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OVERFLOW VARIABILITY IN DENMARK STRAIT

by

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ABSTRACT

The moored instruments placed in Denmark Strait during Overflow '73 showed the existence of a strongly variable, intense overflow current. Although the current was strongly variable, it was almost always present somewhere on the Greenland slope. The dominant time scale of variability was 1.8 days; thought to be due to a baroclinic instability in the overflow. The composition of the cold water was found to be variable with the salinity varying by up to 0.5 °/oo. The volume transport of cold water was measured to vary from 1 to 7 x 10^6 m^3s^{-1} with a mean of 2.5 x 10^6 m^3s^{-1}. The scale of variability was several days with an indication that it might be associated with meteorological forcing.

INTRODUCTION

The contribution of the cold, dense water flowing through the Denmark Strait to the formation of North Atlantic Deep Water has been known for some time (Lee and Ellett, 1967). It has been characterized as an intermittent overflow (Cooper 1955, Worthington 1969) of variable composition (Mann 1969). Although all investigations have shown the Denmark Strait overflow to be very variable, none have shown it to be non-existent. The Overflow '73 Experiment provided the first detailed data of the overflow from moored instruments.

The moored instruments installed by C.S.S. Hudson were in three sections (Fig. 1). The primary section (Moorings 1 to 4) was located 30-35 km south of the sill. Additional moorings were located further downstream as well as north of the sill. South of the sill the overflow water is found up the Greenland slope and the instruments were distributed to monitor the overflow (Fig. 2).

TEMPERATURE VARIABILITY

The temperature time series as recorded at the twelve instruments immediately south of the sill are presented in Figure 3. The mooring number corresponding to Figure 1 is given on the right side of the figure and the arrows indicate the depths of the instruments. Each instrument encountered, at some time, water warmer than 4°C as well as water colder than 0°C. One notices large amounts of water warmer than 4°C and water colder than 2°C but the division (2-4°C) between the two is quite sharp.

The thickness of the cold water at Moorings 2 and 3 varies between less than 15 m (distance from bottom of deepest instrument) to greater than 250 m (distance from bottom of shallowest instrument). At Mooring 4, there is one instance of the cold water being thicker than 550 m. Although the amount of cold water present in this section varies considerably with time, it is very seldom that it is not present at all (2% of the time there is simultaneously water warmer than 1°C at all four bottom instruments). It is generally true that the onset of cold water at a mooring is much more gradual than the change to warm water.

SALINITY VARIABILITY

At Moorings 1, 2, and 3 there was a conductivity cell on the instruments 100 m above the bottom. Although we did not have much confidence in the salinity measurements we feel that when calibrated in situ against nearby CTP stations that the salinity from the moored instrument should be accurate to about 0.1 °/₀₀. These instruments were in water colder than 1°C for more than one-third of the time. The joint distribution of temperature and salinity is given in Table 1. It is readily apparent that the salinity of the cold water is variable over the large 34.4 to 35.1 °/₀₀. At Moorings 2 and 3 the cold water has a salinity greater than 34.9 °/₀₀ for about two-thirds of the time and is almost always greater than 34.7 °/₀₀. The instrument of Mooring 1 is dominated by much lower salinities.

CURRENT VARIABILITY

The currents measured at Moorings 1 to 4 show a strong overflow parallelling the local bathymetry. Figure 4 shows the velocity vectors for the instruments at Mooring 3. The other moorings on this section are qualitatively similar. The strongest overflow currents are found in the lower 100 m with a peak current in excess of 1.5 ms^{-1}. The current reversals are generally associated with an onset of warm Atlantic water. The spectra (Fig. 5) of the downstream component show that the dominant variability scale is near 1.8 days. This has been attributed (Smith 1976) to a baroclinic instability in the overflow current. Smith used measured values of physical parameters in a quasi-geostrophic, two-layer model of channel flow with a sloping bottom. He found the flow to be unstable over a limited range of wavelengths and frequencies with the most unstable wave having a period of 2.1 days. This variability is present even with a constant source of overflow water.

The currents measured further downstream at Moorings 51 to 53 show a strong overflow with reduced variability (Ross 1977). The dominant time scale remains at 1.8 days. North of the sill the currents are weaker and the semidiurnal tidal signal is dominant. Moorings 6 and 9 show some low frequency strength in their signal but they are difficult to correlate with the measurements downstream.

