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Stratiform Clouds and their Interaction with Atmospheric Motion
under the direction of

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for the period of
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1. OBSERVATIONS

The spatial patterns of stratocumulus cloud frequency for the continental United States and adjacent oceans were routinely obtained from surface cloud observations every six hours. These frequencies were correlated with upper air patterns at 850, 700 and 500 mb. Significant frequency maxima were found near trough axes over marine areas during relatively stationary large-scale wave patterns. These maxima tended to occur to the east of trough axes. Over continental regions, there was little relationship between stratocumulus and synoptic-scale flows patterns, probably because of the short lifetime of cloud over land.

A summary of these findings follows.

A Stratocumulus Cloud Climatology

Meteorology 496

Spring Semester 1991

by

Charles Pavloski and Jim Calkins

CONTENTS

Chapter 1

STATEMENT OF PURPOSE

Our intention is to use the Department of Meteorology synoptic database to develop a stratocumulus cloud climatology and its accompanied upper air flow patterns for several different mean upper air patterns. The eventual goal is to use these results to guide in parameterization of the heating effects of low-level stratocumulus in a multi-layered quasi-qeostrophic model.

Chapter 2

MEAN STRATOCUMULUS FREQUENCY

The presence of stratocumulus over a region for long periods of time can be represented statistically using the frequency of occurence. The sparceness in space and time of observations over the water forced us to compute mean charts of stratocumulus frequency instead of displaying instantaneous cases. Only one of the databases available proved to be useful for this project.

2.1 Surface Observations Databases

The main database used in our stratocumulus climatology was the WMO standard six hourly synoptic data set that includes ship reports. Other data types did not report reliably enough and did not contain enough ship reports for coverage over the ocean.

The frequency of ship reports proved to be a limiting factor in the amount of data coverage over the oceans. To simply create an instantaneous chart of stratocumulus would leave too many gaps in the data. To correct this problem, an average coverage over three to five days was used. This eventually created a chart that approximately represented the actual stratocumulus patterns as found in the corresponding satellite pictures.

2.2 Computing Stratocumulus Frequency

To compute the stratocumulus frequency, we used the following definition: Stratocumulus was assumed to be present when the sky was 4/8 or more covered with clouds having bases between 500 and 5000 feet. This definiton should remove most unwanted boundary layer clouds, such as scattered cumulus, low stratus and fog.

To account for ship motion, the data were gridded into six degree latitude by six degree longitude blocks. When a ship moved into a specific block, the data was put into the grid point at the center of that block. This method normalizes the data and enables us to calculuate percent frequency of stratocumulus. The program that was used in this study was "SYNSTRAT.FOR" and a copy of the sourcecode is included at the end of this paper.

After compiling the data into a hemispheric data set, we processed it for plotting by using a standard 1-4-1 Cressman data smoothing routine. By comparison of the before and after smoothing charts, we determined that the smoothed charts removed only some of the unwanted smaller features, and still retained the major patterns. For this study, it is these large-scale features that are of primary importance.

2.3 Contouring Notes

It should be noted that the contouring programs have a tendency to create non-existent maxima and minima along the edges of the contoured data field. This problem becomes apparent in the stratocumulus frequency countoured field. Examination of the raw data for the stratocumulus frequency justifies this claim. Comparison of the raw and contoured results should always be preformed to identify such poorly represented areas.

Chapter 3

MEAN UPPER AIR FLOW PATTERN CLIMATOLOGY

The mean upper air patterns are necessary in order to provide a means for parameterizing the stratocumulus effects within a quasi-geostrophic model. By inferring advection from the flow implied by the mean height patterns in the lowest layer, (850 to 1000 mb), we can get a sense of when to switch on and off the stratocumulus heating. In order to create such a database, a data analyzing program, "SYNSTRAT", was created and implemented.

3.1 Upper Air Databases

Unlike suface reports, there are only a few data sets from which to choose for the upper air analyses. In this study, the global mandatory upper air data set was used. No other sets were incorporated because this set provided adequate coverage for the height levels desired over the entire Northern Hemisphere.

3.2 Computing Mean Upper Air Patterns

The mean upper air flow patterns were derived via averaging the 12 hourly mandatory upper air reports, also known as TTAA's, over the entire period of interest. The data set included some satellite and pilot extrapolated data for the oceanic regions, so there was some data over most of the oceans. Smoothing and plotting of the data were processed by the same routines as those used in the stratocumulus frequency.

The charts that were dervied from this data analysis include the following: 1000 mb heights, 850 mb heights, 700 mb heights, and 500 mb heights. From these charts, advection patterns can be inferred for each specific case, leading to a correlation of marine stratocumulus with upper air patterns.

Chapter 4

CASE STUDIES AND FEATURES

The case studies were broken into either the "Trough - Ridge - Trough" case over the Eastern Pacific Ocean, the North America Continent, and the Northern Atlantic Ocean respectively, or a "Ridge - Trough - Ridge" over the same region. The case studies processed were the following:

1. November 17 thru 21, 1990 (Trough - Ridge - Trough)
2. December 24 thru 28, 1990 (Ridge - Trough - Ridge)
3. January 26 thru 30, 1991 (Rigde - Trough - Ridge)
4. April 2 thru 6, 1991 (Trough - Ridge - Trough)

For each of the individual cases, the figures contained in this report include:

1. The stratocumulus frequency (%), contoured in blue, superimposed onto the mean height fields (m), contoured in red.
2. The raw number of reports per grid box.
3. The raw stratocumulus frequency (%) per grid box.

4.1 November 17 thru 21, 1990 (T-R-T)

This case features a well defined Pacific stratocumulus maximum centered about halfway across the ocean. The 500 mb wave number for this pattern is either three or four, which sets up nicely the trough - ridge - trough pattern over the Pacific - North America - Atlantic domain. There is also a very weak trough over the Atlantic near Europe and a weak corresponding stratocumulus maximum of 39%.

4.1.1 500 mb Heights vs Stratocumulus Maxima (Fig. 1)

In both the Pacific and the Atlantic, the maximum in stratocumulus corresponded to a location slightly downstream of the trough axis. A shortwave ridge propagating through the Pacific trough does not seem have an effect on the overall stratocumulus pattern. The trough over the eastern United States is too far inland to lead to any significant stratocumulus development off the east coast, there is likely to be warm advection over the Western Atlantic.

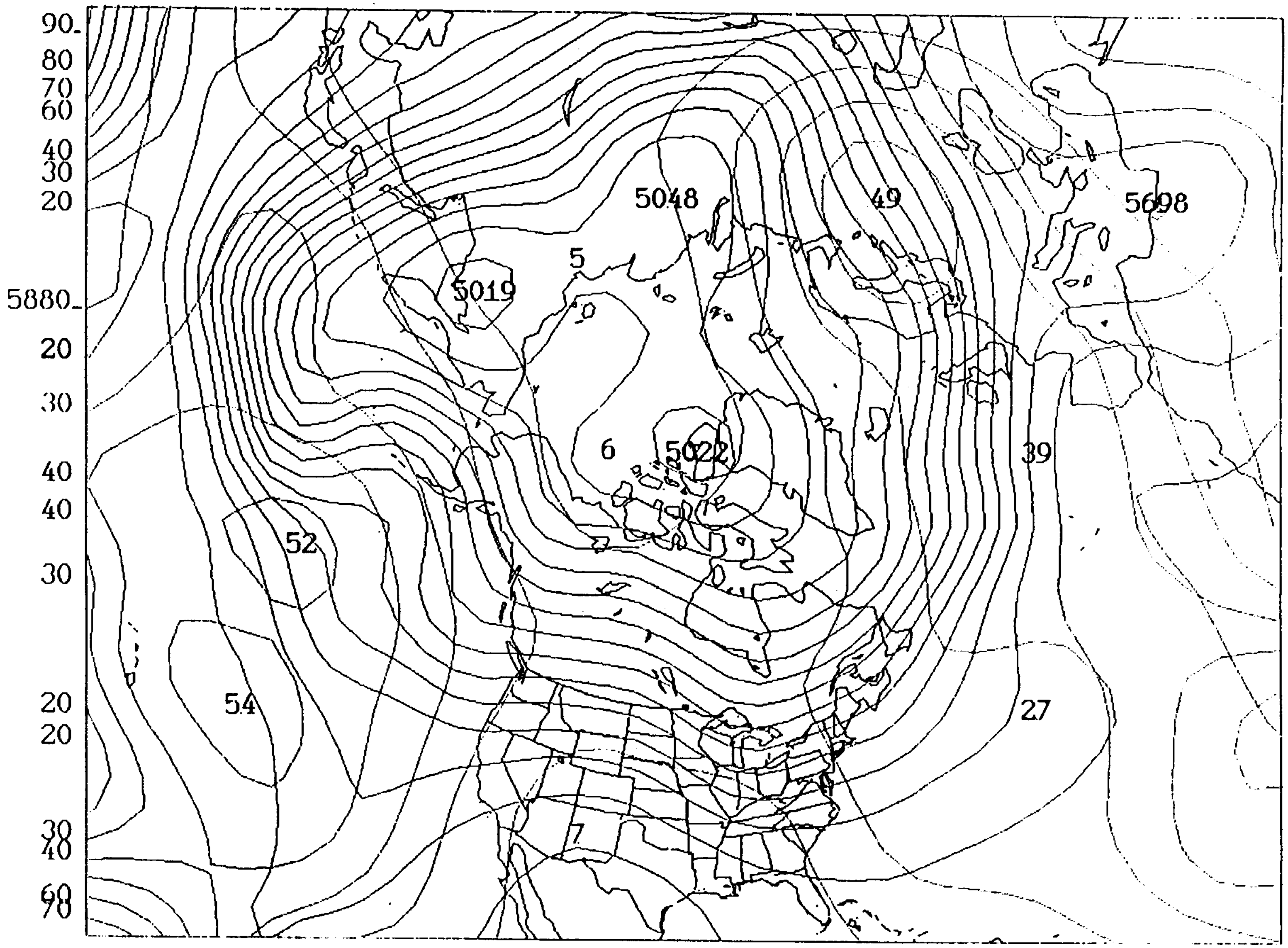

Figure 1
November 17 thru 21, 1990
500 mb heights (m) vs. Stratocumulus Frequency (%)

Key:

Red contours --- 500 mb heights (m)
Blue contours -- Stratocumulus Frequency (%)

4.1.2 850 mb Heights vs Stratocumulus Maxima (Fig. 2)

Most 500 mb features also apply to the 850 mb level pattern. The 850 mb pattern, however, is oriented a bit farther eastward than the 500 mb pattern, as expected.

