RECENT PROGRESS OF THE OPERATIONAL TOVS PROCESSING SYSTEM IN MSC

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1. INTRODUCTION

NOAA satellite series, the most famous meteorological satellites have been used for global meteorological observation for about 35 years. The vertical soundings began in 1970's. At Meteorological Satellite Center (MSC) in Japan, the operational TOVS processing was started in 1983.

First, we confirm the roles of direct broadcast HRPT data in MSC. There are two restrictions as to utilization of the data. One is the data coverage only around Japan. The other is that our old type reception facility allows us only one satellite processing. In spite of such restrictions, the direct broadcast HRPT data have following advantages:

- Direct receiving enables us to process the data earlier than global area coverage (GAC) data so that the processing completes within 2 hours after the reception.
- High spatial resolution of AVHRR data enables us to observe more detail phenomena than GMS and GAC data.
- Multi sensors and multi channels enables us to extract meteorological parameters that GMS cannot extract.
- 10 bits AVHRR data and 13 bits TOVS data enables us to observe atmosphere and surface with high accuracy.

Our concepts regarding regional products are based on these advantages.

Now we make four products from NOAA data as follows.

- Vertical profile of temperature and water vapor is main object of TOVS. The HRPT data received at MSC are processed in host computers and the products are sent to JMA Head Quarter. Conversely sonde data and numerical weather prediction (NWP) products are sent to MSC and used for satellite data processing as ancillary data. We implemented the physical scheme for retrieval in November 1993 although the vertical profiles were calculated by a regression method before. Details will be introduced later.
- Sea surface temperature was retrieved by the regression method with some window channels of HIRS before. Because the accuracy of the product is insufficient, we implemented MCSST method with AVHRR data to SST derivation in October 1993 (Shirakawa, 1994). It is produced once a day with 0.25 degree spatial resolution.
- Total ozone product became in operation in October 1994 (Yoshizaki, 1992). Total ozone are retrieved by a regression method with some HIRS channels. At present the total ozone amount values are given at 1 degree grid points and sent to JMA HQ. The product match with TOMS products well.
- Sea ice fax imagery around the Okhotsk sea is produced from AVHRR ch.4 data in winter when sun

altitude is very low and sea ice cannot be observed by visible channel of GMS.

We recently changed our operational TOVS processing system (Takeuchi, 1991). A brief description of the new system which retrieve the vertical profile of temperature and water vapor is presented in this paper. The new system is characterized by follows:

- The object is to retrieve temperature and dewpoint in clear region with high resolution and high accuracy. We should leave the retrieval in cloudy region to AMSU.
- Careful pre-processing like nonlinear calibration and accurate earth location yield reliable measurements.
- A strict and flexible cloud detection is performed with all AVHRR channels by each AVHRR FOV.
- Minimum variance method with iteration is applied. It includes the original forward calculation with radiation bias. The NWP forecast is used as an initial guess.

The new system has been operational since November 1993 except for the strict cloud detection subsystem which has been operational since June 1994, and we have monitored the accuracy of products. The system performance is also presented.

2. PROGRESS POINTS

2.1 Pre-processing

Table. 1 shows the differences between old system and new system. In June 1994 the pre-processing subsystem was changed. First, non-linearity correction (Planet, 1988) was added to AVHRR calibration to improve blackbody temperature TBB calculation. Second the orbit calculation and earth location were changed. The satellite orbit is calculated by using TBUS IV parameters instead of extrapolation of TBUS II predicted orbit. Then we correct the orbit by using doppler shift of signals from ARGOS stationary platforms (Kigawa, 1993). The technique is available even if cloud cover the station. Finally we correct the earth location by land mark matching. A 0.01 degree latitude/ longitude map data is used to land mark matching. These changes assure the earth location within 2 km accuracy.

2.2 Cloud detection in HIRS FOV by using AVHRR multi channels

2.2 Cloud detection

We have adopted a cloud detection subsystem by using both TOVS and AVHRR traditionally. In old system we used only AVHRR ch.4 to determinate cloudy FOVs. If ch.4 TBB of an AVHRR FOV is colder than a threshold dependent on month, latitude, scan angle and TOVS- SST, we assign cloud flag to the FOV. In June 1994 we changed the cloud detection subsystem as we use all AVHRR channels to exclude cloud effects with high accuracy. Fig. 1 shows general flow of cloud detection subsystem. First of all, we divide an AVHRR imagery area into 11 categories characterized by land/sea/coast, sunglint/no glint and daytime/dawn/nighttime. The categories for cloud detection are the same as Gleau (1989) and determined by using 0.25 degree latitude/ longitude map data and the observation time. Then we combined target albedo A and TBB of five channels to make eight classification parameters which are used in the sequence of cloud tests shown in Fig. 1. These parameters consist of target albedo of ch. 2, albedo ratio ch.2/ch.1, TBB of ch.4, TBB difference between ch.3-ch.4, ch.3-ch.5 and ch.4-ch.5, and local variance of ch.2 and ch.4. In our system we do not use complex texture parameters because they waste computer time and have little contribution to improvement of accuracy.

