A Regional Storm Surge Model for the Alaska Region and Updating Sea Ice Options in ADCIRC

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April 2018

Western Alaska LCC
Outline

1 Alaska Regional ADCIRC Model
   - Model Description
   - Sea Ice Implementation to Circulation Modelling
   - Modelling Storm Surge in the Presence of Ice Coverage
     - November 2011
     - February 2011
     - January 2017
   - Moving Forward

2 Updating Sea Ice in ADCIRC
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2. Updating Sea Ice in ADCIRC
Grid Development

Model Bathymetry

8070796 elements, 4061175 nodes, 25 m coastal resolution
8070796 elements, 4061175 nodes, 25 m coastal resolution
$M_2$ Amplitude

M2 Model Amplitude

- Amplitude values range from 0.00 to 3.50 meters.
- The map covers a wide area with latitude from 40° to 80° N and longitude from -200° to -130° W.
- The color bar indicates the amplitude levels with varying shades from pink (3.50) to black (0.00).
\( M_2 \) Validation

- Good performance everywhere but Kuskokwim River
- Includes SAL, parameterized internal tide dissipation, bottom friction - all contribute to accuracy of solution

\[ R^2 = 0.96289 \]
\[ y = 0.98916x \]
\[ \sigma = 0.15773 \]
\[ |\epsilon| = 0.08006 \]
\[ \Delta = 0.4 \]
Atmospheric Forcing

- National Centers for Environmental Prediction’s Climate Forecast System Reanalysis (CFSv2) [4].
- Hourly wind speeds at a 10 m height with a horizontal resolution of 0.205 degrees by 0.204 degrees
- Hourly atmospheric pressure at a resolution of 0.5 degrees.
Stations

[Map image showing stations in Alaska, including Prudhoe Bay, Red Dog Dock, and Nome.]
Nome

Water Surface Elevation at Station 9468756

- WSE (m)
  - Aug 01
  - Aug 05
  - Aug 09
  - Aug 13
  - Aug 17
  - Aug 21
  - Aug 25
  - Aug 29

- COOPS - observed
- ADCIRC
August 2012 Validation

Red Dog Dock

Water Surface Elevation at Station 9491094

COOPS - observed
ADCIRC
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2 Updating Sea Ice in ADCIRC
Base Implementation to ADCIRC

Used by ACOE (Chapman 2005, 2009)

\[
C_{d, iceoriginal} = \max(C_{d, Garratt}, C_{d, Chapman}).
\]  

(1)

where

\[
C_{d, Chapman} = 0.00075 + 0.0075AF - 0.009AF^2 + 0.002AF^3
\]  

(2)

- \(AF\) = area fraction ice
- Observation based
- Solely a function on \(AF\)
- Under high wind speeds, this drag coefficient essentially ignores the presence of ice coverage
Our Implementation to ADCIRC

\[ C_D = (AF)C_{D,is} + (1 - AF)C_{D,w} + C_{D,if} \]  \hspace{1cm} (3)

\[ C_{D,is} = 0.0015 \]
\[ C_{D,w} = \text{GarrattDrag} \]
\[ C_{D,if}(0) = 0, \quad C_{D,if}(1) = 0 \]
\[ C_{D,if}(0.5) = C_{D,if,\text{max}} = 0.0025 \]

- Decompose the flux coefficient into contributions which are a function of both wind speed and ice coverage
- Area weighted approach [6, 1, 2]
- Considers both the form and skin drag over ice floes
- Form drag determined by number of ice face/obstacles
- Sea ice concentration from NCEP Automated Sea Ice Concentration Analysis - 5’ resolution, satellite based
Ice Parameterization - $C_d$
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2 Updating Sea Ice in ADCIRC
November 2011 Ice Coverage

Nov 2011 Ice

21.75 days

AF

90
80
70
60
50
40
30
20
10
0

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February 2011 Ice Coverage

Feb 2011 Ice

27.62 days

AF

100
90
80
70
60
50
40
30
20
10
0
January 2017 Ice Coverage

Jan 2017 Ice

-200° -190° -180° -170° -160° -150° -140° -130°
40° 50° 60° 70° 80°

14.00 days
AF
90 80 70 60 50 40 30 20 10 0

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Nome

Water Surface Elevation at Station 9468756

- WSE (m)
- Oct 24, Oct 28, Nov 01, Nov 05, Nov 09, Nov 13, Nov 17, Nov 21
November 2011 Validation

Red Dog Dock

Water Surface Elevation at Station 9491094

- WSE (m)
- Oct 24 to Nov 21
November 2011 Effect of Ice

November 2011 WSE Diff

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February 2011 Ice Coverage

Feb 2011 Ice

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Nome

Water Surface Elevation at Station 9468756

- COOPS - observed
- CFS + no ice
- CFS + ice

WSE (m)

Feb 01   Feb 05   Feb 09   Feb 13   Feb 17   Feb 21   Feb 25   Mar 01
February 2011 Validation

