Past and Future Hurricane Intensity Change along the U.S. East Coast

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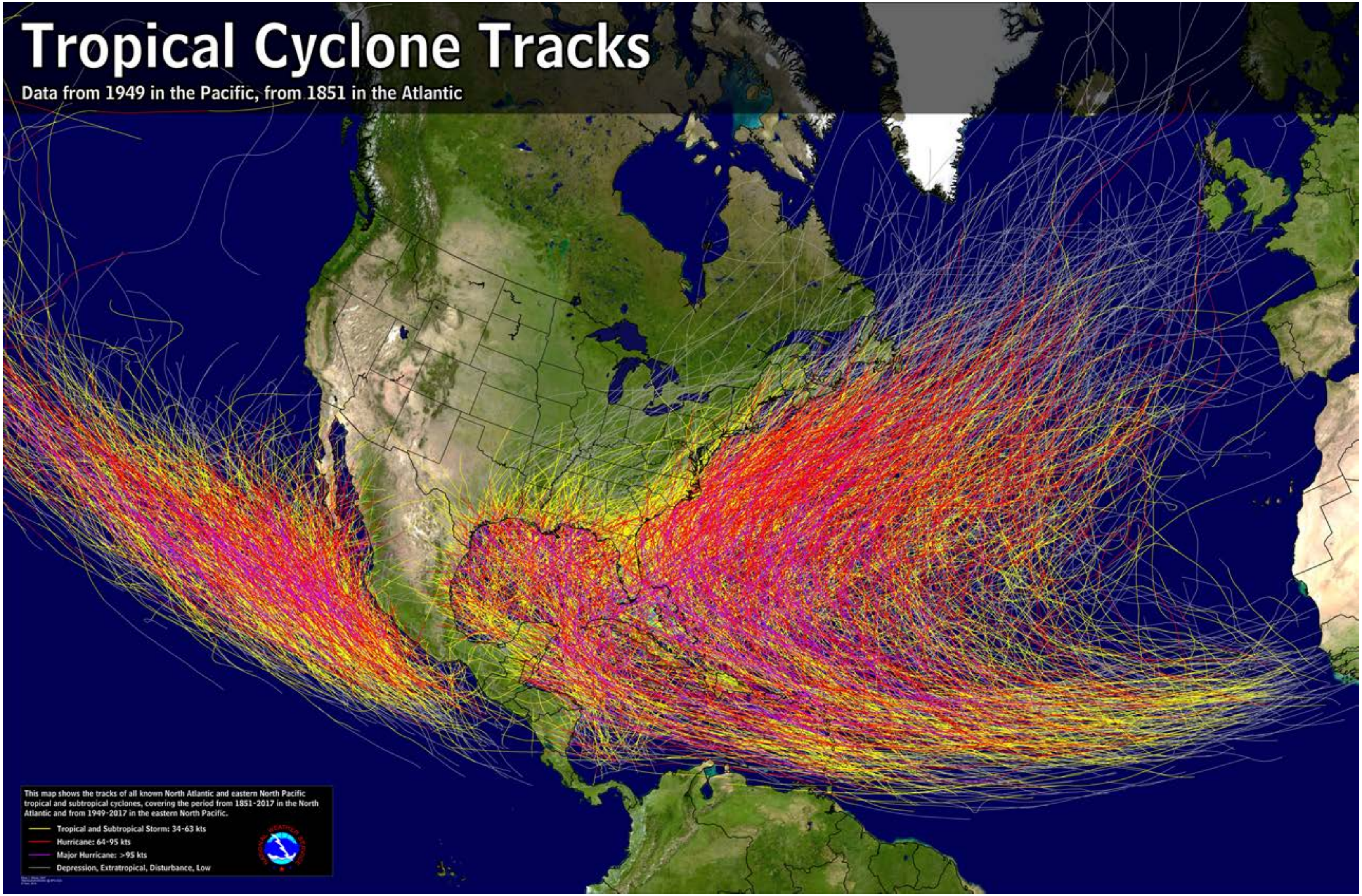
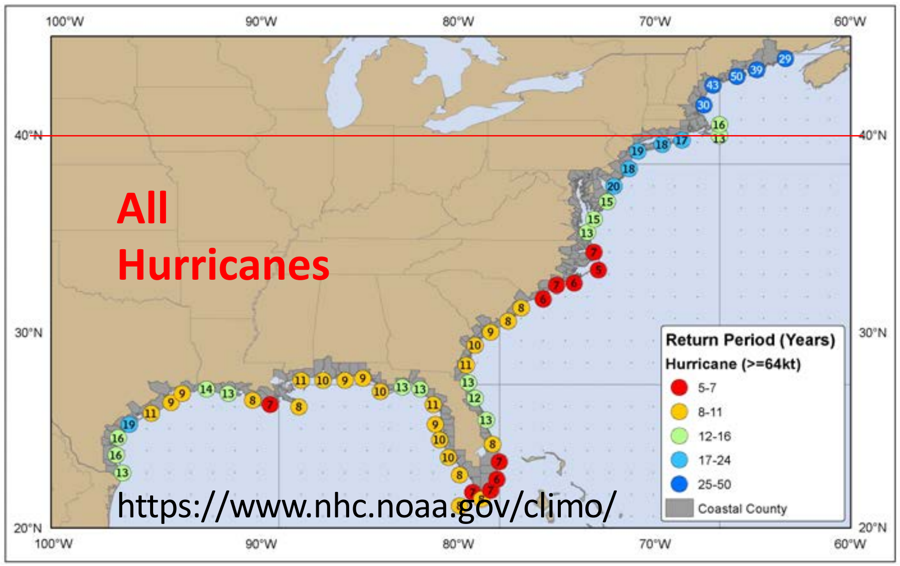
Large Ensemble Workshop, Boulder, July 24-26, 2019

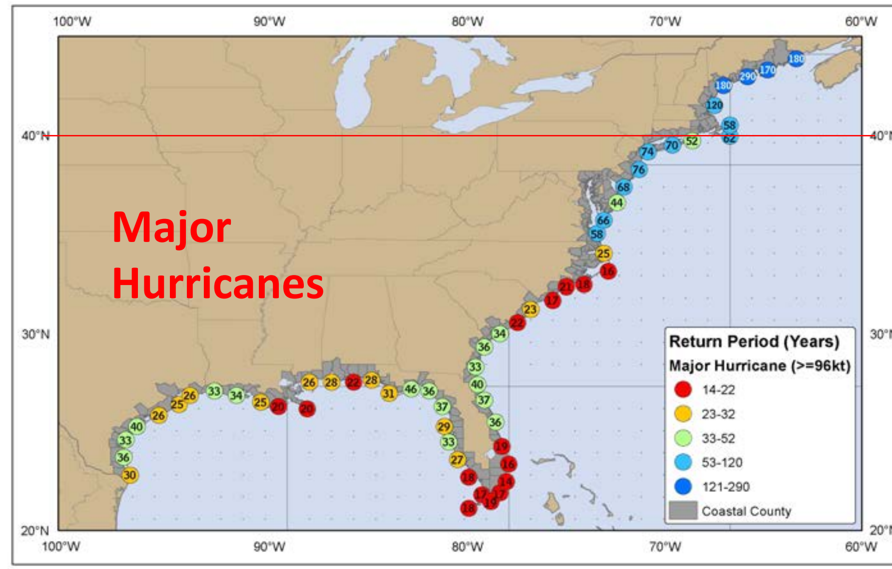
Ting et al., Past and Future Hurricane Intensity Change along the U.S. East Coast. Scientific Reports, (2019) 9:7795, https://doi.org/10.1038/s41598-019-44252-w


Tropical Cyclone Tracks
Data from 1949 in the Pacific, from 1851 in the Atlantic
This map shows the tracks of all known North Atlantic and eastern North Pacific tropical and subtropical cyclones, covering the period from 1851-2017 in the North Atlantic and from 1949-2017 in the eastern North Pacific.
Tropical and Subtropical Storm: 34-63 kts
Hurricane: 64-95 kts
Major Hurricane: >95 kts
Depression, Extratropical, Disturbance, Low

Hurricanes and major hurricanes return period

The information on return period is generated with the 1987 HURISK program, but uses data through 2010.





