

Implementation of the Wave Radiation Stress Gradient as a Forcing for
the ADCIRC Hydrodynamic Model:
Upgrades and Documentation for ADCIRC Version 34.12

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FORMULATION

It is well known that nonlinearities in the momentum balance of surface gravity waves result in momentum being transferred from the surface wave frequency to low frequency. Specifically, waves whose amplitude and period are constant in time generate momentum at zero frequency (steady) via what has been termed “radiation stresses” (e.g., Longuet-Higgins and Stewart, 1964). Newton’s second law of motion requires that gradients in these radiation stresses must be balanced by a steady force and consequently wave setup or setdown and longshore currents result (Massel, 1989; Dean and Dalrymple, 1991).

If we assume that the wave field changes slowly in time, the radiation stress gradients can be included in the momentum balance of long wave models such as ADCIRC (Luettich et al, 1992, Westerink et al, 1994, Luettich and Westerink, 1999). In this case the momentum equations are modified from those given by Eqs. (25,26) in Luettich et al. (1992) to:

$$\frac{\partial U}{\partial t} + U \frac{\partial U}{\partial x} + V \frac{\partial U}{\partial x} - fV = -\frac{\partial}{\partial x} \left[\frac{p_s}{\rho_o} + g(\zeta - \alpha\eta) \right] + \frac{1}{H} \left[M_x + D_x + B_x + R_x + \frac{\tau_{sx}}{\rho_o} - \frac{\tau_{bx}}{\rho_o} \right]$$

$$\frac{\partial V}{\partial t} + U \frac{\partial V}{\partial x} + V \frac{\partial V}{\partial x} + fU = -\frac{\partial}{\partial y} \left[\frac{p_s}{\rho_o} + g(\zeta - \alpha\eta) \right] + \frac{1}{H} \left[M_y + D_y + B_y + R_y + \frac{\tau_{sy}}{\rho_o} - \frac{\tau_{by}}{\rho_o} \right]$$

All variables are as defined in Luettich et al, (1992), with the exception of the radiation stress gradient terms which are defined as:

$$R_x \equiv \frac{1}{\rho_o} \left[\frac{\partial S_{xx}}{\partial x} + \frac{\partial S_{xy}}{\partial y} \right] \quad \text{and} \quad R_y \equiv \frac{1}{\rho_o} \left[\frac{\partial S_{xy}}{\partial x} + \frac{\partial S_{yy}}{\partial y} \right]$$

where S_{xx} , S_{yy} , $S_{xy} = S_{yx}$ are the radiation stresses, presumably computed from a short wave model. *It is important to note that the stress gradients must be computed using a coordinate system that is oriented in the same direction as the long wave model, which is likely to be different than that used for the short wave model.*

ACTIVATING WAVE RADIATION STRESSES IN ADCIRC VERSION 34.12

The radiation stress gradients R_x and R_y appear as external forcing terms in the long wave momentum equations and must be input to the calculation in much the same way as the wind stress terms τ_{sx}/ρ_o and τ_{sy}/ρ_o . Therefore, in ADCIRC we have bundled these terms with the wind stresses. If desired, radiation stress gradients are read in at a specified time interval from a **fort.23** file during the course of the simulation. The parameter NWS located in the master input parameter file (**fort.15**) controls whether ADCIRC will attempt to read meteorological (wind and pressure) forcing (from **fort.22** or **fort.200** series files), radiation stress forcing (from a **fort.23** file) or both. The parameter RSTIMINC in the master input parameter

file (*fort.15*) controls the time interval between radiation stress values. This may be assigned a value that is different from the parameter in the master parameter file (*fort.15*) that controls the time interval between meteorological input values (WTIMINC).

