FRANCE ENERGIES MARINES

2C NOW webinar

Impacts of Climate Change on Wind resource and Wind Energy Production

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Impacts of Climate Change on Wind resource and Wind Energy Production

OBJECTIVES

- Assessment of the quality of **reanalyses** on French seafronts in comparison to measurements and selection of the best reanalysis
- **Statistical downscaling** of wind
- Assessment of the impact of climate change on **wind resource and energy production**

Evaluation of ERA5, COSMO-REA6 and CERRA in simulating wind speed along the French coastline

Measurements

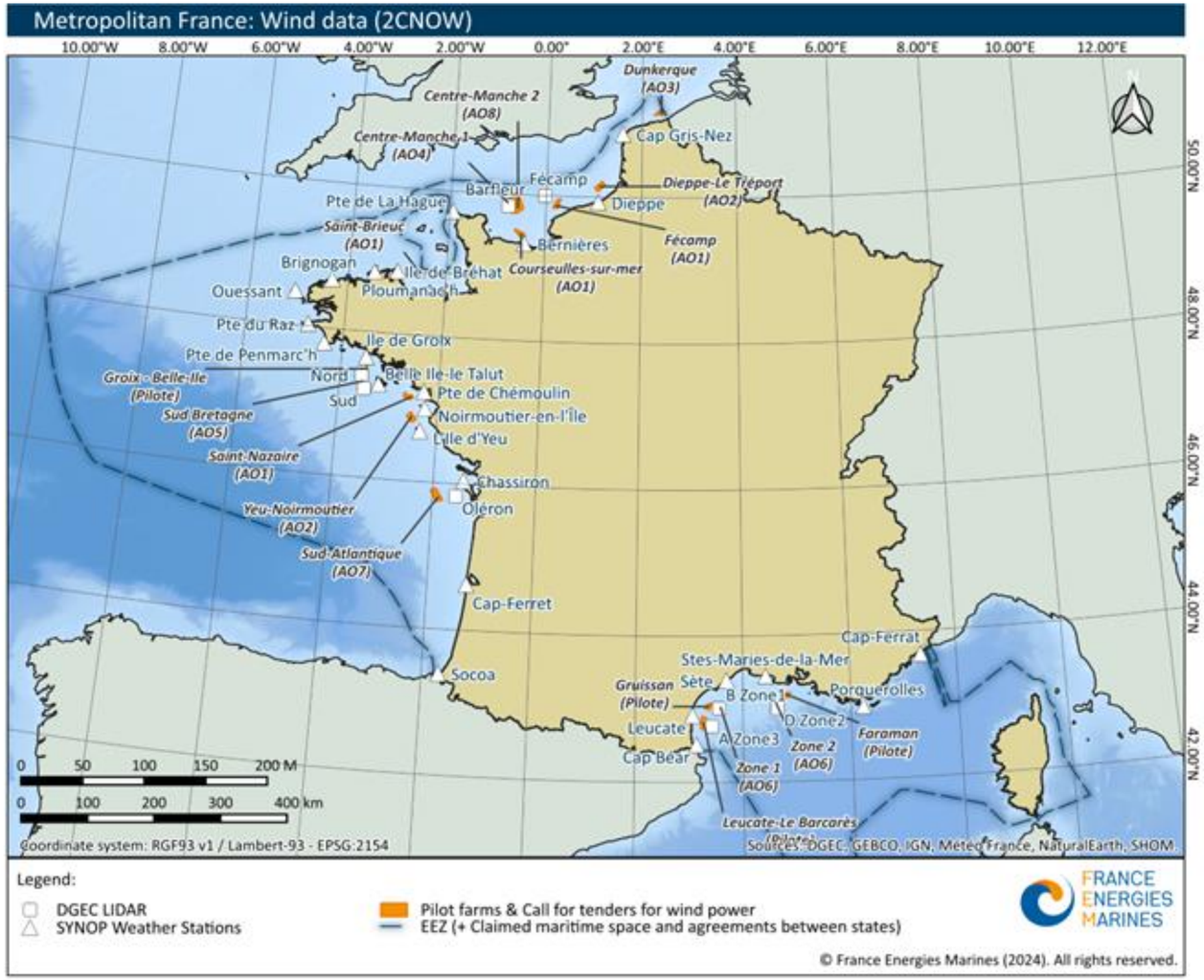
Météo-France SYNOP Weather Stations (10m) (1995-2018)

- 7 stations for the English Channel coast
- 11 for the Atlantic coast
- 6 for the Mediterranean coast

DGEC* Lidar (100 m, 160m, 190m) (12 to 18 months)

Reanalyses (1995-2018)

Data	Spatial resolution	Temporal resolution	Height level
COSMO-REA6 (regional)	6 km	hourly	10m & 100m
CERRA (Forecast) (regional)	5,5 km		
ERA-5 (Forecast) (global)	~30 km		



*Direction Générale de l'Énergie et du Climat

Evaluation of ERA5, COSMO-REA6 and CERRA in simulating wind speed along the French coastline