Main advantage of the subsystem is flexibility of algorithms and thresholds. The thresholds are made from NWP forecast, MCSST, scan angle and the category. For coast category we can determine whether an AVHRR FOV is on land or on sea by the parameter CH2/CH1 in the daytime. The problem regarding this subsystem is that we do not have effective and powerful tool for algorithm production and threshold determination namely man-machine interactive algorithm adjustment subsystem. Now we design algorithm and determine thresholds by simple image display and analysis tool.

Then we carry out a succession of threshold tests for each AVHRR FOV depending on the category. The thresholds can be given at 2.5 degree latitude/ longitude grid and calculated every day by using algorithm definition file, NWP forecast data and MCSST data. Because the almighty algorithm do not exist, our subsystem are designed as we can change the algorithms and thresholds easily. It is also useful when some channels of AVHRR become unavailable. An example of category image, AVHRR parameters and cloud image is shown in Fig.1.

Next AVHRR FOV's are matched to a HIRS FOV (Aoki, 1982). For each HIRS FOV we calculate the percentage of cloud area. We also calculate average, maximum and minimum of the AVHRR parameters. By using AVHRR parameter statistics such as partial cloudiness and radiances of HIRS channels, we decide the HIRS FOV as clear or not.

2.3 <u>Retrievals</u>

2.3.1 <u>Redefinition of categories for retrievals</u>

In old system categories for retrievals are clear, cloudy, and stratosphere. The FOVs with partial cloudiness below 0.95 are classified as clear category and the radiance measured by satellite is corrected to clear radiance (i.e. cloud cleaning). However the error induced by cloud cleaning cannot be ignored. Then we set up the categories as clear, low cloud and stratosphere. Our concept is that it is meaningless to retrieve under cloud even if there is some cloud free area because cloud is a large error source. In present system, a FOV of which partial cloudiness below 0.05 and passed HIRS cloud recheck is defined as clear and the cloud cleaning is not performed. The low cloud category is defined as cloud top temperature is higher than the temperature at 850 hPa. Now we operationally retrieve temperature 1000 hPa through 10 hPa and dewpoint 1000 hPa through 150 hPa only in clear category.

2.3.2 <u>application of NWP forecast JMA as a initial guess for retrieval</u>

Fig. 2 shows the general flow of retrieval subsystem. To set up the initial guess of vertical profile we interpolate the temperature and dewpoint given by NWP forecast to observation time and to HIRS FOVs' center and besides we extrapolate them upward and downward where the forecast values are not given.

2.3.3 <u>Forward calculation</u>

The forward calculation used in our system is characterized by follows:

- The atmospheric model is composed of 16 layers from surface to 10 hPa. The 16 is fewer than the number of layers used in NESDIS-TOVS (i.e. 40) because we have no more layers we can give initial value from NWP forecast without interpolation and the vertical resolution of TOVS is not good.

- The transmittance database independent of satellite is prepared. Five transmittance values based on k-profile method are stored in the database by 5 cm^{-1} wave number spacing, 7 temperatures, 5 dewpoint depressions and 15 pressures (i.e. 1000 hPa through 10 hPa).
- An effective vertical integration scheme enables us to consider the inhomogeneity of temperature and water vapor in a single layer. The scheme fairly compensate the fewer layers above mentioned. - The radiation bias depending on calculated brightness temperature and scan angle is used to exclude the errors due to incomplete initial guess, radiative transfer model, aerosol effect etc..

2.3.4 Application of minimum variance method with iteration

We calculate not only simulated brightness temperature but also sensitivity matrix in the step of forward calculation. Observation error covariance matrix is estimated by using sonde-TOVS collocation data at the same time as radiation bias calculation. Initial guess error covariance is given as a preset constant matrix based on sonde-NWP forecast collocation data. Iteration is limited twice at present to save the computer time. We carefully select HIRS channel to retrieve temperature and dewpoint at a level in order to use only sensitive channels at the level.

3. RADIATION BIAS & PRODUCT MONITORING

3.1 Radiation bias

Figs.3 are statistics of radiation bias November 1993 through February 1995. The constant term of radiation bias (i.e. a_0 in Fig. 2) shown in Figs. 3 a)-d) is almost stable through all period. This means monthly update of radiation bias correction work well. It also seems some seasonal variation of radiation bias of some channels. By removing the radiation bias we can reduce standard deviation between observed TBB and calculated TBB (Figs. 3e)-h)). These standard deviations are the square root of diagonal elements of the observation error matrix.

It is remarkable that standard deviations of HIRS ch.11 and ch. 12 are decreased and stabilized after June 1994 when we set up new cloud detection subsystem. The improvement is apparent for day orbit data (i.e. 08LT zone). The result are attributed to inclusion of visible parameters in cloud detection.

