4.5C DETERMINATION OF HORIZONTAL AND VERTICAL WAVELENGTHS OF GRAVITY WAVES IN THE MESOSPHERE BY SPACED WIND MEASUREMENTS

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INTRODUCTION

The work reported below describes the reduction of spaced wind measurements taken over a range of heights. Briefly, the equipment used is a medium frequency radar (2.22 MHz) with one site consisting of a vertically pointing transmitter and spaced receiving antennas, and two remote receiving sites (∿ 40 km distant, forming an approximately equilateral triangle) with spaced antennas. Assuming approximately horizontally stratified scatterers, horizontal winds are thus available at the corners of a triangle of side ∿ 20 km in the GRAVNET system. A more detailed system description was given at the 1983 Urbana MST Workshop.

HORIZONTAL WAVELENGTH AND PHASE VELOCITY

Each site has northward and eastward velocity components available for analysis. One of these components is selected and spectra are calculated for each height over a small range of heights. Cross spectra between pairs of sites are then found for each height and averaged over the height range, so that the phase differences ($\Delta\phi$) given from the cross spectra are independent. The "normalized phase discrepancy" (NOD) is defined as $|\Sigma\Delta\phi|/\Sigma|\Delta\phi|$, where the sum is done around the site pairs, and is analogous to the normalized time discrepancy used in individual determinations of wind from fading records. It indicates the "coherence" of the fluctuations at each site within the bandwidth of the spectral analysis. Consequently, it can be used for data selection. However a low NOD does not necessarily indicate the presence of a single wave, as will be shown later; it merely means that there is a well-defined oscillation at each site.

There are two ambiguities in this process. The first is in $\Delta\phi$, which could be in error by $\pm 2\pi n$, $n = 1,2...$. An assumption must be made that the horizontal wavelength is at least twice as large as the array, thus restricting $\Delta\phi$ to $\pm\pi$. During data selection the further restriction is made that the $|\Delta\phi|$ be less than $\pi/2$, in order that the direction of propagation be unambiguous. A slight relaxation of these conditions is reasonable, e.g., if two of the are less than $\pi/2$ and one is greater, but NOD ∿ 0, the data are probably acceptable. The wide transmitter antenna beam widths used at MF are helpful in attenuating the shorter wavelength oscillations, but is is difficult to estimate this because the effective beam width depends on the scattering process.

The second ambiguity is in frequency. A 5-min data sample is used to determine the wind, giving a Nyquist frequency of 10 min. However, if the 5-min sample is assumed to be block average there is some attenuation of short-period fluctuations as shown in Figure 1.

Once the $\Delta\phi$ are found, the wavelength and direction can be found by a least squares fit to the phase differences. Each phase difference could be weighted by the appropriate coherence, but this is not done at present. Data with low NOD will give the same results regardless of weighting in any case.

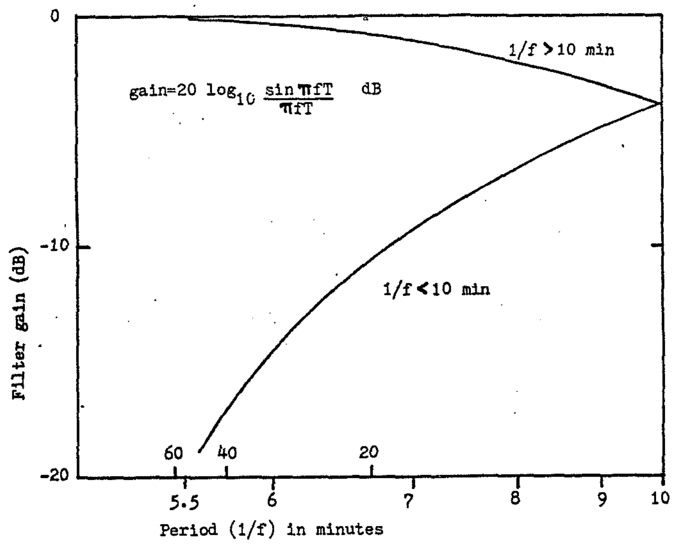

Figure 1. Attenuation due to a block fliter of length T=5 min.

Further cross checking is possible by combining N and E components for a given spectral frequency to form an elliptical oscillation at each site. For a gravity wave, the horizontal component of oscillation in the wind vector should be along the direction of propagation, consequently, the tilt angles of the ellipses should all be in this direction. In practice, because of analysis noise and other possible factors discussed later, this is seldom the case.

VERTICAL VELOCITY AND WAVELENGTH

These can be found by cross spectral analysis between different heights at the same site. The calculated phase difference at the smallest height separation, $\Delta\phi_v$ should again be between $\pm\ \pi/2$ to reduce doubt in the correct quadrant for the phase. This restriction can be relaxed if, for example, it is assumed that the phase velocity is always downward, or that there are no waves present with wavelength less than twice the minimum height separation. The above restriction limits the minimum acceptable wavelength to 12 km with our system (3-km transmitter pulse width). However, assuming that the scattering layers vary with height, or that there is volume scatter present over the 5- or 6-hr observing period, the shorter wavelengths should be attenuated and alleviate the problem of phase ambiguity.

