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REANALYSIS IMPACT ON QUALITY CONTROLS OF LONG-TERM SATELLITE SOUNDING OBSERVATION

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1. INTRODUCTION

Japan Meteorological Agency (JMA) and Central Research Institute of Electric Power Industry (CRIEPI) are about to complete the 26-year (1979 - 2004) reanalysis project: JRA-25. (Visit our web site http://www.jreap.org/index-e.html .) It has been found that a reanalysis can be affected crucially by the satellite sounding observations from the TIROS Operational Vertical Sounders (TOVS) on board the Polar Orbital Environmental Satellites. Authors have been experiencing TOVS application to JRA-25, and learn how essential the way to use TOVS data is.

To understand more about the TOVS observation and improve our application methods, we started follow-up studies. As a kick-off study, the atmospheric vertical profile of each reanalysis was compared with real observation. This study brings us vital information, such as relative bias tendencies and suitability of each channel, of each instrument, of each satellite, and of each period. It is also informative in terms of the way to use reanalyses as references in the calibration procedure of time series of TOVS observation.

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2.OBSERVATION DATA

In this study, observations from the High Resolution Infrared Radiation Sounder (HIRS) and the Microwave Sounding Unit (MSU) were coupled together and used as level-1d (earth located brightness temperature data, in which instruments are combined). For HIRS and MSU, their consistency should be examined by comparison with each other. The Stratospheric Sounding Unit (SSU) observation was independently used as level-1c, because its weighting functions are rather isolated from other instruments.

Combining of HIRS and MSU (so called `mapping`) was implemented using the nearest neighbor method. In this method, only the HIRS spots closest to the center of MSU Instantaneous Field Of Views (IFOV) were selected, and spots that have longer distance between the centers of HIRS and MSU than the diameter of HIRS's IFOV (1.25deg in satellite zenith angle) were rejected. As shown in Fig. 1, this procedure provided level-1d with low IFOV position errors, although IFOV position dependence of original scan conditions (Koehler, 1988) remained.

3.REANALYSIS DATA

JRA-25, ERA-40 (Uppala et al. 2005), ERA-15 (Gibson et al. 1997), and the NCEP-NCAR reanalysis (Kalney et al. 1996) were compared with TOVS observations. Every reanalysis is used as 2.5deg grid pressure level values. Pressure levels of each reanalysis are shown in Table 1. JRA-25 and ERA-40 have pressure level ozone concentration records. But ERA-15 and NCEP-NCAR don't. So the ozone distribution of JRA-25 is applied for the evaluation for them. NCEP-NCAR reanalysis has only lower 8 layers of specific humidity, and it is not enough to evaluate HIRS channel-11 and 12 observations.

Table 1. Pressure Levels of Each Reanalysis

JRA-25 (23-layers)	ERA-40 (23-layers)	ERA-15 (17 layers)	NCEP-NCAR (17 layers)
0.4hPa			
1.0hPa	1.0hPa		
2.0hPa	2.0hPa		
3.0hPa	3.0hPa		
5.0hPa	5.0hPa		
7.0hPa	7.0hPa		
10hPa	10hPa	10hPa	10hPa
20hPa	20hPa		20hPa
30hPa	30hPa	30hPa	30hPa
50hPa	50hPa	50hPa	50hPa
70hPa	70hPa	70hPa	70hPa
100hPa	100hPa	100hPa	100hPa
150hPa	150hPa	150hPa	150hPa
200hPa	200hPa	200hPa	200hPa
250hPa	250hPa	250hPa	250hPa
300hPa	300hPa	300hPa	300hPa
400hPa	400hPa	400hPa	400hPa
500hPa	500hPa	500hPa	500hPa
600hPa	600hPa	600hPa	600hPa
700hPa	700hPa	700hPa	700hPa
	775hPa	775hPa	
850hPa	850hPa	850hPa	850hPa
925hPa	925hPa	925hPa	925hPa
1000hPa	1000hPa	1000hPa	1000hPa

4.FORWARD CALCULATION

In this study, the forward model of the fast radiative transfer model RTTOV-6 (Saunders et al., 1999) was applied. RTTOV-6 had also been used in JRA-25 and ERA-40. Atmospheric vertical profiles and surface conditions of each reanalysis are linearly interpolated or extrapolated into the position of observation spots.