4.2 December 24 thru 28, 1990 (R-T-R)

This case features a deep trough over central North America, and two corresponding ridges over the Eastern Pacific and Western Atlantic. There are also well defined stratocumulus maxima over the Central Atlantic and the Pacific, east of the Hawaiian Islands. It should be noted that there was a severe cold outbreak for the western US during this time interval.

4.2.1 500 mb Heights vs Stratocumulus Maxima (Fig. 5)

The Atlantic stratocumulus maximum is located near the axis of the Eastern Atlantic trough. One difference from the previous case is that the stratocumulus maximum is on the western side of the trough. As for the Pacific, there are two relatively weak troughs, each having a weak stratocumulus maximum for each of the repective trough axes.

4.2.2 850 mb Heights vs Stratocumulus Maxima (Fig. 6)

The 850 mb pattern closely resembles the 500 mb pattern, but the features are much less pronounced.

4.3 January 26 thru 30, 1991 (R-T-R)

The 500 mb pattern here is dominated by an east-west wave number three. There are two well-defined areas of stratocumulus maxima over both the Central Atlantic and the Central Pacific.

4.3.1 500 mb Heights vs Stratocumulus Maxima (Fig. 9)

Over the Atlantic Ocean, the stratocumulus maximum once again is just downstream of the 500 mb trough axis. In contrast, the Pacific Ocean stratocumulus maximum is coincident with a trough axis. At the base of the Atlantic trough, there seems to be a hint of an elongated cloud cover maximum. There is no hint of a maximum in either ocean upstream of the trough axis. The two troughs over the Atlantic seem to correspond to these elongated stratocumulus contours.

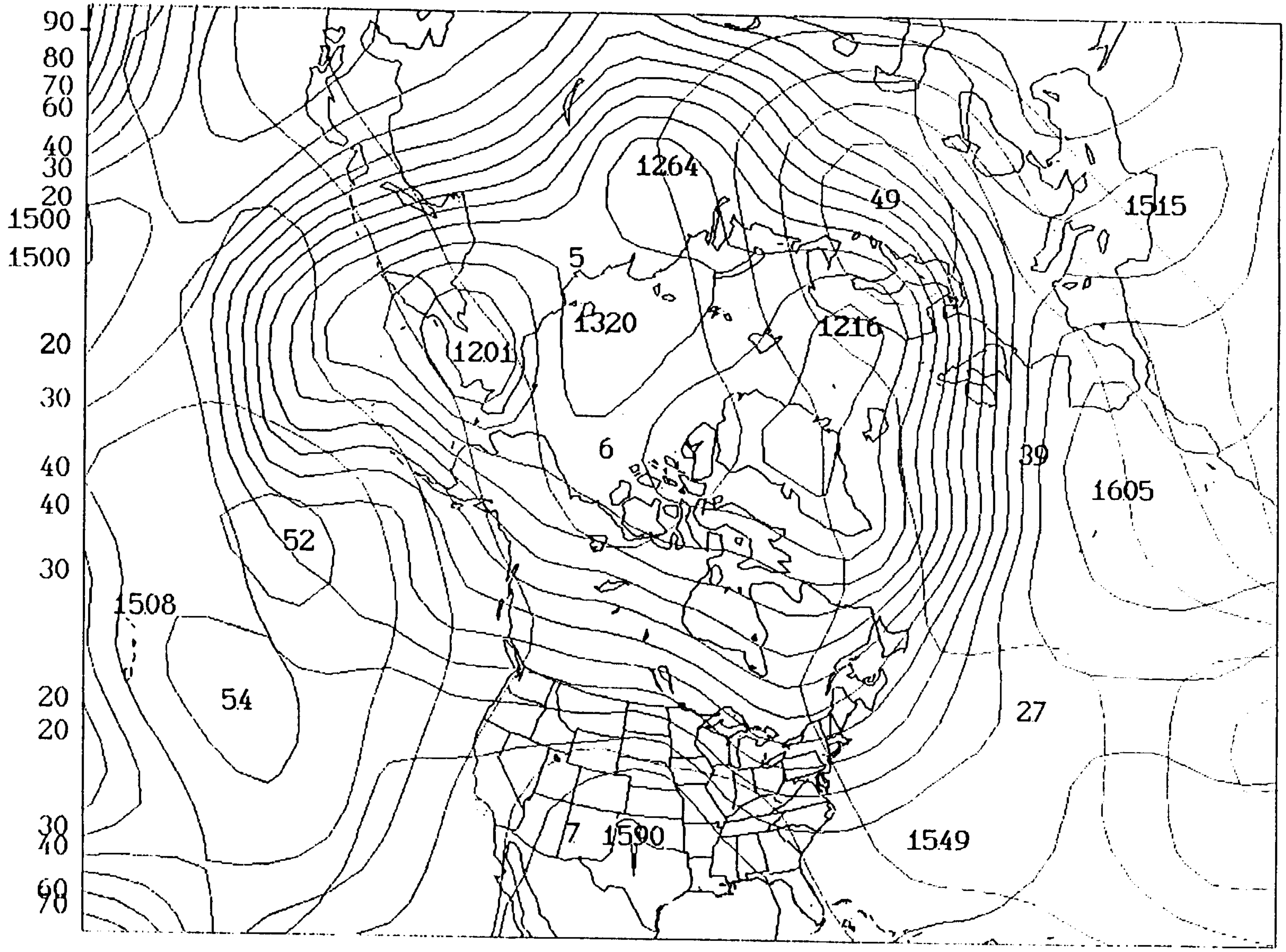

Figure 2
November 17 thru 21, 1990
850 mb heights (m) vs. Stratocumulus Frequency (%)

Key:

Red contours --- 850 mb heights (m)
Blue contours -- Stratocumulus Frequency (%)

