

Coupled Tides, Storm Surge and Waves Under Varying Ice Coverages Along Alaska's Bering, Chukchi and Beaufort Coasts

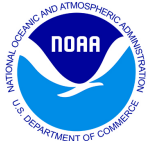
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Department of Civil and Environmental Engineering and Earth Sciences
University of Notre Dame

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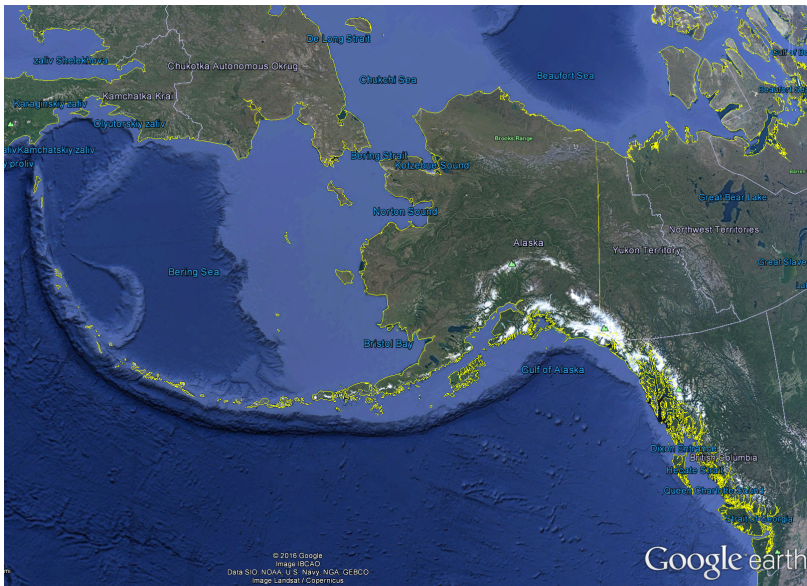
July 30th, 2018

Western Alaska LCC

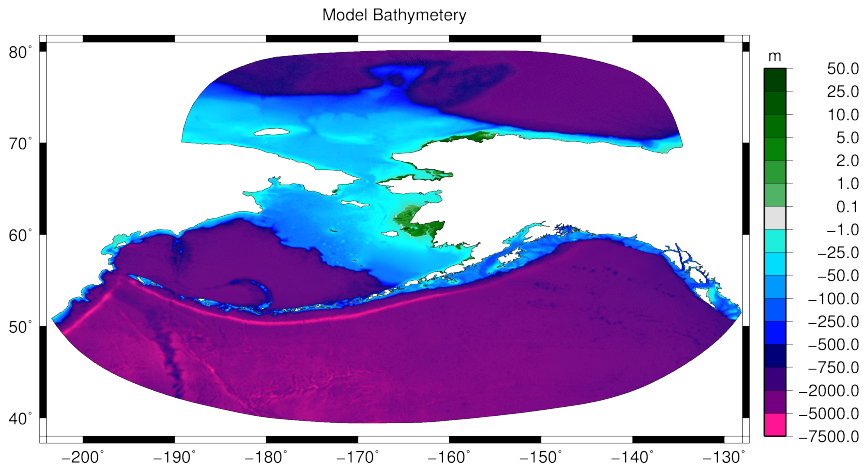


- Model Description
- Sea Ice Implementation to Circulation Modelling
- Modelling Storm Surge in the Presence of Ice Coverage
 - November 2011
 - February 2011
 - January 2017
- Moving Forward

Region

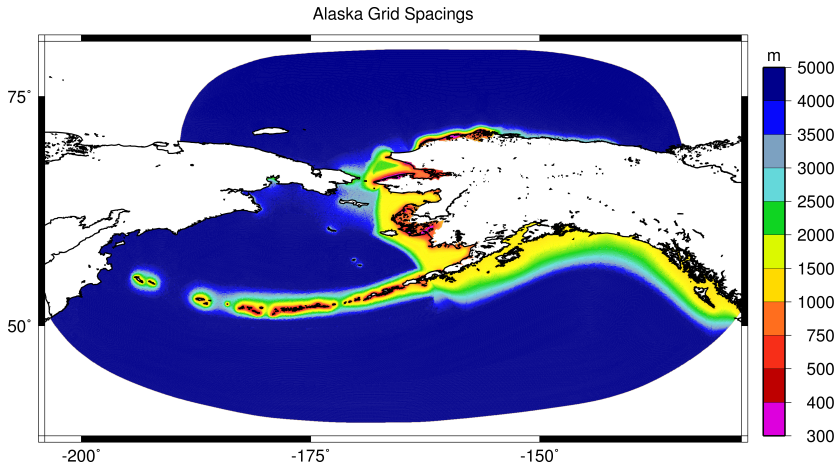


Grid Development



8070796 elements, 4061175 nodes, 25 m coastal resolution

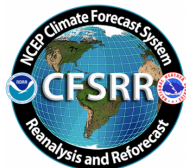
Grid Development



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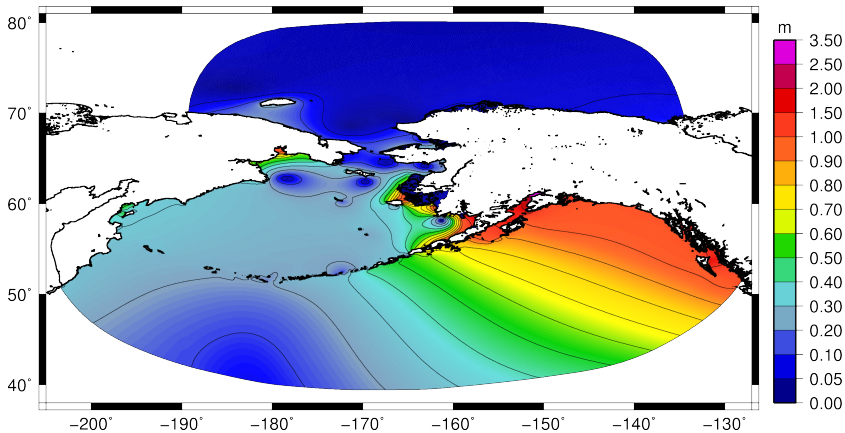
Model Forcing

- Tidal Forcing
 - Boundary forcing from FES 2014 global model (TPXO 8 for K_1 on northern boundary)
 - Self Attraction and Load Tide from FES 2014 global model
 - Internal tide parameterization informed by World Ocean Atlas database.
- Atmospheric Forcing
 - National Centers for Environmental Prediction's Climate Forecast System Reanalysis (CFSv2).
 - 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.



