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SATELLITE ALTIMETER DATA TO IMPROVE THE UNDERSTANDING OF WAVE STORM STATISTICS

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3 Research Fellow, Maritime Engineering Division University of Salerno (MEDUS), Department of Civil Engineering,
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C.U.G.RI.
CONSORZIO INTER - UNIVERSITARIO
per la Previsione e Prevenzione dei GRandi RIschi
Università di Salerno - Università di Napoli "Federico II"

What’s is it all about:

1) Very briefly recall well known application
-Satellite measurement of SWH and wind
- Application of satellite measurements to wave modelling

2) Suggest a possible cause of error of wave climate evaluation (Small Scale Storm Variations, “Gustiness”)
- Showing how Satellite Altimetry may help clarifying the presence and the effects of SSSV/Gustiness

Will deal with enclosed, semi enclosed seas: short fetches, rapidly varying
Weather. Tyrrhenian Sea, Arabian/Persian Sea

Wave climate (mostly: extreme SWH)

The evaluation of wave climate and particularly of storm extremes is one of the most important aspects of sea related activities, such as coastal and offshore constructions, civil protection of coastal areas and sea route planning.

As new and more accurate sources of data become available and at the same time the design requirements become more stringent, the **methodologies to estimate wave climate parameters must be constantly updated**

On sites with a long historical record of wavemeter data, **the use of measured data is** the obvious choice;

Weather and wave models

However, on most locations there is no adequate history of recorded data he use of "synthetic" data is a necessity.

In the last few years the use of global and local weather and wave models to extract wave statistics has become popular.

The method is based upon synthetic (analysis, reanalysis) data deriving from the chain:

1 **Global Weather Model Archive Data.**
2 Local Area Weather Model(s).
3 Wave Generation and Propagation Model.
4Statistical analysis of the synthetic wave data on the site.

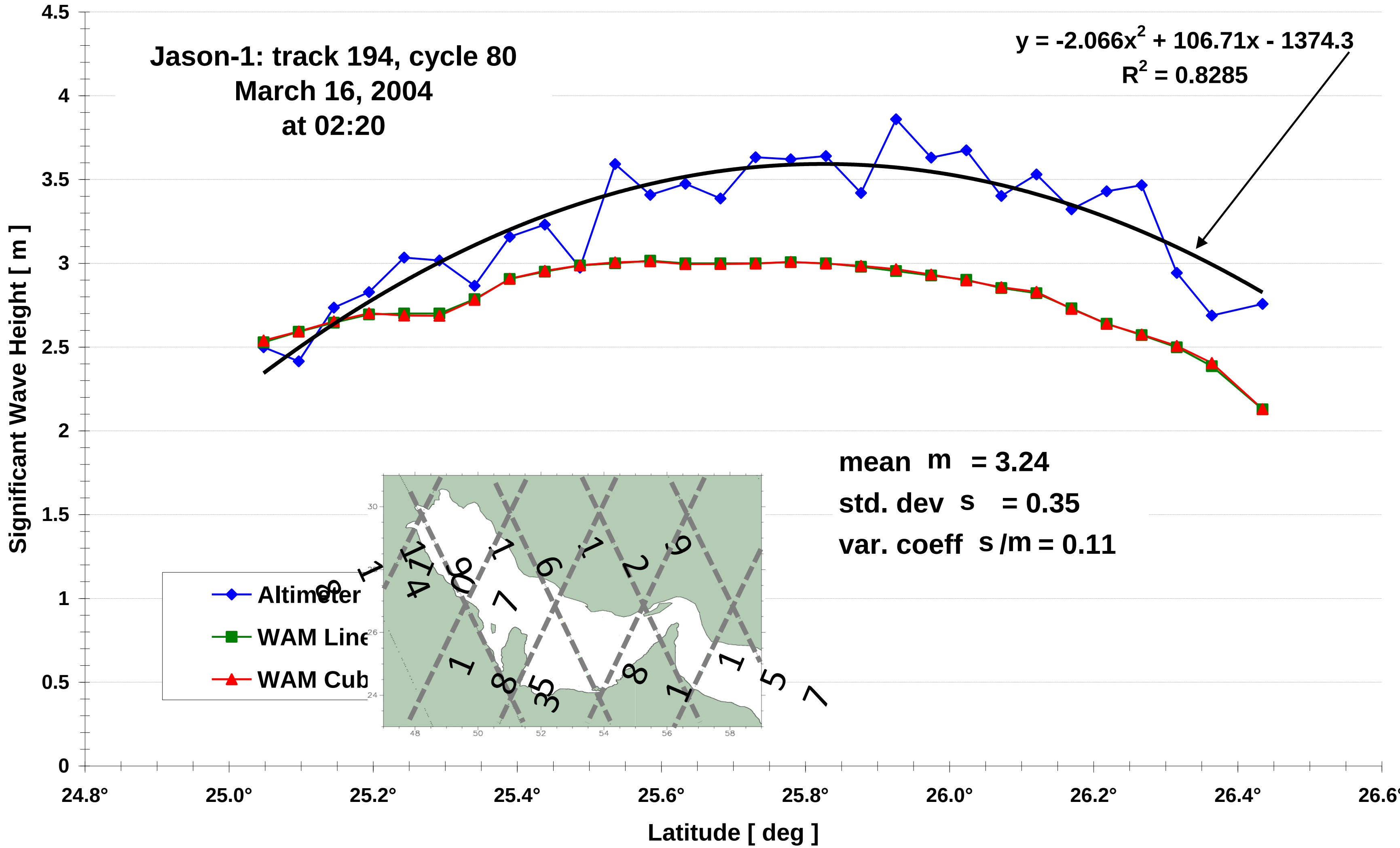
(Wave transformation on shallow water can be added to either step **3** or **4.)**

numerical weather forecast models are now widely available, together with long records of past analyses and forecasts:
ECMWF, NECP, State Agencies...

At a price!

UKMO, Oceanweather....

Unfortunately, when it comes to models
… not everything turns out as it should …



WAM model
KISR Kuwait Institute for Scientific Research
No calibration

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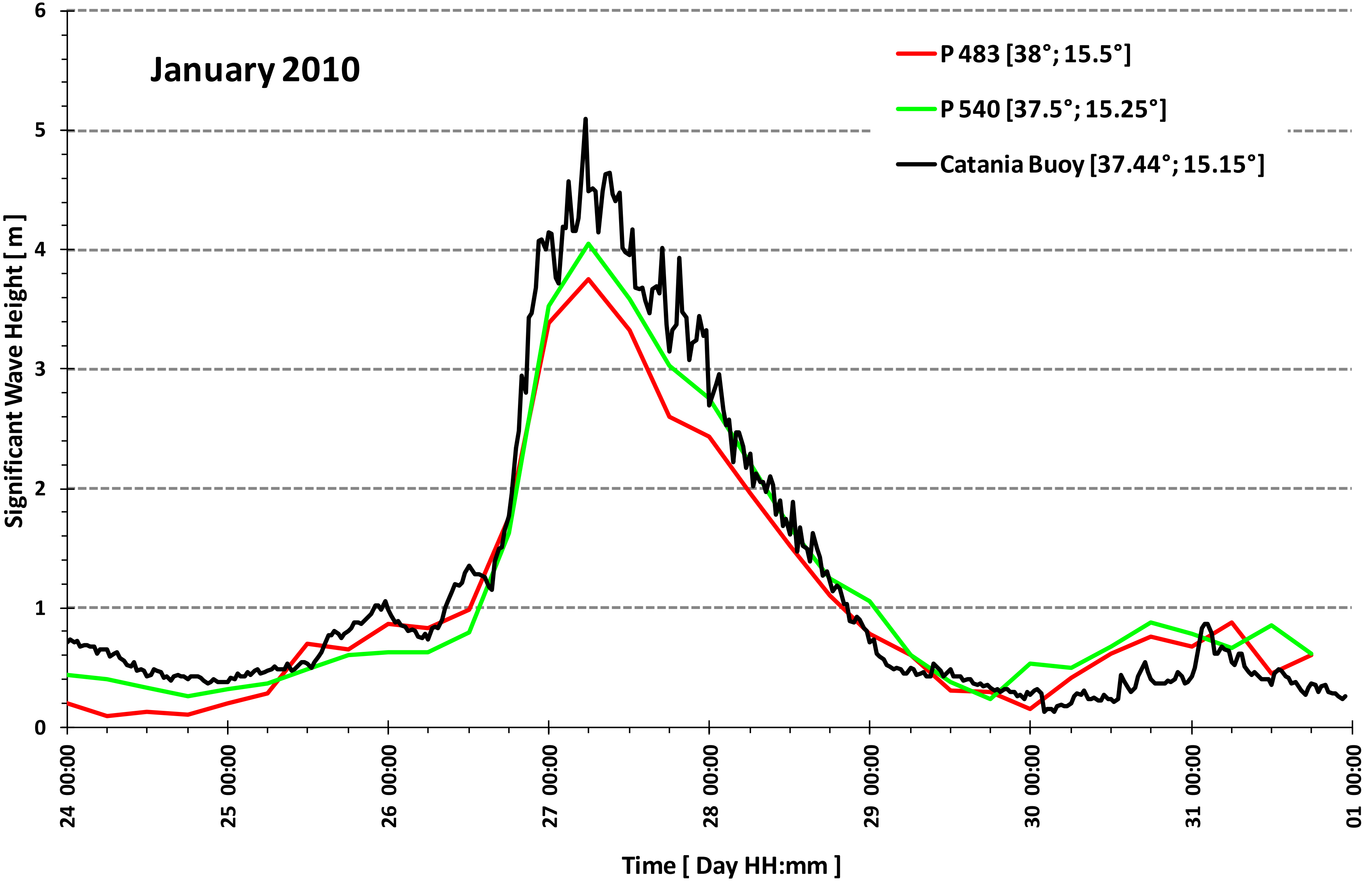


Catania Buoy data vs ECMWF points 483 and 540

Models are affected by errors

Wind and SWH satellite altimeter data can help, and do help

Since 1985 a number of satellites (Geosat, ERS-1, TOPEX/Poseidon, ERS-2, Jason-1, Envisat, Jason-2, CryoSat- *Cryosat, Indian Satellite)* have been providing radio altimeter data for all the seas of the word.

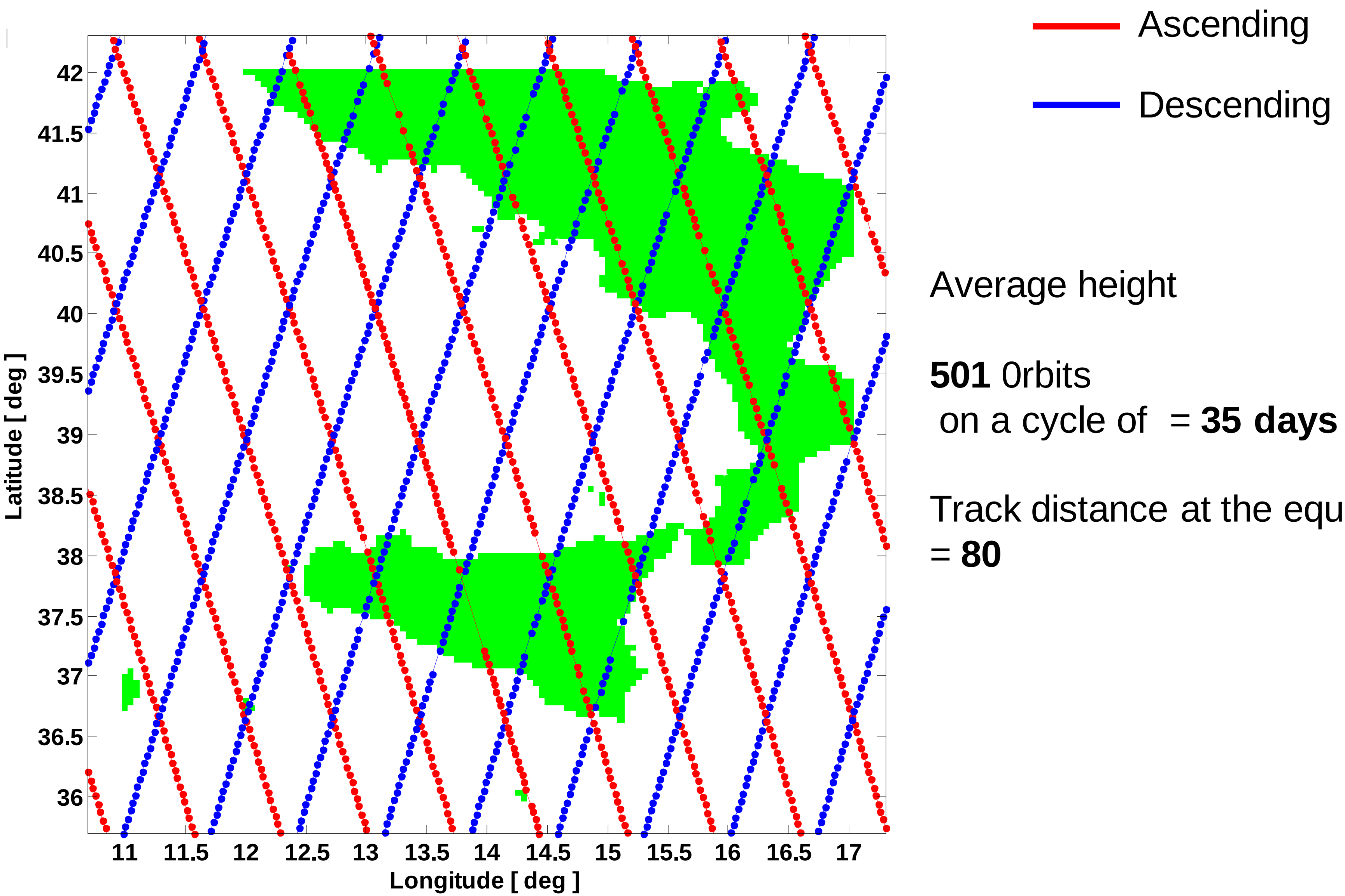
Satellite altimeter data are routinely *__assimilated__* by Weather Centres in to improve prediction and analysis of the sea state

They have also often been used to asses wave climate studies,

Altimeter data are now routinely assimilated into wave models
Altimeter/buoy (wind, waves) data calibration: 1988 (Monaldo)
Altimeter/Model comparison:
2006 (Abdalla & Cavaleri)
(2007) (Ardhuin, Bertotti, Bidlot, Cavaleri, Filipetto, Lefevre, Wittmann)

Old news

Coverage of ERS1, Ers2, Envisat altimeter satellites on The Mediterranean

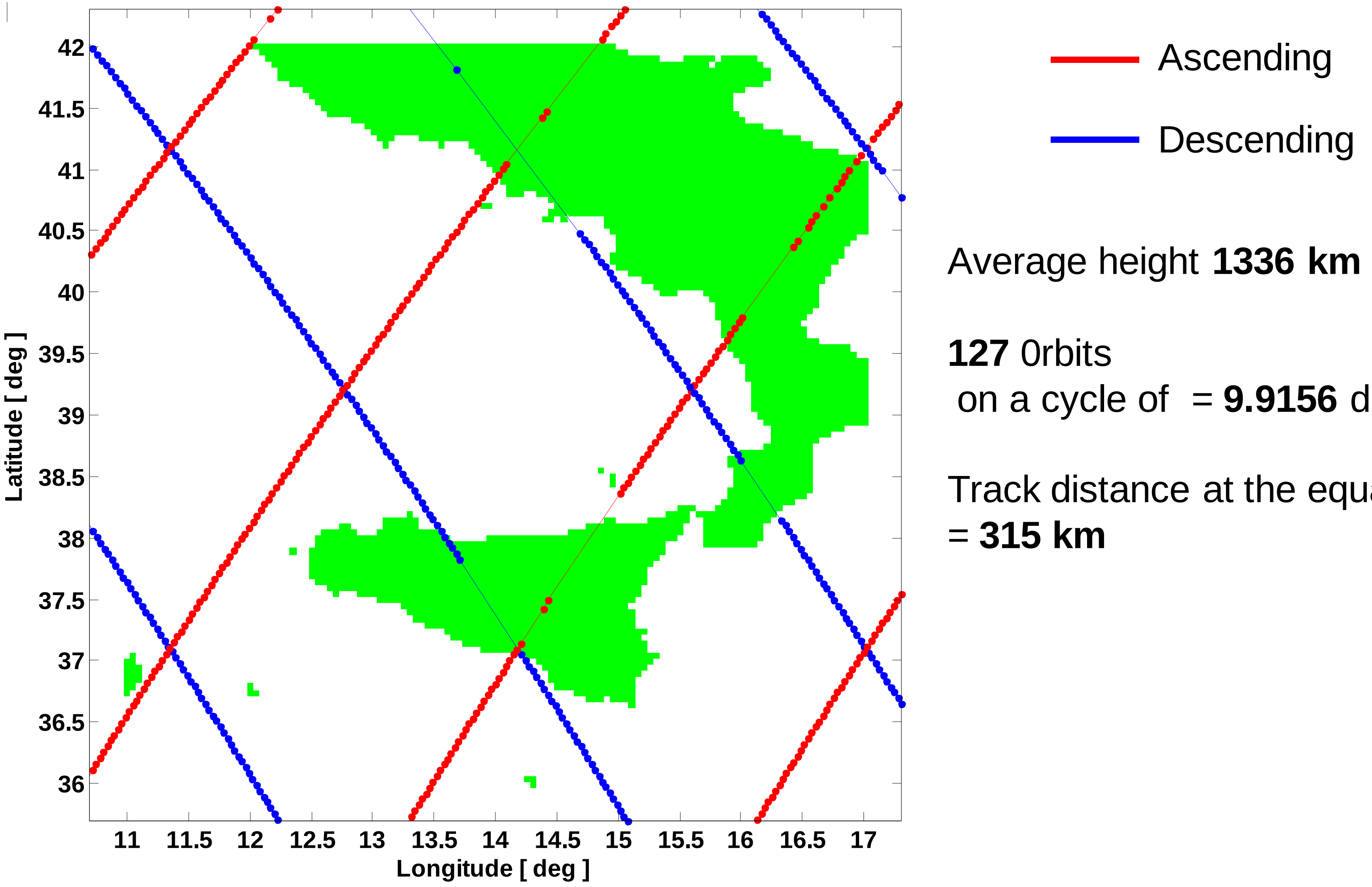


Average height

501 0rbits
on a cycle of = **35 days**

Track distance at the equator = **80**

Coverage of Jason -1 e Jason-2 altimeter satellites on The Mediterranean



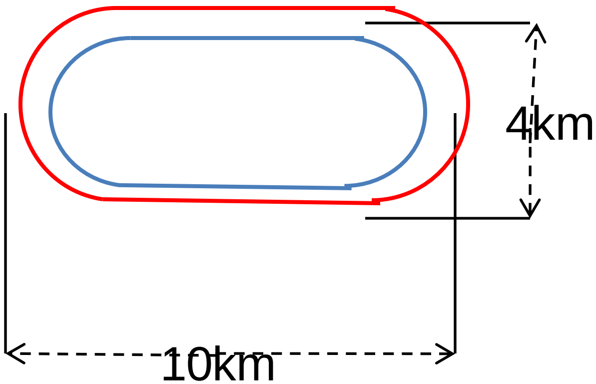
Average height **1336 km**

127 0rbits
on a cycle of = **9.9156** days

Track distance at the equator
= **315 km**

Wind and SWH measurements are carried out along track

Impulses are averaged over about 1 second to provide 1 Hz measurements, i.e. about 7 km apart from each other, with a footprint about 12 km long and 6 km wide.



Unlike SWH, altimeter wind measurements are often unreliable (rain..)

Sample area is different for wind and waves

Lots of work in applications of altimeter measures to wave climate..

