U.S. NAVAL RESEARCH LABORATORY

Optimized drifter observations: An efficient and cheap way for operational hindcast of the circulation in the Chukchi Sea

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Objectives

- *Validate an inexpensive and efficient drifter observation program in the Chukchi Sea which provides a comprehensive observational dataset sufficient for accurate operational hindcast of the circulation in the Chukchi Sea.*
- *Compare efficiency of drifter observations with observations from High Frequency Radars using the Observing System Simulation Experiments approach.*
- *Develop a tool for dynamical optimization of a biological sampling strategy through the Observing System Simulation experiments.*
- *Analyze the errors in the reconstruction of the passive tracer by 4Dvar and conventional (linear and optimal interpolation) approaches.*

OSSE (observing system simulation experiment)

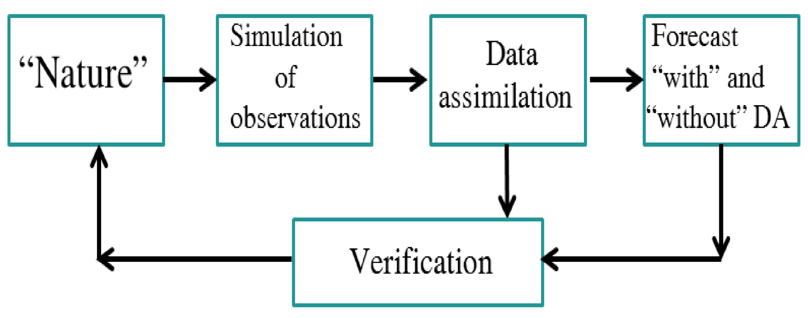


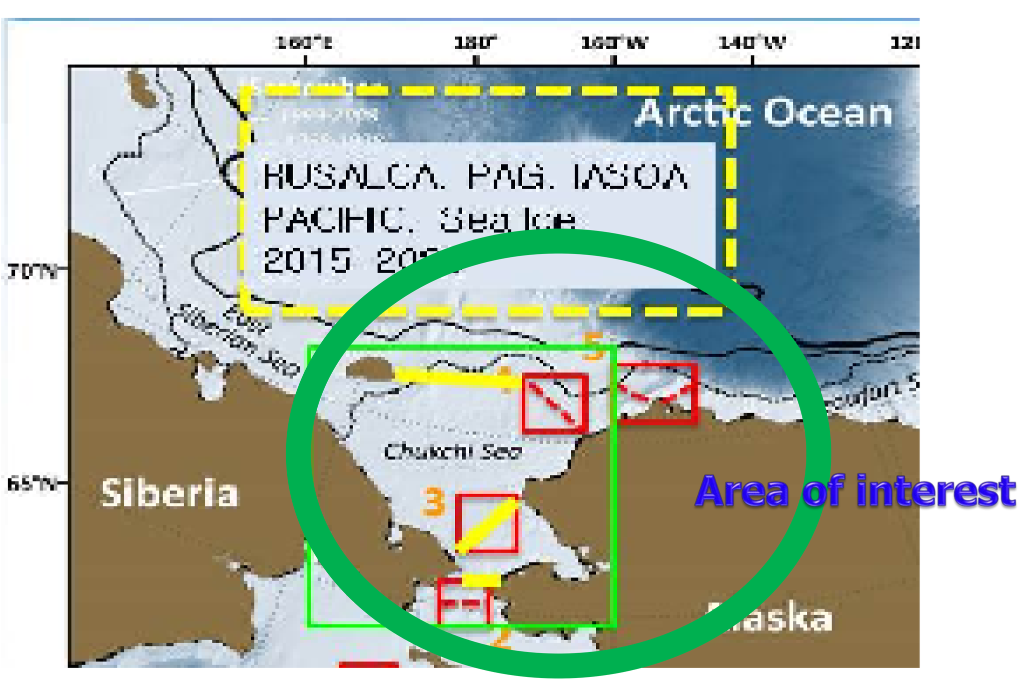
Figure 1. Schematic of a typical OSSE.

