Benefits of ice-ocean coupling for medium-range forecasts in polar and sub-polar regions

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ECMWF

INTER-ACT

APPLICATE
Advanced prediction in Polar regions and beyond

1. Background and Objectives

Dynamic sea ice and ocean have long been recognised as an important component in the Earth System Models used to generate climate change projections and more recently seasonal forecasts. However, the benefit on the timescales of days to weeks has received less attention. Until recently it was assumed that sea-ice-ocean fields change so slowly that it is acceptable to keep them fixed for the period covered by global medium-range forecasts. However, at the ice edge the presence of sea ice dramatically influences surface fluxes, particularly when the overlying atmosphere is much colder than the open ocean, so errors in the position of the sea ice could degrade the skill of atmospheric forecasts. As part of a drive to develop a forecasting system that is seamless across timescales ECMWF took the pioneering step of coupling sea ice cover and SSTs from the dynamic–thermodynamic sea ice-ocean model LIM-NEMO to the Integrated Forecast System for all time ranges, thereby developing the first coupled medium-range forecasting system (Keeley and Mogensen, 2018).

By comparing as set of 10-day coupled forecasts with a set which are uncoupled experiment (observed sea ice concentration is persisted from the initial time of each forecast) enables us to explore three questions:

1. On what timescales does dynamic coupling to the sea ice produce noticeably improved forecasts of the ice edge?
2. Does a dynamic sea ice edge improve skill in all conditions, or during specific episodes?
3. Is there evidence that the coupling to the dynamic ice-ocean has an impact on downstream atmospheric conditions?

2. Improved sea ice forecast skill

We compare the coupled and uncoupled sea ice forecasts using the Integrated Ice Edge Error (IIEE) metric (Goessling et al., 2016) which measures the skill of forecasts of the ice edge by summing up regions where ice is observed but not forecast and the reverse. To verify the forecasts, daily mean sea ice concentration from the forecasts is compared with the operational OSI-SAF analysis for the appropriate day. These are calculated for the northern hemisphere as a whole and also for the Nordic Seas (-20W-80E, 65N-90N).

