MULTISATELLITE MAPPING AND STEREO-RELIEF CONSTRUCTION FOR THE INTERNATIONAL GEOSPHERE-BIOSPHERE PROGRAM IN THE NEPAL AND TIBET HIMALAYAS : A CODATA PROJECT

Claude Bardinet*¹ and Gottfried Gabert*²

*1 Ecole Normale Supérieure de Paris, 45, rue d'Ulm, F - 75230 Paris Cedex 05, France

*2 CODATA - Germany, D - 30916 Isernhagen, Germany

Abstract : For projects of the International Geosphere - Biosphere Program, satellite data in conjunction with existing geoscientific databases provide effective means. These databases cover scattered areas and comprise topographical and geological map data, remotely sensed data (aerial photographs and satellite images at various scales), geophysical and geochemical data files, geological field reports and geoscientific publications.

For Nepal, the elaboration of modern thematic maps at useful scales has to be based on data from appropriate satellites, primarily from LANDSAT Thematic Mapper taking into account also SPOT data for the High Himalaya where no air photo coverage exists. The combination and evaluation of multisatellite data together with aerial photographs reveal geomorphological, geological, tectonic, soil and vegetation features as well as erosion and landslide phenomena.

The results of satellite data evaluation and air photo interpretation are integrated with existing unbiased geoscience data and supplemented by ground truth data. In selected areas, digital elevation models will be constructed using SPOT data and existing topographic data. The resulting information will be integrated with data from snow - hydrological stations in the Himalayan mountains permitting, for example, the estimation of snow - melting run - off. Using GIS techniques, the results finally achieved will be displayed in thematic maps at different scales.

Key words : LANDSAT, SPOT, Digital elevation model (DEM), Snow - hydrologic data, GIS

HISTORY OF THE CASE STUDY IN THE HIMALAYAS

Submitted by the CODATA Task Group on Multisatellite Thematic Mapping (MSTM), a CODATA - Proposal for Cooperation with ICSU - IGBP, Unesco and ESCAP (Bardin et al., 1988) was approved in 1988 by CODATA (16th General Assembly of CODATA, Karlsruhe, September 1988), and at the Task Group meetings in Hannover at BGR (October 1988), in Darmstadt at ESOC (October 1988) and at Unesco-Geo in Paris (October 1988). This proposal has been submitted at the First Meeting of the Scientific Advisory Council of the ICSU International Geosphere-Biosphere Program (IGBP) "A Study of Global Change" held in Stockholm on 24 - 28 October 1988.

In accordance with the aim of the IGBP to interact with ICSU's scientific members, the activities of CODATA are coordinated with the following IGBP Coordinating Panels and working Groups: Effects of Climate Change on Terrestrial Ecosystems, Data and Information Systems, Geosphere - Biosphere Observatories.

During 1989 - 1990, the Task Group MSTM concentrated its efforts on two aspects of the IGBP: Geographical Information Systems (GIS) and Geocoded Referenced Databases in Relation to Multisatellite Data, and it studied the possibility of promoting a "Test Site Study Case In the Himalayas". In 1990, at

the 17th General Assembly of CODATA held in Columbus (Ohio), the Task Group on Multisatellite Thematic Mapping gave its last report of activity, and it presented its works and publications on methodology and applications in the field of multisatellite thematic mapping (Bardin et al., 1986, 1988, 1989, 1991, 1992).

The conclusions of the Task Group MSTM were made in the field of "Earth observation for Global Change" and concerned mainly large scale changes of the land surface (deforestation, erosion), seasonal and secular variations of geomorphology and landscape units, and factors determining the variations. In this way, we proposed to promote the use of GIS to process, analyze and interpret "Global Data" and "Multisatellite Data".

In 1991, the activities of CODATA relating to the "Global Change" program were assigned to a CODATA Commission on Global Change Data. Chinnery from NOAA - NGDC (Boulder, USA) was designated as chairman of this new commission, and Bardin et al., as a member of this commission, was requested to continue the investigation. In order to promote, together with the International Center for Integrated Mountain Development (ICIMOD) in Kathmandu, the proposed case study in the Himalayas. In April 1991, G. Gabert invited C. Bardin et al. to Kathmandu and they proposed to S. Shrestha of ICIMOD to test, in coopera-

tion with CODATA, the needs for data for environmental research on the Himalayas in the field of IGBP.