Suhe Surendran*, Raj Kumar, Abhijit Sarkar and Vijay K. Agarwal
EXTREME WAVE ANALYSIS USING SATELLITE, IN-SITU AND WAVE MODEL DATA

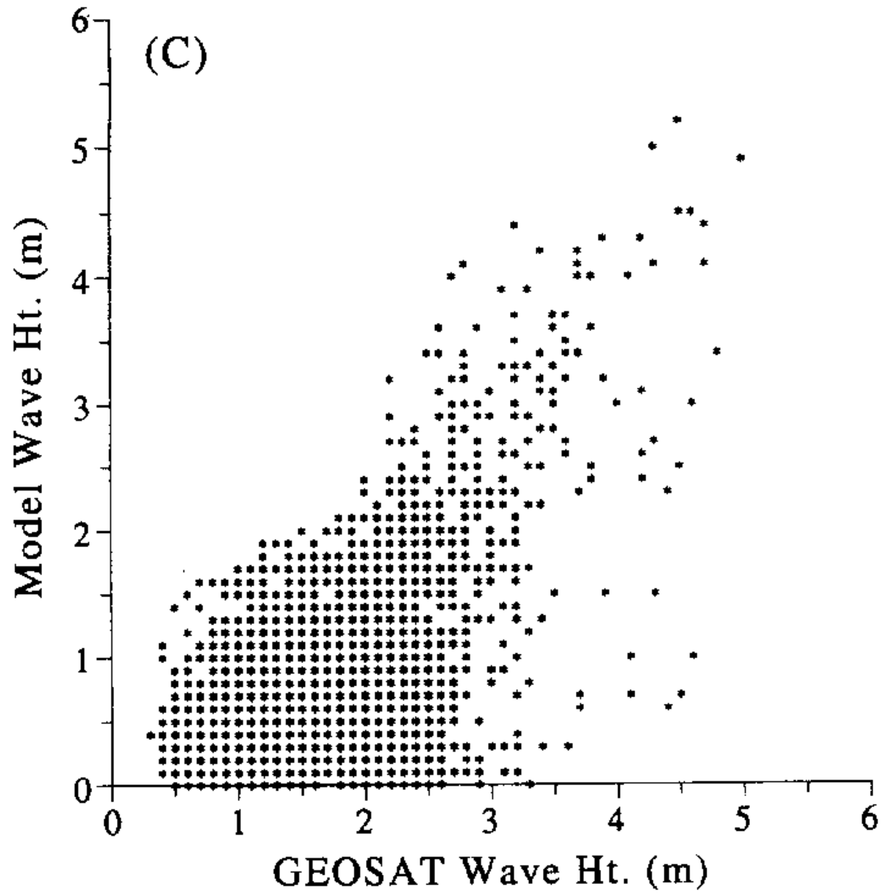
Woolf, P.D. Cotton, and P.G. Challenor, 2003 “Measurements of the offshore wave climate around the British Isles by satellite altimeter” Phil. Trans. Roy. Soc. London Series a-

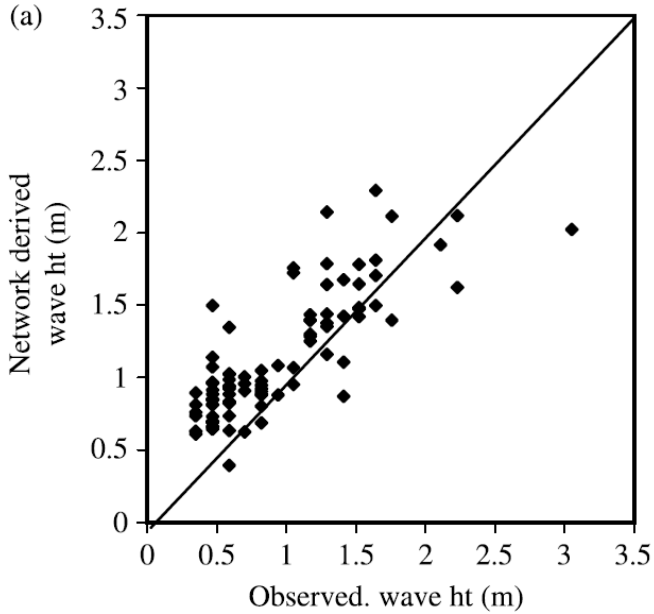
Ruchi Kalra, M.C. Deo, Raj Kumar, Vijay K. Agarwal 2005 Artificial neural network to translate offshore satellite wave data to coastal locations Ocean Engineering, Volume 32, Pages 1917-1932

INTER-COMPARISON OF MODEL-PREDICTED WAVE HEIGHTS WITH SATELLITE ALTIMETER MEASUREMENTS IN THE NORTH INDIAN OCEAN

Abhijit Sarkar, M. Mohan and Raj Kumar

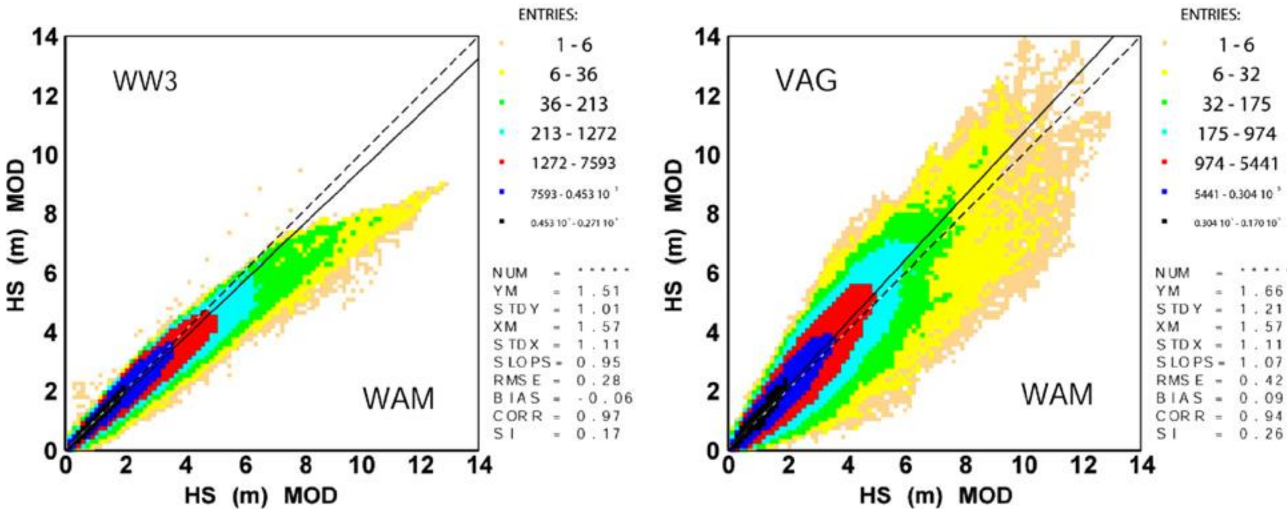
Ocean Eng 1997





Ruchi Kalraa, M.C. Deoa, Raj Kumarb, Vijay K. Agarwalb (2005) Artificial neural network to translate offshore satellite wave data to coastal locations Ocean Engineering 32

Cavaleri, L. and Sclavo, M. 2006. The calibration of wind and wave model data I
n the Mediterranean Sea. Coastal Engineering, Vol.53 No. 7 pp. 613–627.



Woolf, P.D. Cotton, and P.G. Challenor, 2003 “Measurements of the offshore wave climate around the British Isles by satellite altimeter” Phil. Trans. Roy. Soc. London Series a-

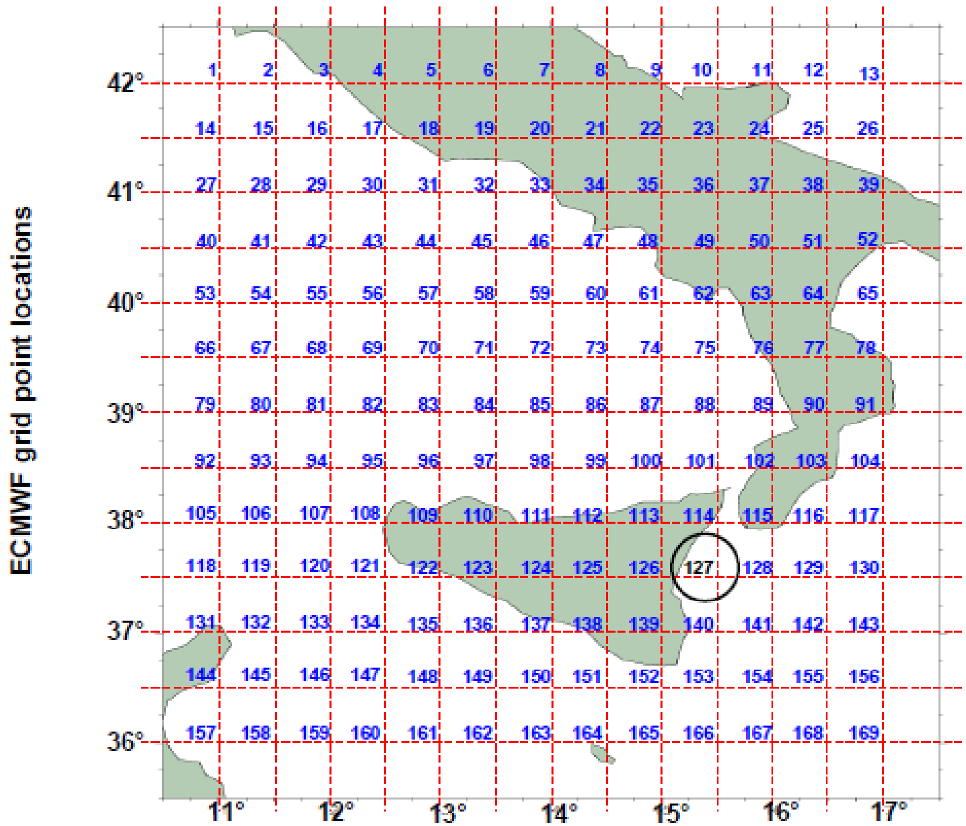
Models are being improved all the time

better data,
better parametrization
assimilation

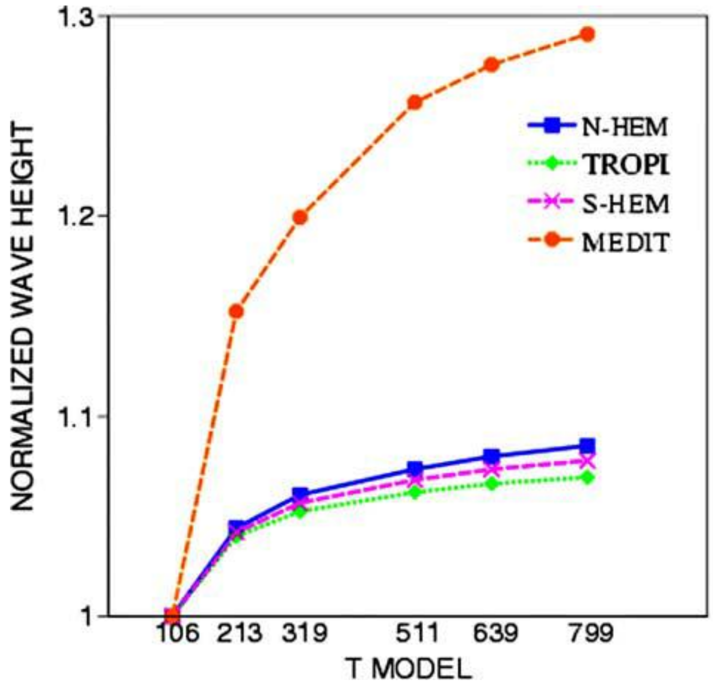
above all:

Higher resolution, (Smaller grids, shorter time steps)

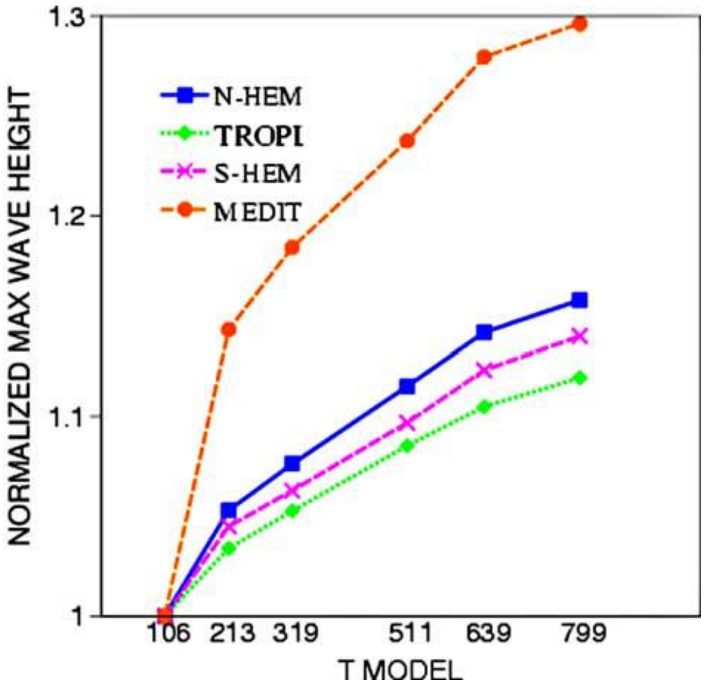
Specially
for
Reanalysis data



The improvement of modelled wind and wave fields with increasing resolution
Ocean Engineering
Volume: 33, Issue: 5-6, April, 2006, pp. 553-565
L. Cavaleri, L. Bertotti



relative increase of SWH with the resolution of the meteorological model.



relative increase of SWH with the resolution of the meteorological model.

Note: Increasing resolution is very important , specially so in the Med, enclosed seas

The improvement of modelled wind and wave fields with increasing resolution
Ocean Engineering
Volume: 33, Issue: 5-6, April, 2006, pp. 553-565
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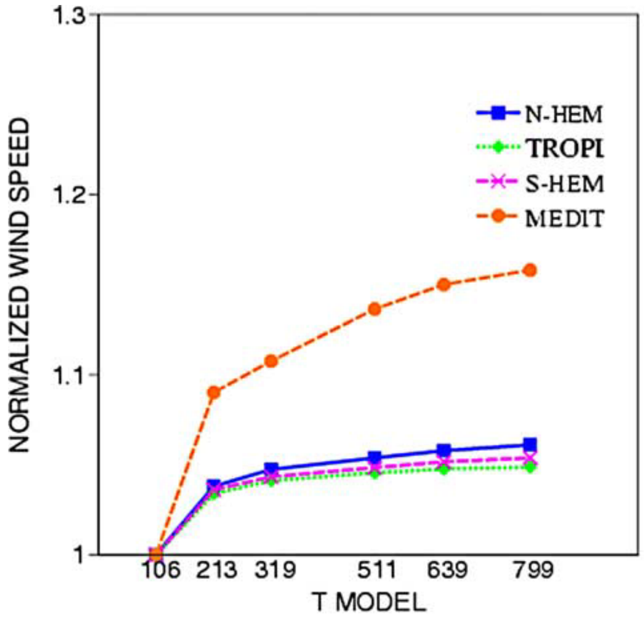
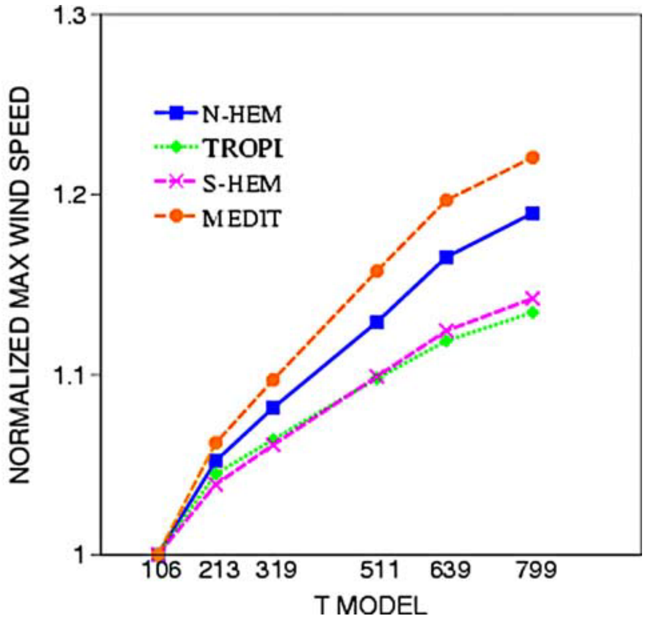


relative increase of the wind speeds with the resolution of the meteorological model.



relative increase of the maximum wind speeds with the resolution of the meteorological model

So there are errors.

But we reasonably hope that, when performing climate studies, averaging over a long time series random errors will cancel out

Specially
for
Reanalysis data

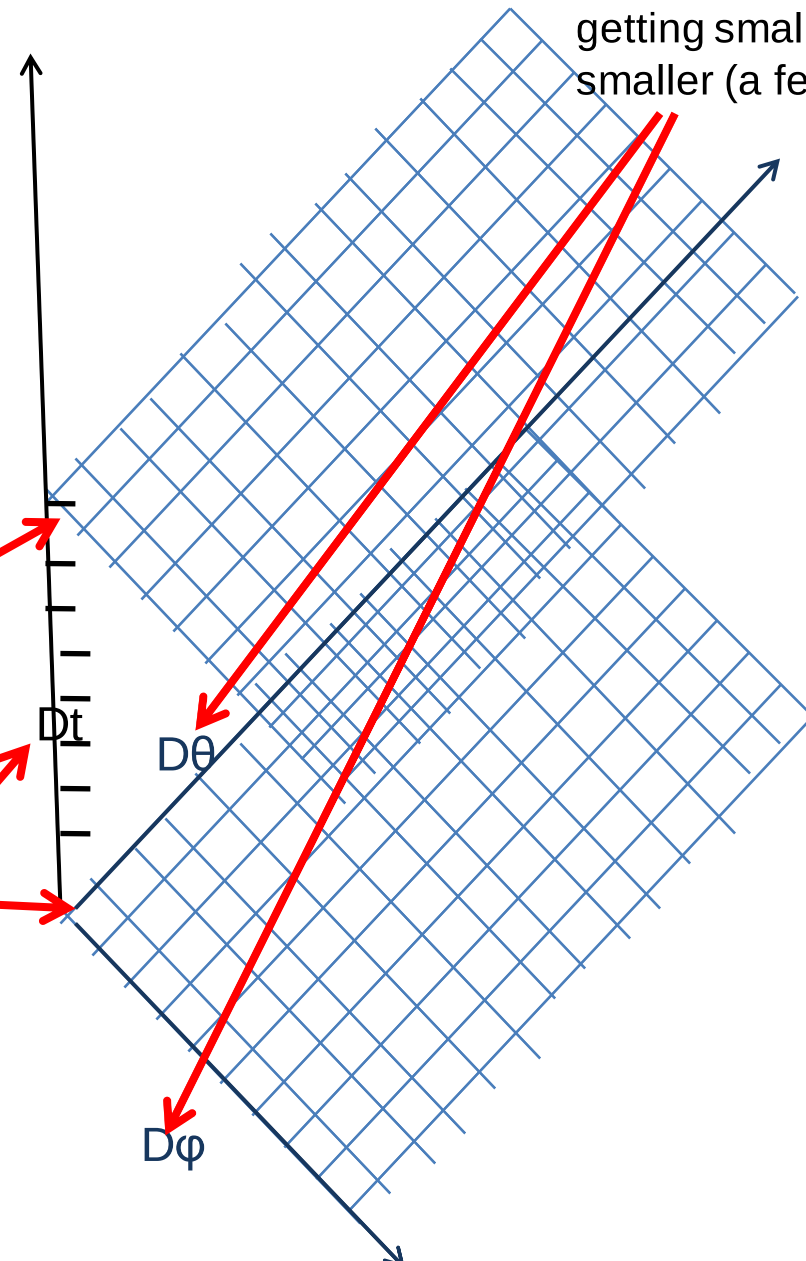
But

If we are interested in extreme values, and we use standard analysis or re-analysis data there are some big ones!