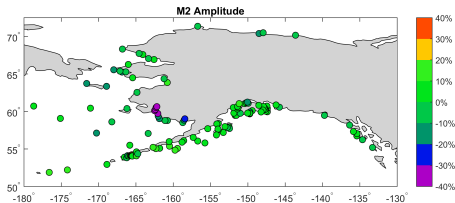
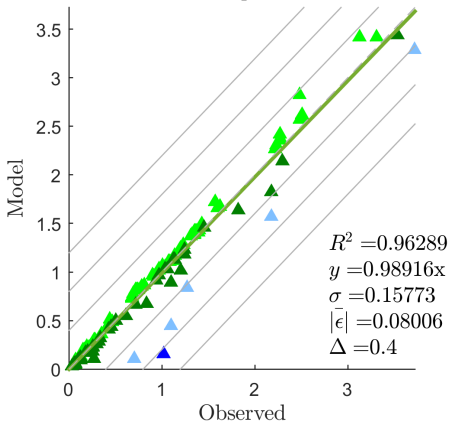
M_2 Amplitude

M2 Model Amplitude



M_2 Validation

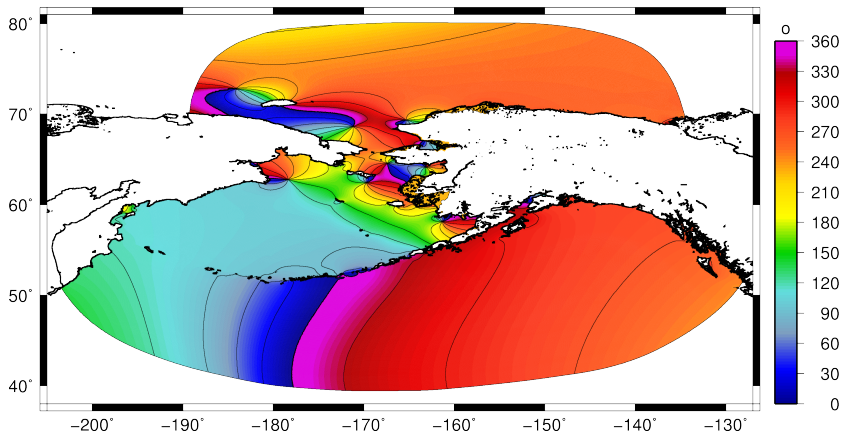
M_2 Amplitude



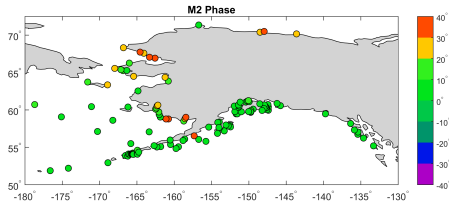
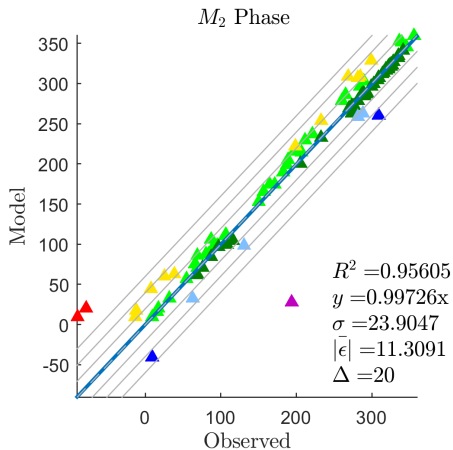
- Good performance everywhere but Kuskokwim River
- Includes SAL, parameterized internal tide dissipation, bottom friction - all contribute to accuracy of solution

M_2 Phase

M2 Model Phase



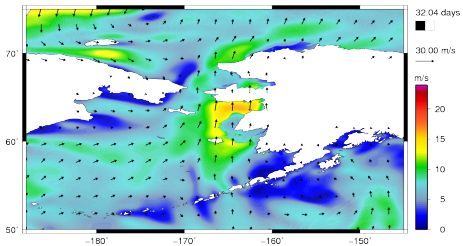
M₂ Phase Validation



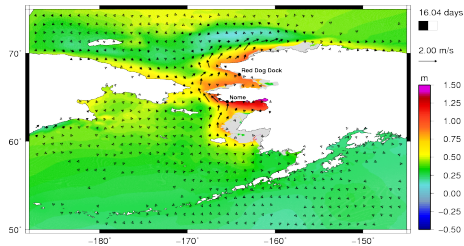
- Despite complexity, only small highly localized errors

