Future Sea-Ice Decline Predicted to Bring the Arctic Nations Closer Together

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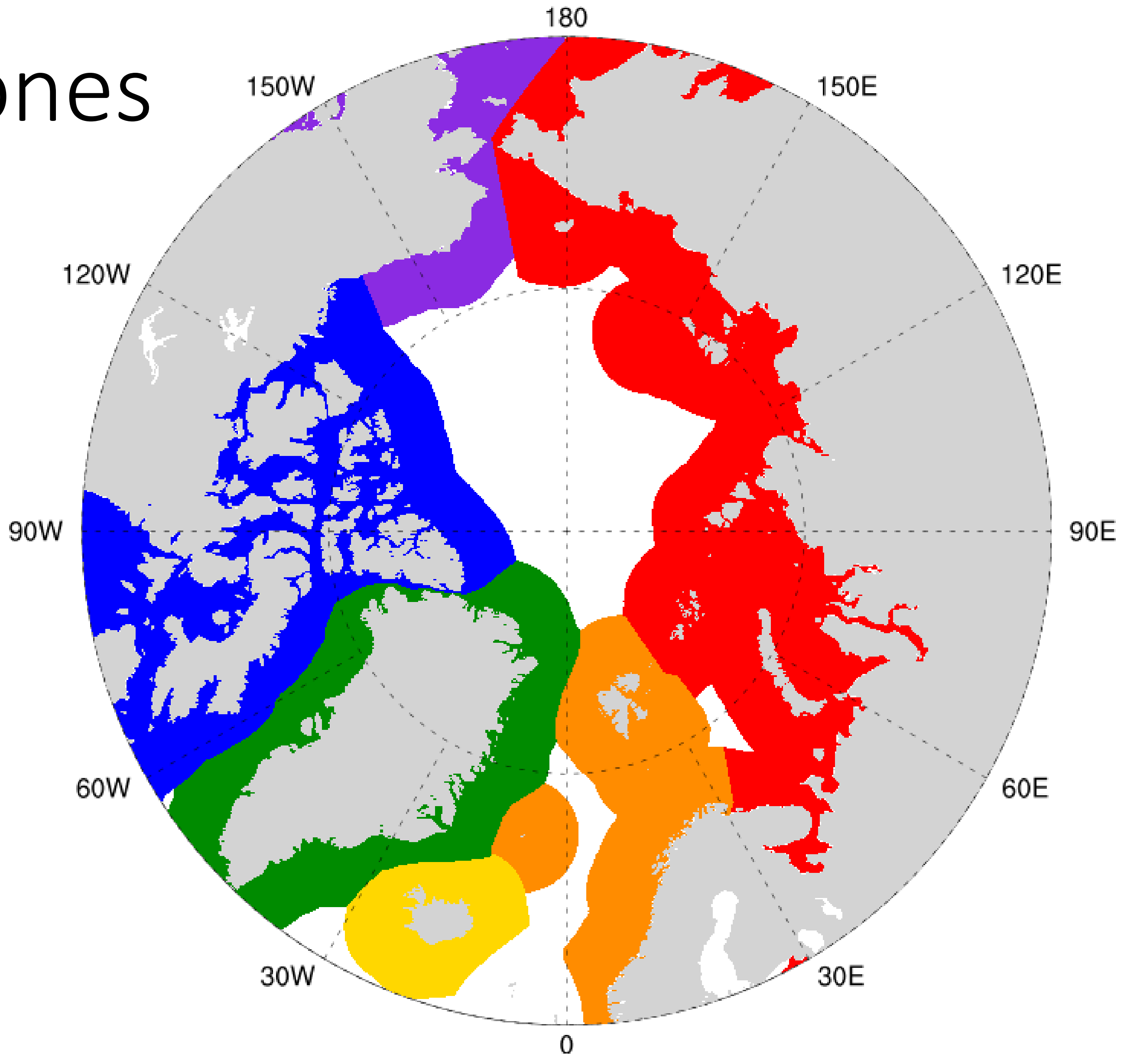
Motivation

- Reported decrease in Arctic sea-ice cover and increase in ice drift speed over the satellite era
- The Arctic is expected to experience an increase in shipping, development activities, political interest & territorial claim
- Sea ice can raft various materials:
  - Aeolian dust
  - Aerosol deposits
  - Sediments
  - Biological communities
  - Freshwater
  - Pollutants (mercury, lead, etc.)
- We are interested in how ice transport between EEZs changes as the Arctic transitions towards seasonally ice-free conditions

