Climate Change and North-Atlantic Polar Lows: Statistical-Deterministic Projections based on CMIP5 Models

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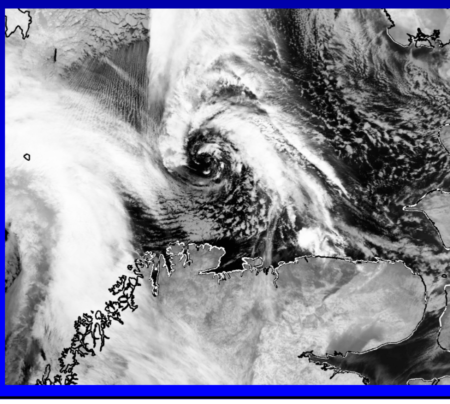
MOTIVATION

Polar lows are physically analogous to tropical cyclones (warm-core, surface flux-driven). These extreme windstorms pose serious threat to the affected islands and coastal regions and can adversely affect open sea activities such as shipping and gas and oil platforms operations:

- *Future changes in frequency, intensity or regional variability ?*
- *No systematic effort to answer this question in the context of CMIP5*



THIS WORK: Statistical-deterministic approach

Developed by Emanuel and his team in the context of the long-term wind risk associated with tropical cyclones:

- *Low-cost generation of thousands of synthetic storms*
- *Statistically robust assessment of risk (e.g. return periods for winds)*

- *Genesis: Random draws from observed PDF or Random seeding*
- *Track: Randomly varying synthetic winds (respecting climatology)*
- *Environment: Previous winds + monthly-mean thermodynamic fields*
- *Intensity and radial distribution of winds: CHIPS model*

ADAPTATION OF THE METHOD

The separation of timescales made in the tropics between the synthetic wind field (fast scale) and the thermodynamic environment (slow scale) is not appropriate to represent the movement, growth and decay of mid/high-latitude weather systems. In addition, existing data of NA polar low genesis is too sparse to form a reasonable PDF of genesis, and random seeding would be very inefficient:

- *For each month, decomposition through PCA of 10-day synoptic evolutions of z250, z850, T600, R600 and PINT into the new space of independent PCs*
- *Random selection + random perturbation of the set of PCs*
- *This perturbed set of PCs is converted back into physical space*
- *This is tantamount to generating 10-day sequences of spatiotemporal coherent z250, z850, T600, R600 and PINT synthetic fields which also respect their mutual covariances*

- *Potential Genesis: Based on the GENIX parameter*

- *Application of an* ***empirical index of genesis***:

$$I = \left|10^5 \eta\right|^{3/2} \left(\frac{H}{50}\right)^3 \left(\frac{V_{pot}}{70}\right)^3 \left(1 + 0.1 V_{shear}\right)^{-2},$$

GENIX parameter
(Emanuel and Nolan, 2004)

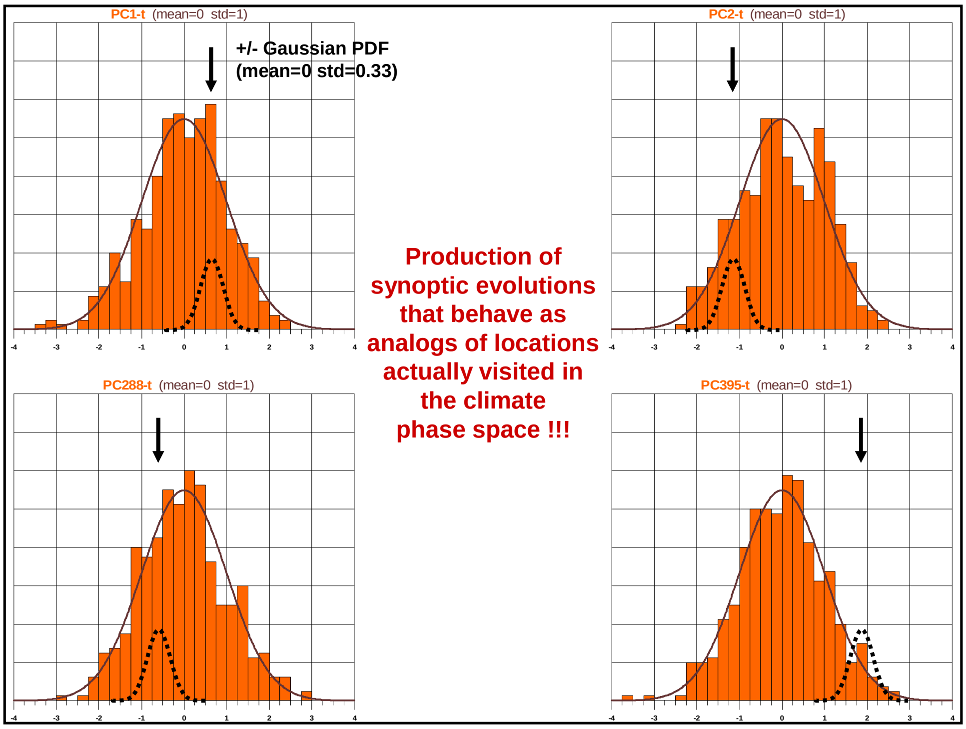
$\eta \equiv 850\ hPa\ absolute\ vorticity\ (s^{-1}),$

