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# LONG-TERM CHARACTERISTICS OF THE WIND ONSHORE AND OFFSHORE WESTERN BLACK SEA

**Teodor-Mihai Cristescu**

*National Institute for Marine Research and Development "Grigore Antipa",300 Mamaia Blvd., Constanța; retired*
**theodor.mihai.cristescu@gmail.com*

## *ABSTRACT*

Based on 6 years in studying air-sea interaction due to wind and 15 years studying and modelling the scattering process and modification of oil into the sea (adaptation and implementation - at NIMRD “Grigore Antipa” of (NOAA & EPA) GNOME software - Cats, Gnome, Gnome Analyst and also Adios2, participation for 7 years to National Contingency Plan for Hydrocarbon Pollution and working as technical expert and member since 2006 of European Group of Experts on remote sensing monitoring of Marine Pollution (EGEMP), the author emphasizes:

- on the one hand the problem of knowledge of Black Sea specific hydrological and meteorological conditions,
- on the other hand the importance of the wind and its variability, and additionally, touches the question of confidence in forecasts and necessity of the understanding of phenomenon variability.

In this respect, using appropriate statistical and mathematical analysis, the considered parameter, the (vector) wind speed, is analyzed from long datasets in several locations on the shore (oldest since 1932) and from the offshore historical marine records (since 1855), that allows estimates of the real phenomenon in nature. Synthetic statistical parameters, as well as comparisons were done.

A deep analysis applies to important long-term sets: distribution type study and tests to display possible links to the extreme weather/climate change.

The results are intended as a background help for scientists or technicians dealing with western “half” of Black Sea wind data.

***Key-Words****:* *Black Sea, long-term, wind, onshore and offshore, statistics*

## *INTRODUCTION*

The purpose of this work was to get valuable information on wind on shore and offshore western Black Sea from long term data. Such information is important for maritime activity (carriers, tanks, drilling rigs, wind farms etc.), on shore activities (harbors, industry, wind farms, tourism etc.) for planning the aforementioned activities or create blueprints for the necessary facilities.

As usual, normal statistical coefficients do not describe the nature; a deep look on distribution of the wind speed as well as the direction distribution may offer better knowledge. Space and time variability of the wind vector displays its local or general specificity. The long time variability may indicate the way the general climate change reflects on local conditions. Statistical or even visual comparisons permit to reveal any unexpected process.

The idea of wind as a (energy) resource generated extensive studies on characteristics mainly concentrated on the energy to be obtained (meaning a given range of speed). Most papers refers to Weibul distribution as a standard to be used [1],[2],[3],[4].Recent researches not only point to other distribution but also generate new complex distributions / models[5][6][7][8] to 'catch' the best and the most of the phenomenon, the last but not the least being the idea of maximum entropy probability distributions [9][10].

This paper is just trying to generate interest and offer a block start for the next researches; the regional and mainly local specificity cannot be neglected.

The region of interest is the western Black Sea (Fig. 1).

## *DATA AND METHODS*

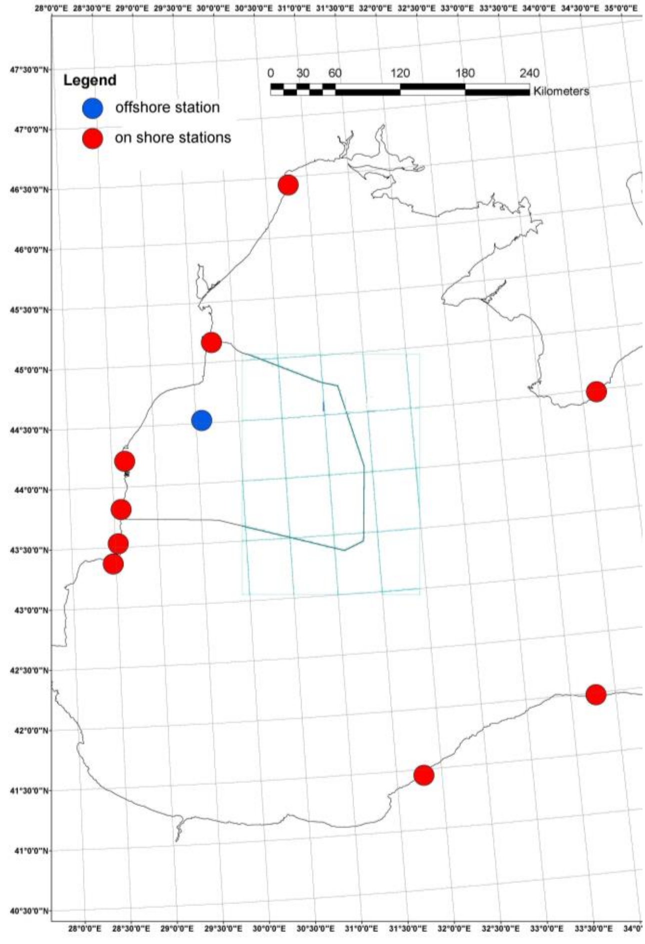
The main criteria in choosing the stations to be data sources was the time length of the dataset, followed by geographical position (to cover the region of interest) and last but not least the region of direct interest to Romania.

