COMPARISON OF DIFFERENT METHODOLOGIES IN VERTICAL WIND EXTRAPOLATION FOR SATELLITE RETRIEVALS

Alberto Rabaneda
Matthew Stickland
University of Strathclyde
Mechanical and Aerospace Engineering Department

Outline

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2. U* methodologies
3. Z_0 methodologies
4. Z_0 regimes
5. Locations
6. Data computation
7. Results
8. Conclusions

Introduction

Hub height wind resource estimation

$$U(z) = \frac{U_*}{k}[ln(z/z_0) + \Psi_s(z/L_s)] \qquad z \rangle\rangle z_0$$

Rewritten equation

$$U(z) = \frac{U_*}{k}\left[\ln\left(\frac{z}{z_0}\right) - \Psi_m\right]$$

Neutral winds at 10 m over the sea

$$U(z) = \frac{U_*}{k}\left[\ln\left(\frac{z}{z_0}\right)\right]$$

2 measurements at
different heights required

$$U(z) = U(z_r)\left[\frac{ln(z/z_0)}{ln(z_r/z_0)}\right]$$

U* methodologies

Wu method

$$C_{10} = [0.8 + 0.065 \times U_{10} \times 10^{-3}]$$

$$C_{10} = \frac{{u_*}^2}{{U_{10}}^2}$$

- U10 dependant
- Best fit U<15 m/s

C_{10} = drag coefficent at 10 m
U_{10} = wind speed at 10 m
u* = friction velocity

Wu, Wind-Stress Coefficients Over Sea Surface From Breeze to Hurricane, J. of geophysical research, November 1982.

U* methodologies

ECMWF method

$$C_{10n} = \left(\frac{k}{b_{fit}}\right)^2$$

$$b_{\alpha} = 2.65 - 144\times\log A - 0.0015\times(\log A)^2$$

$$b_{fit} = [(b_v)^p + (b_\alpha)^p]^{1/p}$$

$$b_v = -1.47 + 0.93\log_{10}\left[\frac{z\times k\times U_{10}}{v\times\alpha_M}\right]$$

$$A = \frac{\alpha_{Ch}}{g\times z}\times(k\times U_{10})^2$$

- Charnock parameter, kinematic viscosity & U_{10} dependant.
- It can be used for different heights and wind speeds.

v = Kinematic viscosity of air
α_{ch} = Charnock parameter
α_M = 0.11
z = height

Hersbach, Sea-surface roughness as function of neutral wind speed, ECMWF, July 2010

U* methodologies

Maat method

$$H_* = B \times (c_p / u_*)^{3/2}$$

$$H_* = \frac{g \times H_S}{(u_*)^2}$$

$$u_* = \frac{g^2 \times (H_S)^2}{B^2 \times (c_p)^3}$$

- Wave age and wave height dependant.
- It is supposed to hold for growing pure wind waves.

H* = Dimensionless wave height
C_p = phase speed at the peak frequency
B = empirical coefficient
g = gravitational acceleration
H_s = Significant wave height

Maat et al., The roughness of wind waves, Boundary-layer Meteorology, 1991.

U* methodologies

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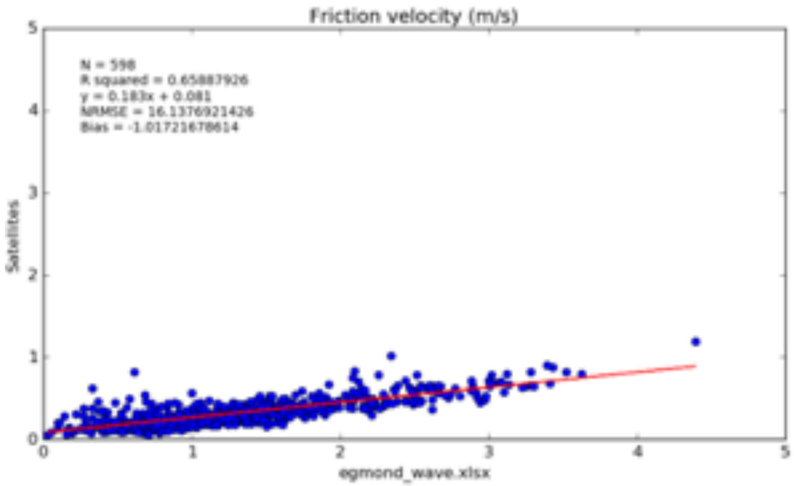
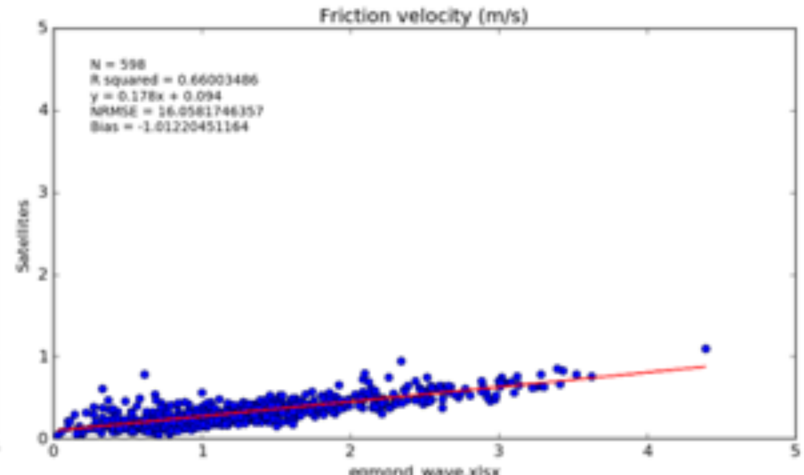
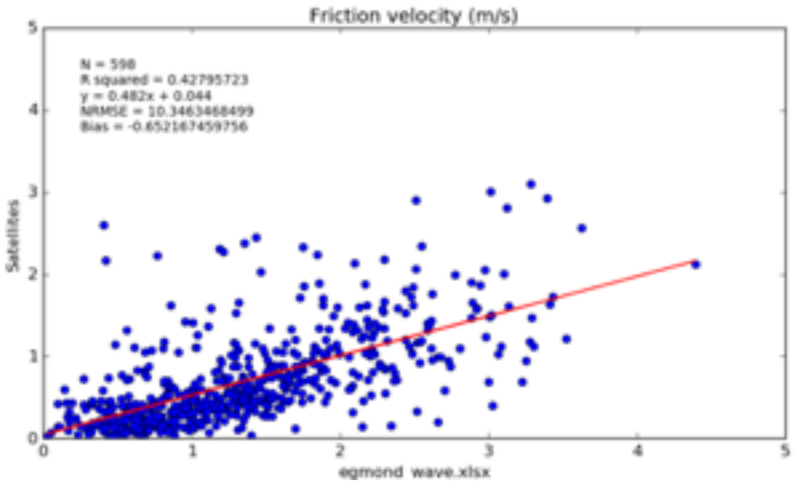
ECMWF



