CLEAR RADIANCE RETRIEVAL OF HIRS CHANNELS WITH THE USE OF AVHRR DATA

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1. Introduction

Because of its simplicity, many of the retrieval methods for the atmospheric temperature and composition profiles are based on the clear radiance R, which is not a directly observed quantity but one that must be estimated from cloud-contaminated observed radiances. The observed radiance I is written as

$$I = (n-1)R + nI_c = R + n(I_c - R), \qquad (1)$$

where n is the cloud amount within the Field of View (FOV) and I_c is the cloudy radiance.

How can R be determined from I? Currently, this is essentially done by the so-called N* method of Smith (1968) under the assumption that I_c is constant within two or more neighboring FOVs, although some improvements have been made (Smith and Woolf, 1976; McMillin, 1978). However, since the radius of the HIRS (High resolution Infrared Radiometer Sounder) FOV is about about 17 km and the distance between two FOVs is about 42 km or more, the assumption of constant I_c will rarely be met over this broad area.

If we obtain information about the value of $n(I_c-R)$, in addition to I, we will be able to make a better determination of R in (1). We will do this by using the AVHRR (Advanced Very High Resolution Radiometer) data: the radius of the AVHRR FOV is about 1.1 km and, during one scan of HIRS, the AVHRR scans about 38.4 lines (HIRS scan time is 6.4 sec while AVHRR scan time is .16 sec), so that one HIRS FOV contains 300 to 450 AVHRR FOVs (Figure 1). From these AVHRR data, we can obtain the cloud amount and other physical quantities related to the cloud characteristics within each HIRS FOV.

2. HIRS-AVHRR Matching

Before calculating various physical quantities from AVHRR data within a HIRS FOV, it is necessary to know the relative position of HIRS and AVHRR FOVs accurately. This is complicated by the fact that the rotational axes of HIRS and AVHRR scan mirrors and the centers of the scan lines of both radiometers do not exactly coincide. We will represent the deviation of the footprint of the HIRS FOV from its nominal position with respect to the AVHRR coordinate system by four parameters, ΔI, ΔJ, θ_{AH}, θ_A, which are defined as in Figures 2 and 3. These parameters are determined so as to minimize the following quantity:

$$\sigma = \sum_{i=1}^{56} [I_A(i) - I_H(i)]^2 \qquad (2)$$

where $I_A(i)$ is the average radiance of AVHRR 4th channel within the i-th HIRS FOV and $I_H(i)$ is the radiance of the 8th channel of the HIRS in the i-th FOV. The details of the procedure to determine these four parameters are given in

Aoki (1980a). The results for NOAA-7 and 8 are shown in Table 1, where ΔI and ΔJ are scaled by AVHRR line number and FOV number, respectively (Aoki and Nakajima, 1983).

Once these parameters are determined, we can obtain the cloud amount n, mean radiance I_A, mean radiance only over cloudy area I_{AC}, maximum radiance $I_A(max)$, and minimum radiance $I_A(min)$ within each HIRS FOV. These quantities are used together for retrieving the clear radiances of HIRS channels.

One scan line of AVHRR normally crosses the FOVs of two or three HIRS lines. To calculate the quantities n, I_A, I_{AC}, etc., it is necessary to know the first and last AVHRR FOV numbers, N_A and N_B, that are contained in each HIRS FOV. The numbers N_A and N_B can be determined if the parameters ΔI, ΔJ, θ_{AH}, and θ_A are known. Although the number of AVHRR scan lines during one HIRS scan is not exactly an integer (38.4, as mentioned before), we assume that the same pattern of the crossings of AVHRR lines to HIRS FOVs repeats for every 6.4 sec, and then, the numbers, N_A and N_B, are determined once for 39 of AVHRR lines and for each satellite.