To categorize conditions of each spot, evaluation of weather condition and skin surface condition was performed by the same procedure with the JRA-25 TOVS assimilation (Sakamoto et al. 2005). Especially for the distinction of low stratiform clouds prevailing over the ocean along western coasts of continents (Klein and Hartmann 1993), the comparison between surface and 850hPa temperatures and the evaluation of lower specific humidity were additionally executed.

5.High Resolution Infrared Radiation Sounder

The specification of each channel of HIRS is shown in Table 2, and some examples of monthly averaged departures of each channel against reanalysis profiles are presented in Fig 2.

Table 2. Channel Specification of HIRS

Channel	Level of peak energy contribution	Central Wave Number (cm-1)	Principal Absorbing Constituent
1	30hPa	668	CO2
2	60hPa	679	CO2
3	100hPa	691	CO2
4	400hPa	704	CO2
5	600hPa	716	CO2
6	800hPa	732	CO2/H2O
7	900hPa	748	CO2/H2O
8	Surface	898	Window
9	25hPa	1028	O3
10	900hPa	1217	H2O
11	700hPa	1364	H2O
12	500hPa	1484	H2O
13	1000hPa	2190	N2O
14	950hPa	2213	N2O
15	700hPa	2240	CO2/N2O
16	400hPa	2276	CO2/N2O
17	5hPa	2361	CO2
18	Surface	2512	Window
19	Surface	2671	Window
20	Cloud	14367	Window

Generally JRA-25 and ERA-40 show smaller biases against observations than the other two. The CO2 absorption channels for the lower troposphere (channel 7) and for lower stratosphere (channel 2 and 3), the window channels (8, 18, and 19), and the water vapor absorption channels (10, 11, and 12) especially have small departures.

On the other, the CO2 channels for the upper and mid troposphere (channel 4 and 5) designate larger departures for all reanalysis. For ERA-15 and

NCEP-NCAR the lower N2O absorption channels (channel 13 and 14) also denote critically large departures. Channels with broad weighting functions (channel 1 and 17) seem to be difficult to handle, because they require sufficient accuracy over many layers (Weinreb et al. 1981).

6.MICROWAVE SOUNDING UNIT

The specification of each channel of MSU is shown in Table 3, and examples of monthly averaged departures of each channel against reanalysis profiles are presented in Fig 3.

Table 3. Channel Specification of MSU

Channel	Level of peak energy contribution	Frequency (GHz)	Principal Absorbing Constituent
1	Surface	50.31	Window
2	700hPa	53.73	O2
3	300hPa	54.96	O2
4	90hPa	57.95	O2

Large departures of channel 1 observation are not only due to insufficient accuracy of surface conditions of reanalyses, but also derived from the wrong estimation of surface emissivities performed by the module in RTTOV-6.

Biases from channel 2 have almost the same values for all reanalyses. This reflects the relatively high accuracy of this channel among the lower tropospheric observing ones. Therefore this channel has been sometimes referred to monitor how the lower troposphere temperature had been changing. (Mears et al. 2003)

The biases for channel 4 of JRA-25 looks the smallest among all. This came from the fact that the channel had the strongest impact around the height of the peak of its weighting function.

7.STRATOSPHERIC SOUNDING UNIT

The specification of each channel of SSU is shown in Table 4, and monthly averaged departures of each channel against reanalysis profiles are presented in Fig 4.

Table 4. Channel Specification of SSU

Channel	Level of peak energy contribution	Central Wave Number (cm –1)	Principal Absorbing Constituent
1	15hPa	668	CO2
2	4.0hPa	668	CO2
3	1.5hPa	668	CO2

Biases of All channels are found to be small for both JRA-25 and ERA-40. This does not suggest that SSU observation had precise accuracy. But it reflects that there were no other reliable observations around those heights and SSU observation had inevitable impact on the upper stratosphere temperature. For the forecast models, which provided background field to the assimilation systems, have larger errors in the upper stratosphere.

8.CHANNEL SUITABILITY ASSESSMENT

To assess which channels were effective, time series of brightness temperature and its departure between real observation and reanalyses, and their standard deviation have been monitored. Those values of HIRS channel 2 and 4 of TIROS-N are shown in Fig. 5 and 6.