In night orbit data (i.e. 19LT zone) there are also undesirable feature such as abnormal large bias and standard deviation of AVHRR ch.4, HIRS ch.7, ch.8, ch.10, ch.13, ch.14 and ch.17 (i.e. lower tropospheric channels) in this winter. The reason will be considered later.

3.2 Product monitoring

Fig.4 is the retrieval accuracies of temperature and dewpoint from November 1993 to February 1995. Sonde data of eight stations located in the oceanic region are used in this statistics. Retrieved data within 50km from the stations are used. NWP analysis and forecast data are given at 2.5 degree latitude/ longitude grid point and interpolated to the sonde station.

Both bias error and RMS error of temperature retrieval are smaller than NWP forecast except at 1000hPa and over 100 hPa. It means the usefulness of TOVS retrievals as input of the NWP model. Mean and RMS error in the lower level is bad due to surface temperature diurnal variation.

Retrieved dewpoint tends to a little wetter than sonde observation except for summer. RMS error of dewpoint is improved above 700 hPa.

Fig. 5 is the results of the monthly monitoring of the retrieval accuracies. As for temperature retrieval bias error at lower troposphere has seasonal variation with small fluctuation. RMS error is excellent and has the range between 0.8K and 1.5K. As for dewpoint retrieval RMS error was improved after June 1994. Fortunately the retrieval accuracy did not suffered the abnormal radiation bias much because we carry out a quality check before and after the retrieval step.

3.3 Examination for improvement

There are undesirable features namely abnormal radiation bias and standard deviation of lower tropospheric channels. As a result of examination we find low level cloud are included in the TOVS-sonde collocation data for the bias calculation. Fig.6 shows the histgram of observed TBB - calculated TBB in September 1994 (normal bias period) and in January 1995 (abnormal bias period). Apparently two peaks are exist in latter case. One corresponds to a clear surface scene and the other low cloud scene. This result means that more strict thresholds of AVHRR ch.4 to exclude low cloud completely. Figs. 7 are the results after the collocation data are selected with the improved thresholds. The abnormal bias and standard deviation are excluded.

Another problem is positive bias of dewpoint retrieval as shown in Fig. 4. We should pay attention to that the bias has apparent seasonal variation so that we can exclude the bias error by using the bias in the preceding month. The result is shown in Fig. 8 and the bias error is reduced.

4. FUTURE PLANS

4.1 Renewal of NOAA satellite data reception facility

The NOAA satellite data reception facility was renewed in March 1995. We will be able to use 6 hourly data by NOAA-12 and NOAA-14. Moreover the data coverage will be also enlarged. It enables us to monitor the eruption of volcanos located at Aleutians islands.

4.2 Renewal of the ground computer system

The renewal of the ground computer system is planned in June 1995 in accordance with launch of GMS-5. The system is composed of five host computers and linked to NOAA reception facility by a Local Area Network. Calculation time of NOAA data processing will be reduced by improvement of the computer capability.

4.3 Use of Japan Spectral Model forecasts

Regarding TOVS processing system it is possible to improve the initial guess. Now we have plan to use the forecast of Japan Spectral Model produced by JMA. The resolution of the data is about 30 km so that we expect to reduce the interpolation error. However we should use both GSM and JSM because the forecast of JSM is given in the limited area and vertical range.

4.4 Preparation for AMSU and AVHRR/3

The development of AMSU and AVHRR/3 processing system will be initiated in April 1995. We will have an additional staff and budget for the development. We are studying new products like temperature and water vapor in cloudy area, sea ice distribution in cloudy area, cloud liquid water, precipitation rate, snow area and sea ice thickness. We also expect the improvement of temperature retrieval in stratosphere.

4.5 Investigation for AMSR data

The investigation of utilization of AMSR data installed on ADEOS2. ADEOS2 will be launched in 1999. The AMSR has higher spacial resolution than AMSU so that it is useful for monitoring typhoons and baiu fronts in detail.

5. CONCLUSION

This paper introduced the present TOVS processing system in MSC and summarized its advantages. The accuracy of temperature and dew point exceed that of initial guess from NWP forecast. As a result of product monitoring effectiveness and a few problems were reported and studied. However the development of cloud detection subsystem seems to be halfway. So we must optimize the algorithm and thresholds in further investigation.

6. REFERENCES

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Table 1 Difference between old system and new system.