TRANSPORT VARIABILITY

The volume transport of overflow water flowing through the Denmark Strait can be computed from the current meters at Moorings 1 to 4. For this computation the overflow water is defined to be water colder than 2°C. The temperature chosen in the range of 1 to 4°C is not critical as the temperature records (Fig. 3) showed the transition was quite sharp.

Figure 6 shows the time series of the volume transport of water colder than 2°C past Moorings 1 to 4. The flow is always towards the Atlantic and varies from 1 to 7 x 10^6 m^3s^{-1}. The average transport is 2.5 x 10^6 m^3s^{-1} with a standard deviation of 1.5 x 10^6 m^3s^{-1}.

The exact composition of the overflow water is far from constant as shown by the previous temperature/salinity distributions (Table 1). To be dense enough to enter into deep (>1500m) water formation the 1°C water should have a salinity greater than 34.7°/oo. This is almost always true at Moorings 2 and 3, whereas Mooring 1 has almost half its cold water with salinity less than 34.7 °/oo. However, this instrument only contributes about 13% of the mean cold water transport.

As seen in Figure 3 the instruments do not always enclose the overflow water. This introduces an underestimate in the peak period overflow by some indeterminant amount. However, the mean overflow is expected to be reasonably accurate.

The volume transport is dominated by bursts of overflow, typically of 1-day's duration, occurring at intervals of several days. An attempt was made (Ross 1976) to determine a relationship between the transport and some meteorological forcing. The results were not totally convincing with a possible similarity to the high pass filtered atmospheric pressure gradient across the sill in Denmark Strait. A definitive understanding of the forcing mechanism will have to await a significantly longer time series of the overflow. The measurements will have to be done with at least the spatial resolution accomplished in Moorings 1 to 4 because the integrated overflow transport has a much different signal than current speed at any given point.

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LIST OF FIGURES

Figure 1: Location of current meter moorings in Denmark Strait placed by C.S.S. Hudson.

Figure 2: A temperature section observed in same area as Moorings 1 to 4 showing location of moored instruments.

Figure 3: Time series of temperature vs depth at Moorings 1 to 4. Arrows indicate the depth of instruments.

Figure 4: Stick diagram of currents measured at Mooring 3. The time series has been filtered over 13 hours.

Figure 5: Frequency times spectral density for the downstream (250°T) component of velocity of Mooring 3.

Figure 6: Time series of the volume transport of water colder than 2°C as measured at Moorings 1 to 4.

TEMPERATURE	34.4		34.6		34.8		35.0
1.0	0.1	1.3	1.7	2.4	2.9	1.2	
	0.3	1.4	1.3	2.2	1.1	0.8	
0.5		0.3	0.9	1.9	4.1	1.8	
		1.0	0.8	1.8	1.6	0.6	
0.0	0.3	0.3	2.4	2.1	0.3	0.6	
	0.3	1.1	2.4	1.3		0.6	
-0.5	0.2	1.2	1.6	0.1			
		1.3	1.1				
-1.0			0.2	0.1			

SALINITY

TEMPERATURE	34.4		34.6		34.8		35.0
1.0			0.6	0.9	1.1	3.4	0.1
		0.1	0.2	0.6	1.8	3.9	
0.5		0.1	0.4	0.4	3.1	3.5	
				0.4	2.4	3.9	0.2
0.0			0.2	0.4	0.1	5.7	
			0.1	0.9		1.7	
-0.5				0.1			
-1.0							

SALINITY

TEMPERATURE	34.4		34.6		34.8		35.0
1.0			0.4	0.2	1.2	6.4	
			0.2	0.7	3.0	3.5	0.1
0.5			1.0	0.7	2.8	4.9	
		0.1	0.7	2.2	2.0	3.8	
0.0			1.5	2.4	0.8	4.8	0.1
		0.1	0.3	0.6		4.0	
-0.5			0.1	0.1			
-1.0							

SALINITY

TABLE 1

Joint distribution of temperature - salinity for temperatures less than 1C for instruments at; a)287m mooring 1, b)418m mooring 2, and c)565m mooring 3. Distribution is expressed as percentage of total record falling in interval.

