Toward a reliable wave hindcast/forecast in the Bering Sea

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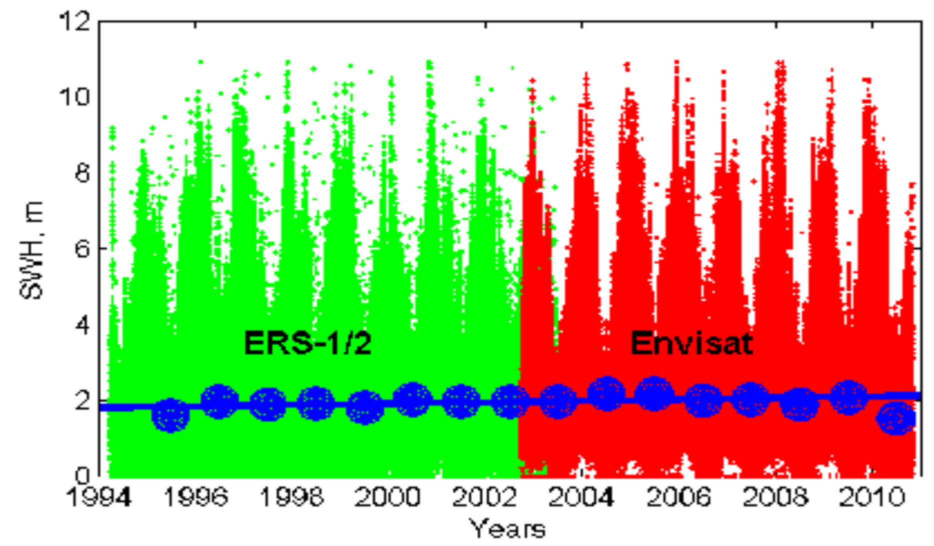
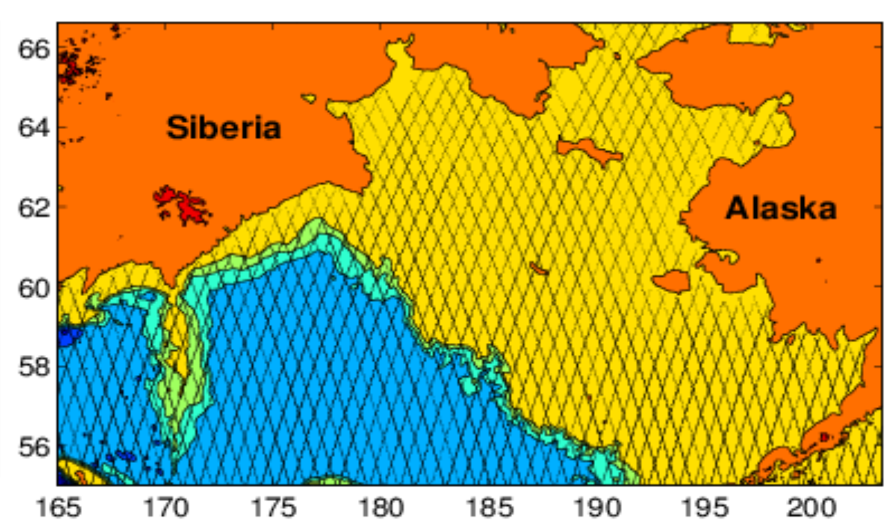
Motivation

1. To validate the quality of available wind products through application of the WAM model Cycle 4.5 and satellite observations
2. To analyze effects of high resolution atmospheric model downscaling and data assimilation
3. To analyze summer surface wave condition in the Bering Sea during the years, 2007-2011
4. To explore the possibility of developing a new algorithm for a dynamically constrained minimizing function without employing the adjoint of the dynamical system (Chukchi Sea application – see bottom right of this poster)

SWH from ERS-1/2 and Envisat satellites in the Bering Sea



Tracks of ERS-1/2 and Envisat satellites in the Bering Sea



Models

Validation approach:

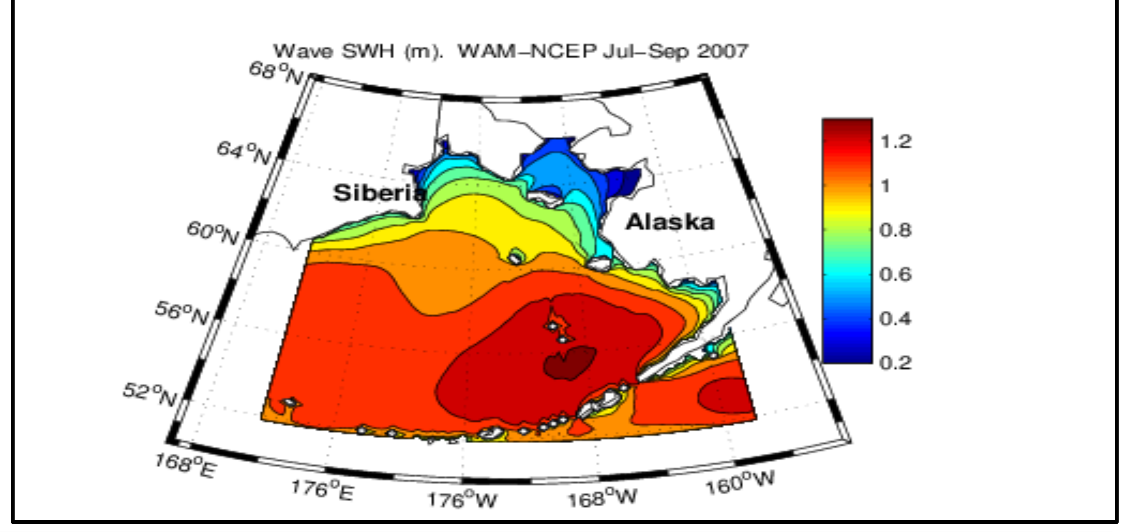
Atmospheric reanalysis or results of WRF based downscaling: 10-m wind and ice concentration → Regional WAM model → Maps of significant wave height

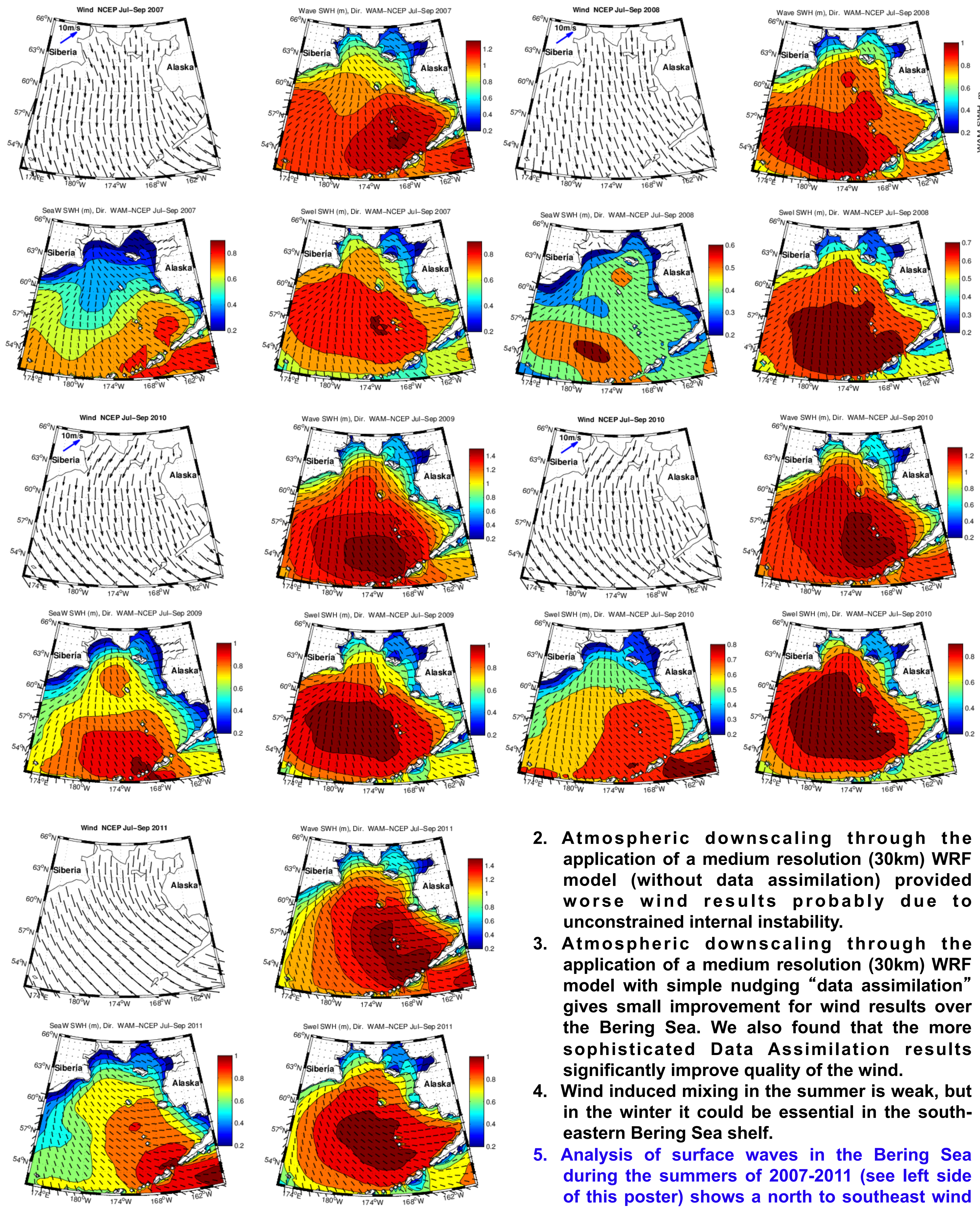
Alongtrack satellite (Envisat) observations of Significant Wave Height (SWH)

