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Report to the WCRP Joint Scientific Committee
Climate and Cryosphere (CliC) Project
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1. Highlights achieved since JSC-43

1.1 MODELLING ACTIVITIES

Ice Sheet Model Intercomparison Project 6 (ISMIP6): (i) Designed, launched and simulated projections for Antarctica to 2300 based on CMIP5 and CMIP6 climate forcings under different scenarios (Appendix figure 1). Assessed the stability of basins around Antarctica beyond 2100 from an ensemble of ice sheet models, and the uncertainty coming from ice flow models and climate forcings. Also evaluated the role of ice shelf collapse in future projections and compared the results when climate forcing until 2300 is used to simulations for which forcings from the end of the 21st century is repeated after 2100. (ii) Identified crucial areas that need improvement for CMIP7 which requires interdisciplinary collaboration and the development of a new framework. "Experimental design for the second marine ice sheet and ocean model intercomparison project" in preparation to Geoscientific Model Development:

Marine Ice- Model Intercomparison Project Phase 2 (MISOMIP2): investigated the performance of existing ocean and coupled ocean-ice-sheet models in a range of Antarctic environments (comparisons to interannual observational data in the Amundsen and Weddell Seas). Have put together a MIPkit that combines datasets for model validation to evaluate ocean and ice sheet models and will be published in Geoscientific Model Development (manuscript in preparation).

Glacier Model Intercomparison Project (GlacierMIP): working on equilibrium response of glaciers at varying temperature increases above pre-industrial levels. Future: widen community outside Europe and USA, update the estimates of sea level rise from glaciers and reconstruction of past glaciers changes, including detection and attribution experiments

Diagnostic Sea Ice Model Intercomparison Project (SIMIP): the project has achieved its goal: to close the gap "Inability to diagnose how sea ice melts" by defining a set of essential diagnostic variables to understand the evolution of sea ice in any experiment using the sea ice model as part of CMIP, a major contribution as the community is preparing for CMIP7.

Earth System Modelling-snowMIP: improvements in model evaluation for tundra snow; comparison of snow models with ice-sheet models. Future: increase involvement of local communities in essential measurements of snow and expand the community to include Southern Hemisphere regions.

1.2 OBSERVATIONS, PROCESS STUDIES & INTERDISCIPLINARY ACTIVITIES:

Arctic Sea Ice Working Group (ASIWG): (i) Contributions to the State of the Climate and the Arctic Report Card: Despite recent rebounds in Arctic sea ice coverage, its long-term decline continues (BAMS 2022, in review, Meier et al., Meier and Stroeve, 2022. Appendix figure 2), (ii) Contributions to the The Oceanographic Society´s special issue on "The New Arctic Ocean", ASIWG co-chair guest editor with several articles by ASIWG members (Danielson et al., Holland et al., Lee et al., Perovich, D., Weingartner et al., 2022), (iii) A review and philosophical design for observing Arctic sea ice to accelerate understanding of the Arctic sea ice system (Webster et al., 2022. Figure 3, Appendix), (iv) The Sea Ice Outlook (SIO) led by ASIWG member W. Meier. Seasonal forecasts of Arctic sea ice extent for 2022 are shown in Appendix figure 4.

Antarctic Sea Ice Processes &Climate (ASPeCt): Published a new structure for the Sea Ice Essential Climate variables of the Global Climate Observing system (GCOS; Lavergne & Kern et al. 2022) which includes standardization of observation protocols and development of best practices. This initiative occurs in concert with WMO´s Global Cryosphere Watch (GCW) Sea Ice best practices. Continue to develop *ASPeCt* ship-based observations system and database for sea ice measurements by remote vessels (airborne and under ice), ship-based instrumentation and sampling. ASPeCt updated and quality controlled its database with new data and made the database accessible to the larger public by formatting the data to make it easier for incorporating into climate models, analysing the data and writing up the results. An outcome of this is their newly updated sea ice cards for training of sea-ice observers on our icebreakers.

Ice Sheet Mass Balance (ISMASS): Publication of *A High-End Estimate of Sea Level Rise for Practitioners* (van de Wal et al. 2022) after a community effort of scientists and practitioners to discuss the physical evidence to quantify high-end global SLR for practitioners (approach complementary to IPCC6). Large and growing difference between long-term scenarios at centennial time scales. Both process understanding and emission scenario control high-end SLR. *The workshop: "Ice Sheets: Weather versus Climate"* explored the degree to which short-term fluctuations and extreme events in the ice sheets (both Greenland and Antarctica) in the past two decades reflect their longer-term evolution and response to ongoing climate change. A review paper summarizing the outcomes is submitted. *ISMASS* contributes to SCAR Instabilities & -Thresholds in Antarctica (INSTANT) project by leading a working group on "Inter ice-sheet models simulation design" bridging the gap between past and present/future modelling.

