CORRELATIONS BETWEEN EDDY HEAT FLUXES

AND BAROCLINIC INSTABILITY

by

RICHARD ST. PIERRE

B.S., Lowell Technological Institute
(1974)

SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE
DEGREE OF
MASTER OF SCIENCE
at the
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
January, 1979

Signature of Author ....
Department of Meteorology, January 19, 1979.

Certified by ....
Thesis Supervisor.

Accepted by ....
Chairman, Departmental Committee.

CORRELATIONS BETWEEN EDDY HEAT FLUXES AND BAROCLINIC INSTABILITY

by

RICHARD ST. PIERRE

Submitted to the Department of Meteorology on January 19, 1979
in Partial Fulfillment of the Requirements for
the Degree of Master of Science

ABSTRACT

The two-layer model baroclinic stability parameter, meridional surface temperature gradients, and monthly mean meridional stationary, transient and total eddy heat transports, computed as functions of latitude and longitude for three individual Januaries, are described and discussed. Correlation analyses for all possible combinations are computed, and relationships between these quantities are discussed. The results indicate that no direct relationship exists between stationary eddy heat transports and baroclinically unstable conditions. However, a direct relationship is found between transient eddy heat transports and baroclinically unstable conditions. For example, the correlation between the transient eddy flux and the two-layer instability parameter is .52, which is statistically significant at the 99% confidence level. However, the strength of the correlation suggests that the degree of baroclinic instability only accounts for some of the variation in the transient eddy heat transport. Apparently, other factors also play an important role in the forcing of transient eddy heat transports.

THESIS SUPERVISOR: Peter H. Stone

TITLE: Professor of Meteorology

ACKNOWLEDGEMENTS

I would like to express my gratitude to Professor Peter H. Stone, who supervised the research and writing of this thesis. Appreciation is also expressed to Judson E. Stailey, who initially suggested this topic and helped with the computer programming and initial work. Thanks is also due to Frank Marks for his help in computer programming.

I also want to thank the Air Force Institute of Technology for providing me the opportunity to perform this research.

Finally, my sincere appreciation is expressed to my wife and son, whose unending patience, support, and love made this all possible.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE

INTRODUCTION

1.1 Background

In the troposphere, the equator is warmer than the poles, and this is a result of radiational imbalances. We observe a net heating due to radiation at the equator, and at the poles a net radiational cooling occurs. If this was the only process working, the equator to pole temperature gradient would change and become larger. Looking at a long-term average, the temperature structure of the atmosphere is essentially in equilibrium. For this condition to exist, heat must be transported poleward.

In the atmosphere, the south-to-north transport of sensible heat at a given time and location can be expressed mathematically as

$$HT = (\rho C_p \Delta Z) VT \tag{1.1}$$

where HT is the local south-to-north sensible heat transport, V is the south-to-north wind component, T is the absolute temperature, C_p is the specific heat of dry air at constant pressure, ρ is the density of the air, and ΔZ is the thickness of the layer in which the heat transport is to be computed. In developing the thermodynamic equation for practical use and study, this transport is often averaged over an appropriate time interval and averaged zonally (i.e. averaged around a latitude circle). This averaging may be represented symbolically by:

$$\overline{[HT]} = (\rho C_p \Delta Z) \overline{[VT]} \tag{1.2}$$

where the bar represents a time average and the brackets represent an average around a latitude circle. Equation 1.2 represents the mean meridional heat transport. This transport is commonly broken down into three components by expressing the individual instantaneous values, V and T, in terms of their means and anomalies, as

$$V = \overline{V} + V', \ \overline{V} = [\overline{V}] + \overline{V}^*, \quad T = \overline{T} + T', \ \overline{T} = [\overline{T}] + \overline{T}^*$$

The bars and brackets have their previously defined meanings, and the prime and asterisk superscripts represent departures from the time and space averages, respectively. By making the above substitutions, we see that

$$[\overline{VT}] = [\overline{V}][\overline{T}] + [\overline{V}^*\overline{T}^*] + [\overline{V'T'}] \qquad (1.3)$$

recognizing that the time and zonal averages of the departures are zero by definition.

The first term on the right hand side of equation 1.3 represents the heat transport due to the mean meridional circulation. This is the heat transport due to the Hadley, Ferrel, and Polar cells. The last two terms represent the meridional eddy heat transport broken down into its components. The term $[\overline{V}^*\overline{T}^*]$ depicts the standing or stationary eddy heat transport. Stationary eddies are waves in the mean flow that persist over the averaging time period. For example, if we select an averaging time of a month, then the waves on a monthly mean 500 mb map would be stationary eddies. The last term in equation 1.3 represents the meridional transient eddy heat transports. Transient eddies are all deviations in the eddy circulations within the averaging time period. For example, according to Clapp (1970), if the averaging time interval is a month, transient eddies are the part of the mean meridional heat transport due largely to traveling cyclones and anticyclones.

Steady state models used to simulate climate cannot calculate transient eddy heat transports. The other two terms (the stationary eddy and mean meridional circulation heat transports) involve the covariance or product of the time-averaged quantities and can, therefore, (at least in principle) be predicted explicitly by a steady state model (Clapp, 1970). For this reason, studies have been directed toward the understanding and parameterization of the transient eddy heat transports.

1.2 Brief Review of Previous Work

Parameterization of transient eddy heat transport using an "Austausch coefficient" approach was originally proposed by Defant (1921). In this approach, the transient eddy heat transport term in equation 1.3 is approximated by

$$[\overline{T'V'}] = -K(\partial[\overline{T}]/\partial Y) \tag{1.4}$$

where the bar and brackets signify time and zonal averages as before, and K is the Austausch coefficient. White and Jung (1951) were among the first to estimate the Austausch coefficient using mean heat transports computed from synoptic weather maps. In their study, they also observed a negative correlation between eddy heat transports and temperature gradients for short averaging periods up to twelve days; however, they did not separate stationary and transient eddy components in their computations. Later Saltzman (1967), basing his ideas on the linear-perturbation form of the hydrodynamic and thermodynamic equations, suggested that

$$K = -B(\partial[\overline{T}]/\partial Y) \qquad (1.5)$$

where B is a stability coefficient. Substituting equation 1.5 into equation 1.4 gives

$$[\overline{T'V'}] = B(\partial[\overline{T}]/\partial Y)^2 \qquad (1.6)$$

indicating that the transient eddy heat transport is proportional to the square of the temperature gradient.

Clapp (1970) used two independent sets of data to obtain new estimates of K and B, and investigated the Austausch formulae. His investigation suggests that the Austausch formulae may be fairly successful in estimating the zonally averaged meridional transport. In attempting to extend this test to explain longitudinal variations, his preliminary efforts were not successful. This suggests that further investigations and observations of meridional eddy heat transports are needed, especially studies containing longitudinal variations.

Oort and Rasmusson (1971) have compiled a very complete set of computed transports for the five year period May 1958 to April 1963. Their computations included meridional heat transports for each month broken down into the three components described previously. All their work was directed at zonally averaged quantities, so they could not observe lonqitudinal differences. Latitudinal, seasonal and monthly variations in the heat transports were observed and discussed. Many of their observations are relevant to our investigation, and we will refer to their work often in the course of this paper.

Blackmon et al. (1977) performed an observational and statistical study of heat fluxes. They used time-filters to study fluctuations of different periods. The most definitive results involved "band-pass" fluctuations (fluctuations having a period of 2.5-6 days) which appeared to be associated with developing baroclinic waves. Their investigation suggested a relationship between poleward eddy heat fluxes and baroclinic instability associated with the strong thermal gradients at the earth's surface. This is one of the results that influenced the structure of our study.

The main motivation for our study was a paper by Stone (1978). In his paper, he compared zonal mean meridional temperature gradients in the atmosphere to critical temperature gradients predicted by a two-layer baroclinic model. Stone observed that eddy heat fluxes are sensitive to changes in meridional temperature gradients (i.e. baroclinic instability). This observation suggests a relationship between these two quantities.

We intend to statistically investigate the relationship between meridional eddy heat transports, meridional surface temperature gradients, and the two-layer model stability parameter, since baroclinic theory and results from previous studies have suggested a possible relationship between these quantities. We will deal only with the Northern Hemisphere, where the raw data are more abundant. In order to observe latitude and longitude variations, quantities were used which had been calculated for evenly spaced grid points. In this study, values of the total tropospheric meridional eddy heat transport were used which were defined as follows:

$$\overline{EF} = \overline{\int_0^h \rho C_p (V-[V])(T-[T])dZ} \qquad (1.7)$$

A time averaging period of a month was used, and h is the height of the tropopause. This flux was divided into two components. The meridional stationary eddy heat transport at each grid point was computed from the equation

$$\overline{SE} = \int_0^h \rho C_p (\overline{V}^*\overline{T}^*)dZ \qquad (1.8)$$

i.e., $\overline{SE}$ represents the monthly mean meridional stationary eddy heat transport. Once the stationary and total eddy heat transport were computed, a transient eddy heat transport was simply determined by subtraction,

$$\overline{TE} = \overline{EF} - \overline{SE} \qquad (1.9)$$

where $\overline{TE}$ is the monthly mean meridional transient eddy heat transport. It is important to note that fluctuations in the meridional mean circulation are not included in the $\overline{TE}$ term, but are included in the transient eddy heat transport term in equation 1.3.

With the quantities calculated at each grid point, we are able to perform a correlation analysis for all possible combinations of these quantities. We will concentrate our investigation on longitudinal variations, since this area has not been explored. Once the correlation analysis is performed, empirical parameterization schemes for the meridional transient eddy heat transport will be investigated.

CHAPTER TWO

SOURCES AND DESCRIPTION OF DATA

2.1 Meridional Eddy Heat Transport Data

The meridional eddy heat transport data was calculated at the Goddard Institute for Space Studies (GISS), under the direction of Professor Peter H. Stone, Massachusetts Institute of Technology. The raw data for the calculations was provided by the National Meteorological Center (NMC). Mean monthly values of eddy heat transport were available for January 1973, 1974, and 1975. The data was recorded for every four degrees of latitude 90°S, 86°S, ... 86°N, 90°N, and every ten degrees of longitude 175°W, 165°W, ... 165°E, 175°E. This study was based on the data between 18°N and 70°N latitude. All the meridional eddy heat transport data are vertically averaged values for the troposphere, and are in units of 10^{17} calories per day per five degrees longitude with positive indicating northward. Before the vertical averaging, the tropopause was determined separately for each grid point. The meridional eddy heat transport data was separated into stationary eddy and transient eddy components for the monthly mean data.

2.1.1 Meridional Stationary Eddy Heat Transport Data

Oort and Rasmusson (1971) observed that the meridional staticnary eddy heat transports (MSEHT) were strongest in the winter. This is one of the main reasons the month of January was used for our study. Haines and Winston (1963) first noted that the MSEHTs were dominated by three main features, the Aleutian low, the Icelandic low, and the Siberian high pressure systems. They also observed that the peaks of the transports are located to the east of these features, i.e. the transport of cold air southward by the northerly flow over eastern Siberia and the transport of warm air northward over the central North Atlantic and Gulf of Alaska. The exact position and relative importance of these features varies from year to year, as pointed out by Blackmon et al. (1977). Tables 2.1, 2.2, and 2.3 contain the MSEHT data for our three months. From the tables, we can see that the Icelandic low was very strong and the dominant feature for the monthly mean MSEHT in January 1973. For January 1974, all three features were strong, but the Icelandic low was still slightly dominant and shifted 20°E of its previous years position. In January 1975, the Siberian high and the Aleutian low pressure systems were the dominant features.

The latitude of the peak MSEHT fluctuates annually. Table 2.4 contains the MSEHT summed around each latitude circle. By examining the summed values of our MSEHT, we see the peak transport occurred at 58°N for January 1973. In January 1974, the peak MSEHT was located at 46°N. January 1975's peak was situated at 50°N. These fluctuations from year to year indicate not only the variability of the transports, but also that we have a variety of data to study, rather than a bias sampling of one particular case. The position of the peak MSEHT for the average over the three months was at latitude 50°N. Oort and Rasmusson (1971) also found the peak MSEHT in this location with data over a five year period.

2.1.2 Meridional Transient Eddy Heat Transport Data

The meridional transient eddy heat transport (MTEHT) is of the same order of magnitude as the MSEHT, when comparing the summed values in Table

Stationary Eddy Heat Flux

January 1973

Longitude

	175	165	155	145	135	125	115	105	95	85	75	65	55	45	35	25	15	5	5	15	25	35	45	55	65	75	85	95	105	115	125	135	145	155	165	175	
70	-2	-1	0	0	0	-1	-1	0	3	4	3	0	4	3	14	27	29	25	15	0	-11	-15	-10	0	6	4	0	-1	2	2	0	1	2	-1	-5	-4	70
66	-1	0	1	2	3	-2	-3	-1	4	6	5	2	1	3	26	51	53	37	15	-5	-16	-21	-11	4	10	4	-2	-3	3	5	6	8	6	-1	-6	-5	66
62	0	1	2	5	8	1	-5	-2	3	7	7	8	0	6	37	72	66	37	8	-8	-18	-23	-9	8	11	0	-7	-4	5	9	15	20	11	-2	-7	-5	62
L 58	1	2	2	10	15	6	-5	-5	1	7	8	10	3	12	46	75	63	24	-4	-10	-14	-18	-6	9	8	-10	-14	-5	6	13	21	25	16	-2	-7	-5	58
A 54	2	5	1	9	20	11	-3	-7	-2	4	7	8	3	15	48	66	47	8	-11	-10	-10	-10	-2	11	1	-15	-13	-2	9	16	24	20	17	3	-5	-4	54
T 50	4	4	2	11	22	14	-1	-8	-4	0	4	4	3	18	45	53	29	-7	-13	-5	-6	-4	1	9	-6	-9	-5	4	12	14	24	18	13	4	-3	-2	50
I 46	3	3	3	12	23	13	-1	-7	-4	-2	0	1	6	22	37	36	10	-17	-14	0	-2	-1	1	6	-9	-3	1	3	11	11	21	16	5	1	-1	2	46
T 42	2	1	3	13	18	4	-3	-3	-2	1	0	2	11	18	23	17	-2	-16	-10	0	0	0	1	3	-6	-3	0	0	8	11	16	8	0	0	3	5	42
U 38	0	-3	3	13	7	-5	-3	0	3	7	5	3	11	9	6	2	-6	-7	-1	0	-1	0	0	2	-1	-2	5	-5	1	7	9	4	1	6	9	7	38
D 34	-6	-4	3	6	0	-7	-2	1	7	12	9	0	8	3	1	-4	-3	0	7	0	-4	0	0	0	0	0	14	-1	-1	4	5	4	8	12	11	3	34
E 30	-8	-3	0	2	1	-3	-1	3	9	11	10	2	5	1	1	-2	0	4	9	2	-7	-2	1	-1	-1	0	0	1	-3	4	8	10	14	11	7	-9	30
26	-7	0	-2	2	1	0	0	7	11	8	6	2	3	4	3	-1	1	6	7	2	-8	-4	2	-3	-3	0	1	1	-3	4	9	8	11	6	3	-15	26
22	-3	4	-1	1	0	0	-1	5	7	5	2	1	3	7	2	-3	0	5	4	1	-8	-5	1	-3	-1	1	1	1	-3	3	4	2	6	6	-3	-12	22
18	-3	0	1	1	0	0	0	-2	1	3	1	1	3	1	0	0	-1	0	-1	-1	-3	-6	0	0	1	-1	2	1	-3	1	2	5	0	-4	-11	-9	18
	175	165	155	145	135	125	115	105	95	85	75	65	55	45	35	25	15	5	5	15	25	35	45	55	65	75	85	95	105	115	125	135	145	155	165	175	

Table 2.1

Stationary Eddy Heat Flux

January 1974

Latitude	175	165	155	145	135	125	115	105	95	85	75	65	55	45	35	25	15	5	5	15	25	35	45	55	65	75	85	95	105	115	125	135	145	155	165	175	
70	0	-2	-4	-5	-2	6	14	16	9	-1	-2	-2	-3	-4	-2	1	18	37	36	19	8	1	-1	-1	-1	2	3	1	-1	-3	-5	-2	2	4	3	1	70
66	1	0	-3	-6	-6	3	16	20	12	-2	-2	2	-4	-4	-5	14	40	57	47	20	8	-2	-5	-1	2	6	9	3	-3	-8	-7	-3	3	5	3	1	66
62	5	6	-1	-7	-10	-4	11	13	15	1	0	6	-1	-4	-4	23	53	59	51	19	6	-3	-4	1	6	8	13	9	0	-8	-4	-2	1	5	4	2	62
58	14	20	6	-6	-11	-10	1	14	14	6	0	12	7	-3	-1	24	55	66	43	8	0	-4	-1	4	6	2	7	9	7	1	5	2	-2	3	3	5	58
54	21	33	26	6	-16	-13	-9	4	7	5	2	11	9	-1	2	24	53	60	30	-9	-6	-2	2	5	3	-4	0	8	11	11	14	9	0	-2	-1	8	54
50	21	34	52	22	-19	-14	-9	-3	2	1	1	5	3	1	7	24	50	50	12	-15	-9	1	4	5	-1	-5	-1	5	9	14	25	22	11	-1	-2	9	50
46	18	32	59	35	-16	-16	-6	-5	2	7	3	-1	0	5	11	18	40	24	-10	-10	-3	3	3	6	-5	-5	1	2	7	14	34	39	23	4	-3	6	46
42	14	26	48	41	-10	-16	-4	-1	11	20	7	-2	1	6	4	11	16	3	-25	-6	7	3	-2	1	-7	-3	0	1	4	10	31	40	27	5	-4	3	42
38	11	22	35	38	-5	-16	-4	4	22	26	11	-2	-3	0	-3	1	0	-4	-18	1	18	1	-7	-5	-4	-1	-2	1	1	6	19	30	16	4	0	8	38
34	9	18	22	24	1	-13	-1	8	23	18	14	-6	-3	-4	-3	-8	-1	-2	-1	12	24	-1	-9	-6	0	-1	-1	-1	-1	4	12	13	6	4	9	12	34
30	4	8	8	14	6	-8	0	8	13	11	10	1	-1	-1	-2	-3	2	1	4	16	25	-7	-10	-5	-1	-3	1	-1	0	10	12	4	5	6	13	6	30
26	-2	-5	3	11	3	1	-2	4	10	5	5	0	0	-1	-2	0	4	2	1	12	18	-14	-10	-3	-2	-4	-5	2	4	12	13	3	2	7	11	0	26
22	-8	10	2	6	1	2	2	1	0	1	0	0	-2	-1	-2	1	0	1	0	5	6	-7	-8	-3	0	-5	-5	4	1	7	7	5	0	0	4	-3	22
18	-10	-9	0	0	2	1	1	-2	-2	-1	-1	2	-3	0	0	1	0	0	0	0	0	-1	1	1	-2	-5	-2	1	-3	-3	8	2	1	3	5	-5	18
	175	165	155	145	135	125	115	105	95	85	75	65	55	45	35	25	15	5	5	15	25	35	45	55	65	75	85	95	105	115	125	135	145	155	165	175	

