Projected Future Changes in Tropical Cyclones at Regional Scale

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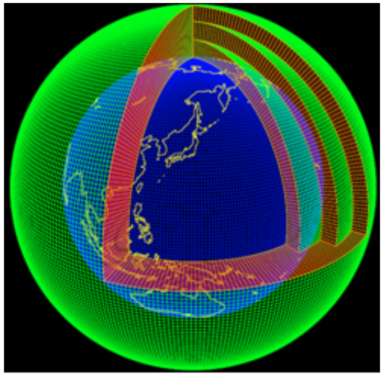
MRI model developers

Outline

- Review of previous studies on projected future changes in tropical cyclones (TCs)
- MRI AGCM (20km, version 3.1)
- Projected future changes in TC activity at regional scale
    - North Atlantic
    - Western North Pacific
    - Central Pacific (near Hawaii)



20-km mesh global model

Review of effect of global warming on TC activity

nature geoscience | REVIEW ARTICLE
PUBLISHED ONLINE: 21 FEBRUARY 2010 | DOI: 10.1038/NGEO779

Knutson et al. (2010, *Nat. Geosci.*)

Tropical cyclones and climate change

Thomas R. Knutson[1*], John L. McBride[2], Johnny Chan[3], Kerry Emanuel[4], Greg Holland[5], Chris Landsea[6], Isaac Held[1], James P. Kossin[7], A. K. Srivastava[8] and Masato Sugi[9]

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1. **Consistent results** (robustness)
   - Decrease in frequency of global TCs
   - Increase in frequency of intense TCs
2. **Inconsistent results** (uncertainty)
   - Projected future changes in TC frequency in a specific ocean basin

   Among 13 previous numerical studies, 5 indicated an increase in the WNP, while 7 reported a decreasing frequency (Murakami and Wang, 2010)

Future changes in regional TC activity remain uncertain!

IPCC Assessment Reports

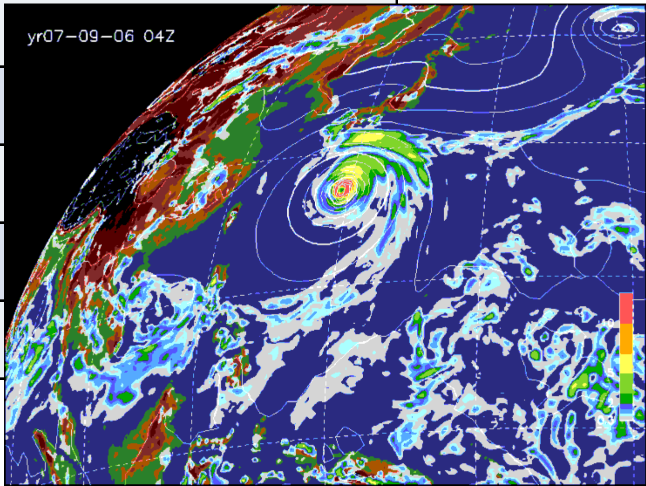
				

	FAR 1990 **11 Chapters**	SAR 1995 **11 Chapters**	TAR 2001 **14 Chapters**	AR4 2007 **11 Chapters**	AR5 2013 **14 Chapters**
observations	✓	✓	✓	✓✓✓	✓✓✓
paleoclimate				✓	✓
sea level	✓	✓	✓		✓
clouds					✓
carbon cycle			✓		✓
regional change			✓	✓	✓✓✓

To address regional climate change was one of the most important topics for the IPCC AR5.

Model Specifications

	MRI-AGCM3.1 (developed in 2007; Mizuta et al. 2006)
Horizontal resolution	TL959 (20km)
Vertical resolution	60 levels (top at 0.1hPa)
Time integration	Semi-Lagrangian
Time step	6minutes
Cumulus convection	Prognostic Arakara-Schubert
Cloud	Smith (1990)
Radiation	Shibata and Aoki (1989) Shibata and Uchiyama(1992)
GWD	Iwasaki et al. (1989)
Land surface	SiB ver0109(Hirai et al.2007)
Boundary layer	MellorYamada Level2
Aerosol (direct)	Sulfate aerosol
Aerosol (indirect)	No



Experimental Designs

- Model: MRI AGCM 3.1 (20 km-mesh)
- Projection periods:

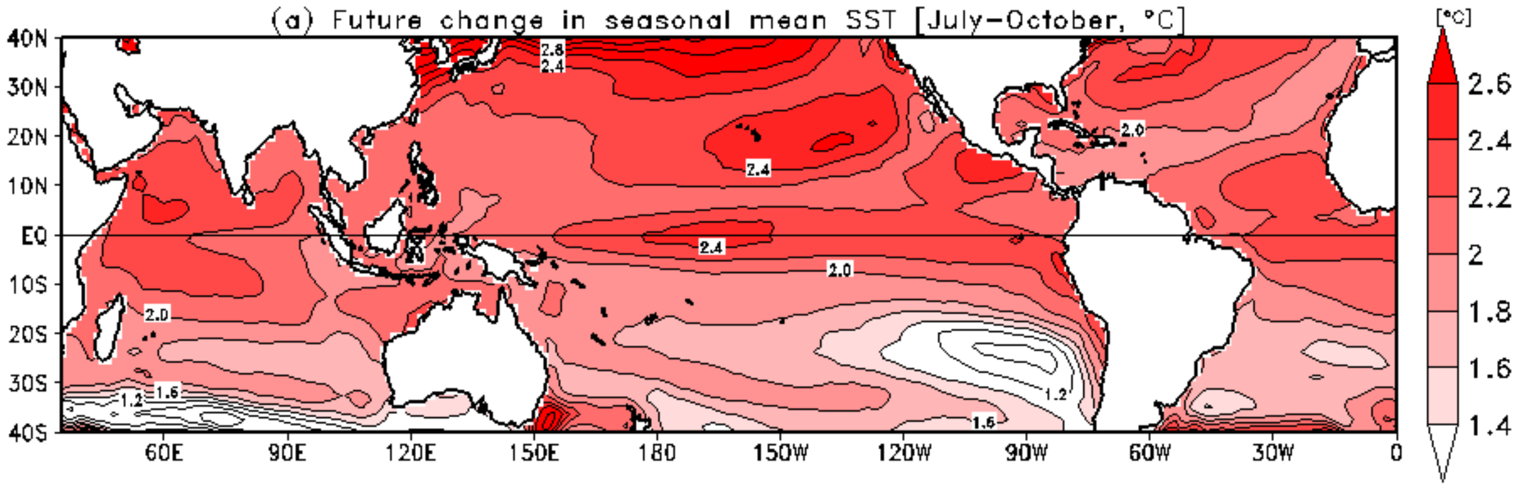
  Present-day exp. (PD) : 1979-2003 (25 yr)

  Future global warmed exp. (GW): 2075-2099 (25 yr)

- Prescribed lower boundary conditions of SST, Sea ice:

  PD: Observations (HadISST1)

  GW: Future changes in 18 CMIP3 MME (A1B) + observed



▪ Relatively larger increase in SST in the Northern Hemisphere than in the Southern Hemisphere.

▪ The SST increase is the largest in the tropical Central Pacific.

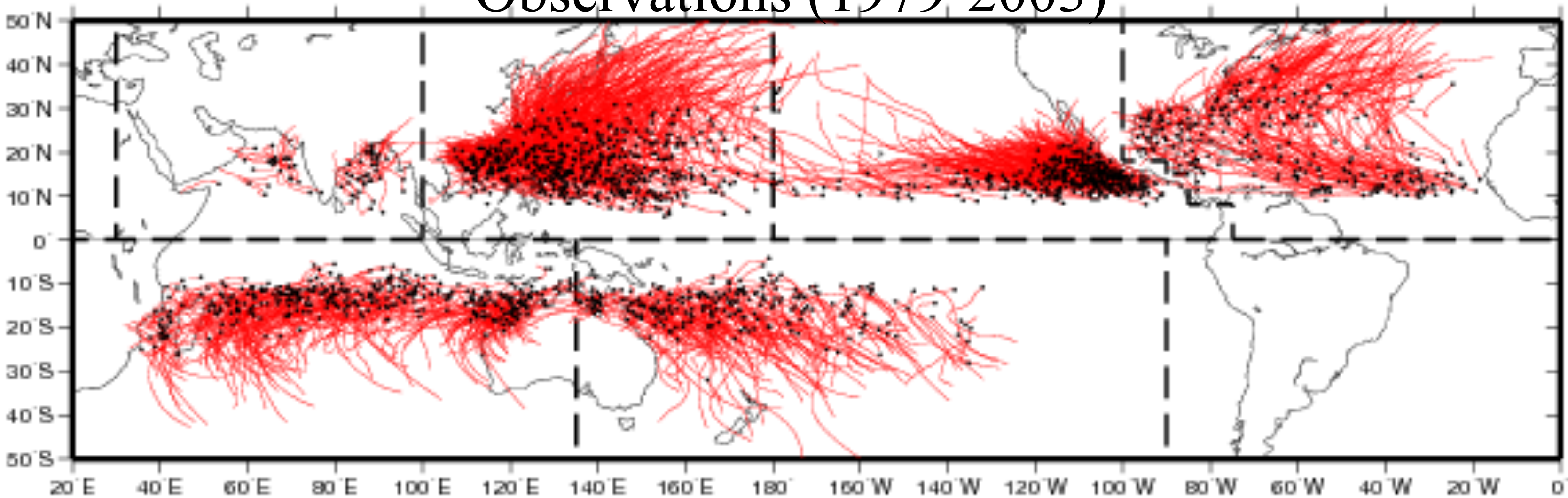
TC Detection Criteria

Based on Oouchi et al. (2006)

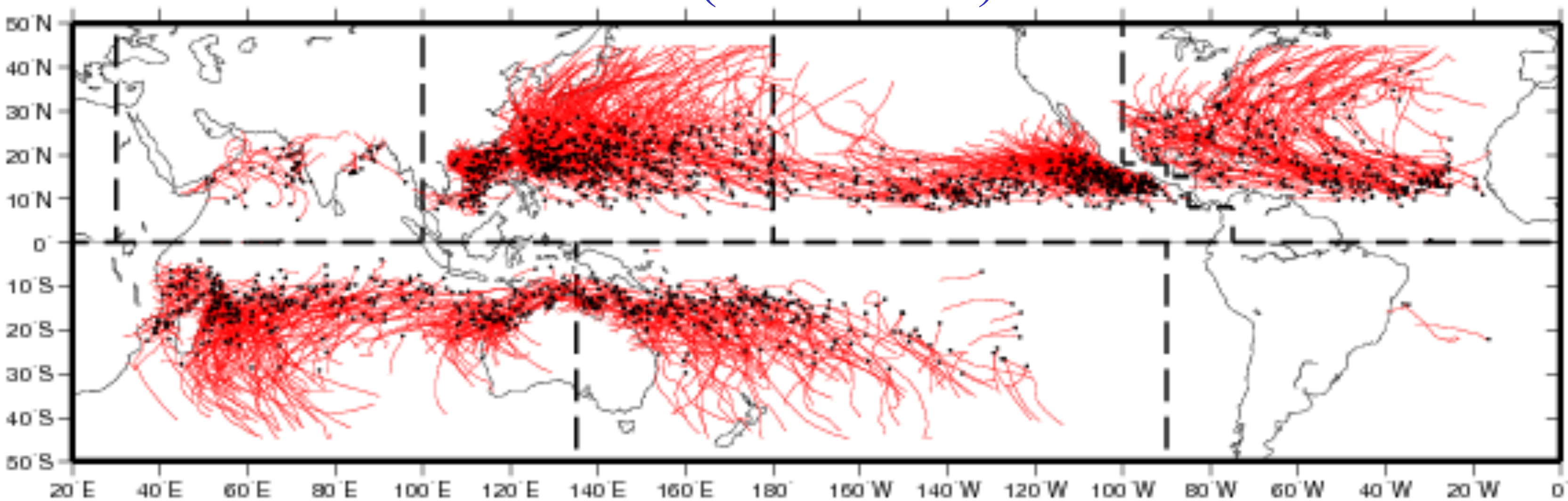
- Sea level pressure = 2.0 hPa lower than the surroundings area.
- 850 hPa Relative volticity = 3.0×10^{-5} /s
- 850 hPa Maximum wind speed = 10.0 m/s
- Warm Core: 1.0 K
- Duration =36 hours
- Maximum wind speed at 850 hPa should be greater than the 300 hPa
  (to exclude extra-tropical cyclones).