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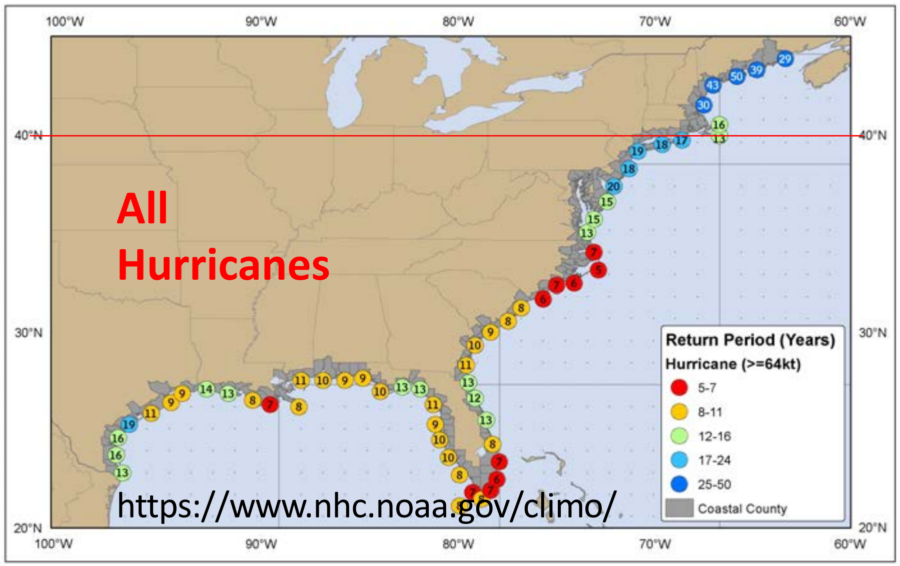
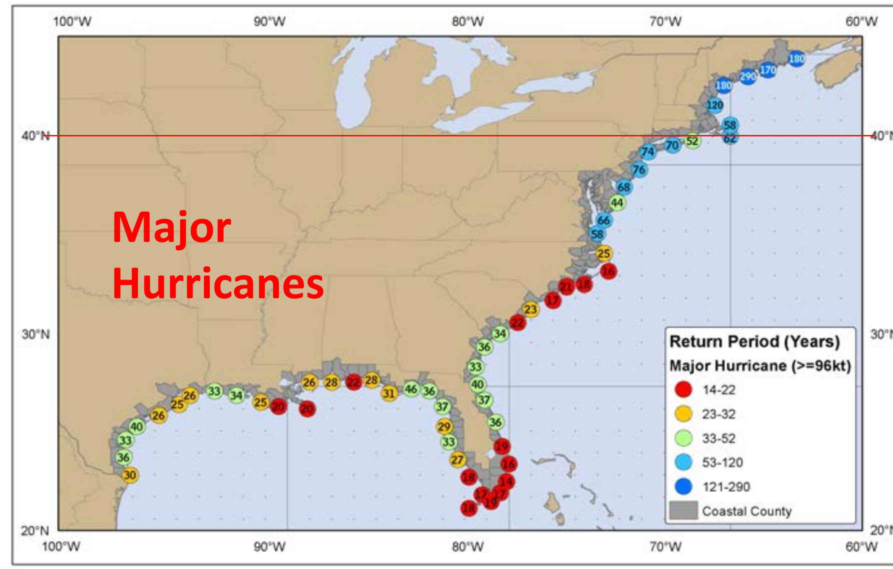
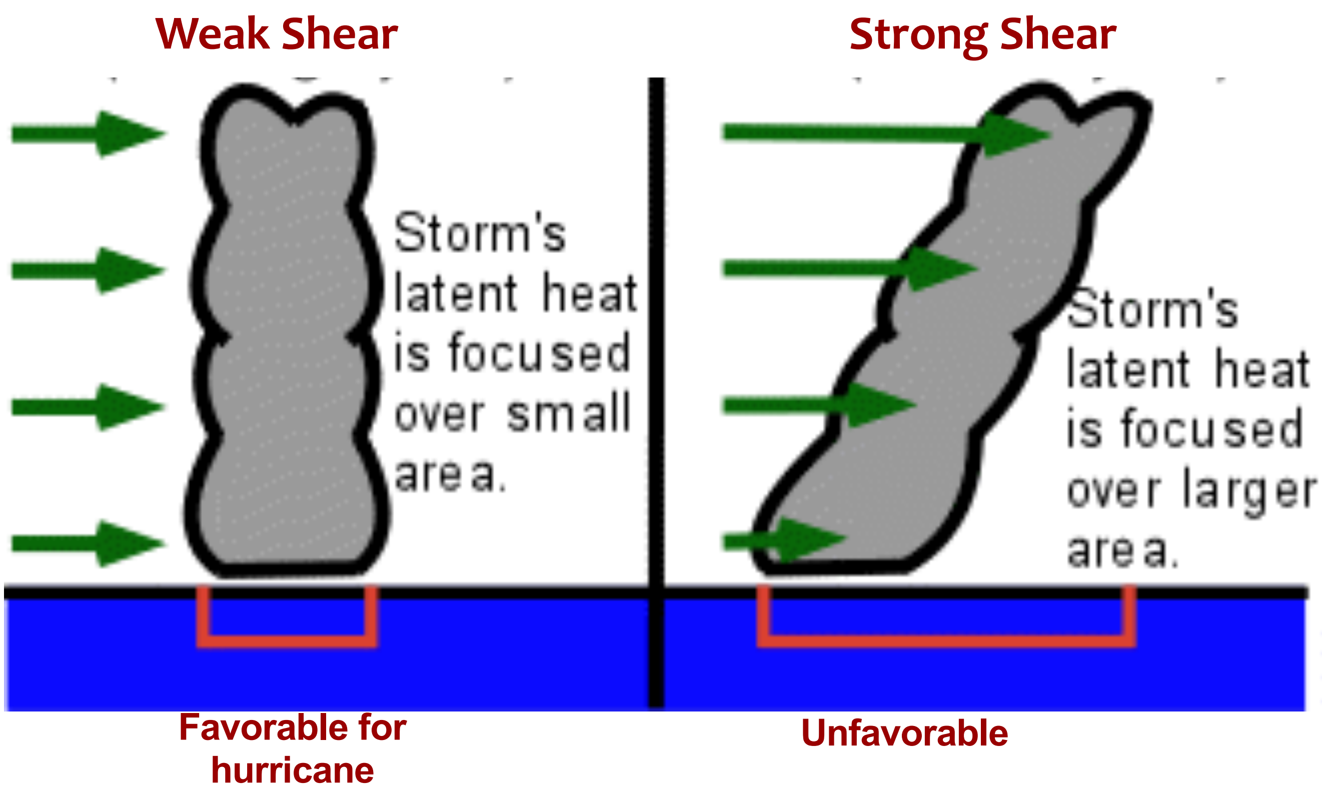




