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THESIS

COMPARISON OF THE NAVAL OPERATIONAL GLOBAL ATMOSPHERIC PREDICTION SYSTEM CLOUD ANALYSES AND FORECASTS WITH THE AIR FORCE REAL TIME NEPHANALYSES CLOUD MODEL

by

Gary E. Marsteller

June 1998

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REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE June 1998	3. REPORT TYPE AND DATES COVERED Master's Thesis

4. TITLE AND SUBTITLE: COMPARISON OF THE NAVAL OPRATIONAL GLOBAL ATMOSPHERIC PREDICTION SYSTEM CLOUD ANALYSES AND FORECASTS WITH THE AIR FORCE REAL TIME NEPHANALYSES CLOUD MODEL

5. FUNDING NUMBERS

6. AUTHOR:
Marsteller, Gary E.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Postgraduate School
Monterey CA 93943-5000

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(maximum 200 words)*

This thesis compares RTNEPH and NOGAPS analyses for high, middle, and low clouds during January 1998 and October 1997. We believe that the RTNEPH analyses are reasonably accurate except for in the polar regions and the low clouds. NOGAPS forecasts at 12, 24, 36, and 48h are compared with the appropriate RTNEPH analyses. The difference fields averaged over a month show a rapid increase inthe first 12 h over the forecast, followed by a slow growth to 48 h. The rapid increase is caused by model adjustment. The RTNEPH and NOGAPS (including forecasts) are separated into nine categories: clear, 0-20%, 20-40%, 40-60%, 60-80%, and 80-100%. When the clear and 0-20% categories are combined the RTNEPH and NOGAPS analyses compare well for high and middle clouds. However the RTNEPH and NOGAPS analyses are distributed differently for the other categories, and the RTNEPH has many more occurrances for the cloudiest category (80-100%). For low clouds the RTNEPH and the NOGAPS are quite different, since the RTNEPH has difficulty analyzing clouds at night. The NOGAPS and the RTNEPH (except for low clouds) generally agree on the clear areas. However, it appears that NOGAPS underestimates the number of mostly cloudy cases and the distribution of categories is different.

14. SUBJECT TERMS
Cloud cover analysis and forecast

15. NUMBER OF PAGES 105

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18 298-102

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Submitted in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE IN METEOROLOGY

from the

NAVAL POSTGRADUATE SCHOOL
June 1998

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ABSTRACT

This thesis compares RTNEPH and NOGAPS analyses for high, middle, and low clouds during January 1998 and October 1997. We believe that the RTNEPH analyses are reasonably accurate except for in the polar regions and the low clouds. NOGAPS forecasts at 12, 24, 36, and 48h are compared with the appropriate RTNEPH analyses. The difference fields averaged over a month show a rapid increase in the first 12h over the forecast, followed by a slow growth to 48h. The rapid increase is caused by model adjustment. The RTNEPH and NOGAPS (including forecasts) are separated into nine categories: clear, 0-20, 20-40, 40-60, 60-80, and 80-100. When the clear and 0-20% categories are combined the RTNEPH and NOGAPS analyses compare well for high and middle clouds. However the RTNEPH and NOGAPS analyses are distributed differently for the other categories, and the RTNEPH has many more occurrances for the cloudiest category (80-100%). For low clouds the RTNEPH and the NOGAPS are quite different, since the RTNEPH has difficulty analyzing clouds at night. The NOGAPS and the RTNEPH (except for low clouds) generally agree on the clear areas. However, it appears that NOGAPS underestimates the number of mostly cloudy cases and the distribution of categories is different.

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ACKNOWLEDGEMENT

The author would like to especially thank Dr. Tim Hogan of the Naval Research Laboratory for providing the data and carrying out mean and RMS analyses of the differences between the RTNEPH and NOGAPS fields. Mr. Robert Creasey of NPS provided critical assistance with the coding of the category and cross-correlation analyses during the last frantic weeks of the quarter. The author would also like to thank Professor Pat Harr of NPS and Major Randy Lefevre and Dr. Tom Kopp of Air Force Global Weather Central.

Advisor support for this thesis in support of the Navy Fleet Numerical Meteorology and Oceanography Command was provided by the Marine Meteorology Program of the Office of Naval Research (Dr. Scott Sandgathe).

I. INTRODUCTION

Cloudiness is an important weather parameter which is not directly predicted by most operational weather prediction models. The main forecast variables are wind, temperature, and pressure. Moisture has been added as a predictive variable in order that the latent heat of condensation can be allowed to affect the predicted temperature field. In the Navy Operational Global Atmospheric Prediction System (NOGAPS) model cloud cover is computed diagnostically at three levels. The main use of cloud cover is in computing the radiation heating in the model. The objective of this thesis is to evaluate the accuracy of the cloud cover fields produced by the current NOGAPS model. This will be accomplished by comparing it with the Air Force's Real-Time Nephanalysis (RTNEPH) model which is a cloud model whose data originates form Defense Meteorological Satellite Program (DMSP) satellites. It has some limitations which include misinterpreting low cloud amounts, especially the low stratus over snow and/or ice. This will be evident in some of our results.

Work done previously in two pilot studies (Rennick, 1990 and 1993) aided in the direction of this thesis. Time series of twice a day cloud cover data for October 1997 and January 1998 will be compared. The monthly mean cloud deviations and the root mean square (rms) differences will be examined at the three levels in the tropics, the northern mid-latitudes, and the northern polar regions. Besides the initial fields, forecast data in 12h intervals will be compared with the RTNEPH fields. These difference fields will be compared with model temperature error parameters to see if they are related.

The data will be further analyzed by placing it in one of six categories: 0, 0-20, 20-40, 40-60, 60-80, and 80-100 which represent per cent of cloudiness at each level. This will also be done for the NOGAPS monthly forecast data and compared to the RTNEPH analysis. The two data sets will be cross-correlated. This will allow us to see how the NOGAPS forecasts or analyses are spread to other categories for a given RTNEPH observed category.

Cloud cover is an important parameter to any weather prediction model or process. We hope to find information about NOGAPS that will give better insight to how well clouds are predicted and how the prediction can be improved. The end result may be another step in the continuous improvement process for weather prediction and operational forecasting.

II. MODEL DESCRIPTIONS

A. NAVY OPERATIONAL GLOBAL ATMOSPHERIC PREDICTION SYSTEM

1. General Description

According to Baylor and Lewit (1992), NOGAPS is a global spectral model of 159 spectral waves which include 18 vertical levels to 10 mb. The vertical coordinate structure follows the terrain at the lower levels. The model physics include long- and short-wave radiation, boundary layer processes, and stable and convective cloud and precipitation parameterizations. The NOGAPS output fields and the quality controlled observations are used as final products and are input into other Fleet Numerical Meteorological Oceanography Center (FNMOC) models. The operational schedule is divided into two 12 hour watches (00z and 12z) that correspond to the synoptic time scale of worldwide meteorological observations.

NOGAPS generates 60 types of output fields for every forecast hour. Listed in Table 2.1 are these output fields.

Table 2.1. Summary of NOGAPS output fields.

clouds, convective	omega
clouds, stable	precipitation, convective
clouds, total	precipitation, large scale
cloud cover, high	precipitation, total
cloud cover, middle	pressure, sea level
cloud cover, low	pressure, sea level 3h tendency
cloud cover, total	pressure, terrain
dewpoint depression	radiation, solar top
drag, surface	radiation, long-range top
energy, PBL static	roughness, surface
flux, cumulative mass	sea-ice concentration
flux, solar radiant heat	snow depth
flux, surface buoyancy	stream function
flux, surface heat	stress, surface
flux, surface moisture	temperature
flux, surface IR radiant	temperature, ground
flux, surface sensible and latent heat	temperature, 2-m
flux, total surface heat	terrain, d-value
geopotential heights	terrain height
heat, latent	u,v wind components
heating, cumulus	u,v wind components, boundary layer
heating, diabatic	u,v wind components neutral stability
heating, radiant	vapor pressure
humidity, relative	vapor pressure, 2-m
isotachs	velocity potential
lifting condensation level	vorticity
moisture function: [sqrt(1-RH)]	wetness, ground

2. Cloud Cover Fields

The cloud cover fields are grouped into high, middle, and low levels and the total cloud cover. The total is computed using the dew point depression at 850, 700, and 500 mb. Cloud computations are made by NOGAPS due to each of the stable and convective clouds at each sigma level. According to Rennick (1990), the stable cloud cover fraction is based on the proximity of relative humidity to a critical value for that level. The non-stratus/stable field depends on relative humidity, where 80 per cent is the starting threshold. The stratus/stable depends on vertical motion, the lapse rate, and relative humidity with values above 60 per cent. The convective cloud cover fraction is computed by the cumulus parameterization section of the model. It depends on the amount of cumulus precipitation that reaches the ground. The top and bottom layers depend on the mass flux from the Arakawa-Schubert parameterization (Slingo, 1987). The combined cloud fraction is computed using the assumption that clouds of two types are randomly correlated to each other. The cloud cover field is then interpolated to 21 standard output pressure levels of the model. The standard pressure level cloud cover fields are then combined to produce fields for high, middle, and low levels of the atmosphere along with a total field for the whole atmosphere.

B. AIR FORCE REAL-TIME NEPHANALYSIS MODEL

1. Introduction

The RTNEPH is a cloud model generated at the Air Force Weather Agency (AFWA) at Offutt AFB, NE. The data originate from DMSP satellites. Both conventional cloud observations and NOAA polar-orbiting data are used. The data are archived in a polar-stereographic database at 25 nm resolution at 60 degrees north and south latitude as total and layered cloud amounts, cloud bases and tops, and cloud types.

One purpose of the RTNEPH is the initialization of trajectory-based cloud forecast models run at AFGWC (Crum, 1987). These models are used to produce aviation forecasts. The RTNEPH also is used to verify these cloud forecasts.

2. Design

According to Hamill et al. (1992), the RTNEPH processes visible (VIS) and infra-red (IR) imagery separately. It is designed to maximize its cloud detection. If both conventional and satellite data are available, the RTNEPH chooses the cloudiest one.

The RTNEPH processes in two modes: limited-area mode and synoptic mode. In the limited area mode, data is provided by new polar-orbiting satellite imagery. The steps in this mode are as follows: First is a mapping of the new data to the Satellite Global Database (SGDB) at 6 km resolution. New imagery data is then pulled out and processed by the satellite data processor into a 48 km resolution polar-stereographic satellite analysis. Then the merge processor combines the analysis with the surface data analyses from each hour through the conventional data processor. The synthesized nephanalysis is stored in the RTNEPH database. Operational forecasters quality control the new nephanalysis database and assimilate it into the final nephanalysis. Data from this analysis are used in this thesis.

In the synoptic mode, a world-wide domain is analyzed every three hours at a time the is 1.5h after the "data time" (1330z for 1200z). The time delay allows for assimilation of as many conventional cloud observations as possible into the nephanalysis. This more describes the cloud conditions. The synoptic RTNEPH is used to initialize hemispheric cloud forecast models and goes to outside users (NOAA, NESDIS, etc.). The merge processor combines the satellite and new surface data. The output is not quality controlled.

3. Limitations

The new RTNEPH database goes to the Air Force Combat Climatology Center (AFCCC) every three hours. Only the conventional observations are valid at the synoptic time. The rest are satellite derived, so they are rarely valid at the synoptic time. They are constrained by the time of the polar-orbiter passes.

a. Cloud Amount Problems

As seen in Hamill (1992), the RTNEPH relies mostly on IR-derived nephanalysis, thus making it vulnerable to misinterpretation of low cloud amounts. Many low clouds go undetected, especially the stratus associated with inversions in the lower troposphere that occur during night time or over snow and/or ice. It may also misanalyze the cloud tops as AFWA's surface temperature model is not perfect. Land rms errors of 3-4 degrees K can occur in estimating the true IR clear-column temperature. This leads to errors in determining cloud/no-cloud temperature threshold which causes over- or under-analysis of cloud amount. It also over-analyzes clear or totally cloudy conditions while it under-analyzes the extent of partly cloudy conditions. It has difficulty representing layered amounts. There is no way of detecting low- and mid-level clouds when an obscuring high-level deck exists, unless it is supplemented by a conventional observation. The RTNEPH also has problems in the polar regions.

b. Cloud Height Problems

Problems in determining cloud heights have not been extensively studied. The RTNEPH under-analyzes the frequency of thin clouds (especially cirrus) and places these clouds lower than they should be.

c. Cloud Typing Problems

These problems are based on two criteria: cloud height and pixel grayshade variance within a layer cloud grayshade interval. The typing method only distinguishes between cumuliform and stratiform clouds. Cirriform and mid-level clouds get incorrectly typed as lower clouds. This is from the assumption that cloud emissivity is equal to 1.0. There is also an over-abundance of cumulonimbus clouds. This results from a low height threshold for cumulonimbus in the satellite data processor (NEFSAT), which is the satellite cloud-detection algorithm that produces separate analyses of VIS and IR imagery.

d. Conclusions

In general we feel that the RTNEPH analyses will provide an excellent test of NOGAPS cloud analyses and forecasts outside of polar regions and above the low cloud region. An important point is the quality control of RTNEPH analyses by operational forecasters.

III. METHODOLOGY

A. STATISTICAL ANALYSIS OF NOGAPS CLOUD FIELDS WITH RTNEPH ANALYSIS

For this process we looked at NOGAPS cloud fields from 1 Oct 97 - 31 Jan 98 and compared them with the RTNEPH analyses. All the data were averaged into 1 degree by 1 degree areas before they were compared. A few data points were missing from each set of RTNEPH cloud fields and the corresponding data point from the NOGAPS data then was removed. The cloud fields were low, middle, and high. These levels are defined as follows: Low clouds are those clouds with tops below 2000 meters. Middle clouds are those clouds with tops above 2000 meters and below 7200 meters. High clouds are those clouds with tops above 7200 meters. The cloud deviations examined were mean error, rms error, standard error, and RTNEPH value. We also specifically examined the NOGAPS height (500 mb) and temperature (250 mb) statistics to look for possible error correlations. We compared NOGAPS analyses along with 12h, 24h, 36h, and 48h forecasts with the corresponding RTNEPH analyses.

Initially we looked at the following areas: tropics (20S to 20N), northern mid-latitudes (20N to 60N), northern polar region (60N to 90N), and northern hemisphere (20N to 80N). Next we examined some smaller regions: Central Tropical Pacific (0N to 20N, 180W to 150W) and Western United States (35N to 50N, 130W to 112.5W).

We then focused on the monthly mean deviations for October 1997 and January 1998. A discussion of these results including figures can be found in Chapter IV. Similarly, we computed the monthly rms deviations for October 1997 and January 1998. Again, these results can be found in Chapter IV. For the monthly averages, the focus was on the following regions described above: tropics, northern mid-latitudes, northern polar, and northern hemisphere.

B. CROSS-CORRELATION OF NOGAPS AND RTNEPH FIELDS

Cross-correlations of NOGAPS and RTNEPH fields were obtained in order to gain a better comparison of the two fields. We first took the NOGAPS fields from January 1998 and placed the cloud data into "bins" of data. These bins represented per cent of cloudiness for each level: low, middle, and high. The percentages used first were set up as follows: 0-20, 20-40, 40-60, 60-80, and 80-100. This was similarly accomplished for the RTNEPH cloud fields. Due to the results of the initial run, a separate "0 bin" was introduced into the program.

Next a cross-correlation routine was accomplished on both data sets in order to determine how well they correlated with each other. The RTNEPH analysis fields were first matched with the NOGAPS analysis fields. Then the RTNEPH fields were matched with the corresponding NOGAPS forecast fields based on valid times. A discussion of our findings along with charts and graphs can be found in Chapter IV.

IV. RESULTS

The various comparisons between the RTNEPH cloud analyses and NOGAPS analyses and predictions will be presented in this chapter. These comparisons will be used to evaluate the NOGAPS cloudiness fields for middle and higher clouds outside of the polar regions.

A. STATISTICAL ANALYSIS OF NOGAPS CLOUD FIELDS

1. Mean Cloud Deviations

In this section each figure contains a monthly time series which includes data every 12h. The initial field and the 12h, 24h, 36h, and 48h forecasts are examined. We first look at the mean cloud cover difference between NOGAPS analyses and forecasts and RTNEPH analyses for January 1998 in the northern mid-latitudes region (20N to 60N latitude). Figure 4.1 shows the 00h analysis for the high cloud mean difference for the month of January. In the figure the values are generally between -2 and 6. A few of the data points have been removed and replaced with straight line segments. These represented values that were obviously in error. These values were removed from all subsequent time series and the mean data reflects their removal. The mean values were derived by subtracting RTNEPH values from NOGAPS, so a positive value means NOGAPS has a higher percentage of cloud cover value than the RTNEPH. Later in this chapter we will discuss monthly mean values for each forecast time for various regions. The values of the time series seem to oscillate with a high frequency; however, the magnitude of deviation of high cloudiness between NOGAPS and RTNEPH is small.

Figures 4.2-4.5 give the 12h, 24h, 36h, and 48h NOGAPS forecast monthly high cloud mean differences from RTNEPH for the same month and region as seen in Figure 4.1. The top of each figure also includes the 250mb mean temperature errors from the model in order to see if they are correlated with the mean cloud differences. Examination of these sequences does not show any significant correlations between the two. The 12h values range between 7 and 15; these values show larger deviations than for 00h. Beyond 12h the values increase slowly up to 48 h. Note that the deviations at the various times are correlated. This is not surprising since they are related through the forecast process. The amount of NOGAPS forecast high cloudiness increases during the forecast compared to the RTNEPH analysis. Figures 4.6 and 4.7 give the middle and low cloud mean differences respectively at 00h. Figure 4.6 shows that NOGAPS has considerably less cloud cover than RTNEPH in the middle layer, and Figure 4.7 shows that NOGAPS has more cloud cover than RTNEPH in the lower layer.

Figures 4.8, 4.9, and 4.10 give the high, middle, and low cloud mean differences respectively at 00h for the tropics (20S to 20N). Note that low and middle clouds have smaller deviations, but the relations are similar to the northern mid-latitudes. Figures 4.11, 4.12, and 4.13 give the same mean cloud information for the northern polar region (60N to 90N). The middle cloud deviations are of opposite sign (i.e. positive) compared with the other regions.

Much of this data can be conveniently summarized by comparing monthly mean values. Each figure includes the averaged cloud differences for the following regions: tropics, northern mid-latitudes, polar, and northern hemisphere as a function of forecast period.

Figure 4.14 shows the mean high cloud deviation versus the forecast time period for January 1998. One notable item is that the polar region does not experience a 12h increase (the increase will be seen in the October data). Another notable feature is a steady increase over the first 12h for the other three regions. This is a consistent feature that will be seen in the other figures.

Figure 4.15 details the mean middle cloud deviation versus the forecast time period for January 1998. The tropics deviation tends to decrease for the middle clouds. The largest deviation can be seen in the polar region. This will also be seen in the later October 1997 figure. NOGAPS tends to under-forecast middle clouds (except in the polar region) over the 48h when compared to the RTNEPH. Figure 4.16 shows the mean low cloud deviation versus the forecast time period for January 1998. The largest deviation can be seen in the northern polar region. This is consistent with the RTNEPH being less accurate with low clouds over ice surfaces as mentioned in Chapter II.

Figure 4.17 shows the mean high cloud deviation versus the forecast time period now for October 1997. NOGAPS seems to forecast higher cloud amounts in the tropics than in the other regions. After the first 12h, the polar region has the lowest mean cloud deviation. Figure 4.18 shows the mean middle cloud deviation versus the forecast time for October 1997. This figure shows similar results to what were seen in January, except that the overall deviations for the northern polar region are smaller. Figure 4.19 shows the mean low cloud deviation versus the forecast time for October 1997. The results detailed in the figure are also very similar to those observed in January.

In general, the following results were found dealing with the monthly mean cloud deviation:

- Monthly mean cloud deviations tend to have the largest increase occurring in the first 12h followed by a slow increase out to 48h.
- The increase seen in the first 12h is apparently due to model adjustment.
- Low and middle monthly mean cloud deviations are highest in the polar region.
- NOGAPS tends to under-forecast monthly middle cloud amounts except in the polar region.
- The tropics tend to have the highest monthly high cloud deviations.
- The monthly mean middle cloud differences in the tropics tend to decrease slightly over the 48h period.
- The tropics tend to have the lowest monthly low cloud mean deviations.

These results suggest that NOGAPS produces too much mean high cloudiness with most of the excess developing in the first 12 h. For the middle clouds NOGAPS generates too small a mean cloud cover, but it improves during the forecast.

2. RMS Cloud Deviations

After examining the monthly mean cloud deviations for January 1998 and October 1997, we did the same procedure on the root mean square (rms) cloud deviation. The rms allows for a more accurate representation since positive and negative deviations are not able to cancel each other out as in the mean deviations. In Figure 4.20 we see the rms deviation for high clouds for January 1998. A steady increase for the rms high cloud deviation for all four regions is present. The tropics have the highest values. Figure 4.21 shows rms middle cloud deviation versus forecast period for January also. It seems to be more grouped together by region. There is not as much difference between the four regions as there is in the other cases. Figure 4.22 shows the polar region having the highest rms low cloud deviations. There is an increase in the first 12h as seen in the mean cloud deviation cases. Figure 4.23 shows rms high cloud deviation over the forecast time for October 1997. One feature that stands out is the overall decrease in the first 12h except in the northern polar region. Here the tropics have the highest deviation values as seen in the mean high cloud deviations for October. Figure 4.24 shows the rms middle cloud deviation over the forecast time for October 1997. Three of the regions decrease over the first 12h. Only the tropics remain steady throughout. In Figure 4.25, the item that stands out is how the rms low cloud deviation decreases over the first 12h for all regions. After that, the values seem to hold fairly steady.

In general, the following results were found for the rms cloud deviation over 48h:

- The steady mean cloud deviation increase over the first 12h for nearly all regions in both months was not as large in the rms cloud deviation cases.
- The rms cloud deviations exhibited less increase or decrease than did the mean cloud deviations (they were more steady).
- In October 1997, the rms cloud deviations decrease over the first 12h and then are fairly steady while the January 1998 behavior is the opposite.
- The rms low cloud deviation is largest on the polar region for both months examined.
- The rms high cloud deviation is largest in the tropics for both months as was the mean cloud deviation.

The RMS analysis suggests that the NOGAPS clouds have a larger error for middle clouds than for high clouds although the average cloud cover error is less for the middle clouds. Apparently there are more middle clouds, but NOGAPS does not position them accurately.

B. SEPARATION OF DATA INTO CLOUD CATEGORIES AND CROSS-CORRELATION

1. Occurrences of Cloudiness at Various Levels

We begin the separation into cloud categories with high clouds for the northern mid-latitudes for the month of January 1998. The results can be seen in the histogram from Figure 4.26. The most notable item is the high number of clear or zero cloud occurrences in the RTNEPH data. This feature is evident in all regions, especially at the high and low cloud levels. Other percentage categories for the RTNEPH and NOGAPS are small. The pattern is concave for the RTNEPH with a peak at each end. The NOGAPS data has a lower maximum in the zero cloud cover bin and it decreases steadily as the cloud cover increases. Note that if categories zero and 0-20% are added, the NOGAPS is closer to the RTNEPH. It can be seen that total cloudiness from NOGAPS is greater than RTNEPH in agreement with Figure 4.14 (The total cover can be calculated approximately by adding the product of each cloud cover with its category amount). The middle clouds seem to be a bit more evenly distributed as seen in Figure 4.27. The zero category is still high (nearly 50 per cent) for the RTNEPH but not as much as the high and low cloud amounts. The 80-100% category is also higher than the middle ones. The difference in NOGAPS analyses is that it starts high at 0% cloud cover and drops off steadily as the cloud cover increases. In this case it can be seen that the average cloudiness is less for NOGAPS than RTNEPH in agreement with Figure 4.15. As mentioned above NOGAPS has a larger RMS error for middle clouds than for high clouds. This difference is partly caused by lower amounts in the categories. Figure 4.28, shows a very different RTNEPH pattern compared with the NOGAPS pattern. In this case the NOGAPS data is likely to be more accurate than the RTENPH data. In particular the large clear category is a result of the difficulty RTNEPH has with low clouds at night.

Moving on to the 12h forecast histograms in Figures 4.29, 4.30, and 4.31, we see similar results as those in the analysis histograms. One notable item is that the zero category for the high clouds increases over the 12h as seen in Figure 4.29, but there is also an increase in the 80-100% category. This gives the profile a slightly concave shape while also increasing the mean value. Another result is that the middle cloud amounts for the zero and 0-20% categories decrease a bit, but the 80-100% increases. Here the mean cloud cover increases which decreases its error (Figures 4.15 and 4.21). The low level clouds keep the same shape, but the values increase the mean cover which increases its difference from RTNEPH. Of course there is no change to the RTNEPH as it is the same as it was in the analysis histogram.

Looking at the 24h forecast for NOGAPS we see similar shapes of the histogram pattern along with similar values for the number of occurrences for each cloudiness category. This can be seen in Figures 4.32, 4.33, and 4.34. The 36h and 48h forecasts (not shown) were nearly identical to the 24h.

The next area studied was the tropics, where the high, middle, and low cloudiness is examined for January 1998. Looking at the high clouds analysis, Figure 4.35, the shape of the histograms for NOGAPS and RTNEPH is similar to the northern mid-latitudes case from earlier. There are higher percentages of high cloudiness in NOGAPS in the tropics than in mid-latitudes. The middle and high cloud histograms seen in Figures 4.36 and 4.37 are more similar to the mid-latitudes results (Figures 4.27 and 4.28). One notable difference is that the high cloud cloudiness occurrences for NOGAPS is higher for the 40-60% and the 60-80% categories as seen in Figure 4.35. A difference in the RTNEPH histograms is that the middle cloud 80-100% cloudiness occurrences seem to be lower in the tropics than in the northern mid-latitudes as seen in Figure 4.27. Another difference is that the values for the NOGAPS low clouds are larger in the tropics in the 0-20%, 20-40%, and the 40-60% categories than in the northern mid-latitudes as seen in Figure 4.37.

The 12h forecast histograms in the tropics (Figures 4.38, 4.39, and 4.40) show similar patterns and cloudiness values as the analysis values shown in Figures 4.35, 4.36, and 4.37. The 24h forecast is almost identical to the 12h forecast as seen in Figures 4.41, 4.42, and 4.43. There is almost no deviation in pattern or cloudiness category occurrences. This is consistent with the small changes in Figures 4.14, 4.15, and 4.16.

We next moved on to the northern polar case for the high, middle, and low clouds. In Figure 4.44, the high clouds zero category value is large for NOGAPS and then steadily decreases as the cloudiness category increases. The RTNEPH pattern is similar to the other patterns at lower latitudes. For the middle cloud histogram shown in Figure 4.45, the NOGAPS has a weak maximum at the zero category and decreases steadily as the cloudiness category increases. The RTNEPH pattern is not much different from the high cloud pattern. The notable difference is that the zero category is slightly smaller, but still greater than 65 while the 80-100% category is higher than the high cloud amount. The low clouds for NOGAPS as seen in Figure 4.46 are infrequently in the zero category and steadily increase in occurrences as the cloudiness category is increases. They reach a maximum of 40 at the 80-100% category. Again the RTNEPH which has over 80% clear cases is very likely in error.

Moving on to the 12h forecast from Figures 4.47, 4.48, and 4.49, we see a similar histogram pattern for NOGAPS and RTNEPH as we saw with the analysis. While the NOGAPS pattern is the same, most of the cloudiness category occurrences are larger depicting an increase in forecast cloudiness in the first 12h. This is consistent with the mean cloud cover differences we saw in the northern polar region from Figures 4.14, 4.15, and 4.16 along with the rms cloud deviation from Figures 4.20, 4.21, an 4.22. The only significant change in the NOGAPS is an overall increase of the 80-100% cloudiness category occurrence for low and middle clouds.

The 24h forecast histogram pattern for NOGAPS is similar to the 12h for high, middle, and low clouds. This can be seen in Figures 4.50, 4.51, and 4.52. There is no significant change in any of the NOGAPS cloudiness occurrences, except for the continuing increases in the 80-100% category.

From this we can conclude that the northern polar region is not too different from the northern mid-latitudes except for the low clouds. The most significant increase for NOGAPS is in the first 12h.

Next we examined at two smaller sub-regions: The central tropical Pacific and the western United States. In these two cases we see more variation as the regions are much smaller than those examined earlier. Looking first at the central tropical Pacific region, Figure 4.53 shows that NOGAPS and RTNEPH seem to follow a similar pattern for the high clouds. The RTNEPH zero cloudiness category is quite high (greater than 85) and the NOGAPS is not too far behind. Both take a large drop off as the cloudiness category increases continuing through the 80-100% category. In the middle cloud analysis NOGAPS still has a high frequency of clear areas. It is nearly the same as the RTNEPH typical value as seen in Figure 4.54. The NOGAPS then decreases as you move up to each higher cloudiness amount leading to nearly a zero value for the 80-100% category. The RTNEPH drops off as before and then increases at the 80-100% category. For the low clouds Figure 4.55 shows very few clear occurrences for NOGAPS. The frequency increases as the cloud cover category increases reaching a peak at the 20-40% category and then decreasing to nearly zero at the 80-100% category. For the low clouds the RTNEPH seems to have its usual problem of too many clear occurrences and then dropping off significantly for the increased cloudiness categories.