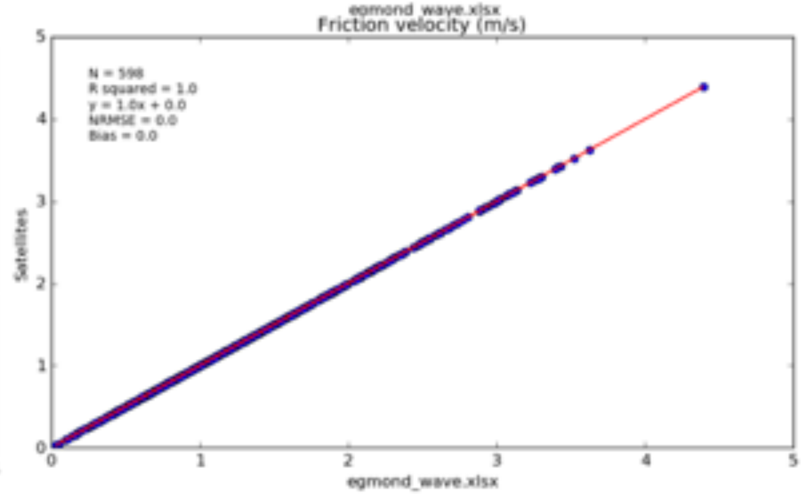
Wu



Maat



Control



Z_0 methodologies

Iteration

$$U(z) = \frac{U_*}{k}\left[\ln\left(\frac{z}{z_0}\right)\right]$$

+

$$z_0 = \alpha_c \frac{U_*^2}{g}$$

g = gravity

α_c = Charnock's parameter (0.0144)

U(10) = satellite neutral wind speed

1. **Calculate U* and z_0 at 10 m**
2. **Calculate U when z is the hub height**

Z_0 methodologies

Fetch, Fetch_min & DTU_age methods

$$\alpha = 1.89\left(\frac{u_*}{c_p}\right)^{1.59}\left[1 + 47.165\left(\frac{u_*}{c_p}\right)^{2.59} + 11.791\left(\frac{u_*}{c_p}\right)^{4.59}\right]^{-1}$$

$$u_* = \frac{u_*}{c_p} = \frac{3.5}{2\pi}\times\left(\frac{(U_{10})^2}{x\times g}\right)^{1/3}$$

x = fetch

- For fully develop, wind generated waves over deep seas
- 10m neutral wind speed and fetch dependant
- DTU_age is only dependant of wave age

Astrup et al., WAsP engineering flow model for wind over land and sea, DTU, 1999.

Z_0 methodologies

Log law

$$C_{10} = \frac{u_*^2}{U_{10}^2} = \left[\frac{k}{\ln(z/z_0) - \Psi_m}\right]^2$$

- Under neutral conditions this method is friction velocity and 10m neutral wind speed dependant

Smith & Toba

$$\alpha = 0.48(u_*/c_p)$$

$$\alpha = 0.025(u_*/c_p)$$

- Empirical equations
- Wave age dependant

Smith et al., Sea surface wind stress and drag coefficients: The hexos results, 1992.