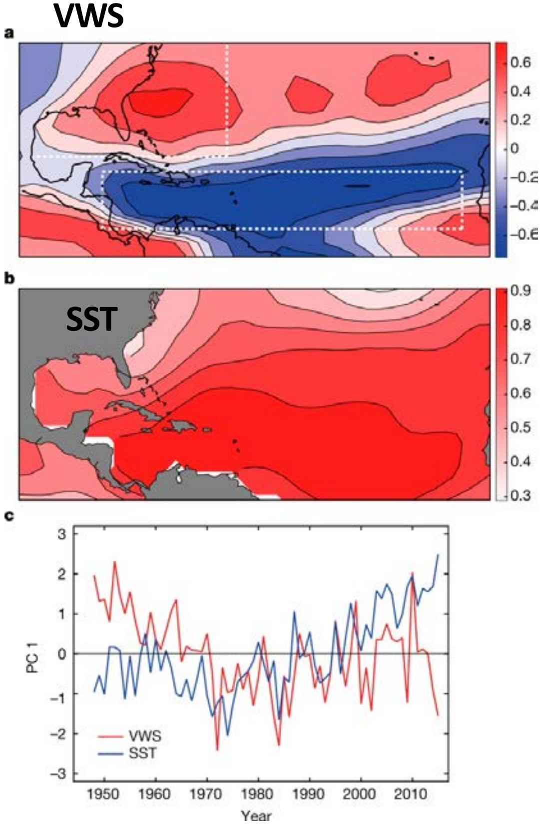
Factors that can contribute to hurricane intensity change:

- Change in sea surface temperature – warmer SST leads to stronger intensity
- Change in vertical wind shear (difference in winds at upper and lower troposphere) – weaker wind shear leads to favorable hurricane intensification

The Impact of Vertical Wind Shear



Dominant Patterns of Atlantic VWS and SST variability in Observations



J P Kossin *et al. Nature* 1–4 (2017)
doi:10.1038/nature20783

nature

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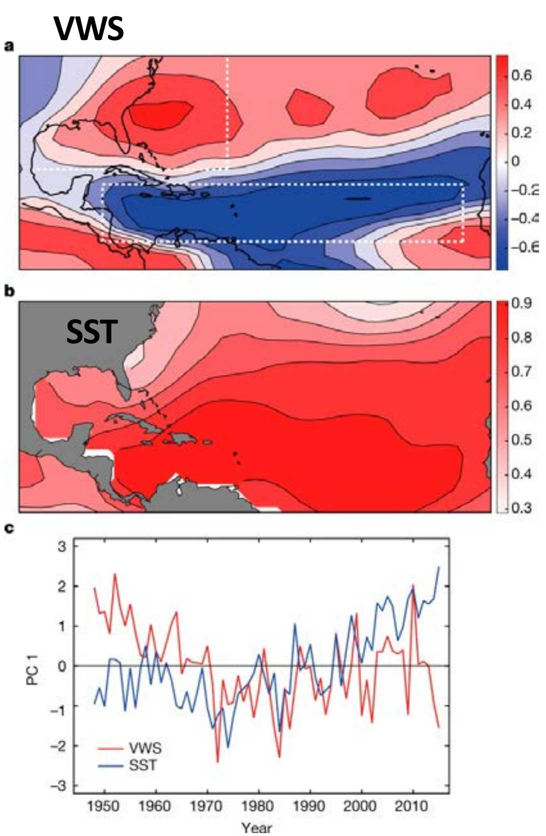

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Table 1: Means and variances of 6-hour intensification rates near the US coast

	Mean		Variance		Sample size		Basin-wide count		Near-coast count	
	HU	MH	HU	MH	HU	MH	HU	MH	HU	MH
1947–1969	+0.6**	–0.5*	32.3***	32.8***	1,077	313	149	68	101	48
1970–1992	+1.4	+0.9	53.3	103.7	429	79	119	37	65	23
1993–2015	–0.2***	–1.5**	40.5***	55.5***	735	197	165	72	88	35

HU – Hurricane, MU – Major Hurricane

- ***Recent period shows active basin-wide hurricane activity but relatively suppressed near-coast activity***

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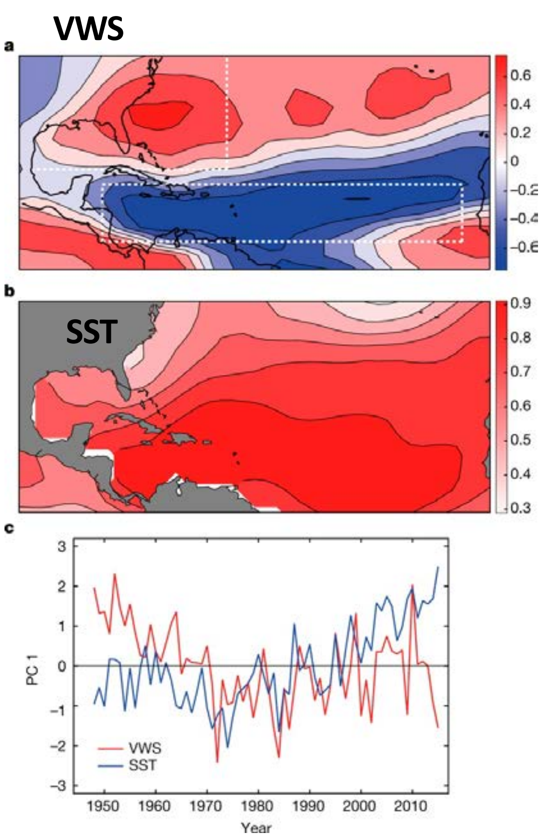

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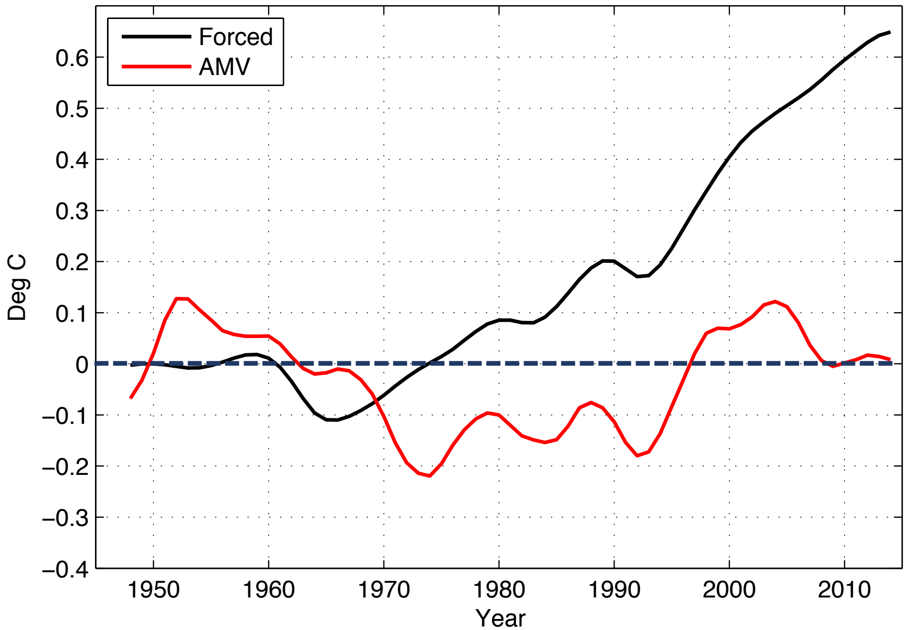
Q: Is the suppression of hurricane intensification rates near the US coast due to Anthropogenic forcing or natural multidecadal variability?