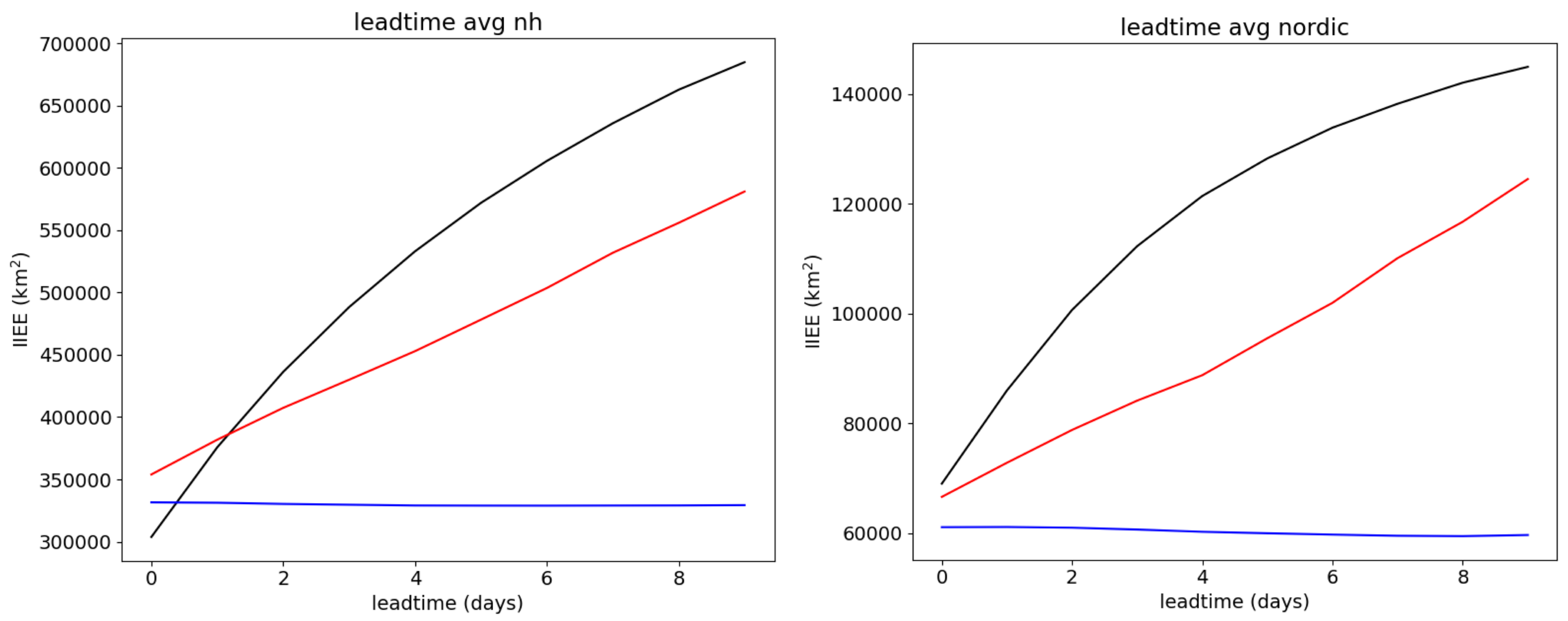

Fig 1: Lead-time averaged Integrated Ice Edge Error (IIEE), for the whole northern hemisphere (left) and in the Nordic Seas (right).

The coupled forecasts have a smaller IIEE for the Northern Hemisphere than uncoupled forecasts from day one (from day 0 when considering the Nordic Seas region only). The IIEE for the coupled forecast also grows much less rapidly than the uncoupled, particularly in the first four days. Part of this will be because a persistence forecast will miss the mean expansion of the sea ice as it will not capture the mean seasonal cycle.

The IIEE of the coupled forecast is larger than the uncoupled at day 0 indicates error or inconsistency between the sea ice concentration in ECMWF ocean analysis, OCEAN5, used to initialise the forecasts, and OSI-SAF which is used in the verification. It is striking that the uncertainty in the analysis, expressed as the IIEE of the OCEAN5 fields (Fig 1), is larger than the difference in IIEE between the coupled and uncoupled forecasts, suggesting it is a major source of forecast uncertainty.

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3. Enhanced skill during ice advance and retreat

Dynamic sea ice adds most value to weather forecasts that are initialised just prior to, or during synoptic situations where the sea ice edge is moving rapidly. This is demonstrated by a highly significant correlation between the change in forecast IIEE and the size of the observed change in sea ice extent at day-3 (r=0.47, p=10-8) and Fig 2.

Compositing on the highest tercile of ice extent change (highlighted by red dots in Fig 2a) demonstrates that anomalous advances in sea ice cover occur during situations with north easterly flow (Fig 2b). During such situations southward advection of the sea ice due anomalous wind stress and antecedent conditions for thermodynamic growth lead to a positive 3-day change in sea ice concentration (Fig 2c). Comparison of this composite with the forecast 3-day change in concentration shows that the forecast captures this behaviour, but does not increase as rapidly as seen in observations (Fig 2d).