Red Dog Dock

Water Surface Elevation at Station 9491094

- COOPS - observed
- CFS + no ice
- CFS + ice

WSE (m)

Feb 01  Feb 05  Feb 09  Feb 13  Feb 17  Feb 21  Feb 25  Mar 01
February 2011 Ice Coverage
February 2011 Effect of Ice

February 2011 WSE Diff

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January 2017 Ice Coverage
Nome

Water Surface Elevation at Station 9468756

- WSE (m)
- Dec 22, 2016 to Jan 11, 2017

Graph showing water surface elevation over time with different models compared to observed data.
Unalakleet

Water Surface Elevation at Station 9468333

-1.5 -1 -0.5 0 0.5 1 1.5 2 2.5 3 3.5

WSE (m)

- COOPS - observed
- CFS + no ice
- CFS + ice
Red Dog Dock

Water Surface Elevation at Station 9491094

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January 2017 Ice Coverage
January 2017 Effect of Ice

January 2017 WSE Diff

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2 Updating Sea Ice in ADCIRC
Coupled Wave Model

Already running with ADCIRC+SWAN — no real ice physics

WAVEWATCH III wave model

- Incorporated ice physics developed as part of an Office of Naval Research (ONR) Directed Research Initiative (DRI)
- Four different options for wave dissipation due to ice that covers a variety of ice conditions. 3 are physics based, one empirical
- Allows for two wave scattering and dispersion due to ice as well as an option for ice breakup due to waves
- Earth System Modelling Framework (ESMF) provides structure and communication paradigm for coupling to be completed
Still significant uncertainty in air-sea-ice interaction in this context

- Only considers atmospheric side
  - Assumes proportional relationship between the wind speed and the ice drift-ocean current differential
  - Assumes proportional relationship between air-ice drag and ice-ocean drag
  - Assumes no direction change in ice drift with respect to wind speed
  - Does not affect tidal solution

- Doesn’t consider fast ice

- Data limitations
  - Relatively low resolution in time (only daily evolution of the ice field)
  - Missing important sea ice parameters (only area fraction at high spatial resolution)
Sea Ice Types

- Fast ice
- Drift (pack) ice
- Land
- Shear zone
- Small floes
- Multiyear ice (MYI) floe
- 1st year ice (FYI) floe
- Fracture
- Winds
- Lead
- Tension
- Compression
- Old pressure ridge
- New pressure ridge
- Ice canopy
- Tides
- Seabed
Coupled Sea Ice Model

- Couple to a sea ice model (ex. Los Alamos Sea Ice Model (CICE))
  - Computes a number of factors including ice floe size, ridge height, and the presence of melt ponds
  - Includes a well developed description of the drag coefficient on both the atmosphere-ice and ice-ocean interfaces [5]
  - Computes ice drift speeds

\[ C_{d,a-i} = C_{d,skin} + C_{d,ridge} + C_{d,floe} + C_{d,pond} \]  \hspace{1cm} (4)

\[ C_{d,i-o} = C_{d,skin} + C_{d,ridge} + C_{d,floe} \]  \hspace{1cm} (5)
Coupled Sea Ice Model

Ice ocean stress [3]

\[ \tau_{i-o} = \rho_w C_{d,i-o} |u_i - u_o| (u_i - u_o) \]  

(6)

Total ocean stress

\[ \tau_{ocn} = (1 - AF)\tau_{a-o} + (AF)\tau_{i-o} \]  

(7)

- Compliant with ESMF for coupling with both ADCIRC+WWIII
- Requires wind velocity, specific humidity, air potential temperature, air temperature, incoming shortwave and longwave radiation, rainfall, snowfall, sea surface temperature and salinity (Through ESMF/other model solutions)
- ADCIRC+WAVEWATCH III will be capable of providing ocean currents and sea surface gradients
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\[ WSX = (1 - AF) \times (WSX) + AF \times WSX_{ice} \]  

(8)

\[ WSX_{ice} = C_{d-ice} \times (IceDriftX - U/0.86) \times IceDriftDiffMag \]  

(9)

- Built into NWS options (NCICE = 13)
- Depth averaged current used to estimate surface current
- \( C_{d-ice} = [0.0025, 0.018] \), highly dependent on sea ice type/size/thickness etc.
- Currently testing two approaches:
  - Data Driven Sea Ice Drift - from CFSv2 (0.5 degree resolution)
  - Parametric Ice Drift - 2% at 30 degrees to the right of the wind speed (Nansen’s rule)
Using NCEP Sea Ice Concentration and CFSv2 Ice Drift
Sea Ice Drift - November 2011

Paramterized Wind Drag

Sea Ice Drift
Sea Ice Drift - January 2017

Paramterized Wind Drag

Sea Ice Drift
Sea Ice Drift Effect on $M_2$ amplitude

Sea Ice Drift Effect on $M_2$ phase
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