Simulated Global TC Tracks

Observations (1979-2003)



PD (1979-2003)

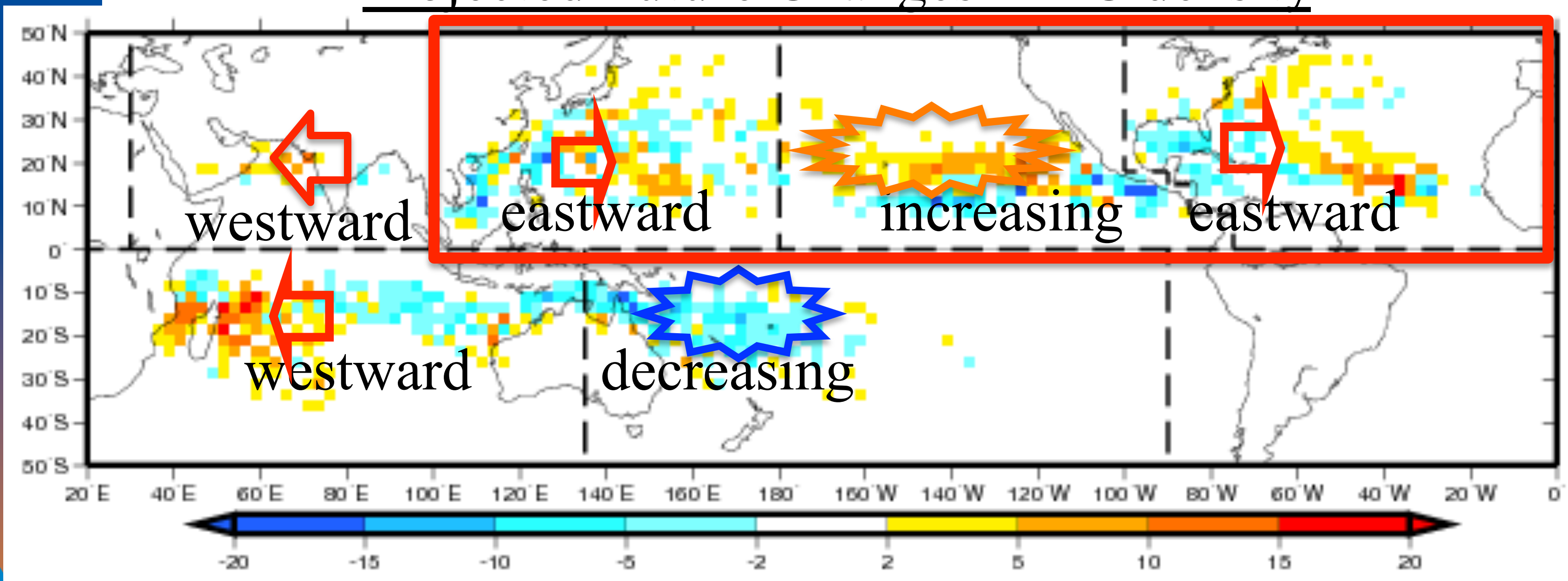


TC tracks are well simulated by the PD experiment.

TC density

TC density is defined as the total count of TC passage for each 2.5 x 2.5 degree grid box at 6-hour interval.

Projected Future Changes in TC density

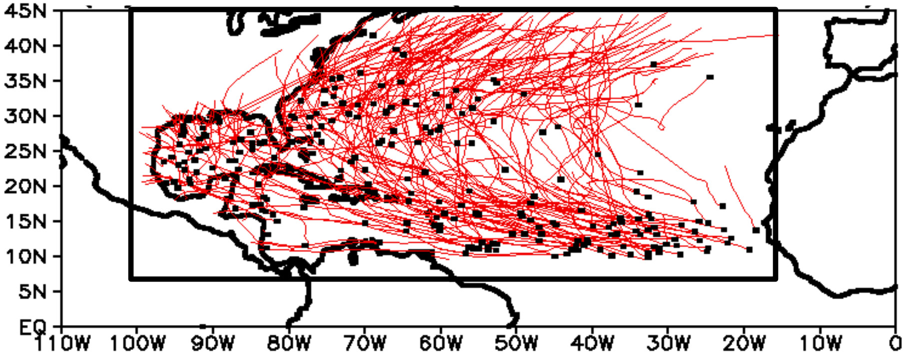


North Atlantic

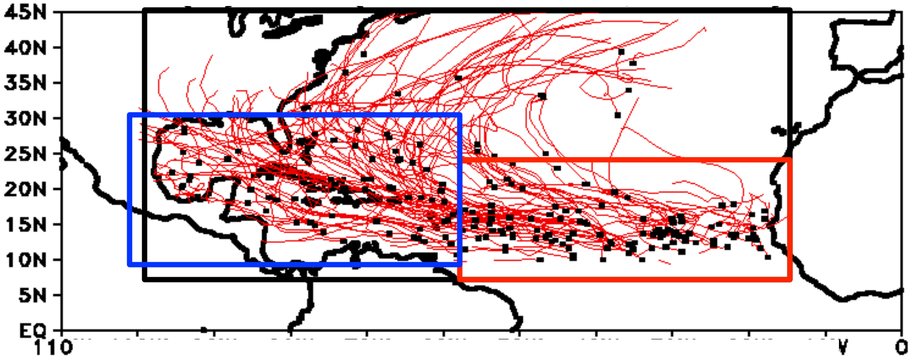
Murakami, H., and B. Wang, 2010: Future change of North Atlantic tropical cyclone tracks: Projection by a 20-km-mesh global atmospheric model. *J. Climate*, **23,** 2699-2721.

TC tracks in North Atlantic

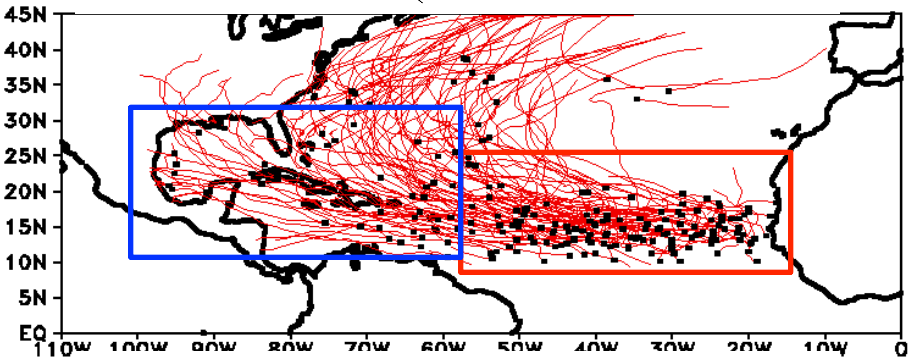
Observations (1979−2003)



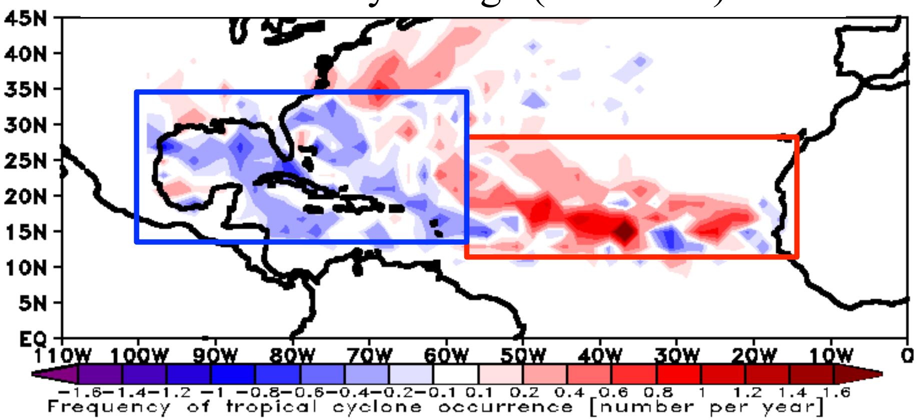
PD (1979−2003)



GW (2075—2099)



TC density change (GW – PD)



- TC tracks by PD exp is realistic.
- Higher TC density in the eastern NA.
- Lower TC density in the western NA.

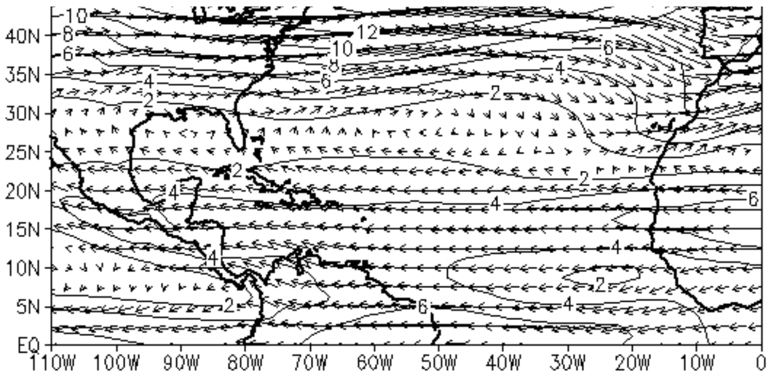
What causes this east-west contrast?

Any changes in steering flows?

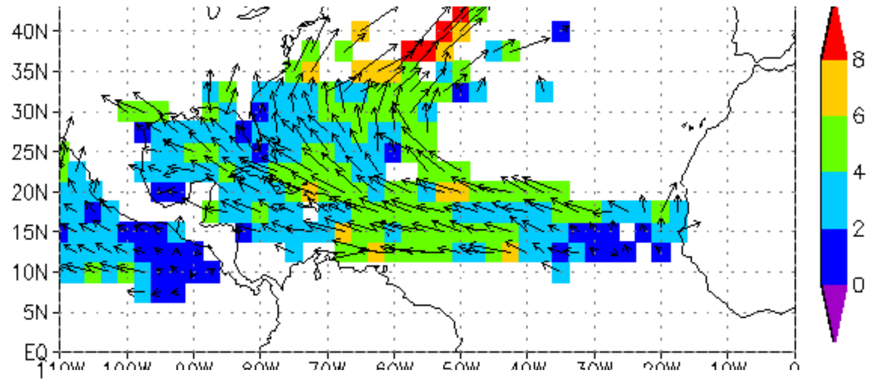
Any changes in genesis location?

Steering flows and mean TC translation vectors (Jul - Oct)

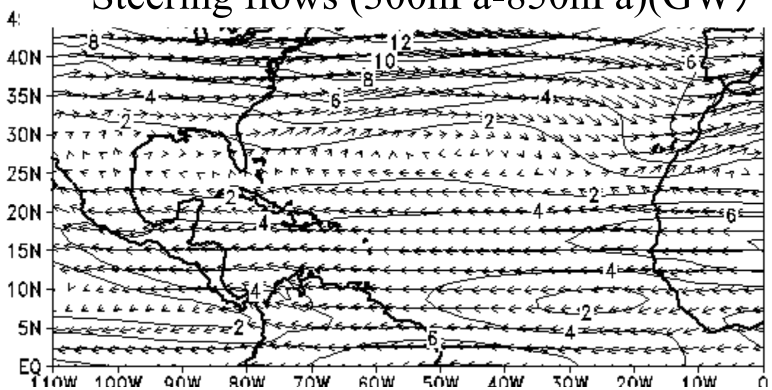
Steering flows (300hPa-850hPa)(PD)



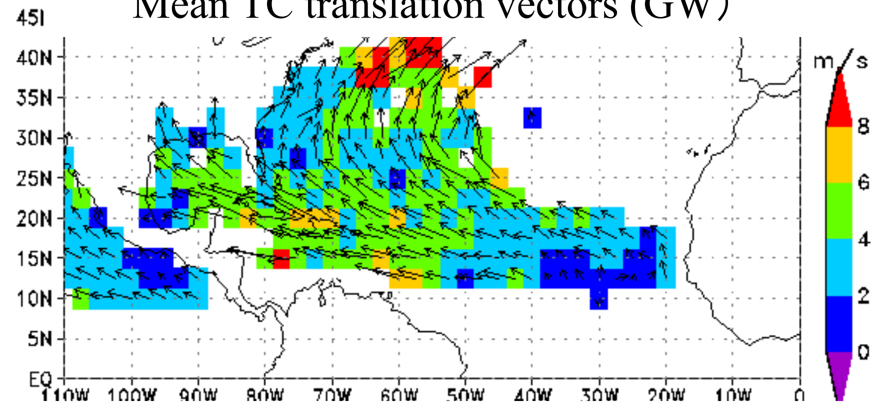
Mean TC translation vectors (PD)



