Investigation of a Combined Effect of the Mediterranean Sea Breeze and Complex Topography on the Diurnal Wind Patterns

Isabella Osetinsky-Tzidaki, ICCLIPP (admin@icclipp.com),
Erick Fredj, Jerusalem College of Technology (fredj@jct.ac.il)

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Motivation

Wind energy production requires carrying out the extensive research to determine optimal locations for wind turbines and their optimal operation.

While seasonal and monthly variations in wind regimes across the regions of interest are widely studied, less attention is paid to diurnal variations. However, considering that wind turbines do not operate all 24 hours a day due to too weak or too strong wind speeds, research of diurnal variations in wind regimes can make a significant contribution to planning wind turbine locations and their optimal operation plan.

The special features in diurnal patterns of wind speed in summer under the combined effect of the Mediterranean Sea Breeze and complex topography of S. Levant was conducted using the wind data from 24 Automated Weather Stations (AWSs) of the Israel Meteorological Service. Out of total 74 AWSs with wind records, these 24 AWSs are less affected by urbanization, forests and farming. All AWSs are located between the Mediterranean coast and the Dead Sea Valley characterized by the extremely heterogeneous, rapidly changing relief - mountains, valleys, plateaus and steppes. The present work show the wind data from the 12 most representative AWSs.

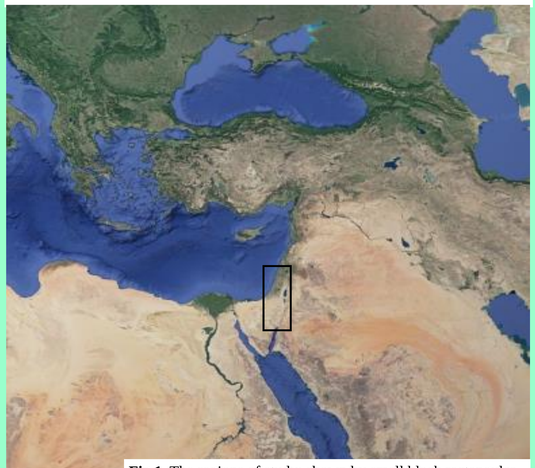


Fig.1. The regions of study: shown by small black rectangular on the Eastern Mediterranean map.

Data and Methods

For each AWS, its 10-minute wind speed data have been:
(1) averaged into the hourly data (2) then, for each hour of a day, averaged across all days in each month. These hourly-monthly wind speed data (WS) are presented here on the "HOUR, YEAR" axes month by month (Fig. 5). The x-axis "HOUR" is divided into 24 hours. The y-axis "YEAR" starts at 1993 when several of the presented AWSs were installed.
These 3D plots allow:
1) For each calendar month, to identify the optimal working hours for wind turbines;
2) Define whether the seasonal and diurnal patterns of wind regimes have been affected by climate changes.

References and Acknowledgements:
[1] Wind speed data are provided by the IMS - Israel Meteorological Service [ref].
[2] Reanalysis data are provided by Kalnay E. and Coauthors, 1996: The NCEP/NCAR 40-Year Reanalysis Project. *Bull. Amer. Meteor. Soc.*, 77, 437–472, [ref].
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[8] Naor R. et al., 2015: An observational study of the summer Mediterranean Sea breeze front penetration into the complex topography of the Jordan Rift Valley, *Theor. Appl. Clim.* [DOI]
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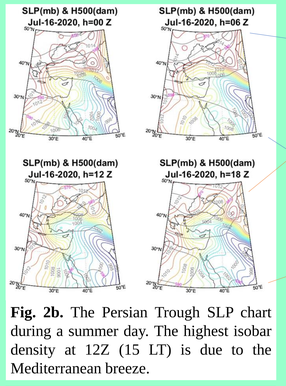


Fig. 2b. The Persian Trough SLP chart during a summer day. The highest isobar density at 12Z (15 LT) is due to the Mediterranean breeze.

