User Guide for MASNUM-WAM 2.2

MASNUM Wave Model (Version 2.2)

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1. Introduction

The third-generation Wave Model LAGFD-WAM was proposed early in 1990s in LAGFD (Laboratory of Geophysical Fluid Dynamics), FIO (First Institute of Oceanography) of SOA (State Oceanic Administration), China. It has marked originality in

1) The energy and action energy spectrum balance equations,

2) The source functions of dissipation and bottom friction,

3) The wave-current interaction source function and

4) The computational scheme.

The model has been compared with WAM model in typical wind fields and gave concerted results in general sea state and good improvement in high sea state. Also the model has been used in China seas for forecast and hindcast practices and got results consistent with filed measured data.

In order to evaluate the wave-induced mixing in the upper ocean and the impact of surface waves on ocean-atmosphere fluxes, a global wave numerical model in spherical coordinates was developed based on the previous LAGFD-WAM regional model. Since the LAGFD became MASNUM (Key Lab of Marine Science and Numerical Modeling, SOA, China), this model is also referred as MASNUM wave model. In the model, the wave energy spectrum balance equation and its complicated characteristic equations are derived in wave-number space. The breaking dissipation source function is adopted a theoretical result based on statistical study of breaking waves (Yuan et al, 1986). The characteristic inlaid method is applied to integrate the wave energy spectrum balance equation.

The current documentation is a report for the version 2.2 of the MASNUM Wave Numerical Model which is improved version from LAGFD-WAM model by Yongzeng Yang and Xunqiang Yin in 2009. A short history of this model is listed in the following table.

Here in this program (Version 2.2), module process was arranged by Xunqiang

Yin for widely application, especially for students study. There are 7 FORTRAN modules:

(1) **time_mod** Used to deal with the time.
(2) **netcdf_mod** Used to input/output data through NetCDF format.
(3) **wamvar_mod** Include all the global variables used in this model.
(4) **wamfio_mod** Subroutines for I/O data or model results.
(5) **wamcpl_mod** Subroutines for coupling w/current model.
(6) **wamcor_mod** The core subroutines of this model.
(7) **wamnst_mod** The subroutines for model nesting.

Table 1 Summarizes of the model evolution

Model	Version	Period	Coordinate	Scale	Assimilation	FORTRAN
LAGFD -WAM	1.1	1990s	Orthogonal	Regional	No	F77
	1.2	2000	Orthogonal	Regional	Yes	F77
MASNUM-WAM	2.1	2005 -2009	Spherical	Regional /Global	No	F77
	2.2	2009 - now	Spherical	Regional /Global	No	F90 Modularized

2. Basic theory of surface waves and its numerical implementation

2.1 Basic equations for surface waves

The wave energy spectrum balance equation in spherical coordinates can be written as

$$\frac{\partial \boldsymbol{E}}{\partial \boldsymbol{t}}+\left(\frac{\boldsymbol{C}_{\boldsymbol{g}\boldsymbol{\lambda}}+\boldsymbol{U}_{\boldsymbol{\lambda}}}{\boldsymbol{R}\boldsymbol{cos}\boldsymbol{\phi}}\right)\frac{\partial \boldsymbol{E}}{\partial \boldsymbol{\lambda}}+\left(\frac{\boldsymbol{C}_{\boldsymbol{g}\boldsymbol{\phi}}+\boldsymbol{U}_{\boldsymbol{\phi}}}{\boldsymbol{R}}\right)\frac{\partial \boldsymbol{E}}{\partial \boldsymbol{\phi}}-\frac{(\boldsymbol{C}_{\boldsymbol{g}\boldsymbol{\phi}}+\boldsymbol{U}_{\boldsymbol{\phi}})\boldsymbol{tan}\boldsymbol{\phi}}{\boldsymbol{R}}\boldsymbol{E}=\boldsymbol{SS}(\boldsymbol{E}) \quad (1)$$

Where $E = E(K, \lambda, \phi, t)$ is the wave-number spectrum as a function of the vector for wave-number$\vec{K} = (k_\lambda, \mathrm{k}_\phi)$, latitude ϕ and longitudeλ; $\vec{U} = (U_\lambda, U_\phi)$ is background current velocity; and $\vec{C}_g = (C_{g\lambda}, C_{g\phi})$ represents the group velocity. The right term of *SS(E)* consists of the wind input source function，the wave breaking dissipation function，the bottom friction dissipation function, the wave-wave weak nonlinear interaction function and the wave-current interaction. Detailed descriptions of these source functions can be found in the following section.

2.2 Complicated characteristic equations

The complicated characteristic equations in spherical coordinates may be written,

$$\frac{d\lambda}{dt}=\frac{C_{g\lambda}+U_\lambda}{R\cos\phi} \quad (2)$$

$$\frac{d\phi}{dt}=\frac{C_{g\phi}+U_\phi}{R} \quad (3)$$

The variation law of the mode and angle of the wave-number is governed by the following equations:

$$\begin{aligned}
&\frac{\partial K}{\partial t}+\frac{C_{g\lambda}+U_\lambda}{R\cos\phi}\frac{\partial K}{\partial\lambda}+\frac{C_{g\phi}+U_\phi}{R}\frac{\partial K}{\partial\phi}+\left(U_\lambda\sin\theta_1-U_\phi\cos\theta_1\right)\tan\phi R^{-1}K\cos\theta_1\\
&=-\frac{\cos\theta_1}{R\cos\phi}\left(\frac{\partial\sigma}{\partial D}\frac{\partial D}{\partial\lambda}+K\cos\theta_1\frac{\partial U_\lambda}{\partial\lambda}+K\sin\theta_1\frac{\partial U_\phi}{\partial\lambda}\right)\\
&\quad-\frac{\sin\theta_1}{R}\left(\frac{\partial\sigma}{\partial D}\frac{\partial D}{\partial\phi}+K\cos\theta_1\frac{\partial U_\lambda}{\partial\phi}+K\sin\theta_1\frac{\partial U_\phi}{\partial\phi}\right)
\end{aligned} \quad (4)$$