Southern & Northern Ocean Regional Panels (SORP & NORP, both w/CLIVAR): New insights into the sources, pathways, and impact of Polar freshwater (FW) on the Arctic and Southern Ocean: local processes at the mesoscale and release depth are important for dispersion and export of FW which are not resolved at 1 degree-resolution climate models. SORP also contributed to the "Southern Ocean Action Plan 2021-2030", which was in turn a contribution to the UN decade of the ocean.

Permafrost Carbon Network (PCN): The major science highlight was the publication of a decade of permafrost carbon science including nine scenarios of cumulative greenhouse gas (methane, carbon dioxide) release and the potential effects on climate change. Future impacts depend both on human actions and the response of Arctic ecosystems (Schuur et al 2022, Appendix Figure 5).

PolarCordex: Antarctic: Model projections suggest large differences in future Antarctic surface melting even for similar greenhouse gas scenarios and warming rates, hence leading to large uncertainties in future sea level rise. Clouds containing a larger amount of liquid water led to stronger melt (Kittel et al. 2022) so clouds could be a major source of uncertainties in projections of sea level rise. Arctic: A high-resolution (2.5 km horizontal resolution) regional climate modelling using HARMONIE Climate (HCLIM), provided a multi-decadal convection-permitting climate projection dataset covering Svalbard for the years 1991-2060 following the SSP5-8.5 scenario. Projected future changes in the distributions, focusing on precipitation and snow, were quantified (Landgren et al. 2022).

Biogeochemical Exchange Processes at Sea Ice Interfaces (BEPSII; w/ SOLAS & SCAR Action Group): Organized a Sea-Ice school at the Canadian High Arctic Research Stations (CHARS) in Cambridge Bay, Nunavut, attended by 30 participants worldwide. The sea ice also served as the research ground for some of the lecturers and students who participated in the SCOR-WG ECV-ice inter-calibration experiment. BEPSII is preparing a *Position Analysis on Antarctica sea ice and ecosystems services* as well as a *Policy Brief for Antarctica* highlighting the position analysis on the Antarctic component of the sea-ice ecosystem services paper. A paper on Antarctica fast-ice nutrient data compilation has been submitted and accompanying data products (Kenley et al. 2022).s

Linkages between Arctic Climate Change and Mid-latitude Weather Extremes (LINKAGES): Both the North America and eastern Asia show examples of a causal connection from global warming through atmospheric and ocean physics to ecosystem disruption and human impacts. Warming influences are more than a local heating response but follow a chain of events involving disruption of the jet stream.

Polar Climate Predictability Initiative (PCPI): the project held no activities in 2022. In Spring/early summer of 2023 co-Chairs and theme leaders will meet to discuss the way forward for PCPI and to determine if there is still a place for the work that PCPI was initially intended to do or if that work has been done and it is time to wind up the initiative.

1.3 CLiC GRANTS

First call 2021/2022: Four grants were awarded to ECRs from Uzbekistan, Pakistan, Argentina, and Germany to conduct research in glaciers and snowpack in the Himalayas and the Argentinian Andes. Three were completed, the one was delayed and will start in 2023. Highlights of outcomes are described below:

Glacier monitoring and educational activities in the Karakoram Mts: (i) Production of one of the most comprehensive ablation datasets available for the region that allows for the study the influence of different meteorological variables on ice melt; a better understanding of glacier ablation processes; (ii) A basis for long-term glacier monitoring in the region sustained by local guides and students; (iii) Capacity building: training of local guides in glaciological measurements techniques.

Meteorological forecasts for the early warning of hazards in the glacierized catchments in Uzbekistan and Kazakhstan: (i) Recommendation of ecPoint Rainfall as proxy for the operational application of heavy rainfall leading to debris flow formation to support impact-orientated forecasting and early warning systems in Central Asia, and implementation in decision-making in collaboration with the Central Asian Regional Glaciological Centre (CARGC), Kazakhstan State Agency for Mudflow Protection (KSAMP), representatives from the educational system (National University of Uzbekistan, Al-Farabi Kazakh National University), and local authorities. (ii) Recommendations for the national decision-makers on the implementation of the new method of meteorological forecast in risk reduction and hazard control; (iii) Improved research capacity in Uzbekistan and new and links between Hydrometeorological Research Institute in Uzbekistan, University Reading in the UK and international organisations such as the ECMWF.

