Hurricanes and typhoons in the global climate system

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[7] ECMF
[8] ISAC-CNR
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Co-funded by
the European Union

Motivation: TCs as rare, albeit significant contributors to climate

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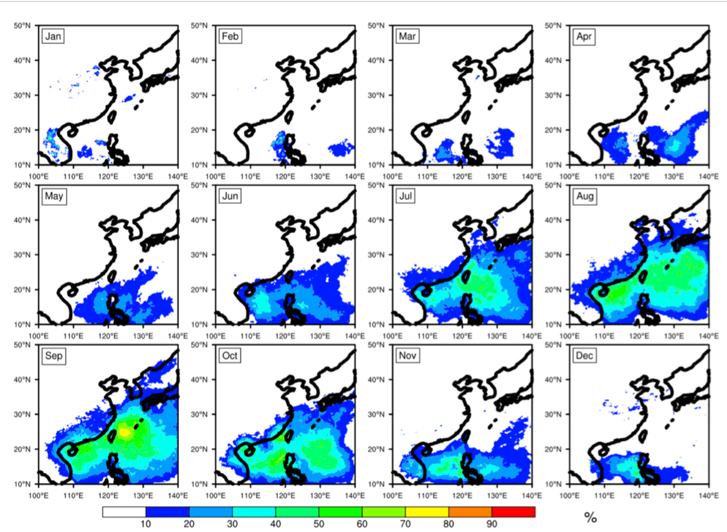


FIG. 2. Monthly mean fractional contribution of TC rainfall amount to the total rainfall calculated using TRMM 3B42 rainfall data. Units: %.

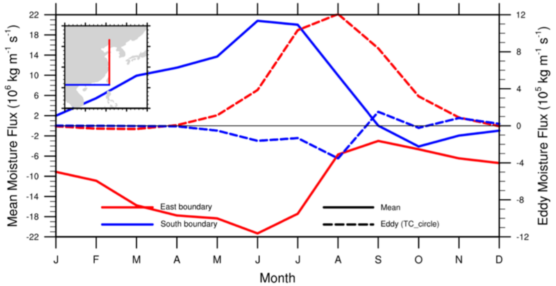
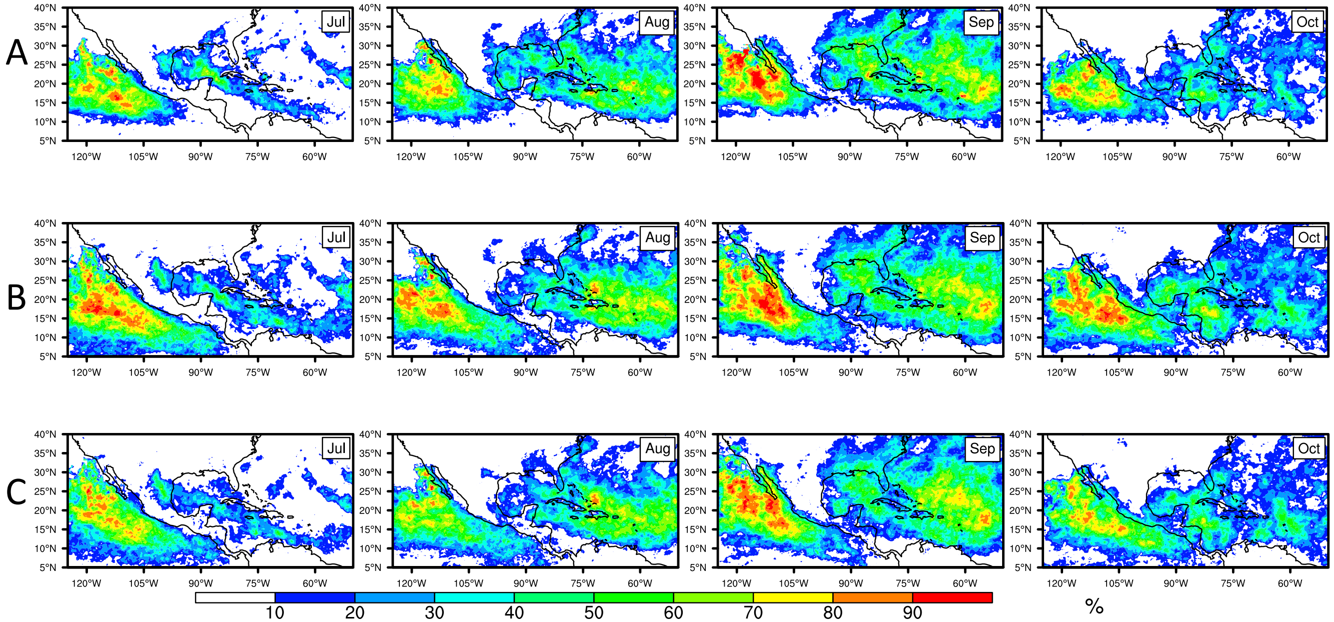


FIG. 5. Seasonal cycle of monthly mean vertically integrated moisture flux passing through the southern (blue) and eastern (red) boundaries. Mean flow moisture fluxes are shown as solid lines and TC eddy moisture fluxes as dash lines. The inner panel shows the definition of the southern and eastern boundaries. Units: kg/m/s.

Guo et al. 2017



Contribution of TCs to the extreme rainfall (amount fraction) (%) from July to October, employing TCs tracks from (a) IBTrACS, (b) JRA-55 and (c) ERA-Interim. **Climatology for 1998-2015**

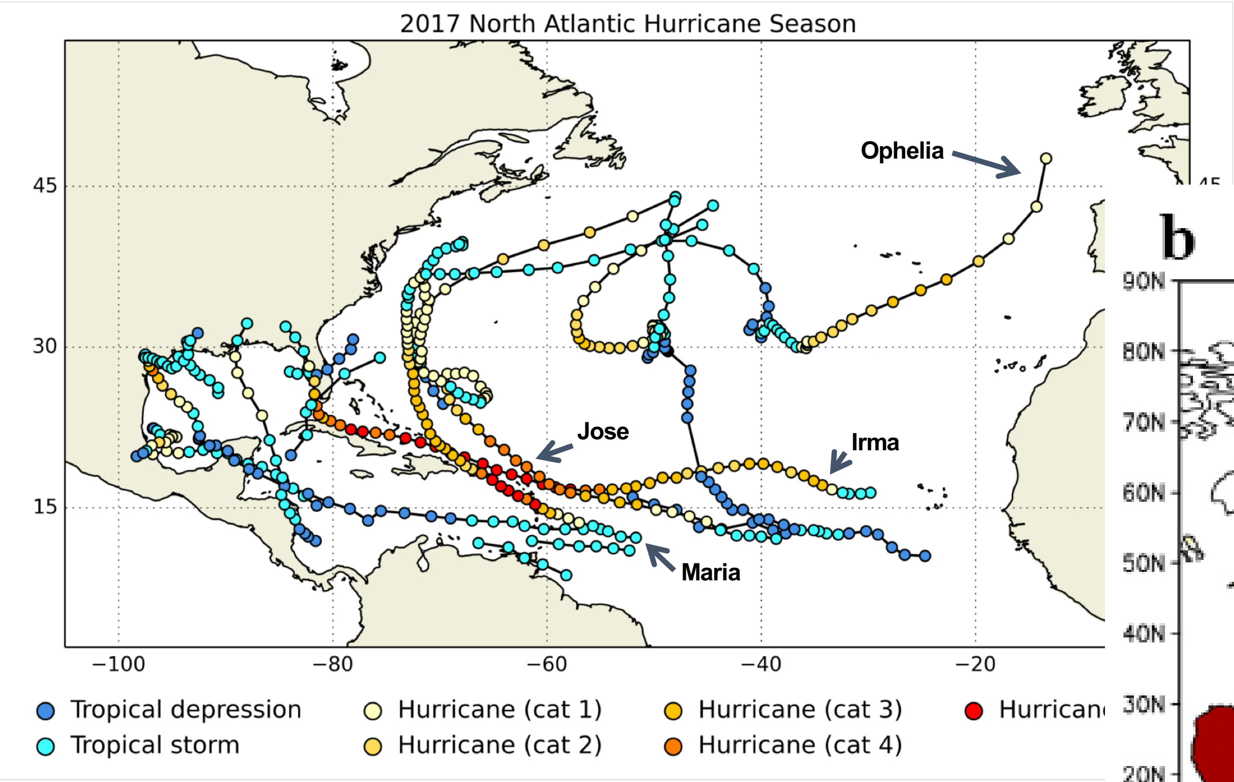
Franco-Diaz et al. 2018 in prep.

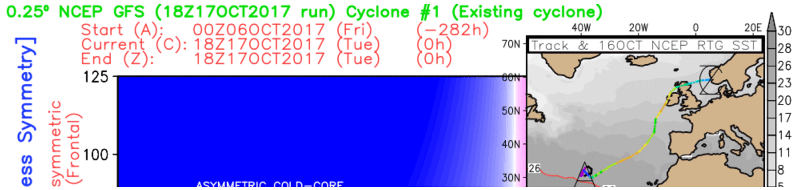
Re-analyses very likely <u>under-estimating the role of TCs</u> in producing precipitation and moisture transports.

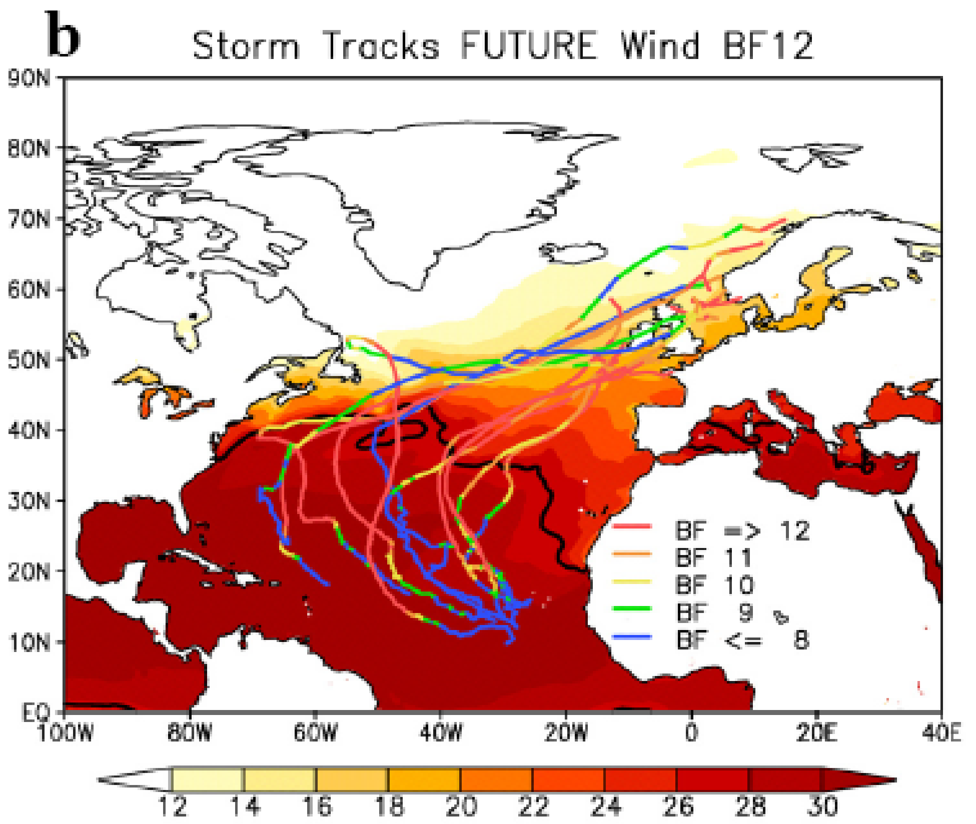
What is the role of model resolution, model physics, DA?

National Centre for Atmospheric Science
NATURAL ENVIRONMENT RESEARCH COUNCIL

Motivation II: a changing risk from TCs







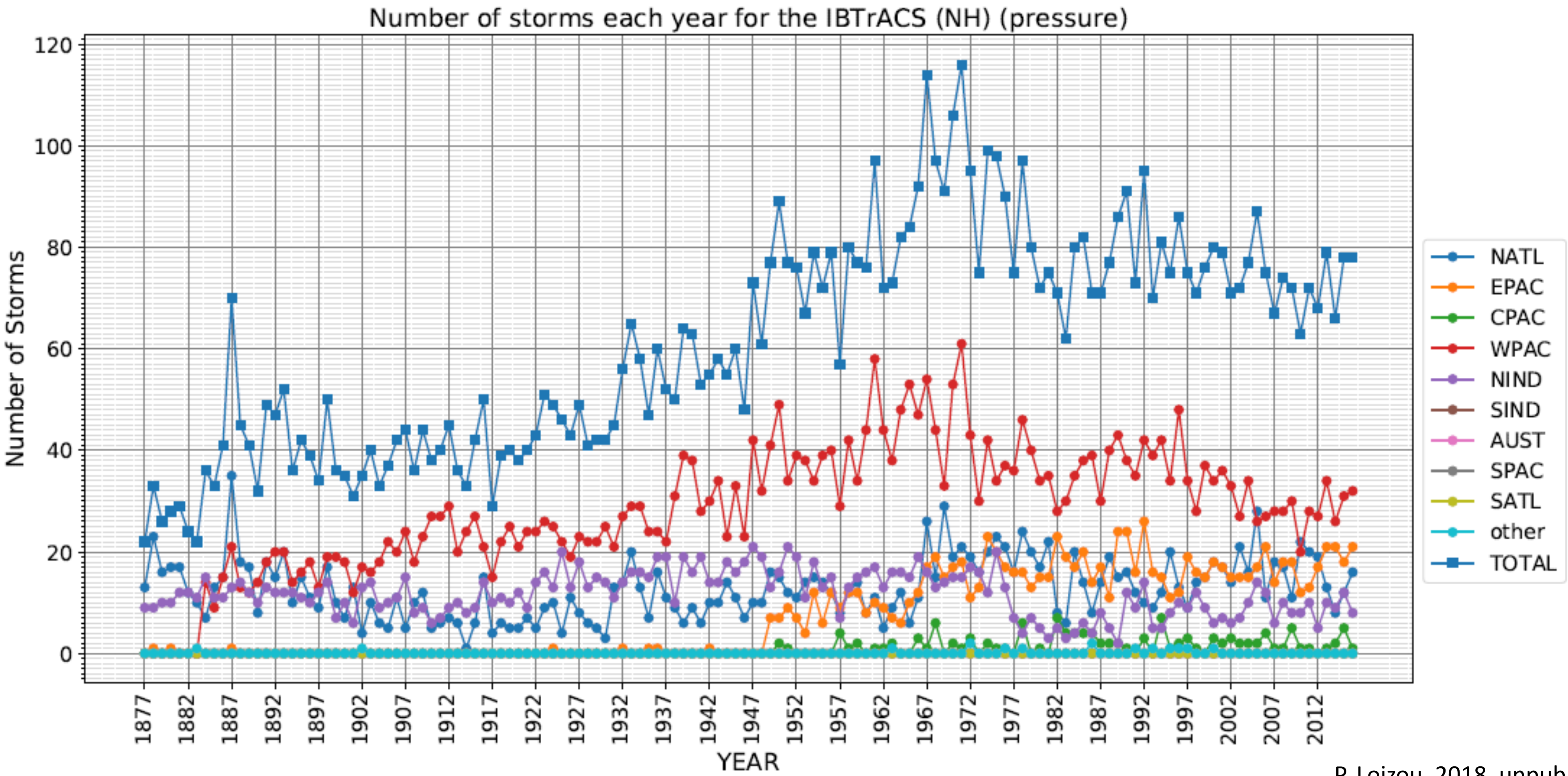
Total storms: 17

- 17 tropical storms (39+ mph)
- 10 hurricanes (74+ mph)
- 6 major hurricanes (111+ mph)