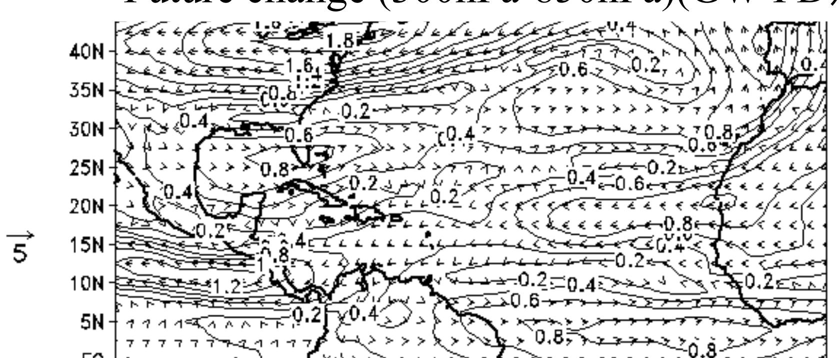
Steering flows (300hPa-850hPa)(GW)



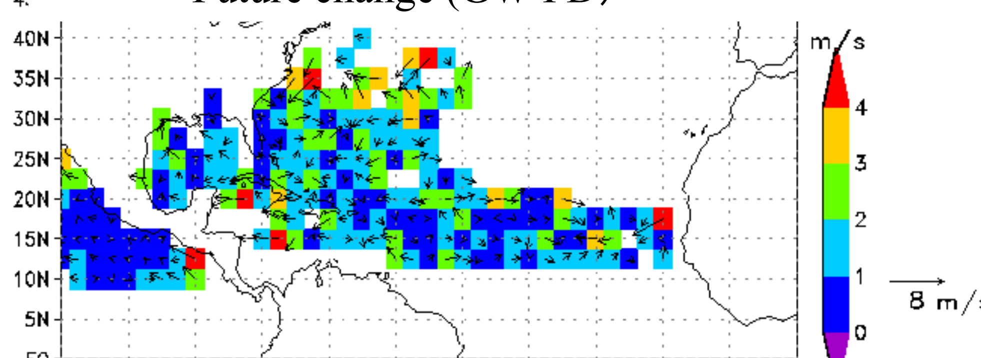
Mean TC translation vectors (GW)



Future change (300hPa-850hPa)(GW-PD)



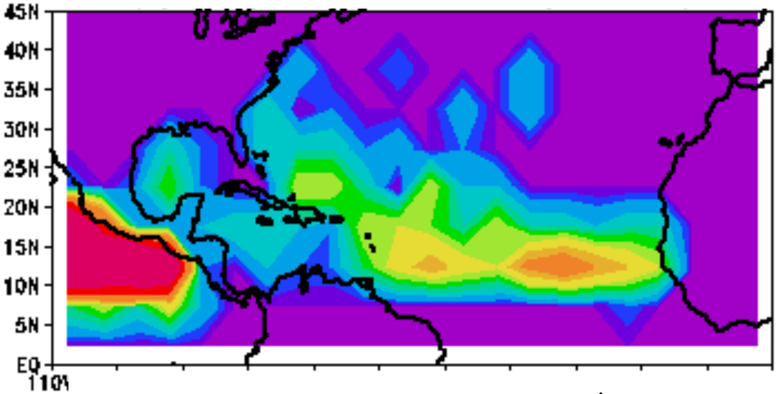
Future change (GW-PD)



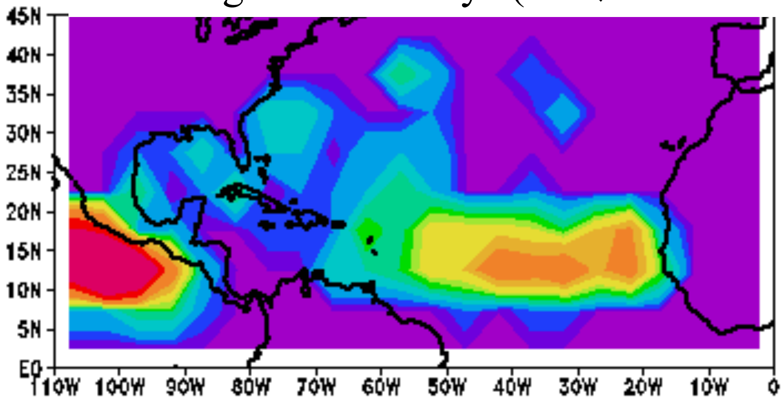
Changes in steering flows are very small. => Less contribution to the projected shift in TC tracks.

TC genesis density (Jul - Oct)

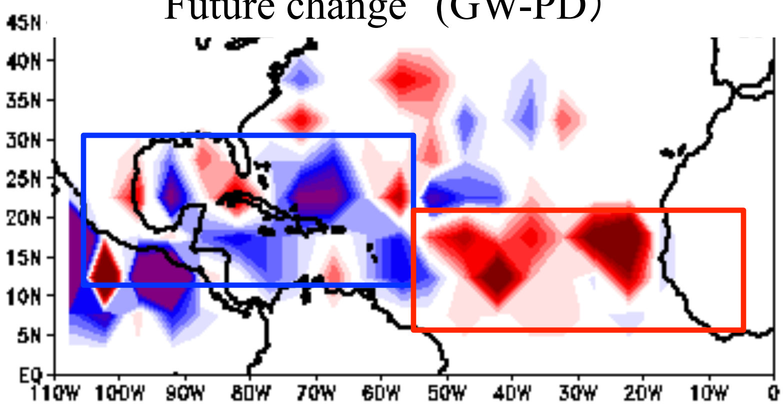
TC genesis density (PD)



TC genesis density (GW)



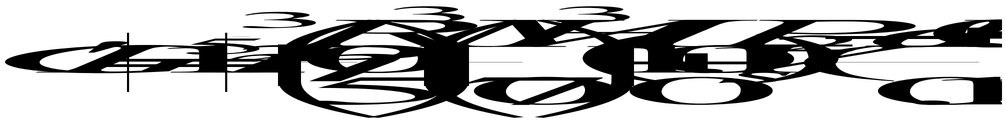
Future change (GW-PD)



- An eastward shift in TC genesis appears to be a major factor for the TC track shift.
- Why more (less) TC genesis in the eastern (western) NA?

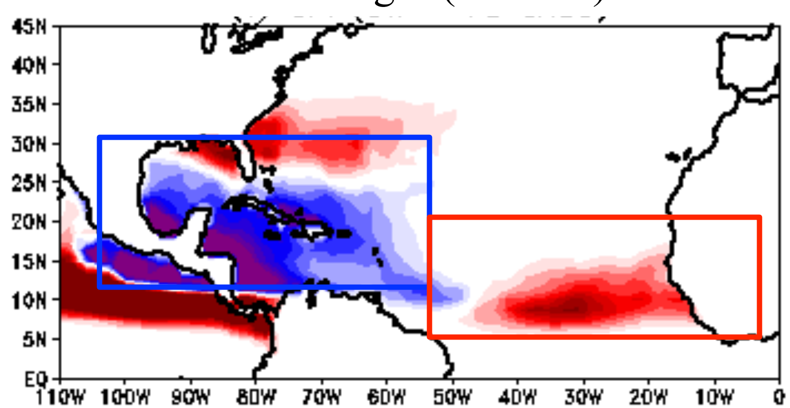
⇒ Genesis Potential Index (GPI) can identify critical factors for the genesis changes.

- Modified version of Genesis Potential Index (GPI) by Emanuel and Nolan (2004)

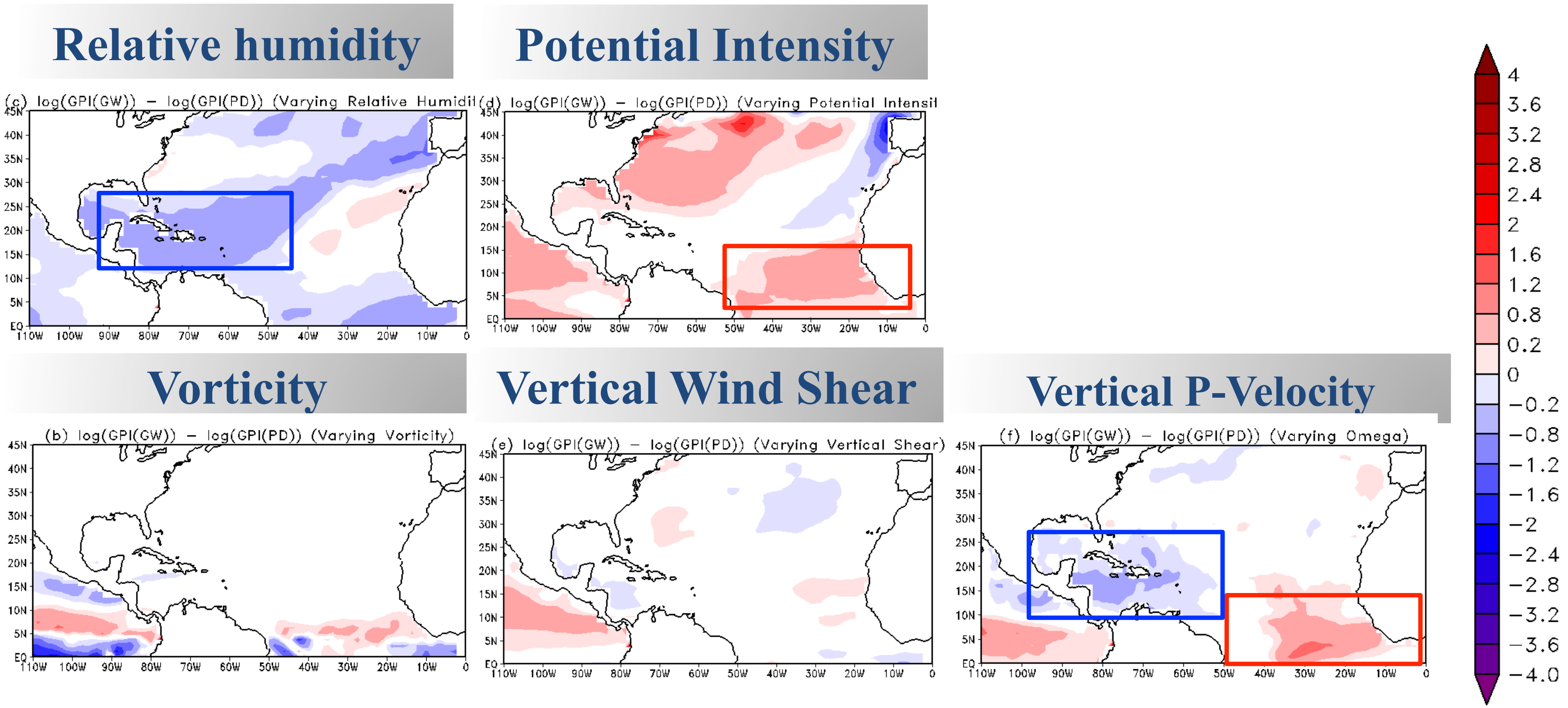


Low-level (850hPa) vorticity (s^{-1})	Mid-level (700hPa) relative humidity (%)	Maximum Potential Intensity (m/s)	Vertical wind shear (850-200hPa, m/s)	Vertical p-velocity at 500hPa (Pa/s)

GPI changes (GW-PD)



Each term contribution to the changes in GPI

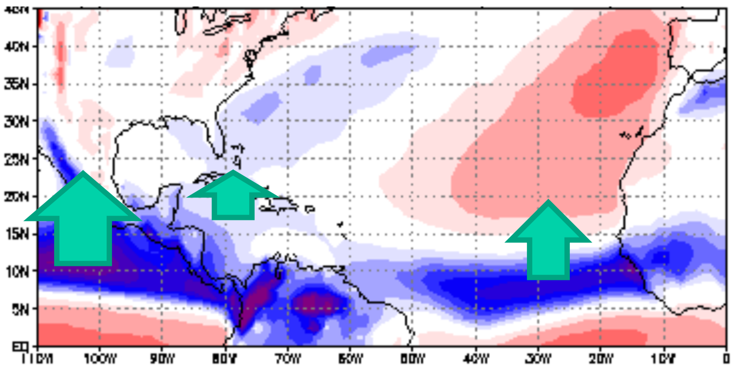


For the eastern NA, increases in ascending motion and potential intensity are responsible for the GPI increase.

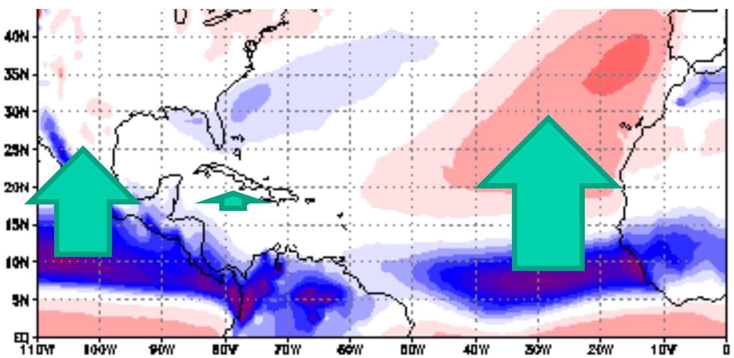
For the western NA, decrease in relative humidity and descending anomaly are responsible for the GPI decrease.

