Modelling Storm Surge Under Varying Ice Conditions in the Alaska Region

Joannes Westerink[1], Brian Joyce[1], Robert Grumbine[2] and Andre Van der Westhuysen[2], Jesse Feyen[3]

Computational Hydraulics Laboratory
Department of Civil and Environmental Engineering and Earth Sciences
University of Notre Dame [1]

NOAA/NCEP/NOS [2]

Great Lakes Environmental Research Lab[3]

1st International Workshop on Waves, Storm Surges and Coastal Hazards

September 2017

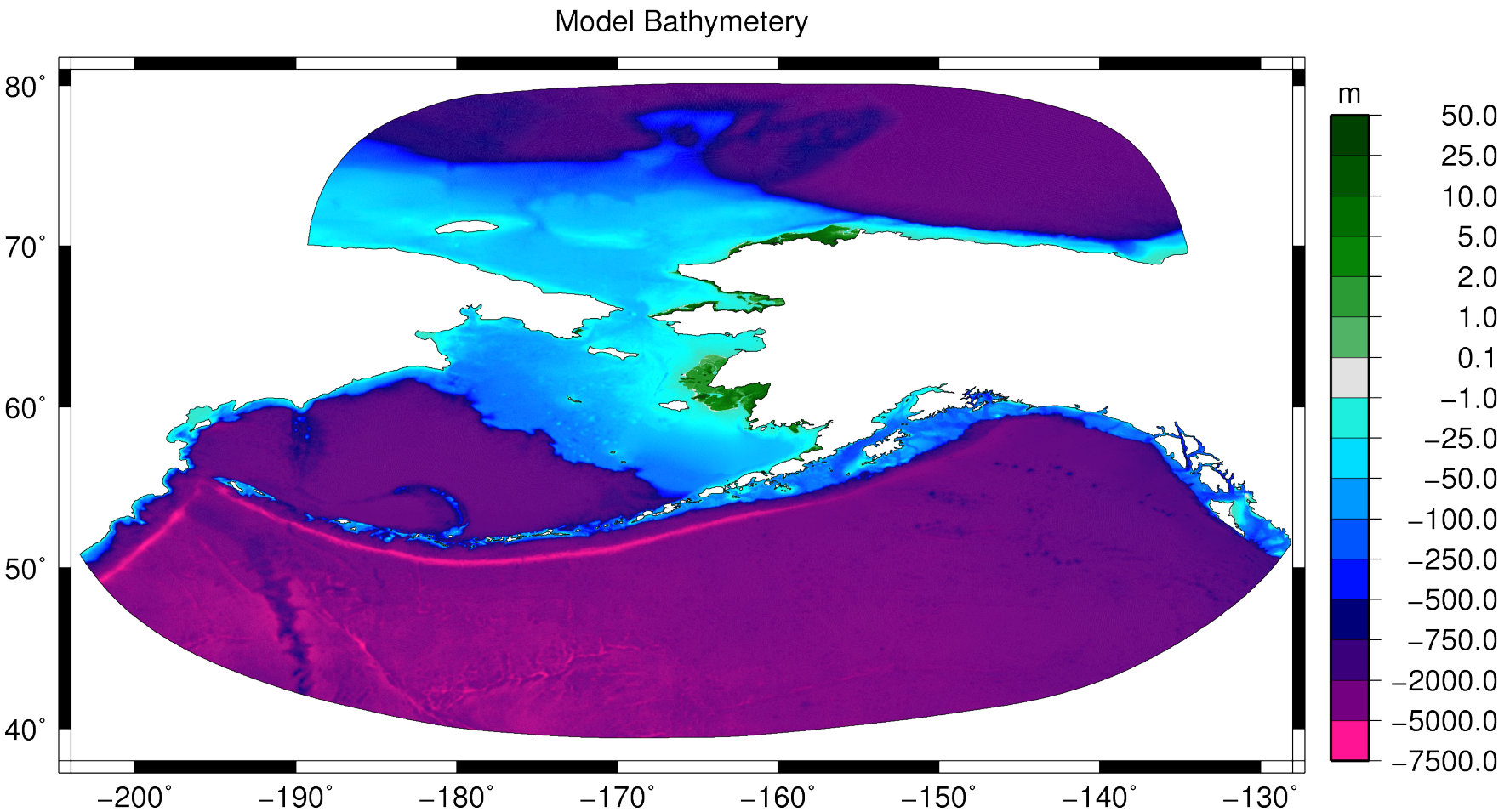
Outline

1. Model Description
2. Validation of Tides and Summer Storms
3. Sea Ice Implementation to Circulation Modelling
4. Modelling Storm Surge in the Presence of Ice Coverage
   - November 2011
   - February 2011
   - January 2017
5. Proposed

Outline

1. Model Description
2. Validation of Tides and Summer Storms
3. Sea Ice Implementation to Circulation Modelling
4. Modelling Storm Surge in the Presence of Ice Coverage
   - November 2011
   - February 2011
   - January 2017
5. Proposed

Grid Development

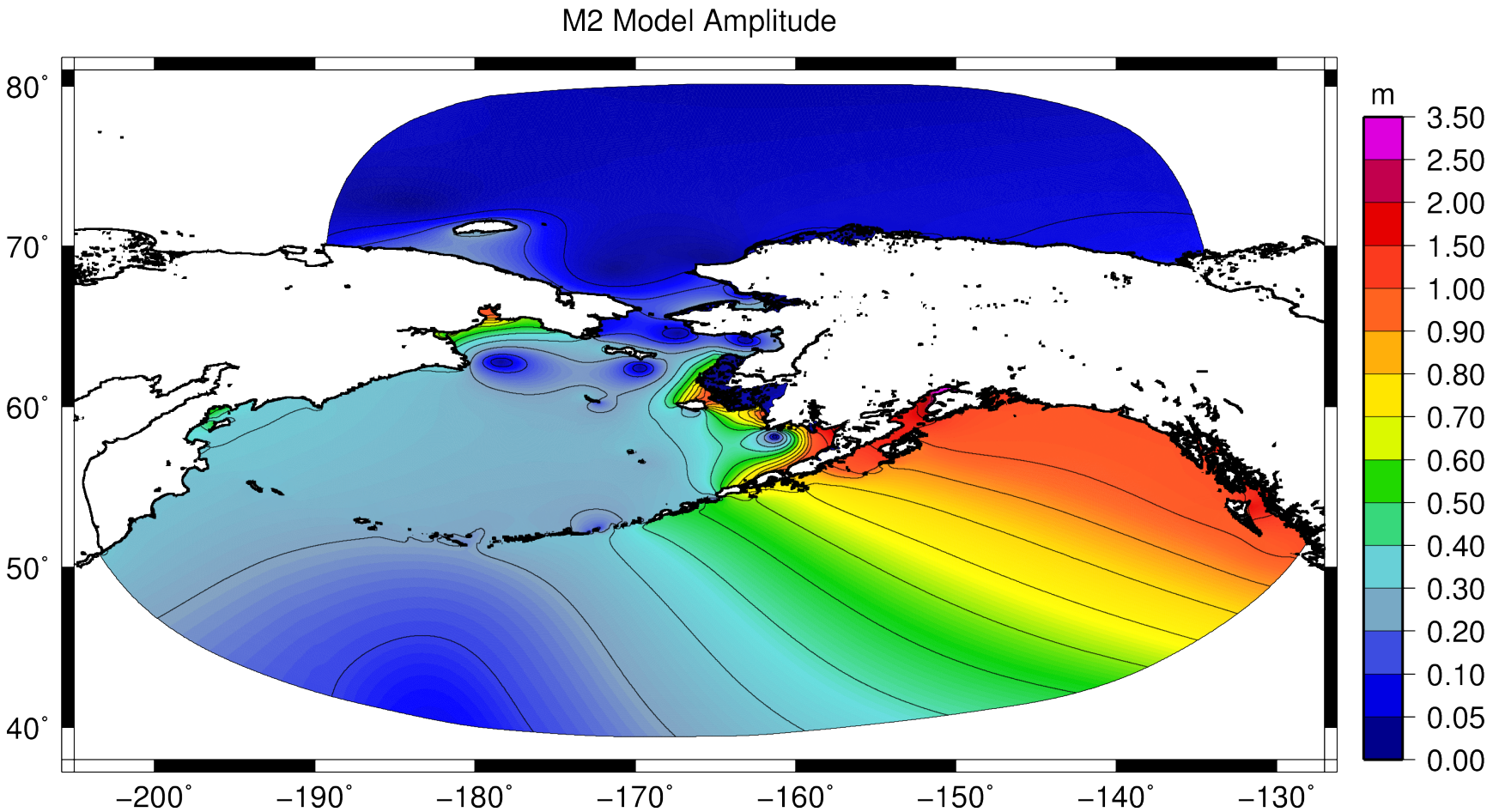


4,061,175 nodes, 5 km to 25 m coastal resolution

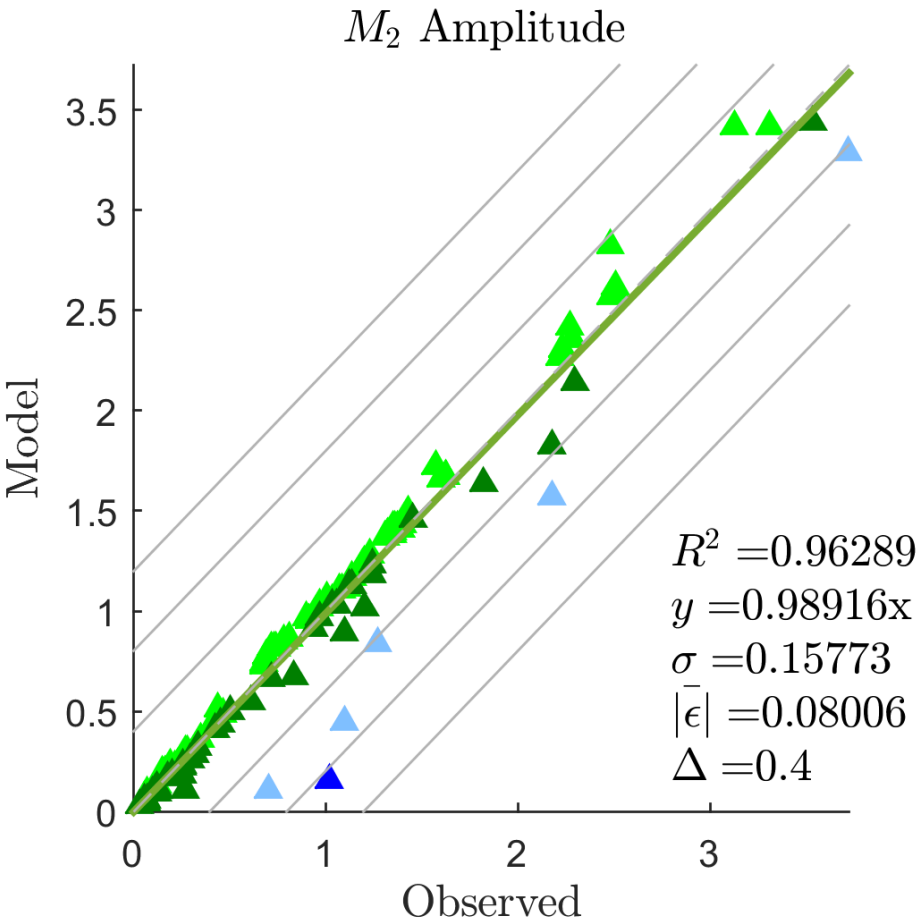
Outline

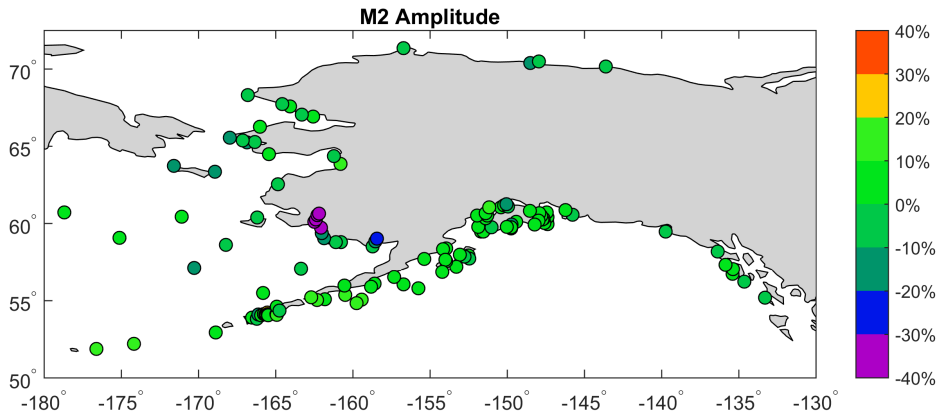
1. Model Description
2. Validation of Tides and Summer Storms
3. Sea Ice Implementation to Circulation Modelling
4. Modelling Storm Surge in the Presence of Ice Coverage
   - November 2011
   - February 2011
   - January 2017
5. Proposed

M_2 Amplitude



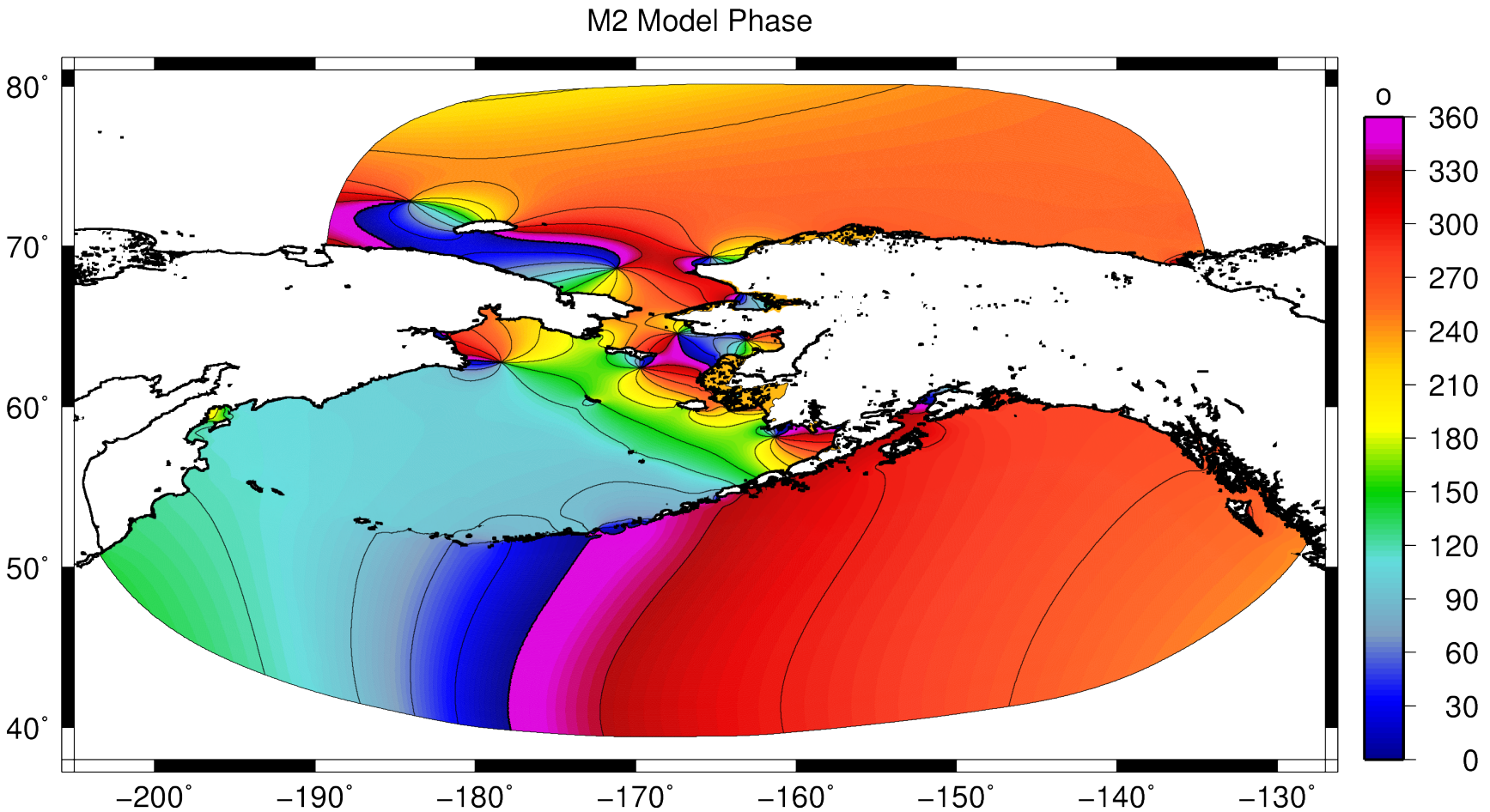
M_2 Validation



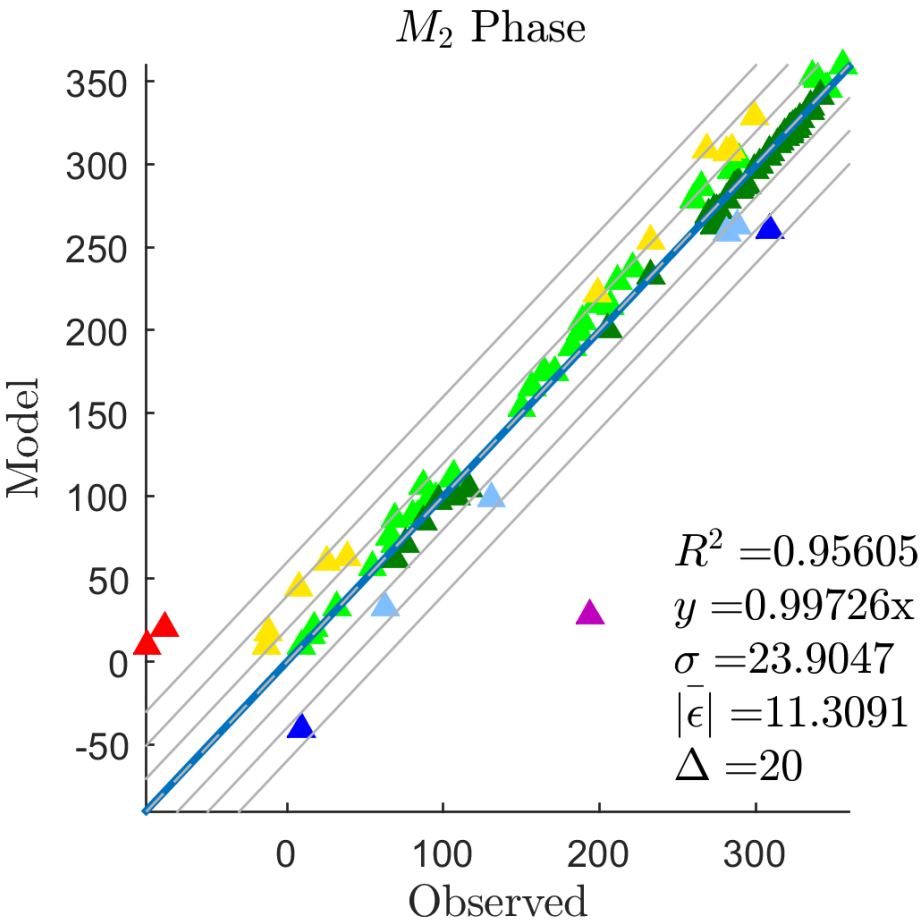


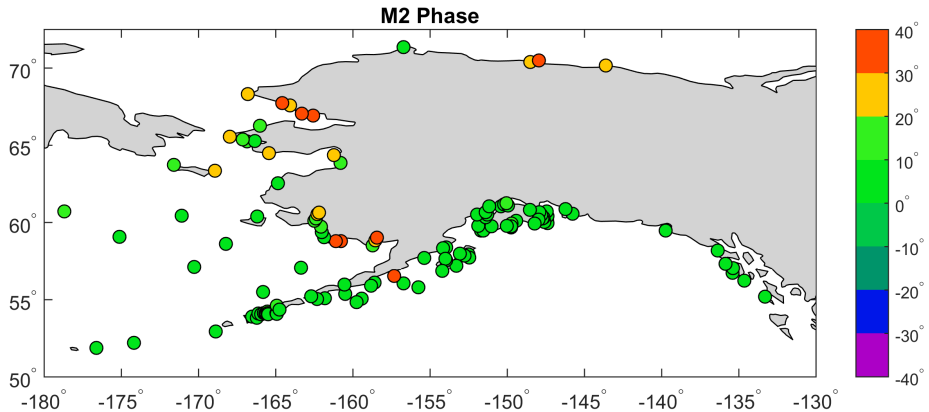
- Good performance everywhere but Kuskokwim River
- Performance greatly improved in Aleutians with f_l

M_2 Phase


M2 Model Phase
80˚
70˚
60˚
50˚
40˚
−200˚
−190˚
−180˚
−170˚
−160˚
−150˚
−140˚
−130˚
o
360
330
300
270
240
210
180
150
120
90
60
30
0

M_2 Phase Validation

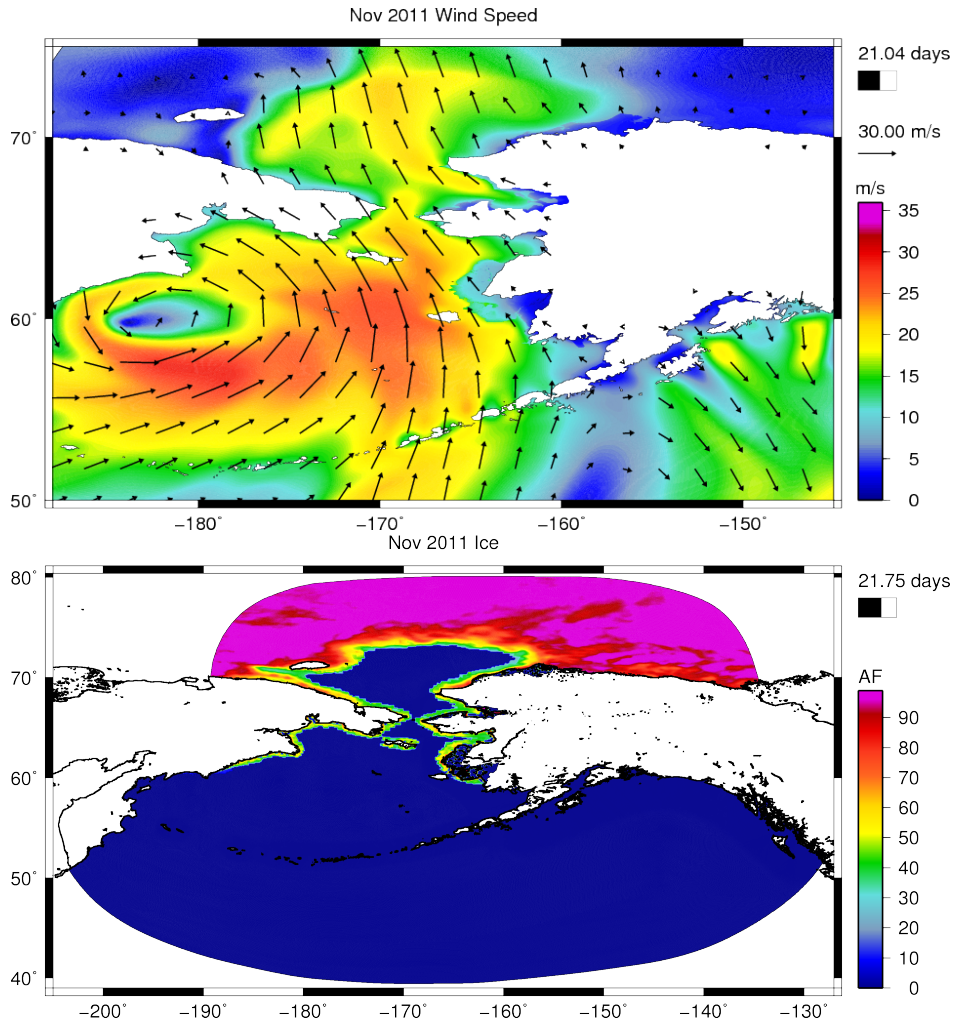




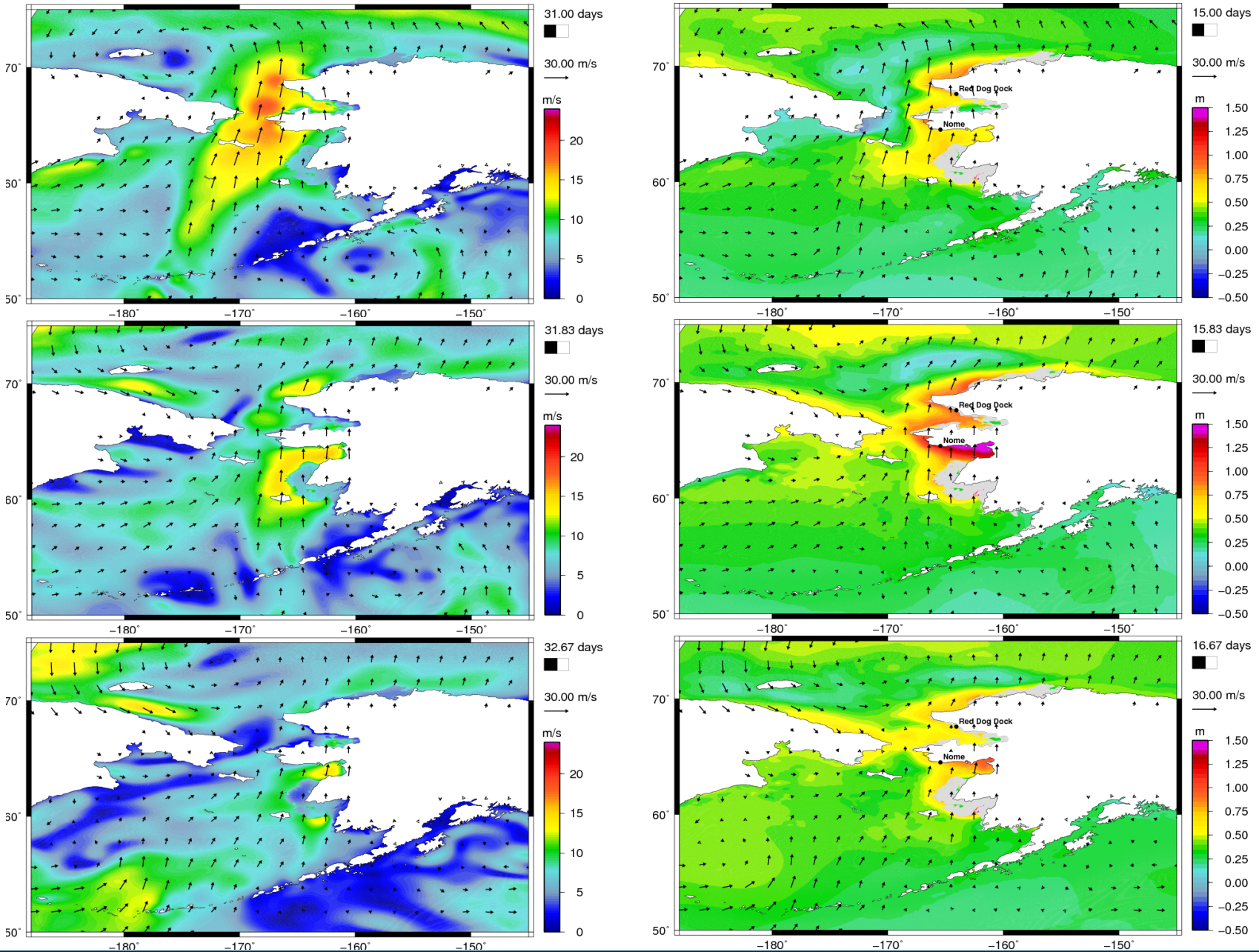
- Despite complexity, only small highly localized errors

Atmospheric and Sea Ice Forcing

- National Centers for Environmental Predictions Climate Forecast System Reanalysis (CFSv2) [3].
- 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.
- Sea ice from NCEP Automated Sea Ice Concentration Analysis 0.08333 degrees satellite based



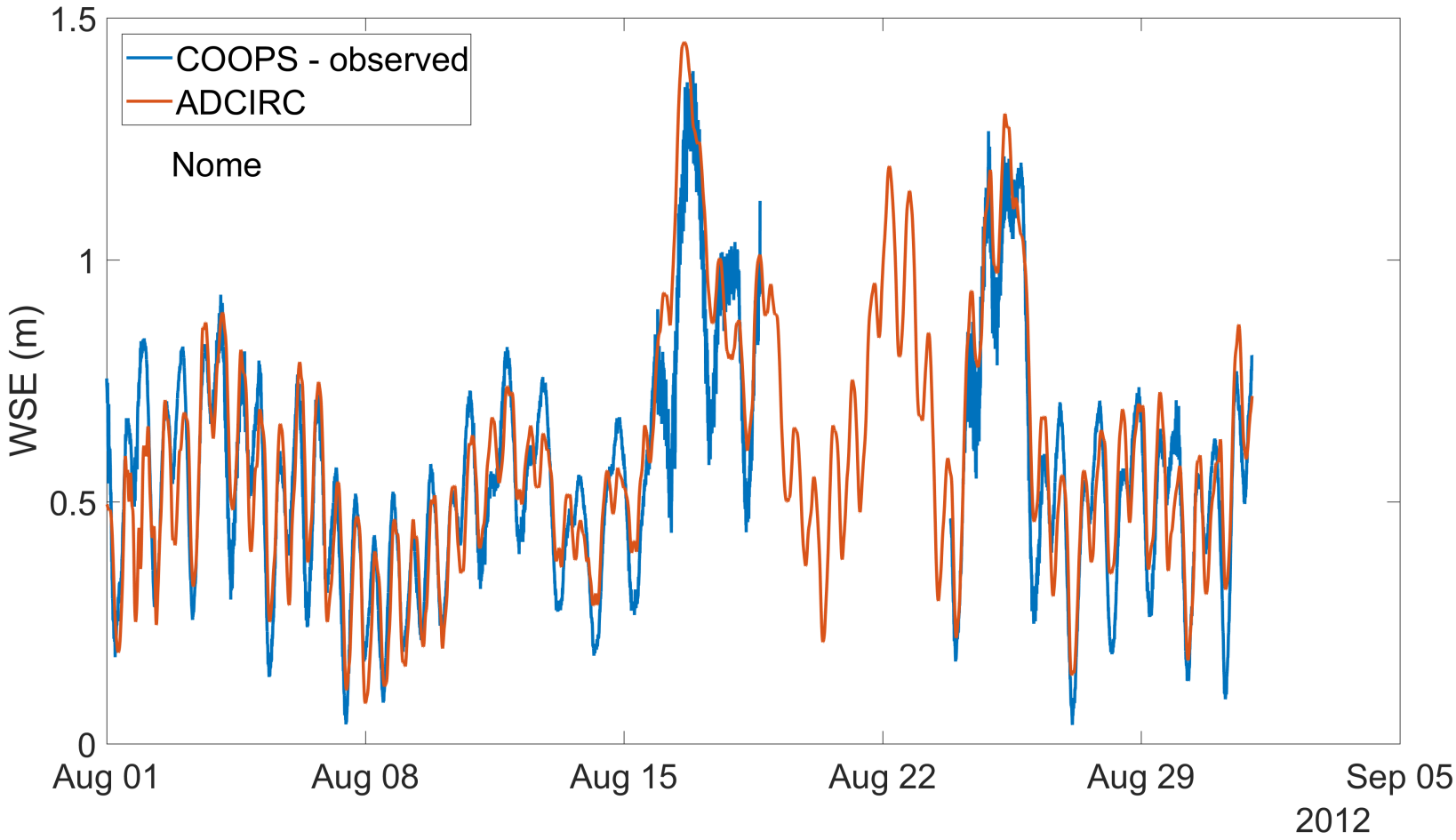
Summer Storm Validation - August 2012



Stations

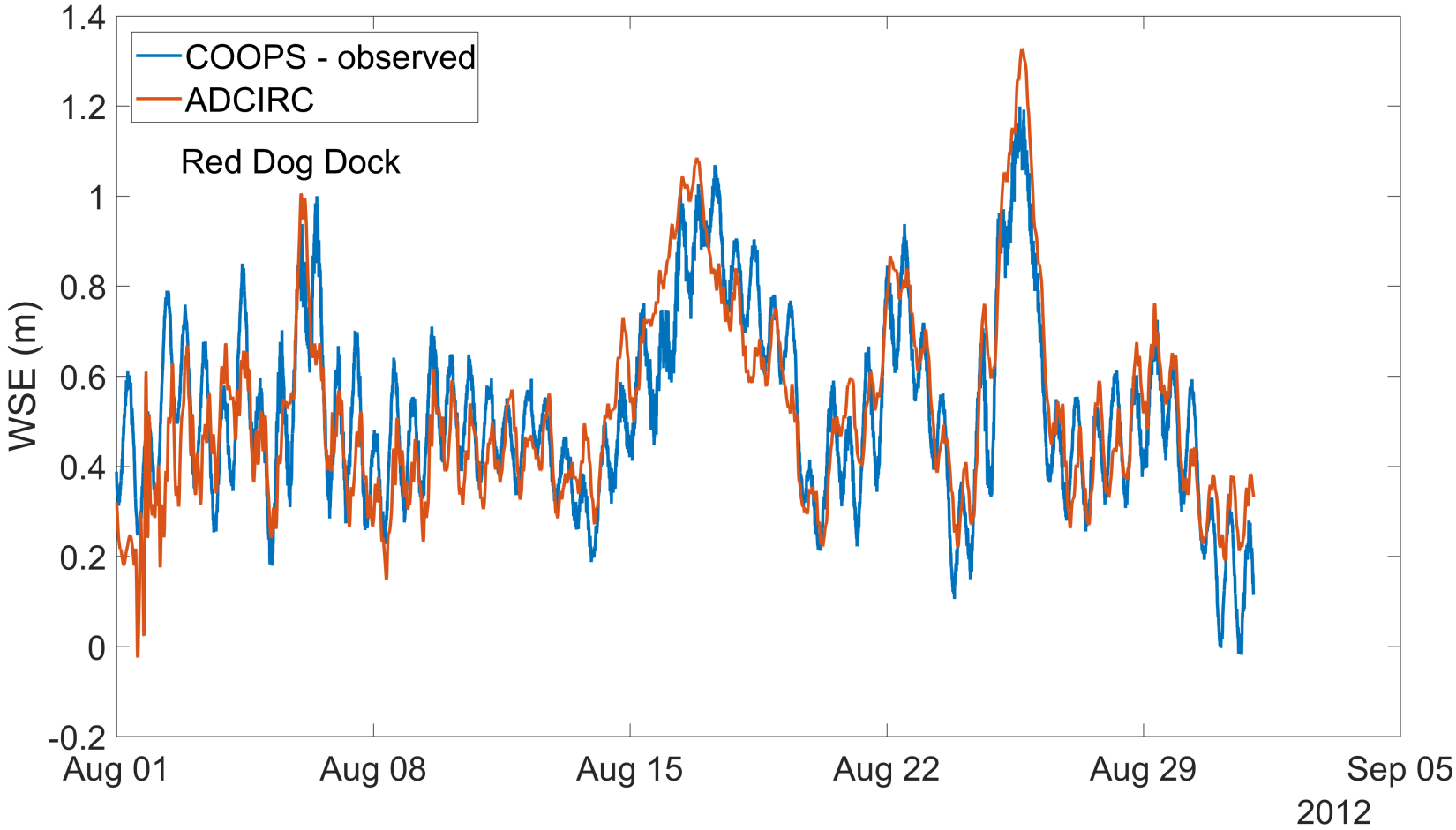
August 2012 Validation

Nome



August 2012 Validation

Red Dog Dock



Outline

1. Model Description
2. Validation of Tides and Summer Storms
3. Sea Ice Implementation to Circulation Modelling
4. Modelling Storm Surge in the Presence of Ice Coverage
   - November 2011
   - February 2011
   - January 2017
5. Proposed