Thanks to Jo Camp

Accumulated Cyclone Energy (ACE) index = 226

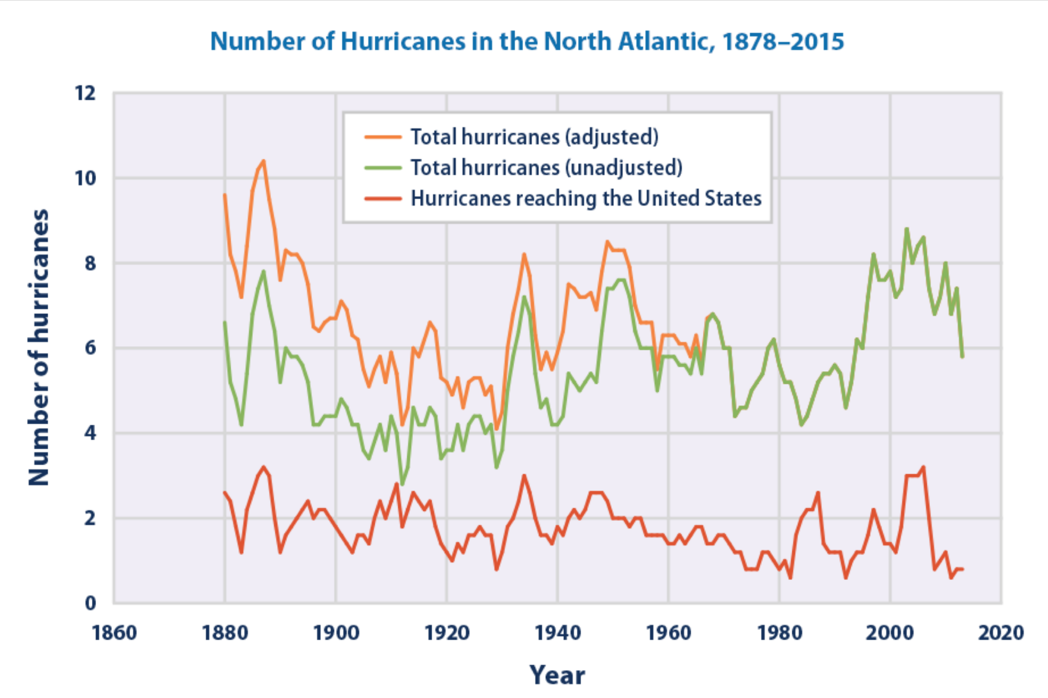
TC observations are just a mess… (K. Hodges, 2018)



P. Loizou, 2018, unpublished

There is a constant effort to re-visit and complete TC observations

Careful with fitting linear trends…



Data sources:

- NOAA (National Oceanic and Atmospheric Administration). 2016. The Atlantic Hurricane Database Re-analysis Project. www.aoml.noaa.gov/hrd/hurdat/comparison_table.html.
- Vecchi, G.A., and T.R. Knutson. 2011. Estimating annual numbers of Atlantic hurricanes missing from the HURDAT database (1878–1965) using ship track density. J. Climate 24(6):1736–1746. www.gfdl.noaa.gov/bibliography/related_files/gav_2010JCLI3810.pdf.

For more information, visit U.S. EPA's "Climate Change Indicators in the United States" at www.epa.gov/climate-indicators.

Vecchi and Knutson 2011

Analyses of long time series (basically NATL) show that **substantial decadal variability is present** and needs to be considered in risk estimates and management actions.

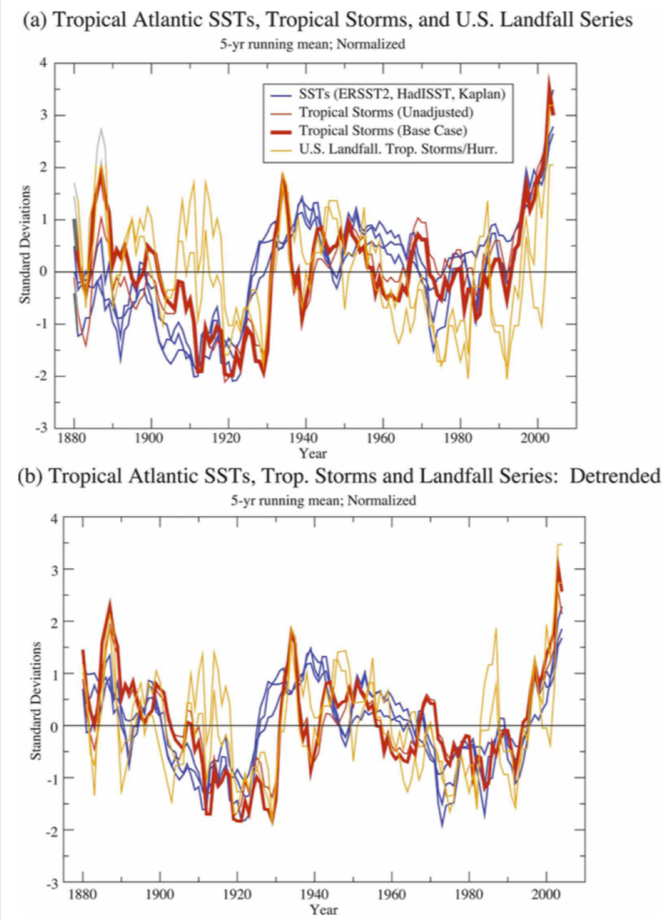


FIG. 10. (a) The 5-yr running mean normalized Atlantic MDR SST indices from three different reconstructions of SST (see text) overlaid on Atlantic TC counts. Blue curves are the three MDR SST reconstructions. The heavy red curve is the base-case TC count. The light red curve is the unadjusted TC count. The orange curves are U.S. landfalling tropical storm and hurricane count series from HURDAT. Curves in (b) have been detrended using ordinary least squares best fits.

Vecchi and Knutson 2008

TCs in 6 re-analyses

University of Reading

DATASET	PERIOD	MODEL RESOLUTION	DATA GRID
IBTrACS	1877-2017		
ERAI	1979-2016	TL255L60 (80 km)	512 × 256
MERRA	1979-2015	$1/2° \times 2/3°$ L72 (55 km)	540 × 361
MERRA-2	1980-2016	Cubed sphere (50 km)	576 × 361
NCEP	1979-2016	T382L64 (38 km)	720 × 361
JRA-25	1979-2013	T106L40 (120 km)	288 × 145
JRA-55	1958-2017	TL319L60 (55 km)	288 × 145

Main finding: re-analyses are able to credibly reproduce TCs in the higher categories, but are challenged in the TD, TS and CAT1 categories.

We created a complementary TC database that can be used to assist risk assessment, by:

1. increasing the sample size and
2. providing physically based estimates of model uncertainty.

15 JULY 2017 HODGES ET AL. 5255

TABLE 3. Storms that match and do not match with IBTrACS in the NH by storm category, for each reanalysis, storms identified by the objective detection method applied to the reanalysis tracks and, in parentheses, the direct matching method, performed in section 3a. Values are number per year.

Category		ERAI	JRA-25	JRA-55	NCEP-CFSR	MERRA	MERRA-2
TD	Match	2.91 (7.94)	3.26 (7.94)	5.24 (8.03)	3.50 (8.00)	2.29 (7.85)	3.48 (7.67)
	No match	5.56 (0.53)	5.21 (0.53)	3.24 (0.44)	4.97 (0.47)	6.18 (0.62)	4.91 (0.73)
TS	Match	11.85 (22.38)	18.62 (22.53)	18.32 (22.53)	14.76 (22.32)	9.85 (22.44)	14.24 (22.45)
	No match	11.85 (1.32)	5.09 (1.18)	5.38 (1.18)	8.94 (1.38)	13.85 (1.26)	9.73 (1.52)
CAT1	Match	8.74 (12.23)	11.18 (12.23)	11.17 (12.24)	10.09 (12.12)	7.74 (12.21)	9.76 (12.33)
	No match	3.44 (0.00)	1.00 (0.00)	1.00 (0.00)	2.09 (0.06)	4.44 (0.00)	2.55 (0.00)
CAT2	Match	5.29 (6.35)	6.15 (6.38)	6.00 (6.35)	5.82 (6.38)	4.76 (6.35)	5.64 (6.39)
	No match	1.06 (0.00)	0.21 (0.00)	0.35 (0.00)	0.53 (0.00)	1.59 (0.00)	0.73 (0.00)
CAT3	Match	6.15 (7.00)	6.91 (7.06)	6.82 (7.03)	6.71 (7.06)	5.82 (7.03)	6.42 (7.06)
	No match	0.88 (0.03)	0.12 (0.00)	0.21 (0.00)	0.32 (0.00)	1.21 (0.00)	0.64 (0.00)
CAT4	Match	5.97 (6.79)	6.76 (6.79)	6.71 (6.74)	6.47 (6.79)	5.76 (6.76)	6.48 (6.76)
	No match	0.82 (0.00)	0.03 (0.00)	0.09 (0.06)	0.32 (0.00)	1.03 (0.03)	0.33 (0.06)
CAT5	Match	1.09 (1.12)	1.12 (1.12)	1.12 (1.12)	1.12 (1.12)	1.03 (1.12)	1.09 (1.09)
	No match	0.03 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.09 (0.00)	0.00 (0.00)

There is no trace of TC trends in the re-analyses: Re-analyses are inherently wrong, but consistent!

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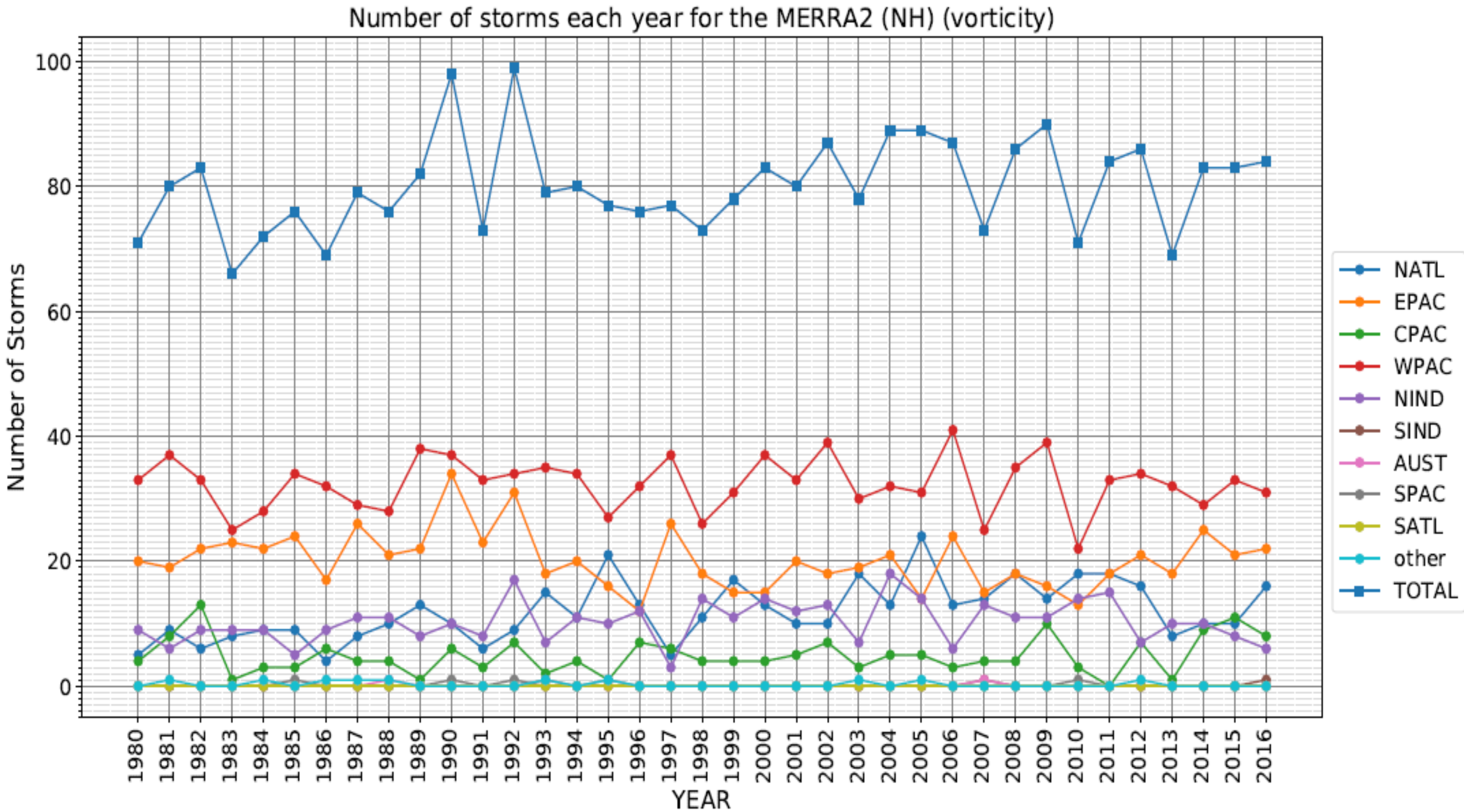
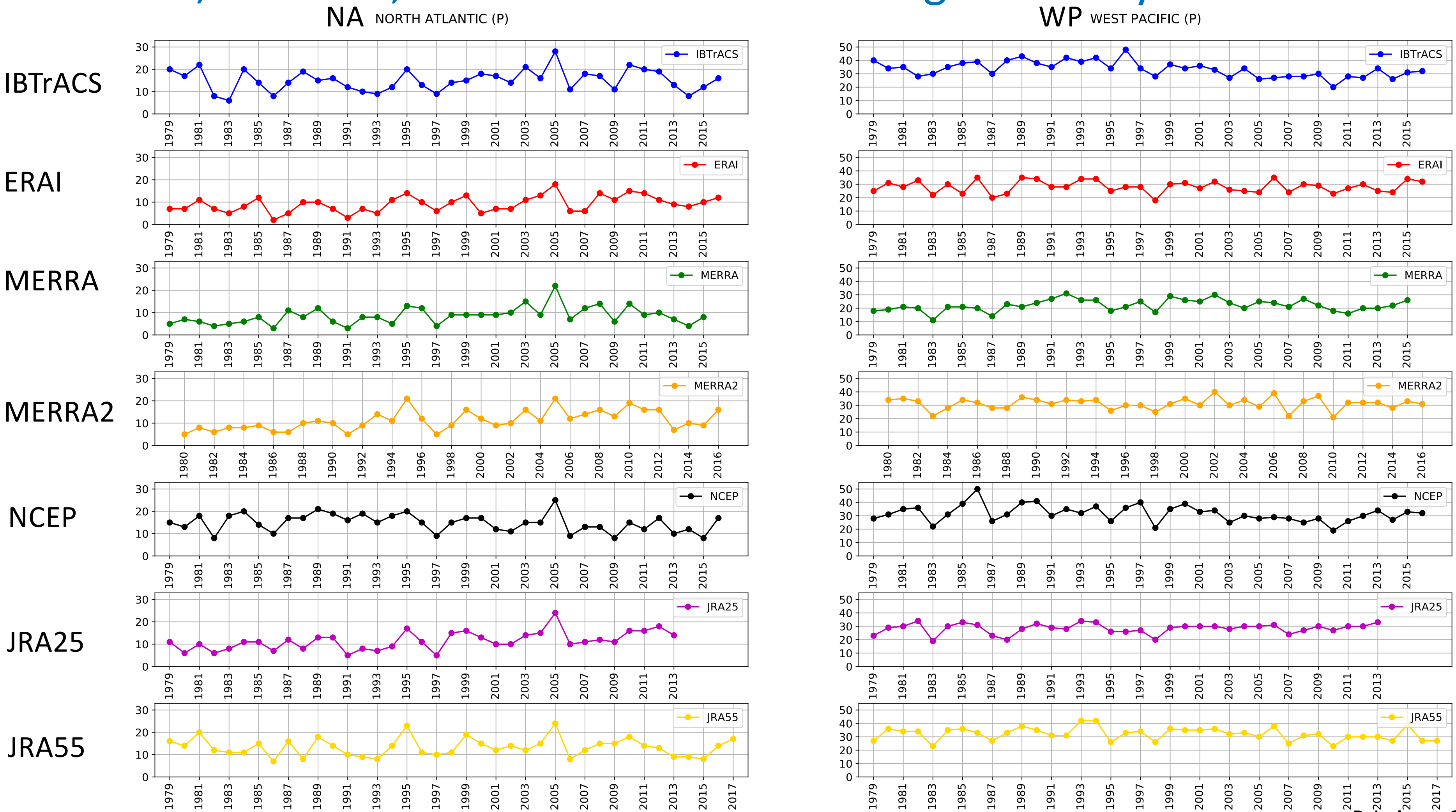