Observing System Simulation Experiments are widely used for skill assessment of DA systems (Wunsch, 1996). Oceanic OSSEs consist of controlled, quantitative assessments of the impact of a system of observations, determined by numerical modeling of the governing dynamical processes. Application of a typical OSSE includes five major steps:

(1) generating an appropriate "Realistic Run" (assumed truth) of the model which is validated against available observations;
(2) extracting the synthetic observations from the "Realistic" model run;
(3) characterizing observational error of the synthetic observations;
(4) assimilating the synthetic observations into a forecast model (typically different from the "Realistic Run" and referred to as the operational model); and
(5) evaluating the added value of the assimilated observations in terms of increased analysis and forecast skill and other metrics.

The schematic of the OSSE to be used in this project is shown in Figure 1.

Figure 2. Area of interest for drifter observations shown in green circle (figure taken from NPRB report).



The 4Dvar advection-diffusion model

The *Advection-Diffusion Biological Tracer Model (ADBTM)* is based on modified advection-diffusion equations which are the part of SIOM. Currently ADBTM includes exponential mortality/growth (*m*) and biological tracer horizontal and vertical (sinking) velocity (u_B, v_B, w_B) and fluxes F_{BO}, F_{BH} at the surface and at the bottom:

$$\partial B/\partial t+(u+u_b)\partial B/\partial x+(v+v_b)\partial B/\partial y+(w+w_b)\partial B/\partial z=\Delta B+\partial^2 B/\partial z^2-mB,$$

$$\partial B/\partial z=F_{B0},\ z=0; \quad \partial B/\partial z=F_{BH},\ z=H$$

According to the conventional 4Dvar DA approach, ADBTM assimilates biological data by minimizing the following cost function:

$$J=J_{data}+J_{sm}+J_{cntr}, \qquad J_{data}=\sum W_{data}^{-1}(RB-B^*)^2$$

$$J_{sm}=\int_{\Omega}\int_{T} W_{sm}^{-1}(\Delta(B))^2\, d\varpi dt \qquad J_{cntr}=\sum W_{cntr}^{-1}(c-c_{fg})^2$$

Here B denotes the vector of the ADBTM solution, B^* is the vector of biological tracer observations, R is an operator projecting B onto data locations, and c is the vector of ADBTM control parameters including initial/boundary and surface conditions, spatial distribution of passive tracer velocity (u_B, v_B, w_B), and mortality (*m*). The vector c_{fg} represents the first-guess values of these parameters. The vector of observations B^* includes observations of biological tracer concentrations and surface/bottom fluxes measured at different times and locations. The cost function term J_{data} attracts the model solution toward the data; J_{smooth} insures a reasonably smooth solution. The term J_{cntr} penalizes the amplitude of the control vector changes during the minimization procedure and makes the DA problem formally well-posed. The elements of the W_{data} matrix are specified as the estimates of error variance of the corresponding data, and W_{cntr} represents the prior estimates of the first-guess solution error variance at the locations of the ADBTM control variables. The matrix W_{sm} will be estimated from the analysis of typical spatial and temporal scales of variability (e.g. Panteleev et al., 2000; Panteleev et al., 2006). Recently this model was applied to reconstruct the climatological distribution of BS silicate (http://people.iarc.uaf.edu/~gleb/nprb_aleutian_passes/chemestri_atlas_b_s/chemistri.html).

The ADBTM DA system will be used to optimize the 3D biological tracer field, in the OSSEs, and in the adjoint sensitivity analysis. Thus, this system will be the basic tool for optimizing the sampling strategy in the BS and GoA. The robustness, linearity, and fast convergence of the ADBTM model are attractive features that will allow us to use it as a basic modeling tool on the interactive web server.

