Hydrodynamic models and satellite remote sensing data help study the beluga whale habitat in Cook Inlet

Tal Ezer
Center for Coastal Physical Oceanography (CCPO)
Old Dominion University (ODU)

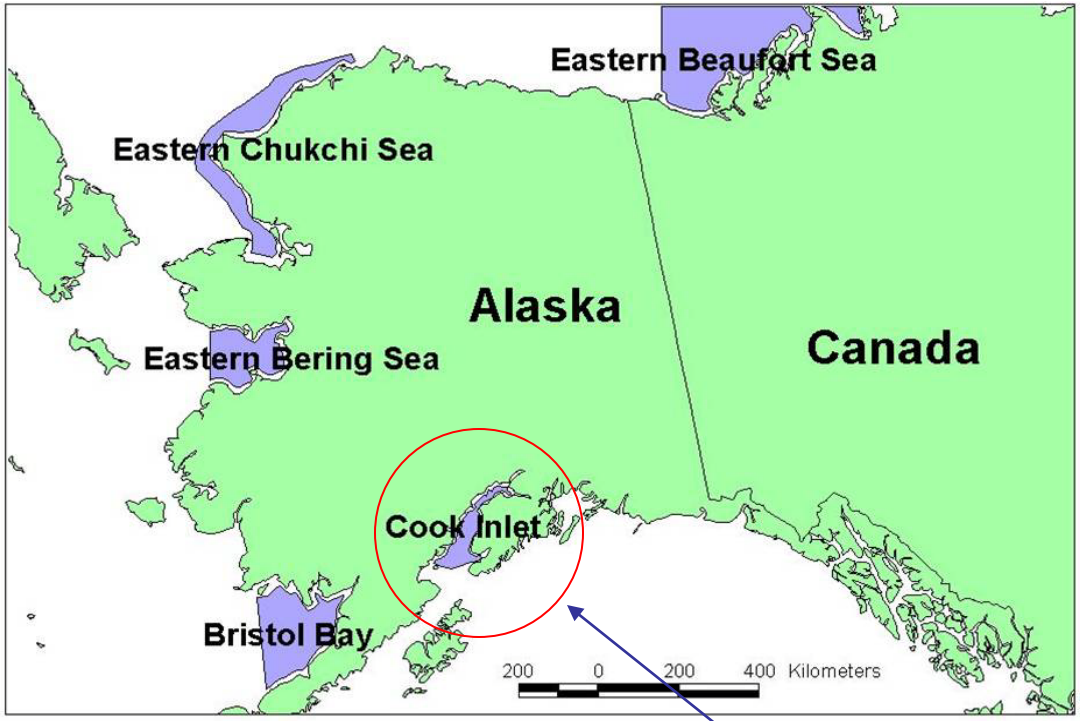
In collaboration with:
Leo Oey, AOS, Princeton University (model development)
Hua Liu, Geog. Dept., ODU (remote sensing)
Rod Hobbs (beluga)

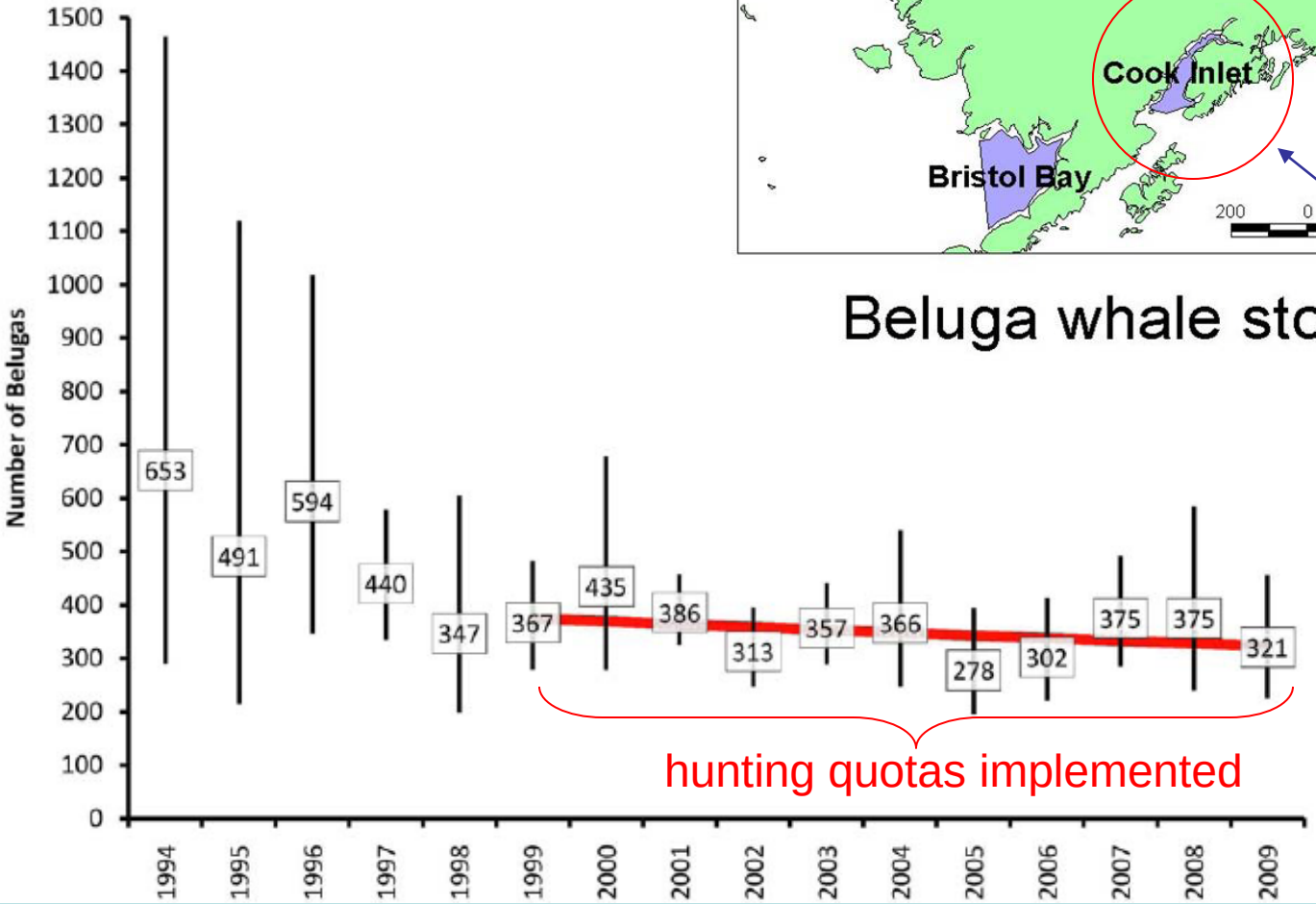
Supported by:
NOAA/Fisheries (Belugas studies)
MMS (model development)

Presented at:

Cook Inlet Beluga Whale Science Workshop, Anchorage, Oct.11-12, 2010

Cook Inlet is home to declining population of Beluga Whales (*Delphinapterus Leucas*) which were declared "***Endangered Species***" in 2008





Belugas in Cook Inlet are the most geographically and genetically isolated of the five Alaska stocks (Hobbs et al., O'Corry et al.)

Purpose of Study:

- Study the beluga whales habitat and the changing environmental conditions in Cook Inlet
- Try to better understand the relation between the beluga whales behavior, movements and survival to environmental conditions

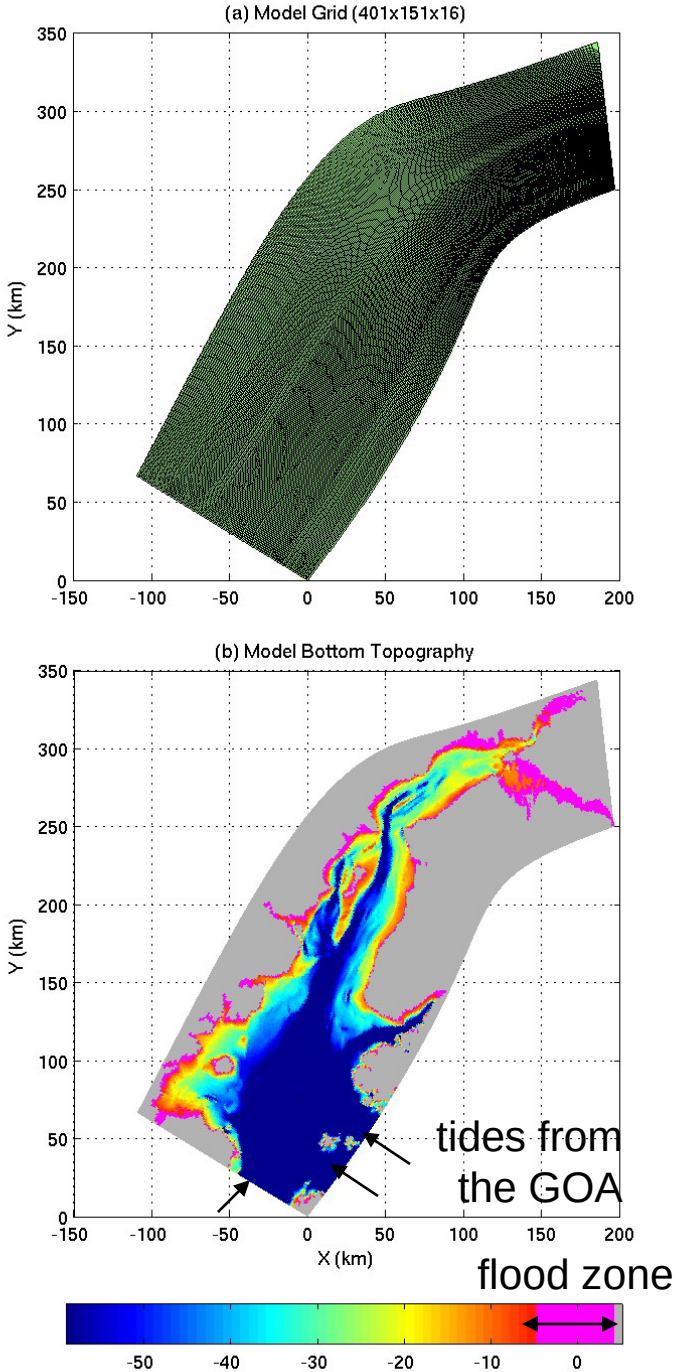
Data Used:

- Satellite tracked beluga movements
- Hydrodynamic/Inundation ocean models
- Satellite remote sensing data
- Local observations (when available)

Why do we need a hydrodynamic/ inundation (flood) model?

- to capture “wetting/drying”

- mudflats largely inaccessible, so models and satellite data can “fill the gap” of environmental information



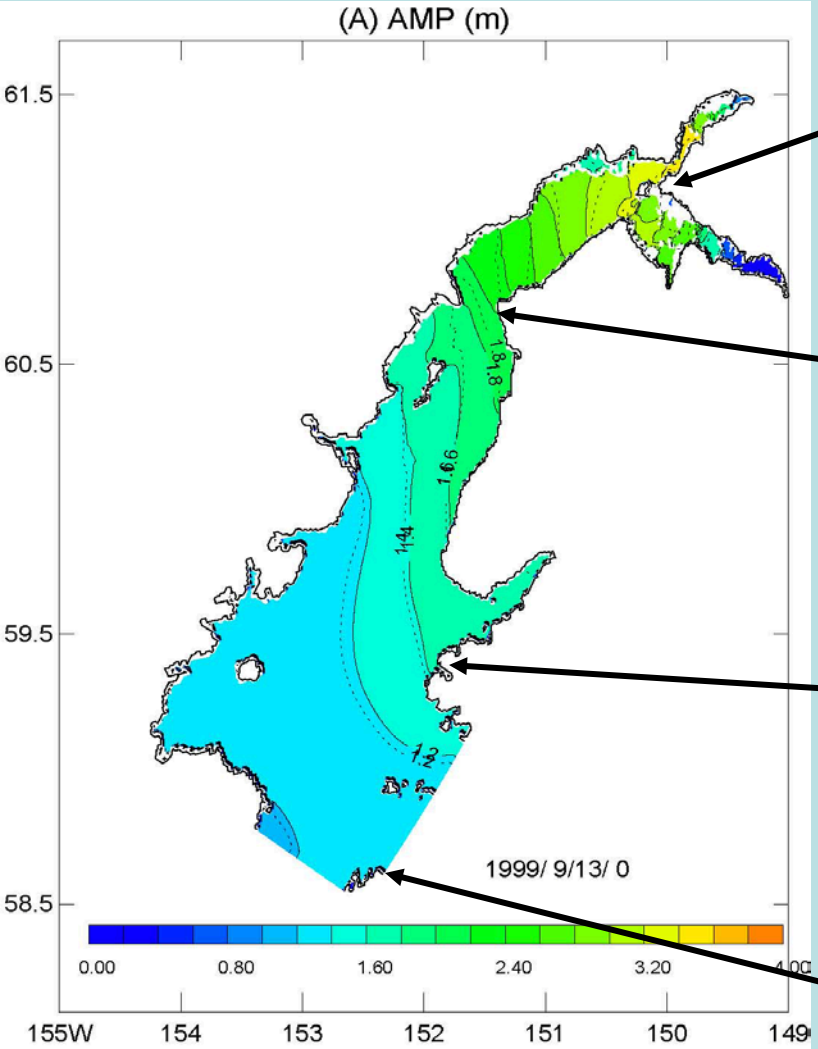
Princeton Ocean Model with Wetting And Drying (POM-WAD) Model:

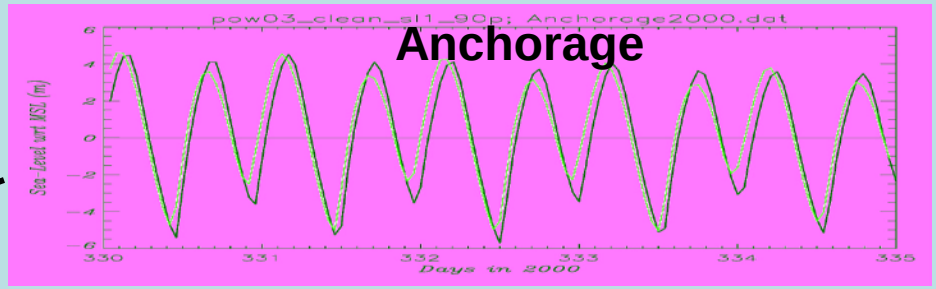
1. Curvilinear grid (0.5-1 km)
2. Topography of mud-flat areas
3. Temp./Sal. stratification
4. Winds from local NOAA stations
5. Rivers runoff from USGS
6. Tidal forcing in south boundary

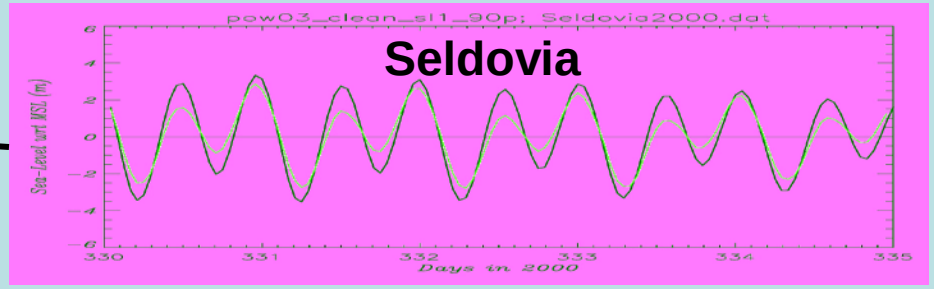
Model Simulations Output:

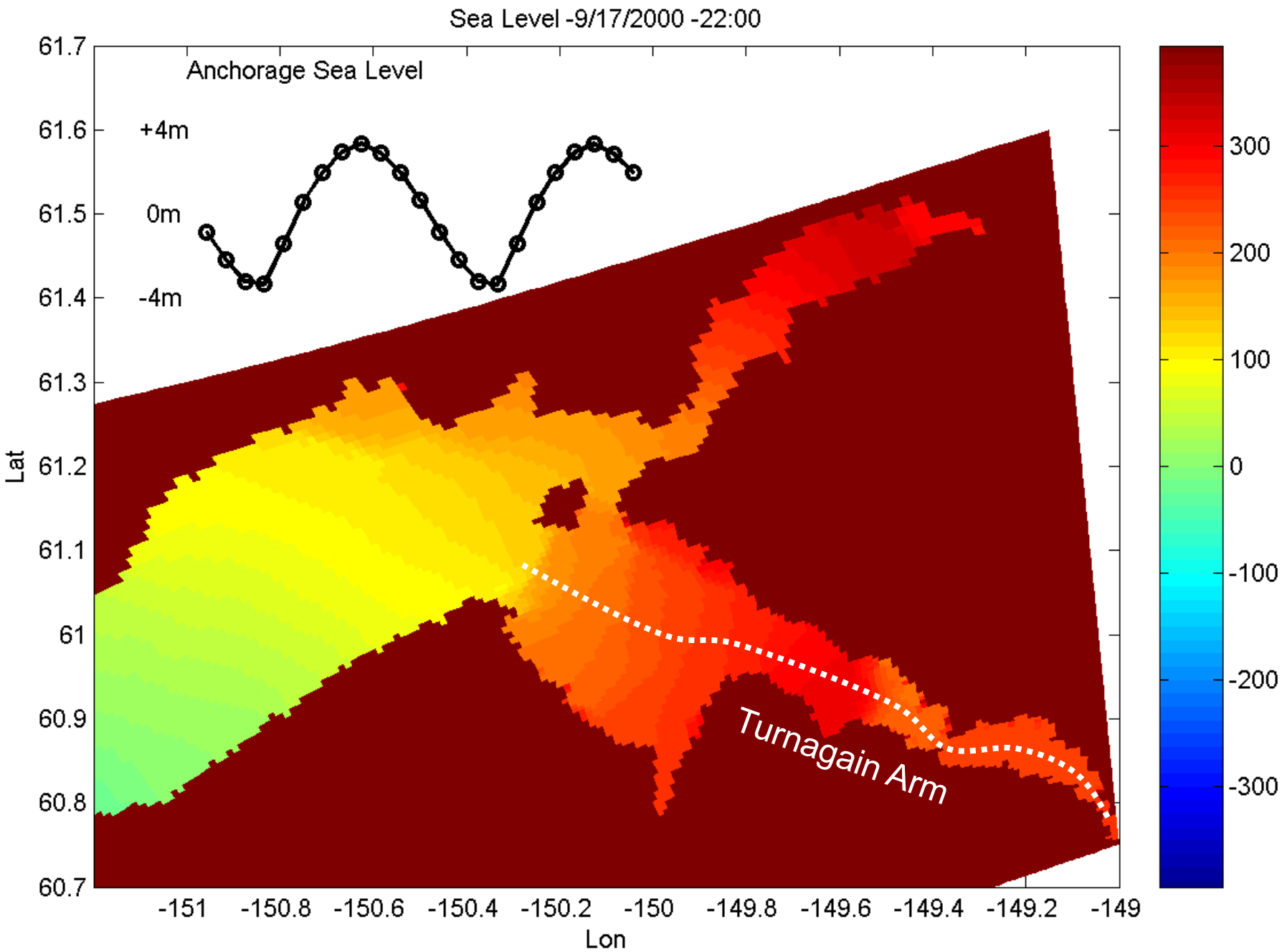
1. Temperature
2. Salinity
3. Currents
4. Water level
5. Water coverage/ mudflat exposure

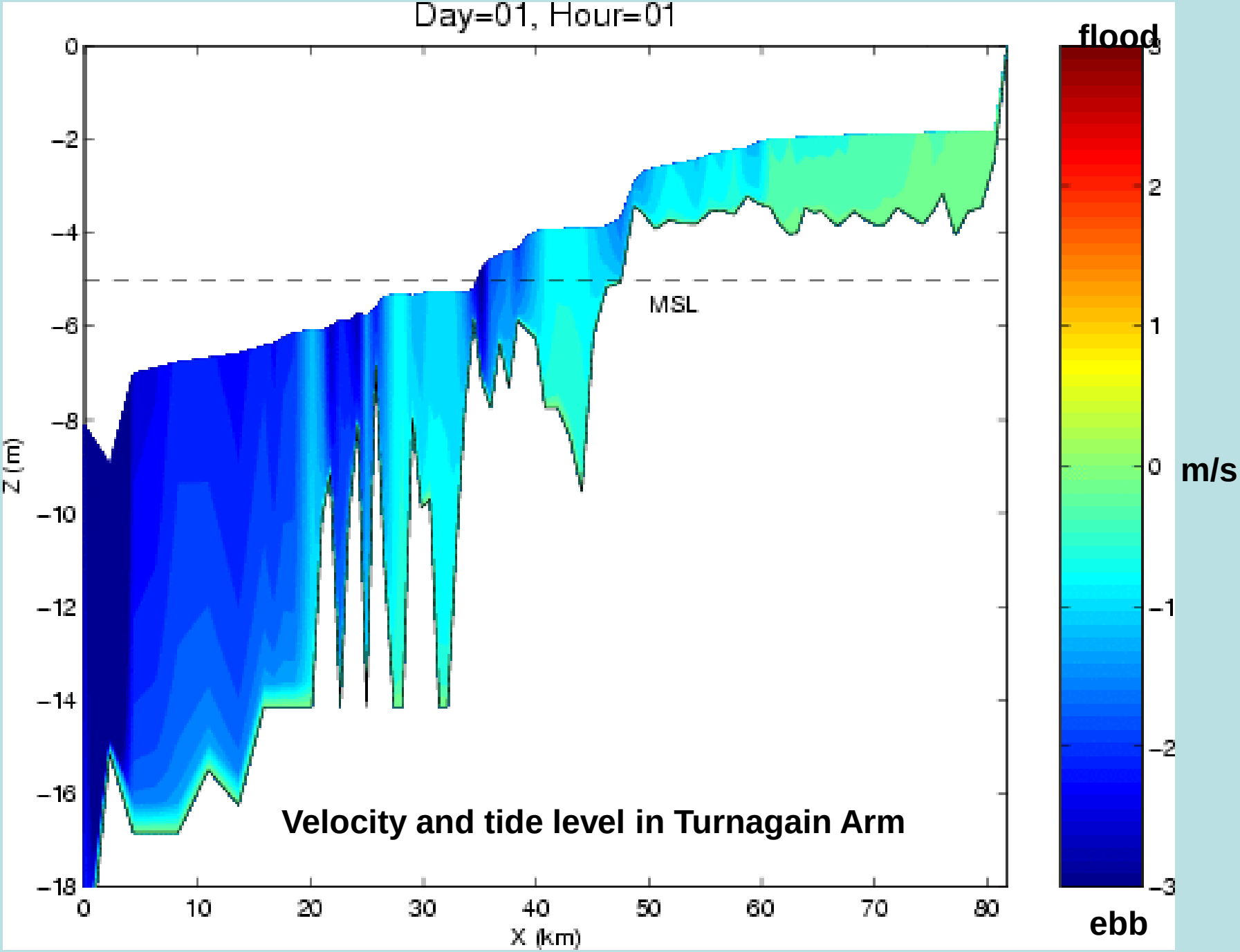
The amplification of the tides in the inlet are simulated quite well



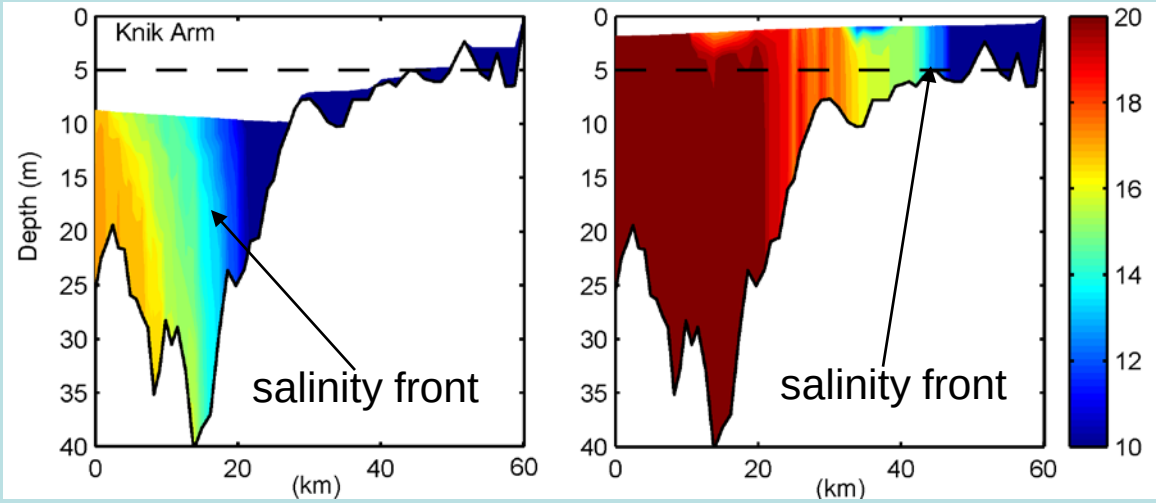


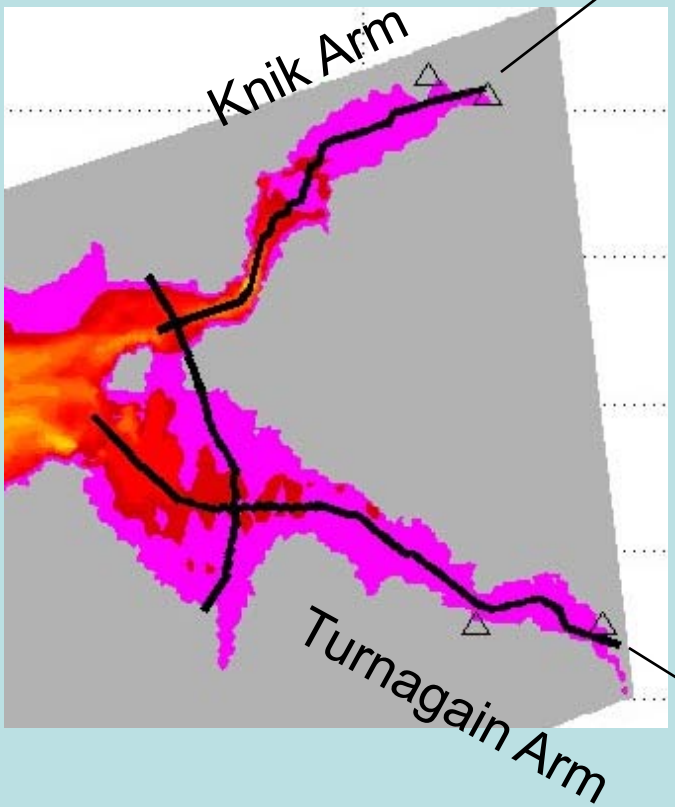



Sea Level -9/17/2000 -22:00
Anchorage Sea Level
+4m
0m
-4m
Turnagain Arm
Lat
Lon
61.7
61.6
61.5
61.4
61.3
61.2
61.1
61
60.9
60.8
60.7
-151
-150.8
-150.6
-150.4
-150.2
-150
-149.8
-149.6
-149.4
-149.2
-149
300
200
100
0
-100
-200
-300


Day=01, Hour=01
flood
ebb
m/s
MSL
Z (m)
X (km)
Velocity and tide level in Turnagain Arm

The transition of the salinity front with the tides is very different in the two arms (impact on beluga?)



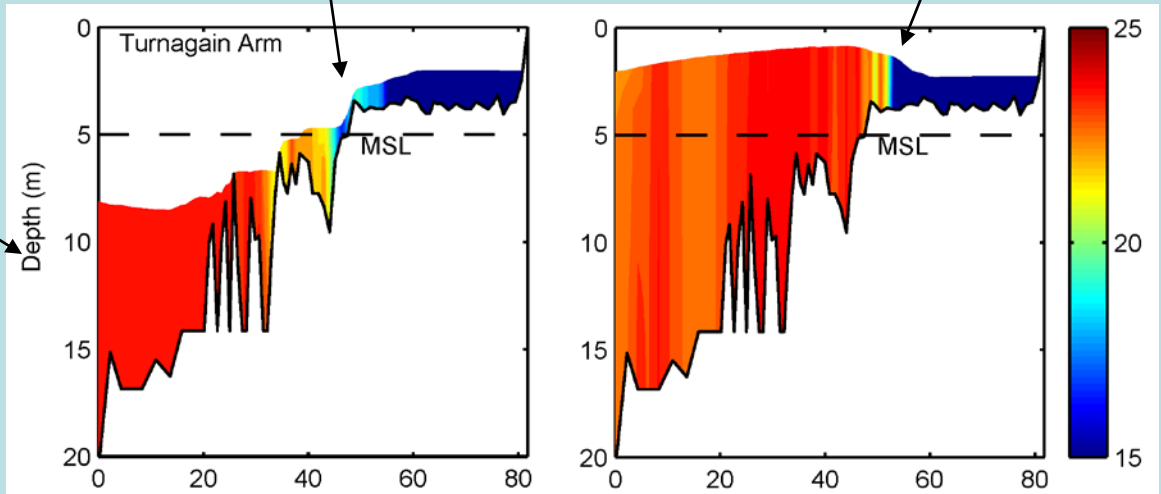


low tide

high tide

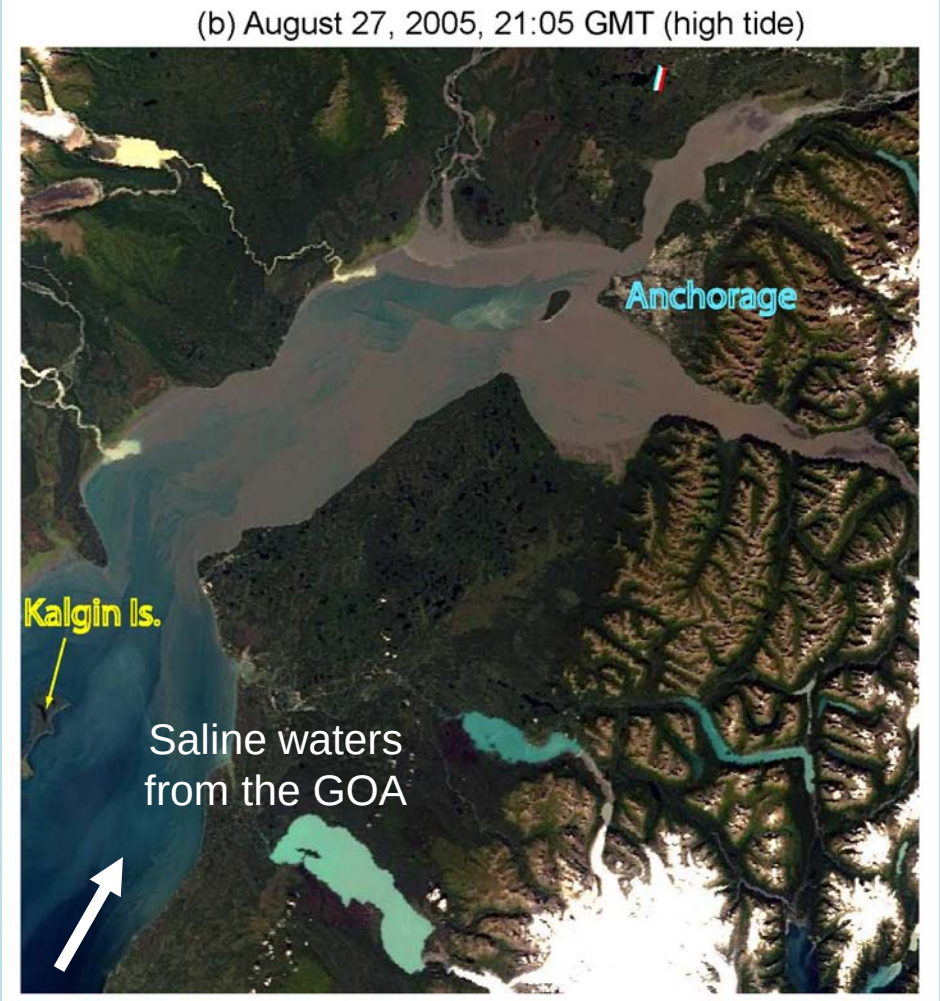
slow draining during ebb

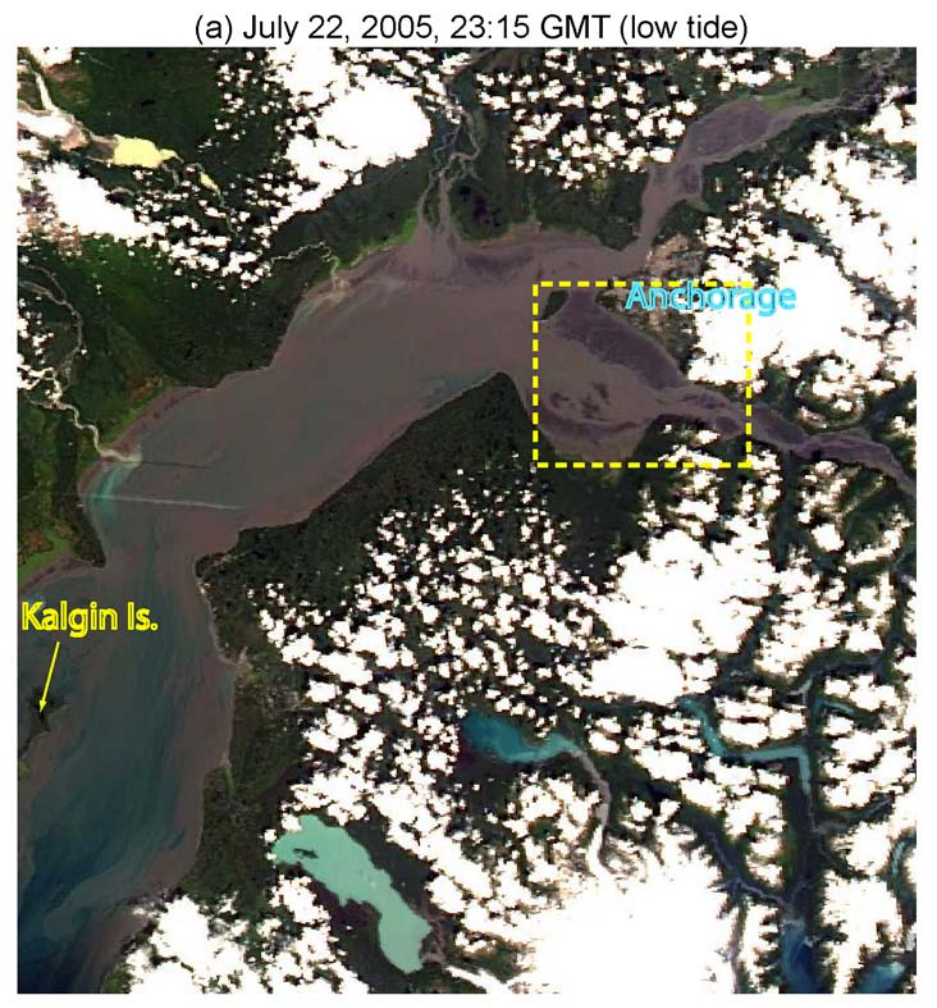
tidal “bore”