The parameter NWS is located on line 16 of the *fort.15* file and may have the following values:

- NWS = 0 No wind *stress*, wind *velocity*, pressure or radiation stress gradient forcings are used.
- NWS = 1 Wind *stress* and pressure are read in at all grid nodes from an input file (*fort.22*) at a wind time interval that is equal to the model time step. It is assumed that the first values in the *fort.22* file correspond to the beginning of the model run (i.e., the cold start time). If the model is hot started, initial values in the *fort.22* file will be skipped until the model hot start time is reached. Units of input stress are $(length/time)^2$ - which is actually stress/reference density of water - and of pressure are *length of water* - which is actually pressure/reference density of water/acceleration of gravity. In both cases *length* must match the units used in the grid. If a lon, lat coordinate system is used in the grid, *length* units are assumed to be meters.
- NWS = 2 Wind *stress* and pressure are read in at all grid nodes from an input file (*fort.22*) at a wind time interval that is not equal to the model time step. It is assumed that the first values in the *fort.22* file correspond to the beginning of the model run (i.e., the cold start time). If the model is hot started, initial values in the *fort.22* file will be skipped until the model hot start time is reached. Interpolation in time is used to synchronize the stress and pressure fields with the model time step. Units of input stress are $(length/time)^2$ - which is actually (force/area)/reference density of water - and of pressure are *length of water* - which is actually (force/area)/reference density of water/acceleration of gravity. In both cases *length* must match the units used in the grid. If a lon, lat coordinate system is used in the grid, *length* units are assumed to be meters. The wind time interval (WTIMINC) must be specified in the input parameter file (*fort.15*).
- NWS = 3 Wind *speed* and *direction* (10 m) are read in from a US Navy Fleet Numeric format file (*fort.22*) that provides data on a Cartesian grid at a wind time interval that is not equal to the model time step. Velocity is interpolated in space onto the ADCIRC grid. Based on the specified beginning time of the run, ADCIRC will attempt to locate the proper place to begin in the *fort.22* file. Interpolation in time is used to synchronize the velocity fields with the model time step. The unit of wind speed is meters/sec and of wind direction is degrees clockwise from North. Direction references the direction the wind is blowing from. No pressure information is read in and therefore it is assumed that the surface pressure gradient is zero. Several parameters describing the fleet numeric wind file, including the wind time interval (WTIMINC) and the beginning time of the run must be specified in the input parameter (*fort.15*) file. Garret's formula is used to compute wind stress from wind speed and direction.

- NWS = 4 Wind *velocity* (10 m) and pressure (surface) are read in from a PBL format file (*fort.22*) at a subset of ADCIRC grid nodes at a wind time interval that is not equal to the model time step. It is assumed that the first values in the *fort.22* file correspond to the beginning of the model run (i.e., the cold start time). If the model is hot started, initial values in the *fort.22* file will be skipped until the model hot start time is reached. Interpolation in time is used to synchronize the velocity and pressure fields with the model time step. Units of velocity are knots and of pressure are Pascals = Newtons/m². Velocity references the direction the wind is blowing toward. The wind time interval (WTIMINC) must be specified in the input parameter file (*fort.15*). Garret's formula is used to compute wind stress from velocity.
- NWS = -4 Wind *velocity* (10 m) and pressure (surface) are read in from a PBL format file (*fort.22*) at a subset of ADCIRC grid nodes at a wind time interval that is not equal to the model time step. This option is different from NWS = 4 because it is assumed that the first values in the *fort.22* file correspond either to (i) the beginning of the model run (i.e., the cold start time) if the run has been cold started or (ii) the hot start time if the model has been hot started. Regardless of whether the model is cold started or hot started, ADCIRC will not skip any values at the beginning of the *fort.22* file. Interpolation in time is used to synchronize the velocity and pressure fields with the model time step. Units of velocity are knots and of pressure are Pascals = Newtons/m². Velocity references the direction the wind is blowing toward. The wind time interval (WTIMINC) must be specified in the input parameter file (*fort.15*). Garret's formula is used to compute wind stress from velocity.
- NWS = 5 Wind *velocity* (10 m) and pressure (surface) are read in at all grid nodes from an input file (*fort.22*) at a wind time interval that is not equal to the model time step. It is assumed that the first values in the *fort.22* file correspond to the beginning of the model run (i.e., the cold start time). If the model is hot started, initial values in the *fort.22* file will be skipped until the model hot start time is reached. Interpolation in time is used to synchronize the velocity and pressure fields with the model time step. Units of velocity are *length/time* and of pressure are *length of water*. Velocity references the direction the wind is blowing toward. In both cases *length* must match the units used in the grid. If a lon, lat coordinate system is used in the grid, *length* units are assumed to be meters. The wind time interval (WTIMINC) must be specified in the input parameter file (*fort.15*). Garret's formula is used to compute wind stress from velocity.
- NWS = -5 Wind *velocity* (10 m) and pressure (surface) are read in at all grid nodes from an input file (*fort.22*) at a wind time interval that is not equal to the model time step. This option is different from NWS = 5 because it is assumed that the first values in the *fort.22* file correspond either to (i) the beginning of the model run (i.e., the cold start time) if the run has been cold started or (ii) the hot start time if the model has been hot started. Regardless of whether the model is cold started or hot started, ADCIRC will not skip any values at the beginning of the *fort.22* file. Interpolation in time is used to synchronize the velocity and pressure fields with the model time step. Units of velocity are *length/time* and of pressure are *length*

