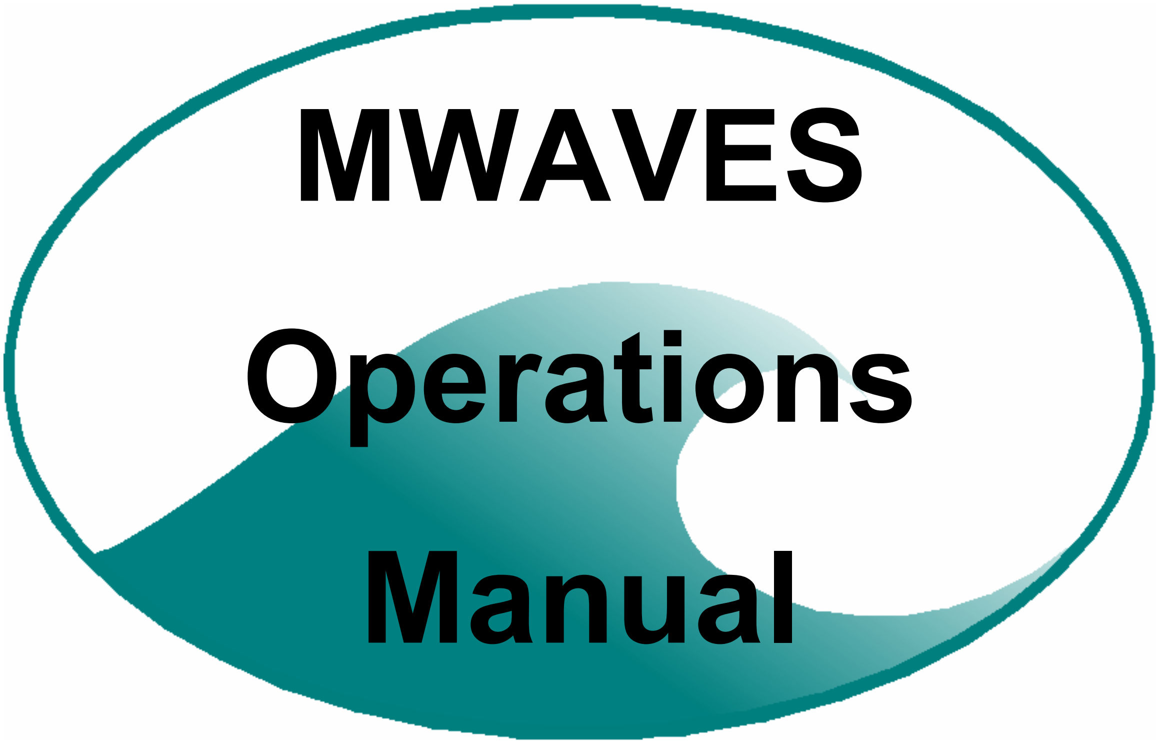

MWAVES Operations Manual

Version 2.6

Nobska Development
Corporation
October 14, 2007

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General Notes

Required Reading

The MWAVES Operations Manual assumes you are familiar with the operation and terminology of MAVS-3 current meters. Copies of the MAVS-3 Operations Manual are included with each MAVS-3 instrument and are available from Nobska Development. Current contact information can be found on our web site: www.nobska.net.

Compatibility with Previous Versions of MWAVES

In general, leaving previous versions of MWAVES installed on your PC will not cause any operational problems for the most recent version of the program. However, the previous versions may encounter problems. This may be due to interaction of command path structure (the most recent version is always first) and upgrades to the dynamically linked libraries copied to your PC during each installation. We suggest removing previous versions of MWAVES before installing new versions. See Uninstalling MWAVES for more information.

For the Record

MWAVES is designed to post-process MAVS-3 measurements. It does not include a serial communications utility and it cannot be used to program or otherwise control a MAVS-3 current meter.

Operating System Compatibility

MWAVES is compatible with several current versions of the Windows operating system. We have run the program successfully under Windows 2000, Windows XP, and Windows Vista. It may also run under previous versions of the Windows OS. MWAVES is not compatible with UNIX, Linux, or Macintosh computers. The program is distributed on compact disks and should be installed from the CD drive of your PC as described below.

Quick Start

For a color coded one page summary of MWAVES operation and a companion processing map see the sections titled:

- Operating MWAVES – One Page Summary
- Operating MWAVES – Data Processing Map

Installing MWAVES

Installing MWAVES

The MWAVES installation is performed manually. This is mildly awkward, but more reliable across several versions of the Windows OS. Contact Nobska if you need assistance. You should be logged in as an administrator to perform these operations. Place the MWAVES distribution CD in the CD drive of your PC. In the instructions below we assume that the drive letter of the CD drive is D:\.

- Copy the D:\Nobska folder from the CD drive to the C:\Program Files\ folder on the hard drive of your PC.
    - You can do this by dragging the Nobska folder from D:\ to C:\Program Files\ with your mouse or by using the tools in Windows Explorer.
    - The Nobska folder will occupy approximately 5 Mbytes on your hard disk. Depending on the transfer speed, the copy operation may take several seconds to a minute to finish.
    - The MWAVES program and several subfolders are now resident on your hard drive. MWAVES will not run if this file structure is altered.
- Change the status of the Read Only attribute of the MWAVES file structure. Files and folders copied from a CD-ROM will generally have the Read Only attribute set and this can interfere with the operation of MWAVES.
    - Right click on C:\Program Files\Nobska\ and select Properties from the pop-up menu.
    - Under the General tab in the Properties pop-up, deselect the Read Only attribute and click OK. (Do the same for the Hidden attribute if it is set.)
    - In the Confirm Attribute Changes pop-up, select Apply changes to this folder, subfolders and files and click OK.
- Copy D:\MCRInstaller.exe to your Desktop and run it by double clicking the icon.
    - Close any applications that are currently running before running the installer.
    - You may wish to copy or print this portion of the installation instructions so that they will be available to you while running the MCR Installer.
    - Select the default value at each prompt
    - We suggest installing for all users
    - The MCR Installer will:
        - Add a set of libraries rooted at C:\Program Files\MATLAB
        - Extend the DOS/Windows command path
        - Add entries to the Windows Registry
- Delete MCRInstaller.exe or archive it at C:\Program Files\Nobska\MWAVES
- Copy D:\MAVS3 to C:\MAVS3.
    - This is the default MAVS data folder. Skip this step if the folder already exists on your hard drive.
    - MWAVES looks in this folder for data during initialization. You can browse to other locations once MWAVES is running.
- Copy D:\R2006b to C:\Program Files\MATLAB\R2006b.
    - These folders are empty, but need to exists to prevent the generation of warnings when MWAVES is run.
- Remove the MWAVES Distribution CD from the drive and keep it in a safe place.

Installing the MWAVES License File

A personal license file, mwaves_license.dat, is distributed with each copy of MWAVES purchased from Nobska. A valid license file is required to enable the processing capabilities of MWAVES. The license file is typically provided on a separate CD or via email.

Copy your license file, mwaves_license.dat, to C:\Program Files\Nobska\mwaves_license.dat. MWAVES will not run if you place the license file in a different folder or if the license file is not valid. Contact Nobska if you require assistance.

This completes the required portion of the MWAVES Version 2.6 installation.

Creating an MWAVES Desktop Shortcut (Optional)

You may wish to create shortcuts to the MWAVES executable and place them on your Desktop for convenience. This is an optional step, but it will make it easier for you to operate the program. Follow the steps below to create a Desktop shortcut with the MWAVES wave icon.

- Open the C:\Program Files\Nobska\MWAVES\MWAVES_Version_2_6\ folder, right click the mwaves.exe icon, and select Create Shortcut from the menu.
- Right click the mwaves.exe shortcut icon and select Properties from the menu.
- Select the Shortcut tab and click the Change icon… button. This will probably generate a warning message. Click OK to get past the warning.
- Click the Browse button, navigate to C:\Program Files\Nobska\MWAVES\MWAVES_Version_2_6\, and set the Files of type: box to All Files.
- Select wave.bmp in the Change Icon window.
- Select the OK button in the Change Icon window.
- Click the Apply button and then the OK button in the mwaves.exe Properties window.
- Rename the shortcut MWAVES 2.6 and drag it onto your Desktop.

You can now run MWAVES from your Desktop by double clicking the MWAVES 2.6 wave icon.

Uninstalling MWAVES

Like the install, the uninstall is performed manually and you should be logged in as an administrator to perform these operations. To begin, delete the following folders and files:

- C:\Program Files\Nobska\MWAVES\ MWAVES_Version_2_6\
- MWAVES shortcut icon from your Desktop if present

If you are not running other versions of MWAVES, delete the following folders and files:

- C:\Program Files\Nobska\MWAVES\
- C:\Program Files\Nobska\mwaves_license.dat
- C:\MAVS3 (unless you wish to use this folder for MAVS-3 data files)
- C:\Program Files\MATLAB

Note that your individual license file works with all versions of MWAVES. You should always maintain an archival copy of your mwaves_license.dat file in case you reinstall the program or upgrade to a newer version.

Finally, follow the click path below to restore your original command path.

My Computer >> Control Panel >> System >> Advanced tab >> Environment Variables

In the Environment Variables window, scroll down under System variables, select the Path variable, and click Edit. In the edit Window, use the arrow keys and your mouse to find and Select:

;C:\Program Files\MATLAB\MATLAB Component Runtime\v75\runtime\win32

and delete it, including the semicolon at the beginning, from the end of the path. Leave the rest of the path in place. If you are running other versions of MWAVES you must leave those additions to your command path in place. Click back through the OK buttons to save the change and close the Control Panel.

MAVS-3 Sampling for Analysis with MWAVES

General Deployment Guidelines

Measurements of waves should be made from a fixed, commonly bottom mounted platform. While measurements can, in theory, be made from a mooring mounted sensor, experience demonstrates that mooring motions severely contaminate the signal and leave the results of post-processing open to considerable doubt. You should use a fixed mount.

A small, light tripod with broad, weighted foot pads is a good choice for many situations. It is easily deployed and recovered with relatively small vessels and it is stable on sand, mud, and cobble bottoms. The MAVS-3 instrument can be mounted inside the frame to provide protection from physical damage. Alternatively, the sensor can be mounted extending above the apex of the tripod, possibly inside a light protective frame. The flow inside the tripod frame will always suffer some contamination from wakes. Obstructions on the bottom may also disturb the near-bottom flow.

Small tripods, approximately 1.5 meters tall, are available from Nobska. Complete mechanical drawings are also available if you wish to make your own tripods. The cost to you is significantly reduced when you make your own and we are only too happy to assist by providing the drawings.

Standard MAVS-3 instruments should be mounted in either the Vertical/Up or Vertical/Down sensor orientation. Selected bent-sensor models can be mounted Horizontal/Bent Up or Horizontal/Bent Down. In these orientations, with the sensor rings parallel to the bottom, MAVS-3 has a very uniform response to changing directions of horizontal flow.

The Rules of Thumb for MWAVES Deployments

The first important rule of thumb is to mount the sensor no more than 10 to 15 meters below the surface. The actual limit depends strongly on anticipated wave frequencies. The velocity and pressure variations associated with waves and measured by MAVS-3 decrease hyperbolically with depth as a function of wave frequency and bottom depth. Shorter wavelengths attenuate more rapidly. If the instrument is placed too deep the attenuated variations are simply too small to measure. The high velocity sensitivity of the MAVS-3 allows it to make accurate measurements of relatively low amplitude and short period waves 30 or more meters below the surface under some conditions. However, you will enjoy cleaner, more reliable results if you observe the more restrictive limit of 10 to 15 meters.

Because of the attenuation with depth and proximity to the bottom, the second important rule of thumb is to position the sensor reasonably high above the bottom. A minimum height above bottom of 0.75 to 1 meter is recommended. 1.5 to 2 meters is preferred.

A Critical Measurement for MWAVES Deployments

It is critically important for post-processing that you measure and record the height above bottom of the center of the velocity sensor. If you are using a pressure sensor (recommended), you should also measure the height above bottom of the pressure port. As noted above, the attenuation of wave motions with depth depends on bottom depth. MWAVES cannot accurately map sub-surface measurements to the surface unless the water depth and sensor height above bottom are known.

When equipped with a pressure sensor, MWAVES will automatically and dynamically calculate bottom depth from the pressure measurement and the sensor height above bottom provided by the operator. When calculating directional wave spectra from velocity measurements alone, both the sensor height and the bottom depth must be provided by the operator.

General Sampling Guidelines

Familiarity with the operation and terminology of MAVS-3 current meters is assumed in the discussion below. In particular, you should be familiar with the *deployment definition* parameters and the terms *measurement*, *sample*, and *burst* as defined in the MAVS-3 Operations Manual.

Waves are an inherently stochastic process; therefore it is critically important that the deployment is structured to sample the waves in a statistically meaningful way. Surface gravity waves occupy a band from roughly 0.05 Hz to 0.33 Hz (periods of 20 seconds down to 3 seconds). Phenomena well outside this band, such as tides and infra-gravity waves, may also be of interest. Wave characteristics depend on local wind forcing, distant sources, local and intervening bathymetry, and other factors, some of which will be changing. First, measurements must be fast enough to avoid aliasing these signals.

MWAVES is designed to use a MAVS-3 burst of measurements as the ensemble of time-series measurements to be processed. The output of MWAVES is a series of directional spectra, each calculated from an individual burst in the time-series. Therefore each burst should encompass enough wave cycles to be representative, but not last so long that the assumption of statistical stationarity is no longer valid. Processing issues such as the trade-off between frequency resolution and spectral confidence intervals for a time-series of given length should be considered. As always, sampling is constrained by the availability of power and memory.

Thus it is necessary to consider all of the MAVS-3 schedule parameters when planning a deployment. These include the measurement frequency, the number of measurements per sample, the sample period, the number of samples in each burst, and the burst interval.