Implication of the GPI analysis

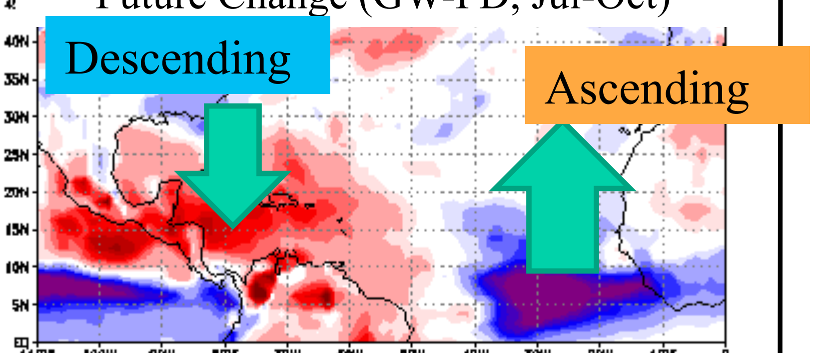
500 hPa p-velosity (PD, Jul-Oct)



500 hPa p-velocity (GW, Jul-Oct)

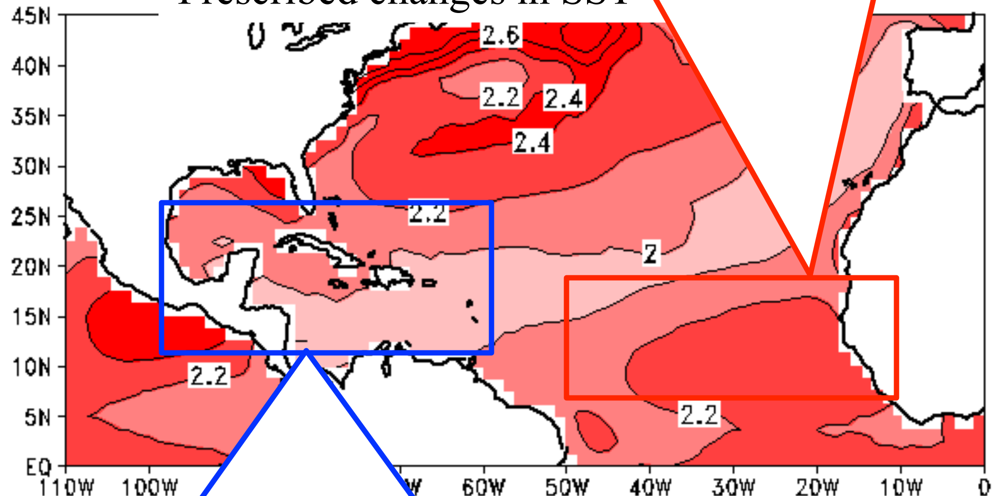


Future Change (GW-PD, Jul-Oct)



Larger SST increase => Increase in TC genesis

Prescribed changes in SST

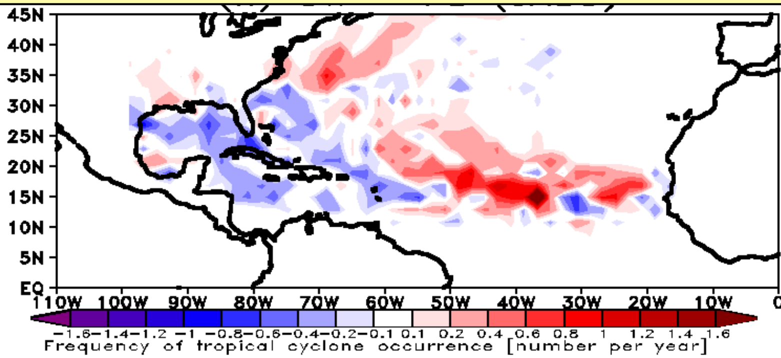


Smaller SST increase.
However, descending anomaly due to more active convection at eastern North Atlantic.

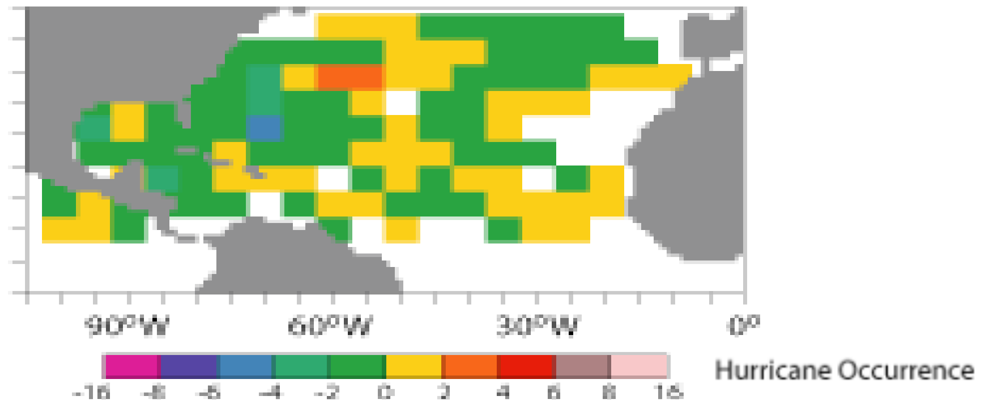
Local SST increase relative to mean increase is important not only for the local TC activity, but also for the remote TC activity through teleconnection.

Similar projected changes and observed trend by other studies

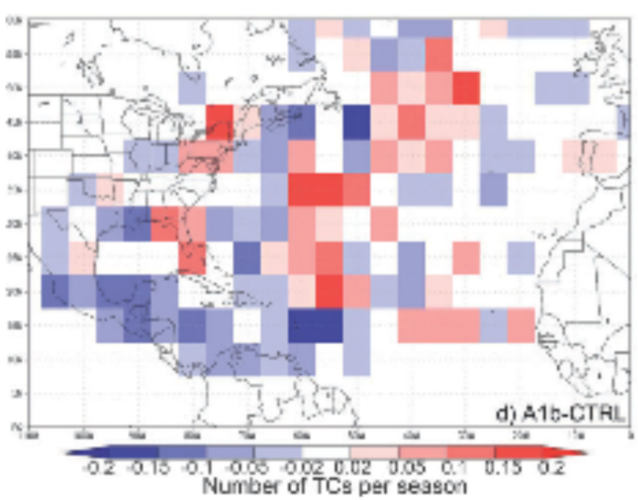
Murakami and Wang (2010)
(SST=CMIP3 multi model ensemble mean)



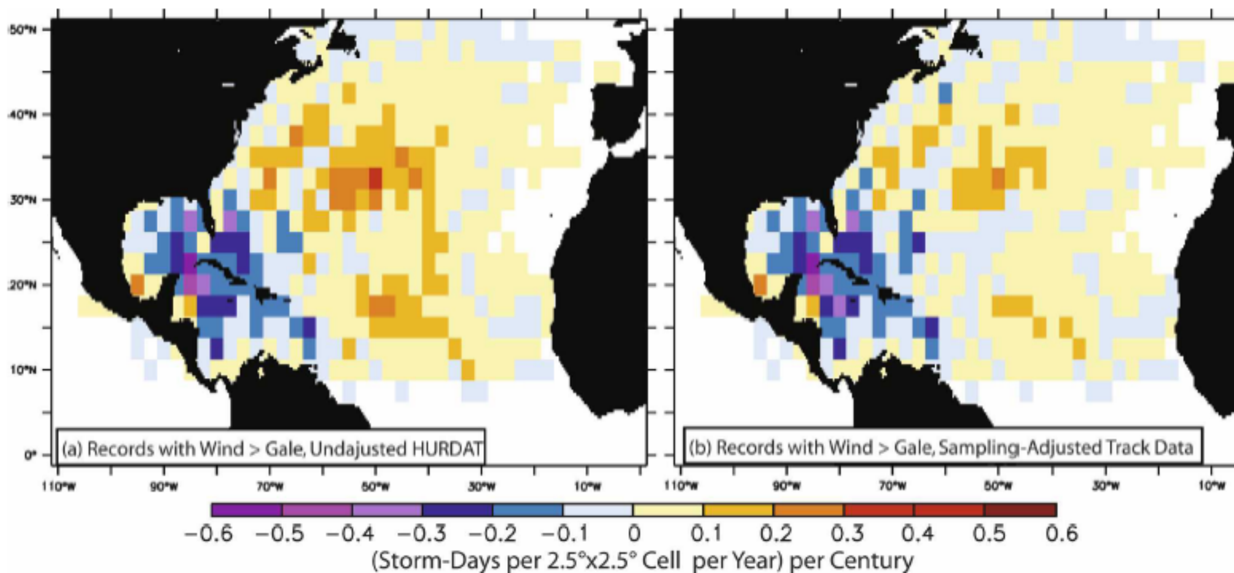
Knutson et al. (*Nature Geoscience*, 2008)
(SST=CMIP3 multi model ensemble mean)



Colbert et al. (*J. Climate*, 2012)
(Trajectory model; CMIP3 models)



Vecchi and Knutson (*J. Climate*, 2008)
(Observed trend 1878 - 2006)



Summary (North Atlantic)

The projected TC activity change in the North Atlantic (NA) indicates:

(a) Positions of the prevailing northward recurving TC tracks will shift eastward over the open ocean of the NA.

(b) TC track changes are primarily owning to the changes in TC-genesis locations.

(c) A SST change relative to other regions is important not only for local TC activity, but also for inhibiting remote TC activity via teleconnection.

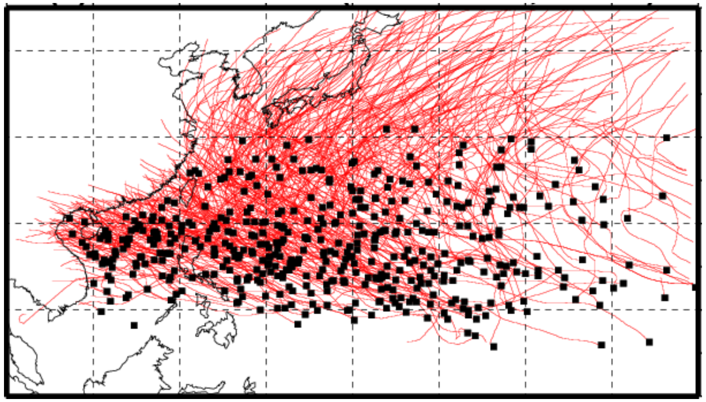
(d) Similar shifts in TC tracks are also seen in other observed trend and future projection studies.

Western North Pacific

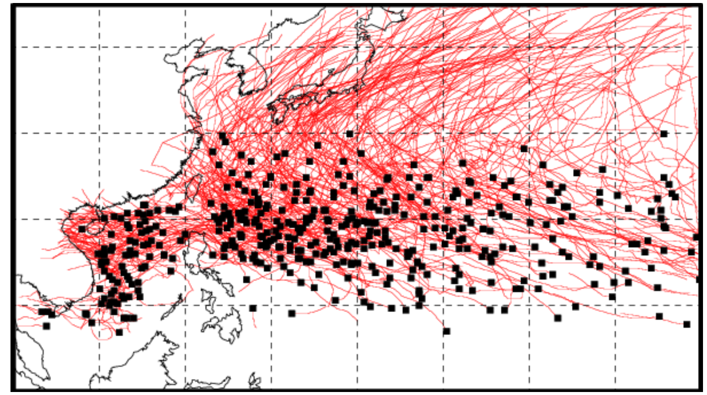
Murakami, H., B. Wang, and A. Kitoh, 2011: Future change of western North Pacific typhoons: Prjections by a 20-km-mesh global atmospheric model. *J. Climate*, **24,** 1154-1169.