Snowpack characteristics in the Karakoram Mts via in-situ measurements and surface modelling: Measurements of snowpack characterizing variables were carried out for the first time in Pakistan, at three catchment locations (i.e., Gabin Jabba, Khyber Pakhtunkhwa, Skardu, Gilgit Baltista and Chitral). The data was used to evaluate performance and validation of the snow models SNOWPACK and Alpine3D, which are energy balance-based models developed at WSL Institute of Snow and Avalanche Research (SLF) to simulate accumulation and ablation of snow. SNOWPACK was able to simulate the start of accumulation and ablation seasons but overestimated the magnitude of snow depth compared to the in-situ data. Decadal timeseries show a decreasing trend in show depth amplitude variations. Snow accumulation simulated by Alpine3D underestimated snow depth compared to in-situ data. The snow modelling framework will be shared with the Aga Khan Agency for Habitat (AKAH) to enhance their cryospheric monitoring capacity in Pakistan. AKAH is a non-profit organization and works to provide the local mountain communities information regarding potential hazards. AKAH shared the ground measurements that have been collected by them during the last five years to improve this study and will be provided the necessary help in building their capacity to operationally run snow models.

Glacier related hazards in the Northern Patagonian Andes of Argentina: *This project has been delayed and it will start in 2023. We present here the project descritption*: The glaciers in Northern Patagonian Andes of Argentina have experienced considerably mass loss in the past decades. In particular, the retreat and thinning of the Manso glacier, the region's largest glacier and a major turist attraction, gave rise to a proglacial lake and in 2009, without any warning, the terminal moraine partially collapsed, provoking a *glacier lake outburst flood* (GLOF), isolating the nearby population, and severely affecting the area's infrastructure. After the GLOF, the glacier thinning, and retreat rate has progressed considerably since then. Simultaneously, the lake grew faster than any other proglacial lake in the region and nowadays is twice its pre-GLOF size, raising the concern among the inhabitants and the tourist companies. The growth rate of the lake and the rate of glacier retreat respond to frontal ablation. The project aims at the monitoring the frontal ablation rate and projecting its future rate to develop adaptation measures and assessment of eventual new GLOF.

Second call 2022/2023: Four ECRs from Canada, Japan, UK and Mongolia were awarded grants to carry out research on mountains hazards and water availability in Nepal and the Chilean Andes, Remote sensing method development for sea ice for the Arctic and Antarctica and on permafrost degradation in Mongolia.

1.4 DIALOGUES WITH LEADERS OF CLIC ENDORSED ACTIVITIES:

The co-chairs met with leaders of the fifteen endorsed activities to discuss future plans, e.g., continue under the umbrella of CliC and if so, how they would target the CliC´s new vision and objectives. Key messages are summarized below:

- Leaders acknowledged the role of CliC as a catalyst for gathering scattered research communities notably the modelling communities under the WCRP Grand Challenge: *Melting Ice and Global Consequences (2014-2021)*.
- Most activities have achieved their original goals and are now in the process of synthesising results, summarizing lessons learned as well as working on new research questions or identifying gaps in their field. Some will re-structure and/or seek new leadership. Thirteen of the fifteen activities wish to continue under the CliC umbrella, while two are considering sunsetting.
- Future expectations for CliC: (i) To be a promoter of the international research effort under its umbrella, (ii) Become a repository and curator of the legacy of endorsed activities, (iii) Assist the modelling community to design a funding strategy regarding data availability, storage and processing, (iv) CliC as coordinator or co-lead of an effort to produce a *Report Card for Antarctica.*

1.5 THE INTERNATIONAL PROJECT OFFICE (IPO)

The IPO, hosted by the Bjerknes Centre for Climate Research (Norway) since 2020, closed its doors in December 2022. The office will move to its new host: the University of Massachusetts at Amherst and will be staffed with an Executive Director (ED) and Executive Officer (EO) and a communications expert. Candidates have been interviewed for the ED and EO; and the EO is expected to be in place in June 2023. The WCRP secretariat is providing administrative support to the project during the transition.

2. Planned science initiatives and major events

- *Implementation of CliC Strategy Plan 2022-2031. N*ew CliC activities will be launched that target strategic areas. They will be time-limited and with clear objectives, outcomes, and deliverables. New activities shall showcase the impact of CliC contribution to local communities in regions affected by a decreasing cryosphere and enhance WCRP visibility.
- *Re-structuring of CliC* to accommodate for new vision, objectives and research activities.
- *Joint CliC-WMO call for Grants 2023/2024*: WMO has allocated additional to launch a joint call with CliC for Grants to Early Career Scientists with the goal to build linkages with WMO cryospheric activties such as the Global Cryosphere Watch, and the polar regional climate centres and outlook fora.
- *CLIC Open Science Conference in 2025*: Dates and venue to be determined.