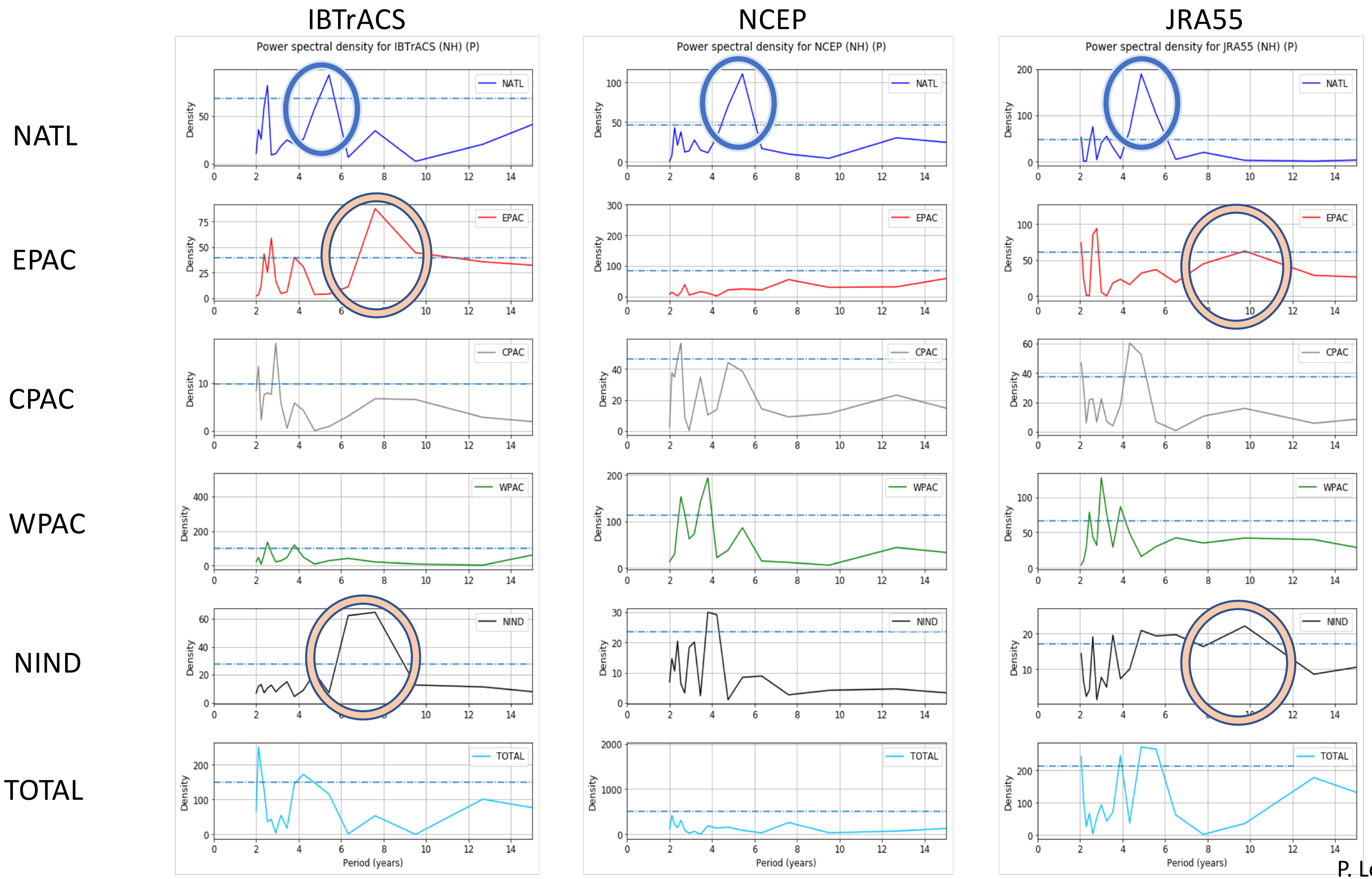
P. Loizou, 2018, unpublished

There is no trace of TC trends in the re-analyses: there is, however, substantial and interesting variability



P. Loizou, 2018, unpublished

Power spectra of TC time series in different basins, from 3 data sets



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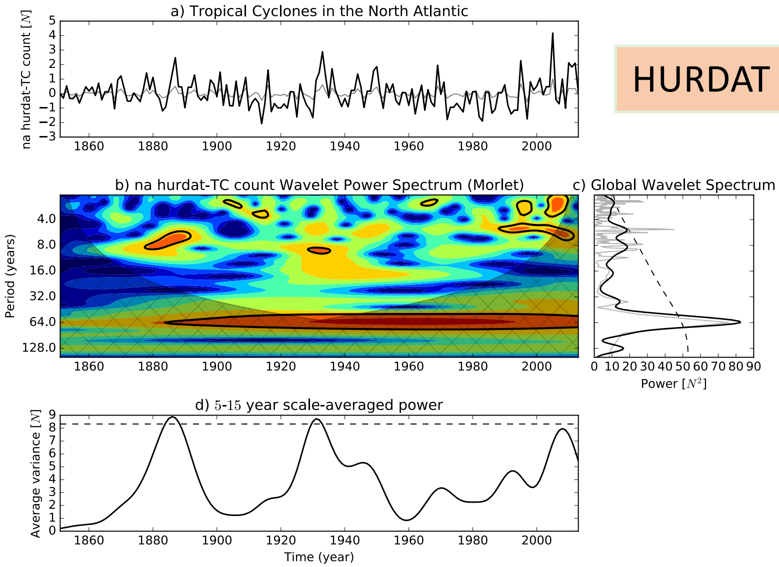
P. Loizou, 2018, unpublished

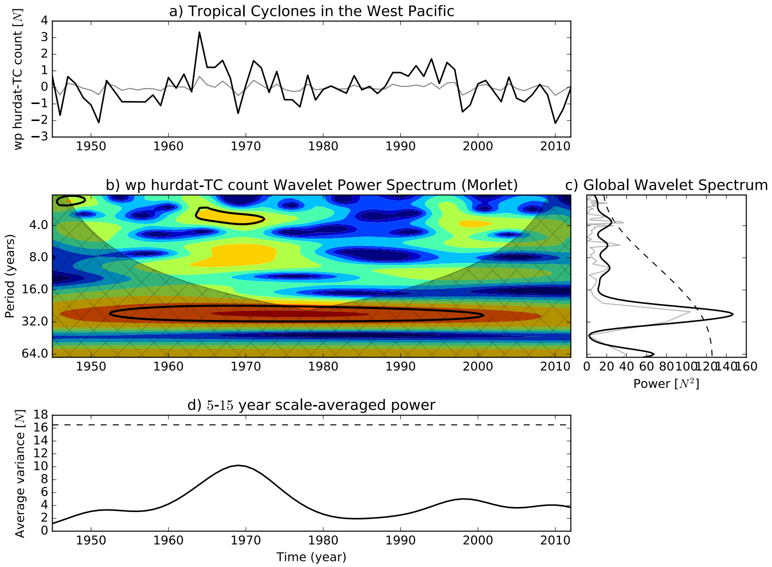
Natural variability of TCs

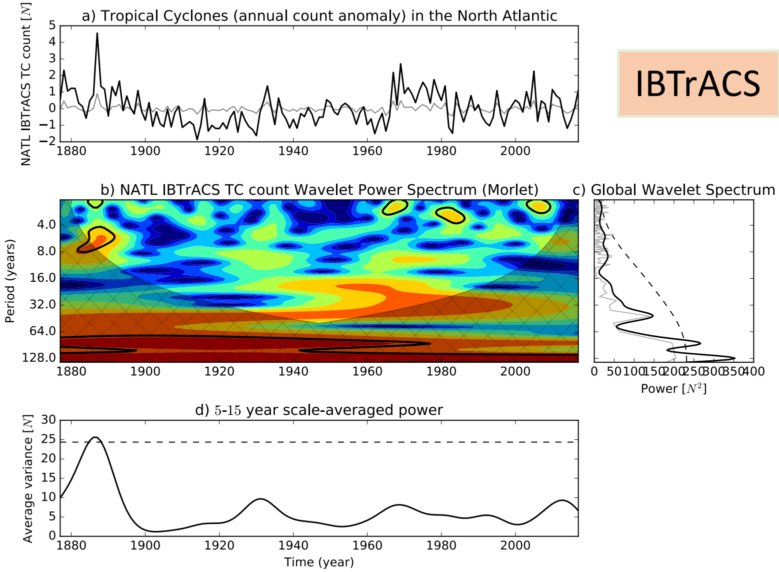
North Atlantic

West Pacific

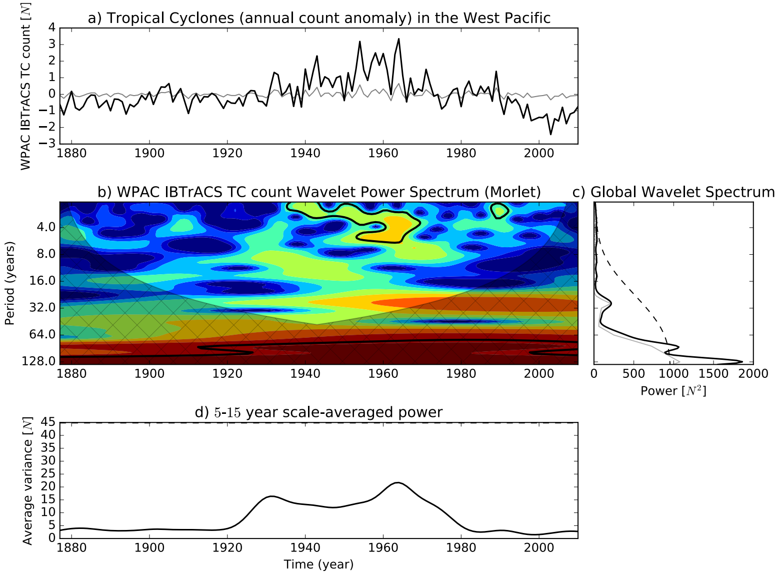


HURDAT





IBTrACS



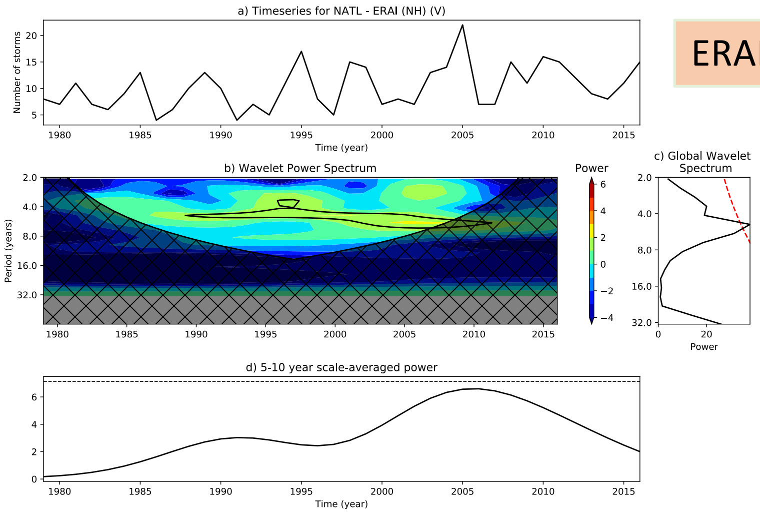
Some evidence of TC variability in the ENSO frequency range. There is also evidence of decadal variability, but the time series are too short for robustness.

Can GCMs help in understanding whether or not this is a robust feature of the climate system?