Drifters

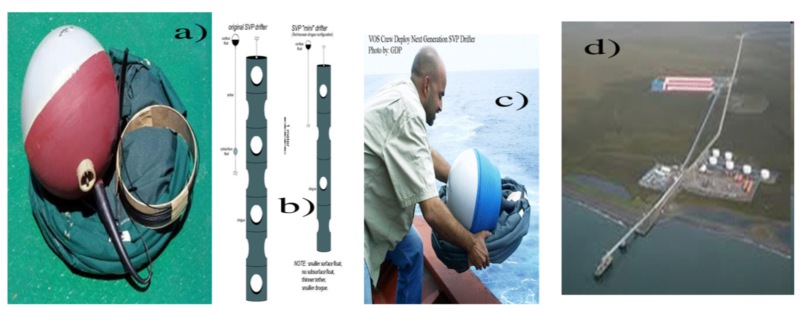
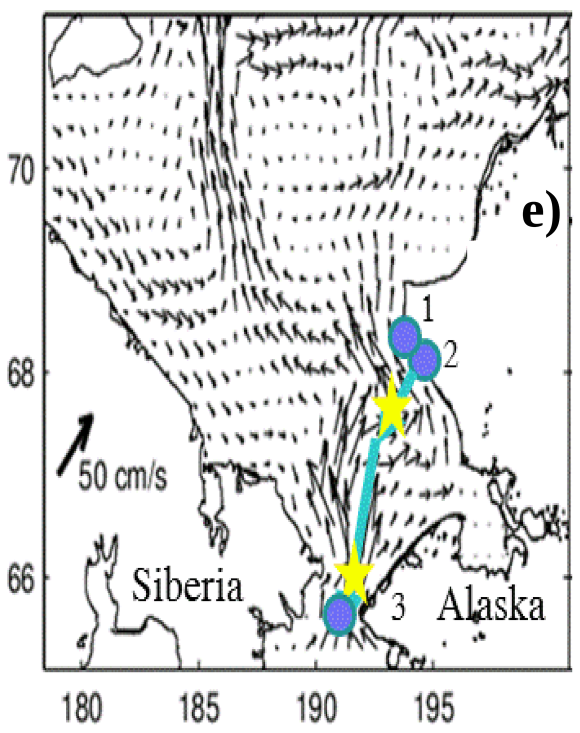


Figure 3. a),b),c), Sea Surface Drifters and a typical way of its deployment. d) Red Dog Port terminal in the Chukchi Sea: serves as a gate for loading zinc ore onto ships that steam toward Japan through the Bering Strait. e) Dots show shore locations 1) Pt. Hope, 2) Red Dog, 3) Little Diomede and yellow stars show drifter launch locations.