Computational space intervals are getting smaller and smaller (a few miles)

not all data are stored
and

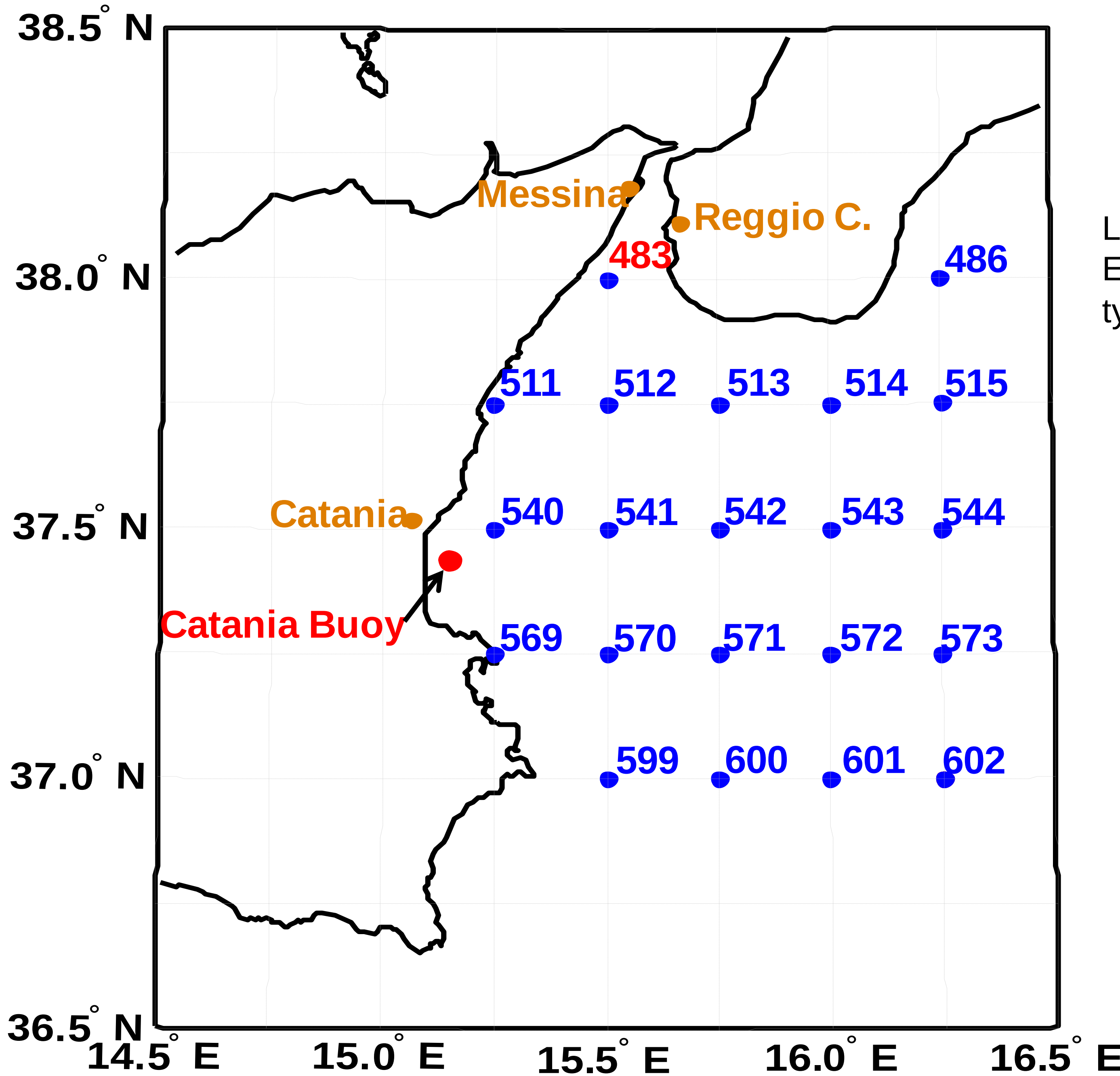
You lose maxima!



Storage interval
Interval
(1,3 , 6 hrs)

Some are better than others
UKMO: hourly

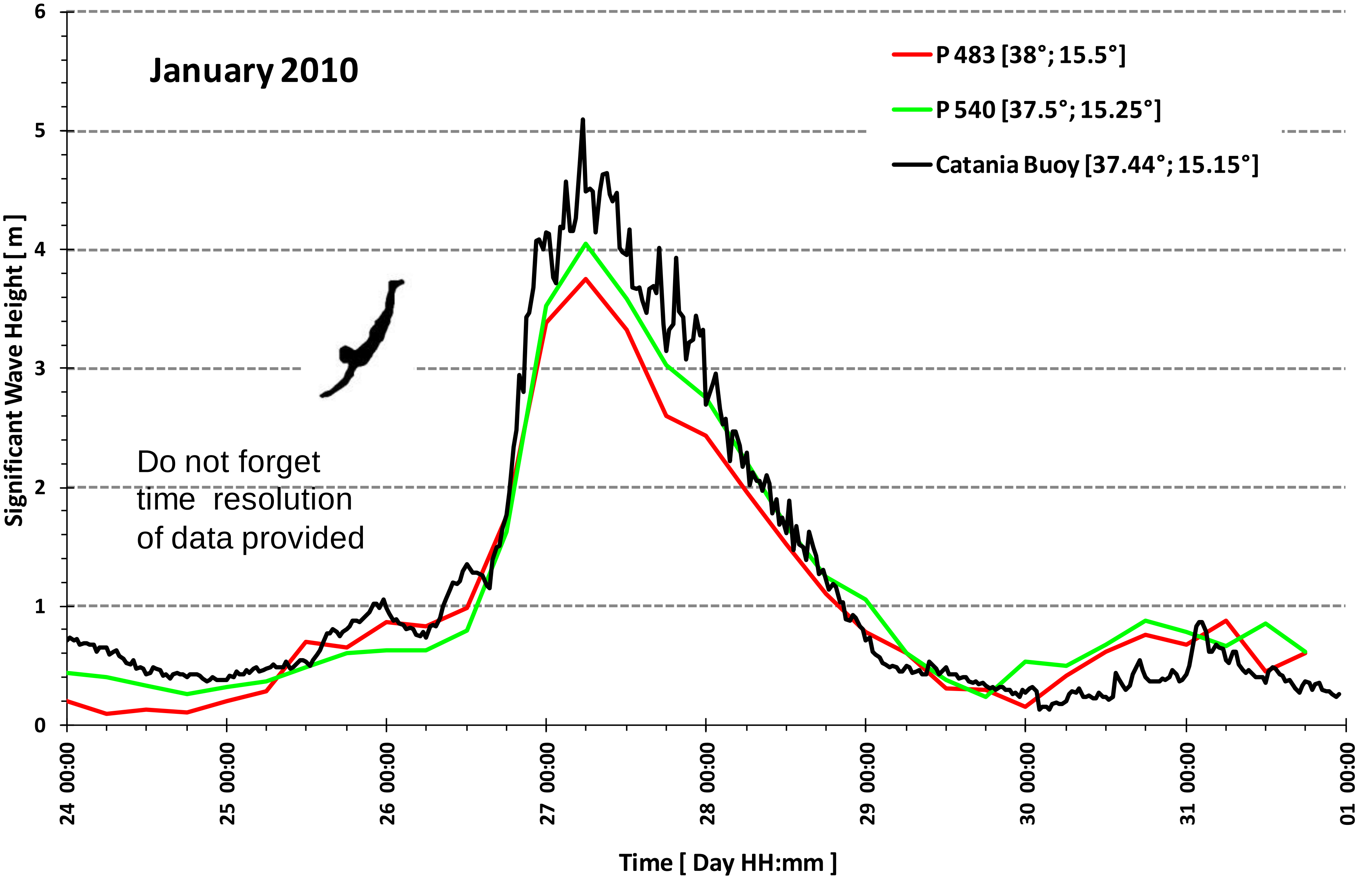
Computational
Interval
(minutes)



Let's try and compare ECMWF with buoy for a typical storm

it shows!

Catania Buoy data vs ECMWF points



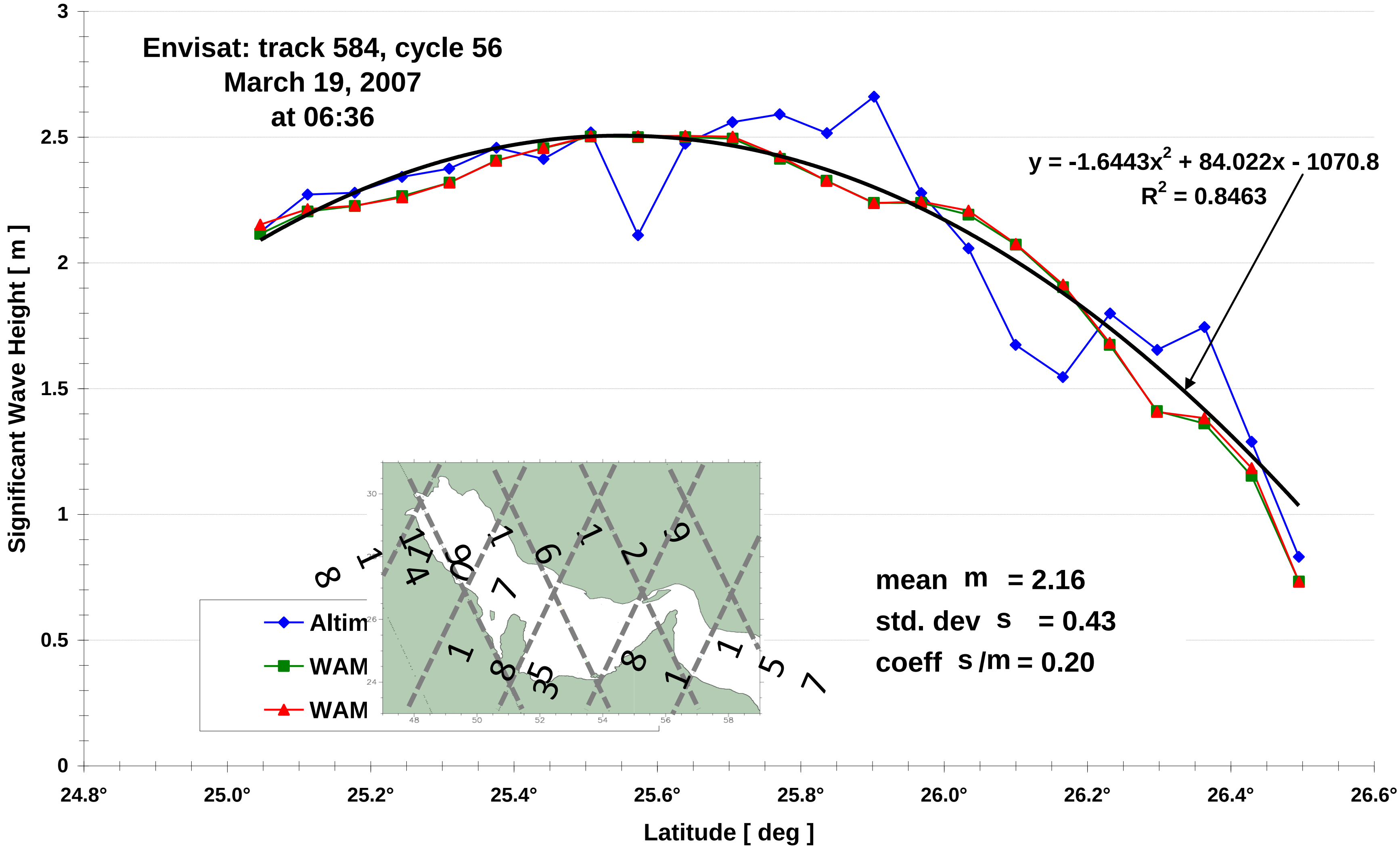
Better modelling techniques can do a lot:

Resolution is improving all the time
Some agencies (ECMWF) are planning to provide <u>maxima</u> within time

But there is more:

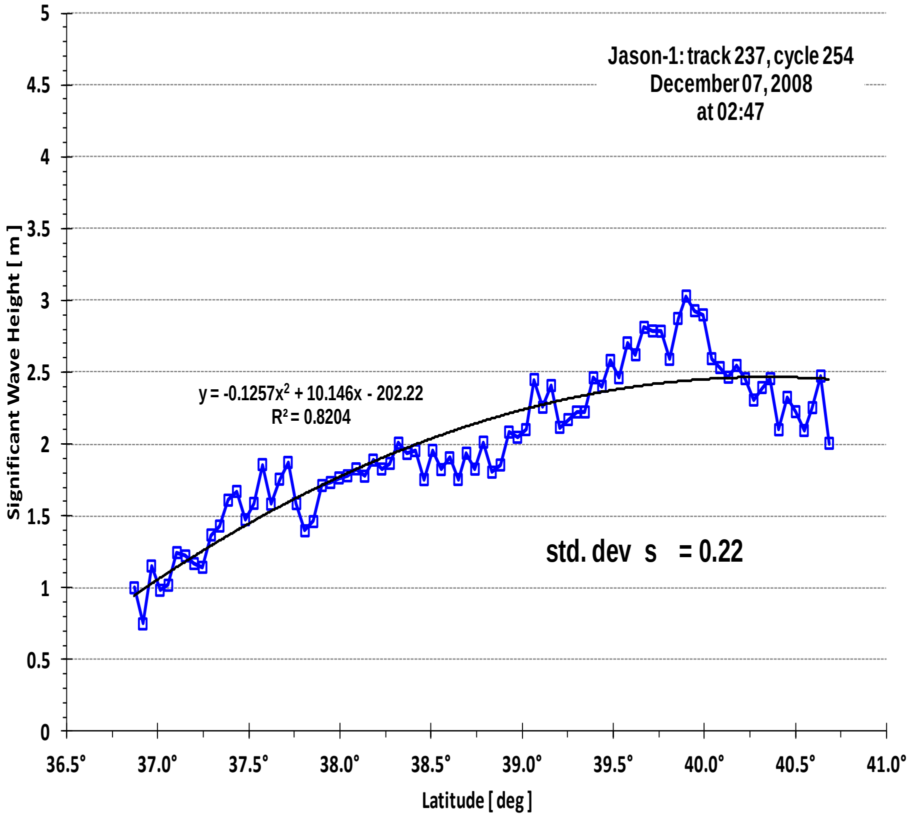
Bingo!

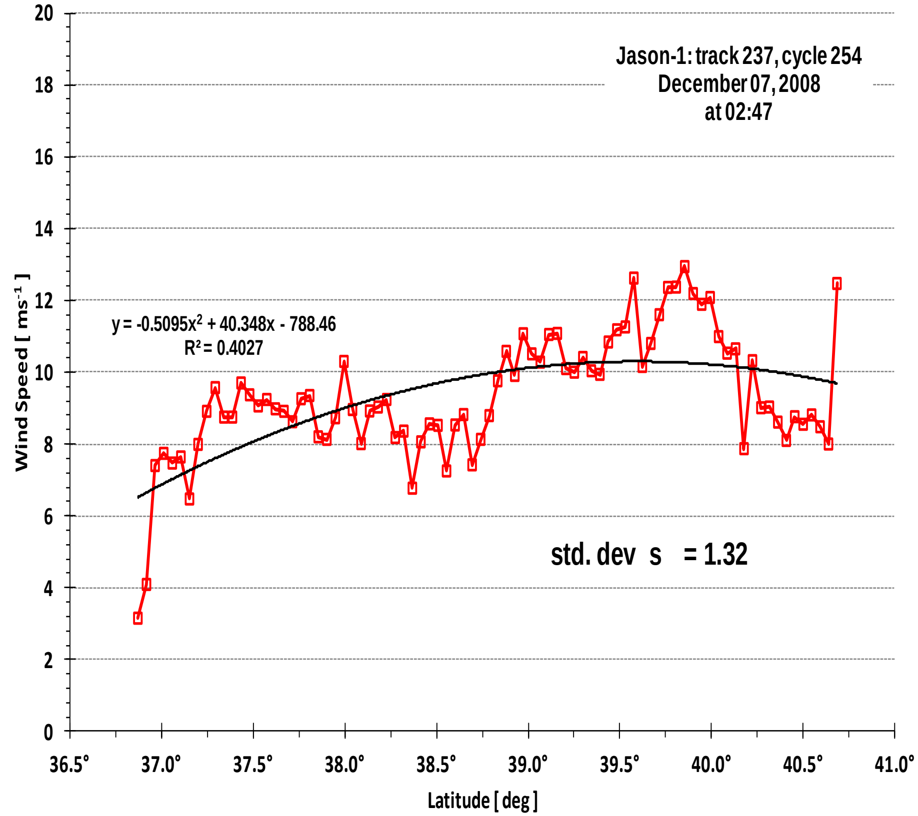
Let's take a good example of model result:



WAM model
KISR Kuwait Institute for Scientific Research
No calibration

SWH *as measured by satellite (nearly) always shows relevant oscillations around its interpolated value : Small Scale Storm Variations...*





Small Scale Storm Variability
SSSV

Gustyness

Jason altimeter data in the Southern Tyrrhenian Sea.
. Left: SWH; right: wind speed; curve: best fit parabola.

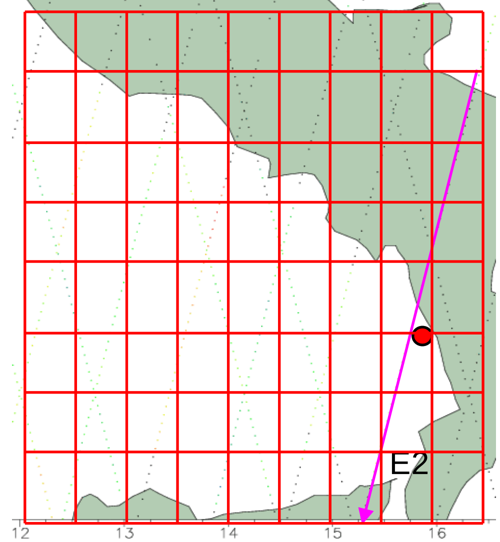
... Small Scale Storm Variations, which are linked to oscillation in wind intensity

