Geophysical model function for wind speed retrieval from SARAL AltiKa: A sensitivity study

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Objective of the study:

- To develop a Geophysical Model Function for estimation of the microwave nadir-viewing radar backscatter of sea surface at Ka-band as a function of wind speed based on both theoretical and empirical basis.

- Estimation of wind speed and its validation using other radar altimeter and buoy data.

- Demonstration of wind speed for various case studies on regional to global scale.

Background:

- The radar reflectivity and backscatter not only depends on sea wave slope statistics but also on the roughness and sea foam and whitecaps caused by the near-surface ocean winds due to breaking of waves.

- Foam and sea water form a layered media which distort the fine structure of the surface and alter reflectivity due to resonant phenomenon.

- Whitecaps are the surface signature of buoyant bubble plumes caused by energetic breaking wind-generated gravity waves and they affect a wide range of oceanographically related processes.

Specular point model:

The average scattering cross-section for a radar altimeter is given by

$$\sigma^0(\theta) = \pi |R(\theta)|^2 \, \mathrm{Sec}^4\theta \, p(\zeta_x, \zeta_y)$$

where, θ = incidence angle

$p(\zeta_x, \zeta_y)$ = surface slope pdf

$$\zeta_x = \frac{\partial n}{\partial x}, \quad \zeta_y = \frac{\partial n}{\partial y}, \quad n = \text{surface elevation}$$

$R(\theta)$ = Fresnel reflection coefficient of air to surface interface at incidence angle θ

Under the classical assumption when the sea surface slopes are nearly Gaussian and isotropic in their distribution, the pdf and the scattering coefficient is given by

$$p(\zeta_x, \zeta_y) = \frac{1}{\pi \overline{S^2}} \exp\left(-\tan^2\theta / \overline{S^2}\right)$$

$$\overline{S^2} = \left\langle \zeta_x^2 + \zeta_y^2 \right\rangle = \text{Mean square slope}$$

$$\sigma^0(\theta) = \frac{|R(\theta)|^2}{\overline{S}^2} \sec(\theta) \exp\left(-\tan^2(\theta) / \overline{S}^2\right)$$

The effect of foam on wind speed estimation

The backscattering coefficient for normal incidence is given by

$$\sigma^0 = |R(0)|^2 / \overline{S}^2$$

where $\overline{S}^2 = a \ln U_{10} + b$

$|R(0)|^2$ = Reflectivity of the air to surface interface at normal incidence

Brown (1979) obtained an empirical expression using ship data (39 points) for swell conditions which is given by

$$\sigma^0 = -2.1 - 10 \log_{10}\left(A \ln U_{10} + B\right)$$

where $A = 0.02098 \quad B = 0.01075$ for $U_{10} \leq 9.2\ m/s$

$A = 0.08289 \quad B = -0.12664$ for $U_{10} \geq 9.2\ m/s$

Under high sea state conditions, the coverage of whitecaps will change the microwave reflectivity of the sea surface and modified backscattering coefficient can be expressed as

$$\sigma^0 = \left[|R(0)|^2 (1 - F) + r_f F \right] / \bar{S}^2$$

F = Significant coverage of whitecaps

r_f = Reflectivity of whitecaps

where a = 0.010 b = 0.012 for $U_{10} \leq 7$ m/s

a = 0.085 b = -0.145 for $U_{10} \geq 7$ m/s

The frequency dependent fractional foam coverage is given by

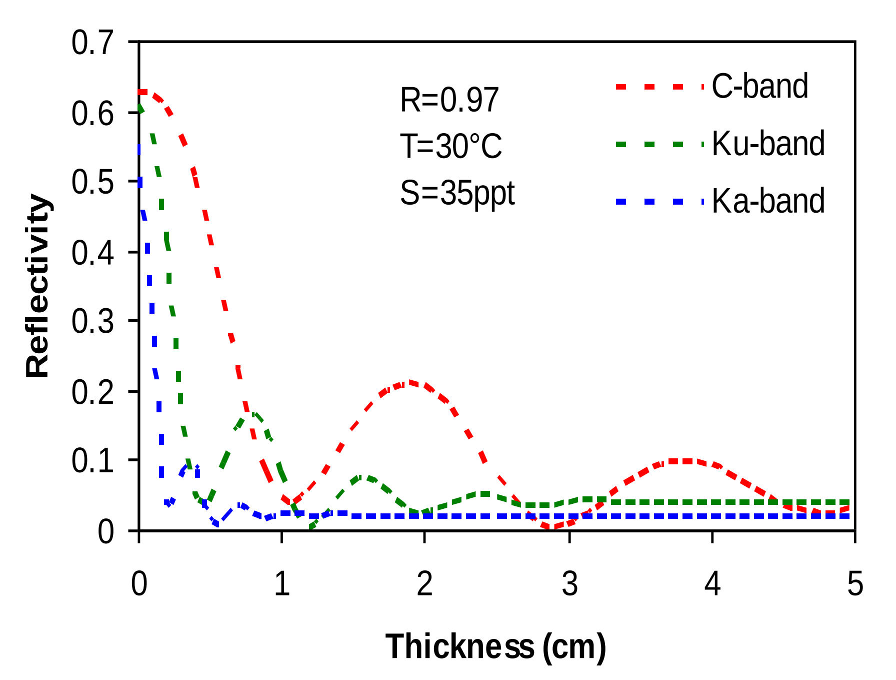
$$F = a_0 + a_1 U_{10} + a_2 U_{10}$$

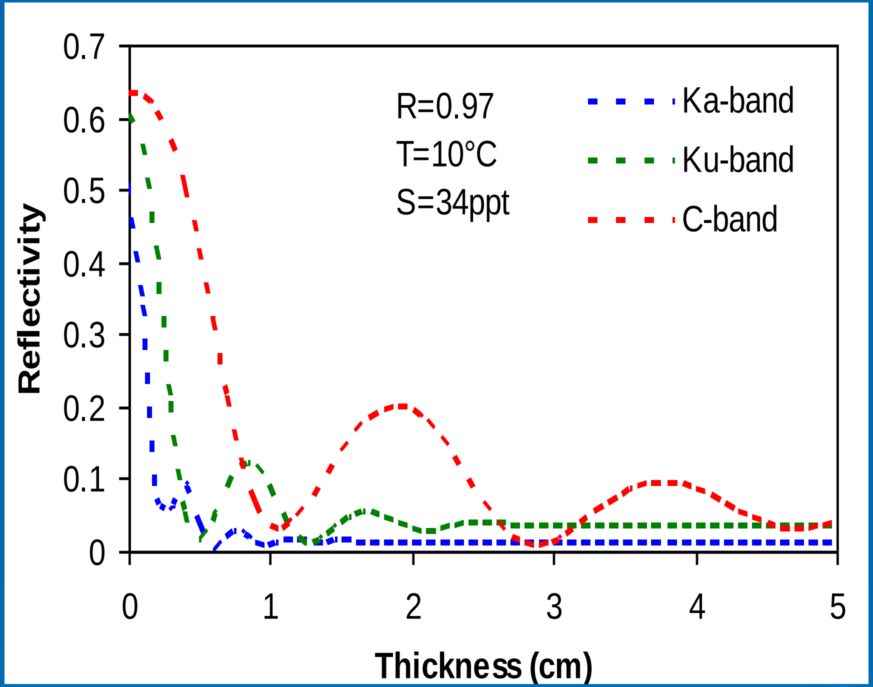
where $a_0 = 1.707 \times 10^{-2} + 8.560 \times 10^{-4} \nu + 1.120 \times 10^{-5} \nu^2$