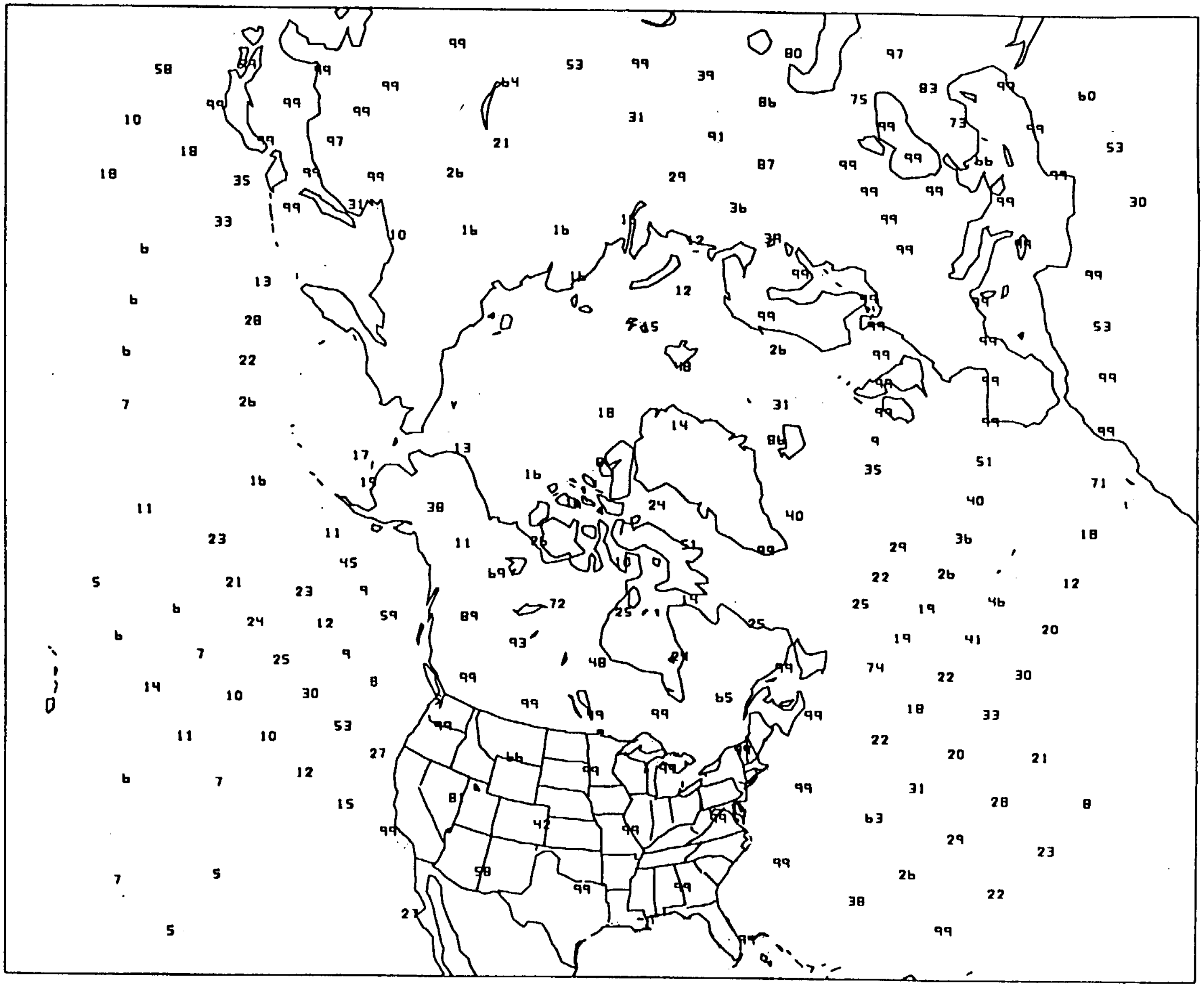

Figure 3
November 17 thru 21, 1990
Total Reports Over Period

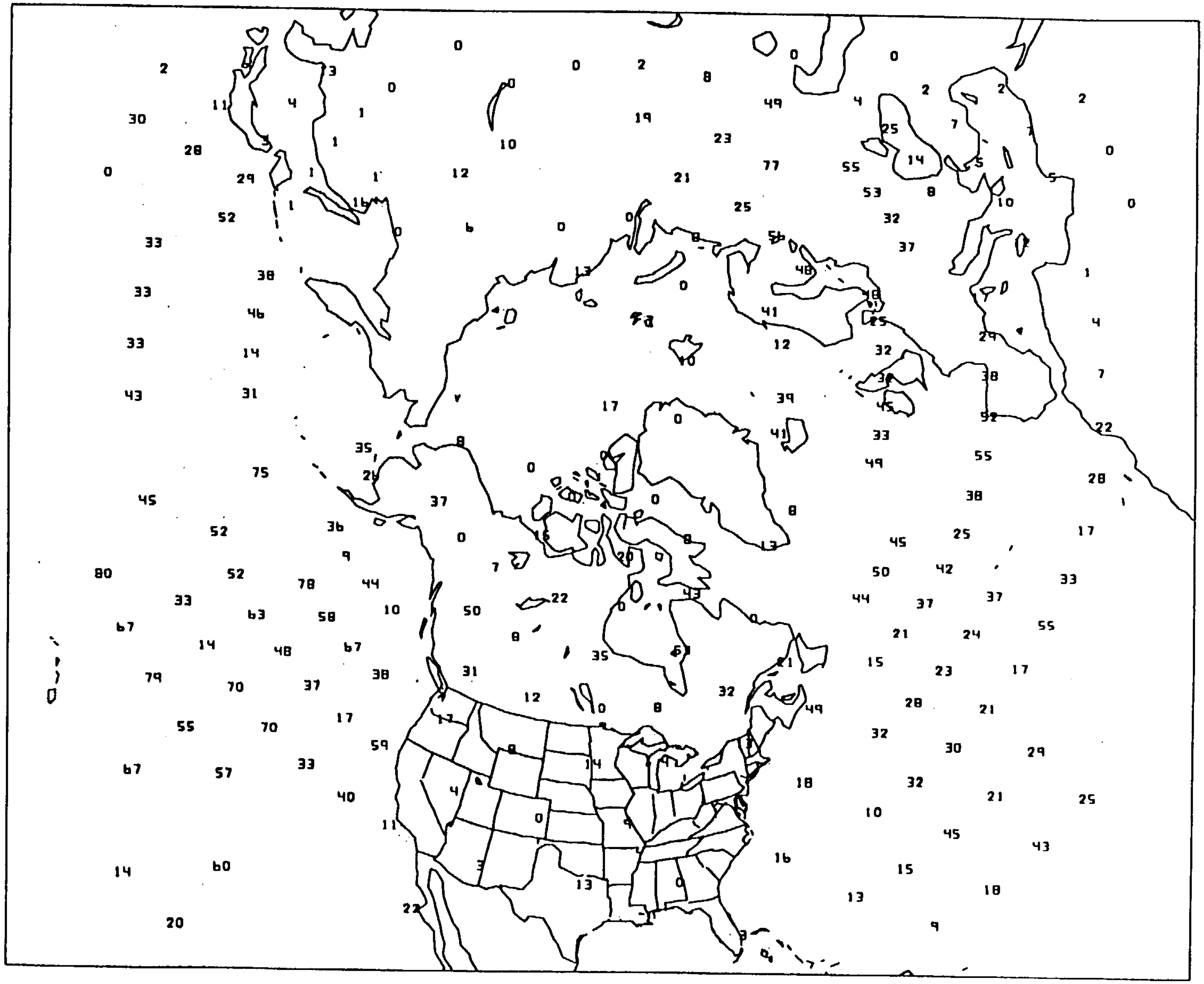

Figure 4
November 17 thru 21, 1990
Stratocumulus Frequency (%)

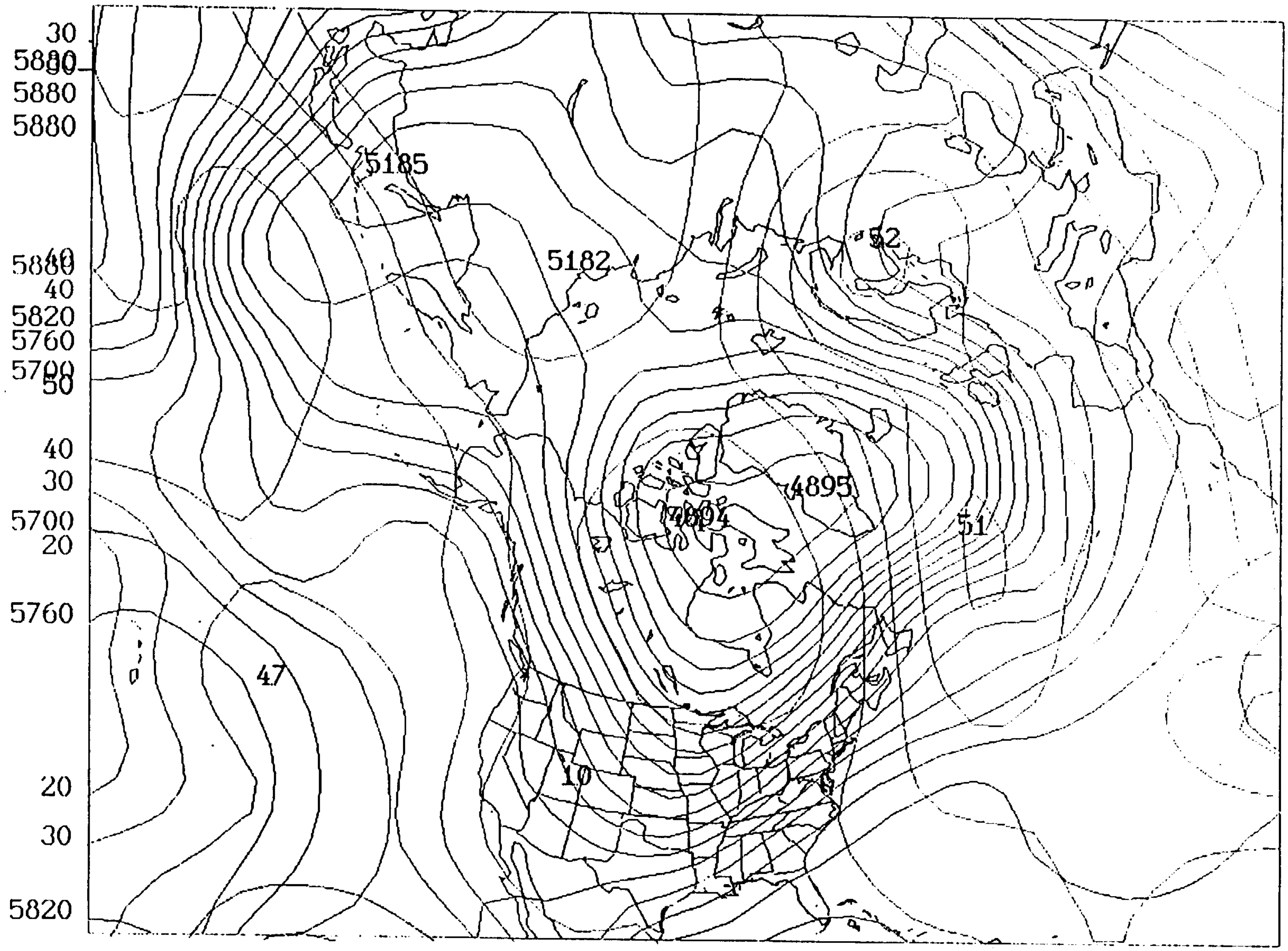

Figure 5
December 24 thru 28, 1990
500 mb heights (m) vs. Stratocumulus Frequency (%)

Key:

Red contours --- 500 mb heights (m)
Blue contours -- Stratocumulus Frequency (%)