Longitude

Table 2.2

Stationary Eddy Heat Flux

January 1975

Longitude

		175	165	155	145	135	125	115	105	95	85	75	65	55	45	35	25	15	5	5	15	25	35	45	55	65	75	85	95	105	115	125	135	145	155	165	175	
	70	0	0	0	0	1	3	3	6	7	0	-3	-4	-1	0	0	-1	-3	0	8	8	4	3	1	-1	0	1	1	0	0	0	-1	0	2	1	0	0	70
	66	0	0	0	1	0	0	1	5	12	3	-2	-3	-3	-1	-1	2	3	11	17	9	3	1	-1	-1	0	1	1	0	1	0	0	4	3	1	-1	0	66
	62	0	0	0	3	2	-2	0	2	13	6	-1	-1	-1	-1	2	8	18	24	18	6	-2	-3	-2	0	1	3	1	1	3	5	4	10	4	-1	-1	-1	62
L	58	0	3	3	7	8	-1	-5	0	9	7	-2	1	1	0	8	11	27	25	12	-3	-10	-8	-2	1	1	2	2	2	9	16	11	12	6	-2	-2	-1	58
A	54	2	7	8	12	13	-2	-9	-2	6	5	-3	1	3	11	15	13	29	18	7	-14	-14	-9	-2	2	1	1	1	4	15	29	22	13	8	-2	-5	-3	54
T	50	3	14	18	22	12	-8	-13	-6	4	0	-3	2	4	19	18	18	20	9	-1	-16	-11	-6	-1	1	0	0	0	4	14	37	33	21	6	-5	-8	-4	50
I	46	6	21	28	30	7	-21	-15	-9	2	0	2	3	7	18	12	14	5	0	-9	-9	-5	-1	1	0	0	0	0	1	10	37	37	28	2	-12	-9	-3	46
T	42	10	28	29	28	9	-33	-16	-7	1	4	7	3	6	10	8	4	-3	-4	-10	-1	1	1	0	0	-1	0	0	-2	6	25	36	20	-1	-11	-2	2	42
U	38	10	26	20	20	8	-32	-14	-3	3	10	11	-1	-4	2	1	-3	-4	-1	-4	8	4	-2	-1	0	0	0	0	-1	2	11	21	10	-2	2	7	4	38
D	34	1	15	11	12	2	-13	-8	0	6	4	10	-6	-11	-3	-1	-3	0	1	2	10	3	-4	0	0	-1	1	0	0	-1	2	8	6	9	13	9	-1	34
E	30	-6	3	3	4	2	-5	0	0	-1	5	8	-7	-9	-3	-1	1	2	1	2	3	3	-2	2	-2	-3	0	0	2	0	2	4	6	9	13	0	-10	30
	26	-8	-4	0	1	1	-1	0	-3	-4	3	4	-3	-4	0	1	0	2	1	1	-1	2	2	5	-3	-2	-1	1	3	2	4	5	3	7	7	-7	-13	26
	22	-8	-6	-1	0	0	1	-2	-2	-6	1	0	0	0	1	1	-1	0	1	0	-1	0	3	3	0	-1	-2	1	3	2	3	7	-1	4	1	-8	-11	22
	18	-8	-5	-1	-1	-1	0	0	-1	-3	-3	0	1	0	0	0	-1	-1	1	0	0	0	0	0	1	0	-2	0	2	0	1	2	2	0	0	-5	-6	18
		175	165	155	145	135	125	115	105	95	85	75	65	55	45	35	25	15	5	5	15	25	35	45	55	65	75	85	95	105	115	125	135	145	155	165	175	

Table 2.3

Latitude °N	MSEHT (10^{19} cal/day)			MTEHT (10^{19} cal/day)			Total EHT (10^{19} cal/day)		
	1973	1974	1975	1973	1974	1975	1973	1974	1975
70	1.79	2.76	0.65	1.66	1.47	2.29	3.46	4.23	2.94
66	3.51	4.24	1.31	2.10	1.70	2.73	5.61	5.93	4.04
62	5.12	5.60	2.23	2.67	1.74	3.13	7.79	7.34	5.36
58	5.61	6.15	3.00	3.18	2.05	3.63	8.79	8.20	6.63
54	5.29	6.10	3.60	3.77	2.97	4.15	9.06	9.07	7.75
50	4.85	6.27	3.80	4.80	3.80	4.69	9.64	10.07	8.49
46	3.75	6.35	3.59	5.81	3.63	4.79	9.56	9.98	8.38
42	2.48	5.26	2.99	6.34	2.89	4.66	8.82	8.15	7.65
38	1.69	4.07	2.14	5.82	2.27	4.20	7.51	6.34	6.34
34	1.63	3.35	1.35	4.21	1.85	3.02	5.83	5.21	4.37
30	1.56	2.86	0.53	2.33	1.13	1.54	3.89	3.99	2.07
26	1.30	1.70	0.02	1.11	0.43	0.46	2.41	2.14	0.48
22	0.61	-.02	-.40	0.41	0.04	0.03	1.02	0.03	-.37
18	-.43	-.38	-.50	0.05	-.10	-.11	-.38	-.48	-.61

Table 2.4

2.4; however, the peaks of the MSEHT are generally larger than the peaks of the MTEHT. The MTEHT are spread more uniformly over the globe than the MSEHT. Even though the MTEHTs are dispersed around the globe, there are locations where peak transports do exist. Tables 2.5, 2.6, and 2.7 display the transient compound of the meridional eddy heat transports. Notice that the position of the peaks supports the observation made by Blackmon et al. (1977) that the peaks are closely related to the major storm tracks. Three major storm tracks, along the east coast of the United States extending to Greenland, along the east coast of Asia up to Alaska, and a short track along the west coast of the United States and Canada, are primarily emphasized by our data. The exact position and strength of these peaks varies annually. In January 1973, the peaks were mainly along the east coasts of Asia and the United States. These two peaks were again the dominant features in January 1974; however, they were displaced further north and east of the previous year's position. January 1975 was dominated by three peaks. The peaks along the east coasts of Asia and the United States were still evident and were located primarily between the January 1973 and January 1974 positions. A third peak was located along the west coast of Canada and the United States. It was smaller in area coverage but of the same magnitude as the other two peaks. The variability of these peaks reflect the variability of the storm tracks from year to year.

Comparing the summed values of the MSEHT and the MTEHT listed in

Transient Eddy Heat Flux

January 1973

Longitude

Latitude		175	165	155	145	135	125	115	105	95	85	75	65	55	45	35	25	15	5	5	15	25	35	45	55	65	75	85	95	105	115	125	135	145	155	165	175	
	70	8	16	15	9	1	0	1	3	4	3	2	3	4	3	4	2	1	1	1	2	2	1	-1	-2	-2	-2	0	-1	-2	-4	-2	-1	0	3	6	5	70
	66	11	25	21	6	-3	0	2	6	6	4	2	4	4	4	5	0	-2	-1	1	0	1	4	-1	-4	-2	-1	1	0	-2	-2	0	1	1	4	6	4	66
	62	11	30	22	2	-4	4	6	7	8	5	2	7	9	7	8	0	-5	-1	1	-2	0	4	-5	-5	0	0	1	1	0	0	2	3	1	3	6	5	62
L	58	8	23	16	-4	-2	10	11	7	11	8	8	10	18	16	13	2	-5	-1	-1	-2	-3	1	-6	-4	0	1	1	2	4	3	3	4	0	1	6	6	58
A	54	9	12	12	-1	-2	14	13	6	12	13	12	12	22	26	18	6	-1	-2	-1	-2	-6	-1	-6	-3	1	1	1	0	3	5	3	3	0	2	4	6	54
T	50	8	10	13	4	0	14	11	2	10	17	18	13	24	31	18	7	8	-1	-4	-1	-3	0	-7	1	4	2	1	0	2	6	4	3	2	4	6	10	50
I	46	11	10	14	10	1	12	6	-1	10	20	2[illegible]	17	24	29	17	10	9	-1	-6	1	2	2	-4	5	4	2	0	1	3	6	5	5	7	10	13	14	46
T	42	14	9	13	12	4	8	5	1	15	22	15	16	21	21	15	9	4	-1	-5	5	5	3	0	6	2	2	1	2	4	6	5	10	14	17	20	18	42
U	38	13	8	10	9	3	4	6	5	19	21	11	10	17	15	13	5	-1	-1	-3	7	8	1	3	4	3	1	0	1	5	5	4	14	16	15	19	19	38
D	34	12	11	7	4	-3	2	6	8	20	16	6	4	11	9	6	1	-2	1	-1	7	7	3	5	1	2	2	-8	-3	5	3	3	11	13	10	14	15	34
E	30	6	9	3	1	-6	1	5	8	20	11	1	3	7	4	2	-1	-2	1	0	6	5	3	5	-1	2	3	-8	-1	3	0	0	4	4	4	7	10	30
	26	4	4	0	-1	-4	-1	3	4	12	6	0	2	5	2	0	-1	-1	0	0	4	3	4	2	1	3	2	-2	-2	0	0	-1	0	1	2	2	5	26
	22	3	2	-1	-2	-3	0	1	2	4	3	1	1	3	1	-2	-1	0	2	-1	1	3	5	-2	-1	1	0	-1	-1	0	0	-1	-1	1	1	1	2	22
	18	-1	0	-1	-1	-2	0	0	2	0	2	1	1	1	-1	-1	0	1	1	0	0	0	5	0	-1	0	-1	-1	1	0	1	-2	-1	0	0	2	0	18
		175	165	155	145	135	125	115	105	95	85	75	65	55	45	35	25	15	5	5	15	25	35	45	55	65	75	85	95	105	115	125	135	145	155	165	175	

Table 2.5

Transient Eddy Heat Flux

January 1974

Longitude

		175	165	155	145	135	125	115	105	95	85	75	65	55	45	35	25	15	5	5	15	25	35	45	55	65	75	85	95	105	115	125	135	145	155	165	175	
	70	14	18	11	3	-2	-5	-3	0	0	-1	-1	-1	1	1	1	2	3	4	4	3	3	5	5	4	3	0	-1	-2	-2	0	2	4	4	0	-4	3	70
	66	17	24	15	1	-6	-8	-3	3	3	0	-1	0	1	1	1	2	2	1	1	1	3	5	6	5	4	0	-3	-2	-3	1	4	4	5	2	-3	2	66
	62	14	29	20	1	-9	-9	0	7	4	1	0	2	1	1	0	3	2	-1	-1	-3	2	5	0	3	5	1	-4	-1	-3	0	5	3	2	3	1	2	62
L	58	9	29	29	0	-16	-6	8	10	4	1	3	5	3	0	2	8	3	0	-3	-4	-1	3	-3	2	4	2	-2	-1	1	0	4	-1	0	4	5	4	58
A	54	5	21	35	3	-19	2	18	13	2	-3	8	12	8	5	12	12	5	0	-1	-3	-4	0	-2	1	3	3	1	2	3	2	0	-4	-3	1	6	6	54
T	50	1	13	33	9	-9	10	22	10	-1	-3	11	17	12	11	18	12	5	1	1	-4	-1	-1	1	2	3	2	3	2	4	4	-2	-3	-2	-2	4	6	50
I	46	0	9	27	13	2	17	15	1	-1	0	10	19	12	10	14	7	5	3	0	-6	2	0	1	2	3	1	1	1	3	4	0	0	1	-1	2	5	46
T	42	2	13	19	9	10	17	7	-5	0	1	7	12	7	6	7	3	3	0	-1	-7	2	2	0	2	3	1	1	0	1	2	3	3	2	3	3	3	42
U	38	7	14	10	2	15	12	0	-6	2	1	4	6	5	2	4	2	2	-1	-2	-5	4	1	0	2	5	1	1	0	1	2	5	5	4	5	3	1	38
D	34	7	9	2	2	14	8	-6	-3	-1	3	2	5	2	2	3	1	1	-1	-4	-1	4	1	3	1	6	0	0	0	1	5	6	6	4	6	3	-1	34
E	30	5	5	-2	0	6	4	-7	-2	1	1	3	0	1	2	2	1	1	1	-2	1	5	2	4	0	3	0	-1	-1	2	3	4	3	4	2	0	0	30
	26	4	2	-2	-1	3	0	-4	-2	-1	0	2	0	0	2	0	1	2	2	-1	1	7	3	-1	-2	-1	-1	-1	-1	0	2	3	2	1	1	0	1	26
	22	2	1	-2	-1	0	-1	-1	-1	0	0	0	0	0	2	-1	-1	1	1	0	0	6	6	-6	-1	-2	-2	-1	-1	0	1	0	1	0	0	1	0	22
	18	1	2	-3	-1	-2	-1	0	-1	0	0	0	0	-2	0	-1	0	0	0	0	0	0	5	0	0	0	-2	-1	-1	1	1	-1	0	0	0	1	0	18
		175	165	155	145	135	125	115	105	95	85	75	65	55	45	35	25	15	5	5	15	25	35	45	55	65	75	85	95	105	115	125	135	145	155	165	175	

Table 2.6

Transient Eddy Heat Flux

January 1975

Longitude

	Lat.	175	165	155	145	135	125	115	105	95	85	75	65	55	45	35	25	15	5	5	15	25	35	45	55	65	75	85	95	105	115	125	135	145	155	165	175	
	70	6	7	7	5	2	0	3	7	10	5	2	-1	-2	0	0	2	2	3	4	5	5	4	1	1	3	5	6	5	4	5	4	3	1	-3	-1	4	70
	66	11	12	12	6	2	-2	3	8	12	6	3	-2	-2	0	1	4	3	3	4	6	6	3	0	-1	1	3	6	7	4	4	3	3	2	-3	1	6	66
	62	16	17	15	5	4	-1	1	6	12	7	4	1	-1	3	8	5	4	3	2	6	8	5	1	-1	0	0	4	7	3	1	2	3	2	-1	3	8	62
L	58	17	16	11	6	5	1	1	3	12	9	7	5	2	9	14	12	8	1	1	6	9	7	1	-1	-3	-2	2	3	-1	-1	3	3	2	2	6	10	58
A	54	14	11	6	9	9	4	0	2	12	13	11	7	6	15	19	18	5	1	0	6	9	5	2	0	-5	-2	1	0	-2	-2	3	3	3	6	9	12	54
T	50	12	7	4	10	19	6	-1	0	12	15	15	11	12	21	20	8	2	2	-1	5	6	2	4	2	-3	-1	1	0	-1	0	3	3	7	9	10	12	50
I	46	9	5	0	9	21	9	-2	0	15	18	16	14	17	20	15	2	0	2	-2	4	2	-1	2	4	1	0	0	0	0	2	3	5	11	11	12	11	46
T	42	7	5	3	8	18	12	-1	3	18	19	15	13	14	16	10	1	-2	0	-1	4	1	-1	1	5	3	1	0	-1	1	3	6	8	12	14	14	6	42
U	38	7	7	7	9	15	11	1	6	14	15	7	9	8	9	6	1	0	-1	0	0	1	2	2	3	2	0	0	0	1	4	9	10	15	14	14	7	38
D	34	6	4	5	6	12	1	1	6	9	12	3	4	3	3	4	1	2	-1	0	0	2	5	3	2	0	-1	1	0	1	5	6	9	9	9	10	8	34
E	30	5	0	1	3	6	4	0	4	9	4	0	1	2	0	3	1	3	-1	0	0	2	3	1	0	0	-1	0	0	1	3	3	3	4	5	4	5	30
	26	2	-2	-2	0	3	1	2	3	4	2	-1	0	1	-2	2	2	2	-1	1	0	1	1	1	-1	-1	-2	0	0	1	1	1	1	1	2	1	2	26
	22	0	-1	-4	-1	1	0	1	1	1	1	-1	1	1	-1	0	0	2	-1	0	0	0	0	0	0	0	-2	-1	0	0	0	0	1	0	1	0	1	22
	18	0	-1	-3	-1	0	0	0	0	0	1	0	0	1	-1	0	0	1	0	0	0	0	0	0	0	0	-1	-1	0	0	0	0	1	0	0	0	0	18
		175	165	155	145	135	125	115	105	95	85	75	65	55	45	35	25	15	5	5	15	25	35	45	55	65	75	85	95	105	115	125	135	145	155	165	175	

Table 2.7

Table 2.4, we can see the annual variability of the dominance of the stationary and transient components with latitude. The transient component was larger at all the latitudes for January 1975. Just the opposite was observed in January 1974. January 1973 had the stationary component larger from 50°N to 70°N, and the transient component was larger from 30°N to 46°N.

Also looking at Table 2.4, we see that the peak of the MTEHT varied in latitude from year to year. In January 1973, the peak was at 42°N. The peak in January 1974 was at 50°N. Latitude 46°N was the location of the peak in January 1975. When averaged over the three months, the peak was at 46°N. Oort and Rasmusson (1971) also observed the peak in this location over their five years of data. This indicates our data set is representative of a typical set of Januaries.

2.1.3 Total Meridional Eddy Heat Transport Data

Since the total meridional eddy heat transport is just the sum of the stationary and transient components, it contains some of the characteristics described above. These transports are displayed in Tables 2.8, 2.9, and 2.10. The total meridional eddy heat transport resembles the MSEHT to a large extent, because of the dominance of the stationary peaks. This is particularly true because there are some similarities between the stationary and transient components so that when added together they reinforce each other. This is especially noticeable in the North Atlantic.

Looking at the summed values in Table 2.4, we see that the peak transports did not vary with latitude annually. For all three months, the peak was found at 50°N. Oort and Rasmusson (1971) observed that over their five-year period, the peak transport was also located at 50°N.

Total Eddy Heat Flux

January 1973

Longitude

		175	165	155	145	135	125	115	105	95	85	75	65	55	45	35	25	15	5	5	15	25	35	45	55	65	75	85	95	105	115	125	135	145	155	165	175	
	70	6	15	15	9	1	-1	0	3	7	7	5	3	8	8	18	29	30	26	16	2	-9	-14	-11	-2	4	2	0	-2	0	-2	-2	0	2	2	1	1	70
	66	10	25	22	8	0	-2	-1	5	10	10	7	6	5	7	31	51	51	36	16	-5	-15	-17	-12	0	8	3	-1	-3	1	3	6	9	7	3	0	-1	66
	62	11	31	24	7	4	5	1	5	11	12	9	13	9	13	45	72	61	36	9	-10	-18	-19	-14	3	11	0	-6	-3	5	9	17	23	12	1	-1	0	62
L	58	9	25	18	6	13	16	6	2	12	15	14	20	19	28	59	77	58	23	-5	-12	-17	-17	-12	5	8	-9	-13	-3	10	16	24	29	16	-1	-1	1	58
A	54	11	17	13	8	18	25	10	-1	10	17	19	20	25	41	66	72	46	6	-12	-12	-16	-11	-8	8	2	-14	-12	-2	12	21	27	23	17	5	-1	2	54
T	50	12	14	15	15	22	28	10	-6	6	17	22	17	27	49	63	60	35	-8	-17	-6	-9	-4	-6	10	-2	-7	-4	4	14	20	28	21	15	8	3	8	50
I	46	14	13	17	22	24	25	5	-8	6	18	26	18	30	51	54	46	19	-18	-20	1	0	1	-3	11	-5	-1	1	4	14	17	26	21	12	11	12	16	46
T	42	16	10	16	25	22	12	2	-2	13	23	15	18	32	39	38	26	2	-17	-15	5	5	3	1	9	-4	-1	1	2	12	17	21	18	14	17	23	23	42
U	38	13	5	13	22	10	-1	3	5	22	28	16	13	28	24	19	7	-7	-8	-4	7	7	1	3	6	2	-1	5	-4	6	12	13	18	17	21	28	26	38
D	34	6	7	10	10	-3	-5	4	9	27	28	15	4	19	12	7	-3	-5	1	6	7	3	3	5	1	2	2	6	-4	4	7	8	15	21	22	25	18	34
E	30	-2	6	3	3	-5	-2	4	11	29	22	11	5	12	5	3	-3	-2	5	9	8	-2	1	6	-2	1	3	-8	0	0	4	8	14	18	15	14	1	30
	26	-3	4	-2	1	-3	-1	3	11	23	14	6	4	8	6	3	-2	0	6	7	6	-5	0	4	-2	0	2	-1	-1	-3	4	8	8	12	8	5	-10	26
	22	0	6	-2	-1	-3	0	0	7	11	8	3	2	6	8	0	-4	0	7	3	2	-5	0	-1	-4	0	1	0	0	-3	3	3	1	7	7	-2	-10	22
	18	-4	0	0	0	-2	0	0	0	1	5	2	2	4	0	-1	0	0	1	-1	-1	-3	-1	0	-1	1	-2	1	2	-3	2	0	4	0	-4	-9	-9	18
		175	165	155	145	135	125	115	105	95	85	75	65	55	45	35	25	15	5	5	15	25	35	45	55	65	75	85	95	105	115	125	135	145	155	165	175	