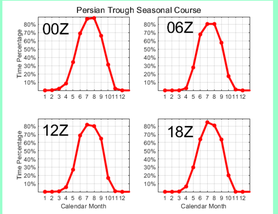


Fig. 2c. The Persian Trough seasonal course of at different times of a day.

Wind turbines require a minimum wind speed (generally 12-14 km/h, or 7.5-8.7 mph, or 3.3-3.9 m/s) to begin turning and generate electricity [4].
At the rated wind speed, the turbine is able to generate electricity at its maximum, or rated, capacity. The rated speed is usually in the range of 25 to 35 mph (11.2-15.6 m/s). At the cut-out wind speed (25 m/s), the turbine shuts down to avoid damage [5], [6] (Fig. 3).

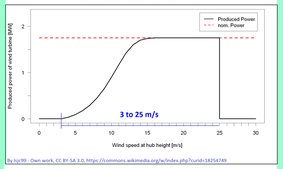


Fig. 3. Power production of a typical wind turbine.

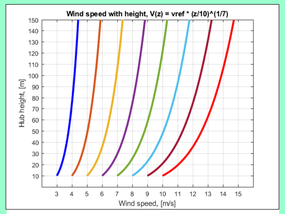


Fig. 4. Calculated wind speed at wind turbine hub heights up to 150 m given wind speed measured at the AWS anemometer height of 10 m. The hub height h=150 m corresponds to 4.2 MW capacity.

Figure 4 shows a wind speed at different wind turbine hub heights up to 150 m, calculated with a wind profile power law formula:

$$v = v_{ref} \times \left(\frac{z}{z_{ref}}\right)^{\alpha}$$, where

- v is the wind speed at height z,
- v_{ref} is the known wind speed at a reference height z_{ref},
- α is approximately 0.143 for neutral stability conditions

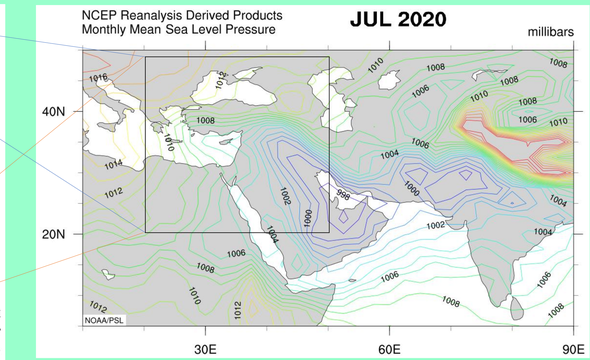


Fig. 2a. The Indian summer monsoon and its westward tongue reaching Greece and called the Persian Trough (due to its extension over the Persian Gulf). Shown is the SLP chart for July 2020.

The Persian Trough (PT) which is the governing summer synoptic system over the E. Mediterranean is the westward tongue of the Indian summer monsoon (Fig. 2a) and persisting in JJAS (Fig. 2b). The **Mediterranean sea breeze (MSB)** over the study region in S. Levant (Fig. 1) is supported by the PT and mixing with it. The PT occurrences are highest in July and August, 80%-90% of time (Fig. 2c). In the rest 10%-20% of time, when the PT is weakening and retreating a bit eastward, its place over the S. Levant is taken by its counterpart, the Subtropical High advancing from the west.

Still, the WNW airflows persist and mix with the **MSB** and enhance it. As a result, the **MSB** only consists of the sea-to-land airflows, while the typical for the sea breeze land-to-sea airflows aloft are absent.



However, the mesoscale feature of the diurnal variability of the sea breeze is still expressed in the wind speeds: night winds are significantly weaker than daytime winds almost everywhere (Fig. 5) (except for the very specific location of AWS Har Kenaan).

