香港科技大學
THE HONG KONG UNIVERSITY OF SCIENCE AND TECHNOLOGY

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CliMet Lab
雲天探測

Insights of tropical cyclones responses to global warming from GNSS RO data over the past 16 years

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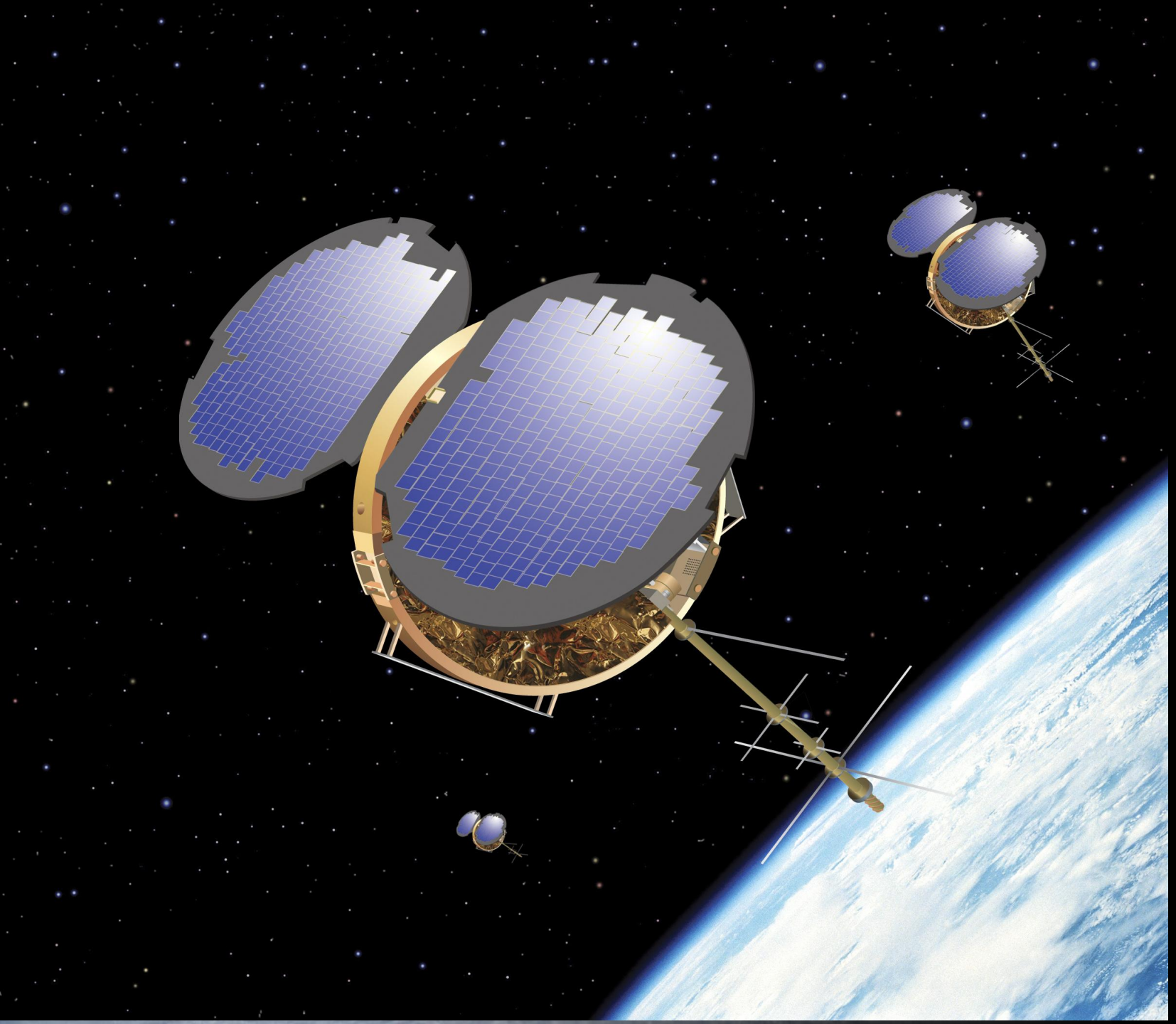
COSMIC/JCSDA Workshop & IROWG-10 in Boulder, Colorado



Content

Climate changes

Carbon Dioxide
↑ 420 parts per million

Global Temperature
↑ 1.1 °C since preindustrial

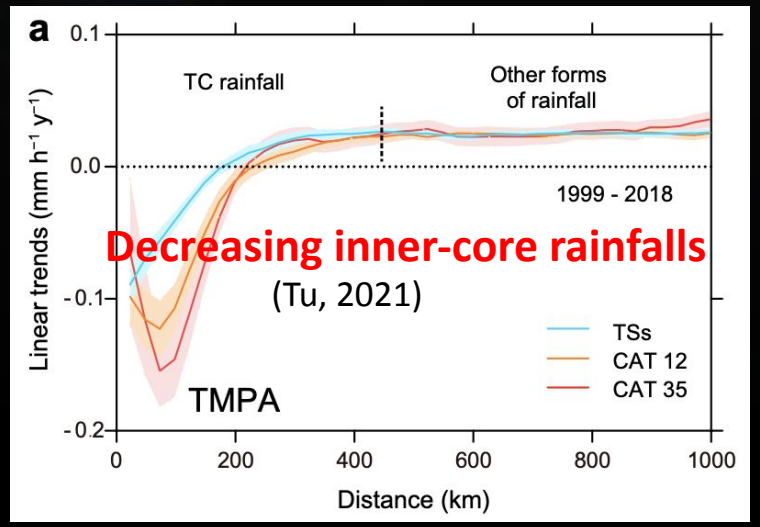
Methane
↑ 1923.6 parts per billion

Arctic Sea Ice Minimum Extent
↓ 12.3 percent per decade since 1979

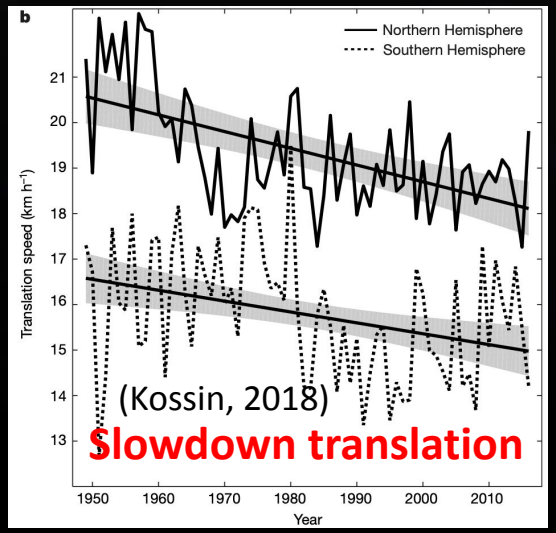
Ice Sheets
↓ 424 billion metric tons per year

Sea Level
↑ 4 inches since January 1993

Ocean Warming
↑ 345 zettajoules since 1955

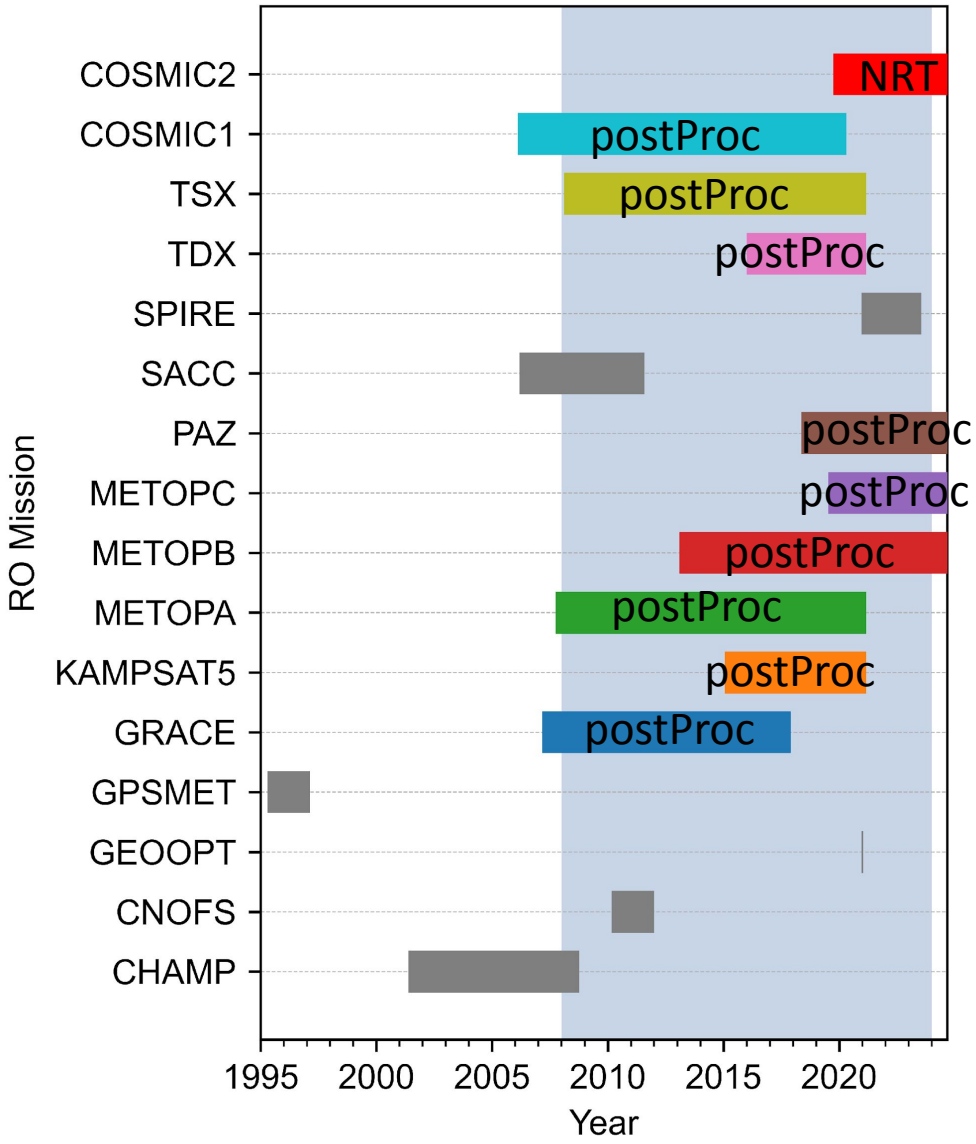


Decreasing inner-core rainfalls
(Tu, 2021)



