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Satellite-Derived Moisture Profiles

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SATELLITE-DERIVED MOISTURE PROFILES

Andrew Timchalk

Satellite Applications Laboratory
National Environmental Satellite, Data, and Information Service
Washington, DC 20233

ABSTRACT. An evaluation of relative humidity and mixing ratio profiles determined by two different satellite methods is presented. One method (bogus), which is used operationally, uses GOES cloud imagery to prescribe vertical moisture profiles. The second method (TOVS) uses a 15-channel algorithm with polar orbiting satellite data. The accuracies of both methods, although inferior to moisture profiles obtained from rawinsondes, show sufficient accuracy to be useful as input into forecast models whose domain includes large oceanic areas.

TOVS moisture profiles were more accurate in clear and partly cloudy areas, whereas the bogus profiles were more accurate in the broken cloud cover areas. An advantage of the TOVS method is that it is fully automated and can be applied globally; however, some accompanying disadvantages are that the retrievals are asynoptic and that they are made only in clear and partly cloudy areas.

The major advantage of the bogus method is that profiles are available at synoptic times and over areas where no TOVS moisture values are retrieved. The disadvantage of the bogus method is that the moisture values are less accurate than the TOVS values in clear and partly cloudy areas. Furthermore, the method is only partially automated and requires subjective interpretation of cloud imagery.

I. INTRODUCTION

The derivation of an accurate spatial and temporal atmospheric water vapor distribution still remains a problem especially over sparse data areas. Rawinsonde measurements of moisture are by far the most reliable; however, relatively few rawinsonde measurements are made over the vast oceanic areas of the Earth.

Beginning as early as 1968, the National Environmental Satellite Service (NESS now NESDIS) prepared bogus moisture information for the National Meteorological Center (NMC) from subjective evaluation of satellite cloud pictures. This procedure, after going through some evolutionary development, has third priority in specifying the moisture fields that are assimilated into the NMC forecast models. Neither remotely sounded moisture values from the TIROS Operational Vertical Sounder (TOVS) nor the VISSIR Atmospheric Sounder (VAS) are used directly by the forecast models. TOVS mixing ratios, however, are used to calculate the mean layer (virtual) temperatures and mean (virtual) thicknesses transmitted to NMC and over the Global Telecommunications System, respectively. VAS temperature and moisture retrievals are currently being evaluated on an experimental basis by members of NMC and the NESDIS Development Laboratory, SSEC, Madison, Wisconsin (Smith 1983).

Most early studies of satellite moisture retrievals evaluated moisture values in terms of precipitable water. Such studies were made by McClain (1966), Smith (1966), Shen and Smith (1973), Staelin et al. (1976), and Grody et al. (1980).

More recent studies by Weinreb and Crosby (1977), Gruber and Watkins (1979), Hayden et al. (1981), McMillin and Sanyal (1983) have begun to probe the vertical distribution of moisture at fixed pressure levels and the distribution near the Earth's surface where water vapor is concentrated.

The main objective of this study is to determine whether the TOVS moisture profiles are more (less) accurate than those bogus profiles derived from GOES cloud pictures. The results should serve as a quantitative measure of the present state-of-the-art in determining moisture profiles from weather satellites. In addition, the results also reveal the strengths and weaknesses in each of the satellite moisture retrieval methods.

II. METHODS

2.1 Cloud bogus method

The category system of relative humidity profiles, the categories being assigned by examining cloud pictures, was introduced into NMC operational data processing in the early 1970's. Bogus profiles were to be used over ocean areas and parts of Mexico only if no rawinsonde observations (RAOB) or surface ship observations were present. Chu (1977) and Parrish (1977) describe the method used to obtain humidity analyses for the NMC operational models. Studies performed by NMC's Systems Evaluation Branch by Hirano and Polger (1977, 1978) and Hirano (1978), showed mixed results when the bogus humidity profiles were incorporated into the operational models. They found in evaluating forecasts for periods up to 48 hours, that moisture bogusing tended to alleviate a 12hr dry bias, but in doing so, bogusing induced excessive rainfall in the plains to the north of the Gulf of Mexico. Precipitation threat scores were similar or better at 12hr with bogusing, but much variability was found in the later forecast periods.

By the early 1980's, the satellite bogus method had evolved into a thirteen relative humidity (RH) profile category system. At the present time, these humidity profiles are provided twice daily to NMC for the 2.5 lat x 2.5 long grid area (ocean areas only) shown in Figure 1. The cloud bogus RH profiles to be supplied to these grid points are shown in Table 1. The profiles were developed over a period of time by correlating RH profiles with synoptic situations as identified by satellite imagery.

Moisture is assimilated into the operational models with various vertical coordinates. Table 1a shows the RH values assigned to each of the six mandatory pressure levels for each of the 13 categories to be used in the global models. The bogus RH values shown in Table 1b are those assigned to the three layers for use in the LFM model.

Figure 2a shows a work copy of the GOES West image that illustrates the anlayst's assigned bogus RH categories. For example, the area designated 13 (Cat. 13) represents an area of mostly overcast high and middle clouds without significant low level moisture. This category is usually associated with the leading sections of frontal waves and assigned toward the middle sections of very dense subtropical jet streams. The area designated as Category 2 in Figure 2b, for example, represents an area of vertically solid cloudiness resulting in continuous precipitation. It is an area of overcast cloudiness associated with baroclinic zones or solid lines of cumulonimbi (CB's). Category 2 normally surrounds a Category 1 area within a baroclinic zone. It includes overcast areas of bright cloudiness in infrared (IR) imagery which is associated with a well developed vorticity center or bent-back occlusion.

Any area, within the analysis boundaries where the category is unspecified is assigned Category 8 (default category). Category 8 is the most commonly observed category. It represents regions where no weather systems are present or extratropical regions of scattered to broken low clouds in the form of stratocumulus or stratus. It also represents areas of flat stratocumulus in the region of a ridge (low inversion), which are frequently seen off the U.S. west coast. In addition, it can also represent clear sky areas in tropical regimes. For a complete description of the moisture bogus program, refer to Smigielski et al. (1982).

Of the 460 grid points shown in Figure 1, Category 8 is normally assigned to more than one-half of the points. It is in these large areas (Cat. 8) that one would expect the TOVS moisture values to outperform or improve upon those obtained via the cloud bogus moisture categories.

2.2 TOVS METHOD

The TOVS moisture values are determined by using a statistical eigenvector regression method developed by Smith et al. (1979). TOVS mixing ratio values are calculated by using Equation (1) at the 15 pressure levels shown in Table 2a and the 15 TOVS channels shown in Table 2b.

$$MRi = MRAi + \sum_{j=1}^{15} Cij(TBOj - TBAj) \qquad \text{Eq. (1)}$$

In Equation (1), MRi is the retrieved mixing ratio at the ith level (Table 2a). MRAi is the average mixing ratio, TBAj is the average brightness temperature for channel j, and the Cij's are the coefficients for each of the 15 channels (j) and for each of the 15 different pressure levels (i). All of the terms on the right hand side of Equation (1), except for TBOj, are obtained a priori and are updated on a weekly basis. TBOj is the TOVS observed brightness temperature for each of the 15 channels at the location for which the temperature and moisture retrieval is made.

Equation (1) is applied only when a clear or N* retrieval can be made. The N* procedure allows retrievals to be made under partly cloudy and broken cloud conditions, by providing to Equation (1) an equivalent clear-column brightness temperature (TBOj). Clear-column brightness temperatures (radiances) are obtained by filtering cloud amounts from adjacent scan spots by using paired frequencies (McMillin 1966).

For this study, TOVS retrievals used for comparisons were extracted from the operational NESDIS Data Staging Disk (DSD3) files. There is a separate file for each polar orbiting satellite; e.g., one for NOAA 7 and one for NOAA 8. Each disk has a capacity to store 40,000 records, or about 5 days of the most recent retrievals. In order to mesh the TOVS retrievals with the bogus and RAOB moisture values, the ground rules given in the next section were stipulated.

III. PROCEDURE

3.1 Moisture comparison method

Ground rules were stipulated and used as follows:

* Use the cloud bogus relative humidity categories assigned by members of the Synoptic Analysis Branch (SAB) and for the 0115 GMT and 1315 GMT operational runs

* Use TOVS mixing ratio values extracted from the DSD3 files. Values are retrieved for only clear and partly cloudy (N*) conditions

* Collect only cases in which moisture values were obtained by each of the three different methods: RAOB, bogus, and TOVS

* Bogus RH and TOVS MR locations were required to be within 90 n mi of the RAOB station

* TOVS retrieval times were required to fall within 3 hrs of the RAOB time. Bogus times were nominally one hour before RAOB times

* When two or more TOVS retrievals were located within the prescribed distance and time windows, use the retrieval nearest in location

* Use RAOB moisture profiles only if values were available at three or more of the six mandatory pressure levels

* If RAOB temperatures or dew point depressions were garbled or appeared unreasonable, exclude that case from the data set

* Bogus RH profiles were given for ocean areas only, thus matchups were possible only with coastal and oceanic stations

In order to intercompare the moisture values from the three different methods, some precalculations had to be performed. Since the NMC models ingest the moisture data as relative humidities and subsequently calculate specific humidities, moisture values in terms of relative humidity as well as mixing ratio were precalculated.

To calculate the RH and MR values, vapor pressures and saturation vapor pressures were calculated by using Teten's (1967) formula over water. For RAOB data, relative humidity (RH) and mixing ratios (MR) were calculated for all mandatory and significant pressure levels. For the TOVS retrievals, TOVS temperatures and MR values were used to calculate TOVS RH values at the 15 pressure levels shown in Table 2a. Given the bogus relative humidities, bogus mixing ratios were calculated by borrowing the air temperature from the RAOB for which the matchup occurred at the six mandatory pressure levels shown in Table 1a.

3.2 Data

The rules of Section 2.3 were applied to all the cases in this study. The majority of the matchups were collected from the operational files during the period May-Sept 1984 as planned. It was the intent of this study to concentrate the data collection during the summer season when mixing ratios at 1000 mb in the lower latitudes can exceed 20 g/kg and moisture variability is large.

Although data collection began in January of 1984, a program that expedited the process was put in place by May 1984. Data was then collected through Sept 1984. Over the entire period, Jan-Sept, 1105 coincident matchups were obtained. Table 3 shows the monthly frequency of matchups for each of the 13 bogus categories. As expected, bogus Category 8 had the highest frequency, 679, while there was no matchup for Category 1. Category 1 is a profile to be assigned to areas of vertically solid cloudiness with moderate to heavy precipitation. In such areas, it is unlikely that a clear or partly cloudy TOVS retrieval could be made; however, the lack of matchups in certain categories was strongly related to the lack of areal extent of those categories.

An examination of the GOES images and bogus RH listings indicate that the assignment of Category 1 was nonexistent or extremely rare in 1984. Similarily, Bogus Category 5 was rarely assigned; only one matchup was obtained for Category 5 during the entire period. Initially, it was expected that the number of matchups would be inversely related to the likelihood of precipitation associated with certain individual bogus categories, this was not always the case.

The second column in Table 3 represents the likelihood that precipitation is associated with that category. Note in Category 3, where precipitation is likely (PL), that a relatively large number of matchups occurred (107).

Despite being in an active weather area where TOVS retrievals are usually made via the cloudy path (no MR values), the number of matchups was still large because Category 3 is a commonly assigned category. Category 3 is assigned to areas of broken/overcast cloudiness along weak to moderate baroclinic zones associated with light intermittent or showery precipitation as well as to areas of scattered cumulonimbi.

Prior to streamlining the data collection procedure in May 1984, the data collection was sporatic with no data being collected during March (Table 3). Even during the May-Sept period, data was not collected over weekends and holidays; this is because the cloud bogus RH files were overwritten on a daily basis. The lack of continuous data coverage, however, should have little or no effect upon the accuracy assessments made in the next sections.

3.3 Statistical calculations

Relative humidity is used in the NMC models to determine whether clouds exist and thus affect the radiation balance, as well as to determine the onset or occurrence of precipitation. Mixing ratios, on the other hand, are used: (1) to predict precipitation amounts; (2) to compute latent heats of condensation/evaporation; and (3) for calculating radiation effects due to water vapor absorption. For these reasons, moisture values were extracted and intercompared in terms of both relative humidity and mixing ratio.

By using the RAOB RH and MR values as the true measure, bogus and TOVS RH and MR values were intercompared at six mandatory pressure levels: 1000, 850, 700, 500, 400, and 300 mb. This was done for 11 of the 13 cloud bogus categories shown in Table 3. At each pressure level, the following statistics were calculated for the RAOB values, bogus values, TOVS values, bogus minus RAOB values (bogus errors), and TOVS minus RAOB values (TOVS errors):

1. algebraic average
2. absolute average
3. RMSE (except for RAOB values)
4. standard deviation
5. cumulative frequency of bogus error
6. cumulative frequency of TOVS error
7. bogus values regressed on RAOB values
8. TOVS values regressed on RAOB values
9. bogus values regressed on TOVS values

Statistics were first calculated for each bogus category separately and then later for the combined set.

For Category 8 cases, data were further separated and analyzed by RAOB station, TOVS retrieval type, and TOVS land/sea tags. This was performed primarily to search for possible latitudinal or regional biases or in biases of the TOVS retrieval type or retrieval location. No strong biases were detected.

IV. RESULTS

4.1 Moisture profiles---Bogus Category 8

Figures 3a-3d show graphically a comparison of the average humidity profiles for the Category 8 cases. Similar graphs for the remaining categories are also presented.

Inspection of Figure 3a reveals that above the 700 mb level, the TOVS values are too high relative to the RAOB profile while the bogus values are too low. Figure 3b shows that the Root Mean Square Error (RMSE) of the TOVS RH values were smaller than the bogus values at 850 and 700 mb, but larger at 400 and 300 mb.

When Category 8 matchups were examined in terms of mixing ratio values (Figures 3c and 3d), as expected the average MR values show biases comparable to those of the RH values.

Figure 3c shows a comparison of the average mixing ratio profiles for the Category 8 cases. The dry bias at 1000 mb and the moist biases at the upper levels are most noticeable in the TOVS profile. The moist bias at 850 mb and the dry biases in the upper pressure levels stand out in the bogus profile.

Figure 3d shows that the RMSE of the TOVS MR values were markedly smaller than the bogus values at the lowest three pressure levels. At the upper levels the values were nearly equal.

Overall, the TOVS moisture values for Category 8 agree better with the RAOB values. At 700 mb and below the TOVS RMSE values were smaller than the bogus values. Above 700 mb, the TOVS RMSE were only slightly larger than the bogus values.

4.2 Moisture profile characteristics for the other categories

Figures 4a-4j show the average RH values for the remaining categories. The purpose for showing these figures is to examine each individual category and each level separately for possible biases that might be correctable in future operational use.

Figure 4a shows that the average bogus RH profiles for Category 2 were biased on the moist side; while the TOVS values were biased on the dry side. The largest biases in the bogus values occurred at the 500, 700, and 850 mb levels; the largest bias for the TOVS occurred at the 400 mb level. It should be noted that the sample size of only six matchups for Category 2 is quite small and may not be representative.

Figure 4b shows the average RH profiles for Category 3. In this category the bogus RH values were too moist at all levels except the 1000 mb level. The TOVS RH values were too low at 1000 mb and too high at the 300 mb level. At the remaining four levels, the TOVS values agreed with the RAOB values reasonably well.

Figure 4c shows the average RH profiles for Category 4. Biases for this category were largest at 400 and 300 mb, but less than 15% at any level.

Figure 4d shows the average RH profiles for Category 6. Large positive bogus biases occurred at 700 and 850 mb with negative biases at 500 and 400 mb. The TOVS RH was too low at 1000 mb and too high at the four upper levels. Here as in Category 2, the sample size is small, only 11 samples.

Figure 4e shows the average RH profiles for Category 7. The bogus values showed a positive bias at 850 mb and a negative bias at 400 mb. The TOVS profile showed a small negative bias at 1000 mb and large positive biases at the 500, 400, and 300 mb levels.

Figure 4f shows the average RH profiles for Category 9. Small TOVS biases occurred at the 700 and 500 mb levels. Bogus biases were very large at the 400 and 300 mb levels.

Figure 4g shows the average RH profiles for Category 10, the driest of all the bogus categories. Except for the 1000 mb level, the TOVS values were all positively biased. Bogus values on the other hand were negatively biased, except at the 300 mb level.

Figure 4h shows the average RH profiles for Category 11. Only seven matchups occurred here. TOVS biases were small except for the 19% bias at 1000 mb. The bogus values showed larger biases in this category than in any of the others, especially at the lowest four levels.

Figure 4i shows the average RH profiles for Category 12. Here as in Category 11 the bogus biases at 400 and 300 mb were positive and large. It will be seen later in terms of mixing ratio, these large biases are not nearly as important as they would be if they had occurred at the lower levels where the normal atmospheric MR values are much larger. For example, the positive 26% bogus bias at 850 mb is much more serious in terms of specific or absolute humidity than is the 43% RH bias at 400 mb.

Figure 4j shows the average RH profiles for Category 13. The largest TOVS bias occurred at 300 mb. Large bogus biases occurred at 700, 500, 400, and 300 mb.

The next group of figures show the average MR profiles for each of the categories. Although the RH values best define the departure from saturation and the onset of condensation or precipitation, the MR values are a more useful measure of precipitable water, water vapor absorption, and heat released/absorbed during phase change. Figures 5a-5j show the MR values which correspond to the RH values shown in Figures 4a-4j.

Figure 5a shows that the average MR profiles for Category 2 were biased similarily to the RH values. The bogus values were biased to the moist side while the TOVS values were biased to the dry side. The largest biases in the bogus values were at 850 mb, 700 mb, and 500 mb. The largest TOVS MR biases were at 1000 mb, 850 mb, and 700 mb. As mentioned earlier, large errors or biases in relative humidity values are not as serious in the upper levels as they are in the lower levels.

For example, in Category 2 the 2.25 g/kg moist bias in the bogus MR value at 850 mb is equivalent to only a 13.5% moist bias in the RH value, whereas at 500 mb the moist MR bogus bias of 1.01 g/kg is equivalent to a 24.2% moist RH bias. This is because the RAOB MR value was more than four times larger at 850 mb than it was at 500 mb (9.78 vs 2.42 g/kg).

Figure 5b shows the average MR profiles for Category 3. The average bogus MR values were slightly too moist at all levels except the 1000 mb level. The TOVS MR values were too low at the 1000, 850, and 700 mb levels.

Figure 5c shows the average MR profiles for Category 4. Both the bogus and TOVS values were too low at the 1000 mb level, but there were no strong biases in this category for either method.

Figure 5d shows the average MR profiles for Category 6. There were large positive bogus biases at 700 and 850 mb, and negative biases occurred at the 500 and 400 mb levels. The TOVS MR was much too dry at 1000 mb and too moist at the four upper levels.

Figure 5e shows the average MR profiles for Category 7. The bogus MR values were too low at 1000 mb and too high at 850 mb. The TOVS showed a negative bias at 1000 mb with positive biases at the 500, 400, and 300 mb levels.

Figure 5f shows the average MR profiles for Category 9. The largest TOVS bias (negative) occurred at 1000 mb, but positive TOVS biases were recorded at 700 and 500 mb. At 400 and 300 mb, the bogus MR values were strongly positively biased.

Figure 5g shows the average MR profiles for Category 10. The TOVS MR values were all positively biased with the largest bias located at the 850 mb level. The bogus values, on the other hand, were all negatively biased except at the 300 mb level (no bias).

Figure 5h shows the average MR profiles for Category 11. Only seven matchups occurred here. The largest TOVS biases occurred at 850 and 500 mb. Very large positive bogus biases occurred at the 1000, 850, 700, and 500 mb levels.

Figure 5i shows the average MR profiles for Category 12. The bogus bias of 4.00 g/kg at 850 mb is equal to the 26% RH bias seen earlier in Figure 4i. Although the bogus RH biases were large at the 400 mb (+43%) and 300 mb (+35%) levels, the MR biases were only +0.69 and +0.18 g/kg respectively. This again demonstrates that in terms of measuring total water vapor content, it is much more important to minimize the RH errors and biases in the lower moist levels than in the relatively dry upper levels.

Figure 5j shows the average MR profiles for Category 13. TOVS biases were small, while large negative bogus biases occurred at the 700, 850, and 1000 mb levels.

In summary, the TOVS moisture values were negatively biased at the 1000 mb and 850 mb levels in most categories, especially the lower numbered ones. This was particularly so at the 1000 mb level. At 700 mb and above, the TOVS values were nearly always positively biased. Bogus biases varied from pressure level to pressure level and were usually smaller than the TOVS biases in the lower numbered categories, but larger in the higher numbered ones.

4.3 Moisture profile RMSE for the remaining bogus categories

Since MR and RH profiles parallel each other closely, only the RMSE MR profiles will be presented and summarized.

Figures 6a-6j show the average profiles of the RAOB MR values, the RMSE of the bogus values, and the RMSE of the TOVS values for each of the categories. On these figures, as done earlier with the RH RMSE values, the average RAOB MR is plotted along with the RMSE values to show the sizes of the bogus and the TOVS RMS errors relative to the RAOB values. Note that the maximum plotted MR value is now 12 g/kg instead of the 16 g/kg shown in Figures 5a-5j. This scale was chosen to better amplify the RMSE differences. In these figures one would like to see the RMSE values as small as possible.

Inspection of Figures 6a-6j reveals that the bogus RMSE values at 1000 mb were smaller than the TOVS values for the lower numbered categories but larger for the higher category numbers (Cat. 8-13). At the 850 and 700 mb levels the TOVS RMSE values were smaller than the bogus values for all categories. At the 500, 400, and 300 mb levels, results were mixed but generally the bogus MR RMSE values were smaller than the TOVS values. At the upper levels, a large part of the TOVS RMSE was caused by the pervasively positive bias in the lower numbered categories in which precipitation is likely. A closer examination of the numerical values of these data is presented and discussed in Section 4.7.

4.4 Moisture profiles for all categories combined

By examining the statistics of all the categories combined, one can appraise the accuracy of the TOVS moisture profiles somewhat independently of the bogus category frequency and type. Of course, one would expect the results to be most similar to Category 8 simply because about 61% of the matchups were of the Category 8 type. Figures 7a-7d show graphically the profiles of the moisture comparisons for all categories combined.

Figure 7a shows that when all categories are combined the bogus and TOVS RH profiles were very similar to those seen for Category 8. The TOVS RH profile was biased on the moist side at 700 mb and above, whereas there was a dry bias at 1000 mb. The bogus values were biased on the dry side at the 1000, 700, 500, and 400 mb levels, with small moist biases at the 850 and 300 mb levels. Numerical values of these biases are shown under the Avg Alg Diff columns (8-9) of Table 4a. A quick scan of columns shows that the largest bogus bias was at the 700 mb level, while fairly large positive TOVS biases occurred at all three upper pressure levels.

Figure 7b shows the RMSE profiles of the RH values. The largest bogus value occurred at 700 mb while the largest TOVS value was at the 400 mb level (see columns 5 and 6 of Table 4b).

Figure 7c shows the average MR profiles for the combined categories. Numerical average values are given in columns 5-7 of Table 5a. The departures from the average RAOB values (biases) are given in columns 8 and 9 of Table 5a. The largest bogus bias occurred at 850 mb, while the largest TOVS bias occurred at the 1000 mb level.

Figure 7d shows the RMSE MR profiles for the combined categories. The numerical average values are shown in columns 5 and 6 of Table 5b. It is seen that the largest bogus RMSE occurred at 850 mb, while the largest TOVS RMSE occurred at the 1000 mb level.

Overall, figures 7a-7d show that the TOVS moisture values were too low at the 1000 mb level and too high above the 700 mb level. The bogus values, on the other hand, show fairly small biases for the combined category set; the TOVS RMSE values, however, were equal to or smaller than the bogus RMSE at all levels except 400 and 300 mb. Table 5b shows that the RAOB moisture values at 400 and 300 mb were quite small. As a matter of fact, the RMSE of both the bogus and the TOVS were larger than the average RAOB values there.

4.5 Bogus and TOVS correlations with RAOB values

Tables 6a-16a and 6b-16b show the bogus and TOVS MR values regressed on the RAOB values for each of the individual categories. Included in these tables are: sample size, average value, standard deviation, and correlation coefficient (R value) at the six mandatory pressure levels. Comparison of the R values in column 7 of Tables 6a-16a to those of Tables 6b-16b shows how well the bogus and TOVS values are related to the RAOB values.

For these comparisons it is important to note the sample size within each category; i.e., the smaller the sample size, the less reliable the statistics. Further, the degree of correlation should be appraised along with bias and RMSE magnitudes. This appraisal is necessary simply because high linear correlations can be calculated when strong biases exist. Biases can be examined by comparing the Avg values shown in columns 3 and 4 of these tables. RMSE values are presented in Tables 20a and 20b.

Examination of the regression tables for the individual categories shows that the highest R values were found at pressure levels near the surface and in the low numbered categories. R values were highest at 1000 mb and lowest at 300 mb. Correlations for both methods were highest in Category 2 and lowest in Category 10. Further, it is seen that R values for either method were directly proportional to moisture content.

Of the 11 categories for which matchups occurred, the TOVS R values were higher (better) than the bogus values in most of the categories at all levels except 300 mb. TOVS R values were better than the bogus ones in: 7 of the 11 categories at 1000 mb, 8 of the 11 categories at 850 mb, 10 of the 11 categories at 700 mb, all 11 categories at 500 mb, 10 of the 11 categories at 400 mb, and 5 of the 11 categories at 300 mb.

When the regressions are calculated for all of the categories combined, results are very much similar to those for the individual categories. Table 17a and 17b show the bogus and TOVS Relative Humidity (RH) values regressed on the RAOB values for all of the categories combined. The R values at all levels were small but positive. None of the values exceeded 0.56. Generally, high R values were associated with large RAOB variability (large SD). For the combined category set, the TOVS R values were higher than the bogus ones at all levels except 400 and 300 mb.

Tables 18a and 18b show the bogus and TOVS Mixing-Ratio (MR) values regressed on the RAOB values for all categories combined. The R values ranged from .44 to .81. The TOVS R values were higher than the bogus R values at all levels, even the 400 and 300 mb levels. Further, for either method, we see that the mixing ratio values, at all pressure levels, were better correlated with the RAOB values than were the relative humidity values.

4.6 Magnitudes of moisture errors

It is desirable to minimize the inclusion of extreme errors in assimilated data for any operational method. To explore the distribution of moisture error magnitudes, a cumulative frequency distribution of the errors was examined and is presented for each of the six pressure levels. Tables 19a-19f show the frequency intervals, frequency counts (n), and cumulative frequency percentage (CF) of: observed RAOB MR values, bogus errors, and TOVS errors. The bottom row shows the total number of matchups for each method.

Overall, these tables show that the TOVS method yielded smaller extremes errors than the bogus method.