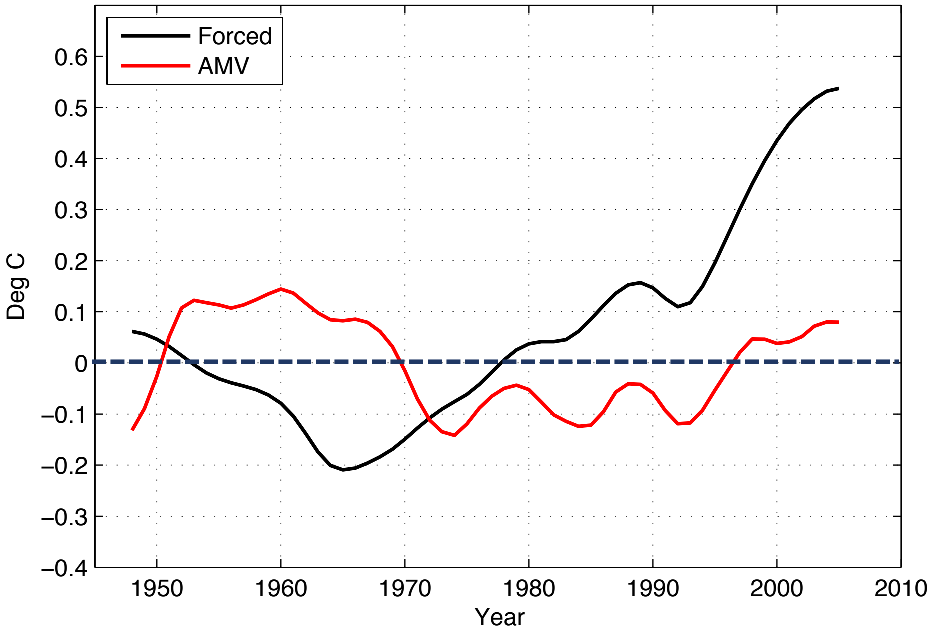
Forced and AMV Time series

(Forced Component derived from 27 CMIP5 Multi-model and 42 Members of NCAR LENS using S/N Maximizing EOF)

Forced and AMV Indices (Forced based on CMIP5 Multi-model)



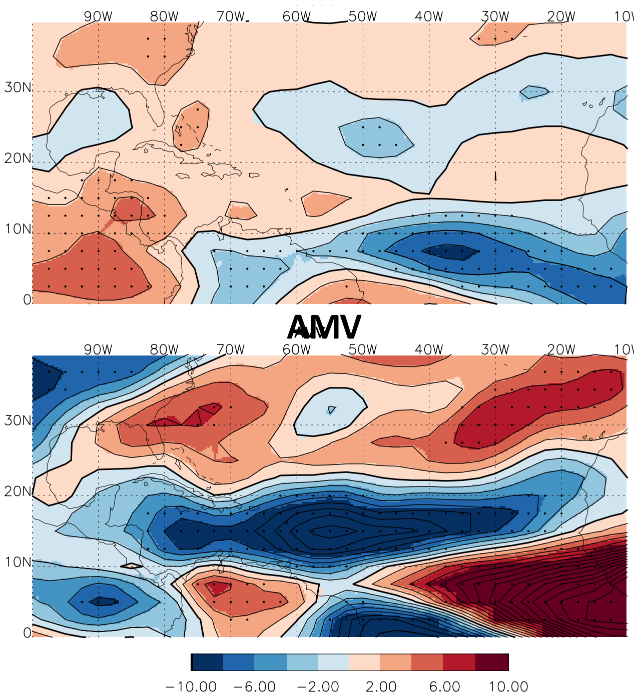
Forced and AMV Indices (Forced from NCAR LENS)



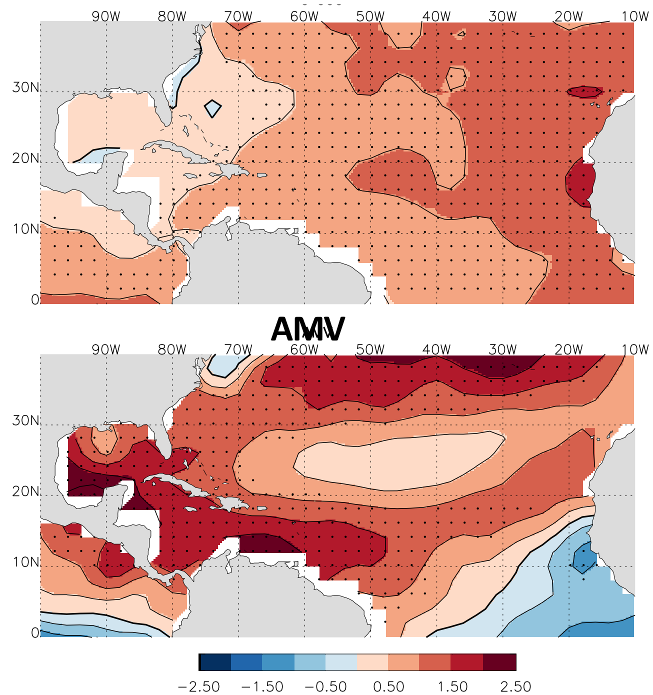
AMV: Atlantic Multidecadal Variability

Tropical Atlantic Vertical Wind Shear and SST (Obs.) Regressed onto Forced (based on LE) and AMV SST indices (1948-2014)

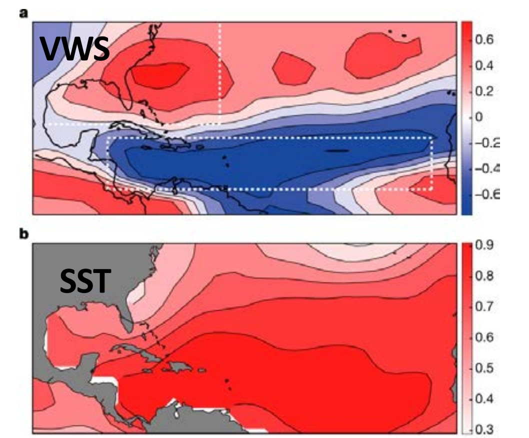
Vertical Wind Shear Regression (ASO) Forced