$a_1 = -1.501 \times 10^{-2} + 1.821 \times 10^{-3} \nu - 4.634 \times 10^{-5} \nu^2$

$a_2 = 2.442 \times 10^{-2} - 2.282 \times 10^{-6} \nu + 4.194 \times 10^{-7} \nu^2$

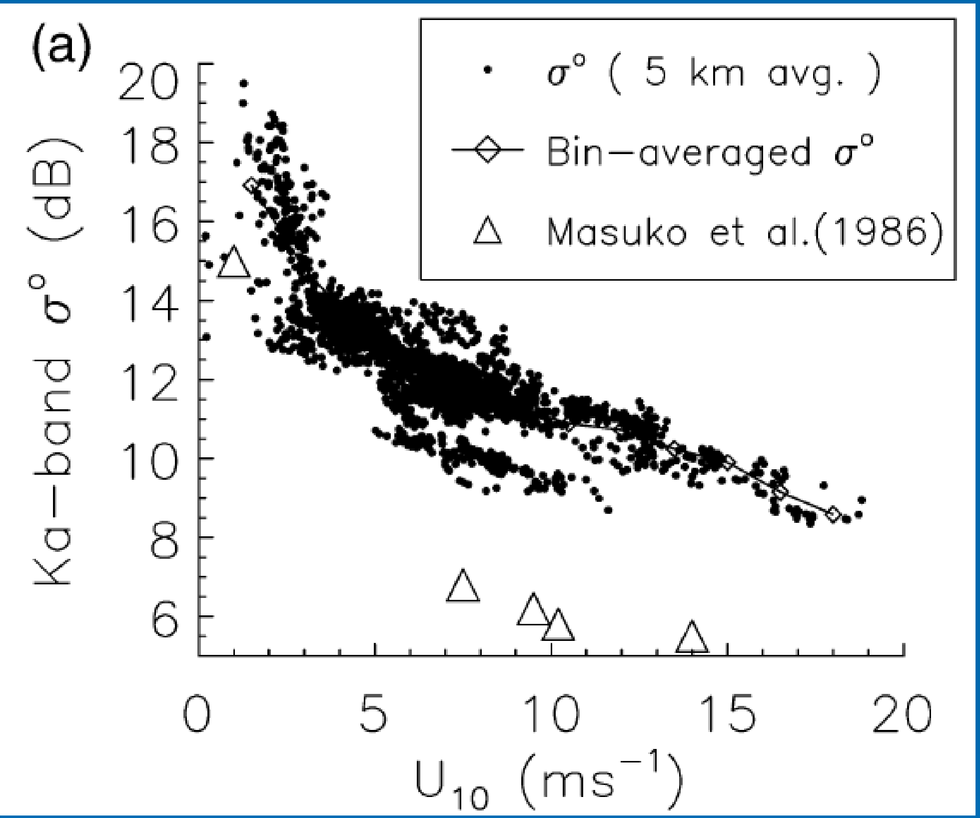
Microwave reflectivity versus thickness of whitecaps

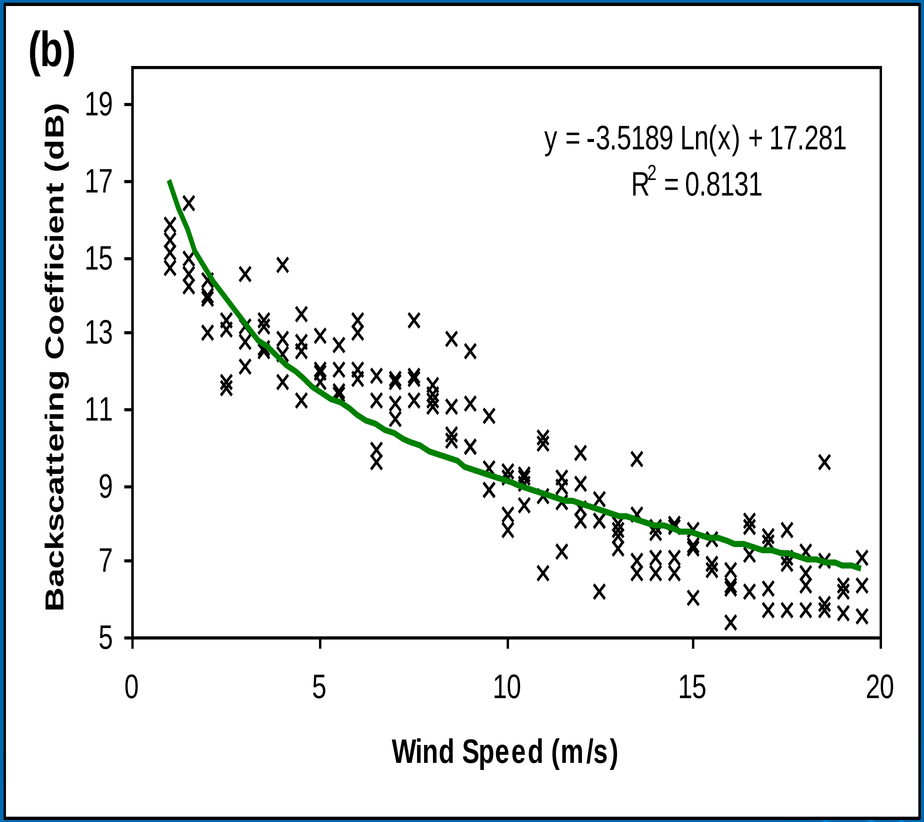




- The power reflectivity declined rapidly with increasing foam thickness.
- The minimax points were caused by the resonant absorption of the foam layer.