	Old System	New System
Ingest		*March '95*
Reception Facility	Mini Computer	Work Station
Link to Main Computer	'79 MTbase ⇨ '88 Online ⇨	*June '95* LAN
Pre-Processing		*June '94 -*
Calibration	Linear Calibration (AVHRR)	Non-Linearity Correction (AVHRR)
Orbit Calculation	TBUS PART II	TBUS PART IV
Orbit Correction	No Correction	ARGOS Method
Earth Location	No GCP Correction	GCP Correction
Cloud Detection		*June '94 -*
Used Sensor/ Ch.	1 km AVHRR ch4	1 km AVHRR all channels
Classification Parameter	ch4	ch2, ch2/ch1, ver (ch2), ch4, ch3-ch4, ch3-ch5, ch4-ch5, ver (ch4)
Step of Cloud Test	1 Step	Max 20 Steps
Algorithm	Fixed Algorithm	Flexible Algorithm
Thresholds	Dep. on Month, Latitude, Scan Angle, TOVS-SST	Dep. on NWP forecast, MCSST, Scan Angle, Category
Category for Cloud Detection	No	Land/ Sea/ Coast, Day/ Night/ Dawn, Glint/ No Glint
Retrievals		*November '93 -*
Category for Retrievals	Clear: Partial Cloudiness < 0.95 Cloudy: the others	Clear: Partial Cloudiness < 0.05
Clear Radiance Calculation	Yes	No
Method	Statical Method Regression	Physical Method Minimum Variance Method with Iteration
Initial data	No	NWP Analysis/12h & 18h Forecast
Forward Calc.	No	k-Profile Method Effective Vertical Integration Radiation Bias
Coefficient Update	Regression Coefficients Updated by 5 Days	Radiation Bias & Observation Error Matrices Updated Once a Month
Products		*November '93 -*
Parameter	Temperature, Precipitable Water, Cloudiness, Cloud Top Pressure	Temperature, Dewpoint
Resolution	40km (2 × 2 HIRS FOV's)	20km (1 HIRS FOV)
Region	Clear + Cloudy	Clear
Performance		
RMS	T: 2-3K	T: 0.8-1.5K Td: 2-8K

