Climate Change and the Future of Medicanes: Statistical-Deterministic Projections based on CMIP5 Models

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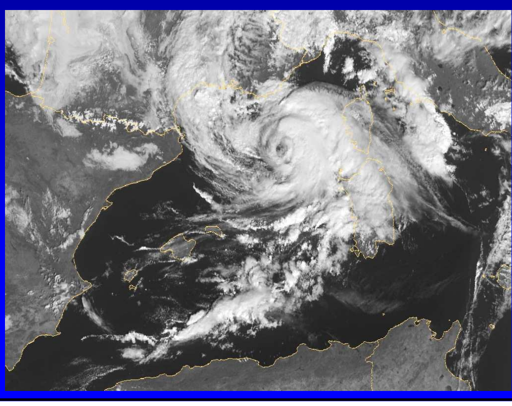
MOTIVATION

***Medicanes** 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 fishing, cruises and recreational boating:*

- ***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-latitude weather systems. In addition, existing data of medicane 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*

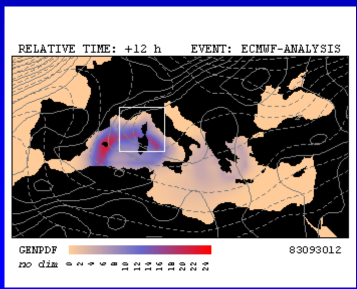
- Application of an *empirical index of genesis*:

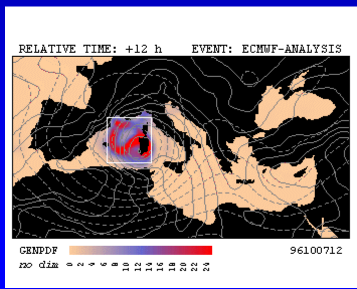
$$I = \left|10^5 \eta\right|^{3/2} \left(\frac{H}{50}\right)^3 \left(\frac{V_{pot}}{70}\right)^3 \left(1 + 0.1 V_{shear}\right)^{-2},$$

GENIX parameter
(Emanuel and Nolan, 2004)

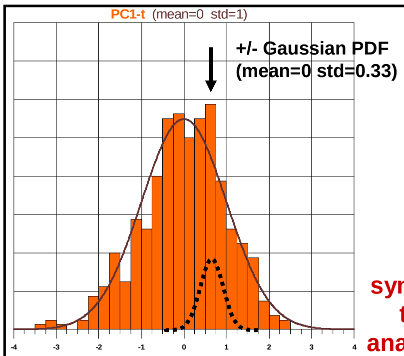
$\eta \equiv 850\ hPa\ absolute\ vorticity\ (s^{-1})$, $H \equiv 600\ mb\ relative\ humidity\ (\%)$,

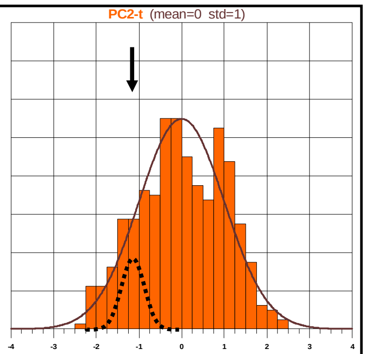
$V_{pot} \equiv Potential\ wind\ speed\ (ms^{-1})$, $V_{shear} \equiv \left|\mathbf{V}_{850} - \mathbf{V}_{250}\right|\ (ms^{-1})$.



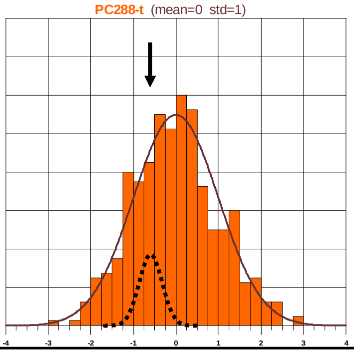


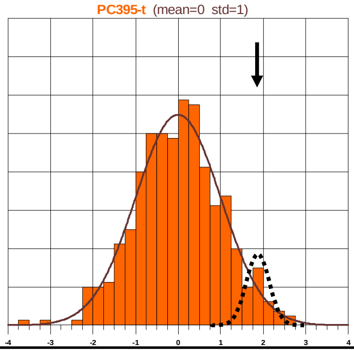
- *Necessary but no sufficient* **ingredient …**

