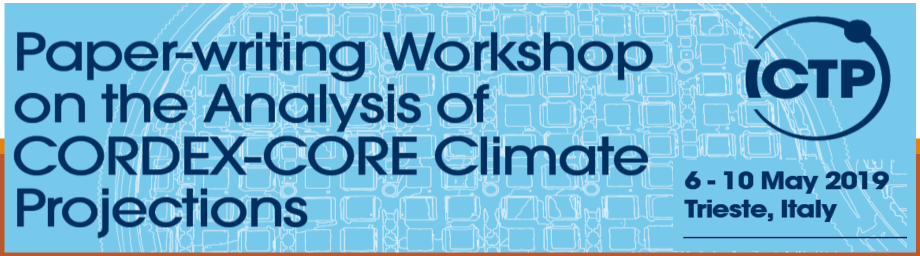
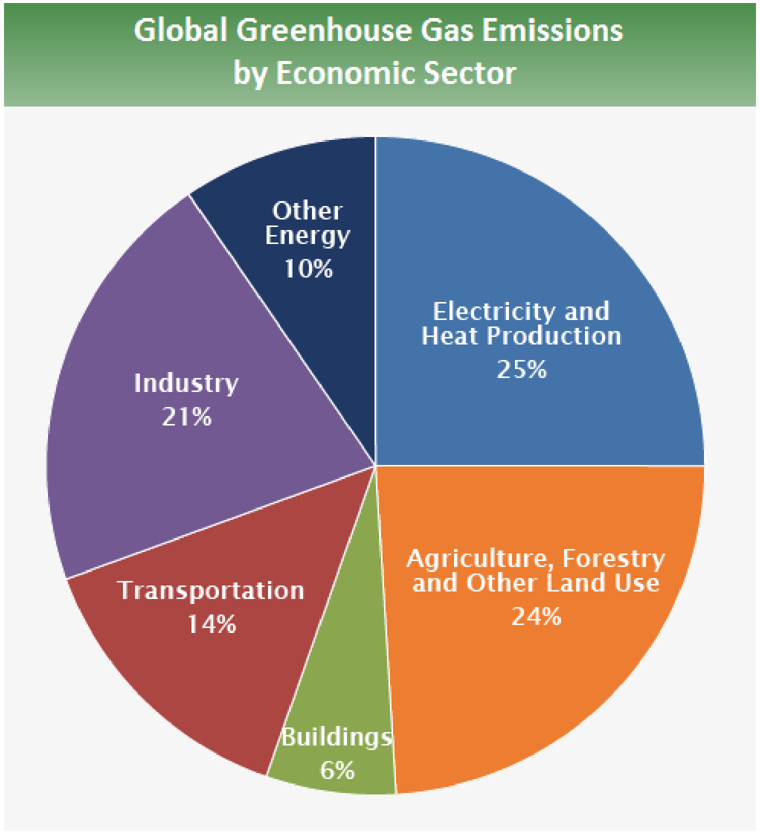
Present and Future Changes in Low-Level Wind Circulation in Mexico

Oscar M. García Santiago and Tereza Cavazos

Department of Physical Oceanography, CICESE
Baja California, Mexico



The largest global emitter of greenhouse gases is the energy sector (IPCC, 2014)



Increase research and development on renewable energy sources

e.g.

Review of Winds (≤ 100 m) in CORDEX Domains

- **RCMs capture well** the distribution of winds patterns **above 10 m** in Europe (e.g., Pryor et al., 2012; RCA3).

- **Higher resol. (< 20 km)** not always improve the skill at 10 m, but it is important for intense winds (e.g., 10 km REMO, Kunz et al., 2010).

- Over Europe (e.g., Frei et al., 2006; Hirschi et al., 2007, Pryor et al., 2005) and CORDEX-NA (Rasmussen et al., 2011) **RCMs are sensitive to GCM forcings**; important to compare several forcings GCMs and RCMs.

- **At 10 m, RCM winds tend to disagree** due to land cover, topography, forcing GCMs and parameterizations (e.g., Moemken et al., 2018; RCA4 in Euro Cordex). They used bias correction

To obtain "more accurate" **wind energy from RCMs → NO!!**

Wind Review in CORDEX Domains

Several studies have used wind simulations from RCMs (0.44 and 0.[illegible]º grid spacing) **to estimate present and future mean local w[illegible]gy or power energy output** in Europe (e.g., Pryor et al., 20[illegible]eg[illegible]t al., 2013; Moemken et al., 2018):

RCM output for hourly 10-m wind speed forms the basis of the present analysis. The high spatial and temporal resolution of the wind data allows avoidance of any considerations regarding data distribution. Following Manwell et al. (2009), mean WED $\overline{E}$ is computed from time series of wind velocities U_i in a time span N:

$$\overline{E} = \left(\frac{1}{2}\right)\rho\frac{1}{N}\sum_{i=1}^{N} U_i^3 . \qquad (1)$$

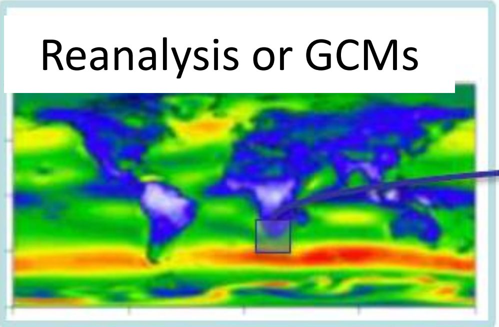
1) There is no energy output below cut-in wind velocity ($3.5\ \mathrm{m\ s^{-1}}$) and above cut-out wind velocity ($25\ \mathrm{m\ s^{-1}}$).
2) Between cut-in wind velocity ($3.5\ \mathrm{m\ s^{-1}}$) and rated wind velocity ($12.5\ \mathrm{m\ s^{-1}}$) the power output is proportional to the wind velocity as

$$E_{\mathrm{out}} = C_p\frac{1}{2}\rho\pi R^2 U^3 , \qquad (3)$$

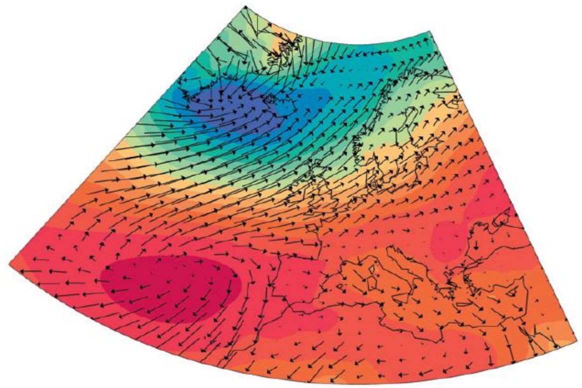
with a constant power coefficient Cp of 0.35 and a rotor radius R of 50 m.

From Hueging et al., (2013)

Dynamical-Statistical Downscaling to Estimate Local Wind Energy



Regional



Winds from RCMs

Microscale Model:

- Convective permitting (1-2 km RCM)
- WAsP or other linear/non linear method.
<u>Local Factors:</u> Orography, roughness, land use and vegetation type and height

Risø DTU
National Laboratory for Sustainable Energy

WAsP: Wind Atlas Analysis and Application
(widely used wind resource tool)

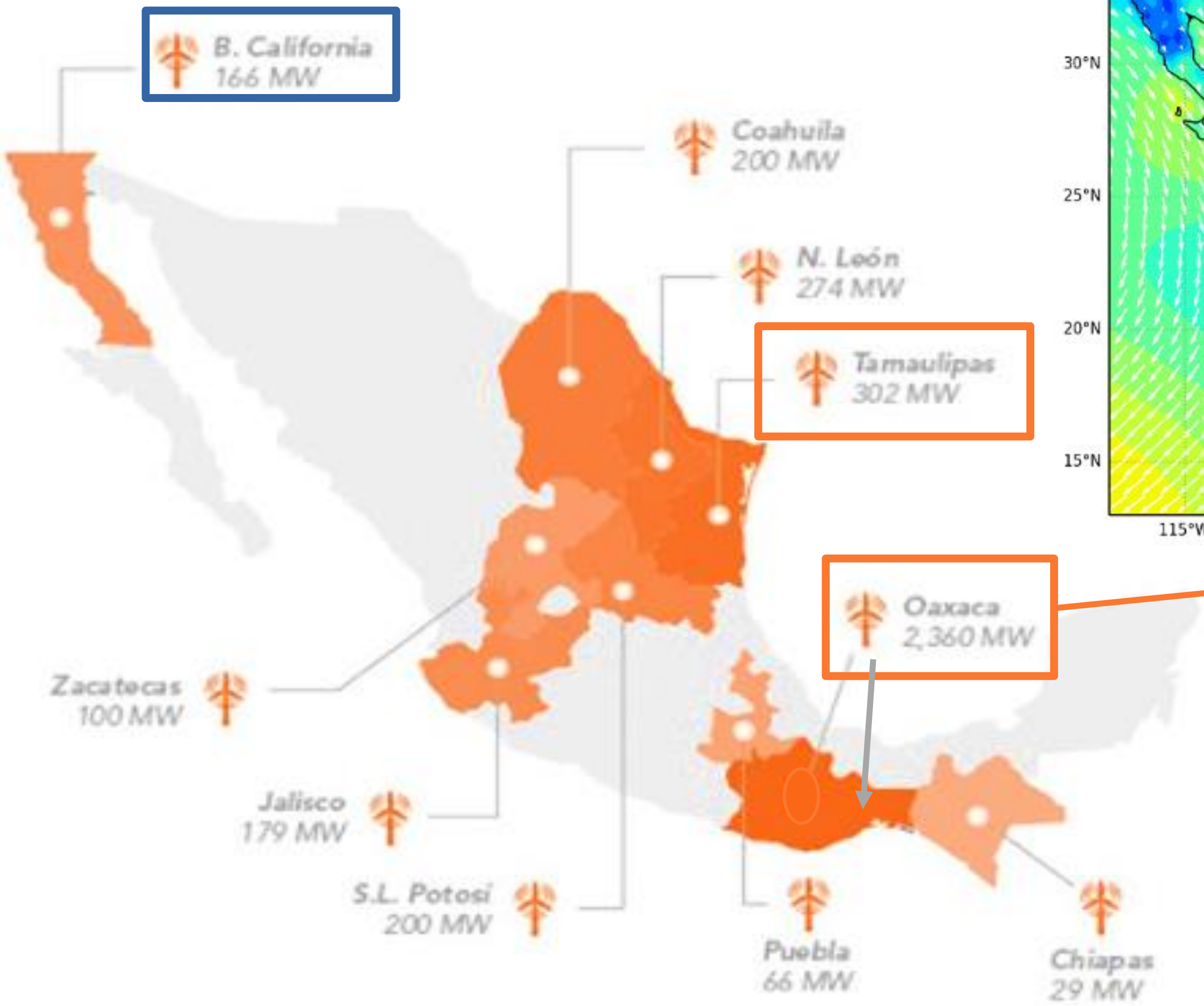
Objective

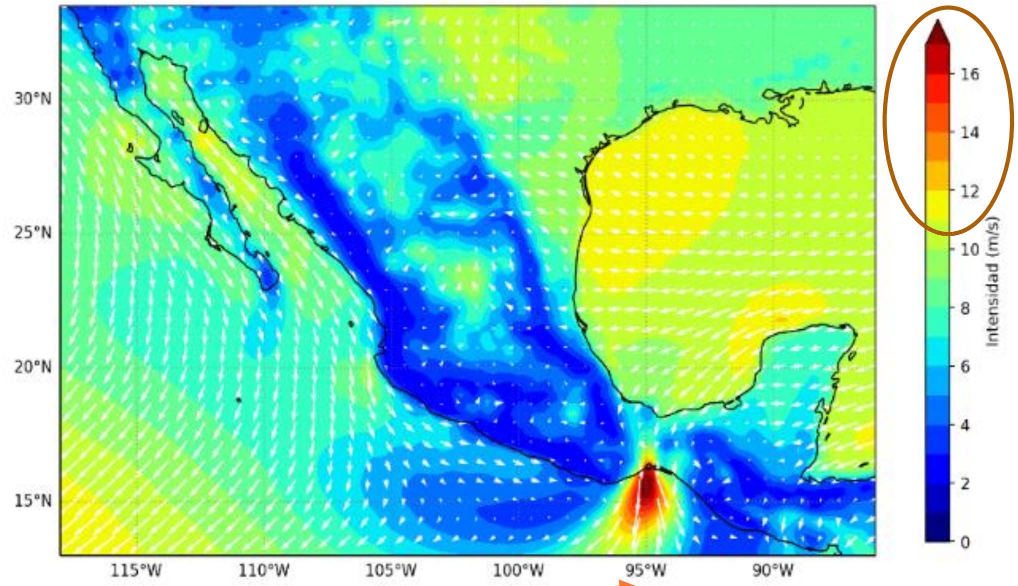
Analyse present and future changes of winds at or below 100 m in Mexico