3. Active or planed collaborations with other Core Projects, Lighthouse Activities etc.

On-going collaboration:

CLIVAR: Joint Southern and Northern Ocean Regions Panels (SORP & NORP)
SPARC: Polar Climate Predictability Initiative (PCPI)
GEWEX: Land surface, snow and soil moisture MIP (LS3MIP)
CORDEX: PolarCORDEX (Regional downscaling in Arctic and Antarctica)
*CMIP***:** ISMIP6, SIMIP, MISOMIP, GlacierMIP, ESM-snowMIP/LS3MIP
Safe Landing Climates: Ice Sheet Mass Balance and Sea Level (ISMASS)

Planned collaboration:

- *GEWEX***:** (i) Join the Global Precipitation Experiment (GPEX); (ii) the Regional Hydroclimate Project ANDEX
- *EMSO***:** All CliC modelling activities will liaise with ESMO.

- *RifS*: Arrange for a dialogue to explore venues of cooperation with RifS planned 4 clusters: #1 "Regional climate and projections", #2" Sub-seasonal to Decadal predictability" and #3 "Weather and climate Extremes", #4 "Communication and Societal Engagement"
- *MyClimate Risk*: Explore venues of collaboration with the ICIMOD Himalayan Hub
- *Safe Landing Climates*: pertinent topics (i) Arctic-tropics teleconnections of water resources, (ii) permafrost (in connection to methane mitigation)
- *Digital Earth:* The cryosphere is missing in this LHA. Potential CliC involvement through modelling of the physical climate system that resolve storms in the atmosphere, eddies and boundary currents in the ocean, streamflow in catchments on the land and large glaciers in the cryosphere.
- *Academy*: Promote capacity building and training opportunities endorsed by CliC.
- *WWRP*: Participate in the Polar Project 2024-2028

3a. Requests for the WCRP Academy to support your training activities?

- Promote capacity building and training opportunities endorsed by CliC

4. Partnerships & Liaisons

CliC co-endorsed activities	**Partner**
Antarctica Sea Ice Processes & Climate (ASPeCt)	SCAR & WMO GCW
Ice-sheet Mass Balance & Sea Level (ISMASS)	SCAR & IASC
Linkages Arctic Climate Change and Mid-Latitude Weather Extremes (LINKAGES)	
Southern Oceans Regional Panel (SORP)	SCAR & CLIVAR
Biogeochemical Processes at Sea Ice Interfaces (BEPSII)	SCAR, IASC & SOLAS
Permafrost Carbon Network (PCN)	NSF, ARCUS, SEARCH

Liaisons	**Organisation**
Atmosphere Working Group: J. H. Christensen (past WCRP JSC member & CliC)	IASC
Cryosphere Working Group. SSG member T. Meloth	
SSC ICARP Fourth International conference on Arctic Research Planning (ICARP IV): CliC co-chair A. Lovecraft.	
Arctic-Subarctic Ocean Fluxes (ASOF): F. Straneo (past CliC chair)	ASOF
Association of Polar Early Career Scientists (APEsCS): J. Höfer (past Exec Committee)	APECS
Executive Council Panel on Polar and High Mountain Observations Research and Services (EC-PHORS): SSG member T. Meloth	WMO EC-PHORS

5. Issues and challenges*:*

1. **CliC progress**: the SSG has not met in person since 2019, at time when many new members joined in. During the same period, the project had very limited support from an understaffed IPO. All this has thwarted the regular progress of the project. CliC will pick up pace this year with the prospect of an SSG meeting in-person and benefiting from the support of a fully staffed IPO at its new host.
2. **New structure for CliC?** With thirteen endorsed activities wishing to continue under the umbrella of CliC, and with plans of launching new activities from 2024 that target CliC new objectives and strategic areas in the coming decade, it exerts a pressure on the budget which means the project won´t be able to support everything at the same level as before. This calls for a re-structuring of the project to encompass its new vision and strategic areas, as well as setting of funding priorities.
3. **Partnerships and liaisons:** re-visit the cooperation and liaisons with pertinent partners/organisations to avoid duplication of efforts and co-fund of activities.
4. **Model data**: The modelling community is concerned with the lack of support for data archival, availability and accessibility, and have inquired whether CliC could assist in the design a funding strategy with the international community.