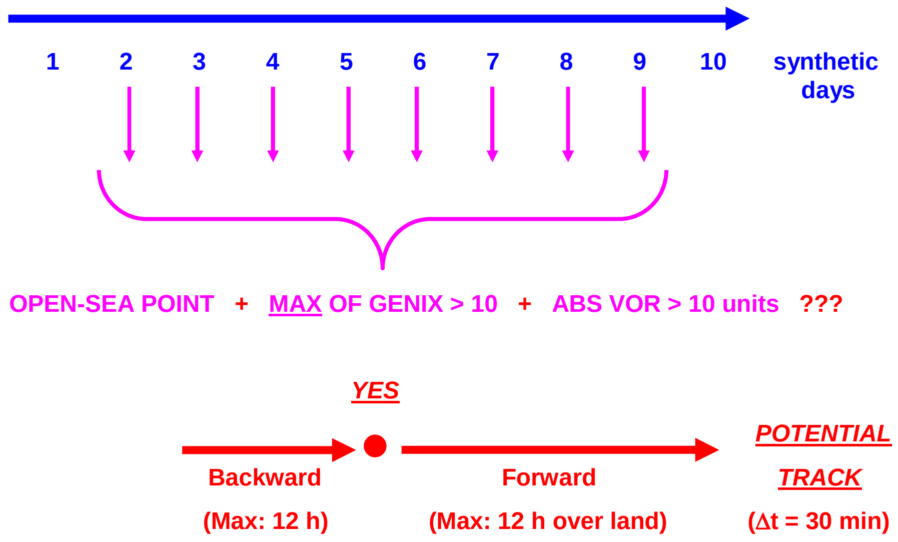
$V_{pot} \equiv Potential\ wind\ speed\ (ms^{-1}),$

$H \equiv 600\ mb\ relative\ humidity\ (\%),$

$V_{shear} \equiv \left|\mathbf{V}_{850} - \mathbf{V}_{250}\right|\ (ms^{-1}).$

- ***Necessary but no sufficient ingredient …***





$$\begin{cases} u_{track} = \alpha\, \underline{u}_{850} + (1 - \alpha)\, \underline{u}_{250} \\ v_{track} = \alpha\, \underline{v}_{850} + (1 - \alpha)\, \underline{v}_{250} \end{cases}$$

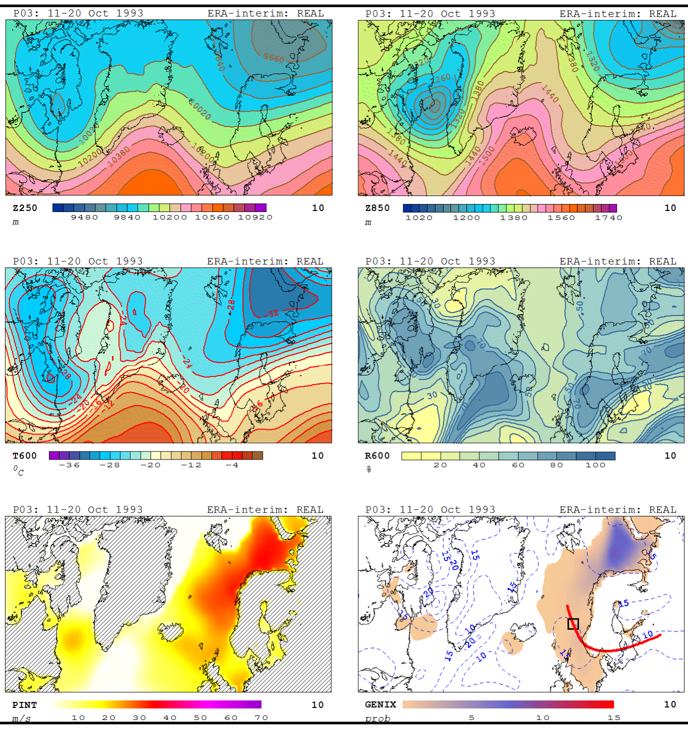
$\underline{AVG}_{time\text{-}space}$

$\alpha = 0.8$

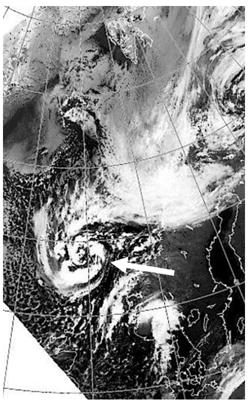
ILLUSTRATIVE EXAMPLE

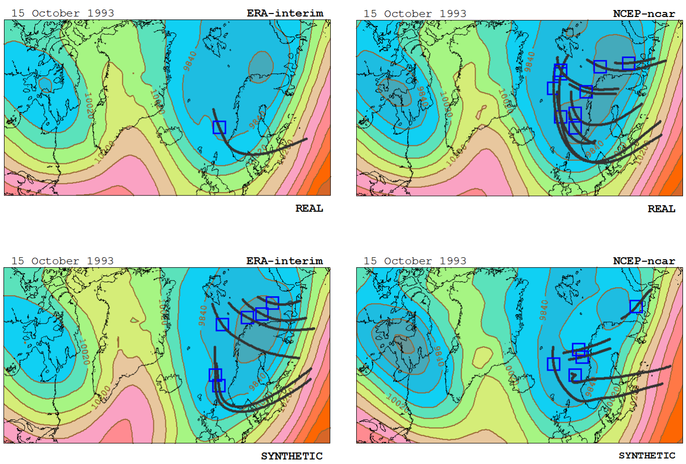
POLAR LOW "LE CYGNE"
Norwegian Sea, 13-15 October 1993

TRACKING
method



SYNTHETIC
analogues





REANALYSES AND CMIP5 MODELS

REANALYSIS 1

ERA-interim

ECMWF
(Europe)

LON 0.75º x LAT 0.75º

REANALYSIS 2

NCEP-ncar

NOAA
(USA)