Projected Future Changes in TC tracks in Western North Pacific

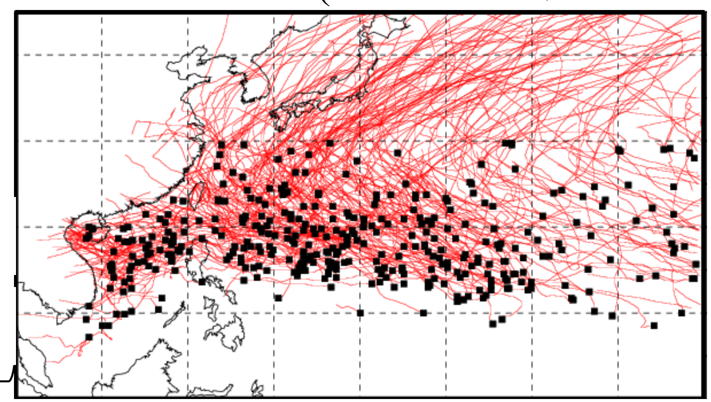
Observations (1979−2003)



PD (1979−2003)



GW (2075—2099)



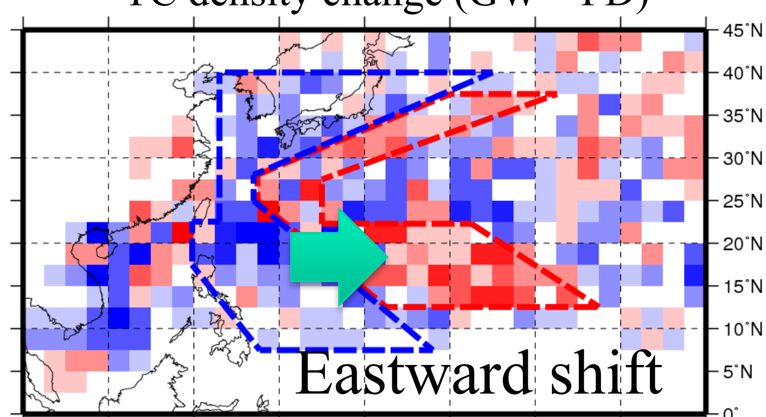
- TC tracks by PD exp is realistic.
- Higher TC density in the eastern WNP.
- Lower TC density in the western WNP.

What causes this east-west contrast?

Any changes in steering flows?

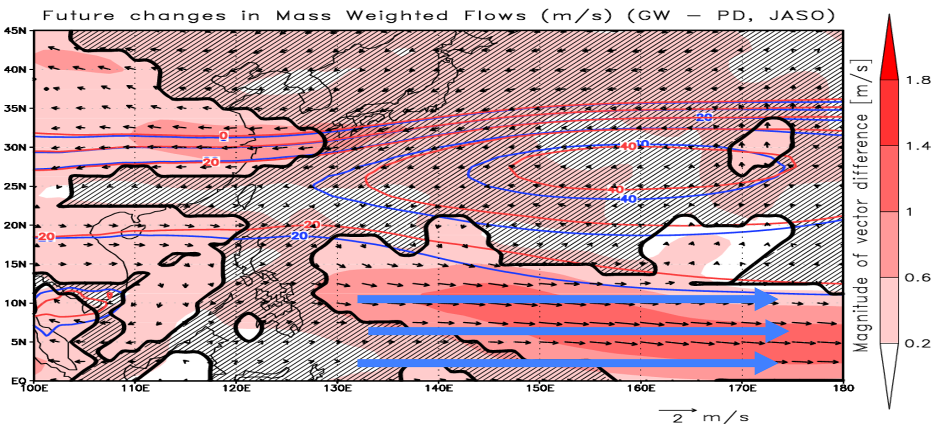
Any changes in genesis location?

TC density change (GW – PD)



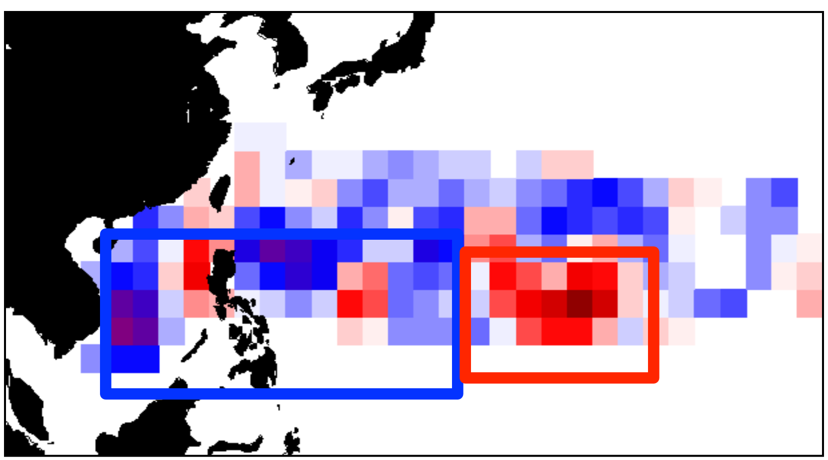
What causes TC track changes?

Steering flow (850-300hPa) changes



Steering flow changes (westerly flow anomaly) can explain TC track changes by inhibiting westward TC motion.

TC genesis frequency changes



TC genesis location changes (eastward shift) can also explain TC track changes.

Genesis potential index

To determine the factors behind such genesis changes, we used a Genesis Potential Index (GPI) by Emanuel and Nolan (2004) with some modifications.

[illegible]

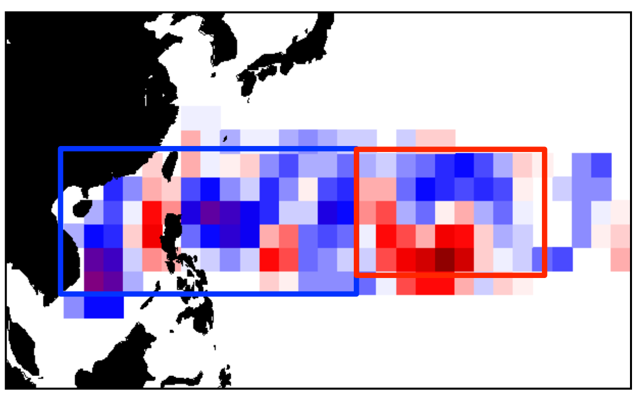
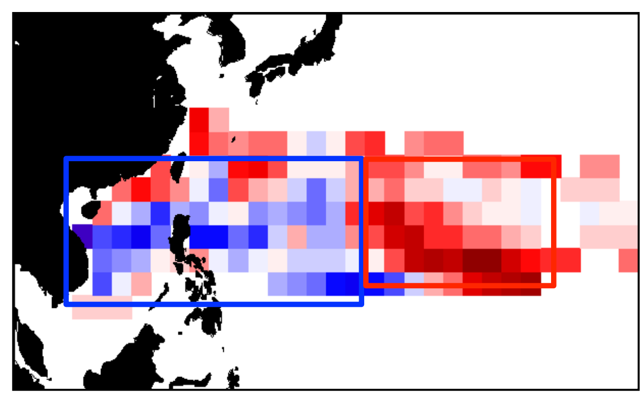
Absolute Vorticity at 850hPa

Relative Humidity at 700hPa

Maximum Potential Intensity

Vertical Wind Shear (850-200hPa)

Vertical p-velocity at 500hPa

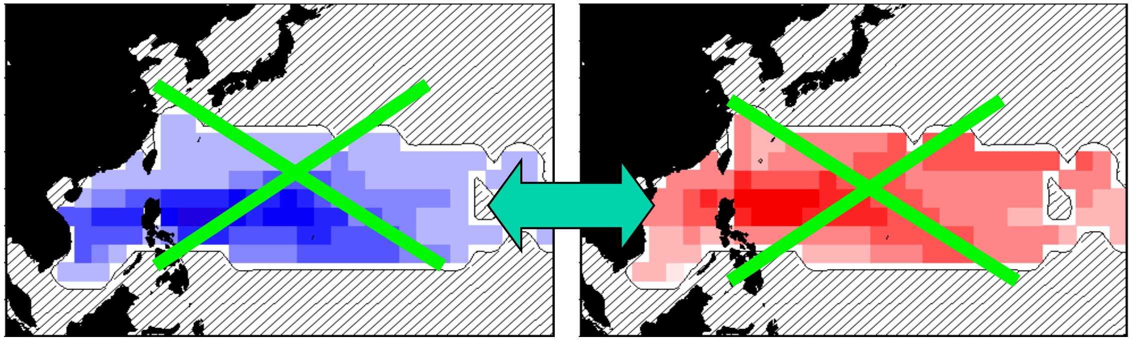
Future changes in TC genesis frequency	GPI changes
	

Spatial correlation coefficient is 0.55.

GPI performs reasonably well in reflecting the changes in TC genesis frequency.

Each term contribution to the changes in GPI

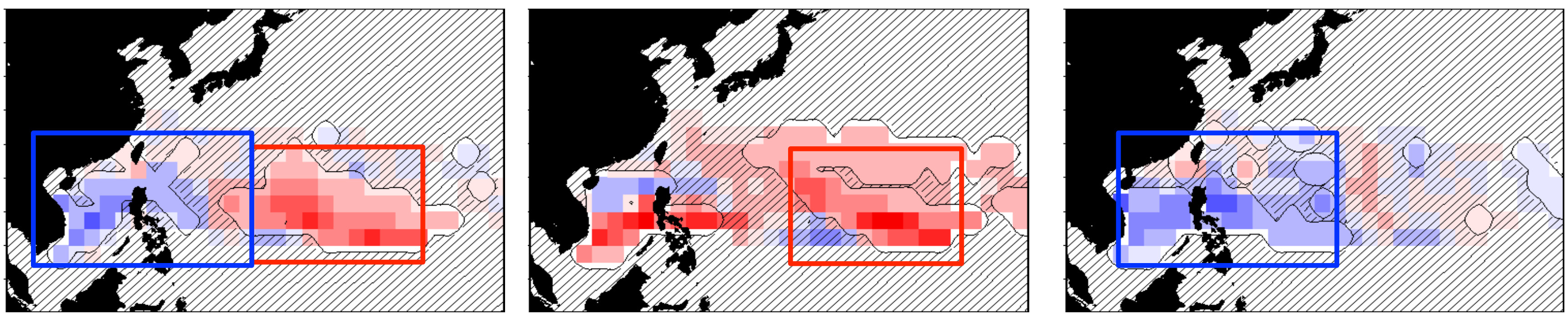
Relative humidity | **Potential Intensity**

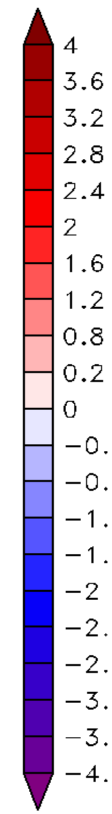


1. Thermodynamic changes has less influence.

=>Relative humidity and Potential intensity tend to cancel each other.

Vorticity | **Vertical Wind Shear** | **Vertical P-Velocity**





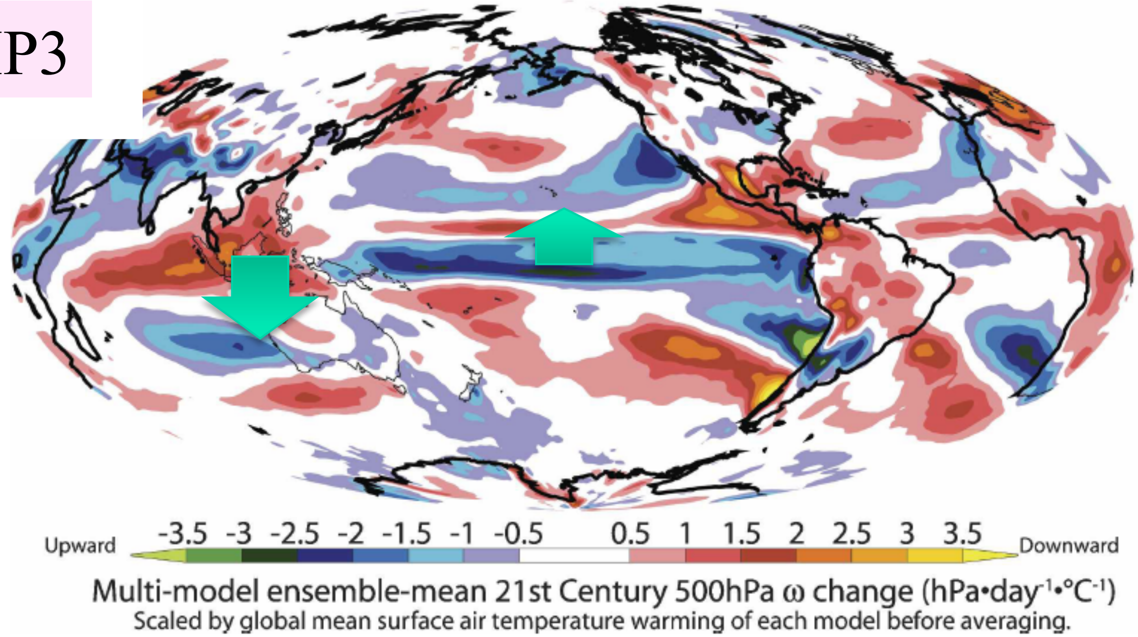
2. Dynamical changes have great influences.