Regarding to HIRS channel 2, departures and their standard deviations of JRA-25 and ERA-40 were fairly constant comparing to those of real observations.

On the other hand, those of ERA-15 and NCEP-NCAR for HIRS channel 4 indicate larger values and tend to be very unstable. Such observations are not very consistent with the data assimilation system, and the standard deviations of departure larger than that of observation mean that the field was too rough to assimilate the observation. However the smaller variations of time sequence of departures do not necessarily mean identical background for the assimilation and good compatibility between the system and the observation. When the impact of the channel was dominant and the forecast and data assimilation went in balance to some extent, they necessarily denote small and stable values.

Those ideas provide kind of the criteria for evaluation of suitability of observation and stability of data assimilation process, those are,

a) the smaller bias means the observation and the assimilation system agree well spontaneously in their values themselves.

b) The stability of the departure time sequence represents the suitability of observation to the system (or stability of observation in the system).

c) The stability of spatial Standard Deviation of Departure (SDD) reflects the balance of the data assimilation system.

d) Amount of the SDD accounts for contribution of the observation to the system. In case when SDD is nearly equal to or larger than the standard deviation of observation time series, it means that the field of the system is too rough to assimilate the observation.

Among those, item a) is essentially important but it is relatively easy to handle. Items b) and c) have linear correlation between each other to some extend. Therefore, the following parameters are monitored by plotting them on the orthogonal axes diagram to assure how effective the observation was in the system,

b) the standard deviation of time series of departure,

d) the average of the ratio SDD to standard deviation of observed TBB.

As shown in Fig. 7, almost all the channels work in both JRA-25 and ERA-40 systems in a similar way. Differences in lower tropospheric channels reflect accuracy of skin surface conditions of both reanalyses. MSU channel 4 also shows substantial difference, ERA-40 system seems to be slightly going well with this observation. The diagram for SSU observation denotes assimilation of each channel of this instrument was still unstable in the both systems.

9.REANALYSIS AS A REFERENCE

To repair the discontinuity of TOVS observation and create consistent time series of observation records, appropriate references are required.

Generally, data assimilation methods and bias correction schemes differ among reanalyses. Despite those differences, reanalyses as a whole can provide useful information to adjust discontinuity of records.

Fig. 8 shows time sequence of TIROS-N MSU channel 2 observation and departure of reanalyses from that. An apparent jump happened on June 27 in 1979, when NOAA-6 launched. All of the analyses simultaneously show almost the same amount of discontinuity in their departures, and after then all the reanalyses show their stable departure again. Consequently TIROS-N MSU channel 2 observation seems to have been available, but it was not used in ERA-40 for the entire period of NOAA-6 operation. Fig. 8 suggests it could contribute after that by adjusting a bias setting.

For such purposes, JRA-25 could contribute vital information for the quality control of tropospheric observing channels, because the use of those channels was strictly confined in JRA-25 and therefore contamination raised from the irregularities of those channels are relatively small. (Sakamoto et al. 2005)

10.SUMMARY

An investigation of TOVS observation was launched as follow-up studies of JRA-25. Through comparison between the observation and atmospheric profiles of reanalyses, authors found,

1) Suitability of each channel for the system can be diagnosed by evaluating stability and amount of departure from profiles.
2) In some cases, reanalyses can contribute vital information to quality control of TOVS observation.

11.ACKNOWLEDGEMENTS

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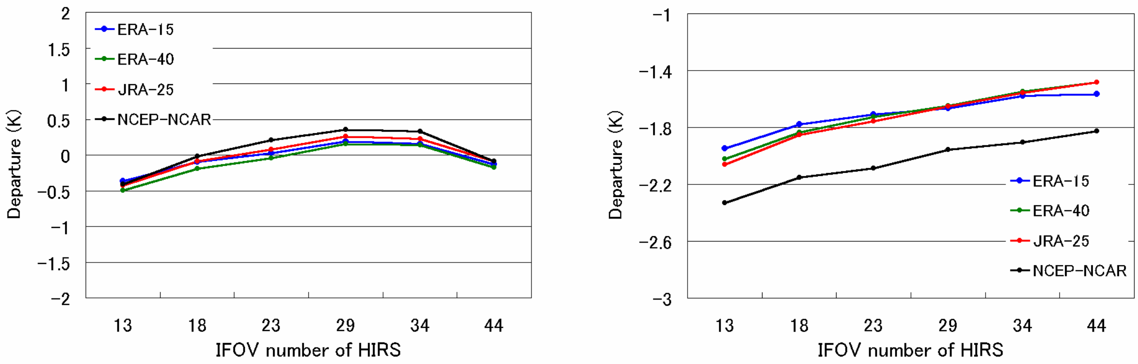


