Dominant Role of Subtropical Pacific Warming on the Extreme 2015 Central Pacific Hurricane Season

Hiroyuki Murakami, G.A. Vecchi, T.L. Delworth, A.T. Wittenberg, S. Underwood, R. Gudgel, X. Yang, L. Jia, K. Paffendorf, and W. Zhang

Princeton University / Geophysical Fluid Dynamics Laboratory/NOAA, Princeton, NJ, USA *Hiroyuki.Murakami@noaa.gov*

1. Motivation

The 2015 hurricane season in the Eastern and Central Pacific Oceans (EPO and CPO), particularly around Hawaii, has been extremely active (Fig. 1a). A number of factors have been linked to the enhancements of EPO and CPO hurricane activity, such as greenhouse-induced global warming as well as natural variations. Indeed, a strong El Niño had developed during the 2015 boreal summer season (Fig. 1c). However, even for the similar strong El Niño event in 1997 (Fig. 1c), 1997 hurricane season had not been extremely active (Fig. 1b).

Why has the 2015 hurricane season been so active in the EPO and CPO?

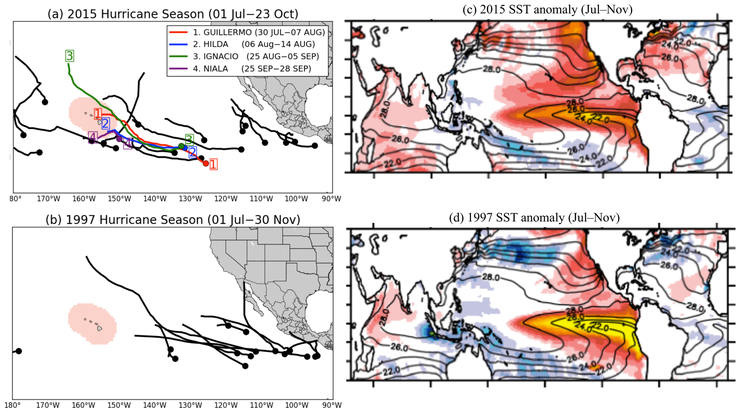

Fig. 1. *(a) TC tracks in 2015, (b) TC tracks in 1997. (c) SST anomaly in 2015, (d) SST anomaly in 1997.*

2. Internal Variability in Observations (1958–2015)

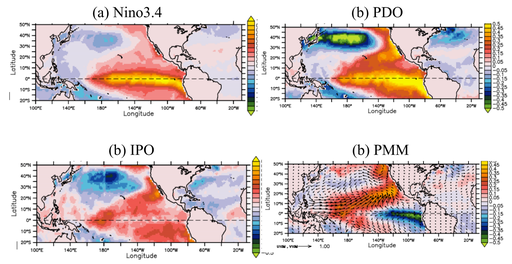

Fig. 2. *Regression of SST on the natural variability [K/σ].*

Four indices of Nino3.4, PDO, IPO, and PMM are considered for the influence of natural variability.

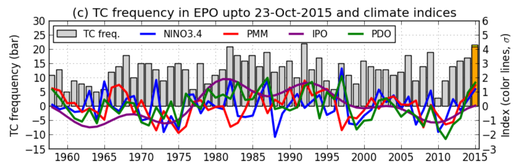

Fig. 3. *TC frequency (bar) and natural variability of NINO3.4, PMM, IPO, and PDO from observations*

El Niño is not the only factor to determine an extremely active TC year in the ENP (e.g., 1992, 1984) .

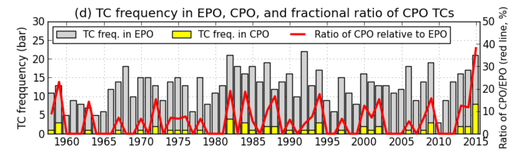

Fig. 4. *Observed total TC frequency in EPO (grey bar) and Central Pacific (yellow bar), and its fractional ratio relative to EPO frequency (red line).*

TC frequency in the Central Pacific Ocean is the highest in the history.