Results for Ka-band:

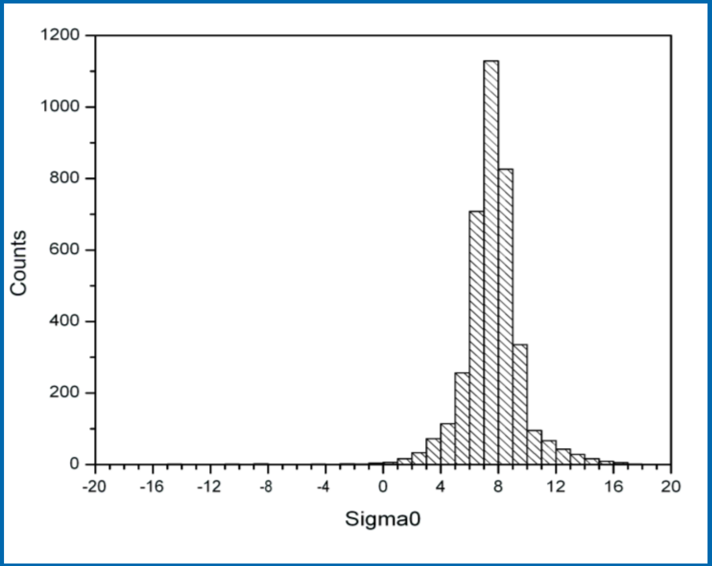


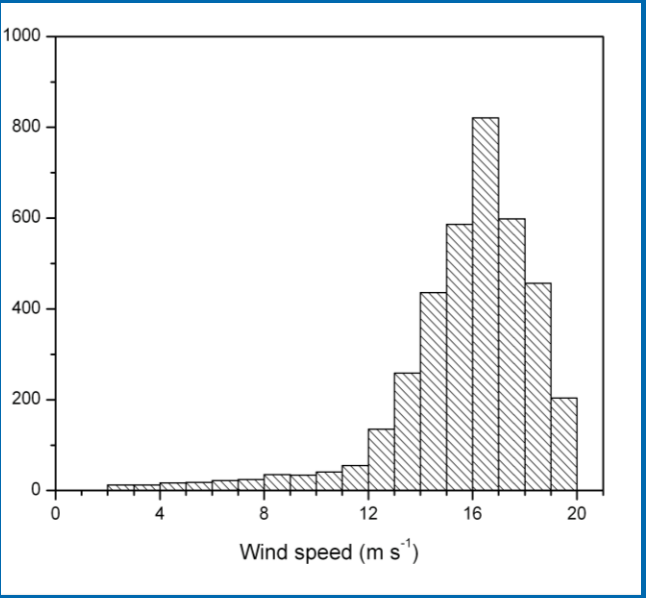


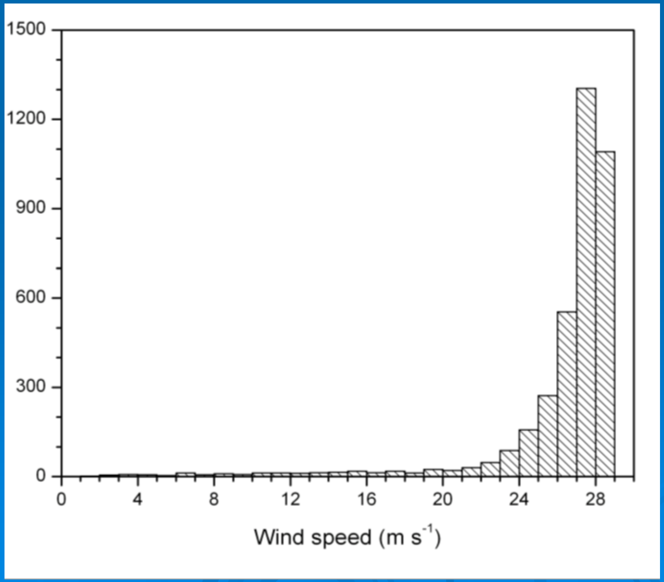
Vandermark *et al.* (2004), J. Phys. Oceanogr.