$$\frac{\partial\theta_1}{\partial t}+\frac{C_{g\lambda}+U_\lambda}{R\cos\phi}\frac{\partial\theta_1}{\partial\lambda}+\frac{C_{g\phi}+U_\phi}{R}\frac{\partial\theta_1}{\partial\phi}+\left(U_\lambda\cos\theta_1+U_\phi\sin\theta_1\right)\tan\phi R^{-1}\cos\theta_1$$
$$+C_g\tan\phi R^{-1}\cos\theta_1$$
$$=\frac{\sin\theta_1}{R\cos\phi}\left(\frac{1}{K}\frac{\partial\sigma}{\partial D}\frac{\partial D}{\partial\lambda}+\cos\theta_1\frac{\partial U_\lambda}{\partial\lambda}+\sin\theta_1\frac{\partial U_\phi}{\partial\lambda}\right) \tag{5}$$
$$-\frac{\cos\theta_1}{R}\left(\frac{1}{K}\frac{\partial\sigma}{\partial D}\frac{\partial D}{\partial\phi}+\cos\theta_1\frac{\partial U_\lambda}{\partial\phi}+\sin\theta_1\frac{\partial U_\phi}{\partial\phi}\right)$$

where θ_1 is wave direction (measured anticlockwise relative to true east). In equation (4) and (5), the modulation of background current to wave evolution and the refraction of waves propagating along great circles are included. $\vec{K}=(k\cos\theta, k\sin\theta)$ and $\vec{L}=(\cos\theta, \sin\theta)$ are the wave vector and its unit vector; and $\omega=\omega(\vec{K},D)$ is dispersion relation. Equations (2~5) are the complicated characteristics equations describing the effect of unsteady and current on the wave propagation.

2.3 Source functions

The net source function SS may be represented as a superposition of wind input (S_{in}), wave breaking dissipation (S_{ds}), bottom friction dissipation (S_{bo}), wave-wave weak interaction (S_{nl}) and wave-current interaction (S_{cu})

$$\boldsymbol{SS}=\boldsymbol{S_{in}}+\boldsymbol{S_{ds}}+\boldsymbol{S_{bo}}+\boldsymbol{S_{nl}}+\boldsymbol{S_{cu}} \tag{6}$$

(1) Wind input source function

The wind input source function (S_{in}) adopted from Willmarth and Woolridge (1962) and Snyder et al. (1981) is formulated as

$$\boldsymbol{S_{in}(E)}=\boldsymbol{\alpha}+\boldsymbol{\beta E(\vec{K})} \tag{7}$$

Where

$$\alpha=80\left(\frac{\rho_a}{\rho_w}\right)^2\frac{U_*^4\sigma}{g^2K^2}\cos^4(\theta_1-\Theta)\cdot H[\cos(\theta_1-\Theta)]$$

The $\rho_a(\rho_w)$ is the density of air (water), and $\rho_a/\rho_w=1.25\times10^{-3}$, U_* is the friction velocity, $\theta_1(\Theta)$ is the wave-number angle (wind direction, the direction wind go away, positive means anticlockwise and 0 is for eastward), $H(\cdot)$ represents the Heaviside function. Drag coefficient C_d followed Wu (1982) is

$$C_d = \left(\frac{U_*}{W}\right)^2 = (0.8 + 0.065W) \times 10^{-3}$$

Where W is the wind speed at 10m above the sea surface.

The coefficient β can be given as

$$\beta = 0.25\frac{\rho_a}{\rho_w}\sigma\left[\frac{28U_*\cos(\theta_1 - \Theta)}{C_d} - 1\right] H\left[\frac{28U_*\cos(\theta_1 - \Theta)}{C_d} - 1\right] E(\vec{K})$$

where $C = \sigma/K$ is the wave speed.

(2) The dissipation source function

The dissipation source function (S_{ds}) proposed by Komen et al. (1984) was improved by Yuan et al. (1986) as follows.

$$S_{ds}(E) = -d_1\hat{\sigma}\left(\frac{\sigma}{\hat{\sigma}}\right)^2\left(\frac{\hat{\alpha}}{\hat{\alpha}_{PM}}\right)^{1/2}\exp\left\{-d_2(1-\in^2)\frac{\hat{\alpha}_{PM}}{\hat{\alpha}}\right\}E(\vec{k}) \tag{8}$$

Where

$$\bar{E} = \iint E(\vec{K})d\vec{K}, \hat{\sigma} = \left(\iint E(\vec{K})\sigma^{-1}d\vec{K} / \bar{E}\right)^{-1}, \hat{\alpha} = \bar{E}\hat{\sigma}^4 g^{-2}$$

$$d_1 = 1.32\times10^{-4}, d_2 = 2.61, \hat{\alpha}_{PM} = 3.02\times10^{-3}$$

Spectrum width $\in$=0.6 is used in this model for practical application.

(3) The bottom dissipation source function

The bottom dissipation source function (S_{bo}) was as follows.

$$S_{bo}(E) = -C_b\frac{8K}{sh2Kd}\hat{\sigma}\bar{E}^{\frac{1}{2}}E(\vec{K}) \tag{9}$$

Where the coefficient C_b=2.5×10-3.

(4) The nonlinear wave-wave interaction source function

The nonlinear wave-wave interaction source function (S_{nl}) proposed by Hasselmann (1962, 1963) is

$$S_{nl}(E) = R(KD)\sigma \iiint A(\vec{K}_1,\vec{K}_2,\vec{K}_3,\vec{K})[N_1N_2(N_3+N) - N_3N(N_1+N_2)] \\ \delta(\vec{K}_1+\vec{K}_2-\vec{K}_3-\vec{K})\delta(\sigma_1+\sigma_2-\sigma_3-\sigma)d\vec{K}_1d\vec{K}_2d\vec{K}_3 \tag{10}$$