And this happens everywhere, and nearly always

E2) ENVISAT1 Discendente

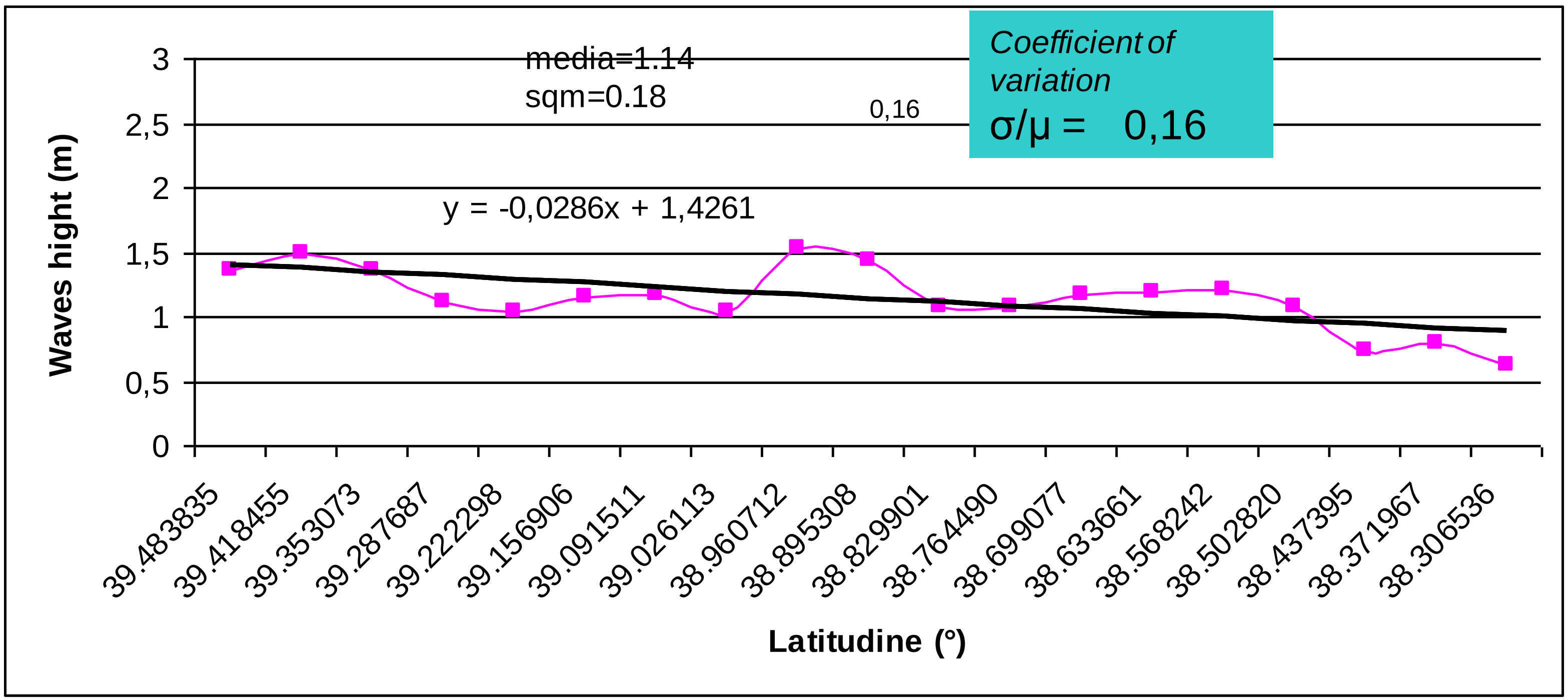
23/03/08 time 09:36 N1p0158C067

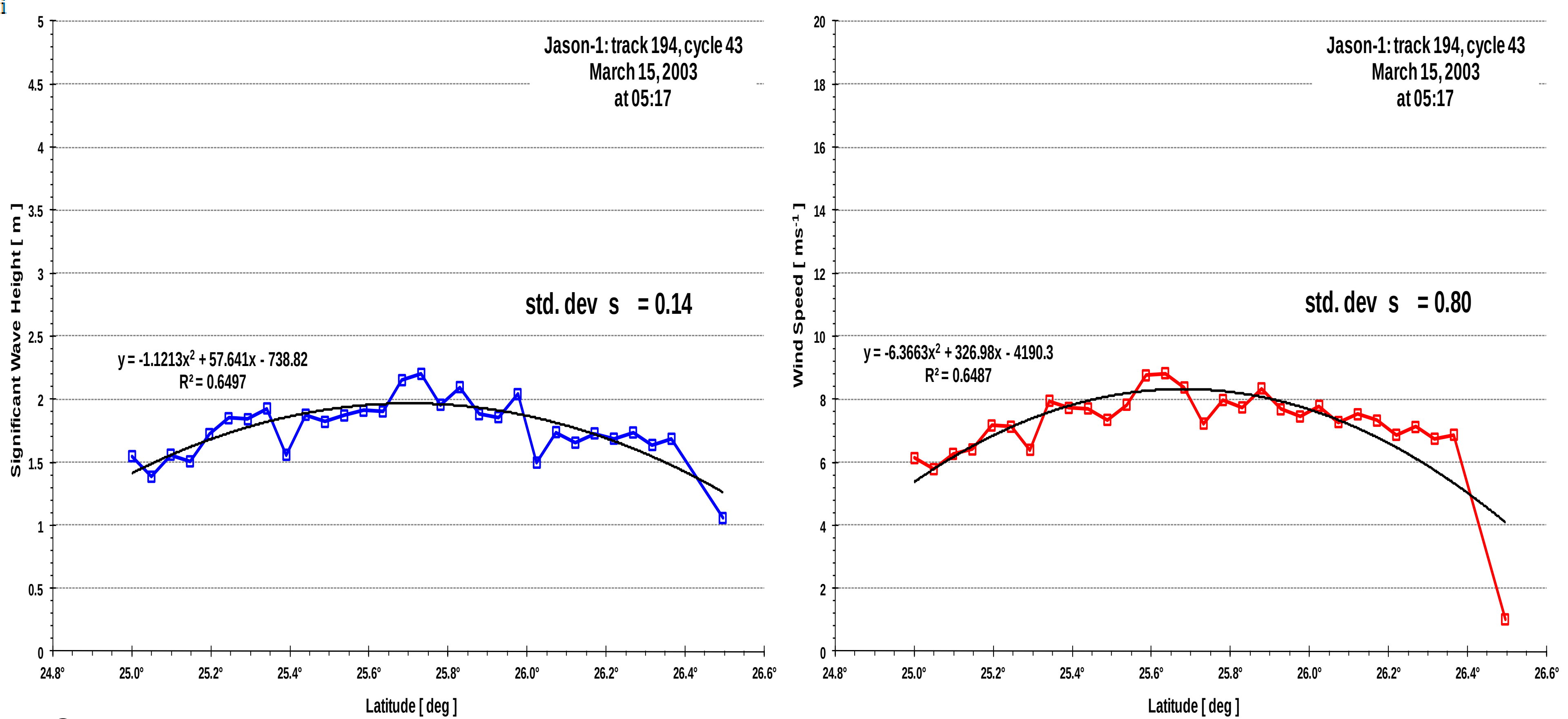
Cetraro Buoy



WAVES

ENVISAT (09:36) 23/03/2008



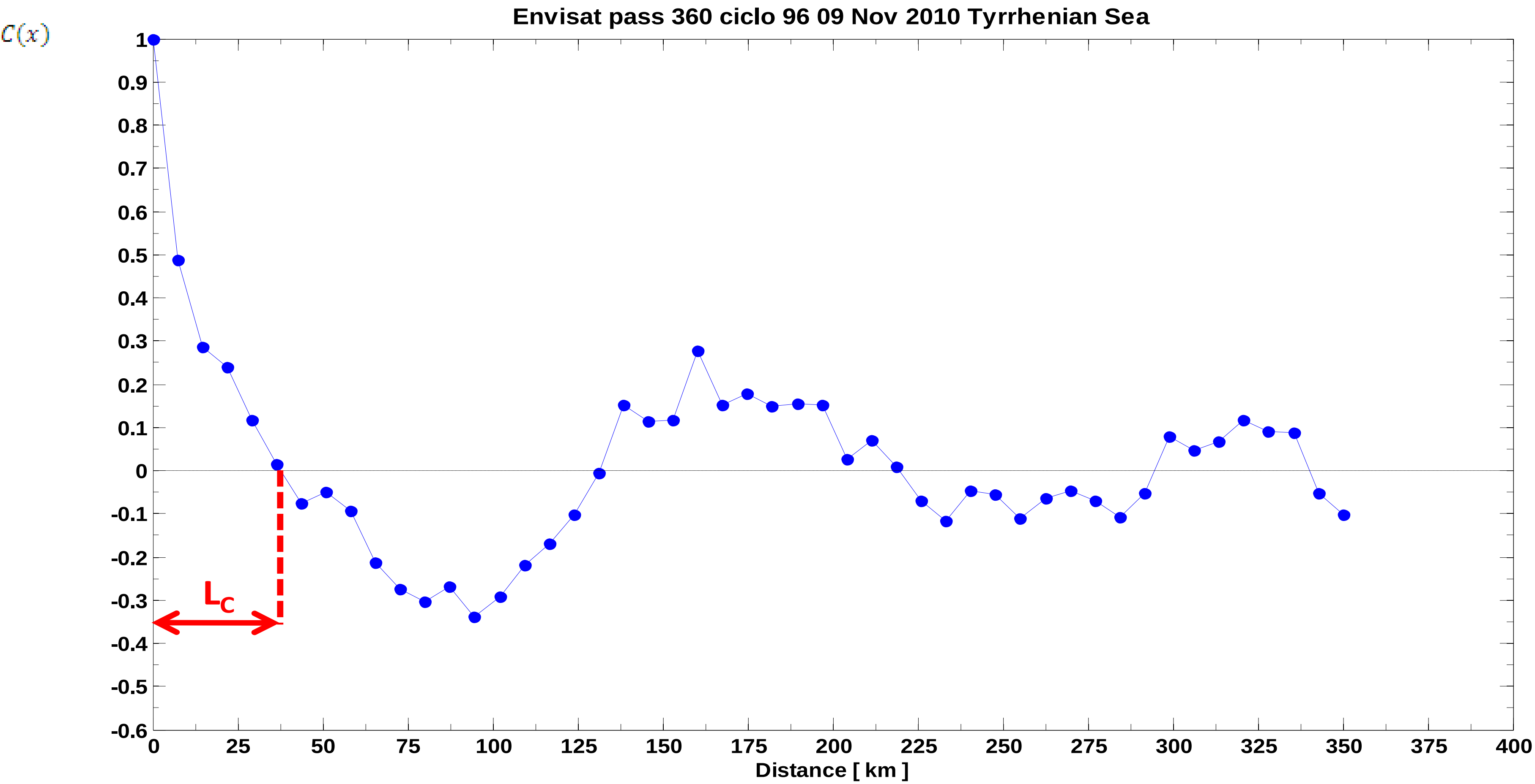


So we may want to quantify it

Jason altimeter data in the Persian/Arabian Gulf
Left: SWH; right: wind speed; curve: best fit parabola.

$$\sigma = \sqrt{\frac{\sum_{1=1}^{N}(Y_i - T_i)^2}{(N-1)}}$$

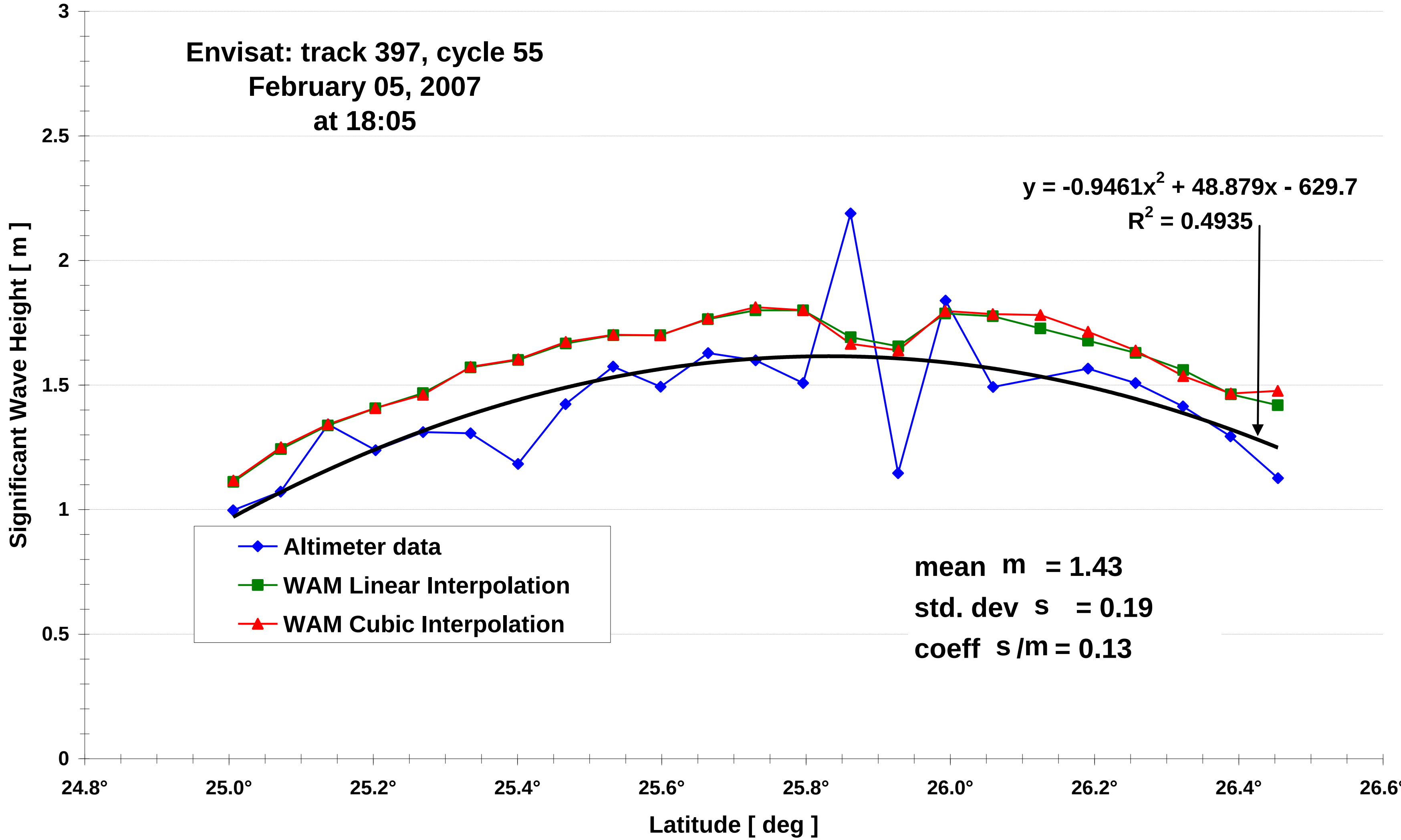
Yi measured value Ti trend at the same position,
N number of measurements
The scatter index σ/A
(standard deviation normalized by the mean of the data)



$$C(i) = \frac{\sum_{m=.\infty}^{+\infty} Y(m) \cdot Y(i+m)}{\sum_{j=1}^{N} Y_j^2}$$

L_C : first zero-crossing of Cross Correlation indicator of the space scale of the SSSVs

!Space scale of altimeter data 6km!



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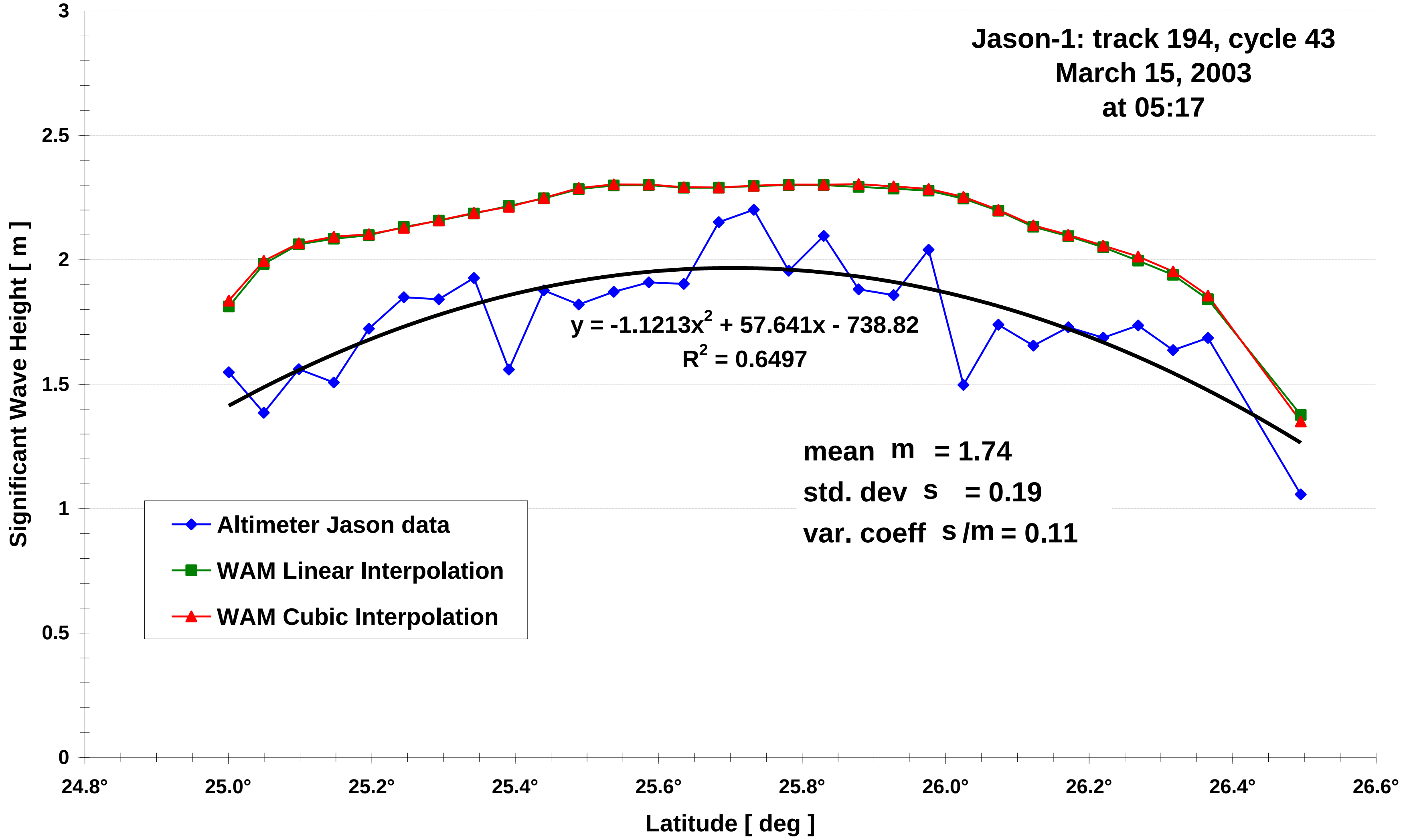

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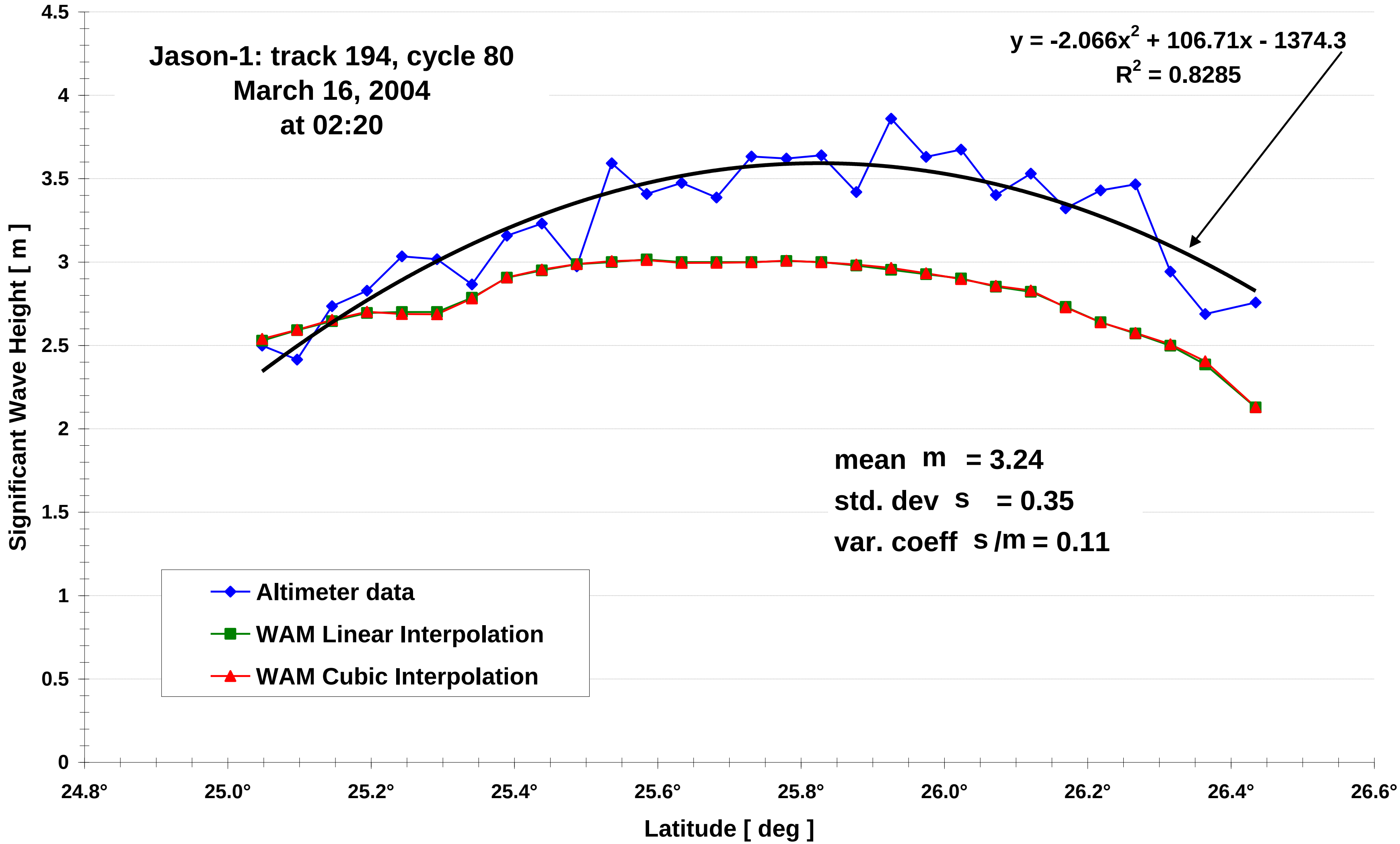

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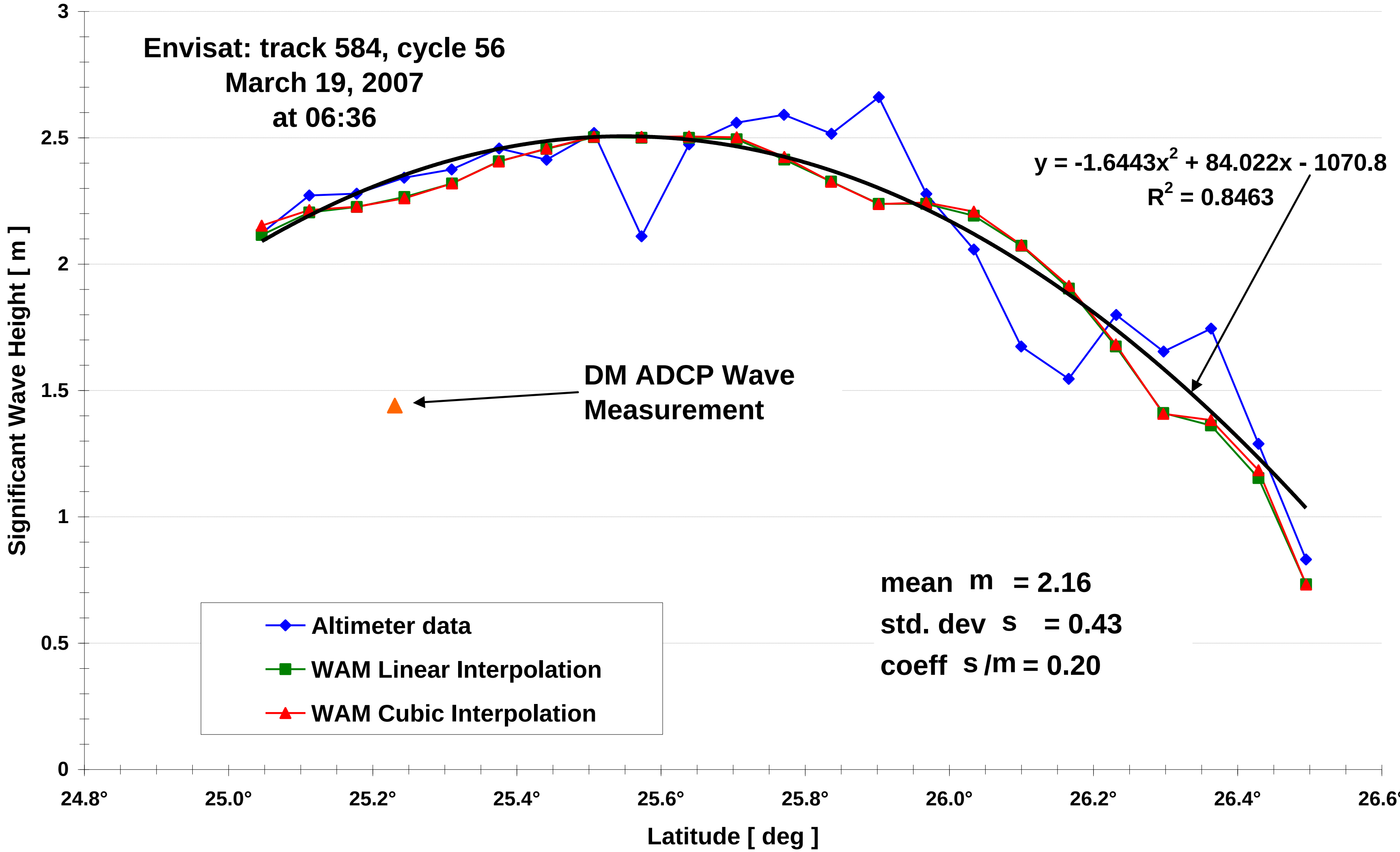