LON 2.5º x LAT 2.5º

HISTORICAL scenario

1986-2005

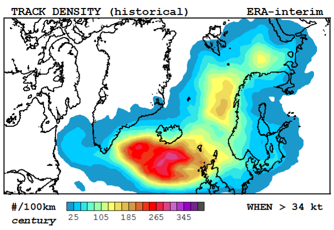
GCM-01 *ACCESS1.0* CSIRO and BOM (Australia) LON 1.88º x LAT 1.25º	GCM-02 *ACCESS1.3* CSIRO and BOM (Australia) LON 1.88º x LAT 1.25º	GCM-06 *CanESM2* Cent. Clim. Mod. Anal. (Canada) LON 2.81º x LAT 2.79º	GCM-07 *CCSM4* NCAR (USA) LON 1.25º x LAT 0.94º	GCM-11 *CNRM-CM5* CNRM and CERFACS (France) LON 1.41º x LAT 1.40º	GCM-12 *CSIRO-Mk3.6.0* QCCCE and CSIRO (Australia) LON 1.88º x LAT 1.86º
GCM-03 *BCC-CSM1.1* Beijing Climate Center (China) LON 2.81º x LAT 2.79º	GCM-04 *BCC-CSM1.1(m)* Beijing Climate Center (China) LON 1.13º x LAT 1.12º	GCM-08 *CMCC-CESM* Cent. EuroMed C.Clim. (Italy) LON 3.75º x LAT 3.71º	GCM-09 *CMCC-CM* Cent. EuroMed C.Clim. (Italy) LON 0.75º x LAT 0.75º	GCM-13 *EC-EARTH* EC-Earth Consortium (Europe) LON 1.13º x LAT 1.12º	GCM-14 *FGOALS-g2* LASG-CESS (China) LON 2.81º x LAT 2.81º
GCM-05 *BNU-ESM* Beijing Normal University (China) LON 2.81º x LAT 2.79º	***HISTORICAL scenario*** **1986-2005**	GCM-10 *CMCC-CMS* Cent. EuroMed C.Clim. (Italy) LON 1.88º x LAT 1.86º	***RCP85 scenario*** **2081-2100**	GCM-15 *GFDL-CM3* NOAA GFDL (USA) LON 2.50º x LAT 2.00º	
GCM-16 *GFDL-ESM2G* NOAA GFDL (USA) LON 2.50º x LAT 2.00º	GCM-17 *GFDL-ESM2M* NOAA GFDL (USA) LON 2.50º x LAT 2.00º	GCM-21 *IPSL-CM5A-MR* IPSL (France) LON 2.50º x LAT 1.27º	GCM-22 *IPSL-CM5B-LR* IPSL (France) LON 3.75º x LAT 1.89º	GCM-26 *MPI-ESM-LR* Max Planck Int. Meteor. (Germany) LON 1.88º x LAT 1.86º	GCM-27 *MPI-ESM-MR* Max Planck Int. Meteor. (Germany) LON 1.88º x LAT 1.86º
GCM-18 *HadGEM2-CC* Met Office Hadley Cent (UK) LON 1.88º x LAT 1.25º	GCM-19 *INM-CM4* Rus. Inst. Num. Math. (Russia) LON 2.00º x LAT 1.50º	GCM-23 *MIROC5* U.Tok-NIES-JAMSTEC (Japan) LON 1.41º x LAT 1.40º	GCM-24 *MIROC-ESM* U.Tok-NIES-JAMSTEC (Japan) LON 2.81º x LAT 2.79º	GCM-28 *MRI-CGCM3* Meteor. Res. Inst. (Japan) LON 1.13º x LAT 1.12º	GCM-29 *MRI-ESM1* Meteor. Res. Inst. (Japan) LON 1.13º x LAT 1.12º
GCM-20 *IPSL-CM5A-LR* IPSL (France) LON 3.75º x LAT 1.89º		GCM-25 *MIROC-ESM-CHEM* U.Tok-NIES-JAMSTEC (Japan) LON 2.81º x LAT 2.79º		GCM-30 *NorESM1-M* Nor. Clim. Cent. (Norway) LON 2.50º x LAT 1.90º	

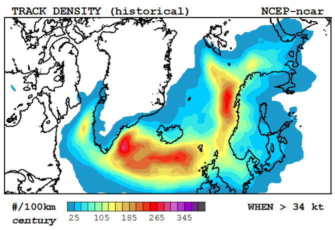
RESULTS

REANALYSIS 1	REANALYSIS 2
ERA-interim 20178 tracks 3898 survivors 3000 storms/century	***NCEP-ncar*** 20638 tracks 3223 survivors 3000 storms/century

HISTORICAL scenario

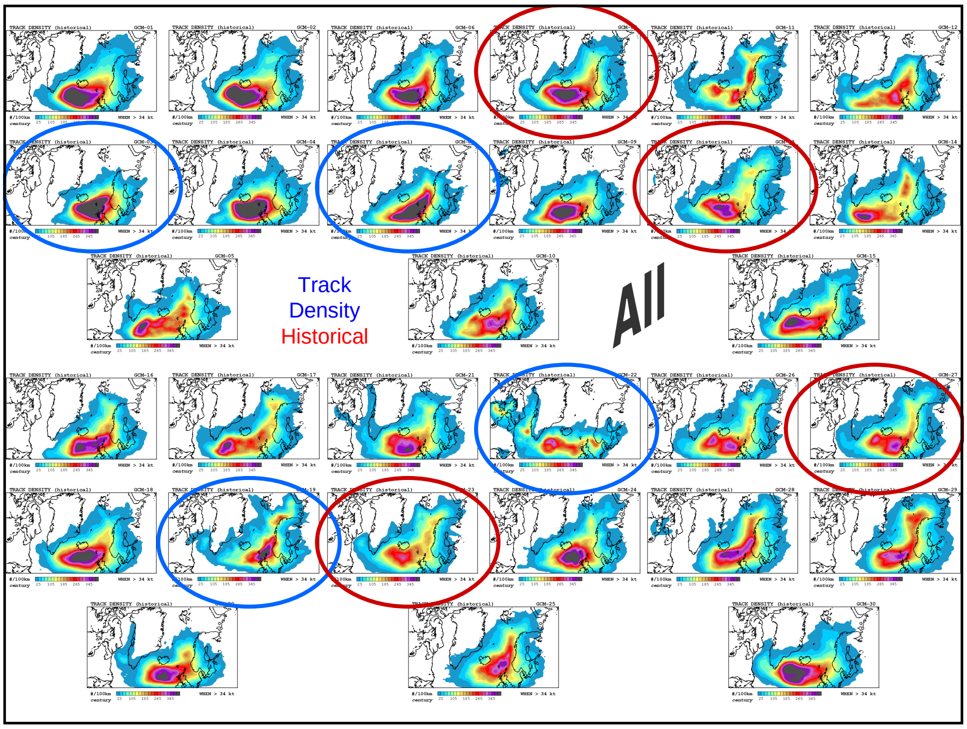
3000 storms
(per century)