If one examines the error distributions at or near cumulative frequency quartiles, we see that the 1000 mb error distributions were very similar for both methods except at the 4th quartile, where the TOVS values showed fewer extreme errors. At the 850 and 700 mb levels, the TOVS errors were smaller at all quartiles. At the 500, 400, and 300 mb levels, the bogus errors were smaller than the TOVS errors at the first three quartiles but larger at the 4th quartile. At these three upper levels, it is clear that a strong TOVS bias was responsible for the larger CF errors at the first three quartiles there.

4.7 Recapitulation of comparisons

The single best measure of accuracy for most operational purposes is the RMSE. Tables 20a and 20b show the bogus and TOVS RMSE values separated by a slash for each category individually and at the bottom for all categories combined. RMSE profiles have already been shown in figures 6a-6j and discussed in Sections 4.3. Table 20a shows the RH comparisons and Table 20b shows the MR comparisons.

At 1000 mb, we see that the RMSE for the bogus RH and MR values in Categories 2-7 were better (smaller) than those of the TOVS values. But in Categories 8-13, the TOVS RMSE values were better. Table 3 (col 2) showed the the likelihood of precipitation for each category. For Categories 2-7, precipitation was likely (PL or PP), except for Category 5. In Categories 8-13, no precipitation was likely (NP), except for Categories 11 and 12. Typically, in the higher numbered categories where the bogus RH value was 70% or greater, the bogus values showed very large positive biases. This finding suggests that the RH values prescribed in Category 11 were too high at the 1000, 850, 700, and 500 mb levels. Further, in Categories 9, 12, and 13, the 70% RH values prescribed at the 400 and 300 mb levels were also too high. Finally, the strong bias in Categories 2, 6, 11, and 12 indicate that, when bogus RH values were prescribed to be 70% or higher, they were set too high.

Before one tampers with the prescribed bogus RH values, one should note the manner in which the comparisons were made. Because moisture values are not calculated for the cloudy path retrievals, and because all three moisture determination methods were required for a given matchup, the bogus selection was skewed toward the dry side, i.e., clear and N* retrievals. Therefore, one would expect the bogus statistics in areas of precipitation and dense clouds to show even better agreement with the RAOB values than they now do.

Further, horizontal and vertical distributions of moisture are much more variable than, say, temperature fields. Very large horizontal and vertical gradients of moisture are found in the real atmosphere. They are amplified by geographical sources and sinks of moisture that are dependent upon land/water proximity as well as the precipitation process. The next section exhibits some of the variability in moisture distributions.

4.8 Moisture variations

Figures 8a-8d illustrate a large horizontal moisture gradient between two RAOB stations. Figure 8a shows a GOES East visible image at 2300 GMT on 03 Apr 1984 with the bogus RH categories superimposed. Of particular interest are the locations of the stations: Boothsville, LA (72232); Lake Charles, LA (72240); and Brownsville, TX (72250). The distance between Boothsville and Lake Charles is 204 n mi and the distance from Lake Charles to Brownsville is 336 n mi. Figure 8b shows the comparison of MR profiles at Boothsville at 00 GMT on 04 Apr 1984. The mixing ratio profiles are designated by R for RAOB, B for bogus Category 8, and N and O are two different NOAA 8 MR retrievals within 90 n mi of Boothsville. For matchup purposes, the retrieval labelled N was used. The profile represented by the circled dots shows what the bogus MR values would have been if Boothsville had been located some 60 n mi to the east or southeast where the bogus classification was Category 3 (Figure 8a). For matchup purposes, however, Bogus Category 8 was used and, it was included as one of this Category's 678 cases. Yet we see that this case was within 60 n mi of being assigned Bogus Category 3.

On Figure 8b we see that the RAOB MR value at 1000 mb was about 14 g/kg and that both the bogus and TOVS MR values were negatively biased by -3.34 and -6.51 g/kg respectively. Had the bogus category been assigned Category 3 instead of Category 8, the MR value at the 1000 mb level would have been increased to 11.39 g/kg; thus reducing the bogus negative bias to only -2.32 g/kg. At 920 mb and 850 mb the Category 3 profile would have been a much better approximation to the RAOB values at those levels and would have actually reproduced the mixing ratio inversion.

Figure 8c shows the MR profiles at Lake Charles (72240) also for 00 GMT, 04 Apr 1984. Near the 1000 mb level, the RAOB MR value was quite low, only about 4 g/kg. Thus over the 204 n mi distance between Boothsville and Lake Charles there was a gradient of 10 g/kg. This is equivalent to a horizontal gradient of about 1 g/kg per 20 n mi. With gradients this large, it is not surprising to see the RMSE larger than 3 g/kg at the 1000 mb level (see Table 20b). Coincidentally, this case exemplifies the problem encountered in specifying the bogus RH profiles in cloud free areas. The bogus MR value at Lake Charles was highly biased on the moist side. For example, the derived 17.81 g/kg bogus MR value for 1000 mb was the result of the high temperature (28C) coupled with the 73% bogus RH value specified there in Category 8. There were four TOVS retrievals within 90 n mi of Lake Charles; the one labelled A was closest to the RAOB location and was used as the TOVS matchup value for the statistical calculations.

Figure 8d shows the MR profiles at Brownsville, also for 00 GMT on 04 Apr 1984. Here the 1000 mb RAOB MR value was 4.96 g/kg. This corroborates the existence of a dry air mass in the cloud free area which extended toward the east and encompassed Lake Charles. As at Lake Charles, the high temperatures at the low levels, coupled with the 73% and 65% RH values prescribed in Category 8 at the 1000 and 850 mb levels again, produced bogus MR estimates that were too large.

The next figure illustrates some of the large vertical moisture gradients observed by RAOBs. Figure 9 shows the MR profiles at 00 GMT on 16 Feb 1984 for Tampa, Fl (72210). The RAOB MR value at the 861 mb level was 6.82 g/kg while at the 850 mb level it had dropped off to 1.29 g/kg. In the lower levels, both the bogus and TOVS derived MR values were somewhat insensitive to the increase of RAOB MR from 7.04 g/kg at 997 mb to 7.34 g/kg at 875 mb as well as to the very dry air at the 850 and 777 mb levels.

Figures 8 through 9 demonstrate that large horizontal and vertical moisture gradients are observed in the real atmosphere, and they give some indication of the sensitivity of the two satellite moisture derivation methods to such conditions. Near cloudy areas, such as the Boothsville case, the bogus moisture values were more sensitive than were the TOVS values; whereas in relatively cloud free areas, the TOVS values were the more sensitive.

V. SUMMARY

Typically, Bogus Category 8 is assigned to over half the oceanic grid points. It is in these areas where the TOVS clear and N* retrievals are most likely to be made. In Category 8 TOVS moisture values showed a dry bias at 1000 mb and a moist bias at 700 mb and above. The bogus method for Category 8 showed a moist bias at 850 mb with a dry bias at 700 mb and above. At the lowest three pressure levels, where moisture content is concentrated, the TOVS RMSE were less than the bogus RMSE. At the upper three levels, the TOVS RMSE were only slightly larger than the bogus values.

In the remaining categories, the TOVS moisture values were negatively biased at the 1000 mb and 850 mb levels in most categories, especially the lower numbered ones. At and above 700 mb, the TOVS values were nearly always positively biased, especially in the lower numbered categories. Bogus biases in the remaining categories varied from pressure level to pressure level and were generally smaller than the TOVS biases in the lower numbered categories but larger in the higher numbered ones.

For data used operationally, the single best measure of accuracy is the RMSE. Bogus RMSE values at 1000 mb were smaller than the TOVS values for the lower numbered categories but larger for the higher category numbers (Cat. 8-13). At the 850 and 700 mb levels, the TOVS RMSE values were smaller than the bogus values for all categories. At the 500, 400, and 300 mb levels, results were mixed, but generally the bogus MR RMSE values were only slightly smaller than the TOVS values.

For all categories combined, the TOVS moisture values were too dry at the 1000 mb and too moist above the 700 mb level. The bogus values showed fairly small biases for the combined category set; but, the TOVS RMSE values were still equal to or smaller than the bogus RMSE at all levels except at 400 and 300 mb. At these two upper levels, the RMSE of both methods was larger than the observed average of the RAOB values.

Correlation coefficients (R values) with respect to either method and the RAOB values decreased with elevation. The R values were usually highest at 1000 mb and lowest at 300 mb. Higher R values for both methods were found in the lower numbered (more moist) bogus categories. This was expected with the bogus method, but not with the TOVS method. Further, the degree of correlation for both methods was directly related to the magnitude of the RAOB moisture variance.

Cumulative frequency (CF) statistics showed the TOVS error distribution having smaller extreme errors than the bogus. At 500 mb and levels above, the bogus errors were smaller than the TOVS at the 3rd quartile level (75% CF); but at the 100% level, the TOVS errors were still smaller than the bogus errors. This type of cf error distribution at and above 500 mb reflects the relatively large positive biases that were prevalent in the TOVS moisture errors there.

Finally, this study indicates that when TOVS moisture values are available, they are on par with or better than the bogus moisture values. Except for matchups near dense broken/overcast cloud areas and at levels above 500 mb, the TOVS method showed less RMSE with respect to RAOB values than did the bogus values. At and above 500 mb, TOVS values were equal to or only slightly worse than the bogus values. It should be noted that in terms of total precipitable water, the upper three levels contributed relatively little of the total amount.

Large horizontal and vertical gradients of moisture were found in the real atmosphere. Neither the bogus nor the TOVS method was sensitive enough to detect these sharp gradients. However, the results do indicate that, over large oceanic areas where RAOB measurements are few, the satellite derived values can be a useful input into the moisture data base.

Overall, there are advantages and disadvantages associated with both methods. The advantages of the TOVS method are that the method is fully automated and that it can be applied globally. Further, it is more accurate in clear and partly cloudy areas, which typically comprise about 60-65% of the bogus grid area now in use. In addition, TOVS errors showed less extremes than did the bogus errors.

Disadvantages of the TOVS method are that no moisture is retrieved in heavily clouded areas and that TOVS retrievals tend to cluster around the mean values, showing smaller variances than either the RAOB or bogus values (this is characteristic of regression-based techniques). Further, retrievals are made at asynoptic times with availability delayed as much as 2-3 hours after orbit time. For the North American region, however, the two-polar-orbiting satellite system yields adequate coverage within 3 hours of the 00 GMT and 12 GMT synoptic times.

Advantages of the bogus method are that profiles are available at synoptic times and over cloudy areas where no TOVS moisture values are retrieved. Further, the bogus method accuracies become better than the TOVS accuracies as the cloud coverage increases to broken/overcast. In the TOVS method, no TOVS MR retrievals are made when the N* value exceeds 0.86.

Disadvantages of the bogus method are that moisture values are less accurate than the TOVS values in clear and partly cloudy areas. Also the bogus errors show larger extremes than do the TOVS errors. In addition, the method requires subjective interpretation of cloud imagery. Presently, the method is only partially automated. Finally, coverage is restricted to about 60 degrees of great circle radial distance from each GOES subpoint making adequate global coverage more unlikely.

In conclusion, the TOVS method performed better than the bogus method in clear and partly cloudy areas whereas the bogus method performed better in the broken/overcast areas. The TOVS method cannot totally replace the bogus method since no TOVS mixing ratios are retrieved for the TOVS cloudy path and because of TOVS coverage gaps. This study does indicate, however, that the TOVS moisture values can be obtained globally and could nicely supplement the bogus method by providing moisture values over clear and partly cloudy oceanic areas where no conventional moisture measurements are made.

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Table 1. Bogus Relative Humidity (%): (a) Values Supplied to Global Model, (b) Values Supplied to LFM Model.

	(a)						(b)		
Cat.	Pressure Level(mb)						Layer		
No	1000	850	700	500	400	300	BNDRY	SIGMA1	SIGMA2
1	95	98	95	90	85	75	98	96	92
2	90	93	87	83	74	55	95	90	85
3	80	86	76	67	67	53	83	80	71
4	72	70	62	54	44	34	62	60	58
5	68	39	50	85	50	10	62	52	68
6	84	92	79	20	10	10	90	87	38
7	76	89	50	25	10	10	72	70	35
8	73	65	25	15	10	10	62	49	20
9	69	60	25	25	70	70	62	49	25
10	45	35	10	10	10	10	45	33	10
11	90	92	90	85	20	10	95	90	85
12	76	89	50	32	70	70	72	70	35
13	68	50	25	85	70	70	62	49	55

Table 2

TOVS

(a) Retrieval Levels		(b) Channels Used	
Pressure (mb)	Level (j)	Channel (no)	Wavelength (μm)
300	15	HIRS (4)	14.2
350	14	HIRS (5)	14.0
400	13	HIRS (6)	13.7
430	12	HIRS (7)	13.4
475	11	HIRS (8)	11.1
500	10	HIRS (9)	9.7
570	9	HIRS (10)	8.3
620	8	HIRS (11)	7.3
670	7	HIRS (12)	6.7
700	6	HIRS (13)	4.57
780	5	HIRS (14)	4.52
850	4	HIRS (15)	4.46
920	3	HIRS (16)	4.40
950	2	MSU (2)	0.558 (cm)
1000	1	MSU (3)	0.546 (cm)

Table 3. Number of Matchups 1984

CAT	PRECIP	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
2	PL	0	0	0	0	2	0	1	1	2	6
3	PL	0	1	0	6	16	9	32	13	30	107
4	PP	0	0	0	1	7	13	7	17	15	60
5	NP	0	0	0	0	0	0	0	0	1	1
6	PL	0	0	0	0	3	1	1	6	0	11
7	PP	2	0	0	1	8	7	12	16	11	57
8	NP	11	4	0	20	132	84	87	155	186	679
9	NP	3	1	0	4	26	5	8	16	5	68
10	NP	1	0	0	0	8	7	9	20	18	63
11	PL	0	0	0	2	1	0	0	0	4	7
12	PP	0	2	0	0	2	2	0	5	2	13
13	NP	0	1	0	2	7	3	2	7	11	33
		17	9	0	36	212	131	159	256	285	1105

*PL = Precip Likely PP = Precip Possible NP = No Precip

Table 4a. Comparison RH Statistics for All Categories Combined

Level	Sample Size			Average RH (%)			Avg Alg Diff	
P (mb)	Raob	Bogus	TOVS	Raob	Bogus	TOVS	Bogus	TOVS
1000	992	992	752	75.6	72.4	67.2	- 3.2	- 8.4
850	1103	1103	1100	62.3	66.9	63.5	4.6	1.2
700	1103	1103	1103	44.5	33.9	51.0	-10.6	6.5
500	1104	1104	1104	30.8	26.2	44.3	- 4.6	13.5
400	1096	1096	1096	25.8	24.0	41.6	- 1.8	15.8
300	1090	1090	1090	18.0	21.9	34.5	3.9	16.5

Table 4b. Additional Comparison RH Statistics for All Categories Combined

Level	Avg	Avg Abs Diff		RMSE		Standard Dev		
P (mb)	Raob	Bogus	TOVS	Bogus	TOVS	Raob	Bogus	TOVS
1000	75.6	16.6	16.3	20.3	19.7	19.7	20.0	17.8
850	62.3	20.8	17.6	26.1	22.5	26.2	25.7	22.5
700	44.5	23.1	19.0	29.2	23.4	27.2	27.2	22.5
500	30.8	19.7	21.9	26.2	25.7	26.3	25.8	21.9
400	25.8	19.4	23.9	26.9	28.0	23.9	26.8	23.1
300	18.0	18.4	22.4	24.9	26.2	19.6	24.6	20.3

Table 5a. Comparison MR Statistics for All Categories Combined

Level P(mb)	Sample Size RAOB	Bogus	TOVS	Average MR (g/kg) RAOB	Bogus	TOVS	Avg Alg Diff Bogus	TOVS
1000	992	992	752	11.44	11.17	9.95	-0.27	-1.49
850	1103	1103	1100	7.11	8.06	7.20	0.95	0.09
700	1103	1103	1103	3.49	2.68	3.95	-0.81	0.46
500	1104	1104	1104	1.03	0.89	1.49	-0.14	0.46
400	1096	1096	1096	0.42	0.40	0.69	-0.02	0.27
300	1090	1090	1090	0.11	0.12	0.18	0.01	0.07

Table 5b. Additional Comparison MR Statistics for All Categories Combined

Level P(mb)	Avg RAOB	Avg Abs Diff Bogus	TOVS	RMSE Bogus	TOVS	Standard Dev RAOB	Bogus	TOVS
1000	11.44	2.58	2.59	3.43	3.31	5.04	3.42	2.96
850	7.11	2.65	1.92	3.69	2.47	3.56	3.57	2.47
700	3.49	1.81	1.37	2.36	1.70	2.35	2.22	1.64
500	1.03	0.65	0.72	0.91	0.89	1.11	0.90	0.76
400	0.42	0.31	0.40	0.47	0.50	0.45	0.47	0.42
300	0.11	0.10	0.11	0.14	0.14	0.13	0.14	0.12

Table 6a. Bogus MR Values Regressed on RAOB Values Category 2

Level	No	Avg RAOB	Avg Bogus	SD RAOB	SD Bogus	Corr(R)
1000	6	15.32	15.76	4.22	4.52	.96
850	6	9.78	12.03	2.47	3.94	.79
700	6	6.24	7.71	2.88	1.65	.61
500	6	2.42	3.43	1.29	.51	.31
400	6	1.33	1.54	.60	.29	.72
300	6	.33	.39	.14	.09	.71

Table 6b. TOVS MR Values Regressed on RAOB Values Category 2

Level	No	Avg RAOB	Avg TOVS	SD RAOB	SD TOVS	Corr(R)
1000	5	14.79	12.69	4.43	4.67	.96
850	6	9.78	8.78	2.47	2.99	.70
700	6	6.24	5.06	2.88	1.89	.96
500	6	2.42	1.91	1.29	.73	.82
400	6	1.33	.93	.60	.41	.86
300	6	.33	.25	.14	.12	.64

Table 7a. Bogus MR Values Regressed on RAOB Values Category 3

Level	No	Avg RAOB	Avg Bogus	SD RAOB	SD Bogus	Corr(R)
1000	104	11.91	11.72	5.26	4.91	.88
850	107	7.80	8.87	3.37	3.67	.81
700	107	4.64	5.18	2.22	2.02	.73
500	107	1.56	1.98	1.22	.92	.59
400	107	.70	1.02	.61	.53	.60
300	107	.16	.26	.18	.15	.72

Table 7b. TOVS MR Values Regressed on RAOB Values Category 3

Level	No	Avg RAOB	Avg TOVS	SD RAOB	SD TOVS	Corr(R)
1000	73	13.87	11.51	4.67	4.12	.79
850	106	7.74	7.03	3.32	2.93	.78
700	107	4.64	4.18	2.22	1.80	.77
500	107	1.57	1.57	1.22	.73	.69
400	107	.70	.71	.61	.39	.62
300	107	.16	.19	.18	.11	.70

Table 8a. Bogus MR Values Regressed on RAOB Values Category 4

Level	No	Avg RAOB	Avg Bogus	SD RAOB	SD Bogus	Corr(R)
1000	55	12.34	10.72	5.75	4.40	.88
850	60	7.71	8.65	3.88	4.25	.51
700	60	4.28	4.87	2.40	2.06	.58
500	60	1.96	2.01	2.48	2.30	.89
400	60	.59	.73	.51	.35	.47
300	58	.15	.19	.18	.09	.55

Table 8b. TOVS MR Values Regressed on RAOB Values Category 4

Level	No	Avg RAOB	Avg TOVS	SD RAOB	SD TOVS	Corr(R)
1000	39	13.43	11.47	5.85	4.01	.81
850	60	7.71	7.61	3.88	2.81	.79
700	60	4.28	4.66	2.40	1.90	.71
500	60	1.96	2.04	2.48	2.40	.93
400	60	.59	.83	.51	.43	.45
300	58	.15	.22	.18	.12	.44

Table 9a. Bogus MR Values Regressed on RAOB Values Category 6

Level	No	Avg RAOB	Avg Bogus	SD RAOB	SD Bogus	Corr(R)
1000	11	11.35	10.90	5.37	4.70	.89
850	11	6.89	8.72	3.46	3.84	.75
700	11	3.27	5.22	2.71	2.15	.59
500	11	1.07	.71	.93	.44	.59
400	11	.44	.15	.48	.08	.58
300	10	.09	.04	.14	.02	.56

Table 9b. TOVS MR Values Regressed on RAOB Values Category 6

Level	No	Avg RAOB	Avg TOVS	SD RAOB	SD TOVS	Corr(R)
1000	5	15.57	11.61	5.30	4.06	.96
850	11	6.89	7.06	3.46	2.66	.79
700	11	3.27	4.11	2.71	1.56	.56
500	11	1.07	1.52	.93	.65	.81
400	11	.44	.69	.48	.36	.84
300	10	.09	.18	.14	.10	.68

Table 10a. Bogus MR Values Regressed on RAOB Values Category 7

Level	No	Avg RAOB	Avg Bogus	SD RAOB	SD Bogus	Corr(R)
1000	52	11.34	10.21	5.54	4.72	.94
850	57	7.00	8.49	3.43	4.06	.73
700	57	3.37	3.23	2.11	1.55	.68
500	57	.90	.76	.92	.50	.47
400	57	.32	.15	.31	.10	.33
300	57	.07	.06	.10	.07	.43

Table 10b. TOVS MR Values Regressed on RAOB Values Category 7

Level	No	Avg RAOB	Avg TOVS	SD RAOB	SD TOVS	Corr(R)
1000	38	12.74	10.60	5.65	4.12	.94
850	57	7.00	6.86	3.43	2.87	.80
700	57	3.37	3.89	2.11	1.72	.76
500	57	.90	1.45	.92	.69	.57
400	57	.32	.66	.31	.38	.40
300	57	.07	.18	.10	.11	.56

Table 11a. Bogus MR Values Regressed on RAOB Values Category 8

Level	No	Avg RAOB	Avg Bogus	SD RAOB	SD Bogus	Corr(R)
1000	605	11.59	11.68	4.93	4.44	.72
850	678	7.09	8.26	3.56	3.16	.40
700	678	3.33	2.15	2.27	.77	.40
500	679	.86	.55	.82	.21	.31
400	673	.34	.18	.37	.08	.34
300	670	.09	.06	.11	.03	.33

Table 11b. TOVS MR Values Regressed on RAOB Values Category 8

Level	No	Avg RAOB	Avg TOVS	SD RAOB	SD TOVS	Corr(R)
1000	479	12.20	10.77	4.94	3.48	.81
850	676	7.09	7.25	3.55	2.40	.71
700	678	3.33	3.87	2.27	1.56	.71
500	679	.86	1.45	.82	.64	.61
400	673	.34	.68	.37	.33	.43
300	670	.09	.18	.11	.09	.46

Table 12a. Bogus MR Values Regressed on RAOB Values Category 9

Level	No	Avg RAOB	Avg Bogus	SD RAOB	SD Bogus	Corr(R)
1000	64	11.59	10.85	4.65	4.14	.72
850	68	7.65	7.04	3.49	2.56	.55
700	68	3.16	2.11	2.53	.71	.34
500	68	1.05	.90	.89	.27	.09
400	68	.54	1.21	.45	.41	.02
300	68	.19	.39	.16	.16	.52

Table 12b. TOVS MR Values Regressed on RAOB Values Category 9

Level	No	Avg RAOB	Avg TOVS	SD RAOB	SD TOVS	Corr(R)
1000	53	12.61	11.30	4.31	3.39	.73
850	68	7.65	7.45	3.49	2.36	.70
700	68	3.16	4.01	2.53	1.39	.62
500	68	1.05	1.49	.89	.55	.47
400	68	.54	.69	.45	.29	.24
300	68	.19	.19	.16	.08	.40

Table 13a. Bogus MR Values Regressed on RAOB Values Category 10

Level	No	Avg RAOB	Avg Bogus	SD RAOB	SD Bogus	Corr(R)
1000	50	8.08	5.97	2.69	1.97	-.12
850	63	5.40	4.72	3.08	1.51	.33
700	63	2.49	.90	2.00	.24	.25
500	63	.66	.36	.62	.12	.40
400	62	.25	.16	.21	.05	-.10
300	62	.04	.05	.06	.02	.31

Table 13b. TOVS MR Values Regressed on RAOB Values Category 10

Level	No	Avg RAOB	Avg TOVS	SD RAOB	SD TOVS	Corr(R)
1000	25	8.91	9.47	2.71	1.76	.46
850	63	5.40	6.42	3.08	1.37	.54
700	63	2.49	3.22	2.00	1.15	.74
500	63	.66	1.19	.62	.49	.53
400	62	.25	.53	.22	.25	.24
300	62	.04	.14	.06	.07	.34

Table 14a. Bogus MR Values Regressed on RAOB Values Category 11

Level	No	Avg RAOB	Avg Bogus	SD RAOB	SD Bogus	Corr(R)
1000	6	5.90	11.26	2.50	5.84	.78
850	7	4.44	9.46	1.60	6.11	.78
700	7	2.98	5.77	2.15	2.83	.52
500	7	1.61	2.16	1.33	.74	.65
400	7	.49	.24	.55	.08	.79
300	7	.13	.04	.12	.01	.75

Table 14b. TOVS MR Values Regressed on RAOB Values Category 11

Level	No	Avg RAOB	Avg TOVS	SD RAOB	SD TOVS	Corr(R)
1000	3	5.14	5.37	1.78	2.83	.74
850	7	4.44	5.13	1.60	2.22	.78
700	7	2.98	3.34	2.15	1.47	.63
500	7	1.61	1.16	1.33	.62	.73
400	7	.49	.48	.55	.29	.84
300	7	.13	.13	.12	.08	.82

Table 15a. Bogus MR Values Regressed on RAOB Values Category 12

Level	No	Avg RAOB	Avg Bogus	SD RAOB	SD Bogus	Corr(R)
1000	13	11.54	12.10	5.05	4.69	.47
850	13	6.75	10.75	3.63	4.54	.22
700	13	2.69	3.97	1.67	1.45	.05
500	13	.71	1.05	.64	.36	.15
400	13	.43	1.13	.46	.44	.38
300	13	.20	.37	.13	.13	.60

Table 15b. TOVS MR Values Regressed on RAOB Values Category 12

Level	No	Avg RAOB	Avg TOVS	SD RAOB	SD TOVS	Corr(R)
1000	10	12.98	11.30	4.77	3.80	.91
850	13	6.75	7.28	3.63	2.14	.67
700	13	2.69	3.70	1.67	1.44	.65
500	13	.71	1.35	.64	.54	.58
400	13	.43	.64	.46	.27	.54
300	13	.20	.16	.13	.07	.25

Table 16a. Bogus MR Values Regressed on RAOB Values Category 13

Level	No	Avg RAOB	Avg Bogus	SD RAOB	SD Bogus	Corr(R)
1000	26	11.00	9.45	5.45	3.60	.88
850	33	6.89	5.76	3.73	2.24	.69
700	33	4.33	1.88	2.62	.63	.68
500	33	1.87	2.83	1.30	.99	.53
400	32	.87	1.16	.62	.49	.63
300	32	.14	.37	.14	.18	.49