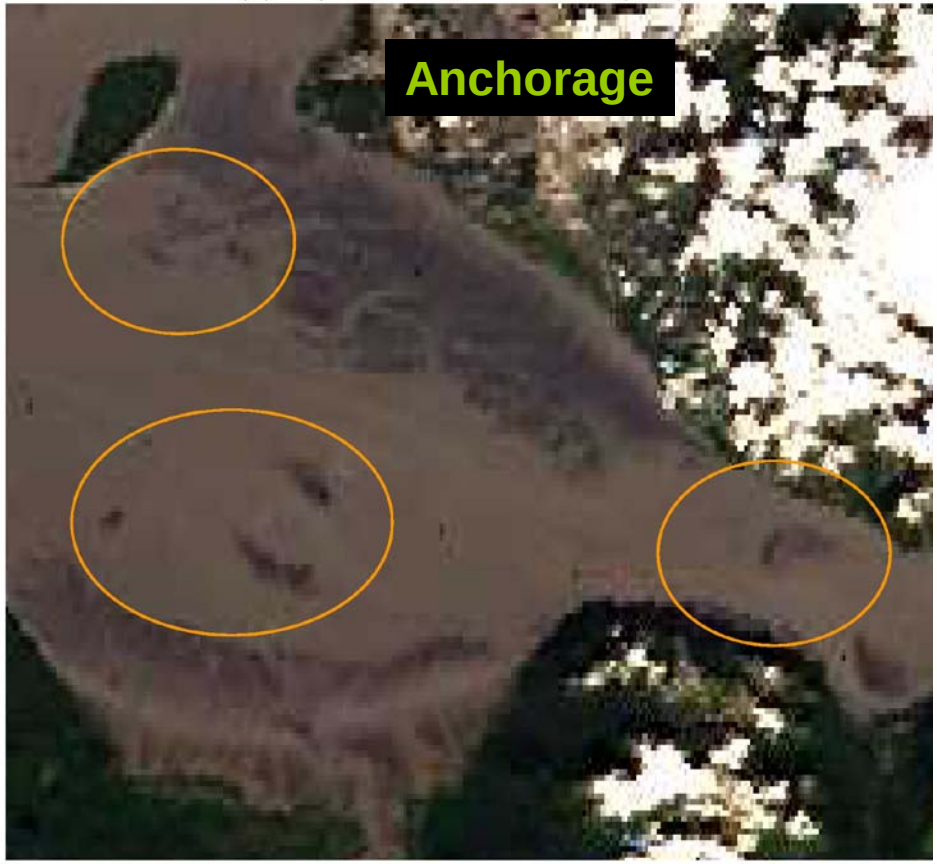
Satellite Remote Sensing Data

- allow us to map the mudflat area where local observations are difficult to obtain

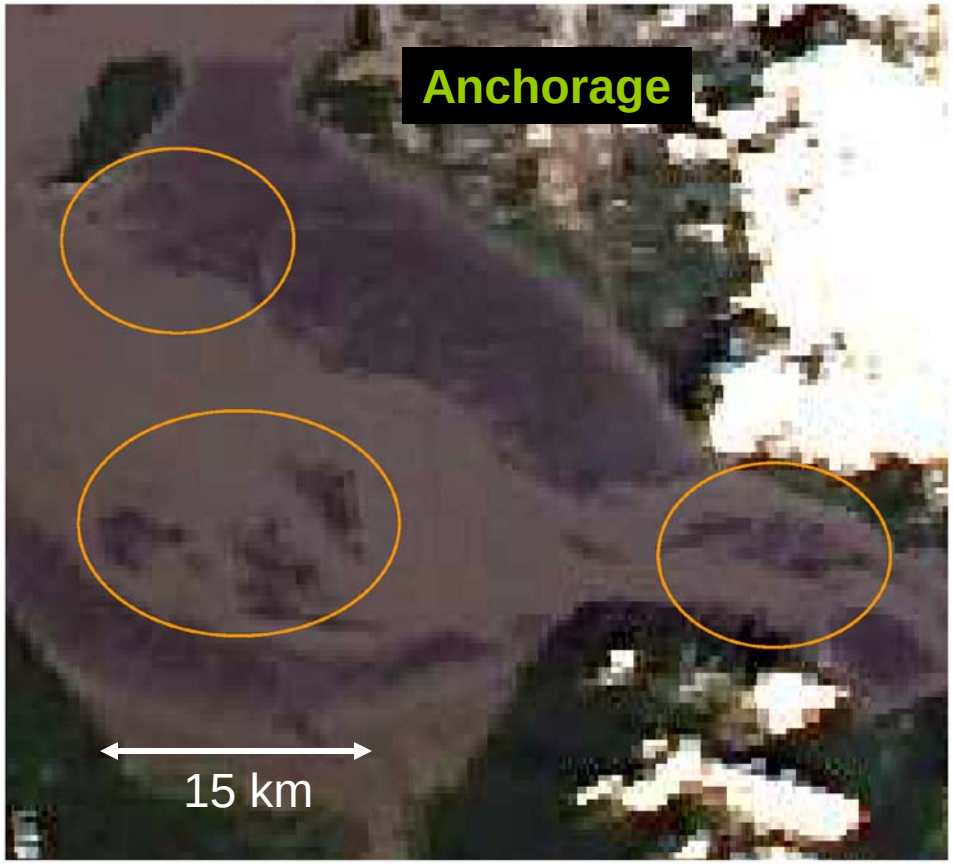




(a) July 22, 2005, 21:30 GMT (ebb)

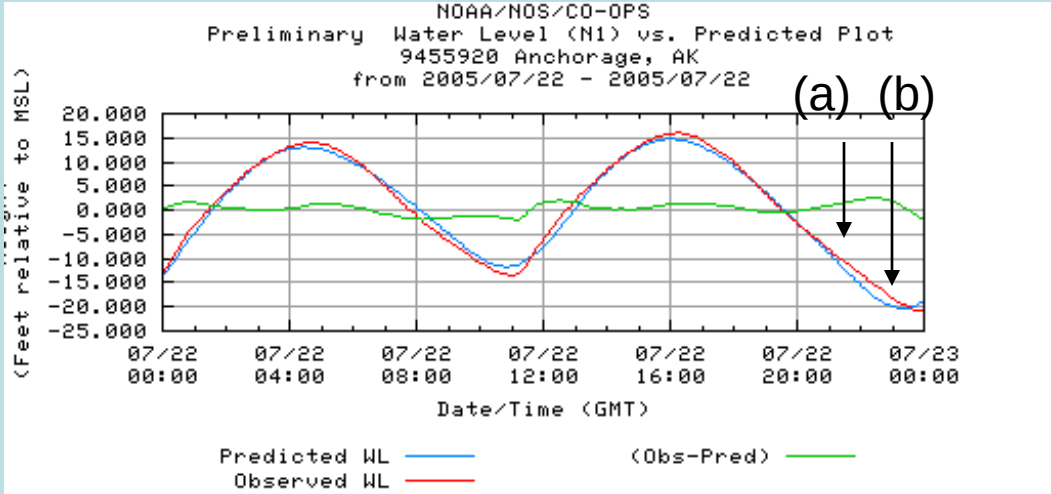


(b) July 22, 2005, 23:15 GMT (end ebb)

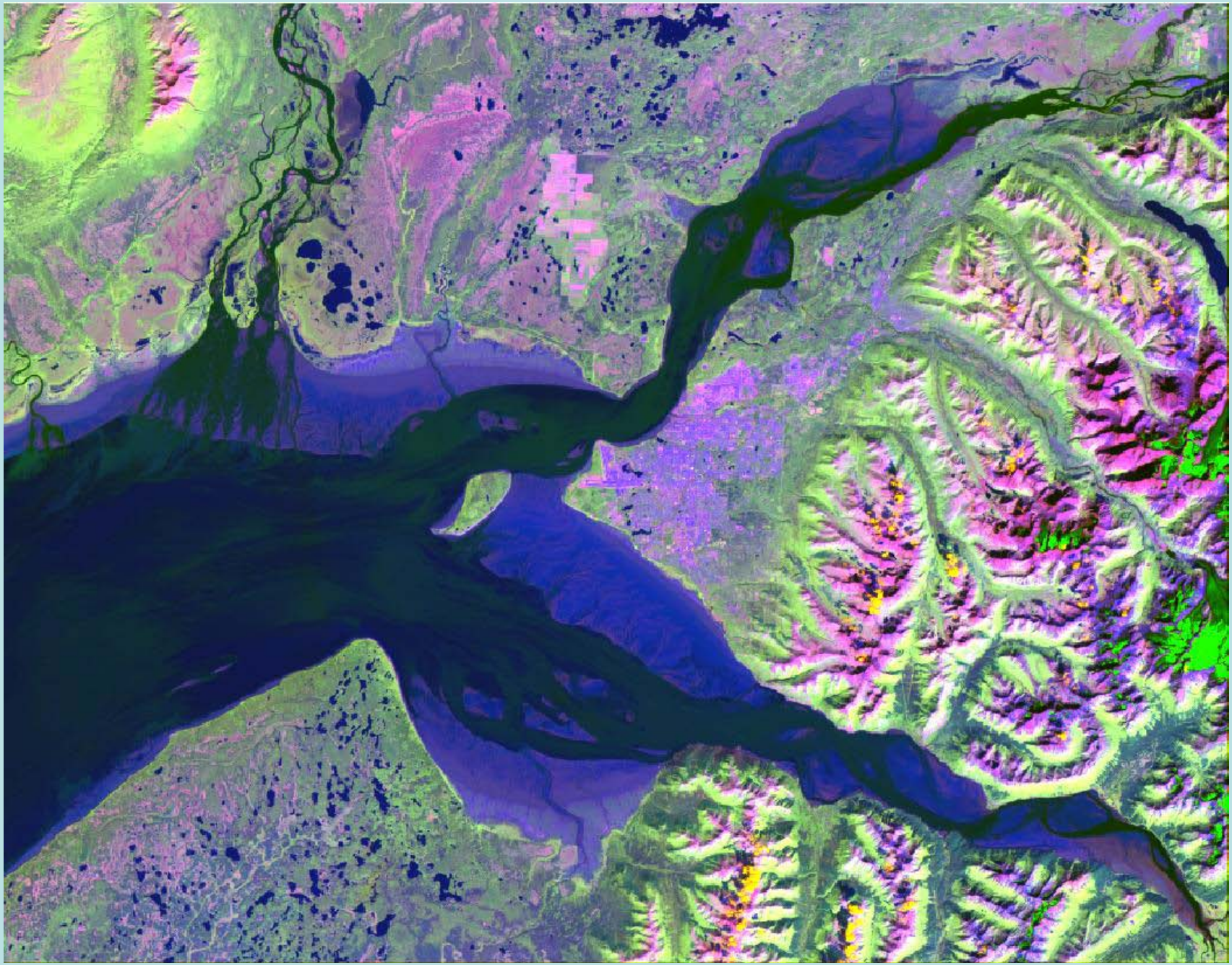


MODIS images from the Terra & Aqua satellites (1:45 h apart) show the progress of exposing land during ebb.

→ Can we use more images to map the flooded regions?



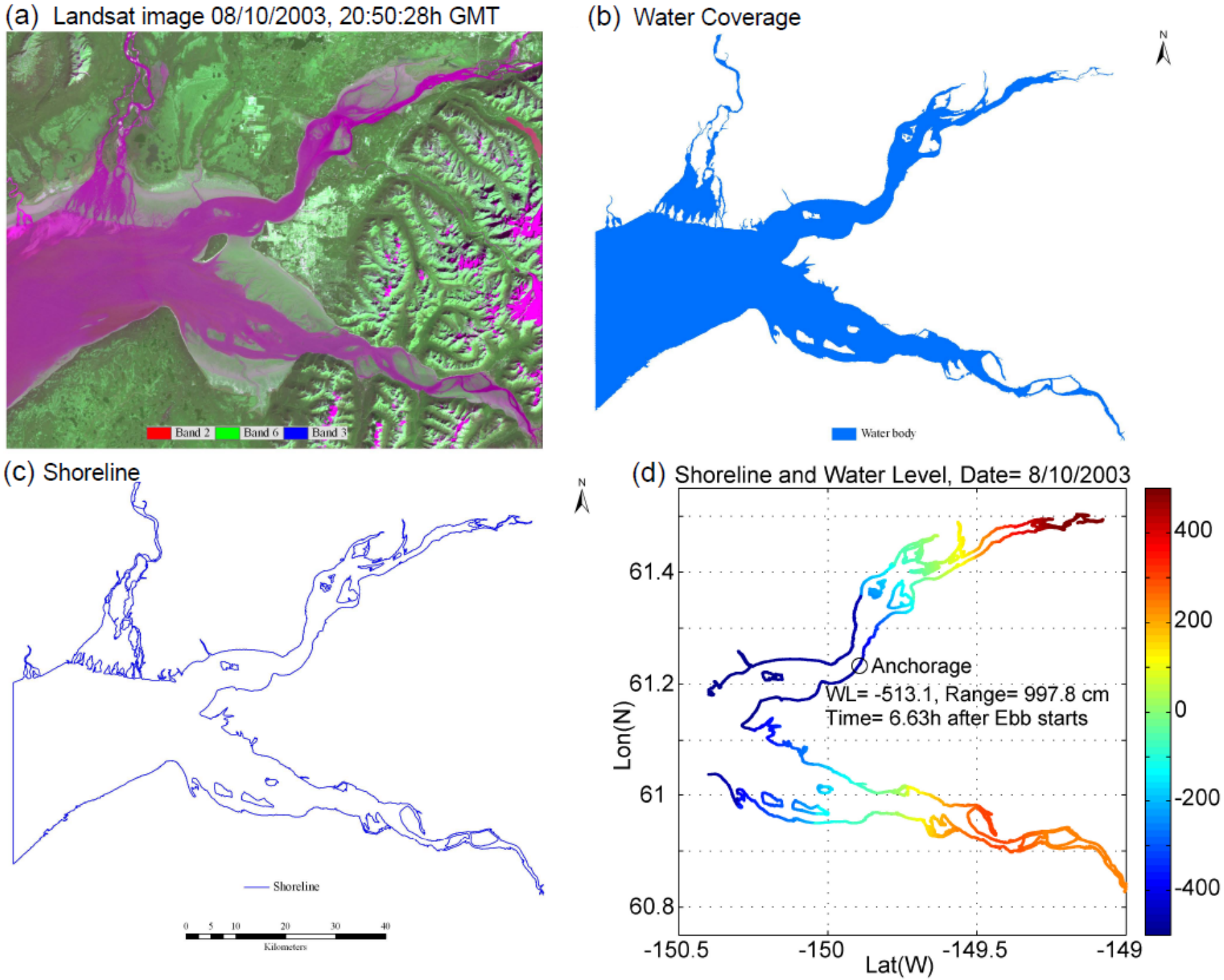
Landsat Image, Aug. 10, 2003 (during low tide)



Collected many satellite images, trying to capture different stages of the tidal cycle

Landsat acquisition data/time (GMT)	Cloud cover (%)	Anchorage tide (m)	Anchorage tidal stage	Wind speed (m/s)	Air temp (°C)	Water temp (°C)
2003/03/11, 21:02:19	18	2.201	00:08 h after high tide	2.000	−6.300	−0.900
2001/06/25, 21:02:56	18	1.237	02:26 h after high tide	2.100	15.600	14.700
2003/09/11, 20:51:03	10	−2.007	04:27 h after high tide	2.400	14.300	12.700
2003/08/10, 20:50:28	0	−5.131	00:58 h before low tide	2.500	17.000	15.300
2001/06/02, 20:57:20	9	−3.768	01:03 h after low tide	0.100	15.800	11.100
2002/10/02, 21:01:18	13	−1.875	02:01 h after low tide	1.000	9.500	8.800
2000/08/09, 21:04:39	7	−0.761	02:34 h after low tide	0.100	16.500	13.100
2002/05/20, 20:56:06	0	1.889	04:08 h after low tide	1.700	0.000	7.100

Can the satellite analysis be used to map the changing mudflats?

