PolarRES: Polar Regions in the Earth System

Description of WP5 tasks - Antarctic processes and ocean-atmosphere-ice interactions in the coupled climate system

Leads: Willem Jan van de Berg (UU) and Andrew Orr (BAS)

This document is a summary of WP 5, covering: i) a brief description of the work for each task and the participants involved (section 1), ii) an overall description of WP5 and how the tasks are aligned and will improve our understanding of Antarctic processes and ocean-atmosphere-ice interactions (section 2), and iii) a more detailed description of each task (section 3). The names of Institutes and the people involved is given at the end of the document (section 4).

**1.****Brief task description and information on participants and task leaders**

**Task 5.1: Aerosol-cloud interactions over polynyas**

Lead: BAS (Andrew Orr)

Participants: BAS, NASC, ULg, UU, ULe

Deliverable: D5.1 Report on improved understanding of aerosol-cloud interactions over polynyas (Lead BAS, month 30)

Milestone: MS5.1 Cloud droplet number concentration estimates for Antarctic polynya and non-polynya sea-ice conditions (Lead BAS, month 12)

*We will investigate the potential of polynyas to alter aerosol-cloud interactions by using UKCA-1km to simulate aerosol number concentrations and subsequently activated cloud droplet number concentrations over polynyas for several 10-day period case studies. Output from the UKCA-1km simulations will be used to develop an optimised estimate of cloud droplet number concentration for both polynya and non-polynya conditions (MS5.1) that can be used as input for RCMs (MetUM, MAR, RACMO2, Polar WRF) that currently make use of fixed droplet number concentration for the same cases, enabling enhanced understanding of how polynyas impact cloud cover, ABL, surface energy budget (links to Task 5.2 and 5.3) and hydrological cycle (D5.1). The RCMs will also be used to undertake further sensitivity studies to e.g. cloud tuning parameters.*

**Task 5.2: Atmospheric boundary layer over sea ice**

Lead: FMI (Timo Vihma)

Participants: ULg

Deliverable: D5.2 Report on new understanding of ABL over ice surfaces in the Antarctic (Lead FMI, month 30)

*We will analyse in detail ABL measurements from the sea ice zone in order to investigate differences between very stable and weakly stable cases, how large-scale forcing interacts with local ABL processes, turbulence-katabatic wind interactions, and the surface energy budget (links to Tasks 5.1 and 5.4). We will also analyse measurements over the ice sheet and ice shelves and make the first systematic comparison of differences in the ABL structure and turbulent flux profiles over sea ice, ice sheet and ice shelf. The representation of the ABL in the MAR model will then be examined and compared with the observations (D5.2).*

**Task 5.3: Extreme precipitation and temperature events over coastal West Antarctica**

Lead: NASC (Denys Pishniak)

Participants: NASC, UU, DMI

Deliverable: D5.3 Report on improved understanding of extreme events over coastal West Antarctica (lead NASC, month 30)

*We will investigate the role played by the Amundsen Sea Low in triggering extreme precipitation and temperature events over the coastal regions of West Antarctica by disentangling the role of large-scale forcing (e.g., advection of warm, moist air masses) versus local dynamics (e.g., orographically generated fine-scale flow patterns and foehn warming) (D5.3). This will be achieved by running simulations using HCLIM and Polar WRF at a resolution of 1-2 km to represent the key local features.*

**Task 5.4: Sea-ice albedo and surface energy budget**

Lead: UU (Willem Jan de Berg)

Participants: FMI, UHel, ULg, SJTU

Deliverable: D5.4 Report on new knowledge of sea ice albedo and surface energy budget (lead UU, month 30)

*We will investigate the effects of snow microstructure on the surface albedo of snow-covered sea ice and thus the surface energy budget (links to Tasks 5.1 and 5.2). Detailed observations from the ISPOL campaign on sea ice in the Weddell Sea and satellite products will be used, as well as output from RCM simulations. Additional sensitivity tests with MAR-NEMO and HCLIM-SICE will be carried out in which the snow/sea ice albedo parameterizations will be varied, enabling improved understanding of how variability in snow/sea ice albedo impacts the surface energy budget (D5.4).*