(a) Departures of MSU channel 2 (b) Departures of MSU channel 3

Fig. 1 Monthly Mean Departures of MSU channel-2 and channel-3 for each IFOV of HIRS of TIROS-N in Jan 1979. As for tropospheric observing channels (channel 4 – 16, 18, and 19) statistics were derived from observations of clear spots over oceans between 40S and 40N. Departure denotes difference of observed TBB from estimated one with reanalysis here after.

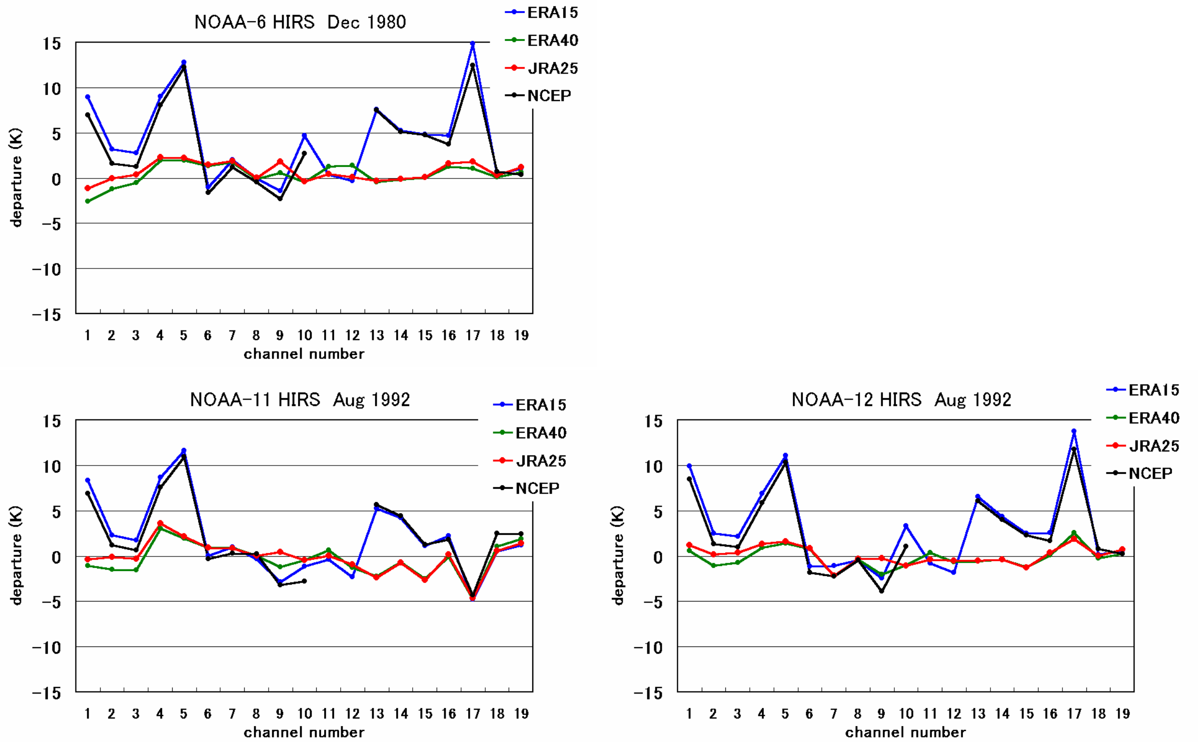


Fig. 2 Departures for each channel of HIRS of NOAA-6 in Dec. 1980 (upper left), of NOAA-11 in Aug 1992 (lower left), and of NOAA-12 in Aug 1992 (lower right). As for tropospheric observing channels (channel 4 – 16, 18, and 19) statistics were derived from observations of clear spots over oceans between 40S and 40N.