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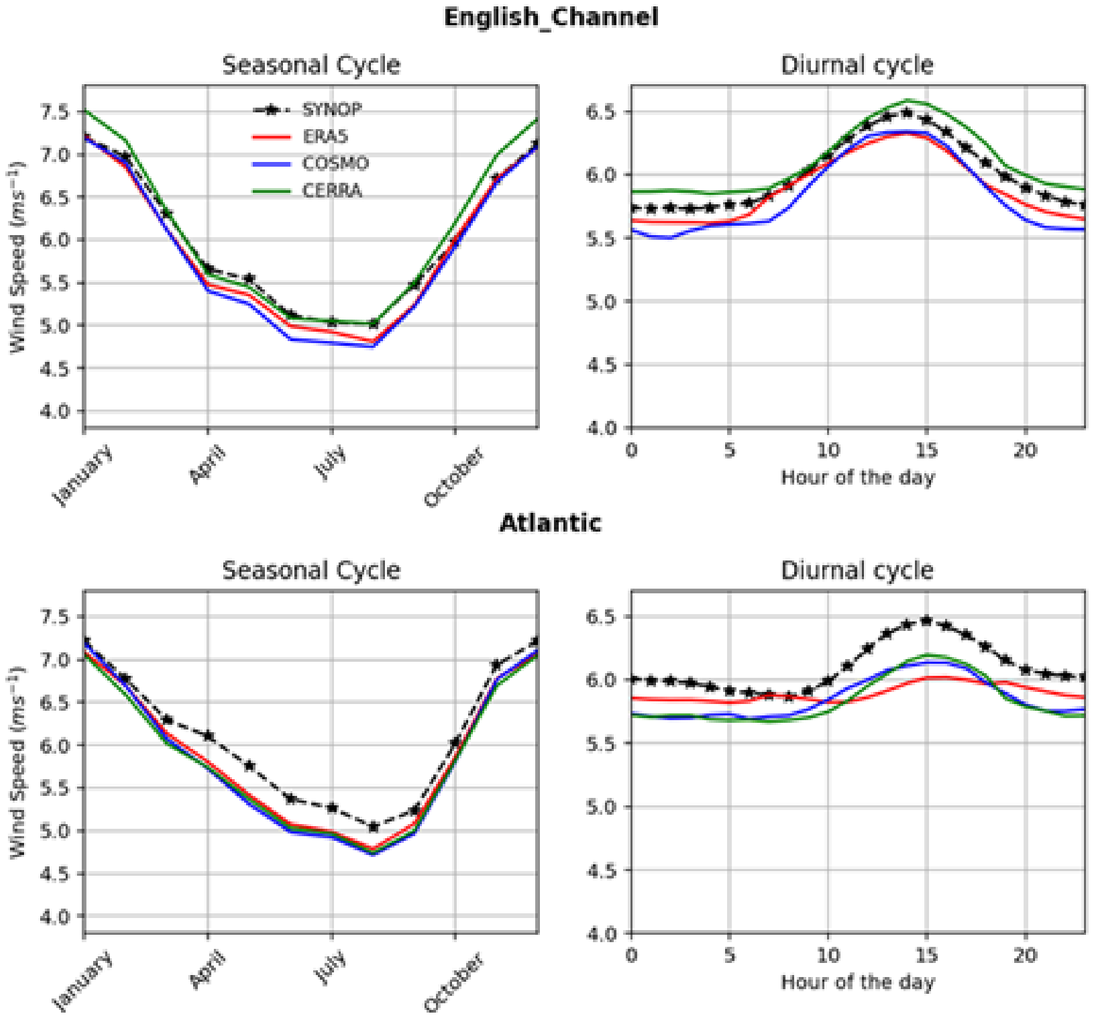
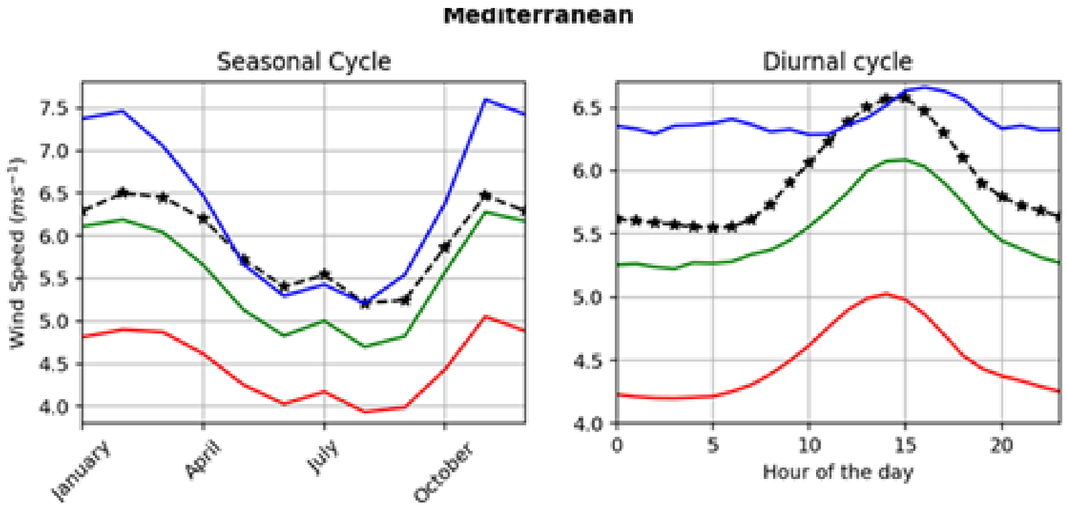
Measurements vs Reanalyses: 10m Wind Speed over 1995-2018





→Seasonal cycle well represented by reanalyses

→Underestimation of mean wind by ERA5 in the Mediterranean coast

→Diurnal cycle missrepresented in COSMO in the Mediterranean coast

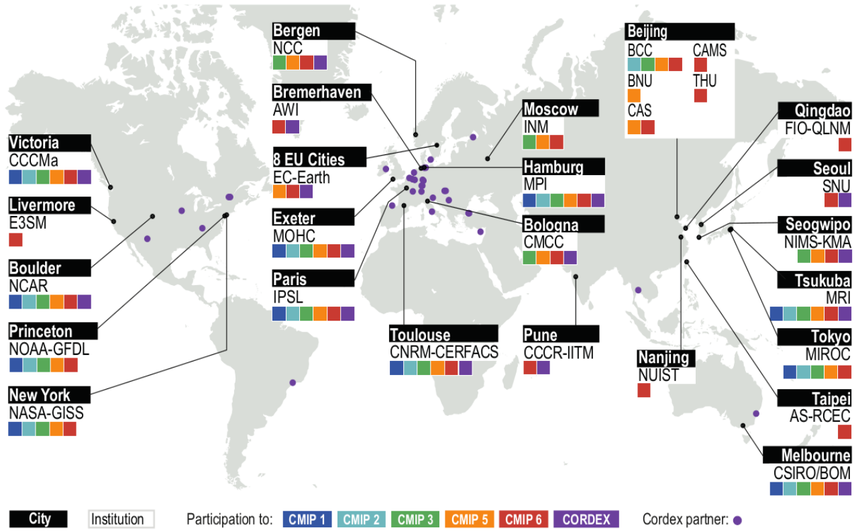
→**Overall, CERRA performs well for all three coastlines (shape of diurnal cycle, mean bias, distribution, 100m wind): Selected as the best reanalysis**

Patra et al., (2024) Evaluation of ERA5, COSMO-REA6 and CERRA in simulating wind speed along the French coastline for wind energy applications, Advances in Science and Research, submitted.

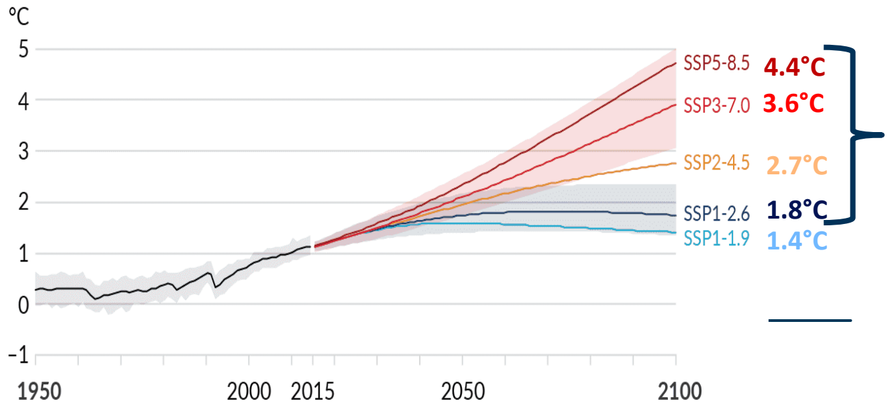
Climate Change impact on Wind resource and Wind Energy Production

CMIP6* climate models and Scenarios

World map showing the increased diversity of modelling centres contributing to CMIP and CORDEX, IPCC AR6 (2021)



(a) Global surface temperature change relative to 1850–1900



Selected CMIP6 models

Michelangeli et al., Selection of a sub-ensemble of CMIP6 projections for the EDF in-house climate service, EGU General Assembly 2023, Vienna, Austria, 2023, EGU23-7848 [Collaboration with CERFACS]

Criteria:

- Representativeness of the whole CMIP6 projection ensemble
- (roughly) Independent models
- Performance across France in the historical period

Selected SSP (Shared Socio-economic Pathways) scenarios

*Coupled Model Intercomparison project-6th phase

EDF Climate Service

Model	ECS (°C)
ACCESS-ESM1-5	3.87
AWI-CM-1-1-MR	3.16
BCC-CSM2-MR	3.04
CAMS-CSM1-0	2.29
CanESM5	5.62
CESM2-WACCM	4.75
CMCC-CM2-SR5	3.52
CNRM-ESM2-1	4.76
EC-Earth3	4.10
FGOALS-g3	2.88
GFDL-ESM4	2.60
GISS-E2-1-G	2.72
IPSL-CM6A-LR	4.56
KACE-1-0-G	4.48
MIROC-ES2L	2.68
MPI-ESM1-2-LR	3.00
MRI-ESM2-0	3.15
NorESM2-LM	2.54
UKESM1-0-LL	5.34

