Size-dependent sensitivity of northern hemisphere extratropical cyclones to atmosphere resolution change in the GFDL SPEAR model

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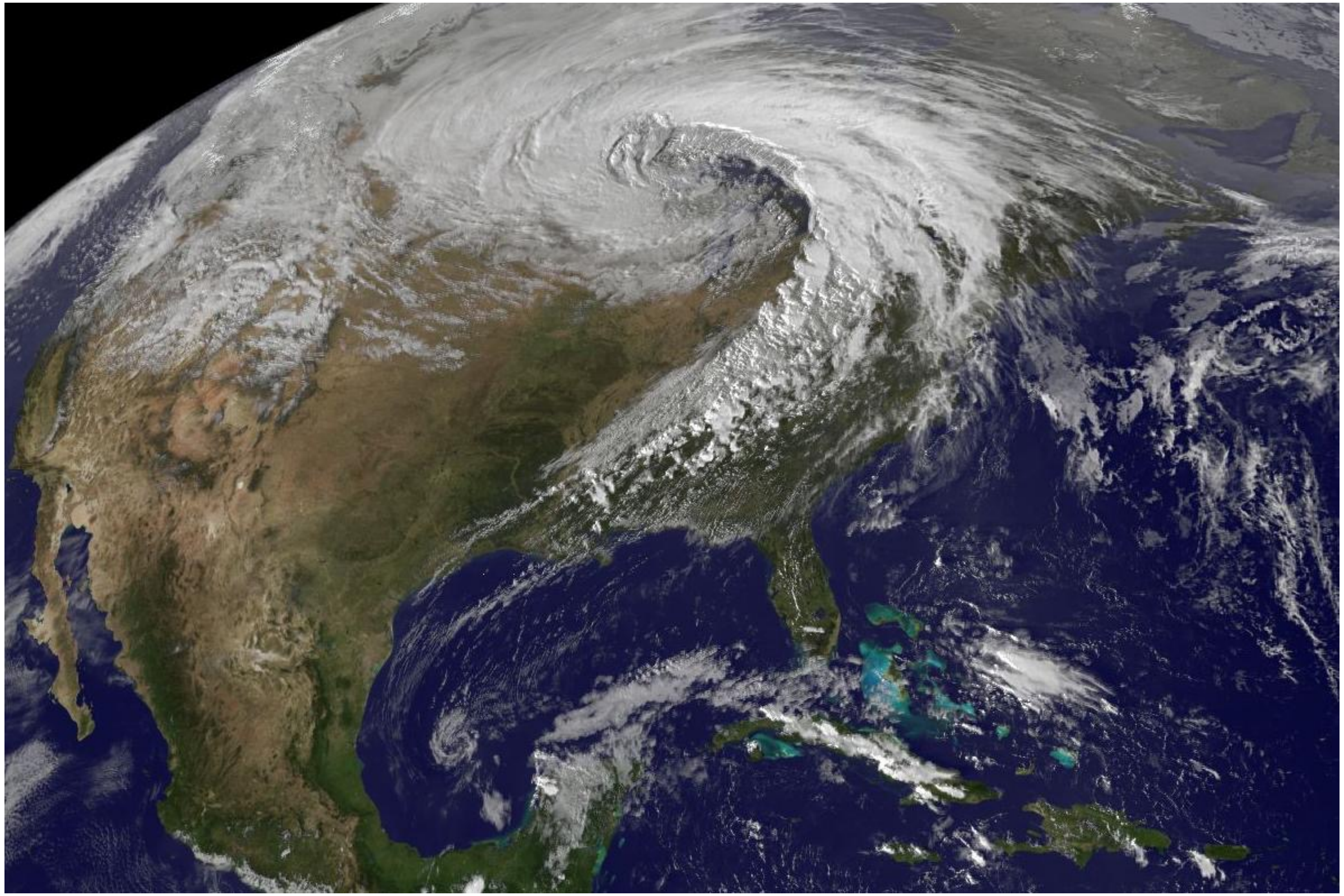
ETCs are accompanied by local weather impacts at midlatitude

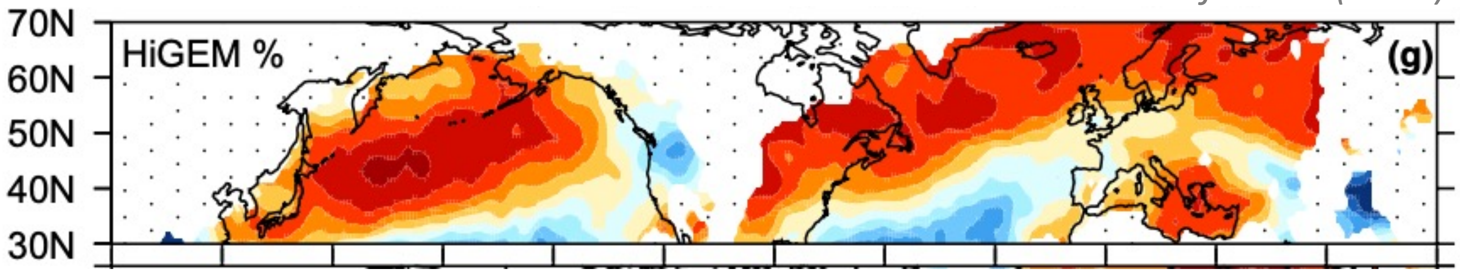


Satellite image for extratropical cyclone (ETC) over the North America

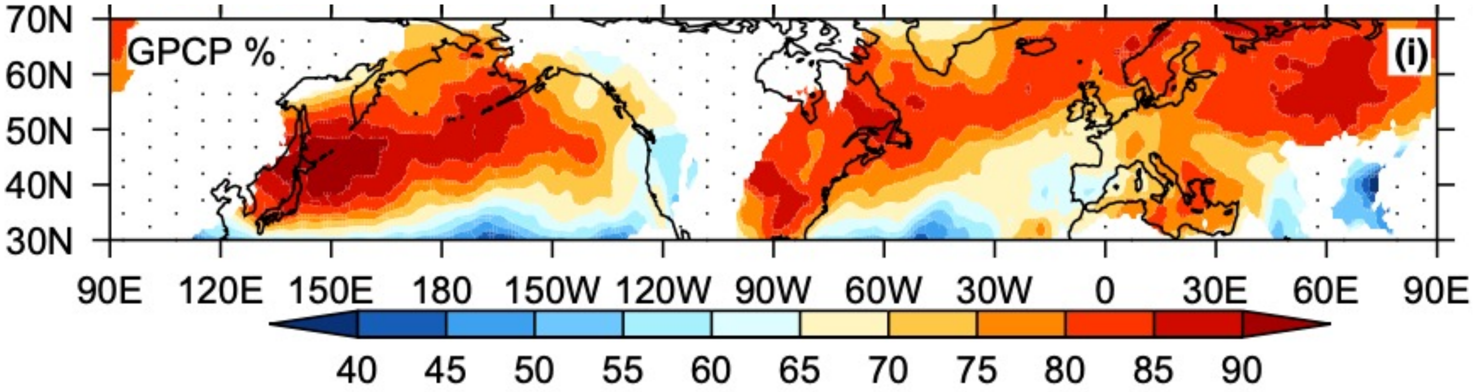
The accurate simulation of ETCs is important for better prediction of local weather