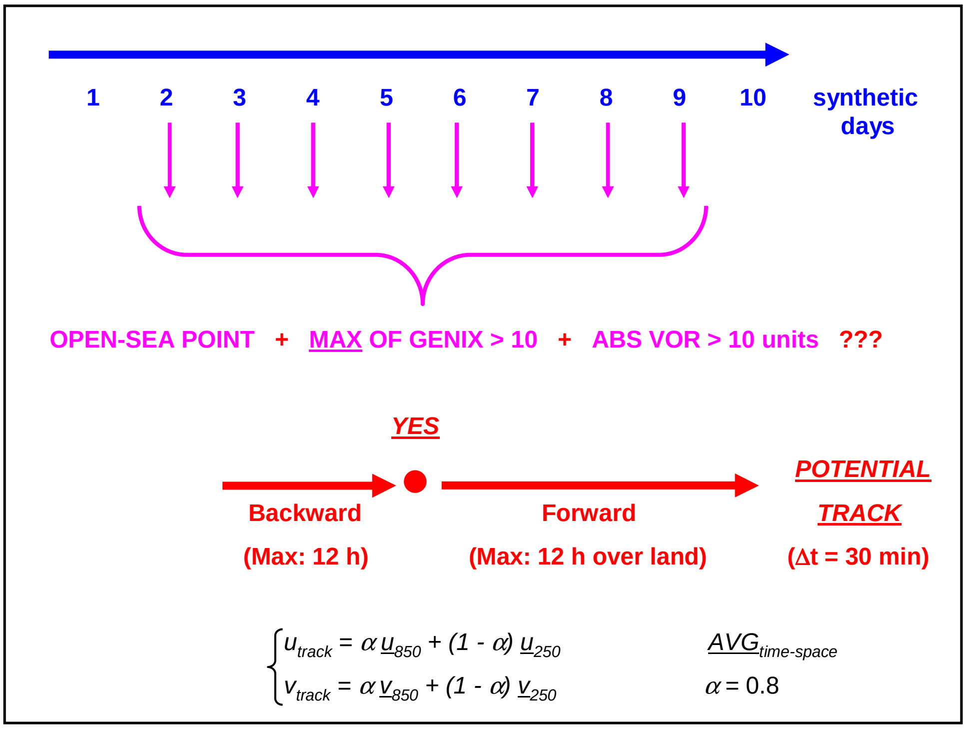




Production of synoptic evolutions that behave as analogs of locations actually visited in the climate phase space !!!



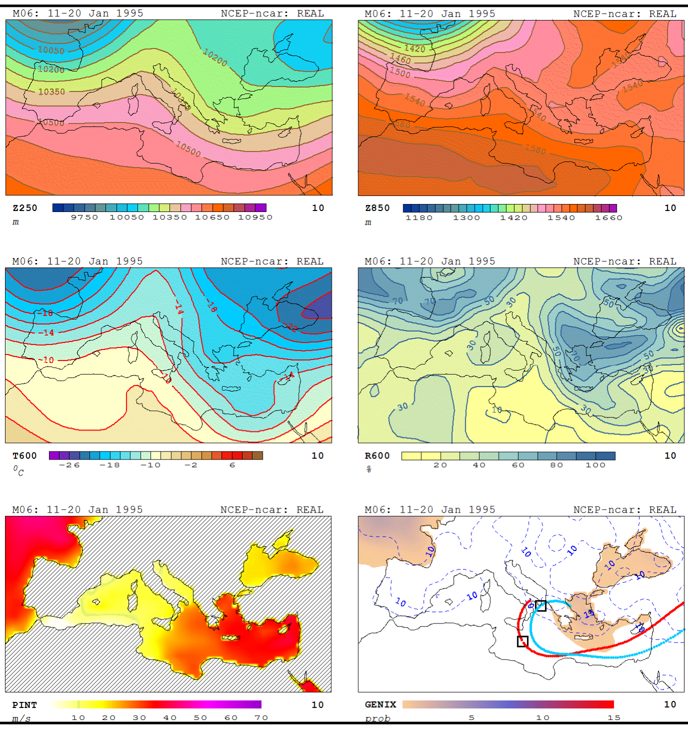




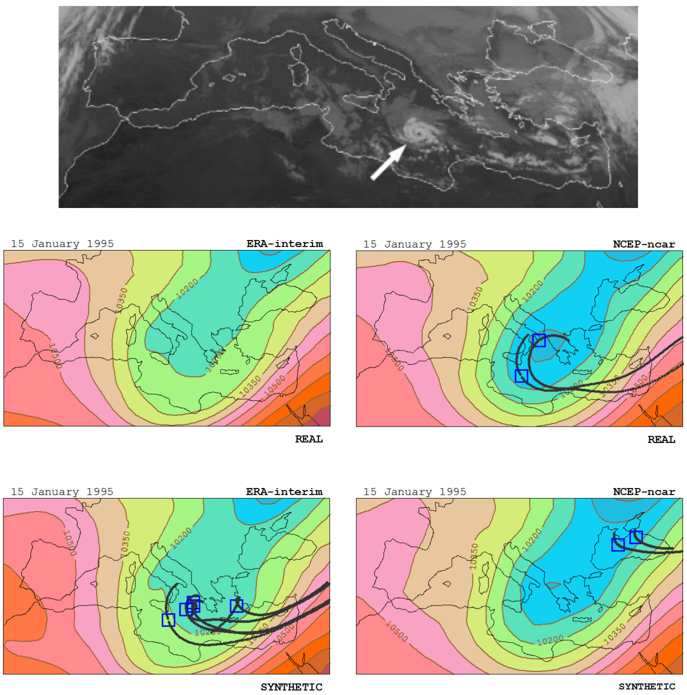
ILLUSTRATIVE EXAMPLE

“LYBIAN” MEDICANE
Central Mediterranean, 15-16 January 1995

TRACKING method



SYNTHETIC analogues



REANALYSES AND CMIP5 MODELS

REANALYSIS 1	***REANALYSIS 2***
ERA-interim	***NCEP-ncar***
ECMWF (Europe)	NOAA (USA)
LON 0.75º x LAT 0.75º	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

