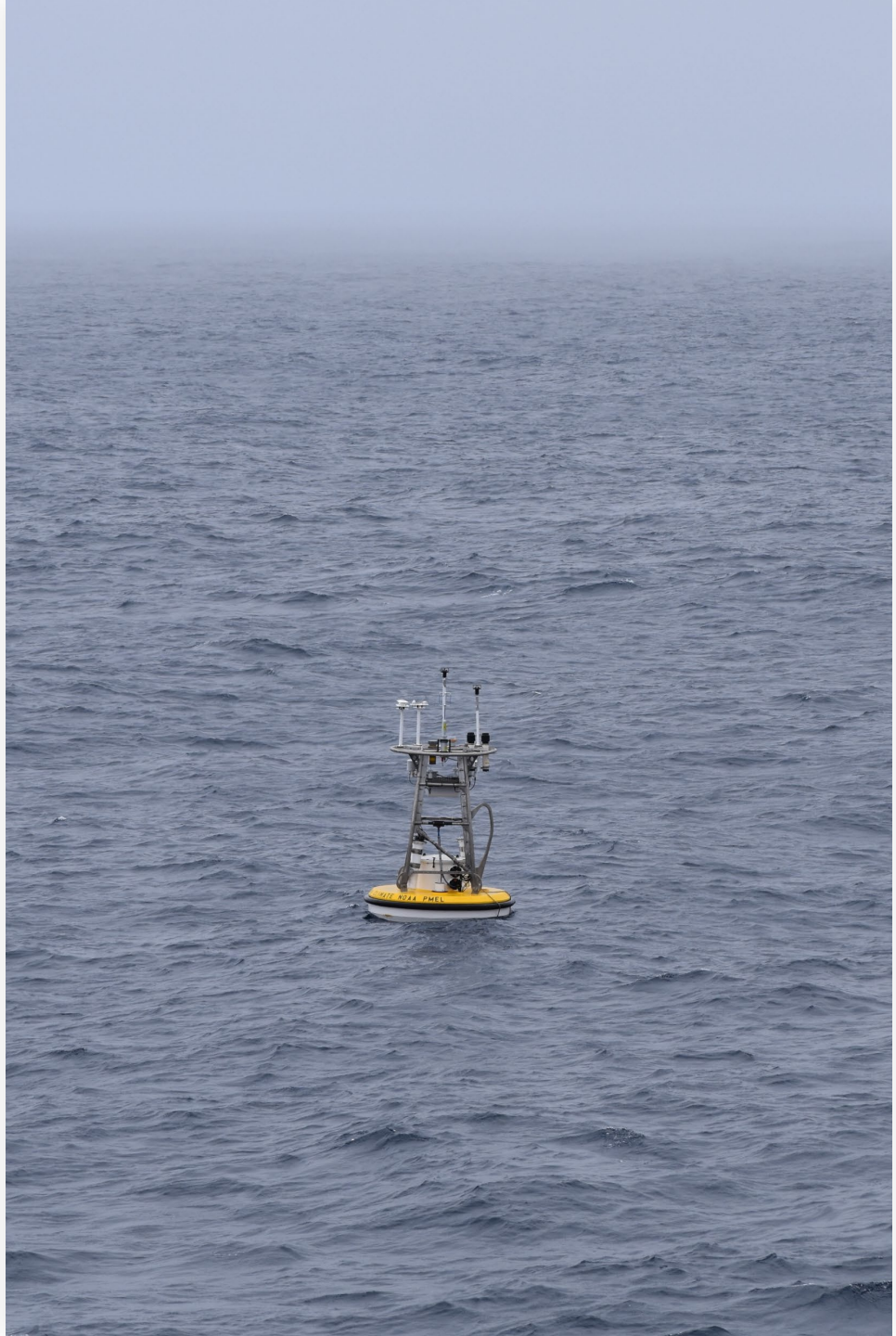
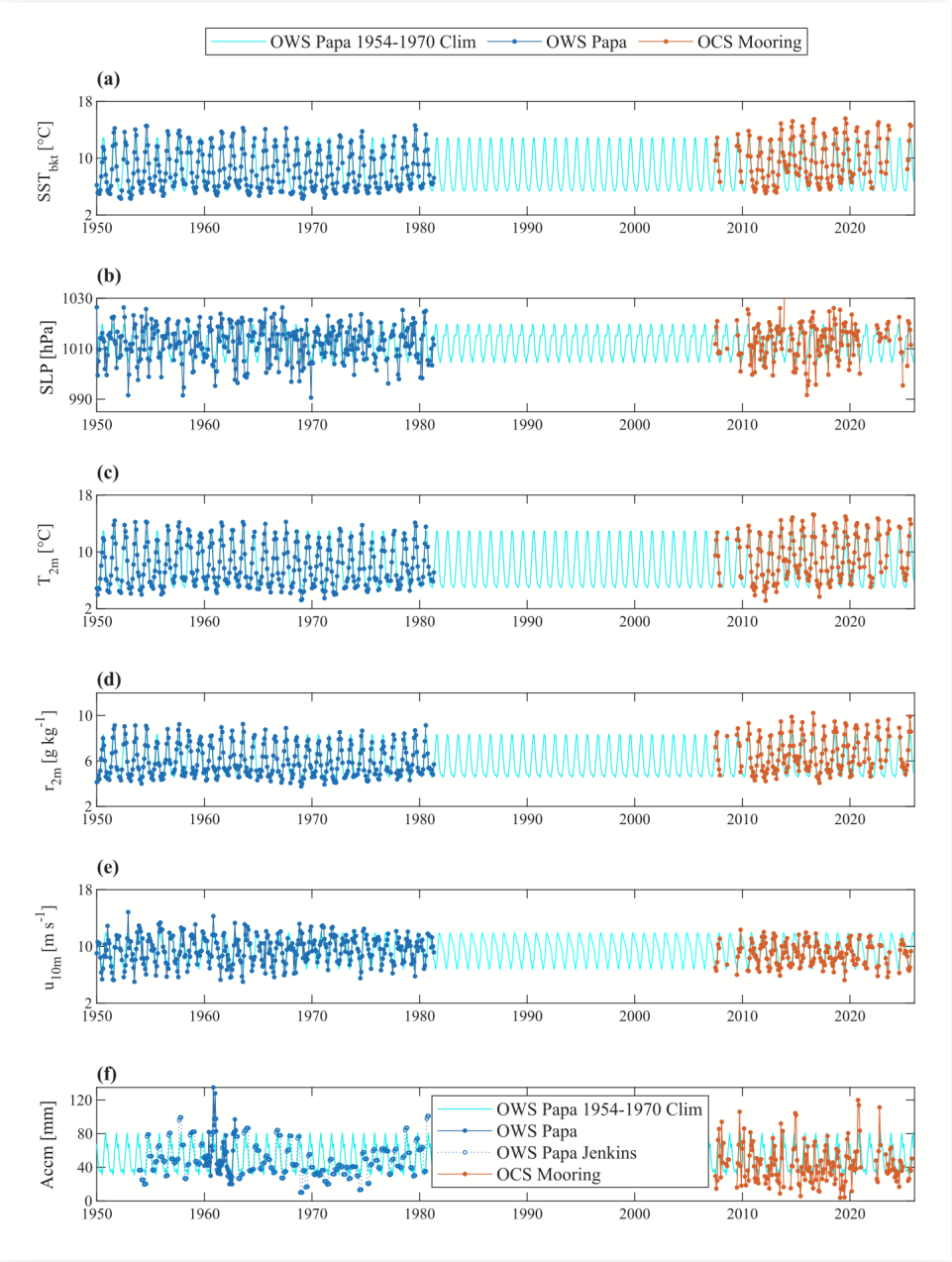
THE “FRESHER” GOT “DRIER” OVER 7 DECADES AT OCEAN STATION PAPA IN THE NORTHEAST PACIFIC