of water. Velocity references the direction the wind is blowing toward. In both cases *length* must match the units used in the grid. If a lon, lat coordinate system is used in the grid, *length* units are assumed to be meters. The wind time interval (WTIMINC) must be specified in the input parameter file (**fort.15**). Garret's formula is used to compute wind stress from velocity.

NWS = 6 Wind *velocity* (10 m) and pressure (surface) are read in from an input file (**fort.22**) that provides data on a Cartesian grid (either in lon,lat or lineal coordinates – consistent with the grid) at a wind time interval that is not equal to the model time step. Velocity and pressure are interpolated in space onto the ADCIRC grid. It is assumed that the first values in the **fort.22** file correspond to the beginning of the model run (i.e., the cold start time). If the model is hot started, initial values in the **fort.22** file will be skipped until the model hot start time is reached. Interpolation in time is used to synchronize the velocity and pressure fields with the model time step. Units of velocity are meters/sec and of pressure are Pascals = Newtons/m². Velocity references the direction the wind is blowing toward. The wind time interval (WTIMINC) must be specified in the input parameter file (**fort.15**). Garret's formula is used to compute wind stress from velocity.

NWS = 10 Wind *velocity* (10 m) and pressure (surface) are read in from a sequence of "SFLUX" type files from the National Weather Service AVN meteorological model that provides data on a Gaussian lon/lat grid at one time per file. The first data set is found in file **fort.200** and corresponds either to (i) the beginning of the model run (i.e., the cold start time) if the run has been cold started or (ii) the hot start time if the model has been hot started. The second data set is found in file **fort.XX1** where $XX1=200+WTIMINC/3600$ and WTIMINC is the time interval in seconds. The third data set is found in file **fort.XX2** where $XX2=200+2*WTIMINC/3600$. Succeeding data sets are found in similarly named files. For example, if the time between meteorological files is 3 hours, WTIMINC=10800 and met files should be named **fort.200**, **fort.203**, **fort.206**, **fort.209**, Velocity and pressure are interpolated in space onto the ADCIRC grid. Interpolation in time is used to synchronize the velocity and pressure fields with the model time step. Units of velocity are meters/sec and of pressure are Pascals = Newtons/m². Velocity references the direction the wind is blowing toward. The wind time interval (WTIMINC) must be specified in the input parameter file (**fort.15**). Garret's formula is used to compute wind stress from velocity.

Note, the SFLUX files are assumed to have been generated by the UNPKGRB1 program. Prior to version 34.05, it was assumed that these files were in binary grib format. Starting with version 34.05 it is assumed that these files are in ASCII tabular format.

Note, if the model is hot started, it must be done at a time that corresponds to a wind file time, (e.g., an even multiple of WTIMINC).