ERA-interim

20349 tracks
7918 survivors

200 storms/century

REANALYSIS 2

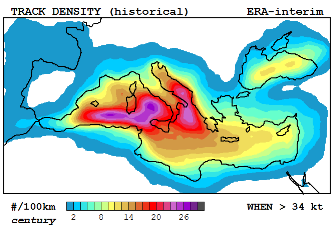
NCEP-ncar

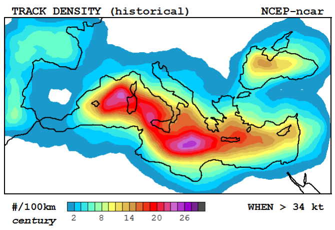
20276 tracks
6379 survivors

200 storms/century

HISTORICAL scenario

200 storms
(per century)





GCM-01
ACCESS1.0
20325 tracks
7188 survivors
200 storms/century

GCM-02
ACCESS1.3
20086 tracks
7281 survivors
200 storms/century

GCM-06
CanESM2
20097 tracks
5268 survivors
200 storms/century

GCM-07
CCSM4
20405 tracks
7012 survivors
200 storms/century

GCM-11
CNRM-CM5
20329 tracks
6535 survivors
200 storms/century

GCM-12
CSIRO-Mk3.6.0
20048 tracks
6034 survivors
200 storms/century

GCM-03
BCC-CSM1.1
20083 tracks
3045 survivors
200 storms/century

GCM-04
BCC-CSM1.1(m)
20142 tracks
5167 survivors
200 storms/century

GCM-08
CMCC-CESM
20106 tracks
4733 survivors
200 storms/century

GCM-09
CMCC-CM
20085 tracks
6368 survivors
200 storms/century

GCM-13
EC-EARTH
20180 tracks
7793 survivors
200 storms/century

GCM-14
FGOALS-g2
20481 tracks
1925 survivors
200 storms/century

GCM-05
BNU-ESM
20071 tracks
2946 survivors
200 storms/century

HISTORICAL scenario

200 storms
(per century)