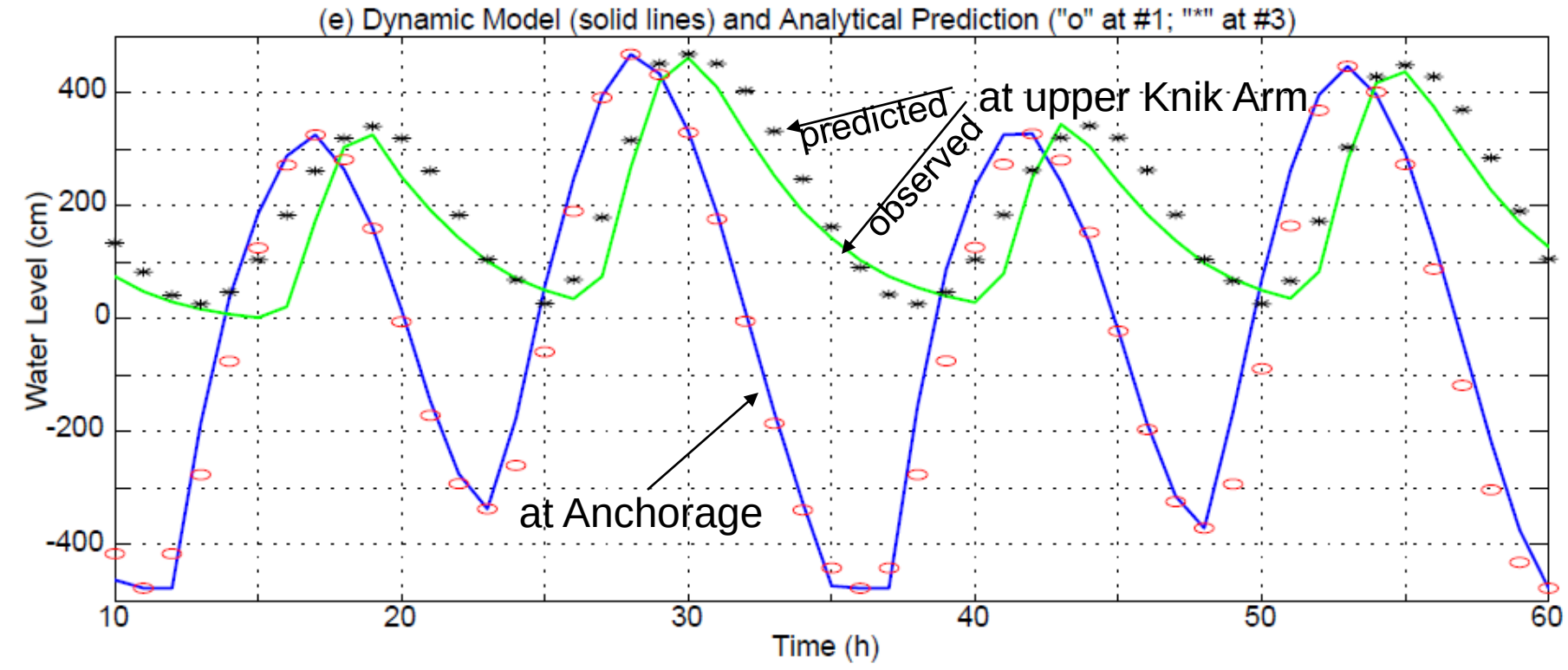

(a) Landsat image 08/10/2003, 20:50:28h GMT
Band 2
Band 6
Band 3
(b) Water Coverage
N
Water body
(c) Shoreline
N
Shoreline
0 5 10 20 30 40
Kilometers
(d) Shoreline and Water Level, Date= 8/10/2003
Anchorage
WL= -513.1, Range= 997.8 cm
Time= 6.63h after Ebb starts
Lon(N)
61.4
61.2
61
60.8
-150.5
-150
-149.5
-149
Lat(W)
400
200
0
-200
-400

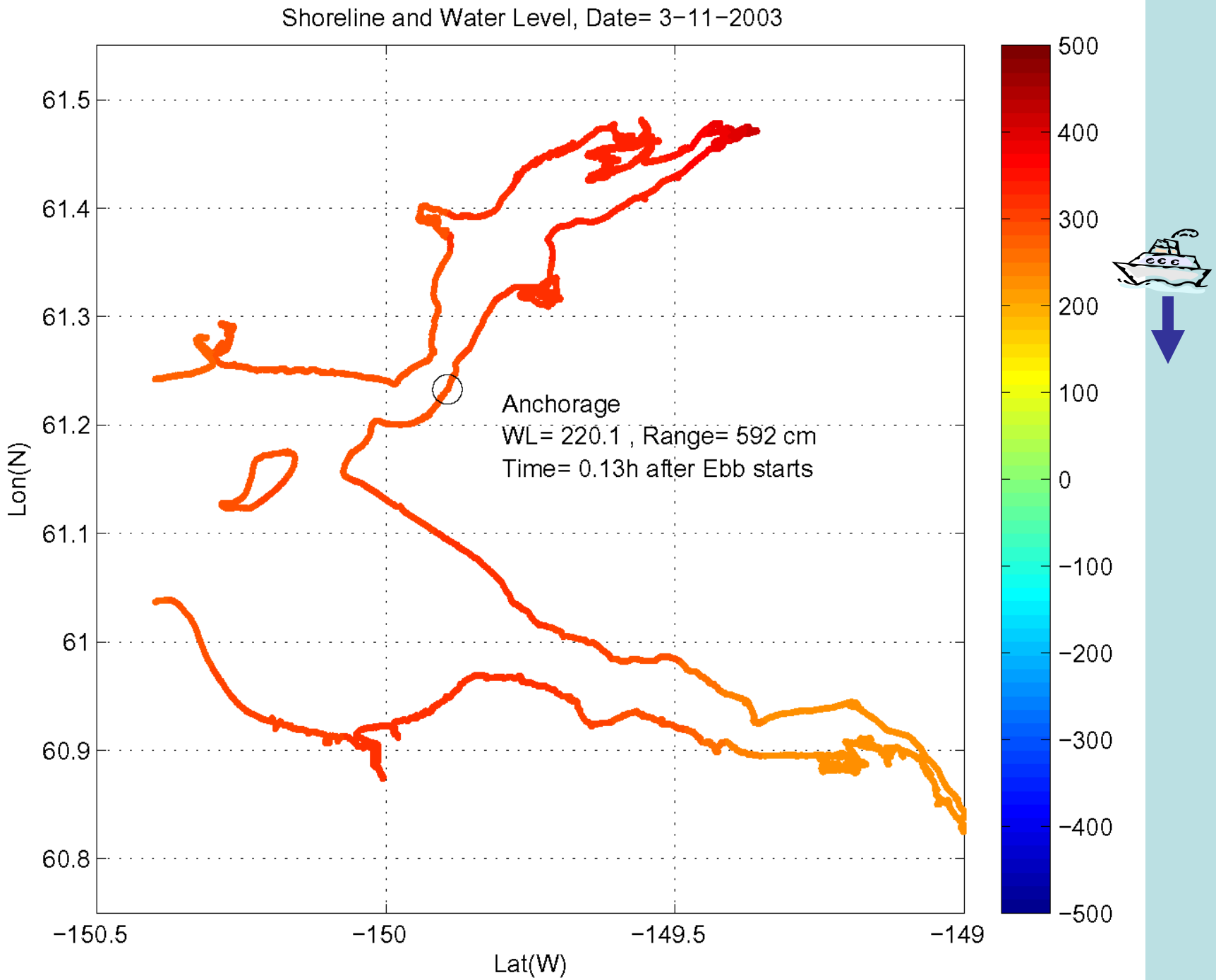
Water Level Prediction:

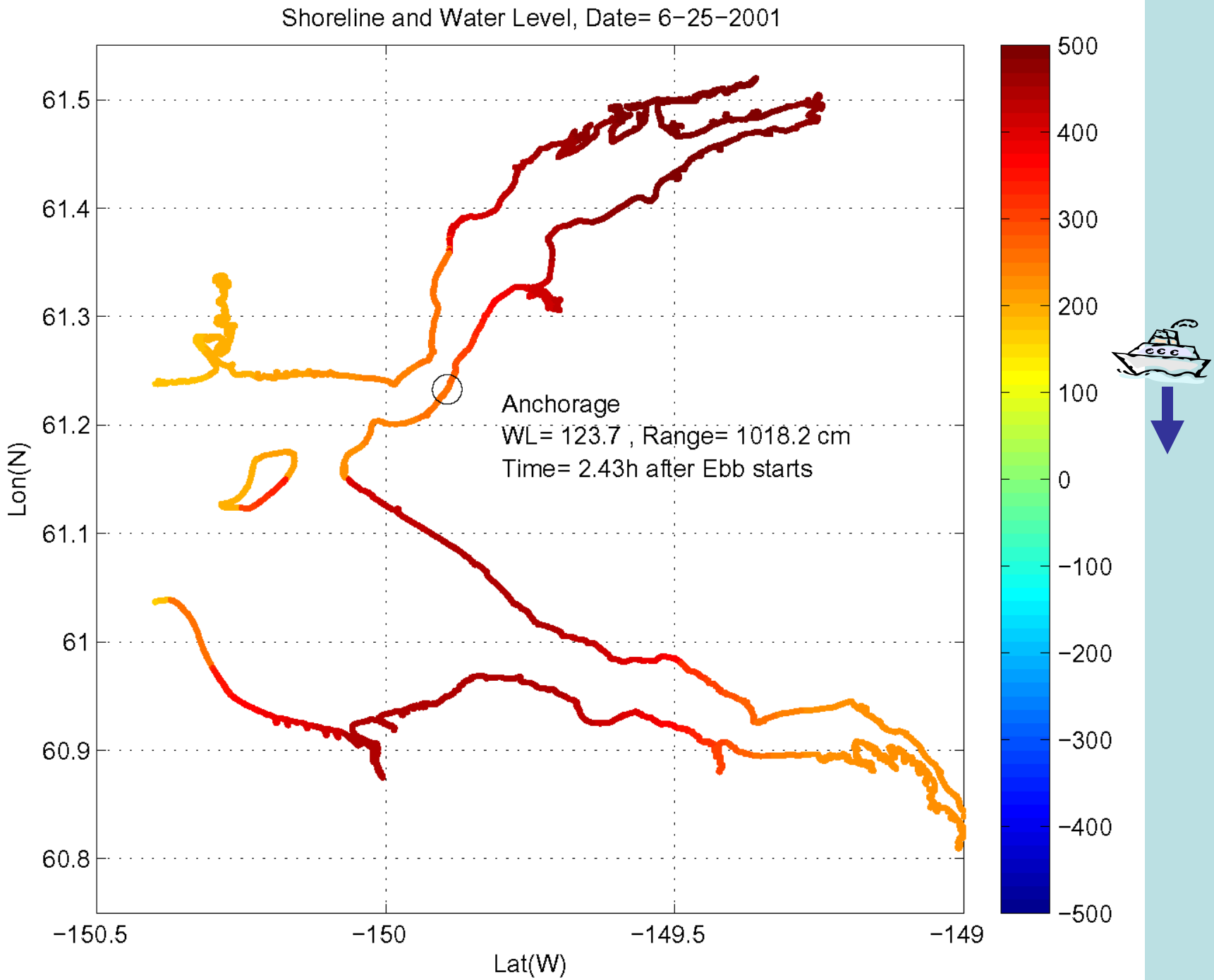
$$\eta(x,y,t)=\eta^{obs}(t)A(x,y)\cos[B(x,y)]+C(x,y)$$

