A comparative study of the atmospheric water cycling between the Atacama and Namib desert: Is the increase of stratocumulus clouds cooling the Southeast Pacific in recent decades?

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Earth – Evolution at the dry limit

1 How does global warming effect the moisture supply to the driest (Atacama) and the oldest (Namib) desert?

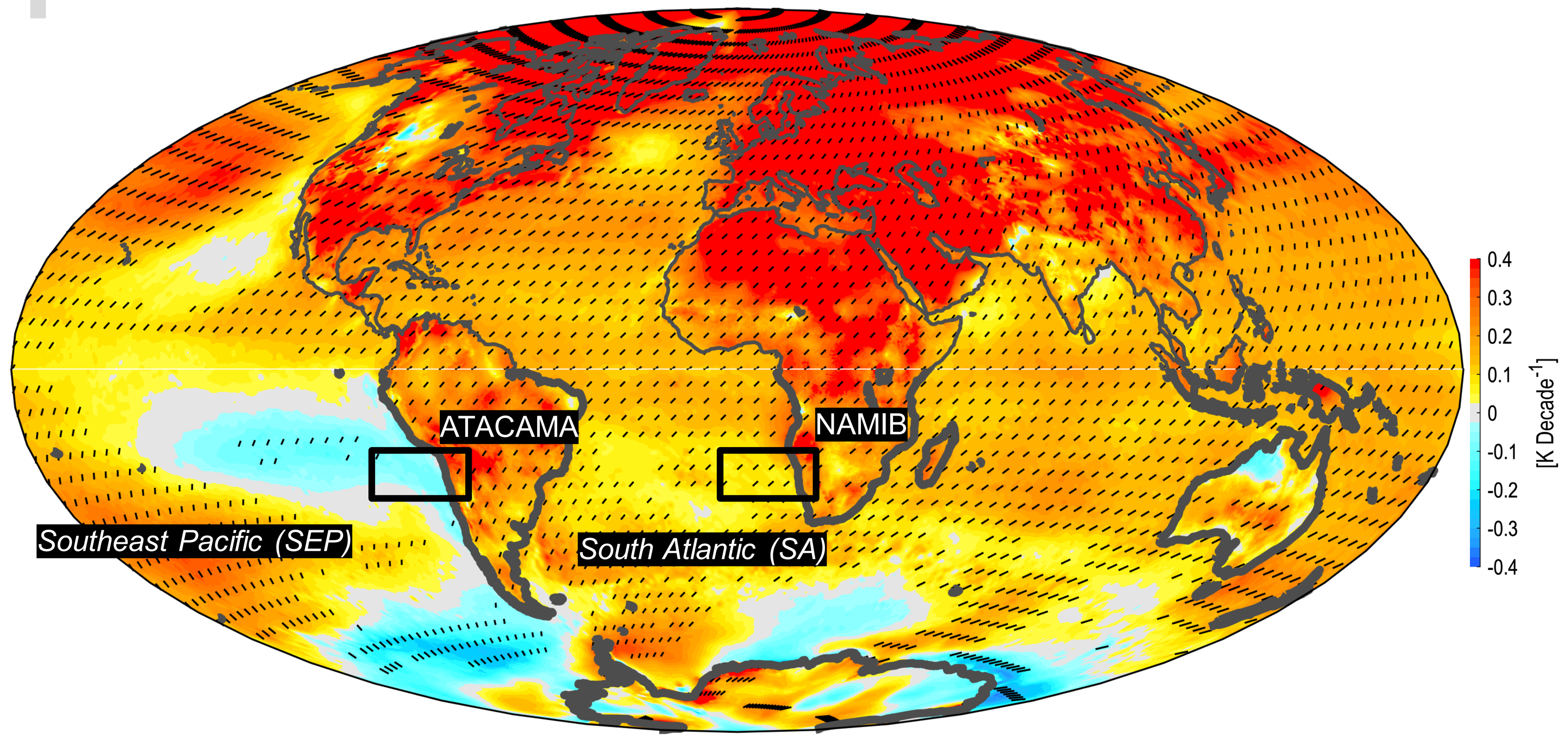

Fig. 1. Linear trend (1979—2023) of the annual mean of 2 m air temperature from ERA5. The dots indicate statistical significance at 95%. Data from ERA5.