GCM-10
CMCC-CMS
20119 tracks
5738 survivors
200 storms/century

ALL

GCM-15
GFDL-CM3
20475 tracks
5307 survivors
200 storms/century

GCM-16
GFDL-ESM2G
20444 tracks
5309 survivors
200 storms/century

GCM-17
GFDL-ESM2M
20374 tracks
5596 survivors
200 storms/century

GCM-21
IPSL-CM5A-MR
20178 tracks
4919 survivors
200 storms/century

GCM-22
IPSL-CM5B-LR
20592 tracks
5681 survivors
200 storms/century

GCM-26
MPI-ESM-LR
20082 tracks
6015 survivors
200 storms/century

GCM-27
MPI-ESM-MR
20745 tracks
5678 survivors
200 storms/century

GCM-18
HadGEM2-CC
20392 tracks
7860 survivors
200 storms/century

GCM-19
INM-CM4
20018 tracks
5047 survivors
200 storms/century

GCM-23
MIROC5
20651 tracks
6651 survivors
200 storms/century

GCM-24
MIROC-ESM
20268 tracks
5709 survivors
200 storms/century

GCM-28
MRI-CGCM3
20541 tracks
5647 survivors
200 storms/century

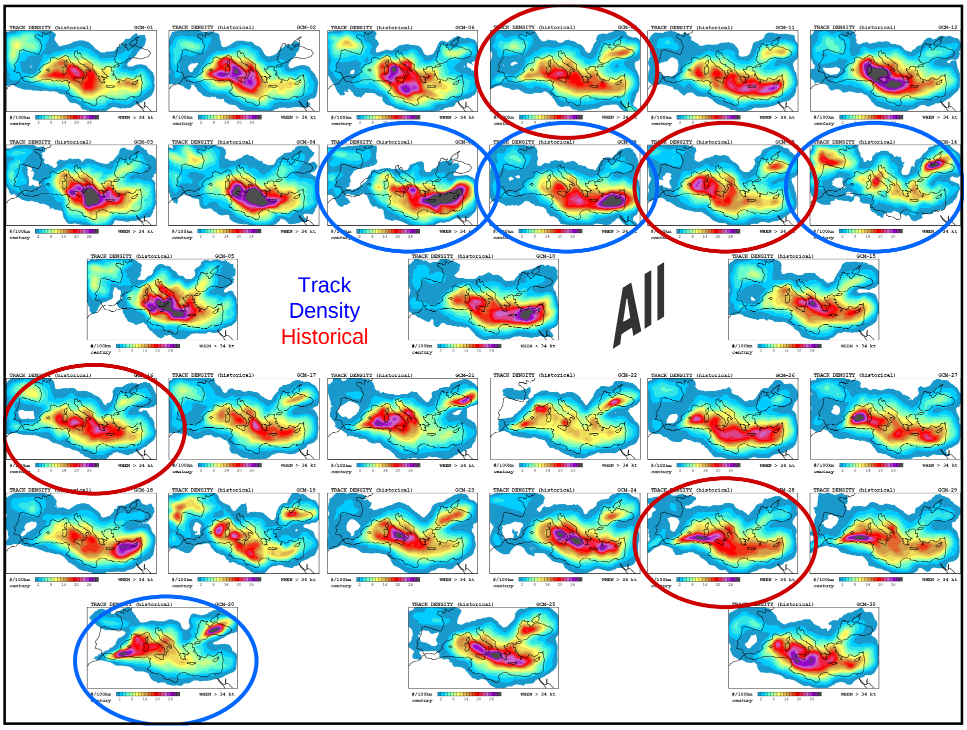
GCM-29
MRI-ESM1
21203 tracks
5898 survivors
200 storms/century

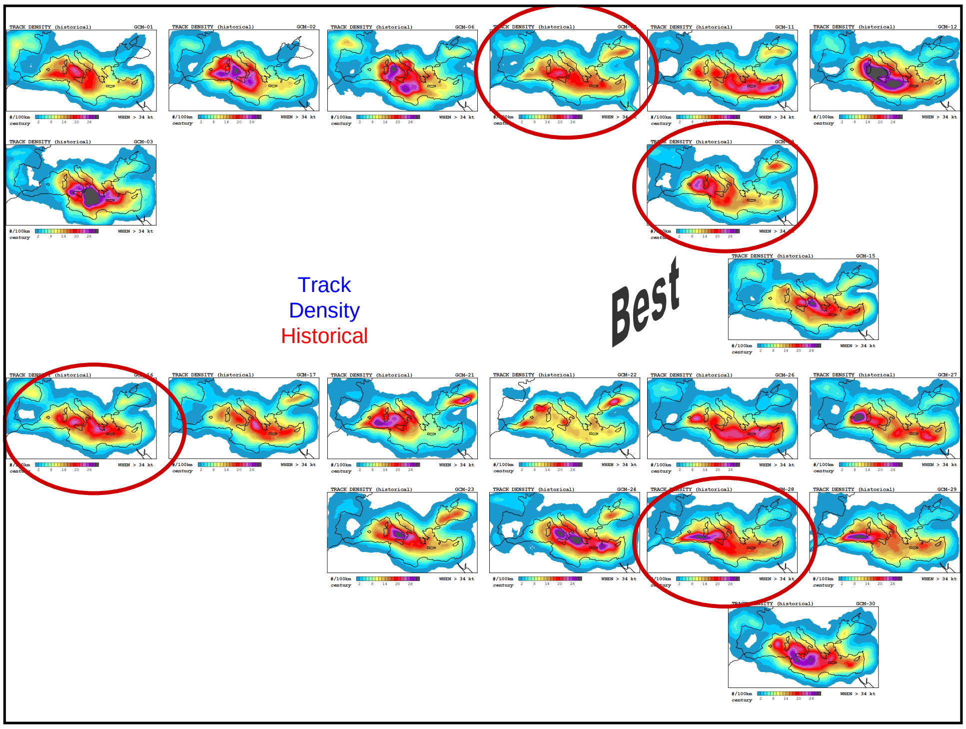
GCM-20
IPSL-CM5A-LR
20176 tracks
5064 survivors
200 storms/century

