"Improvement of wave height forecast in deep and intermediate waters with the use of stochastic methods"

Zoe Theocharis, Constantine Memos,
Demetris Koutsoyiannis

National Technical University of Athens
School of Civil Engineering

Presentation Structure

1. Introduction
2. Methodology
3. Applications
4. Conclusions

Introduction

Introduction

OBJECTIVE: Improvement of the forecast power of numerical wave models using real time measurements

Improvement of wave predictions can be achieved by three different approaches:

- **Data assimilation techniques (require re-run and space coverage)**
- **Stochastic tools**
- **Neural networks techniques**

- **Only a few stochastic applications concerning real time improvement of the wave forecast**
- **Caires & Sterl, 2004: non parametric correction of ERA-40 reanalysis data, using a learning dataset**

In this work a stochastic technique is applied to measured data of wave height for improving forecasts of the wave model

Methodology

Bivariate Linear Regression models

$$\hat{Y}_{t+k\Delta t} = a_k X_{t+k\Delta t} + \beta_k Y_t + \gamma_\kappa$$

$\hat{Y}$: Wave height estimate

Y : Wave height measurement

X : Wave height model forecast

- *k=0,1,2 → < model 0,1,2 >*
- *Trivariate linear model → < model 3>*

Bivariate Non-Linear Regression models

$$Y^{\lambda}_{t+\Delta t} = \alpha_1 X^{\lambda}_{t+\Delta t} + \beta_1 Y^{\lambda}_{t} + \gamma_1, \quad \text{if} \quad Y_t \leq c,$$

$$Y^{\lambda}_{t+\Delta t} = \alpha_1 X^{\lambda}_{t+\Delta t} + \beta_2 Y^{\lambda}_{t} + \gamma_2, \quad \text{if} \quad Y_t \geq c$$

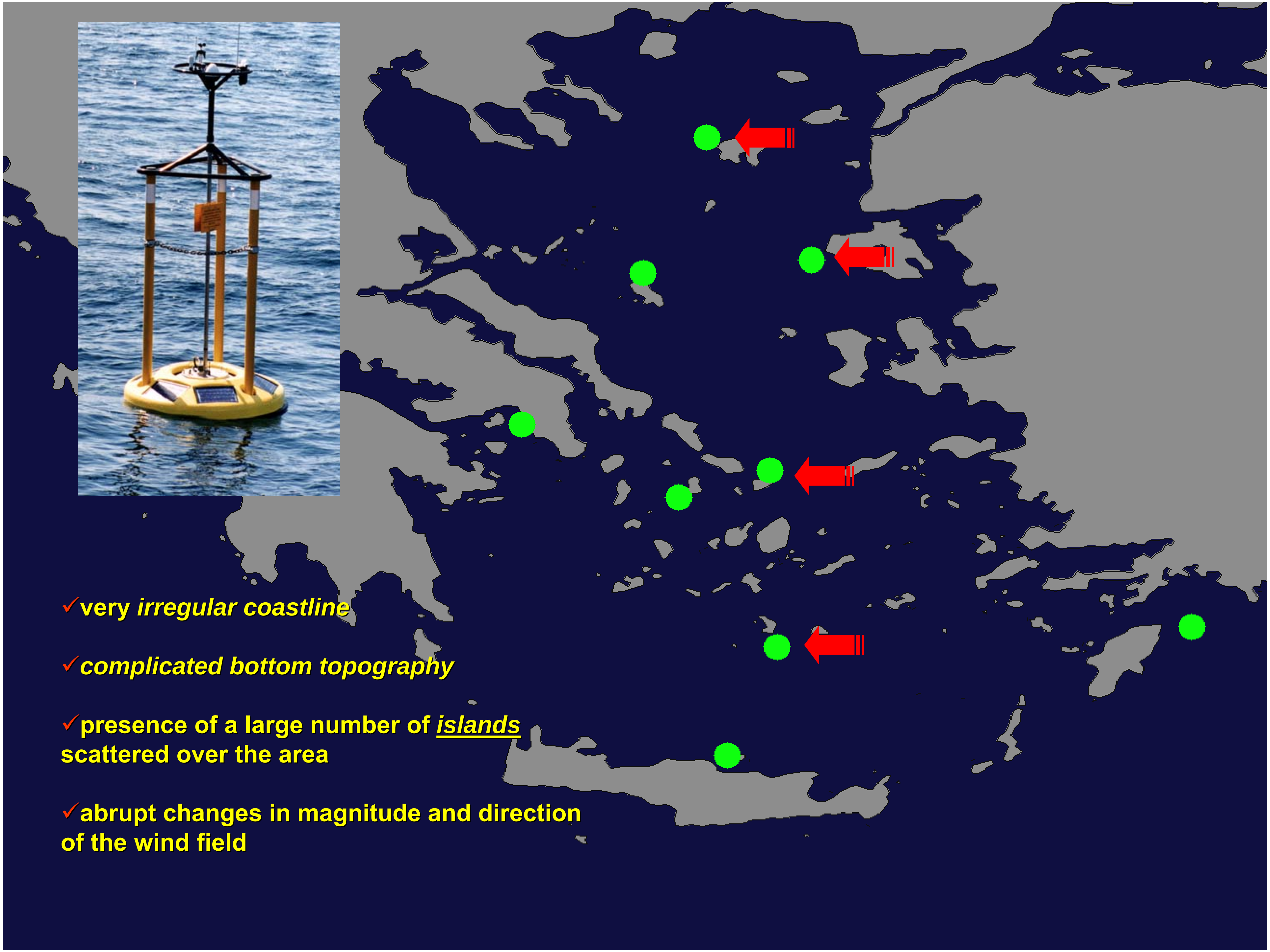
$\gamma_2 = \gamma_1 + (\beta_1 - \beta_2)\, c^{\lambda}$ (continuity c)