Z_0 methodologies

Speed & Age

$$\alpha = mU_{10} + b$$

$$\alpha = A\left(\frac{u_*}{c_p}\right)^B$$

- For wave age > 33

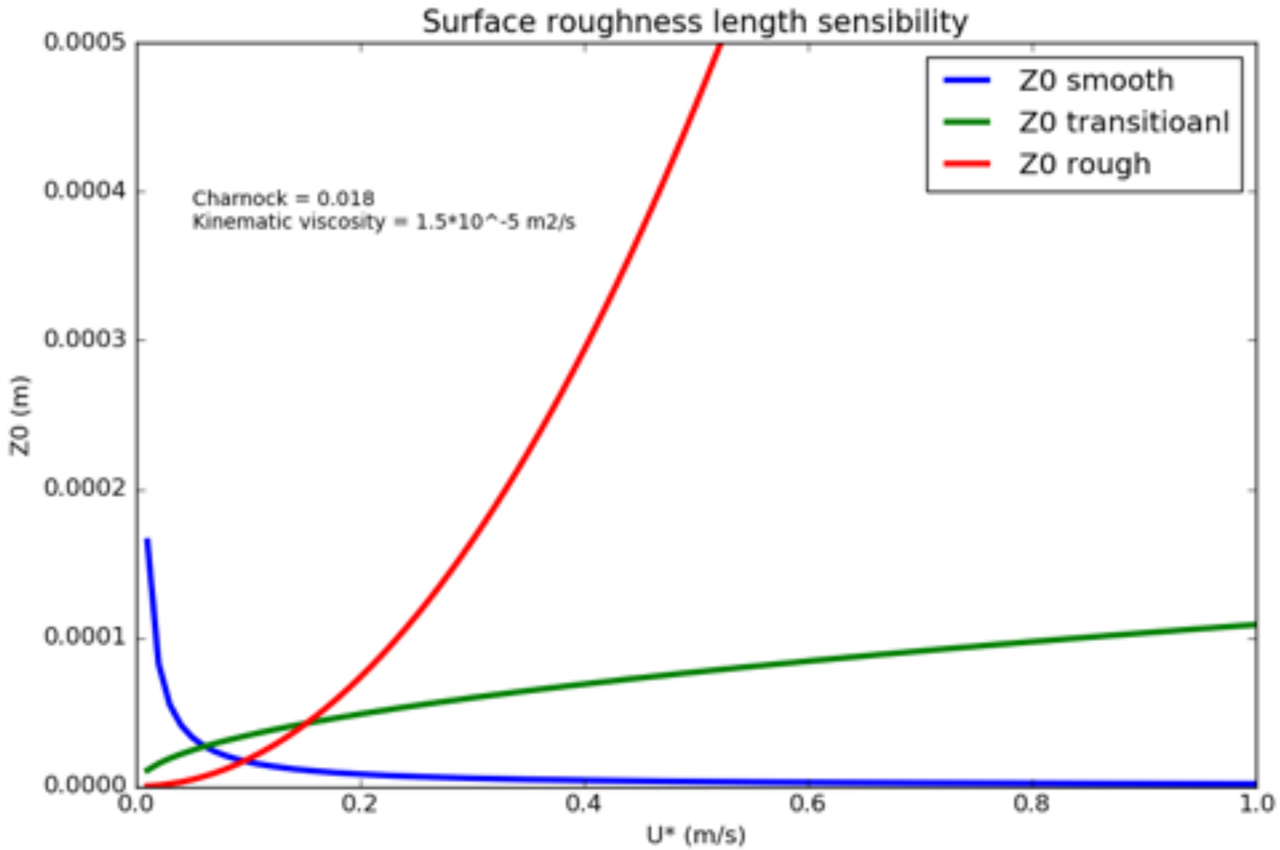
Sea state

$$z_{0\,rough} = \frac{D \times H_S \times 2\pi \times (u_*)^2}{g \times L}$$

D = Empirical coefficient
L = Wave length

Edson et al., On the exchange of momentum over the open ocean, American Meteorological Society, August 2013.

Z_0 regimes



$$Z_{os} = 0.11\frac{v}{u}$$

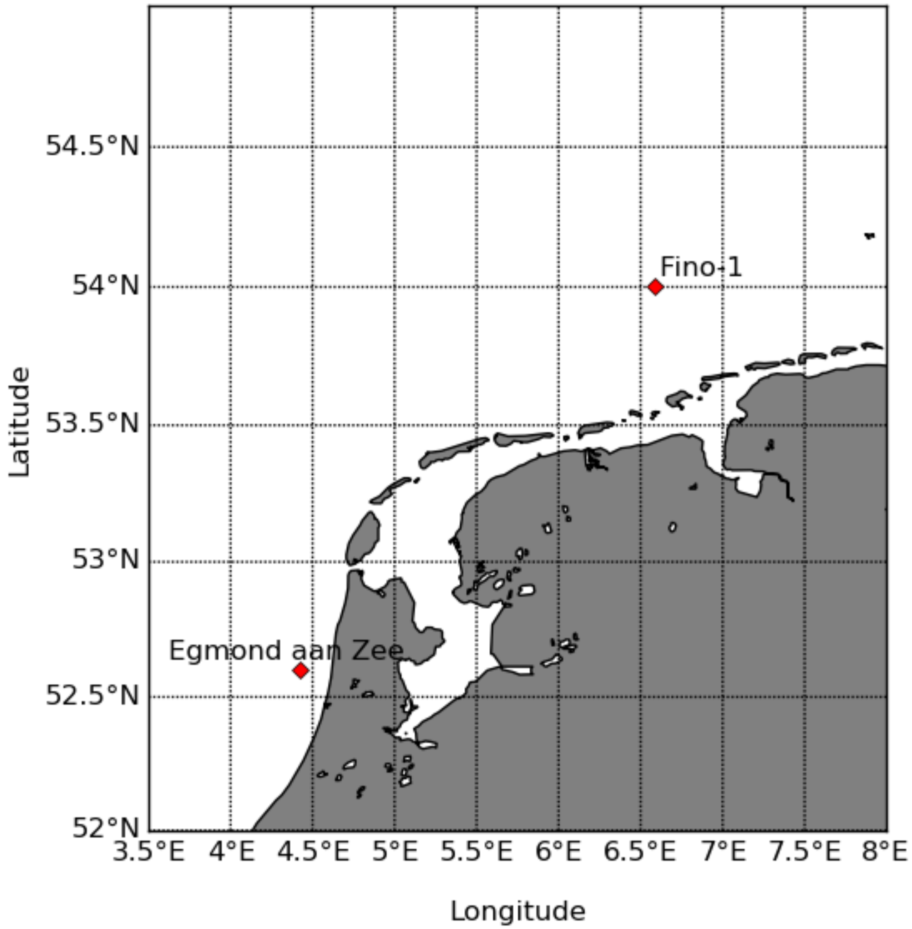
$$z_{ot} = 0.088 \times \left(\frac{vu_*}{g}\right)^{1/2}$$

$$Z_{or} = 0.018 \times \frac{u_*^2}{g}$$

Locations

- Insitu data composed by two meteorological masts in the North Sea, Fino-1 & Egmond aan Zee.