High frequency radars

Objectives

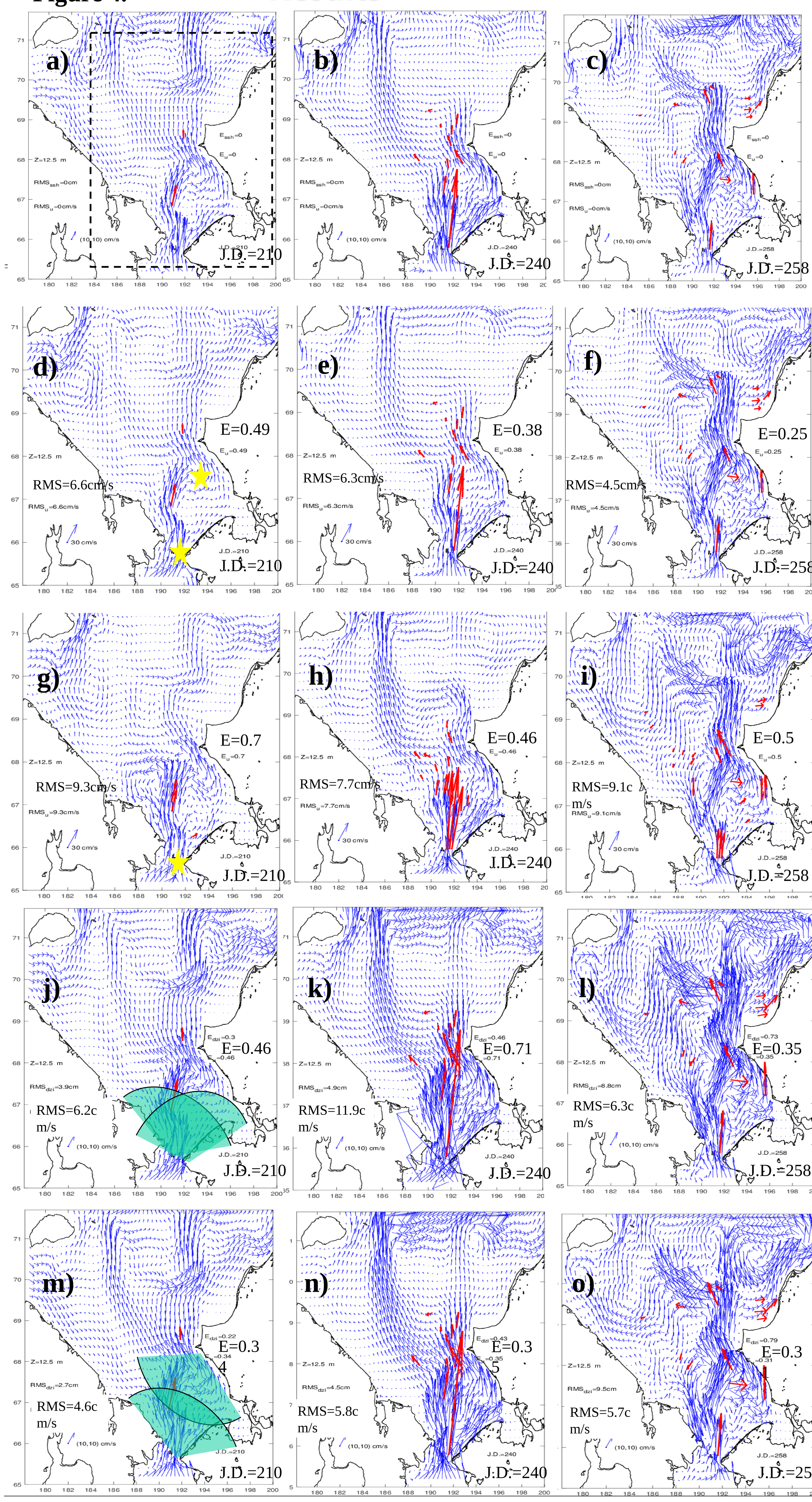
- **Analyze the efficiency of the drifter and High Frequency Radar observations in the Chukchi Sea with the goal of reconstructing the circulation in the Chukchi Sea.**
- **Develop an optimal observational strategy for the drifter and High Frequency Radar observations.**
- **Develop an algorithm for optimization of biological observations in the Chukchi Sea.**

Metrics:

RMS: $= \left[\langle (N_1-N_2)^2\rangle\right]^{1/2}$ **Error:** $= \left[\dfrac{\langle (N_1-N_2)^2\rangle}{\sqrt{\langle N_1'^2\rangle\langle N_2'^2\rangle}}\right]^{1/2}$

Results

Figure 4.



True solution:

Figure 4. a),b),c) As a nature model run mimicking a "true ocean" state, we utilized the realistic circulation during July 15, 1991-September 15, 1991 derived through the assimilation of velocity, temperature and salinity observations from 11 moorings (Panteleev et al., 2010). Initial velocity and boundary conditions before data assimilation were zero. Temperature and salinity were taken from climatological observations. In the *first OSSE*, we mimicked drifter observations from 14 drifters gradually "released" into the water every 9 days in the areas shown by yellow stars (Figure 3e): 1 drifter in the BS and 1 drifter near Red Dog Port. In the *second OSSE* 2 drifters were released in the Bering Strait every 9 days. In the *third and fourth OSSE* radial velocities from 2 HFRs deployed in the Diomede-Wales (both looking northward) and Wales (looking northward)-Point Hope (looking southward) were assimilated. Climatological distribution of the temperature/salinity with zero velocity field was used as a first guess. Relative error and RMS metrics were used for the analysis.