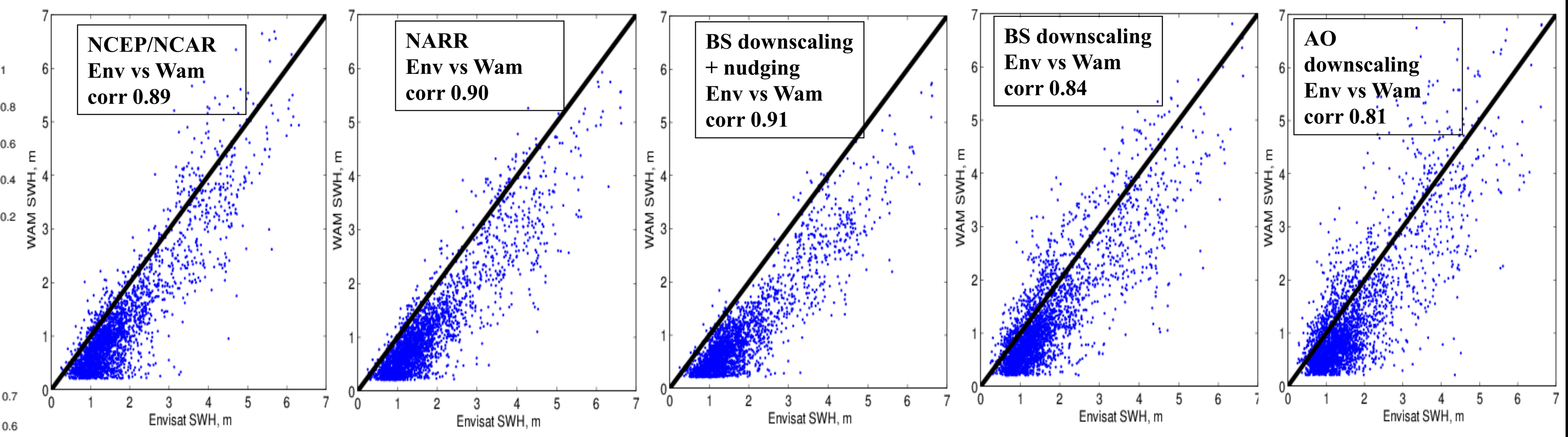
Compare: satellite and wave model results

WAM (wave model Cycle 4.5)

WAM was configured for the Bering Sea domain for validation of available wind products and analysis of interannual variability of wave conditions during the summer.