SST Regression (ASO) Forced



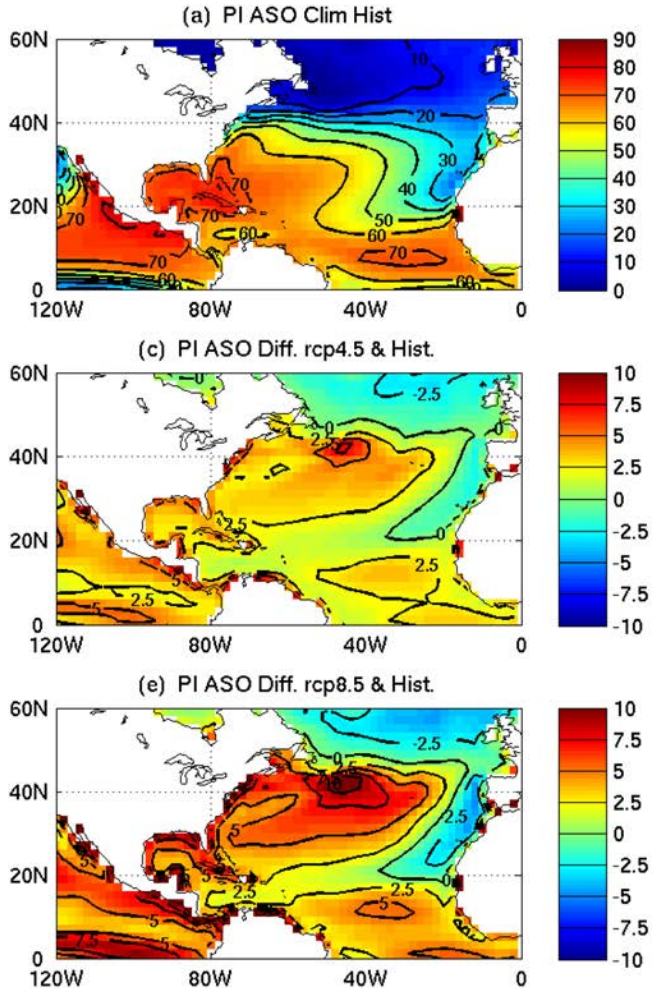
Observed EOF1 for Vertical Wind Shear and SST



- *VWS dipole pattern between tropical Atlantic and US East Coast is mainly due to AMV – Natural variability during the historical period*
- *Dipole pattern provides a natural protective barrier for US East Coast from strong hurricane landfall*

- What about the future? How would hurricane intensity change (or intensification rate change) in the future under GHG forcing?
- What are the relative importance of forced and internal (AMV) variability?

Atlantic Hurricane PI (left) during Peak Hurricane Season (ASO) from CMIP5 Historical, rcp4.5 – Hist., and rcp8.5 – Hist.



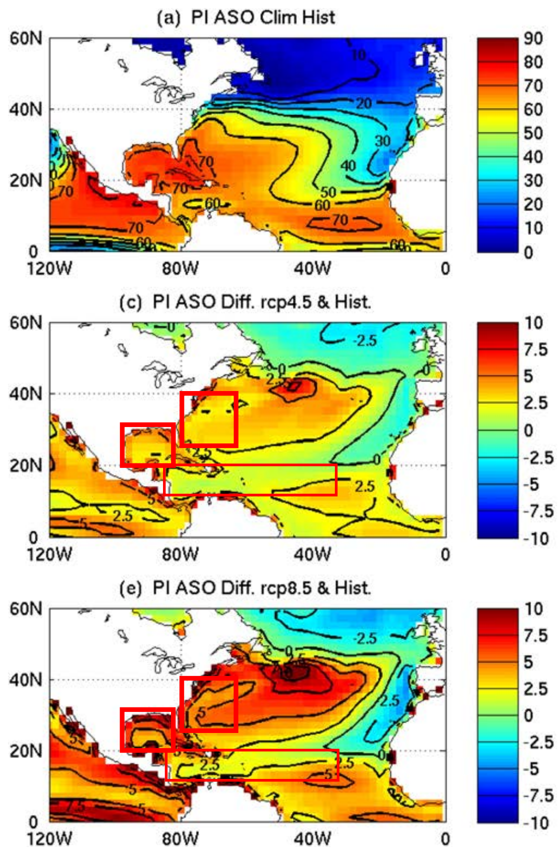
- Potential Intensity – Maximum possible intensity a tropical cyclone can attain given the large scale atmosphere and ocean surface conditions.

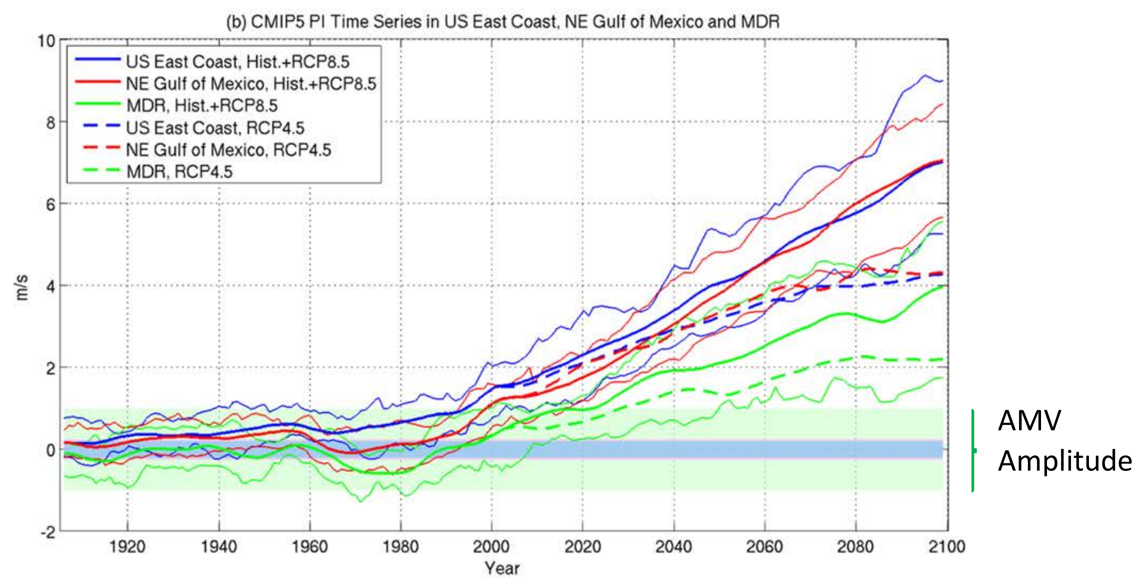
$$PI = \frac{C_k}{C_d}\frac{T_s}{T_0}\left(CAPE^* - CAPE^b\right)$$

- Coastal regions are seen to have the largest increase due to anthropogenic forcing under both rcp4.5 and 8.5 scenarios

Ting et al., 2015: Natural and Forced North Atlantic Hurricane Potential Intensity Change in CMIP5 Models. J Climate

