REGIONAL CENTRES FOR SPACE SCIENCE AND TECHNOLOGY EDUCATION

Satellite meteorology and global climate

Education curriculum

United Nations

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(AFFILIATED TO THE UNITED NATIONS)

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Office for Outer Space Affairs
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Preface

Human beings have no doubt always had a fascination with and a practical interest in the weather. Meteorological phenomena were a major subject of speculation in the philosophical works of classical antiquity, but scientific study of the weather is generally dated from the invention of the thermometer and barometer in the seventeenth century. There were sporadic attempts to plot weather maps from surface observations in the eighteenth century. The invention of the telegraph in the nineteenth century opened the prospect of producing and disseminating real-time forecasts using data gathered over a large geographical area. Government-sponsored observing networks were begun in several countries in the mid- and late nineteenth century. The nineteenth century also saw important developments in basic fluid dynamics and thermodynamics, which put the study of the atmosphere on a firm basis as a problem in applied physics. In recent decades, spectacular advances have been made in both observational and theoretical studies of the atmosphere. Such progress has been greatly facilitated by the availability of satellite platforms for atmospheric observing systems and the development of digital computers for the non-linear governing equations.

Historically, the study of the atmosphere has been divided into the disciplines of meteorology and climatology. Climatology could be defined as the study of those processes that determine the time-mean state of the atmosphere, where the mean is defined as an average over a substantial period (a year or perhaps a number of years). Meteorology deals with the physics of the higher-frequency components of atmospheric variability. It has become increasingly obvious that the distinction is quite arbitrary and not particularly useful. The circulation in the atmosphere displays variability at all time scales, and there are important interactions among the various frequency components.

Much recent work on atmospheric monitoring and modelling has been motivated by an awareness that humanity has the potential to alter significantly (if inadvertently) the global climate. Particular concerns have been raised about the increasing atmospheric levels of so-called greenhouse gases such as CO2 caused by industrial and agricultural activities. Reliable predictions of the sensitivity of climate to such anthropogenic influences would be enormously valuable in formulating strategies to mitigate the social and economic consequences of global environmental change.

Contents

Explanatory notes

0-D	zero-dimensional
1-D	one-dimensional
2-D	two-dimensional
3-D	three-dimensional
APT	automatic picture transmission
ATSR	along-track scanning radiometer
AVHRR	advanced very high resolution radiometer
CCD	charge-coupled device
DMSP	Defense Meteorological Satellite Program
ENSO	El Niño Southern Oscillation
ERS	European remote sensing satellite
GIS	geographic information system
GMS	geostationary meteorological satellite
GOES	Geostationary Operational Environmental Satellite
GPCP	Global Precipitation Climatology Project
HRPT	high-resolution picture transmission
INSAT	Indian National Satellite System
IRS	Indian Remote Sensing Satellite
ISCCP	International Satellite Cloud Climatology Project
ISLSCP	International Satellite Land Surface Climatology Project
ITPP	International TOVS Processing Package
LOWTRAN	low resolution transmittance
MSMR	multichannel scanning microwave radiometer
NCAR	National Centre for Atmospheric Research
NCEP	National Centres for Environmental Prediction
NDVI	normalized difference vegetative index
NOAA	National Oceanic and Atmospheric Administration
NWP	numerical weather prediction
OLR	outgoing longwave radiation
SSM/I	special sensor microwave imager
SST	sea surface temperature
TIROS	television and infrared observation satellite

TOVS	TIROS operational vertical sounder
TRMM	Tropical Rainfall Measuring Mission
VHRR	very high resolution radiometer
WEFAX	weather facsimile
WMO	World Meteorological Organization

Introduction

Space science and technology education can be pursued at the elementary, secondary and university levels. In spacefaring nations, elements of space science and technology have been introduced into science curricula at those levels. Such an innovation has not taken place in many developing countries, partly because the benefits of space science and technology have not been appreciated enough and partly because the facilities and resources for teaching science and technology at educational institutions are not yet well developed. Education in space science and technology in developed countries has become highly interactive; the World Wide Web and other information technologies have become useful tools in education programmes at all levels.

The incorporation of elements of space science and technology into university- level science curricula can serve a dual purpose for developed and developing countries. It can enable all countries to take advantage of the benefits inherent in the new technologies, which, in many cases, are spin-offs from space science and technology. It can revitalize the educational system, introduce the concepts of high technology in a non-esoteric fashion and help create national capacities in science and technology in general. In that regard, Lewis Pyenson emphasized in his recent work entitled *Servants of Nature*[1] that:

> "Both geographical decentralization and interdisciplinary innovation have become watchwords in academic science. Electronic information processing to some extent obviates the necessity for a scientist or scholar to reside at an ancient college of learning. Universities everywhere have adapted to new socioeconomic conditions by expanding curricula. They have always responded in this way, although never as quickly as their critics would like. Measured and deliberate innovation is one of academia's heavy burdens. It is also a great strength. Emerging fields of knowledge become new scientific disciplines only after they have found a secure place in universities. We look to universities for an authoritative word about the latest innovations. New scientific ideas emerge in a variety of settings, but they become the common heritage of humanity only when processed by an institution for advanced instruction like the modern university."