Exclusive Economic Zones

- Sea zone prescribed by the United Nations Convention on the Law of the Sea over which a state has special rights regarding the exploration and use of marine resources, including energy production
- It extends 200 nautical miles from the coastline

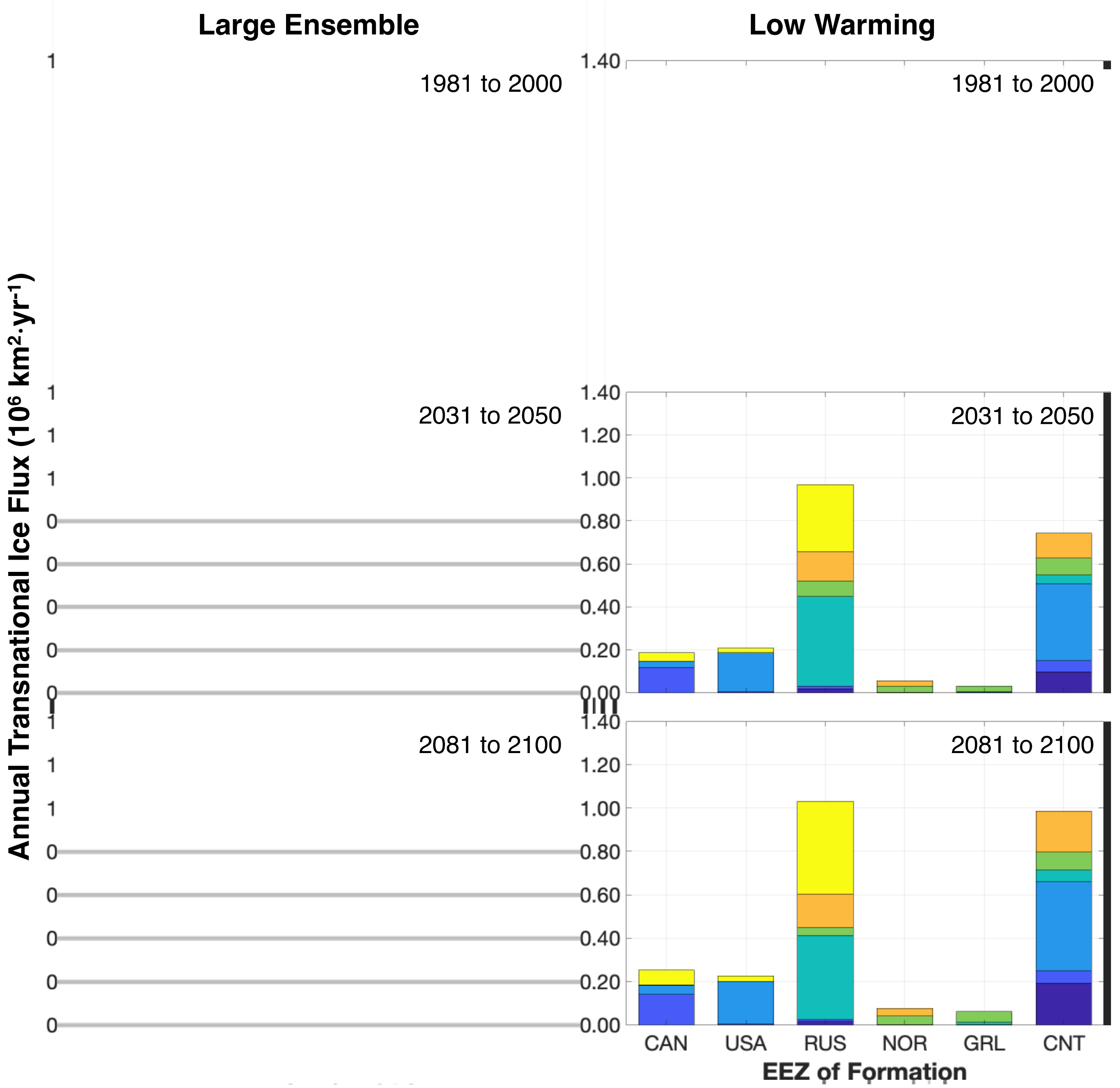


Methods

- Community Earth System Model Large Ensemble (CESMLE; *Kay et al., 2015*) from 1920 to 2100
  - Reaches consistent ice-free conditions with a global mean warming of over 4℃ by the end of the 21st century (*Jahn, 2018*)
- Community Earth System Model 2℃ target Low Warming simulation (CESMLW; *Sanderson et al., 2017*) from 2006 to 2100
  - 11 ensemble members
  - Follows an emission scenario designed so that the multi-year global mean temperature never exceed 2℃ above pre-industrial levels
- We use a Lagrangian Ice Tracking System (*DeRepentigny et al.,* 2016) to track ice floe from the location where they form to where they ultimately melt
- All data is interpolated onto the 25km Equal-Area Scalable Earth Grid (EASE-Grid; *Brodzik et al., 2012*) before tracking