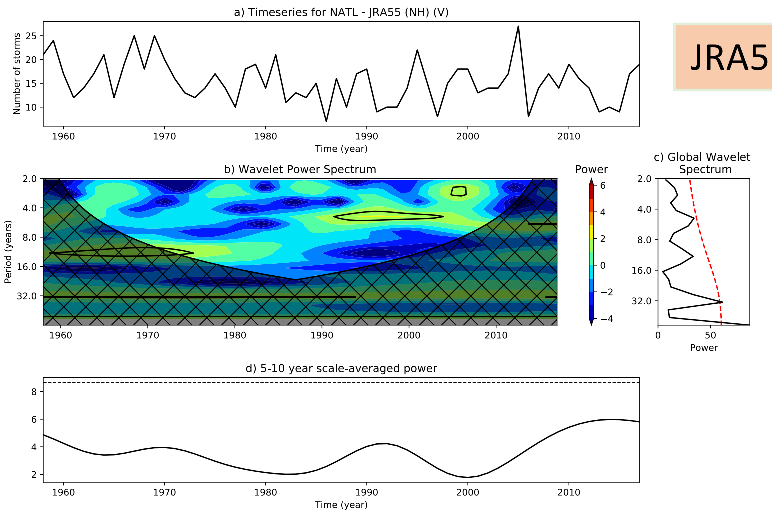
P.L. Vidale et al., 2018, unpublished

Natural variability of TCs

North Atlantic

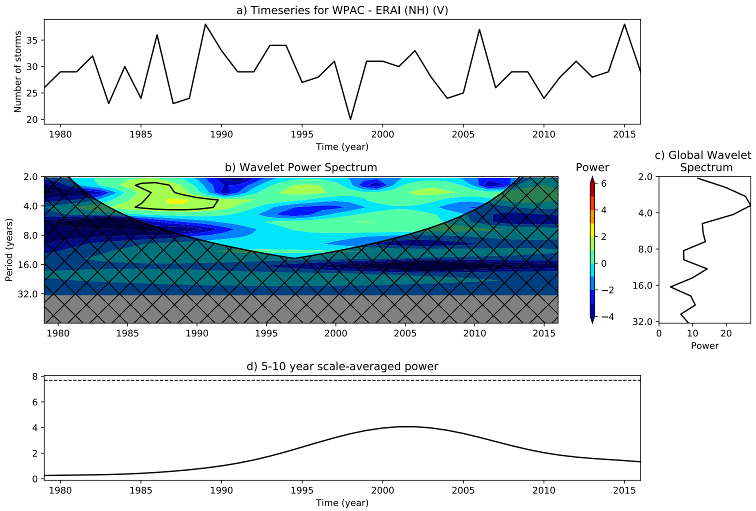


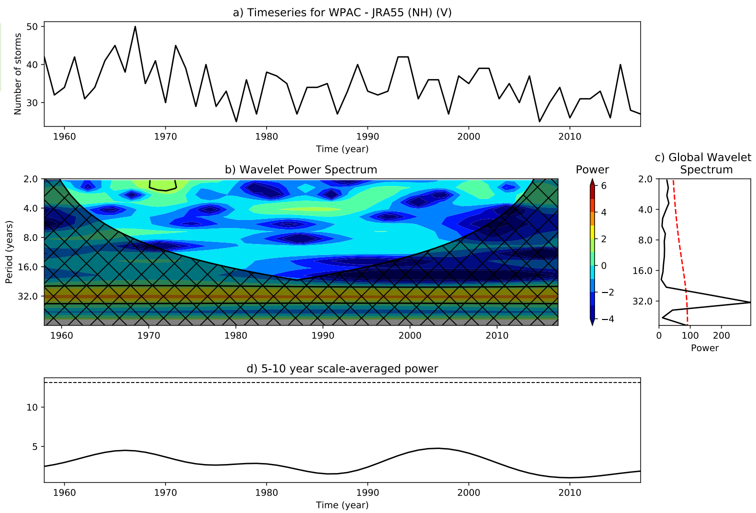
ERAI



JRA55

West Pacific





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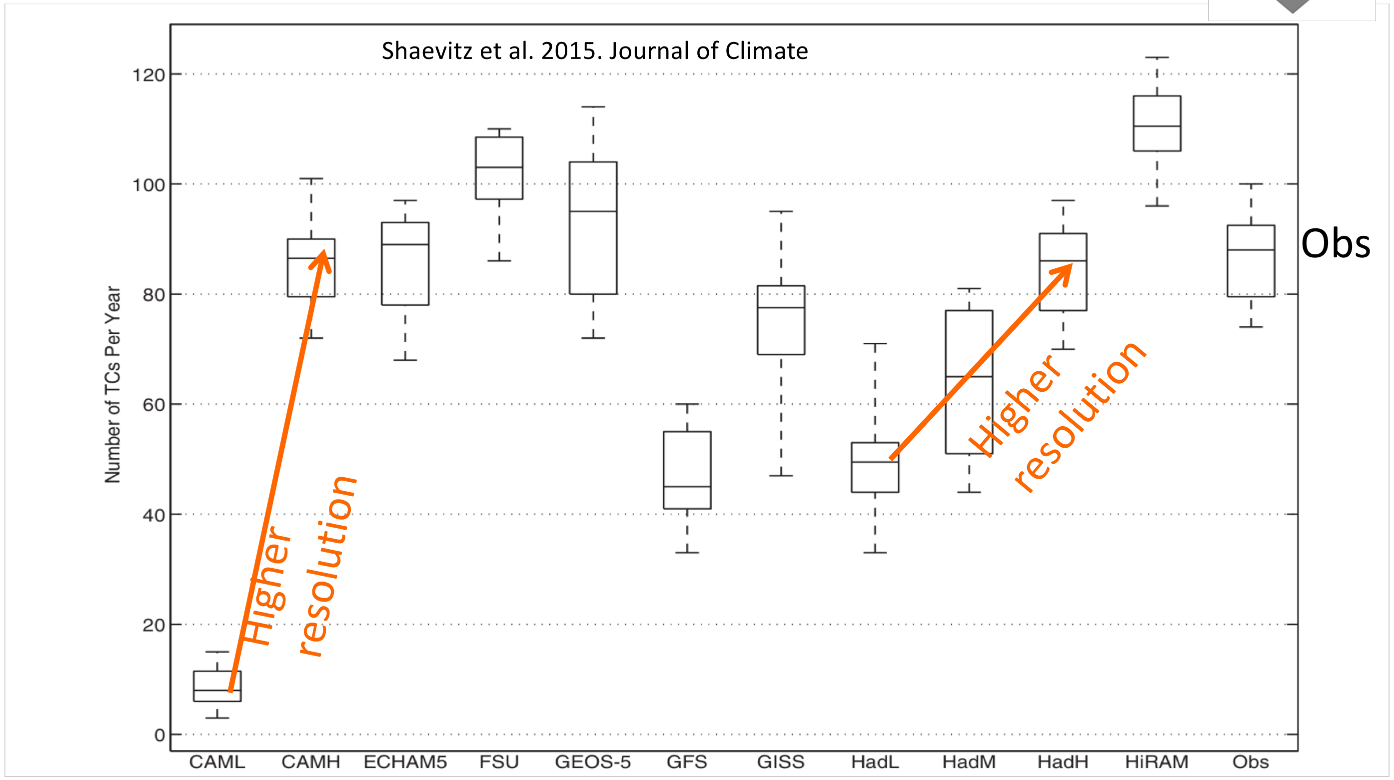
Tropical Cyclones "emerge" at high resolution

Results finally confirmed by the US CLIVAR Hurricane Working Group (HWG), via a **systematic** multi-model intercomparison:

- TC tracks and interannual variability in frequency are credibly represented at 20km;
- however, intensity is still underestimated by some of the GCMs at this resolution
- HRCM played a strong role in the first HWG; even stronger role in next phase

SPECIAL
U.S. CLIVAR Hurricanes
COLLECTION

Met Office
NATURAL ENVIRONMENT RESEARCH COUNCIL
Joint Weather & Climate Research Programme
A partnership in climate research



Shaevitz et al. 2015. Journal of Climate

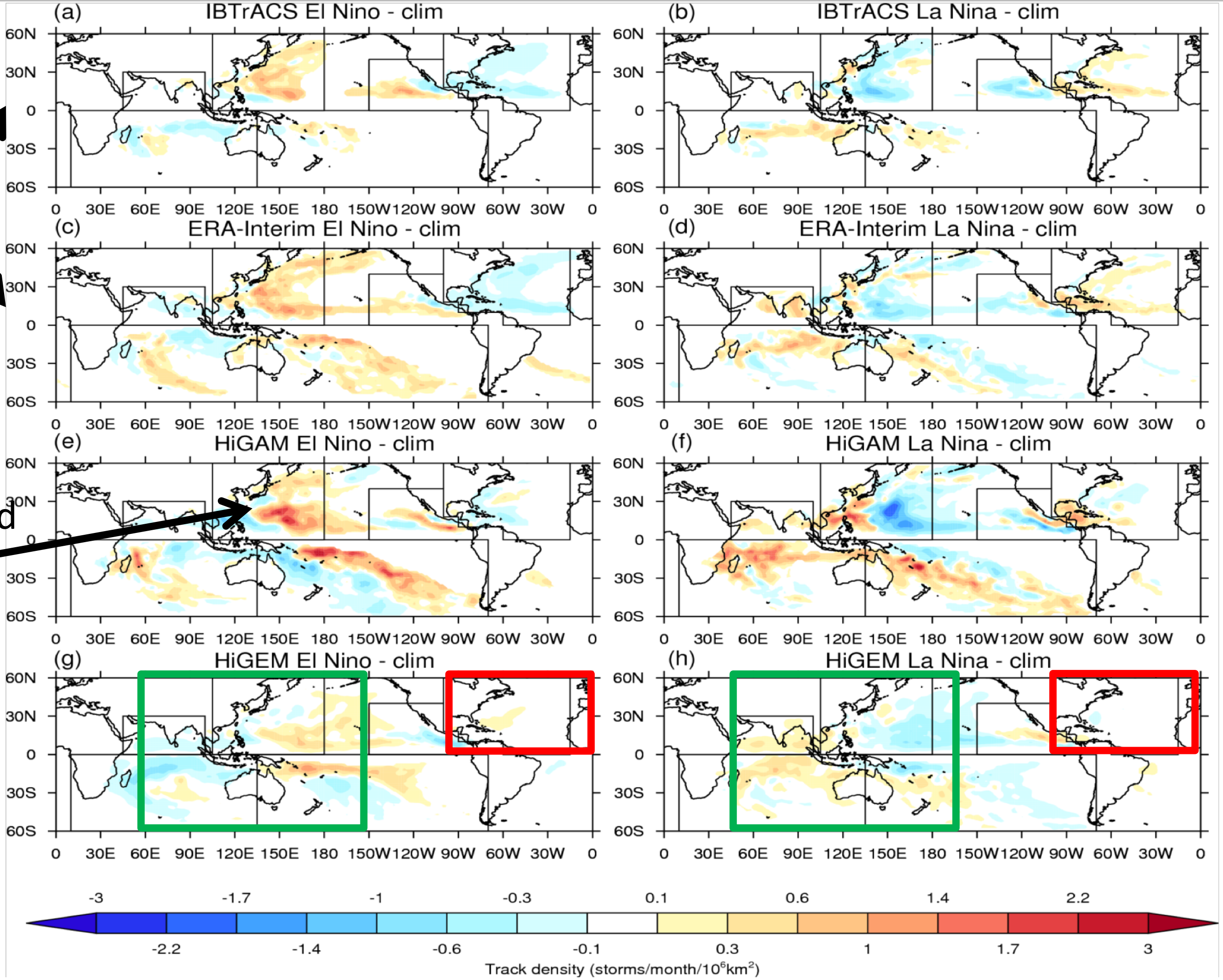
Distribution of the number of TCs per year