Consistency in the data is checked by comparing the wavelengths (and sense, up or down) for two different height separations. As in the horizontal wave measurement, the velocity is found from the wavelength and frequency.

CONSIDERATIONS IN NUMERICAL ANALYSIS

Some of the problems encountered in analysis are low frequency resolution, particularly at periods of an hour or more, and gaps in the data sequence combined with possible sidelobes of strong spectral peaks (particularly the semidiurnal tide, which is removed before analysis).

The frequency resolution problem is to a large extent inherent in the attempted measurement. Even if the gravity wave source sends out a continuous wave train, changes in the background wind field (especially tidal motions) will change propagation conditions over periods of several hours, so that the wave cannot be expected to be statistically stationary for longer periods of observation. Given that longer periods of observation do not help in measuring single waves, the resolution problem becomes acute at long periods. For example, a 6-hr observation period will have Fourier components at 6, 3, 2, 1.5 ... hr. When the data are tapered to reduce possible sidelobes, the resolution becomes even poorer, and waves of period say, 1-3 hr, may be combined in one spectral estimate. Higher frequency waves have smaller amplitude oscillations and run into analysis noise problems (from the individual wind determinations).

For ideal data, all values in the sequence are present, and the effect of tapering can be calculated. Gaps produce extra sidelobes which depend on the gap distribution, and it is possible that in extreme cases, tapering could do more harm that good.

These problems may be the reason that spectral peaks at the three sites (or even between N and E components at one site) are often at different frequencies; which is why methods other than spectral peak selection have been used in the choice of data.

SOME PUZZLING DATA

N and E spectral analysis for a 5-hr period are shown in Figures 2 and 3. A 10% cosine taper has been used at each end of the raw data, and the cross spectra smoothed somewhat before calculating the phase differences. The wave parameters shown have been calculated from spectral components which are above the noise level (i.e., the average amplitude between 20- and 10-min period), and have an NOD less than 0.3. The N and E spectra are quite different in places, which might be expected if the wave direction is close to N or E; and the single component spectra differ between sites, possibly due to analysis noise or gap distribution problems (each site is required to have more than 50% data existence before spectra are calculated) which are likely to cause sidelobes at different frequencies. The two periods of interest are near 2-hr and just below 1-hr period, where both components have wave parameters. Approximate parameters are shown below.

	N			E		
Period	θ	λ	V	θ	λ	V
2 hr	160°	100 km	20 m/s	350°	120 km	15 m/s
1 hr	330°	110 km	30 m/s	80°	200 km	50 m/s

The tilt angles were fairly stable around 2 hr and are shown below.

Site	Tilt (E of N)	Axial Rat(Maj/Min)
Park	120°	2.4
Drews	90°	2.2
Watson	90°	4.6

It can be seen that the wave directions given by N and E components are almost diametrically opposite for the 2-hr data, and the oscillations in wind are at right angles to both! The data are not normally quite this contradictory, but this puzzle must be explained before confidence can be placed in the rest of the results.

One possibility, which unfortunately does not appear to have a solution at present, is that there is more than one wave present in the spectral bandwidth, with possibly different speed, wavelength, and directions. If the directions are the same, then significant cancellation can occur at different sites. Table 1 shows some examples of the results expected if two waves at the same frequency

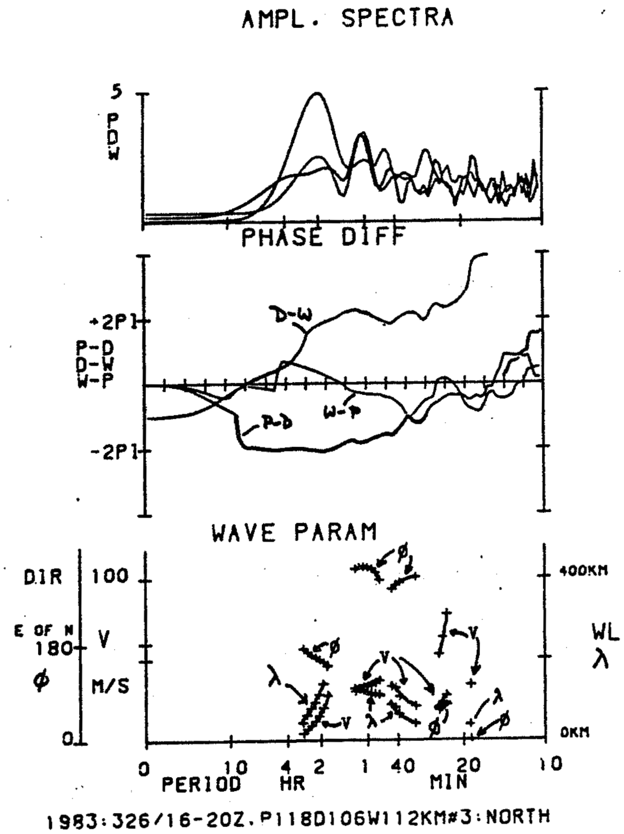

Figure 2. Results for northward component.

are summed. The amplitude of oscillation, direction of propagation (E of N), the wavelength (km) and the absolute phase (e.g., at one site) are given for each wave. The resulting N and E spectral amplitudes, tilt angle and axial ratio of the elliptical oscillation are shown for each site, and the calculated wavelength and direction for the resulting wave for separate N and E components. The NOD is by definition identically zero, since the frequency of oscillation is the same at each site.

