560 METHODOLOGY TOWARD A LONG-TERM REALISTIC WIND RESOURCE ASSESSMENT APPLIED IN COLIMA VALLEY, MEXICO

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1. Abstract

*In the present work SODAR technology combined with a specific meteorological tower network are used to investigate characteristics and evolution of the planetary boundary layer in the valley of Colima, central western Mexico, and its wind power generation potential. Relevant mesoscale phenomena such as Supergeostrophic Low Level Jets (LLJ) are for the first time reported in this part of the tropics. These meso β phenomena are very relevant for wind power generation, and their presence in the region under study show the critical importance of the methodology used for wind power assessment. The ability to detect, monitor and include in wind power assessment such phenomena ignored by the classical approach in tropical regions with complex topography shows the need of a methodology that considers modern tools such as SODAR and LIDAR technology for a long term and reliable development of this renewable energy source.

2. Introduction and back ground information

Wind speed is known to vary greatly temporally and spatially which can make wind power assessment quite challenging depending of the region and the complexity of its topography. The power extracted from the wind by a wind turbine is dependant of the cubic value of the wind speed, so any under or over estimation of the wind speed at a specific height in a specific region will affect greatly the associated regional wind power potential and possible development of this kind of renewable energy source.
Wind resource assessment is typically conducted analysing World Meteorological Organisation (WMO) weather station network data with typical wind measurement at 10 meters Above Ground Level (AGL), and in some cases rawinsonde data, to develop 40 to 50 km grided wind maps as a first approach, in general at 50 meters AGL. This wind maps are developed using a logarithmic extrapolation from data at lower height. Once some regions are catalogued with a good wind potential, up to 80 meter AGL instrumented towers are typically installed by companies involved in wind farm development to further investigate the potential of selected sites, as typically observed in Oaxaca, southern Mexico, and Baja California regions. Sometimes mesoscale modelling is used to determine the local wind field from these 80 meter measurements.
Obviously, it can be easily observed that sites designated as high potential using this methodology are concentrated in specific regions at first pinpointed by the logarithmic extrapolation method which has the tendency to result in a dense network of wind farms in these regions making challenging grid balance and energy distribution to other regions and limits the long term development of wind energy as an extended renewable energy source. A more geographically distributed wind farm network will make grid balance easier and this kind of renewable energy of widespread use enhancing its long term development.
Also hub height for wind turbines has evolved quite drastically since the early 1980s with rated capacity of 25-60 kW and rotor diameter of 10-20 meters working in the surface layer to modern wind turbines of rated capacity over 3.6 MW with rotor diameter of around 100 meters and hub height around or over 120 meters AGL in 2011 (Kelley *etal*., 2007). These latter wind turbines are evolving outside of the surface layer, in the Planetary Boundary Layer (PBL), not assessed by the 10-m WMO surface stations and only assessed through rawinsonde measurements at specific sites and specific hours of the day (most of the time twice a day at 00Z and 12Z). In some parts of the world the PBL has been quite well studied and it has been shown in previous work the great importance to wind power generation of mesoscale phenomena such as Low Level Jets (LLJ) that develop in the PBL, as for example over the North American Great Plains and Northern Europe. Important work has been made to investigate the mechanisms of such phenomena in these specific regions but not in the region of interest of the present study.
These points make typical wind assessment using logarithmic extrapolation not suitable for modern wind farm sitting and for long term development of wind energy and sometime completely invalid as it will be shown in the present work with specific examples for a specific region and motivate the development of a methodology that includes modern technology such as SODAR or LIDAR technology; technology which is reliable and able to monitor and assess the PBL at, below and above the hub height of modern wind turbines (Kelley *etal*., 2007).

3. Region of interest, network and data

The region of interest is the Colima Valley, in Colima state (marked in green in Figure 1), in central western Mexico. As shown in Figure 2 the topography of the region is quite complex, ranging from sea level on the Pacific coast to more than

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4,000 meters in the western part of the Mexican transverse volcanic axis. This region is typically considered to have a very low wind power generation potential from the logarithmic extrapolation method as many other parts of the Mexican transverse volcanic axis and other regions with complex topography. Other studies had tried to pin point regions in the world where conditions favourable for consistent Low Level Jets exist. The latter studies also use WMO weather station network data integrating rawinsonde data into mesoscale modelling. For regions with complex topography such as the one of the present study, LLJ phenomena don't appear in the results of such studies. It is possible that the scale of such phenomena escape to these specific approaches, and it must be considered that WMO network is designed to comply with civil aviation and other weather related important needs and not for wind resource assessment.