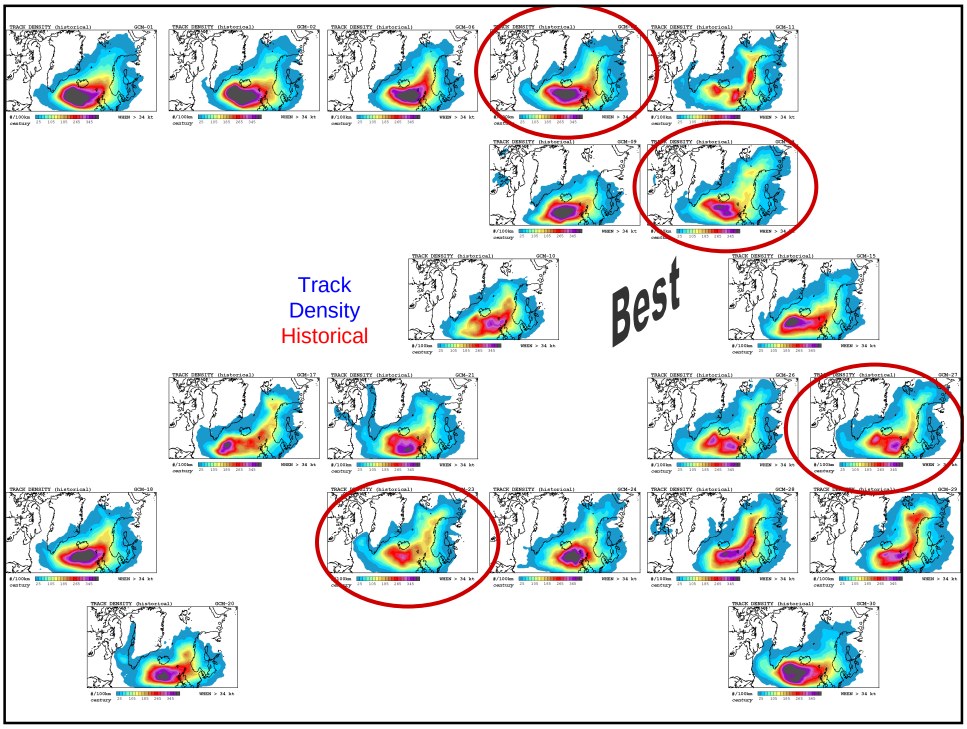




GCM-01 ***ACCESS1.0*** 20054 tracks 7882 survivors 3000 storms/century	GCM-02 ***ACCESS1.3*** 20022 tracks 8093 survivors 3000 storms/century	GCM-06 ***CanESM2*** 20875 tracks 5130 survivors 3000 storms/century	GCM-07 ***CCSM4*** 20491 tracks 6256 survivors 3000 storms/century	GCM-11 ***CNRM-CM5*** 20274 tracks 2436 survivors 3000 storms/century	GCM-12 ***CSIRO-Mk3.6.0*** 20222 tracks 3911 survivors 3000 storms/century
GCM-03 ***BCC-CSM1.1*** 20076 tracks 3713 survivors 3000 storms/century	GCM-04 ***BCC-CSM1.1(m)*** 20045 tracks 4552 survivors 3000 storms/century	GCM-08 ***CMCC-CESM*** 20345 tracks 2654 survivors 3000 storms/century	GCM-09 ***CMCC-CM*** 20304 tracks 4905 survivors 3000 storms/century	GCM-13 ***EC-EARTH*** 20193 tracks 4475 survivors 3000 storms/century	GCM-14 ***FGOALS-g2*** 20677 tracks 5279 survivors 3000 storms/century
GCM-05 ***BNU-ESM*** 20477 tracks 3212 survivors 3000 storms/century	**HISTORICAL scenario** **3000** storms (per century)	GCM-10 ***CMCC-CMS*** 20464 tracks 3936 survivors 3000 storms/century	**ALL**	GCM-15 ***GFDL-CM3*** 20923 tracks 5211 survivors 3000 storms/century	
GCM-16 ***GFDL-ESM2G*** 20277 tracks 4269 survivors 3000 storms/century	GCM-17 ***GFDL-ESM2M*** 20432 tracks 3998 survivors 3000 storms/century	GCM-21 ***IPSL-CM5A-MR*** 20125 tracks 4733 survivors 3000 storms/century	GCM-22 ***IPSL-CM5B-LR*** 20054 tracks 2890 survivors 3000 storms/century	GCM-26 ***MPI-ESM-LR*** 20430 tracks 3631 survivors 3000 storms/century	GCM-27 ***MPI-ESM-MR*** 20280 tracks 3707 survivors 3000 storms/century
GCM-18 ***HadGEM2-CC*** 20378 tracks 7298 survivors 3000 storms/century	GCM-19 ***INM-CM4*** 20052 tracks 2604 survivors 3000 storms/century	GCM-23 ***MIROC5*** 20124 tracks 4567 survivors 3000 storms/century	GCM-24 ***MIROC-ESM*** 20271 tracks 3105 survivors 3000 storms/century	GCM-28 ***MRI-CGCM3*** 20675 tracks 4140 survivors 3000 storms/century	GCM-29 ***MRI-ESM1*** 21114 tracks 4191 survivors 3000 storms/century
GCM-20 ***IPSL-CM5A-LR*** 20137 tracks 4307 survivors 3000 storms/century	GCM-25 ***MIROC-ESM-CHEM*** 20453 tracks 3487 survivors 3000 storms/century	GCM-30 ***NorESM1-M*** 20548 tracks 5520 survivors 3000 storms/century			