There are two groups of data (Table 1):

- on shore datasets (from meteorological stations)
- offshore datasets: PG and GANM for a single observation point, WMN1 from ships observations; the WMN2 and MN datasets contain not only data from ships but also from buoys, drifters etc.

Almost all data (except GANM [11]) were extracted from free access databases: ICOADS (International Comprehensive Ocean - Atmosphere Data Set) and NOAA - CDO (Climate data online). [12][13]

As for all datasets QC is more or less acceptable due to the nature of problem, a statistical and visual verifying followed by rejecting some data based on an (more or less) educated guess was done. This is the reason some length of dataset are not the same in this paper.




Depending on cliffs' heights and the distance shore-meteorological station an increased frequency and speed is to be expected (for the component perpendicular to the shore). The wind speed distribution is strongly influenced by so called local conditions mainly meaning the 'environmental' landscape - the manmade modifications [14]. A good example (from the author knowledge) is Constanța station: the landscape was completely modified during time (not to mention the last 25 years) since its establishing so the data might be affected by the wind field new conditions.

Data processing was based on ad hoc or older created Fortran programs under Force 2.0 support, Microsoft Excel and AddIns and so on.

The author 'created' a global wind dataset GW as a sum of all onshore data.

**Fig. 1. Map of data sources positions**

## *RESULTS AND DISCUSSION*

The first data processing was to suppose the data are distributed approximately normal and to obtain statistical characteristics. (Table 2 and Table 3)

The first thing to underline is the evident difference between data from PG / GANM (evidenced by italics) and from the mobile data sources (WMN1, WMN2 and MN):

- The average speed is superior;
- The higher degree moments (skewness and kurtosis) are lesser at PG and GANM;
- Values for the 2$^{nd}$ and 3$^{rd}$ quartiles are evidently greater.

**Table 1 - Wind datasets (on shore stations 1-9, off shore stations 11-14)**

| No. | Code | Name | AWS code | φ °lat. N | λ °lon.E | H (m) | No. of values | Start year | End year |
|---|---|---|---|---|---|---|---|---|---|
| On shore stations datasets | | | | | | | | | |
| 1 | CT | Constanţa | 154800 | 44.217 | 28.650 | 14 | 263457 | 1936 | 2013 |
| 2 | SU | Sulina | 153600 | 45.167 | 29.733 | 9 | 232840 | 1936 | 2013 |
| 3 | OD | Odessa | 338370 | 46.433 | 30.767 | 42 | 488249 | 1932 | 2013 |
| 4 | YA | Yalta | 339900 | 44.483 | 34.167 | 72 | 58455 | 1948 | 2013 |
| 5 | IN | Inebolu | 170240 | 41.983 | 33.783 | 64 | 118795 | 1973 | 2013 |
| 6 | ZO | Zonguldak | 170220 | 41.45 | 31.8 | 137 | 65090 | 1995 | 2011 |
| 7 | KA | Kaliacra | 155620 | 43.367 | 28.467 | 64 | 63009 | 1975 | 2013 |
| 8 | SH | Shabla | 155610 | 43.533 | 28.533 | 28 | 62291 | 1975 | 2013 |
| 9 | MA | Mangalia | 154990 | 43.817 | 28.583 | 9 | 129427 | 1964 | 2012 |
| 10 | GW | | | | | | 1515905 | 1932 | 2013 |
| Offshore datasets | | | | | | | | | |
| 11 | PG | Gloria Platform | 154770 | 44.517 | 29.567 | 24/ 28 | 59424/ 59680 | 1983 | 2002/ 2012* |
| 12 | GANM | Gloria (ANM) | | | | | 84621 | 1995 | 2007 |
| 13 | WMN1 | Ship data | - | | ≤ 34° | n/a | 45137 | 1870 | 2013 |
| 14 | WMN2 | All data | - | | ≤ 34 ° | n/a | 192799 | 1854 | 2015 |
| 15 | MN | All data | - | 41°÷47° | 27°÷42° | n/a | 293297 | 1854 | 2015 |