3. Idealized Seasonal Forecast Experiments using GFDL AM2.5

To identify which of SST anomaly is important for active TCs in ENP, six AMIP experiments are conducted with AM2.5.

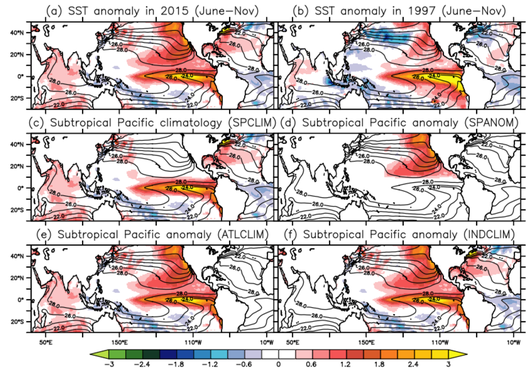

Fig. 5. *Prescribed SST anomaly for idealized seasonal prediction. (a) All SST anomaly in 2015, (b) All SST anomaly in 1997, (c) Climatological mean in subtropical Pacific, (d) Climatological mean in tropics, (e) Climatological mean in Atlantic, (f) Climatological mean in Indian Ocean.*

Models Used:

1. GFDL AM2.5 (50-km, physical schemes are based on CM2.5)
2. GFDL FLOR (Forecast-oriented Low Ocean Resolution) 50-km Atmosphere + 100-km Ocean Global Coupled model.

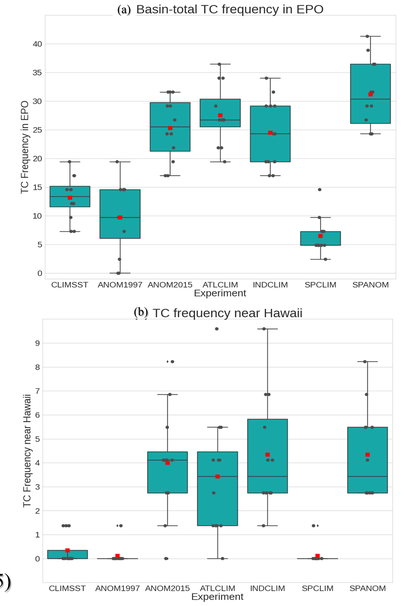

Fig. 6. *TC frequency by the idealized experiment for (a) EPO and (b) Hawaiian Islands.*

1. AM2.5 reasonably predict active (inactive) TCs given the 2015 (1997) SST anomaly.
2. Atlantic SST anomalies do not play important role for TCs in 2015.
3. Subtropical Pacific SST anomaly gives largest impact on the TC frequency.

5. Relative Importance of Natural Variability and Anthropogenic Forcing on the active TC year like 2015

To elucidate the potential influence of anthropogenic forcing on extreme event of TC activity, we analyzed two control experiments of 1860-Control and 1990-Control using FLOR.

Control Experiments

1990 Control

Fixed Radiative Forcing (CO_2, Aerosols, Ozone, etc) at 1990 Level , 500-year simulations

1860 Control

Fixed Radiative Forcing at 1860 level, 3500-year simulations

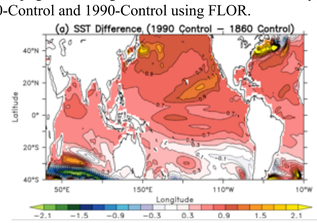

Fig. 7. *Difference in mean SST between 1990- and 1860 Controls.*

To estimate the potential probability of occurrence for the extreme TC-incidence years like 2015, we examine the empirical probability of exceedance for the frequency.

$$P(x) = \text{Number of years with TC number} \geq x / \text{Total number of years}$$

where x is TC frequency.

We compute P(21) for EPO and P(4) for Hawaiian TCs to represents the probability of extreme TC year of 2015.