NWS = 11 Wind *velocity* (10 m) and pressure (surface) are read in from a sequence of files from the National Weather Service ETA-29 meteorological model that provides data on an ETA grid at one day per file. Within each day data is provided every 3

hours beginning at 3:00Z and ending at 24:00Z. For a model hot start, file *fort.200* must contain data from the day before the hot started so that the 24:00Z fields can be used as initial meteorological conditions for the model run. For a cold start, the initial conditions are assumed to be at rest and therefore the *fort.200* file is not used. The first day of data after either a cold or a hot start is found in file *fort.201*, the second day of data in file *fort.202*, the third day of data in file *fort.203*, etc. Velocity is converted to from the ETA coordinate system to an East, North coordinate system and all fields are interpolated in space to the ADCIRC grid. Interpolation in time is used to synchronize the velocity and pressure fields with the model time step. Units of velocity are meters/sec and of pressure are 100*Pascals = 100*Newtons/m². Velocity references the direction the wind is blowing toward. The wind time interval is assumed to be 3 hours (WTIMINC=10800) and therefore is not read in the input parameter file (*fort.15*). Garret's formula is used to compute wind stress from velocity.

Note, the input files are assumed to be in binary.

Note, the model must always be started at the beginning of a day. (e.g., 0:00Z).

- NWS = 100 Radiation stress gradients are read in from a PBL format file (*fort.23*) at a subset of ADCIRC grid nodes at a radiation stress time interval that is not equal to the model time step. It is assumed that the first values in the *fort.23* file correspond either to (i) the beginning of the model run (i.e., the cold start time) if the run has been cold started or (ii) the hot start time if the model has been hot started. Therefore, regardless of whether the model is cold started or hot started, ADCIRC will not skip any values at the beginning of the *fort.23* file. Interpolation in time is used to synchronize the radiation stress fields with the model time step. Units of radiation stress gradient are $(length/time)^2$ - which is actually (force/area)/reference density of water. *Length* must match the units used in the grid. If a lon, lat coordinate system is used in the grid, *length* units are assumed to be meters. The radiation stress time interval (RSTIMINC) must be specified in the input parameter file (*fort.15*).
- NWS = 101 Radiation stress gradients, wind *stress* and pressure are read in. Radiation stress input is as described for NWS = 100. Wind stress and pressure input is as described for NWS = 1.
- NWS = 102 Radiation stress gradients, wind *stress* and pressure are read in. Radiation stress input is as described for NWS = 100. Wind stress and pressure input is as described for NWS = 2.
- NWS = 103 Radiation stress gradients and wind *speed* and *direction* are read in. Radiation stress input is as described for NWS = 100. Wind velocity input is as described for NWS = 3.
- NWS = 104 Radiation stress gradients, wind *velocity* and pressure are read in. Radiation stress input is as described for NWS = 100. Wind stress and pressure input is as described for NWS = 4.
- NWS = -104 Radiation stress gradients, wind *velocity* and pressure are read in. Radiation stress input is as described for NWS = 100. Wind stress and pressure input is as described for NWS = -4.

- NWS = 105 Radiation stress gradients, wind *velocity* and pressure are read in. Radiation stress input is as described for NWS = 100. Wind stress and pressure input is as described for NWS = 5.
- NWS = -105 Radiation stress gradients, wind *velocity* and pressure are read in. Radiation stress input is as described for NWS = 100. Wind stress and pressure input is as described for NWS = -5.
- NWS = 106 Radiation stress gradients, wind *velocity* and pressure are read in. Radiation stress input is as described for NWS = 100. Wind stress and pressure input is as described for NWS = 6.
- NWS = 110 Radiation stress gradients, wind *velocity* and pressure are read in. Radiation stress input is as described for NWS = 100. Wind stress and pressure input is as described for NWS = 110.
- NWS = 111 Radiation stress gradients, wind *velocity* and pressure are read in. Radiation stress input is as described for NWS = 100. Wind stress and pressure input is as described for NWS = 111.

Depending on the value of the NWS parameter, the following additional parameters must be set in the *fort.15* file:

NWS = 0 No further meteorological or radiation stress parameters are required.

NWS = 2, 4, -4, 5, -5, 6, 10

line 23: WTIMINC

where, WTIMINC = time in seconds between data in the met file

NWS = 3 line 23: IREFYR,IREFMO,IREFDAY,IREFHR,IREFMIN,REFSEC
line 24:NWLAT,NWLON,WLATMAX,WLONMIN,WLATINC,WLONINC,
WTIMINC

where, IREFYR = year of the start of the simulation

IREFMO = month of the start of the simulation

IREFDAY = day of the start of the simulation

IREFHR = hour of the start of the simulation

IREFMIN = minute of the start of the simulation

REFSEC = second of the start of the simulation

NWLAT = number of latitude values in the met file

NWLON = number of longitude values in the met file

WLATMAX = maximum latitude (deg) of data in the met file (< 0 south of the equator)

WLONMIN = minimum longitude (deg) of data in the met file (< 0 west of the Greenwich meridian)

WLATINC = latitude increment (deg) of data in the met file (must be >0)

WLONINC = longitude increment (deg) of data in the met file (must be >0)

WTIMINC = time interval in sec between data in the met file.