* the PG set stops in 2002 and was completed with 256 values mainly for 2012

**Table 2. Normal statistics for offshore datasets and global onshore data**

| **Dataset** | **PG** | **GANM** | **WMN1** | **WMN2** | **MN** | **GW** |
|---|---|---|---|---|---|---|
| **N** | 59564 | 84619 | 45135 | 191783 | 292879 | 1515905 |
| **Mean±CI(95%) (m/s)** | *7.68± 0.033* | *7.97 ± 0.027* | 5.96 ± 0.036 | 6.17 ± 0.018 | 5.96 ± 0.015 | 4.22 ± 0.005 |
| **Std. dev.** | 4.15 | 4.01 | 3.91 | 4.05 | 4.06 | 3.10 |
| **Coeff.of Var.** | *0.54* | *0.50* | 0.66 | 0.66 | 0.68 | 0.74 |
| **Skewness** | *0.43* | *0.37* | 0.87 | 0.88 | 0.97 | 1.33 |
| **Kurtosis** | *0.59* | *0.22* | 1.22 | 1.33 | 1.66 | 3.24 |
| Percentiles | | | | | | |
| **Minimum** | 0 | 0 | 0 | 0 | 0 | 0 |
| **1st quartile** | *4.9* | *5.0* | 3.1 | 3.0 | 3.0 | 1.8 |
| **2nd quartile** | *8.1* | *8.0* | 5.1 | 6.0 | 5.1 | 4.0 |
| **3rd quartile** | *9.8* | *10.0* | 8.2 | 8.7 | 8.2 | 5.8 |
| **Maximum** | 32.2 | 32.0 | 35.0 | 35.5 | 37.6 | 41.7 |

In spite of the fact that the platform carrying the measurement system is at sea, the main reason of difference is the height of the measurement system (it appears that the initial provider did not apply the necessary corrections to reduce the speed 'at' sea level or standard level).

**Table 3. Normal statistics for on shore datasets**

| Dataset | CT | SU | OD | YA | IN | ZO | KA | SH | MA |
|---|---|---|---|---|---|---|---|---|---|
| **N** | 260510 | 229765 | 488249 | 123259 | 118292 | 64956 | 62487 | 62291 | 126731 |
| **Mean ± CI(95%) (m/s)** | 3.58 ± 0.011 | *6.21 ± 0.015* | 4.17 ± 0.008 | 2.15 ± 0.011 | 3.42 ± 0.013 | 2.37± 0.012 | 5.72± 0.032 | 5.27± 0.024 | 3.41± 0.022 |
| **Std. dev.** | 2.95 | *3.68* | 2.62 | 2.06 | 2.32 | 1.53 | 4.11 | 2.99 | 2.98 |
| **Coeff.of Var.** | 0.82 | *0.59* | 0.63 | 0.96 | 0.68 | 0.65 | 0.72 | 0.57 | 0.80 |
| **Skewness** | 1.37 | *1.00* | 0.87 | 2.90 | 1.05 | 1.21 | 1.35 | 1.23 | 1.11 |
| **Kurtosis** | 3.25 | *1.67* | 2.06 | 13.06 | 2.10 | 2.73 | 3.18 | 3.49 | 2.25 |
| Percentiles | | | | | | | | | |
| **Minimum** | 0 | *0* | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **1st quartile** | 1.8 | *4.0* | 1.8 | 0.9 | 1.3 | 1.3 | 3.1 | 4.0 | 1.8 |
| **2nd quartile** | 3.1 | *5.8* | 4.0 | 1.8 | 3.2 | 2.2 | 4.9 | 4.9 | 3.1 |
| **3rd quartile** | 4.9 | *8.0* | 5.8 | 3.1 | 4.9 | 3.1 | 8.0 | 7.1 | 5.8 |
| **Maximum** | 41.7 | 40.9 | 32.0 | 29.8 | 22.6 | 20.4 | 39.5 | 39.5 | 32.9 |

Taking into account the datasets lengths is not necessary to verify that there are nine (even very) different sets of data. The spreading of the values is mainly determined by the specificity (local conditions) of every zone and by the measurement systems heights. To be more specific it appears that for every different environment we obtain different statistics. Anyhow the set for SU dataset (evidenced by *italics*) is clearly the most different to the rest.