Ice Free Storms - August 2012

Aug 2012 Wind Speed



Aug 2012 WSE + Velocities

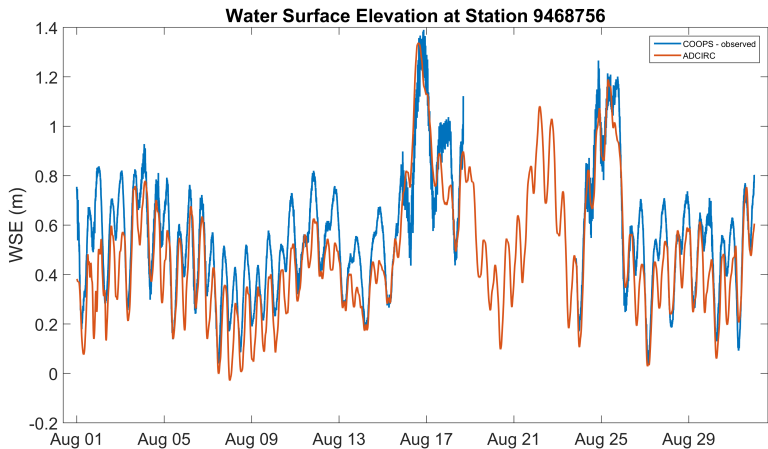


Stations



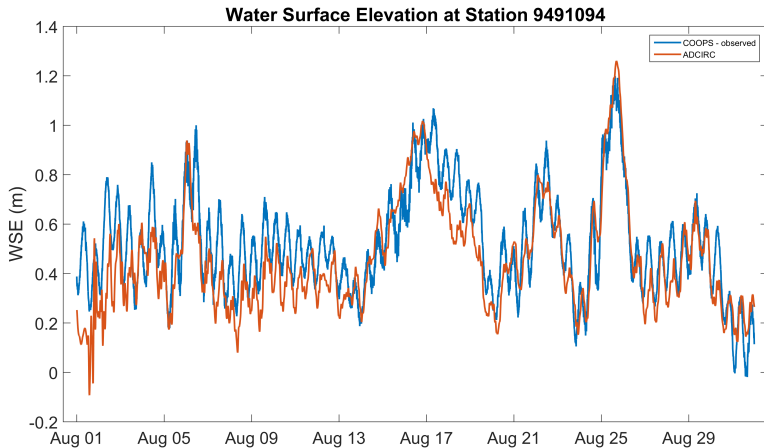
August 2012 Validation

Nome



August 2012 Validation

Red Dog Dock



Sea Ice Implementation in ADCIRC

$$C_D = (AF)C_{D,is} + (1 - AF)C_{D,w} + C_{D,if} \quad (1)$$

- Decompose the flux coefficient into contributions which are a function of both wind speed and ice coverage
- Area weighted approach
- 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