Table 2.8

Total Eddy Heat Flux

January 1974

Longitude

		175	165	155	145	135	125	115	105	95	85	75	65	55	45	35	25	15	5	5	15	25	35	45	55	65	75	85	95	105	115	125	135	145	155	165	175	
	70	14	16	7	-2	-4	1	11	16	9	-2	-3	-3	-2	-3	-1	3	21	41	40	22	11	6	4	3	2	2	2	-1	-3	-3	-3	2	6	4	-1	4	70
	66	18	24	12	-5	-12	-5	13	23	15	-2	-3	2	-3	-3	-4	16	42	58	48	21	11	3	1	4	6	6	6	1	-6	-7	-3	1	8	7	0	3	66
	62	19	35	19	-6	-19	-13	11	26	19	2	0	8	0	-3	-4	26	55	68	50	16	8	2	-4	4	11	9	9	8	-3	-8	1	1	3	8	5	4	62
L	58	23	49	35	-6	-27	-16	9	24	18	7	3	17	10	-3	1	32	58	66	40	4	-1	-1	-4	6	10	4	5	8	8	1	9	1	-2	7	8	9	58
A	54	26	54	61	9	-35	-11	9	17	9	2	10	23	17	4	14	36	58	60	29	-12	-10	-2	0	6	6	-1	1	10	14	13	14	5	-3	-1	5	14	54
T	50	22	47	85	31	-28	-4	13	7	1	-2	12	22	15	12	25	36	55	51	13	-19	-10	0	5	7	2	-3	2	7	13	18	23	19	9	-3	2	15	50
I	46	18	41	86	48	-14	1	9	-4	1	7	13	18	12	15	25	25	45	27	-10	-16	-1	3	4	8	-2	-4	2	3	10	18	34	39	24	3	-1	11	46
T	42	16	39	67	50	0	1	3	-6	11	21	14	10	8	12	11	14	19	3	-26	-13	9	5	-2	3	-4	-2	1	1	5	12	34	43	29	8	-1	6	42
U	38	18	36	45	40	10	-4	-4	-2	24	27	15	4	2	2	1	3	2	-5	-20	-4	22	2	-7	-3	1	0	-1	1	2	8	24	35	20	9	3	9	38
D	34	16	27	24	26	15	-5	-7	5	22	21	16	-1	-1	-2	0	-7	0	-3	-5	11	28	0	-6	-5	6	-1	-1	-1	0	9	18	19	10	10	12	11	34
E	30	9	13	6	14	12	-4	-7	6	14	12	13	1	0	1	0	-2	3	2	2	17	30	-5	-6	-5	2	-3	0	-2	2	13	16	7	9	8	13	6	30
	26	2	-3	1	10	6	1	-6	2	9	5	7	0	0	1	-2	1	6	4	0	13	25	-11	-11	-5	-3	-5	-6	1	4	14	16	5	3	8	11	1	26
	22	-6	11	0	5	1	1	1	0	0	1	0	0	-2	1	-3	0	1	2	0	5	12	-1	-14	-4	-2	-7	-6	3	1	8	7	6	0	0	5	-3	22
	18	-9	-7	-3	-1	0	0	1	-3	-2	-1	-1	2	-5	0	-1	1	0	0	0	0	0	4	1	1	-2	-7	-3	0	-2	-2	7	2	1	3	6	-5	18
		175	165	155	145	135	125	115	105	95	85	75	65	55	45	35	25	15	5	5	15	25	35	45	55	65	75	85	95	105	115	125	135	145	155	165	175	

Table 2.9

Total Eddy Heat Flux

January 1975

LATITUDE	175	165	155	145	135	125	115	105	95	85	75	65	55	45	35	25	15	5	5	15	25	35	45	55	65	75	85	95	105	115	125	135	145	155	165	175	
70	6	7	7	5	3	3	6	13	17	5	-1	-5	-3	0	0	1	-1	3	12	13	9	7	2	0	3	6	7	5	4	5	3	3	3	-2	-1	4	70
66	11	12	12	7	2	-2	4	13	24	9	1	-5	-5	-1	0	8	8	14	21	15	9	4	-1	-2	1	4	7	7	5	4	3	7	5	-2	0	6	66
62	16	17	15	8	6	-3	1	8	25	13	3	0	-2	2	8	13	20	27	20	12	8	2	-1	-1	1	3	5	8	6	6	6	13	6	-2	2	7	62
58	17	19	14	13	13	0	-4	3	21	16	5	6	3	9	22	23	33	26	13	3	-1	-1	-1	0	-2	0	4	5	8	15	14	15	8	0	4	9	58
54	16	18	14	21	22	2	-9	0	18	18	8	8	9	26	34	29	34	19	7	-8	-5	-4	0	2	-4	-1	2	4	13	27	25	16	11	4	4	9	54
50	15	21	22	32	31	-2	-14	-6	16	15	12	13	16	40	36	24	22	11	-2	-11	-5	-4	3	3	-3	-1	1	4	13	37	36	24	13	4	2	8	50
46	15	26	28	39	28	-12	-17	-9	17	18	18	17	24	38	27	16	5	2	-11	-5	-3	-2	3	4	1	0	0	1	10	39	40	33	13	-1	3	8	46
42	17	33	32	36	27	21	-17	-4	19	23	22	16	20	26	18	5	-5	-4	-11	3	2	0	1	5	2	1	0	-3	7	28	42	28	11	3	12	8	42
38	17	33	27	29	23	-21	-13	3	17	25	18	8	4	11	7	-2	-4	-2	-4	8	5	0	1	3	2	0	0	-1	3	15	30	20	13	16	21	11	38
34	7	19	16	18	14	-12	-7	6	15	16	13	-2	-8	0	3	-2	2	0	2	10	5	1	3	2	-1	0	1	0	0	7	14	15	18	22	19	7	34
30	-1	3	4	7	8	-1	0	4	8	9	8	-6	-7	-3	2	2	5	0	2	3	5	1	3	-2	-3	-1	0	2	1	5	7	9	13	18	4	-5	30
26	-6	-6	-2	1	4	0	2	0	0	5	3	-3	-3	-2	3	2	4	0	2	-1	3	3	6	-4	-3	-3	1	3	3	5	6	4	8	9	-6	-11	26
22	-8	-7	-5	-1	1	1	-1	-1	-5	2	-1	1	1	0	1	-1	2	0	0	-1	0	3	3	0	-1	-4	0	3	2	3	7	0	4	2	-8	-10	22
18	-8	-6	-4	-2	-1	0	0	-1	-3	-2	0	1	1	-1	0	-1	0	1	0	0	0	0	0	1	0	-3	-1	2	0	1	2	3	0	0	-5	-6	18
	175	165	155	145	135	125	115	105	95	85	75	65	55	45	35	25	15	5	5	15	25	35	45	55	65	75	85	95	105	115	125	135	145	155	165	175	

Longitude

Table 2.10

2.2 Meridional Surface Temperature Gradient

2.2.1 Acquisition of Data

Land stations' mean surface temperatures for January 1973, 1974, and 1975 were obtained from "Climatic Data of the World", published monthly by the U.S. Environmental Data Service (NOAA). Effects of elevation were taken into account by reducing the temperature to sea level based on the U.S. Standard Atmosphere lower tropospheric lapse rate of 6.5 degrees Celsius per kilometer. The temperatures were plotted and analyzed on a northern hemispheric map. Temperatures every ten degrees of longitude and every four degrees of latitude were read and recorded on a separate table to use in obtaining meridional temperature gradients at the points where the meridional eddy heat transport data was available. Meridional surface temperature gradients were determined by taking north-south centered differences, and are recorded in units of degrees Celsius per four degrees latitude. Negative values mean that the temperature is decreasing toward the north. The meridional surface temperature gradients are listed in Tables 2.11, 2.12, and 2.13.

Some problems with the data occurred, causing the analysis to be somewhat subjective. High elevation stations, when reduced to sea level, gave unrepresentative temperatures compared to the surrounding lower elevation stations. The problem was primarily in the Alps, and these stations were discarded. Large data-sparse areas occurred in the Sahara, the Arabian Peninsula, and the People's Republic of China. In these areas, we followed the general pattern of the surrounding isotherms and thus lost any small scale features which may have existed.

Meridional Surface Temperature Gradient

January 1973

		Longitude																																			
		175	165	155	145	135	125	115	105	95	85	75	65	55	45	35	25	15	5	5	15	25	35	45	55	65	75	85	95	105	115	125	135	145	155	165	175	
	70	-7	-3	-1	1	0	-2	-2	-2	-2	-2	-4	-4	-2	-4	-4	-6	-8	-4	-4	-2	5	3	0	3	1	2	-2	-2	-1	0	1	7	3	3	5	-7	70
	66	-10	-6	3	-4	-3	-3	-5	-5	-4	-2	0	2	-2	-4	-5	-8	-5	-4	-2	-1	-3	2	6	1	0	-2	-3	-3	-3	-4	-1	-2	7	6	-14	-13	66
	62	-8	-5	-10	-12	-9	-5	-4	-4	-5	-4	-3	-1	-1	-1	-3	-3	-2	0	1	2	-2	-1	-1	-3	-3	-3	-3	-8	-9	-5	-2	-12	-19	-19	-7	-4	62
L	58	-2	-8	-9	-7	-12	-11	-13	-9	-3	-4	-5	-2	1	-2	-3	0	-1	0	1	-2	2	1	-1	-2	-2	-2	-5	-1	-3	0	-2	-7	-11	-10	-11	-5	58
A	54	-2	-4	-8	-1	-5	-9	-9	-6	-6	-5	-6	-6	-1	-1	1	0	-2	-1	-1	1	0	-1	-1	0	-1	-7	-4	-4	-3	-4	-6	4	0	-5	-4	-3	54
T	50	-2	-2	-2	-2	-2	-4	1	-3	-4	-8	-6	-6	-4	0	-2	-3	0	0	2	0	-2	-2	-2	-1	-5	-4	-3	-3	-4	-6	5	-7	-3	-5	-3	-2	50
I	46	-3	-2	-3	-2	-2	-1	-3	-6	-4	-6	-7	-7	-4	-5	-3	-1	-1	-1	-4	-6	-1	-5	-6	-7	-6	-5	-5	-4	-3	-6	-8	-10	-9	-6	-4	-4	46
T	42	-3	-3	-2	-3	-2	-2	-1	4	-5	-4	-6	-7	-6	-5	-2	-1	-3	-2	-5	-3	-6	5	-7	-8	-5	-4	-5	-6	-5	-5	-7	-9	-7	-4	-5	-4	42
U	38	-3	-3	-3	-3	0	-2	-4	-7	-4	-5	-4	-7	-7	-3	-4	-2	-3	-2	-1	-3	-7	-5	-3	-5	-9	-8	-8	-9	-6	-5	-5	-4	-4	-4	-4	-4	38
D	34	-3	-3	-3	-3	-4	-2	-9	-7	-5	-2	-6	-8	1	-1	-6	-2	-1	-2	-2	0	-3	-3	-4	-4	-4	-8	-6	-6	-8	-6	-7	-6	-4	-3	-3	-2	34
E	30	-3	-3	-3	-1	-1	-2	-5	-4	-1	-5	-6	-2	-4	-5	-5	-4	1	-2	-2	-2	1	-3	-2	-4	-2	-2	-3	-4	-4	-5	-6	-2	-3	-3	-3	-3	30
	26	-2	-3	-2	-2	-2	-2	-2	-6	-6	-7	-4	-1	-5	-4	0	2	-4	-4	-2	-2	-2	-2	-4	-4	-7	-4	-3	-3	-3	-3	-4	-2	-2	-2	-2	-2	26
	22	-1	-2	-2	-1	-2	-3	-4	-2	-4	-4	-2	-3	-2	0	3	-4	-2	-1	-1	-4	-3	-4	-4	-3	-4	-4	-5	-3	-2	-5	-5	-2	-2	-1	-1	-1	22
	18	-1	-1	-1	-1	-2	-2	-2	-3	-6	-2	-1	-1	0	1	-3	2	0	-2	-6	-4	-4	-4	-4	-3	-3	-4	-3	-1	-2	-3	-5	-2	-2	-1	-1	-1	18
		175	165	155	145	135	125	115	105	95	85	75	65	55	45	35	25	15	5	5	15	25	35	45	55	65	75	85	95	105	115	125	135	145	155	165	175	

Table 2.11

Meridional Surface Temperature Gradient

January 1974

		175	165	155	145	135	125	115	105	95	85	75	65	55	45	35	25	15	5	5	15	25	35	45	55	65	75	85	95	105	115	125	135	145	155	165	175	
	70	-3	-3	-2	-1	0	-2	-1	0	2	3	1	0	-4	-5	-4	-5	-6	-2	-3	-1	1	2	-1	1	2	2	2	2	3	4	4	8	6	6	5	0	70
	66	-7	-6	2	2	0	-1	0	-2	3	0	0	1	-2	-4	-7	-6	-5	-4	-2	2	0	3	5	1	1	0	0	0	-1	-3	-2	-5	-1	-1	-6	-7	66
	62	-8	-4	-10	-14	-5	-1	-2	-1	-4	-4	-3	-1	0	-2	-2	-3	-2	-1	-1	-2	-1	0	1	0	-1	-2	-5	-9	-11	-7	-9	-14	-21	-20	-15	-11	62
L	58	-7	-9	-11	-10	-19	-11	-9	-5	-4	-4	-2	-1	0	-2	-2	-2	-2	-1	1	-1	0	-2	0	0	-2	-4	-7	-10	-11	-4	-4	-2	-3	-6	-8	-11	58
A	54	-3	-4	-4	-2	-3	-13	-10	-7	-5	-4	-3	-3	-1	-2	-3	-1	-1	-1	-1	-1	0	-1	-1	-1	-2	-6	-6	-4	-2	-5	-2	-1	-4	-3	-6	-3	54
T	50	-3	-1	-1	-1	-1	-3	-8	-10	-9	-13	-9	-10	-5	-3	-2	-2	-2	-1	-1	-1	0	-3	-4	-6	-4	-3	-10	-4	-4	-6	-3	-5	-5	-3	-2	-3	50
I	46	-3	-3	-2	-2	-2	-2	-4	-9	-5	-8	-11	-10	-8	-5	-3	-2	-1	-1	-2	-3	-1	-5	-8	-4	-8	-10	-3	-9	-8	-7	-6	-4	-2	-3	-4	-4	46
T	42	-5	-3	-3	-3	-3	-2	-3	-3	-7	-7	-10	-14	-10	-5	-2	-2	-1	-2	-3	-3	-6	-6	-4	-6	-7	-5	-5	-5	-6	-8	-8	-10	-5	-6	-6	-5	42
U	38	-3	-3	-3	-2	-3	-2	-3	-5	-7	-7	-9	-5	-4	-3	-2	-2	-1	-3	-1	-2	-6	-3	-3	-5	-4	-8	-8	-7	-6	-6	-5	-5	-3	-5	-4	-3	38
D	34	-2	-4	-4	-4	-4	-2	-7	-5	-7	-7	-6	-4	-1	-2	-2	-2	-2	-2	-1	-2	-2	-3	-2	-6	-10	-6	-5	-5	-6	-7	-7	-6	-3	-3	-3	-3	34
E	30	-3	-3	-2	-2	-1	-2	-3	-6	-5	-3	-3	-2	-2	-1	-1	-2	-1	-1	-1	-1	-1	-2	-4	-5	-4	-3	-2	-2	-2	-3	-5	-7	-1	-2	-2	-2	30
	26	-3	-3	-3	-2	-2	-2	-2	-1	-4	-3	-2	-2	-1	-1	-1	-1	-1	-3	-2	-2	-1	-3	-6	-4	-3	-4	-2	-3	-3	-2	-4	-2	-4	-3	-3	-3	26
	22	-2	-1	-1	-1	-1	-2	-4	-3	-3	-2	-1	-1	-1	-2	-1	0	-2	-2	-3	-4	-2	-4	-2	-2	-2	-3	-3	-3	-3	-4	-3	-2	-2	-2	-2	-2	22
	18	-1	-1	1	-1	-1	-1	-3	-2	-4	0	-2	-2	-1	-1	0	-1	-3	-1	-3	-2	-4	-3	-4	-4	-4	-4	-1	0	-2	-2	-2	-2	-2	-2	-1	-1	18
		175	165	155	145	135	125	115	105	95	85	75	65	55	45	35	25	15	5	5	15	25	35	45	55	65	75	85	95	105	115	125	135	145	155	165	175	

Longitude (column headings); LATITUDE (row labels)

Table 2.12

Meridional Surface Temperature Gradient

January 1975

Longitude

Latitude	175	165	155	145	135	125	115	105	95	85	75	65	55	45	35	25	15	5	5	15	25	35	45	55	65	75	85	95	105	115	125	135	145	155	165	175	
70	-2	-3	-4	-3	-2	-5	-4	-3	0	0	-1	0	-2	-4	-5	-10	-10	-5	-4	-3	0	1	-2	-2	0	0	-1	0	0	1	3	8	5	4	7	1	70
66	-7	-6	-3	-11	-13	-5	-2	-3	-1	-2	-2	0	-3	-6	-8	-11	-7	-4	-3	1	0	-2	-3	-3	-3	-3	-4	-4	-3	-3	0	-2	7	6	-7	-6	66
62	-9	-6	-9	-13	-10	-11	-7	-6	-5	-5	-4	-1	-4	-2	-8	-5	-3	-2	-2	-3	-4	-4	-4	-6	-4	-5	-4	-7	-6	-6	-14	-19	-20	-16	-12	-13	62
L 58	-9	-9	-10	-8	-11	-13	-12	-7	-6	-5	-4	-2	2	-3	-2	-1	-2	-2	-1	-4	0	-2	-1	-1	-3	-3	-4	-8	-6	-1	-2	-3	-10	-10	-10	-11	58
A 54	-7	-9	-9	-2	-3	-6	-11	-8	-5	-5	-5	-5	-1	-2	-3	-2	-1	-2	-1	-1	-1	-1	0	1	2	1	-1	-4	-3	-1	0	3	1	-6	-10	-5	54
T 50	-3	-1	-1	-2	-2	-4	-3	-10	-8	-10	-7	-7	-5	-1	-4	-2	-1	-1	-1	0	-1	-1	-2	0	-1	-2	-4	-6	-6	-8	-5	-7	-5	-9	-3	-3	50
I 46	-3	-3	-2	-2	-2	-1	-4	-4	-6	-7	-10	-11	-6	-4	-2	-2	-1	-1	-2	-3	1	-2	-6	-9	-13	-10	-7	-5	-8	-7	-6	-6	-6	-2	-2	-2	46
T 42	-4	-3	-3	-4	-3	-1	-3	-2	-5	-5	-8	-7	-7	-6	-2	-2	-2	-1	-2	0	-2	-4	-4	-4	-3	-6	-5	-4	-4	-7	-6	-8	-4	-7	-5	-4	42
U 38	-3	-3	-4	-2	-2	-1	-4	-4	-6	-6	-4	-7	-7	-3	-2	-2	-2	-3	-2	-3	-7	-4	-4	-4	-3	-4	-4	-4	-4	-5	-6	-5	-6	-5	-4	-4	38
D 34	-4	-5	-4	-5	-3	-3	-2	-5	-5	-4	-6	-7	-2	-1	-2	-2	-1	-1	-1	-1	0	-2	1	-3	-4	-4	-3	-4	-5	-5	-7	-7	-5	-3	-3	-3	34
E 30	-3	-3	-2	-1	-1	-2	-1	-4	-3	-4	-5	-1	-1	-1	-2	-1	-1	-1	-1	0	-1	-3	-4	-3	-4	-2	-2	-4	-3	-3	-6	-6	-2	-2	-3	-3	30
26	-3	-2	-1	0	0	-1	-2	-1	-3	-6	-2	-1	-2	-1	-2	-1	2	-2	-1	-1	-1	-3	-4	-5	-4	-4	-3	-4	-6	-3	-6	-3	-4	-4	-4	-4	26
22	-1	-1	-1	-1	-1	-2	-3	-4	-2	-1	-1	-1	-2	-2	0	0	-3	-2	-3	-1	-3	-3	-2	-4	-3	-3	-4	-2	-2	-5	-2	-1	-2	-2	-2	-1	22
18	-1	-1	-1	-1	-2	-3	-2	-4	-6	-3	-1	-1	-1	-1	0	0	-2	-3	-2	-6	-3	-4	-4	-3	-3	-3	-2	-2	-1	-3	-3	-2	-1	-1	-1	-1	18
	175	165	155	145	135	125	115	105	95	85	75	65	55	45	35	25	15	5	5	15	25	35	45	55	65	75	85	95	105	115	125	135	145	155	165	175	

Table 2.13

Air temperature data was not available over the oceans, and so we used sea surface temperatures. Although these temperatures may not relate directly to corresponding air temperatures, their gradients are likely to correspond. Mean sea surface temperatures were available directly from data compiled by the National Marine Fisheries Service (NOAA). The temperatures were averaged values over a five-by-five degree square and were in degrees Celsius. They were plotted, analyzed, and the gradients were determined in the same manner as over the land. Whenever land and sea data analysis overlapped, the land analysis was used. This did not occur enough to make a reasonable comparison of the gradients.

2.2.2 Data Characteristics

The strongest meridional surface temperature gradients for all three months occurred where oceans lie to the south of land in the upper mid-latitudes. The strongest of these was in eastern Asia, north of Japan. Southern Alaska and western Canada's coastline also had a very strong surface temperature gradient that was present for all three months. Looking at the zonally averaged meridional surface temperature gradients, we see that the peak was always at 62°N. In January 1974 and 1975, the temperature gradient on the south coast of Nova Scotia was quite noticeably strong; however, in January 1973 the temperature gradient was only half as intense. Minor peak temperature gradients occurred just to the south of the semi-permanent cold core highs in Siberia and Northern Canada. The Siberian high produced the stronger of the two gradients. The position and magnitude of these last two meridional surface temperature gradients varied slightly from year to year. The data south of 30°N should not be trusted to any large extent, because this area contains large data-sparse areas, and very large areas where sea surface temperature data was used.

