Using inundation modeling and remote sensing data to study hydrodynamic and environmental impacts on the survival of Cook Inlet's Beluga whales

Final Report for the period:
1-October, 2010 to 30-September, 2011

Submitted to:
National Oceanic & Atmospheric Administration (NOAA)
(Project RFQ# NOAA_NMFS_AKR_10_0802_2G)

PI: Tal Ezer
Center for Coastal Physical Oceanography
Old Dominion University
4111 Monarch Way, Norfolk, VA 23508
(tezer@odu.edu)

September, 2011

Abstract

The population of the endangered Cook Inlet Beluga Whales (CIBW) in Alaska has been in decline over the past decades and no convincing explanation has been offered so far for this trend. Therefore, the aim of this project was to continue the analysis of satellite-tracked beluga whale movements (Hobbs et al., 2005; Ezer et al., 2008) and study how environmental parameters such as inlet morphology, tidal currents, temperatures, river flow, ice coverage, etc. may impact the beluga's habitat. Beluga tracking data from ~20 whales in 1999-2003 were analyzed as well as data on beluga stranding events reported in 1999-2010. Environmental data include local observations, hydrodynamic model results (Oey et al., 2007), remote sensing imagery (Ezer and Liu, 2009, 2010), and some regional climatic data. Preliminary results show how the seasonal movement of the CIBW within the inlet is controlled not only by temperature and ice coverage, but also largely by the seasonal flow pattern of various rivers, suggesting that the availability of salmon and other fish in river mouths control the beluga's behavior. The annual counted numbers of beluga whales in CI, as well as the number of reported stranding events show interannual variations which resemble the Pacific Decadal Oscillation index. However, the way that large-scale climatic variations may impact the beluga population needs further research. This short-term NOAA supported project allows us to start a longer study of CIBW under the support of the Kenai Peninsula Borough; the new interdisciplinary project will include additional experts in GIS/remote sensing and in fisheries ecology.

An animation of the seasonal movement of the belugas and the relation to the CI water temperature can be viewed or downloaded from:
http://www.ccpo.odu.edu/~tezer/CI/Beluga_Weekly_anim.gif

1. Data Collection, Quality Control and Analysis

(a) Satellite tracking data

The satellite-tracked beluga whale data were initially described by Hobbs et al. (2005) and later, a short subset data of 2 whales during few weeks were used by Ezer et al. (2008) to show how the belugas move up and down the upper Knik and Turnagain Arms using the tides for their advantage. In the analysis we conduct here, the area of interest in the mid- and upper CI was divided into 4 sub-regions (Fig. 1).

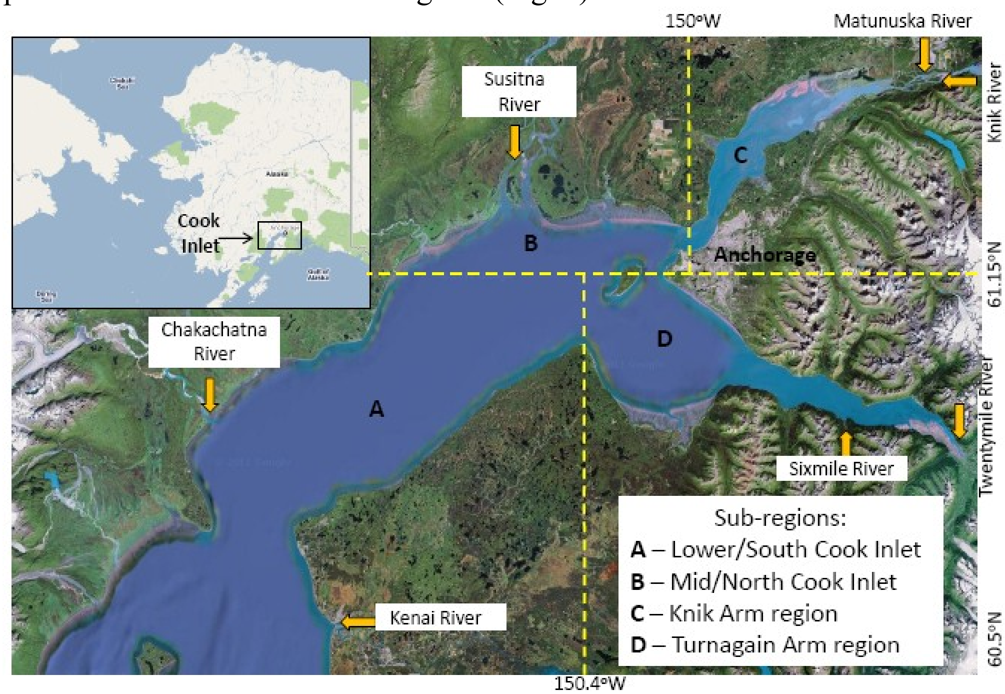

***Fig. 1**. The study area of upper Cook Inlet (large image based on Google maps) and its location in Alaska and the larger region (inset at the top-left corner). In the analysis the area is divided into 4 sub-regions (A-D) shown by yellow dashed lines. The locations where rivers enter the Cook Inlet are shown by yellow arrows; the USGS river flow data from these 7 major rivers are taken upstream in the rivers.*

The raw data obtained from NOAA/Fisheries includes about 20 animals, tracked between May-1999 to May-2003. However, the distribution of tracking data is very uneven (Fig. 2), from 1 whale in 1999 to ~10 in 2001 and with much more data in late summer and fall (August-November) and very little or no data at all in winter and spring. Some days have multiple tracking points while another period has no data for many weeks. Moreover, the accuracy of each location (~100s m) and bad data points make quality control a challenge. Therefore, first we mapped all the raw data points for each animal on top of a low and high tide shorelines obtained from satellite imagery (Ezer and Liu, 2009, 2010). Then we manually identified the points that clearly fell outside the high water-level shoreline of the inlet (using MATLAB zooming tools) and remove them from the data set. We also checked for cases where the same animal was tracked at too far locations within too small time interval. Typically, between 10s to a few 100s points were removed from each animal file.