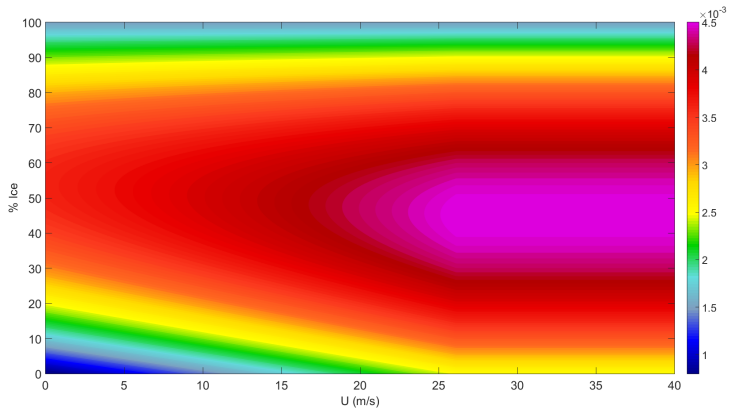
$$C_{D,is} = 0.0015$$

$$C_{D,w} = \text{GarrattDrag}$$

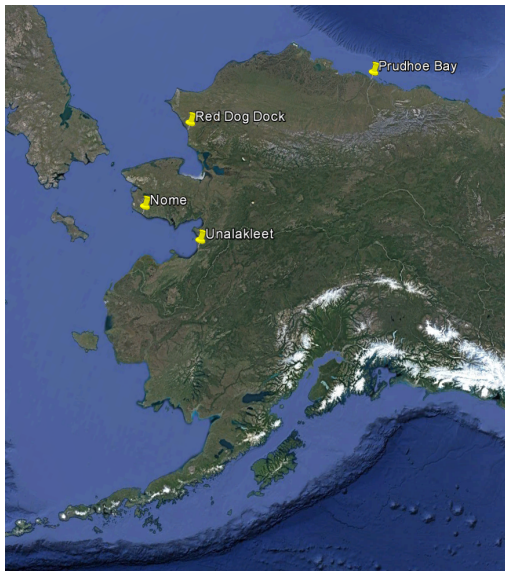
$$C_{D,if}(0) = 0, C_{D,if}(1) = 0$$

$$C_{D,if}(.5) = C_{D,if,max} = .0025$$

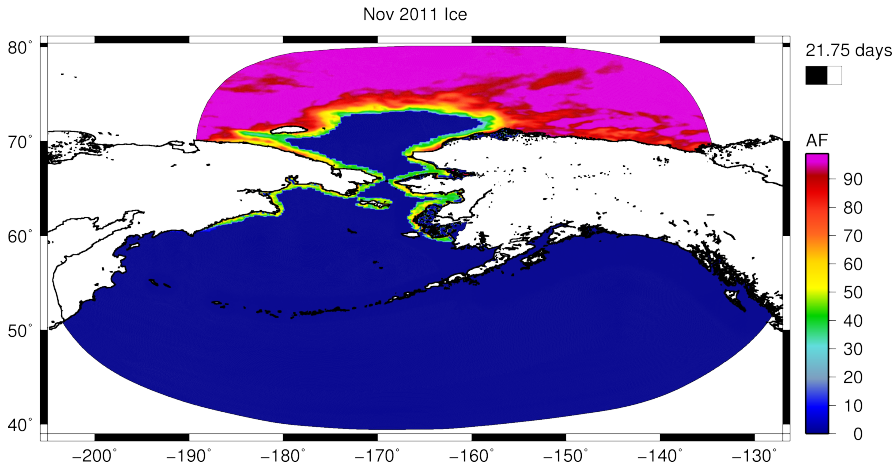
Ice Parameterization - C_d



Stations

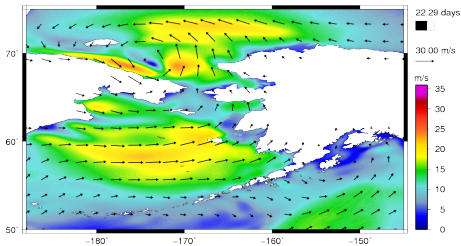


November 2011 Ice Coverage

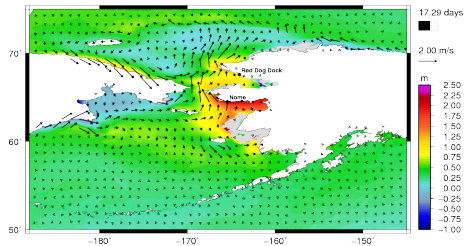


November 2011

Nov 2011 Wind Speed

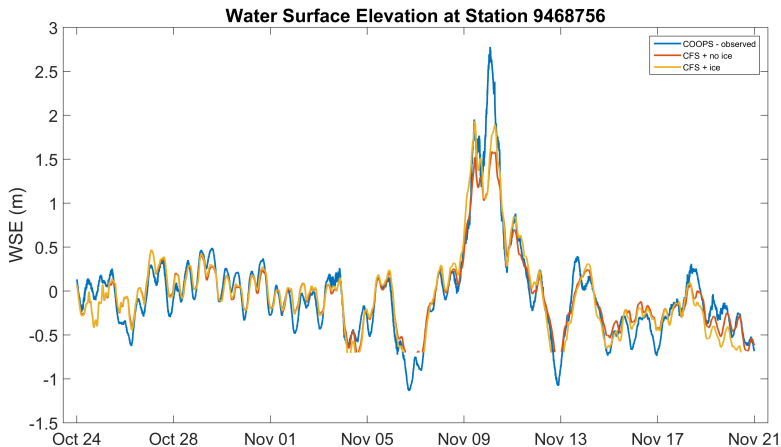


Nov 2011 WSE + Velocities



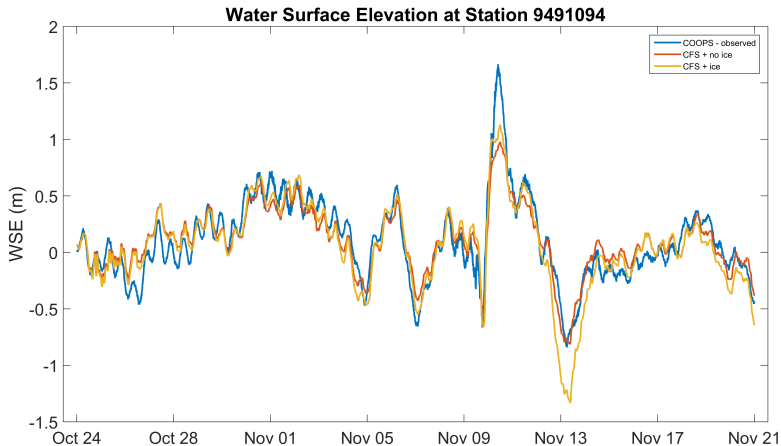