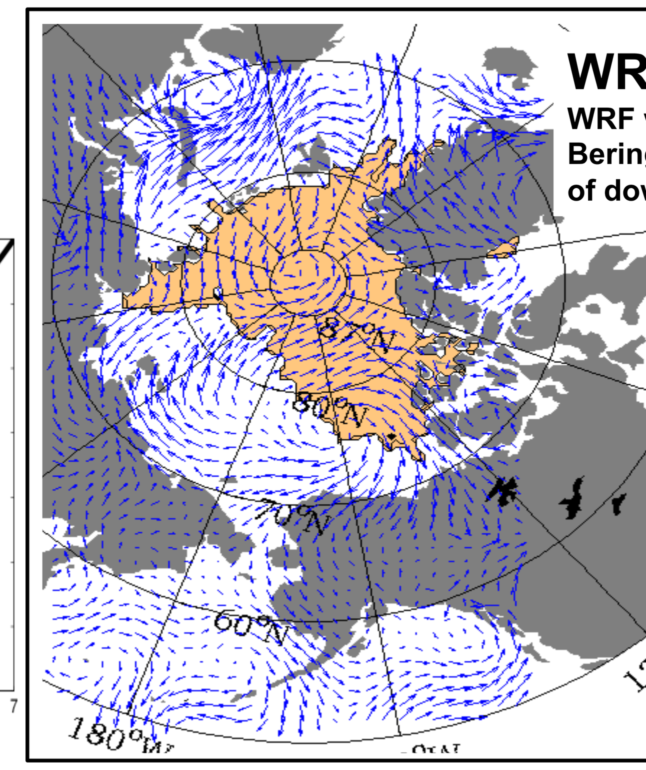


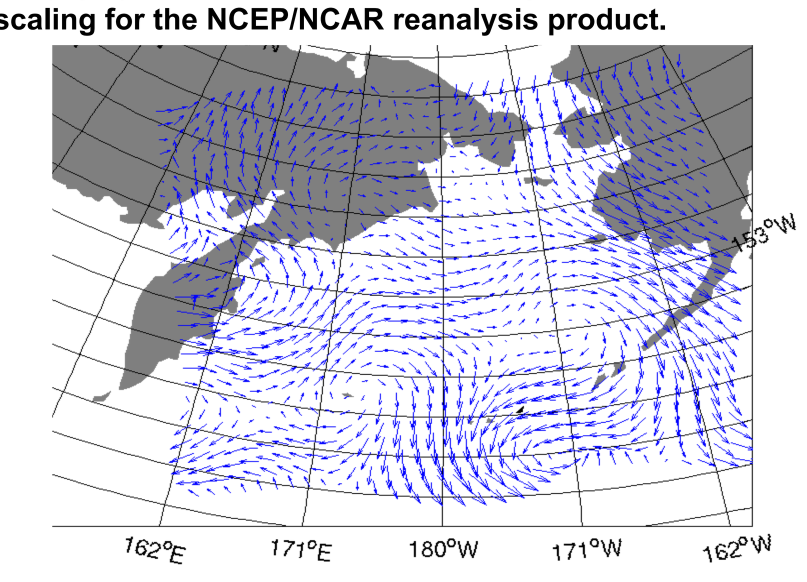




WRF (atmospheric model)

WRF was configured for the Arctic Ocean (left) and Bering Sea (right) domains in order to investigate results of downscaling for the NCEP/NCAR reanalysis product.





Reduced Space 4Dvar Theory

External loop

$$x_0^0 \longrightarrow \{x_0(t^n)\} \longrightarrow EOF\{x_0(t^n)\} \longrightarrow \{e_0^m\} \longrightarrow \mathcal{K}_0^m = \mathrm{span}\{e_0^m\}$$

$$J = \frac{1}{2}[\mathbf{S}(x^0\quad) - \mathbf{d}]^\dagger[\mathbf{S}(x^0\quad) - \mathbf{d}] \rightarrow \min_{x^0 \in \mathcal{K}_0^m}$$

$$x_1^0 = x_0^0 - \tilde{x}_0^0 \equiv x_0^0 - P_0 H_0^{-1}\nabla_0 J; \quad \tilde{x} = \tilde{x}_0^0$$

$$x_1^0 \longrightarrow \{x_1(t^n)\} \longrightarrow EOF\{x_1(t^n)\} \longrightarrow \{e_1^m\} \longrightarrow \mathcal{K}_1^m = \mathrm{span}\{e_1^m\}$$

$$J = \frac{1}{2}[\mathbf{S}(x^0 + \tilde{x}) - \mathbf{d}]^\dagger[\mathbf{S}(x^0 + \tilde{x}) - \mathbf{d}] \rightarrow \min_{x^0 \in \mathcal{K}_1^m}$$

$$x_2^0 = x_1^0 - \tilde{x}_1^0 \equiv x_1^0 - P_1 H_1^{-1}\nabla_1 J; \quad \tilde{x} = \tilde{x} + \tilde{x}_1^0$$