Missing wind data in ESGF
To be added
Removed because biased

Climate Change impact on Wind resource and Wind Energy Production

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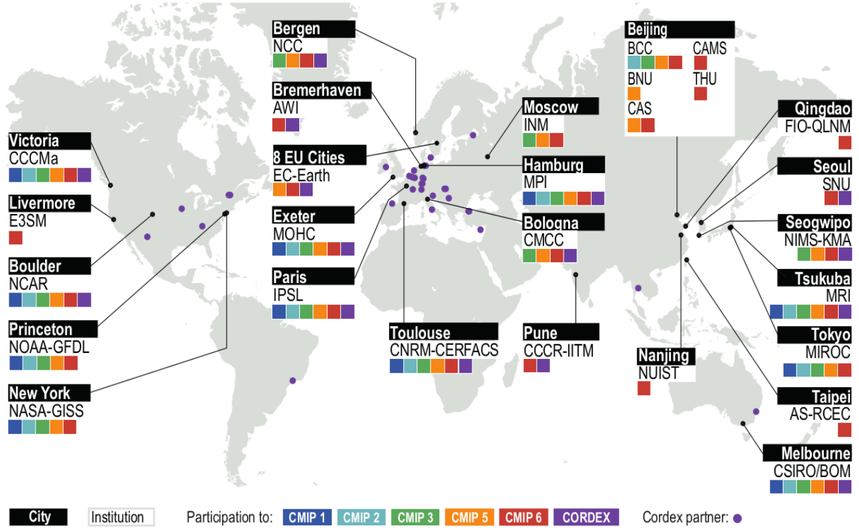

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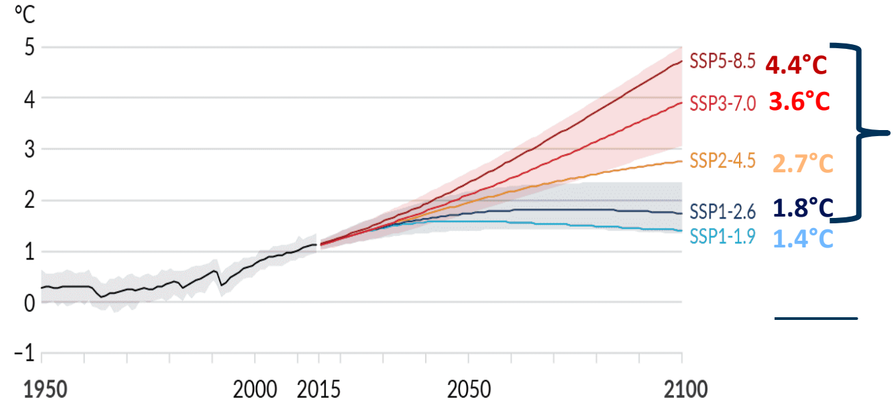

Selected SSP

Selected CMIP6 models

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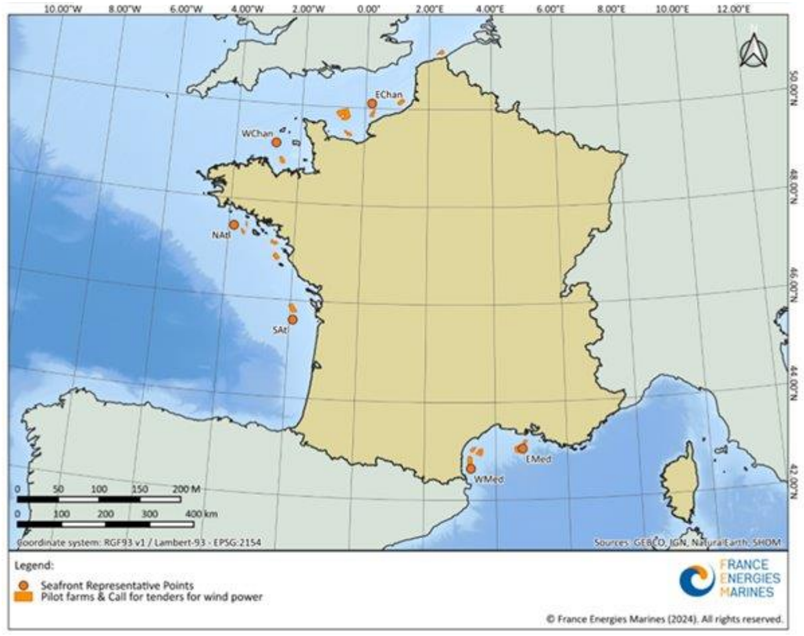
Seafront Representative Points around France