Here $A(\vec{K}_1,\vec{K}_2,\vec{K}_3,\vec{K})$ is the function of wave-wave interaction; and $N_i = E(\vec{K}_i)/\sigma_i$ represents the action densities. The shallow water factor obtained by JONSWAP data fitting:

$$R(KD) = 1 + \frac{5.5}{KD}(1-\frac{5KD}{6})\exp(-\frac{5KD}{4})$$

In the MASNUM wave model, a parameterized approach (Yuan et al., 1991) is designed to compute this nonlinear interaction source function on the basis of the Hasselmann's computational test (Hasselmann et al., 1985). The parameterized discrete interaction approximation in wave-number space is derived as follow,

$$\begin{Bmatrix} \delta S_{nl} \\ \delta S_{nl+} \\ \delta S_{nl-} \end{Bmatrix} = \begin{Bmatrix} -2 \\ \dfrac{1}{(1+\lambda)^3} \\ \dfrac{1}{(1-\lambda)^3} \end{Bmatrix} C_L g^{\frac{1}{2}} K^{\frac{17}{2}} \left[E^2\left(\frac{E_+}{1+\lambda} + \frac{E_-}{1-\lambda}\right) - 2\frac{EE_+E_-}{1-\lambda^2} \right],$$

where $\lambda = 0.25$, $C_L = 7.86$, and E_+, E_- are the nearby discrete wave-number spectrum. All the increments are concentrated at the nearby discrete points to get the discrete nonlinear interaction term.

(5) The wave-current interaction source function

The wave-current interaction source function (S_{cu}) is

$$S_{cu}(E) = -\{[\frac{C_g}{C}(1+\cos^2\theta_1) - \frac{1}{2}]\frac{\partial U_x}{\partial x} + \frac{C_g}{C}\sin\theta_1\cos\theta_1(\frac{\partial U_x}{\partial y} + \frac{\partial U_y}{\partial x}) \\ +[\frac{C_g}{C}(1+\sin^2\theta_1)] - \frac{1}{2}]\frac{\partial U_y}{\partial y}\}E(\vec{K}) \tag{11}$$

2.4 Numerical scheme: Discretization

The computational phase space is discretized as follows:

$$K(\alpha) = K_{\min} \exp\{(\alpha - 1)\Delta K\}, \qquad \alpha = 1, \cdots, n; \qquad \Delta K = \frac{1}{n-1} \ln \frac{K_{\max}}{K_{\min}},$$

where n=25 in numerical model, $K_{\max} = 0.6894, K_{\min} = 0.0071$

$$\theta(\beta) = (\beta - 1)\Delta\theta, \qquad \beta = 1, \cdots, m; \qquad \Delta\theta = \frac{2\theta}{m}$$

where m=12, $\Delta t = 15\text{min}$ (It should be adjusted according to CFL condition).

The basic computational configuration of MASNUM Wave Model is as follows.

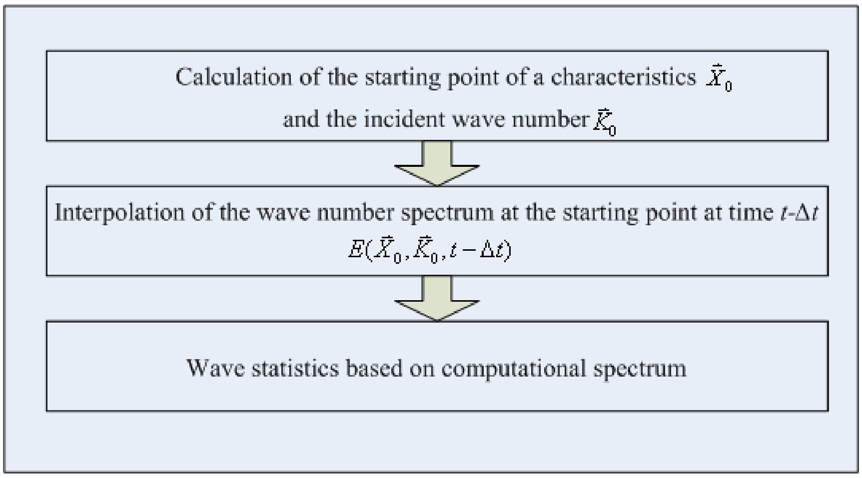


Fig. 1 Characteristic inlaid scheme

In the numerical scheme of the model, a semi-implicit formula is applied for integration,

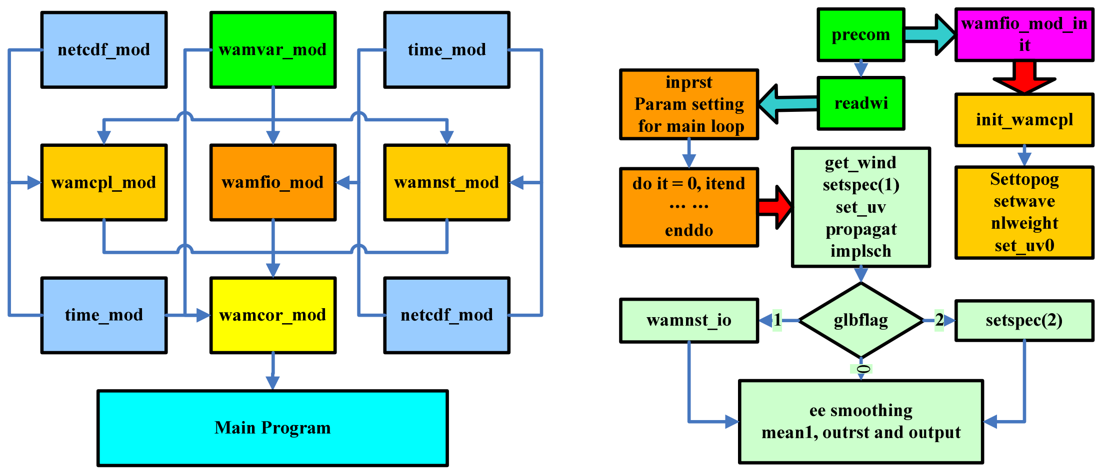
$$E(\vec{X}, \vec{K}, t) = E(\vec{X}_0, \vec{K}_0, t - \Delta t) + \Delta t \begin{Bmatrix} \dfrac{SS(E(\vec{X}, \vec{K}, t - \Delta t)}{1 - \dfrac{\Delta t}{2} \dfrac{\partial SS}{\partial E}}, & 1 - \dfrac{\Delta t}{2} \dfrac{\partial SS}{\partial E} > 1 \\ SS(E(\vec{X}, \vec{K}, t - \Delta t), & 1 - \dfrac{\Delta t}{2} \dfrac{\partial SS}{\partial E} \leq 1 \end{Bmatrix}$$