2.3 Two-Layer Model Stability Parameter

In the two-layer model, the troposphere is divided into two equal mass layers. The mass averaged parameters describing the lower layer will be denoted by the subscript 1, the subscript 2 will denote the upper layer. The stability parameter can now be defined as: $U_2 - U_1 - U_c$; Stone (1978). $U_2 - U_1$ is just the vertical shear of the two layer troposphere. U_c is the critical wind shear, and was determined by Phillips (1954) and Stone (1978) as:

$$U_c = \frac{BR(\theta_2 - \theta_1)}{f^2} \tag{2.1}$$

where $B = \frac{\partial f}{\partial y}$, $f = 2\Omega \sin\phi$, R is the gas constant, and θ_1 and θ_2 are the mass averaged potential temperatures of the two layers. The stability parameter was provided from the same source and in the same format as the meridional eddy heat transport data. Units are meters per second, and positive values indicate instability, while negative values indicate stability.

2.3.1 Model Stability Parameter Characteristics

The model stability parameter is noisy, mainly because of the large variation in $U_2 - U_1$. To solve this problem, the stability parameter was smoothed over a number of degrees of longitude. The smoothing distance was $2\overline{L_r(\phi)}$ rounded to the nearest 5 degrees, where $\overline{L_r(\phi)}$ is the mean radius of deformation. For example, the smoothing distance for the latitudes 38°N to 50°N was 40 degrees longitude.

To a good approximation, U_c was constant along a latitude circle (Stone, personal communication). Having U_c essentially constant on a latitude circle enables us to calculate the variation of the vertical wind shear from the variation of the model stability parameter. The vertical wind shear can be related to the horizontal temperature gradient by the thermal wind relationship. Thus to a large extent, we will be correlating the mean meridional tropospheric horizontal temperature gradient to the meridional eddy heat transports, when we correlate the latter with the stability parameter.

2.3.2 Data Characteristics

Tables 2.14, 2.15, and 2.16 contain the stability parameter. One striking feature of the data was the dominance of negative values south of 30°N. The reason for this is two-fold. Primarily, it is because U_c increases as the latitude decreases. Also, the vertical wind shear is much smaller in the tropics than in the extratropical latitudes, so U_2-U_1 decreases as we move into the tropics. Obviously, the atmosphere is not as completely stable as the model stability parameter indicates at and below 30°N, since the eddy transports are not zero. Nevertheless, they are relatively small in this region.

There are two main areas where the mean monthly stability parameter has a large positive value for all three months. One unstable area is just off the east coast of Japan. The other unstable area is located south of Nova Scotia. It is interesting to notice that these areas are located in

Two-layer Model Stability Parameter

January 1973

		Longitude																																			
		175	165	155	145	135	125	115	105	95	85	75	65	55	45	35	25	15	5	5	15	25	35	45	55	65	75	85	95	105	115	125	135	145	155	165	175	
	70	1	2	3	3	4	3	3	2	1	0	-1	-1	0	1	2	2	3	4	4	3	2	2	1	1	0	-1	-1	-1	-2	-2	-2	-2	-2	-1	-1	0	70
	66	2	3	4	5	5	5	4	3	2	1	0	0	1	1	2	3	3	3	3	3	2	1	1	0	0	-1	-1	-1	-1	-1	-2	-2	-1	0	0	1	66
	62	3	4	4	4	4	4	4	3	2	1	0	0	0	0	1	2	2	2	1	1	0	0	0	-1	0	0	-1	0	-1	-1	-1	0	0	0	1	2	62
L	58	3	3	3	3	3	3	3	3	2	2	1	0	0	-1	0	0	0	-1	-2	-2	-2	-2	-2	-1	0	0	1	1	1	1	0	0	0	1	2	2	58
A	54	2	2	2	2	1	1	1	1	1	2	1	1	0	0	-1	-1	-2	-3	-4	-5	-5	-4	-3	-2	0	1	3	3	3	1	0	0	0	1	2	2	54
T	50	2	1	1	1	1	0	1	0	0	1	2	2	1	1	-1	-2	-4	-6	-6	-6	-6	-4	-3	-2	0	2	2	3	2	0	0	1	1	2	3	2	50
I	46	2	1	0	0	0	0	0	0	1	2	3	4	3	2	0	-3	-5	-7	-7	-7	-5	-4	-2	-1	1	2	2	2	0	0	0	2	3	4	4	3	46
T	42	4	2	1	0	0	-1	-1	0	2	4	6	6	5	2	0	-3	-5	-6	-6	-5	-3		-1	1	2	1	2	2	1	2	3	5	6	7	7	5	42
U	38	5	3	1	0	-1	-2	-3	-1	1	3	5	5	3	0	-2	-5	-6	-6	-4	-2	0	2	3	3	2	3	3	3	5	6	7	9	10	10	9	7	38
D	34	-4	0	-2	-2	-2	-3	-2	-1	0	-1	-6	-7	-9	-10	-11	-6	-5	-4	-3	-1	0	2	4	5	9	12	11	11	12	10	8	8	8	7	0	-2	34
E	30	-15	-16	-16	-14	-13	-12	-4	-4	-11	-12	-14	-16	-17	-17	-17	-15	-14	-5	-4	-3	-2	-9	0	0	4	4	4	3	4	-2	-5	-5	-7	-10	-12	-13	30
	26	-30	-29	-28	-25	-23	-22	-21	-21	-22	-23	-24	-26	-26	-25	-24	-23	-21	-20	-9	-8	-7	-17	-17	-18	-19	-20	-21	-22	-23	-24	-24	-26	-26	-28	-29	-30	26
	22	-54	-53	-51	-48	-46	-44	-43	-43	-44	-44	-44	-44	-44	-42	-41	-39	-37	-36	-34	-33	-34	-34	-35	-37	-40	-43	-46	-48	-50	-51	-53	-54	-55	-56	-56	-56	22
	18	-87	-84	-81	-78	-77	-76	-76	-75	-75	-75	-75	-75	-74	-72	-71	-70	-67	-66	-65	-66	-67	-67	-69	-71	-74	-78	-82	-85	-88	-90	-92	-94	-93	-92	-91	-90	18
		175	165	155	145	135	125	115	105	95	85	75	65	55	45	35	25	15	5	5	15	25	35	45	55	65	75	85	95	105	115	125	135	145	155	165	175	

Table 2.14

Units are meters per second

Two-layer Model Stability Parameter

January 1974

Longitude

		175	165	155	145	135	125	115	105	95	85	75	65	55	45	35	25	15	5	5	15	25	35	45	55	65	75	85	95	105	115	125	135	145	155	165	175	
	70	4	4	3	2	1	0	-1	-2	-3	-3	-3	-3	-2	-1	0	1	2	2	2	2	2	1	0	-1	-2	-3	-2	-2	-3	-3	-3	-1	0	2	3	4	70
	66	5	6	5	4	3	2	0	-1	-3	-3	-4	-3	-3	-2	-1	1	2	2	2	2	1	0	-1	-1	-2	-3	-3	-3	-3	-4	-3	-2	-1	1	2	4	66
	62	4	5	6	6	5	4	3	1	-1	-2	-3	-4	-4	-3	-2	0	1	2	2	1	0	-1	-2	-2	-2	-1	-1	-1	-2	-3	-3	-3	-3	-2	0	2	62
L	58	1	4	5	6	6	6	5	4	3	1	0	-1	-2	-2	-2	-1	0	1	0	-1	-2	-3	-4	-3	-2	-1	0	0	0	-1	-2	-3	-5	-4	-2	-1	58
A	54	-2	0	2	4	6	6	6	6	7	7	6	5	4	3	2	2	2	1	0	-2	-4	-4	-4	-4	-2	0	1	2	1	-1	-2	-4	-6	-6	-5	-4	54
T	50	-5	-4	-2	0	1	2	4	6	8	11	13	13	11	9	7	5	3	1	-1	-3	-4	-4	-3	-2	0	2	4	4	3	1	-2	-4	-5	-5	-7	-7	50
I	46	-5	-4	-4	-3	-2	0	3	6	9	13	14	15	13	11	8	5	2	0	-2	-3	-3	-3	-2	1	3	4	5	6	5	3	1	-2	-3	-4	-5	-5	46
T	42	0	-2	-2	-2	-1	1	4	6	8	9	9	8	7	5	3	1	-2	-3	-4	-5	-3	-2	0	3	4	6	7	6	6	6	4	4	3	2	2	1	42
U	38	4	2	-1	-2	-1	0	1	2	1	0	-1	-1	-1	-2	-2	-4	-6	-8	-8	-7	-4	-1	2	5	4	3	2	1	2	5	7	9	10	10	10	8	38
D	34	4	1	-3	-5	-5	-5	-5	-5	-6	-11	-11	-7	-7	-6	-7	-8	-9	-10	-9	-7	-3	1	4	6	2	-1	-3	-4	-1	2	8	12	13	13	11	8	34
E	30	-11	-14	-16	-18	-18	-12	-12	-12	-17	-17	-17	-17	-11	-11	-11	-10	-9	-8	-7	-5	-2	0	1	2	-2	-5	-7	-7	-7	-9	-6	-5	-4	-5	-7	-9	30
	26	-28	-28	-28	-28	-28	-28	-27	-19	-26	-26	-24	-23	-16	-14	-12	-10	-9	-7	-6	-5	-4	-4	-4	-5	-6	-17	-20	-13	-24	-25	-26	-27	-27	-26	-27	-27	26
	22	-48	-46	-44	-44	-44	-44	-43	-43	-43	-41	-39	-37	-34	-31	-29	-27	-25	-24	-24	-23	-15	-16	-27	-30	-34	-38	-44	-47	-50	-51	-52	-53	-51	-50	-49	-49	22
	18	-79	-77	-75	-73	-71	-70	-68	-68	-67	-66	-65	-64	-64	-64	-64	-63	-62	-61	-61	-62	-63	-63	-64	-66	-69	-74	-79	-82	-84	-86	-87	-88	-87	-86	-84	-81	18
		175	165	155	145	135	125	115	105	95	85	75	65	55	45	35	25	15	5	5	15	25	35	45	55	65	75	85	95	105	115	125	135	145	155	165	175	

Table 2.15

Units are meters per second

Two-layer Model Stability Parameter

January 1975

Longitude

		175	165	155	145	135	125	115	105	95	85	75	65	55	45	35	25	15	5
	70	1	2	3	3	3	3	2	1	0	0	-1	-1	0	1	2	3	4	5
	66	1	2	2	3	3	4	3	3	2	1	0	0	1	2	4	5	6	7
	62	2	2	2	3	3	4	4	3	3	2	1	1	1	2	4	6	7	7
L	58	3	4	5	5	5	5	5	4	3	3	3	3	4	4	8	6	6	5
A	54	3	5	7	8	8	7	5	4	3	4	6	7	8	9	9	8	5	3
T	50	4	6	8	9	9	7	5	4	4	5	7	9	10	9	8	5	3	0
I	46	6	6	6	5	5	4	4	4	5	7	8	8	7	5	2	0	-2	-4
T	42	8	5	1	0	-1	-1	0	3	5	7	7	6	3	-1	-4	-6	-7	-8
U	38	5	0	-4	-12	-12	-7	-5	-1	2	3	3	1	-2	-4	-7	-9	-10	-10
D	34	-7	-12	-16	-19	-19	-18	-9	-7	-4	-9	-9	-10	-12	-14	-15	-10	-11	-9
E	30	-18	-21	-24	-26	-26	-24	-22	-13	-18	-17	-18	-20	-21	-21	-20	-19	-11	-9
	26	-30	-31	-32	-33	-32	-32	-31	-31	-29	-29	-29	-29	-29	-28	-26	-24	-22	-12
	22	-48	-48	-47	-46	-46	-46	-46	-46	-45	-44	-44	-43	-41	-39	-38	-36	-36	-37
	18	-80	-78	-76	-75	-74	-73	-73	-73	-72	-71	-70	-69	-68	-67	-67	-67	-68	-70
		175	165	155	145	135	125	115	105	95	85	75	65	55	45	35	25	15	5

		5	15	25	35	45	55	65	75	85	95	105	115	125	135	145	155	165	175	
	70	5	5	5	4	4	4	3	3	2	1	0	-1	-2	-3	-3	-2	-2	-1	70
	66	6	6	5	4	4	4	4	3	2	0	-1	-2	-3	-3	-3	-2	-1	0	66
	62	6	5	4	3	3	3	3	3	1	0	-2	-3	-3	-3	-2	-1	0	1	62
L	58	4	3	2	1	1	1	1	1	1	0	-1	-2	-3	-3	-2	-1	1	2	58
A	54	1	0	-1	-1	-1	-1	-1	0	0	-1	-1	-3	-3	-4	-3	-2	0	2	54
T	50	-2	-2	-3	-2	-2	-2	-1	-1	-1	-1	-2	-3	-3	-3	-2	0	2	3	50
I	46	-5	-5	-5	-4	-3	-2	-1	-1	-1	-1	-1	-2	-1	0	2	4	6	6	46
T	42	-8	-8	-6	-5	-3	-2	-1	-1	-2	-1	0	1	3	6	8	9	10	9	42
U	38	-9	-8	-5	-2	0	1	0	-2	-3	-2	0	4	8	11	13	13	12	8	38
D	34	-7	-5	-3	-1	1	0	-2	-4	-4	-3	-1	3	3	6	6	5	2	-3	34
E	30	-6	-4	-3	-2	-2	-3	-5	-7	-7	-6	-6	-11	-9	-8	-8	-10	-12	-14	30
	26	-11	-11	-20	-21	-21	-22	-23	-15	-16	-16	-27	-28	-29	-29	-29	-29	-29	-29	26
	22	-38	-40	-41	-42	-43	-44	-44	-45	-47	-48	-49	51	-52	-52	-52	-51	-50	-49	22
	18	-72	-75	-77	-79	-80	-81	-81	-82	-83	-83	-83	-84	-85	-85	-84	-84	-83	-81	18
		5	15	25	35	45	55	65	75	85	95	105	115	125	135	145	155	165	175	

Table 2.16

Units are meters per second

the vicinity of the major winter storm tracks. The position and magnitude of these unstable region varies slightly from year to year. The area off the east coast of Japan had the largest values for January 1973, and 1975. The area south of Nova Scotia was the dominant peak in January 1974. For January 1973, both areas were noticeably weaker compared with the other two months. A third, smaller unstable area appeared in January 1975 along the west coast of Canada. This area was not present in the previous two years.

CHAPTER THREE

METHODS OF ANALYSIS

3.1 Correlation Analysis

Correlations were only performed along the latitude circles for several reasons. Latitudinal correlations were not performed because of the limited degrees of freedom in that direction, and because the results are fairly obvious just by examining the data tables (i.e. peak transports occur in mid-latitudes where baroclinic instability is the largest). Also, latitudinal correlations were not computed because the quality of the data was not as good below 34°N latitude. Therefore, each of the fourteen latitudes were treated separately. It is important to note that any similarities between different latitude correlations must be attributed solely to the data, so the persistence of large correlations at different latitudes adds to the significance of the correlations.

The correlation coefficients for the 36 points around the latitude circle was computed as follows:

$$r = \frac{\Sigma\,(X-X_m)\,(Y-Y_m)}{36\ \sigma_x\ \sigma_y} \tag{3.1}$$

where r is the correlation coefficient, X and Y are the variable values, X_m and Y_m are the zonal averages of the two variables, and σ_x and σ_y are the individual standard deviations. The correlation coefficients were not only computed directly, but also using spatial lags of 10 to 350 degrees of longitude in increments of ten degrees. To better explain the use of the term spatial lags, let us take an example of correlating two arrays X versus Y. This means that we are correlating the first array $X(\lambda)$ with the second array $Y(\lambda+\Delta)$, where λ is the longitude, and $\Delta = 0, 10, 20, \ldots$ 350 degrees longitude is the eastward shift of the second variable (spatial lag). This allowed us to calculate 36 correlation coefficients for each of the 14 latitudes, for each pair of input arrays. Since the data along the latitude circle looped completely around the earth, there was no lop-off error with the spatial lags.

Each January had five input arrays. By correlating each input array with itself and the other four arrays, we obtained fifteen different correlation coefficient arrays per year. Of the fifteen combinations, five were autocorrelations which were used for determining the degrees of freedom in the data. The other ten combinations are the crux of our investigation. By comparing these ten different combinations for each January, it was obvious that the patterns were quite similar. There were some minor differences from year to year, and we will refer to these differences as noise. This noise may have been caused by any of a number of factors, such as errors in data measurements or handling, or natural variability, etc. Our data does not span a long enough period to test any explanation for the interannual variability, so the noise is of little importance to this investigation. To reduce the noise level, we averaged the correlation coefficient arrays over the three Januaries. The averaging reduced the peak correlation coefficients, but did not change the significance of the important peaks, because it tripled the number of data points, thus increasing the degrees of freedom. These averaged correlation coefficient arrays are contained in the tables and will be discussed in the next chapter.

3.2 Significance Testing

The major difficulty in significance testing is determining the degrees of freedom of the data. To determine the degrees of freedom, we used a method prescribed by Davis (1976). In our case, the degrees of freedom (N) are defined as

$$N = 3\left(\frac{36\Delta\lambda}{\lambda N}\right) \qquad (3.2)$$

where

$$\frac{\lambda N}{\Delta\lambda} = \sum_{\lambda_i = -90}^{90} C_x(\lambda_i) C_y(\lambda_i) \qquad (3.3)$$

$C_x(\lambda_i)$ and $C_y(\lambda_i)$ are the autocorrelation functions for the two correlated data arrays averaged over the three Januaries. The three in the definition of N is present because we are averaging over the three completely independent Januaries. Unlike Davis, we limited our spatial lags to $\pm$ 90 degrees in order to avoid the influence of continents, which introduces a strong wave number two component in the data. As it turned out, this procedure only slightly affected our confidence level determination. The series for $\frac{\lambda N}{\Delta\lambda}$ converges very rapidly as we can see in the examples in Figure 3.1. Because of the continental effect, we limit our discussion of correlation peaks to those within ± 90 degrees spatial lag.