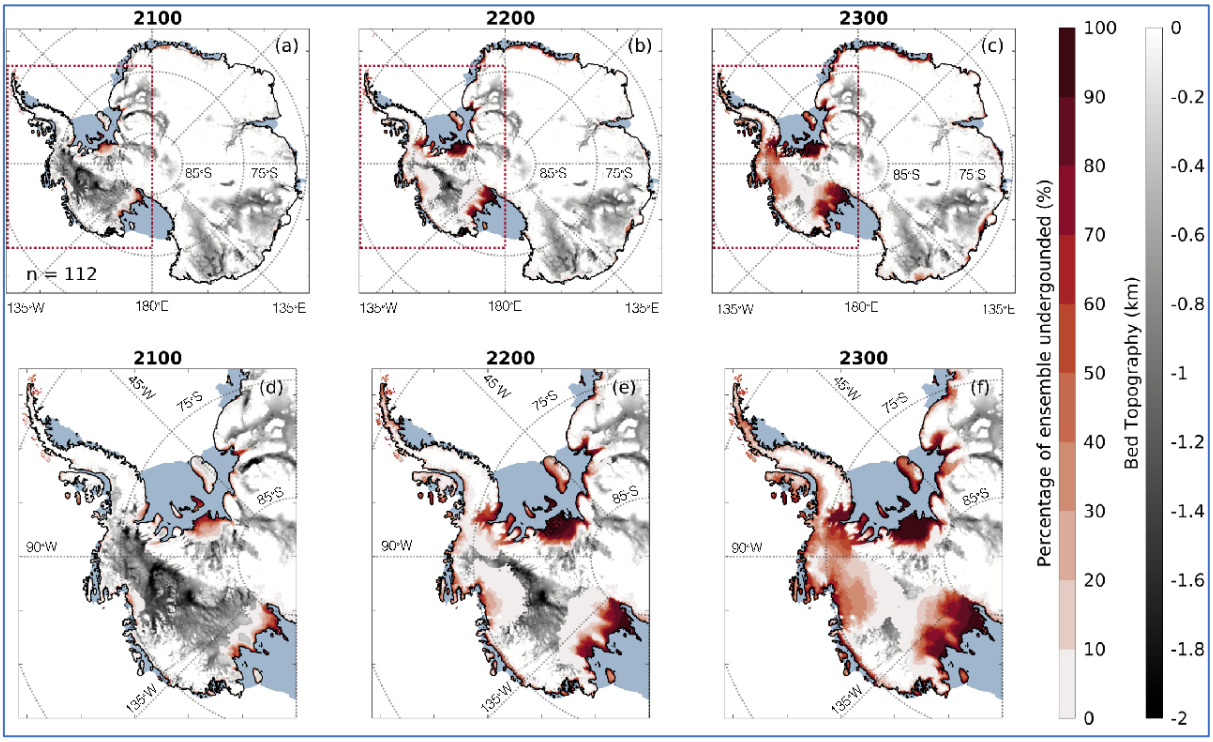

Figure 1 ISMIP6: Grounding line retreat in years 2100, 2200 and 2300 from over 110 ice sheet simulations in response to multiple climate models under high emission scenarios (RCP8.5 and ssp5-85).