Semi Implicit Ocean Model (SIOM, Panteleev et al., 2010) was used in all OSSEs.

Reconstruction using drifters (~$90,000)

Figure 4.

14 drifters gradually "released" into the water every 9 days in the areas shown by yellow asterisks: 1 drifter in the Bering Strait and 1 drifter near Red Dog Port.

d-f)

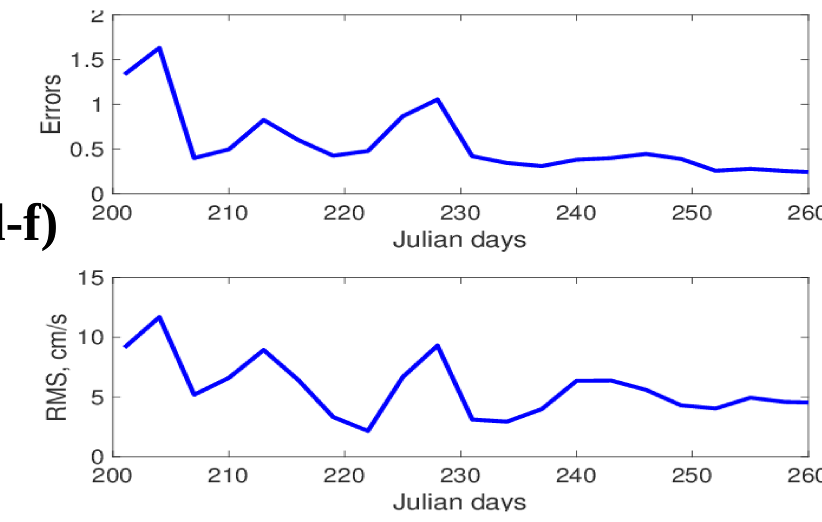
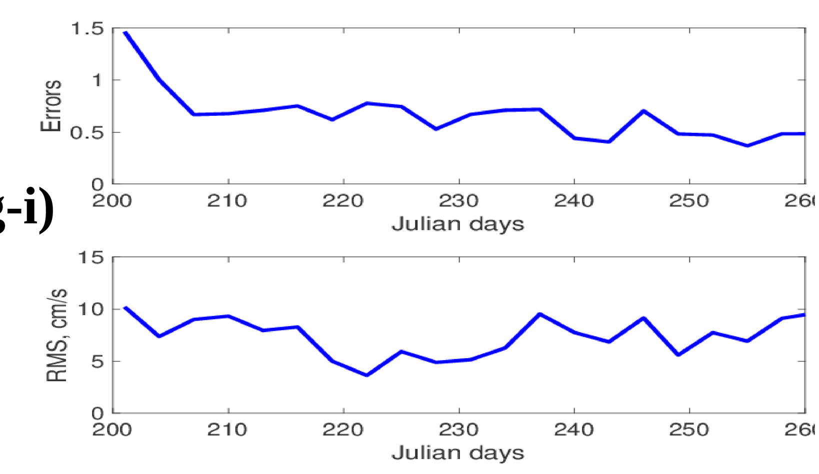


Figure 4. g),h),i) 2 drifters were released in the Bering Strait every 9 days.

g-i)



Reconstruction using High Frequency Radars (~$150,000)

Figure 4. j),k),l) Radial velocities from 2 HFRs deployed in the Diomede-Wales (both looking northward)

j-l)