General Flow of Cloud Detection Subsystem

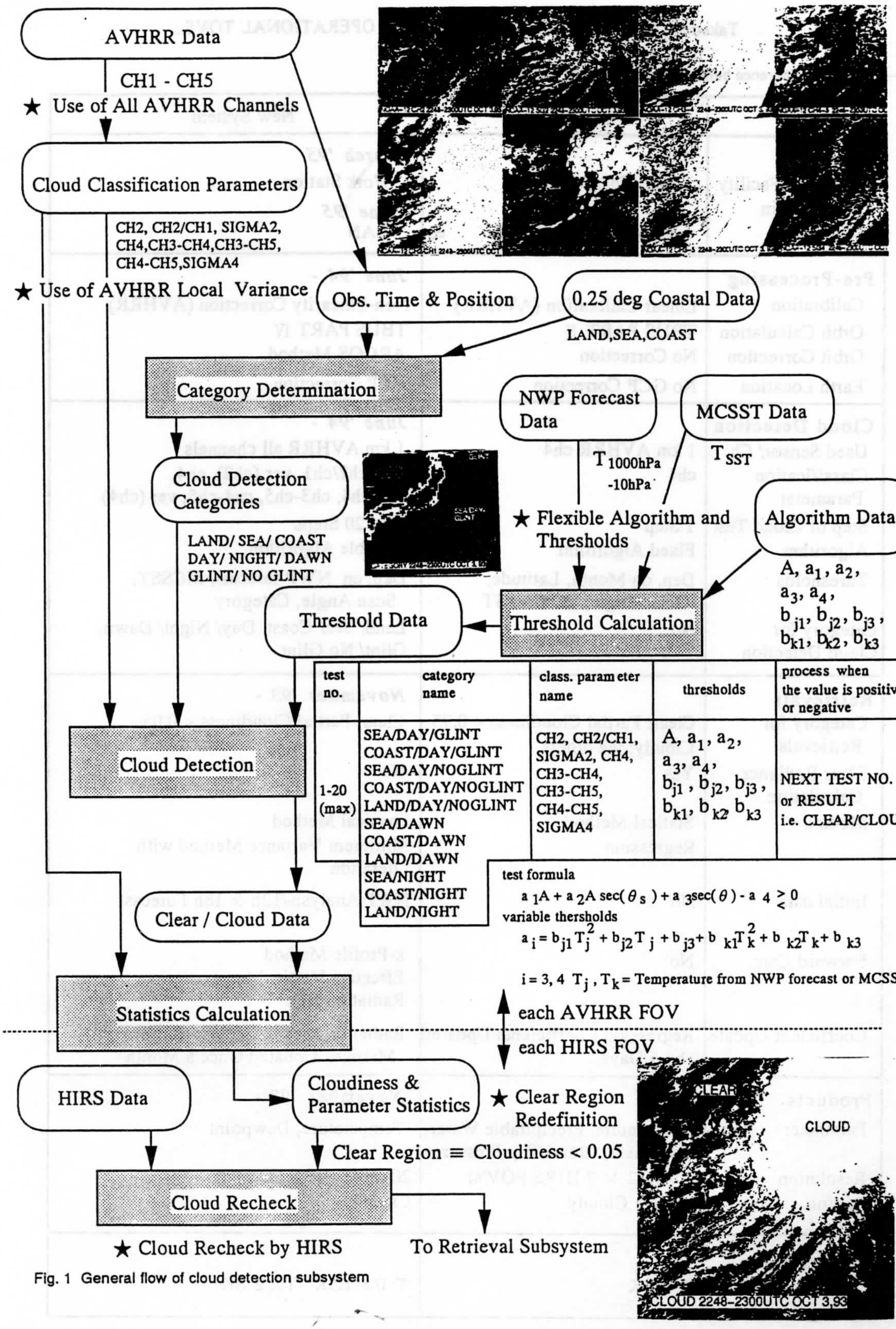

Fig. 1 General flow of cloud detection subsystem

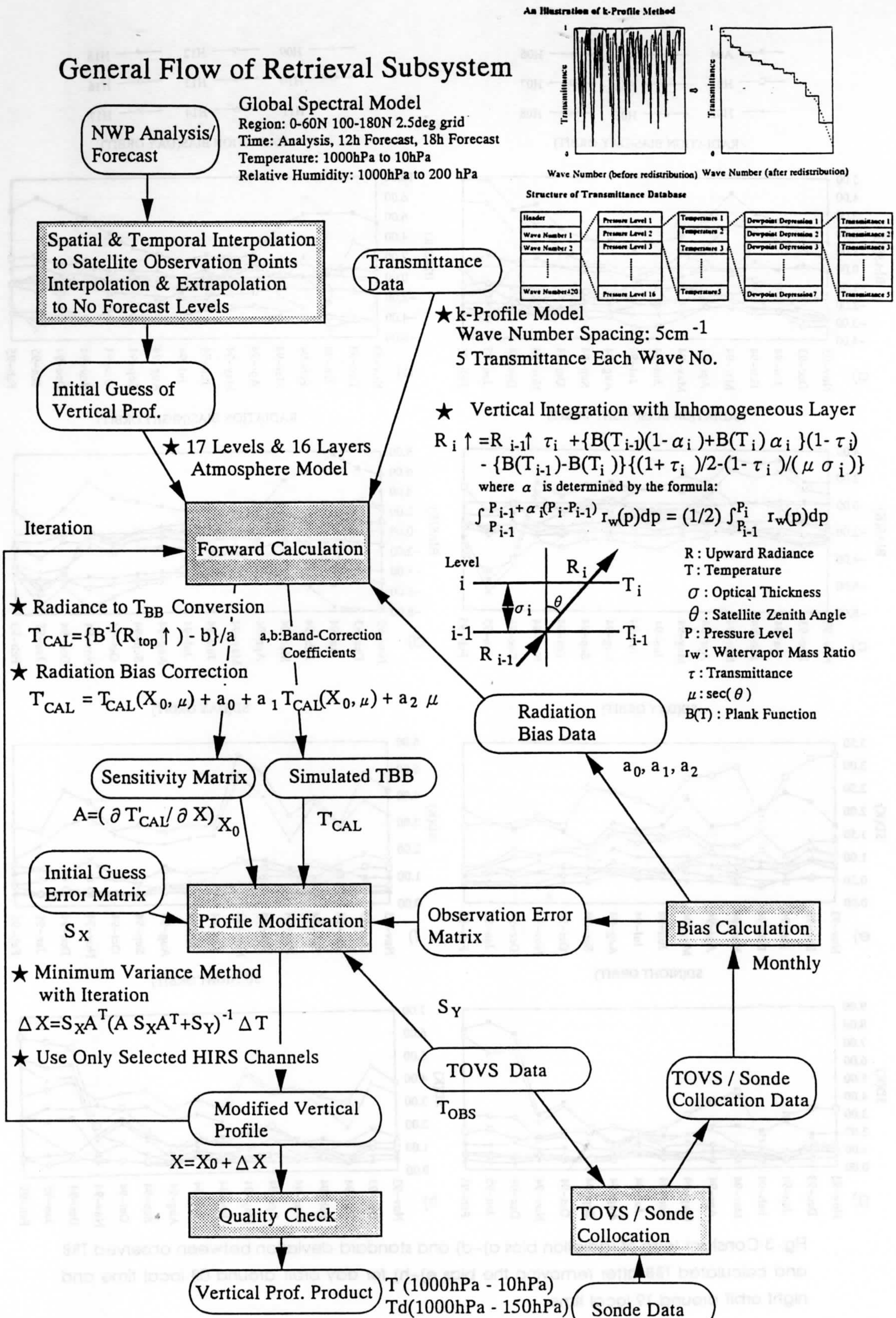

Fig.2 General flow of retrieval subsystem.