In the 12h forecast for NOGAPS we see very similar patterns for high, middle, and low cloud histograms. The high and middle cloud forecasts have virtually no change from the analysis. This is generally true in the tropics. The only real difference is that NOGAPS peaks at the 40-60% cloudiness category in the low cloud forecast as seen in Figure 4.56. The 24h, 36h, and 48h forecast for NOGAPS has similar patterns as the 12h forecast. There is very little change to the shape of the histograms or the cloudiness category amounts.

Looking now at the western United States region, we see a little bit more variability in the fields. Starting with the high clouds analysis there is a large zero category value for NOGAPS and RTNEPH which decreases as the cloudiness category increases. This can be seen in Figure 4.57. The RTNEPH then does its usual increase at the 80-100% category. Looking then at the middle clouds analysis, NOGAPS seems to be a bit more evenly distributed throughout the cloudiness categories. It is higher at the zero and 0-20%

categories and then slowly decreases frequency as the cloudiness category increases. The RTNEPH has a lower than usual clear value (30) and it has a maximum at the 80-100% cloudiness category. This is the biggest change in pattern for the RTNEPH that we have seen thus far. This can be seen in Figure 4.58. Moving on to the low clouds analysis we see an initial increase from the zero to the 0-20% cloudiness category and then a steady decrease as the cloudiness category increases to 80-100%. The RTNEPH has its usual high clear category with a drastic drop off and then slight increase as you get to the 80-100% category (Fig. 4.59). The RTNEPH is again unrealistic for the low clouds.

In the 12h high clouds forecast, the clear category decreases while the 80-100% category increases. This can be seen in Figure 4.60. The 12 h middle cloud forecast (Figure 4.61) shows a large increase in the 80-100% category which nearly reaches the RTNEPH value. The lower cloudiness categories (zero and 0-20%) are lower so that all categories except for 80-100% are about the same. This pattern has really settled in when moving on to the 24h, 36h, and 48h forecasts. The shape is virtually the same and the deviations are minimal.

The consideration of smaller regions produced more deviations to the initial patterns and cloudiness occurrence values especially in the first 12h. Once these patterns were set, they seemed to settle in and not change much after the 24h forecast (up to the 48h forecasts).

2. Direct Cross-Correlation of NOGAPS and RTNEPH

We first consider the cross-correlation of the NOGAPS and RTNEPH fields on the whole globe. Table 4.1 gives the cross-correlation values. The left side of the table shows the six RTNEPH cloudiness categories ranging from zero to 80-100%, and the top gives

NOGAPS cloudiness categories. For instance, in the lower left hand corner cell the value is 58.1. This means that RTNEPH and NOGAPS both have clear conditions 58.1% of the time. Moving all the way over to the right hand corner the value is 2.1. This means that when RTNEPH is in the clear category, NOGAPS is in the 80-100% category 2.1% of the time. These values were averaged over the month of January.

This table shows that RTNEPH and NOGAPS are most likely to agree under clear conditions. On the other hand when the RTNEPH cloudiness is between 80 and 100 per cent, the NOGAPS analyses are almost equally scattered between all categories with a maximum for the clear category.

Table 4.1. Total Globe Cross-Correlations of High Clouds

	NOGAPS 0%	NOGAPS 0-20%	NOGAPS 20-40%	NOGAPS 40-60%	NOGAPS 60-80%	NOGAPS 80-100%
RTNEPH 80-100%	1.4	0.8	0.6	0.7	0.8	0.6
RTNEPH 60-80%	0.8	0.3	0.2	0.2	0.1	0.1
RTNEPH 40-60%	0.7	0.2	0.1	0.1	0.1	0.1
RTNEPH 20-40%	0.6	0.3	0.2	0.2	0.2	0.1
RTNEPH 0-20%	0.7	0.3	0.2	0.2	0.2	0.2
RTNEPH 0%	58.1	13.5	6.4	4.8	3.7	2.1

Table 4.2 shows the cross-correlations for tropical high clouds. This is very similar

to Table 4.1 with 50% of the time NOGAPS and RTNEPH both giving clear skies. The clear areas for the high clouds are even larger for the northern mid-latitudes and the northern polar regions.

Table 4.2. Tropical Region Cross-Correlations of High Clouds

	NOGAPS 0%	NOGAPS 0-20%	NOGAPS 20-40%	NOGAPS 40-60%	NOGAPS 60-80%	NOGAPS 80-100%
RTNEPH 80-100%	2.0	1.4	1.3	1.8	2.0	1.5
RTNEPH 60-80%	0.6	0.2	0.2	0.3	0.3	0.2
RTNEPH 40-60%	0.6	0.3	0.2	0.3	0.3	0.2
RTNEPH 20-40%	0.8	0.4	0.3	0.4	0.4	0.3
RTNEPH 0-20%	1.2	0.6	0.4	0.6	0.6	0.4
RTNEPH 0%	50.1	9.7	6.0	6.4	5.0	2.7

Table 4.3 shows that clear areas are least correlated for low clouds in the northern polar region. For example, nearly 35% of the time the RTNEPH had clear conditions whenever NOGAPS was in the 80-100% (nearly overcast) cloudiness category. This provides support to the statement that RTNEPH has a major problem in representing low clouds over ice and snow as mentioned in Chapter II.

Table 4.3. Northern Polar Region Cross-Correlations of Low Clouds

	NOGAPS 0%	NOGAPS 0-20%	NOGAPS 20-40%	NOGAPS 40-60%	NOGAPS 60-80%	NOGAPS 80-100%
RTNEPH 80-100%	0.2	0.8	1.0	1.4	2.0	3.7
RTNEPH 60-80%	0.1	0.3	0.4	0.6	0.9	1.6
RTNEPH 40-60%	0	0.2	0.2	0.3	0.4	0.6
RTNEPH 20-40%	0	0.2	0.1	0.1	0.1	0.2
RTNEPH 0-20%	0	0.2	0.1	0.1	0	0
RTNEPH 0%	3.7	5.5	8.3	13.8	18.5	34.5

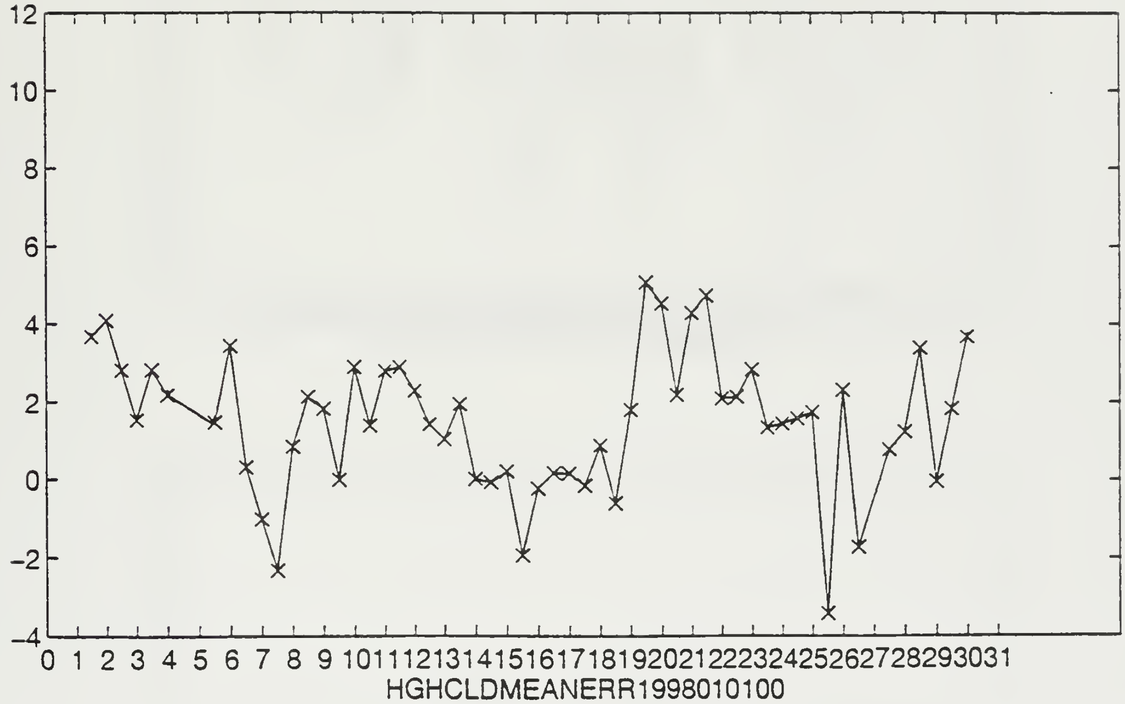

Figure 4.1. High cloud mean 00hr deviation over January 1998 for 20N to 60N (Northern Mid-latitudes). The column axis is per cent cloud deviation while the row axis represents the days of the month. Data points are exist for every 12 hours. Obvious error points have been removed and replaced with straight line segments.

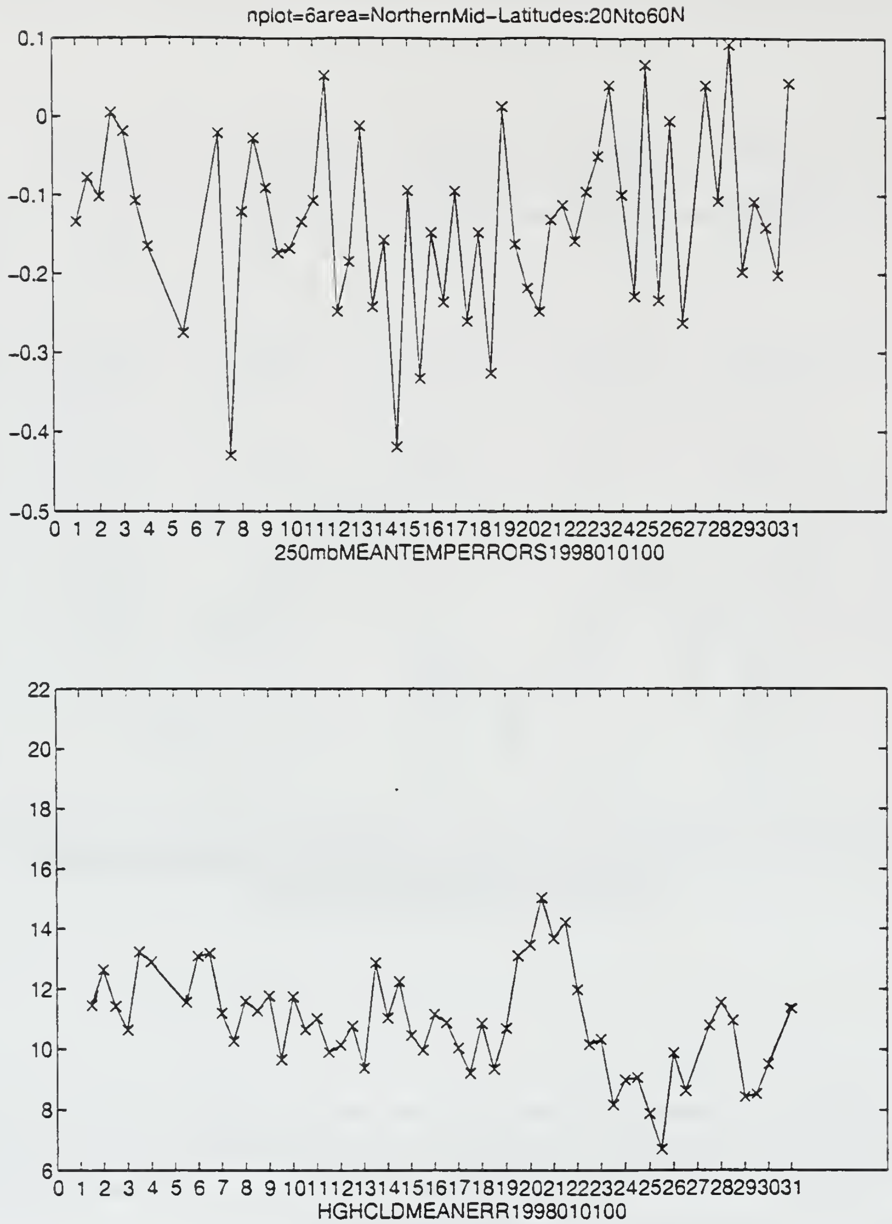

Figure 4.2. Top portion represents 250mb mean 12hr temperature errors over January 1998 for 20N to 60N. Bottom portion represents high cloud mean 12hr deviation for the same time period and region.

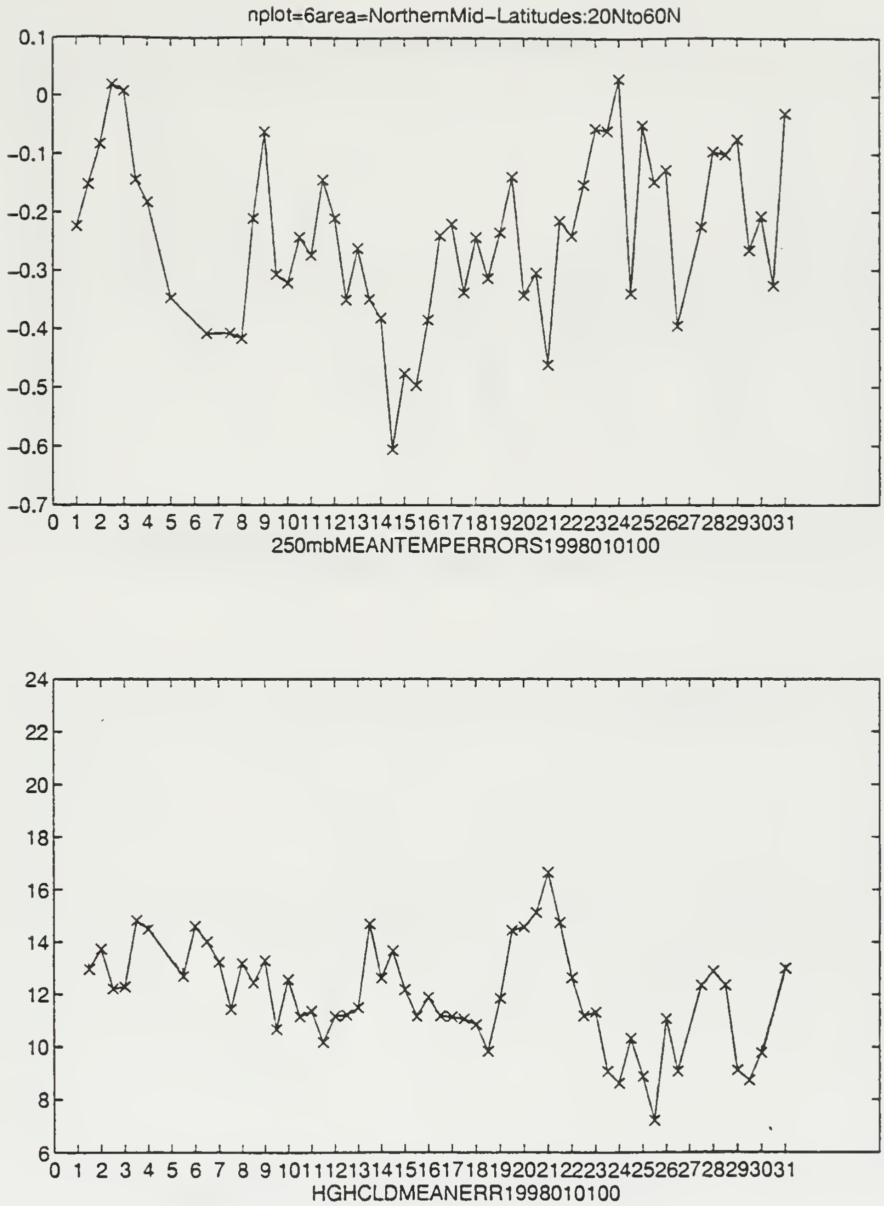

Figure 4.3. Top portion represents 250mb mean 24hr temperature errors over January 1998 for 20N to 60N. Bottom portion represents high cloud mean 24hr deviation for the same time period and region.

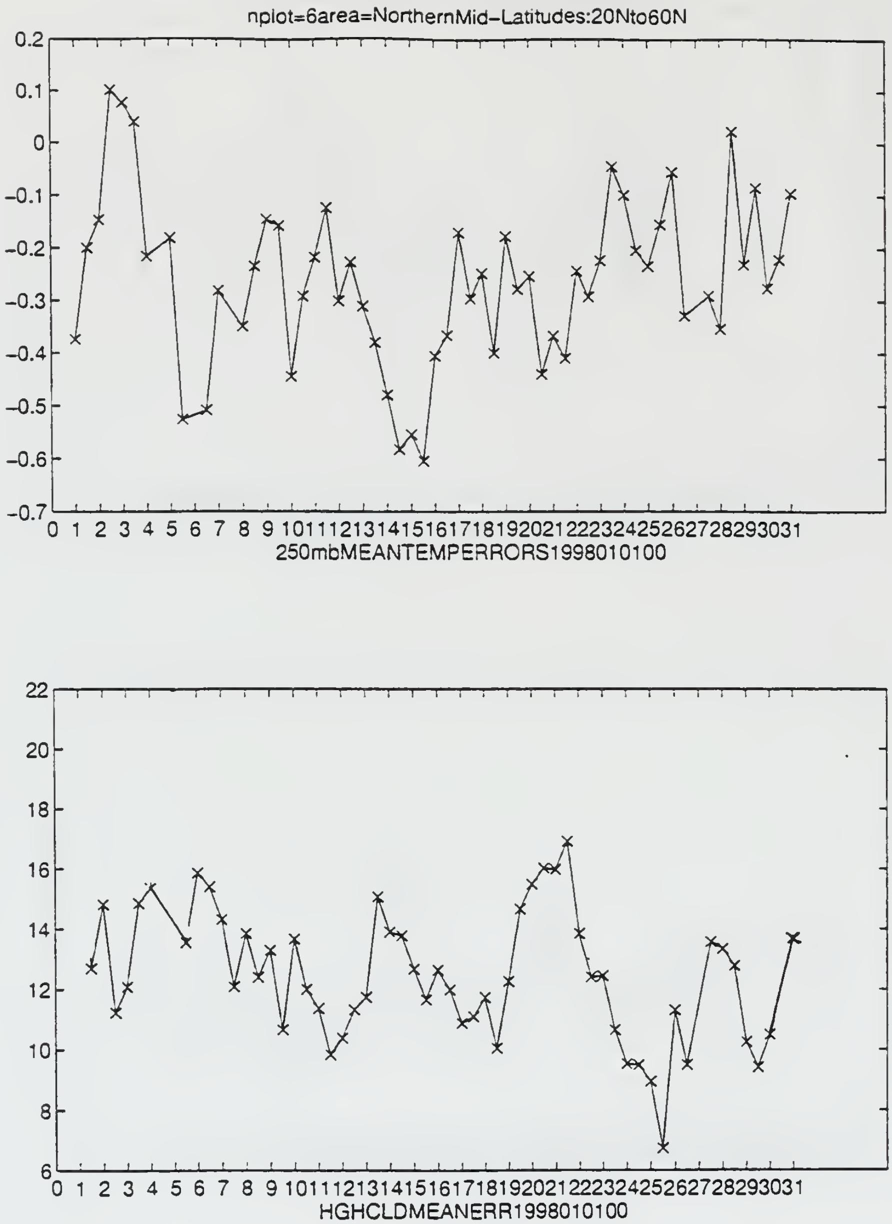

Figure 4.4. Top portion represents 250mb mean 36hr temperature errors over January 1998 for 20N to 60N. Bottom portion represents high cloud mean 36hr deviation for the same time period and region.

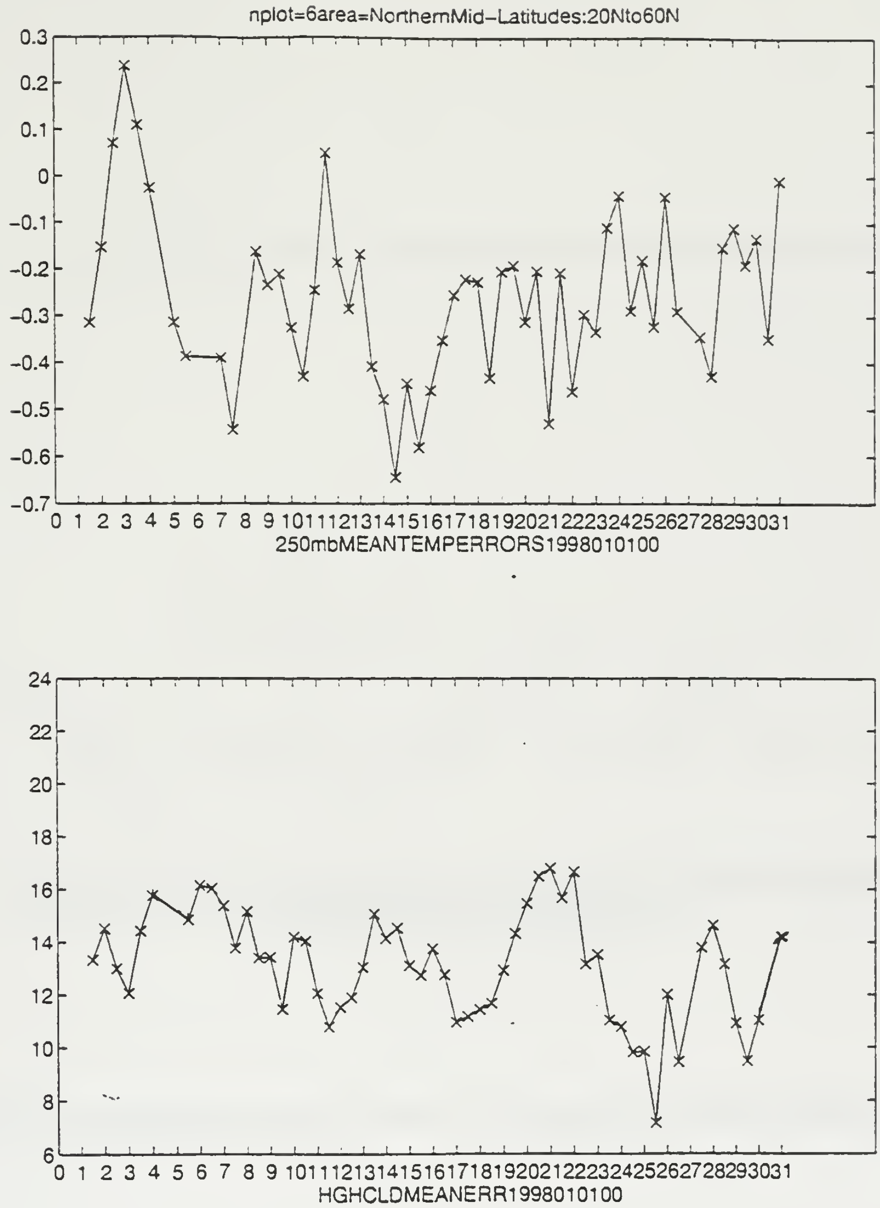

Figure 4.5. Top portion represents 250mb mean 48hr temperature errors over January 1998 for 20N to 60N. Bottom portion represents high cloud mean 48hr deviation for the same time period and region.

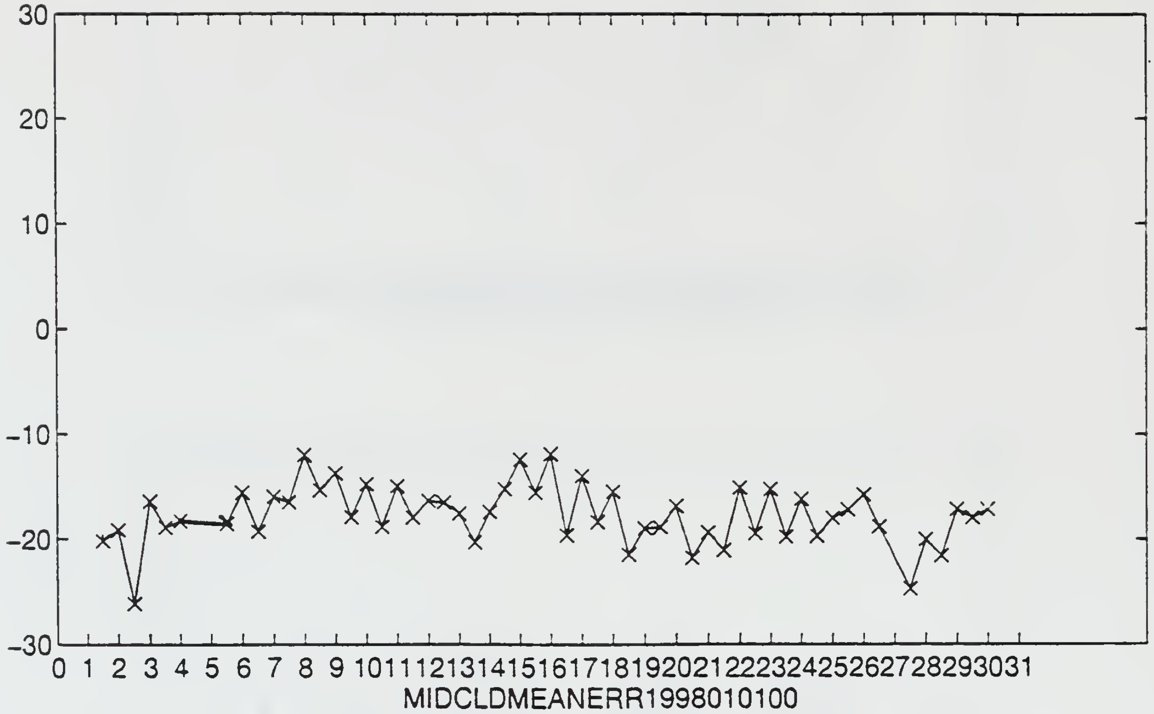

Figure 4.6. Middle cloud mean 00hr deviation over January 1998 for 20N to 60N.

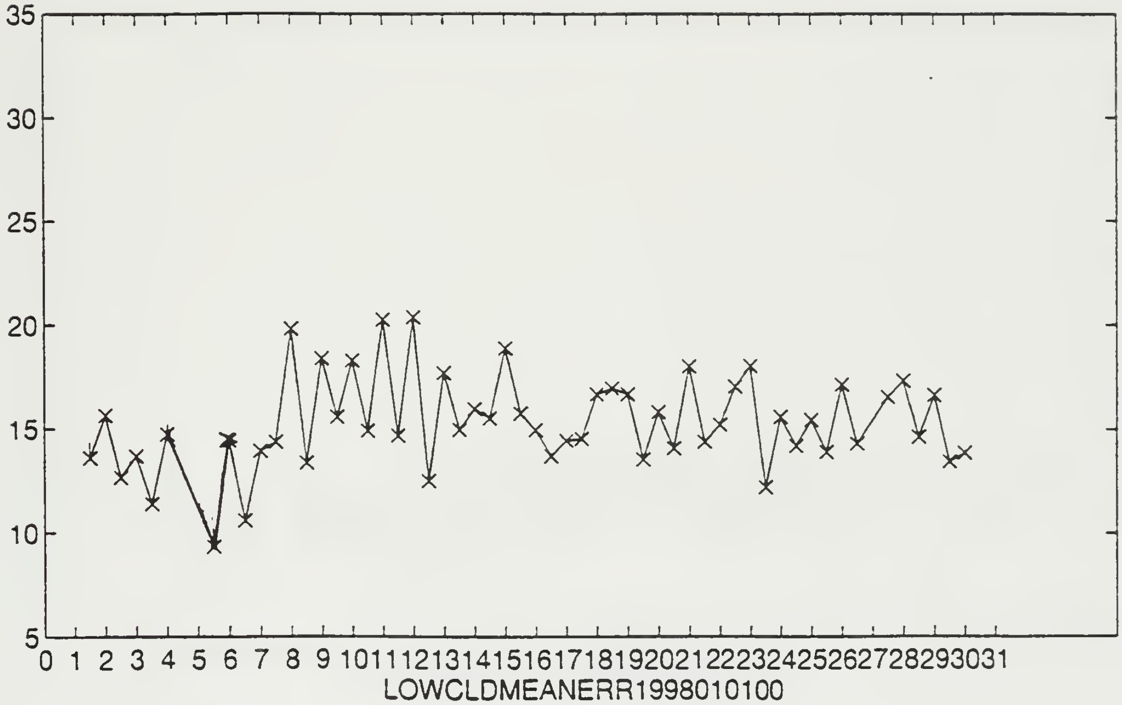

Figure 4.7. Low cloud mean 00hr deviation over January 1998 for 20N to 60N.

