A REPORT ON

THE FIFTH INTERNATIONAL TOVS STUDY CONFERENCE

Toulouse, France

24-28 July 1989

sponsored by

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National Oceanic and Atmospheric Administration
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International Association of Meteorology and Atmospheric Physics (IAMAP)

World Meteorological Organization (WMO)

prepared by

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First Draft
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Second Draft
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future activities, and to formulate recommendations to the WMO.

Our fifth meeting (ITSC-V) was held in Toulouse, France during the last week of July. This report summarizes the scientific exchange. A companion publication entitled the Technical Proceedings of ITSC-V will contain the complete text of the presentations. These documents indicate that we had a very productive stay in Toulouse.

This was largely possible through the efforts of our friends in the Meteorologie Nationale : we thank Claude Pastre for his interest and support, and Thierry Phulpin for making Toulouse so accessible to us. The city fathers made us feel very welcome in their beautiful country.

On-site help with organizational and secretarial tasks was provided by several people : Laura Beckett, Sandra Dusson, Alain and Patricia Marek deserve mention for their cheerful and capable assistance in everything from typing the abstracts to translating our dinner requests.

We gratefully acknowledge the cooperation of ENM and CNRM ; they opened their facilities to us for the week and provided computer support for PC demonstrations. Spot Image also arranged a very impressive tour.

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Madison, October 1989
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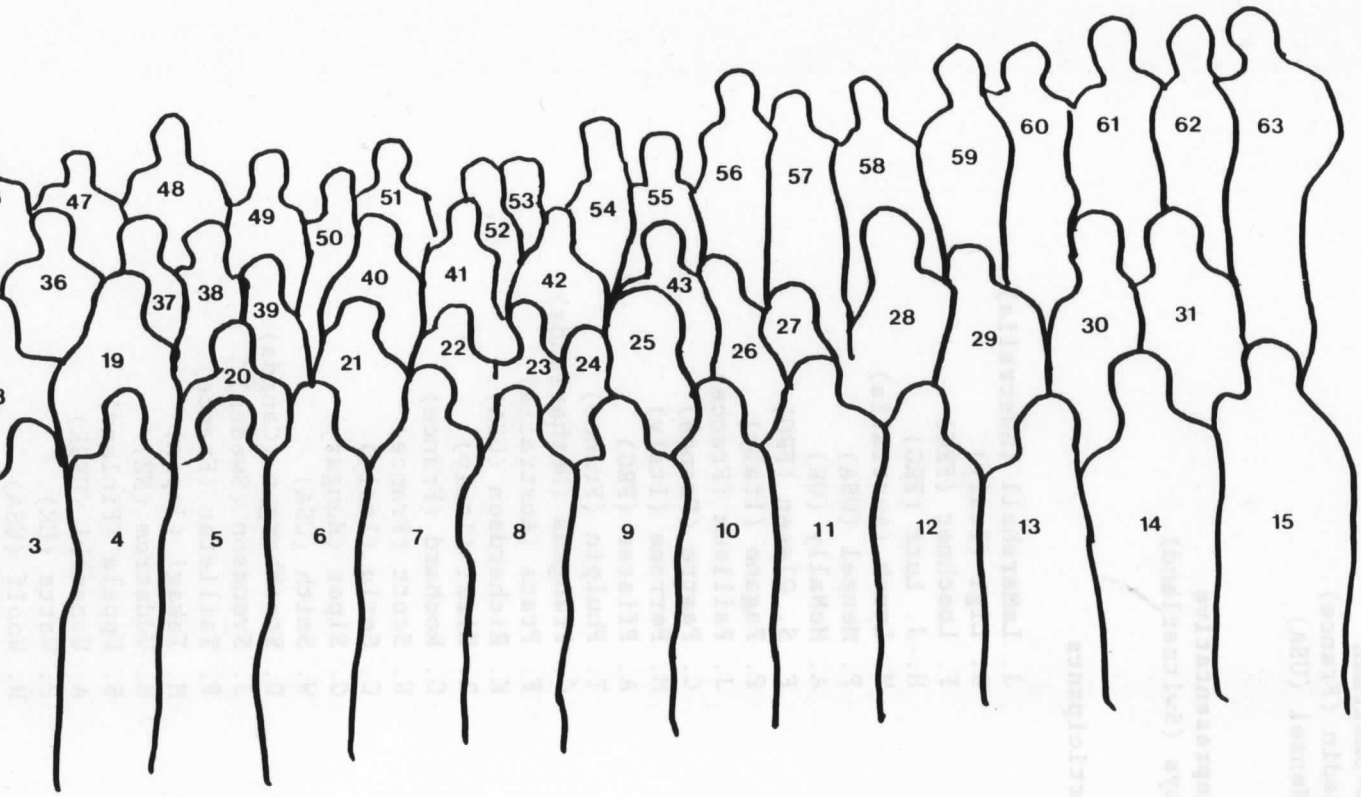

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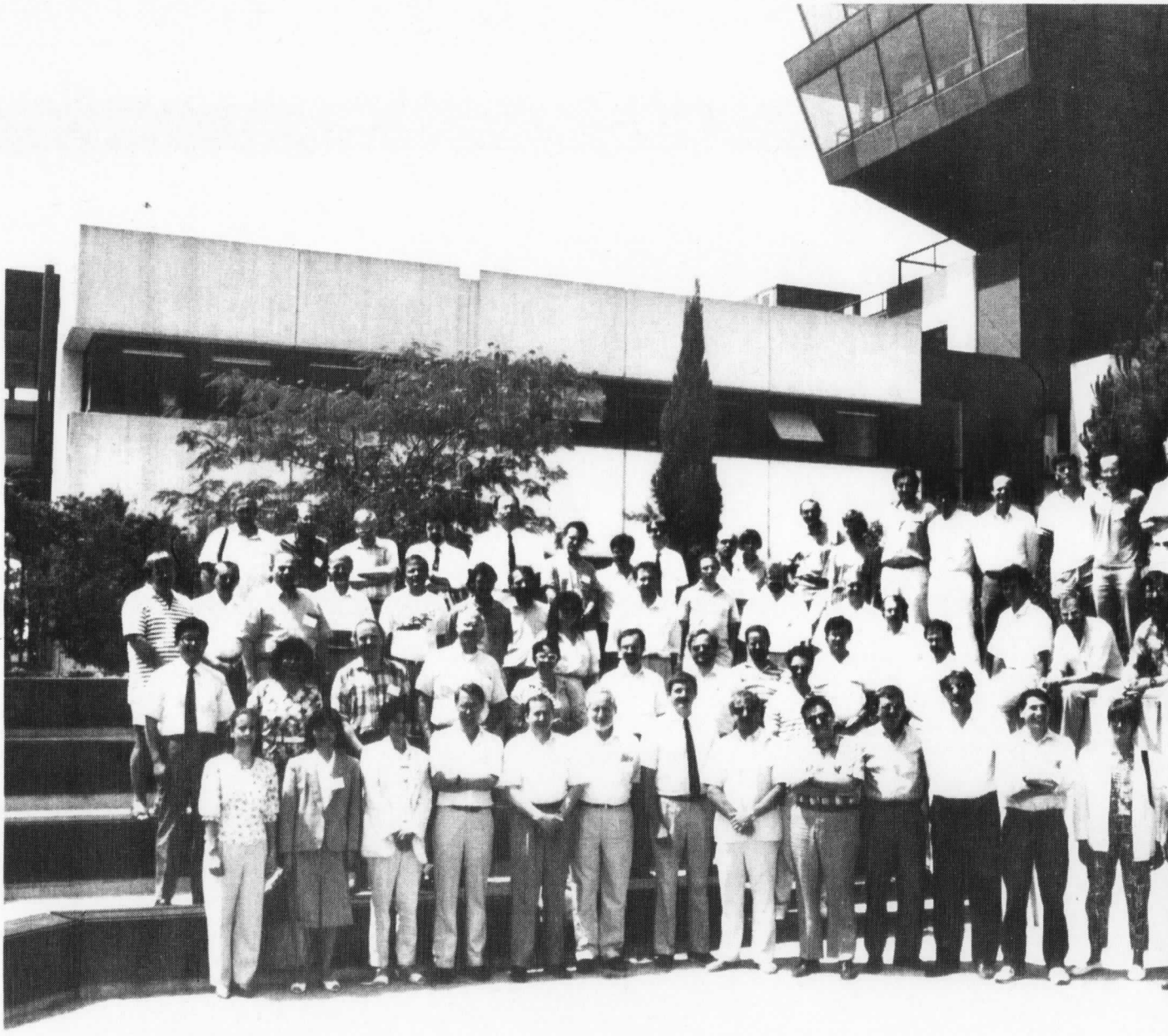

The agenda for the ITSC-V can be found in Appendix A. The first two days were occupied with scientific presentations that fell into the broad categories of TOVS usage at various centers, TOVS data and numerical weather prediction (NWP), applications of TOVS to global, polar and oceanic studies, and finally retrieval algorithm improvements. Section III of this Report records the abstracts of the scientific contributions by delegates. The corresponding papers are published separately in the Technical Proceedings of the Fifth International TOVS Study Conference.