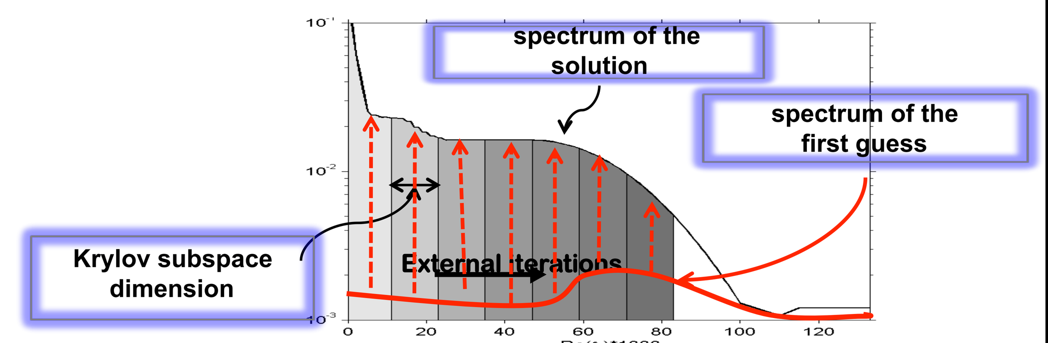
Internal loop

$$\vdots$$

$$x_j^0 \longrightarrow \{x_j(t^n)\} \longrightarrow EOF\{x_j(t^n)\} \longrightarrow \{e_j^m\} \longrightarrow \mathcal{K}_j^m = \mathrm{span}\{e_j^m\}$$

$$J = \frac{1}{2}[\mathbf{S}(x^0 + \tilde{x}) - \mathbf{d}]^\dagger[\mathbf{S}(x^0 + \tilde{x}) - \mathbf{d}] \rightarrow \min_{x^0 \in \mathcal{K}_j^m}$$

$$x_{j+1}^0 = x_j^0 - \tilde{x}_j^0 \equiv x_j^0 - P_j H_j^{-1}\nabla_j J; \quad \tilde{x} = \sum_j \tilde{x}_j^0$$



