Monitoring tidal movements in Cook Inlet, Alaska, using the integration of remote sensing data, GIS, and inundation models

Hua Liu
Department of political Science and Geography
Old Dominion University (ODU), Norfolk, Virginia, USA

Tal Ezer
Center for Coastal Physical Oceanography (CCPO)
& Virginia Modeling, Analysis & Simulation Center (VMASC)
Old Dominion University (ODU), Norfolk, Virginia, USA

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MMS (model development)
NOAA/Fisheries (Belugas studies)
ODU Office of Research (remote sensing)

Objective

- To investigate and map the tidal movements and associated changing water coverage over extensive mudflats, based on the integration of satellite remote sensing data, geographic information systems (GIS), and inundation models.

Significance

- The results will
  - Allow the mapping of the topography of flood zones, and
  - Improve inundation models that are used to simulate catastrophic floods such as those associated with hurricane storm surges and tsunamis

Methodology

- Study area.
- Remote sensing data processing.
- Water level prediction.

Cook Inlet: Subarctic Estuary

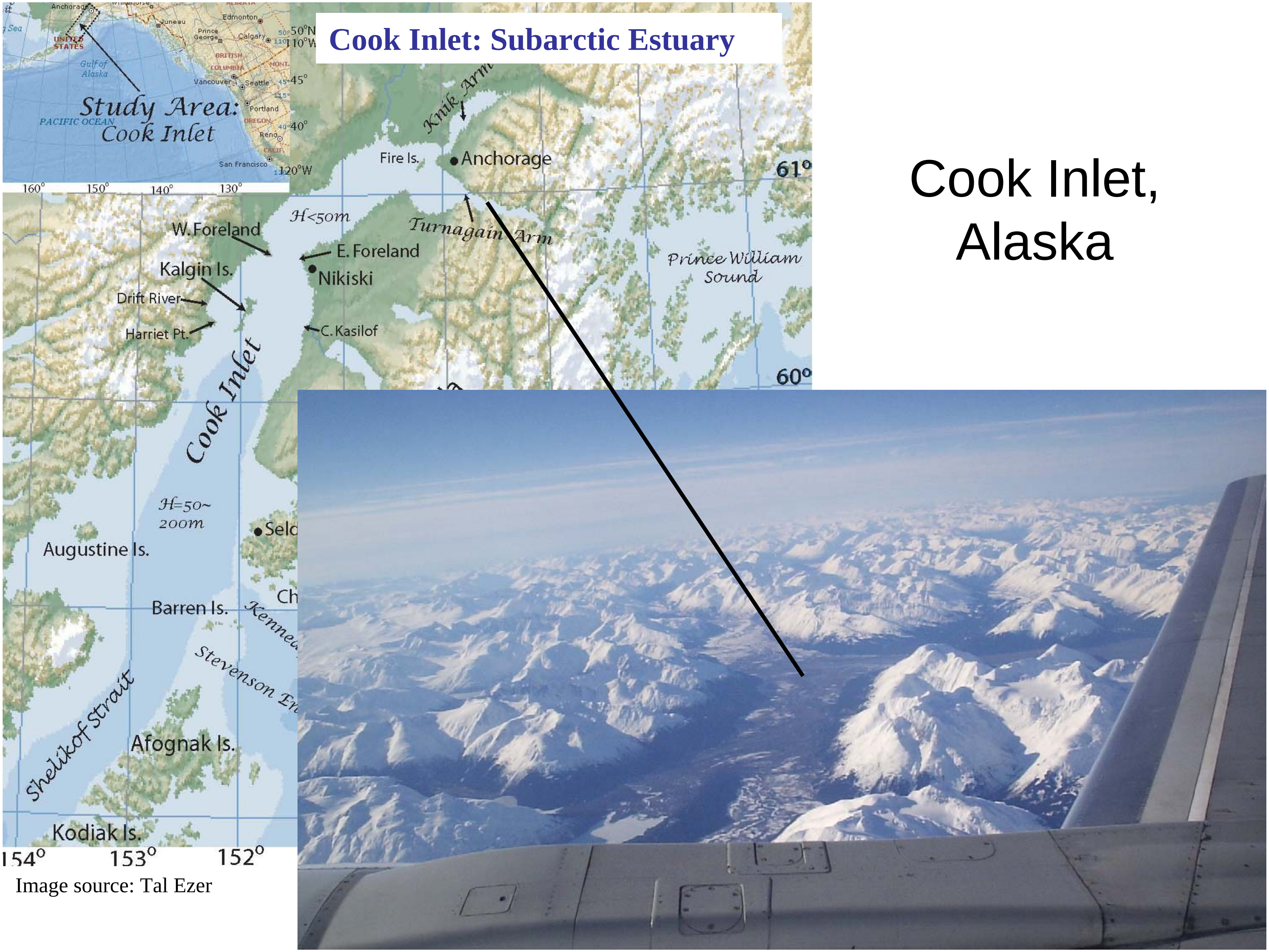


Image source: Tal Ezer

Cook Inlet, Alaska

Cook Inlet, Alaska

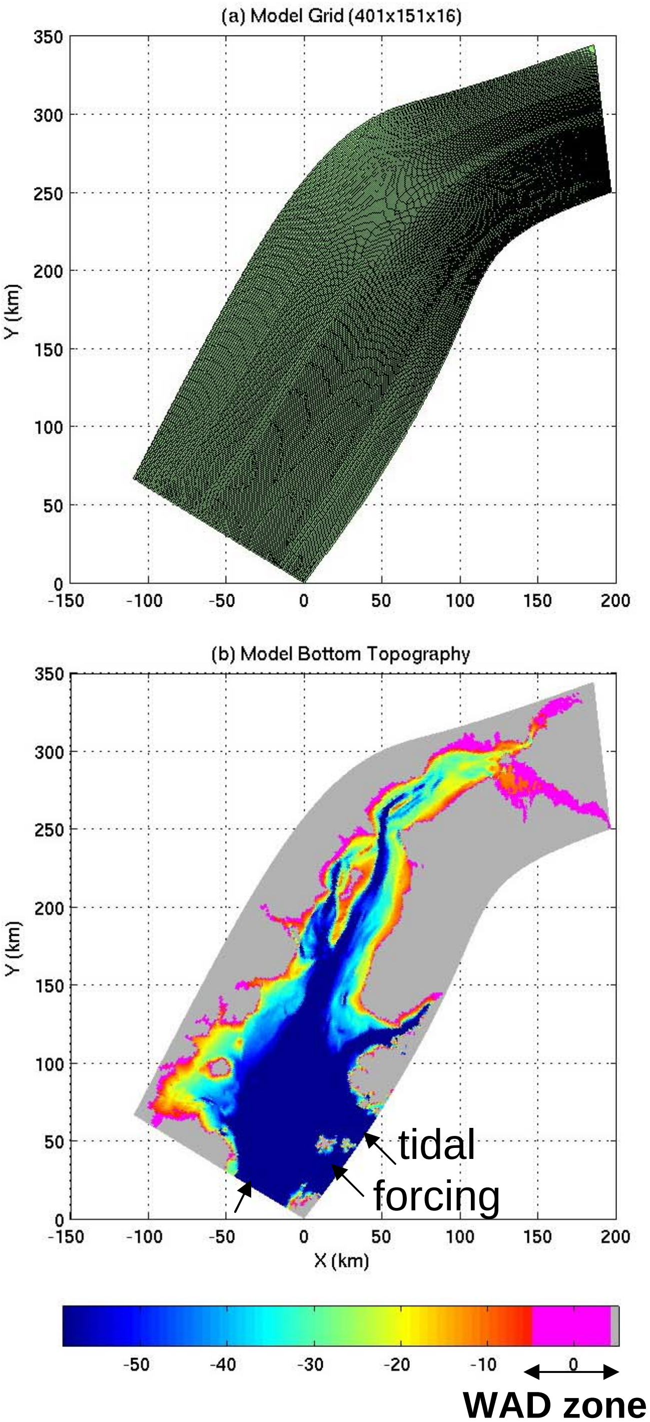
- Stretches 290 km from the Gulf of Alaska to the City of Anchorage.
- Receives water from its tributaries: Susitna River, Knik River & other streams.
- Contains active volcanoes.
- Large semi-diurnal tides (8-10 m range)
- 100s of square kilometers of mudflats are flooded twice daily (mostly M2 tide).

Photo of flood zone in upper Cook Inlet, Alaska (Knik Arm) during low tide

Image source: Tal Ez

Mudflats in upper Cook Inlet (Turnagain Arm) during low tide

Upper Cook Inlet (Turnagain Arm) during high tide



POM-WAD Model (Oey, 2005, 2006)

(POM with Wetting And Drying):

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

Applications:

1. Processes: rip tides, tidal bores, etc.
2. Beluga whale movement
3. Remote sensing

Major Problems:

1. No reliable mudflat topography data
2. How to evaluate the model WAD?

Solution: Remote sensing

References

(http://www.ccpo.odu.edu/~tezer/Pub.html; http://aos.princeton.edu/WWWPUBLIC/PROFS/)

POM-WAD Inundation Model

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Cook Inlet Model

- Oey, L.-Y., T. Ezer, C. Hu and F. Muller-Karger, Baroclinic tidal flows and inundation processes in Cook Inlet, Alaska: Numerical modeling and satellite observations, *Ocean Dynamics*, 57, 205-221, doi:10.1007/s10236-007-0103-8, 2007.

