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Technical Note

30 Year Wave Hindcasts using WAVEWATCH III® with CFSR winds[†]
Phase 1

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This report presents phase 1 of a 30 year wave hindcast study that is being developed in 3 phases using the WAVEWATCH III® model. At this phase the model has conducted a simulation of the 30 year period using the Tolman-Chalikov physics package with 16 regular lat-lon grids and the new NCEP Climate Forecast System Reanalysis Reforecast (CFSRR) homogeneous data set of hourly 1/2° spatial resolution winds, to generate a wave climatology. This report contains detailed information on available products.

This report is available as a pdf file from:

http://polar.ncep.noaa.gov/waves

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1   Introduction

A new NCEP Climate Forecast System Reanalysis Reforecast (CFSRR) system has been recently developed and entails a coupled reanalysis of the atmospheric, oceanic, sea-ice and land data from 1979 through 2010 (Saha et al., 2010). This reanalysis has much higher horizontal and vertical resolution of the atmosphere than the Global and the North American Reanalysis, and can thus be used to develop a long-term hindcast wave database.

The wave model used at NCEP is a third generation wind wave model WAVE-WATCH III$^{®}$ (Tolman, 2009). In 2007, the model was expanded to run as a mosaic of two–way nested grids (Tolman, 2008). The nested grid driver is described in Tolman (2007a,b). To drive the waves the wave model requires two input fields: ice and winds (including the air-sea temperature difference). The high resolution winds used here are the 10m (above Mean Sea Level) winds on an hourly temporal and $1/2°$ spatial resolution which cover the globe from 90°S–90°N. The reanalysis daily ice concentration fields are $1/2°$ spatial resolution, and are derived from passive microwave from the SMMR and SSMI using the NASA Team algorithm.

This hindcast database is foreseen to be developed in three phases. In the first phase, the wave model has been run (for the 31 year hindcast period from 1979 to 2009) using the same physics packages that are currently used in NCEP operations (with minor exceptions these are also the default settings described in Tolman (2009)). This sets the baseline skill for the wave model. The database will be regenerated in phase 2 and 3 with newer physics packages as they become available, courtesy of a concurrent NOPP initiative to improve physics in operational wind wave models. However, the model setup and products will remain unchanged at the different stages[1]. The mosaic approach to wave modeling in WAVEWATCH III allows us to develop a detailed modeling system with high resolution grids in areas of interest.

The purpose of this report is to provide detailed information on available products from phase 1 of the wave hindcast database. A manuscript providing detailed analysis of the wave climate and the winds (10 m above MSL) is currently under development and shall be released when available. Apart from this report, two additional reports providing some initial analysis on the winds (Spindler et al., 2011) and information on model grids and output points (Chawla et al., 2011) are also available.

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[1]This may change depending on developments in model capability and/or database generation

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2   Grids

The WAVEWATCH III model can be run as a mosaic of grids with two–way interaction between the higher and lower resolution grids. This facilitates increased computational efficiencies by restricting the higher resolution grids only in the necessary areas. The global domain was separated into sixteen computational grids. Individual grid details are provided in Table 2.1. See Chawla et al. (2011) for detailed information on grids and output point locations.

Table 2.1: WAVEWATCH III grid particulars. All output data associated with a particular grid are identified by their grid labels.