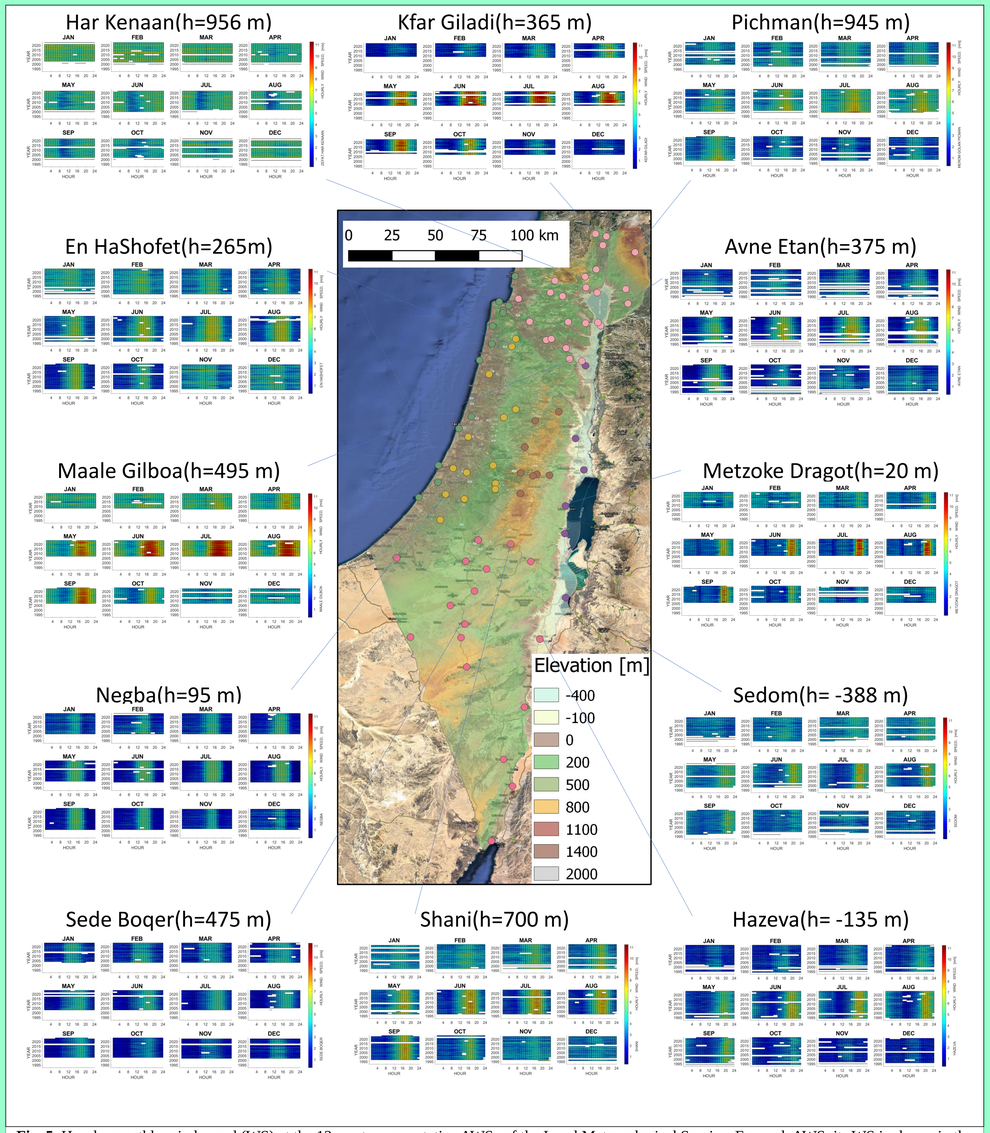


Fig. 5. Hourly-monthly wind speed (WS) at the 12 most representative AWSs of the Israel Meteorological Service. For each AWS, its WS is shown in the monthly 3D plots with x-axis for hours (1 to 24) and y-axis for years (1993 to 2024). The height of each AWS above M.S.L. is shown next to its name.