GCM-25
MIROC-ESM-CHEM
20026 tracks
5517 survivors
200 storms/century

GCM-30
NorESM1-M
20022 tracks
6558 survivors
200 storms/century

GCM-01 *ACCESS1.0* 22539 tracks 7521 survivors 209.27 storms/century	GCM-02 *ACCESS1.3* 28304 tracks 8335 survivors 228.95 storms/century	GCM-06 *CanESM2* 14750 tracks 3843 survivors 145.90 storms/century	GCM-07 *CCSM4* 20560 tracks 6236 survivors 177.87 storms/century	GCM-11 *CNRM-CM5* 30505 tracks 8689 survivors 265.92 storms/century	GCM-12 *CSIRO-Mk3.6.0* 12085 tracks 2382 survivors 78.95 storms/century
GCM-03 *BCC-CSM1.1* 20439 tracks 2932 survivors 192.58 storms/century	GCM-04 *BCC-CSM1.1(m)* 13761 tracks 3523 survivors 136.37 storms/century	GCM-08 *CMCC-CESM* 17277 tracks 3772 survivors 159.39 storms/century	GCM-09 *CMCC-CM* 22778 tracks 7300 survivors 229.27 storms/century	GCM-13 *EC-EARTH* 32781 tracks 12359 survivors 317.18 storms/century	GCM-14 *FGOALS-g2* 29286 tracks 2730 survivors 283.64 storms/century
GCM-05 *BNU-ESM* 27750 tracks 3820 survivors 259.34 storms/century	*RCP85 scenario* 198.52 storms (per century)	GCM-10 *CMCC-CMS* 20675 tracks 6194 survivors 215.89 storms/century	ALL	GCM-15 *GFDL-CM3* 17779 tracks 4171 survivors 157.19 storms/century	
GCM-16 *GFDL-ESM2G* 20348 tracks 4686 survivors 176.53 storms/century	GCM-17 *GFDL-ESM2M* 16884 tracks 3996 survivors 142.82 storms/century	GCM-21 *IPSL-CM5A-MR* 14172 tracks 2382 survivors 96.85 storms/century	GCM-22 *IPSL-CM5B-LR* 23922 tracks 6328 survivors 222.78 storms/century	GCM-26 *MPI-ESM-LR* 19684 tracks 6708 survivors 223.04 storms/century	GCM-27 *MPI-ESM-MR* 21590 tracks 6969 survivors 245.47 storms/century
GCM-18 *HadGEM2-CC* 24510 tracks 7503 survivors 190.92 storms/century	GCM-19 *INM-CM4* 12250 tracks 2844 survivors 112.70 storms/century	GCM-23 *MIROC5* 29654 tracks 9216 survivors 277.13 storms/century	GCM-24 *MIROC-ESM* 27239 tracks 5499 survivors 192.64 storms/century	GCM-28 *MRI-CGCM3* 22758 tracks 5993 survivors 212.25 storms/century	GCM-29 *MRI-ESM1* 23950 tracks 6432 survivors 218.11 storms/century
GCM-20 *IPSL-CM5A-LR* 23722 tracks 5438 survivors 214.77 storms/century	15 models ▼▼▼	GCM-25 *MIROC-ESM-CHEM* 26010 tracks 5283 survivors 191.52 storms/century	15 models ▲▲▲	GCM-30 *NorESM1-M* 22427 tracks 5914 survivors 180.36 storms/century	