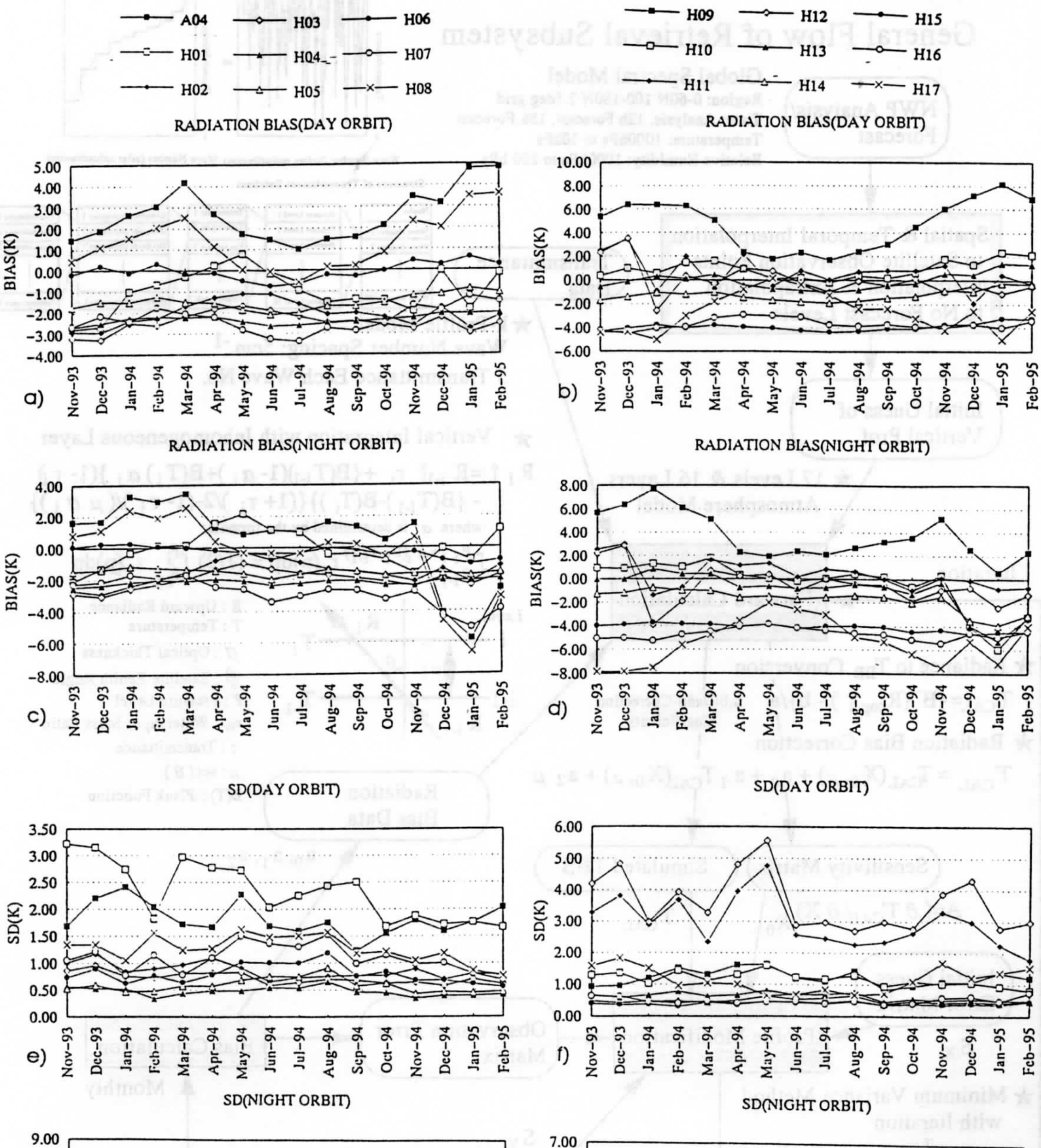

Fig. 3 Constant term of radiation bias a)-d) and standard deviation between observed TBB and calculated TBB after removing the bias e)-h) for day orbit around 08 local time and night orbit around 19 local time.