3. Clear Radiance Retrieval for HIRS Channels

We define

$$(X_1,\ldots,X_M) = (R, Q_1,\ldots,Q_M),$$
$$Q_j = n_j(I_{c,j} - R), \tag{3}$$

where the suffix j denotes the j-th FOV of HIRS. The clear radiance R is assumed to be constant over M of the HIRS FOVs. The observed radiance I of the i-th FOV of HIRS is written as, from (1),

$$I_i = \sum_{j=1}^{M+1} K_{ij} X_j, \tag{4}$$

where $K_{ij}=1$ for j=1 or i+1 and $K_{ij}=0$ for others. The maximum likelihood estimate for X becomes

$$\hat{X} = X^\circ + S_x K^t (K S_x K^t + S_I)^{-1} (I - K X^\circ), \tag{5}$$

where X° is the initial guess for X, S_x the covariance matrix of the error in the initial guess and S_I the covariance matrix of the measurement error in I. The initial guess for R, R°, is given by the theoretical calculation of the radiance which uses the initial guess of the sea surface temperature, atmospheric temperature and moisture profiles.

On the other hand, the initial guess for Q is given by

$$Q^\circ = Q_A r(\nu, \nu_A), \tag{6}$$

where $Q_A = I_A - R_A = -n(R_A - I_c(\nu_A))$ and R_A is the clear radiance of AVHRR, which is known as shown in preceding sections, and $r(\nu, \nu_A)$ is the ratio of Q for the channel ν to that of the AVHRR 4th channel ν_A and is given by

$$r(\nu,\nu_A) = \frac{\varepsilon(\nu) I_{rd}^*(\nu)}{\varepsilon(\nu_A) I_{rd}^*(\nu_A)}, \tag{7}$$

where $I_{rd}^*(\nu_A) = R(\nu_A) - I_c^*(\nu_A)$ and $I_c^*(\nu_A)$ is the blackbody radiance of the cloud. An example of the function $r(\nu, \nu_A)$ under the assumption $\varepsilon(\nu) = \varepsilon(\nu_A)$ is shown in Figure 4. It is apparent in Figure 4 that the r is given by a simple function of $I_{rd}^*(\nu_A)$. $I_{rd}^*(\nu_A)$ is given by

$$I_{rd}^*(\nu_A) = \{[R_A - I_A(\min)] \times I_{rd}^*(\max)\}^{\frac{1}{2}}, \tag{8}$$

where $I_{rd}^*(\max)$ is the possible maximum value of $I_{rd}^*(\nu_A)$ (for details see Aoki, 1980 and 1982). The alternative to (8) is

$$I_{rd}^*(\nu_A) = R_A - I_A(\min), \tag{9}$$

which is obtained under the assumption that $I_A(\min) = I_c^*(\nu_A)$.

4. Accuracy of the Present Method

Figure 5 is an example of the retrieved clear radiances for the 6th channel of HIRS, where the present method is known as the 'Method-QA', and compared with the McMillin's method and the so-called 'Method-Q8' of Aoki (1982). In the lower part of the figure, the mean cloud amount over M of HIRS FOVs, $\bar{n}$, is also shown. The blackened symbols denote the flagged data which are determined by each method as the bad data.

The sea surface temperature over the region studied here changes only slightly so that the clear radiances of the 6th channel of HIRS should not change rapidly from point to point as is the case of McMillin's method. Although we have no ground truth for the clear radiance, the accuracy of the present method was estimated by comparing the following three results for clear radiances: the first one (QA1) was obtained by using Eq.(8) for the initial value of Q; the second (QA2) was obtained by using Eq.(9); the last one (QA3) was obtained from the initial clear radiance that is different from that of QA1, where the different value of the clear radiance for QA3 was created by the Gaussian random number generator with the mean value that is equal to the initial guess of QA1 and the standard deviation of 10% for the channels 3-12 and 20% for the channels 13-19.

The average rms deviations of QA2 and QA3 from QA1 are shown in Figure 6, where the data are not used when one of QA1, QA2 and QA3 is flagged. The rms deviations of the initial guess used in QA1, Method-Q8 and McMillin's method from QA1 are also shown. It was found that the rms difference between QA1 and initial value of clear radiance used in QA1 (i.e., the accuracy of the initial clear radiance) is the order of 10% for channels 3-12 and 20-30% for the higher number channels, respectively. The standard deviation that is adopted in the random number generator to create the initial clear radiance for QA3 is of the same order as the rms error of the initial guess of the clear radiance used in QA1. Thus, the rms error in QA1 caused by the error in the initial guess of clear radiance may roughly be given by the rms difference between QA1 and QA3.

On the other hand, the error caused by the adoption of Eq.(8) may roughly be given by the difference between QA1 and QA2. These differences, QA2-QA1 and QA3-QA1, may together indicate the accuracy of the present method, which is of the order 1% or less for the small channel numbers as shown in Figure 6.