Remote Sensing in CI

- Ezer, T. and H. Liu, Combining remote sensing data and inundation modeling to map tidal mudflat regions and improve flood predictions: A proof of concept demonstration in Cook Inlet, Alaska. *Geophys. Res. Let*., 36, L04605, doi:10.29/2008GL036873, 2009.
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Beluga Whales in CI

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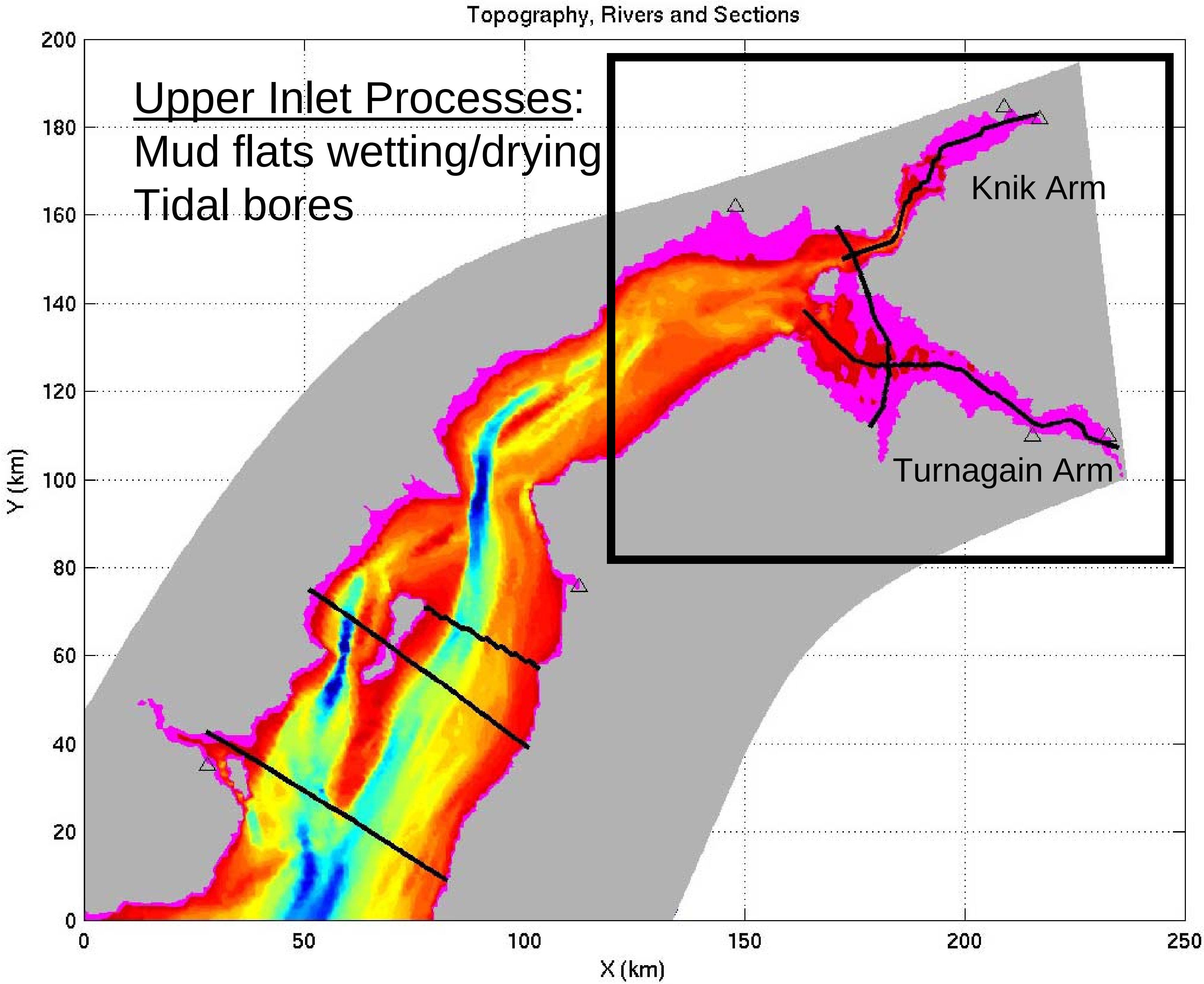
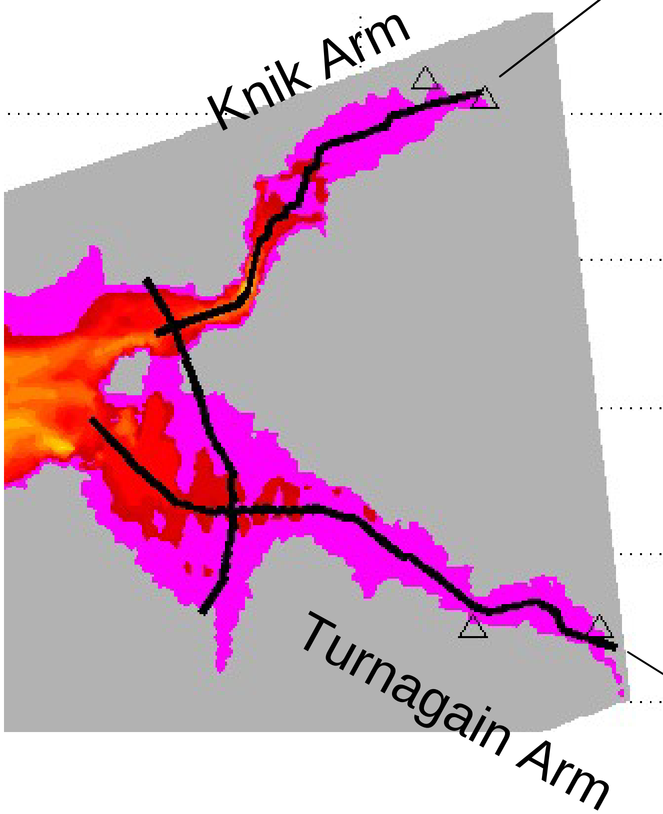
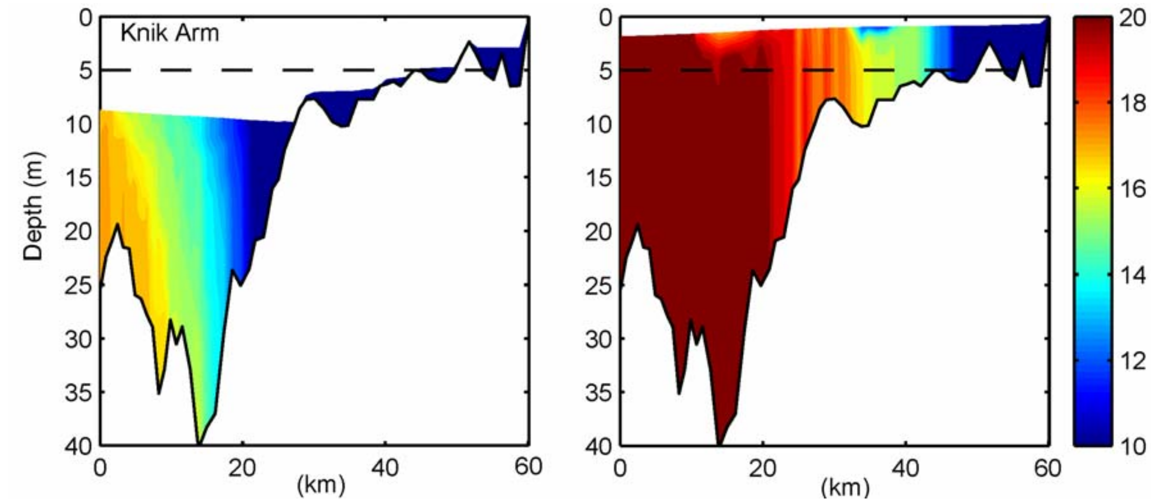

Topography, Rivers and Sections
Upper Inlet Processes:
Mud flats wetting/drying
Tidal bores
Knik Arm
Turnagain Arm
Y (km)
X (km)
200
180
160
140
120
100
80
60
40
20
0
0
50
100
150
200
250

The transition of the salinity front with the tides is very different in the two arms (implication for biol.?)