In August 1991 M. Chinnery organized in Paris at the CODATA - ICSU Office the first meeting of the commission, and C. Bardinet proposed to consider the multisatellite program in the Himalayas as a case study on "the accessibility of data for IGBP in a regional center and at regional scale".

METHODOLOGY: MAPPING 2D/3D MULTISATELLITE GEOREFERENCED DATA

Digital mapping in geosciences uses three complementary approaches of knowledge pattern recognition in geomorphology and land cover analysis: Firstly, the automatic detection of contours and lineaments, secondly the question of classification, and thirdly stereo digital analysis and the production of digital elevation models (DEM).

These objectives have been studied by the CODATA Task Group on Multisatellite Thematic Mapping since 1982 - 1988, and further by the IUGS Program on Geological Application of Remote Sensing (GARS); the applications were mainly in Tanzania and in Burundi (Lavreau et al. 1988, 1990; Bardinet et al., 1990; Gabert, 1990). In cooperation with IRSA (Beijing) and CODATA (China), new developments were studied in China from 1986 to 1988.

For the first objective, we have developed multisatellite data evaluation techniques and applied them to geological and geomorphological mapping of multiscale test areas in Tanzania (area of Iringa at 1:500,000 and western region of Tanzania at 1:2,500,000). The main aims of this multisatellite project were to:

- discriminate lithological units based on the reflective and thermal properties of rocks and soils;
- record the geomorphological and structural features;
- characterize the relations between soil and vegetation cover.

The classification of the multisatellite data (METEOSAT, NOAA and LANDSAT) were controlled by the interactive use of geoscience data from different sources, particularly for the identification of lineaments, faults, and geological boundaries.

For the second objective, we have built a dictionary of forms using primitives to describe objects and lineaments. Some of the results obtained from remote sensing images (LANDSAT TM) were located in the Karema area (Lake Tanganyika in Tanzania), and some others (LANDSAT MSS) were located in the area of the Lin Cheng dam in Taihang Shan (Hebei, China).

For the third objective (Bardinet et al., 1990), we have used correlation techniques for the construction of a DEM using SPOT stereo images. The most important steps to stereo - restitution are:

- the recognition of similarities between the two views of one object (corresponding ground control points are selected in each image);

- the rectification of the views in an epipolar geometry;
- the computation of a disparity image (for each point in the left image, determination of a corresponding point in the right image);
- for each pixel in the image, computation of the corresponding disparity level and determination of the altitude.

The applications concerned aerial photographs in the Karema area, SPOT data in the south - east region of Burundi, and SPOT data in the Loess Plateau area of Yan'an (Shaanxi).

APPLICATION AREAS: THE HIMALAYAS OF NEPAL AND TIBET

The themes of the project are the Himalayan and Tibetan Plateau areas in relation to the flooding in Bangladesh, and the aims are to determine the potential for the use of Geographical Information Systems (GIS), Digital Elevation Models (DEM) and remotely sensed data in support of the International Geosphere - Biosphere Program (IGBP) (Bardinet et al., 1992).

The methodology consists in georeferencing and rectifying the multisatellite data, mainly LANDSAT TM, SPOT panchromatic and multispectral, and ERS - 1, in order to combine all of them in a digital elevation model (DEM). This DEM has to be constructed using digital correlation techniques for processing two stereoradiometric registrations of SPOT images.

As with the CODATA and GARS projects, the results will be presented in form of textural classifications (land cover) and structural analyses (lineaments and hydrography), using computer aided mapping techniques for the automatic processing of relief and slope classifications, of erosion and landslide locations, and of hydrographic networks and drainage areas.

The proposed case study in the Himalayas (Hindukush - Himalayan Region) relates to several countries (Nepal, China with Tibet, India, Butan, Bangladesh, Myanmar, Pakistan, Afghanistan). It is proposed to determine the potential use of GIS and the need of data in support of IGBP (mainly remote sensing data, digital terrain model data, and ground truth data). This involves the analysis of the need of data to study the following themes in the field of the geo - environment:

- Deforestation in the fluvial basins of the Ganges and Brahmaputra;
- Snow melting in the Himalayas of Nepal and Tibet in relation to flooding in the lower valleys;
- Landslide and soil erosion in relation to deforestation;
- Socio - economic conditions of land use;
- Global and regional change in climatic conditions.