Sensitivity to wind forcing

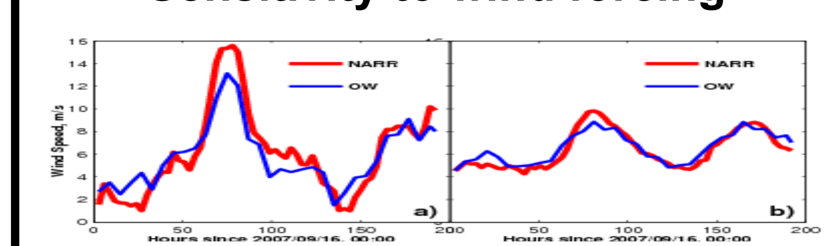
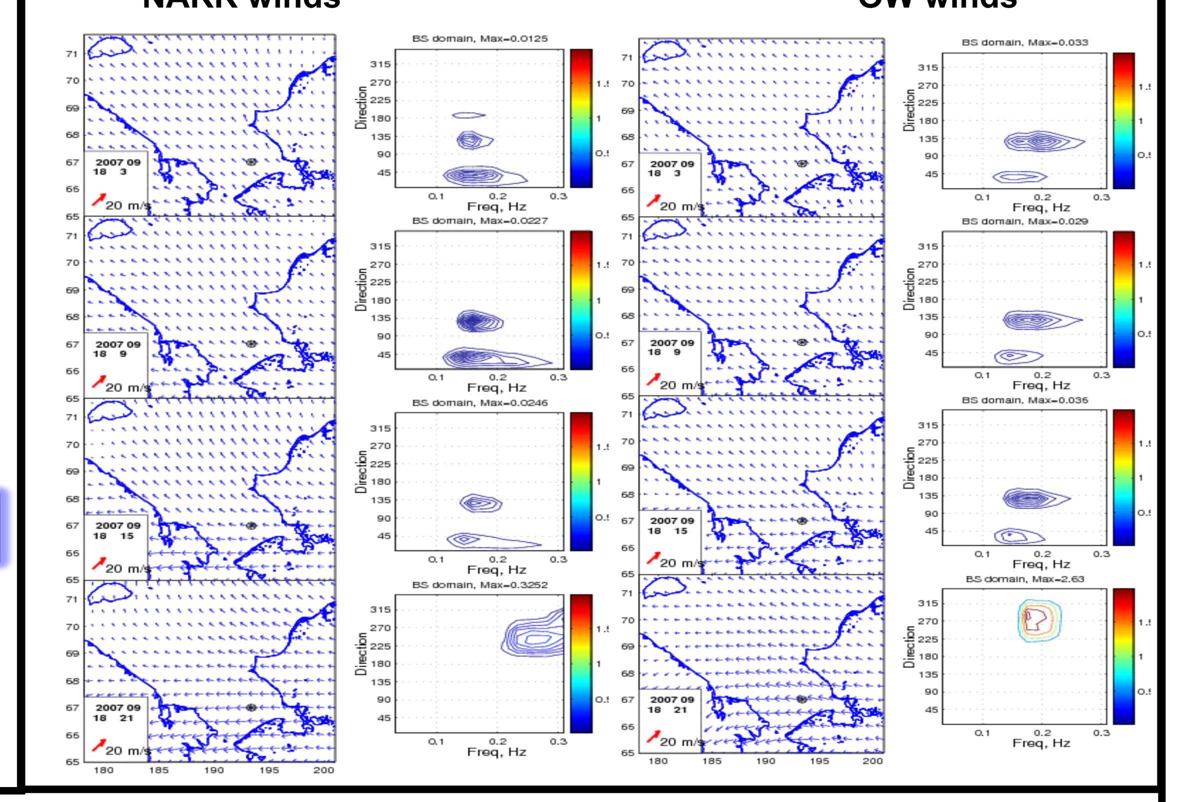
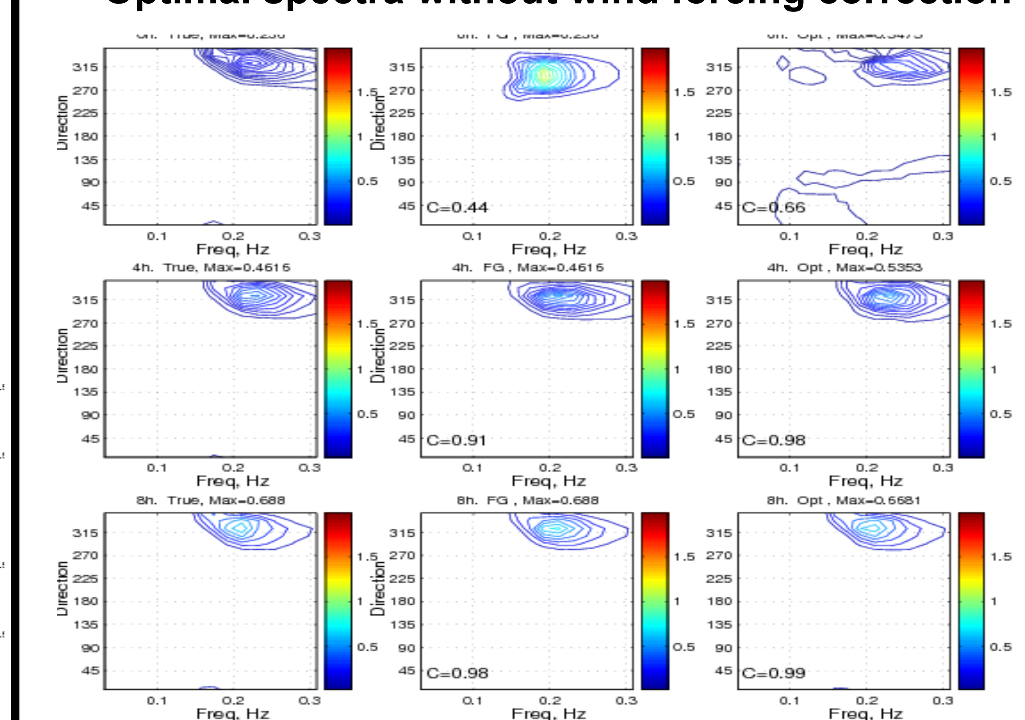