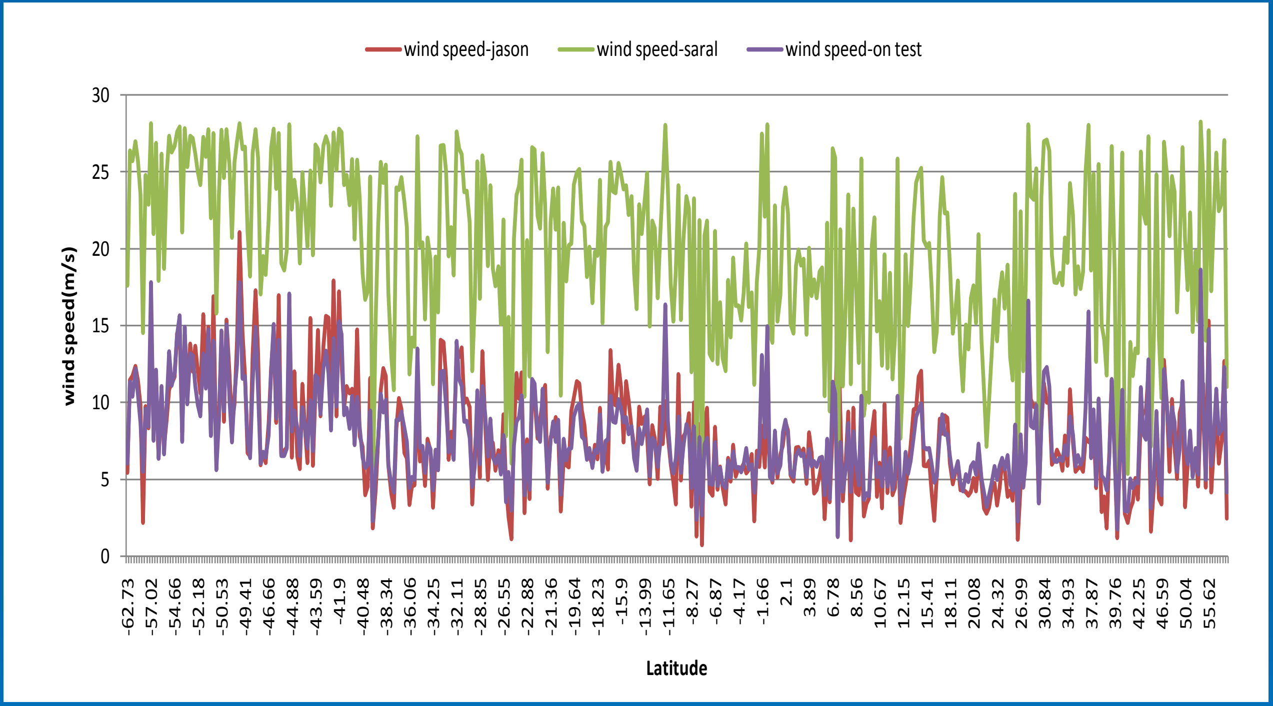
Present Model Function

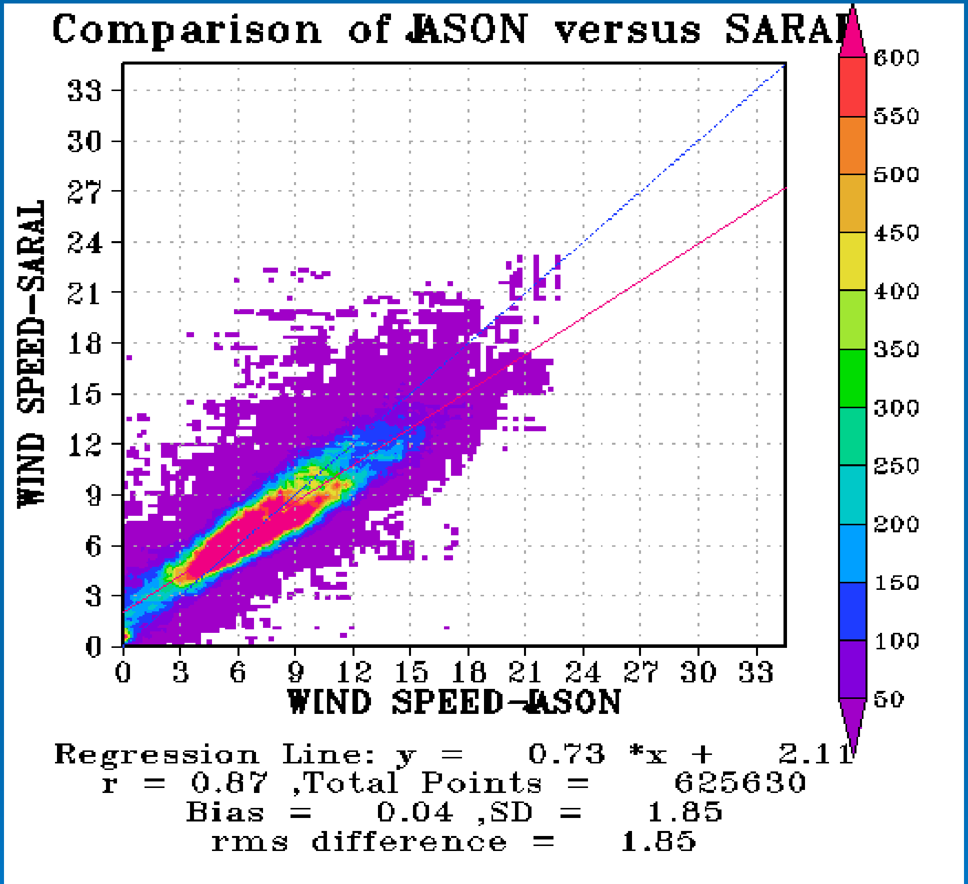
Figure: Histogram of SARAL-sigma0, retrieved wind from SAC and CNES (Patch-1)



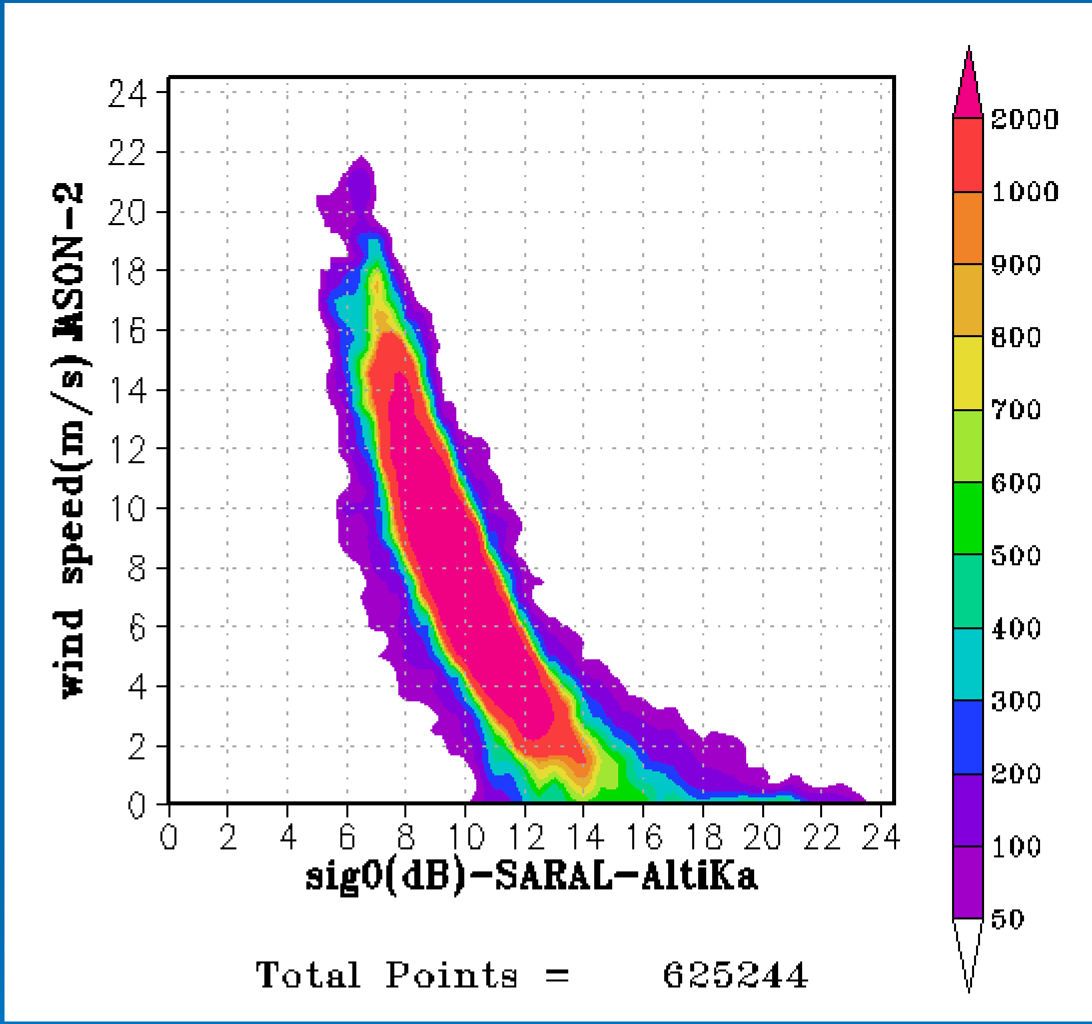





wind speed-jason
wind speed-saral
wind speed-on test
30
25
20
15
10
5
0
wind speed(m/s)
-62.73
-57.02
-54.66
-52.18
-50.53
-49.41
-46.66
-44.88
-43.59
-41.9
-40.48
-38.34
-36.06
-34.25
-32.11
-28.85
-26.55
-22.88
-21.36
-19.64
-18.23
-15.9
-13.99
-11.65
-8.27
-6.87
-4.17
-1.66
2.1
3.89
6.78
8.56
10.67
12.15
15.41
18.11
20.08
24.32
26.99
30.84
34.93
37.87
39.76
42.25
46.59
50.04
55.62
Latitude