<model 4>

Applications

First Application: The Aegean Sea

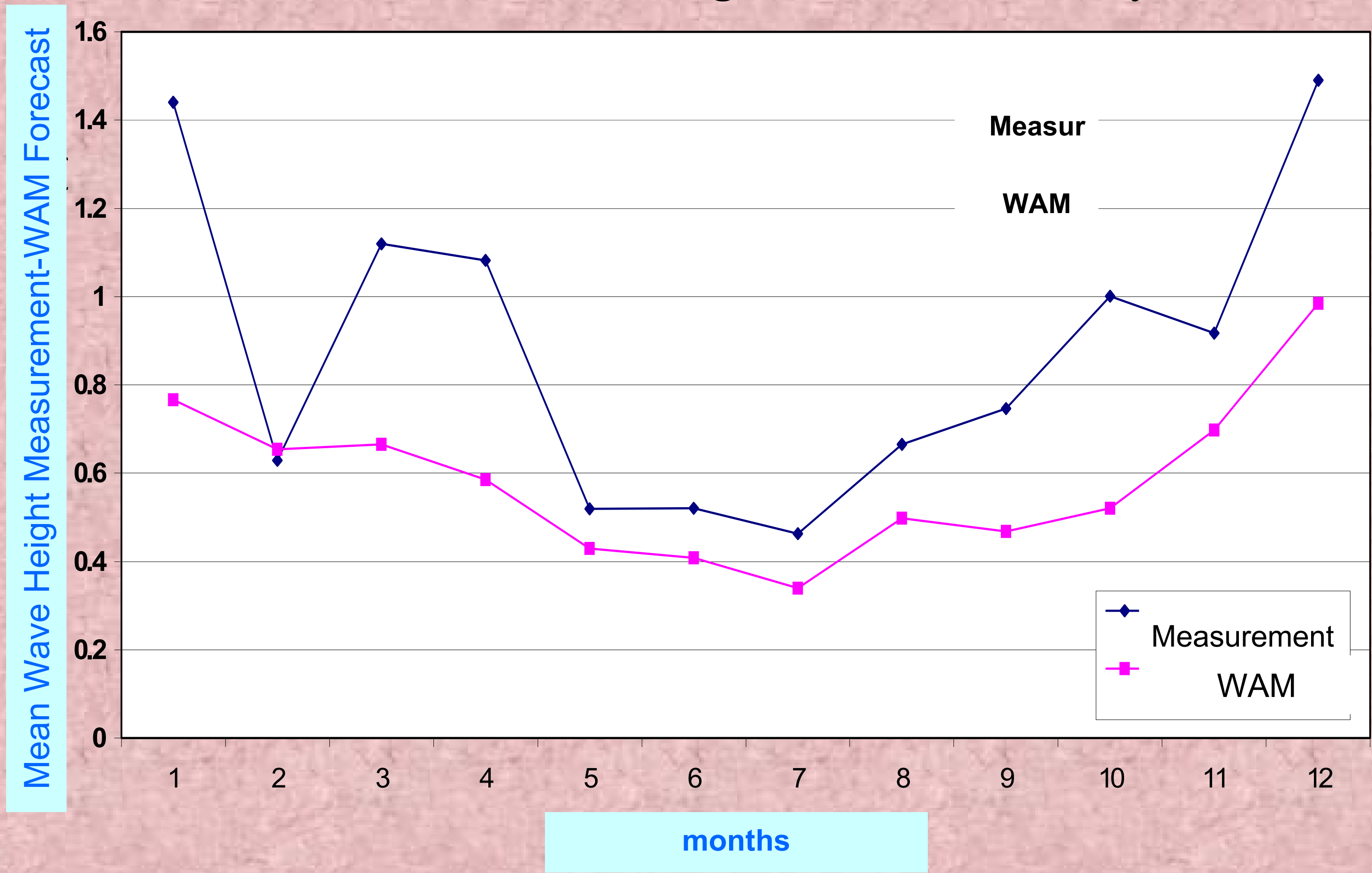
The Stations Used



- ✓very *irregular coastline*
- ✓*complicated bottom topography*
- ✓presence of a large number of ***islands*** scattered over the area
- ✓abrupt changes in magnitude and direction of the wind field