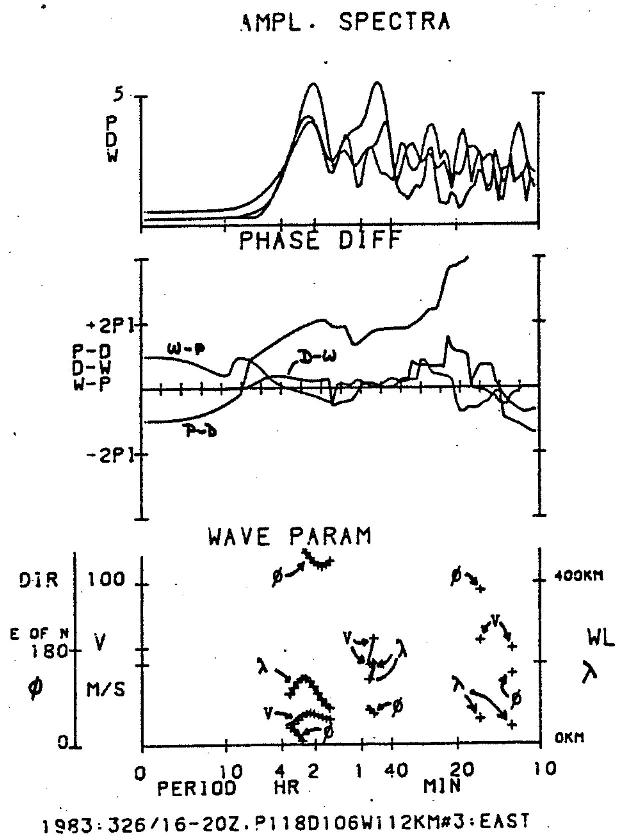

Figure 3. Results for eastward component.

Table 1. Numerical simulation of resulting wave parameters when two waves are combined in the measurement.

WAVE#1				WAVE#2				PARK				DREWS				WATSON				NCOMP			ECOMP		
M/S	DIR	WVL	PHI	M/S	DIR	WVL	PHI	AH	AE	TILT	RAT	AN	AE	TILT	RAT	AN	AE	TILT	RAT	WVL	DIR	NPD	WVL	DIR	NPD
20.	60.	300.	110.	20.	61.	100.	120.	20.	35.	61.	99.0	16.	29.	60.	99.0	19.	34.	60.	99.0	152.	61.	.00	150.	61.	.00
20.	60.	300.	110.	20.	61.	100.	140.	19.	34.	60.	99.0	14.	25.	60.	99.0	18.	32.	60.	99.0	152.	61.	.00	150.	61.	.00
20.	60.	300.	110.	20.	61.	100.	160.	18.	32.	60.	99.0	12.	20.	60.	83.4	16.	29.	60.	99.0	153.	61.	.00	150.	61.	.00
20.	60.	300.	110.	20.	61.	100.	220.	11.	20.	60.	80.2	2.	4.	60.	12.2	9.	15.	60.	56.7	173.	64.	.00	144.	61.	.00
20.	60.	300.	110.	20.	160.	100.	120.	9.	24.	110.	9.6	9.	24.	110.	7.6	17.	21.	110.	1.4	65.	171.	.00	307.	113.	.00
20.	60.	300.	110.	20.	160.	100.	140.	11.	23.	110.	3.1	9.	24.	110.	12.9	20.	19.	20.	1.1	84.	170.	.00	324.	108.	.00
20.	60.	300.	110.	20.	160.	100.	180.	18.	21.	110.	1.2	14.	23.	110.	1.9	26.	15.	20.	2.2	127.	158.	.00	372.	83.	.00
20.	60.	300.	110.	20.	160.	100.	210.	23.	17.	20.	1.4	19.	20.	110.	1.0	28.	12.	20.	5.0	145.	153.	.00	296.	42.	.00
20.	60.	300.	100.	10.	160.	100.	120.	3.	21.	87.	6.3	1.	21.	88.	49.0	12.	19.	68.	2.1	63.	54.	.00	345.	87.	.00
20.	60.	300.	110.	10.	160.	100.	160.	8.	20.	80.	2.6	5.	20.	86.	4.6	15.	17.	49.	2.2	219.	133.	.00	348.	76.	.00
20.	60.	300.	110.	10.	160.	100.	210.	15.	17.	51.	2.2	12.	18.	65.	2.0	19.	14.	37.	6.2	208.	138.	.00	285.	47.	.00