There are many challenges in the teaching of science at university level, both in developing and developed countries, but the challenges are of a higher magnitude in developing countries. The general problem confronting science education is the inability of students to see or experience the phenomena being taught, which often leads to an inability to learn basic principles and to see the relationship between two or more concepts and their practical relevance to problems in real life. Added to those problems are a lack of skills in the relevant aspects of mathematics and in problem-solving strategies. There are also language problems in countries in which science is not taught in the national language(s). Over the years, developed countries have overcome most of the basic problems, except perhaps a psychological problem, namely that students may consider science to be a difficult subject. In developing countries, however, basic problems linger, exacerbated by the fact that there are not enough academically and professionally well-trained teachers.

Establishment of the regional centres for space science and technology education

The General Assembly, in its resolution 45/72 of 11 December 1990, endorsed the recommendation of the Working Group of the Whole of the Scientific and Technical Subcommittee, as endorsed by the Committee on the Peaceful Uses of Outer Space, that the United Nations should lead, with the active support of its specialized agencies and other international organizations, an international effort to establish regional centres for space science and technology education in existing national/regional educational institutions in the developing countries (A/AC.105/456, annex II, para. 4 (n)).

The General Assembly, in its resolution 50/27 of 6 December 1995, paragraph 30, also endorsed the recommendation of the Committee on the Peaceful Uses of Outer Space that those centres be established on the basis of affiliation to the United Nations as early as possible and that such affiliation would provide the centres with the necessary recognition and would strengthen the possibilities of attracting donors and of establishing academic relationships with national and international space-related institutions.

Regional centres have been established in India for Asia and the Pacific, in Morocco and Nigeria for Africa, in Brazil and Mexico for Latin America and the Caribbean and in Jordan for Western Asia, under the auspices of the Programme on Space Applications, implemented by the Office for Outer Space Affairs (A/AC.105/749). The objective of the centres is to enhance the capabilities of Member States, at the regional and international levels, in various disciplines of space science and technology that can advance their scientific, economic and social development. Each of the centres provides postgraduate education, research and application programmes with emphasis on remote sensing, satellite communications, satellite meteorology and space science for university educators and research and application scientists. All centres are implementing nine-month postgraduate courses (in remote sensing, satellite communications, meteorological satellite applications, and space and atmospheric sciences) based on model curricula that emanated from the United Nations/Spain Meeting of Experts on the Development of Education Curricula for the Regional Centres for Space Science and Technology Education, held in Granada, Spain, in 1995. Since 1995, these curricula (A/AC.105/649 and http://www.oosa.unvienna.org/SAP/centres/centres.htm) have been presented and discussed at regional and international educational meetings.

The Third United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE III), held in Vienna in July 1999, recommended that collaboration should be established between the regional centres and other national, regional and international organizations to strengthen components of their education curricula.[2] In its resolution 54/68 of 6 December 1999, the General Assembly endorsed the resolution of UNISPACE III entitled “The Space Millennium: Vienna Declaration on Space and Human Development”, in which action was recommended to ensure sustainable funding mechanisms for the regional centres.[3]

United Nations Expert Meeting on the Regional Centres for Space Science and Technology Education: Status and Future Developments

The Office for Outer Space Affairs of the Secretariat organized, in cooperation with the European Space Agency (ESA), the United Nations Expert Meeting on the Regional Centres for Space Science and Technology Education: Status and Future Development in Frascati, Italy, from 3 to 7 September 2001. The Meeting was hosted by the ESA European Space Research Institute in Frascati.

The Meeting reviewed the status of establishment and operation of the regional centres with a view to enhancing cooperation between the centres. The main objective of the Meeting was to review and update curricula at the university level and across cultures in four areas: remote sensing, satellite meteorology, satellite communications and space science. The Meeting considered that education varied significantly between countries and even between institutions within the same country which led to differences in space science and technology education curricula in terms of course content and modes of presentation. The Meeting noted that the model curricula (A/AC.105/649) had contributed to resolving such problems.

The Meeting established five working groups to focus on the following specific topics and respective education curriculum: (a) management issues of the centres; (b) remote sensing; (c) satellite meteorology; (d) satellite communications; and (e) space science. The working groups drew on the knowledge and expertise of participants, thereby taking into account the results of previous nine-month postgraduate courses, particularly those organized since 1996 at the Centre for Space Science and Technology Education in Asia and the Pacific and since 1998 at the African Centre for Space Science and Technology—in French Language and the African Regional Centre for Space Science and Technology Education—in English Language.

The Meeting, through its working groups, updated the four education curricula and drew up course syllabuses that differ from most of those available in literature and on the World Wide Web. They are based on physics, mathematics and engineering as taught in many universities around the world. They are not tailored to any specific space-related project or mission that may have been or will be executed by any specific institution.

Curriculum on satellite meteorology and global climate

The present chapter contains the deliberations of the working group on satellite meteorology and global climate, which was established during the United Nations Expert Meeting on the Regional Centres for Space Science and Technology Education: Status and Future Development. The working group discussed the purpose of holding courses in that field, reviewed the existing curriculum of and experience gained through courses that had been held at regional centres (annex I) and developed the objectives, requirements, structure and revised curriculum of new courses.

Purpose of courses in satellite meteorology and global climate

A meteorological satellite application course is a specific component of space science and technology education. It is important because, while meteorological satellites have operated in space for over three decades, the majority of the world's scientific, professional and educational communities are unaware that observations from those satellites are freely accessible and that they can be applied directly or combined with other information to benefit large segments of a country's population or to help resolve specific problems affecting those populations, especially where the saving of lives, the protection of property or the responsible management of natural resources may be involved.