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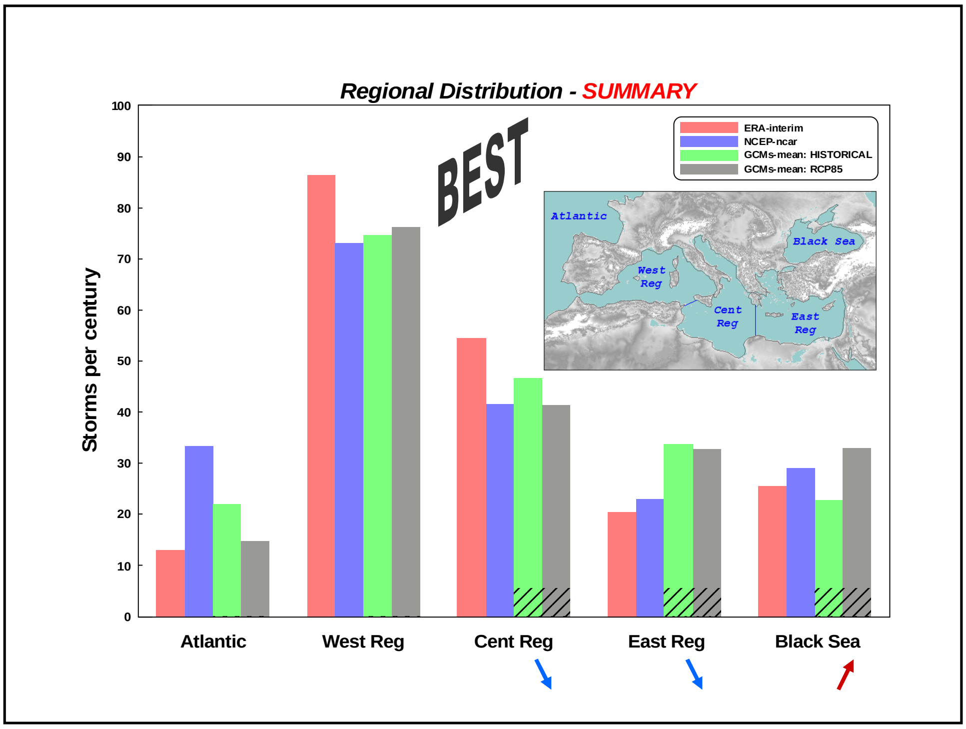
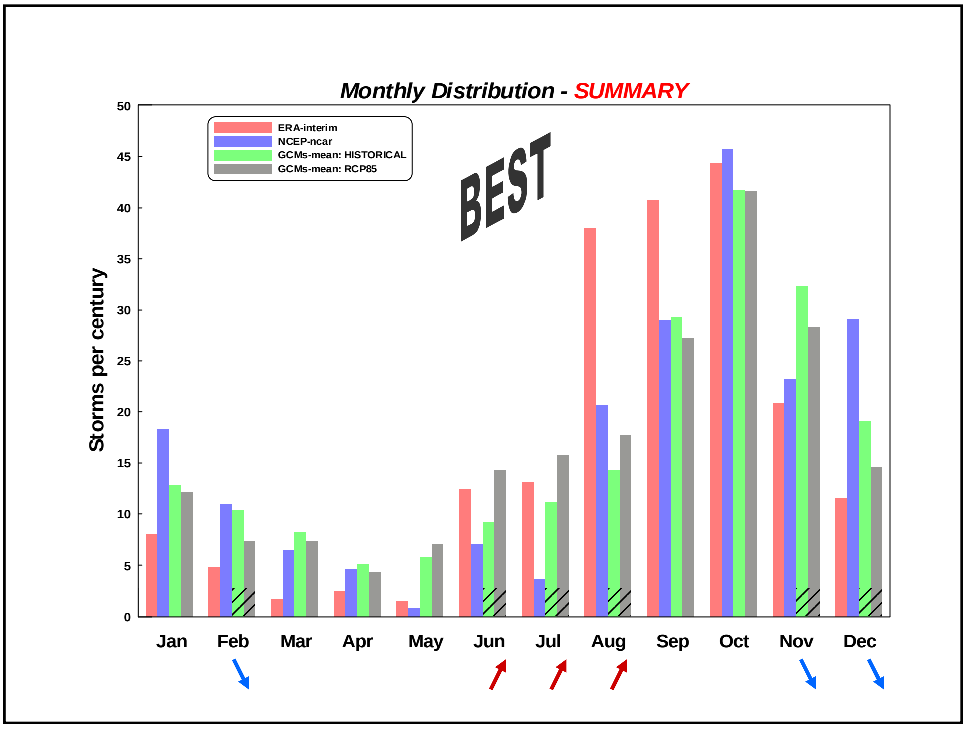