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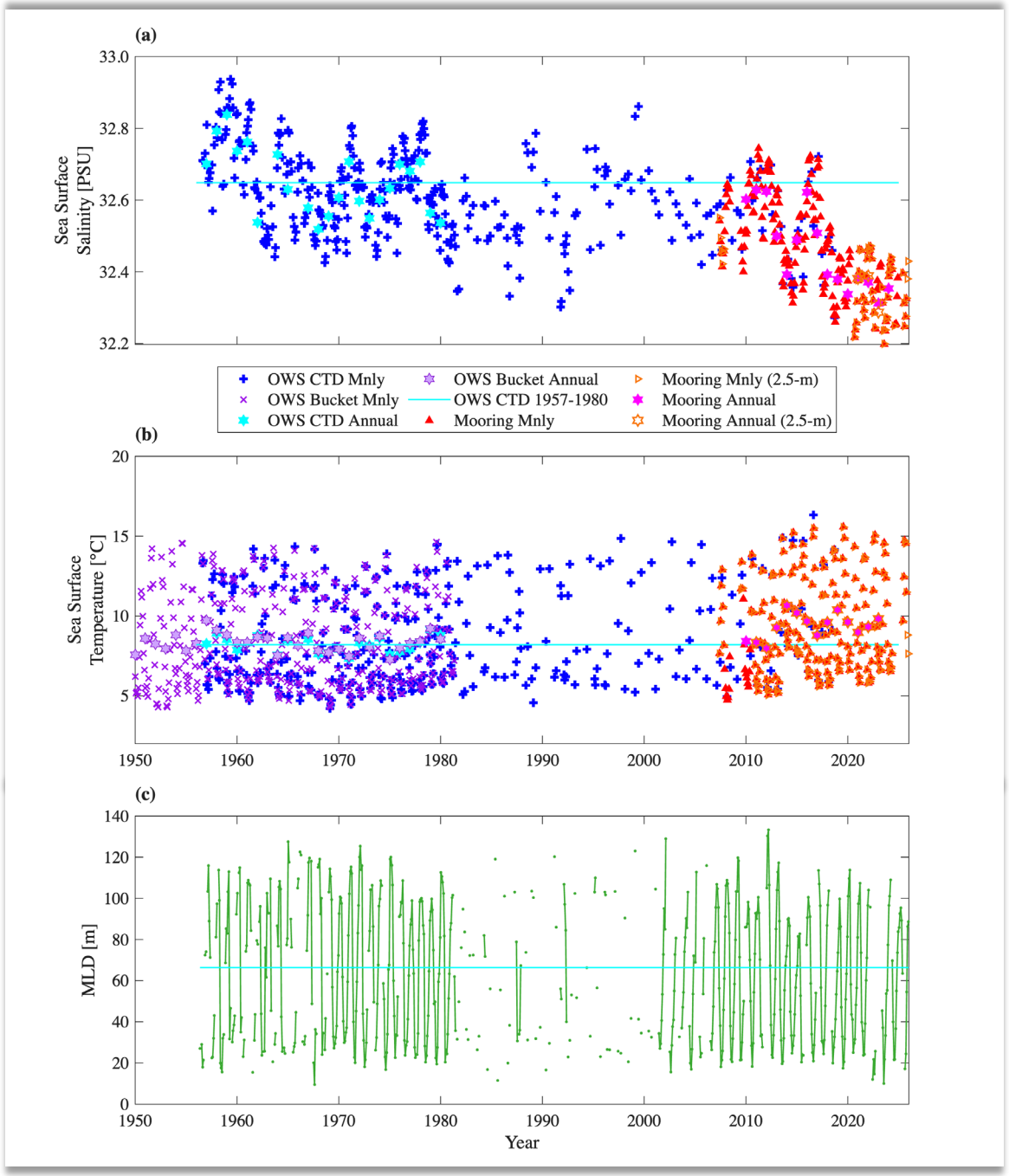
BACKGROUND ON STATION PAPA

- Ocean Weather Station (OWS) Papa at 50°N, 145°W was manned by Canadian ships from 1949-1981 with oceanographic Line P cruises continuing until the present day.
- NOAA Ocean Climate Stations (OCS) group installed a mooring at Station Papa in 2007, restarting the meteorological observations and collecting subsurface ocean profiles on a continuous basis through present day.