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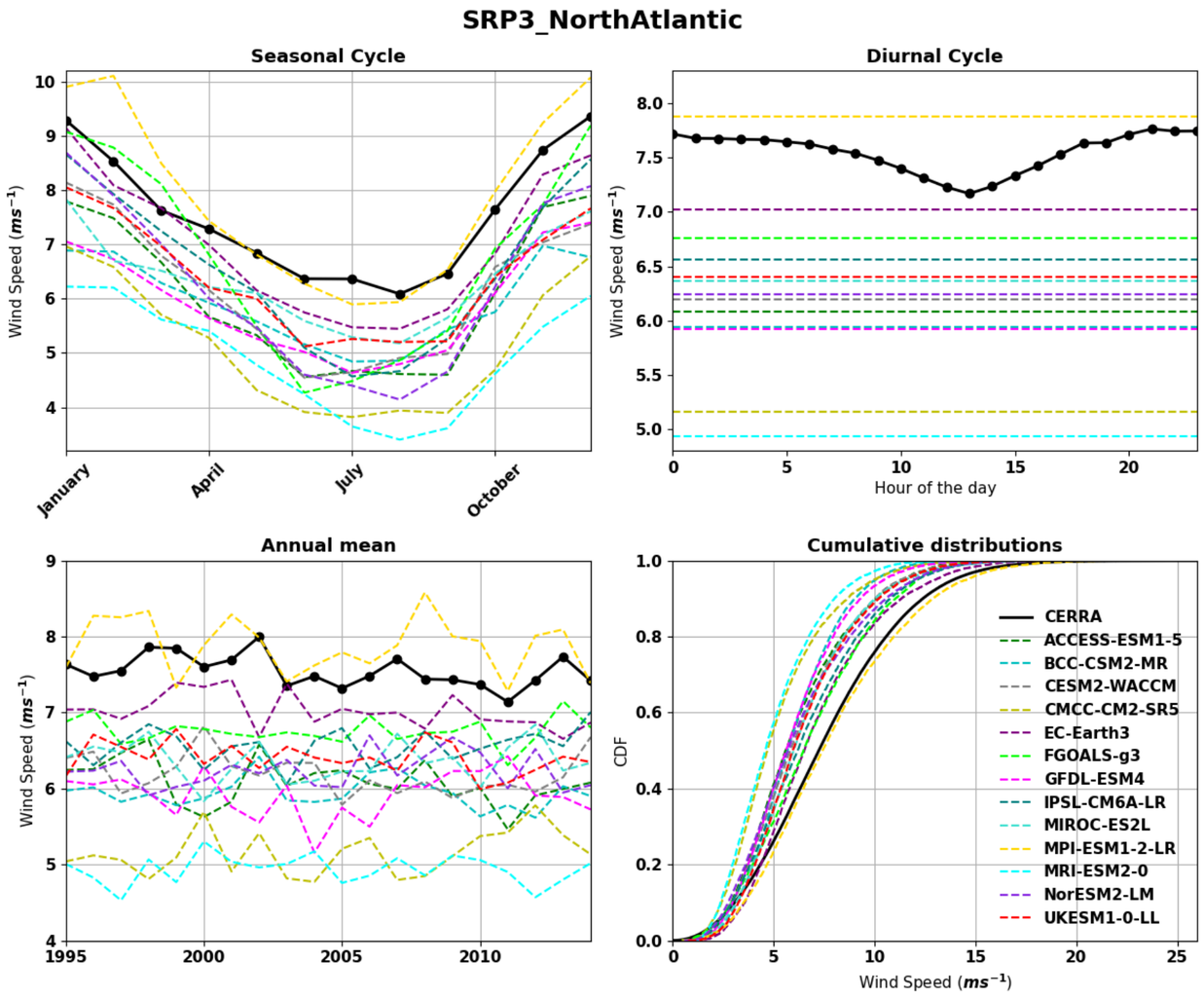
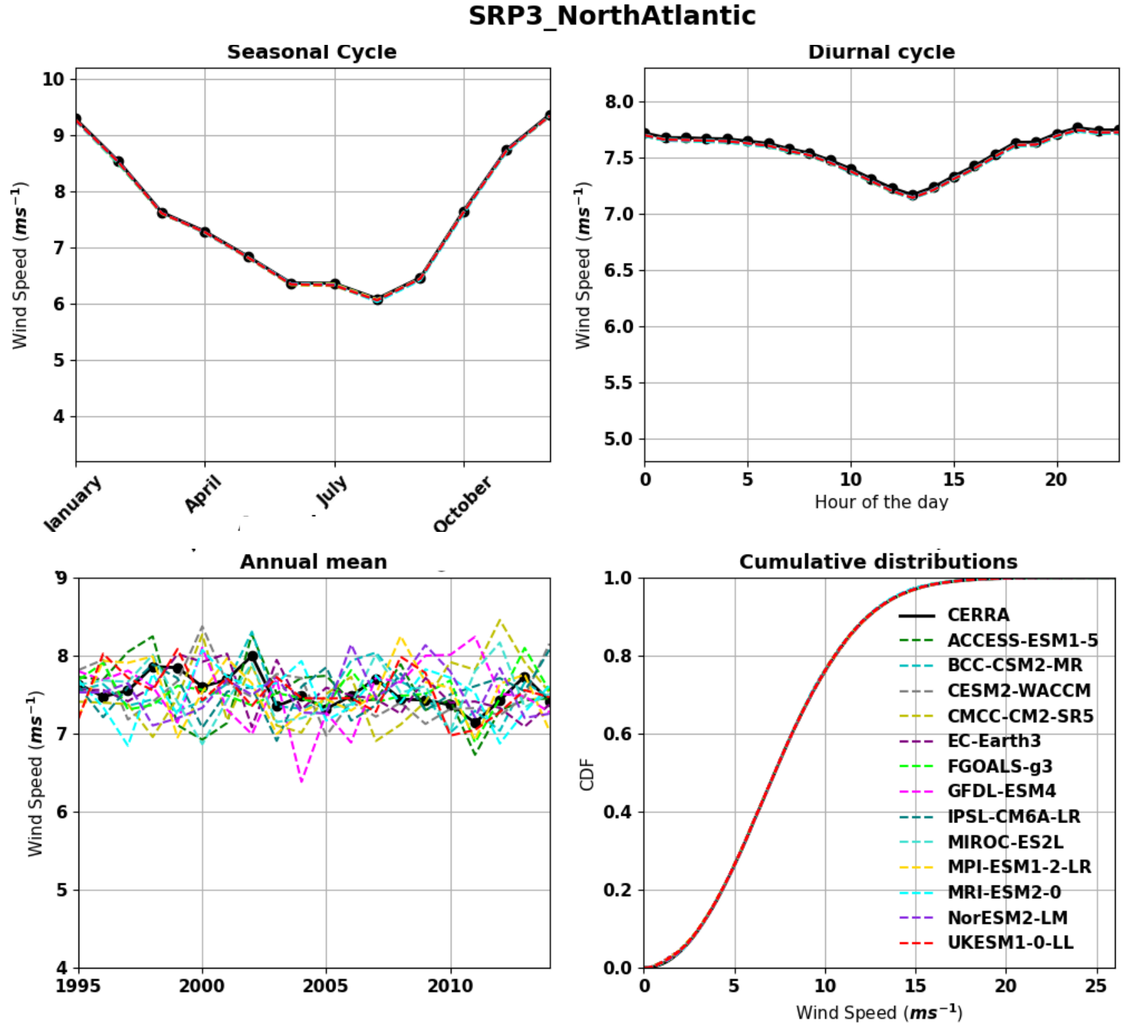
Downscaling Climate Models with CERRA using CDFt*

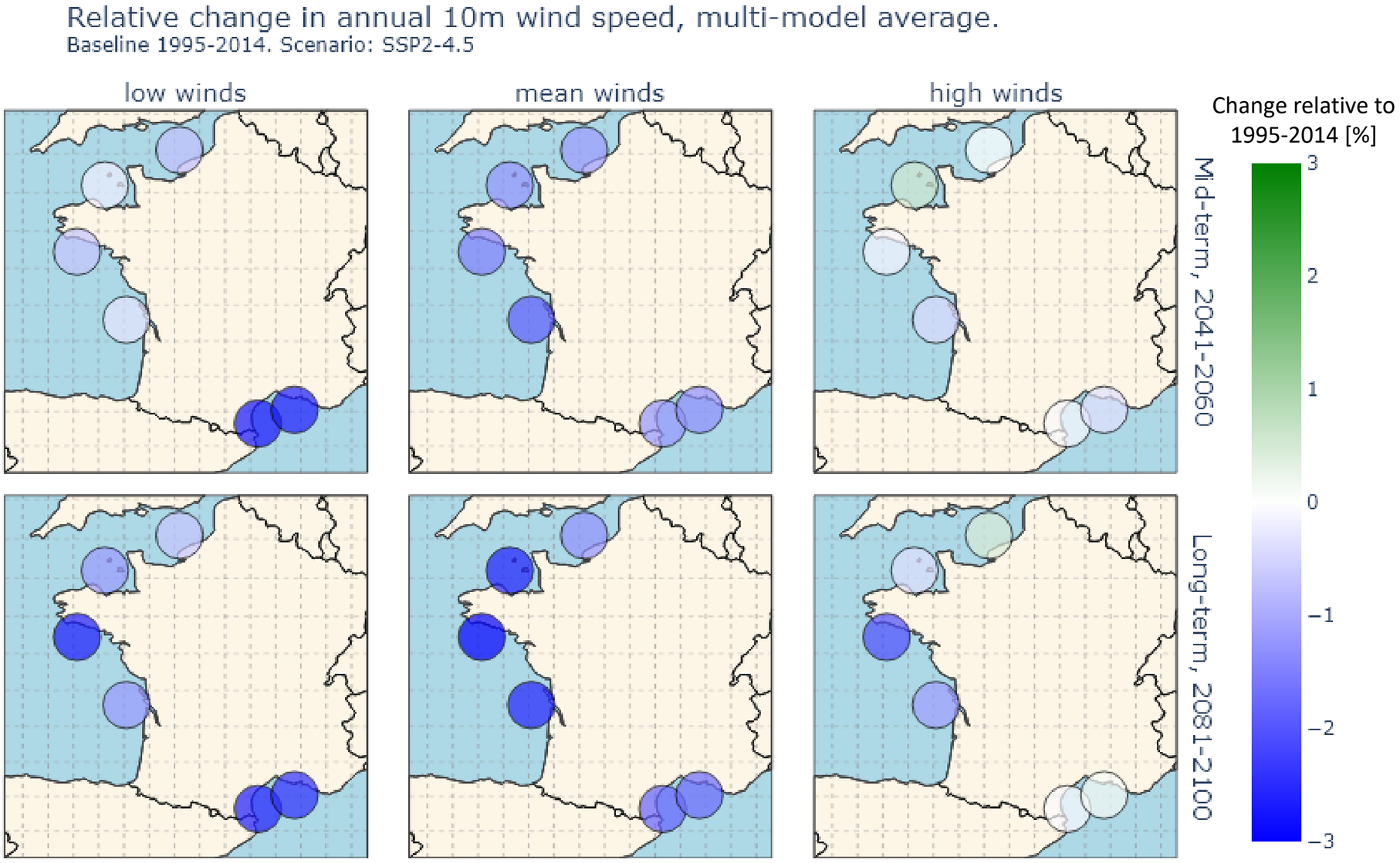
Illustration of the results in North Atlantic