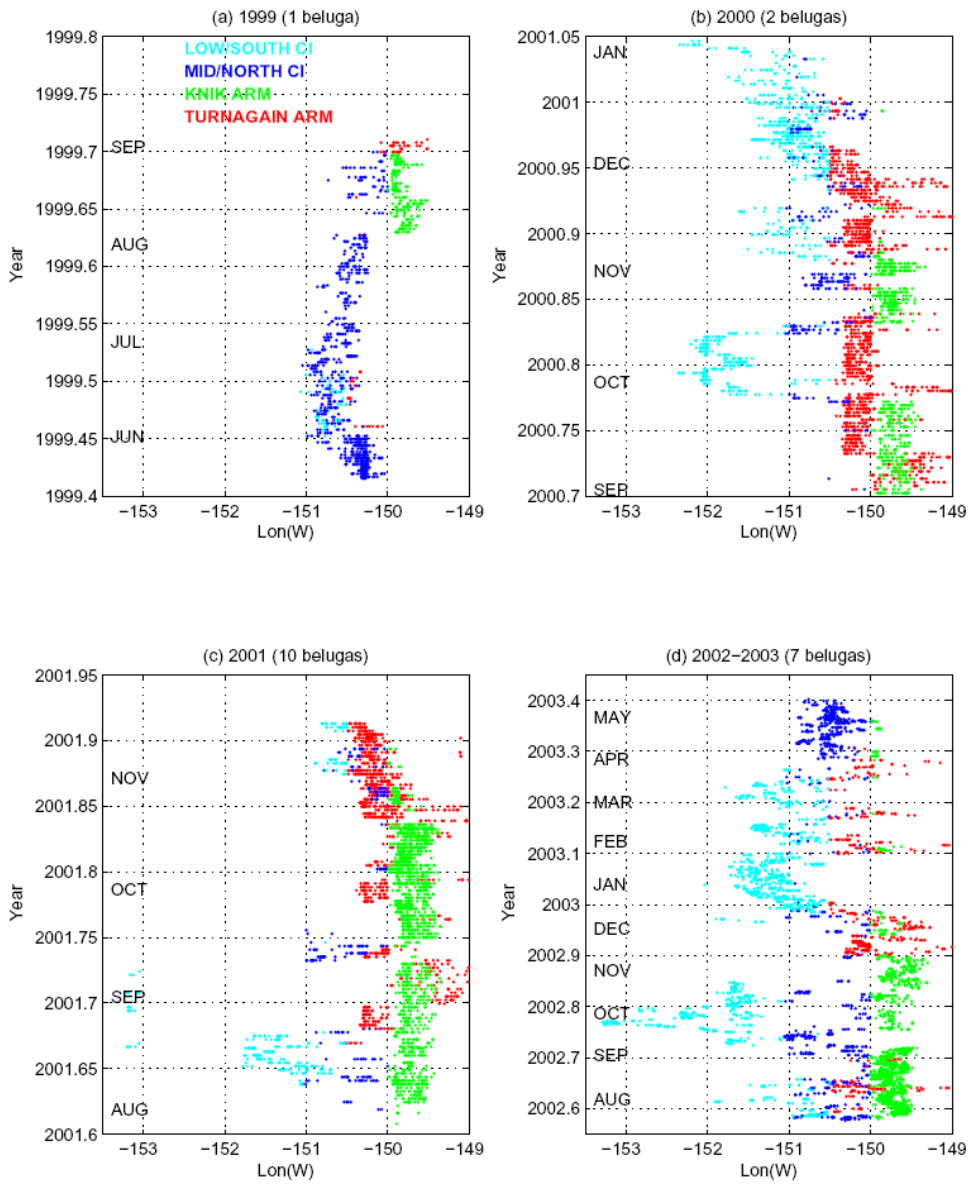

Fig. 2. *The seasonal distribution of the belugas from the satellite tracking data for 1999 to 2003. Shown are the locations as a function of longitude and time of year. The different colors represent different sub-region (see key in panel a and sub-region definition in Fig. 1).*

(b) Stranding data

Reports on beluga stranding events (Vos et al., 2005) are sparse and the exact location is not always indicated. Moreover, some reports may include animals that have been dead for some time until reported, while some live stranded belugas may survived and escaped with the next high tide. We mapped the stranding locations from the few reports that were digitized and provided to us by NOAA (thanks to Kaili Jackson and Barbara Mahoney) on top of the satellite derived shorelines (Fig. 3). We also try to compare the timing of stranding events with water level (Fig. 4); the comparison indeed indicates more stranding events during spring tide when variations in water level are high.