Specific Objectives

- Characterize the low-level circulation **near seven wind energy sites in Mexico during 2018** (wind towers, reanalyses, and RegCM4.7)
- Evaluate the wind climatologies of **RegCM4.7 for a reference period (1980-2010)**
- Determine the possible changes of the wind circulation in the near future **(2021-2040) under the RCP8.5 scenario**

Relatively New Wind Farms in Mexico





Winter
Strong Tehuano Gap Winds
Oaxaca → 2.36 GW

Tehuano low-level winds

2014

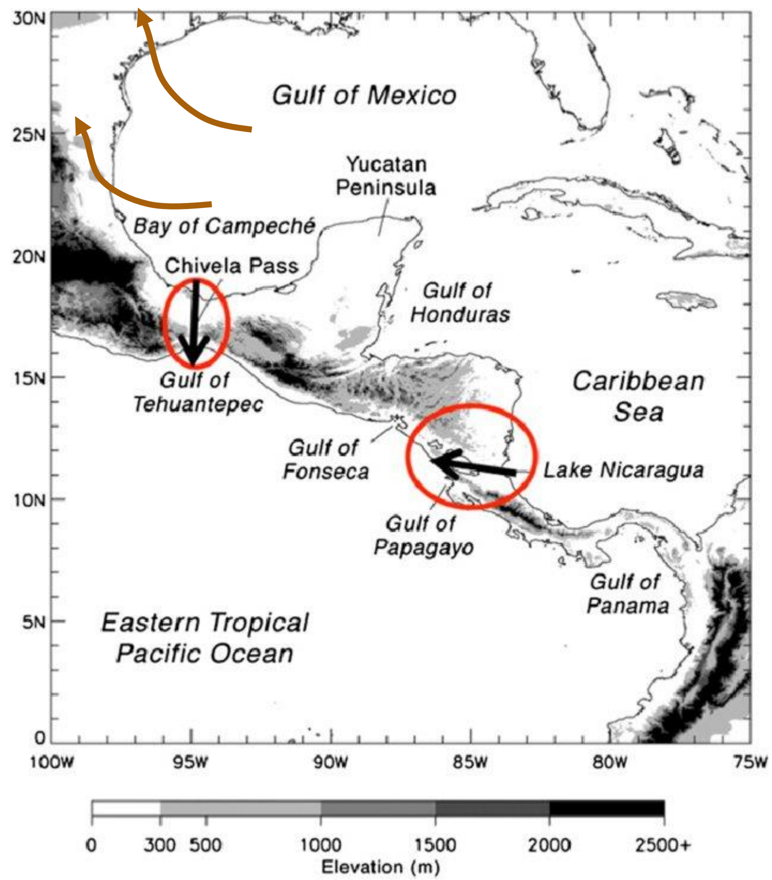
1312 MONTHLY WEATHER REVIEW VOLUME 142

The Effects of Gap-Wind-Induced Vorticity, the Monsoon Trough, and the ITCZ on East Pacific Tropical Cyclogenesis

HEATHER M. HOLBACH AND MARK A. BOURASSA

TABLE 1. Wind speed threshold values of weak, moderate, strong, and very strong gap wind events for the Gulf of Papagayo and Gulf of Tehuantepec.

Gap wind strength	Gulf of Papagayo	Gulf of Tehuantepec
Weak	$4.5 \leq U < 7.9\,\mathrm{m\,s^{-1}}$	$4.6 \leq U < 9.7\,\mathrm{m\,s^{-1}}$
Moderate	$7.9 \leq U < 8.9\,\mathrm{m\,s^{-1}}$	$9.7 \leq U < 11.7\,\mathrm{m\,s^{-1}}$
Strong	$8.9 \leq U < 10.1\,\mathrm{m\,s^{-1}}$	$11.7 \leq U < 14.1\,\mathrm{m\,s^{-1}}$
Very strong	$U \geq 10.1\,\mathrm{m\,s^{-1}}$	$U \geq 14.1\,\mathrm{m\,s^{-1}}$



← **QuikScat sfc winds 1999-2009**

Wind classification by Elliott and Schwartz (1993)

3016 M. Li, X. Li / Energy Conversion and Management 46 (2005) 3014–3033

Table 1
Commercially international system of classification for wind by Elliott and Schwartz [4] from the Pacific Northwest Laboratory (PNL)

Wind power class	10 m Wind power density (W/m^2)	10 m Speed (m/s)	30 m Wind power density (W/m^2)	30 m Speed (m/s)	50 m Wind power density (W/m^2)	50 m Speed (m/s)
1	$\leqslant 100$	$\leqslant 4.4$	$\leqslant 160$	$\leqslant 5.1$	$\leqslant 200$	$\leqslant 5.6$
2	$\leqslant 150$	$\leqslant 5.1$	$\leqslant 240$	$\leqslant 5.9$	$\leqslant 300$	$\leqslant 6.4$
3	$\leqslant 200$	$\leqslant 5.6$	$\leqslant 320$	$\leqslant 6.5$	$\leqslant 400$	$\leqslant 7.0$
4	$\leqslant 250$	$\leqslant 6.0$	$\leqslant 400$	$\leqslant 7.0$	$\leqslant 500$	$\leqslant 7.5$
5	$\leqslant 300$	$\leqslant 6.4$	$\leqslant 480$	$\leqslant 7.4$	$\leqslant 600$	$\leqslant 8.0$
6	$\leqslant 400$	$\leqslant 7.0$	$\leqslant 640$	$\leqslant 8.2$	$\leqslant 800$	$\leqslant 8.8$
7	$\leqslant 1000$	$\leqslant 9.4$	$\leqslant 1600$	$\leqslant 11.0$	$\leqslant 2000$	$\leqslant 11.9$

It is popularly accepted that Class 4 and above are suitable for large-scale electricity generation with modern wind turbine technology.

Data

1. Hourly winds for 2018:

80 m winds from seven wind towers in Mexico

2. Reanalyses (1980-2018) for 50 and 80 m winds:

Dataset	Spatial Grid	Temp Res (hr)
ERA5 (Copernicus Climate Change Service (C3S) (2017))	0.28125° ~ 31 km	1
MERRA-II (Gelaro *et al.*, 2017)	0.5° x 0.65° (lat x lon)	1
ERA-Interim (Dee *et al.*, 2011)	0.75° x 0.75° (~83 km)	3

3. RCMs (2018, 1980-2010, 2021-2040) for 100 m winds:

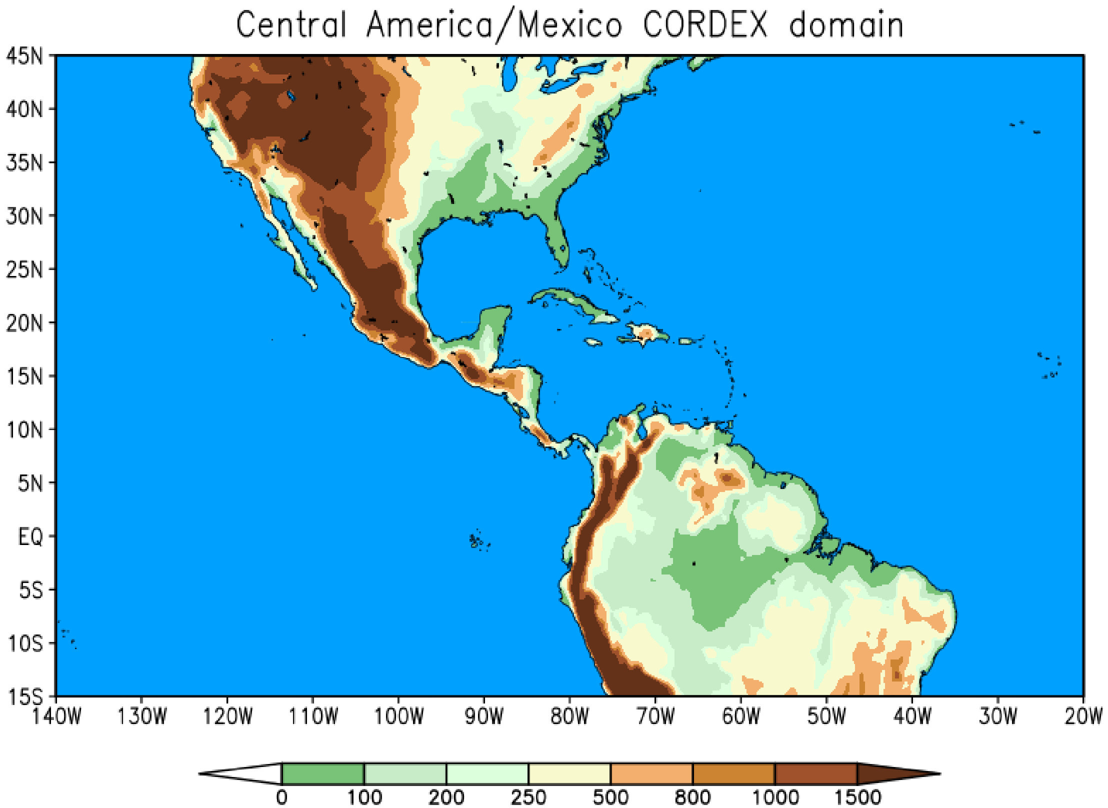
RegCM4.7 (Giorgi *et al.*, 2012)	~ 25 km	3
RCA4 (Samuelsson *et al.*, 2011)	~ 25 km	3

RegCM4.7 simulation for 2018
ICTP configuration

Initial and boundary conditions:
ERA-Int 75 every 6 hours

Domain Specifications

Domain points	576 x 346
Time period	Dec 2017 - Dec 2018
Spin up	Dec 2017
Resolution	25 km
Vertical levels	23

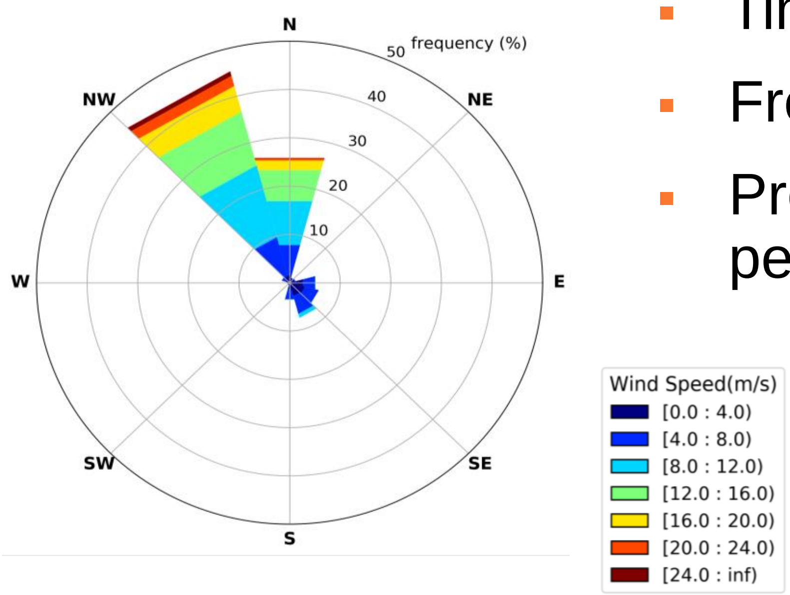


Topography (m) of the CORDEX-CAM domain.