GCM-01 *ACCESS1.0* 13794 tracks 3876 survivors 1475.3 storms/century	GCM-02 *ACCESS1.3* 15212 tracks 4725 survivors 1751.5 storms/century	GCM-06 *CanESM2* 27035 tracks 5578 survivors 3262.0 storms/century	GCM-07 *CCSM4* 19217 tracks 5353 survivors 2567.0 storms/century	GCM-11 *CNRM-CM5* 15277 tracks 1351 survivors 1663.8 storms/century	GCM-12 *CSIRO-Mk3.6.0* 13710 tracks 1458 survivors 1118.4 storms/century
GCM-03 *BCC-CSM1.1* 23528 tracks 2845 survivors 2298.7 storms/century	GCM-04 *BCC-CSM1.1(m)* 19276 tracks 3268 survivors 2153.8 storms/century	GCM-08 *CMCC-CESM* 40425 tracks 4364 survivors 4932.9 storms/century	GCM-09 *CMCC-CM* 51229 tracks 7962 survivors 4869.7 storms/century	GCM-13 *EC-EARTH* 16691 tracks 3513 survivors 2355.1 storms/century	GCM-14 *FGOALS-g2* 34225 tracks 8766 survivors 4981.6 storms/century
GCM-05 *BNU-ESM* 19724 tracks 1886 survivors 1761.5 storms/century	***RCP85 scenario*** 2806.5 storms (per century)	GCM-10 *CMCC-CMS* 32433 tracks 4320 survivors 3292.7 storms/century	**ALL**	GCM-15 *GFDL-CM3* 26208 tracks 4126 survivors 2375.4 storms/century	
GCM-16 *GFDL-ESM2G* 32751 tracks 6024 survivors 4233.3 storms/century	GCM-17 *GFDL-ESM2M* 14802 tracks 1994 survivors 1496.3 storms/century	GCM-21 *IPSL-CM5A-MR* 16072 tracks 2692 survivors 1706.3 storms/century	GCM-22 *IPSL-CM5B-LR* 48981 tracks 5686 survivors 5902.4 storms/century	GCM-26 *MPI-ESM-LR* 21306 tracks 3290 survivors 2718.3 storms/century	GCM-27 *MPI-ESM-MR* 15744 tracks 2070 survivors 1675.2 storms/century
GCM-18 *HadGEM2-CC* 18125 tracks 4075 survivors 1675.1 storms/century	GCM-19 *INM-CM4* 16465 tracks 1305 survivors 1503.5 storms/century	GCM-23 *MIROC5* 16300 tracks 2291 survivors 1504.9 storms/century	GCM-24 *MIROC-ESM* 18160 tracks 2603 survivors 2515.0 storms/century	GCM-28 *MRI-CGCM3* 40967 tracks 7367 survivors 5338.4 storms/century	GCM-29 *MRI-ESM1* 38784 tracks 7043 survivors 5041.5 storms/century
GCM-20 *IPSL-CM5A-LR* 30113 tracks 4033 survivors 2809.2 storms/century	20 models ▼▼▼	GCM-25 *MIROC-ESM-CHEM* 24243 tracks 3660 survivors 3148.8 storms/century	10 models ▲▲▲	GCM-30 *NorESM1-M* 18125 tracks 3803 survivors 2066.9 storms/century	





GCM-01
ACCESS1.0
13794 tracks
3876 survivors
1475.3 storms/century

GCM-02
ACCESS1.3
15212 tracks
4725 survivors
1751.5 storms/century

GCM-06
CanESM2
27035 tracks
5578 survivors
3262.0 storms/century

GCM-07
CCSM4
19217 tracks
5353 survivors
2567.0 storms/century

GCM-11
CNRM-CM5
15277 tracks
1351 survivors
1663.8 storms/century

GCM-09
CMCC-CM
51229 tracks
7962 survivors
4869.7 storms/century

GCM-13
EC-EARTH
16691 tracks
3513 survivors
2355.1 storms/century

RCP85 scenario
2608.0 storms (per century)