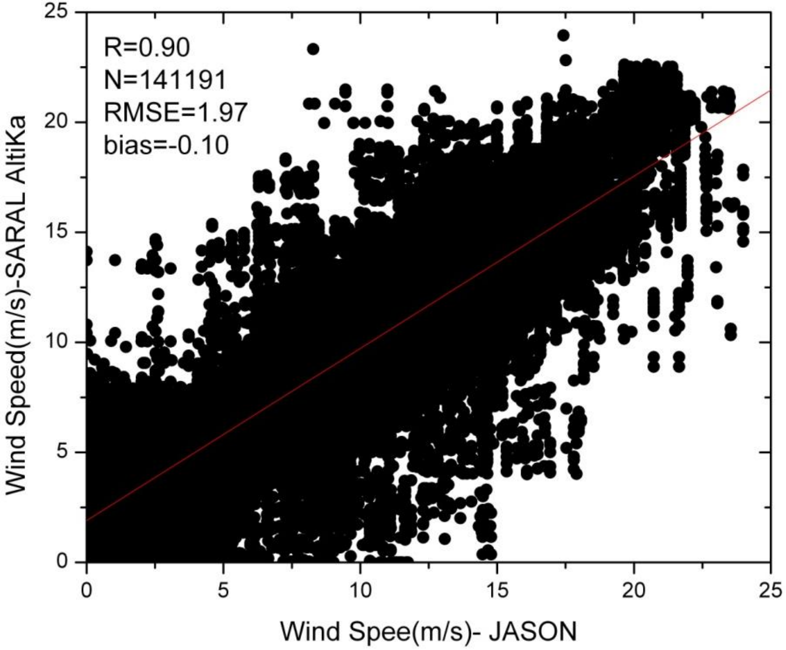
Comparison of JASON versus SARAL
WIND SPEED-SARAL
WIND SPEED-JASON
0 3 6 9 12 15 18 21 24 27 30 33
600 550 500 450 400 350 300 250 200 150 100 50
Regression Line: y = 0.73 *x + 2.11
r = 0.87 ,Total Points = 625630
Bias = 0.04 ,SD = 1.85
rms difference = 1.85

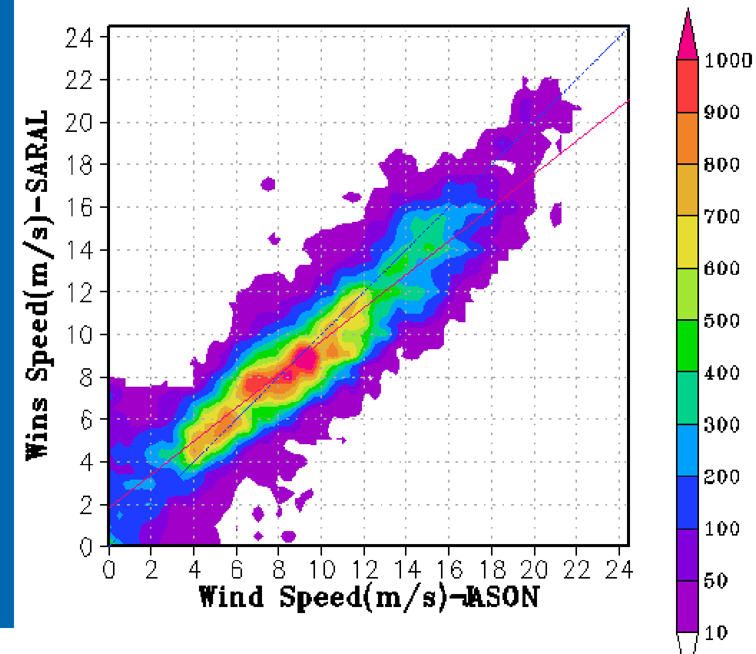


Empirically derived equation

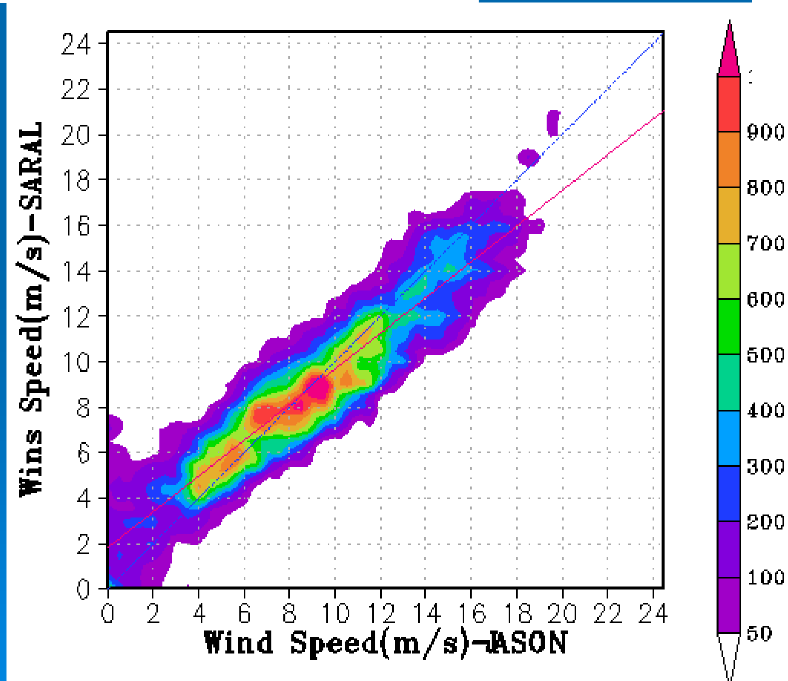
WS=-3.26847+43.6725*exp(-0.151199*sig)+0.523281*swh

Where sig is the back scatter coefficient(dB) and swh is the significant wave height(m)

