

40 anni di osservazioni: l'andamento delle temperature nelle serie di lungo periodo

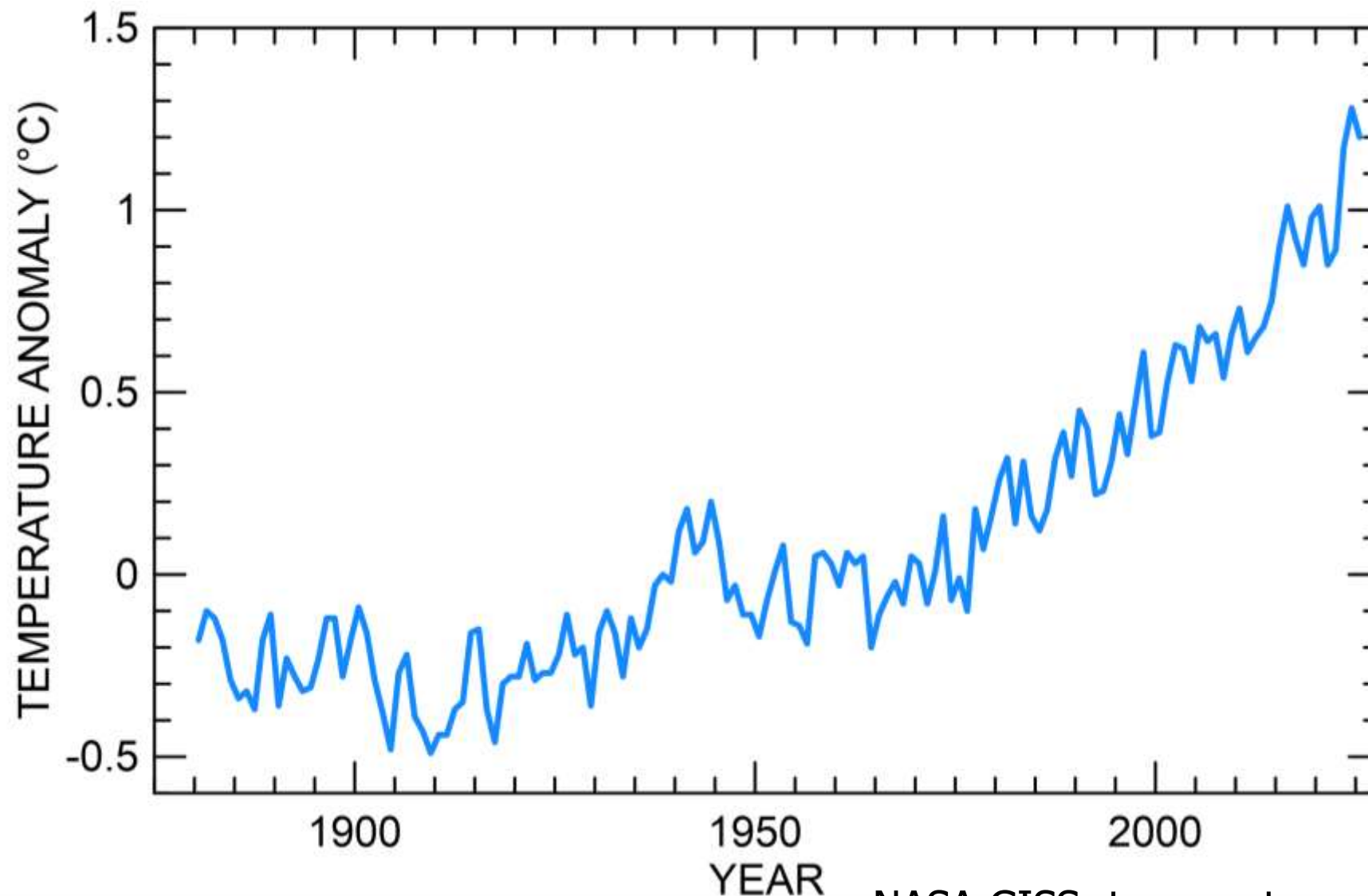
***40 anni di osservazioni in un clima
che cambia***

Virginia Ciardini, ENEA - Laboratorio Modelli e Misure per la Qualità
dell'Aria ed Osservazioni Climatiche



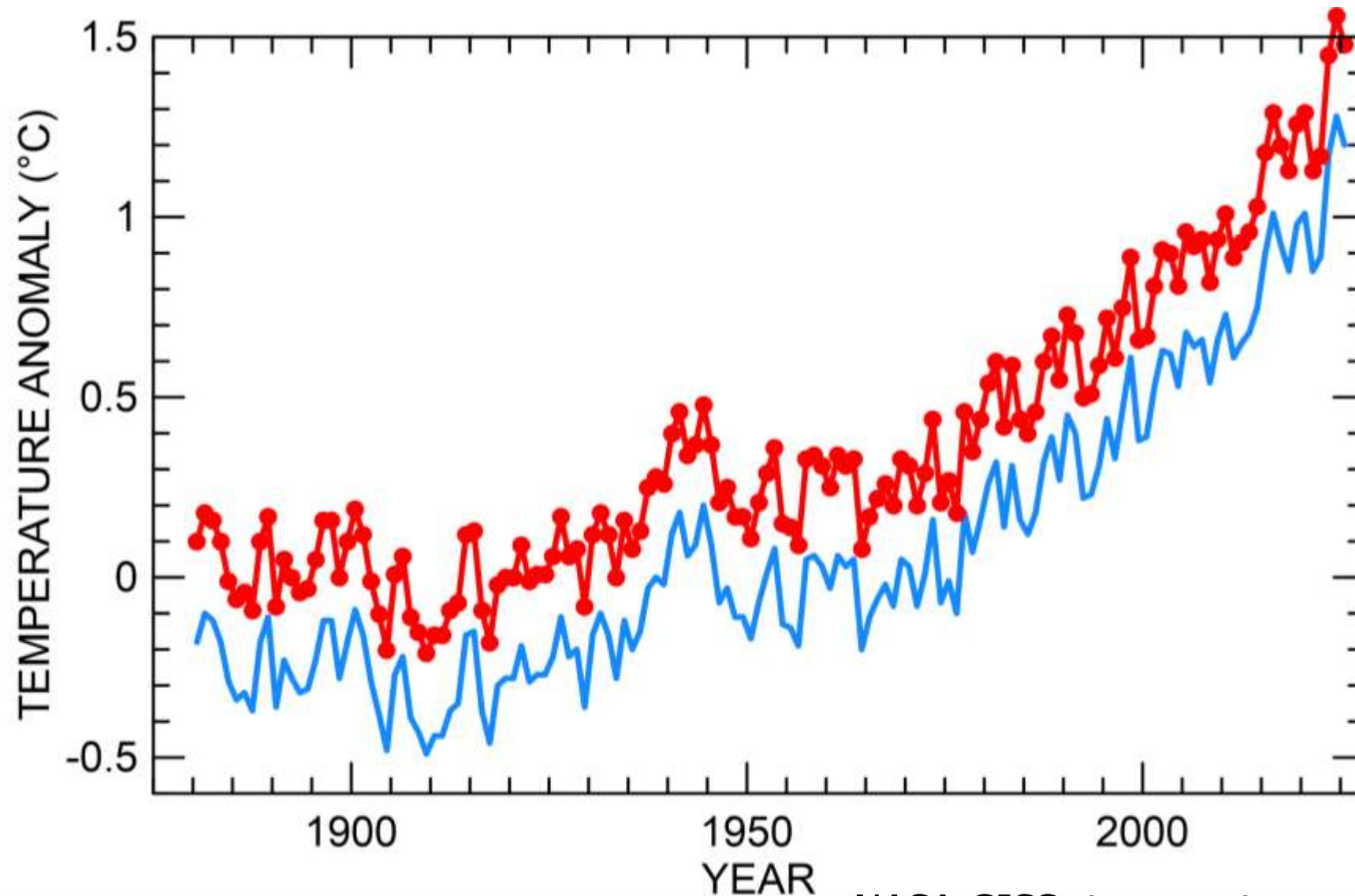
Cambiamenti in atto

Periodo di riferimento: 1901-2000

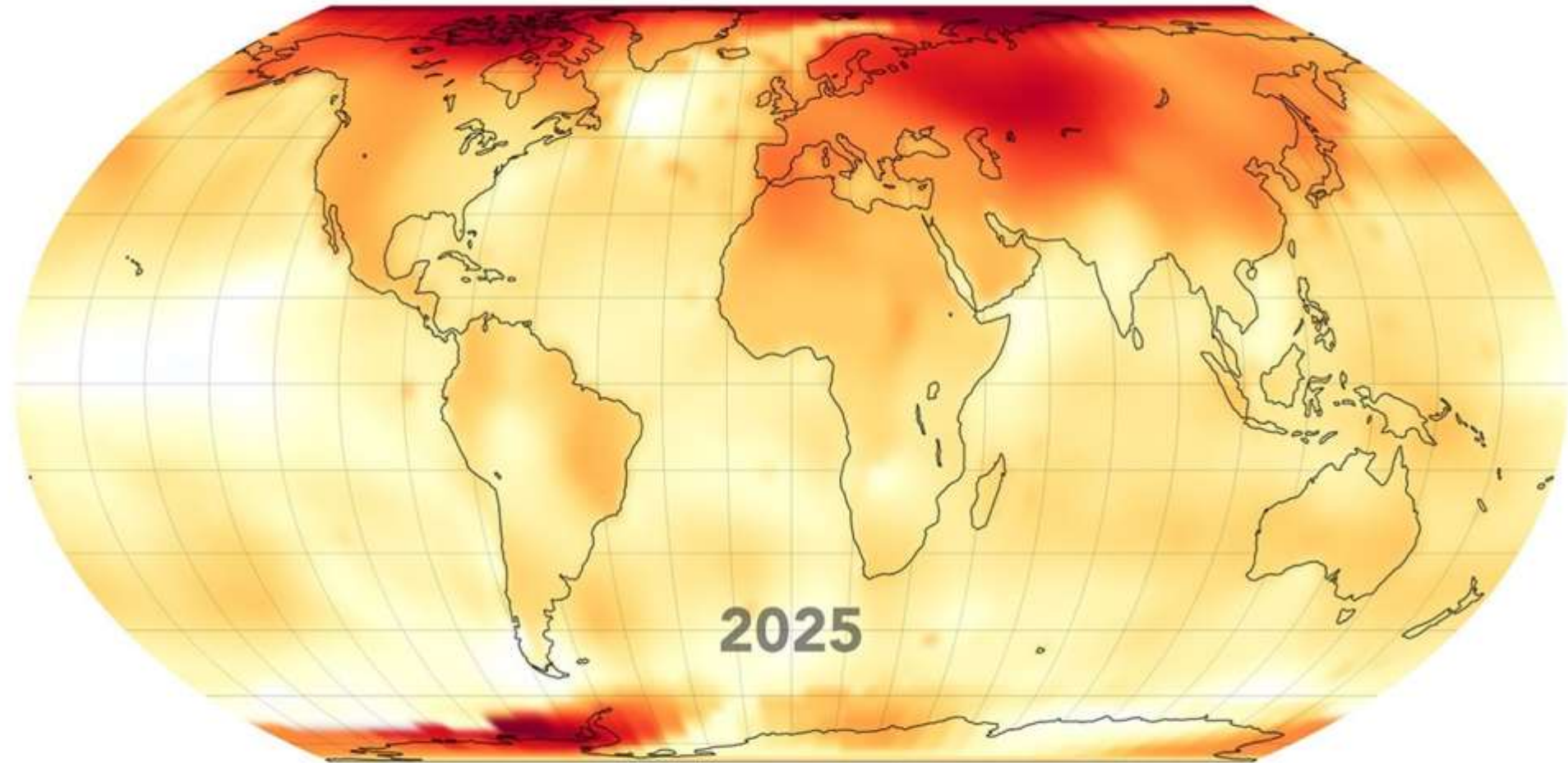


Cambiamenti in atto

Periodo di riferimento: 1880-1920

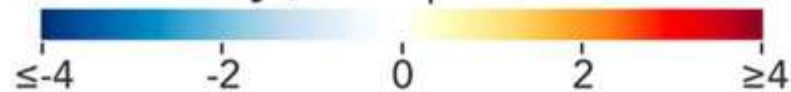


L'Artide così come in alcune regini dell'Antartide la temperatura è aumenta di più rispetto alla media globale.
In Artide, il tasso di riscaldamento osservato durante le ultime due decadi è circa 2-3 VOLTE superiore a quanto si osserva a scala globale.

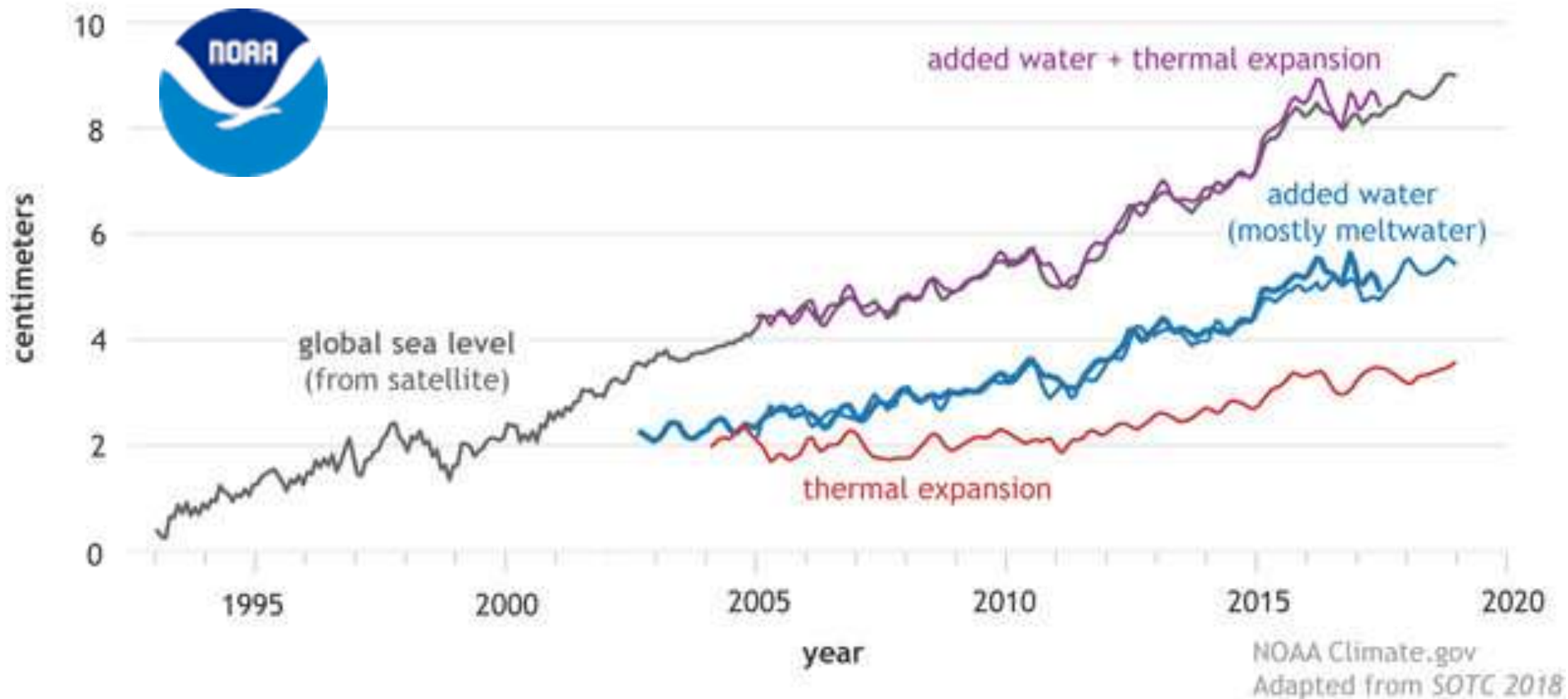


NASA GISS

Temperature Anomaly (°C compared to 1951-1980 average)



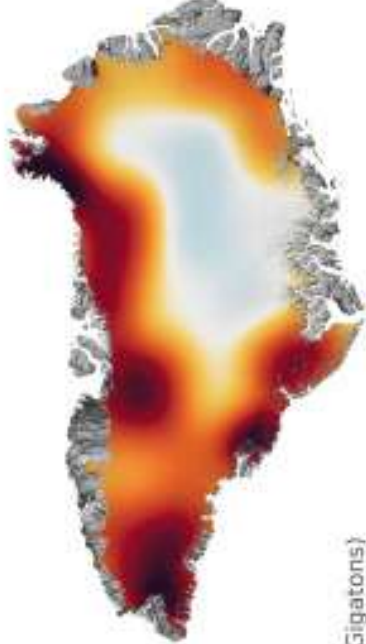
Contributors to global sea level rise (1993-2018)