***Cumulative Distribution Function transform (Michelangeli et al., 2009)**

Relative change in mean, High (p95) and Low (p5) wind speed
A multi-model approach

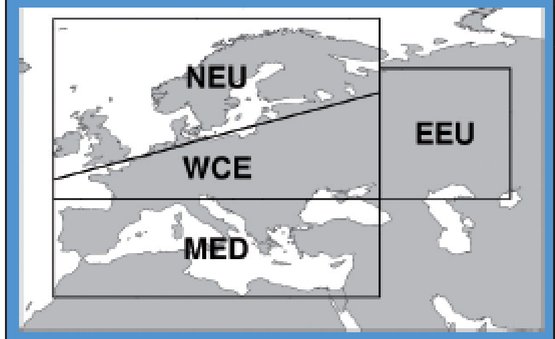


→**Mean wind**: Weakening trend, especially for the long-term future period (-1 to -3% for SSP2-4.5, -5% in EMed for SSP5-8.5) in line with the IPCC 6th AR

→**Low winds**: Decrease on the 3 seafronts of continental France, especially in the Mediterranean coast (Highly significant results for Med), in line with literature

→**High winds**: Stagnation/decrease (Med), decrease (Atl) and increase (Chan) (Highly significant results of decrease for Atl and Med, especially for SSP5-8.5

Summary of confidence in direction of mid-century change in climatic impact-drivers, SSP2-4.5, IPCC AR6



Region	Heat and Cold				Wet and Dry								Wind				Snow and Ice						Coastal and Oceanic					Other		
	Mean air temperature	Extreme heat	Cold spell	Frost	Mean precipitation	River flood	Heavy precipitation and pluvial flood	Landslide	Aridity	Hydrological drought	Agricultural and ecological drought	Fire weather	Mean wind speed	Severe wind storm	Tropical cyclone	Sand and dust storm	Snow, glacier and ice sheet	Permafrost	Lake, river and sea ice	Heavy snowfall and ice storm	Hail	Snow avalanche	Relative sea level	Coastal flood	Coastal erosion	Marine heatwave	Ocean acidity	Air pollution weather	Atmospheric CO_2 at surface	Radiation at surface
Mediterranean (MED)	●	●	●		●		5						6	7					●				●		2		●		●	
Western and Central Europe (WCE)	●	●	●					4									●		●				●		2		●		●	
Eastern Europe (EEU)	●	●	●														●												●	
Northern Europe (NEU)	●	●	●		●	1											●		●				●	8	2,3		●		●	

1. Excluding southern UK.
2. Along sandy coasts and in the absence of additional sediment sinks/sources or any physical barriers to shoreline retreat.
3. The Baltic Sea shoreline is projected to prograde if present-day ambient shoreline change rates continue.
4. For the Alps, conditions conducive to landslides are expected to increase.
5. Low confidence of decrease in the southernmost part of the region.
6. General decrease except in Aegean Sea.
7. Medium confidence of decrease in frequency and increase in intensities.
8. Except in the northern Baltic Sea region.

● Already emerged in the historical period (*medium* to *high confidence*)
● Emerging by 2050 at least in scenarios RCP8.5/SSP5-8.5 (*medium* to *high confidence*)
● Emerging after 2050 and by 2100 at least in scenarios RCP8.5/SSP5-8.5 (*medium* to *high confidence*)

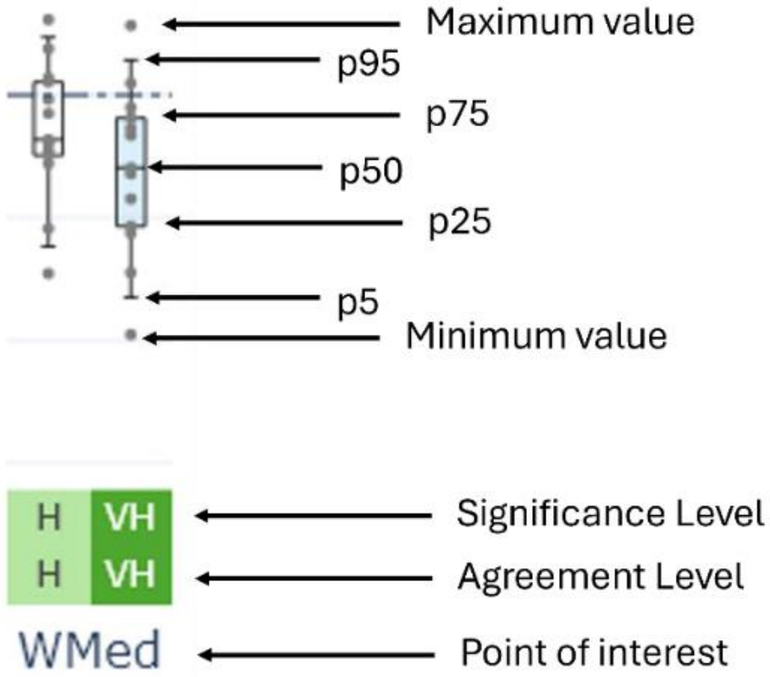
High confidence of decrease | Medium confidence of decrease | Low confidence in direction of change | Medium confidence of increase | High confidence of increase | Not broadly relevant

IPCC AR6 Chapter 12 (2021)

AR6 Climate Change 2021: The Physical Science Basis — IPCC

Relative change in annual mean 10 m wind speed
Focus on model uncertainties and level of confidence of the future change

➢ Boxplots are used to provide a synthetic view of the behavior of the different models and the spread of future changes (IPCC, 2021)