As any part of nature is expected to obey to a law, so it is (or could be) a good approach to study its distributions.

The goodness of fit for a lot of distributions was estimated using KS (Kolmogorov Smirnov test) to establish if null hypothesis could be rejected or not for a lot of samples.

Four time randomized samples from the GW set were tested but for every distribution the null hypothesis of similarity/equality was rejected for confidence levels higher than 80 %. As GW is a Black Sea 'global' dataset the test was applied to complete sets of successive longer or shorter subsets for different stations to test not only local but also for specific periods: there are considered the periods between minimum numbers of Solar spots (Sun cycles) as in Table 4.

**Table 4. Periods used to split long datasets**

| Code | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| Sun cycle no. | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
| Start \| Year<br>Date \| Month | 1867<br>03 | 1878<br>04 | 1889<br>01 | 1901<br>04 | 1912<br>10 | 1923<br>08 | 1933<br>10 |

| Code | H | I | J | K | L | M | N |
|---|---|---|---|---|---|---|---|
| Sun cycle no. | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| Start \| Year<br>date \| Month | 1944<br>1 | 1954<br>1 | 1964<br>8 | 1976<br>2 | 1986<br>1 | 1996<br>5 | 2008<br>9 |

There were tested for equality to one of the 47 distributions (in EasyFit AddIn) more than 38 datasets or subsets: 9 for CT, 9 for SU, 4 for YA, 4 for IN, 1 for MA and 11 for OD. The KS test of distribution similarity resulted in rejection of null hypothesis for any degree of confidence greater than 80 %. The distributions KS were sorted by increasing KS statistics and ranked (for the first 10). The final result in Table 5 , column 2 must be carefully interpreted, as the number of parameters is linked to distribution versatility; the final marks in column 5 are the computed marks in column 3 'pondered' by number of parameters. For the first four positions there are little differences so one cannot sustain a distribution or another describes the wind in long time.

As the author did not identify any proof that a distribution or another are implied by physical (meteorological) complex phenomena he is tempted to accept that if this approach was not very successful it was helpful offering more data/information to his colleagues.

**Table 5. Ranking distribution by fitness to wind speed data**

| Distribution | Ranking points | Mark(max.10) | Parameters number | Final mark | **FINAL RANKING** | |
|---|---|---|---|---|---|---|
| Wakeby | 332 | 8.74 | 5 | 1.75 | **GenExtreme** | **1.88** |
| GenExtreme | 214 | 5.63 | 3 | 1.88 | **GumbelMax** | **1.87** |
| JohnsonSB | 181 | 4.76 | 4 | 1.19 | **Wakeby** | **1.75** |
| GenPareto | 156 | 4.11 | 3 | 1.37 | **Gamma** | **1.62** |
| GumbelMax | 142 | 3.74 | 2 | 1.87 | **Weibull** | **1.39** |
| GenLogistic | 129 | 3.39 | 3 | 1.13 | **GenPareto** | **1.37** |
| Gamma | 123 | 3.24 | 2 | 1.62 | **JohnsonSB** | **1.19** |
| Weibull | 106 | 2.79 | 2 | 1.39 | **GenLogistic** | **1.13** |

The variability of the coefficients for every distribution was also analyzed. The tiniest ranges are for Gamma, GumbelMax and Weibull while the greatest for Wakeby and GenExtreme; it is another reason to dig deeper into wind speed distributions in the future.

The good thing of the distribution approach was the idea to split the subsets to compare between and reveal any time tendency, as there are not enough points for space analyze.

Most dataset (full dataset being noted as ALL) were split in two subsets - A and B consisting in the first 47.5 % values and last 47.5 % values, respectively. The distribution 'tails' (usually for V>7 m/s) offer a nice support to link to global climate change.