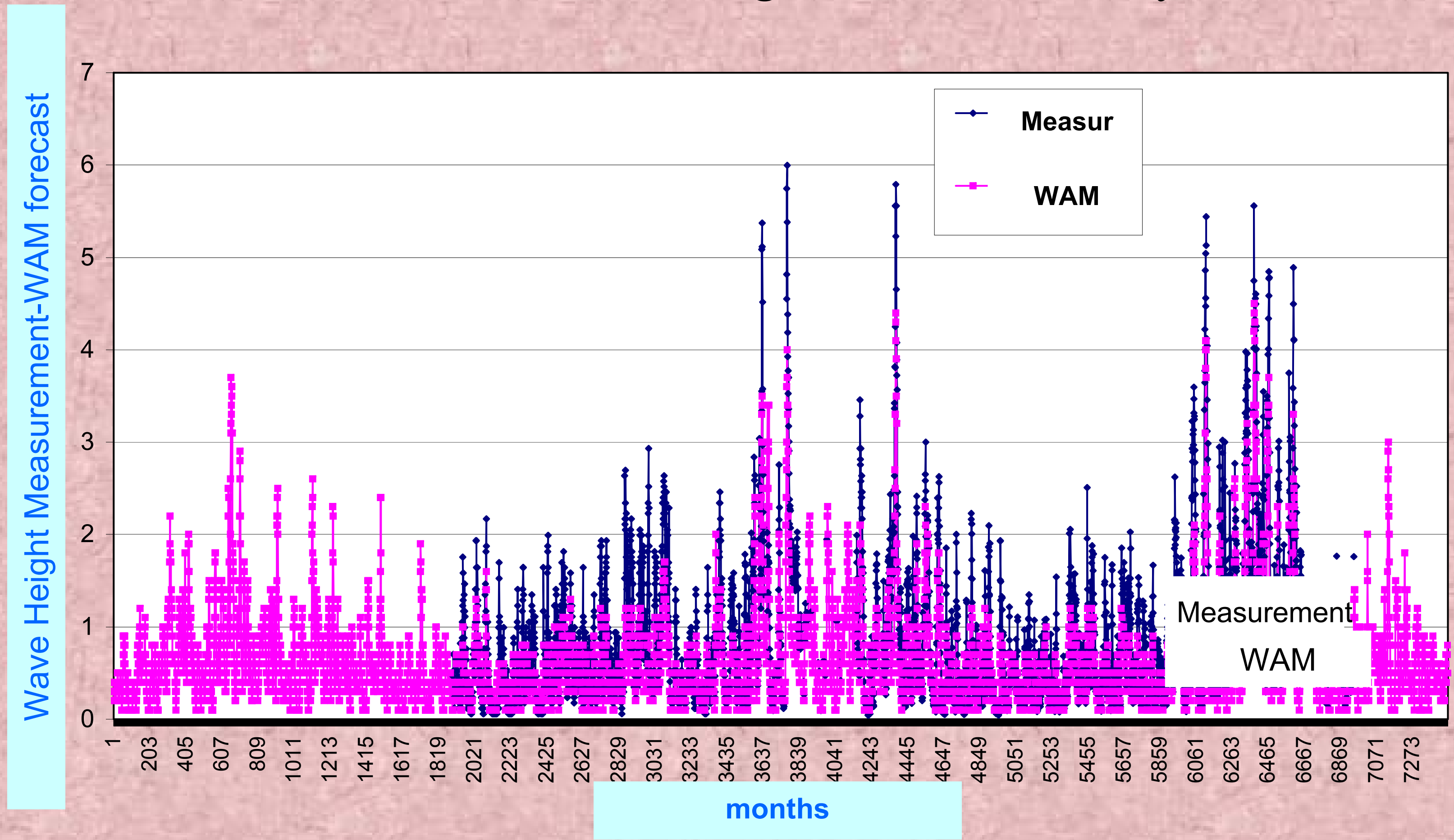
WAM Underestimation

Measurements through POSEIDON System



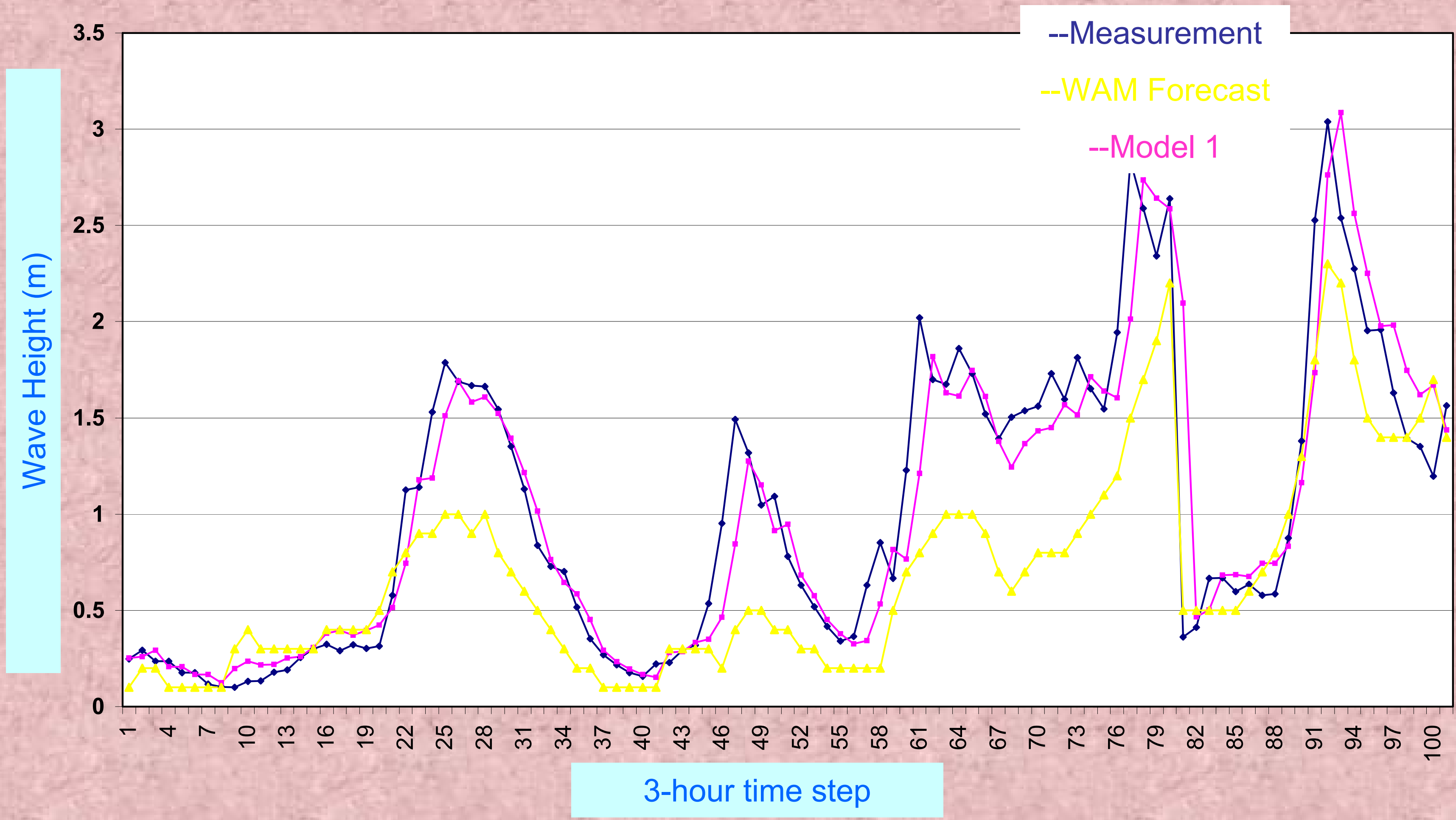
WAM Underestimation

Measurements through POSEIDON System

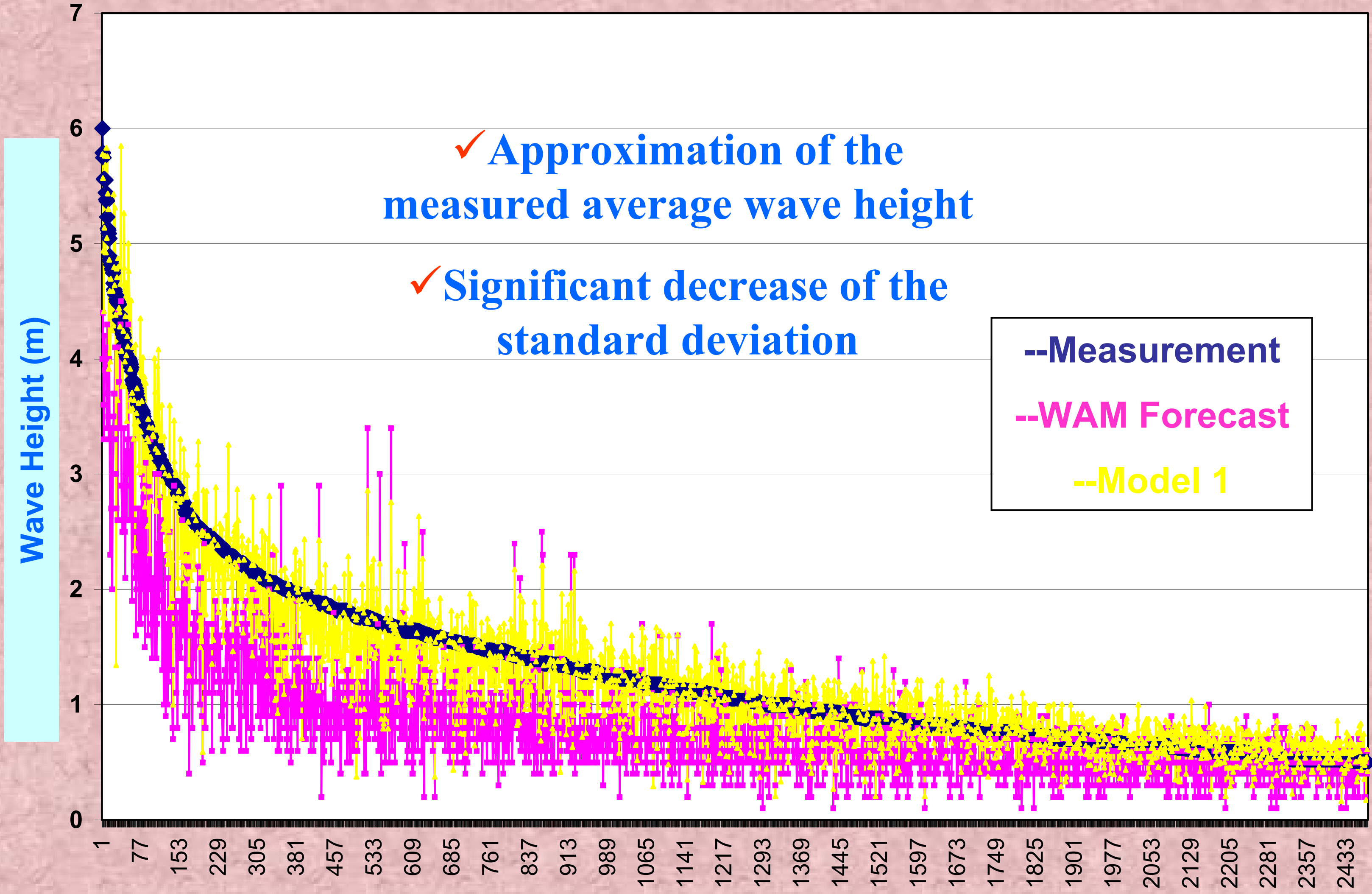


ATHOS STATION

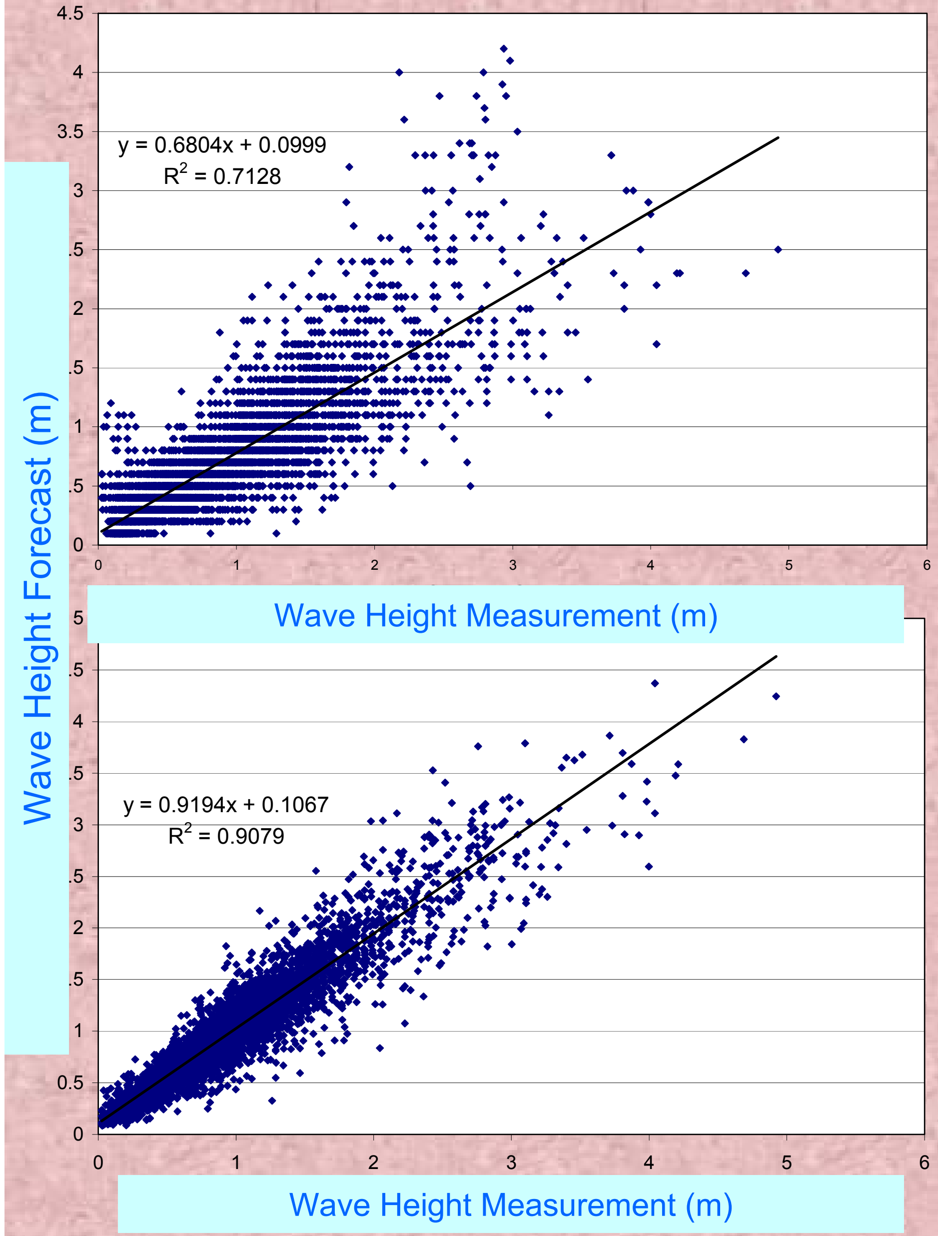
Model 1