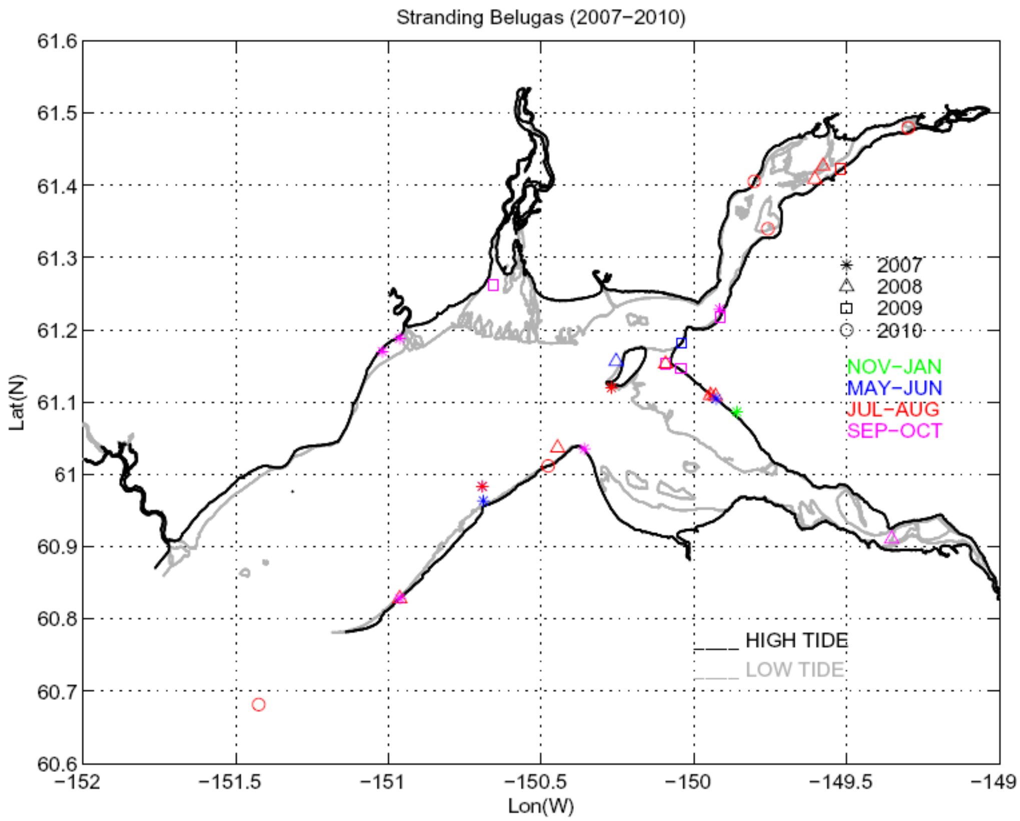

Fig. 3. *Location of reported stranded belugas. Color indicates the reported month and shape indicates year; some locations include multiple number of animals.*

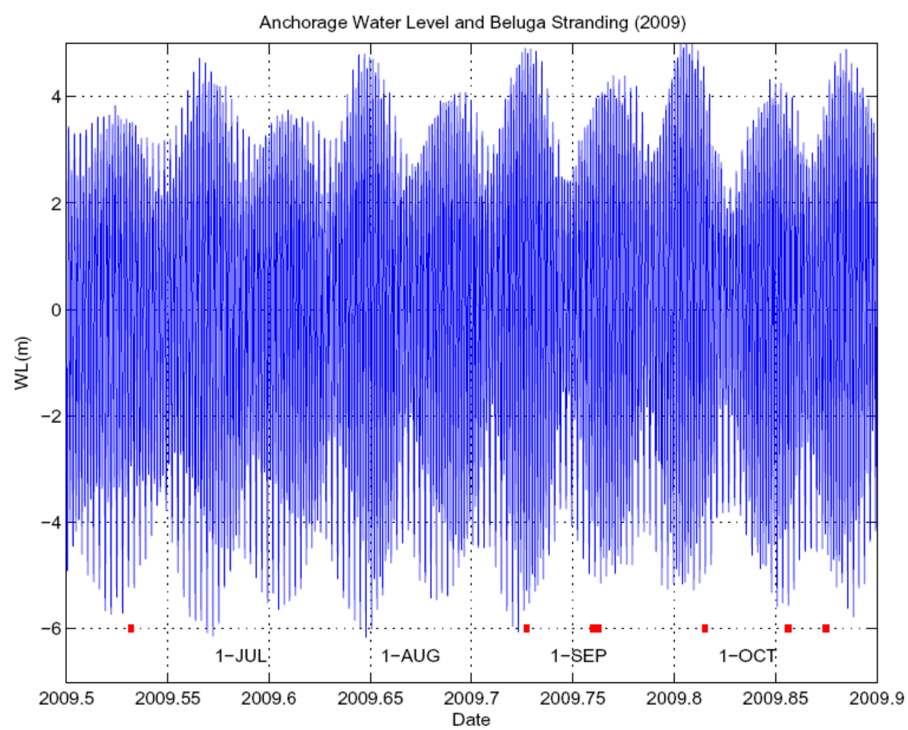

Fig. 4. *Tidal water level in Anchorage (blue line) and time of reported beluga stranding (red marks at bottom) during summer and fall 2009.*

The exact location of stranding belugas on the mudflat is not always exactly known, but the assumption is that they are close enough to shore to be seen, so animals that died further offshore may be missing from the statistics. Statistics of the total annual live and dead stranding events have been provided to us by Barbara Mahoney. It is also unclear if all the dead animals were stranded before they died, as there are evidence of a few belugas that may have been attacked by killer whales, or may died of other causes. Therefore, our initial analysis of physical parameters that may influence location or timing of stranding is quite limited at this point.

(c) Environmental data

Water level and temperature data are available from the NOAA station in Anchorage. The CIBW may be influenced by the large changes of temperatures between one year to another (Fig. 5), where recent years seem to have longer summers and warmer temperatures. Monthly averaged river flow data is available from the USGS; the location of some of the major rivers is shown in Fig. 1. Note however, that stream flow is often measured farther upstream, not in the location where the flow reaches the inlet. We focused our analysis on 7 major rivers with good data, 2 rivers are located in the mid and lower CI, 2 in each of the upper Arms and one, the Susitna River, in the mid-north inlet. Additional data from the hydrodynamic model have been reported before (Oey et al., 2007; Ezer et al. 2008). They demonstrate how the belugas move up and down the shallow Arms with the tides during the fall and early winter period (Fig. 6), when the Knik and Turnagain Arms are still ice free.