MOTIVATION

- OWS Papa observations show a decrease in sea surface salinity (SSS) and an increase in sea surface temperature (SST) through at least 2018 (Freeland et al. 1997; Whitney and Freeland 1999; Freeland 2013; Cummins and Ross 2020).
- Data since 2018 only confirms these trends.
- Mixed layer depth (MLD) changes at OWS Papa show no significant trends through 2018 (Cummins and Ross 2020), with updated analyses through 2025 giving similar results.
- Satellite record (since 2011 for SSS and 1981 for SST) is only just beginning to capture decadal trends and variability.

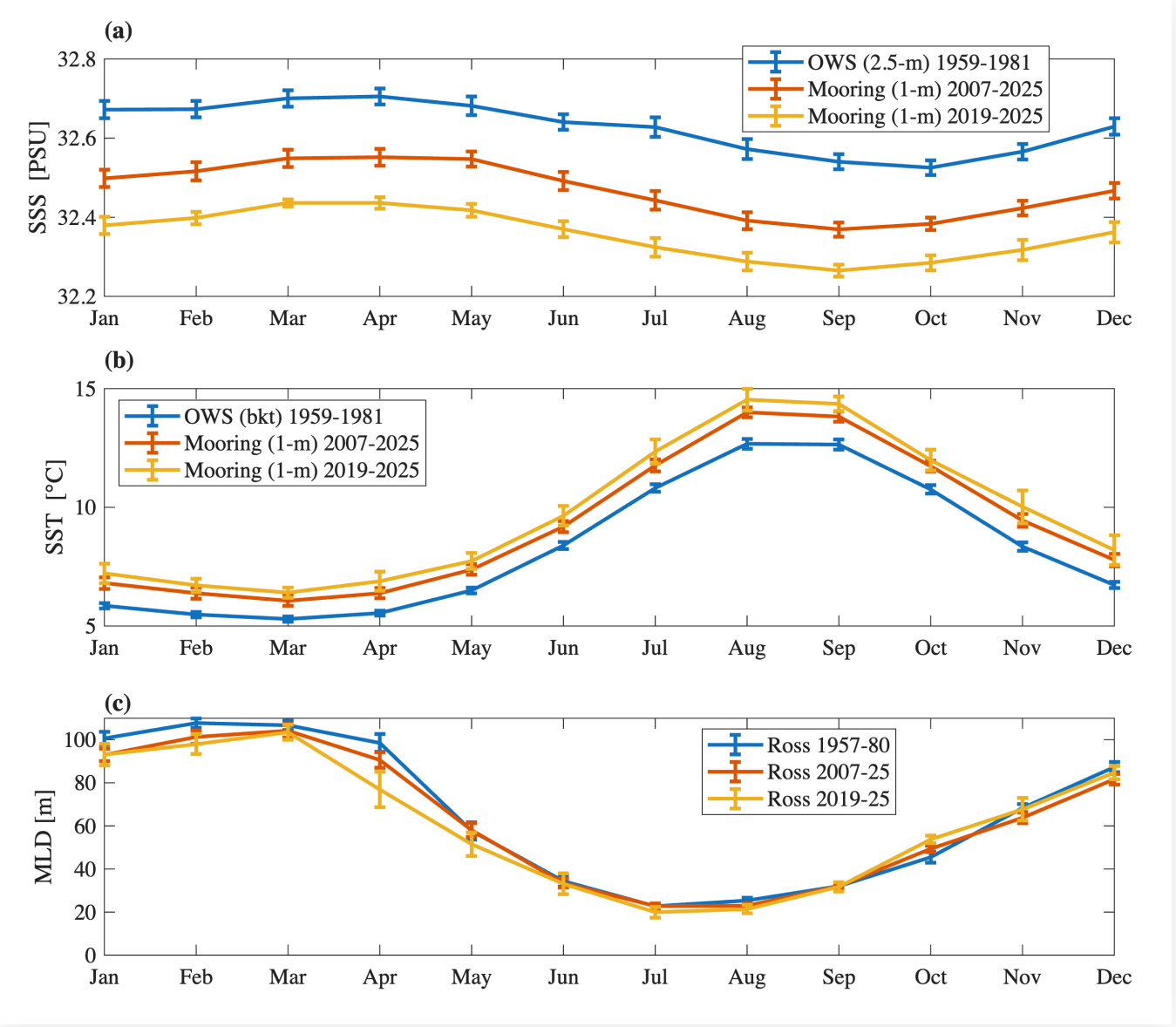


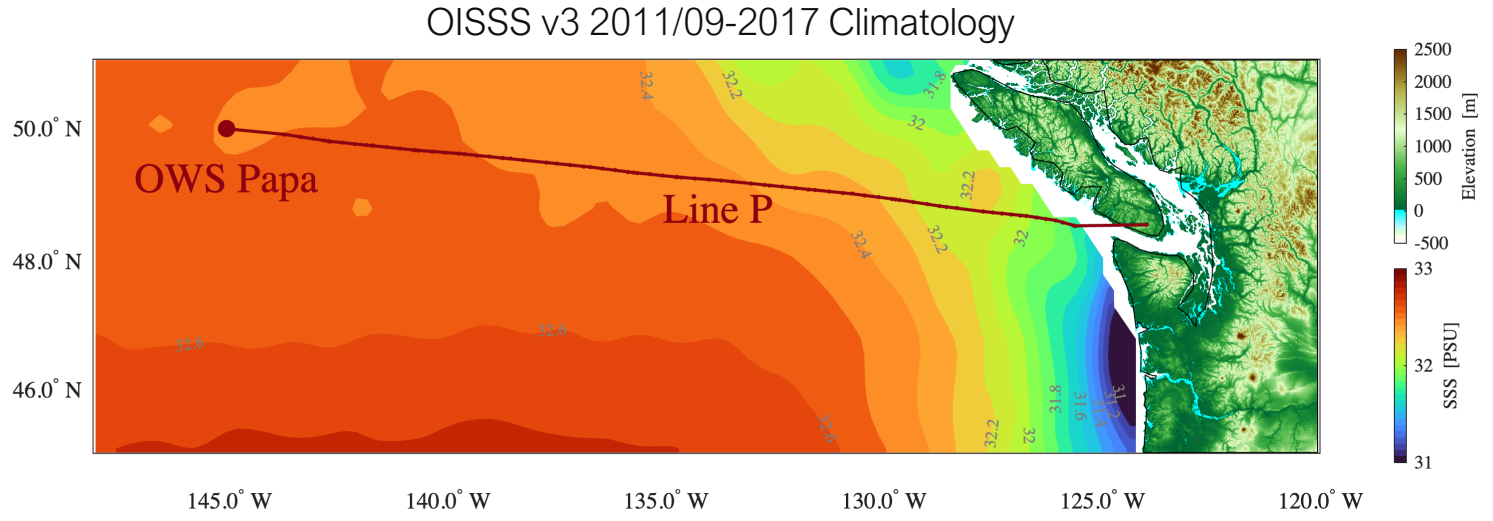
MOTIVATION

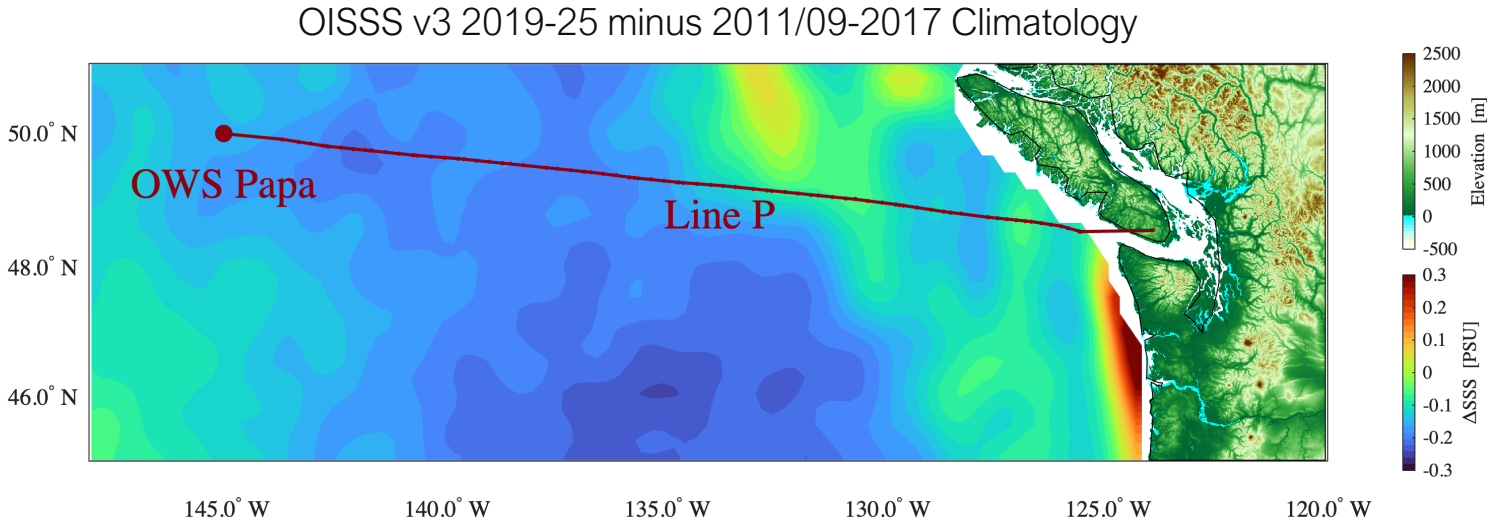
Because 2018 seems to be a critical turning point, we look at changes in SSS, SST and MLD since this time.

We also look at the seasonality of these variables to determine if changes are particular to certain months.

- Significant changes in SSS for all months are seen since 2018, even with respect to 2007-25. These changes are significant at the 95%/2-SDOM level.
- Changes in SST for 2019-25 are not significantly different from 2007-25 for any month, but warming in this period is consistent for all months.
- Significant (67%/1-SDOM) changes in MLD from the 1957-80 mean are seen in **April** for both 2007-25 and, with greater significance, 2019-25. In general, MLD is getting shallower in the winter months, but with less than a 67%/1-SDOM significance in these changes for all months but April.







QUESTION

Can changes in precipitation explain the decrease in SSS observed at Station Papa over the now 70-year record? Since 2018?