Once the degrees of freedom were known, it was a simple procedure to use the t test tables to determine the 95% and 99% confidence levels

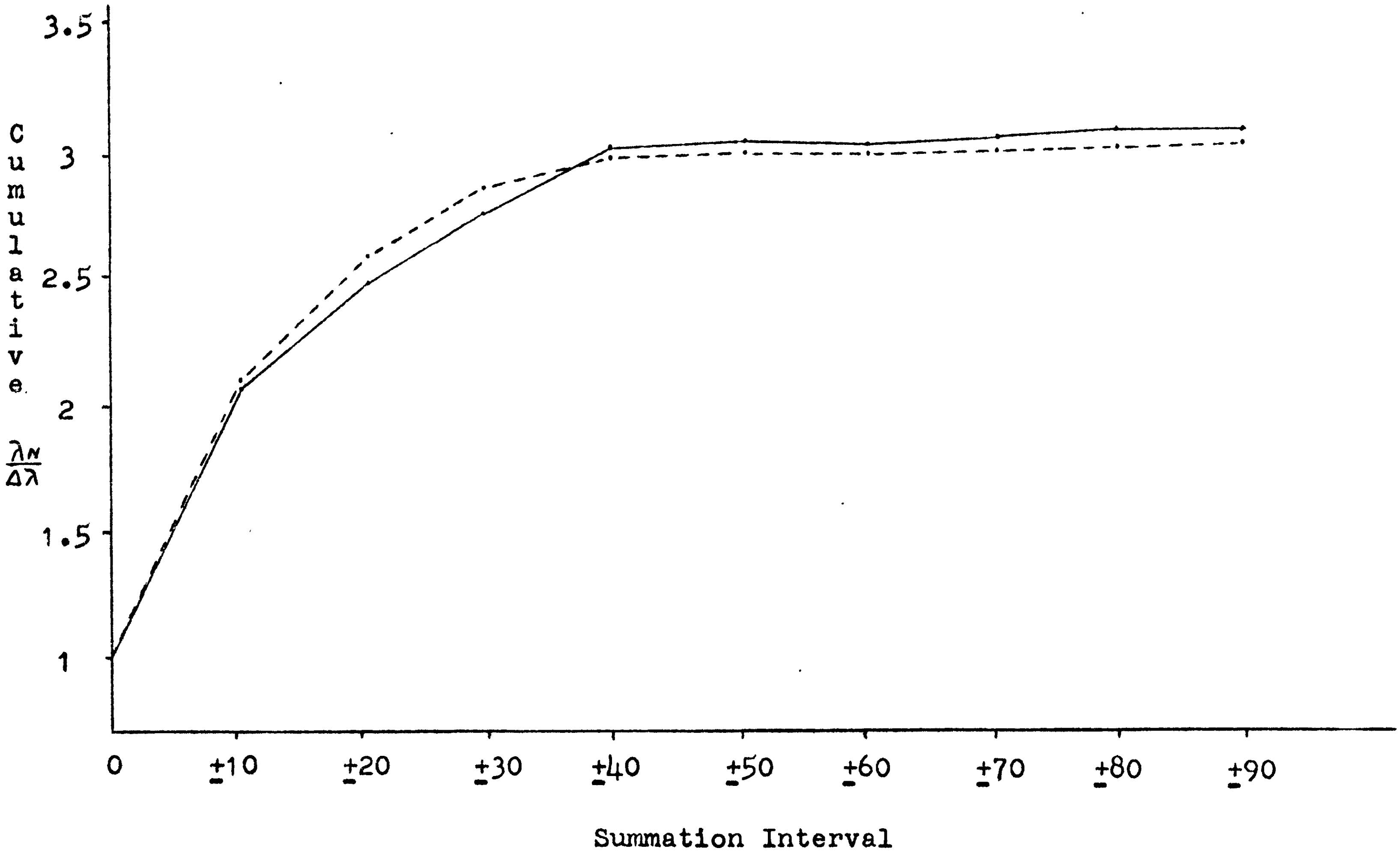

Figure 3.1: Convergence of series for $\lambda_N/\Delta\lambda$, for correlation of Model Stability Parameter with Transient Eddy Heat Transport (Avg 1973, 1974, and 1975) —— Latitude 50°N, ---- Latitude 38°N, (see Eq. 3.3)

for an individual correlation. These confidence levels apply to a priori correlation peaks. A priori correlation peaks are correlation peaks centered around zero degrees spatial lag, because correlation peaks at zero degrees spatial lag are physically expected. Correlation peaks centered at other spatial lags are a posteriori peaks. We are limited in our ability to test the significance of the a posteriori peaks, because we only have three months of data. This allows us only three degrees of freedom for these peaks, giving their 95% and 99% confidence levels as .80 and .93, respectively. A larger data base would be necessary to fully test the relationship suggested by peaks at finite lags.

The confidence levels for the a priori correlation peaks are listed in Table 3.1 for the two correlations of most interest. There was no significance testing performed for the other combinations, since preliminary investigation showed results of little importance (Stailey, personal communication). It is interesting to note from Table 3.1 that there is little latitudinal variation in the 99% confidence level for the combination of surface temperature gradient versus transient eddy heat transport. Latitudinal variation is a little more pronounced for the model stability parameter versus transient eddy heat transport, and the degrees of freedom are noticeably smaller than for the first combination. This can be explained by the fact that the model stability parameter was smoothed longitudinally. One final point to note is that the degrees of freedom are fewest in mid-latitudes for both combinations. This would indicate that the variables do not differ as rapidly with longitude as they do for the other latitude circles.

Table 3.1: Significance Testing								
	Surface Temperature Gradient versus Transient Eddy Heat Transport				Two-Layer Model Stability Parameter versus Transient Eddy Heat Transport			
Latitude °N	$\frac{\lambda_N}{\Delta\lambda}$	Degrees of Freedom N	95% Confidence Level	99% Confidence Level	$\frac{\lambda_N}{\Delta\lambda}$	Degrees of Freedom N	95% Confidence Level	99% Confidence Level
70	2.29	47	.24	.33	2.94	37	.27	.37
66	1.87	58	.22	.30	1.88	57	.22	.30
62	1.94	56	.22	.31	1.90	57	.22	.30
58	2.11	51	.23	.32	2.29	47	.24	.33
54	2.05	53	.23	.31	2.90	37	.27	.37
50	2.41	45	.24	.34	3.11	35	.27	.38
46	2.47	44	.25	.34	3.27	33	.28	.39
42	2.38	45	.24	.34	3.36	32	.29	.40
38	2.20	49	.23	.32	3.04	36	.27	.38
34	1.84	59	.21	.30	2.42	45	.24	.34

Table 3.1

CHAPTER FOUR

DISCUSSION OF CORRELATIONS

All of the averaged correlation coefficient arrays, except for the autocorrelations and the two trivial combinations, transient eddy heat transport versus total eddy heat transport and stationary eddy heat transport versus total eddy heat transport, will be discussed in this chapter. The discussion will be confined primarily to the area between and including latitudes 34°N to 70°N and ± 90 degrees spatial lag, for the reasons mentioned earlier. Significance testing was performed on the two combinations, surface temperature gradient versus transient eddy heat transport and two-layer model stability parameter versus transient eddy heat transport, because from baroclinic theory one expects a correlation. For these combinations, the correlation coefficients greater than or equal to the 99% confidence level for an individual correlation are contoured with a solid line. The other combinations are also of some interest, and for these combinations, correlation coefficients exceeding .34 are contoured with a dashed line. The .34 cutoff was selected because this would approximately be the 99% confidence level.

4.1 Meridional Surface Temperature Gradient versus Two-Layer Model Stability Parameter

The results are contained in Tables 4.1A and 4.1B. The large negative correlations are easily explained. Since U_c is essentially independent of longitude, it is normalized out in the correlation process, and in essence we are correlating the meridional surface temperature gradient with the meridional mean tropospheric temperature gradient. It is not

SURFACE TEMPERATURE GRADIENT VS MODEL STABILITY PARAMETER (JAN 73, 74, 75)

Eastward Shift of Second Variable (degrees longitude)

LATITUDE	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
70	-.45	-.46	-.41	-.33	-.23	-.11	.01	.08	.13	.17	.16	.13	.09	.04	.02	.03	.05	.07	.10
66	-.28	-.40	-.47	-.46	-.42	-.33	-.22	-.12	-.02	.05	.11	.16	.18	.17	.15	.16	.12	.10	.06
62	.15	.03	-.11	-.24	-.34	-.38	-.41	-.43	-.43	-.44	-.41	-.34	-.24	-.13	-.02	.05	.09	.07	.02
58	-.48	-.55	-.55	-.52	-.45	-.39	-.34	-.30	-.30	-.30	-.31	-.27	-.20	-.12	-.02	.08	.17	.23	.26
54	-.44	-.50	-.49	-.48	-.45	-.39	-.31	-.23	-.16	-.10	-.04	.00	.05	.11	.18	.21	.22	.22	.22
50	-.39	-.48	-.50	-.49	-.42	-.30	-.16	-.01	.14	.23	.25	.24	.19	.12	.02	-.07	-.16	-.19	-.17
46	-.36	-.46	-.46	-.37	-.21	-.01	.16	.29	.33	.32	.27	.18	.07	-.06	-.18	-.27	-.32	-.32	-.28
42	-.54	-.52	-.42	-.26	-.08	.09	.21	.29	.28	.21	.10	-.03	-.15	-.23	-.27	-.27	-.21	-.13	-.08
38	-.40	-.43	-.42	-.37	-.28	-.17	-.07	.01	.04	.03	.01	-.04	-.07	-.05	.00	.08	.15	.20	.20
34	-.25	-.22	-.16	-.10	-.06	-.02	.08	.15	.24	.32	.35	.34	.30	.27	.24	.24	.25	.19	.15
30	-.10	.04	.18	.27	.29	.26	.31	.31	.31	.26	.17	.12	.04	.00	.07	.11	.12	.11	.05
26	-.01	.05	.09	.23	.33	.36	.36	.37	.32	.26	.17	.17	.22	.21	.25	.21	.11	.06	-.03
22	-.01	.10	.18	.28	.35	.42	.44	.42	.40	.37	.33	.27	.21	.16	.12	.08	.07	.05	.03
18	-.10	.00	.09	.17	.24	.28	.34	.37	.38	.39	.37	.36	.33	.29	.23	.17	.10	.05	.01

Table 4.1A

SURFACE TEMPERATURE GRADIENT VS MODEL STABILITY PARAMETER (JAN 73, 74, 75)

Eastward Shift of Second Variable (degrees longitude)

	190	200	210	220	230	240	250	260	270	280	290	300	310	320	330	340	350
70	.12	.12	.10	.09	.09	.11	.14	.15	.18	.23	.24	.20	.12	.00	-.14	-.27	-.38
66	.00	-.06	-.12	-.12	-.13	-.11	-.04	.05	.17	.27	.37	.43	.43	.36	.22	.04	-.14
62	-.05	-.08	-.07	-.03	.06	.14	.22	.29	.29	.31	.34	.38	.42	.44	.42	.36	.26
L 58	.31	.36	.43	.47	.50	.51	.50	.49	.45	.41	.34	.27	.16	.03	-.10	-.23	-.36
A 54	.20	.19	.22	.25	.30	.33	.38	.37	.36	.30	.23	.19	.10	-.03	-.14	-.28	-.38
T 50	-.10	.01	.13	.23	.32	.38	.41	.42	.38	.33	.24	.13	.04	-.03	-.11	-.19	-.29
I 46	-.20	-.15	-.10	-.06	-.03	.03	.11	.20	.29	.37	.42	.42	.38	.29	.15	-.02	-.21
T 42	-.01	.02	.03	.05	.08	.16	.25	.36	.45	.49	.49	.40	.27	.09	-.12	-.32	-.47
U 38	.14	.03	-.08	-.14	-.15	-.09	.03	.18	.35	.48	.51	.46	.36	.18	-.01	-.20	-.32
D 34	.09	.07	.02	-.03	-.08	-.08	-.10	-.14	-.16	-.14	-.14	-.16	-.19	-.22	-.28	-.30	-.29
E 30	.04	.03	-.02	-.04	-.07	-.13	-.21	-.24	-.23	-.27	-.25	-.23	-.21	-.24	-.28	-.22	-.17
26	-.04	-.04	-.08	-.06	-.08	-.12	-.21	-.27	-.28	-.28	-.29	-.36	-.40	-.37	-.32	-.19	-.13
22	.00	-.03	-.07	-.10	-.14	-.18	-.23	-.29	-.36	-.41	-.42	-.42	-.42	-.37	-.29	-.21	-.12
18	-.03	-.07	-.09	-.11	-.13	-.16	-.19	-.22	-.26	-.31	-.36	-.39	-.39	-.37	-.33	-.27	-.20

Table 4.1B

surprising, then, to have a strong correlation between these two quantities near zero degrees spatial lag. The negative sign exists because of the opposite sign convention of the two quantities. A large negative surface temperature gradient means a strong northward decrease in temperature; whereas a large positive model stability parameter means large baroclinic instability, which in the Northern Hemisphere indicates a strong decrease in temperature to the North.

The strongest negative correlations occurred, on the average, at a spatial lag of 10 to 20 degrees. This indicates that the peak baroclinic instability occurs 10 to 20 degrees downstream (to the east) of the peak surface temperature gradients. Obviously, this just reveals the vertical slope of the mean temperature field. It is interesting to observe that the only latitude which strongly deviates from this behavior is latitude 62°N, where the surface temperature gradients were the strongest.

Looking at the spatial lags 270 to 330 degrees, we see positive peak correlations. These correlations appear to differ in location with latitude; however, on the average the positive peak correlations are about 90 degrees apart from the negative peaks. This indicates that both quantities have, in general, a two wave cycle around the earth, corresponding with two major land masses and two oceans. The variation in latitude can be explained by the variation in land and ocean distribution around the latitude circles. At and above 58°N, the latitude circles are dominated by land masses. This would explain the disruption in the two wave pattern at these latitudes. The two wave pattern is clearly visible in the latitudes from 42°N to 54°N. South of 42°N, the continent of North America becomes much smaller than the Asian continent, and again the two wave pattern is disrupted. Looking at the autocorrelations, this continental effect is most strongly evident with the surface temperature gradients.

Interannual variability is interesting in this case. The correlation patterns and values are very similar for January 1973 and 1974. The peak correlation coefficients occurred at latitude 58°N, with spatial lags of 10 and 20 degrees. The average correlation coefficient for this location was -.74. January 1975 was radically different, especially for latitude 58°N. The correlations were weaker and shifted considerably farther eastward. To explain this phenomenon, we would need a much larger data base, but this does suggest that the relationship between these two quantities is dependent on other variables.

4.2 Meridional Stationary Eddy Heat Transport versus Meridional Transient Eddy Heat Transport

The relationship between the two components of the total meridional eddy heat transport was investigated by using the correlation analysis scheme. Tables 4.2A and 4.2B contain the results. Looking at these tables, we see there is no strong systematic relationship between these two components. We do have a peak in the correlation coefficients at latitudes 34°N and 38°N with spatial lags of 10 and 20 degrees, but this peak is weak and covering a very few points, suggesting it is not significant. Another peak is centered at latitude 62°N with a spatial lag of 200 degrees. The spatial lag is so large that the significance of this peak is questionable at best. Therefore, no obvious relationship exists between these components. Looking at the individual monthly correlations, we see this observation supported in each case. This suggests that the position and strength of the stationary and transient eddy heat transports are

STATIONARY EDDY HEAT TRANSPORT VS TRANSIENT EDDY HEAT TRANSPORT (JAN 73, 74, 75)

Eastward Shift of Second Variable (degrees longitude)

	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
70	.10	.12	.09	.04	-.02	-.04	-.08	-.13	-.17	-.16	-.10	-.04	-.06	-.13	-.24	-.30	-.20	.02	.28
66	.01	.00	-.04	-.07	-.07	-.04	-.04	-.08	-.14	-.13	-.08	-.02	.02	-.03	-.14	-.26	-.23	-.04	.25
62	-.07	-.12	-.13	-.10	-.06	-.01	-.02	-.09	-.16	-.14	-.12	-.08	-.04	-.02	-.10	-.20	-.25	-.12	.16
L 58	.02	-.12	-.18	-.16	-.07	.00	.01	-.04	-.11	-.14	-.14	-.15	-.12	-.09	-.10	-.16	-.20	-.11	.09
A 54	.16	-.01	-.17	-.19	-.09	.01	.03	-.01	-.05	-.07	-.06	-.08	-.09	-.10	-.09	-.12	-.13	-.06	.05
T 50	.22	.04	-.13	-.16	-.10	-.03	-.03	-.03	.03	.11	.13	.12	.03	-.09	-.12	-.08	-.06	-.01	.09
I 46	.22	.15	.02	-.05	-.08	-.07	-.05	.01	.15	.27	.30	.21	.00	-.15	-.14	-.02	.02	.03	.15
T 42	.25	.28	.23	.10	.01	.01	.03	.08	.20	.31	.33	.17	-.08	-.21	-.17	-.07	-.07	-.04	.04
U 38	.32	.45	.39	.20	.08	.14	.08	.00	.01	.15	.24	.13	-.06	-.11	-.12	-.13	-.16	-.19	-.23
D 34	.23	.39	.35	.20	.08	.10	.12	-.04	-.16	-.11	.13	.18	.14	.09	-.06	-.13	-.15	-.21	-.21
E 30	.08	.23	.28	.16	.10	.03	.02	-.11	-.35	-.35	.04	.30	.30	.18	.06	-.08	-.04	.01	-.08
26	.09	.22	.26	.17	.06	.03	-.02	-.18	-.38	-.40	-.06	.21	.27	.15	.05	-.04	.00	.12	.09
22	.02	.11	.24	.28	.18	.02	-.09	-.08	-.25	-.23	-.09	.00	.07	-.03	.02	.10	.02	.01	.09
18	-.15	.11	.32	.32	.28	.15	.05	-.06	-.25	-.22	-.11	-.17	-.01	.01	-.01	.07	.00	.03	-.04

Table 4.2A

STATIONARY EDDY HEAT TRANSPORT VS TRANSIENT EDDY HEAT TRANSPORT (JAN 73, 74, 75)

Eastward Shift of Second Variable (degrees longitude)

LATITUDE	190	200	210	220	230	240	250	260	270	280	290	300	310	320	330	340	350
70	.45	.46	.35	.22	.11	.04	-.03	-.14	-.21	-.18	-.04	.10	.14	.05	-.05	-.07	.01
66	.50	.58	.46	.21	-.03	-.14	-.10	-.01	.03	.04	.04	.04	.00	-.07	-.11	-.08	-.03
62	.47	.61	.55	.30	-.02	-.20	-.15	.05	.15	.13	.07	.00	-.03	-.02	-.02	-.02	-.04
58	.31	.48	.48	.26	-.07	-.25	-.14	.08	.14	.07	-.01	-.04	-.03	.06	.22	.25	.16
54	.16	.30	.35	.18	-.10	-.24	-.16	.01	.02	-.09	-.14	-.09	-.02	.11	.29	.35	.30
50	.18	.23	.21	.08	-.10	-.19	-.16	-.10	-.16	-.27	-.23	-.12	-.01	.13	.24	.26	.26
46	.21	.14	.07	-.02	-.15	-.19	-.17	-.19	-.28	-.33	-.23	-.10	-.02	.06	.12	.12	.16
42	.09	.07	.02	-.12	-.27	-.26	-.20	-.23	-.29	-.26	-.11	.03	.06	.04	.01	.06	.16
38	-.18	-.04	.02	-.11	-.23	-.21	-.20	-.24	-.23	-.17	-.03	.12	.14	.08	.01	.06	.20
34	-.19	-.04	.02	-.10	-.14	-.14	-.08	-.03	-.05	-.13	-.09	.04	.03	.03	-.02	.01	.15
30	-.09	-.02	.00	-.17	-.14	-.04	.11	.25	-.13	-.07	-.10	-.06	-.11	-.15	-.10	-.01	-.02
26	-.07	-.09	-.07	-.04	.00	-.01	.10	.31	.21	.00	-.07	-.09	-.15	-.14	-.11	-.13	-.14
22	.13	.03	-.31	-.05	.02	.03	.09	.20	.15	.04	-.05	.07	-.10	-.15	-.13	-.14	-.05
18	.01	-.15	-.14	-.14	-.05	.06	.16	.23	.08	-.06	-.08	.02	-.01	-.08	.01	.05	-.06

Table 4.2B

mainly caused by different, and unrelated factors.

4.3 Meridional Surface Temperature Gradient versus Meridional Stationary Eddy Heat Transport

Due to the sign convention used for the surface temperature gradient, a direct relationship will be indicated by a negative correlation. This fact should be remembered whenever we are discussing a correlation with the surface temperature gradient. Obviously, Tables 4.3A and 4.3B indicate that there is no convincing relationship between the surface temperature gradient and the stationary eddy heat transport. We do have two peaks in our correlation coefficients; however, they involve very few points and are weak. The low correlation coefficients cannot be attributed to the averaging because the individual monthly correlation coefficients are small and there is no large interannual variation in the correlation pattern. In general, it is interesting to observe that the correlation coefficients at zero degrees spatial lag are very weak. This indicates that for the monthly mean values the surface temperature gradient peaks do not occur in the same location as the stationary eddy heat transport peaks. A possible explanation for this observation is that the stationary eddy heat transports are so strong and effective in alleviating temperature differences that strong surface temperature gradients cannot develop in their location.