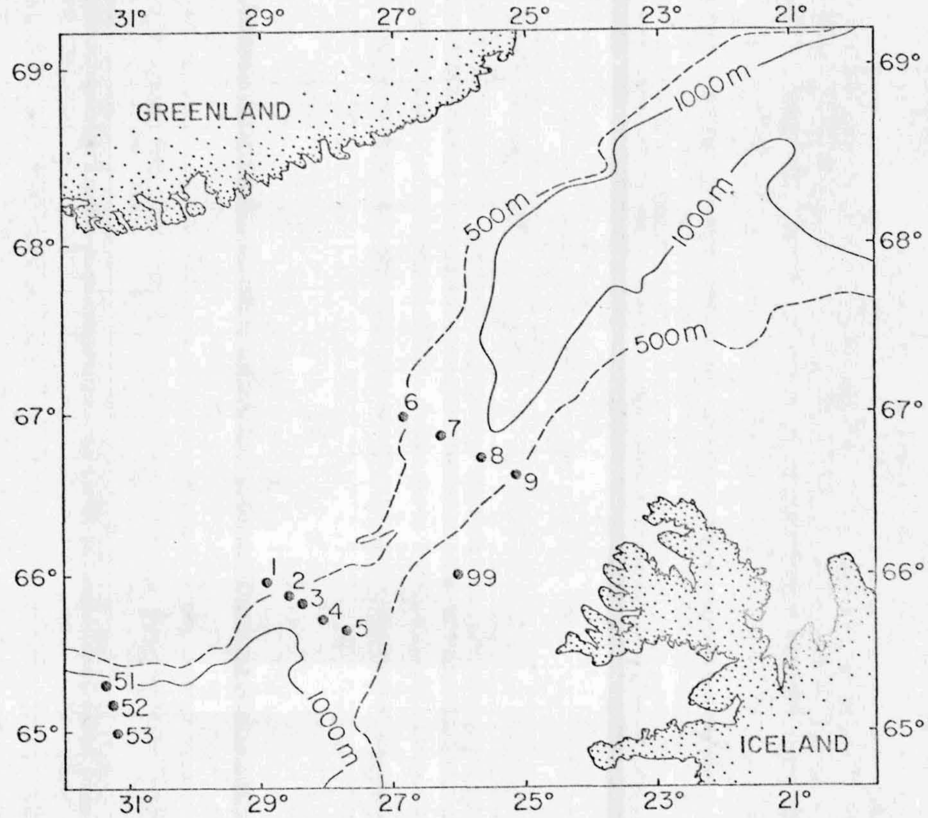
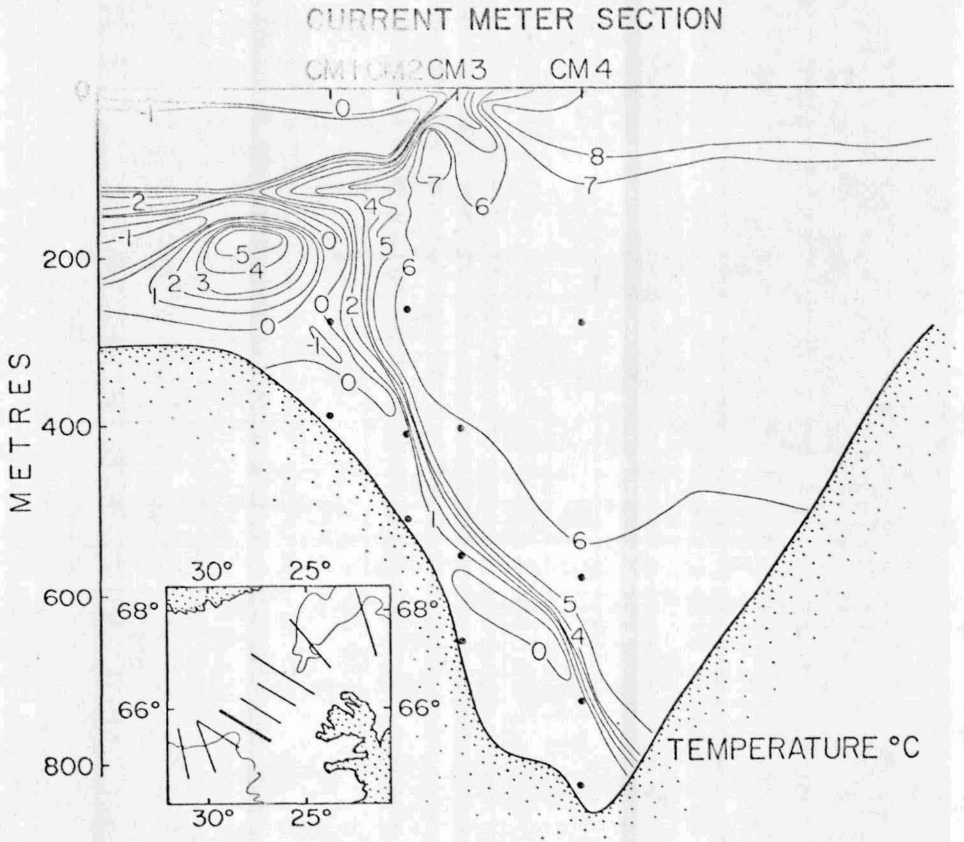


