Theme 7: Variability, extremes, and tipping in a changing Antarctic climate

ANTARCTICA INSYNC

Chairs: Mathieu Casado, Irina Gorodetskaya, Louise Sime, Martin Werner

White Paper:

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Theme 7: Climate variability

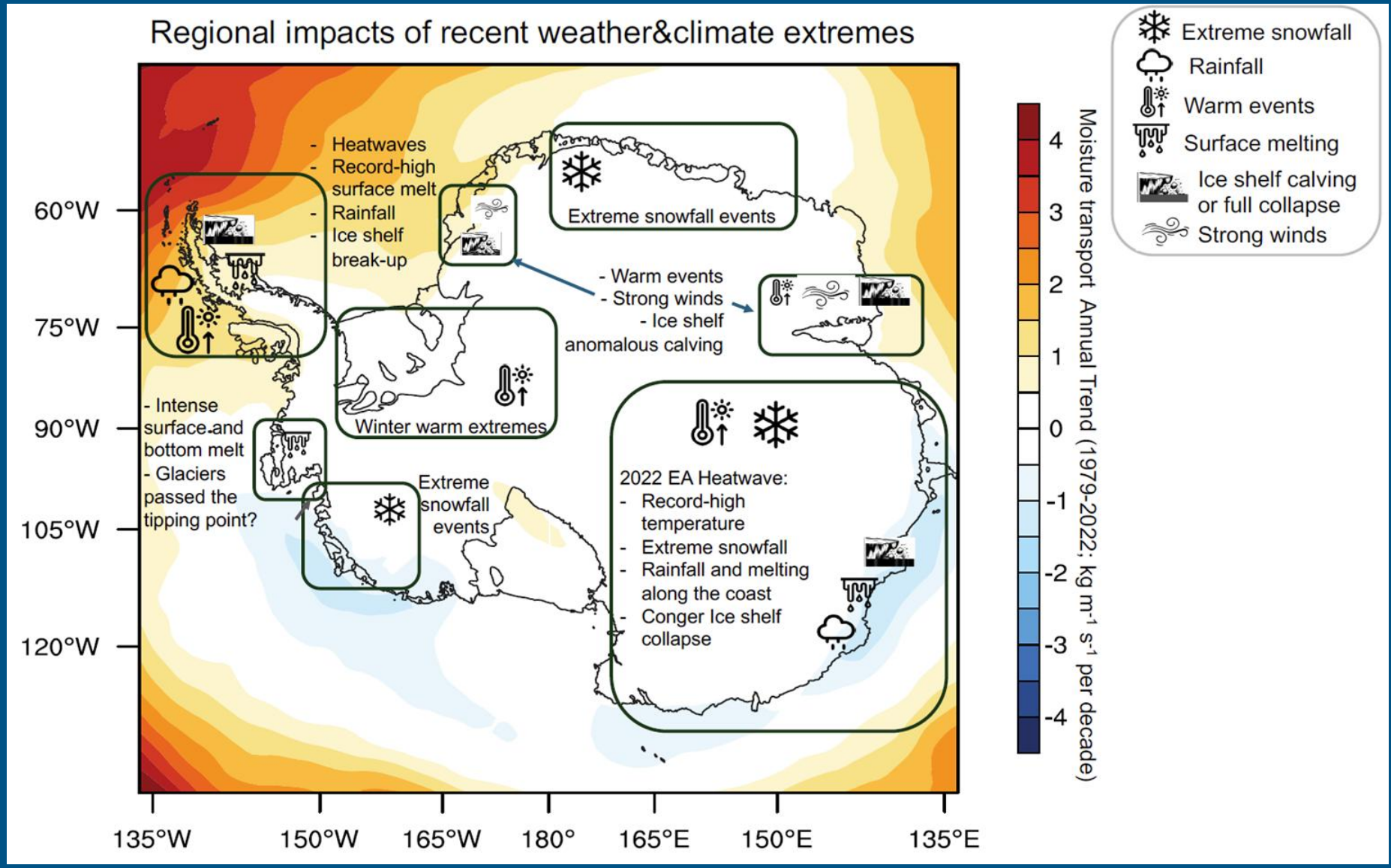
- **put observations collected during Antarctica InSync (2027-2029) into a longer-term climatic perspective**, **focussing on climate variability, extreme events, and rapid climatic changes, such as tipping points**
- **link changes at time scales ranging from events** (storms, atmospheric rivers, heat waves, major surface melt) **to multi-decadal and even longer-term observations** (surface mass balance, Antarctic contributions to global sea level and broader water-cycle changes), which are also addressed by other themes
- use a **wide array of tools** (including but not limited to shallow ice and sediment cores, isotopes, and long-term historical records from e.g. weather station data)
- consolidate the Antarctica InSync community efforts around Antarctic past and future variability in observations

Theme 7: Climate variability

- ***Theme 7 principal focus:***

- **Snow, firn and SMB:** Fund coordinated field and satellite-calibration measurements to reduce the largest uncertainty in sea-level projections: how snowfall, melt, refreezing and runoff will change
- **Atmosphere and water cycle:** Expand weather, precipitation and water-isotope observations to track storms and moisture transport inland – essential for forecasting extremes and future snowfall/rainfall shifts.
- **Ocean–sea ice–atmosphere coupling:** Invest in marginal-ice-zone observations to understand how sea-ice loss and ocean warming amplify extremes, alter heat/moisture exchange, and threaten deep-water formation.
- **Variability and warming detection:** Combine new observations with ice-core and marine records to separate human-driven trends from natural variability and identify early warning signals of irreversible change.