5. Conclusion and Discussion

The present method is able to obtain good accuracy for clear radiances by incorporating the information of cloudy radiances of AVHRR. The method is stochastic and is able to incorporate the error characteristics of the measured radiances and initial guesses, in contrast to the current deterministic methods of Smith (1968) and McMillin (1978): the deterministic methods sometimes make large errors caused by errors in measured radiances and assumptions such as constant cloud height. The present method also incorporates all information of M FOVs, whereas in other current methods only two or three FOVs are used and other FOVs are not used.

The present method, however, cannot be applied to obtain vertical soundings over the entire globe area because AVHRR data over this area cannot be obtained at a single receiving site. To apply the present method to obtain vertical soundings over the global area, it will be necessary to develop a hardware system for obtaining, on board base, the histogram of AVHRR radiance within each HIRS FOV, as proposed by Aoki (1982).

References

Aoki, T., 1980a: A method for matching the HIRS/2 and AVHRR pictures of TIROS-N satellites. Meteor. Satellite Center Tech. Note, 2, 15-26.

_______, 1980b: Statistical determination of clear radiance from cloud-contaminated radiances. J. Meteor. Soc. Japan, 58, 528-536.

_______, 1982: An improved method to retrieve the clear radiance from partially cloudy spots of radiometer on board satellite, J. Meteor. Soc. Japan, 60, 758-764.

_______ and S. Nakajima, 1983: Determination of the location and partial cloud amount in each HIRS spot, Meteor. Satellite Center Tech. Note, Special Issue; Summary of TOVS data processing system, 57-66.

McMillin, L.M., 1978: An improved technique for obtaining clear radiances from cloud-contaminated radiances, Mon. Wea. Rev., 106, 1590-1597.

Smith, W.L., 1968: An improved method for calculating tropospheric temperature and moisture from satellite radiometer measurements, Mon. Wea. Rev., 96, 387-396.

_______ and H.M. Woolf, 1976: The use of eigenvectors of statistical covariance matrices for interpreting satellite sounding radiometer observations, J. Atmos. Sci., 33, 1127-1140.

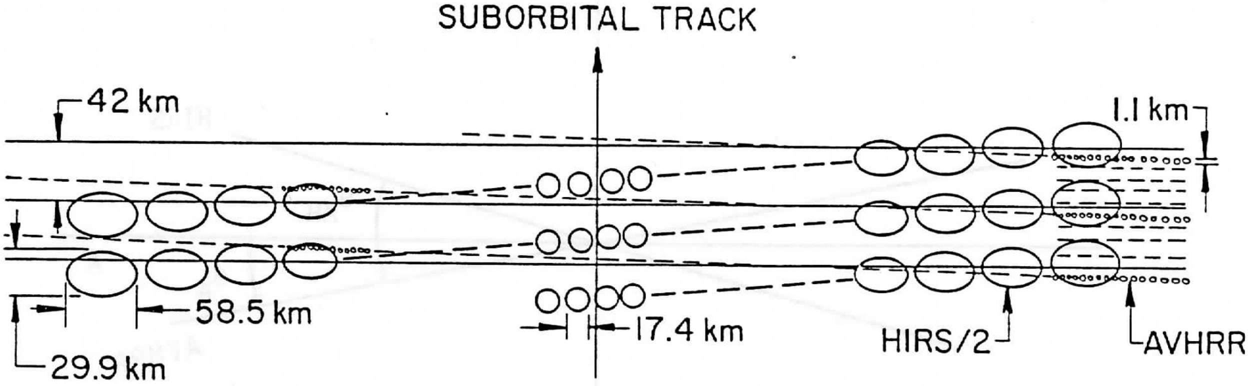

FIGURE 1. Scan patterns of HIRS/2 (larger elipses) and AVHRR (smaller elipses).