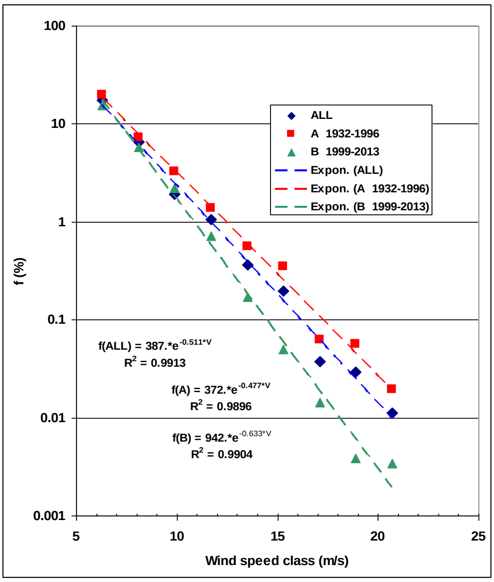



Fig. 2. Wind speed distribution - OD

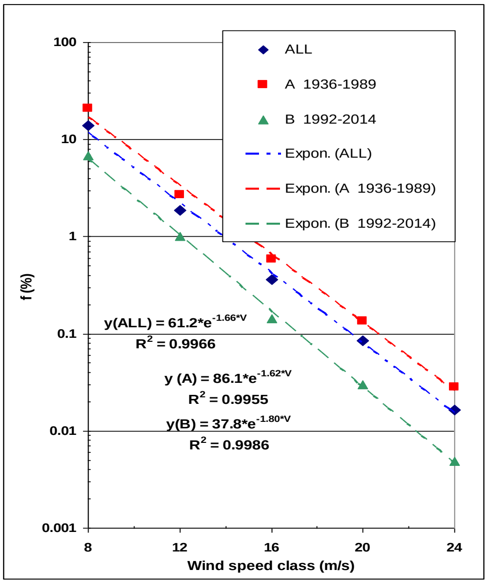



Fig. 3. Wind speed distribution - CT

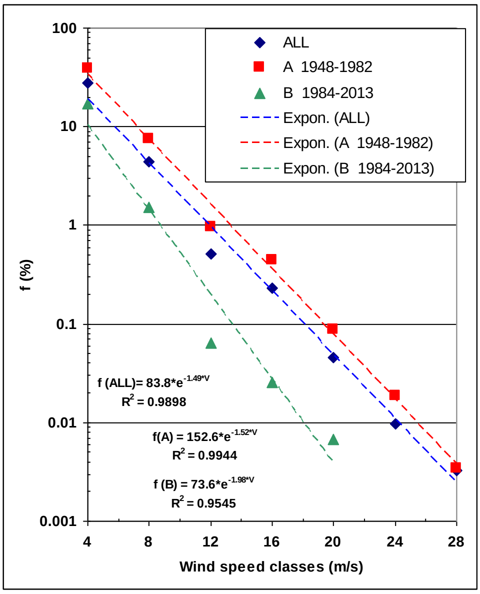



**Fig. 4. Wind speed distribution - YA**

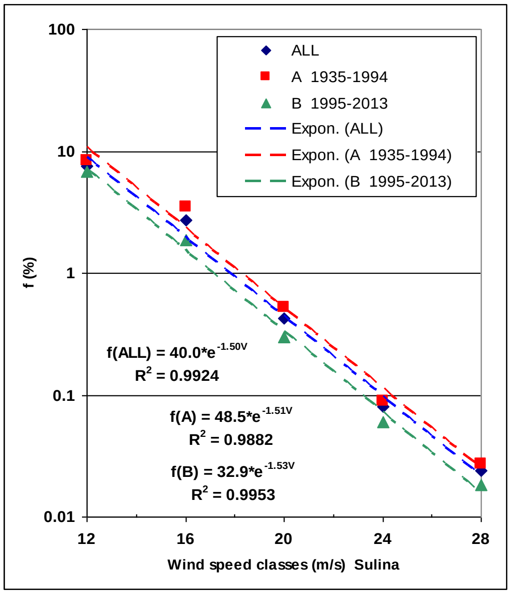



**Fig. 5. Wind speed distribution - SU**

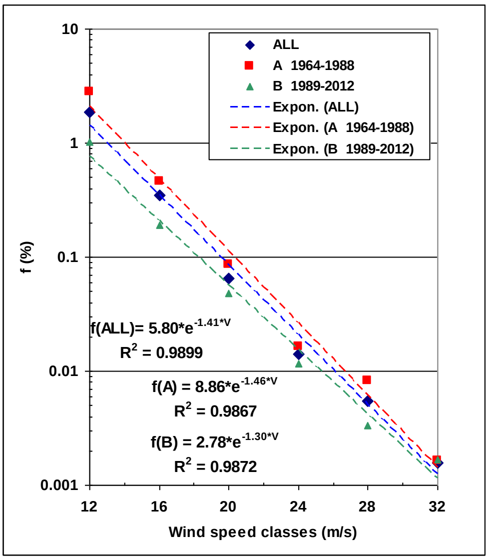



**Fig. 6. Wind speed distribution - MA**

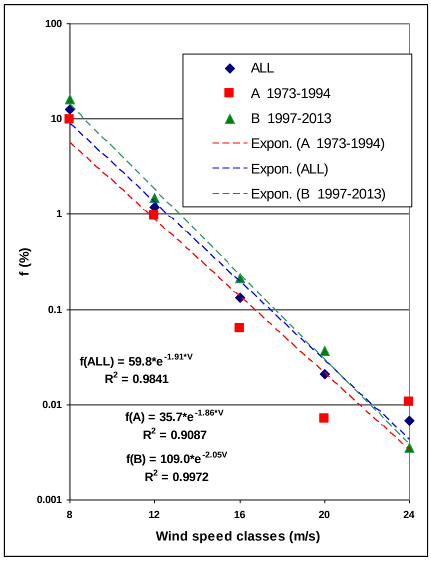



**Fig. 7. Wind speed distribution - IN**

IN (Inebolu) dataset is different to the sets for CT, OD, YA, SU and MA, the mean wind speed for the last period is significant greater at the 99.9999% confidence level (for $\alpha<0.000001$). The other five sets show a *decrease* of speed significant at 99.9999% confidence level.

As statistic tests (supposing however normality) reject averages equality for sets and subsets not only for onshore but also for offshore data:

- WMN1: two equal length splits (1870 - 1977.09.15 and 1977.09.16 - 2013.11.01, and seven little equal length splits (cutting dates 1937.10.11, 1977.07.01, 1984.06.04, 1988.04.25, 1991.08.20) of 6013 values;
- WMN2 data split into four quasi equal samples of ~49000 values (cutting at 1958, 1971, 1985);
- MN set split into 14 samples (see Tab. 3) from A to N,

the author considers that the randomness of the phenomenon might be just described.

As all data considered (onshore and offshore) present such variability and randomness it is to accept that weather forecasts (even at the recent level) imply more uncertainty than we usually think. Variability of the distribution for the nine onshore stations is represented in Fig. 8 and Fig. 9. The envelope (red/green) clearly displays the high degree of variability [2] [15]. In Fig. 10 is displayed only the envelope and the mean wind rose for weighted onshore (by dataset lengths) data.

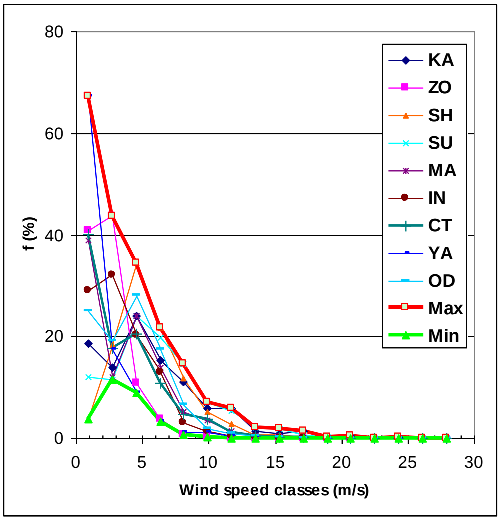



**Fig. 8. Distributions of all onshore sets and envelope**

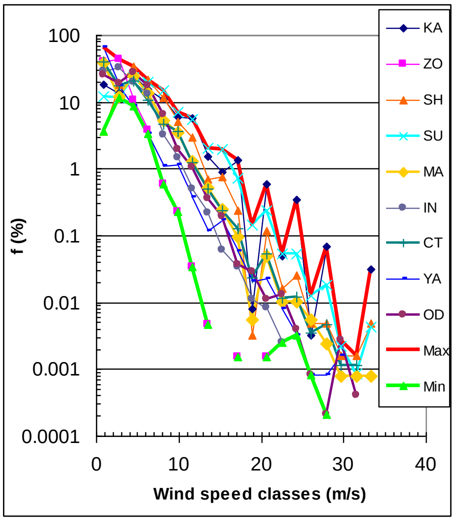
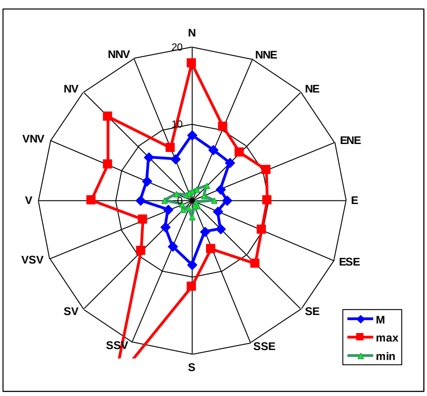