November 2011 Validation

Nome

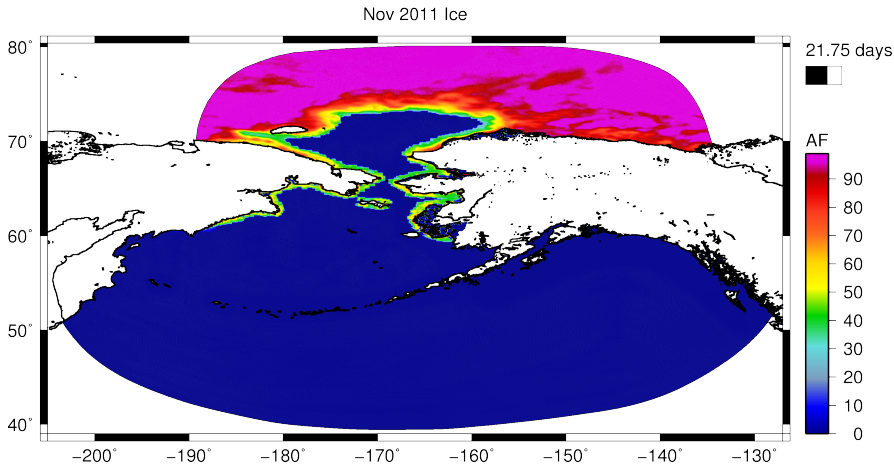


November 2011 Validation

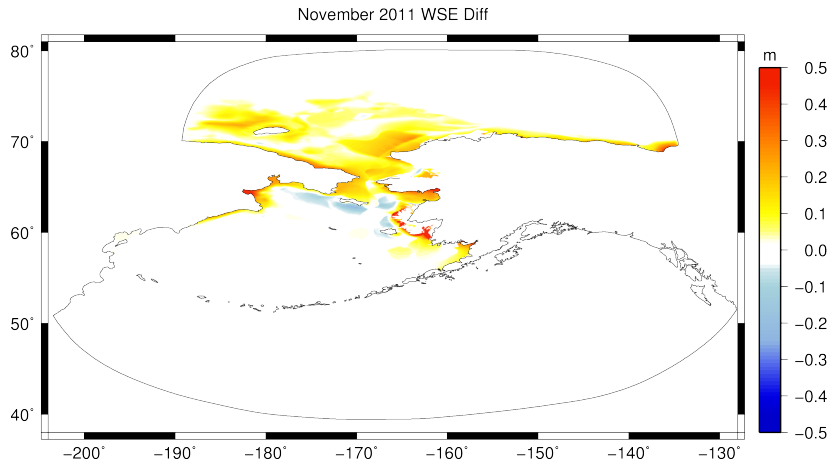
Red Dog Dock



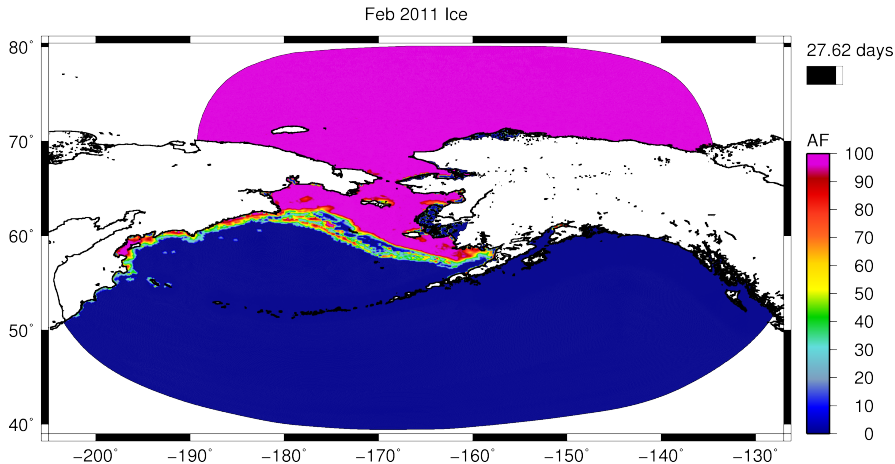
November 2011 Ice Coverage



November 2011 Effect of Ice

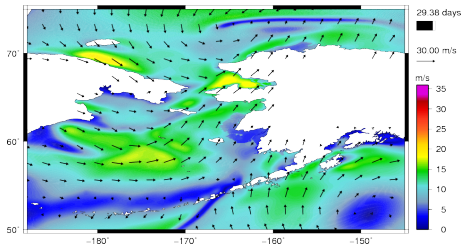


February 2011 Ice Coverage

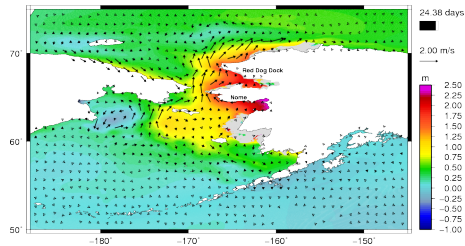


February 2011

Feb 2011 Wind Speed

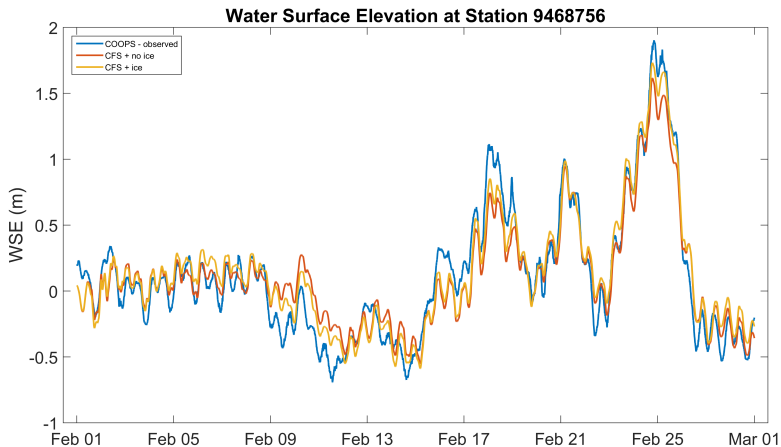


Feb 2011 WSE + Velocities



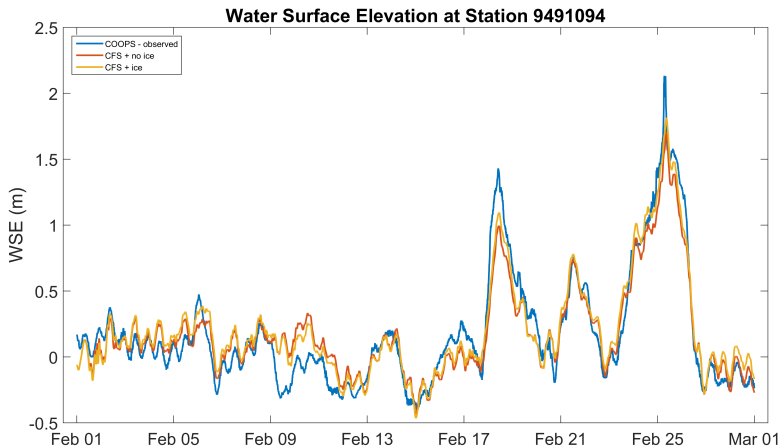
February 2011 Validation

Nome