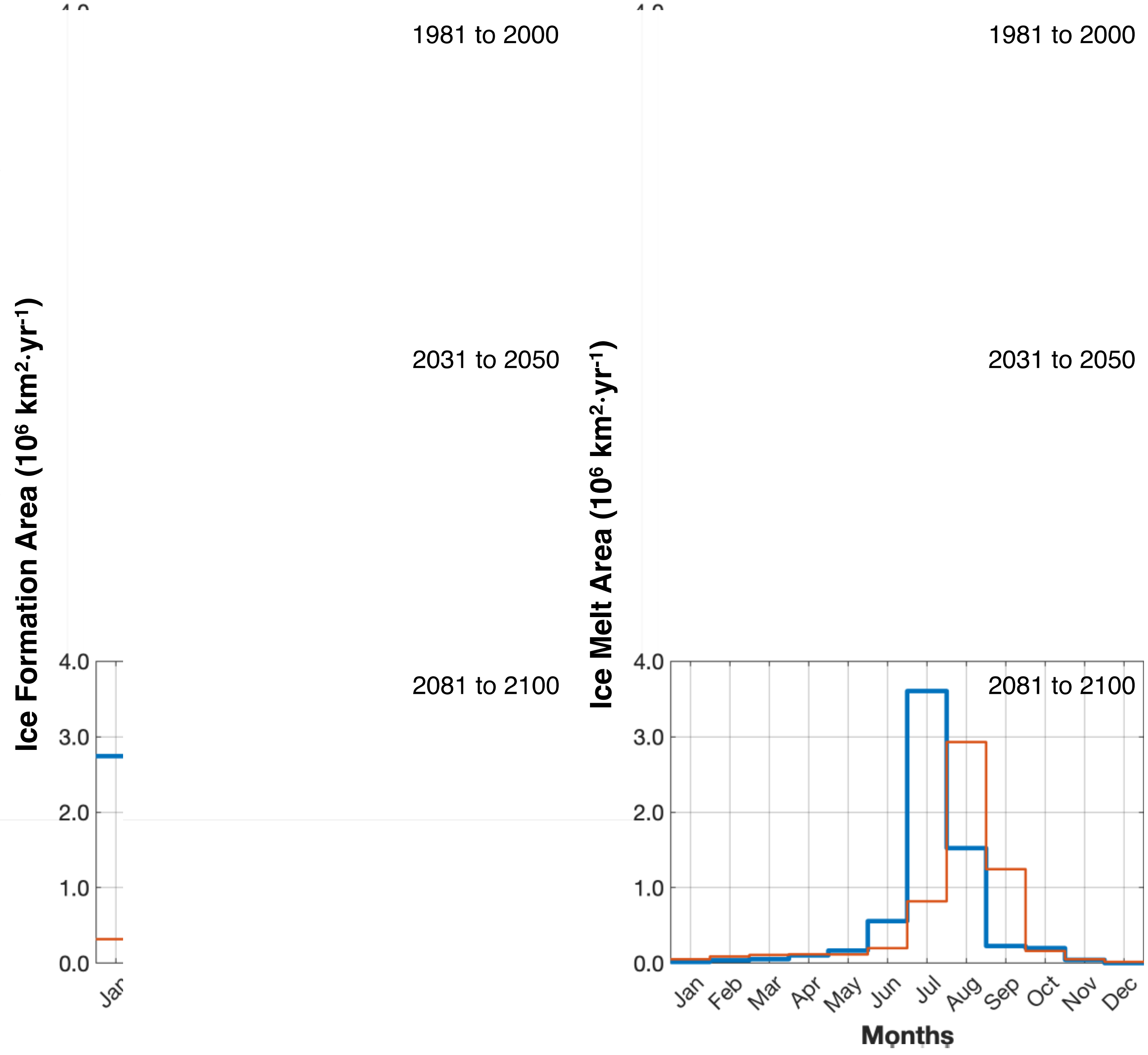
Increase in Transnational Ice Exchange due to Larger SIZ