WAM model
KISR Kuwait Institute for Scientific Research
No calibration

E2) ENVISAT1 Discendente

23/03/08 time 09:36 N1p0158C067

Cetraro Buoy

ALSO Wind

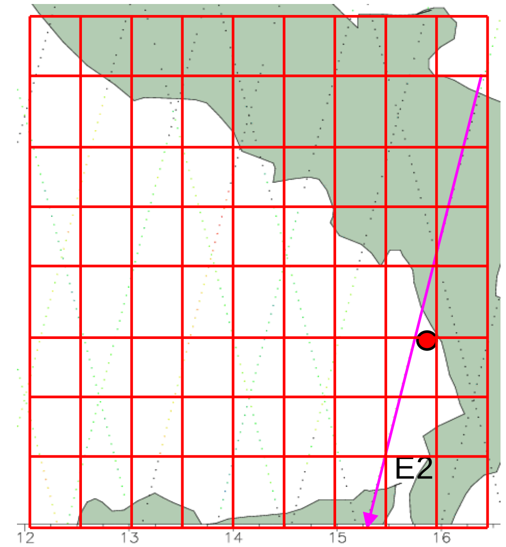
ENVISAT (09:36) 23/03/2008

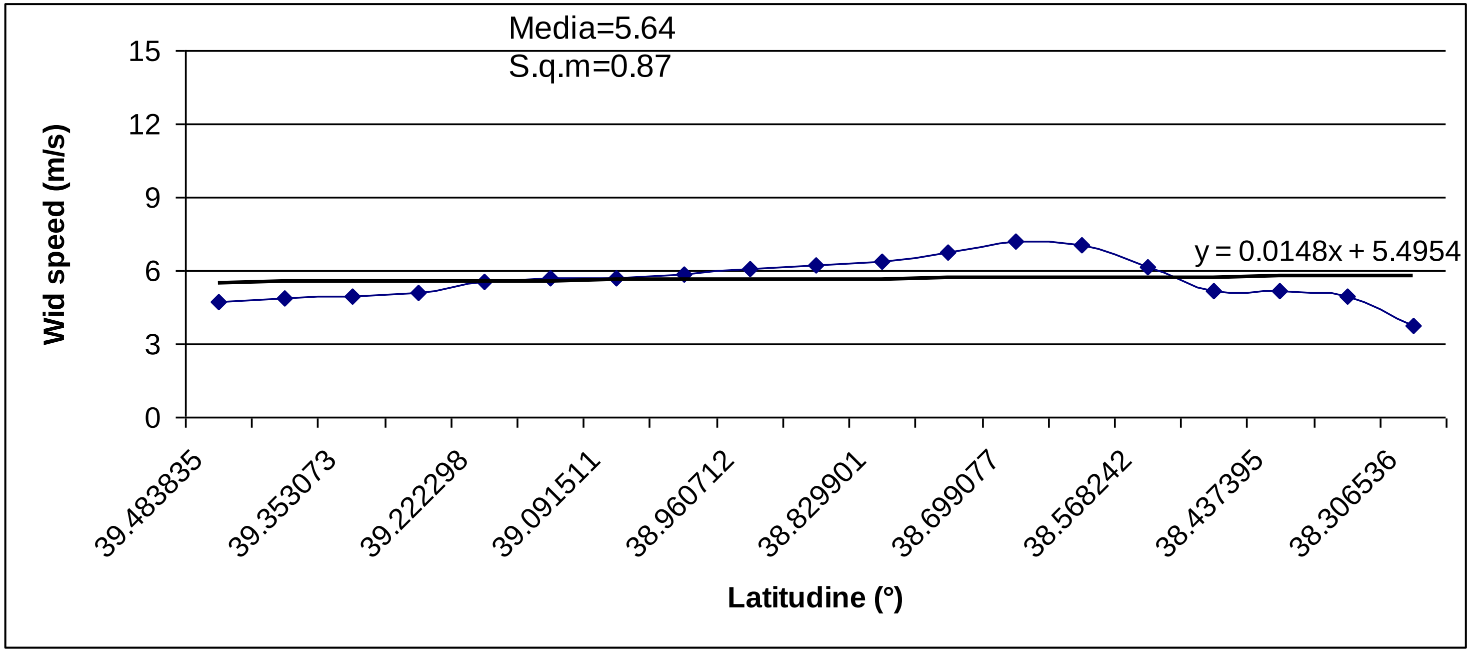
Wind Gustyness

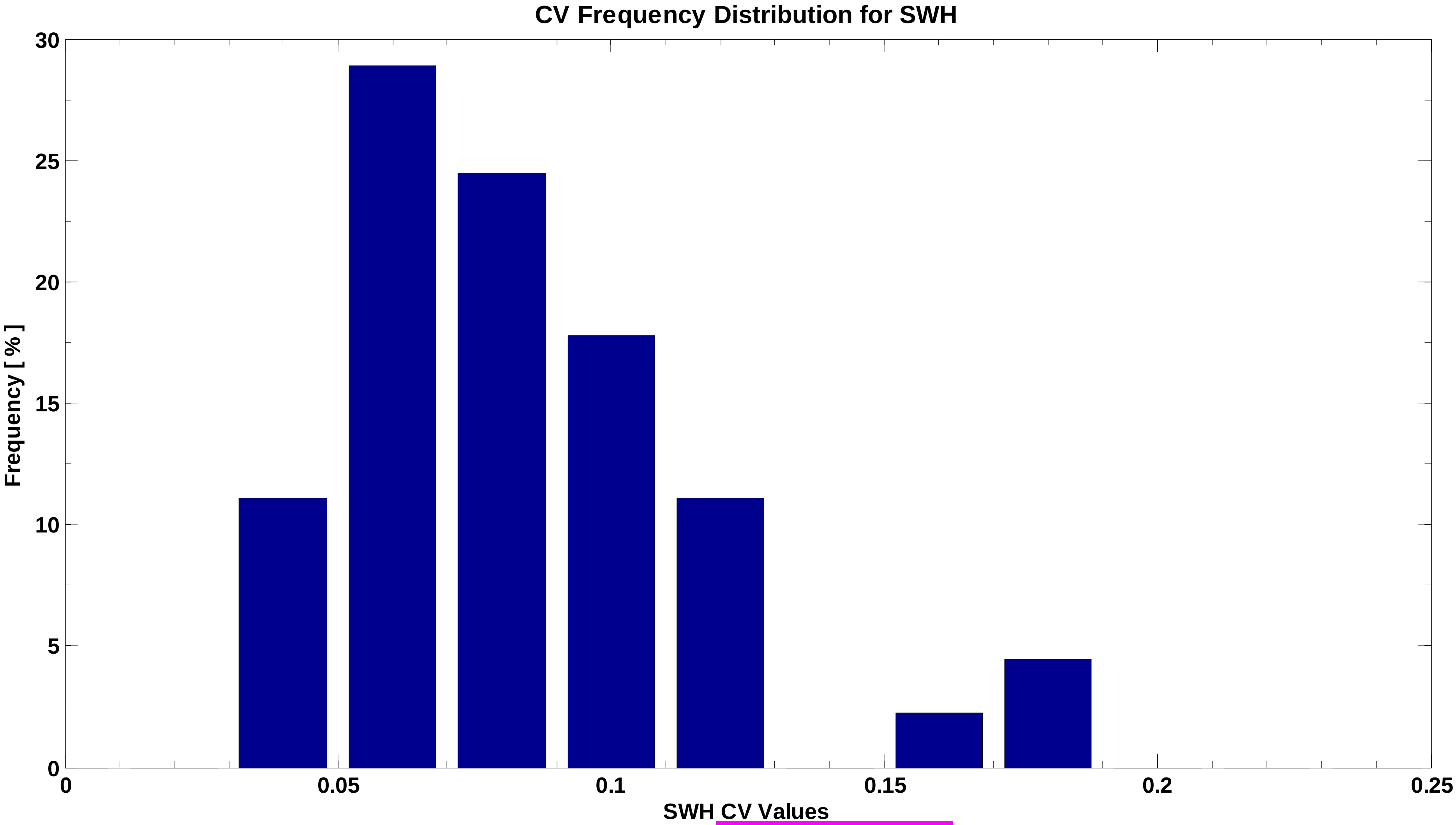
But do not trust so much

Coefficient of variation

σ/μ = 0,15

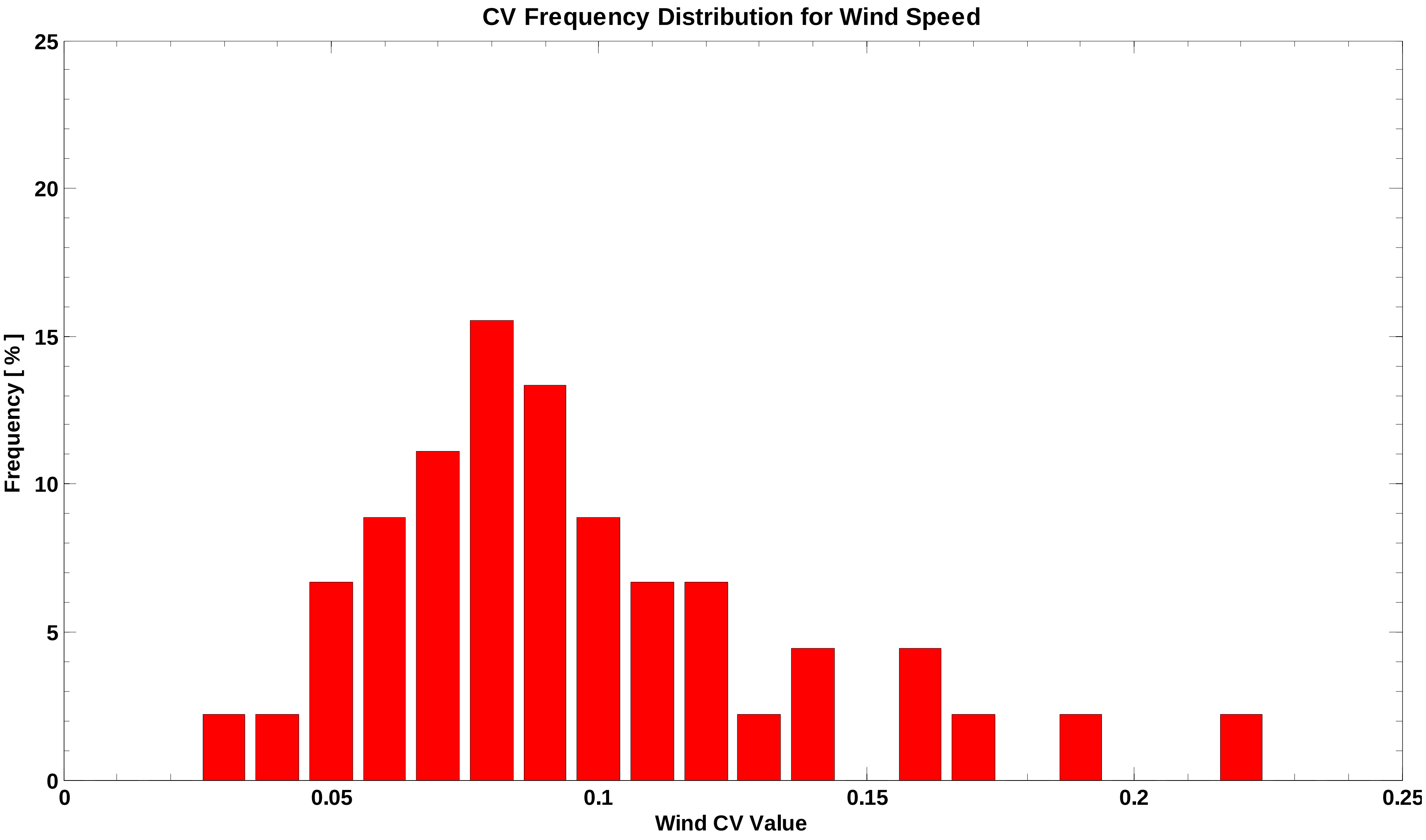






Coefficient of variation

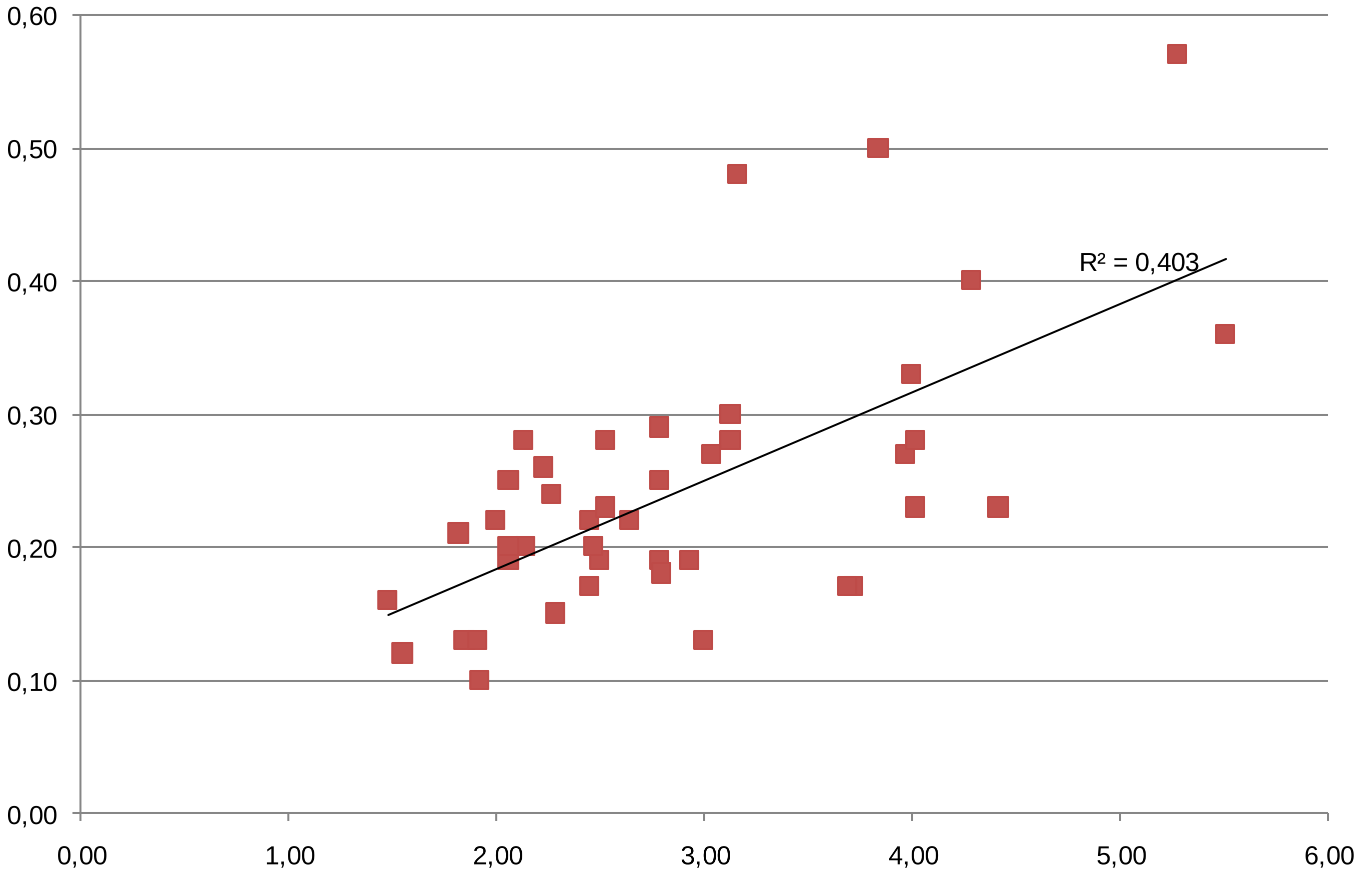
σ/A



Coefficient of variation

σ/A

std dev



No meaningful correlation between parameters except Std dev vs Hs

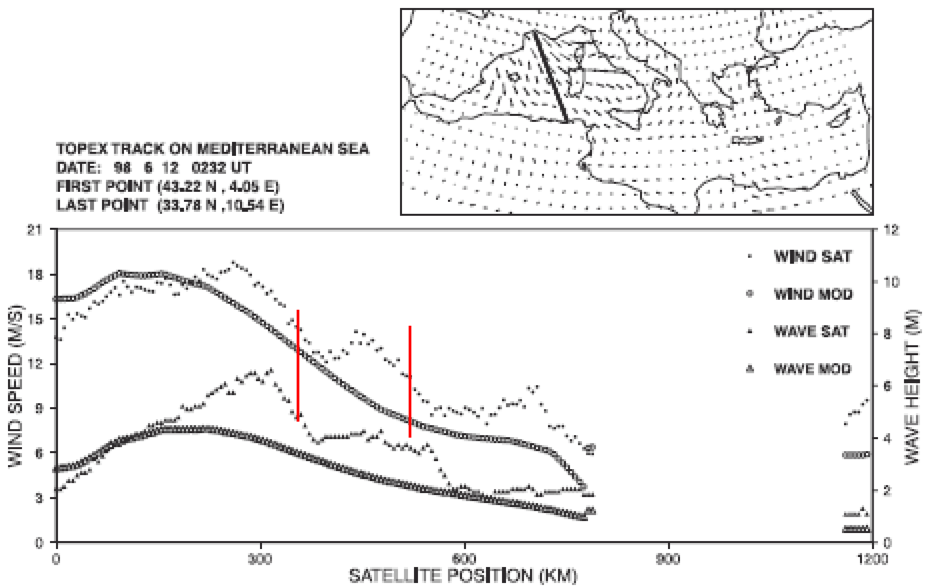
Stronger seas, stronger SSSV

Subgrid variations
can account for greater than expected
extreme values
- is still an open problem

"Gustyness"
Has been numerically
explored before
Abdalla, Cavaleri, Jansenn
…

ABDALLA AND CAVALERI: GUSTINESS AND AIR DENSITY EFFECTS ON WAVES

But
on a larger
scale



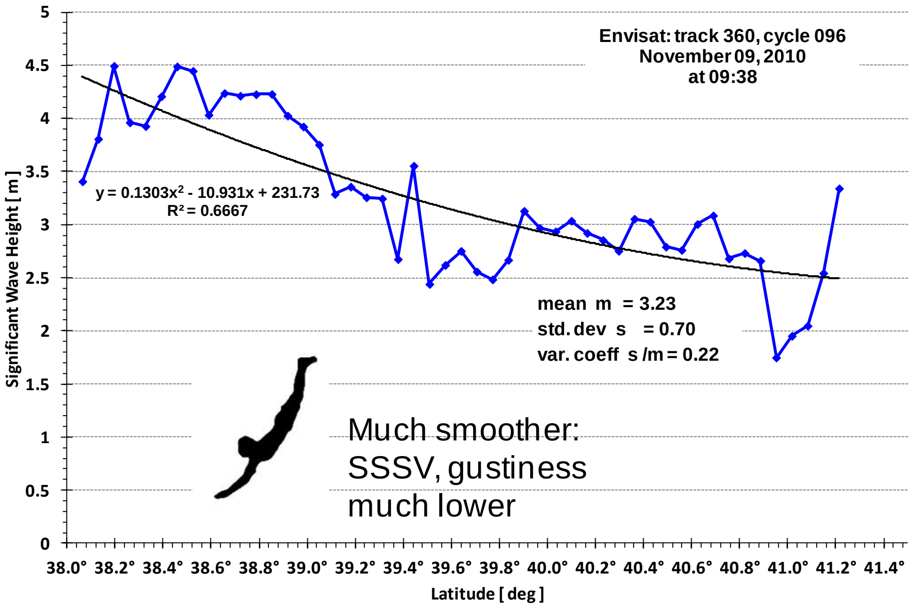
And then,
why is
wind
"smoother"
than
Waves
?

