

**A REPORT ON
THE NINTH INTERNATIONAL TOVS STUDY CONFERENCE**

Igls, Austria

20-26 February 1997

sponsored by

EUMETSAT

World Meteorological Organisation

City of Innsbruck and Province of Tyrol

European Centre for Medium-range Weather Forecasts

prepared by J R Eyre and M J Uddstrom

April 1997

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By Anon

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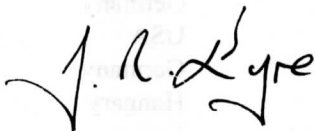
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FOREWORD

The International TOVS Working Group (ITWG) is convened as a sub-group of the Radiation Commission of the International Association of Meteorology and Atmospheric Physics (IAMAP). ITWG continues to organise International TOVS Study Conferences (ITSCs) which have met every 18-24 months since 1983. Through this forum, operational and research users of TIROS Operational Vertical Sounder (TOVS) data from the NOAA series of polar orbiting satellites have exchanged information on methods for extracting information from TOVS data on the atmospheric temperature/moisture field and on the impact of these data in numerical weather prediction and in climate studies. They have also prepared recommendations to guide the directions of future research and to influence relevant programmes of WMO and other agencies.

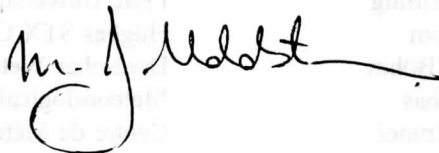
Our ninth conference, ITSC-IX, was held in Igls, Austria, from 20-26 February 1997. This "Report on ITSC-IX" summarizes the scientific exchanges and outcomes of the meeting. A companion document entitled "The Technical Proceedings of ITSC-IX" will contain the complete text of the scientific presentations. These documents reflect the conduct of a highly successful meeting in Igls; an active and mature community of TOVS data users now exists, and considerable progress and positive results were reported in a number of areas.

ITSC-IX was sponsored by the City of Innsbruck and the Province of Tyrol, EUMETSAT, WMO and ECMWF. Their support and assistance is gratefully acknowledged. We thank the staff of the Kongresszentrum, Igls, for their assistance during the conference. We also acknowledge the contribution of the ECMWF staff who assisted with the preparation and publication of this report.



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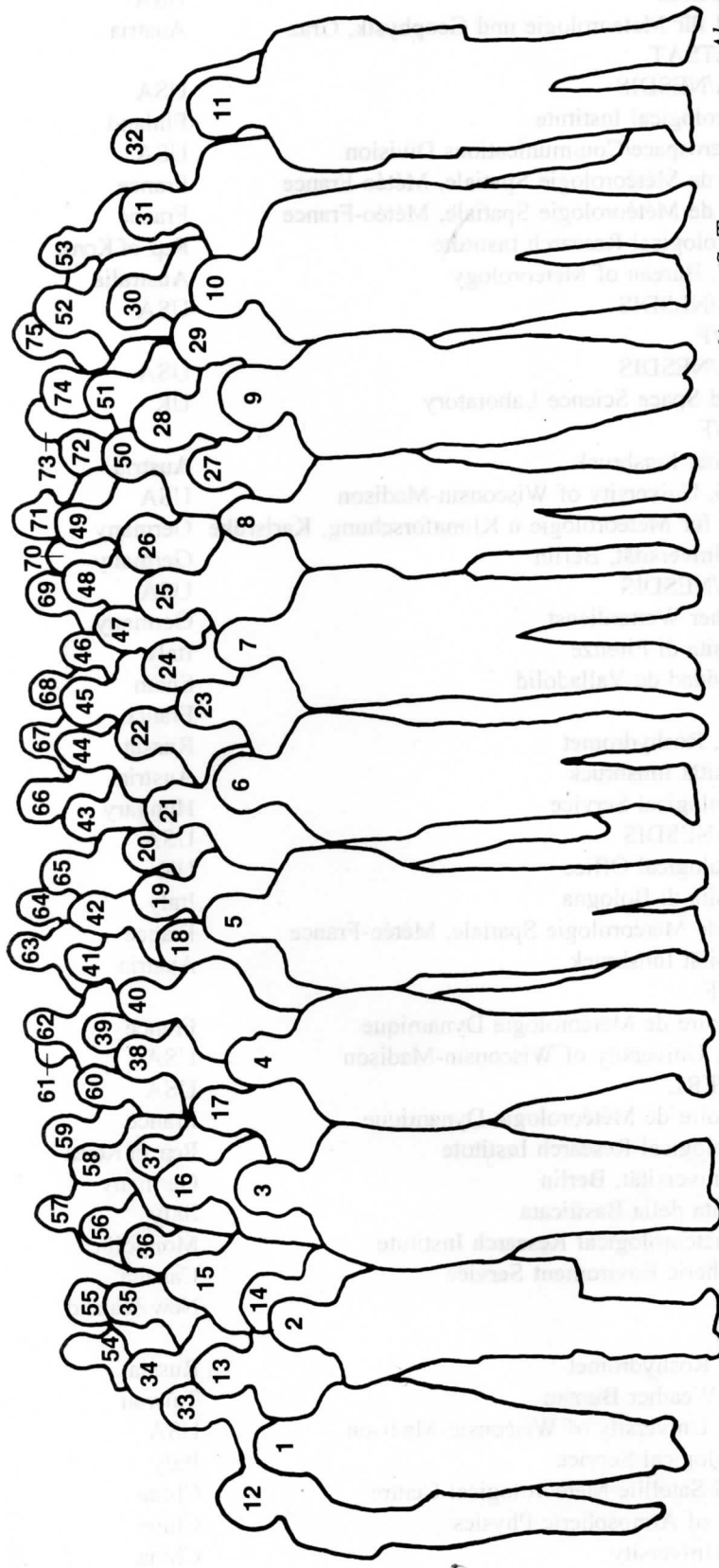
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1. EXECUTIVE SUMMARY

1.1 INTRODUCTION

The Ninth International TOVS Study Conference, ITSC-IX, was held in Igls, Austria, 20-26 February 1997. 84 participants attended the meeting and provided scientific contributions. 19 countries and 3 international organisations were represented: Australia, Austria, Canada, China, Czech Republic, Finland, France, Germany, Hungary, Italy, Kenya, Republic of Korea, Mongolia, New Zealand, Russia, Spain, Taiwan, United Kingdom, United States of America, ECMWF, EUMETSAT and WMO.

The agenda for ITSC-IX can be found at Appendix A. Most of the meeting was occupied with scientific presentations on a range of issues including: the application of TOVS data in numerical weather prediction and climate studies, preparations for Advanced TOVS (ATOVS) data and for data from advanced infra-red sounders, and relevant plans of operational satellite agencies. Section 4 of this report records the abstracts of all the scientific contributions. The corresponding papers are published separately in the "Technical Proceedings of the Ninth International TOVS Study Conference" available through the co-chairs of the International TOVS Working Group (ITWG).

At ITSC-IX, Working Groups were formed to consider five of the main issues identified prior to the conference: TOVS data in numerical weather prediction, TOVS data in climate studies, preparations for Advanced TOVS (ATOVS) data, advanced infra-red sounders, and international issues and future systems. The Working Groups reviewed recent progress in these areas, made recommendations on key areas of concern and identified items for action. The reports of these Working Groups are given in Section 2. During the conference, a session on Status Reports considered summaries of relevant meetings and activities that had taken place since ITSC-VIII and reviewed progress on the action items identified by the ITSC-VIII Working Groups. Many of these issues formed the basis for further discussion by the Working Groups at ITSC-IX.

During one session, the conference divided into three Technical Sub-Groups to discuss developments and plans concerning specific software packages in common use among TOVS processing centres. Brief reports on the sub-group meetings are recorded in Section 3.

1.2 CONCLUSIONS AND RECOMMENDATIONS

As a result of the activities of the Working Groups and their reports to the conference, the following conclusions and recommendations were adopted as a summary of the main findings of ITWG at ITSC-IX. More details and specific technical recommendations and actions are given in the Working Groups' full reports in Section 2.

1.2.1 TOVS data in numerical weather prediction (NWP)

1.2.1.1 ITWG noted the substantial progress that had recently been made at several centres on the application of TOVS data in NWP. Direct use of radiance data had advanced considerably; positive forecast impacts were reported in all latitude zones, with substantial improvements in the tropics. Improvements in forecast impact through assimilation of NESDIS retrievals were also reported.

1.2.1.2 ITWG plans to prepare and maintain a comprehensive list to document the use of TOVS data at operational NWP centres, including the form of the data used (e.g.

retrievals, clear radiances, raw radiances).

- 1.2.1.3 Inaccuracies in radiative transfer modelling are still significant sources of error affecting the use of TOVS data in NWP; radiative transfer models must be improved. ITWG recommended that major NWP centres and NESDIS co-operate on the evaluation and improvement of fast radiative transfer models. These activities should be co-ordinated with the plans of ITRA.
 - 1.2.1.4 Noting the potential impact on NWP of data from advanced infra-red sounders, ITWG recommended that NESDIS and major NWP centres investigate how AIRS data/products might be distributed in near real-time.
 - 1.2.1.5 ITWG encourages the use of Observing System Simulation Experiments (OSSEs) as a contribution to evaluating the expected impact on NWP of future sounding systems.
 - 1.2.1.6 A growing number of institutions is interested in the use of TOVS data in NWP. New users need access to basic information on TOVS instruments and data and on effective assimilation methods.
- 1.2.2 TOVS data in climate studies
- 1.2.2.1 TOVS data are now widely used in climate studies. Time series of radiance data are being employed to investigate tropospheric temperature and water vapour variability and trends. Extensive use has also been made of TOVS data in re-analysis projects at ECMWF and NCEP, where they have been shown to contribute significant information. TOVS data are also being used to validate general circulation models.
 - 1.2.2.2 Studies of ECMWF re-analysis products demonstrate that the accuracy of these products is dependent upon the volume of data available from the polar systems. Analysis errors are lower for those periods when data from two satellites are available. Similar conclusions can be drawn from studies at NOAA/ERL.
 - 1.2.2.3 Climate studies will benefit from easy access to TOVS Level 1B data. ITWG encourages NESDIS to continue efforts to make these data available via the Satellite Active Archive (SAA) in a timely manner, at reasonable cost, on high density media.
 - 1.2.2.4 It is recognised that advances in processing TOVS data beyond Level 1B have led to improvements in the characteristics of subsequent products. ITWG recommended that re-analysis centres consider the use of Level 1B data in future re-analysis projects.
 - 1.2.2.5 Concerning the interpretation of satellite data from different spacecraft, ITWG recognised the great importance of maintaining satellite-radiosonde collocation data archives. It is recommended that these be developed further, especially in regard to establishing a full audit-trail for all data on these archives. To aid understanding of inter-satellite biases, and their effect upon climate observations, ITWG further recommended that there be a substantial overlap period of data processing after the launch of each new satellite, and that collocation archives for both satellites be maintained during these periods.
 - 1.2.2.6 With further regard to the problem of inter-satellite data calibration, ITWG

- recommended that satellite agencies provide improved characterisation of total system spectral responses.
- 1.2.2.7 Future re-analysis projects are likely to require access to SSU and VTPR data. ITWG recommended that the calibration data and processing procedures, including software, for these instruments be fully preserved and documented.
- 1.2.3 Preparations for Advanced TOVS (ATOVS) Data
- 1.2.3.1 ITWG reviewed ATOVS processing systems being developed at NESDIS, at CIMSS and in Europe, and was encouraged by the significant progress that had been made since ITSC-VIII. In particular the development of the AAPP (ATOVS and AVHRR Processing Package) package is of great interest to ITWG members.
- 1.2.3.2 Recognising the flexible design of the AAPP, ITWG recommended that all software developers conform to the AAPP common software framework, code interfaces and file formats, as far as is possible.
- 1.2.3.3 To ensure early and effective use of ATOVS data after the launch of NOAA-K, a detailed short-term action plan was developed to enable collaborative interchange of the information on instruments, software and file formats.
- 1.2.3.4 To facilitate radiance tuning for ATOVS, there is a requirement for continuing access to a well defined archive of collocated radiosonde and satellite data. In this regard, ITWG would welcome the opportunity to review and comment on NESDIS plans for development of a Match Data Base.
- 1.2.3.5 Recognising the higher spatial resolution of ATOVS data products, compared to TOVS, global- and regional-scale users are recommended to advise NESDIS of their requirements for ATOVS data/products.
- 1.2.3.6 Given the impending launch of NOAA-K, and the new scientific opportunities arising from ATOVS data, ITWG will define some ATOVS case studies for presentation at ITSC-X.
- 1.2.4 Advanced sounders
- 1.2.4.1 Noting the significant increase in cloud-free soundings expected from the 10 km field-of-view on HIRS/4, ITWG recommended that NESDIS consider early flight of HIRS/4 on NOAA-L or NOAA-M.
- 1.2.4.2 ITWG expressed concern that advanced infra-red sounders are planned to be operational on only one satellite during the period 2002-2009. It recommended that operational agencies consider how these plans might be improved towards providing sooner comparable advanced sounding capability in both morning and afternoon orbits. In particular, it recommended that NESDIS consider upgrading HIRS to provide advanced sounding capability on NOAA satellites from 2002.
- 1.2.4.3 ITWG noted and supported the plans of the Integrated Program Office (IPO) in the

- USA to study the relative merits of cross-track and conical scanning for future sounders.
- 1.2.4.4 Recognising the ability of new data assimilation methods to take advantage of observations at high temporal resolution, ITWG recommended to CGMS that satellite operators consider the implementation of advanced sounders on future geostationary satellites.
- 1.2.4.5 ITWG recommended that ITRA consider organising a comparison exercise in support of advanced infra-red sounders, including line-by-line radiative transfer models, fast radiative transfer models and collocated field measurements.
- 1.2.4.6 ITWG recommended to the International Radiation Commission (IRC) that the scope of ITWG be revised to cover all passive sounders on operational polar and geostationary satellites.
- 1.2.5 International Issues and Future Systems
- 1.2.5.1 At ITSC-IX, operational satellite agencies presented their plans for passive sounding systems. ITWG found these presentations, and the subsequent discussion, very valuable and encouraged the continuation of such presentations at future conferences.
- 1.2.5.2 ITWG recommended to CGMS that satellite operators consider how their future plans might best be co-ordinated in order to improve the effectiveness of their satellites in meeting international requirements when considered as one global system.
- 1.2.5.3 ITWG noted with interest the USA's planned activities aimed at defining the payload and processing systems for the National Polar-Orbiting Environmental Satellite System (NPOESS) and indicated its readiness to participate in the activities of the NPOESS Sounding Operational Algorithm Team (SOAT) upon invitation.
- 1.2.5.4 ITWG members expressed interest in access to direct read-out data from AIRS and MODIS on EOS satellites and suggested that information on plans for direct read-out of these data and associated calibration/validation activities be distributed more widely.
- 1.2.5.5 Concerning the allocation and protection of microwave frequencies used for passive remote sensing, ITWG appreciated the excellent work recently undertaken in this area but noted the lack of adequate resources for its continuation. ITWG:
- recommended that WMO consider promoting well-resourced activities through international bodies, as appropriate,
 - strongly supported the protection of frequency bands planned for use by operational instruments over the next 20 years, and
 - recommended to satellite operators that instruments should be designed to use only frequencies in protected bands.
- 1.2.5.6 Concerning workstations for satellite data acquisition and processing, ITWG noted and supported the plans of WMO and CGMS to facilitate the acquisition of workstations for developing countries.

- 1.2.5.7 Concerning education and training (E+T) on the use of satellite data, ITWG welcomed the present efforts of CGMS members in this area and reconfirmed ITWG's commitment to assist through provision of expertise on sounding data, with increased emphasis on E+T techniques that make use of new computer media and networks.

1.3 FUTURE PLANS

At ITSC-VII, ITWG endorsed a strategy document entitled "ITWG: a strategy for the 1990s". At ITSC-IX, ITWG reviewed progress against this plan and confirmed that the general direction and balance of activities should continue, with emphasis on:

- improvements in the exploitation of TOVS data in the key applications of NWP and climate studies,
- preparation for effective use of data from new sounding systems: ATOVS and advanced infra-red sounders,
- liaison with appropriate bodies, including IRC, WMO and CGMS.

ITWG also suggested that increased consideration be given at future conferences to:

- scientific issues relevant to ATOVS data processing, including appropriate case studies,
- new opportunities for use of ATOVS data in synoptic meteorology and tropical analyses,
- the overlap between TOVS and ATOVS data, as it affects climate studies,
- data from geostationary sounders, and
- planning for future sounding systems, including those on NPOESS.

At ITSC-IX, the current co-chairs completed their terms of office, and nominations were obtained for new co-chairs. Following ITSC-IX, a postal election within the ITWG membership was conducted, and Mr Guy Rochard (France) and Dr John Le Marshall (Australia) were elected as the new co-chairs of ITWG.

The next meeting of ITWG will be at ITSC-X, probably in early 1999. In the interim, ITWG will seek to make progress on many issues identified by the working groups at ITSC-IX; details of the actions items are given in the working group reports. The activities of ITWG will be reported to IRC, CGMS and WMO at relevant meetings by its co-chairs and rapporteurs, as appropriate.

2. WORKING GROUP REPORTS

2.1 TOVS DATA IN NUMERICAL WEATHER PREDICTION

C Chouinard (chair), with T Böhm, J Derber, P Dibben, S English, B Harris, J Joiner, G Kelly, D Kim, T Kleespies, A McNally, P F Pellegrini, R Randriamampianina, T Reale, R Renshaw and N Tsengel.

2.1.1 Introduction

There had been substantial progress in the assimilation of TOVS data at NWP centres. Direct use of radiance data had advanced considerably; positive impact on forecasts were reported at all latitude zones with substantial improvements in the Tropics. In particular the Working Group noted significant improvements in tropical wind circulations and moisture analyses reported by ECMWF and NCEP in their 3DVAR analysis systems. In the extra-tropics, the improvements were most significant in the Southern Hemisphere with relatively minor improvements in the Northern Hemisphere. Improvements of forecasts through assimilation of NESDIS and 1DVAR retrievals were also reported.

There were still serious problems concerning the direct assimilation of radiances. It was noted by various groups that large systematic errors in some TOVS channels indicated that radiative transfer (RT) models used in data assimilation must be improved. Quality control and daily monitoring of errors in each channel remained very important components of a successful data assimilation system.

2.1.2 Evaluation and use of TOVS data

At ITSC-VIII, it was agreed that members of the Working Group would exchange information on biases and correction procedures in order to seek an acceptable solution to bias reductions and to get a better estimate of the errors associated with cloud-cleared radiances. The exchange of such information is a long process and it was particularly tedious to initiate. During the year prior to ITSC-IX, a dataset had been prepared and distributed to interested members of the Working Group. Bias and standard deviation error estimates had already been collected from four of the participating centres, assembled in a common format and ported to an Internet site, so that each centre could view and compare its results with those of others very efficiently.

The Working Group proposed to pursue this activity at least until ITSC-X and to encourage more groups to participate in this exchange so as to gain more experience with the use of TOVS data. **(Action: C Chouinard to co-ordinate)**

The specification of 3D error covariance structures is a very critical component of a variational data assimilation system. At ITSC-VIII, it was agreed to exchange information on background error structures. Some centres had already exchanged background error statistics and the Working Group encouraged others to do so on a bilateral basis.

The Working Group recognized that TOVS data are being used at a growing number of research institutes and operational NWP centres. Some use radiance data whilst others use retrievals, and yet others use a combination of both. The community is growing fast, and it is becoming difficult to manage the distribution of RT code updates and to advise users of problems with data.

The Working Group plans to prepare and maintain a comprehensive list in order to document the use of TOVS data at research institutes and operational NWP centres, including the form of the data used (e.g. retrievals, clear radiances, raw radiances). (**Action: A McNally to co-ordinate**)

A number of NWP centres and research institutes represented at this ITSC for the first time expressed an interest in assimilating retrieval or radiance data. It was noted that there is a lack of generally available information on how to access and assimilate TOVS data, either in radiance or retrieval form.

The group recommended that a number of publications describing the TOVS sounding instruments, the preparation of TOVS data and their use in a data assimilation system be compiled and distributed to new users. (**Action: C Chouinard to co-ordinate**).

There were a number of presentations at ITSC-IX describing successful cloud detection algorithms. Cloud detection is not to be confused with cloud-clearing; it is a necessary step in the preparation of cloud-cleared radiances. There was no consensus among the Working Group on how to proceed in the preparation of cloud-cleared radiances and which of the many available cloud-detection algorithms to use. The Working Group recognized that the sounders such as HIRS/4, with smaller fields-of-view (fovs), will effectively double the number of clear fovs, making cloud-clearing less of an issue. In the meantime, cloud-clearing remains a rather complex procedure which it appears NESDIS has mastered well and to which the only alternative is the assimilation of cloudy/slant-path radiances.

2.1.3 Forward modelling

The Working Group encouraged the sharing of software of general utility, particularly RT code such as RTATOV or similar packages. In this context, updates to RTATOV transmittance coefficient files should be made available to all users and shared as quickly as possible, particularly when updates address known problems.

The Working Group recommended that the transmittance coefficient files of RTATOV be made available to RTATOV users on request. To facilitate this, it was agreed to maintain an email list of RTATOV users and to use it to advise of changes in the coefficient files and/or source code with minimum delay. (**Action: R Saunders to co-ordinate**).

The Working Group recognized that there were still serious problems remaining in the assimilation of TOVS radiances. The RT models were still problematic and produced unacceptably large biases in some channels, such as HIRS channel 15. In cold atmospheres near the poles, MSU channel 2, which "sees" the surface to a significant extent, has an effective surface emissivity less than the value of unity which is commonly assumed. Since this channel is used in most bias correction schemes, an effective surface emissivity should be parameterized to account for surface properties and to avoid propagating errors to other channels. RT models for the water vapour channels currently contain significant biases that are very difficult to reduce with current bias correction procedures. The inclusion of OPTRAN into RTATOV shows improved forward modelling accuracy in the water vapour channels, including a reduction of scan-dependent biases.