Many national meteorological agencies have realized the importance of conducting courses in satellite meteorology for their operational needs. Their regular training courses include a small segment on satellite meteorology, covering primarily the synoptic studies of the weather system with imageries.

The issues related to global warming, ozone depletion, the El Niño Southern Oscillation (ENSO) and ocean atmosphere interaction and global climate change, once only of academic interest, have now become extremely relevant. The course, besides imparting knowledge in basics of satellite meteorology and advanced issues, caters primarily to education in this field. Handling of satellite digital data, working with dynamical models, problem solving and executing projects of relevance to the home country, has been the prime focus of the course.

Meteorological satellites have been operating almost continuously since the beginning of the space age. Their continuing presence in space for decades to come is virtually assured because of the importance that society at large places on the observations and forecasting of weather phenomena. Spacecraft have been launched by some countries specifically to meet the needs of professional government meteorologists in those countries who are responsible for providing weather forecasts for civil and military interests. However, most countries that launch weather satellites have designed the satellites to operate in such a manner that anyone who is within radio receiving range of the satellites can acquire the data free and use the data for any purpose. Thus, it is feasible to use real-time, direct readout observations from the satellites as an educational resource in schools. Such observations can also be used as a tool for managing and forecasting weather, detecting forest fires, supporting air, sea and land transportation, supporting agricultural and fishing interests, and for a wide range of other non-meteorological purposes. In addition to operational satellites, a few research and development satellites, giving more information about the atmosphere and oceans, are now available. The inclusion of satellite data in numerical weather prediction is possible. Information from geographic information systems (GIS) has to be included in meteorological and climatological studies. The course curriculum should include all these aspects.

Global access to meteorological satellite data was initiated by the World Meteorological Organization (WMO) to help ensure that knowledge of aerospace sciences and technologies that have evolved as a result of the free access to meteorological satellite observations can and will be utilized by individuals, organizations and countries, especially developing countries. WMO does this by endowing a core group of specialists in different countries with the analytical skills and technical knowledge that will enable them to investigate and sustain a wide variety of indigenous programmes in which technology supports scientific, economic, educational and humanitarian programmes that will enhance the quality of life for broad segments of the population.

Review of the existing curriculum and experience gained

The United Nations has developed a model curriculum in satellite meteorological applications for the regional centres. The initial work on this curriculum was carried out at the United Nations/Spain Meeting of Experts on the Development of Education Curricula for the Regional Centres for Space Science and Technology Education, held in Grenada, Spain, in 1995. In order to attain international recognition and certification, the model curriculum was prepared to provide the regional centres with a benchmark of the academic level necessary to maintain the international standard and character of the course as well as the regional centres.

The course consists of nine months of study at a regional centre, followed by the implementation and completion of a one-year pilot project in the participant's home country.

Experts at the meeting held in 1995 envisaged that participants would participate in a course of instruction designed to increase their scientific knowledge in the application of meteorological satellite-derived data and develop and extend their computational and analytical experience in order to allow them to initiate and implement the benefits of this science and technology in their home countries.

The experts also suggested that the following topics should be covered by the course:

> Atmospheric compositions; radiation laws; general circulation of atmosphere and oceans
>
> Basic radiometry; interaction of electromagnetic radiation and matter
>
> Thermodynamics; dynamics; tropical and extra-tropical motion systems; meso-scale and synoptic scale systems
>
> Weather forecasting; combined use of satellite, radar and conventional data; numerical weather prediction
>
> Essentials of satellite types, orbits and sensors; vertical sounding systems on board satellites, as well as in situ data collection platforms; retrieval of meteorological products
>
> Specialized treatment and application of satellite data acquired by polar orbiting and geostationary satellites in several areas of human endeavours, e.g. agriculture, determination of shelter temperature, estimation of soil skin temperature; estimation of amount and distribution of precipitation, crop inventory, livestock management, fisheries etc.

Two courses have been held and a third is in progress. The working group reviewed the curricula of the courses, as discussed below.

First course

The first postgraduate course in satellite meteorology and global climate was held at the Centre for Space Science and Technology Education in Asia and the Pacific from 1 March to 30 November 1998. The syllabus for the first course was based on the broad guidelines established at the 1995 meeting (A/AC.105/649). The modules covered in the course are shown in annex I, table 1. The breakdown of the course curriculum in terms of classroom lectures, laboratory work, tutorials, library, technical visits etc., which helped a great deal in the preparation of the schedules during the course, is provided in figure I.

The following comments were received from the participants and faculty as feedback:

(a) Too much emphasis was placed on tropical meteorology. More topics related to mid-latitude systems should be included;

(b) More case studies (e.g. on satellite data application in numerical weather prediction (NWP) models) and sample numerical problems would be desirable;

(c) An introductory course on basic physics, mathematics and computer programming would be desirable;

(d) More time should be allotted to topics such as climate change, radiative transfer etc.;

(e) The number of tutorials should be increased.

Second course

The second postgraduate course was held at the Centre for Space Science and Technology Education in Asia and the Pacific from 1 July 2000 to 31 March 2001. Based on the feedback received from the participants and faculty of the first course, the following modifications were made to the course curriculum to be followed during the second course:

(a) An orientation module covering the basics of mathematics, statistical methods and computers was included;

(b) Emphasis on tropical meteorology, including monsoons and tropical severe weather systems, was significantly reduced;

(c) New lecture topics covering mid-latitude and extra-tropical systems were introduced.