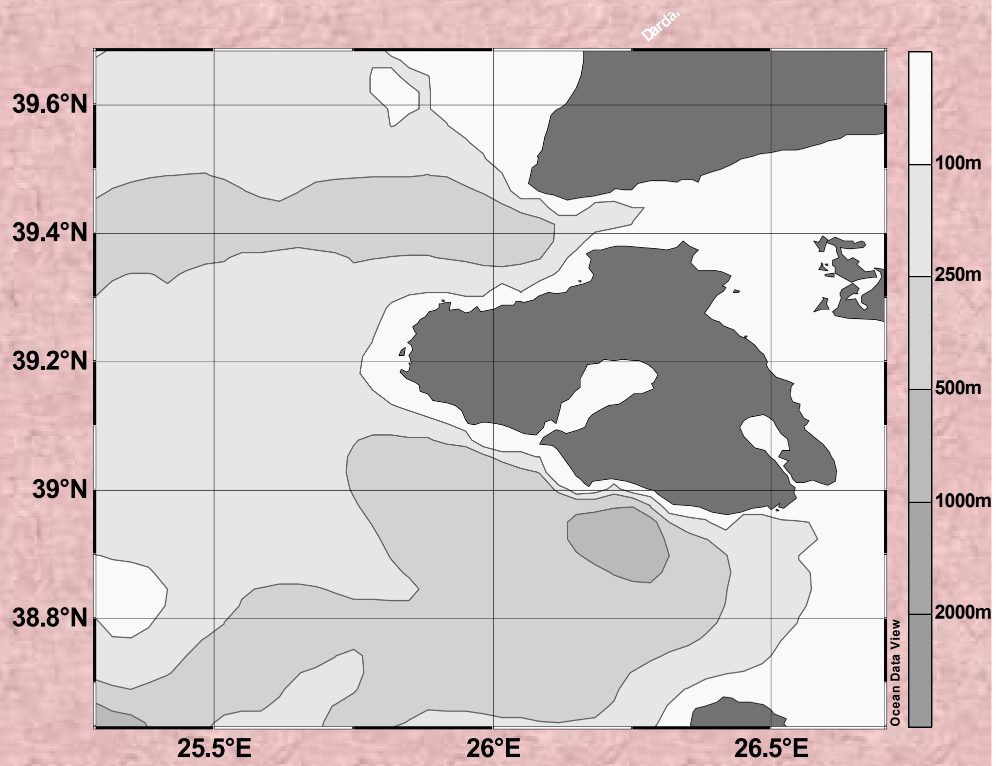


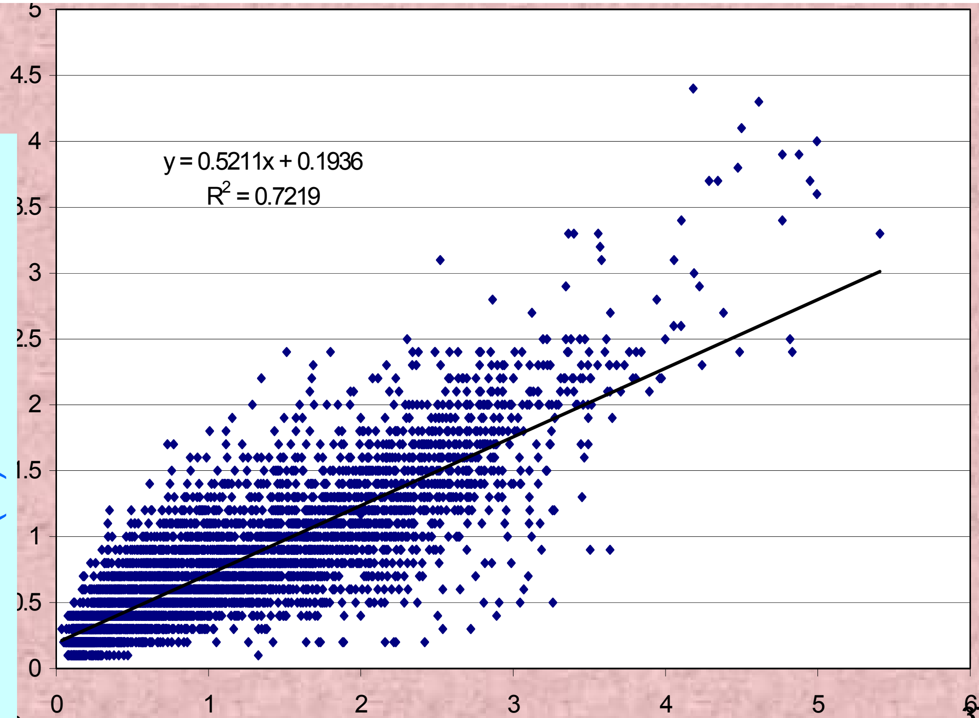
ATHOS STATION

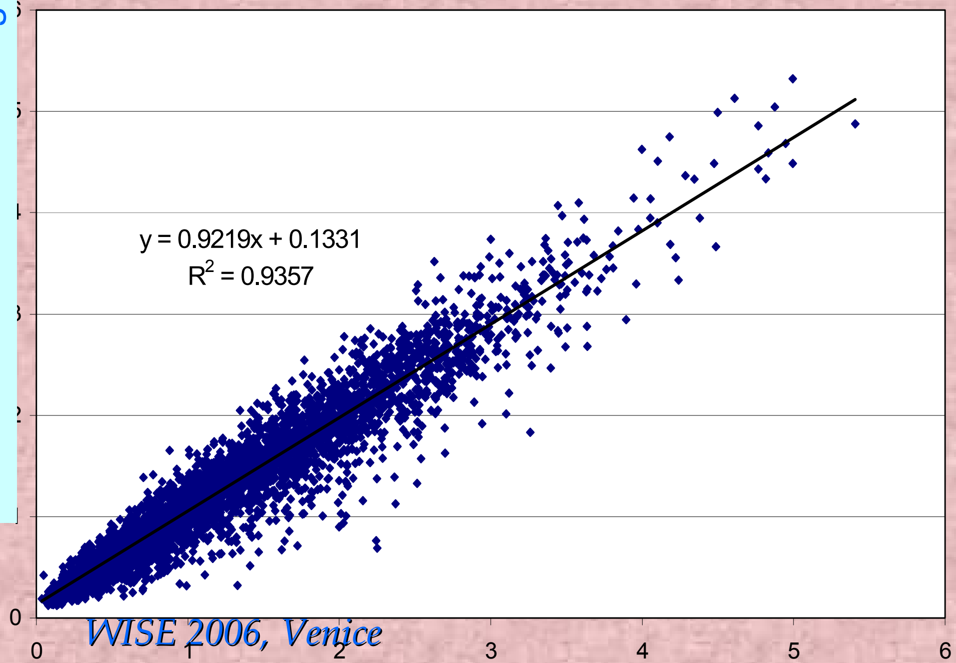


✓Approximation of the measured average wave height
✓Significant decrease of the standard deviation
--Measurement
--WAM Forecast
--Model 1
Wave Height (m)
7
6
5
4
3
2
1
0
1
77
153
229
305
381
457
533
609
685
761
837
913
989
1065
1141
1217
1293
1369
1445
1521
1597
1673
1749
1825
1901
1977
2053
2129
2205
2281
2357
2433


Wave Height Forecast (m)
y = 0.6804x + 0.0999
R^2 = 0.7128
Wave Height Measurement (m)
y = 0.9194x + 0.1067
R^2 = 0.9079
Wave Height Measurement (m)