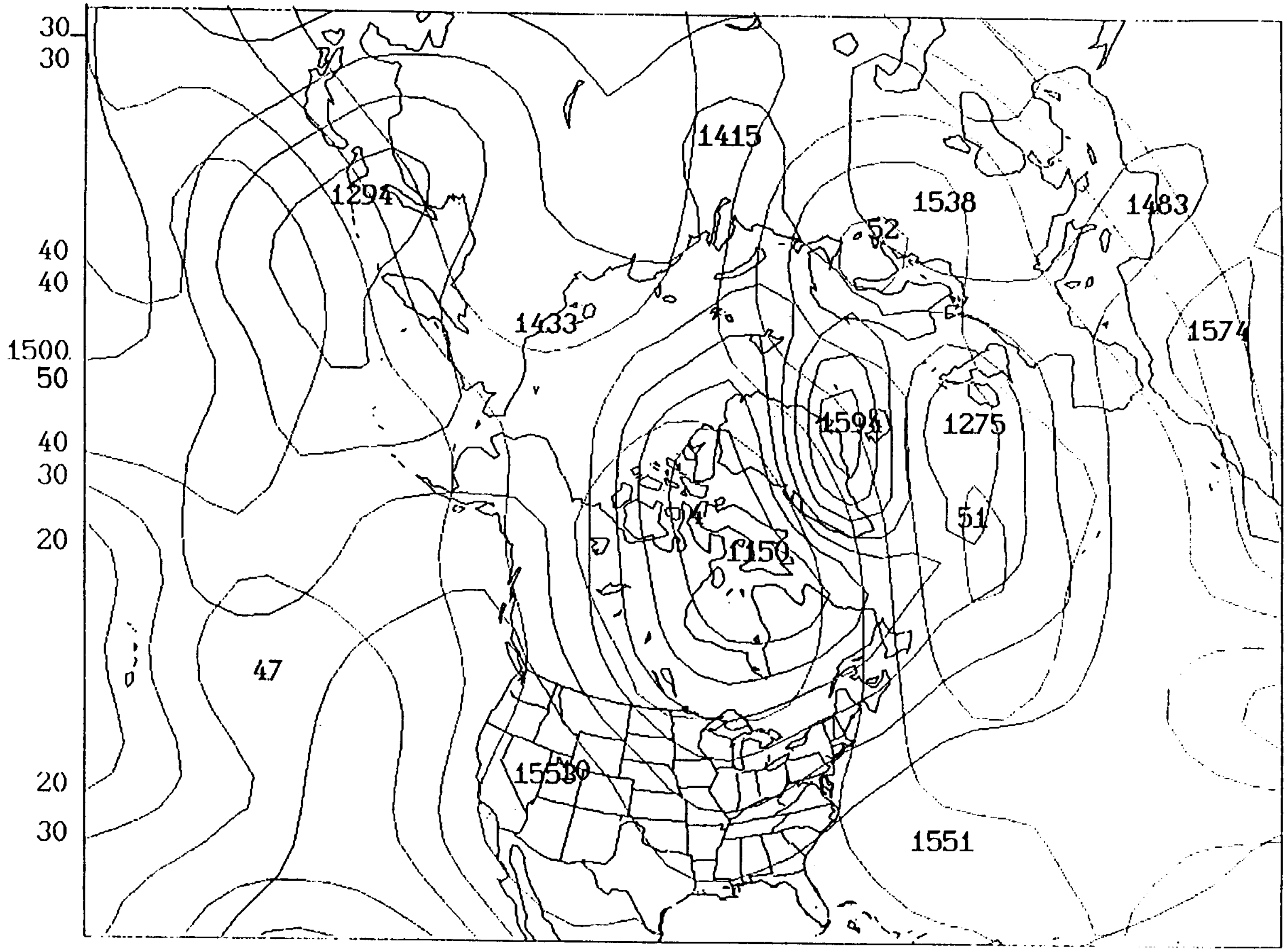

Figure 6
December 24 thru 28, 1990
850 mb heights (m) vs. Stratocumulus Frequency (%)

Key:

Red contours --- 850 mb heights (m)
Blue contours -- Stratocumulus Frequency (%)