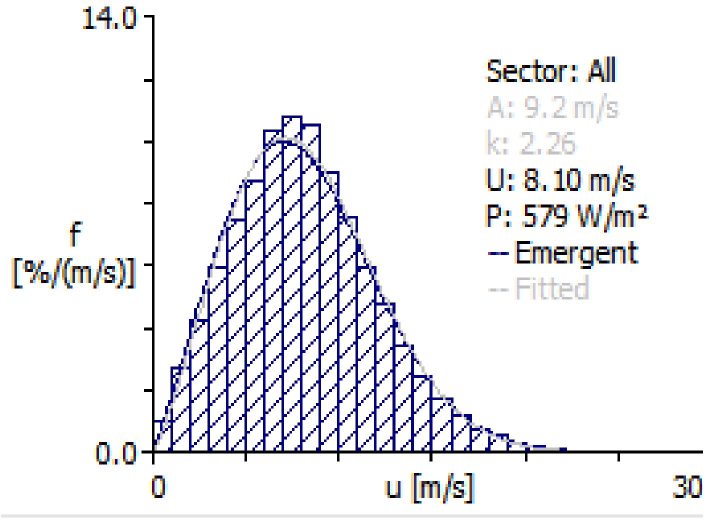
Methodology

Characterization of the wind fields:

- Diurnal and seasonal cyles of wind speed and direction
- Spectral analysis to determine variability at different scales
- Wind clasification using Self Organized Maps (SOMs)



- Wind roses
- Time series
- Frequency distributions
- Probabilities and return periods



Methodology

Metrics for wind evaluation

- Mean absolute error:

$$\text{MAE} = \frac{\boldsymbol{1}}{\boldsymbol{n}}\sum_{\mathbf{i=1}}^{\boldsymbol{n}} |\boldsymbol{WS_{model}} - \boldsymbol{WS_{mast}}|$$

- Root mean squared error:

$$\text{RMSE} = \sqrt{\frac{\sum_{\mathbf{i=1}}^{\boldsymbol{n}} (\boldsymbol{WS_{model}} - \boldsymbol{WS_{mast}})^{\mathbf{2}}}{\boldsymbol{n}}}$$

- Percent hit angle:

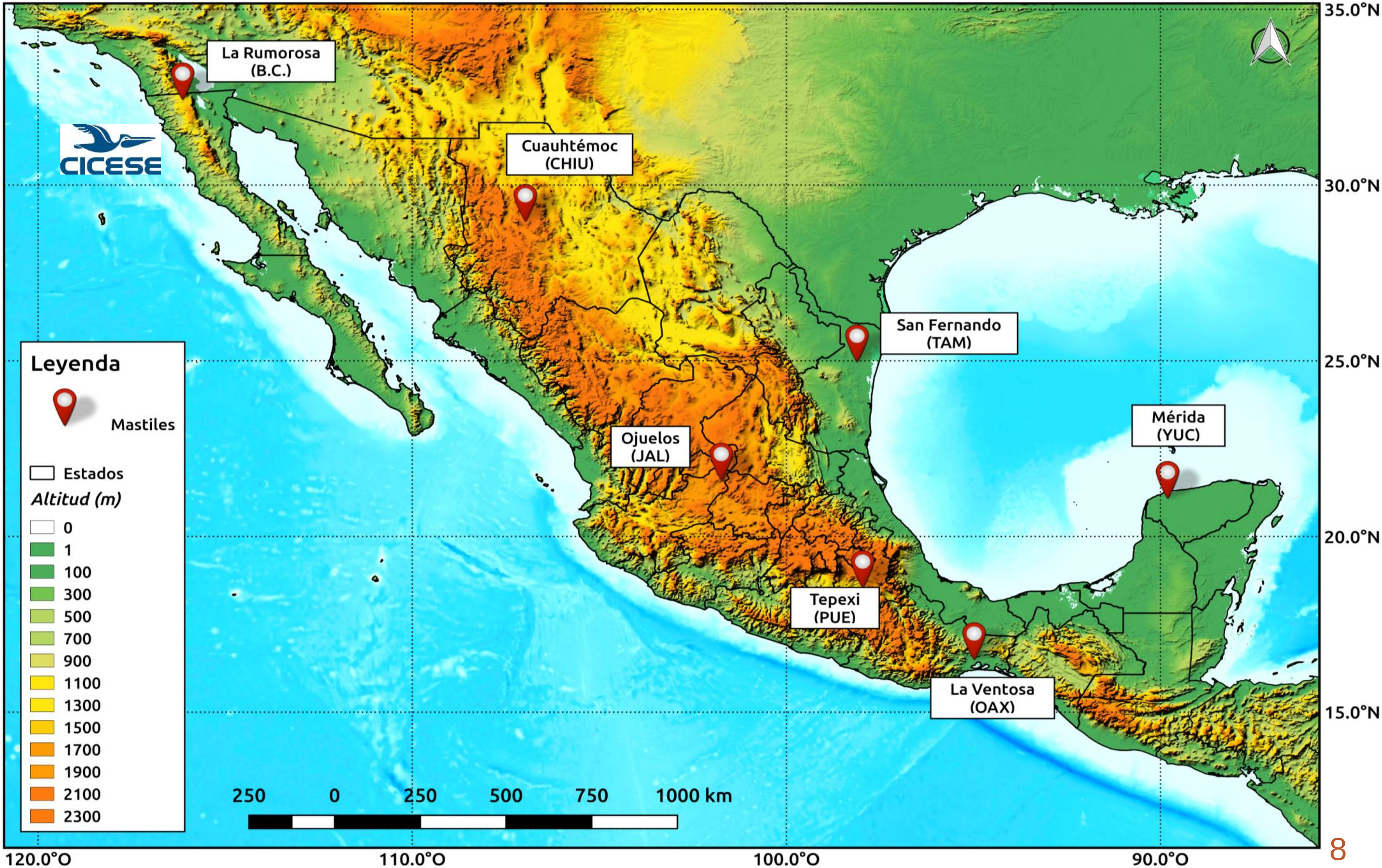
PHA = Percent match of the model wind direction with “observations”

- Circular absolute error (in wind direction):

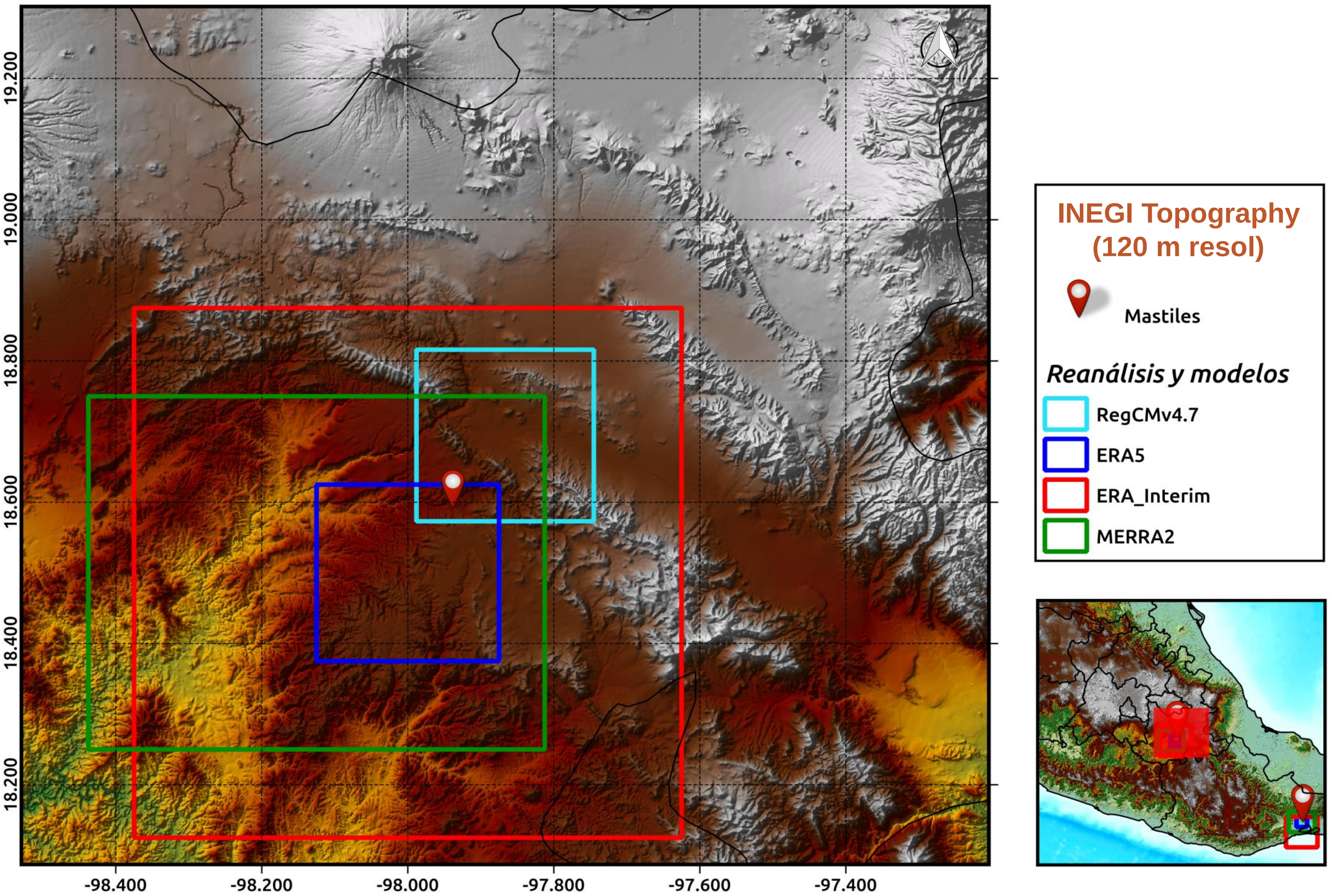
$$\text{CAE} = \frac{\boldsymbol{1}}{\boldsymbol{n}}\sum_{\mathbf{i=1}}^{\boldsymbol{n}} \boldsymbol{min}\,(|\boldsymbol{WS_{model}} - \boldsymbol{WS_{mast}}|, \mathbf{360} - |\boldsymbol{WS_{model}} - \boldsymbol{WS_{mast}}|)$$

Seven Wind Energy Sites in Mexico

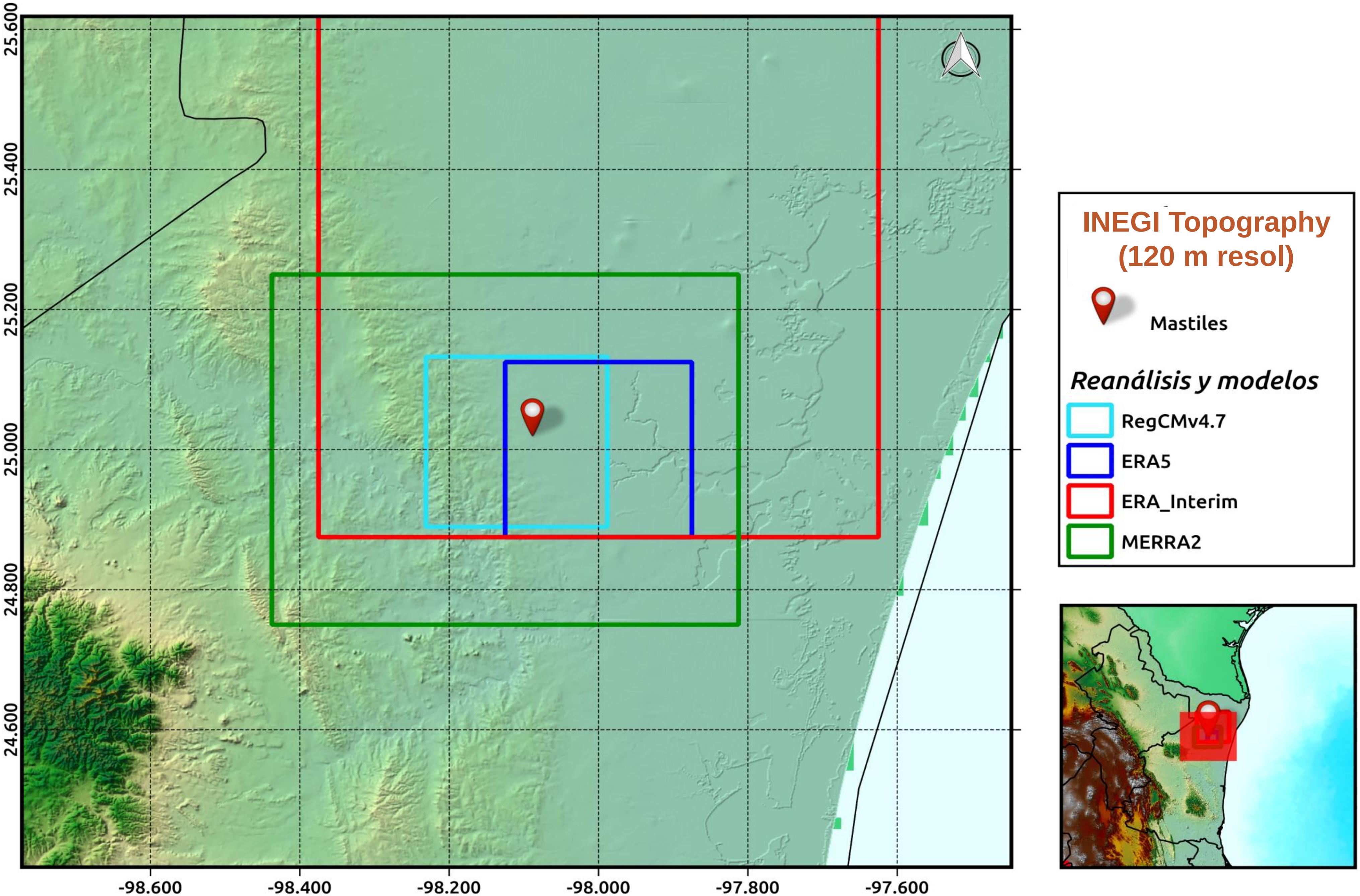
(Hourly wind observations at 80 m height for 2018)