The third day was spent on reports concerning previous issues/problems and the actions which have been taken toward resolution. These status reports for ITSC-V are also in Section III of this document.

On the fourth day, several invited presentations addressed future sensing and sounding capabilities as well as assessment on the best use of satellite data in NWP impact studies. These included new developments in retrieval techniques as well as in instrumentation. Thereafter, the conference divided into four Working Groups which discussed issues in the following areas; the science affecting the quality and utility of atmospheric sounding, the software and associated algorithms for deriving products from satellite data, applications of TOVS products and impact studies in numerical weather prediction, and international coordination of satellite activities. The Working Groups spent the next days reviewing, debating, and making recommendations on the key issues of concern and items for action. The Reports of these Working Groups are detailed in Section II.

The executive summary of the ITSC-V now follows. The significant conclusions or observations of the International TOVS Working Group are:

(1) The use of TOVS products by the meteorological community has played a fundamental role in advancing Numerical Weather Prediction (NWP) over the past ten years. The use of TOVS data has been essential for global analyses and on the average the impact of TOVS on global forecasts is large and positive.

(2) The forward calculation of radiances from temperature profiles remains an important research problem and is inextricably linked with the radiosonde error problem. It is believed that the Baseline Upper Air Network (BUAN) data archive, properly quality controlled, may identify the error characteristics

of radiosonde sounding systems and forward calculations. The ITOVS scientists will pursue this.

(3) Concerning the sounding software, several points were made. (a) This fifth meeting of the ITOVS working group has been seen continuing expansion of the user community in the two directions of research and numerical weather prediction through impact studies. (b) The two main software packages 3I and ITPP have been further developed and documented to facilitate implementation by more diverse users. (c) User familiarity with the content and optimal use of these software systems is essential for obtaining accurate and reliable results. Training and dialogue between users and providers are strongly encouraged. (d) The ITPP and 3I systems represent significant investments of resources over long periods of time. A vital need for support has been stressed. The main aim is not to cover real costs, but is seen as an opportunity for the community to assist with support.

(4) Satellite data can have many interfaces with an assimilation system and there is no consensus on which is the best. There is a strong need to clarify the choice of retrieved variables and to properly assess their quality. In addition, the response of the analysis system to satellite products depends on the way the variance/covariance matrices of observation and forecast error have been estimated. They should be mutually consistent and particular attention should be given to dependence on air mass, viewing angle, etc.

(5) The ITSC participants have gained considerable expertise regarding the calibration, navigation and pre-processing of satellite data. By 1993, there will be the need for a new Advanced TOVS (ATOVS) software package. The effort required to reach a successful system for use at launch is considerable. It is the opinion of the ITOVS scientists that considerable efficiency will be gained by the coordinated development of modular and well documented ATOVS processing packages. This collaboration should begin soon.

(6) Concerning the Advanced Medium Resolution Infrared Radiometer (AMRIR), it was noted that the high spatial resolution of AMRIR allows improved cloud clearing and the presence of sounding channels may enhance the vertical resolution of the Advanced Microwave Sounding Unit (AMSU) sufficiently to be comparable with TOVS (but inferior to AMSU plus HIRS) in the lower troposphere. However, the ITOVS community emphasized that AMRIR cannot be considered as a stand-alone sounder. Therefore, ITOVS recommends that AMRIR should replace AVHRR/3 as soon as possible, but HIRS/3 should be maintained until advanced sounding instruments can replace HIRS.

(7) Current numerical models are approaching the point where further gains will be severely limited until improvements are made in observations. The vertical resolution of satellite soundings has emerged as a significant

(3) The ITSC community should consider participating in the 1992 World Ocean Circulation Experiment (WOCE)/Weddell Sea experiment.

(4) A common intercomparison retrieval file structure should be developed. The resulting structure should include specific details relating to each retrieval quality control flags, expected error variances, and prior information used.

• The Working Group on Software recommended:

(5) Since the ITPP and 3I systems represent investments of many tens of person-years in science and software development, CIMSS and LMD are encouraged to include invoices for a nominal charge with each system tape. This is not an attempt to recover full costs, but represents an opportunity for the user community to contribute to the costs of continued and improved support.

(6) A users' guide to TOVS processing, with contributions from several members of ITSC should be prepared. Initial liaison should explore the scope and content of such a guide, using the existing 3I users guide as a starting point. (Smith, Scott)

(7) A prospective for training should be prepared for the possible use by the WMO. The prospective should include the objectives of the training, the level of education and experience needed by the student, and the sources of instructors and training material.

(8) It was agreed that it will be desirable to seek a standard international package for converting raw ATOVS data to Level IB data. The use or conversion of code developed for NESDIS global data for this purpose should be investigated. Beyond Level IB stage, standard code was not likely to be developed, nor would this be desirable. Nonetheless, a small subcommittee should be established to promote collaborative development on ATOVS software. The subcommittee should prepare a software development agenda and strategy, and it should consider the presentation of detailed software structure(s) for discussion at the next ITSC.

• The Working Group on TOVS Applications and Impact Studies had the following recommendations:

(9) There will be an ongoing need to produce TOVS retrievals. It is primarily for direct use in most of the analysis systems. Also, even in a variational analysis using radiances directly, retrieved profiles are still useful for quality control and visualization of the satellite information.

(10) As a result of increasing NWP requirements for improved vertical resolution in the retrievals, an advanced high spectral resolution infrared sounder should be flown experimentally on a satellite within six years with a view to operational implementation during the latter part of the next decade.

(11) Research groups should perform TOVS experiments on selected data sets from certain time periods. They should exchange data and results, in order to benefit from cross-checks of these results. Scientists involved in TOVS impact studies should carefully check each step of the experiments; this implies stepwise exchange of results with agreement at each step before moving to the next one. Results should be presented at the next TOVS conference (ECMWF, UK Met Office, DMN, LMD, DNMI, NMC, GLA, NESDIS, CMC, ...).

(12) Research and development of TOVS-based synoptic tools, in combination with other synoptic information, should be more fully and more systematically pursued. Training programs for operational forecasters should be developed as part of these activities.

• The Working Group on International Coordination of Satellite Activities recommended:

(13) Advanced IR instrumentation should be flown as soon as possible on geostationary and polar platforms. Operational use in a.m. and p.m. orbits of such advanced instruments should be sought before the end of the century.

(14) To foster the utility of TOVS data in Earth system science pursuits, the HIRS/2 program should be continued until the sounder may be replaced by operational advanced sounders with an increased spectral resolution allowing the synthetization of HIRS/2 channel.

(15) AMRIR should replace AVHRR/3 as soon as possible. The instrumental system AMSU plus AMRIR plus HIRS/3 should be maintained until advanced sounding instruments can replace HIRS.

(16) Similar, if not identical, instruments should be installed in the geoplatforms of different agencies. The same spectral information should be obtainable from geo and polar orbit instrumentation. A study should be undertaken to evaluate the impact of sounding data from a geostationary microwave sounder.

Information theory indicates that for any estimation problem, the worst impact that incorporation of new measurements can have on the estimate of a variable is no impact at all. If addition of a new measurement degrades the value of the estimate of a variable, then the information in the measurement has either not been properly characterized, or the estimation algorithm has misused the measurement information.

This entirely general result has obvious implications with regard to the TOVS product generation (radiances or retrieved profiles) and NWP assimilation, since many NWP centers find that TOVS products have negative impacts on their assimilation/forecast cycles.

Accordingly, with regard to characterization of the quality of TOVS products, the working group identified a number of issues which need to be addressed. They concern the quality of all measurements used in the generation of TOVS products, and characterization of errors in TOVS products. There are three principal ways in which TOVS radiances may be used:

- in regression retrieval algorithms,
- in physical retrieval algorithms, and
- directly in an NWP assimilation.

If the data are used either directly, or in a physical retrieval algorithm, then the most significant outstanding problem relates to the "forward model" whereby the radiative transfer equation is utilized to compute TOVS equivalent radiances for a given atmosphere and scan angle. The accuracy and precision of the forward models must be characterized, and properly used, if physical and direct assimilation methods are to yield information which is always better than that provided by a regression scheme.

2. The Forward Problem

In regard to the forward problem, two important issues were identified. The first involves determination of the systematic errors in all radiosonde data used to estimate forward model error characteristics. The second concerns generation of appropriate methods for extrapolating radiosonde and model profiles to the top pressure level of the forward models.

It is believed that the BUAN data archive, after proper quality control, will enable identification of the error characteristics of radiosonde sounding

systems as well as inadequacies in current forward models. The working group noted that it is important to appreciate that the "forward model" problem is inextricably connected with radiosonde measurement errors. Radiosonde errors first must be identified before the forward model problems can be characterized.

With regard to extrapolating the temperature profile to the top of the atmosphere for radiance calculations, it is evident that there is significant information in the SSU radiances which are not currently utilized by most methods. Increased use of these data should be encouraged.

There are also a large number of other issues relating to the measurement problem, e.g., calibration, clouds, surface effects, etc. These were identified by the ITSC-IV Science Working Group, and in nearly all cases, remain outstanding. This report should be read in conjunction with that report.