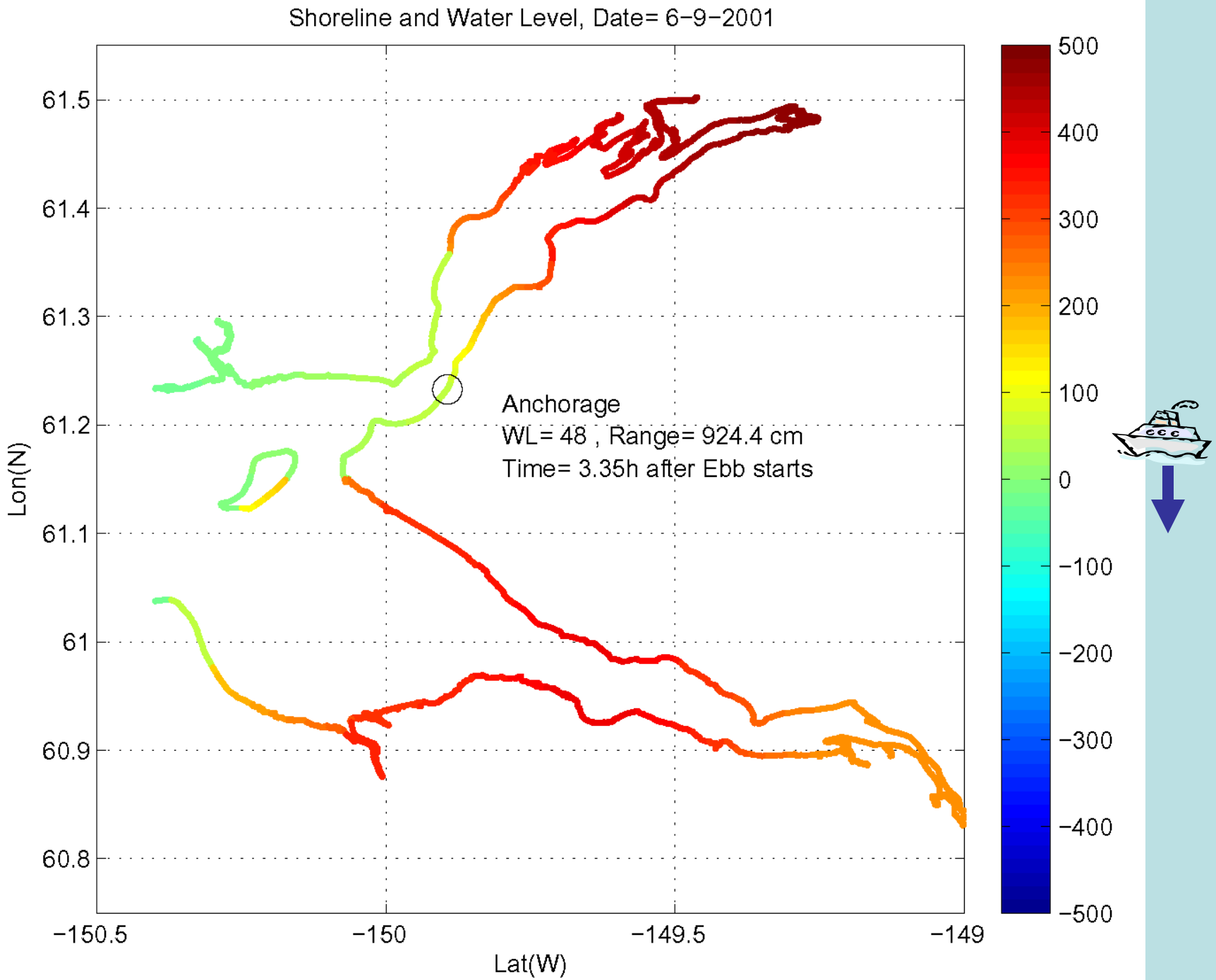
η^{obs}=observed WL in Anchorage

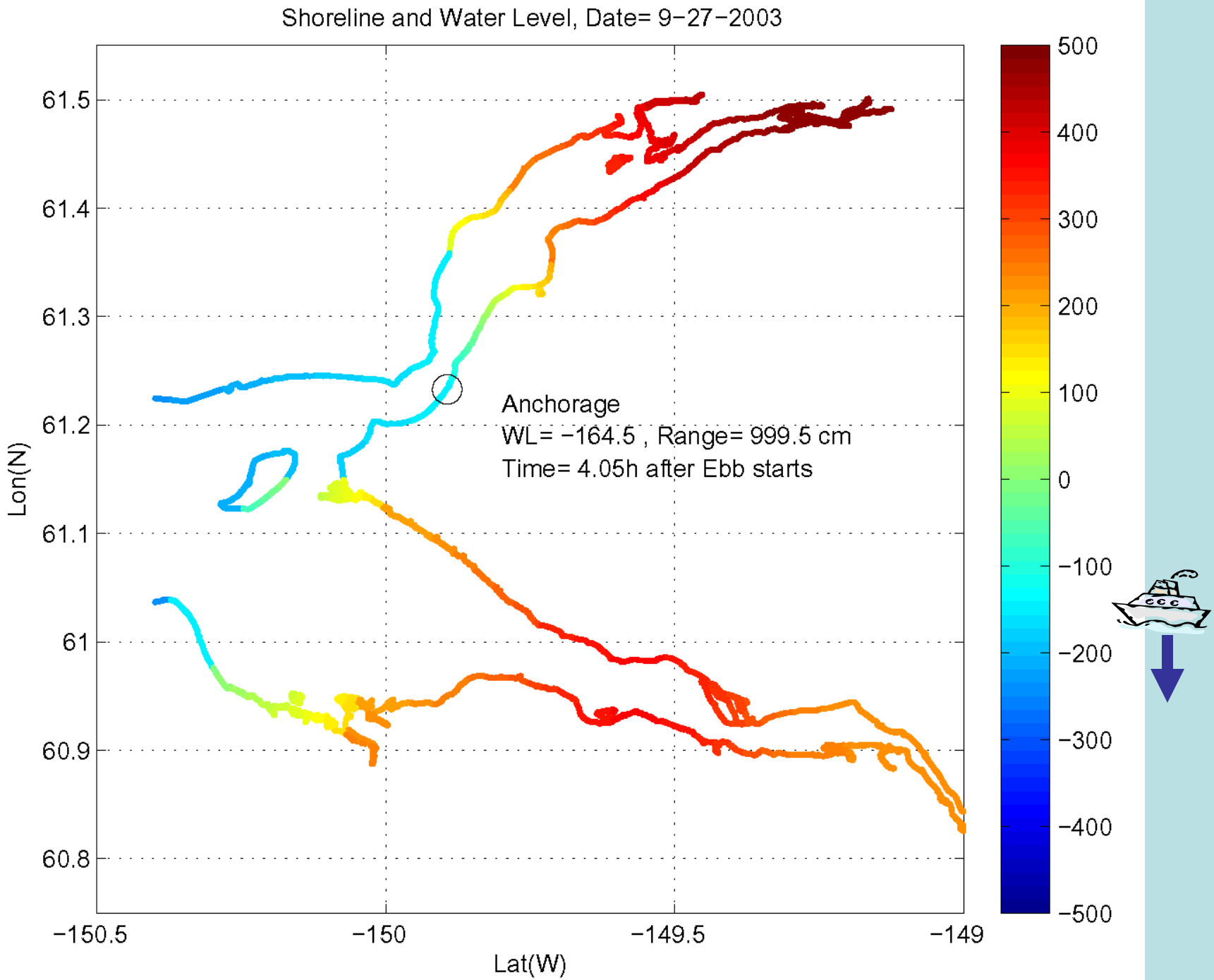
A, B, C = empirical parameters obtained from the statistics of the inundation model

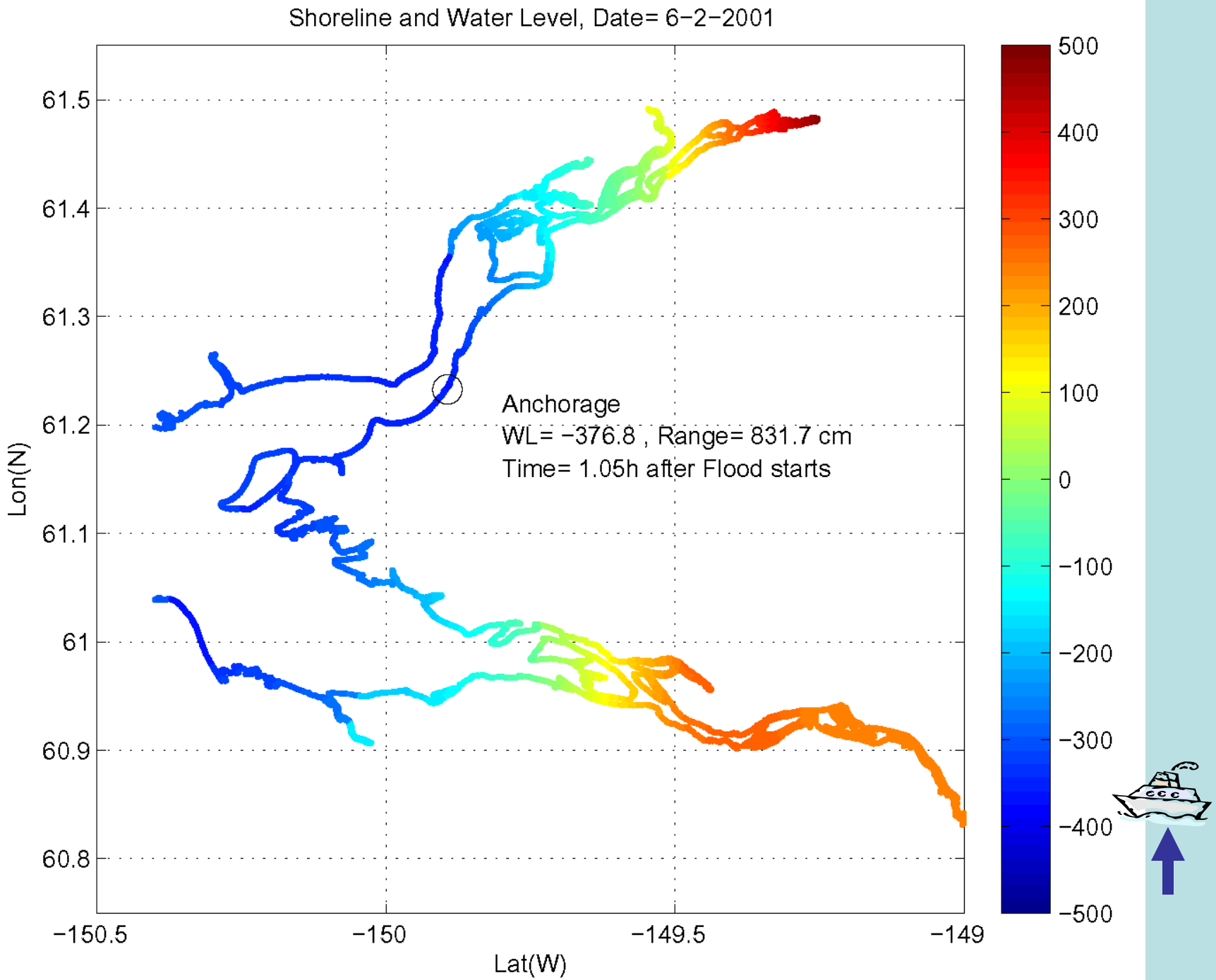


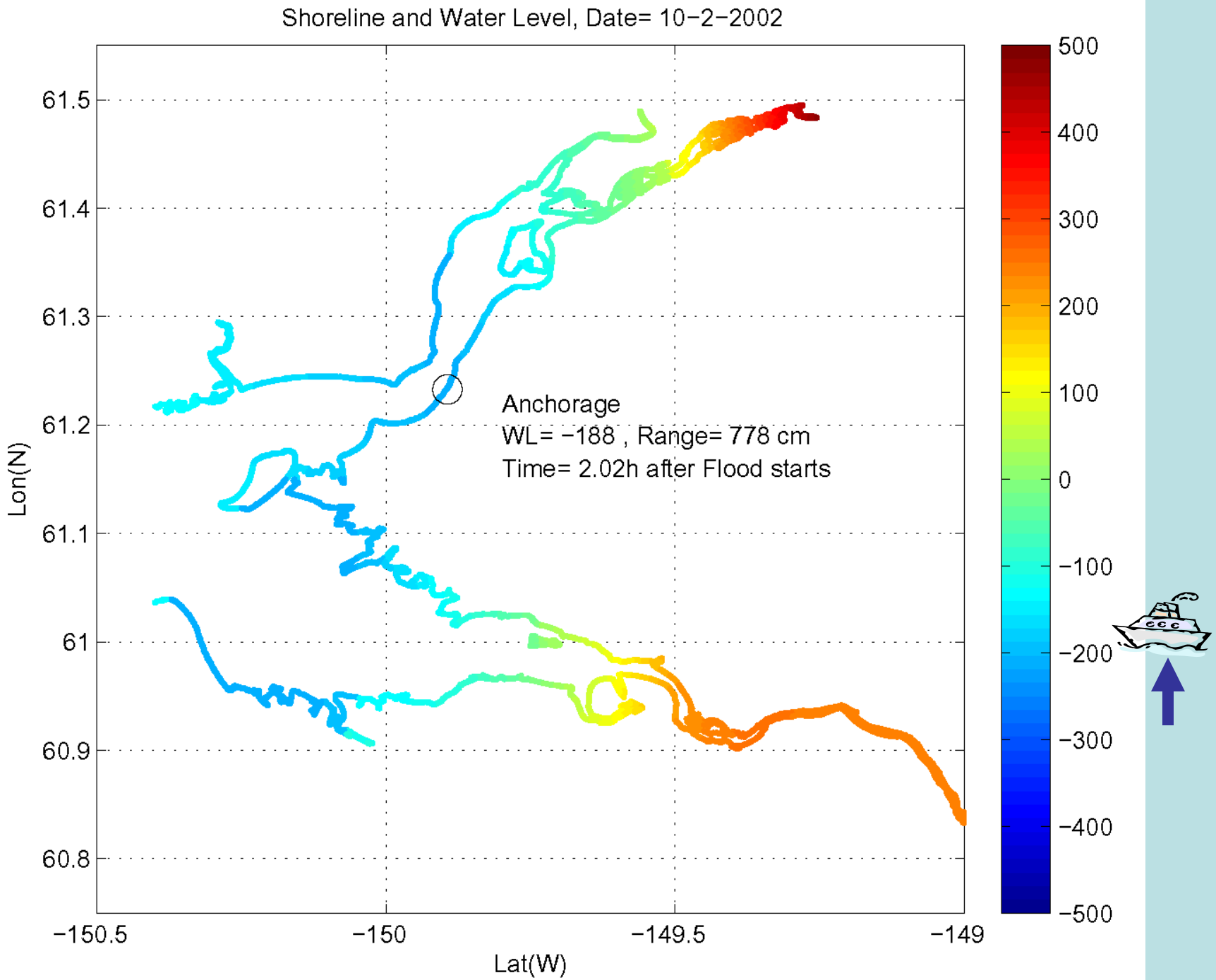

Shoreline and Water Level, Date= 3-11-2003
Anchorage
WL= 220.1 , Range= 592 cm
Time= 0.13h after Ebb starts
Lon(N)
Lat(W)
61.5
61.4
61.3
61.2
61.1
61
60.9
60.8
−150.5
−150
−149.5
−149
500
400
300
200
100
0
−100
−200
−300
−400
−500

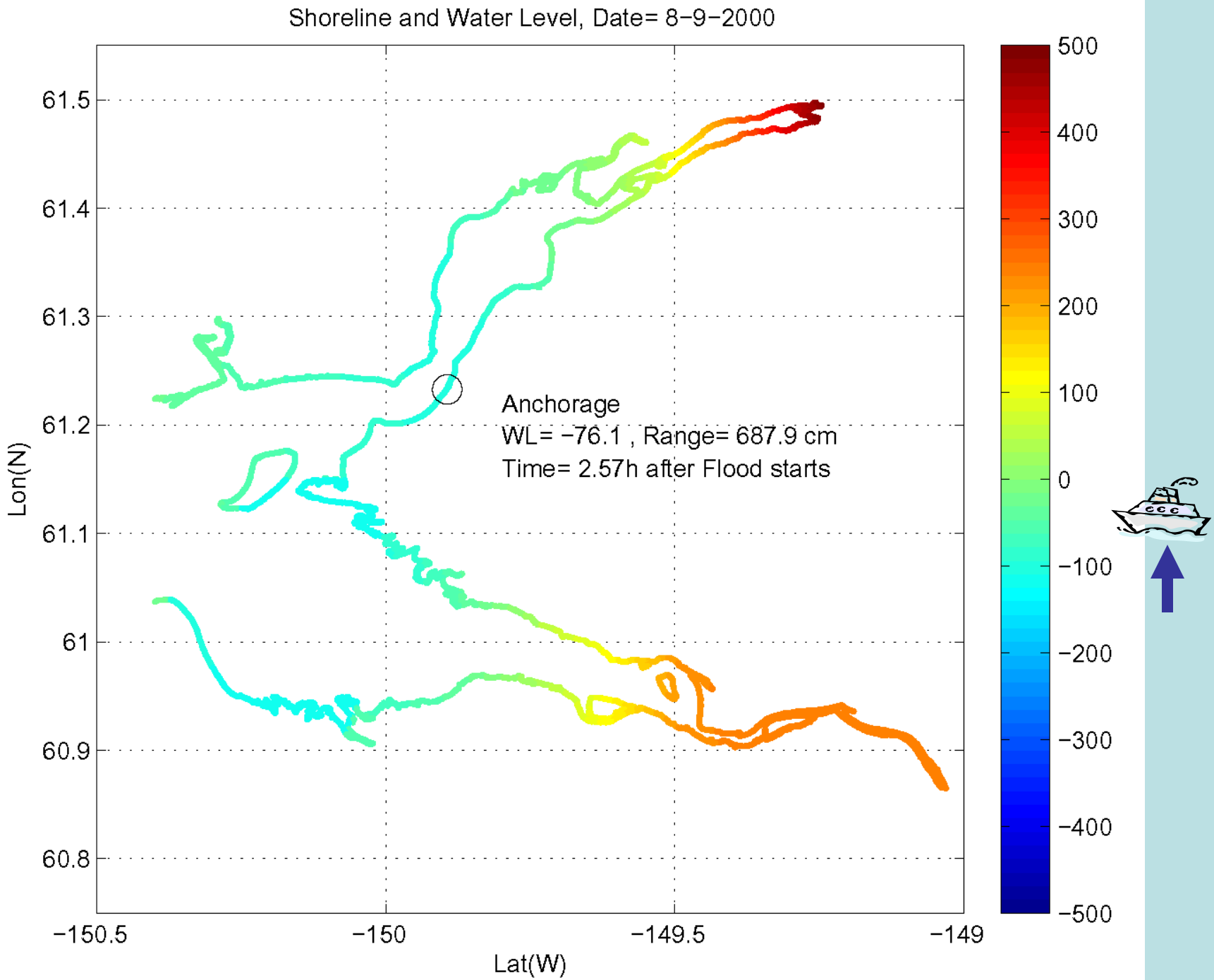

Shoreline and Water Level, Date= 6-25-2001
Anchorage
WL= 123.7 , Range= 1018.2 cm
Time= 2.43h after Ebb starts
Lon(N)
Lat(W)
61.5
61.4
61.3
61.2
61.1
61
60.9
60.8
−150.5
−150
−149.5
−149
500
400
300
200
100
0
−100
−200
−300
−400
−500