Table 16b. TOVS MR Values Regressed on RAOB Values Category 13

Level	No	Avg RAOB	Avg TOVS	SD RAOB	SD TOVS	Corr(R)
1000	22	11.17	10.97	5.31	5.48	.89
850	33	6.89	7.48	3.73	2.99	.74
700	33	4.33	4.59	2.62	1.83	.80
500	33	1.87	1.76	1.30	.75	.69
400	32	.87	.79	.62	.40	.74
300	32	.14	.21	.14	.11	.36

Table 17a. Bogus RH Values Regressed on RAOB Values All Categories Combined

Level	No	Avg RAOB	Avg Bogus	SD RAOB	SD Bogus	Corr(R)
1000	992	75.6	72.4	19.7	7.2	.14
850	1103	62.3	67.0	26.2	12.4	.28
700	1103	44.5	34.0	27.2	19.4	.35
500	1104	30.8	26.1	26.3	21.0	.42
400	1096	25.8	24.0	23.9	24.0	.37
300	1090	18.0	22.0	19.6	21.3	.28

Table 17b. TOVS RH Values Regressed on RAOB Values All Categories Combined

Level	No	Avg RAOB	Avg TOVS	SD RAOB	SD TOVS	Corr(R)
1000	752	77.1	68.8	18.5	10.9	.36
850	1100	62.3	63.5	26.2	14.9	.52
700	1103	44.5	51.1	27.2	16.0	.56
500	1104	30.8	44.3	26.3	14.0	.56
400	1096	25.8	41.6	23.9	11.4	.31
300	1090	18.0	34.5	19.6	10.0	.18

Table 18a. Bogus MR Values Regressed on RAOB Values All Categories Combined

Level	No	Avg RAOB	Avg Bogus	SD RAOB	SD Bogus	Corr(R)
1000	992	11.44	11.17	5.04	4.60	.75
850	1103	7.11	8.06	3.56	3.44	.48
700	1103	3.49	2.67	2.35	1.69	.44
500	1104	1.03	.89	1.11	.94	.62
400	1096	.42	.40	.45	.46	.46
300	1090	.11	.12	.13	.14	.47

Table 18b. TOVS MR Values Regressed on RAOB Values All Categories Combined

Level	No	Avg RAOB	Avg TOVS	SD RAOB	SD TOVS	Corr(R)
1000	752	12.37	10.87	5.01	3.69	.81
850	1100	7.10	7.19	3.55	2.50	.72
700	1103	3.49	3.94	2.35	1.62	.72
500	1104	1.03	1.49	1.11	.85	.73
400	1096	.42	.69	.45	.35	.47
300	1090	.11	.18	.13	.10	.49

Table 19a. Frequency (n) and Cumulative Frequency (%) 1000 mb for all categories Combined (g/kg)

Interval	RAOB Values (n)	RAOB Values (CF)	Bogus Errors (n)	Bogus Errors (CF)	TOVS Errors (n)	TOVS Errors (CF)
0.00-0.25			59	5.9%	40	5.3%
0.26-0.50			44	10.4%	47	11.6%
0.51-0.75			82	18.6%	59	19.4%
0.76-1.00			59	24.6%	46	25.5%
1.01-1.50	2	0.2%	120	36.7%	86	37.0%
1.51-2.00	2	0.4%	129	49.7%	91	49.4%
2.01-2.50	8	1.2%	89	58.7%	71	58.5%
2.51-3.00	8	2.0%	76	66.3%	57	66.1%
3.01-4.00	29	4.9%	132	79.6%	86	77.5%
4.01-5.00	35	8.5%	111	90.8%	62	85.5%
5.01-6.00	73	15.8%	36	94.5%	46	91.9%
6.01-7.00	84	24.3%	17	96.2%	33	96.3%
7.01-8.00	86	33.0%	10	97.2%	16	98.4%
8.01-9.00	79	40.9%	7	97.9%	3	98.8%
9.01-10.0	56	46.6%	5	98.4%	6	99.6%
10.0-11.0	43	50.9%	4	98.8%	1	99.7%
11.0-12.0	22	53.1%	2	99.0%	2	100 %
12.0-13.0	49	58.1%	3	99.3%		
13.0-14.0	53	63.4%	3	99.6%		
14.0-15.0	72	70.7%	1	99.7%		
15.0-16.0	54	76.1%	1	99.8%		
16.0-17.0	51	81.3%	1	99.9%		
17.0-18.0	64	87.7%	-			
18.0-19.0	61	93.9%	-			
19.0-20.0	42	98.1%	-			
>20.0	19	100 %	1	100 %		
Total		992		992		752

Table 19b. Frequency (n) and Cumulative Frequency (%) 850 mb for All Categories Combined (g/kg)

Interval	RAOB Values (n)	RAOB Values (CF)	Bogus Errors (n)	Bogus Errors (CF)	TOVS Errors (n)	TOVS Errors (CF)
0.00-0.25			101	9.2%	95	8.6%
0.26-0.50	1	0.1%	102	18.4%	103	18.0%
0.51-0.75	5	0.5%	79	25.6%	113	28.6%
0.76-1.00	14	1.8%	75	32.4%	95	36.9%
1.01-1.50	30	4.5%	107	42.1%	158	51.3%
1.51-2.00	27	7.0%	100	51.1%	107	61.0%
2.01-2.50	37	10.3%	82	58.6%	95	69.6%
2.51-3.00	50	14.9%	84	66.2%	83	77.2%
3.01-4.00	106	24.5%	141	79.0%	121	88.2%
4.01-5.00	106	34.1%	76	85.9%	64	94.0%
5.01-6.00	105	43.6%	45	89.9%	55	99.0%
6.01-7.00	72	50.1%	38	93.4%	7	99.6%
7.01-8.00	70	56.5%	20	95.2%	3	99.9%
8.01-9.00	95	65.1%	15	96.6%	1	100%
9.01-10.0	80	72.3%	12	97.6%		
10.0-11.0	125	83.7%	10	98.5%		
11.0-12.0	95	92.3%	4	98.9%		
12.0-13.0	50	96.8%	6	99.5%		
13.0-14.0	24	99.0%	3	99.7%		
14.0-15.0	6	99.5%	1	99.8%		
15.0-16.0	5	100%	1	99.9%		
16.0-17.0			-			
17.0-18.0			1	100%		
Total		1103		1103		1100

Table 19c. Frequency (n) and Cumulative Frequency (%) 700 mb for All Categories Combined (g/kg)

Interval	RAOB Values (n)	RAOB Values (CF)	Bogus Errors (n)	Bogus Errors (CF)	TOVS Errors (n)	TOVS Errors (CF)
0.00-0.25	9	0.8%	133	12.1%	128	11.6%
0.26-0.50	36	4.1%	97	20.9%	122	22.7%
0.51-0.75	58	9.3%	85	28.6%	120	33.5%
0.76-1.00	103	18.7%	81	35.9%	114	43.9%
1.01-1.50	104	28.1%	200	54.0%	187	60.8%
1.51-2.00	79	35.3%	133	66.1%	158	75.2%
2.01-2.50	89	43.3%	78	73.2%	112	85.3%
2.51-3.00	68	49.5	68	79.3%	81	92.7%
3.01-4.00	111	59.6%	111	89.4%	69	98.9%
4.01-5.00	118	70.3%	64	95.2%	9	99.7%
5.01-6.00	133	82.3%	38	98.6%	2	99.9%
6.01-7.00	109	92.2%	11	99.6%	1	100%
7.01-8.00	59	97.6%	2	99.8%		
8.01-9.00	21	99.5%	1	99.9%		
9.01-10.0	4	99.8%	1	100%		
10.0-11.0	-					
11.0-12.0	-					
12.0-13.0	2	100%				
Total	1103		1103		1103	

Table 19d. Frequency (n) and Cumulative Frequency (%) 500 mb for All Categories Combined (g/kg)

Interval	RAOB Values		Bogus Errors		TOVS Errors	
	(n)	(CF)	(n)	(CF)	(n)	(CF)
0.00-0.02	1	0.1%	17	1.5%	26	2.4%
0.02-0.04	11	1.1%	7	2.2%	22	4.3%
0.04-0.06	12	2.2%	6	2.7%	19	6.1%
0.06-0.08	14	3.4%	14	4.0%	14	7.3%
0.08-0.10	6	4.0%	26	6.3%	24	9.5%
0.10-0.15	30	6.7%	80	13.6%	45	13.6%
0.15-0.20	52	11.4%	49	18.0%	46	17.8%
0.20-0.25	95	20.0%	69	24.3%	50	22.3%
0.25-0.30	112	30.2%	76	31.2%	35	25.5%
0.30-0.40	142	43.0%	247	53.5%	91	33.7%
0.40-0.50	37	46.4%	80	60.8%	78	40.8%
0.50-0.60	30	49.1%	45	64.9%	75	47.6%
0.60-0.70	24	51.3%	57	70.0%	61	53.1%
0.70-0.80	39	54.8%	41	73.7%	86	60.9%
0.80-1.00	83	62.3%	75	80.5%	119	71.6%
1.00-1.20	72	68.8%	56	85.6%	109	81.5%
1.20-1.40	55	73.8%	22	87.6%	75	88.3%
1.40-1.60	46	78.0%	28	90.1%	60	93.8%
1.60-1.80	34	81.1%	25	92.4%	34	96.8%
1.80-2.00	33	84.1%	20	94.2%	16	98.3%
2.00-2.20	24	86.2%	12	95.3%	11	99.3%
2.20-2.40	21	88.1%	15	96.6%	7	99.9%
2.40-2.60	18	89.8%	14	97.9%	1	100%
2.60-2.80	22	91.8%	8	98.6%		
2.80-3.00	22	93.8%	4	99.0%		
>3.01	69	100%	11	100%		
Total	1104		1104		1104	

Table 19e. Frequency (n) and Cumulative Frequency (%) 400 mb for All Categories Combined (g/kg)

Interval	RAOB Values		Bogus Errors		TOVS Errors	
	(n)	(CF)	(n)	(CF)	(n)	(CF)
0.00-0.02	51	4.7%	42	3.8%	46	4.2%
0.02-0.04	30	7.4%	46	8.0%	38	7.7%
0.04-0.06	52	12.1%	30	10.8%	30	10.4%
0.06-0.08	76	19.1%	97	19.6%	35	13.6%
0.08-0.10	112	29.3%	154	33.7%	33	16.6%
0.10-0.15	172	45.0%	185	50.5%	88	24.6%
0.15-0.20	44	49.0%	62	56.2%	98	33.6%
0.20-0.25	27	51.5%	67	62.3%	67	39.7%
0.25-0.30	33	54.5%	60	67.8%	73	46.4%
0.30-0.40	79	61.7%	86	75.6%	120	57.3%
0.40-0.50	83	69.3%	48	80.0%	114	67.7%
0.50-0.60	57	74.5%	36	83.3%	95	76.4%
0.60-0.70	62	80.1%	37	86.7%	72	82.9%
0.70-0.80	33	83.1%	27	89.1%	52	87.7%
0.80-1.00	64	89.0%	48	93.5%	91	96.0%
1.00-1.20	37	92.3%	36	96.8%	35	99.2%
1.20-1.40	39	95.9%	12	97.9%	9	100%
1.40-1.60	16	97.4%	10	98.8%		
1.60-1.80	12	98.4%	10	99.7%		
1.80-2.00	7	99.1%	2	99.9%		
2.00-2.20	6	99.6%	-			
2.20-2.40	2	99.8%	1	100%		
2.40-2.60	1	99.9%				
2.60-2.80	1	100%				
Total	1096		1096		1096	

Table 19f. Frequency (n) and Cumulative frequency (%) 300 mb for All Categories Combined (g/kg)

Interval	RAOB Values		Bogus Errors		TOVS Errors	
	(n)	(CF)	(n)	(CF)	(n)	(CF)
0.00-0.02	505	46.3%	201	18.4%	141	12.9%
0.02-0.04	90	54.6%	217	38.3%	119	23.9%
0.04-0.06	13	55.8%	198	56.5%	121	35.0%
0.06-0.08	18	57.4%	88	64.6%	116	45.6%
0.08-0.10	30	60.2%	64	70.5%	122	56.8%
0.10-0.15	101	69.4%	116	81.1%	180	73.3%
0.15-0.20	107	79.3%	61	86.7%	123	84.6%
0.20-0.25	78	86.4%	47	91.0%	83	92.2%
0.25-0.30	49	90.9%	34	94.1%	48	96.6%
0.30-0.40	56	96.1%	42	98.0%	36	99.9%
0.40-0.50	27	98.5%	18	99.6%	1	100%
0.50-0.60	11	99.5%	2	99.8%		
0.60-0.70	4	99.9%	1	99.9%		
0.70-0.80	1	100%	1	100%		
Total	1096		1090		1090	

Table 20a

RELATIVE HUMIDITY
RMSE (%) Bogus/TOVS

Pressure Level (mb)

Cat	No	1000	850	700
1	-	-	-	-
2	6	6.7/9.5	20.3/22.3	35.6/19.4
3	107	16.2/19.9	21.2/21.5	25.0/23.1
4	60	20.1/22.4	26.1/22.8	25.9/24.1
5	-	-	-	-
6	11	15.7/20.2	28.8/19.9	42.8/36.6
7	57	15.1/19.3	24.3/20.9	27.0/26.6
8	678	19.6/19.6	26.4/22.2	29.1/22.3
9	68	21.5/19.2	24.3/23.5	29.1/28.0
10	63	32.4/22.0	25.7/23.9	27.9/21.7
11	7	42.8/21.5	44.3/17.6	51.9/32.8
12	13	21.4/18.8	39.5/27.0	31.6/24.4
13	33	20.8/17.0	27.9/28.1	40.4/23.9
Total	1103	20.3/19.7	26.1/22.5	29.2/23.4

Cat	No	500	400	300
1	-	-	-	-
2	6	40.1/26.3	27.4/25.7	16.9/17.9
3	107	32.4/27.3	35.5/28.8	36.9/29.6
4	60	30.8/28.9	27.5/31.8	25.0/28.6
5	-	-	-	-
6	11	30.6/30.0	27.2/33.0	22.1/29.9
7	57	30.2/31.8	27.7 34.2	17.9/29.7
8	678	23.0/24.7	22.1/27.8	17.5/25.1
9	68	28.3/25.0	45.1/26.3	46.6/25.3
10	63	18.1/20.8	17.5/21.9	12.1/23.5
11	7	49.1/37.7	31.2/25.0	31.6/28.4
12	13	23.3/26.2	48.8/24.6	40.1/23.4
13	33	42.2/27.7	30.9/23.7	50.9/32.0
Total	1103	26.2/25.7	26.9/28.0	24.9/26.2

Table 20b

MIXING RATIO

RMSE (g/kg) Bogus/TOVS

Pressure Level (mb)

Cat	No	1000	850	700
1	-	-	-	-
2	6	1.32/2.45	3.37/2.39	2.71/1.67
3	107	2.54/3.75	2.45/2.21	1.65/1.49
4	60	3.28/4.01	4.14/2.38	2.16/1.75
5	-	-	-	-
6	11	2.53/4.34	3.19/2.12	2.98/2.40
7	57	2.25/3.12	3.18/2.06	1.56/1.48
8	678	3.54/3.28	3.88/2.52	2.40/1.69
9	68	3.42/3.24	3.05/2.49	2.61/2.17
10	63	4.11/2.52	3.03/2.81	2.52/1.57
11	7	6.82/1.95	7.05/1.57	3.74/1.71
12	13	5.06/2.67	6.51/2.77	2.51/1.66
13	33	3.25/2.55	2.95/2.58	3.31/1.61
	1103	3.43/3.31	3.69/2.47	2.36/1.70

Cat	No	500	400	300
1	-	-	-	-
2	6	1.60/0.96	0.49/0.51	0.12/0.14
3	107	1.09/0.89	0.61/0.48	0.16/0.13
4	60	1.15/0.92	0.48/0.55	0.15/0.17
5	-	-	-	-
6	11	0.84/0.72	0.53/0.37	0.13/0.13
7	57	0.82/0.95	0.34/0.51	0.10/0.51
8	678	0.84/0.89	0.38/0.51	0.11/0.14
9	68	0.92/0.91	0.90/0.50	0.26/0.14
10	63	0.65/0.76	0.24/0.40	0.06/0.12
11	7	1.16/1.07	0.55/0.34	0.14/0.07
12	13	0.76/0.84	0.86/0.49	0.21/0.14
13	33	1.49/0.96	0.57/0.43	0.28/0.16
	1103	0.91/0.89	0.47/0.50	0.14/0.14

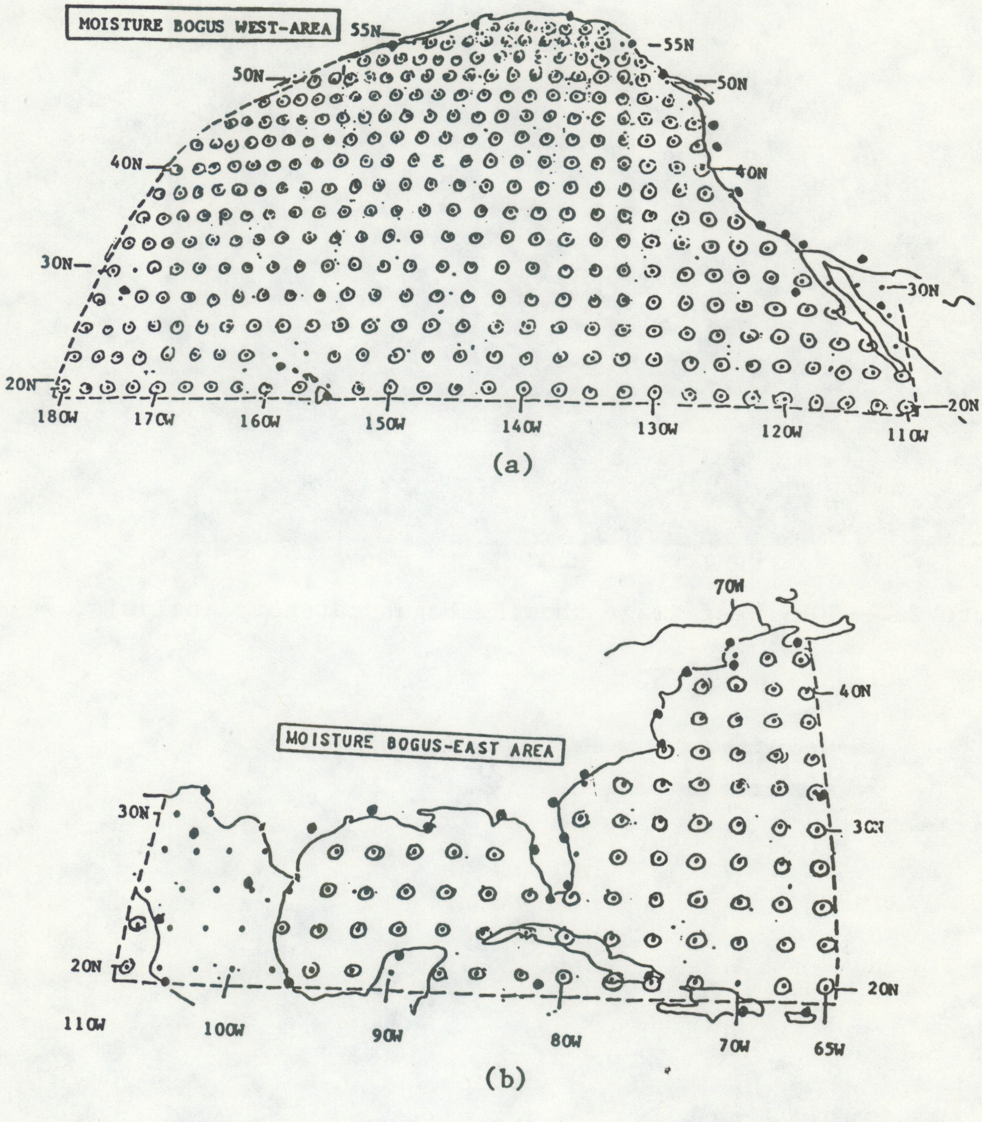

Figure 1.--Boundaries and grid points for GOES moisture bogus categories (a) West area, (b) East area