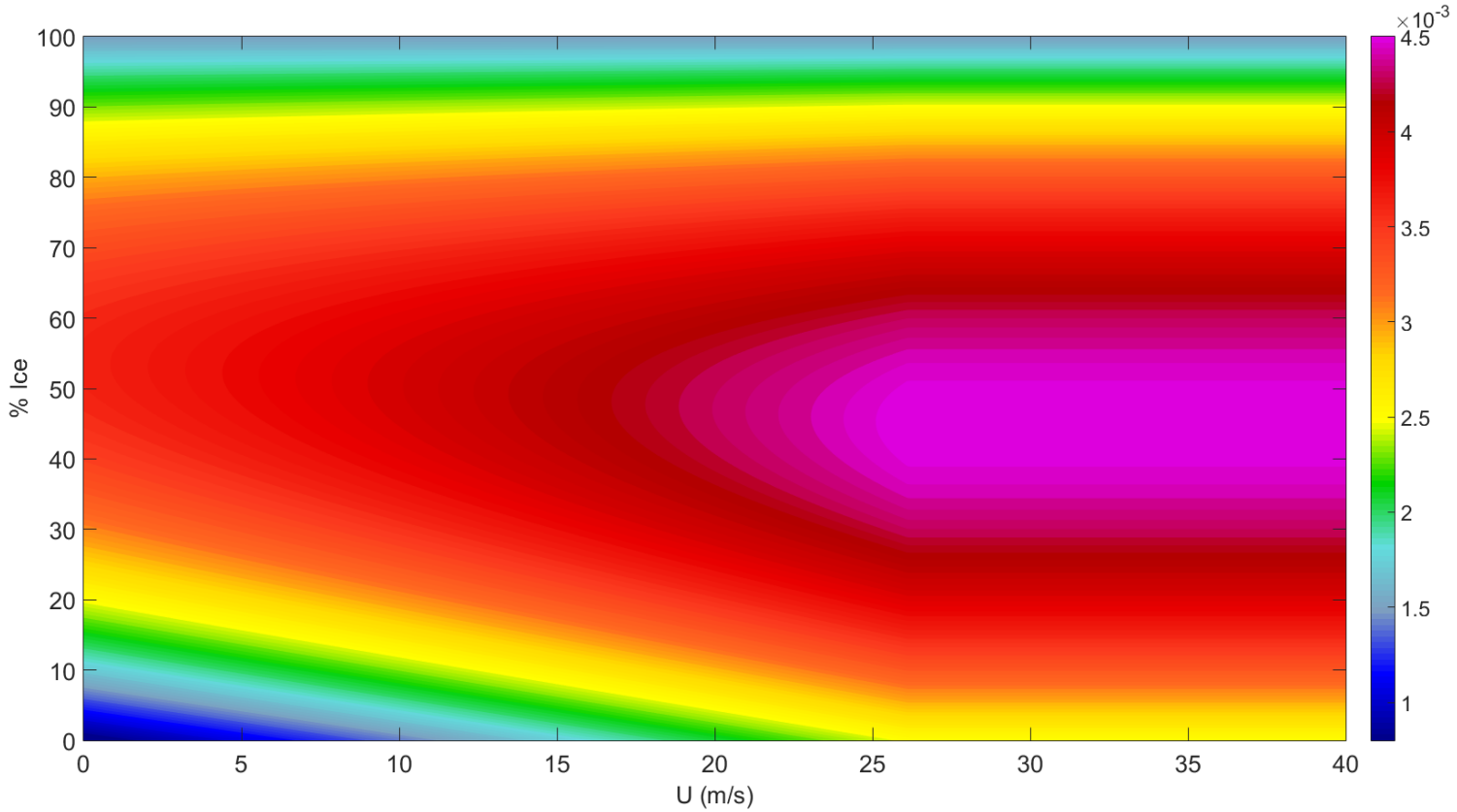
Investigated Implementation to ADCIRC

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

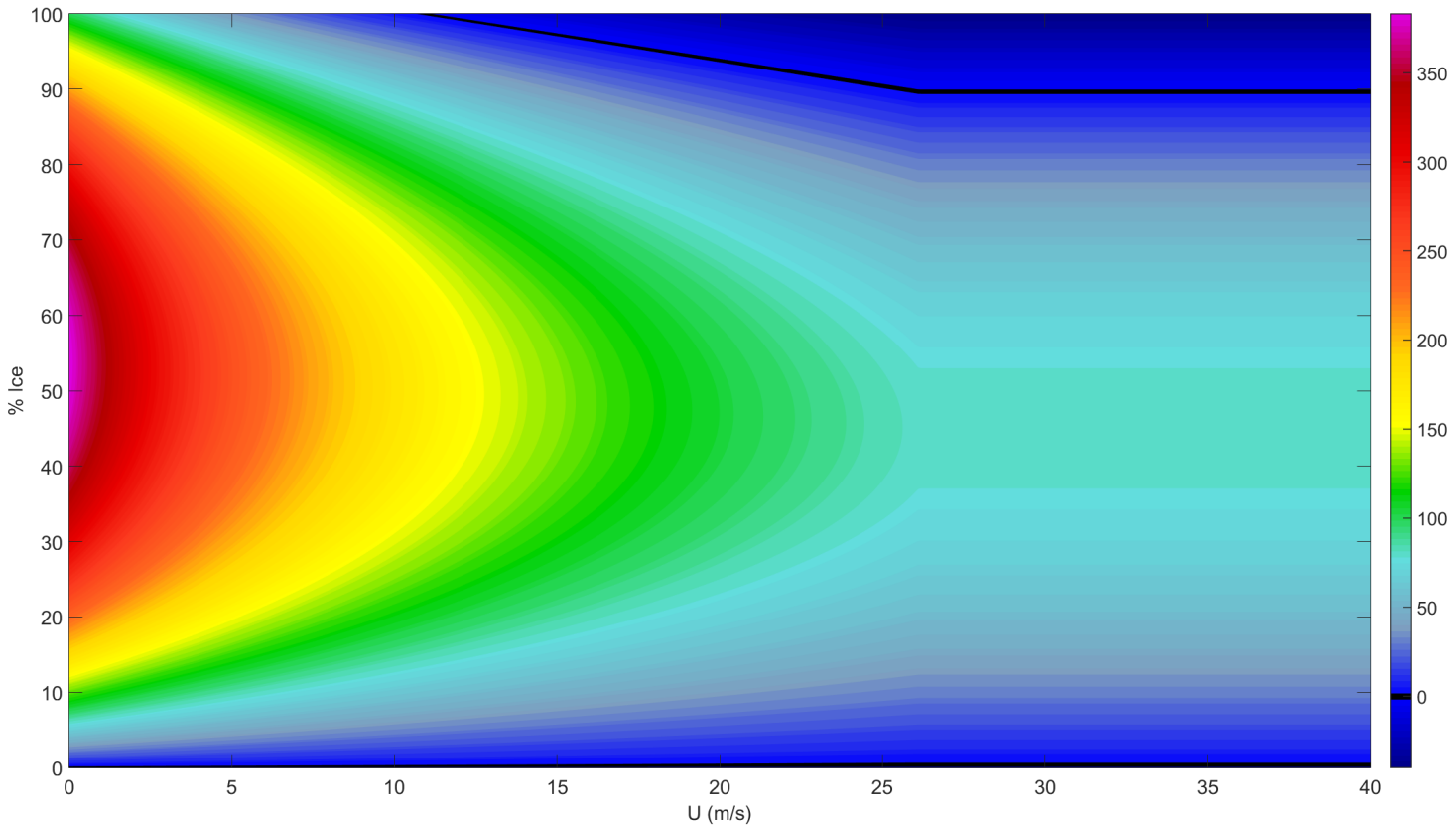
$C_{D,is}$ = ice skin drag = 0.0015
$C_{D,w}$ = Garratt drag law
$C_{D,if}$ = ice form drag
$C_{D,if}(0) = 0$, $C_{D,if}(1) = 0$
$C_{D,if}(.5) = C_{D,if,max} = .0025$

- Decompose the flux coefficient into contributions which are a function of both wind speed and ice coverage
- Area weighted approach [5, 1, 2]
- Considers both the form and skin drag over ice floes
- Form drag determined by number of ice face/obstacles

New Ice Parameterization - C_d



New Ice Parameterization - % Change



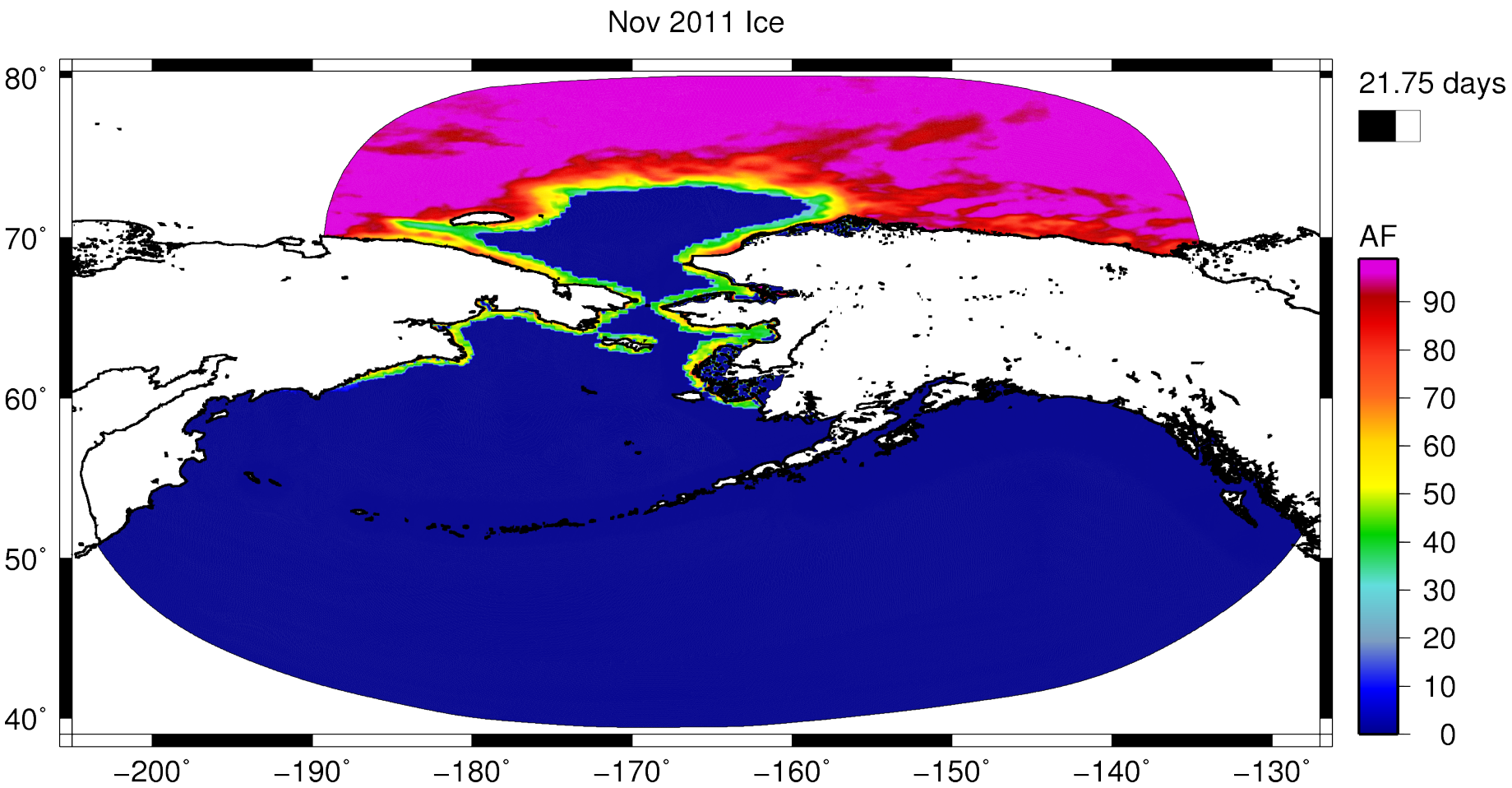
New Ice Parameterization - Assumptions and Limitations

- 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
- Doesn't consider fast ice
- Data limitations
  - Low resolution temporally (only daily evolution of the ice field)
  - Missing features of the ice (only area fraction)

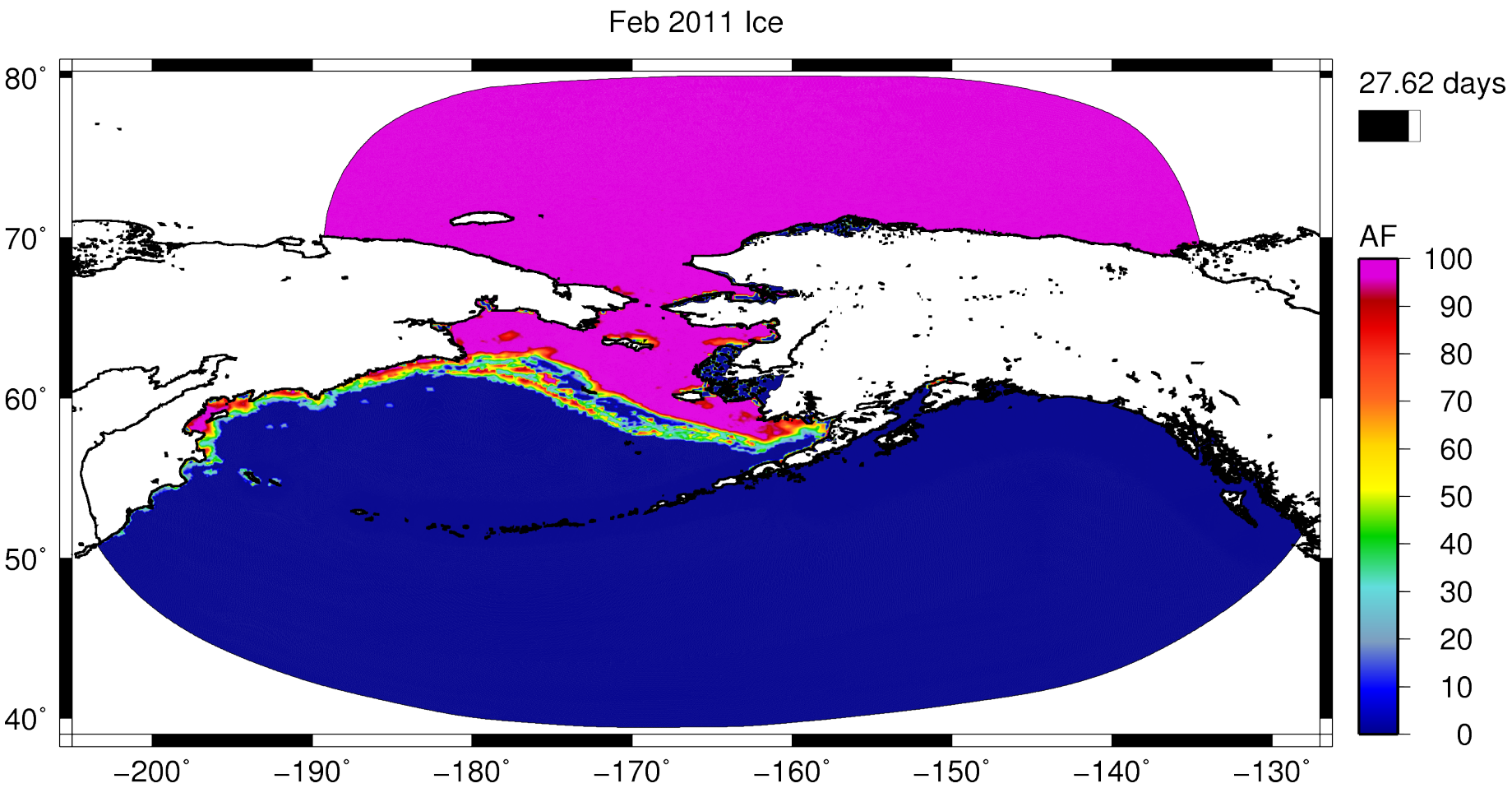
Outline

1. Model Description
2. Validation of Tides and Summer Storms
3. Sea Ice Implementation to Circulation Modelling
4. Modelling Storm Surge in the Presence of Ice Coverage
   - November 2011
   - February 2011
   - January 2017
5. Proposed