(Kossin, 2018)
Slowdown translation

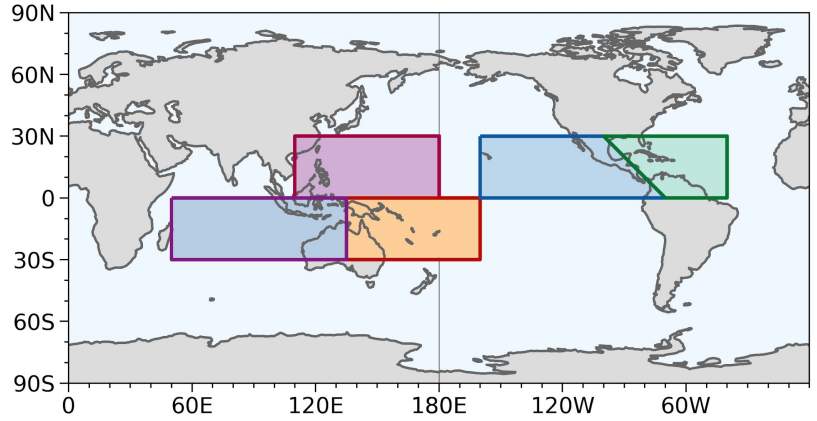
GNSS RO data



Water vapor accuracy compared with ground GNSS station and Radiosonde with 1-hour and 150 km matching rule

Satellite Mission	GNSS		Radiosonde	
	# of points	RMSE (mm)	# of points	RMSE (mm)
COSMIC1	20097	3.0	5267	2.7
COSMIC2	25388	***3.7***	5209	***3.7***
TSX	13075	2.9	4764	2.7
TDX	5469	3.1	1804	2.8
PAZ	3265	2.9	1075	2.6
METOPC	2778	2.9	663	2.6
METOPB	18434	3.0	4782	2.9
METOPA	18206	3.0	4536	2.9
KOMPAST5	14658	2.9	5173	2.6
GRACE	4353	***2.5***	1459	***2.2***

Tropical cyclone ocean basins

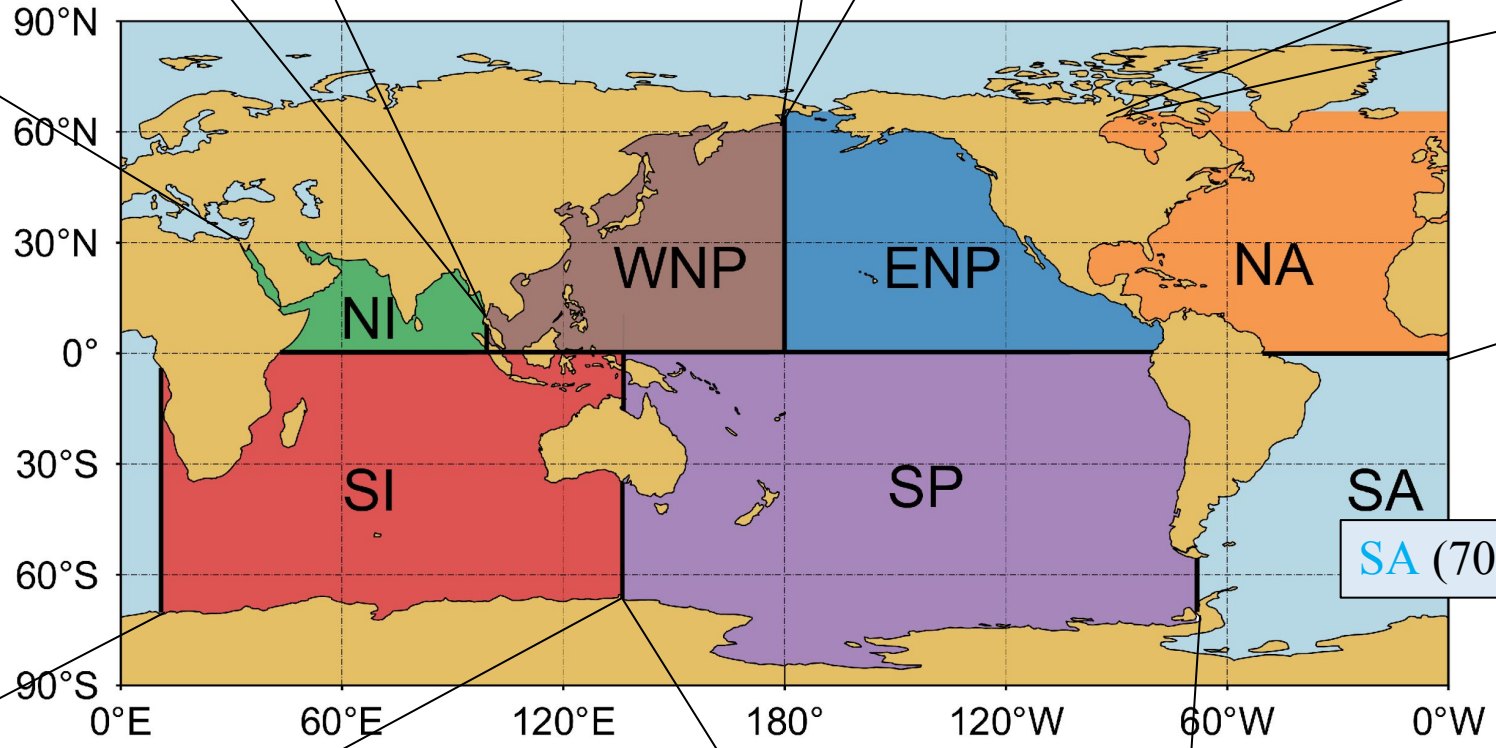


ENP (western boundary is 180° E, eastern boundary is the coastline of the North America on the North Atlantic)

NI (30° E ~100° E)

WNP (100° E ~180° E)

NA (western boundary is the coastline of the North America on the Eastern Pacific, the eastern boundary is 30° E)

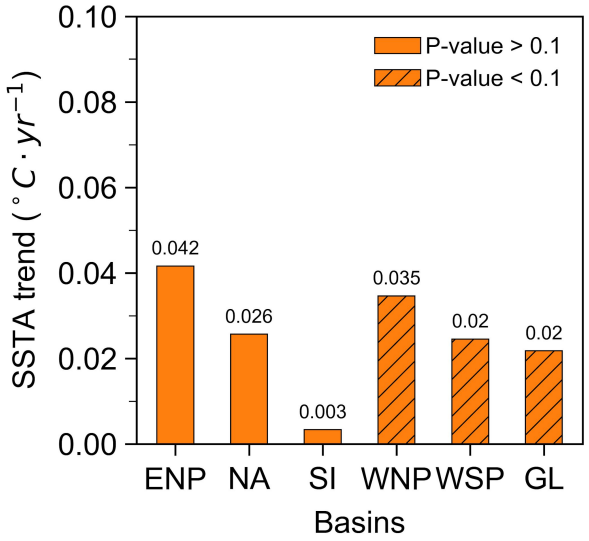


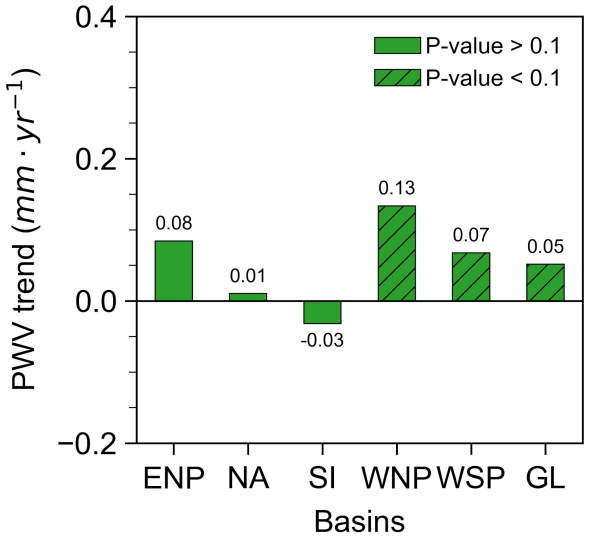
SA (70° W ~10° E)

SI (10° E ~135° E)

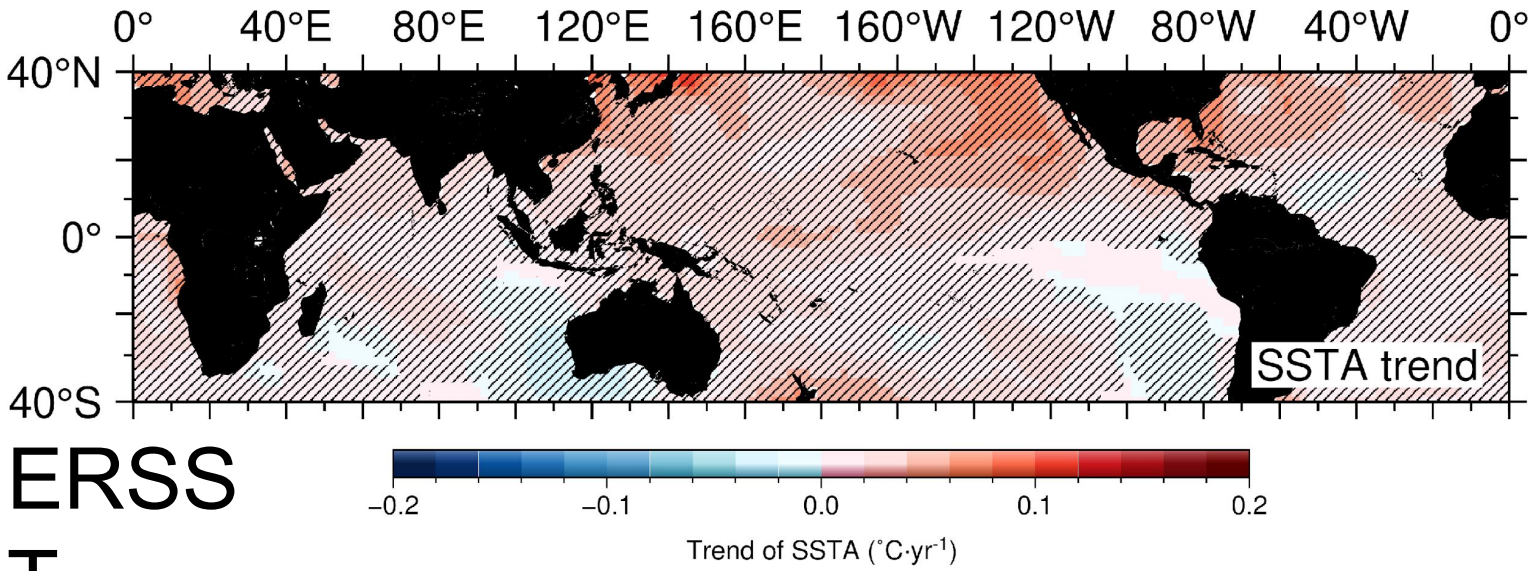
SP (135° E ~70° W)