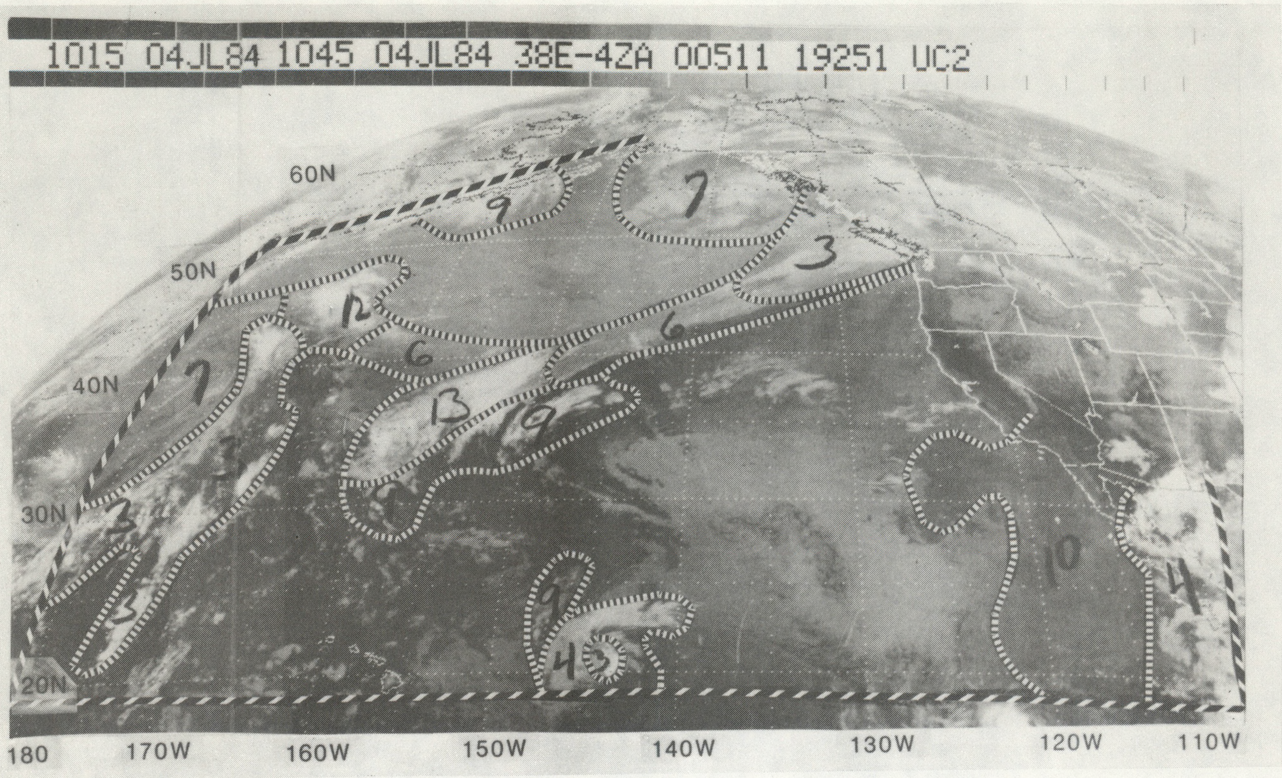

Figure 2a.--GOES West image showing bogus category analysis, 7-4-84

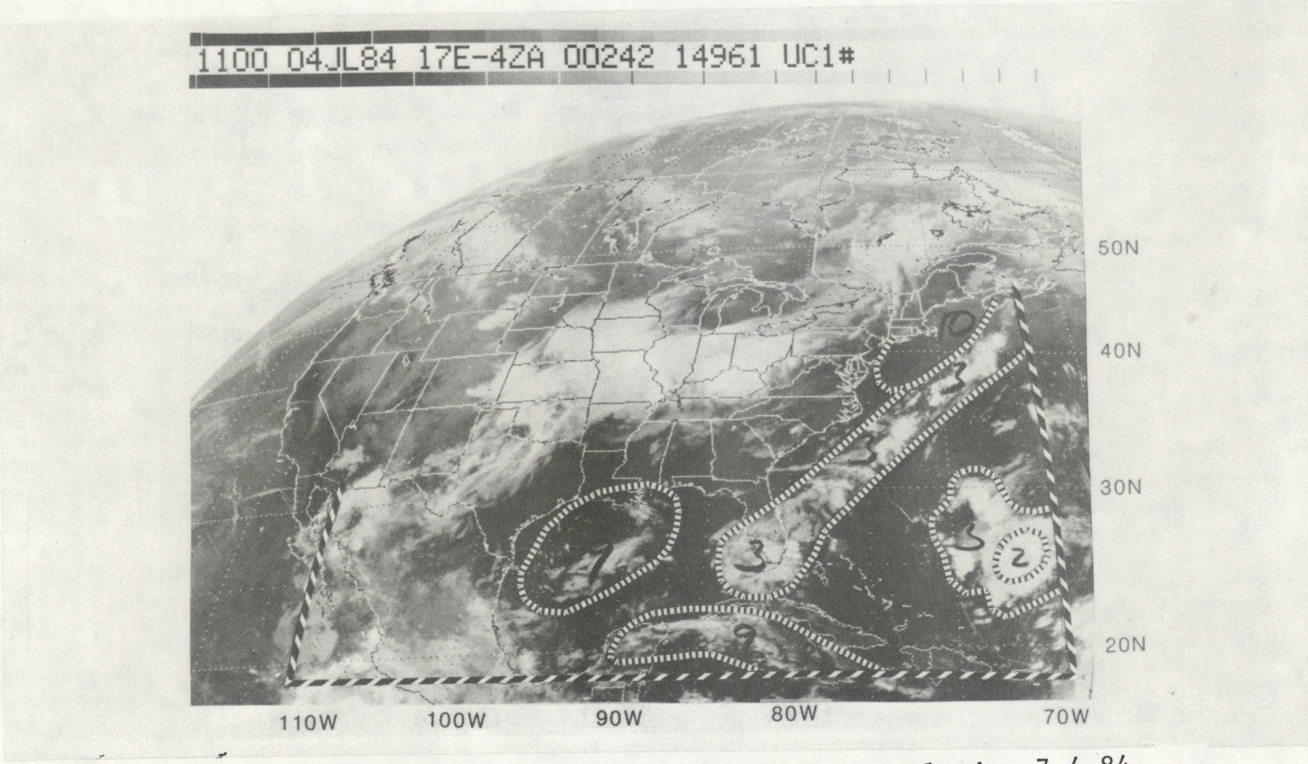

Figure 2b.--GOES East image showing bogus category analysis, 7-4-84

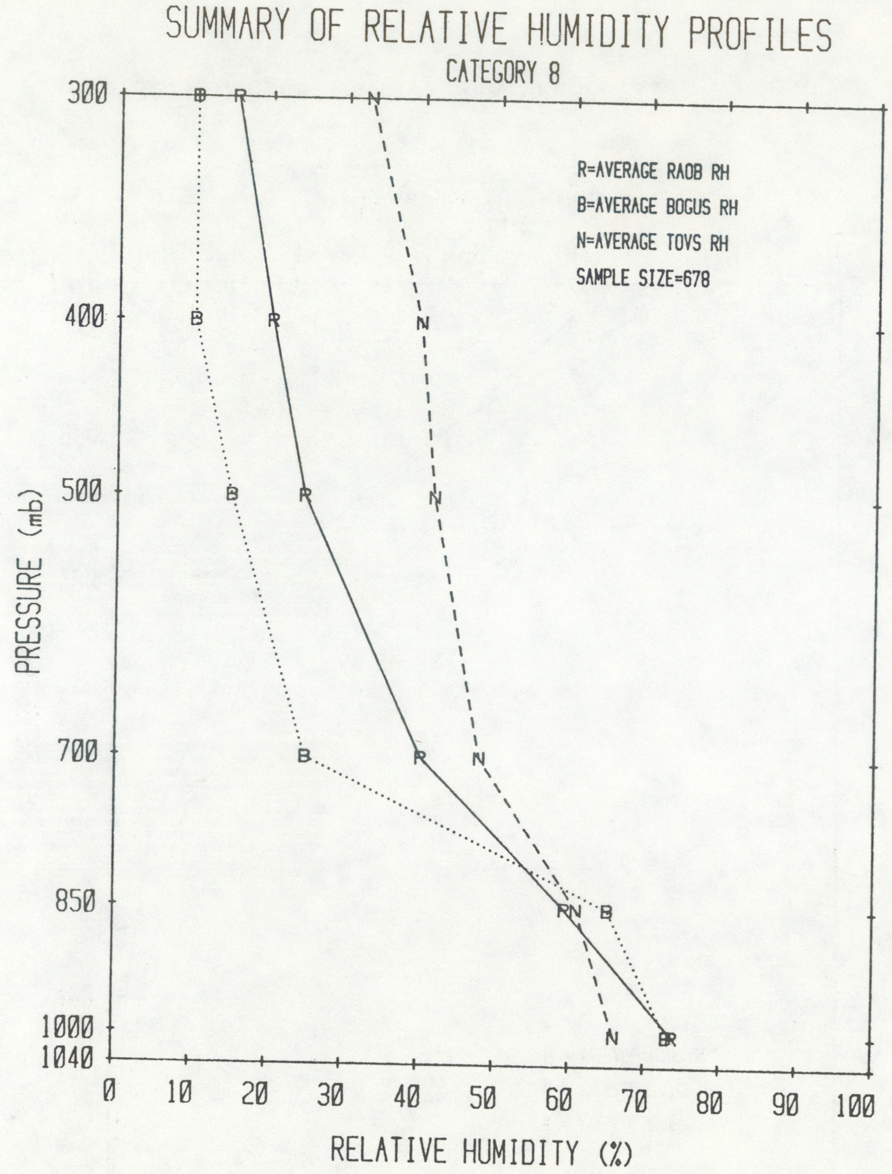

Figure 3a.--Comparison average RH profiles Category 8

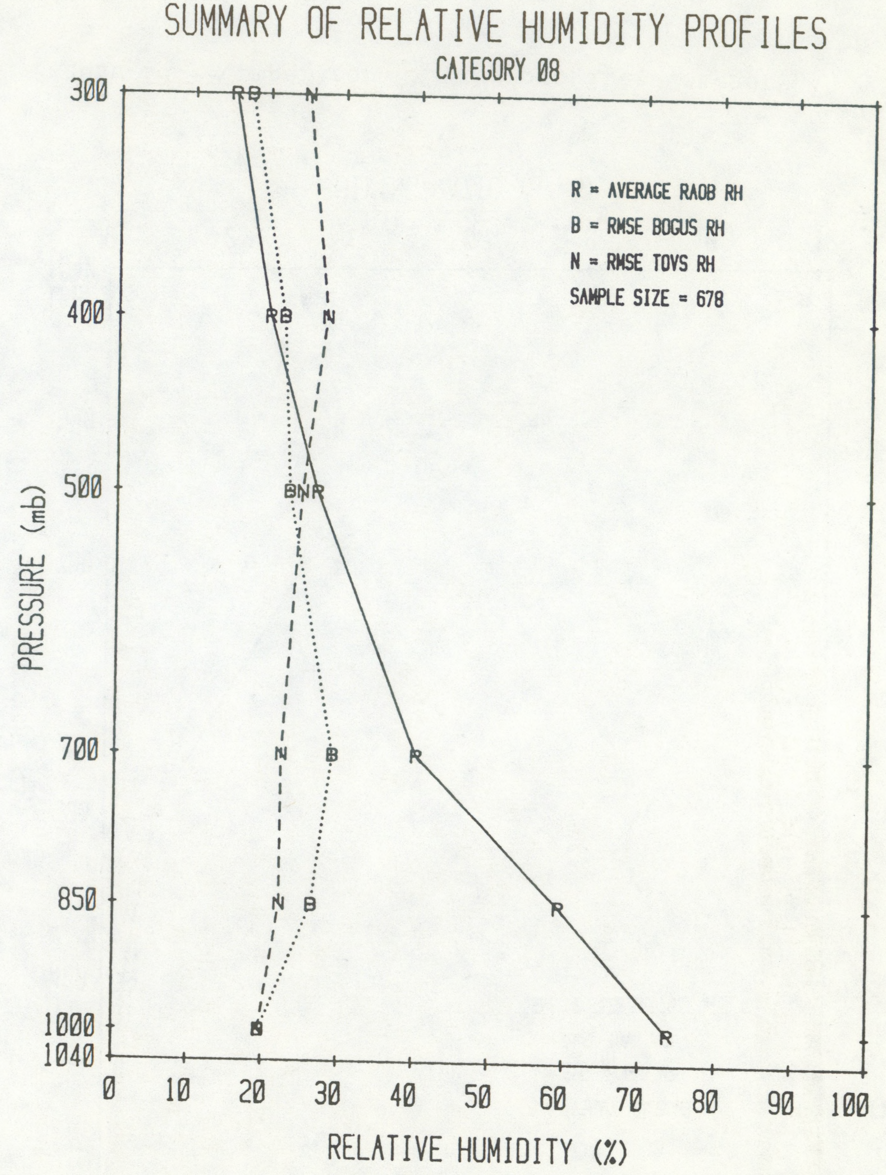

Figure 3b.--Comparison RMSE RH profiles Category 8

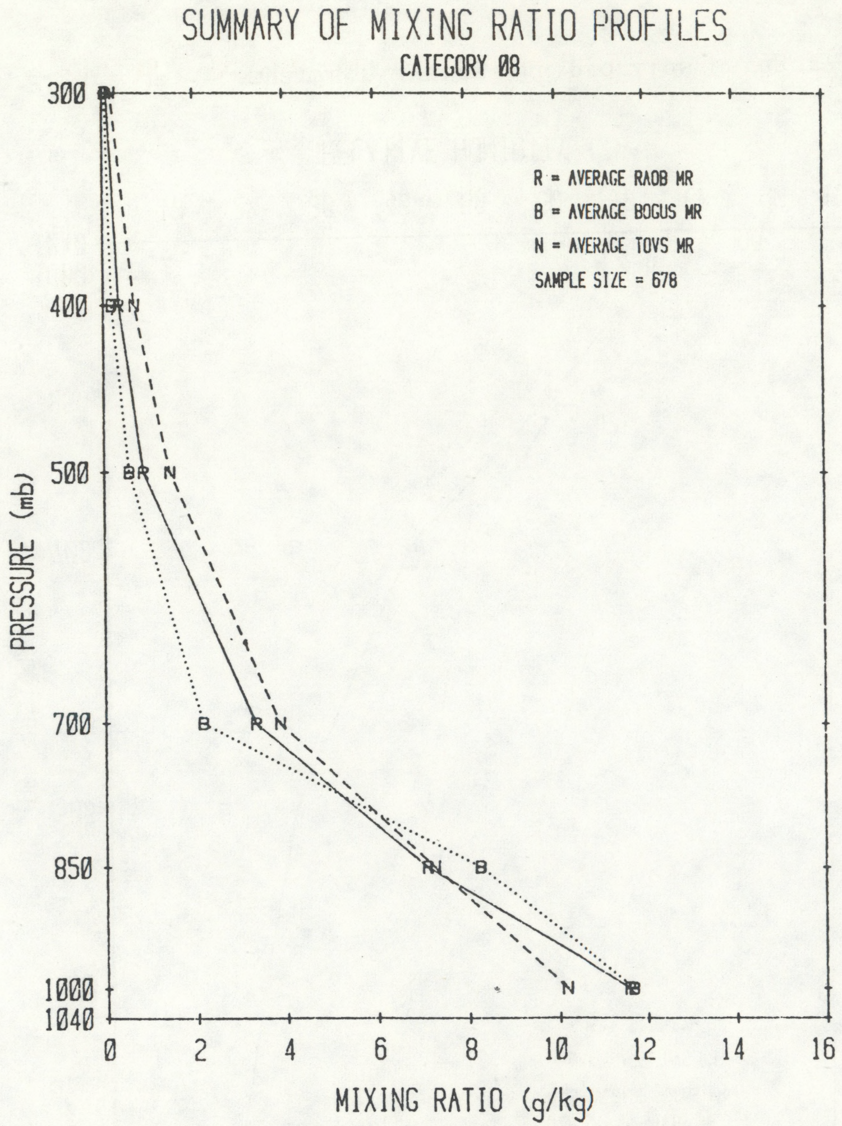

Figure 3c.--Comparison average MR profiles Category 8

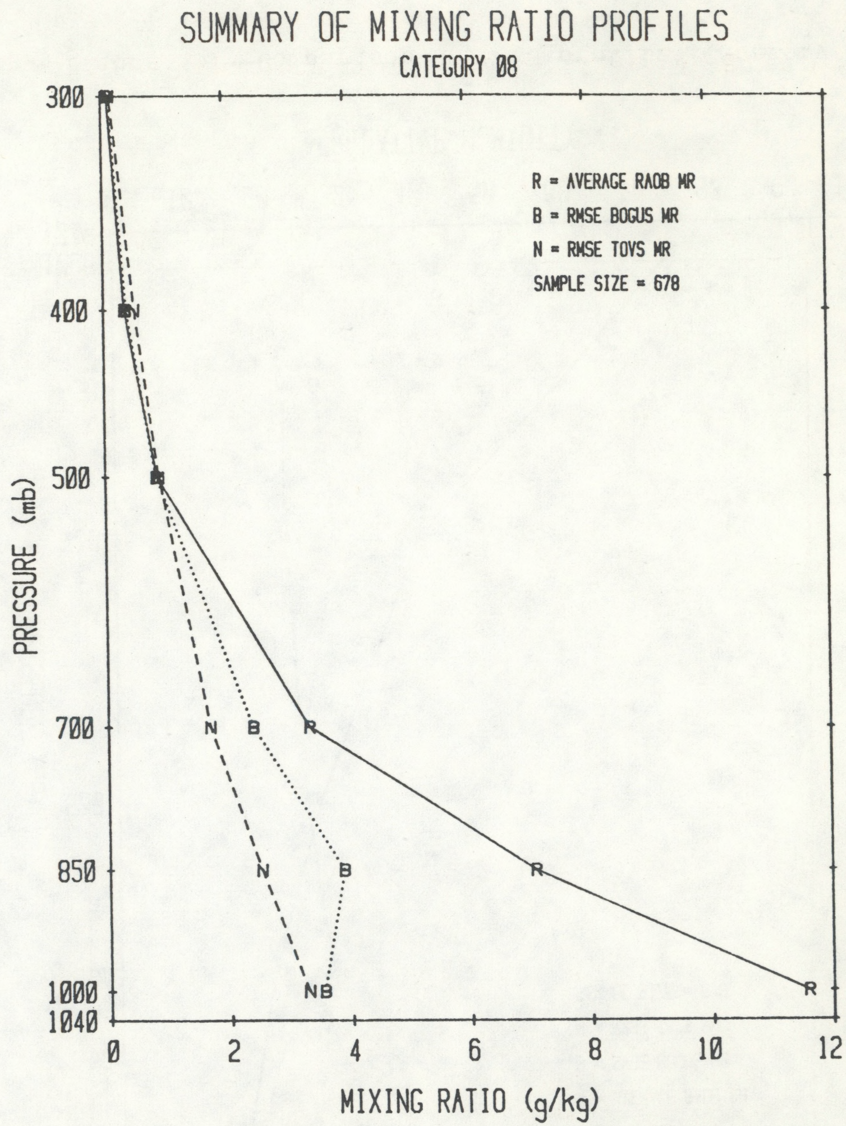

Figure 3d.--Comparison RMSE MR profiles Category 8

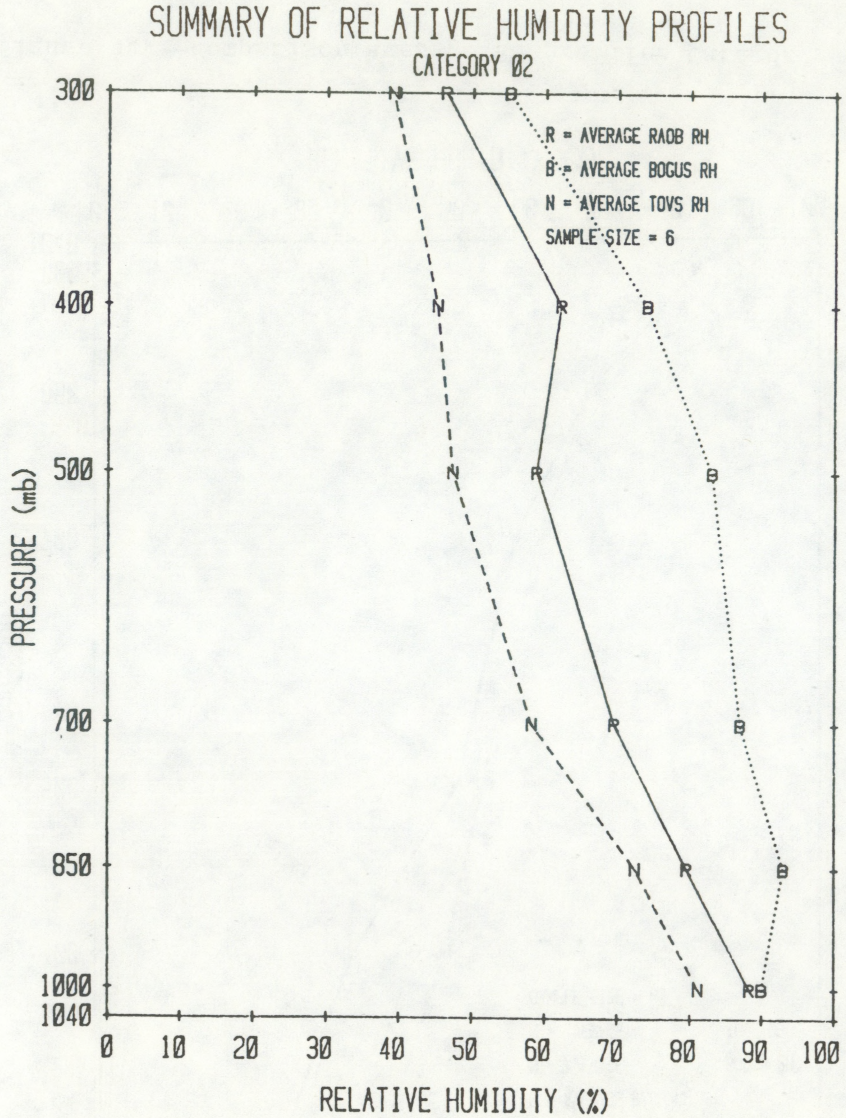

Figure 4a.--Comparison average RH profiles Category 2

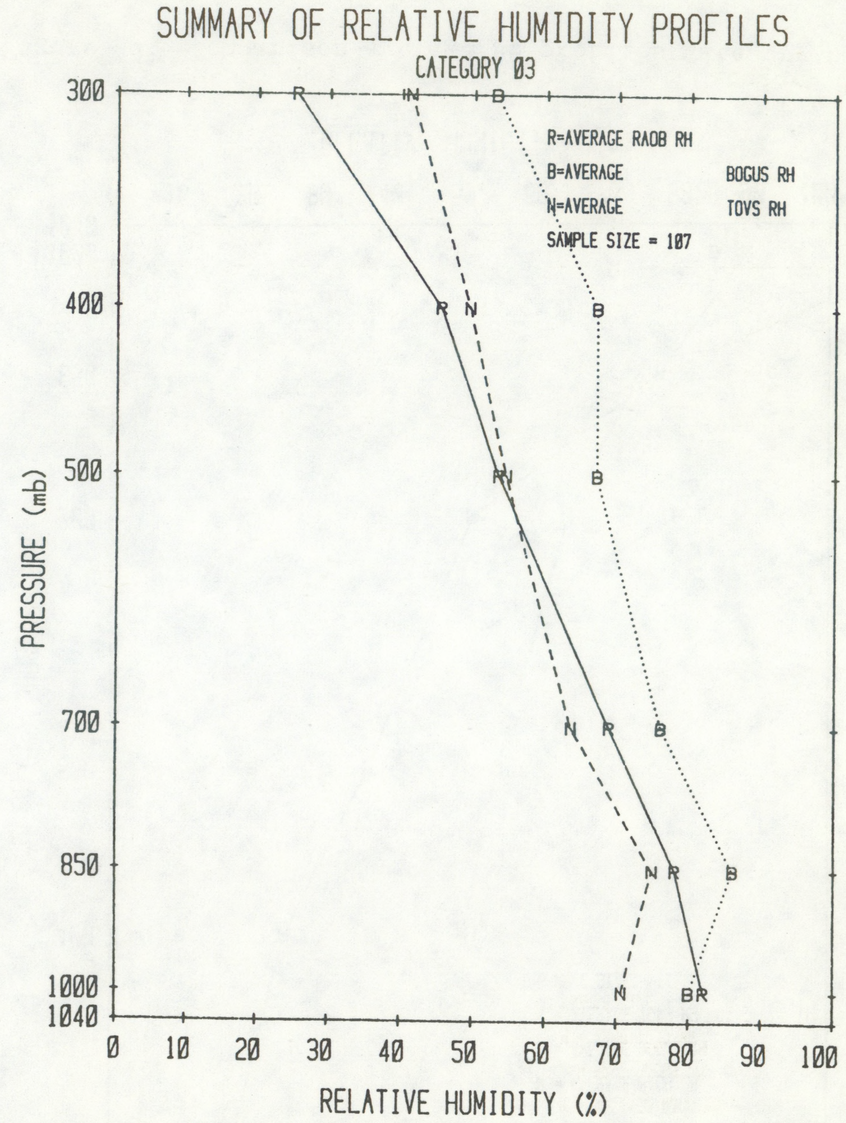

Figure 4b.--Comparison average RH profiles Category 3

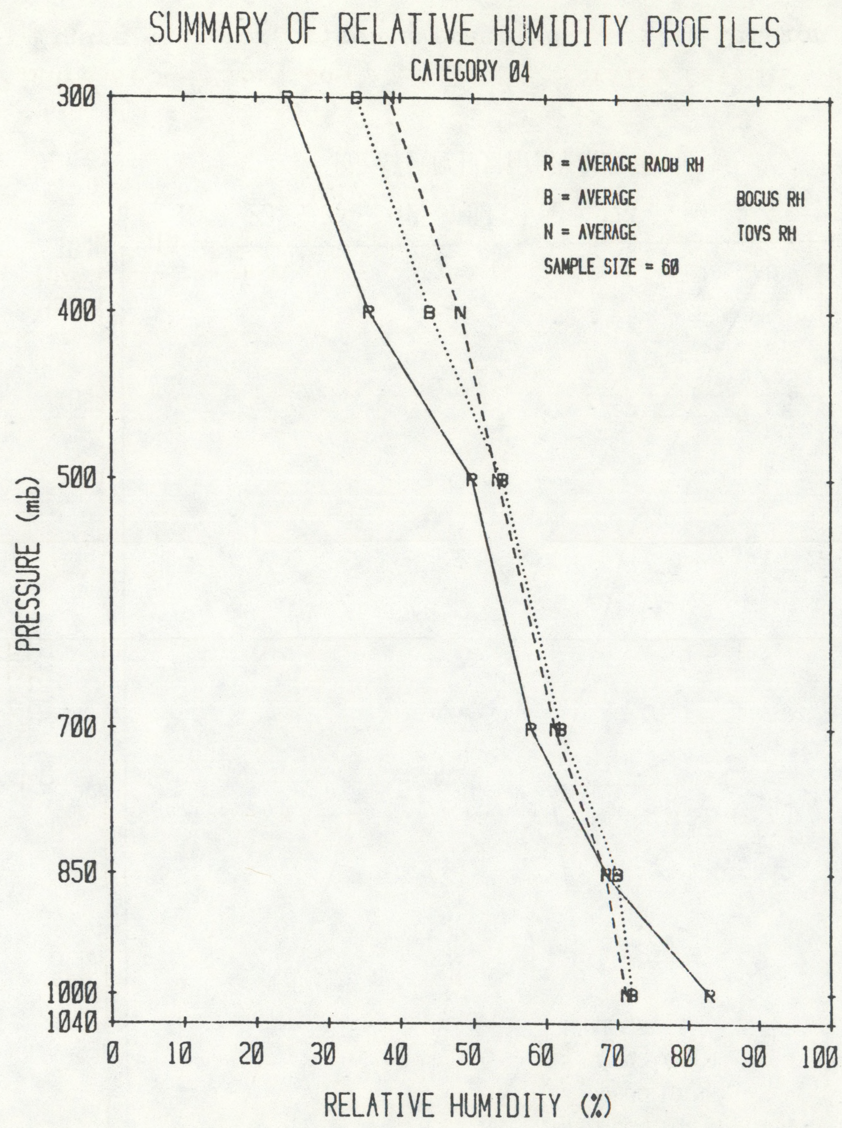

Figure 4c.--Comparison average RH profiles Category 4

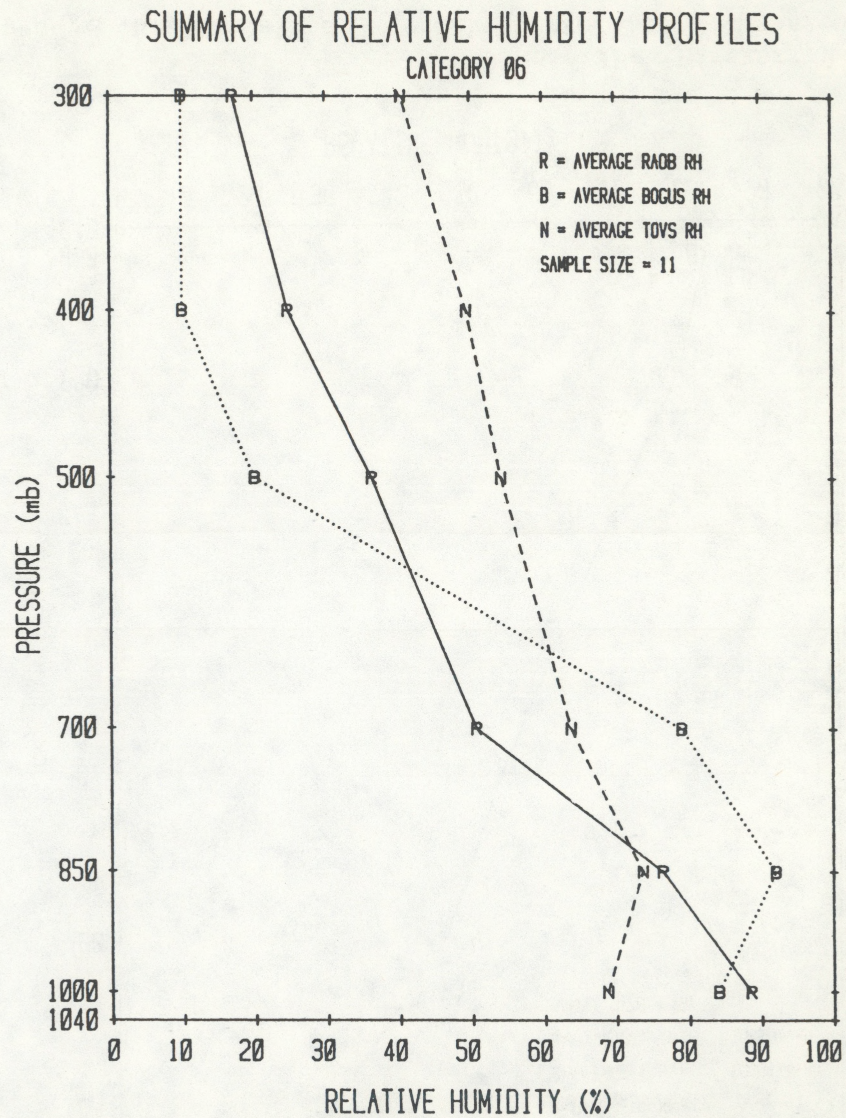

Figure 4d.--Comparison average RH profiles Category 6

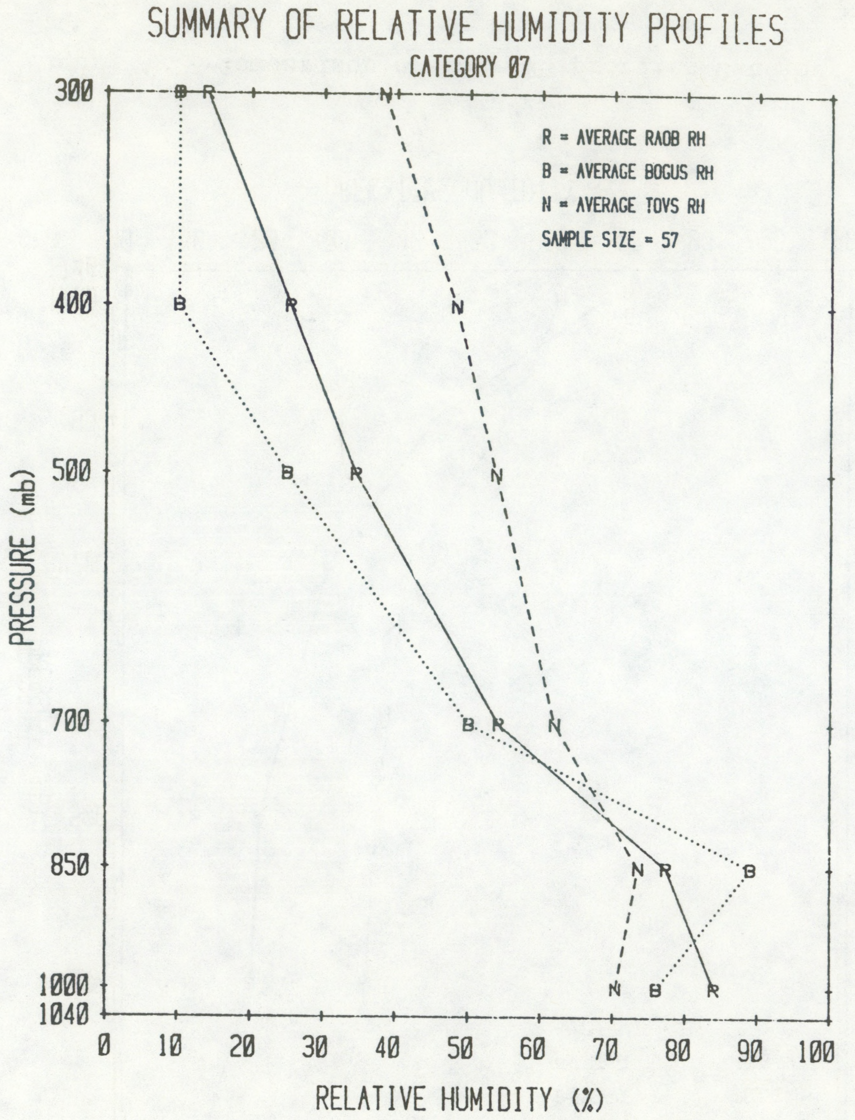

Figure 4e.--Comparison average RH profiles Category 7

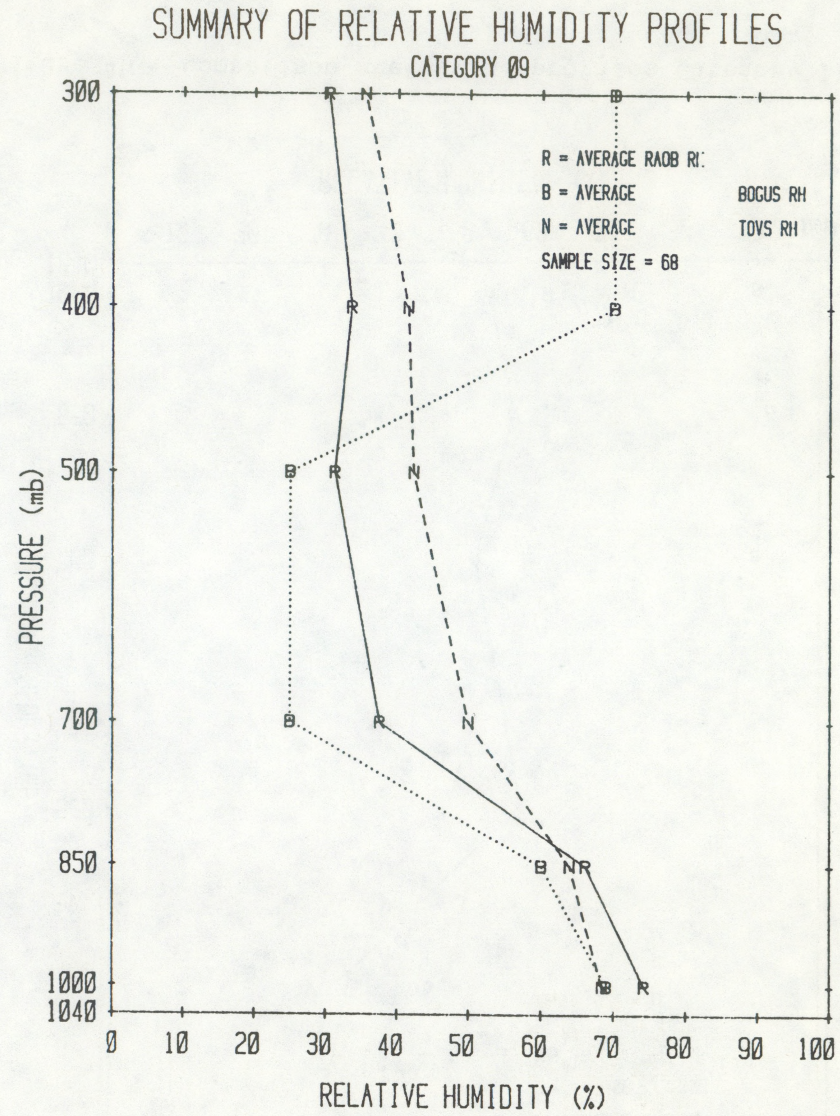