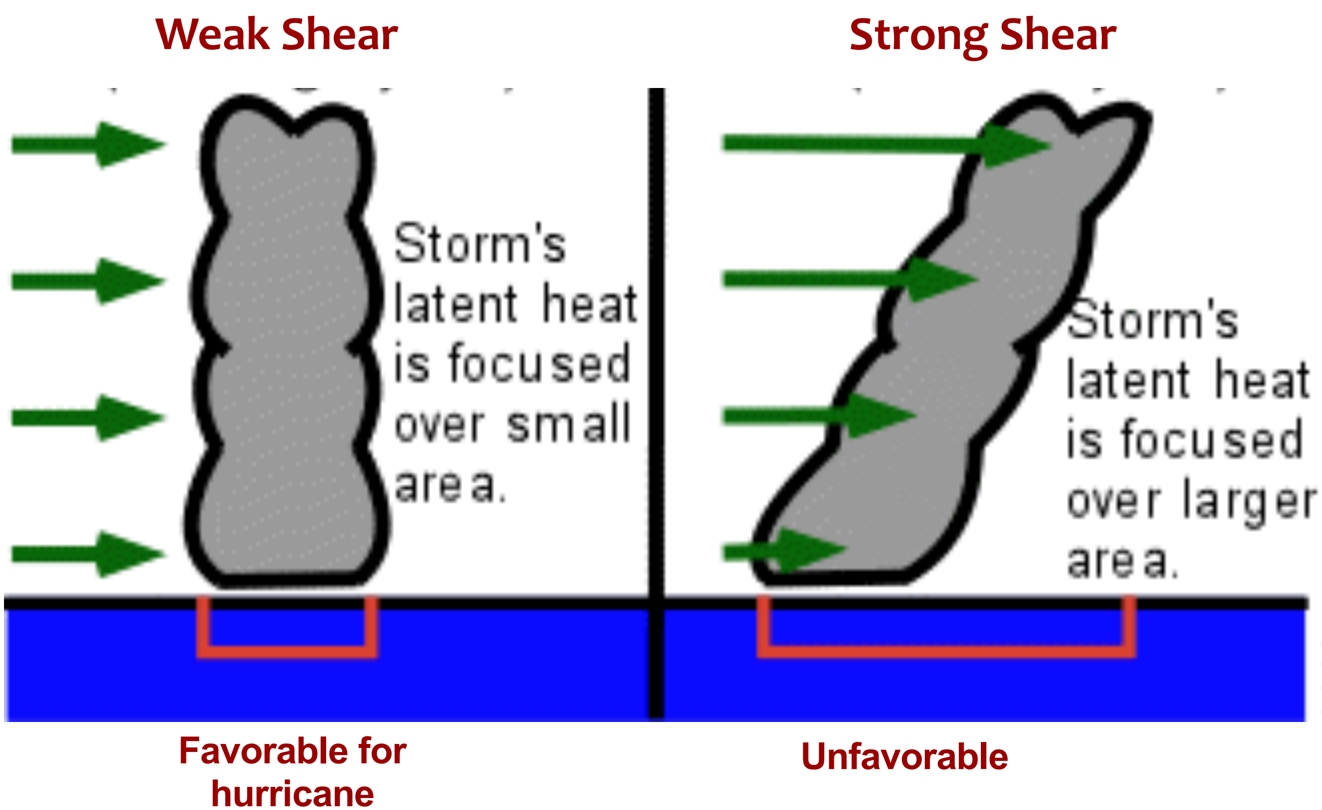
Atlantic Hurricane PI (left) during Peak Hurricane Season (ASO) from CMIP5 Historical, rcp4.5 – Hist., and rcp8.5 – Hist.





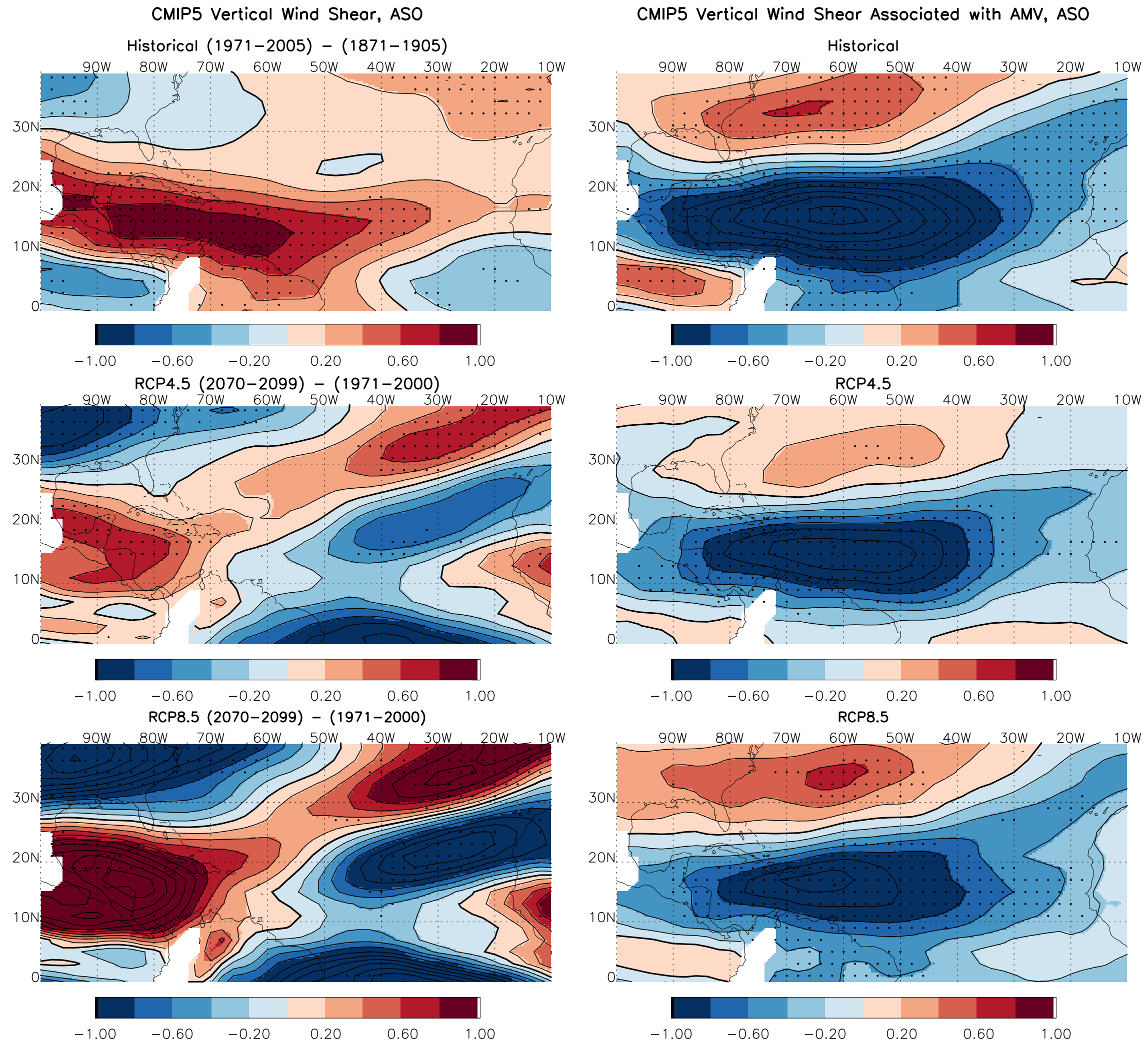
- *Potential intensity increases more than 10% along East and Gulf Coasts by end of 21st Century with rcp8.5*

What about vertical wind shear changes?