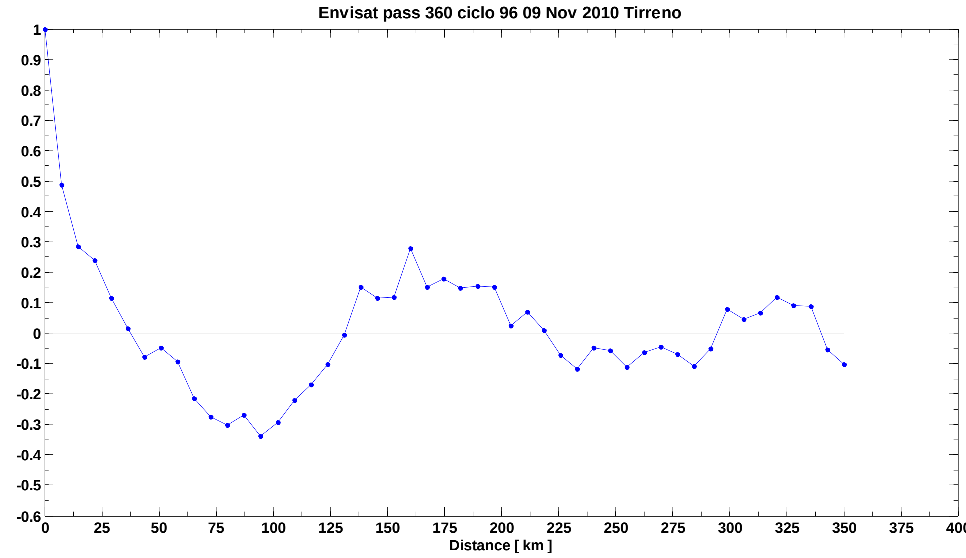
Figure 1. Comparison between model and TOPEX altimeter–measured wind speeds and significant wave heights during a Mistral storm in the western Mediterranean Sea. The thick line in the small map shows the satellite ground track.

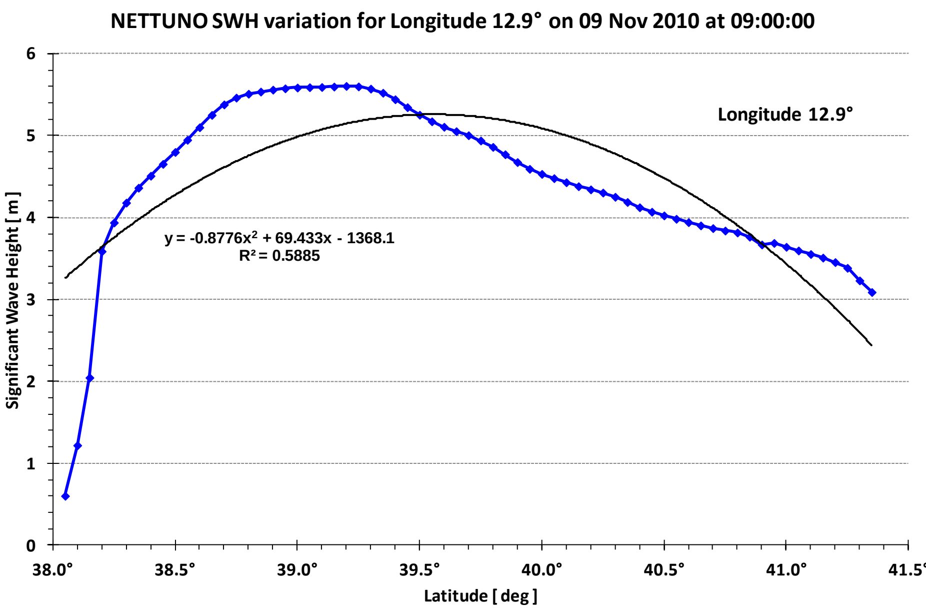
Cavalleri Abdalla JGR vol 107 2002

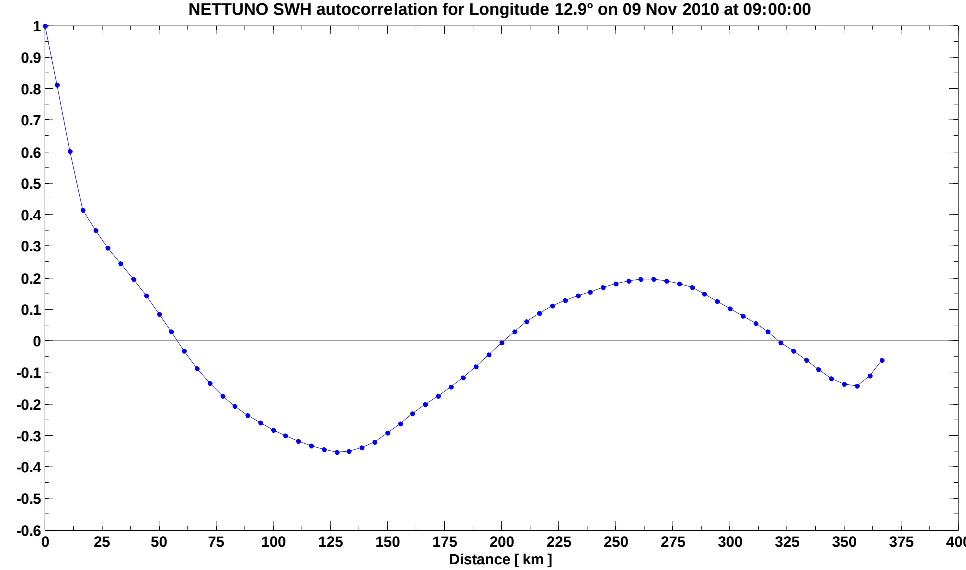
Is this variation is revealed by models?

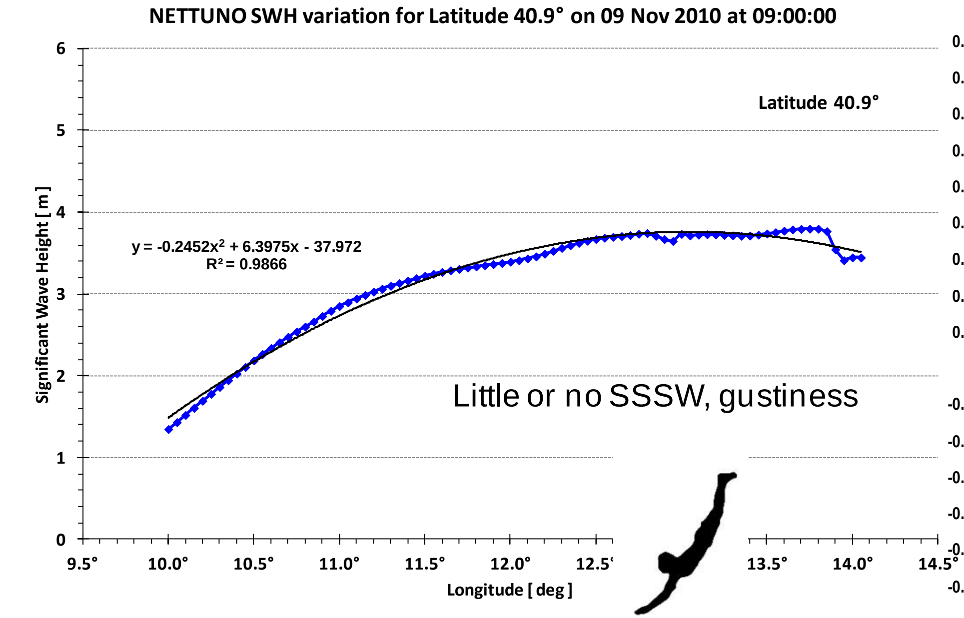
And if not, could it be linked to some physically measurable or computable parameter?

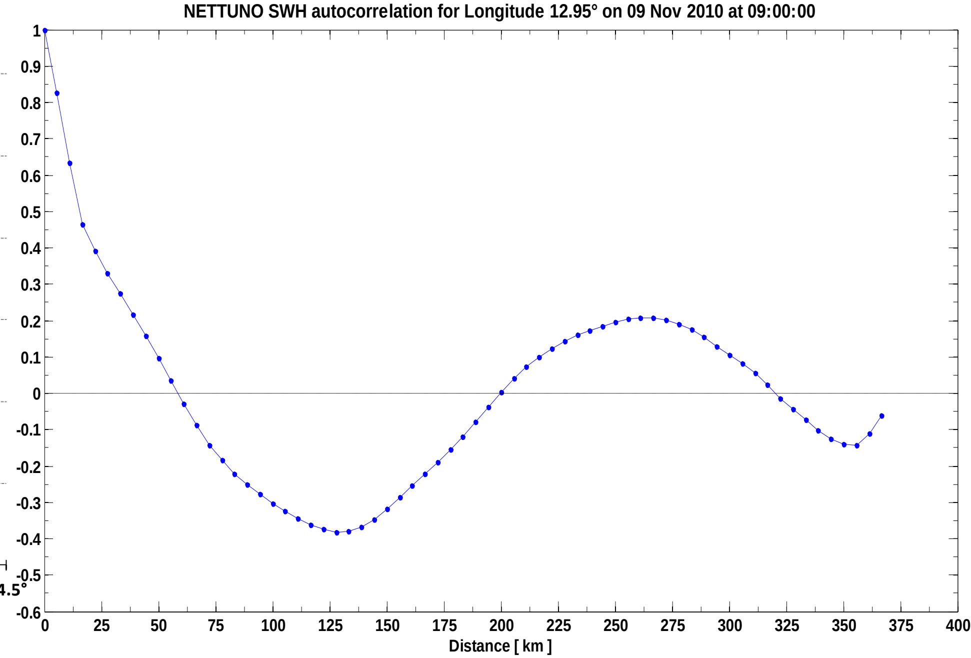

Envisat: track 360, cycle 096
November 09, 2010
at 09:38
y = 0.1303x² - 10.931x + 231.73
R² = 0.6667
mean m = 3.23
std. dev s = 0.70
var. coeff s /m = 0.22
Much smoother:
SSSV, gustiness
much lower
Significant Wave Height [m]
Latitude [deg]

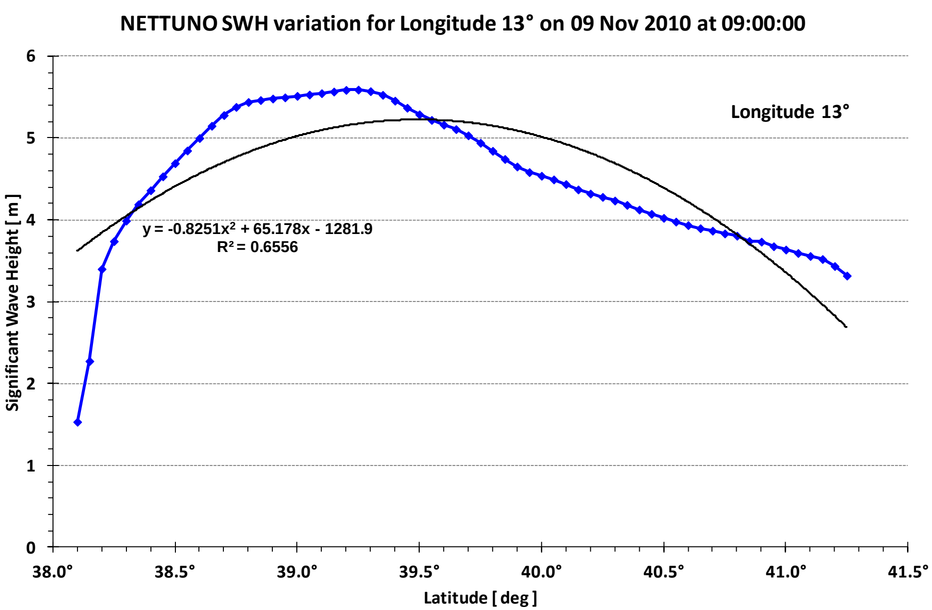

Envisat pass 360 ciclo 96 09 Nov 2010 Tirreno
Distance [km]

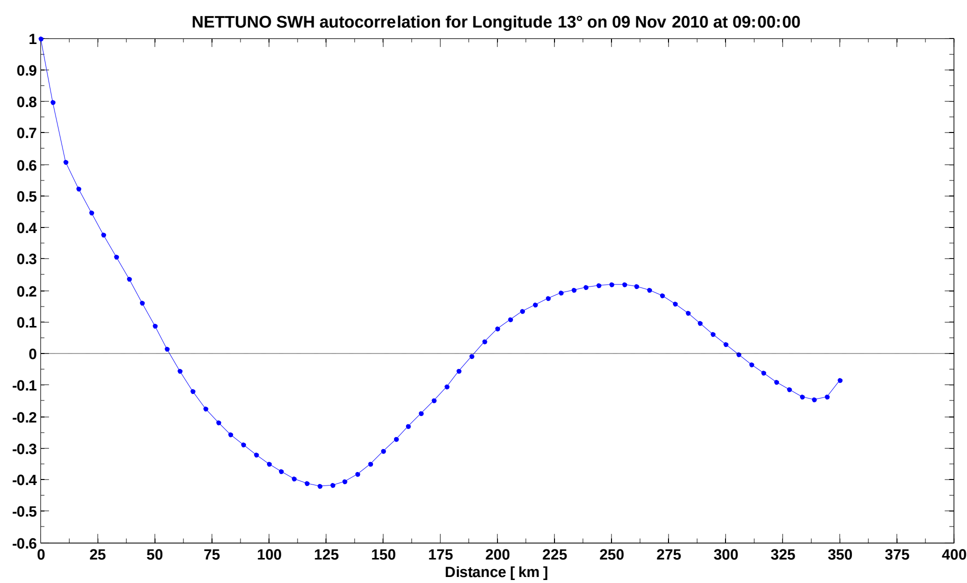

NETTUNO SWH variation for Longitude 12.9° on 09 Nov 2010 at 09:00:00
Longitude 12.9°
y = -0.8776x² + 69.433x - 1368.1
R² = 0.5885
Significant Wave Height [m]
Latitude [deg]


NETTUNO SWH autocorrelation for Longitude 12.9° on 09 Nov 2010 at 09:00:00
Distance [km]


NETTUNO SWH variation for Latitude 40.9° on 09 Nov 2010 at 09:00:00
Latitude 40.9°
y = -0.2452x² + 6.3975x - 37.972
R² = 0.9866
Little or no SSSW, gustiness
Significant Wave Height [m]
Longitude [deg]
9.5° 10.0° 10.5° 11.0° 11.5° 12.0° 12.5° 13.5° 14.0° 14.5°
0 1 2 3 4 5 6


NETTUNO SWH autocorrelation for Longitude 12.95° on 09 Nov 2010 at 09:00:00
Distance [km]
0 25 50 75 100 125 150 175 200 225 250 275 300 325 350 375 400
1 0.9 0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1 0 -0.1 -0.2 -0.3 -0.4 -0.5 -0.6


NETTUNO SWH variation for Longitude 13° on 09 Nov 2010 at 09:00:00
Longitude 13°
y = -0.8251x² + 65.178x - 1281.9
R² = 0.6556
Significant Wave Height [m]
Latitude [deg]
38.0° 38.5° 39.0° 39.5° 40.0° 40.5° 41.0° 41.5°
0 1 2 3 4 5 6

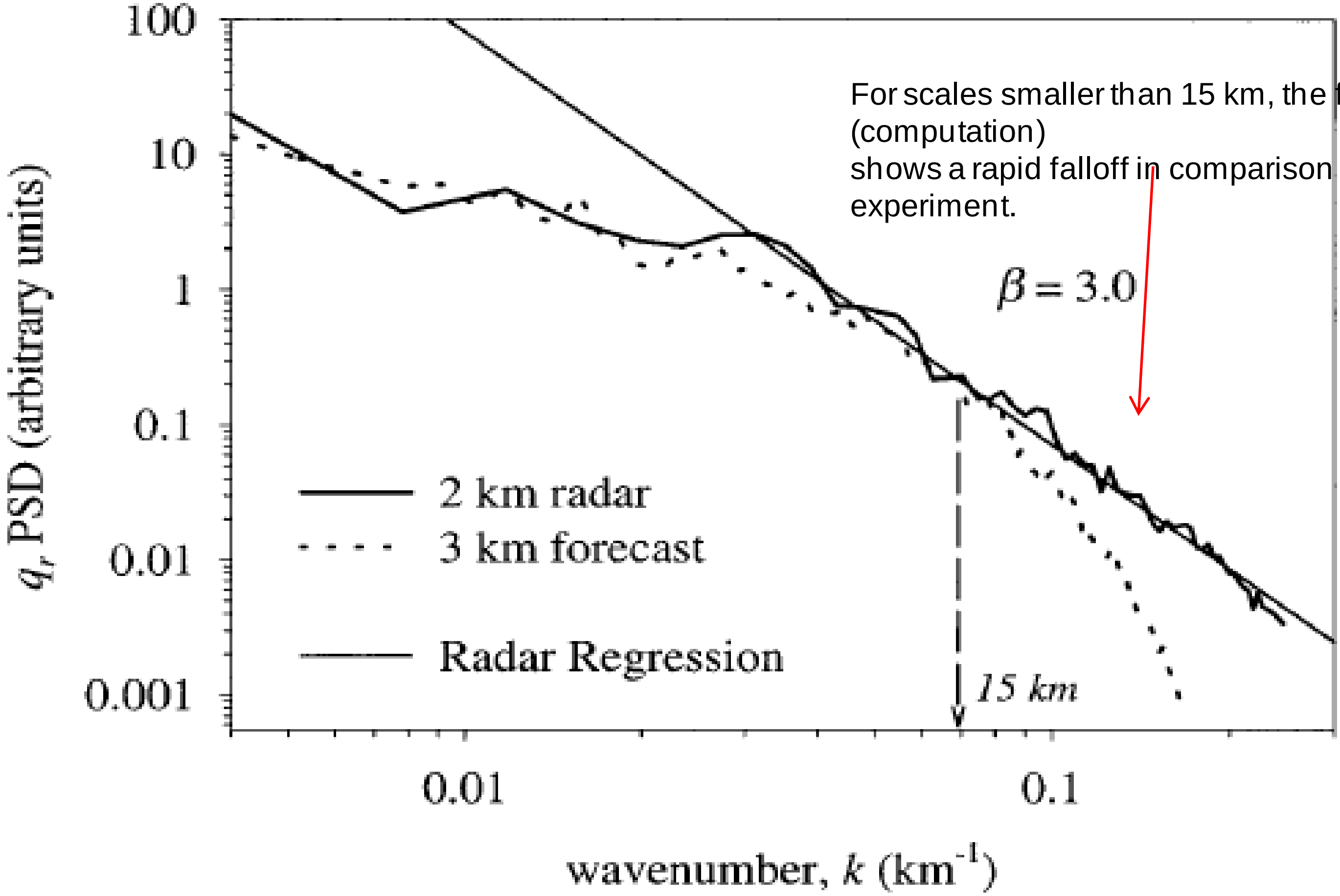

NETTUNO SWH autocorrelation for Longitude 13° on 09 Nov 2010 at 09:00:00
Distance [km]
0 25 50 75 100 125 150 175 200 225 250 275 300 325 350 375 400
1 0.9 0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1 0 -0.1 -0.2 -0.3 -0.4 -0.5 -0.6

Can this variation is revealed by models?