The Rules of Thumb for MWAVES Sampling

- Measurement frequencies of 2 Hz to 4 Hz are recommended. The minimum measurement frequency is 1 Hz.
- The number of measurements per sample should always be 1. Do not average the measurements. Averaging smoothes the signal unnecessarily. It also tends to hide actual bad measurements, which MWAVES otherwise would detect and replace with a linearly interpolated value.
- Bursts of 2048 to 8192 samples are recommended. The minimum number of samples per burst is 512. The number of samples in a burst should generally be a power of 2. The time-series is processed using a Fast Fourier Transform (FFT) algorithm. It will be automatically padded with zeroes to give it a length that is a power of 2 if it is not already.
- The duration of a burst should generally be at least 10 minutes, but not longer than 30 minutes to 45 minutes. The choice depends strongly on the speed with which conditions are likely to change. The duration of a burst in seconds is the product of the sample period and the number of samples per burst.
- The length of the burst interval should be chosen to sample the time scales over which the wave field is changing. 3 hours or longer may be sufficient to accurately characterize tidal modulations. Shorter intervals or continuous bursts allow a more detailed examination of the evolution of the waves. Power or memory constraints may force the use of longer intervals.

Keep in mind that these are general guidelines, not rigid rules. They will work in many situations, but you may have to be flexible and creative in adapting to more exotic conditions. You can use the tools built into the MAVS-3 system control program to evaluate and select possible variations.

Two example sampling schedules are show below. Example 1 is displayed using the MAVS-3 Deployment menu. Example 2 is displayed using the equivalent MAVSoft Deployment Parameters window.

Note that both deployments are programmed to store both raw axes (always recommended!) and the East-North-Up velocity vector. Consider that it is the direction of wave propagation in the Earth frame that is generally of interest. This setting is recommended if the data will be processed using MWAVES.

MWAVES will automatically calculate directional spectra from raw axes measurements or from instrument frame velocity vectors if compass information has also been recorded. In the absence of compass measurements, MWAVES will calculate directional spectra with respect to the instrument frame. Note that MWAVES cannot calculate spectra if MAVS-3 was programmed to only record speed and direction in the Earth frame. Always record the raw axes and DO NOT USE THE SPEED AND DIRECTION VELOCITY FRAME FOR AN MWAVES DEPLOYMENT!

Deployment Example 1

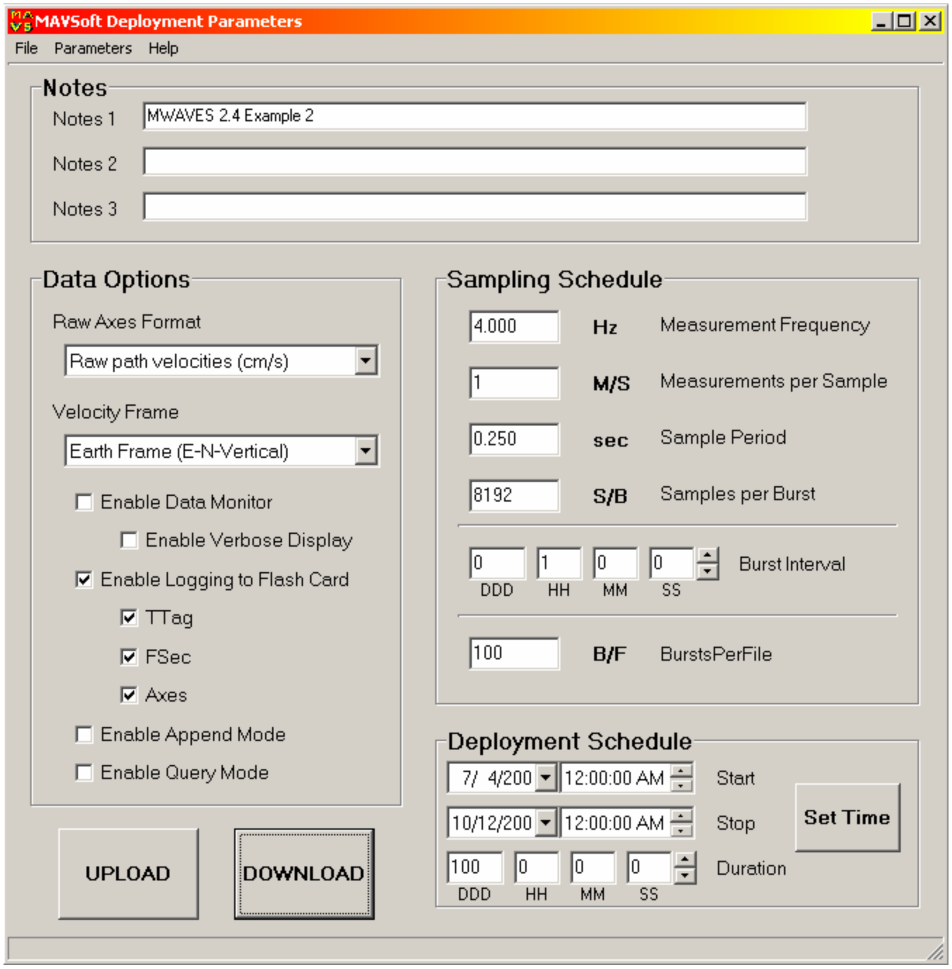
```
Notes 1| MWAVES 2.6 Example 1
      2|
      3|

Time  N| Time Now             07/03/2004  17:03:06  [MM/DD/YYYY  HH:MM:SS]
      S| Start Time           07/04/2004  00:00:00  [MM/DD/YYYY  HH:MM:SS]
      T| Stop Time            10/12/2004  00:00:00  [MM/DD/YYYY  HH:MM:SS]
      D| Duration                    100  00:00:00  [DDD HH:MM:SS]

Data  F| Velocity Frame       Earth Frame (E, N, W)         TTag FSec Axes
      M| Monitor              Disabled                       On   On   SI
      L| Internal Logging     Enabled     (34 bytes/sample)
      A| Append Mode          Disabled    (0 of 507 files in use)
      V| Verbose Display      Disabled
      Q| Query Mode           Disabled

Sched 4| Measurement Frequency                 2.0  [Hz]
      5| Measurements/Sample                     1  [M/S]
      6| Sample Period                        0.50  [sec]
      7| Samples/Burst                        2048  [S/B]
      8| Burst Interval              000  03:00:00  [DDD HH:MM:SS]
      9| Bursts/File                           100  [B/F]

      G| Go (<CTRL>-<G> skips checks)

        Selection  ?
```

Example 1 might be described as a general purpose sampling scheme for long term site monitoring. The measurement frequency, number of samples per burst, and resulting 17 minute burst duration support the calculation of medium to high resolution directional spectra. The 3 hour burst interval captures tidal modulations of the wave field without rapidly exhausting power and memory resources.

Using this schedule a MAVS-3 equipped with a 9.6 Ahr alkaline battery pack has an endurance limit of approximately 71 days. Planned servicing intervals of 2 months to replace batteries and harvest the data would also afford an opportunity to remove bio-fouling. The collected measurements, approximately 40 Mbytes, will fit comfortably on a 64 Mbyte compact flash card. System endurance increases to over 140 days (4.5 months) with a 19.2 Ahr lithium battery pack and a 128 Mbyte card.

As part of an observatory site providing external power and a data file download link, deployment duration would be limited only by the rate of bio-fouling.

Deployment Example 2



Notes 1: MWAVES 2.4 Example 2
Notes 2:
Notes 3:

Raw Axes Format: Raw path velocities (cm/s)
Velocity Frame: Earth Frame (E-N-Vertical)

☐ Enable Data Monitor
  ☐ Enable Verbose Display
☑ Enable Logging to Flash Card
  ☑ TTag
  ☑ FSec
  ☑ Axes
☐ Enable Append Mode
☐ Enable Query Mode

4.000 Hz Measurement Frequency
1 M/S Measurements per Sample
0.250 sec Sample Period
8192 S/B Samples per Burst
0 DDD 1 HH 0 MM 0 SS Burst Interval
100 B/F BurstsPerFile

7/ 4/200 12:00:00 AM Start
10/12/200 12:00:00 AM Stop
100 DDD 0 HH 0 MM 0 SS Duration

This is a much more aggressive sampling scheme, with a higher measurement frequency (4 Hz), many more measurements per burst (8192), and more frequent bursts of longer duration (a 34 minute burst every hour). Among other advantages, this will allow the operator to narrow the spectral confidence limits without sacrificing spectral resolution compared to Example 1.[1]

---

[1] Recall that the spectral bandwidth of a given time-series is half of the measurement frequency (Nyquist) and the number of frequency bins into which this bandwidth is divided is half of the length of the FFT. MWAVES allows the operator to set the FFT length during processing, which allows adjustment of spectral resolution (frequency bin width) within the limit imposed by the finite length of the time series.

When the FFT length is less than the number of measurements in the time-series, the time-series is processed in sequential FFT-length pieces (with zero padding as necessary and no overlapping). The actual spectrum is a bin-wise average of these multiple realizations. Increasing the number of realizations narrows the confidence limits (error bars) of the spectrum. An important limit here is keeping the pieces of the time-series long enough to remain statistically significant representations of the stochastic wave process.

The important consequence of these relationships is the need (opportunity!) for the operator to strike a balance between spectral resolution and spectral confidence limits when setting the length

The cost, of course, is more rapid exhaustion of power and memory resources. A MAVS-3 programmed with this schedule and equipped with a 19.2 Ahr lithium battery will have a maximum deployment duration of 15 days. A 128 Mbyte compact flash card will be required to record the measurements made in that period.

Additional References

Two published references with additional discussions of wave sampling and directional wave spectra using MAVS instruments are available.

- Williams, A. J., 3rd, Terray, E. A., "Measurement of Directional Wave Spectrum with a Modular Acoustic Velocity Sensor", *Proceedings of OCEANS 2000*, MTS/IEEE/OES, September 11-14, 2000, Vol. 2, pp. 1175-1180.

- Morrison, A. T., III, "MWAVES – Software for Calculating the Directional Spectra and Statistical Properties of the Wave Field From MAVS-3 Triplet Measurements", *Proceedings of the IEEE Seventh Working Conference on Current Measurement*, IEEE/OES, March 2003, pp. 128-134.

Both papers are available for download from the Nobska website. Browse to www.nobska.net and select "Papers" from the navigation bar on the left of the Nobska home page. From the index of papers select "Directional Wave Spectrum with MAVS.pdf" to download Williams and Terray and "mwaves.doc" to download Morrison. Note that Morrison is also the author of this manual and of MWAVES, the latter in collaboration with Williams and Terray. We think the papers will be helpful to you. Morrison in particular discusses the underlying operations that take place in the MWAVES kernel and also some of the theoretical background of the calculations. But don't expect an entirely different viewpoint.

Deployment Planning Assistance

If you are having difficulty planning a deployment, need some assistance or advice, or just want to double check and discuss your depths and schedules with someone, we would be delighted to work with you.

Dan Schaaf	941-766-0706	nobska@compuserve.com
Todd Morrison	508-360-2393	atmorrison@nobska.net
Sandy Williams	508-289-2725	awilliams@nobska.net
Fax	941-766-0707	
Web		www.nobska.net

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of the FFT. You should anticipate this tradeoff when programming a deployment and plan accordingly. One real advantage of the sampling schedule in Example 2 is that it gives you more room to adjust the balance, but you'll pay a price when the battery and memory bills come due.

For more complete discussions we suggest Oppenheim and Schafer, Discrete-Time Signal Processing, Prentice-Hall, 1989 and Press, Flannery, Teukolsky, and Vetterling, Numerical Recipes in C, Cambridge University Press, 1988.

Operating MWAVES

Data Files

Before running MWAVES the target data set needs to be unpacked with MAVSPack. See the MAVS-3 Operations Manual for full instructions on off-loading and unpacking MAVS-3 data.[2] When running MAVSPack you should select the "Use format specified when data was collected" option for the Path Units. MWAVES expects this.

MWAVES assumes the data set will be in the default MAVS-3 data folder, C:\MAVS3, when it first starts. However, you can easily browse to an alternate folder, which can be associated with a particular project. For convenience we will assume here that the target data folder, with all of the necessary files from the data set, is C:\MAVS3\MWAVES-2004.

The files that must be present in the MWAVES data folder are:

- CONFIG.BIN – This is the binary form of the system configuration file. It is also used by MAVSPack, so it should already be in the MAVSPack source folder.
- DEPLOY.BIN – This is the binary form of the deployment definition file. It is also used by MAVSPack, so it should already be in the MAVSPack source folder.
- DATA0001.DAT, DATA0002.DAT, …, DATANNNN.DAT – These are the unpacked data files in MAVS-3 ASCII text format.

It makes no difference to MWAVES if the other binary and ASCII files are present in the data folder. The easiest procedure may simply be to copy the entire contents of the compact flash card to the data folder and then run MAVSPack using the data folder as both source and destination. Then just browse to the data folder after starting MWAVES.

Starting MWAVES

There are two ways to start MWAVES:

- Double click the Desktop icon, MWAVES 2.6, if you created one.
- Navigate to C:\Program Files\Nobska\MWAVES\MWAVES_Version_2_6 and double click on mwaves.exe.

This will bring up the MWAVES Control Panel and three independent plot windows. The independent plots will be used to display non-directional and directional wave height spectra. The non-directional spectra are plotted as functions of the logarithm of the wave period. The directional spectra are plotted on direction of propagation versus wave frequency grids, in Cartesian and polar formats, with color indicating wave intensity. There will also be an empty DOS command window, which you can ignore or collapse onto the Windows task bar using the minimize button in the upper right corner.

---

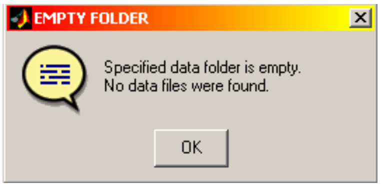
[2] If you use the on-board unpacker to generate the ASCII text data file instead of MAVSPack, be sure to name the file DATA0001.DAT to be compatible with MWAVES.

The first time you run MWAVES the Control Panel and the three independent plot windows will be displayed in their default positions and sizes. However, all four windows can be resized and repositioned on your screen. Each time you exit MWAVES the size and position information is recorded in C:\Program Files\Nobska\MWAVES\MWAVES_Version_2_6\gui_size.txt. The next time you start MWAVES the Control Panel and plot windows will be where you left them.