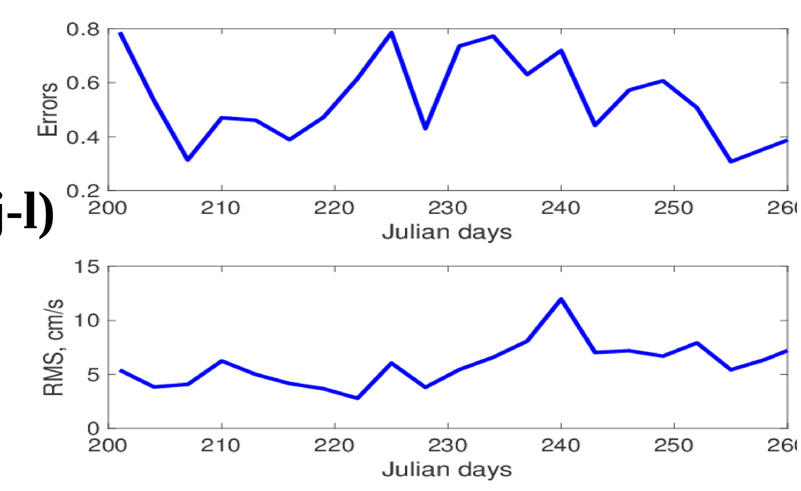


Figure 4. m),n),o) Radial velocities from 2 HFRs deployed in the Diomede- (looking northward) - Point Hope (looking southward) were assimilated.

m-o)

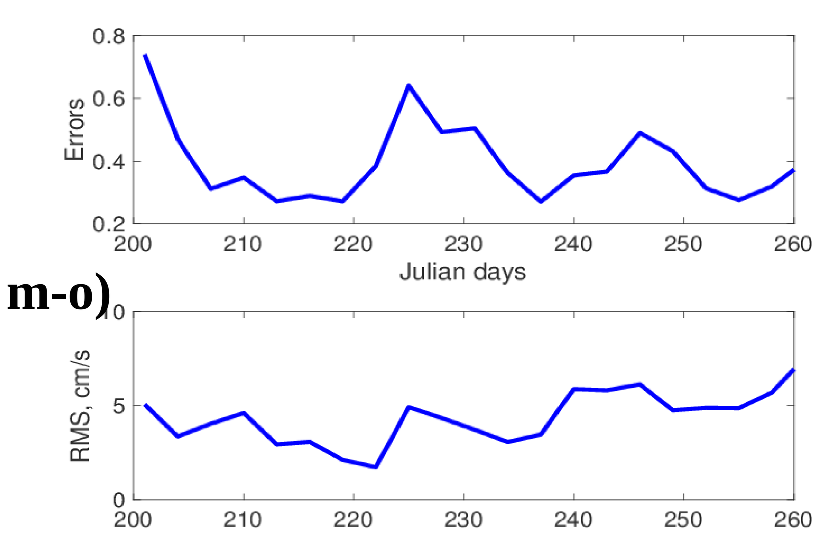
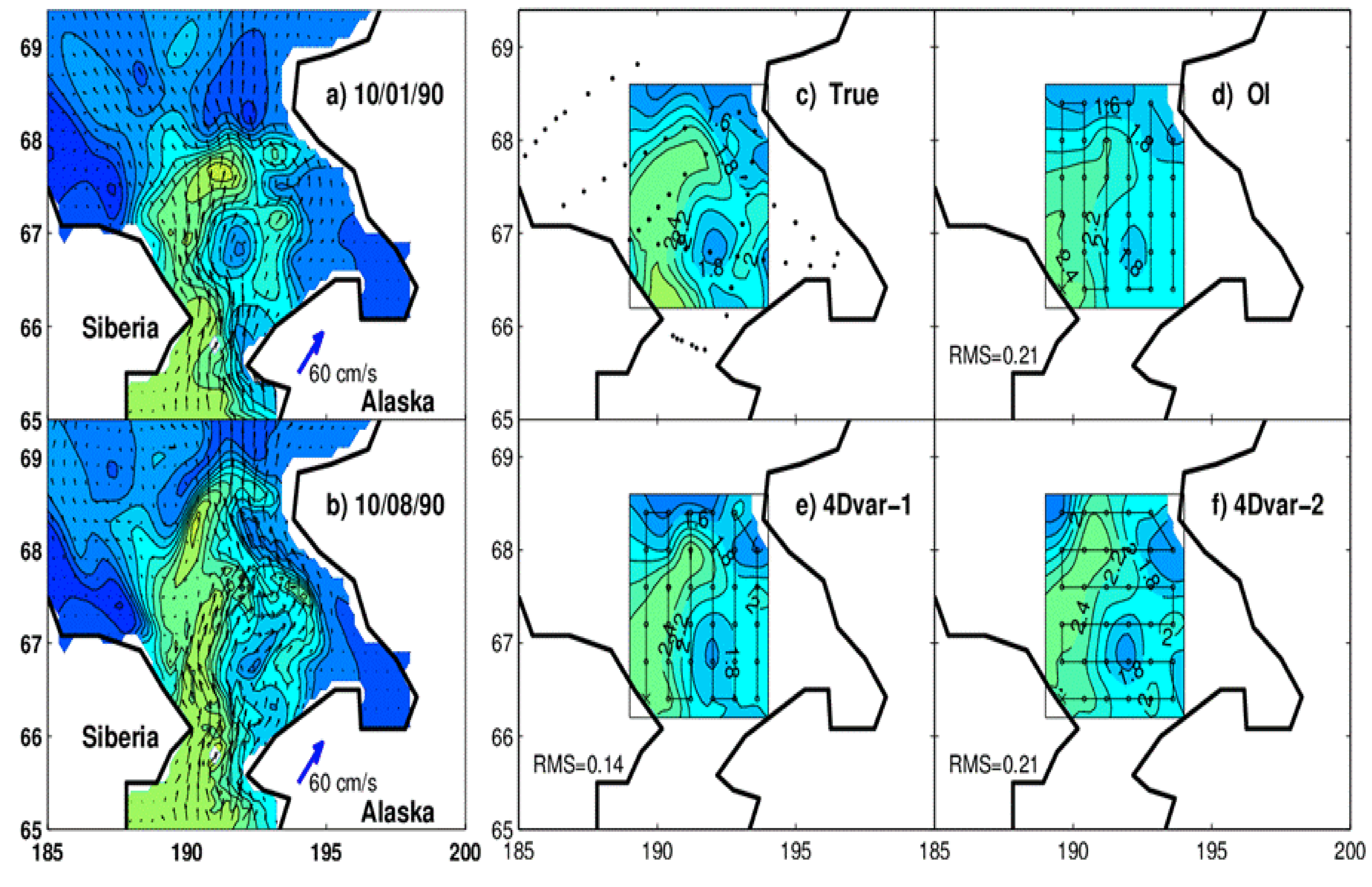