**Task 5.5: Wind-driven sea-ice drift and thermodynamics**

Lead: FMI (Bin Cheng)

Participants: UHel

Deliverable: D5.5 Report on new knowledge of sea ice albedo and wind forcing (lead FMI, month 36)

*We will use outputs from hindcasts using the ROMS ocean model to investigate aspects such as the impact of synoptic-scale cyclones and katabatic flow on sea ice drift, the disintegration of land-fast sea ice due to strong wind forcing, the opening and closing of coastal polynyas, sea-ice formation in polynyas and how an ice-shelf attenuates the katabatic flow and so modulates wind-driven sea ice drift (D5.5). This work will complement Task 5.1 and build on previous studies on winds and sea ice in the Antarctic coastal zone.*

**Task 5.6: Ice shelf-ocean interactions and bottom water formation**

Lead: IMMSP (Vladimir Maderich)

Participants: UHel

Deliverable: D5.6 Report on improved understanding of the role of surface forcing in controlling ice shelf-ocean interactions and bottom water formation (lead IMMSP, month 40)

Milestone: MS5.2 Pan-Antarctic ROMS hindcast (1979-2020) with interactive biogeochemistry (lead UHel, month 24)

*We will use the pan-Antarctic configuration of the ROMS ocean model and the unstructured-grid ocean model SCHISM (which includes the 2D Filchner-Ronne Ice Shelf (FRIS) ‘cavity’ model) to explore how local oceanic transport processes respond to fine-scale variability in surface conditions/forcing (e.g. due to wind stress, sea ice, coastal polynyas (link to Task 5.1), and air-ocean heat and fresh water fluxes). The surface forcing for the models will be derived from output from the high-resolution RCM simulations, and ROMS output (MS5.2) is used to force SCHISM. Observations will be used to tune the models. Output from these simulations will enable us (i) quantify how atmosphere-ice-ocean interactions control the rate of ice shelf basal melting and variability around Antarctica, (ii) provide detailed process understanding on the link between atmospheric surface forcing and basal melt underneath the Filchner-Ronne Ice Shelf, (iii) clarify the circulation pathways of Ice Shelf Water under the Filchner-Ronne Ice Shelf and obtain flow rates / budget information for the formation of Weddell Sea Bottom Water (D5.6).*

**Task 5.7: Interactions between ocean physics and biogeochemistry**

Lead: NORCE (Siv Kari Lauvset)

Participants: UHel

Deliverable: D5.7 Report on the interactions between ocean physics and biogeochemistry (lead NORCE, month 36)

*Output from ROMS, run in pan-Antarctic configuration and with interactive biogeochemistry module (MS5.2), will be used to further our understanding of how local ocean circulation affects key ocean biogeochemical processes such as CO2 uptake, acidification, and the depth of the calcium carbonate saturation horizon. This will allow us to assess the impact of localised ocean circulation patterns on the Southern Ocean carbonate chemistry and thus the biogeochemical changes causing rapid shallowing of the aragonite saturation horizon (D5.7). Observations and state estimates will be used to evaluate, and if necessary bias correct, output from the ROMS simulations.*

**Task 5.8: Synthesizing new understandings and interactions in the fully coupled climate system**

Lead: ULg (Xavier Fetweis)

Participants: All participants in WP5

Deliverable: D5.8 Report on the improved understanding of key processes and O-A-I interactions from Tasks 5.1-5.7 (lead ULg, month 45)

*This task integrates the process understanding improvement of Tasks 5.1-5.7 on the key Antarctic local processes related to ocean-atmosphere-ice interactions and identifies, together with Task 4.4, similarities and differences with key Arctic processes (D5.8). This task serves as starting point for the analysis of the storyline based Antarctic projections.*