Short-term trends in SSTA & PWV (2008-2023)

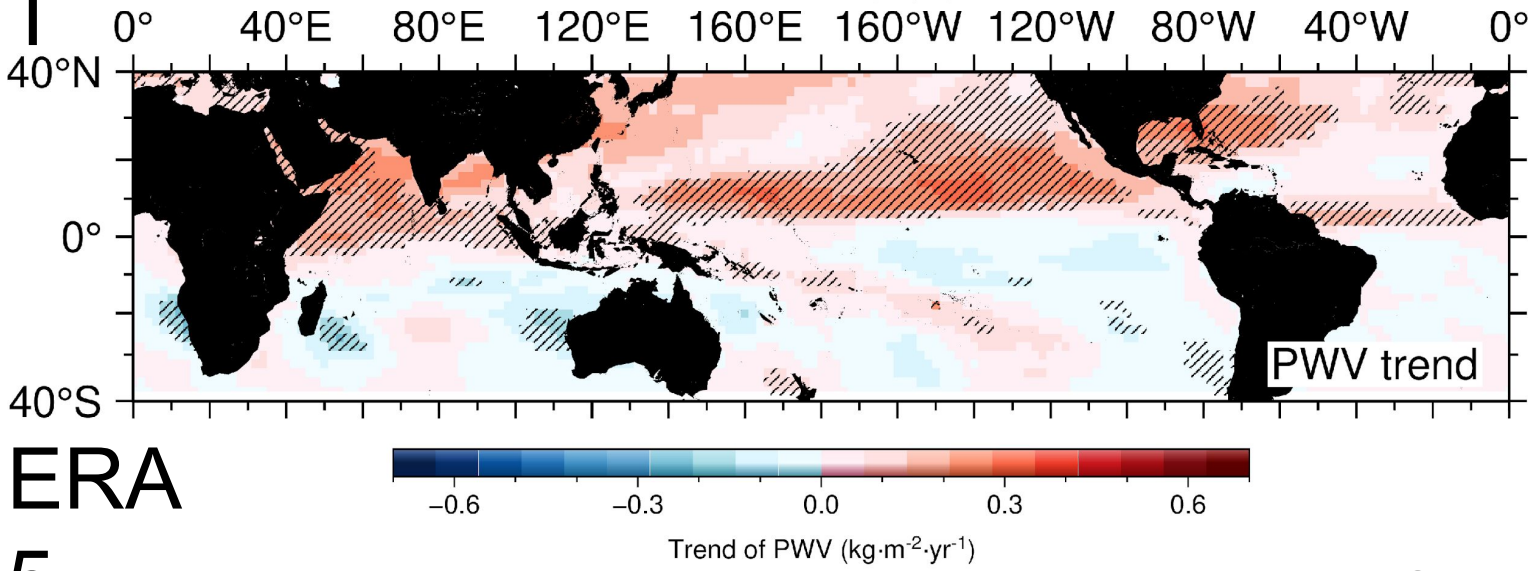




ERSST



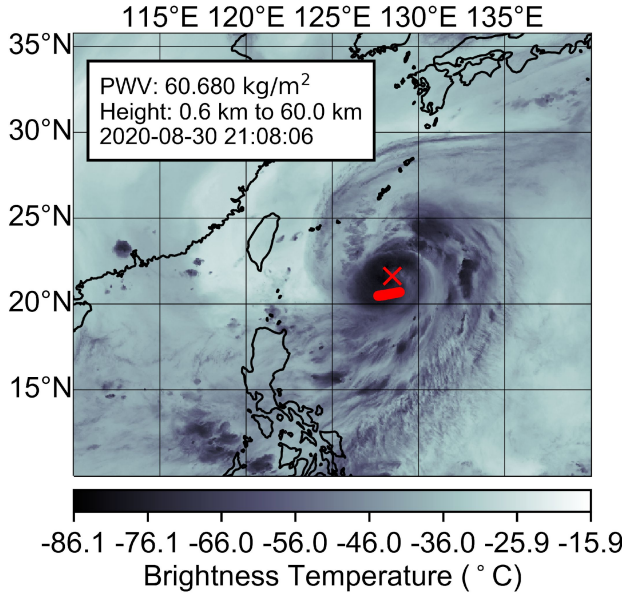
ERA5



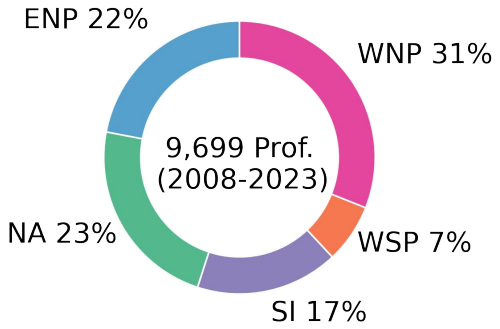
RO observations

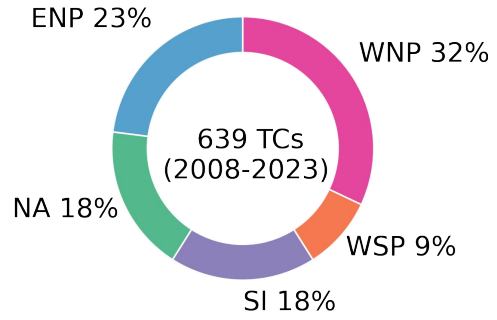
QC:

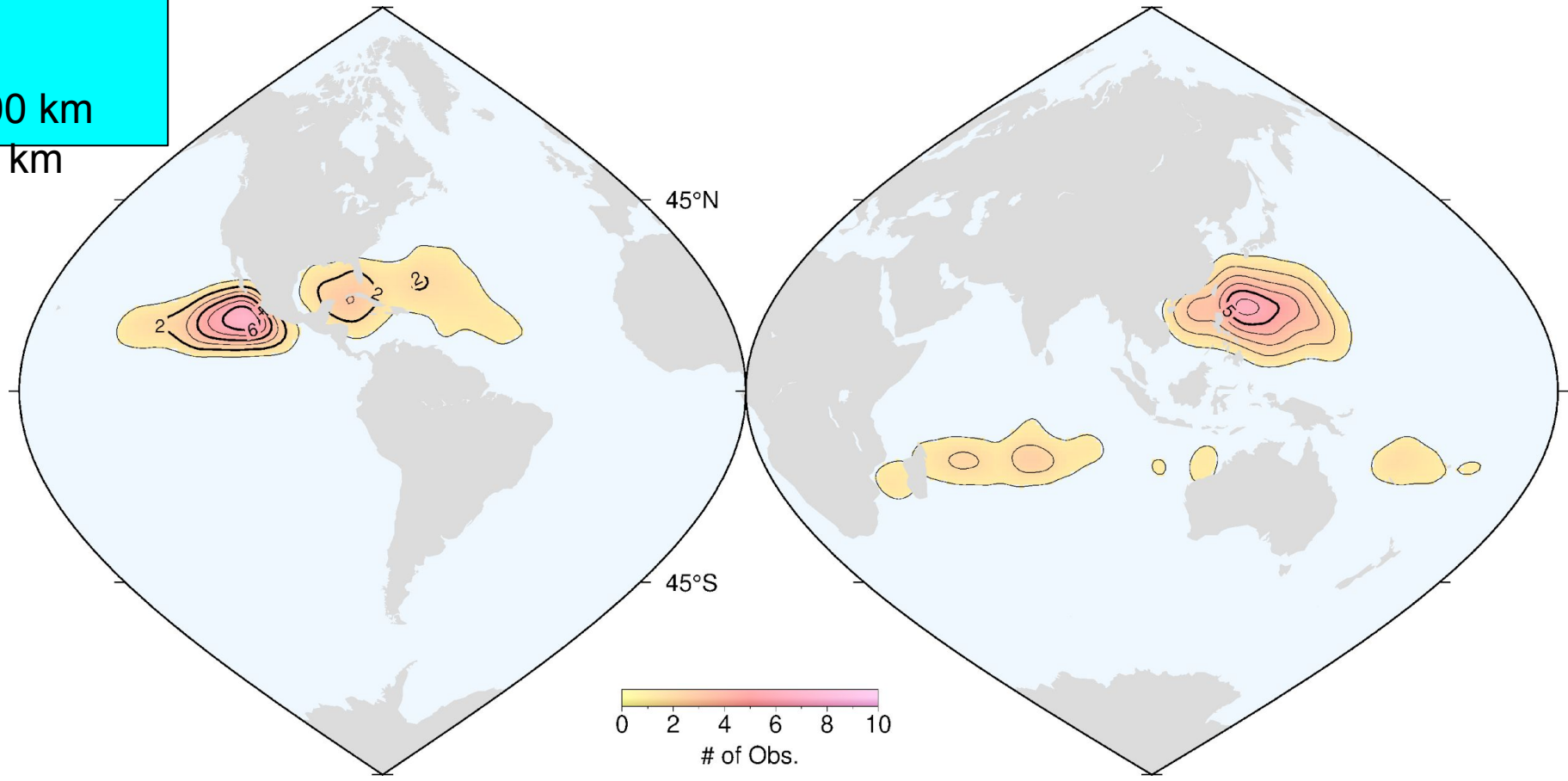
1. TC intensity with USA_SSHS Cat. 1-5
2. TC in developing stage with δUSA_WIND/δt >0
3. Distance from TC center < 600 km
4. Penetrate depth reaching 1.6 km