PRACE
UPSCALE

ENSO-TC: track density anomalies

Match well

Overpronounced variability



Bell et al. J. Clim 2012

TCs and ENSO in CLIVAR HWG exercise

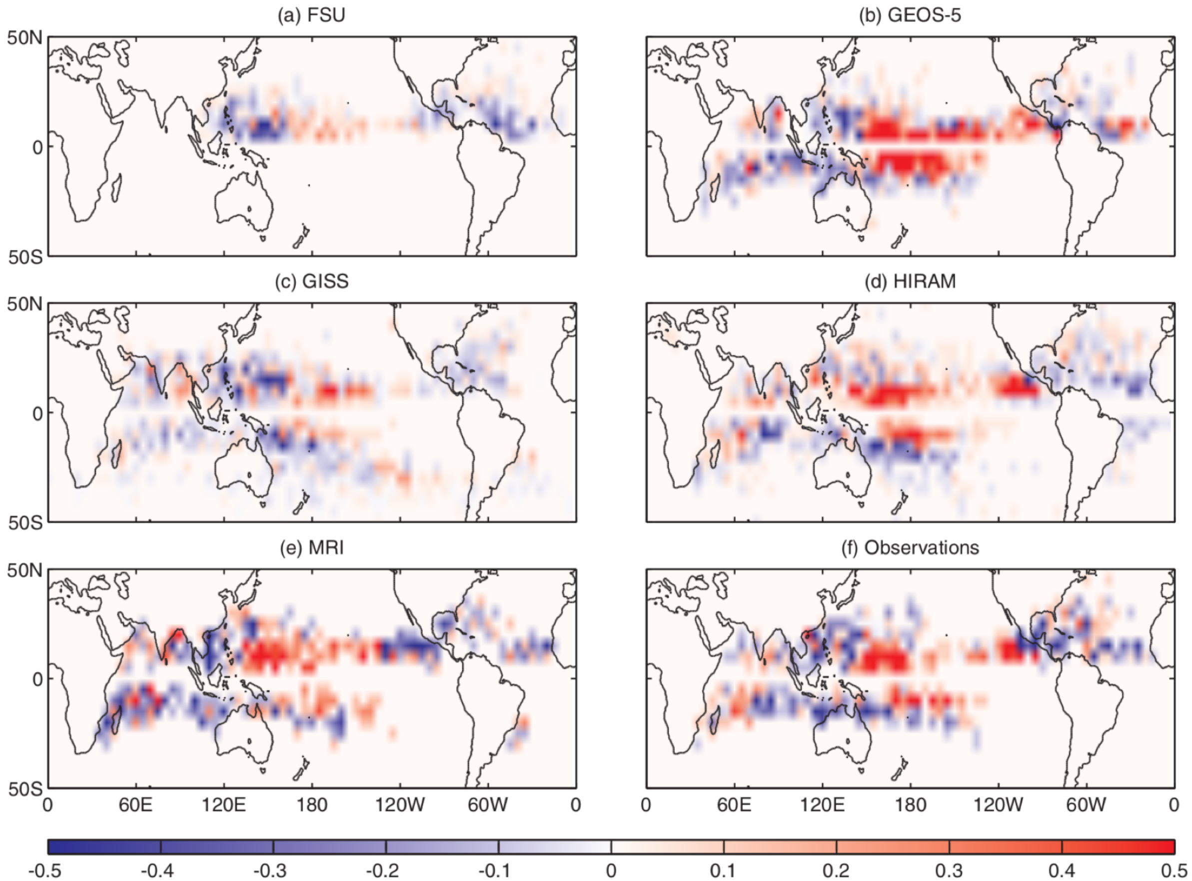
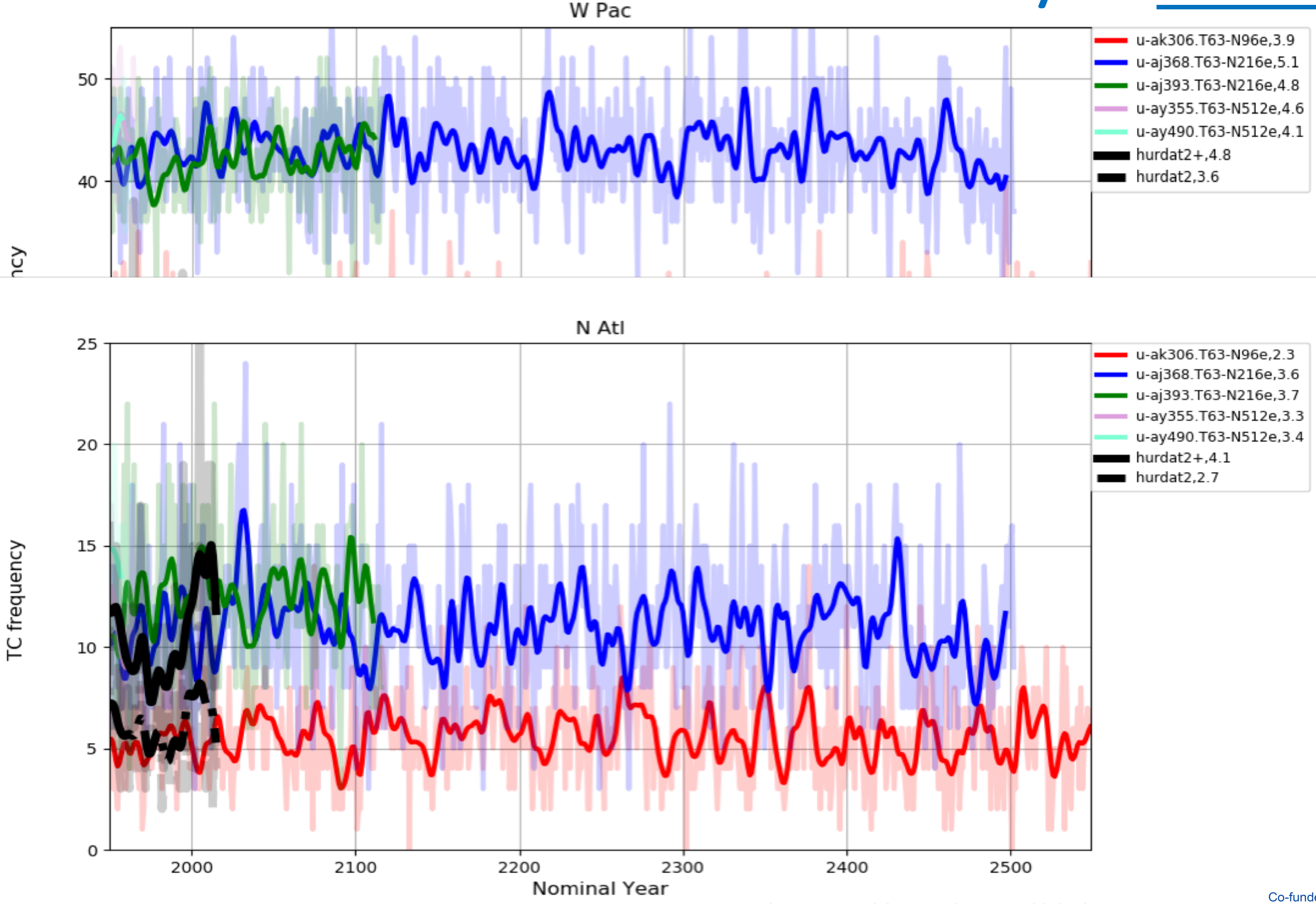


Figure 11. Difference of TC genesis density in El Niño and La Niña in models and observations. The genesis density is defined as the mean TC formation per 5° × 5° box per year.

From Shaevitz et al. 2014

PRIMAVERA: decadal variability in unforced runs



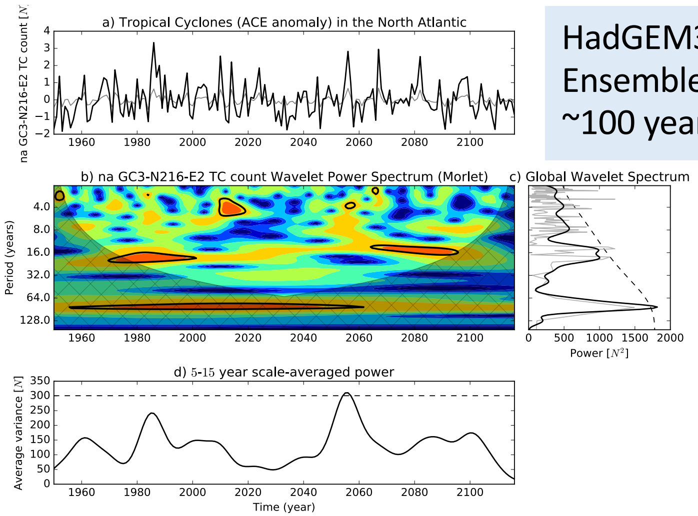
M. Roberts, P. L. Vidale, K. Hodges, unpublished

N96-ORCA1
N216-ORCA025
N216-ORCA12
N512-ORCA025
N512-ORCA12

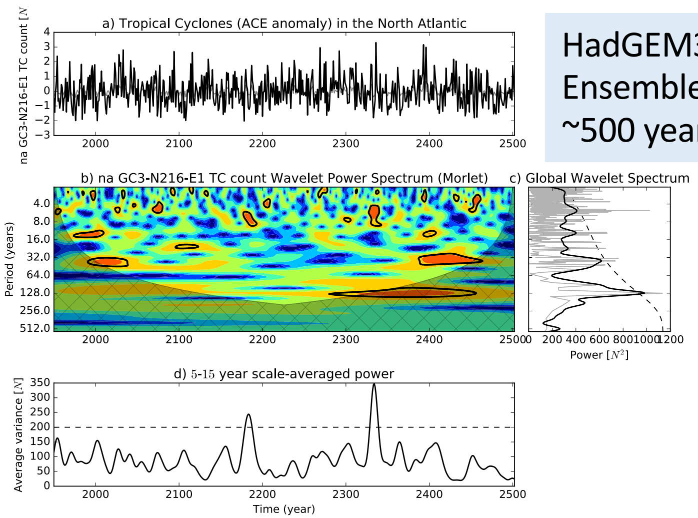
Co-funded by the European Union

TC ACE variability from centennial free-running AOGCM simulations

North Atlantic

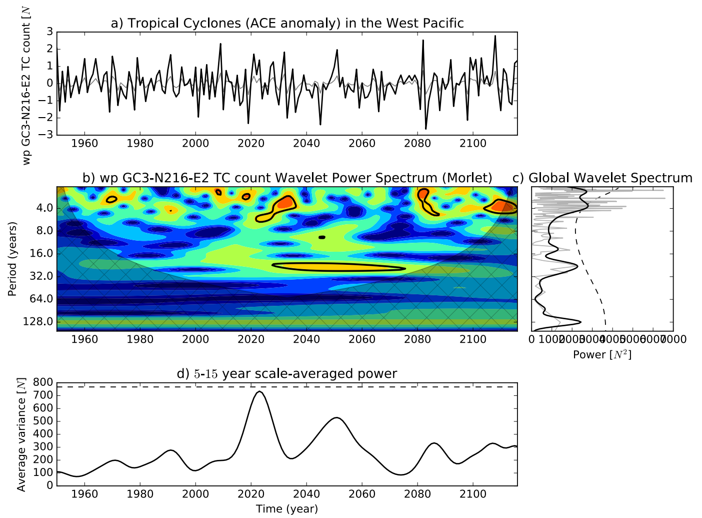


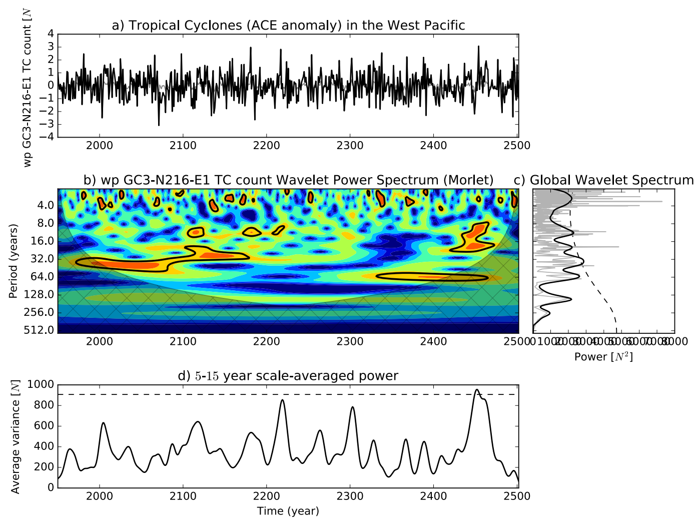
HadGEM3-GC2
Ensemble Member 1
~100 years



HadGEM3-GC3.1
Ensemble Member 2
~500 years

West Pacific





Both NA and WP basins exhibit **TC variability in the decadal range**, for periods of up to 50 years.

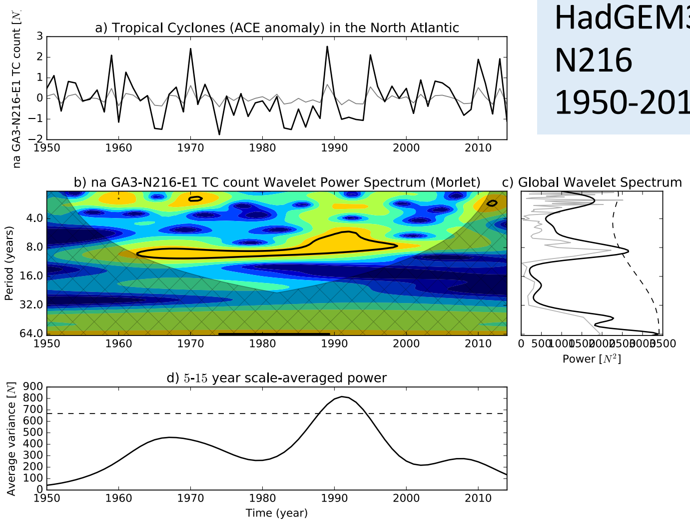
These two simulations impose constant anthropogenic forcing, that is: *we have denied the climate change of the last 65+ years.*

The existence of such natural variability makes the interpretation of climate change complicated.

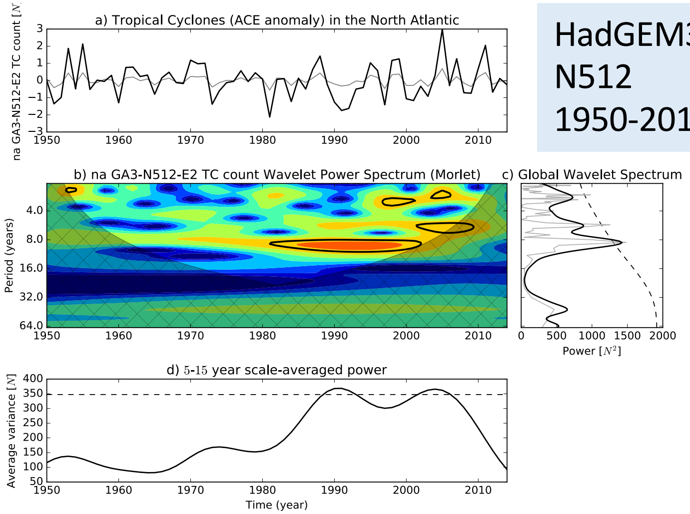
Variability of TC ACE in GCMs forced with high resolution SSTs (HadISST2.2)

North Atlantic

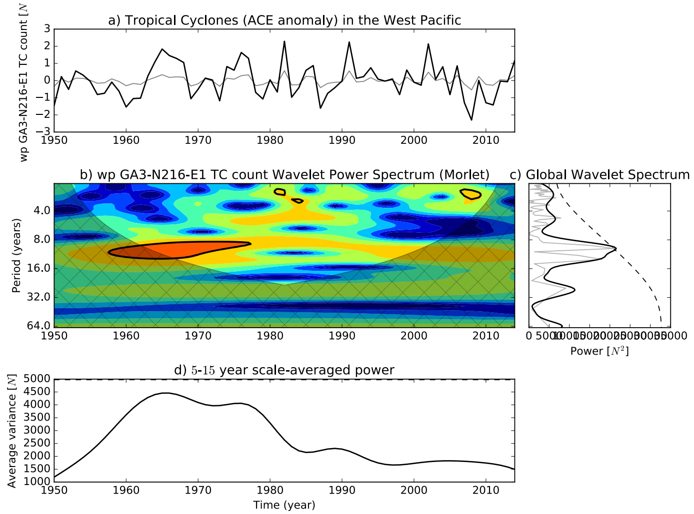
HadGEM3
N216
1950-2014

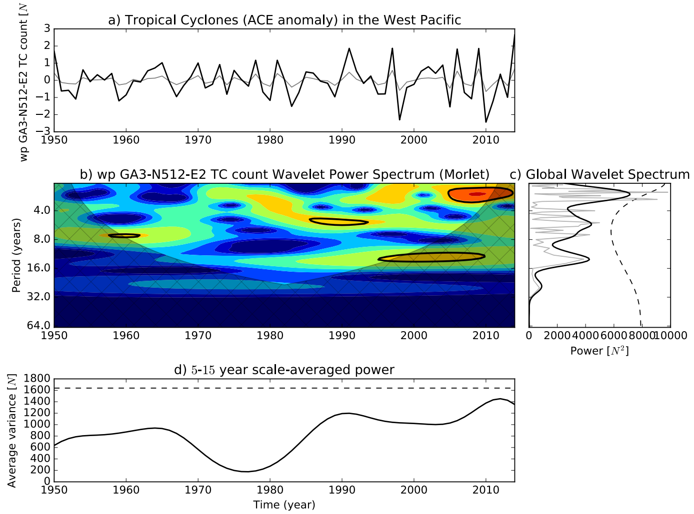


HadGEM3
N512
1950-2014



West Pacific





What will happen to TCs in the future?