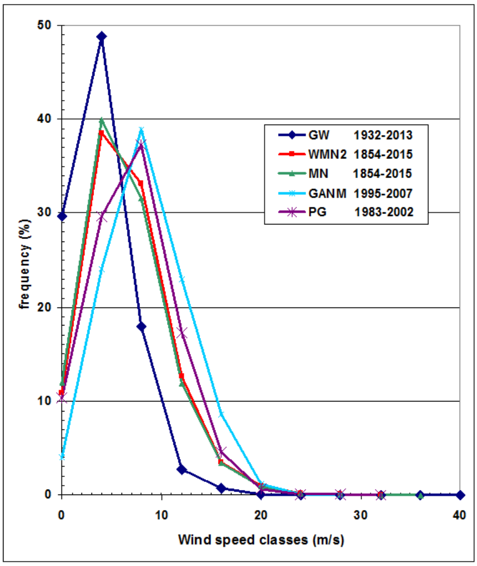

**Fig. 9. Distributions of all onshore sets (tails) and envelope**

The distributions of the offshore sets of data are different not only of GW (all onshore), but also each to other (Fig. 11 and Fig. 12). Only the "slopes" for GW, WMN2 and MN are quite the same (Fig.12) to prove there is a link to regional characteristics[16], while those for PG and GANM show the differences due to



measurement conditions.

**Fig. 10. On shore wind roses (weighted mean and extreme values)**



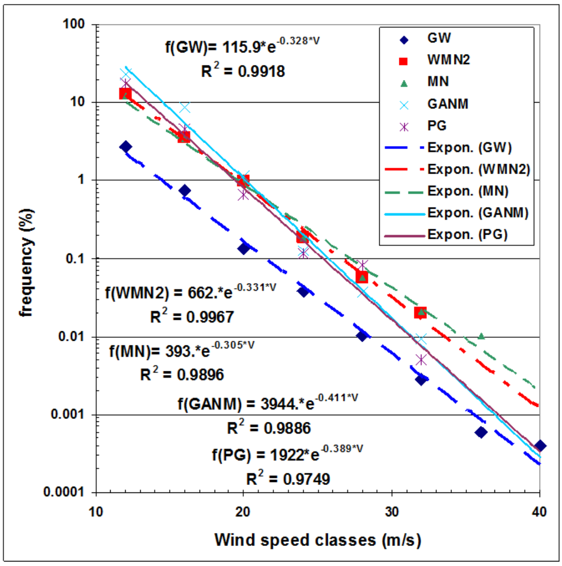




**Fig. 11. Long-term wind speed distributions on shore and offshore**

**Fig. 12. Long-term wind speed and distributions on shore and offshore (tails)**

The reason of presenting the on shore datasets split in two parts (Fig. 2 - Fig. 7) was the intention to reveal any modification in time to be linked to global climate change[15]. The graph of percentiles for offshore data sets in Fig. 13 represents WMN1 data split in seven equal length parts. The four split set WMN2 in Fig. 14 suggest also the wind speed values increased in time.

The display of the increasing/decreasing of the wind speed values offshore/on shore in Fig 15 is a quite strange and amazing picture deserving a thorough analyze. The last 40 years show a slow decrease of mean wind on shore as well as a slow increase of the wind offshore.