GCM-10
CMCC-CMS
32433 tracks
4320 survivors
3292.7 storms/century

BEST

GCM-15
GFDL-CM3
26208 tracks
4126 survivors
2375.4 storms/century

GCM-17
GFDL-ESM2M
14802 tracks
1994 survivors
1496.3 storms/century

GCM-21
IPSL-CM5A-MR
16072 tracks
2692 survivors
1706.3 storms/century

GCM-26
MPI-ESM-LR
21306 tracks
3290 survivors
2718.3 storms/century

GCM-27
MPI-ESM-MR
15744 tracks
2070 survivors
1675.2 storms/century

GCM-18
HadGEM2-CC
18125 tracks
4075 survivors
1675.1 storms/century

GCM-23
MIROC5
16300 tracks
2291 survivors
1504.9 storms/century

GCM-24
MIROC-ESM
18160 tracks
2603 survivors
2515.0 storms/century

GCM-28
MRI-CGCM3
40967 tracks
7367 survivors
5338.4 storms/century

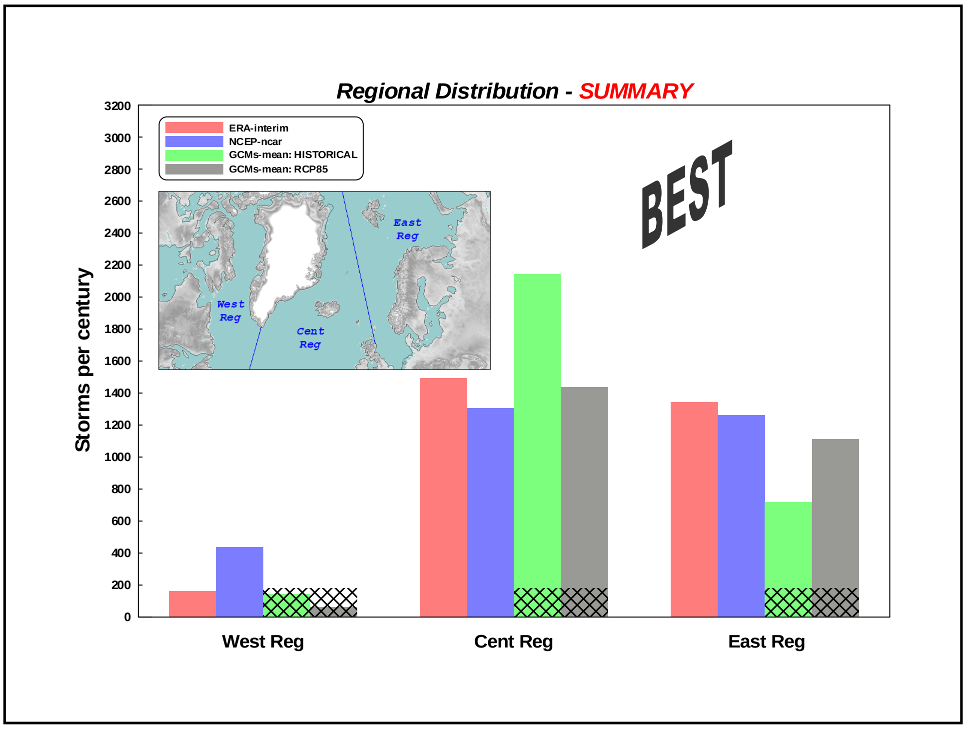
GCM-29
MRI-ESM1
38784 tracks
7043 survivors
5041.5 storms/century