The modules covered during the second course are shown in annex I, table 2 and the corresponding breakdown of the time schedule is given in figure II. The inclusion of the orientation module covering the basics of mathematics, statistics and computers was welcomed by participants and helped them in improving their knowledge.

Prior to the course, it was decided to introduce three elective papers in specialized fields covering 20 lectures in the second course, namely: (a) parameter retrieval using satellite data; (b) data assimilation and numerical models; and (c) climate change. Basis on discussions with and background of participants and the time available, the elective option was dropped. The important aspects of each were included in the respective modules. In addition, a number of changes in the curriculum were implemented (e.g. the inclusion of lectures on dynamic meteorology and physical oceanography in the orientation module).

Third course

The third course, which is being held at the Centre for Space Science and Technology Education in Asia and the Pacific, will begin on 1 August 2002 and will end on 30 April 2003. Following an in-depth review of the second course, the following changes were made for the third course:

(a) Physical oceanography topics were introduced in the introduction sub-module;

(b) Emphasis on advanced topics on radiative transfer and parameter retrievals was reduced;

(c) More stress was put on applications of satellite data;

(d) The lectures on global climate were increased. Lectures on short-term climate variability and long-term climate changes were introduced.

The modules being covered during the third course are shown in annex I, table 3.

Practical exercises

In addition to theory classes, classes involving practical exercises in the use of satellite imagery, digital data applications, meteorological parameter retrieval and interpretation of numerical model outputs are held in the afternoons. A list for each of the three courses is contained in annex I, section B.

Pilot projects

The details of the pilot projects carried out by participants during the first and the second courses are provided in annex I, section C.

Evolution of the curriculum

Curriculum development is a continuous process that should take into account, among other things, various technological developments, new emerging application scenarios and feedback received from participants and faculty. The evolution of the curriculum is shown in annex I, section B, table 4. Feedback was received from the participants at the end of each module, and the suggestions received from them were discussed and implemented to the extent possible. At the end of each of the courses, an extensive feedback form was filled by each of the participants. Faculty members were also asked to give their feedback for each course. All the feedback is taken into account and discussed by a board of studies (a group of experts established for that purpose). The recommendations are taken into account in conducting subsequent courses.

Revised curriculum for the course on satellite meteorology and global climate

Objectives

The objectives of the course on satellite meteorology include the following:

(a) To educate specialists from developing countries in meteorological satellite applications in support of their development and socio-economics well-being;

(b) To promote the utilization of meteorological satellite data and techniques for the monitoring and assessment of the environment and severe meteorological phenomena.

It is anticipated that, at the end of the course, participants will be able:

(a) To serve as focal points for furthering the skills and knowledge of other professionals in their countries;

(b) To contribute to policy-making, planning, development and management of operational meteorological satellite data and applications in their countries;

(c) To enhance and increase the self-reliance of their countries so as to lessen dependence on external experts.

Programme requirements

Participants in the course are required to have a Bachelor of Science degree in mathematics, physics or meteorology and at least five years of professional experience in meteorology or related fields.

Structure of the curriculum

The proposed course will consist of a nine-month work programme followed by a one-year pilot project in the participant's home country. The nine-month course has four components: basic concepts (two months); applications of data derived from meteorological satellites (two months); numerical models and climate change (two months); and project development and proposals (three months). The first three components are organized into three modules, respectively. A fourth extracurricular module is suggested for more advanced students and consists of topics on potential uses of future satellites, instruments etc. In designing the structure of the curriculum, the working group benefited from the experience of the Centre for Space Science and Technology Education in Asia and the Pacific.

Lectures and practical exercises

The working group suggested that 15 hours of lectures be accompanied by 20 hours of practical work per week.

Equipment

The equipment and products that are needed as part of the course (A/AC.105/649), including those already specified in document A/AC.105/534, are as follows:

High-resolution picture transmission (HRPT) ground station
Microcomputers (with modems, CD ROM players etc.)*
Printers
Internet capacity
Facsimile machine
High-resolution geostationary satellite ground stations
Data files
Graphical analysis and display system
Image processing and meteorological software
Access to radar and national weather prediction products*
Workstations*
Automatic picture weather facsimile (APT/WEFAX) station
Geographic information system (GIS)
Climatological atlases*
Topographic material
Textbooks

Invitation/questionnaire

Prospective participants are required to complete a questionnaire to assist the regional centres in the selection process. Each regional centre may prepare its own questionnaire.

Revised curriculum

The revised curriculum for the satellite meteorology and global climate course is presented below.

Module 1: Basic concepts (two months)

1. Meteorology

   Atmospheric dynamics
   General circulation of the atmosphere
   Tropical and extra-tropical weather systems

2. Climatology

   Components of the Earth's climate
   Annual and semi-annual cycles
   Climate variability
   Overview of world climate

3. Oceanography

   Role of oceans in weather and climate
   Oceanographic parameters
   Ocean circulation
   Air-sea interactions

* The amount of equipment needed will depend on the number of participants selected for the course.