RO-TC pair

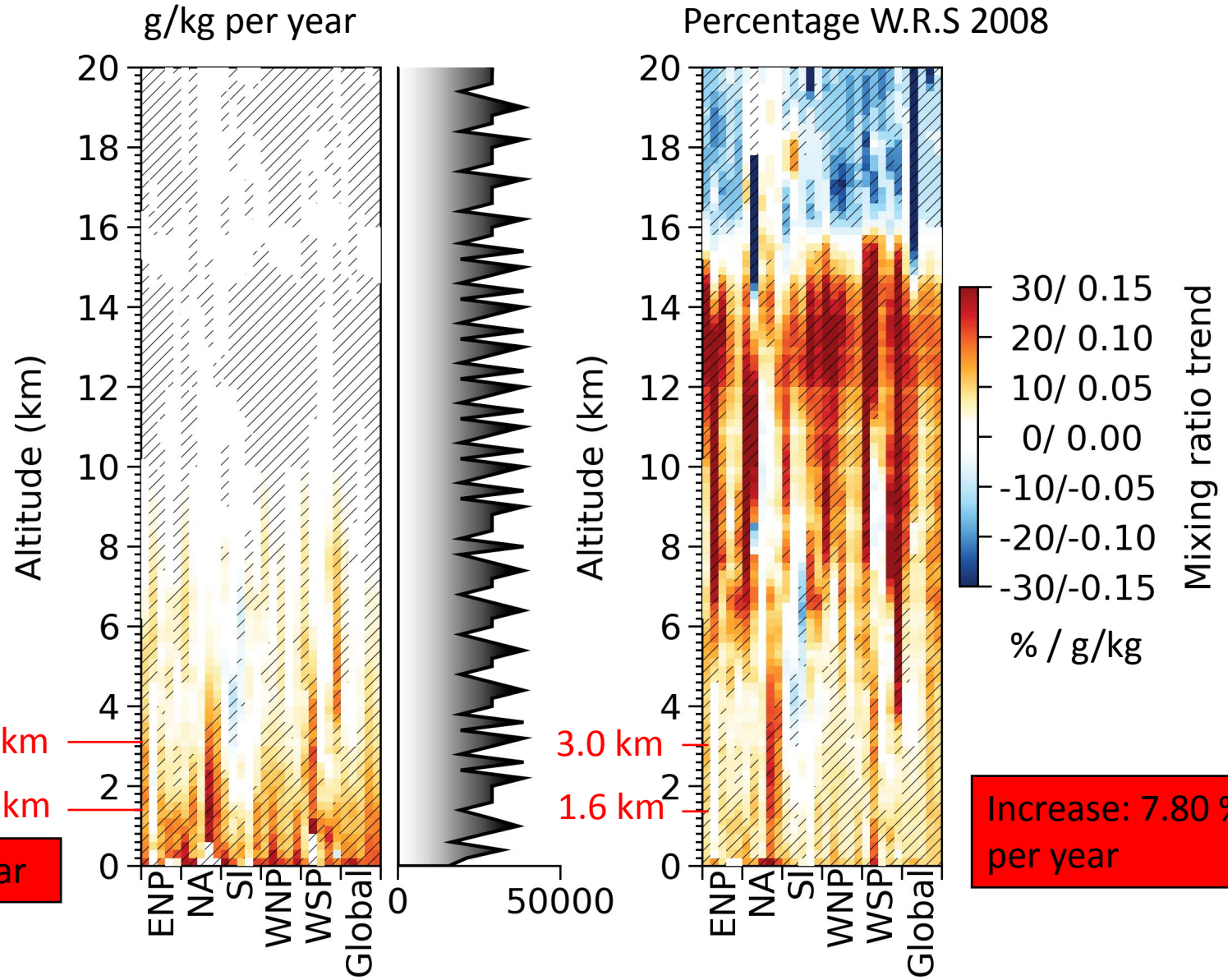






Mixing ratio trend in different altitudes

Mixing ratio trend in g/kg per yr (left) and percentage (right) over the ENP, NA, SI, WNP, WSP, and Global scales. The cross shadow denotes the trend is statistically significant above the 90% confidence level according to a Wald's t test on the linear regression result.

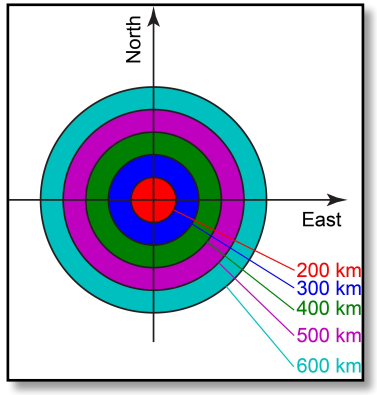


Increase: 0.03 g/kg per year

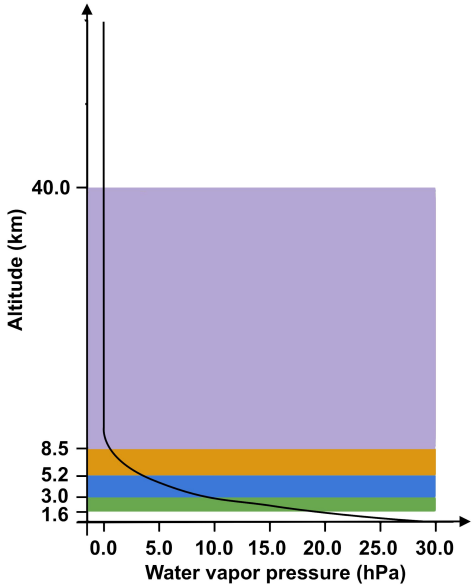
Increase: 7.80 % per year

TC water vapor trend @ 1.6-3.0 km (different bands & basins)