=>Vorticity and vertical wind shear contribute to the increase in GPI in the eastern WNP.

=>Vorticity and vertical wind velocity contribute to the decrease in GPI in the western WNP.

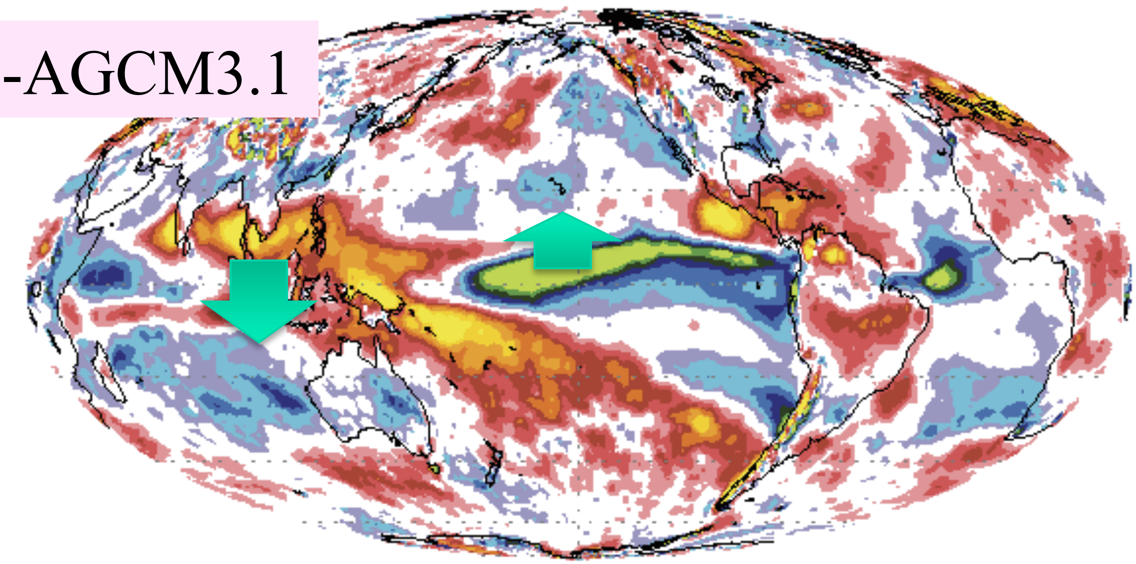
Weakening of Walker Circulation

CMIP3



Vecchi and Soden (2007, *J. Climate*) documented that CMIP3 models consistently project weakening of Pacific Walker Circulation in the future.

MRI-AGCM3.1

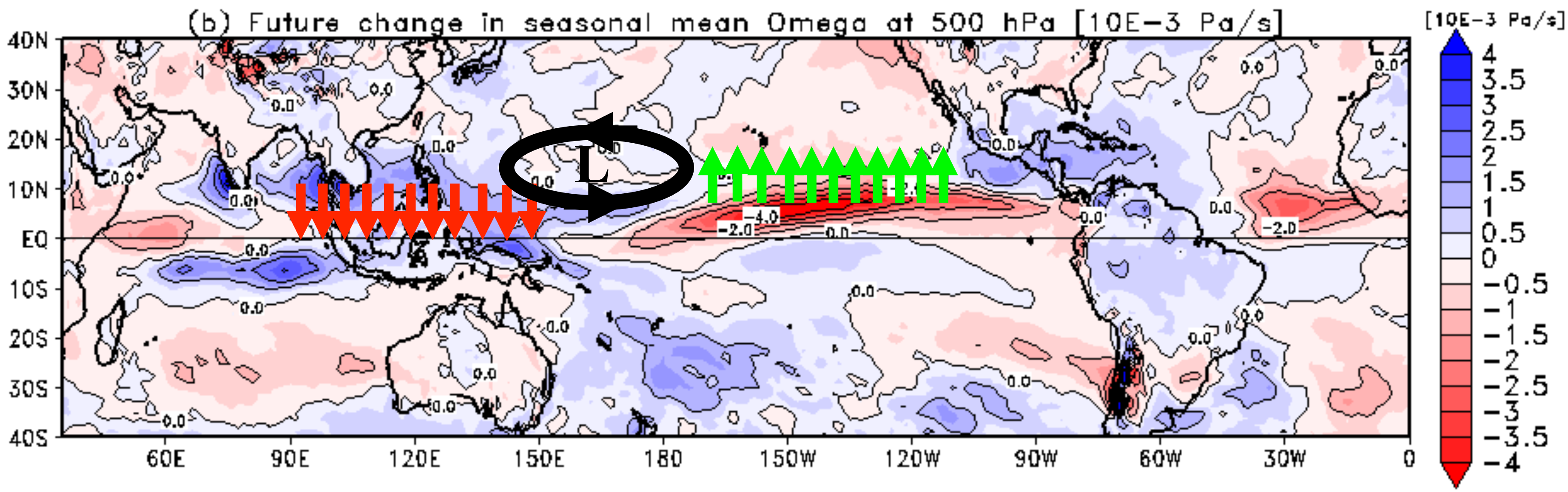


Mechanisms of future changes in TC genesis

Future changes in vertical wind velocity at 500 hPa

Rossby wave response:
Positive vorticity => Increase in TC genesis in the eastern WNP

Descending anomaly

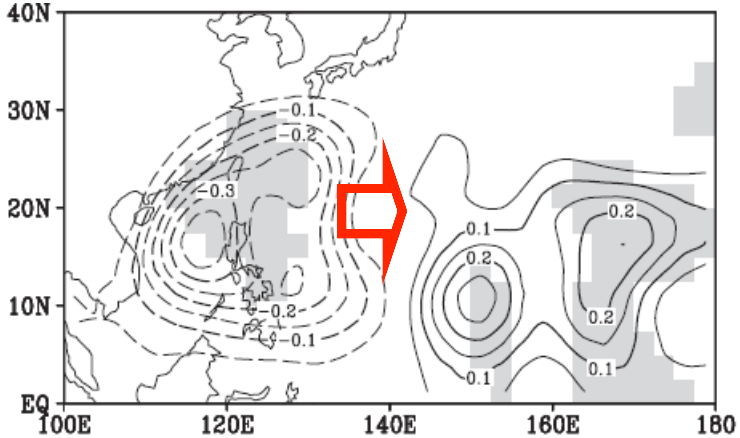


Weakening of the Walker circulation:
Decrease in upward motion => Decrease in TC genesis in the western WNP

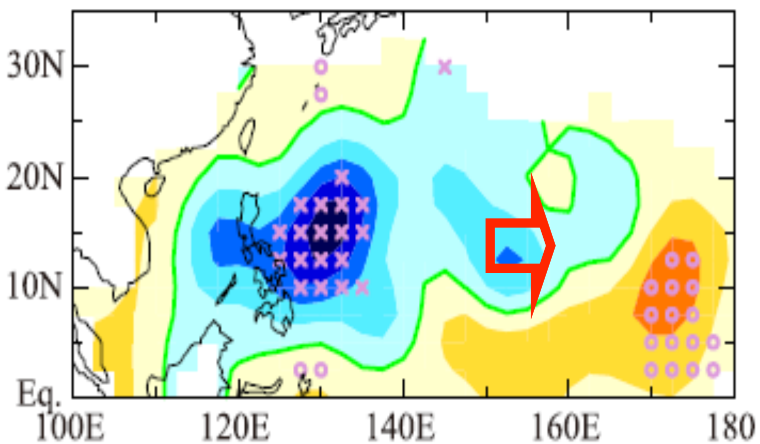
Ascending anomaly

Is the projected eastward shift robust?

CMIP3 models (Yokoi and Takayabu 2009)



CMIP5 models (Yokoi et al. 2012)



A number of models also project eastward shift in TC tracks.

Summary (western North Pacific)

The projected TC activity change in the western North Pacific (WNP) indicates:

(a) In the same way as NA, positions of the prevailing northward recurving TC tracks will shift eastward over the open ocean of the WNP.

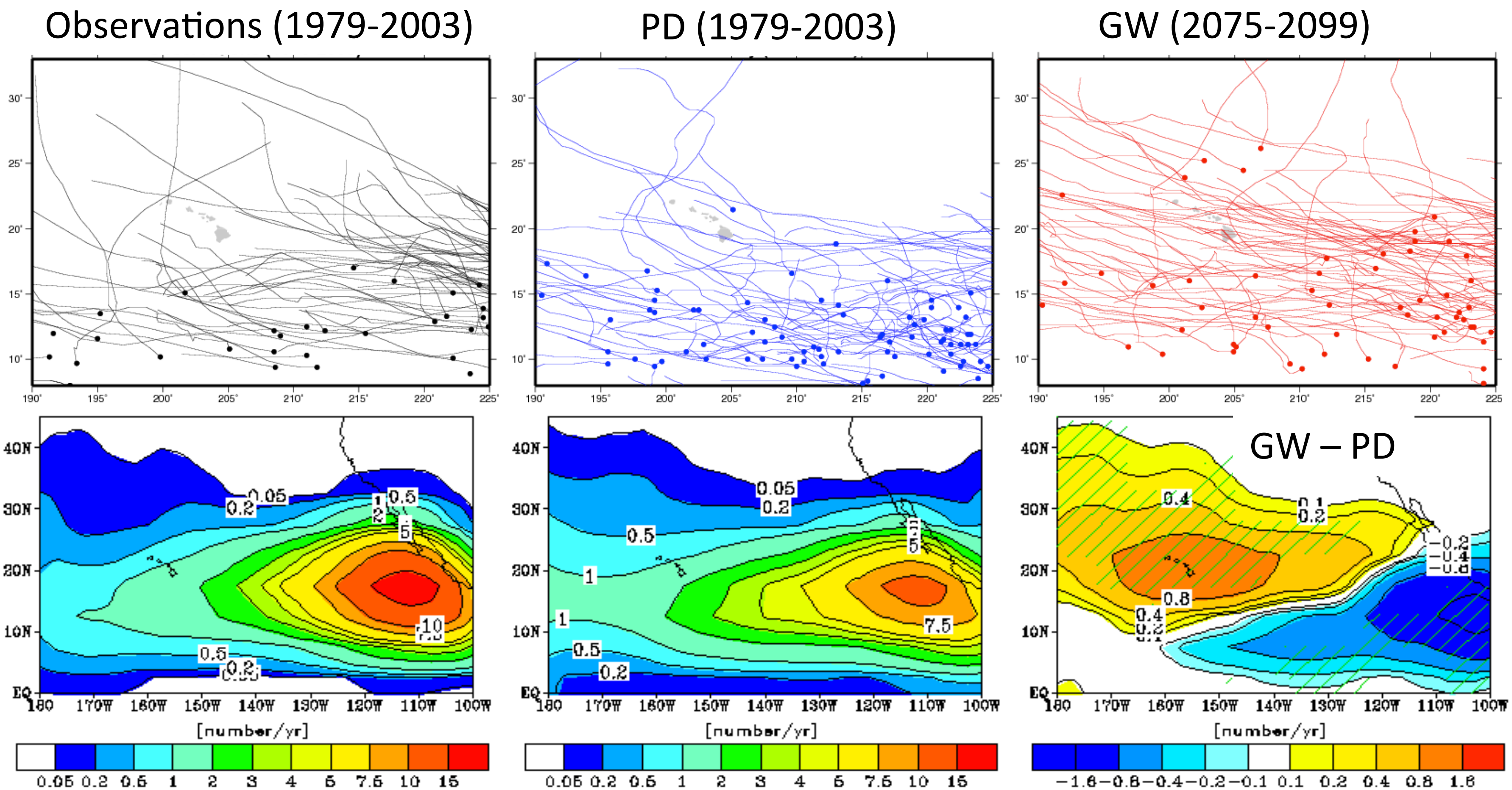
(b) TC track changes are partially due to changes of the large scale steering flows, but primarily owning to the changes in TC-genesis locations which is related to projected weakening of Walker circulation.

(c) The projected shift in TC tracks is robustly projected by different models under different future scenarios.

Central Pacific (Hawaiian Islands)

Murakami, H., B. Wang, T. Li, and A. Kitoh, 2013:Projected increase in tropical cyclones near Hawaii. *Nat. Climate Change*, **3,** 749-754.