4. Atmospheric physics

   Composition of the atmosphere
   Thermodynamics
   Radiation laws
   Electromagnetic spectrum

5. Mathematics

   Matrices
   Partial and total differential equations
   Integrals and derivatives

6. Statistics

   Data analysis
   Supervised and unsupervised classification

7. Computer techniques

   Different computational environments
   Computer language
   Meteorological software
   Graphic tools
   Multimedia

8. Overview of meteorological satellites/orbits

   Orbital dynamics
   Polar and geostationary satellite
   Operational meteorological satellite

Afternoon sessions

   Language enhancement course(s), as required
   Laboratory exercises, computer familiarization, useful World Wide Web sites

Module 2: Applications (two months)

Image processing and GIS

1. Instrumentation and meteorological sensors

   Passive and active sensors
   Sensor technology: optical/infrared/water vapour
   Sensor technology: microwave
   Concept of resolution: spatial, temporal
   Spectrometers
   Imagers versus sounders

2. Image interpretation and application

   Synoptic and meso-scale systems
   Tropical and extra-tropical weather systems
   Atmospheric pollutants (dust, haze, smoke, forest fires etc.)
   Ocean monitoring

3. Image processing techniques

   Projection software
   Image registration/navigation, radiometric and geometric correction
   Atmospheric correction
   Image classification, clustering etc.

4. Basic GIS

   Basic concepts
   Data management
   Data manipulation
   Implementation of GIS
   Multi-layer map production
   Applications for meteorology and climatology

Satellite data retrieval and applications

5. Geophysical parameter retrieval

   Statistical and inversion methods
   Weighting functions

6. Atmospheric parameters

   Winds
   Atmospheric profiles
   Precipitation
   Outgoing longwave radiation (OLR)
   Aerosol concentration
   Cloud information
   Radiation budget

7. Land and ocean parameters

   Sea-surface temperature
   Sea-surface winds
   Vegetation index
   Land-surface parameters

8. Application of derived parameters

   Intra-seasonal variability
   Tropical/extra-tropical systems
   Drought monitoring
   Rainfall variability
   Air-sea interaction
   Regional/local weather systems

   Laboratory sessions in this module may be designed on the basis of the above topics and the resources available at the regional centres.

Module 3: Numerical models and global climate (two months)

Numerical models and satellite data assimilation

1. Regional and global models

Simple models and zero-, one-, two- and three-dimensional (0-D, 1-D, 2-D, 3-D) models
Basic model structure
Role of satellite data for parameterization

2. Concept of data assimilation

Basic of data assimilation
Observing systems
Subjective, objective analysis
Assimilation cycle
Model output

3. Satellite data assimilation

Humidity, wind, temperature
Rainfall
Impact

Global climate

4. Climate change

Basics of climate monitoring
Greenhouse effect and global warming
Short- and long-term variability
Radiation budget and feedback mechanisms
Anthropogenic effects

5. Impact of climate change

El Niño-type impacts
Upwelling
Icecap
Sea level and coastal inundations
Future climate projections

6. Climatology based upon satellite data

Cloud climatology (International Satellite Cloud Climatology Project (ISCCP))
Land surface climatology (International Satellite Land Surface Climatology Project (ISLSCP)
Global precipitation (Global Precipitation Climatology Project (GPCP))

Environmental issues

7. Atmospheric chemistry

Ozone
Other trace gases

Role of pollutants
Satellite observation programmes

8. Environmental protocols

Global climate change and policy implications
Agenda 21: integrated sustainable development
Kyoto Protocol to the United Nations Framework Convention on Climate Change

9. Disaster management

Monitoring techniques
Dissemination of information
Satellite-based warning systems

Laboratory sessions for this module may be designed on the basis of the above topics and the resources available at the regional centres.

Extracurricular module 4 (optional for advanced students)

This optional module can be conducted concurrently with other modules depending on the academic background, need and convenience of participants. Participants may choose any one topic in:

Potential uses of future satellite instruments
Advanced applications of satellite data
Advanced satellite data assimilation in NWP
Advanced GIS

Pilot project (three months)

Teaching material

A list of recommended teaching material is attached as annex II.

Notes

[1] L. Pyenson and S. Sheets-Pyenson, *Servants of Nature: a History of Scientific Institution, Enterprises, and Sensibilities* (New York, W. W. Norton and Company, 1999).

[2] *Report of the Third United Nations Conference on the Exploration and Peaceful Uses of Outer Space, Vienna, 9-30 July 1999* (United Nations publication, Sales No. E.00.I.3), chap. II, sect. G, para. 220.

[3] Ibid., chap. I, resolution 1, para. 1 (e) (ii). The Declaration is also available on the home page of the Office for Outer Space Affairs (http://www.oosa.unvienna.org).

Annex I

Curriculum for the first three courses

Modules

Table 1
First course at a glance

Module/ submodule	*Topic*	*Number of lectures*
1	Fundamentals of meteorology, climatology and remote sensing	
1.1	Concepts in meteorology and climatology	
	Basic concepts of meteorology	25
	Basic concepts of climatology	20
1.2	Concepts in satellite meteorology	
	Introduction to satellite meteorology	23
	Meteorological satellite orbits, instrumentation and data products	26
1.3	Applications of satellite imagery and digital image processing	
	Use of satellite imagery in meteorology and weather forecasting	15
	Statistics, digital image processing techniques and GIS	17
2	Advanced concepts in satellite meteorology, parameter retrieval and applications	
2.1	Radiative transfer and parameter retrieval	
	Concepts of radiative transfer	25
	Meteorological and oceanographic parameter retrieval	38
2.2	Applications using digital satellite data	
	Applications of digital satellite data in meteorology and weather forecasting	29
	Applications in oceanography	23
	Applications in climate studies	15
2.3	Environmental problems and numerical models	
	Environment issues and societal impacts	17
	Satellite data assimilation and modelling	28
3	Pilot projects (three months)	