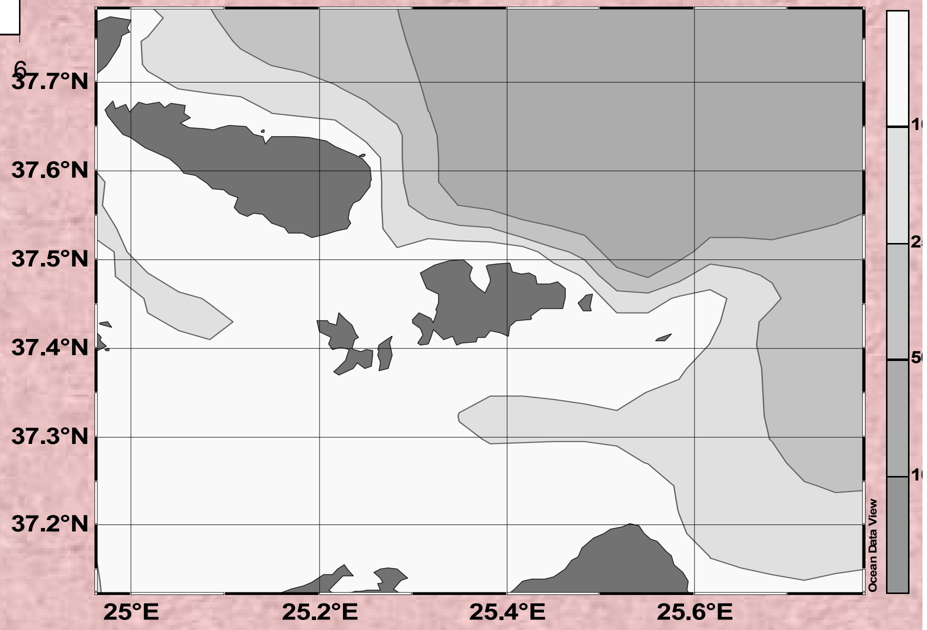

39.6°N
39.4°N
39.2°N
39°N
38.8°N
25.5°E
26°E
26.5°E
100m
250m
500m
1000m
2000m
Ocean Data View

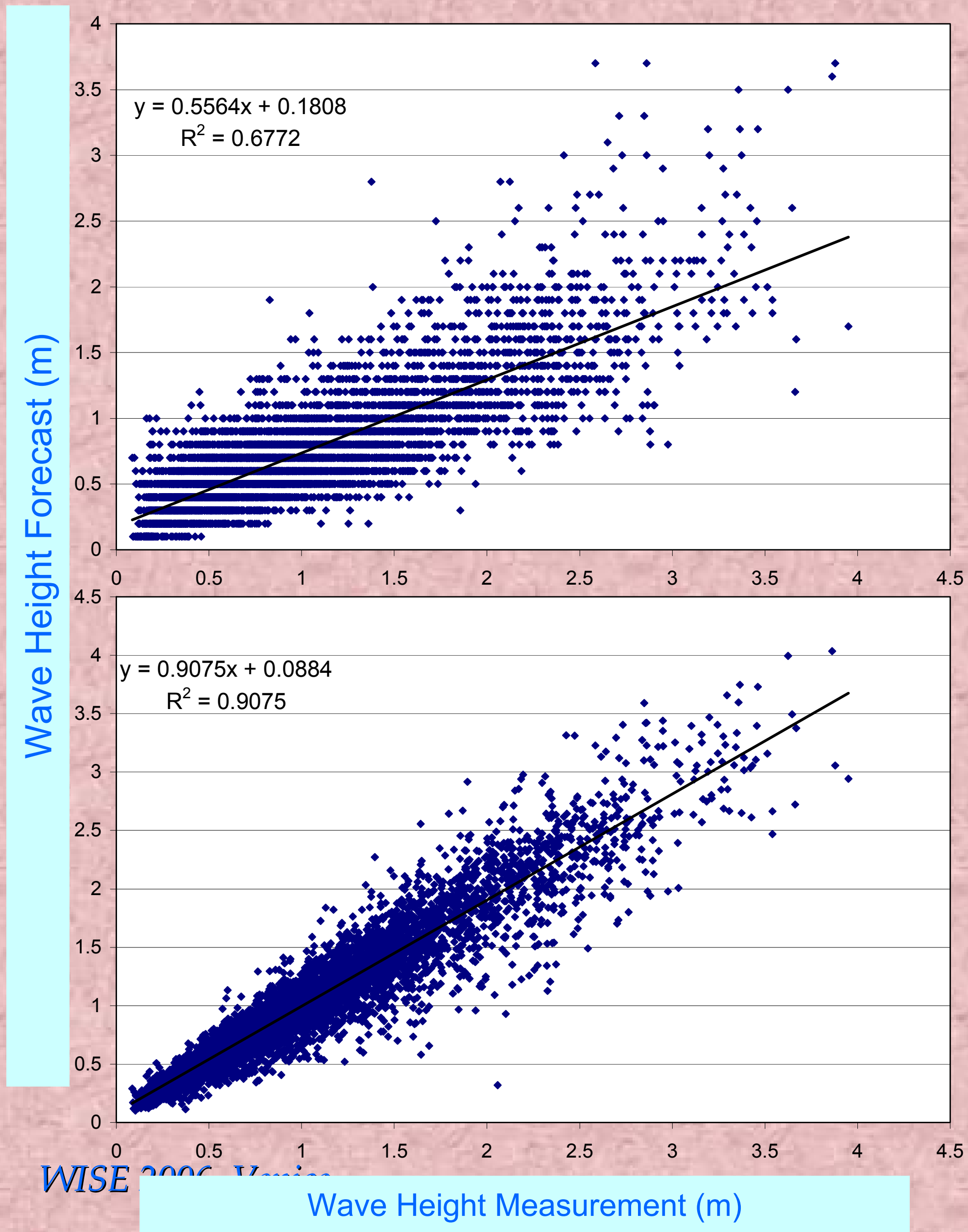


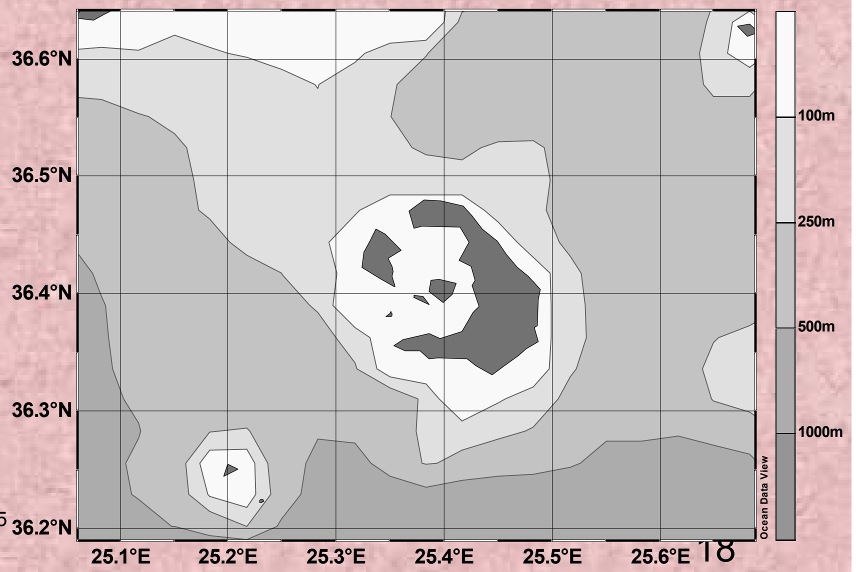


Wave Height Forecast (m)

Wave Height Measurement (m)