Nearest gripoints of datasets to the wind park in Puebla, Mexico



Nearest gridpoints of datasets to the wind park in Tamaulipas



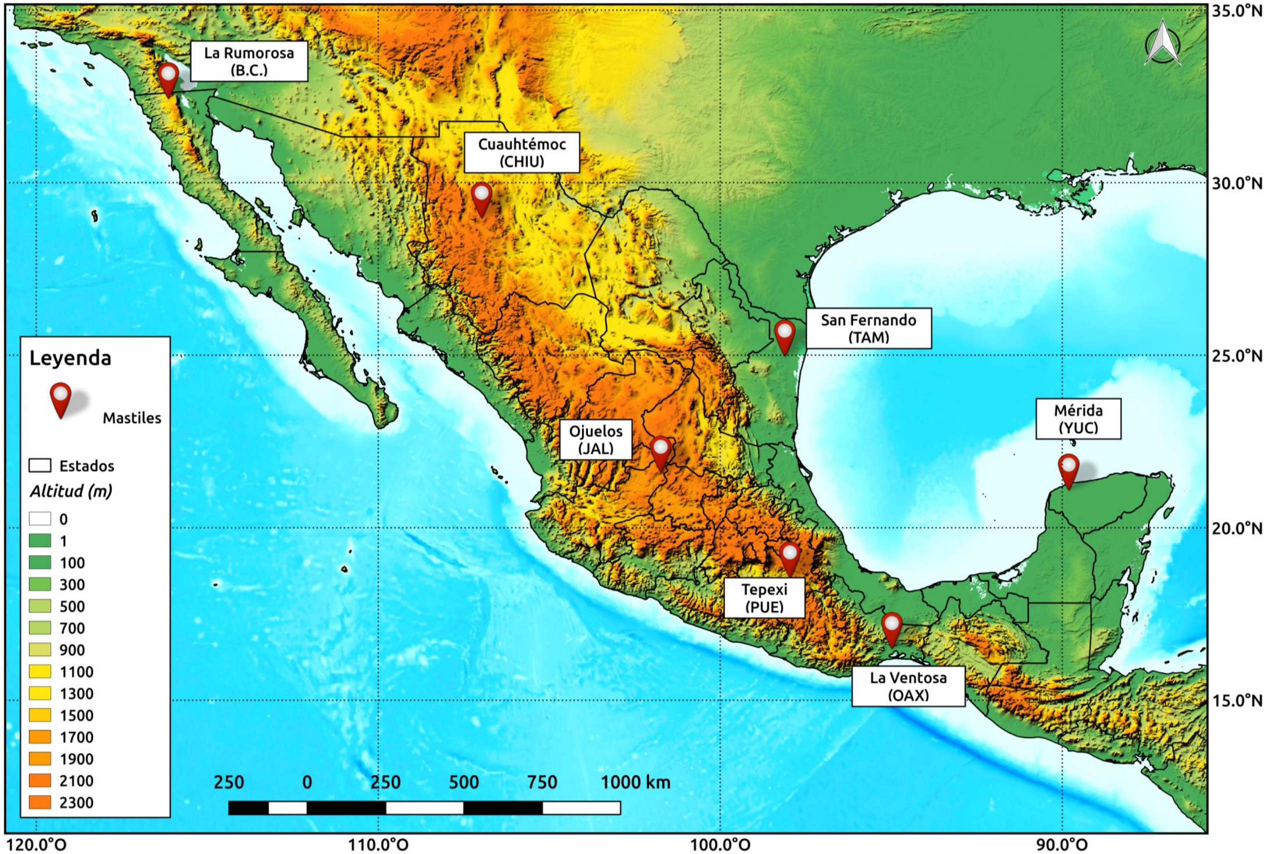
RESULTS

Characterization of winds near the seven sites during 2018

Wind towers at 80 m

Reanalyses at 50-80 m

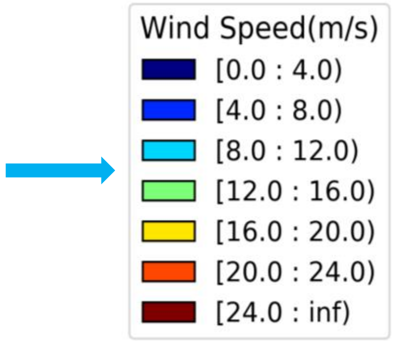
RegCM4.7 at 80 m



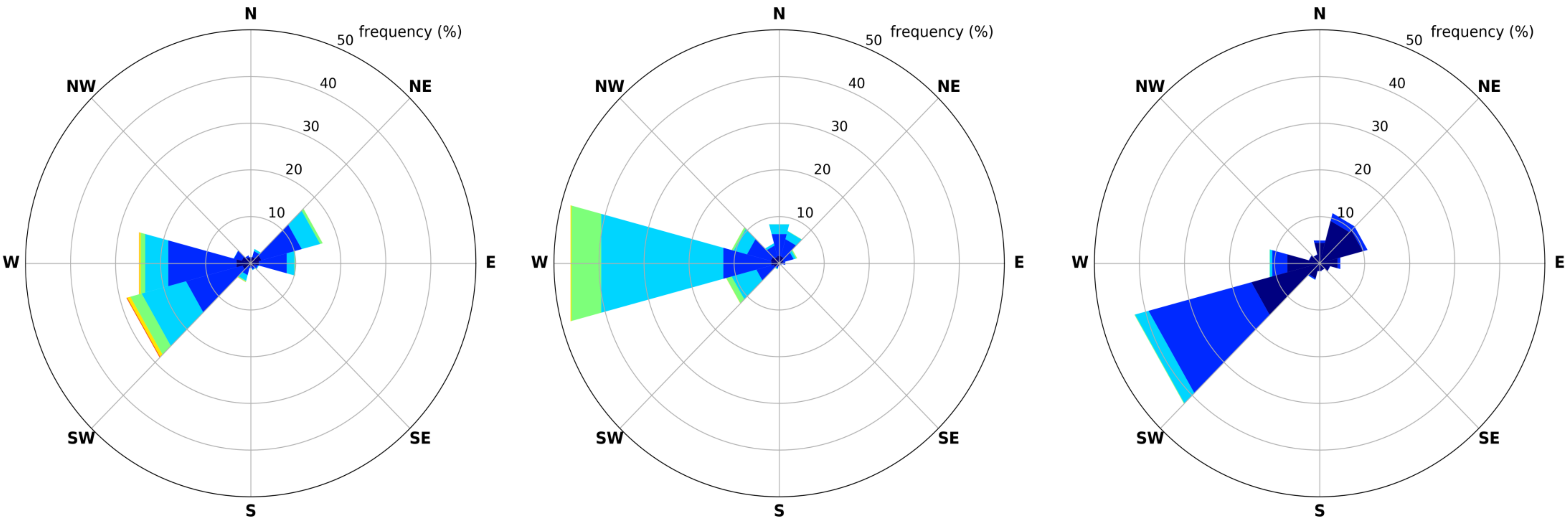
La Rumorosa, B.C.

Wind roses of hourly winds during 2018

Nearest gridpoint to the mast



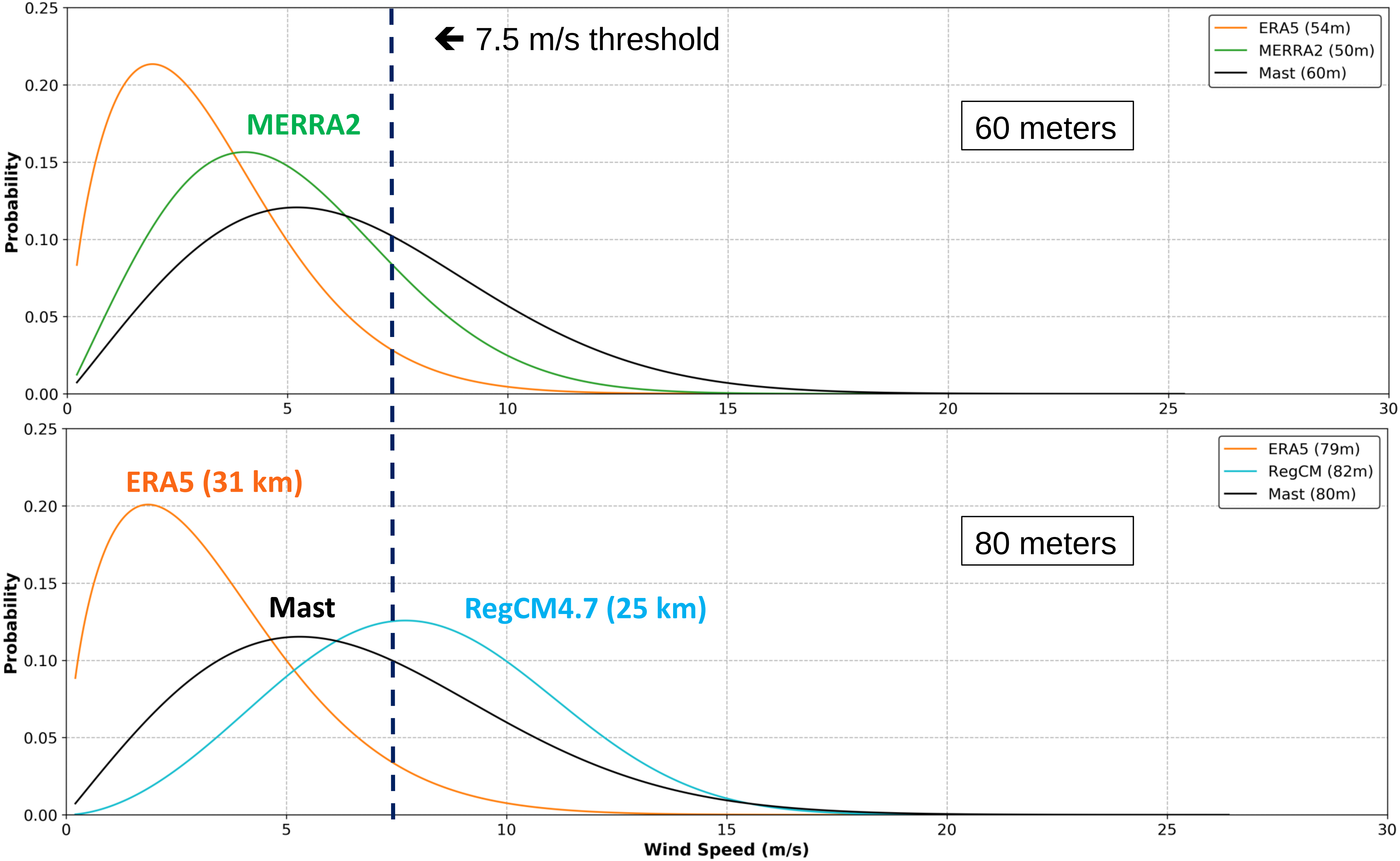
Mast at 80 m | **RegCM4.7 at 80 m** | **ERA5 at 79 m**



SW and Westerly winds

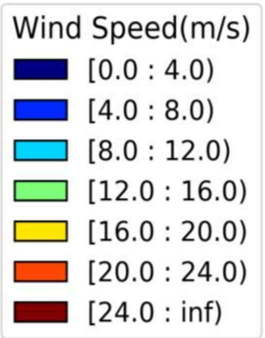
La Rumorosa, B.C.