	Fino-1	Egmond
Distance to shore	40 km	14.5 km
Depth	30 m	16.5 m
From	1/1/04	1/7/05
To	30/11/11	31/12/08
Highest anemometer	90 m	116 m



Data computation

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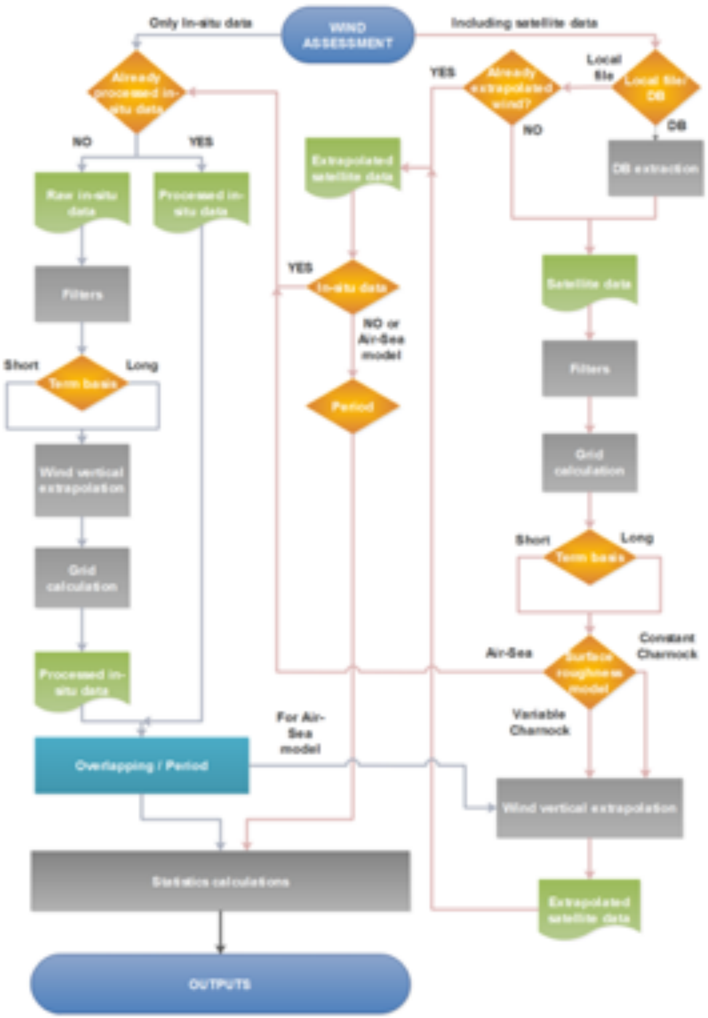


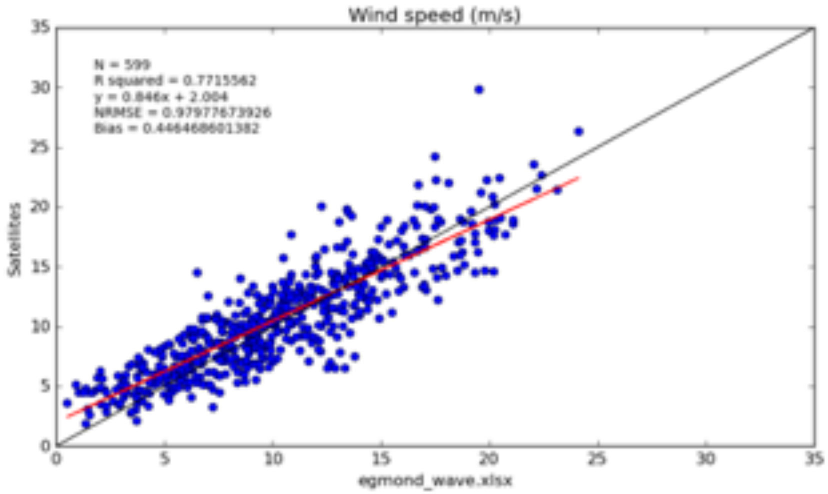
- Quikscat + ASCAT are compared with 50-min averages from Egmond aan Zee and Fino-1.
- Rain free measurements.
- Only measurements under neutral conditions, $T_{sea} \simeq T_{air}$.

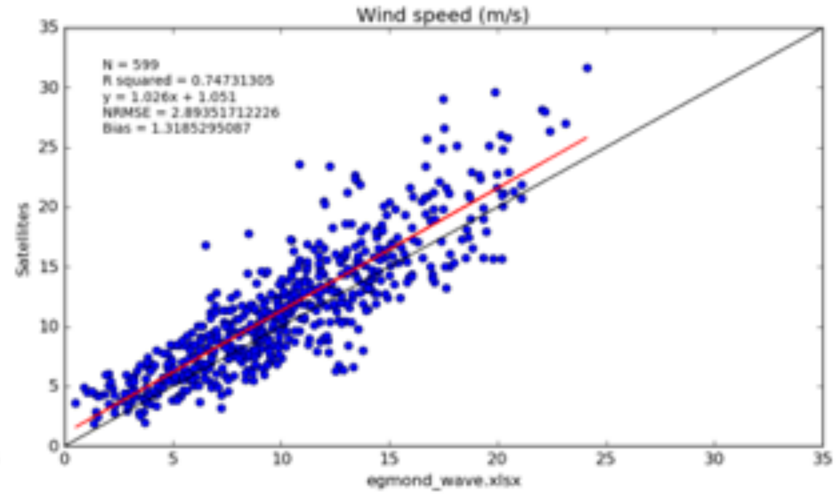
	Fino-1	Egmond
U10 interval (m/s)	0.6 - 17.2	1.4 -23
Cp interval (m/s)	5.3 - 22.32	3.13 - 9.26
Wave age interval	3.8 - 330	1.8 - 202
Hs interval (m)	0.2 - 5.7	0.14 - 4
Measurements	64	598