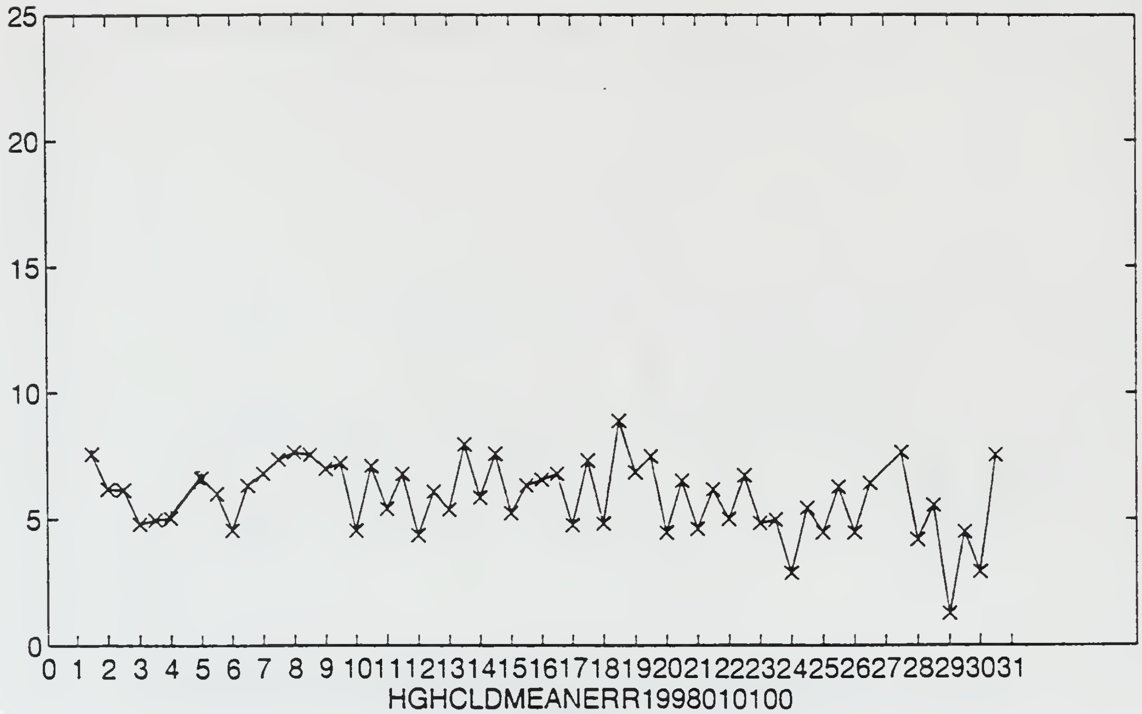

Figure 4.8. High cloud mean 00hr deviation over January 1998 for 20S to 20N (Tropics).

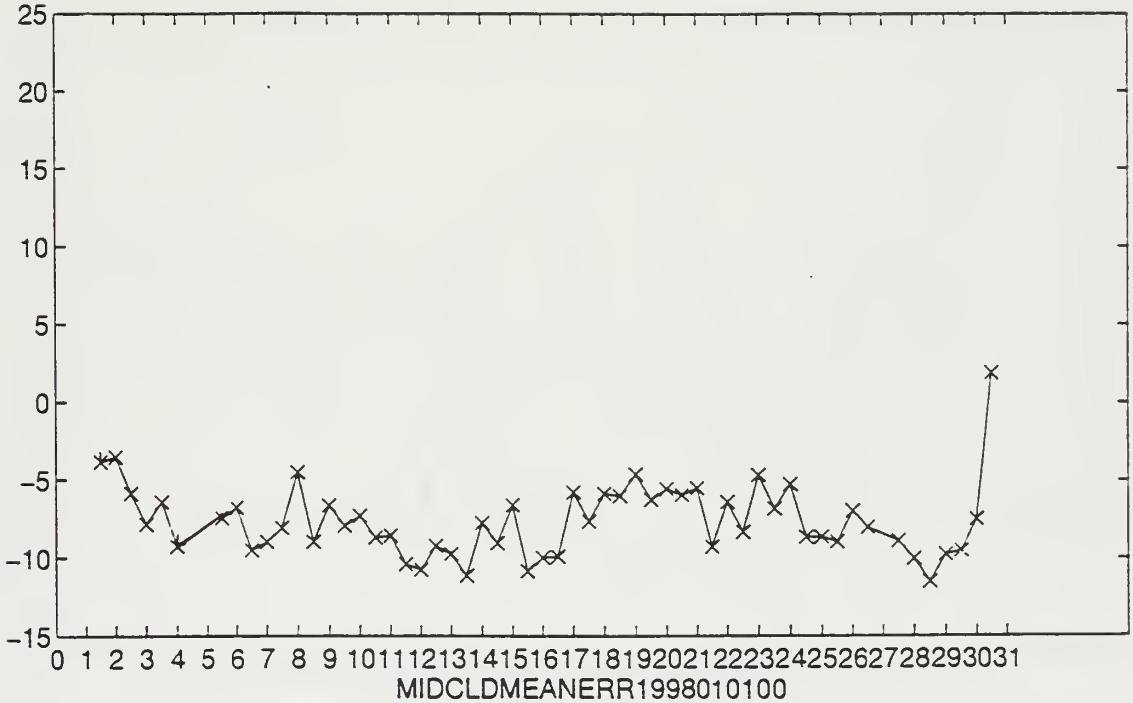

Figure 4.9. Middle cloud mean 00hr deviation over January 1998 for 20S to 20N.

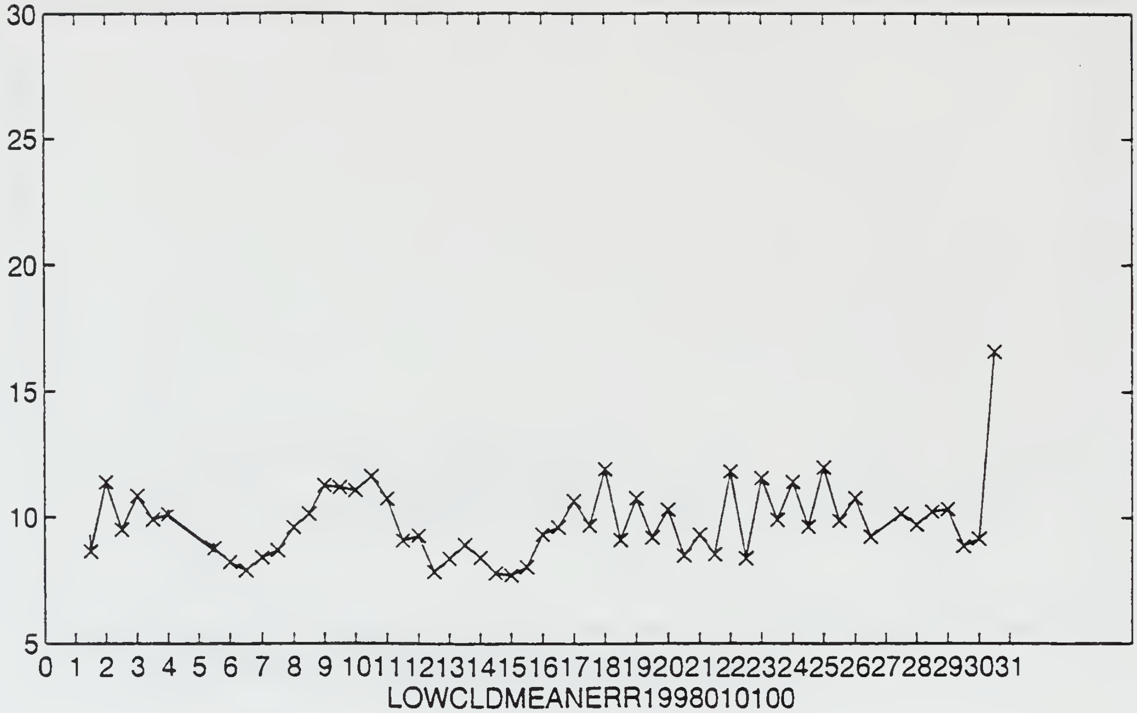

Figure 4.10. Low cloud mean 00hr deviation over January 1998 for 20S to 20N.

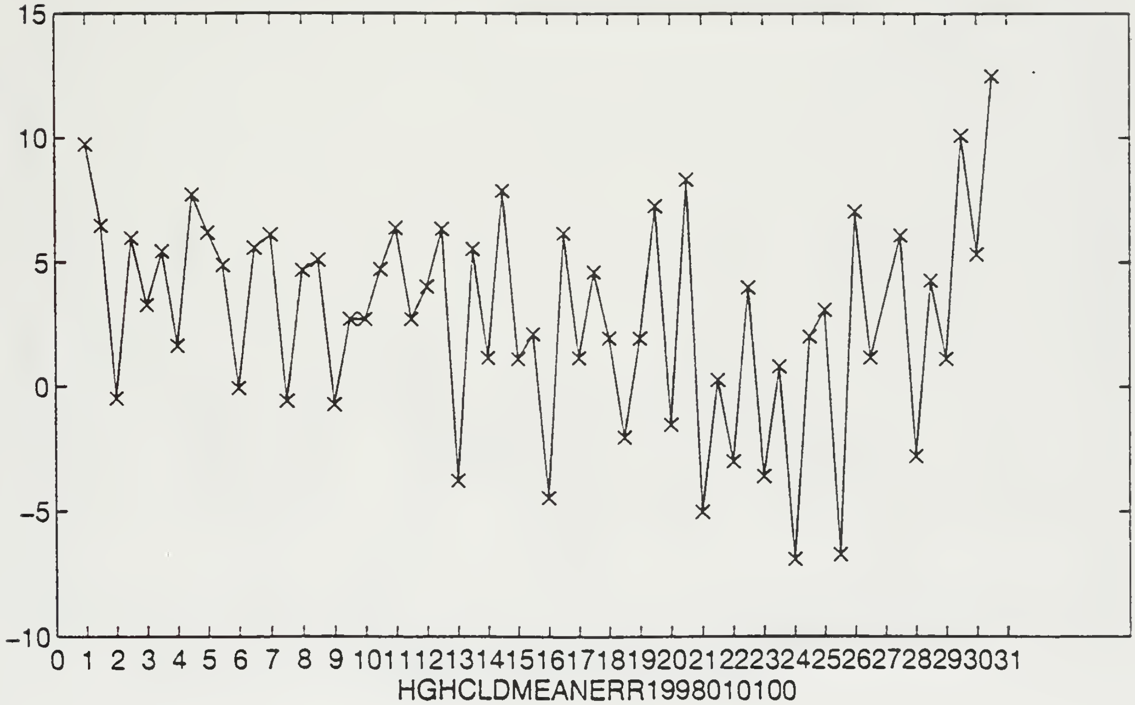

Figure 4.11. High cloud mean 00hr deviation over January 1998 for 60N to 90N (Northern Polar).

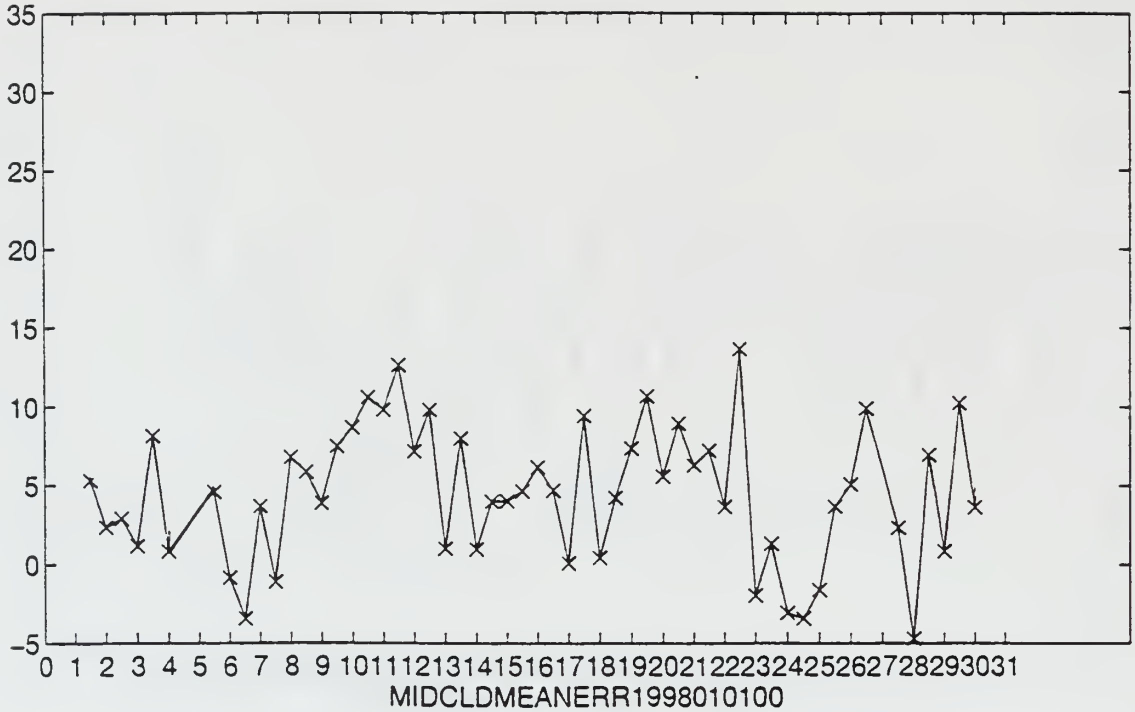

Figure 4.12. Middle cloud mean 00hr deviation over January 1998 for 60N to 90N (Northern Polar).

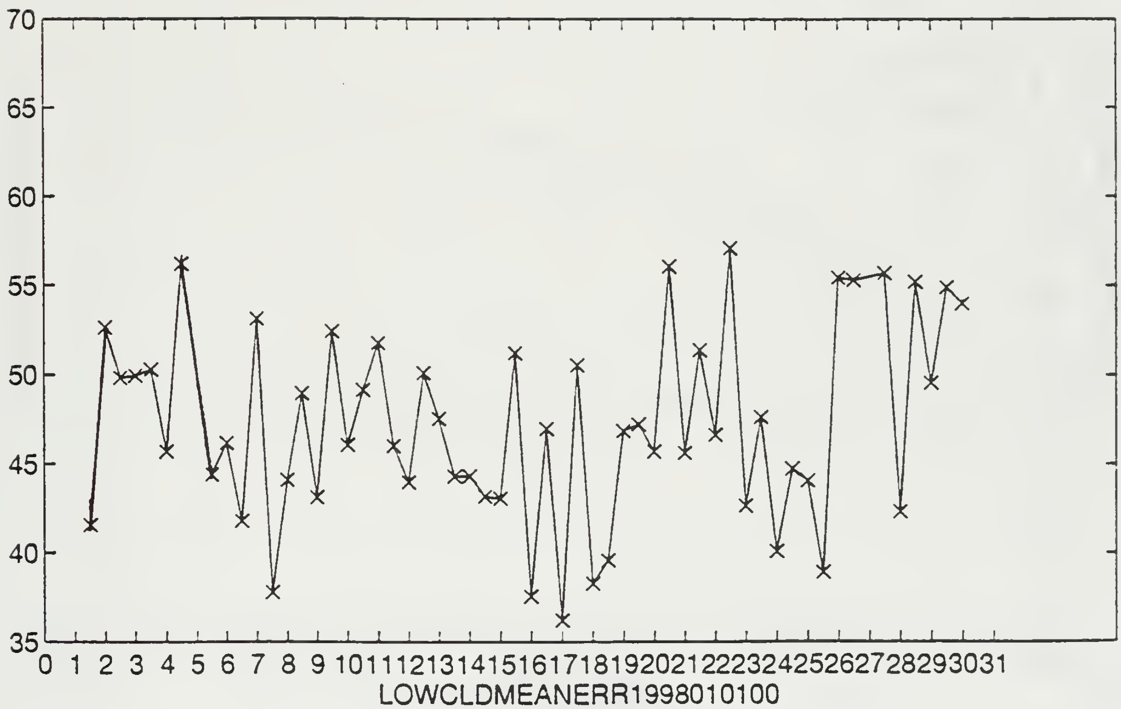

Figure 4.13. Low cloud mean 00hr deviation over January 1998 for 60N to 90N (Northern Polar).

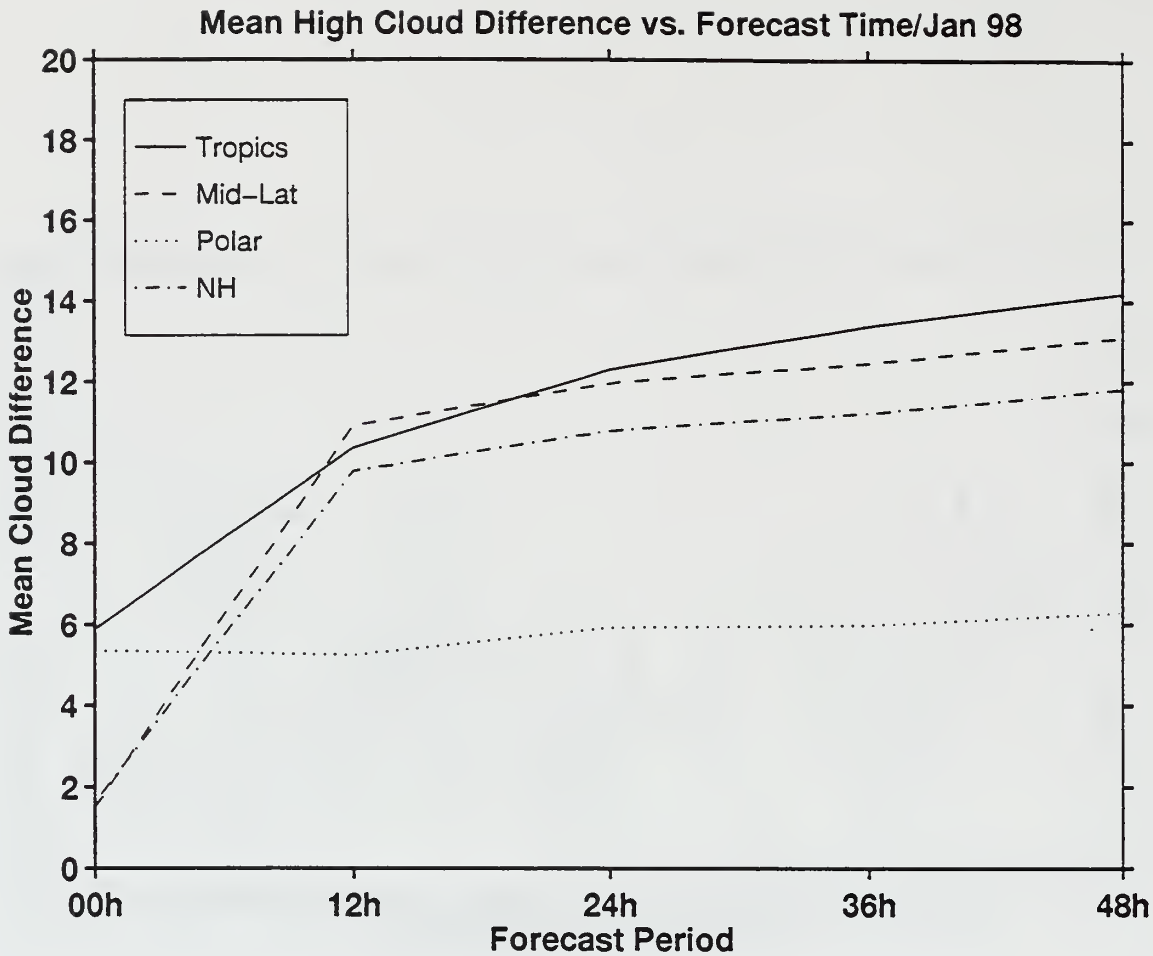

Figure 4.14. Mean high cloud difference versus forecast time for January 1998. Three of the four regions experience a 12 hour increase while the Northern Polar Region actually sees a decrease.

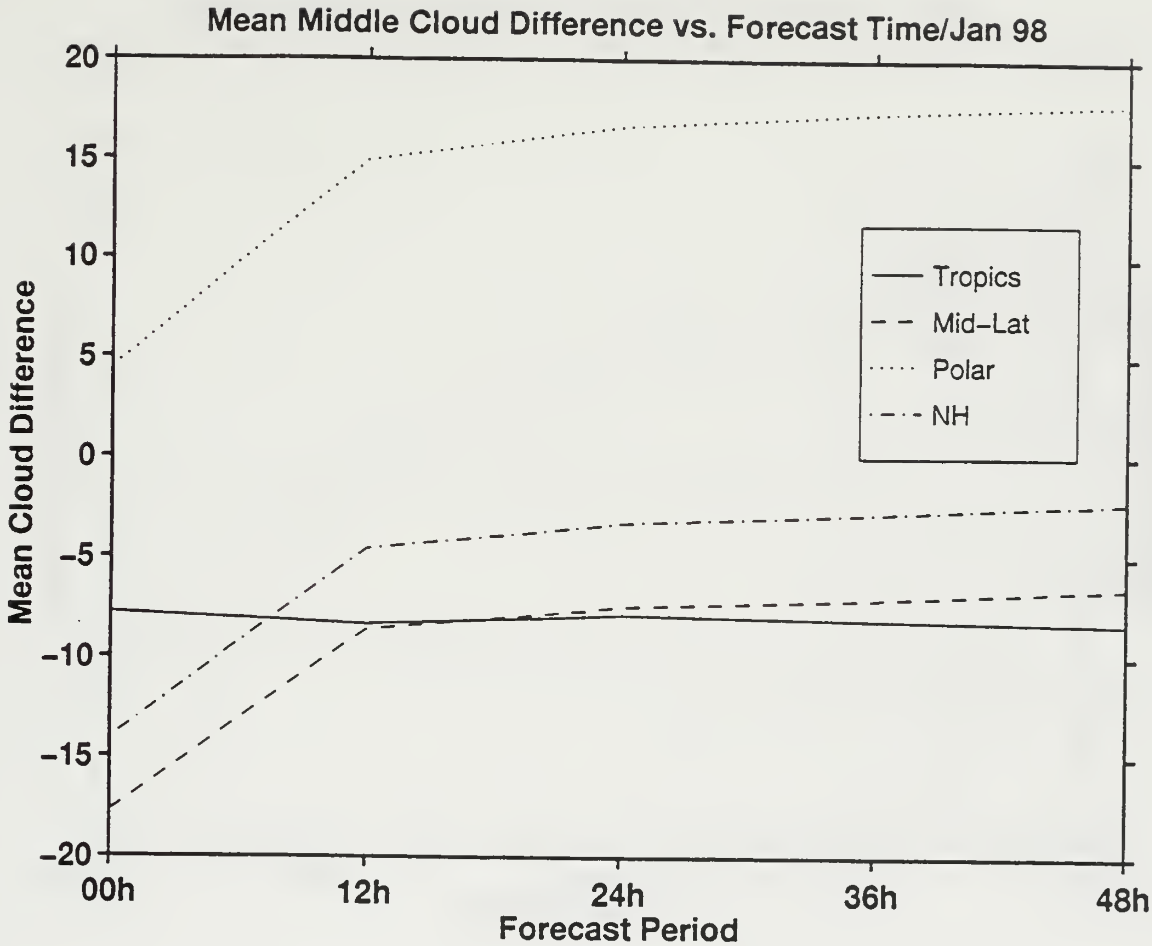

Figure 4.15. Mean middle cloud difference versus forecast time for January 1998. Tropics tends to decrease steadily for middle cloud difference while the other three regions have a significant increase in the first 12 hours. The Polar Region is the only one to have a positive deviation in mean clouds.

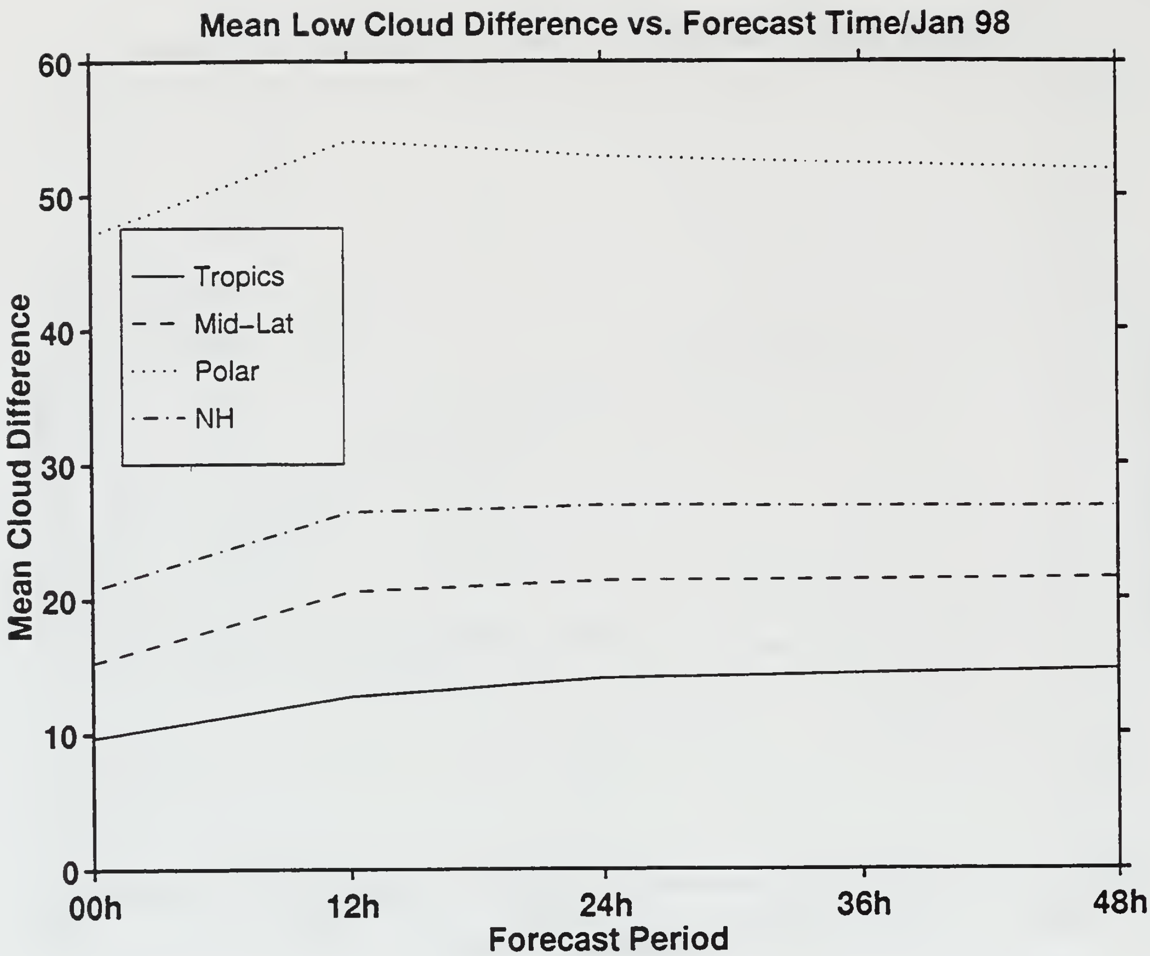

Figure 4.16. Mean low cloud difference versus forecast time for January 1998. The Northern Polar Region has a significantly higher low cloud difference than the other regions throughout the entire forecast period. This is consistent with the RTNEPH being less accurate representing low clouds over cooler surfaces such as ice or snow.

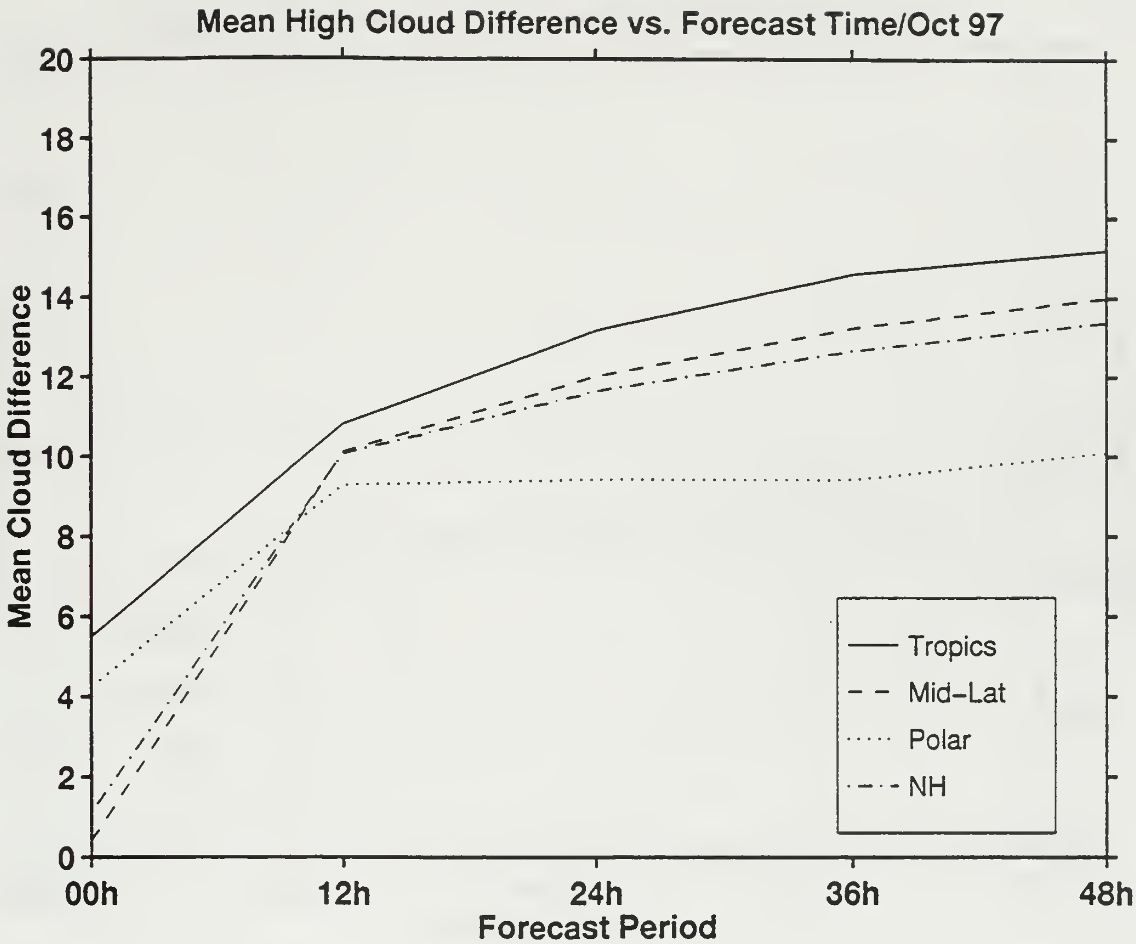

Figure 4.17. Mean high cloud difference versus forecast time for October 1997. After 12 hours, the Northern Polar Region has the lowest mean cloud difference while the Tropics has the highest.