GCM-20
IPSL-CM5A-LR
30113 tracks
4033 survivors
2809.2 storms/century

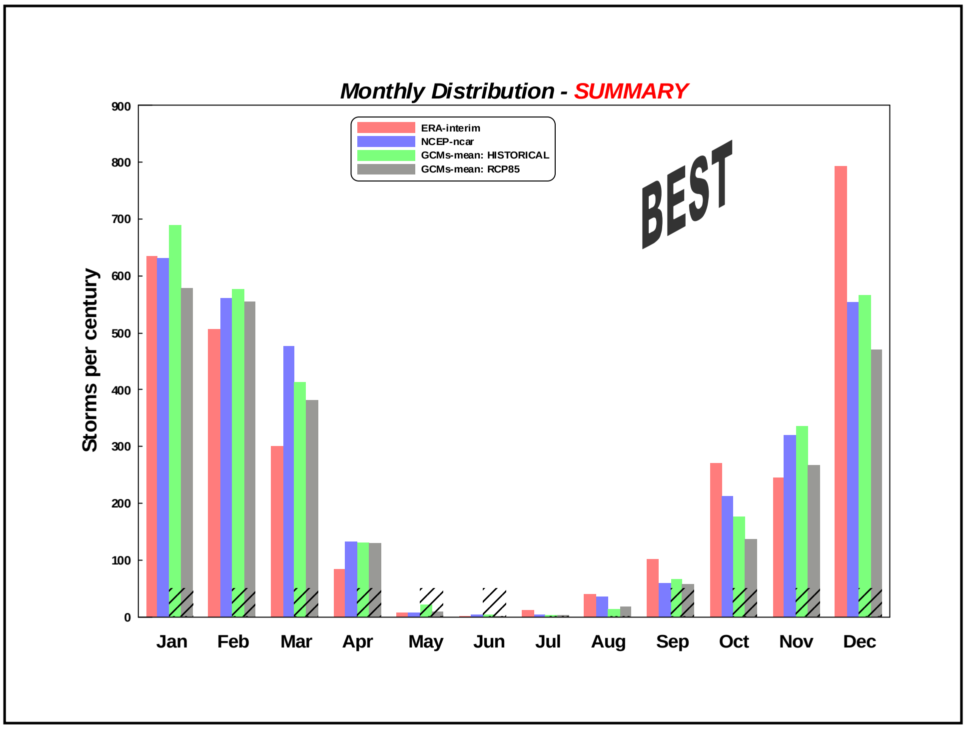
15 models ▼▼▼

5 models ▲▲▲

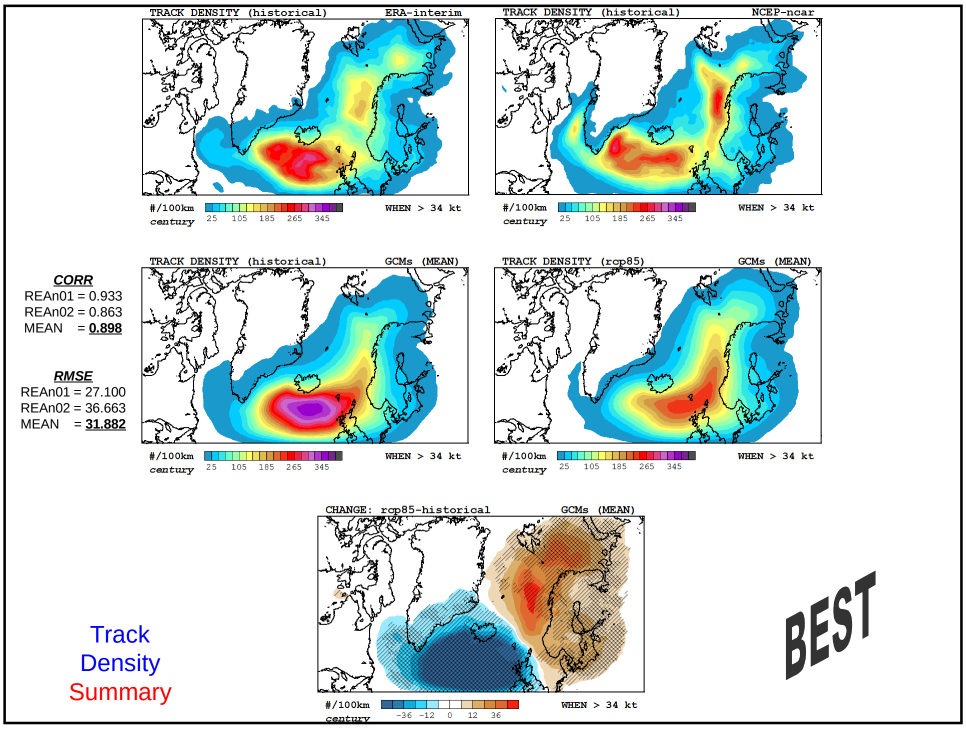
GCM-30
NorESM1-M
18125 tracks
3803 survivors
2066.9 storms/century

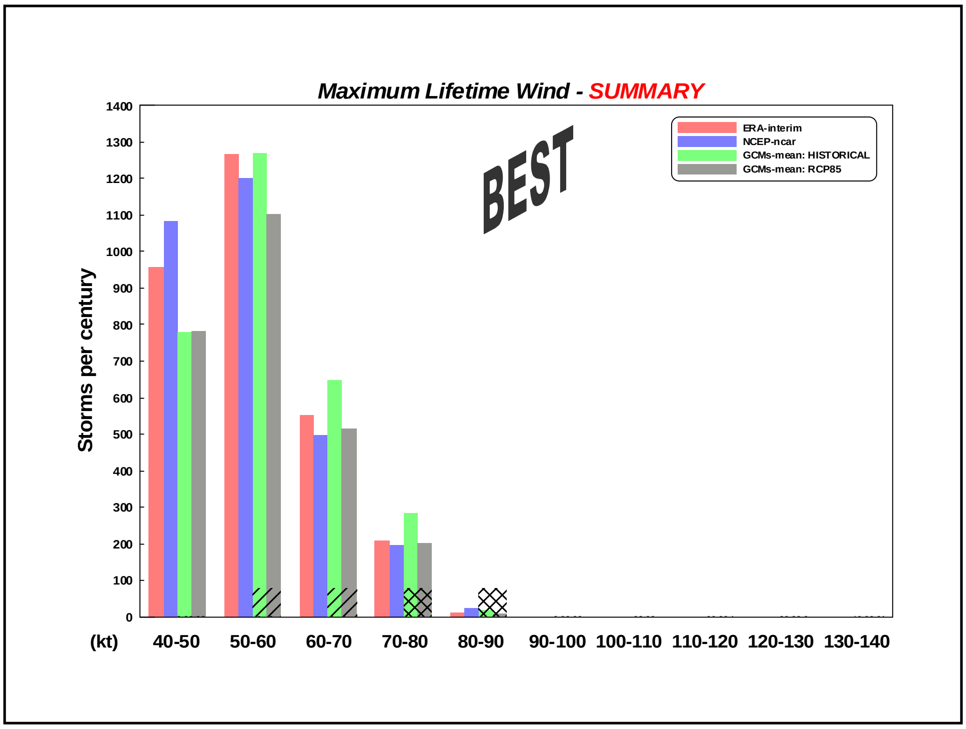


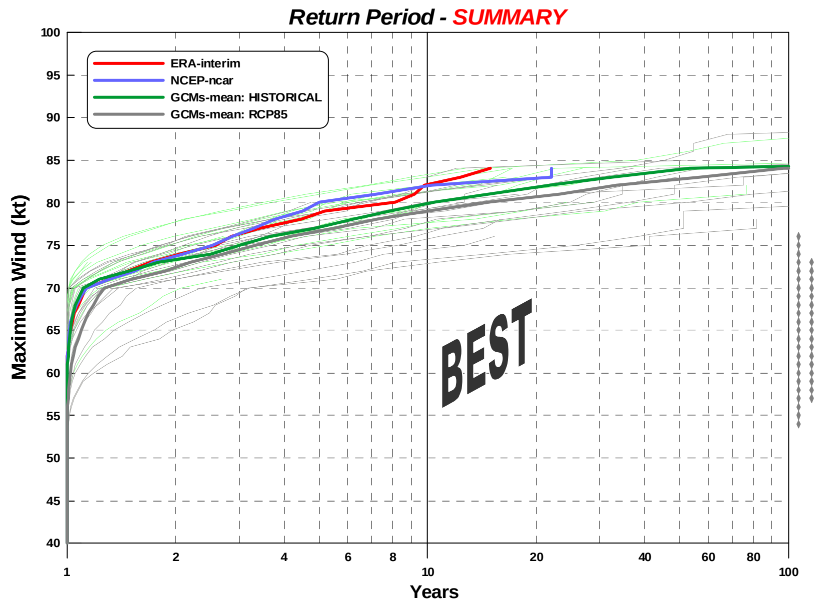
Regional Distribution - SUMMARY
ERA-interim
NCEP-ncar
GCMs-mean: HISTORICAL
GCMs-mean: RCP85
East Reg
West Reg
Cent Reg
BEST
Storms per century
3200
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
West Reg
Cent Reg
East Reg



Monthly Distribution - SUMMARY
ERA-interim
NCEP-ncar
GCMs-mean: HISTORICAL
GCMs-mean: RCP85
BEST
Storms per century
900
800
700
600
500
400
300
200
100
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