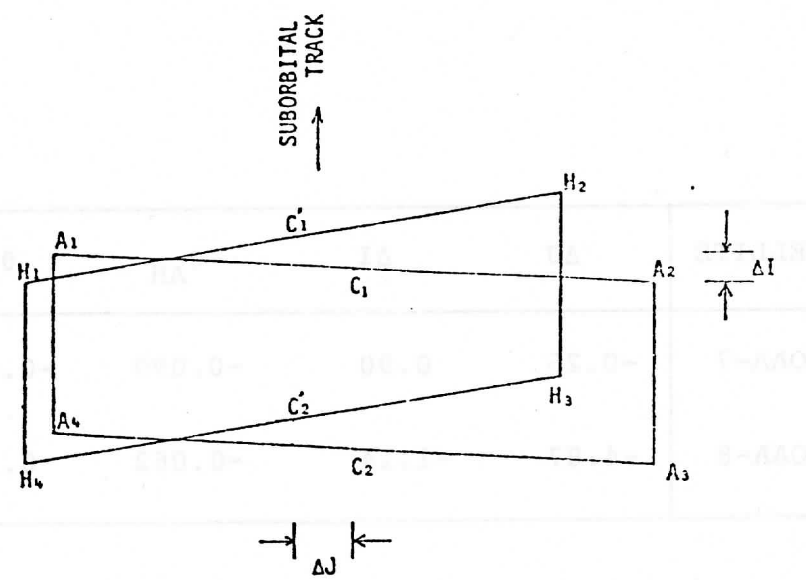

FIGURE 2. An illustration of the shifted scan areas of HIRS/2 ($H_1H_2H_3H_4$) relative to that of AVHRR ($A_1A_2A_3A_4$)

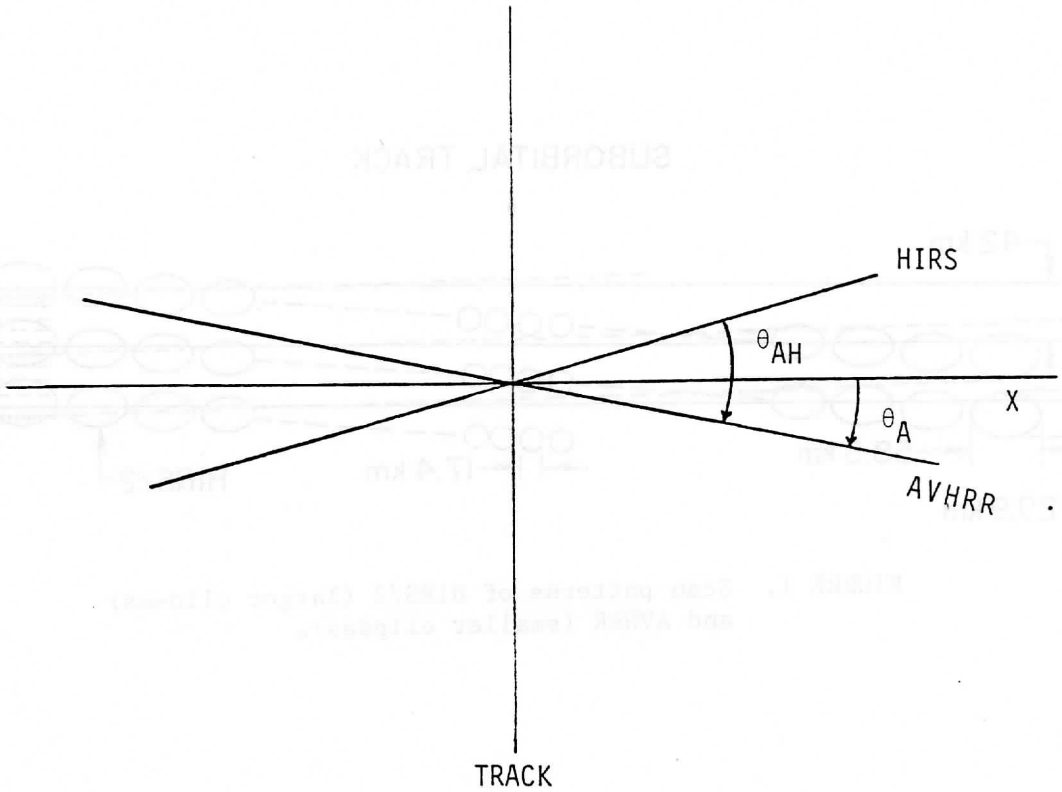

FIGURE 3. Definition of θ_{AH} and θ_A.