Probability density functions of hourly winds at 60 and 80 m during 2018

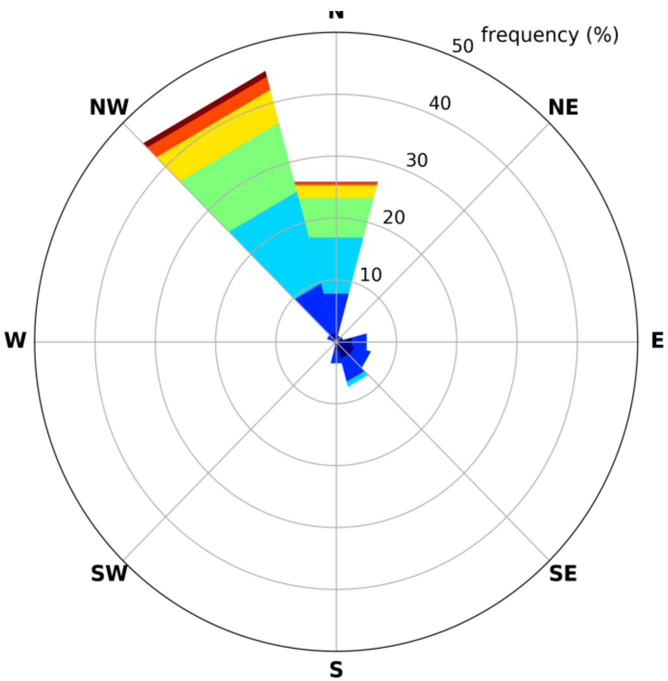


La Ventosa, Oax ➔ Tehuano Gap Winds

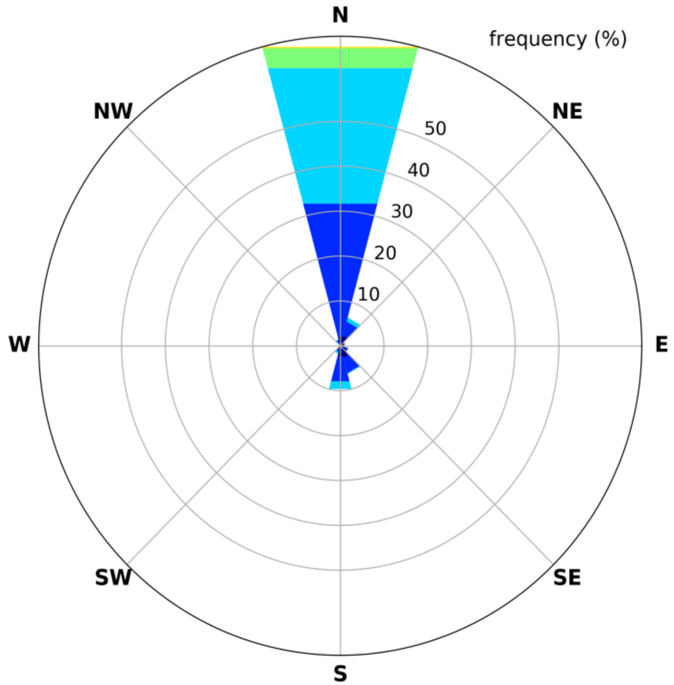
Wind roses of hourly winds during 2018



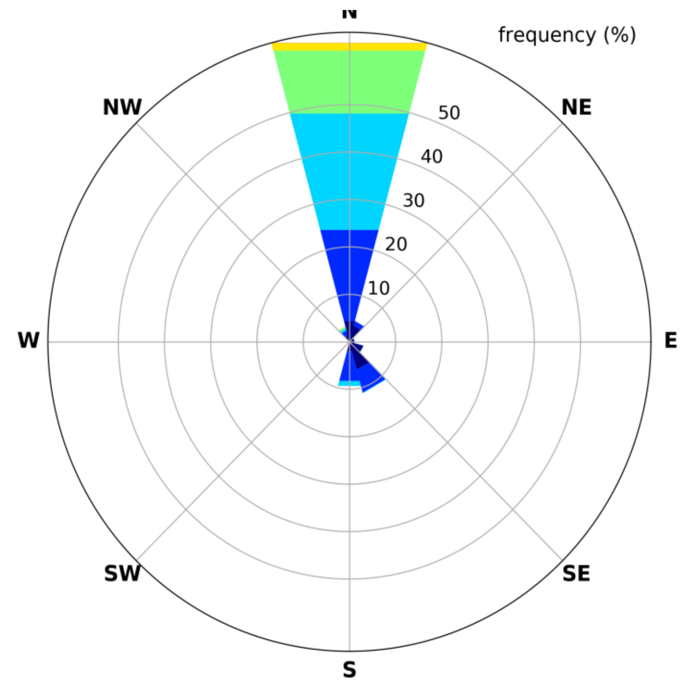
Mast at 80 m



RegCM4.7 at 80 m



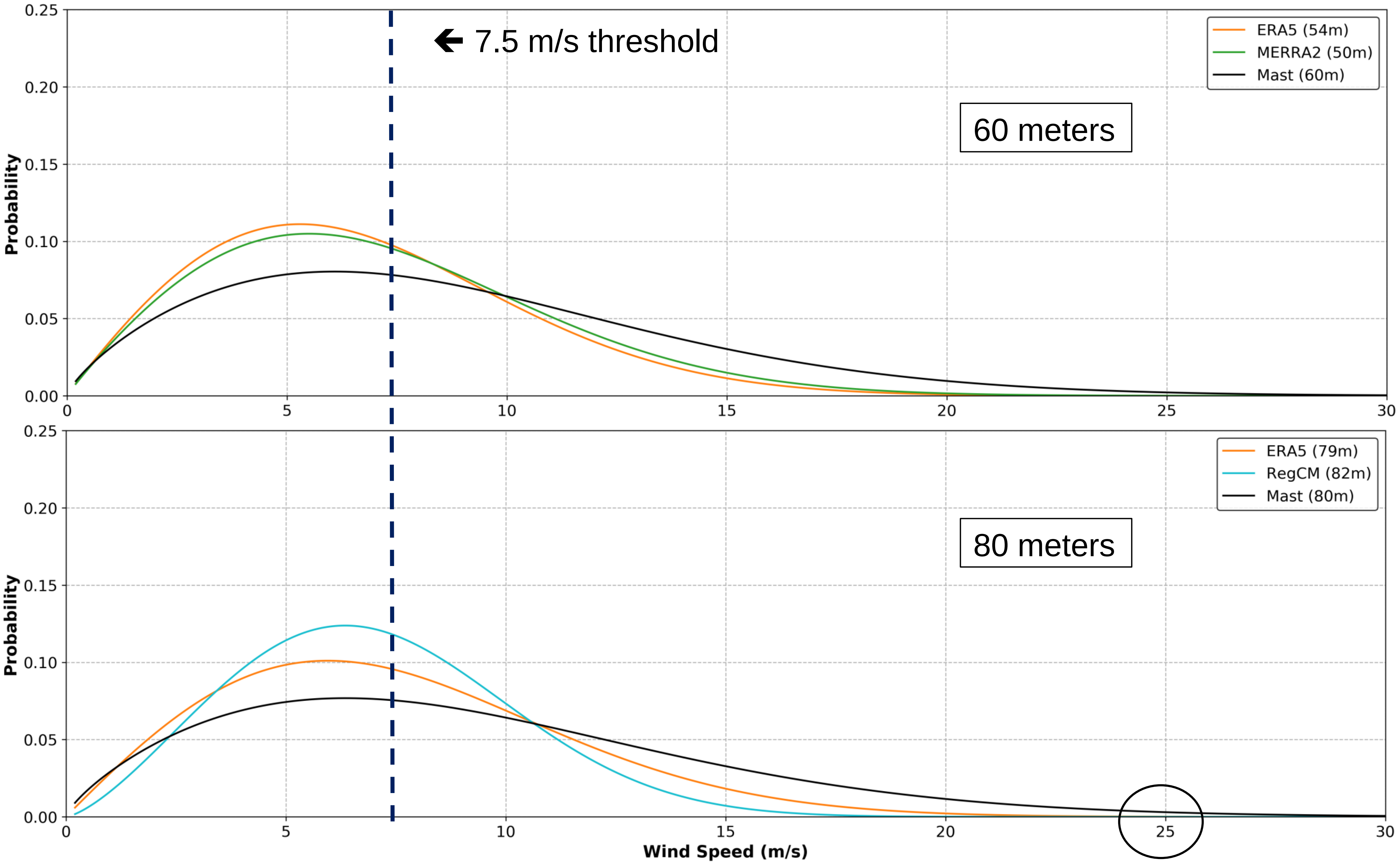
ERA5 at 79 m



NW and Northerly winds

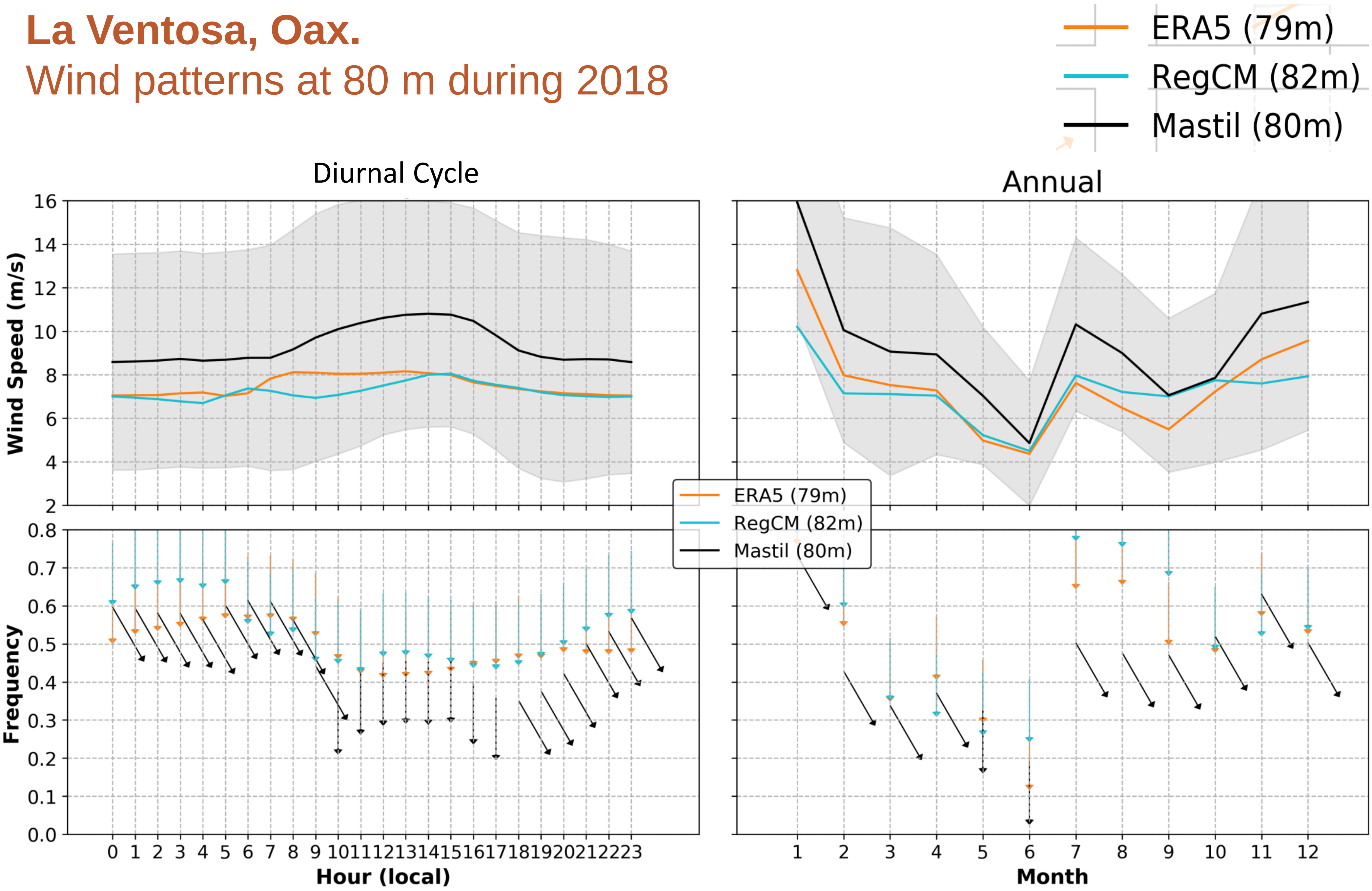
La Ventosa, Oax.

PDFof hourly winds at 60 and 80 m during 2018



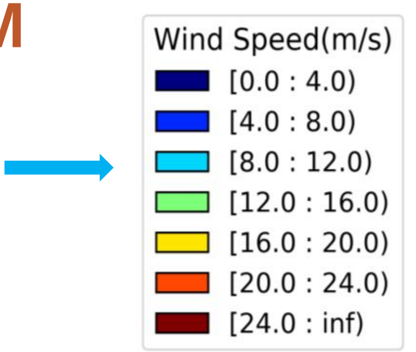
La Ventosa, Oax.