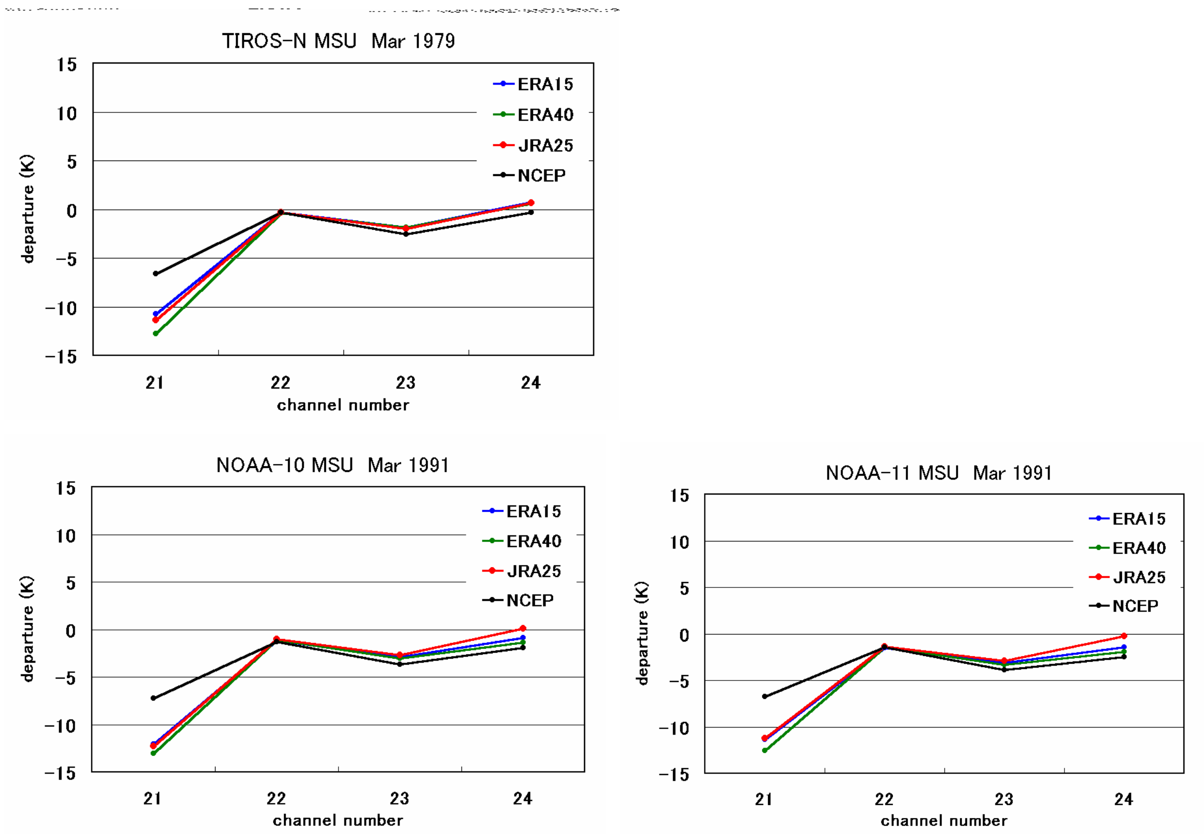


Fig. 3 Departures for each channel of MSU of TIROS-N in Mar 1979 (upper left), of NOAA-10 in Mar 1991 (lower left), and of NOAA-11 in Mar 1991 (lower right). For lower tropospheric observing channels (channel 1 and 2) statistics were derived from observations over oceans between 40S and 40N. Channel numbers 21, 22, 23, and 24 in these figures denote channel 1, 2, 3, and 4 of MSU respectively.