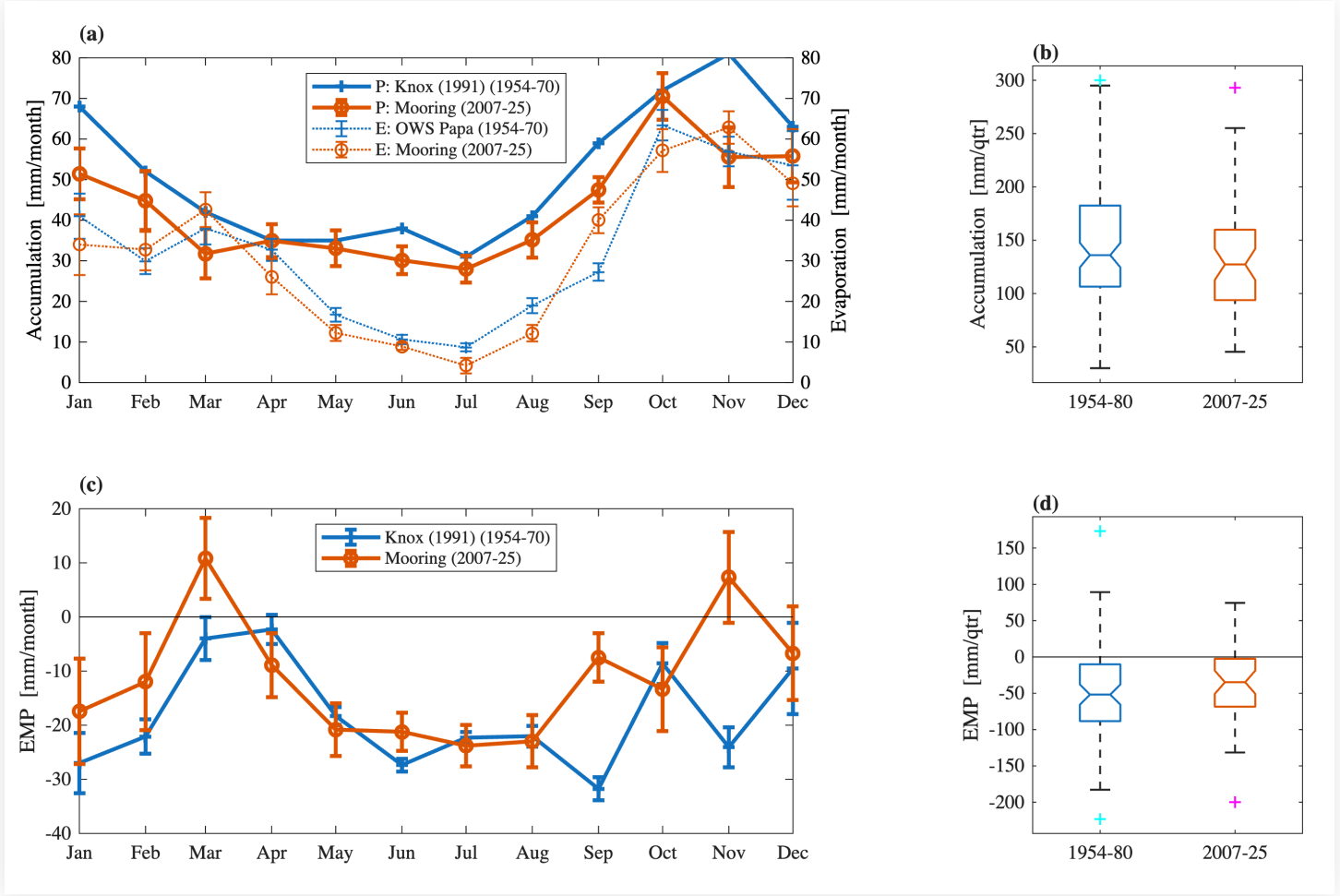
https://www.esr.org/data-products/oisss/data-access/

THE DATA

- ~1950 to 1981 surface meteorological data and bucket SST provided by the OWS ships that were regularly stationed at Station Papa. https://osdp-psdo.canada.ca/dp/en/search/metadata/NRCAN-FGP-1-561d3400-2e4c-4eb7-a042-f3135ab38224/print
- ~1950 to present oceanic profiles from ship CTD from Line P cruises within 1° of Station Papa. These profiles also provide 2.5-m SST. https://www.dfo-mpo.gc.ca/science/data-donnees/line-p/data-eng.html
- 2007 – present surface meteorological data and oceanic profiles provided by the NOAA OCS mooring at Station Papa, including 1-m SSS and SST, precipitation, and downwelling solar and longwave radiation. https://www.pmel.noaa.gov/ocs/data/disdel/
- 1959-1981 hourly solar radiation from OWS provided to the project by Fisheries and Oceans Canada (not currently publicly available). We additionally use monthly GEWEX net solar radiation available from 1983-07 to 2017-06. https://doi.org/10.5067/GEWEXSRB/REL4-IP_SHORTWAVE_MONTHLY_UTC_1
- Precipitation data from OWS ships are only available as a 1954-1970 monthly climatology from Knox (1991), 1954-1980 quarterly accumulations from Jenkins et al. (1994), and 1959-1981 annual accumulations (Bill Large, personal communication, 19 Novbember 2019). The 1960-1962 monthly accumulations were also provided by Bill Large (personal communication, 19 Novbember 2019).
- Surface evaporation, 10-m wind speed, 2-m air temperature and humidity estimated using the COARE bulk flux algorithm v3.6, Matlab version, (https://github.com/NOAA-PSL/COARE-algorithm) for both the historical and modern periods.
- Mixed layer depth (MLD) estimated by first combining OWS ship CTD and Argo floats within 1° of Station Papa to obtain a hybrid dataset of sigma profiles since 1956 (as in Cummings and Ross 2020). The MLD method has also been updated to combine these data with NOAA mooring data after 2007 for this study.