Name	Grid label	Latitude	Longitude	Resolution (lat x lon)
Global	glo_30m	$90°S : 90°N$	$180°E : 180°W$	$1/2°$ x $1/2°$
Arctic	ao_30m	$55°N : 90°N$	$180°E : 180°W$	$1/2°$ x $1/2°$
Mid-Globe	mid_30m	$65°S : 65°N$	$180°E : 180°W$	$1/2°$ x $1/2°$
Antarctic	ac_30m	$90°S : 55°S$	$180°E : 180°W$	$1/2°$ x $1/2°$
East Coast US	ecg_10m	$0°N : 55°N$	$100°W : 50°W$	$1/6°$ x $1/6°$
West Coast US	wc_10m	$25°N : 50°N$	$150°W : 110°W$	$1/6°$ x $1/6°$
Alaska	ak_10m	$44°N : 75°N$	$140°E : 120°W$	$1/6°$ x $1/4°$
Pacific Isl.	pi_10m	$20°S : 30°N$	$130°E : 145°W$	$1/6°$ x $1/6°$
Australia	oz_10m	$50°S : 0°N$	$105°E : 165°E$	$1/6°$ x $1/6°$
North Sea	nsb_10m	$42°N : 75°N$	$28°W : 31°E$	$1/6°$ x $1/4°$
Mediterranean	med_10m	$30°S : 48°N$	$7°W : 43°E$	$1/6°$ x $1/6°$
NW Indian O.	nwio_10m	$20°S : 31°N$	$30°E : 70°E$	$1/6°$ x $1/6°$
East Coast US	ecg_4m	$15°N : 47°N$	$101°W : 60°W$	$1/15°$ x $1/15°$
West Coast US	wc_4m	$15°N : 50°N$	$165°W : 116°W$	$1/15°$ x $1/15°$
Alaska	ak_4m	$48°N : 74°N$	$165°E : 122°W$	$1/15°$ x $2/15°$
Australia	oz_4m	$50°S : 0°N$	$105°E : 165°E$	$1/15°$ x $1/15°$
North Sea	nsb_4m	$42°N : 68°N$	$28°W : 31°E$	$1/15°$ x $2/15°$

The spectral domain has been divided into 50 frequency and 36 directional bins (directional resolution of $10°$). The minimum frequency has been set at 0.035 Hz and the frequency increment factor has been set at 1.07, providing a frequency range of 0.035–0.963. A parametric tail is fitted beyond the highest computed frequency.

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3   Physics packages

In WAVEWATCH III the packages used are defined by switches during the compile stage of the wave model(Tolman, 2009). The switches that are being used at this stage of the database development are as follows:

NCEP2   NCEP GRIB2 package for IBM (being used in generating GRIB2 output)

LRB4   4 Byte words (this is the record length in direct access files)

LLG   Spherical grid

PR3   ULTIMATE QUICKEST propagation scheme with averaging technique for Garden Sprinkler alleviation

FLX3   Friction velocity from Tolman and Chalikov input with a cap (see manual for details)

LN1   Cavaleri and Malanotte-Rizoli linear growth term with a filter

ST2   Tolman and Chalikov source term package (Tolman and Chalikov, 1996)

STAB2   Stability correction for Tolman and Chalikov package (see manual)

NL1   DIA approximation for non-linear interactions

BT1   JONSWAP bottom friction formulation

DB1   Battjes-Janssen shallow water depth breaking

MLIM   Miche-style shallow water limiter for maximum energy (see manual for details)

TR0   No Triad interactions

BS0   No bottom scattering

WNT1   Linear interpolation of wind in time

WNX1   Linear interpolation of wind speed in space

The key points are, that at this first phase of the database, DIA formulation is used to account for non-linear interactions, shallow water wave breaking is simulated using the Battjes-Janssen formulation and the Tolman-Chalikov source term packages are used for wave generation and dissipation. In later phases of the database development one or more of these packages will be changed.

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4 Products

All wave output products are broken up into month long segments. Broadly speaking, the output products include bulk spectral properties on grid layout, spectral partition information on grid layout, detailed spectral information at specific point locations, and when available model results collocated along altimeter tracks. For this study the altimeter archive at IFREMER was used. Unless otherwise specified all units are MKS.

4.1 Grib Files

Field output are produced on the different model grid layouts and are produced in GRIB2 format. The file naming convention is as follows

multi_reanal.[GRID ID].[VARIABLE].[YYYYMM].grb2

where

GRID ID Is the grid label for a specific grid (see Table 2.1). For the global grids (ao_30m, mid_30m and ac_30m) the results are merged into one grid (glo_30m).

VARIABLE This identifies the variable. The options are

wind Provides the 10m (above MSL) wind speed and direction, interpolated from the input forcing grid to the output grid.

hs Provides the overall significant wave height.

tp Provides the peak period of the spectrum.

dp Provides the average direction (at peak period). Direction is in nautical notation (ranging from 0 to 360, with 0 corresponds to waves propagating from the North.)

YYYYMM Year and month corresponding to output file.