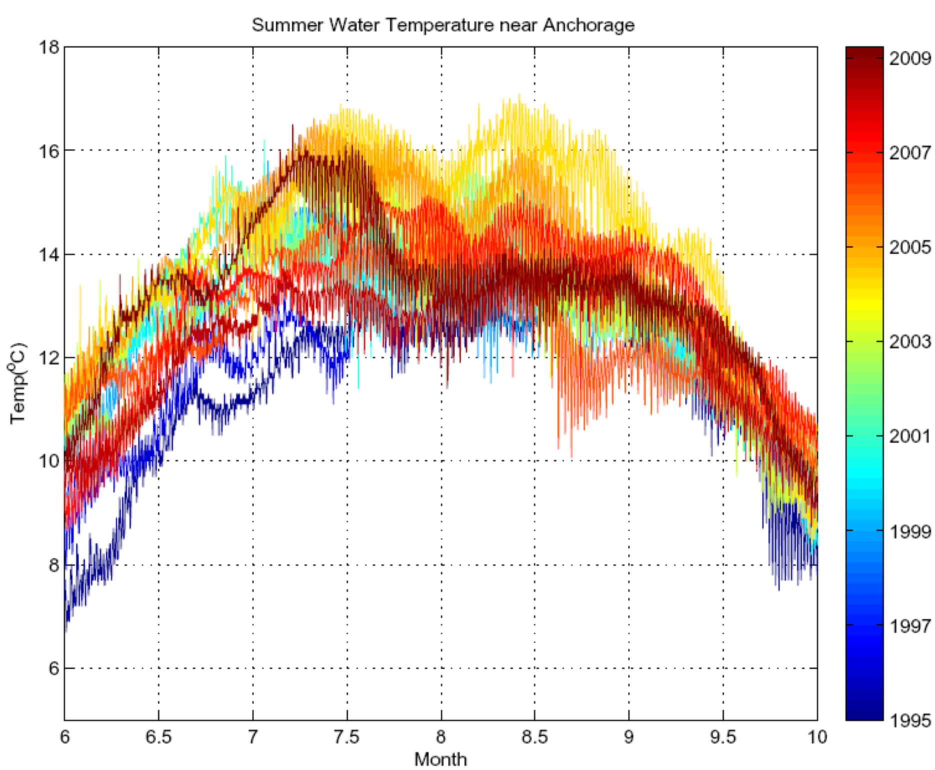

***Fig. 5**. June-October hourly water temperature measured near Anchorage from 1995 to 2009 (each year is represented by different color, as indicated by the colorbar).*

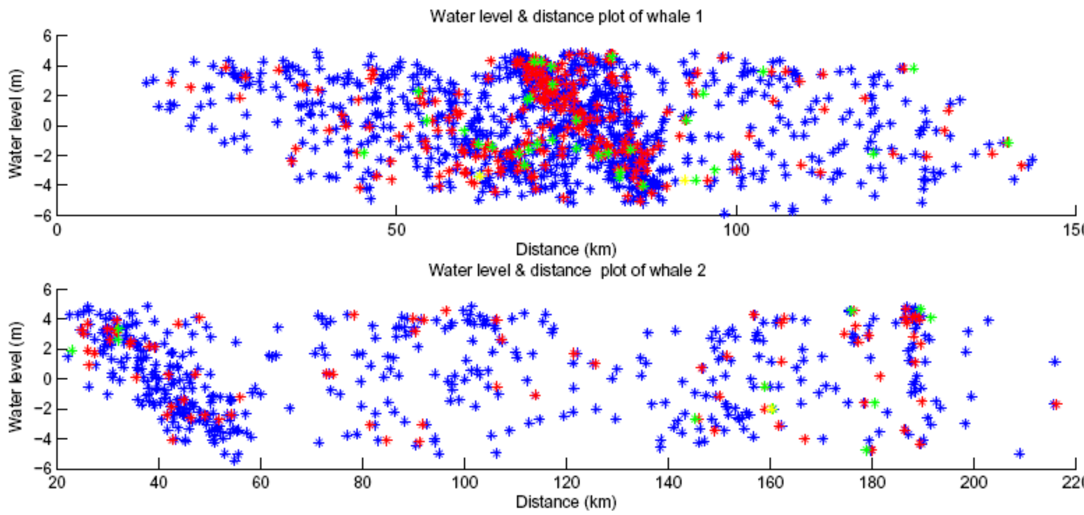

Fig. 6*. Location of 2 belugas as a function of distance from the shallowest area and water level during September-December, 2000 (blue/red/green/yellow represents how often tracks are recorded each hour, 1/2/3/4 times). Top panel is for a whale in Turnagain Arm and bottom panel for Knik Arma. Note that the whales can reach the farthest shallowest regions (left most points) only during high tide.*

Our remote sensing data (Ezer and Liu, 2009, 2010) already identified significant changes in the morphology of the upper inlet, whereas the strong tidal currents transport large amounts of sediment from one place to another, blocking channels or opening new ones. These changes could lead to beluga stranding if they do not learn to adjust to the new morphology of the mudflats. The research on this topic has just started and will continue under the new Kenai Peninsula Borough funding. This analysis can identify particular “danger zones”, where stranding may occur.

2. Results

(a) Seasonal movement of CIBW and environmental causes

Because of the uneven distribution of the CIBW tracking data, the analysis combines tracking data by month and by region (see definition of regions in Fig. 1), rather than looking at the movements of an individual whale (as was done in Ezer et al., 2008). Fig. 7 shows the monthly distribution (for brevity, only every other month is shown), as well as the year and animal tracking number (colors and symbols). The results provide more details and larger data set than previous descriptions of the seasonal trends (Hobbs et al., 2005). The general seasonal pattern of the beluga movements is quite clear. The CIBW spend the winter months, when the upper inlet is partly ice covered, in the mid and lower inlet (Fig. 7a,b). Then, in late spring and early summer, when the snow and ice melt and the river flows are at their peak, they move first to the area near the Susitna River (Fig. 7c,d), and later in the fall to the Turnagain and Knik Arms (Fig. 7e,f).