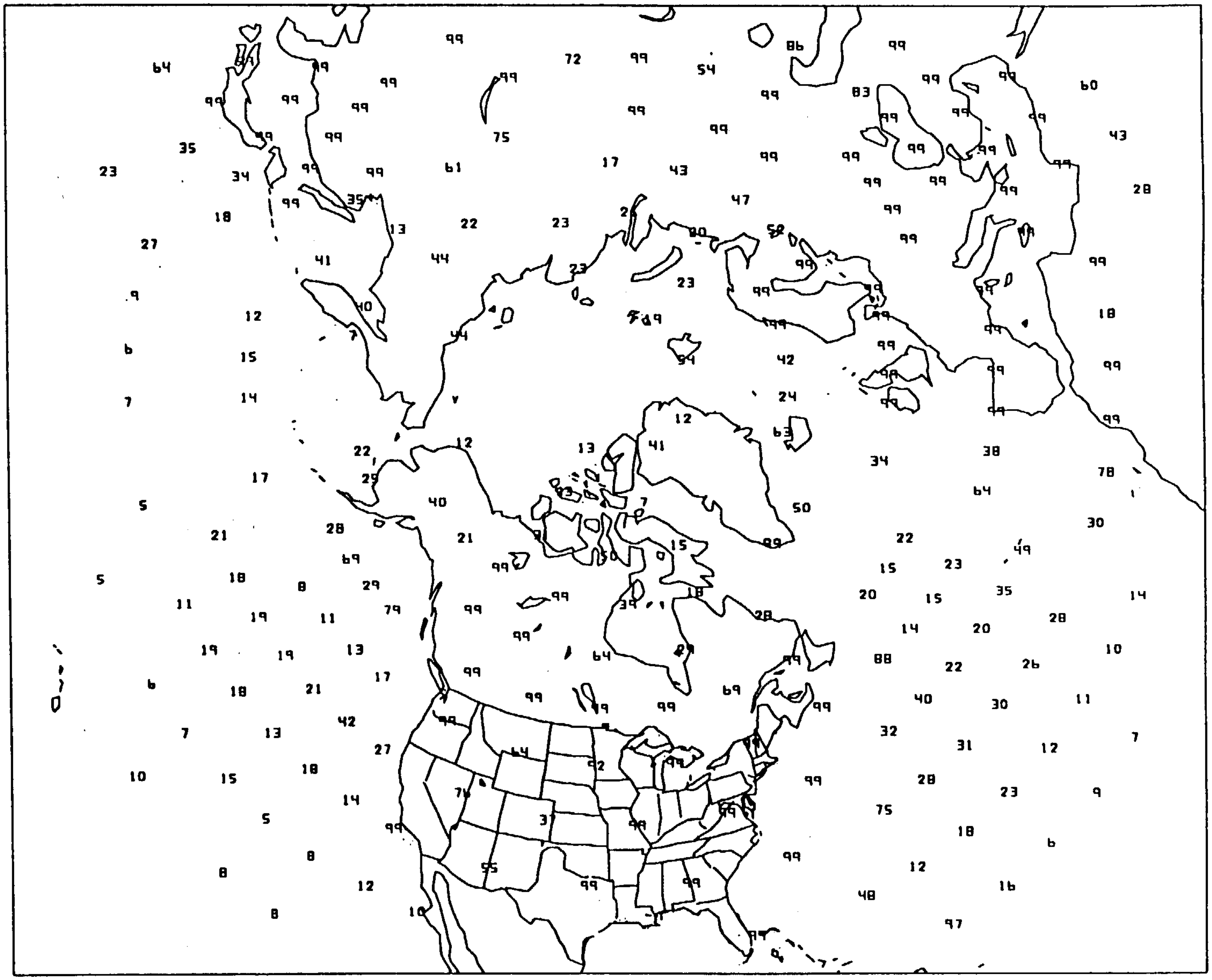

Figure 7
December 24 thru 28, 1990
Total Reports Over Period

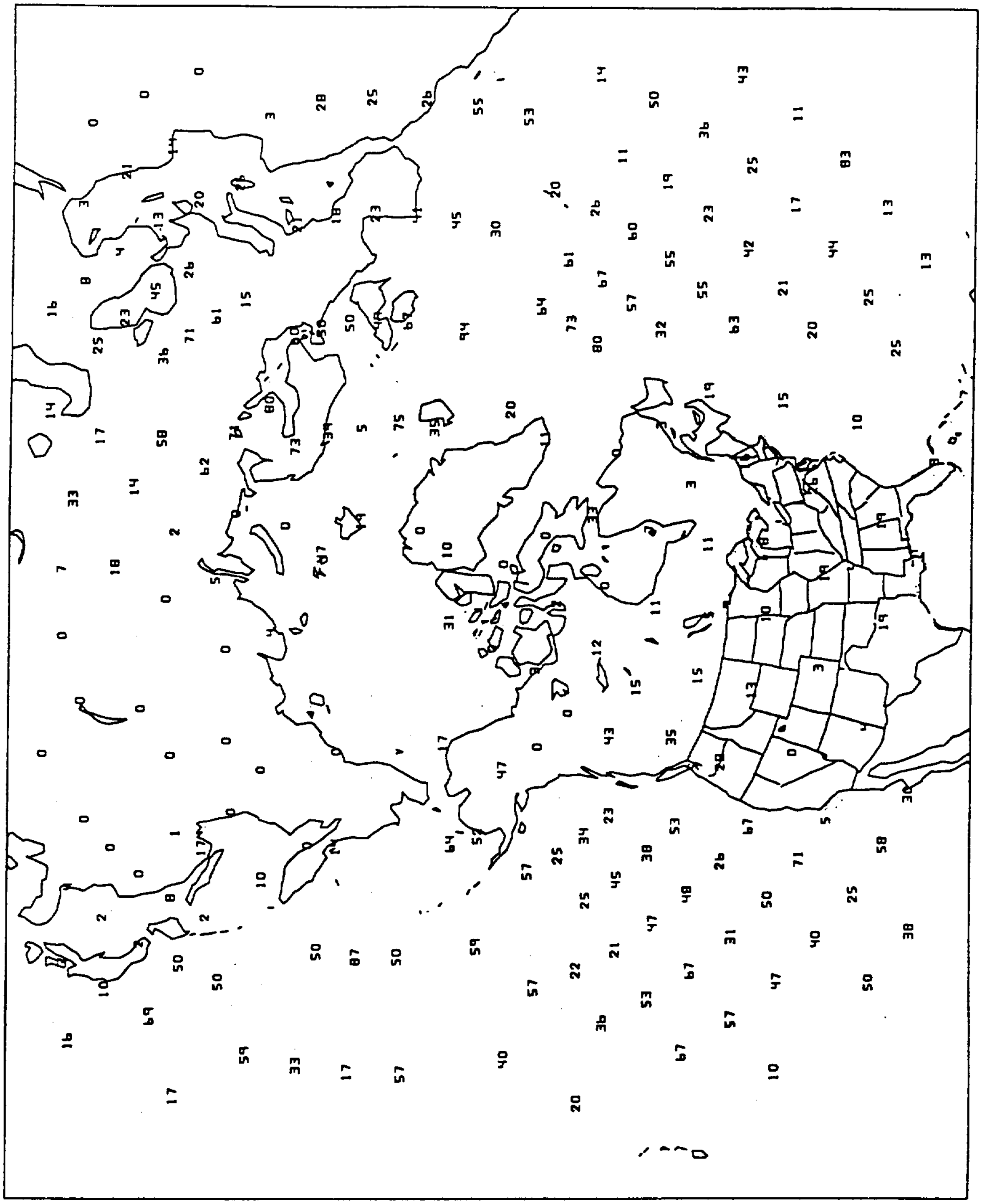

Figure 8
December 24 thru 28, 1990
Stratocumulus Frequency (%)

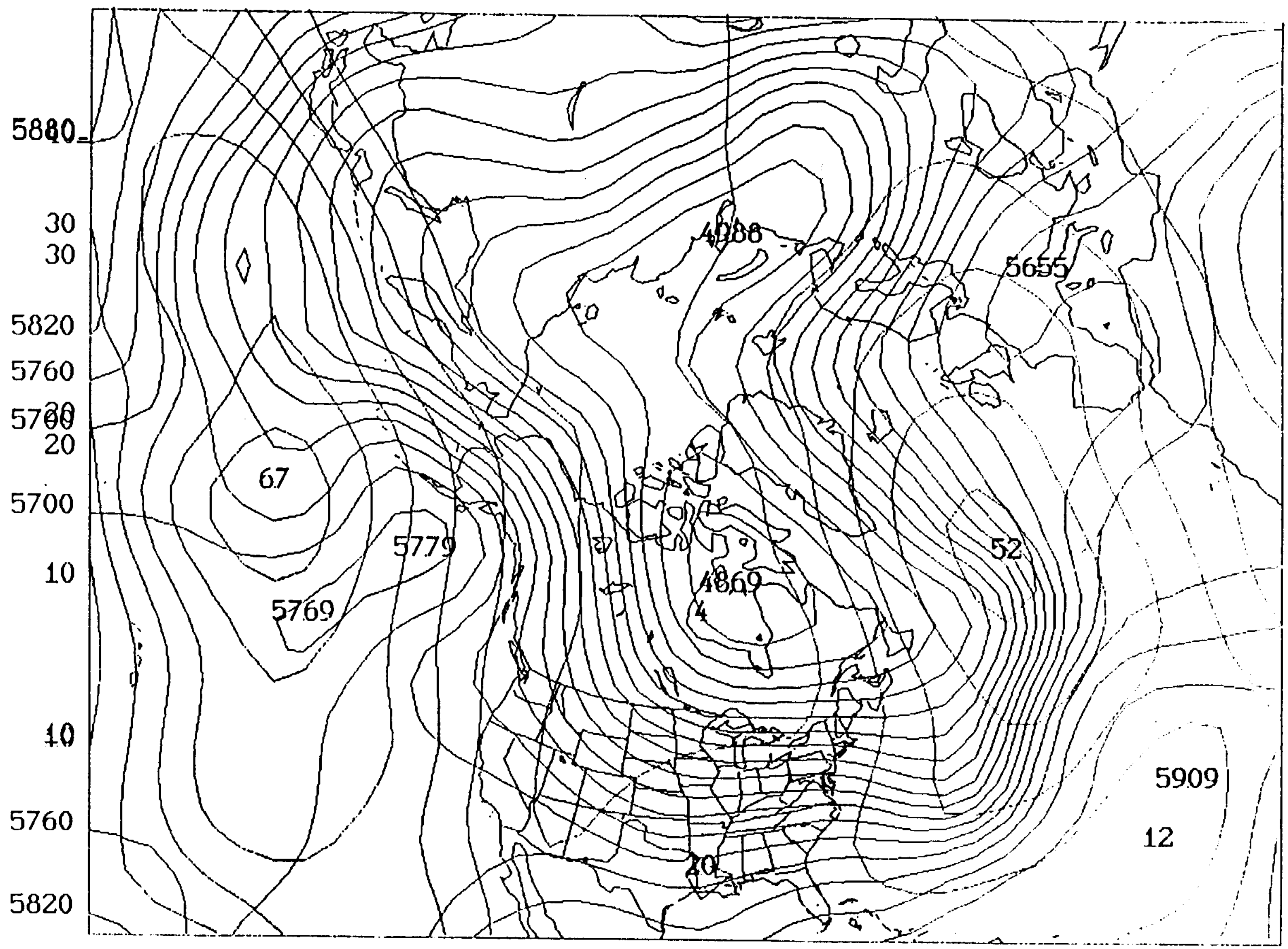

Figure 9
January 26 thru 30, 1991
500 mb heights (m) vs. Stratocumulus Frequency (%)

Key:

Red contours --- 500 mb heights (m)
Blue contours -- Stratocumulus Frequency (%)

4.3.2 850 mb Heights vs Stratocumulus Maxima (Fig. 10)

Over both oceans, the stratocumulus maxima were downstream of the trough axis.

4.4 April 2 thru 6, 1991 (T-R-T)

This real-time case was observed to be a very stationary one and, results similar to the previous cases were observed: Distinct stratocumulus maxima occurred in both the Central Atlantic and Pacific Oceans.

4.4.1 500 mb Heights vs Stratocumulus Maxima (Fig. 13)

As with the December 24 thru 28, 1990 case, we observed that the stratocumulus maxima occurred just slightly upstream of the corresponding trough axis. We also noticed that the approximate width of the first stratocumulus contour was close to the wavelength of the 500 mb trough.

4.4.2 850 mb Heights vs Stratocumulus Maxima (Fig. 14)

The Aleutian low that shows up quite predominately over the Northern Pacific has a corresponding stratocumulus maximum in the region just upstream of its trough axis. Notice that the trough over the eastern US does not have a corresponding stratocumulus maximum near its axis, because the flow is characterized by warm advection over the Atlantic and so few stratocumulus.