Recommendation: The Working Group recommended that major NWP centres and NESDIS cooperate on the evaluation and improvement of fast radiative transfer models. These activities should be co-ordinated with plans of ITRA.

2.1.4 Future platforms and access to real-time data.

There was at least one presentation at ITSC-IX on the use of Level 1b TOVS data. The Working Group was concerned about the availability of these data, both for research purposes or for real-time processing. It discussed related problems: how should these data be prepared by NESDIS so as to ensure investigators are not required to undertake routine tasks in which they are not experienced (i.e. calibration and navigation), how much processing would this imply at NESDIS, and how might this large volume of data be distributed on the GTS.

The Working Group was also concerned that, in a relatively short time, there will be an abundance of new data from such instruments as AIRS and IASI, and yet there had been little scientific work undertaken on its assimilation within ITWG.

Recognizing that some studies had taken place in other fora, the Working Group proposed that development should start within ITWG as soon as possible, so as to be ready when data from these new instruments become available. This would enable early validation of RT models, products and processing procedures.

Recommendation: The Working Group recommended that NESDIS and major NWP centres investigate how AIRS data/products might be distributed in near real-time.

Most NWP centres that have data assimilation systems have the capability to undertake Observing Systems Simulation Experiment (OSSEs). The Working Group encouraged such experiments to provide feedback to instrument designers and to obtain assessments of likely impact before launch. Whilst recognizing that OSSE results are imperfect, they are the best mechanism currently available to provide useful information on the relative impact of new instruments.

Recommendation: The Working Group encouraged the use of OSSEs as a contribution to evaluating the expected impact on NWP of future sounding systems.

2.2 TOVS DATA IN CLIMATE STUDIES

J Bates (chair), with H Billing, F Chevallier, M Goldberg, A Kaifel, P Menzel, N Scott, C Stubenrauch and S Uppala.

2.2.1 Unique contributions of TOVS data to climate studies

2.2.1.1 Temperature

MSU deep layer mean temperature data are routinely used in monitoring global temperature trends. Originally, this was done using each scan spot of MSU channel 2 data. More recently, in order to eliminate the contribution of the stratosphere and increase the contribution of the lower troposphere, a retrieval scheme using MSU channel 2 data at different scan spots has been implemented (referred to as MSU2R). These MSU2R data have been used to study the magnitude and evolution of lower troposphere temperature anomalies following the eruption of Mt. Pinatubo in 1991. These data were also used as validation data for GCM simulations of the cooling effect of the stratospheric aerosol cloud from the eruption on climate. The global MSU2R data show a much smaller temperature trend in the last 17 years than do data from in situ temperature surface observations. This has led to considerable controversy over the true magnitude of the global warming signal for the recent past. Both the satellite and in situ records have many uncertainties, and one of the most controversial aspects of the MSU2R record is the procedure used for inter-satellite calibration.

2.2.1.2 Water vapour

The use of the HIRS water vapour channel data, particularly data from the upper tropospheric water vapour channel (HIRS-12), for climate monitoring and diagnosis has increased greatly in the past few years. Process studies using HIRS-12 suggest these data may be useful for prediction of early or late onset of the southeast Asian summer monsoon. In the context of global change studies, it has been suggested that the upper tropospheric water vapour feedback may be quite different from the lower troposphere water vapour feedback. HIRS-12 data have been used in several studies of the upper tropospheric water vapour feedback, but these studies have not reached a consensus. HIRS-12 data have also been used to validate GCM simulations including the Atmospheric Model Intercomparison Project (AMIP). Comparisons with models of the early 1990s showed considerable discrepancies between the observations and simulations, but comparisons with more recent models appear much better. The use of water vapour information derived from HIRS radiances has also been shown to have a dramatic effect on the climatology of water vapour fields provided by re-analysis projects (see section 2.2).

2.2.1.3 Ozone

The advantage of the TOVS data for ozone retrieval, compared to other satellite instruments (e.g. TOMS, SBUV and GOME) which use solar radiation, is that ozone can be retrieved during the night. This is particularly important in polar regions during polar night. Recent studies have shown that it is possible to retrieve ozone from TOVS data with an r.m.s. error of about 10 Dobson Units for all weather conditions (clear/cloudy, day/night). This retrieval scheme, based on neural networks, will be applied within the next 2 years to a long-term global TOVS data (1990-1996) in order to produce a consistent, accurate data set for ozone.

2.2.1.4 Cloud and radiation studies

The TOVS multi-spectral infra-red data have been used to examine global transmissive cirrus clouds day and night for the past eight years, during which the occurrence of cirrus has increased by roughly 10%. Extension of the cirrus climatology to roughly 20 years total is anticipated within the TOVS Pathfinder reprocessing; this will facilitate investigation of the cirrus trends and their physical causes.

Further studies on the effect of heterogeneity and multi-layer clouds on the retrieval of TOVS cloud parameters are under investigation, again in combination with space-time collocated ISCCP cloud products. Ice/water phase and ice cloud particle sizes can be extracted from TOVS, during the period when the 8.2 μm channel is available (until NOAA-12). Vertical fluxes from top of the atmosphere to surface have also been estimated from TOVS data. Validation continues in comparison to ERBE and ECMWF re-analysis fluxes.

Recommendation (to NOAA/NESDIS): The Working Group encouraged NOAA/NESDIS to continue its efforts to make TOVS Level 1B data available, via the Satellite Active Archive (SAA), at low cost on efficient mass storage media.

Recommendation (to CGMS): The Working Group recommended that satellite operators take all reasonable steps to ensure that a two-satellite constellation of polar-orbiting satellites is maintained, including overlap periods between successive operational satellites (i.e. a minimum of 6 months).

2.2.2 TOVS pathfinders

The TOVS pathfinder project was organized into three paths each utilizing, or not, a priori information. Path A is a priori model dependent and a priori data dependent, Path B is model independent and a priori data dependent, and Path C is both model and a priori data independent. These retrieval pathfinders produced retrievals for a 2-year period and underwent extensive evaluation. As a result of this evaluation, Path B was chosen as the primary high vertical resolution TOVS pathfinder, although some work on Path A will continue within the context of the GSFC DAO re-analysis.

The TOVS pathfinder Path B, using the LMD 3I method, has undergone significant improvements as part of this pathfinder process. The TIGR-2 database has been expanded in the tropics to include a much wider range of water vapour amounts. Cloud detection, especially stratus over the oceans, has been improved as well as the water vapour retrieval. Most importantly, a method for inter-satellite calibration has been implemented using matches between radiosondes and TOVS observations. Processing of the entire TOVS 1B data set will proceed in the near future. A TOVS pathfinder Path B polar, using a modified version of 3I in the Arctic region only, will continue in a research mode.

TOVS pathfinder Path C and Path radiance are also continuing in research mode. These TOVS pathfinder paths are independent of model constraints and a priori data and are concentrating on retrieval of deep-layer mean temperature and water vapour and the fundamental properties of the TOVS radiances. Path C1 uses only MSU data to derive deep-layer mean temperature products, such as the MSU2 and MSU2R products described above. The TOVS radiance pathfinder is focusing on inter-satellite calibration, on a cloud-cleared radiance data set, and on cloud, water vapour and ozone products. The Path C2 reprocessing effort is focusing on the generation of first guess independent products for long-term monitoring of climate and global change. These products will include cloud-cleared infra-red radiances, deep layer mean temperatures, a deep layer mean moisture, total ozone, and outgoing longwave radiation.

Recommendation: The Working Group recommended continued support of the NOAA/NASA TOVS pathfinders. It noted that, to have maximum use for climate studies, the pathfinders need to process and document the longest possible time series of TOVS data.

2.2.3 Use of TOVS data in re-analysis efforts

2.2.3.1 ECMWF re-analysis

ECMWF has completed the re-analysis of the period 1979-1993. TOVS data were used in the form of cloud-cleared radiances (CCRs) from the NESDIS operational processing. These radiances were bias-corrected globally using synthetic radiances computed from the ECMWF first guess 6-hour forecast. The mean bias calculated from the previous month's radiance departures, i.e. first guess minus cloud cleared radiances, was removed from the satellite data before the 1DVAR retrievals were derived. This ensured a bias-free set of radiances were used in the analysis. When a new satellite radiance data set was introduced into the analysis, the radiances were used passively for a period of 2-4 weeks in order to evaluate the initial biases, and only then the derived 1DVAR retrievals were used in the optimal interpolation. This ensured a smooth transition from satellite to satellite. The 1DVAR retrievals were used globally below 100 hPa; in the extra-tropical stratosphere, NESDIS retrievals were used. The operational CCR data contained some gaps in time, and these were filled during the data assimilation with TOVS level 1b data using the ITPP preprocessing software. A document describing the ECMWF re-analysis is under preparation.

The use of TOVS radiances, in place of retrievals, was found to have significant impacts on the climatology of the analyzed fields, particularly for water vapour at low latitudes, but also for the energetics of the southern hemisphere. It was also confirmed that analysis errors were lower during those periods when TOVS data were available from two satellites.

2.2.3.2 NCEP re-analysis

The NCEP re-analysis for the period 1973-1996 is complete and a quasi real-time climate data assimilation is continuing into the future. Satellite retrievals from the VTPR were used from 1975-1978 and operational NESDIS TOVS retrievals were used from 1979 to the present. An evaluation of the re-analysis system with and without satellite data found that the satellite data had significant positive impact on the quality of the analysis, especially in the southern hemisphere. Further comparisons of the impact of the NESDIS operational retrievals versus direct radiance assimilation within the climate data assimilation revealed considerable differences. Use of direct radiance assimilation produced a considerably larger positive impact than use of retrievals, and so is being considered for future re-analysis.

2.2.3.3 NASA DAO re-analysis

The mission of the NASA GSFC Data Assimilation Office (DAO) is to provide climate data sets for the Earth science community and to support NASA aircraft and shuttle missions, as well as the product generation and validation for NASA's Earth observing system (EOS). The first DAO re-analysis[, since its formation in 1992,] is called the Goddard Earth observing system-1 (GEOS-1). Currently, the DAO has produced a re-analysis beginning in 1980 and ending in February 1994, and will soon complete 1979 and the remainder of 1994. The system uses the NESDIS TOVS retrievals and

conventional data.

The new assimilation system, GEOS-2, uses a global solver called the physical-space statistical analysis system. GEOS-2 is currently undergoing validation and is being used for preliminary studies with NSCAT scatterometer data. Following validation, a re-analysis of the 1979 FGGE year with merged GLA-NESDIS TOVS retrievals will be performed. The GEOS-3 system, currently in the design phase, will allow the introduction of new data types including improved use of TOVS data. To support EOS instrument teams, a "first-look" analysis will run in 12-24 hours after data acquisition. Several months after data acquisition, a "final-platform" analysis will be run, which will include EOS and other non-operational data. At various times, a full multi-year re-analysis will be run. The DAO will also produce "pocket analyses" covering a limited time period with specialized input data to assess data impact. Off-line analysis will also be produced such as assimilation of constituent gases using a Kalman filter and wind data produced by the in-line analysis system.

Recommendation (to re-analysis centres): In order to take advantage of advances in the pre-processing of TOVS data (i.e. processing from Level 1B radiances to cloud-cleared radiances), the Working Group recommended the use of TOVS 1b data, either in variational radiance assimilation or retrieval schemes, in future re-analyses.

2.2.4 Long-term calibration and validation of TOVS data

Since 1979, the NOAA satellites have provided an invaluable archive of Earth observations which are now used in re-analyses, pathfinders and operational climate data assimilation. It is well recognized that the sensitivity and behaviour of the individual channels may evolve over the lifetime of the satellite and also differ from satellite to satellite. Both retrieval and assimilation methods make use of the difference between observed and computed radiances, either from a model short-term forecast or radiosondes, to adjust the observed radiances in the process of deriving geophysical parameters. Thus, it is necessary to evaluate carefully the empirical bias adjustments in order to ensure as much coherence and consistency as possible between the observations and the output of retrieval and assimilation systems.

The Working Group concluded that a number of complimentary techniques for calibration of satellite data sets be pursued. These techniques include vicarious calibration, long-term in situ calibration, and in-orbit satellite-to-satellite and aircraft-to-satellite calibration in a number of climatic regions.

Action (co-chairs, with J Bates): The Working Group requested that representatives from the TOVS instrument manufacturers be invited to make presentations at the next ITSC on the pre-launch calibration procedure used for past TOVS instruments.

Action (S Uppala, J Derber): The Working Group requested NCEP and ECMWF to make available time series of biases between corrected and uncorrected TOVS radiances from their operational NWP assimilation systems.

Action (J Bates, with M Uddstrom, L McMillin): The Working Group requested coordination of the structure of the NESDIS ATOVS radiosonde match data base (in coordination with the recommendation of the Working Group on Preparation for ATOVS data).

Recommendation (to CGMS): The Working Group recommended that satellite operators pursue the best possible characterization of the total system spectral response for sounding instruments.

2.2.5 Other issues

2.2.5.1 Use of VTPR data

Re-analysis projects have begun to make use of operational satellite sounder data from the pre-TOVS era. These data may also be useful for other climate analysis efforts. Fortunately, knowledge of instrument performance and processing are still available. However, we run the risk of losing this information unless a conscious effort is made to document the calibration and in-orbit performance of the VTPR instruments.

Recommendation (to NESDIS): The Working Group recommended improved documentation of the calibration and in-orbit performance of VTPR.

2.2.5.2 Use of SSU data

Although the use of SSU data in climate studies has not been as great as the use of the MSU and HIRS instruments, SSU data remain an important climate data set. The SSU will be discontinued in the AMSU era when the AMSU-A instrument replaces it. There is concern that, with this change, the information about processing SSU data may be lost.

Recommendation (to NESDIS and UK Met Office): The Working Group recommended that software for SSU be documented and preserved.

2.2.5.3 Observing system experiment climate impact studies

Impact studies on the use of satellite sounding data in NWP and also the re-analysis efforts have focused on the impact of satellite data for relatively short time periods on the order of weeks. Many climate processes, such as the El Nino / Southern Oscillation, the quasi-biennial oscillation and seasonal drought/flood cycles, have longer time scales. It is of interest to attempt to quantify better the impact and most appropriate use of satellite sounding data for climate monitoring and for determining the optimal future climate observing system.

The Working Group concluded that longer-term observing system experiments need to be performed to optimize the use of TOVS data in climate data assimilation systems.

2.2.5.4 Frequency protection

The utility of satellite data for long-term climate monitoring and diagnosis depends critically upon obtaining long time series of observations in nearly identical regions of the spectrum. The telecommunications revolution is increasingly causing pressure on portions of the microwave spectrum essential for passive remote sensing of the Earth from space. The Working Group supported continued efforts in frequency protection for passive microwave, including those frequencies planned for future operational satellites (see also section 2.5.4).

2.3 PREPARATIONS FOR ATOVS DATA

R Saunders (chair), with V Achard, T Ahtor, R Armante, A Arriaga, H Billing, H Bloom, T Böhm, E Borbas, P Brunel, R Buell, P Burt, I Csiszár, M Derrien, P Dibben, S English, J Eyre (part time), G Gitonga (part-time), M Hervéou, K Hlavatý, D Klaes, S Johnson, T Kleespies (part-time), A Korpela, T Labrot, L Lavanant (part-time), S Nieman, F Olesen (part-time), C Paris, G Rochard (part-time), N Scott (part-time), A Thoss, S Turner, M Uddstrom, H Woolf, F Zauli, Zhang Wenjian (part-time), Zhao Gao-Xiang and Zhu Yuanjing.

2.3.1 Progress since ITSC-VIII

The recommendations and actions from ITSC-VIII were reviewed by the group. All were closed or incorporated within new actions. The one action not discussed below was: J Bates and T Kleespies to provide access to a small sample of collocated SSM/I, SSM/T and SSM/T-2 data on the World Wide Web. This is now available at www.cdc.noaa.gov/~climsat/other.html.

2.3.2 Status of ATOVS processing software

During the plenary session there were presentations on the current status of three processing systems for ATOVS data, and these were reviewed in more detail by the Working Group. There had been significant developments since ITSC-VIII, and these are briefly summarised below.

The NESDIS software for processing ATOVS data is a development of their RTOVS processing system, which is to replace the operational TOVS processing. Products from the RTOVS system were, at the time of the meeting, being sent to NWP centres for evaluation. The ATOVS system is an upgrade of the RTOVS system, with new science added to address the new microwave channels on AMSU-A. The high-resolution AMSU-B moisture products will be generated by a separate package based on a system developed for SSM/T-2 data. The science of the NESDIS system is described in a draft document available from D Wark at NESDIS.

The European groups developing the ATOVS and AVHRR Processing Package (AAPP), co-ordinated by EUMETSAT, had progressed to the point where a package existed for the processing of TOVS data from ingest to re-mapped processed radiances. AAPP had been in operation at CMS Lannion for almost a year using data from NOAA-12 and -14, and it was under test at other European Met. Services as recommended by this Working Group. This testing had helped to make the system more robust to corrupt data. AAPP includes modules for processing ATOVS data, and the ingest and calibration parts of the code has been checked by passing through the system pre-launch NOAA-K data obtained during thermal vacuum tests. It was recognised that an important test for the AAPP code will be to compare the Level 1B files generated by NESDIS with the 1B files generated from corresponding locally received HRPT data. A recent development had been to plan for the inclusion of a set of compatible retrieval modules within AAPP. These could be either stand-alone modules or require first-guess profiles from a NWP model. Retrieval modules currently planned to be compatible with AAPP are ICI (Météo-France), 1DVAR (ECMWF) and 3I (LMD), with the third to be distributed separately from LMD.

The Working Group requested that an overview documentation of the AAPP software be produced to inform the ITWG members of the capabilities of the package. (Action: D Klaes)

CIMSS had also received a copy of the AAPP modules from the developers of the code and had

started testing in preparation for their Advanced TOVS Processing Package (ATPP). They plan to use AAPP modules for ingest and calibration but then to develop modules for retrieving products on AMSU-A fields-of-view (fovs). (The AAPP default is on HIRS fovs.) The ATPP software will share the common file structures of AAPP so that the software from either package could be used with the files.

Recommendation (to ATOVS code developers): The Working Group recommended that the ATPP and AAPP code developers try, as much as possible, to use the same framework for generic tasks in the preprocessing (e.g. re-mapping) in order to maintain commonality between the two packages.

The use of AVHRR data in the packages is planned, although it may not be supported in the initial releases. The inclusion of AVHRR data will be in two phases; the first will use the data only as a cloud mask, but later AVHRR cloud and surface parameters mapped into the HIRS/AMSU fovs could be included.

2.3.3 Dissemination of ATOVS related information

The Working Group acknowledged that there are some types of information related to ATOVS that require effective dissemination to the users before the launch of NOAA-K. These are listed below, along with a strategy for their dissemination to users.

- NOAA-K HIRS and AMSU instrument parameter files:

The Working Group requested AAPP module developers to provide to D Klaes (EUMETSAT) a list of the instrument parameters that are required by the AAPP software. (**Action: R Saunders, S English and G Rochard**)

The Working Group requested D Klaes to pass the complete list on to T Kleespies (NESDIS). (**Action: D Klaes**)

The Working Group requested NESDIS to provide NOAA-K instrument parameters on the World Wide Web, after noting the input from EUMETSAT. (**Action: T Kleespies**)

- ATOVS file formats:

The Working Group gratefully acknowledged the provision by NESDIS of the ATOVS level 1B file formats which can be found at: psbsgil.nesdis.noaa.gov:8080/ebb/ml/nic10.html. For potential users of the NESDIS ATOVS "UK Products file", the Working Group requested that this file format be added to the list of file formats which can be accessed on the World Wide Web. (**Action: S English**, to provide EUMETSAT with a web page defining the "UK Products file").

The Working Group requested that EUMETSAT provide a link on their ATOVS home page to the NESDIS ATOVS file formats and to the instrument parameter web pages. (**Action: D Klaes**)

2.3.4 Distribution of global ATOVS data

Recommendation (to NOAA): The Working Group noted the value of the TOVS radiosonde collocation files produced by NESDIS and recommended that these files be included in the list of those files archived at the NOAA's National Climate Data Center (NCDC). It also recommended that

the documentation of the history of the exact contents of the files be maintained and made available to users on request (radiance and retrieval processing, radiosonde selection criteria and corrections applied, etc.).

To facilitate radiance tuning for ATOVS, there is a requirement for continuing access to a well-defined archive of collocated radiosonde and satellite data. Hence for NOAA-K and beyond, the Working Group noted that it was essential for users of the ATOVS packages for a file to be generated of the collocation statistics for the uncorrected Level 1B data in addition to the retrievals with radiosondes. This should be generated at one centre but made available to all users on request. The Working Group would welcome the opportunity to review and comment on NESDIS plans for the development of such a match-up dataset.

The Working Group were informed of the present plans by NESDIS for the operational distribution of global ATOVS data. These consist of 500 km SATEM data on the GTS, world-wide. The following global datasets will be sent from Washington to European global NWP centres via Bracknell: a "60 km" ATOVS products dataset, the ATOVS Level 1B datasets, and a dataset containing a subset of AVHRR-GAC data. At ITSC-VIII, it was noted that this does not meet the stated WMO requirement for global distribution of data for NWP, in terms of horizontal resolution for users outside of the USA and Europe. The Working Group were informed that NESDIS was considering an intermediate resolution product for these users, providing access by whatever means was feasible.

Recommendation (to operational users of ATOVS data): The Working Group recommended operational centres outside Europe to contact NESDIS (E Brown) to define their requirement for global ATOVS data as soon as possible.