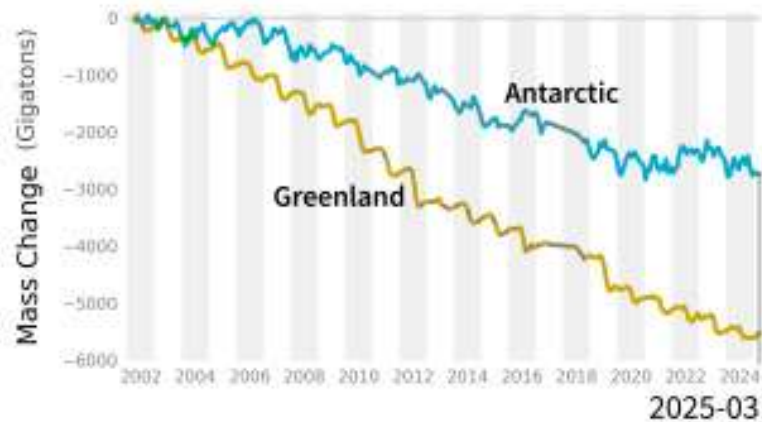
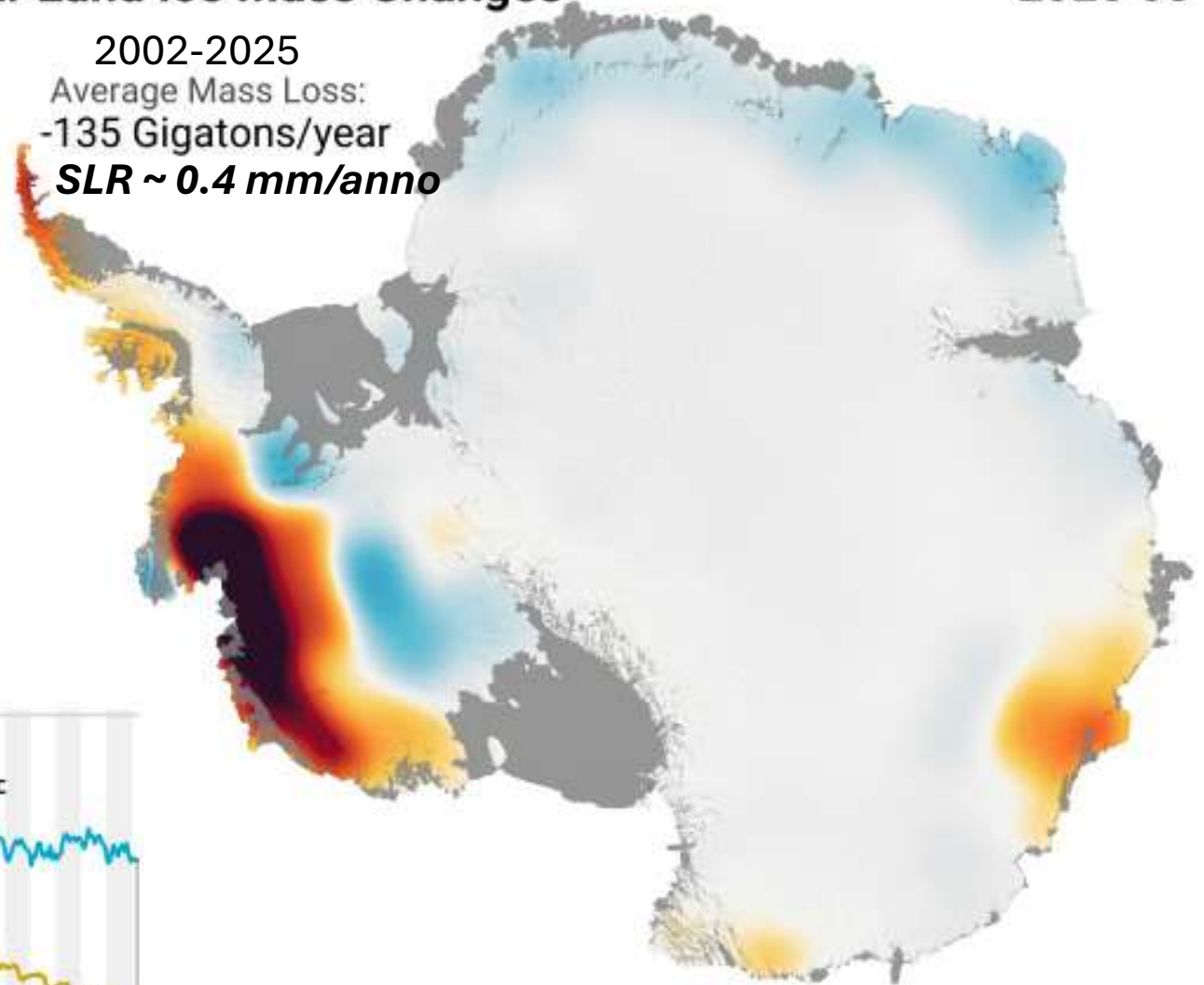
GRACE AND GRACE-FO Observations of Polar Land Ice Mass Changes

2025-03

Average Mass Loss:
-264 Gigatons/year
SLR ~ 0.8 mm/anno



2002-2025
Average Mass Loss:
-135 Gigatons/year
SLR ~ 0.4 mm/anno



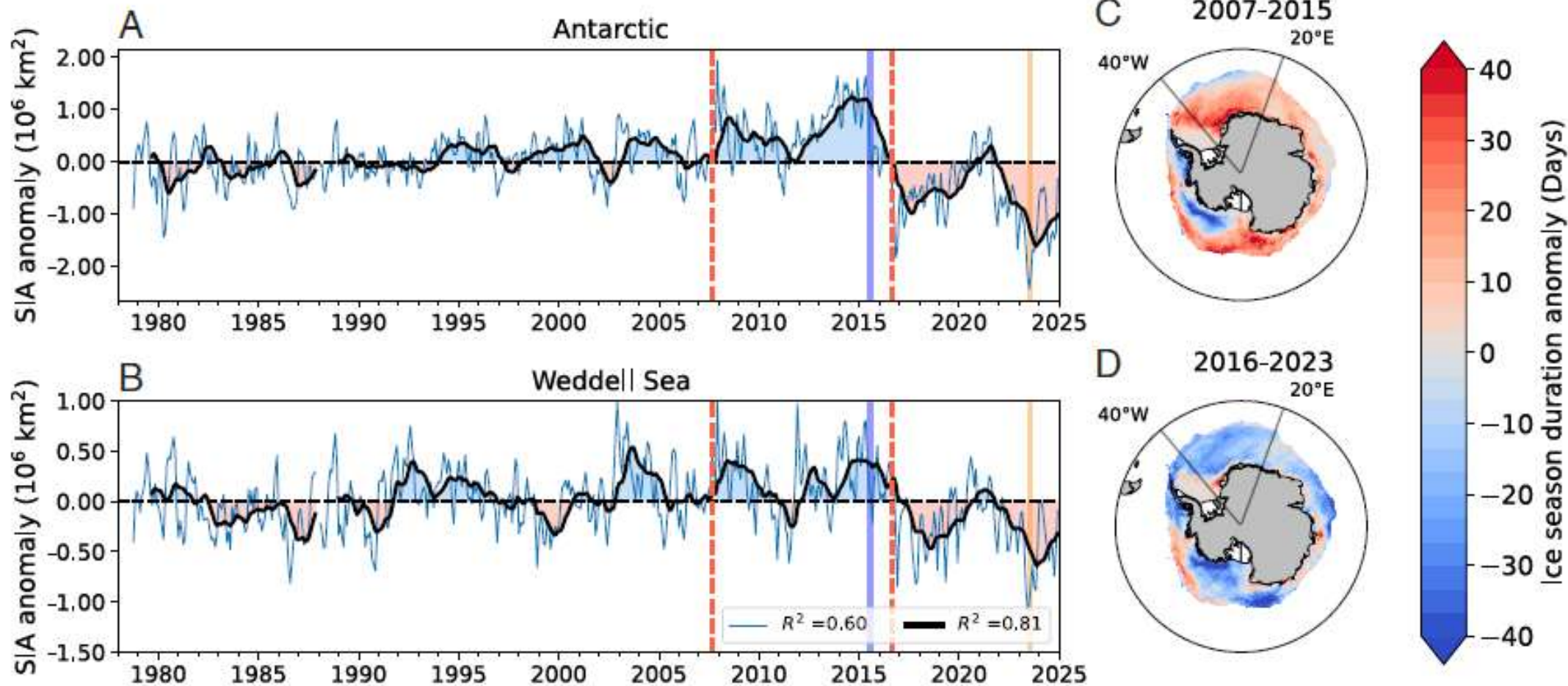


Fig. 1. Southern Ocean sea ice trends. (A and B) Monthly sea ice area (SIA) for the Antarctic and Weddell Sea, between 40°W and 20°E . Anomalies are defined relative to the monthly climatology for 1980–2010. Black lines represent a 12-mo running mean. The dashed red lines highlight September 2007 and 2016, the starts of the accelerated sea ice expansion and decline periods as defined by ref. 8. The blue and orange vertical bars indicate the winter SIA maximum and minimum in 2015 and 2023, respectively. R^2 values in (B) indicate the fraction of variance in circumpolar SIA anomalies explained by corresponding anomalies in the Weddell Sea since 2007. (C and D) Sea ice season duration anomalies for 2007–2015 and 2016–2023 for regions where the climatological season duration is greater than 3 mo (*Materials and Methods*).

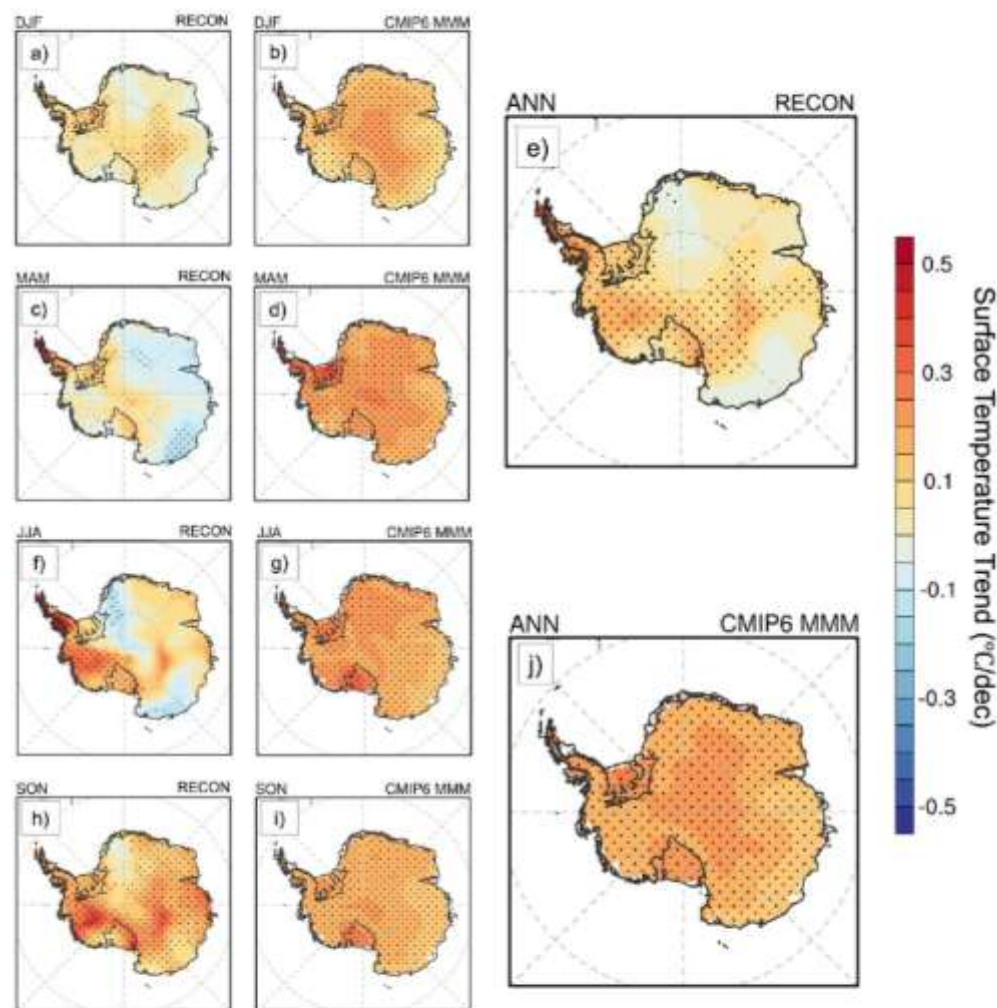
Trend temperatura alla superficie 1958-2022

Trend continentale $0.13^{\circ}\text{C}/\text{decade}$

Disomogeneità spaziale e
stagionale

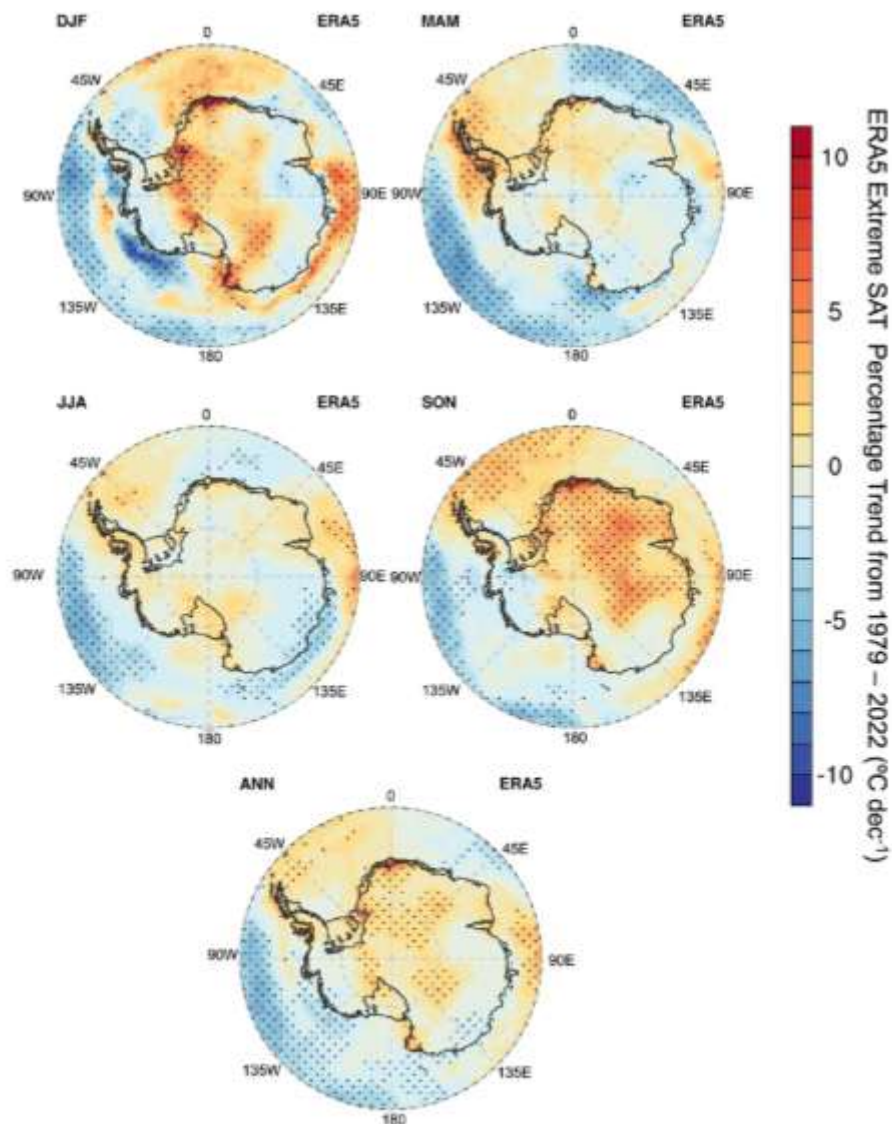
Differenze reanalisi/modelli

Fig. 1: Antarctic air temperature trends from RECON and CMIP6



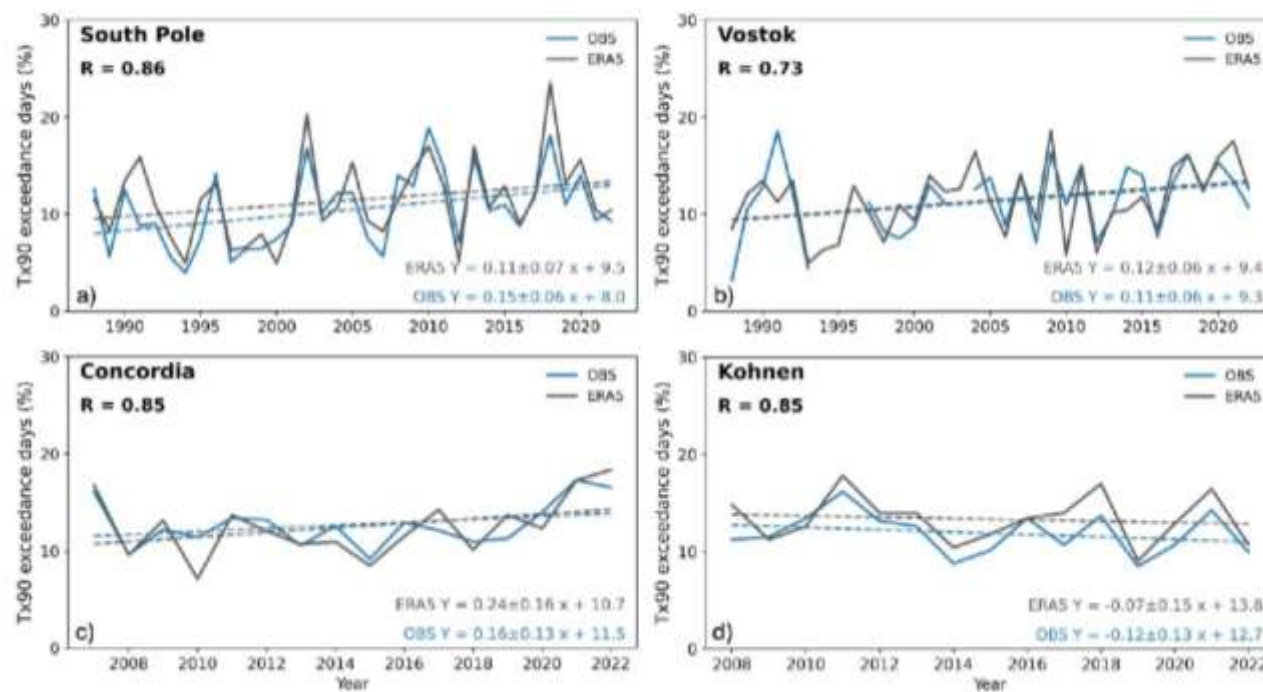
Spatial map of annual and seasonal surface air temperature (SAT) trends from 1958 to 2022 based on RECON (a,c,f,h,e) and CMIP6 MMM (b,d,g,i,j). The dot pattern represents trends that are significantly different from zero at $P < 0.05$ after removing the impact of autocorrelation from the residuals⁷⁹.

estremi di temperatura



Annual and seasonal extreme warm surface air temperature (SAT) trend based on 3-hrly ERA5 reanalysis data from 1979 to 2022. The dot pattern represents extreme SAT trends that are significantly different from zero at $P < 0.05$. Extreme warm SAT trend is calculated based on the percentage of timesteps with a daily maximum SAT greater than the reference threshold.