The project involves data collection, data exchange and integration, setting up mechanisms for interfacing with other organizations (UNEP - GRID/UNITAR, ESCAP, EARSel, NOAA - NGDC, WDC, I.T. C. , CODATA, IRSA, ICIMOD), and assistance

Fig.1. LANDSAT TM Scene of S-Central Nepal showing (from S to N): Sub-Himalaya with Gangetic Plains of N-India and S-Nepal, and with the Siwaliks striking WNW-ESE; Lesser Himalaya with the Kathmandu Basin in the Mountainous Midland Complex; and parts of the High Himalaya covered by snow and ice. In all the geomorphological units the drainage pattern of the Ganges tributaries is clearly visible.

for training and education. In fact, this project will be carried out by an international team: for EARSeL M. Buchroithner from Graz (Austria), for CODATA C. Bardinet from Paris (France) and G. Gabert from Hannover (Germany), for IRSA Wang Chang-Yao from Beijing (China), for I.T.C. Van Genderen from Enschede (Netherlands) and for ICIMOD S. Shrestha from Kathmandu (Nepal).

The required data are partially available at IRSA (Beijing) and ICIMOD (Kathmandu), principally:

- Metric Camera and Large Format Camera;
- SIR.A and SIR.B,
- SPOT Stereo and XS;
- LANDSAT MSS and TM;
- NOAA AVHRR;

- Chinese Wind and Cloud AVHRR - WC 1.

In addition, new data from more recent satellites (EEC, Russia, India, Japan), ERS-1 SAR, ALMAZ, IRS-1 and IRS-2, MOS-1, and from airborne surveys will be used.

The snow-melting run-off of the Himalaya Mountain Range mainly flows into the tributaries of the Ganges (Karnali, Kali Gandaki, Bagmati and Arun rivers) and of the Tsang-Po/Brahmaputra/Jamuna river.

The hydrologic conditions are manifold as high-altitude Nepalese rivers receive unspecified contributions of snow-melt. The waters of the Himalayan tributaries show large variations reflecting a wide range of hydro-meteorological conditions; for exam-

Fig.2. LANDSAT TM Scene of N - Central Nepal showing (from S to N): Lesser Himalaya with the Pokhara Valley; High Himalaya with the Annapurna massif covered by snow and glaciers; and the Takkhola and Manang areas with the valley of the Kali Gandaki river set in a half - graben striking N - S; the latter areas merge with the S - part of the Tibetan Highlands, about 4000 m above sea level.

ple within the Sapt Kosi river basin in eastern Nepal, the discharges are for the Arun 580 mm/y and for the Tamor 1920 mm/y (Bruijnzeel et al., 1989). The Tamor receives important contributions in form of melt water from the glaciers of Mt. Kanchenjunga, and the Arun has 90 % of its drainage area located north of the main range in the Trans - Himalaya where both precipitation and snow - melt contributions are modest. But the snow - melting run - off of the Arun - Tamor River is the major water source for irrigation and hydropower development in the Kingdom of Nepal.

The lower reaches of the Brahmaputra River in Bangladesh are often flooded and this constitutes a serious natural hazard for Bangladesh. The water in the Brahmaputra River comes partly from the snow -

melting run - off and collapsing glaciers which have to be measured. A study of the snow - melting run - off is not only important for scientific research; it also has practical consequences for the economic development of the affected countries.

Satellite remote sensing provides effective means for this study. In 1985, a pilot study for the estimation of snow - melting run - off in the Himalaya Mountains was supported by the Remote Sensing Unit of ESCAP - UN in Bangkok and the National Remote Sensing Center of China in collaboration with the National Remote Sensing Center of Nepal. In this pilot study, periodical LANDSAT and NOAA image data, Metric Camera photos from Space Lab and Large Format Camera photos from the Space Shuttle were used. The

pilot study which was accomplished at the end of 1987 has shown that it is quite feasible to use remote sensing techniques to estimate snow - melting run - off. It is expected that much better results can be obtained by using multiplatform, multitemporal remote sensing data in combination with data collected from snow - hydro stations in the mountains for the purpose of snow - melting - run - off estimation. Therefore, it is proposed to carry out further studies on this subject. As the proposed project relates to several countries (e. g. Nepal, China with Tibet, Bangladesh, and India), international cooperation and technical and financial support from those and developed countries are necessary.