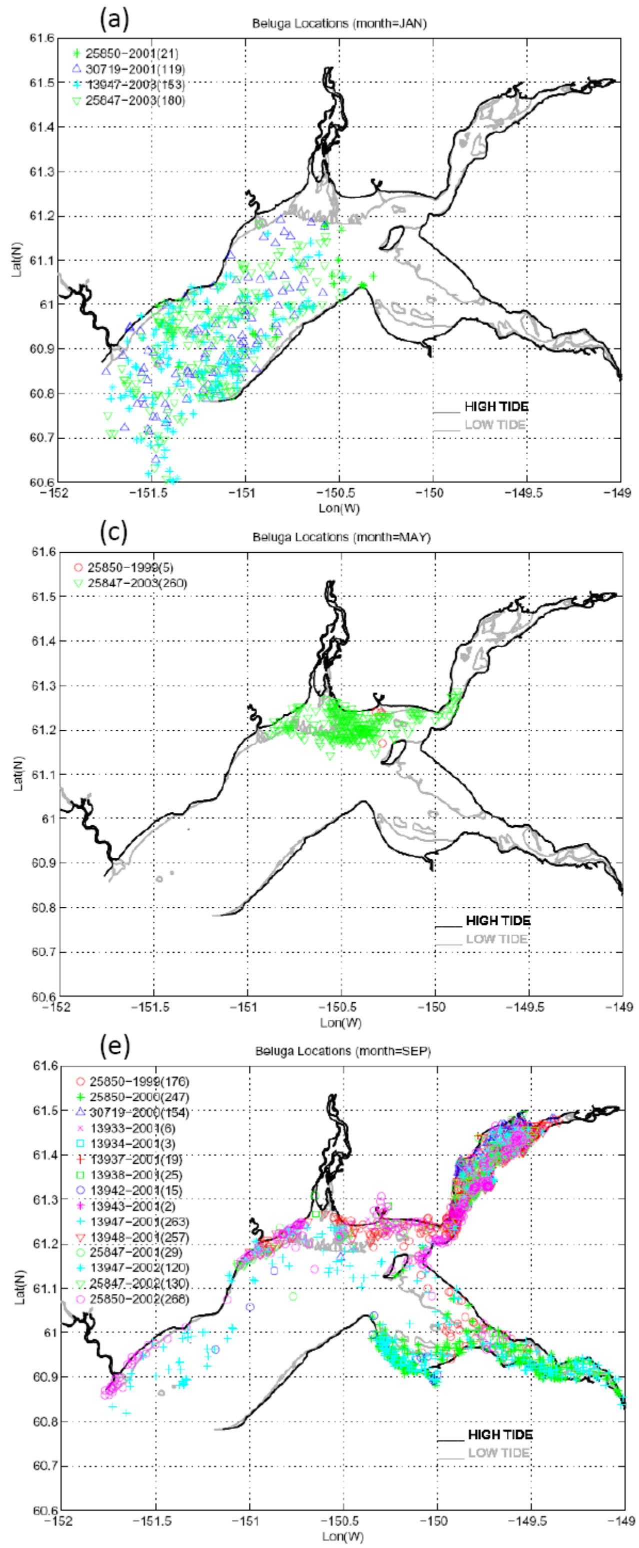

Fig. 7. *The location of all belugas found in each month. In each panel, different colors or shapes represent either different animals or animals tracked during different years. The black and gray lines are satellite-derived shorelines (see Ezer and Liu 2009, for details) for very high and very low water levels, respectively.*

While similar seasonal pattern seem to repeat in different years, there are considerable variations between the movements of one animal to another, and between one year to another. There seem to be larger variations in the movements of the CIBW during the fall compared with other seasons. However, there are also many more tracking data during the fall, which could create a bias in the analysis. Therefore, we looked closely at weekly composites of the tracking data and the relation of the CIBW location to water temperatures. The complete analysis can be seen in the animation http://www.ccpo.odu.edu/~tezer/CI/Beluga_Weekly_anim.gif.

Examples are shown in Fig. 8. This figure demonstrates how even a small change in water temperature between one year and another may cause a large change in the beluga behavior. For example, in the first week of March the water was below freezing in 2002, but started slight warming in 2003, and as a result the belugas in 2003 started moving to the upper inlet earlier than they did in 2002 (Fig. 8a). During the fall and early winter (early September to late December), the water temperature in 2002 was higher than the temperature in other years, and as a result the belugas in 2002 (blue diamonds in Fig. 8) spent more time in the upper Knik Arm (Fig. 8b,c) and then in Turnagain Arm (Fig. 8d). In particular, during the third week of December, the water temperature in Anchorage during 2002 was still slightly above freezing, while the temperature in 1999, 2000, 2001 and 2003 was already below freezing at that time (Fig. 8d); this difference in environmental conditions influenced the CIBW, so they moved to the lower inlet in 2000, but remain in Knik Arm, Turnagain Arm and near the Susitna River at this time in 2002.

The seasonal and interannual variations in water temperatures can impact the CIBW directly, as shown in Fig. 8. However, climatic changes in air temperature may also impact the CIBW indirectly by affecting the timing of snow melt, the amount of river flow, and possibly the amount of fish availability at river mouths. To test this hypothesis, at each month we compare the preferred location of the CIBW between the 4 sub-regions with the monthly rivers that flow into each region (Fig. 9). During January to March, while not many belugas are tracked (Fig. 9a), 70%-100% of them spent time in the lower/mid inlet. During April to July 60%-90% of the CIBW are found near the Susitna River (Fig. 9c), which by May has the largest relative flow contribution, ~50%, of all the rivers analyzed. The CIBW move first to Knik Arm (August to November, Fig. 9d) and then to Turnagain Arm (September to December, Fig. 9e). The CIBW preference between the two Arms is nicely correlated with the decrease of river flow in Knik Arm (Fig. 9i) and the increase of flow into Turnagain Arm (Fig. 9j) during the fall. The results show how the different timing of river flow into different locations in CI force the CIBW to optimize their movements and to take maximum advantage of even small changes in river flow.