SATELLITE	ΔJ	ΔI	θ_{AH}	θ_A
NOAA-7	-0.25	0.90	-0.090	-0.030
NOAA-8	-4.87	-1.14	-0.062	0.189

TABLE 1. Mean values of ΔJ, ΔI, θ_{AH} and θ_A for NOAA-7 and NOAA-8. The unit of ΔJ and ΔI are pixel and line number, respectively, and that for θ_{AH} and θ_A is degree. H-A matching was carried out with using HIRS 8th channel and AVHRR 4th channel.

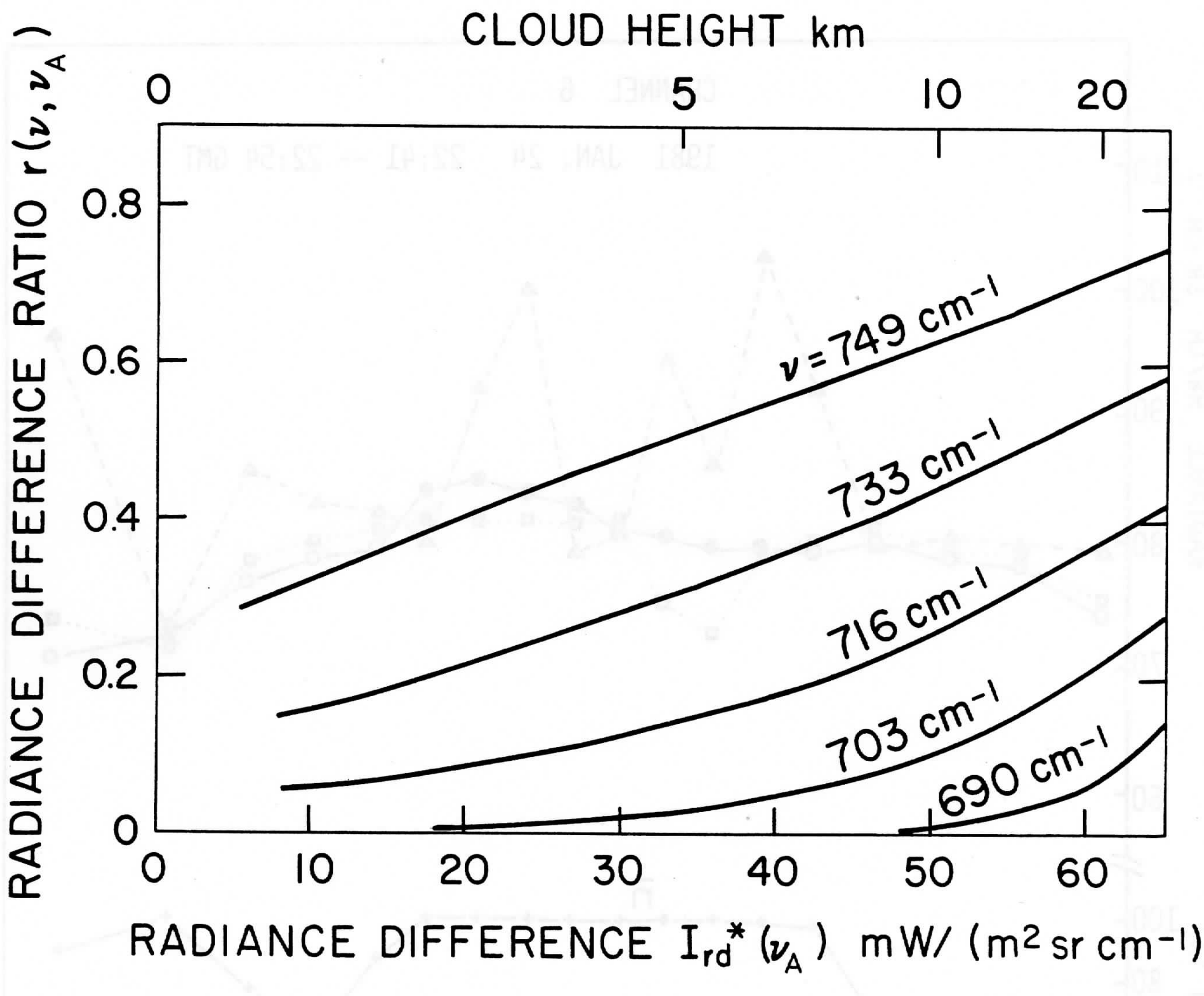

FIGURE 4. Radiance difference ratio $r(\nu,\nu a)$ ($\nu_a \approx 900 cm^{-1}$) as a function the radiance difference I_{rd}* and cloud height.