- The presence of water in all its phases is crucial for life and landscape evolution in deserts
- Advection of the subtropical stratocumulus (fog) is a major moisture source for vegetation
- **In a warming World, the Southeast Pacific is the only subtropical ocean cooling**
- What is the role of water cycle components in the temperature decline?

2 Differences in clouds and moisture transport between the Atacama and the Namib derived from ERA5 (*Vicencio et al. 2024*)

- Namib has higher column water vapor but the Atacama has moister marine boundary layer
- In Atacama, the Andes blocks any moisture/air mass exchange with the continent
- Marine boundary layer is frequently perturbed by continental air mass in the Namib
- More prominent cloud feature offshore Atacama compared to the Namib year round.

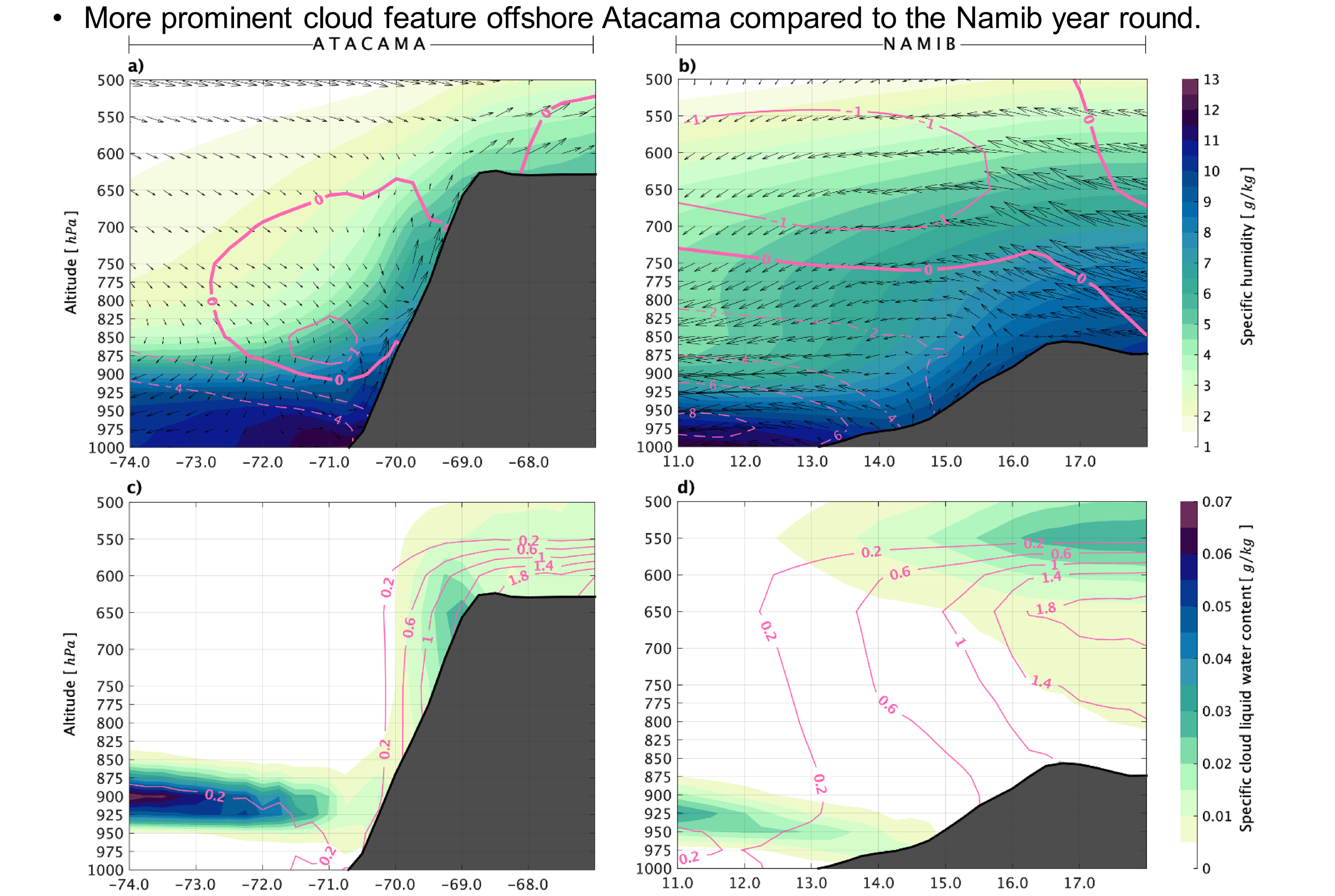

Fig. 2. Austral summer (DJF, 1981—2020) longitude-height cross-sections between 18 and 28ºS from ERA5. Upper panels (a,b), specific humidity (shaded colors), meridional wind (pink contours, every 1 m/s for negative values and every 2 m/s for positive values) and zonal-vertical winds (arrows, in m/s). Bottom panels (c,d), specific cloud liquid water content (shaded colors) and specific rain water content (pink contours, in 10^6 kg/kg)-