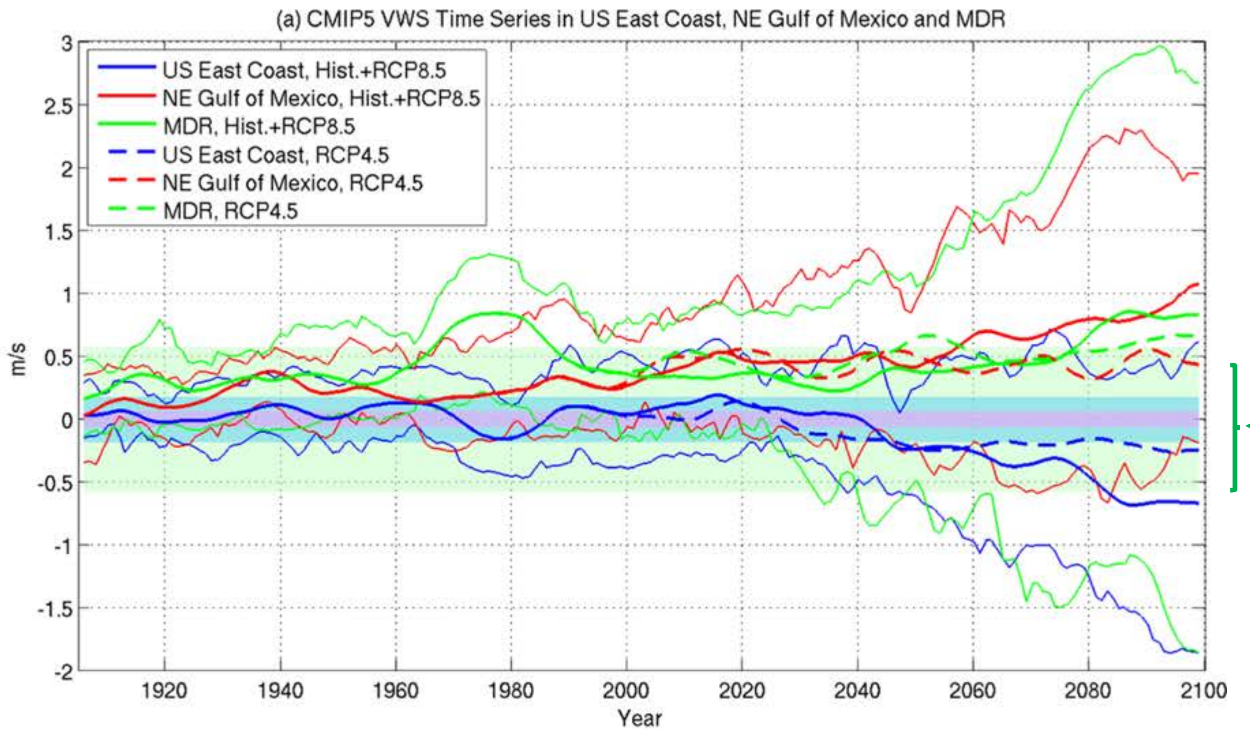


Vertical Wind Shear due to anthropogenic forcing and AMV *(27 CMIP5 Models)*

- VWS due to +AMV and anthropogenic forcing tends to be opposite along the east coast of US
- The reduction in land-falling hurricane in the recent past may be due to internal multidecadal variability, but future change could be dominated by GHG warming



Wind shear changes in the 20th and 21st Century along US East Coast, Gulf Coast, and MDR

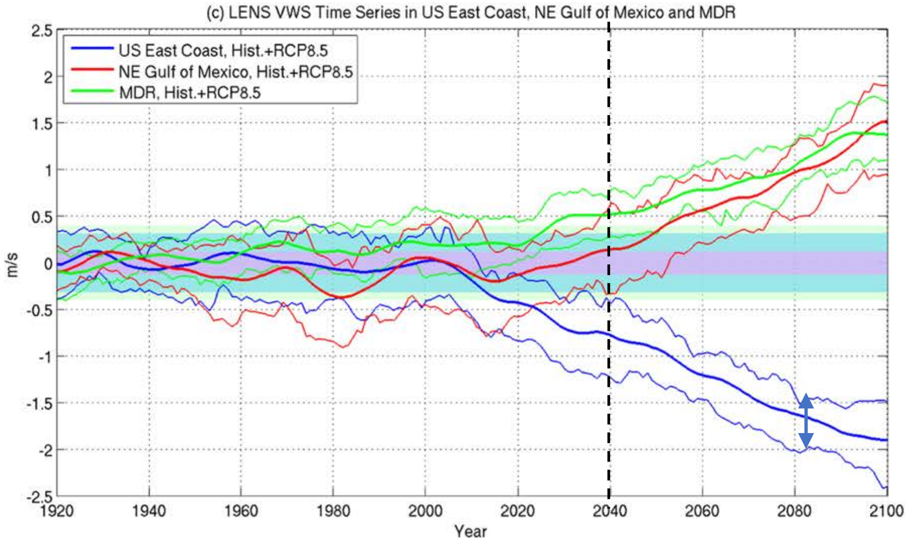


Shadings indicate average amplitude of AMV in different regions

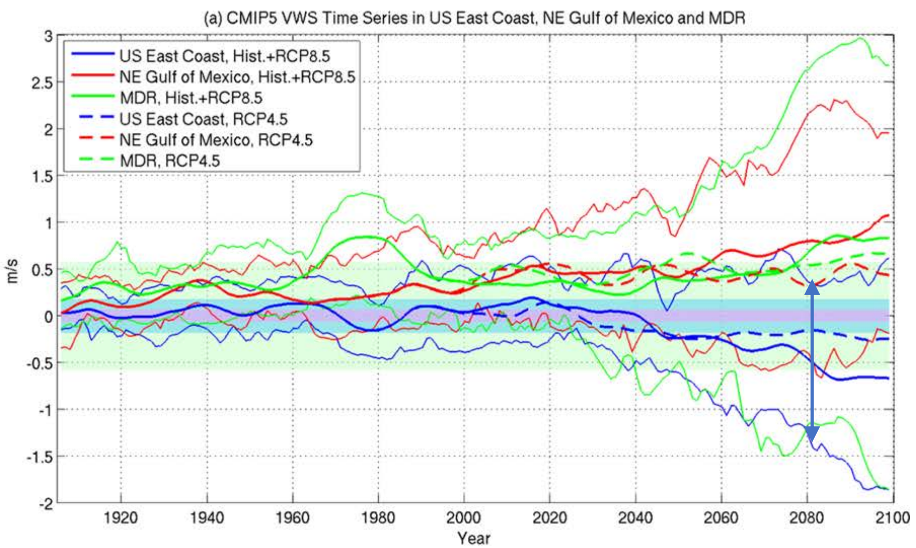
Vertical Wind Shear due to anthropogenic forcing and AMV

- *VWS change in LENS is at the strong end of the CMIP5 Model spectrum*
- *Very large spread due to model structural differences compared to internal variability*
- *Time of emergence (forced signal above internal variability) near 2040 for NCAR LENS, but varies widely in CMIP5 models*