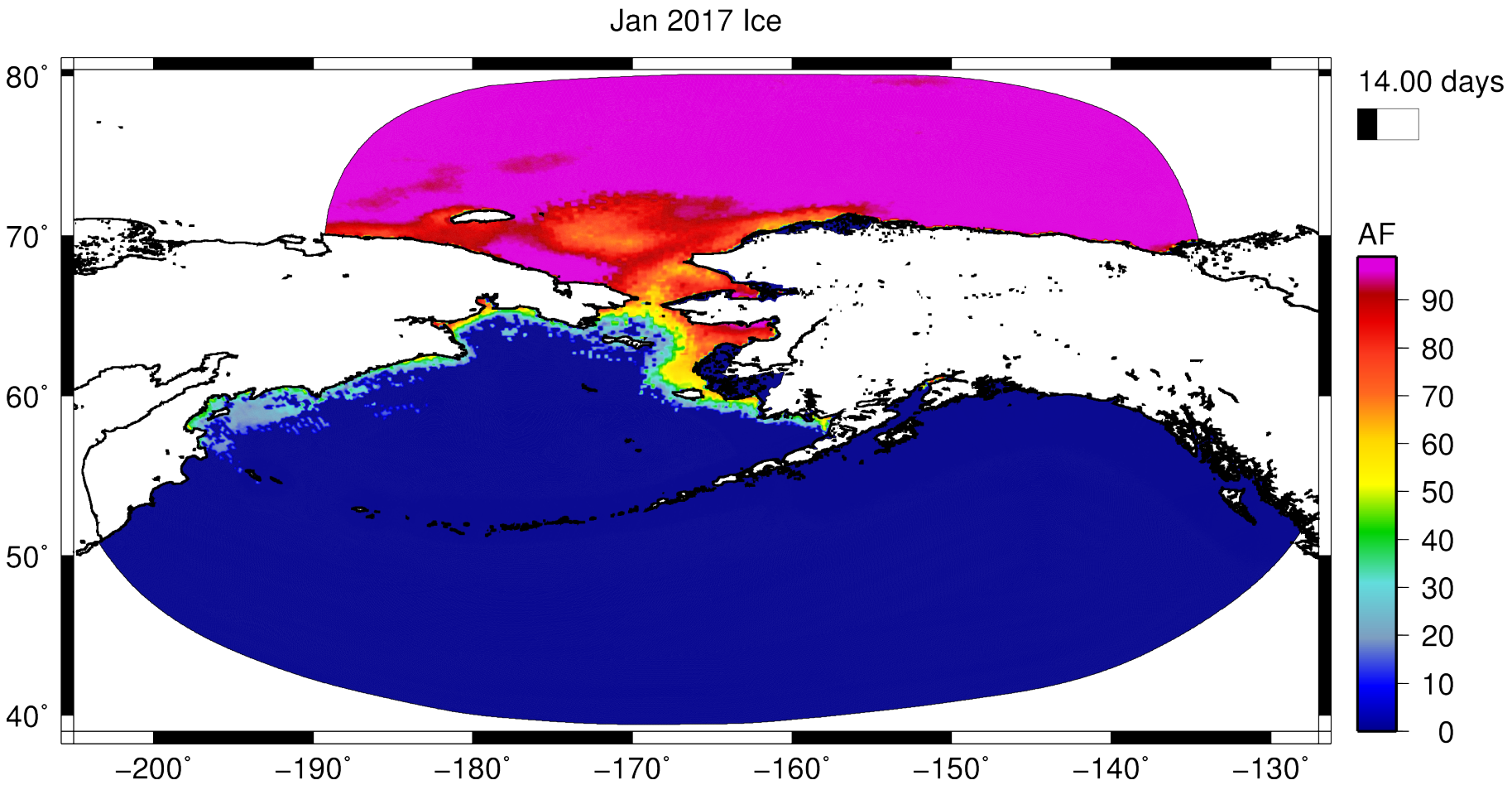
November 2011 Ice Coverage



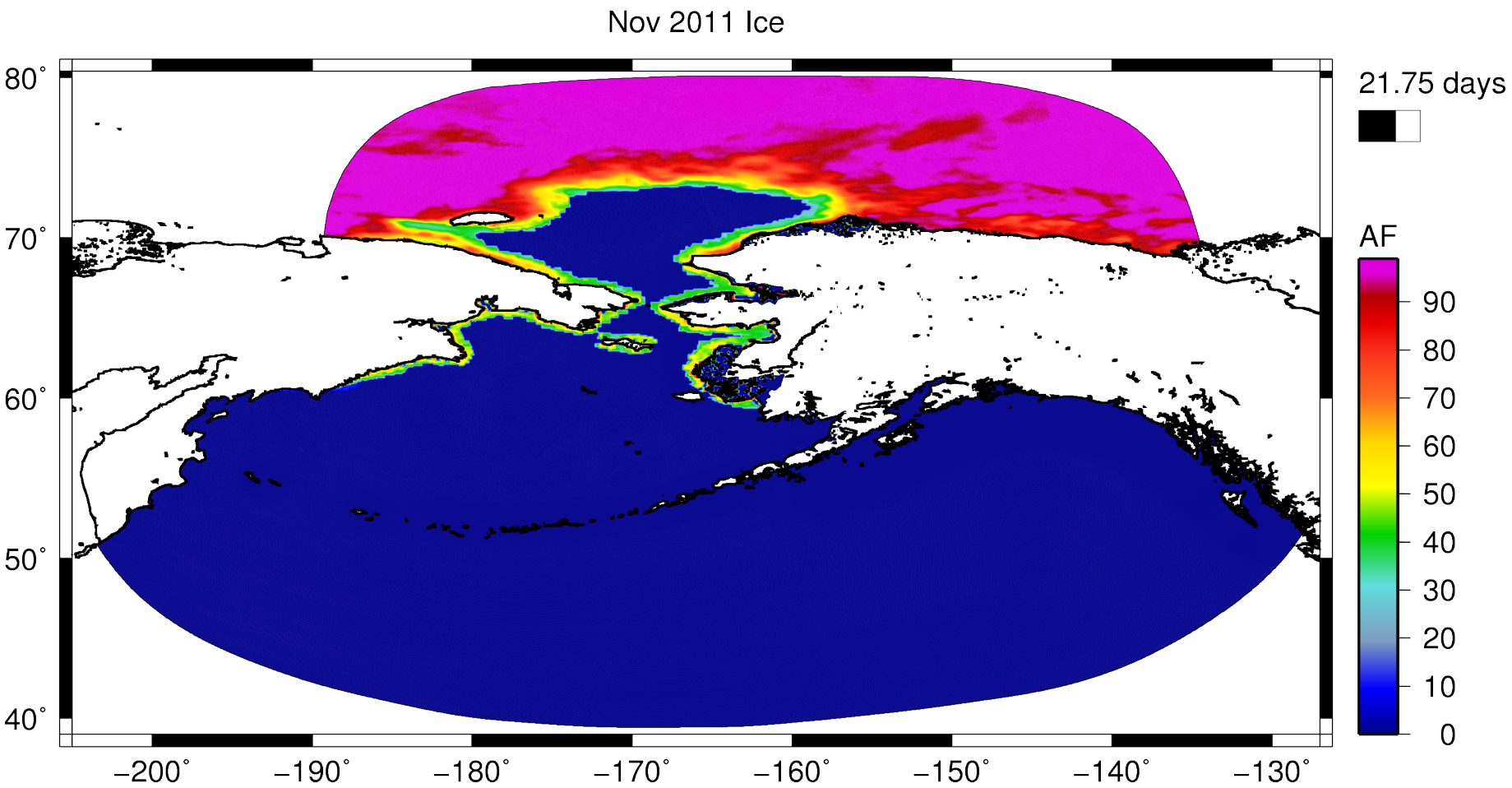
February 2011 Ice Coverage



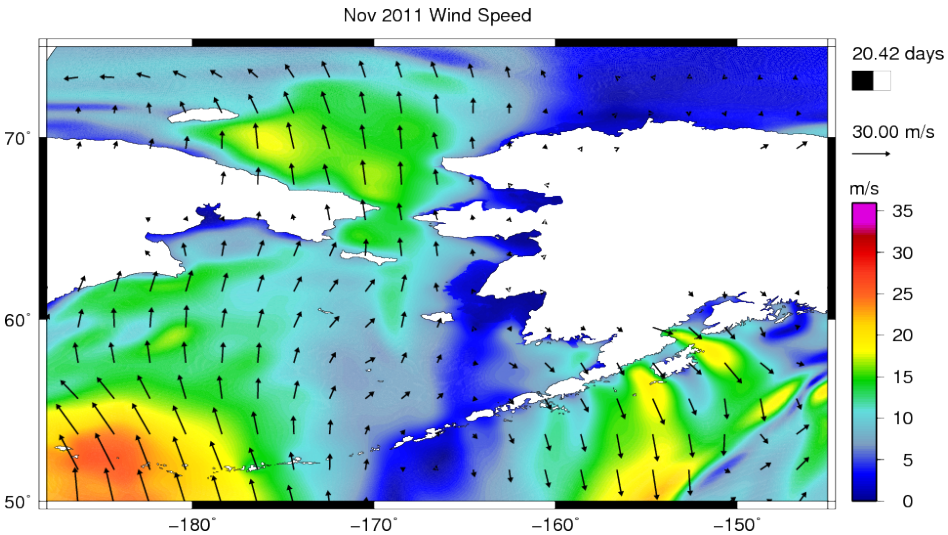
January 2017 Ice Coverage

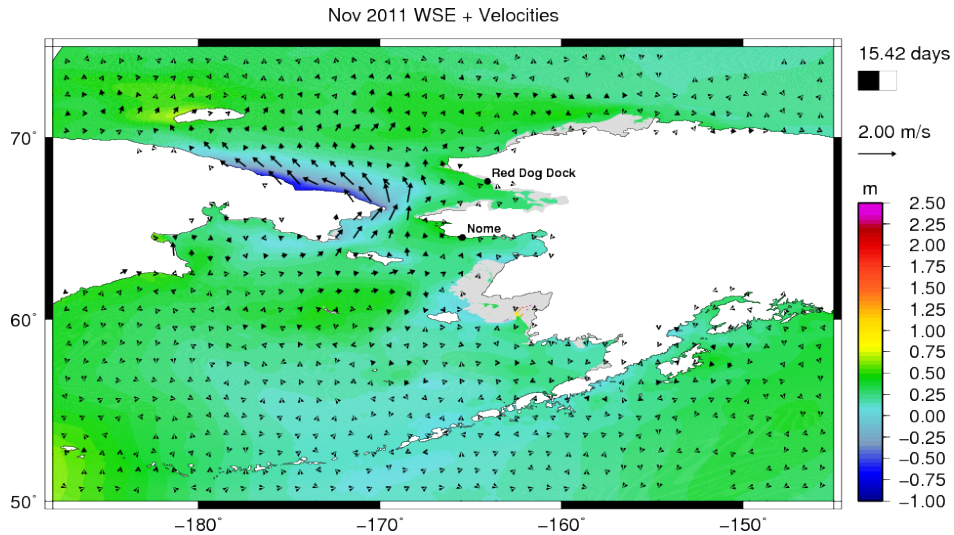


November 2011 Ice Coverage

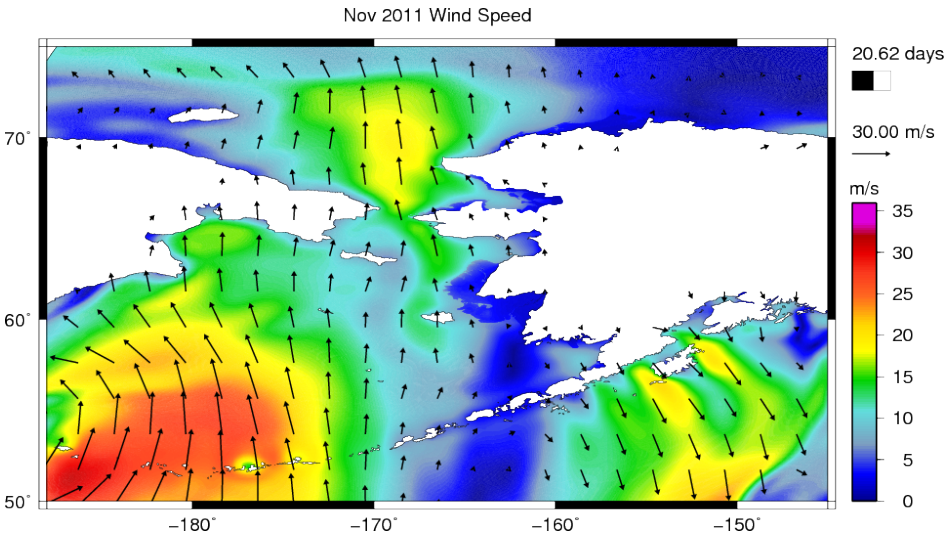


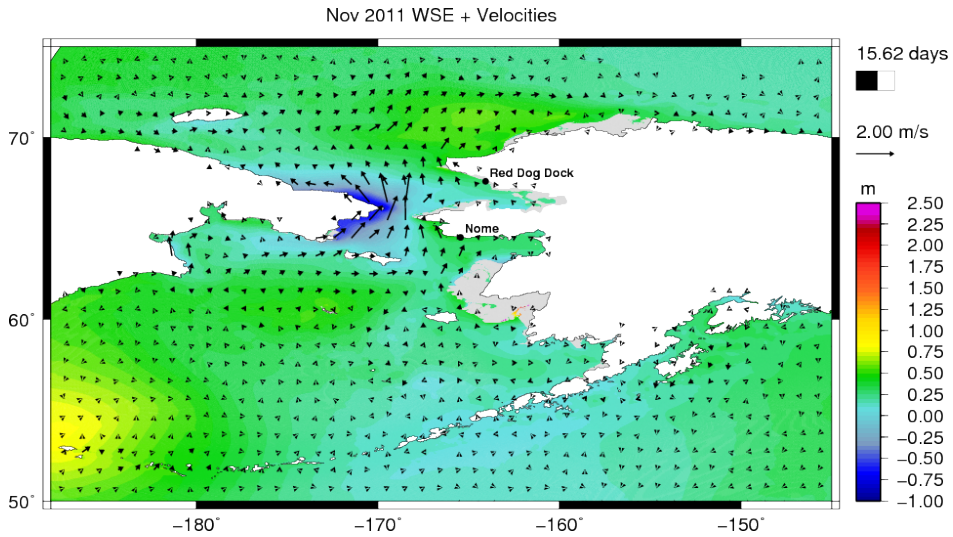
November 2011



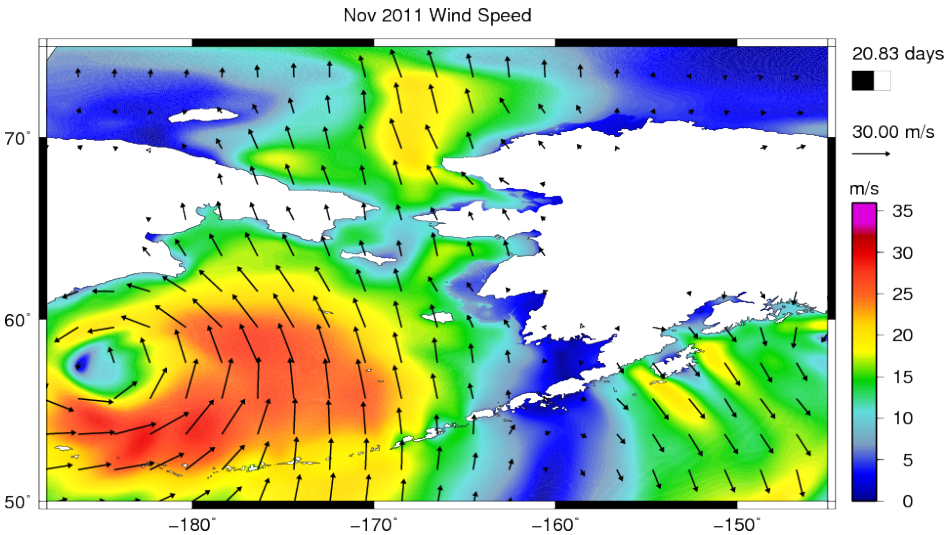


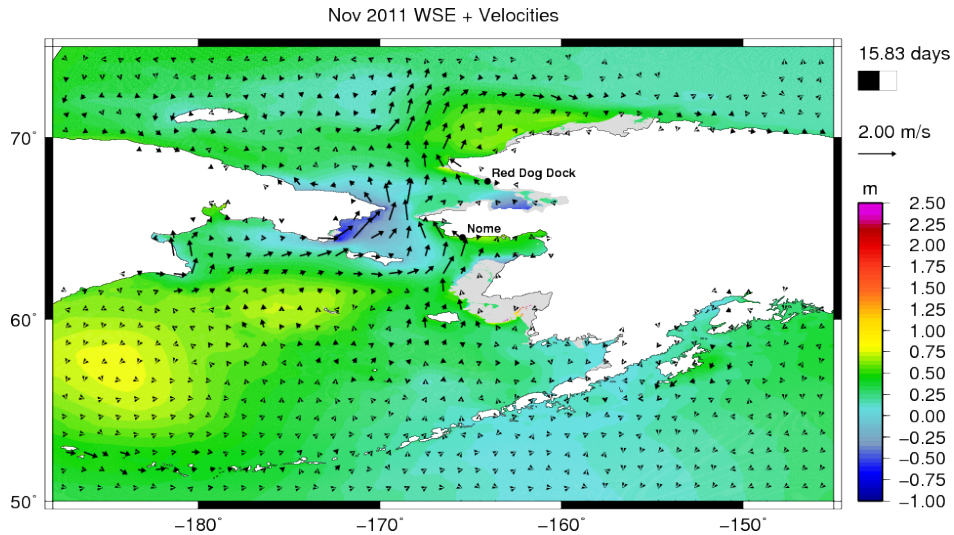
November 2011



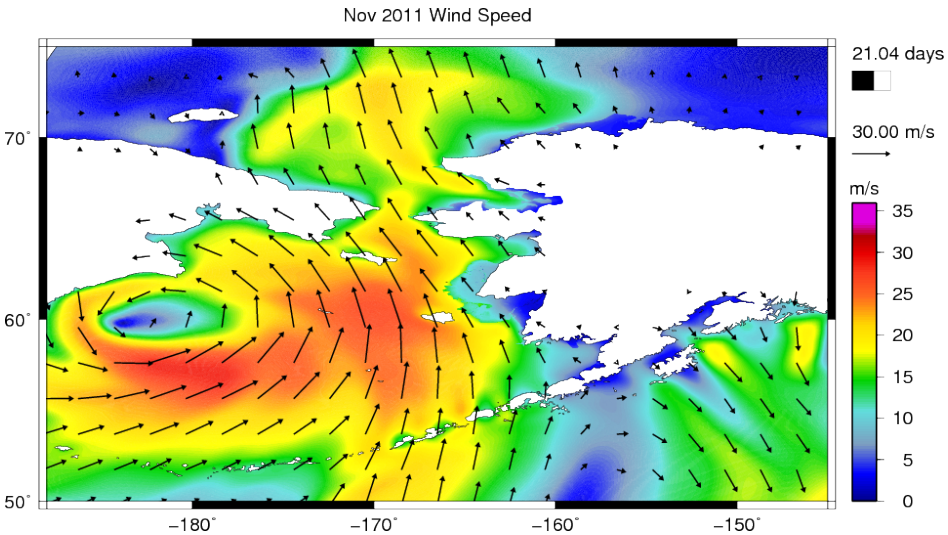


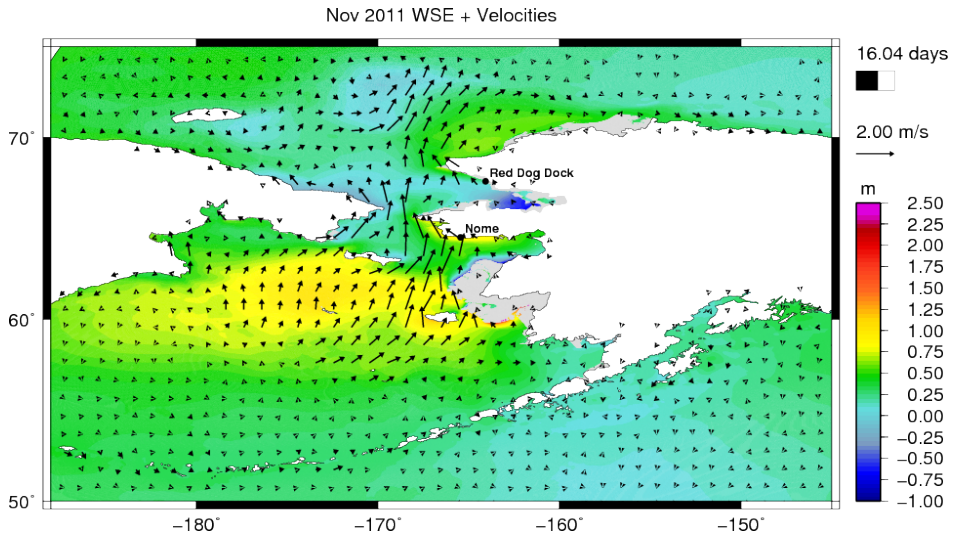
November 2011



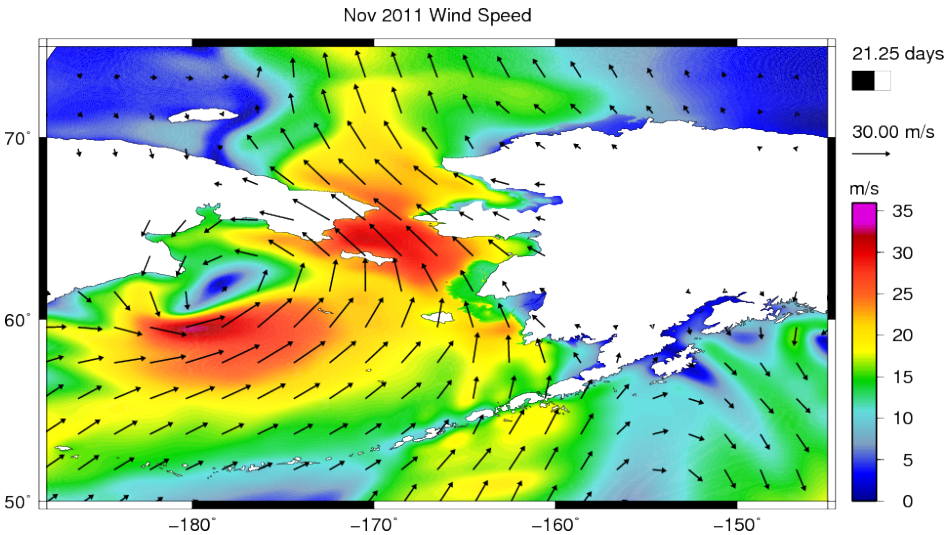


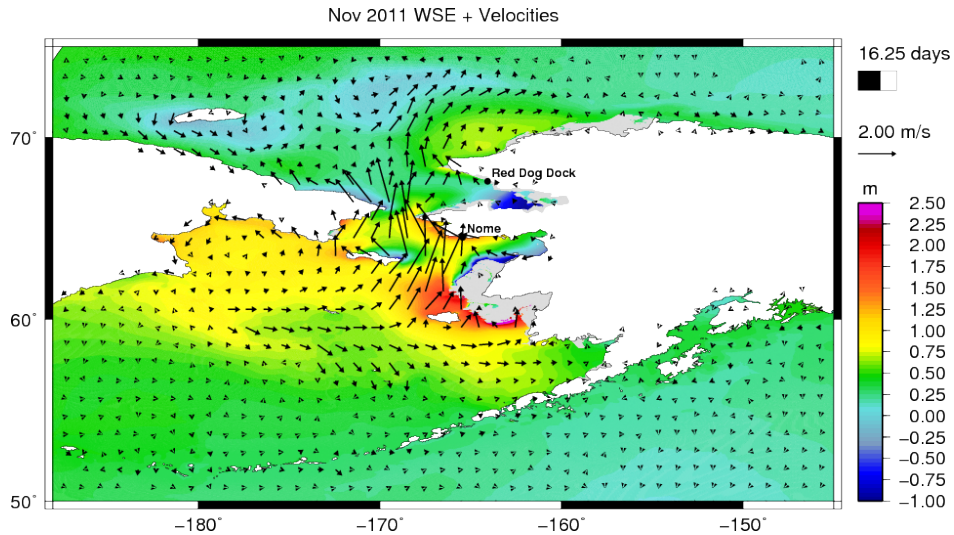
November 2011



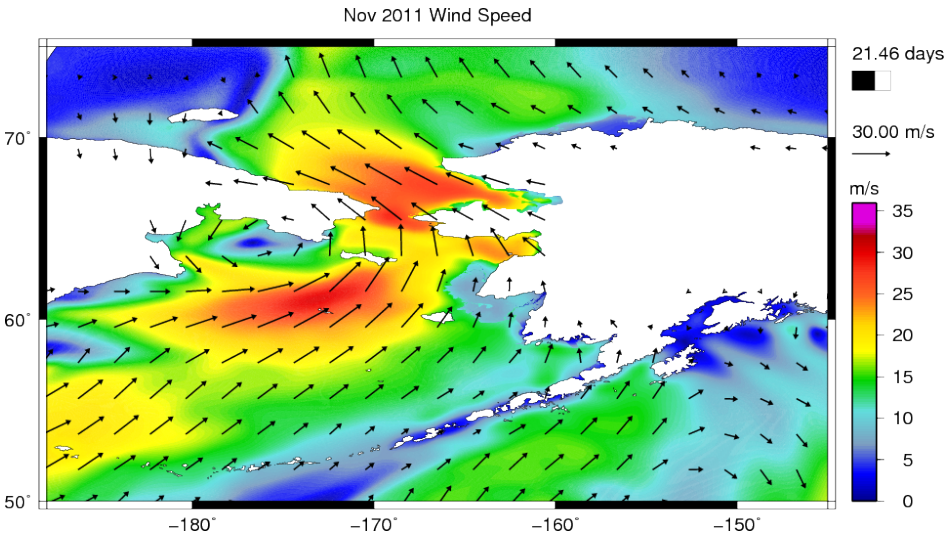


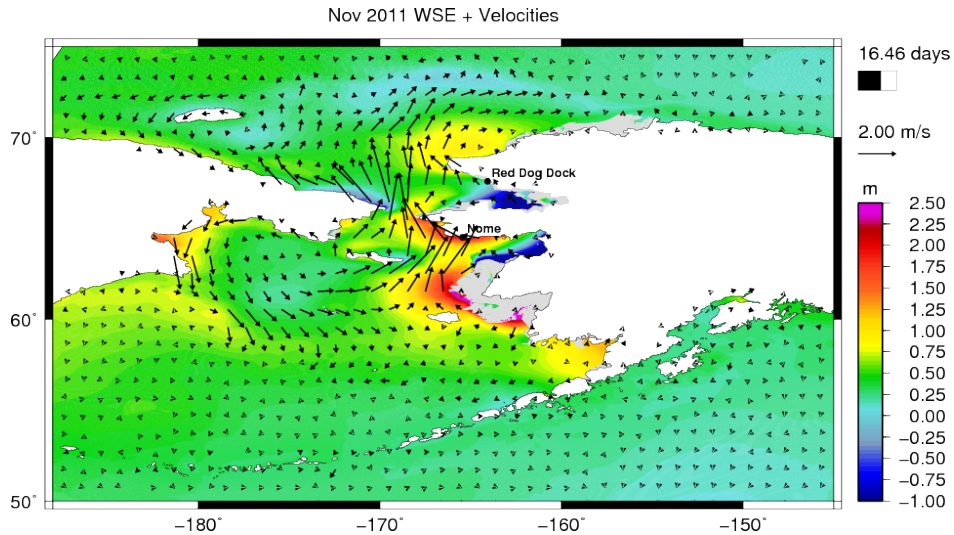
November 2011



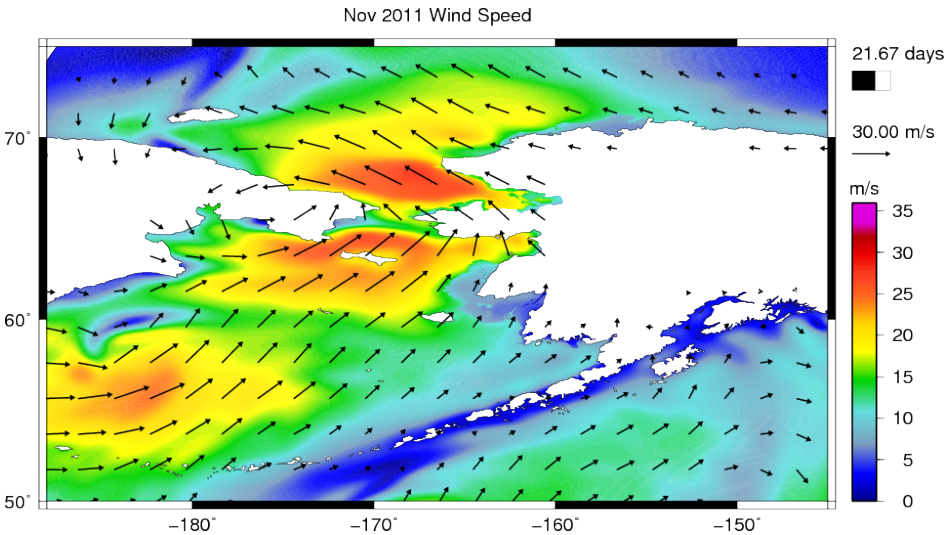


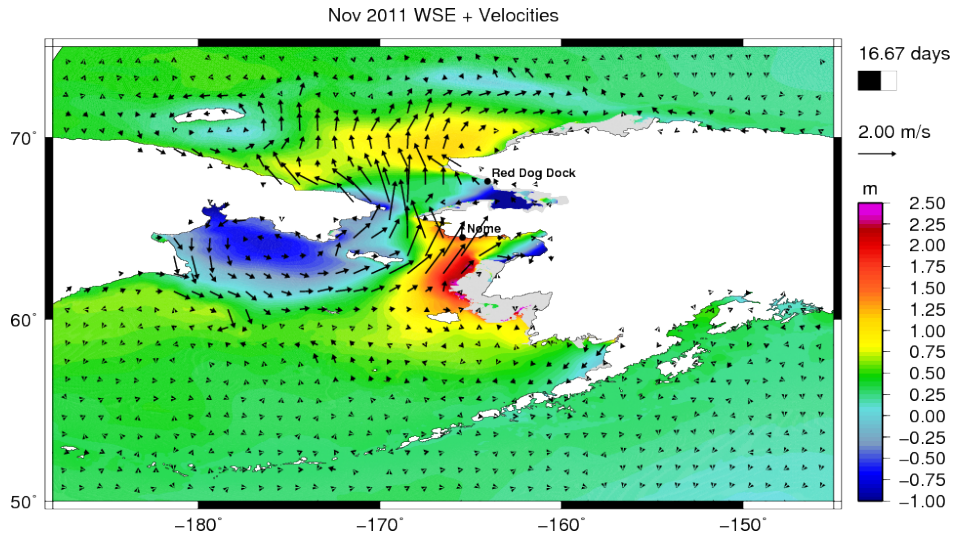
November 2011



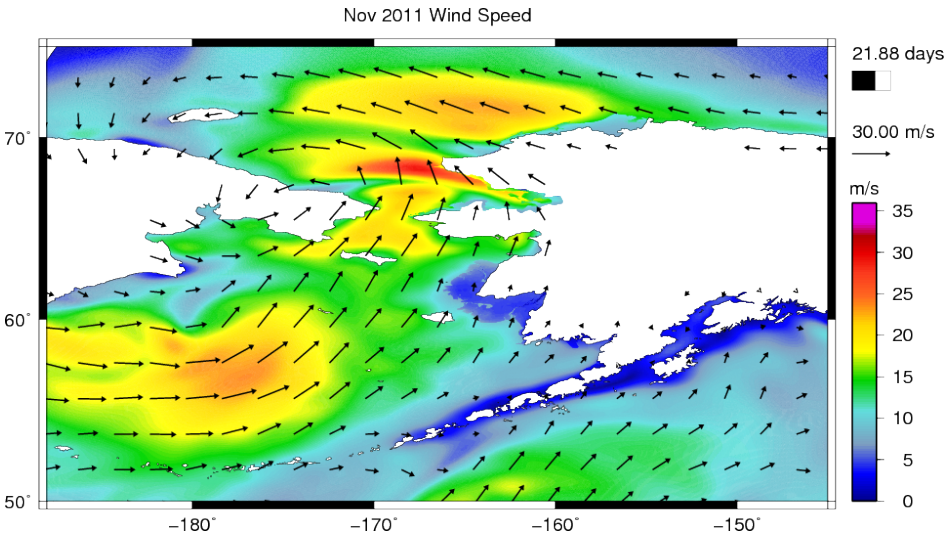


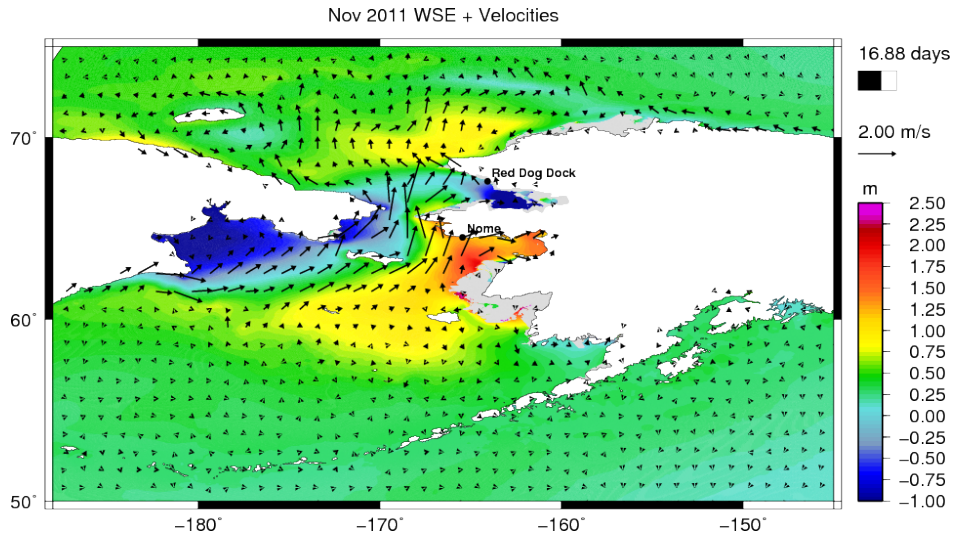
November 2011



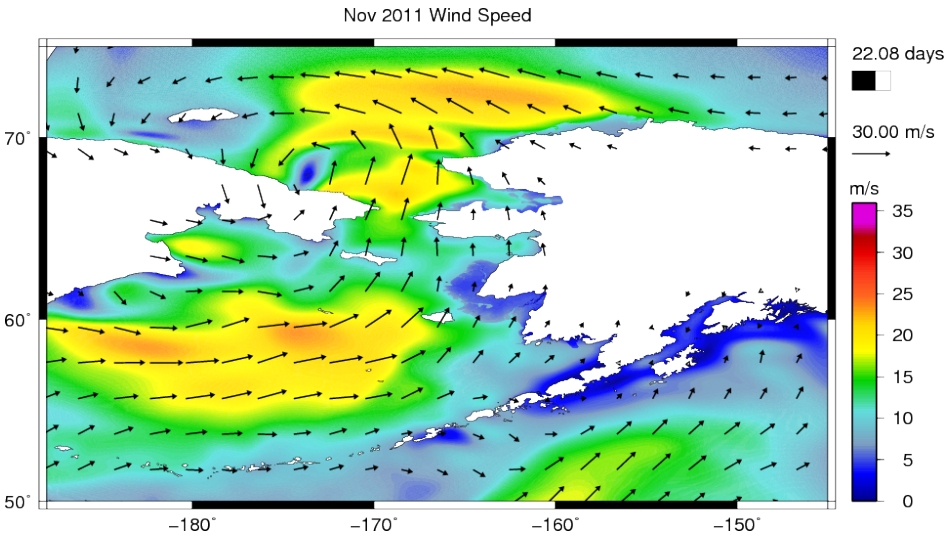


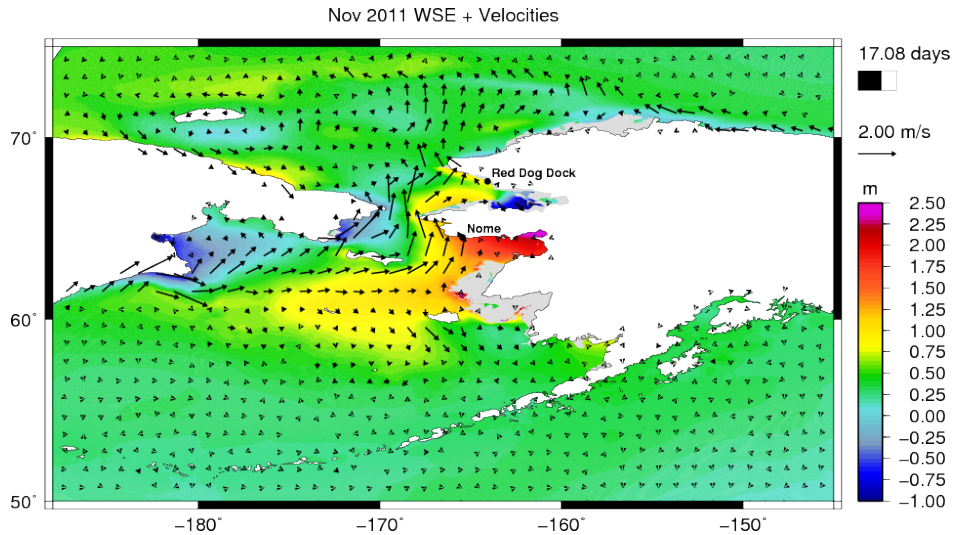
November 2011



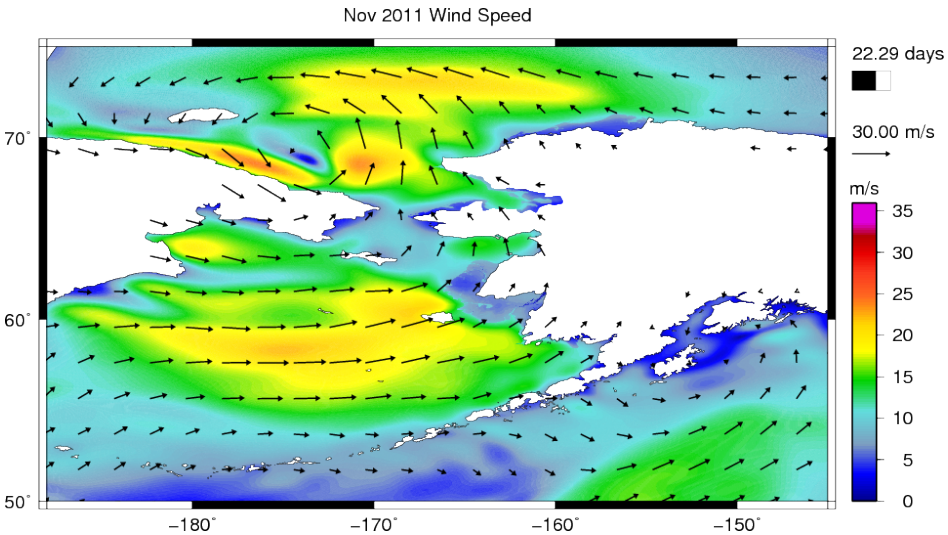


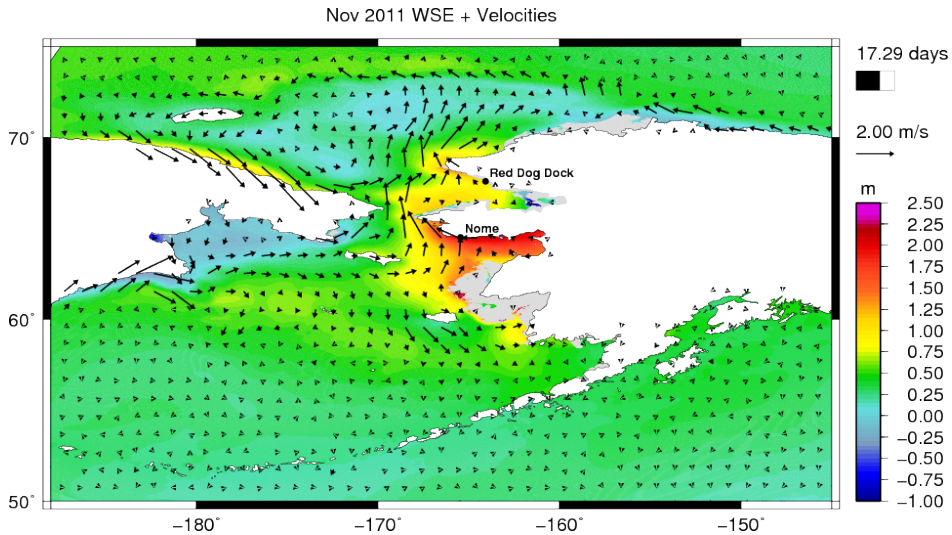
November 2011