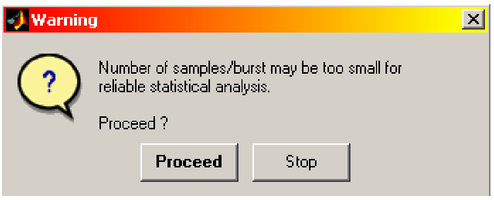
Possible Warnings

When started, MWAVES automatically tries to load the default data folder, C:\MAVS3. The load process checks for the presence of data files and checks the deployment schedule to verify that the waves were sampled in a statistically meaningful way. As a result, you may receive one or more warnings when starting MWAVES.

For example, if there are no data files in C:\MAVS3, a pop-up with the warning "Specified data folder is empty. No data files were found." will appear. If data and configuration files are present you will receive warnings if the sampling schedule used to collect the data was in some way inappropriate for waves. Some examples are shown below. Just click OK or Proceed to dismiss each warning.

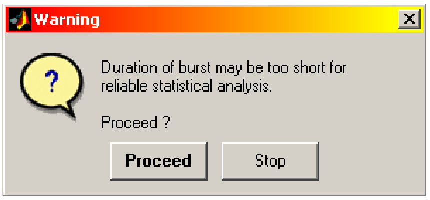


Specified data folder is empty.
No data files were found.



Number of samples/burst may be too small for
reliable statistical analysis.

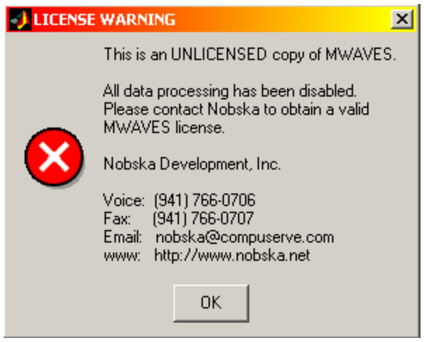
Proceed ?



Duration of burst may be too short for
reliable statistical analysis.

Proceed ?

You may also receive a warning indicating that you are operating an "UNLICENSED copy of MWAVES". Refer to Installing the MWAVES License File. The license file must be copied to C:\Program Files\Nobska\ mwaves_license.dat and must match the target data set. Contact Nobska if you require assistance. Click OK to dismiss the warning. You will need to resolve the license warning before MWAVES can be used to process data.



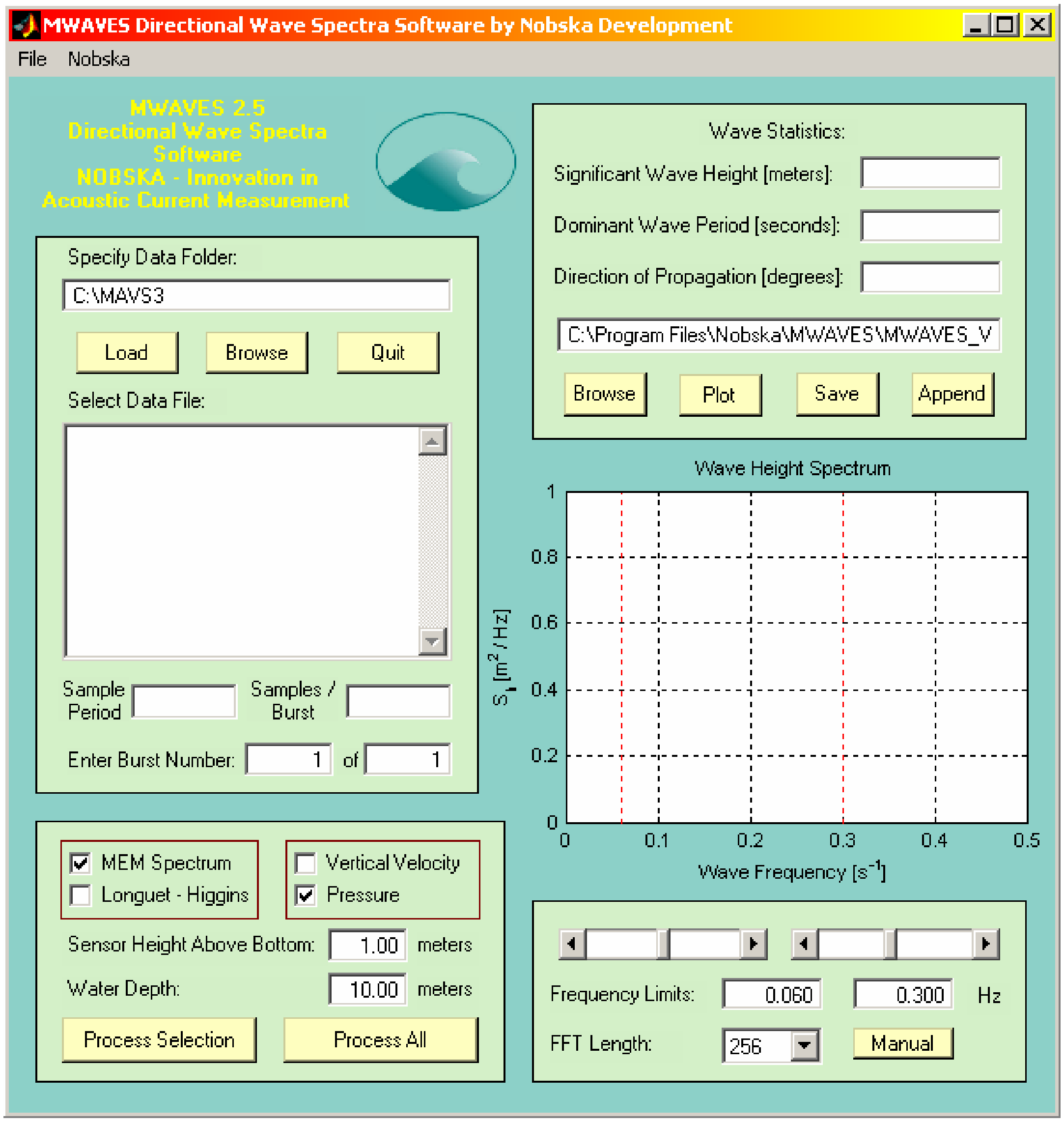
This is an UNLICENSED copy of MWAVES.

All data processing has been disabled.
Please contact Nobska to obtain a valid
MWAVES license.

Nobska Development, Inc.

Voice: (941) 766-0706
Fax: (941) 766-0707
Email: nobska@compuserve.com
www: http://www.nobska.net

The MWAVES Control Panel



Specify Data Folder: C:\MAVS3

Enter Burst Number: 1 of 1

☑ MEM Spectrum
☐ Longuet - Higgins
☐ Vertical Velocity
☑ Pressure

Sensor Height Above Bottom: 1.00 meters

Water Depth: 10.00 meters

C:\Program Files\Nobska\MWAVES\MWAVES_V

Frequency Limits: 0.060 0.300 Hz

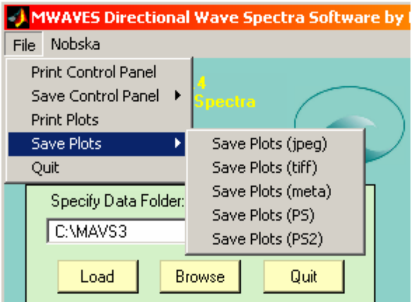
FFT Length: 256

The MWAVES Control Panel is a full-featured, graphical interface, through which the operator guides and controls the calculation of directional wave spectra and wave statistics. The Control Panel includes two utility menus, four frames that group related controls, and an Interactive Plot of the non-directional wave height spectrum as a function of wave frequency.

The sections that follow explain the use of the menus and controls. The MAVS-3 data used in the examples were acquired by graduate students at the Woods Hole Oceanographic Institution enrolled in Oceanographic Instrument Systems, a course taught by Sandy Williams and Jim Irish. The instrument was deployed in Vineyard Sound, south of Woods Hole, Massachusetts, in late April of 2004.

The File Menu

Use the File menu to print or save MWAVES graphics. The Control Panel and the three independent plot windows can be sent directly to your printer using the print options. Or the Control Panel and the plots can be saved to disk in jpeg, tiff, Windows metafile, or PostScript formats using the save options. See the example below.

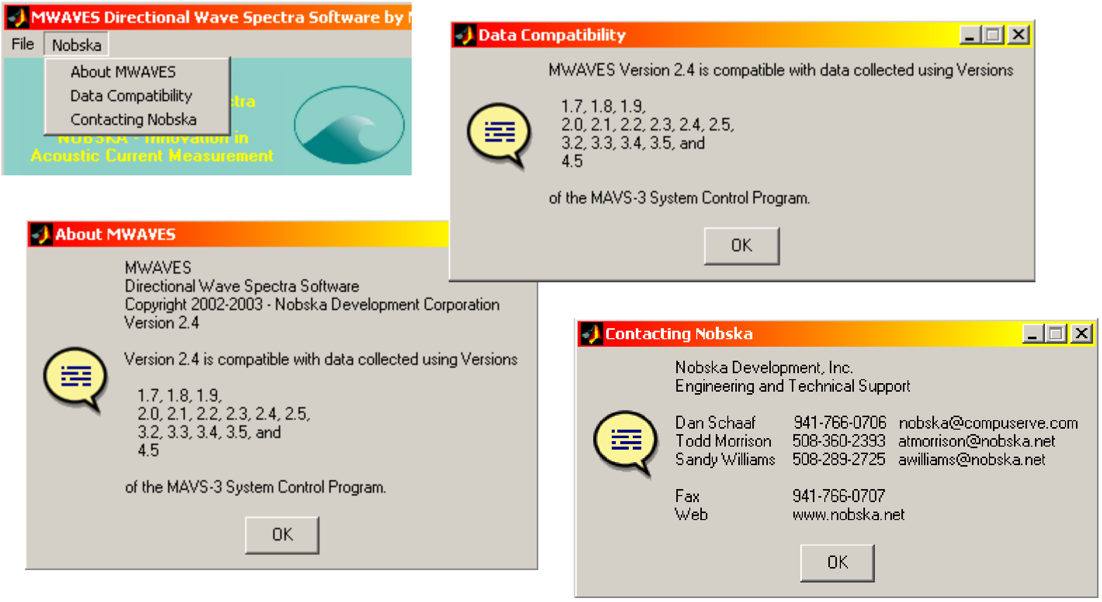


Images are saved to the target data folder, which is specified in the text box at the top of the Data Selection Frame. In the example above the images would be saved to C:\MAVS3.

The Quit option exits from MWAVES. You can also exit using the Windows close buttons in the upper right corners of the Control Panel and plot windows.

The Nobska Menu

Use the Nobska menu to view the MWAVES version number, to verify MWAVES compatibility with a particular version of the MAVS-3 System Control Program, or to view contact information for Nobska Engineering and Technical Support. Examples are shown below.



MWAVES Version 2.4 is compatible with data collected using Versions

1.7, 1.8, 1.9,
2.0, 2.1, 2.2, 2.3, 2.4, 2.5,
3.2, 3.3, 3.4, 3.5, and
4.5

of the MAVS-3 System Control Program.

MWAVES
Directional Wave Spectra Software
Copyright 2002-2003 - Nobska Development Corporation
Version 2.4

Version 2.4 is compatible with data collected using Versions

1.7, 1.8, 1.9,
2.0, 2.1, 2.2, 2.3, 2.4, 2.5,
3.2, 3.3, 3.4, 3.5, and
4.5

of the MAVS-3 System Control Program.

Nobska Development, Inc.
Engineering and Technical Support

Dan Schaaf	941-766-0706	nobska@compuserve.com
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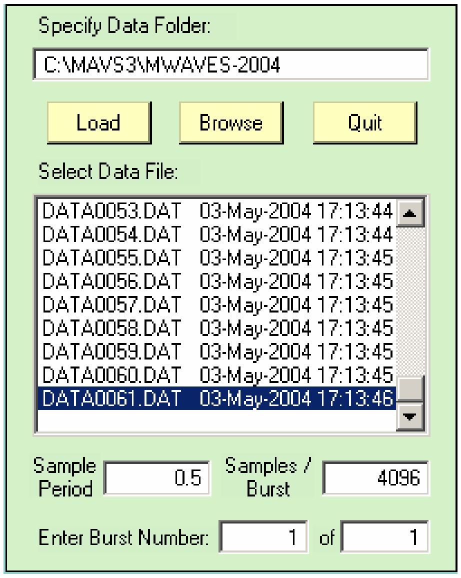
Fax	941-766-0707	
Web	www.nobska.net	

The Data Selection Frame

The Control Panel Data Selection Frame is shown below. This is where most processing will begin.



Specify Data Folder: C:\MAVS3\MWAVES-2004

Select Data File:

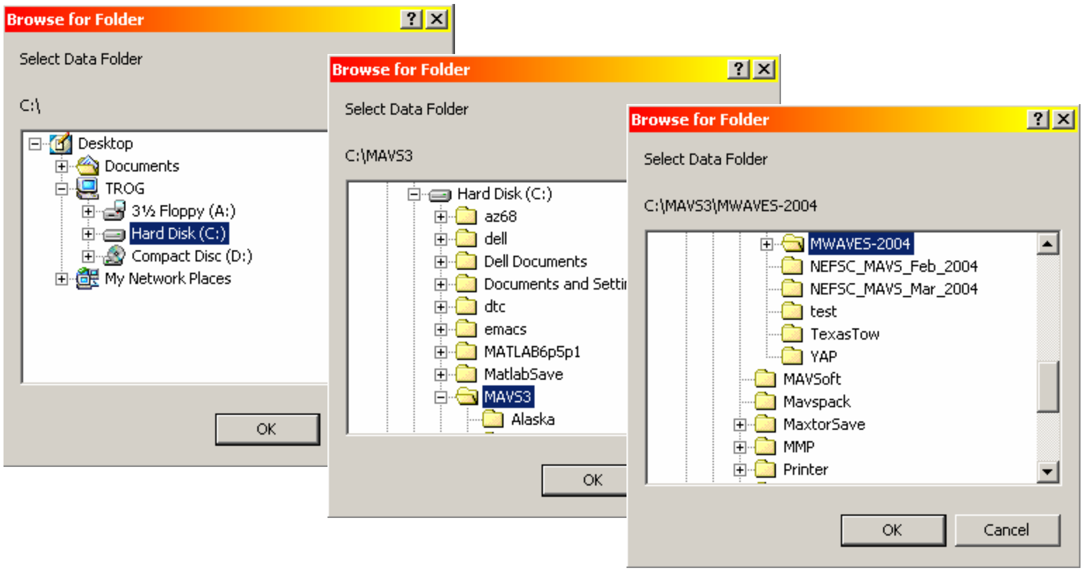
```
DATA0053.DAT  03-May-2004 17:13:44
DATA0054.DAT  03-May-2004 17:13:44
DATA0055.DAT  03-May-2004 17:13:45
DATA0056.DAT  03-May-2004 17:13:45
DATA0057.DAT  03-May-2004 17:13:45
DATA0058.DAT  03-May-2004 17:13:45
DATA0059.DAT  03-May-2004 17:13:45
DATA0060.DAT  03-May-2004 17:13:45
DATA0061.DAT  03-May-2004 17:13:46
```

Sample Period: 0.5

Samples / Burst: 4096

Enter Burst Number: 1 of 1

Enter the target data folder, C:\MAVS3\MWAVES-2004 in this example, in the text box at the top of the frame. You can type the name manually or use the Browse button to open a navigation window as shown below.