Results

Egmond aan Zee

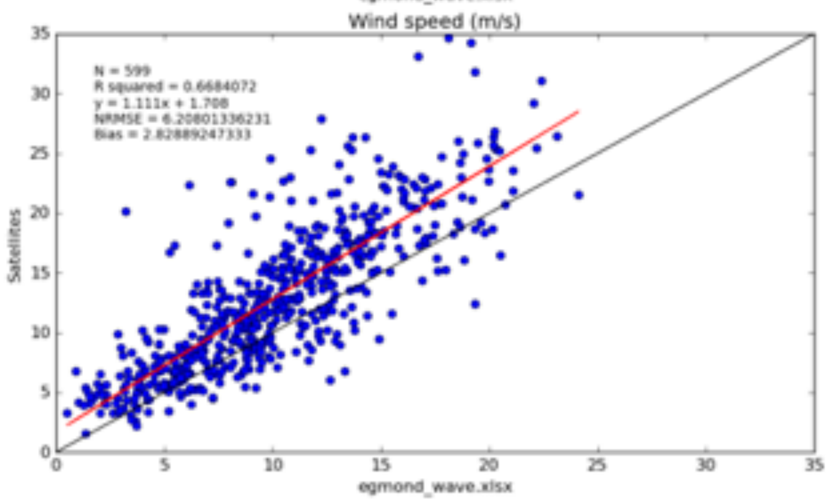
Age + ECMWF

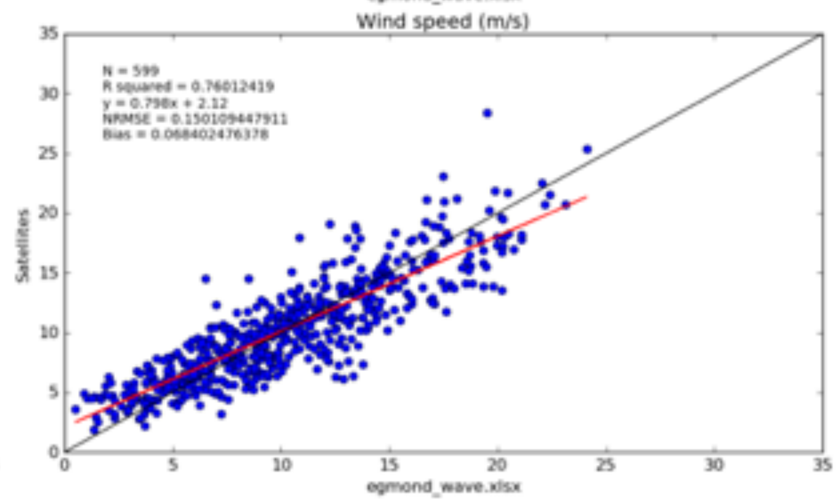




Fetch_min + ECMWF

Log_law + Maat





Sea state + ECMWF

Results

Non-sea/wave dependant methods

		Fino-1		Egmond aan Zee	
u^* \ Z_0		Iteration	Fetch	Iteration	Fetch
Iter/ECMWF	R^2	0,810	0,824	0,775	0,746
	Slope	0,892	0,984	0,868	1,025
	NMRSE	0,124	0,064	1,198	2,910
	Bias	0,171	0,088	0,546	1,326
Wu	R^2		0,822		0,752
	Slope		0,970		1,001
	NMRSE		0,041		3,259
	Bias		0,057		1,485

	Values
R^2	>0.9
Slope	>0.87
Slope	<1.13
Bias	<1

Classification parameters

Results

Fino-1

u* \ Z0		Fetch_min	Smith	Toba	Speed	Age	DTU_age	Log_law	Sea_state
ECMWF	R^2	0,824	0,817	0,823	0,818	0,821	0,809	0,820	0,809
	Slope	0,985	0,850	1,130	0,657	0,879	0,887	0,880	0,861
	NMRSE	0,064	0,182	1,026	1,426	0,111	0,132	0,232	0,091
	Bias	0,089	0,253	1,420	1,973	0,154	0,183	0,322	0,126
Wu	R^2	0,822	0,818	0,818	0,815	0,815	0,802	0,818	0,801
	Slope	0,970	0,838	1,114	0,647	0,867	0,875	0,877	0,848
	NMRSE	0,041	0,081	1,171	1,337	0,006	0,239	0,212	0,021
	Bias	0,056	0,112	1,621	1,850	0,009	0,331	0,294	0,029
Maat	R^2	0,634	0,629	0,626	0,594	0,626	0,633	0,827	0,624
	Slope	0,908	0,819	1,022	0,635	0,836	0,862	0,859	0,871
	NMRSE	2,402	2,479	1,809	3,322	2,438	2,292	0,643	2,521
	Bias	3,324	3,430	2,504	4,597	3,374	3,171	0,891	3,488

Results

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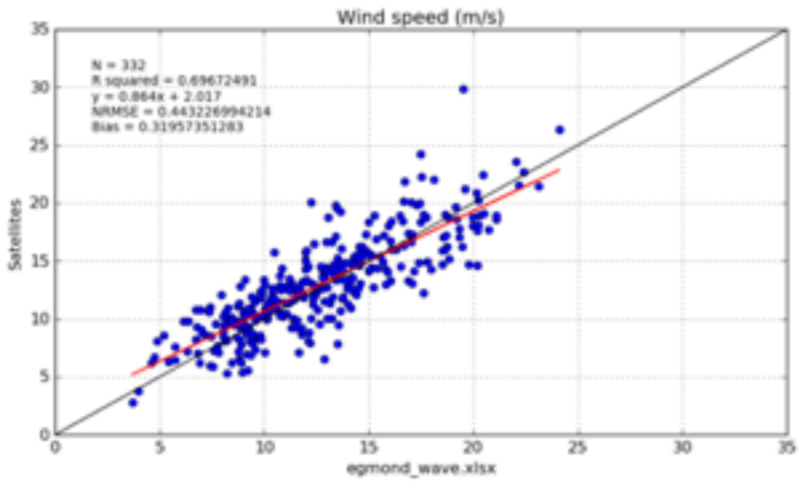
Egmond aan Zee