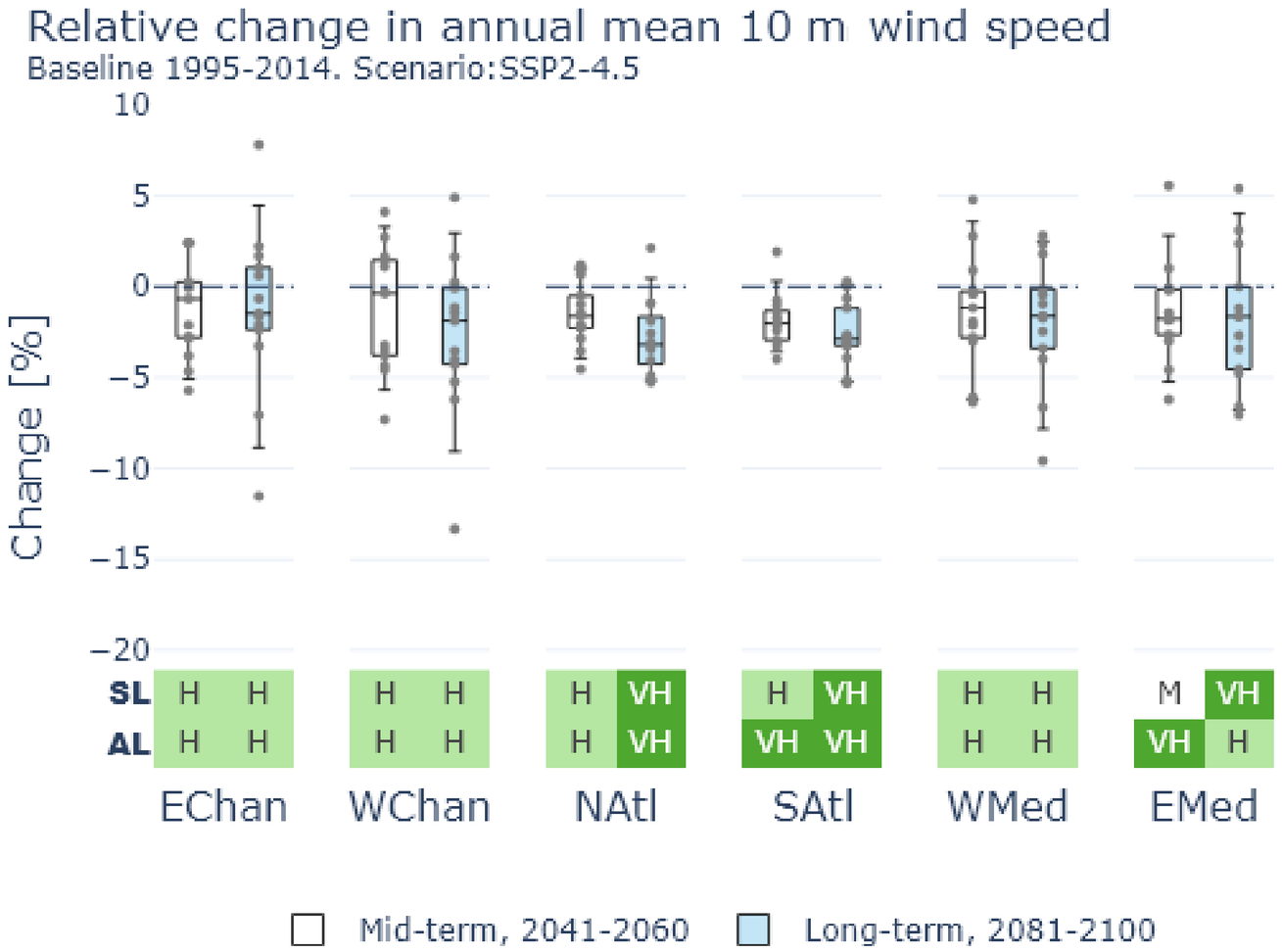


SL = Significance Level				
AL = Agreement Level				
VL	L	M	H	VH
[0;20%[	[20%;40%[	[40%;60%[	[60%;80%[	[80%;100%[

2 Confidence levels :

- The Significance Level ("SL"): it indicates the percentage of models that present a significant change in the sense of the Cramer Von Mises test
- The Agreement Level ("AL"): it indicates the percentage of models that agree on the sign of the change (increase or decrease).

Relative change in annual mean 10 m wind speed
Focus on model uncertainties and level of confidence of the future change



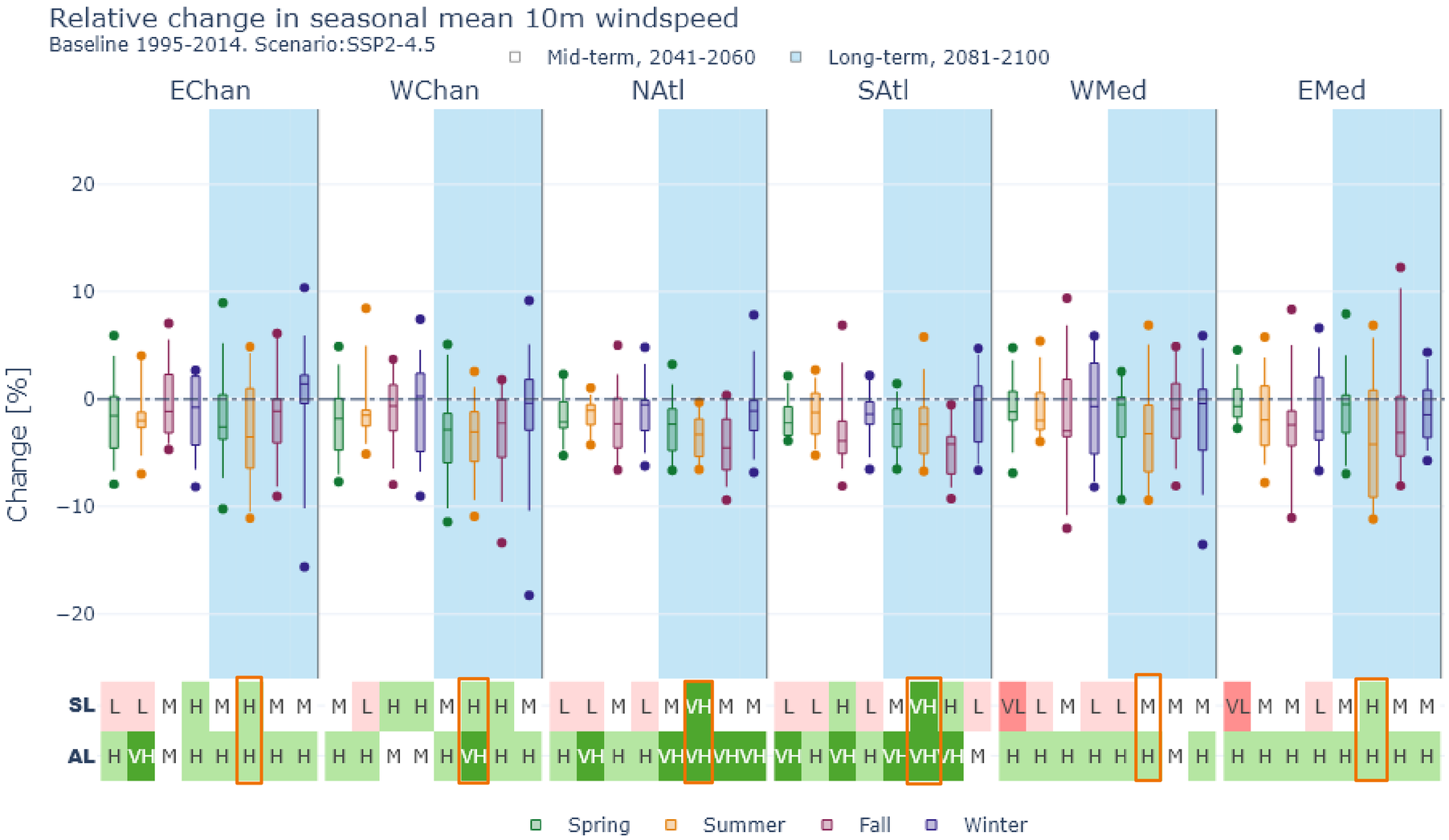
→Robust weakening of wind (High to Very High confidence indices), particularly for the long-term future period, with **higher significance in the Atlantic (-3%) and Eastern Mediterranean coast (-2%)** under SSP2-4.5 scenario

→**Large model uncertainties**: Some climate models show a decrease of more than 5% under SSP2-4.5 scenario reaching locally a decrease of 10 to 15% (EChan & WChan & WMed).