In the region under study 5 weather stations have been installed for this study, 4 of them with typical 10 meter AGL measurements and one 55 meter AGL tower with measurements at 30 m. and 50 m., all of them sampling a 10 minute interval averaged of wind speed, wind direction, solar radiation, air temperature and atmospheric pressure. A Scintec's Flat Array SODAR-MFAS was installed in the area. The SODAR has been placed at 3 of the sites at different times to assess which site is best suited for this instrument; both to reduce environmental noise to small surrounding settlements and to find the site with lower background noise for the instrument. The data from the SODAR shown here are from the Comision Federal de Electridad's Sub-Station site mark as a red polygon on the map (Figure 2) close to one of the 10 meter station (the CFE is the Mexican national electric company in charge of electric production and energy grid), so far this site has been the most suitable for both of the aforementioned reasons and for the ease of possibility of integrating any renewable energy source to the grid in case of positive results as far as wind energy assessment. The SODAR provides measurements of wind speed (horizontal and vertical) and direction every 10 meters from 30 meters AGL up to 1,000 meters AGL. Due to the wind power assessment orientation of the present study here we focused especially on the first 500 m. AGL using 30 minute averaged data both from the SODAR and weather stations taken at specific time periods during the 2010-early-2012 measurement period.

4. Results

Measurements during this time period has shown that two wind directions prevail at two specific time of the day, one from the south west in the afternoon corresponding with the sea breeze and one from the north east during the night and particularly intense, since the wind speed maximum at night appearing before or around sunrise as a LLJ is typically stronger than the wind speed maximum of the afternoon sea breeze as can be seen on Figure 3. This corresponds to a 10-day time series of wind speed and surface pressure from the 25th of March 2012 to the 3rd of April 2010. Note that both of these maximum correspond to a minimum in surface pressure and that wind speed shows a strong diurnal variation. The surface pressure measurements correspond to Cumbre site (see Figure 2) on a ridge that is 250 meters above the valley floor where is place the SODAR but are also observed at the surface station at SODAR site (not shown here).

To evaluate more specifically this potential, the supergeostrophic low level jets were characterised in Colima valley for measurements done during the period March 2010 to January 2012 (Arfeuille *etal.*, 2012). This characterisation was done considering criteria defined in previous studies of the Low Level Jets of the North American Great Plains and refined by others using similar monitoring tools as the ones used in the present study, such as in CASES-99, Lamar Project and ABLE studies (Song *etal.*,2005, and Kelley *etal.*, 2004). Almost every night shows the development of at least one Jet with nose height between 100 m and 700 m above the valley floor with categories ranging from sub-zero up to category 2 jets (rarely 3), with lower height zero-category jets dominating with a consistent northerly direction (Figure 4). The region of study being in the tropics, most of the year the horizontal pressure gradient is typically small as shown by the pressure field map in Figure 1, implying a relatively weak geostrophic back ground state in the wind field making the observed jets strongly supergeostrophic. The onset of the jets is typically later than in other regions since the region of study is only at 19.23° north. Wind profiles and time evolution of wind direction at nose level are investigated to determine if inertial oscillation mechanism (Blackadar, 1957) is dominating over baroclinicity over sloping terrain (Holton, 1967). So far it is not clear which one is the leading mechanism and more work is needed to determine that aspect and analyse the key forcing affecting the region of interest, even it is clear the ocean-land interaction and topography play an important role (Stull, 1988).

As aforementioned, hub height for modern wind turbines is typically around or greater than 100 meters AGL, and typically measured vertical wind profiles either from the sea breeze in the afternoon or the LLJ at night show a non-logarithmic wind profile in the lower 500 m of the PBL, especially at night and early morning, due to the systematic presence of supergeostrophic low level jets. As an example in Figure 5 is shown a vertical wind profile measured on the 2nd of January 2012 from the SODAR (black curve) in the morning just after sunrise. It is a quite typical nose shape class-1 LLJ profile that can be observed in the Colima valley around sunrise. The maximum speed is 13.1 m/s at 130 meters AGL with the first minimum at 350 meters AGL with a value of 7.1 m/s. From 10 meter wind measurements the corresponding logarithmic profile (blue curve) was evaluated taking the typical α value as 0.14 as often done in wind power assessments. From the black measured profile and estimated profile it is quite clear that logarithmic extrapolation from 10 meter measurements is invalid and barely reach the first minimum above the nose. Also around hub height, here taken as 100 m