Theme 7: Climate variability



Theme 7 White Paper: Identified Knowledge Gaps

- **Snow, firn and the Antarctic SMB**
  - What will be the overall Antarctic SMB changes under uncertainty in its components?
  - How do atmospheric drivers and firn processes affect susceptibility to hydrofracture?
- **Atmospheric circulation, extremes and the water cycle**
  - How will climate change affect atmospheric circulation and the hydrological cycle in Antarctica?
  - How will the Antarctic precipitation origins and pathway processes change under anthropogenic forcing?
- **Sea surface interactions with the atmosphere**
  - How does sea-ice loss modify marginal-ice-zone fluxes and boundary-layer dynamics?
  - Are Southern Ocean warming and sea-ice loss already reshaping Antarctic SMB and extremes?
  - What is the potential for ongoing atmospheric changes to cause abrupt changes in ABW formation and SO overturning?
- **Characterising climate variability and warming**
  - What will be the magnitude and trajectory of climate warming amplification over Antarctica?
  - How will climate variability across timescales evolve as Antarctica warms?
  - How can palaeoclimate archives be better used to constrain Antarctic and Southern Ocean variability and warming?

Theme 7 White Paper: Key Variables

Table 1: Antarctic Key Variables including links to key questions, time scales, observing platforms, and climate archives.

System domain	Key variables on short time scales	Key variables on long time scales	Key question	Primary observing platforms	Why this matters
Precipitation & accumulation	Snowfall rate	Thickness/density of annual layers	2.1a, 2.2a	AWS (precip sensors), precipitation, disdrometers, radar, satellite, ice cores, stake networks, GPR, firn cores, sounding	Dominant mass-gain term; largest SMB uncertainty
	Rainfall rate & phase	Ice lenses/crusts	2.1b, 2.2a		Controls firn saturation and runoff onset
	Accumulation	Accumulation	2.1a, 2.4a		Calibration of satellite SMB; trend detection
	Vertical precipitation structure		2.2a		Links circulation and orography to snowfall
Wind-driven snow processes	Blowing/drifting snow flux		2.1a	AWS, snow particle counters, satellite, flux tower, water isotopes, ice chemistry	Major redistribution and sublimation loss
	Sublimation rate	Metamorphism	2.1a, 2.4c		Often missing SMB term in models
Near-surface meteorology	Air temperature	Temperature reconstruction	2.1b, 2.4a	AWS, automatic stations, flux towers, eddy covariance, masts, ships, water isotopes, dusts	Melt threshold; firn thermal state
	Humidity		2.1a, 2.2a		Sublimation and surface fluxes
	Wind speed & direction		2.1a, 2.2a		Snow transport; circulation signal
	Turbulence	Dust particles	2.1b		Controls sensible/latent heat exchange
Surface energy balance	SW & LW radiation (↓/↑)	Insolation	1.1, 2.1b, 2.2a, 2.3a	AWS, flux towers radiometers, satellite, models	Primary control on melt and refreezing
	Sensible & latent heat fluxes		2.1a, 2.1b, 2.3a		Close surface energy and water budgets
Cloud properties	Cloud fraction, phase, optics		2.2a,2.3a	Satellite, cloud radar, lidar	Radiative forcing; precipitation formation
Atmos. structure & circulation	Boundary-layer profiles (T, q, wind)		2.2a, 2.3a	Radiosondes, UAVs, AWS towers, wind profilers, reanalysis, models	Coupling circulation to SMB response
	Vertical wind profiles		2.2a, 2.3a		Moisture transport pathways
	Integrated moisture transport		2.2b,2.4		Source regions of future snowfall
Water-isotope tracers	Precipitation isotopes	snow pit and ice core isotopes	2.2b,2.3b,2.4a	Precip collectors, firn cores, stations, ships	Identify moisture origin and pathways
	Vapour isotopes (continuous)		2.2b,2.3b,2.4a		Real-time tracking of extremes (e.g. ARs)

[more table entries ...]

Theme 7: Climate variability

- **There is still time to join Theme 7:** https://forms.gle/ojE23zskuGw5Y3SD7
- **Contact us if you need anything:**
  Mathieu Casado (LSCE), Louise Sime (BAS), Irina Gorodetskaya (CIIMAR), Martin Werner (AWI)
- **So far, 11 planned InSync Working Groups are affiliated to Theme 7:**
  - Past, Present and Future Surface Mass Balance of the Antarctic Ice Sheet *(A. Zuhr, O. Eisen, T. Laepple, H. Huwald)*
  - Ice Shelf–Ocean Interactions *(Darelius, Davis, Nakayama, Zhao, et al.)*
  - Hotspots of atmosphere-ice-ocean interaction *(Caton Harrison, Silvano, Weiss, Bracegirdle)*
  - Coastal Connection and Hydrographic Drivers of Antarctic Biogeochemistry and Carbon Cycling *(I. Schloss)*
  - Atmospheric Monitoring in the Northern Antarctic Peninsula: Understanding the Drivers of Climate Extremes *(R. Cordero, G. Casassa)*
  - [6 more…]

More to be submitted. If you need help to suggest a new WG, don't hesitate to reach out to us!

Thanks for your attention

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Mailing list:

https://www.listserv.dfn.de/sympa/info/antarctica-insync-climate-variability

unesco Intergovernmental Oceanographic Commission

2021 2030 United Nations Decade of Ocean Science for Sustainable Development

COMNAP Council of Managers of National Antarctic Programs

SCAR International Science Council Scientific Committee on Antarctic Research

Theme 7 White Paper: Key Variables

How to organise the different domains ?

Separating short and long time scales

Key questions as numbers require to go through the manuscript

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