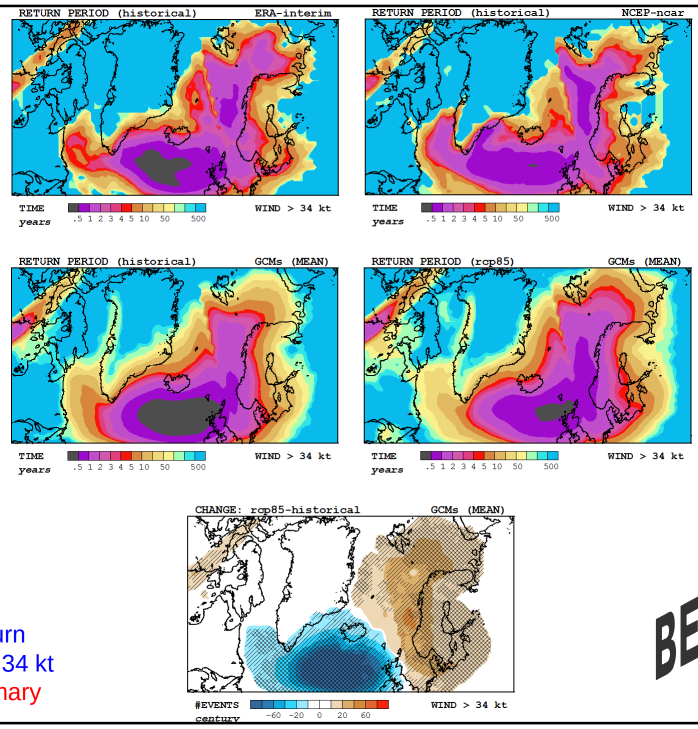

TRACK DENSITY (historical) ERA-interim
TRACK DENSITY (historical) NCEP-ncar
TRACK DENSITY (historical) GCMs (MEAN)
TRACK DENSITY (rcp85) GCMs (MEAN)
CHANGE: rcp85-historical GCMs (MEAN)
#/100km century
25 105 185 265 345
-36 -12 0 12 36
WHEN > 34 kt
CORR
REAn01 = 0.933
REAn02 = 0.863
MEAN = 0.898
RMSE
REAn01 = 27.100
REAn02 = 36.663
MEAN = 31.882
Track
Density
Summary
BEST


Maximum Lifetime Wind - SUMMARY
ERA-interim
NCEP-ncar
GCMs-mean: HISTORICAL
GCMs-mean: RCP85
BEST
Storms per century
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
(kt)
40-50
50-60
60-70
70-80
80-90
90-100
100-110
110-120
120-130
130-140



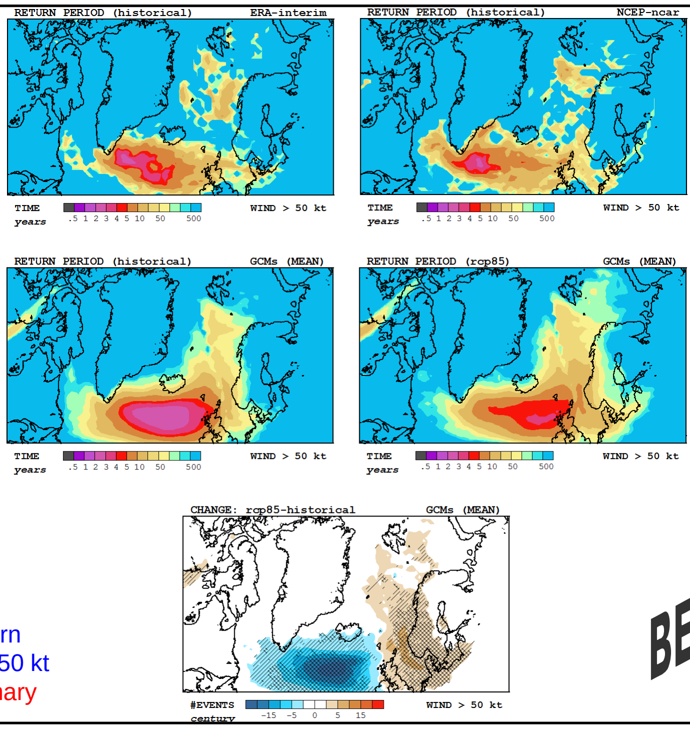
CORR
REAn01 = 0.694
REAn02 = 0.684
MEAN = **0.689**

RMSE
REAn01 = 9.232
REAn02 = 9.445
MEAN = **9.339**



Return
Period 34 kt
Summary

BEST



CORR
REAn01 = 0.675
REAn02 = 0.686
MEAN = **0.680**

RMSE
REAn01 = 9.780
REAn02 = 9.637
MEAN = **9.709**

Return Period 50 kt Summary

BEST

CONCLUSIONS

- ***Our statistical-deterministic approach is a good alternative to computationally expensive classical methods (e.g. dynamical downscaling of polar lows), with the extra benefit of producing statistically large populations of events***

- ***We expect a future reduction in the overall frequency of NA polar lows that would uniformly affect the full spectrum of storm intensities over all cold season months: 10-15% fewer storms on average (but great uncertainty among models)***

- ***The future decrease of polar lows is far from uniform across the North Atlantic basin. Rather, a very robust regional redistribution of cases is projected, namely a shift of polar low activity from the south Greenland-Icelandic sector towards the Nordic Seas closer to Scandinavia***

- ***Future conditions do not seem to lead to any significant variation in the relative weights of weak, moderate and strong polar lows at basin scale. But since the number of storms is expected to decrease, we project a reduced probability of any surface wind threshold (i.e. longer return periods), considering the basin as a whole***

- ***Again, large regional variability is expected, and while the future risk of strong polar low winds is projected to be lower in the western half of the North Atlantic, more extreme events are expected eastwards, thus potentially affecting the coasts of Europe***