Statistical Emulation of High-Resolution SAR Wind Fields from Low-Resolution Model Predictions

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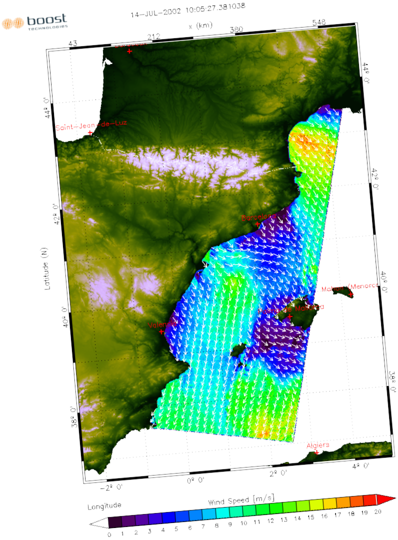


Source: *CLS (ex. Boost Technologies)*

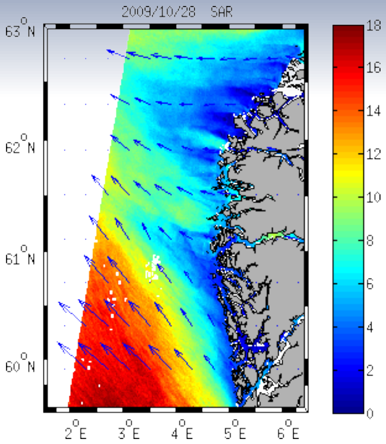
High-Resolution Data Application

- Describe and analyze the ocean dynamics in detail, particularly in coastal area
- Extend and improve numerical prediction models
- Aid energy production, track oil spill disasters
- Help the assessment of risks relevant to marine engineering, environment pollution
- ...

Motivation (1)

Satellite SAR (Synthetic Aperture Radar) Systems

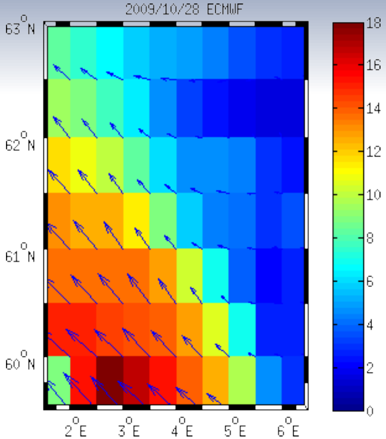
- ☺ High spatial resolution, $< 0.01°$, $\approx 1\,\mathrm{km}$
- ☹ Irregular sampling for a given region
- ☹ Low temporal resolution, every 7-to-10 days for temperate zones



Motivation (2)

Numerical Model Predictions

- ☺ High temporal resolution, every $3\,\mathrm{h}$ or $6\,\mathrm{h}$
- ☺ Global coverage
- ☹ Low spatial resolution, $0.5°$ for example



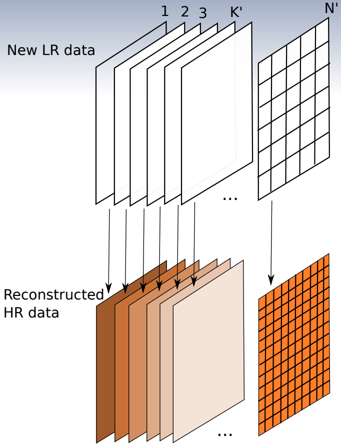
Motivation (3)

Use statistical emulation model

- to learn low-high resolution relationship

For new input LR data

- Derive HR (High Resolution) information from LR (Low Resolution) information
- Reconstruct HR wind fields for anywhere and at anytime



Problem Formulation

Regression Problem

- $y = f(x)$
- x and y are two-dimensional vector fields parameterized according to the zonal and meridional wind components

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Learning Scheme

- Goal: learn regression function f
- From a training set $\{(x_k, y_k)\}$, $k \in (1, n)$
- Find an optimal f^*: minimize the regression errors $\sum_{k=1}^{n}(y_k - f^*(x_k))$ or $\sum_{k=1}^{n}(y_k - f^*(x_k))^2$