Figure I
Percentage of time spent on each activity during the first course

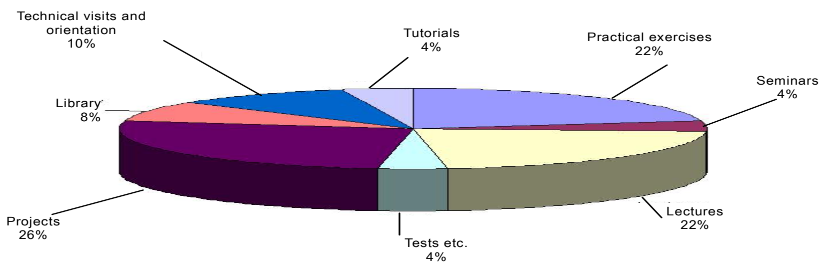

Table 2
Second course at a glance

Module/ submodule	*Topic*	*Number of lectures*
1	Fundamentals of meteorology, climatology and remote sensing (three months)	
1.1	Concepts in meteorology and climatology	
	Basic concepts of meteorology	20
	Basic concepts of climatology	10
1.2	Concepts in satellite meteorology	
	Mathematical and computational techniques for satellite meteorology	20
	Introduction to satellite meteorology	25
	Meteorological satellite orbits and instrumentation	20
1.3	Applications of satellite imagery and digital image processing	
	Use of satellite imagery in meteorology and weather forecasting	20
	Statistics, digital image processing techniques and GIS	15
2	Advanced concepts in satellite meteorology, parameter retrieval and applications (three months)	
2.1	Radiative transfer and parameter retrieval	
	Concepts of radiative transfer	30
	Meteorological and oceanographic parameter retrieval	30
2.2	Applications using digital satellite data	
	Applications of digital satellite data in meteorology and weather forecasting	25
	Applications in oceanography	15
	Satellite data assimilation and numerical models	10
2.3	Applications in climate and environmental studies	
	Climate studies	15
	Environment issues and societal impacts	15
2.4	Advanced applications (electives)	
	Advanced meteorological and oceanographic parameter retrieval	20
	Advanced applications in climate studies	20
	Advanced satellite data assimilation and modelling	20
3	Pilot projects (three months)	

Figure II
Percentage of time spent on each activity during the second course

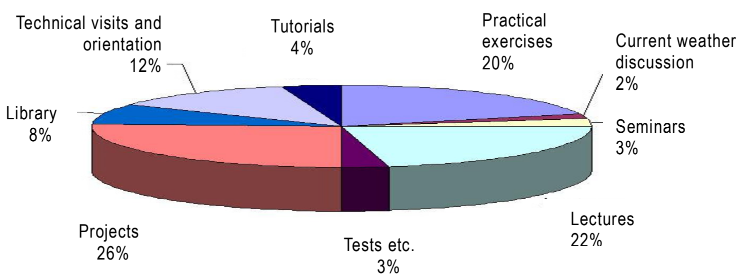

Table 3
Third course

Module/ submodule	*Topic*	*Number of lectures*
1	Fundamentals of meteorology, climatology and remote sensing (three months)	
1.1	Concepts in meteorology and climatology	
1.1 MATH	Mathematical and computational techniques for satellite meteorology	20
	Matrices	
	Partial and total differential equations	
	Integral and derivatives	
	Basic concepts of statistics	
1.1 MET	Basic concepts of meteorology, climatology and oceanography	30
	Dynamic and physical meteorology	
	Extra-tropical weather systems	
	Tropical weather systems	
	Climate of the region	
	Ocean and climate	
1.2	Concepts in satellite meteorology	
1.2 SM	Radiative transfer in satellite meteorology	25
	Characteristics of electromagnetic radiation	
	Passive remote sensing	
	Active remote sensing	
	Parameter retrieval and validation	
1.2 MSI	Meteorological satellite orbits and instrumentation	15
	Orbits and navigation	
	Operational polar-orbiting satellites	
	Operational geostationary satellites	
	Other satellites	
	Satellite data archive	
1.3	Image processing and interpretation	
1.3 WF	Image interpretation in meteorology and weather forecasting	30
	Satellite imagery	
	Spectral properties	
	Identification of meso-scale systems	
	Tropical synoptic systems	
	Extra-tropical synoptic systems	
	Radar imagery	
1.3 DIP	Image processing techniques and GIS	15
	Map projection	
	Satellite positioning systems	
	Image registration, radiometric and geometric correction	
	Image classification	
	GIS	
2.1	Geophysical parameter retrieval	
2.1 AP	Atmospheric parameters	15
	Winds	
	Temperature profile	

Module/ submodule	*Topic*	*Number of lectures*
	Humidity profile	
	Precipitation	
	Outgoing longwave radiation	
	Clouds and aerosols	
2.2 LOP	Land and oceanic parameters	10
	Sea-surface temperature	
	Sea-surface winds	
	Vegetation index	
	Land-surface parameters	
2.2	Applications of satellite-derived parameters	
2.2 AWF	Applications in meteorology and weather forecasting	30
	Onset of monsoon	
	Intra-seasonal and inter-annual variability	
	Tropical cyclones	
	Extra-tropical cyclones	
	Drought monitoring	
	Air-sea interaction	
2.2 NM	Satellite data assimilation in numerical models	15
	General circulation models	
	Concepts of data assimilation	
	Satellite data assimilation	
	Impact of satellite data assimilation	
2.3	Global climate and environment	
2.3 SC	Short-term climate variability	25
	El Niño and tele-connection	
	Cloud climatology	
	Land-surface changes	
	Ozone and other trace gases	
2.3 LC	Long-term climate change	25
	Climate change	
	Greenhouse effect and global warming	
	Changes in cryosphere	
	Future climate scenario and satellite missions	
2.3 ESI	Environment issues and societal impacts	10
	Oceanic biological productivity	
	Coastal zone environment	
	Pollution	
	Disaster management	
	Mass communications	
3	Pilot projects (three months)	30