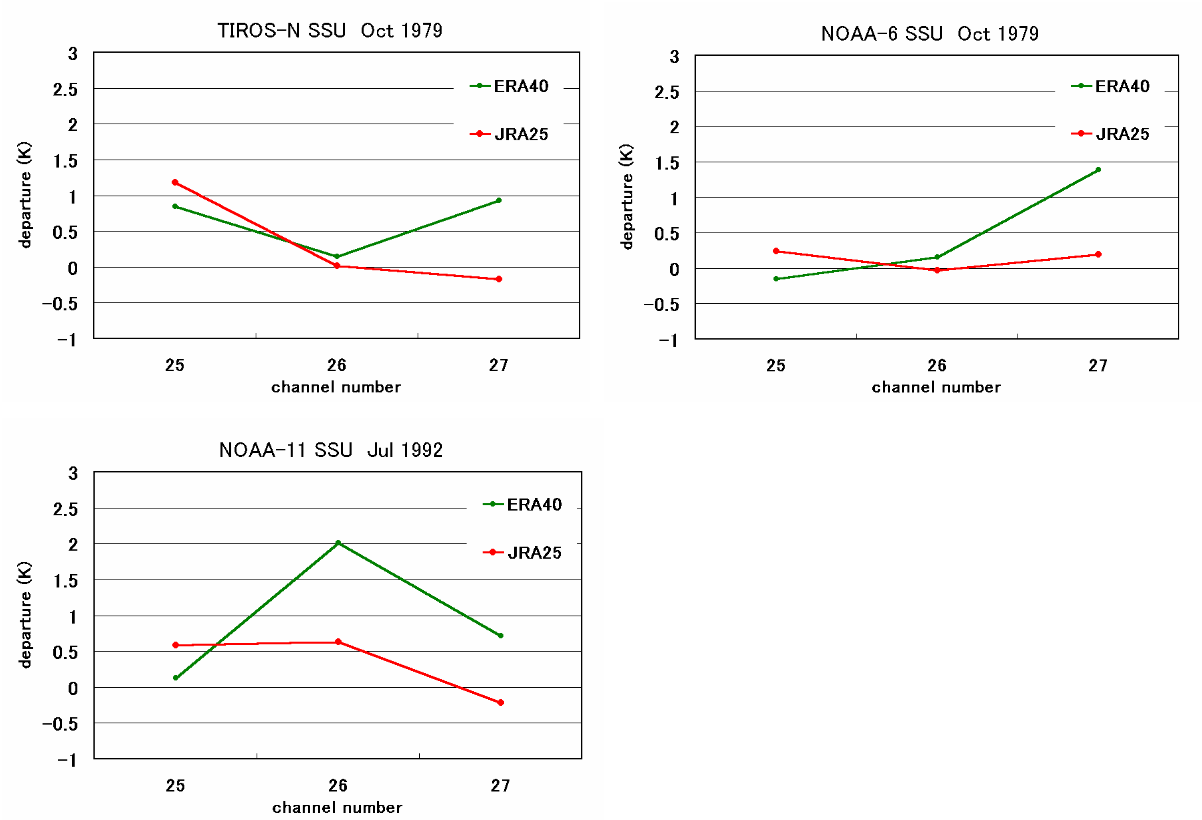
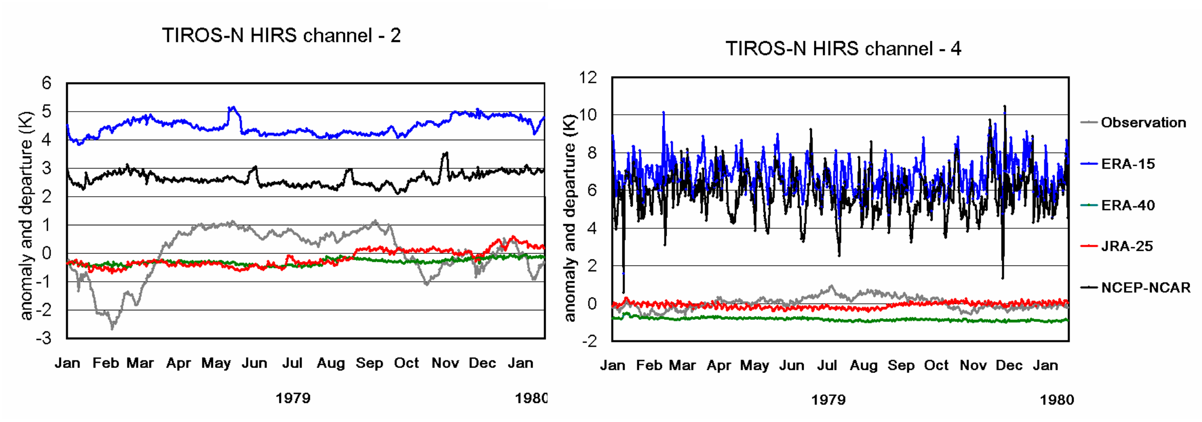