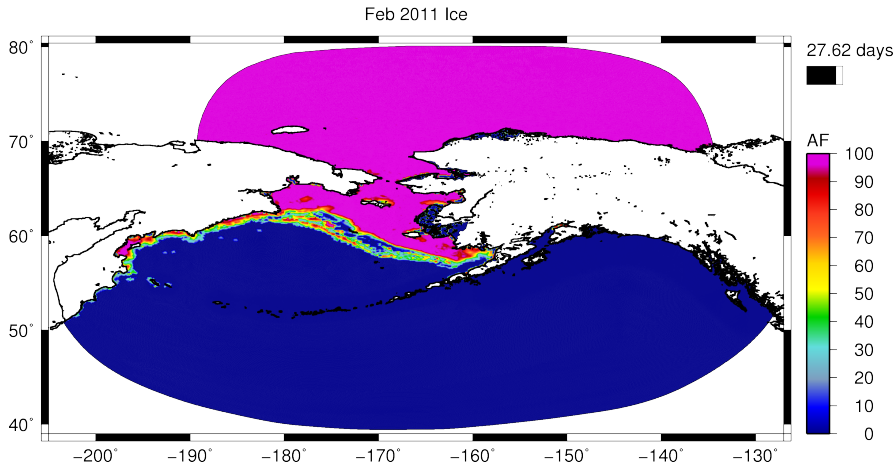


February 2011 Validation

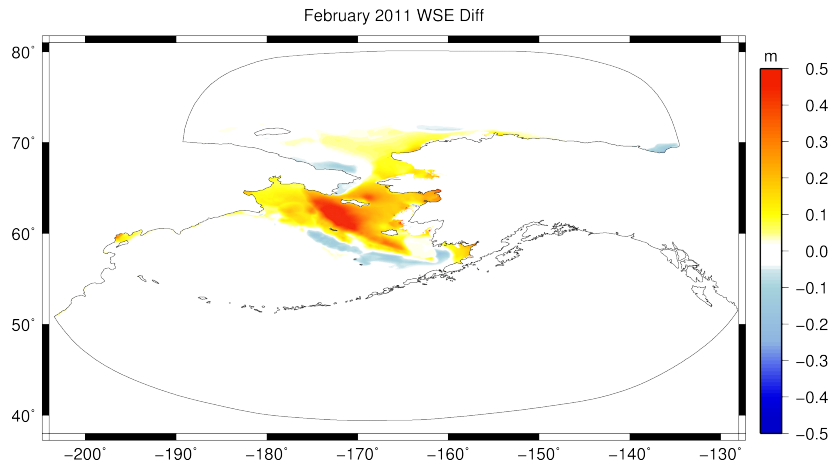
Red Dog Dock



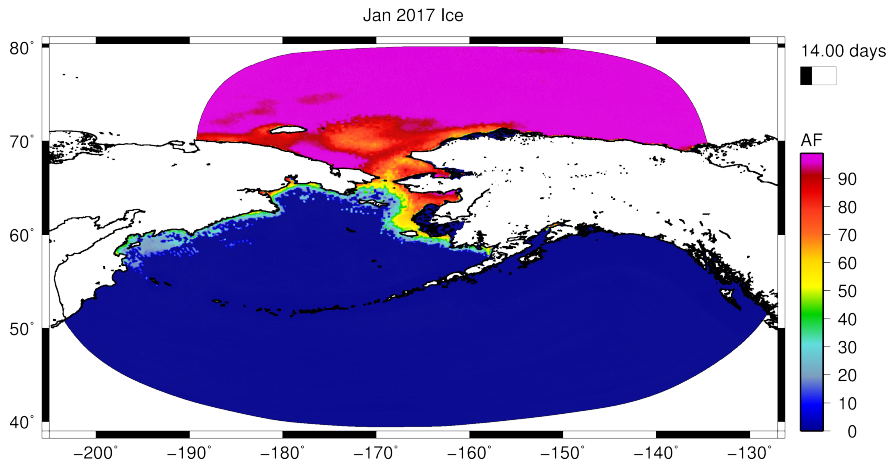
February 2011 Ice Coverage



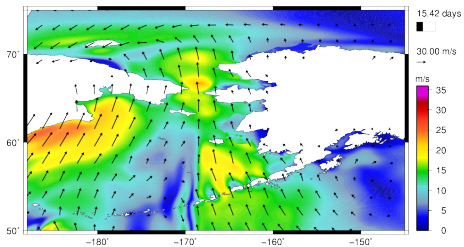
February 2011 Effect of Ice



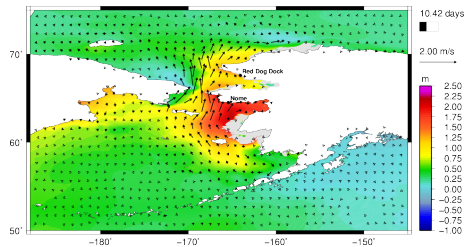
January 2017 Ice Coverage



Jan 2017 Wind Speed

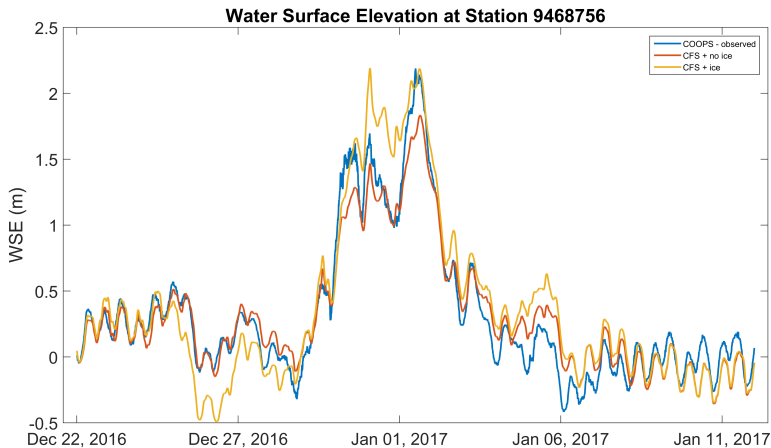


Jan 2017 WSE + Velocities



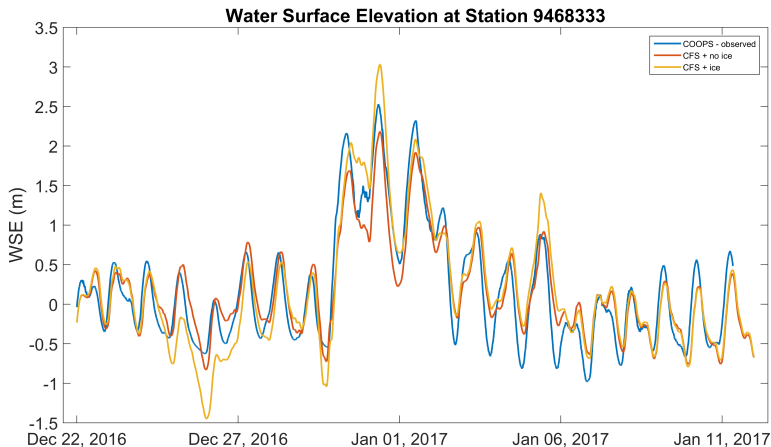
January 2017 Validation

Nome



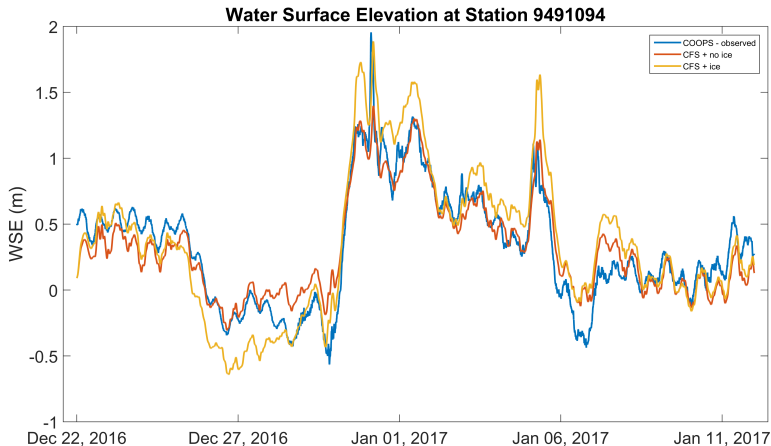
January 2017 Validation