Fig. 8: Time series of interior warm temperature extremes from ERA5 and observations

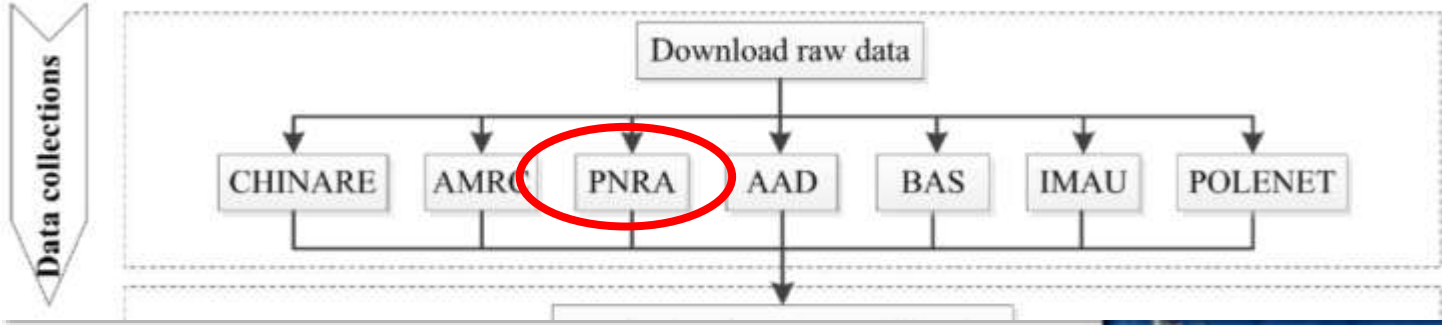


L'importanza delle reti osservative di AWS



- La quantificazione di **variabilità e trend di variabili meteorologiche (es. temperatura)** richiede **misure accurate, continue e di lungo periodo**.
- variazioni delle variabili atmosferiche (in particolare temperatura dell'aria, ma anche vento e accumulo nevoso) hanno **impatti diretti** sul bilancio energetico superficiale, massa e dinamica della calotta glaciale come sugli ecosistemi
- Le **stazioni meteorologiche automatiche (AWS)** permettono osservazioni ad alta risoluzione, in aree remote e condizioni estreme, durante tutto il corso dell'anno.
- Le **AWS forniscono dati necessari per** studi scientifici (es. accumulo nevoso, bilancio energetico, massa della calotta), attività logistiche in Antartide, modelli numerici previsionali, validazione di reanalisi atmosferiche e modelli climatici, verifica di prodotti satellitari, analisi climatiche di lungo periodo.

7 Antarctic AWS project databases

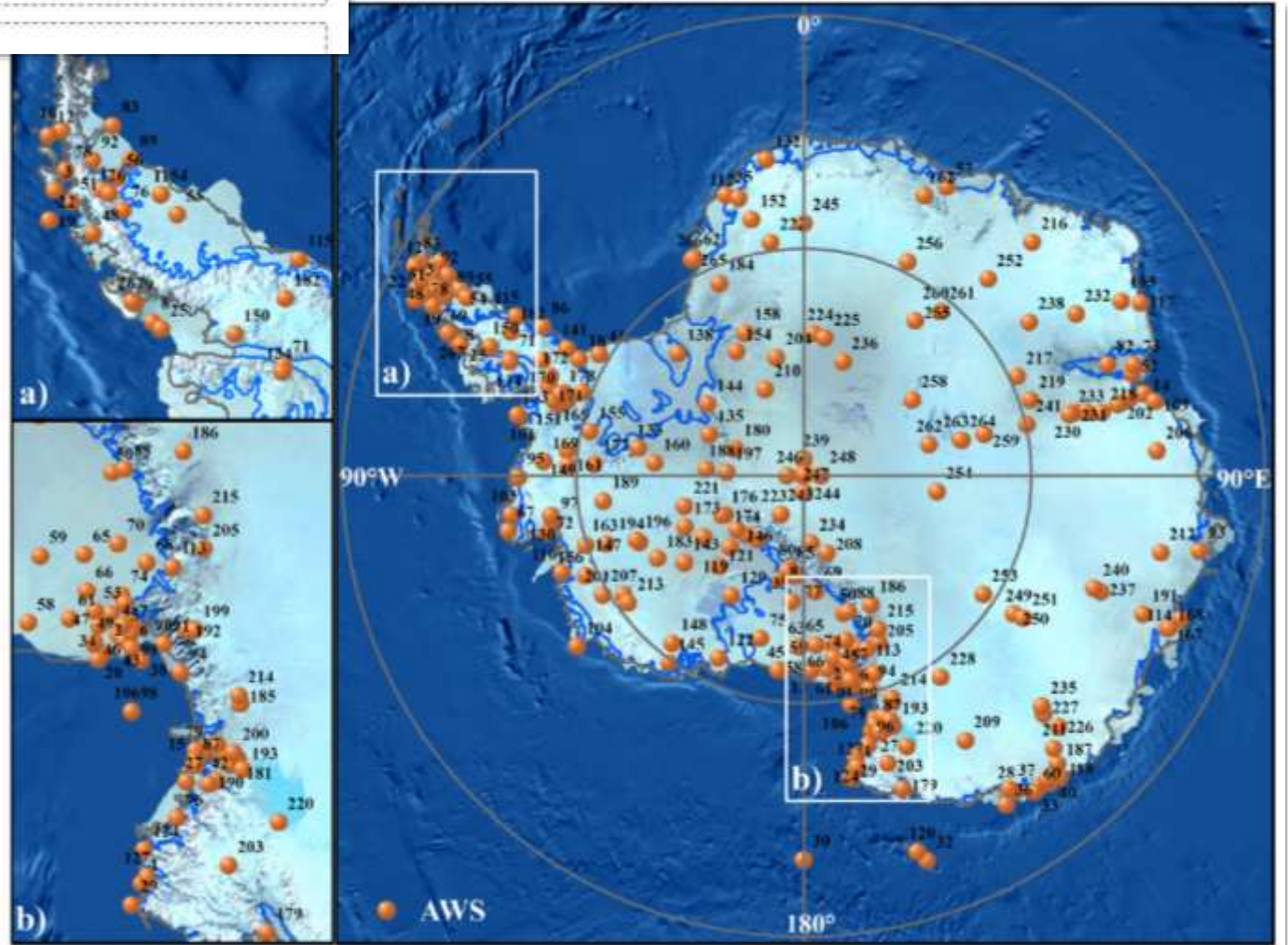


The AntAWS dataset: a compilation of Antarctic automatic weather station observations

Yetang Wang¹★, Xueying Zhang¹★, Wentao Ning¹, Matthew A. Lazzara², Minghu Ding¹, Carleen H. Reijmer¹, Paul C. J. P. Smeets¹, Paolo Grigioni⁵, Petra Heil^{6,7}, Elizabeth R. Thomas⁸, David Mikolajczyk², Lee J. Welhouse², Linda M. Keller², Zhaosheng Zhai¹, Yuqi Sun¹, and Shugui Hou⁹

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<https://doi.org/10.5194/essd-15-411-2023>



Map of the 267 automatic weather stations (AWSs) in this study, where the numbers (1–267) correspond to “NO.” in



Challenges in surface mass balance estimation at Dome C: stake farm comparisons, measurement uncertainties, and station-induced biases

Claudio Scarchilli^{1,2}, Barbara Steini^{1,2}, Marco Masoli^{1,2}, Giuliano Drossi^{1,2}, Vincent Fortin³, Francesca Berra^{1,2},
Claudio Scarchilli^{1,2}, Paolo Grigioni^{1,2}, Paolo Carozzi^{1,2}, and Massimo Frezzotti^{1,2}

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Polar Science

journal homepage: www.elsevier.com/locate/jgl

Diurnal variation of the planetary boundary layer over Dome C (Antarctica) impacting the formation of supercooled liquid water clouds

Philippe Ricaud^{1,2}, Pierre Durand^{1,2}, Paolo Grigioni^{1,2}, Vincent Fortin³, Virginia Ciardini¹,
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⁵MDPI



Trends in Atmospheric Humidity and Temperature above Dome C, Antarctica Evaluated from Observations and Reanalyses

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In situ observations of supercooled liquid water clouds over Dome C, Antarctica, by balloonborne sensors

Philippe Ricaud^{1,2}, Pierre Durand^{1,2}, Paolo Grigioni^{1,2}, Vincent Fortin³, Giuseppe Camporeale⁴, Axel Rey¹,
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A decade (2008–2017) of water stable isotope composition of precipitation at Concordia Station, East Antarctica

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Mathias Casado³, Annabelle Landais³, Martine Werner³, Alexandre Cassin³, Pierluigi Casassa³,
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Factors controlling atmospheric DMS and its oxidation products (MSA and nssSO₄²⁻) in the aerosol at Terra Nova Bay, Antarctica

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Matteo Poltrone^{1,2}, Paolo Grigioni^{1,2}, Jost Heintzenberg³, Luigi Lanzara^{1,2}, Michel Legrand¹,
Alice Madonna^{1,2}, Marco Morcillo^{1,2}, Chiara Mellini^{1,2}, Daniela Meloni^{1,2}, Caterina Nasci^{1,2},
Gianmichele Pace^{1,2}, Ri-Ye Park^{1,2}, Susanne Probst^{1,2}, Mirko Severi^{1,2}, Marco Vecchiato^{1,2},
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Seasonal Evolution of Size-Segregated Particulate Mercury in the Atmospheric Aerosol Over Terra Nova Bay, Antarctica

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Virginia Ciardini¹, Paolo Grigioni^{1,2}, Federico Girolametti^{1,2}, Flavio Vagnoni^{1,2},
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BILANCIO DI MASSA
SUPERFICIALE
BOUNDARY LAYER
TREND
NUBIE
MICROFISICA
AEROSOL

ISOTOPIE
PRECIPITAZIONE



A statistical study of precipitation on the eastern antarctic plateau (Dome-C) using remote sensing and in-situ instrumentation

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Journal of Glaciology



Article

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Key words: Accumulation; ice in the atmosphere; remote sensing; surface mass budget; wind-blown snow

Characterization of snowfall estimated by in situ and ground-based remote-sensing observations at Terra Nova Bay, Victoria Land, Antarctica

Claudio Scarchilli¹, Virginia Ciardini¹, Paolo Grigioni¹, Antonio Iaccarino¹,
Lorenzo De Silvestri¹, Marco Proposito^{1,2}, Stefano Dolci^{1,2}, Giuseppe Camporeale³,
Riccardo Schioppa⁴, Adriano Antonucci⁵, Luca Baldini¹, Nicoletta Roberto²,
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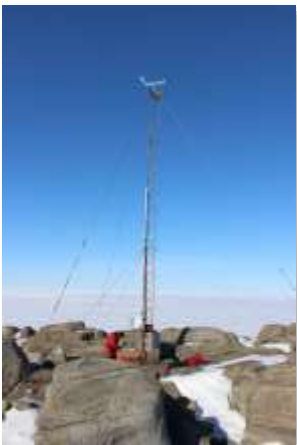
Quantitative Precipitation Estimation over Antarctica Using Different Ze-SR Relationships Based on Snowfall Classification Combining Ground Observations

Alessandro Bracci^{1,2,3}, Luca Baldini^{1,4}, Nicoletta Roberto¹, Elisa Adirosi^{1,5}, Mario Montopoli^{1,6},
Claudio Scarchilli¹, Paolo Grigioni^{1,7}, Virginia Ciardini^{1,8}, Vincenzo Levizzani^{4,9} and Federico Porco^{2,10}

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La rete di AWS di IAMCO

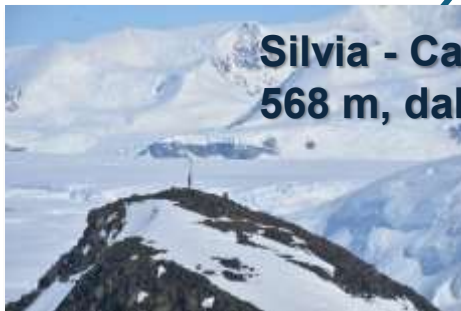
Arelis - Cape Ross
150 m - dal 02/01/1990