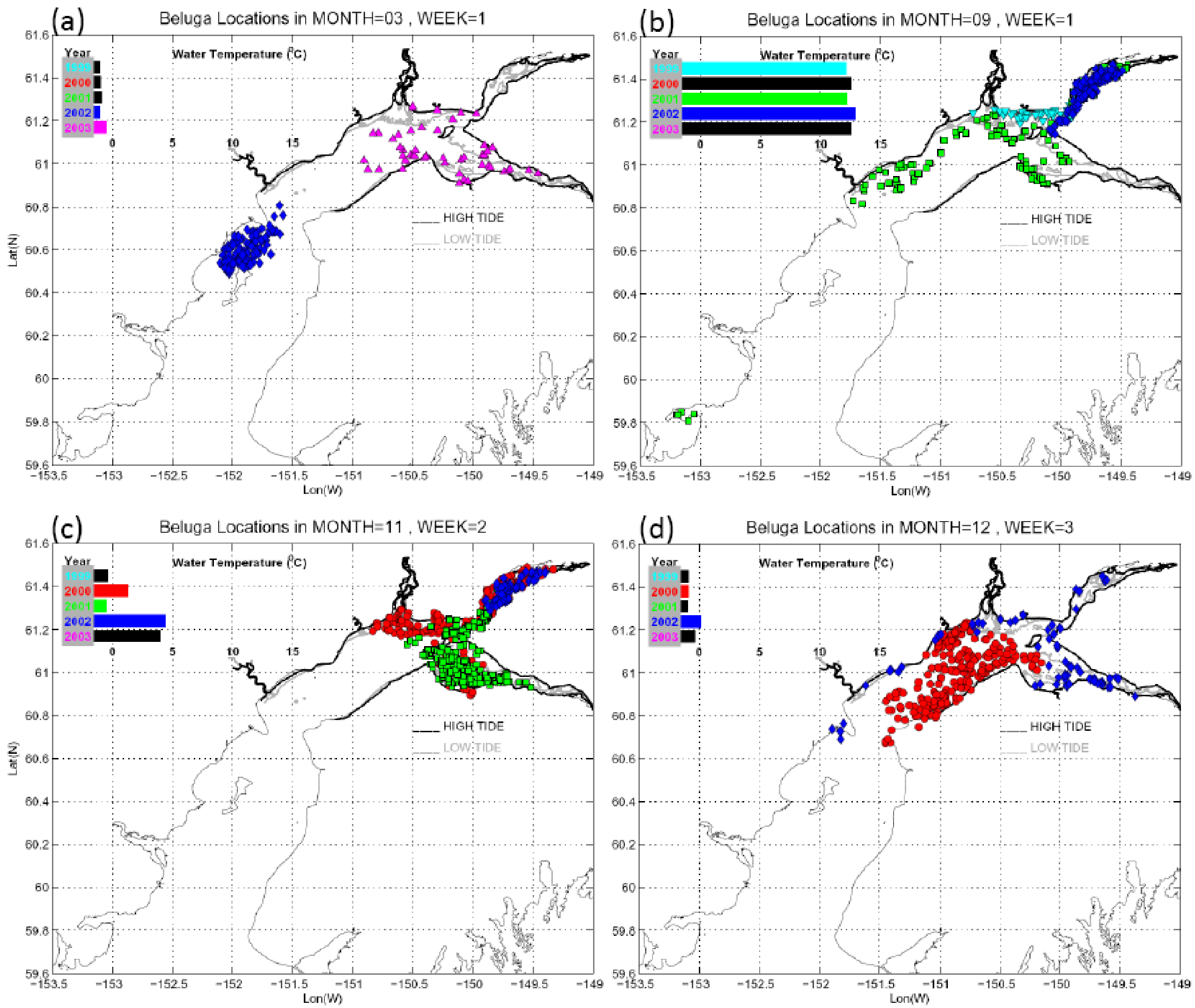

Fig. 8. *Examples of beluga locations and variations in water temperature. In each panel, each color represents all the animals tracked during a 1-week period in a particular year. The water temperature near Anchorage is shown in the upper-left corner of each panel; black bars are for years with no tracking data.*

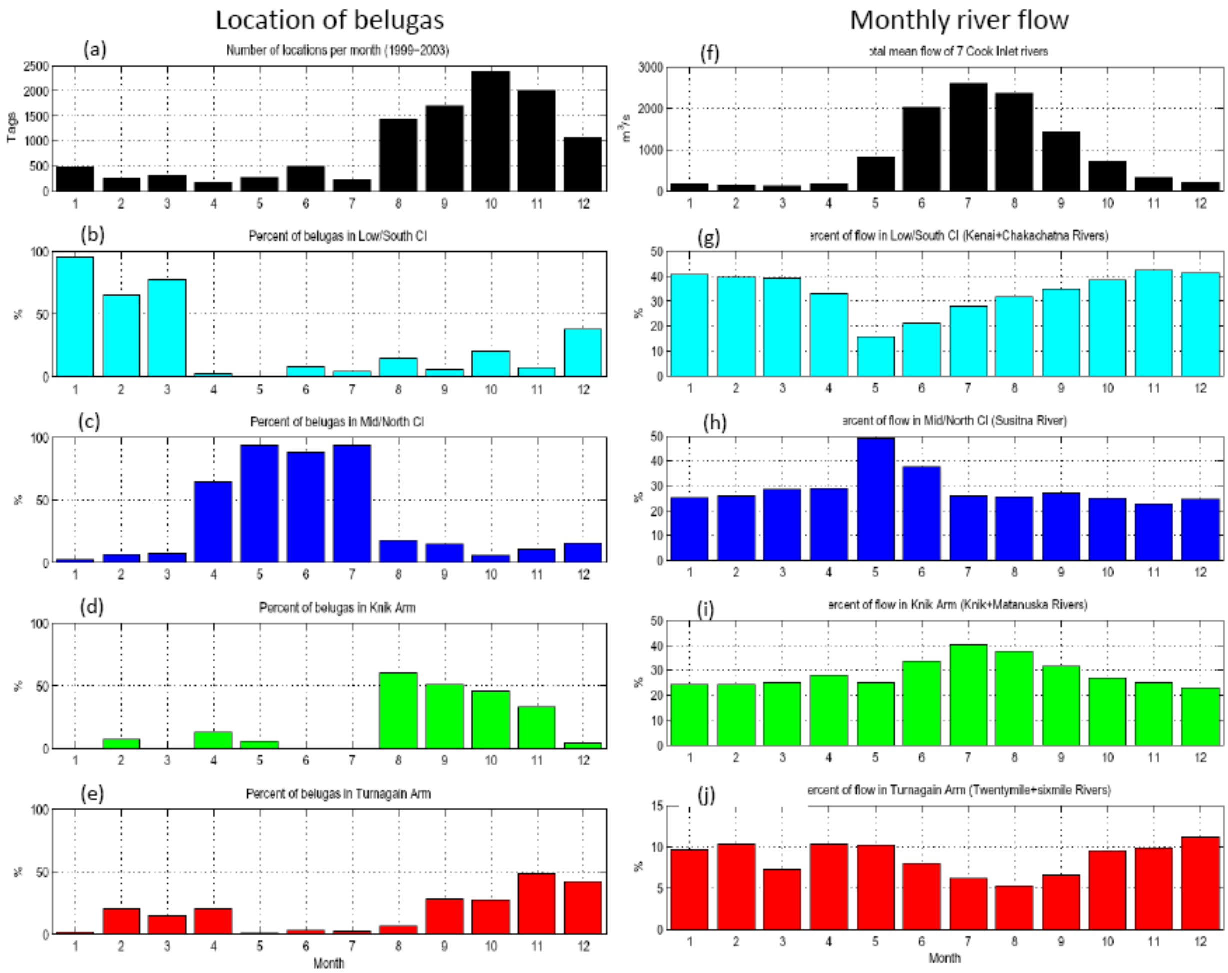

Fig. 9. *The spatial monthly distribution of the tracked belugas (left panels) and the monthly mean flow of 7 major rivers (right panels). The top panels show the total numbers of (a) tagging data and (f) river flow in* $m^3\ s^{-1}$*, while the other panels show the percentage of beluga seen in each region (b-e) and the percentage of flow in the rivers found in those regions (g-j).*