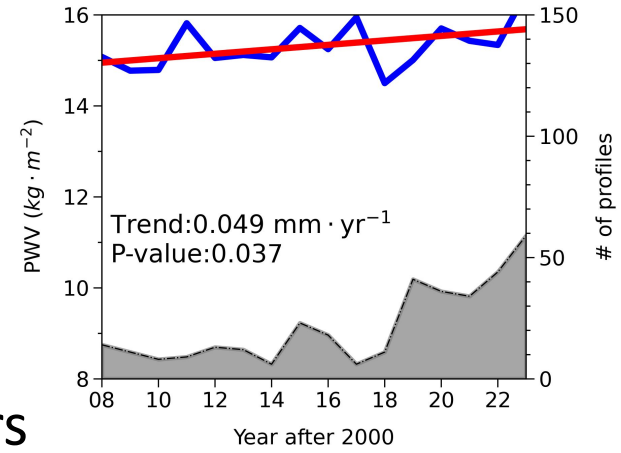
- Different distance bands



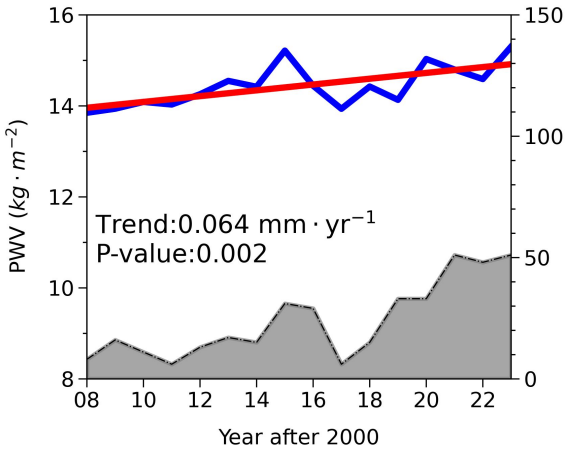
- Different altitude layers



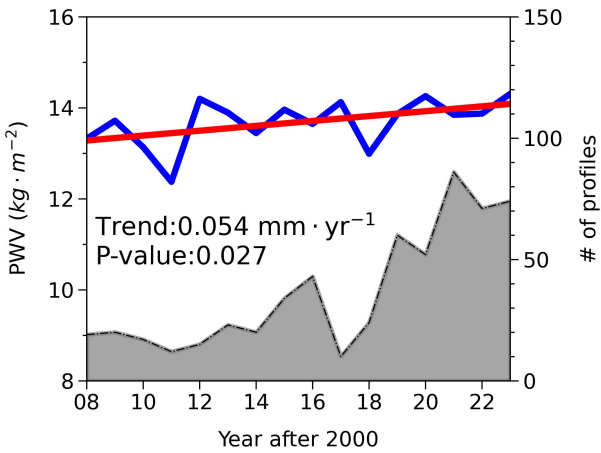
(a) WNP, 0-200 km @ 1.6-3.0 km



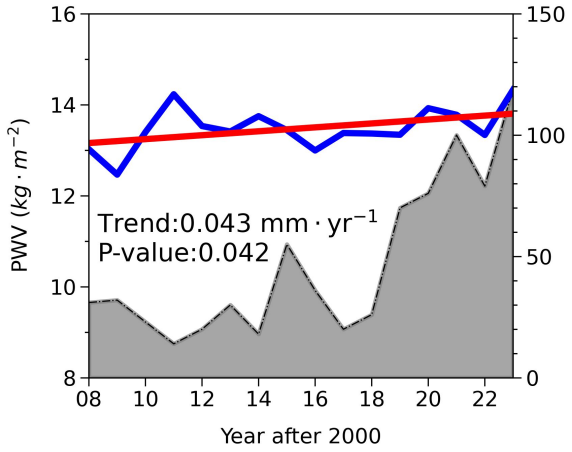
(b) WNP, 200-300 km @ 1.6-3.0 km



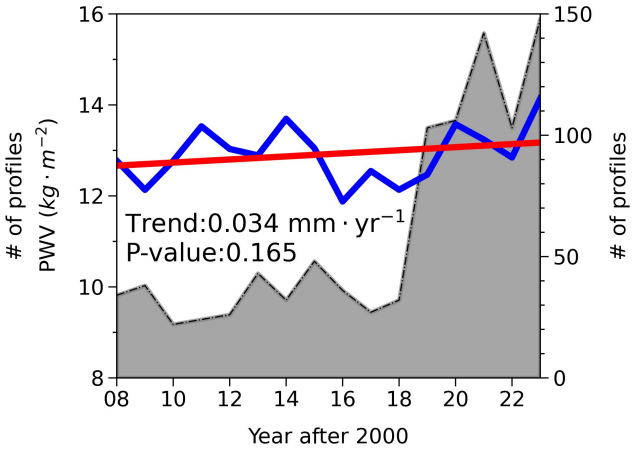
(c) WNP, 300-400 km @ 1.6-3.0 km



(d) WNP, 400-500 km @ 1.6-3.0 km

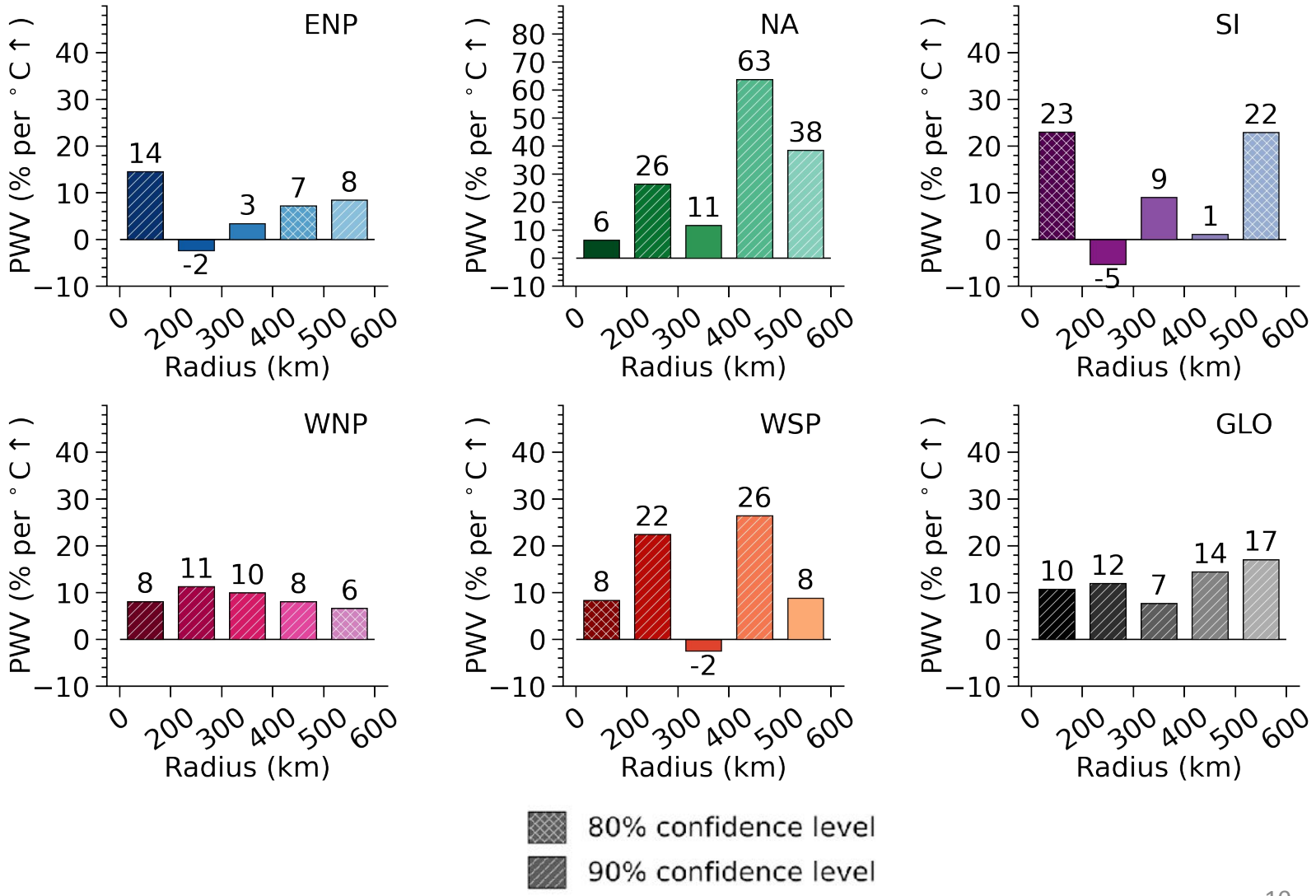


(e) WNP, 500-600 km @ 1.6-3.0 km

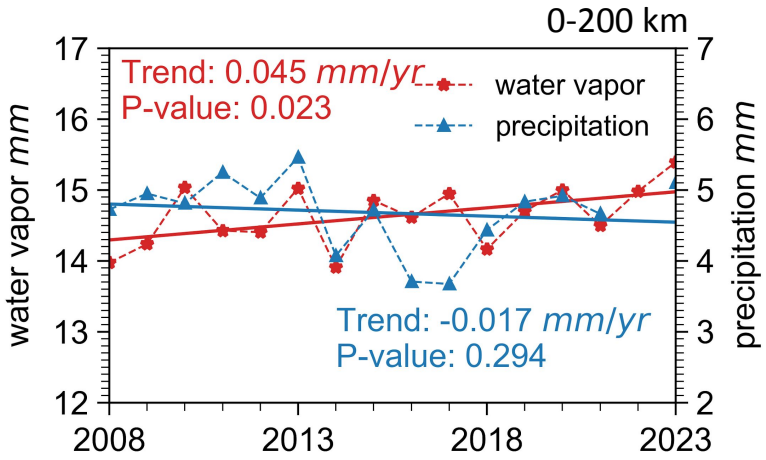


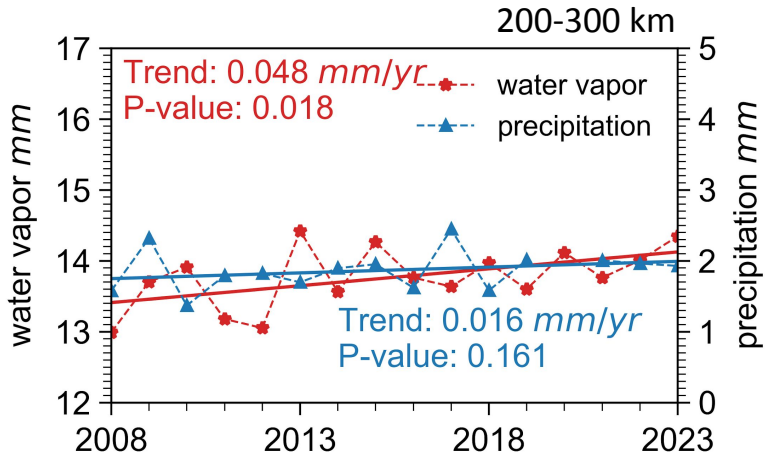
Significant increase trend of water vapor (1.6-3.0 km)

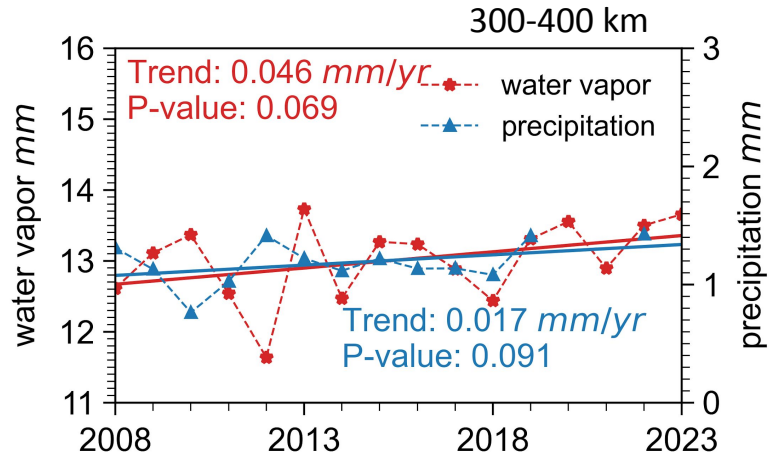
TC water vapor trend (%) responding to a 1-℃ increase of corresponding air temperature. Bar with cross/slash denotes the water vapor trend is statistically significant above the 80%/90% confidence level according to a Wald's test

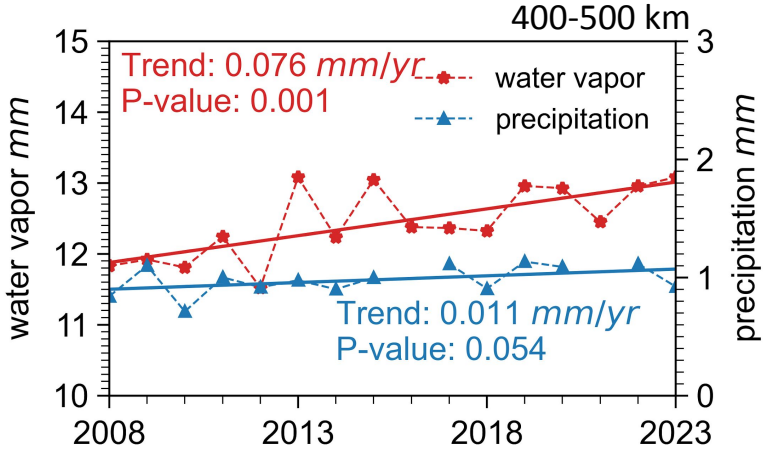


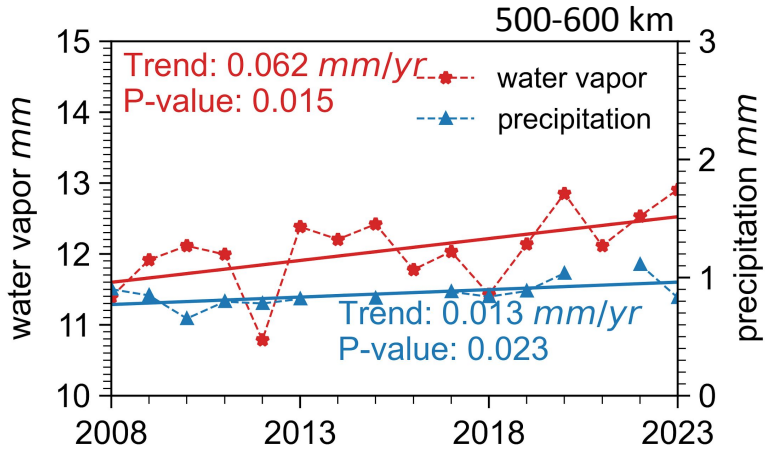
TC PWV & TP trend (different bands)





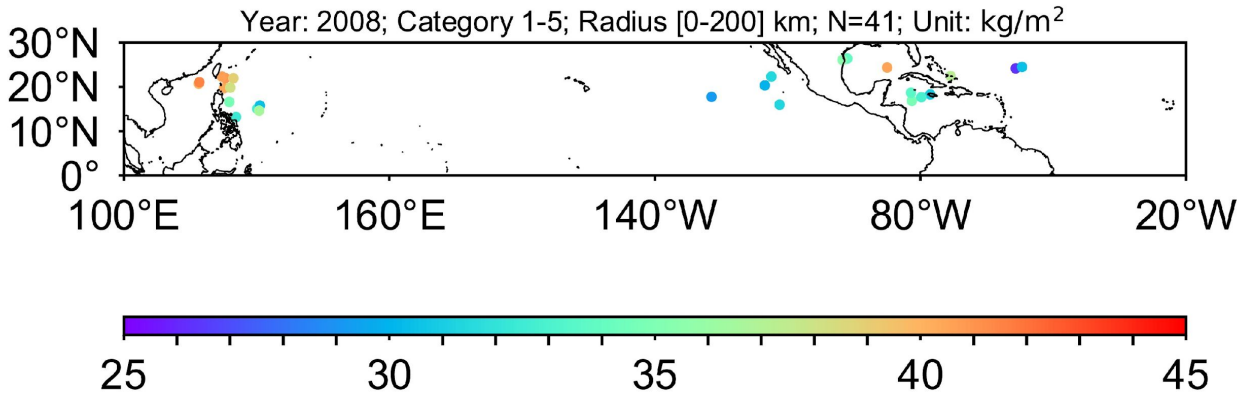


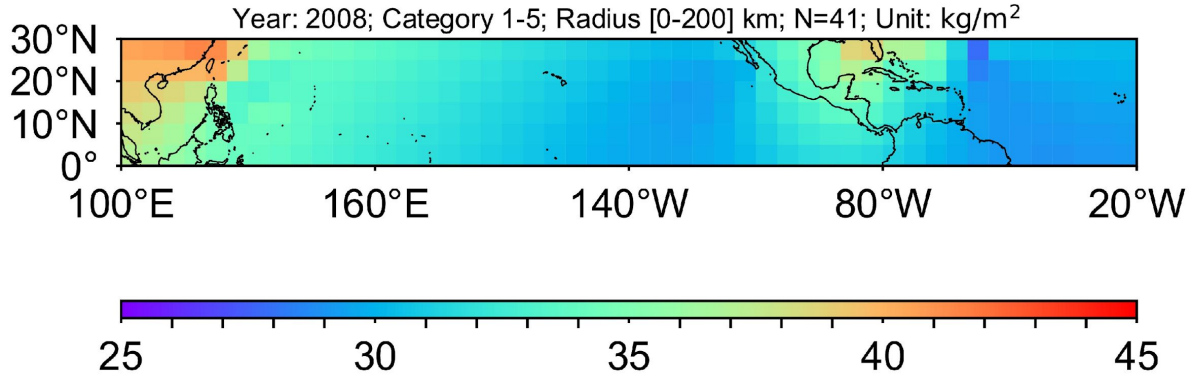




TC water vapor trend (red) and total precipitation trend (blue) at different bands