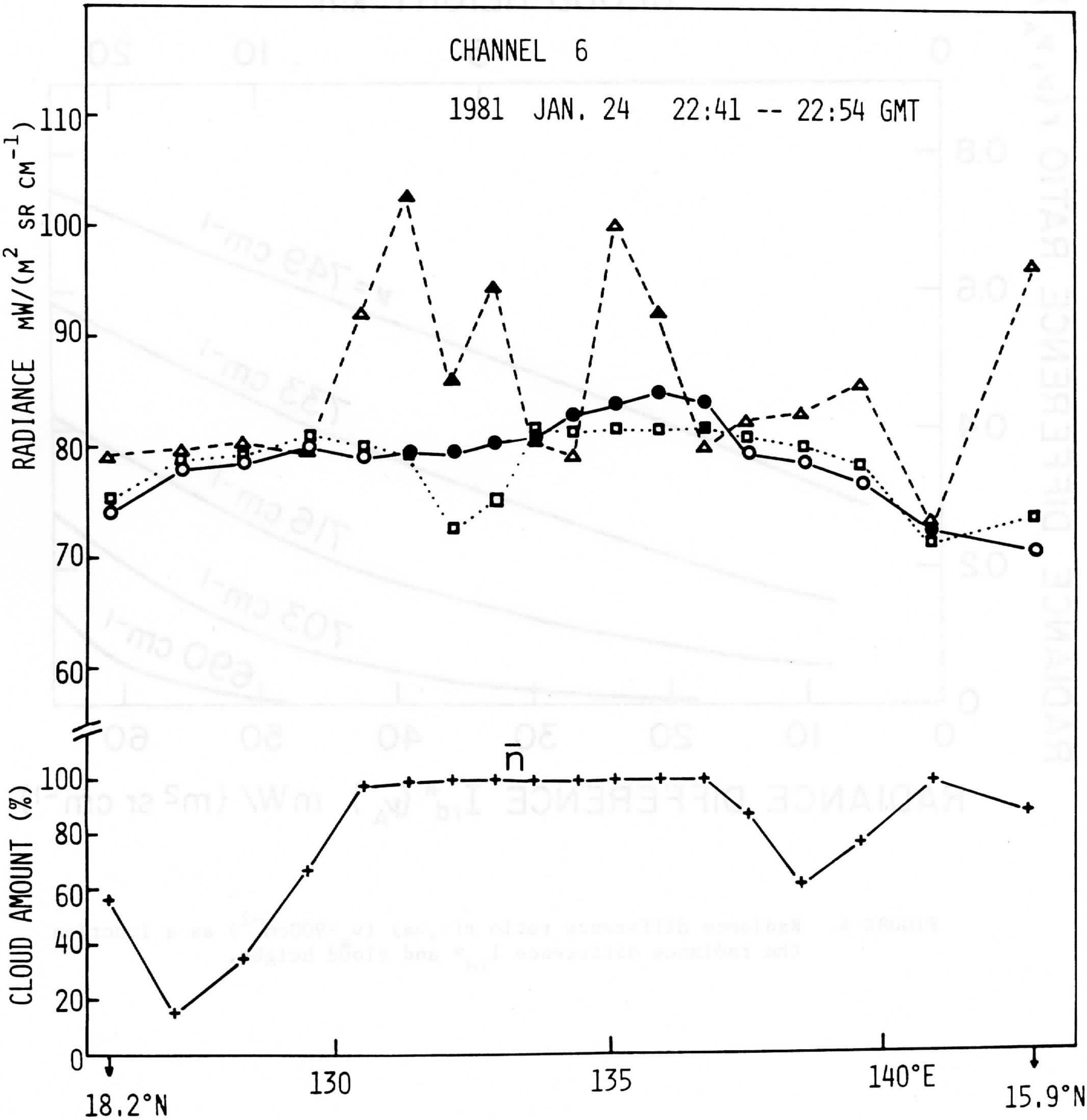

FIGURE 5. Comparison of the retrieved clear radiances by the Method-Q8 (square), Method QA (circle) and McMillin's methods (triangle) from NOAA-6 satellite observed radiance data on Jan. 23, 1981. The mean cloud amount $\bar{n}$ is also shown in the lower part of the figure.