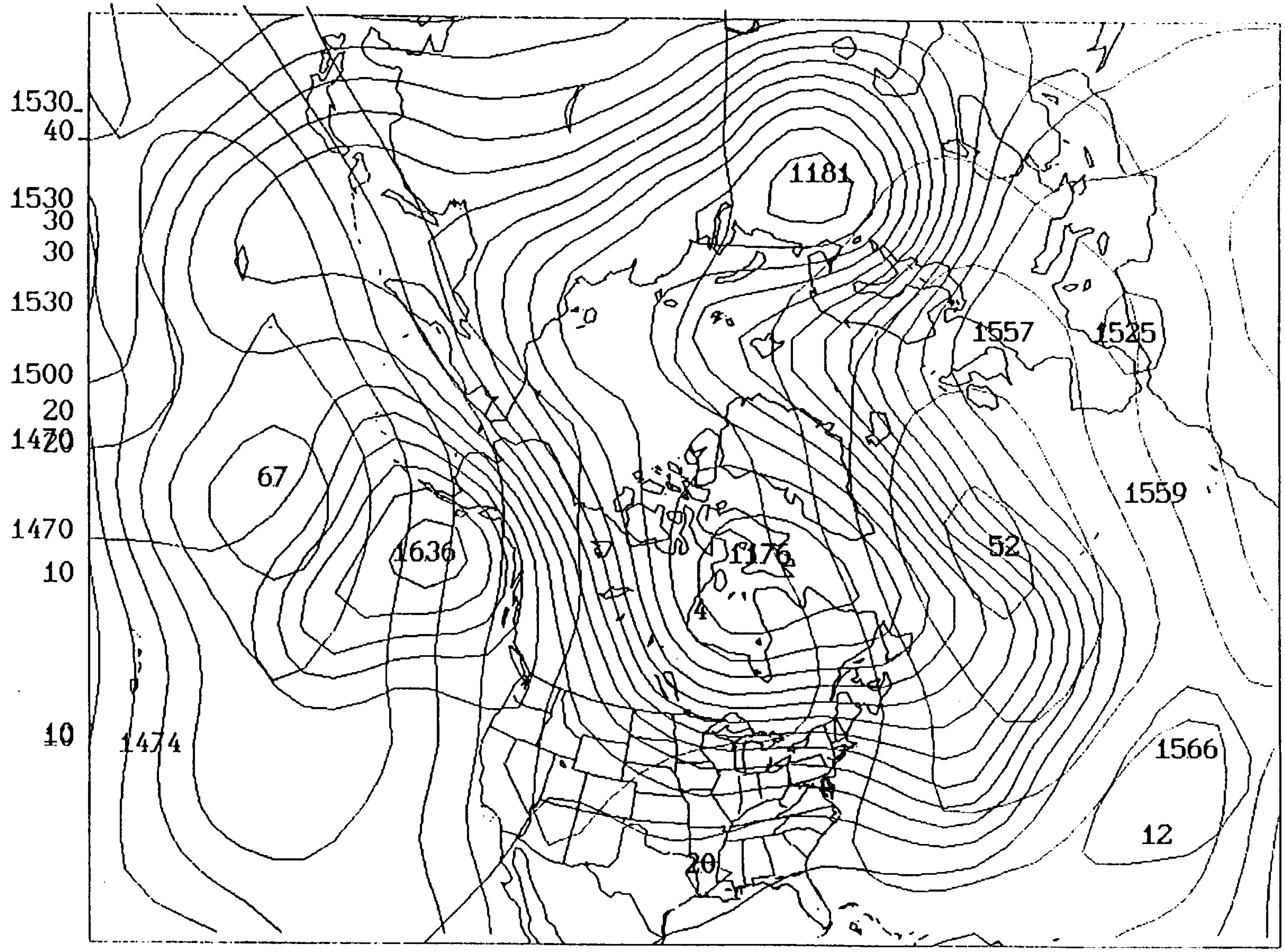

Figure 10
January 26 thru 30, 1991
850 mb heights (m) vs. Stratocumulus Frequency (%)

Key:

Red contours --- 850 mb heights (m)
Blue contours -- Stratocumulus Frequency (%)

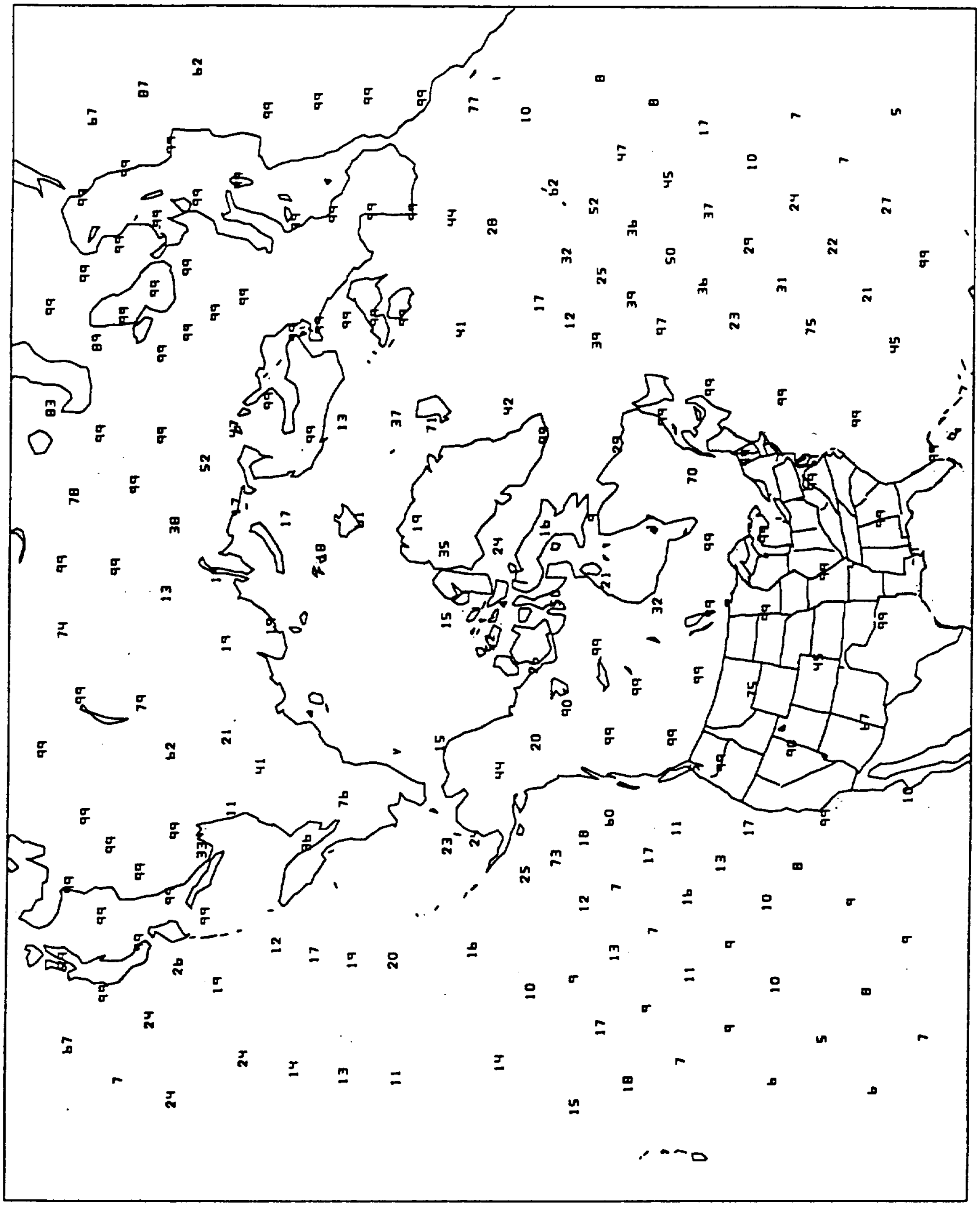

Figure 11
January 26 thru 30, 1991
Total Reports Over Period

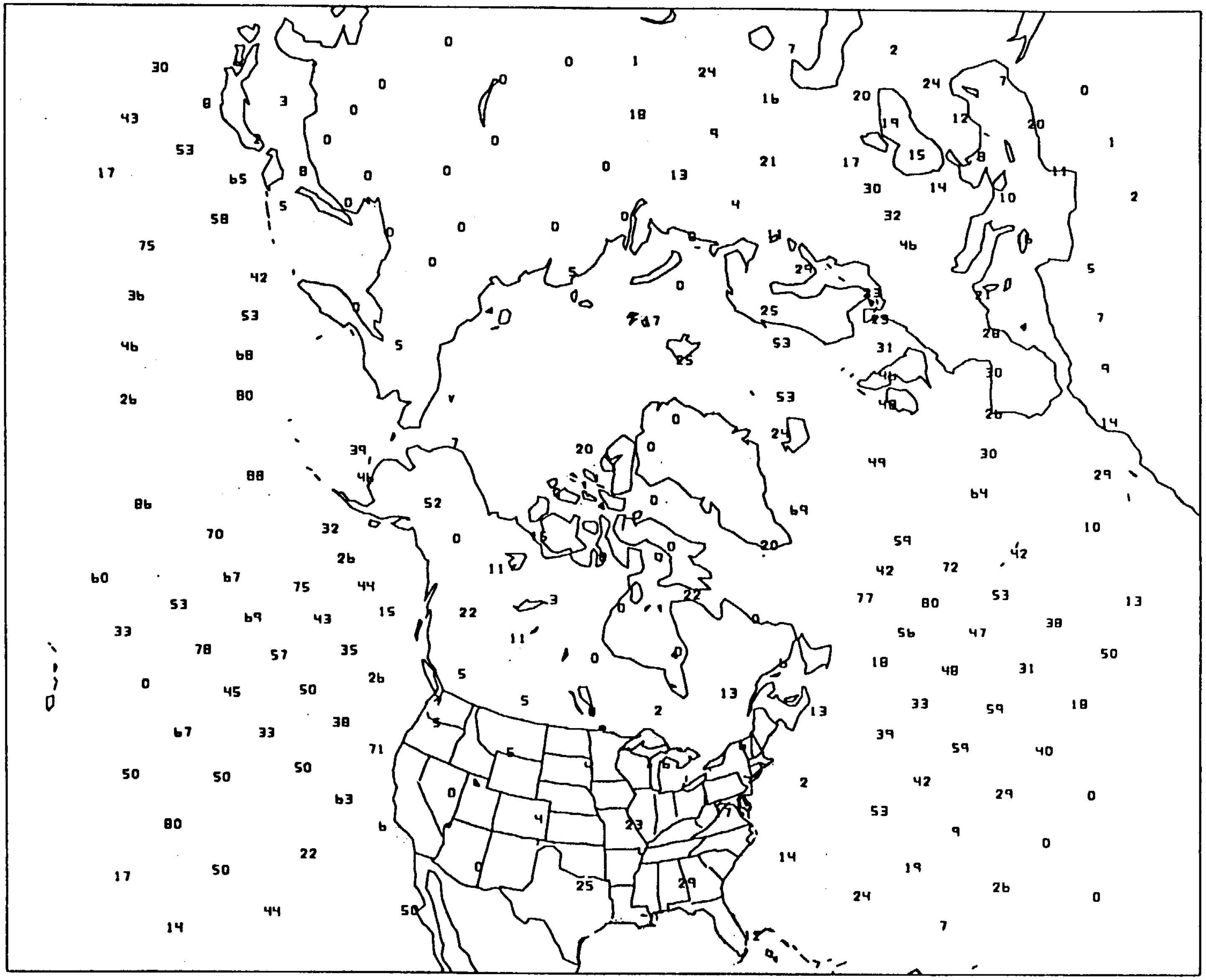

Figure 12
January 26 thru 30, 1991
Stratocumulus Frequency (%)