In the above formula the first term $E(\vec{X}_0, \vec{K}_0, t - \Delta t)$ shows the propagation contribution of wave energy spectrum, and the second term ΔE shows the increment of the spectrum due to the source functions in one computation time step Δt ,where $\vec{k}_0$ is the wave packet at location $\vec{X}_0$ at time $t - \Delta t$, which propagates to grid point $\vec{X}$ at time t and becomes wave number $\vec{k}$. The $(\vec{X}_0, \vec{k}_0)$ can be calculated with the unsteady ray equations. And the corresponding spectrum $E(\vec{k}_0, \vec{x}_0, t - \Delta t)$ at last step can be gained by interpolation procedures both in phase space and in physical space. ΔE will be limited by Phillips' saturation form,

$$\Delta E_p = p\cos^2(\theta-\Theta)H[\cos(\theta-\Theta)]\frac{u_*}{c}k^{-4}.$$

3. Modularization of MASNUM Wave Model

This model is arranged by 7 modules, including 5 main modules and 2 separate modules for useful tools. The dependence of these modules is given in Fig. 2a. By this kind of arranging, the program become much clear and it becomes easier for further development. The flowchart of the main procedures is given in Fig. 2b. The flow of this model is similar as the old version. Some new control flags, and interfaces are added for model input/output, coupling, nesting and etc.



(A) (B)

Fig. 2 The code structure of MASNUM-Wave model
(A: the dependence between different modules.
B: the flowchart of the main program and some key subroutines.)

3.1 Independent modules

The modules of “**netcdf_mod**” and “**time_mod**” are developed by Dr. Xunqiang Yin for personal use. With his advice and permission, these two modules are contained in this model. Module “**netcdf_mod**” contains functions/subroutines can be used to deal with files with NetCDF format. Although this module is developed based on the interfaces provided for handling NetCDF files, this module will accelerate the coding procedure and reducing the chance for coding error. The “**time_mod**” is another separate module contains functions similar as in MATLAB to transfer time within different formats: vector for year, month, day, hour, minute and second; days since from a referred time; string of the time. These two modules can be used for other purpose outside this model, but you'd better ask Yin (XunqiangYin@gmail.com) for an exact guide for the usage and/or the newest versions.

3.2 Module of variables

Module "**wamvar_mod**" is designed for the most variables used in this model, including parameters, constants and arrays. All the arrays are designed as size-alterable, and a contained subroutine is used to allocate memory for these arrays.

3.3 Module of file input/output

Module "**wamfio_mod**" is for the input/output of this model. The input files include control parameters, topography, and wind data. The model size will be specified in this module by detecting the size of topography and the related settings including longitude, latitude, grid spacing and etc. will be calculated then. For some popular wind data, some subroutines are added into this module for interpolation automatically. The output files include the statistic fields of ocean surface wave and the wave-current mixing coefficients. The statistic fields are listed in the follows.

(1) Frequency-direction energy spectrum

$$E(f,\theta) = 2\pi E(\vec{k})k\left(\frac{\partial\omega}{\partial k}\right)^{-1}$$

where the frequency division is taken as below,

$$f_i = \frac{\omega_i}{2\pi} = \frac{1}{2\pi}\sqrt{gk_i thk_i d}, \qquad i = 1,\cdots,n-1$$

(2) Frequency energy spectrum

$$E(f) = 2\pi\int_0^{2\pi} E(\vec{k})k\left(\frac{\partial\omega}{\partial k}\right)^{-1} d\theta = 2\pi k\left(\frac{\partial\omega}{\partial k}\right)^{-1}\int_0^{2\pi} E(\vec{k})d\theta$$

(3) Significant wave height

The significant height of wave is formulated as

$$Hs = 4.0\sqrt{\mu_0}$$

Here $\mu_0 = \iint_k E(\vec{k})kdkd\theta$ is zero order moment of the spectrum.

(4) Zero-crossing wave period

Zero-crossing wave period is calculated as

$$Tz = 2\pi\left(\frac{\mu_0}{\mu_2}\right)^{1/2}$$

Where $\mu_2 = \iint_k \omega^2 E(\vec{k})kdkd\theta$ is 2 order moment of the spectrum and the dispersion relation $\omega = (gkthkd)^{1/2}$ is used.

(5) Spectrum peak wave period

The spectrum peak wave period is defined as

$$Tp = 2\pi\left(\frac{\mu_{-2}\mu_1}{\mu_0{}^2}\right)$$

Where

$$\mu_{-2} = \iint_k \omega^{-2} E(\vec{k})kdkd\theta$$

$$\mu_1 = \iint_k \omega E(\vec{k})kdkd\theta$$

represent the -2 and 1 order moment of the spectrum.

(6) Mean wave direction

The mean wave direction is defined as

$$\theta = \tan^{-1}\frac{\int_{k_1}^{k_2}\int_0^{2\pi}\sin\theta Ekdkd\theta}{\int_{k_1}^{k_2}\int_0^{2\pi}\cos\theta E(k)kdkd\theta}$$

Here, $k_1 \geq k\left(\frac{0.8}{Tp}\right)$, $k_2 \leq \left(\frac{1.4}{Tp}\right)$

3.4 Module for core subroutines

This module contains the core subroutines of wave model, including PRECOM, READWI, PROPAGAT, IMPLSCH, SETSPEC, MEAN1, MEAN2 and INTER. The first 2 subroutines are for the main loop and initialization respectively, and the other subroutines are set to be private used only in this module. The detailed descriptions for some main subroutines are given in the following.

(1) SUBROUTINE PROPAGAT

This subroutine calculates the location $\vec{X}_0$, wave-number $\vec{K}_0$ of the wave packet at time $t-\Delta t$ which propagates to grid point $\vec{X}$ at time t and becomes wave-number $\vec{K}$ through the complicated characteristic equations (2-5). Then the corresponding spectrum $E(\vec{K}_0, X_0, t-\Delta t)$ at time t is gained by interpolation procedures both in phase space and in physical space.