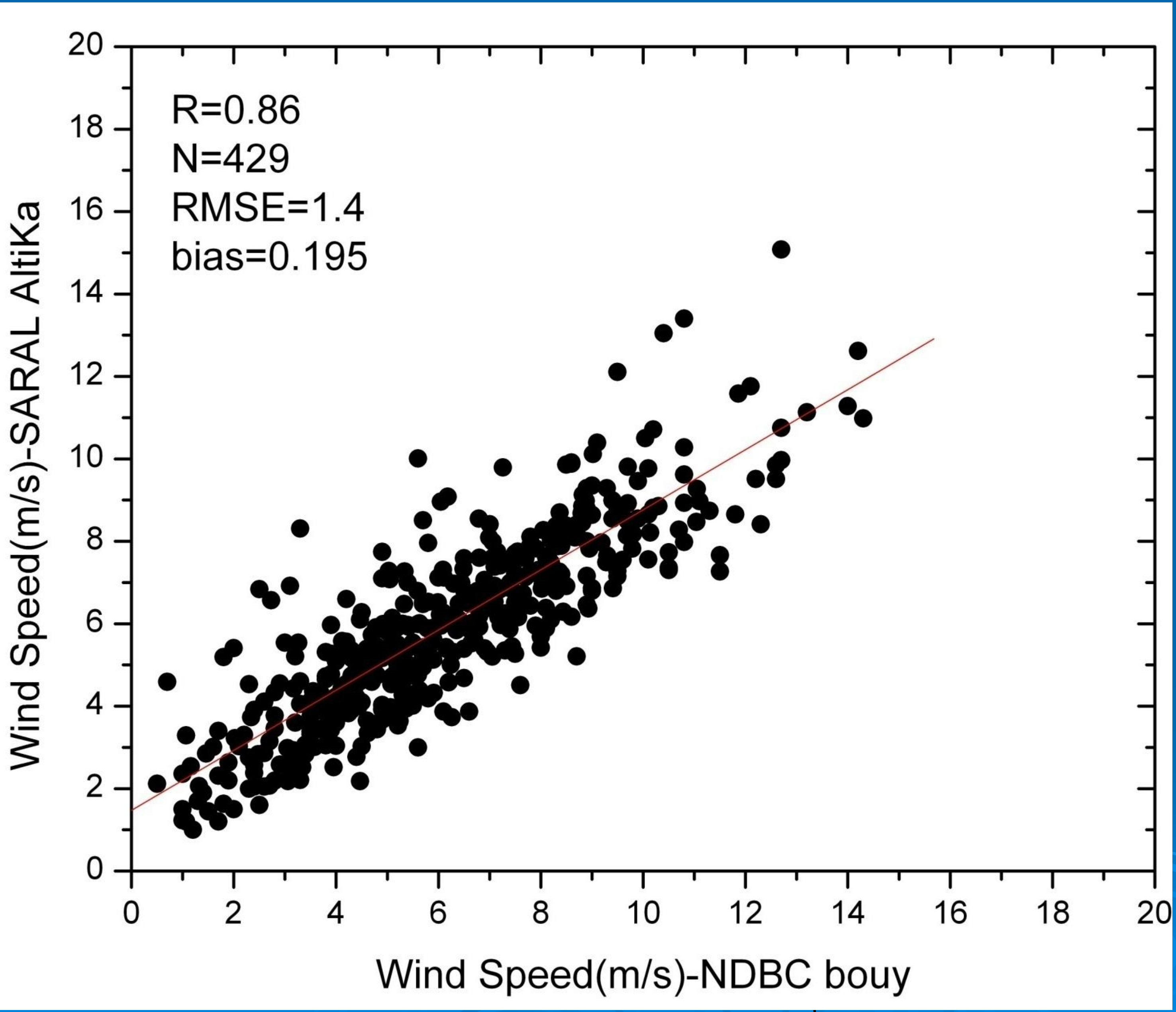




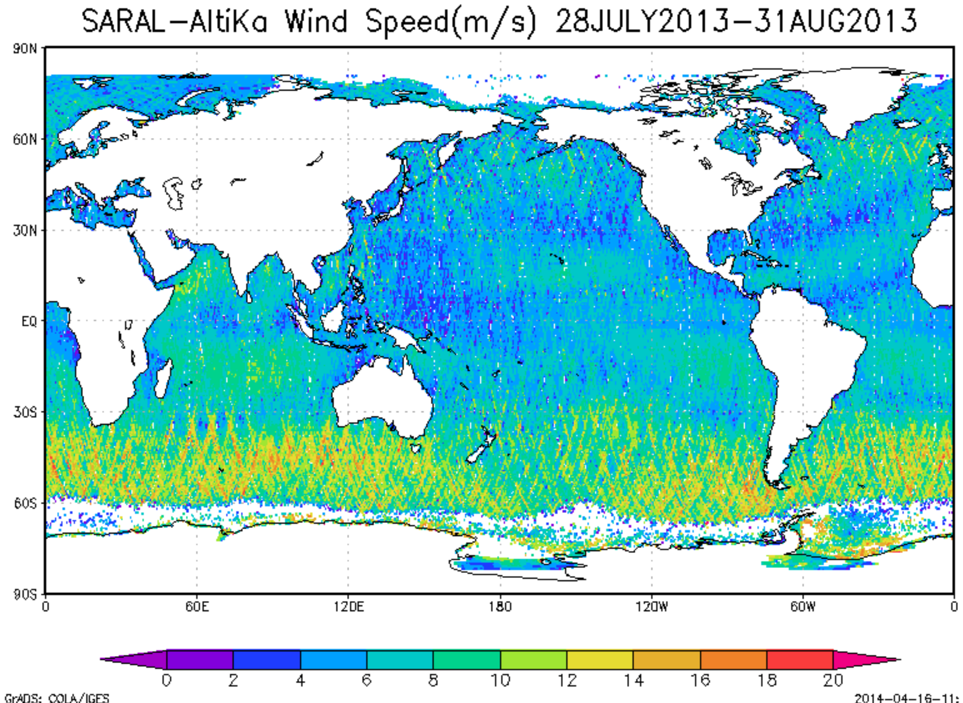
r = 0.90 ,Total Points = 141191
Bias = -0.10 ,RMSE =1.97