2.3.5 Distribution of ATOVS processing packages

The Working Group noted that, in the past, the free exchange of TOVS software (e.g. ITPP, 3I) had both helped operational meteorological services to establish TOVS processing capabilities, and also provided the basic tools for research studies using TOVS data. The Working Group were informed that users who wish to obtain a copy of the AAPP or ATPP packages should contact D Klaes (at klaes@eumetsat.de) or T Achtor (at toma@ssec.wisc.edu) respectively and register their interest. **(Action: All members of ITWG, to consider)**

It is planned that AAPP will be distributed by FTP or CDROM. ATPP will be distributed on floppy disks. For information on the ITPP/ATPP code, there is a web page at: cimss.ssec.wisc.edu/poes/itpp/tovs.html.

The Working Group requested that an ITPP/ATPP list server be set up, so that users can exchange comments on the package. **(Action: S Nieman)**

The EUMETSAT Data User Service plans to set up an AAPP web page once distribution starts.

AAPP and ATPP are currently only supported on UNIX platforms, and the Working Group noted that there is no support to make the code run on other platforms. Several users from developing countries expressed a desire for the packages to be available on a PC. However the Working Group noted that there were no resources currently available for porting the packages to a PC environment. One presentation during the conference described an initiative to put the ITPP on a PC which could be extended to ATOVS processing.

2.3.6 ATOVS case studies

During the development of the TOVS packages, the ITWG identified several meteorologically interesting case studies, which allowed ITWG members to compare the results of their TOVS processing. These experiments allowed deficiencies in some of the systems to be identified.

The Working Group proposed that at least two different atmospheric regimes be selected for ATOVS case studies. (Action: Co-chairs, to arrange the initiation of proposed case studies and their presentation at ITSC-X)

2.4.2.1 Sounder instrument status
Improvements to the current polar-orbiting environmental satellite (POES) systems

Planned proposed sounders of high spectral resolution will provide enhanced accuracy and vertical resolution, and increased capabilities for deriving new parameters. Scientific communities involved in Earth sciences - operational meteorology, climate research and monitoring, and atmospheric minor constituents and chemistry - will benefit from such improvements as long as the information content of the spectra and/or products is properly interpreted.

The implementation of advanced sounding systems will provide the potential for major improvements in operational and research areas, including NWP and studies of climate change (i.e. the global hydrology cycle, descriptions of surface-atmosphere processes, etc.)

2.4.2.2 Infrared sounders of high spectral resolution

Instrument designs applying high spectral resolution to improve the sounding data products compared with those now available from the POES system, are summarized in Table 2.4.1.

The AIRS uses a cross-dispersed grating design with several linear detector arrays, while the others use Fourier transform spectrometers (FTS) for spectral separation.

The AIRS is in Phase C/D for the NASA EOS programme PM platform. The AIRS design is finalized and critical subsystems have been breadboarded. The engineering model will be fabricated and ready for testing by the end of June 1997. The flight model will be delivered in December 1998.

The TIS is in the design phase (B) for EUMETSAT as a joint project of CNRS and EUMETSAT. Phase C will begin before the end of December 1997.

A recent development, the HIRS-TTS has been designed to upgrade HIRS to provide an advanced sounding capability from the current NOAA series of satellites. The HIRS-TTS is an upgrade of HIRS-4 for potential flight aboard NOAA satellite beginning with NOAA-17.

The TTS was originally designed for EUMETSAT at the Phase A level by the University of Wisconsin and Santa Barbara Research Center. Limited sub-system breadboarding has been performed for NOAA-17SDIS by Jacobs Laboratories. An airborne prototype is being fabricated for flight testing about the NASA ER-2 before the end of 1997.

2.4 ADVANCED INFRA-RED SOUNDERS

N Scott (chair), with R Armante, A Arriaga, H Bloom, M Goldberg, A Huang, W Krug, D Klaes, L McMillin, R Rizzi, W Smith, V Tramutoli, H Woolf and F Zauli, and contributions from V Achard, J Le Marshall and C Stubenrauch.

2.4.1 Progress on recommendations from ITSC-VIII

Implementation of higher spatial resolution (10 km) for HIRS is under way for NOAA-N and METOP.

2.4.2 Sounder instrument status

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The IASI is in the design phase (B) for EUMETSAT as a joint project of CNES and EUMETSAT. Phase C will begin before the end of December 1997.

A recent development, the HIRS-ITS has been designed to upgrade HIRS to provide an advanced sounding capability from the current NOAA series of satellites. The HIRS-ITS is an upgrade of HIRS-4 for potential flight aboard NOAA satellite (beginning with NOAA-N).

The ITS was originally designed for EUMETSAT at the Phase A level by the University of Wisconsin and Santa Barbara Research Center. Limited sub-system breadboarding has been performed for NOAA/NESDIS by Lincoln Laboratories. An airborne prototype is being fabricated for flight testing aboard the NASA ER2 before the end of 1997.

Table 2.4.1 Plans for Advanced Sounders

	AIRS	IASI	HIRS+ITS	ITS	IRFS
Approach	grating	FTS	FTS+Filters	FTS	FTS
Hardware group	JPL/NASA/ LORAL	CNES/ EUMETSAT	ITT/Bomem	95:Lincoln Labs/NOAA 91:UW/SBRC	Russian Space Agency
Spectral range (cm ⁻¹)	LW:469-1135 MW:1217-1613 SW:2169-2674	contiguous 645-2940	LW:620-1150 MW:1210-1740 SW:2150-2720	LW:620-1150 MW:1210-1740 SW:2150-2720	LW:5-16µm SW:2-4.5µm
Spectral resolving power	1000-1400	2000-4000	1000-2000	900-1800	1200-40000
Spatial footprint (km)	14x28	12	10	10	20
Sampling density per 50 km square	9	4	2+	9	1
Power (W)	225	200	24+32	73	70
Mass (Kg)	140	160	34+13	40	50
Platform (target)	EOS PM	METOP	NOAA-N	NOAA/NASA DoD C-1	Meteor
Launch date	2000	2002	2002	2009	2000
Primary assets	best noise performance especially for SW + new technology	most versatile spectral coverage + resolution	low costs + fits on NOAA spacecraft with HIRS	small + best spatial sampling for cloud clearing	nadir + limb scanning, has highest spectral resolution

The Infra-red Spectrometer Interferometer Sounder (IRFS) is under development by Russia for flight on future METEOR satellites. An engineering model is undergoing testing. A flight instrument is under development, pending financial resources.

In addition to these instruments, specifically designed as high spectral resolution sounders of temperature and water vapour for weather forecasting applications, there is the Interferometer for Monitoring Greenhouse Gases (IMG), designed exclusively for climate applications. The IMG was launched in August 1996 on ADEOS and has been operating since September 1996. The spectral resolution of the IMG is very high, with resolving powers of 7,000 to 30,000 for the spectral range 700 to 3000 cm⁻¹. The spatial coverage of IMG is limited to the satellite sub-track, with samples spaced at intervals of 84 km. The field-of-view (fov) of each sample is 8 km. Whilst not suited directly to meteorological sounding, the IMG will be very useful for addressing remaining problems with the forward radiative transfer models used for other advanced sounders.

2.4.3 Future operational sounder system plans

For more than 3 decades, the main source of meteorological satellite data has been the NOAA polar satellites of the USA. NOAA currently operates two operational satellites in complementary polar orbits, one crossing the equator in descending node in the morning, and the other in the afternoon. From the year 2002 onwards NOAA is discontinuing the coverage of the morning orbit.

EUMETSAT plans to implement a corresponding system in the morning orbit, with an equator-crossing time of 0900. The first of three planned METOP (METeorological Operational Polar) satellites is planned to be launched in 2002. The first two satellites will be companion satellites of NOAA-N and -N'.

The third METOP spacecraft is planned to accompany the new generation of satellites of the USA - the National Polar-Orbiting Environmental Satellite System (NPOESS). The first launch for NPOESS is planned for 2009.

2.4.4 Recommendations and conclusions: advanced sounders

Recommendation (to NOAA/NESDIS): HIRS-4 will be available during 1997 to fly on the NOAA satellites and will improve by a factor of 2 the clear air radiance yield compared with HIRS-3. It is recommended that NOAA/NESDIS consider flying HIRS-4 beginning with the NOAA-L satellite. Regarding the remaining two HIRS-3 instruments, it is recommended to consider modification of one to the HIRS-4 design for flight on NOAA-M and of the other to the HIRS+ITS design for flight on NOAA-N.

Recommendation (to NOAA/NESDIS): IASI will be aboard the European METOP-1 beginning in 2002. Given the importance of sounding from two or more polar satellites for global NWP, it is strongly recommended that the HIRS be upgraded to include an advanced sounding capability from the NOAA operational satellites beyond 2002. This will provide the needed NOAA satellite complement to the METOP IASI sounding system. Although the EOS PM platform AIRS will also be in orbit during this time period, it is noted that this is an experiment with no plans for replacement.

Recommendation (to CGMS): Conical scanning has certain advantages for microwave remote sensing in surface-sensitive spectral channels. Also, it is advantageous to have complementary visible and infra-red sensors on the same platforms to sense the complete radiative spectrum. It is therefore recommended that studies be undertaken to compare the advantages and disadvantages of cross-track versus conical scanning for scan-coordinated infra-red and microwave sounding systems.

Recommendation (to CGMS): Observations of temperature, humidity and wind at high temporal frequency have potential for improving global and regional NWP through 4-dimensional data assimilation. It is therefore recommended that CGMS encourage the provision of infra-red sounding instruments of high spectral resolution as part of the payloads of future geostationary satellites.

Recommendation (to CGMS): In order to address the requirements of NWP, advanced atmospheric sounders should have: high spectral resolution with coverage from long-wave to short-wave infra-red, small fields of view, and high spatial sampling density. High spectral resolution is needed to improve the vertical resolution. High spatial sampling with a small field of view is needed to provide an adequate number of clear soundings in the presence of broken clouds. To achieve an optimal yet practical instrument design, scientific trades-off must be made. In this respect, the Working Group's consensus is that the horizontal sampling density should be greater than that of HIRS/3 and that the

fov size should, if practicable, be no greater than 10 km.

2.4.5 Research needed

Significant contributions are required in the following fields:

- development or extension of new, high-performance suites of forward and inverse algorithms,
- definition and derivation of new products or by-products,
- definition and application of validation plans, and of quality control strategies,
- methods for operational assimilation of advanced sounder data and/or products in NWP.

2.4.5.1 Forward modelling

Over many years, several generations of forward models have been developed, ranging from the basic line-by-line and layer-by-layer approach to highly parameterized approaches with comparable accuracy but saving impressive amounts of computation time.

Accurate fast and hyper-fast forward models will be used to simulate advanced sounder observations to be used in variational methods for analyses and retrievals, validation processes, etc. In data assimilation for NWP, they will be used to compute the model-equivalent of the observation.

Other applications of forward models include:

- studies of the expected dynamic range of measured spectra with respect to atmospheric and surface variables,
- selection of appropriate spectral intervals for retrieval of each atmospheric or surface variable,
- studies of the information content of the data.

Some important problems still remain that could hamper the benefit expected from sounders of high spectral resolution.

Recommendation (to ITWG members): The Working Group strongly endorsed the plans of ITRA to improve forward models for high resolution sounders through appropriate validation activities, especially comparisons of line-by-line models and fast models, with each other and with coincident field data. The Working Group strongly recommended the largest possible participation in these validation activities, including the distribution of ground-truth data sets (HIS, ARM, SPECTRE, IMG, TRAFTS, etc.). It strongly supported the development of airborne instruments (such as the NPOESS atmospheric sounding test-bed) which can be used to simulate all the advanced sounders under consideration and to test different forward models.

2.4.5.2 Validation and error characterization

A key requirement is for studies that lead to a full, quantitative understanding of the error characteristics of the radiance spectra and derived geophysical parameters, over a range of environmental conditions. This is necessary if they are to be used optimally for NWP and other applications. The Working Group recognized that such studies are an invaluable component of validation and characterization studies.

Recommendation: It is recommended that plans for development and extension of forward models and retrieval schemes include a thorough assessment and documentation of their error characteristics.

2.4.5.3

Preparatory research and development for operational NWP

Weather forecast models require the complete specification of the initial values of the model variables, including wind, temperature, humidity, clouds and surface variables. A current trend is to move towards direct assimilation of radiance data, rather than to use retrieved profiles of temperature and humidity. Due to the huge difference in the number of channels between TOVS and advanced sounders, assimilation of such data is undoubtedly a field for further urgent investigation.

The details of atmospheric absorption and scattering processes affect the choice of observed wavelengths and of those used to retrieve information on different meteorological parameters. Considerable research is required in the selection/combination of sounding channels (according to their information content). This is an important problem as it may affect decisions on the transmission of data to operational centres (i.e. which channels are to be used for which information: temperature, humidity, ozone, clouds, etc.). Research is urgently needed on how to make best use of the information content of the whole spectrum.

Recommendation (to ITWG co-chairs): In order to enhance collaboration among groups dealing with advanced sounding issues, it is recommended that at the next conference, papers are again invited from such groups.

Recommendation (to President of IRC): Recognizing the number of valuable activities in the field of inverse and forward modelling, for passive sounders other than TOVS (i.e. ATOVS, high spectral resolution sounders, geostationary sounders), the Working Group recommended that IRC formally expand the scope of ITWG to include work related to the above-mentioned sounders.

Recommendation (to CGMS): The Working Group encourages EUMETSAT and NOAA/NESDIS to coordinate their plans for the distribution of global data and products to assure consistency and compatibility. Coordination within CGMS is proposed.

Recommendation (to ITWG members): Recognizing that agencies are in early stages of planning data processing systems for advanced sounders, the Working Group recommended the initiation of experiments to compare products from different retrieval methods, using common fast radiative transfer codes and evaluation datasets.

2.5 INTERNATIONAL ISSUES AND FUTURE SYSTEMS

D Hinsman (chair), with J Eyre, G Gitonga, S Johnson, J Le Marshall, P Menzel, G Rochard, M Uddstrom, A Uspensky and Zhang Wenjian.

2.5.1 Background

Following discussions during the first sessions of ITSC-IX, various topics were assigned to the Working Group for "International Issues and Future Systems". The primary focus of the Working Group was a review of future systems with regard to programmatic issues that may become of interest to ITWG and related topics.

The Working Group considered matters under the following topical areas:

- a review and comments on the plans for future systems,
- a review of previous ITSC actions,
- mechanisms for scientific input on requirements for the "converged system",
- frequency protection from 1 to 200 GHz,
- education and training,
- small PC workstations, and
- interactions between ITWG and other bodies.

2.5.2 Review and comments of plans for future systems

The Working Group recalled that ITSC-VIII agreed that all satellite agencies should be invited to make detailed presentations of the present status of operational systems and future plans for instruments and missions at ITSC-IX. The Working Group then considered the information contained in the presentations on future systems made by NOAA/NESDIS, EUMETSAT, the People's Republic of China and the Russian Federation in the session entitled "Future Systems and International Issues".

Since this was the first opportunity to discuss the invited presentations, a review of the utility of such presentations was conducted. The Working Group unanimously felt that the presentations were valuable and provided an opportunity for an ITSC to view, from a global perspective, the plans of the various satellite operators. The presentations also afforded ITSC the opportunity to suggest changes to the satellite operators. The Working Group emphasized the need for the presentations to cover both geostationary and polar-orbiting satellite programmes while focusing in more detail on the portion of the programmes as they relate to sounding instruments. Additionally, the satellite operators were encouraged to include in their presentations aspects of the availability of data.

Action (co-chairs): All satellite operators should be invited to make detailed presentations of the present status of operational systems and future plans for instruments and mission at future meetings of the ITSC.

The Working Group also considered in detail each presentation. While impressed with the comprehensive plans being considered, the Working Group felt that there was a lack of an overall view of how the individual plans could be integrated into a global system. Due to the potential for overlap and redundancy, the Working Group agreed that it was important that a mechanism be established by the satellite operators to allow them to develop an integrated global observing system. The Working Group expressed concern that the presentations also identified only one apparent advanced operational sounder, i.e. IASI. It recalled that previous ITSCs had strongly encouraged

satellite agencies to implement "common" and advanced sounders in the morning and afternoon satellites. The presentations also highlighted the possibility for ITWG participation in the NPOESS activities and felt that such participation would be most beneficial. The Working Group also recalled its previous recommendations to space agencies to provide or implement as appropriate a direct broadcast capability for sounder and related image data. It, therefore, felt it appropriate to recommend further actions with regard to direct readout of MODIS and AIRS. Finally, the Working Group greatly appreciated the presentations on the possibility for sounding from the geostationary orbit. It felt that the potential for such soundings to meet WMO requirements of hourly soundings with 1 km vertical resolution with 1 K r.m.s. error warranted further activity in this area. The Working Group, based on the above discussions, provided the following actions/comments/recommendations:

Recommendation (to CGMS): Consideration should be given to developing a mechanism whereby the plans of individual space agencies for instruments and missions could be integrated into an overarching strategy that would best address individual countries' needs and international requirements.

Recommendation (to CGMS): ITWG is concerned that the present plans of the operational satellite operators only include one advanced sounder (IASI) before 2009 and recommended that consideration should be given to providing comparable advanced sounding capabilities sooner in both the morning and afternoon orbit.

Action (co-chairs): The USA's Integrated Programme Office should be informed that ITWG is ready to participate in NPOESS planning, if invited, on the Sounder Operational Algorithm Team (SOAT).

Action (P Menzel to co-ordinate): NASA should be contacted for further information concerning access to direct readout data from MODIS and AIRS (X-band reception) as well as activities related to CAL/VAL.

Recommendation (to CGMS): It is recommended that NOAA/NESDIS continue its initiative to develop a high resolution sounder for the geostationary orbit, for example GHIS.

Action (co-chairs): The programmes for future ITSCs should include presentations covering passive remote sensing on operational satellites in polar and geostationary orbits.

2.5.3 Review of previous ITSC actions

The Working Group reviewed the status reports with regard to action items and recommendations from ITSC-VIII. It was felt that all action items and recommendations had been completed although several of the responses to recommendations to CGMS needed further clarification. The Rapporteur to CGMS from the ITWG (P Menzel) informed the Working Group of his activities towards seeking the clarification from CGMS. The Working Group was confident that the Rapporteur's action would enable all ITSC-VIII actions and recommendations to be completed at CGMS-XXV in June 1997.

2.5.4 Frequency protection for 1 to 200 GHz

The Working Group reviewed the activities of the Rapporteur for frequency matters (G Rochard) and expressed great appreciations for his activities especially in light of the success in protecting microwave frequencies at the recent World Radio Conference in 1995 (WRC-95). However, the Working Group also noted that he participated in more than 20 related meetings since ITSC-VIII. The Working Group stressed the importance of the meteorological community being strongly represented

in all discussions concerning the allocation and protection of microwave frequencies used for passive remote sensing, but it noted that resources were not currently available to ensure adequate representation at all necessary meetings. The Working Group considered that well-resourced international activity was urgently needed at a regional level. It recommended that WMO consider promoting such activities through its Regional Associations and/or other appropriate international bodies. The Working Group was also strongly supportive of the need to reconfirm its commitment to the protection of the required frequencies but also to encourage satellite operators to utilize those bands in which protection already exists while avoiding bands where the frequency allocation already allowed competing activities.

Recommendation (to WMO): WMO and/or other appropriate international organizations consider promoting well-resourced activities towards protection of the necessary microwave frequencies.

Recommendation (to CGMS): ITWG reaffirms its strong support for the protection of frequencies planned to be used by operational sounding instruments for the next 20 years.

Recommendation (to CGMS): ITWG encourages that sounding instruments use bands where protected allocations exist and avoid using bands not allocated to passive remote sensing.

The Working Group considered an urgent issue related to the 31.3 to 31.8 GHz band. It strongly supported that the current allocation in 31.3 to 31.8 GHz band be maintained and that any upgrade of another service in the band be opposed. In so doing, it noted that 500 MHz bandwidth in this band are needed to achieve an accuracy of 0.2 K with a resolution of 15 km for research and future operational soundings. Furthermore, the 31.3 to 31.8 GHz band, used in close combination with the 50 to 60 GHz band, should have contaminated data not exceeding 0.01%.

Recommendation (to CGMS): ITWG strongly supported: that the current allocation in 31.3 to 31.8 GHz band be maintained; that any upgrade of another service in the band be opposed; that 500 MHz bandwidth in this band are needed to achieve an accuracy of 0.2 K with a resolution of 15 km for research and future operational soundings; and that the band, used in close combination with the 50 to 60 GHz band, should have contaminated data not to exceed 0.01%.

2.5.5 Education and training

The Working Group noted with appreciation the support by the satellite operators in the development and implementation of the new WMO Strategy for Education and Training in Satellite Matters in developing countries. The Working Group reaffirmed the ITSC recommendation to provide expertise for sounding-related education and training with an increased emphasis on new techniques and media.

Recommendation (to CGMS): ITWG strongly commends CGMS Members for their initiatives to increase education and training in developing countries. ITWG reaffirms its commitment to provide expertise in sounding-related training.

2.5.6 Workstations

The Working Group recognized the need for support in the acquisition of cost-effective workstations for developing countries within the framework of WMO and satellite operators, especially with regard to the increase in workstation capabilities and the decrease in the availability of in situ data.

Recommendation (to WMO and CGMS): ITWG recognizes the need for support for the acquisition of cost-effective workstations, especially for developing countries and in light of the increase in workstation capabilities and the decrease in the availability of in situ data.

2.5.7 Relationships between ITWG and other bodies

The Working Group reviewed the existing relationships with WMO, CGMS and IRC. In particular it discussed the effectiveness of the existing mechanisms and means to improve them. It was felt that the existing mechanisms were functioning well and that actions and recommendations were being received and acted upon. Additionally, mechanisms were also in place to provide ITWG with necessary feedback to allow for improvements in the relationship in the future if required.