(b) Long-term and climatic environmental variations

The declining numbers of CIBW (Fig. 10b) and the reported stranding events (Fig. 10c), both show some oscillations and trends that may relate to long-term climatic changes in the region, such as the Pacific Decadal Oscillation (PDO) index over the past 15 years (Fig. 10a). The PDO represents temperature variations over the Northeast Pacific Ocean, and has been found to correlate with ecosystems and biological productivity in regions such as the Bering Sea (Jin et al., 2009). The 15-year trends and the 3-4 year oscillations are clearly noticeable in Fig. 10, but the exact mechanism needs further research. It is possible, for example that large-scale climatic changes over the north Pacific influence the temperature and river flow in the CI area and thus the movement and feeding of the CIBW. Long-term changes in sea level in the Gulf of Alaska may also impact the CI water level.

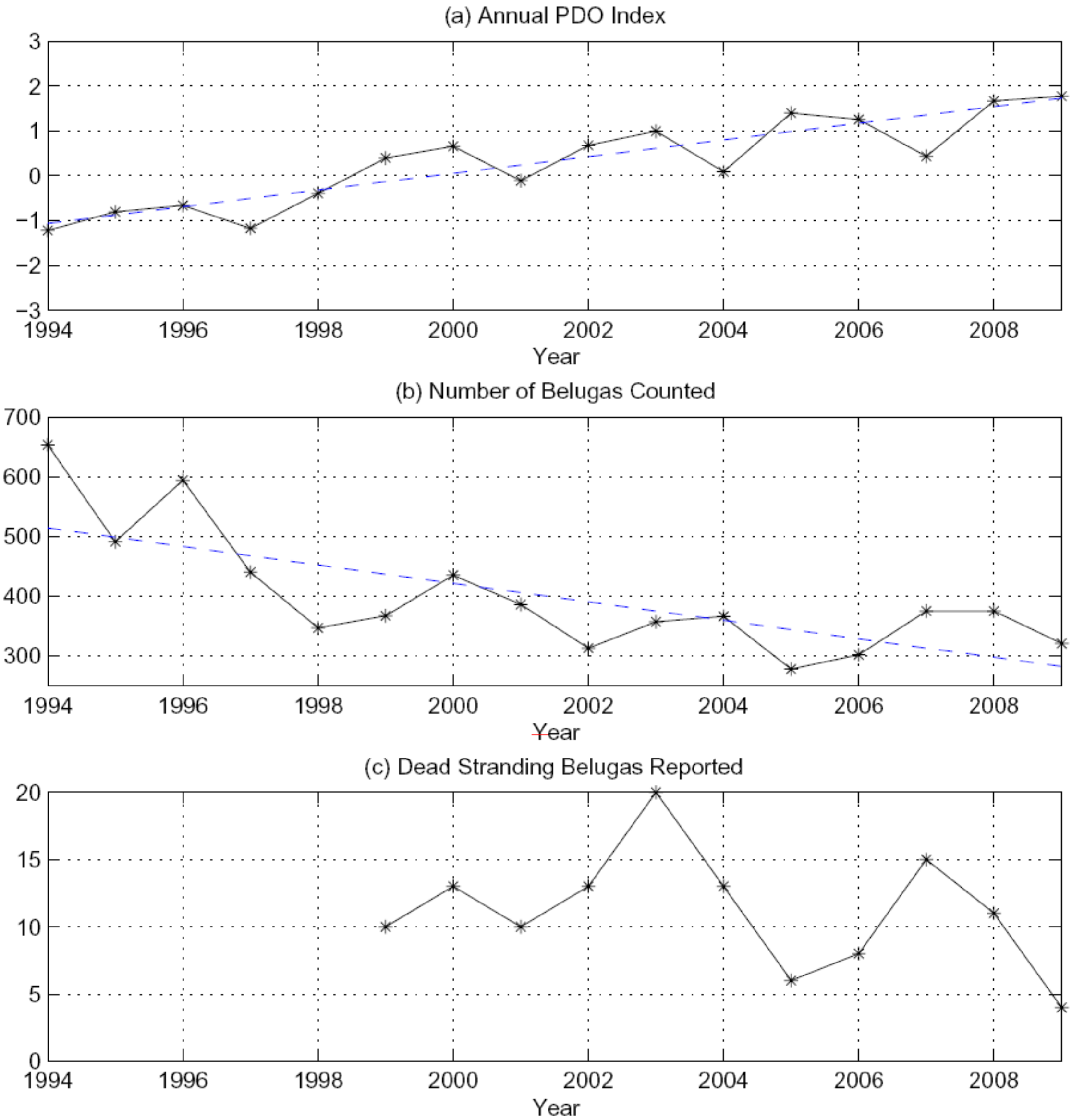

Fig. 10. *Annual averages of (a) PDO index, (b) number of beluga counted in CI and (c) number of stranded belugas found dead.*

Even longer-term climatic changes over 38 years are shown in Fig. 11. They show 5-10 year oscillations in water level that are correlated with the PDO. Changes in the Kenai and Susitna River flows also show significant interannual and decadal variations, whereas large maximum flows occur less frequent in the last decade compare with previous decades. Years with relative more flow in one river relative to another would impact the CIBW movement, as shown before in Fig. 9.