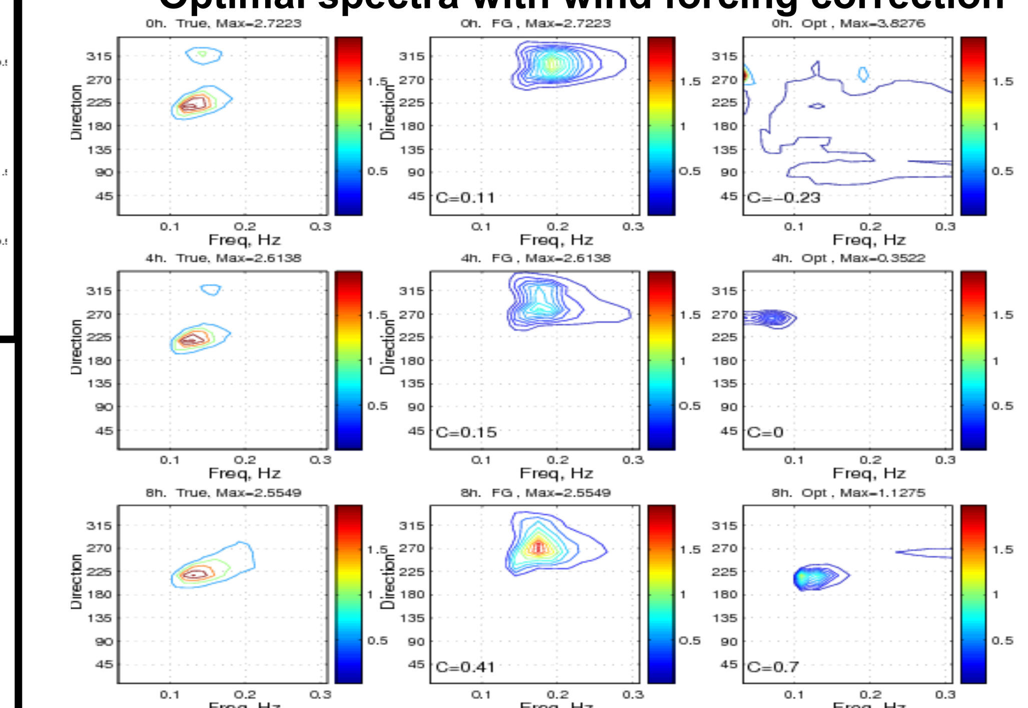
Figure 2 Evolution of the RMS wind speed over the domain for the cases of NARR and OW wind forcings in September 2007.



Optimal spectra without wind forcing correction



Optimal spectra with wind forcing correction



2. Atmospheric downscaling through the application of a medium resolution (30km) WRF model (without data assimilation) provided worse wind results probably due to unconstrained internal instability.
3. Atmospheric downscaling through the application of a medium resolution (30km) WRF model with simple nudging "data assimilation" gives small improvement for wind results over the Bering Sea. We also found that the more sophisticated Data Assimilation results significantly improve quality of the wind.
4. Wind induced mixing in the summer is weak, but in the winter it could be essential in the south-eastern Bering Sea shelf.
5. Analysis of surface waves in the Bering Sea during the summers of 2007-2011 (see left side of this poster) shows a north to southeast wind direction with matching wave direction.
6. Large low pressure systems over the North Pacific / southern Bering Sea are the biggest contributor to waves. This can be seen by the wind sea and swell results which generated the highest wave heights north of the Aleutian Islands.