→**Very High confidence on wind decrease**, particularly for the long-term future period, under **SSP3-7.0 and SSP5-8.5** scenarios for Atlantic and Mediterranean coasts (-3 to –5%)

SL = Significance Level				
AL = Agreement Level				
VL	L	M	H	VH
[0;20%[	[20%;40%[	[40%;60%[	[60%;80%[	[80%;100%[

Relative change in seasonal mean 10 m wind speed
Focus on model uncertainties and level of confidence of the future change



→High confidence of decrease in summer for long-term period (Carvalho et al, 2017, 2021 ; Costoya et al, 2022)

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VL	L	M	H	VH
[0;20%[	[20%;40%[	[40%;60%[	[60%;80%[	[80%;100%[

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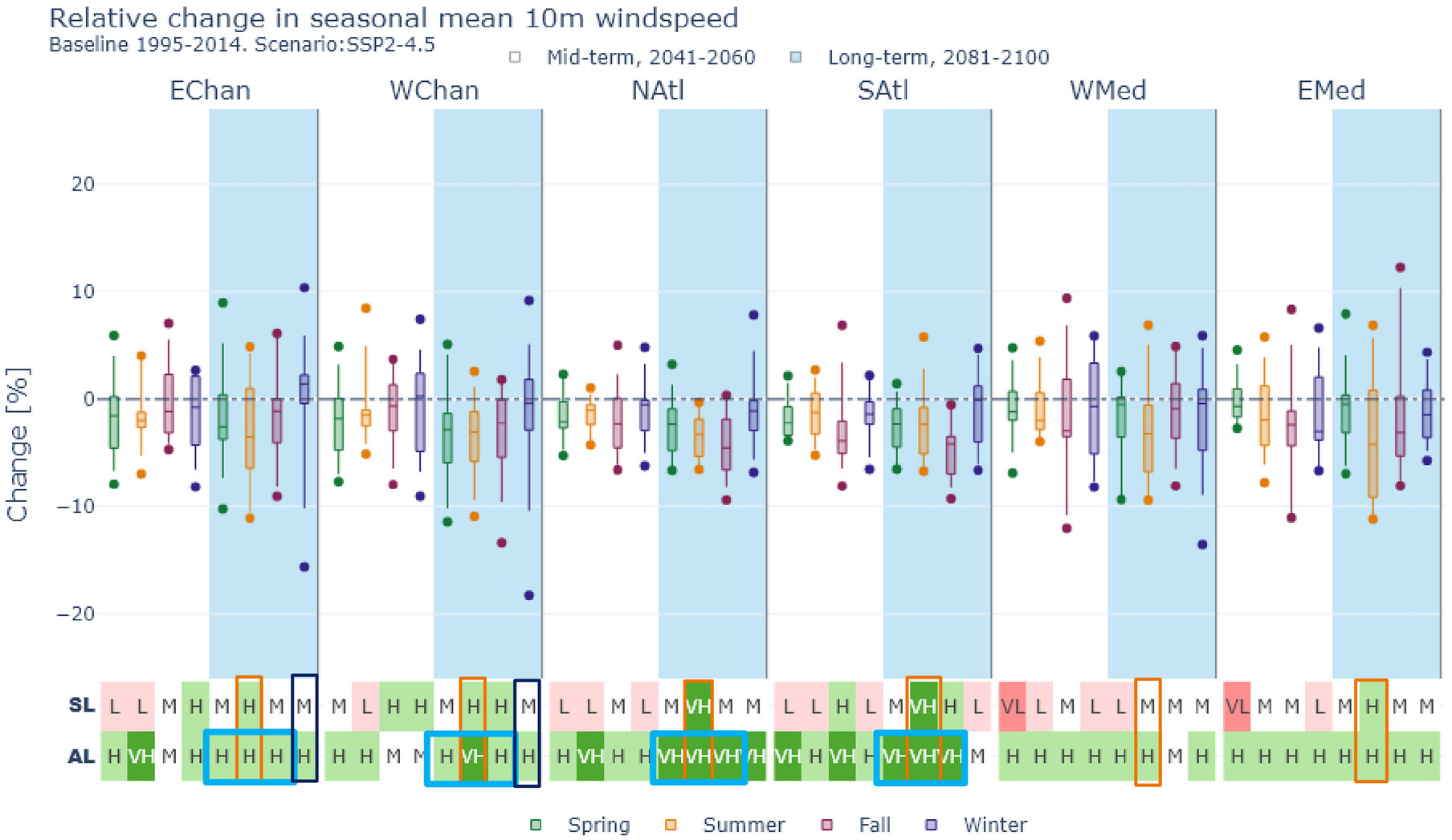

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→High confidence of decrease in summer for long-term period (Barkanov et al, 2024; Carvalho et al, 2017, 2021 ; Costoya et al, 2022)

→Decrease during spring and fall for the long-term period (Atlantic and Channel coasts).

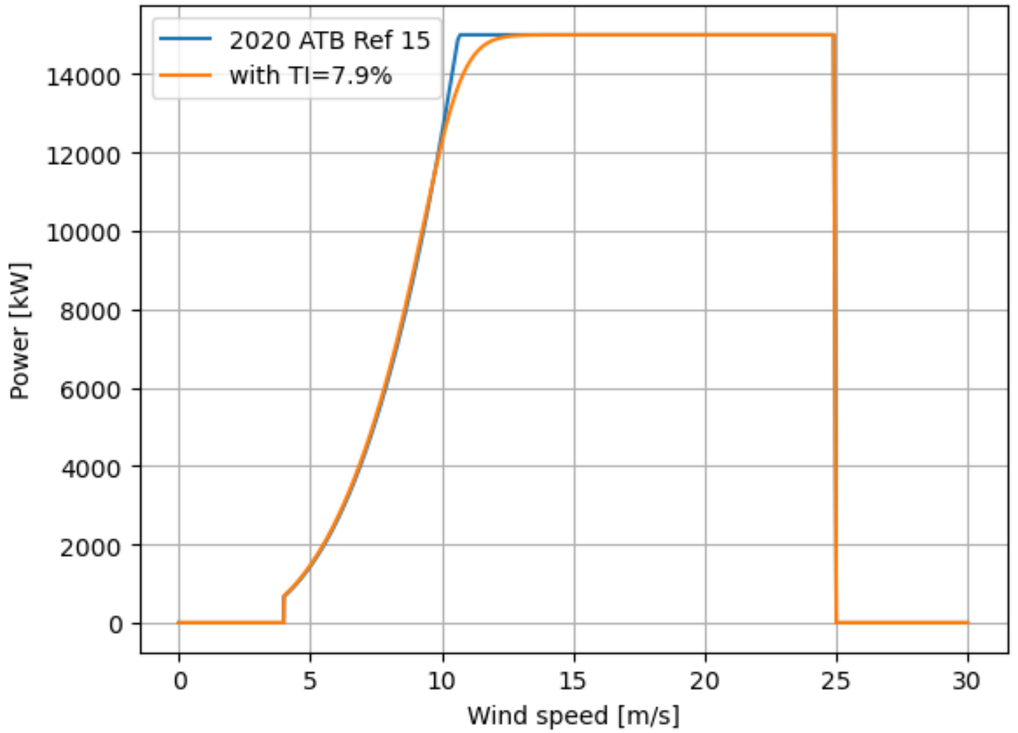
→Stagnation or even an increase during winter (EChan) with Medium confidence