Typhoons will migrate poleward … and a NA hurricane reduction

SPECIAL U.S. CLIVAR Hurricanes COLLECTION

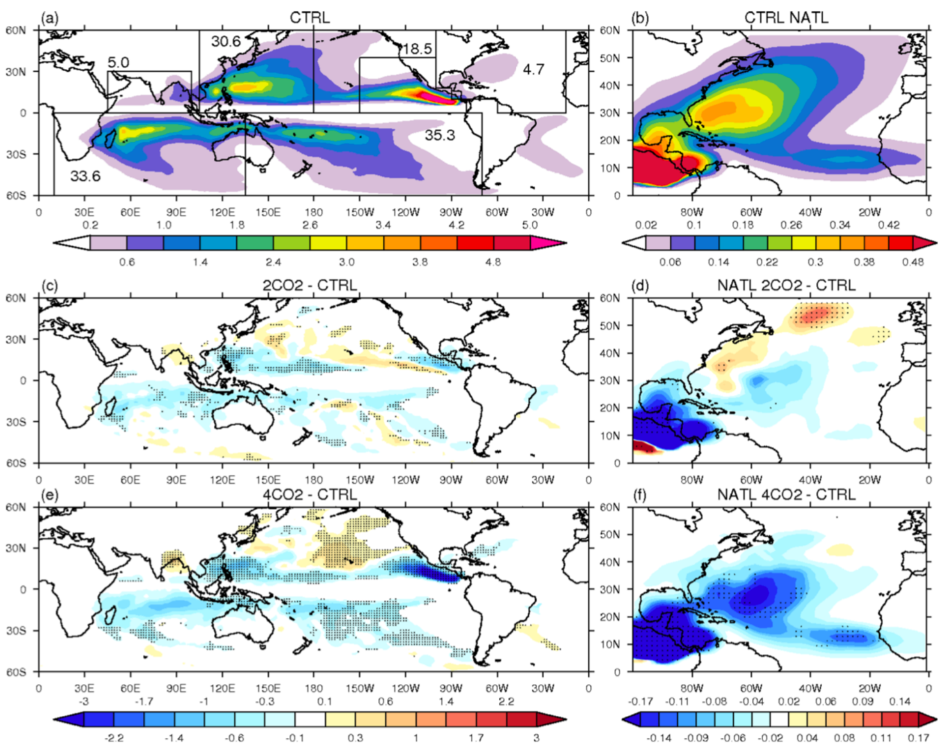
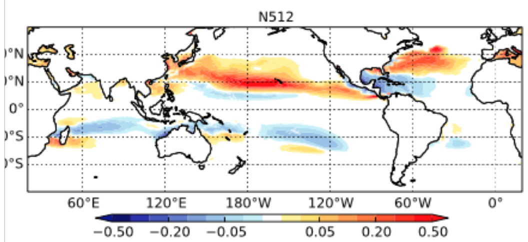


FIG. 2. Tropical cyclone track density, same as figure 1, for (a) HiGEM present-day simulation (b) The same as for (a) but North Atlantic (c) 2CO2 - present-day simulation (d) North Atlantic 2CO2 - present-day simulation (e) 4CO2 - present-day simulation and (f) North Atlantic 4CO2 - present-day simulation. Stippling shows where changes are outside the range of 5×30-year present-day simulations.

Bell et al. J. Clim. 2012, idealised HiGEM simulations

GPI-based estimates agree in the Pacific, albeit not in the Atlantic



PRACE

UPSCALE

2012 UPSCALE MODELLING CAMPAIGN

JOURNAL OF CLIMATE

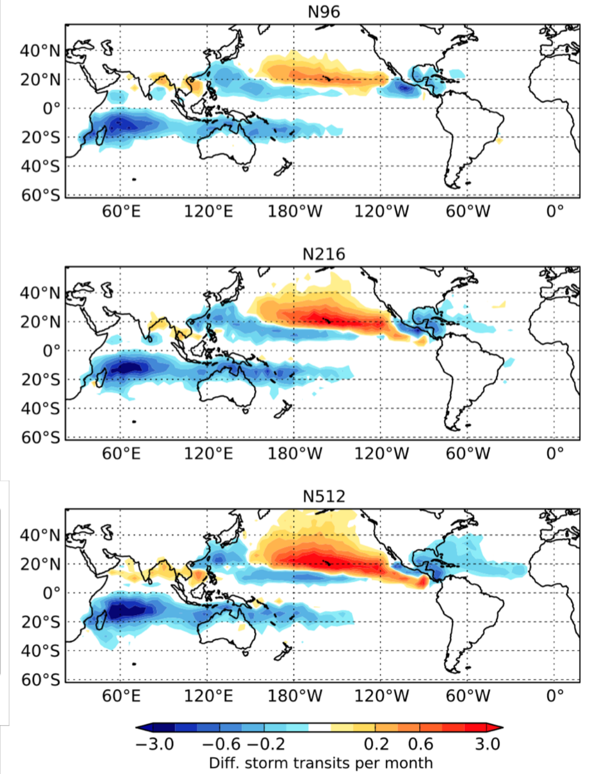
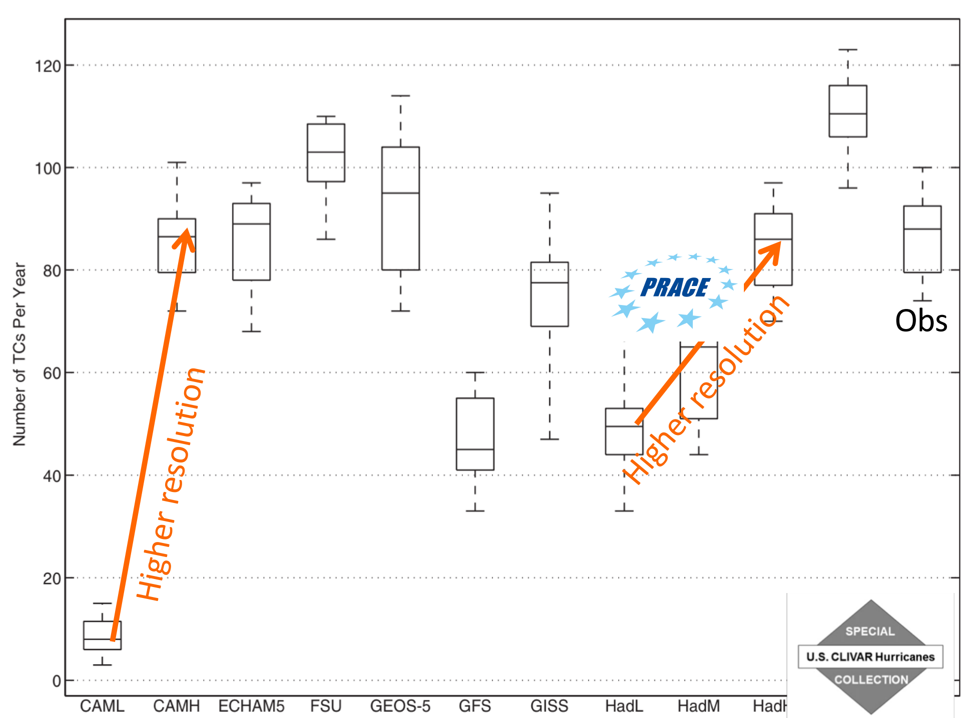


FIG. 12. Change in tropical cyclone track density (storm transits per month per unit area equivalent to a 4° spherical cap) between the future climate and present climate integrations for the whole 1986–2010 period and for the whole ensemble at each model resolution: (top)–(bottom) N96, N216, and N512.

Roberts et al. 2015. Journal of Climate, RCP 8.5 scenario

Tropical Cyclones "emerge" at high resolution

From US CLIVAR Hurricane Working Group (2015)



Shaevitz et al. 2015. Journal of Climate

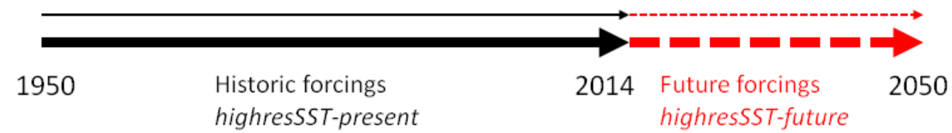
Our main question: **is this a robust result**?
We need a multi-model, multi-resolution, ensemble approach

to

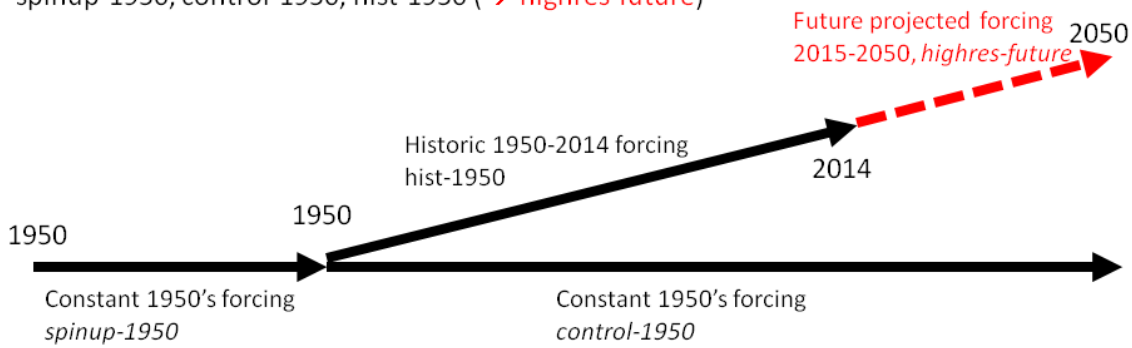
CMIP6-HighResMIP TC simulations

PRIMAVERA, 2018

Atmosphere-land-only, 1950-2014 (→ 2050)
Forced by observed SST and sea-ice and historic forcings (→ projected)
highresSST-present (→ highresSST-future)



Coupled climate, 1950-2014 (→ 2050)
Forced by constant 1950 and historic forcings (→ projected)
Initial coupled spin-up period ~ 30-50 years from 1950 EN4 ocean climatology
spinup-1950, control-1950, hist-1950 (→ highres-future)



Co-funded by the European Union

Models in PRIMAVERA *running* HighResMIP protocol

Institution	MOHC, UREAD, NERC	EC-Earth KNMI,SHMI, BSC, CNR	CERFACS	MPI-M	AWI	CMCC	ECMWF
Model name	HadGEM3 GC3.1	EC-Earth3.3	CNRM-CM6	MPIESM-1-2	AWI-CM 1.0	CMCC-CM2	ECMWF-IFS
Model components	UM NEMO3.6 CICE5.1	IFS cy36r4 NEMO3.6 LIM3	ARPEGE6.3 NEMO3.6 GELATO6.1	ECHAM6.3 MPIOM1.63 MPIOM1.63	ECHAM6.3 FESOM1.4 FESIM1.4	CAM4 NEMO3.6 CICE4.0	IFS cycle43r1 NEMO3.4 LIM2
Atmos dynamical scheme (grid)	Grid point (SISL, lat-long)	Spectral (linear, reduced Gaussian)	Spectral (linear, reduced Gaussian)	Spectral (triangular, Gaussian)	Spectral (triangular, Gaussian)	Grid point (finite volume, lat-long)	Spectral (cubic octohedral, reduced Gaussian)
Atmos grid name	N96 , N216, N512 (L,M,H)	Tl255, Tl511	Tl127, Tl359	T127, T255	T63, T127	1x1, 0.25x0.25	Tco199, Tco399
Atmos mesh spacing 0N	208, 93, 39	78, 39	156, 55	100, 52	200, 100	100, 28	50, 25
Atmos mesh spacing 50N	135, 60, 25	71, 36	142, 50	67, 34	129, 67	64, 18	50, 25
Atmos nominal res (CMIP6)	250, 100, 50	100, 50	250, 50	100, 50	250, 100	100, 25	50, 25
Atmos model levels (top)	85 (85km)	91 (0.01 hPa)	91 (78.4 km)	95 (0.01 hPa)	95 (0.01 hPa)	26 (2 hPa)	91 (0.01 hPa)
Ocean grid name	ORCA	ORCA	ORCA	TP	FESOM (unstructured)	ORCA	ORCA
Ocean res nominal (km)	100, 25, 8 (L,M,H)	100, 25	100, 25	40, 40	50, 25	25, 25	100, 25
Ocean levels	75	75	75	40	47	50	75

HighResMIP: Haarsma et al., GMD, 2016

6 different atmosphere-only GCMs

7 different coupled GCMs
(though some common components)

Range of resolutions: from 100km to 20km
… and further to sub-10km

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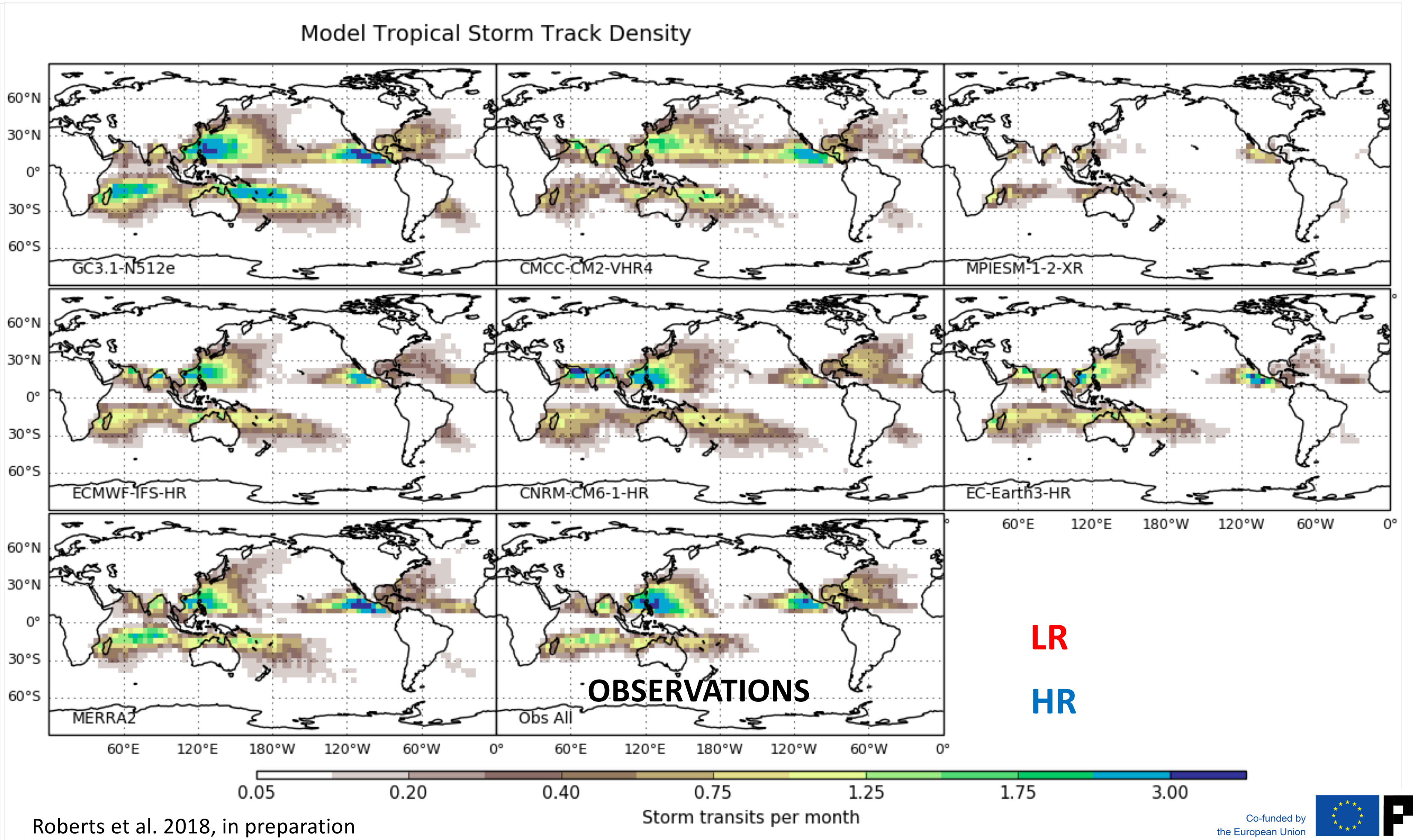
Tropical Cyclone **track density: 65 year climatologies**