Practical exercises

List of practical exercises for the first course

Module 1. Operational meteorological satellite data handling and applications

1. Computer facilities and familiarization
2. Geostationary satellite (Indian National Satellite System (INSAT) and geostationary meteorological satellites (GMS)) data applications
3. National Oceanic and Atmospheric Administration (NOAA) advanced very high resolution radiometer (AVHRR) data applications
4. Cloud motion vectors from INSAT and their applications
5. Applications of satellite data in tropical cyclone intensity estimation
6. Applications of satellite data in tropical cyclone track prediction
7. Multimedia demonstration of Meteosat/Geostationary Operational Environmental Satellite (GOES)/cyclone data
8. Visualization packages

Module 2. Parameter retrieval and numerical modelling

1. Estimation of outgoing longwave radiation (OLR) using INSAT very high resolution radiometer (VHRR) and GMS data
2. Estimation of daily and weekly rainfall using INSAT-VHRR data
3. Sea-surface temperature estimation from NOAA-AVHRR data and applications in oceanic circulation studies
4. Study of average layer humidity and temperatures over different regions using NOAA television and infrared observation satellite (TIROS) operational vertical sounder (TOVS) finished products
5. Processing of the International TOVS Processing Package (ITPP) 5 software for estimation of the temperature profile using NOAA/TOVS data
6. Interpretation of general circulation model results
7. Study of model simulation results from CO_2-doubling using general circulation models
8. Snow-cover estimation from NOAA-AVHRR data
9. Normalized vegetation index from NOAA-AVHRR data
10. Use of satellite meteorological data in GIS
11. Surface winds from scatterometer data
12. Sea level from altimeter data
13. Familiarization with the low resolution transmittance (LOWTRAN) calculation package

List of practical exercises for the second course

Module 1. Operational meteorological satellite data handling and applications

1. Computer facilities and familiarization
2. Geostationary satellite (INSAT, GMS) data applications
3. NOAA-AVHRR data applications
4. Cloud motion vectors from INSAT and their applications
5. Applications of satellite data in tropical cyclone intensity estimation
6. Applications of satellite data in tropical cyclone track prediction
7. Multimedia demonstration of Meteosat/GOES/cyclone data and visualization packages
8. Estimation of OLR using INSAT-VHRR and GMS data, Meteosat applications

Module 2. Parameter retrieval and numerical modelling

1. Estimation of daily and weekly rainfall using INSAT-VHRR data
2. Sea-surface temperature estimation from NOAA-AVHRR data and applications in oceanic circulation studies
3. Processing of the ITPP 5.01 software for estimation of the temperature profile using NOAA/TOVS data
4. Interpretation of general circulation model results
5. Snow cover, normalized vegetation index, sea ice, forest fire from NOAA-AVHRR data
6. Use of satellite meteorological data in GIS
7. Surface winds from scatterometer data
8. Familiarization with LOWTRAN package (demonstration)
9. Multichannel scanning microwave radiometer (MSMR) retrieval
10. Aerosol applications

Suggested list of practical exercises for the third course

Module 1. Operational meteorological satellite data handling and applications

1. Computer facilities and familiarization
2. INSAT-VHRR data applications
3. NOAA-AVHRR data applications
4. Visualization techniques
5. Cloud motion vectors from geostationary satellites and their applications
6. Applications of satellite data in tropical cyclone intensity estimation

7. Application of satellite data in tropical cyclone track prediction
8. Multimedia demonstration of Meteosat/GOES/cyclone data and visualization packages
9. Estimation of OLR using VHRR data and applications

Module 2. Parameter retrieval and numerical modelling

1. Estimation of daily and weekly rainfall using VHRR data
2. Sea-surface temperature estimation from NOAA-AVHRR data and applications in oceanic circulation studies
3. Estimation of the temperature and humidity profile using NOAA/TOVS data
4. Interpretation of general circulation model results
5. Snow cover, normalized vegetation index, sea ice, forest fire from NOAA-AVHRR data (demonstration)
6. Use of satellite meteorological data in GIS (demonstration)
7. Surface winds from scatterometer data (demonstration)
8. Familiarization with LOWTRAN package (demonstration)
9. Geophysical parameter retrievals from microwave radiometers
10. Objective analysis of wind
11. Objective analysis of temperature

Pilot projects

Pilot projects carried out by participants in the first course

1. Soil moisture estimation using the normalized difference vegetative index (NDVI) from NOAA/AVHRR data over Mongolia
2. Retrieval, validation and applications of the sea surface temperature (SST) around Sri Lanka using the European remote sensing satellite (ERS) along-track scanning radiometer (ATSR) data
3. Rainfall estimation using cloud indexing
4. Cloud analysis of western disturbances
5. Wildfire danger estimation and monitoring using NOAA-AVHRR, Indian Remote Sensing Satellite (IRS) and GIS techniques
6. NDVI and estimation of soil moisture over Bangladesh
7. Retrieval, validation and applications of atmospheric temperature and humidity profiles from NOAA/TOVS satellite sounding data over Mongolia
8. Tropical cyclone track prediction using cloud top temperature and chaos theory