TC PWV & TP trend (different bands & basins)





TC PWV/TP points at bands over North Pacific Ocean and North Atlantic Ocean

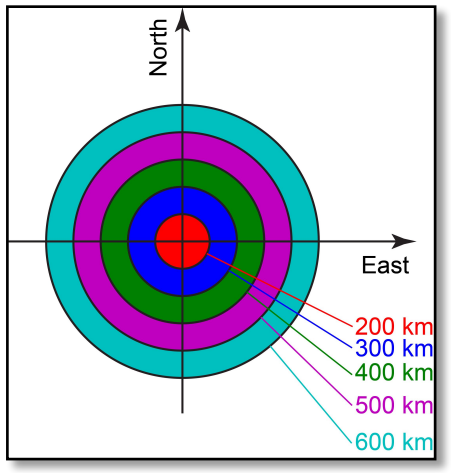
Radial basis function (RBF) Interpolation (5°x5°)

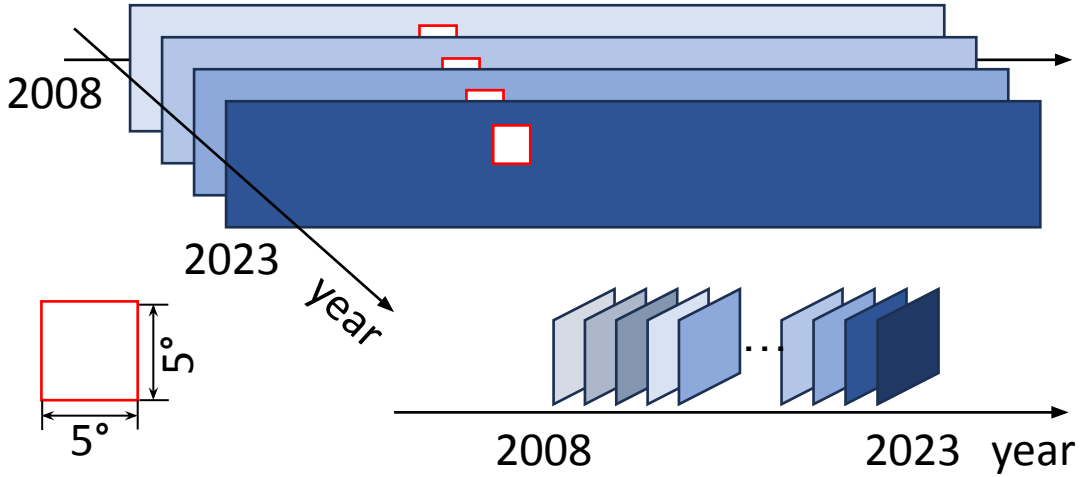
TC PWV/TP map at bands over North Pacific Ocean and North Atlantic Ocean

$$s(X) = \sum_{i=1}^{n} \lambda_i \phi(\|X - X_i\|), \qquad X \in \mathbb{R}^d$$

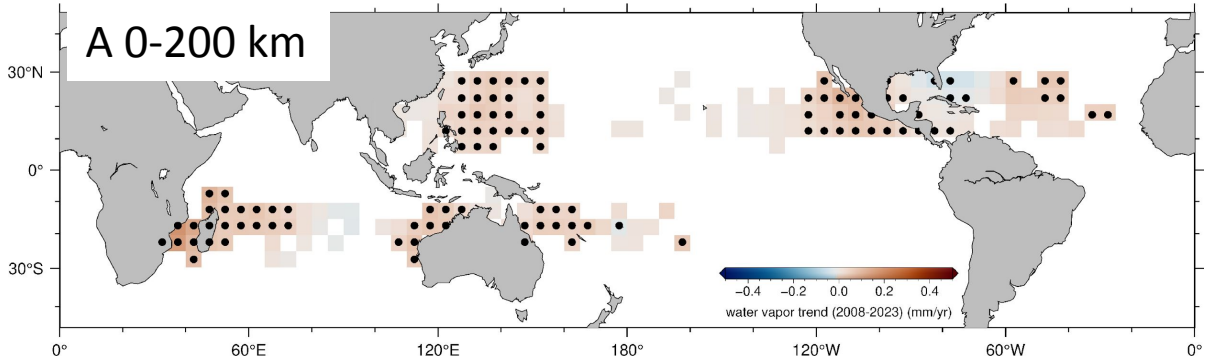
$s(X)$ is the interpolant
λ_i is the coefficients for the RBF $\phi(\|X - X_i\|)$ which can be simplified as $\phi(r)$

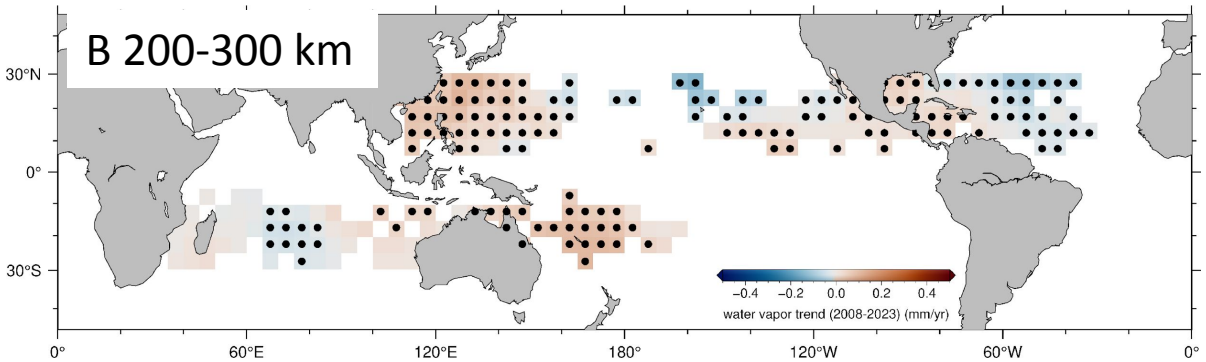
$$\phi(r) = r, \qquad \text{Linear RBF function}$$

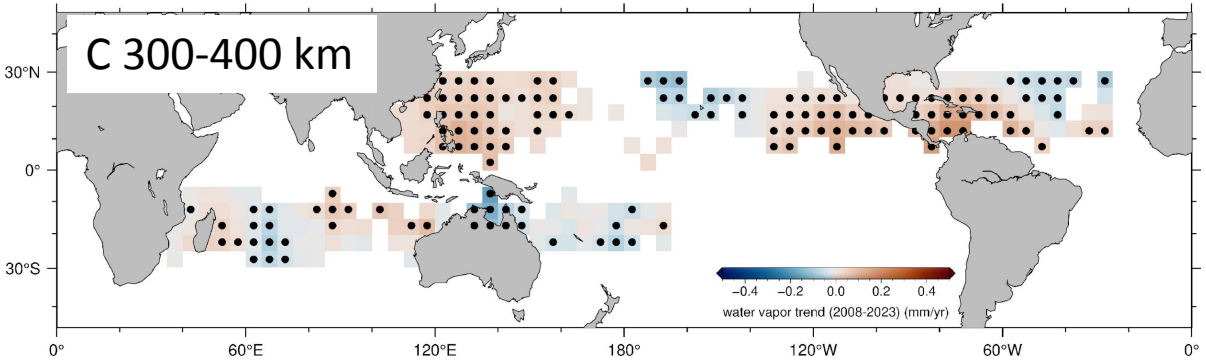


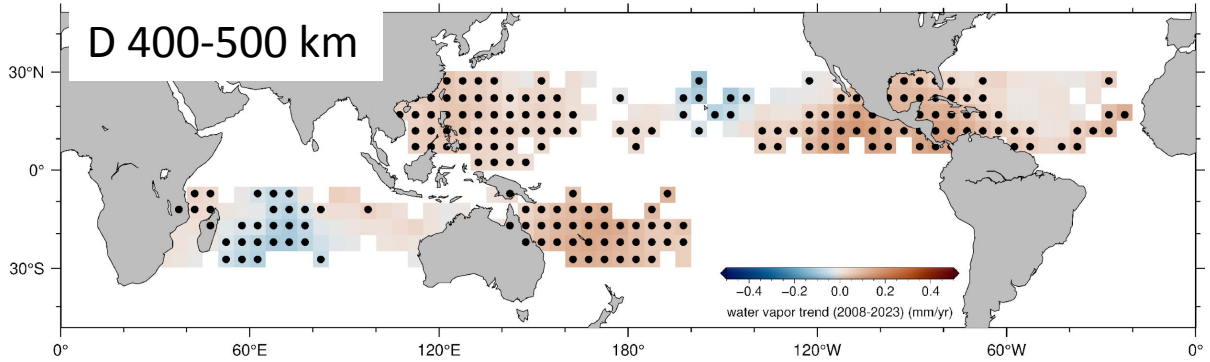


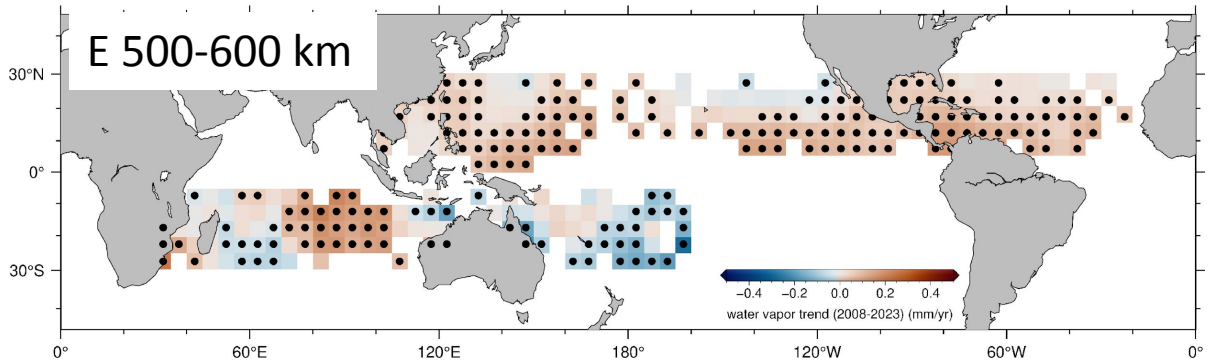
TC water vapor trend (different bands)