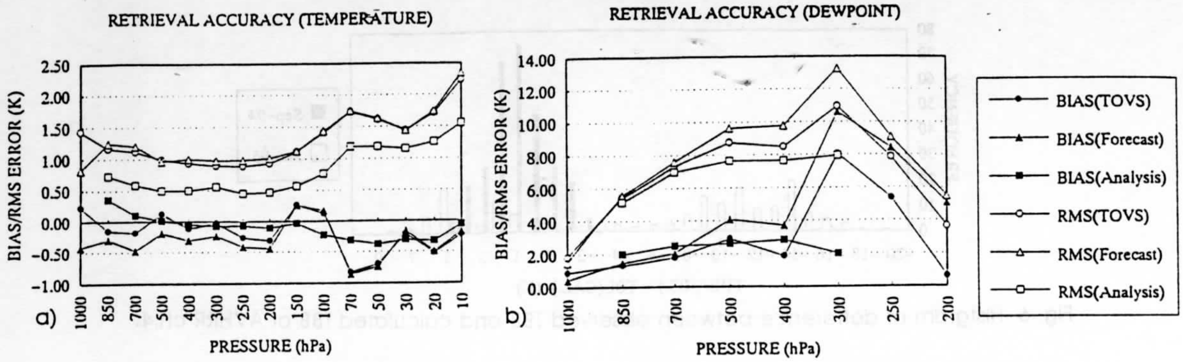

Fig. 4 Retrieval accuracies of temperature a) and dewpoint b) as a function of pressure. Data period is November 1993 through February 1995.

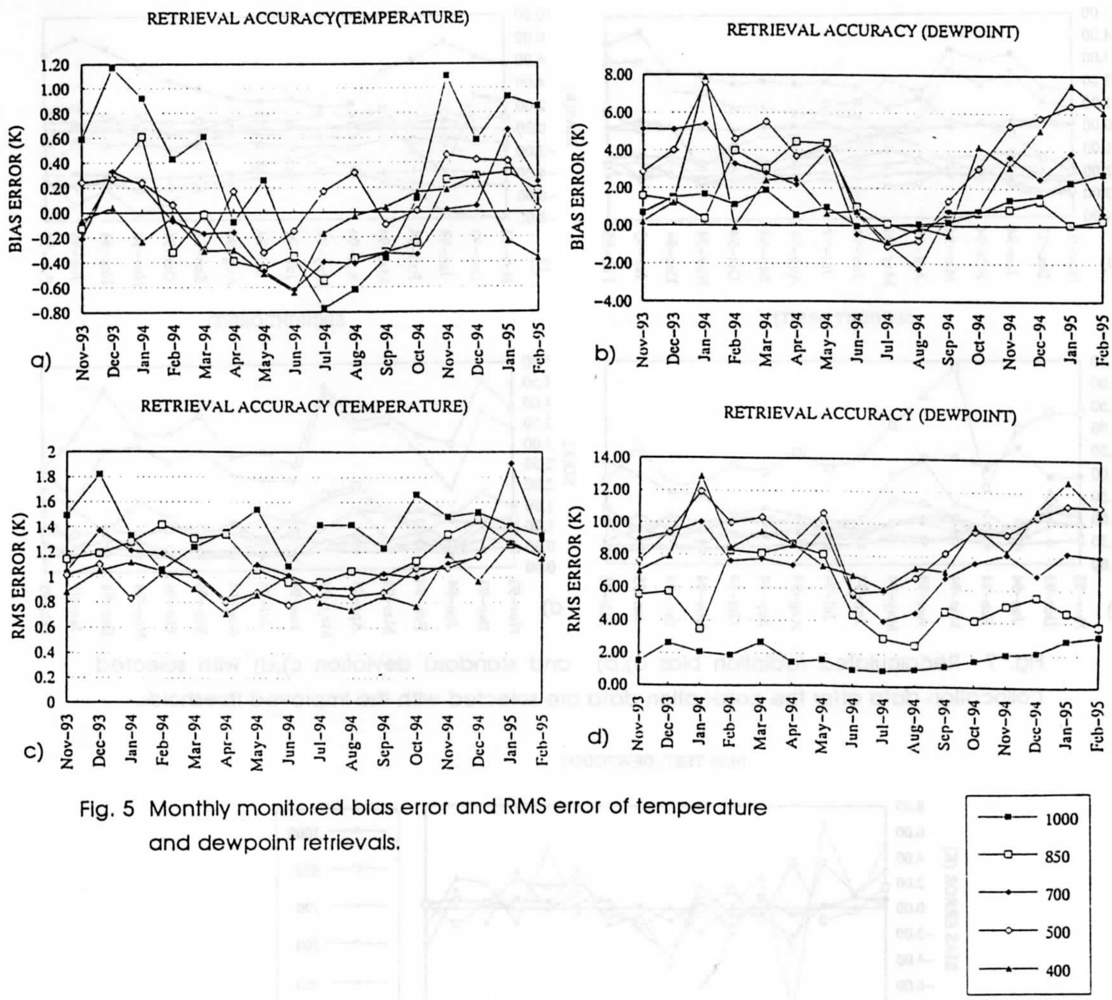

Fig. 5 Monthly monitored bias error and RMS error of temperature and dewpoint retrievals.