In GCM

Hawcroft et al. (2015)



In observation

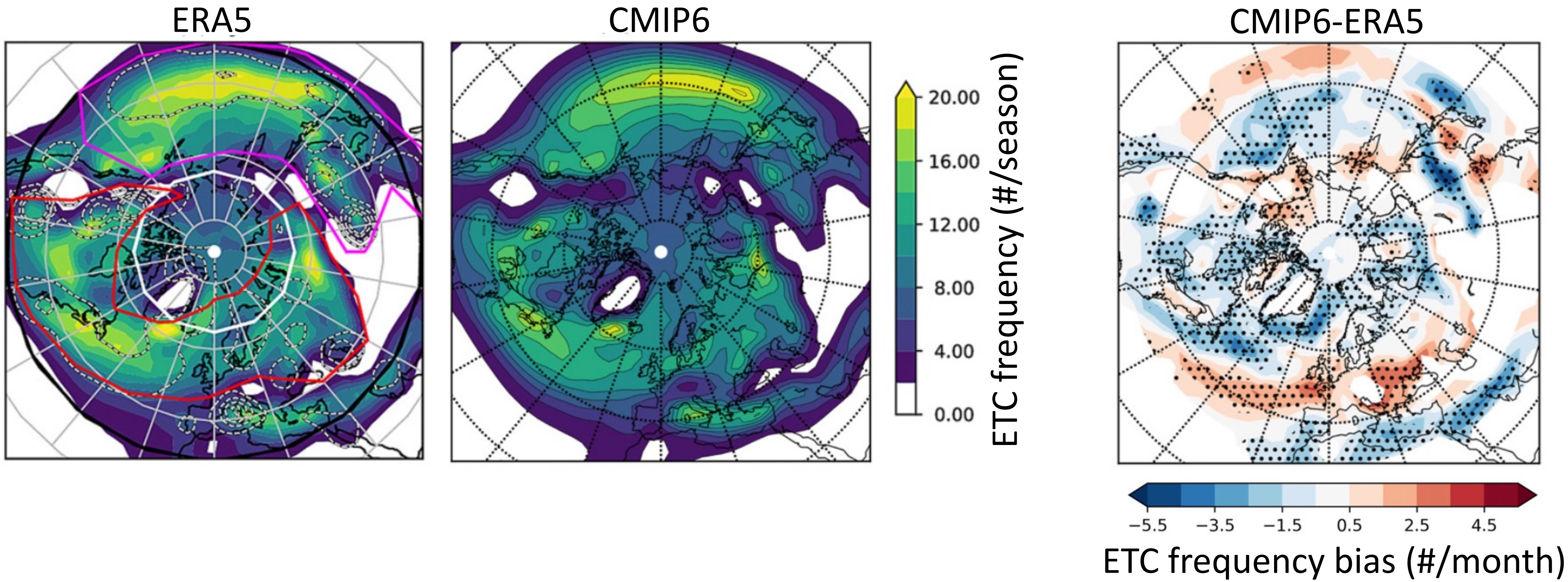


Contribution of ETCs to wintertime total precipitation (%)

- Up to 85% of wintertime precipitation is responsible for ETCs in both observation and GCM.

GCMs struggle to accurately simulate ETCs

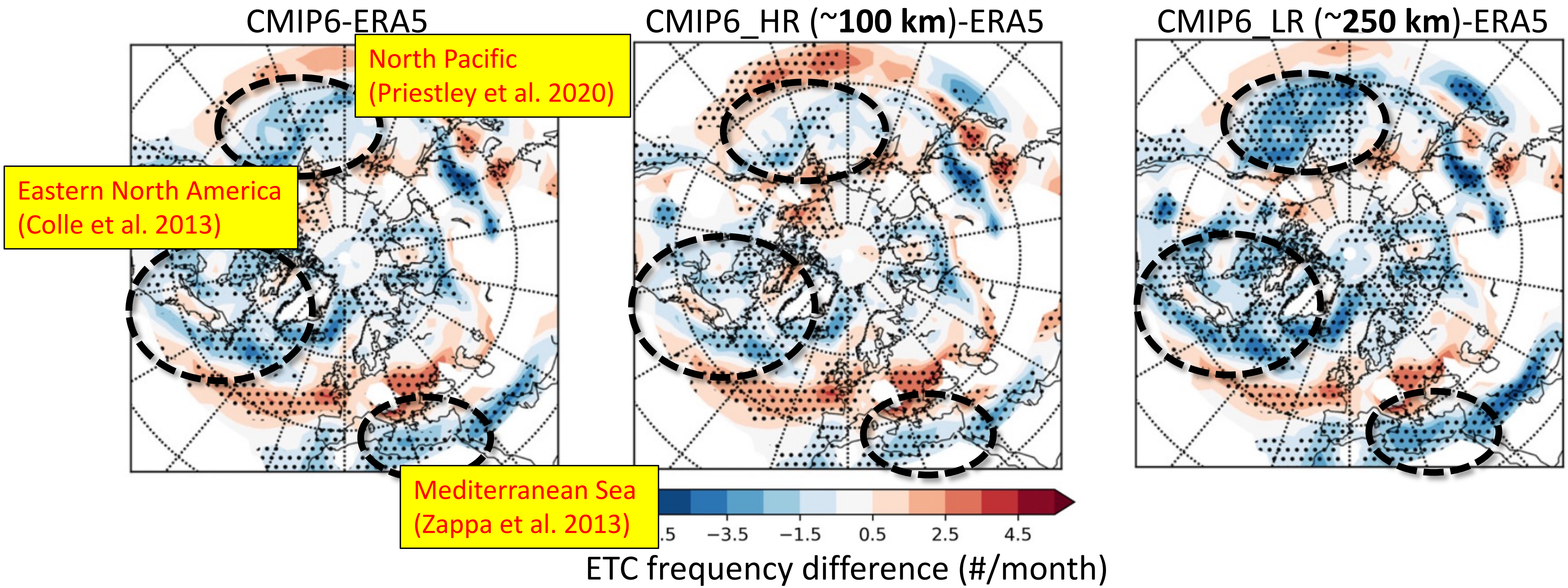
Priestley et al. 2020



- The state-of-the-art CMIP models can capture storm track locations, but still have some biases.