**2. Summary of WP5: Antarctic processes and ocean-atmosphere-ice interactions**

If we are to understand how the Antarctic coupled climate system will evolve over the coming decades then it is essential to know how it varies in response to regional or hemispheric-wide climate variability and local processes, and their interplay (e.g. Turner et al., 2017). This contribution is not intended to cover all Antarctic processes but, instead, will focus on developing an improved understanding of key local atmosphere-ocean-ice processes that are closely linked/impacted by the regional changes associated with the WP1 storylines involving the SAM (e.g. due to its impact on the strength of the Southern Hemisphere westerly winds and influence on the Amundsen Sea Low; Hosking et al., 2013), sea ice extent, and the Atlantic meridional overturning circulation (AMOC). Many of the processes we intend to investigate in the Antarctic were also chosen for the Arctic in WP4.

Pressing challenges related to Antarctic sea ice that require better understanding are (i) the factors that control variations in its surface albedo (e.g. melting and changes in the snow layer; Zhou et al., 2007), (ii) the structure of the ABL over sea ice and its dependence on local processes (e.g. Tastula et al., 2012), (iii) the influence of localised wind forcing on sea ice in the Antarctic coastal zone (e.g. katabatic winds; Vihma et al., 2011), and (iv) the importance of persistent regions of open water and/or thin ice (e.g. polynyas) as sources of marine aerosols and their potential to alter cloud microphysical properties such as cloud droplet number (e.g. Gabric et al., 2018). Furthermore, these coastal regions experience both high accumulation and surface melt episodes, often due to strong meridional flow originating from the tropics (Turner el al., 2019). However, the role that complex coastal orography plays in locally amplifying both warming and accumulation is currently not well understood. Together, these shortcomings are responsible for sizeable errors in climate models (e.g. Gilbert et al, 2020) which limits our ability to predict climate change, including modelling atmosphere-ice-ocean interactions as they evolve in the future.

Around Antarctica, the influx of relatively warm circumpolar deep water onto the continental shelf and towards the floating ice shelves is highly variable and has a strong influence on shelf water heat content and basal melt. Furthermore, water modified by passage under ice shelves, particularly the Filchner-Ronne Ice Shelf in the Weddell Sea, is vital for the production of Antarctic Bottom Water, which is one of the globally most important deep water masses (Vernet et al., 2019). Both of these processes are strongly controlled by atmosphere-sea ice-ocean interactions, with both local (e.g. wind stress at the shelf break, air-ocean heat and fresh water fluxes; Webber et al., 2017) and hemispheric-wide variability exerting an influence. However, understanding these linkages is currently incomplete (Webber et al., 2017; Maderich et al., 2017), yet vital if we are to diagnose or predict melt rates beneath ice shelves (and therefore also ice sheet melt rates) and Antarctic Bottom Water production rates and thus global ocean circulation and climate. In addition, the circulation patterns around Antarctica accumulate CO2-rich water from the deep ocean in the thermocline which results in local carbonate ion minima at relatively shallow depths. Where these minima occur, the ocean is more sensitive to acidification due to the accumulation of anthropogenic CO2. Earth System models project that the Southern Ocean will likely become undersaturated with respect to aragonite (the least stable form of calcium carbonate) by the end of the century (Orr et al., 2005), and that this undersaturation will arise very rapidly – often within a single year (Negrete-Garcia et al., 2019). However, these models have very course resolution (~100 km) so our understanding of the influence of local circulation patterns and mesoscale atmosphere-sea ice-ocean interactions is currently incomplete, but necessary if we are to diagnose ocean ecosystem impacts of future ocean acidification.