4.4 Two-Layer Model Stability Parameter versus Meridional Stationary Eddy Heat Transport

Tables 4.4A and 4.4B contain the correlation analysis. There is

SURFACE TEMPERATURE GRADIENT VS STATIONARY EDDY HEAT TRANSPORT (JAN 73, 74, 75)

Eastward Shift of Second Variable (degrees longitude)

LATITUDE	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
70	-.25	-.34	-.42	-.42	-.35	-.30	-.20	-.05	.08	.18	.22	.19	.12	.02	-.07	-.17	-.24	-.19	-.08
66	-.05	-.20	-.30	-.30	-.22	-.06	.09	.12	.06	.02	.02	.09	.13	.07	-.03	-.18	-.34	-.42	-.30
62	.16	.19	.21	.18	.18	.21	.22	.17	.10	.06	.05	-.04	-.16	-.23	-.22	-.13	-.06	-.12	-.27
58	.23	.22	.17	.13	.14	.14	.10	.00	-.10	-.21	-.29	-.33	-.37	-.30	-.14	-.04	-.05	-.14	-.20
54	.30	.18	-.03	-.12	-.07	-.05	-.08	-.08	-.05	-.16	-.31	-.32	-.16	.06	.16	.14	.10	.07	.06
50	.05	-.02	-.07	-.15	-.27	-.34	-.38	-.27	-.10	.03	.14	.21	.32	.38	.37	.27	.15	.07	-.07
46	.10	-.04	-.15	-.21	-.30	-.33	-.30	-.24	-.12	-.01	.14	.23	.25	.21	.14	.13	.07	.00	-.09
42	-.15	-.18	-.18	-.21	-.19	-.11	-.01	.03	-.02	-.05	.04	.12	.18	.16	.14	.10	.04	-.16	-.26
38	-.11	-.17	-.19	-.09	-.08	-.13	-.13	-.09	-.04	-.04	-.09	-.05	-.03	.00	.04	.12	.15	.05	-.09
34	-.16	-.21	-.20	-.15	-.07	-.04	-.17	-.20	-.19	-.07	.08	.16	.12	.18	.11	.01	.15	.32	.20
30	-.13	-.12	-.17	-.21	-.04	.12	.10	.04	-.14	-.19	-.01	.06	.04	.18	.28	.01	.00	.08	.09
26	-.05	-.10	-.05	.06	.06	-.07	-.10	-.06	-.12	-.14	-.02	.13	.21	.31	.25	.18	.07	.02	.05
22	-.05	-.14	-.09	-.12	-.06	.11	.00	-.08	-.03	.00	-.04	-.03	.02	.09	.12	.27	.17	.15	.08
18	-.05	-.09	-.12	-.03	.02	-.02	-.01	-.03	-.18	-.17	-.13	.03	.13	.29	.31	.37	.33	.27	.08

Table 4.3A

SURFACE TEMPERATURE GRADIENT VS STATIONARY EDDY HEAT TRANSPORT (JAN 73, 74, 75)

Eastward Shift of Second Variable (degrees longitude)

		190	200	210	220	230	240	250	260	270	280	290	300	310	320	330	340	350
	70	.14	.36	.45	.45	.40	.23	.07	-.01	-.02	.00	.07	.14	.14	.10	.08	.00	-.14
	66	-.09	.13	.30	.27	.15	.04	-.03	-.04	-.02	.02	.10	.18	.22	.24	.21	.20	.12
	62	-.46	-.55	-.49	-.35	-.19	-.05	.04	.06	.08	.10	.17	.22	.25	.25	.23	.18	.15
L	58	-.15	-.04	.10	.19	.15	.02	-.13	-.18	-.06	.10	.21	.25	.22	.16	.10	.11	.18
A	54	.12	.18	.11	-.03	-.12	-.16	-.17	-.11	-.01	.08	.05	-.03	-.05	.03	.13	.21	.29
T	50	-.20	-.33	-.37	-.26	-.11	.01	.03	.02	.01	.03	.02	-.01	.08	.19	.31	.30	.15
I	46	-.20	-.24	-.14	.04	.09	.07	-.01	-.10	-.19	-.18	.00	.19	.27	.30	.31	.29	.23
T	42	-.26	-.16	.00	.13	.28	.20	.07	-.11	-.26	-.17	.08	.26	.31	.28	.23	.08	-.06
U	38	-.18	-.02	.08	-.05	-.09	-.01	.02	.04	.00	-.03	.13	.26	.26	.29	.25	.16	.03
D	34	.08	.04	.09	.01	-.02	.04	.03	.03	.01	-.11	-.09	.07	.03	.01	.14	.06	-.09
E	30	-.01	.01	-.01	-.10	-.12	-.12	-.06	.25	.27	.26	.19	.05	-.14	-.20	-.08	.04	-.02
	26	.05	-.12	-.25	-.23	-.15	-.14	.10	.24	.28	.16	.11	-.05	-.14	-.07	-.16	-.08	.03
	22	.12	-.11	-.30	-.21	-.20	-.24	-.13	.06	.19	.15	.21	.26	.12	.05	-.04	-.10	-.03
	18	-.09	-.07	-.13	-.35	-.31	-.22	-.03	.07	.15	.26	.21	.07	.01	.06	-.09	-.22	-.10

Table 4.3B

MODEL STABILITY PARAMETER VS STATIONARY EDDY HEAT TRANSPORT (JAN 73, 74, 75)

Eastward Shift of Second Variable (degrees longitude)

		0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
	70	.29	.28	.24	.16	.06	-.01	-.08	-.13	-.15	-.13	-.09	-.05	.00	.04	.09	.13	.15	.14	.10
	66	.27	.26	.19	.10	-.01	-.09	-.13	-.12	-.07	.02	.11	.18	.23	.24	.23	.20	.16	.10	.02
	62	.22	.16	.05	-.07	-.17	-.20	-.15	-.04	.09	.21	.29	.34	.37	.37	.35	.30	.20	.08	-.07
L	58	.03	.02	.00	-.03	-.05	-.02	.04	.11	.18	.25	.31	.36	.38	.38	.35	.28	.17	.02	-.13
A	54	.02	.11	.16	.17	.15	.12	.10	.06	.03	.03	.07	.13	.18	.18	.14	.06	-.02	-.09	-.14
T	50	.01	.10	.17	.21	.21	.17	.07	-.03	-.09	-.11	-.10	-.09	-.06	-.04	-.04	-.02	-.01	.00	-.01
I	46	-.01	.11	.20	.26	.25	.19	.08	-.04	-.14	-.21	-.25	-.26	-.24	-.19	-.11	-.02	.03	.07	.08
T	42	.13	.25	.34	.38	.34	.25	.13	.00	-.11	-.19	-.24	-.27	-.25	-.19	-.13	-.07	-.02	.00	-.01
U	38	.30	.40	.44	.40	.34	.28	.21	.16	.12	.06	.02	.00	.02	.03	.05	.02	-.06	-.16	-.24
D	34	.17	.30	.35	.32	.30	.30	.30	.29	.26	.21	.16	.15	.13	.10	.05	-.01	-.09	-.15	-.22
E	30	-.04	.01	.06	.08	.06	.08	.11	.13	.11	.11	.15	.20	.22	.18	.13	.06	-.06	-.09	-.09
	26	-.04	-.05	-.03	.02	.01	.02	.05	.04	-.03	-.05	.02	.11	.17	.14	.07	-.07	-.19	-.27	-.22
	22	-.08	-.09	-.05	.00	.03	.05	.08	.09	.10	.09	.08	.05	.04	.05	.03	-.02	-.03	-.04	-.07
	18	.04	.09	.14	.18	.21	.24	.26	.25	.24	.22	.18	.13	.08	.04	.00	-.03	-.07	-.11	-.14

Table 4.4A

MODEL STABILITY PARAMETER VS STATIONARY EDDY HEAT TRANSPORT (JAN 73, 74, 75)

Eastward Shift of Second Variable (degrees longitude)

LATITUDE		190	200	210	220	230	240	250	260	270	280	290	300	310	320	330	340	350
	70	.04	-.03	-.09	-.16	-.21	-.22	-.20	-.16	-.13	-.12	-.11	-.08	-.02	.05	.12	.20	.26
	66	-.08	-.18	-.28	-.33	-.33	-.30	-.23	-.17	-.12	-.09	-.07	-.04	.00	.04	.09	.16	.22
	62	-.20	-.30	-.37	-.39	-.35	-.27	-.18	-.08	-.02	.00	-.03	-.08	-.10	-.07	.00	.10	.19
L	58	-.26	-.33	-.33	-.24	-.12	-.01	.06	.07	.02	-.07	-.16	-.23	-.26	-.26	-.20	-.12	-.03
A	54	-.18	-.19	-.14	-.02	.11	.22	.27	.23	.11	-.04	-.18	-.28	-.33	-.33	-.27	-.17	-.07
T	50	-.03	-.04	-.02	.04	.16	.29	.36	.35	.24	.08	-.09	-.23	-.31	-.33	-.30	-.22	-.11
I	46	.07	.04	.03	.06	.13	.22	.28	.28	.24	.14	.02	-.10	-.20	-.25	-.25	-.20	-.12
T	42	-.01	-.04	-.05	-.04	-.03	.01	.03	.06	.08	.08	.05	.01	-.05	-.10	-.11	-.07	.03
U	38	-.28	-.28	-.24	-.19	-.16	-.15	-.16	-.19	-.21	-.20	-.17	-.14	-.10	-.04	.02	.10	.20
D	34	-.25	-.21	-.13	-.05	-.04	-.08	-.16	-.26	-.33	-.37	-.31	-.24	-.15	-.11	-.06	-.03	.04
E	30	-.04	.04	.09	.14	.14	.09	.00	-.07	-.18	-.27	-.32	-.28	-.23	-.14	-.08	-.07	-.05
	26	-.12	-.03	.03	.07	.12	.14	.14	.13	.10	.05	.01	-.06	-.01	.01	-.02	-.04	-.03
	22	-.10	-.09	-.05	-.02	.02	.06	.07	.08	.06	.04	.02	.01	-.01	-.04	-.06	-.07	-.07
	18	-.17	-.17	-.16	-.14	-.12	-.10	-.10	-.09	-.08	-.08	-.09	-.10	-.11	-.11	-.09	-.04	.00

Table 4.4B

one peak in the correlation coefficients at latitude 38°N and a spatial lag of 20 degrees. This peak contains only five points and the correlation coefficients are weak, indicating that the importance of the peak is questionable. Looking at the individual monthly correlation arrays, we noticed that this peak was always present. Other than this peak, no large correlations appeared in the analysis. It is interesting to observe that this peak is located in the same vicinity as the peak in the correlation analysis for the stationary eddy heat transport versus transient eddy heat transport, Table 4.2A. This indicates that the only place where the model stability parameter and the stationary eddy heat transport is even slightly related is where the stationary eddy heat transport behaves similarly to the transient eddy heat transport. Since the peak in the correlation analysis covers such a small number of points and the correlation coefficients are weak, no strong relationship is indicated between these two quantities.

4.5 Meridional Surface Temperature Gradient versus Meridional Transient Eddy Heat Transport

Since our correlation involves the surface temperature gradients, a direct relationship is indicated by a negative correlation coefficient. Tables 4.5A and 4.5B display a large area of high correlation coefficients, located between latitudes 46°N and 70°N, and centered around 30 to 50 degrees spatial lag. The largest correlation coefficient, -.73, is located at latitude 62°N and 50 degrees spatial lag. For the individual monthly correlation arrays, the strongest correlation was always found in this location. The largest correlation coefficient, -.83, was found in January 1973. Interannual variability of the correlation coefficients is quite interesting

SURFACE TEMPERATURE GRADIENT VS TRANSIENT EDDY HEAT TRANSPORT (JAN 73, 74, 75)

Eastward Shift of Second Variable (degrees longitude)

	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
70	-.19	-.27	-.23	-.03	.19	.30	.30	.22	.13	.09	.09	.12	.15	.15	.11	.07	.06	.07	.01
66	-.15	-.34	-.40	-.30	-.03	.17	.14	.02	-.03	-.01	.12	.21	.20	.16	.15	.17	.17	.13	.11
62	-.06	-.05	-.15	-.37	-.64	-.73	-.49	-.15	-.02	-.08	-.16	-.12	-.04	.05	.10	.12	.13	.12	.20
L 58	-.15	-.17	-.29	-.40	-.39	-.27	-.19	-.21	-.27	-.35	-.37	-.27	-.08	.08	.14	.13	.11	.14	.24
A 54	-.28	-.36	-.32	-.36	-.35	-.27	-.25	-.30	-.38	-.30	-.10	-.04	-.07	.03	.21	.24	.16	.21	.32
T 50	-.12	-.25	-.33	-.41	-.44	-.40	-.25	-.11	.02	.11	.18	.13	.07	.09	.07	-.04	-.08	-.05	-.03
I 46	.00	-.13	-.23	-.23	-.17	-.02	.09	.14	.17	.17	.10	.08	.06	-.07	-.11	-.09	-.23	-.24	-.11
T 42	-.19	-.25	-.22	-.18	-.04	.06	.13	.09	.09	.01	-.11	-.18	-.11	-.13	-.16	-.18	-.15	-.14	-.16
U 38	-.03	-.14	-.16	-.14	-.05	-.01	-.02	-.08	-.05	-.01	-.12	-.23	-.24	-.16	-.10	.01	.13	.11	.09
D 34	-.06	-.20	-.27	-.29	-.21	-.28	-.35	-.26	-.18	-.11	-.05	.03	.10	.03	.06	.18	.14	.17	.28
E 30	-.04	-.06	-.09	.06	.07	-.09	-.22	-.20	-.07	-.18	-.18	.09	.06	-.10	-.14	.00	.17	.20	.16
26	-.08	.11	.15	.13	.19	.10	.05	-.03	-.06	-.01	-.01	-.14	-.26	-.10	-.01	.04	.15	.12	-.02
22	-.11	.00	-.10	.08	.03	.10	.11	.06	.05	.16	.02	-.07	-.04	-.07	-.05	-.12	.07	.12	.07
18	-.18	-.13	-.07	-.19	-.04	.02	.21	.11	.10	.08	-.05	-.07	-.04	-.18	-.04	.03	.13	.26	.30

Table 4.5A

SURFACE TEMPERATURE GRADIENT VS TRANSIENT EDDY HEAT TRANSPORT (JAN 73, 74, 75)

Eastward Shift of Second Variable (degrees longitude)

LATITUDE	190	200	210	220	230	240	250	260	270	280	290	300	310	320	330	340	350
70	-.12	-.25	-.30	-.26	-.18	-.11	-.03	.02	.03	.05	.04	.02	.01	.01	.01	-.03	-.10
66	.04	-.11	-.23	-.31	-.24	-.04	.12	.15	.14	.07	.03	.01	-.04	-.02	.03	.05	.02
62	.29	.29	.20	.16	.17	.20	.30	.35	.31	.21	.16	.15	.14	.06	-.09	-.20	-.18
L 58	.33	.41	.39	.33	.30	.34	.40	.43	.36	.24	.13	-.01	-.16	-.19	-.21	-.19	-.14
A 54	.29	.26	.24	.23	.22	.22	.28	.36	.28	.16	.09	.05	.00	-.10	-.10	.00	-.07
T 50	-.01	-.01	.06	.13	.15	.12	.13	.10	.12	.13	.16	.20	.22	.20	.17	.15	.00
I 46	-.10	-.11	-.08	-.15	-.15	-.10	-.15	-.10	.00	.07	.19	.28	.28	.38	.42	.23	.10
T 42	-.10	-.05	-.02	.01	.02	.08	.12	.08	.09	.10	.15	.24	.38	.41	.27	.17	.01
U 38	.04	-.13	-.19	-.10	-.11	-.14	-.03	.14	.16	.16	.21	.26	.28	.23	.20	.22	.16
D 34	.26	.16	.07	.11	.13	.12	.14	.11	.06	.04	.05	.01	.04	.12	.07	-.01	-.02
E 30	.19	.12	-.03	-.11	.02	.15	.05	.02	.09	.16	.03	.03	.10	.18	.06	-.15	-.15
26	-.06	-.07	-.02	-.03	.00	-.02	.07	-.01	-.05	.00	.18	.17	.02	.02	.08	-.15	-.26
22	.02	.11	.06	-.02	-.19	-.17	-.06	-.20	-.30	-.17	.02	.08	.13	.24	.23	.09	-.01
18	.37	.21	.05	.07	-.20	-.22	-.17	-.23	-.16	-.12	-.10	.35	.20	.17	-.02	-.13	-.15

Table 4.5B

in this case. Although the largest correlation coefficient always occurred in the same location, the area of high correlation coefficients varied from year to year. In January 1973, the area extended from latitude 46°N to 66°N. High correlation coefficients existed only at latitudes 62°N and 66°N in January 1974. No high correlation coefficients existed at latitude 66°N, but they did occur for the latitudes 50°N to 62°N in January 1975. Latitude 62°N was the only latitude where high correlation coefficients existed for all three months. An interesting observation is that the strongest correlation always occurred at the latitude where the surface temperature gradient had its largest value. On the other hand, where the transient eddy heat transport was the strongest, at latitudes 42°N and 46°N, the correlation was weak. This would indicate that the relationship between these two variables is weak, and the transient eddy heat transports may depend mainly on other factors. The positive correlation coefficients occurring in Table 4.5B are due to the wave characteristics of the two quantities around the latitude circles.

The contoured area of correlation coefficients in Table 4.5A is significant at the 99% confidence level for an a priori correlation peak; however, the area exists away from the zero degrees spatial lag. This indicates that it is an a posteriori probability peak, and has only three degrees of freedom. In that case, the 95% confidence level is for correlation coefficients greater than .80. None of the correlation coefficients are this large. The largest correlation is only at the 91% confidence level. This does not mean that the spatial relationship does not exist, it just indicates that the spatial relationship is not certain. In order to completely test this relationship, a larger data base would be needed.

4.6 Two-Layer Model Stability Parameter versus Meridional Transient Eddy Heat Transport

Tables 4.6A and 4.6B display a large area of positive correlations. Considering all the latitudes from 34°N to 70°N, we see that the area is centered at zero degrees spatial lag. This indicates that it is an a priori probability peak, and the contoured area is significant at the 99% confidence level. The significance of the correlations is strengthened, since adjacent latitudes display the same relationship. The analysis discloses that the peak transient eddy heat transports occur at approximately the same location as the peak baroclinic instability. This observation supports the theory that transient eddy heat transports are in part caused by and exist to alleviate baroclinic instability (i.e. mean tropospheric temperature gradients). Obviously, the analysis indicates a direct relationship between these two quantities.

At latitudes 66°N and 70°N, a negative correlation peak exists at approximately 80 degrees spatial lag. This observation can be explained by looking over the whole latitude circle. Clearly, a two-wave pattern exists for both quantities at these latitudes, and this observation is supported by their autocorrelations. At latitudes 34°N and 38°N, a negative peak occurs between 290 and 310 degrees spatial lag. Again, this can be explained by the cyclic behavior of both quantities. In this case, both quantities have a single wave pattern around the latitude circles. Another interesting observation is that the area of positive correlation appears to have a slope from low latitudes with a small positive lag, to high lati-

MODEL STABILITY PARAMETER VS TRANSIENT EDDY HEAT TRANSPORT (JAN 73, 74, 75)

Eastward Shift of Second Variable (degrees longitude)

		0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
	70	.38	.35	.28	.16	.02	-.14	-.27	-.38	-.43	-.43	-.38	-.33	-.27	-.18	-.06	.07	.20	.29	.34
	66	.27	.22	.13	.01	-.12	-.23	-.32	-.38	-.37	-.33	-.28	-.24	-.19	-.14	-.08	-.01	.05	.13	.22
	62	.28	.20	.11	.00	-.11	-.18	-.22	-.26	-.27	-.23	-.16	-.12	-.11	-.14	-.20	-.21	-.16	-.09	.02
L	58	.37	.29	.20	.14	.10	.05	.03	.07	.10	.09	.04	-.02	-.11	-.20	-.29	-.36	-.38	-.35	-.30
A	54	.41	.36	.32	.27	.21	.16	.14	.16	.16	.15	.12	.04	-.07	-.19	-.28	-.33	-.34	-.35	-.34
T	50	.48	.47	.42	.32	.23	.16	.11	.08	.08	.08	.08	.03	-.06	-.13	-.19	-.26	-.31	-.33	-.33
I	46	.49	.52	.48	.39	.28	.18	.08	.02	.00	.00	.01	.02	.01	-.03	-.09	-.17	-.26	-.31	-.32
T	42	.42	.46	.45	.39	.30	.20	.12	.06	.07	.10	.13	.17	.21	.17	.10	.02	-.11	-.22	-.29
U	38	.40	.44	.45	.43	.36	.30	.27	.27	.27	.28	.30	.30	.28	.25	.19	.11	.01	-.11	-.24
D	34	.09	.16	.19	.23	.25	.27	.31	.31	.32	.32	.32	.32	.32	.31	.27	.24	.20	.09	-.03
E	30	-.13	-.09	-.05	-.07	-.07	-.01	-.02	.05	.12	.15	.17	.19	.25	.34	.31	.30	.29	.27	.17
	26	-.06	.00	.00	.00	-.06	-.10	-.14	-.17	-.17	-.12	-.13	-.14	-.07	.08	.13	.14	.19	.22	.12
	22	.12	.05	.01	.00	-.02	-.04	-.05	-.08	-.10	-.13	-.14	-.12	-.11	-.08	-.05	-.02	-.02	-.05	-.07
	18	.12	.12	.15	.17	.20	.20	.17	.17	.14	.12	.10	.09	.07	.05	.02	.00	-.02	-.05	-.08

Table 4.6A

MODEL STABILITY PARAMETER VS TRANSIENT EDDY HEAT TRANSPORT (JAN 73, 74, 75)

Eastward Shift of Second Variable (degrees longitude)

		190	200	210	220	230	240	250	260	270	280	290	300	310	320	330	340	350
	70	.36	.35	.27	.16	.04	-.08	-.18	-.25	-.28	-.27	-.19	-.08	.04	.15	.24	.32	.37
	66	.27	.28	.23	.13	.01	-.10	-.16	-.17	-.14	-.06	.04	.14	.22	.26	.29	.29	.30
	62	.11	.15	.11	.02	-.10	-.21	-.23	-.16	-.06	.07	.21	.31	.38	.40	.38	.34	.33
L	58	-.26	-.19	-.15	-.17	-.22	-.25	-.23	-.17	-.09	.02	.12	.23	.33	.39	.44	.45	.43
A	54	-.28	-.19	-.12	-.10	-.11	-.14	-.17	-.20	-.22	-.20	-.13	-.04	.08	.22	.34	.41	.43
T	50	-.30	-.24	-.16	-.11	-.07	-.08	-.11	-.16	-.19	-.19	-.18	-.12	-.01	.12	.24	.36	.45
I	46	-.31	-.26	-.17	-.10	-.04	-.03	-.05	-.11	-.16	-.19	-.22	-.18	-.12	-.01	.13	.28	.42
T	42	-.33	-.31	-.24	-.17	-.11	-.08	-.12	-.19	-.27	-.31	-.33	-.31	-.23	-.11	.03	.19	.33
U	38	-.34	-.38	-.35	-.28	-.23	-.20	-.23	-.30	-.39	-.48	-.52	-.48	-.38	-.22	-.03	.16	.30
D	34	-.15	-.23	-.26	-.24	-.18	-.17	-.16	-.20	-.27	-.33	-.41	-.47	-.49	-.36	-.23	-.12	-.02
E	30	.08	.01	-.02	.00	.00	.06	.04	-.05	-.12	-.19	-.27	-.31	-.30	-.29	-.26	-.20	-.18
	26	-.01	-.14	-.11	-.04	.05	.15	.24	.19	.09	.05	.09	.02	-.03	-.03	.00	-.06	-.06
	22	-.07	-.10	-.12	-.11	-.07	-.02	.02	.08	.14	.17	.18	.19	.19	.20	.15	.13	.12
	18	-.12	-.17	-.20	-.23	-.24	-.22	-.20	-.18	-.13	-.09	-.05	-.01	.02	.04	.06	.08	.11

Table 4.6B

tudes with a small negative lag. This apparent slope is not clearly represented in all the individual monthly correlation arrays, and may be just a result of the averaging process. Obviously, more observations would be necessary to draw any conclusions about the validity of this apparent slope.