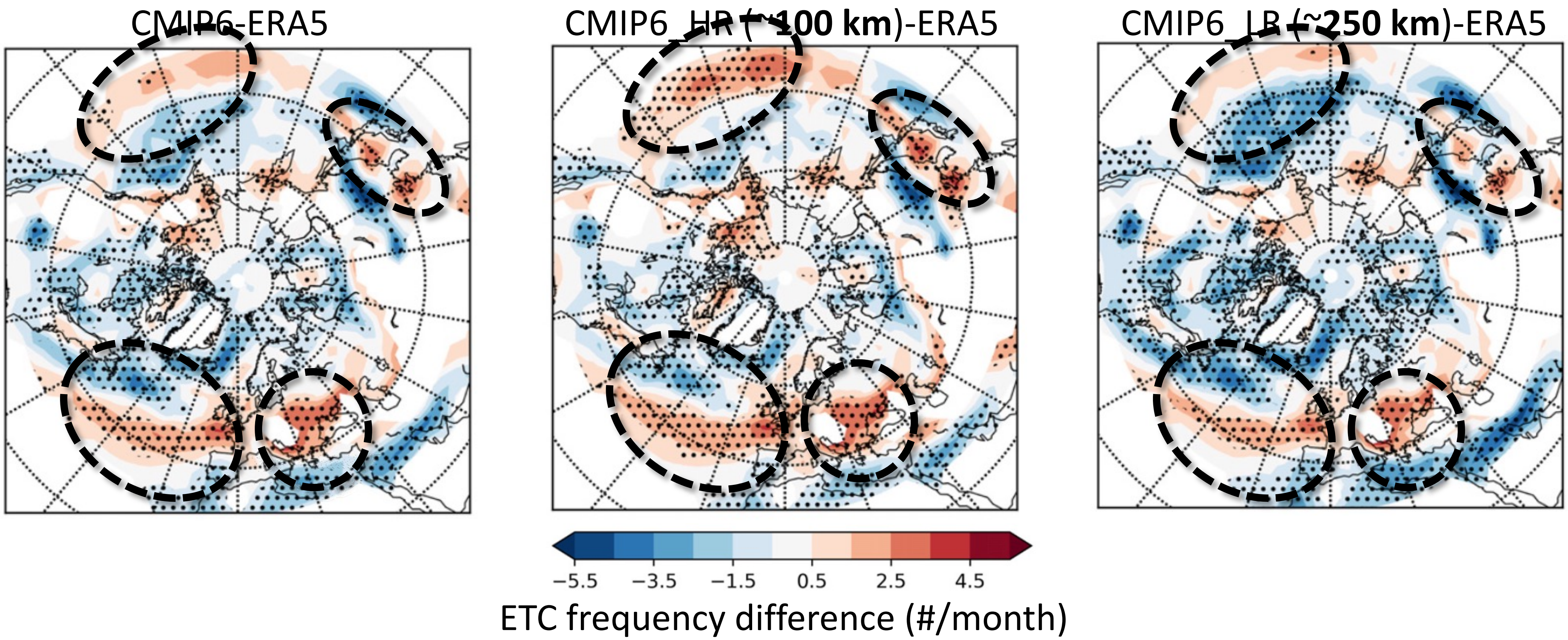
High-resolution GCMs show better representation for ETCs in some regions

Priestley et al. 2020



- High-resolution GCMs show regionally reduced underestimation of ETC frequency relative to reanalysis data (Colle et al. 2013; Zappa et al. 2013; Priestley et al. 2020).

The impact of increasing resolution on ETC representation in GCMs is not fully understood



- However, there are still larger ETC bias in relatively high-resolution GCMs than in low-resolution GCMs in some regions.

Objectives

- The sensitivity of simulated ETC frequency during cool-season (from Nov. to Feb.) in high-resolution GFDL SPEAR model (100~25 km) to atmosphere resolution change.

- Characteristics of sensitive ETCs to atmosphere resolution change.

GFDL SPEAR (**S**eamless System for **P**rediction and **EA**rth System **R**esearch) model

- Newly developed GFDL climate model (SPEAR model; Delworth et al. 2020) for 30 years (**1991~2020**) is used in this study.
- SPEAR model uses different resolution **AM4.0** and **LM4.0** (Zhao et al. 2018a,b) with dynamical vegetation model **from 100 km to 25 km**.
- For modeling ocean and sea ice, SPEAR model uses **1º MOM6** (Adcroft et al. 2019) and **SIS2** for reducing computational cost.
- An extra horizontal viscosity poleward of 50º is applied to empirically improve some aspects from coarse-resolution ocean model.

Model name	Atmosphere	Land	Ocean	Sea ice
SPEAR-LO (10 members)	AM4.0 (100 km)	LM4.0+DynVeg (100 km)	MOM6 (1º)	SIS2 (1º)
SPEAR-MED (10 members)	AM4.0 (50 km)	LM4.0+DynVeg (50 km)	MOM6 (1º)	SIS2 (1º)
SPEAR-HI (10 members)	AM4.0 (25 km)	LM4.0+DynVeg (25 km)	MOM6 (1º)	SIS2 (1º)

TRACK algorithm and ETC effective area detector

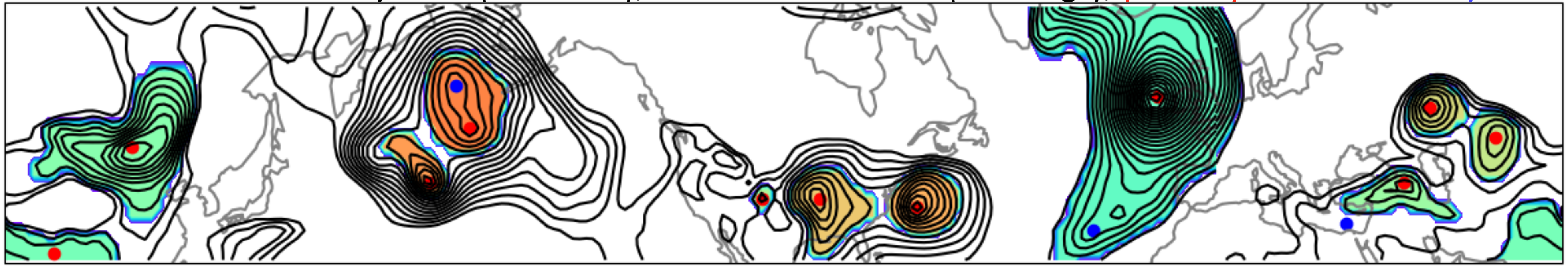
ETC tracking and detection

- ETCs are detected and tracked by using TRACK algorithm (Hodges 1994; 1995; 1997).
- ETCs are detected on 6-hourly anomalous SLP field truncated at **T42** and **T106**.