In order to accurately predict how the Antarctic coupled system will evolve over the coming decades (WP3), a step change in our understanding of these key local atmospheric, oceanic, snow and ice processes, including their interactions and how they are linked/impacted to the WP1 storylines, is essential. As in WP4, the path towards this will be based on analysing novel information obtained from existing observations and state-of-the-art coupled and uncoupled model simulations, including from (i) a number of high-resolution atmospheric RCMs which are able to resolve local effects (MetUM, Polar WRF, RACMO2, HCLIM), (ii) the high-resolution coupled regional chemistry-climate model UKCA-1km (which uses the UK Chemistry and Aerosol (UKCA) module; Gordon et al., 2018), (iii) the high-resolution coupled ocean-atmosphere model MAR-NEMO, (iv) the eddy-resolving ocean model ROMS, which includes biogeochemistry, and (iv) the unstructured-grid ocean model SCHISM, which will be forced at its boundaries by output from ROMS, and includes the 2D Filchner-Ronne Ice Shelf (FRIS) ‘cavity’ model. Note that both ocean models can resolve the complex Antarctic continental shelves and sub-ice-shelf cavities and will use output from the fine-scale RCM simulations in (i) to provide improved understanding of how oceanic transport processes respond to variability in local surface conditions / atmospheric forcing.

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**3. Full task descriptions**

*Task 5.1: Aerosol-cloud interactions over polynyas*

Clouds exert an important influence on the energy budget and hydrological cycle (including surface temperature) of the Southern Ocean and the coastal areas around Antarctica. Clouds forming in these regions are highly sensitive to marine aerosols, which act as cloud condensation nuclei and can modulate the radiative effect of clouds via the aerosol indirect effect. However, the radiative impact of changes in aerosol on cloud formation is highly uncertain (Brooks and Thornton, 2018), and is thought to be responsible for sizeable errors in climate models – evident by their poor representation of surface radiation measurements (Gilbert et al., 2020). Moreover, while previous work has shown that seasonal sea ice extent influences aerosol concentrations (Gabric et al., 2018), the importance of persistent localised areas of open water as sources of aerosols (e.g. polynyas and leads) and their potential to alter cloud microphysical properties such as cloud droplet number has never been tested.

In this WP we will address this issue by using the regional configuration of the MetUM at kilometre scale spatial resolution, coupled to the UK Chemistry and Aerosol (UKCA) module (Gordon et al., 2018), to simulate aerosol number concentrations and subsequently activated cloud droplet number concentrations over localised areas of open water (e.g. Weddell Sea polynyas). UKCA computes prognostic aerosol concentrations, including sulphate, sea salt, black carbon, and organic carbon chemical components (Gordon et al., 2018). This represents a step-change in our ability to model atmospheric composition as the enhanced spatial resolution enables us to resolve the aerosol sources and sinks, interactions with clouds, and wind dynamics (e.g. turbulence, convection) that happen on small scales. The model will be run over the region of interest for 10-day case study periods. The simulations will use a hierarchy of model resolution and complexity (including the application of single and double moment microphysics) to explore how polynyas affect aerosol and ultimately cloud and radiation characteristics. The periods chosen will be selected to coincide with the availability of satellite and surface observations, including direct observations of clouds (Lachlan Cope et al., 2016).

We will further test the hypothesis that cloud droplet number concentration is different over polynyas by using output from the UKCA-1km simulations to develop the most appropriate cloud droplet number concentration based on environmental conditions that can be adopted by other regional climate models that make use of fixed droplet number concentration. This estimate of cloud droplet number concentration will be used as input for RACMO2.4, HClim, MetUM, WRF, and MAR for the same cases and allow us to determine how cloud cover, atmospheric boundary layer, energy budget and hydrological cycle differ for different sea ice extents across the suite of models. Note that the other regional climate models will also be used to undertake further sensitivity studies, such as cloud tuning parameters, to further our understanding of the representation of clouds in models (Listowski et al., 2017). Note also that this work is Bi-Polar, so can also be undertaken for the Arctic (e.g. May et al., 2016).