3. Correcting for Clouds

It is recognized that the effects of clouds represent a significant problem in the inversion of infrared measurements. A variety of approaches have been applied to the problem. Despite the diversities of the methods used, we recommend that intercomparison be aimed at establishing the effectiveness of "cloud-handling". Principally, we recommend intercomparing cloud coverage/height fields and cleared radiance fields (direct and indirect). For those retrieval systems based on angle corrected radiances, we recommend restricting the comparison to near nadir viewing.

4. Validation

In addition to the validation of the radiance measurements with forward model calculation, there is the problem of the validation of the various retrieval algorithms. In order to address this issue, the working group suggests that the analysis of case study results should continue and that an extensive common retrieval file structure be adopted. These files should both be exchanged among centers and centrally analyzed. In the analysis of the intercomparison results, special attention should be given to trying to understand the retrieval results in situations where the different algorithms systematically yield disparate profiles.

5. Water Vapor Retrievals

The working group also identified a number of issues relating to water vapor retrievals. The TOVS instrument provides limited water vapor information near the surface, and therefore the use of additional information provided by such

(Kelly, Woolf, Chedin)

(c) Data for the June 7, 1987 and AMEX case studies should be distributed to all interested centers. (Uddstrom, Kelly, Woolf, LeMarshall, Rochard)

(d) To benefit retrieval verification studies, emphasis should be given to assembling all data derived from a previous case study over the ocean such as ERICA. If possible, these data should be coincident in time and space with the extensive ECMWF satellite (TOVS, SSM/I, SSM/T) data archive of February 1989. (Bates, Kelly)

(e) The ITSC community should consider participating in the 1992 World Ocean Circulation Experiment (WOCE)/Weddell Sea experiment. (Lutz, Heinemann)

(f) The problem with NOAA-10, channel 10 data over cold surfaces should be investigated further. The science issues that this problem raises with respect to the use of TOVS water vapor sounding channels are significant. (Lutz)

(g) To aid intercomparison, a common retrieval file structure should be developed. The resulting structure should include specific details relating to each retrieval quality control flags, expected error variances, and prior information used. (Uddstrom, LeMarshall, Chedin)

B. WORKING GROUP REPORT ON SOFTWARE

Co-Chairpersons: J. Eyre and N. Scott, with L. Baranski, R. Buell, B. Greaves, G. Haugen, T. Lachlan-Cope, F. S. Olesen, A. Pfister, K. Richardson, G. Rochard, H. Woolf, F.-Y. Zhang, and F.-X. Zhou contributing.

1. TOVS Processing Software

There have been several updates to TOVS Processing Software Since ITSC-IV. They are summarized briefly here.

The International TOVS Processing Package (ITPP) is currently working with two versions. Version 3.3 was released in February 1989 and has (1) navigation software upgraded by implementation of Brouwer-Lyddane model, (2) NOAA-11 capability provided in the form of new coefficients and minor software

modifications. Version 4.0 is estimated for release in October 1989 and will have (1) linearized RTE solution with "dry" and "wet" transmittance separation, (2) dynamic tuning with regression estimation of deltas from MSU observations while gammas and epsilons remain fixed, (3) improved treatment of cold surfaces through inversion detection with cold shortwave TBB check, (4) use of cold blackbody for HIRS calibration under conditions of extremely low temperature and humidity such as found in Antarctica, (5) corrections to high latitude TOVS geometry, and (6) documentation based on U.S. Navy Environmental Prediction Research Facility (NEPRF) standards.

Recent Improvements Implemented in the 3I System include: (1) the computation of the variance/covariance temperature matrix now exactly follows the way the initial guess is determined in the temperature inversion procedure. The angular dependence has also been taken into account. (2) Cloud clearing of channels 3 and 4 of HIRS-2 has been refined through a regression relying upon MSU channels (MSU 2,3,4) and HIRS-2 channel 2. This regression makes use of the TIGR data set. (3) A new mapping of the MSU observations within the HIRS-2 spots. (4) A new test for detecting low clouds over sea ice during the day. (5) The assimilation of the sea surface temperature from conventional analysis maps (themselves derived from AVHRR) in the water vapor retrieval. (6) The capability of reading TOVS data in level 1B format, or equivalently, the Master Plus format of Centre de Meteorologie Spatiale (EERM, Lannion, France). (7) A test for detecting rain over sea, similar to the one proposed by Philips (Bull. Amer. Meteor. Soc., 61, 712-717, 1980).

The Working Group noted that TOVS processing at a number of centers is now operational or approaching operational status. However, support for those systems based on ITPP or 3I could only be offered on an informal research basis. This situation is clearly unsatisfactory for the operational community, but no early solution to the problem was foreseen. Users aiming at operational status should be aware of this problem.

New and potential users of TOVS software should be advised that these packages have not yet achieved the stability and reliability at which they can be used satisfactorily in "turn-key" or "black-box" mode. They should recognize that effective use of TOVS software involves a considerable commitment in staff training and system maintenance and that adequate education in the underlying physical principles and techniques is necessary.

Recommendations for Software Support include:

(a) The ITPP and 3I systems represent investments of many tens of person-years in science and software development. CIMSS and LMD intend to include invoices for a nominal charge with each system tape, commencing with the next version. This is not an attempt to recover full costs, but represents an

(f) A prospective for training should be prepared for the possible use by the WMO. The prospective should include the objectives of the training, the level of education and experience needed by the student, and the sources of instructors and training material. (Giraytys)

2. Software for ATOVS Processing

Starting with NOAA-K, currently scheduled for launch in 1993, the present TOVS instruments will be replaced by the Advanced TOVS (ATOVS), comprising HIRS, AMSU-A and AMSU-B. Over the next four years, the international TOVS community will have to make preparations to process ATOVS data. Several centers plan to have a quasi-operational processing capability on "day 1." The development required to reach this stage is considerable and planning should start soon.

(g) It was agreed that it will be desirable to seek a standard international package for converting raw ATOVS data to Level IB data. The use or conversion of code developed for NESDIS global data for this purpose should be investigated.

(h) Beyond Level IB stage, standard code was not likely to be developed, nor would this be desirable. However, collaboration on development of software modules should be encouraged.

(i) Improved treatment of the forward problem for AMSU channels should be sought through the ITRA group. (Chedin)

(j) A small subcommittee should be established to promote collaborative development on ATOVS software. The chairman of the NESDIS Sounding Products Oversight Panel should be approached concerning this. The subcommittee should prepare a software development agenda and strategy, and it should consider the presentation of detailed software structure(s) for discussion at the next ITSC. (Eyre)

3. SSM/T and SSM/I Data

It was recognized that the availability of SSM/T and SSM/I data presents opportunities for exploring and anticipating some of the problems which will arise with ATOVS processing.

(k) It was agreed that a list of references on SSM/I and SSM/T instruments and data research should be prepared and included in the ITSC-V Technical Proceedings. (Contributions should be sent to G. Rochard by 15 September 1989; these will be collated and sent to A. Chedin by 30 September 1989).

C. WORKING GROUP REPORT ON TOVS APPLICATIONS AND IMPACT STUDIES

Co-chairpersons: J. Pailleux and G. Prangsma, with W. Baker, C. Chouinard, P. Dibben, J. Giraytys, M. Homleid, G. Kelly, J. LeMarshall, D. Steenbergen, S. Uppala, and F.-Y. Zhang contributing.

1. Introduction

The use of TOVS products by the meteorological community has played a fundamental role in advancing Numerical Weather Prediction (NWP) over the past ten years. Progress came also from using TOVS data for synoptic applications.

In the southern hemisphere, the use of TOVS data is essential for accurate analyses, with a large and consistently positive impact on the resulting forecasts. In the northern hemisphere, the forecast impact has been small on the average, with large regional variations in individual cases.

The different error characteristics of the satellite retrievals compared to conventional data (e.g., radiosondes, aircraft, etc.) accelerated the application of more sophisticated analyses techniques to the NWP problem, such as Optimum Interpolation (OI) in the 1970s. This, in turn, resulted in a more accurate initial state for the forecast model. The largely satellite-based analyses over the oceans also provided improved verification fields for model parameterization developments. As the accuracy of the forecast models has improved over the past several years, the accuracy of the retrieved products has also steadily improved through the use of the model forecast as a first-guess for the retrievals. Some recent results using this approach have been quite encouraging, with a consistently positive forecast impact over the northern hemisphere extratropics (corroboration of these findings using other NWP systems is needed).

More recent work in the four-dimensional assimilation using variational techniques (4-d var) has opened the way to using directly all the radiance information in a fully consistent way for NWP. Such a development should lead to a considerable increase of the benefit to NWP from satellite data.

As investigations of man's possible impact on the climate move forward, it is essential to have the capability to examine the Earth as a total system and to monitor the evolution of the atmosphere, oceans and cryosphere and their

Transfer Equation (RTE), then combining the traditional analysis and the inversion in a single process. These techniques are still in the development stage.

The main mathematical tool needed in variational analysis is the adjoint of all the operators used (for the gradient computations). The quality control has to be done in the same way in a variational or an OI approach.

The Working Group had the following recommendations:

(a) There is a need for efficient direct/adjoint radiative transfer routines. The vectorization for super-computers should be considered and should treat several profiles at the same time.