3. REPORTS OF TECHNICAL SUB-GROUPS

3.1 TECHNICAL SUB-GROUP ON TOVS PROCESSING SOFTWARE, 3I/3R

Since ITSC-VIII, several improvements had been made to the 3I software, and these were presented during ITSC-IX. They were:

- New neural network approach for water vapour:
Chaboureaux J P, A Chédin, R Armante and N A Scott. A new approach for the vertical characterization of water vapour from TOVS.
- New approach for cloud parameter retrieval:
Stubenrauch C J, A Chédin, R Armante and N A Scott. A new approach for cloud parameter determination in the 3I algorithm.
- Automatic determination of deltas for correction of radiance biases:
Armante R, A Chédin and N A Scott. Description of the corrections for radiance biases in the 3I re-analysis of TOVS data.

The new deltas for NOAA-12 and -14 will be available at the end of 1997.

Changes in the 3I code had been made so that the same 3I version can be used for local and global application.

The group decided to establish a web page at LMD for user support, where users can get modifications and updates of 3I and 3R code and data files. For discussion of 3I/3R users, a mailing list will be set up.

The current TIGR dataset contains some super-saturated profiles. N Scott announced that this will be checked at LMD and, in June 1997, a new TIGR dataset will be available.

The incorporation of AVHRR into 3I was discussed. There were no plans at present to mount this effort at LMD but, if significant benefit were demonstrated, it might be considered for future work. Users were encouraged to pursue the task.

3.2 TECHNICAL SUB-GROUP ON TOVS PROCESSING SOFTWARE, ITPP

3.2.1 General

There had been much helpful feedback from users since the release of ITPP 5.0. Many of the issues raised at ITSC-VIII had been addressed to the user community's satisfaction. The following issues remain open or are newly arisen.

3.2.2 HIRS calibration

There is a logical flaw in the code that interpolates between calibrations. When a correction has been devised and checked out, it will be released.

3.2.3 MSU to HIRS mapping

Evidence was presented suggesting an oscillation within the HIRS scan line, and possible instability at the extremes (limbs) of the scan. Comparisons will be made with the schemes employed by NESDIS and the Australian Bureau of Meteorology.

3.2.4 Ozone retrieval

Several users noted biases between ITPP total ozone estimates and independent measurements. This problem, as well as the ozone retrieval algorithm itself, will be investigated as CIMSS resources permit.

3.2.5 Documentation of forward radiative transfer models

These had been something of a "moving target", and so difficult to document. It was thought that they were settling down, and this issue will be addressed shortly. In regard to retrospective processing, coefficients will be provided to permit application of the package to all satellites from TIROS-N to NOAA-14.

3.2.6 Test data

The installation procedure for ITPP 5.0 includes a small sample of TIP data which is run end-to-end and compared with the included benchmark. There is interest in being able to view the results of this comparison at intermediate stages. CIMSS will evaluate the difficulty of providing such capability.

3.2.7 Surface and guess grids

A request was made to provide information on accessing grids other than latitude-longitude, which should be possible with the existing software but is not obvious to those attempting to modify it. CIMSS will investigate and provide information as appropriate.

3.2.8 Off-line software for radiative transfer tuning, regression retrieval, etc.

The relatively small amount of software required for these operations, beyond what is already in the package, could be supplied upon request as an appendix to the ITPP. CIMSS will prepare for this - again, as resources permit.

3.2.9 Information exchange

Some interest was expressed in establishing an ITPP list-server, which would provide a forum for users to communicate freely in regard to the package, as well as a mechanism for disseminating corrections and suggestions.

3.3 TECHNICAL SUB-GROUP ON FAST RADIATIVE TRANSFER MODEL, RTTOV/RTATOV, AND RELATED DEVELOPMENTS

3.3.1 Current status

There were several presentations at ITSC-IX on the status of fast radiative transfer and transmittance models including RTATOV (Saunders and Matricardi), OPTRAN (Kleespies), PLOD (Woolf and van Delst), a new physically based model (Garand et al.) and 3R (see section 3.1). All models have the capability to simulate TOVS data, and some have already been adapted to simulate AMSU data, SSM/I data and geostationary sounder radiances (e.g. as presented by Kelly).

3.3.2 RTATOV status

The export version of RTATOV has been distributed to over 30 different groups worldwide. The current version of the code, version 3, is identical to that described in the ECMWF Tech. Memo. 176. In July 1996, it was updated to support NOAA-14, and the water vapour transmittance coefficients for NOAA-12 and -14 were modified to use line-by-line transmittances generated by HARTCODE, instead of the old TRANH values. This allows water vapour transmittances above 100 hPa to be computed properly (which is useful for HIRS channel 12). The MSU coefficients were replaced with those based on the Liebe MPM line-by-line model. The first release of these coefficients contained some corrupt data, and so corrected files were emailed to all affected users in January 1997.

At ECMWF, RTATOV has undergone some developments to include ozone as a variable profile to allow simulations of HIRS channel 9. In addition, modifying the water vapour transmittance predictors has given improved accuracy for window, water vapour and ozone channels. The other development reported was the creation of a documented ASCII file for input of all the coefficients. It would be desirable if all the models could interface with this or a similar file. It was planned to release RTATOV version 4 with these upgrades and to include NOAA-K coefficients before the launch of NOAA-K.

3.3.3 OPTRAN status

The forward model component for mixed gases, water vapour and ozone was reported to be working for both HIRS and AMSU. The coding of the tangent linear, adjoint and K matrix of the radiative transfer (RT) model was almost completed. Initial comparisons had shown that the RT model including OPTRAN can give an improved accuracy over the current RTATOV for the water vapour channels of AMSU. In common with the transmittance routine in RTATOV, OPTRAN is based on line-by-line transmittances from HARTCODE for the infra-red and MPM Liebe for the microwave. The forward model had been released to NCEP for testing and comparisons with RTATOV, and it will be released to several other groups for testing.

It was planned that OPTRAN and RTATOV would converge into a common model with the transmittance part of the computation following the OPTRAN approach but the overall framework of RTATOV being retained. This version would supersede RTATOV version 4.

3.3.4 PLOD status

A new model similar to RTATOV called PLOD (Pressure Levels to Optical Depth), developed at the

University of Maryland, is being adapted for use at CIMSS. It differs from RTATOV in the predictors used. In the future this may be a candidate for inclusion as part of the ATPP software package.

3.3.5 Future developments for fast models

The sub-group discussed several items common to these fast models:

- For the microwave radiometers it will be important to have a fast model for surface emissivity both over sea and land. It was pointed out that the 4-parameter Grody model will not work well over snow and ice. The sub-group noted that work is under way to develop a land surface microwave emissivity atlas.
- Users should note that ozone profiles are required for input to OPTRAN and RTATOV (version 4). It was suggested the mean ozone profile be included in the package.
- For the planned high resolution infra-red sounders, the atmospheric layering needs reassessment. One proposal is to use the AIRS 101 levels to replace the 40 NESDIS levels currently in use. The current top level of 0.1 hPa is not high enough for accurate simulations.

3.3.6 Actions

- The transmittance coefficients for RTATOV (and later OPTRAN) should be posted on the ITWG home page. (**Action: R Saunders, T Kleespies**)
- A list of email addresses for all RTATOV/OPTRAN users will be compiled to allow effective dissemination of RTATOV/OPTRAN developments and general reporting of problems or suggestions for improvements. (**Actions: R Saunders** to compile list, and **RTATOV/OPTRAN users** to email r.saunders@ecmwf.int if they want to be on the list.)
- RTATOV/OPTRAN should use a common file format for instrument specific parameters and coefficients. (**Action: R Saunders** to send T Kleespies and H Woolf the new RTATOV input file)

4. ABSTRACTS OF ITSC-IX PRESENTATIONS

TEMPERATURE AND WATER VAPOUR RETRIEVALS WITH THE IASI/ATOVs SYSTEM

F Aires, N A Scott, R Armante, M Hervéou, N Jacquinet, F Chéruy and A Chédin
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Our research has been devoted:

- to preparing the processing of the new operational sounders AMSU/NOAA, AIRS/EOS/NASA and IASI/CNES/EUMETSAT, with the "required" (by international agencies) accuracy concerning the temperature and water vapour profiles, and
- to identifying new "products" (trace gases total content or profiles, etc.) to be derived with this new suite of instruments in stand alone mode or when processed together.

To take up this challenge we have found it necessary to couple expertise in the field of spectroscopy, and forward and inverse modelling of the radiative transfer in the infra-red and microwaves. So far, in a research mode, we have undertaken (or performed) the following tasks:

- generate the "TIGR" dataset to be used within the frame of the AMSU-A, MHS and IASI,
- further validate forward algorithms for the computation of transmittances, radiances in the infra-red and microwaves,
- refine the currently available retrieval algorithms to produce temperature profiles, sea surface temperatures, water vapour profiles through the use of neural network techniques,
- perform selection of spectral channels relying on the "best" information content for temperature profiles, sea surface temperature and water vapour profiles retrievals,
- improve the spectroscopic information in the GEISA data bank in the spectral regions of interest, and
- test the retrieval algorithms - this has been done on simulated radiances and will be done on actual observations (space-borne observations).

This work is also within the frame of the ISSWG/CNES/EUMETSAT.

DESCRIPTION OF THE CORRECTIONS FOR RADIANCE BIASES IN THE 3I RE-ANALYSIS OF TOVS DATA

R Armante, N A Scott and A Chédin
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The 3I physical retrieval method makes use of the difference between observed and computed brightness temperatures to adjust the values of derived geophysical parameters. Thus, systematic biases between computed and observed brightness temperatures can be particularly damaging from the point of view of:

- retrieval accuracy, and
- monitoring climate variability and trends,

as these biases will differ from satellite to satellite, and spurious trends may result. Use is made of collocated satellite-radiosonde datasets (from TIROS-N to NOAA-xx) to infer and regularly update these biases:

- on a 3-monthly basis,
- for land and sea situations,
- for five air-mass types (tropical, 2 mid-latitude, 2 polar).

The origin of these collocated information is from NOAA/NESDIS: the so-called DSD5 files.

TROPICAL HYDROLOGICAL CYCLE STATES REVEALED IN HIRS WATER VAPOUR DATA

John J Bates
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Evidence that the Earth's climate made rapid global reversals to different states has become firmly established in the past several years. Ice cores from Greenland, New Zealand and Chile indicate that global temperatures dropped by several degrees in just several decades following changes in the North Atlantic ocean circulation. Originally, the abrupt changes in the Greenland ice cores were thought to be related only to regional climate changes. However, other ice cores from New Zealand and Chile, and other proxy paleoclimate records such as rock varnish from the US Great Basin, indicate these changes were rapid and global. Paleoclimatologists have hypothesized that changes in the oceanic thermohaline conveyor cause a redistribution of tropical convection resulting in changes of water vapour that lead to negative water vapour forcing until a new equilibrium state is reached.

In the last 20 years, the only time when the atmospheric circulation was such as to maintain paleo-lakes in the US Great Basin at a size consistent with these dramatic global cold events was during the 1982-83 ENSO warm SST event. The record of HIRS 12 upper tropospheric water vapour channel data over the past 17 years reveals that the most dramatic change occurred during this event. The global tropical upper tropospheric relative humidity dropped by over 1% during this event, even though the tropical tropospheric temperature increased. This is a dramatic evidence of negative water vapour forcing. If this climate mode had continued, it could have lead to even greater drying of the upper troposphere and, eventually, a dramatic cooling of the tropics.

PROCESSING AND USING OF TOVS DATA IN MONGOLIA

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HRPT data have been received at the Information and Computer Centre (ICC) of the Ministry for Nature and Environment of Mongolia since 1988, and AVHRR images have been processed and displayed operationally. From the end of 1995, the TOVS data processing became fully operationally. At present, the TOVS data processing is being carried out automatically with the ITPP-4 software from the University of Wisconsin, USA, using the climate data base as first guess field for the retrieval through the real-time system at the ICC. At present the usage of the data is in a trial mode.

The physically-based operational TOVS retrieval system which is currently used to generate meteorological fields from locally received TOVS raw radiance data in the Mongolian region is described in the paper. The paper summarises the results of systematic comparisons of the satellite sounding products (temperature, humidity and geopotential thickness profiles) with collocated radiosonde data. The impact of these local TOVS data on operational forecasts in the Mongolian region is shown.

At Weather Forecasting Section in Mongolia, TOVS outputs have been regarded as a potentially useful data set for identifying synoptic patterns particularly in data-sparse area. In future TOVS data will be used in a two ways: as input data for the numerical analysis and as a diagnostic tool in an interactive graphic system for nowcasting purposes.

RETRIEVAL OF PRECIPITATION AND COLUMNAR WATER VAPOUR CONTENT FROM AMSU-A/B

Ralf Bennartz, Anke Thoss and Juergen Fischer
Institute for Space Sciences, Freie Universität Berlin, Germany

Radiative transfer calculations were carried out for a global radiosounding dataset in order to derive rain and cloud parameters from AMSU-A/B channel combinations. The radiative transfer calculations take account of the variations in observer zenith angle and of the rotation of the polarization state of the AMSU antenna which are due to AMSU's cross-track scanning concept.

Retrieval algorithms for deriving instantaneous rain rates, cloud liquid water content and columnar water vapour content were built using linear regression and neural networks. The relative benefits of the different approaches are compared.

RETRIEVAL OF SURFACE TEMPERATURES FROM TM, METEOSAT AND AVHRR DATA DURING AN EXPERIMENT IN TUSCANY IN AUGUST 1996 IN COMPARISON WITH IN SITU MEASUREMENTS

Heiner Billing, Matthias Eckardt and Ines Langer
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The derivation of surface temperatures gives information on evaporation and hence on ground properties. Especially from METEOSAT data, the daily temperature course can be derived. The in situ measurements, however, can only be compared with Landsat data, as AVHRR and METEOSAT data are integrated over several square kilometres. The influence of the atmosphere on the radiation, measured at the satellite, can be corrected by means of a radiative transfer program like LOWTRAN, if the distribution of temperature and water vapour along the line of sight is known. At first, nearby radiosoundings are used.

In order to use TOVS data for desertification studies in the Mediterranean, different simple methods are investigated:

- from AVHRR data only, the atmospheric influence can be compensated by a split window method over Land (Casalles, 1996),
- regression coefficients, including HIRS channel 8 data, are given by Schuessel (1987),
- a simple correction, using the HIRS data, is performed by comparing the HIRS temperatures with temperatures, calculated with LOWTRAN for those channels from the radiosoundings.

The difference in TOVS temperatures over the experiment site and over the radiosounding station will be used to correct the atmospheric profile, which is used for the surface temperature correction.

CURRENT STATUS OF THE RTOVS SOFTWARE SYSTEM AND ENHANCEMENTS TO THE ATOVS SOFTWARE SYSTEM IN PREPARATION FOR LAUNCH OF NOAA-K

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The RTOVS software system is now producing candidate operational quality products and is in the

process of replacing the TOVS software system as the NOAA/NESDIS operation. Enhancements are being made to the ATOVS software system based on "lessons learned" from RTOVS processing results. The RTOVS system has a more dense retrieval coverage, modernized software structures and the use of AVHRR in cloud detection. The ATOVS software system includes the above features in addition to retrieval processing using the Advanced Microwave Sounding Unit (AMSU), updated (corrected) HIRS/3 water vapour spectral bands (7.3 μm and 6.7 μm) and vector software structure on a CRAY J916 workstation.

This paper describes the RTOVS retrieval system relative to the current TOVS operation, ongoing development activities, and the status of the current "day-1" ATOVS software system on the NESDIS CRAY J916 and IBM mainframe computers. Included are such topics as pre-launch support for NOAA-K, NOAA-K fall-back capabilities, and planned upgrades to the "day-1" ATOVS software system to meet operational requirements.

OPERATIONAL USE AND EVALUATION OF ITPP5 PRODUCTS AT THE HUNGARIAN METEOROLOGICAL SERVICE

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The operational use of TOVS data has become an integral part of the meteorological data processing system of the Hungarian Meteorological Service. Data from all available NOAA satellite overpasses acquired at the Service's HRPT satellite receiving station are processed real-time by ITPP5 (International TOVS Processing Package). In the processing, ECMWF analysis and forecast products are used as surface and first-guess information. The derived geophysical fields are transferred to the recently developed FX-type Hungarian Meteorological Workstation for meteorological analysis. The quality of the products is continuously evaluated. In the paper two kinds of evaluation results are presented. First, the TOVS-derived precipitable water amounts are compared to collocated radiosonde and GPS (Global Positioning System) data. Second, the operational applicability of ITPP total ozone retrievals is discussed on the basis of a comparison to Dobson measurements for a one-year period.

DIFFERENCES BETWEEN THE MSU TEMPERATURES OF TWO WORKING SCHEMES OWING TO DIFFERENT CALIBRATION

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Starting from the European level-1 representation SHARP-1 LV-TOVS, a level-2A representation for calibrated and earth-located MSU (and HIRS/2) measurements was carried out (program system INGTSH). To assess the efficiency of the working line SHARP-1-LV-TOVS - INGTSH codes, its results are compared with the analogous results of the working line ITPP-INGTOV (evaluation of directly received HRPT data). The following MSU antenna temperature differences arise: an overall average of 0.3 K, averages for scanning-line groups of up to 0.5 K (averaging of several passes) or 0.7 K (individual passes) and single values up to over 0.7 K are returned from investigation of subpolar/polar NOAA-10 passes. The values are to be ascribed to different methods of smoothing and of treating the space view calibration point (pre-launch radiances, or temperature). The contribution from the latter may vary with the antenna temperature in earth view. When deriving climatological values the data included are not permitted as a rule to come from differently calibrated sources. With the AMSU, the findings should be kept in view.

PC-TOVS: A DESKTOP PC PROGRAM FOR THE EXTRACTION AND ANALYSIS OF TOVS DATA

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The development of low-cost, reliable, PC-based satellite reception systems has enabled developing countries to access data which are used to enhance their natural resources management programmes. The atmospheric profile data provided by TOVS are especially versatile. NRI has developed and field-tested a PC-based TOVS extraction and analysis program, in collaboration with the University of Wisconsin (using ITPP-4 and -5) and the British Antarctic Survey. Users can display wind, temperature, dew point and geopotential height data at selected pressure heights, or map total column water vapour and ozone, horizontally, as well as display associated NOAA AVHRR imagery, all within minutes of local data reception. Vertical profiles of dew point and temperature can be extracted as tephigrams for the TOVS sounding points. Displayed data can be printed, or incorporated into other geographical analysis programs. The operation of PC-TOVS is demonstrated by reference to a study from Punta Arenas, Chile. The further potential of the software is discussed.

HIRS/4+ITS: AN OPERATIONAL INFRA-RED SOUNDER WITH ADVANCED SOUNDER CAPABILITY

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Recent studies completed at ITT have shown that adding a high spectral resolution Michelson interferometer to the HIRS/4 instrument can provide an operational sounding capability that approaches the 1 K / 1 km goals of temperature sounding from low Earth orbit. The HIRS+ITS combines the existing operational HIRS instrument with a three-band interferometer subsystem that covers the full spectral range of the Interferometer Thermal Sounder (ITS). Using space-qualified Michelson interferometer technology being developed at ITT as part of the GOES High-resolution Interferometric Sounder (GHIS) programme, HIRS+ITS offers a relatively low-cost, low-risk approach to providing advanced sounding data products without affecting current operational TOVS capability and data output.

A NEW APPROACH FOR THE VERTICAL CHARACTERIZATION OF WATER VAPOUR FROM TOVS

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The main difficulties arising when retrieving water vapour from current instruments are the coarse vertical resolution of the water vapour sensitive channels (mainly TOVS channels 10, 11 and 12), the limited information content near the surface, the contamination by surface conditions, the cloud-handling (cloud coverage, cloud clearing, etc.).

The 3I algorithm has currently implemented a ridge linearized type estimation procedure. More

recently, a totally different approach has been derived which relies upon a neural network approach: inputs are brightness temperatures, outputs are water vapour content in 4 layers (surface, 850, 700, 500, 300 hPa). The training is so far done with an extended version of the current TIGR (more humid situations have been included). Results display better agreement with both radiosondes and SSM/I retrievals. This improved determination of water vapour allows for better a characterization of its variability in space (3D) and time, implying a more accurate estimate of the feedbacks due to water vapour, clouds and other variables (SST, sea-ice, etc.).

USE OF THE VERTICAL SOUNDING IN THE INFRA-RED FOR THE RETRIEVAL AND THE ANALYSIS OF THE LONGWAVE RADIATIVE BUDGET

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We have combined the global long-term database of thermodynamic variables we are currently elaborating within the framework of the NOAA/NASA Pathfinder/TOVS and GEWEX-GVap programmes with collocated computed vertical components of the Earth energy budget. The 3D thermodynamic structure and the cloud properties are inferred from TOVS through the application of the 3I algorithm. The radiative quantities are obtained by applying the ECMWF radiative code to the thermodynamic profiles and the cloud properties. Comparisons of the computed OLR and the one observed by ERBE for several months are made. Sensitivity studies are also performed in order to assess the accuracy of the flux profiles with respect to the uncertainties in the thermodynamic variables. Another part of the presentation is devoted to the characterization of the coupling between the variations of the atmospheric greenhouse trapping and thermodynamic variables, such as the water vapour in the upper and the middle troposphere, the lapse rate and the cloud parameters.