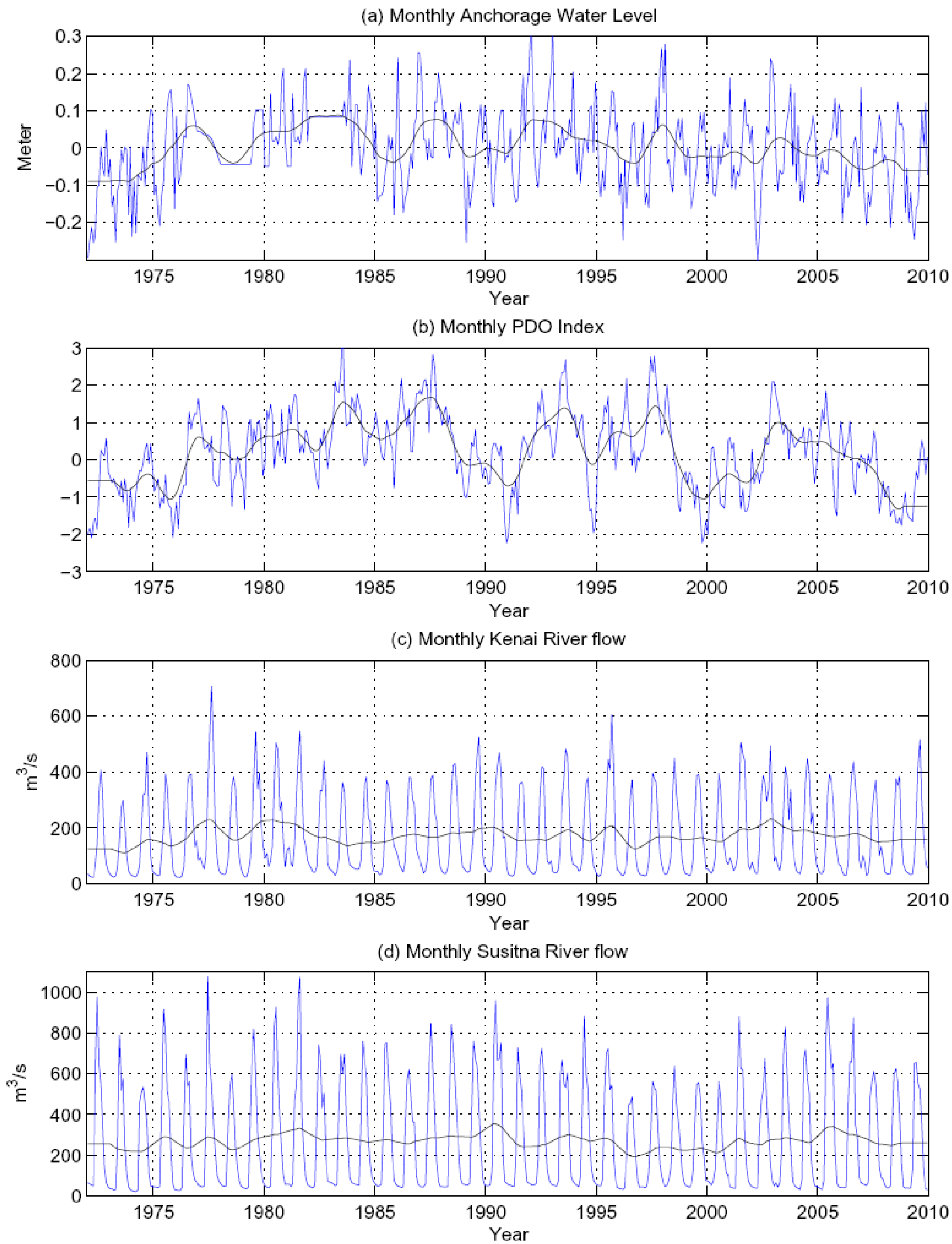

Fig. 11. *(a) Water level, (b) PDO index, (c) Kenai River flow and (d) Susitna River flow. Blue lines are for monthly values and black lines are for filtered records after the seasonal signal is removed.*

3. Summary

The preliminary research results from this NOAA-supported one-year project show how various physical and environmental parameters may impact the CIBW movements, survival strategies and potential future recovery. It is demonstrated that water level, water temperature, ice, and possibly large-scale climatic changes can impact the CIBW. For example, we show how the seasonal movements of the CIBW within the inlet are controlled by the different timing of maximum flow in each river, and how even a small change in water temperature between one year to another, affects the CIBW movement. This short-term project allows us to collect CIBW data, as well as local and regional physical data that will be used with further analysis. This project initiated a larger project, under the support of the Kenai Peninsula Borough, which will continue the research started here. The new research will also add to the team a group of fisheries ecologies that will provide more data and the CIBW's feeding and the possible connections with the physical data presented here. It is clear that further research is needed to better understand the mechanism in which all those physical parameters affect the CIBW.

We greatly thank NOAA's support (in particular, Barbara Mahoney, Rod Hobbs and Kaili Jackson, who provided us the CIBW data) and hope to continue the collaboration with the NOAA scientists.

4. References

Ezer, T., R. Hobbs and L.-Y. Oey, On the movement of beluga whales in Cook Inlet, Alaska: Simulations of tidal and environmental impacts using a hydrodynamic inundation model, Oceanography, Vol. 21, No. 4, 186-195, 2008.

Ezer, T., Hydrodynamic numerical ocean models support environmental Studies and conservation efforts: From an arctic estuary to a Caribbean coral reef, CCPO Circulation, Spring 2008, Vol. 15, No. 1, 1-3, 2008.

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.

Ezer, T. and H. Liu, On the dynamics and morphology of extensive tidal mudflats: Integrating remote sensing data with an inundation model of Cook Inlet, Alaska, Ocean Dynamics, doi:10.1007/s10236-010-0319-x, 2010.

Hobbs, R. C., K. L. Laidre, D. J. Vos, B. A. Mahoney and M. Eagleton, Movements and area of use of Belugas, Delphinapterus leucas, in a subarctic Alaskan estuary. Arctic, 58, 331-340, 2005.

Jin, M., C. Deal, ,J. Wang and C. P. McRoy, Response of lower trophic level production to long-term climate change in the southeastern Bering Sea, J. Geophys. Res.,114, C04010, doi:10.1029/2008JC005105, 2009.

Liu, H. and T. Ezer, Integration of Landsat imagery and an inundation model in flood assessment and predictions: A case study in Cook Inlet, Alaska, The 17th International Conference on Geoinformatics, Aug. 12-14, Fairfax, VA, IEEE Xplore Publ., 2009.

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, 2007.

Vos, D. J. and K. E. W. Shelden, Unusual Mortality in the Depleted Cook Inlet Beluga (Delphinapterus leucas) Population, Northwestern Naturalist, 86(2), 59-65, 2005.