(b) There will be an ongoing need to produce TOVS retrievals. It is primarily for direct use in most of the analysis systems. Also, even in a variational analysis using radiances directly, retrieved profiles are still useful for at least two reasons: quality control and visualization of the satellite information (for monitoring and possibly non-NWP applications).

The ECMWF/EUMETSAT Workshop (held at Reading, England in May 1989) has also addressed the problem of retrieval methods, data assimilation and also examined the implication of NWP of proposed changes in satellite soundings over the next decade. The following sentences will attempt to summarize the recommendations from that workshop. The importance of a fast and accurate forward model, quality control, the first guess, variance/covariance matrices and the data assimilation methodology was noted. With respect to assimilation, the continued requirements for global centers and for direct readout and local data processing for high resolution NWP was noted. Recent Northern Hemisphere impact studies which have failed to fully exploit the information context of TOVS have resulted in moves to use for example variational methods which will allow the retrieval to be done as part of the analysis cycle. The contribution of these systems to northern hemisphere should be felt during the next few years. The meeting also endorsed continuation of impact studies with more attention to improving the assimilation methodology. It also endorsed the concept of both observing system simulation experiment (OSSE) and observing system experiments (OSE). The implication for NWP of planned and proposed changes in satellite soundings was also examined. The potential gain from present and next generation systems were noted, but the basic problem of inherently poor vertical

resolution in the sounders led to an important recommendation to accelerate programs to implement high resolution infrared sounders. The meeting also addressed generation of wind data from space and the use of other satellite products for NWP and other purposes such as ice, rain and snow detection, ozone estimation, albedo and cloud properties.

Accordingly this Working Group strongly recommends:

(c) As a result of increasing NWP requirements, an advanced high spectral resolution infrared sounder should be flown experimentally on a satellite within six years with a view to operational implementation during the latter part of the next decade.

3. Impact Studies

As many groups as possible should concentrate their TOVS research on some specific periods or cases which have been already chosen at various meetings for various reasons. The current study periods are 6-19 February 1989, the AMEX period of January 1987, and 7 June 1987. Regarding data sets, the co-chairmen can be contacted and the data will be gathered from centers such as ECMWF, NMC, CIMSS, LMD, and BMRC.

Mutual benefits by working on the same period will be gained by cross-checking the results. The impact studies normally involved a long chain of software, and it is important to check carefully the results of one step before moving to the next step. As an example, a long assimilation can be run only after having evaluated carefully the results of the cloud-clearing, inversion and analysis steps which are coming before.

(d) Research groups should perform TOVS experiments on the periods/data sets listed above. They should exchange data and results, in order to benefit from cross-checks of these results. Results should be presented at the next TOVS conference (ECMWF, UK Met Office, DMN, LMD, DNMI, NMC, GLA, NESDIS, CMC, ...). Some centers should work on sub-periods to be specified later.

(e) Scientists involved in TOVS impact studies should carefully check each step of the experiments; this implies stepwise exchange of results with agreement at each step before moving to the next one.

4. Feedback Regarding TOVS Quality

Currently, tools to assist in monitoring TOVS are produced by several centers, either for use in an operational mode or to answer a specific research question. These tools include collocations with radiosondes (including daily/monthly statistics) and departures from the first guess on several

- stability index fields
- MSU temperature anomaly maps (showing skill in the detection and characterization of developing tropical storms)

These examples all have implication for nowcasting as well as for operational short-range forecasting. They indicate that there is cause for optimism in applying TOVS analyses. It has been recognized that these applications of TOVS have not been exhaustive and that there seems to be considerable potential for such use of TOVS products in the operational/synoptic practice of weather services. Timeliness and continuity of data, as well as proper understanding of the meteorological contents of derived products, are essential for successful use of TOVS in operational synoptic forecasting.

(g) It is recommended that research and development of TOVS-based synoptic tools, in combination with other synoptic information, should be more fully and more systematically taken in hand. In order to get an overview of what has already been achieved in this area, ITOVS Working Group participants are urged to send details on their systems and techniques within three months to G. Prangsma who will compile and send out an inventory in about six months. (Participants/Prangsma)

(h) It is recommended that adequate and timely training programs for operational forecasters be devised as part of the development activities. Although such training programs will tend to be specific for every weather service, exchange of training material is strongly encouraged.

(i) It is recommended that synoptic forecasting workstations are developed in a stable software environment and are based on well-understood algorithms which include quality control modules. These developments should be performed in close contact with the author(s) of the algorithms used.

(j) It is understood that synoptic techniques based on TOVS have potential in both the nowcasting and short-range forecasting context. It is recommended to more fully explore this potential, paying special attention to the selected case studies and possibly other severe weather events.

D. *WORKING GROUP REPORT ON INTERNATIONAL COORDINATION OF SATELLITE ACTIVITIES*

Co-Chairpersons: R. Rizzi and J. Giraytys, with J. Bates, G. Kelly, P. Pagano, M. Perrone, W. Smith, and A. Uspensky contributing.

1. Improved Sounding Capability

Over the last decade, there has been a considerable improvement in the techniques of numerical weather prediction with significant gains in forecasting skill; over the same period, there has been little development in operational instrument technology. The impact of TOVS products is noticeable only in the southern hemisphere; problems are encountered when using satellite soundings in regional models in the northern hemisphere.

The main limiting factor in temperature and humidity remote sensing is the limited vertical resolution. There is definite evidence that advanced sounders with high spectral resolution produce soundings with higher vertical resolution in cloud-free areas and possibly over partially opaque clouds.

Therefore it is recommended that:

(a) Advanced IR instrumentation should be flown as soon as possible on geostationary and polar platforms.

(b) Operational use in a.m. and p.m. orbits of such advanced instruments should be sought before the end of the century.

2. Data Continuity

The development of Earth system science has triggered an increasing number of applications of TOVS data beyond those in operational meteorology. A 30-year baseline is commonly recognized as the minimum required to extract climatological mean geophysical values. Ten years of continuous global TOVS data is now available to the international community. Therefore,

(c) Accurate calibration of TOVS data, as pursued through the activities of the TOVS working groups, should be continued. This is necessary because systematic errors seriously degrade the utility of data.

(d) The HIRS/2 program should be continued until the sounder may be replaced by operational advanced sounders with an increased spectral resolution allowing the synthetization of HIRS/2 channels.

3. Planning of Future Polar Sounding System

(g) The instrumental system AMSU plus AMRIR plus HIRS/3 should be maintained until advanced sounding instruments can replace HIRS.

4. Planning for the Geostationary Platform

The geostationary sounding mission is complementary to polar sounding mission. Meteorological information available from geostationary orbit is comparable to that available from polar orbit; the main difference is the temporal resolution of the measurements. Geostationary orbit does offer the possibility of moving platforms to optimize the spatial coverage in case of failure of one component of the geostationary system.

For sounding data to become more useful in nowcasting requires increased vertical resolution, hence there is a need for the development and launch of advanced sounding instrumentation.

Recognizing these facts, it is recommended that:

(h) Similar, if not identical, instruments should be installed in the geoplatforms of different agencies.

(i) The same spectral information should be obtainable from geo and polar orbit instrumentation.

(j) A study should be undertaken to evaluate the impact of sounding data from a geostationary microwave sounder.

(k) Intensified airborne campaign for microwave imagers and sounders should be undertaken to assist in solving the remaining scientific problems.

(l) International cooperation should be encouraged on the basis of the present common phase of planning.

5. Direct Readout

Direct readout continues to be of particular importance for nowcasting purposes and regional NWP. It involves the deployment of a network of user receiving stations that can be operated without sophisticated ground infrastructures. Therefore,

(m) Direct readout should be maintained on the operational polar orbiting satellites.

(n) More generally, access is desired to data from the NASA Eos Research Facility instruments (e.g., AIRS) through EosDIS for research purposes and via a possible NOAA Data Information System for operational purposes.

(jointly with the National Environmental Satellite Data and Information Service (NESDIS)) a new interactive analysis/forecast/retrieval system.

The realization of the importance of the satellite retrieval problem to numerical weather prediction culminated recently in the formation of an Interagency Satellite Retrieval Working Group in the United States which includes satellite retrieval and NWP experts from the National Aeronautics and Space Administration (NASA) and the National Oceanic and Atmospheric Administration (NOAA). The charge to this Working Group is to develop as soon as possible a state-of-the-art satellite retrieval system for numerical weather forecasting. This system will take advantage of the best components of the operational system at NESDIS and those from experimental approaches at NESDIS and at NASA.

*Under contract through the National Environmental Satellite Data and Information Service (NESDIS) with ST Systems Corporation (STX)
**NESDIS
***Under contract through the National Meteorological Center with Centel Federal Services Corporation
****NASA Goddard Space Flight Center, Laboratory for Atmospheres

ATMOSAT INTERACTIVE IBM-PC/AT SYSTEM FOR PROCESSING OF TOVS DATA

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The interactive informatic system ATMOSAT has been established on the base of an IBM-PC/AT, where the data base and partial software from the TOVS Export Package (Version 3) was applied. In comparison to the TOVS Export Package, the procedures for graphic presentation of final and indirect computing results were added. The graphic capabilities of IBM/PC-AT with EGA color monitor were fully utilized. The software of ATMOSAT system consist of seven programs for preprocessing of TOVS data (TIPEXT, TIPINS, TIPPRE, TIPLOC, TIPRTV, TIPISO, TIPPLO), retrieval of the atmospheric temperature, moisture, and ozone profiles and graphic presentation of the results.