Figure 1



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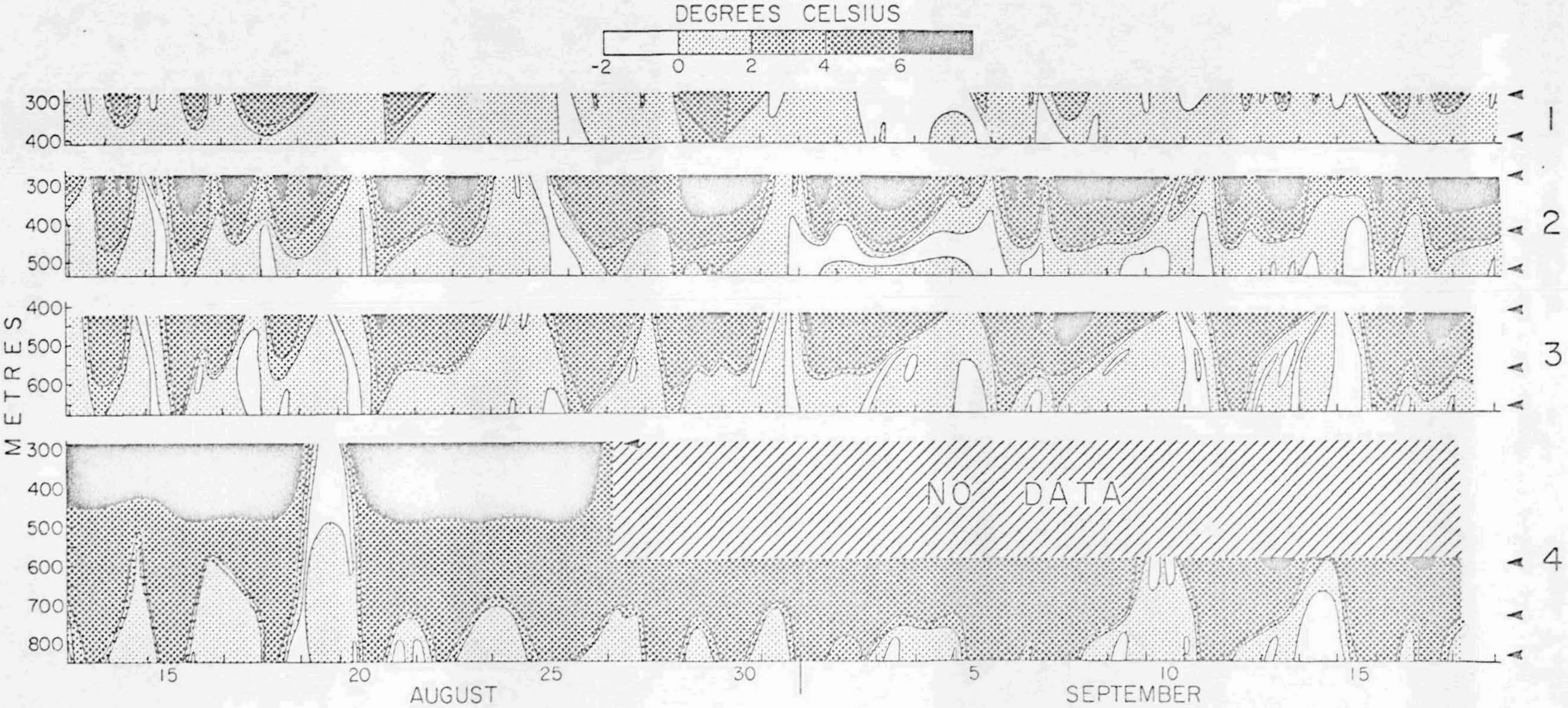
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METRES
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15
AUGUST
SEPTEMBER