NWS = 11 No further meteorological or radiation stress parameter are required. WTIMINC is assumed to be 10800 sec.

NWS = 100, 111
line 23: RSTIMINC
where, RSTIMINC = time in seconds between data in the radiation stress gradient file

NWS = 102, 104, -104, 105, -105, 106, 110
line 23: WTIMINC, RSTIMINC
where, WTIMINC = time in seconds between data in the met file
RSTIMINC = time in seconds between data in the radiation stress gradient file

NWS = 103 line 23: IREFYR,IREFMO,IREFDAY,IREFHR,IREFMIN,REFSEC
line 24:NWLAT,NWLON,WLATMAX,WLONMIN,WLATINC,WLONINC,
WTIMINC, RSTIMINC
where, RSTIMINC = time in seconds between data in the radiation stress gradient file
all other values as in NWS = 3

FORMAT OF THE RADIATION STRESS GRADIENT INPUT FILE

The format for the *fort.23*, radiation stress gradient file, is the following:

```
I, RSX2(I),RSY2(I)
.
.
#
I, RSX2(I),RSY2(I)
.
#
```

where, I = node number in the ADCIRC grid where the radiation stress gradient is being specified

$RSX2(I) = R_x$ in units of $(length/time)^2$ where *length* must match the units used in the grid. If a lon, lat coordinate system is used in the grid, *length* units are assumed to be meters

$RSY2(I) = R_y$ in units of $(length/time)^2$ where *length* must match the units used in the grid. If a lon, lat coordinate system is used in the grid, *length* units are assumed to be meters

A data line must have the format I8, 2E13.5

A data line is repeated for as many ADCIRC grid nodes as desired

A line containing the # symbol in column 2 indicates the radiation stress gradients beginning on the following data line apply to the next time increment. At each time increment, every node that is not explicitly referenced by a data line is assumed to have a radiation stress gradient of zero. If the model is cold started, the first data correspond to the beginning time of the model run. If the model is hot started the first data correspond to the hot start time. Subsequent data sets (separated by # lines) are provided every RSTIMINC seconds. Data must be provided for the entire model run, or the run will crash.

REFERENCES

- Dean, R.G. and R.A. Dalrymple, 1991, Water Wave Mechanics for Engineers and Scientists, World Scientific, New Jersey, 353p.
- Longuet – Higgins, M.S. and R.W. Stewart, 1964, Radiation stress in water waves; a physical discussion, with applications, *Deep-Sea Research*, 11:529-562.
- Luetlich, R.A. Jr., J.J. Westerink and N.W. Scheffner, 1992, ADCIRC: An Advanced Three-Dimensional Circulation Model for Shelves, Coasts and Estuaries, Report 1: Theory and Methodology of ADCIRC-2DDI and ADCIRC-3DL, DRP Technical Report DRP-92-6, Department of the Army, US Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS., November 1992, 137p.
- Westerink, J.J., R.A. Luetlich, Jr. and N.W. Scheffner, 1994, ADCIRC: An Advanced Three-Dimensional Circulation Model for Shelves, Coasts and Estuaries, Report 2: Users Manual for ADCIRC-2DDI, DRP Technical Report DRP-92-6, Department of the Army, US Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS., January 1994, 156p.
- Luetlich, R.A., Jr. and J.J. Westerink, 1994, Elemental Wetting and Drying in the ADCIRC Hydrodynamic Model: Upgrades and Documentation for ADCIRC Version 34.XX, Contractors Report, department of the Army, US Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS, March 11, 1999, 8 p.
- Massel, S.R., 1989, Hydrodynamics of Coastal Zones, Elsevier, Amsterdam, 336p.