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*Task 5.2: Atmospheric boundary layer over sea ice*

Over the Antarctic cryosphere the atmospheric boundary layer (ABL) is predominately stably stratified and determines the atmosphere-ice exchange of key properties such as momentum and heat. The structure of the ABL is influenced by the large-scale advection of heat and moisture as well as by local processes that depend on the characteristics of the underlying ice surface, and therefore vary between the sea ice zone, sloping ice sheet, and flat ice shelves. However, despite thus being essential for the momentum and energy budget of Antarctica, these local processes are currently not well understood, resulting in their poor representation in climate models and errors in winds and temperatures.

To better understand these atmosphere-ice interactions in Antarctica this work will analyse in detail ABL measurements from the sea ice zone (Tastula et al., 2013; Valkonen et al., 2014; Jonassen et al., 2015, 2019), ice sheet (Kouznetsov et al., 2013; Nygård et al., 2017), and ice shelves (Mateling et al., 2018). It will make the first systematic comparison of differences in the ABL structure and turbulent flux profiles over sea ice, ice sheet and ice shelf. It will further investigate differences between very stable and weakly stable cases, how large-scale forcing interacts with local ABL processes, and turbulence-katabatic wind interactions. Finally, the ability of the ERA5 forced regional models used in this project will then be examined and compared with the observations as done over Arctic by Sedlar et al. (2020).

Jonassen, M. O., P. Tisler, B. Altstädter, A. Scholtz, T. Vihma, A. Lampert, G. König-Langlo, C. Lüpkes (2015). Application of remotely piloted aircraft systems in observing the atmospheric boundary layer over Antarctic sea ice in winter. Polar Res., 34, 25651, <http://dx.doi.org/10.3402/polar.v34.25651>.

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*Task 5.3: Extreme precipitation and temperature events over coastal West Antarctica*

The coastal zone of the Antarctic Peninsula (AP) and the Amundsen Sea Embayment (ASE) sector of West Antarctica consists of a number of outlet glaciers that drain the interior ice sheet down to the coastline and onto the ocean surface in the form of floating ice shelves, which then lose ice either by calving of icebergs or basal melting (Turner et al., 2017). Over recent decades many of these outlet glaciers such as Thwaites Glacier and Pine Island Glacier have accelerated and thinned, while the ice shelves have thinned and even collapsed, causing an increase in ice discharge into the ocean (The IMBIE team, 2018; IPCC, 2019).

These intense ice/ocean interactions and the climate of this region are strongly regulated by atmospheric variability, which is larger in the ASE than anywhere on Earth (Connolley, 1997). This is primarily determined by the strength and location of the Amundsen Sea Low, which controls the advection of atmospheric heat and moisture to the continent (Hosking et al., 2013). These coastal regions receive some of the highest snowfall amounts in Antarctica, often from short-lived intrusions of maritime air in the form of extreme events, which occur during periods of strong meridional flow originating from the tropics (Turner el al., 2019). They also experience the occurrence of extreme temperature and surface melt episodes, which is again linked to large-scale circulation patterns such as El Nino events (Deb et al., 2018). However, the complex coastal orography that characterises this region can also locally amplify both warming and accumulation, i.e. causing highly spatially heterogenous rates of surface melting and accumulation that are currently not well understood.

The objective of this work will be to investigate how large-scale forcing can play a part in triggering extreme precipitation and temperature events, i.e. disentangle the role of large-scale forcing (i.e., warm air advection) versus local dynamics (i.e., foehn warming). This will be achieved by running simulations using the HClim and Polar WRF regional climate models at a fine enough resolution of 1-2 km to representing the key local features. We will also make use of meteorological observations and satellite data such as the MODIS Antarctic Ice Shelf Image Archive, available athttps://nsidc.org/data/iceshelves\_images/.