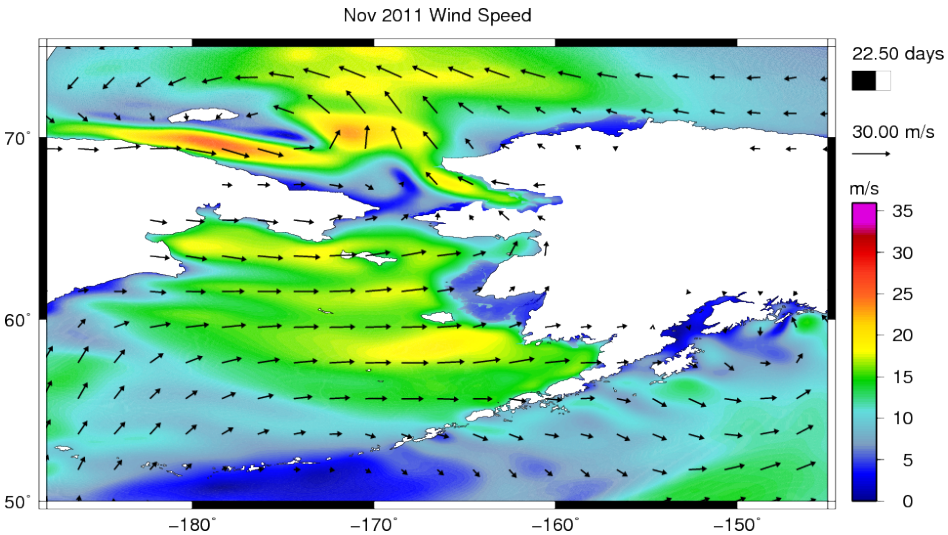


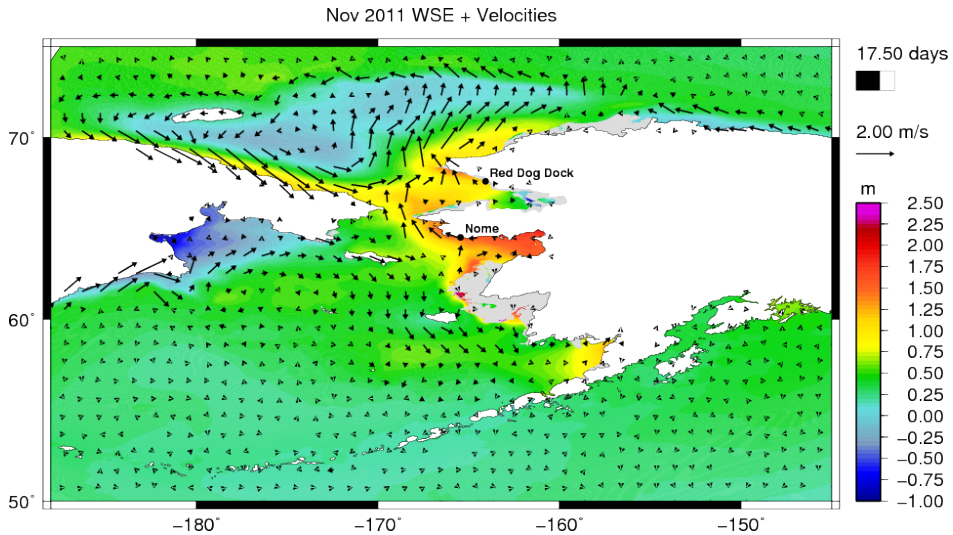
November 2011



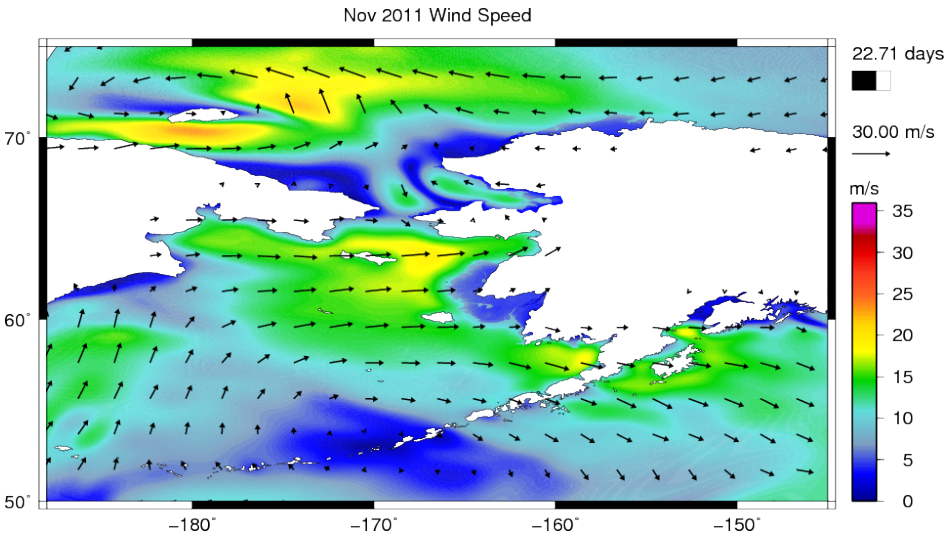


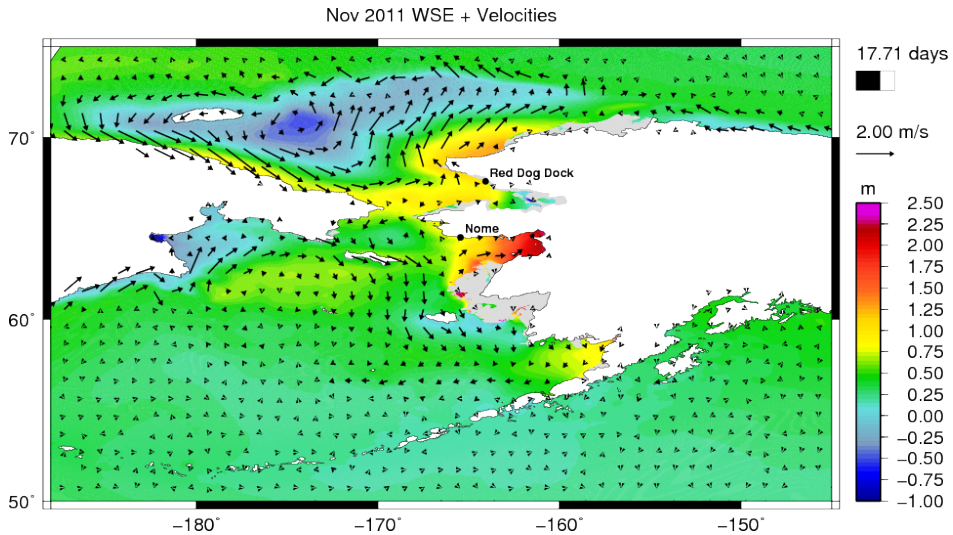
November 2011



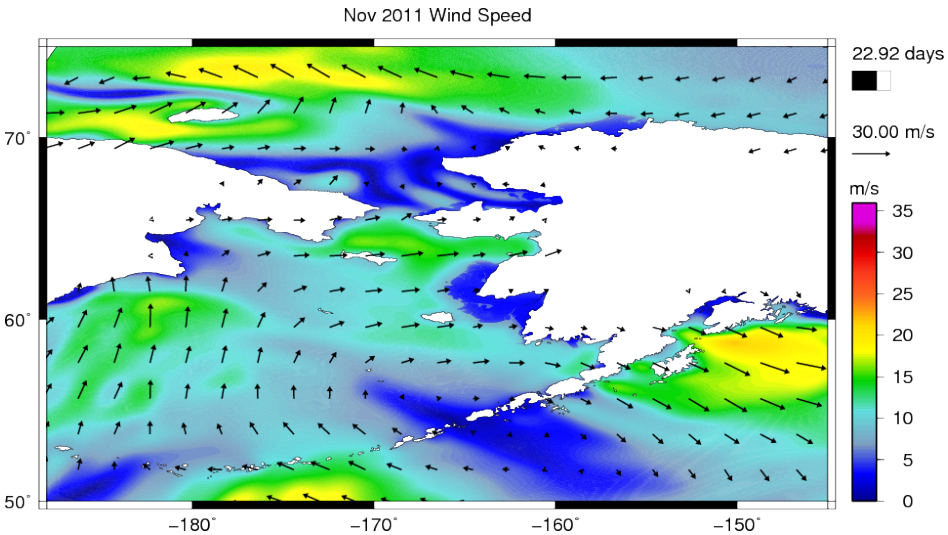


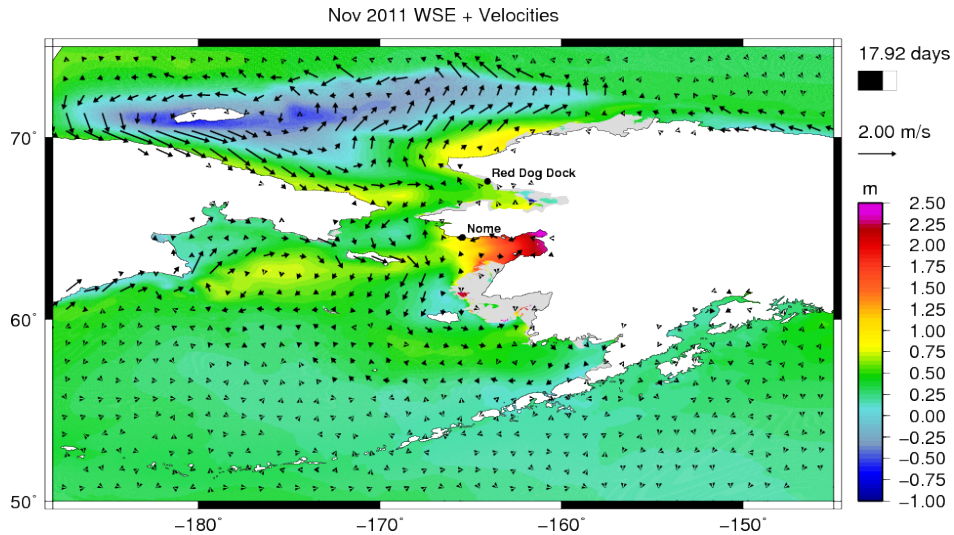
November 2011



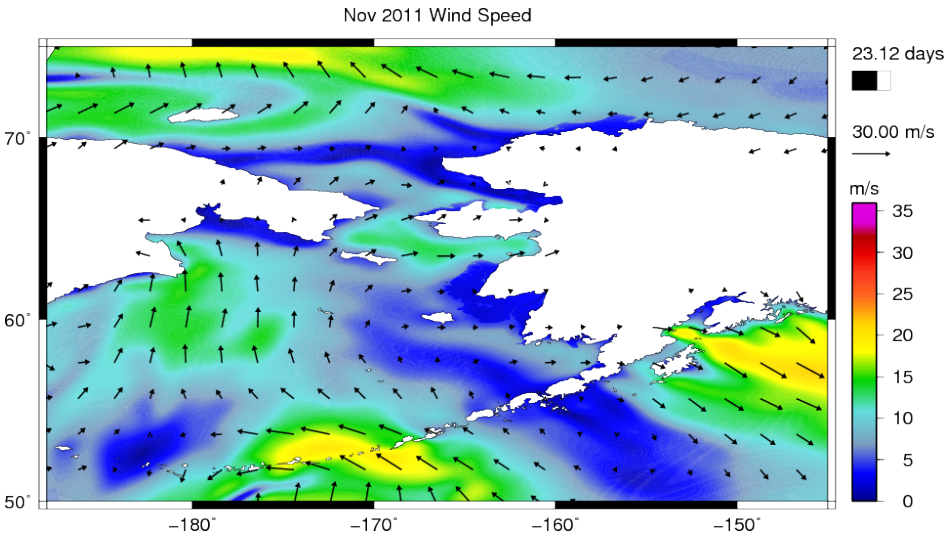


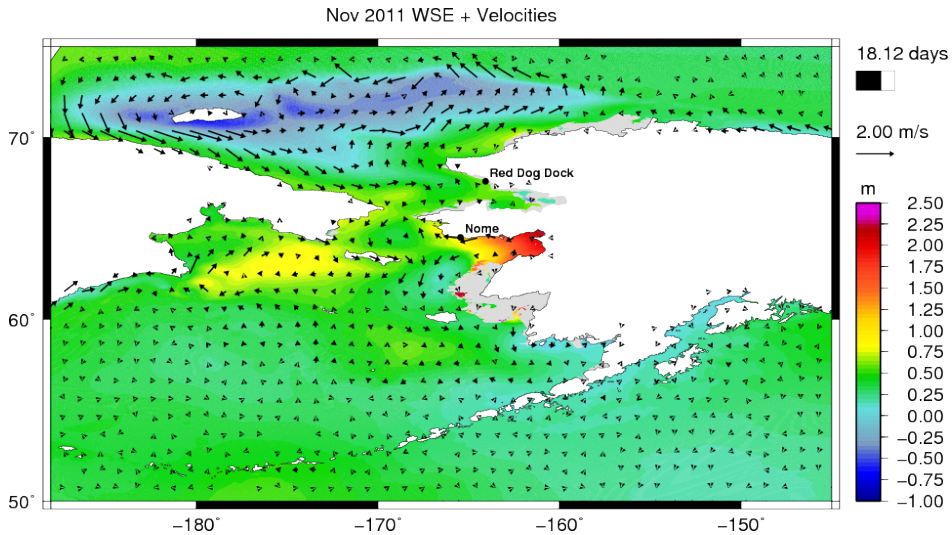
November 2011





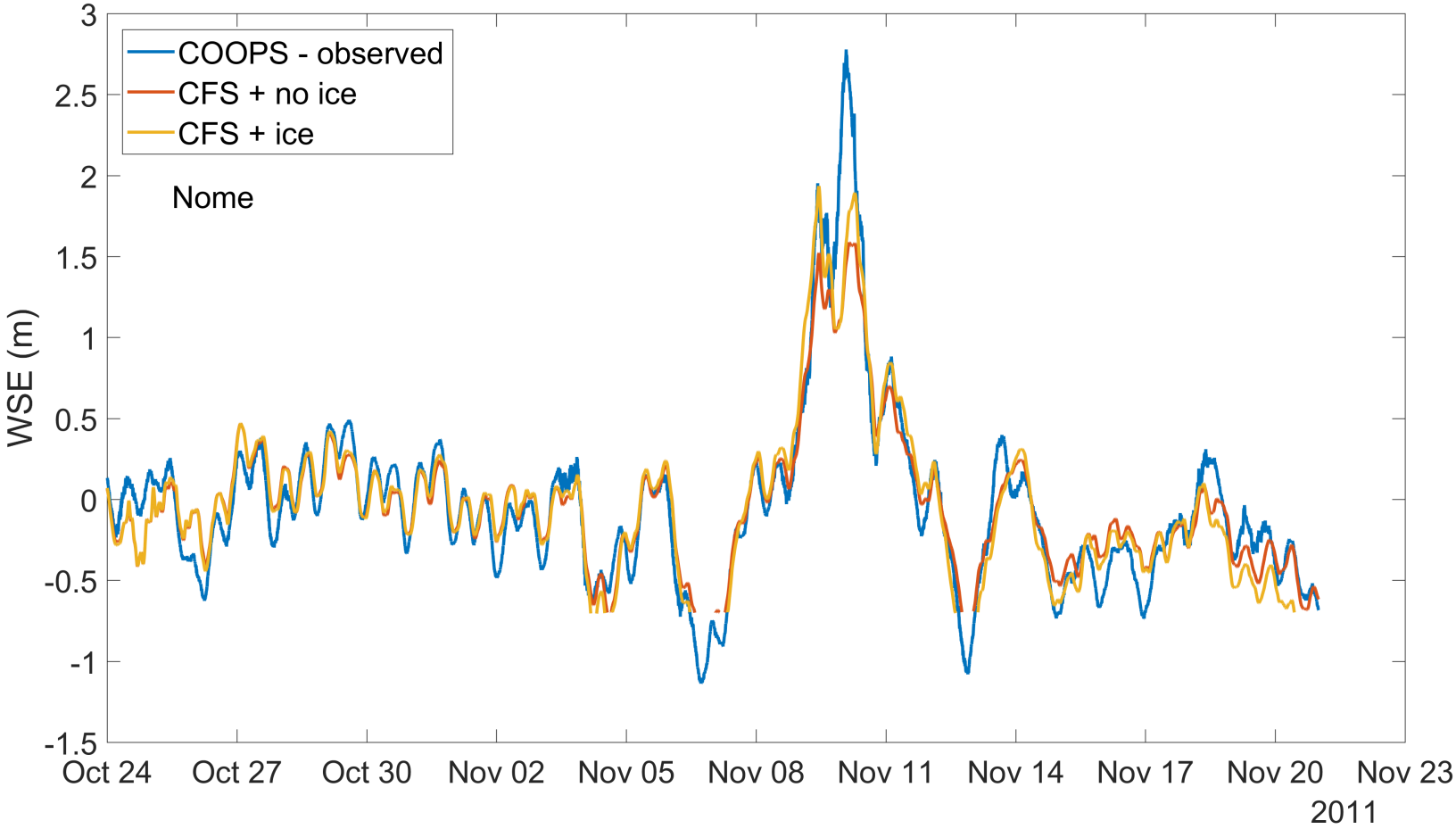
November 2011





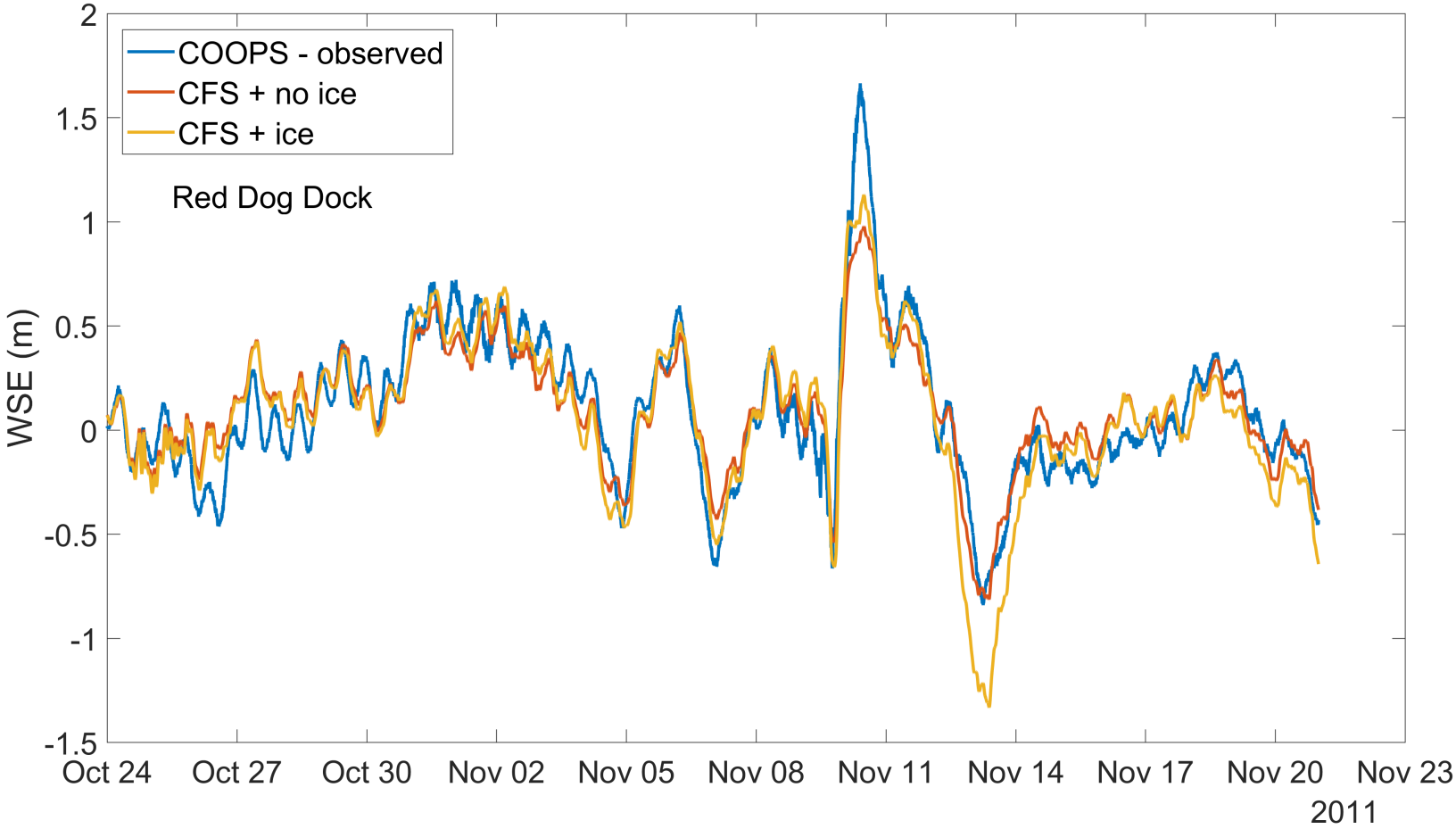
November 2011 Validation

Nome

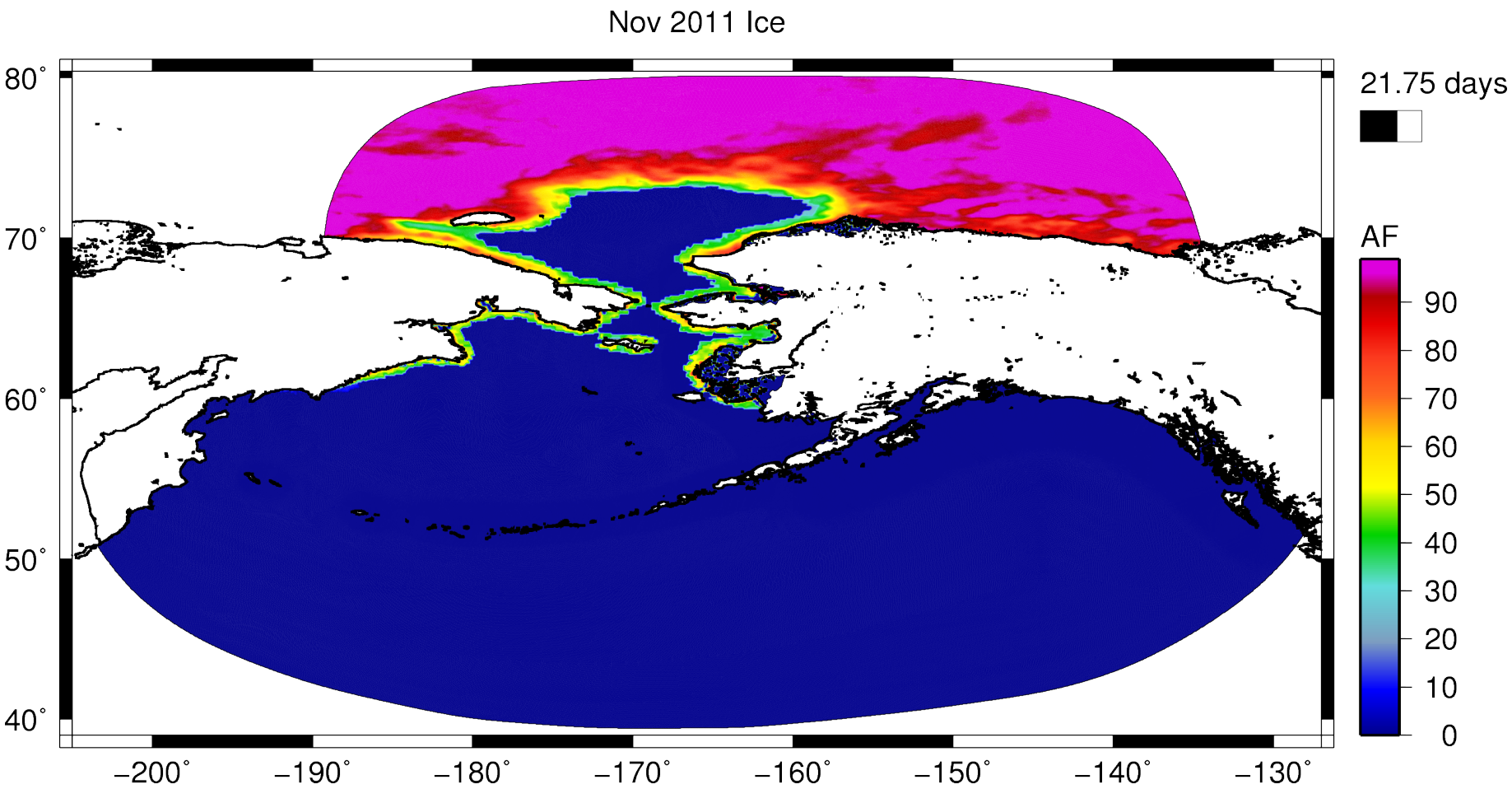


November 2011 Validation

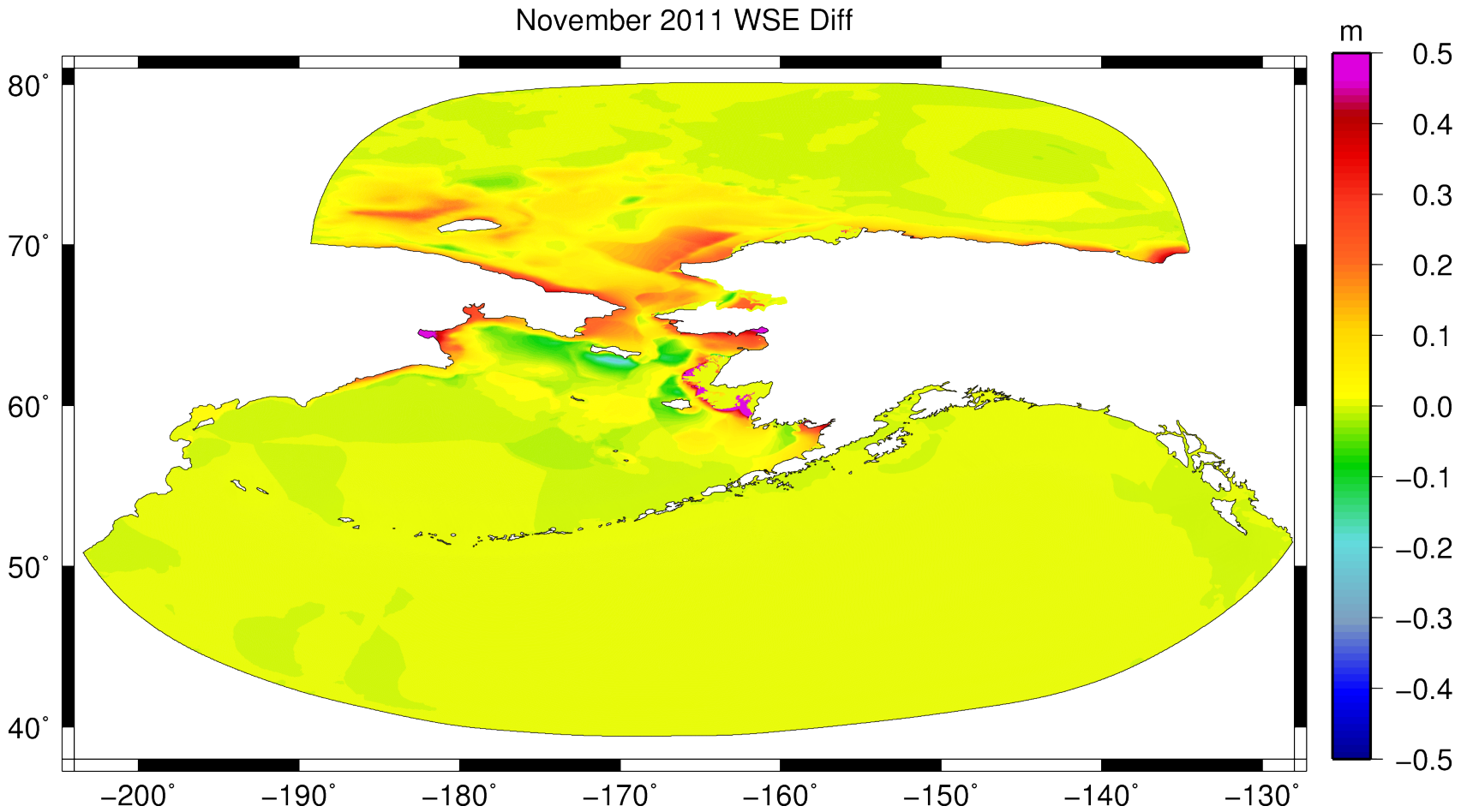
Red Dog Dock



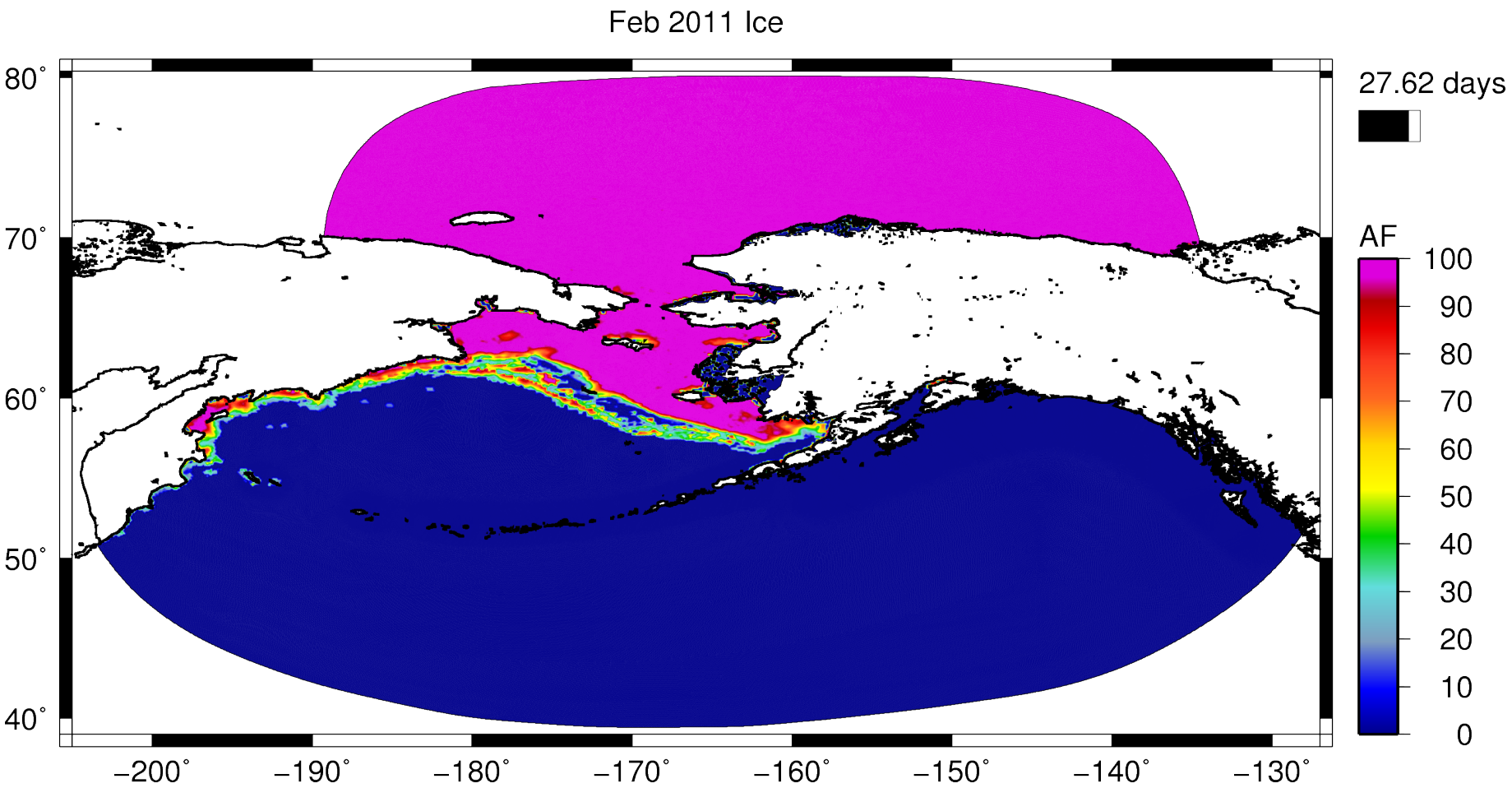
November 2011 Ice Coverage



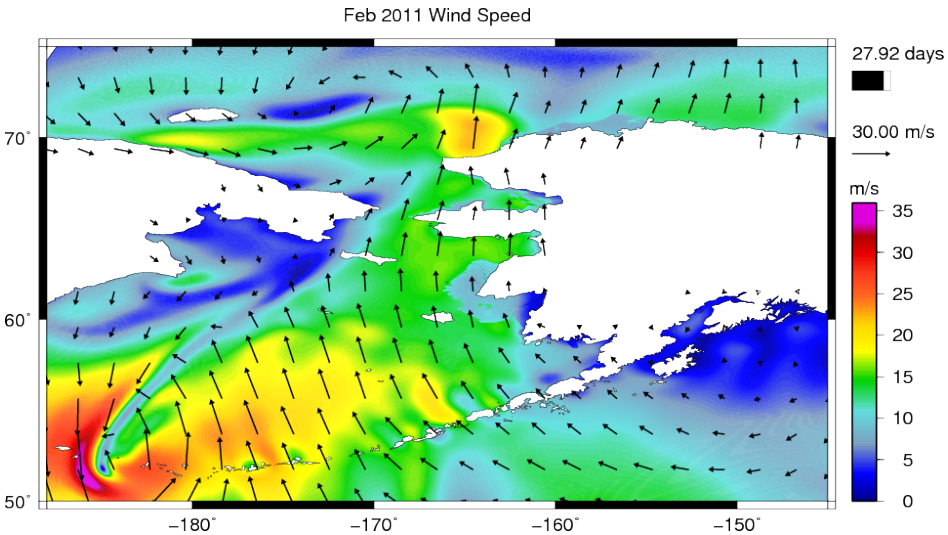
November 2011 Effect of Ice

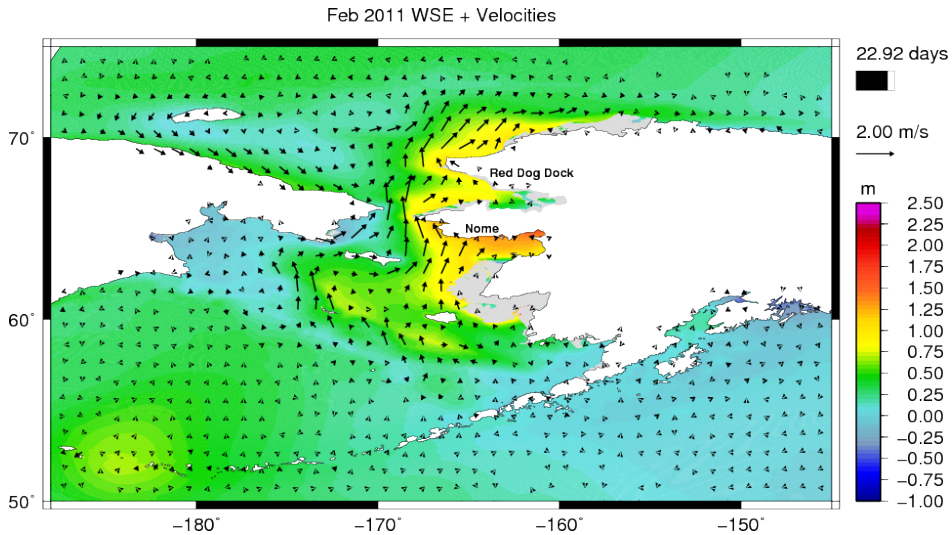


February 2011 Ice Coverage

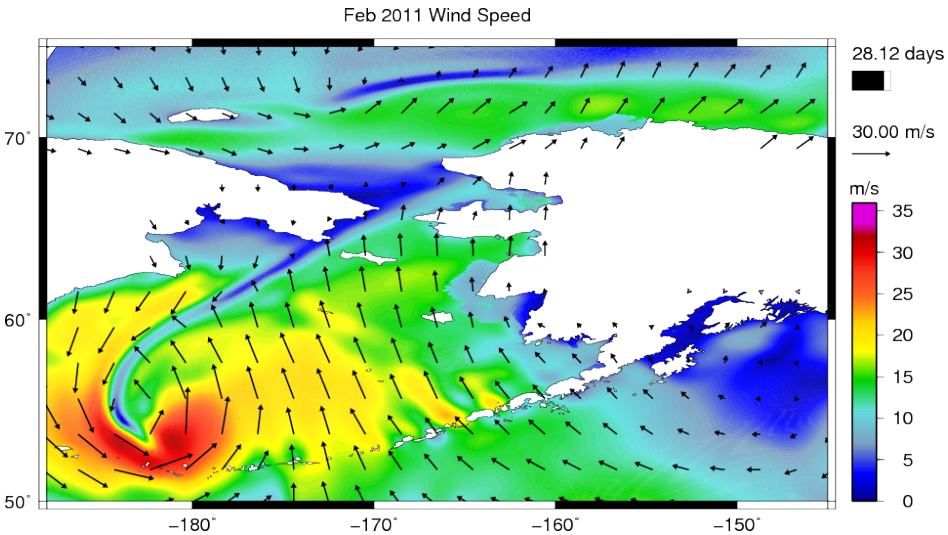


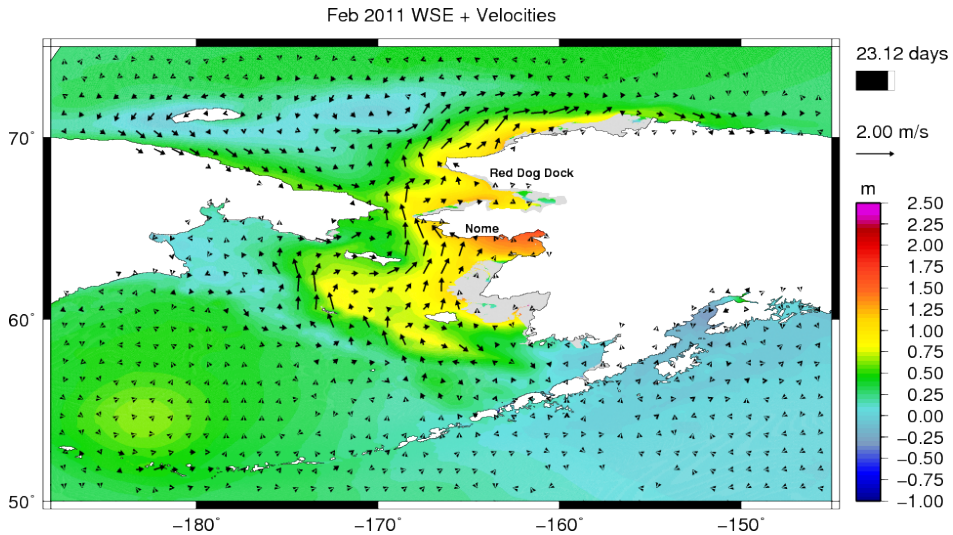
February 2011



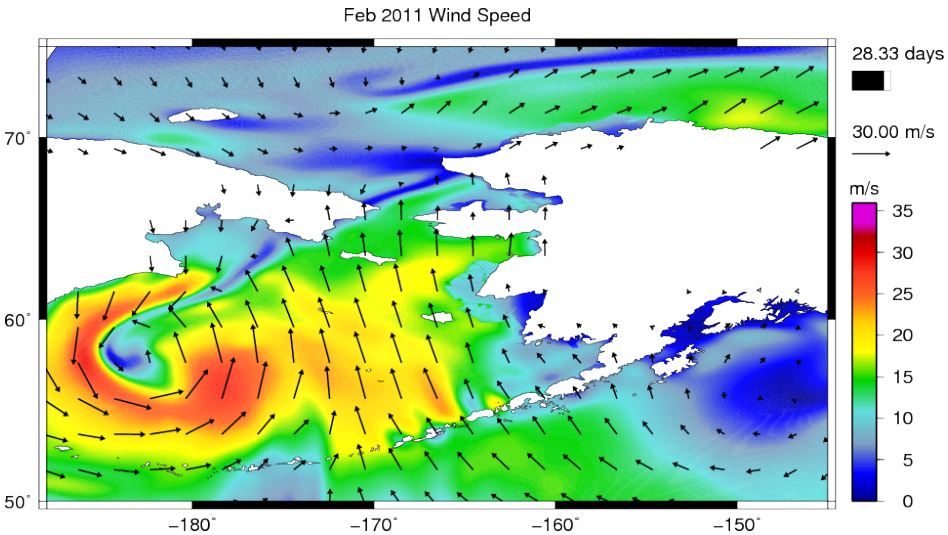


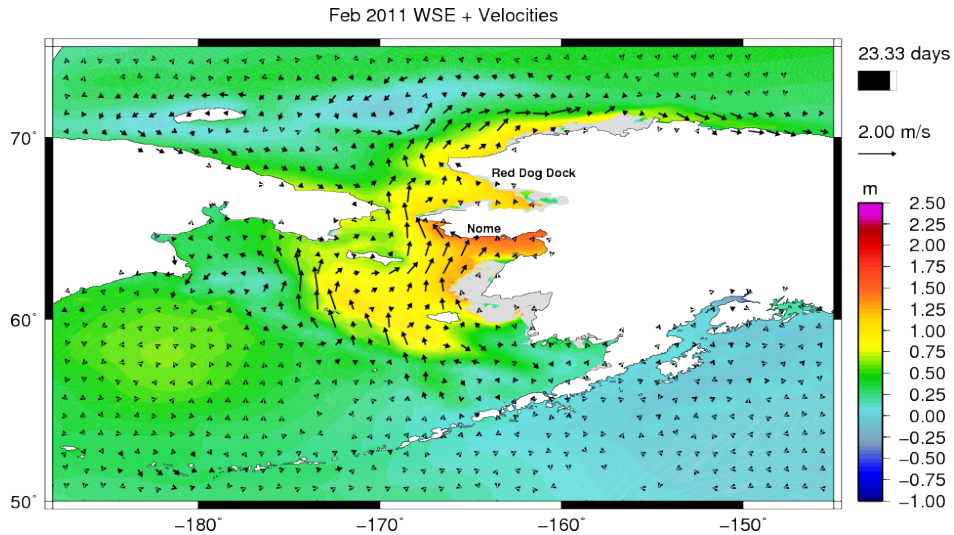
February 2011



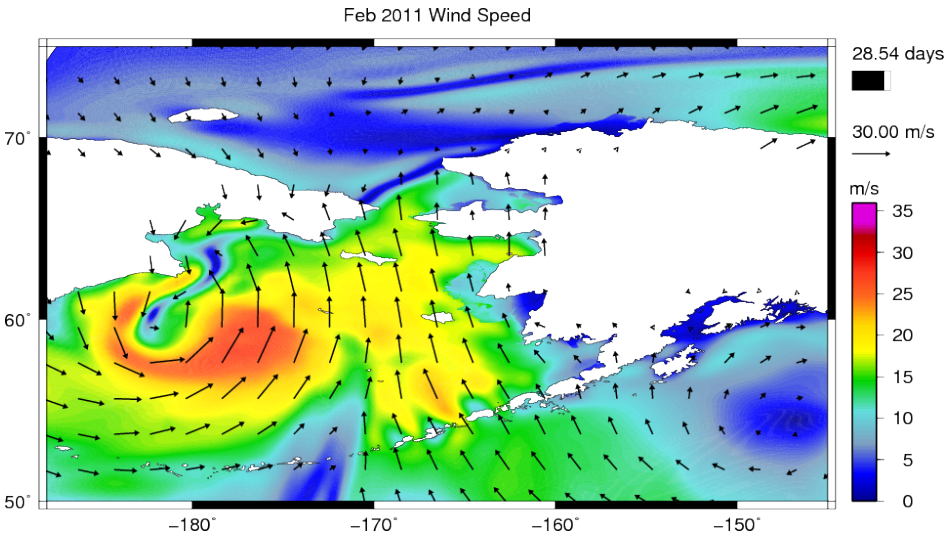


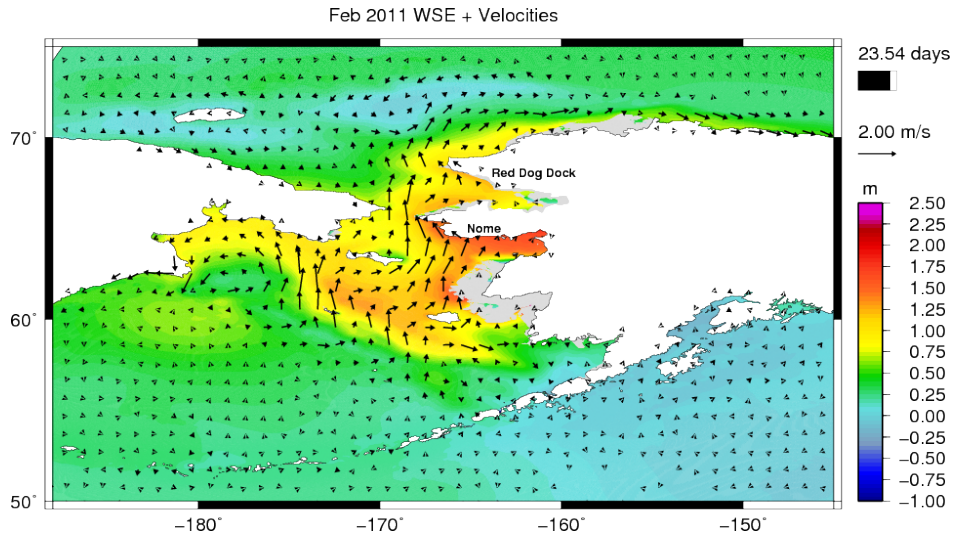
February 2011



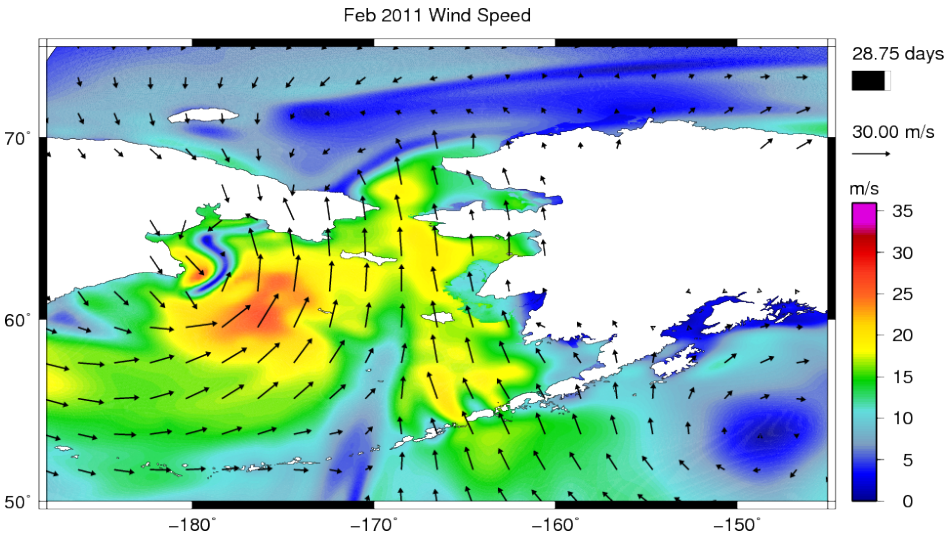