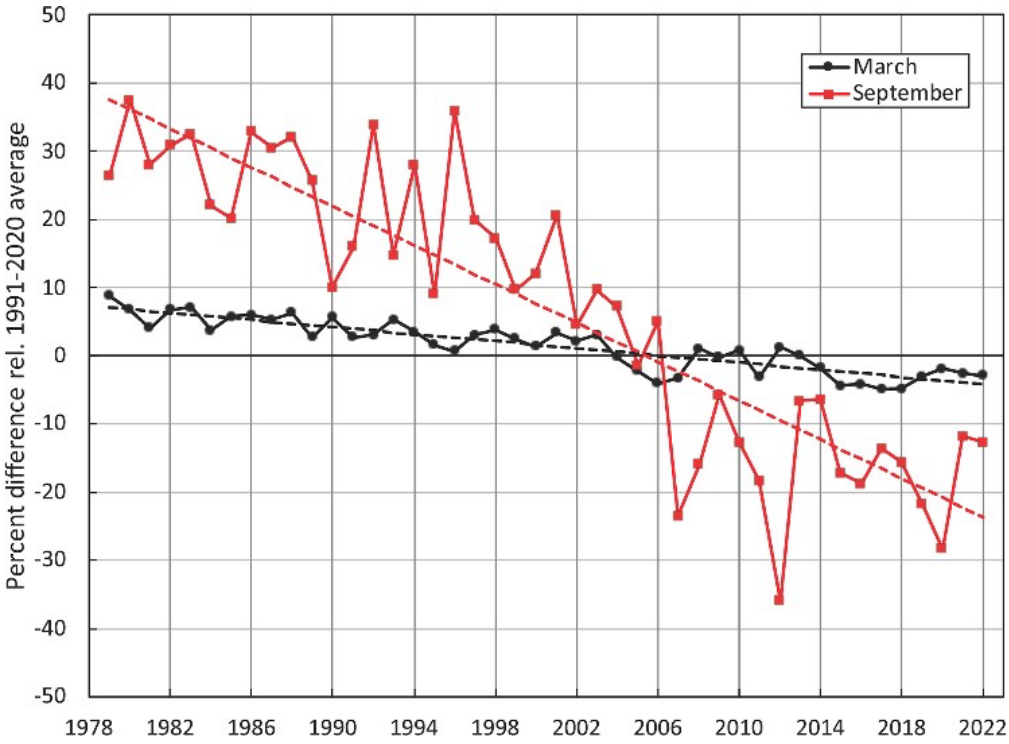

Figure 2 ASIWG: Monthly sea ice extent anomalies (solid lines) and linear trend lines (dashed lines) for March (black) and September (red) 1979 to 2022. The anomalies are relative to the 1991 to 2020 average for each month; note that this represents a change from 2013- 2021 reports which used a 1981 to 2010 baseline average. (This if figure 1 in Sea Ice of the Arctic Report Card 2022: https://arctic.noaa.gov/Report-Card)