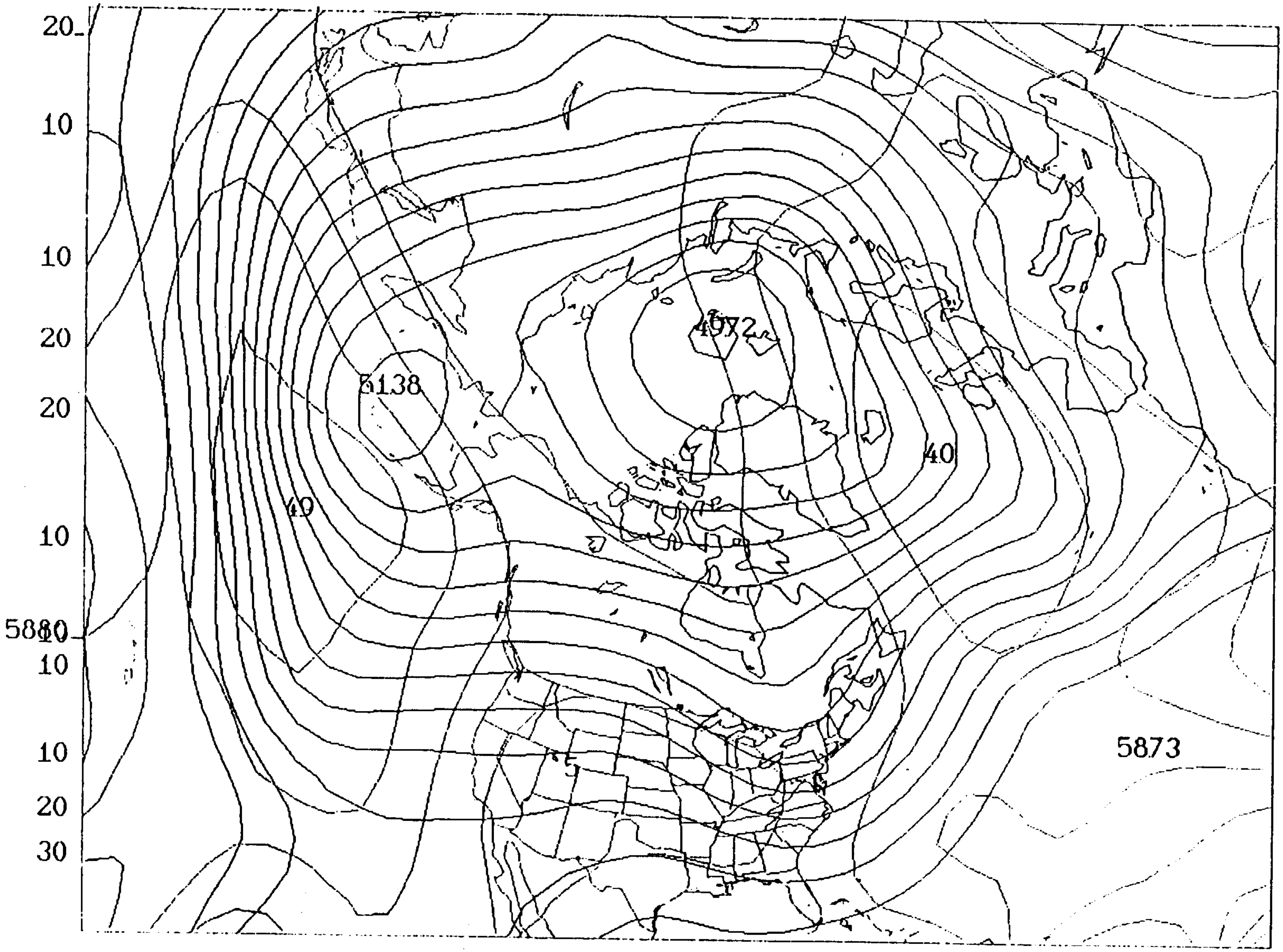

Figure 13
April 2 thru 6, 1991
500 mb heights (m) vs. Stratocumulus Frequency (%)

Key:

Red contours --- 500 mb heights (m)
Blue contours -- Stratocumulus Frequency (%)

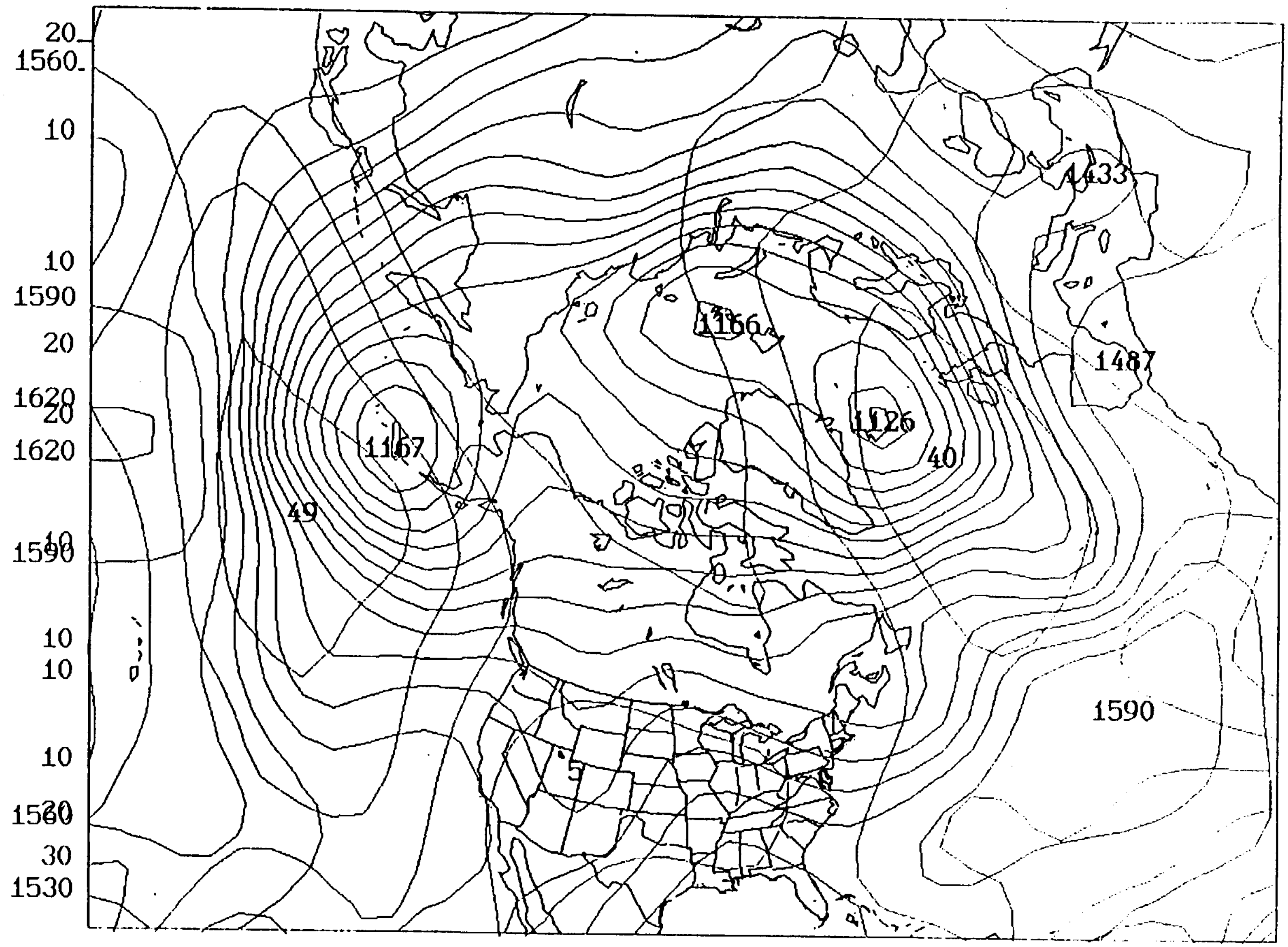

Figure 14
April 2 thru 6, 1991
850 mb heights (m) vs. Stratocumulus Frequency (%)

Key:

Red contours --- 850 mb heights (m)
Blue contours -- Stratocumulus Frequency (%)