Figure 4f.--Comparison average RH profiles Category 9

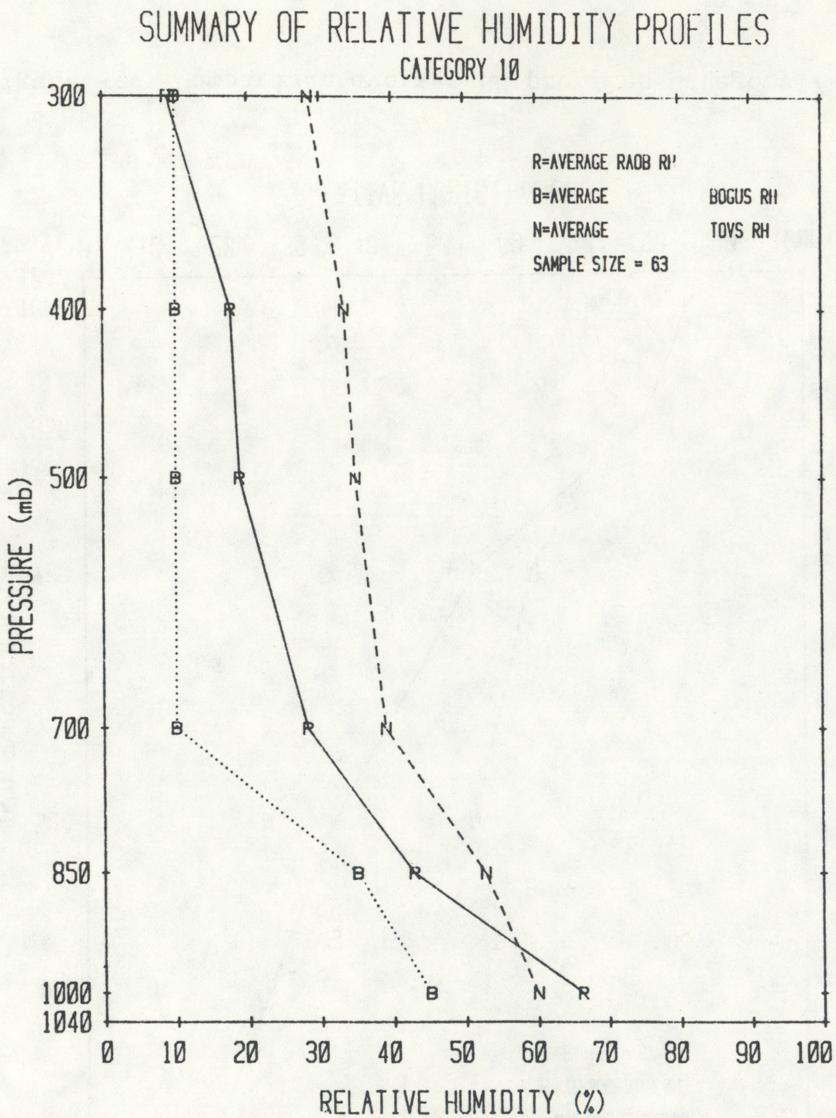

Figure 4g.--Comparison average RH profiles Category 10

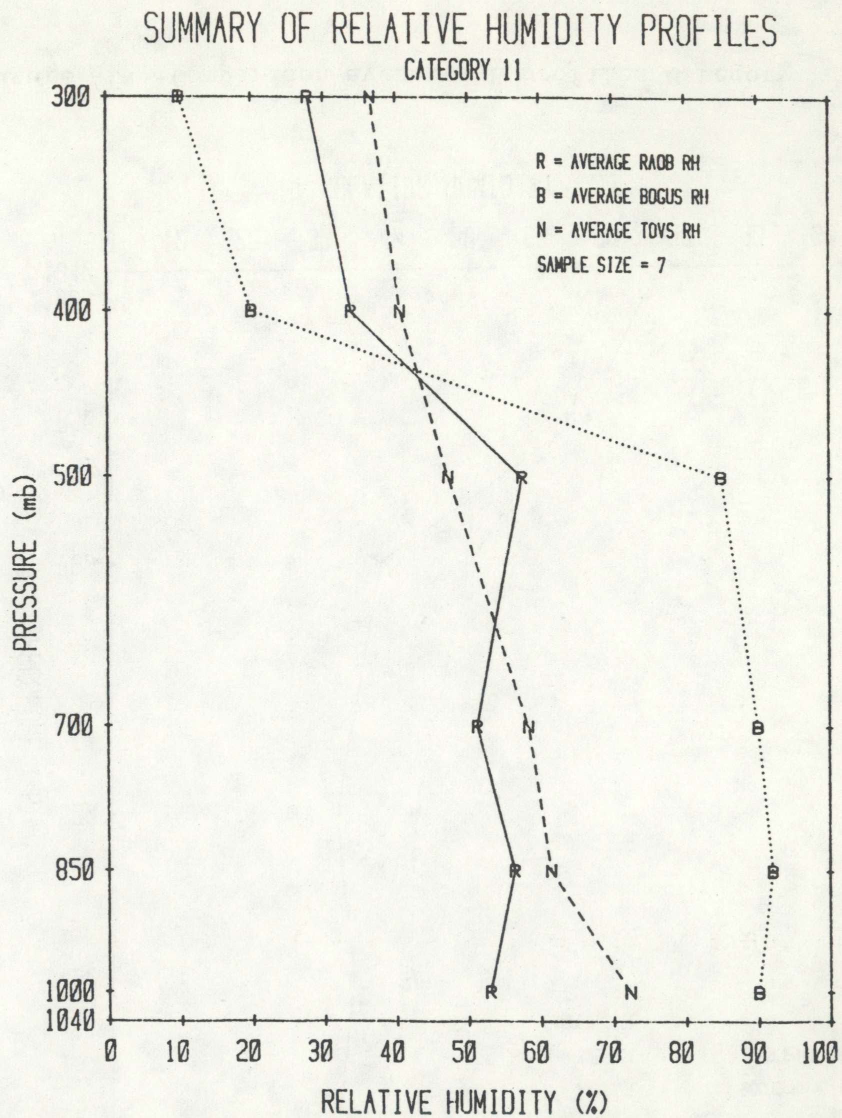

Figure 4h.--Comparison average RH profiles Category 11

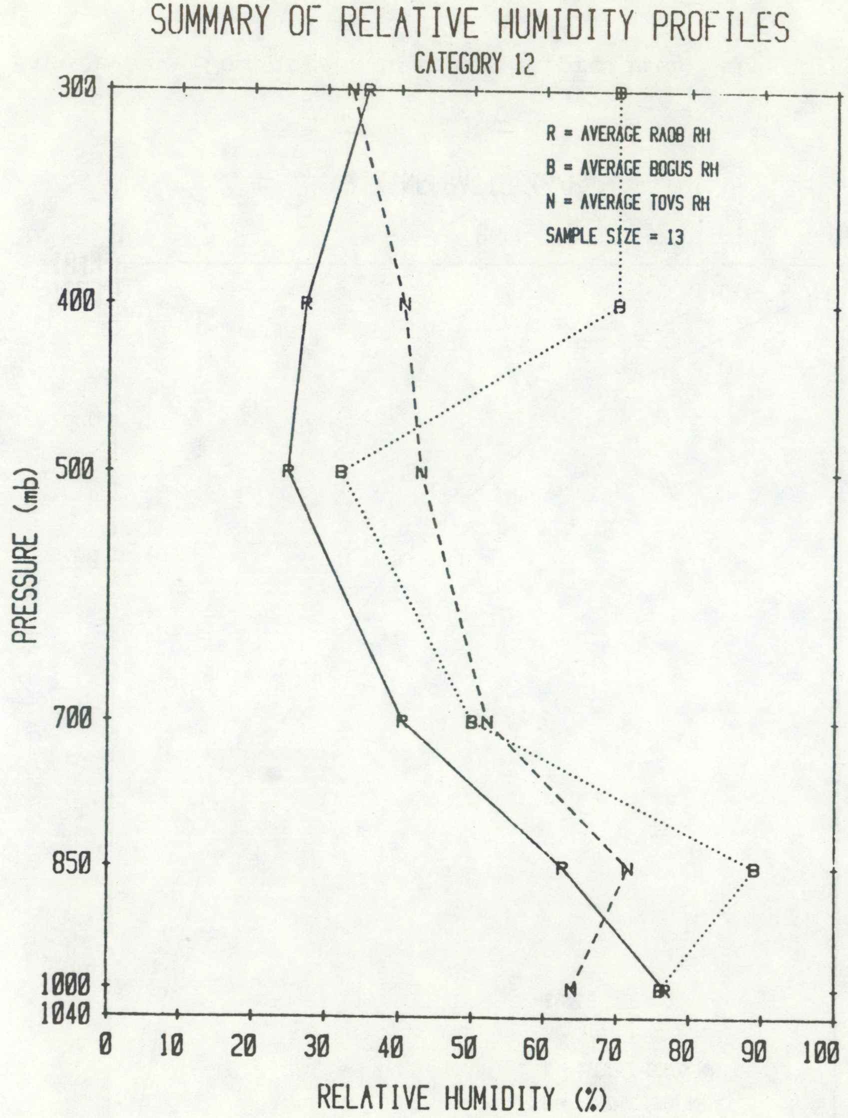

Figure 4i.--Comparison average RH profiles Category 12

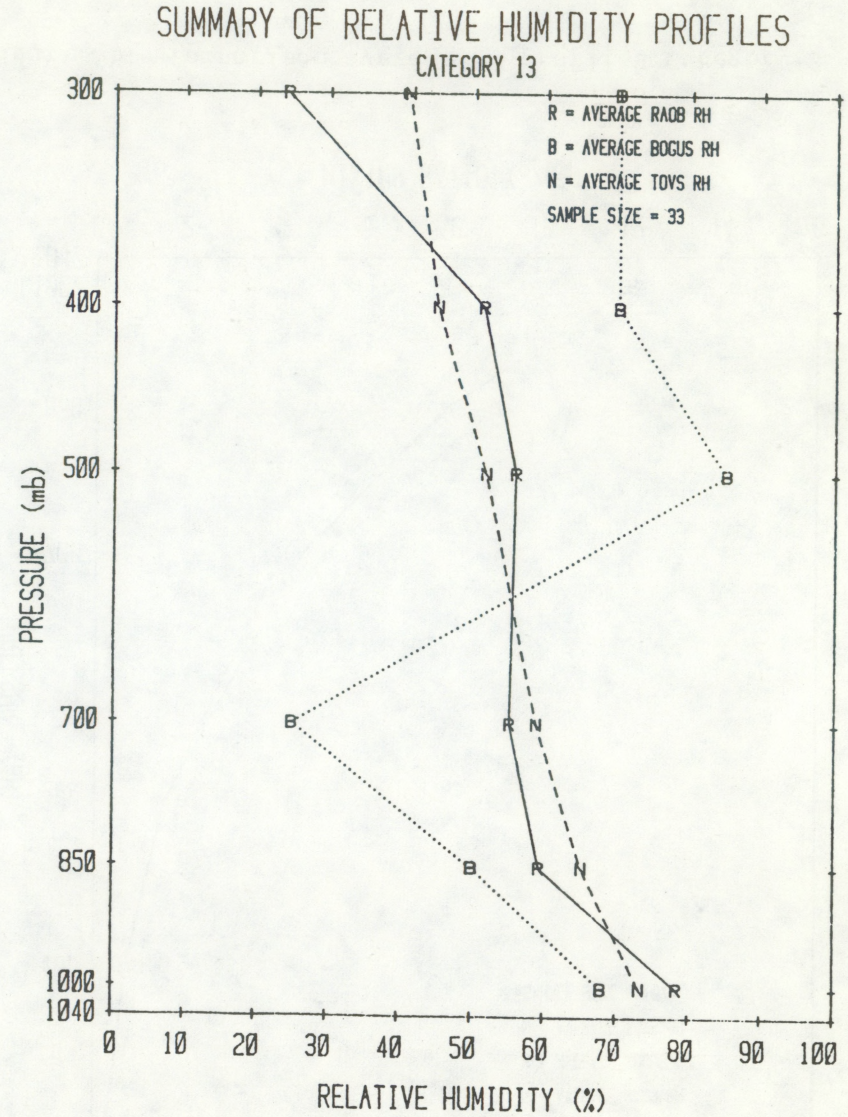

Figure 4j.--Comparison average RH profiles Category 13

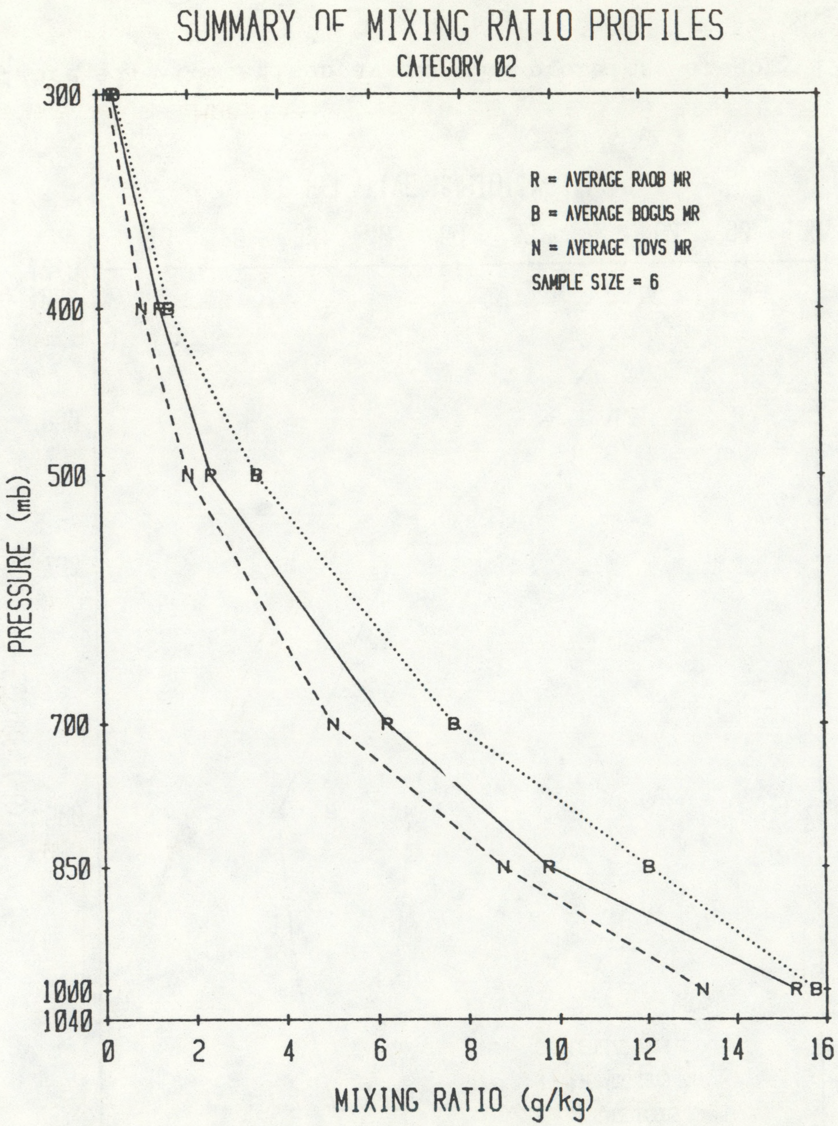

Figure 5a.--Comparison average MR profiles Category 2

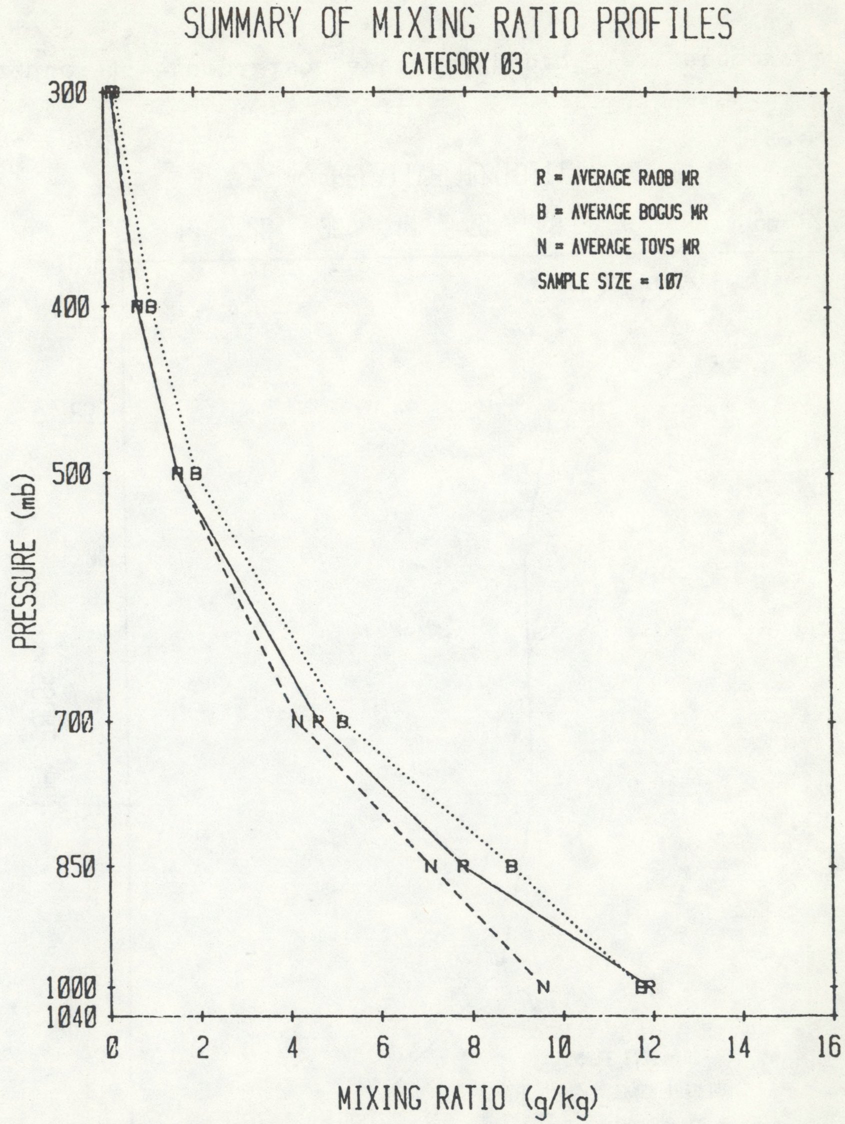

Figure 5b.--Comparison average MR profiles Category 3

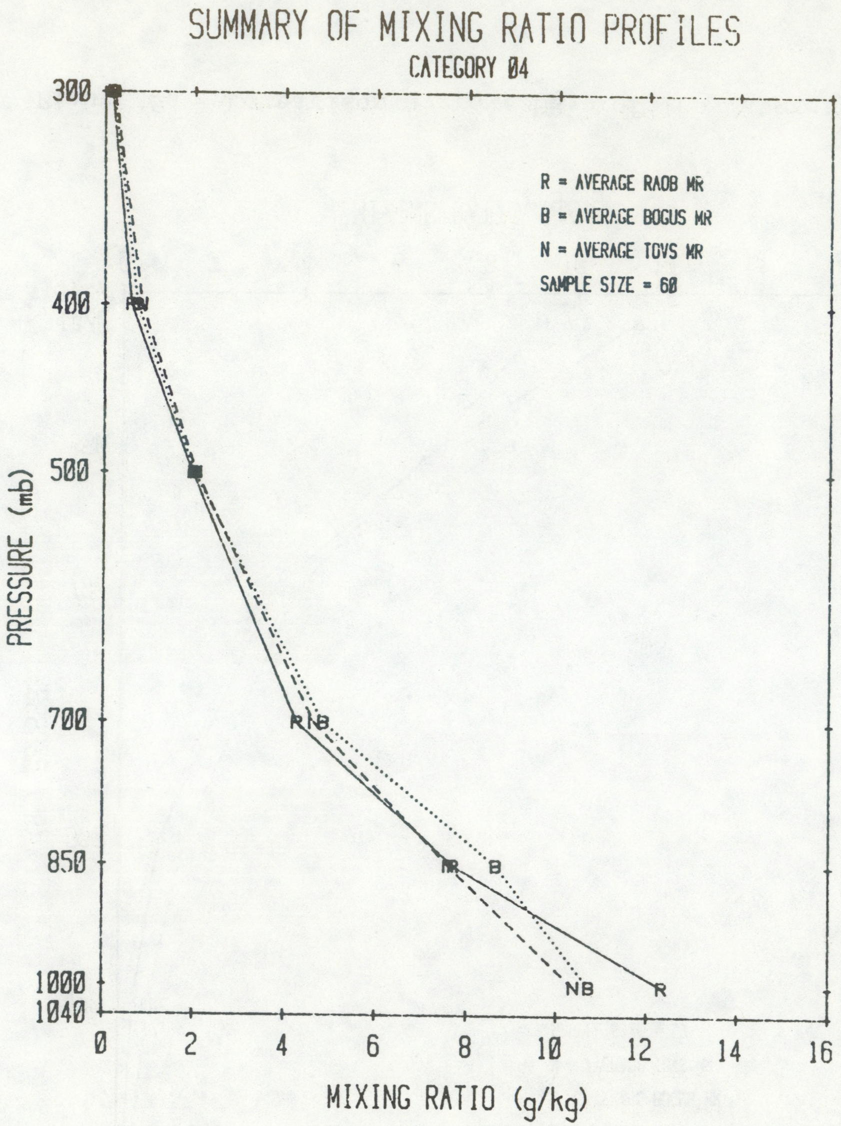

Figure 5c.--Comparison average MR profiles Category 4

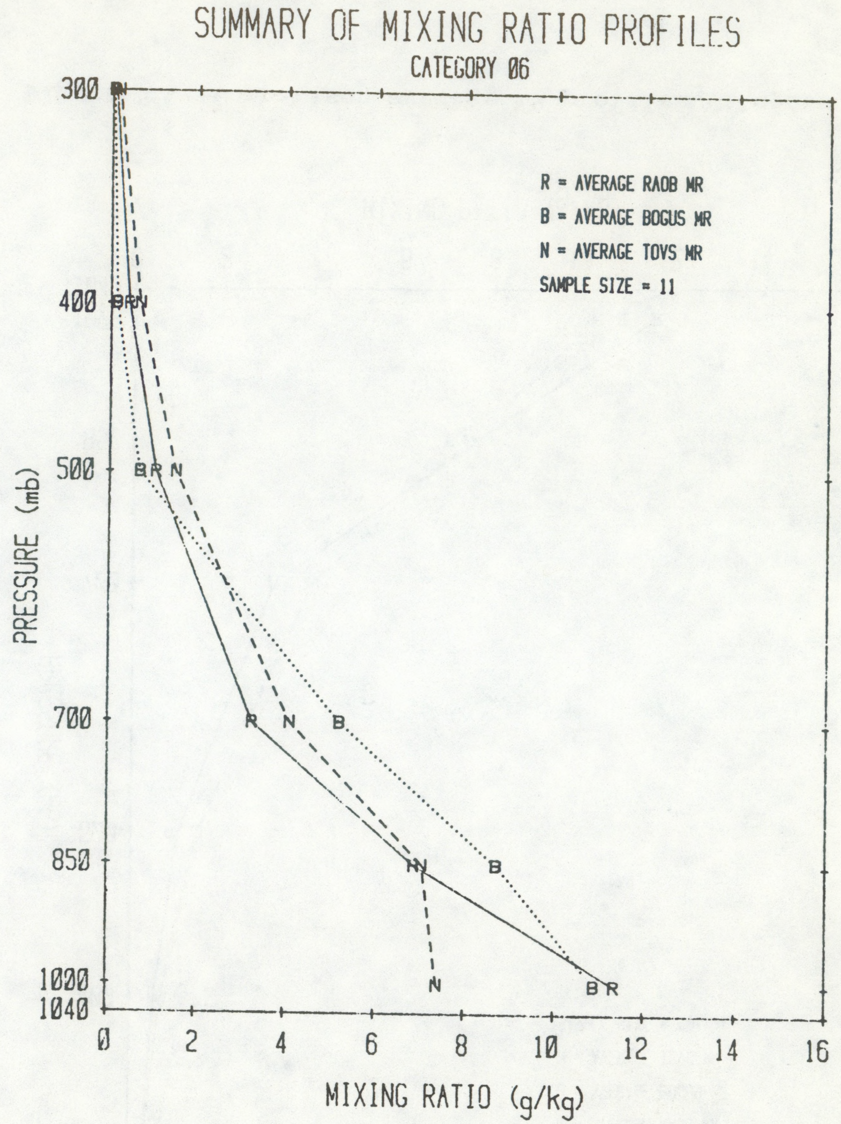

Figure 5d.--Comparison average MR profiles Category 6

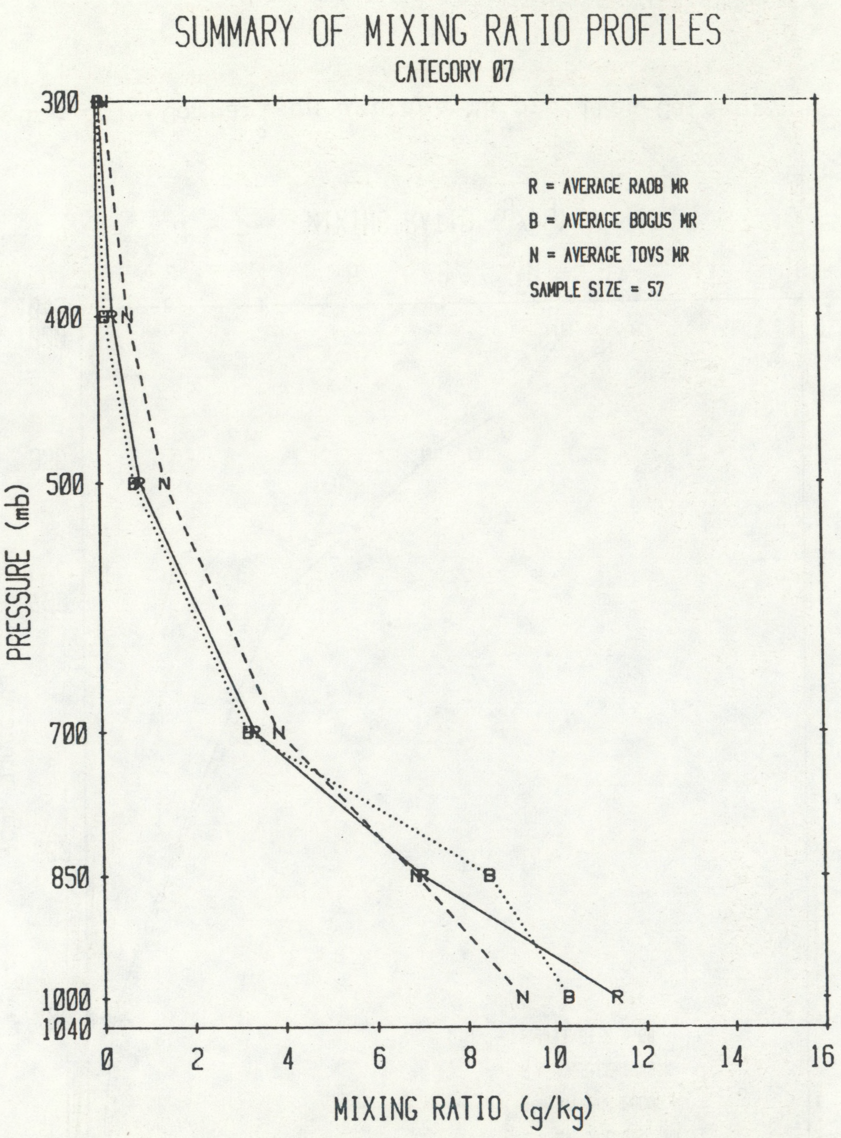

Figure 5e.--Comparison average MR profiles Category 7

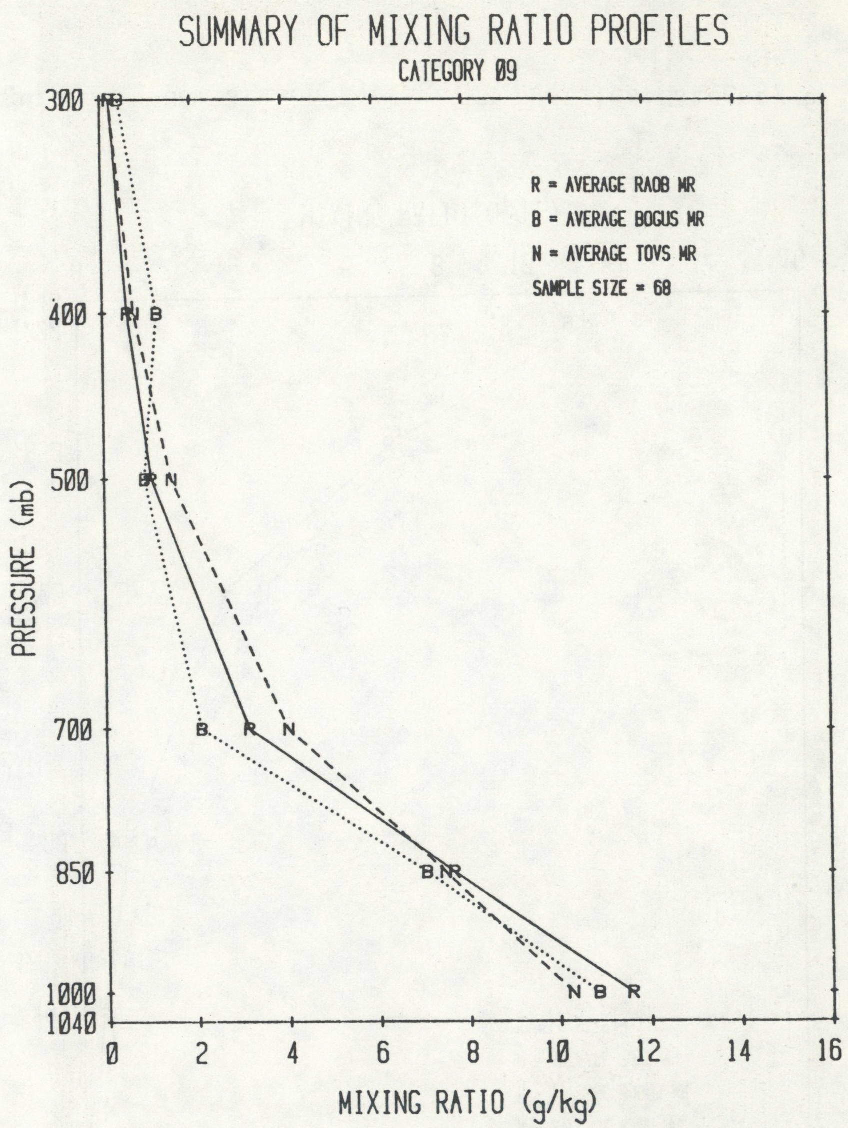

Figure 5f.--Comparison average MR profiles Category 9

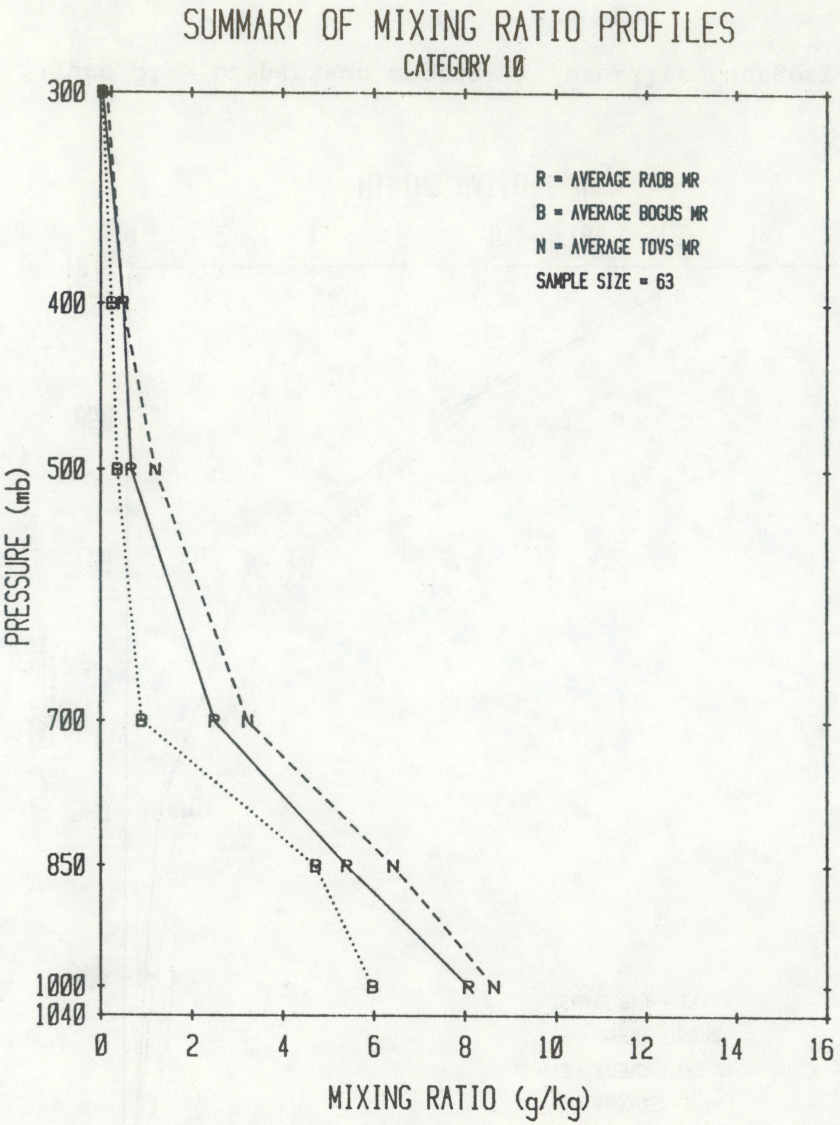

Figure 5g.--Comparison average MR profiles Category 10