just below nose height, the estimated wind speed is around 6 m/s while the measured wind speed is 12 m/s, underestimating the power by a factor of 8. To complement this example, the logarithmic extrapolation was done from the 30-m measurement and in that case the wind speed at hub height is estimated to be around 8.5 m/s still way below the real value.
This being a specific case and to make our point more general a one week time series was used from the 10 meter measurements and the SODAR measurements. The logarithmic extrapolation was done using the 10-m measurements. These are compared in Figure 6 with SODAR measurements for the first 300 meters AGL. It can be clearly seen from this figure that the diurnal cycle is not completely present in the extrapolated part (A). The sea breeze is present but weaker and the nocturnal LLJs are much weaker or non existent (obviously here stability play an important role). For this same time period, the 24 hour averaged wind speed is shown in Figure 7 and clearly the diurnal cycle is weaker, narrower in time for the sea breeze and very weak for the LLJ events, with an averaged maximum of 5 m/s for the logarithmic extrapolation to an averaged maximum of 9 m/s for the measured wind speed.
These examples clearly invalidate typical logarithmic extrapolation from lower heights as used normally for wind resource assessment; and the presence of LLJs in the region increase drastically the potential for wind power generation.
Therefore, considering the high cost of investment for a typical modern wind farm and for the long term validity of wind power assessments, there is a clear need of a methodology that includes modern and flexible technology such as for example SODAR technology as used in the present study. As an example of such a scheme a diagram of the methodology used in the presence study is shown in figure 8, which takes into account the different feedback necessary during the assessment and the flexibility of easily movable sensors such as SODARs and LIDARs compared with high towers that are quite costly to re-implement around the same site in the same region or for other assessments in other regions.

5. Conclusion

First of all it is important to mention that these LLJ phenomena had not been reported in this tropical region before. The presence of LLJ in the region of interest invalidates typical logarithmic extrapolation from lower heights as used normally for wind resource assessment; and the presence of such phenomena increases drastically the potential for wind power generation in such region. So far it is not clear which is the leading mechanism and more work is needed to determine that aspect and analyze the key forcing affecting the region of interest. Also the spatial scale of such meso β scale phenomena reaches farther than our monitoring network and this makes mesoscale modeling a fundamental complementary tool to realize a complete study. Therefore another approach than the traditional one for wind resource assessment is needed to be able to determine realistically the availability of such renewable energy in other regions than the typically known high potential regions. As the present study shows, it can be done integrating classical instrumented towers, wind profiler technology such as SODAR or LIDAR. Mesoscale modeling must be included as a next step. This kind of methodology can also be useful at existing wind farm for managing purposes doing short range mesoscale forecast.

6. References

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7. Figures

Figure 1: Averaged SLP map for March-April 2010, corresponding to time of time series of following figures. The region of interest is marked in green.

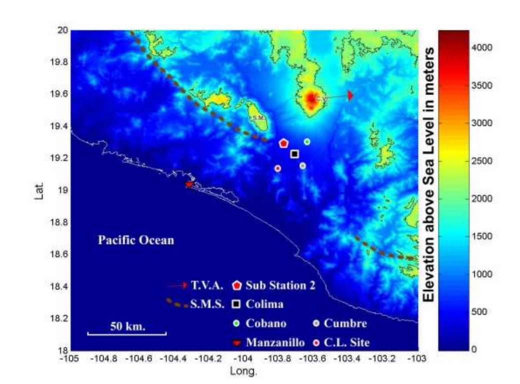

Figure 2: Map showing the complex topography of the region and the monitoring sites.

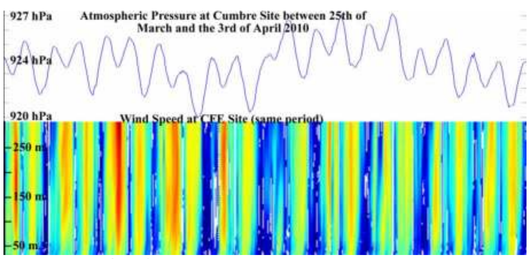

Figure 3: Surface pressure and wind speed time series starting on March 25th 2010 at 00 LST and ending on April 4th 00 LST. Light blue corresponds to 3.5 m/s and red to 16 m/s.