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*Task 5.4: Sea-ice albedo and surface energy budget*

The surface albedo of Antarctic sea ice and its influence on climate are important to understand as Antarctic sea ice coverage is likely to decline in the future (Roach et al., 2020). In summer, substantial incident solar radiation is absorbed by the Antarctic sea ice, which causes the physical state of the snow/ice surface to change rapidly (due to e.g. melting), leading to dramatic changes in snow/ice surface albedo, and hence the surface energy budget (Zhou et al., 2007). However, the factors that control variations in the snow/ice albedo over Antarctic sea ice, such as snow microstructure, surface energy fluxes, and precipitation, are still poorly understood (is this true). Improved understanding of the key processes that influence snow/ice albedo, and how the resulting change in albedo that accompanies variations in sea ice coverage impact on the climate, is vital for predicting the long-term effects of future climate change.

By using satellite products (Sentinel-3 albedo, snow microstructure, and surface temperature; SMOS surface melt; MODIS albedo and surface temperature; SSMIS sea ice concentration), observations from the R/V Polarstern ISPOL campaign on sea ice in the Weddell Sea in 2004-2005 (Vihma et al., 2009), as well as atmospheric reanalyses and existing RCM simulations obtained from Antarctic CORDEX, the effect of snow microstructure (i.e. grain size) on the sea ice surface albedo will be studied by FMI (Pirazzini et al., 2015). For evaluation purposes, a comprehensive reference dataset of sea ice surface properties will be compiled (MS-5.3). The observations will be used to investigate the effects of snow/sea ice albedo on cloud radiative forcing. Next, sensitivity tests with MAR-NEMO and HCLIM-SICE will be carried out in which the snow/sea ice albedo parameterizations will be varied. These simulations will be compared with the observations provided by MS-5.3, and used to further improve our understanding of how variability in snow/sea ice albedo impacts the surface radiative budget, as well as how recent changes in sea ice extent might have affected the climate of Antarctica (Zhou et al.; 2019).

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Pirazzini, R., P. Räisänen, T. Vihma, M. Johansson, and E.-M. Tastula (2015). Measurements and modelling of snow particle size and shortwave infrared albedo over a melting Antarctic ice sheet, The Cryosphere, 9, 2357-2381, doi:10.5194/tc-9-2357-2015.

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Zhou, X.; Li, S.; Morris, K.; Jeffries, M.O. Albedo of summer snow on sea ice, Ross Sea, Antarctica.J. Geophys.Res. Atmos.2007,112.

Zhou, C.; Zhang, T.; Zheng, L. The Characteristics of Surface Albedo Change Trends over the Antarctic Sea Ice Region during Recent Decades. Remote Sens. 2019, 11, 821.

*Task 5.5: Wind-driven sea-ice drift and thermodynamics*

Wind forcing is the primary factor controlling the drift of Antarctic sea ice (Kottmeier and Sellmann, 1996). On large-scale, the effect of wind is fairly well known, as the sea ice concentration in the Southern Ocean is typically low enough to allow free ice drift driven by the atmospheric and oceanic forcing (Vihma et al., 1996). Recent advances have been made in understanding the role of large-scale atmospheric circulation patterns, such as the Southern Annular Model (Zhang et al., 2018) and planetary waves (Meehl et al, 2019), on sea ice drift. However, we will address the open research questions that still exist related to localised atmospheric forcing on sea ice dynamics in the Antarctic coastal zone. There the ice dynamics is complicated by the internal resistance of the sea ice field, often packed against the coast or ice shelves, and the complicated mesoscale dynamics of the atmosphere, including interaction of synoptic- and mesoscale cyclones (Pezza et al., 2016), katabatic winds (Vihma et al., 2011), and sea/land-breeze type circulations (Savijärvi, 2011). This results in ice drift that is strongly variable in time and space, yet poorly understood. This shortcoming poses a significant uncertainty in climate predictions, including modelling atmosphere-ice-ocean interactions as they evolve in the future.