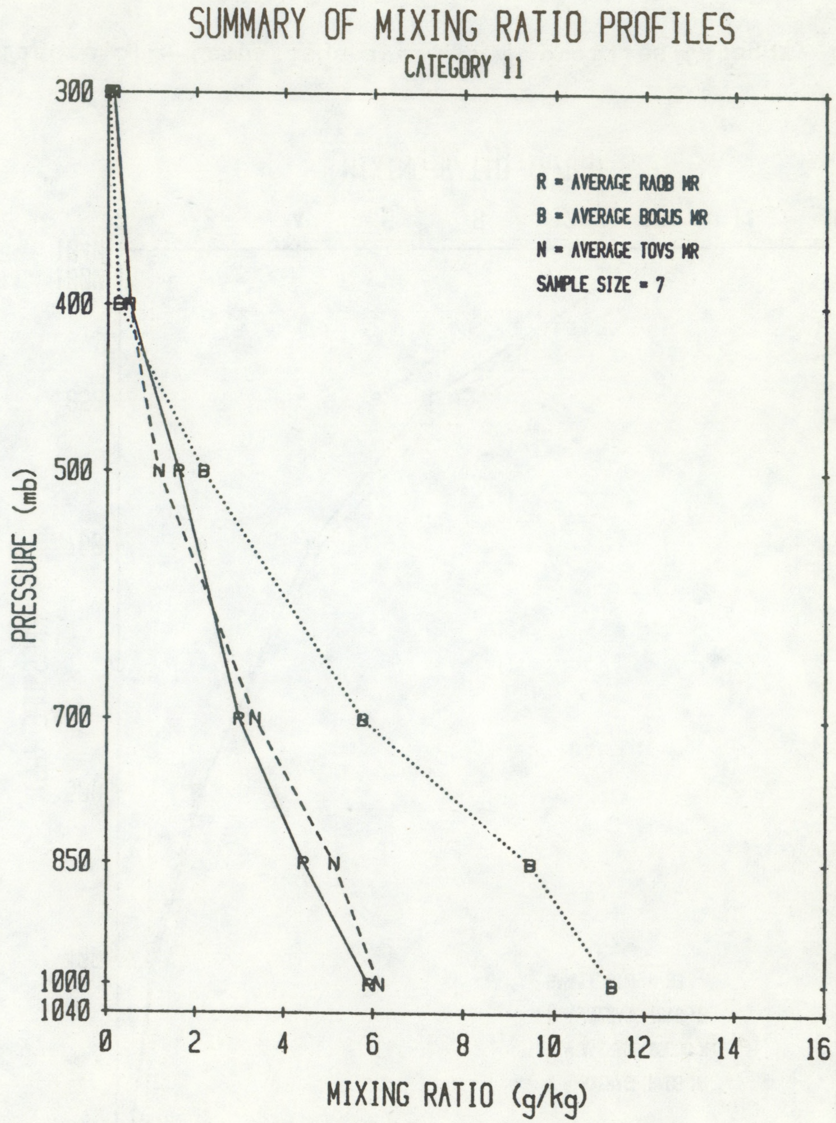

Figure 5h.--Comparison average MR profiles Category 11

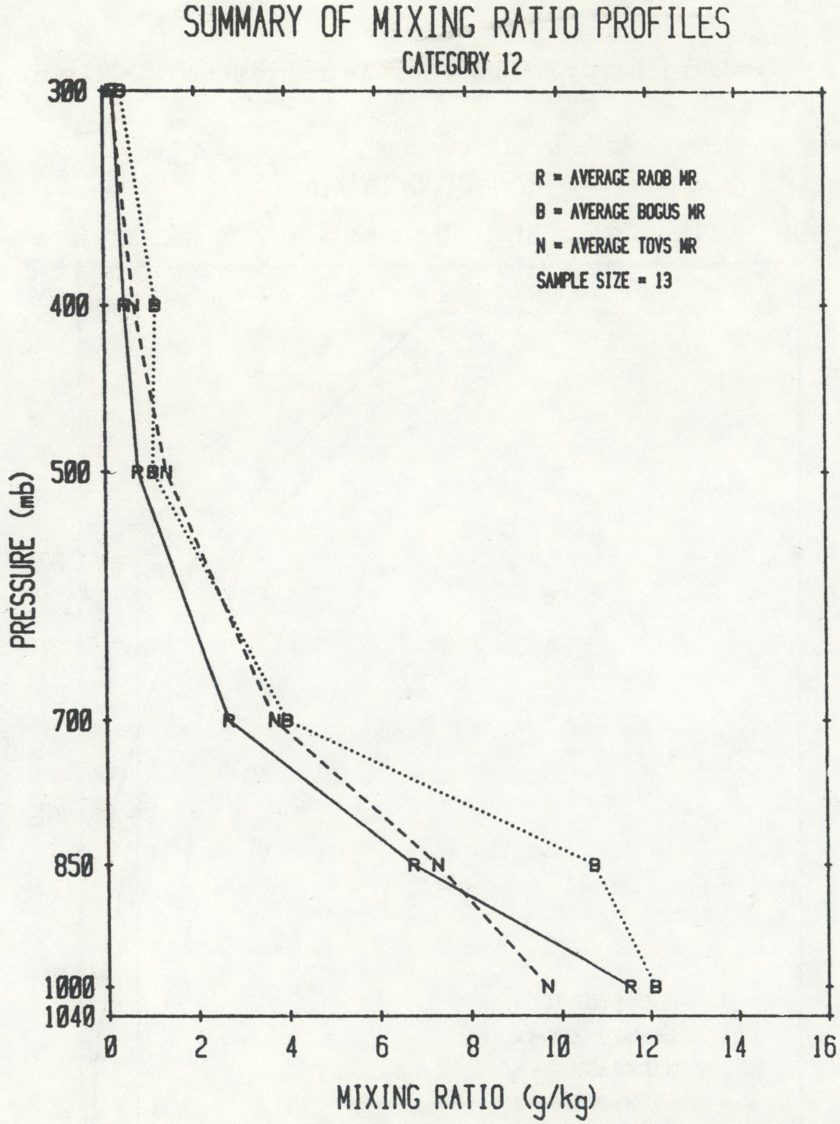

Figure 5i.--Comparison average MR profiles Category 12

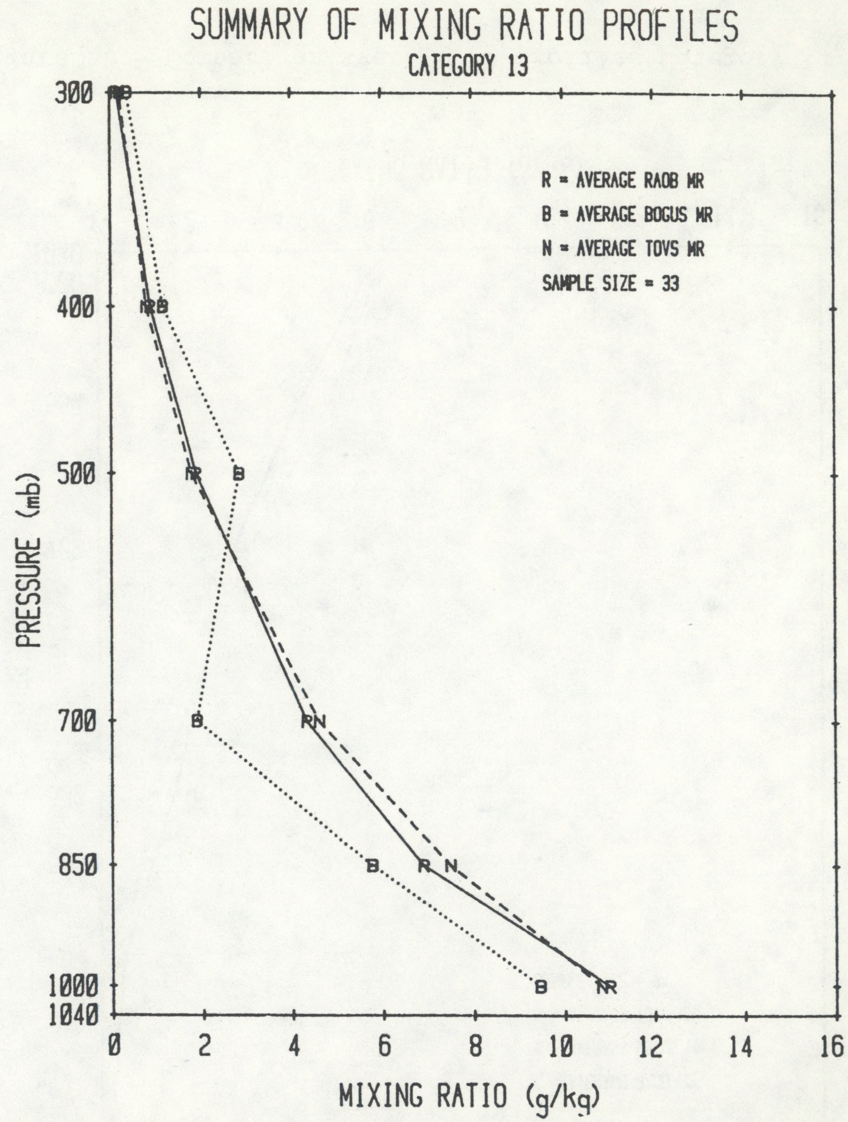

Figure 5j.--Comparison average MR profiles Category 13

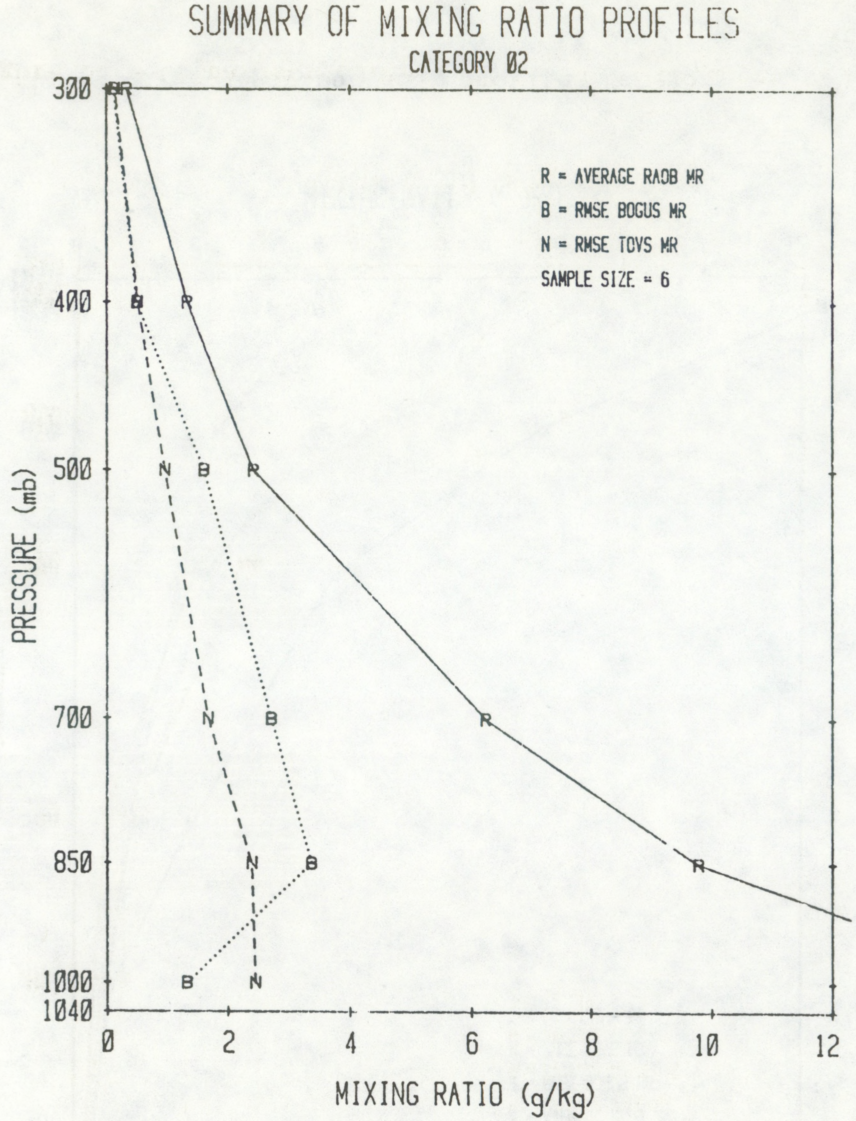

Figure 6a.--Comparison RMSE profiles Category 2

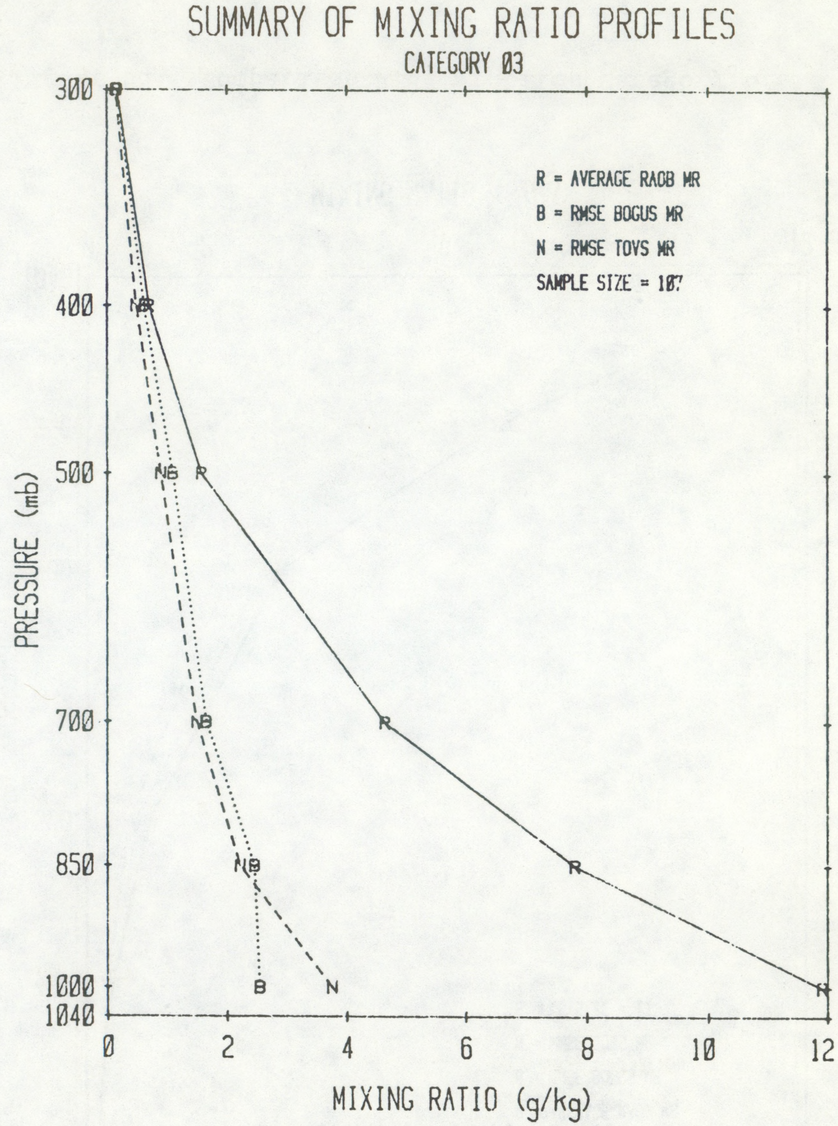

Figure 6b.--Comparison RMSE profiles Category 3

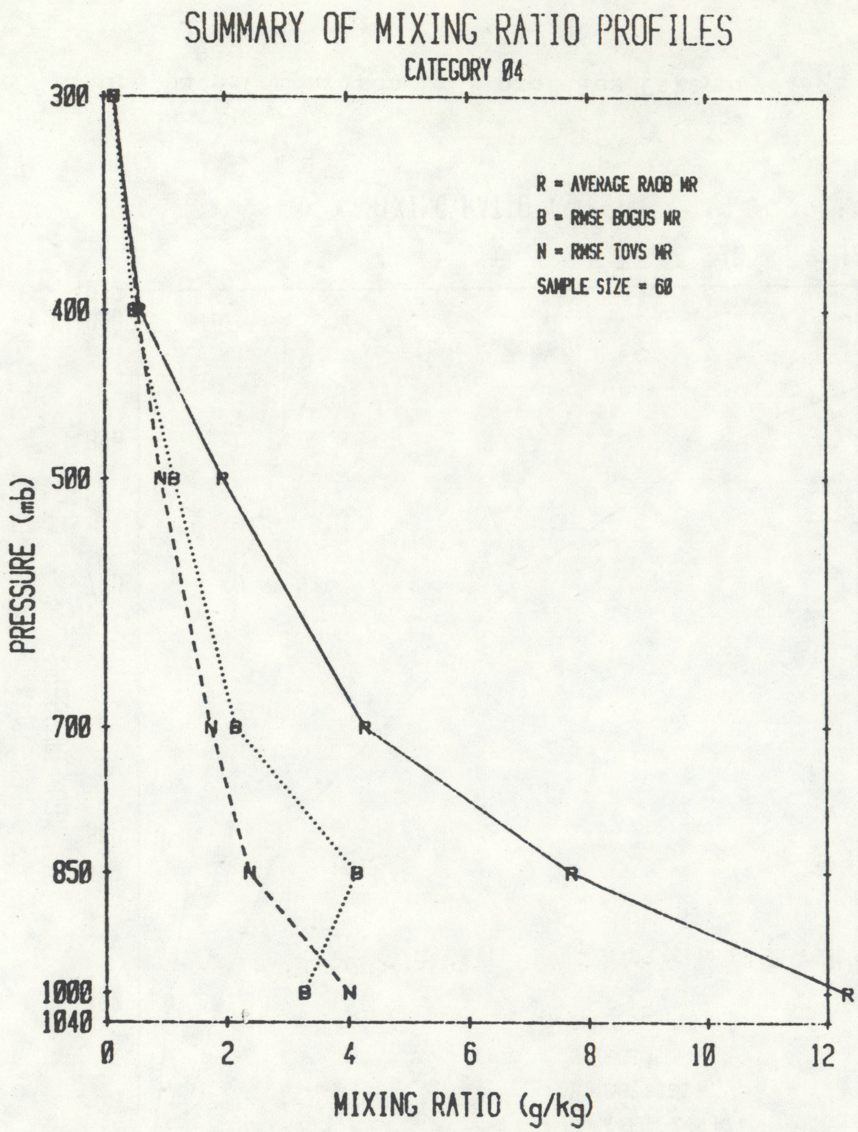

Figure 6c.--Comparison RMSE profiles Category 4

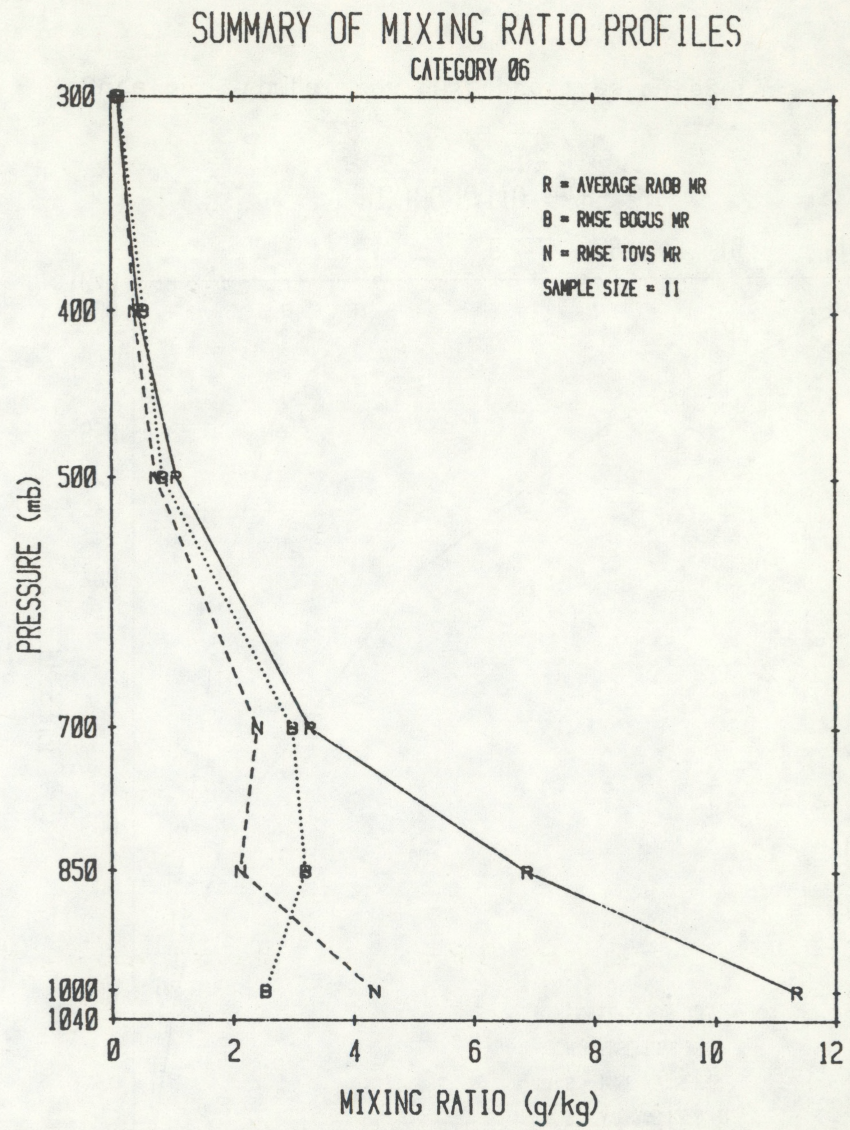

Figure 6d.--Comparison RMSE profiles Category 6

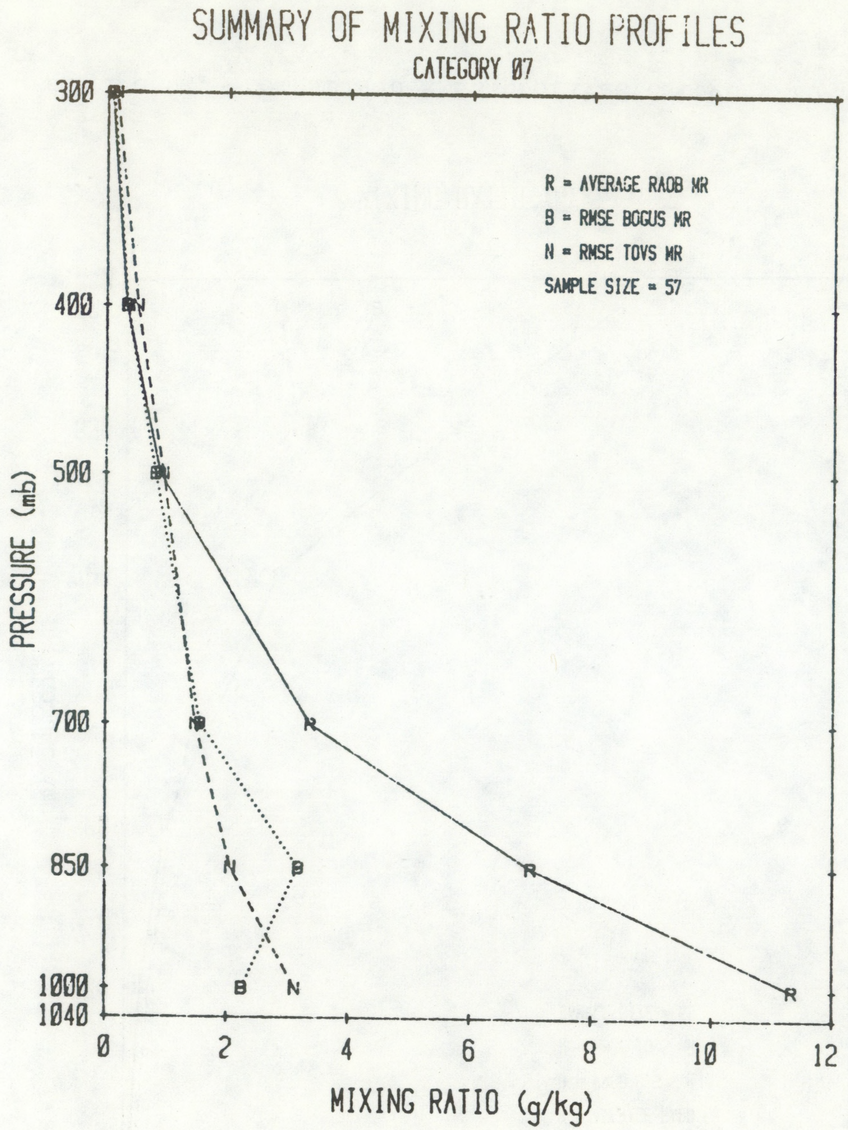

Figure 6e.--Comparison RMSE profiles Category 7

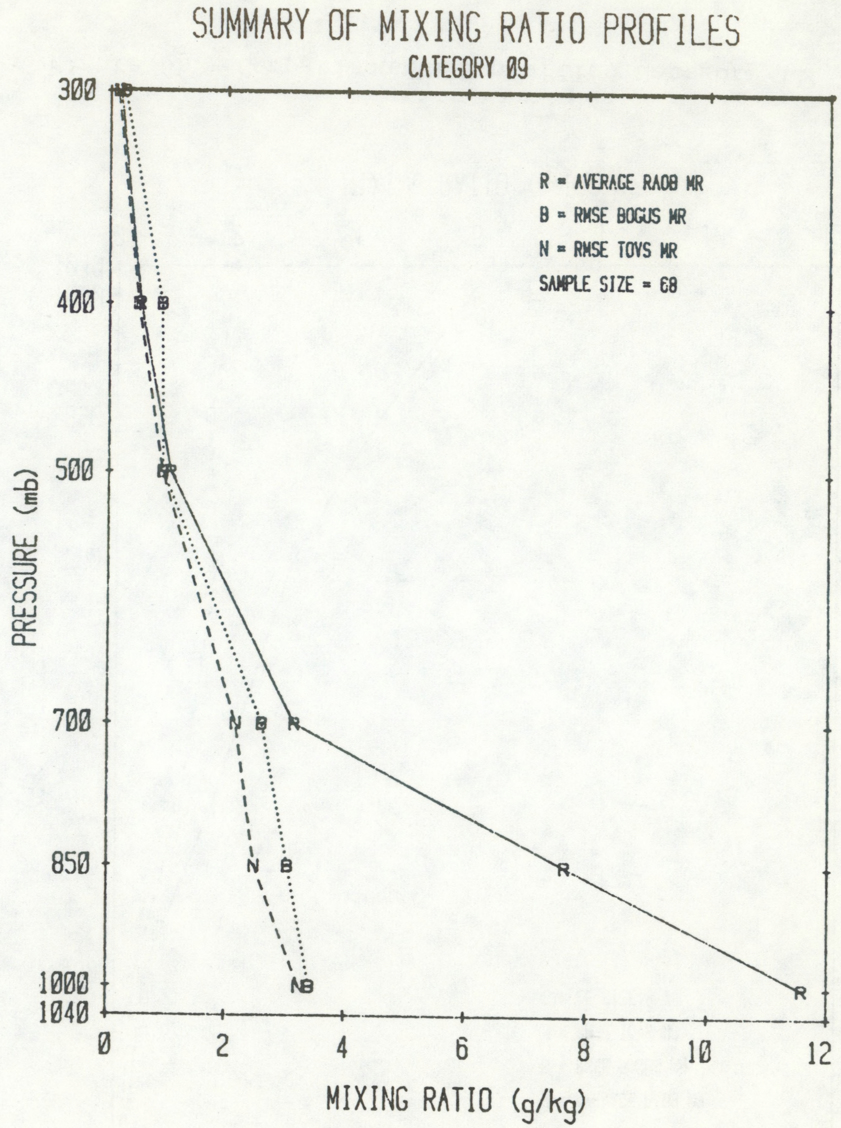

Figure 6f.--Comparison RMSE profiles Category 9

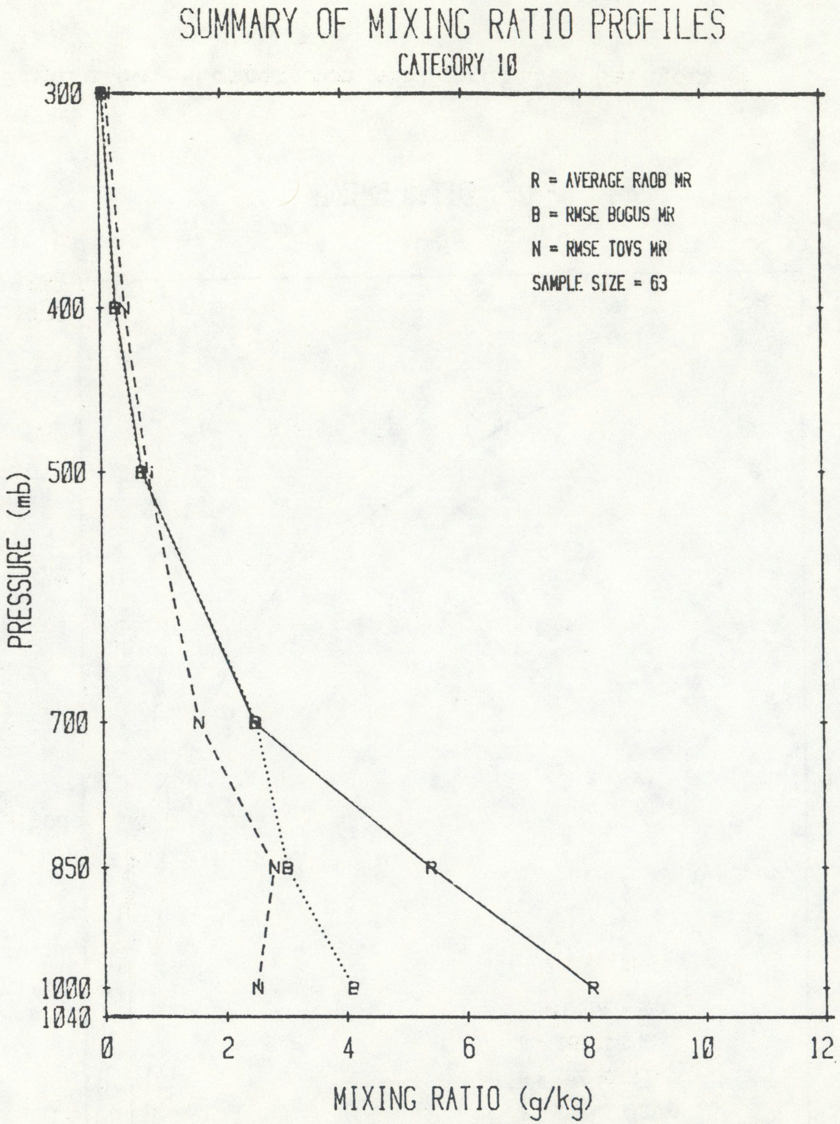

Figure 6g.--Comparison RMSE profiles Category 10

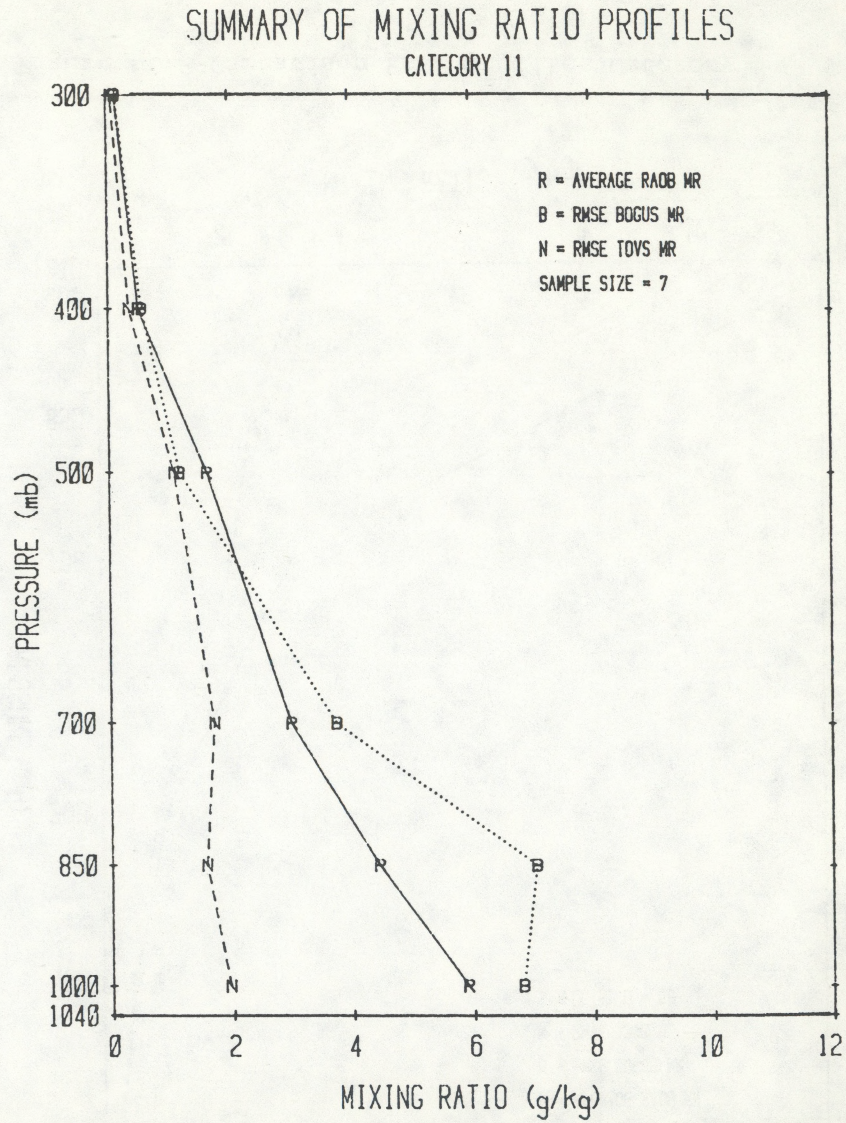

Figure 6h.--Comparison RMSE profiles Category 11

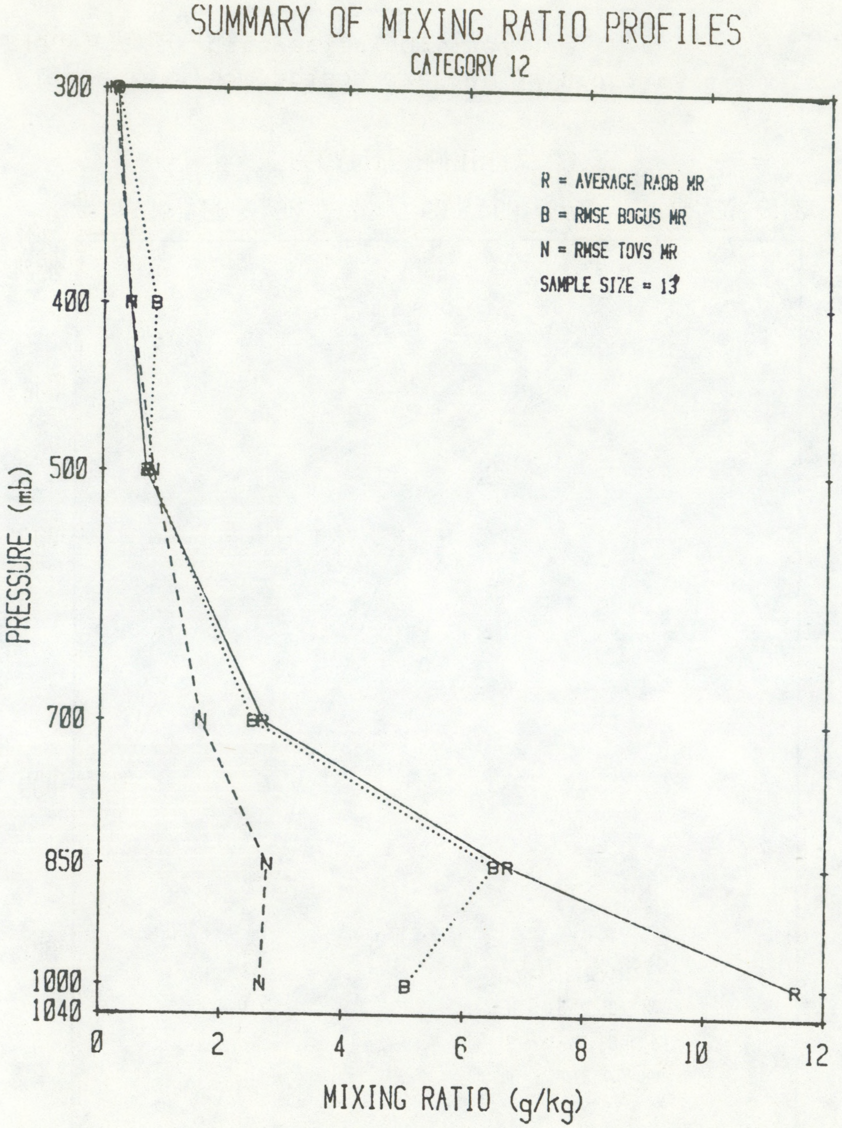

Figure 6i.--Comparison RMSE profiles Category 12

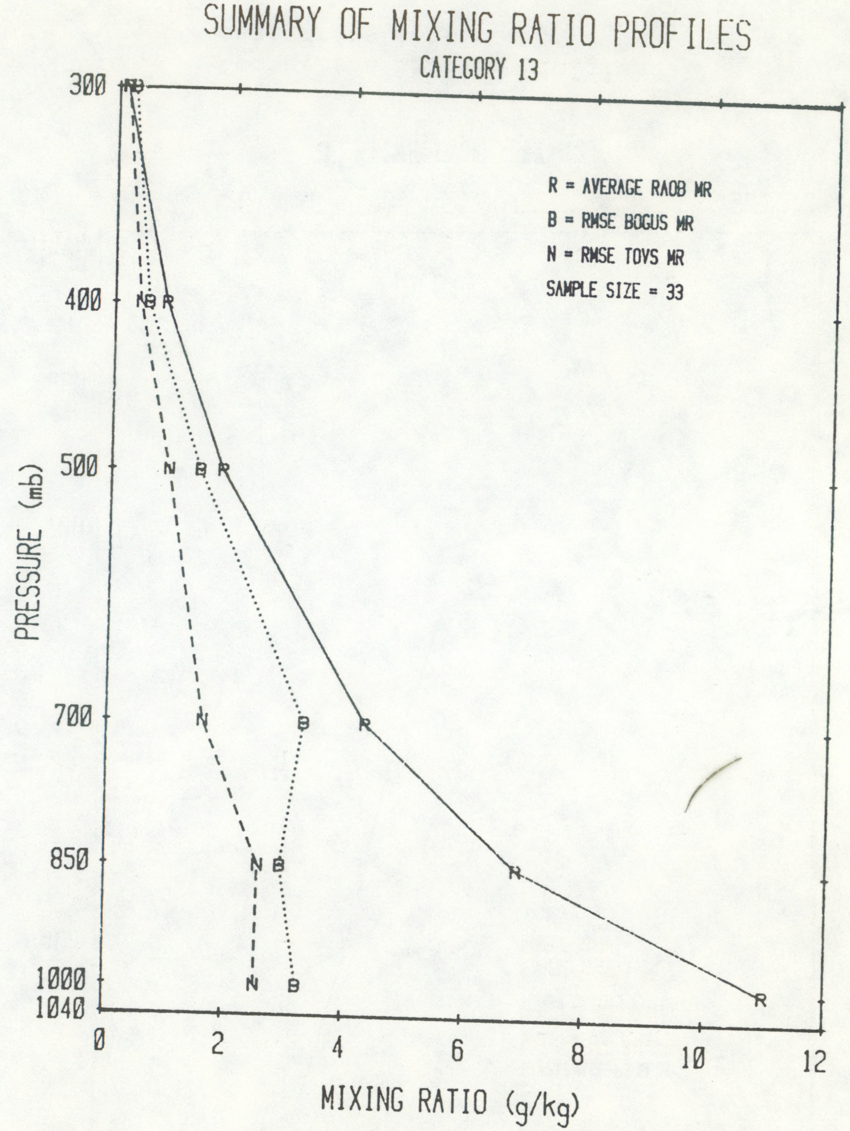