4.2 Partition Data

WAVEWATCH III uses a digital image processing watershed algorithm (Vincent and Soille, 1991) to separate the 2D wave spectra into partitions by identifying the different peaks in the spectrum (Hanson and Jenson, 2004; Hanson et al., 2009). Individual peaks are identified as wind seas or swells using an inverse wave age criteria. This algorithm not only provides a natural way to separate wind seas from swells, but also identifies multiple swell fields in the spectrum. The file naming scheme for the partitioned data is as follows

multi_reanal.partition.[GRID ID].[YYYYMM].gz

where **GRID ID** and **YYYYMM** are the same as defined above for grib files. These are ascii files that are compressed using gzip. The output in each file is as follows

```
<yyyymmdd> <hhmmss> <lat> <lon> <name> <nprt> <depth> <uabs> <udir> <cabs> <cdir>
  <partition #> <Hs> <Tp> <Lp> <Theta> <Sp> <Wf>
  repeat for all partitions
  .
  .
  .
repeat for all times and grid points
.
.
.
```

where

nprt Number of partitions

uabs,udir Wind speed and direction

cabs,cdir Current speed and direction

Hs, Tp, Lp, Theta, Sp, Wf Spectral estimates for each partition, corresponding to significant wave height, peak period, wave length at peak period, average direction at peak period (in nautical terms), spectral width and wind fraction respectively. Wind fraction identifies the portion of the spectral partition under the influence of wind (using a directional inverse wave age formulation) and values of 1 and 0 signify wind seas and swells respectively.

Partition data is output at every grid point for all the grids except the global grids, where they are output every alternate grid point. Data is output on an hourly temporal resolution. Unlike the grib files, the data for the global grids are not merged into a one single global grid, however in mid_30m output from the part of the domains that overlap ao_30m and ac_30m are omitted.

4.3   Point Output

There are 2050 output points where spectral information is being stored in ascii files. See Chawla et al. (2011) for a list of all the output points and their locations. There is a separate file for each station and output type. For convenience these files are tarred by output type and a point classification. The file naming

scheme is as follows

multi_reanal_base.[POINT TYPE].[OUTPUT TYPE].[YYYYMM].tar.gz

where

POINT TYPE Output points are classified broadly into 5 types

> **BUOYS** These correspond to buoy locations (buoy locations from several different reporting agencies – NDBC, WMO, UKMO etc. – have been accounted for, using the identifiers assigned by the respective agencies) as well as additional points (virtual buoys and boundary points) where output data was needed.

> **WIS_ALASKA, WIS_PACIFIC, WIS_GULF, WIS_ATLANTIC** These correspond to USACE Wave Information Studies (WIS) points in Alaskan, US West Coast, Gulf and US East Coast coastal waters respectively.

OUTPUT TYPE Files separated into types of output. These are

> **part** Similar to the partitioned data files but at a single output location.

> **wmo** Bulk spectral properties written out in WMO specific format.

> **spec** Full 2D spectra.

The format for the WMO files are

```
<year> <month> <day> <hour> <uabs> <udir> <Hs> <Tp>
repeat for all times
.
.
.
```

The format for the spec files are

```
<Text string> <Nfr> <Nd> <Np> <Text String>
<fr> (for all frequency bins)
<dir> (for all direction bins)
<yymmdd> <hhmmss>
<Text string> <lat> <lon> <d> <uabs> <udir> <cabs> <cdir>
<E(fr,dir)> (for all frequencies and directions)
repeat for all times
.
.
.
```

where

Nfr,Nd,Np are the number of frequencies, directions and points respectively. Since a separate file is being generated for each point, Np is set at 1.

fr,dir are the discretized frequency (in Hz) and direction (in radians) bins. Direction is in oceanographic convention.

lat,lon,d are the latitude, longitude and water depth (in m) at the point

E(fr,dir) are the wave spectra in m^2/Hz.

Unlike the partition and wmo files, the spectral data have a temporal resolution of 3 hrs. An example matlab script for reading spectral data files is given in Appendix A.