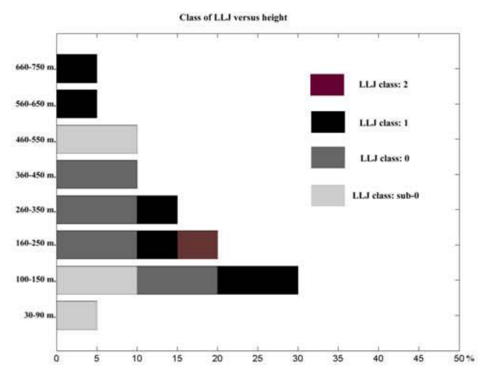

Figure 4: LLJ observed classes versus height during the 10 days time series of figure 3.

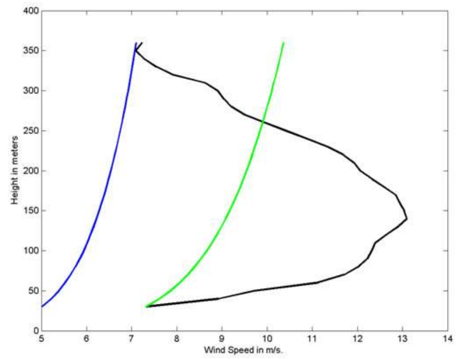

Figure 5: Vertical wind speed profiles measured (black line) and estimated from 10-m measurement (blue) and from 30-m measurement (green) on the 2nd of January 2012 at 0830 LST.

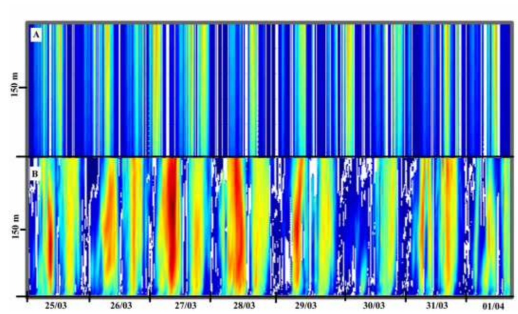

Figure 6: Comparison of the estimated and measured time series of vertical profile for the first 300 meters for a one week period.

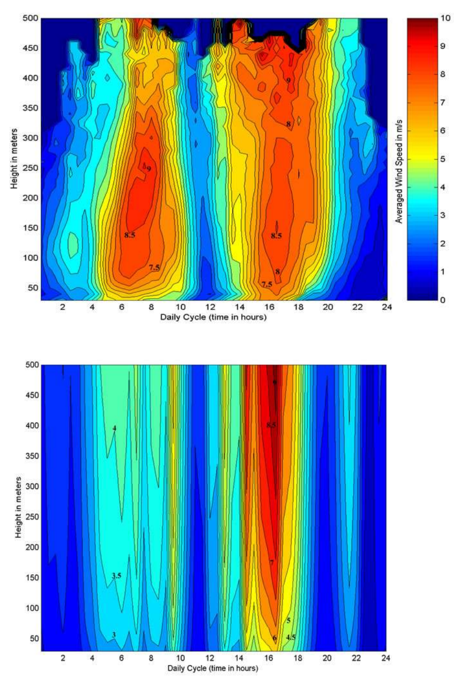

Figure 7: One week averaged vertical wind speed times series (upper: measured, lower: estimated)

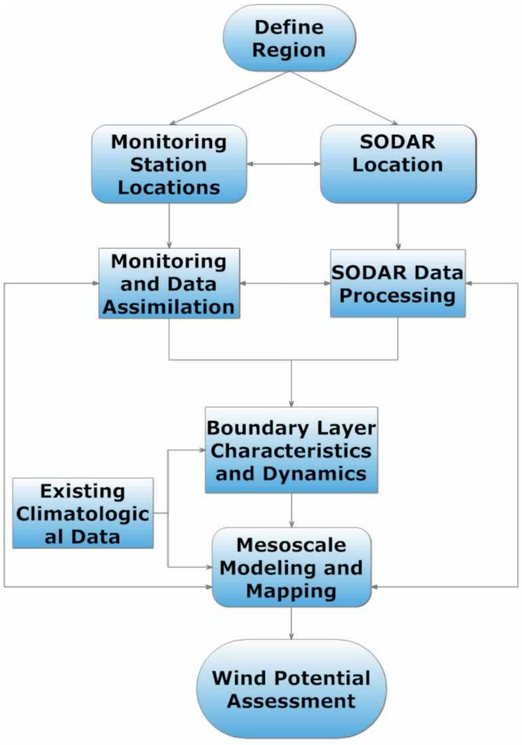

Figure 8: Proposed methodology.