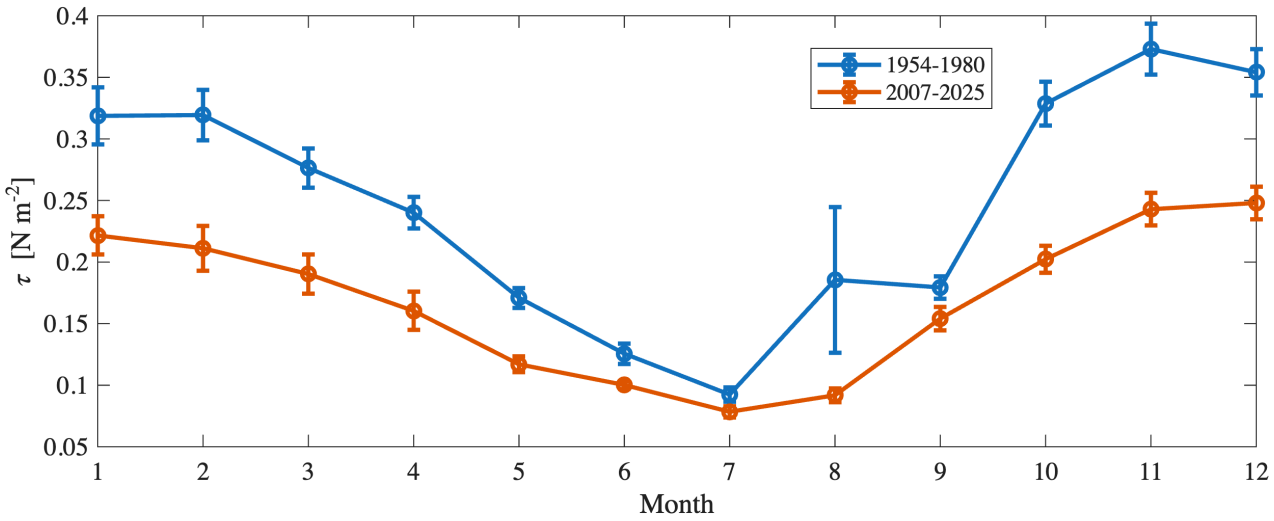
SEASONAL CYCLE IN PRECIPITATION AND EVAPORATION

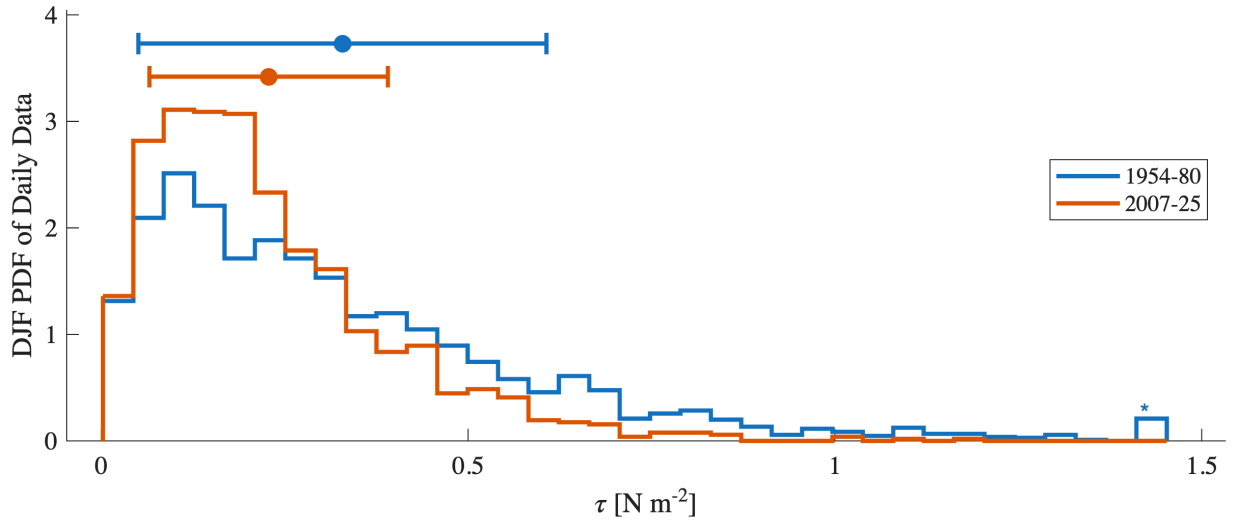
- We compare seasonal cycles from earlier decades (1954-70) based on Knox (1991) to later decades from OCS mooring (2007-25) using monthly rainfall accumulations, a quantity we think we know best.
- Significant decreases in precipitation appear throughout the year, with the largest decreases in winter, while changes in evaporation can be either positive or negative.
- Evaporation minus precipitation (EMP) becomes positive in March and November, something not seen for the earlier period, while EMP is overall less negative in winter and fall when the largest reduction in precipitation is seen.
- The decrease in precipitation and overall tendency towards less negative EMP suggests freshwater forcing cannot easily explain the freshening seen at Station Papa since the 1950-70s.



WIND STRESS

- We compare wind stress τ for the 1954-80 period to those of the 2007-25 period to understand if changes in atmospheric wind stress at the ocean surface may have resulted in less wind-driven mixing.
- Monthly wind stress is lower in the present decade than in the past, perhaps providing some clue as to the freshening at Station Papa.
- Daily wind stress also suggest high and median wind events may happen less frequently in the present decade during winter, although there is no significant difference in the median wind stress of the distribution at this sampling interval for December-January-February (DJF).