The work will build on previous studies on sea ice in the Antarctic coastal zone, including the modelling studies by Savijärvi (2011), Vihma et al. (2011) and Zhang et al. (2015). However, our analyses will be based on outputs from the ROMS ocean model hindcasts produced by UHel, which will be used to investigate aspects such as the impact of synoptic-scale cyclones and katabatic flow on sea ice drift, the disintegration of land-fast sea ice due to strong wind forcing, the opening and closing of coastal polynyas, and how an ice-shelf attenuates the katabatic flow and so modulates wind-driven sea ice drift. The ROMS model will be forced by either ERA5, the RCM simulations performed in this project, or previous simulations from Antarctic CORDEX.

Kottmeier, C., and Sellmann, L. ( 1996), Atmospheric and oceanic forcing of Weddell Sea ice motion, *J. Geophys. Res.*, 101( C9), 20809– 20824, doi:[10.1029/96JC01293](https://doi.org/10.1029/96JC01293).

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Savijärvi, H. (2011), Antarctic local wind dynamics and polynya effects on the Adélie Land coast. Q.J.R. Meteorol. Soc., 137: 1804-1811. doi:[10.1002/qj.874](https://doi.org/10.1002/qj.874)

*Task 5.6: Ice shelf-ocean interactions and bottom water formation*

***How do atmosphere-ocean-sea ice interactions affect ice shelf basal melting***

In Antarctica, the influx of relatively warm circumpolar deep water onto the continental shelf and towards the floating ice shelves is highly variable and has a strong influence on shelf water heat content and basal melt (and therefore also ice sheet melt rates). Both of these processes are strongly controlled by interactions among the atmosphere, ocean and sea ice on a range of time scales, with both local and hemispheric-wide variability exerting an influence. For example, the flow of water onto the continental shelf is influenced by the local wind stress at the shelf break, while local air-sea heat fluxes and sea ice formation over the continental shelf strongly influence the depth of the mixed layer and small-scale convective activity, which in turn modulate the water temperature at the key depths where melting occurs under the ice shelves (Webber et al. 2017). Additionally, melt water from ice shelves feeds back to the ocean circulation. However, understanding these linkages is currently incomplete, yet vital if we are to diagnose or predict melt rates beneath ice shelves and consequently how the mass balance of Antarctica could evolve over the coming decades and its possible impact on sea level (Rintoul 2018).

Although advances in the understanding of dynamic-thermodynamic processes of ice shelf/ocean interaction have been made in recent years (Dinniman et al., 2016), further improvements are needed by analysing high-resolution eddy-resolving ocean models that are able to resolve the complex Antarctic continental shelves and slopes, as well as the sub-ice-shelf cavities (Richter et al. 2020). Additionally, oceanographic models, which are highly sensitive to forcing data (e.g. Condron and Renfrew 2013), are usually driven by meteorological reanalysis, which typically misses the small-scale variability in both wind and sea-ice (e.g. polynyas) that are argued to be critical for the delivery of ocean heat to the ice shelves (Carvajal et al. 2013).

We will address both these issues in this work by forcing the eddy-resolving ROMS ocean model (which also includes sub-ice-shelf cavities and realistic topography) with atmospheric forcing derived from both ERA5 reanalysis and also existing high-resolution Polar CORDEX regional climate model simulations (UHel team). The model output will provide novel understanding of how mesoscale oceanic transport processes respond to changing surface conditions (e.g. by capturing realistic air-ocean heat and salt fluxes in coastal polynyas), enabling us to quantify how atmosphere-ice-ocean interactions control the rate of basal melting and variability. Additionally, the IMMSP team will use their 2D FRIS cave model embedded into regional cross-scale circulation model SCHISM (Zhang et al., 2016), which will be forced at its boundaries by output from the ROMS simulations. The FRIS model will describe transfers of heat, salt and momentum between ice and water, enabling a detailed understanding of sub-ice-shelf water properties and transport.

Condron, A., Renfrew, I. The impact of polar mesoscale storms on northeast Atlantic Ocean circulation. *Nature Geosci* **6,** 34–37 (2013). <https://doi.org/10.1038/ngeo1661>

Carvajal, G.K.; Wåhlin, A.K.; Eriksson, L.E.; Ulander, L.M. Correlation between Synthetic Aperture Radar Surface Winds and Deep Water Velocity in the Amundsen Sea, Antarctica. Remote Sens. **2013**, 5, 4088-4106.