Figure 5. How reconstruction of the circulation can be used?

Optimal passive tracer survey : optimal planning and optimal procession



Conclusions

- **A properly constructed drifter observation in the Chukchi Sea would allow for accurate reconstruction of the circulation.**
- **Efficiency of the drifter observations outperform efficiency of the HFR observations in the Chukchi Sea.**
- **The ship traffic through the Bering Strait allows for the organization of a relatively cheap and efficient drifter observation program that will allow for accurate reconstruction of the circulation.**
- **The reconstructed circulation can be efficiently used for optimization and post processing of the biological surveys in the Chukchi Sea.**
- **The approach for biological passive tracer post processing is based on the assimilation of the passive tracer observations into a simple advective-diffusion model and OSSE experiments and allows 30-50% more accurate reconstruction of the biological parameters.**

Figure 5.
Realistic circulation **(a)** and phosphate distribution [μg/l] **(b)** in the Southern Chukchi Sea during Oct 1-8, 1990; **(c)** temporally mean "true" phosphate averaged for the OSSE's region. Black dots designate the locations of the phosphate observation in September 1990 utilized for the obtaining initial phosphate distribution (Fig.4a); **(d)** phosphate distributions derived from an idealized survey using conventional optimal interpolation; **(e)-(f)** temporally averaged phosphate distributions derived through 4Dvar data assimilation of the observations derived from two possible surveys. Black cross and dots designate the first station and direction of the surveys. The RMS between reconstructed and "true" phosphate distribution are shown.