3 SST, water vapor, and stratocumulus clouds coupling

- Offshore Atacama boundary layer water vapor W_{BL} is strongly coupled to SST
- For Namib.dry-warm air mass intrusions from the continent disturb coupling
- Stratocumulus (low cloud cover, i.e., LCC) can occur in a wide range of SSTs.
- In a well coupled region (Atacama) the SST seasonality is in phase with the LCC.
- In a less coupled region (Namib) the SST and LCC are partially out of phase.

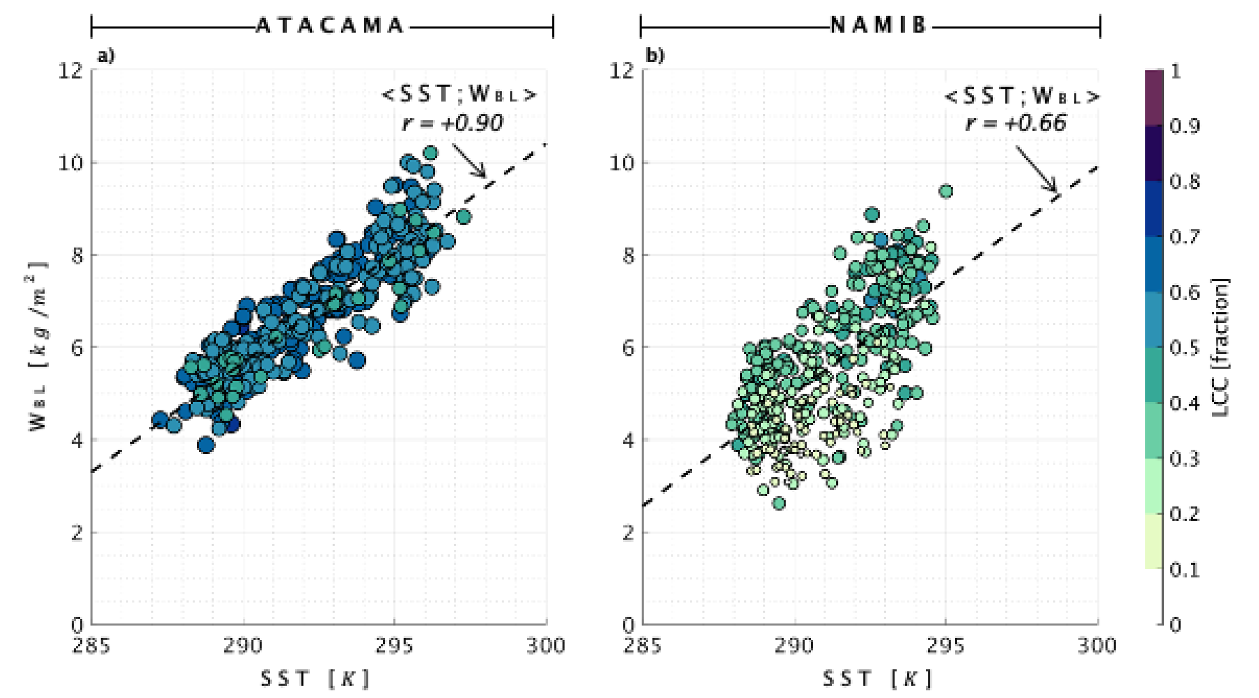

Fig. 3. Scatter plot of monthly means (upper panels) of SST-W_{BL} pairs for the Atacama Oceanic Region (left panels) and the Namib Oceanic Region (right panels) for the period between 1988 and 2020 (396 concurrent values for each subregion). The colour of the filled circle, as well as the size of the marker, represents the LCC. The dashed black and red line denotes the best ordinary linear fit. The asterisk (*) indicates statistical significance at 95%. Data from ERA5. *Vicencio et al. (2024)*