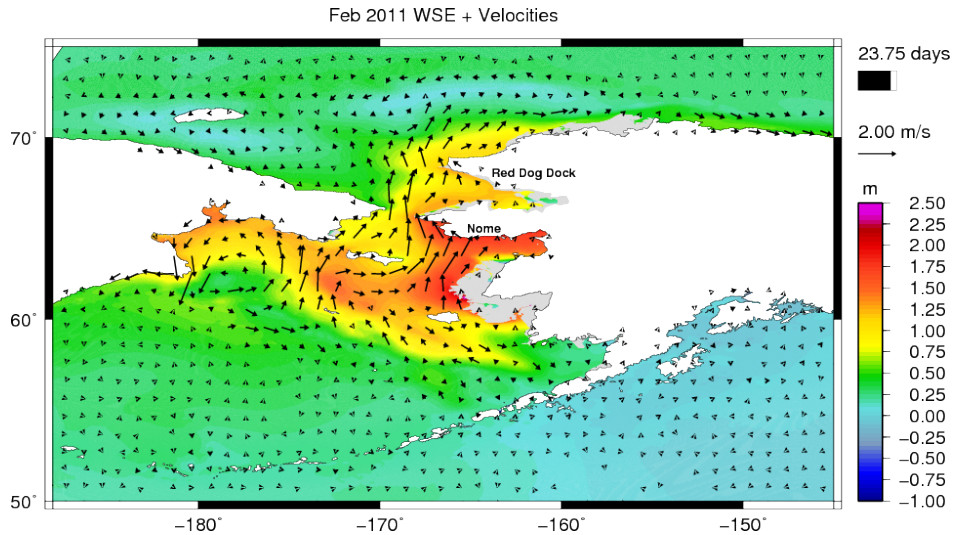
February 2011



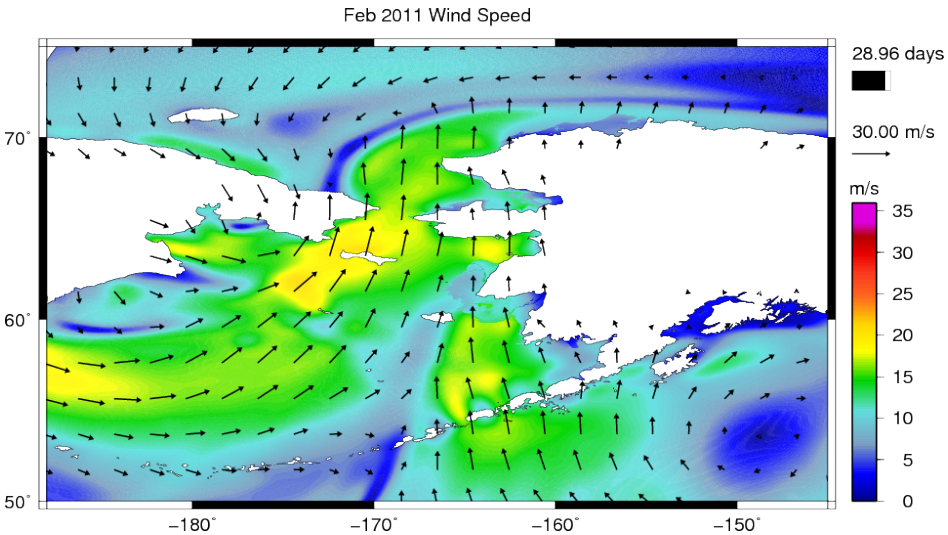


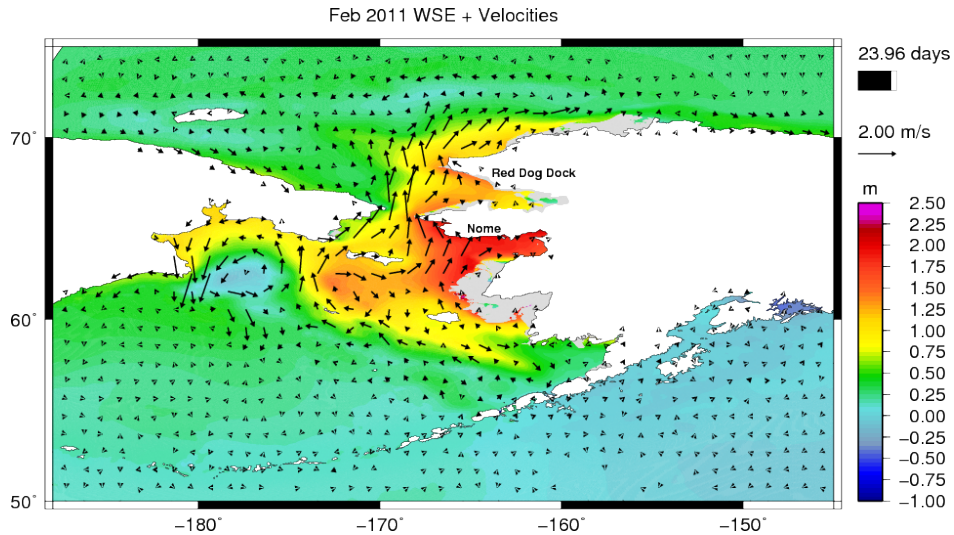
February 2011



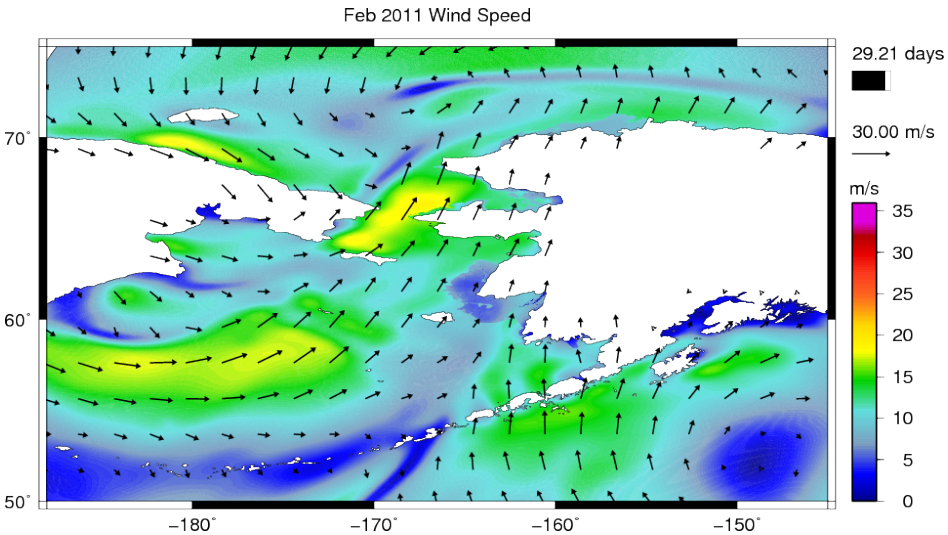


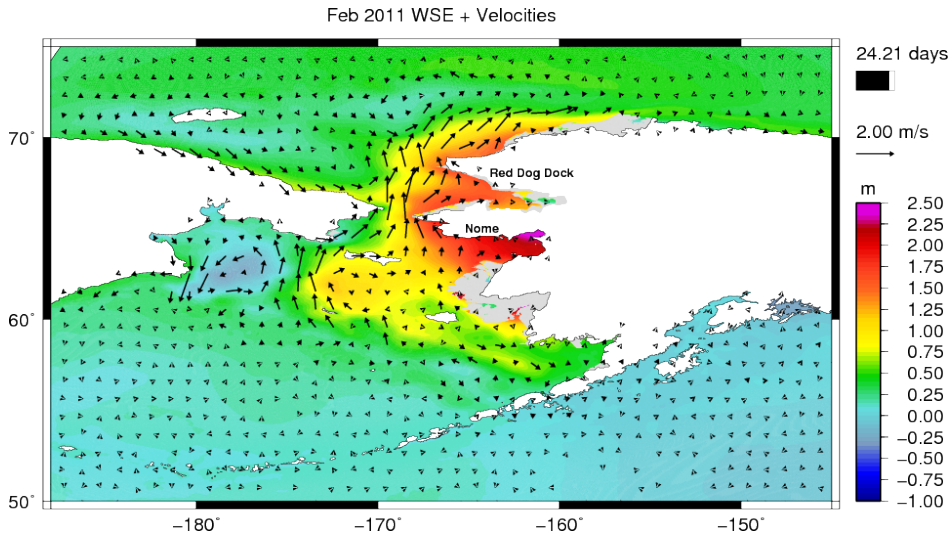
February 2011



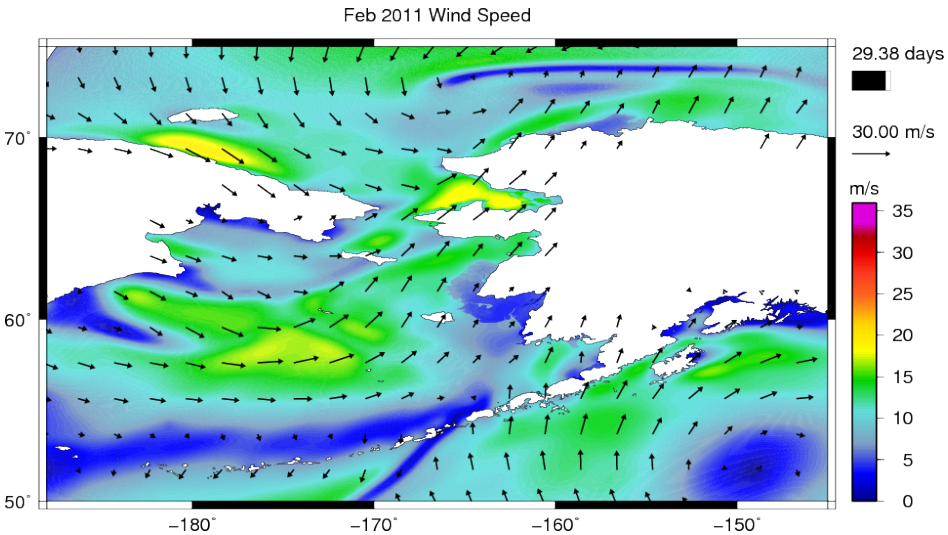


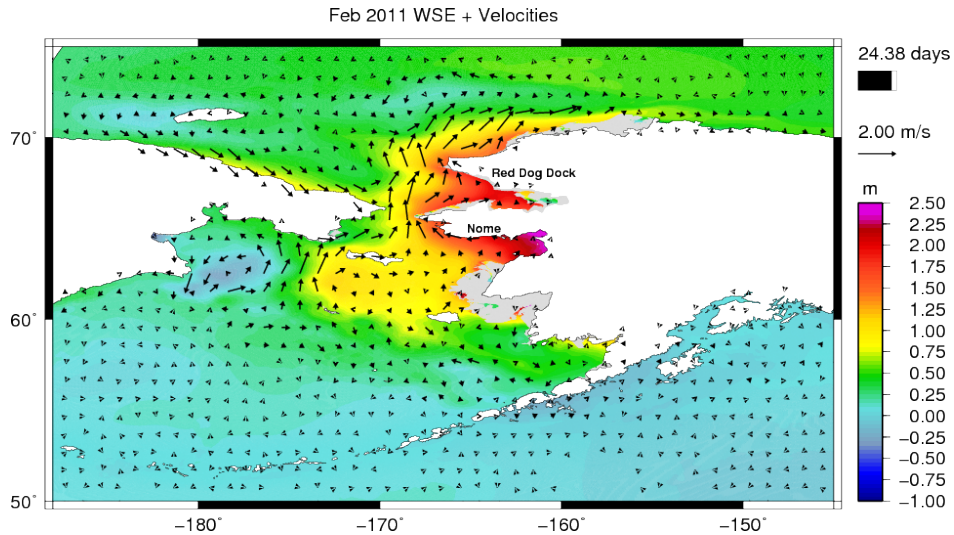
February 2011



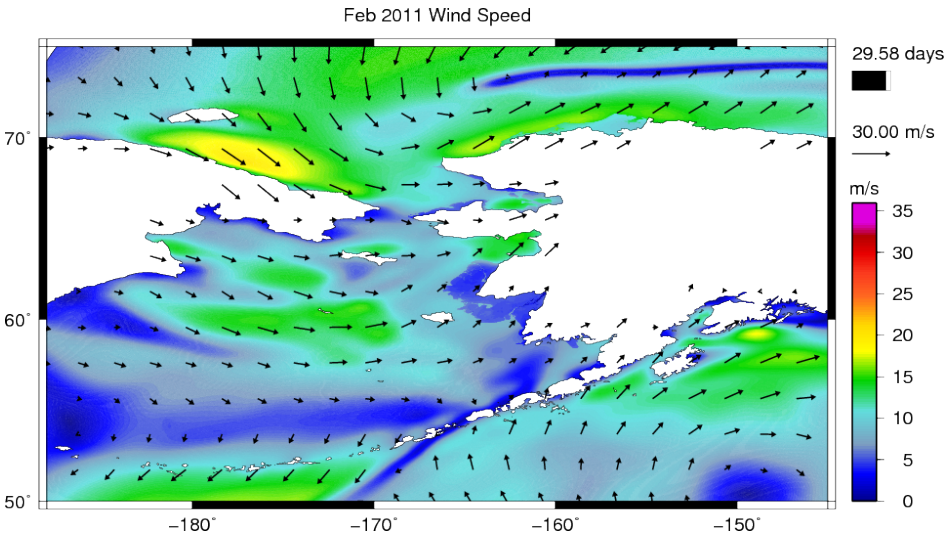


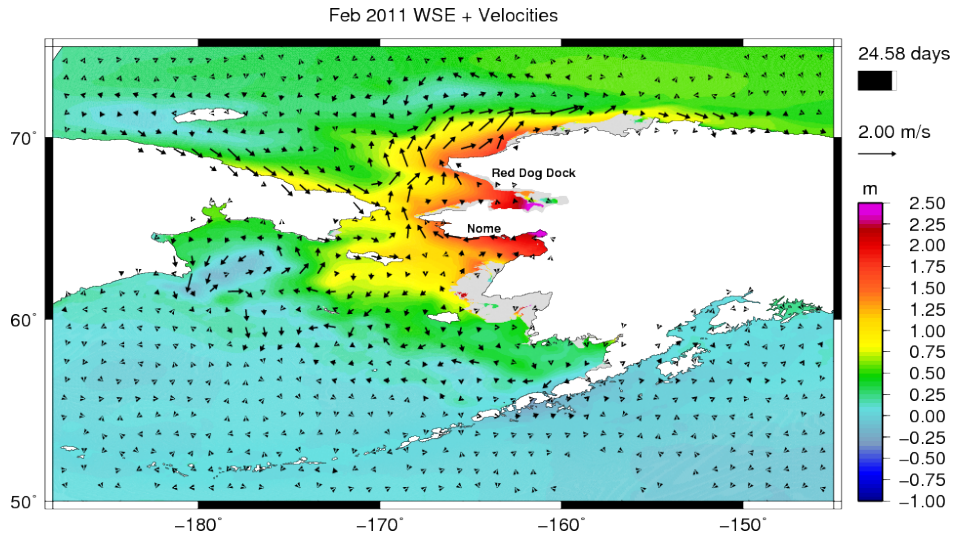
February 2011



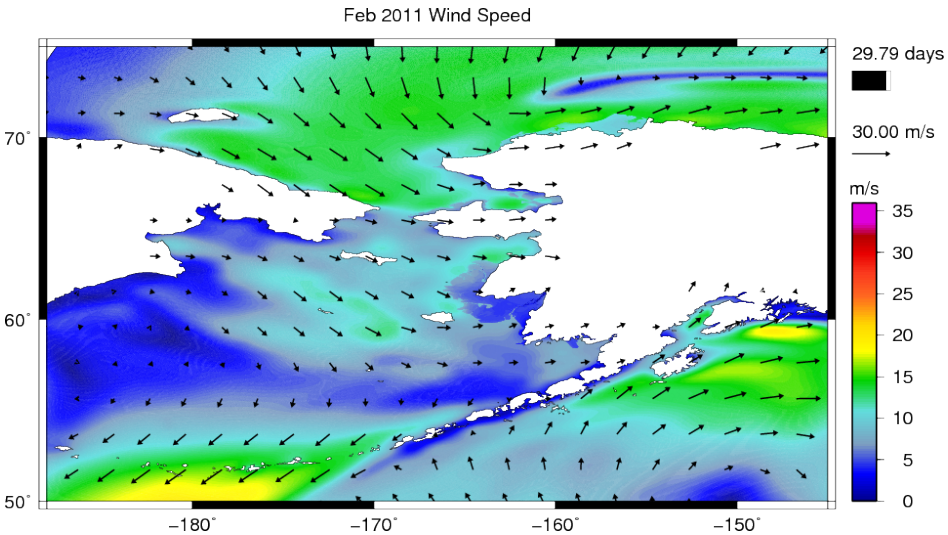


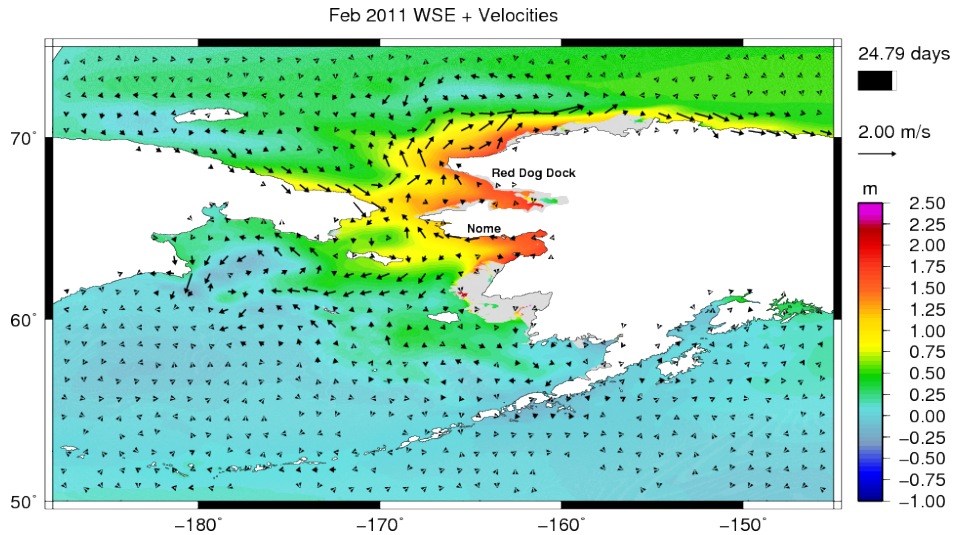
February 2011



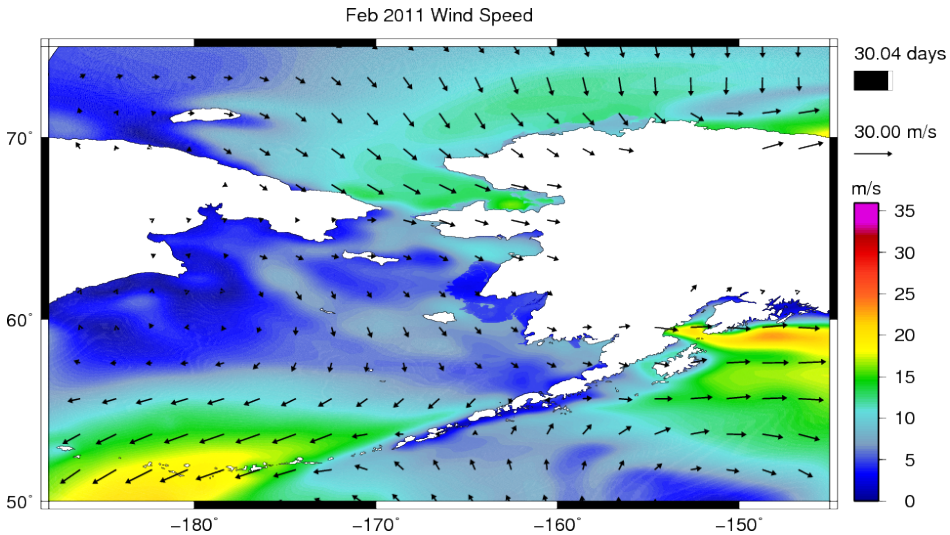


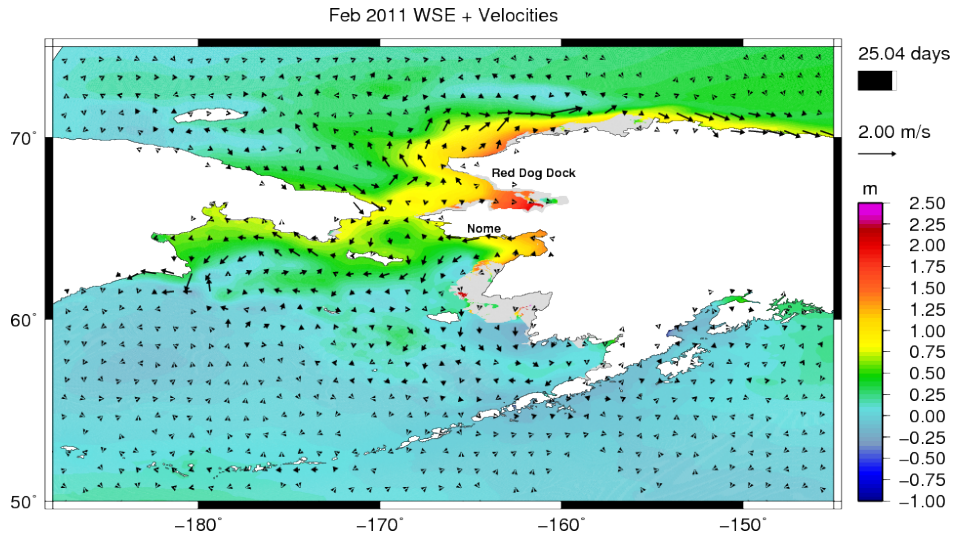
February 2011



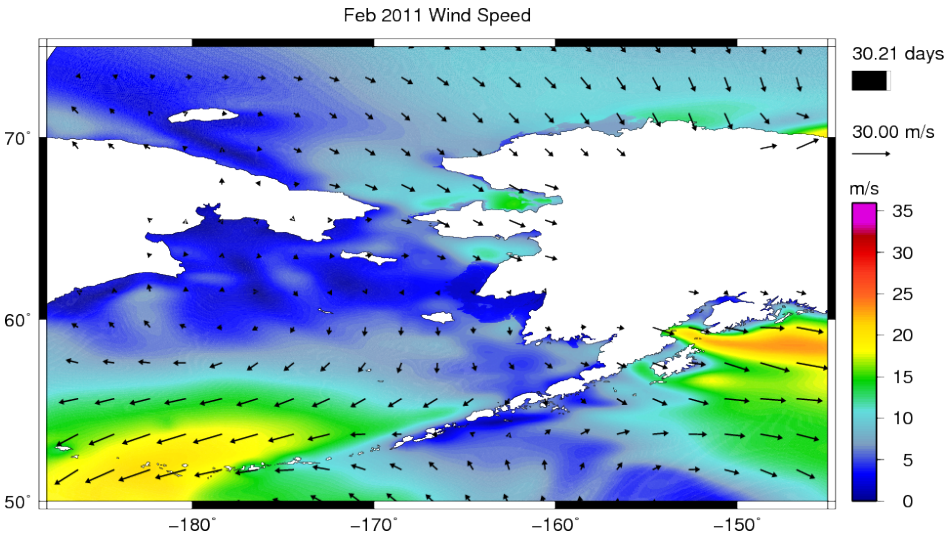


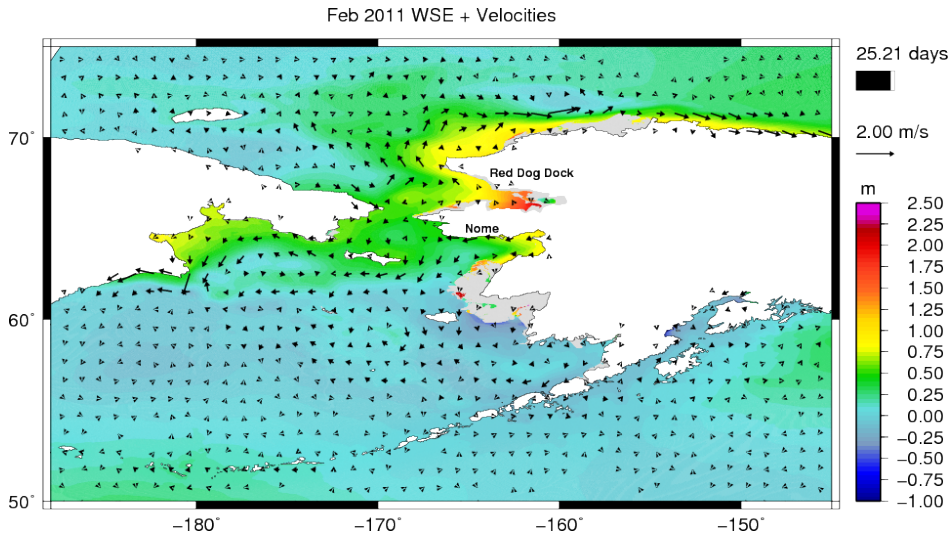
February 2011



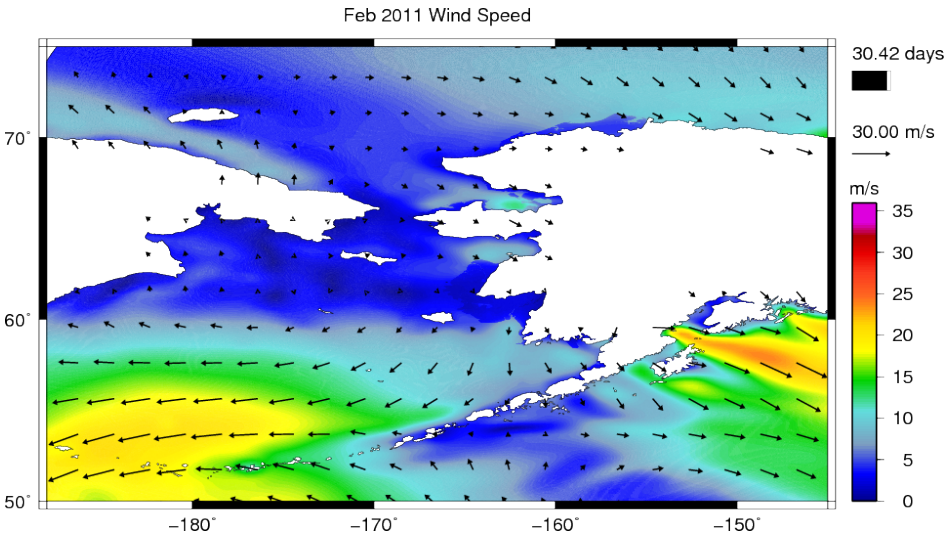


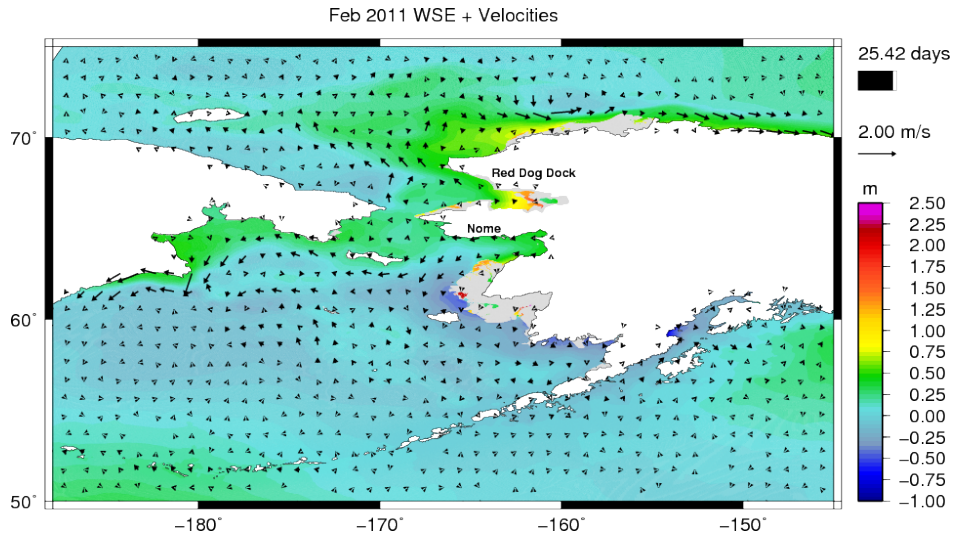
February 2011



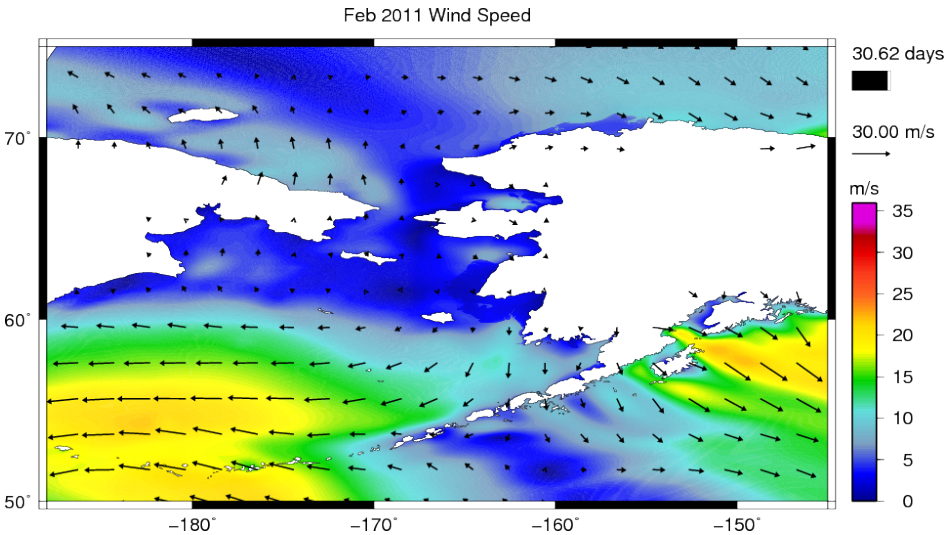


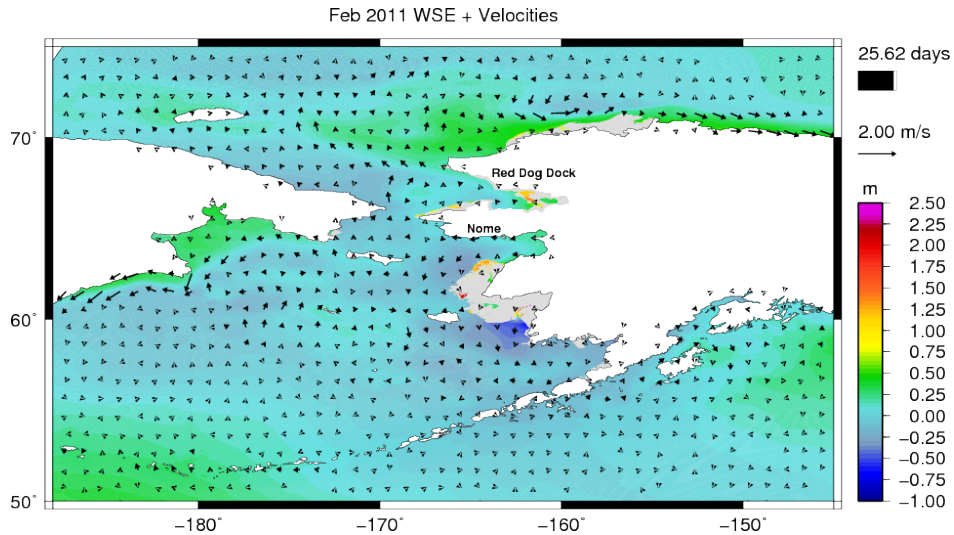
February 2011





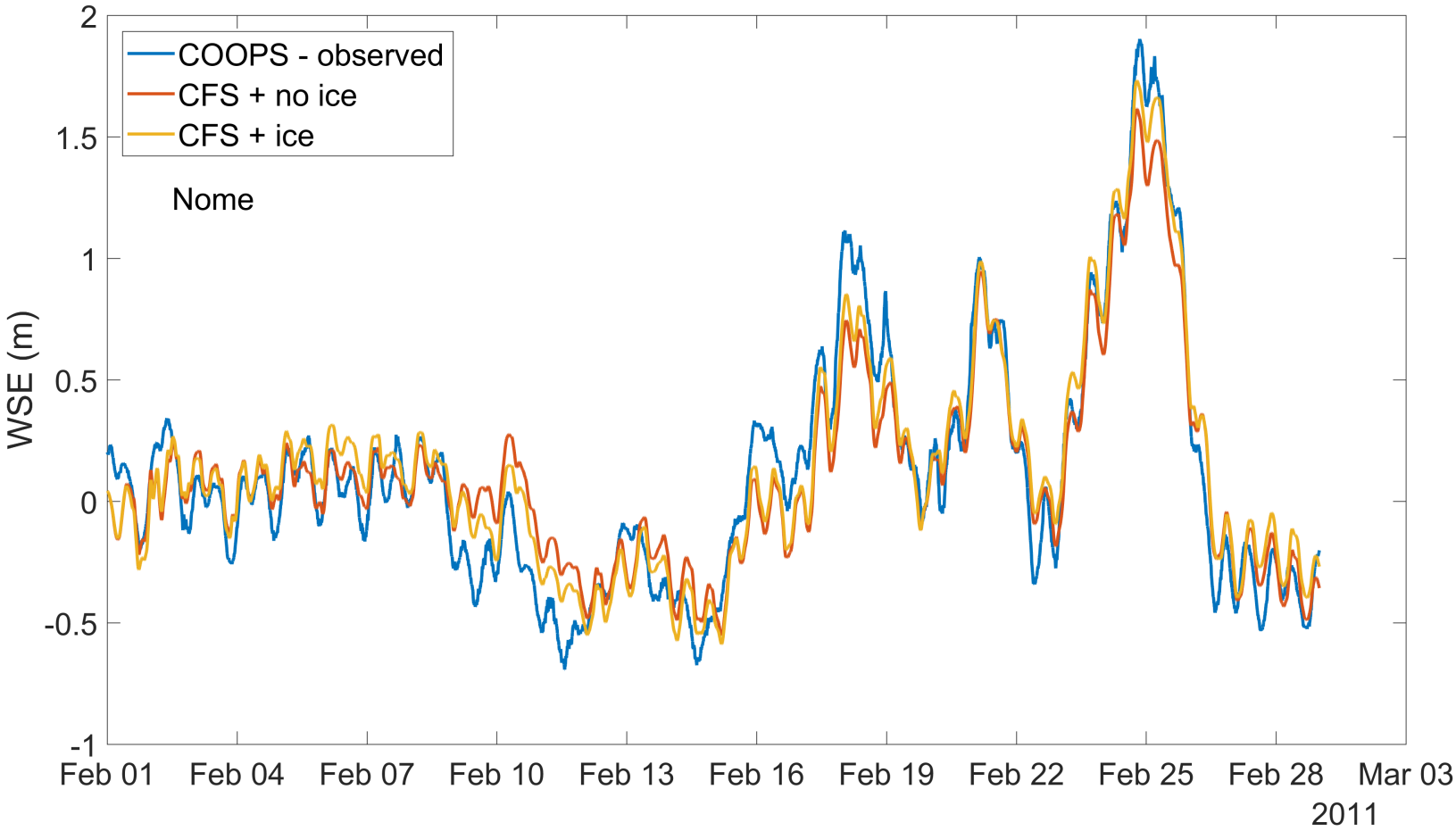
February 2011





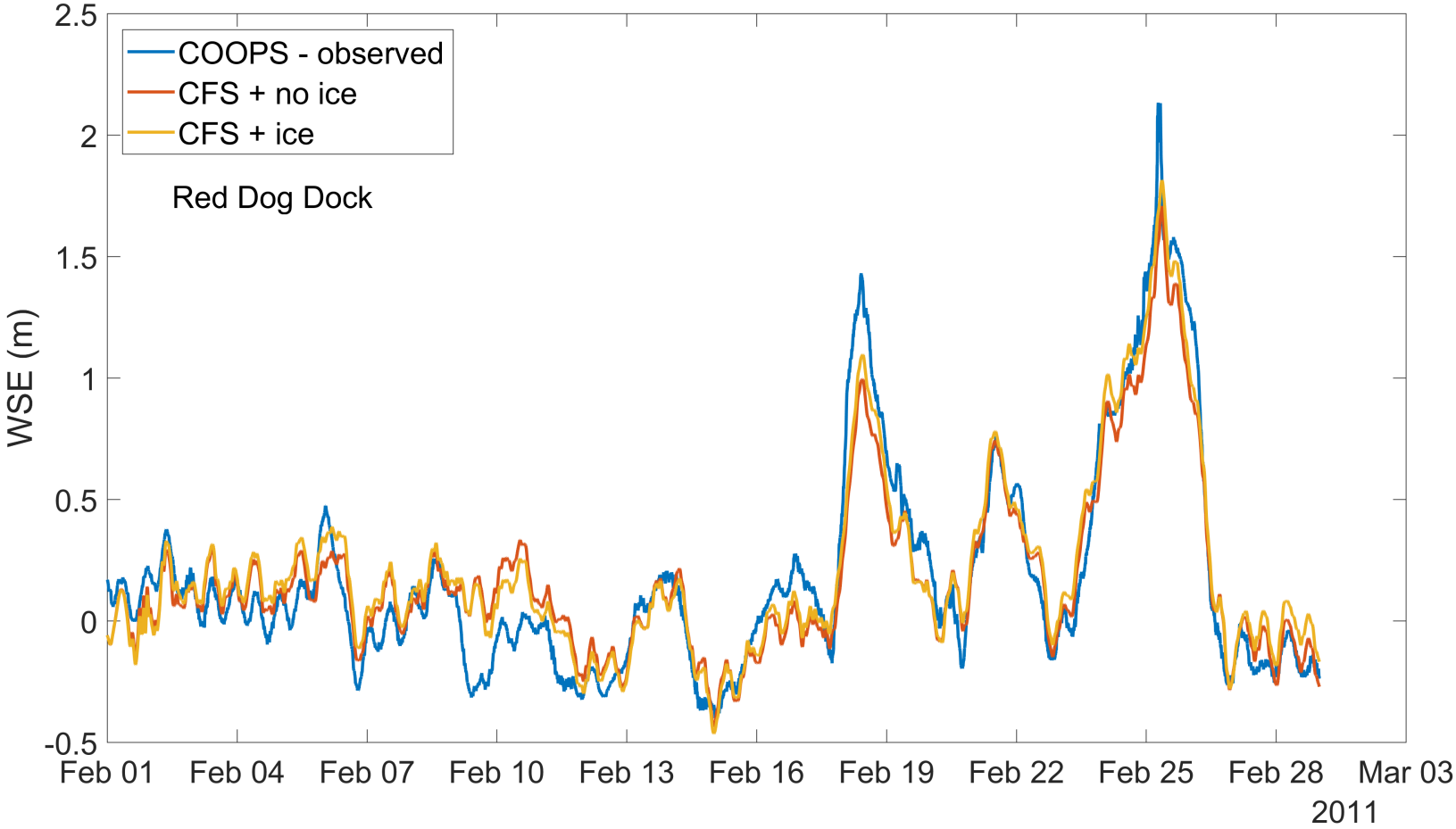
February 2011 Validation

Nome

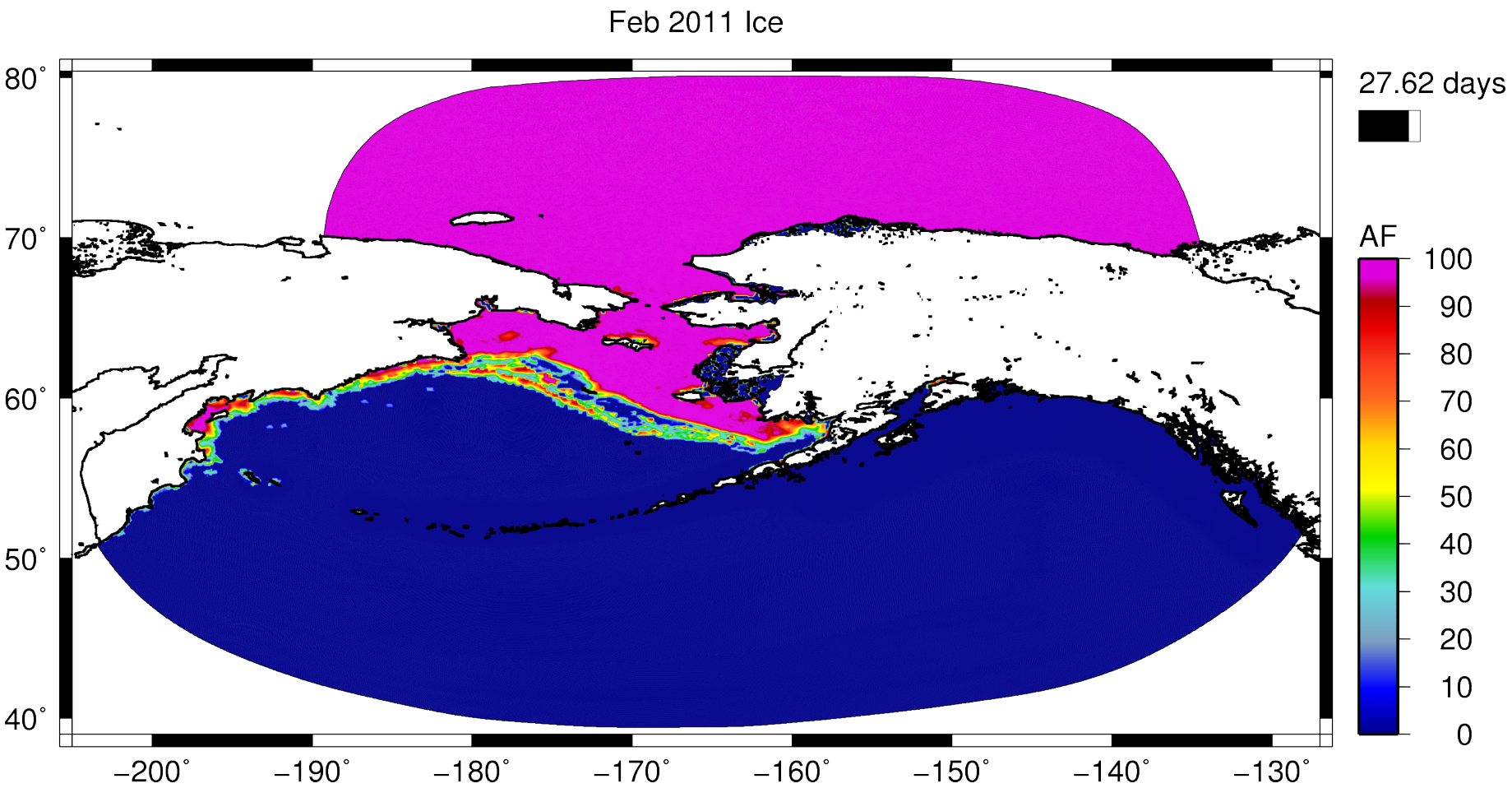


February 2011 Validation

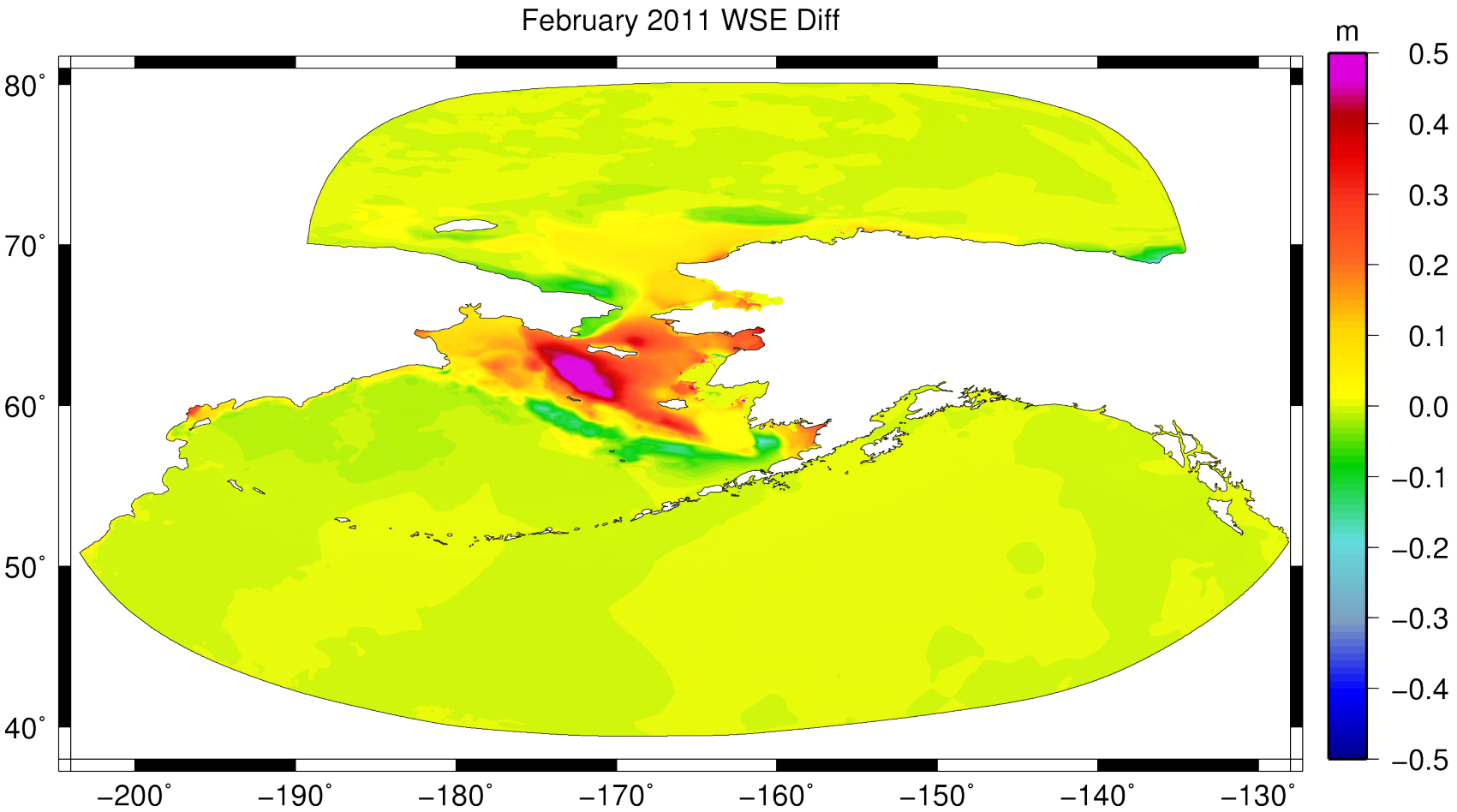