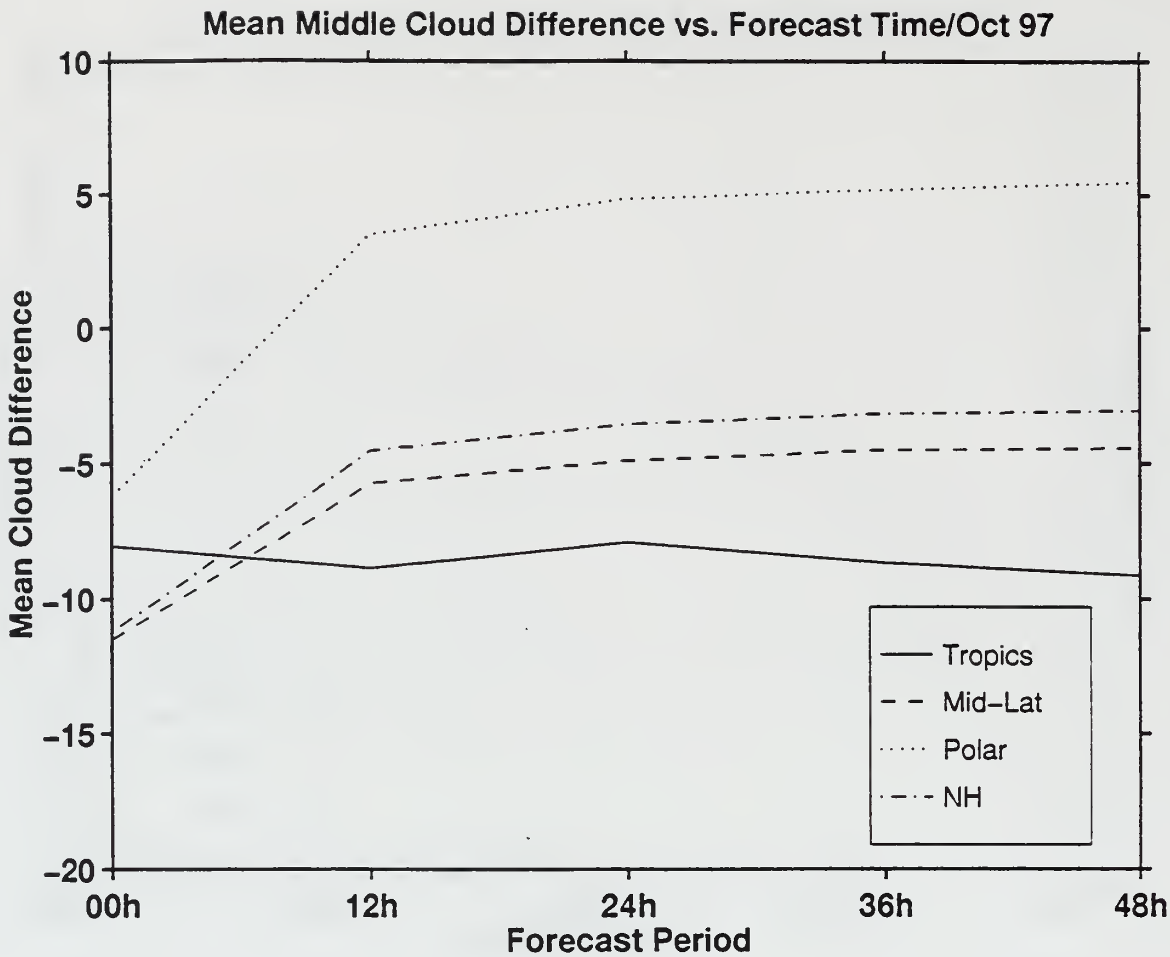

Figure 4.18. Mean middle cloud difference versus forecast time for October 1997. Similar to figure 4.15.

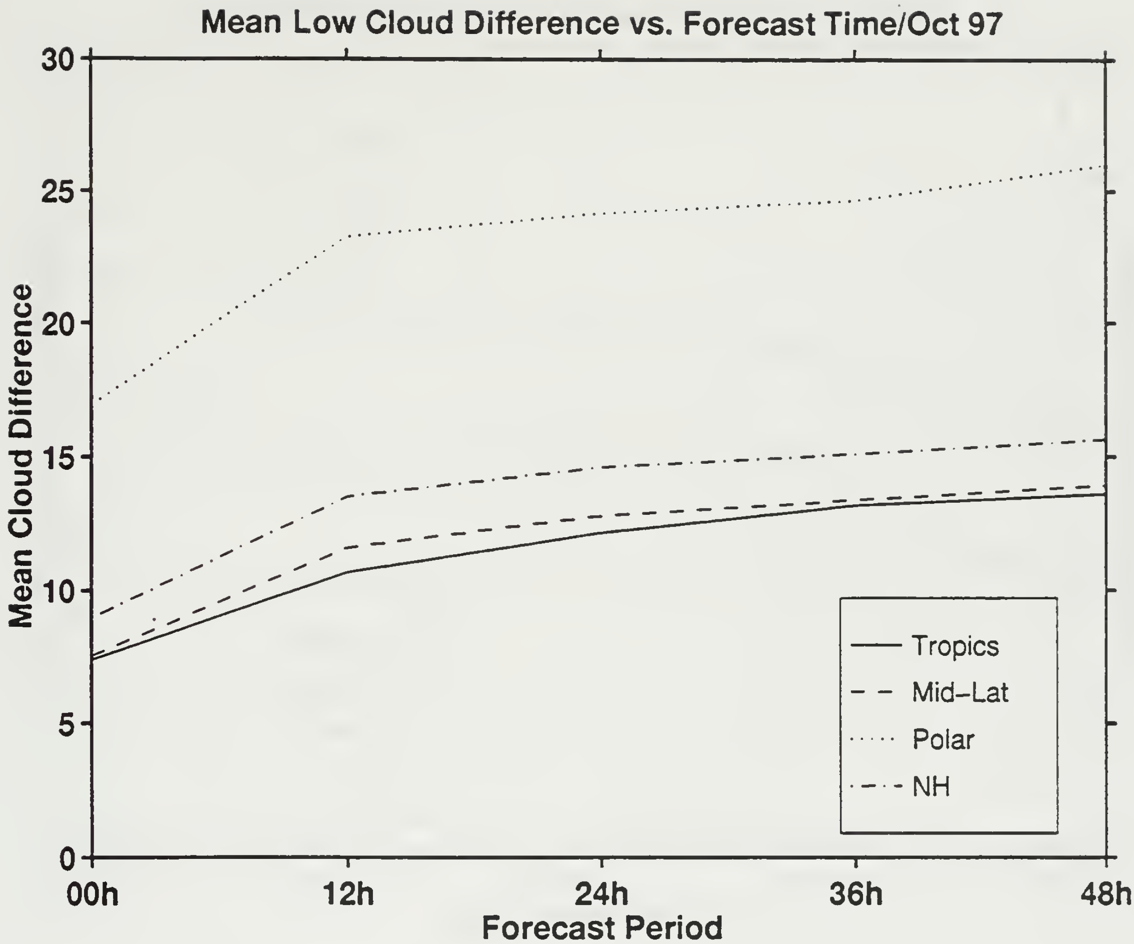

Figure 4.19. Mean low cloud difference versus forecast time for October 1997. Similar to figure 4.16.

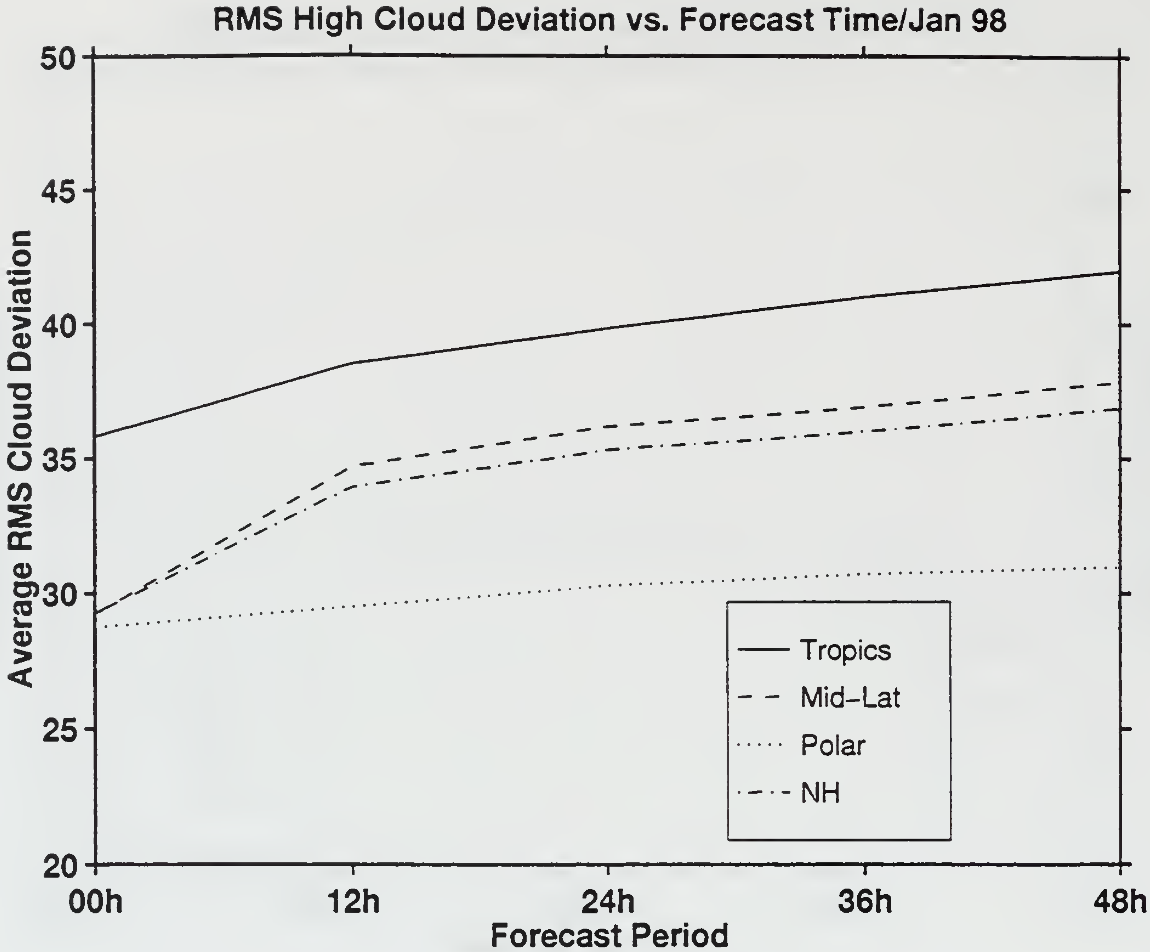

Figure 4.20. RMS high cloud deviation versus forecast time for January 1998. Overall steady increase for all four regions is present.

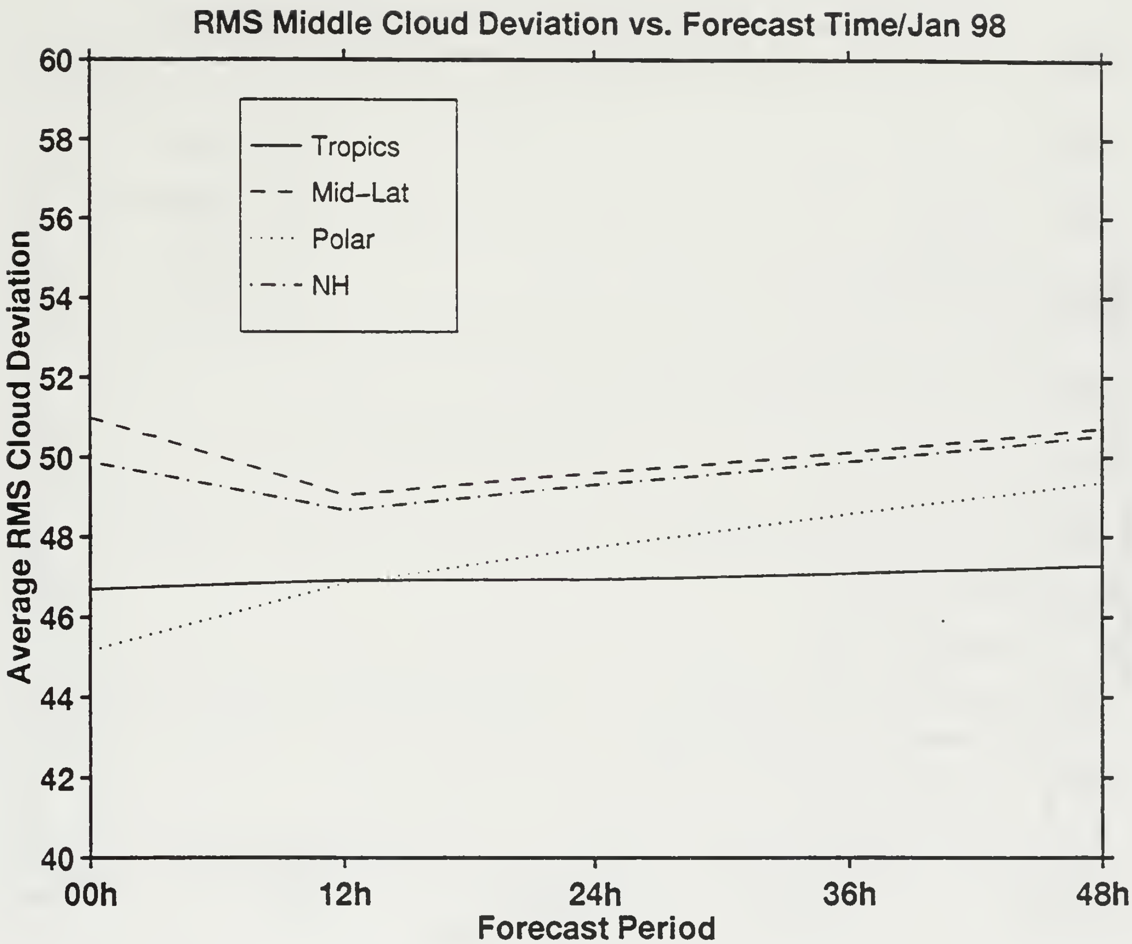

Figure 4.21. RMS middle cloud deviation versus forecast time for January 1998.

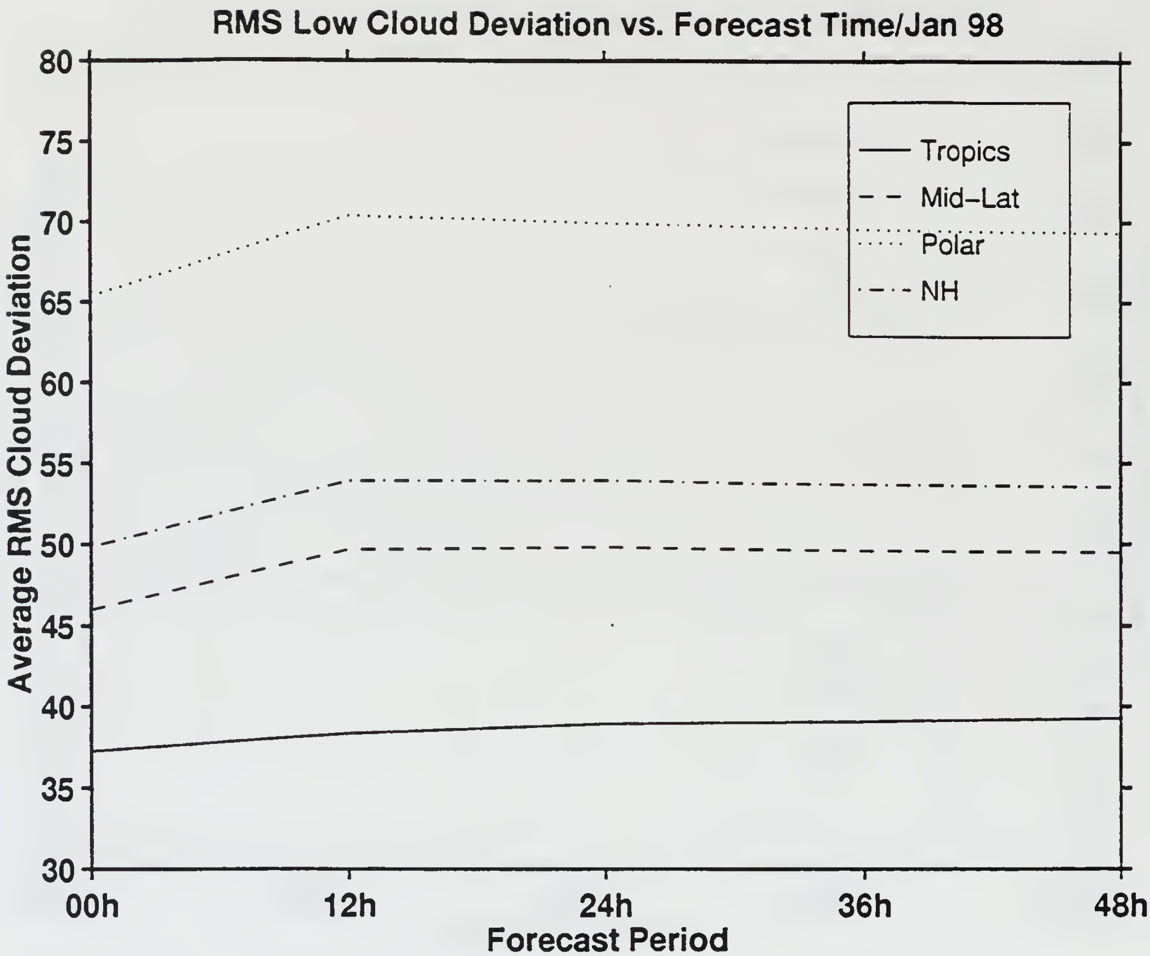

Figure 4.22. RMS low cloud deviation versus forecast time for January 1998. Overall increase in the first 12 hours as seen in the mean cloud deviation cases.

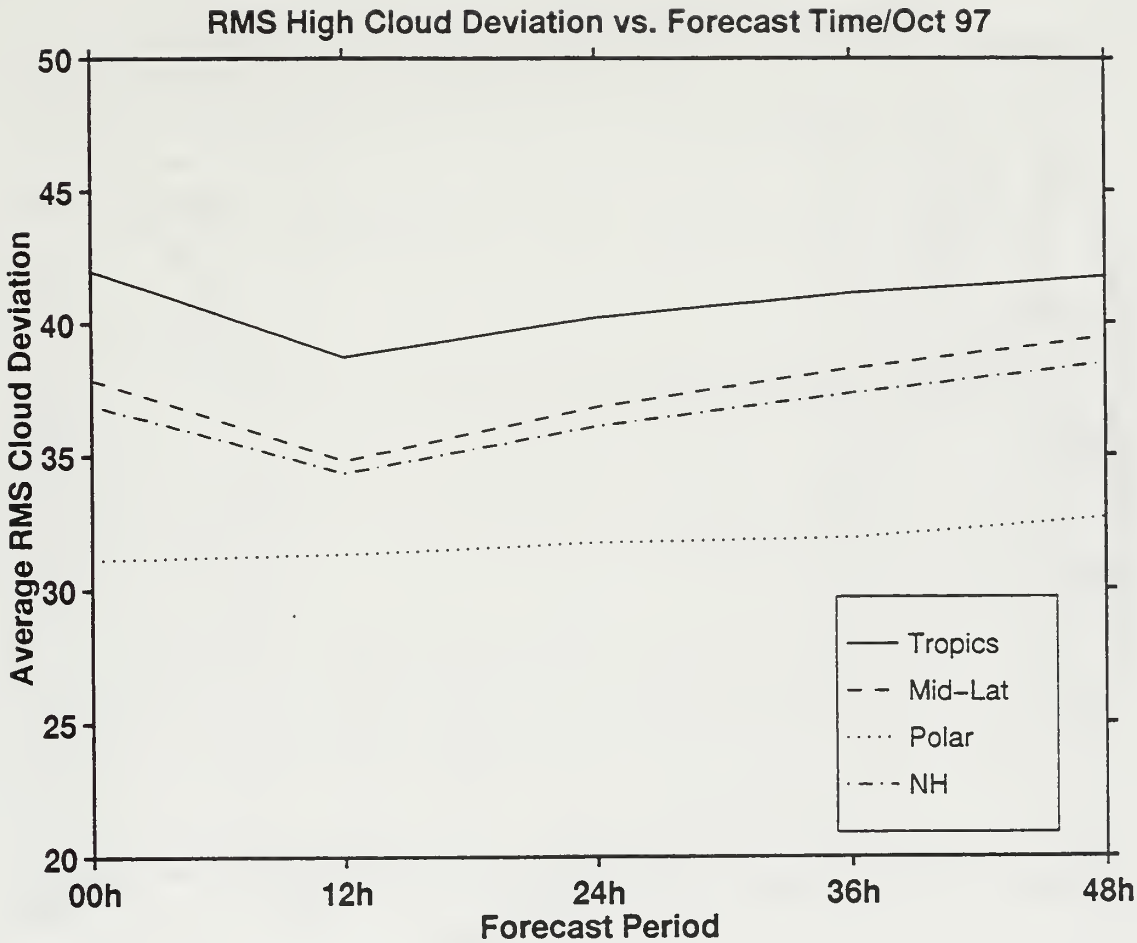

Figure 4.23. RMS high cloud deviation versus forecast time for October 1997. Overall decrease in the first 12 hours except in the Northern Polar Region. Tropics has the highest values which is similar to the mean high cloud differences seen in figure 4.17.

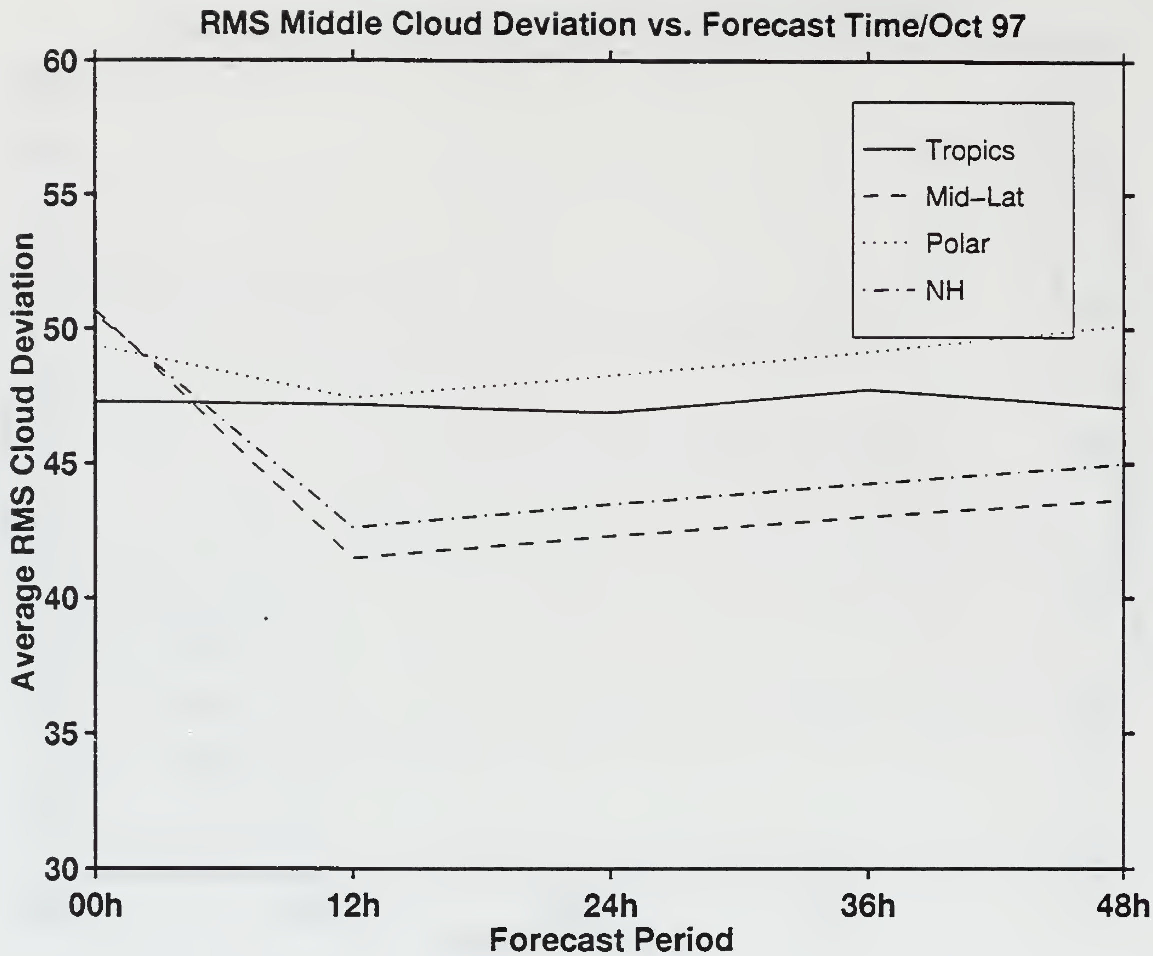

Figure 4.24. RMS middle cloud deviation versus forecast time for October 1997. Notice how only the Tropics remain steady throughout the forecast period.

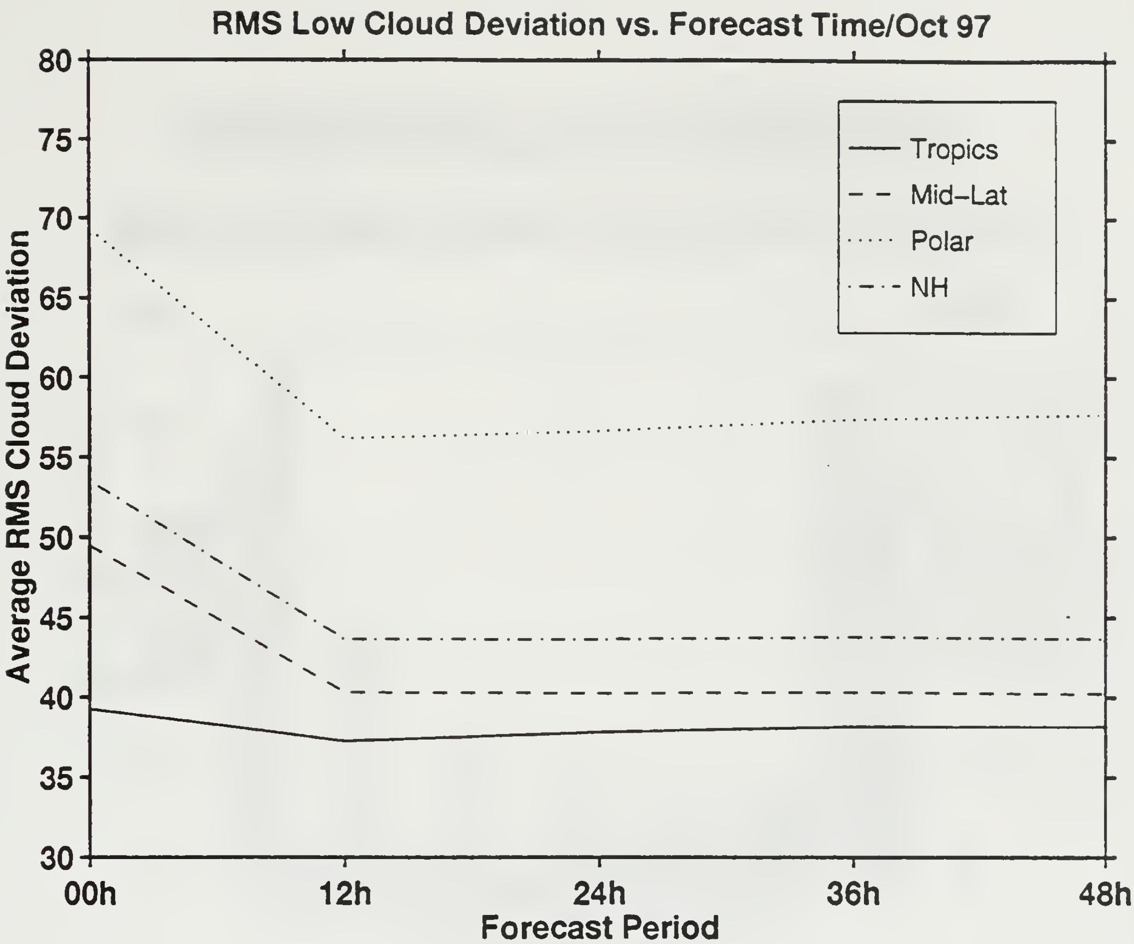

Figure 4.25. RMS low cloud deviation versus forecast time for October 1997.