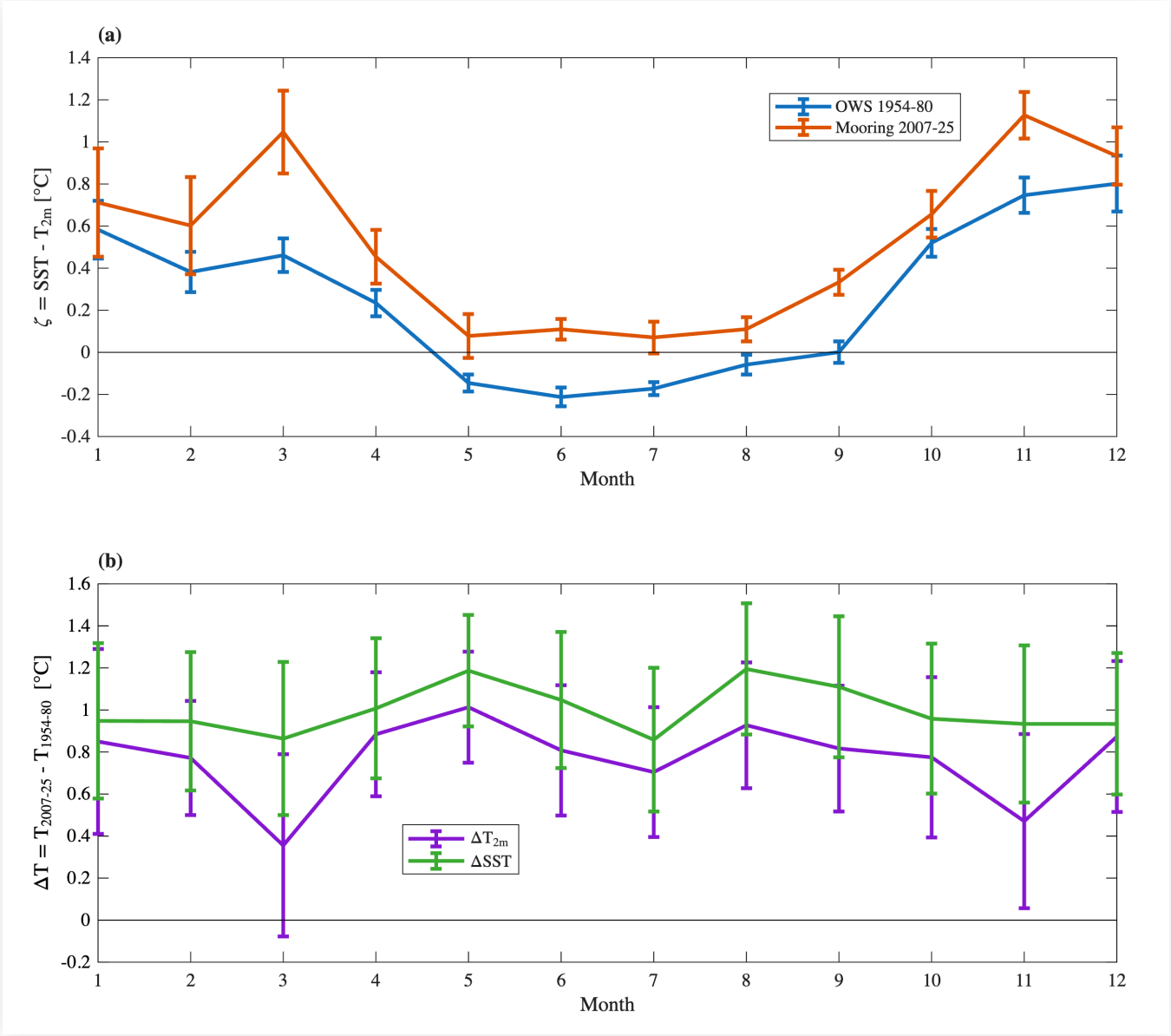


NEAR SURFACE STABILITY

The near surface stability ζ is estimated by the air-sea temperature difference at Station Papa,

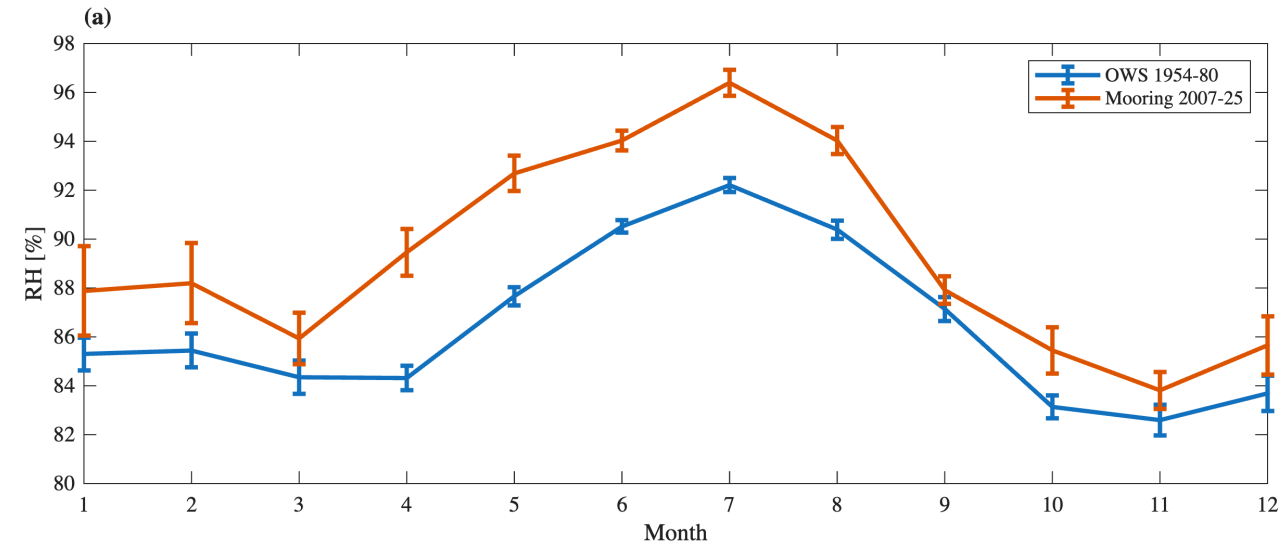
$$\zeta = SST - T_{2m}$$

- More unstable (ζ>0) conditions are seen throughout the year compared to the earlier period and previously stable summer conditions have become unstable.
- Decreased stability is a result of both warmer air and sea temperatures, with SST differences greater than T_{2m} differences for all months.



HUMIDITY AND SOLAR RADIATION

- Relative humidity increases in the lower atmospheric boundary layer as the boundary layer increases in temperature, with the largest increases seen in spring and summer months.
- Reduction in net surface solar radiation between the OCS mooring and OWS ship data is seen particularly in the spring (Apr-May) but also into the summer months (Jun-Jul), suggesting more reflective (typically lower) clouds than in the past.
- GEWEX data also indicate a reduction in net solar radiation between 1983-95 and 2007-17 in May, when differences between OWS ships and OCS mooring are largest. GEWEX data also match the mooring data later in the summer indicating lower insulation values than in the earlier decades at Papa.