A FAST AND ACCURATE NEURAL NETWORK-BASED COMPUTATION OF LONGWAVE RADIATIVE BUDGET IN CLEAR AND IN CLOUDY SITUATIONS

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We have developed a method for the fast and accurate computation of longwave flux profiles, in clear sky as well as in cloudy situations, based on the multilayer perceptron (Rumelhart et al., 1986). An improved version of the TIGR dataset constituted the inputs of the learning set, from which we inferred the neural network parameters. Sampled from both radiosonde reports and satellite retrieved thermodynamic profiles (3I/TOVS product), this improved TIGR databank is a more representative set of the temperature and the water vapour distribution in the atmosphere than the previous TIGR dataset. The outputs of the learning set were computed with a standard radiative transfer model. We have tested our approach by direct comparison of the calculations with a wide-band model for two years of global data provided by the analysis of TOVS data with the 3I algorithm. Although our approach relies on a statistical method, the neural network method performs equally for the whole period, showing that its results are independent of the learning dataset. The dramatic saving of computing time induced by the neural network technique, 7 times faster than the ECMWF wide band model in clear situations, allows for using more accurate radiative schemes for computing the longwave radiative budget in climate simulations.

THE VARIATIONAL ASSIMILATION OF TOVS RADIANCE OBSERVATIONS: FORMULATION AND EVALUATION IN 1D AND 3D MODE

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The current optimal interpolation (OI) global data assimilation system of the Canadian Meteorological Centre (CMC) is about to be replaced with a variational (VAR) multivariate analysis system. The system has been formulated in a relatively general framework allowing for data to be assimilated in either 1D/3D and univariate/multivariate mode. The 1DVAR system has been developed and fully validated against the 3DVAR system for the assimilation of one observation. However, the 1DVAR has been designed and is used for the quality control of the radiances.

This variational system analyses geopotential as mass variable which is dynamically related to the wind components by a local geostrophic balance constraint. In the first version, the moisture analysis variable is $(T-T_d)$. However, in order to improve the rate of convergence of the minimization, we are in the process of converting to $\ln(q)$ as moisture variable. As a first approximation, error statistics (standard deviations) were simply recalculated based on recent 6-hour global forecasts, and there is ongoing work to derive correlation statistics based on 24- and 48-hour forecasts. Statistics for moisture in the form of $\ln(q)$ have been derived consistently from the $(T-T_d)$ statistics of the global system.

A complete visualization and evaluation system has been developed to help in the interpretation and evaluation of assimilation cycles. This has been particularly useful for diagnosing problems and for designing the quality control and assimilation of TOVS radiances. With the help of this software, we have been able to compare 1DVAR temperature retrievals to SATEMs and some results will be presented. The first operational 3DVAR system which assimilates SATEMs will be compared to a revised system assimilating TOVS radiances directly. Forecasts issued from each system will be evaluated and presented.

ANALYSIS OF THE SPATIO-TEMPORAL VARIABILITY OF TOVS-DERIVED STRATOSPHERIC TEMPERATURES

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Global observations from the satellites of the TIROS-N series, equipped with the HIRS-2 and MSU radiometers permit the determination of atmospheric temperature profiles up to 10 hPa (about 30 km). At the present time, 31 months of TOVS data have been processed using the Improved Initialization Inversion (3I) developed at Laboratoire de Météorologie Dynamique. Mean layer temperatures for the layers 100-70, 70-50, 50-30, and 30-10 hPa are thus available on a day-by-day basis, but also averaged over pentads and over months, with a spatial resolution of 1 degree in latitude by 1 degree in longitude. Collocations with radiosondes as well as comparisons with stratospheric analyses indicate that the retrieved stratospheric temperatures obtained through 3I are realistic, with specific events like stratospheric coolings or warmings well represented. Comparisons between monthly-mean temperatures obtained by 3I and produced independently by the Free University of Berlin over the Northern Hemisphere will be presented and discussed. The high inter-annual variability of the temperatures will be shown, with an emphasis on polar regions.

HIRS/2-LIKE TOTAL WATER VAPOUR COLUMNAR CONTENT MEASUREMENTS FROM AVHRR

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Merging of data-processing products coming from different satellites or sounders usually exhibits strong inhomogeneity mainly due to differences in instrument capabilities (spatial, spectral, temporal resolution and coverage) and retrieval techniques (global/local algorithms and validation datasets) which can be enhanced from the intrinsic space-time dynamic of the variable under study. In this paper we face this problem in the case of total water vapour columnar content (TWVCC) measurements performed at the global scale by using HIRS/2- and AVHRR-based techniques. Observed TWVCC spatial variability related to observation conditions (land/sea, dry/wet atmosphere, sea/night) has been analyzed by using several satellite passes and collocated radiosondes over Europe. An optimal merging technique able to reproduce HIRS/2-like (no-bias, same error structure) TWVCC retrievals from AVHRR data in partly cloudy HIRS/2 locations has been then proposed and results compared with coincident radiosondes.

THE USE OF TOVS RADIANCES AT NCEP

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TOVS radiances have been used operationally at the National Centers for Environmental Prediction (NCEP, formerly the National Meteorological Center) in the global data assimilation system since October 1995. A large positive impact on the forecast skill over that produced using the NESDIS retrievals was found. The direct use of radiances was made possible by the development and operational use of a 3-D variational analysis system known as Spectral Statistical Interpolation (SSI). The incorporation of the radiances required the use of a fast radiative transfer model (RTTOV, acquired from the ECMWF) and the development of a bias correction scheme, a total ozone and skin temperature analysis, and a radiance-based quality control system. In addition to these aspects and the basic assimilation scheme, recent results and future plans for the improved use of the TOVS data and other satellite-based radiance data will be presented.

A PILOT AAPP-BASED OPERATIONAL PROCESSING SCHEME

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Since April 1996, Météo-France has been using AAPP ingest as a preprocessor to the NOAA TOVS, DCS and AVHRR data. The AAPP code both developed by Météo-France and UK Met Office, and later integrated by KNMI, has been included in a common home-made architecture allowing the processing of NOAA satellite data, but also METEOSAT and GOES-8 on UNIX work stations.

The status of the current implementation will be presented as an illustration of the AAPP usability in its present state and its adaptability to monitoring functions.

PLANS FOR THE PROCESSING OF ATOVS DATA AT UK METEOROLOGICAL OFFICE

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The UK Meteorological Office will process two streams of ATOVS data: a global stream from NOAA/NESDIS and a local stream from a local satellite reception station. Processing of both streams will make use of software being developed under the Eumetsat-sponsored ATOVS initiative. The global data stream will be pre-processed and then presented for direct assimilation into the UK Met Office's global NWP model. It will also be passed on to a number of European NWP centres. One potential application of the local stream will be to provide timely AMSU imagery products to "on the bench" forecasters. AMSU-B housekeeping data will be used for detailed instrument monitoring and more general monitoring of the system will also take place to assess quality and support tuning procedures.

THE AAPP MODULE FOR IDENTIFYING PRECIPITATION / ICE CLOUD, LIQUID CLOUD AND SURFACE TYPE ON THE AMSU-A GRID

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A preprocessing package has been developed for the Advanced Microwave Sounding Unit (AMSU) at the UK Met Office. This is designed to identify observations contaminated by scattering by ice cloud and precipitation, high values of cloud liquid water path, and to identify the surface type. Since AMSU measures a single polarisation, the preprocessor has to be designed using only frequency comparison and spatial homogeneity tests. We have selected a number of ideas previously tested in the literature and brought them together to form a package for AMSU. The tests are applied on the AMSU-A grid and determine how data are mapped to the HIRS grid, where the retrieval/assimilation step will be performed, and which channel radiances should be assimilated. The tests include a scattering index, a maximum probability test for cloud and surface type, a cloud/rain emission test and a spatial homogeneity test of AMSU-B 89 GHz data on the AMSU-A grid. The preprocessor tests have been applied to simulated AMSU datasets generated using an independent radiative transfer model using UK Met Office mesoscale model fields.

SIX YEARS OF MICROWAVE RADIATIVE TRANSFER VALIDATION USING AIRBORNE RADIOMETERS: THE MAIN RESULTS

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Radiometers with channels at 23.8, 50.1, 89.0 and 157.0 GHz are fitted to the UK Met Office's C-130 aircraft. Field studies have been carried out to test the validity of the radiative transfer model for the Advanced Microwave Sounding Unit. Laboratory measurements of the strength of the microwave

water vapour continuum are not consistent, which has resulted in a number of different empirical models. Comparisons with the aircraft data have been used to compare different models. The oxygen model has been similarly tested. Validation of models of cloud liquid water are difficult because of a lack of reliable in situ data. We do not expect large errors in the cloud model. If we minimise all other sources of error and use a simple cloud model to retrieve cloud liquid water content from the aircraft radiometer, we get reasonable agreement with observed values. A geometric optics sea surface emissivity model gives good agreement at high frequency, but a bias exists at low frequency. Currently estimates of emissivity for other surfaces are being collected, and study continues of radiative transfer through ice cloud and precipitation.

RETURNING TO A PHYSICAL FORMULATION OF TOVS TRANSMITTANCES

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For the operational assimilation of infra-red and microwave satellite sounding radiances, the route chosen so far has been that of fitting by regression the optical depth of water vapour, ozone and mixed gases. The regression (generally about 10 parameters per absorber type) is based on an ensemble of atmospheric profiles defined on 40 pressure levels for which accurate upward radiances were calculated using a line-by-line (LBL) model. Here, an attempt is made to compute the optical depths directly using the classical Goody random model formulation. Such an approach works directly on the NWP model coordinate; there is no need to interpolate to and from a fixed pressure grid. The frequency integration is approximated by using averaged spectroscopic parameters for the absorption coefficient and temperature effects. Due to this approximation, a final tuning is necessary: a single coefficient (for each of the five gases considered) typically near unity which multiplies the optical depth. Independent LBL radiances were used for the validation, and results so far are very encouraging. The biases after tuning are negligible and r.m.s. brightness temperature errors are generally below 0.3 K for the first 12 TOVS channels tested. The physical model rivals the regression approach in terms of speed and it is straightforward to derive the adjoint of the model.

COMPARISON OF RADIATIVE TRANSFER CALCULATIONS USING THREE FAST TRANSMITTANCE ALGORITHMS

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A four-way comparison of radiative transfer calculations versus TOVS observations is presented. TOVS nadir radiances are collocated with rawinsondes. Radiances are computed using RTTOV with ECMWF generated coefficients, RTTOV with Météo-France coefficients, OPTRAN and TRANH. Bias and standard deviations of differences between measured and computed are presented.

ATMOSPHERIC INFRARED SOUNDER (AIRS)

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The Atmospheric InfraRed Sounder (AIRS) is a grating spectrometer measuring thermal infrared radiation for 2378 spectral samples between wavenumbers 650 and 2700 cm^{-1} with an average spectral

resolution of 1200. AIRS is to fly on the second Earth Observing System polar orbiting platform, EOS-PM1, scheduled for December 2000. The same platform will also carry AMSU-A and an AMSU-B-like microwave humidity sounder. AIRS is designed to meet NOAA's temperature and moisture retrieval requirement of 1 K and 15 %, respectively, for 1 km thick layers in the troposphere. Algorithms for cloud clearing radiances and retrieving surface properties and atmospheric profiles of temperature and moisture have been developed and tested.

An overview of the AIRS instrument design and specifications is presented, followed by a detailed description of the retrieval algorithms and results. AIRS retrieval accuracy is compared with ATOVS.

THE RETRIEVAL OF TEMPERATURE AND WATER VAPOUR PROFILES FROM ATOVS DATA: AN ADAPTATION OF THE 3I SCHEME

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To study global change, there is a need for an accurate long-term observational dataset. To serve this purpose, the 3I-scheme has been developed to get benefit from the NOAA long-term TOVS dataset, by performing the retrieval of temperature and water vapour profiles from TOVS data (NOAA/NASA Pathfinder programme). However, in the near future, on-board the NOAA-next platform, the Microwave Sounding Unit (4 channels near 50 GHz) will be replaced by an Advanced MSU, grouping AMSU-A (15 channels) and AMSU-B (5 channels). Thus, apart from the improvement of horizontal spatial resolution, the new scheme has to deal with the change in microwave information (nature and amount).

This presentation is to describe the adaptation of the current 3I algorithm to this new type of soundings. The line-by-line radiative transfer model STRANSAC has been used to extend the current TOVS TIGR to ATOVS data. A neural network approach has been derived to infer the first guess for the temperature retrieval process of ATOVS data as well as for the H₂O retrievals based on a coupling of MHS and AMSU-A. This suite of algorithms is presently tested using the OSSE-ATOVS data base created at ECMWF. A description of the algorithms as well as results of the retrievals will be given.

THE EFFECT OF QUADRATURE ERRORS ON SIMULATED AMSU-A BRIGHTNESS TEMPERATURE

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The Advanced Microwave Sounding Unit (AMSU), which consists of 15 channels thermal sounding instrument (AMSU-A) and a 5 channel water vapour sounder (AMSU-B), is expected to provide improved vertical resolution. Owing to its relatively narrow weighting functions, the effect of quadrature errors on simulated brightness temperature values is studied. The effect of quadrature errors depends on two sources: one is resulting from the integration of the radiative transfer equation; the other is due to interpolations resulting from the inability of a discrete set of points to fit the whole atmospheric profiles. Compared with the results using the piecewise cubic Bessel interpolation and the composite Simpson's 3/8 rule with a uniform pressure subgrid of 0.01 mb, the brightness temperature errors using a 40-level transmittance model without interpolation are shown to be significant for AMSU-A channels 8-14. These channels are responsible for the retrieval of temperature

profile in the upper atmosphere.

A HYBRID ITERATIVE METHOD FOR ATOVS TEMPERATURE PROFILE RETRIEVAL

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A hybrid iteration method is proposed for temperature profile retrieval. It combines the advantages of Smith's iteration method (1970) and Chahine's relaxation method (1970), and is faster and more accurate than either method applied independently. Using ATOVS channels, the validity of the method is illustrated through the determination of temperature profiles and surface temperatures for atmospheres, ranging from tropical to arctic winter.

EXPECTED PERFORMANCE EVALUATION OF ATOVS SOUNDING PRODUCTS

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The ATOVS (AMSU/HIRS) system is expected to provide improved sounding accuracy and vertical resolution as well as lead to the development of new sounding products. Using objective techniques emphasizing information analysis and inversion methods, this paper quantitatively measures the anticipated sounding accuracy and vertical resolution. A simulated orbital pass consisting of HIRS/3 infra-red radiances and AMSU-A (15 channels, 50 km fov at nadir) and AMSU-B (5 channels, 17 km fov at nadir) microwave thermal and moisture brightness temperature measurements are used to demonstrate the expected performance of the ATOVS. The analytical procedures used in this study are described in detail. The expected improvements due to ATOVS are also compared to the capabilities of contemporary and proposed advanced sounding systems.

EVALUATION OF MODEL OLR IN CLOUDY REGIONS USING TOVS 1B DATA

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With the introduction of the new cloud scheme at ECMWF, a cold tropospheric bias already existing in the extra-tropics of both hemispheres has been increased. Tracing the increase of this bias it was found that there is a marked increase in longwave flux divergence over the extra-tropical oceans. This increase explains an additional radiative cooling of the atmosphere. Further diagnostics reveal that the increase in flux divergence could be related to an overestimation of OLR. A new study was carried out with the latest version of the ECMWF IFS model which put emphasis on clouds over the extra-tropical oceans and over land. It has been found that the IFS model generally overestimates OLR in cloudy conditions. The worst cases identified are those of deep convective clouds over tropical land areas. However, there is also a strong overestimation in frontal situations in the extra-tropics of both hemispheres. This results mainly from the fact that the low OLR signatures of these features are too narrow. The reason for that is unknown and needs further investigation.

INVESTIGATION OF SYSTEMATIC ERRORS AND CORRECTION MODELS

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Systematic errors in observed and computed radiances can arise from several sources including the use of incorrect physics or parameters in the radiative transfer model (e.g. incorrect spectroscopic parameters, specification of "fixed-gas" mixing ratios, filter functions, and errors from fast transmittance models, etc), calibration errors, pitch and roll of the satellite, and detector non-linearity. In most retrieval and data assimilation systems it is assumed that systematic errors have been removed or bias predictors are included directly in the state vector. Because biases can be as large or larger than the random component of radiance errors, the ultimate success of any algorithm depends upon the effective treatment of bias. We have developed a hybrid physical-empirical parameterization to correct for systematic errors in TOVS radiances. We compare our approach with other bias-correction schemes using both simulated data and collocated radiosonde data. Improvement in fast transmittance models may eliminate the need for empirical air-mass terms in the parameterization.

EFFICIENT METHODS TO ASSIMILATE DATA FROM FUTURE REMOTE SOUNDING INSTRUMENTS

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It is currently feasible to assimilate radiances from TOVS using a three-dimensional variational scheme. Advanced sounding instruments, such as IASI and AIRS, will have orders of magnitude more spectral elements than TOVS. The tremendous increase in data volume may prohibit the complete use of these data in data assimilation systems. We have investigated several methods to compress the information contained in high-resolution spectra, thereby greatly reducing computational costs in data assimilation systems. Costs are reduced in three ways: (1) linearization of the radiative transfer is performed in 1D rather than in 3D; (2) data reduction reduces the size of the observation vector; (3) the conditioning of the statistical analysis equations to be solved improves. The data compression step can be thought of as either a transformation of radiances, a retrieval with no background contamination, or in the context of "super-channels".

RECENT IMPROVEMENTS AND EVALUATION OF NEURAL NETWORK APPROACH FOR TOTAL OZONE RETRIEVAL FROM NOAA-TOVS DATA

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The approach of using neural networks for ozone retrieval from TOVS data presented at ITSC-8 will be improved and evaluated by applying it to different long term data sets. Two case studies are carried out covering whole Europe, North Africa and parts of the Atlantic Ocean. The first data set covers the period of July and August 1993 and the second one range from June 1994 to November 1994.

TOVS data are classified into day/night and cloud free/cloudy pixels and collocated with ground measurements of total ozone content. The collocated pixels are divided into a training and test data set. For all cases (clear/cloudy, day/night) the absolute mean error of the improved neural network

approach for the total ozone retrieval of the test data set is about 9 Dobson Units for the two ozone ground measurement station of German Weather Service (DWD), Hohenpeissenberg and Potsdam.

The studies show that it is possible to retrieve the total ozone content of the atmosphere with an accuracy of about 2% for all weather conditions. The advantage of the TOVS data compared to other satellite instruments for ozone retrieval (TOMS, SBUV, GOME) using the solar spectrum is that also during night good accuracy of the ozone data can be achieved and that long term TOVS data (global coverage) are available for the last 19 years.

IMPACT OF OBSERVATIONS ON THE OPERATIONAL ECMWF SYSTEM

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A series of 15-day data assimilation experiments and 10-day forecasts at T213/L31 were run to examine the impact of various combinations of satellite and conventional data on the operational 3D-VAR system. Not since 1990 have these type of OSEs been run in a systematic way at operational resolution. In the past OSEs (1990), it was shown that there were problems with the use of TOVS in the Northern Hemisphere and they were removed until the introduction of 1D-VAR. These new experiments involved the systematic removal of TOVS, AMWs (SATOBS), RAOBs, AIREPS, PAOB, TOVS and AMWs (NOSAT), ERS2, all space (ERS2 and TOVS and AMWs). These experiments were designed the test whether the new 3D-VAR system was tuned in a way to extract information from all observation systems and examine if there were any problems with the use of combinations of observing systems. The overall results look very encouraging, as the new 3D-VAR derives important benefit from both the space system and conventional observations.

THE ASSIMILATION OF GEOSTATIONARY RADIANCES

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Geostationary satellites radiances now provide high spatial resolution and comparable or better signal to noise than the polar satellites. These data are now being investigated for use in variational analysis, especially for use in 4DVAR, where the high time frequency of these observations can be exploited. The usual problems of calibration, forward modelling and bias tuning will be discussed together with some preliminary results.

EVALUATION OF MULTILEVEL CLOUD PARAMETERS WITH CLOUD PROFILING RADAR

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NOAA's Forecast Systems Laboratory (FSL) produces cloud parameters at each HIRS field-of-view identified by matching with full resolution AVHRR image in real-time (Kim and Chou 1995). Since the product is independent of any NWP first guess, it will be used as a initial guess to multilevel cloud parameters for cloudy TOVS radiance data assimilation to real-time assimilation system called

Mesoscale Analysis and Prediction System (MAPS) operated by FSL. The initial cloud parameter guess is being used as a weak constraint in the minimization problem. The solution of constrained minimization is compared with cloud profiling radar which is operated by NOAA Environmental Technology Laboratory and is situated in the southern plains of the United States.

ATOVS DATA PROCESSING IN EUROPE

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In reaction to a requirement from the user community, EUMETSAT is coordinating the development of a software package to process locally received ATOVS and AVHRR data from the HRPT data stream of the NOAA-K,L,M spacecraft. The package developed in the first step, the ATOVS and AVHRR Processing Package (AAPP), will perform the ingest process, i.e. the decommutation, Earth location and calibration of the data, and also the pre-processing. The latter module is intended to fulfil the analysis of the data for effects (e.g. precipitation contamination, contamination by large ice particles, etc.) which deem them unsuitable for further processing. A development group of European organizations has designed and developed AAPP. The package is available in a first integrated form and is being tested with current TOVS data. After the launch of NOAA-K a second round of testing with ATOVS data is foreseen. Through 1997 the development of the retrieval step is planned.

EUMETSAT FUTURE PLANS

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EUMETSAT plans for future satellite systems are presented with emphasis on sounding capabilities. In the framework of the METEOSAT Second Generation Programme (MSG), the SEVIRI instrument will provide some sounding capabilities. The major EUMETSAT contribution to the sounding community will be provided by the EUMETSAT Polar System (EPS). The launch of METOP-1, the first satellite in the EPS Programme, is planned for 2002. The core payload for operational meteorology will be the High-resolution Infrared Radiation Sounder (HIRS/4), the Advanced Microwave Sounding Unit-A (AMSU-A), the Microwave Humidity Sounder (MHS), the Advanced Very High Resolution Radiometer (AVHRR) and the Infrared Atmospheric Sounding Interferometer (IASI), the latter providing advanced sounding capabilities. In addition, a GNSS Receiver for Atmospheric Sounding (GRAS) will complement the sounding capabilities using the signals of GPS and GLONASS navigation system satellites. Additional instruments embarked will be an Advanced Scatterometer (ASCAT) and an Ozone Monitoring Instrument. The Space Environment Monitor (SEM) and also the Search and Rescue (S&R) system form auxiliary components.