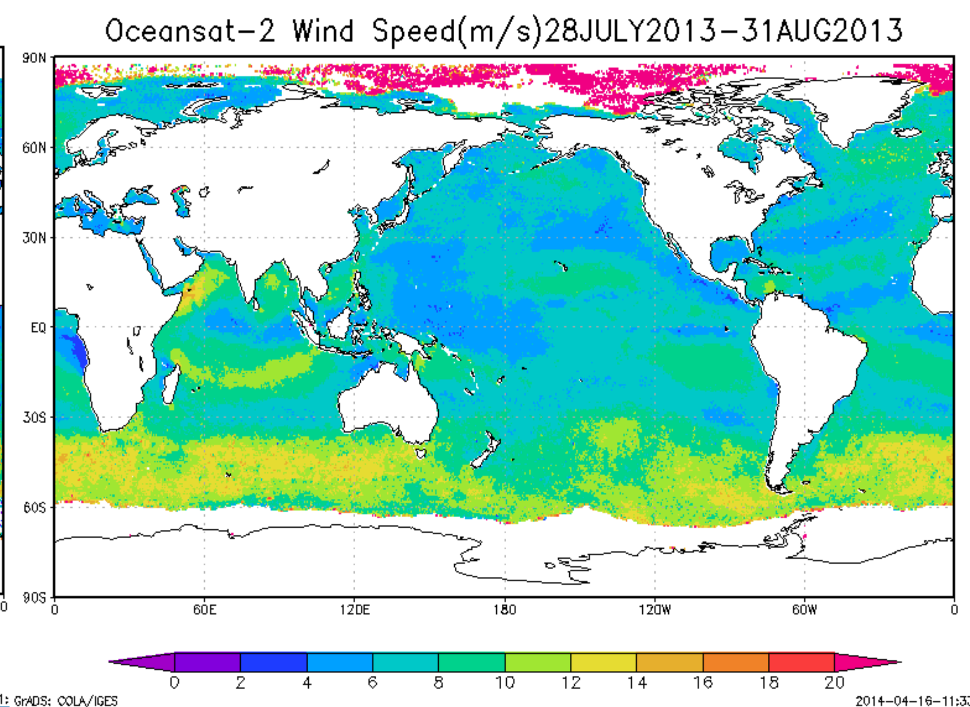


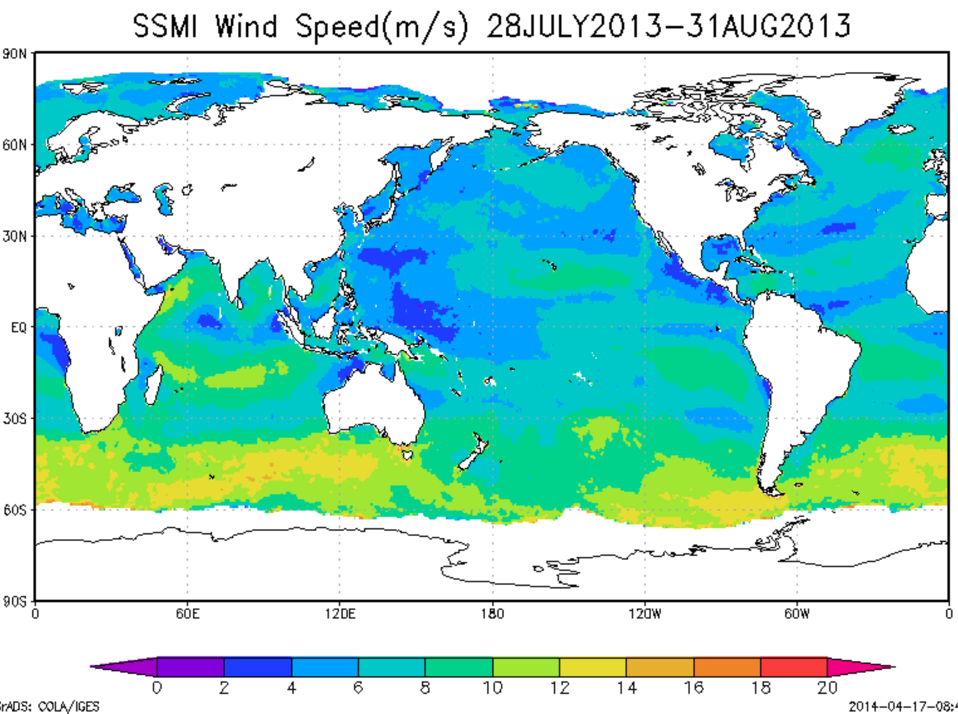
r = 0.90 ,Total Points = 141191
Bias = -0.10 ,RMSE =1.97