The ATMOSAT system is connected to the HRPT and DSB receiving stations and has been working satisfactorily in Poland since 1987.

The intercomparison analysis was made for temperature and moisture vertical profiles retrieved from TOVS data by using the ATMOSAT system versus radiosonde measurements obtained from seven aerological stations placed in Middle Europe. The statistical material from TOVS transmission and time coincident aerological data are used for calculation of the regression coefficients to establish the relationship between stratospheric HIRS channel and ozone mixing ratio profiles. The determination of the regression coefficients representative for Middle Europe climate conditions is the main goal of this work.

The ATMOSAT software will be extended by including SSU data processing.

EXPERIENCES WITH ITPP AND 3I RETRIEVALS OVER THE OCEAN

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Both the International TOVS Processing Package (ITPP) and the Improved Initialization Inversion (3I) software package have been applied to direct readout TOVS passes over the ocean during air-sea interaction experiments. The most extensive comparisons were conducted during the Frontal Air-Sea INteractive EXperiment (FASINEX) which took place during February 1986 in the northwest Atlantic Ocean. Comparisons with ship-launched radiosondes showed that both retrieval packages produced low level temperature and dewpoint temperature profiles that were biased low relative to the radiosondes. The 3I package often showed a sharp drop in moisture content above the marine boundary layer in agreement with observations. The ITPP retrievals often showed excessive drying at mid-levels with a linear trend toward more moist conditions at the surface. The 3I package was also applied to two other air-sea interaction experiments off the west coast of the USA.

Two strategies are suggested for improving TOVS retrievals of low level temperature and moisture profiles over the oceans. One is an ad hoc method based on adjustment the low level profiles to accurate estimates of sea surface temperature. The other is a thermodynamic constraint assuming an idealized convective boundary layer and then using a mixing line model. These suggestions, however, have yet to be tested.

HIRS channels, but not the split window term.

AN INTERCOMPARISON OF GEOPOTENTIAL AND TEMPERATURE FIELDS OVER EUROPE DERIVED FROM TOVS AND CONVENTIONAL DATA

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Geopotential and temperature fields over Europe derived from satellite and conventional radiosondes have been compared in order to perform a preliminary validation of the ITPP/3 package.

Quantitative statistic differences between TOVS and collocated radiosonde profiles have been estimated and qualitative intercomparisons between retrieved and conventional geopotential thickness fields have been evaluated. Quantitative statistics show a cold bias in the lower levels of the troposphere, that should be removed with the inclusion of surface data in the retrieval scheme. In the middle and upper troposphere, bias values are less than 1 K and standard differences are less than 2-3 K. Satellite retrieved geopotential fields are in good agreement with the conventional ones.

LOCAL AND GLOBAL APPLICATIONS OF THE "3I" SYSTEM

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Aiming at the three-dimensional analysis of the Earth's atmosphere structure from observations of the operational meteorological satellites of

the TIROS-N/NOAA series, algorithm "3I" (Improved Initialization Inversion), since the last meeting of the International TOVS working group, has been developed and refined following five main directions:

- As a feedback to the extensive series of experiments carried out at ECMWF and aiming at measuring the impact of satellite data, processed by the 3I scheme on middle range weather forecasting, modifications to the algorithm have been introduced and applied to several pathological NOAA-9 and NOAA-10 passes. The main improvements concern the temperature variance/covariance matrices involved in the solution estimation method, the cloud-clearing technique, the introduction of a rain detection test, the detection of low clouds over sea ice at day. Significant improvements have been obtained and are illustrated through comparisons with analyses.

- Numerous applications to special situations have been carried out, in particular over Arctic and Antarctic areas, with the aim of studying polar low formation and development.

- Coming space altimetry experiments (TOPEX-POSEIDON, ERS1) have led us to pursue quantitative evaluation of TOVS vertical water vapor distribution for several study cases as well as to global scale (cooperation with ECMWF).

- Two rapidly evolving severe weather situations have been analyzed and comparisons have been made with conventional data so as to evaluate their differences. Assimilation of satellite data in limited area models is studied in cooperation with KNMI (Netherlands Meteorological Institute) and DNMI (Norwegian Meteorological Institute).

- Retrieval of total ozone amount maps has been attempted from TOVS observations. Sensitivity of ozone channel to the shape of ozone vertical distribution has been quantified leading to the conclusion that particular care must be exercised in the interpretation of such maps.

SCENARIO FOR AN OPTIMAL USE OF SATELLITE RETRIEVALS

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The recent joint ECMWF/EUMETSAT workshop on "The Use of Satellite Data in Operational Weather Prediction" (Reading, May 1989) has given the opportunity to raise question on how best to use satellite data in a

includes the simultaneous physical retrieval and the possibility of injecting surface data obtained by ECMWF six-hour forecasts. A first comparison with raobs shows a good matching, with a standard deviation contained with 1.5°C.

PLANNING FOR ATOVS DATA

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The international TOVS community must make preparations for processing data from the Advanced TOVS (ATOVS) currently scheduled for first flight on NOAA-K in 1993. Although ATOVS will resemble TOVS in many respects, and similar processing methods and software systems will be appropriate, a number of new procedures will have to be developed and new scientific problems understood.

The first part of this paper reviews the component parts of an ATOVS processing system. It attempts to identify areas where additional research and development is necessary or desirable, and it highlights some of the options available in processing methods. The second part descries briefly some recent simulation studies to quantify the retrieval performance and information content potentially available from ATOVS data.

TOVS-N/NOAA RECEPTION IN BRAZIL: PROGRESS AND PLANS

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The TIROS-N/NOAA Receiving Station has recently been adapted to ingest HRPT signals directly into a PC-based working station. The imagery data are currently used as input to methodologies designed for monitoring forest fires and vegetation index. Projects underway include the implementation

of the PC-TOVS package (CIMSS-UW) and the development of sea surface temperature (SST) algorithms for research and operational purposes.

The receiving capabilities shall be expanded before the end of 1989 by the introduction of a Micro-VAX 3600 computer to act as the satellite data processor. The new architecture also allows the use of PC-based working stations. The International TOVS processing Package (ITPP), presently installed in a Burroughs 6800 (48 bits) computer, shall be adapted to run operationally in the Micro-VAX as soon as possible. Sounding products will be useful for very short range and numerical weather prediction applications.

All these activities are conducted at CSA - Centro de Aplicacao Satelites Amientais ("Brazilian" Center for Applications of Environmental Satellites). This Center was created in 1988 with the main objective of providing environmental (meteorological and oceanographic) satellite imagery data and products to the Brazilian System of Meteorology, which primarily includes operational weather forecasting agencies and research institutions.

ADVANCED MEDIUM RESOLUTION IMAGING RADIOMETER (AMRIR)

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The AMRIR has been specified and designed to replace and improve the Advanced Very High Resolution Radiometer (AVHRR) and the High resolution Infrared Radiometer Sounder (HIRS). The AMRIR contains the six spectral channels that were contained in the AVHRR, NOAA K, L, M version, AVHRR/3, with some minor adjustments to the spectral bands. In addition to the six AVHRR channels that are contained in the AMRIR, there have been added three sounding channels, a total ozone channel and an additional sea surface temperature channel. Simulation of sounding data has shown that this combination of channels, when combined with the 20 AMSU channels, offer a sounding accuracy that are superior to the HIRS/AMSU combination on NOAA K, L, M series. The first flight of AMRIR is scheduled for 1997.

A PC-BASED ITPP-3 SYNTHETIC RETRIEVAL PACKAGE

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APPLICATION OF AN ITPP-3 SYNTHETIC RETRIEVAL PACKAGE TO THE INVESTIGATION OF MICROWAVE DUCTING

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Vertical structure in atmospheric moisture can significantly affect microwave propagation characteristics. The extent to which current satellite sensors could contribute to the measurement of atmospheric refractivity variations has been investigated using a synthetic retrieval software package. Atmospheric radiances are synthesized from model temperature and moisture profiles to simulate radiances that would be measured by the NOAA polar orbiting satellite. An inversion scheme is applied to the synthetic radiances to determine the thermodynamic profiles and the atmospheric refractivity corresponding to such an atmosphere. Using this approach, it is possible to evaluate the capability of current satellite sensors to contribute to the identification of ducting situations.

ON THE USE OF TOVS DATA FOR STUDIES OF MESOSCALE VORTICES IN THE WEDDELL SEA (ANTARCTICA)

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As only few stations performing meteorological observations exist in the Antarctic, atmospheric temperatures derived from TOVS data have quite

better temporal and spatial coverage than conventional measurements. Results of retrievals of the 3I, ITPP-3, and operational NESDIS products are used to getting insight into the environmental conditions of mesoscale vortices (100-1000 km scale) in the Weddell Sea region (60W-0W).