4 Stratocumulus clouds trend

- Cloud cover fraction for low-level clouds (CFC_{Low}) trend is 2-8% decade^{-1} over the SEP derived from CLARA-A3; stronger in winter-spring (up to 10% decade^{-1}).
- Stratocumulus region covering CFC >50% is expanding in all directions.
- Trend is also positive over the SA, although weaker than the SEP.
- Moderate-good agreement in trends between CLARA-A3 and ERA5 for both regions

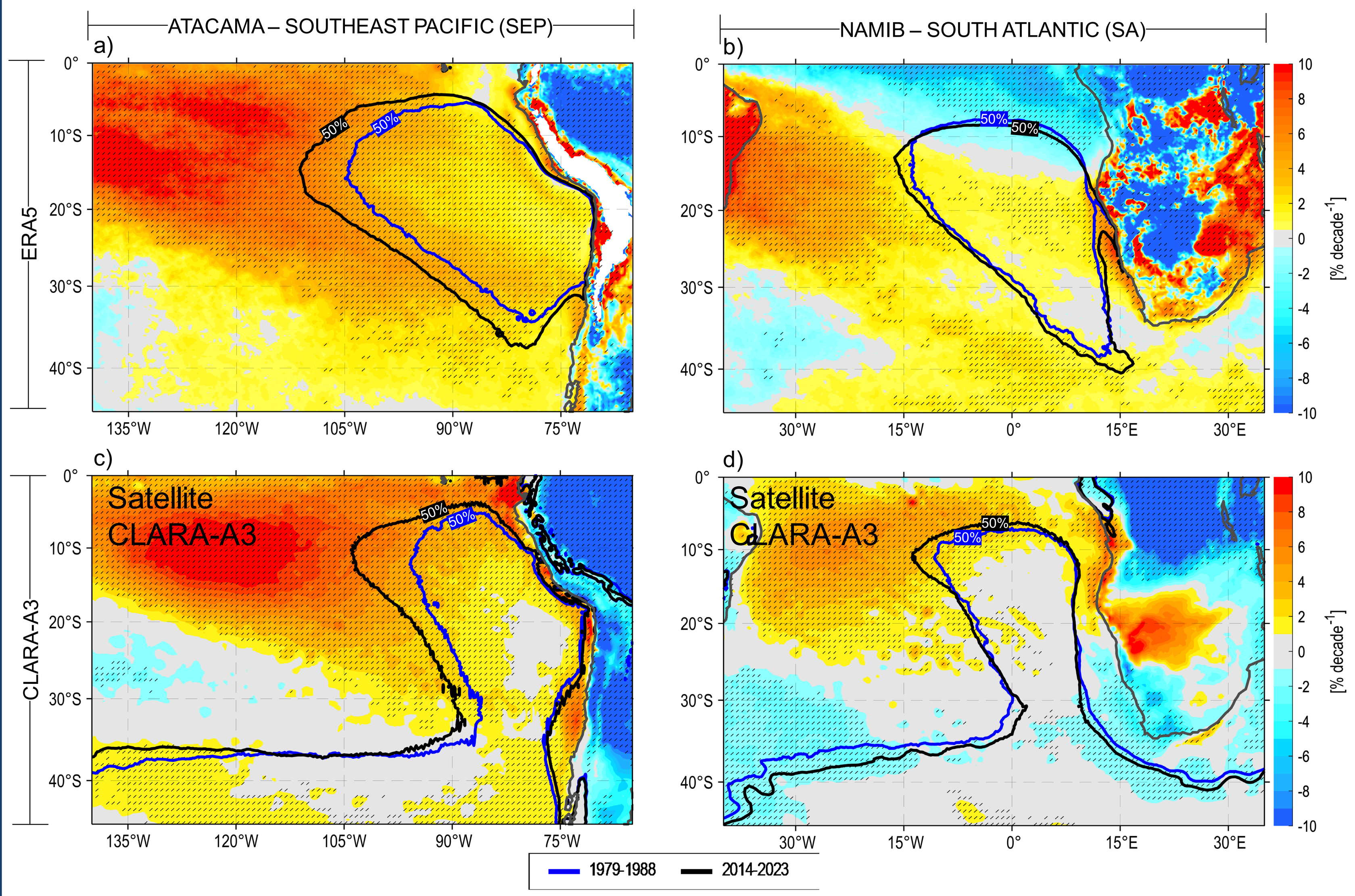

Fig. 4. Annual mean trend (1979—2023) for the CFC_{LOW} derived from CLARA-A3 (upper panels) and ERA5 (bottom panels) for the Atacama (left panels) and the Namib (right panels). Areas with black stripes indicate statistical significance of 95% of confidence level. Short-term climatology is shown in blue (1979—1988) and black (2014—2023) contours. Data from ERA5.