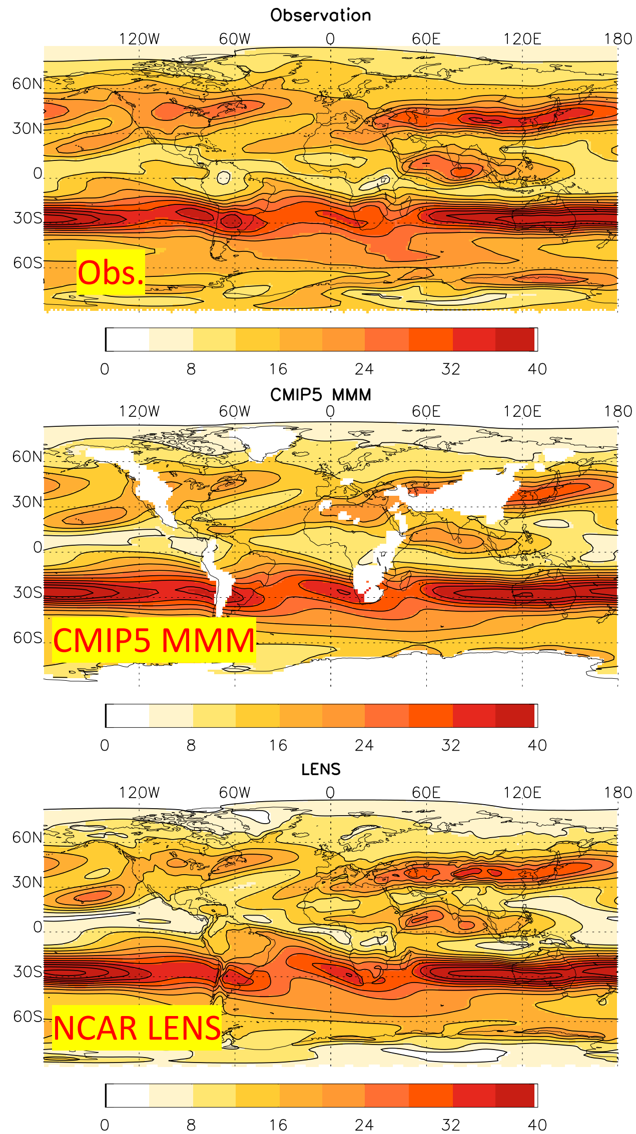
NCAR LENS



CMIP5 Models



Global VWS Climatology (1971-2000)



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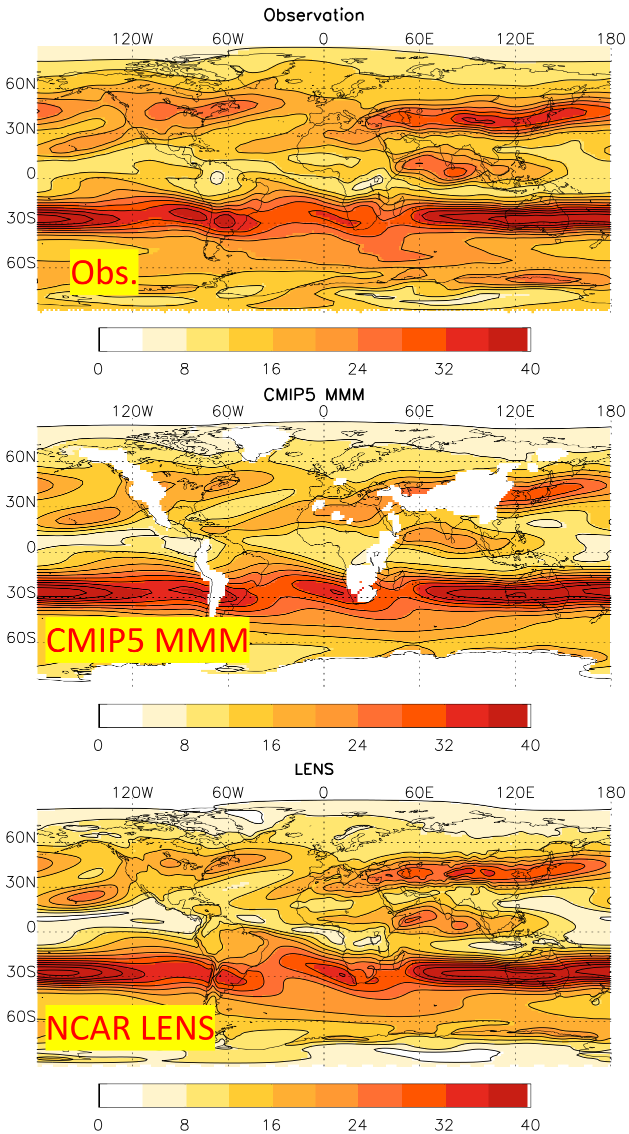
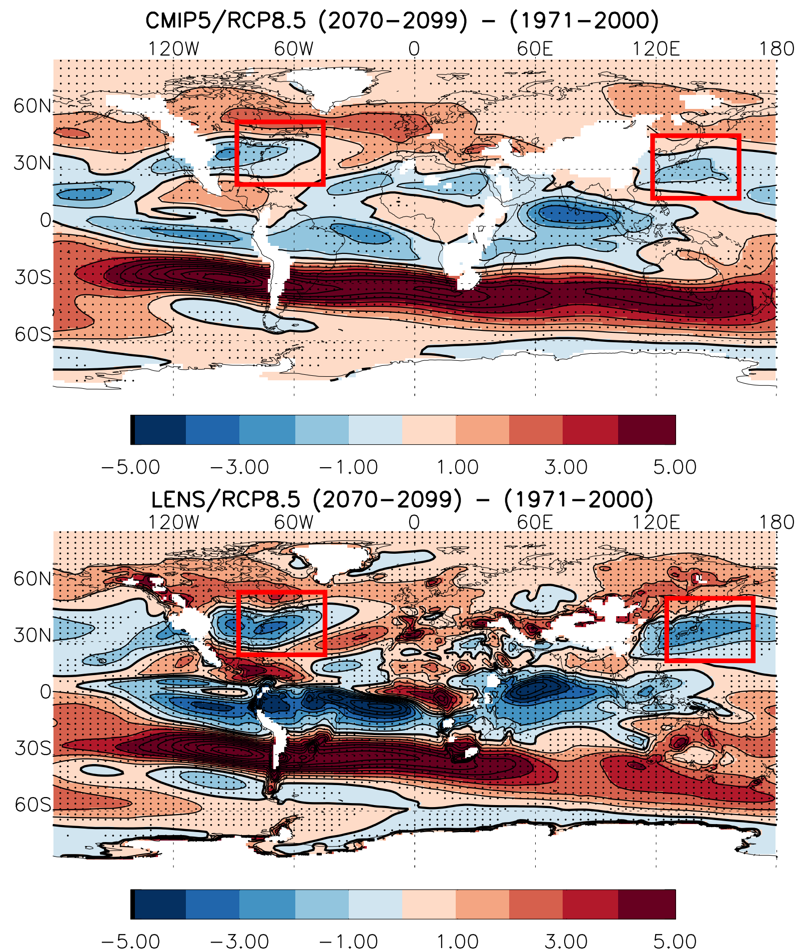


Global VWS Differences for CMIP5 MMM vs. LENS



- VWS change is associated with jet stream response to anthropogenic forcing – northward shift of the jet
- Future VWS in tropical cyclone active regions, such as US east coast, E Asian coasts, and Indian ocean, will have substantial decrease in VWS, making land-falling tropical cyclones stronger

Summary

- Tropical cyclone (Hurricane/Typhoon) maximum potential intensities are increasing due to greenhouse warming, particularly along the coastal regions and further north of the current regions of tropical cyclone activities
- Weak vertical wind shear (VWS) is one of the most important conditions for tropical cyclone intensification. While natural variability may dominate the recent past tropical cyclone intensifications, in the future, both the US and China east coasts will experience reduction in VWS due to GHG warming, thus potentially stronger tropical cyclones at their landfall.
- Anthropogenic forcing tend to erode the protective barrier due to the dominant natural VWS variability associated with AMV. The protective barrier prevents strong tropical cyclones from forming along the East Coast of US during the historical period
- There are large spreads among the CMIP5 models in future VWS changes, largely due to model structural differences. NCAR LE shows a much smaller spread in future VWS changes purely due to internal variability, and indicates a time of emergence of the forced signal above the AMV natural variability by ~2040