u* \ Z0		Fetch_min	Smith	Toba	Speed	Age	DTU_age	Log_law	Sea_state
ECMWF	R^2	0,747	0,772	0,772	0,775	0,771	0,772	0,774	0,760
	Slope	1,026	0,795	1,078	0,652	0,846	0,799	0,878	0,798
	NMRSE	2,893	0,309	5,020	2,795	0,979	0,877	1,292	0,150
	Bias	1,318	0,138	2,287	1,273	0,446	0,399	0,589	0,068
Wu	R^2	0,752	0,775	0,775	0,777	0,775	0,774	0,775	0,766
	Slope	1,002	0,776	1,052	0,635	0,826	0,780	0,873	0,793
	NMRSE	3,247	0,611	5,444	2,506	1,303	1,185	1,360	0,535
	Bias	1,479	0,278	2,481	1,142	0,593	0,540	0,619	0,244
Maat	R^2	0,420	0,409	0,400	0,385	0,410	0,412	0,668	0,409
	Slope	1,476	1,269	1,453	1,138	1,329	1,252	1,111	1,380
	NMRSE	16,841	13,989	19,227	10,531	15,020	13,896	6,208	14,830
	Bias	7,633	6,379	8,779	4,824	6,852	6,336	2,828	6,766

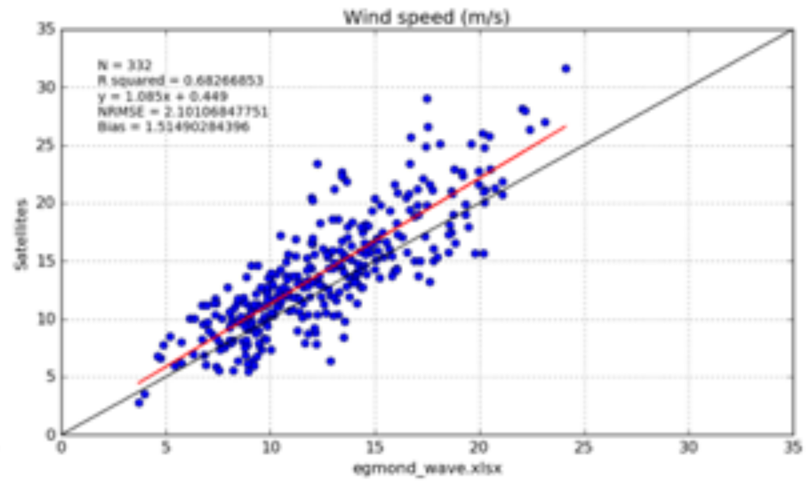
Results

Egmond wage age < 5

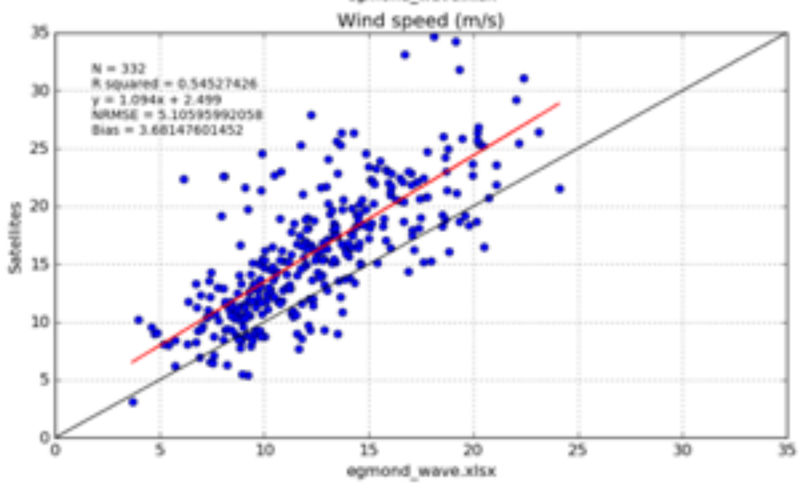
Age + ECMWF



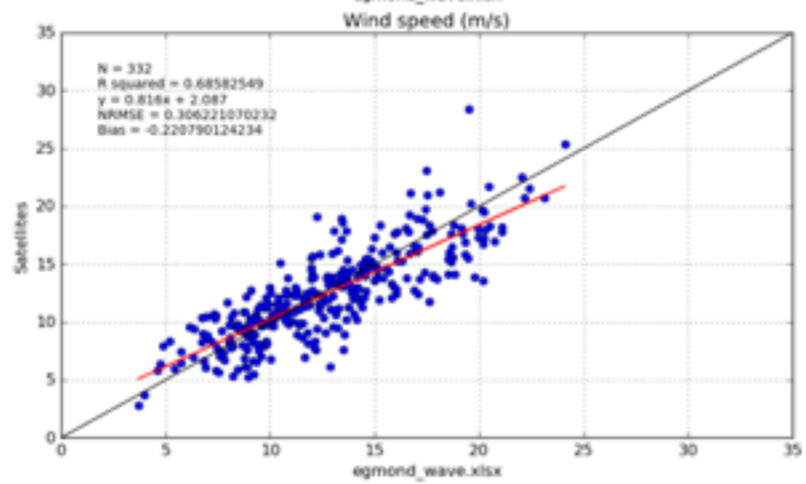
Fetch_min + ECMWF



Log_law + Maat



Sea state + ECMWF



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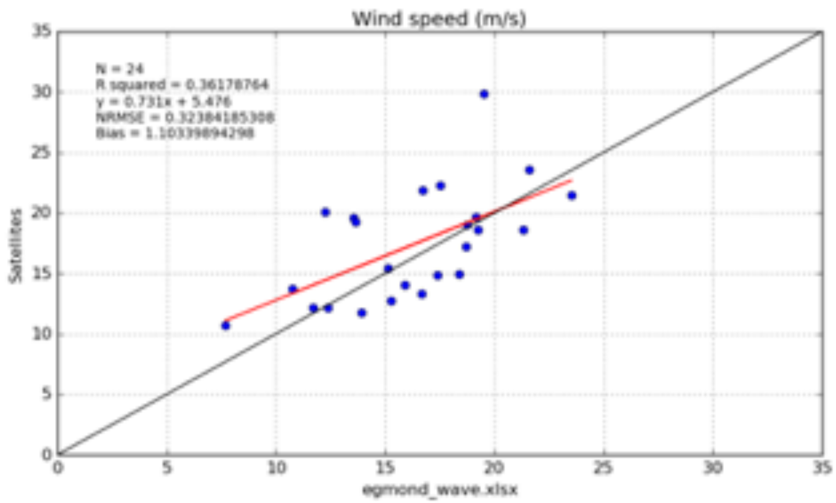
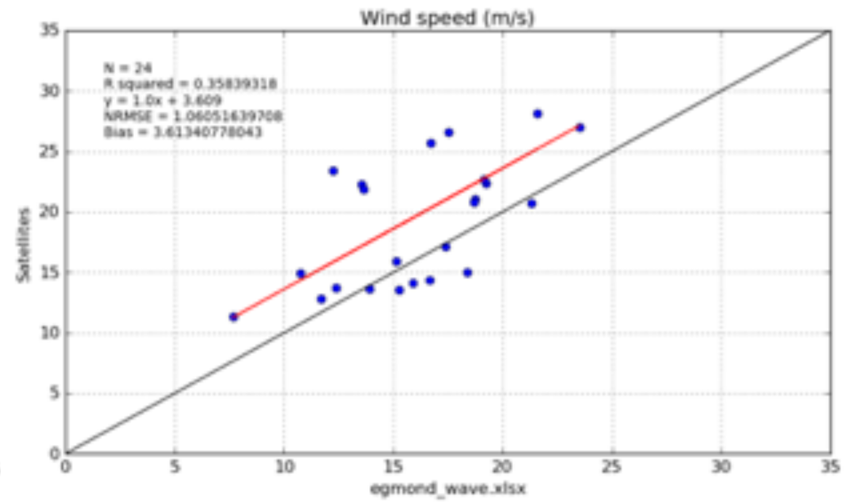
Results