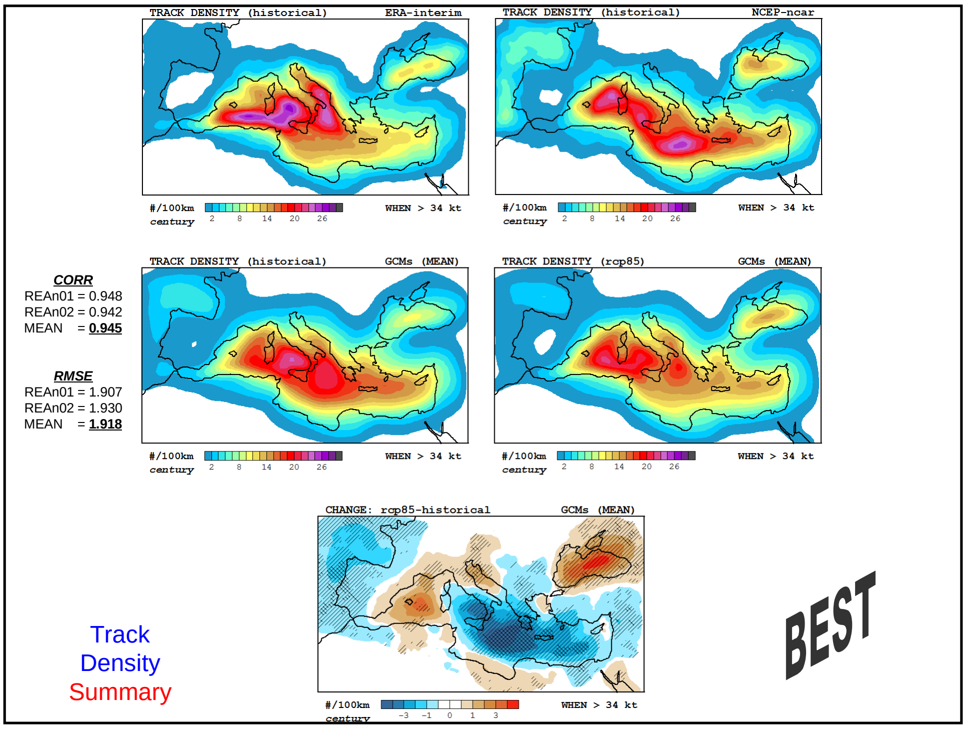
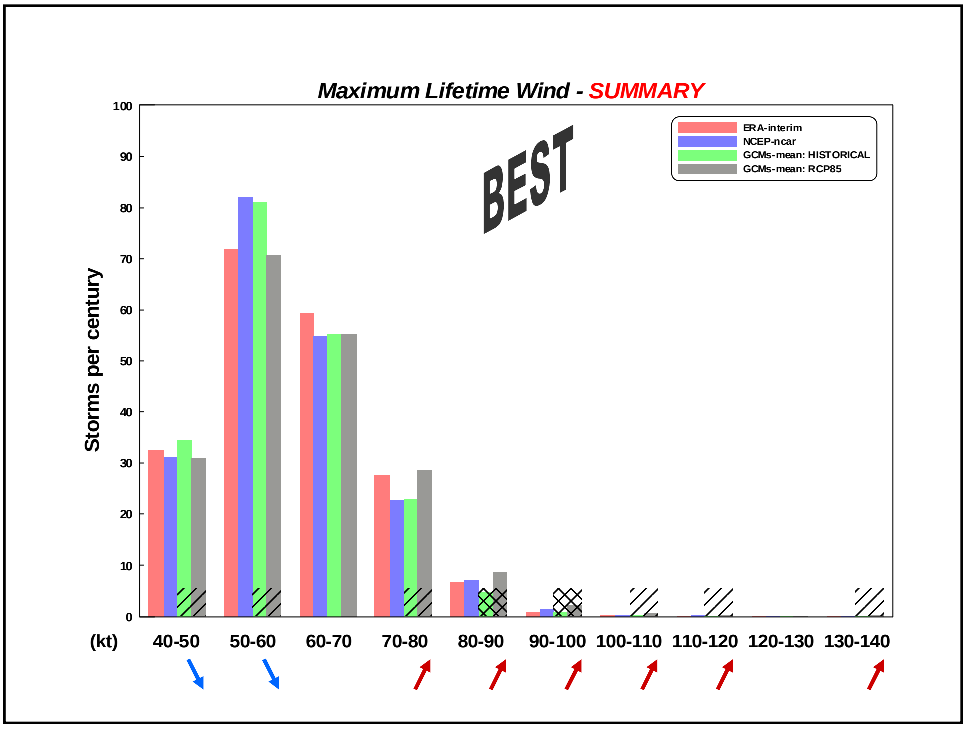
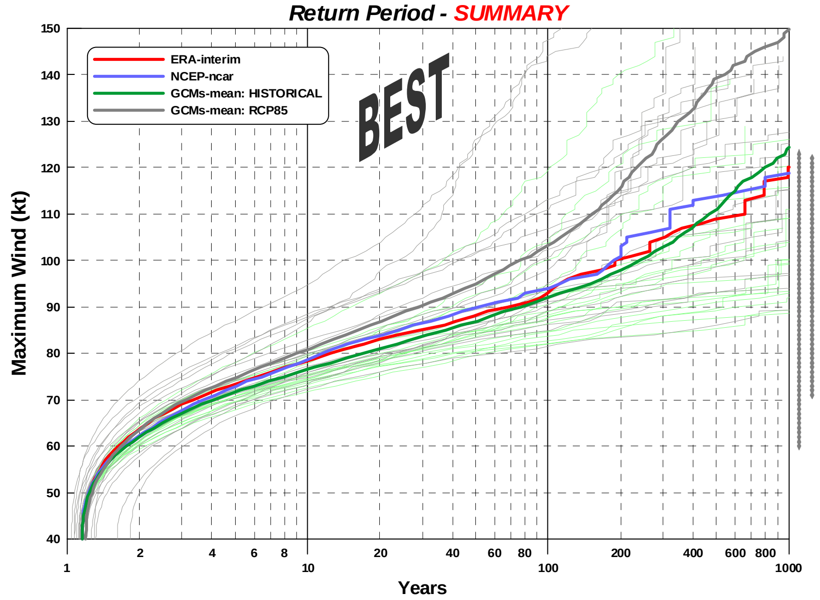
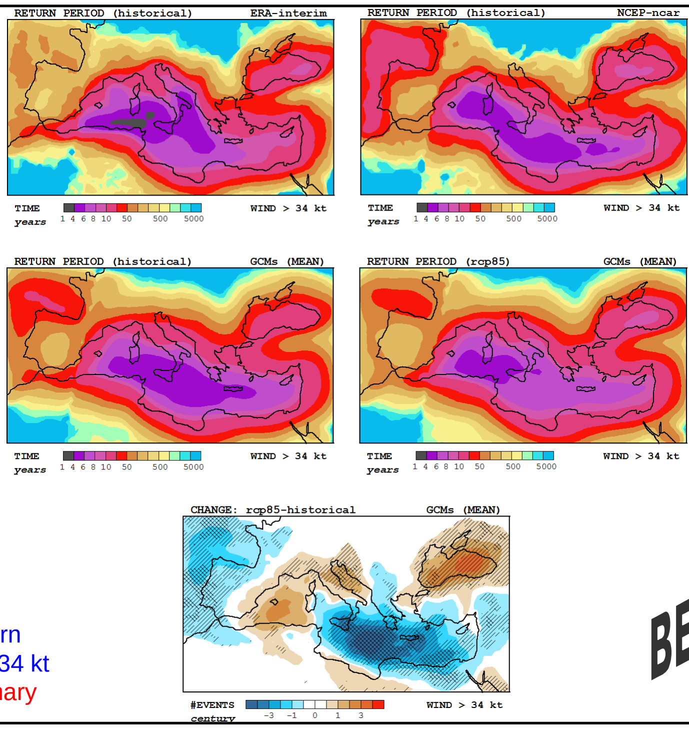