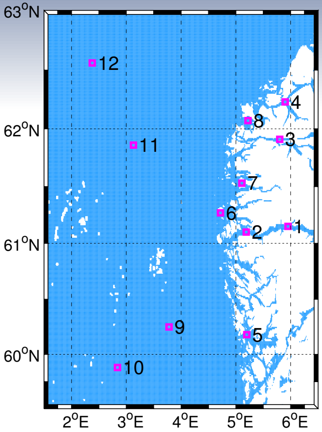
Data Set and Study area

Data set

- Select the closest ECMWF data to SAR data acquisition ; very different pairs are rejected
- 758 pairs for the period 2005–2010

Study Area

- Southwestern coastal sea of Bergen, Norway
- Many islands, mountains, and fjords in coastal area



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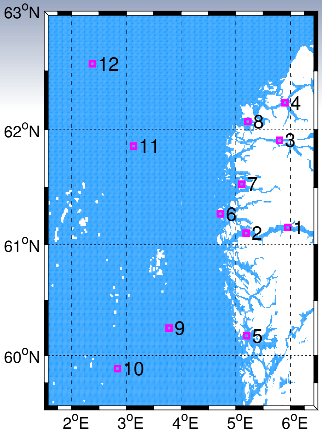
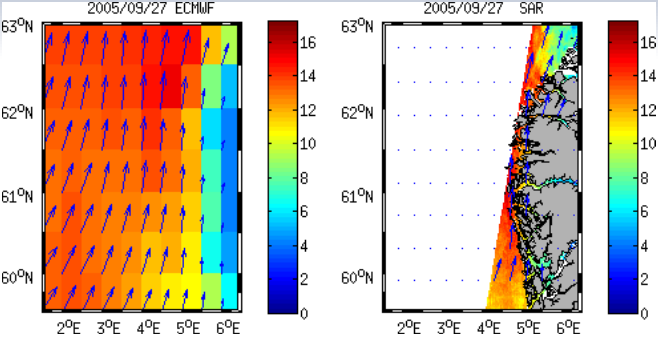
Study Area

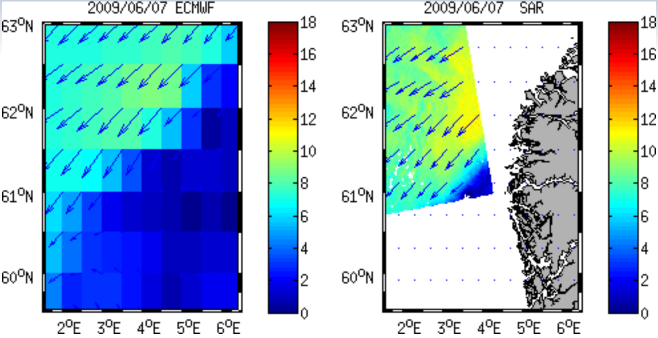
- Southwestern coastal sea of Bergen, Norway
- Many islands, mountains, and fjords in coastal area ⇒ Remarkable local effects: coastal jets, wind shadows, land-sea breezes. . .



Data Set Examples (1)

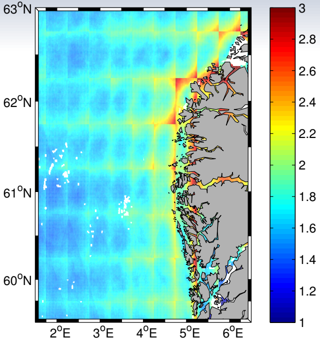


Data Set Examples (2)

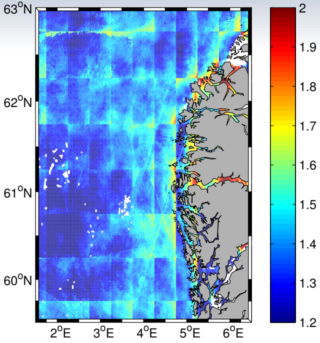


Physical Constraint Analyses (1)

Global Analyses



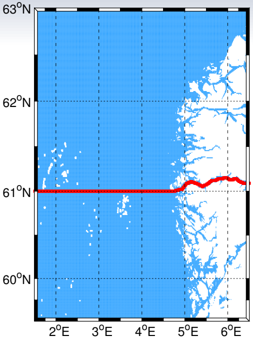
Mean of the difference between ECMWF and SAR