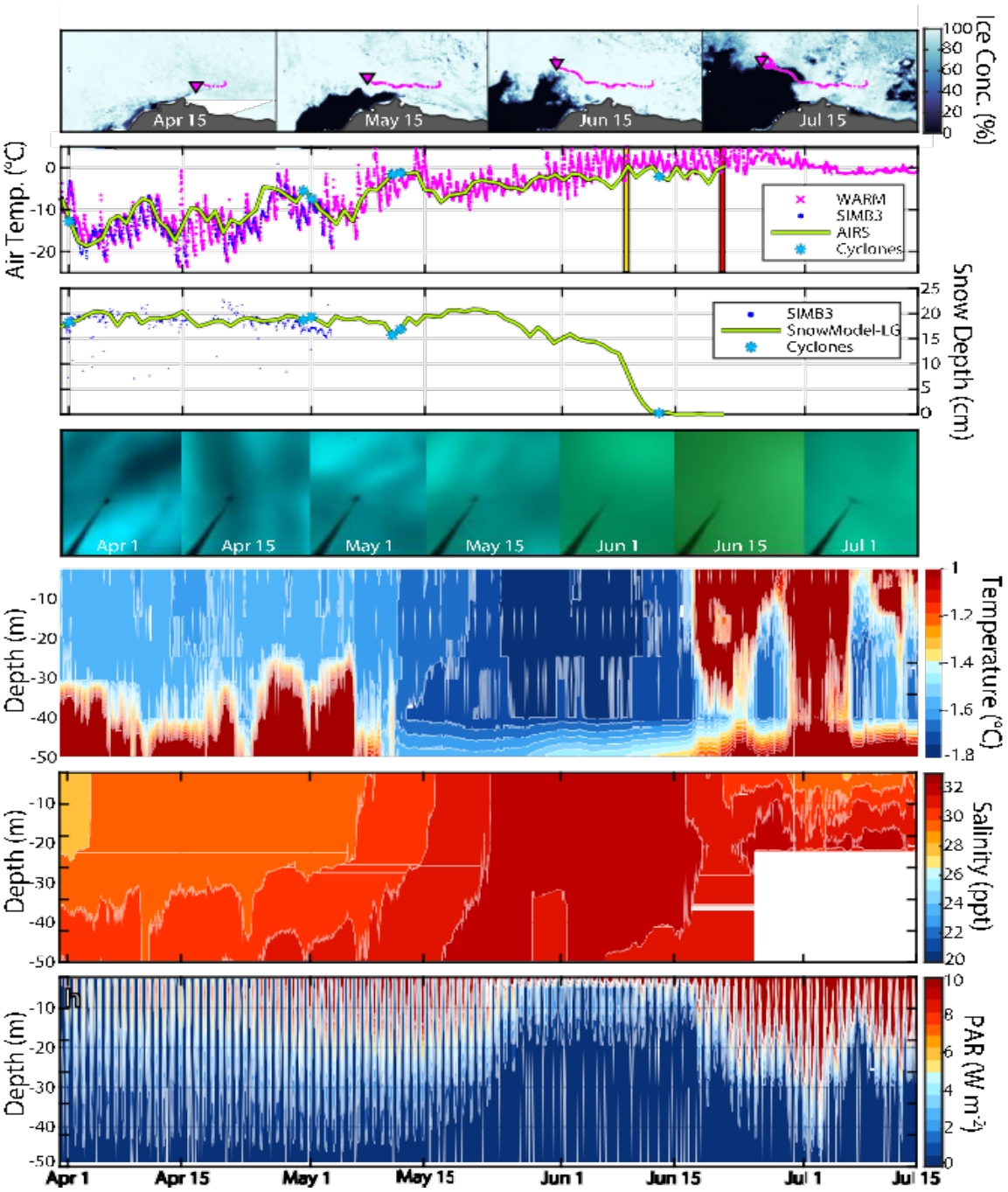

Figure 3 ASIWG: Harmonizing disciplinary datasets from satellites, models, & field observations can reveal critical interactions between the atmosphere, snow, sea ice, ocean, and ecosystem conditions. Adapted from Webster et al., 2022.

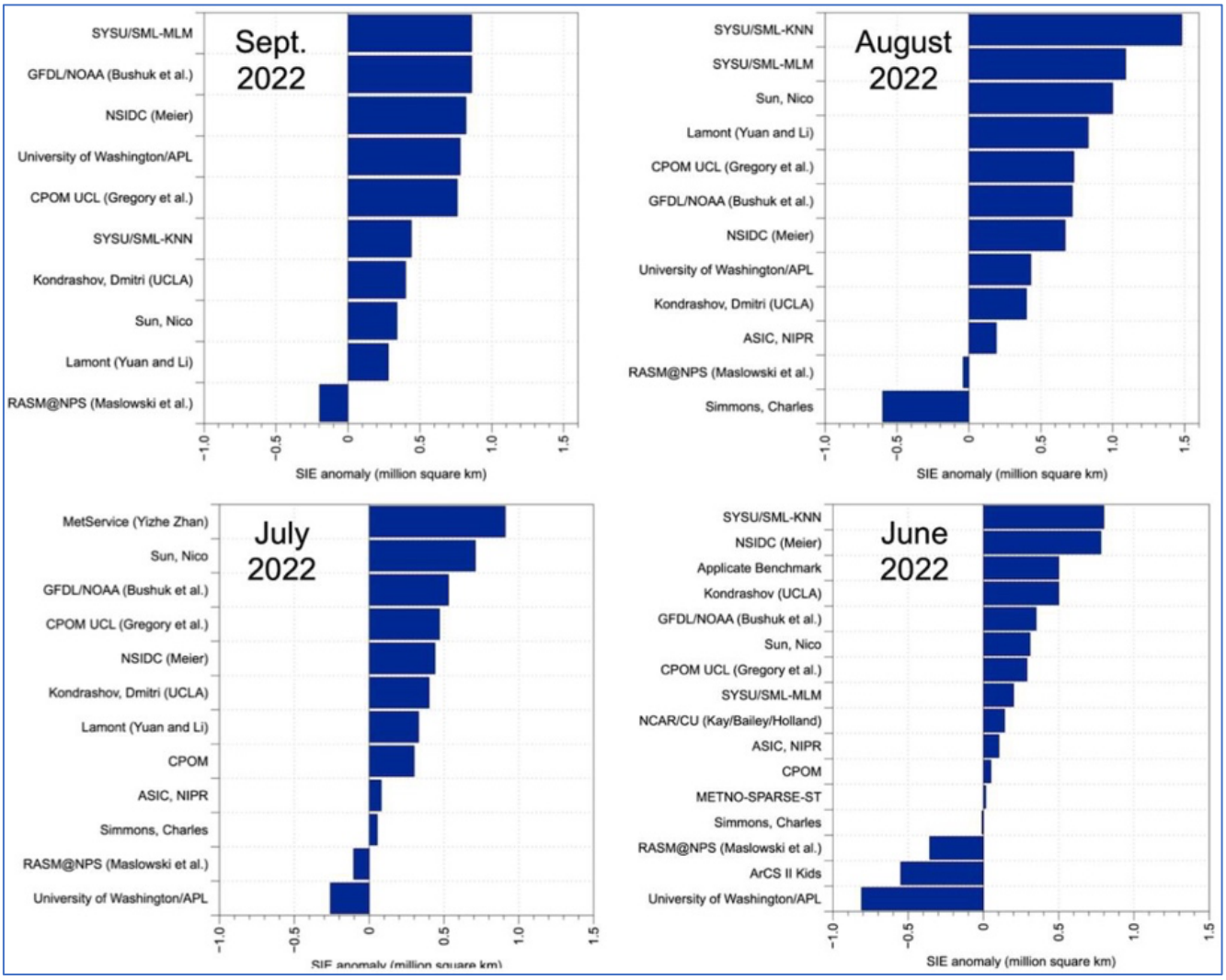

Figure 4 ASIWG. Artic sea ice extent forecasts for September (top left), August (top right), July (bottom left), and June (bottom right). Sea Ice Outlook forecasts for 2022 September sea-ice extent anomaly in millions of square kilometres (2022 Sea Ice Outlook report here: https://www.arcus.org/sipn/sea-ice-outlook/2022/post-season