Let’s have a closer look at how models behave with higher resolution (dt, dx, dy smaller and smaller)

Accuracy, depends on wind more than on Wave modelling

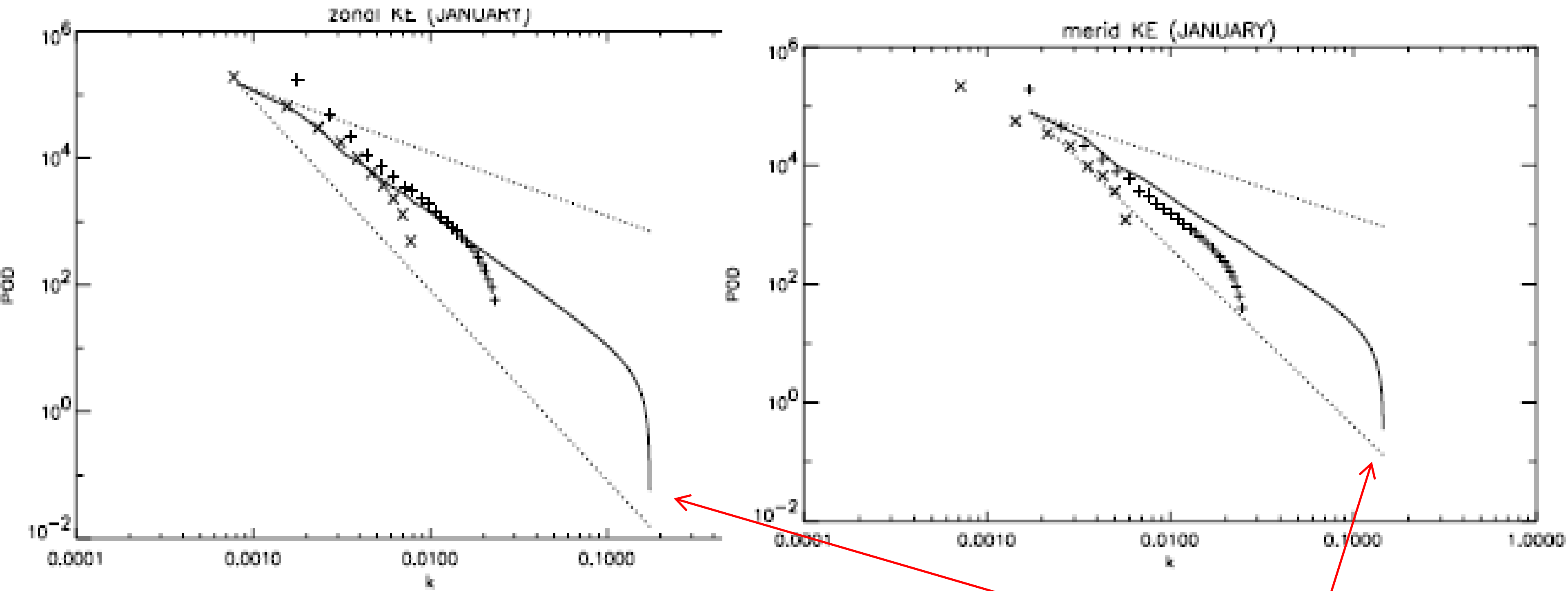
Rain



For scales smaller than 15 km, the forecast (computation)
shows a rapid falloff in comparison with the experiment.

Spatial Fourier power spectral density (PSD) for forecast (*dotted line)* and radar-observed r *solid line r*ain
Reasonable agreement at scales larger than 15 km

Daniel Harris D., Foufoula-Georgiou E., Droegemeier K., Levit J.J.,2001. *Multiscale Statistical Properties of a High-resolution Precipitation Forecast*, J o u r n a l o f H y d r o m e t e o r o l o g y Volume 2



Kinetic energy as a function of zonal and meridional wave number
NCEP reanalysis ( ) LMDZ (+) BOLAM (solid line).

Maximum resolved scale about 40 km

Things improve as computational grid become smaller
"The impact of dissipative schemes is to remove 2Δ x and 3 Δx waves. So the smallest resolvable wave is at least 3 Δx The real numerical resolution is actually even lower"

Cheruy, Speranza, Sutera and Tartaglione: Surface winds in the Euro-Mediterranean area: the real resolution of numerical grids Annales Geophysicae (2004)

Better resolution improves results

Big deal!

In common practice, do not rely on global weather model
Need LAM!

In restricted seas
In the ocean, it may be different

But: is it enough ? **Will a very small grid give us a prefect forecast/analysis**?

Remeber turbulence!

A great variability
Below a certain
scale
(50-10 km)

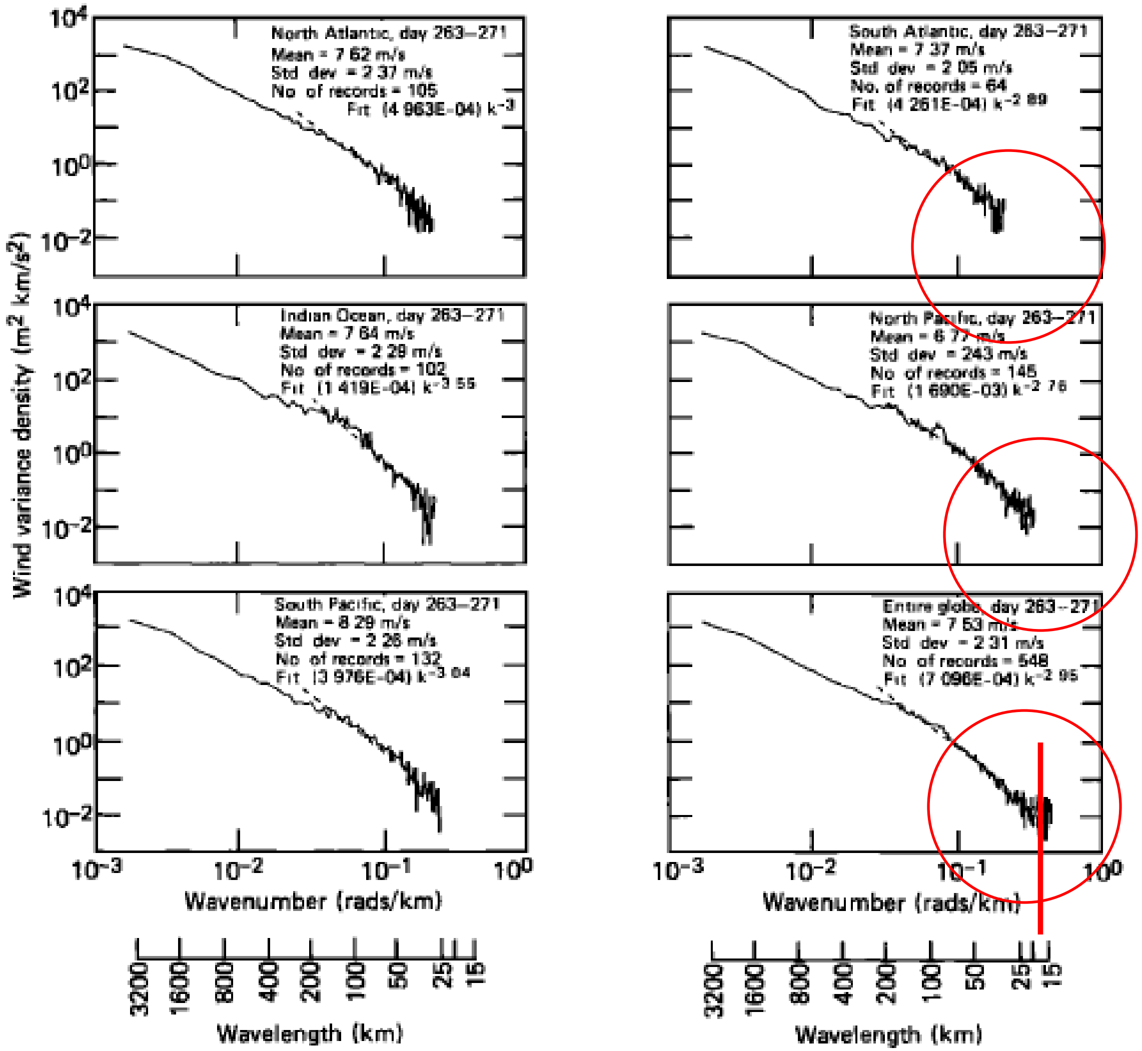
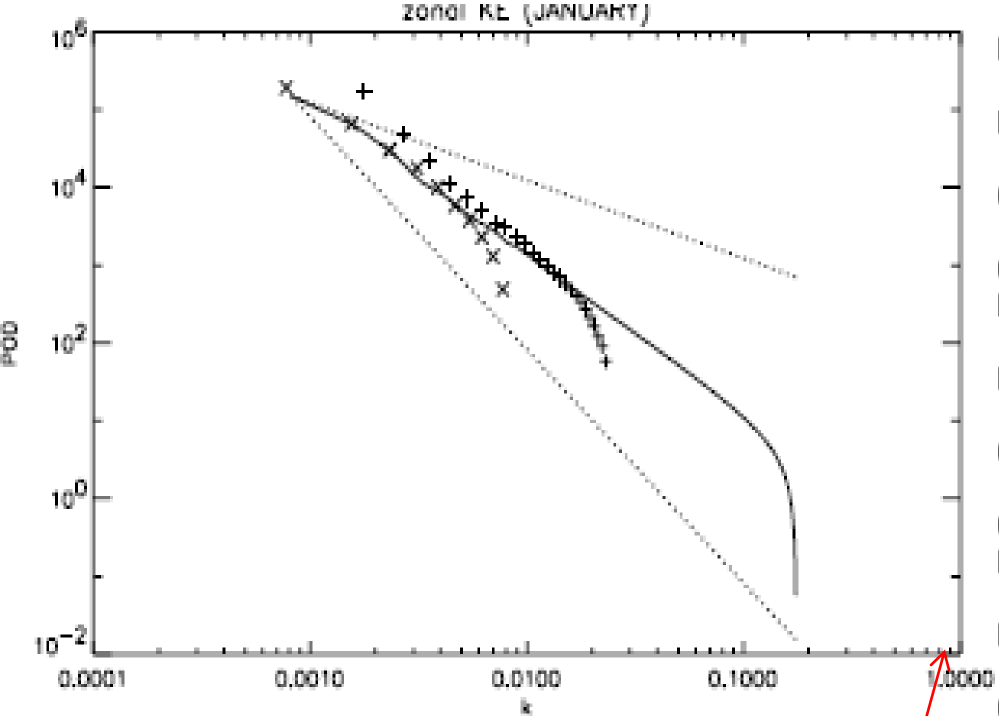
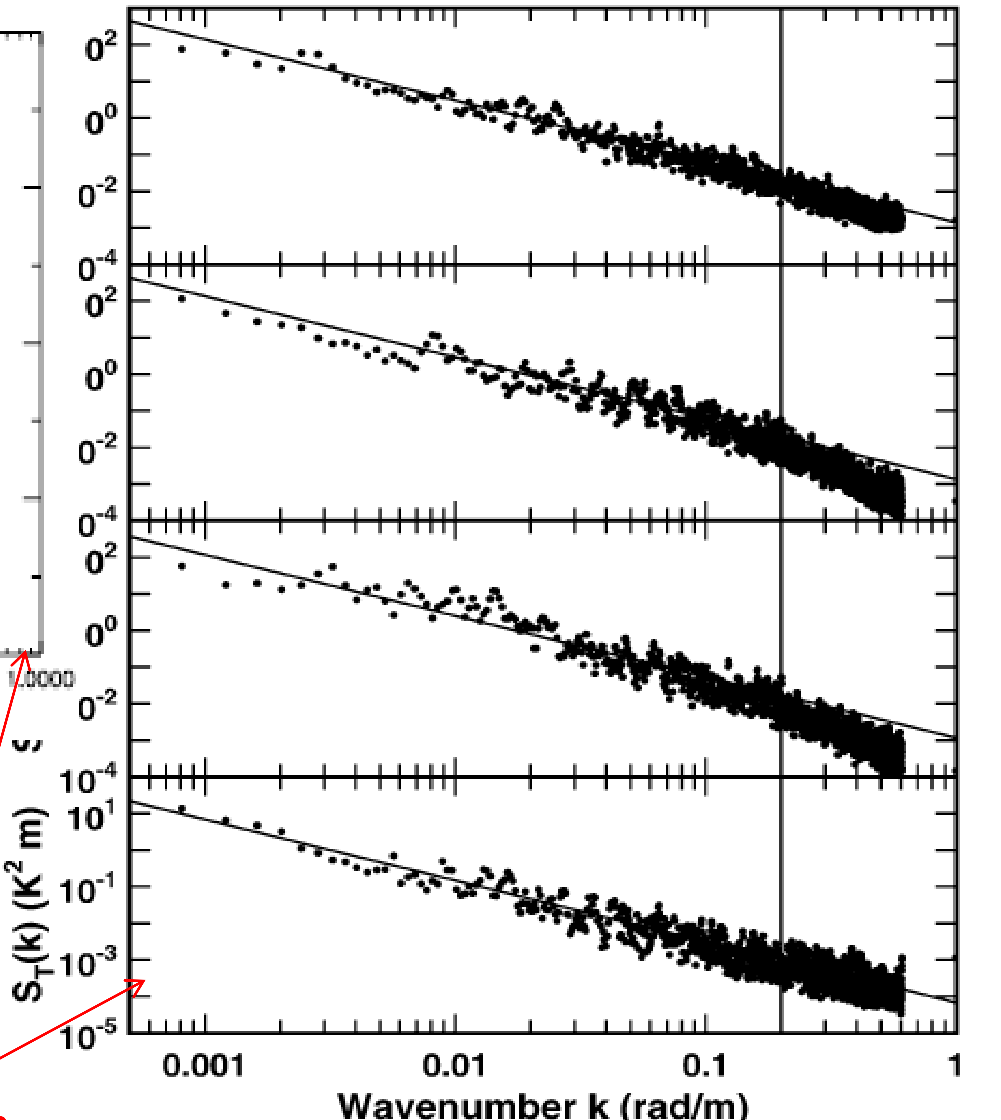


Fig. 9. Wind-speed variance spectra calculated from Seasat altimeter wind speed estimates for days 263 through 271, 1978. For each plot, a fit of the form ak^{-b} is shown as a dashed line. The spectral forms shown here have an approximate k^{-3} dependence.





Model resolve only down to a certain scale

Scale: 6km

Again *from Cheruy et al*
Annales Geophysicae (2004)

Lower scales are "turbulence"
(only statistical Knowledge)

Turbulent
velocity and temperature spectra

“Depending on the model numerics and filtering used, a (mesoscale) model will in general show **an energy deficit** ….and generally this deficit will be largest for the smallest scales resolved by the model”

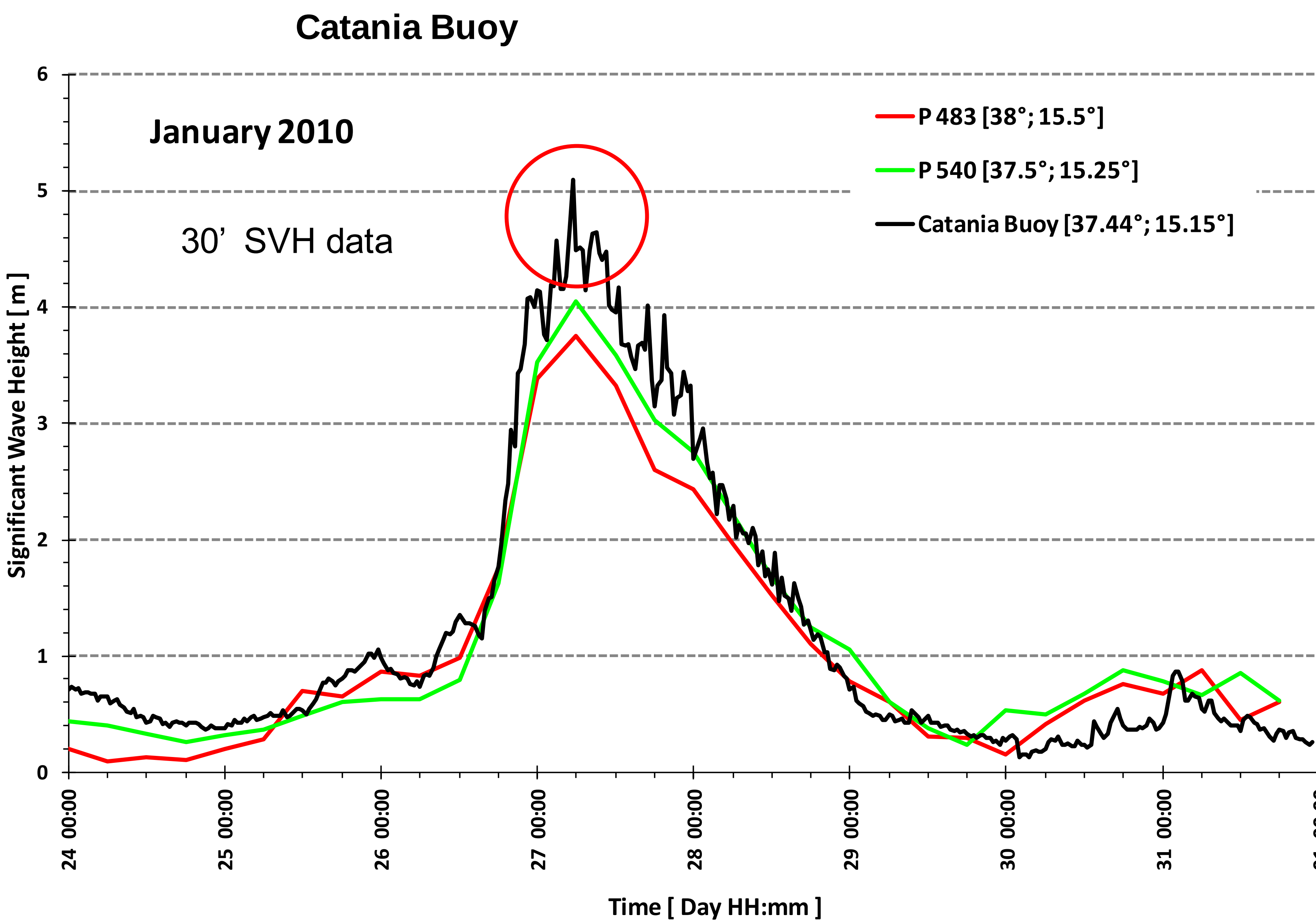
(The term ‘‘small scale’’ refers to the smallest resolvable scales of an atmospheric dynamical model , i.e., scales smaller than the filter scale)

Frehlich & Sharman 2004 “Estimates Of Turbulence from Numerical Weather Prediction Model Output with Applications to Turbulence Diagnosis and Data Assimilation “ M o n t h l y We a t h e r R e v i e w

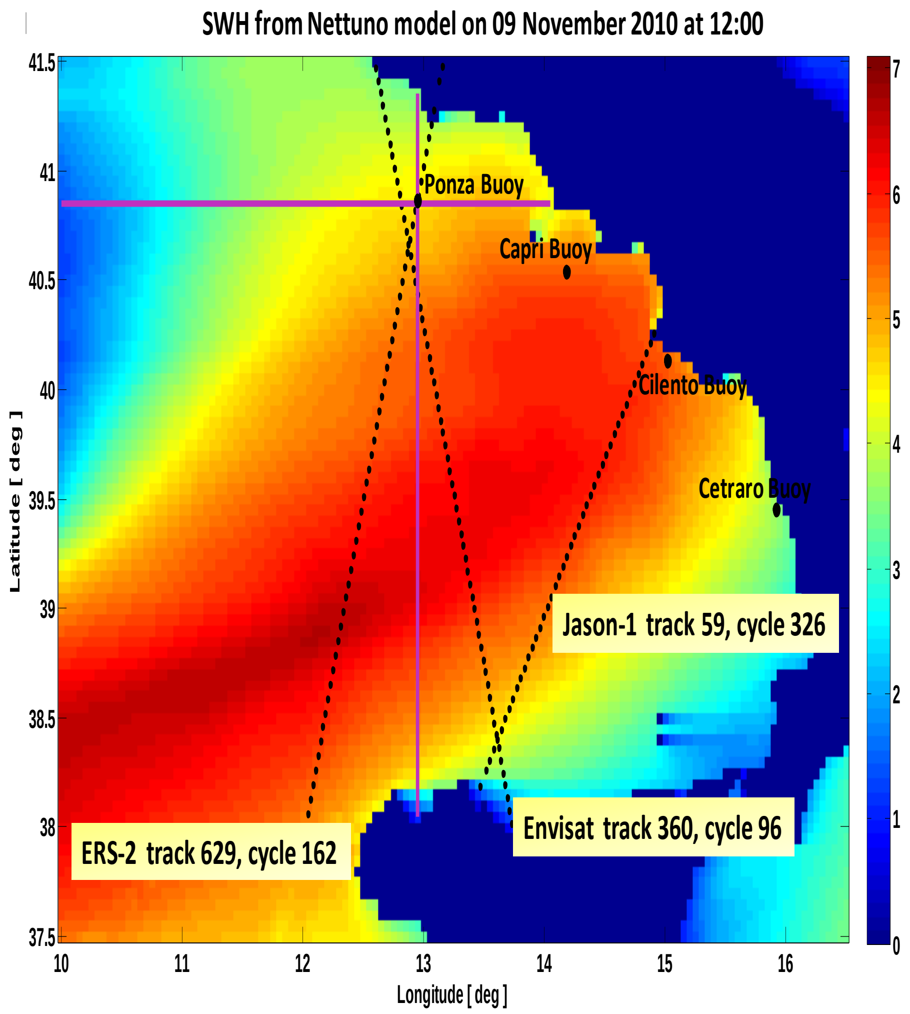
Hopefully, eventually, some deterministic paramter might be found to infer the magnitude of ‘‘subgrid’’ scale motions