OPTRAN FOR DATA ASSIMILATION: DEVELOPMENT OF THE TANGENT LINEAR AND ADJOINT

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OPTRAN has been adapted for use in direct radiance assimilation. The transmittance code in RTATOV has been replaced with OPTRAN. The tangent linear and adjoint of the OPTRAN code

have been generated and inserted into RTATOVTL and RTATOVAD. This paper will describe some of the pitfalls of generating adjoint code, and will present some preliminary results in comparison of level 1B radiances with RTATOV/OPTRAN.

HIRS/4, THE 10 KM IFOV INSTRUMENT

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Studies performed in 1993 analyzed effects of reducing HIRS ifov size on probability of achieving cloud-free infra-red soundings. These studies showed reducing HIRS nadir ifov size from 20 km to 10 km will provide twice as many clear soundings. NASA/NOAA directed ITT to proceed with modifications required to reduce ifov size to 10 km. Subsystems affected include the radiant cooler, infra-red detector electronics and telescope assembly. HIRS Engineering Test Model (HETM) data have shown excellent responsivity, noise and ifov performance. Ifov registration and size matching are better than previous instruments. Responsivity and noise for all channels except Channel 1 (14.95 μm) are better than specification goals. Based on the HETM success, instruments scheduled for flight on POES N and N' and METOP satellites will have a 10 km ifov. Reallocation of telemetry bandwidth to allow for transmission of more temperature sensor data will enhance HIRS/4 calibration capability. Additional temperature sensors have been placed on the internal warm target and on the telescope baffle. Better information on background radiation and stability of the warm target will allow for higher calibration resolution. Data products such as spectral response and calibration coefficients have also been enhanced to provide for more accurate calibration of instrument data.

CURRENT STATUS FOR THE ICI RETRIEVAL SCHEME

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The ICI (Inversion Coupled with the Imager) model processes the TOVS sounding measurements together with imaging cloud information to produce sounding retrievals in the CMS acquisition zone. In the beginning of 1996, the software was restructured to take into account the operational requirements of an acquisition station and to include a tuning/validation scheme. This software has been operational for one year. We will present the current software status and the departure between the ICI retrievals and the numerical weather analysis for one year of results.

IMPROVING WEATHER FORECASTS IN THE AUSTRALIAN REGION BY CONTINUOUS ASSIMILATION OF DIRECT READ-OUT DATA

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Observations, directly received in real time from the NOAA-11, -12 and -14 satellites and the Geostationary Meteorological Satellite, GMS-5, are vital to real-time mesoscale analysis and forecasting in the Australian Region. Physically-based methods for determining temperature, moisture

and total ozone column have been established to use radiance observations from the AVHRR and TOVS instruments aboard the NOAA satellites. These methods provide real-time estimates of atmospheric state for operational use over the Australian region. Physically-based methods have also been established to estimate wind speed from visible window and water vapour wind observations over the Australian region at hourly intervals for operational and research purposes.

This paper records the utility of these data and documents their respective impacts on analysis and forecasting in the Australian region. It shows that TOVS data, in general, are necessary to maintain high numerical weather prediction accuracy and that, in particular cases, their impact is essential. Examples of the utility of a multi-instrument approach, namely TOVS and AVHRR for temperature and absorber concentration, and TOVS and SBUV/2 for estimating ozone concentration, are also shown. The relative importance of both visible and infra-red based hourly cloud motion vectors for forecasts in the Australian region is also noted. The results shown have been derived using both intermittent and continuous data assimilation techniques. In summary, it has been established that the timely nature of direct readout satellite data, in conjunction with their high spatial and temporal resolution, are vital for specifying current and future atmospheric states.

THE USE OF SUPER CHANNELS FOR HIGH RESOLUTION SOUNDINGS

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When satellite radiances are used to produce temperature soundings, the radiances are used in two conflicting ways. Because the radiances represent broad regions of the atmosphere, they must be differenced to extract values appropriate for finer regions. But if the channels are too similar, this amplifies noise. In fact, channels which are similar should be averaged to reduce the random noise. Super channels are a way of doing both at once. Channels whose correlation exceed a given level are averaged into a single value called a super channel. Super channels are used for the retrieval. Doing this reduces the number of channels required for the retrievals. In a model that uses radiances, fewer channels must be assimilated. For the AIRS instrument, a set of about 350 super channels is compared to the results of other solutions such as eigenvector regression. The use of super channels is a way to use the information in all the channels. Preliminary tests show retrieval accuracies equal to or better than those of alternative approaches such as eigenvector regression.

USE OF TOVS LEVEL 1B RADIANCES IN NWP

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Variational analysis methods allow the direct assimilation of radiance data into numerical weather prediction schemes. TOVS clear radiances are operationally assimilated in a number of major centres currently, but in principle the variational methods have the ability to assimilate radiances contaminated by cloud, non-linear surface effects and scan geometry. Therefore there is an interest in assimilating the "raw" TOVS data. Firstly, the processing stages required to produce "clear" radiances can introduce large random and systematic errors into the data that will subsequently degrade the quality of the numerical forecasts. Secondly, treating cloud and surface parameters as analysis variables (rather than contaminants) provides useful real-time global estimates of these quantities for model diagnosis/assimilation. This paper discusses the scientific (and technical) difficulties associated with using TOVS level 1b data and presents a possible strategy for operational assimilation. Some

encouraging preliminary results are also presented.

EIGHT YEARS OF GLOBAL CIRRUS CLOUD STATISTICS USING HIRS

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Global upper tropospheric transmissive cirrus cloud cover has been charted for the past eight years (June 1989 - December 1996) using NOAA polar orbiting HIRS multispectral infrared data. Cloud occurrence, height and effective emissivity are determined with the CO₂ slicing technique that accounts for clouds partially filling the sensor field of view and semi-transparency of some clouds. High semi-transparent cloud detection has increased by roughly ten percent since summer 1989, with thin cirrus accounting for seven of those ten percent; total cloud detection has remained about the same. Comparisons with cloud studies conducted by the International Satellite Cloud Climatology Project reveal similar trends. Causes for the apparent increase in high transmissive cloud are under investigation.

NOAA'S PLANS FOR POLAR SATELLITES: THE 1990'S AND BEYOND

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The primary sensors flown on board the two operational (morning and afternoon) POES have changed only slightly over the past fifteen years since the launch of TIROS-N in October 1978. The next significant instrument changes will take place on NOAA-K starting in 1997 when the Advanced Microwave Sounding Unit (AMSU) replaces the Microwave Sounding Unit (MSU) and Stratospheric Sounding Unit (SSU), and the Advanced Very High Resolution Radiometer (AVHRR) will time-share channel 3 between 3.7 μm at night and 1.6 μm at day (for snow mapping). Later in this series of five satellites, the High resolution Infrared Radiation Sounder (HIRS) will be upgraded to a 10 km footprint. The NPOESS series of satellites will introduce even more significant changes starting about 2007. The notional payloads are Visible/IR imager with ocean colour and low light capabilities, cross-track infra-red sounder, cross-track microwave sounder, conical microwave imager/sounder, and ozone and Earth radiation budget sensors. The convergence of military and civilian satellites and the agreement that Europe provides the morning satellite make it likely that there will be polar orbiters at 0530, 0930 and 1330 local time. NOAA is working on the goal of providing uninterrupted, global observations from the POES series which will be periodically upgraded in an evolutionary manner.

SEA-SURFACE TEMPERATURE AND NEAR-SURFACE HUMIDITY FROM 3.7, 11 and 12 μm BRIGHTNESS TEMPERATURES

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The joint and accurate retrieval of sea-surface temperature and near-surface water vapour is necessary for improving global estimates of evaporation (latent heat flux) from the oceans. Current measurements of latent heat flux are less accurate than is needed for understanding climate processes

(required accuracy: 10 W m^{-2} monthly mean for a 2×10 degree box). We compare the capabilities of single-view (e.g. AVHRR) and dual-view (e.g. ATSR) instruments, and compare the success of linear and non-linear retrieval. The methods are robust against varying optical thicknesses of stratospheric aerosol and the effects of wind speed on surface emissivity. Our simulation study suggests that dual-view, 3-channel algorithms are able to retrieve globally the water vapour density in the lowest 500 m to better than 1.3 g m^{-3} (matching results obtained by others (i) by combining AVHRR and HIRS observations, and (ii) using SSM/I).

UTILIZATION OF AAPP WITHIN ATPP-1

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The Cooperative Institute for Meteorological Satellite Studies (CIMSS) has initiated the software design phase for the Advanced TOVS Processing Package (ATPP-1). In late fall of 1996, visits were made to Météo-France, the UK Met Office and the European Centre for Medium-range Weather Forecasts to discuss collaboration on NOAA-KLM software development. Preliminary versions of the ATOVS and AVHRR Processing Package (AAPP) were obtained and an early assessment of the code found it to contain consistent processing strategies and code structure, and a significant amount of documentation.

CIMSS is jointly cooperating with the European community in development and testing of the AAPP to both benefit from and help to improve the package. To that end, ATPP-1 will be designed to take advantage of many AAPP processing strategies and all AAPP data formats. This standardization will provide a consistent platform for future experiments in ATOVS retrieval science.

It is expected that ATPP-1 will utilize AAPP decommutation, calibration and navigation. After this point, some ATPP-1 routines will begin to differ. ATPP-1 will combine geometric intra-instrument mapping utilities available within AAPP with those developed at CIMSS. Strategies for the use of AVHRR, consistent with ITPP-5 procedures, will be introduced. The capability of processing full orbits and the use of numerical model forecast data as a first guess will be added. Finally, the first ATPP-1 retrieval algorithm is currently planned to operate with the AMSU-A field of view as a basis, rather than the HIRS-based strategy currently employed by ITPP-5 and the AAPP.

OPERATIONAL PROCESSING OF RTOVS VS TOVS

Cecil A Paris

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The forthcoming NOAA-K, -L and -M satellite series represents a major improvement in the basic instrument complement on the NOAA series of sun-synchronous POES spacecraft employed since the launch of TIROS-N in October 1978. An improved atmospheric sounding capability of NOAA-K, -L and -M instruments will result from the replacement of the current SSU and MSU by Advanced Microwave Sounding Units (AMSU/A and AMSU/B).

Due to the structure of the TOVS ground processing system, it could not be easily modified to retrieve the sounding products from radiance measurements of the instruments on the NOAA-K, -L and -M

satellites. Hence, concepts for a new software system (ATOVS, for Advanced TOVS) to retrieve the sounding products from the NOAA-K, -L and -M satellite data were developed.

RTOVS serves as a bridge between TOVS and ATOVS. With expectations of having RTOVS implemented operationally by February 1997, the changes in software, retrieval processing and concepts will be discussed in this paper.

IMPROVING DATA ASSIMILATION AND FORECASTS BY REVISING THE QUALITY CONTROL FOR SATEM DATA

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At DWD, temperature and humidity profiles from polar-orbiting satellites as provided by NESDIS are used at a resolution of 500 km. A recent inspection of the quality control procedures for these "SATEM" data within the Optimum Interpolation analysis has shown serious deficiencies. The previous operational scheme for data checking had too weak error-limits. Tightening the error-limits for checking observation against forecast and against nearby observations increased space and time consistency of analyses of geopotential height and temperature fields and led to marked improvements in forecast quality.

IASI, A NEW GENERATION ATMOSPHERIC SOUNDER FOR THE EUMETSAT POLAR SYSTEM

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IASI is a Michelson interferometer dedicated to measurements of atmospheric parameters for operational meteorology, climate monitoring and also for research-related activities. It has been designed to be embarked on the METOP series of polar satellites to be launched and operated by EUMETSAT. The launch of METOP-1 is anticipated for the year 2002. The main mission objective of IASI is to provide vertical profiles of temperature and water vapour with improved accuracy and vertical resolution compared to previous sounders (e.g. HIRS). Other objectives are the retrieval of the total amount and possibly profiles of ozone, the total amounts of further trace gases (CO, CH₄, N₂O, SO₂, CFCs), of cloud parameters and surface temperatures. The mission rationale and requirements for IASI have been approved by the IASI Sounding Scientific Working Group (ISSWG) which has been set up jointly by CNES and EUMETSAT for the scientific preparation of the IASI mission. The instrument will sample in 30 steps along a scan line which is about +/- 49 degrees wide. At each step, four interferograms are measured, related to four IASI sub-pixels of 12 km (possibly 9 km) diameter, arranged in the form of a 2x2 matrix. The size and number of sub-pixels has been optimized to get the highest probability of cloud-free radiances under cloudy conditions. IASI has an unapodized spectral resolution of 0.35 cm⁻¹ (full-width half-maximum). The radiometric noise NEDT in channels of 0.5 cm⁻¹ is close to 0.2 K (at 280 K) for the spectral regions of interest. Results of scientific studies performed within the framework of ISSWG activities have demonstrated that with the specified radiometric and spectral performances the objectives of 1 K accuracy and 1 km resolution for retrieved temperature profiles can be achieved.

**A SOLUTION OF THE NON-LINEAR INVERSE PROBLEM
OF SIMULTANEOUS ESTIMATION OF THE ATMOSPHERIC TEMPERATURE
AND UNDERLYING SURFACE EMISSIVITY ON THE BASIS OF THE SATELLITE
SPECTRAL MEASUREMENT OF THE MICROWAVE REGION SPECTRUM**

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In the processing of microwave (MW) information there is a principal aspect involving the estimation of underlying surface emissivity (SE). A question of the interdependence of estimates of SE and temperature parameters is under consideration. The disturbance of the problem operator in the radiative transfer equation (RTE) due to the SE error generates error correlating with the desired solution. It explains the mechanism of the change for worse of the first guess temperature profiles when sounding in heavy cloudy conditions; if the accuracy of the first guess of surface temperature (ST) used to estimate SE is significantly poorer than the accuracy of the atmospheric temperature first guess, then the ST error is propagated by the SE estimate into the measurement model. Such situation is rather the rule: temperature uncertainty has maximum into the atmospheric lower boundary. An approach for solving a non-linear problem is proposed. It is shown that in the atmosphere the value of the temperature error due to the disturbance of operator can achieve 0.5-1.0 K on the respective levels under the variation of ST of about 5 K.

**STATEMENT OF "TUNING" PROBLEM COMBINED WITH AN INVERSE PROBLEM
SOLUTION IN THE SATELLITE REMOTE SENSING OF GEOPHYSICAL
PARAMETERS OF "UNDERLYING SURFACE + ATMOSPHERE" SYSTEM
ON THE BASIS OF THE INFRA-RED SPECTRAL MEASUREMENTS**

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The problem of accuracy modelling plays an especially important role in interpretation of satellite spectral measurements based upon a numerical solution of the radiative transfer equation (RTE): difficulties in solving the inverse problem (IP) arise because the RTE is substantially non-linear and the problem ill-posed. The IP to be solved numerically must be regularized (approximated by some well-posed problem, the solution of which is unique, is stable and corresponds to the RTE solution in some sense), but the regularization in the case of identification and model errors can only provide a guaranteed stability of solution at the expense of the efficiency of one. As is known, the model used and the measurements must be first adapted to one another to reduce the discrepancy between them. This is traditionally called "tuning". The regression approach commonly used for solution of the tuning problem (TP) allows us to describe a narrow class of measurement conditions. To account for changing conditions in the "underlying surface + atmosphere" system, it is proposed to consider the statement of the TP based upon the general approach to the IP solution. The principal feature of proposed approach to the TP statement is that it is self-contained. The control provides a correspondence of the obtained IP solution to its expected properties defined by the used a priori data to regularize IP. The TP was numerically investigated on the basis of the HIRS/2 data. The TP control of RTE was described as a vector function. The obtained value of control demonstrated strong dependence on the sounding angle, the atmospheric conditions and the cloud parameters.

COUPLING AVHRR AND TOVS FOR IMPROVED SOUNDING USE IN FINE-MESH LIMITED AREA MODELS

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AVHRR-HIRS coupling has been investigated in order to improve the atmospheric temperature and water vapour retrievals for use in NWP. These improvements have been obtained through better cloud handling (detection, clearing and description) and through enhanced land surface emissivity and land surface temperature determinations. In this context AVHRR products have been defined and derived at the HIRS/2 spatial resolution and a number of them will be integrated within the present version of the 3I system. The incorporation of 3I retrievals in the operational HIRLAM NWP model has been elaborated and its impact is under evaluation. Techniques have been developed to merge observations of atmospheric parameters at different spatial resolution, from both satellite and ground-based instrumentation, like AVHRR, HIRS, MSU, lidar, radiosondes and radiometers.

THE IMPACT OF THE SATELLITE TOVS DATA IN 3D VARIATIONAL ANALYSIS AT METEO-FRANCE

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At Météo-France the change of the operational analysis system from Optimal Interpolation (CANARI) to a 3D Variational (3DVAR) is being carried out. The first version of 3DVAR - close to the one that should be applied for operational use - is already available for different tests. This first version has two particularities: a) the 3DVAR incremental, in which the increments for the initialization of the operative model with stretched resolution (T149/C3.5) are calculated in a reduced and uniform spectral space (T106/C1); b) the TOVS data are used through 7 layers of geopotential thickness (this does not correspond to the optimal use of satellite data). This paper studies the global impact of 500 km SATEM data on the 3DVAR assimilation and subsequent forecasts.

OPERATIONAL DMSP ATMOSPHERIC SOUNDING PRODUCTS AT NESDIS

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The following report summarizes the scientific systems and algorithms operated by NOAA/NESDIS in support of the operational Defense Meteorological Satellite Program (DMSP) temperature and moisture products, and presents results. NOAA/NESDIS generates and distributes operational atmospheric soundings products from microwave remote sensors on board DMSP polar orbiting satellites. Data are distributed over the Shared Processing Network. The operational products consist of radiometric data and derived soundings from the Special Sensor Microwave/Temperature (SSM/T1)

and Special Sensor Microwave/Moisture (SSM/T2) sounders currently on board the DMSP F-13 and F-12 satellites, respectively.

Temperature products from the SSM/T1 have been operational at NESDIS since the mid-1980s and provide excellent global coverage and thermal products. Errors are on the order of 2 K r.m.s. in the troposphere and lower stratosphere, when compared with collocated radiosonde observations.

High resolution atmospheric moisture sounding products from SSM/T2 measurements became operational at NESDIS in late 1995. With an approximate 50 km spatial resolution, these measurements and derived products are sensitive to mesoscale and synoptic scale moisture features. Results against radiosondes indicate accuracies for the SSM/T2 moisture sounding on the order of 15% near the surface, and 40% at the higher levels (where moisture values are relatively small). The SSM/T2 products represent the baseline system and algorithms scheduled for operational implementation by NESDIS in conjunction with moisture products from the Advanced Microwave Sounding Unit-B (AMSU-B).

NESDIS operational data are routinely available at <http://orbit7i.nesdis.noaa.gov:8080/>. These data are updated daily.

OPERATIONAL STATUS AND OUTLOOK FOR NESDIS POLAR ORBITING ENVIRONMENTAL SATELLITE PRODUCTS SYSTEMS

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Operational satellite soundings from TOVS on board NOAA polar orbiting satellites are produced and distributed NESDIS. The following report addresses the current scientific algorithms and presents results. The development and implementation of Revised-TOVS (RTOVS), which is intended as the precursor for Advanced-TOVS (ATOVS) temperature product systems scheduled for NOAA-K, is emphasized. Results are based on comparisons of satellite derived products which are collocated with radiosonde and numerical weather prediction forecast model data.

The second part of this report addresses the outlook for NESDIS operational sounding product generation systems by the year 2000. System and scientific algorithm development is currently under way in preparation for ATOVS which includes the Advanced Microwave Sounding Unit (AMSU) A (temperature) and B (moisture) modules. Concurrently, system and algorithm development in support of the Defense Meteorological Satellite Program (DMSP) operational SSM/T2 moisture products is ongoing. These methods represent the proposed baseline method for AMSU-B products. A brief summary of SSM/T2 scientific algorithms and products is provided.

All operational data and products from NESDIS are routinely updated at <http://orbit7i.nesdis.noaa.gov:8080/>.

DEVELOPMENTS IN ASSIMILATING GLOBAL TOVS DATA AT THE UK MET OFFICE

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For several years global TOVS retrieved products from NESDIS/NOAA at 120 km resolution have been assimilated into the UK Met Office global NWP model. In 1996 these were replaced by products from "GLOSS" (GLObal Sounding System), a one-dimensional variational analysis scheme. GLOSS uses TOVS brightness temperatures from the 120 km NESDIS data and vertical profiles of temperature and humidity from a UK Met Office NWP six-hour forecast as constraints to produce statistically optimal temperature and humidity profiles. GLOSS thus provides an interface between the TOVS brightness temperatures and the data assimilation system. This paper describes scientific aspects of the GLOSS processing and presents results from the forecast impact studies that led to the decision to assimilate GLOSS data operationally.

THE DIRECT ASSIMILATION OF TOVS RADIANCES AT ECMWF

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The NOAA-12 and -14 TOVS 120 km pre-processed radiances generated by NESDIS and distributed over the GTS in near real time have been assimilated directly into the ECMWF model analysis since 30 January 1996 using a 3 dimensional variational analysis, 3D-Var. The TOVS 1D-Var retrievals which provided temperature and water vapour profiles that were assimilated in the old Optimal Interpolation analysis is still run before the radiance assimilation for a number of reasons: firstly as a quality control check ensuring all the radiances for one field of view are mutually consistent, secondly to extend the temperature profile above the top of the model (currently 10 hPa), and thirdly to provide a radiative surface skin temperature for 3D-Var. Above 100 hPa the NESDIS temperature retrievals continue to be assimilated in the extra-tropics. Clear positive impacts were seen in the southern hemisphere forecast scores when 3D-Var was introduced. The configuration of the ECMWF 3D-Var system will be described and results presented for the first year of direct radiance assimilation. Future plans for improvements in the use of TOVS will also be outlined.