Figure 3

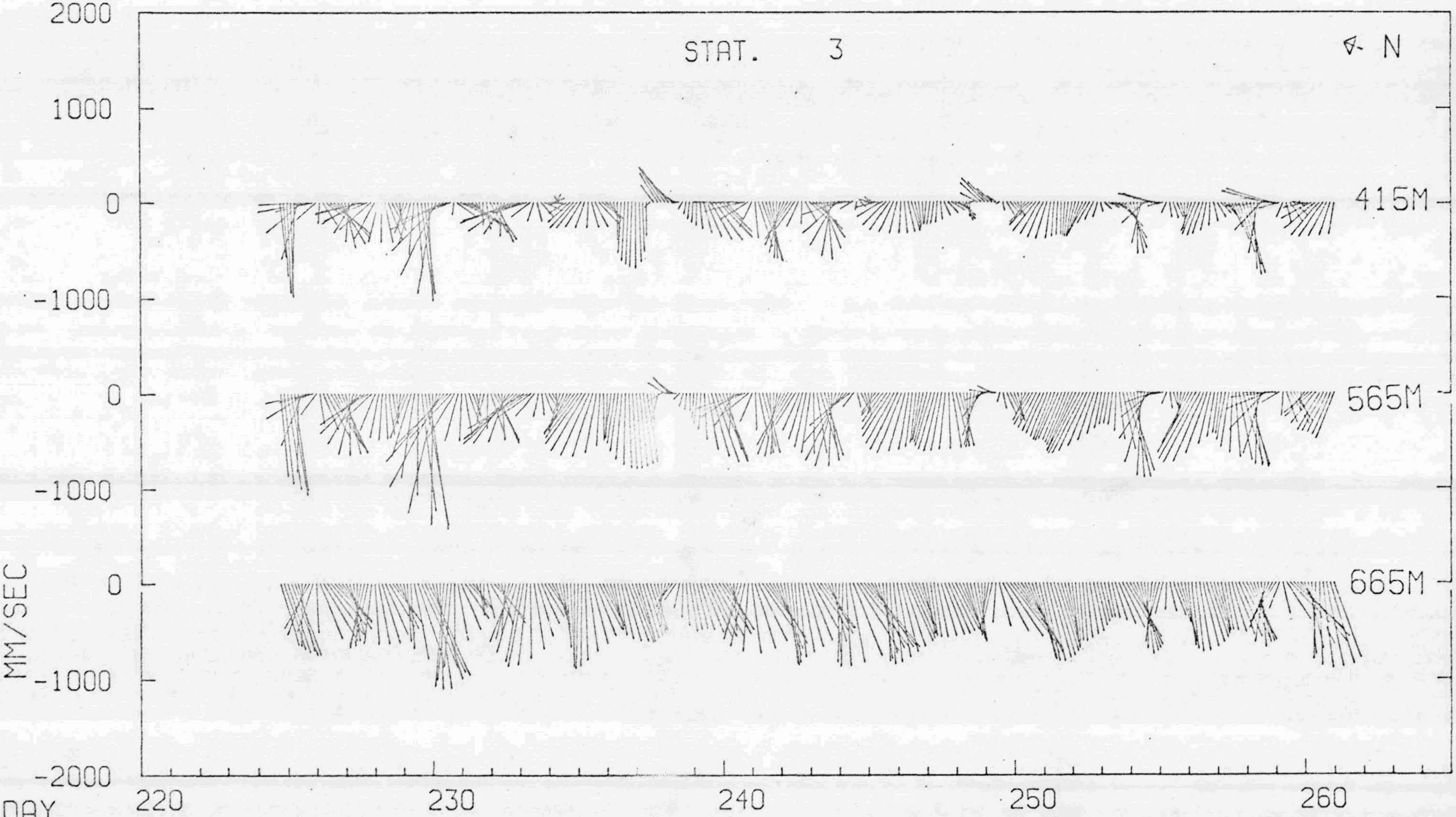
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FIGURE 4