For some case studies, comparisons are made between the 3I and the ITPP-3. The usage of analyses in the 3I gives improved results, especially for the detection of clouds. ITPP retrievals yield higher temperatures compared to 3I results for the lower troposphere, although the structures of the thickness fields are similar. Retrieved temperature fields show the connection of mesoscale vortices with cold air pools and can add new information to ECMWF analyses in data sparse regions like the Antarctic.

INTERPOLATION METHOD OF HIRS/2 IMAGE USING AVHRR

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It is becoming increasingly important to integrate images collected by different remote sensors, but difficult because of different resolutions. In this paper, interpolation method of low resolution image using correlation to other higher resolution image has been proposed and applied to the meteorological satellite NOAA AVHRR and HIRS/2 images. Using this method, the resolution of HIRS/2 images is improved equivalent to that of AVHRR image. As an example, these interpolated images were applied to the precise atmospheric correction method using the combination of AVHRR data and HIRS/2 data to correct atmospheric effects at the area which is smaller than one original pixel of HIRS/2.

TOVS EVALUATION AND ASSIMILATION AT THE NORWEGIAN METEOROLOGICAL INSTITUTE

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Since 1978, polar orbiter HRPT data have been received locally at DNMI in Oslo. AVHRR pictures are processed operationally. The ITPP-3b was implemented in 1987. During 1988, statistical software including graphics was developed as a tool for experimental processing and evaluation of TOVS data. Last year, the first assimilation experiments have been performed.

The segmentation is done by collecting representative samples of each class in a training phase. In this phase, a polynom classifier is adapted. The adapted classifier is then used for the image segmentation in a unsupervised running phase. Thus, the classification can be adapted to different kinds of segmentation problems. The scheme has been successfully adapted for the segmentation of AVHRR images in three classes (clear over land, clear over sea, cloudy).

QUALITY CONTROL OF NESDIS PHYSICAL RETRIEVALS OF TOVS SATELLITE DATA

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Recent work has identified serious errors and biases in the operational statistical retrievals produced by NESDIS in 1987. Similar errors and biases are found in the physical retrievals produced operationally since September 1988. We report on experiments to design quality control algorithms to deal with the errors in the data. We documented the quality control changes implemented in the ECMWF system in January 1989, and evaluated the performance of the changes.

INTRODUCTION OF TOVS PROCESSING IN KOREA

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The introduction of MESDAS (Meteorological Satellite Data Analysis System) at the Korean Meteorological Service (KMS) makes TOVS processing possible in Korea. The paper describes briefly about MESDAS and operational aspects of the processing. The products from the processing system are to be shown and the future work of its application mentioned.

THE USE OF TOVS DATA IN ANTARCTICA

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Comparing the statistical scheme presently in use at the British Antarctic Survey with a new simultaneous physical scheme (ITPP-3), it is found that during the early part of January 1986, the statistical scheme gave significantly better results when compared with radiosonde ascents. Efforts were made to improve the physical retrievals by using radiosonde ascents as a first guess, altering the matrix stabilization parameter and using new values for the transmittance adjustment exponents (gamma) and the brightness temperature bias adjustments (delta). However, these modifications, although producing improvements for individual collocated retrievals and radiosonde ascents, did not produce any improvement in the overall RMS error.

AVHRR/HIRS COUPLING

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Cloud parameters such as cloud cover type, cloud top temperature, effective cloud cover, inferred inside the HIRS-2 field of view (fov) by the AVHRR radiometer, are used to retrieve synthetic cloudy HIRS-2 radiances. In this study, the temperature and humidity profile is known (radiosonde).

For a blackbody cloud layer, the cloud top temperature is directly estimated from the coldest brightness temperature in the ellipse. For a single layered, semi-transparent cloud system, a new method has been developed which determines the cloud top temperature by the least square fit of a theoretical curve on the bi-dimensional histogram (T4/(T4-T5)). the type and number of clouds are given by a threshold technique for different channel combinations.

Synthetic cloudy radiance calculations imply the knowledge of the cloud emissivity variation with wavelength. This variation is obtained by statistical regressions of HIRS effective emissivities with the corresponding AVHRR channel 4 one. This process has been done on the CATHIA data set which is a compilation of collocated data (radiosonde

from the operational numerical analysis and prognosis scheme and are both now undergoing real time data impact tests in the Australian region with the next generational operational forecast model. Their characteristics are summarized, the regional TOVS data assimilation experiment is described, and the application of the data including use in regional offices, is noted. Examples of the schemes' output are shown and the direction of future TOVS-related development work in the Bureau is also summarized.

EVALUATION OF TOVS PRODUCTS

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A project concerning evaluation of TOVS products is in progress at SMHI. TOVS processing has been done in near real-time at the satellite data receiving and processing station PROSAT during one week every two months. The evaluation of the retrieved TOVS products has been done in the following two ways. (a) The first is an objective comparison between TOVS retrievals and radiosondes of temperature and water vapor profiles. So far, only NOAA-10 retrieval comparisons with radiosondes at 06:00 and 18:00 have been done. (b) The second is a subjective analysis of different TOVS products including geopotential height, integrated water vapor, stability index, and ozone. These products can be displayed on an image processing system together with other meteorological parameters, e.g., forecasts from a Limited Area Model and AVHRR data.

The project started in October 1988, and will end in autumn 1989. Some preliminary results are presented.

TOVS OVER POLAR REGIONS - WINTER CASE STUDIES

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In this paper, we deal with the problem of retrieving temperature and moisture profiles in the Antarctic regions at winter time using radiance observation from the TIROS Operational Vertical Sounder (TOVS). The extreme climate of the Antarctic makes it difficult to interpret the radiometer measurements. On the Antarctic plateau there are strong temperature inversions (15K-35K), so that the clouds are warmer than the surface of the plateau. Choosing the coldest spot with a 3x3 box will give the temperature of the clearest field of view. The High resolution Infrared Sounder (HIRS) channels 13-19 (3.5-4.6 microns) are not used on the Antarctic plateau, because the measured energies at these wavelengths are almost as low as the signal-to-noise ratio. The HIRS data should be calibrated with the internal cold and warm blackbodies in order to alleviate apparent calibration discrepancies resulting from using the space as a cold reference. Because of low energies which are measured over the plateau, there are large discrepancies between the data of two consecutive scan lines at which the calibration coefficients are changed. Therefore, the calibration coefficients have to be interpolated between the two successive calibration sections for every scan line. In winter time, very often polar stratospheric clouds are found, so that the measurements of HIRS channels 1-3 (15 microns) cannot automatically be assumed to be cloud-free.

Significant improvements of the retrieval results of the simultaneous retrieval approach have been achieved in using a special climatological first guess for south polar regions and the high plateau area.

CHARACTERISTICS OF GLOBAL CLOUD COVER DERIVED FROM MULTISPECTRAL HIRS OBSERVATIONS

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GENERAL USE AND IMPACT OF TOVS DATA ON GLOBAL MODELLING (INCLUDING VARIATIONAL ANALYSIS)

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After a brief summary of the more recent TOVS impact studies made at ECMWF (section 2), some practical difficulties in using satellite data in a global assimilation scheme are highlighted and discussed. These practical difficulties are one of the reasons to reconsider the traditional Optimum Interpolation (OI) analysis approach, and to develop a variational analysis (presented in section 3). The direct assimilation of clear TOVS radiance in the variational analysis is discussed in section 4, as well as preliminary results and future plans.

NORTHERN HEMISPHERE CASE STUDY (7/6/89)

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The events on the Whit Sunday afternoon (June 7, 1987) on the southwest coast of France presented some extreme problems to normal forecasting procedures. Two main questions have to be answered in the context of the use of satellite observations: (1) Can the nature of the weather system causing the problems be delineated? (2) Which role can satellite data and/or products play in that description? After these questions have been answered, more development work will probably be needed to provide proper forecasting tools for such cases.

With regard to the first question, it has been found that the standard registrations (surface pressure, 10m wind speed and direction, precipitation and to some extent temperature) at synoptic stations along the Spanish north coast provide an insight in the sequence of events. Within a period of about ten minutes, all stations show the following features: a surface pressure increase of around three millibars, wind speeds increasing from around 25 knots to around 40 knots (and occasionally

more) with a strong increase in gustiness (gusts of over 60 knots have been observed); wind direction veered from S-SW (some SE-S) to NW-N. At some stations, rain intensities of up to 10 mm/hr were observed in a total precipitation amount for the event of around 3-5 mm. Where registered, temperature drops of around 5 K are found. This sequence of events is gradually moving at a fairly constant speed from Cape Finisterre (at 08:40 GMT) to Fuenterrabia close to the French border (at 14:40 GMT), just before the events occurred over SW France (around 15:00 GMT).

With regard to the second question, AVHRR cloud imagery (NOAA-9 at 04:40 and NOAA-10 at 08:55) indicates that the above mentioned feature is closely linked with the progression of an otherwise not atypical cold front. Further north, strong deep convective activity is discernible.

Inversion of TOVS data after conversion into a thermal vorticity product for the NOAA-10 pass at 08:55 shows a vorticity structure with strong and alternating gradients in the area of interest, not only for the lower troposphere (1000-500 mbar layer), but also extending into the upper tropospheric layer (500-300 mbar and possibly weaker above as well). Since the advection (by the thermal wind) of the thermal vorticity is one of the major terms in the tendency equation, it can be conjectured that the rapid alternation of thermal vorticity gradients in the direction of advection is closely linked to, or even can explain, the very suddenness of the weather events experienced on that day.