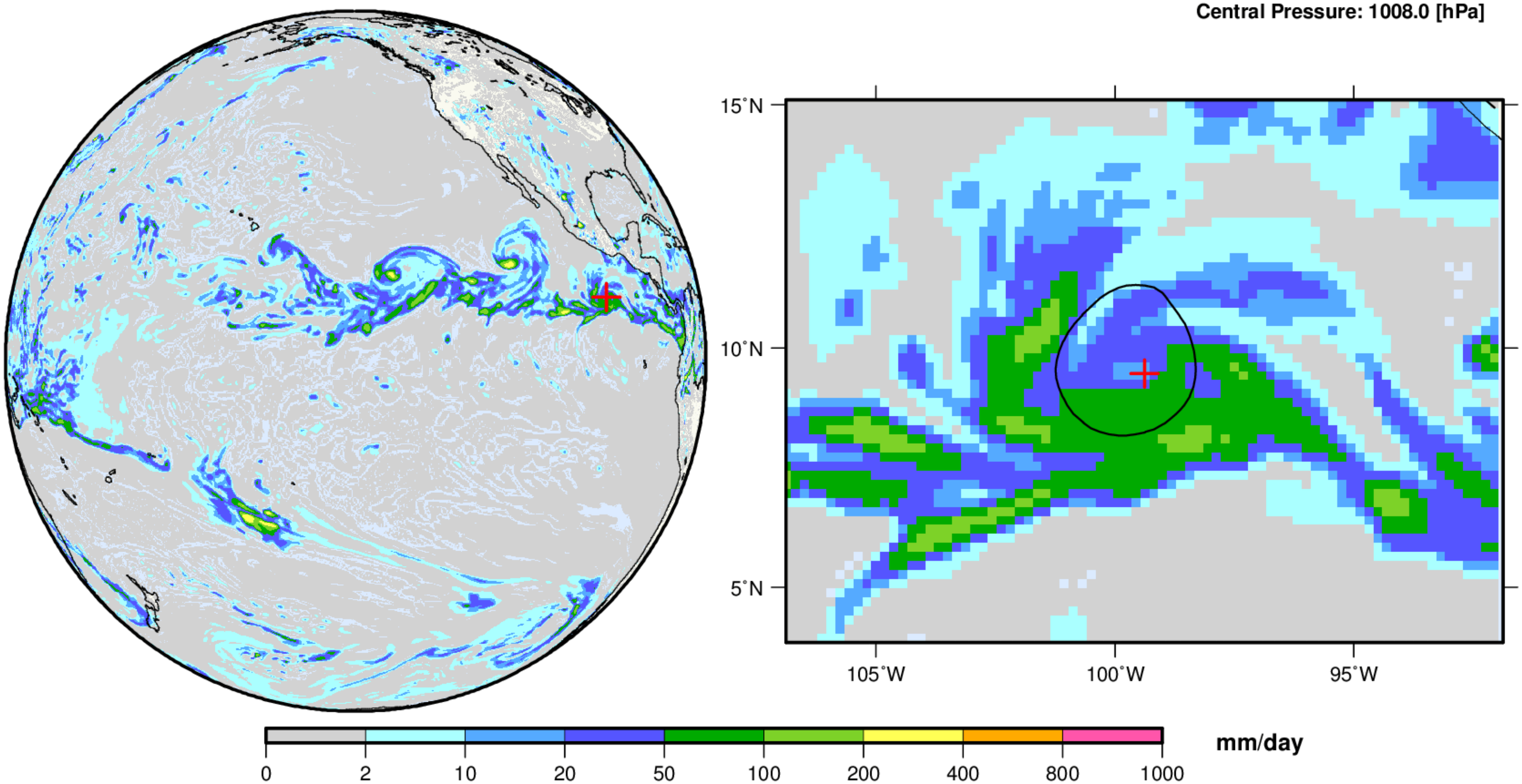
Tropical cyclones near Hawaii



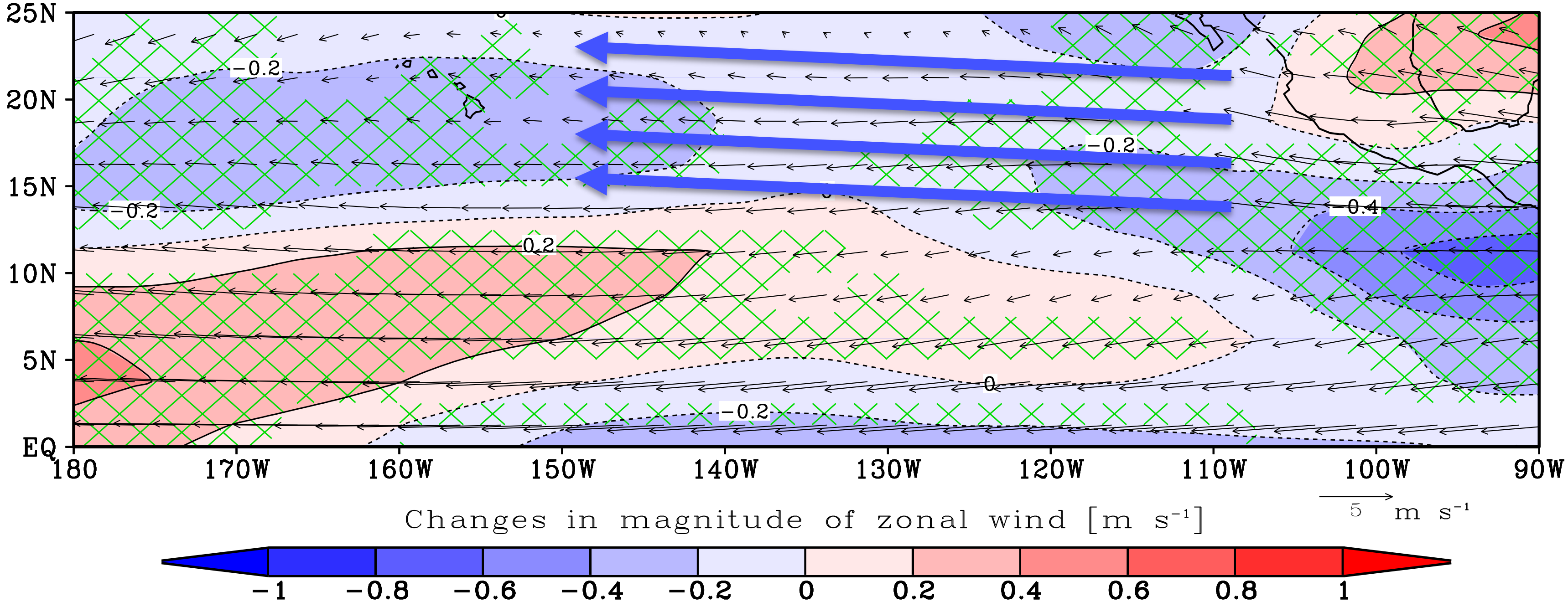
Present-day climate: 1 tropical cyclone for every 4 year approaches the Hawaiian Islands

Future climate : 1 tropical cyclone for every 2 year approaches the Hawaiian Islands

An example of a future projection



Steering flow changes (July–October)

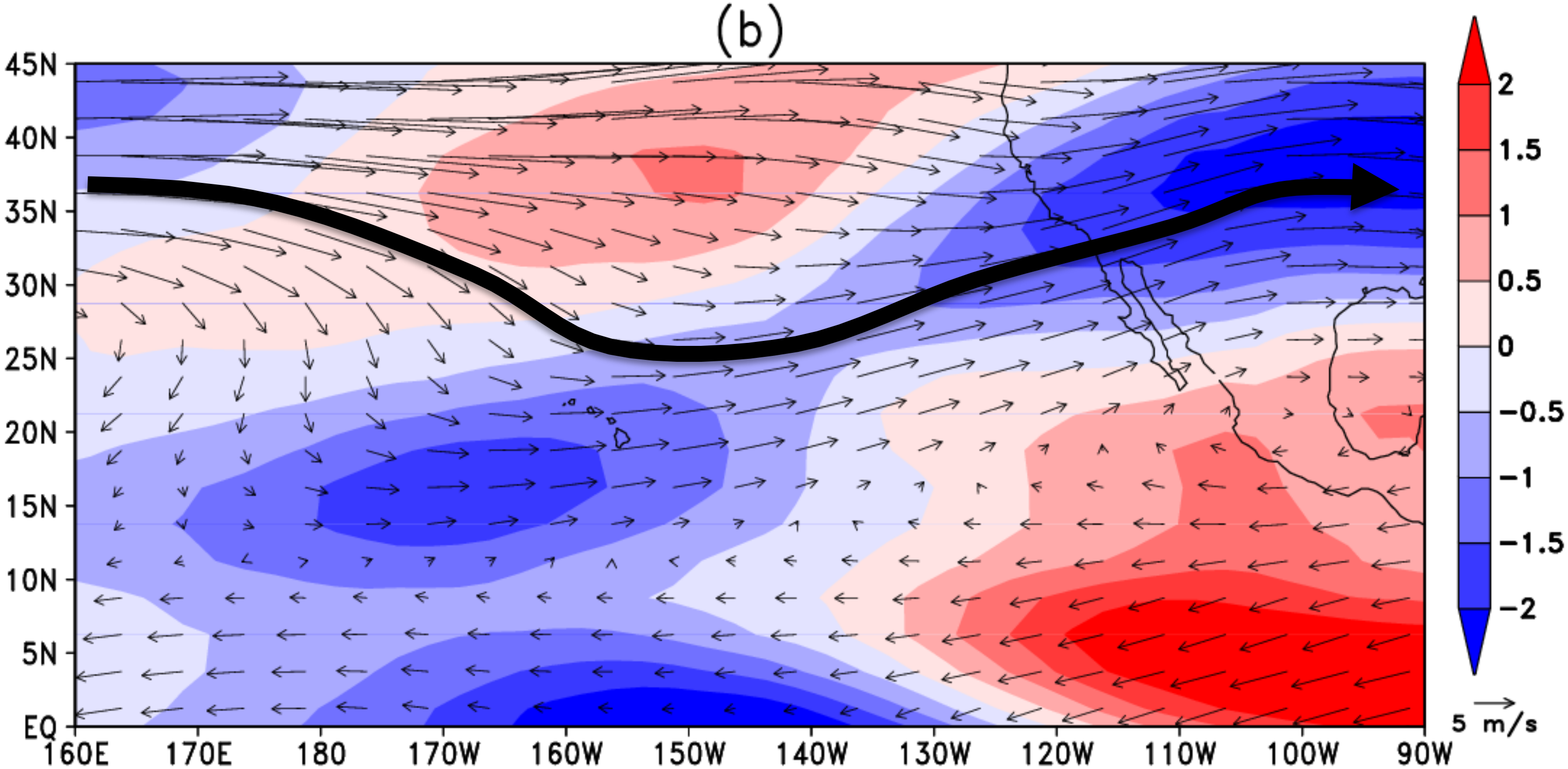


Vectors: present-day mean steering flows.

Shadings: projected future changes in zonal component of steering flows.

Increases in easterly steering flow lead to the westward propagation of TCs.