Alessandra - Cape King
160 m - dal 01/02/1987



Silvia - Cape Phillips
568 m, dal 21/12/1990



Eneide - Baia Terra Nova
91 m, dal 07/01/1987



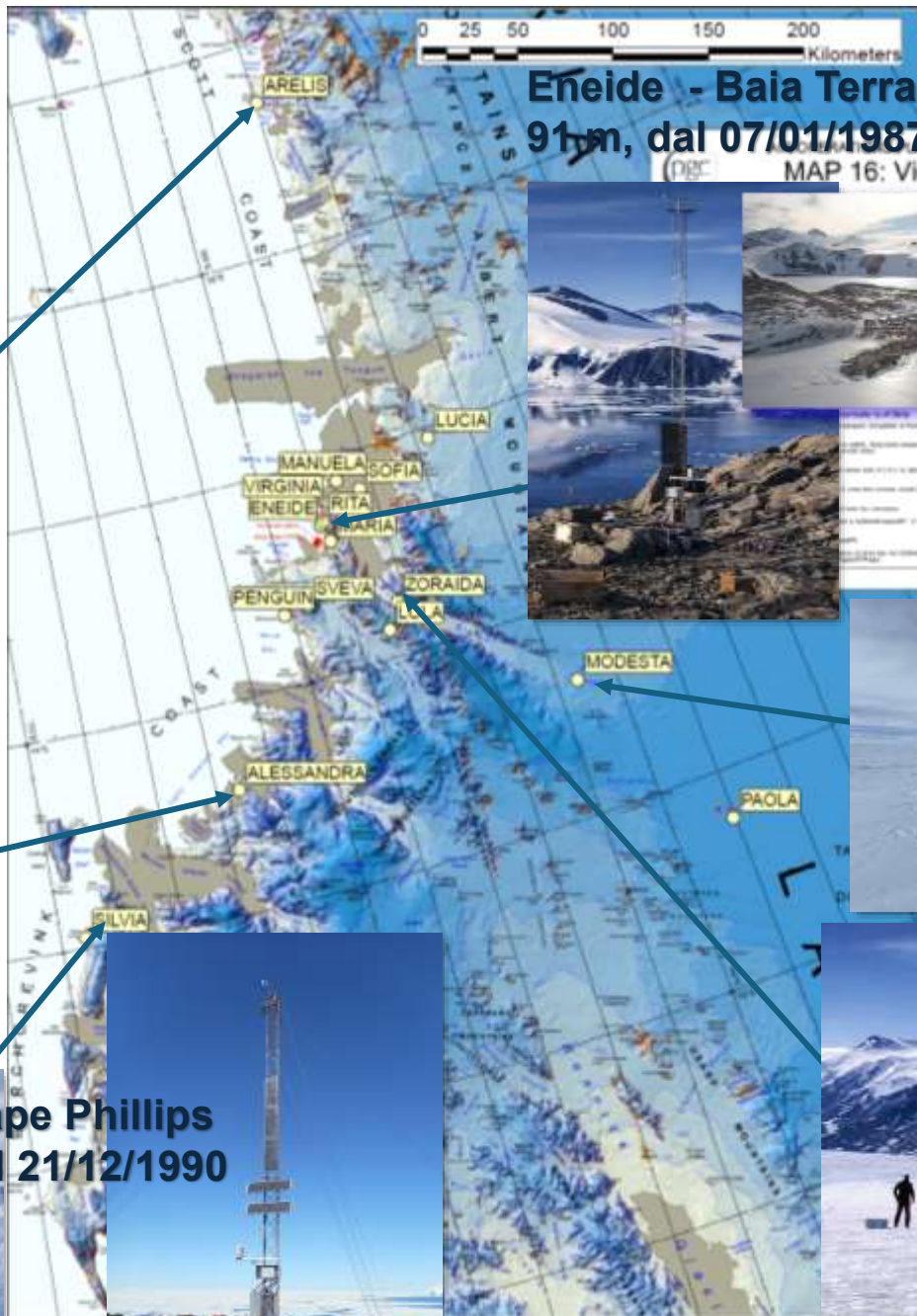
Concordia - Dome C
3230, dal 24/01/2005



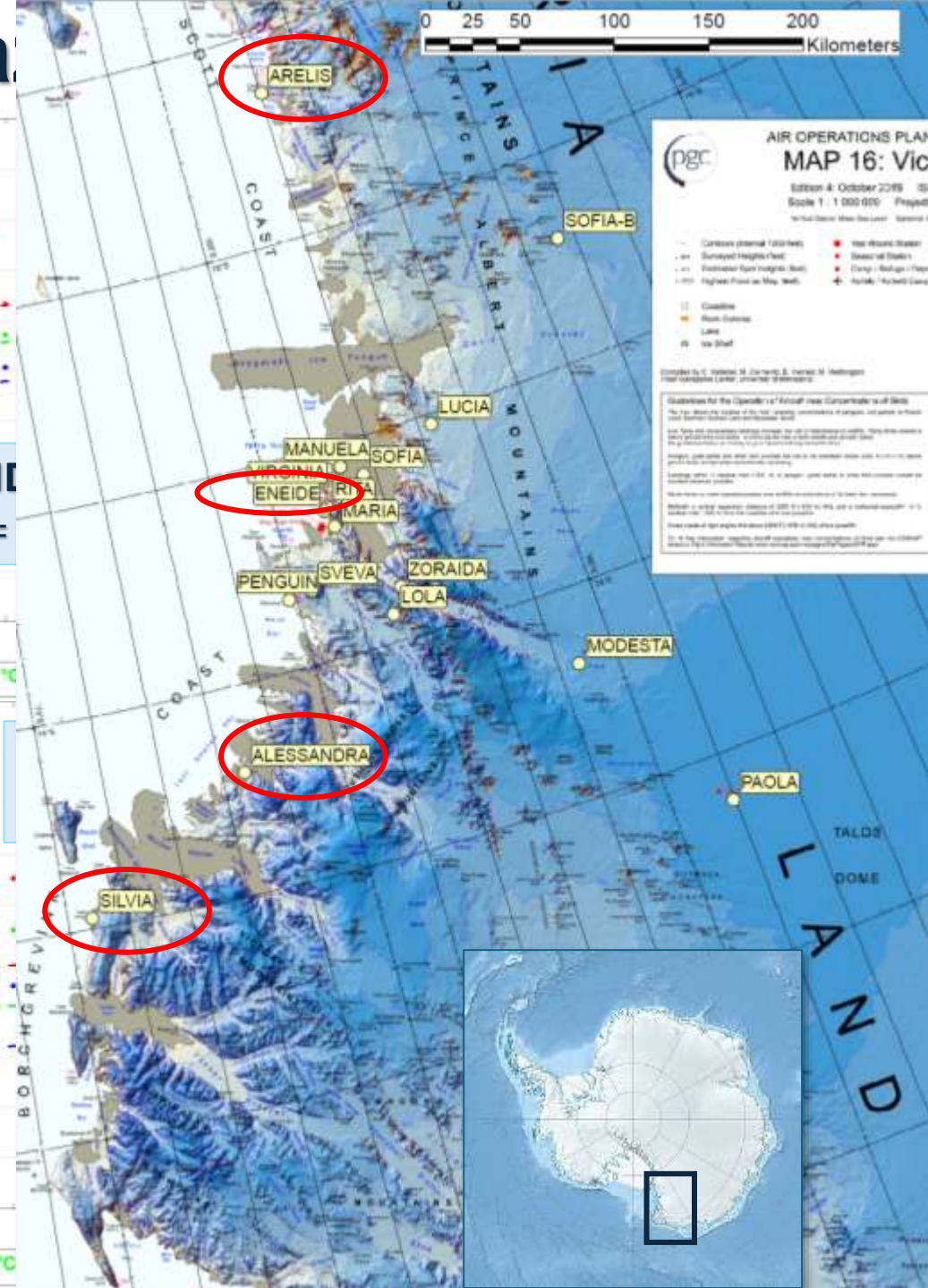
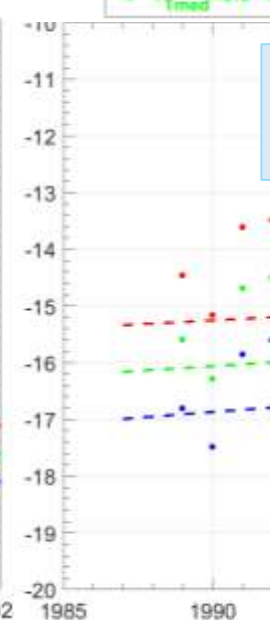
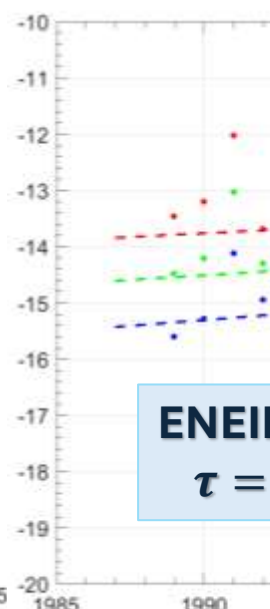
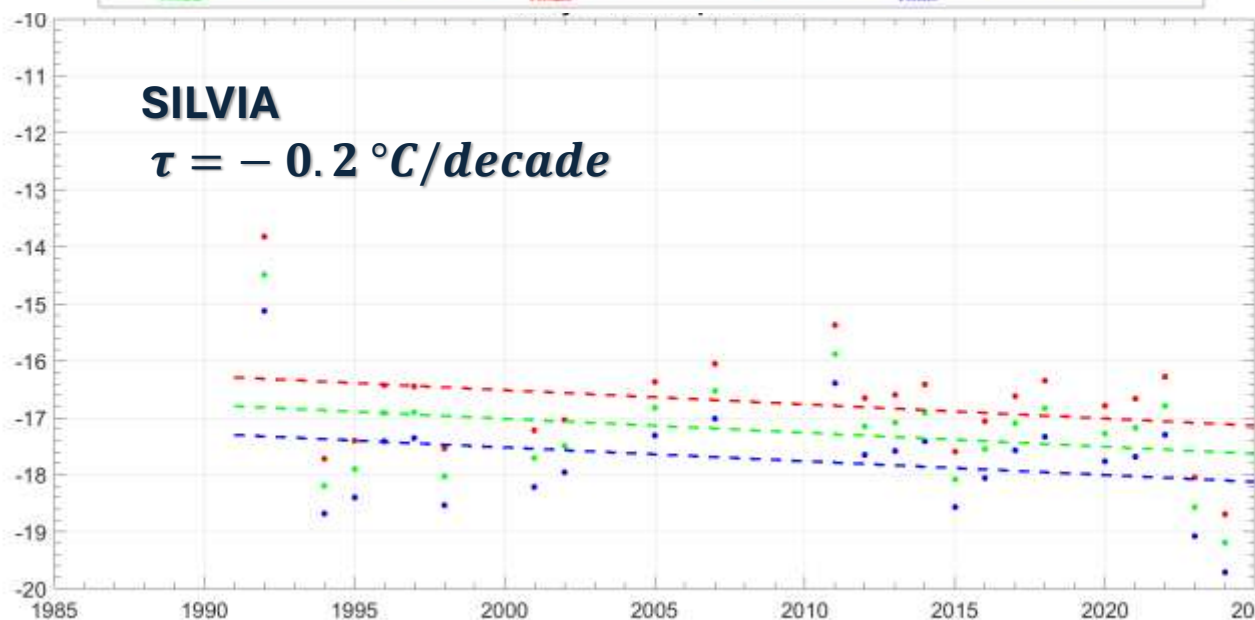
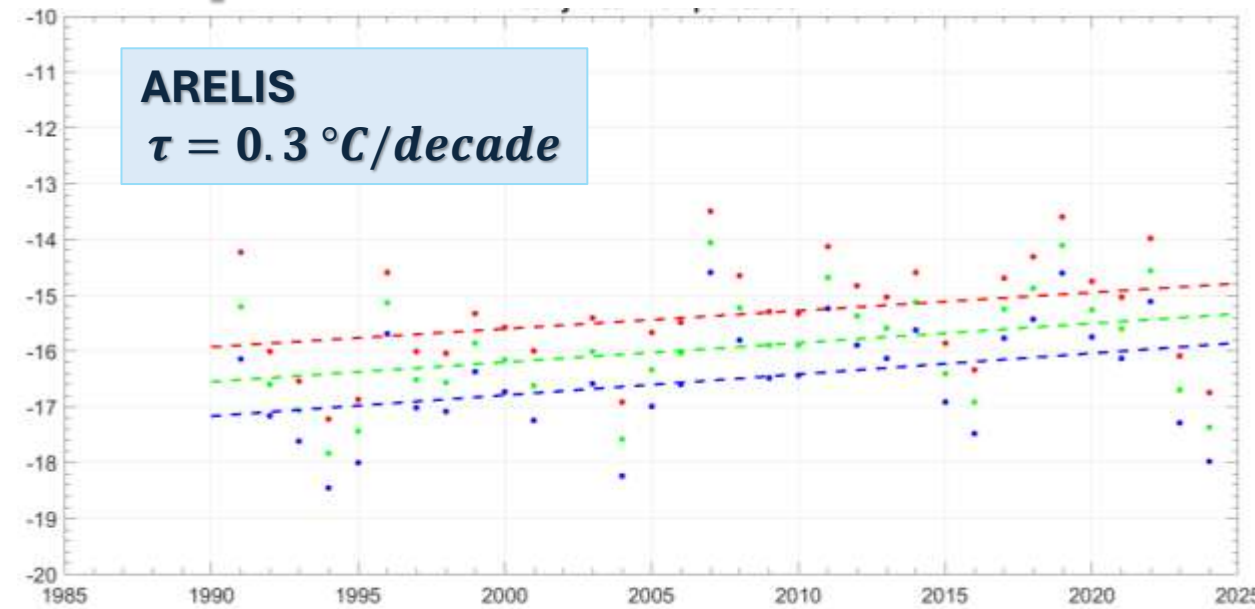
Modesta - Priestley Névé
1924 m, dal 01/02/1989



Zoraida - Priestley Glacier
880 m, dal 18/01/1987



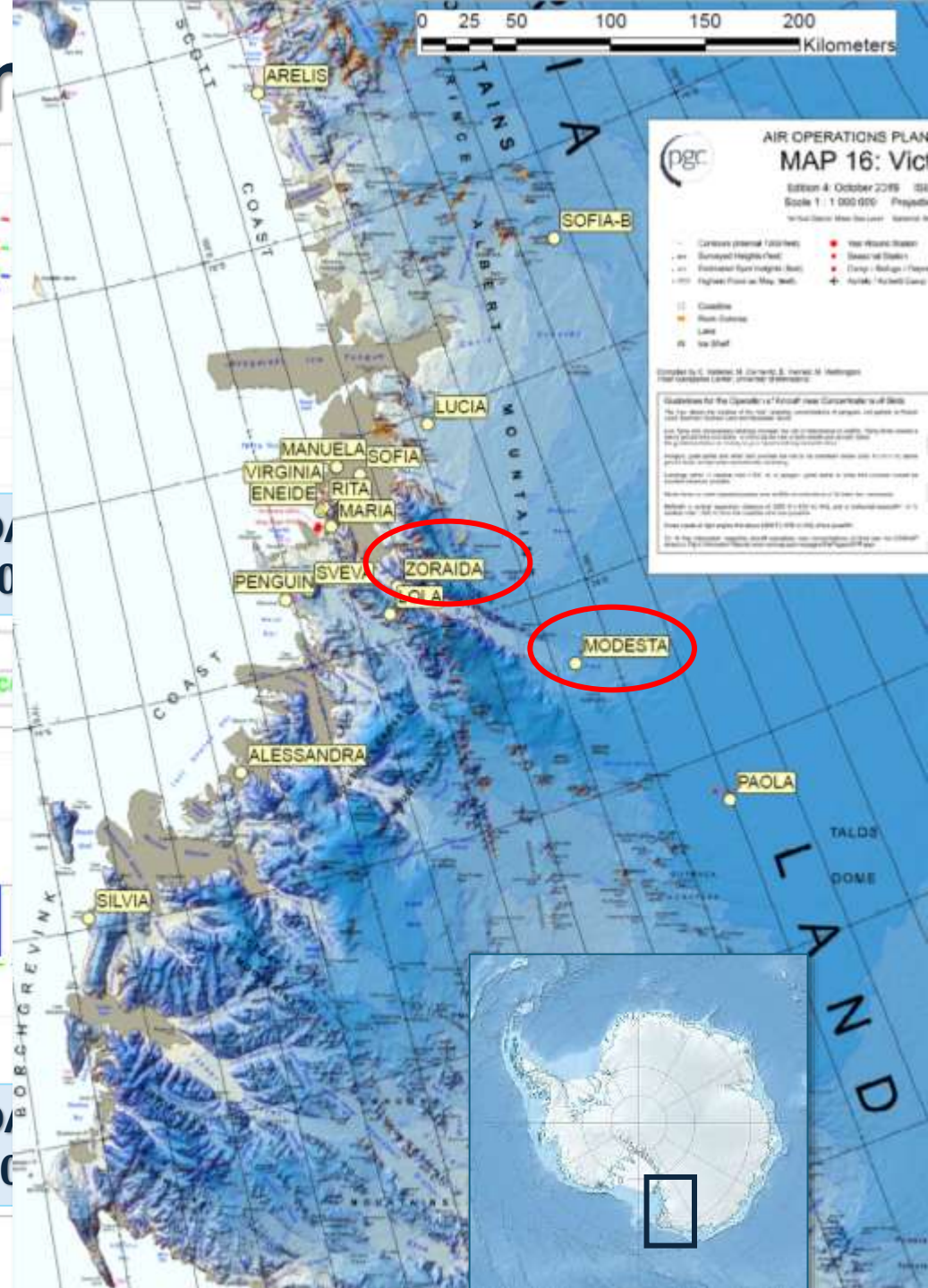
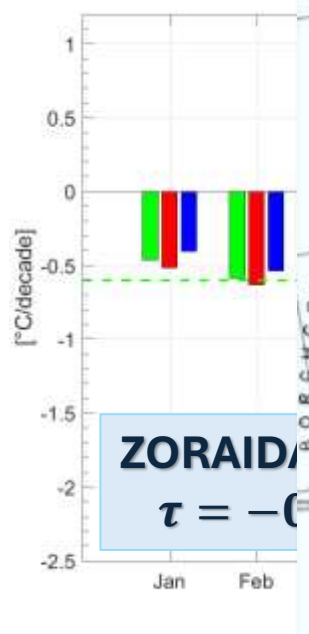
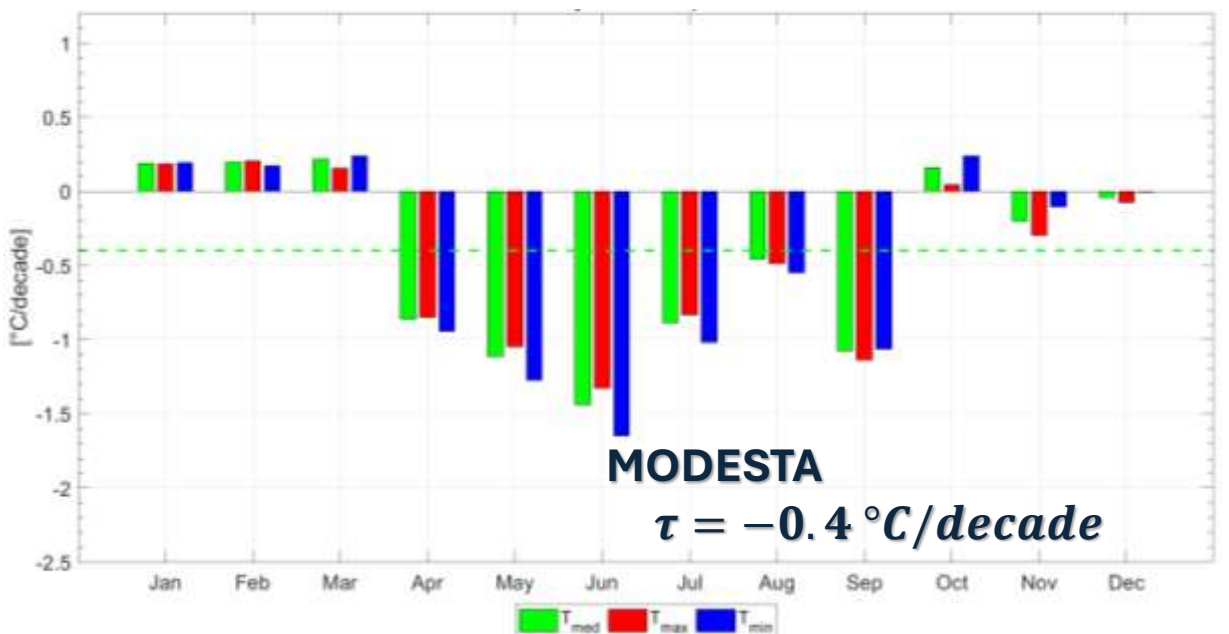
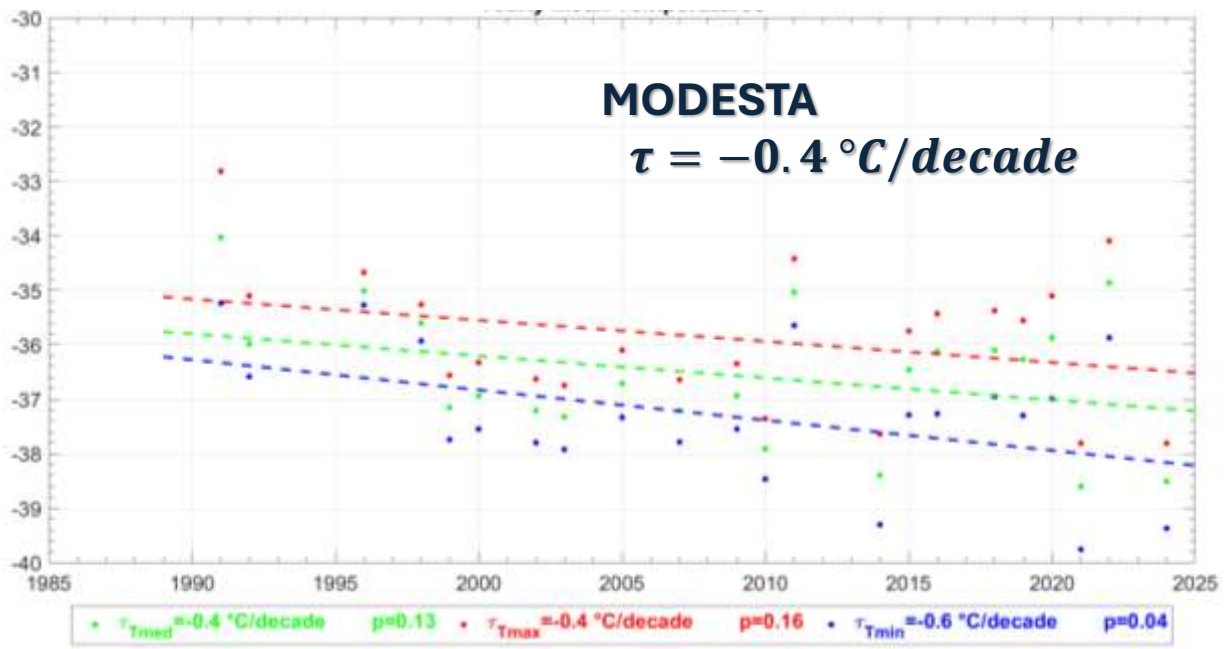
Temperatura media annuale – sta