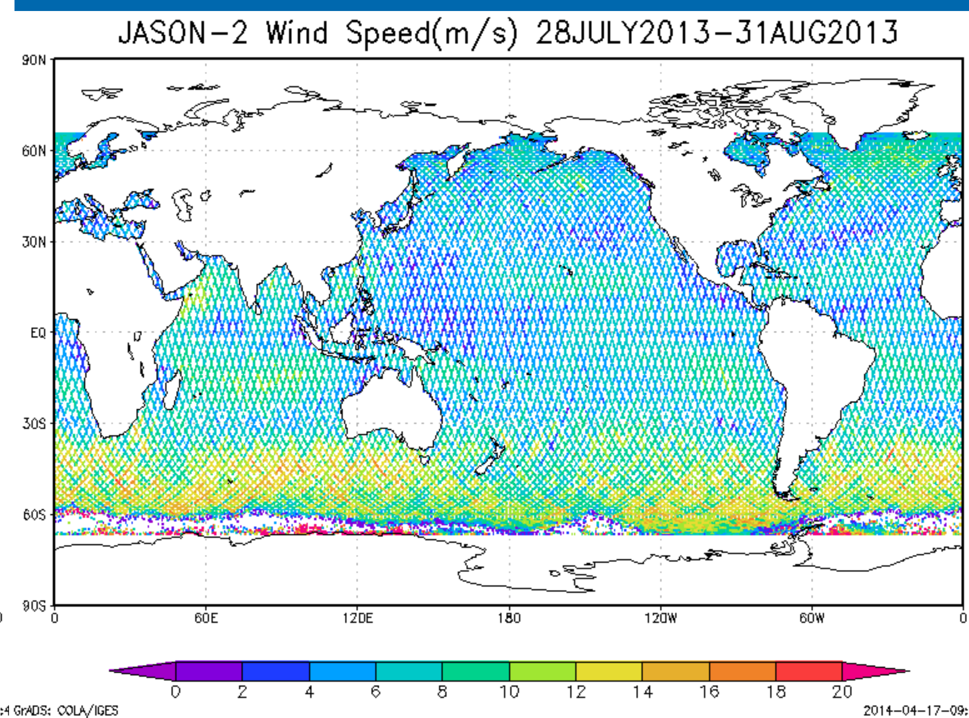


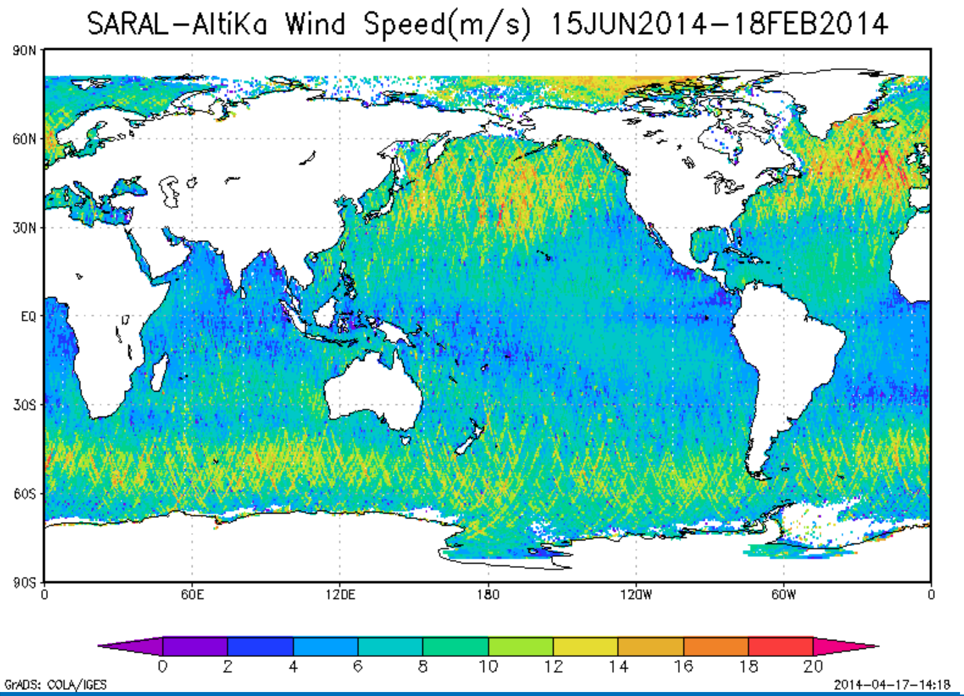
R=0.86
N=429
RMSE=1.4
bias=0.195
Wind Speed(m/s)-SARAL AltiKa
Wind Speed(m/s)-NDBC bouy
0
2
4
6
8
10
12
14
16
18
20

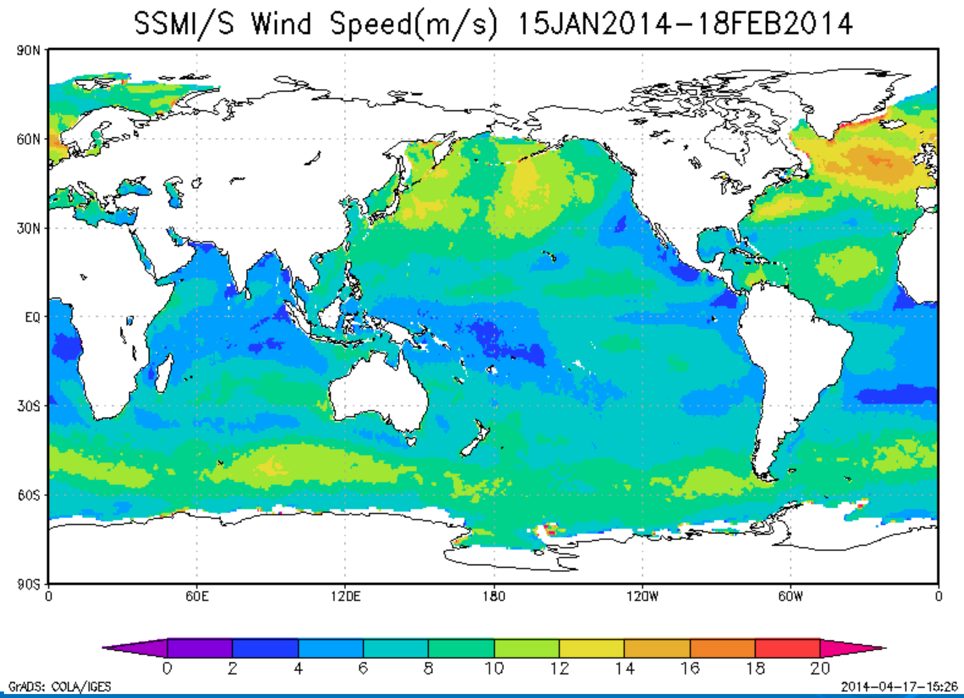

SARAL-AltiKa Wind Speed(m/s) 28JULY2013-31AUG2013
90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W
0
0
2
4
6
8
10
12
14
16
18
20
GrADS: COLA/IGES


Oceansat-2 Wind Speed(m/s)28JULY2013-31AUG2013
90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W
0
0
2
4
6
8
10
12
14
16
18
20
GrADS: COLA/IGES


SSMI Wind Speed(m/s) 28JULY2013-31AUG2013
90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W
0
0
2
4
6
8
10
12
14
16
18
20
GrADS: COLA/IGES

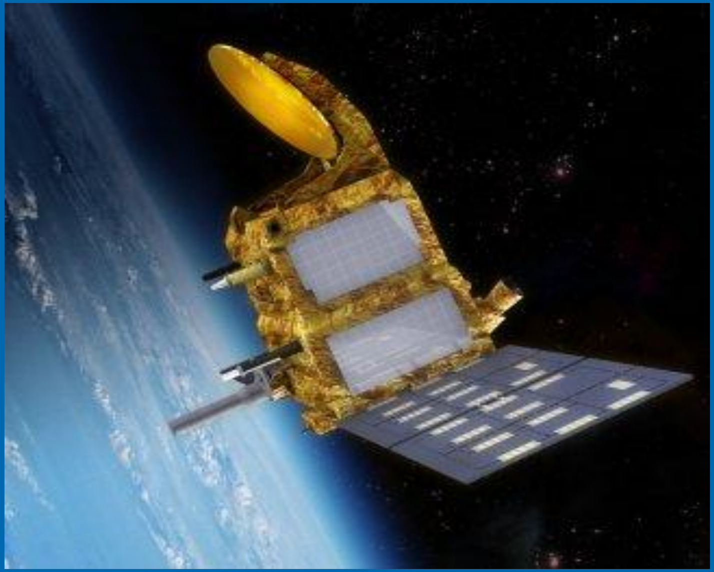

JASON-2 Wind Speed(m/s) 28JULY2013-31AUG2013
90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W
0
0
2
4
6
8
10
12
14
16
18
20
GrADS: COLA/IGES

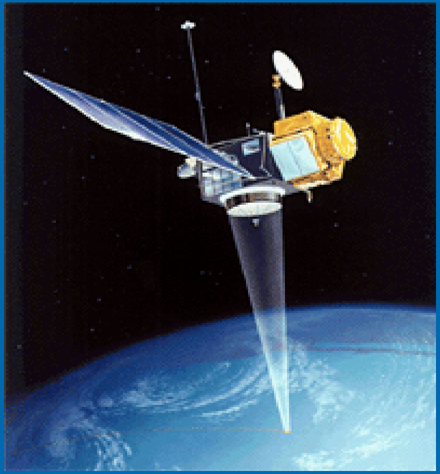

SARAL-AltiKa Wind Speed(m/s) 15JUN2014-18FEB2014
90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W
0
0
2
4
6
8
10
12
14
16
18
20
GrADS: COLA/IGES
2014-04-17-14:18


SSMI/S Wind Speed(m/s) 15JAN2014-18FEB2014
90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W
0
0
2
4
6
8
10
12
14
16
18
20
GrADS: COLA/IGES
2014-04-17-15:26

Conclusion:

- The proposed model provides better agreement with in-situ data and Jason-2 retrieved wind speed.
- The empirical model function provides better wind speed retrievals.





THANKS