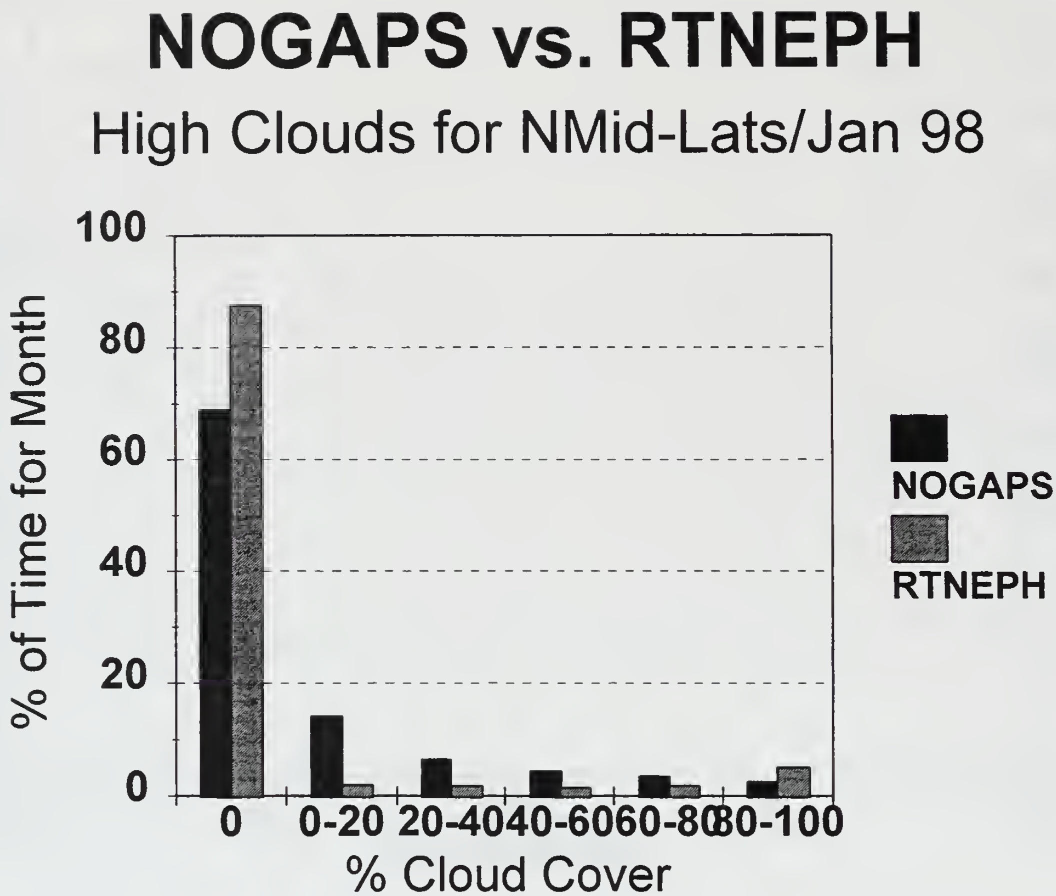

Figure 4.26. NOGAPS and RTNEPH high clouds analyses for the northern mid-latitudes for January 1998. This figure shows what per cent of the time NOGAPS or RTNEPH fall within one of six cloud cover "bins": 0%, 0-20%, 20-40%, 40-60%, 60-80%, or 80-100%. The exceptionally high zero per cent cloud cover category for RTNEPH is prevalent throughout nearly all regions and time periods.

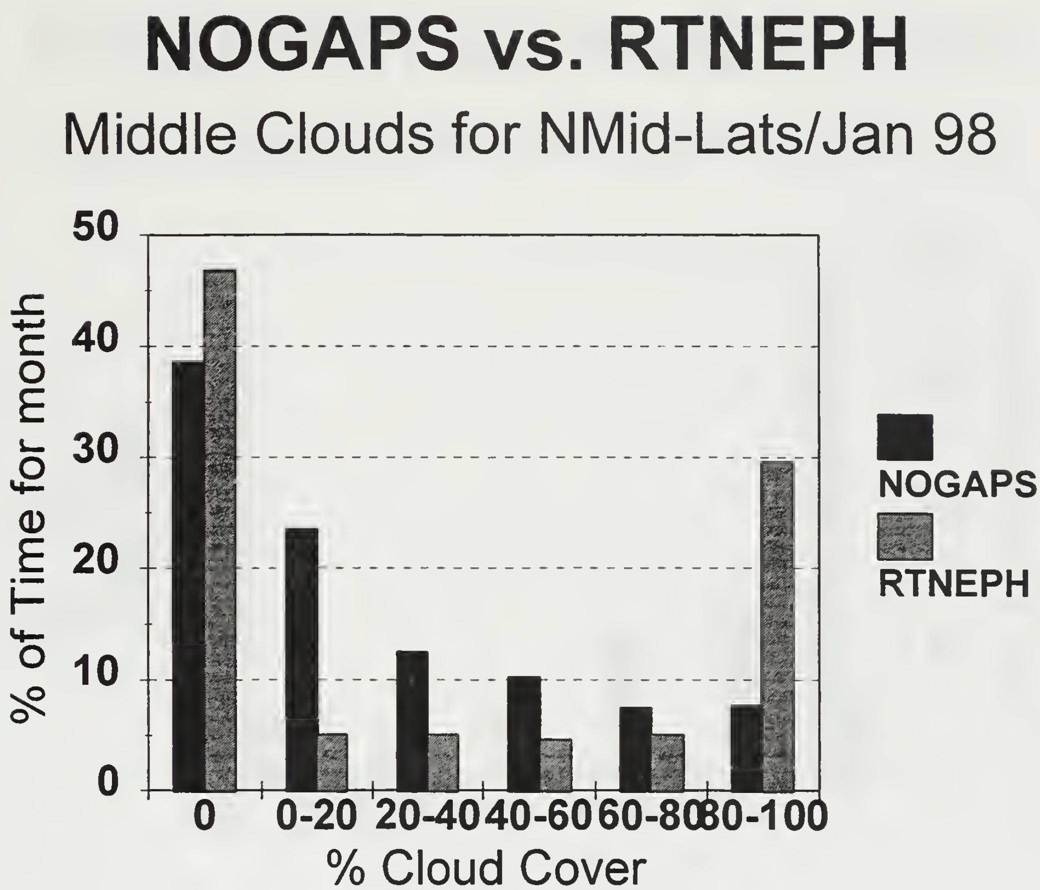

Figure 4.27. NOGAPS and RTNEPH middle clouds analyses for the northern mid-latitudes for January 1998. There seems to be a more even distribution for NOGAPS than at the high clouds level.

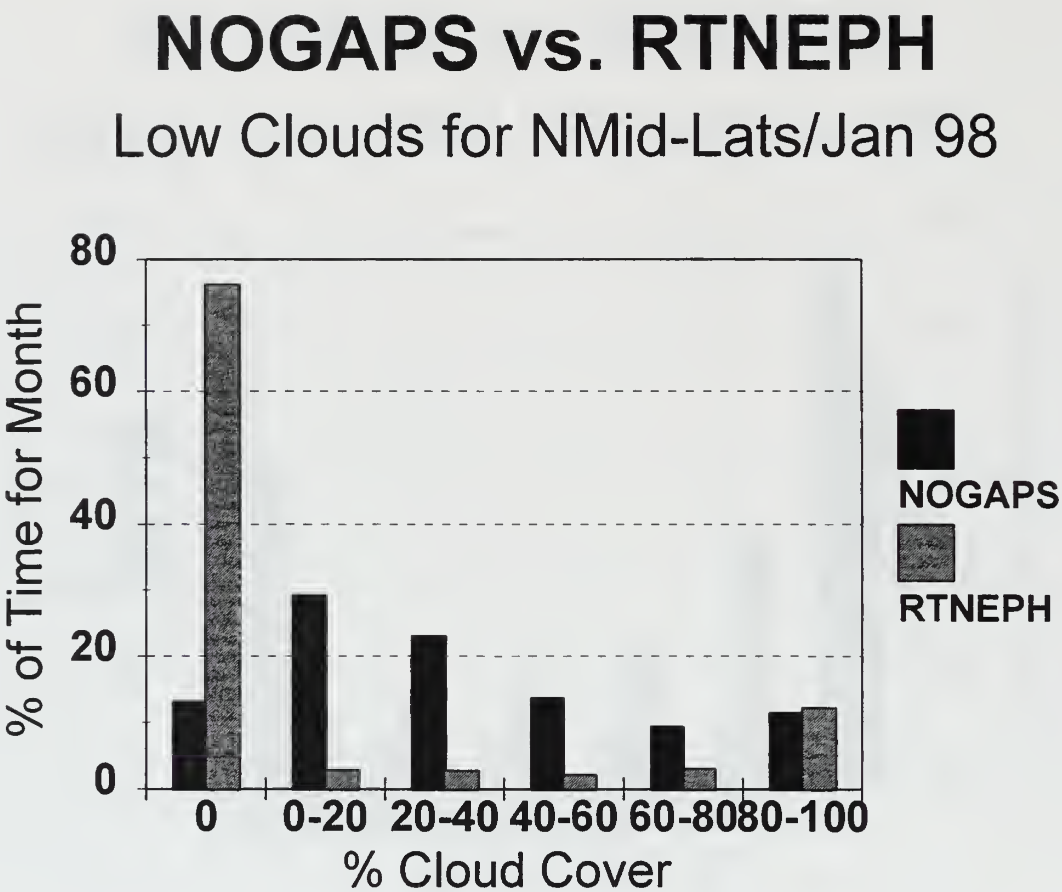

Figure 4.28. NOGAPS and RTNEPH low clouds analyses for the northern mid-latitudes for January 1998. Note the nearly "sinusoidal" pattern for NOGAPS.

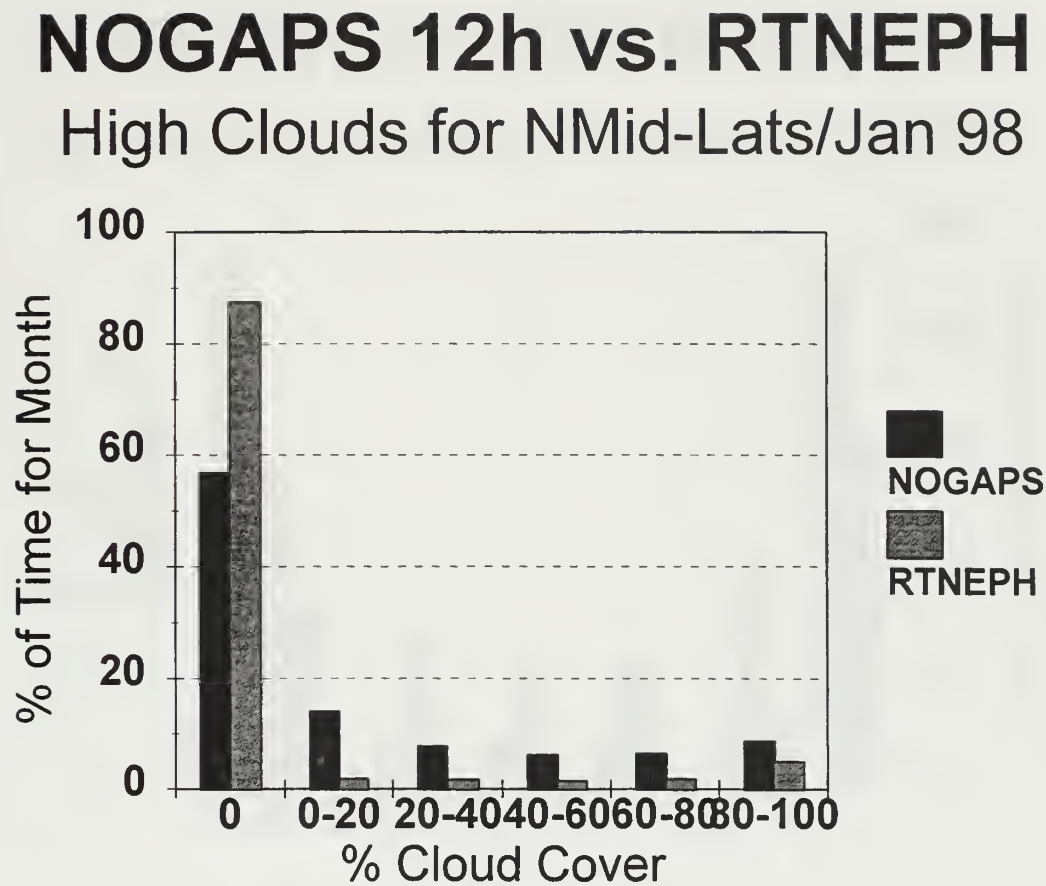

Figure 4.29. 12h NOGAPS and RTNEPH high clouds for the northern mid-latitudes for January 1998. Similar shape as was seen at 00h.

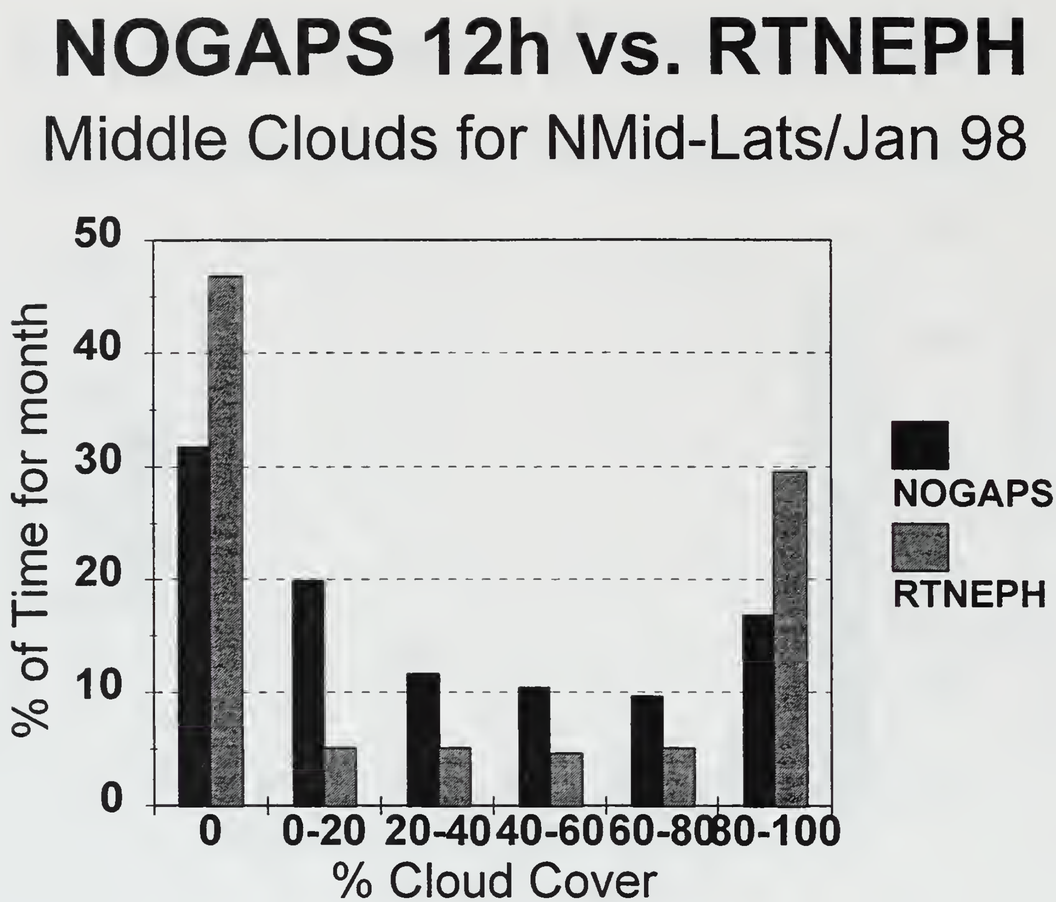

Figure 4.30. 12h NOGAPS and RTNEPH middle clouds for the northern mid-latitudes for January 1998. Slight decrease for the 0% and 0-20% categories which is similar to the results shown in Figure 4.21.

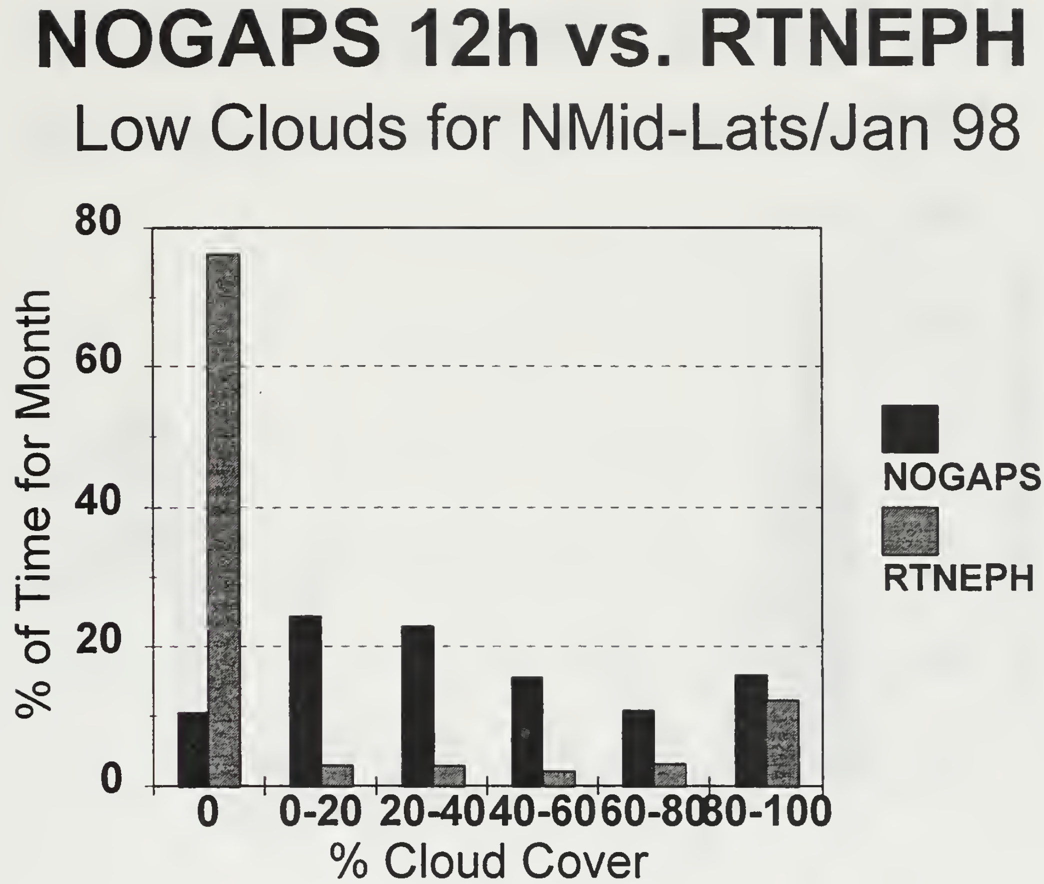

Figure 4.31. 12h NOGAPS and RTNEPH low clouds for the northern mid-latitudes for January 1998.

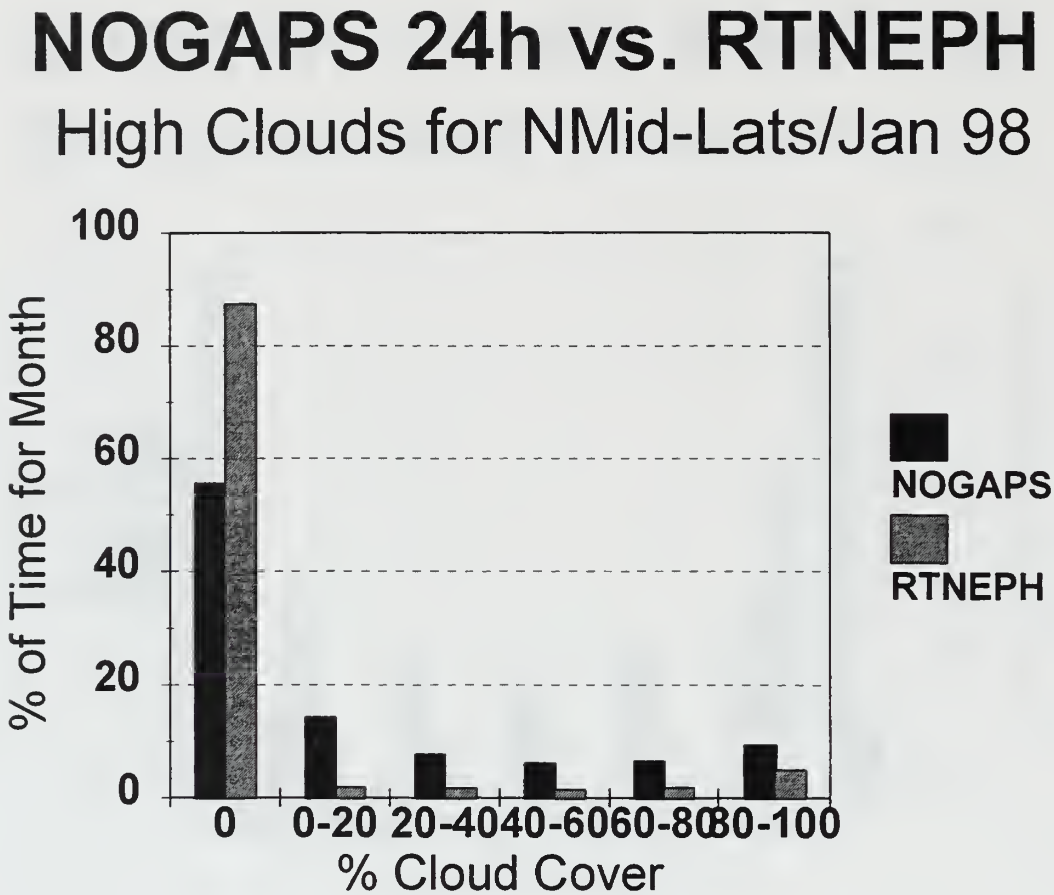

Figure 4.32. 24h NOGAPS and RTNEPH high clouds for the northern mid-latitudes for January 1998.

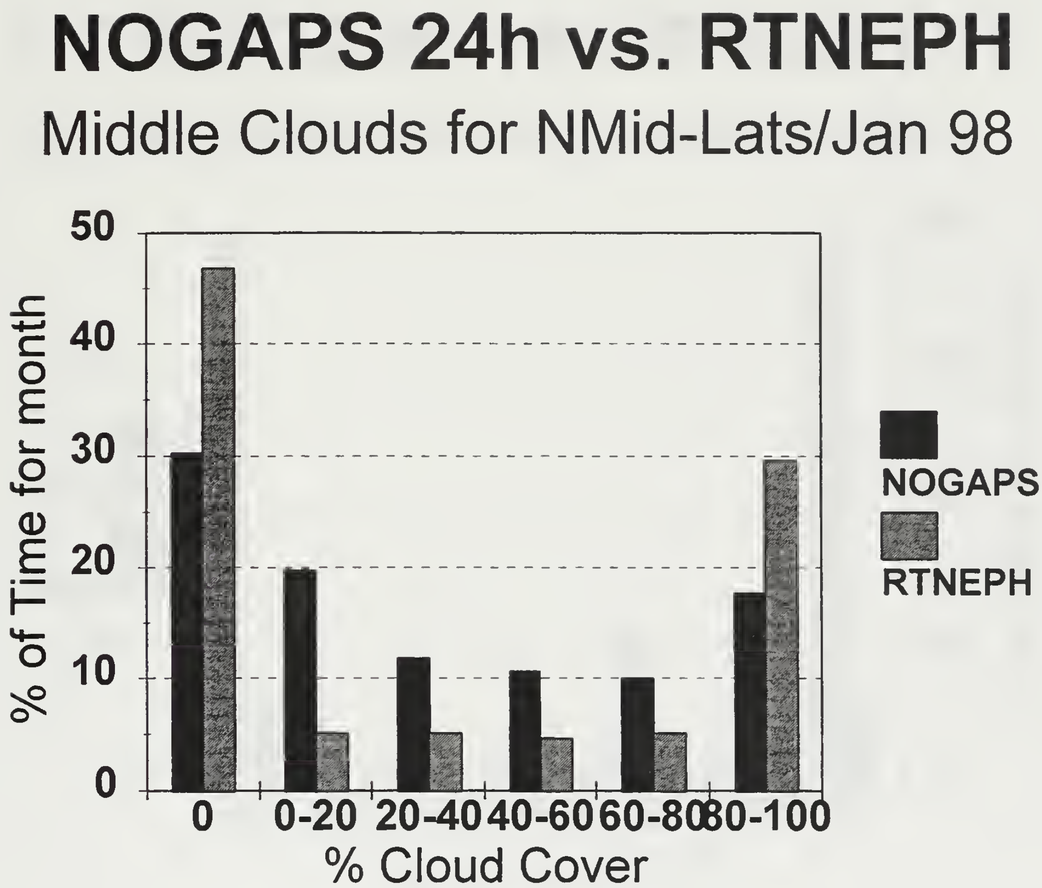

Figure 4.33. 24h NOGAPS and RTNEPH middle clouds for the northern mid-latitudes for January 1998.

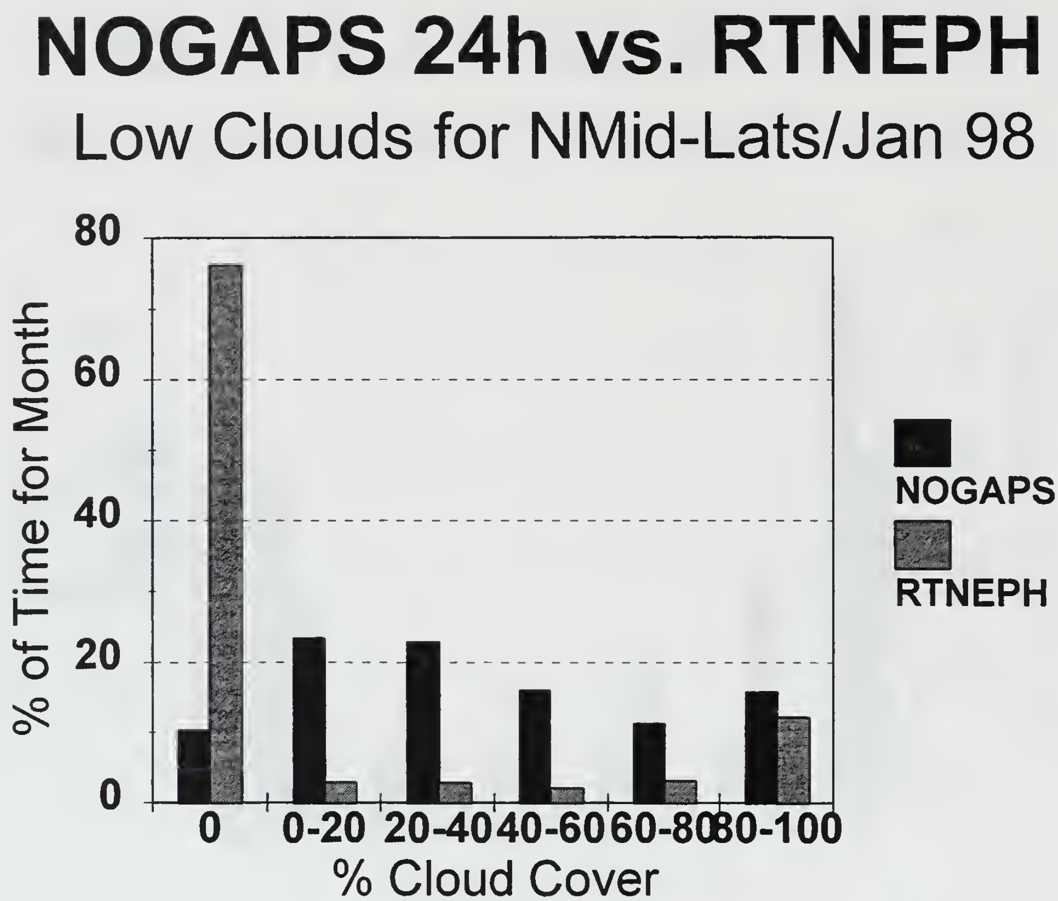

Figure 4.34. 24h NOGAPS and RTNEPH low clouds for the northern mid-latitudes for January 1998.