Red Dog Dock



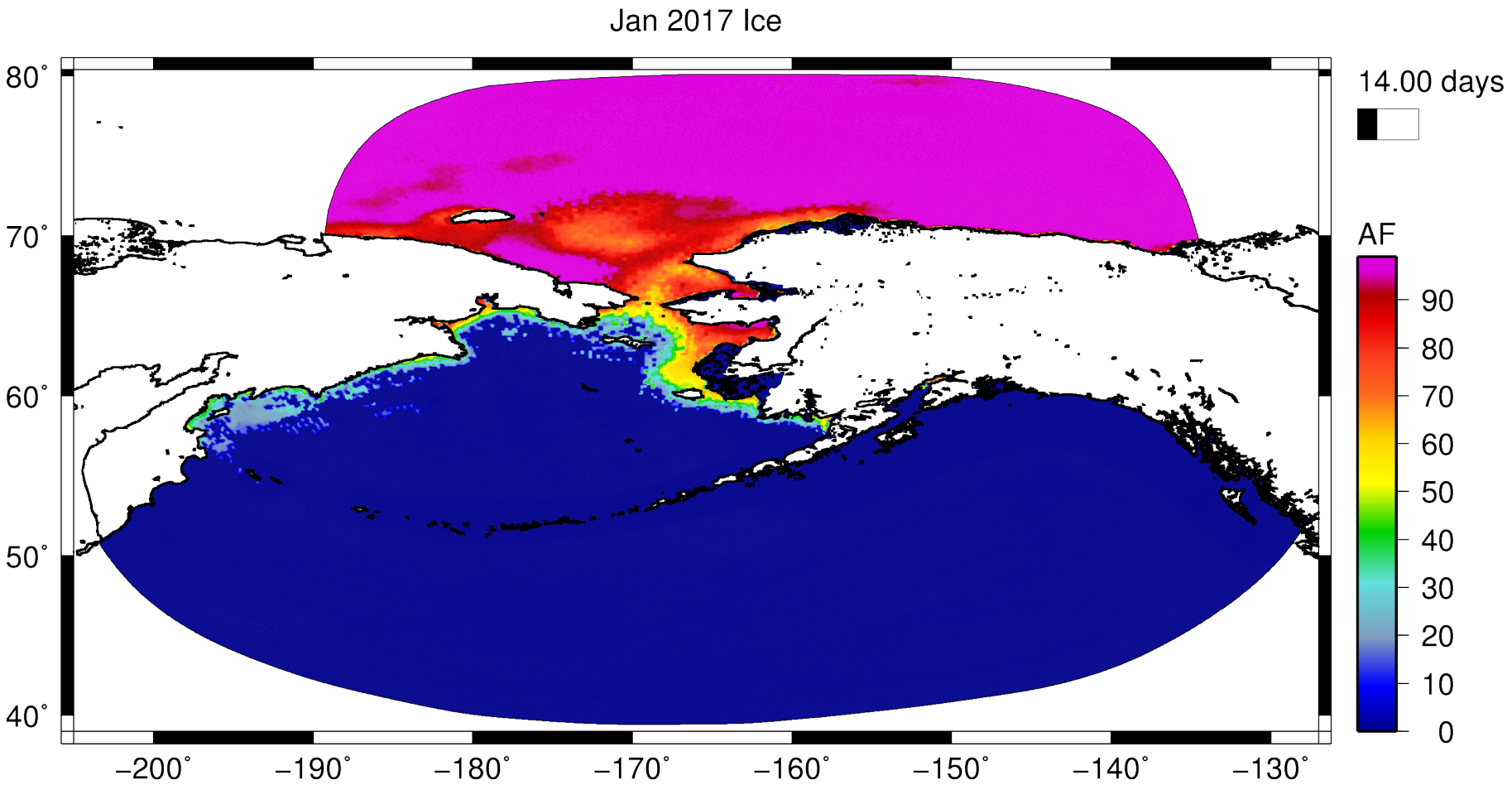
February 2011 Ice Coverage



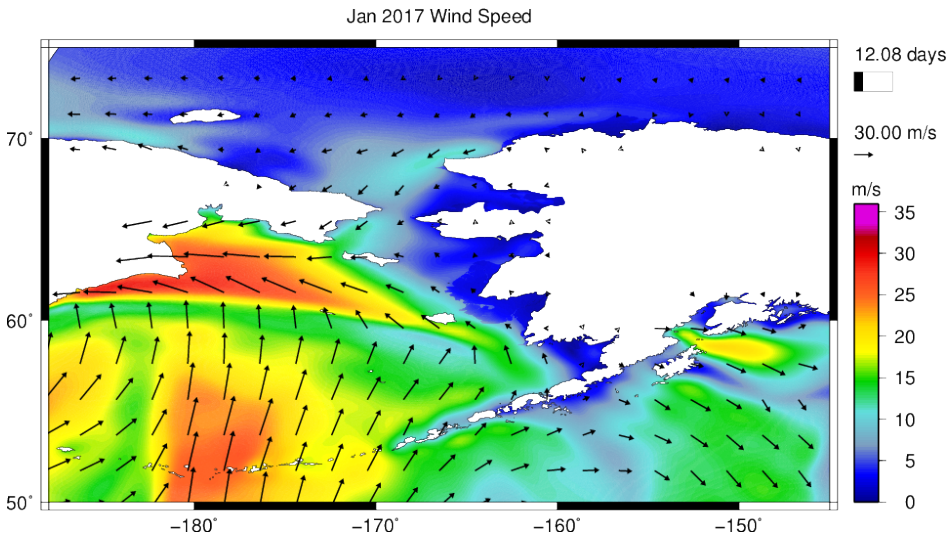
February 2011 Effect of Ice

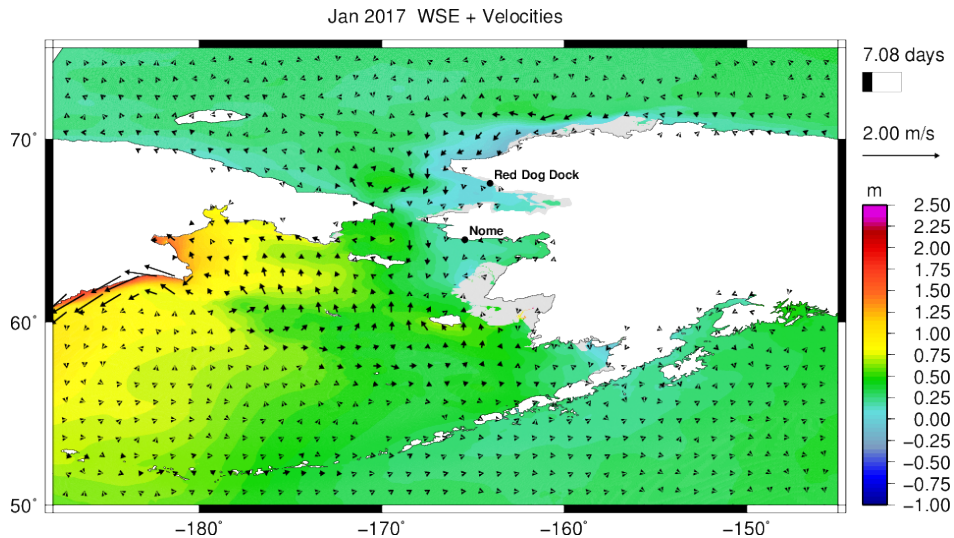


January 2017 Ice Coverage

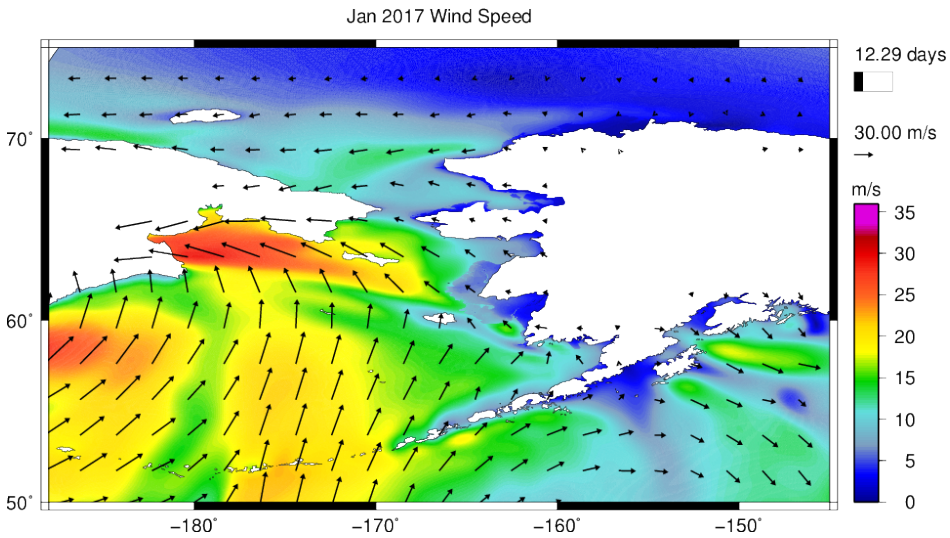


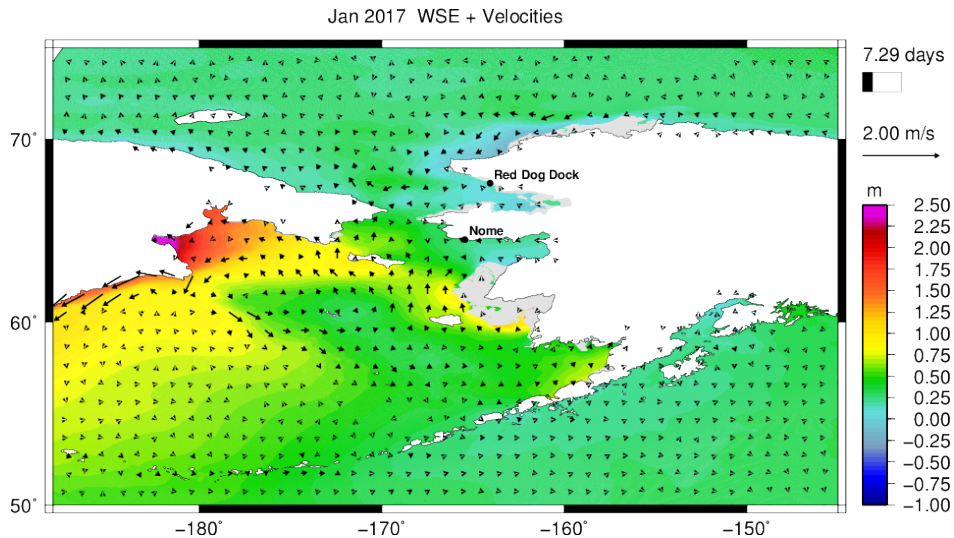
January 2017



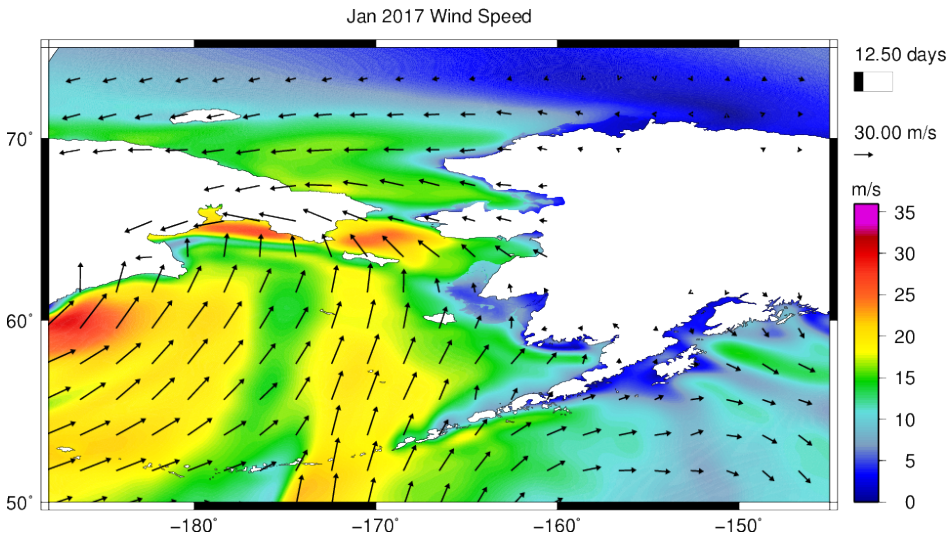


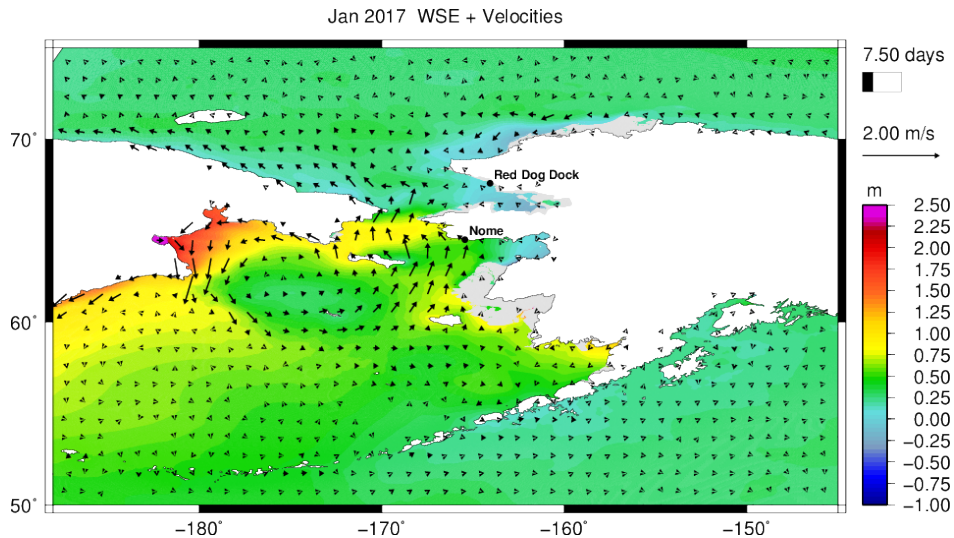
January 2017



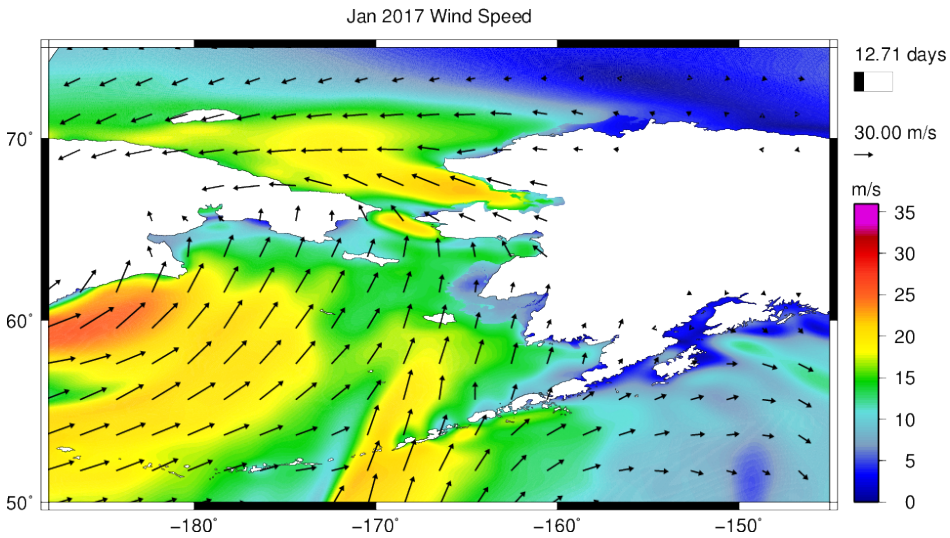


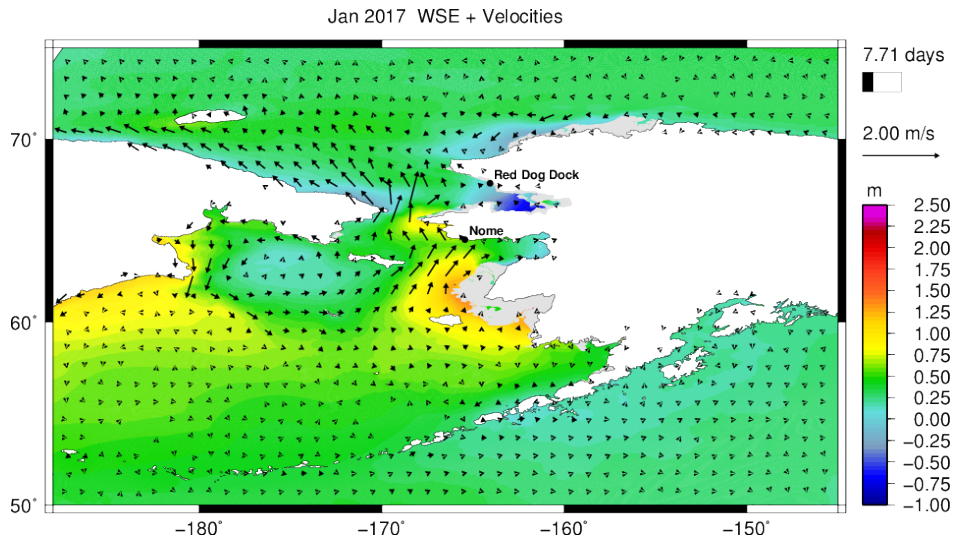
January 2017



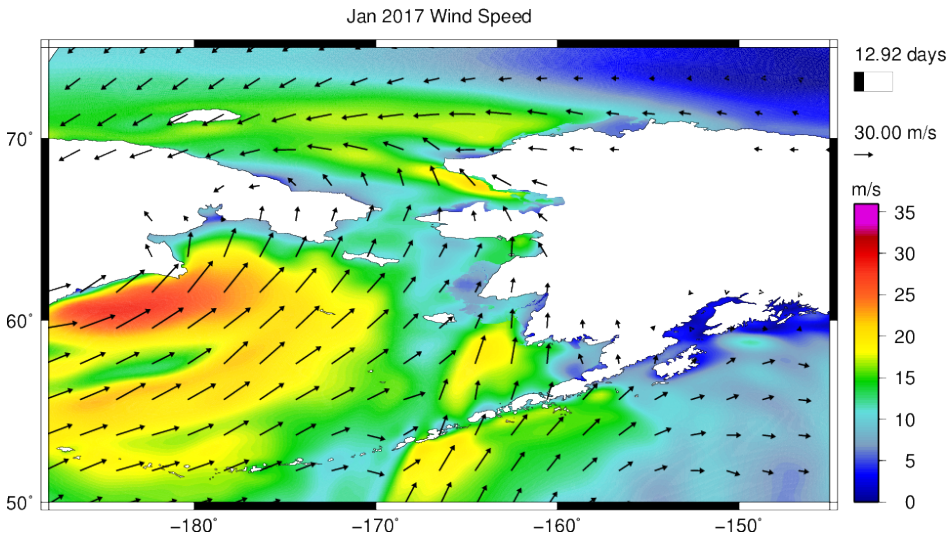


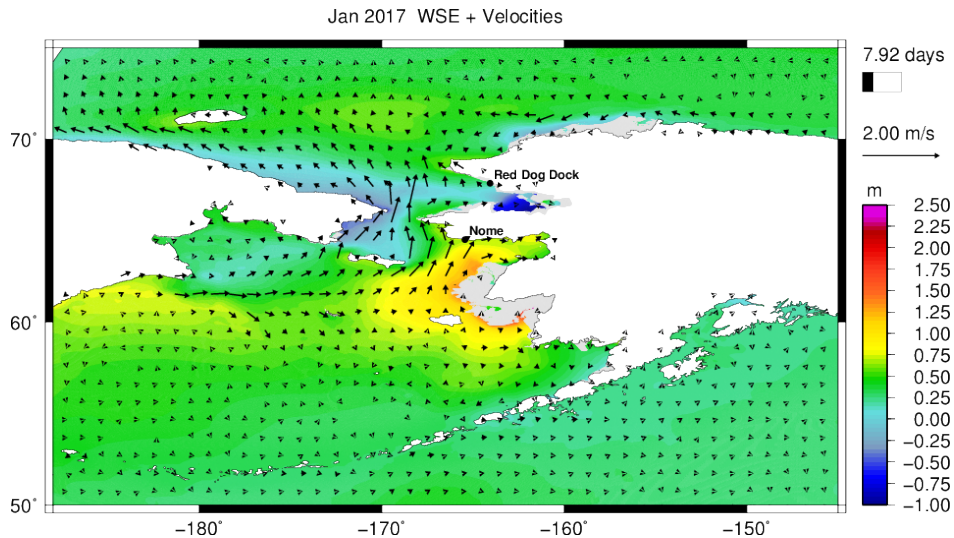
January 2017



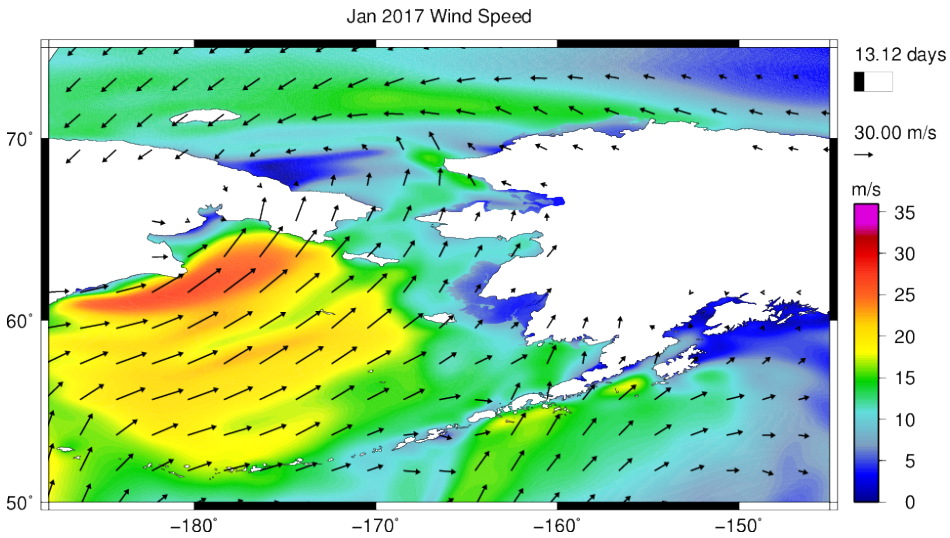


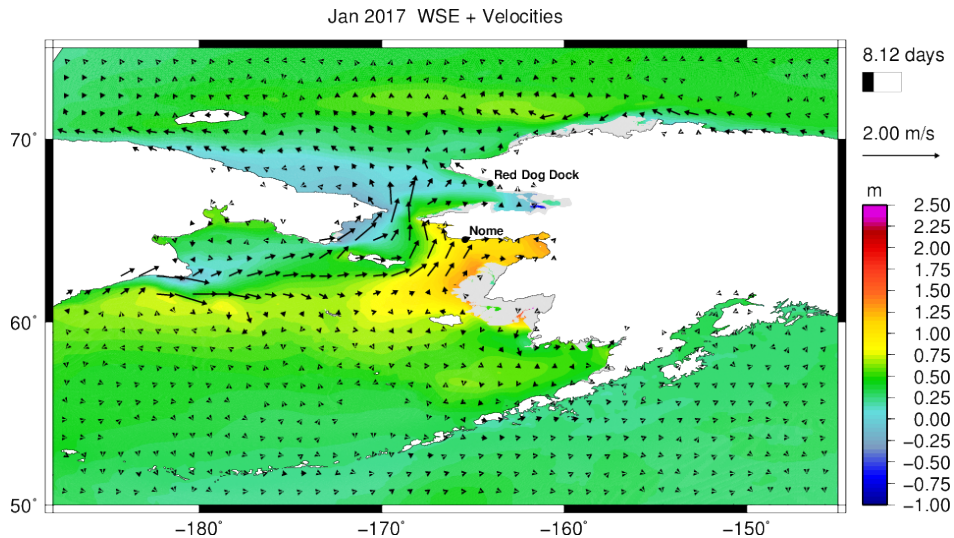
January 2017



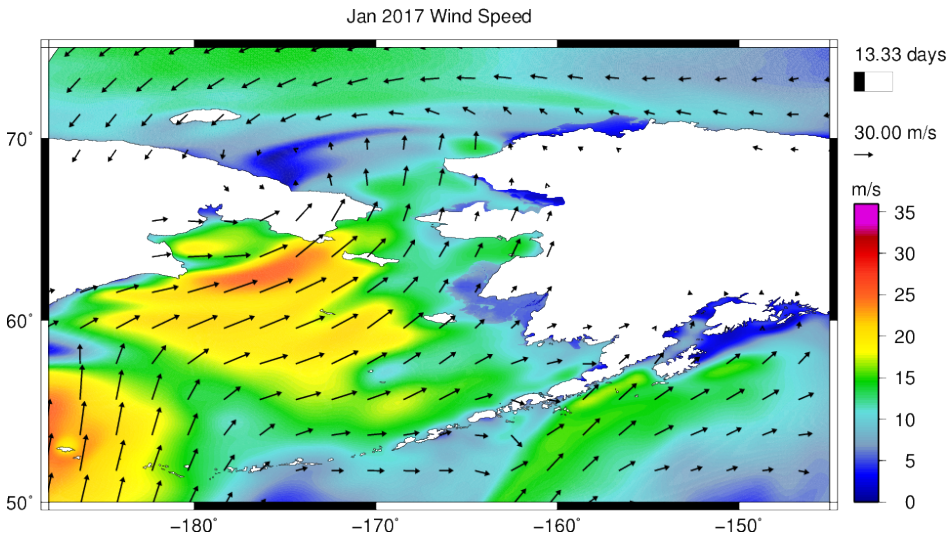


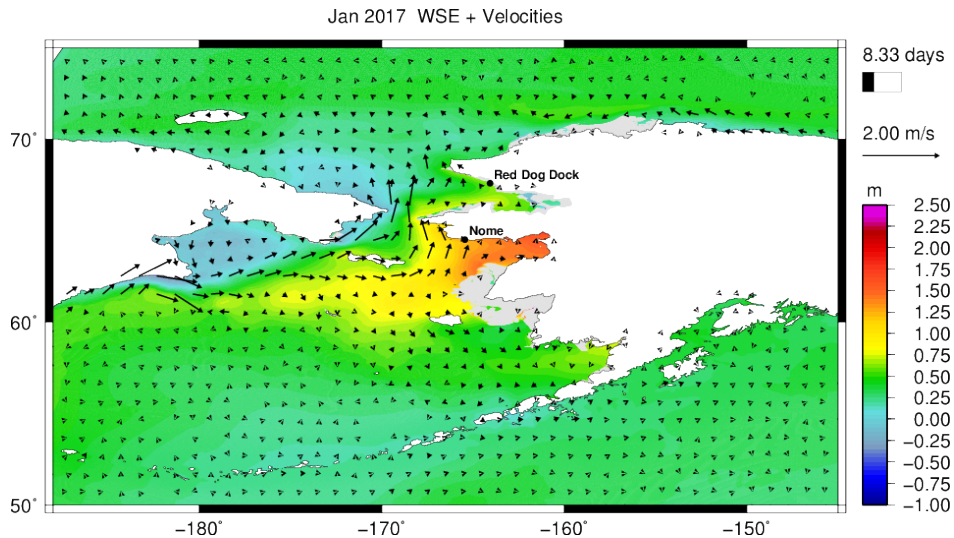
January 2017



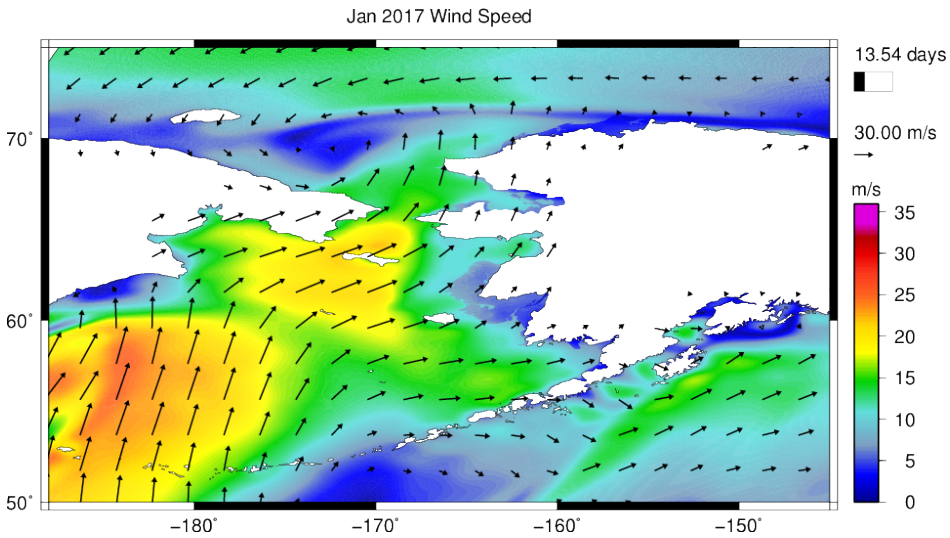


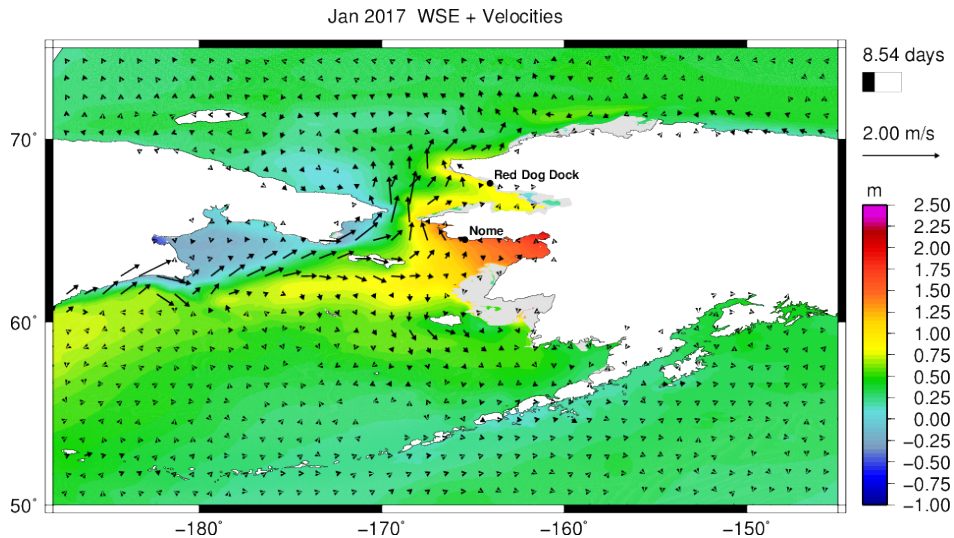
January 2017



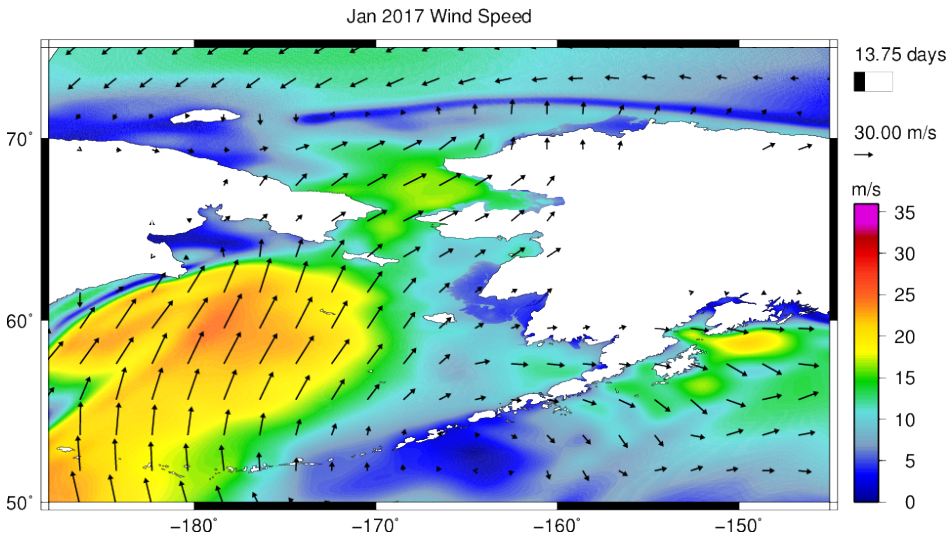


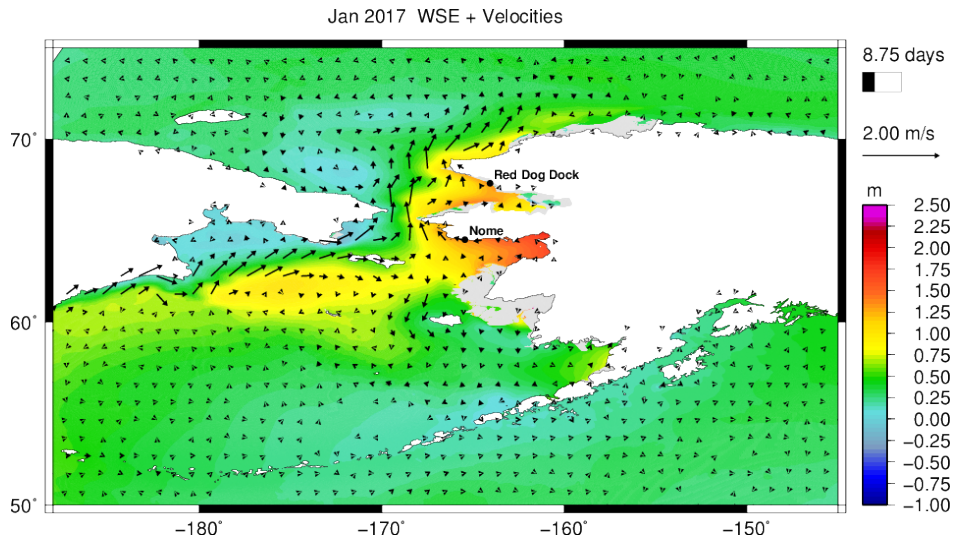
January 2017



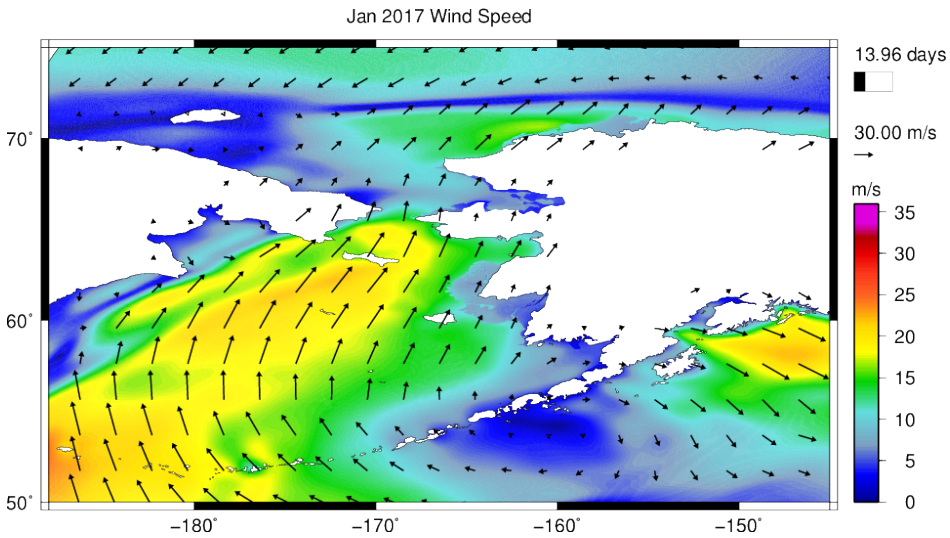


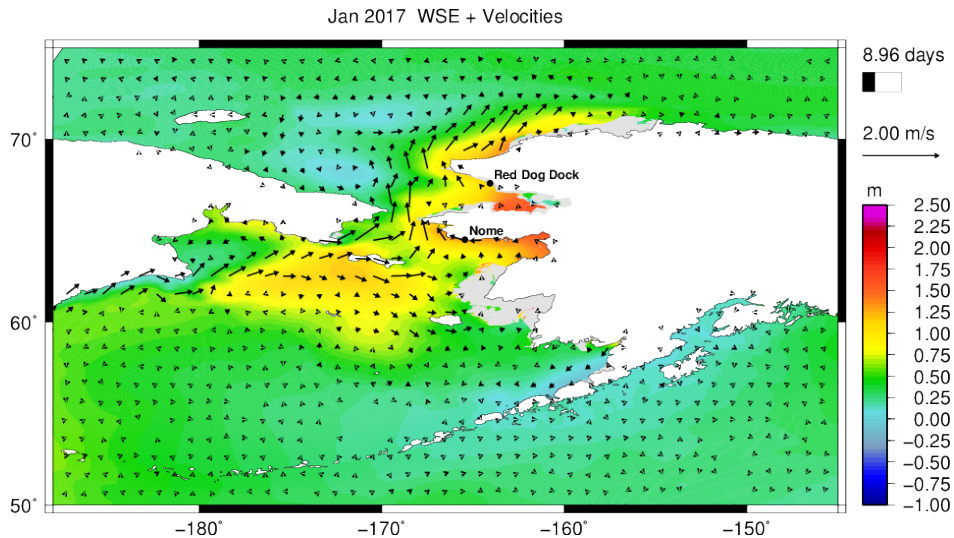
January 2017



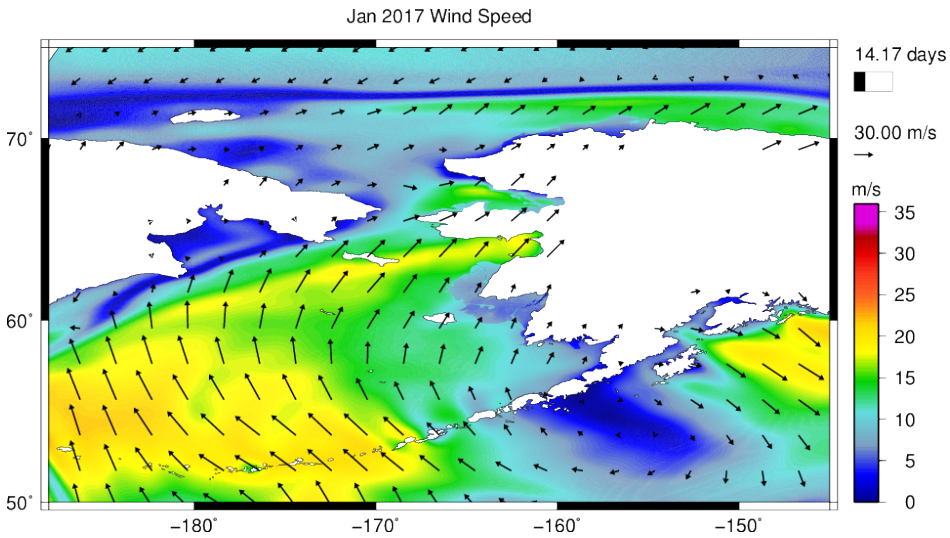


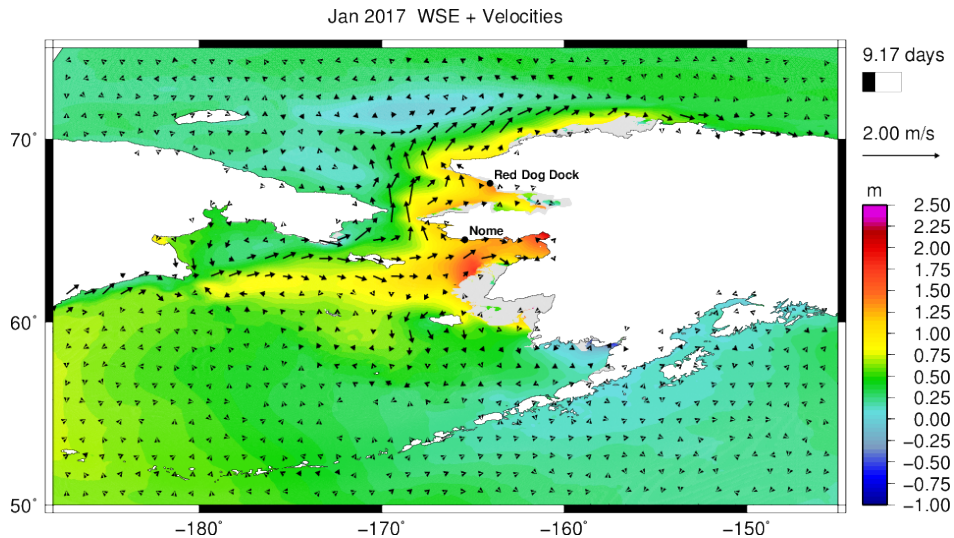