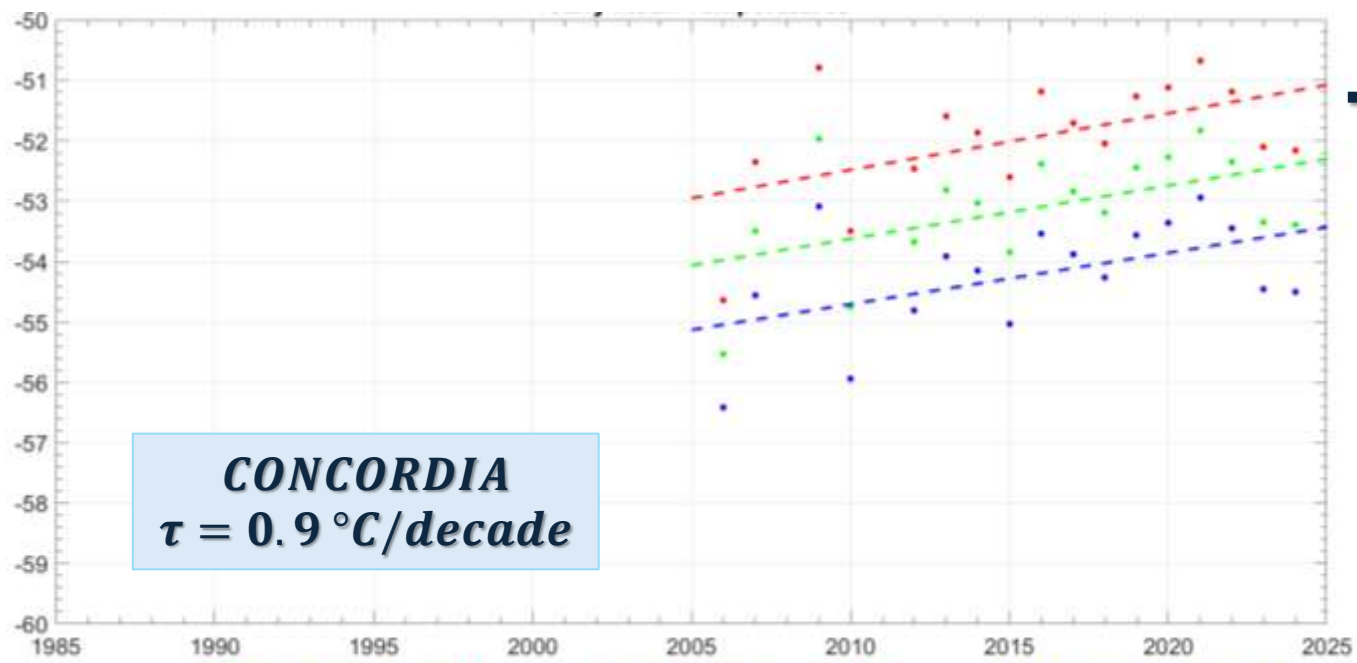


Trend medie mensili – stazioni costiere

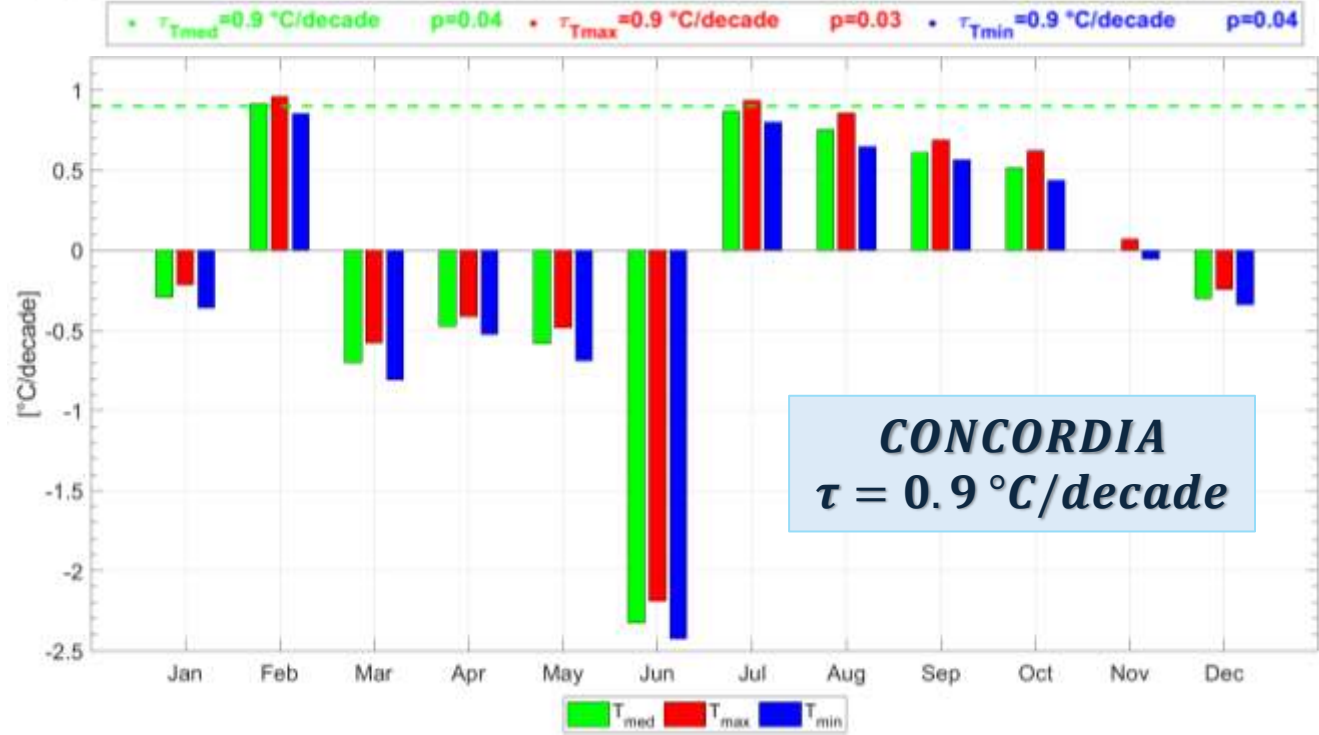


Trend medie mensili – stazioni in



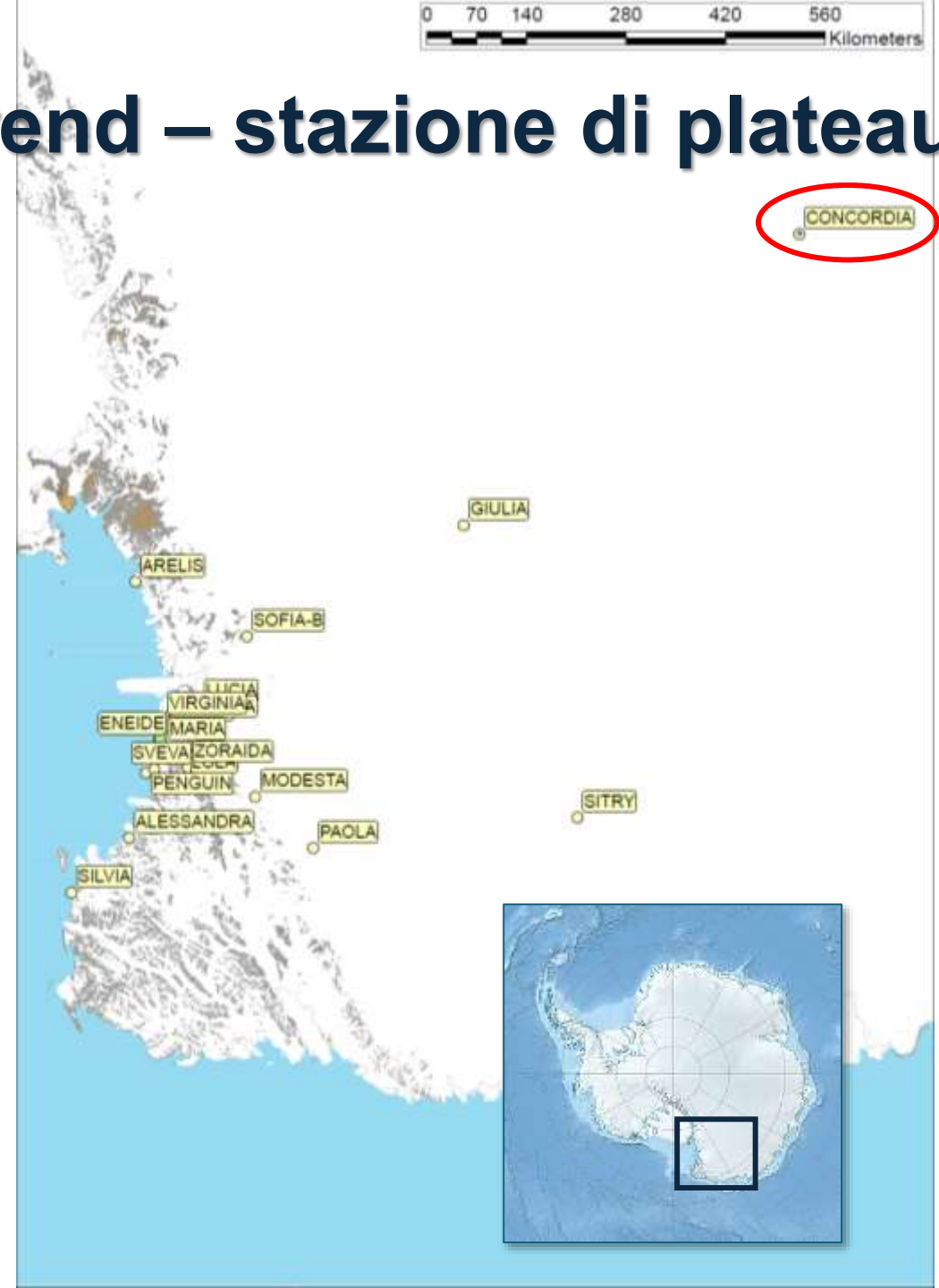


CONCORDIA
 $\tau = 0.9 \text{ }^\circ\text{C/decade}$



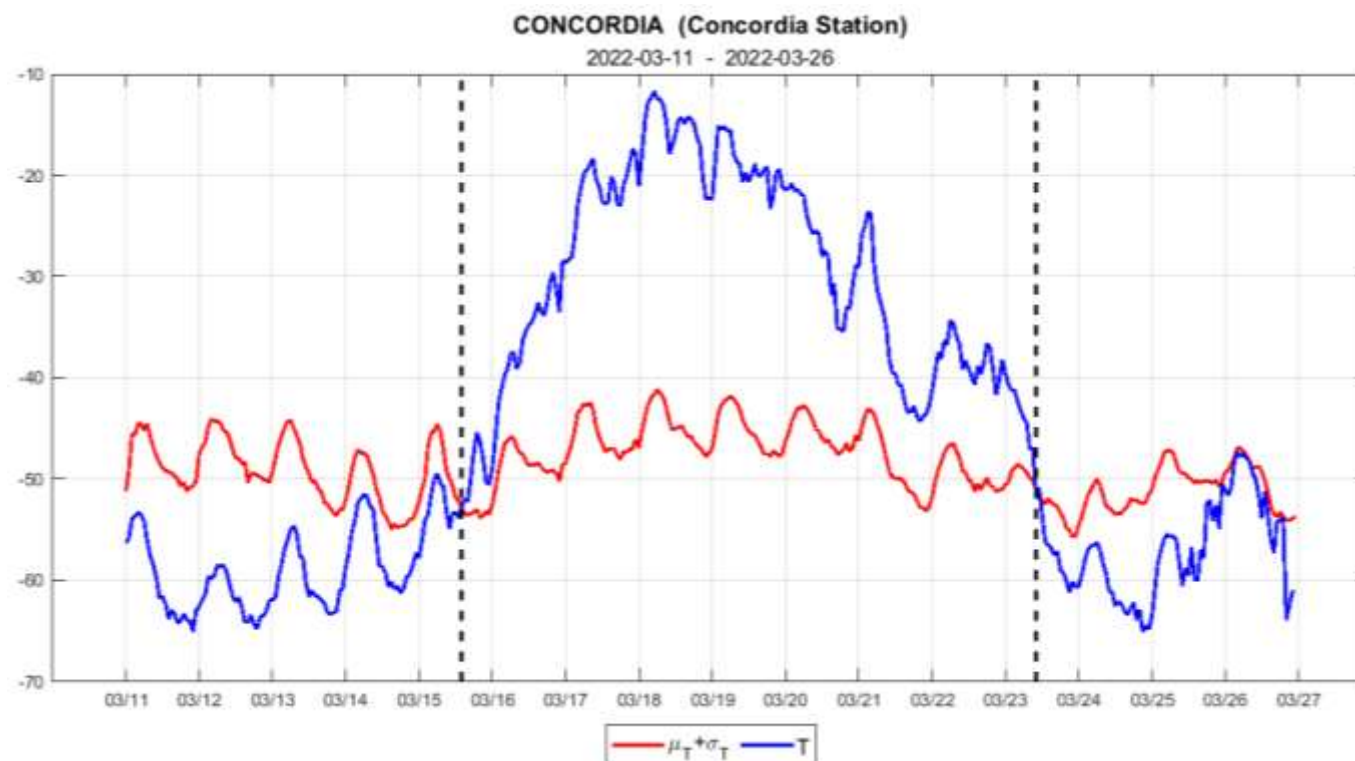
CONCORDIA
 $\tau = 0.9 \text{ }^\circ\text{C/decade}$

Trend – stazione di plateau



eventi estremi (ondate di calore)

- eventi di durata superiore a 3 giorni consecutivi con temperatura oraria superiore di almeno una deviazione standard (calcolata sull'intero periodo disponibile) rispetto alla temperatura media oraria;
- eventi osservati su Concordia il cui segnale è visibile anche sulle altre stazioni;
- sono presentati 2 eventi fra i più intensi:
 - *marzo 2022*
 - *luglio 2016*



La selezione degli eventi è stata ripetuta considerando come soglia il 90° percentile della T nel periodo di riferimento.

Key Points:

- The March 2022 Antarctic heatwave registered the warmest temperature anomaly on record, and resulted from extreme atmospheric heat fluxes
- A widely used climate model cannot simulate equivalent events in a large ensemble, a bias that is improved after nudging its winds to observations
- The thermodynamic amplification of the heatwave by climate change was 2°C, and equivalent heatwaves may warm a further 5–6°C by 2100

Supporting Information:

Supporting information may be found in the online version of this article.

The Largest Ever Recorded Heatwave—Characteristics and Attribution of the Antarctic Heatwave of March 2022

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Abstract An unprecedented heatwave impacted East Antarctica in March 2022, peaking at 39°C above climatology, the largest temperature anomaly ever recorded globally. We investigate the causes of the heatwave, the impact of climate change, and a climate model's ability in simulating such an event. The heatwave, which was skillfully forecast, resulted from a highly anomalous large-scale circulation pattern that advected an Australian airmass to East Antarctica in 4 days and produced record atmospheric heat fluxes. Southern Ocean sea surface temperatures anomalies had a minimal impact on the heatwave's amplitude. Simulations from a climate model fail to simulate such a large temperature anomaly mostly due to biases in its large-scale circulation variability, showcasing a pathway for future model improvement in simulating extreme heatwaves. The heatwave was made 2°C warmer by climate change, and end of 21st century heatwaves may be an additional 5–6°C warmer, raising the prospect of near-melting temperatures over the interior of East Antarctica.

1 FEBRUARY 2024

WILLE ET AL.

779

The Extraordinary March 2022 East Antarctica “Heat” Wave. Part II: Impacts on the Antarctic Ice Sheet

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ABSTRACT Between 15 and 19 March 2022, East Antarctica experienced an exceptional heat wave with widespread 30°–40°C temperature anomalies across the ice sheet. In Part I, we assessed the meteorological drivers that generated an intense atmospheric river (AR) that caused these record-shattering temperature anomalies. Here, we continue our large collaborative study by analyzing the widespread and diverse impacts driven by the AR landfall. These impacts included widespread rain and surface melt that was recorded along coastal areas, but this was outweighed by widespread high snowfall accumulations resulting in a largely positive surface mass balance contribution to the East Antarctic region. An analysis of the surface energy budget indicated that widespread downward longwave radiation anomalies caused by large cloud-liquid water contents along with some scattered solar radiation produced intense surface warming. Isotope measurements of the moisture were highly elevated, likely imprinting a strong signal for past climate reconstruction. The AR event attenuated cosmic ray measurements at Concordia, something previously never observed. Last, an extratropical cyclone west of the AR landfall likely triggered the final collapse of the critically unstable Conger Ice Shelf while further reducing an already record low sea ice extent.

SIGNIFICANCE STATEMENT: Using our diverse collective expertise, we explored the impacts from the March 2022 heat wave and atmospheric river across East Antarctica. One key takeaway is that the Antarctic cryosphere is highly sensitive to meteorological extremes originating from the midlatitudes and subtropics. Despite the large positive temperature anomalies driven from strong downward longwave radiation, this event led to huge amounts of snowfall across the Antarctic interior desert. The isotopes in this snow of warm airmass origin will likely be detectable in future ice cores and potentially detect past climate reconstructions. Even measurements of space activity were affected. Also, the swells generated from this storm helped to trigger the final collapse of an already critically unstable Conger Ice Shelf while further degrading sea ice coverage.