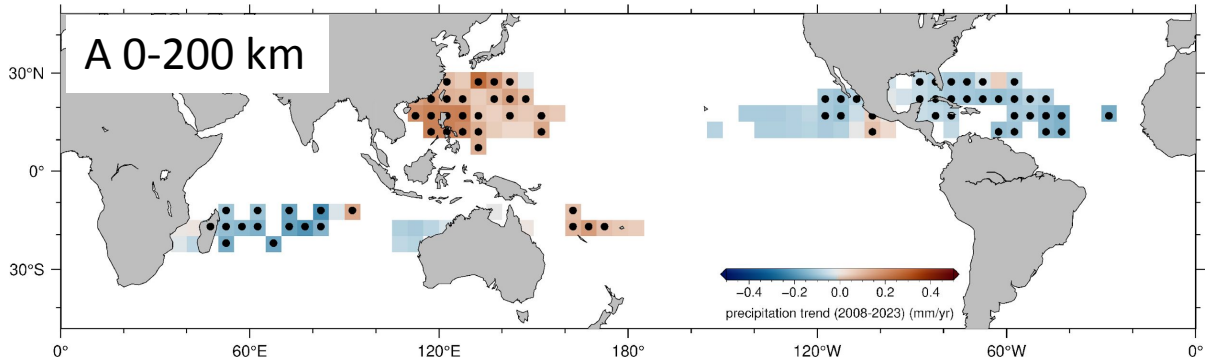


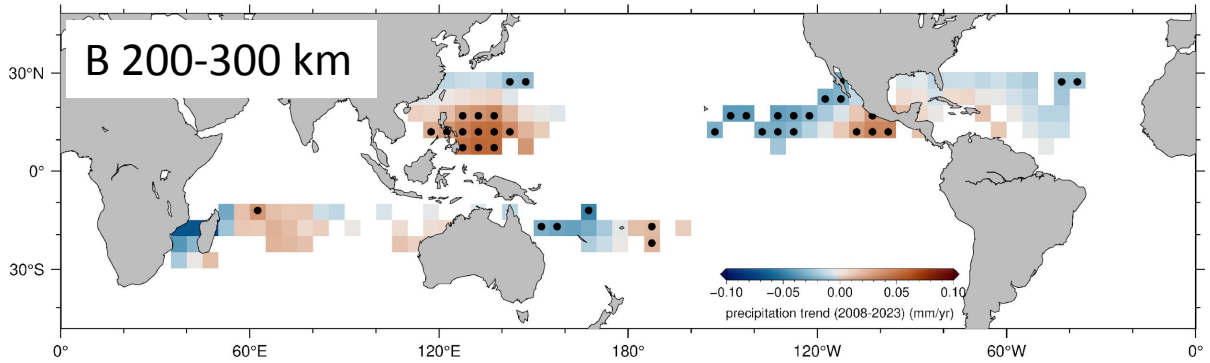


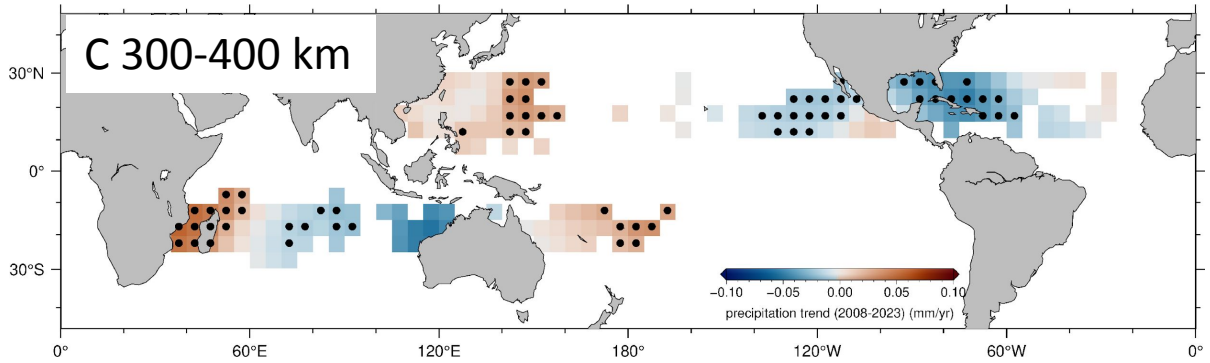


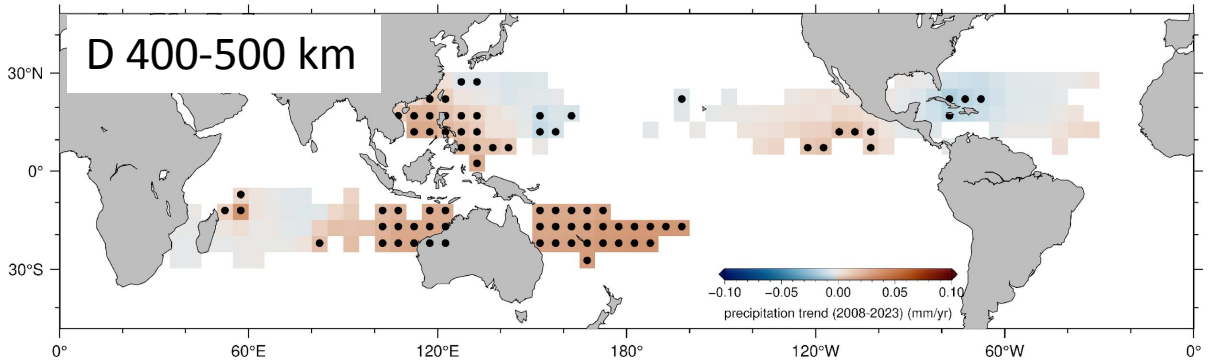
PWV trend at grids with spatial resolution of 5°×5° in latitude and longitude. The black dots in PWV trend indicates the linear trend over the grid cell is **statistically significant at the 95% level** according to the Wald significance test with t-distribution

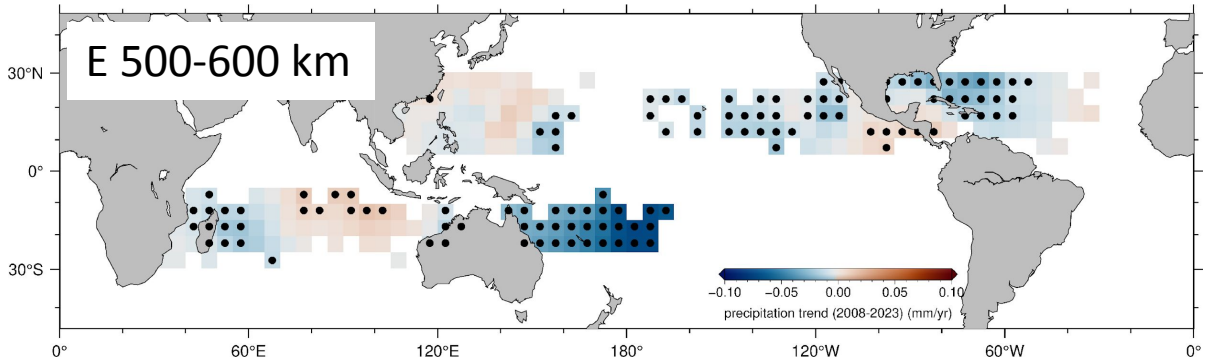
TC total precipitation trend (different bands)











Total precipitation (TP) trend at grids with spatial resolution of 5°×5° in latitude and longitude. The black dots in PWV trend indicates the linear trend over the grid cell is **statistically significant at the 80% level** according to the Wald significance test with t-distribution

Conclusion

- Globally, the SST increases by **0.02 ℃ per year**, and water vapor increases by **0.05 mm per year**.
- TC Mixing ratio @ 1.6-3.0 km increases by **0.03 g/kg per year (7.8% per year)** , correspondingly.
- TC Water vapor @ 1.6-3.0 km increases by ~**12% for 1-℃ increase** in air temperature
- Changes of TC total precipitation is not consistent with the change of water vapor.

CliMet

Thank you!