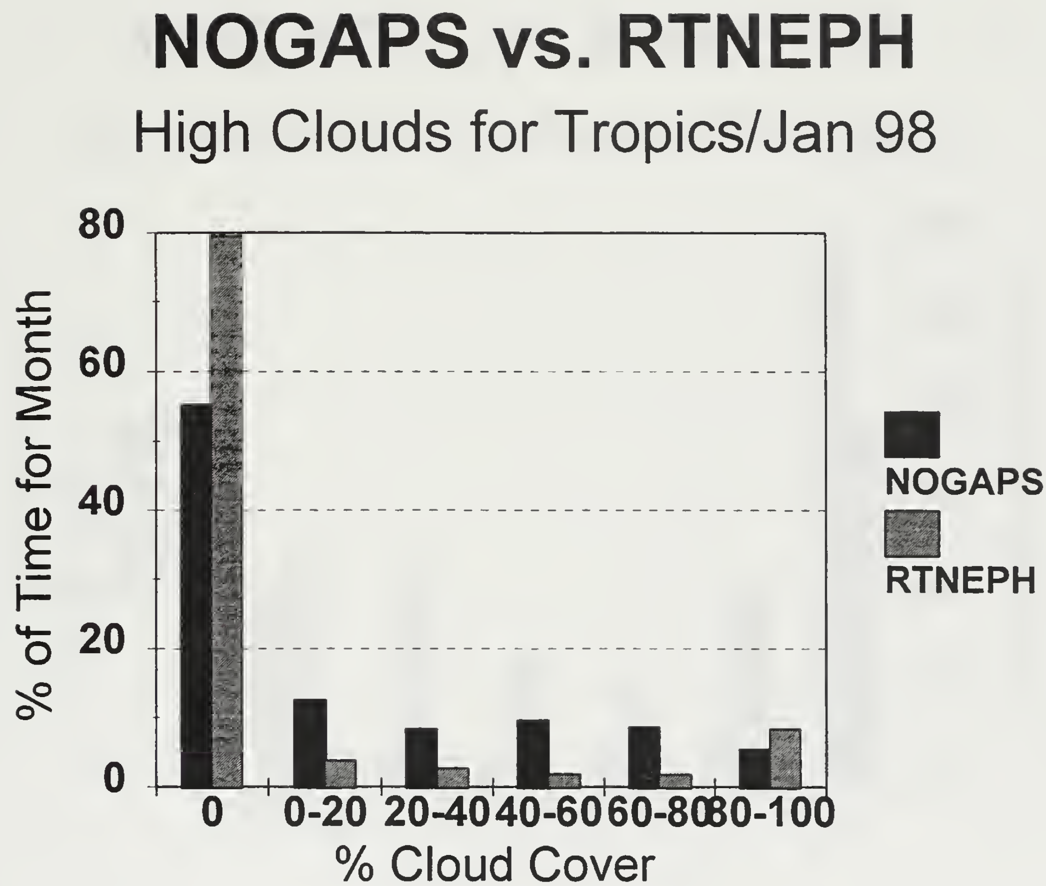

Figure 4.35. NOGAPS and RTNEPH high clouds analyses for the tropics for January 1998. Similar shape as the northern mid-latitudes case shown in Figure 4.26.

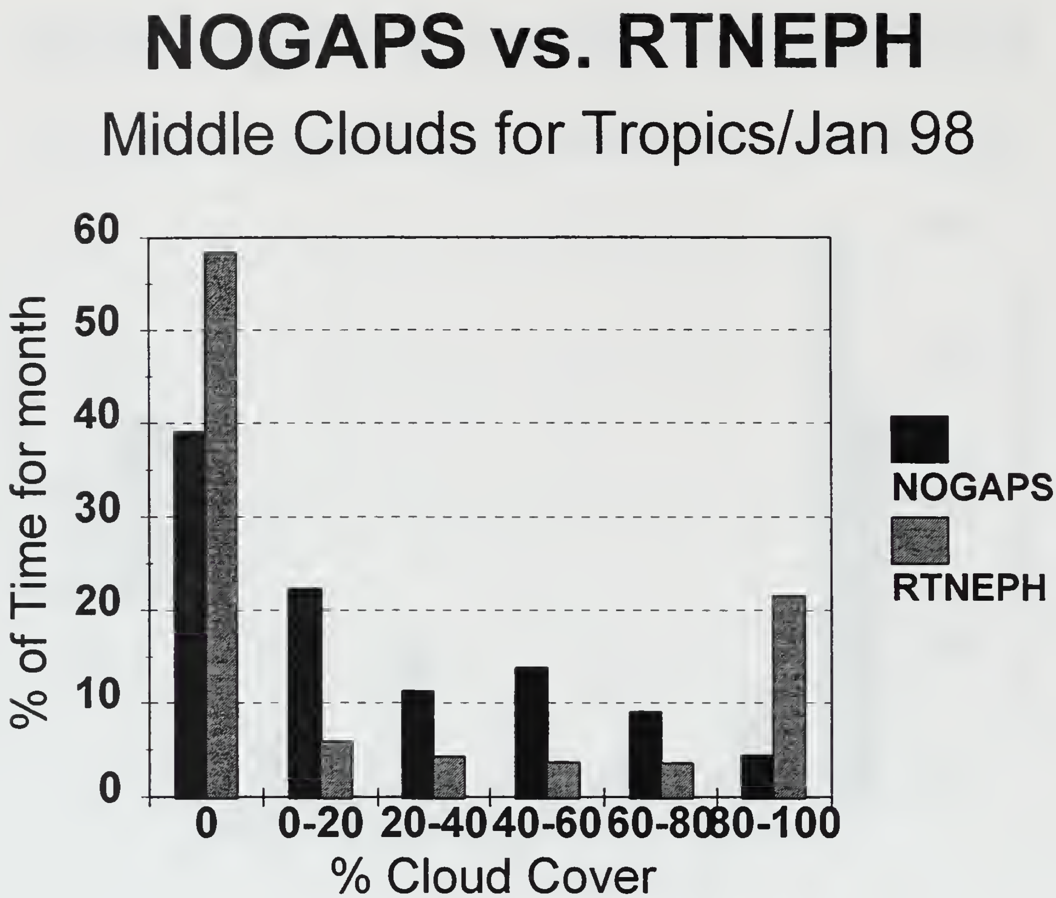

Figure 4.36. NOGAPS and RTNEPH middle clouds analyses for the tropics for January 1998.

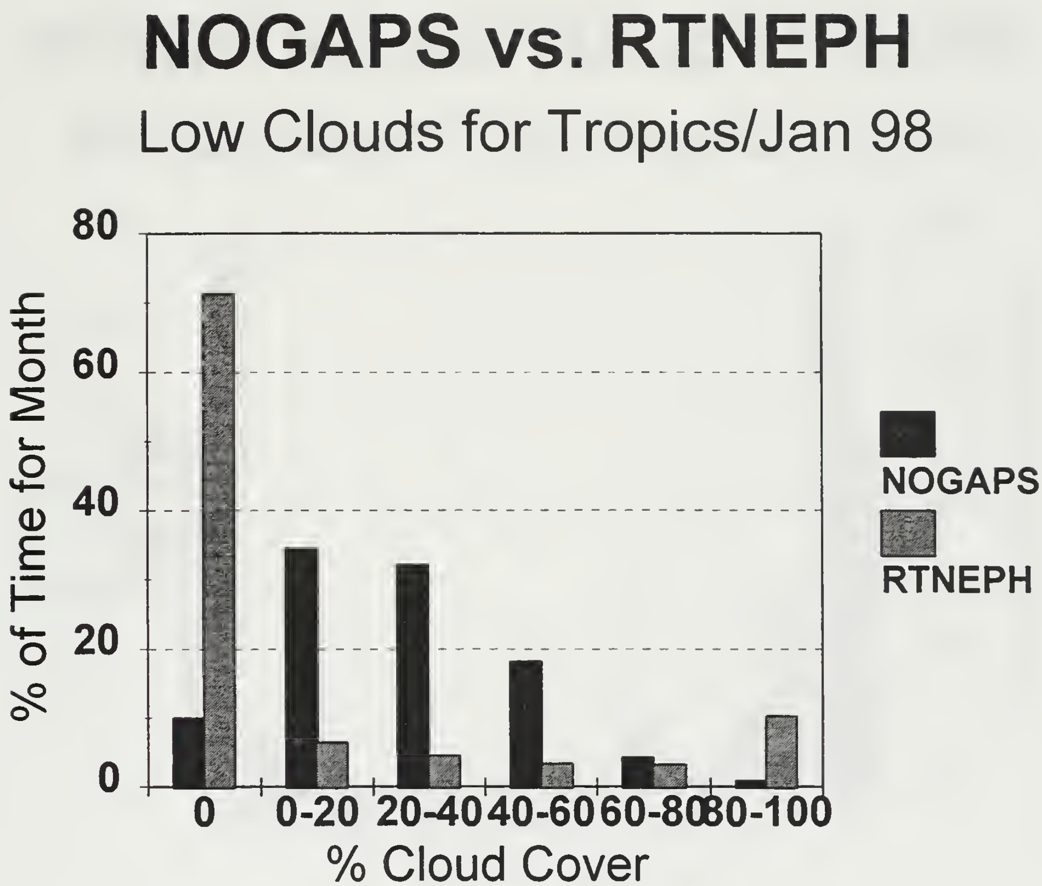

Figure 4.37. NOGAPS and RTNEPH low clouds analyses for the tropics for January 1998.

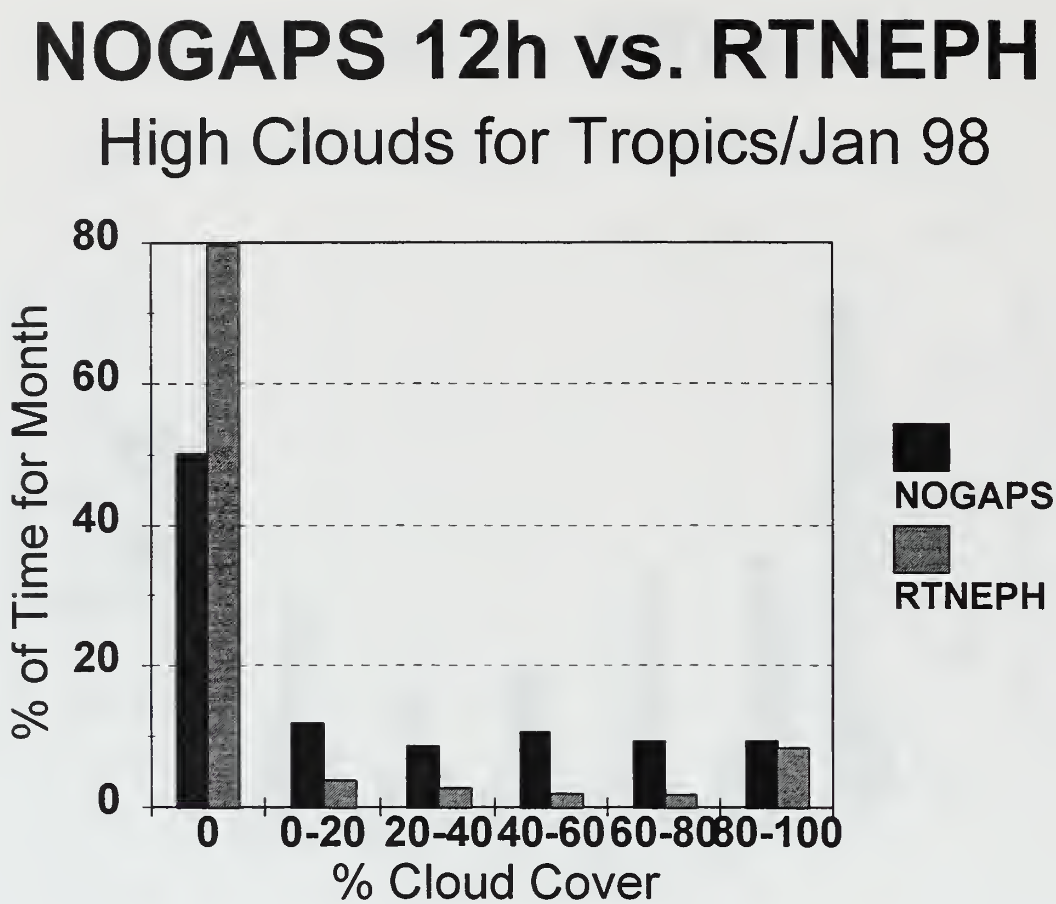

Figure 4.38. 12h NOGAPS and RTNEPH high clouds for the tropics for January 1998.

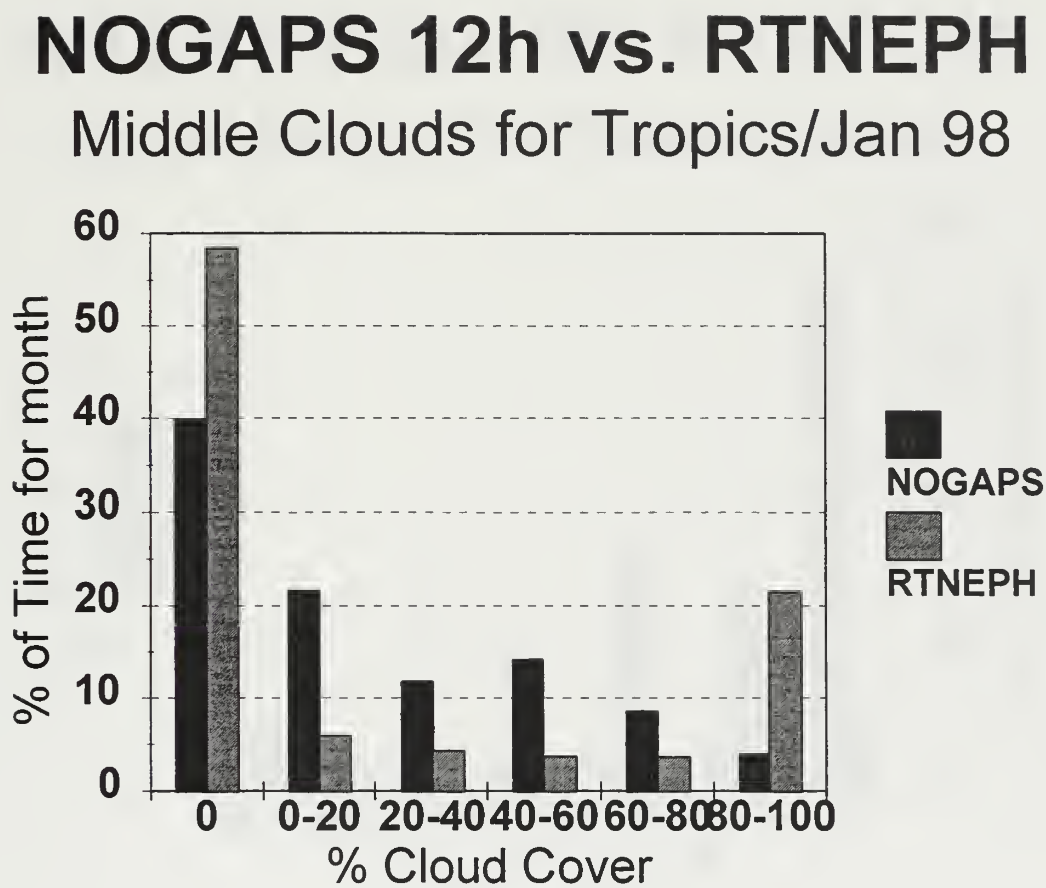

Figure 4.39. 12h NOGAPS and RTNEPH middle clouds for the tropics for January 1998.

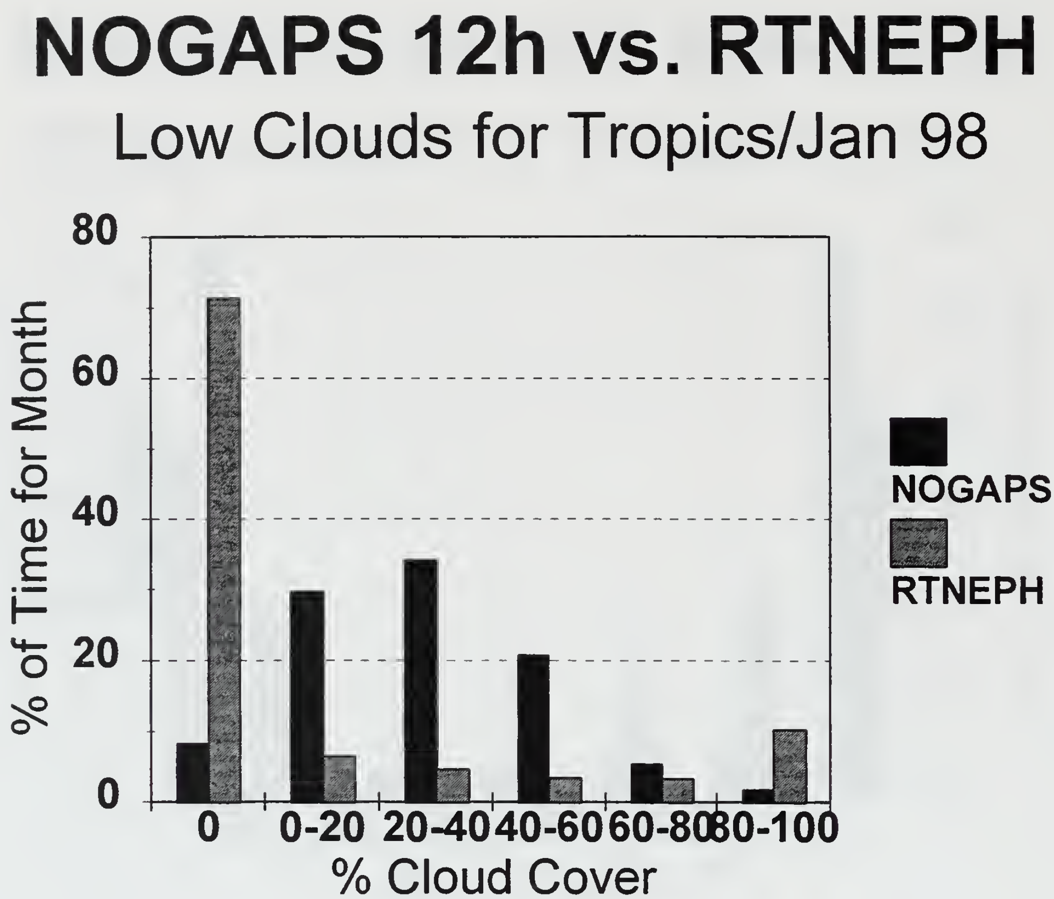

Figure 4.40. 12h NOGAPS and RTNEPH low clouds for the tropics for January 1998.

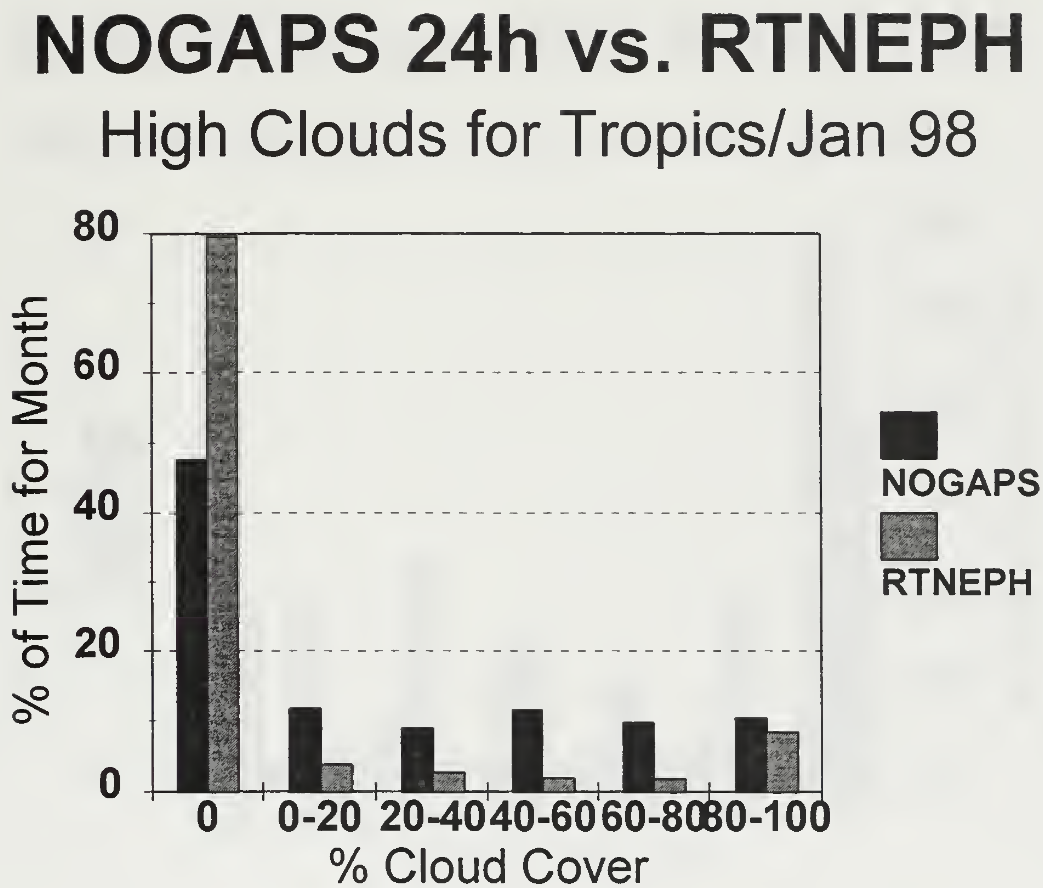

Figure 4.41. 24h NOGAPS and RTNEPH high clouds for the tropics for January 1998.

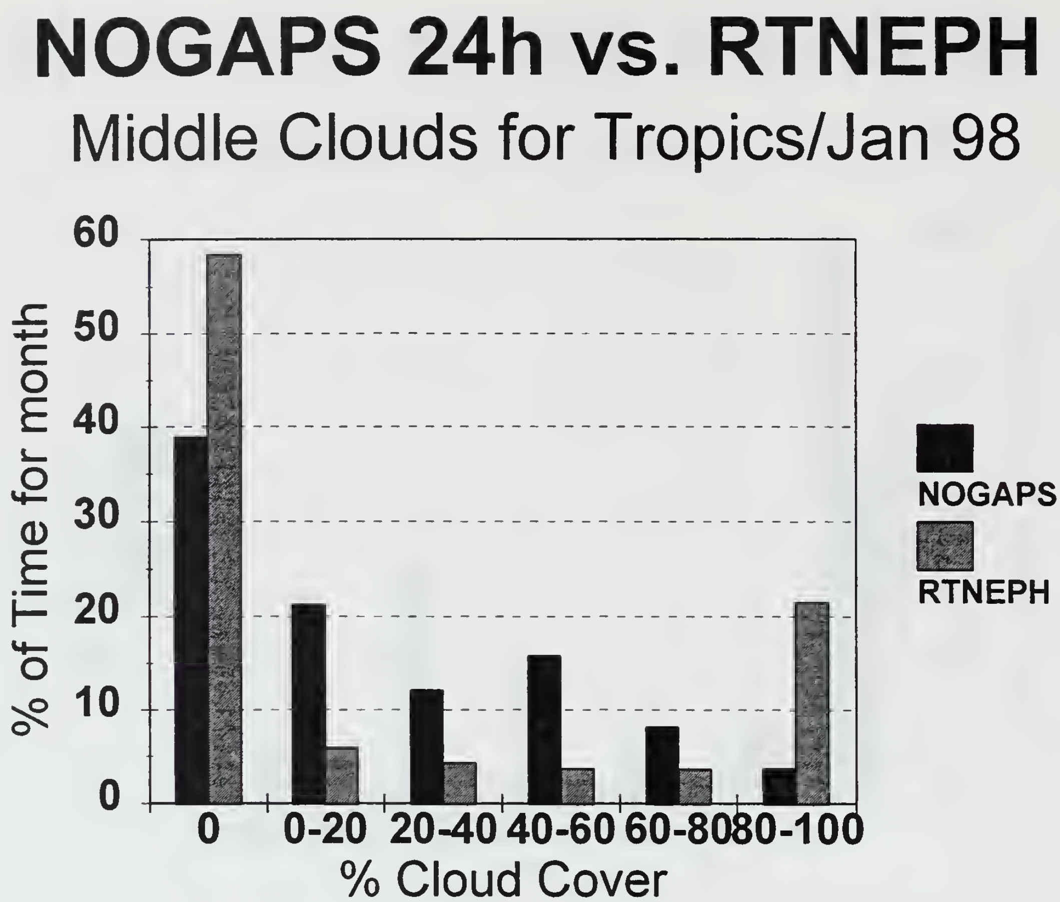

Figure 4.42. 24h NOGAPS and RTNEPH middle clouds for the tropics for January 1998.

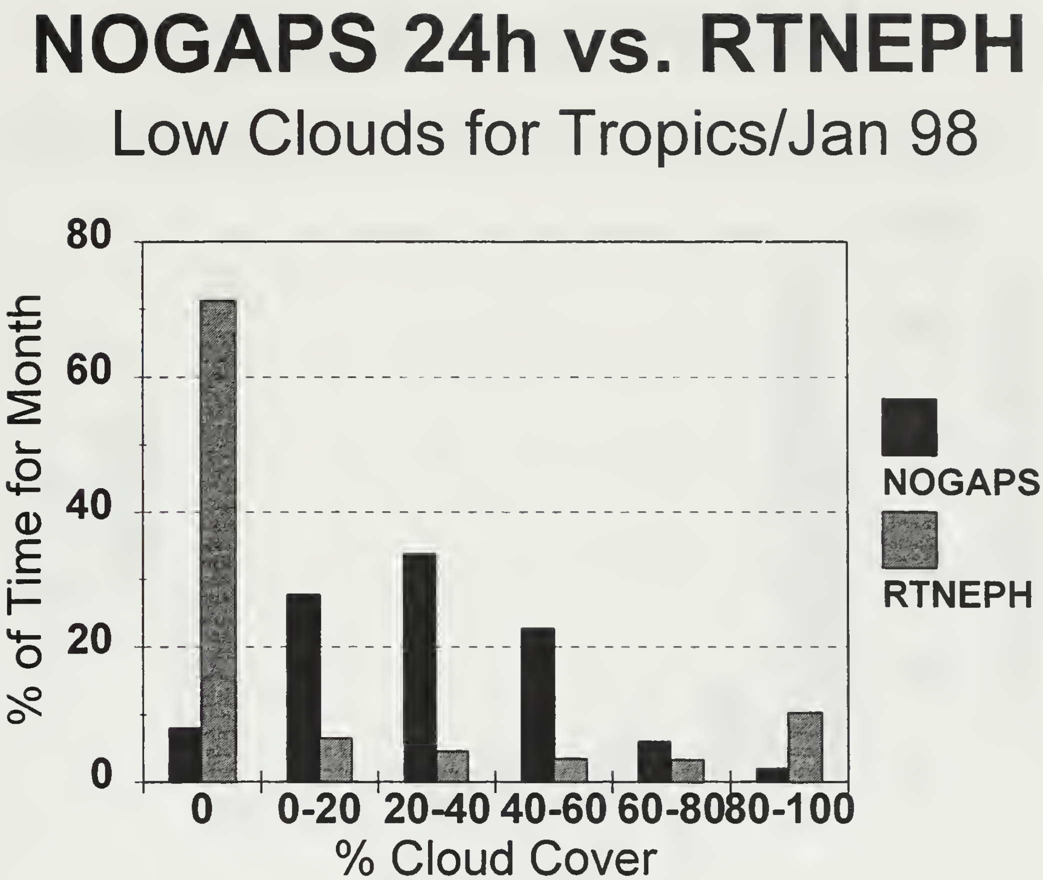

Figure 4.43. 24h NOGAPS and RTNEPH low clouds for the tropics for January 1998.