5 Changes in the stratocumulus drivers and circulation

- Increase in low clouds is linked to the warming of the free troposphere
- Surface subtropical anticyclones are widening and strengthening → enhancement of surface southeasterly winds
- We suspect in the Namib, enhanced easterly winds bring warmer continental air over the ocean, increasing the temperature of the stratocumulus region.
- Andes cordillera blocks potential temperature advection from South America to the ocean.

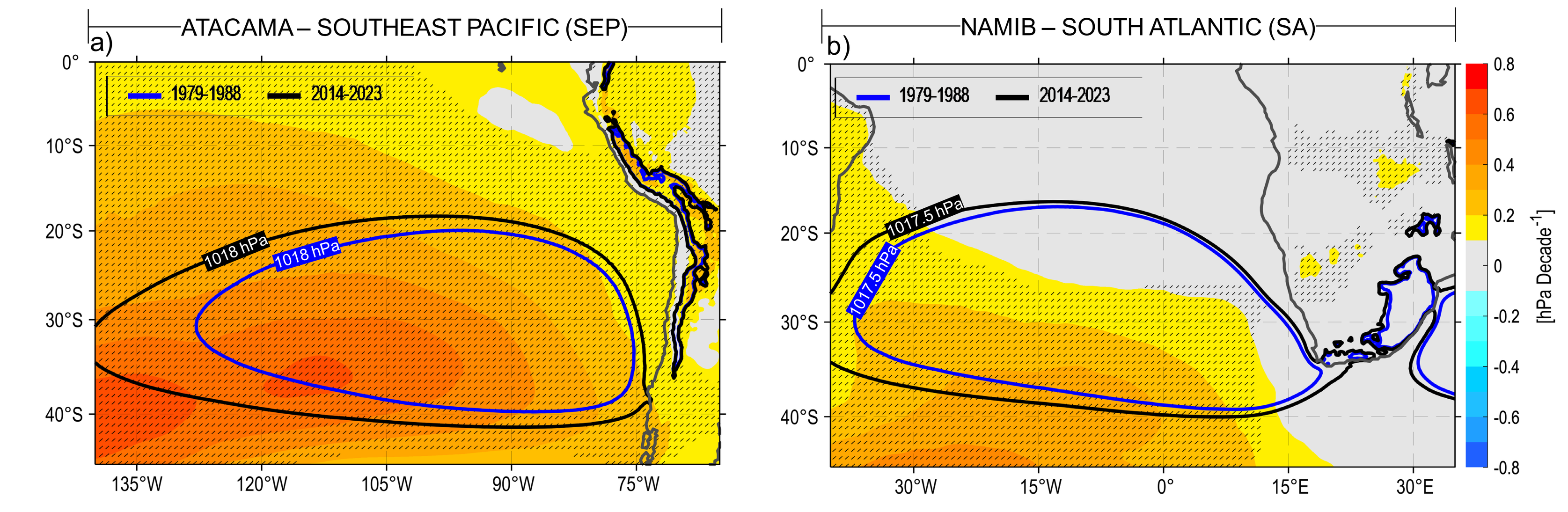

Fig. 5. Sea level pressure annual mean trend (1979—2023) for the Atacama (left panels) and the Namib (right panels. Areas with black stripes indicate statistical significance of 95% of confidence level. Short-term climatology is shown in blue (1979—1988) and black (2014—2023) contours.