(2) SUBROUTINE IMPLSCH

This subroutine calculates the net source function, which contains the input source function S_{in}, the wave breaking dissipation function S_{ds}, the bottom friction dissipation function S_{bs}, the wave-wave weak interaction function S_{nl} and the wave-current interaction S_{cu}. Before to calculate these source functions, several order moments of wave spectrum are integrated by Subroutine mean2. At every location $\vec{X}_0$ at time $t-\Delta t$, the net source function $SS(E)$ is summed, together with the deferential of $SS(E)$ with respect to spectrum E. For the complicated functional derivative matrix of source functions with respect to wave spectrum, only the diagonal part of the matrix is retained. Then the semi-implicit scheme is used to compute the increment of spectrum as stated in Section 4. The growth spectrum limiter is added in the end of the subroutine, and this limiter restrains the singularity of source functions.

3.5 Module for coupling subroutines

Currently, this module contains subroutines for one-way coupling with current and ice. Later, we will add more for the coupling with tide for wet/dry region near the coast. Also, the two-way coupling procedure will be developed from this module.

The coupling with current is composed by 2 processes: one is the source function from background flow and the other part is the wave induced mixing based on the theory developed by Qiao et al. (2004). If only wave model is running, the background current is needed and the relevant mixing coefficients can be output as the wave-induced mixing for the circulation models. For two-way coupling with current, this module should be used in the circulation model to update the background current and get the wave-induced mixing for circulation.

The coupling with ice employed here is only one way couple by means of varying masks according to the coverage of ice. Currently, a climatology mask based on the coverage of ice in the global domain is used in this model. Users can develop new ice coverage file with the same format. It is not necessary to prepare this file at the same grid as the wave model. But the grids should be set as even divided latitude/longitude, and the region for the ice mask has to be greater than the model domain. Once the file for ice mask is ready, the wave model will update its mask by interpolation.

3.6 Module for nesting subroutines

This part is under developing.

4. Format of input/output files in MASNUM-WAM 2.2

The model IO is through files with ASCII or NetCDF format. There are 3 files for input, include: control parameters, topography setting and wind data. The first one is an ASCII file for the controlling parameters and the second one is NETCDF file for the data of topography, land mask, longitude, latitude at each grid points and the layers for output of current coefficient. Wind data can be 4 kinds: default wind data (prepared to have the same grids with the topography), downloaded GSF wind NETCDF data, QuikSCAT blend wind and NCEP re-analysis wind data (daily or 6 hourly). Three kind of output files are used for model restart, wave and mixing results. They are all arranged in NetCDF format.

4.1 Control parameters

File name: ctlparams

This file has to be named as "ctlparams", and the descriptions of its contained parameters are listed in the following table. The frequency for output should be times of time interval and the time interval should exactly divide one day. One can prepare this file by UNIX shell scripts or change this example by hand.

Table 2 The list of parameters in the file of "ctlparams" and an example

<table>
<tr><th>Lines</th><th>Symbols</th><th>Meaning</th><th>example</th></tr>
<tr><td>Line 1</td><td>data path</td><td>The path for file of topography.</td><td rowspan="9">D:\Data\
D:\Data\
&CTLPARAMS
TITLE = glb500,
CISTIME = 20080101,
CIETIME = 20080101,
COOLS_DAYS = 5,
DELTTM = 10.0,
WNDFREQ = 6,
WNDTYPE = 3,
OUTFLAG = 1,
WIOFREQ = 1,
CIOFREQ = 0
RSTFREQ = 1,
/</td></tr>
<tr><td>Line 2</td><td>wind path</td><td>The path for wind data.</td></tr>
<tr><td rowspan="11">Line 3-16</td><td>TITLE</td><td>Symbol for model output.</td></tr>
<tr><td>CISTIME</td><td>Start time for integration.</td></tr>
<tr><td>CIETIME</td><td>End time for integration.</td></tr>
<tr><td>COOLS_DAYS</td><td>The time (days) for cool start.</td></tr>
<tr><td>DELTTM</td><td>Integral time step in minute.</td></tr>
<tr><td>WNDFREQ</td><td>The frequency of wind data, in hours.</td></tr>
<tr><td>WNDTYPE</td><td>Input wind type:
0 Wind with same grid as model;
1 GFS wind data, no interpolation;
2 QuikSCAT blend wind with interpolation.
3 NCEP re-analysis wind data with interpolation.</td></tr>
<tr><td>OUTFLAG</td><td colspan="2">The method of output: 0 One file for each run;
1 One file every year;
2 One file every month;
3 One file for every day.</td></tr>
<tr><td>WIOFREQ</td><td colspan="2">The output frequency for wave results by hours.</td></tr>
<tr><td>CIOFREQ</td><td colspan="2">The output frequency for current coefficients by hours. 0 is no output.</td></tr>
<tr><td>RSTFREQ</td><td colspan="2">The output frequency for restart in hours.</td></tr>
</table>

4.2 Topography setting

File name: wamyyz.nc

This file is an NETCDF file and its descriptions are listed as following. In this file, lon is for longitude and lat is for latitude for the grid as an axis, depyyz is for topography and nspyyz is the land mask (0 for land, 1 for water and 2 for open boundary) for each grid points. This file needs to be prepared in the same format for model setup; zyyz is for the output layers of mixing coefficients for current. If one wants to specify the layers for output of current coefficient, the variable named ‘zyyz’ should be given here.

```
netcdf wamyyz {
dimensions:
        lon = 721 ;     // --- example
        lat = 290 ;     // --- example
        zyyz = 32 ;   // --- example
variables:
        float lon(lon) ;
                lon:units = "degrees_east" ;
                lon:modulo = "" ;
        float lat(lat) ;
                lat:units = "degrees_north" ;
        float zyyz(zyyz) ;
        float depyyz(lat, lon) ;
        int nspyyz(lat, lon) ;
                nspyyz:missing_value = 0.f ;
}
```

4.3 Wind data

Currently, this model can accept 4 kinds of wind input as listed below.