4.4   Altimeter collocation tracks

Model output have also been extracted along collocated altimeter tracks. For this study the Q-C altimeter archive from IFREMER was used. Since this is not an NCEP product, the altimeter data itself is not part of this archive. The data however can be obtained from **www.globwave.org**. To obtain the collocated model results, hourly gridded model results for each grid were interpolated in space and time on to the altimeter tracks. For each grid only those points with valid model results are output (i.e. tracks over land, undefined points, and over ice are ignored). The naming scheme for these files is follows

multi_reanal_base.rerun.[YYYYMM].[ALTIMETER ID].raw.[GRID ID]

where

ALTIMETER ID is a 3 letter identifier for the altimeter instrument.

    tpx refers to TOPEX

    psd refers to POSEIDEN

    er1 refers to ERS-1

    er2 refers to ERS-2

    gfo refers to GFO

    env refers to ENVISAT

    js1 refers to JASON-1

    js2 refers to JASON-2

The format for the altimeter collocated files are

```
<yyyymmdd> <hhmmss> <uabs> <Hs>
repeat for all times
.
.
.
```

where the time stamp is used to identify the track positions. Corresponding track locations and altimeter data can be obtained by matching the time stamps with the altimeter data sets.

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APPENDICES

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A   Matlab script for reading a 2D wave spectra file

```
function b = read_ww3sp(filename)

% M-file to read in data from a 2D spectral file in WW3 V2.22 format
% J. Henrique Alves, March, 2000
% Modified into a function form by A Chawla, June 2011

 if (exist(filename,'file'))
    fid=fopen(filename);
 else
    fprintf(1,'ERROR : File Not found !!');
    return;
 end;

% Scan basic properties of spectra from file
 dum=fscanf(fid,'%c',[23]);
 NF =fscanf(fid,'%g',[1]);
 ND =fscanf(fid,'%g',[1]);
 dum=fscanf(fid,'%s',[1]);
 dum=fscanf(fid,'%c',[33]);
 f=fscanf(fid,'%g',NF);
 dir=fscanf(fid,'%g',ND);
 fprop=f(2)/f(1);
 fdum=[f(1)/fprop;f];
 df=diff(fdum);
 dtheta=abs(dir(2)-dir(1));

 b.f = f;
 b.dir = dir;

 dir(end+1) = dir(1); % Closing for circular integral

% Loop over times
 index = 0;

 b.time = [];
 b.espt = [];
 b.U10 = [];
 b.Udir=[];
 b.cU=[];
```

```
b.cdir=[];
b.sp1d = [];
b.hs = [];
b.dp = [];
b.fp = [];
while ~feof(fid)

    dumdate=fscanf(fid,'%g',2);
    if numel(dumdate)
        year = floor(dumdate(1)/10000);
        month = floor(dumdate(1)/100) - year*100;
        day = dumdate(1) - year*10000 - month*100;
        hr = floor(dumdate(2)/10000);
        mn = floor(dumdate(2)/100) - hr*100;
        sc = dumdate(2) - hr*10000 - mn*100;

        b.time(index+1) = datenum(year,month,day,hr,mn,sc);

        stn=fscanf(fid,'%c',13);
        poslat=fscanf(fid,'%g',1);
        poslon=fscanf(fid,'%g',1);
        depth=fscanf(fid,'%g',1);
        U10=fscanf(fid,'%g',1);
        Udir=fscanf(fid,'%g',1);
        cU = fscanf(fid,'%g',1);
        cdir = fscanf(fid,'%g',1);
        sp2d=fscanf(fid,'%g',[NF,ND]);

        if (index == 0)
            b.name = stn;
            b.lat = poslat;
            b.lon = poslon;
            b.depth = depth;
        end;
        b.U10(index+1) = U10;
        b.Udir(index+1) = Udir;
        b.cU(index+1) = cU;
        b.cdir(index+1) = cdir;

        b.espt{index+1} = sp2d;
        b.sp1d{index+1} = sum(sp2d')*dtheta;
        b.hs(index+1) = 4*sqrt(trapz(f,b.sp1d{index+1}));
```

```
        % Computing peak direction
        sp2d(:,end+1)=sp2d(:,1);
        [tmp,loc]=max(b.sp1d{index+1});
        b1=trapz(dir,sin(dir)'.*sp2d(loc,:));
        a1=trapz(dir,cos(dir)'.*sp2d(loc,:));
        theta_m = atan2(b1,a1);
        if (theta_m < 0)
            theta_m = theta_m + 2*pi;
        end;
        b.dp(index+1) = theta_m;
        b.fp(index+1) = f(loc);

        index = index+1;
    end;
end;

fclose(fid);
return;
```