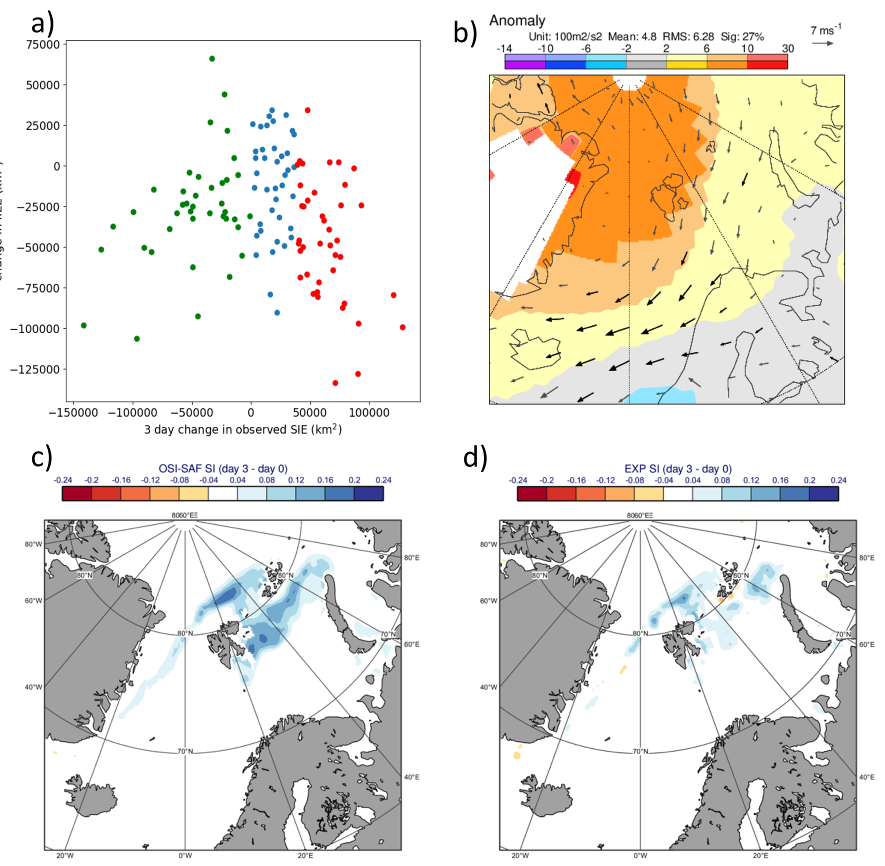

Fig 2: a: Scatter plot of the change in IIEE between coupled and uncoupled forecasts at day-3 and the 3-day change in observed ice extent between the initial time and the verification time for the Nordic Seas. B: composite of 850hPa geopotential and wind anomalies for periods of anomalous 3-day ice growth (top tercile). C: as b but for the 3-day observed change in sea ice concentration. D as C but for the 3-day change in sea ice extent for the forecasts.

4. Importance of ice coupling for the atmosphere

As air is advected across a boundary between distinct surface-types, such as between sea ice and open water, it's properties are modified as it adjusts to the new set of boundary conditions. This modification begins at the surface and is propagated upwards through turbulent diffusion. The layer of air whose properties have been affected by the new surface is called an internal boundary layer and it's depth grows with distance downstream of the boundary between the media, i.e. the edge of the sea ice (see e.g. Gryschka et al., 2008 and Liu et al., 2006).

Fig 3a shows a situation with off-ice-flow, typically seen during Marine Cold Air Outbreaks, where a cold polar air mass is advected across the sea ice edge and over the open ocean. Since this air is much colder and drier than conditions at the surface of the open ocean, anomalous upward sensible and latent heat fluxes are induced which act to warm and moisten the internal boundary layer. Fig 3b shows an idealised on-ice-flow situation where a marine air mass is advected over the sea ice. Since this air mass is much warmer and more humid than conditions at the surface, anomalous downward sensible and latent heat fluxes are induced which act to cool and dry the internal boundary layer.

Because the sea ice concentration is itself modified by anomalous surface wind stress and surface energy fluxes during the situations described above the position of the leading-edge changes over time, influencing boundary layer development. The impact of this dynamics is indicated in Fig 3c & d. As a result not taking ice changes into account has the potential to lead to errors in the atmospheric boundary layer