Available data sets include TOVS data from NOAA-10 orbits on the afternoon of June 6, and in the morning and afternoon on June 7. Cloud imagery is available for the same orbits, plus some NOAA-9 orbits. Possibly Meteosat images, basically at 30 minute intervals, might add in the analysis. Furthermore, rain radar data are available, as well as ECMWF analyses preceding and following the event at six hour intervals (in GRIB code) and eventually observations from the area of interest (in BUFR code).

It is understood that the standard TOVS validation against radiosonde data cannot be applied in this case, mainly due to the timing of the events (away from radiosonde times). Therefore, this case study will have a character entirely different from previous ITOVS case studies.

TOVS PROCESSING AT KNMI

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(horizontal resolution, global/constant density observations), while keeping the weak points (limited vertical resolution) under control (and in mind!). Also, other than current TOVS products will be included in the research to better initialize various model variables. An important aspect of the data handling/retrieval scheme is the uniqueness of the retrieval or, rephrased, the "error-structure around the true profile." Some research is planned into this intriguing aspect of the radiative transfer basis of satellite sounding.

APPLICATIONS: SYNOPTIC USE OF TOVS

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Little real progress has been seen over the past year and a half, but the ideas have become more focussed toward answering the following question. How can TOVS analyses be used to help the operational forecaster in quickly assessing the quality of NWP guidance and pinpointing potential problem areas?

Examples for two severe storm cases over Western Europe (7 June 1987 and 15-16 October 1987) have been presented as possible applications of TOVS derived thermal vorticity (advection) maps. Among the participants, mention has been made of tropical storm detection and characterization using MSU temperature anomalies.

It is understood that to make progress in the field, timely availability of analyses and continuity of systems (instruments, software, etc.) are vital ingredients. Furthermore, adequate workstation technology greatly facilitates the development and use of such operational/synoptic forecasting techniques in both nowcasting and short-range forecasting. Finally, training programs for operational forecasts (and researchers!) have to be devised, preferably in parallel with the system's development, aiming at the proper interpretation of the TOVS products in a synoptic context.

RETRIEVAL OF TEMPERATURE AND WATER VAPOR PROFILES USING TOVS, AVHRR AND SIMULATED ATSR RADIANCES

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Temperature and, in particular, moisture profiles in the lowest layers of the atmosphere are required for the accurate determination of surface temperatures from satellites. Currently, moisture retrievals from the TOVS instrument are poor. In this work, we have attempted to improve the determination of moisture profiles in the boundary layer by including AVHRR radiances directly in the retrieval. Some improvements are obtained. Further improvement results when a multiple regression method is used for the retrieval using a combination of TOVS, AVHRR and simulated ATSR radiances. The regression is based on a set of radiosonde profiles representative of the marine boundary layer, and therefore contains information about the stability and moisture content of their anomalous atmospheres.

NUMERICAL FINE MESH ANALYSIS AND INCORPORATION OF HIGH RESOLUTION TOVS

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A fine mesh numerical analysis model (30 km grid width) is used to follow the trajectories of particles on isotopes. TOVS retrievals are used to update the conventional vertical structure. The coupling of the VAX cluster with the AVHRR receiving station and the meteorological data network makes an integrated use of HIRS data and analysis possible. The TOVS radiances are interpolated to the model grid points and a single point physical retrieval is used, where surface temperature and pressure are taken from the ground stations. The analysis yields the first guess. The ground reported data on cloud amount and cloud height as compared with a cloud classification from satellite images (AVHRR and Meteosat).

THE APPLICATIONS OF THE ITPP FOR USE IN REAL TIME CLOUD ANALYSIS AND NOWCASTING AT SEA

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A procedure to recover high resolution spectra without any intervening window from infrared Fourier spectrometer data is presented. The technique relies on the Wiener-Khinchine theorem, maximum entropy principle in information theory and linear prediction theory. The scheme developed is especially designed: (a) to recover the radiance spectra, and (b) to perform a quality control of experimental data. It can provide an accurate representation for underlying power spectra which have sharp, discrete lines or delta functions. Such characteristics are expected in infrared emission spectrum of the earth. The technique consists of filtering to the measured interferogram the covariance function of an autoregressive process or model. The optimal order of the model which best fits the data is selected using a suitable criterion. The algorithm that we use to identify the optimal order is iterative, so that the procedure can be easily implemented in order to produce an automated scheme for quality control of interferograms. Numerical example are carried out using a high resolution transfer radiative code. The effect of additive noise (e.g., measurement errors) is analyzed, too. The application of the technique is discussed in the context of the remote sensing of atmosphere with high resolution interferometer. Finally, first analysis using HIS data recorded during a flight over the California coast are also shown.

TOWARDS OPERATIONAL USE OF TOVS IN HUNGARY

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Reception of digital transmissions of TIROS-NOAA satellite series will soon be available for the Hungarian Meteorological Service operationally. This would make it possible to derive temperature and humidity profiles by processing TIP data.

The hardware components of the satellite receiving and processing system are as follows: (a) satellite receiver equipped by the Technological University of Budapest, (b) a TPA-11/48 type preprocessing computer, and (c) an IBM PC/AT compatible computer for the final procession of TOVS data.

Software elements include: (a) preprocessing programs developed at our Institute, and (b) derivation of temperature and humidity profiles by utilizing different versions of the TOVS Retrieval Export Package.

Up to now, we have realized numerous experiments for the adaptation of TOVS Export Package, especially for testing the version using statistical approach (results presented at ITSC-IV). Recently, we have been making experiments on the adaptation of the physical version, too. The profiles that we have reproduced are experimentally used both in synoptic and numerical prognostic practice. We intend to establish the scientific foundation of these applications.

FUTURE GEOSTATIONARY SATELLITE CONSIDERATIONS

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There are emerging over the next decade a greatly enhanced number of geostationary satellites. These include satellites as part of new spacecraft programs in Russia and China; the proposed NASA geoplatform system which would include as many as five new spacecraft with highly sophisticated sensors for performing Earth System Science (ESS); and the evolving operational capabilities of European, Japanese, United States, and Indian geostationary satellites.

Because of (a) the scientific advantages reaped from the synergistic use of a global system of geostationary satellites with overlapping coverage, (b) the high cost of developing advanced remote sensors for geostationary applications.

There is a need for a close international coordination of these developments with the attempt to share resources in the development of common sensors so as to evolve toward a global set of consistent meteorological observations as required for weather and climate applications.

STATUS OF PC TOVS

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water vapor. The "linearized" form of the radiative transfer equation separates the overlapping influences of temperature and water vapor on the measured radiances thereby enabling their determination without iteration.

It was also shown from an example of retrievals over Antarctica that the TOVS sounding errors are primarily due to the lack of vertical resolution. Results were presented which showed that the vertical resolution and accuracy of the satellite soundings could be improved by a factor of two to three if the continuous spectrum throughout the intermediate infrared (3.5-17μm) could be measured with a spectral resolution ($\lambda/\Delta\lambda$) of 2000:1. This improvement has been demonstrated experimentally using radiance measurements from aircraft achieved with the High spectral resolution Interferometer Sounder (HIS). It was recommended that the ITOVS working group encourage programs to implement radiometers which achieve both high spectral resolution and quasi-continuous spectral sampling as soon as practically possible.

PRELIMINARY RESULTS FROM USING NON-LINEAR OPTIMAL ESTIMATION RETRIEVALS IN THE CANADIAN REGIONAL ANALYSIS SYSTEM

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We have carried out non-linear optimal estimation retrievals for several TOVS passes over eastern North America and the western Atlantic following the approach developed by Eyre. The background fields were six-hour forecasts produced by the Canadian hemispheric spectral model. Regional analyses on a 100 km grid were performed using the TOVS retrievals only. the TOVS-only analysis increments (i.e., analysis minus trial field differences) were compared to analysis increments based on conventional data. Although the TOVS-only analyses did not account for the error characteristics particular to the retrievals, they did provide an indication of the changes the retrievals could make to the trial field. The retrieval scheme differed slightly from Eyre's in that first order B-splines with the knots at the analysis levels were used as a basis for the

temperature and water vapor profiles, and that relative humidity was used as the water vapor variable.

The TOVS-only temperature analysis increments were generally larger near the surface (i.e., below 700 mb) than further aloft. There was qualitative agreement between the low-level temperature analysis increment patterns obtained from TOVS data and those obtained from conventional data. In the mid-troposphere, the TOVS analysis increments were considerably smaller than the conventional data analysis increments and (as one would expect) showed little vertical structure. The TOVS-only water vapor analysis increments were fairly large above 700 mb and showed considerable horizontal structure. Some of that structure could be related to meteorological features seen in AVHRR imagery. In particular, the retrievals showed drying (relative to the trial field) behind two frontal cloud bands, and moistening in an occluded low.