Select Data Folder: C:\

Select Data Folder: C:\MAVS3

Select Data Folder: C:\MAVS3\MWAVES-2004

If you browse to the target data folder using the navigation window, MWAVES will load it automatically. If you enter the path to the data folder manually you will need to click on the Load button to trigger the load process.

Loading the Data Folder

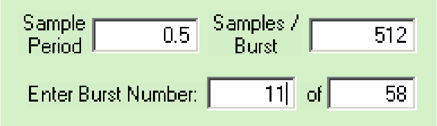
Whether triggered automatically or manually, the load process performs the following functions:

- Checks the specified data folder for unpacked ASCII text data files (files named DATA0001.DAT, DATA0002.DAT, etc.) and lists them in the Select Data File box in the center of the Data Selection Frame.
- Loads the system configuration and deployment definition information from CONFIG.BIN and DEPLOY.BIN.
- Checks the validity of the license file, displaying a warning and disabling the data processing functions if necessary.
- Checks the statistical validity of the sampling schedule, displaying warnings as necessary.
- Enters the Sample Period and the number of Samples per Burst in the text boxes near the bottom of the Data Selection Frame.

The second step, loading CONFIG.BIN and DEPLOY.BIN, has a number of important consequences for operator convenience. You will not need to manually identify the contents of each column in the data files. MWAVES identifies the columns based on the system configuration information. MWAVES also ascertains the availability of pressure measurements for use in calculating directional spectra. See The Process Control Frame for more information.

Loading the deployment definition information eliminates the need to manually input the sampling schedule, measurement frequency, samples/burst, burst interval, etc., all essential information for the calculation of wave spectra.

The remaining controls in the Data Selection Frame are the Quit button, which exits the program, and the burst number boxes. The later are automatically filled when you begin processing a file. The total number of bursts in the file is displayed in the box on the right. The operator can enter the burst number of interest in the left hand box. For example, burst 11 of 58 bursts in the selected file has been entered in the example below.



Sample Period 0.5
Samples / Burst 512
Enter Burst Number: 11 of 58

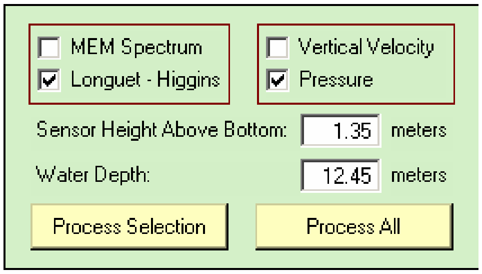
To begin processing, use your mouse to select one of the data files from the list in the Select Data File box of the Data Selection Frame. In the example Data Selection Frame shown at the beginning of this section data file DATA0061.DAT has been selected.

Double click on any of the data files in the list to open a copy of the file in Notepad. This allows you to quickly and easily examine the data and check for problems or features of interest. For example, the first or last file may have been acquired while the instrument was not in the water. MWAVES would have detected and rejected the file. The Notepad feature allows you to quickly verify the cause.

Now you can proceed to the controls in the Process Control Frame.

The Process Control Frame

The Control Panel Process Control Frame is shown below.



☐ MEM Spectrum
☑ Longuet - Higgins
☐ Vertical Velocity
☑ Pressure
Sensor Height Above Bottom: 1.35 meters
Water Depth: 12.45 meters

Controls in this frame allow the operator to:

- Select an algorithm for calculating the directional wave spectrum
- Choose to correlate either pressure or vertical velocity with the horizontal velocity in the calculation
- Enter the sensor height above bottom and depth information recorded when deploying the sensor
- Initiate processing

Selecting a Processing Algorithm

MWAVES can calculate directional wave spectra using either the maximum entropy method (MEM) of Lygre and Krogstad[3] or the approach of Longuet-Higgins.[4] The short discussion quoted below is from Morrison.[5]

> The Longuet-Higgins directional spectrum is generated by calculating the first five Fourier coefficients of the angular distribution of energy in each frequency band directly from the measurements. In contrast, MEM estimates the Fourier coefficients by fitting the data to a model of the process that is complex Gaussian and stationary. MEM estimates exhibit greater angular and frequency resolution than either Longuet-Higgins or the maximum likelihood method (MLM). Arguably, Longuet-Higgins estimates retain more of the raw information contained in the measurements. Both approaches use autocorrelation sequences computed from the measurements at lags greater than or equal to one, so the resulting directional spectra are normalized; the integral over the angular range of each frequency bin is one. MWAVES subsequently weights the result with the [non-directional] wave height spectrum to produce directional wave spectra with units of m^2/Hz.

---

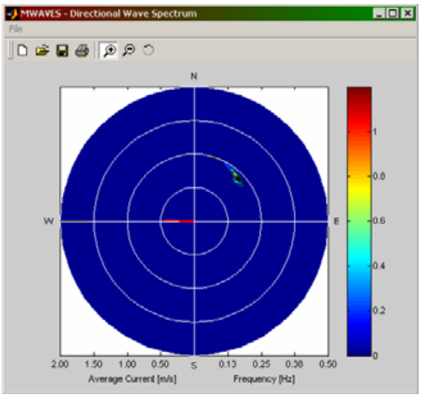
[3] Lygre, A., Krogstad, H. E., "Maximum Entropy Estimation of the Directional Distribution in Ocean Wave Spectra", *Journal of Physical Oceanography*, 1986, Vol. 16, No. 12, pp. 2052-2060.

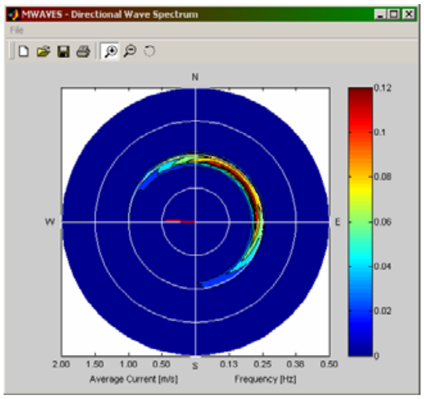
[4] Longuet-Higgins, M. S., Cartwright, D. E., Smith, N. D., Observations of the Directional Spectrum of Sea Waves Using the Motions of a Floating Buoy, Ocean Wave Spectra, Prentice-Hall, 1963, pp. 111-136.

[5] Morrison, A. T., III, "MWAVES – Software for Calculating the Directional Spectra and Statistical Properties of the Wave Field From MAVS-3 Triplet Measurements", *Proceedings of the IEEE Seventh Working Conference on Current Measurement*, IEEE/OES, March 2003, pp. 128-134. This paper can be downloaded from the Nobska web site, www.nobska.net.

> The most obvious characteristic of an MEM estimate of the directional wave spectrum is the extent to which wave energy is localized in both frequency and direction. In comparison, a Longuet-Higgins spectrum is “smeared” over a much broader range of frequency and direction.

The operator may choose either approach by clicking on MEM or Longuet-Higgins. Both methods can be applied to any burst of interest and the results can be compared as in the example polar directional spectra shown below. The MEM spectrum is on the left and the Longuet-Higgins spectrum is on the right. The spectra were calculated from the same data. Note the characteristic “localization” and “smearing” referred to above.





In the polar representation of directional wave spectra, wave frequency increases radially from the center. The angle indicates the direction of wave propagation (north, south, east and west are marked in the margins).

Vertical Velocity or Pressure

MWAVES can calculate the spectra based on the correlation of the horizontal velocity with either the vertical velocity or the pressure. Horizontal velocity and pressure attenuate with depth and wave number as $\cosh(k(z+H))$, where k is the wave number, H is the water depth ($H > 0$), and z is the sensor depth ($z \leq 0$, $z = 0$ at the surface, $z = -H$ at the bottom). Both quantities remain non-zero near the bottom. However, the vertical velocity attenuates as $\sinh(k(z+H))$ and becomes vanishingly small close to the bottom. These characteristics of surface gravity waves are the reasons behind our deployment guidelines for sensor depth and height above bottom.[6]

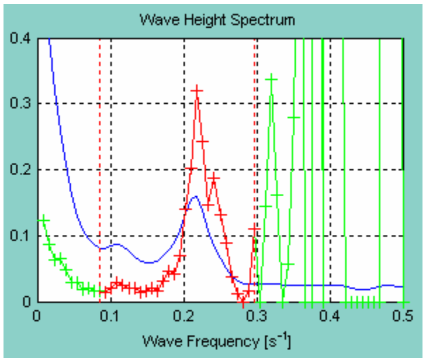
Because of these physical characteristics, MWAVES’ default choice is pressure, if it is available in the data set. The operator has the option of selecting vertical velocity. As with the processing algorithm, you may wish to choose both and compare the results. If vertical velocity is chosen, MWAVES will automatically choose to work with the horizontal velocity if the relative signal strength of the vertical velocity is too low.

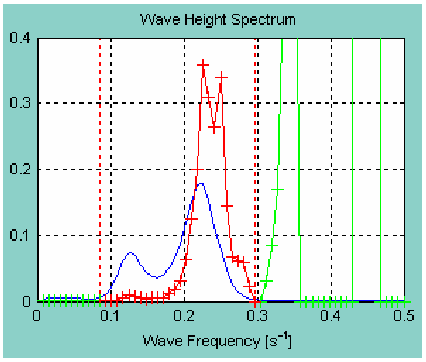
---

[6] See Morrison or Williams and Terray for further discussion.

It is important to recognize that velocity and pressure sensors respond in different ways to the flow and in some sense “see” different things. For example, the velocity sensor can easily measure low frequency geostrophic flows that have no associated pressure signal; they are invisible to the pressure sensor. Comparing the two types of spectra can often lead to a better understanding of the characteristics of a particular site.

Consider, for example, the two non-directional spectra below. Velocity is on the left and pressure is on the right. The spectra were calculated from the same data used in the Longuet-Higgins/MEM example. The burst duration was approximately 34 minutes (4096 samples at 2 Hz). For now, focus only on the solid blue line, the measured and smoothed spectrum at the depth of the sensors. Both spectra have clear double peaks in the wave band at 0.125 Hz (8 s) and 0.225 Hz (4.5 s). A very strong, low frequency or steady signal is painfully apparent in the velocity spectrum, but entirely absent from the pressure spectrum. This is evidence for a geostrophic or tidal flow on which the waves are superposed.





Sensor Height and Water Depth

We quote here from an earlier section of this manual, A Critical Measurement for MWAVES Deployments:

> It is critically important for post-processing that you measure and record the height above bottom of the center of the velocity sensor. If you are using a pressure sensor (recommended), you should also measure the height above bottom of the pressure port. As noted above, the attenuation of wave motions with depth depends on bottom depth. MWAVES cannot accurately map sub-surface measurements to the surface unless the water depth and sensor height above bottom are known.
>
> When equipped with a pressure sensor, MWAVES will automatically and dynamically calculate bottom depth from the pressure measurement and the sensor height above bottom provided by the operator. When calculating directional wave spectra from velocity measurements alone, both the sensor height and the bottom depth must be provided by the operator.

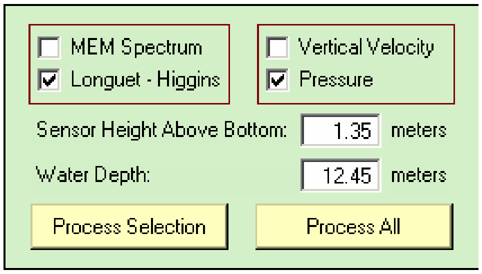
MAVS-3 makes velocity and pressure measurements at some depth below the surface. To mathematically map those measurements to the surface, one of the functions of the MWAVES kernel, the depth of the water column and the height of the sensor above the bottom (or, equivalently, the sensor depth) must be known.[7]

If you select vertical velocity, you must enter both the sensor height above bottom and the water depth manually. If the values are not accurate the directional and non-directions spectra of the waves at the surface will not be accurate.

If you select pressure, you only need to enter the sensor height above bottom. MWAVES will calculate the water depth automatically as the sum of the average pressure during the burst[8] and the sensor height provided by the operator. Again, if the value is not accurate the directional and non-directions spectra of the waves at the surface will not be accurate.

THE ENTERED SENSOR HEIGHT MUST BE THE HEIGHT OF THE SENSOR BEING USED IN THE CALCULATION. If pressure, enter the height of the pressure port on the conical end cap of the instrument. If vertical velocity, enter the height of the center of the velocity sensor, the point halfway between the two rings.

In the example below, the calculation will be based on the pressure measurements. The pressure port was measured to be 1.35 meters above the bottom and the water depth was automatically calculated. The instrument was oriented Vertical/Down in this case, placing the velocity sensor 1 meter above the bottom.



☐ MEM Spectrum
☑ Longuet - Higgins
☐ Vertical Velocity
☑ Pressure
Sensor Height Above Bottom: 1.35 meters
Water Depth: 12.45 meters

Process Selection and Process All

Click on the Process Selection button to process the selected burst. MWAVES will load the selected data file, extract the selected burst, calculate the directional and non-directional spectra, calculate summary statistics for the burst, and display the results. The operator can choose to save the plots and statistical information.