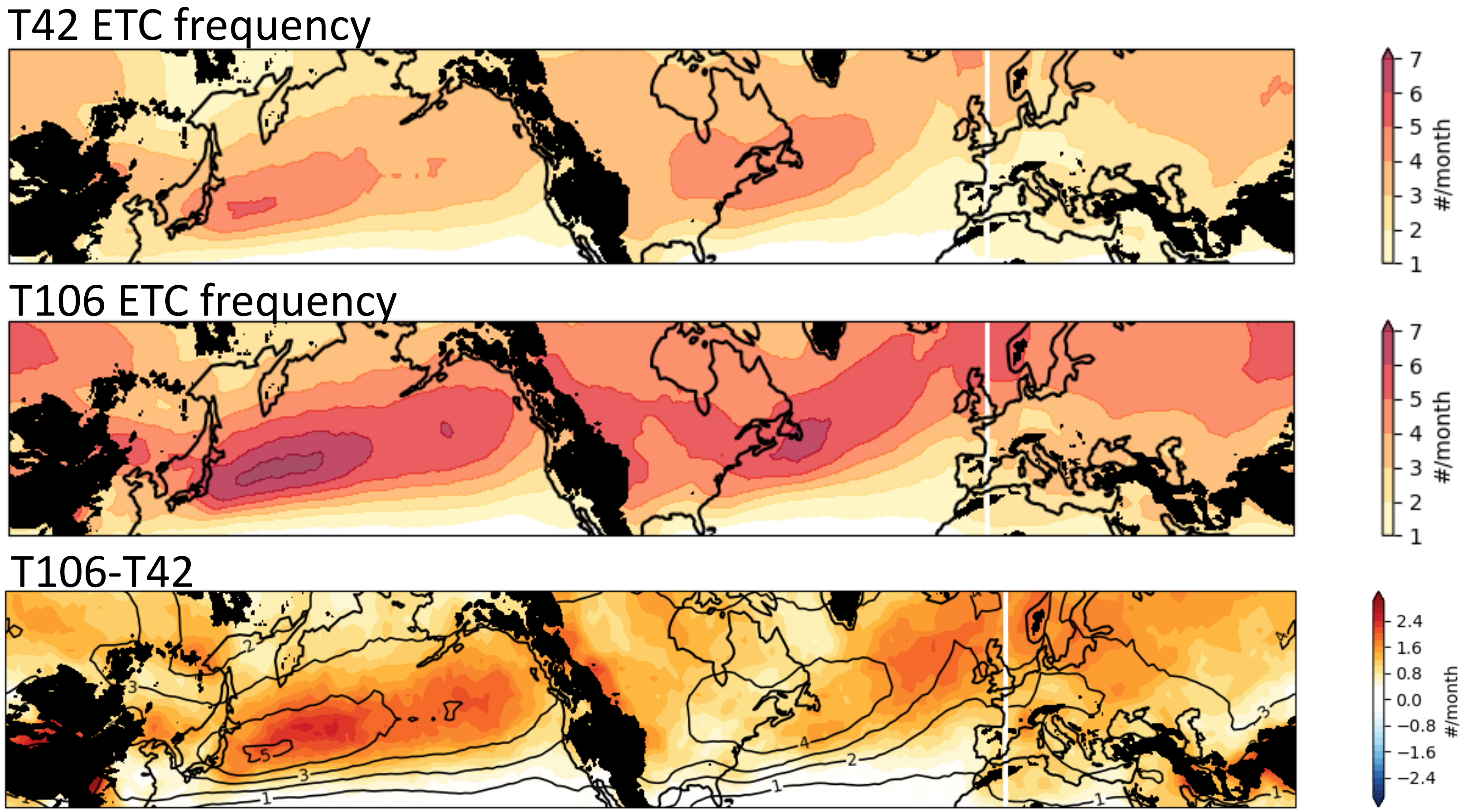
ETC effective area detector

- This detector finds a closed contour from the outmost and defines as ETC effective area.
- If there are primary and secondary ETCs in one closed contour, the information for detected ETC area belongs to primary ETC.
- ETC size (A) is measured by an ETC effective radius ($R_e = \sqrt{A_c/\boldsymbol{\pi}}$) (Rudeva and Gulev, 2007).

An example of detector: SLP anomaly field (contours), detected ETC area (shadings), primary and secondary ETC center (points)



Higher resolution of spectral truncation result in a larger ETC number



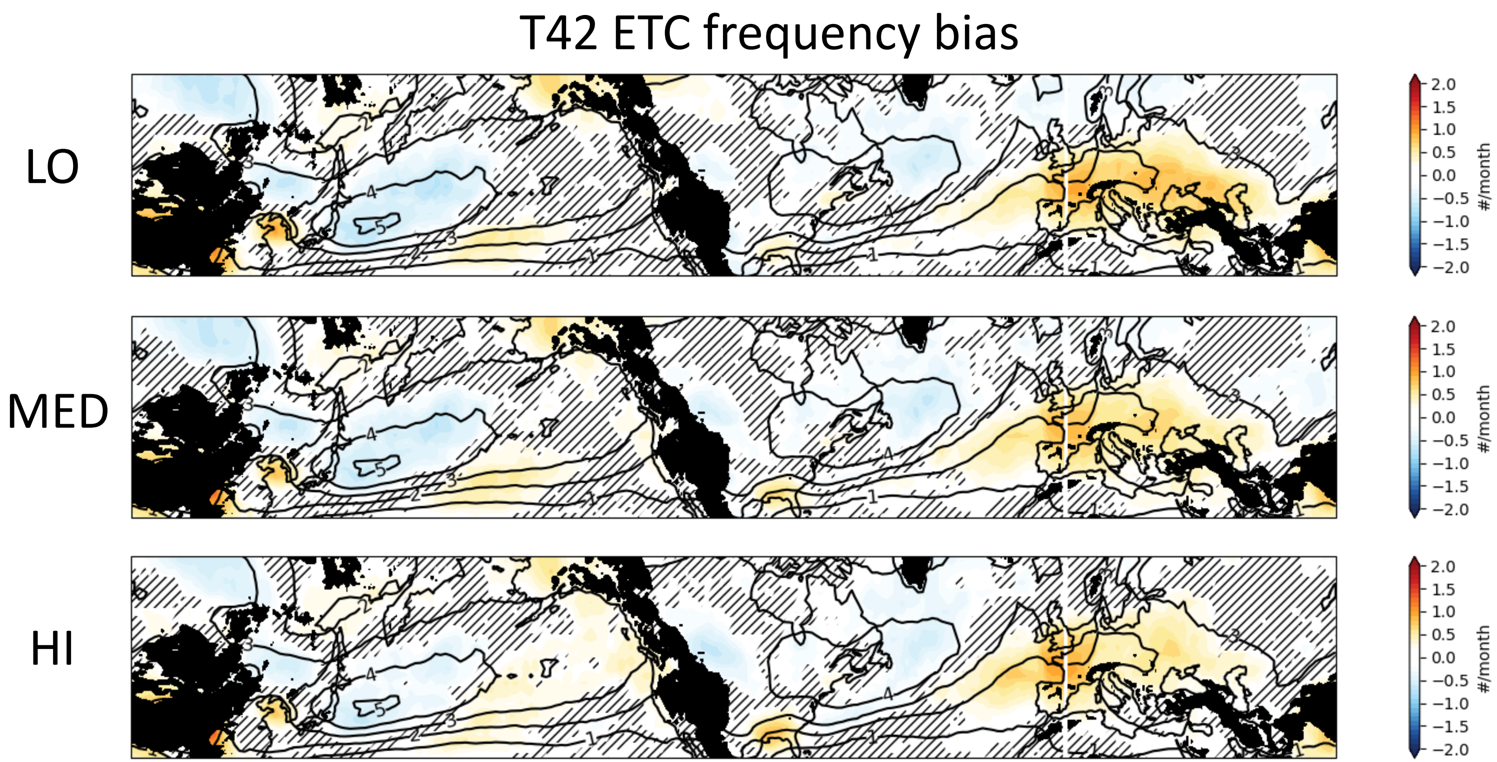
ERA5

ETC frequency:
the number of ETCs passing within the 555-km radius of a grid point

T42 ETC frequency (black contours)

- ERA5 shows similar spatial distributions of cool-season NH ETC frequencies at T42 and T106; However, there is a quantitative difference between T42 and T106.