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Webber, B., Heywood, K., Stevens, D. *et al.* (2017), ‘Mechanisms driving variability in the ocean forcing of Pine Island Glacier’, *Nature Communications,* **8,** <https://doi.org/10.1038/ncomms14507>.

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***Ice-ocean processes under the Filchner-Ronne Ice Shelf***

Interactions between the Filchner-Ronne Ice Shelf (FRIS) and the shelf sea region in which it floats is vital for the production of Weddell Sea-derived Antarctic Bottom Water, which is one of the most globally important deep water masses in the Southern Hemisphere (Nicols et al., 2009; Vernet et al., 2019). Our current understanding is that the production of precursor dense Ice Shelf Water masses are divided into two branches, with one descending branch controlled by gravity and bottom topography and forming the well-known deep-water source of Weddell Sea Bottom Water, and another branch flowing along the continental shelf (Vernet et al., 2019). However, a recent idealised set of simulations by Maderich et al. (2017) suggest that a localised third branch could also exist that follows the continental shelf and eventually returns to under the FRIS, which would therefore potentially significantly affect the estimation of Weddell Sea Bottom Water production, i.e. impacting on Antarctic Bottom Water production rate and thus global climate.

To clarify this new view and obtain flow rates / budget information for the various branches and the formation of Weddell Sea Bottom Water it is therefore necessary to extend the study of Maderich et al. (2017) by realistically resolving the local ocean circulation patterns under the FRIS, and how they are influenced by wind forcing, larger scale ocean flows, and seasonal sea-ice. This will be done by performing very high-resolution simulations using the unstructured-grid ocean model SCHIMS (Zhang et al., 2016), which also includes the ice dynamic-thermodynamic model FESIM (Danilov et al., 2015), as well as a tidal model. This will be forced at its surface boundaries by both ERA5 reanalysis and existing high-resolution Polar CORDEX regional climate model simulations, and in the ocean by output from ROMS simulations (supplied by UHel team). Special attention will be paid to resolving the continental shelf and slope regions, as well as the influence of ridges and troughs, in order to realistically model the propagation of the Ice Shelf Water.

Vernet, M., Geibert, W., Hoppema, M., Brown, P. J., Haas, C., Hellmer, H. H., et al. (2019). The Weddell Gyre, Southern Ocean: Present knowledge and future challenges. Reviews of Geophysics, 57, <https://doi.org/10.1029/2018RG000604>.

Nicholls, K. W., S. Østerhus, K. Makinson, T. Gammelsrød, and E. Fahrbach (2009), Ice-ocean processes over the continental shelf of the southern Weddell Sea, Antarctica: A review, *Rev. Geophys.,* 47, RG3003.

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*Task 5.7: Interactions between ocean physics and biogeochemistry*

The pan-Antarctic configuration of ROMS used in Task 5.6 includes an interactive biogeochemistry module. Output from Task 5.6 will be used to further our understanding of how local ocean circulation affects key ocean biogeochemical processes such as CO2 uptake, acidification, and the depth of the calcium carbonate saturation horizon. This will allow us to assess the impact of localised ocean circulation patterns on the Southern Ocean carbonate chemistry and thus the biogeochemical changes causing rapid shallowing of the aragonite saturation horizon (D5.7). Observations and state estimates will be used to validate, and if necessary bias correct, output from the ROMS simulations.

*Task 5.8: Synthesizing new understandings and interactions in the fully coupled climate system*

This task integrates the process understanding improvement of Tasks 5.1-5.7 on the key Antarctic local processes related to ocean-atmosphere-ice interactions and identifies, together with Task 4.4, similarities and differences with key Arctic processes (D5.8). This task serves as starting point for the analysis of the storyline based Antarctic projections.

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