January 2017



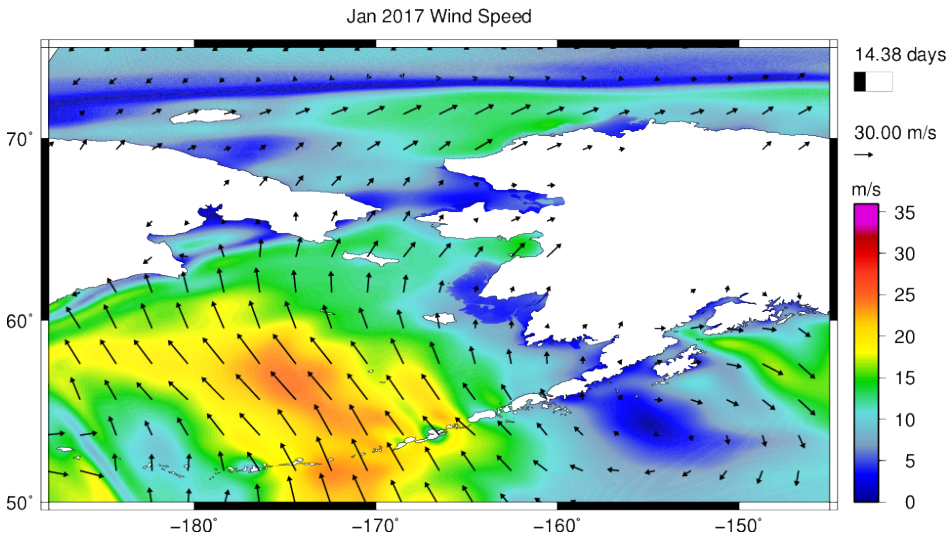


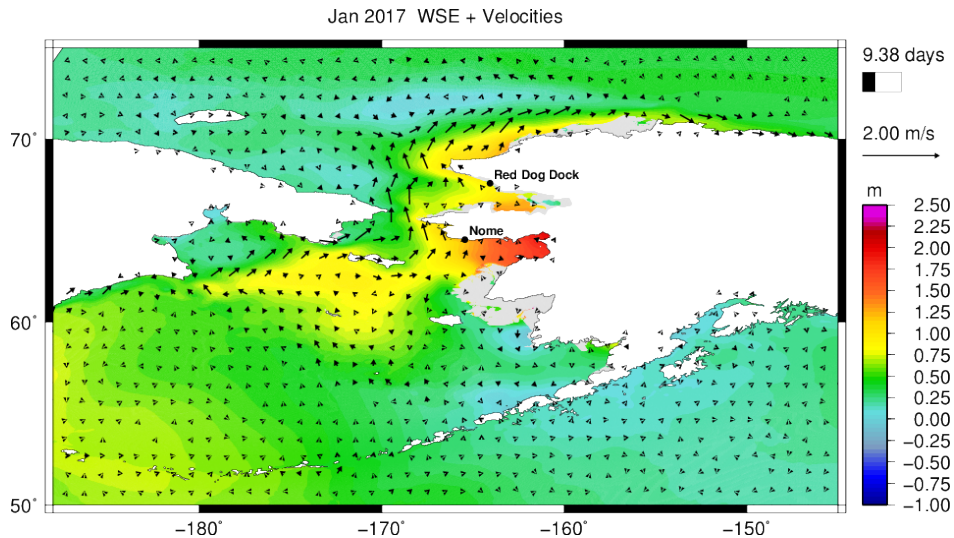
January 2017



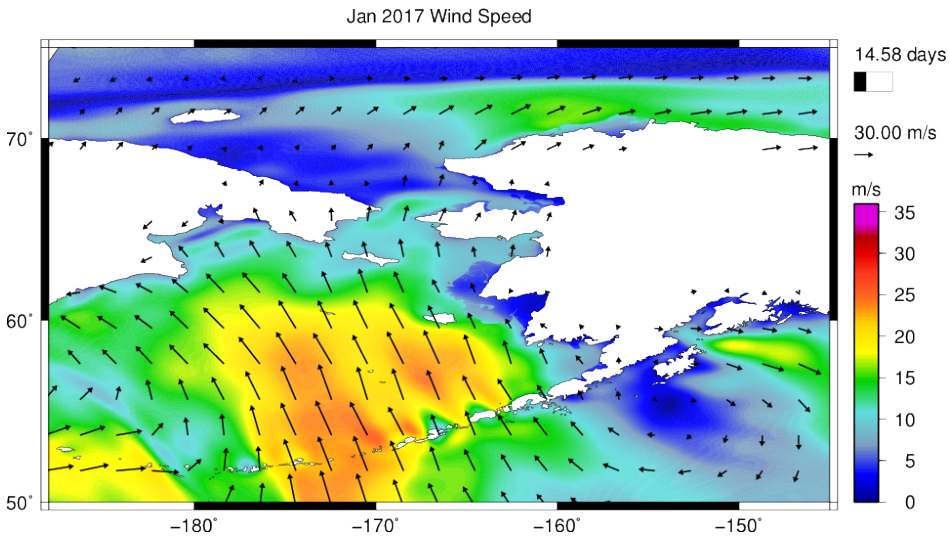


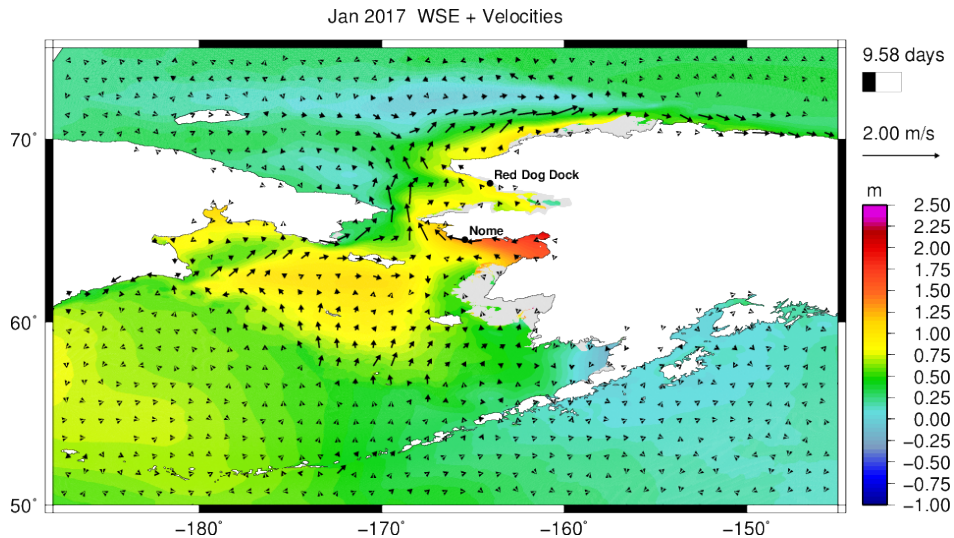
January 2017



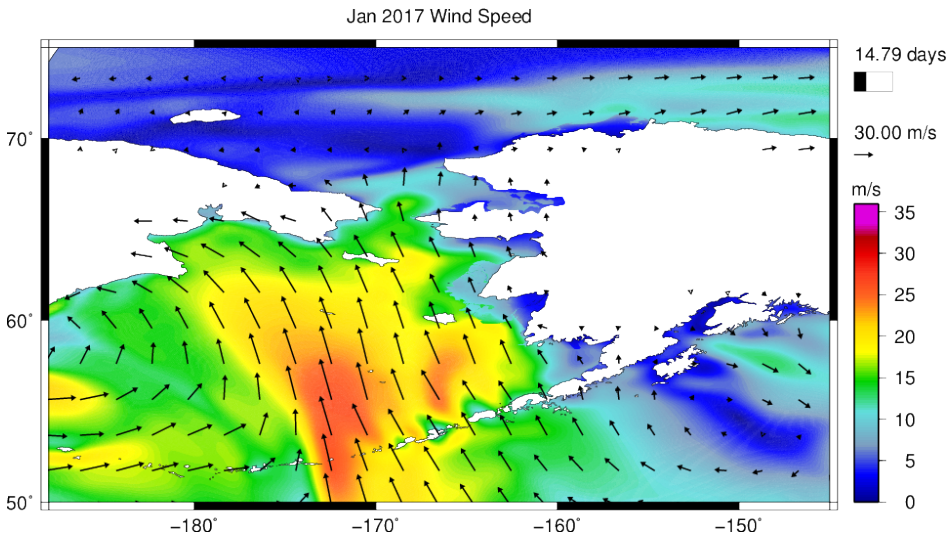


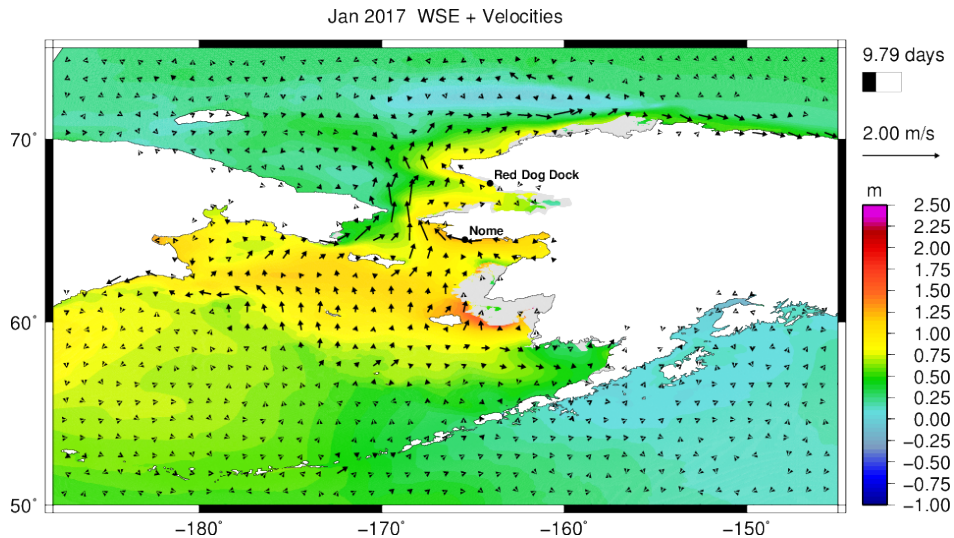
January 2017



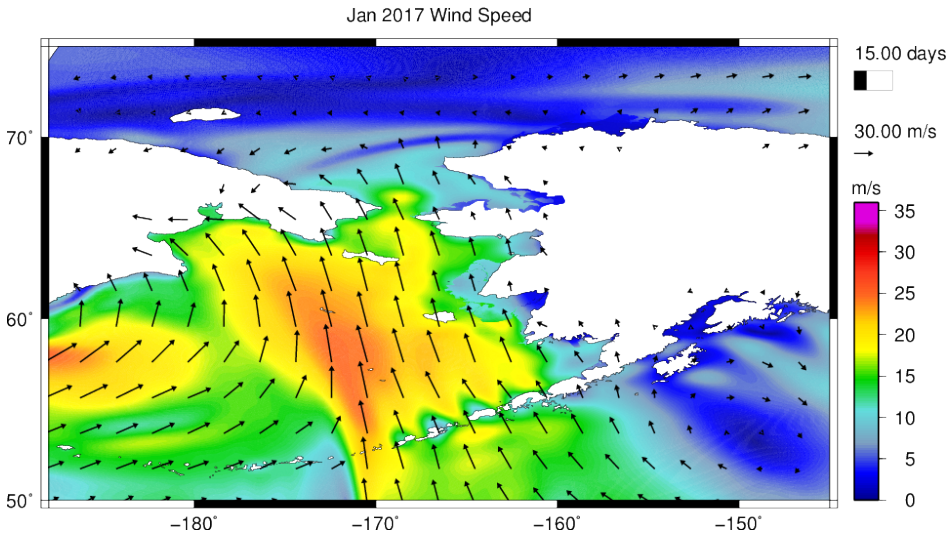


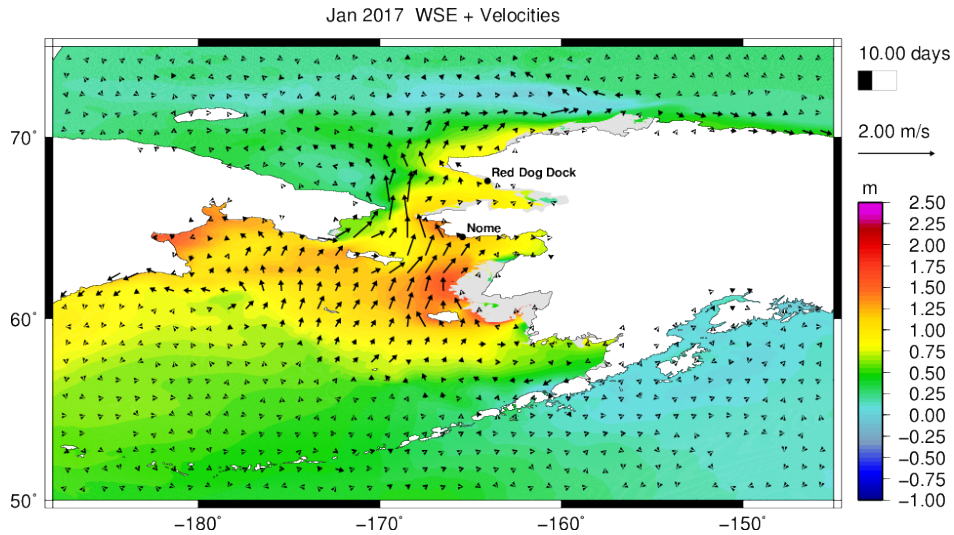
January 2017



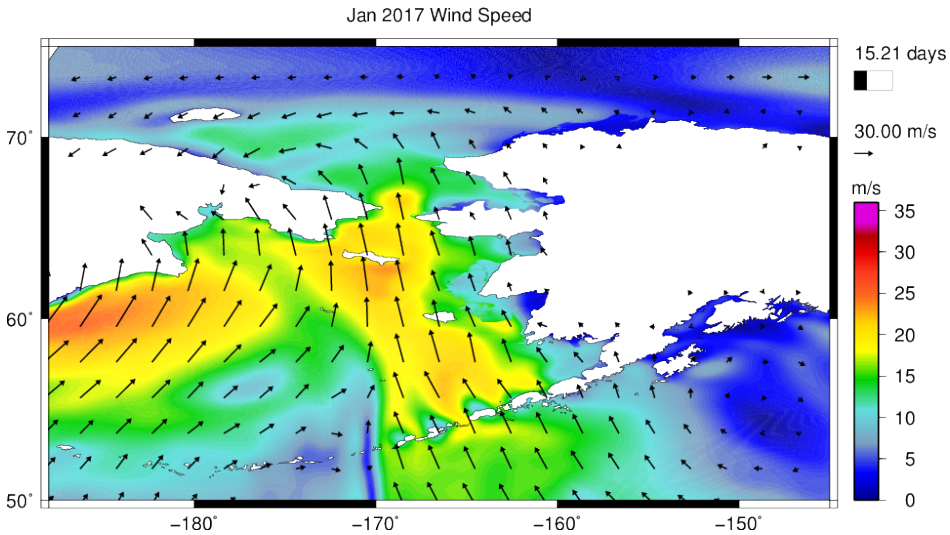


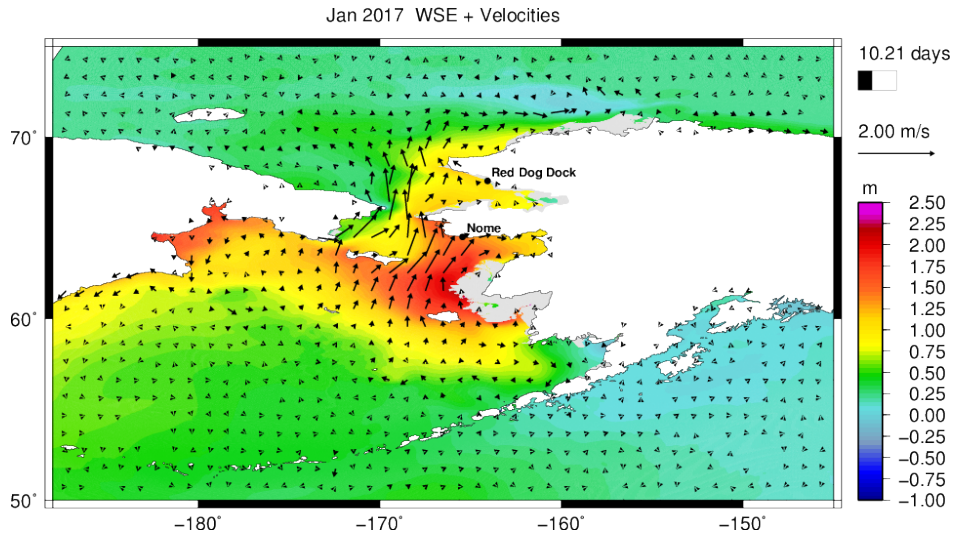
January 2017



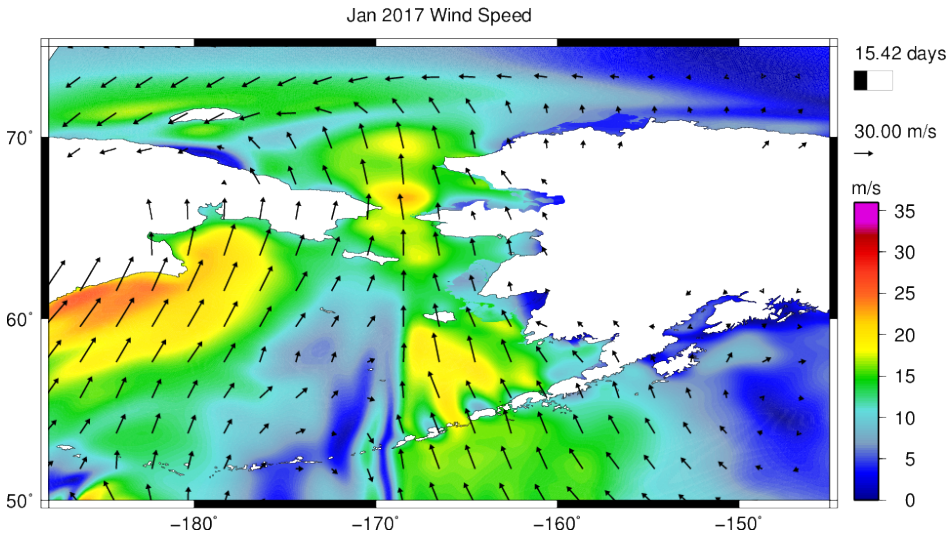


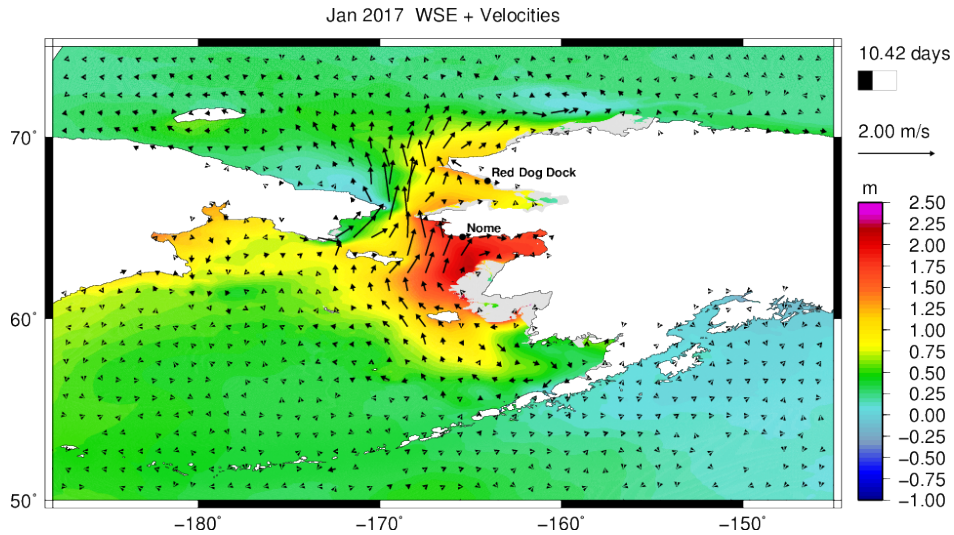
January 2017



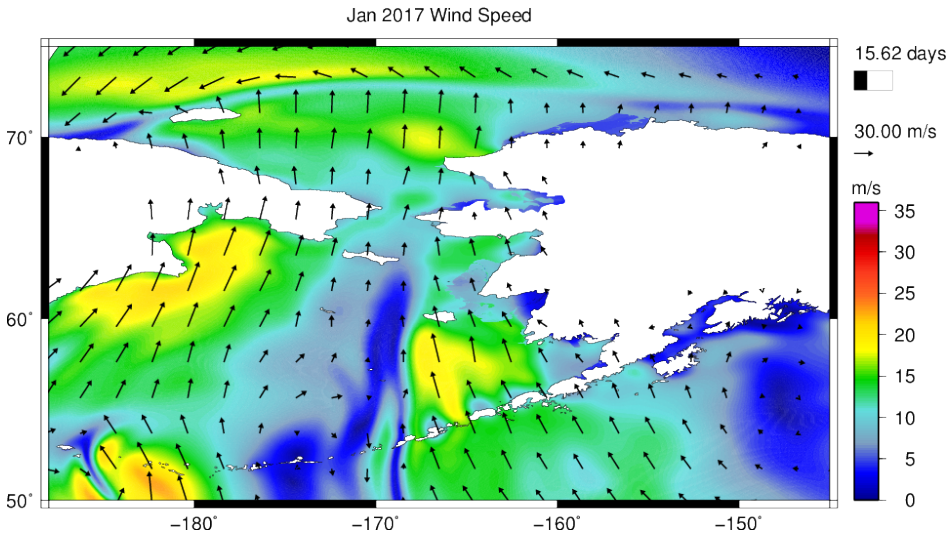


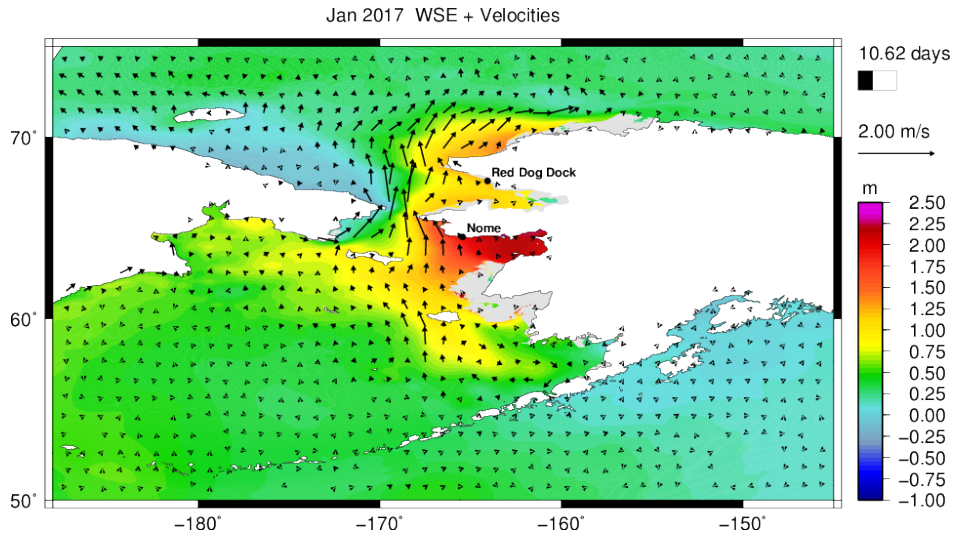
January 2017



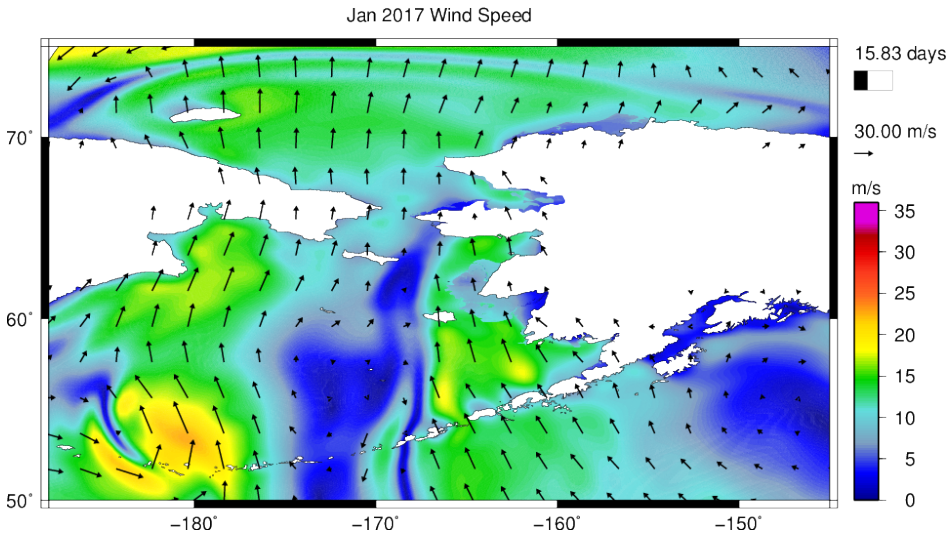


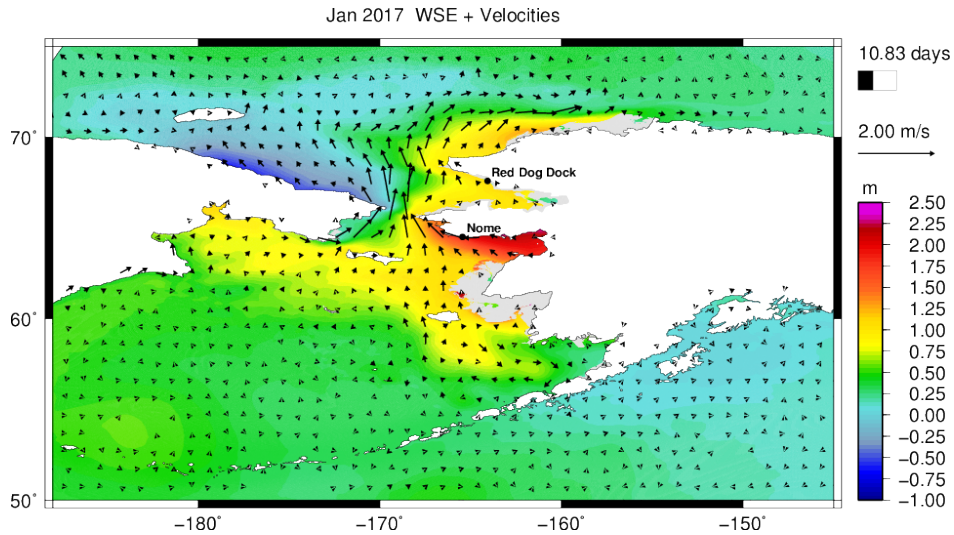
January 2017



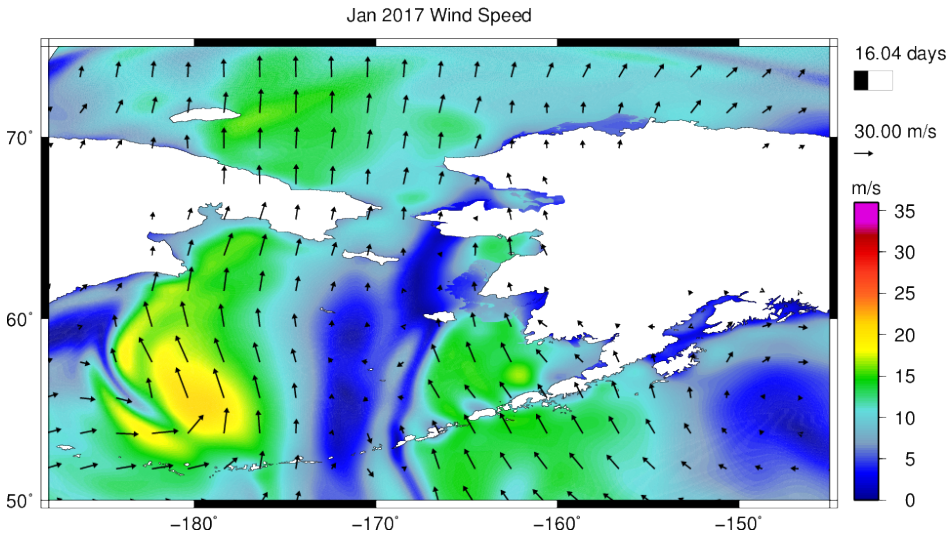


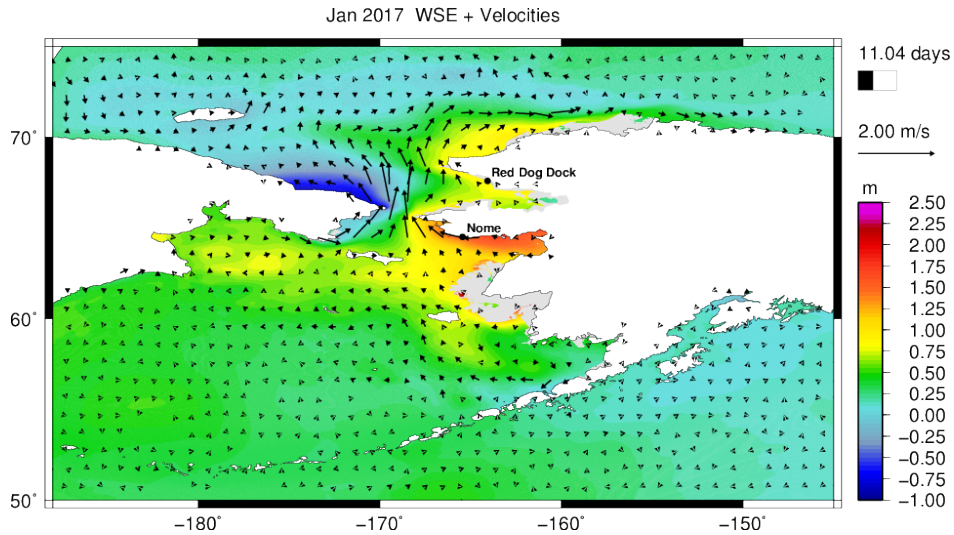
January 2017



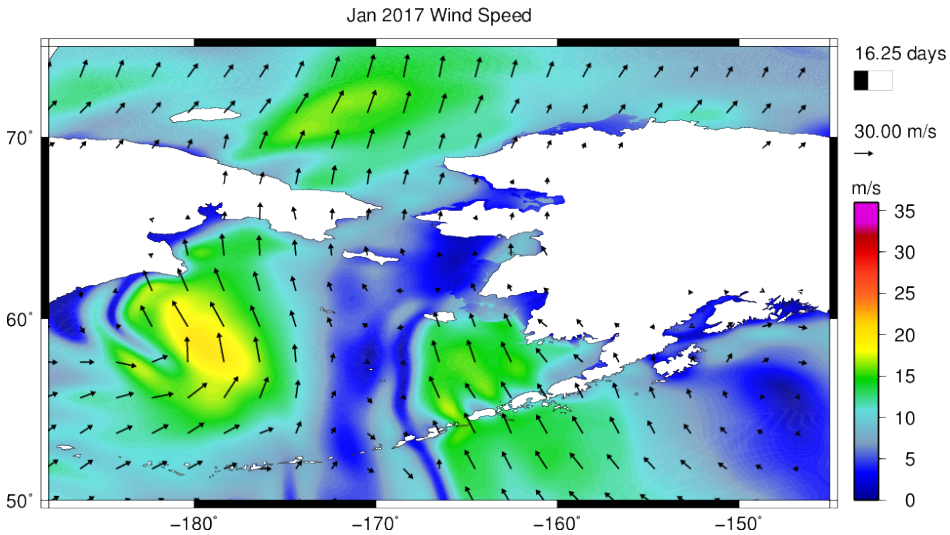


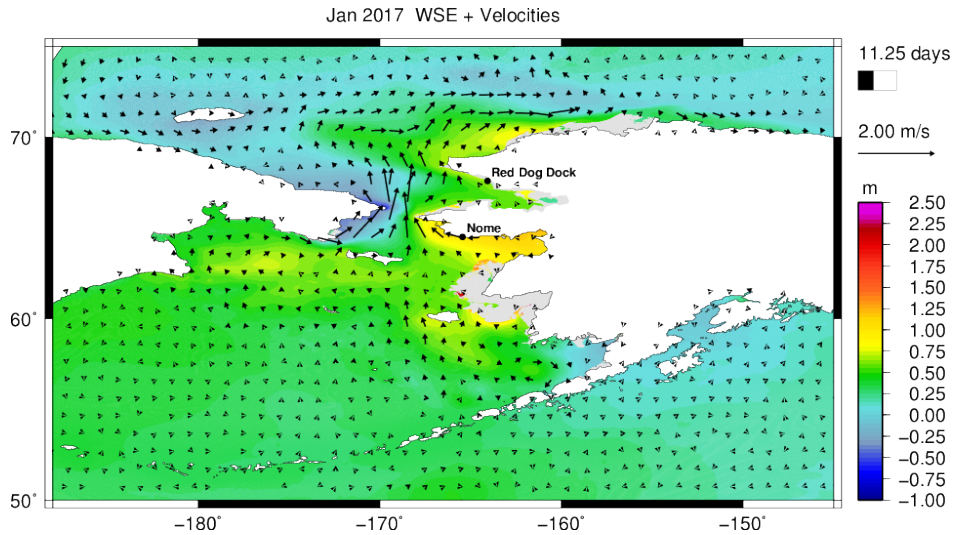
January 2017





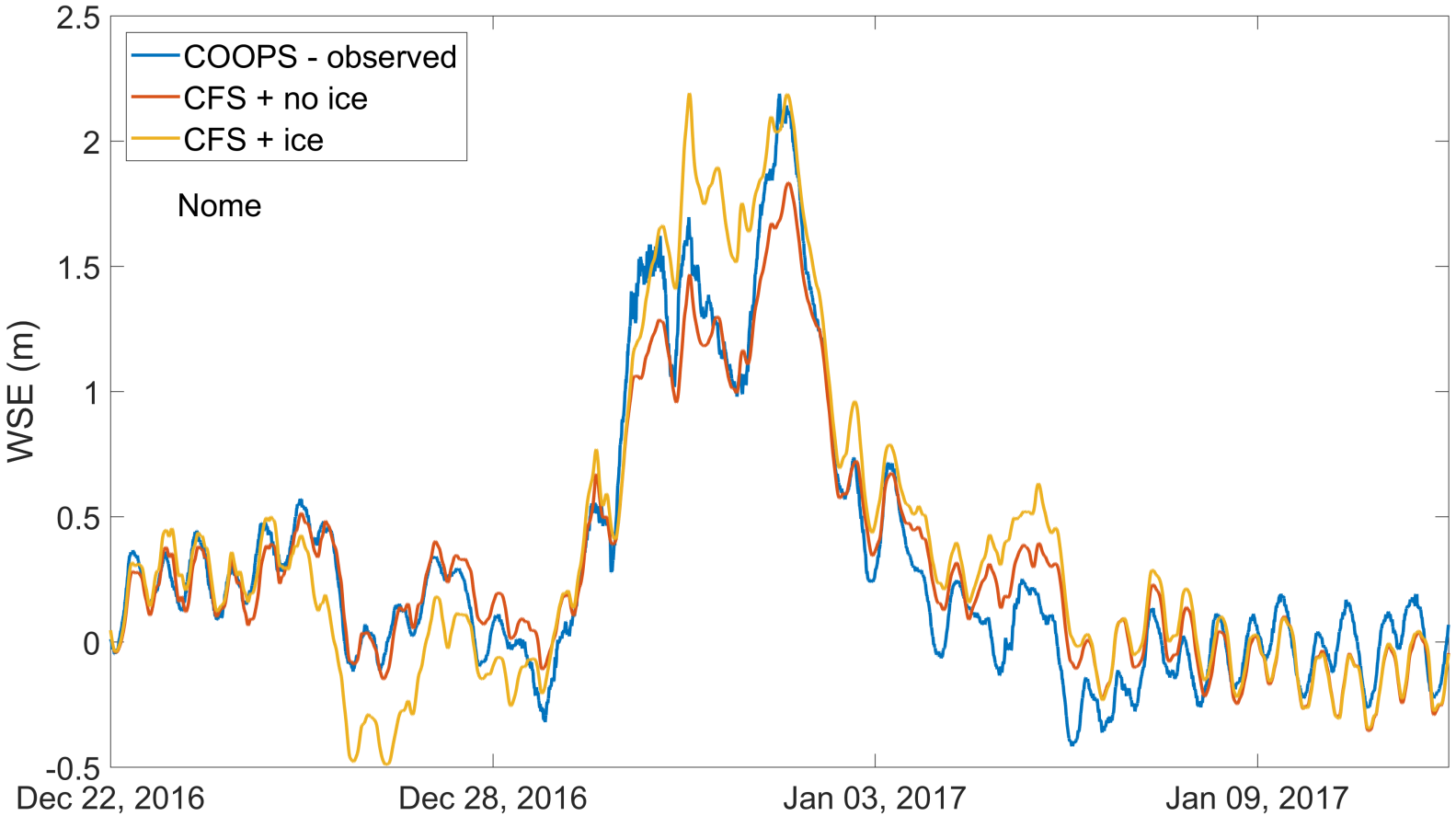
January 2017





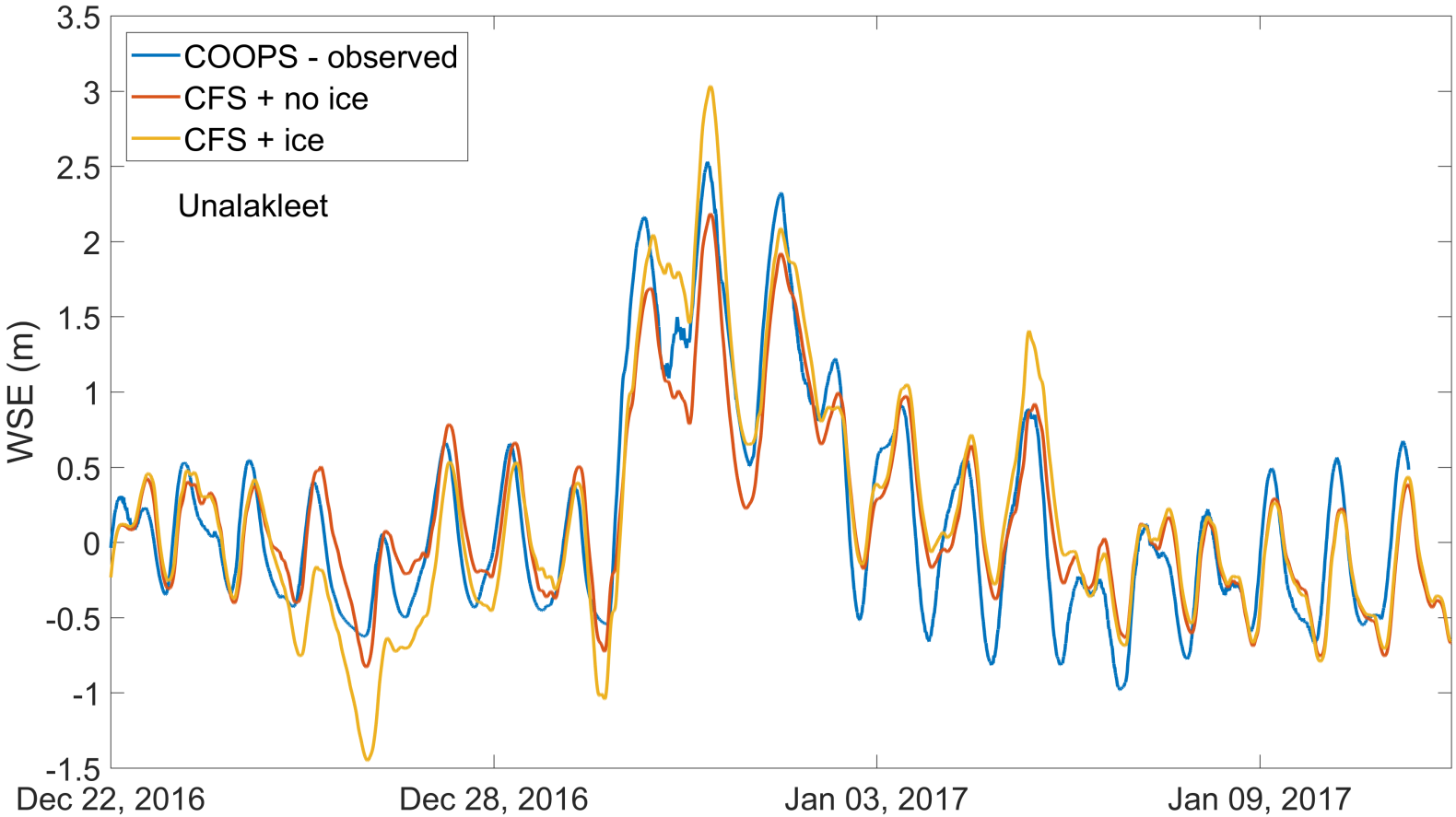
January 2017 Validation

Nome



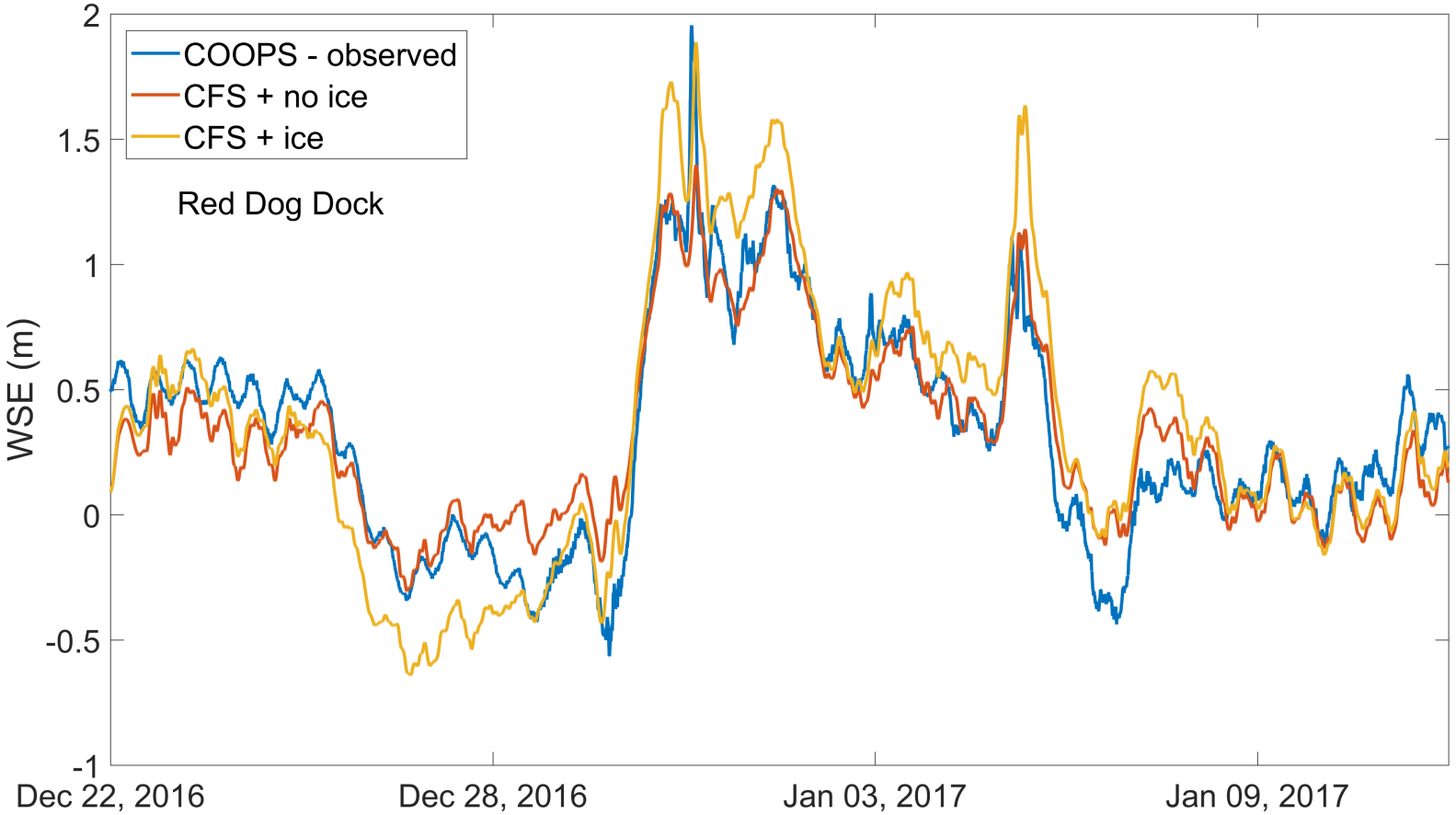