T42 ETC frequency shows very weak sensitivity to atmosphere resolution change

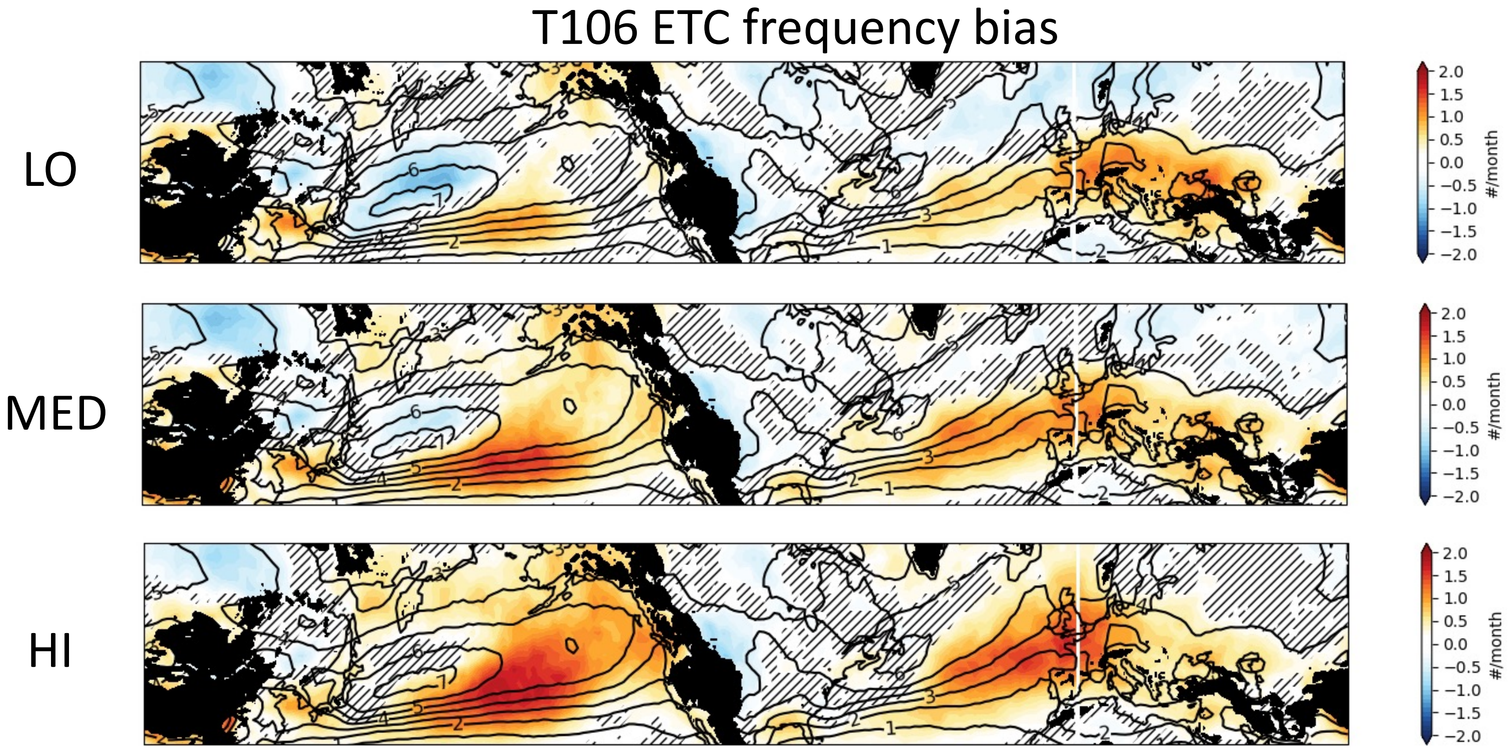


SPEAR-ERA5 (shadings)
ERA5 (black contours)

*Hatched areas mean the region where 90% of all ensembles do not agree with same sign.

- The extent of bias in SPEAR-LO changes slightly in SPEAR-MED and -HI, but it is difficult to identify the qualitative difference between SPEAR models.