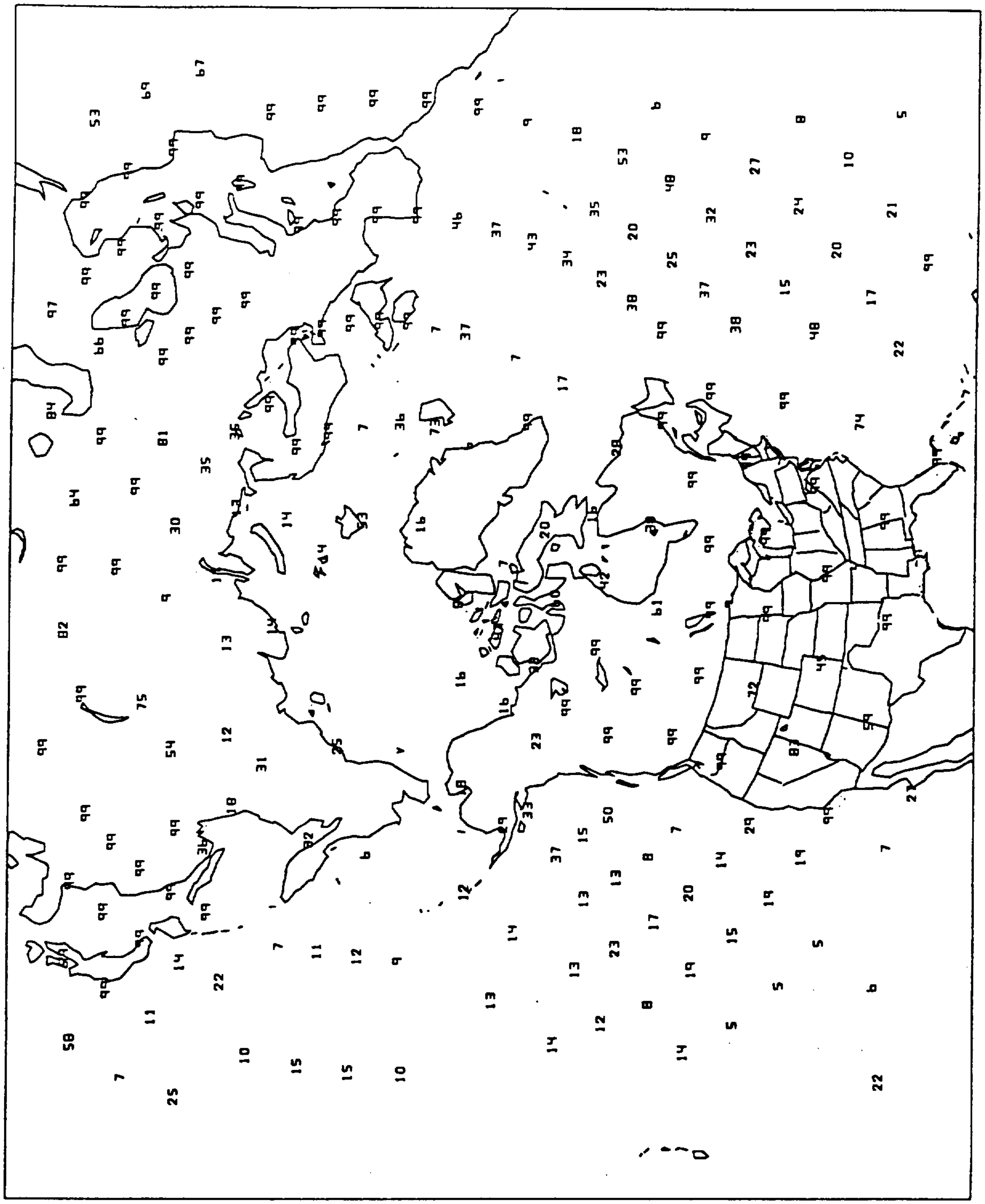

Figure 15
April 2 thru 6, 1991
Total Reports Over Period

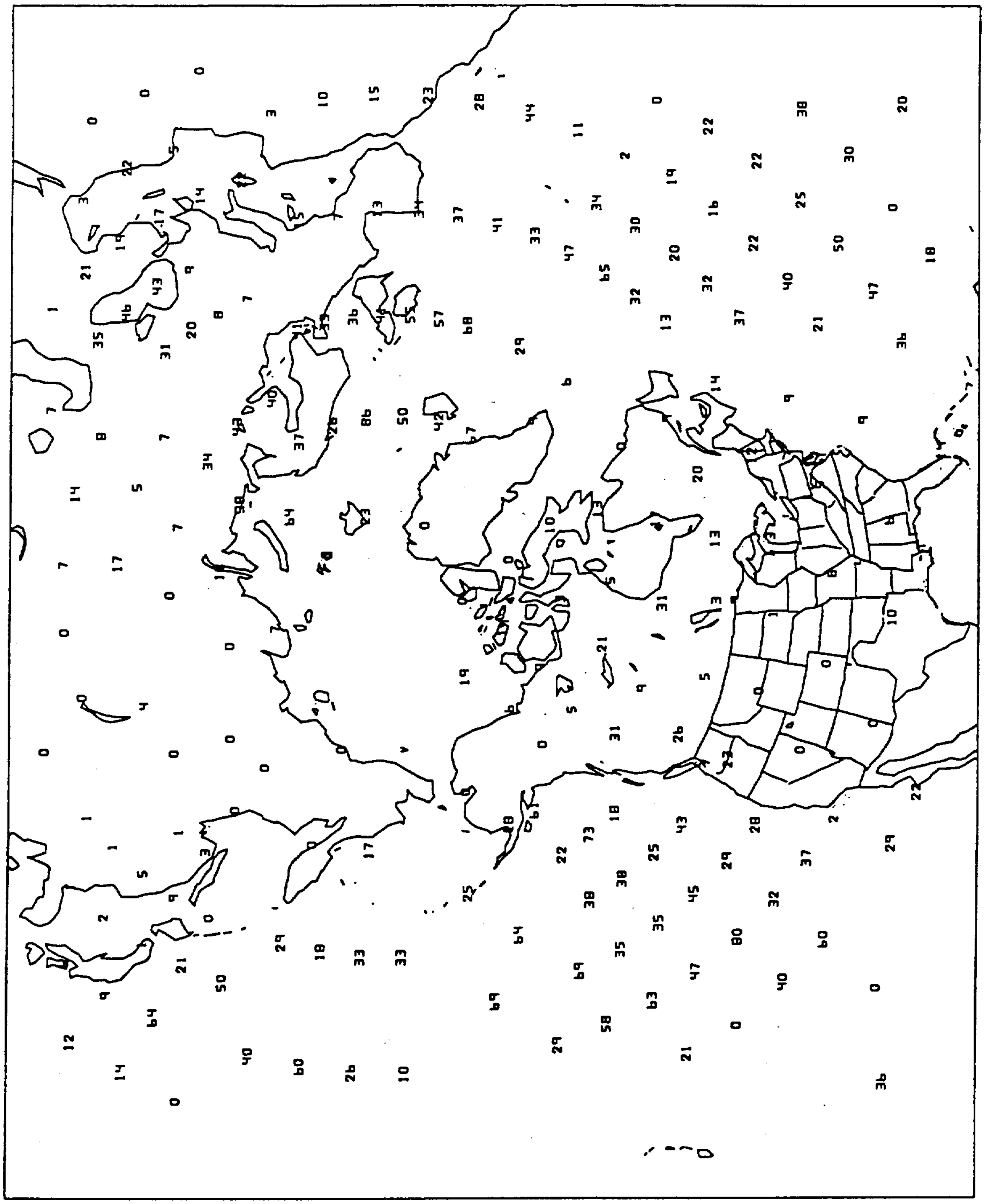

Figure 16
April 2 thru 6, 1991
Stratocumulus Frequency (%)

Chapter 5

CONCLUSIONS

Although a relatively small number of cases were examined, the following correlations between upper air flow and stratocumulus patterns were supported:

1. Significant marine stratocumulus frequency maxima were found near the trough axes over the oceans during relatively stationary large-scale wave patterns.

2. Stratocumulus maxima were located on the eastern side of the trough axes. There was no evidence of a stratocumulus maxima located upstream of the trough axis.

3. The wavelength of the upper air pattern was approximately the same as the width of the major axis of the stratocumulus maximum.

4. Few persistent stratocumulus patterns were found over the North American continent in all four cases, implying that any stratocumulus were short-lived over land.

5. The strength, or amplitude, of the trough is directly correlated with the strength of the stratocumulus frequency value.

5.1 Recommendations for the Parameterization Scheme

In all four case studies, marine stratocumulus correlated well with trough axes. Therefore is seems reasonable to assume that stratocumulus heating or cooling occurs where there is a large-scale trough over either the Atlantic or Pacific Ocean.

Chapter 6

FURTHER RESEARCH

The next study might include an analysis of thermal advection for each case, as well as for new cases. This type of analysis could show better the driving forces for stratocumulus development. This, in combination with a sea surface temperatures analysis, could indicate the probable heat flux into the boundary layer that is linked to stratocumulus development.

Longer range cases could be compiled to show the seasonal conditions. This type of statistical analysis could show some of the seasonal variations of stratocumulus over the oceans.

Another study could try to calculate the wavelengths of stratocumulus and upper air heights via a Fourier analysis to see if wavelengths do correlate well.

2. LOW-ORDER SPECTRAL MODEL OF STRATOCUMULUS CIRCULATIONS

A series of models were developed to study the modifications of background wind and temperatures by convectively and dynamically-driven boundary layer rolls. Vertical heat transports by the the rolls were found to adjust the boundary layer towards a neutral stratification. Convective momentum transports were found to add a constant shear to the background wind, in many cases reducing the overall shear in the cross-roll direction.

A summary of the findings of this study follows in a paper by Haack and Shirer published in the Journal of the Atmospheric Sciences (1992)