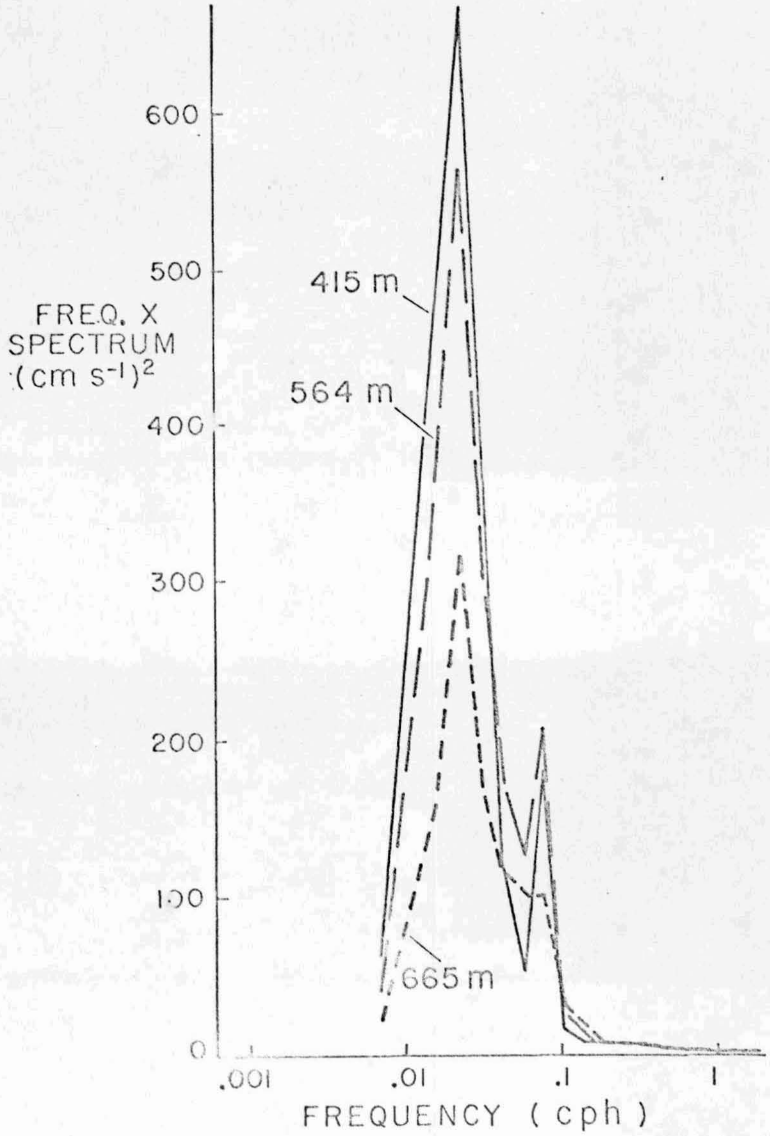

Figure 5

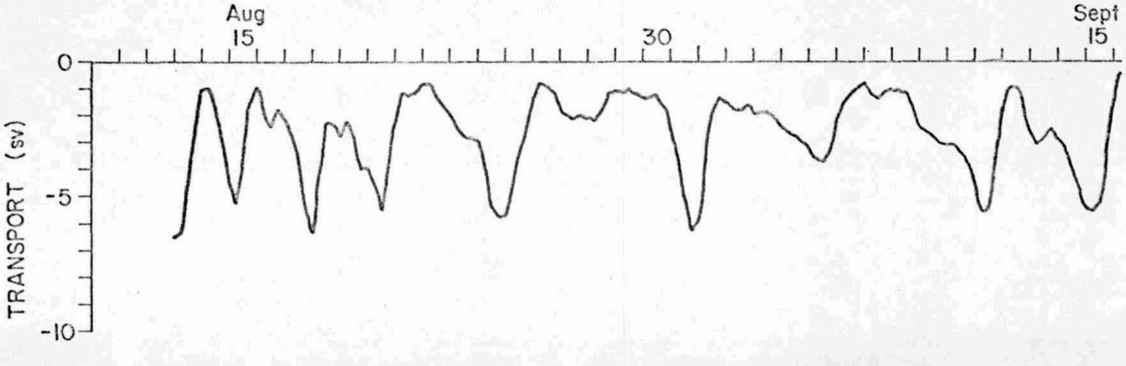

Figure 6