Wind patterns at 80 m during 2018

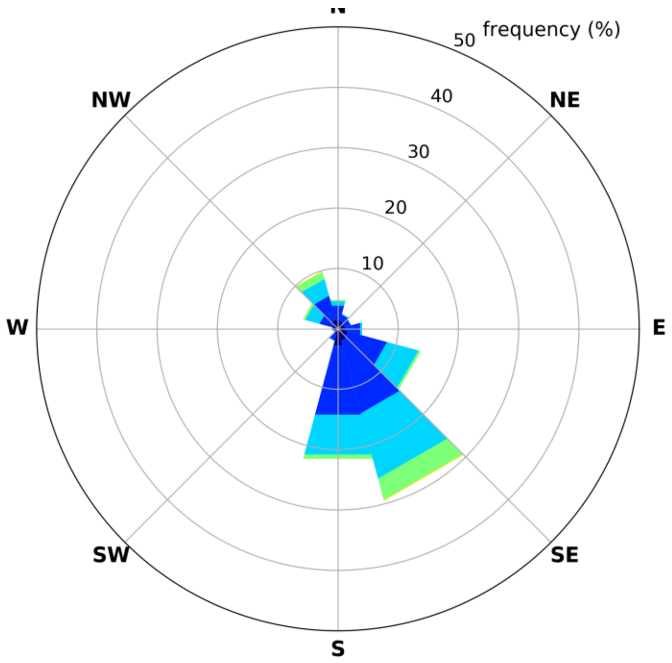


San Fernando, Tam. ➔ Coastal plains of the GoM

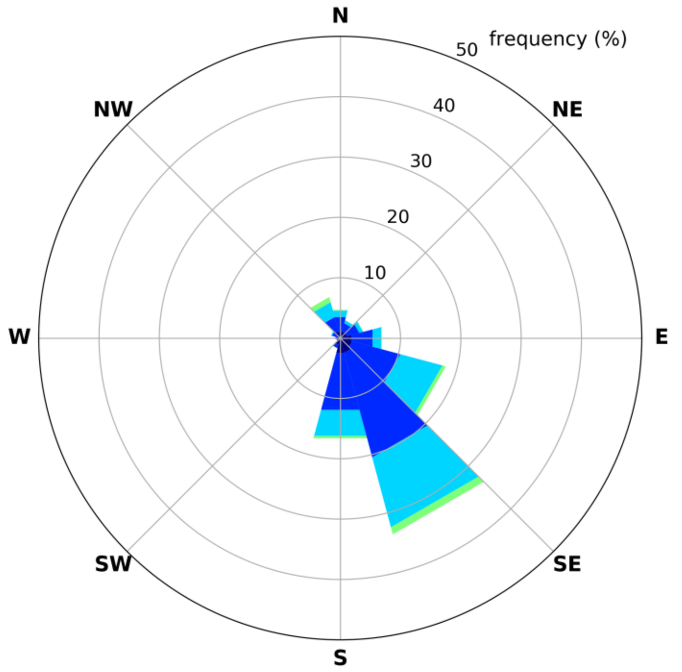
Wind roses of hourly winds during 2018



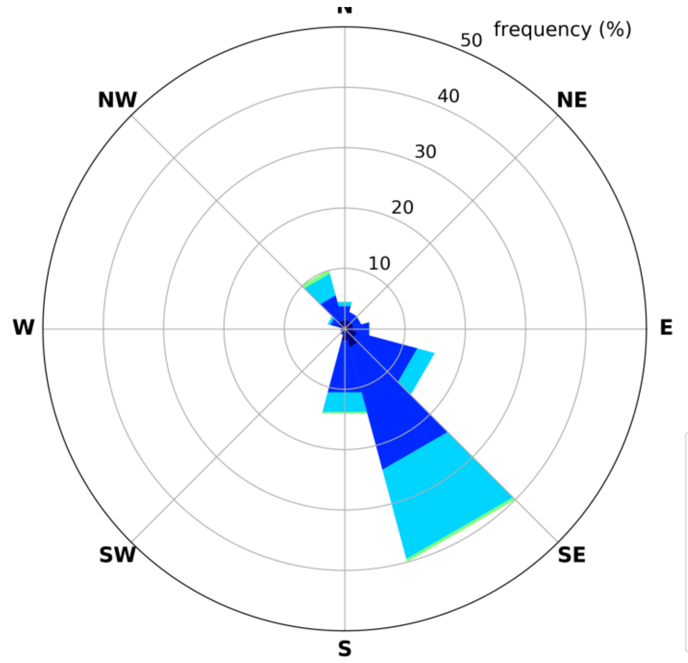
Mast at 80 m



RegCM4.7 at 80 m



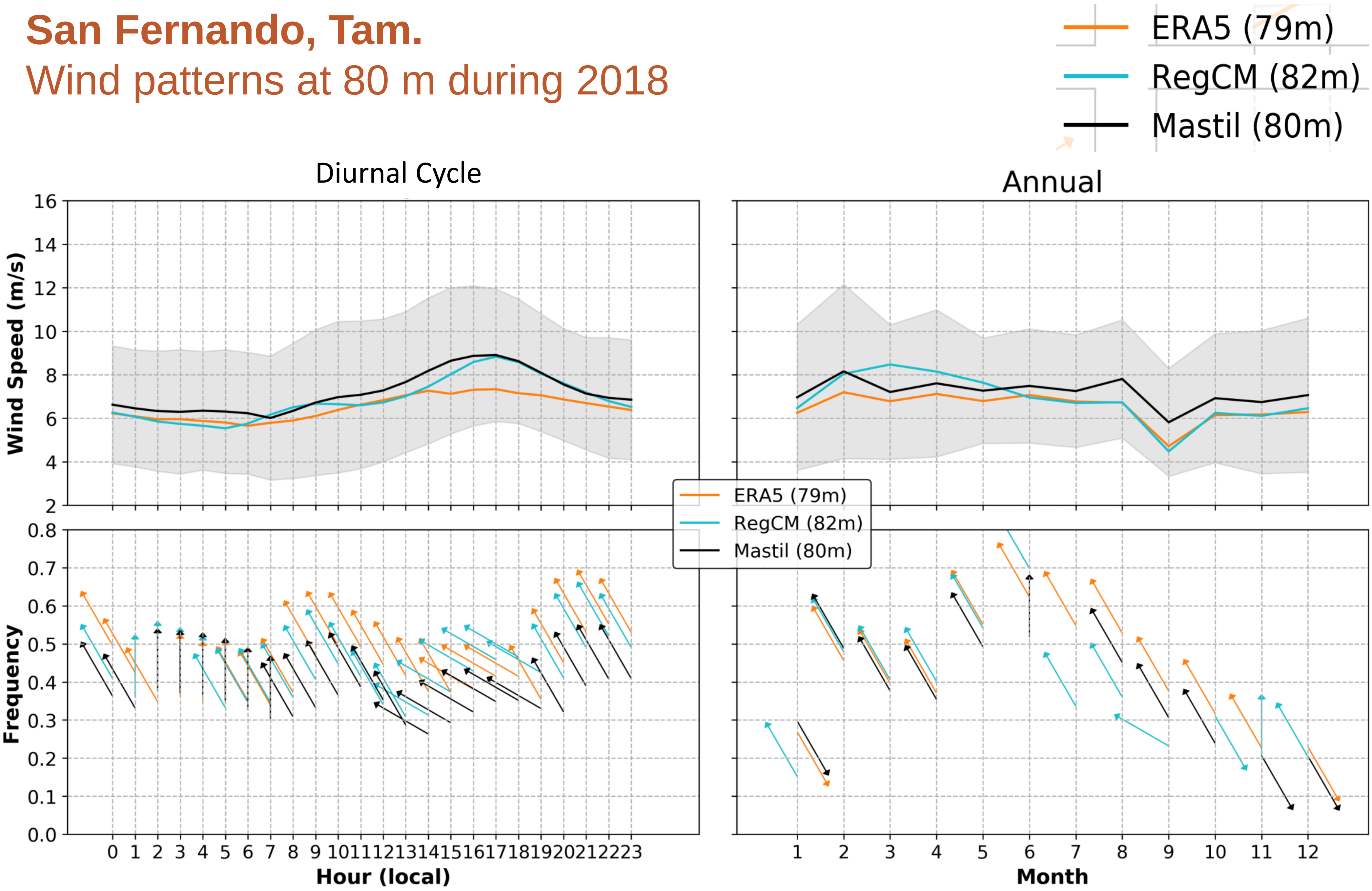
ERA5 at 79 m



SE trade winds

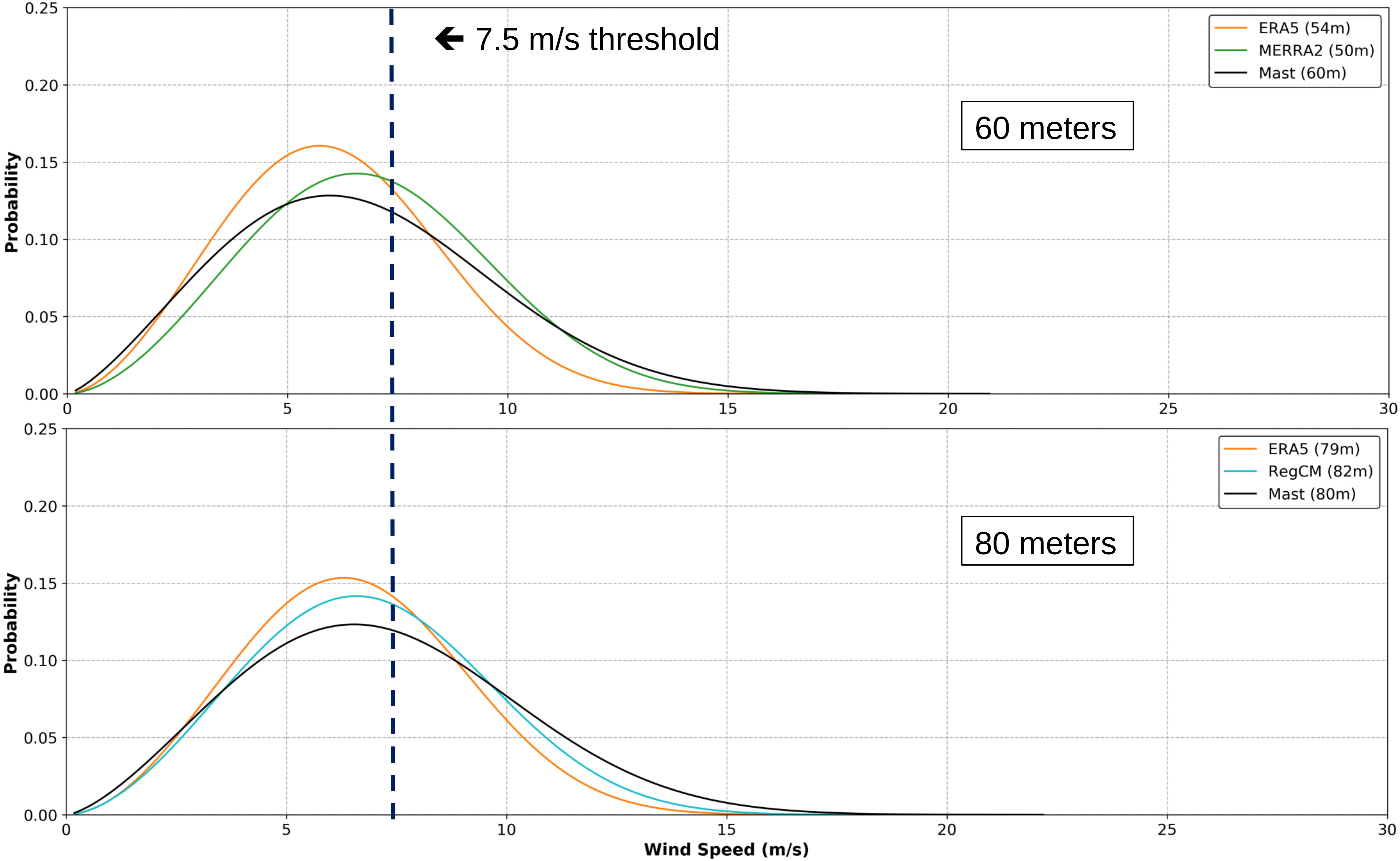
San Fernando, Tam.