CONCLUSIONS 1

1. NCEP/NCAR and NARR reanalysis are of similar quality with respect to hindcasts of surface waves.

Twin-data experiments with the WAM model

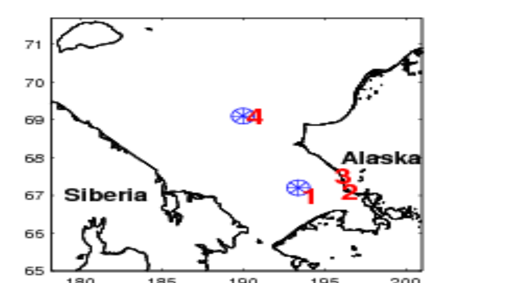
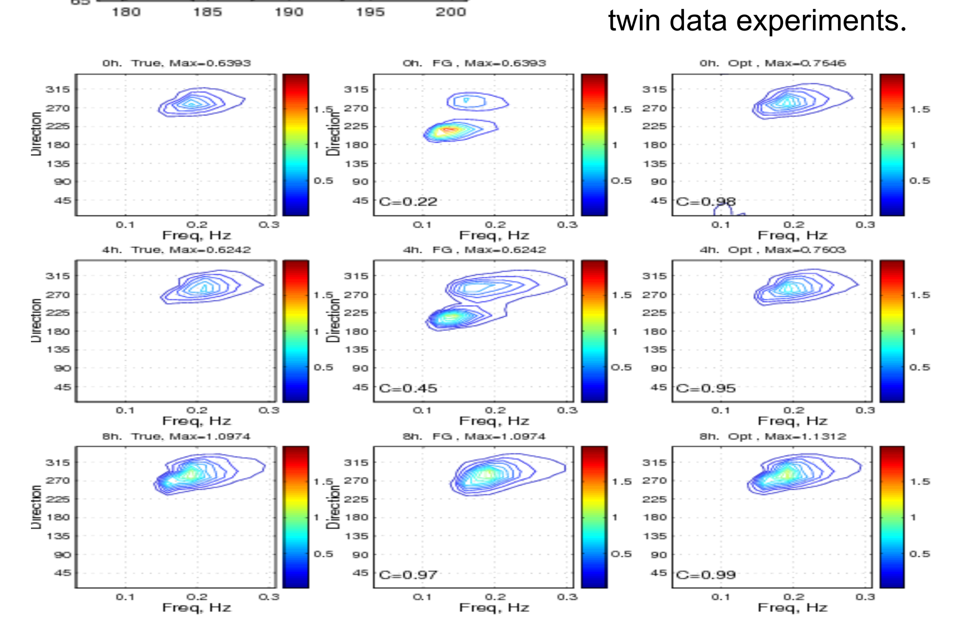
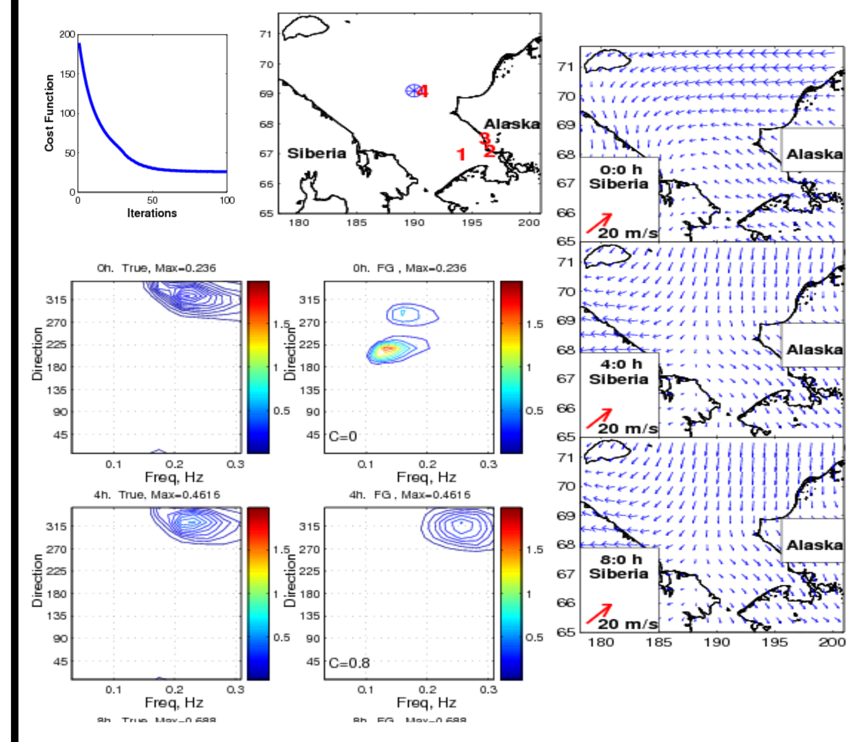


Figure 1 Model domain. Blue circles designate the location where directional wave spectra were extracted from "true" solution and then utilized as simulated data for the twin data experiments.



Setting twin-data experiments with wind forcing corrections as control variables



CONCLUSIONS 2

1. The r4dVar algorithm has been successfully implemented and tested with the WAM model in the framework of twin-data experiments.
2. It is shown that the WAM model solutions in the Chukchi Sea are controlled by wind forcing on time scales larger than 6-8 hours. An extension of the r4dVar method has been proposed to support the external forcing control capability.
3. Preliminary experiments with an idealized MIT model configuration have shown that the r4dVar technique is compatible in numerical efficiency with a standard optimization scheme which employs adjoint code.
4. These results give good prospects for coupled wave-ocean data assimilation using the r4dVar approach.