(1) Default wind

In this case, the wind is prepared specially and has the same grids with the model topography. The description of this data is listed in the following table.

```
netcdf wind_200901 {
dimensions:
        lon = 720 ;
        lat = 353 ;
        char = 10 ;
```

```
        time = UNLIMITED ; // (124 currently)
variables:
        float lon(lon) ;
                lon:units = "degrees_east" ;
                lon:modulo = "" ;
        float lat(lat) ;
                lat:units = "degrees_north" ;
        float char(char) ;
        float time(time) ;
                time:units = "Days since 1950-1-1 00:00:00.0" ;
        float windx(time, lat, lon) ;
        float windy(time, lat, lon) ;
        char ctime(time, char) ;
// global attributes:
                :Creattime = "2009/12/11T14:56:48" ;
                :Sorftware1 = "netcdf 3.5.0 of Apr    4 2001 19:29:34 $" ;
                :Sorftware2 = "netcdf_mod 2.1, by Xunqiang Yin, 2008-3-31
                  23:15. " ;
}
```

(2) GSF wind

This wind should be NetCDF version, and the model grid system should be the same as this wind data. The description of this data is listed in the following table.

```
netcdf wind200901 {
dimensions:
        lon = 720 ;
        lat = 353 ;
        char = 10 ;
        time = UNLIMITED ; // (124 currently)
variables:
```

(3) QuikSCAT blend wind

The wind data have to be re-written in NetCDF format as described in the following.

```
netcdf wind200901 {
dimensions:
        lon = 720 ;
        lat = 353 ;
        char = 10 ;
        time = UNLIMITED ; // (124 currently)
variables:
```

```
        float lon(lon) ;
                lon:units = "degrees_east" ;
                lon:modulo = "" ;
        float lat(lat) ;
                lat:units = "degrees_north" ;
        float char(char) ;
        float time(time) ;
                time:units = "Days since 1950-1-1 00:00:00.0" ;
        float windu(time, lat, lon) ;
        float windv(time, lat, lon) ;
        char ctime(time, char) ;
// global attributes:
                :Creattime = "2009/12/11T14:56:48" ;
                :Sorftware1 = "netcdf 3.5.0 of Apr  4 2001 19:29:34 $" ;
                :Sorftware2 = "netcdf_mod 2.1, by Xunqiang Yin, 2008-3-31
                  23:15. " ;
}
```

(4) NCEP re-analysis wind

In this case, NCEP provided daily and 6 hourly wind data provided by NCEP can be used. For each ear, there are 2 files for U and V respectively. These data can be found on the website of http://www.esrl.noaa.gov/psd/data/reanalysis/.

```
netcdf uwnd.sig995.2008 {
dimensions:
        lon = 144 ;
        lat = 73 ;
        time = UNLIMITED ; // (1464 currently)
variables:
        float lat(lat) ;
                lat:units = "degrees_north" ;
                lat:actual_range = 90.f, -90.f ;
                lat:long_name = "Latitude" ;
        float lon(lon) ;
                lon:units = "degrees_east" ;
                lon:long_name = "Longitude" ;
                lon:actual_range = 0.f, 357.5f ;
        double time(time) ;
                time:units = "hours since 1-1-1 00:00:0.0" ;
                time:long_name = "Time" ;
                time:actual_range = 17593032., 17601810. ;
                time:delta_t = "0000-00-00 06:00:00" ;
        short uwnd(time, lat, lon) ;
```

```
                    uwnd:long_name = "4xDaily u-wind at sigma level 995" ;
                    uwnd:valid_range = -102.2f, 102.2f ;
                    uwnd:actual_range = -38.49998f, 36.2f ;
                    uwnd:units = "m/s" ;
                    uwnd:add_offset = 225.45f ;
                    uwnd:scale_factor = 0.01f ;
                    uwnd:missing_value = 32766s ;
                    uwnd:precision = 2s ;
                    uwnd:least_significant_digit = 1s ;
                    uwnd:GRIB_id = 33s ;
                    uwnd:GRIB_name = "UGRD" ;
                    uwnd:var_desc = "u-wind\n","U" ;
                    uwnd:dataset = "NMC Reanalysis\n", "L" ;
                    uwnd:level_desc = "Surface\n","0" ;
                    uwnd:statistic = "Individual Obs\n", "I" ;
                    uwnd:parent_stat = "Other\n","-" ;
// global attributes:
                    :Conventions = "COARDS" ;
                    :title = "4x daily NMC reanalysis (2008)" ;
                    :history = "created 2007/12 by Hoop (netCDF2.3)" ;
                    :description = "Data is from NMC initialized reanalysis\n",
                    "(4x/day).    These are the 0.9950 sigma level values." ;
                    :platform = "Model" ;
}
netcdf vwnd.sig995.2008 {
dimensions:
          lon = 144 ;
          lat = 73 ;
          time = UNLIMITED ; // (1464 currently)
variables:
          float lat(lat) ;
                    lat:units = "degrees_north" ;
                    lat:actual_range = 90.f, -90.f ;
                    lat:long_name = "Latitude" ;
          float lon(lon) ;
                    lon:units = "degrees_east" ;
                    lon:long_name = "Longitude" ;
                    lon:actual_range = 0.f, 357.5f ;
          double time(time) ;
                    time:units = "hours since 1-1-1 00:00:0.0" ;
                    time:long_name = "Time" ;
                    time:actual_range = 17593032., 17601810. ;
                    time:delta_t = "0000-00-00 06:00:00" ;
          short vwnd(time, lat, lon) ;
```

```
                vwnd:long_name = "4xDaily v wind at sigma level 995" ;
                vwnd:valid_range = -102.2f, 102.2f ;
                vwnd:actual_range = -38.8f, 37.89999f ;
                vwnd:units = "m/s" ;
                vwnd:add_offset = 225.45f ;
                vwnd:scale_factor = 0.01f ;
                vwnd:missing_value = 32766s ;
                vwnd:precision = 2s ;
                vwnd:least_significant_digit = 1s ;
                vwnd:GRIB_id = 34s ;
                vwnd:GRIB_name = "VGRD" ;
                vwnd:var_desc = "v-wind\n", "V" ;
                vwnd:dataset = "NMC Reanalysis\n", "L" ;
                vwnd:level_desc = "Surface\n", "0" ;
                vwnd:statistic = "Individual Obs\n", "I" ;
                vwnd:parent_stat = "Other\n", "-" ;
// global attributes:
                :Conventions = "COARDS" ;
                :title = "4x daily NMC reanalysis (2008)" ;
                :history = "created 2007/12 by Hoop (netCDF2.3)" ;
                :description = "Data is from NMC initialized reanalysis\n",
                      "(4x/day).    These are the 0.9950 sigma level values." ;
                :platform = "Model" ;
}
```