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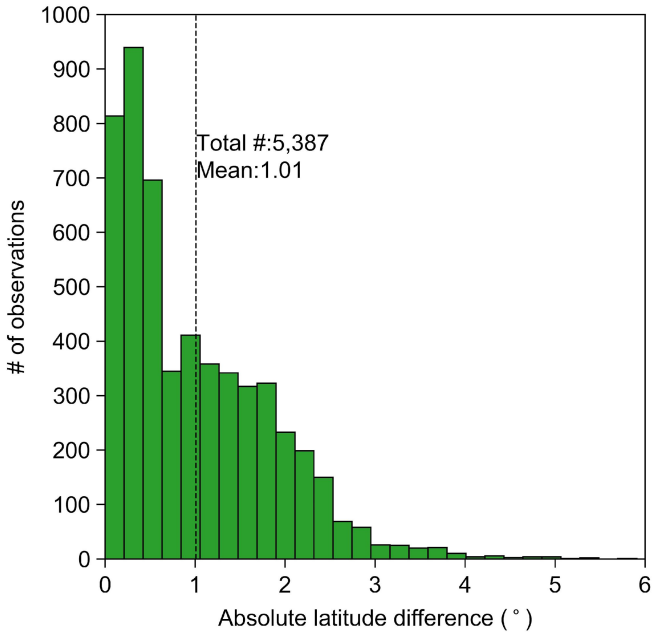
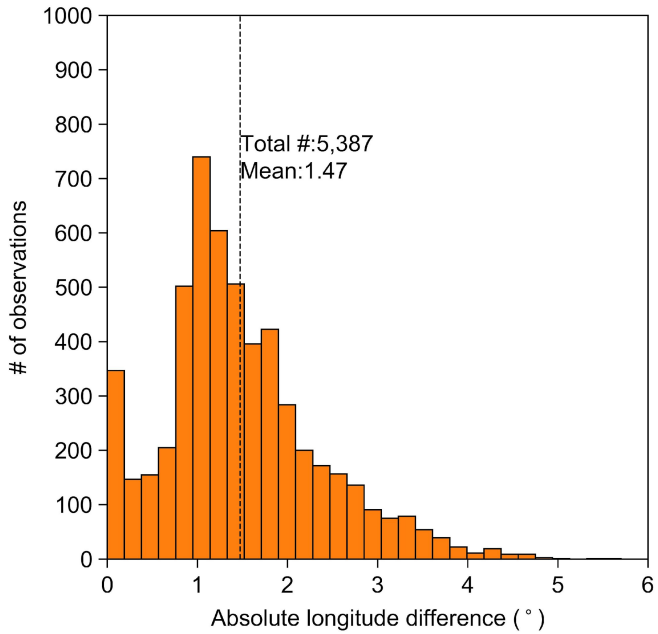
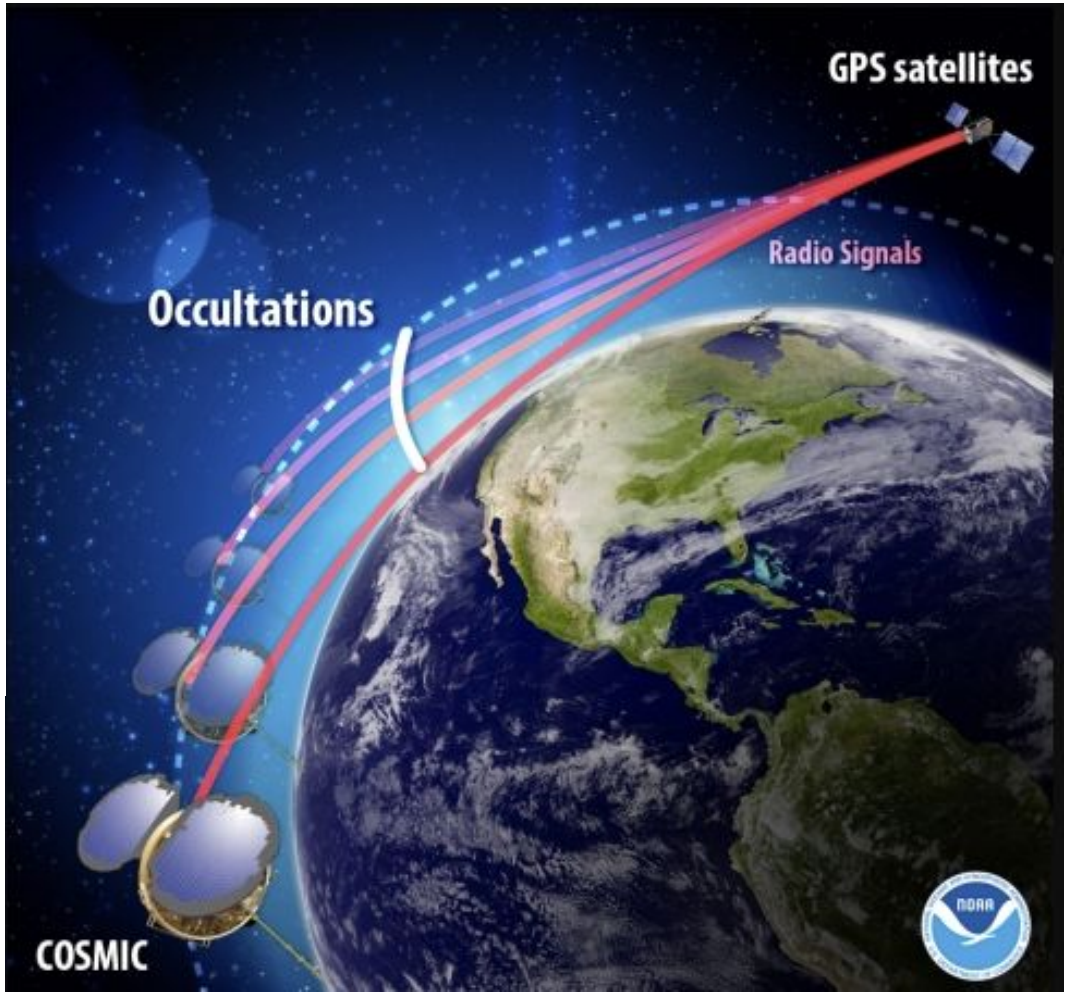
GNSS RO data properties (backup)



Latitude: 1.01°

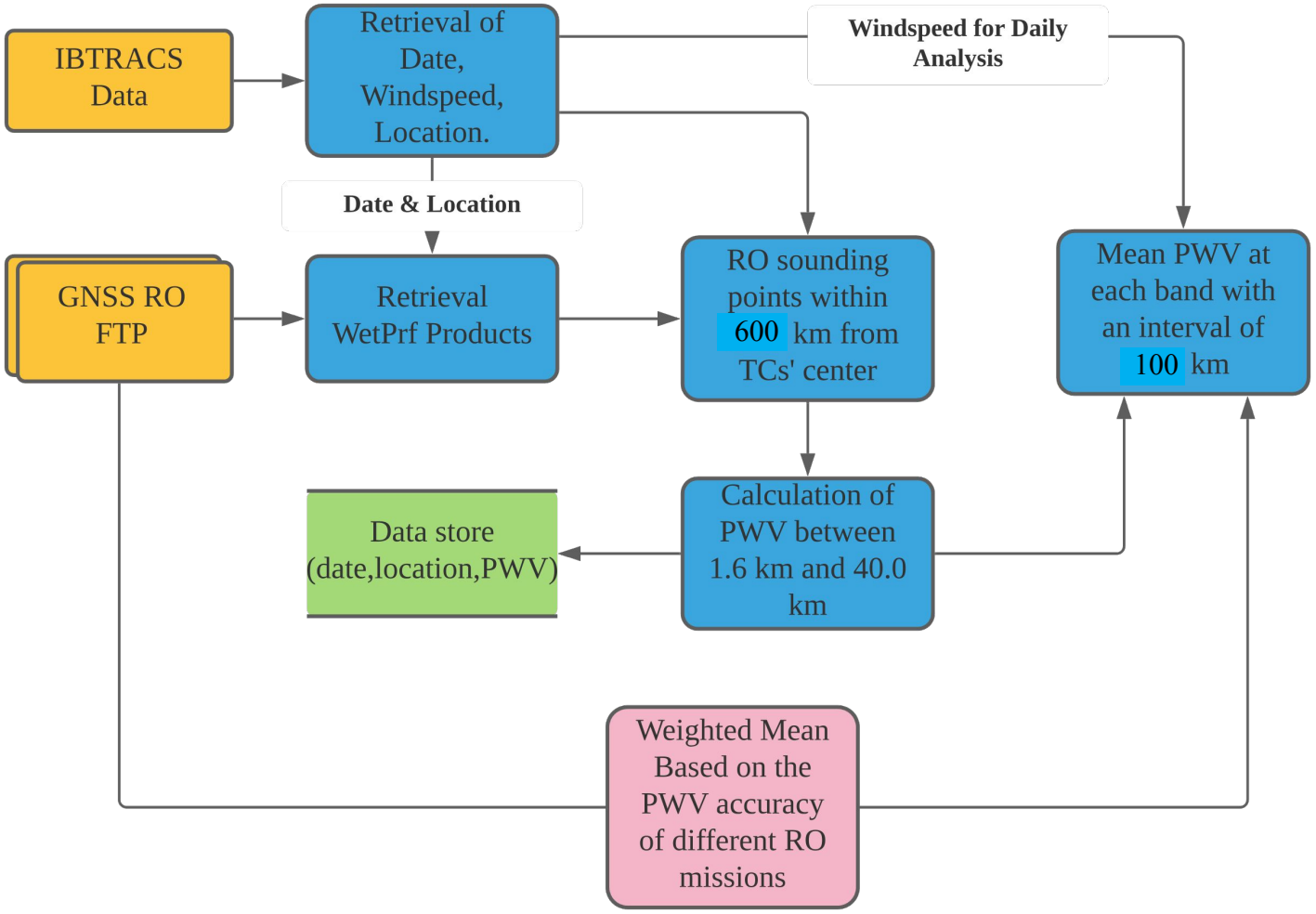


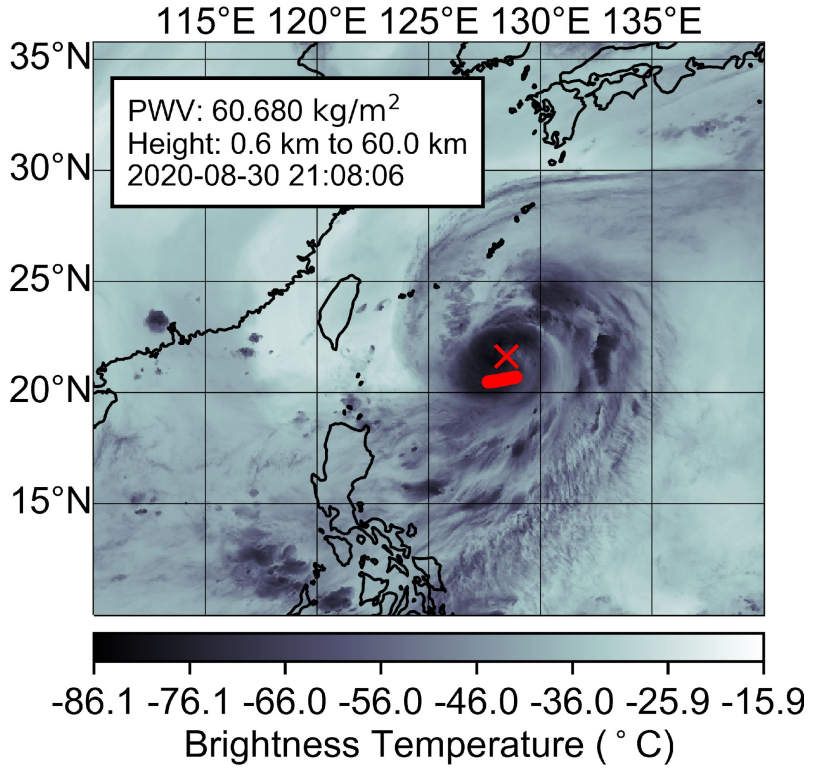
Longitude: 1.47°



Horizontal shift between the first and last sounding point of each RO profile (5,387 in total) in latitude and longitude

GNSS RO data processing (backup)





TC PWV trend from ERA5 (backup)

Legend

RO

ERA5

2008

Decrease

2020

2020

Increase

2008

90% Confidence