Figure 6j.--Comparison RMSE profiles Category 13

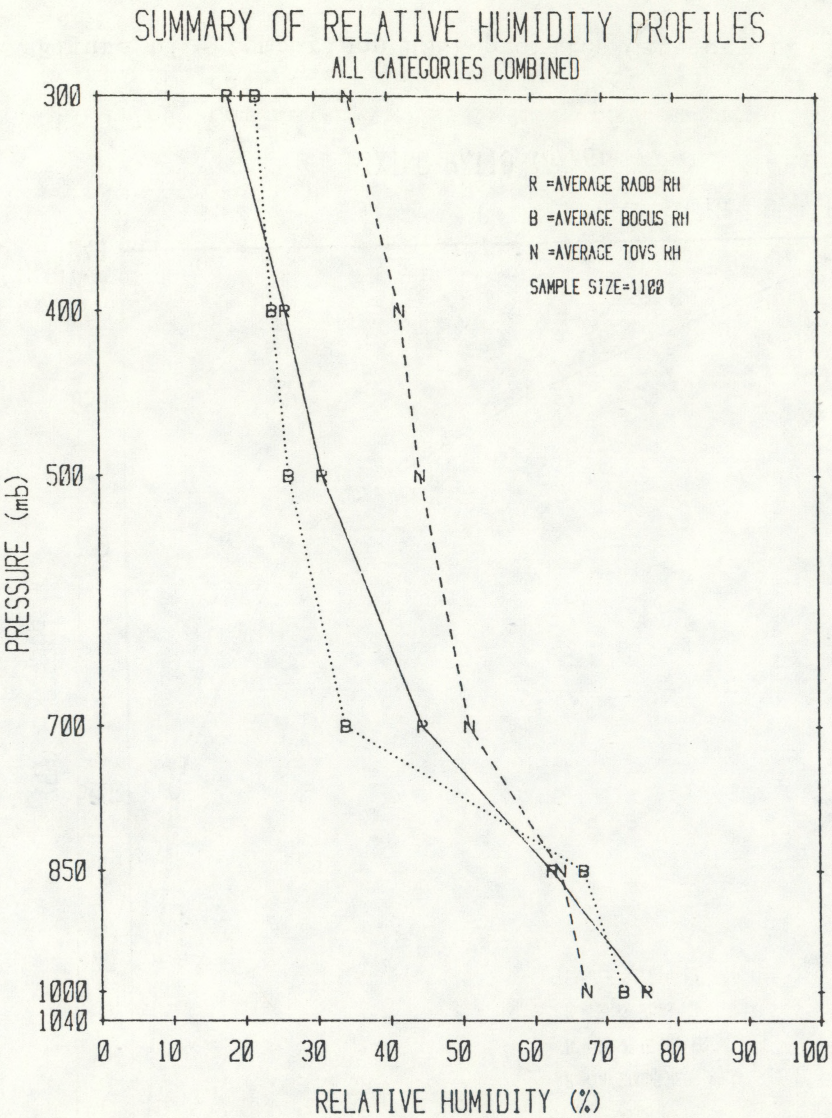

Figure 7a.--Comparison average RH profiles all categories combined

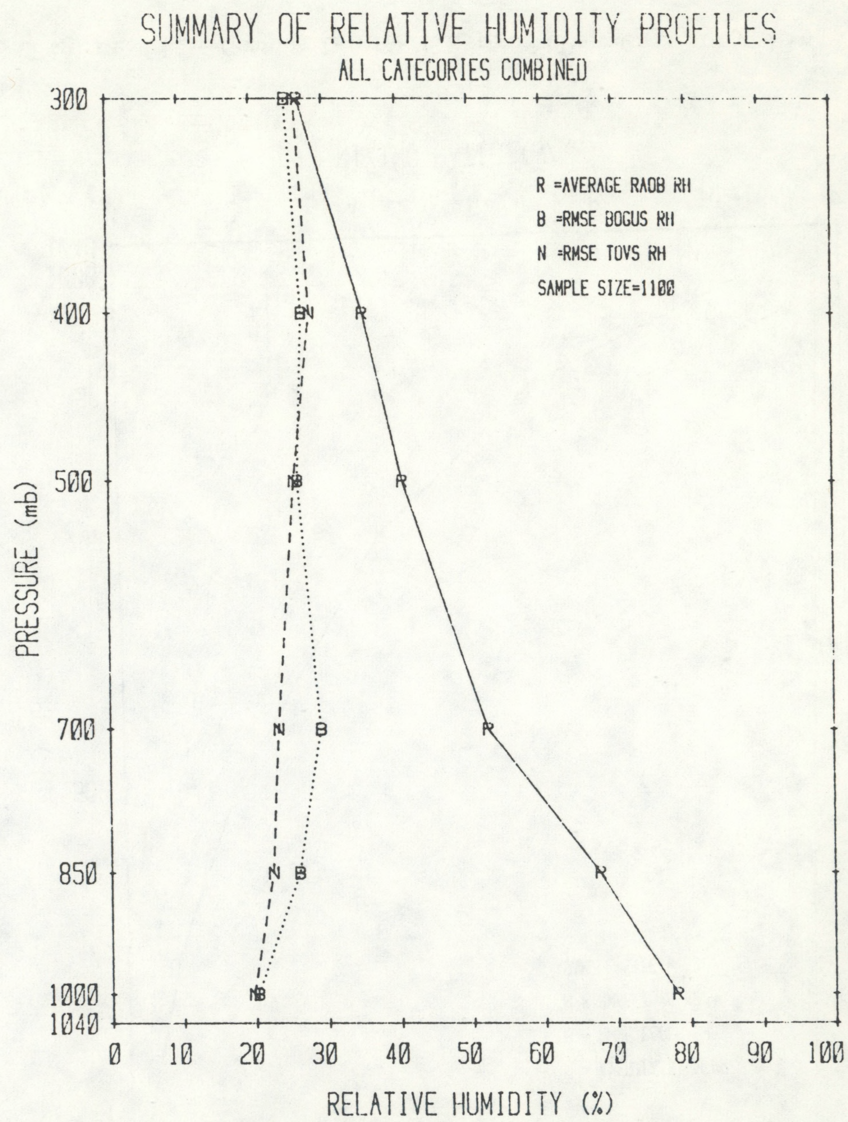

Figure 7b.--Comparison RMSE RH profiles all categories combined

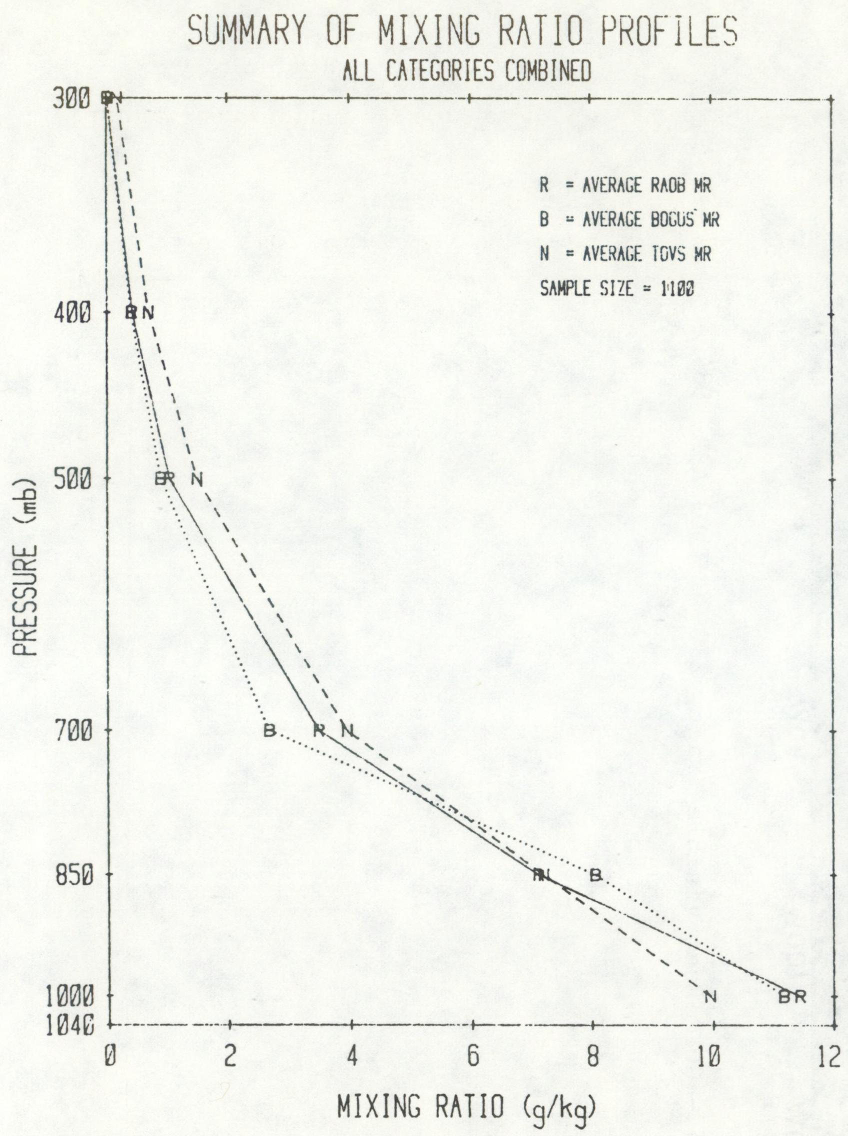

Figure 7c.--Comparison average MR profiles all categories combined

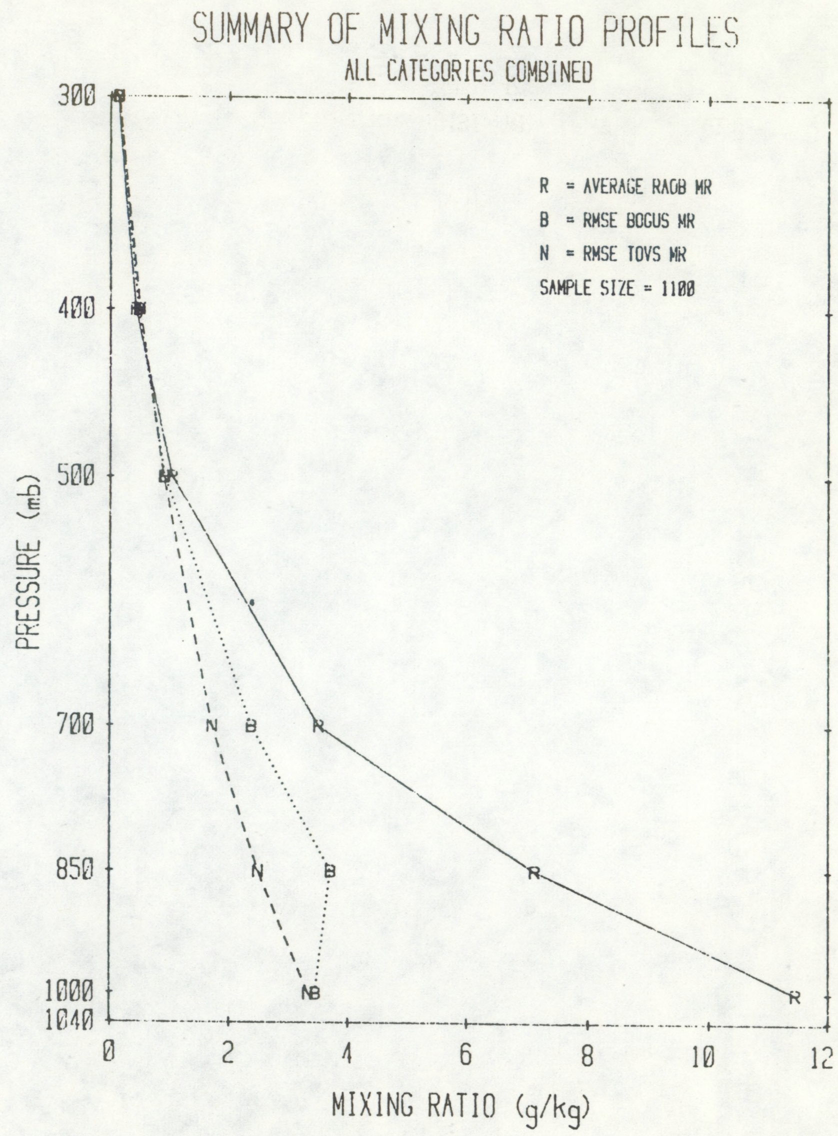

Figure 7d.--Comparison RMSE MR profiles all categories combined

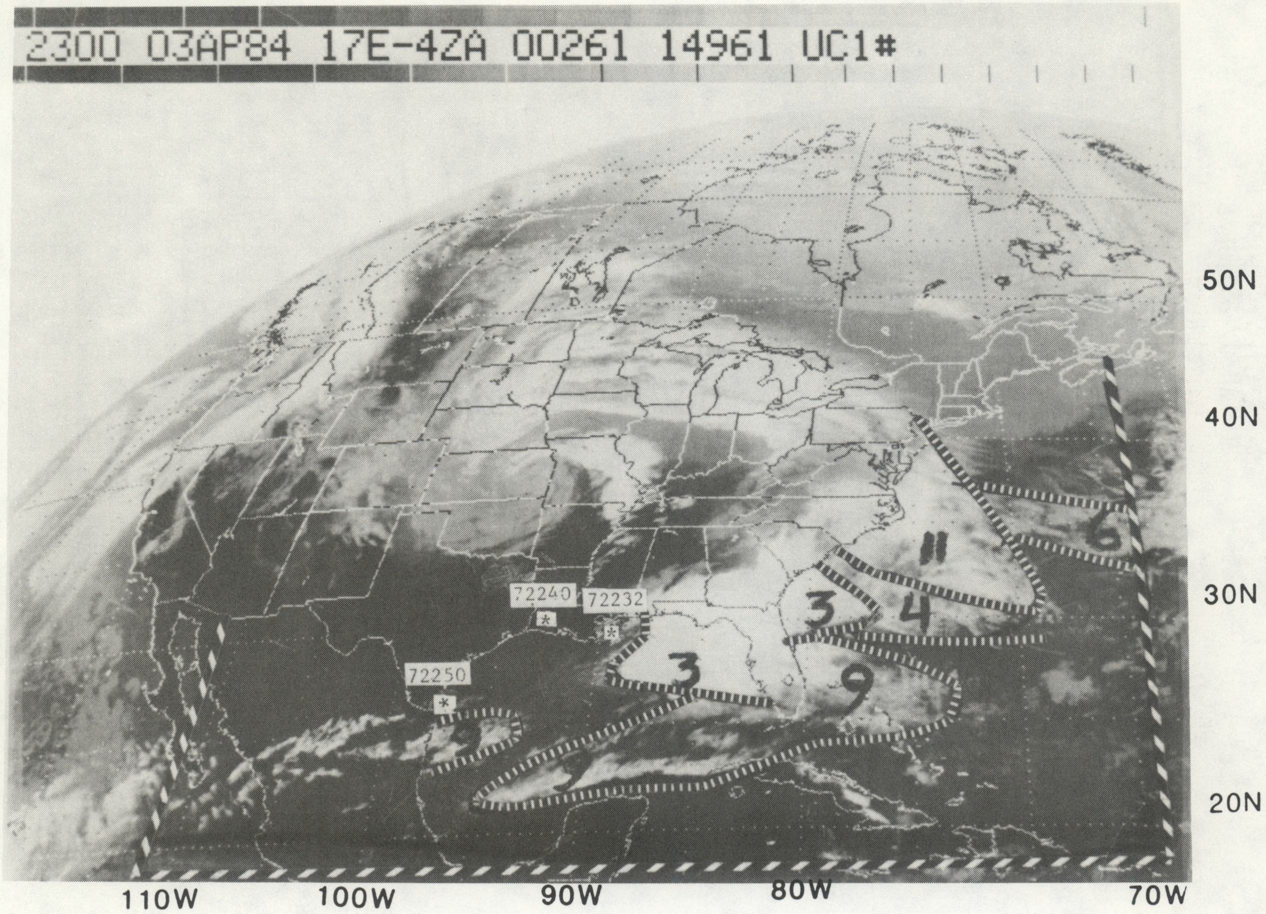

Figure 8a.--GOES East visible image, 2300 GMT 03 APR 1984

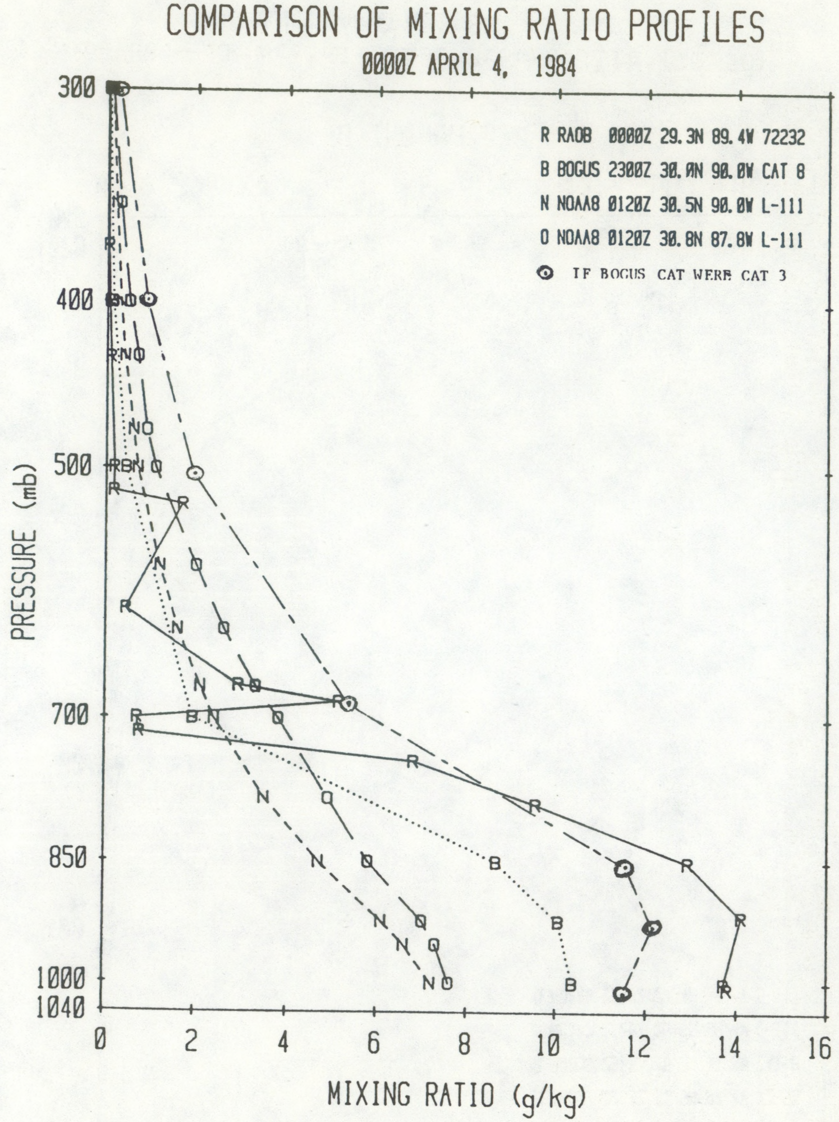

Figure 8b.--MR profiles for Boothsville (72232), 00 GMT 04 APR 1984

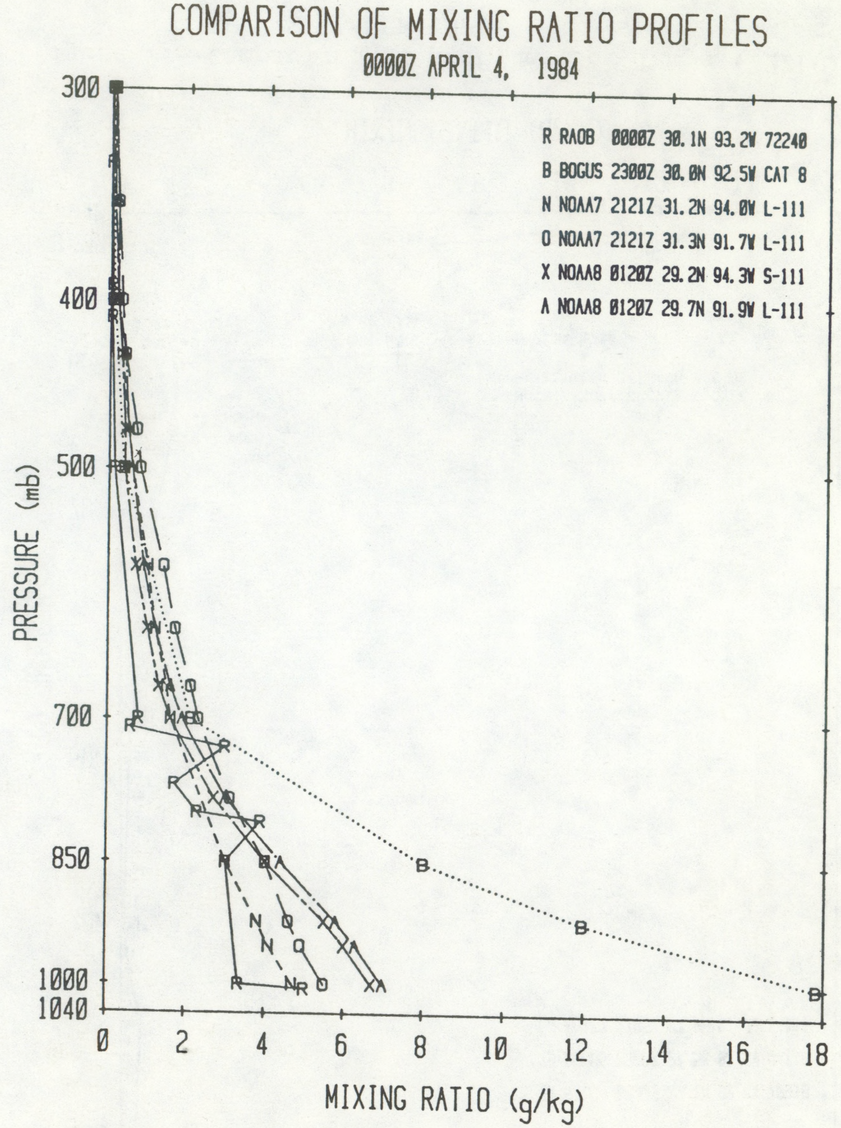

Figure 8c.--MR profiles for Lake Charles (72240), 00 GMT 04 APR 1984

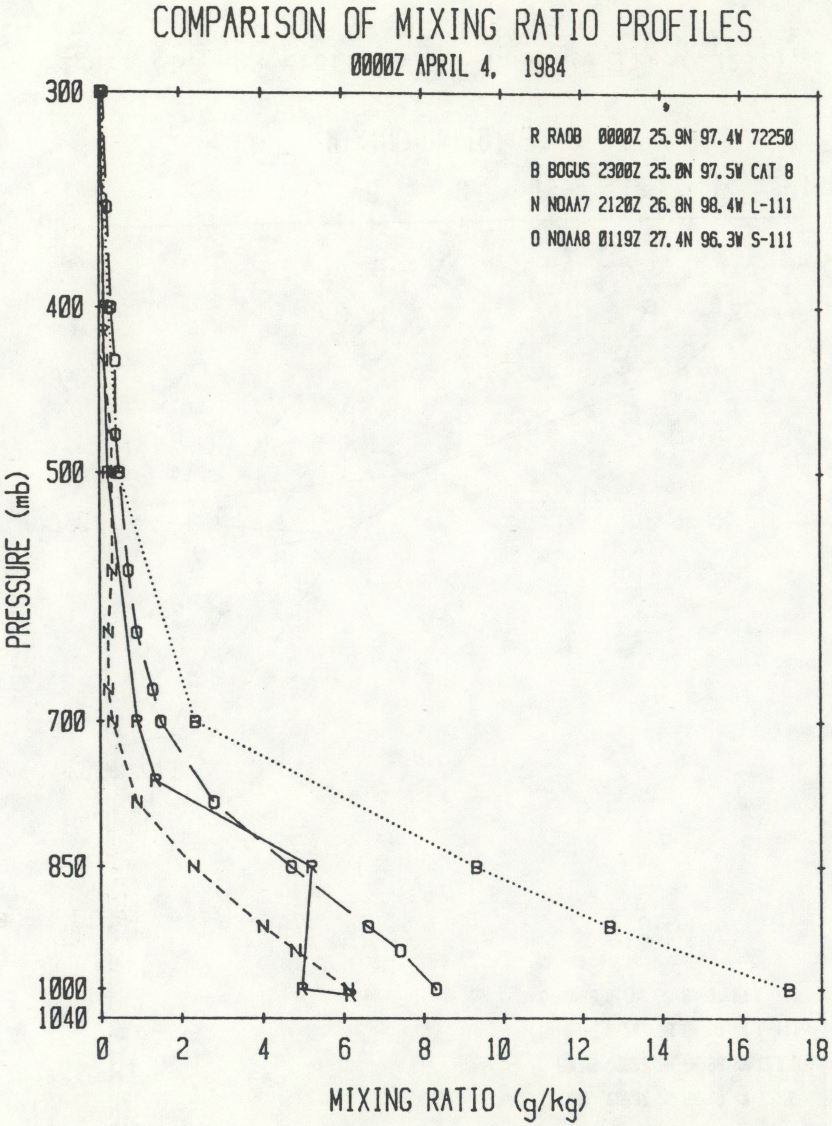

Figure 8d.--MR profiles for Brownsville (72250), 00 GMT 04 APR 1984

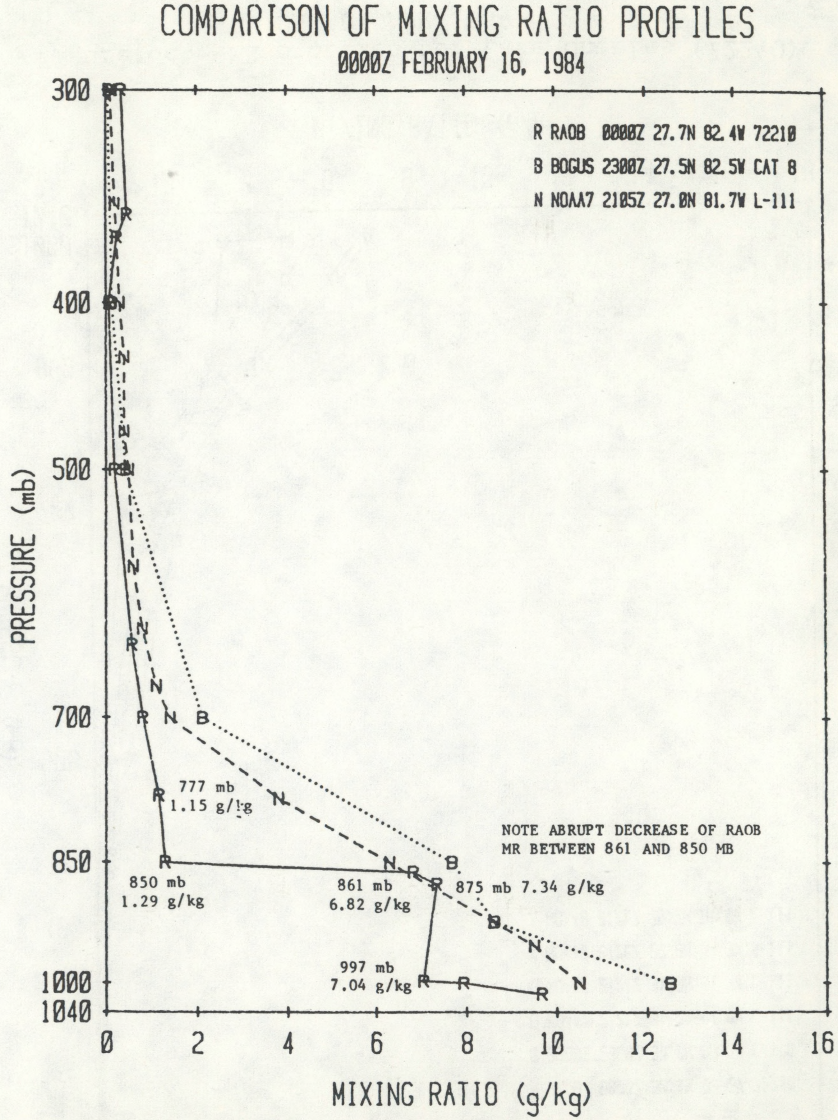

Figure 9.--Comparison MR profiles for Tampa (72210), 00 GMT 16 FEB 1984

(Continued from inside cover)