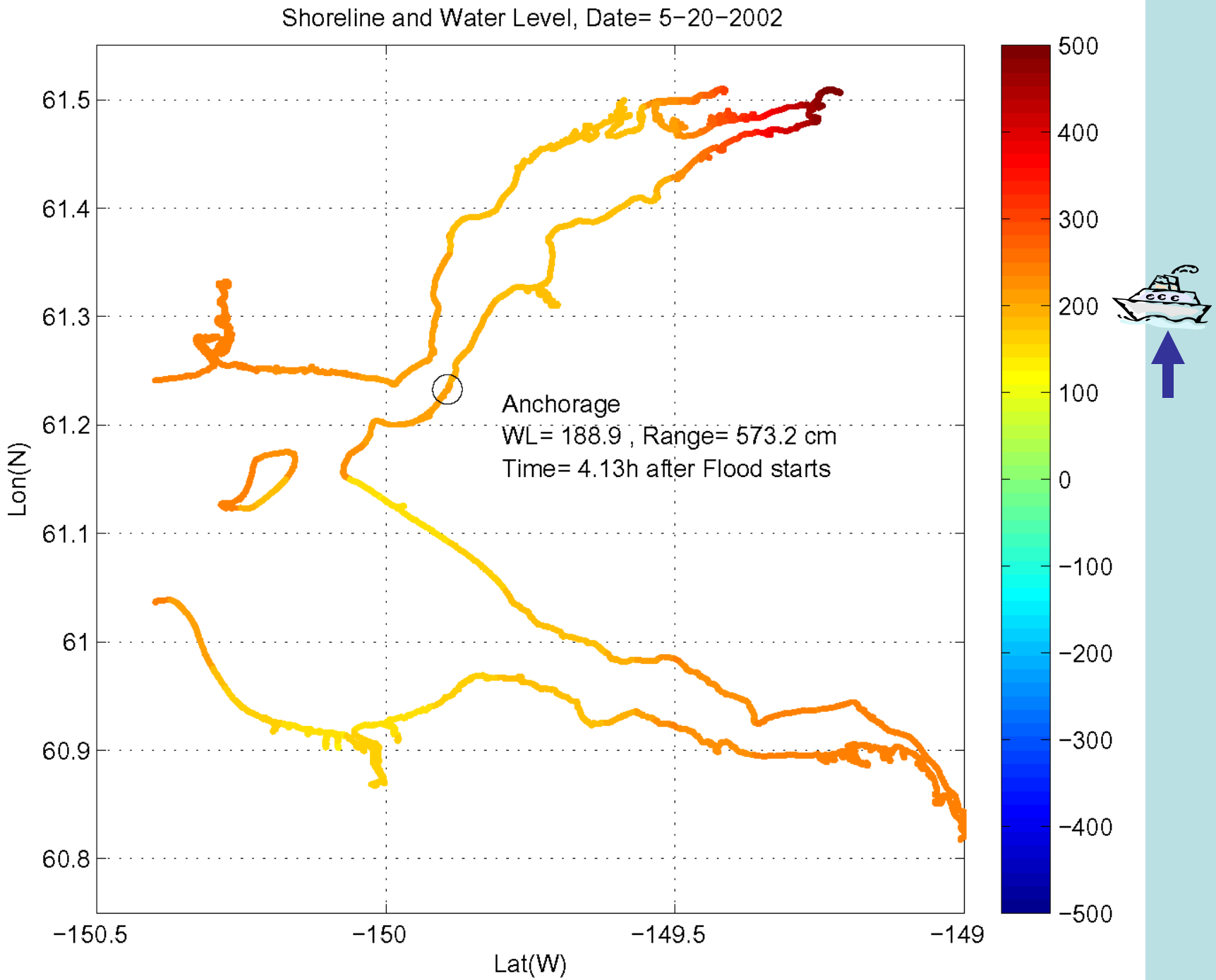

Shoreline and Water Level, Date= 6-9-2001
Anchorage
WL= 48 , Range= 924.4 cm
Time= 3.35h after Ebb starts
Lon(N)
Lat(W)
61.5
61.4
61.3
61.2
61.1
61
60.9
60.8
−150.5
−150
−149.5
−149
500
400
300
200
100
0
−100
−200
−300
−400
−500

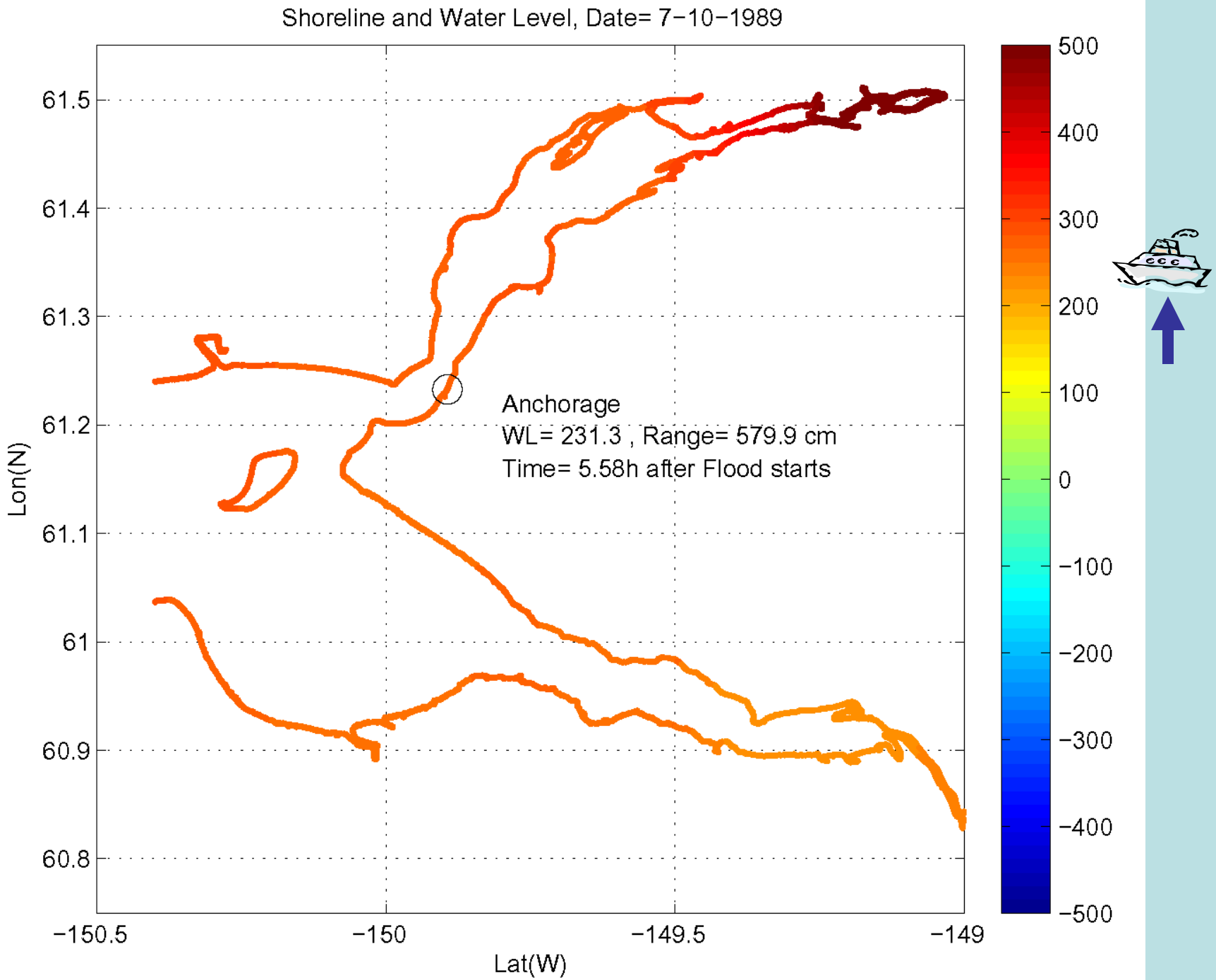

Shoreline and Water Level, Date= 9−27−2003
Anchorage
WL= −164.5 , Range= 999.5 cm
Time= 4.05h after Ebb starts
Lon(N)
Lat(W)
61.5
61.4
61.3
61.2
61.1
61
60.9
60.8
−150.5
−150
−149.5
−149
500
400
300
200
100
0
−100
−200
−300
−400
−500


Shoreline and Water Level, Date= 6−2−2001
Anchorage
WL= −376.8 , Range= 831.7 cm
Time= 1.05h after Flood starts
Lon(N)
Lat(W)
61.5
61.4
61.3
61.2
61.1
61
60.9
60.8
−150.5
−150
−149.5
−149
500
400
300
200
100
0
−100
−200
−300
−400
−500

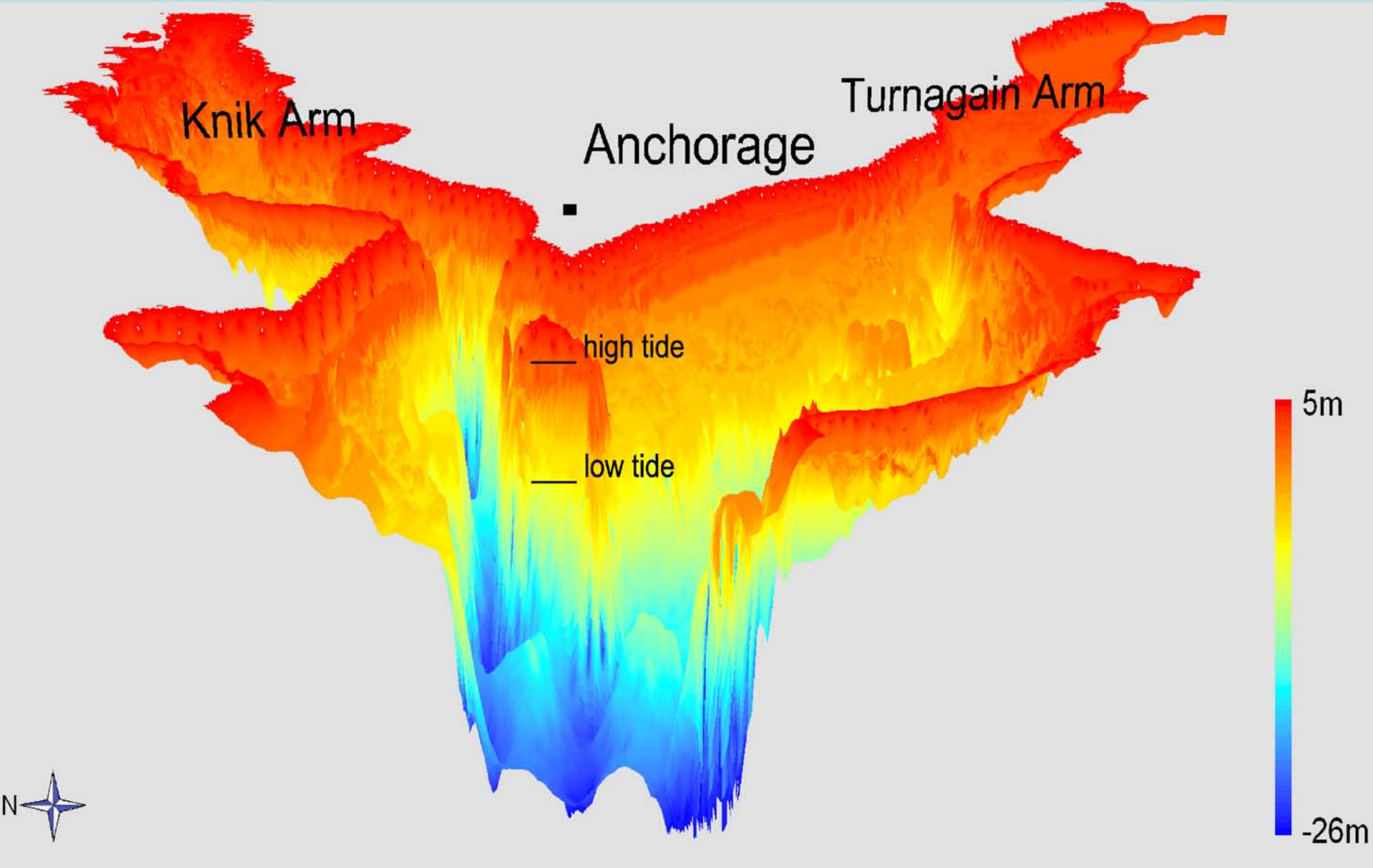

Shoreline and Water Level, Date= 10−2−2002
Anchorage
WL= −188 , Range= 778 cm
Time= 2.02h after Flood starts
Lon(N)
Lat(W)
61.5
61.4
61.3
61.2
61.1
61
60.9
60.8
−150.5
−150
−149.5
−149
500
400
300
200
100
0
−100
−200
−300
−400
−500


Shoreline and Water Level, Date= 8-9-2000
Anchorage
WL= -76.1 , Range= 687.9 cm
Time= 2.57h after Flood starts
Lon(N)
Lat(W)
61.5
61.4
61.3
61.2
61.1
61
60.9
60.8
-150.5
-150
-149.5
-149
500
400
300
200
100
0
-100
-200
-300
-400
-500


Shoreline and Water Level, Date= 5−20−2002
Anchorage
WL= 188.9 , Range= 573.2 cm
Time= 4.13h after Flood starts
Lon(N)
Lat(W)
61.5
61.4
61.3
61.2
61.1
61
60.9
60.8
−150.5
−150
−149.5
−149
500
400
300
200
100
0
−100
−200
−300
−400
−500

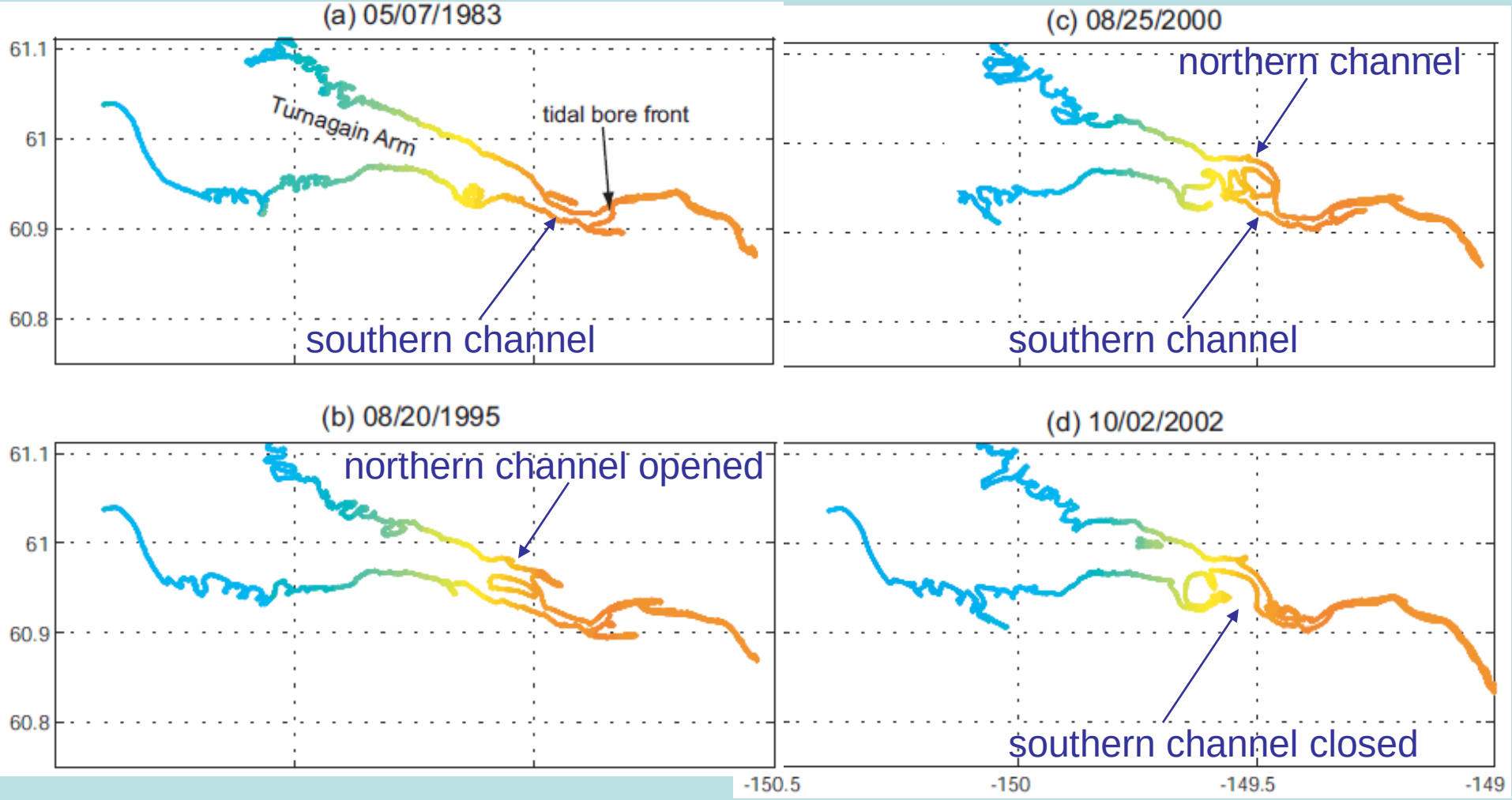

Shoreline and Water Level, Date= 7−10−1989
Anchorage
WL= 231.3 , Range= 579.9 cm
Time= 5.58h after Flood starts
Lon(N)
Lat(W)
61.5
61.4
61.3
61.2
61.1
61
60.9
60.8
−150.5
−150
−149.5
−149
500
400
300
200
100
0
−100
−200
−300
−400
−500

3D CI topography derived from combining ~25 satellite images for inundated regions with model topography for deep regions



Observing long-term morphological changes in the mudflats

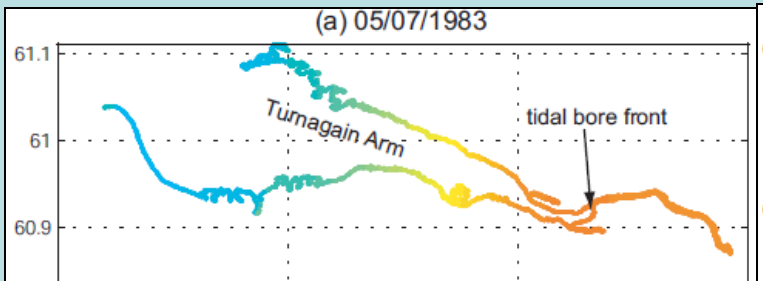
(all images taken ~2h after flood started in Anchorage)

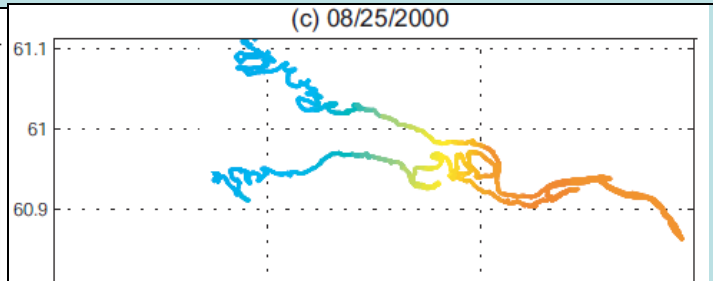


Do beluga whale stranding events relate to unexpected morphology changes?