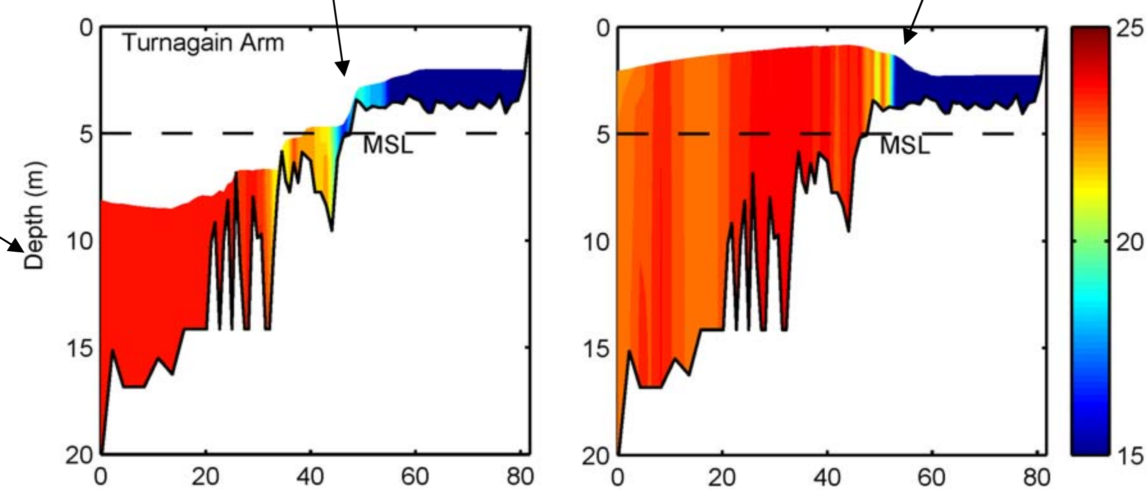


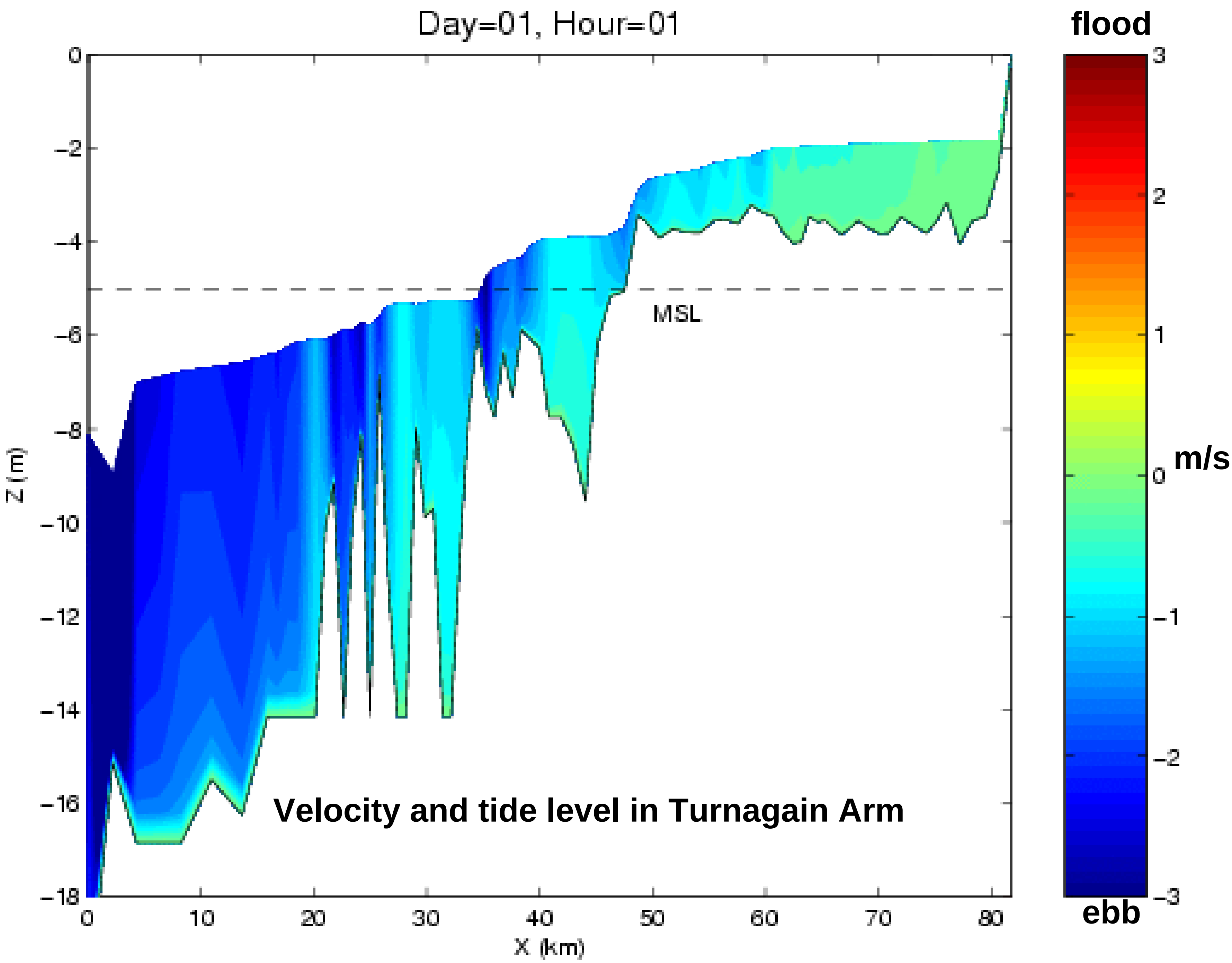
low tide

high tide

slow draining during ebb

tidal “bore”





Day=01, Hour=01
flood
ebb
m/s
MSL
Velocity and tide level in Turnagain Arm
Z (m)
X (km)
0
−2
−4
−6
−8
−10
−12
−14
−16
−18
0
10
20
30
40
50
60
70
80
3
2
1
0
−1
−2
−3

Ezer et al., Oceanography, Vol. 21, No. 4, December, 2008

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

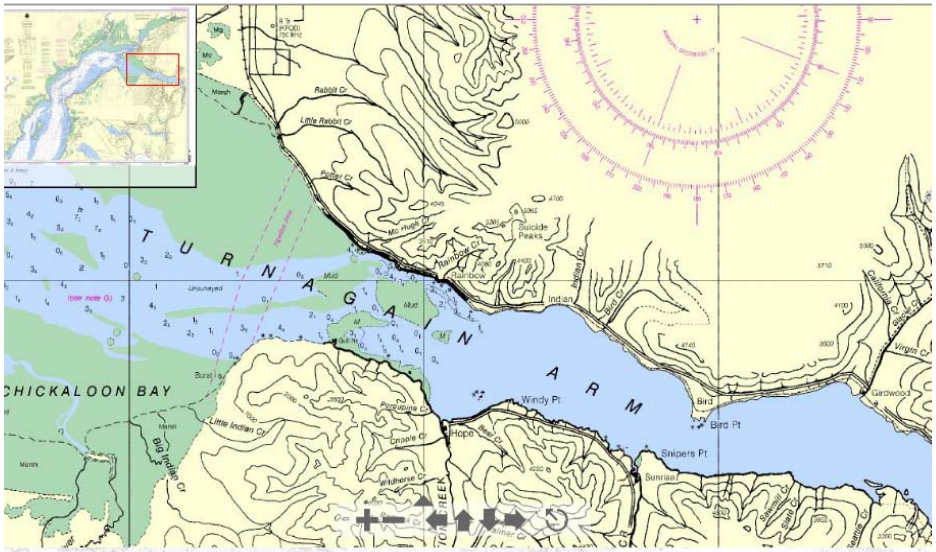
ON THE Movement OF Beluga Whales IN COOK INLET, ALASKA

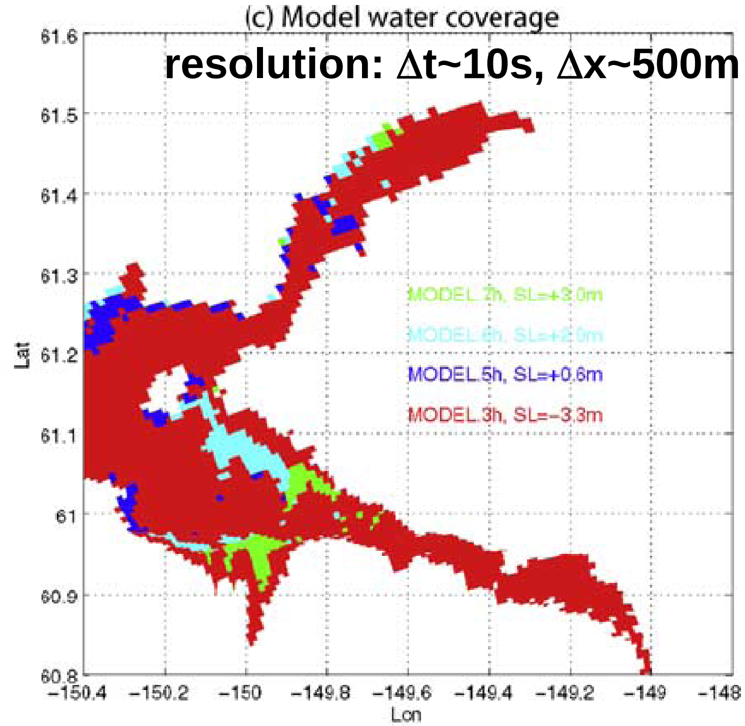
Simulations of Tidal and Environmental Impacts Using a Hydrodynamic Inundation Model

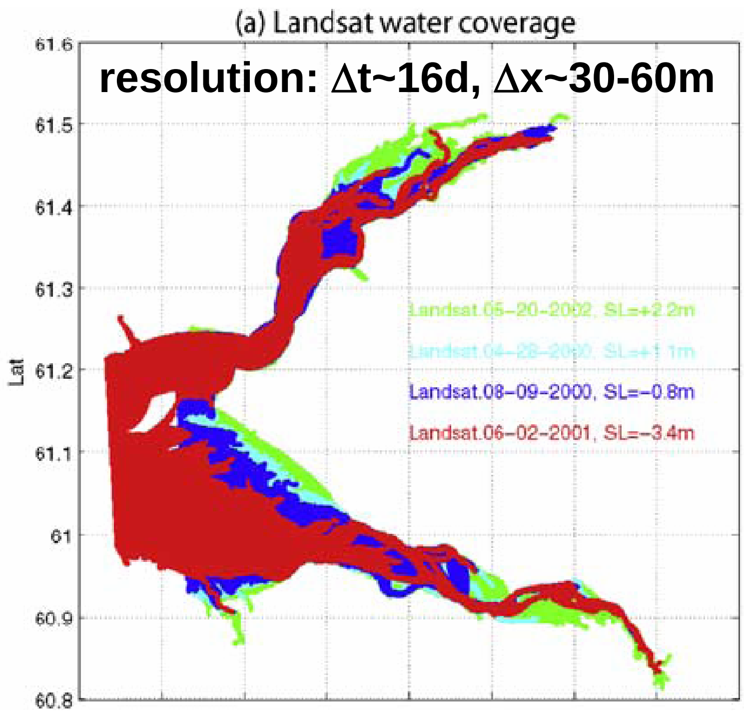
Among aerial and close-up views of Cook's Inlet belugas, a group of researchers gently restrains a whale for tagging. *Inset photos courtesy of NOAA's National Marine Mammal Laboratory*