The Process All button processes every burst in the data set, in sequence, automatically saving a time series of the wave statistics in a text file. The calculated statistical quantities are the significant wave height ($H_{1/3}$), the period of the dominant wave (T_P), and the direction of propagation of the dominant wave (θ_P). The "dominant wave" is the highest peak in the directional wave spectrum.

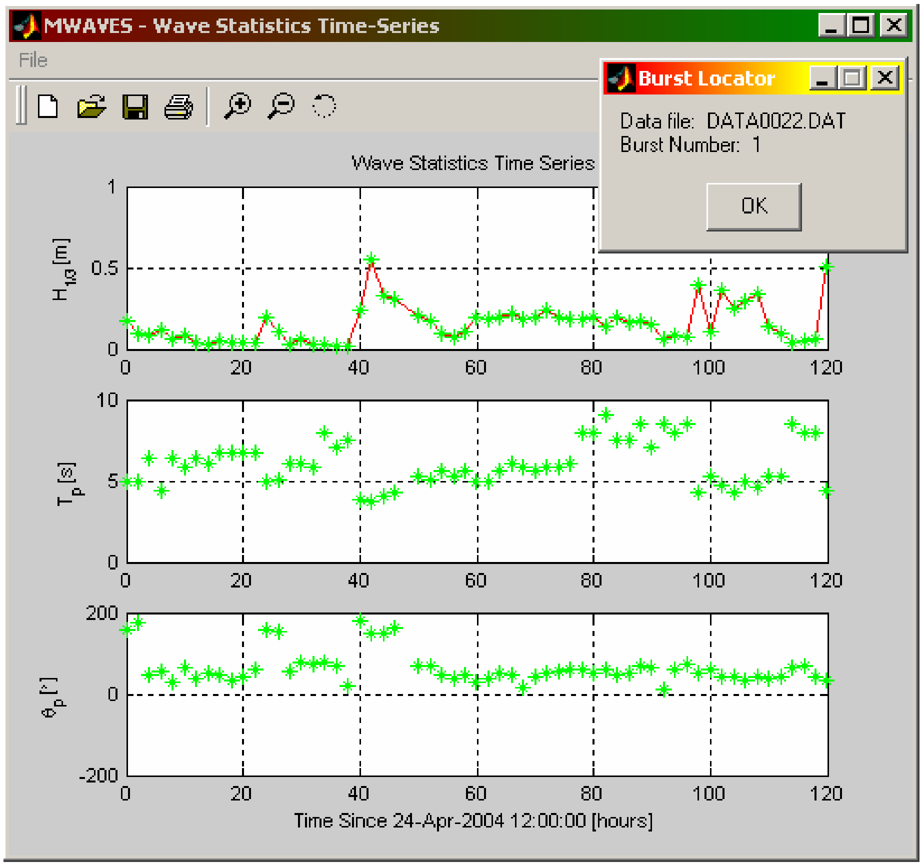
---

[7] See Morrison or Williams and Terray or any text on waves for further discussion.

[8] The pressure measurement is converted to depth assuming a seawater density of 1025 kg/m^3 and a gravitational acceleration of 9.81 m/s^2.

The Triple Plot

When all of the bursts have been processed by Process All, a time-series triple plot showing the time evolution of the wave statistics over the course of the deployment is displayed. Clicking on the triple plot, on a maximum in the history of significant wave height, for example, will pop-up a "burst locator" identifying the data file and burst of interest so that it can be examined individually. An example is shown below.



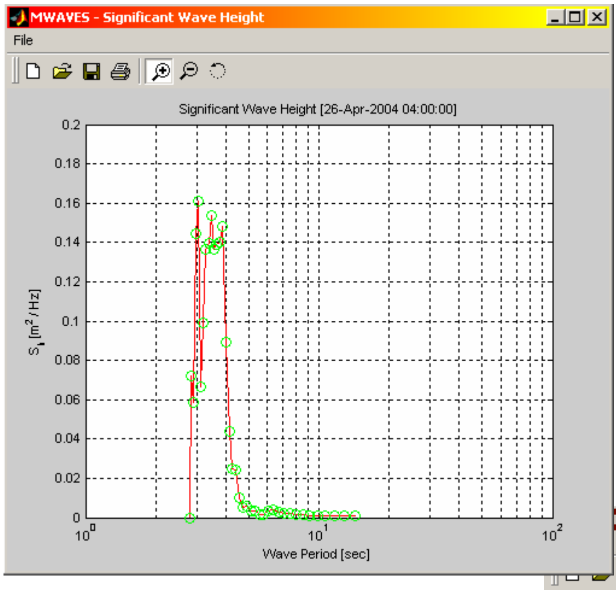
Data file: DATA0022.DAT
Burst Number: 1

DATA0022.DAT, Burst 1 of 1, is the local maxima in significant wave height at just over 40 hours elapsed time. The time-series were calculated based on pressure using the data from the spring 2004 deployment in Vineyard Sound.

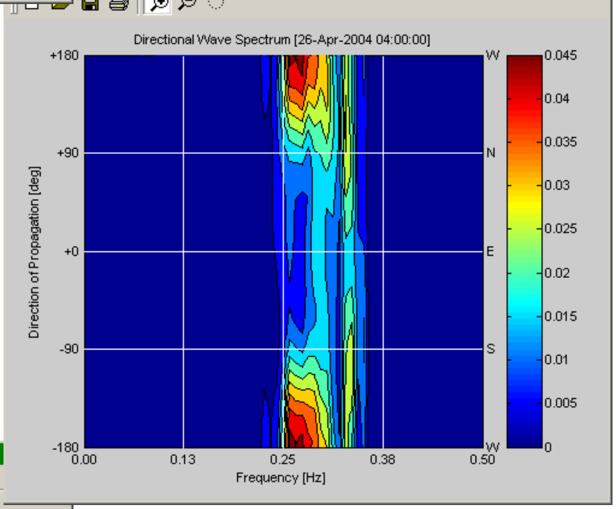
The directional and non-directional spectra for this burst are shown on the next page. The Longuet-Higgins algorithm and the vertical velocity time-series were used in the calculation. Just to provide some mysterious foreshadowing of things to come, we note that the bandwidth was manually set to run from 0.063 Hz to 0.365 Hz.

The calculated significant wave height was 0.48 meters and the dominant period was about 3.5 seconds. This is probably locally generated chop associated with a mid-deployment storm, which lasted most of one day. The waves were propagating to the west at approximately 175° in the "mathematical compass coordinates" used by MWAVES. In this system East is 0°, North is +90° ($+\pi/2$), South is -90° ($-\pi/2$), and West is ±180° ($\pm\pi$).

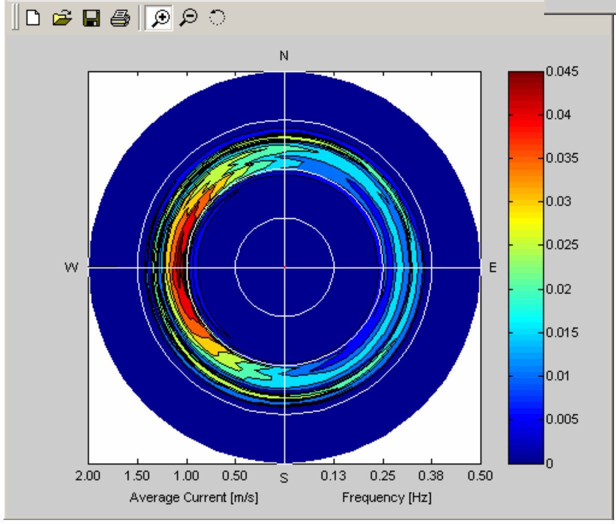
The independent plot windows for “Burst 22” are shown below.



Non-directional wave height spectrum showing 3 to 4 second chop. Each frequency bin is the wave energy in that frequency range summed over all directions of propagation.



Cartesian directional wave height spectra – direction of propagation versus wave frequency. North, South, East, and West are indicated in the margin. These waves are propagating to the West. The color indicates wave intensity.



Polar directional wave height spectra – the wave frequency increases radially and the angle indicates the direction of propagation. North, South, East, and West are indicated in the margins. These waves are propagating to the West. The color indicates wave intensity.

Burst Rejection During Process All

In addition to the triple plot, Process All will create a record of any bursts it rejected and did not process so that the operator can examine these burst manually. MWAVES will generate a pop-up warning during manual processing with the Process Selection button, but the operator is generally free to bypass the warnings. During Process All MWAVES will choose to reject these bursts because they are of questionable quality statistically or pose some risk of a crash that would interrupt the process.

In addition to those bursts that are of questionable significance statistically, potentially rejected bursts include those collected before or after a deployment with the instrument in air and all or most of the velocity measurements flagged full-scale negative. Another example is a short burst at the end of a file, the measurements having been interrupted during recovery by the operator.

The log of rejected bursts is stored in a text file, bad_brst.txt, in the MWAVES folder, C:\Program Files\Nobska\MWAVES\MWAVES_Version_2_6. An example is shown below.

```
Data file:                Burst:    Burst not processed because . . .
_____________________     _______   __________________________________

C:\MAVS3\DATA0007.DAT          56   Burst contains fewer than 256 samples.
```

MWAVES will give you a chance to view the file in Notepad, if there are any entries, when the Process All process is complete. Or you can view it later with a text editor of your choice. Note that the file may be overwritten the next time you run Process All. It can be preserved by renaming it.

The Burst Processing Pipeline and the MWAVES Kernel

One final note, the burst processing pipeline and kernel routines that are called by the Process buttons are not discussed in this manual. See the previously cited paper by Morrison for a description.

First Encounter with a Data Set

We recommend the procedure outlined above as a convenient initial approach to any data set. Run Process All and use the triple plot to identify periods of the deployment that look interesting. These may be significant wave height maxima, sudden changes in the dominant period or direction of propagation, or some other feature. You may also have logged periods of interest based on other observations of the site. Then use the burst locator feature and the other MWAVES tools to make a detailed examination of the bursts of interest.

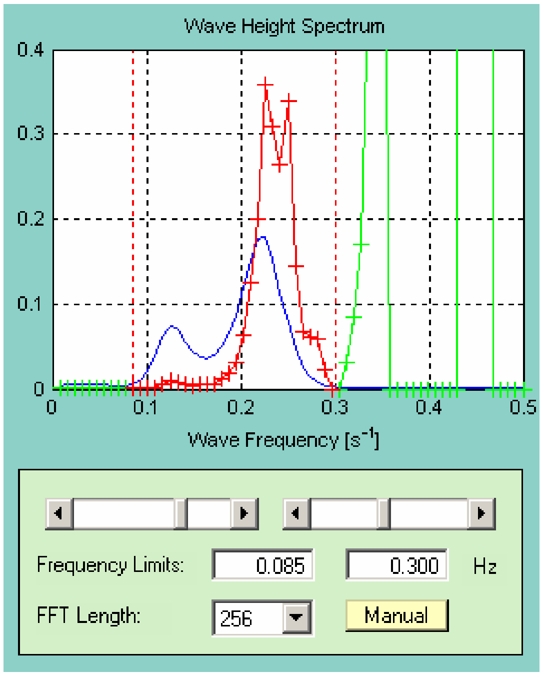
We will return to data processing and issues associated with interpreting the results in a later section. But first we need to discuss bandwidth, FFT length, and the calculation of wave statistics.

The Bandwidth Control Frame and the Interactive Plot

The controls in the Bandwidth Control Frame and the Interactive Plot are used to set lower and upper frequency limits that will isolate the band of frequencies that will be used in the calculation of wave spectra and statistics. The object (usually) is to exclude signals that are not associated with surface gravity waves. At the low end of the spectrum are steady and quasi-steady motions such as infra-gravity waves, tidal currents, and geostrophic flows. At the high end are turbulence and noise. Both regions can overlap the wave band, which is itself variable.

The controls make it easy to place the frequency limits where you want them. The hard part can be deciding where you want them. Often the answer is obvious, but there will be times when you will simply have to make a judgment call based on your own experience. The "right" answer can be elusive. There is an automatic placement algorithm and it does OK most of the time. We are working to improve it. Don't be shy about second guessing the algorithm. The controls make it easy to adjust the limits and view the result.

The Control Panel Bandwidth Control Frame and Interactive Plot are shown below.



Frequency Limits: 0.085 0.300 Hz

FFT Length: 256

Setting the Bandwidth

The bandwidth can be set automatically (by an MWAVES algorithm) or manually (by the operator). The operator can toggle between these modes by clicking on the Manual/Automatic button. The text on the button will change to show the current state, which is Manual in the example above. The limits are shown graphically on the plot by two dashed vertical lines. The lines are red in Manual mode and green in Automatic mode. The mode will automatically switch to Manual whenever the operator uses any of the controls to adjust the limits.

The lower frequency limit can be adjusted between 0.0 Hz and 0.12 Hz (8.3 seconds). The upper frequency limit can be adjusted between 0.13 Hz (7.7 seconds) and 0.50 Hz (2.0 seconds). The non-directional and directional wave height spectra are only calculated and displayed for the frequency band between the limits. Your goal is to isolate the surface gravity waves (or other band of interest) and exclude other signals.

There are three ways to move the lower and upper frequency limits. First, the sliders at the top of the Bandwidth Control Frame can be manipulated with your mouse – click the arrows, click on either side of the slider, or drag the slider. The indicators on the plot and the frequency values in the text boxes below the sliders will change automatically. Second, the limits can be entered in the text boxes below the sliders. The indicators on the plot and the sliders will change automatically. Finally, you can click on the plot to move the limits. If you click between 0 Hz and 0.12 Hz the lower limit will move to the mouse position. If you click between 0.13 Hz and 0.50 Hz the upper limit will move to the mouse position. The sliders and text boxes will change automatically.

Setting the FFT length

The FFT length can be set from 32 points to 4096 points in powers of 2. You can change the value using the FFT Length pull-down menu at the bottom of the Bandwidth Control Frame. The default value is 256 points.