KEYWORDS: Antarctica; Ice shelves; Snow; Energy budget/balance; Paleoclimatology

VOLUME 57

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The Extraordinary March 2022 East Antarctica “Heat” Wave. Part I: Observations and Meteorological Drivers

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ABSTRACT: Between 15 and 19 March 2022, East Antarctica experienced an exceptional heat wave with widespread 30°–40°C temperature anomalies across the ice sheet. This record-shattering event saw numerous monthly temperature records being broken including a new all-time temperature record of −9.4°C on 18 March at Concordia Station despite March typically being a transition month to the Antarctic coreless winter. The driver for these temperature extremes was

deep into the Antarctic interior. The heat wave's meteorological driver records along with the intricate last Antarctica. These efforts describe sea. This led to an atmospheric river teric blocking deep into East Antarcipal surface temperature inversions Antarctica exceeded previous March 100 years, a closer recurrence of such us impacts this extreme event had on



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March 2022 warm event detected in precipitation and surface snow at Concordia Station in East Antarctica

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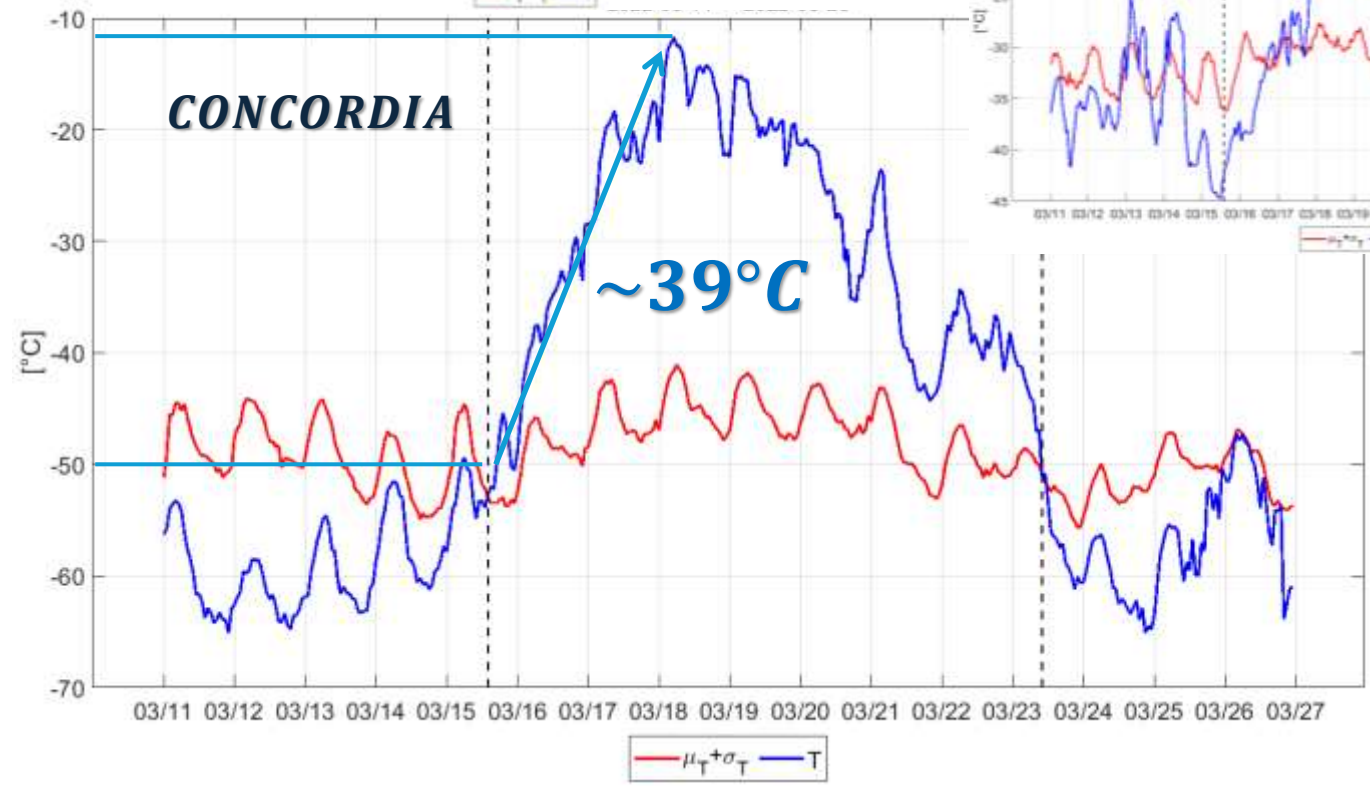
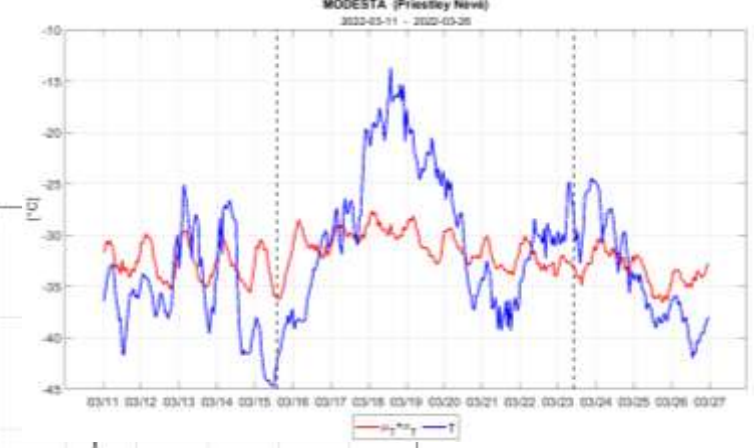
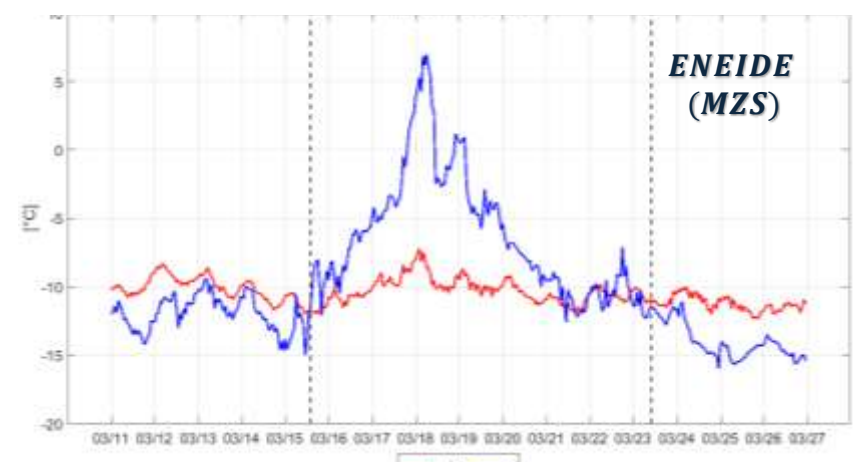
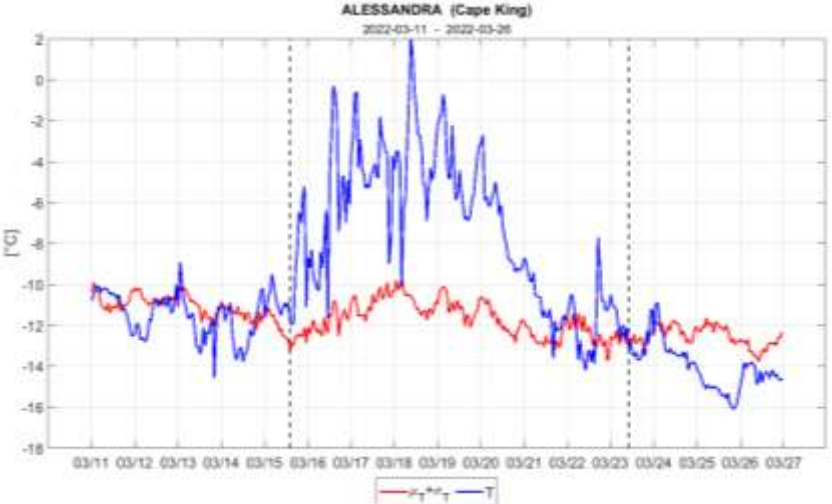
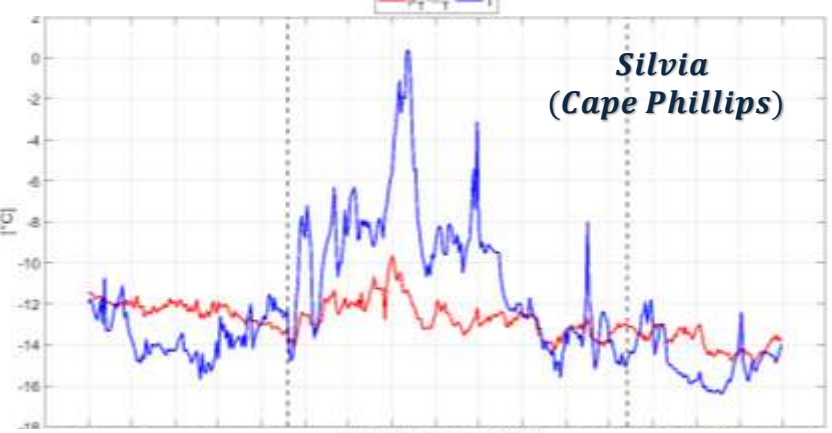
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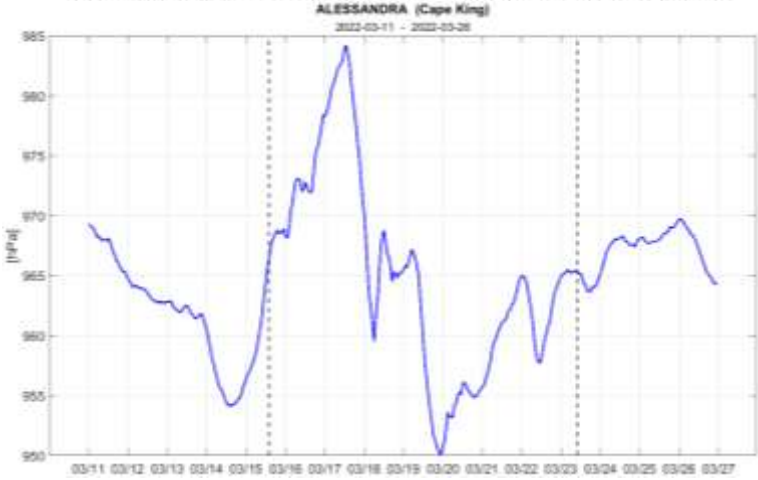
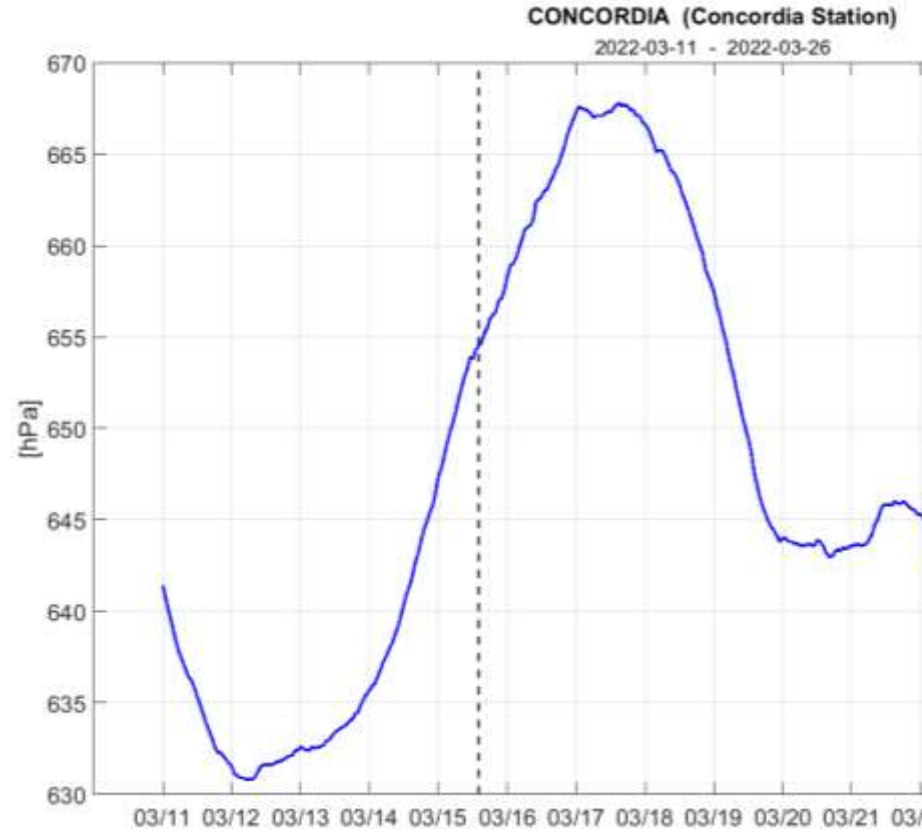
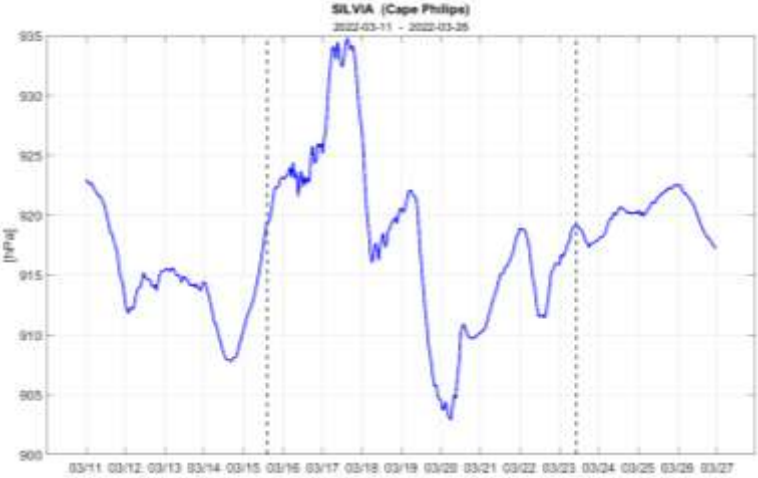
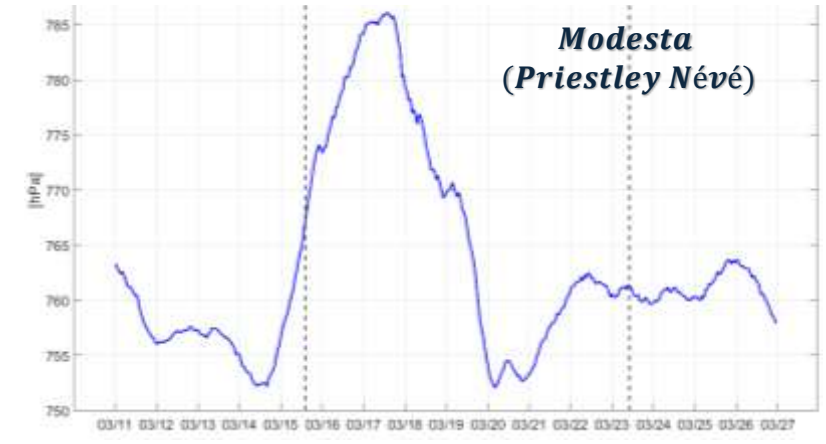
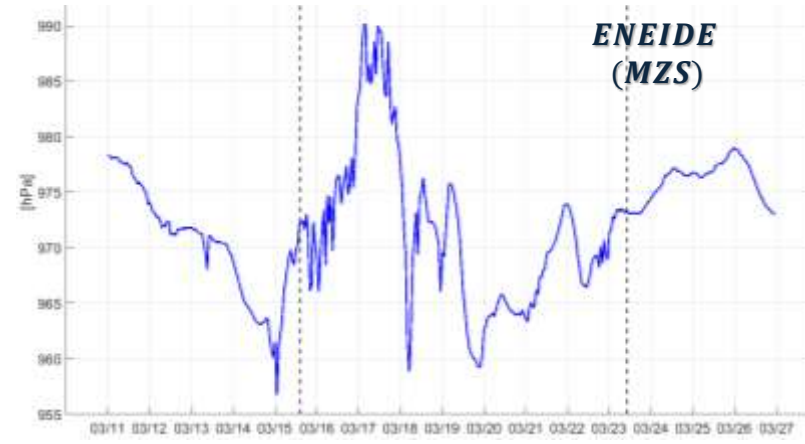
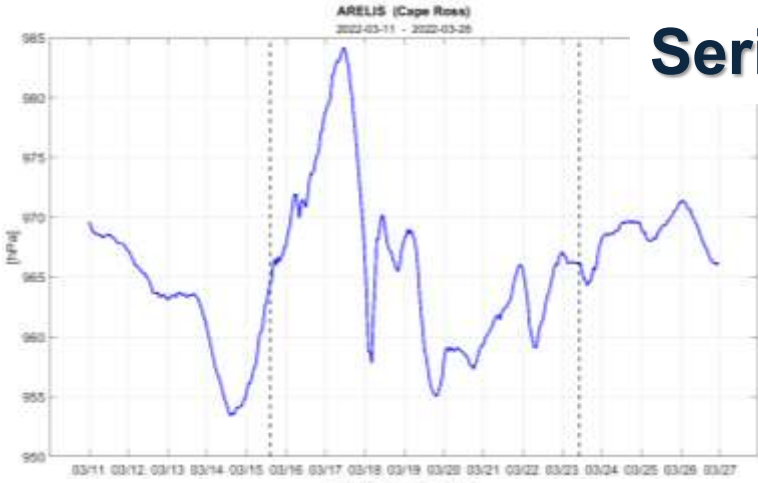
ver caused some of the highest temeretic science community. Using our t within a historical climate context. bations in the midlatitudes and subp the rare chance of occurrence possible, especially given anthropo-