The biggest demand for the electricity in Israel starts at 17:00 (LT) all over a year, when most people return home from work and start their family life and housework, turning on air conditioning, TV, kitchen appliances, washing machine, etc. The electricity tariffs [7] can serve as proxies to estimate the start and the end of these hours (Fig. 6a).

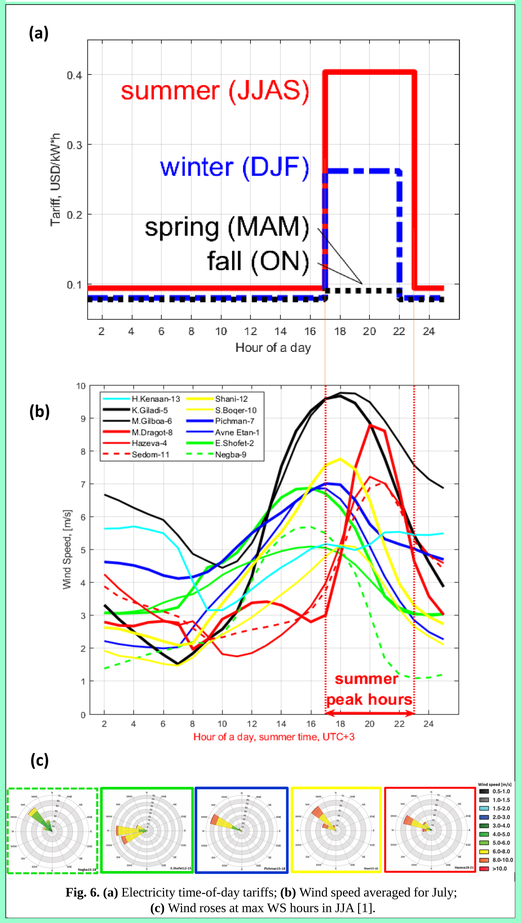


Fig. 6. (a) Electricity time-of-day tariffs; **(b)** Wind speed averaged for July; **(c)** Wind roses at max WS hours in JJA [1].

Figure 6b shows the diurnal variations of wind speeds in summer in several AWSs from the Mediterranean coast to the Dead Sea valley (Fig. 5), with a specific color for each region:

- ✓ Green: coastal plain (Negba) and near-to-coast hills (En HaShofet);
- ✓ Black: northern point (Kfar Giladi) and central/northern hills (M.Gilboa);
- ✓ Yellow: south - the Negev Desert between Shani and Sede Boqer;
- ✓ Blue: north - Golan Height between Pichman and Avne Etan;
- ✓ Red: Dead Sea Valley - Metzoke Dragot, Sedom and Hazeva.

All shown regions (excluding the coastal plain) have a potential for supplying additional energy in the national network during the peak demand hours.

Conclusions. The high demand for electricity during peak hours from 17:00 to 23:00 in the summer months can be partially covered by wind turbines if they are installed above the western shore of the Dead Sea (h = minus 430 m) on steep cliffs, the wind regime of which is represented by the AWS Metzoke Dragot (h=20 m) and/or in the southern part of the Dead Sea valley, called the Arava valley, represented by the AWSs Sedom (h = minus 388 m) and Hazeva (h = minus 135) (Fig. 5). The combination of **MSB** with **the enhanced channeling effect along the Dead Sea valley** due to its being confined between the Judean Mountains to the west and Moab Mountains to the east makes these locations the windiest precisely during peak hours of high electricity demand.

These locations may represent a good alternative to the northern part of the Dead Sea valley - the Golan heights and the Hula and Jordan valley - where the installation of wind turbines poses a risk to wildlife, especially birds, for which that region is a favorite habitat.

Future works. Reconstruction of Sampled Spatiotemporal Scientific Simulation Data of wind regimes along the steep cliffs west to the Dead Sea and along the Arava valley from point cloud observations using a Machine Learning Approach.