How many points (frequency bins) are used in an MWAVES spectrum? An N point FFT evenly distributes N/2 frequency bins from 0 Hz up to the Nyquist frequency, which is half the measurement frequency.[9] A 256 point transform is used to produce a spectrum with 128 frequency bins. Then MWAVES discards frequency bins centered above 0.5 Hz. So, for example, a 256 point transform applied to 4 Hz measurements produces 32 point non-directional and directional spectra in MWAVES.

The number of frequency bins thus depends on the original measurement frequency. You will need to adjust the FFT length to account for this if the measurement frequency changes from deployment to deployment.

Most obviously, changing the FFT length changes the spectral resolution. An "insufficient" number of frequency bins will merge separate spectral peaks into a single broad signal. The FFT length should be long enough to distinguish real peaks. If your spectra have a single smooth wide peak, try increasing the length of the FFT.

Less obviously, the FFT can also be too long. Most texts on numerical analysis and modeling will warn against increasing the number of coefficients in a model to get a "better" match to the data. The problem, of course, is that the model gets closer and closer to the measurements and swings more and more wildly in between and beyond the measurements. If your spectra have many peaks and swing wildly in value from bin to bin, try reducing the length of the FFT.

---

[9] The other N/2 bins cover the range from Nyquist up to the measurement frequency, but the values simply repeat the first N/2 values in reverse order. The information is in the first N/2 points.

Changing the FFT length also changes the spectral confidence intervals (the error bars) and the number of spectral degrees of freedom. If the FFT length is greater than the number of measurements in the burst (unlikely in MWAVES if you have followed the sampling guidelines), the time-series is zero padded to match the length of the FFT. This produces only one realization of the spectrum. If the lengths initially match there will again be only one realization of the spectrum.

Normally, however, the FFT length will be less than the number of measurements in the burst. In this case the burst is divided into non-overlapping time-series segments that match the length of the FFT. The final segment is zero padded if necessary. Each segment is then transformed and these multiple, independent spectral realizations are bin-wise averaged to produce the spectrum. Applying a 256 point FFT to a 4096 measurement burst will produce 16 realizations to be averaged. That averaging narrows the spectral confidence intervals, increasing the reliability of the result.

Note the balance here: the confidence intervals can be narrowed by reducing the spectral resolution OR by increasing the number of measurements in a burst. The latter might be accomplished by increasing the measurement frequency while keeping the burst duration unchanged. Keeping the burst duration unchanged increases the likelihood that the stochastic process, waves, being sampled with remain statistically stationary. Of course, this is going to use up available power and memory more quickly.

The number of spectral degrees of freedom is twice the number of time-series segments transformed and averaged to produce the spectrum. A 256 point transform applied to a 4096 measurement time-series will produce a spectrum from 16 realizations that has 32 degrees of freedom. Increasing the number of degrees of freedom is equivalent to narrowing the confidence intervals and is accomplished by balancing the same trade-offs and constraints outlined above.

Additional References for Spectral Analysis

For those interested, two good references are:

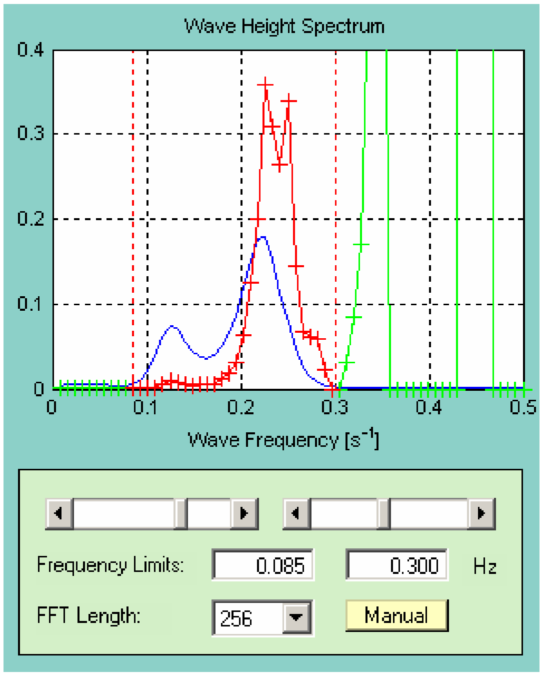
- Spectral Analysis and Its Applications, Gwilym M. Jenkins and Donald G. Watts, Holden-Day, San Francisco, 1968.
- Probability, Random Variables, and Stochastic Processes, 2nd Edition, A. Papoulis, McGraw Hill, New York, 1984.

The Most Important Lesson

The most important lesson here is that deployment planning should anticipate the needs and limits of data analysis. How you collect the data constrains what you can do with them later. Remember, MWAVES post-processing begins the moment you start planning a deployment.

The Interactive Non-Directional Spectra Plot

The Bandwidth Control Frame and Interactive Plot displayed at the beginning of this section are repeated below for easier reference.



Frequency Limits: 0.085 0.300 Hz

FFT Length: 256

Recall that the MAVS-3 sensor makes sub-surface measurements of velocity that must be mapped to the surface using a hyperbolic model that preferentially multiplies higher frequencies. This is done to correct for the frequency dependent attenuation of the original surface signals with depth. The drawback of the mapping is that high frequency turbulence and noise signals, often negligible at depth (and not associated with surface gravity waves!), are exponentially enhanced in the surface spectrum. The upper frequency limit exists to exclude these signals from the surface wave height spectrum. The Interactive Plot displays both the surface and the sub-surface spectra as guides to correct placement of the frequency limits.

The solid blue line is the sub-surface, non-directional spectrum of either horizontal velocity or pressure. It has been smoothed with a digital low-pass filter. It has also been scaled to make it visible on the same plot with the non-directional surface spectrum. The scale factor is calculated to make the sub-surface spectrum half the height of the surface spectrum in the frequency bin containing the maximum of the surface spectrum between the frequency limits. The scale factor is applied equally to all frequency bins.

The sub-surface spectrum is a good indicator of the actual wave band in a given burst. The current version of the automatic bandwidth algorithm bases its initial placement of the limits on the shape and behavior of the sub-surface spectrum.

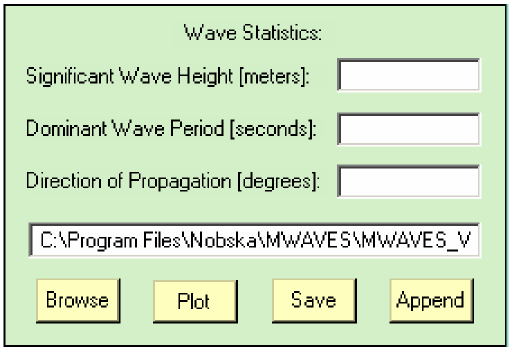
The red '+' symbols mark the value of the surface wave height spectrum in each frequency bin that lies inside the frequency limits. The solid red line is simply drawn to join the '+' symbols. The surface spectrum has not been filtered or otherwise smoothed and has units of m^2/Hz. As previously noted, the dashed vertical lines, which may be either red (as here) or green mark the lower and upper frequency limits.

The green '+' symbols and line mark portions of the surface wave height spectrum that have been excluded by the frequency limits. One might expect the high frequency portion of the surface spectrum to rise exponentially out of the plot. Instead, while many of the values are well off the scale, others are identically zero. This is a result of MWAVES internal correction for sensor and environmental noise.

After it calculates the sub-surface spectrum, MWAVES subtracts the mean value of the high frequency bins from each bin and then resets any resulting negative values to zero. The corrected sub-surface spectrum is then mapped to the surface, with the zero values remaining zero. This is the reason for the up and down behavior of the surface spectrum above the upper frequency limit. Estimating and subtracting the noise floor in this way prevents noise from artificially enhancing the significant wave height.

The Wave Statistics Frame

The Control Panel Wave Statistics Frame is shown below.



C:\Program Files\Nobska\MWAVES\MWAVES_V

Calculating the Wave Statistics

The calculated wave statistics for each burst are displayed in the three text boxes on the right of the frame. These include the significant wave height in meters, the period of the dominant wave in seconds, and the direction of propagation of the dominant wave in mathematical compass coordinate degrees. In this system East is 0°, North is +90° ($+\pi/2$), South is -90° ($-\pi/2$), and West is ±180° ($\pm\pi$).

The tallest peak in the directional wave spectrum is defined to be the “dominant wave”. The dominant period and direction are derived from its frequency and direction coordinates. Note that the highest peak is not necessarily the peak with the most energy under it. A broad peak with more total energy may be upstaged by a narrow, but tall peak with less total energy. Be sure to examine the plots yourself. You may choose to disagree.

The significant wave height is calculated from the non-directional wave spectrum. The non-directional wave spectrum can be thought of as the integral of the directional wave spectrum at each frequency over all directions. To picture this operation, visualize collapsing the Cartesian representation of the directional spectrum onto its frequency axis by adding up the total energy in each frequency bin. The result is the non-directional spectrum.

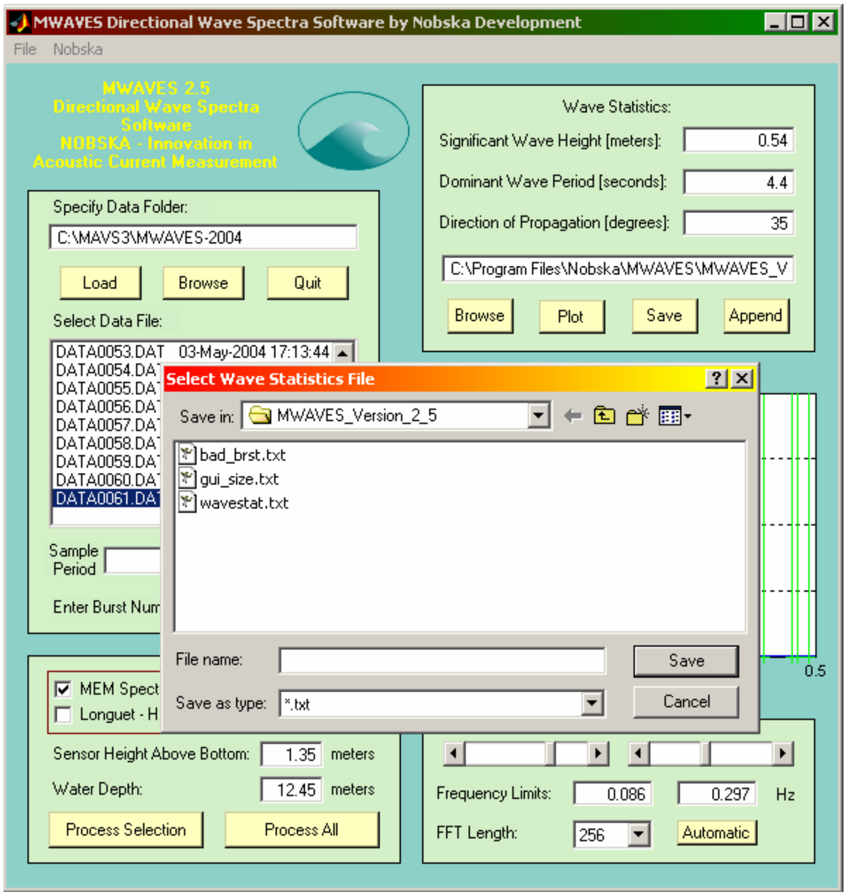
The significant wave height is then derived from the integral of the non-directional wave spectrum between the lower and upper frequency limits. Those limits were set with the tools in the Bandwidth Control Frame and the Interactive Plot. The significant wave height is defined by:

$$H_{1/3} = 4\sqrt{\sum_{f} S_h(f)\delta f}$$

The summation is over the frequency bins between the lower and upper limits, $S_h(f)$ is the non-directional wave height spectrum, and the width of the bins is δf. Significant wave height is thus a measure of the total wave energy within the specified frequency band – the band containing surface gravity waves. It has units of meters and it is scaled such that it is approximately 70% of the height of the tallest waves. This is the value reported historically when sailors have been asked, “How big are the average waves today?” We’re more quantitative today, but we still want a number that makes sense to sailors out on the water.

Saving the Wave Statistics

The calculated wave statistics can be manually saved to a text file. The default file is C:\Program Files\Nobska\MWAVES\MWAVES_Version_2_6\wavestat.txt, listed in the text box near the bottom of the Wave Statistics Frame. You can change the path and file name manually or by clicking the Browse button below the text box. If you enter a file name that does not yet exist, MWAVES will create it. You may, for example, prefer to archive the wave statistics file in the data folder rather than the MWAVES folder.



Wave Statistics:
Significant Wave Height [meters]: 0.54
Dominant Wave Period [seconds]: 4.4
Direction of Propagation [degrees]: 35
C:\Program Files\Nobska\MWAVES\MWAVES_V

Specify Data Folder: C:\MAVS3\MWAVES-2004
Select Data File:
DATA0053.DAT 03-May-2004 17:13:44
DATA0054.DA
DATA0055.DA
DATA0056.DA
DATA0057.DA
DATA0058.DA
DATA0059.DA
DATA0060.DA
DATA0061.DA
Sample Period
Enter Burst Num

Save in: MWAVES_Version_2_5
bad_brst.txt
gui_size.txt
wavestat.txt
File name:
Save as type: *.txt

☑ MEM Spect
☐ Longuet - H
Sensor Height Above Bottom: 1.35 meters
Water Depth: 12.45 meters
Frequency Limits: 0.086 0.297 Hz
FFT Length: 256

The Save button starts a new file. Any statistics previously saved to that file will be lost if you press the Save button.

The Append button will append the current set of wave statistics to the end of the file. It will start a new file if the named file does not yet exist. If you are working through a data set manually, enter a name for the wave statistics and click Append each time you wish to save a new set of statistics. In this way you can generate a time-series of the changing wave statistics.

The Plot button generates a triple plot from an existing wave statistics file to which you have browsed. Note that if you browse to a file that already exists, the system will ask you if it is OK to replace the file. It's OK to click yes; the system will not actually replace the file unless you subsequently click the MWAVES Save button.

The Wave Statistics File

The wave statistics file contains columns of numbers in ASCII text. It can be directly loaded for plotting by most numerical analysis software packages (Matlab, Excel, etc.). A typical line from a file is shown below:

```
4 29 2004 12  0  0.13   0.51    4.4  +35 0.086 0.297 A P
```

The first six numbers are the data and time when the burst started: month, day, year, hour, minute, and second. The time stamp is followed by the significant wave height in meters, the dominant wave period in seconds, and the dominant direction of propagation in mathematical compass coordinate degrees. This burst, acquired at noon on April 29, 2004, was dominated by half meter waves propagating to the northeast with a four and a half second period.