A FAST FORWARD MODEL FOR ATOVS (RTATOV)

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The launch of NOAA-K will provide operational NWP centres with a new source of data, AMSU radiances, which replace the former MSU radiances currently being assimilated into the forecast models. To enable these new radiances to be exploited in the new state-of-the-art variational data assimilation systems a fast forward model, its gradient and adjoint are required, together with the error characteristics of the measurements and forward model. The forward model for TOVS radiances used operationally within the 1D-Var and 3D-Var systems at ECMWF, RTTOV, has been updated to include both the AMSU radiances and HIRS channel 9 radiances. Line-by-line model transmittances for mixed gases, water vapour and ozone at both infra-red and millimetre wavelengths were used as the basis for the fast models. Results will be shown of how the fast model performs when compared with the line-by-line model predictions. The sensitivity of the model to changes in the input profile

vector (i.e. the gradient of the radiative transfer model) and the validity of the tangent linear assumption will also be presented for HIRS, MSU and AMSU radiances.

HIGH SPECTRAL RESOLUTION SOUNDERS - STATUS AND AIRBORNE PROTOTYPE RESULTS

W L Smith, H-L Huang, H E Revercomb and H M Woolf
CIMSS, University of Wisconsin-Madison, USA

The scientific status of AIRS, IASI, ITS and GHIS is provided. Spectral radiance data achieved from the airborne HIS experiment during several field programmes are used to simulate measurements from these instruments in order to investigate their sounding accuracy under a variety of atmospheric conditions. HIS retrievals during the Airborne Southern Hemisphere Ozone Experiment (ASHOE) are used to demonstrate that the accuracy and resolution of advanced sounders is superior to that provided by the current global data analysis/forecast systems. Airborne HIS observations are also used to show that small ice particle cirrus clouds cause large spectral variations in radiance to space which must be accounted for in the profile retrieval process. Accounting for the radiative effects of cirrus requires simultaneous inference of microphysical properties such as effective radius and ice water path. Finally it is shown using AVHRR and TOVS data to simulate advanced sounder spectra that the design of future advanced sounding instruments should use high spatial resolution detector arrays to minimize the impact of clouds on profile retrievals in partly cloudy regions.

HUMIDITY AND TEMPERATURE PROFILES FROM MIXED RETRIEVAL METHOD, ECMWF ANALYSIS AND RADIOSONDES

B Boba Stankov

NOAA/Environmental Technique Laboratory, Boulder, Colorado, USA

This paper compares humidity profiles obtained from combining many diverse remote sensor measurements using Mixed Retrieval Method (MRM), and humidity profiles obtained from ECMWF analyses with the 20 humidity profiles obtained from research radiosonde ascents. The experiment was conducted in the stable maritime air of southern California from 24 August to 27 September 1995. Due to the large-scale subsidence at this time of the year, the boundary layer is topped by a very sharp and strong vertical moisture gradient.

Profiles of humidity gradients observed by the 449 MHz wind profiler system, measurements of total precipitable water vapour by the Global Positioning System (GPS), virtual temperature measurements by the Radio Acoustic Sounding System (RASS), the standard surface meteorological measurements, the lidar ceilometer measurements of cloud-base height and the in situ measurements from ARINC Communications, Addressing and Reporting System (ACARS) were used in a statistical retrieval technique to derive the first guess humidity profiles. Those humidity profiles were then used to combine TOVS data with the ground-based remote sensing data and arrive at the mixed profiles of humidity.

Statistical evaluation of the MRM and ECMWF humidity profiles in comparison with the radiosonde-observed humidity profiles and the technique used will be presented.

A NEW APPROACH FOR CLOUD PARAMETER DETERMINATION IN THE 3I ALGORITHMS

C J Stubenrauch¹, A Chédin¹, R Armante¹, N A Scott¹ and W B Rossow²

¹ LMD/CNRS, Ecole Polytechnique, Palaiseau, France

² NASA/GSFC, Institute for Space Studies, New York, USA

The 3I (Improved Initialization Inversion) algorithm, as it has been developed in recent years, has provided in general reliable information on cloud top pressure and effective cloud amount, as has been shown in a comparison with time-space collocated clouds from the recently reprocessed ISCCP dataset, on a global scale for July 1987 and January 1988. Even low clouds were well identified by the 3I algorithm. The only systematic difference could be found in the stratocumulus regions off the western coasts, where 3I clouds were found mostly thinner and higher than the ISCCP clouds. In the case of low clouds, the method of minimal dispersion of effective cloud amount used in 3I as well as the well known CO₂-slicing method, due to a denominator getting near zero, are very sensitive to the chosen temperature profile and prefer to determine the clouds as high/thin rather than low/opaque. For this reason, a CO₂ method, not including a denominator, has been developed, calculating effective cloud amount by using all CO₂-band channels, but with weights depending on brightness temperature uncertainty inside an airmass and on model cloud height.

COMBINING 3I AND ISCCP CLOUD PARAMETERS FOR BETTER UNDERSTANDING OF CLOUD RADIATIVE EFFECTS

C J Stubenrauch¹, W B Rossow², F Chéruy¹, N A Scott¹ and A Chédin¹

¹ LMD/CNRS, Ecole Polytechnique, Palaiseau, France

² NASA/GSFC, Institute for Space Studies, New York, USA

Due to their relatively good spectral resolution, infra-red sounders can provide interesting information on clouds (especially cirrus) during the day as well as at night. On the other hand, the well-established ISCCP global satellite cloud climatology has relatively good spatial and temporal resolution. The 3I (Improved Initialization Inversion) algorithm - initially developed to determine temperature and water vapour profiles as well as cloud parameters from HIRS/MSU observations - has been revisited in order to provide more reliable information on cloud top pressure and effective cloud amount. Thirty months of data are already available in the framework of the NOAA/NASA Pathfinder Programme. The cloud parameters from two months of this global dataset have been compared with time-space collocated clouds from the current ISCCP dataset as well as from the recently re-processed ISCCP dataset. The 3I cloud parameters are generally in good agreement with the re-processed ISCCP data. Cirrus cloud identification in the recent ISCCP dataset is improved during day, whereas additional cirrus information during night can be provided by the 3I algorithm. Even low clouds are well identified by the 3I algorithm. Cloud radiative effects have been studied in combination with ERBE fluxes.

ON APPLICATION OF TOVS DATA IN KOREA

Ae-Sook Suh and Yong-Seob Lee

Meteorological Research Institute, Seoul, Korea

The International TOVS Process Package (ITPP-4) has been installed at Korea Meteorological Administration (KMA) to generate atmospheric soundings and total ozone amount. Retrieved TOVS

temperatures are utilized as an initial data of a mesoscale numerical weather prediction model. For the verification of satellite data, vertical temperature and dew-point temperature data from TOVS and RAOB are compared. The impact of retrieved TOVS temperatures on the numerical weather prediction model for a case of cyclone development are now being investigated. KMA also is trying to improve the quality of TOVS total ozone amount using real-time synoptic observations in various ways instead of climatological data, because these retrieved data in the new scheme for total ozone presently used at the KMA may be critical to analysis of the long-term trend of ozone structure over the Korean peninsula. A plan for the next generation of meteorological satellites is established to adapt rapidly to NOAA-K and to produce improved products.

RETRIEVAL OF CLOUD OPTICAL PROPERTIES FROM AVHRR FOR USE IN A COMBINED PROCESSING OF AVHRR AND AMSU

Anke Thoss, Ralf Bennartz and Juergen Fischer
Institute for Space Sciences, Freie Universität Berlin, Germany

Radiative transfer simulations using a matrix operator model are undertaken for the AVHRR (NOAA-11 and NOAA-K) in order to quantify the potential of estimating cloud properties such as optical thickness, effective cloud droplet radius and water/ice phase. Both the 1610 nm, as well as the 3740 nm channel are included in the simulations. Preliminary results show a potential for both channels to add information on effective radius and phase during daytime. Should both channels be operated simultaneously on future satellite generations, the retrieval quality could be improved further.

In the microwave region the aim of the simulations is to prepare for rain rate and cloud liquid water retrieval from AMSU data (see abstract of R Bennartz et al.). Both spatial and spectral information extracted from AVHRR channels shall be used to enhance the quality of this retrieval. The approach is to select spectral features from the simulated data set which best represent different cloud and precipitation types. Spatial information shall be added to account for the cloud coverage within the microwave footprint. With the arrival of NOAA-K data these features can be used as input parameters for a neural network to be applied on NOAA-K data for classification of prominent cloud properties and rain detection.

CLOUDS SPATIAL DISTRIBUTION AND INFRA-RED SOUNDING CONTAMINATION: AN IMPACT STUDY ON INFRA-RED SATELLITE SOUNDING OF THE ATMOSPHERE

V Tramutoli¹, C Pietrapertosa² and V Lanorte²

¹ Università della Basilicata, Potenza, Italy

² IMAAA/CNR, Tito Scalo (PZ), Italy

Cloud handling is a crucial task in the infra-red satellite sounding of the atmosphere. The presence of clouds can heavily reduce quality and coverage of the main satellite based infra-red products for meteorological and climatological applications. Most of these require completely cloud-free soundings so that cloud-contaminated infra-red radiances are usually treated as missing data. Many techniques dealing with partly cloudy soundings have been proposed. In this paper cloud spatial distribution, at different scales, has been analyzed by using several satellite passes over Europe. By using AVHRR soundings, spatial resolutions from 3 up to 100 km have been simulated and spatial distribution of differently cloud-contaminated soundings (up to 25% of the fov area) investigated. The trade-off between spatial resolution and cloud-contamination has been analyzed in order to assess its impact on new instrument design and the most common TOVS data applications.

AN ATTEMPT TO UNDERSTAND AND CORRECT SOME OF THE ERRORS OF FORWARD RADIATIVE TRANSFER MODELS

D S Turner and C Chouinard

Atmospheric Environment Service, Downsview, Ontario, Canada

Currently, a series of studies are being conducted with the aim of improving our current parameterized forward radiative transfer models in the longwave (HIRS channels 1-12). Using a fast line-by-line radiative transfer model, two new "truth" databases have been created. One is tentatively a new representative dataset and the other is a test set taken directly from a first guess NWP trial field from the AES Global Spectral Model. These sets are used to calculate regression coefficients for an existing parameterization and a new one using different approaches.

As a by-product of this study, a good estimate of the forward model bias and r.m.s. errors has been obtained. The proper inclusion of ozone and extension of water vapour to TOA have been included in the models. The resulting models are robust enough to use and have been extended in order to use upper tropospheric humidity when it becomes available from the NWP model.

HIGH SPATIAL RESOLUTION CLOUD CHARACTERISATION FOR TOVS AND ATOVS DATA ANALYSIS

Michael Uddstrom and Warren Gray

NIWA-Wellington, Wellington, New Zealand

TOVS and ATOVS measurements are sensitive to effects resulting from cloud and precipitation contamination. However, high spatial resolution (i.e. approximately 1 km) cloud type, inferred rain-rate and cloud-mask information derived from coincident AVHRR data may improve the usefulness of derived products - both radiances and geophysical parameters.

A very large sample of high resolution AVHRR and collocated meteorological scanning radar observations has been used to investigate the relationship between cloud type and rain-rate. Using a supervised classification procedure the AVHRR data have been sampled according to cloud type, and Bayesian cloud-type classifiers developed. When both radiometric and textural features in the AVHRR data are used, 11 "cloud classes" are identifiable (no cloud (land and sea), St, Sc, As, Ac, Ns, Cu, Cb, Ci and thick cirrus), with similar high levels of skill (Kuipers performance index > 0.7) during both day and night hours. Cloud type dependent rain-rate regression equations estimated from the collocated satellite and radar data allow approximately 60% of rain-rate variance (of raining cloud classes) to be explained during daylight hours, and 20 to 30% during night hours. As a result, cloud type and rain-rate estimates may be computed for every AVHRR ifov using 8×8 ifov data tiles. Example cloud classification and rain-rate images will be shown, together with verifying radar data. This approach, whereby cloud classes are identified then rain-rates estimated as a function of cloud type, resolves many of the usual problems associated with standard rain-rate analyses from passive infra-red satellite data.

Using the same data set of AVHRR observations, a high resolution Bayesian cloud mask has also been developed. Using simple feature vectors, it is possible to specify a cloud mask at 1 km resolution (using 3×3 ifov data tiles) that has both high skill (Kuipers performance index > 0.95) and nearly identical performance with day and night observations. Example cloud masks will be shown.

PERFORMANCE OF TOVS DATA IN THE ECMWF RE-ANALYSIS 1979-1993

S Uppala
ECMWF, Reading, UK

The objective of the Reanalysis Project at ECMWF was to create a time-consistent set of global atmospheric analyses for 1979-1993 using a fixed optimised data assimilation system. During the reanalysis period, the global observing system experienced constant changes. The quantity and quality of observations varied in time for both the satellite and conventional data. The TOVS radiances in the form of NESDIS cloud-cleared radiances provided a continuous and high quality global data source throughout the reanalysis period to adjust the temperature and water vapour profiles in the analyses. Cloud-cleared raw TOVS radiances had to be used to fill the major gaps in the NESDIS processed dataset. A one dimensional physical retrieval (1D-Var) with its inherent quality control was applied to the radiances after removal of the global mean bias. This bias tuning was carried out once a month. The 1D-Var retrievals were then used in the OI analysis together with all other data. In general the global observing system improves towards the end of the reanalysis period. A positive signal from the TOVS data can be seen during periods when two satellites were operated. The layer-mean virtual temperature fits the first guess better during these periods compared with the periods with only one satellite. A slightly better first guess fit is also found during these periods with the independent radiosonde geopotential heights. Through the use of temperature and humidity channels the TOVS data have provided valuable data for the whole of reanalysis period especially in the Tropics and other data sparse areas.

SOUNDING INSTRUMENTS FOR FUTURE RUSSIAN METEOROLOGICAL SATELLITES

Alexander Uspensky

Research Center "Planeta" of Hydrometeorological Service of Russia, Moscow, Russia

Russia is continuing her efforts on operating meteorological satellites systems development. In 1998 and 2000 it is planned to start the operations with modernized series of satellites "Meteor" - "Meteor-3M" No.1, "Meteor-3M" No.2. These satellites will be launched on sun-synchronized orbit and will have improved radio downlink. On board of these satellites, modified imagers of visible and infra-red (IR) range, as well as microwave (MW) and IR sounders will be installed.

"Meteor-3M" No.1 will carry a passive MW radiometer "MIVSA" (5 channels in the range 20-90 GHz) for the estimation of total humidity content of the atmosphere and a 15-channel MW radiometer "MTSA" (in the range from 18-90 GHz) for temperature sounding. The last instrument, which has channels similar to AMSU-A is now under development. On board of "Meteor-3M" No.2 it is planned to install together with "MTSA" two other MW radiometers. One of them is instrument called "MVSA" (6 channels in the range 90-183 GHz) for retrieval of atmospheric moisture characteristics. We have begun to design a satellite IR interferometer to provide atmospheric temperature and humidity profiles with high vertical resolution. As being currently planned, the interferometer will be installed on board of "Meteor-3M" No.2. The description of aforementioned instruments is given in the report. In the framework of the Agreement between NASA and the Russian Space Agency, the installation of American instruments SAGE-III and TOMS is planned on board of the satellites "Meteor-3M" No.1 and "Meteor-3M" No.2 respectively. "Meteor-3M" No.1 will also carry the instrument SCARAB for Earth radiation budget measurements.

THE TECHNIQUE TO DERIVE THE SURFACE TEMPERATURES AND PRECIPITABLE WATER CONTENT OVER LAND FROM AVHRR/TOVS IR WINDOW MEASUREMENTS

A B Uspensky and G I Scherbina

Research Center "Planeta" of Hydrometeorological Service of Russia, Moscow, Russia

Satellite measurements of outgoing infra-red (IR) radiation in the atmospheric window 10.5-12.5 μm produced by NOAA AVHRR (channels 4 and 5) and TOVS (channel 8 of HIRS/2) instruments provide retrievals of surface temperature (T_s) and precipitable water content (PW). The cloud-free brightness temperatures (T_r) in the AVHRR channels 4 and 5 are converted to estimates of T_s and PW using different versions of well-known split window method (SWM). Whereas the SWM provides accurate results in the retrieval of T_s and PW over sea, it requires modification for the remote sensing over land. A procedure to estimate land surface temperature (LST) and PW is proposed. To separate the atmospheric and emissivity effects in T_r , the use of combined AVHRR/HIRS measurements has been proposed. The modified SWM employs matched data in the channels 4 and 5 (AVHRR) and 8 (HIRS/2) for the estimation of surface emissivities in the 10.5-12.5 μm band and then for the estimation of LST and PW. The feasibility of producing reliable LST and PW estimates has been proven by the results of experiments with real data. The archive of collocated AVHRR/HIRS and ground-based observations for the central region of Russia has been compiled for the summer periods of 1993-1995. Comparisons of remotely sensed LSTs and PWs with specially constructed "true" ground temperature values and results of humidity objective analyses give r.m.s. errors in the range of 1.5-2.5 K, and 0.3-0.7 cm respectively.

USING NDVI TO ESTIMATE SURFACE EMISSIVITY OVER LAND

Kuang-Hwa Wang

Central Weather Bureau, Taipei, Taiwan

During microwave radiation transfer calculation, surface emissivity is a very important factor. The surface emissivity over land is more complicated than over ocean, so most microwave remote sensing has been done over ocean areas. Over land, data have been limited. Now a log relationship found between AVHRR's NDVI and ground-based microwave radiometer observed emissivity can be used to estimate surface emissivity over land.

FAST TRANSMITTANCE MODELS AND TOVS PROCESSING

Harold Woolf and Paul van Delst

CIMSS, University of Wisconsin-Madison, USA

The evolution of fast transmittance models and their application in TOVS processing is described. Several algorithms are compared, with strengths and weaknesses of each identified and illustrated. Emphasis is on models currently in use with TOVS, and/or under consideration for ATOVS, at CIMSS. Some results of high spectral resolution applications of different algorithms are also described.

CONSIDERATIONS ON SOUNDING INSTRUMENTS FOR FUTURE CHINESE SATELLITES

Zhang Wenjian

National Satellite Meteorological Center, China Meteorological Administration, Beijing, China

Fengyun-3 series, the second generation of China's polar orbiting meteorological satellites, will be launched from 2000-2015 according to present plan. The development of Fengyun-3 series will include two stages, i.e. Stage-I around 2000-2006 involving 3 satellites, and Stage-II during 2008-2016 with 5 satellites. For Stage-I, there will be eleven instruments/payloads on board, and two of them are main sounding instruments. These instruments are Infra-Red Atmospheric Sounder (IRAS) similar to HIRS/2 but with 26 channels, MicroWave Atmospheric Sounder (MWAS) with 8 channels respectively. In the Stage-II, the MWAS will be improved by adding 7 more channels around 60 GHz to enhance the temperature sounding capacity. In addition, two sounding instruments will be added. The two new instruments will be MicroWave Humidity Sounder (MWHs) with 5 channels and Multichannel Infra-Red Sounder (MIRS) with thousands of channels.

The plans of Chinese meteorological satellites, with particular emphasis on plans for sounding instruments will be reported in some detail in this presentation.

TOVS OPERATIONAL SYSTEM UPGRADING AND APPLICATION ASPECTS IN NSMC OF CHINA

Zhang Wenjian, Dong Chaohua, Li Guangqing, Ran Maonong, Zhang Fengying and Hu Xiaoxin
National Satellite Meteorological Center, China Meteorological Administration, Beijing, China

After one year running in parallel with the multi-linear statistical regression method and two successive months validation tests, the Improved Simultaneous Physical Retrieval Method (ISPRM) system has become operational in NSMC since the beginning of 1996. The validation tests for ISPRM system with more than twenty thousand match-ups of collocated radiosondes with retrievals show that the r.m.s. differences for temperature retrievals is below 2 K in most cases for ISPRM system, which demonstrated the good performance of the upgraded system.

In addition, activities have been initiated to TOVS data application research in estimating Earth radiation budget, cloud radiative forcing, as well as drought monitoring. A joint research programme aiming at applications of satellite data in numerical weather prediction (NWP), with participating experts of NSMC and NMC of China, has been initiated, which mainly emphasizes one-dimensional variational analysis of satellite data in NWP model.

The presentation will describe the upgraded operational retrieval system and the results of the validation test. Moreover, some new results of research activities and application aspects will be described in some detail.

ANALYSIS OF THE ABILITY OF TOVS INFRA-RED WATER VAPOUR CHANNEL FOR LOWER ATMOSPHERIC MOISTURE REMOTE SENSING

Zhao Gao-Xiang

Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, China

For satellite remote sensing of surface characteristics, water vapour is a principal factor for atmospheric effects. In order to make atmospheric correction, one way is to combine the vertical sounding of moisture derived from satellite observation (such as TOVS) with radiative transfer model. At present, the accuracy of moisture retrieval of TOVS is not satisfactory. TOVS has three infra-red water vapour channels, the useful water vapour information provided by them being limited. In addition to that, the 1217 cm^{-1} channel for remote sensing of lower atmospheric moisture seems not a proper one. Although the upwelling radiance of this channel comes mainly from the lowest part of the atmosphere, from the equation of remote sensing, the weighting function, which represents the contribution of water vapour change in the atmosphere to radiance change and is the meaningful quantity for remote sensing of water vapour, is rather small at all altitudes, even its peak value, hence, the 1217 cm^{-1} channel seems not an effective moisture remote sensing channel. We find that some other channels have values of weighting function larger than that of 1217 cm^{-1} channel at all altitudes in the middle and lower part in both wet and dry atmospheres. If such channels are used instead of 1217 cm^{-1} channel, the ability of lower atmospheric water vapour remote sensing might be improved.