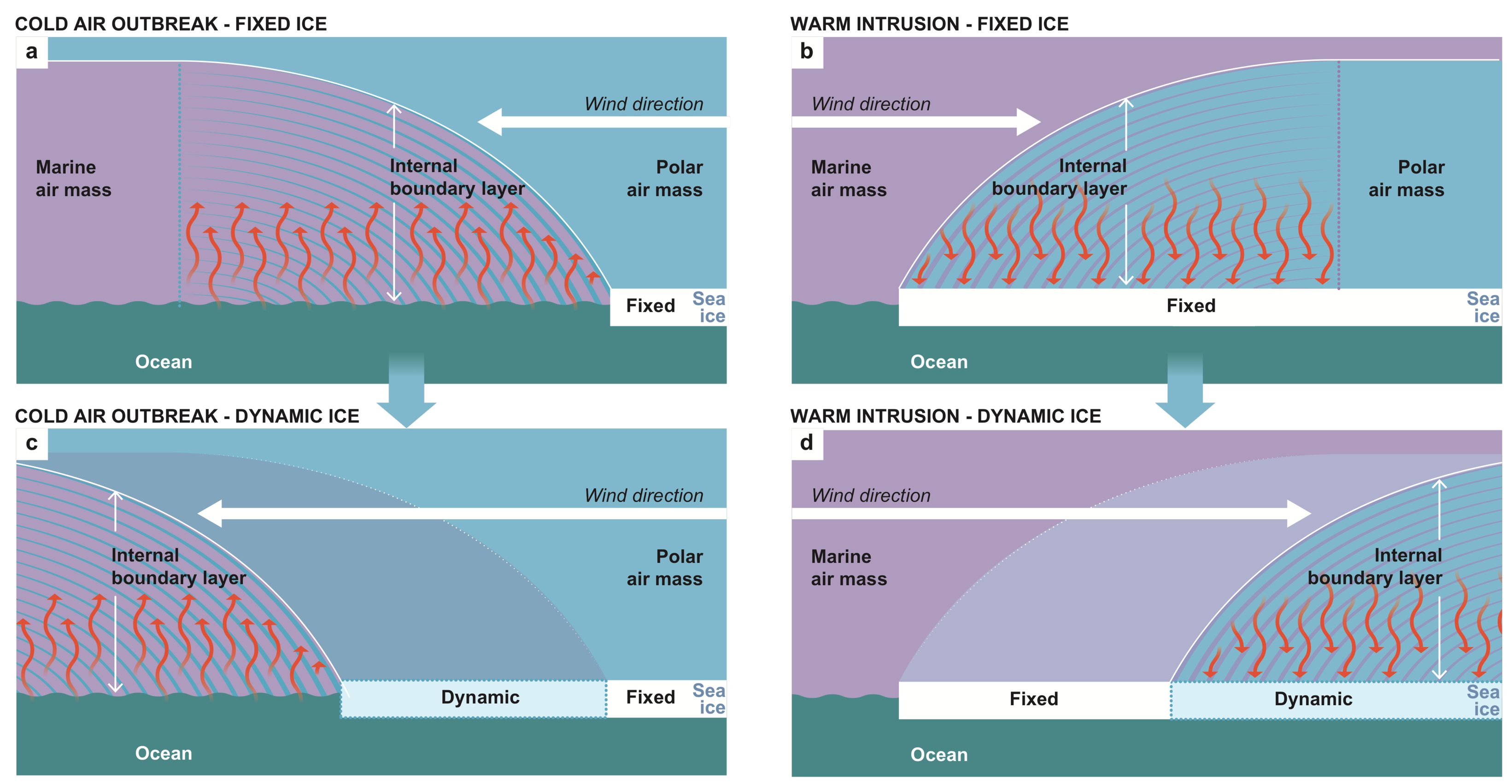

Fig 3: schematic showing the of impact of dynamic sea ice on turbulent exchange and atmospheric boundary layer development during cold air outbreaks and moist intrusions.

5. Improved temperature forecasts during ice-advance

To assess whether on average boundary layer temperature forecasts are improved, one can separate the start dates based on those where the sea ice extent is advancing during the initial 3-days of the forecast. Uncoupled forecasts initialised on these dates have a warm bias extending southwards from the sea ice edge (Fig 4a). The equivalent coupled forecasts are cooler across the same region (Fig 4b). This can be explained by differences in the position of the sea ice edge (or leading-edge) between one set of forecasts and the other.