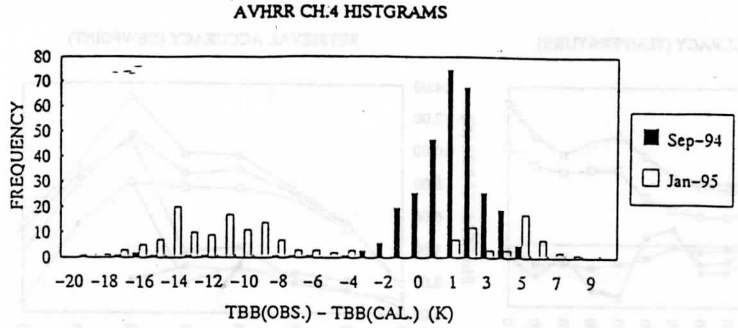

Fig. 6 Histgram of defference between observed TBB and calculated TBB of AVHRR ch.4.

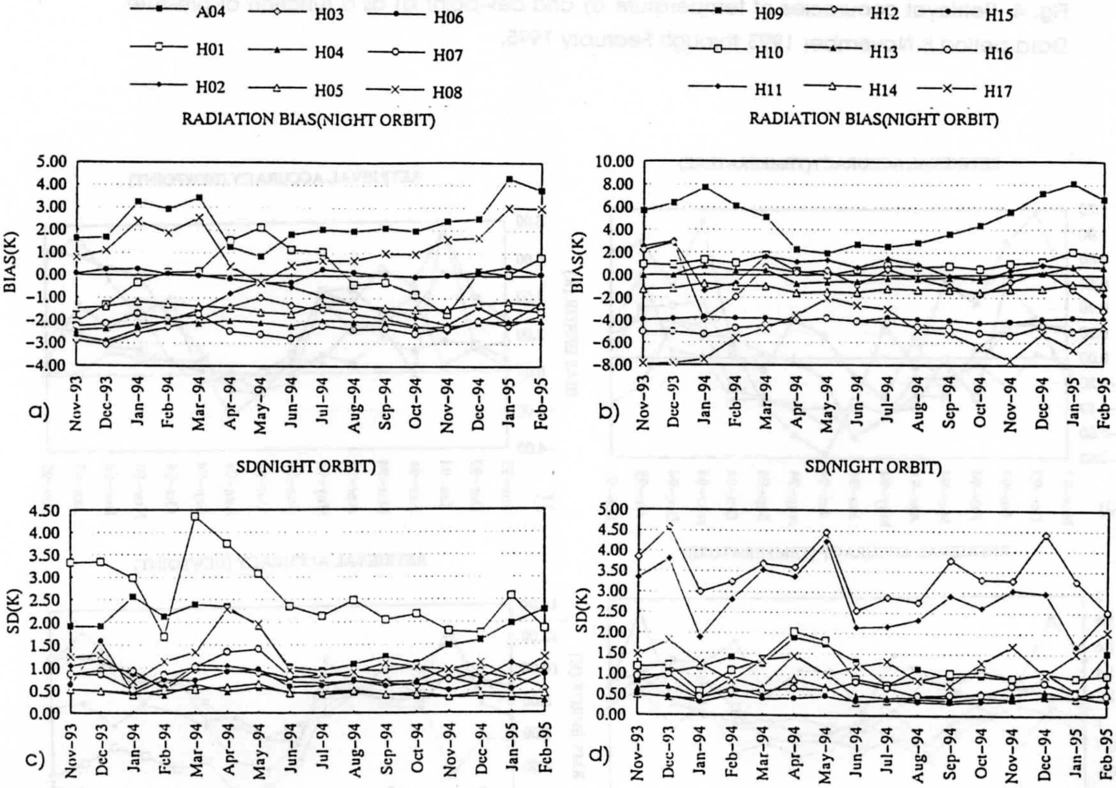

Fig. 7 Recalculated radiation bias a),b) and standard deviation c),d) with selected collocation data after the collocation data are selected with the improved thresholds.

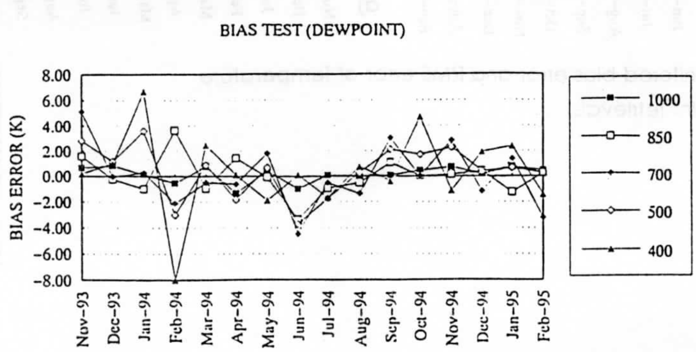

Fig. 8 Recalculated bias error of dewpoint retrieval after we exclude the bias error by using bias in the preceding month.

Technical Proceedings of

The Eighth International Tovs Study Conference

Queenstown, New Zealand

5-11 April 1995

Edited by

J R Eyre

Meteorological Office, Bracknell, U.K.

Published by

European Centre for Medium-range Weather Forecasts
Shinfield Park, Reading, RG2 9AX, U.K.

July 1995