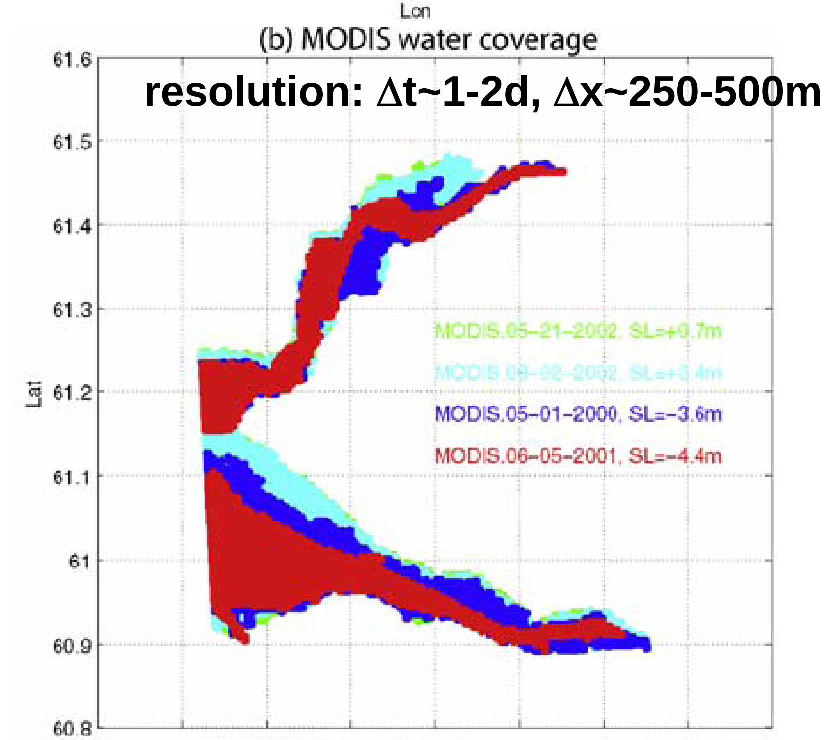
ABSTRACT. The population of beluga whalesin Cook Inlet, Alaska, is in decline, and since 2000 these whales have been under consideration for designation as "endangered" under the Endangered Species Act (and were placed on the list in October 2008, just before this article went to press). In order to study environmental and hydrodynamic impacts on the belugas' movements and survival in the unique habitat of the inlet, a three-dimensional ocean circulation 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 inaccessible 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 predictable, 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 currents. 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 potential impacts of future changes such as shoreline development, which may change flood regions and the belugas' accessibility to their feeding areas.

NOAA Navigation Charts: No topography data for mudflats or upper Turnagain Arm!









Remote Sensing Data Processing

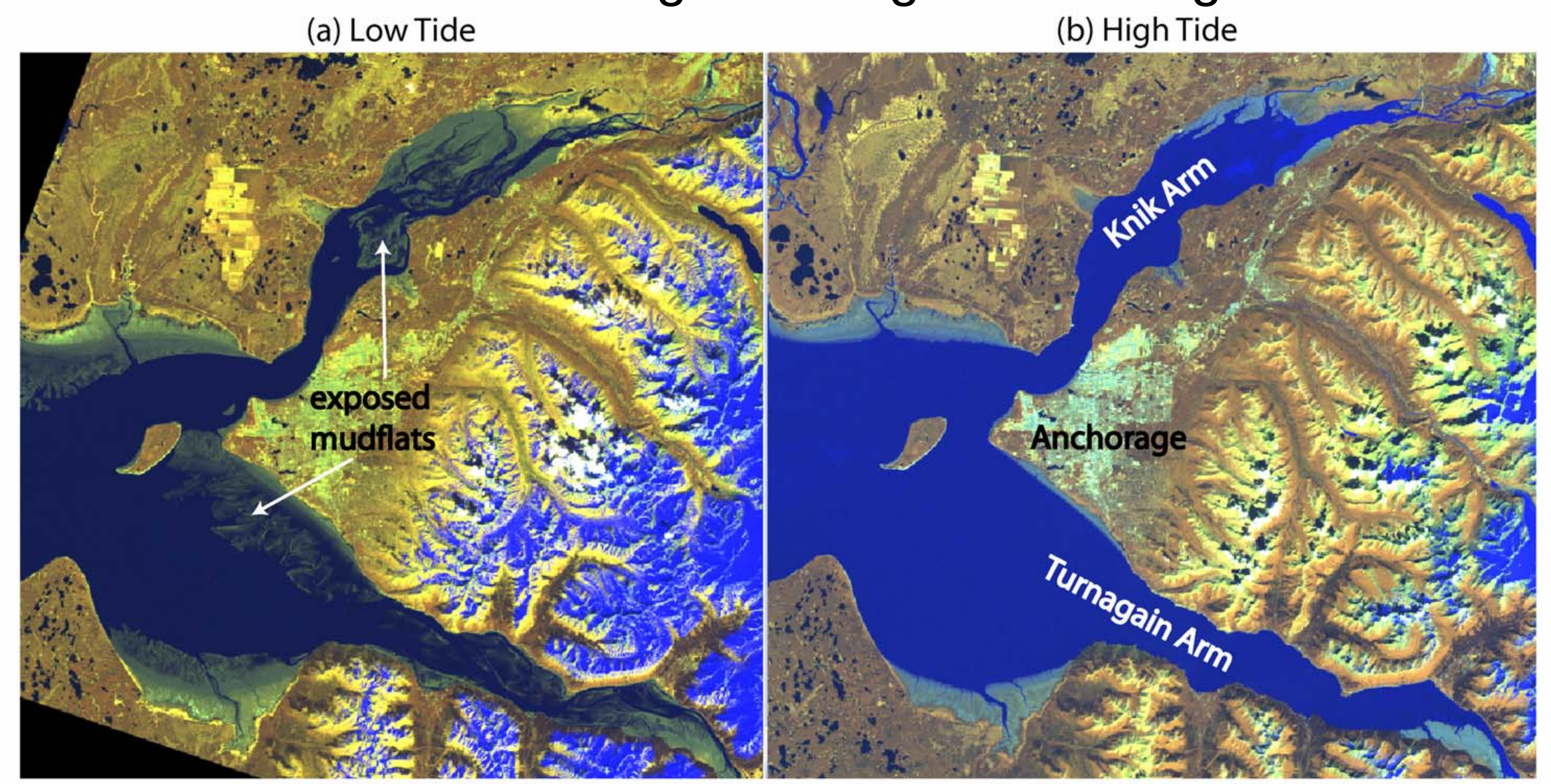
(samples from larger data set with many more images)

- Landsat Thematic Mapper (TM),
- Landsat Enhanced Thematic Mapper Plus (ETM+)

Acquisition Data/Time (*Greenwich Mean Time*)	**Sea Level (*Anchorage*) (*meters*)**	**Observed Tidal Stage**
07-10-1989, 20:47:19 pm	1.340	One hour after maximum sea level
04-28-2000, 20:59:56 pm	1.151	Two hours before maximum sea level
08-09-2000, 21:04:53 pm	-0.811	Three hours after minimum sea level
06-02-2001, 20:57:20 pm	-3.371	One hour after minimum sea level
05-20-2002, 20:56:06 pm	2.158	One hour before maximum sea level
07-30-2002, 21:01:49 pm	1.230	One hour after maximum sea level

The inundation model lacks data on the shallow topography of the mudflats, so we have combined the model and remote sensing data (MODIS & Landsat in past studies, SPOT in the future) in order to improve flood prediction