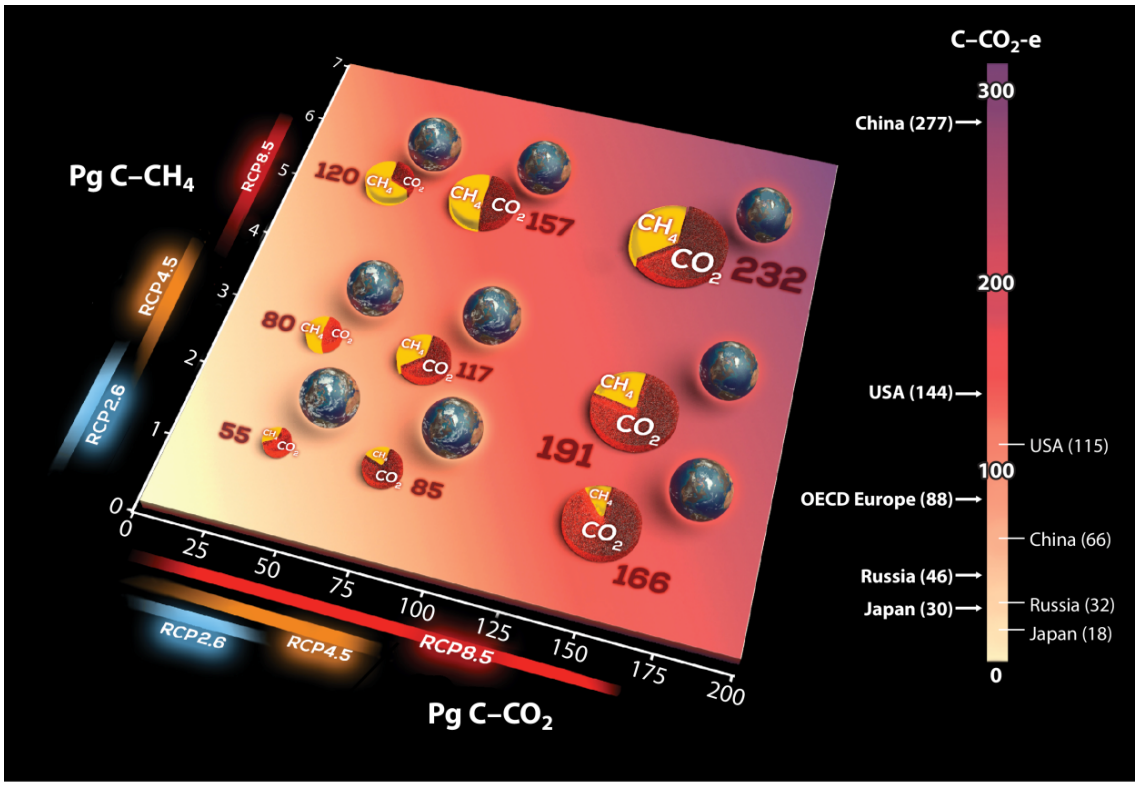

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Figure 5 The Permafrost Carbon Network: Nine example scenarios for cumulative projected greenhouse gas emissions based on three levels (low, medium, high) of net CO2 and three levels (low, medium, high) of net CH4 emissions to the atmosphere for 2000–2099. Axes represent mass of carbon (petagrams) contained in either CO2 or CH4 as a cumulative net release to the atmosphere in addition to preindustrial background carbon exchange. The color scale is the total greenhouse gas equivalents represented by the annual emissions of CO2 and CH4 together, in CO2-equivalent (CO2-e) units (petagrams C) with the weighting of CH4 relative to CO2. The CO2-e unit is also compared to extrapolated 2019 country-level carbon emissions (left labels) and historic (1850–2021) country-level fossil fuel carbon emissions (right labels) for several representative nations. The size of each pie chart is equivalent to the total CO2-e for each particular scenario; the cumulative CO2-e labelled under each pie chart shows the relative contribution of CO2 and CH4 to the total CO2-e. The nine scenarios for which emissions were quantified do not occupy the upper ends of the CO2 and CH4 emissions axes; a decade of projections has not eliminated the possibility of upper-end scenarios that are higher or lower than the range of those nine scenarios depicted here (Schuur et al. 2022)

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