Wave Height Forecast (m)
y = 0.5564x + 0.1808
R2 = 0.6772
y = 0.9075x + 0.0884
R2 = 0.9075
Wave Height Measurement (m)


36.6°N
36.5°N
36.4°N
36.3°N
36.2°N
25.1°E
25.2°E
25.3°E
25.4°E
25.5°E
25.6°E
100m
250m
500m
1000m
Ocean Data View

Summary Table

	R^2 Athos	R^2 Lesvos	R^2 Mykonos	R^2 Santorini
WAM MODEL	*0.781*	*0.713*	*0.722*	*0.676*
MODEL 1	0.920	0.892	0.927	0.906
MODEL 2	0.865	0.813	0.860	0.820
MODEL 3	0.924	0.895	0.931	**0.911**
MODEL 4a	0.929	0.897	**0.936**	0.909
MODEL 4b	**0.929**	**0.898**	0.935	0.908

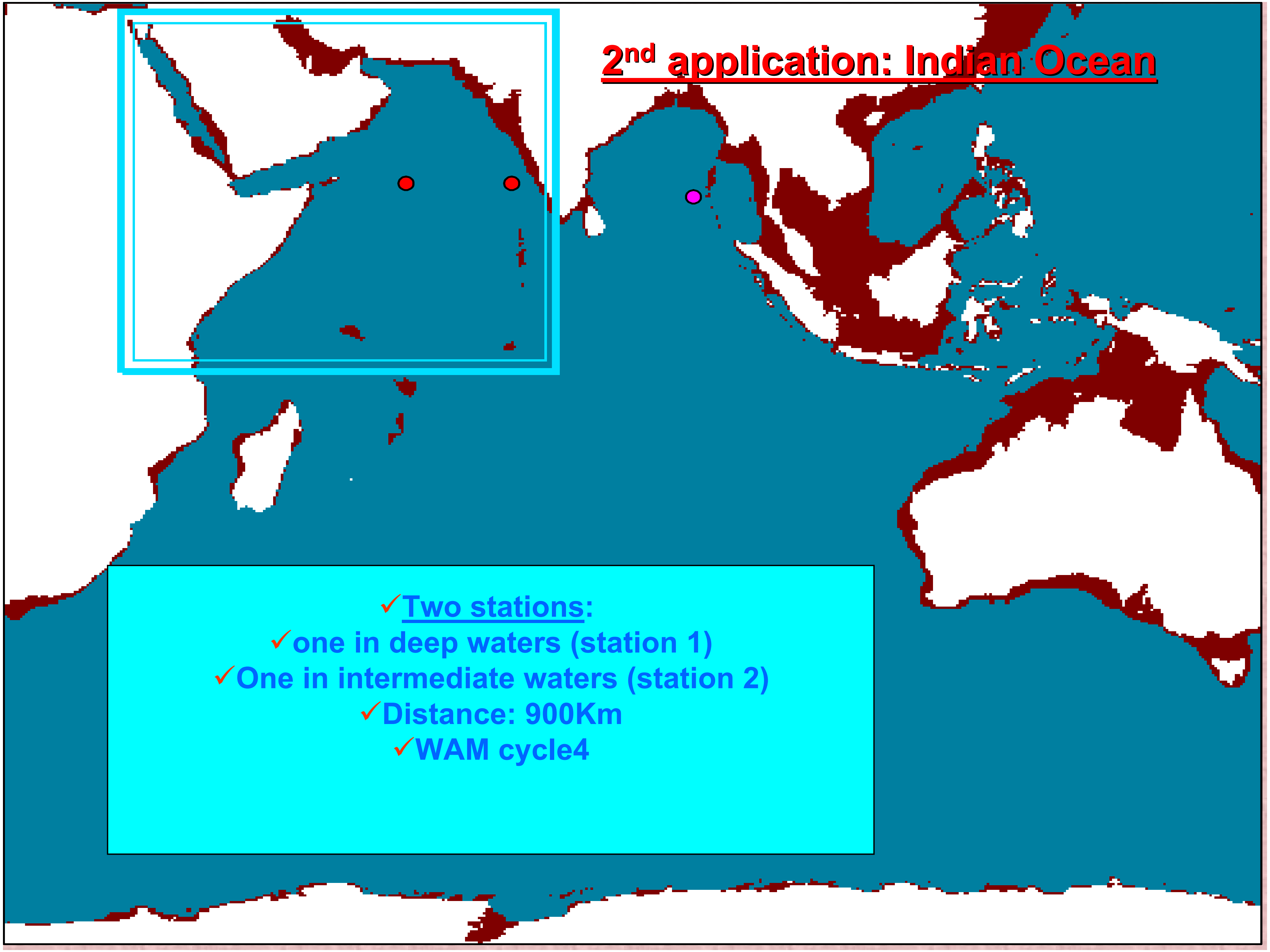
Total improvement obtained:

- For all four stations
- For all four models tested
- For all periods of implementation
- For high and low values of the wave height
- No outliers

✓Increase of the forecast time step decreases the predictive accuracy of our technique

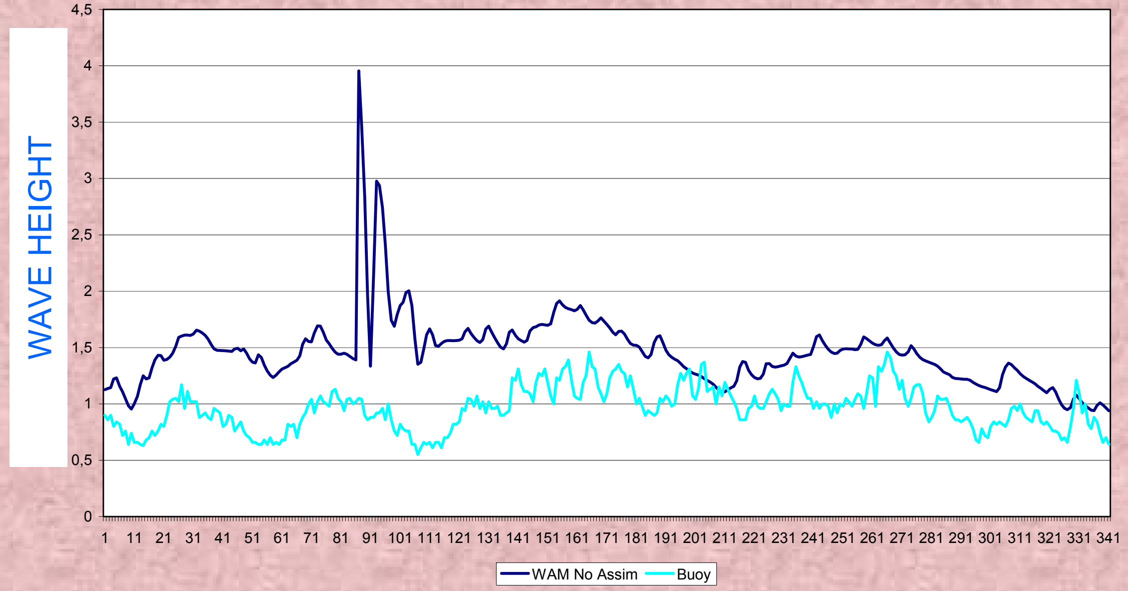
✓Our technique's R^2 equals WAM's for forecasts horizon more than 3 days