Landsat-ETM+ images during low and high tides

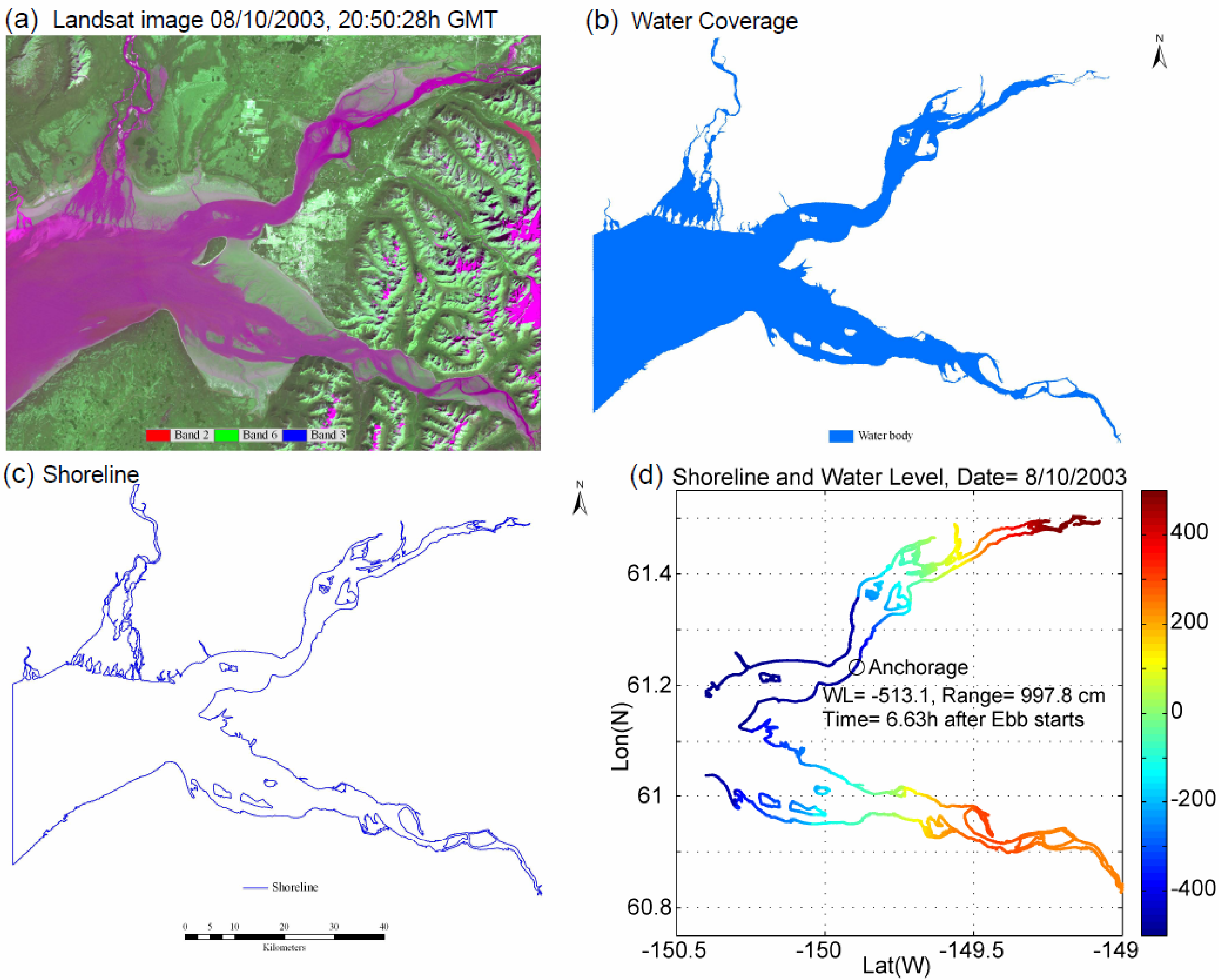


Remote Sensing Data Processing (Cont.)

- Geocorrection
  - Reference: USGS digital raster graphics (DRGs) as reference.
- Supervised image classification
  - Classes: water, wetland, & others.
  - Image refinement.
- Image recoding
  - Water & non-water.

Remote Sensing Data Processing (Cont.)

- Deriving the coordinates of water pixels along the shoreline.
- Using the coordinates as inputs to water level prediction.



(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
61.4
61.2
61
60.8
Lon(N)
-150.5
-150
-149.5
-149
Lat(W)
400
200
0
-200
-400

How to project water level on shoreline?

• One way: run the 3D numerical model for each satellite image time… too computationally expensive!

• Simpler way: use model statistics to form an analytical prediction (extrapolate WL from Anchorage to rest of upper CI)

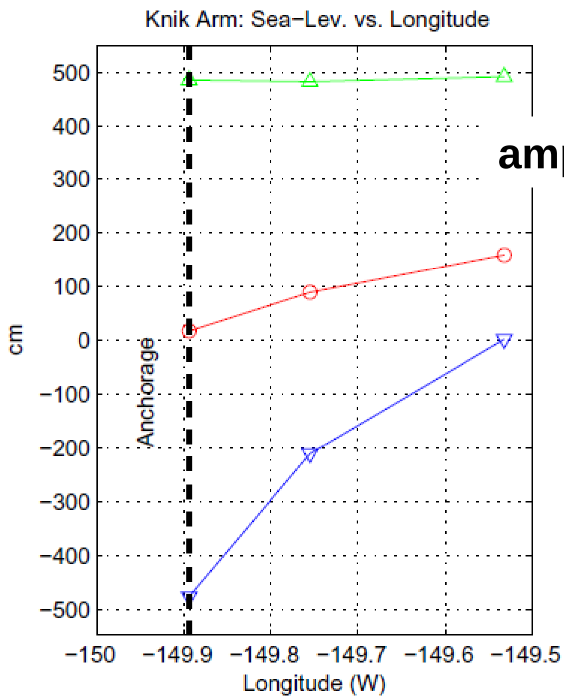
Water Level Prediction:

$$\eta(x,y,t)=\eta^{obs}(t)A_1(x,y)\cos[B_1(x,y)]+C_1(x,y)$$ for Knik Arm

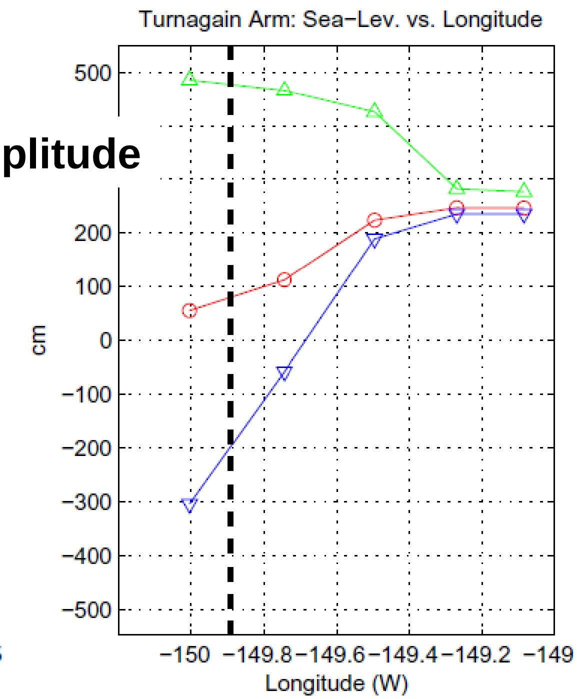
$$\eta(x,y,t)=\eta^{obs}(t)A_2(x,y)\cos[B_2(x,y)]+C_2(x,y)$$ for Turnagain Arm

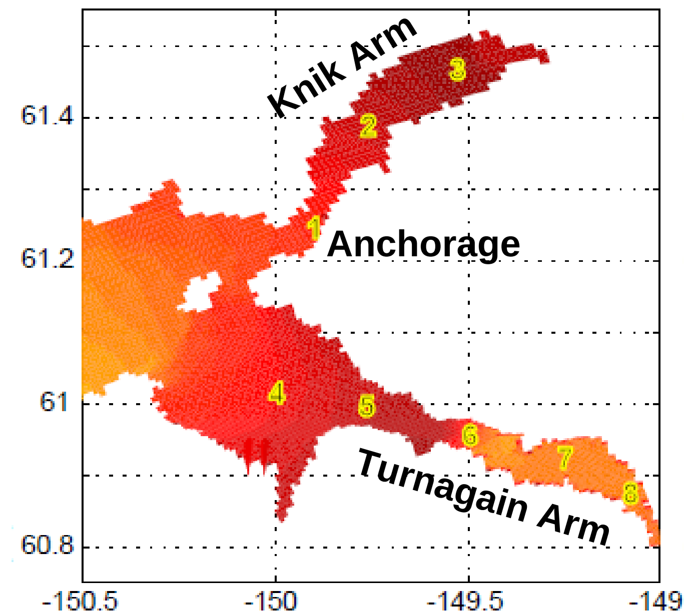
η^{obs}=observed WL in Anchorage

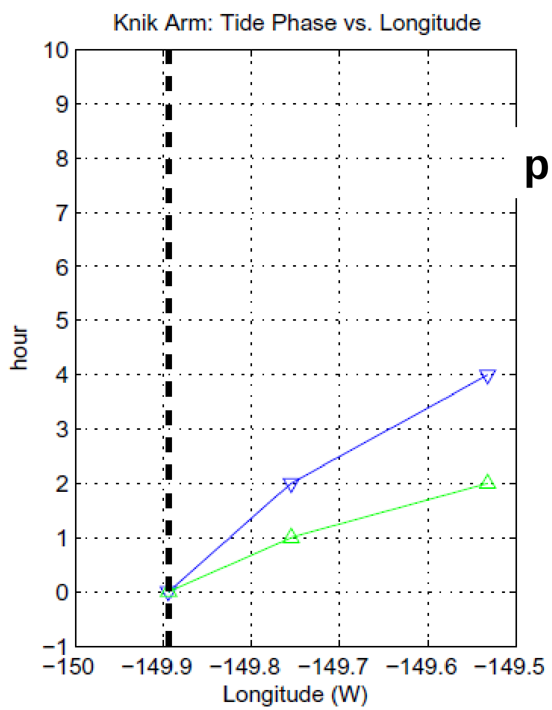
A, B, C = empirical parameters obtained from the statistics of the inundation model