→High significance of decrease in summer, spring and fall for more emissive SSPs

Impact of Climate Change on Wind Energy Production
Conversion of wind speed to wind energy

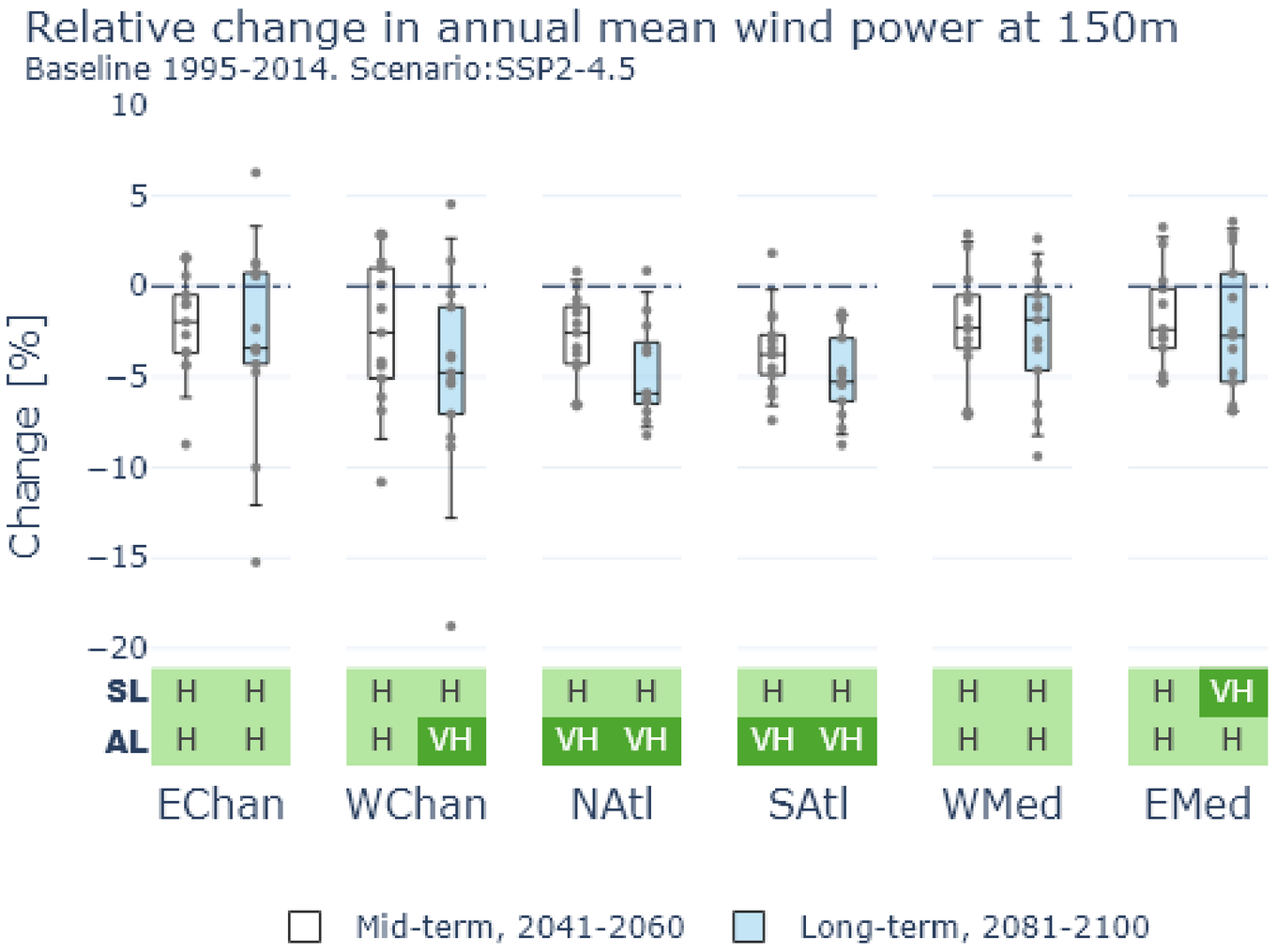
- PyWake : python package to convert 150 m wind speed to wind power, using a **standard Wind Turbine of 15 MW** from the NREL.

Wind turbine Information	Value	Unit
DESIGNATION	2020 ATB Reference 15	N/A
RATED POWER	15000	kW
RATED WIND SPEED	11	m/s
CUT-IN WIND SPEED	4	m/s
CUT-OUT WIND SPEED	25	m/s
ROTOR DIAMETER	240	m
HUB HEIGHT	150	m
DRIVETRAIN	Direct Drive	N/A
CONTROL	Pitch Regulated	N/A



PyWake TopFarm Page : https://topfarm.pages.windenergy.dtu.dk/PyWake/index.html
NREL github page : https://nrel.github.io/turbine-models/2020ATB_NREL_Reference_15MW_240.html
Turbulence Intensity (TI): 7.9% for a wind speed around 15m/s at a height of 140m (Thiébaut et al. 2024)

Relative change in annual mean wind energy production at 150 m
Focus on model uncertainties and level of confidence of the future change



→**Robust weakening of wind energy** (High to Very High confidence indices): -2% to -4% for mid-term, -2% to -6% (Atl) for long-term under SSP2-4.5 scenario

→High confidence of decrease for long-term period in **Summer and Fall** (for Atl and Wchan): -5% (WMed) to -9% (SAtl) (Barkanov et al, 2024; Carvalho et al, 2017; Costoya et al, 2022)

→**Large model uncertainties**: more pronounced for Chan and lower spread for Atl and Med under SSP2-4.5

→Very High confidence on wind energy decrease, for the long-term future period, under SSP3-7.0 and SSP5-8.5 scenarios for Atl and Med (-4 to –8%)

SL = Significance Level				
AL = Agreement Level				
VL	L	M	H	VH
[0;20%[	[20%;40%[	[40%;60%[	[60%;80%[	[80%;100%[

Main results on Climate change impact on wind resource and energy production

Results:

- **General decrease of wind** (-1 to -5%) **and wind energy production** (-2% to -6% for SSP2-4.5, -4 to –8% for SSP5-8.5)
  - In line with literature (IPCC ; Barkanov et al, 2024; Carvalho et al, 2017; Carvalho et al., 2021 ; Costoya et al, 2022)
  - Significant results for Atlantic and Mediterranean coasts
  - More important in summer for long-term period under SSP2-4.5 and Highly significant in summer, spring and fall for SSP3-7.0 and SSP5-8.5
- **Low winds:** Decrease in low wind speed (Highly significant results for Med & SAtl)
- I**ncrease of occurrence of wind speeds below cut-in:** +100 to +200 hours (long-term period vs baseline)
- **High winds:** Less significant results: decrease (Med, Atl) and increase (Chan) (High to VH confidence of decrease for Atl and Med SSP5-8.5)

- **Large model uncertainties**

Main results on Climate change impact on wind resource and energy production

Limitations and future work:

- Climate model spatial and temporal resolution
- Number of models and representativeness of extremes
- Quantification of uncertainty
- Sensitivity of the results to the choice of wind turbine and its characteristics