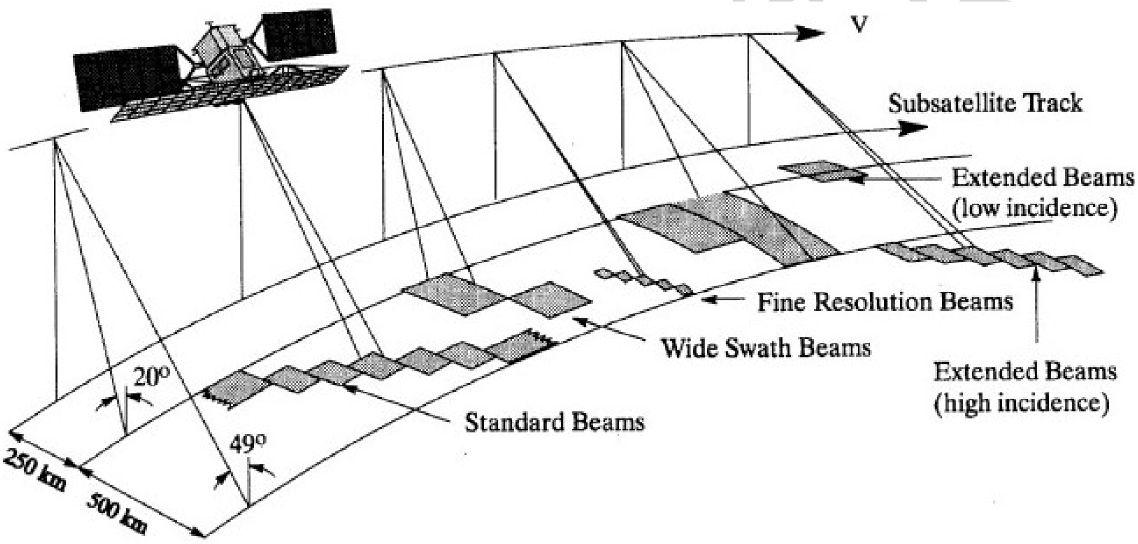

Figure 1. The Radarsat model and illustration of observation geometries (from Kramer H.J. (1996) *Observation of the Earth and Its Environment*, 960 pp., survey of missions and sensors, Springer, Berlin).

The *TES* (Tropospheric Emission Spectrometer) on *EOS-CHEM-1* planned to launch in the year 2002 is a high resolution imaging FTIR spectrometer in the band from 2.3 to 15.4 μm and a spectral resolution of 0.0025 cm^{-1}. TES has the capability to make both limb and nadir observations. In the limb mode, the height resolution is 2.3 km, ranging from the ground up to 32 km. In the nadir modes, TES has a spatial resolution of 50 by 5 km in the global mode, or, 5 by 0.5 km in the local mode. TES is a pointable instrument it can access any target within 45° of the local vertical, or produce region transects up to 1700 km without a gap in the coverage. TES will provide tropospheric ozone and its photochemical precursors. In addition, quantities like NO_y, CO, H_2O, SO_2 and gradients of many other tropospheric species. The data rate produced from TES is up to twelve million Bits per second.

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Biographical Sketches

Werner Karl Graber was born on 14 December 1951, Basel, Switzerland. He received Diplom fuer Physiker and Ph.D. Degrees from Eidgenoessische Technische Hochschule Zuerich in 1977 and 1985 respectively. He is presently Head of the Atmospheric Pollution Section , Paul Scherrer Institute, Villigen-PSI, Switzerland. His research interests include application of instruments for measurements in environmental research, mainly aircraft measurements, field measurements to investigate the production of photo-oxidants, modeling for the description of the link between local and regional wind systems, deposition of atmospheric pollution to the vegetation and interaction with the vegetation, and soil solution modeling and calculation of critical loads and levels of nitrogen (eutrophication) and sulfur (acidification).

Markus Furger was born on 26 Aug 1958. He received a physics Diploma from Eidgenoessische Technische Hochschule (ETH), Zuerich in 1983 and a Ph.D in Geography from the University of Bern in 1990. He received the 1990 Meteotest Award for the latter. During Aug. 1992 - July 1993 he was Adjunct Environmental Scientist at Washington State University, Tri-Cities Campus, spent at Pacific Northwest Laboratory, Richland, Washington. He is presently with Paul Scherrer Institut, Villigen PSI, Switzerland. He took part in various field experiments in the Alps (ALPEX, Pollumet, VOTALP, Ecomont, MAP) and worked on the development of remote sensing applications in mountainous terrain (scintillometer, sodar, radar wind profilers).His research activities include climatological studies of the wind field in the lower troposphere in the vicinity of mountain ranges, Monte Carlo simulation technique to estimate the uncertainties in boundary layer heat budgets obtained from wind profiler data. He is member of American Meteorological Society, American Geophysical Union, Swiss Society of Meteorology, and European Geophysical Society.