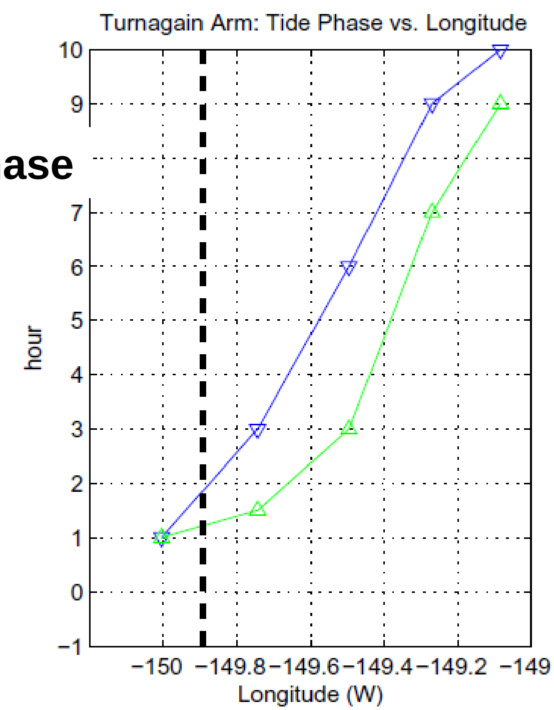
amplitude



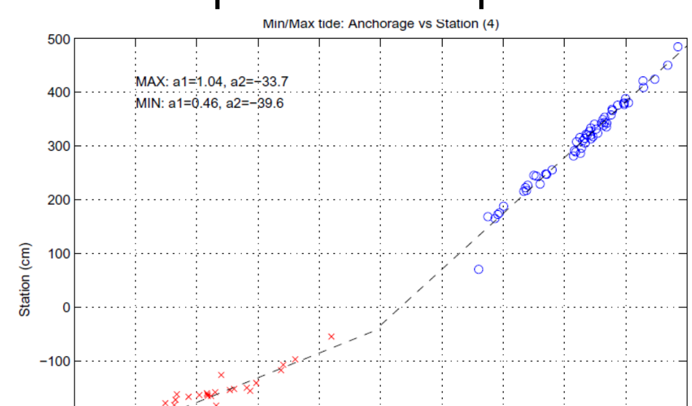




phase



Use these statistics to derive the coefficients for the prediction equation

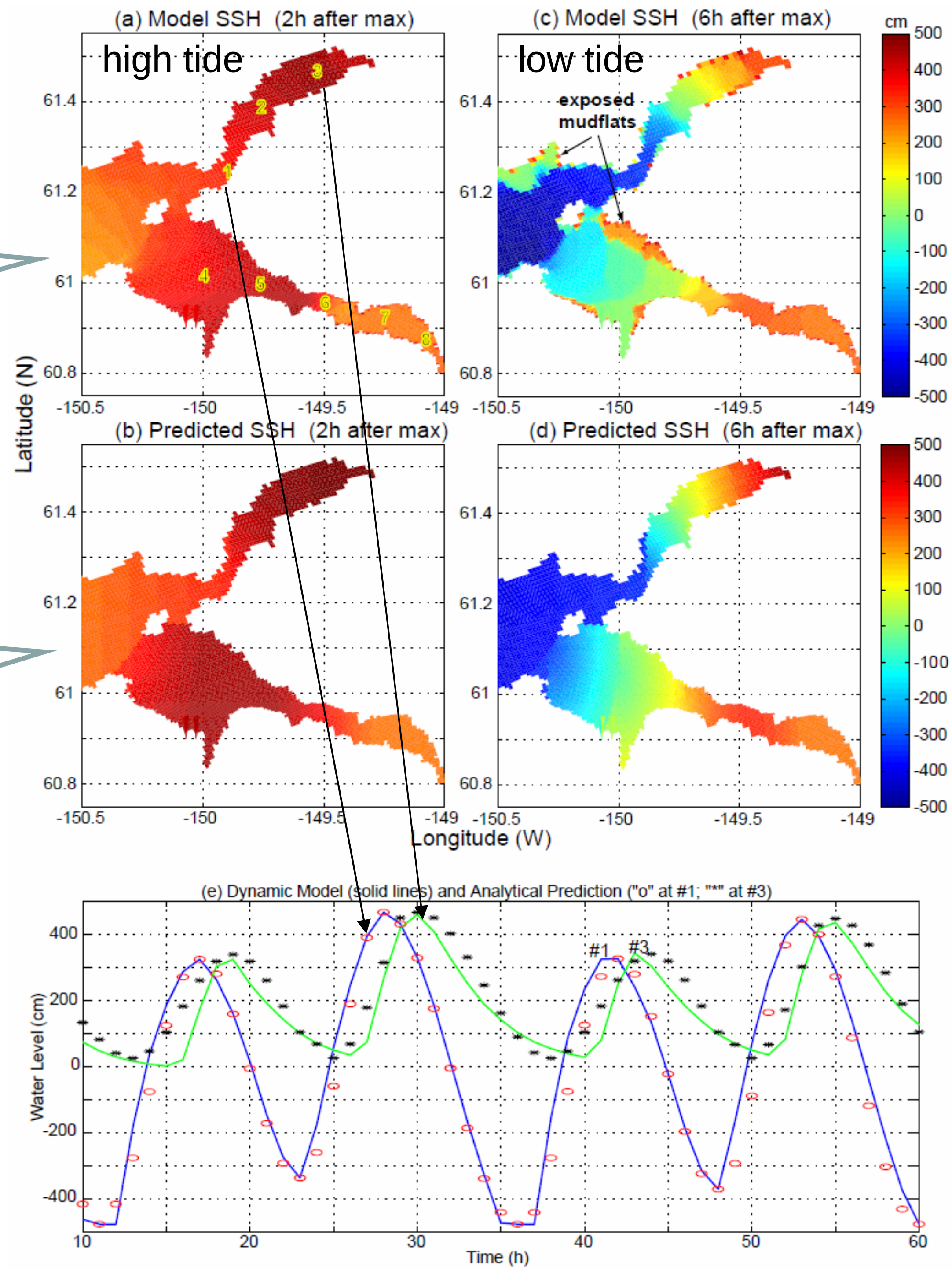


correlation between Anchorage and station 4

TESTING THE PREDICTION MODEL

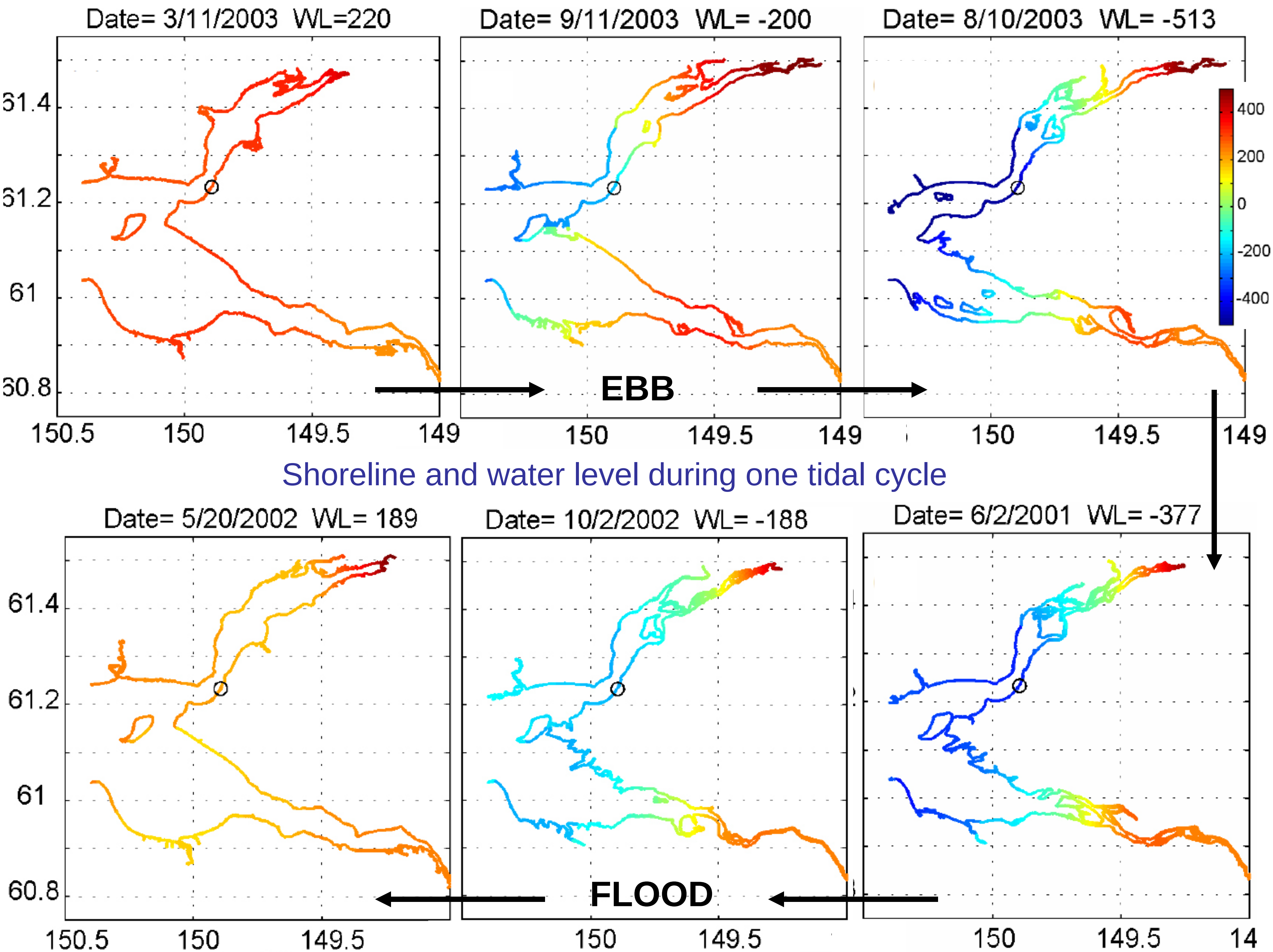
Numerical model

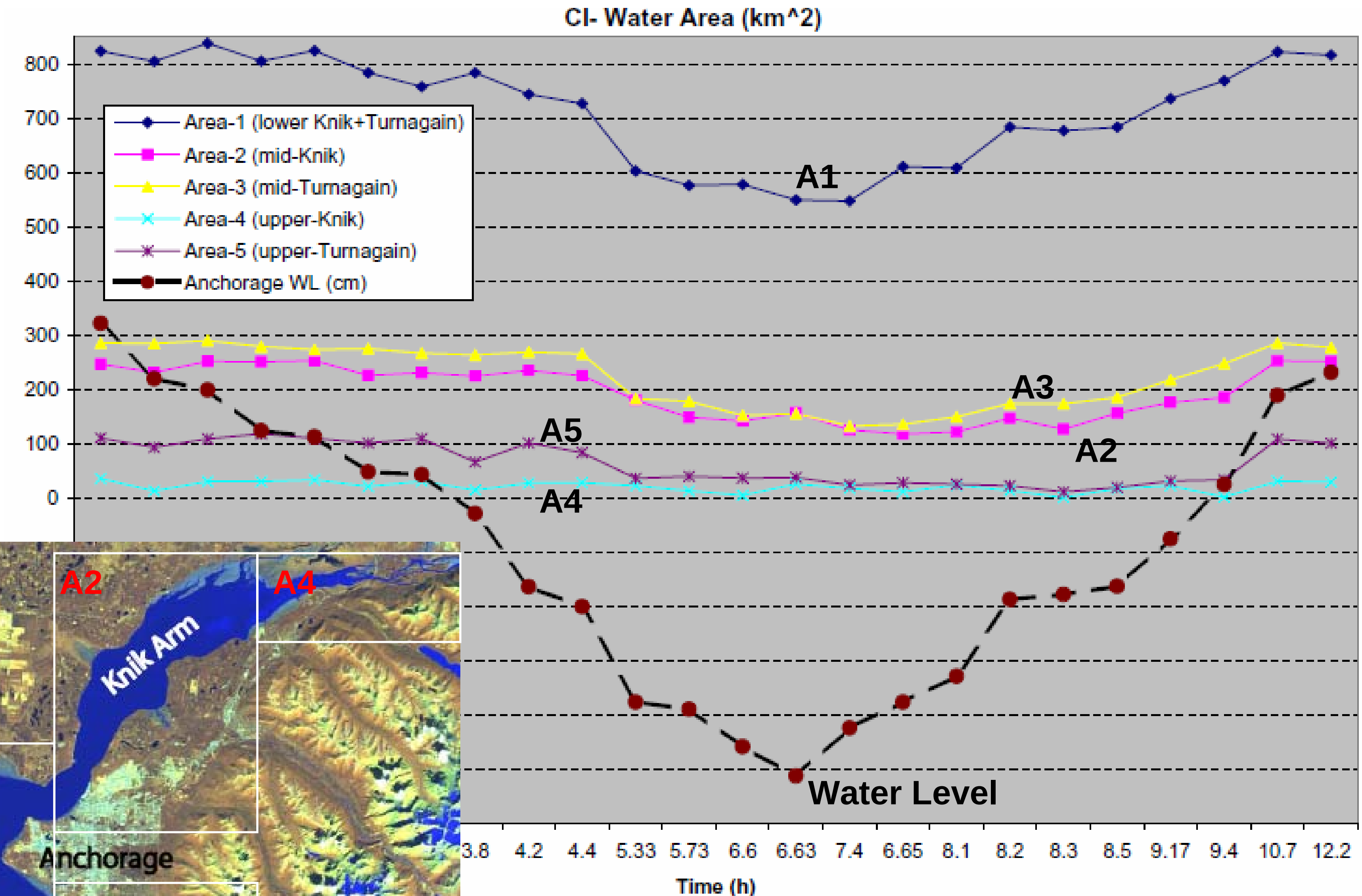
Analytical prediction formula

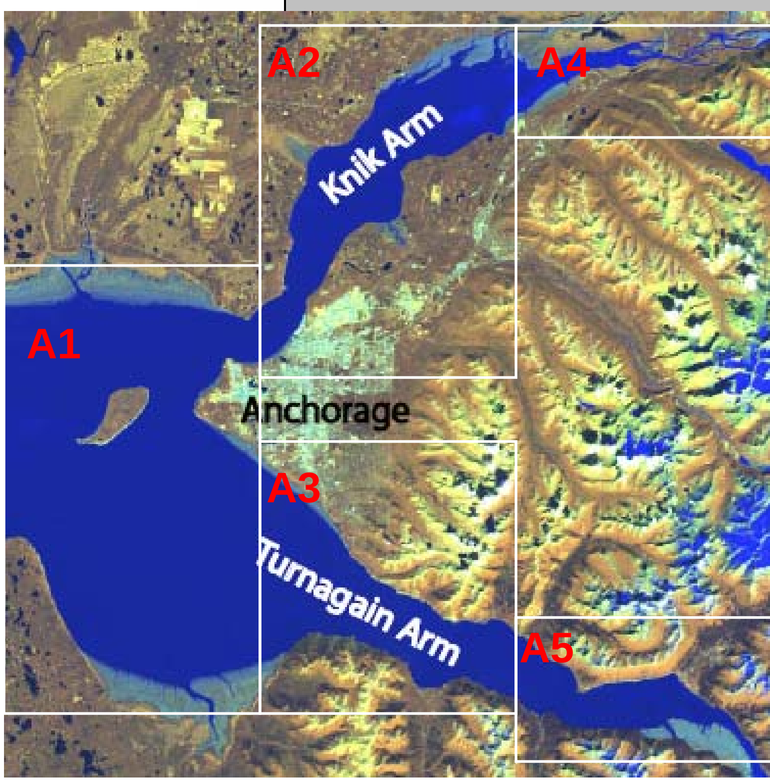


Applications of the inundation model-remote sensing analysis:

- Studying the tidal cycle and calculating the area of the flooded zone
- Studying long-term morphological changes
- Derive new mudflat topography
- Evaluate model predicted WAD


Date= 3/11/2003 WL=220
Date= 9/11/2003 WL= -200
Date= 8/10/2003 WL= -513
400
200
0
-200
-400
61.4
61.2
61
60.8
150.5
150
149.5
149
EBB
Shoreline and water level during one tidal cycle
Date= 5/20/2002 WL= 189
Date= 10/2/2002 WL= -188
Date= 6/2/2001 WL= -377
FLOOD