6 Moisture trends in the Atacama desert

- Changes in circulation are impacting the moisture transport and rainfall in Atacama in summer (*Vicencio et al. In review*)
- Extreme total column water vapor (TCWV) was observed 2019 related to strong rainfall
- Moist Northerlies (MN): moisture is transported from the tropical Pacific towards the Atacama in the lower free-troposphere leads to increasing TCWV (Fig. 6b).
- MN explain 75% of rainfall days in Atacama between 1960—2020
- Hadley cell expansion weakens the westerlies over the subtropics → enhancement of the Bolivian High (250 hPa) and the low-pressure system (850 hPa) offshore Atacama.
- Increased moisture transport leads to changes in the distribution of TCWV (Fig. 6c).

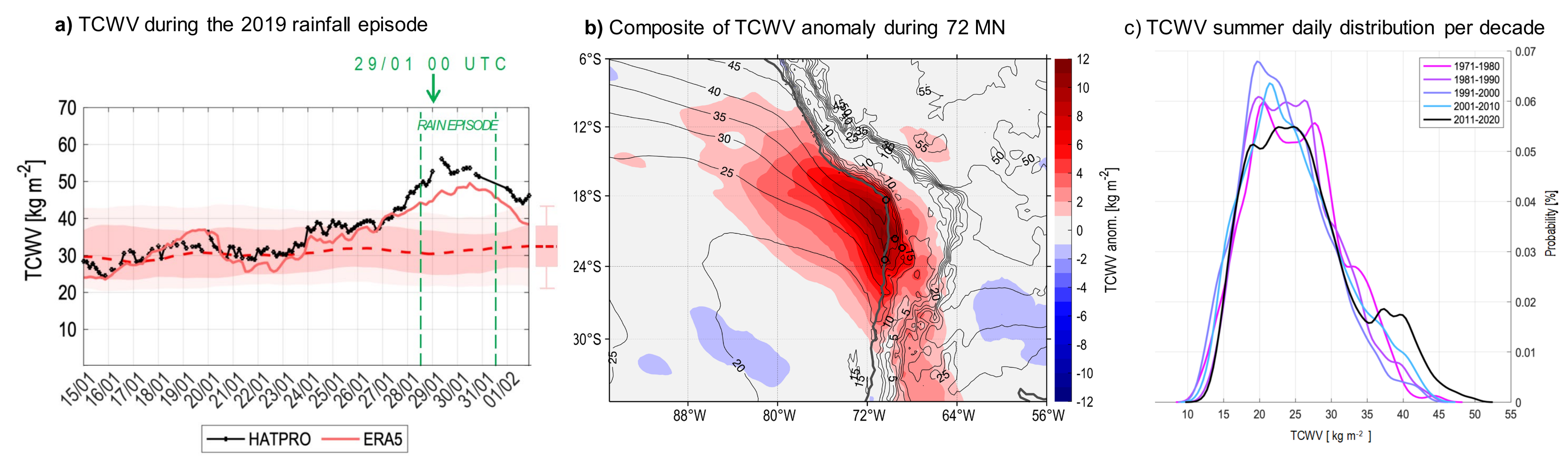

Fig. 6. (a) Three-hourly time series of TCWV retrieved from HATPRO (black line) at Iquique Airport and for ERA5 (red line) for the average of the four nearest grid points to Iquique. ERA5 climatological (1991–2020) information is provided as a boxplot for the interquartile range, and the upper/bottom whiskers are the 10th/90th percentile, respectively. (b) Composite of the mean anomaly of the TCWV for 72 MN identified between 1960—2020. (c) Probability density of daily means of summer TCWV offshore Atacama for different decades (colored lines) from ERA5

7 Outlook

- Investigate role of subtropical anticyclone in past and future changes in stratocumulus cover
- Disentangle the driving factors in the energy and water cycle of the region, e.g. temperature and moisture advection and local changes
- Analyze why global climate projections (e.g. CMIP5) fail to reproduce the cooling of the SEP.

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