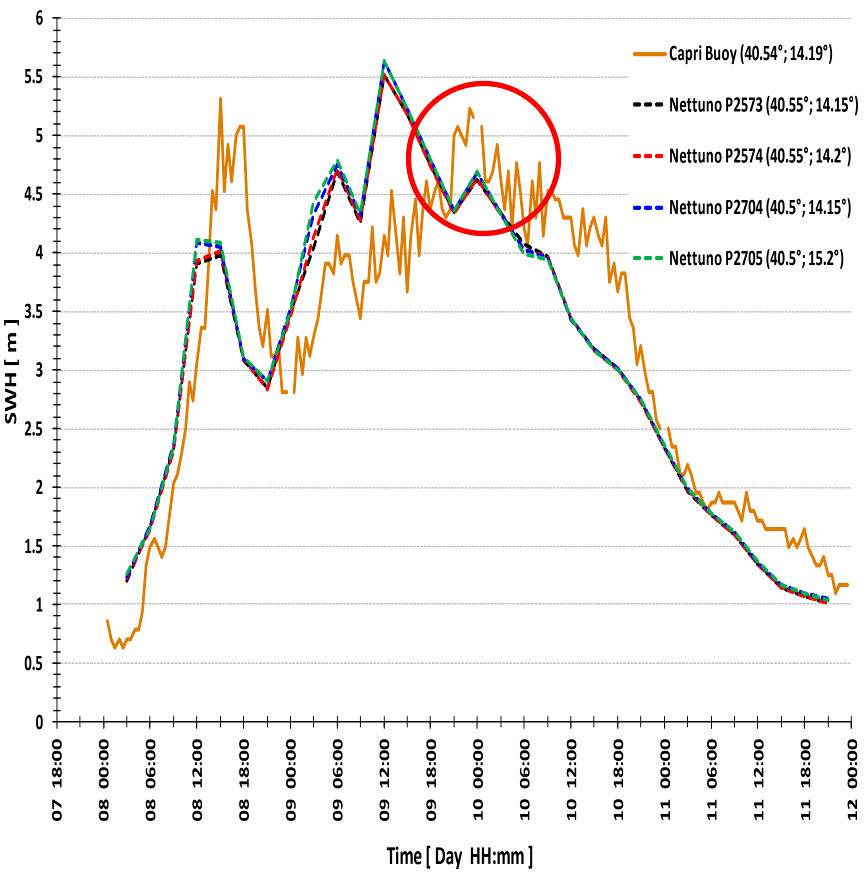
In the mean time, we have to live with gustyness SSSW

SSSV is also visible on buoy data

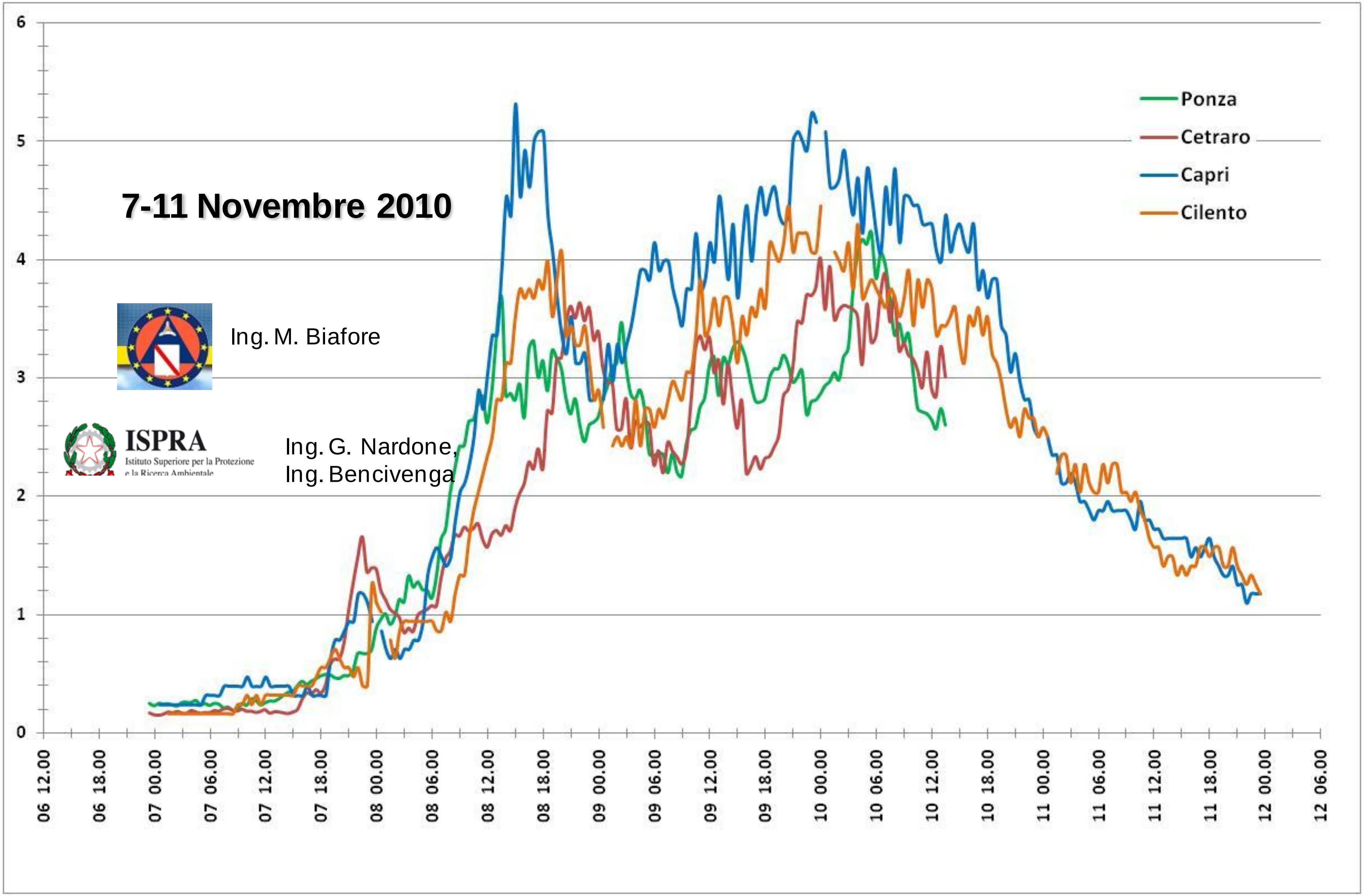


Catania Buoy
January 2010
30' SVH data
P 483 [38°; 15.5°]
P 540 [37.5°; 15.25°]
Catania Buoy [37.44°; 15.15°]
Significant Wave Height [m]
0
1
2
3
4
5
6
24 00:00
25 00:00
26 00:00
27 00:00
28 00:00
29 00:00
30 00:00
31 00:00
01 00:00
Time [Day HH:mm]





Nettuno Model – CNMCA- around buoy


7-11 Novembre 2010
Ing. M. Biafore
ISPRA
Istituto Superiore per la Protezione e la Ricerca Ambientale
Ing. G. Nardone,
Ing. Bencivenga
Ponza
Cetraro
Capri
Cilento
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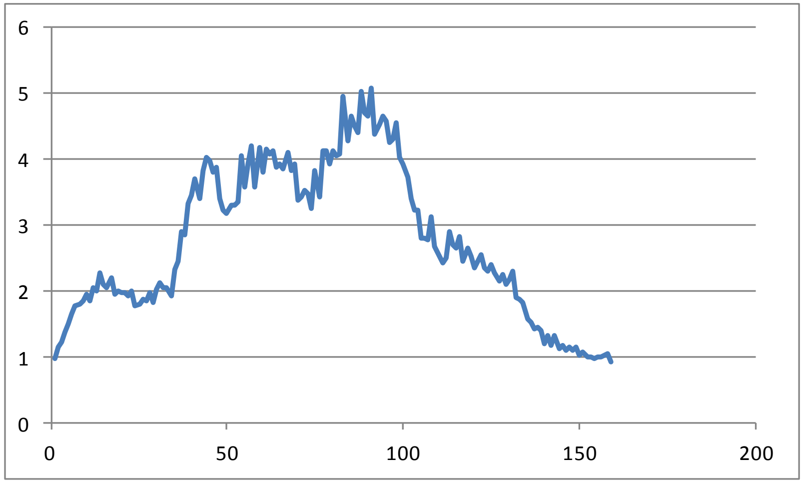
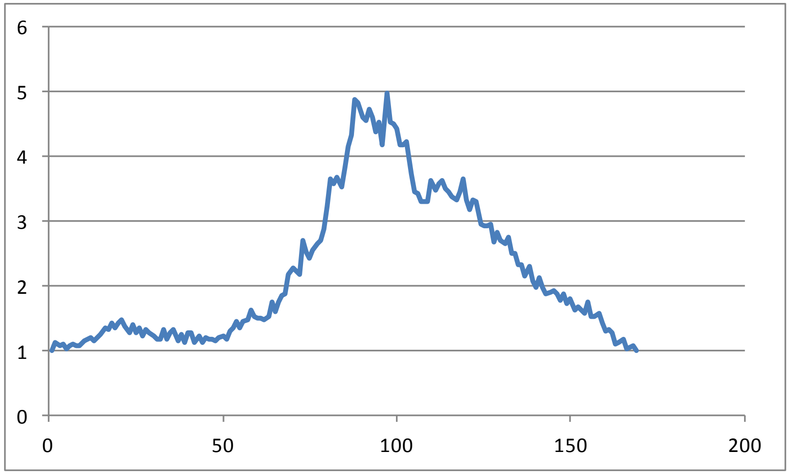
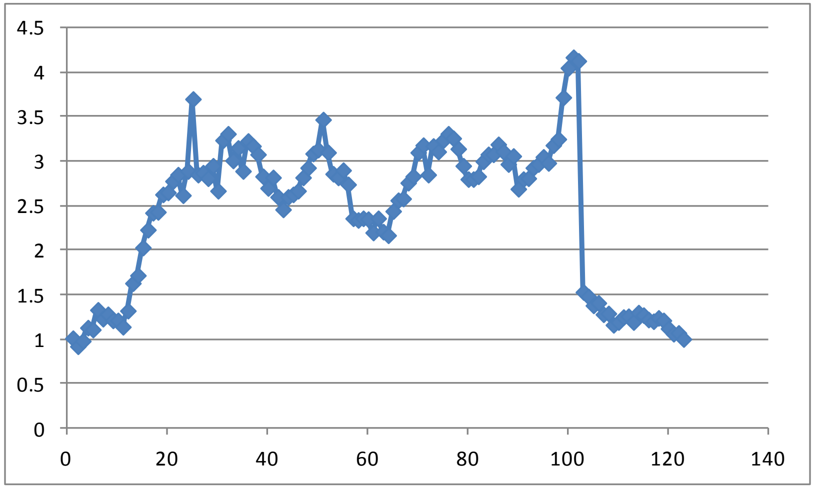


Boa Taranto 12/2008



Boa Taranto 1/2009



Boa Ponza 11/2010

30' data

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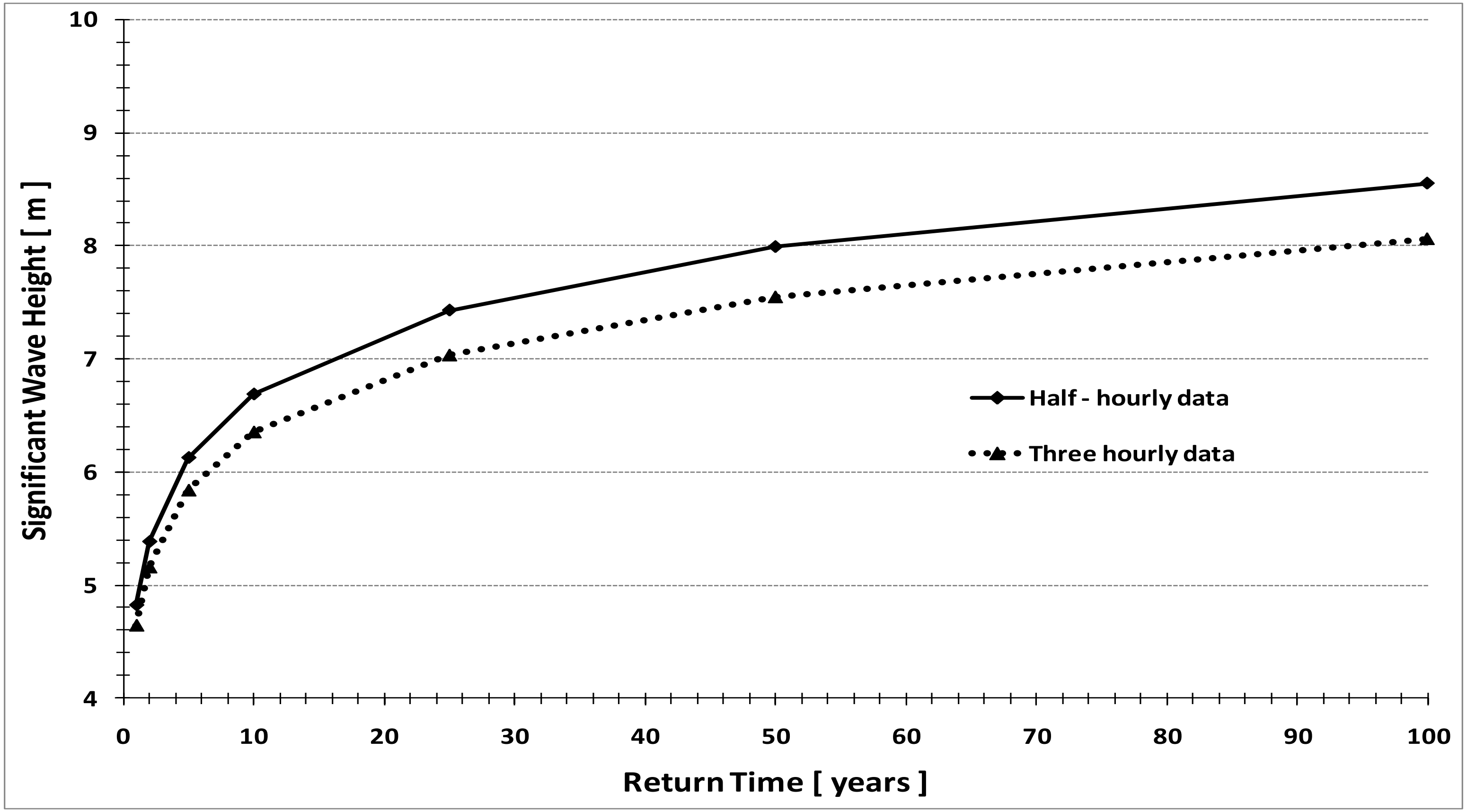


Extreme events as computed with half-hourly and three hourly data at Cetraro; Peak Overt Threshold, wave height threshold = 4 m. (data from Cetraro RON wavemeter).

Ignoring small scale variation of SVH is risky!

So…

Altimeter data
The ever increasing weather model resolution model does enhance the extreme values: this is a good thing, and it helps engineering practise a lot. *Beware of time resolution of data you work with*

But high resolution is not everything: we still have to deal with Small Scale Storm variation which cannot be resolved by models, and possibly never will – they may have to be treated as an extra stochastic parameter

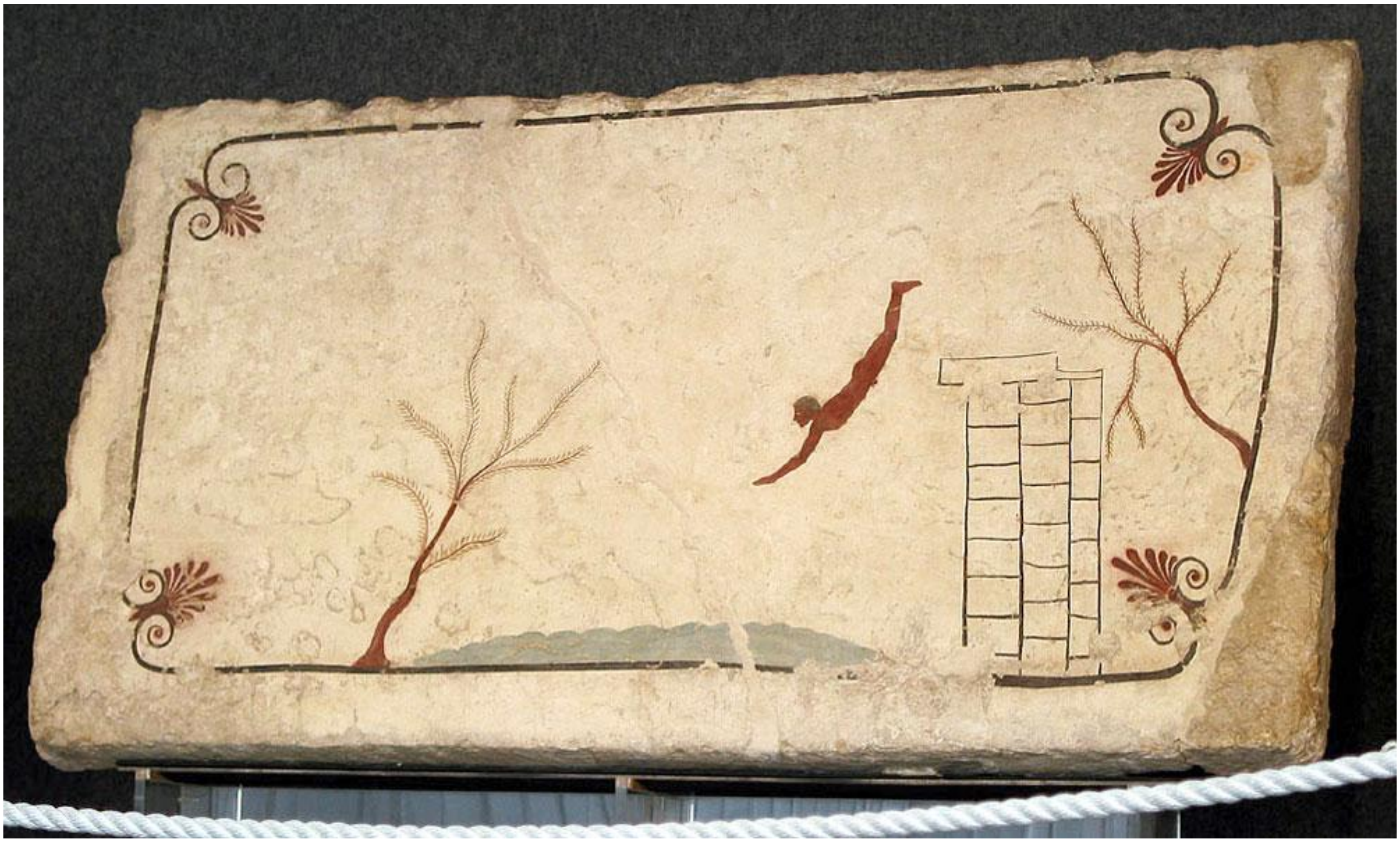
Altimeter SWH data help a lot by supplying an indication of the statistical parameters or such SSSV

Data analysed so far in semi enclosed seas (Tyrrhenian, Gulf) only suggest an order of magnitude of such an effect : 10 about 10%of the average SVH over the storm length. So be careful when estimating extreme SVH from models

What now?

SSSV derive from gustiness, which might in turn be related to air instability parameter :
e.g, difference between the temperature of the water surface and the temperature of the first layers

The diver’s tumb
Paestum , Italy
(ca. 480-470 BC)



Work funded and supported by CUGRI - University Centre for Research on Major Hazards between the Universities of Salerno and Federico II in Naples

Data provided by:

Weather and wave modelling: Italian Air Force Weather Service CNMCA; ECMWF Meteorological Archival and Retrieval System (MARS); Kowait Institute for Scientific Research (KISR)

Altimeter: RADS (Radar Altimeter Database System Satellite) and ESA/EO Project 1172 “Remote Sensing of Wave Transformation”, GlobWave

Buoy data: (Italian Environmental Agency) ISPRA; Civil Protection Service of the Campania Region

Interesting discussion

KISR (K. Rakha)

ISPRA (R. Inghilesi)

NOC Southampton (P. CipollinI)