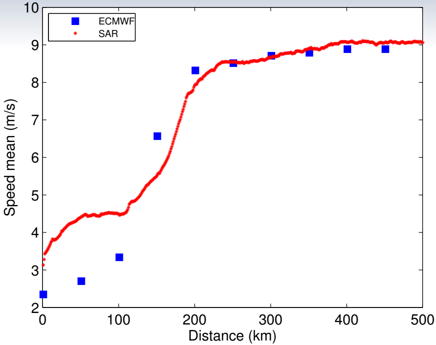
Standard deviation of the difference ECMWF-SAR

Physical Constraint Analyses (2)

Transect perpendicular to the coast



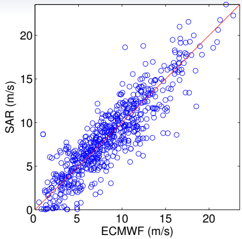
Transect line



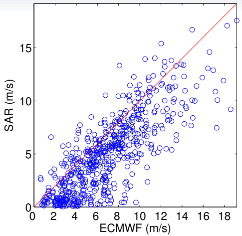
ECMWF and SAR mean

Physical Constraint Analyses (3)

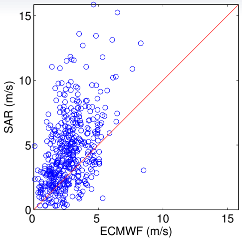
Scatterplots of ECMWF-SAR for: offshore, coast, fjord feature grid point



Offshore feature point 9
(N62.25°, E3.78°)



Coastal feature point 8
(N62.07°, E5.22°)

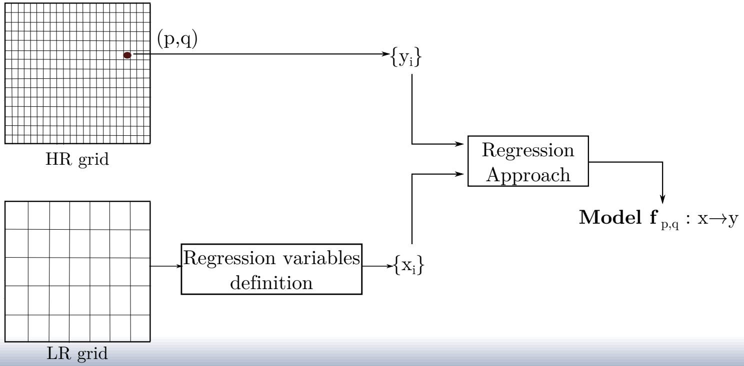


Fjord feature point 1
(N61.15°, E5.95°)

Non-linear LR-HR relationship in coastal and fjord area, compared to offshore area

Proposed Regression Model

- Point-specific model: a transfer function for each HR grid point
- Regression approach choice
- Regression variables (predictors) definition



Regression Technique Choices

- Analog methods – standardized responses of similar cases:

$$f(x) = \sum_{s=1}^{n} w_s \, \mathrm{g}(x, x_s) \tag{1}$$

- Multiple Linear Regression (MLR) – linear relation between inputs and outputs:

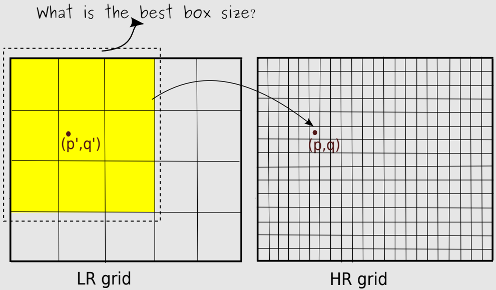
$$f(x) = \omega^t x + b \tag{2}$$

- Non-Linear SVR (Support Vector Regression) – optimal non-linear kernel-based model, linear regression model in a space defined by a non-linear function mapping:

$$f(x) = \omega^t \Phi(x) + b \tag{3}$$

Regression Variable Definition (1)