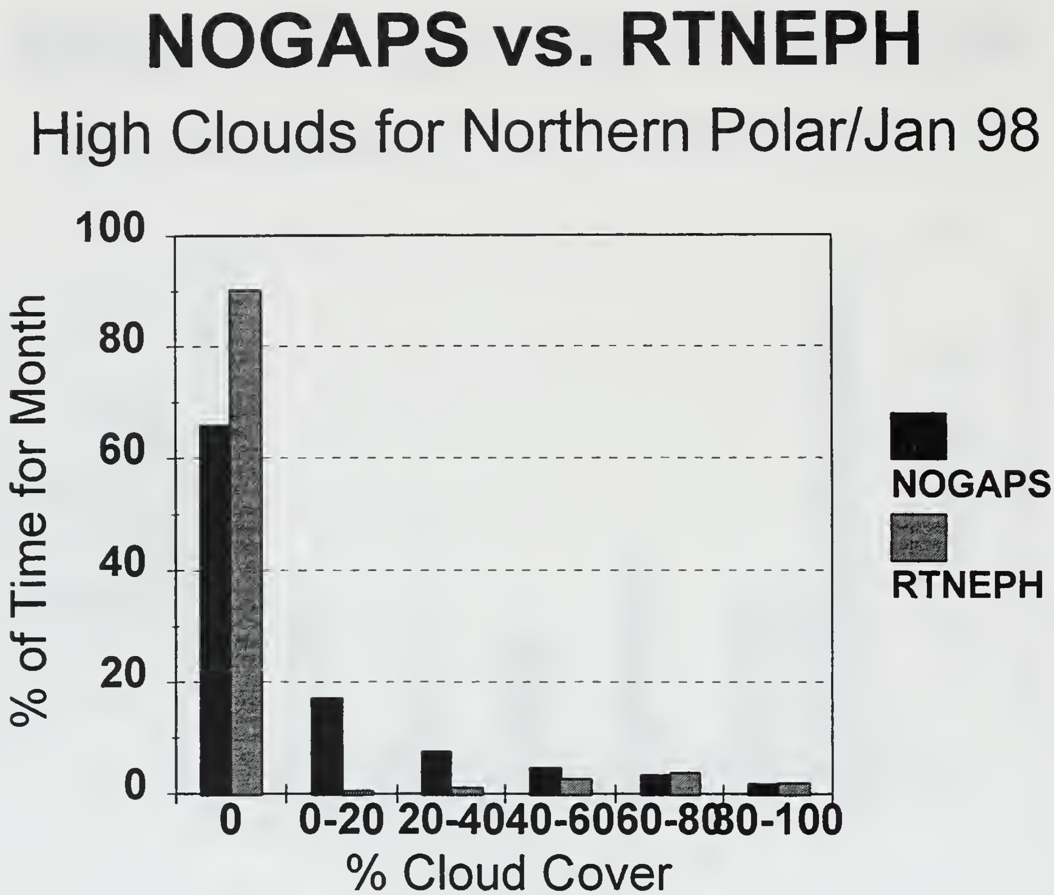

Figure 4.44. NOGAPS and RTNEPH high clouds analyses for the northern polar region for January 1998. Note that the zero category for NOGAPS starts out large and rapidly decreases throughout.

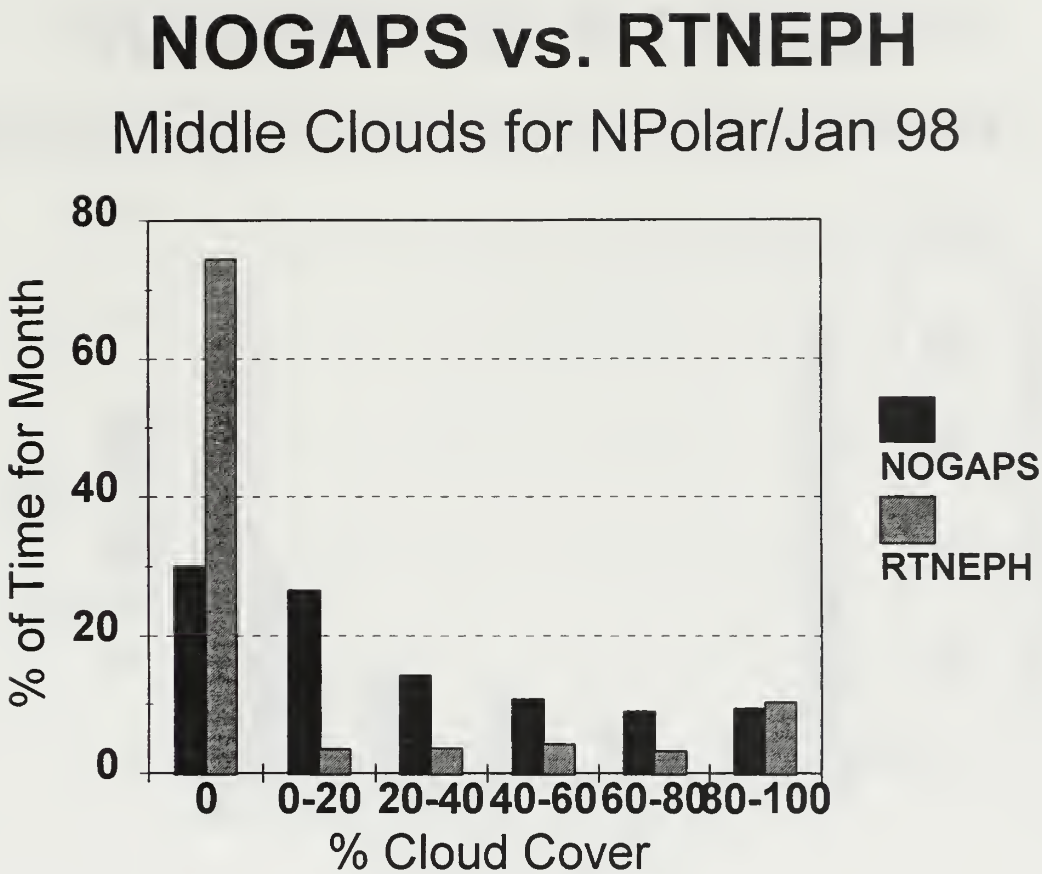

Figure 4.45. NOGAPS and RTNEPH middle clouds analyses for the northern polar region for January 1998. Note steady decrease for NOGAPS throughout the forecast period.

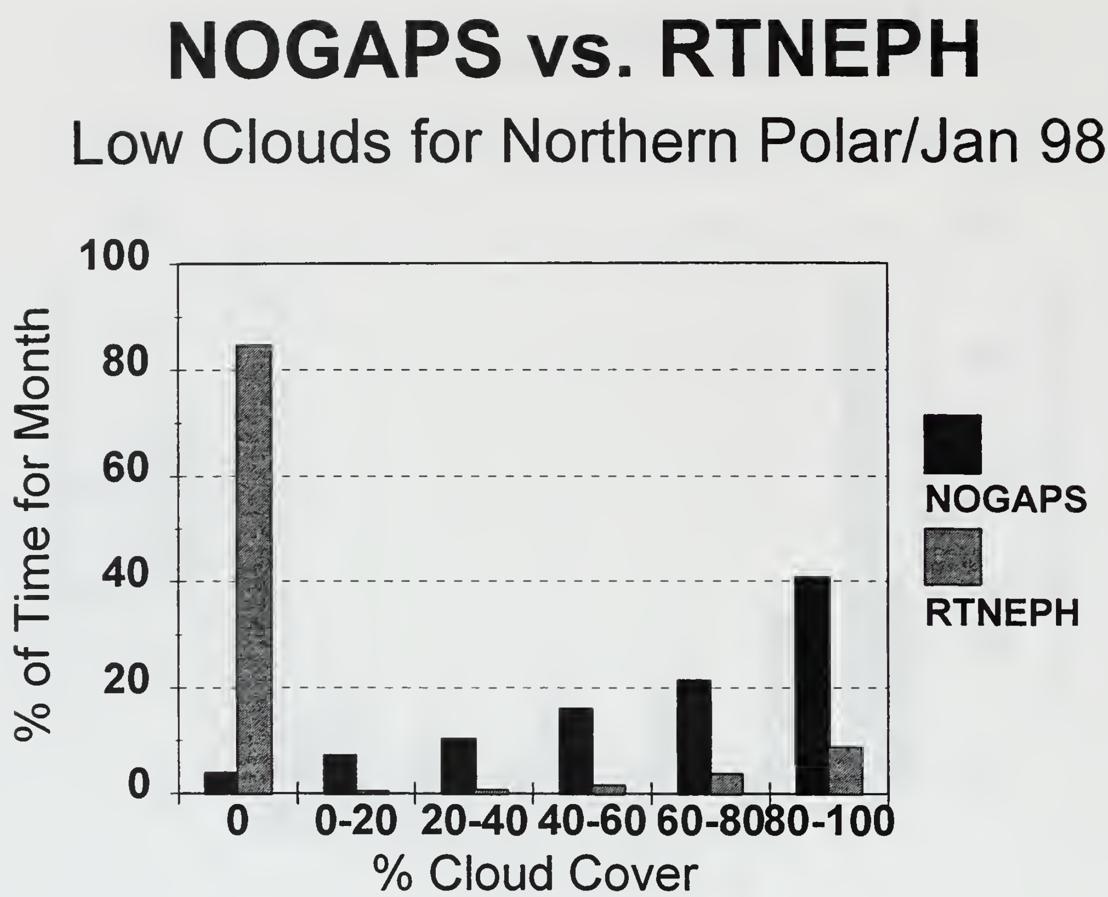

Figure 4.46. NOGAPS and RTNEPH low clouds analyses for the northern polar region for January 1998. Note that NOGAPS starts out small and steadily increases as the cloud cover category increases.

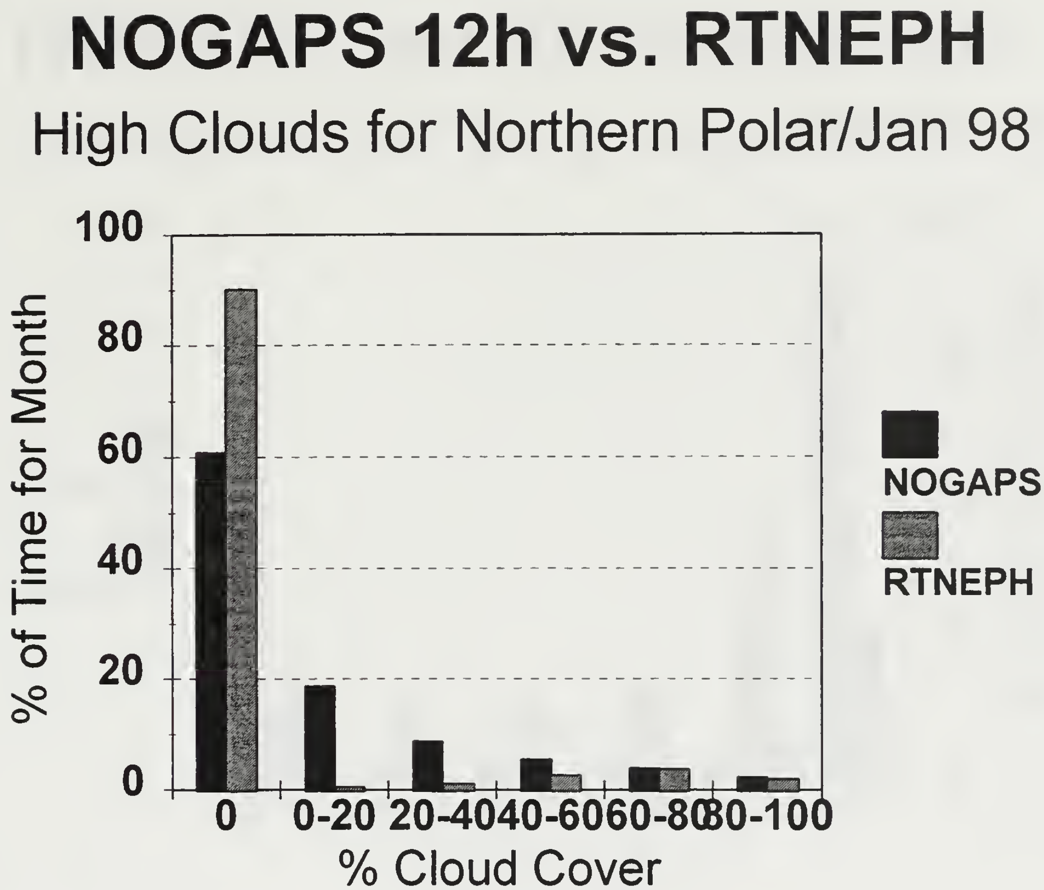

Figure 4.47. 12h NOGAPS and RTNEPH high clouds for the northern polar region for January 1998. Most of the categories are larger than at 00h which is consistent with what is shown in Figures 4.14 and 4.20.

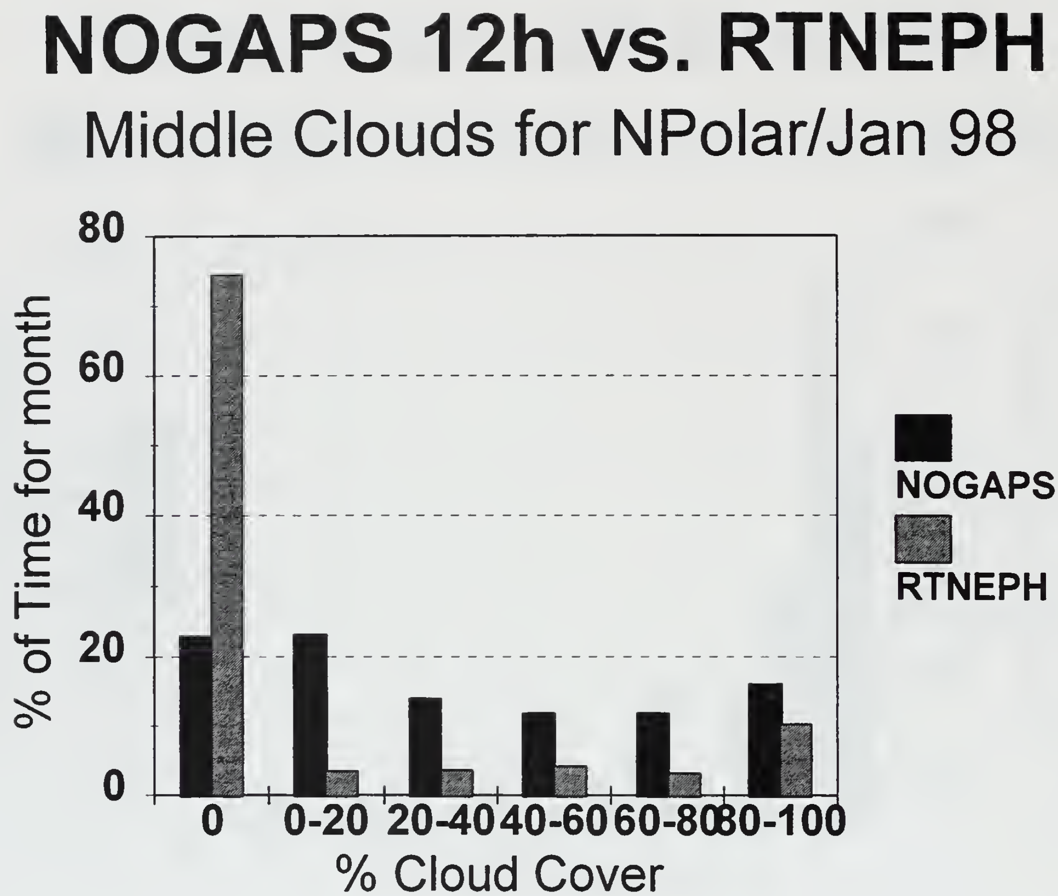

Figure 4.48. 12h NOGAPS and RTNEPH middle clouds for the northern polar region for January 1998. Most of the categories are larger than at 00h which is consistent with what is shown in Figures 4.15 and 4.21.

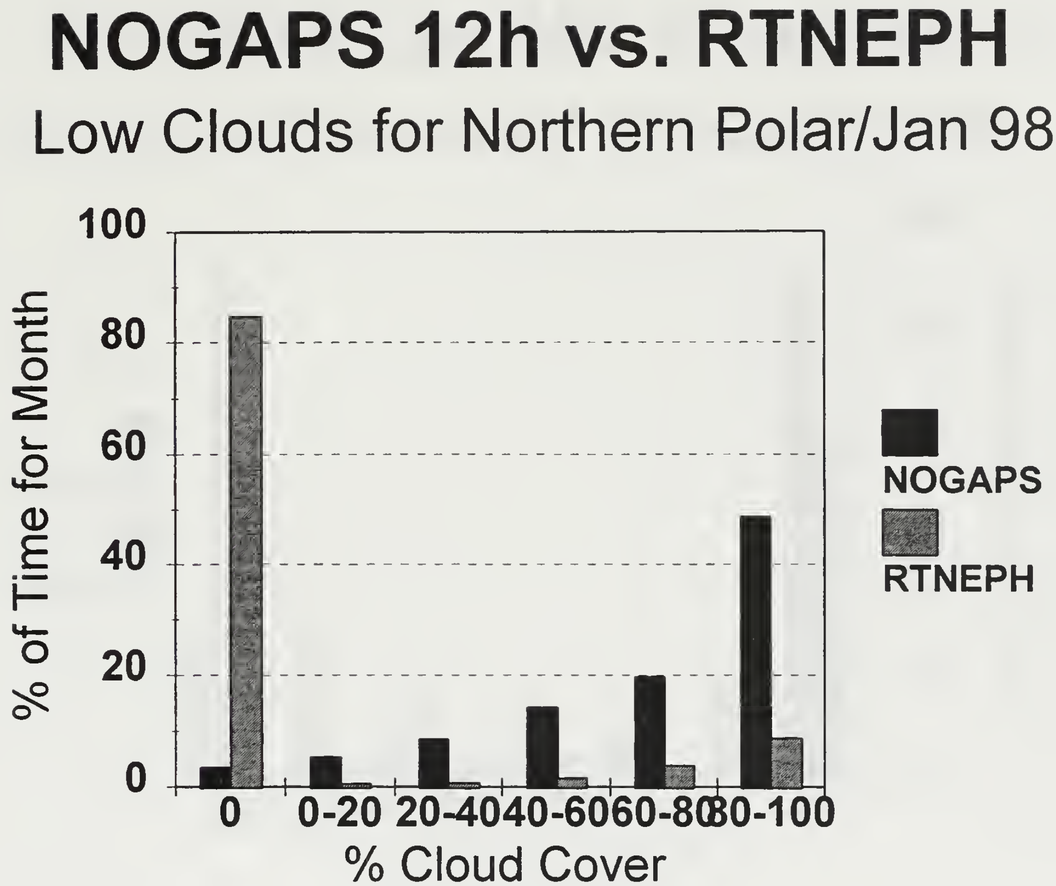

Figure 4.49. 12h NOGAPS and RTNEPH low clouds for the northern polar region for January 1998. Most of the categories are larger than at 00h which is consistent with what is shown in Figures 4.16 and 4.22.

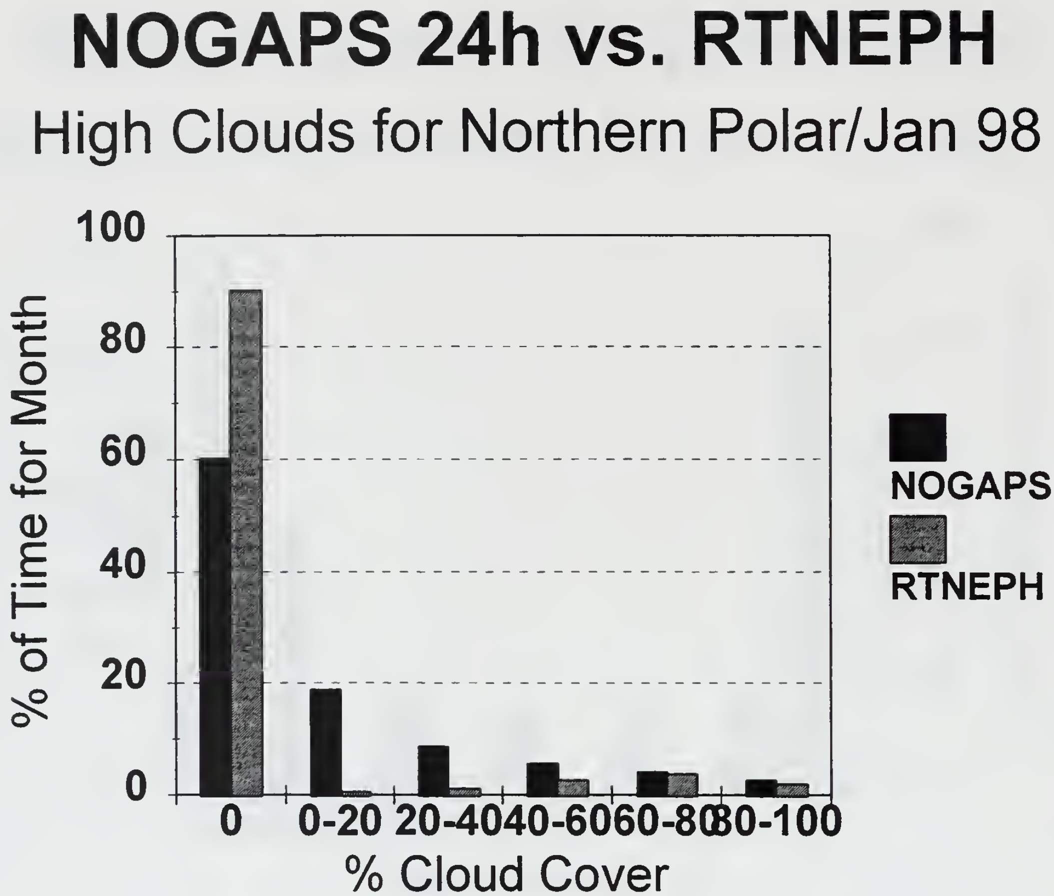

Figure 4.50. 24h NOGAPS and RTNEPH high clouds for the northern polar region for January 1998. This is very similar to the 12h forecast shown in Figure 4.47.

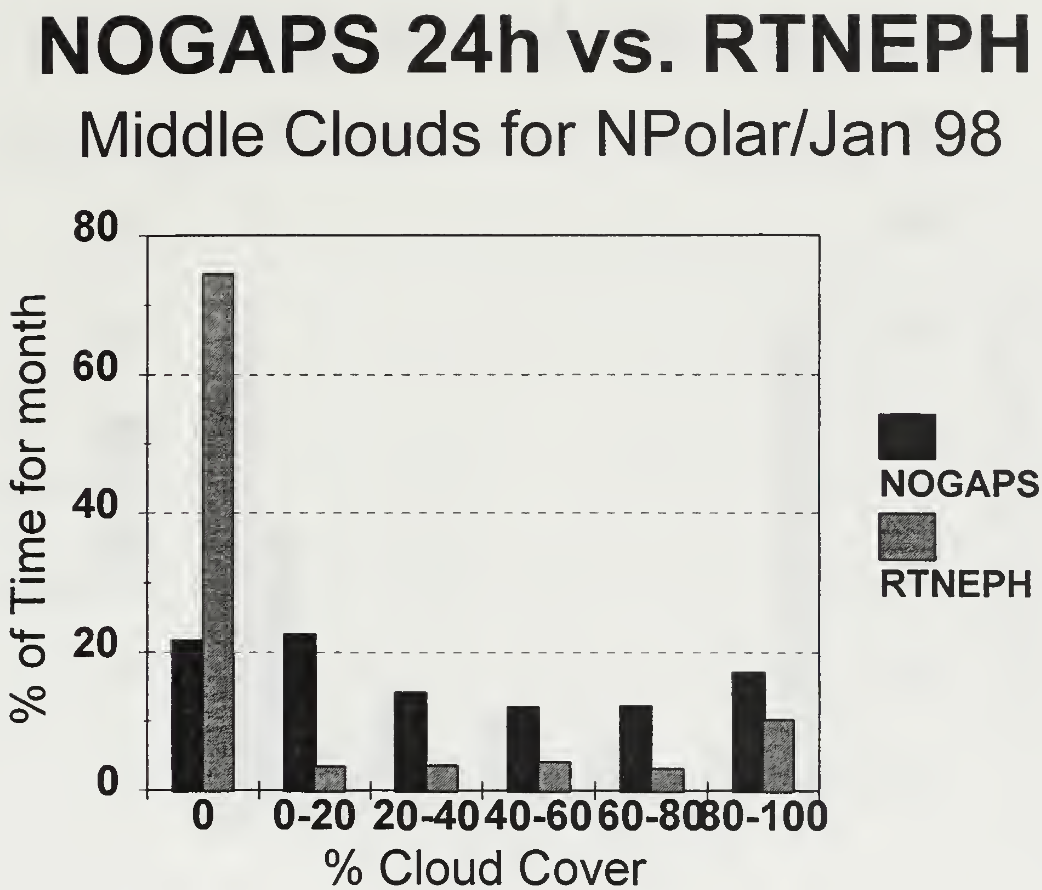

Figure 4.51. 24h NOGAPS and RTNEPH middle clouds for the northern polar region for January 1998. This is very similar to the 12h forecast shown in Figure 4.48.

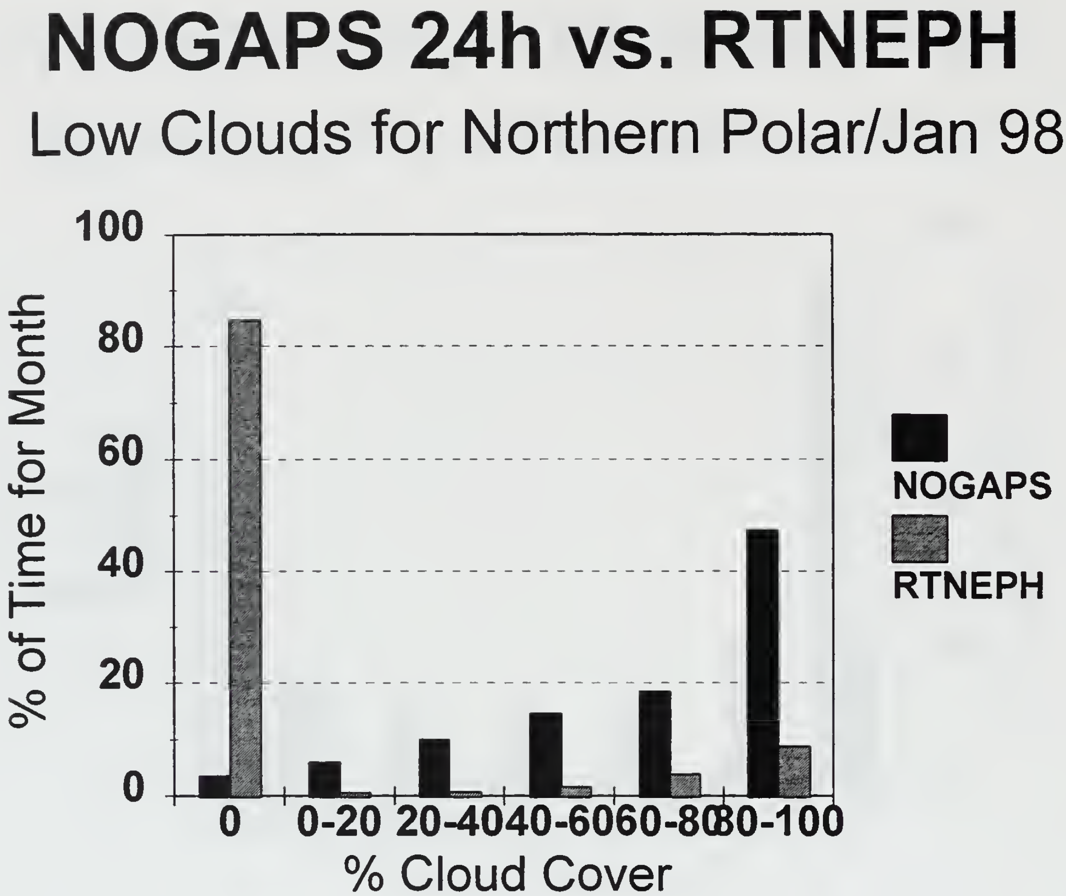

Figure 4.52. 24h NOGAPS and RTNEPH low clouds for the northern polar region for January 1998. This is very similar to the 12h forecast shown in Figure 4.49.

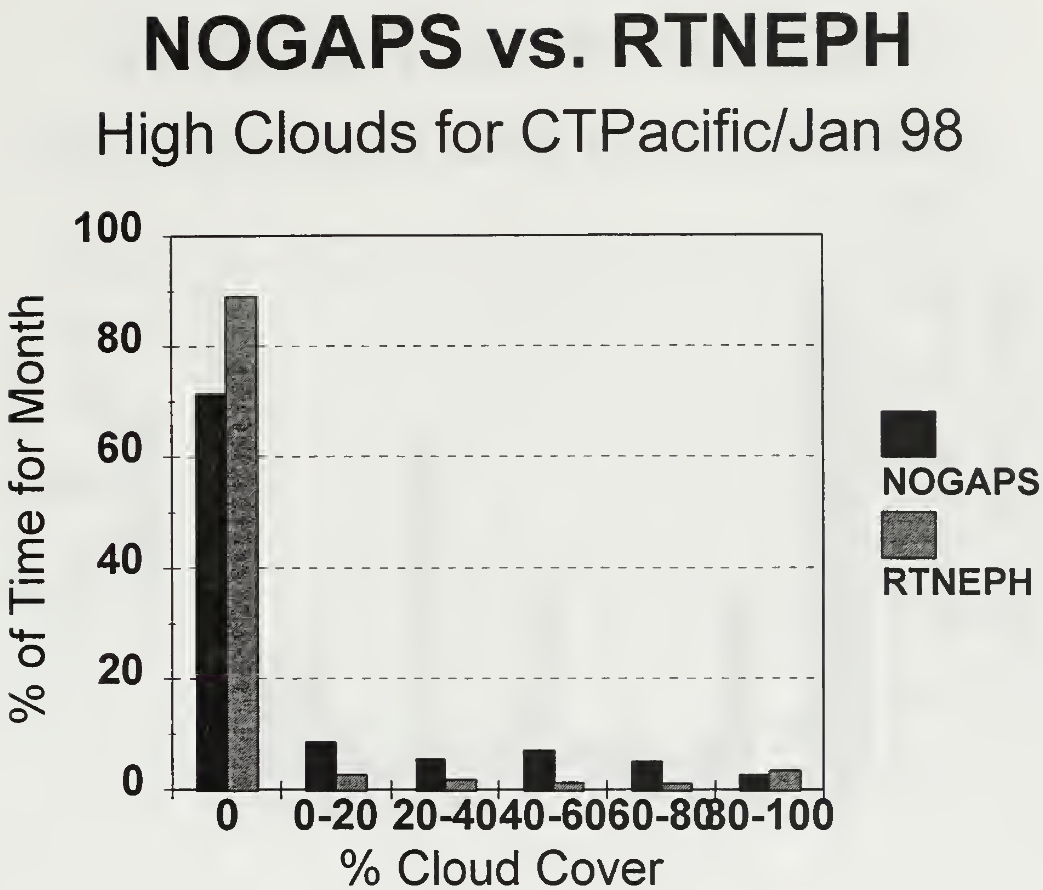

Figure 4.53. NOGAPS and RTNEPH high clouds analyses for the Central Tropical Pacific for January 1998. Both have fairly large zero category values and drop off significantly as you move to the 0-20% category.