stations; Climate records

Serie temporali temperatura atmosferica da AWS - evento 2022

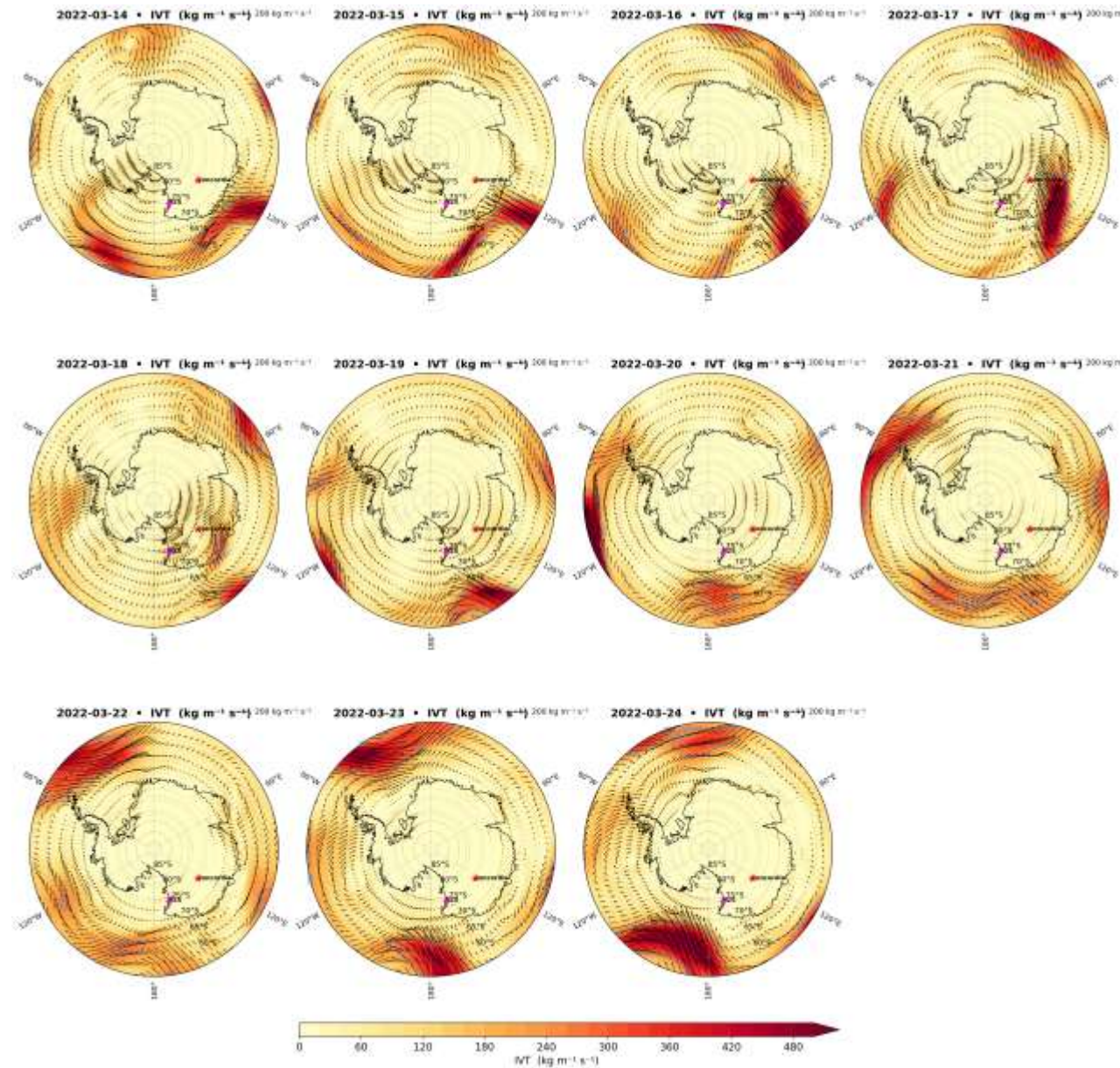


Serie temporali pressione atmosferica da AWS – evento 2022



Reanalisi ERA 5 - ECMWF

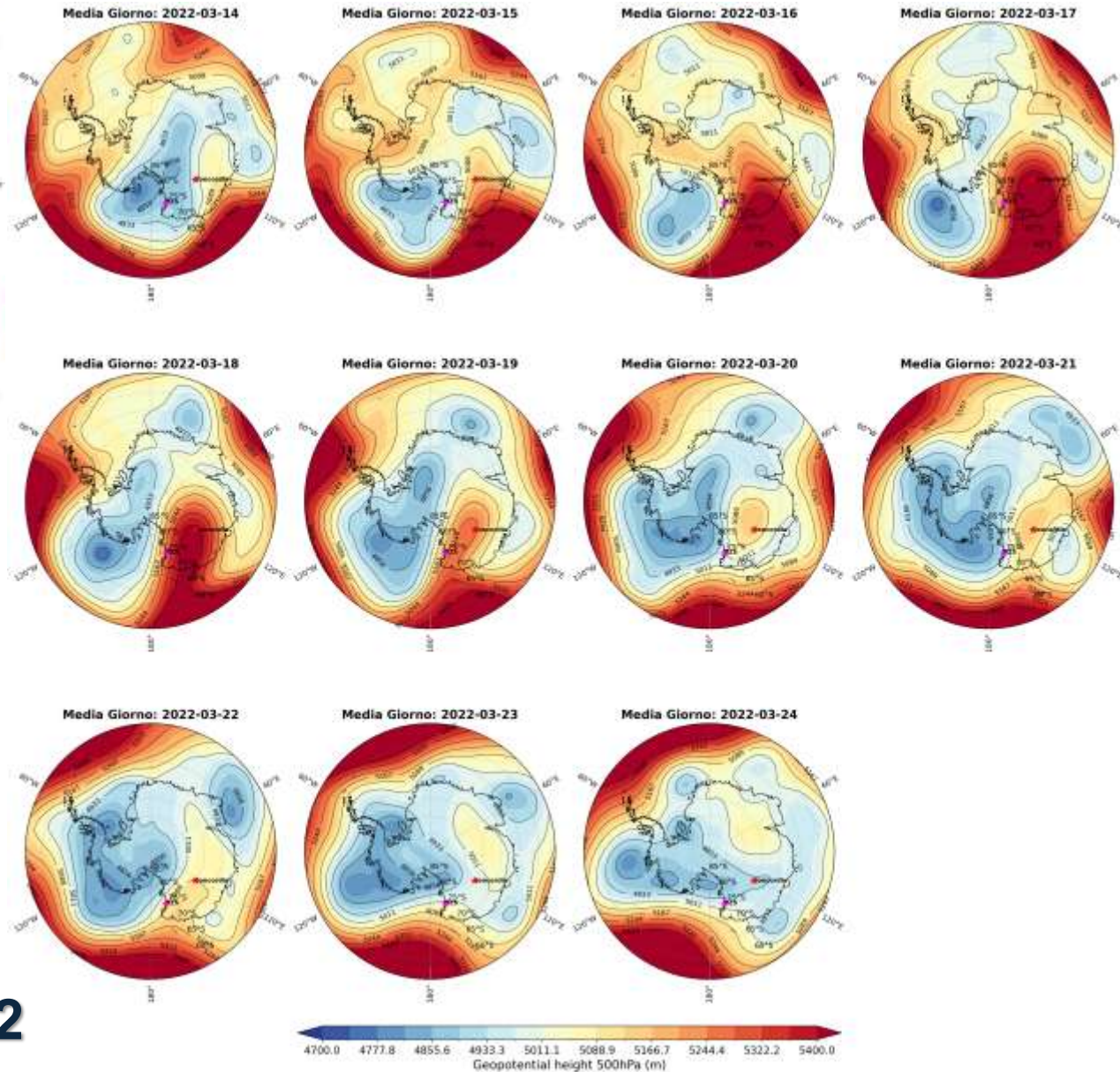
altezza geopotenziale 500 hPa



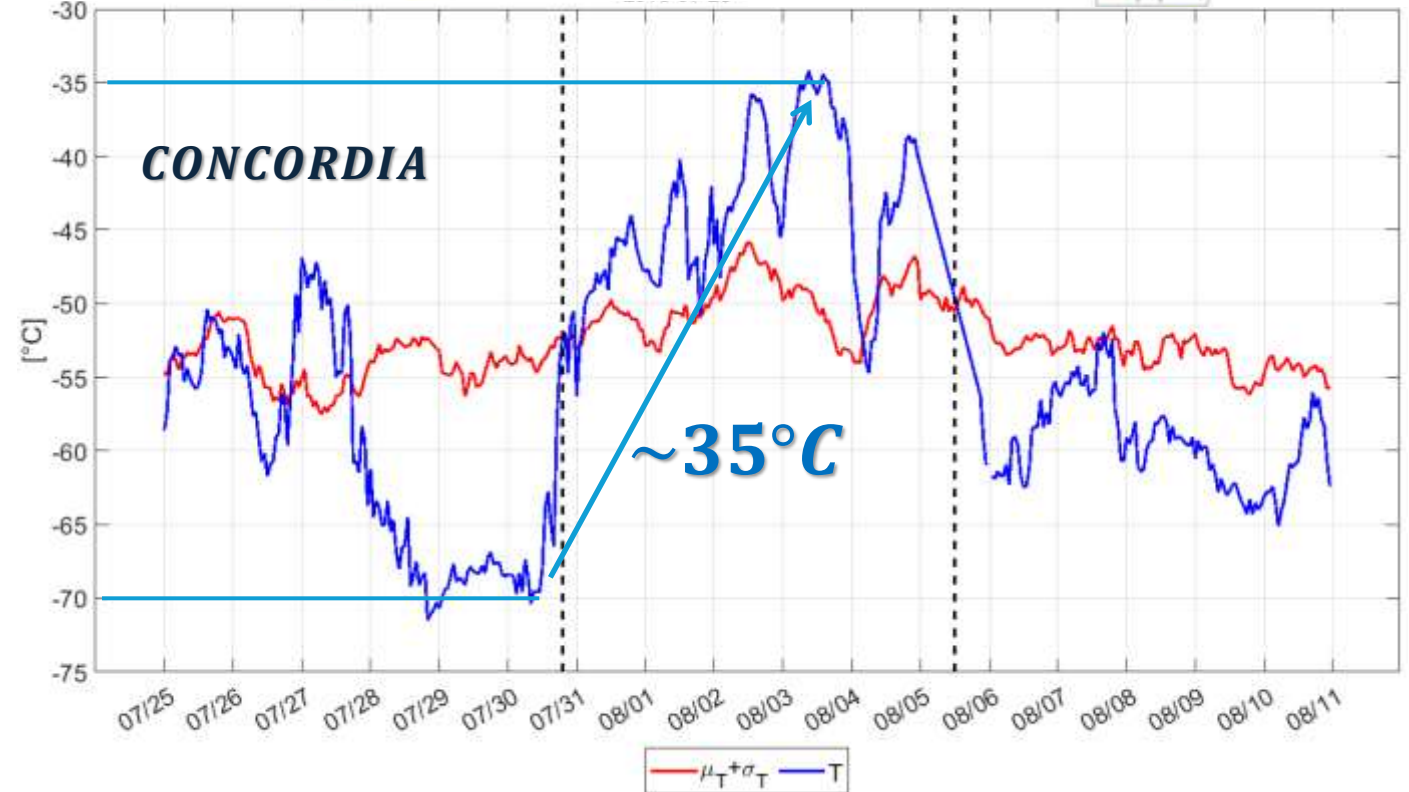
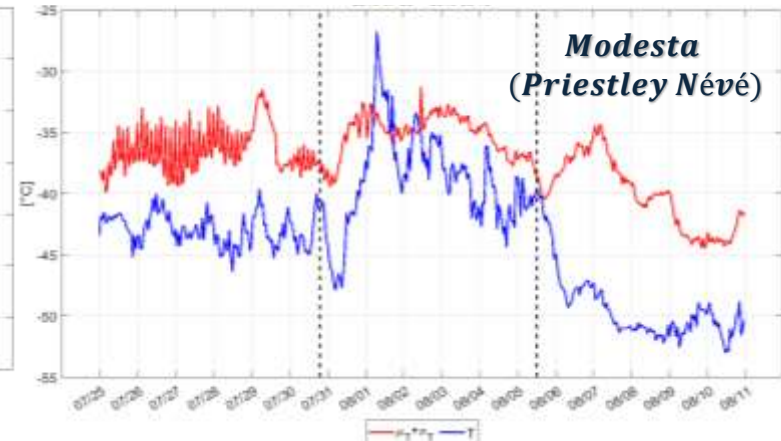
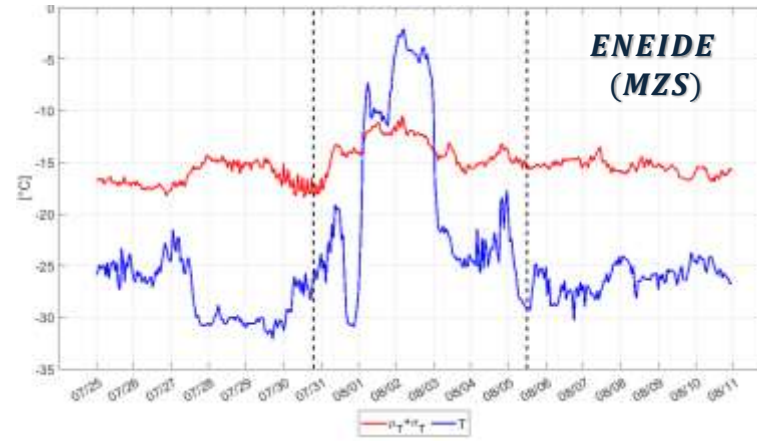
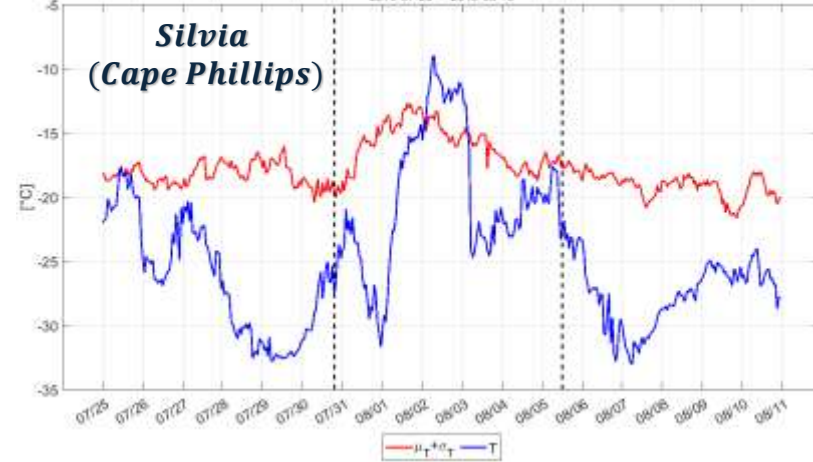
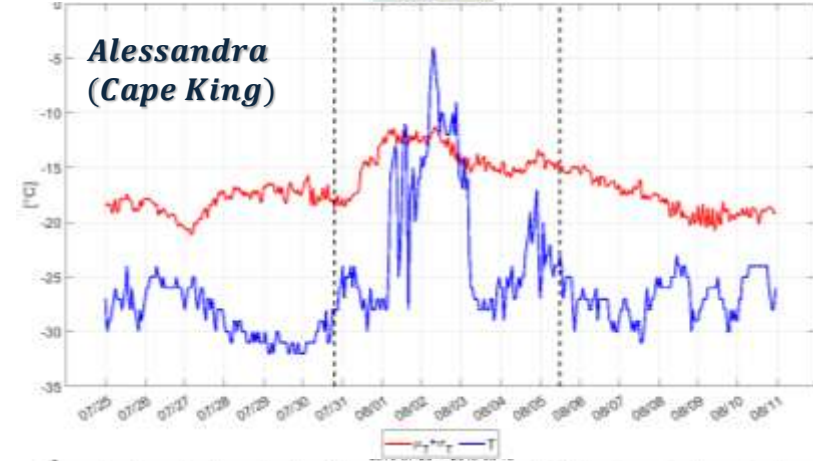
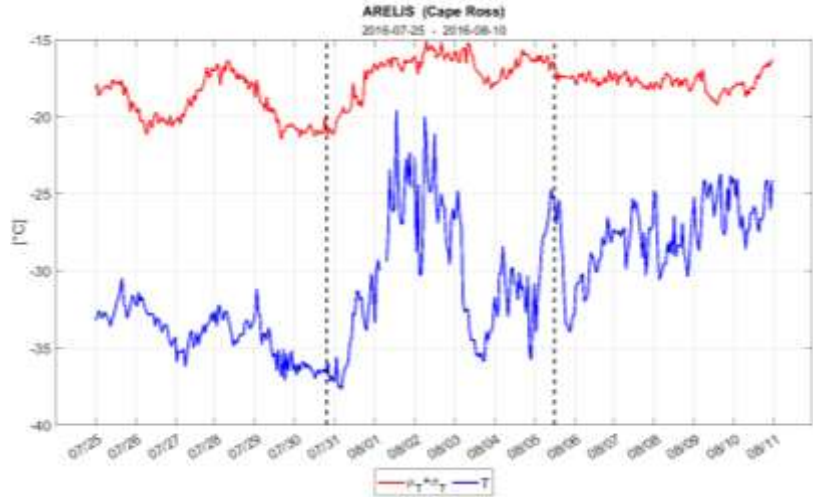
integrated water vapor transport (IVT)