4.4 Files of output

(1) Restart file

Filename: wave_rest.nc

```
netcdf wave_rest {
dimensions:
        kk = 25 ;
        jj = 12 ;
        lon = 721 ;
        lat = 290 ;
variables:
        float kk(kk) ;
        float jj(jj) ;
        float lon(lon) ;
                lon:units = "degrees_east" ;
                lon:modulo = "" ;
        float lat(lat) ;
                lat:units = "degrees_north" ;
```

```
        float ee(lat, lon, jj, kk) ;
// global attributes:
                :ctime = "20080101000000" ;
                :Creattime = "2010/04/11T22:23:42" ;
                :Sorftware1 = "netcdf 3.5.0 of Apr    4 2001 19:29:34 $" ;
                :Sorftware2 = "netcdf_mod 2.1, by Xunqiang Yin, 2008-3-31
                        23:15. " ;
}
```

(2) Wave output.

Filename: [title]_wav_[ctime].nc

The output filename contains the "TITLE" and the start time of this output. If the output is arranged for each run, the time will be 14 characters in the format of "yyyymmddHHMMSS" (e.g. 20080805102819). If the output is arranged by daily, monthly, or yearly, the time will be 8, 6 or 4 respectively. The NetCDF description is listed in the follows.

```
netcdf [title]_wav_[ctime] {
dimensions:
        lon = 721 ;
        lat = 290 ;
        time = UNLIMITED ; // (1 currently)
variables:
        float lon(lon) ;
                lon:units = "degrees_east" ;
                lon:modulo = "" ;
        float lat(lat) ;
                lat:units = "degrees_north" ;
        float time(time) ;
                time:units = "Days since 1950-01-01 00:00:0.0." ;
        short windx(time, lat, lon) ;
                windx:missing_value = -32767 ;
                windx:scale_factor = 0.01f ;
                windx:units = "m/s" ;
                windx:longname = "Zonal Wind Velocity" ;
        short windy(time, lat, lon) ;
                windy:missing_value = -32767 ;
                windy:scale_factor = 0.01f ;
                windy:units = "m/s" ;
                windy:longname = "Meridional Wind Velocity" ;
        short hs(time, lat, lon) ;
```

```
                hs:missing_value = -32767 ;
                hs:scale_factor = 0.01f ;
                hs:units = "m" ;
                hs:longname = "Significant wave height" ;
        short tp(time, lat, lon) ;
                tp:missing_value = -32767 ;
                tp:scale_factor = 0.01f ;
                tp:units = "s" ;
                tp:longname = "Spectrum peak wave period" ;
        short tz(time, lat, lon) ;
                tz:missing_value = -32767 ;
                tz:scale_factor = 0.01f ;
                tz:units = "s" ;
                tz:longname = "Zero-crossing wave period" ;
        short th(time, lat, lon) ;
                th:missing_value = -32767 ;
                th:scale_factor = 0.1f ;
                th:units = "deg" ;
                th:longname = "Mean wave direction" ;
// global attributes:
                :Start_time = "20080101000000" ;
                :Creattime = "2010/04/11T22:34:46" ;
                :Sorftware1 = "netcdf 3.5.0 of Apr    4 2001 19:29:34 $" ;
                :Sorftware2 = "netcdf_mod 2.1, by Xunqiang Yin, 2008-3-31
                        23:15. " ;
}
```

(3) Mixing coefficients

Filename: [title]_mix_[ctime].nc

The filename is similar as wave output. Since the output flag is not applied for this output, the time here is always kept 8 characters in the format of “yyyymmdd”.

```
netcdf [title]_mix_[ctime] {
dimensions:
        lon = 721 ;
        lat = 290 ;
        dep = 32 ;
variables:
        float lon(lon) ;
                lon:units = "degrees_east" ;
                lon:modulo = "" ;
        float lat(lat) ;
                lat:units = "degrees_north" ;
```

```
        float dep(dep) ;
        float tau11(dep, lat, lon) ;
                tau11:missing_value = 9.96921e+036f ;
        float tau12(dep, lat, lon) ;
                tau12:missing_value = 9.96921e+036f ;
        float tau22(dep, lat, lon) ;
                tau22:missing_value = 9.96921e+036f ;
        float tau33(dep, lat, lon) ;
                tau33:missing_value = 9.96921e+036f ;
        float bv(dep, lat, lon) ;
                bv:missing_value = 9.96921e+036f ;
// global attributes:
                :ctime = "20080101000000" ;
                :Creattime = "2010/04/11T22:54:36" ;
                :Sorftware1 = "netcdf 3.5.0 of Apr  4 2001 19:29:34 $" ;
                :Sorftware2 = "netcdf_mod 2.1, by Xunqiang Yin, 2008-3-31
                        23:15. " ;
}
```