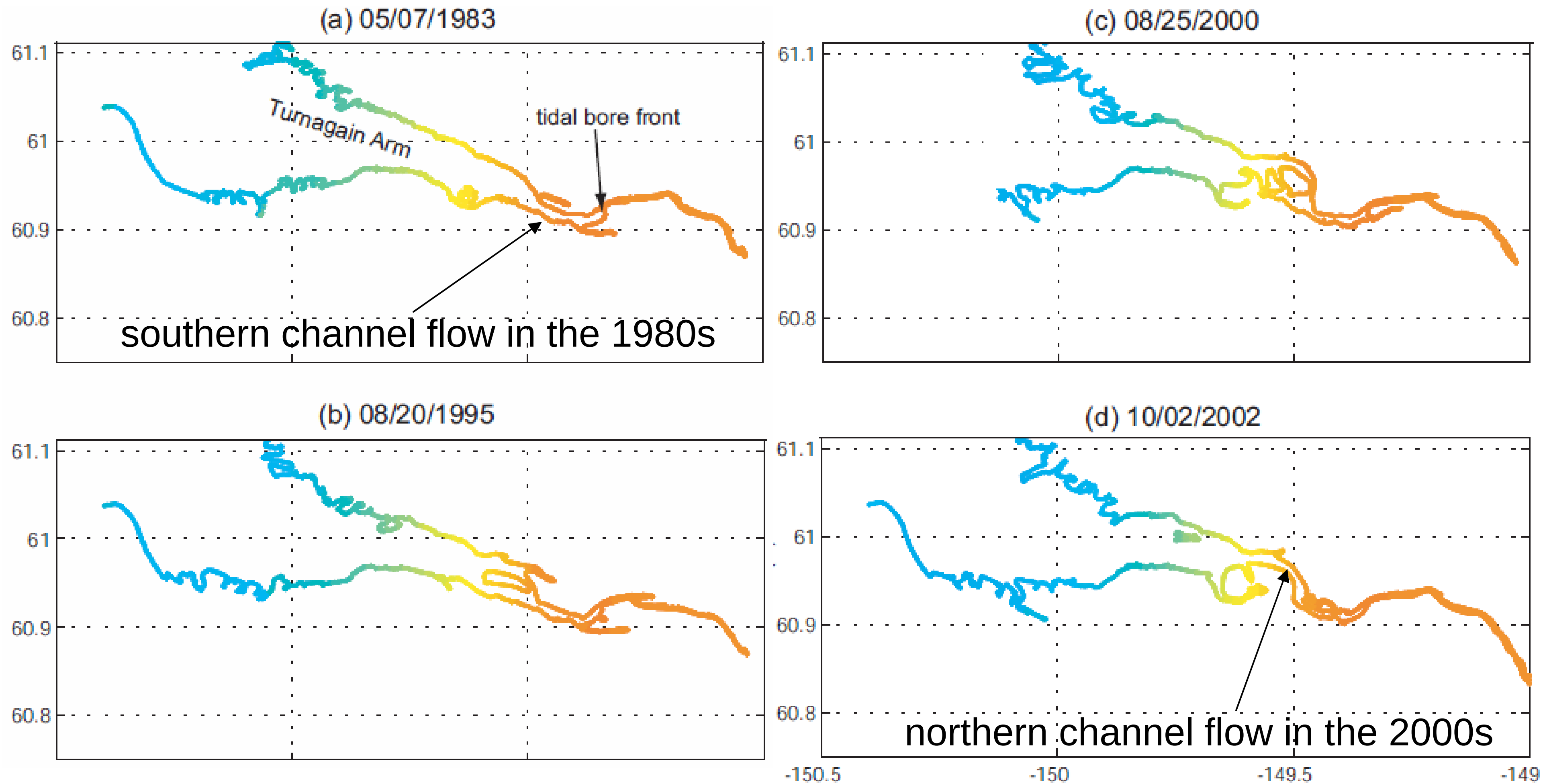




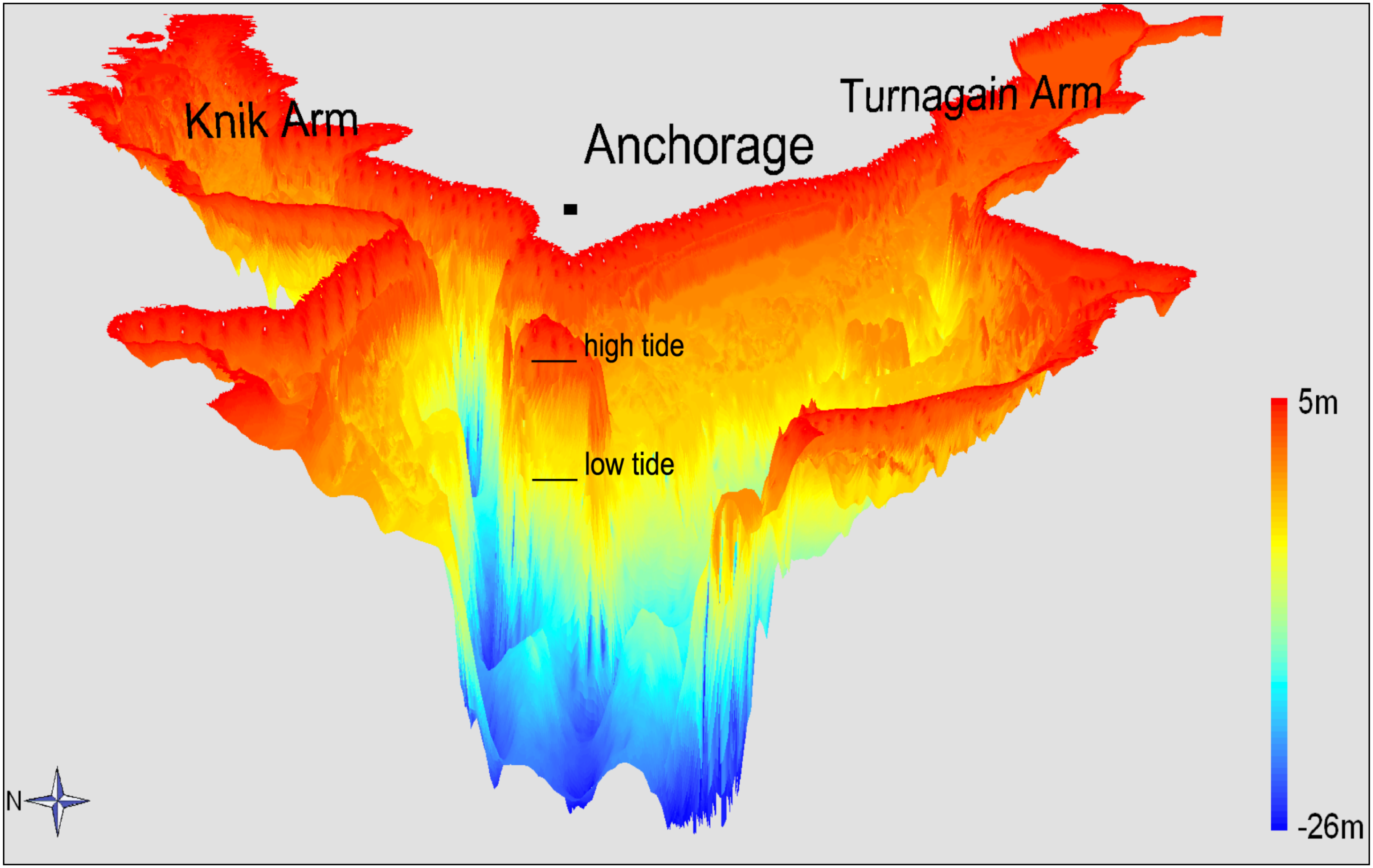
The inundated area of the mudflats were calculated for 5 sub-regions from the satellite data

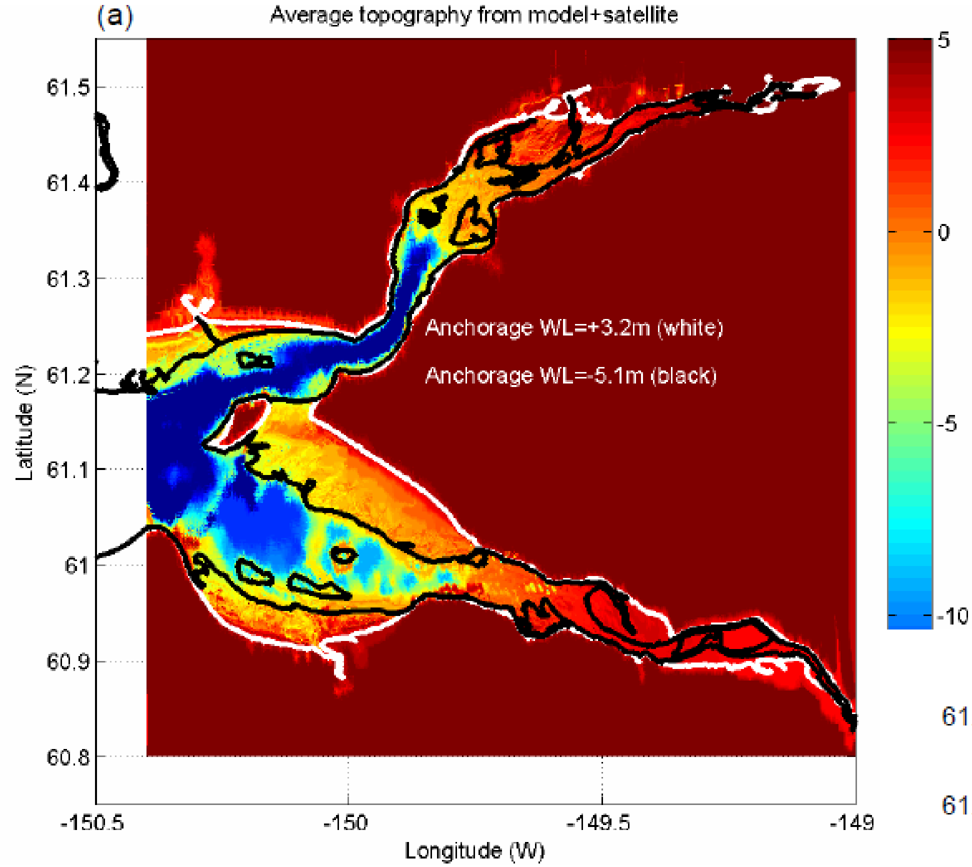
Observing long-term morphological changes in the mudflats

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

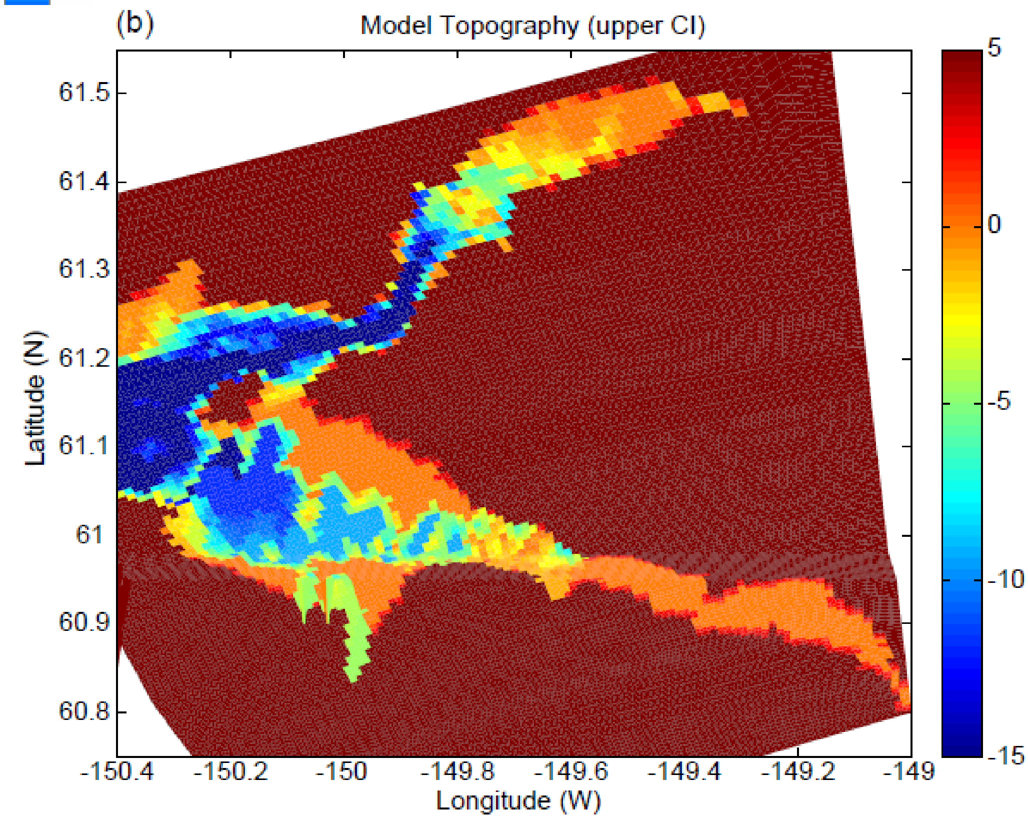


3D CI topography derived from combining ~25 satellite images for inundated regions with model topography for deep regions





Eventually, the remote sensing analysis can be used to produce better topography for high resolution inundation models



Do Beluga Whale strandings relate to unexpected morphology changes?

We are working with NOAA/Fisheries to use our remote sensing data to study this possibility…

Discussions

- The limitations in spatial & temporal resolutions of Landsat data requires an integrated approach
  - Combining available satellite data with different acquisition dates and times with sea level data from observations and from model simulations
  - The methodology can be implemented for many other regions, for improving flood predictions and for studying coastal sea level change


Thank You!