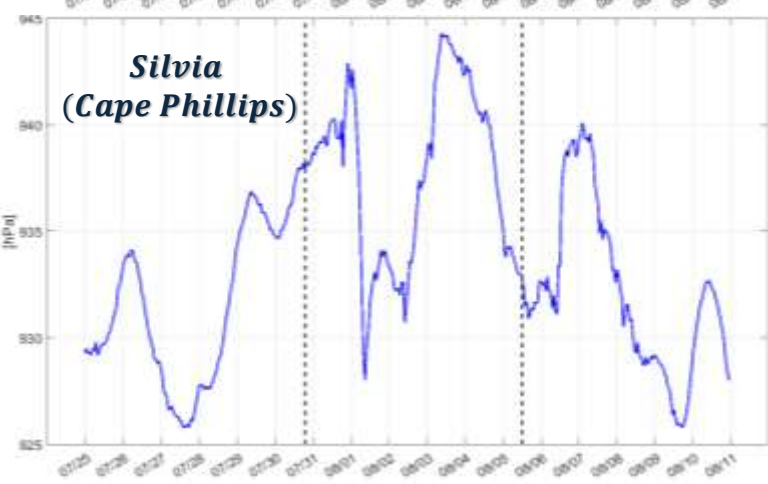
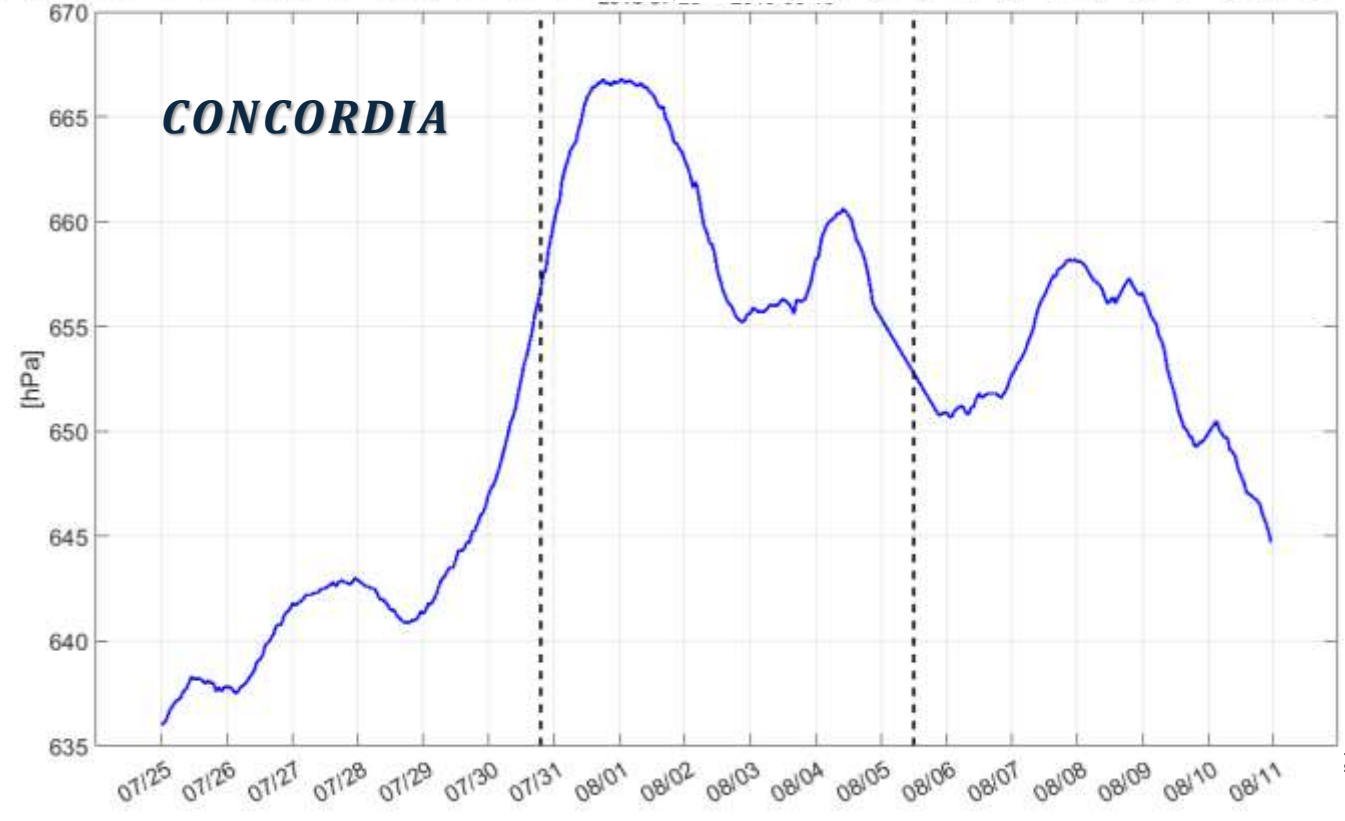
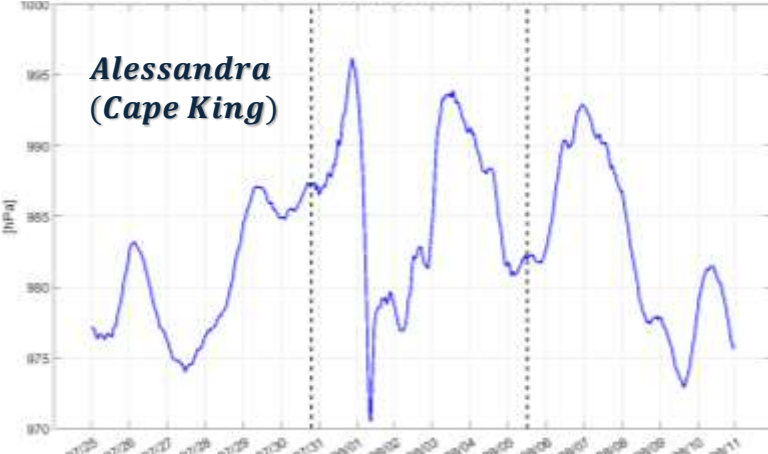
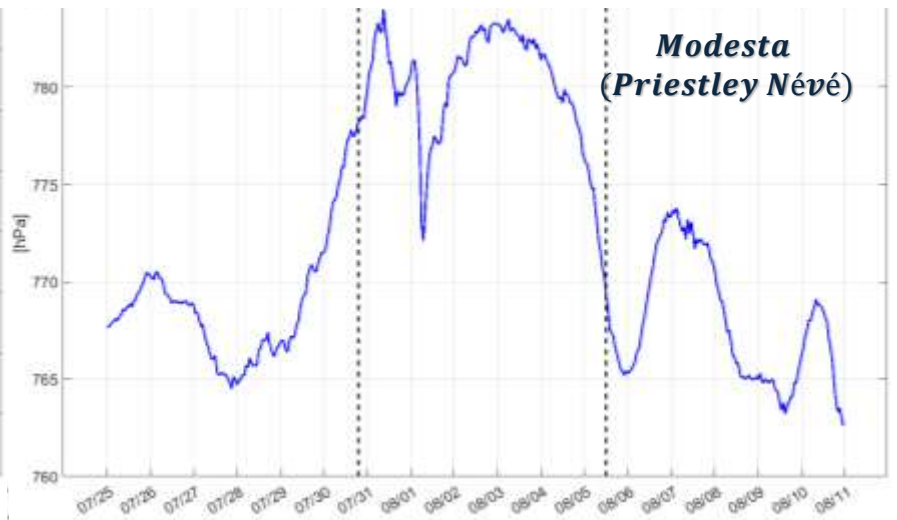
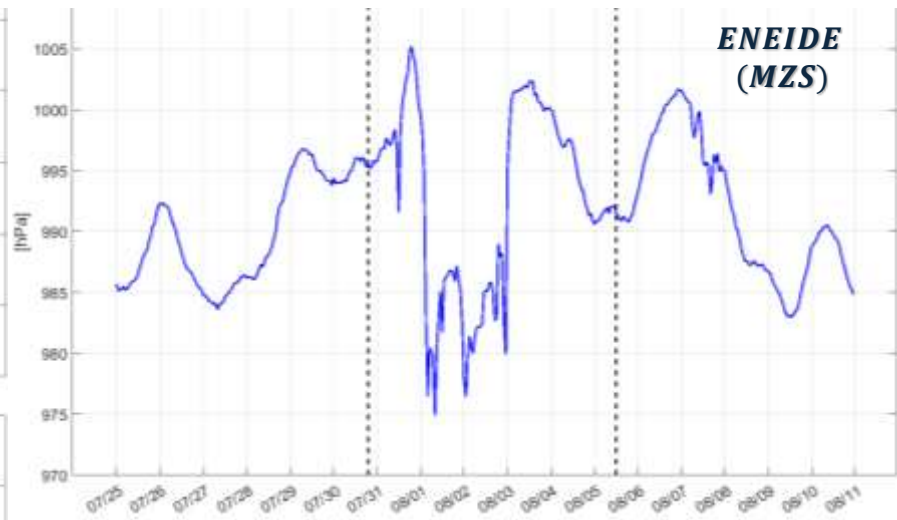
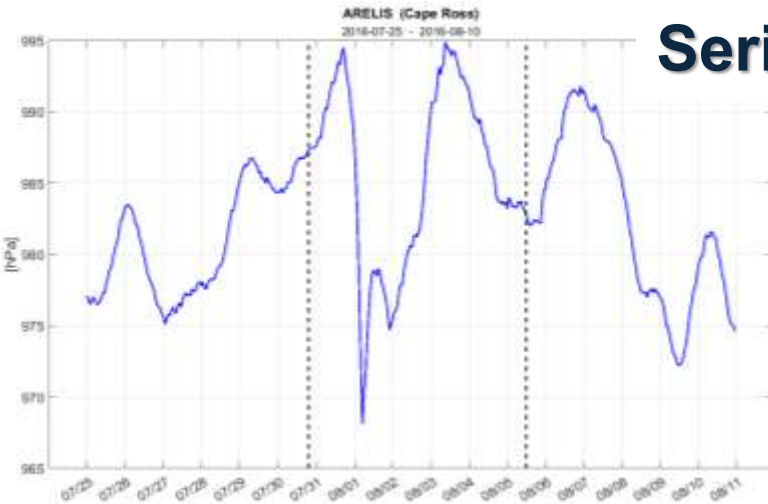
marzo 2022



Serie temporali temperatura atmosferica da AWS - evento 2016

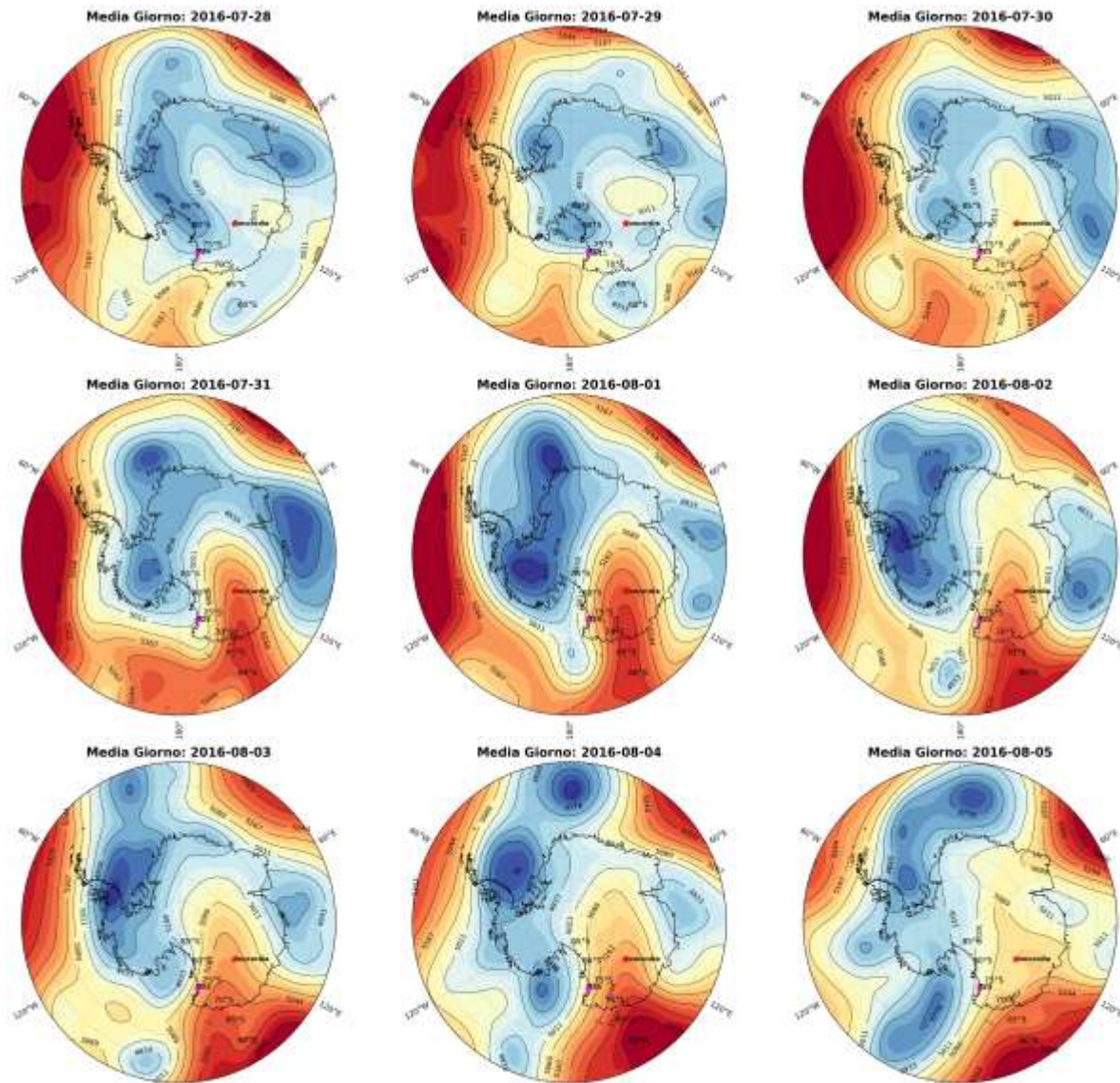
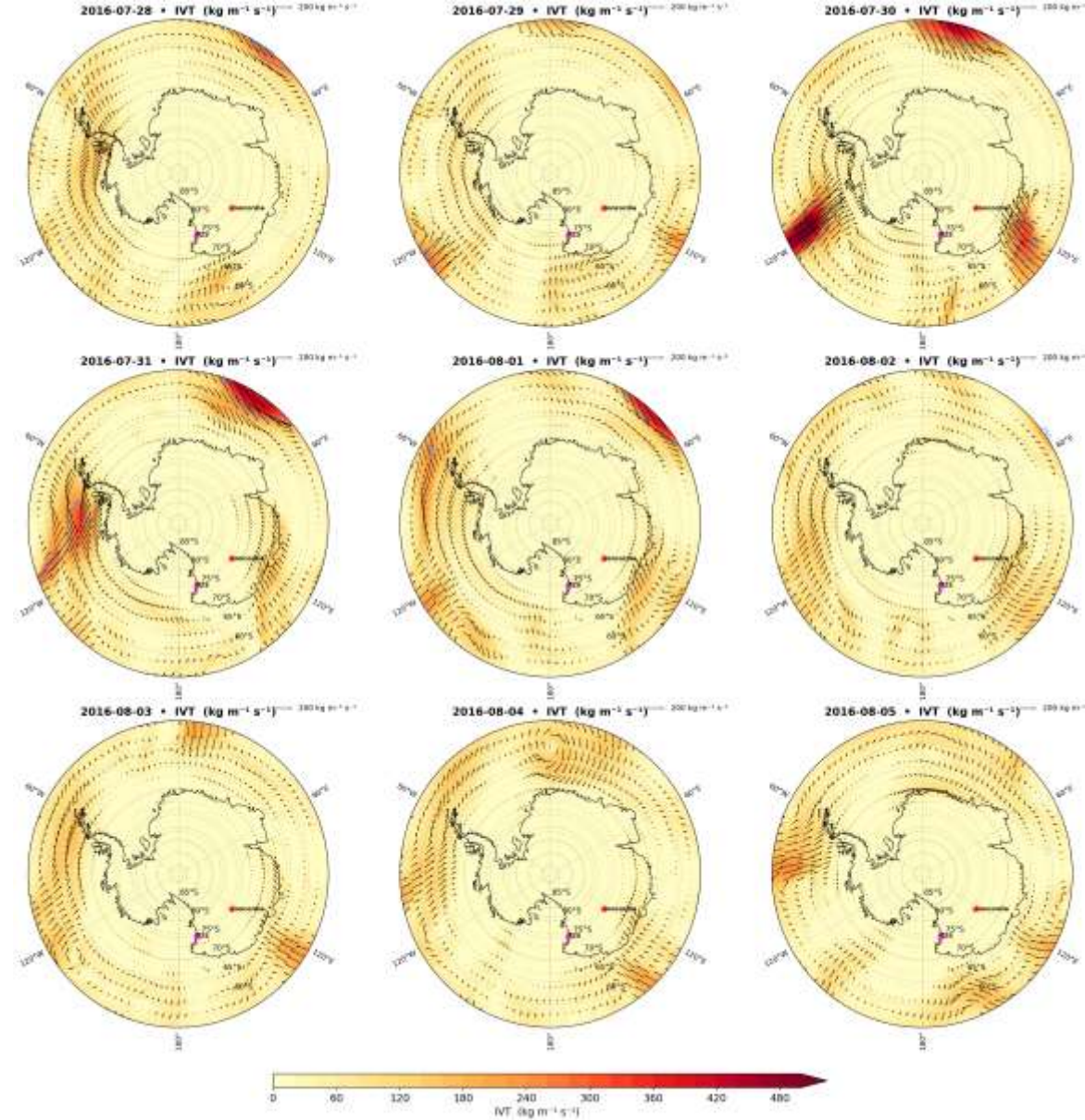


Serie temporali pressione atmosferica da AWS – evento 2016



Reanalisi ERA 5 - ECMWF

altezza geopotenziale 500 hPa



integrated water vapor transport (IVT)



luglio 2016

Conclusioni

- le osservazioni in situ sono fondamentali per studiare la variabilità del sistema sul lungo periodo, in particolar modo in un contesto di cambiamento climatico come quello attuale.
- 40 anni di osservazioni continue grazie a una rete che si è progressivamente ampliata.
- Dati affidabili e di lungo periodo, essenziali per la caratterizzazione meteo-climatica della regione.
- Le osservazioni meteorologiche forniscono un background indispensabile per studi atmosferici, glaciologici, biologici, così come oceanografici,...
- Continuità garantita da personale scientifico, tecnico e logistico
- Operatività mantenuta per 40 anni in condizioni ambientali tra le più difficili del pianeta



Grazie