T106 oceanic ETCs are highly sensitive to atmosphere resolution change

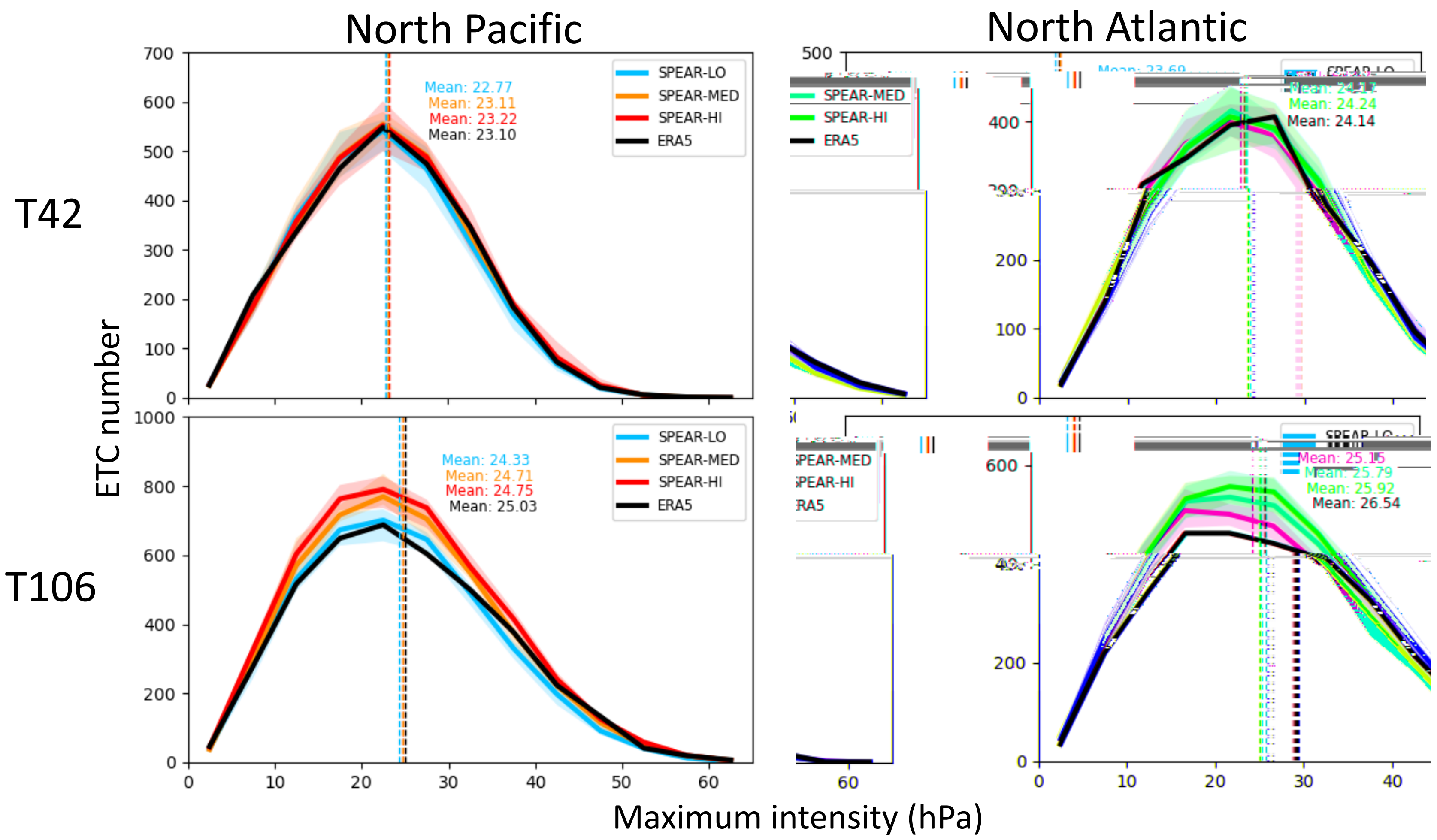


SPEAR-ERA5 (shadings)
ERA5 (black contours)

*Hatched areas mean the region where 90% of all ensembles do not agree with same sign.

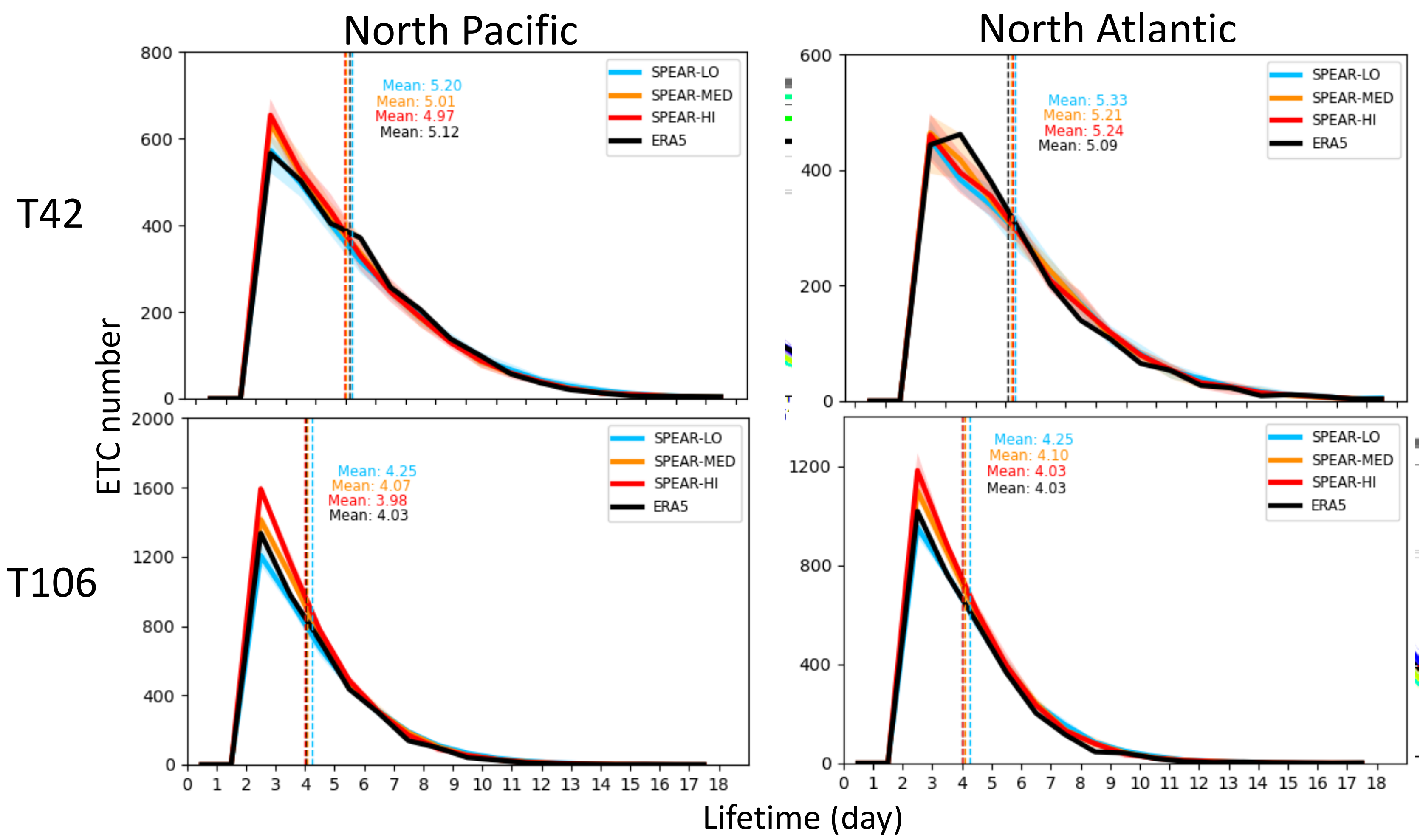
- Increasing resolution leads to noticeable improvement for representation of ETCs along the main storm track regions.
- However, at the same time, it induces strong increment of detected ETC numbers near the downstream regions of major oceanic ETC frequencies.

Increasing resolution leads to better representation for extreme ETCs but exaggerations for weak and moderate ETCs