Egmond wave age < 2.5

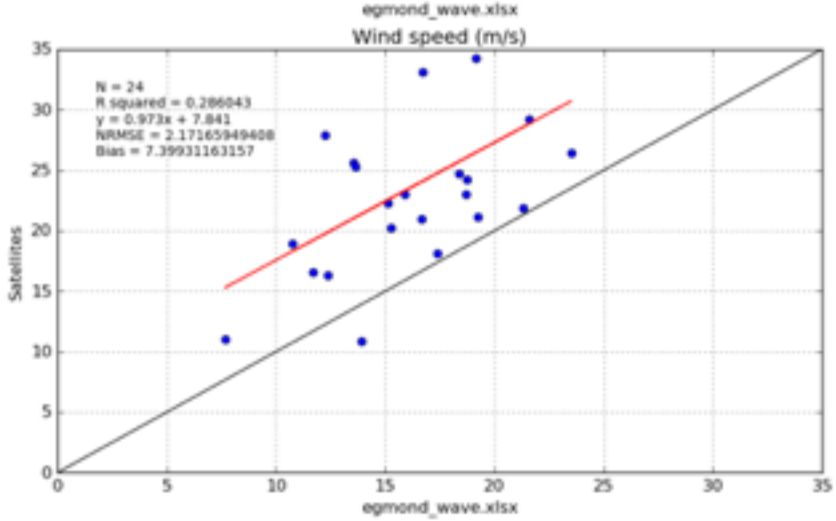
Age + ECMWF



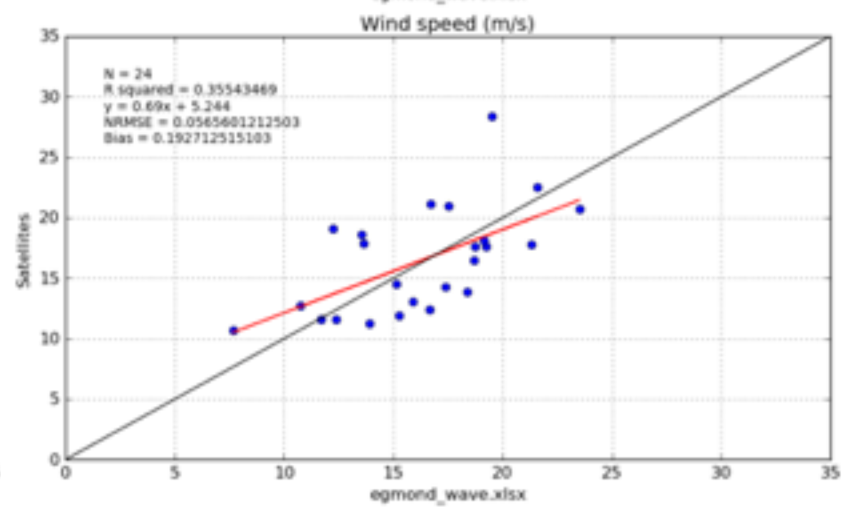
Fetch_min + ECMWF



Log_law + Maat



Sea state + ECMWF



Results

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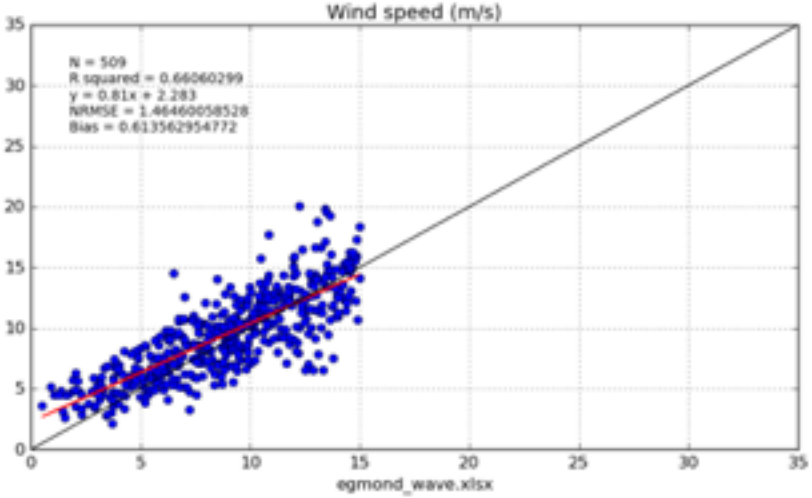
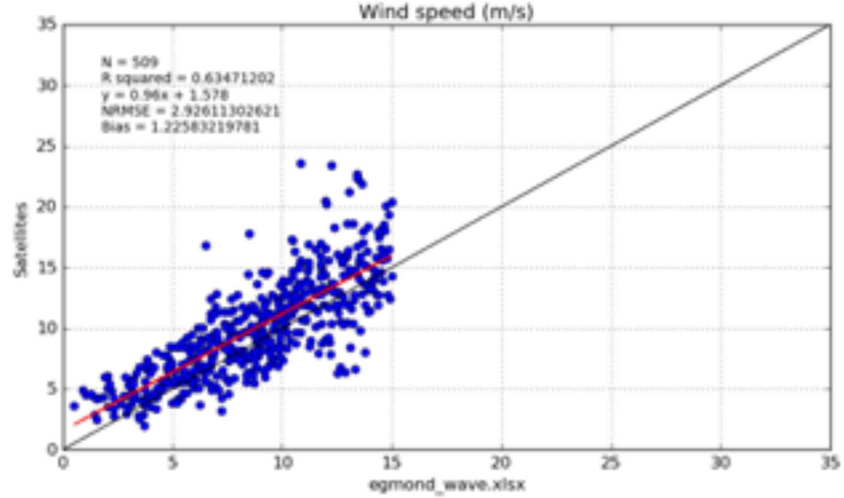
Egmond $U_{10} < 15$ m/s

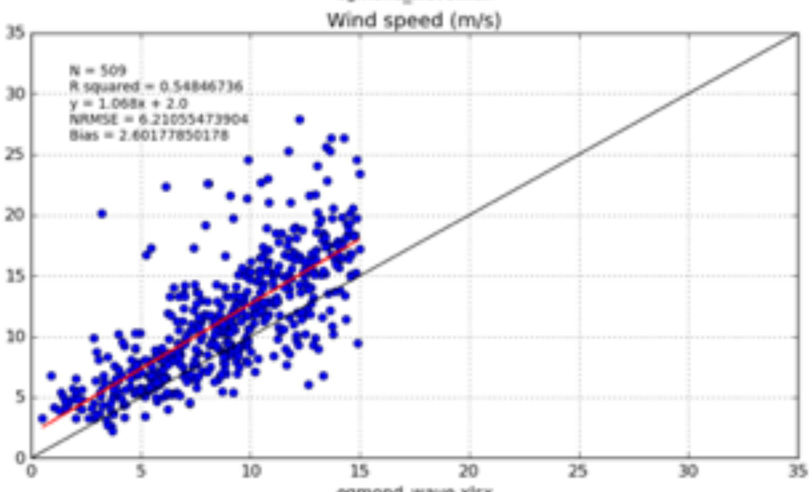
Age + ECMWF



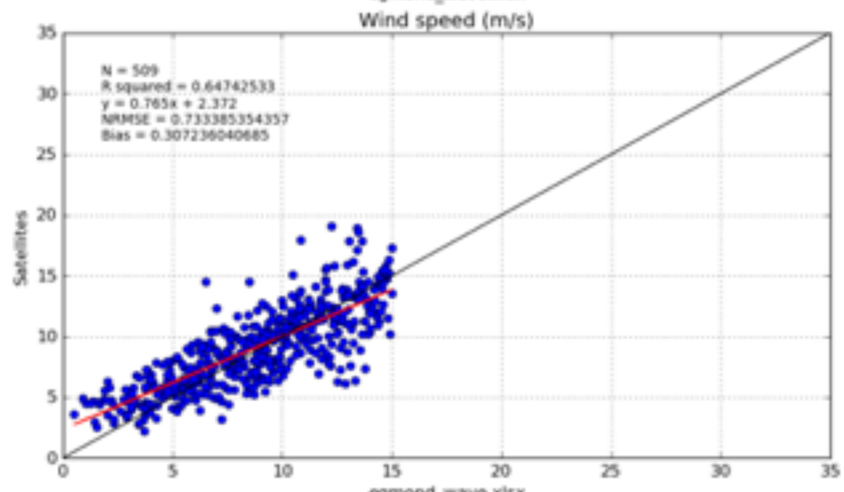
Fetch_min + ECMWF



Log_law + Maat



Sea state + ECMWF



Summary

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- Maat method for friction it is only working for log_law method. Practically, there is no difference between Wu and ECMWF methods.
- Results for Non-sea-data methods are not so far from sea-data results.
- Fetch method presents the best slopes in the regressions lines. However it should be noted that both locations can be considered long fetch.
- After filtering data, most of measurements were taken under rough conditions. So, application of roughness regimes had very small impact, for that reason fetch and fetch_min methods have practically the same results.

Future plans:

- Keep checking methodologies at different locatios, mainly fetch method.
- Try the four selected methods under different wave ages, wind speeds and wave height.
- If we can get wind stress or friction velocity directly from satellites, we “just” need to calculate surface roughness.

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