5. Description of Symbols in MASNUM-WAM 2.2

Table 3 List of symbols in MASNUM-WAM 2.2: Indices, Constants and Arrays

Indices	Description
ia, ic	Horizontal grid indexes.
k, j	Grid indexes in wave-number space.
kh	Vertical grid index: kh = 1 at the top and kh = kb at the bottom.
data_path	Path for model setting.
wind_path	Path for wind.
title	Symbol for model output.
istime	Start time of model integration.
istime	End time of model integration.
cools_days	The time (days) for cool start.
delttm	Length of integration time step, in minutes.
lonref	The referred longitude to ensure that $X(1) \geq 0$.
glbflag	Global flag, 0 for global model, 1 for regional.
wndfreq	The frequency of wind data, in hours.
wndtype	Wind type.
outflag	The method of output.
rstfreq	The output frequency for model restart.
wiofreq	The output frequency for wave results.
ciofreq	The output frequency for current coef.s (mixing).
Constants	**Description**
rs (= 6367451.637)	The global (Earth) radius.
pi (= 3.14159265)	Pi (π).
g (= 9.81)	Acceleration of gravity.
tztz (= 1.099314)	Coefficient for zero-crossing wave period.
wkmax (=0.6894)	Maximum of wave-umber amplitude
wkmin (=0.0071)	Minimum of wave-number amplitude
wfmax (=0.413)	Maximum of wave frequency
wfmin (=0.042)	Minimum of wave frequency
d1 (= 0.000132)	Coefficient in wave-breaking dissipation formula
d2 (= 2.61)	Coefficient in wave-breaking dissipation formula
beta0 (= 1.0)	Coefficient for wind input
ads (= 1.0)	Theoretical coefficient for wave-breaking dissipation
abo (= 1.0)	Theoretical coefficient for bottom dissipation
acu (= 0.)	Theoretical coefficient for wave-current interaction
pwk (= 1.21)	The constant for discretion of wave-number
cksp (= 14.0)	Coefficient for estimation of wave-number range
cksa (= 4.5)	Coefficient for estimation of wave-number range
p (= 0.025)	Coefficient for growth spectrum limiter

cgro (= 0.0003176)	Coefficient for growth spectrum limiter
Small(=0.000001)	Small value.
1-D arrays	**Description**
x(ixs:ixl)	Longitude rang from 0~360.
rx(ixs:ixl)	Real longitude.
y(iys:iyl)	Latitude rang from -90~90.
deltx(iys :iyl)	Grid size along longitude.
delty(iys :iyl)	Grid size along latitude.
zyyz(1:kb)	depth of each layer
rslat(iys:iyl)	*rs × cos(lat.)*.
grolim(kl)	Growth spectrum limiter
thet(jlp1)	Directional discrete for 12 bands (30^0 resolution)
wk(kldp1)	Wave-number discrete for 25 bands on a logarithmic scale, with $K(\alpha)=K_{\min}\exp\{(\alpha-1)\Delta K\},\alpha=1,\cdots,25;\Delta K=\frac{1}{n-1}\ln\frac{K_{max}}{K_{\min}}$
wkh(kldp1)	coefficient for computing high-frenquency spectrum
dwk(kldp1)	Discrete bands of wave-number
wks17(kl)	17/2 exponential of wave-number, that is K**(17/2)
ikp, ikp1, ikm,ikm1 (kl)	wave-number discrete-interaction configurations of nonlinear wave-wave transfer
2-D arrays	**Description**
d(ixs:ixl, iys:iyl)	the bottom depth (m) for topography
nsp(ixs:ixl, iys:iyl)	Computing mask for scalar variables: **0** for land, **1** for water and **2** for open boundary.
noicensp(ixs:ixl, iys:iyl)	Backup of mask without ice covered.
icensp(ixs:ixl, iys:iyl)	Mask for ice, 0 for ice/land, 1 for water.
tim(ixs:ixl, iys:iyl)	Temporary array for maximum time step at each water points.
wx, wy(ixs:ixl, iys:iyl)	Wind velocity along longitude and latitude
w(ixs:ixl, iys:iyl)	The wind speed
ae(ixs:ixl, iys:iyl)	The zero-order moment of the spectrum
awf(ixs:ixl, iys:iyl)	The frequency first-order moment of the spectrum
asi(ixs:ixl, iys:iyl)	The frequency negative first-order moment of the spectrum
awk(ixs:ixl, iys:iyl)	The frequency negative second-order moment of the spectrum
hb, hbb(ixs:ixl, iys:iyl)	The Hs limiter through wave breaking
jp1, jp2, jm1, jm2(2,jl)	Angular discrete-interaction configurations of nonlinear wave-wave transfer

ux, uy, uxx, uxy, uyx, uyy(ixs:ixl, iys:iyl)	Background 2D currents (ux and uy, unit is m/s) and its partial differentials: uxy=dux/dy, uxx=dux/dx, uyy=duy/dy, uyx=duy/dx
se(klp1,jl)	Increment of spectrum (m4/s)
dse(klp1,jl)	Deferential of se with respect to spectrum (s-1)
h1_3(ixs:ixl, iys:iyl)	**hs:** significant wave height (m)
aet(ixs:ixl, iys:iyl)	**th:** mean wave direction (Deg)
tpf(ixs:ixl, iys:iyl)	**tp:** spectrum peak wave period (s)
ape(ixs:ixl, iys:iyl)	**tz:** zero-crossing wave period (s)
dddx, dddy(ixl, iyl)	For d(d)/d(x) and d(d) / d(y).
enh(ixs:ixl, iys:iyl)	shallow water factor for nonlinear wave-wave transfer
ark(ixs:ixl, iys:iyl)	spectral mean of wave-number
ks0(ixs:ixl, iys:iyl)	threshold of wave-number determined by wind speed or spectral mean of wave-number
kpmt0(ixs:ixl, iys:iyl)	threshold of wave-number determined by wind speed
kakt0(ixs:ixl, iys:iyl)	threshold of wave-number determined by spectral mean of wave-number
3-D arrays	**Description**
bv(ixs:ixl, iys:iyl, kb)	Wave-induced mixing (m^2/s)
taubb11,taubb12 taubb22,taubb33 (ixs:ixl, iys:iyl, kb)	Wave-induced Reynolds stresses (m^2/s^2)
wp(kl, 2, 2)	weighting factor of K+ for decomposing wave-wave transfer
wm(kl, 2, 2)	weighting factor of K- for decomposing wave-wave transfer
fconst0 (kl,ixs:ixl, iys:iyl)	computing mask for threshold of wave-number
wf (kldp1,ixs:ixl, iys:iyl)	wave frequency
ccg (kldp1,ixs:ixl, iys:iyl)	group velocity
dwf (kldp1,ixs:ixl, iys:iyl)	discrete bands of wave frequency multiplied by half of directional discrete
4-D arrays	**Description**
e(kl, jl, ixs:ixl, iys:iyl)	Wave spectrum through propagation (m4)
ee(kl, jl, ixs:ixl, iys:iyl)	Wave spectrum (m4)
ea(kl, jl, ixs:ixl, iys:iyl)	Time averaged ee (m4)

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