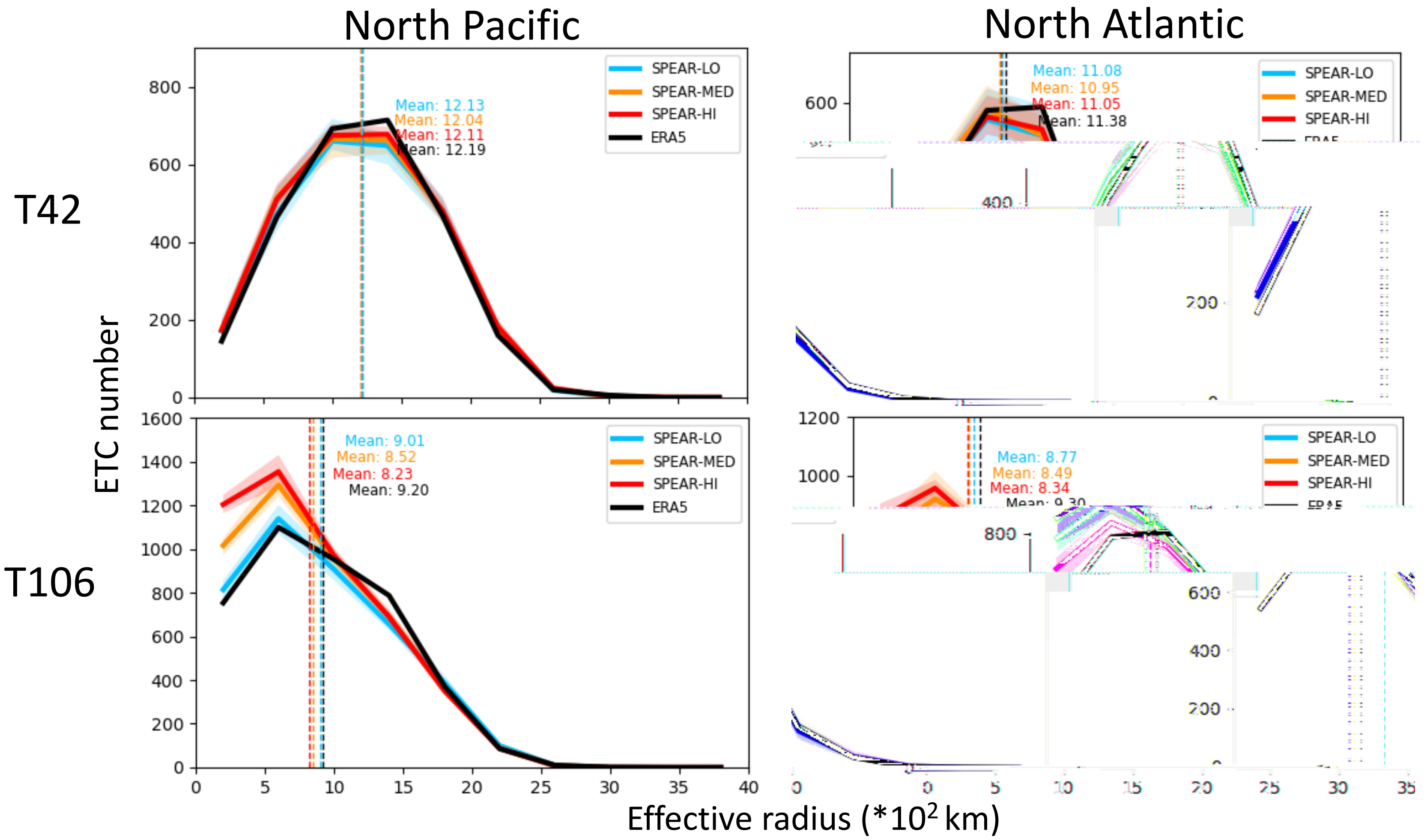


Maximum intensity: The strongest intensity during ETC's lifespan

Increasing resolution also results in better representation for long-lived ETCs but exaggeration of short-lived ETCs



Increasing resolution induces an increase in only small-sized ETCs



Effective radius (R_e):

$$R_e = \sqrt{A_c/\pi}$$

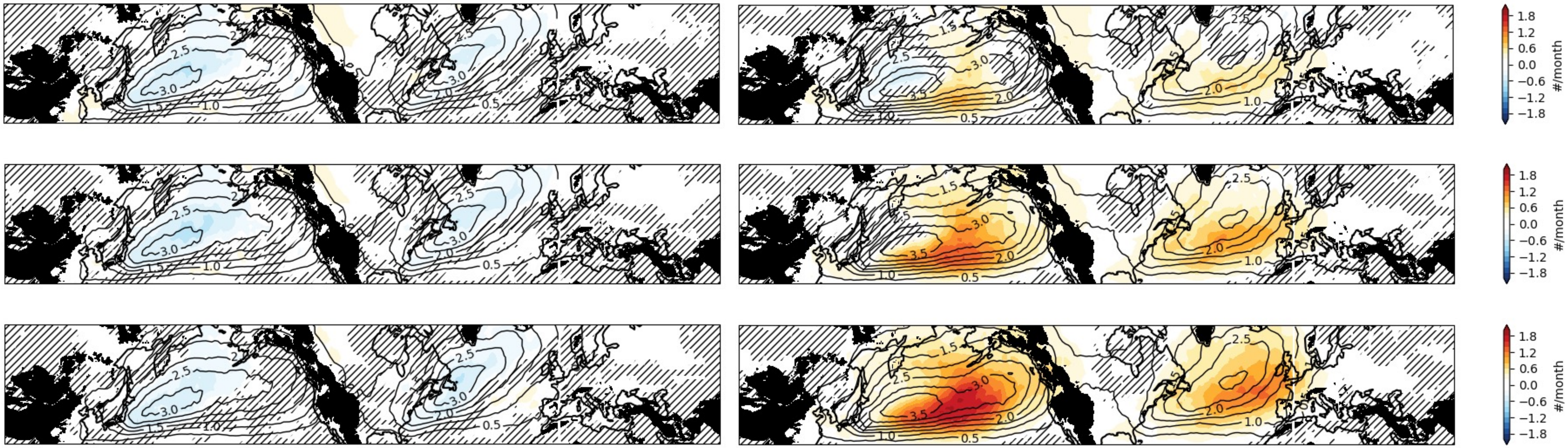
ETC frequency sensitivity to resolution change is mostly associated with a change in small-sized ETCs

Large-sized ETC frequency bias | Small-sized ETC frequency bias

LO

MED

HI



- Highly increased ETC frequency bias over the ocean with increasing atmosphere resolution is mainly attributed to increased small-sized ETC frequency.

ETC frequency sensitivity to resolution change is mostly associated with a change in small-sized ETCs

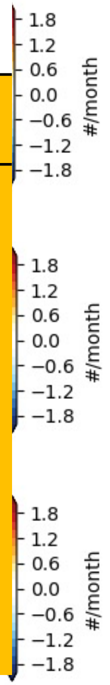
Large-sized ETC frequency bias / Small-sized ETC frequency bias

LO

MED

HI

Model	T42 ETC number		T106 ETC number	
	Large-sized	Small-sized	Large-sized	Small-sized
ERA5	3028	1803	3052	4078
SPEAR-LO (ensemble mean, STD)	2889.9±32.8	1875.0±31.24	2824.2±36.8	4330.9±58.4
SPEAR-MED (ensemble mean, STD)	2899.2±31.8	1968.3±45.2	2825.9±36.9	4947.9±71.74
SPEAR-HI (ensemble mean, STD)	2937.4±26.7	1929.0±32.87	2844.3±35.12	5296.2±67.6



- Highly increased ETC frequency bias over the ocean with increasing atmosphere resolution is mainly attributed to increased small-sized ETC frequency.