NESDIS 6 Spatial and Temporal Distribution of Northern Hemisphere Snow Cover. Burt J. Morse (NESDIS) and Chester F. Ropelewski, October 1983. (PB84 118348)

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NESDIS 10 Atlas of Reflectance Patterns for Uniform Earth and Cloud Surfaces (NIMBUS-7 ERB--61 Days). V.R. Taylor and L.L. Stowe. (PB85 12440)

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NESDIS 14 NOAA N-ROSS/ERS-1 Environmental Data Development (NNEEDD) Activity. John W. Sherman III, February 1985. (PB86 139284 A/S)

NESDIS 15 NOAA N-ROSS/ERS-1 Environmental Data Development (NNEEDD) Products and Services. Franklin E. Kniskern, February 1985. (in press)

NESDIS 16 Temporal and Spatial Analyses of Civil Marine Satellite Requirements. Nancy J. Hooper and John W. Sherman III, February 1985. (in press)

NESDIS 17 reserved

NESDIS 18 Earth Observations and The Polar Platform. John H. McElroy and Stanley R. Schneider, January 1985. (PB85 177624/AS)

NESDIS 19 The Space Station Polar Platform: Integrating Research and Operational Missions. John H. McElroy and Stanley R. Schneider, January 1985. (PB85 195279/AS)

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