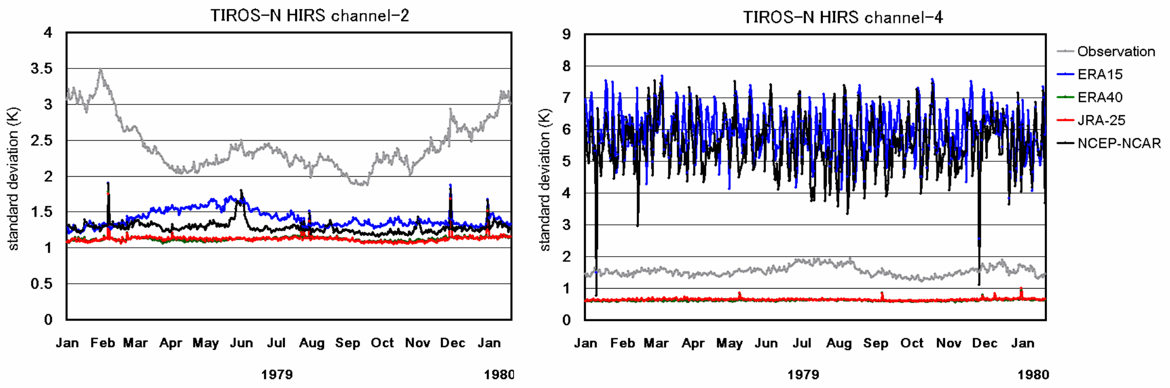
Fig. 4 Departures for each channel of SSU of TIROS-N in Oct 1979 (upper left), of NOAA-6 in Oct 1979 (upper right), and of NOAA-11 in Jul 1991 (lower left). Channel numbers 25, 26, and 27 in these figures denote channel 1, 2, and 3of SSU respectively.



(a) HIRS channel 2 (b) HIRS channel 4

Fig. 5 Anomaly of HIRS observation of TIROS-N and Departures of Reanalyses from observation.

As for channel 4, statistics were derived from observations of clear spots over oceans between 40S and 40N.



(a) HIRS channel 2 (b) HIRS channel 4

Fig. 6 Standard deviation of HIRS observation and Departures of Reanalyses for them of TIROS-N.

As for channel 4, statistics were derived from observations of clear spots over oceans between 40S and 40N.