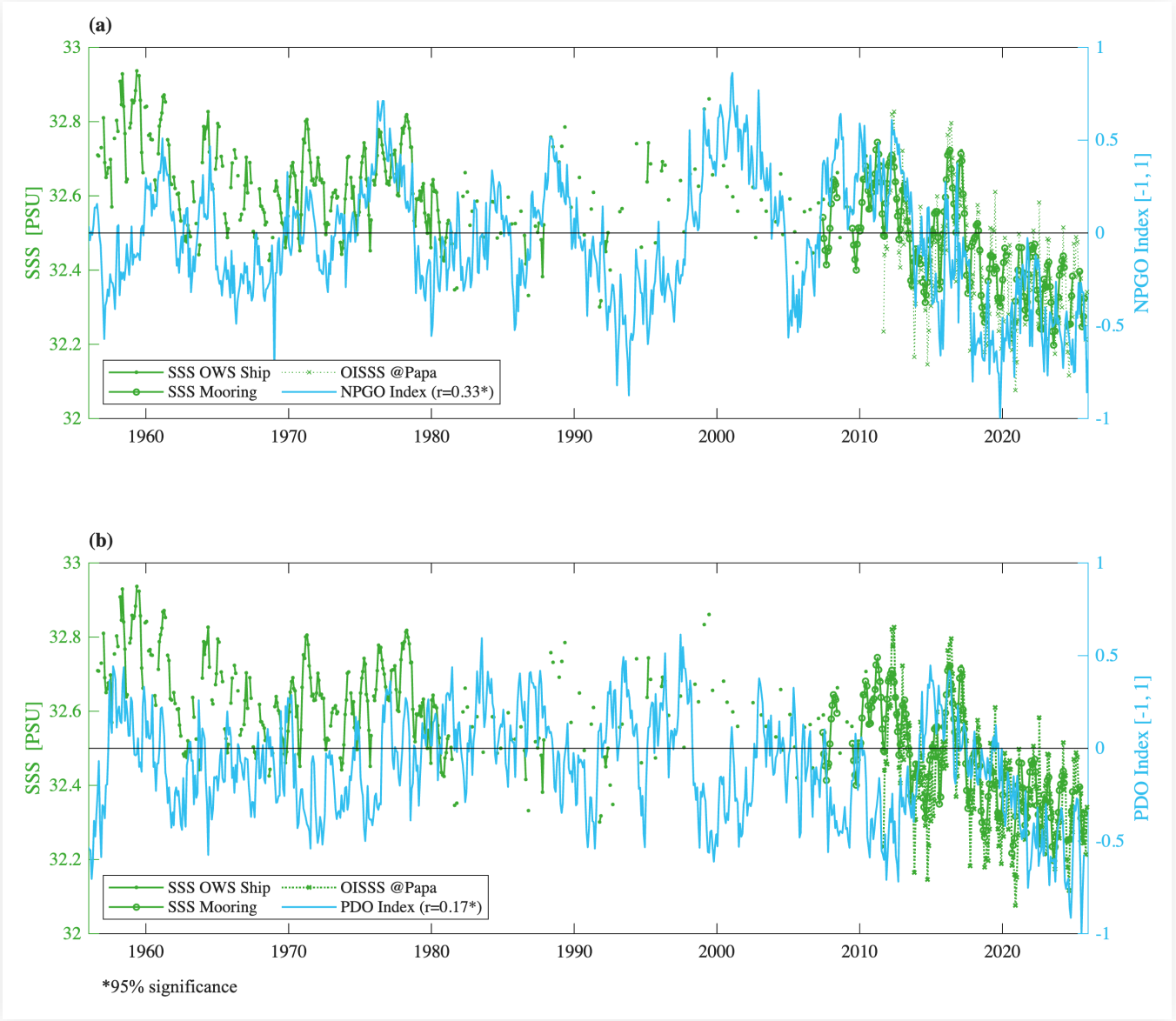


SUMMARY OF WEATHER CHANGES AT STATION PAPA

- **Summertime low clouds:** Warmer atmospheric mixed layer and higher mixed layer relative humidity are consistent with more low cloud formation. This effect will be most pronounced in summer when temperatures are already close to the dewpoint. The change from stable to near neutral conditions in the summer months in the atmospheric mixed layer would also favor low cloud formation. This hypothesis might explain the decrease in summer solar radiation at Station Papa.
- **Reduced wintertime precipitation:** Weaker wind stress in the winter months is consistent with the reductions in winter precipitation, providing some confidence in the precipitation changes found here, despite missing the original hourly precipitation dataset from OWS Papa ships.
- **SSS and SST changes:** Analysis of the Station Papa surface meteorology, fluxes, radiation, and precipitation data does not provide a local explanation for the changes in SSS and SST since the 1954-80 period. MLD changes, while shallower and thus maybe consistent with freshening even if there is less precipitation, are not significant and require a full budget analysis to confirm their impact.

LARGE-SCALE MODES IMPACTING STATION PAPA

- The Pacific Decadal Oscillation (PDO, Manua et al. 1997) and North Pacific Gyre Oscillation (NPGO, Di Lorenzo et al. 2008) are the 1st and 2nd EOF modes of Northeast Pacific SST and sea-surface height (SSH) anomalies over the region 180°W – 110°W, 25°N – 62°N (Di Lorenzo et al. 2008). Both impact upwelling through impacts on surface wind stress.
- The NPGO is well correlated (r=0.33) with SSS at Station Papa. We hypothesize this mode is likely involved in the SSS and SST decadal changes we see, particularly since 2018.
- The PDO is also well correlated (r=0.17) with SSS at Station Papa and may also be involved with the SSS and SST changes seen there.



WHAT NEXT?

- A mixed layer budget analysis is needed to fully understand how local changes in the atmospheric surface forcing, including changes to the fresh-water fluxes and possible changes in ocean MLD, may be impacting the surface salinity and temperature changes at Station Papa.
- Analysis of basin-wide changes resulting from the NPGO and PDO are also needed to understand the larger scale ocean's role in the surface salinity and temperature at Station Papa.