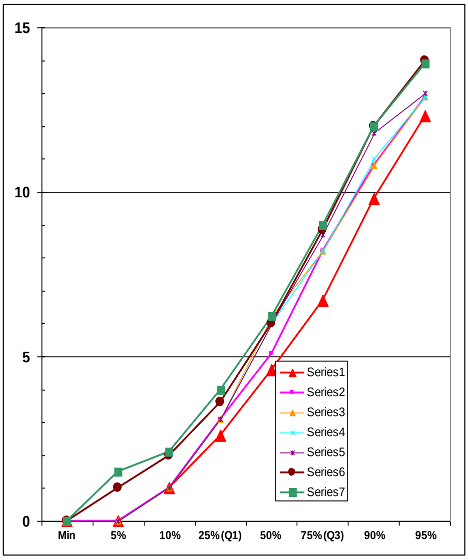



**Fig. 13. Percentiles of 7 equal length subsets from WMN1 set**

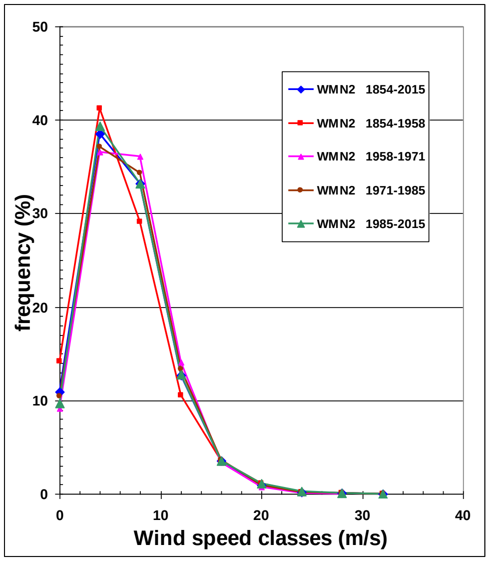



**Fig. 14. Distributions of 4 equal length subsets from WMN2 set**

As the separate data mentioned before (Fig. 2 to Fig. 7) mainly sustain the last assessment it is wise to accept that for the Black Sea:

- On shore the wind is decreasing while the offshore wind tendency is opposite,
- The extremes on shore are also decreasing.

The not yet finalized works show repeating time for extreme wind values is on shore twice than offshore.

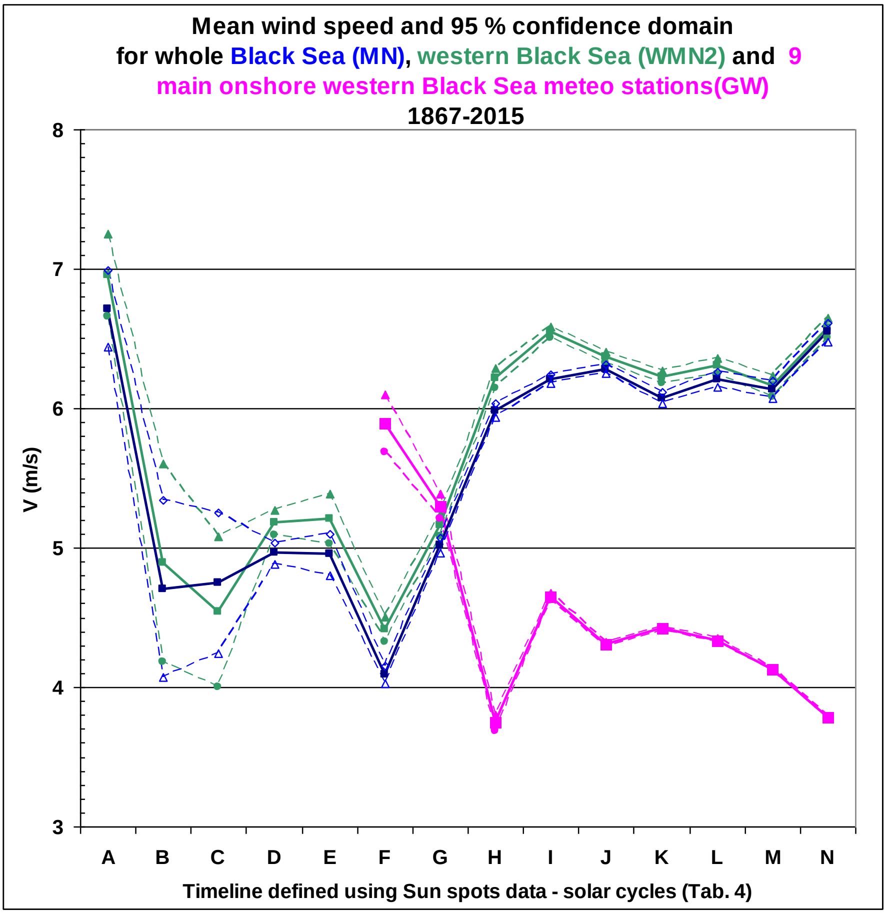



**Fig. 15. Time evolution of mean and confidence interval (95) for GW set (all data on shore), western Black Sea and whole Black Sea**

## *CONCLUSIONS*

The author added together a lot of historical data on wind in the western Black Sea and proceeded to analyze space and time characteristics.

Data distribution study showed there is no distribution to fit the wind data due to differences between sets and subsets on shore and offshore and also in time. KS test is used as the datasets were long enough. GenExtreme, GumbelMax, Wakeby and Gamma distributions proved to be the most appropriate to use.

The evolution in time of the resulted wind characteristics is less expected showing opposite tendencies (increasing at sea and decreasing on shore).

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