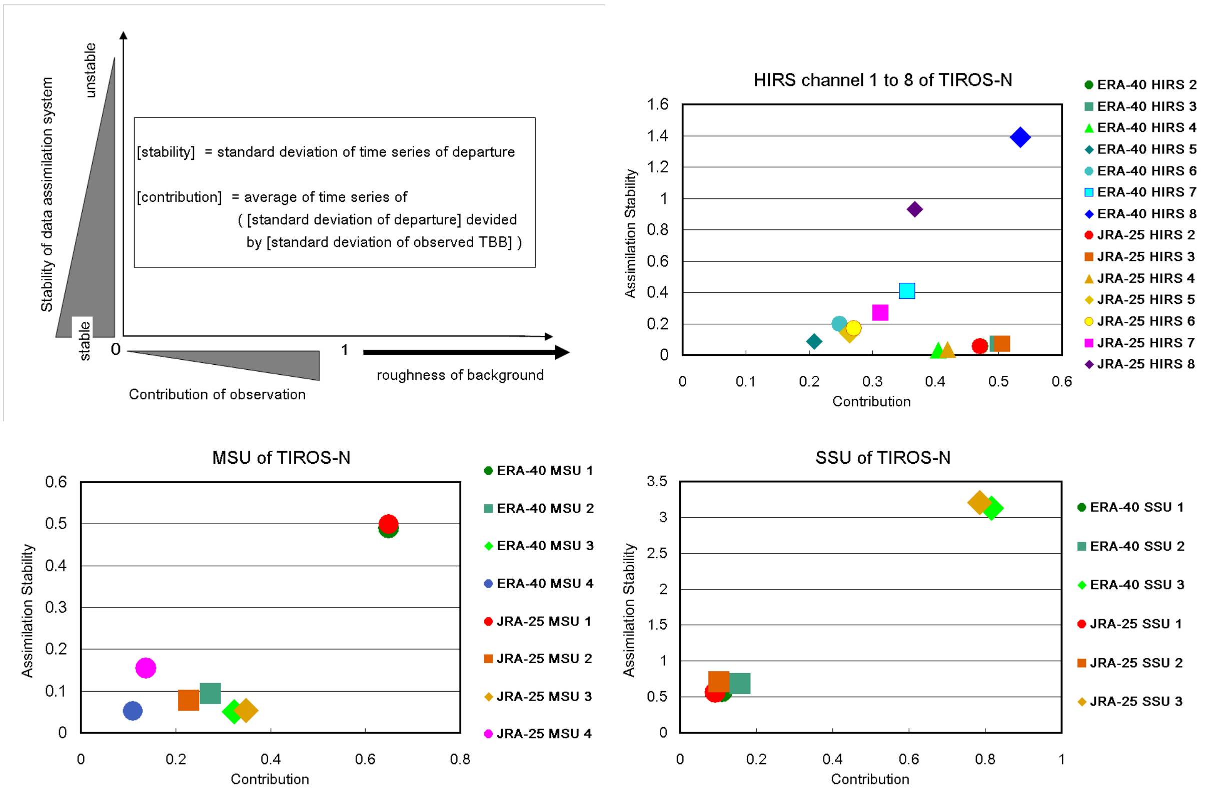


Fig. 7 Diagram for diagnosis of assimilation stability and observation contribution.

Upper left : how to see this diagram, upper right : HIRS channel 2 – 8, lower left : MSU, lower right : SSU of TIROS for JRA-25 and ERA40.

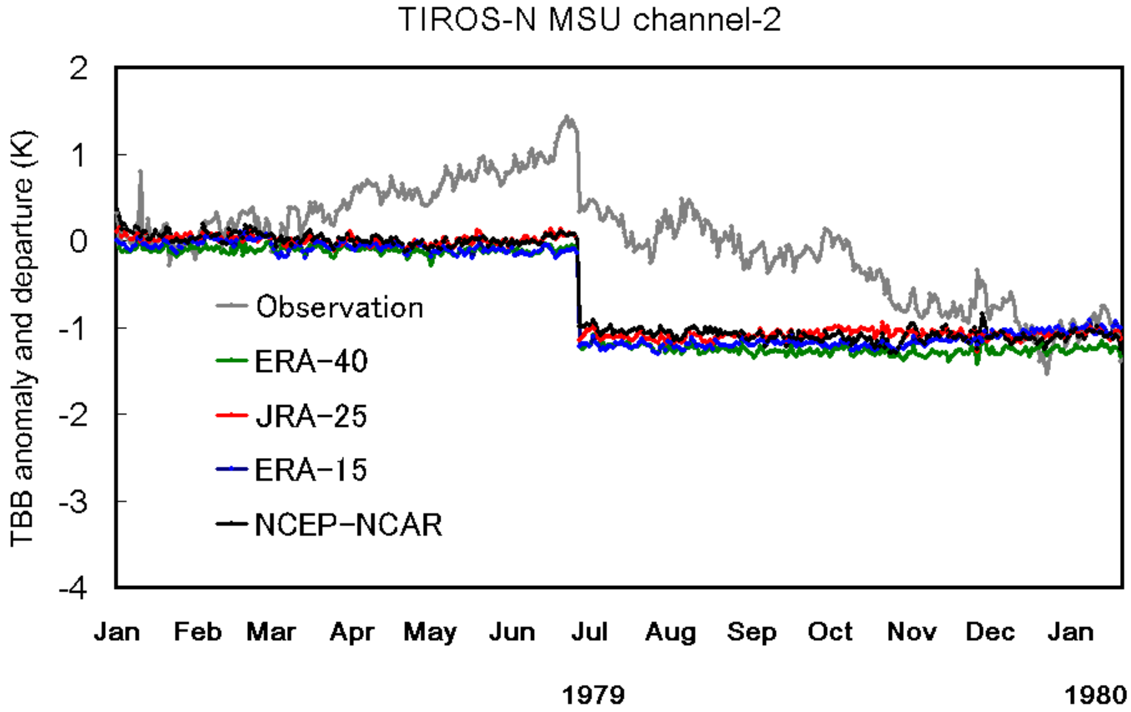


Fig. 8 Anomaly of MSU channel 2 observation of TIROS-N and Departures of Reanalyses from observation. Statistics were derived from observations over oceans between 40S and 40N.