We are working with NOAA/Fisheries to use our remote sensing data to study this possibility and possibly identify “danger” zones of rapid changes.

Same water level but different morphology





Satellite tag on a Cook Inlet beluga whale

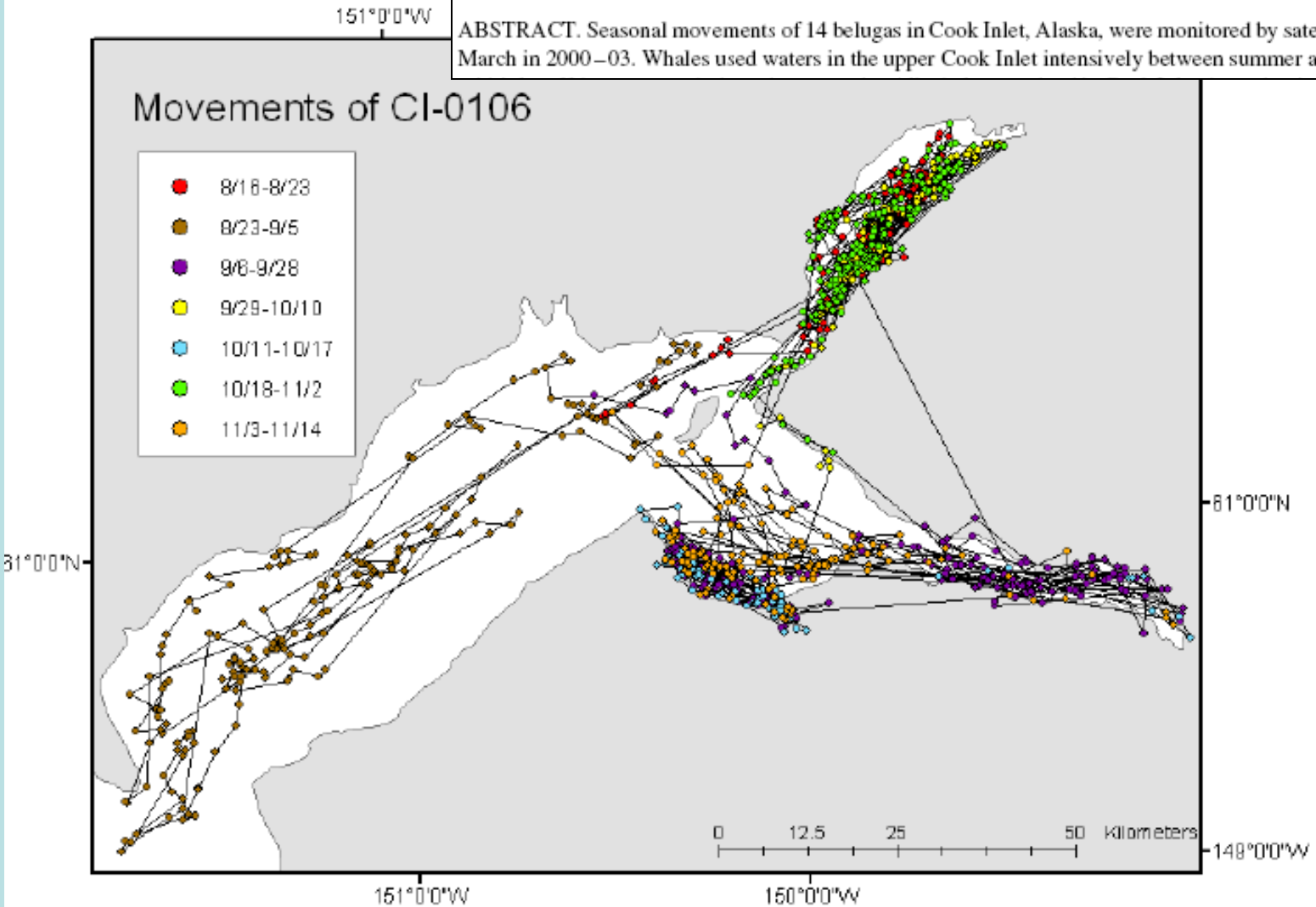
ARCTIC
VOL. 58, NO. 4 (DECEMBER 2005) P. 331–340

Movements and Area Use of Belugas, *Delphinapterus leucas*, in a Subarctic Alaskan Estuary

R.C. HOBBS,[1] K.L. LAIDRE,[2] D.J. VOS,[3] B.A. MAHONEY[3] and M. EAGLETON[3]

(*Received 8 November 2004; accepted in revised form 30 March 2005*)

ABSTRACT. Seasonal movements of 14 belugas in Cook Inlet, Alaska, were monitored by satellite telemetry between July and March in 2000–03. Whales used waters in the upper Cook Inlet intensively between summer and late autumn and dispersed to



Can we use the inundation model to study the beluga movements?

Ezer, Hobbs & Oey, Oceanography, Vol. 21, No. 4, December, 2008

BY TAL EZER, RODERICK HOBBS, AND LIE-YAUW OEY

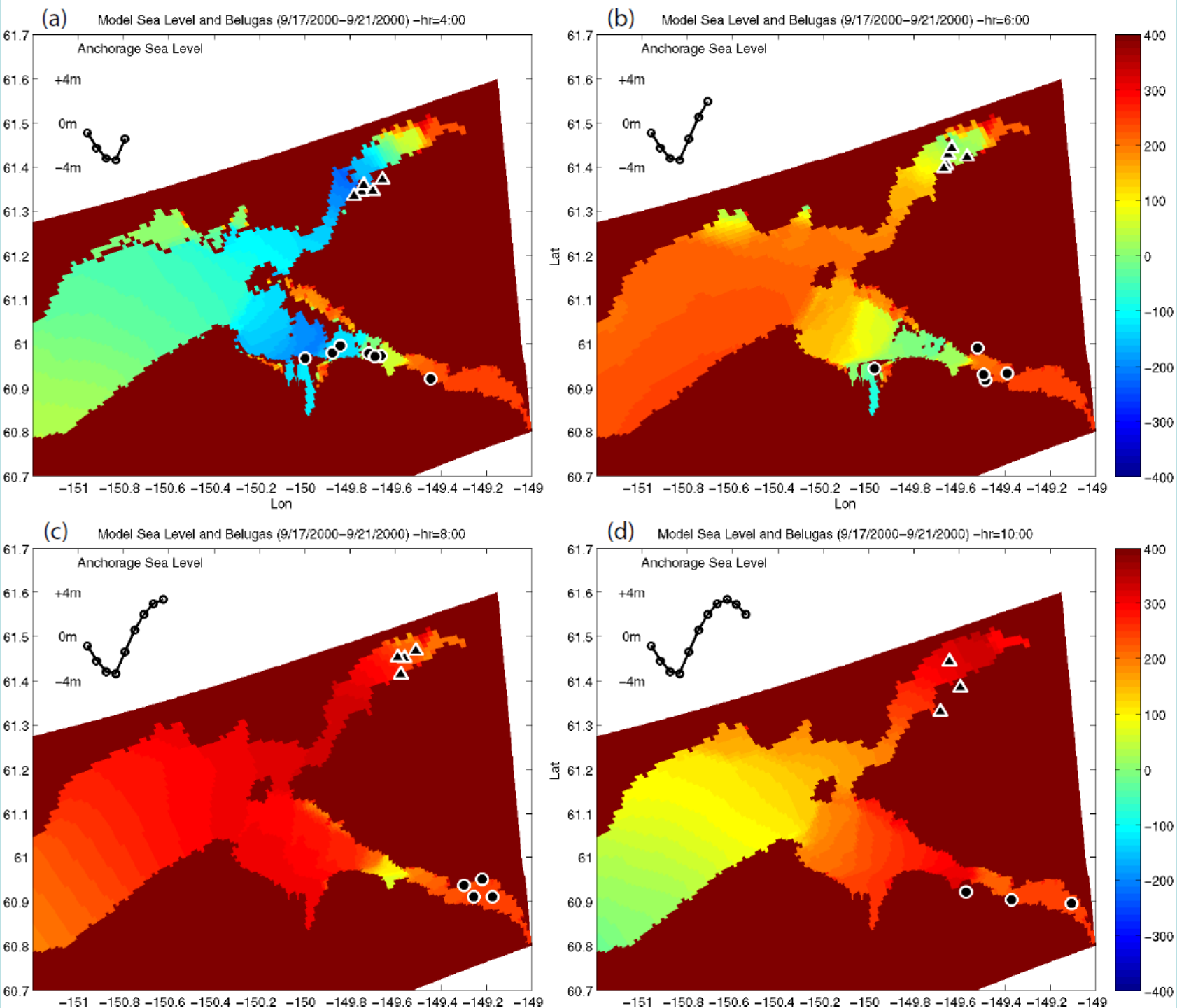
ON THE Movement OF Beluga Whales IN COOK INLET, ALASKA

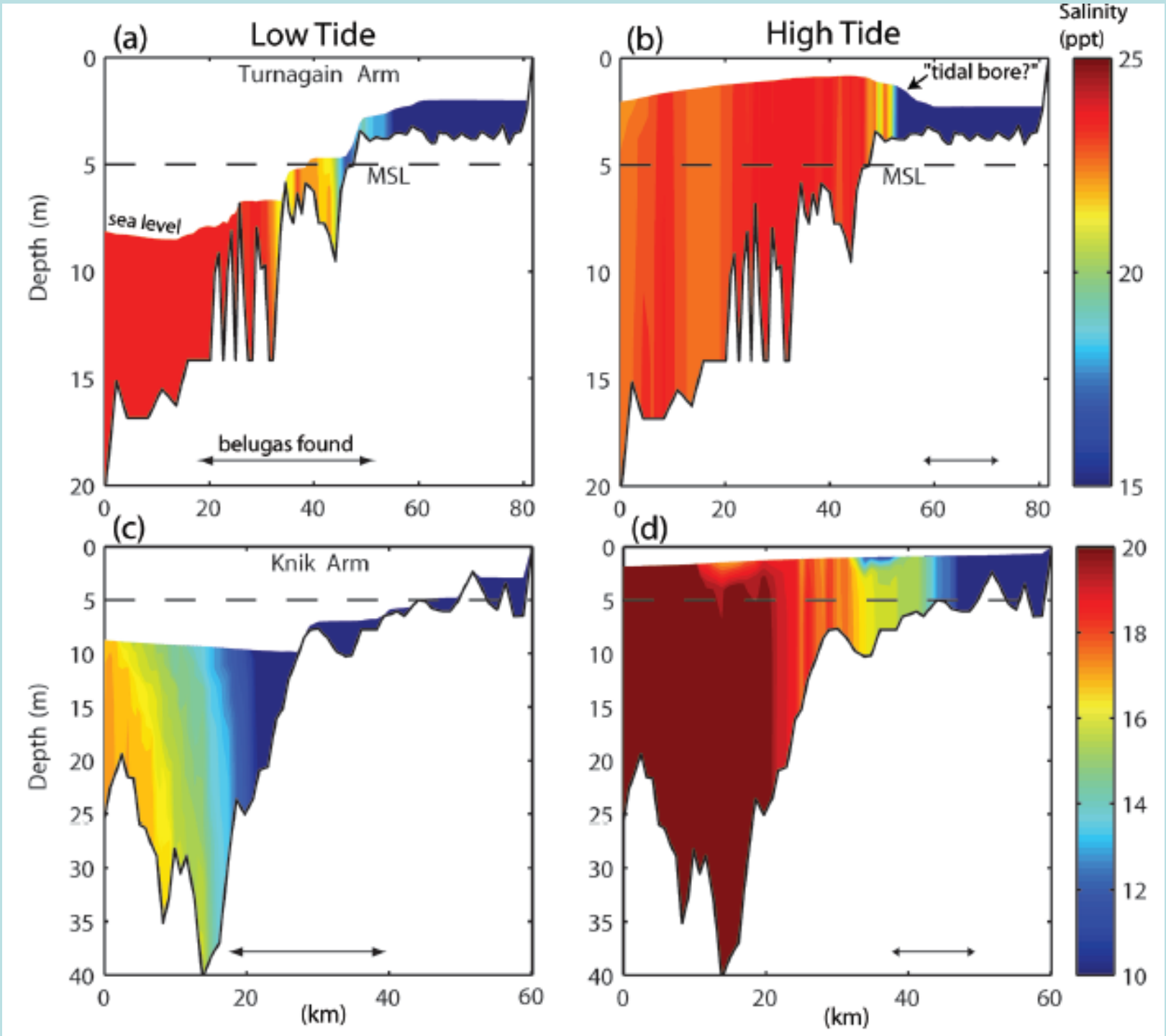
Simulations of Tidal and Environmental Impacts Using a Hydrodynamic Inundation Model

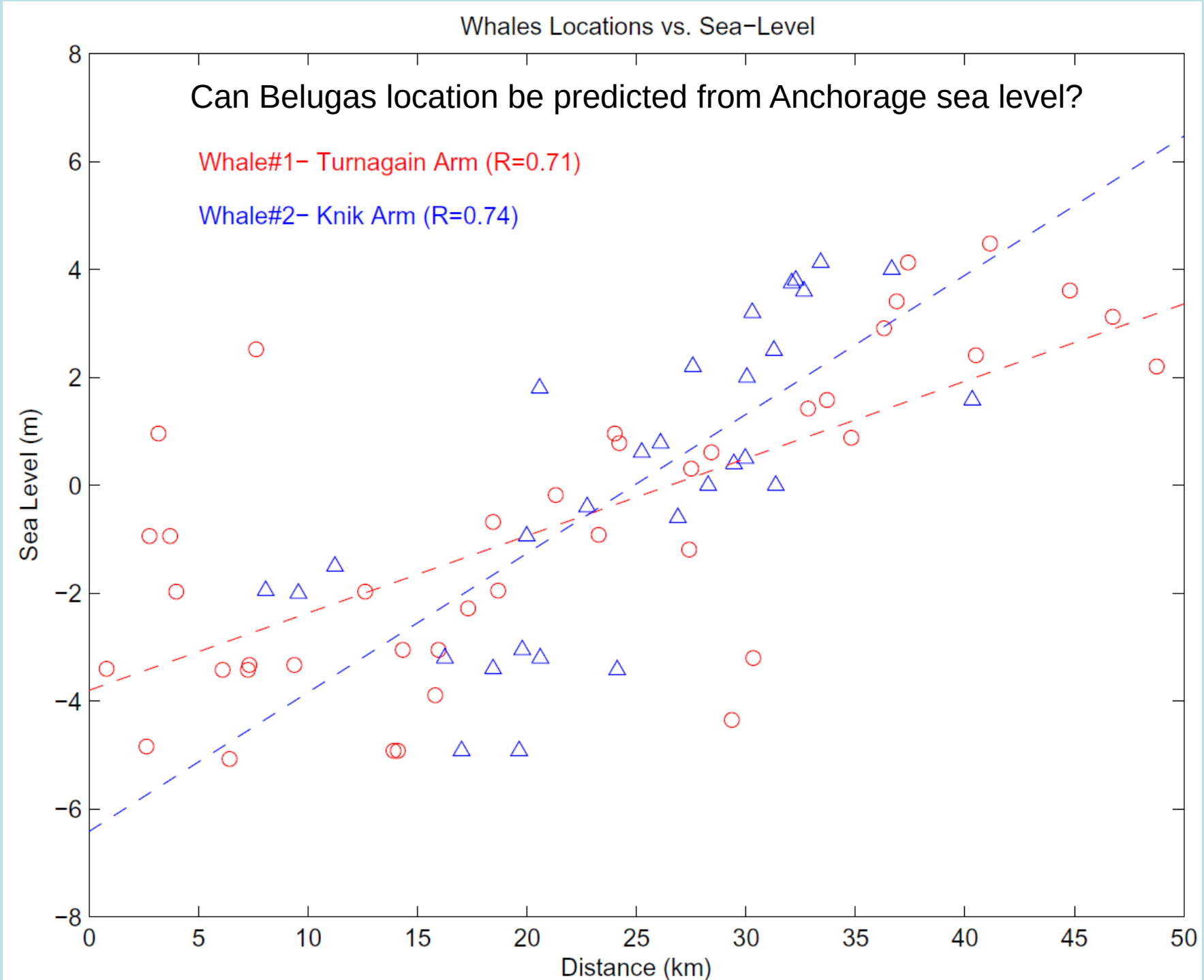
Among aerial and close-up views of Cook's Inlet belugas, a group of researchers gently restrains a whale for tagging. *Inset photos courtesy of NOAA's National Marine Mammal Laboratory*