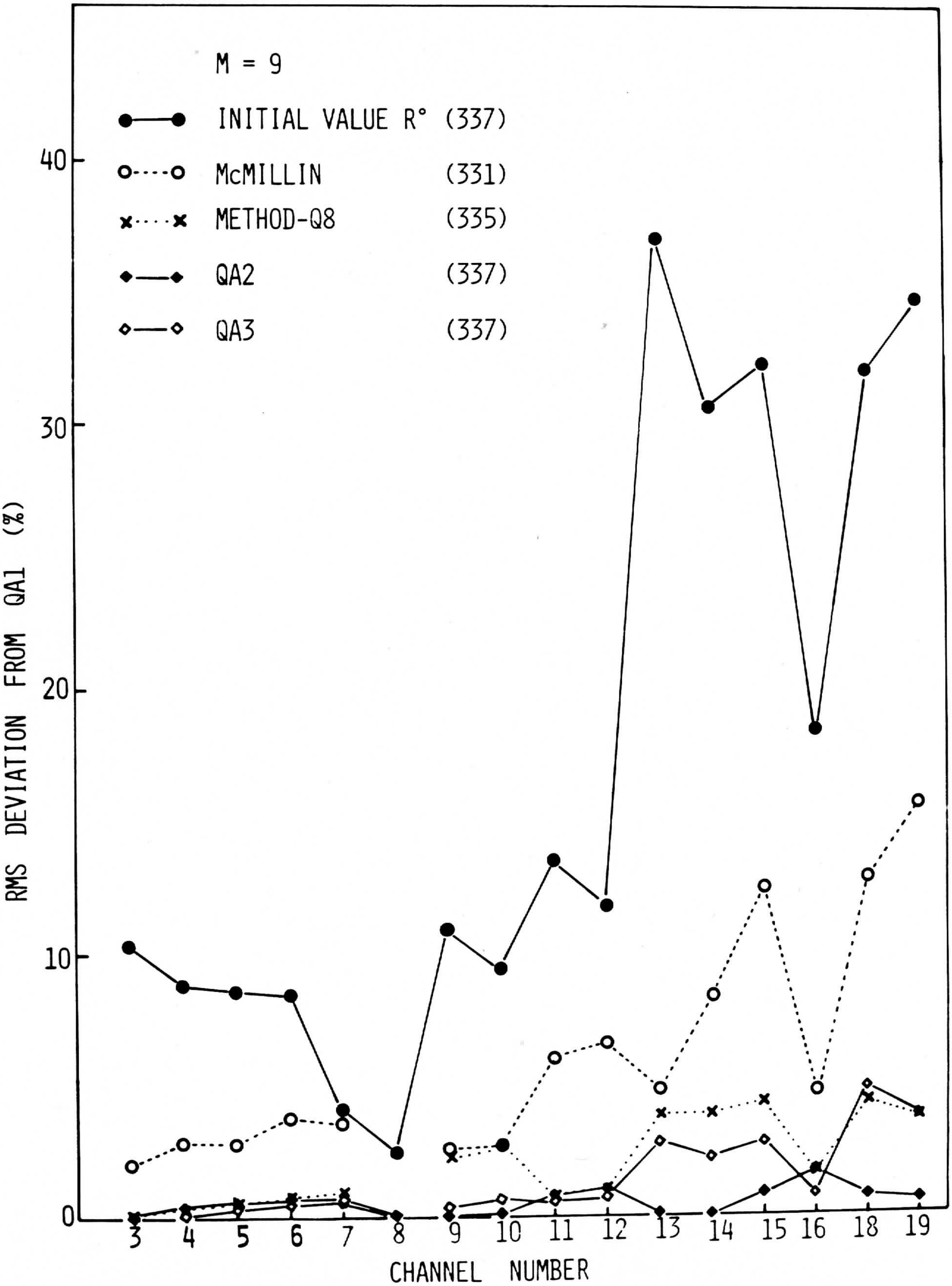

FIGURE 6. The rms deviations, from QA1, of the initial value of the clear radiance used in QA1, the clear radiance by McMillin's method, the clear radiance by Method-Q8, QA2 and QA3 in the case of M-9. In parenthesis are shown the number of the data used.

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