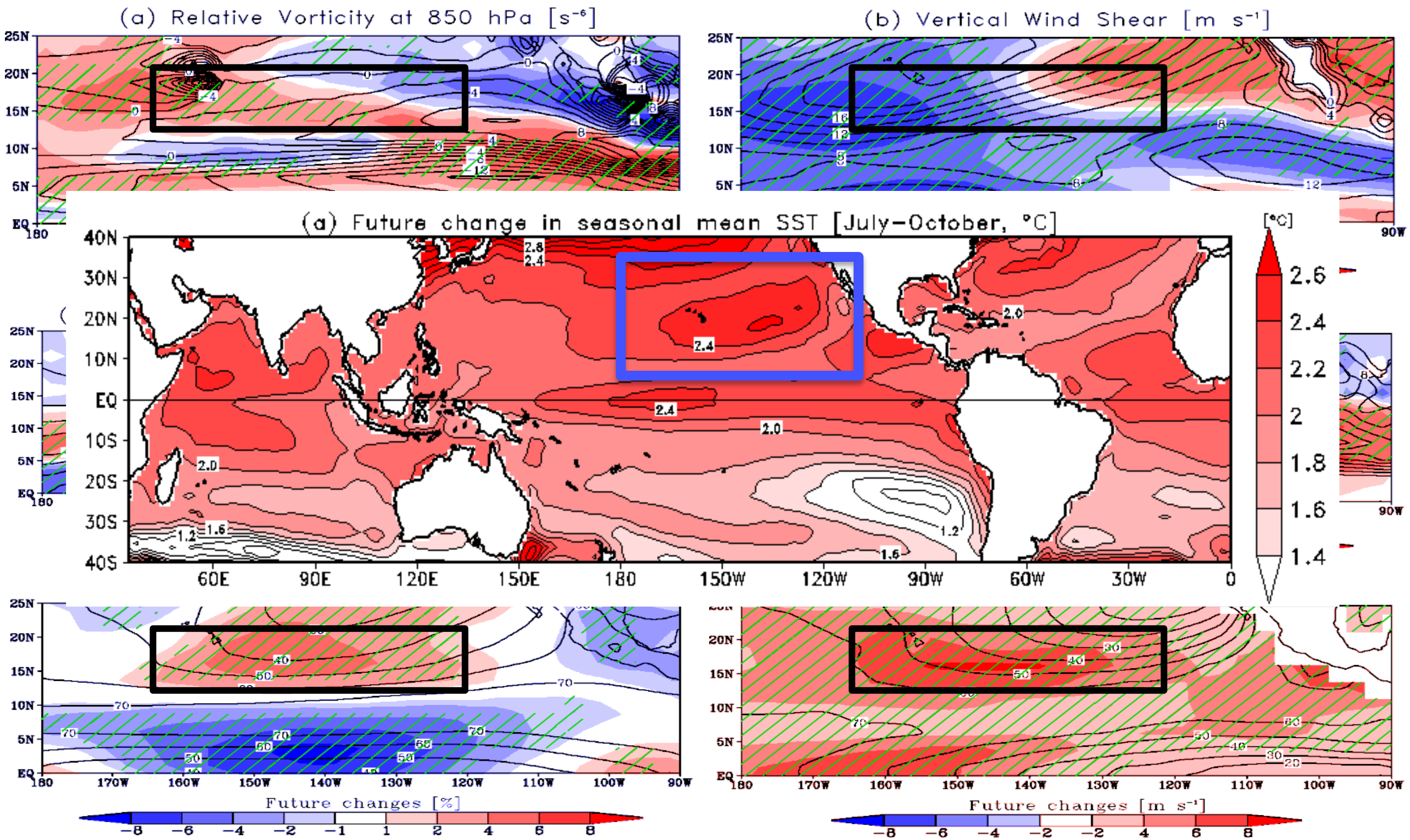
Change in large-scale flow at 300 hPa (Jul-Oct)



Vector ：Simulated present-day July–October mean wind at 300 hPa [m s^{-1}]

Shading: Projected future change in zonal wind

Projected changes in large-scale variables (JJAS)

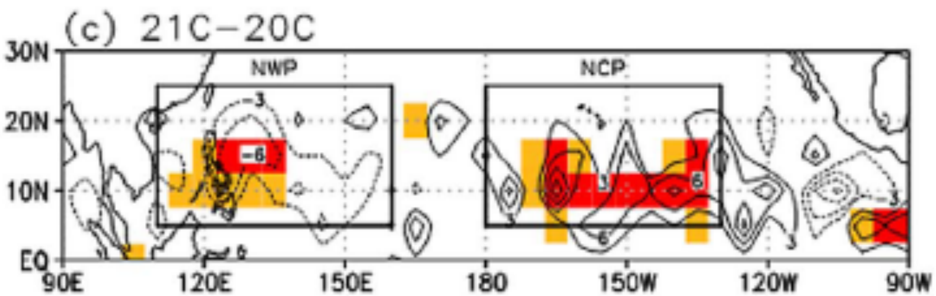


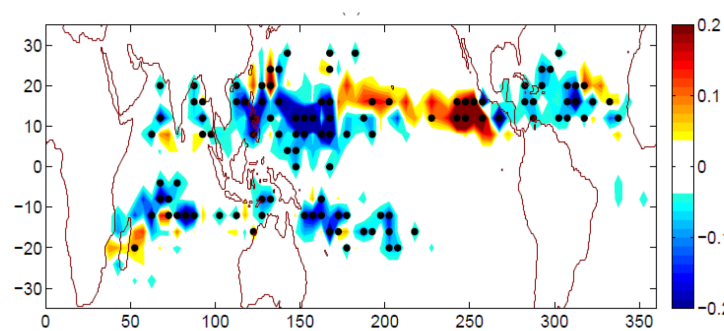
All variables show significant future changes
that are more favorable for TC activity in the subtropical central Pacific.

Consistency in projected increase in TC density in Central Pacific

A few studies also reported that frequency of TC genesis is projected to increase in the tropical Central Pacific.

Projected future change in frequency of TC genesis density





Li et al. (2010, *GRL*)

Zhao and Held (2012, *J. Climate*)

Summary for Central Pacific

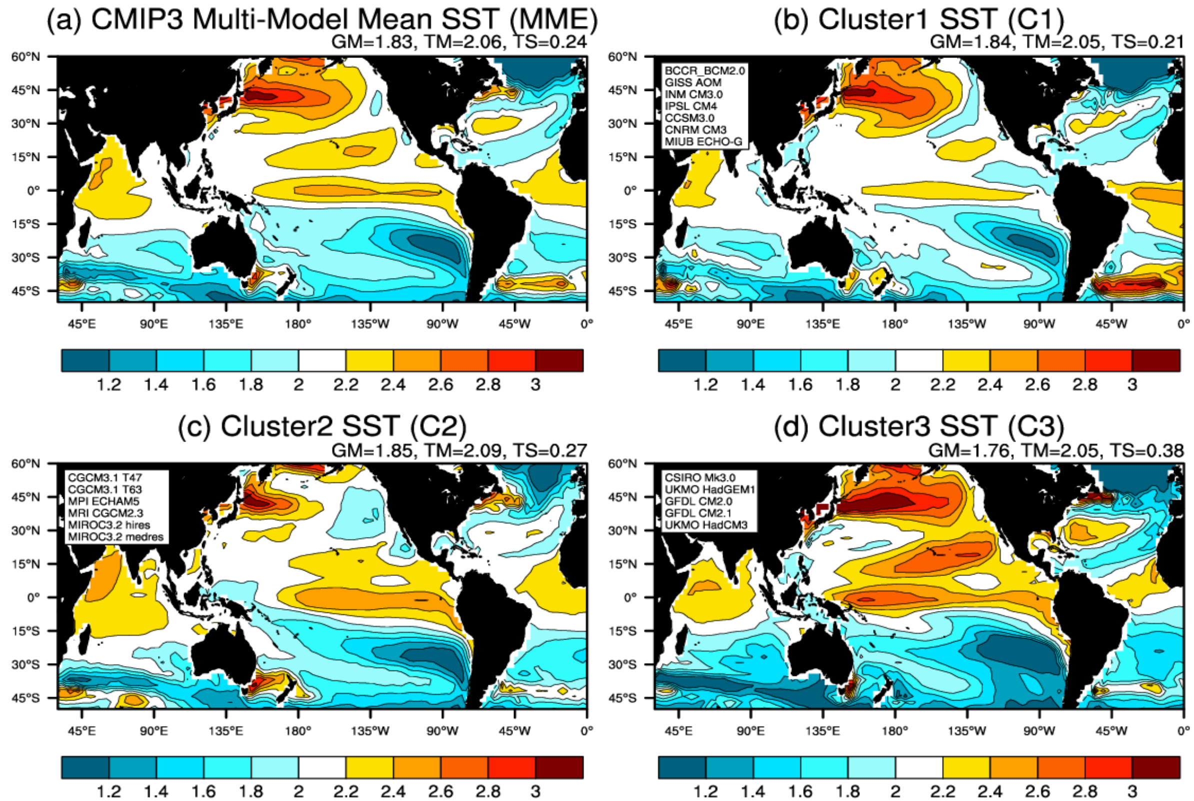
(a) Future experiment (2075-2099) projects **significant increase in TC density around the Hawaiian Islands** relative to the present-day (1979-2003).

(b) The substantial increase of the likelihood of TC density is primarily associated with **a westward expansion of TC tracks in the eastern Pacific**.

(c) In addition, the significant and **robust changes in large-scale environmental conditions** also strengthen *in situ* TC activity in the subtropical central Pacific, which also contribute to the increase of TC frequency of occurrence around the Hawaiian Islands.

(d) Projected increase in TC density in the Central Pacific appears to be robust among the different numerical studies.

Multi-physics & Multi-SST ensemble projections

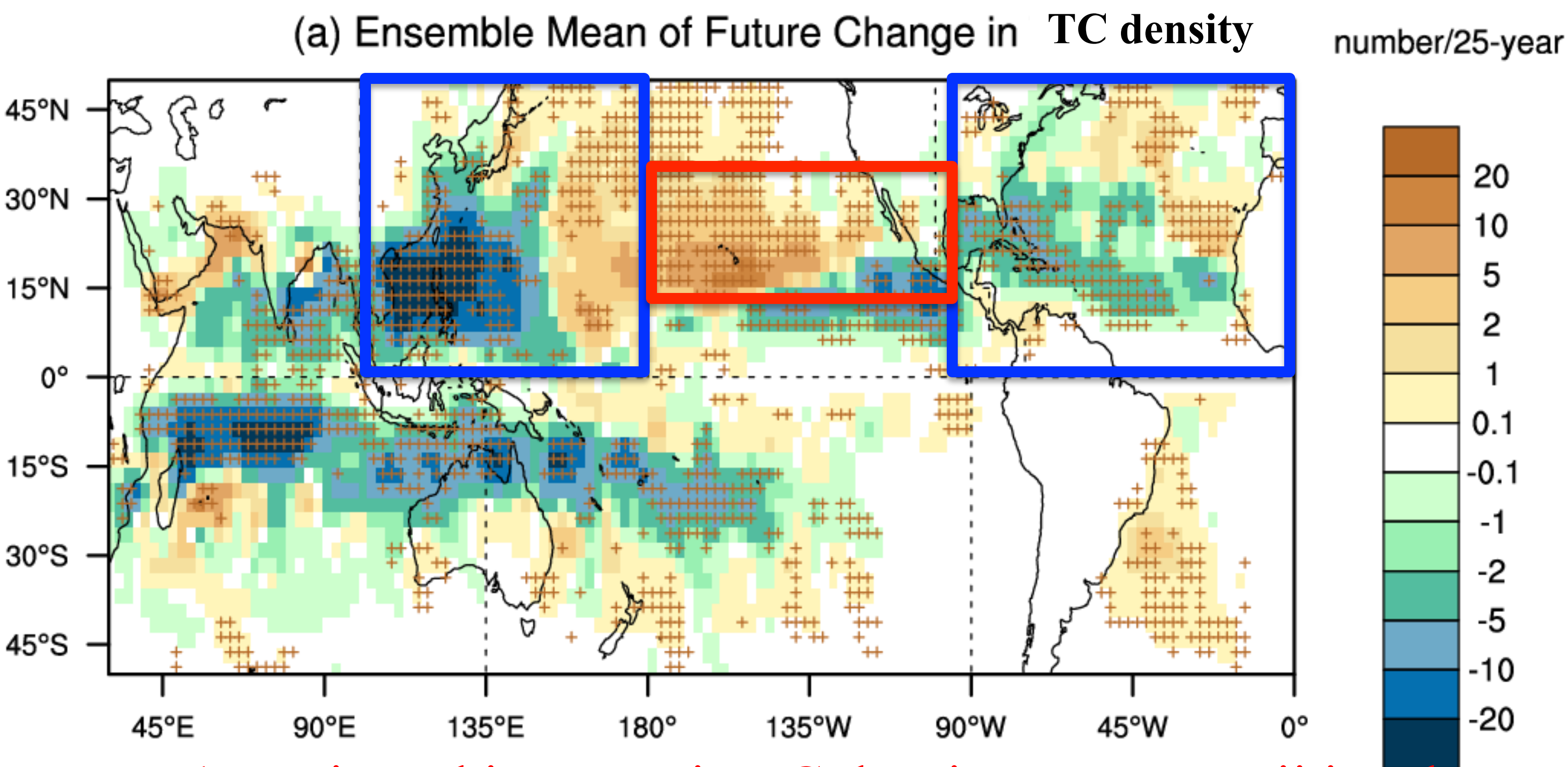


	YS Scheme	KF Scheme	AS Scheme
CMIP3 Mean SST	Y0	K0	A0
Cluster1 SST	Y1	K1	A1
Cluster2 SST	Y2	K2	A2
Cluster3 SST	Y3	K3	A3

3 (cumulus) ×4 (SST) = 12 ensemble experiments

Murakami et al. 2012 *Clim. Dyn.*

Future changes in TC density projected by ensemble experiments



1. Projected increase in TC density near Hawaii is robust among the ensemble experiments.

2. Projected eastward shifts in TC tracks in the WNP and NA are robust among the ensemble experiments.

Cross mark indicates statistical significance and robustness among ensemble experiments.

Conclusion

1. MRI model projects significant and robust changes in regional TC activity in the three ocean basins.

North Atlantic: Eastward shift in TC tracks
Western North Pacific: Eastward shift in TC tracks
Central Pacific: Increase in TC frequency near Hawaii