Because they have a significant effect on the calculation of the wave statistics, the lower and upper frequency limits, in Hz, are included in the next two columns. In this case the limits are 0.086 Hz and 0.297 Hz.

The final columns are letter codes. The first code will be either an ‘A’, indicating that the bandwidth was set by the automatic algorithm, or an ‘M’, indicating that the limits were set manually by the operator. The final letter code will be a ‘P’ for pressure or a ‘V’ for vertical velocity, depending on which measurements from the time-series were used to calculate the spectra.

Operating MWAVES – One Page Summary

Processing Single Bursts:

1) Copy the binary data from the compact flash card of your MAVS-3 to your PC and unpack it with MAVSPack.
2) Start MWAVES and browse to the data folder where MAVSPack put the output DATANNN.DAT files. Place CONFIG.BIN and DEPLOY.BIN in the same folder.
3) Select a data file and a burst number
4) Choose the MEM or the Longuet-Higgins algorithm
5) Choose processing based on Pressure or Vertical Velocity measurements
6) Enter the Sensor Height Above Bottom and the Water Depth
7) Click Process Selection
8) Return to Step (3) and select another burst (repeat as desired)

Processing All Bursts:

1) Copy the binary data from the compact flash card of your MAVS-3 to your PC and unpack it with MAVSPack.
2) Start MWAVES and browse to the data folder where MAVSPack put the output DATANNN.DAT files. Place CONFIG.BIN and DEPLOY.BIN in the same folder.
3) Choose the MEM or the Longuet-Higgins algorithm
4) Choose processing based on Pressure or Vertical Velocity measurements.
5) Enter the Sensor Height Above Bottom and the Water Depth.
6) Click Process All

Settings You May Wish to Adjust:

1) FFT length
2) Bandwidth

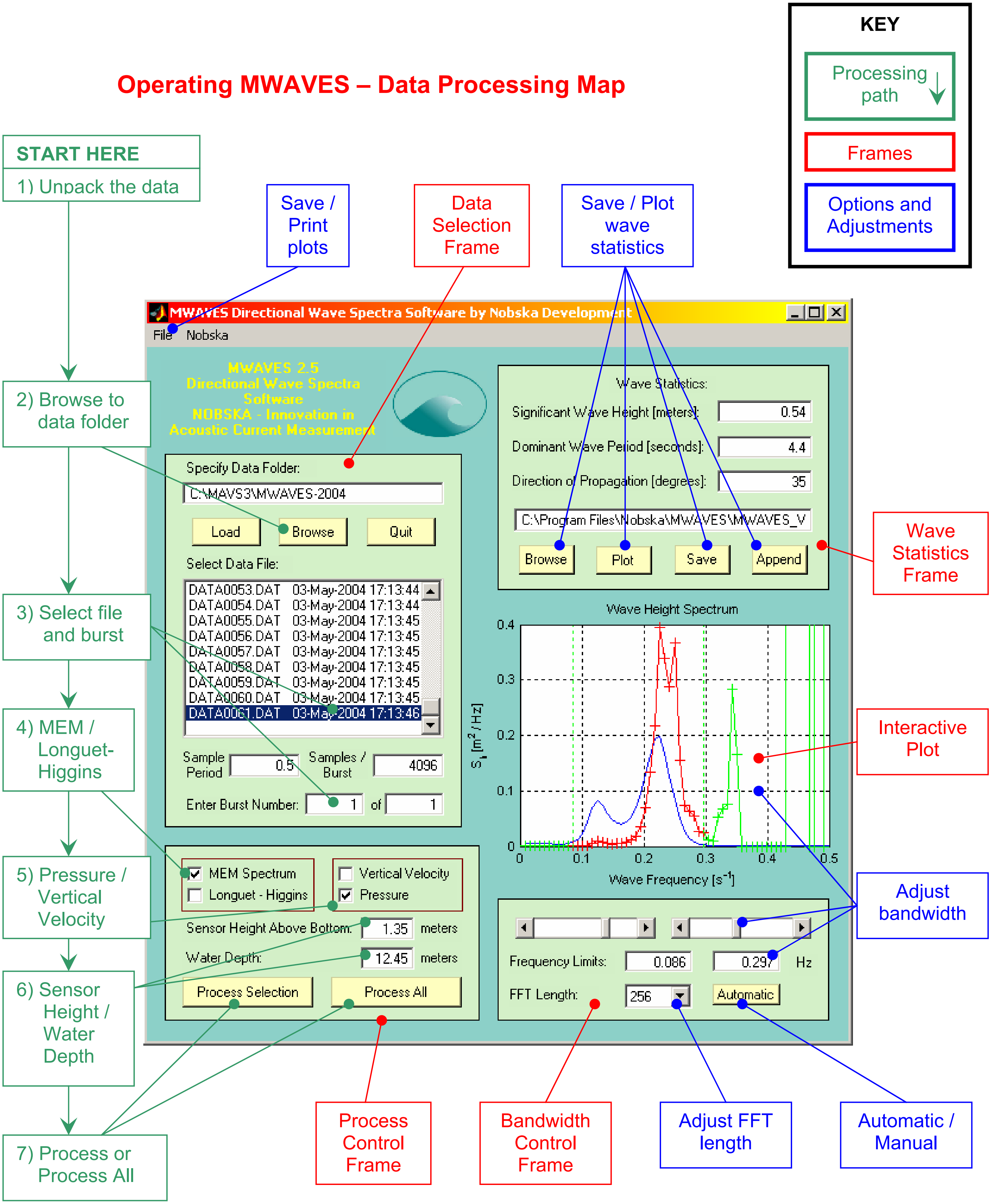
Interesting Comparisons:

1) MEM versus Longuet-Higgins
2) Pressure versus Vertical Velocity

Other Things You May Wish to Do:

1) Use Automatic bandwidth adjustment
2) Save wave statistics to a file
3) Save or print images of the Control Panel and Plots

Operating MWAVES – Data Processing Map



KEY

- Processing path
- Frames
- Options and Adjustments

START HERE

1) Unpack the data

2) Browse to data folder

3) Select file and burst

4) MEM / Longuet-Higgins

5) Pressure / Vertical Velocity

6) Sensor Height / Water Depth

7) Process or Process All

Save / Print plots

Data Selection Frame

Save / Plot wave statistics

Wave Statistics Frame

Interactive Plot

Adjust bandwidth

Process Control Frame

Bandwidth Control Frame

Adjust FFT length

Automatic / Manual

MWAVES Directional Wave Spectra Software by Nobska Development

MWAVES 2.5
Directional Wave Spectra Software
NOBSKA - Innovation in Acoustic Current Measurement

Specify Data Folder: C:\MAVS3\MWAVES-2004

Select Data File:

```
DATA0053.DAT   03-May-2004 17:13:44
DATA0054.DAT   03-May-2004 17:13:44
DATA0055.DAT   03-May-2004 17:13:45
DATA0056.DAT   03-May-2004 17:13:45
DATA0057.DAT   03-May-2004 17:13:45
DATA0058.DAT   03-May-2004 17:13:45
DATA0059.DAT   03-May-2004 17:13:45
DATA0060.DAT   03-May-2004 17:13:45
DATA0061.DAT   03-May-2004 17:13:46
```

Sample Period: 0.5

Samples / Burst: 4096

Enter Burst Number: 1 of 1

☑ MEM Spectrum

☐ Longuet - Higgins

☐ Vertical Velocity

☑ Pressure

Sensor Height Above Bottom: 1.35 meters

Water Depth: 12.45 meters

Wave Statistics:

Significant Wave Height [meters]: 0.54

Dominant Wave Period [seconds]: 4.4

Direction of Propagation [degrees]: 35

C:\Program Files\Nobska\MWAVES\MWAVES_V

Frequency Limits: 0.086 0.297 Hz

FFT Length: 256

Interpreting the Results

This section might be more accurately titled: What the plots are telling you. We'll begin with a brief description of the available controls and features and end with an object lesson from our own experience.

The Independent Plot Windows

Each of the three independent plot windows can be individually printed or saved using options on its File menu or tool bar. The menu and tool bar are located in the upper left corner of each plot.

The zoom function defaults to ON in each plot window. To enlarge a portion of one of the plots position your mouse at one corner of the region of interest, hold down the left mouse button, drag the mouse to the opposite corner, and release the button. The inward zoom can be repeated. Single left clicks will also zoom in. Click the right mouse button to zoom out. The zoom tools can be disabled or re-enabled using the magnifying glass icons on the task bar of each plot window.

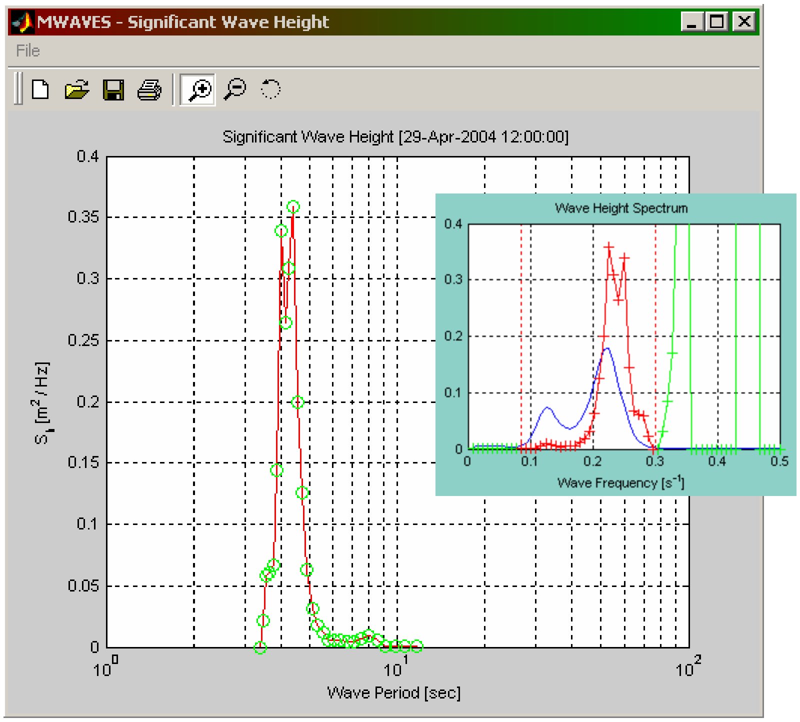
The spectra on the following pages were all calculated from the same burst, acquired starting at noon on April 29, 2004 in Vineyard Sound. The calculations used the MEM algorithm and the pressure time series. The frequency limits were 0.085 Hz and 0.300 Hz and the FFT had a length of 256 points. The original measurements were made at 2 Hz with 4096 measurements in each burst. Water depth was 12.45 meters at the time of the burst. The calculated wave statistics were:

Significant wave height: 0.51 meters
Dominant wave period: 4.4 seconds
Direction of Propagation: 35° (roughly northeast)

Interestingly, this did not quite agree with the observations of the students who were on site preparing to recover the instrument when this burst was acquired. We'll discuss this cautionary tale when we get to the polar directional wave height spectrum.

The Non-Directional Wave Height Spectrum

The non-directional wave height spectrum is shown below with the Interactive Plot inset for comparison.



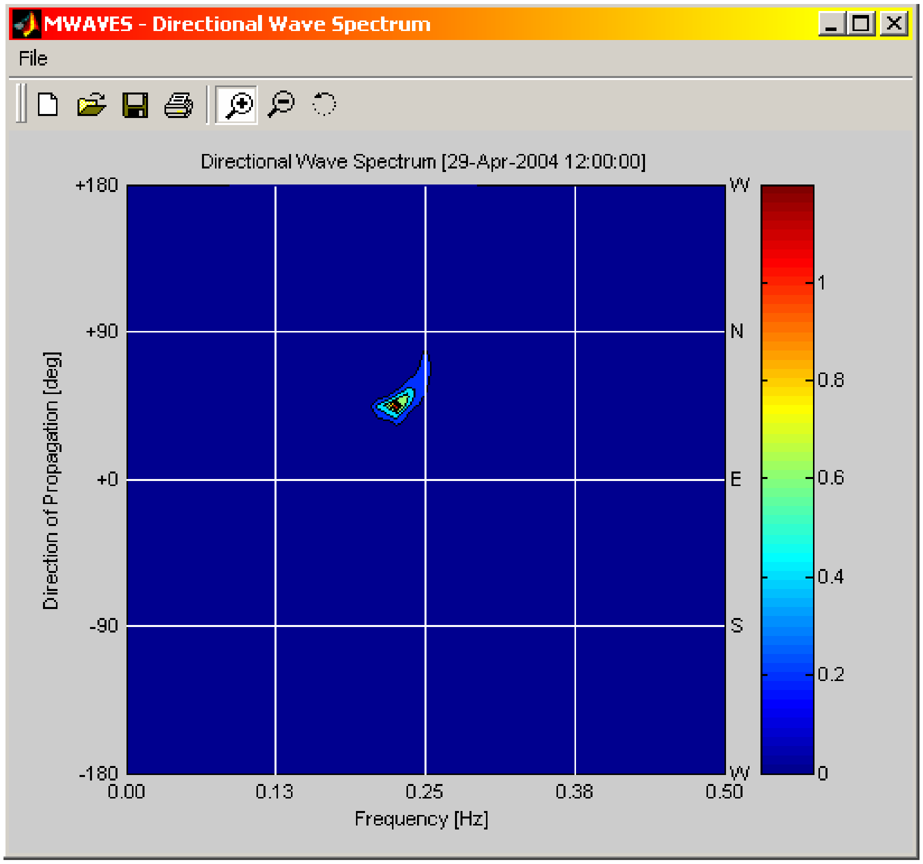
Recall that the non-directional wave spectrum represents the total wave energy from all directions at each frequency. The spectrum has units of m^2/Hz and is denoted S_h. In this representation it has been plotted against the wave period in seconds on a logarithmic axis. Only the portion of the surface wave spectrum between the lower and upper frequency limits is plotted. The green circles are the actual points in the discrete spectrum. The red line connects the points in order. The date and time of the beginning of the burst are included in the title.