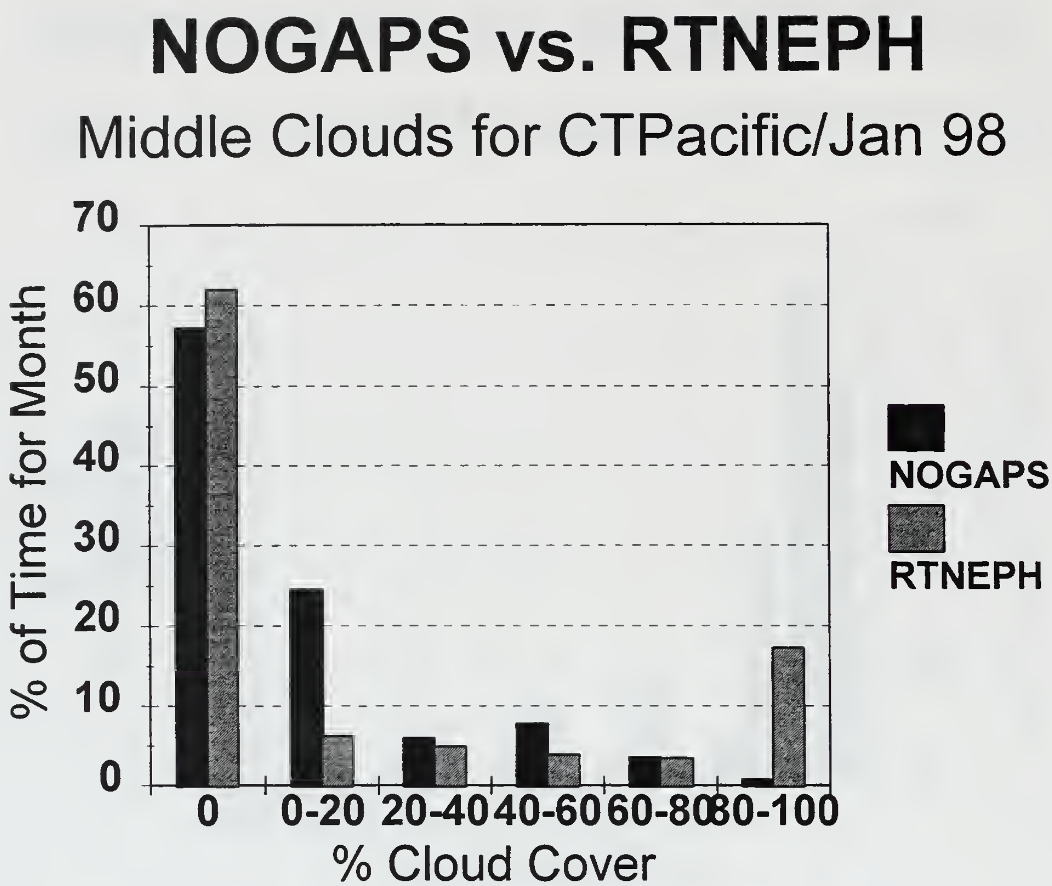

Figure 4.54. NOGAPS and RTNEPH middle clouds analyses for the Central Tropical Pacific for January 1998. Fairly similar pattern for both NOGAPS and RTNEPH that was seen in Figure 4.53.

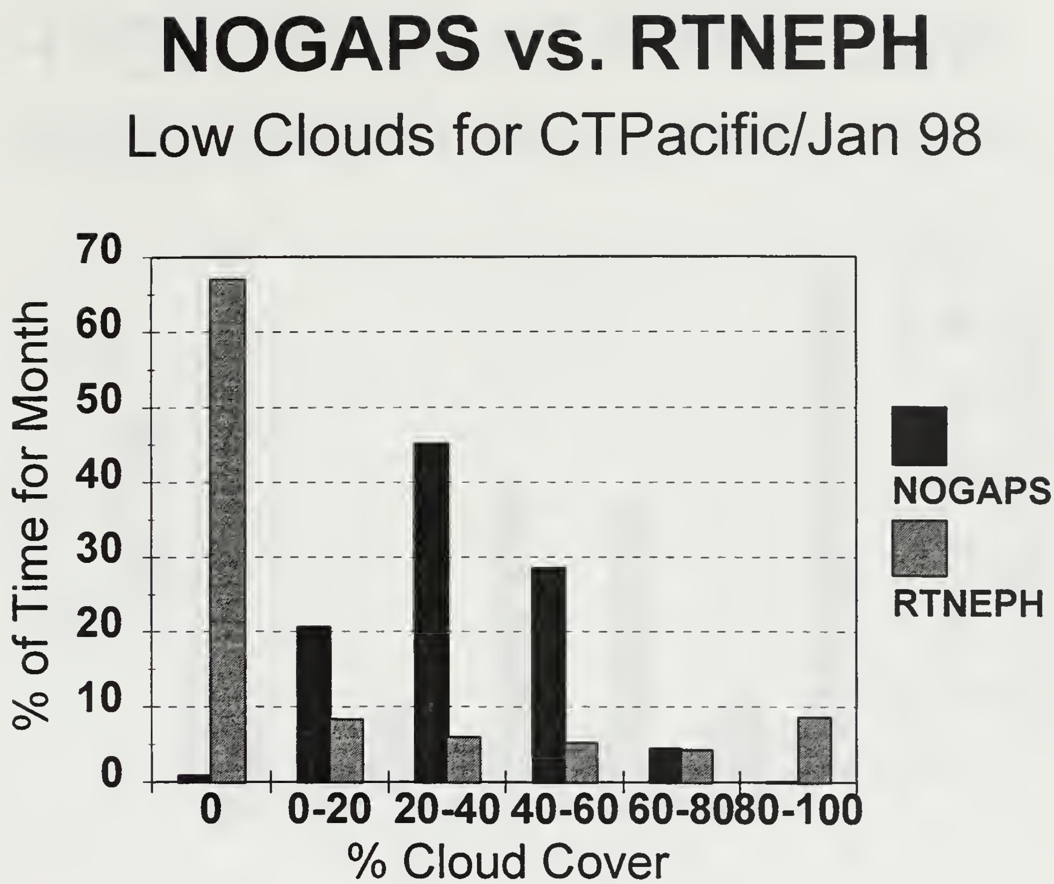

Figure 4.55. NOGAPS and RTNEPH low clouds analyses for the Central Tropical Pacific for January 1998. Note how NOGAPS is very small for the zero category and increases then decreases as you in crease the cloud cover categories.

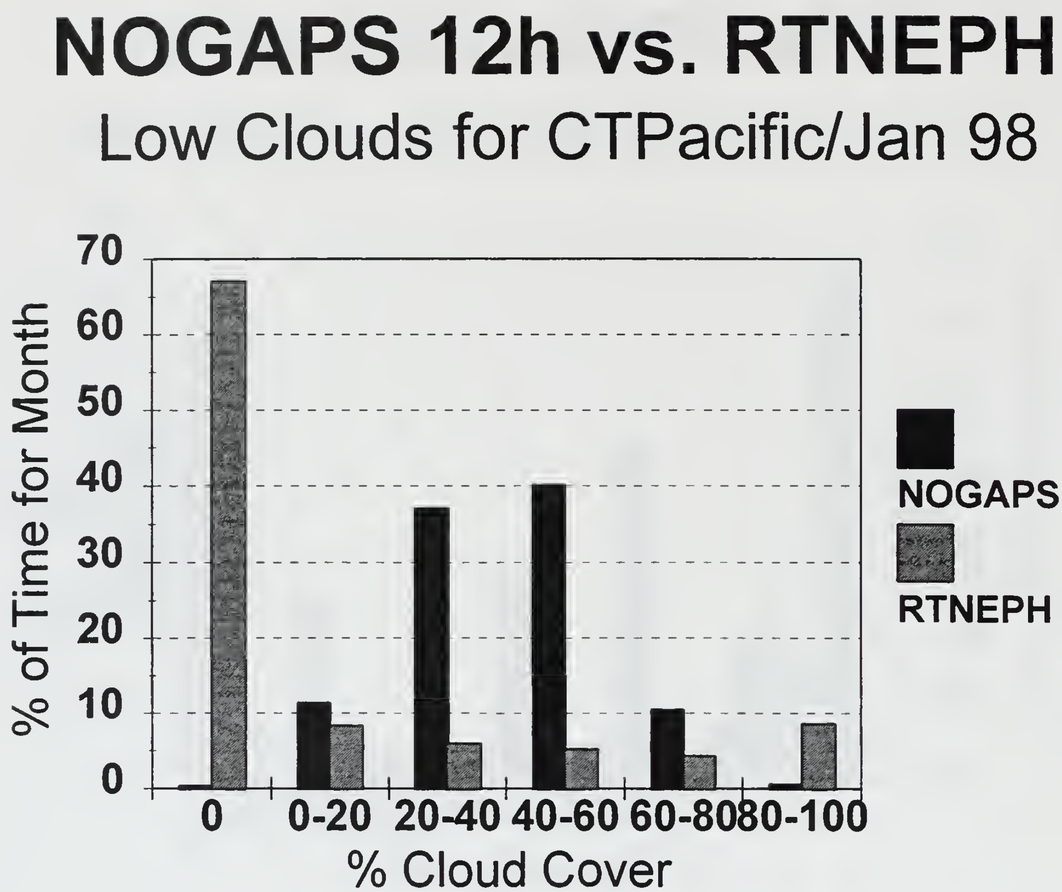

Figure 4.56. 12h NOGAPS and RTNEPH low clouds for the Central Tropical Pacific for January 1998. Note how it peaks at the 40-60% category rather than the 20-40% category for the analysis which was shown in Figure 4.55.

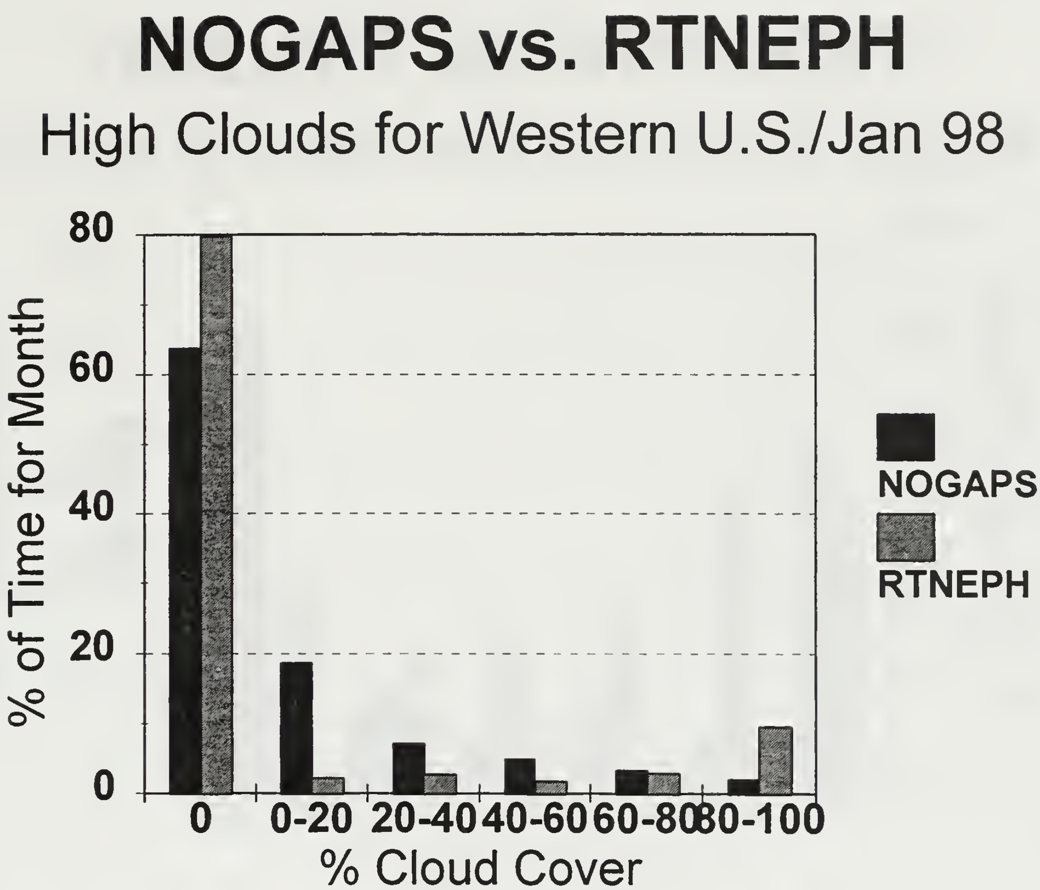

Figure 4.57. NOGAPS and RTNEPH high clouds analyses for the Western United States for January 1998.

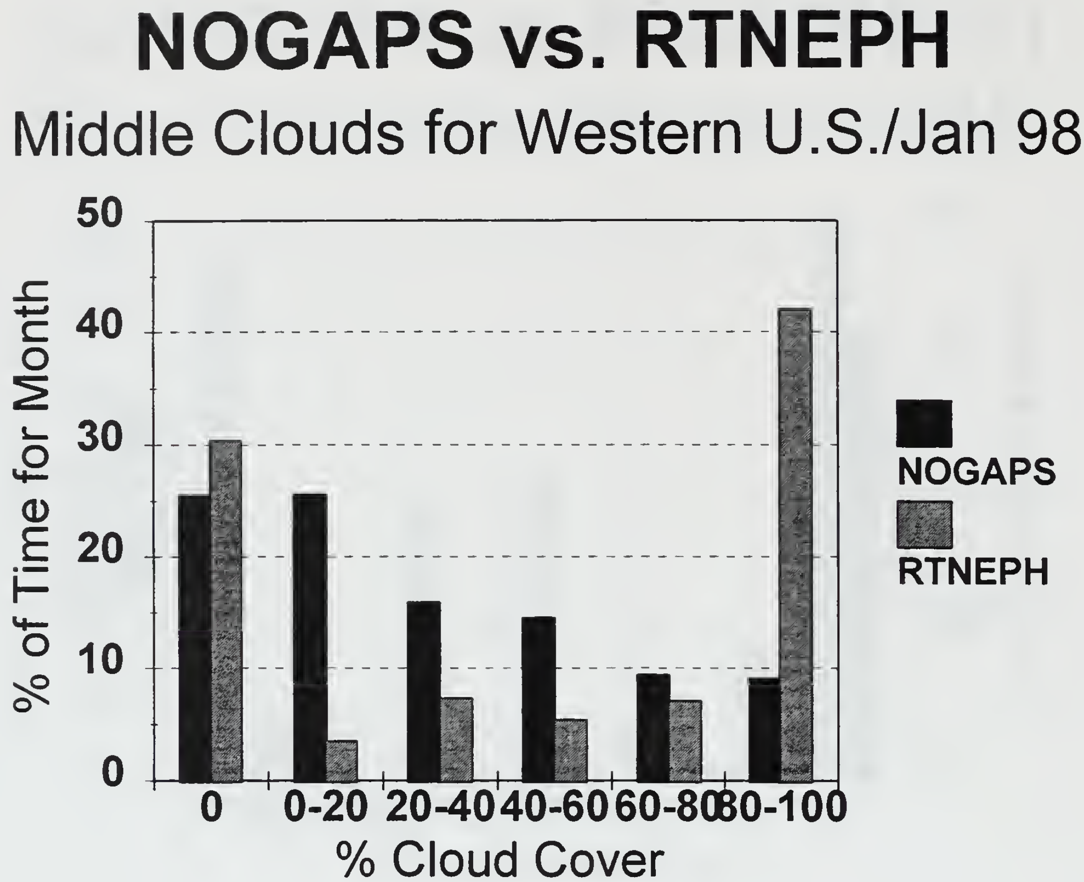

Figure 4.58. NOGAPS and RTNEPH middle clouds analyses for the Western United States for January 1998. NOGAPS seems to be more evenly distributed throughout the categories.

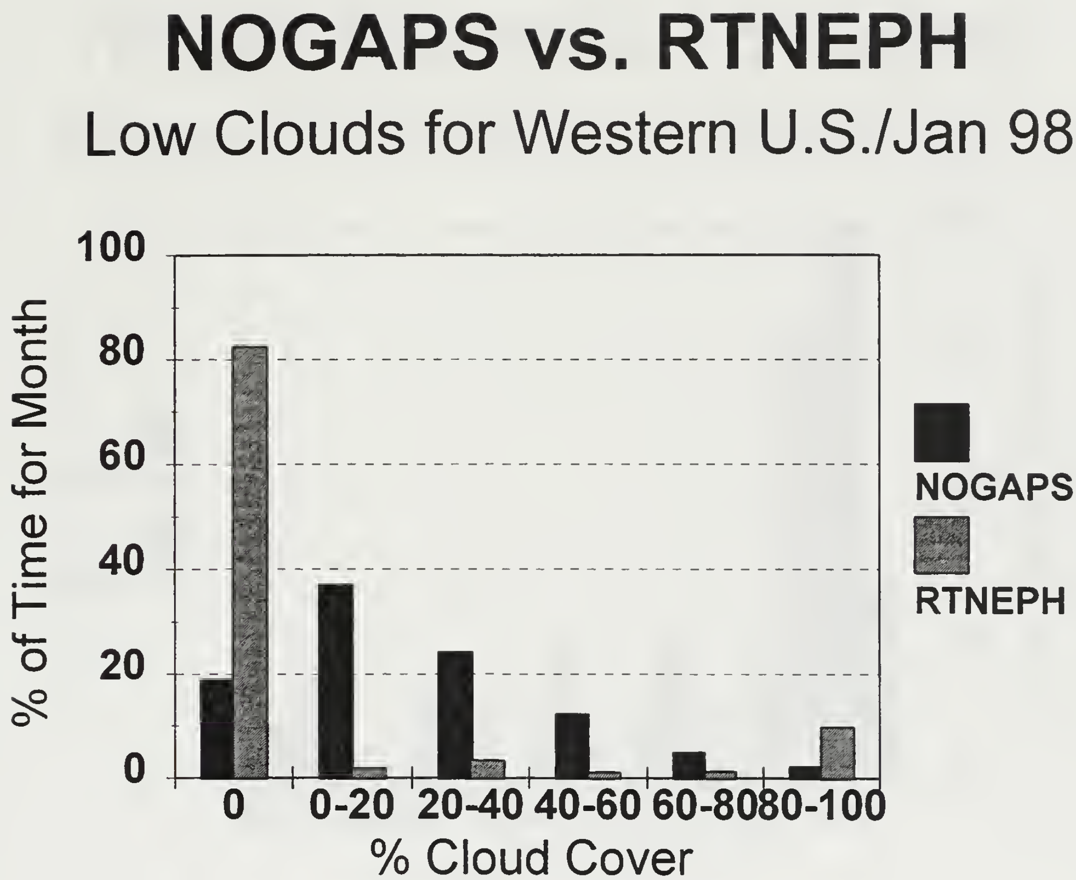

Figure 4.59. NOGAPS and RTNEPH low clouds analyses for the Western United States for January 1998.

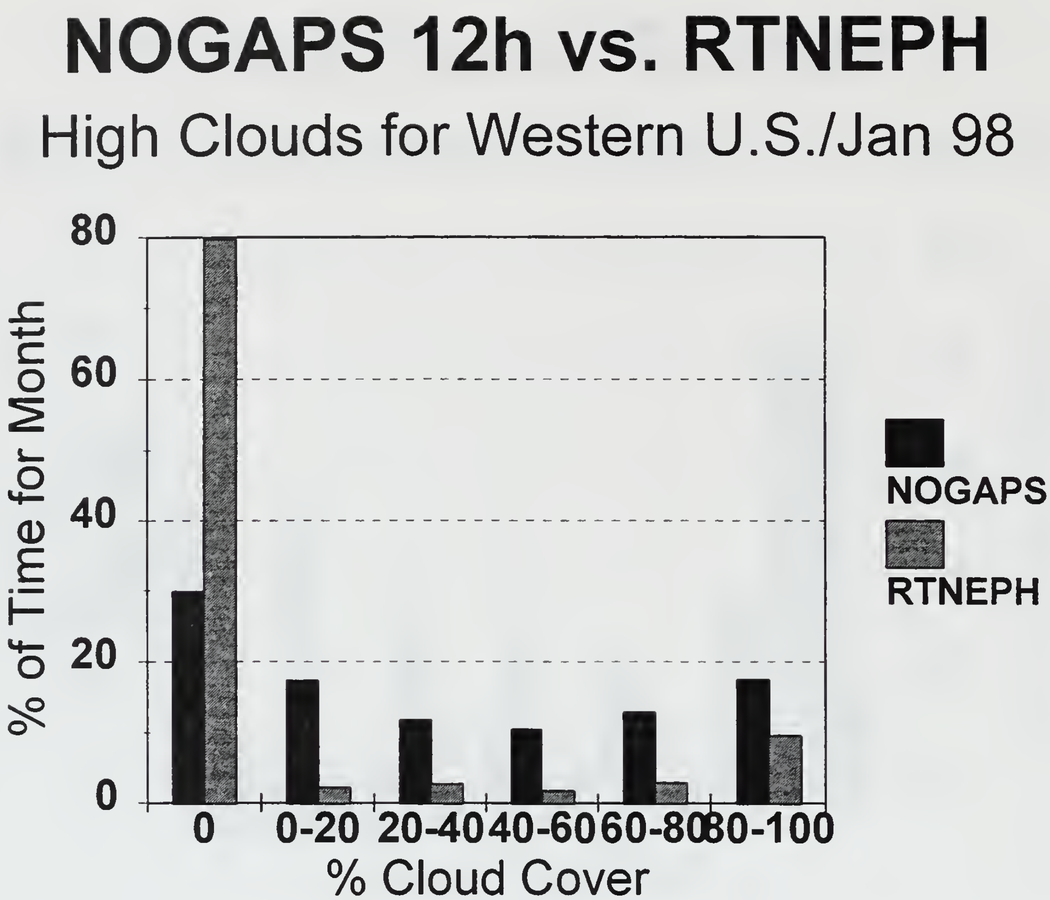

Figure 4.60. 12h NOGAPS and RTNEPH high clouds for the Western United States for January 1998.

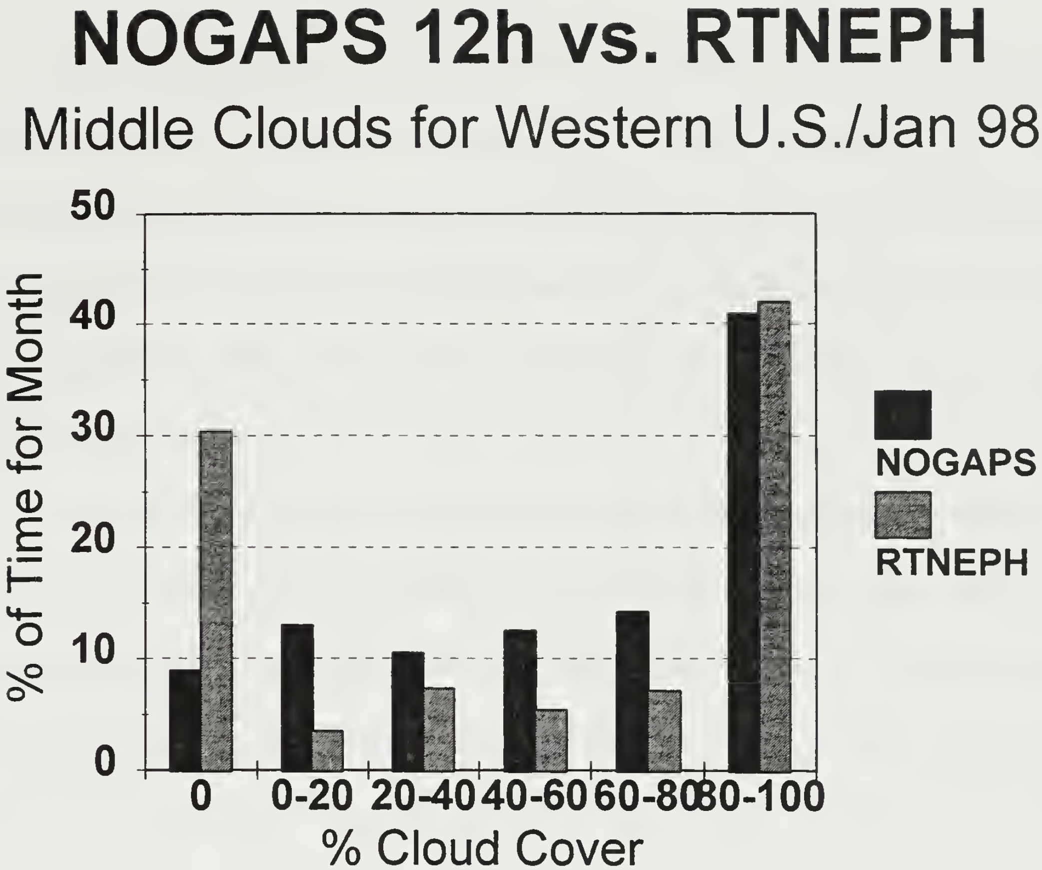

Figure 4.61. 12h NOGAPS and RTNEPH middle clouds for the Western United States for January 1998. Note how the 80-100% category has drastically increased from the analysis in Figure 4.58.

V. CONCLUSIONS AND RECOMMENDATIONS

This thesis compared RTNEPH and NOGAPS analysis for high, middle, and low clouds during January 1998 and October 1997. The daily data contained high frequency oscillations, but the overall behavior was clear. NOGAPS forecasts at 12h, 24h, 36h, and 48h were compared with the appropriate RTNEPH analyses. The difference between these fields were compared with 250 mb temperature errors from the NOGAPS forecasts, but no clear correlations were found.

The difference fields were averaged over each month and plotted as a function of forecast period out to 48h. For the high clouds the mean difference was positive and it increased rapidly in the mid-latitudes and the tropics over the first 12h and it grew more slowly there after. This rapid change was apparently related to model adjustments to initial conditions. For the middle clouds in the mid-latitudes the initial mean difference was negative and it increased rapidly for the first 12h before becoming nearly constant. At the lower levels the difference was positive and it remained so. Similar analyses of the rms differences were in agreement.

The RTNEPH and NOGAPS (including forecasts) were separated into nine categories: clear, 0-20%, 20-40%, 40-60%, 60-80%, and 80-100%. For the high clouds in the mid-latitudes the RTNEPH gave over 80% clear while the NOGAPS gave less then 40% clear. However, the addition of the clear and 0-20% cases brought the NOGAPS up to about 75% of the RTNEPH cases. The NOGAPS had more cases with higher cloud cover so that the average NOGAPS cloud cover was higher than the average RTNEPH cloud cover in agreement with the earlier results. The RTNEPH and NOGAPS histograms had different shapes; RTNEPH had a peak at each end while the NOGAPS decreased monotonously from the peak for clear skies. The histogram pattern for middle clouds for the northern hemisphere was broadly similar. The RTNEPH had a much larger value for the 80-100% category so the mean cloudiness for the RTNEPH was higher than for NOGAPS. For low clouds in the mid-latitudes the RTNEPH has an unusually large number of clear cases and the histogram pattern is very different from the NOGAPS pattern. These differences were most likely the result of problems with the RTNEPH analyses. In particular RTNEPH has trouble identifying low clouds at night from the DMSP infrared retrievals.

We believe that the RTNEPH analyses are reasonable accurate except for in the polar regions and for low clouds. RTNEPH has difficulty identifying low clouds under high level clouds. The RTNEPH and the NOGAPS (except for low clouds) generally agree on the clear areas. However, it appears that NOGAPS underestimates the number of mostly cloudy cases (especially for middle clouds) and the distribution of categories is different. The NOGAPS fields also show a significant change through the first 12h which is partly related to model adjustment. Thereafter the difference between RTNEPH and NOGAPS for high clouds grows slowly with the pattern changing slowly. For the middle clouds the NOGAPS category 80-100% grows slowly which leads to a slow reduction in the mean deviation from the RTNEPH. However, the rms difference still grows slowly.

In order to improve the NOGAPS low cloud fields it might be possible to compare them with RTNEPH analyses which are selected to be in areas of sunlight. Another approach would be to compare the NOGAPS clouds with clouds obtainedfrom certain NOAA satellites.

In any case, the RTNEPH low cloud fields could be improved if they were replaced by the NOGAPS fields.

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