Wind patterns at 80 m during 2018

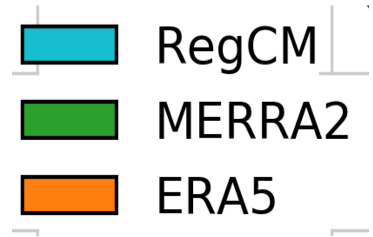


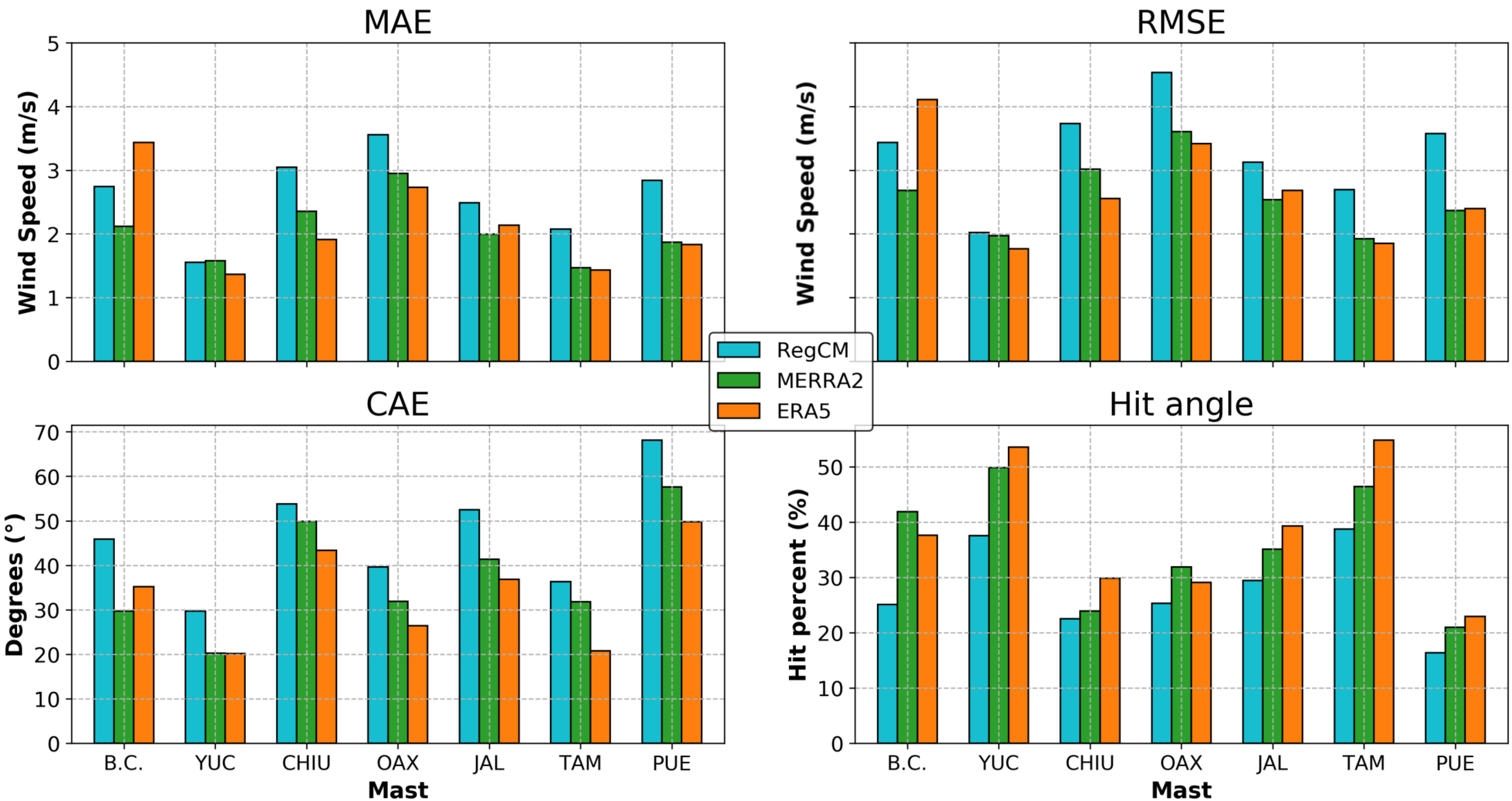
San Fernando, Tam.

PDFs of hourly winds at 60 and 80 m during 2018



Hourly wind evaluation with respect to the observations in the seven sites at 80 m during 2018





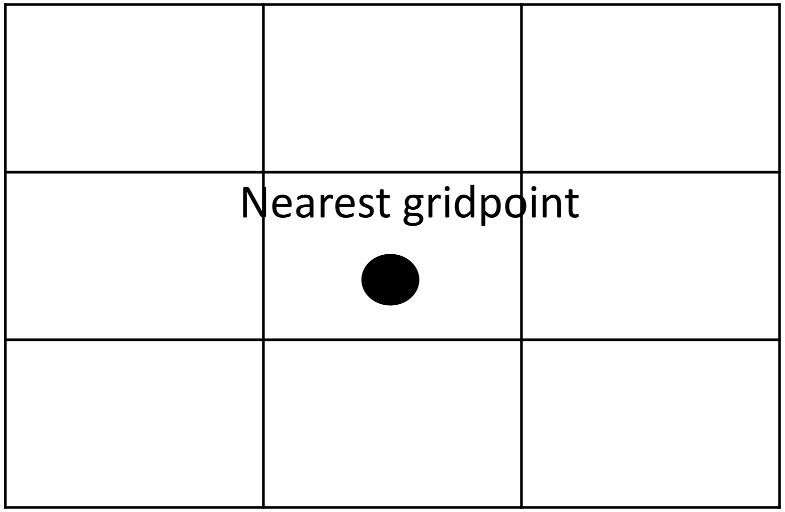
Large differences in wind direction is due to the comparison with a local

Preliminary Conclusions

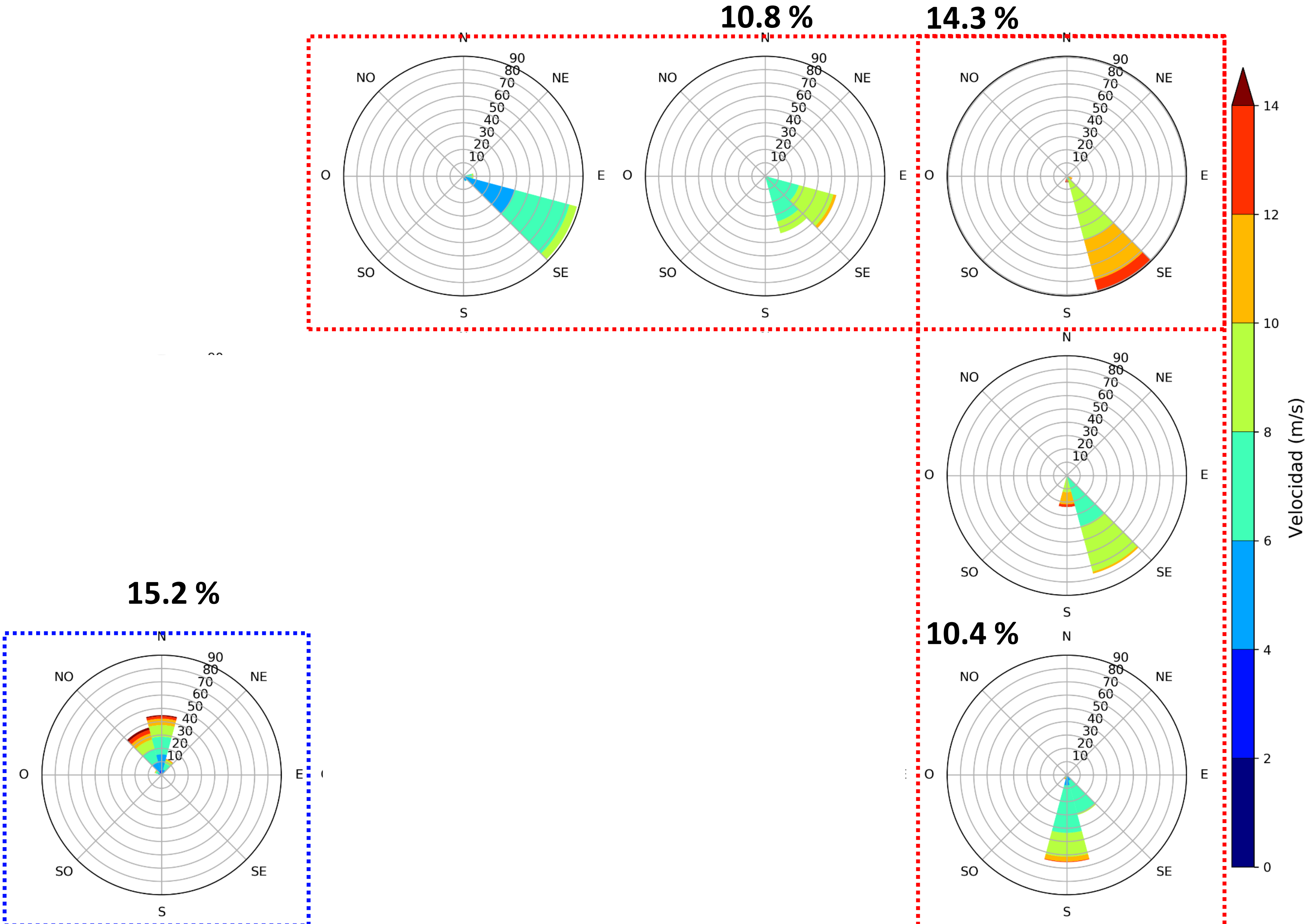
- Overall, RegCM4.7 and the reanalyses reproduce well the wind characteristics at 50-80 m near the seven sites during 2018.
- The reanalyses and RegCM4.7 show small biases in the flat terrain sites (TAM, YUC), but larger wind differences in sites with complex terrain (PUE, CHIU, OAX), as expected.
- RegCM4.7 reproduced relatively well diurnal and annual cycles in most of the seven sites.
- The errors of the datasets in the sites are partially associated to the grid spacing and local effects.

Part II
Wind Classification Using SOMs
San Fernando, Tam.

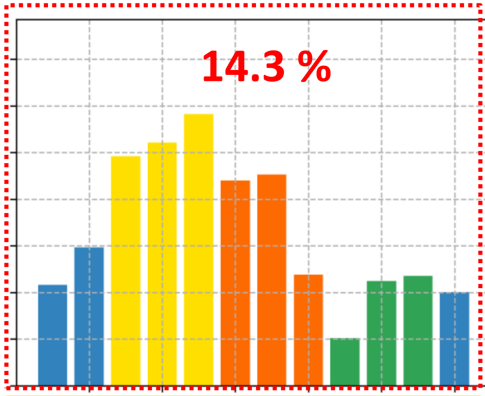
- **Input: Hourly U and V components at 50 m from MERRA2 reanalysis (0.5º x 0.65º)**
- Period of classification: **1981-2010**
- Domain centered at the nearest gridpoint of the wind mast
- Additional wind information from 8 cells surrounding the central gridpoint.
- Different topologies tested (3x3, 3x4, 4x5, 6x6). Optimal representation: **3x4**



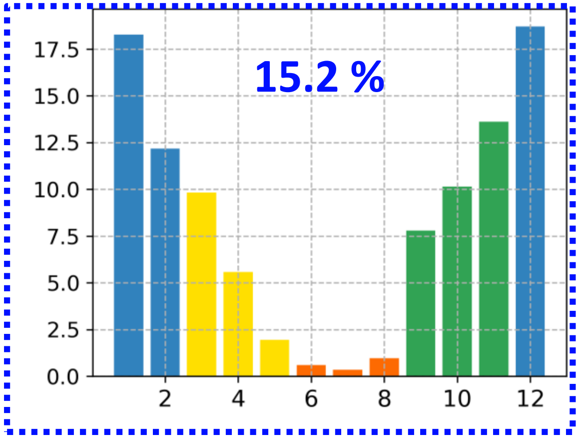
Results – SOMs wind roses near the mast



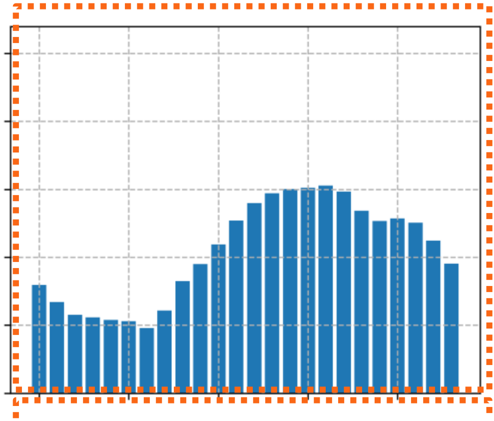
Monthly wind frequency distribution (%)

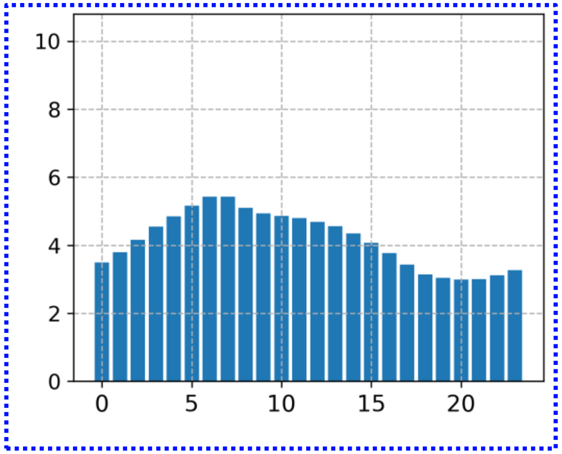


% de datos por nodo



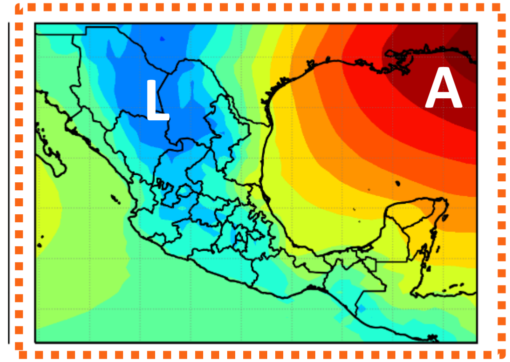
Wind diurnal cycle frequency distribution