The steps of the project will be:

- Estimation of the snow - melting run - off of the Himalaya Mountain range using multiplatform, multisensor and multitemporal remote sensing data including LANDSAT TM, SPOT, NOAA and ERS - 1 data.
- Test of a DEM derived from SPOT stereo data and of the combination with multisatellite data (LANDSAT and ERS - 1).
- Test of collecting meteorological data, and of modeling the snow - melting run - off by using these data together with NOAA - AVHRR data.
- Study of the parameters related to solar radiation and albedo of the soil units, of slopes and aspects of the mountainous regions, and particularly research on the possibility of deriving these parameters from the DEM with additional Information.

Phase 1 of the project should include:

- Selection of a study area within the coverage of one or two LANDSAT TM images (Department of Mines and Geology : DMG)(Figs.1,2)
- Field survey in selected sites of the Himalayan mountain range, and the use of snow - hydro data from existing stations (international cooperation);
- Derivation of DEM, slope and aspect data of the study area using SPOT stereo data (ICIMOD), and development of image processing algorithms for the applications of snow - melting run - off estimation (international cooperation);
- Collection and processing of LANDSAT MSS, TM and SPOT image data seasonally, and NOAA image data weekly (ICIMOD and IRSA);
- Collection and processing of remote sensing data in semi - real time and build - up of the geographical information systems (ICIMOD, IRSA and international cooperation).

The importance of ecology and bioclimatic processes in geomorphological research (Dollfus et al., 1979, Bruijnzeel et al., 1989) has to be emphasized, and the fragility of this high mountain environment has to be studied using multisatellite data. The themes will be:

- glacial lake outburst floods, river flash flooding and risk engineering;
- response to natural hazards in the Himalayas;
- impact of deforestation on landslides and erosion;

- consequences of recent changes in land cover on watershed degradation; anthropogenic erosion and sedimentation processes.

PERSPECTIVE: MAPPING GLOBAL CHANGE AT REGIONAL SCALES

This paper describes a project of knowledge pattern recognition in geomorphology applied to physical landscapes in the Himalayas.

The aims of this research are in relation to the need of synthetic image analysis in earth sciences, as a result of data processing using complex geographical data bases including multisatellite data. At least the final image maps will combine stereo DEM and synthetic images of the landscape, that means classification of physical structures, physical units and land use units, and also automatic detection of lineaments.

The knowledge based pattern recognition system in earth sciences described here, concerns automatic methods and supervised applications using multisatellite data.

We consider that 3 - D geographical object reconstruction aims at improved performance of supervised classification and automated lineament detection. Stereo image processing (3 - D) has as its goal the production of a DEM with detected geographical objects and thematic classifications. We bear, however, in mind that object reconstruction depends on the characteristics of the data. In geosciences, we have to choose the data taking into account the size of the pixel, the spectral bands and the available time series. Geoscientific databases combined with multisatellite data, mainly NOAA, LANDSAT, SPOT and ERS - 1 data are the fundamentals of the geographical information system (GIS) devised as a tool for the study of "Global Change Multiscale Evaluation".

We have in mind the recommendations of Geoscience Unions in the field of databases for Global Change (Bardinet, 1988; Mounsey et al., 1988), and we can resume them as follows:

- Establish standards for the quality of data to be included in global databases and to ensure their accessibility;
- Speeding up the establishment of DEM to which global thematic databases will be referenced in an appropriate coordinate and grid system for global and multiscale analysis;
- Ensure compatibility of global databases in terms of accuracy and information content, with mapping at appropriate scales.

The legend and other attributes will take into account the capabilities offered by expert systems relevant to GIS. The legends will refer to:

- thematic information (taxonomy);
- related data processing information;
- related remote sensing data in terms of pixel size, spectral bands and time series.

At the end of the data processing, and just before producing computer - aided maps combined on a

DEM, relaxation methods (Sigelle, 1992) using Random Markov Field models could include additional knowledge such as initial classification probabilities, and could be very useful in order to enhance the discrimination of classes. Using these relaxation methods, the final legend of each type of thematic map could be adapted to the scale and to the generalization resulting from the number of classes and from the size of the pixels.

In mapping the results of data processing, the relation between the location of the data elements and the location of the thematic/statistical information in the databases will be established through referencing to geographical coordinates, and to the size of ground controlled areas or thematic units, and the characteristics of ground stations.

The perspectives of this research are mainly in the field of the accessibility of the data needed for "Global Change" at the right economic conditions, at the right place and at the right time (Bardinnet et al., 1992). This is a theme of research in CODATA, in the World Data Center of ICSU, and more generally in ICSU's committees and commissions which are involved in the IGBP Program.

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