Unalakleet

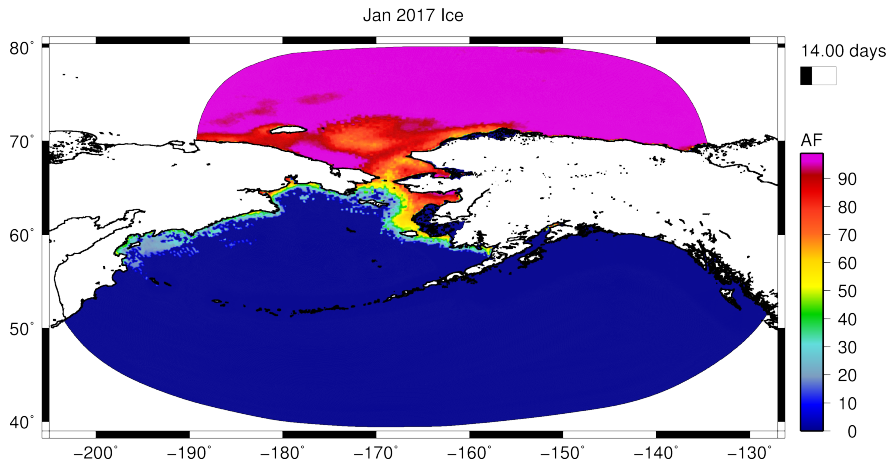


January 2017 Validation

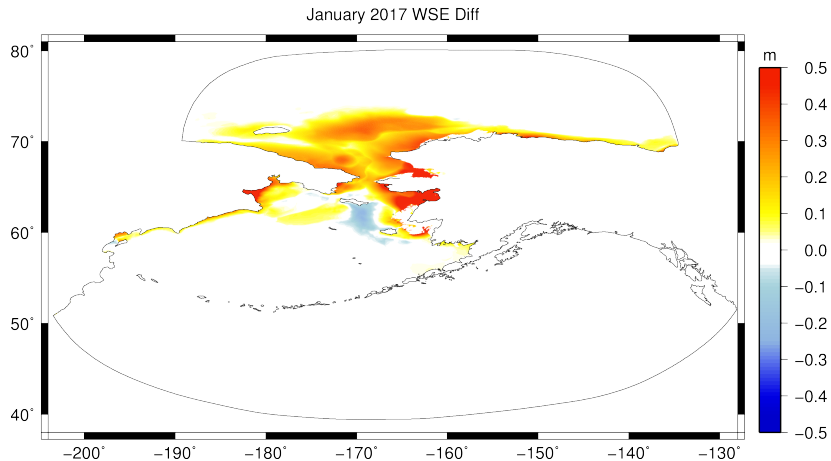
Red Dog Dock



January 2017 Ice Coverage



January 2017 Effect of Ice



Coupled Wave Model

Already running with ADCIRC+SWAN — no real ice physics

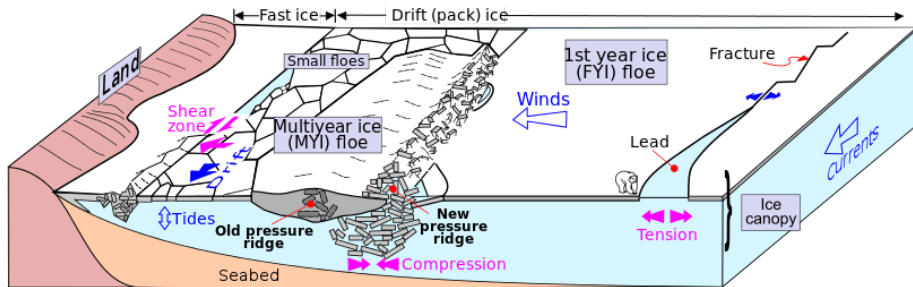
WAVEWATCH III wave model

- 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

Ice Parameterization - Assumptions and Limitations

- 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 wrt 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