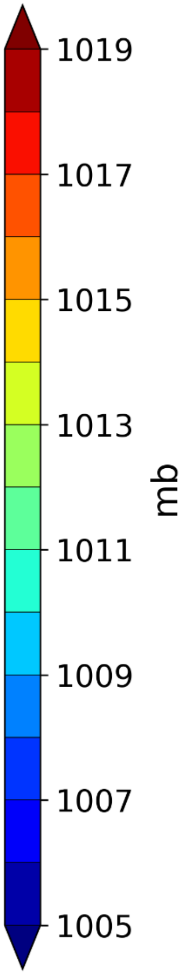




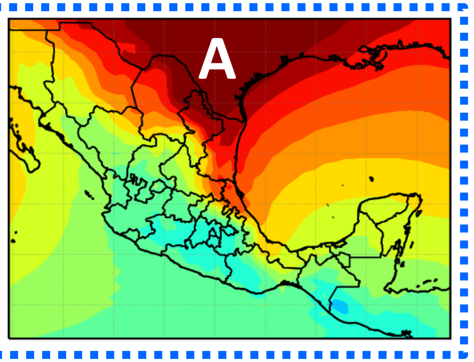
Sea Level Pressure composites

Spring-summer
Stronger easterlies 🡐
Stronger zonal SLP gradient





Winter-autumn
Strong SLP
Passage of CF



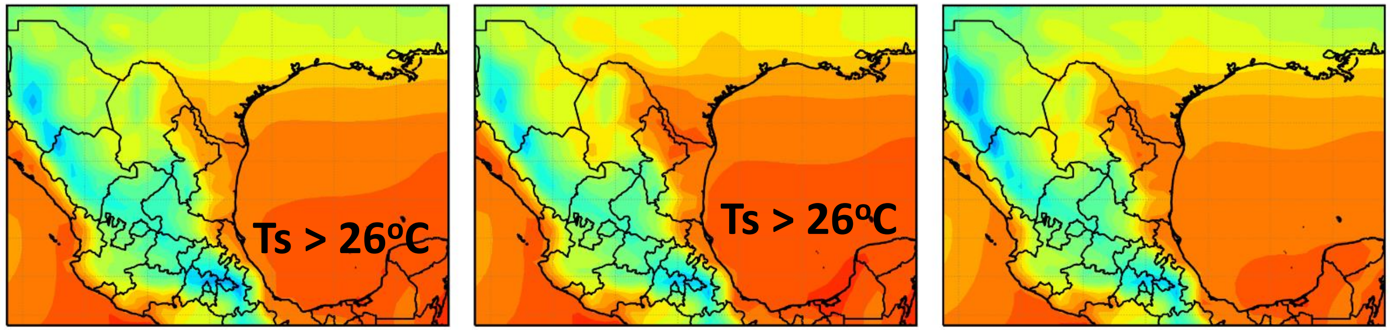
Daily surface temperature composites

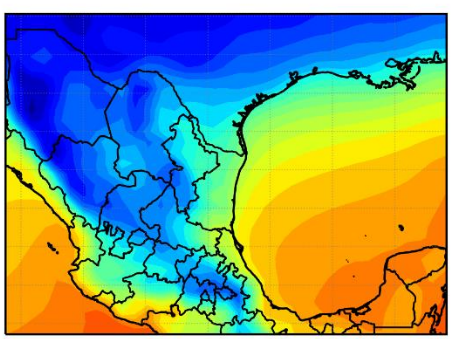
Low Ts during passage of Cold Fronts

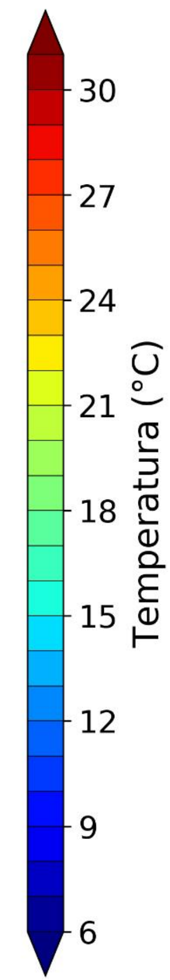
Warmer Ts in GoM weakens easterly winds

Optimal Ts for strong easterly winds

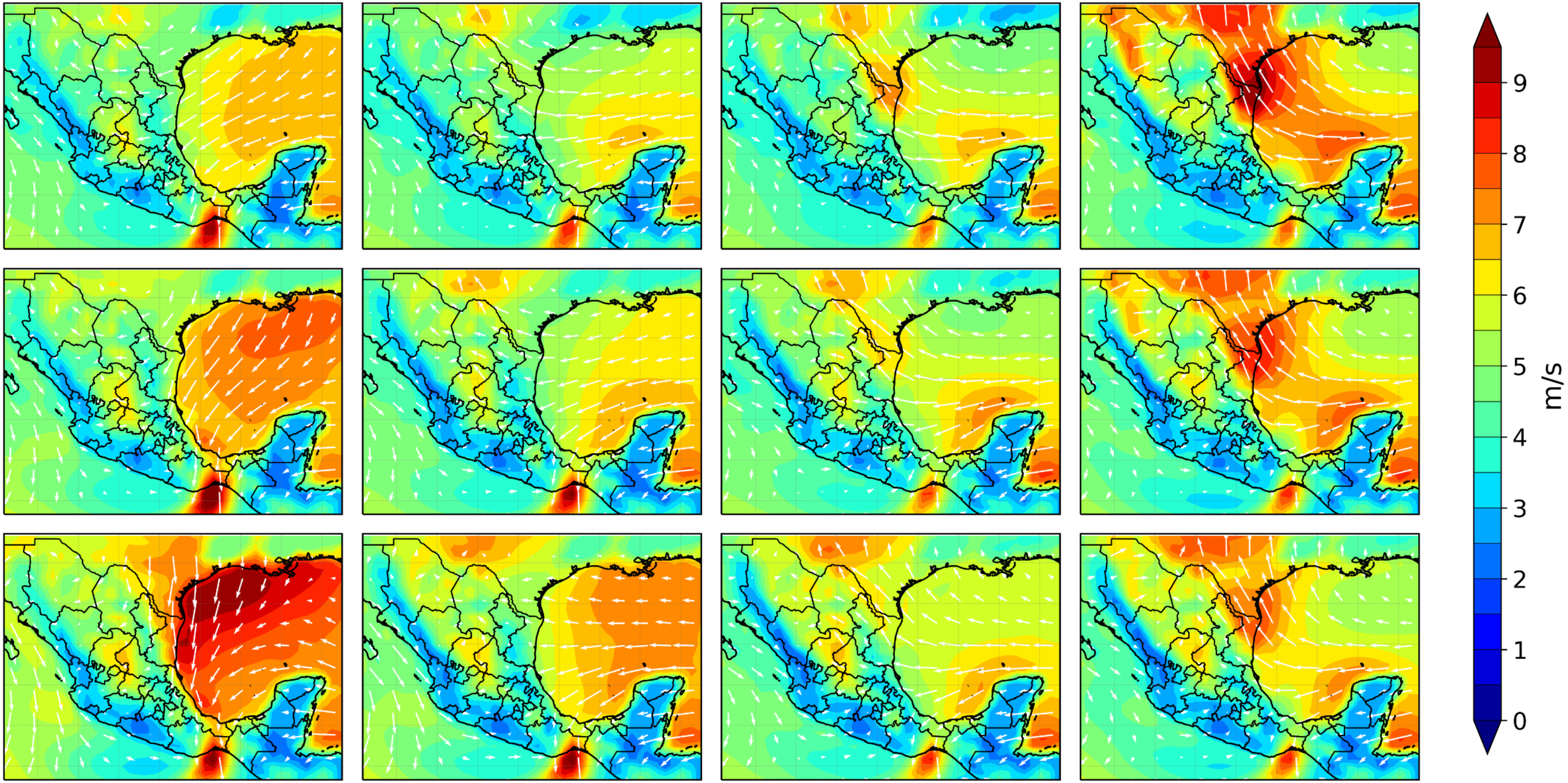
Ts < 25ºC





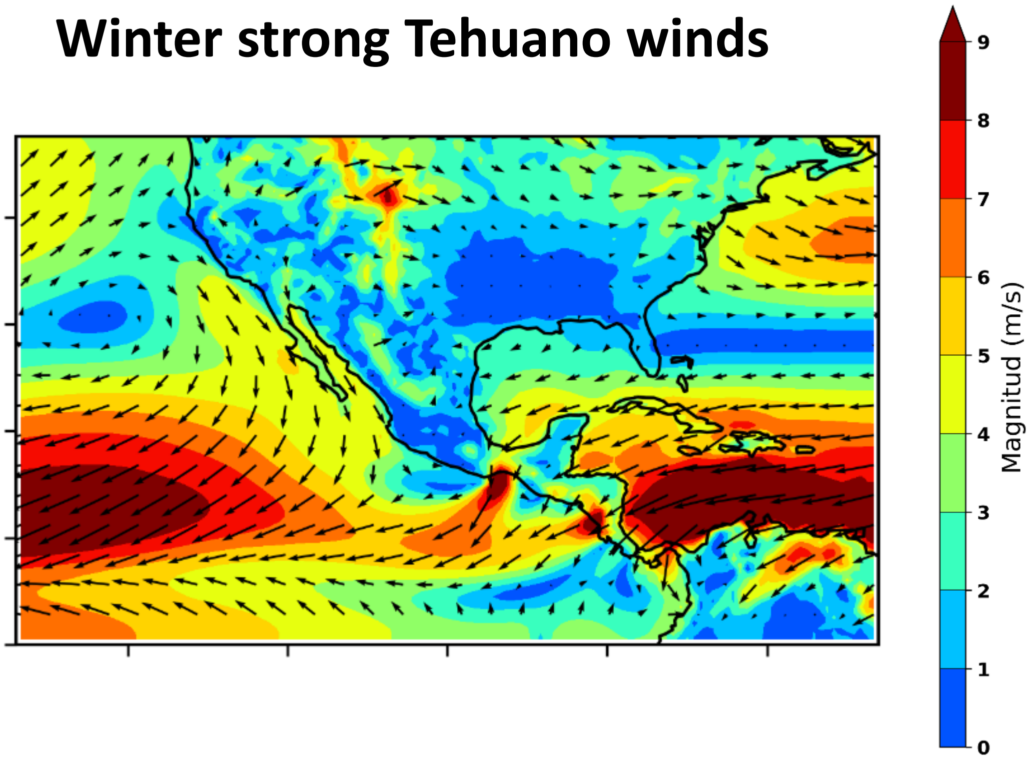


Hourly 50 m wind composites



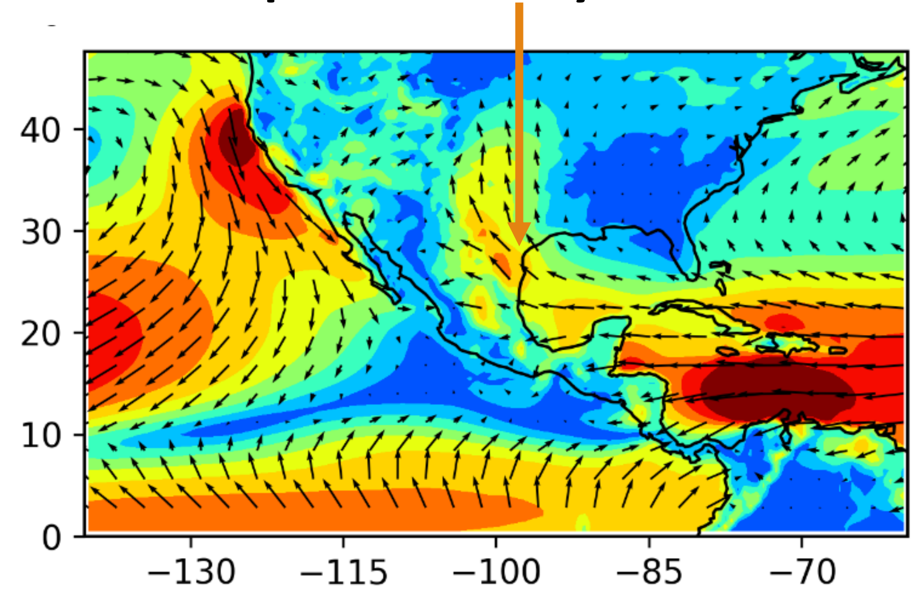
Wind vector composites at 50 m for two nodes

Winter strong Tehuano winds



- **Strong anticyclone**
- **Passage of cold fronts**
- **Strong Norte events**
- **Strong CLLJ**

Spring-summer: strong and most frequent easterly winds



- **Strong zonal SLP gradient**
- **Strong CLLJ**

Conclusions SOMs: winds in the GoM

- The SOMs were able to identify the two types of most frequent and intese winds in Eastern Mexico:
  - **Northerly winds** associated with the passage of cold fronts, which are most common during winter and autumn. ➔ **Strong Tehuano** winds
  - **Easterly winds** produced by a strong pressure gradient linked to the **North Atlantic Subtropical High and temperature surface gradients** between the GoM and the continent. The most intense easterly winds are most common during spring and summer.
- During the summer months, winds from the south are most common in the early hours of the day, while south-easterly winds in the later hours.

- **Tehuano winds** are very persistent all year

Next step: Present and future RegCM 4.7 analysis

tcavazos@cice.mx
omgarcia@cicese.mx