- Global information: the first *m* Principle Components (PCs) in the Empirical Orthogonal Functions (EOFs) space
- Local information: exploits the LR wind information within a local neighborhood



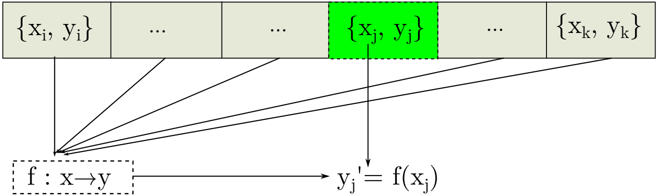
Regression Variable Defintion (2)

- Entropy-based information selection step:
  - Conditional entropy $H(y|x)$ is a measure of amount of uncertainty remaining about y after x is known
  - For a given HR grid point p, we select the LR grid points with the lowest conditional entropy values for HR field at this point:

$$H(y_p|x_q) = -\sum_{j=1}^{m}\sum_{i=1}^{n} P(y_p = y_j, x_q = x_i) \log P(y_p = y_j|x_q = x_i) \quad (4)$$

Evaluation

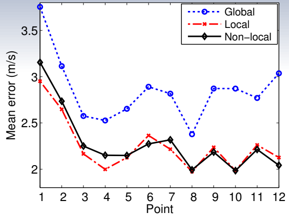
- Qualitative and quantitative evaluation
- Cross validation
  - 95% randomly sampled for training
  - 5% for reconstruction



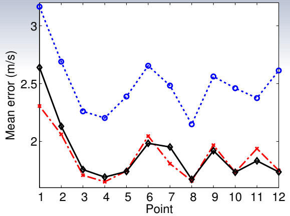
- Regression performance for 12 HR grid points

Regression Variable Influence

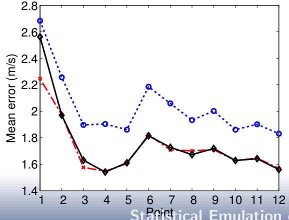
Information type: global, local and entropy-based information



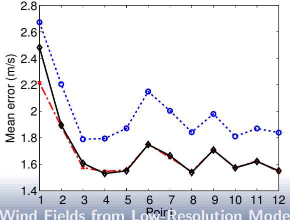
Nearest Neighbor



K-Nearest Neighbor



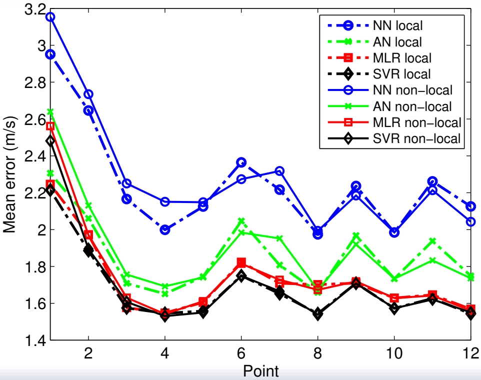
MLR



SVR

Regression Approach Influence

Compared approaches: Nearest Neighbor (NN), Weighted Average Analog (AN), Multiple Linear Regression (MLR), Support Vector Regression (SVR)

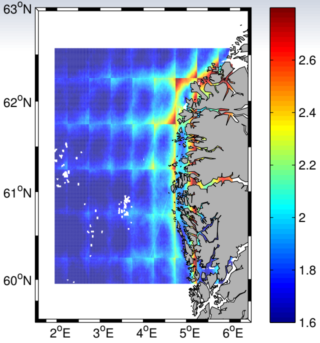


Optimal Regression Model

- SVR
- Local or non-local entropy-based variables' selection

Statistical Properties (1)

Global Analyses



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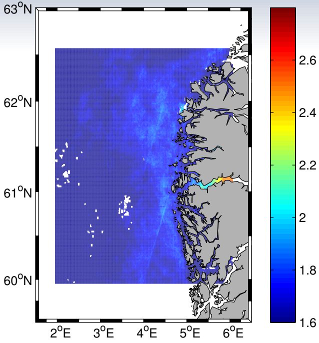
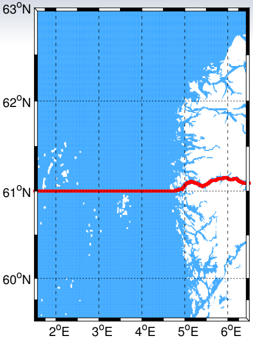