January 2017 Validation

Unalakleet

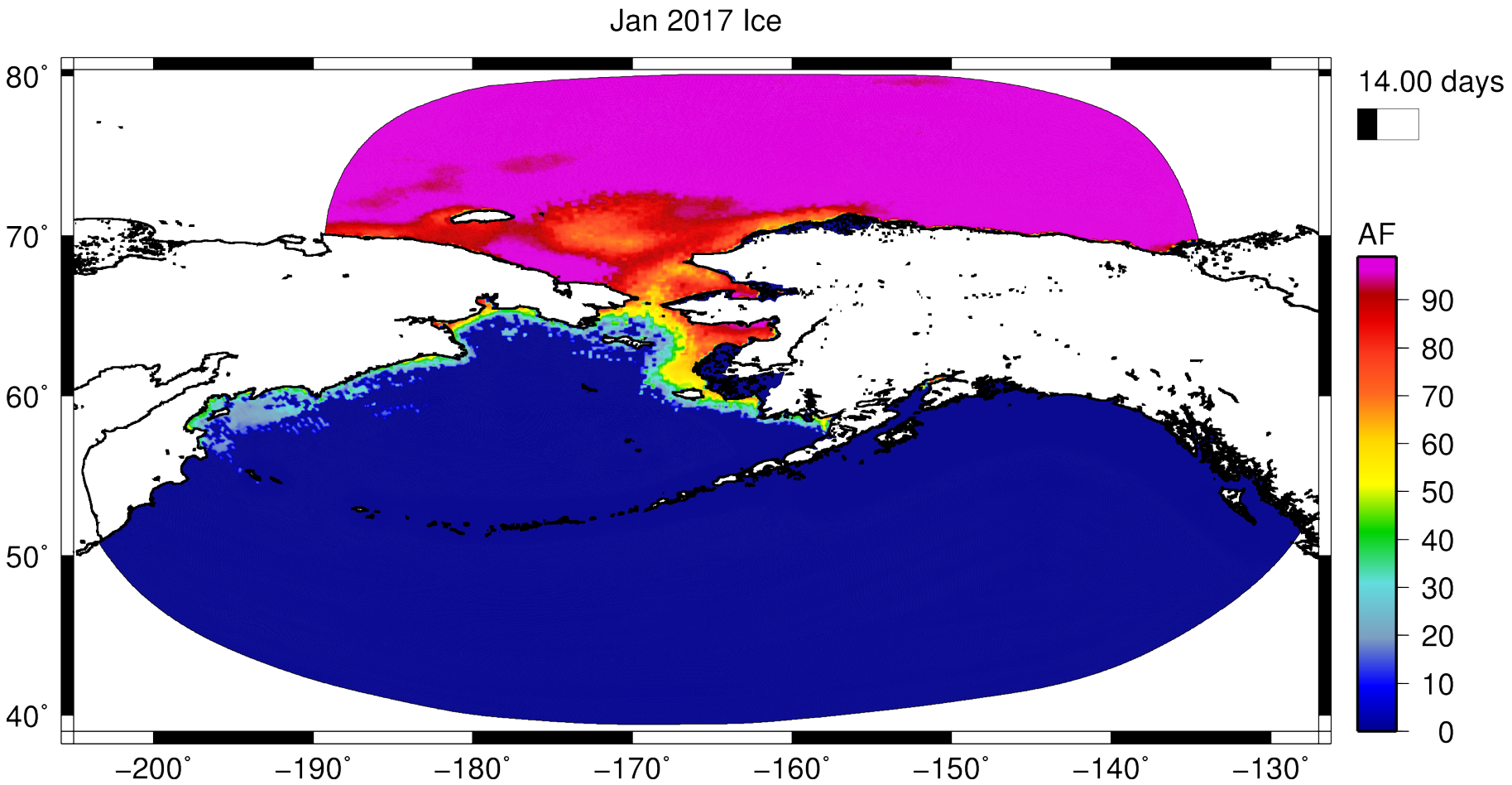


January 2017 Validation

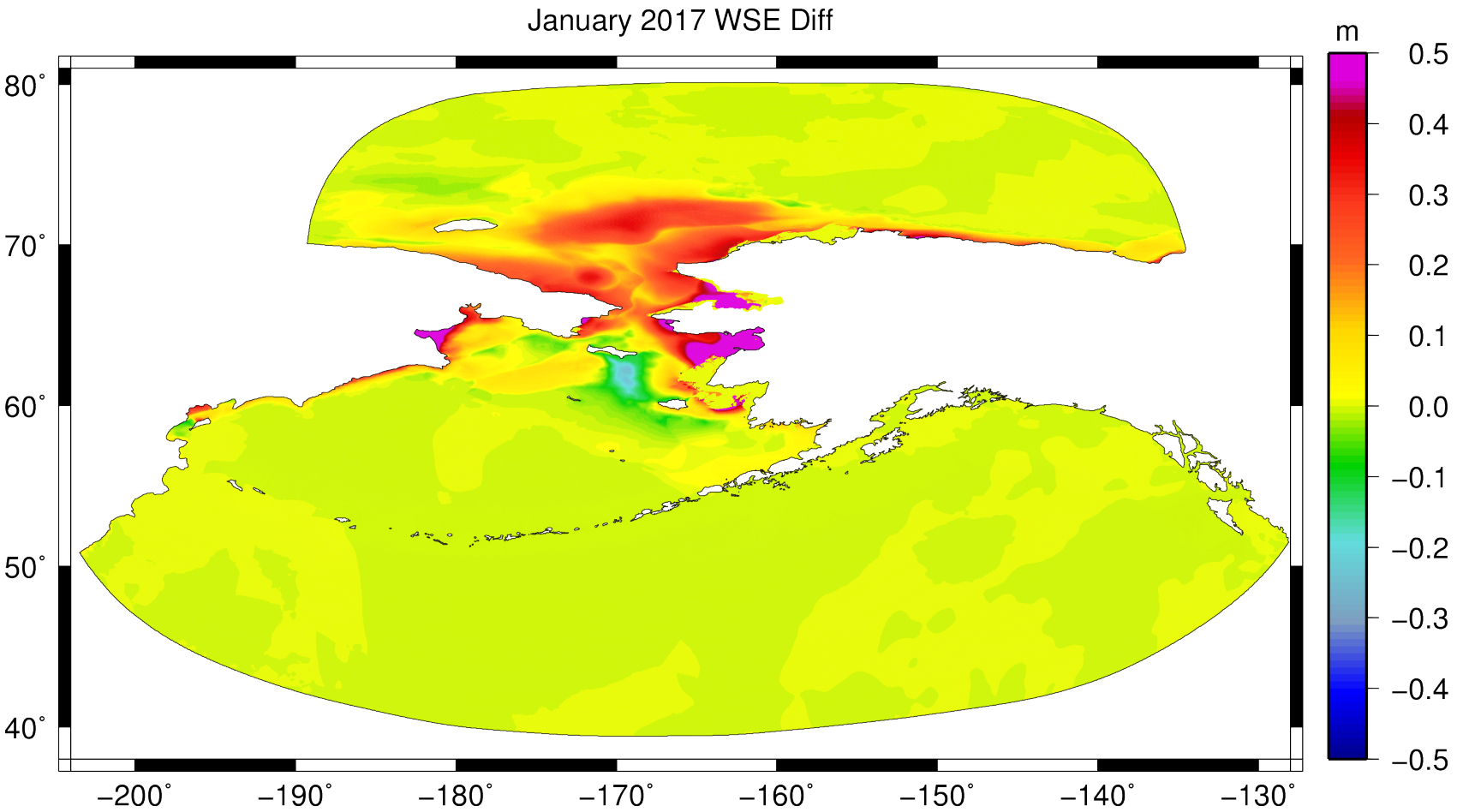
Red Dog Dock



January 2017 Ice Coverage



January 2017 Effect of Ice



Outline

1. Model Description
2. Validation of Tides and Summer Storms
3. Sea Ice Implementation to Circulation Modelling
4. Modelling Storm Surge in the Presence of Ice Coverage
   - November 2011
   - February 2011
   - January 2017
5. Proposed

Proposed - Wind Wave Model

- Typically, ADCIRC is coupled to the Simulating WAves Nearshore (SWAN) model
  - Tight coupling
  - Run simultaneously on the same grid
  - **NO ICE PHYSICS**
- WAVEWATCH III spectral wave model
  - Incorporated recent 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

Proposed - Sea Ice Model

- Still significant uncertainty in air-sea-ice interaction with respect to storm surge
- General limitations on ice product (CFSv2/NCEP)
- Limited to area fraction and thickness
- The 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 [4]
  - Computes ice drift speeds

$$\tau_{i-o} = \rho_w C_{d,i-o} |u_i - u_o| (u_i - u_o) \tag{2}$$

Total ocean stress

$$\tau_{ocn} = (1 - AF)\tau_{a-o} + (AF)\tau_{i-o} \tag{3}$$