(storm transits per month per 4 degree unit area)



Roberts et al. 2018, in preparation

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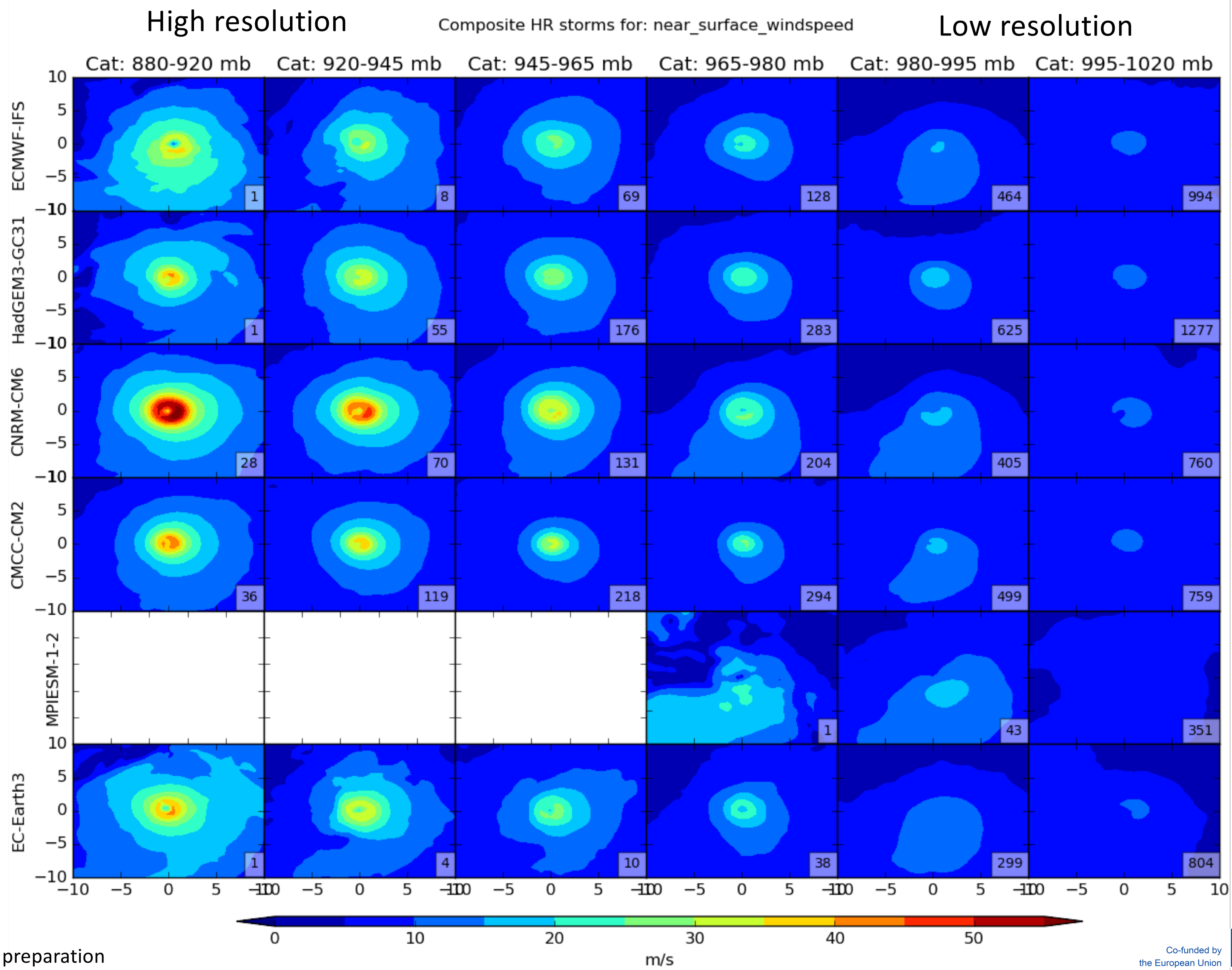

Roberts et al. 2018, in preparation

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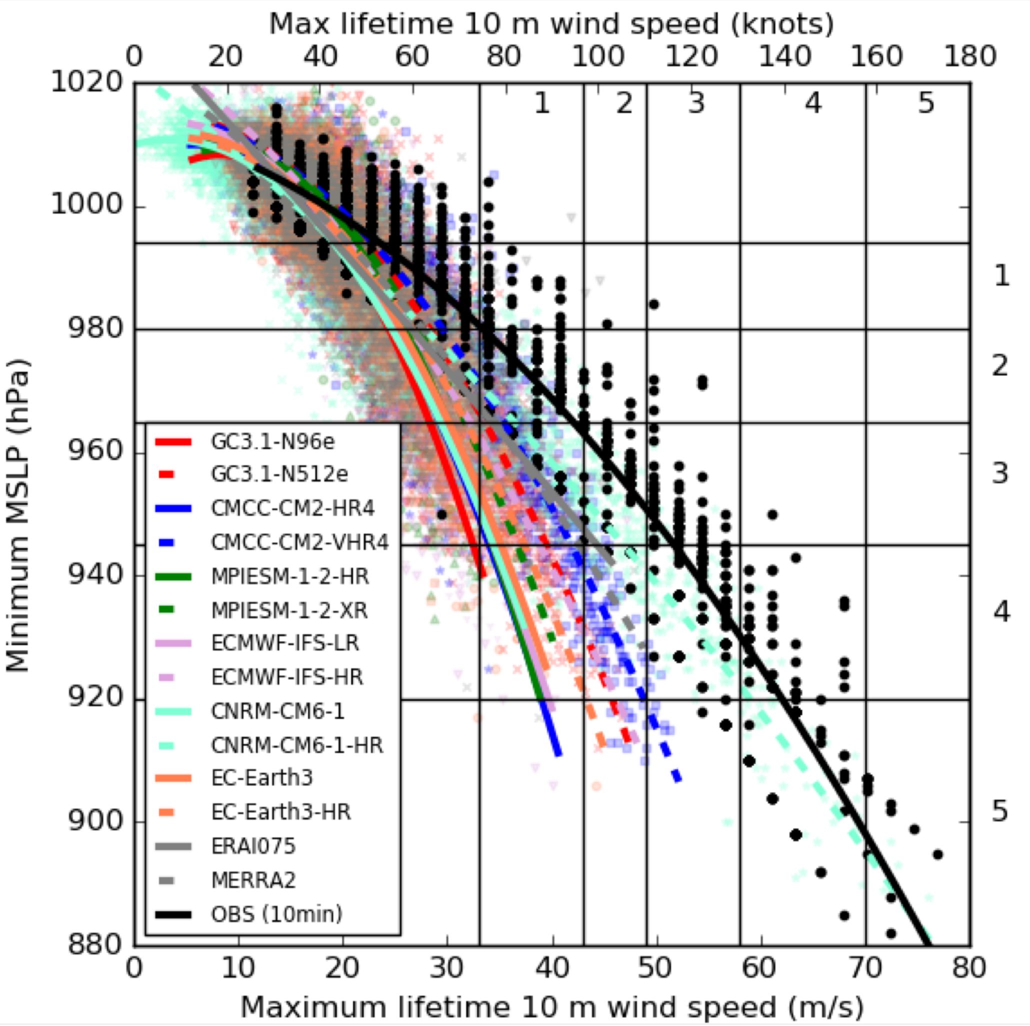
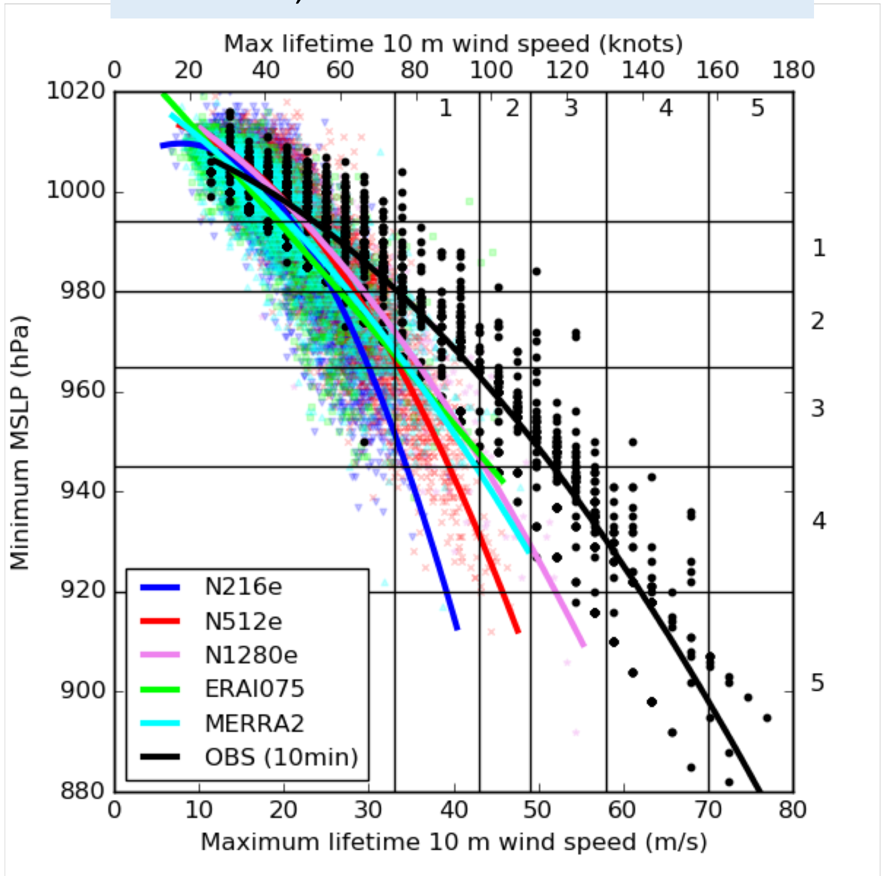
TC intensity using MSLP-10m wind
(instantaneous 6 hourly, not max/min over 6 hours)



Continuous lines are coarser GCMs

Dashed lines are higher resolution GCMs

HadGEM3, from 100 to 10km resolution



Roberts et al. 2018, in preparation

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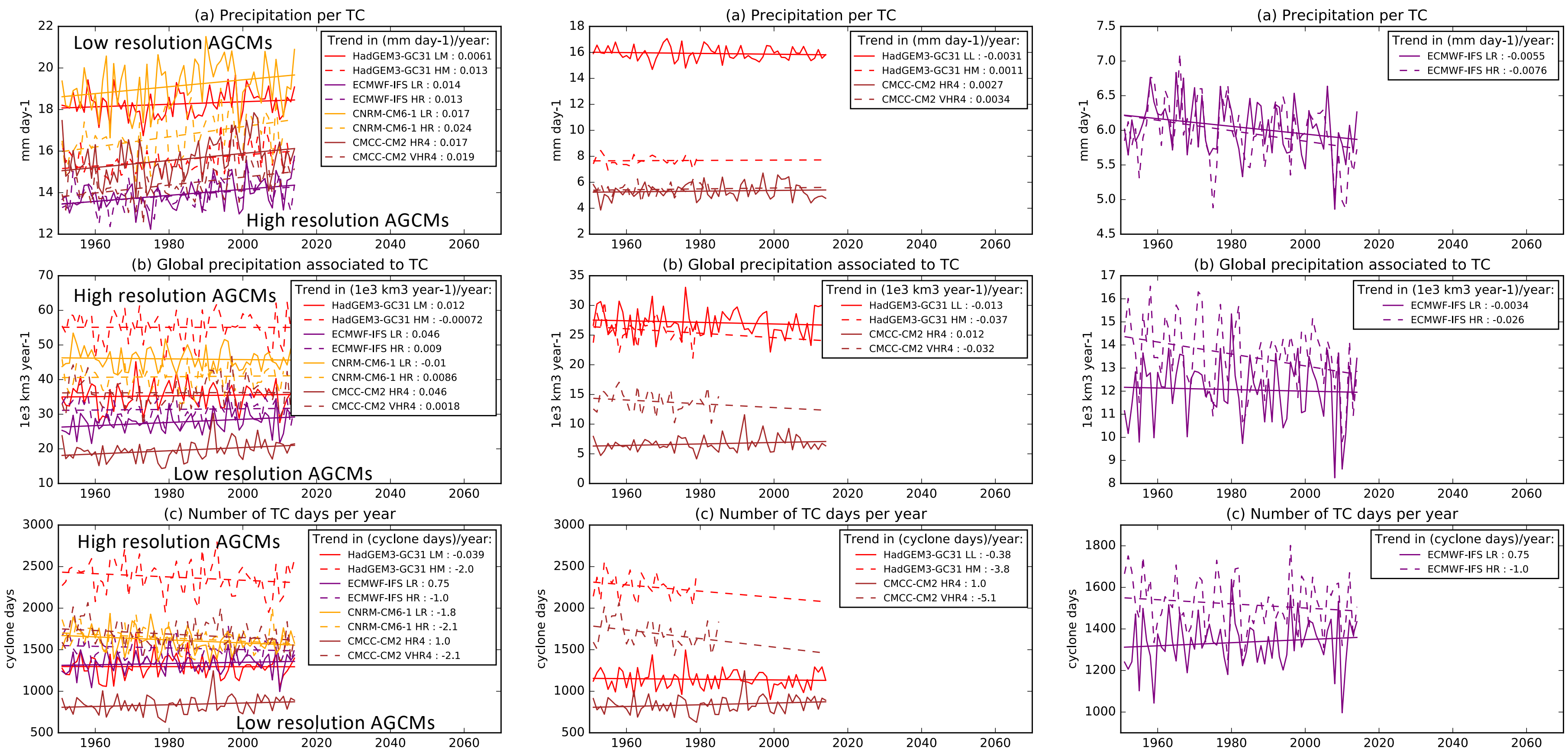
TC Precipitation trends from CMIP6 HighResMIP

National Centre for Atmospheric Science
NATURAL ENVIRONMENT RESEARCH COUNCIL

University of Reading

AMIP-type, HighResSST | CTL, constant 1950s forcing | Historical, EasyAerosol forcing



AGCMs | AOGCMs | AOGCMs

It seems that at higher resolution the models tend to have a larger increasing trend in precipitation per TC and a larger decreasing trend in the number of tropical cyclones days per year.