2nd application: Indian Ocean

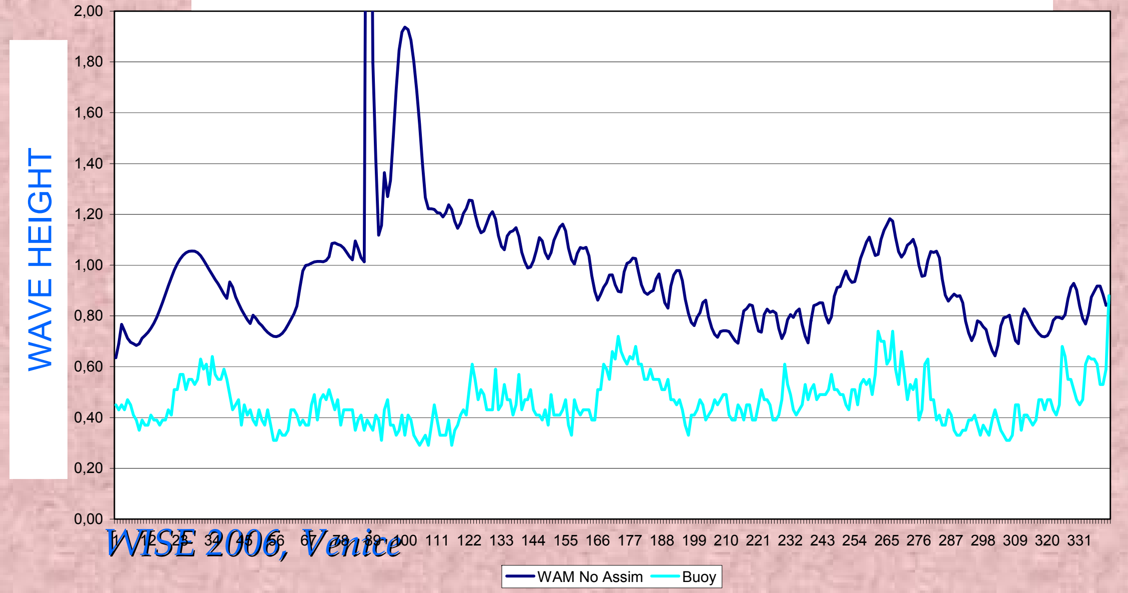


✓Two stations:
✓one in deep waters (station 1)
✓One in intermediate waters (station 2)
✓Distance: 900Km
✓WAM cycle4

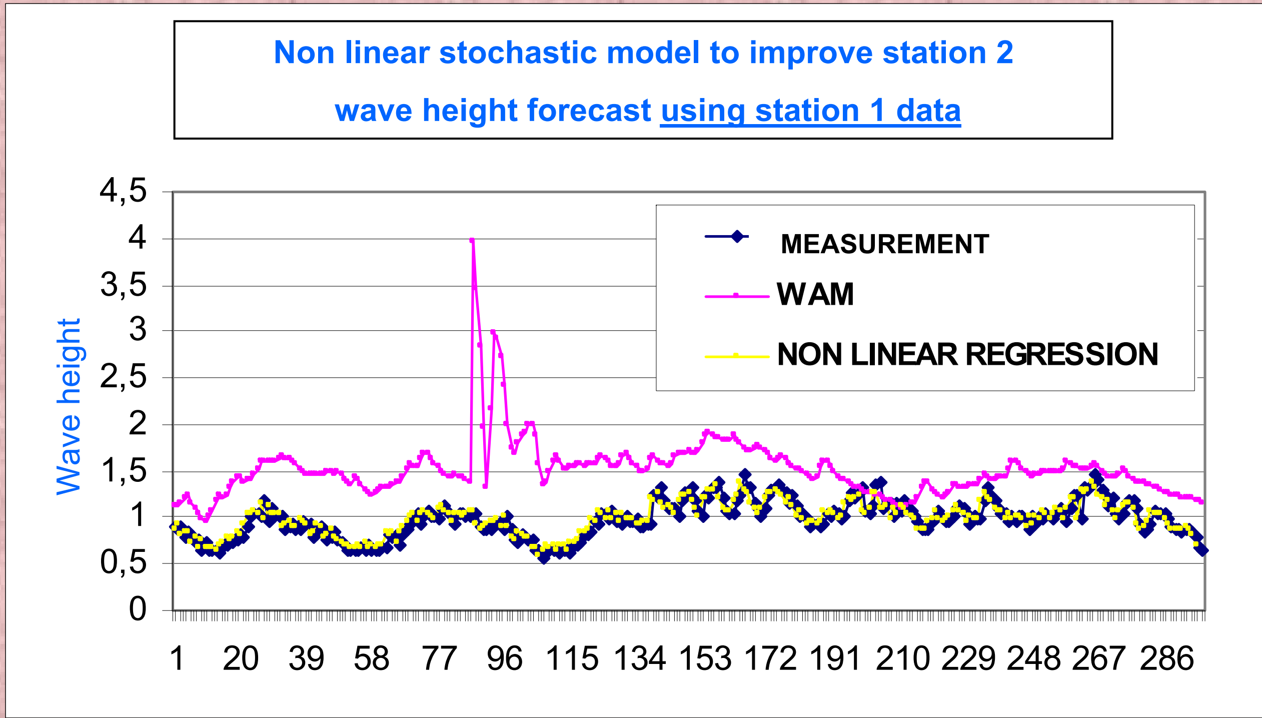
WAVE HEIGHT measurement-WAM (station 1)



WAVE HEIGHT measurement-WAM (station 2)



- **WAM overestimation**
- **Active Swell Subroutine**
- **Outliers for two days both in deep and intermediate waters**



- **Remarkable improvement**
- **Coefficient of determination (R^2=0.9)**
- **Approximation of the measured average wave height**
- **Absorbing the outliers**
- **K time step selection**

Conclusions

- All models improve significantly the forecast in applications tested
- The parameters (weights) in all models indicate the same performance in all stations and in all periods of implementation
- The relation between measurements and predictions seems to be the same (error source, systematic error)
- If we have/measure the wave height for a small period of 3-4 months irrespectively of the season, we can:

1. Estimate the variable weights and then
2. Significantly improve in real time the forecast of the wave model without re-running it and within an area of considerable extent containing the point of measurement

- Stochastic models are a useful tool for wave forecast. Future research is needed