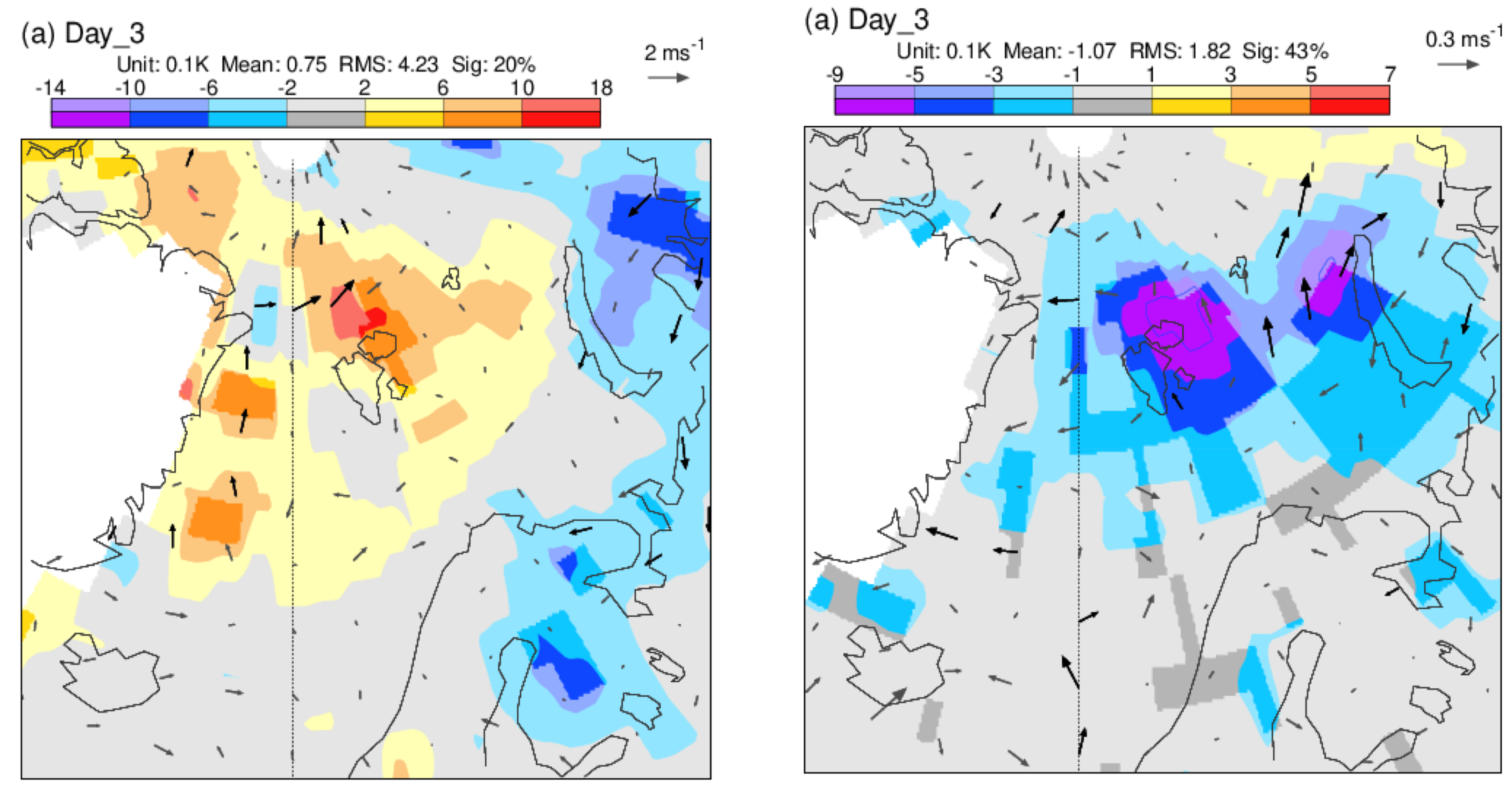

Fig 4: Mean 925hPa temperature forecast error (at T+72h) for the control forecast for periods of observed sea ice advance (left) and mean 925hPa temperature difference between coupled and uncoupled forecasts for the same periods (bottom row). The start dates selected are shown in red dots in Fig 2a

6. Conclusions

- Overall coupling of the IFS to NEMO-LIM2 improves sea ice edge errors in the medium-range compared to persistence (which was previously used in operations at ECMWF).
- Regionally, ice edge forecasts are most improved during periods of rapid ice growth or loss.
- Differences between ECMWF sea ice analysis and OSI-SAF are a large part of the forecast error/difference. **Not clear what the truth is!**
- Dynamic coupling of the sea ice has the potential to improve forecasts in the boundary layer 100s of km downstream of the sea ice edge, during e.g. Cold Air Outbreaks.

7. References

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