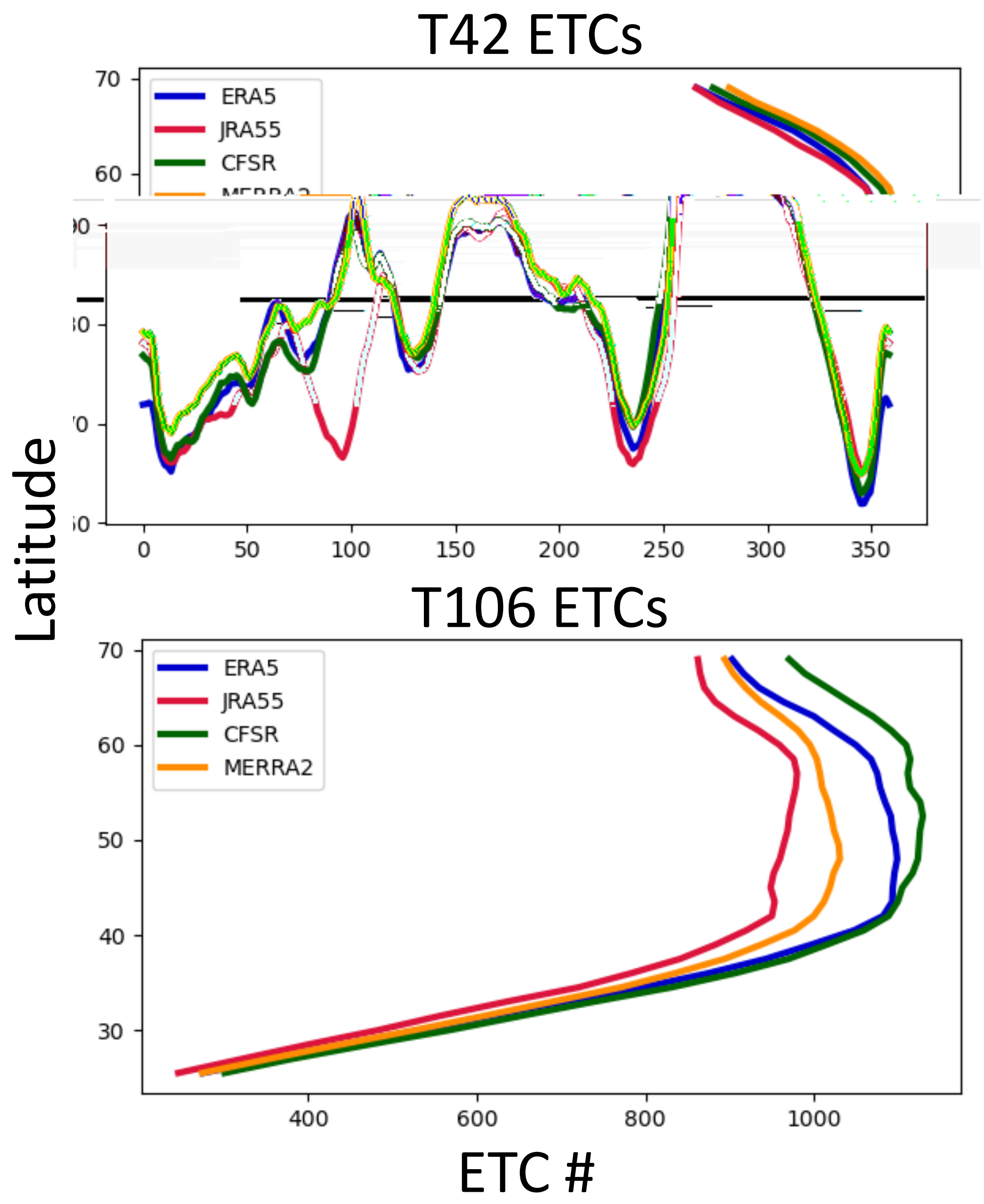
Conclusion

- The impact of increasing atmosphere resolution on representation of ETC frequency is clearly shown in **only T106 oceanic ETC frequency** (e.g., improvement for T106 ETC frequency bias along the main storm track regions and exaggeration of T106 ETC frequency downstream of the main storm track regions), resulting from **increase in small-sized ETCs** with increasing resolution.

- This size-dependent sensitivity of ETCs underscores the importance of considering **high resolution of spectral truncation** in Lagrangian ETC tracking for investigating ETC sensitivity to resolution change.

- Although increasing resolution leads to partly better ETC representation, it should be noted that it also induces an increase in ETC frequency bias, which might contribute to increased precipitation in high-resolution model.

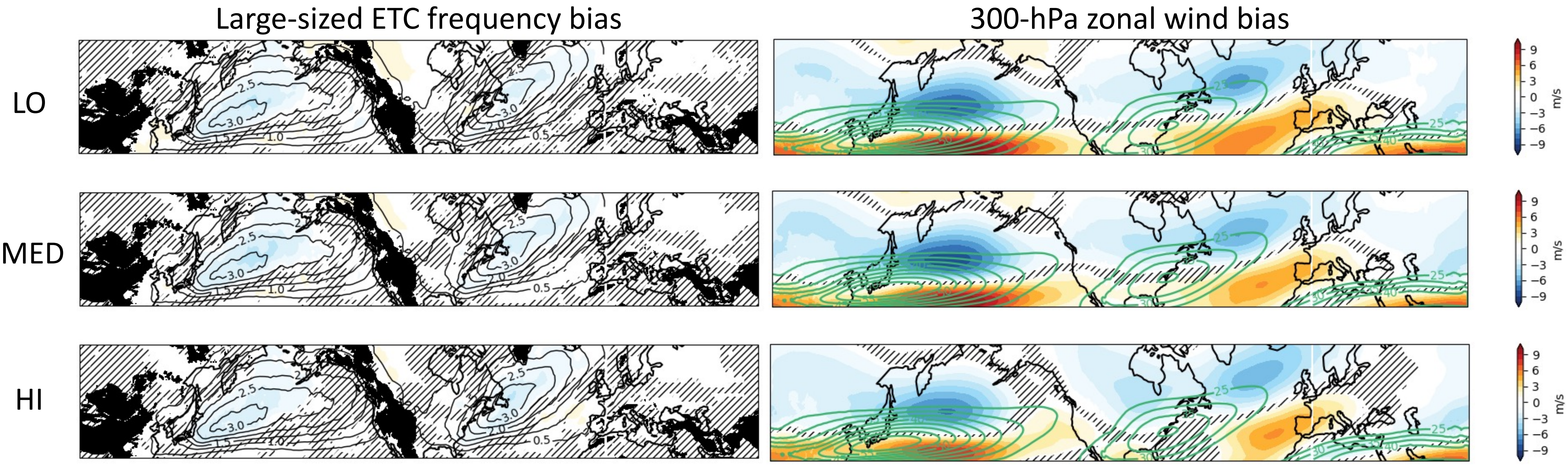
Uncertainty of ETC frequency in reanalysis data



Model name	Resolution for assimilation	Resolution for output
ECMWF ERA5 (Hersbach et al. 2020)	30 km	0.25ºx0.25º
JMA JRA55 (Kobayashi et al. 2015)	60 km	1.25ºx1.25º
NASA MERRA-2 (Gelaro et al. 2017)	60 km	0.6ºx0.5º
NCEP CFSR (Saha et al. 2010) and CFSv2 (Saha et al. 2014)	38 km	0.25ºx0.25º

- The number of ETCs on T42 field are not sensitive to resolutions, but the number on T106 field is very sensitive to resolution (maximum difference between JRA55 and CFSR is about 200 ETCs).

Large-sized ETC frequency bias seems to be related to upper-level zonal wind bias



- Large-sized ETCs generally intensify through mutual interaction with upper-level trough.

Small-sized ETC frequency bias is not related to upper-level zonal wind bias