THE TMS RETRIEVAL ALGORITHM

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The TMS retrieval algorithm is a physical inversion operator that utilizes pattern recognition in both the *a priori* and radiance measurement domains to select appropriate retrieval constraints. The software which implements the TMS concepts is compatible with the International TOVS Processing Package (ITPP).

This paper highlights some practical considerations relating to the implementation of the TMS algorithm, and explains how an air mass dependent, radiative transfer equation "error" scheme is incorporated.

The TMS retrieval estimator is applied to the ITSC case study data set for the June 7, 1989 Whit-Sunday severe weather event over southwestern France. Geopotential height, thickness, temperature and precipitable water fields are presented, together with retrieved cloud height and TMS determined "probability of good retrieval" fields. The results capture a number of the expected features of a storm event of this type.

THE RESEARCH PROCESSING OF TOVS DATA IN THE HYDROMETEOROLOGICAL CENTRE OF THE USSR

A. B. Uspenski, V. I. Solovjev, Ju. V. Plokhenko, and V. E. Tret'jakov

retrieving atmospheric profiles from TOVS measurements can perform significantly sub-optimally if the error characteristics of the measurements are not specified accurately. For example, retrievals using a forecast background constraint could be degraded so that they became less accurate than the background when the measurement errors where assumed to be uncorrelated. Similar effects are obtained when the background errors are erroneously modelled. Measurement error covariances from the U.K. Meteorological Office's Local Area Sounding System (LASS) are currently obtained by assuming that brightness temperatures calculated from collocated radiosondes are "correct" and any deviation of the measured value is the error in the measurement. Using such covariances improved the performance of LASS significantly, but we suspect there are further gains to be made. Certainly, the covariances estimated in such a way will contain significant contributions from collocation errors and from errors in the sonde, both actual and due to different sampling characteristics.

The method developed attempts to parameterize the various contributions, and using optimal estimation techniques, remove "unwanted" components of the collocation derived covariances.

CALIBRATION

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Further evaluation of HIRS data in the Arctic and Antarctic has confirmed that calibration accuracy can be improved by use of the cold blackbody instead of space in very cold, dry conditions. This mode will be incorporated as an option in the HIRS calibration module of the ITPP.

PROCESSING AND INTERPRETATION OF TOVS DATA AT THE INSTITUTE OF PHYSICS OF THE ATMOSPHERE, CZECHOSLOVAKIA ACADEMY OF SCIENCE (IPA)

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The AVHRR data have been received in Czechoslovakia since 1979 and the TOVS data experimentally since 1985, daily since 1988. Both of these data are processed and evaluated at IPA for modelling of atmospheric phenomena and for numerical weather prediction.

For processing TOVS data, we use the statistical method completed at the Meteorological Service of CDR. We use them in refinement of the objective analysis of temperature, heights of geopotential levels, and several cloud characteristics together with the SYNOPT, TEMP, and AVHRR data. The AVHRR data are processed in surrounding of all grid points; picture window of 16x16 or 8x8 pixels are used for pattern recognition. Several cloud characteristics are then derived, which are transferred to relative humidities and analyzed.

Not very large sets of data were used, but evidently, the quality of TOVS products was not satisfactory. On the one hand, at present we started first experiments with the TOVS program package prepared at the Gidrometcenter, Moscow, and on the other hand, we would appreciate to continue our work also with the TOVS-PC program package, because of the installation of PC-AT local area network in our Institute.

RECENT TOVS STUDIES AND APPLICATIONS

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At present time, three meteorological satellite ground stations (Beijing,

TOVS DATA RESEARCH AND APPLICATION

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The research on satellite sounding theoretically was started in the early 1970s at the Institute of Atmospheric Physics and the study on TOVS data was begun in the 1980s. ITPP and the PC TOVS package have greatly helped the Chinese users in the research institutions as well as the operational meteorological organizations. Current and future application are going to be concentrated on the impact study to the different scale of numerical models. The importance of TOVS data on the ocean and plateau region has been recognized. The careful study and comparison must be conducted before any certain conclusion can be drawn.

APPENDIX A. AGENDA FOR THE ITSC-V

FIFTH INTERNATIONAL TOVS STUDY CONFERENCE
TOULOUSE, FRANCE
24-28 JULY 1989

Monday, 24 July (at CNRM, Toulouse)

0800 - 0900 am	Registration
0900 - 0920 am	Welcome and Opening Remarks (Pastre)
0920 - 0930 am	Review of Agenda (Menzel)
0930 - 0945 am	Summary of ITSC-IV (Chedin)
0945 - 1030 am	Discussion of Immediate Goals of ITOVS Working Group (Chedin, Menzel, Giraytys)
1030 - 1100 am	Coffee Break
1100 - 1230 pm	Presentation of New Case Studies Northern Hemisphere (Prangsma) Southern Hemisphere (LeMarshall)
1230 - 0200 pm	Lunch
0200 - 0530 pm	Presentation of Participants (chaired by Menzel)
	LeMarshall (invited) "TOVS at the BMRC"
	Svensson (invited) "Evaluation of TOVS Products"
	Kim "Introduction of TOVS Processing in Korea"
Coffee break around 0330 pm	**Zhang** (invited) "Recent TOVS Studies and Applications in China"
	Prangsma (invited) "TOVS Processing at KNMI"
	Sipos "Towards Operational Use of TOVS in Hungary"
	Ferreira "TIROS-N/NOAA Reception in Brazil: Progress and Plans"
	Lynch (invited) "A PC-based ITPP-3 Synthetic Retrieval Package"
	Uddstrom (invited) "TMS Retrieval Scheme Applied to the Two ITSC

of High Resolution TOVS

Kelly (invited)
"Experiment with Various TOVS Retrieval Methods and Quality Control at ECMWF"

Coffee Break around 1030 am

Pailleux (invited)
"General Use and Impact of TOVS Data on Global Modelling (Including Variational Analysis)"

Juvanon du Vachat
"TOVS Data Impact Studies on the Peridot NWP System on the 7 June 1987 Case"

Zhou (invited)
"TOVS Data Research and Application"

Steenbergen (invited)
"Preliminary Results from Using Non-linear Optimal Estimation Retrievals in the Canadian Regional Analysis System"

1230 - 0130 pm — Lunch

0130 - 0500 pm — Presentation of Participants (chaired by Rizzi)

Menzel (invited)
"Global Cloud Studies Using TOVS"

Richardson
"The Application of the ITPP for Use in Real Time Cloud Analysis and Nowcasting at Sea"

Heinemann (invited)
"On the Use of TOVS Data for Studies of Mesoscale Cyclones in the Weddel Sea"

Lachlan-Cope (invited)
"The Use of TOVS Data in the Antarctic"

Lutz
"TOVS Over Antarctica - Winter Case Studies"

Scott (invited)
"Recent Improvements in the 3I System"

Prata
"Temperature and H_2O Vapor Retrievals Using TOVS, AVHRR, and Simulated ATSR Radiances"

Bates (invited)
"Experiences with ITPP and 3I Retrievals over the Ocean"

Lavanant (invited)
"AVHRR-HIRS Coupling"

Takagi
"Interpolation of HIRS Data Using AVHRR"
Ligi
"An Intercomparison of Temperature and Geopotential Fields over Europe Derived from TOVS and Conventional Data"
Zacharov
"Processing and Interpretation of TOVS Data"
McNally
"Optimal Estimation of Inversion Parameters"

Wednesday, 26 July 1989

0900 - 1230 pm — Status Reports on Previous Action Items (chaired by Rochard (each speaker has up to ten minutes)

SCIENCE
- HIRS Calibration (Woolf, Rochard)
- Limb Correction (Eyre)
- ITRA (Chedin)
- BUAN (Giraytys)
- AMSU (Woolf, Eyre)
- AMRIR (Menzel)
- DMSP (Rochard)

SOFTWARE
- 3I/ITPP-3 Documentation and Maintenance (Scott, Woolf)
- PC/TOVS Status and Future (Smith)
- ATOVS (AMSU+HIRS/3) Status (Eyre)

APPLICATIONS
- Case Studies - Data to be Provided (LeMarshall, Woolf, Rochard, Kelly)
- Synoptic Use of TOVS Analyses (Prangsma)
- Numerical Weather Prediction: Impact of TOVS (Kelly)
- NESDIS Forward Model (Eyre, Woolf)
- BUAN: Details and Description Sent to Major Centers (LeMarshall); Quality Control (Kelly); Coordination with WMO (LeMarshall)

1230 - 0200 pm — Lunch

0200 - 0300 pm — Status Reports - Continued (chaired by Smith)

Rizzi (invited)
"Autoregressive Spectral Estimate in Fourier Spectroscopy Applied to Remote Sensing of the Atmosphere"

Chedin (invited)
"Scenario for an Optimal Use of Satellite Retrievals"

Perrone (invited)
"Plans at EUMETSAT"

1130 - 1230 pm — Poster Presentations (authors M-Z)

1230 - 0200 pm — Lunch

0200 - 0530 pm — Working Group Meetings

Friday, 28 July 1989

0900 - 1130 am — Working Group Reports (chaired by Eyre)

1130 - 0100 pm — Discussion of Recommendations (chaired by Giraytys)

Executive Summary, Future Plans (Chedin, Menzel)

0100 pm — Adjournment

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