ABSTRACT. The population of beluga whalesin Cook Inlet, Alaska, is in decline, and since 2000 these whales have been under consideration for designation as "endangered" under the Endangered Species Act (and were placed on the list in October 2008, just before this article went to press). In order to study environmental and hydrodynamic impacts on the belugas' movements and survival in the unique habitat of the inlet, a three-dimensional ocean circula tion and inundation model is combined with satellite-tracked beluga whale data. Model-whale data comparisons from two whale paths during a five-day period (September 17–21, 2000) covering 10 tidal cycles suggest that daily movements of belugas in the upper Cook Inlet follow propagation of the tides. Both whales took advantage of the twice-daily flood of mudflats by the very large tides (8–10 m range) to swim toward river mouths in shallow regions that are inac cessible during low tide. A significant correlation was found between whale locations and the model sea level. In the Knik Arm, north of Anchorage, ebbing and flooding rates are predict able, and the tracked whale followed the water velocity in direction and speed. However, in the Turnagain Arm, south of Anchorage, where a large change in topography along the arm causes nonlinear flooding and ebbing (including strong tidal bore currents with speeds up to 5 m s^{-1}), the movement of the tracked whale was correlated only with the water level, not with the cur-rents. The encouraging results from this study demonstrate the usefulness of the numerical model to help understand the belugas' behavior and will be followed by a more detailed study using a larger tracking data set and longer simulations. Such a study will help to evaluate poten tial impacts of future changes such as shoreline development, which may change flood regions and the belugas' accessibility to their feeding areas.

Analyze movements of 2 whales during 10 tidal cycles


(a)
Model Sea Level and Belugas (9/17/2000–9/21/2000) –hr=4:00
(b)
Model Sea Level and Belugas (9/17/2000–9/21/2000) –hr=6:00
(c)
Model Sea Level and Belugas (9/17/2000–9/21/2000) –hr=8:00
(d)
Model Sea Level and Belugas (9/17/2000–9/21/2000) –hr=10:00
Anchorage Sea Level
+4m
0m
–4m
Lat
Lon
61.7
61.6
61.5
61.4
61.3
61.2
61.1
61
60.9
60.8
60.7
–151
–150.8
–150.6
–150.4
–150.2
–150
–149.8
–149.6
–149.4
–149.2
–149
400
300
200
100
0
–100
–200
–300
–400

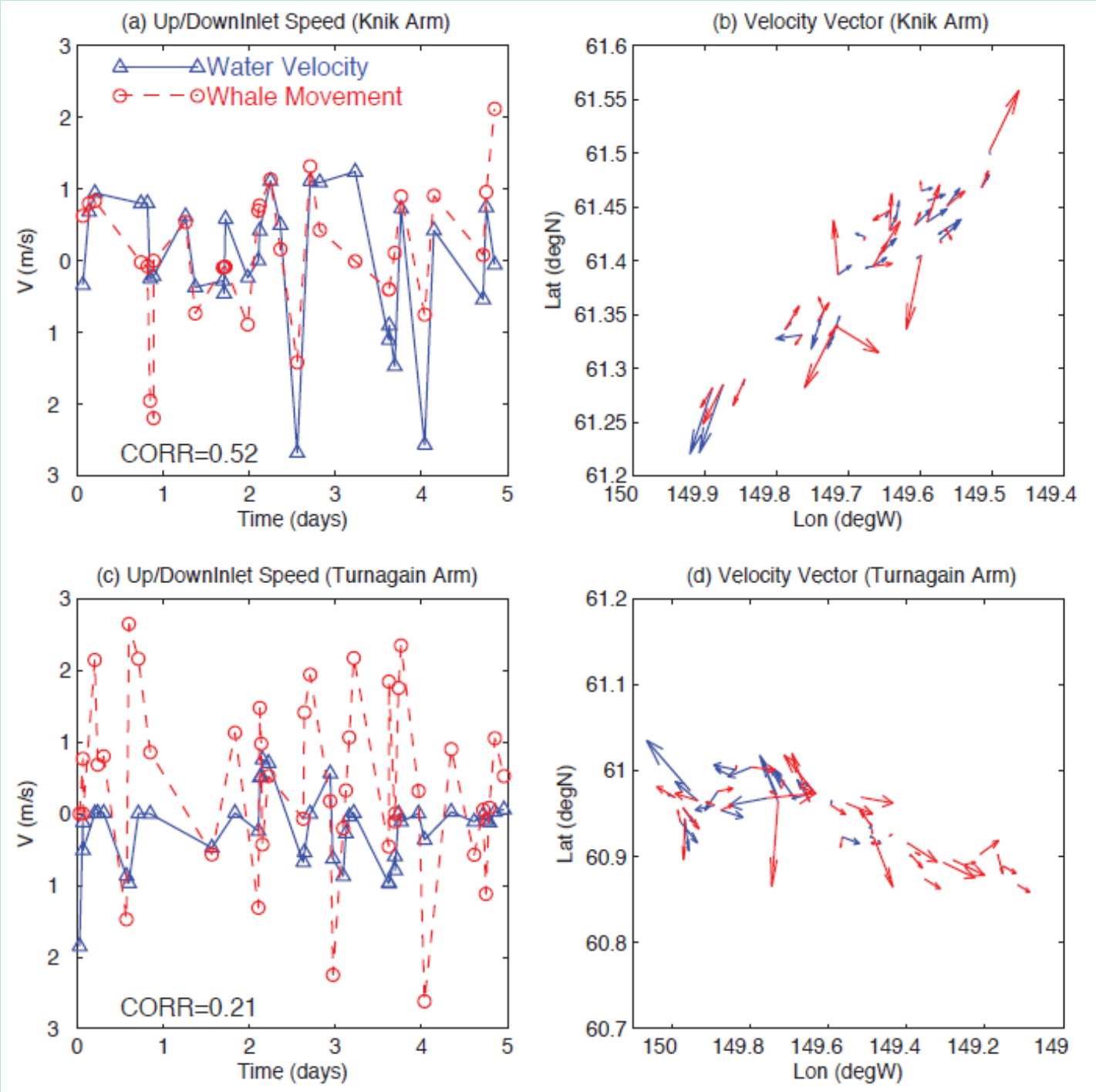

(a)
Low Tide
Turnagain Arm
MSL
sea level
belugas found
Depth (m)
(b)
High Tide
"tidal bore?"
MSL
Salinity (ppt)
(c)
Knik Arm
Depth (m)
(km)
(d)
(km)


Whales Locations vs. Sea−Level
Can Belugas location be predicted from Anchorage sea level?
Whale#1− Turnagain Arm (R=0.71)
Whale#2− Knik Arm (R=0.74)
Sea Level (m)
Distance (km)
8
6
4
2
0
−2
−4
−6
−8
0
5
10
15
20
25
30
35
40
45
50

In Knik Arm: the whale movement was correlated with the tidal currents

But

In Turnagain Arm: the whale motion was not correlated with the tidal currents (only with water level)

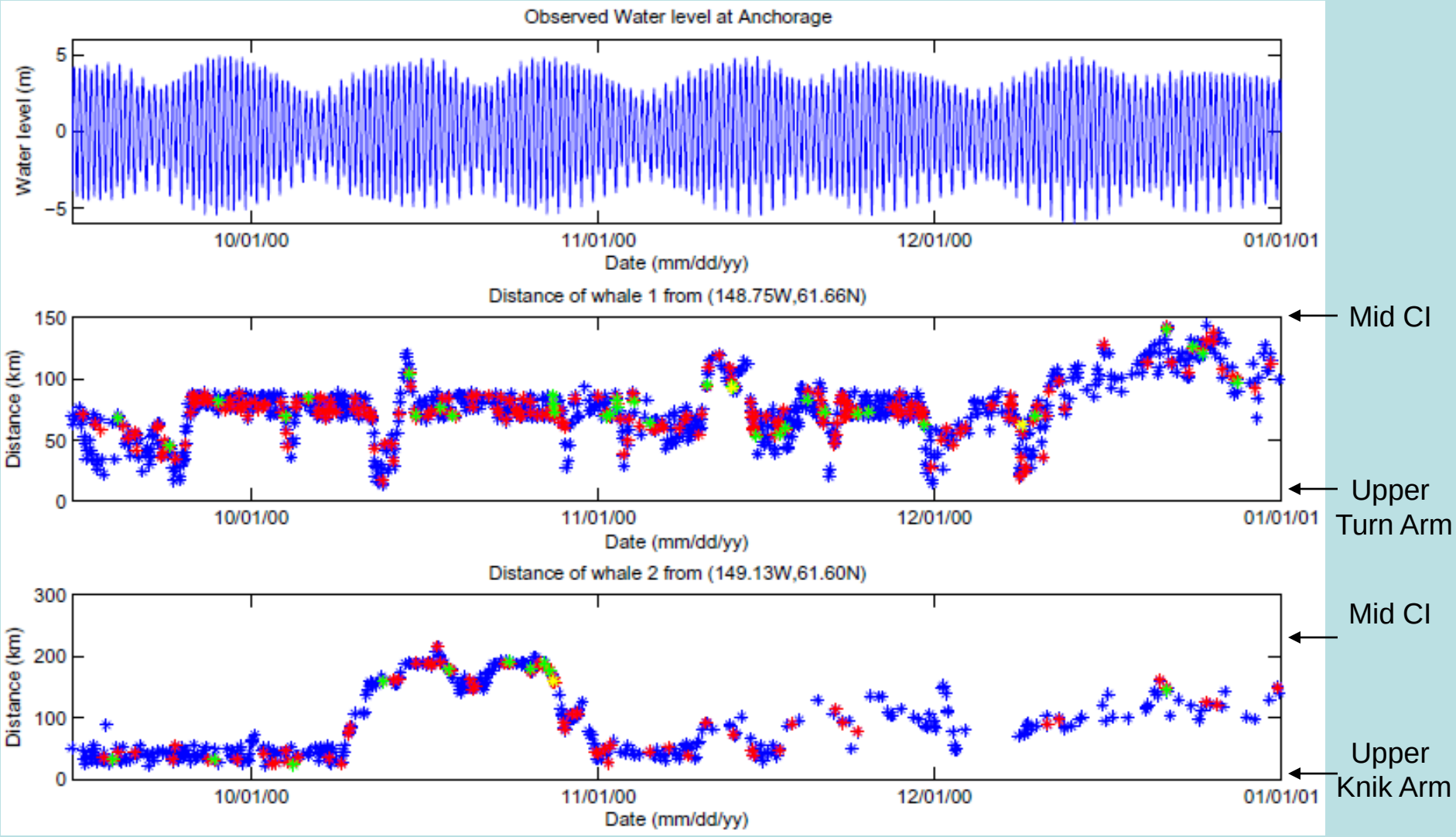


Beluga movements
over 4 months
(Sep-Dec, 2000)

Whale1.
avi

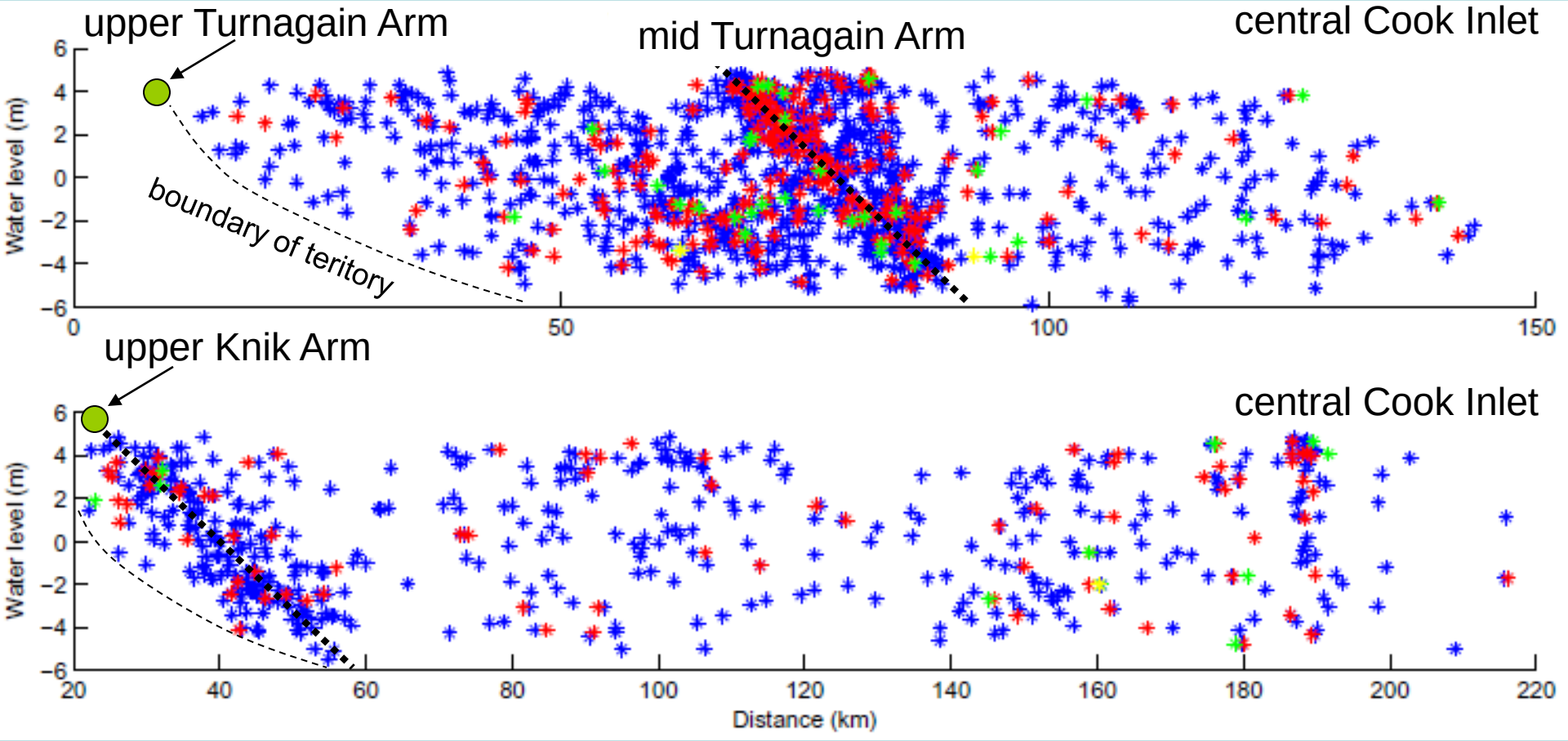
Whale2.
avi

- Over a longer period of time (3.5 mon) whale movements more complex
- Behavior in Knik Arm and Turnagain Arm still different



times whale tracked: * 1st /hr , * 2nd /hr, * 3rd /hr

Correlation between whale location and water level still exists, but other environmental factors may also affect their motion



3.5 months of whale data (Sep-Dec 2000)

Future Work:

- Analyze longer tracking data of the belugas (1999:1 whale; 2000: 2 whales; 2001: 7 whales; 2002: 8 whales)
- Study seasonal and interannual patterns
- Study environmental impacts on the beluga habitat (tides, fronts, sea-ice, etc.)
- Study stranding events and how they may relate to changing topography/water levels, etc.

Thank You