The individual monthly correlation arrays are interesting in this case. For January 1973 and 1975, the peak correlation coefficients occurred at the latitude where the transient eddy heat transport had its largest value. In both cases, the correlation coefficient was greater than .70. This observation did not occur in January 1974. In fact, this month was quite different, having much weaker correlations for almost all latitudes. Perhaps this is because the transient eddy heat transports were much weaker in January 1974 (see Table 2.4). In general, the correlation coefficients appear to increase when the transient eddy heat transports become larger.

4.7 Meridional Surface Temperature Gradient versus Total Meridional Eddy Heat Transport

The result of this correlation, displayed in Tables 4.7A and 4.7B, is one we might have expected. The correlation array appears to be similar to an average of the correlation arrays obtained with the surface temperature gradient versus the two components of the total eddy heat transports. Since the stationary component displayed no clear relationship and the transient component indicated at best a weak relationship, we should have expected only a very weak relationship. The analysis clearly indicates this logic to be true. It is interesting to observe that no different relationships are suggested when we combine the two eddy components.

SURFACE TEMPERATURE GRADIENT VS TOTAL EDDY HEAT FLUX (JAN 73, 74, 75)

Eastward Shift of Second Variable (degrees longitude)

	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
70	-.32	-.43	-.47	-.36	-.20	-.10	-.03	.05	.12	.17	.20	.19	.16	.08	-.01	-.11	-.17	-.12	-.04
66	-.14	-.34	-.42	-.37	-.17	.06	.16	.12	.04	.01	.05	.13	.18	.14	.06	-.07	-.23	-.32	-.21
62	.13	.16	.12	.00	-.11	-.14	-.03	.07	.07	.03	-.01	-.09	-.17	-.20	-.17	-.07	.00	-.06	-.17
L 58	.14	.12	.03	-.05	-.04	.00	.00	-.09	-.21	-.35	-.44	-.43	-.37	-.24	-.07	.02	.00	-.08	-.09
A 54	.13	-.01	-.17	-.26	-.21	-.16	-.18	-.20	-.21	-.26	-.30	-.28	-.16	.06	.21	.21	.15	.15	.19
T 50	-.01	-.13	-.21	-.31	-.41	-.45	-.42	-.27	-.08	.07	.20	.23	.29	.35	.33	.20	.09	.03	-.08
I 46	.08	-.10	-.23	-.28	-.32	-.28	-.23	-.14	-.03	.07	.16	.22	.22	.14	.05	.05	-.04	-.09	-.11
T 42	-.22	-.26	-.22	-.23	-.17	-.06	.04	.06	.02	-.03	.00	.03	.11	.06	.03	-.01	-.03	-.17	-.26
U 38	-.12	-.18	-.19	-.11	-.06	-.10	-.10	-.11	-.08	-.05	-.13	-.16	-.13	-.06	.02	.13	.18	.06	-.05
D 34	-.15	-.24	-.27	-.22	-.14	-.16	-.31	-.29	-.25	-.13	.01	.11	.14	.12	.06	.09	.19	.32	.28
E 30	-.12	-.13	-.20	-.14	.02	.07	-.03	-.08	-.17	-.25	-.11	.07	.04	.11	.16	.01	.09	.19	.16
26	-.10	-.06	.01	.10	.12	-.03	-.07	-.06	-.12	-.12	-.02	.06	.08	.24	.22	.17	.12	.06	.05
22	-.09	-.13	-.12	-.08	-.06	.13	.04	-.05	.00	.06	-.02	-.03	.01	.06	.09	.20	.18	.18	.11
18	-.11	-.15	-.15	-.11	.01	.00	.08	.01	-.13	-.14	-.14	.01	.12	.21	.29	.37	.37	.35	.17

Table 4.7A

SURFACE TEMPERATURE GRADIENT VS TOTAL EDDY HEAT FLUX (JAN 73, 74, 75)

Eastward Shift of Second Variable (degrees longitude)

LATITUDE	190	200	210	220	230	240	250	260	270	280	290	300	310	320	330	340	350
70	.09	.20	.25	.26	.23	.12	.04	.01	.01	.04	.08	.13	.13	.10	.07	-.02	-.18
66	-.05	.07	.14	.07	-.01	-.01	.00	.02	.05	.07	.13	.20	.20	.21	.18	.17	.08
62	-.31	-.38	-.36	-.24	-.10	.04	.17	.21	.21	.20	.24	.27	.28	.25	.18	.10	.08
58	.00	.14	.26	.31	.28	.18	.07	.04	.11	.20	.25	.22	.13	.06	.00	.01	.09
54	.24	.27	.21	.07	.00	-.03	-.02	.06	.12	.14	.07	-.02	-.04	-.03	.06	.16	.20
50	-.17	-.28	-.28	-.17	-.03	.06	.08	.06	.07	.08	.08	.07	.16	.24	.33	.31	.12
46	-.20	-.24	-.16	-.05	-.01	.00	-.09	-.13	-.16	-.12	.09	.29	.36	.43	.44	.34	.23
42	-.25	-.15	-.02	.08	.20	.16	.08	-.07	-.16	-.07	.17	.35	.44	.49	.28	.12	-.06
38	-.12	-.08	-.02	-.08	-.11	-.08	-.03	.07	.07	.05	.19	.32	.33	.34	.29	.21	.06
34	.20	.12	.09	.07	.07	.10	.08	.08	.02	-.08	-.05	.04	.04	.09	.15	.07	-.06
30	.09	.07	-.03	-.14	-.11	-.03	-.02	.22	.28	.29	.17	.04	-.10	-.10	-.03	-.03	-.10
26	.02	-.15	-.24	-.21	-.14	-.14	.10	.21	.23	.15	.17	.03	-.12	-.06	-.11	-.13	-.08
22	.12	-.07	-.25	-.20	-.25	-.27	-.15	-.02	.05	.06	.19	.26	.15	.13	.04	-.06	-.03
18	.03	.00	-.12	-.32	-.37	-.30	-.09	-.01	.08	.20	.16	.19	.08	.12	-.09	-.27	-.16

Table 4.7B

We do have a few peak correlation coefficients; however, they reflect the relationships already discussed. The relationship between the surface temperature gradient and the transient eddy heat transport is greatly reduced, if not eliminated, when both components are considered together. This indicates that the only relationship that exists between the surface temperature gradient and eddy heat transports is the weak relationship with the transient component.

4.8 Two-Layer Model Stability Parameter versus Total Meridional Eddy Heat Transport

Tables 4.8A and 4.8B contain the correlation analysis. Again, there is no different relationship suggested by this analysis other than those already mentioned. The correlation array appears to be like an average of the correlation arrays obtained with the model stability parameter versus the two components of the total eddy heat transport. In general, the correlation coefficients are smaller than those obtained with the model stability parameter versus the transient eddy heat transport, except at low latitudes and small spatial lags. The reason that the correlation coefficients are not reduced in this location is because of the similarity between the stationary and transient components (see Table 4.2A). Thus, the analysis indicates that the only clear relationship is between the model stability parameter and the transient eddy heat transport.

MODEL STABILITY PARAMETER VS TOTAL EDDY HEAT TRANSPORT (JAN 73, 74, 75)

Eastward Shift of Second Variable (degrees longitude)

	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
70	.40	.38	.31	.18	.04	-.09	-.19	-.27	-.29	-.27	-.21	-.15	-.09	-.03	.05	.14	.20	.22	.21
66	.32	.29	.20	.06	-.09	-.20	-.27	-.27	-.21	-.11	.00	.09	.15	.18	.19	.19	.17	.15	.12
62	.30	.22	.08	-.08	-.23	-.29	-.27	-.18	-.05	.08	.20	.27	.31	.30	.26	.20	.13	.06	-.04
L 58	.18	.14	.08	.02	-.01	-.02	.02	.10	.18	.24	.27	.29	.28	.24	.18	.09	-.01	-.13	-.24
A 54	.20	.25	.27	.25	.21	.17	.13	.10	.08	.07	.09	.11	.11	.07	-.01	-.10	-.17	-.23	-.27
T 50	.21	.28	.32	.31	.27	.20	.11	.01	-.05	-.06	-.05	-.06	-.07	-.08	-.11	-.13	-.14	-.14	-.15
I 46	.21	.31	.37	.37	.32	.23	.10	-.02	-.11	-.17	-.19	-.19	-.18	-.16	-.12	-.10	-.09	-.08	-.08
T 42	.31	.41	.48	.48	.40	.29	.15	.03	-.06	-.11	-.13	-.13	-.11	-.09	-.07	-.07	-.09	-.13	-.15
U 38	.40	.50	.53	.49	.41	.34	.27	.24	.22	.18	.15	.14	.14	.14	.12	.05	-.06	-.20	-.32
D 34	.13	.26	.33	.35	.36	.37	.39	.38	.36	.33	.29	.30	.29	.26	.19	.12	.03	-.07	-.19
E 30	-.11	-.05	.02	.02	-.01	.04	.07	.11	.13	.16	.22	.27	.32	.33	.27	.19	.10	.06	.03
26	-.05	-.04	-.02	.02	.00	.00	-.01	-.04	-.11	-.11	-.05	.03	.12	.15	.10	-.01	-.11	-.16	-.16
22	-.02	-.05	-.03	.02	.04	.05	.06	.07	.05	.04	.02	.01	.00	.01	.01	-.03	-.05	-.06	-.11
18	.09	.13	.19	.24	.28	.31	.31	.30	.28	.24	.20	.14	.09	.04	-.01	-.05	-.10	-.15	-.18

Table 4.8A

MODEL STABILITY PARAMETER VS TOTAL EDDY HEAT TRANSPORT (JAN 73, 74, 75)

Eastward Shift of Second Variable (degrees longitude)

	190	200	210	220	230	240	250	260	270	280	290	300	310	320	330	340	350
70	.18	.13	.04	-.06	-.15	-.21	-.24	-.25	-.24	-.23	-.19	-.11	-.01	.10	.20	.31	.38
66	.06	-.02	-.12	-.21	-.27	-.29	-.27	-.23	-.18	-.12	-.06	.00	.07	.13	.19	.24	.30
62	-.11	-.19	-.26	-.32	-.35	-.33	-.25	-.14	-.05	.02	.05	.05	.06	.09	.14	.22	.29
L 58	-.34	-.37	-.35	-.27	-.19	-.10	-.04	.00	-.02	-.05	-.08	-.08	-.08	-.04	.02	.09	.16
A 54	-.28	-.25	-.17	-.07	.05	.13	.16	.11	.00	-.11	-.20	-.24	-.23	-.17	-.07	.04	.14
T 50	-.15	-.13	-.09	-.02	.10	.20	.25	.21	.12	-.01	-.16	-.24	-.26	-.22	-.14	-.02	.11
I 46	-.08	-.07	-.05	.01	.09	.16	.20	.17	.11	.02	-.09	-.17	-.23	-.21	-.15	-.05	.08
T 42	-.16	-.16	-.12	-.08	-.05	-.01	-.02	-.05	-.07	-.10	-.13	-.15	-.16	-.14	-.07	.04	.18
U 38	-.38	-.38	-.31	-.24	-.19	-.18	-.22	-.29	-.36	-.39	-.39	-.33	-.24	-.12	.01	.15	.28
D 34	-.26	-.26	-.21	-.15	-.11	-.15	-.22	-.31	-.40	-.46	-.46	-.43	-.36	-.26	-.17	-.11	-.01
E 30	.03	.05	.08	.12	.11	.09	.01	-.09	-.22	-.32	-.39	-.37	-.32	-.25	-.19	-.18	-.15
26	-.11	-.08	-.02	.04	.13	.19	.23	.20	.14	.07	.05	-.04	-.02	-.01	-.03	-.06	-.05
22	-.13	-.14	-.11	-.07	-.02	.04	.07	.09	.10	.09	.08	.07	.05	.03	.01	-.02	-.01
18	-.21	-.23	-.23	-.21	-.19	-.17	-.15	-.14	-.12	-.10	-.10	-.09	-.10	-.09	-.06	-.01	.05

Table 4.8B

CHAPTER FIVE

SUMMARY AND CONCLUSIONS

5.1 Assessment of Results

In Chapter Four, we looked for possible relationships involving the meridional stationary eddy heat transport. The analysis indicated that no relationship existed between the meridional stationary eddy heat transport and the meridional surface temperature gradient. Also, no convincing relationship was discovered between the stationary eddy heat transport and baroclinic instability (i.e. the two-layer model stability parameter). This indicates that the position and strength of the stationary eddy heat transports are primarily caused by other factors, such as topography.

The meridional transient eddy heat transports, on the other hand, display a spatial relationship with strong meridional surface temperature gradients. A stronger relationship was indicated by the analysis between the transient eddy heat transport and the two-layer model stability parameter. This suggests that meridional temperature gradients act as a direct forcing agent to the transient eddy heat transports. The two-layer model stability parameter has a stronger relationship with the transient eddy heat transport, and this is logical, since the model stability parameter reflects the average meridional temperature gradient for the troposphere. The relationship between the model stability parameter and the transient eddy heat transport will be investigated further in section 5.2.

An interesting, but not totally unexpected observation occurred when we considered the total eddy heat transport. No new relationships were suggested by the analysis, and the relationship was weaker than that between the transient eddy component and the meridional temperature gradients. The relationship was weaker because of the dissimilarity between the stationary and transient components. The dissimilarity between the two eddy components suggests that they are primarily caused by unrelated factors. This indicates that it is necessary to separate the total eddy heat transport into its two eddy components, when investigating for possible relationships.

5.2 Determining the Two-Layer Model Stability Parameter and Meridional Transient Eddy Heat Transport Relationship

The transient eddy heat transport had its largest values at latitudes 42°N and 46°N (see Table 2.4). Looking at Table 4.6A, the largest correlation coefficients at these latitudes occurred with a spatial lag of ten degrees. For these reasons, we used these two locations to investigate an empirical relationship between the model stability parameter and the transient eddy heat transport.

5.2.1 Investigating a Linear Relationship

Figure 5.1 contains a graph of the model stability parameter versus the transient eddy heat transport at latitude 42°N and with a spatial lag of ten degrees. In this graph, all three months of data were used. This provided us with 108 points to determine a linear relationship. A linear regression was performed in order to determine the best fit line. The equation of this line was

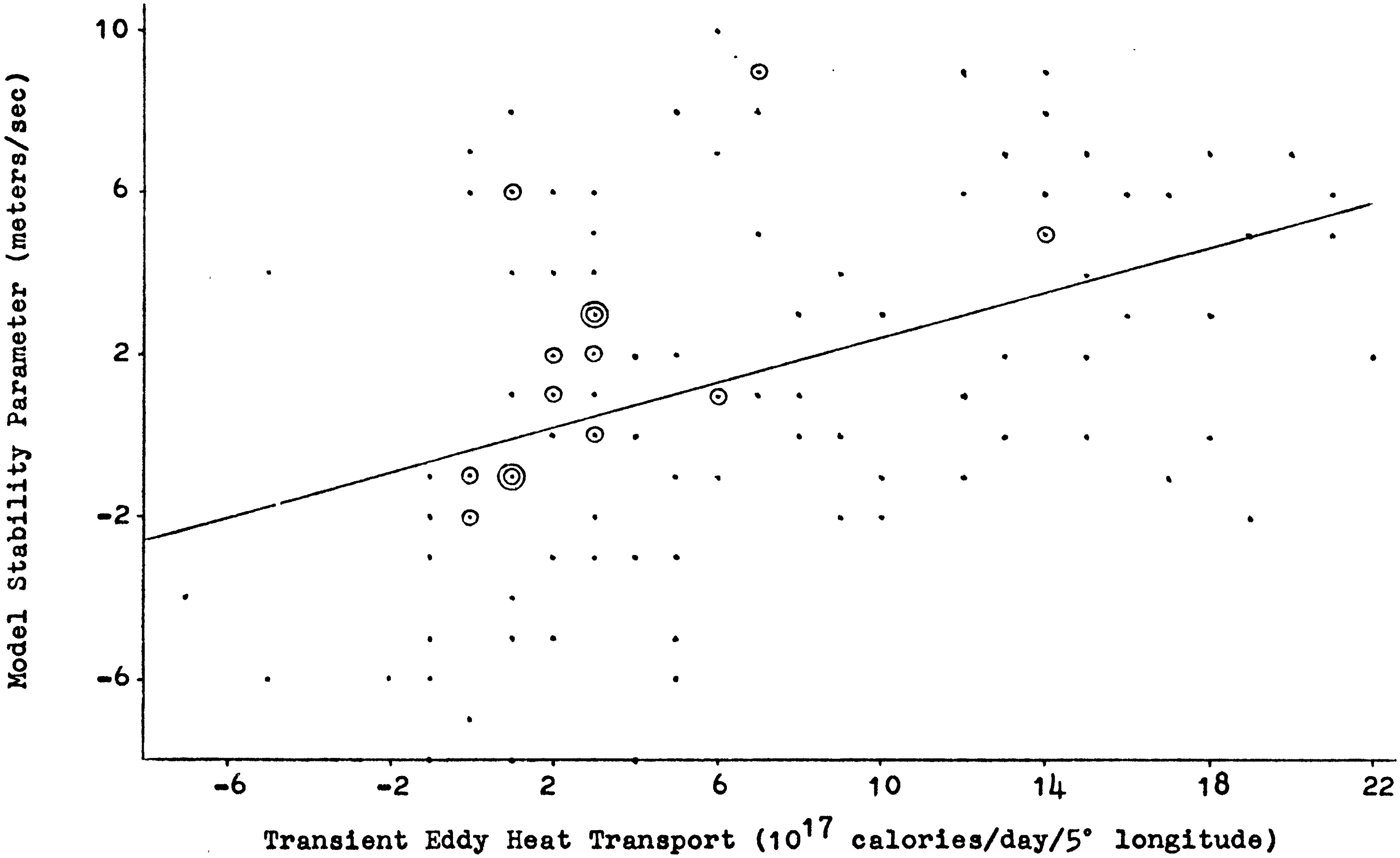

Figure 5.1: Plot of all three months for latitude 42°N and ten degrees spatial lag. Each circle around a point indicates another point at that location.

$$F = 3.57(MSP) + 1.11$$

where F is the transient eddy heat transport in units of 10^{17} calories per day per five degrees longitude and (MSP) is the model stability parameter in units of meters per second. Looking at the graph in Figure 5.1, we see a large scatter around the line. The correlation coefficient between the two quantities was .42, indicating that only 18% of the variation of the transient eddy heat transport is accounted for by differences in the model stability parameter.