Regional Distribution - SUMMARY
Storms per century
ERA-interim
NCEP-ncar
GCMs-mean: HISTORICAL
GCMs-mean: RCP85
BEST
Atlantic
Black Sea
West Reg
Cent Reg
East Reg
0
10
20
30
40
50
60
70
80
90
100
Atlantic
West Reg
Cent Reg
East Reg
Black Sea


Monthly Distribution - SUMMARY
Storms per century
ERA-interim
NCEP-ncar
GCMs-mean: HISTORICAL
GCMs-mean: RCP85
BEST
0
5
10
15
20
25
30
35
40
45
50
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


TRACK DENSITY (historical) ERA-interim
TRACK DENSITY (historical) NCEP-ncar
#/100km century
WHEN > 34 kt
TRACK DENSITY (historical) GCMs (MEAN)
TRACK DENSITY (rcp85) GCMs (MEAN)
CORR
REAn01 = 0.948
REAn02 = 0.942
MEAN = 0.945
RMSE
REAn01 = 1.907
REAn02 = 1.930
MEAN = 1.918
CHANGE: rcp85-historical GCMs (MEAN)
Track
Density
Summary
BEST


Maximum Lifetime Wind - SUMMARY
ERA-interim
NCEP-ncar
GCMs-mean: HISTORICAL
GCMs-mean: RCP85
BEST
Storms per century
(kt)
40-50
50-60
60-70
70-80
80-90
90-100
100-110
110-120
120-130
130-140



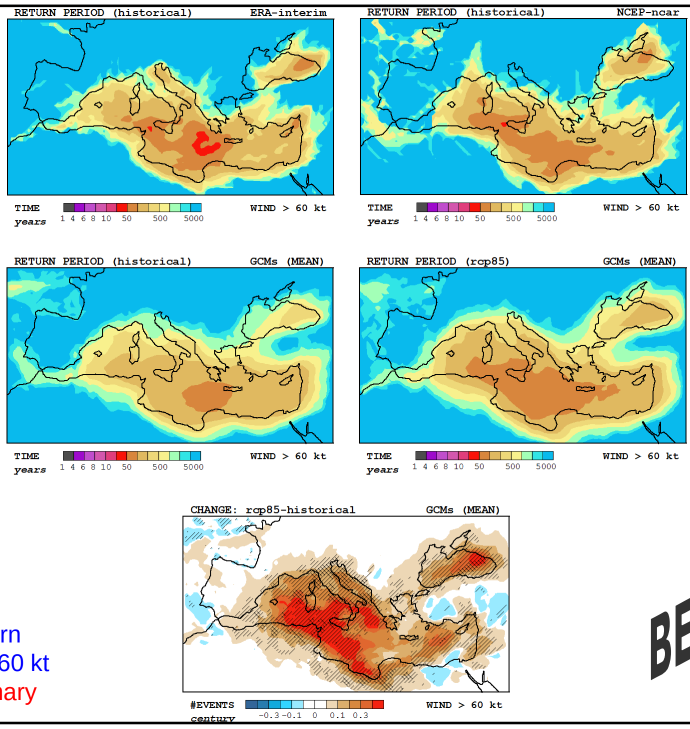


CORR
REAn01 = 0.768
REAn02 = 0.742
MEAN = **0.755**

RMSE
REAn01 = 2.157
REAn02 = 4.131
MEAN = **3.144**

Return
Period 34 kt
Summary

BEST



CORR
REAn01 = 0.604
REAn02 = 0.649
MEAN = **0.626**

RMSE
REAn01 = 4.972
REAn02 = 8.418
MEAN = **6.695**

Return Period 60 kt Summary

BEST

CONCLUSIONS

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

- ***Future change in the number of medicanes is unclear (on average the total frequency of storms does not vary) but a profound redistribution is found. Our method projects an increased occurrence of medicanes in the western Mediterranean and Black Sea, balanced by a reduction of storm tracks in contiguous areas, particularly in the central Mediterranean***

- ***The probability of medicanes may increase during the summer while it may decrease during the late fall and winter; the probability maximum will still occur around October***

- ***We found a remarkable modification of the spectrum of lifetime maximum winds: the results project a higher number of moderate and violent medicanes at the expense of weak storms***

- ***In particular, future extreme events (winds > 60 kt) become more likely in all Mediterranean regions, and the probability of violent medicanes (winds > 90 kt) for the basin as a whole more than doubles the current risk. As the destructive power of the storms is proportional to the wind speed cubed, these projected changes of storm intensity raise concern about the future vulnerability of Mediterranean coastal regions***