What are the mechanism by which resolution influences the latter?

B. Vanniere, 2018, unpublished

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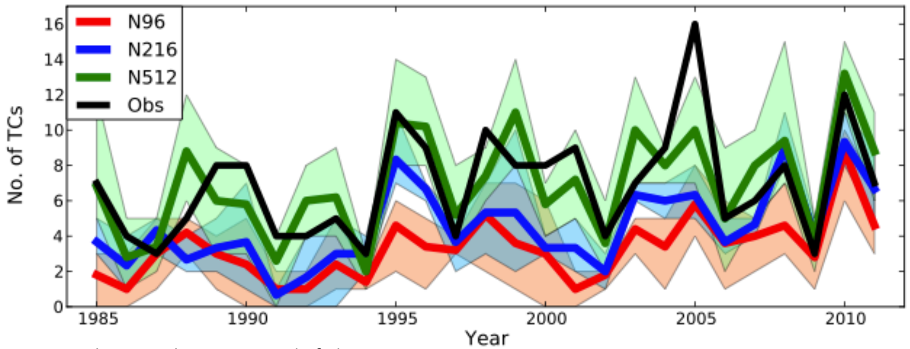
Interannual TC frequency correlation with observations (all/hurr) - 1 member

One of the most important results in the CLIVAR HWG experiment was this: **skill at representing interannual variability improves with model resolution.**

→ Key to seasonal prediction of hurricanes (and typhoons)

In 2015, as part of our work in the *US CLIVAR Hurricane Working Group*
using our 2012 PRACE-UPSCALE data:

TC frequency, track density and interannual



Roberts et al. 2015. Journal of Climate
Previously also shown in Zhao et al. (2010) and Strachan et al. (2011)

SPECIAL U.S. CLIVAR Hurricanes COLLECTION

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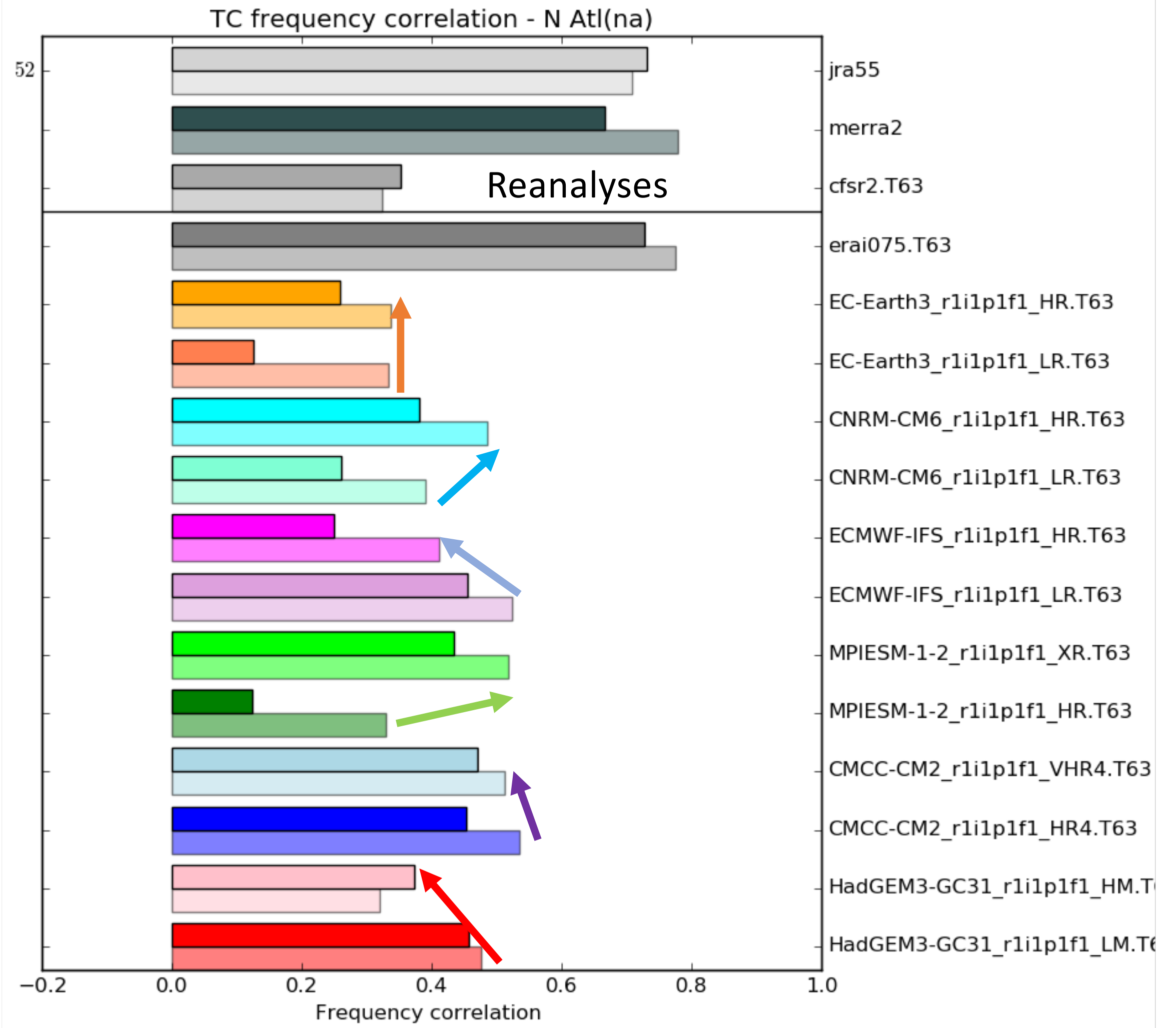
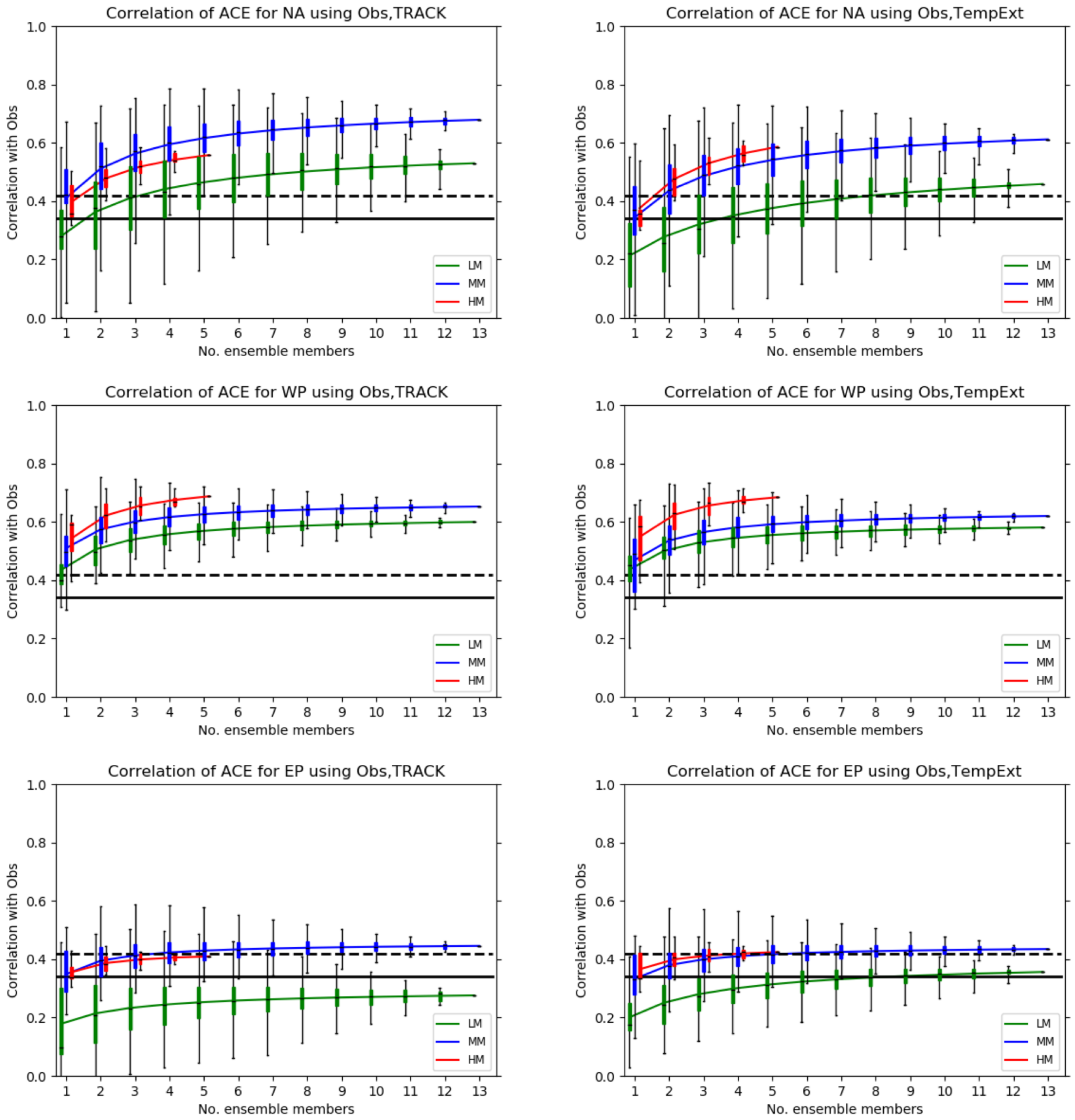


Roberts et al. 2018, in preparation



Is using single ensemble members per GCM enough to robustly represent interannual variability?

Multiple GCM resolutions of ensembles, 2 tracking algorithms

At least **6 ensemble members needed** in the North Atlantic to understand skill in simulating interannual variability

3-4 ensemble members seem sufficient in the West Pacific.

We do have a heterogeneous ensemble in PRIMAVERA, but also small ensembles of each GCM. → need to revisit IV

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Summary

- We have made substantial progress in understanding the role of resolution (dynamics) in the representation of the hydrological cycle in GCMs. As we increase resolution:
  - less water is recycled on land and more water is transported from ocean to land
  - the role of physical parameterisations is therefore reduced
  - cyclones play a role, but so do mountains
- Tropical Cyclones emerge in high-resolution GCMs:
  - The good and the bad:
    - 50-20km resolution: credible representations of track density and interannual variability
    - Structures are credible at ~20km, but TCs still too large in most GCMs.
    - Intensity at ~20km still not sufficient to capture all CAT4,5 in most GCMs (but there are notable exceptions with full spectrum represented)
    - We need ensemble size of at least 5 to robustly represent interannual variability
  - TC-ENSO relationship credibly represented in historical simulations
  - Poleward shift of TCs seen in climate change projections by GCMs capable of resolving TCs
- We are working towards sub-10km GCMs: expect better skill in terms of intensity.
- Much work left to do on post-tropical cyclones, extra-tropical transition, structures, etc.

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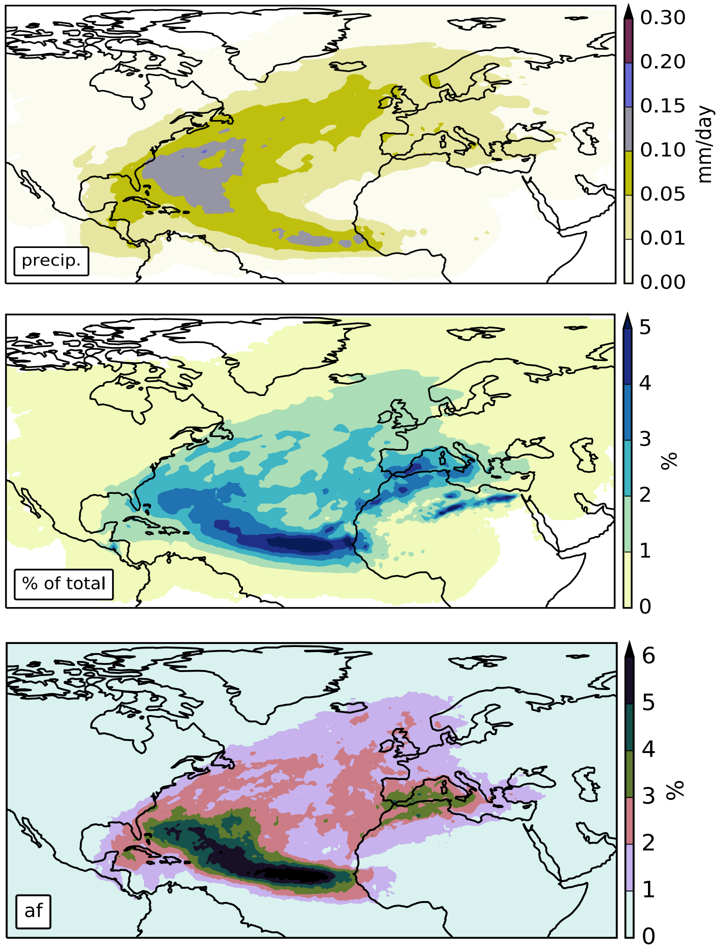
Precipitation attributed to Post-Tropical Cyclones (from ERA-I)

ANNUAL MEAN

PTC-associated precipitation

PTC contribution to total precipitation

Fraction of 95th percentile exceedances attributable to PTCs



METHOD:
Cyclone-associated precipitation is computed by defining 10° radial caps around PTC centres at 6-hourly timesteps (following Hawcroft et al., 2012).

METHOD:
Attribute 6-hourly heavy precipitation events (95th percentile exceedances) to PTC transits (following Pfahl and Wernli, 2012).