The same calculation was performed for latitude 46°N and a spatial lag of ten degrees. Figure 5.2 contains the graph and best fit line. The equation of the line was

$$F = 4(MSP) + 1.48$$

The correlation coefficient in this case was .40; therefore, only 16% of the variation of the transient eddy heat transport is accounted for by the differences in the model stability parameter. Obviously, only a weak linear relationship is indicated in both cases. The accuracy of the fit is questionable because of the large scatter around the lines. It is interesting to observe, however, that the equations are quite similar for the two different latitudes.

The large scatter about the lines may be due at least in part to the smoothing of the model stability parameter. If we had not smoothed the model stability parameter or smoothed this parameter in a different manner, the scatter might have been reduced. On the other hand, the scatter may well be due to other important factors that affect the transient eddy

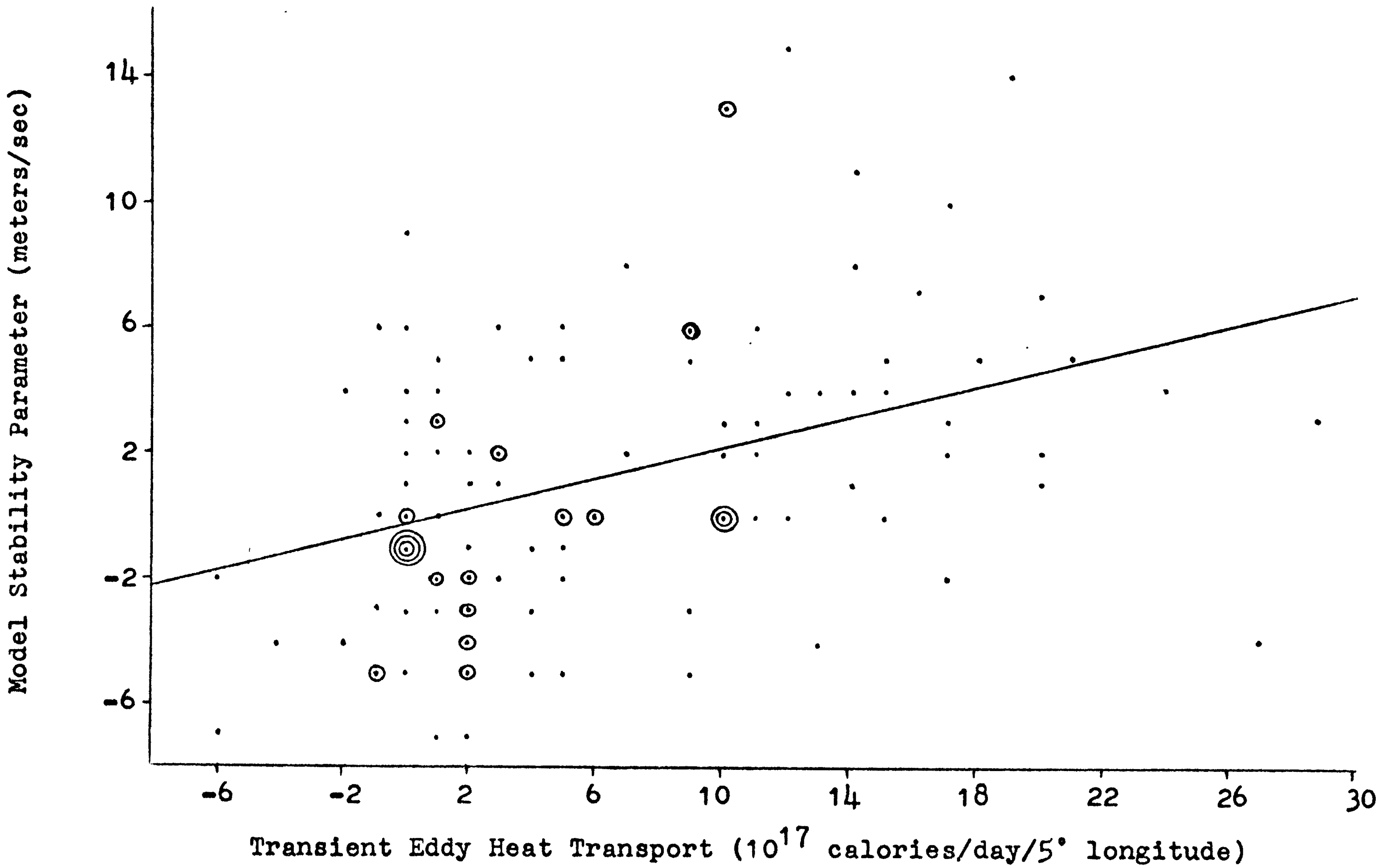

Figure 5.2: Plot of all three months for latitude 46° N and ten degrees spatial lag. Each circle around a point indicates another point at that location.

heat transport. Other possible factors could not be investigated with our present data.

5.2.2 Investigating a Power Relationship

The scatter diagrams in Figures 5.1 and 5.2 did not clearly indicate a power relationship; however, our investigation would not be complete without testing this possibility. In order to test for a power relationship, we added U_c to the model stability parameter. This made all these values positive, so a log relationship could be used. The critical wind shear is essentially a constant with latitude and is related to the smoothing distance, λ_o, by Stone (1978):

$$U_c = \left(\frac{\Omega a \pi^2}{10368}\right) \lambda_o^2 \cos^3 \phi \tag{5.1}$$

where Ω is the earth's angular velocity, a is the mean radius of the earth, ϕ is the latitude, and λ_o is the smoothing distance in increments of five degrees longitude. Using this equation, U_c was calculated as 11.6 meters per second and 9.5 meters per second for latitudes 42°N and 46°N, respectively. The relationship we will be testing is

$$F = b(MSP+U_c)^d \tag{5.2}$$

where F is the transient eddy heat transport, MSP is the model stability parameter, U_c is the critical wind shear, and b and d are constants to be determined. Taking the log of equation 5.2, we have

$$\log F = d \log (MSP+U_c) + \log b \tag{5.3}$$

Equation 5.3 is in the form of a line, and we can perform a linear regression on log F and log $(MSP+U_c)$ to calculate the values of b and d. All of the data points were not used in this investigation, because zero or negative values of the transient eddy heat transport could not be employed in equation 5.3.

Figure 5.3 displays a graph of $(MSP+U_c)$ versus F for our three months plotted on log x log paper for latitude 42°N and a spatial lag of ten degrees. Performing a linear regression on the data, two lines were calculated. Line 1 is the best fit line calculated by minimizing the variation of the transient eddy heat transport about a line, and has the equation

$$F = .59(MSP+U_c)^{.86}$$

As before, $(MSP+U_c)$ is in units of meters per second and F is in units of 10^{17} calories per day per five degrees longitude. Line 2 is the best fit line determined by minimizing the variation of $(MSP+U_c)$ about a line, and its equation is

$$F = (2.6\times10^{-9})(MSP+U_c)^{8.3}$$

If there were an exact relationship between these two quantities, it would lie between or on one of these lines. The large difference between these two lines is due to the large scatter. The correlation coefficient between log F and log $(MSP+U_c)$ is .32, indicating that only 10% of the variation of log F is explained by the differences in log $(MSP+U_c)$.

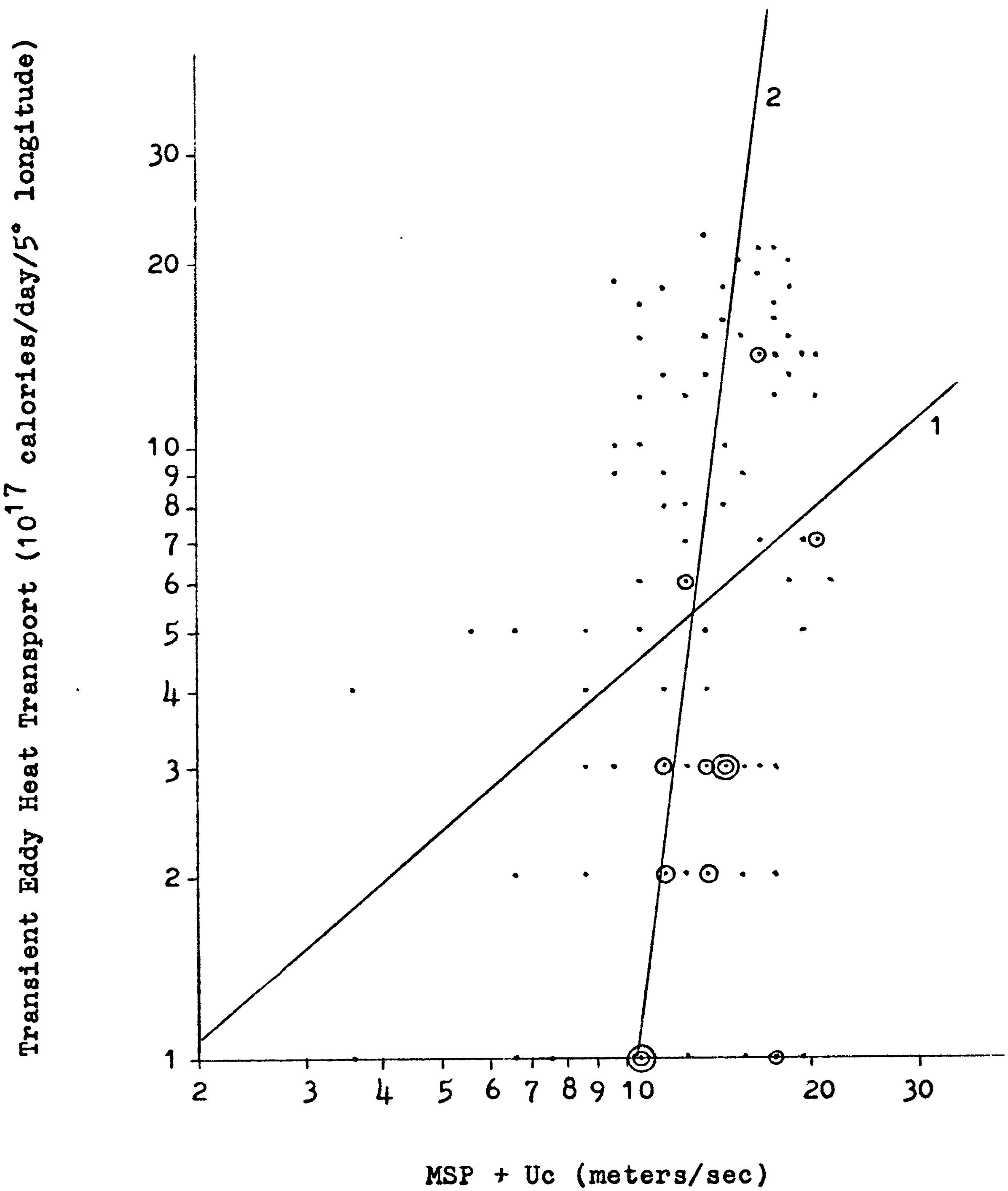

Figure 5.3: Log base ten plot of all three months for latitude 42°N and ten degrees spatial lag. Each circle around a point indicates another point at that location.

A test of the scatter about each line indicated that line 2 was by far the best fit to our data.

Figure 5.4 is a graph of $(MSP+U_c)$ versus F at latitude 46°N and a spatial lag of ten degrees. Line 1 was calculated by minimizing F about a line, and has the equation

$$F = .86(MSP+U_c)^{.91}$$

Line 2's equation is

$$F = (4.29 \times 10^{-5})(MSP+U_c)^{5.1}$$

and was calculated by minimizing $(MSP+U_c)$ about a line. Again, a scatter test was performed, and strongly indicated that line 2 was the best fit to our data. The correlation coefficient for log F and log $(MSP+U_c)$ was .42; therefore, 18% of the variation of log F is explained by differences in log $(MSP+U_c)$. Since the correlation between these quantities is larger than for latitude 42°N, the uncertainty in the relationship and the difference between the two equations is smaller. The equation for line 2 above had the best fit of the relationships determined and agrees with Held's (1978) suggested fifth power dependence. Still, as in the linear investigation, the data is not conclusive enough to give a specific relationship.

5.3 Areas for Further Investigation

As we indicated in section 5.2.1, our smoothing of the model stability parameter may have caused some of the scatter in our graphs. In smoothing, we may have eliminated some of the variation of the model stability parameter related to the variation of the transient eddy heat transport, thus decreasing their correlation. An investigation with an unsmoothed model stability parameter or the model stability parameter smoothed

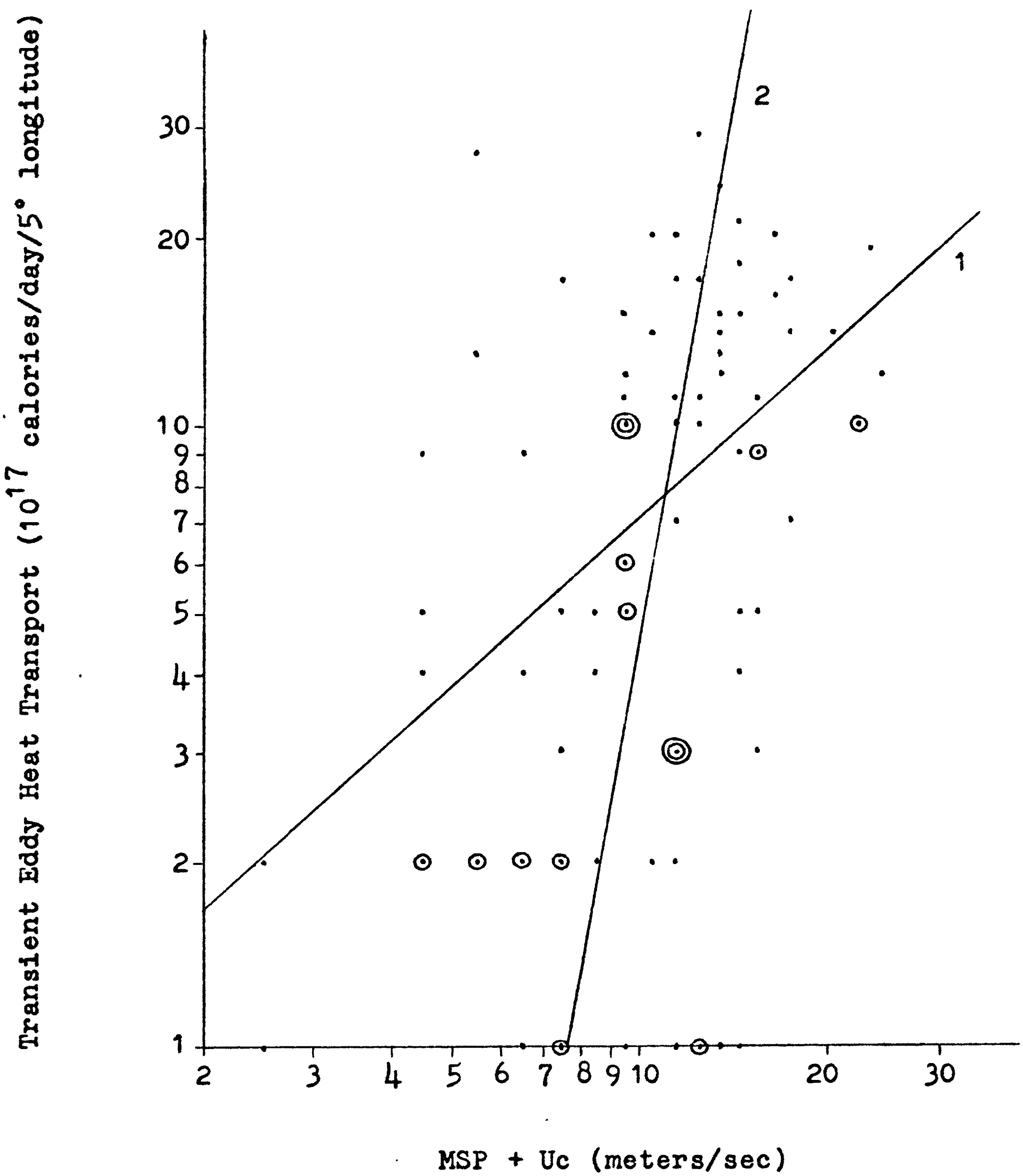

Figure 5.4: Log base ten plot of all three months for latitude 46° N and ten degrees spatial lag. Each circle around a point indicates another point at that location.

in a different manner may prove more fruitful. Another possibility is that the relationship may be improved by performing the same smoothing on both quantities.

Also, the data should be investigated over a much longer time period. Our observations could then be checked to see if they persist, and interannual variations could be investigated. With a larger data base, the a posteriori correlation peak between the surface temperature gradient and the transient eddy heat transport could be investigated more completely. Different months should also be studied, to see if the relationships change with season.

Furthermore, a time series of the local model stability parameter and the transient local eddy heat transport should be examined, so the importance of time lags between the two quantities could be investigated. We attempted to do this over a ten day period in January 1973, with our quantities calculated every twelve hours. Since the raw data was only measured every twelve hours, we could not separate the eddy components. This only allowed us to compare the model stability parameter with the total eddy heat transport. The only peak in the correlation analysis occurred in mid-latitudes at small spatial lags, similar to what we discovered in our previous investigation of these two quantities. The peak was always present in this location, regardless of the time lag, so the analysis provided no new insights. This result may have been caused by the dampening effect of the stationary eddy component on the relationship between the transient eddy heat transport and the model stability parameter, when both eddy components are added together. If we had considered a longer time period and calculated the transient eddy heat transport for every two or three days, then performed our analysis between the model stability parameter and transient eddy heat transport, we may have discovered a greater insight in their relationship.

Finally, relationships between meridional eddy heat transports and other factors should be considered. In our investigation, the correlation between the model stability parameter and the transient eddy heat transport was weak, although significant. Possibly meridional temperature gradients are not the only important forcing agents for meridional transient eddy heat transports. Other factors that may play an imortant role in the formation and maintenance of transient eddy heat transports are topography, latitudinal variations of temperature, etc.

References

Blackmon, M.L., 1976: A climatological spectral study of the 500 mb geopotential height of the Northern Hemisphere. J. Atmos. Sci., 33, 1607-1623.

______________, et al., 1977: An observational study of the Northern Hemisphere wintertime circulation. J. Atmos. Sci., 34, 1040-1053.

Clapp, P.F., 1970: Parameterization of macroscale transient heat transport for use in a mean-motion model of the general circulation. J. Appl. Meteor., 9, 554-563.

Davis, R.E., 1976: Predictability of sea surface temperature and sea level pressure anomalies over the North Pacific Ocean. J. Phys. Oceanogr., 6, 249-266.

Defant, A., 1921: Die Zirkulation der Atmosphäre in den gemässigten Breiten der Erde. Geograf. Ann., 3, 209-266.

Haines, D.A., and J.S. Winston, 1963: Monthly mean values and spatial distribution of meridional transport of sensible heat. Mon. Wea. Rev., 91, 319-328.

Held, I.M., 1978: The vertical scale of an unstable baroclinic wave and its importance for eddy heat flux parameterization. J. Atmos. Sci., 35, 572-576.

Oort, A.H., and E.M. Rasmusson, 1971: Atmospheric circulation statistics. NOAA Prof. Paper 5, 323 pp., U.S. Government Printing Office, Washington, D.C., 1971.

Phillips, N.A., 1954: Energy transformations and meridional circulations associated with simple baroclinic waves in a two-level, quasi-geostrophic model. Tellus, 6, 273-286.

Saltzman, B., 1967: Steady-state solutions for axially-symmetric climatic variables. Research on the theory of climate. Contract Cwb-11389, Rept., Travelers Research Center, 1-38.

Stone, P.H., 1978: Baroclinic adjustment. J. Atmos. Sci., 35, 561-571.

White, R.M., and G.H. Jung, 1951: Large-scale atmospheric exchange processes as diffusion phenomena. J. Meteor., 8, 356-358.