Mean of the difference between Reconstruction and SAR data

Statistical Properties (2)

Transect perpendicular to the coast



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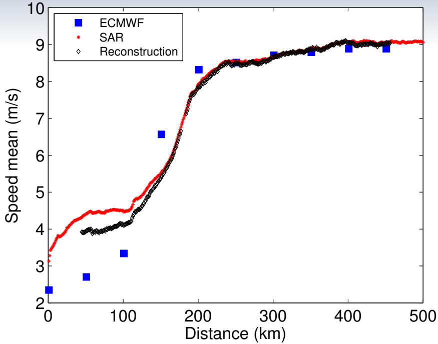
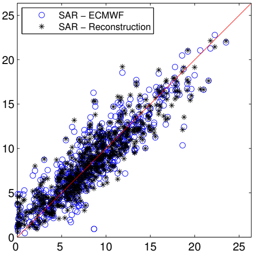


ECMWF, SAR and Reconstruction speed mean

Statistical Properties (3)

Scatterplots of SAR-ECMWF and of SAR-Reconstruction for: offshore, coast, fjord feature grid point



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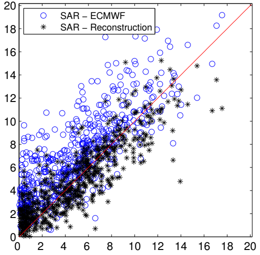

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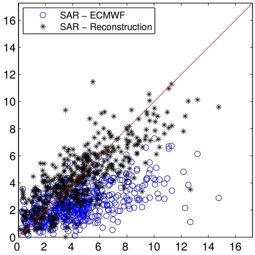
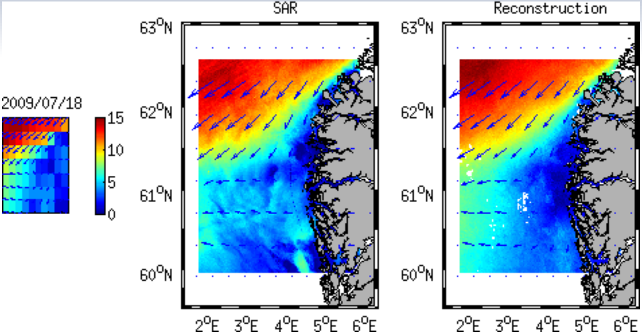
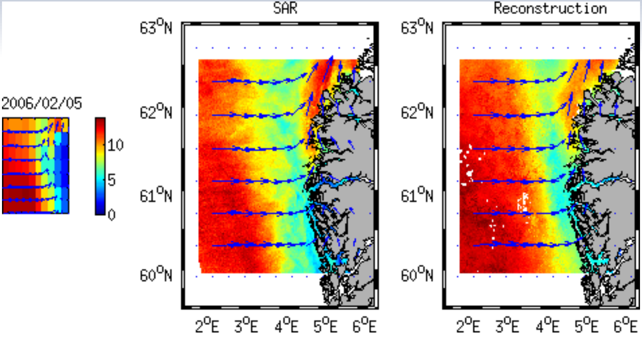


Fjord feature point 3
(N61.91°, E5.80°)

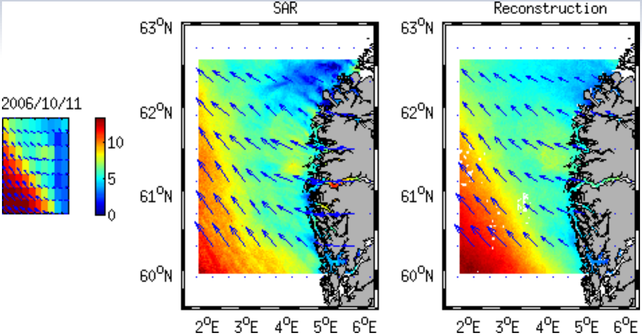
Reconstruction Example (1)



Reconstruction Example (2)



Reconstruction Example (3)



Thanks!