The spectrum shows a relatively narrow, essentially single peak with a period between 4 seconds and 5 seconds. There is a tiny signal, probably of no significance, at approximately 8 seconds. This may be swell that has propagated up the Sound from the open Atlantic or it may have some other source. The short period waves are probably locally generated. Note the relationship to the Interactive Plot, which is the same spectrum plotted against wave frequency rather than wave period. Consider in particular the relative strength of the 4.5 second and 8 second peaks at depth (blue line) and at the surface (red line). Shorter waves attenuate much more quickly with depth.

The significant wave height is the integral under this curve, though it may be easier to visualize that operation when the spectrum is plotted against wave frequency on a linear scale as in the Interactive Plot. The wave period scale was selected to complement the frequency scale used in the Interactive Plot. Many of us think of waves in terms of their periods (“4 second chop”, “12 second swell”, etc.), until it’s time to band limit and then it’s back to frequency. MWAVES includes both representations.

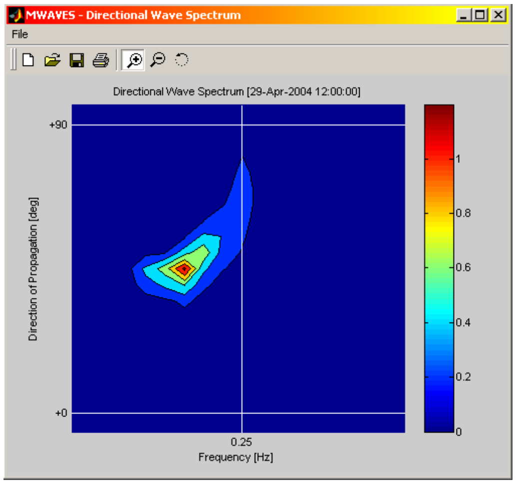
The Cartesian Directional Wave Height Spectrum

The Cartesian directional wave height spectrum is shown below.



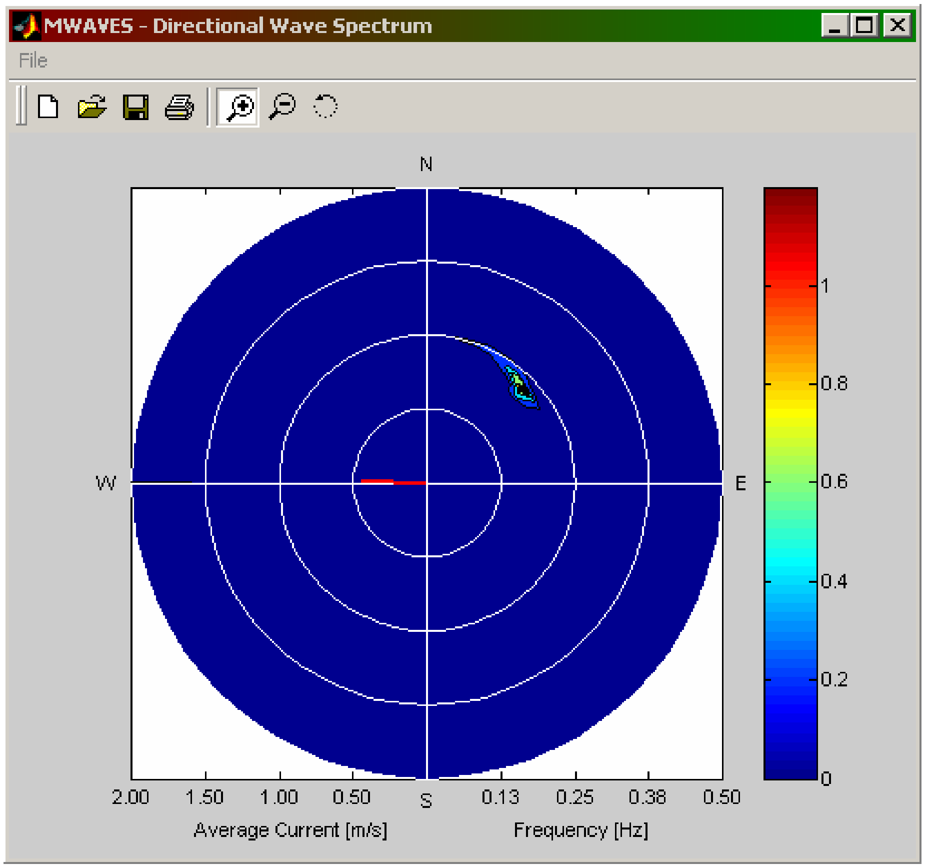
The direction of propagation is plotted along the vertical axis in mathematical compass coordinates. In this system East is 0°, North is +90° (+π/2), South is -90° (-π/2), and West is ±180° (±π). The cardinal points of the compass, North, South, East, and West, are also marked along the right margin of the plot. Wave frequency in Hz is plotted along the horizontal axis. The color bar on the right indicates wave intensity in units of m^2/Hz.

The spectrum shows a single wave system. The waves are propagating to the northeast and the dominant frequency is about 0.22 Hz (4.5 seconds). The representation is mildly abstract, but convenient when you want to estimate the frequency and direction by eye. A close-up view of the wave system, produced using the zoom capability of the independent plots, is shown to the right.



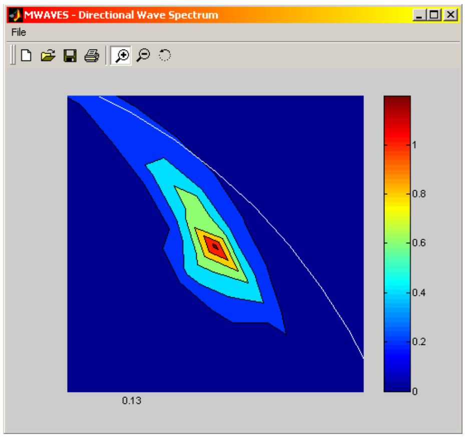
The Polar Directional Wave Height Spectrum

The polar directional wave height spectrum is shown below.



In the polar representation, wave frequency increases with distance from the center of the plot. The frequency scale is given on the right half of the horizontal axis in Hz. The white circles are aligned with the indices on the horizontal axis to make estimation of frequency (radial distance) easier. The direction of propagation is given by the angle measured around the center. The cardinal points of the compass are marked around the periphery. The color bar on the right indicates wave intensity in units of m^2/Hz.

This is the same information provided by the Cartesian directional wave height spectrum. That rectangular grid has simply been warped and stretched onto the polar grid. It should come as no surprise that the spectrum shows a single system of 4.5 second waves propagating to the northeast. The advantage of the polar form is the ease with which it can be interpreted and understood. The direction of propagation is particularly clear. A close-up view of the wave system is shown to the right.



Wave-Current Interaction – A Cautionary Tale

The red line in the center of the polar plot indicates the direction and strength of the average horizontal current during the burst. The angle of the line indicates the direction of flow, almost due west in this case. The length of the line indicates the speed of the flow. The current scale is given on the left side of the horizontal axis in meters/second. Again, the white circles are also aligned with these indices on the horizontal axis to make estimation of the speed of the current (radial distance) easier. At 0.5 m/s, each ring is almost exactly 1 knot (1 kt = 0.514 m/s).

The current in this case, Vineyard Sound at noon on April 29, 2004, is tidal in origin and, at nearly 1 kt, it is not negligible. Vineyard Sound is a complicated study site with multiple wave sources, lots of bathymetry reflecting and refracting the waves, and strong, asymmetric, tidal currents. This is almost ideal for teaching graduate students about collecting, processing, and understanding real measurements. It's also a pretty good place for teaching MWAVES developers.

Here's what happened. MWAVES (Version 2.2, before the red current indicator) calculated a significant wave height of about 0.5 meter. Those who were on the recovery boat said the waves were much smaller, perhaps half that or less. Were the human observations wrong? The students (a group that included some seasoned observers) and several seasoned observers accompanying the students and some photographs made it clear that the average wave height was indeed about a quarter of a meter. Recall that it is this human estimate of average wave height that the calculation of significant wave height is meant to mimic. We wanted better agreement.

Was the calculation wrong in some way? It's comically easy to miss by a factor of two with an FFT. We verified that the code was executing the correct equations (we found and fixed a few problems, but did not eliminate the discrepancy). We verified that the code got the right answer with manufactured "data". We verified that the code got the right answer with real data from other sites where reliable human observations were available for comparison.

So what was different about Burst 61 of the Vineyard Sound data? That's when we thought of the current. The polar directional wave height spectrum on the previous page indicates that the waves were propagating almost directly into a 1 kt current. Not a particularly common situation near most shorelines, where waves propagate on-shore and currents flow along-shore.

The average current shifts the measured wave frequency according to:

$$\omega = \sigma + \vec{k} \cdot \vec{u}$$

Here ω is the measured wave frequency, σ is the intrinsic wave frequency, which satisfies the dispersion relationship below, k is the wave number, u is the average current, g is the acceleration due to gravity, and H is the water depth.

$$\sigma^2 = gk \tanh(kH)$$

For an opposing current the shift is to higher apparent frequencies. Recall that the mapping of sub-surface measurements of velocity and pressure depends hyperbolically on frequency. Higher frequencies attenuate more quickly with depth and so must be enhanced more strongly when mapping them to the surface.

The actual frequency shift in Burst 61 was small, but it was sufficient, after mapping the measurements to the surface and integrating the resulting wave height spectrum, to produce a significant wave height of half a meter rather than a quarter of a meter.

We hasten to point out that this occurs, in some sense, because this is the way the world works. Waves have a non-linear dispersion relation and they attenuate hyperbolically as a function of frequency and they do not propagate independently of the other motions of their medium. It's a tough problem. Interestingly, it does not appear to be widely recognized as a problem, tough or otherwise, by others involved in calculating surface wave spectra.

Fortunately, understanding this phenomenon has pointed the way to a solution. The equations are implicit and non-linear with multiple roots, but there will be a correction for currents in a future version of MWAVES. For now,

- This is only a problem in very strong currents and only to the extent that they are aligned with or against the direction of wave propagation
- This is only a problem for relatively short period waves
- The red current indicator lets you know when you need to be concerned

There are lessons in our cautionary tale about the importance of alternate observations and trusting your eyes and we take those to heart. If you find a situation where you just don't believe the answer, let us know. We look forward to extending our range.

Using MWAVES with Other Current Meters

MWAVES is designed to post-process data collected using a MAVS-3 current sensor. As discussed in Operating MWAVES, the MAVS-3 specific binary files CONFIG.BIN and DEPLOY.BIN are required for operation and the format of the ASCII data files must conform to the MAVS-3 standard.

However, MWAVES has been successfully used to process measurements collected with MAVS-1 and MAVS-2 instruments. System configuration and deployment definition files are not produced by MAVS-1 and MAVS-2 instruments, each of which is run using its own semi-unique program. The output format, which columns are present and in which order, is also semi-unique to individual instruments. To overcome these difficulties, a MAVS-3 instrument was used to generate suitable CONFIG.BIN and DEPLOY.BIN files. The ASCII data files were manually edited, adding, subtracting, and shifting columns as necessary, to conform to the MAVS-3 standard format.

In theory, MWAVES could also be used to process the output of current meters produced by other manufacturers. As with earlier generations of MAVS, binary support files would need to be created and data files would require manual editing. But this could be done, at least in theory.

Please contact us if you need assistance with MAVS-1 or MAVS-2 data sets or wish to explore applications of MWAVES to other current meters.

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Sandy Williams	508-289-2725	awilliams@nobska.net
Fax	941-766-0707	
Web		www.nobska.net

The MWAVES Future

A number of improvements and new features are planned for future versions of MWAVES. These include:

- Additions to the Interactive Plot to make setting the bandwidth easier. For example, the smoothed surface spectrum before subtraction of the noise floor will be included. Menu items will allow the user to turn these features on and off.
- An automatic correction for the frequency shift associated with waves propagating with or against a strong current.
- We will continue to improve the algorithm for automatic bandwidth selection.
- An option to calculate and display the direction of wave propagation in either mathematical or traditional compass coordinates
- The ability to process continuous time-series as well as bursts. The user will be able to define burst lengths and overlapping steps (e.g., 4096 measurements per burst and overlap the bursts to recalculate the spectra every 128 measurements) during post-processing of continuous data sets.
- Processing continuous time-series will lead to Real-Time MWAVES, with the ability to process a real-time data stream from an active MAVS-3 instrument. The operator will define the burst length and the overlapping steps and MWAVES will extract, process, and display these “bursts” as they are received.
- Simultaneous display of pressure and velocity based results for comparison.
- A utility to calculate the amplitude of velocity and pressure variations at the sensor depth as a function of wave period, surface amplitude, water depth, and sensor depth. The calculator can be used when planning a deployment.
- Confidence intervals will be added to the non-directional spectra. This feature may be helpful when the operator is adjusting the length of the FFT.
- A display of the number of spectral degrees of freedom. This may also be helpful when the operator is adjusting the length of the FFT.
- 3-Dimensional directional wave spectra with dynamic adjustment of the viewing angle.
- Contour plots showing the evolution of the non-directional wave height spectrum over time.
- A long term goal is the ability to track the evolution of individual wave systems as they change in strength, spectral content, and direction over time.

We welcome your suggestions for other useful new features.

And if you find a problem, please let us know about that, too.

New with Version 2.5

Three sample definition thresholds have been changed for greater statistical reliability during analysis with MWAVES 2.5. The upper warning generation threshold for burst duration has been changed from 30 minutes to 45 minutes. The lower warning generation threshold for samples per burst has been changed from 4096 to 2048. The lower process termination threshold for samples per burst has been changed from 256 to 512.

The code has been made more robust to the small signal situations that can occur when making wave measurements in large lakes.

The triple plot can now be generated on demand, rather than only by processing a complete data file. Simply select a previously generated statistics file as described in the manual.

New with Version 2.6

Version 2.6 is functionally identical to Version 2.5. It was recompiled to establish compatibility with all current versions of the Windows Operating System, Windows 2000, Windows XP, and Windows Vista.