ALGORITHMS FOR SIMULTANEOUS DETERMINATION OF SURFACE TEMPERATURES AND EMISSIVITIES FROM SATELLITE RADIATIVE MEASUREMENTS

Zhao Gao-Xiang and Wang Hong-Qi

Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, China

Accurate land surface temperatures (LSTs) are of fundamental importance for many applications. Deriving LSTs from satellite radiative measurements is desirable and the problem has received wide attention in recent years. At present many methods have been presented to derive LSTs from satellite measurements, but for most of them the surface emissivities have to be given previously or assumed. The coupling between the surface temperature and emissivity constructs a severe obstacle for the accurate determination of LSTs and the problem has not been properly solved yet. We cannot rely on selecting proper channels or increasing the number of channels to solve this problem, because there will always be more unknowns than available equations, hence, the solution is not unique.

Considering that although the surface emissivity is varied from time to time, its variation is relatively slow. Assuming that the change of emissivity is normally negligible in a short period of time, such as one or two days, a two-channel method has been presented to determine LSTs and emissivities simultaneously, in which a set of measurement data of two channels (e.g. AVHRR channels 1 and 2) made at two different time, day and night or two continuous days or nights, are used.

If there are emissivity variations in two time measurements, but the ratios of emissivities for different channels are same, then a three-channel method can be used to determine LSTs and emissivities simultaneously.

SATELLITE REMOTE SENSING OF METEOROLOGICAL FACTORS IN EAST ASIA

Y Zhu, W Li, W Zhang and B Zhao

Department of Geophysics, Peking University, Beijing, China

On the basis of the real-time receiving and preprocessing of TOVS/HIRS, MSU and GMS-4 data, the study mainly focuses on the retrieval of temperature, cloud parameters and SST in the Northwestern Pacific Ocean. By combining the characteristics of statistical and physical method, a new retrieval method, i.e. the Statistical-Physical Retrieval Method (STPRM), has been developed. We choose retrieval values (temperature) and retrieval factors (HIRS, MSU), and construct a corresponding retrieval coefficient matrix by a statistical method.

On the basis of the radiation transfer equation, a simulation calculation is carried out in order to find sensitive channels for retrieval of temperature without sensitivity to cloud. The channels of HIRS1, MSU2, MSU3, MSU4, $MSU2+0.5 \times MSU1$, $MSU2+1.5 \times MSU3$ and $MSU3+0.4 \times MSU4$ are chosen. Data of 64 radiosonde stations in the area 105-155E and 15-45N have been used for comparison with satellite retrieval results. Satellite data of NOAA-9 and -10 (1986-1989) have been taken in a practical test. The mean deviation between the temperature retrieval results of satellite observations and radiosonde data is 1.8 K. The cloud parameters have been derived from TOVS data. The cloud height and cloud amount have been derived with HIRS channel 4-7 data. The distribution of satellite derived cloud fraction (%) is in agreement with surface observed cloud amount (class). The distribution of satellite-derived top height over ocean with HIRS channel 4-7 data is in good agreement with that of Japanese GMS satellite.

The drought situation of China can be monitored with TOVS/MSU1 data. The distribution of drought degree, derived from retrieval result of satellite data is in agreement with that of meteorological observations. For SST retrieval, multi-channel model is developed using both TOVS and GMS data. Its accuracy is 1.06 K.

SATELLITE REMOTE SENSING OF METEOROLOGICAL FACTORS IN EAST ASIA

Y. Zhai, W. Li, W. Zhang and B. Zhao
Department of Geography, Peking University, Beijing, China

On the basis of the real-time receiving and preprocessing of TOVS/HIRS, MSU and GMS-4 data, the study mainly focuses on the retrieval of temperature, cloud parameters and SST in the Northwestern Pacific Ocean. By combining the characteristics of statistical and physical method, a new retrieval method, i.e. the Statistical-Physical Retrieval Method (SPRM), has been developed. We choose retrieval values (temperature) and retrieval factors (HIRS, MSU) and construct a corresponding retrieval coefficient matrix by a statistical method.

On the basis of the radiation transfer equation, a simulation calculation is carried out in order to find sensitive channels for retrieval of temperature without sensitivity to cloud. The channels of HIRS1, MSU1, MSU2, MSU3, MSU4, MSU5+0.5xMSU1, MSU2+1.5xMSU3 and MSU3+0.4xMSU4 are chosen. Data of 64 radiosonde stations in the area 103-132E and 12-42N have been used for comparison with satellite retrieval results. Satellite data of NOAA-9 and -10 (1986-1989) have been taken in a practical test. The mean deviation between the temperature retrieval results of satellite observations and radiosonde data is 1.8 K. The cloud parameters have been derived from TOVS data. The cloud height and cloud amount have been derived with HIRS channel 4-7 data. The distribution of satellite derived cloud fraction (%) is in agreement with surface observed cloud amount (class). The distribution of satellite-derived top height over ocean with HIRS channel 4-7 data is in good agreement with that of Japanese GMS satellite.

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APPENDIX A.

AGENDA FOR ITSC-IX

**NINTH INTERNATIONAL TOVS STUDY CONFERENCE
IGLS, AUSTRIA; 20-26 FEBRUARY 1997**

Thursday, 20 February 1997

0830-0900

REGISTRATION

0900-1000

INTRODUCTORY SESSION (Chair: Uddstrom/Eyre)

Welcome and opening remarks

Presentation and discussion of agenda

1000-1030

BREAK

1030-1240

SCIENTIFIC PRESENTATIONS (Chair: Eyre)

I. TOVS data in NWP

Derber J.C.

and Wan-shu Wu. The use of TOVS radiances at NCEP. (30 min. - INVITED)

Chouinard C.

and J.Halle. The variational assimilation of TOVS radiance observations: formulation and evaluation in 1D and 3D mode. (20 min.)

Saunders R.,

E.Andersson, G.Kelly, A.McNally and B.Harris. The direct assimilation of TOVS radiances at ECMWF. (20 min.)

Randriamampianina R.,

J.Pailleux, J.-N.Thépaut and P.Moll. The impact of the satellite TOVS data in 3D variational analysis at Météo-France. (20 min.)

Renshaw R.J.,

B.R.Barwell, S.J.English and J.R.Grant. Developments in assimilating global TOVS data at the UK Met. Office. (20 min.)

Joiner J.,

A.da Silva and R.Ménard. Efficient methods to assimilate data from current and future remote sounding instruments.

1240-1400

LUNCH

1400-1540

SCIENTIFIC PRESENTATIONS (Chair: Uddstrom)

I. TOVS data in NWP

Prangmsma G.J.,

S.J.M.Barlag, V.Cuomo, P.Di Girolamo, Z.-L. Li, F.-S.Olesen, A.Pfister, H.Reutter, N.A.Scott, C.Serio, M.-Ph.Stoll, C.Stubenrauch and V.Tramutoli. (Presented by F.-S.Olesen). Coupling AVHRR and TOVS for improved sounding use in fine-mesh limited area models. (20 min.)

McNally A. Use of TOVS 1b radiances in NWP. (20 min.)

Kleespies T.J. OPTRAN for data assimilation: development of the tangent linear and adjoint. (20 min.)

II. TOVS data in climate studies

Menzel W.P., D.P.Wylie, K.I.Strabala and R.Frey. Eight years of global cirrus statistics using HIRS. (20 min.)

Stubenrauch C.J., W.B.Rossow, F.Ch eruy, N.A.Scott and A.Ch edin. Combining 3I and ISCCP cloud parameters for better understanding of cloud radiative effects. (20 min.)

1540-1610 BREAK

1610-1750 SCIENTIFIC PRESENTATIONS (Chair: Menzel)

II. TOVS data in climate studies

Uppala S. Performance of TOVS data in the ECMWF Re-Analysis 1979-1993. (20 min.)

Bates J.J. Tropical hydrological cycle states revealed in HIRS water vapour data. (20 min.)

III. Preparations for ATOVS

Klaes K.D. ATOVS data processing in Europe. (15 min.)

Derrien M. and G.Legendre. A pilot AAPP-based operational processing scheme. (15 min.)

Dibben P.C., S.J.English, J.R.Eyre and R.J.Renshaw. Plans for the processing of ATOVS data at the UK Met Office. (15 min.)

Nieman S., T.Achtor, W.P.Menzel, W.L.Smith, H.M.Woolf, F.Nagle and H.-L.Huang. Utilization of AAPP within ATPP-1. (15 min.)

1800-1900 ICE-BREAKER

Friday, 21 February 1997

0900-1040 SCIENTIFIC PRESENTATIONS (Chair: Chouinard)

III. Preparations for ATOVS

Bloom H.J. and A.Reale. Current status of the RTOVS software system and enhancements to the ATOVS software system in preparation for launch of NOAA-K. (20 min.)

English S.J., R.J.Renshaw, P.C.Dibben and J.R.Eyre. The AAPP module for identifying precipitation / ice cloud, liquid water and surface type on the AMSU-A grid. (20 min.)

Bennartz R., A.Thoss and J.Fischer. Retrieval of precipitation and columnar water vapour content from AMSU-A/B. (20 min.)

Saunders R. and M.Matricardi. A fast forward model for ATOVS (RTATOV). (20 min.)

Hervéou M., N.A.Scott and A.Chédin. The retrieval of temperature and water vapour profiles from ATOVS data: an adaptation of the 3I scheme. (20 min.)

1040-1110 BREAK

1110-1240 SCIENTIFIC PRESENTATIONS (Chair: Scott)

III. Preparations for ATOVS

Plokhenko Y. A solution of the nonlinear inverse problem of simultaneous estimation of the atmospheric temperature and underlying surface emissivity on the basis of the satellite spectral measurement of the microwave region spectrum. (20 min.)

Huang H.-L., W.L.Smith, M.S.Whipple, Bormin Huang, S.J.Nieman and H.M.Woolf. Expected performance evaluation of ATOVS sounding products. (20 min.)

IV. Preparations for advanced IR sounders

Phulpin T., F.R.Cayla, G.Chalon, P.Courtier, M.Langevin, D.Diebel and D.Klaes. IASI, a new generation atmospheric sounder for the EUMETSAT Polar System. (30 min. - INVITED)

Goldberg M.D. and L.M.McMillin. Atmospheric InfraRed Sounder (AIRS). (20 min.)

1240-1400 LUNCH

1400-1530 SCIENTIFIC PRESENTATIONS (Chair: Rizzi)

IV. Preparations for advanced IR sounders

Smith W.L., H.-L.Huang, H.E.Revercomb and H.M.Woolf. High spectral resolution sounders - status and airborne prototype results. (30 min. - INVITED)

Ceckowski D., J.Jenney, D.Melton and J.J.Puschell. (Presented by W.T.Krug) HIRS/4+ITS: an operational infra-red sounder with advanced sounder capability. (20 min.)

Aires F., N.A.Scott, R.Armante, M.Hervéou, N.Jacquinet, F.Chéruy and A.Chédin. (Presented by N.A.Scott). Temperature and water vapour retrievals with the IASI/ATOVS system. (20 min.)

McMillin L.M. and M.D.Goldberg. The use of super channels for high resolution soundings. (20 min.)

1530-1600 **BREAK**
1600-1630 **WORKING GROUP FORMATION (Chair: Uddstrom/Eyre)**

TOVS data in climate studies
TOVS data in NWP
Preparations for ATOVS data
Advanced infra-red sounders
International issues and future systems

1630-1700 **POSTER INTRODUCTIONS (Chair: Bates)**
(each: 1 minute maximum, 1 viewgraph maximum)

1800-1900 **POSTER SESSION**
(see list below for list of posters)

Saturday, 22 February 1997

WORKING GROUP MEETINGS
(including first review of actions from ITSC-VIII)

Sunday, 23 February 1997

WORKING GROUP MEETINGS

Monday, 24 February 1997

0900-1040 **STATUS REPORTS (Chair: Uddstrom/Eyre)**
Relations with other bodies:
- IRC (Smith, 5 min.)
- CGMS (Menzel, 5 min.)
- WMO (Hinsman/Eyre/Menzel/LeMarshall, 5 min.)
- ITRA (Scott, 5 min.)
Reports back on issues raised at ITSC-VIII
- Frequency protection (Rochard, 5 min.)
- Re-analysis at NCEP (Derber, 5 min.)
- Re-analysis at ECMWF (Uppala, 5 min.)
- Re-analysis at GSFC (Joiner, 5 min.)
- TOVS Pathfinder (Goldberg/Scott, 5 min.)
Review of actions from ITSC-VIII (30 min.)
Any other items / discussion

1040-1110 **BREAK**

1110-1230 SCIENTIFIC PRESENTATIONS (Chair: Hinsman)

V. Future systems and international issues

- Menzel W.P. NOAA's plans for polar satellites: the 1990s and beyond. (15 min. - INVITED)
- Klaes K.D. EUMETSAT future plans. (15 min. - INVITED)
- Zhang Wenjian Considerations on sounding instruments for future Chinese satellites. (15 min. - INVITED)
- Uspensky A.B. Sounding instruments for future Russian meteorological satellites. (15 min. - INVITED)
- Rochard G. Status of passive microwave protection. (20 min. - INVITED)

1230-1400 LUNCH

1400-1530 SCIENTIFIC PRESENTATIONS (Chair: Kleespies)

VI. Other scientific studies and developments

**** instruments**

- Krug W.T. HIRS/4, the 10 km ifov instrument. (15 min.)
- ** processing systems**
- Paris C.A. Operational processing of RTOVS vs. TOVS. (15 min.)
- Burt P.J.A., C.B.Sear, T.Lachlan-Cope and T.Achtor. PC-TOVS: a desktop PC program for the extraction and analysis of TOVS data. (15 min.)
- Lavanant L., P.Brunel, G.Rochard, T.Labrot and D.Pochic. (Presented by P.Brunel) Current status for the ICI retrieval scheme. (15 min.)
- Reale T., M.Goldberg, D.Donahue and E.Kratz. Operational DMSP atmospheric sounding products at NESDIS. (15 min.)
- Le Marshall J., R.Seecamp, D.Blank, J.Clark, B.Choi and K.Magari. Improving weather forecasts in the Australian region by continuous assimilation of direct read-out data. (15 min.)

1530-1600 BREAK

1600-1730 PRESENTATIONS ON SOFTWARE PACKAGES (Chair: Uddstrom/Eyre)

- ITPP (Achtor) (5 min.)
- 3R/4A and 3I (Scott) (5 min.)

- RTTOV/RTATOV (Saunders) (5 min.)

TECHNICAL SUB-GROUPS

- ITPP
- 3I/3R
- RTTOV/RTATOV

1800-1900 RECEPTION HOSTED BY CITY OF INNSBRUCK AND PROVINCE OF TYROL

Tuesday, 25 February 1997

0900-1030 SCIENTIFIC PRESENTATIONS (Chair: Rochard)

VI. Other scientific studies and developments

** processing systems

Zhang Wenjian, Dong Chaohua, Li Guangqing, Ran Maonong, Zhang Fengying and Hu Xiaoxin. TOVS operational system upgrading and application aspects in NSMC of China. (15 min.)

Reale T., and H.Bloom. Operational status and outlook for NESDIS polar orbiting environmental satellite products systems. (15 min.)

** temperature

Zhu Y., W.Li, W.Zhang and B.Zhao. Satellite remote sensing of meteorological factors in East Asia. (15 min.)

** water vapour

Chaboureau J.-P., A.Chédin, R.Armante and N.A.Scott. A new approach for the vertical characterization of water vapour from TOVS. (15 min.)

Stankov B.B. Humidity and temperature profiles from mixed retrieval method, ECMWF analysis and radiosondes. (15 min.)

Zhao Gao-Xiang Analysis of the ability of TOVS infra-red water vapour channel for lower atmospheric moisture remote sensing. (15 min.)

1030-1100 BREAK

1100-1230 SCIENTIFIC PRESENTATIONS (Chair: LeMarshall)

VI. Other scientific studies and developments

** surface characteristics

Uspensky A.B. and G.I.Scherbina. The technique to derive the surface temperatures and precipitable water content over land from AVHRR/TOVS IR window measurements. (15 min.)

**** clouds**

Kim D., B.Stankov and K.P.Moran. Evaluation of multi-level cloud parameters with cloud profiling radar. (15 min.)

Stubenrauch C.J., A.Chédin, R.Armante, N.A.Scott and W.B.Rossow. A new approach for cloud parameter determination in the 3I algorithms. (15 min.)

Tramutoli V., C.Pietrapertosa and V.Lanorte. Clouds spatial distribution and infra-red sounding contamination: an impact study of infra-red satellite sounding of the atmosphere. (15 min.)

Uddstrom M., and W.Gray. High spatial resolution cloud characterisation for TOVS and ATOVS data analysis. (15 min.)

Thoss A., R.Bennartz and J.Fischer. Retrieval of cloud optical properties from AVHRR for use in a combined processing of AVHRR and AMSU. (15 min.)

1230-1400 LUNCH

**1400-1430 ATOVS software developments - general discussion
(Chair: Uddstrom/Eyre)**

1430-1730 WORKING GROUP MEETINGS

Evening CONFERENCE DINNER

Wednesday, 26 February 1997

0900-1030 SCIENTIFIC PRESENTATIONS (Chair: Smith)

VI. Other scientific studies and developments

**** ozone**

Kaifel A.K., B.Heisele and P.Berner. Recent improvements and evaluation of neural network approach for total ozone retrieval from NOAA-TOVS data. (15 min.)

**** radiation**

Chevallier F., F.Chéry, N.A.Scott and A.Chédin. A fast and accurate neural network-based computation of longwave radiative budget in clear and in cloudy situations. (15 min.)

**** radiative transfer**

Woolf H.M. and P.van Delst. Fast transmittance models and TOVS processing. (15 min.)

Goldberg M.D. and T.J.Kleespies. Comparison of radiative transfer calculations using three fast transmittance algorithms.

Garand L., D.S.Turner and C.Chouinard. (Presented by C.Chouinard). Returning to a physical formulation of TOVS transmittances.

**** assimilation**

Kelly G.A., M.Tomassini and M.Matricardi. The assimilation of geostationary radiances. (15 min.)

1030-1100 BREAK

1100-1230 ITWG PLENARY SESSION (Chair: Uddstrom/Eyre)
Working Group Reports

1230-1400 LUNCH

1400-1530 ITWG PLENARY SESSION (Chair: Uddstrom/Eyre)
Technical Sub-group Reports
Executive Summary, major recommendations and actions

1530-1600 BREAK

1600-1730 ITWG PLENARY SESSION (Chair: Uddstrom/Eyre)
Election of new co-chair
- announce nominations
- procedures for elections
Review of Progress (against strategy prepared in 1993)
Future Plans
- next meeting
- issues / working groups
- venue

1730 CLOSE

POSTERS

- Armante R., N.A.Scott and A.Chédin. Description of the corrections for radiance biases in the 3I re-analysis of TOVS data.
- Batjargal Z. and N.Tsengel. Processing and using TOVS data in Mongolia.
- Billing H., M.Eckardt and I.Langer. Retrieval of surface temperatures from TM, Meteosat and AVHRR data during an experiment in Tuscany in August 1996 in comparison with in situ measurements.
- Borbás É., I.Csiszár, I.Szenyán, Z.Tóth and E.Zsoldos. Operational use and evaluation of ITPP5 products at the Hungarian Meteorological Service.
- Buell R. Differences between the MSU temperatures of two working schemes owing to different calibration.
- Chéry F, F.Chevallier, C.Stubenrauch and N.A.Scott. Use of the vertical sounding in the infra-red for the retrieval and the analysis of the longwave radiative budget.
- Claud C., N.A.Scott and A.Chédin. Analysis of the spatio-temporal variability of TOVS-derived stratospheric temperatures.
- Cuomo V., N.Pergola, C.Pietrapertosa, F.Romano and V.Tramutoli. HIRS/2-like total water vapour columnar contents from AVHRR.
- English S.J., T.J.Hewison, P.J.Rayer, D.C.Jones, C.Prigent, C.Guillou, G.Anderson and J.Wang. Six years of microwave radiative transfer validation using airborne radiometers: the main results.
- Huang Bormin, H.-L.Huang and W.L.Smith. The effect of quadrature errors on simulated AMSU-A brightness temperature.
- Huang Bormin, W.L.Smith, H.-L.Huang and W.P.Menzel. A hybrid iterative method for ATOVS temperature profile retrieval.
- C.Jakob and R.Rizzi. Evaluation of model OLR in cloudy regions using TOVS 1b data.
- Joiner J. Investigation of systematic errors and correction models.
- Kelly G.A. Impact of observations on the operational ECMWF system.
- Merchant C. Sea-surface temperature and near-surface humidity from 3.7, 11 and 12 μm brightness temperatures.
- Paul G. Improving data assimilation and forecasts by revising the quality control for SATEM data.

- Plokhenko Y. Statement of "tuning" problem combined with an inverse problem solution in the satellite remote sensing of geophysical parameters of "underlying surface + atmosphere" system on the basis of the infra-red spectral measurements.
- Suh Ae-Sook and Yong-Seob Lee. On application of TOVS data in Korea.
- Turner D.S. and C.Chouinard. An attempt to understand and correct some of the errors of forward radiative transfer models.
- Kuang-Hwa Wang Using NDVI to estimate surface emissivity over land.
- Zhao Gao-Xiang and Wang Hong-Qi. Algorithms for simultaneous determination of surface temperatures and emissivities from satellite radiation measurements.

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