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
 - Computes ice drift speeds

$$C_{d,a-i} = C_{d,skin} + C_{d,ridge} + C_{d,floe} + C_{d,pond} \quad (2)$$

$$C_{d,i-o} = C_{d,skin} + C_{d,ridge} + C_{d,floe} \quad (3)$$

Coupled Sea Ice Model

Ice ocean stress

$$\tau_{i-o} = \rho_w C_{d,i-o} |u_i - u_o| (u_i - u_o) \quad (4)$$

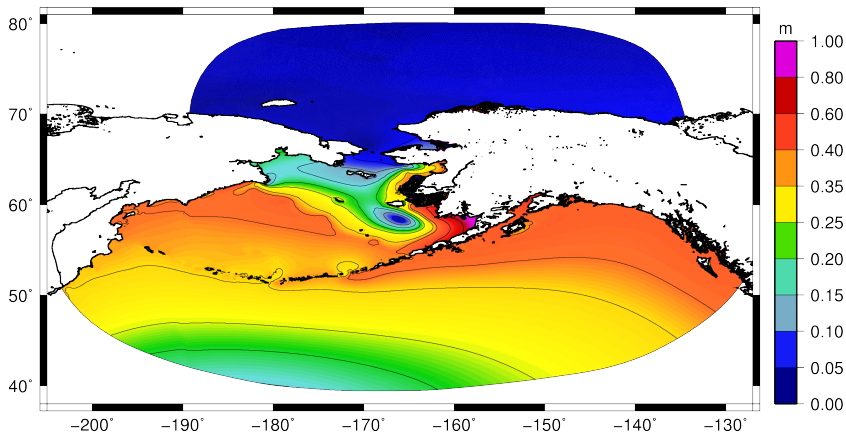
Total ocean stress

$$\tau_{ocn} = (1 - AF)\tau_{a-o} + (AF)\tau_{i-o} \quad (5)$$

- 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

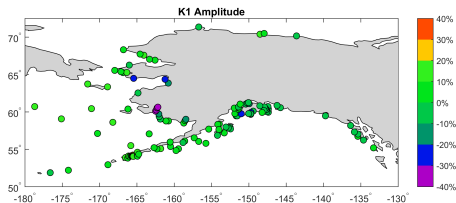
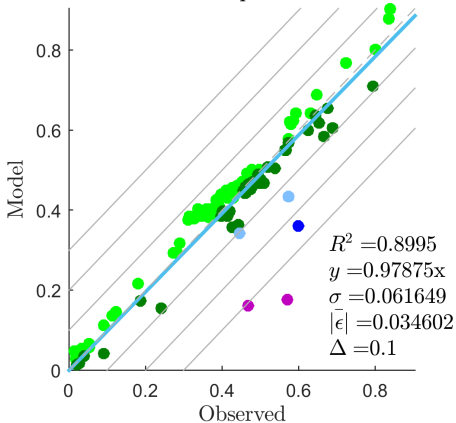
K_1 Amplitude

K1 Model Amplitude



K_1 Amplitude Validation

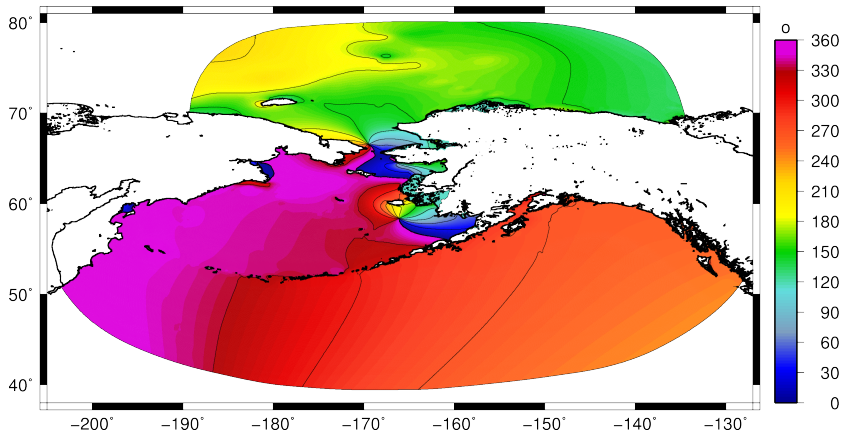
K_1 Amplitude



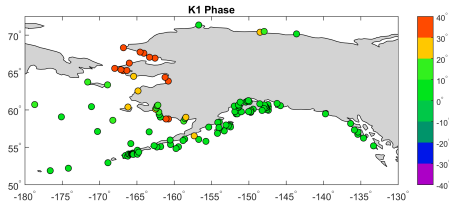
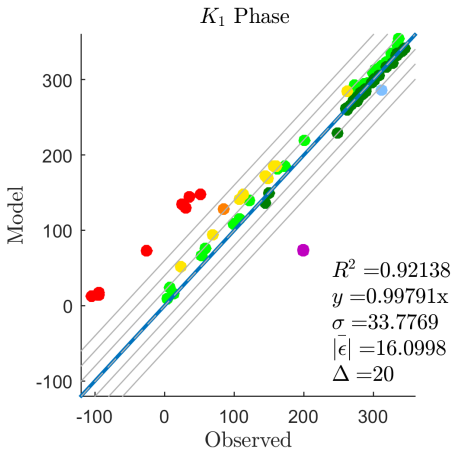
- Very good in the Gulf of Alaska + Aleutians
- Significant under-prediction Kusk. River, Concentrated error in Norton Sound

K_1 Phase

K1 Model Phase



K_1 Phase Validation



- Concentrated error near the amphidromic point north of the Bering Strait