9. Onset of monsoons over Nepal using satellite data
10. Rainfall estimation over Bangladesh and the Bay of Bengal by Arkin's method
11. Temperature and humidity profile over Uzbekistan using NOAA/TOVS data
12. Study of coastal upwelling in the Persian Gulf and Oman Sea
13. Rainfall estimation over the Indonesian region
14. Validation of NWP model output with satellite-derived products vis-à-vis conventional meteorological observations
15. Rainfall estimation over a cyclone using the cloud indexing technique
16. Break and active monsoon over Nepal
17. Ocean circulation modelling using satellite data

Pilot projects carried out by participants in the second course

1. Movement of tropical cyclones near the Philippines using GMS water-vapour imagery
2. Tropical cyclone intensity and track prediction using INSAT-VHRR data
3. Study of tropical cyclone track prediction over the Vietnamese region using GMS data
4. Identifying oceanic and atmospheric features from NOAA-AVHRR data
5. A study of sea-surface temperatures and sea-surface winds over the Indian Sea using the Tropical Rainfall Measuring Mission (TRMM) microwave imager and IRS-P4 MSMR data
6. Retrieval of humidity profiles from MSMR water vapour using the method of empirical orthogonal function analysis
7. Study of MSMR brightness temperature data over India and Kazakhstan and its potential for large-area soil moisture estimation
8. Humidity and temperature profile from NOAA/TOVS satellite data and its comparison with radiosonde and National Centers for Environmental Prediction (NCEP) data
9. Humidity and temperature profile from the NOAA/TOVS package and a comparison with NCEP and Meteosat data
10. Climatology of Mongolia using NCEP National Center for Atmospheric Research (NCAR) data
11. Rainfall estimation over the Indian region derived from the Defense Meteorological Satellite Program (DMSP) special sensor microwave imager (SSM/I) and IRS-P4-MSMR
12. Diurnal cycle of rainfall during the Asian summer monsoon using TRMM observations
13. Multispectral cloud classification using TRMM observations for improving rainfall estimation from visible/infrared techniques

14. Study of western disturbances using satellite data
15. Verification of different model forecasts over Kazakhstan with the analysis and satellite data
16. Comparison of extended range model forecast with Oceansat-1 data
17. A comparative study of sea state estimated by satellite data and conventional fleet forecast over the Arabian Sea
18. SST monitoring during El Niño from satellites and linkage with rainfall over Indonesia
19. Snow monitoring over the western Himalayas
20. Vegetation monitoring using multi-temporal coarse resolution satellite (and weather) data over the Korean peninsula
21. Monitoring of major crops in the Democratic People's Republic of Korea using NOAA-AVHRR channel 1 and 2 satellite data

Table 4
Evolution of the satellite meteorology curricula (theory)

Module	Submodule title	*First course*	*Second course*	*Third course*
		Number of hours		
1	Concepts in meteorology	45	30	30
	Mathematical techniques	-	20	10
	Concepts in satellite	49	45	40
	Applications of satellite	32	35	45
2	Radiative transfer and	63	60	25
	Applications of digital data	52	40	40
	Climate and environmental	32	30	60
	Data assimilation	28	20	15
Orientation		-	20	35
Total		**301**	**300**	**300**

Note: In laboratory exercises, more stress is put on the data products from operational satellites. The recent microwave remote sensing data are introduced in more detail. Emphasis on the validation of satellite data and their use in numerical models is being introduced in the third course.

Annex II

Recommended teaching material

Barrett, E. C., and D. W. Martine. The use of satellite data in rainfall monitoring. London, Academic Press, 1981.

Images in weather forecasting: A practical guide for interpreting satellite and radar imagery. M. J. Bader *and others*, eds. Cambridge, Cambridge University Press, 1995.

Henderson-Sellers, A., and K. McGuffie. A climate modeling primer. 2. ed. New York, John Wiley and Sons, 1997.

Houze, Jr., R. A. Cloud dynamics. San Diego, Academic Press, 1993.

Kidder, S. Q., and T. H. Vonder Haar. Satellite meteorology: An introduction. San Diego, Academic Press, 1995.

Kondratyev, K. Ya., and A. P. Cracknell. Observing global climate change. London and Bristol, Taylor and Francis, 1998.

Centre for Space Science and Technology Education in Asia and the Pacific. Lecture notes on satellite meteorology. 1: Basics, 2: Retrievals, 3: Modeling Climate Change.

Printed by the Space Application Centre, Indian Space Research Organization, 2000.

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Menzel, W. P. Notes on satellite meteorology. Geneva, World Meteorological Organization, 1997. (WMO/TD 824, SAT-17)

Robinson, I. S. Satellite oceanography. Chichester, Ellis Horwood, 1985.

Rao, P. K., *and others*. Weather satellites: Systems, data, and environmental applications. Boston, American Meteorological Society, 1990.

Trenberth, K. E., ed. Climate system modeling. Cambridge, Cambridge University Press, 1992.

Ulaby, F. T., R. K. Moore and A. K. Fung. Microwave remote sensing: Active and passive. II: Radar remote sensing and surface scattering and emission theory. Reading, Massachusetts, Addison-Wesley Publishing Company, 1981.

World Meteorological Organization, Preliminary statement of guidance regarding how well satellite capabilities meet WMO user requirements in several application areas. Geneva, WWW/SAT, 1998. (WMO/TD/913, SAT-21)

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