	1990 Control	1860 Control	1990–1860	FAR
P(21) for EPO	17%	6%	+11%	67%
P(4) for Hawaii	2.4%	0.2%	+2.2%	92%

To elucidate how much the anthropogenic forcing changes the probability, we defined Fraction of Attributable Risk (FAR) defined as follows.

$$FAR(x) = Px1990\ Control - P(x|1860\ Control)/P(x|1990\ Control)$$

Far ranges between 100% (Attributable) to –∞ (Not Attributable).

Anthropogenic forcing increases odds of active TC season like 2015

To discriminate the potential influence of natural variability versus anthropogenic forcing on extreme event of TC activity, we analyzed two 35-member ensembles of simulations, run from 1941 to 2040 using FLOR

Large-Ensemble Experiments

AllForc

Historical anthropogenic forcing and aerosols (1941–2005) historical volcanic events, and future levels based on RCP4.5 scenario (2006–2040). 35 ensemble members, not initialized.

NatForc

Anthropogenic forcing and aerosols are fixed at 1941 levels. 35 ensemble members, not initialized

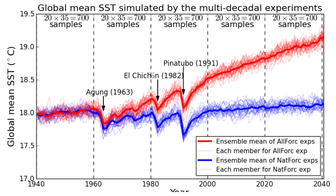

Fig. 8. *Global mean SST in AllForc (red) and NatForc (blue).*

For each decade of 20 years, we can compute $P(x)$ using 700 samples (20 years X 35 members).

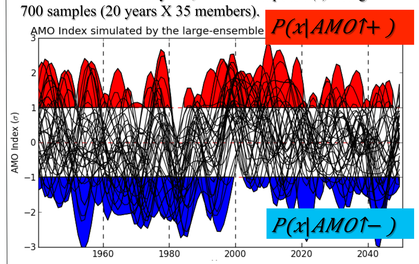

Fig. 9. *AMO index for each ensemble member of large-scale experiments.*

A phase of natural variability is independent among the ensemble members. Therefore, we can also compute conditional probability under any phases of natural variability to clarify impact of natural variability on probability of extreme event like 2015.

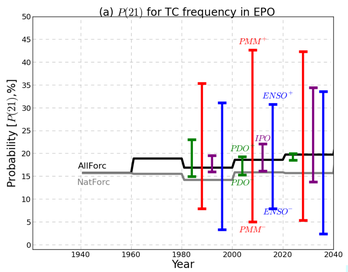

Fig. 10. *(a) P(21) for ENP, (b) P(4) for Hawaiian Islands.*

P(21) is larger in AllForc than NatForc. Anthropogenic forcing increases the probability of occurrence of extreme events.

P(21) is projected to increase in the next decade (2020–2040).

PMM is the largest influence on variability, following ENSO.

Results are the same for Hawaiian TCs.

1. Anthropogenic forcing increases odds of extreme event.
2. Natural variability of PMM and ENSO largely influence the probability. The amplitude is larger than anthropogenic forcing.
3. PMM shows the largest influence on the variability of P(x).
4. Probability of extreme events increases in the next decade, but the increase is dependent on the phase of natural variability.

6. Summary

The influence of anthropogenic forcing and natural variability on the active year of TCs in 2015 in the Eastern Pacific Ocean (E PO) and Central Pacific Ocean (CPO) is investigated using the resolution GFDL models.

(a) The extreme 2015 EPO and CPO hurricane season was *not* primarily induced by the 2015 El Niño's tropical warming, but by warming in the subtropical Pacific Ocean induced by positive PMM.

(b) Anthropogenic forcing largely contributes to the occurrence of active TC year like 2015.

(c) Future projections show a continuing increase of the probability of occurrence of active TC year like 2015. However, the increase is dependent of phase of natural variability like IPO and PDO.

Anthropogenic Forcing

Natural Vari ab ility PMM and El Nino

Both contributed to

Active TC year of 2015 for Eastern Pacific Ocean and Central Pacific Ocean