Figure: Annual transnational ice exchange for CESMLE [*left*] and CESMLW [*right*] for the time periods of 1981-2000 [*top*], 2031-2050 [*middle*] and 2081-2100 [*bottom*]



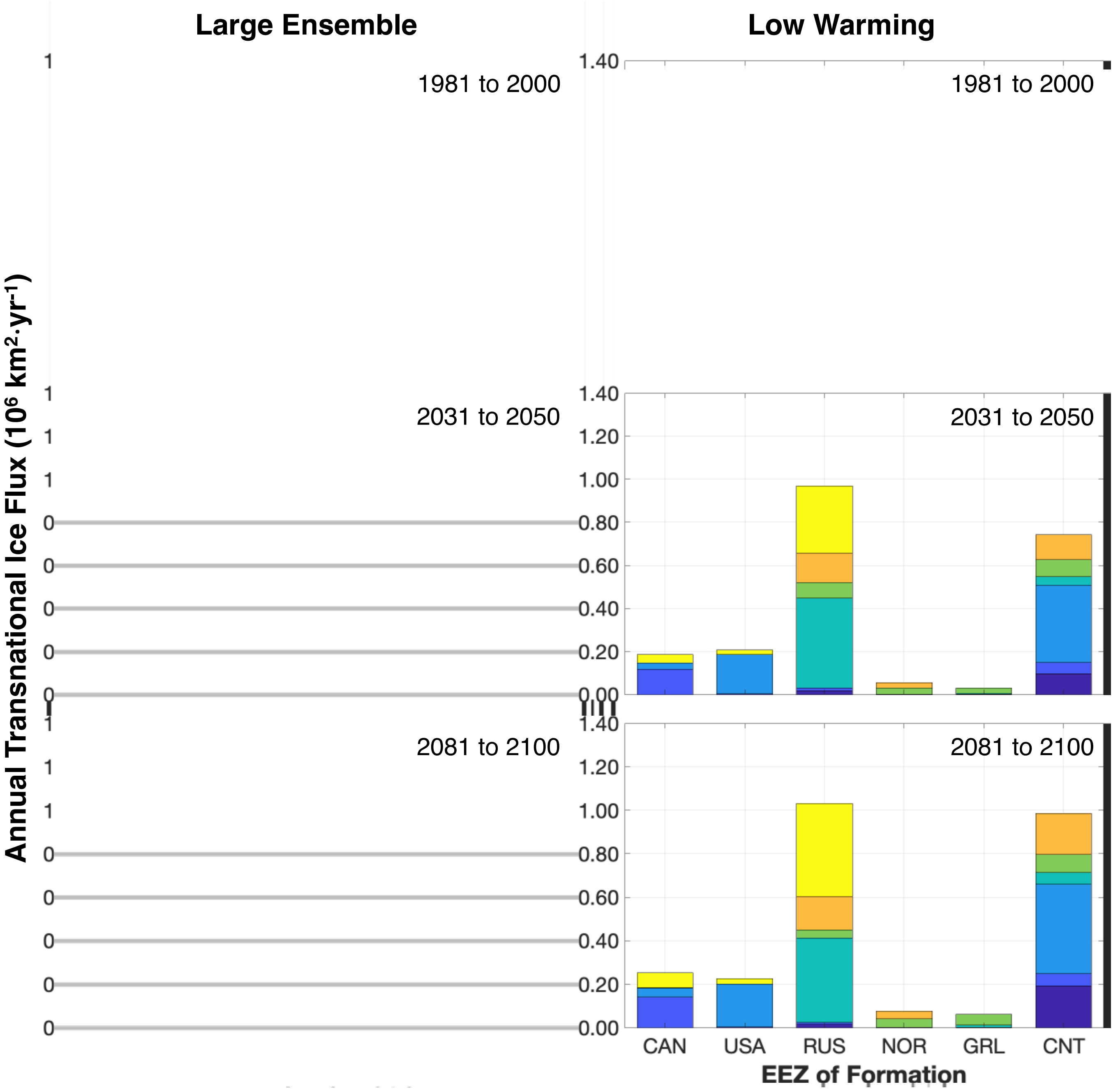
Increase in Ice Formation & Melt

Figure: Annual cycle of ice formation [*left*] and melt [*right*] for the time periods of 1981-2000 [*top*], 2031-2050 [*middle*] and 2081-2100 [*bottom*] for both CESMLE and CESMLW

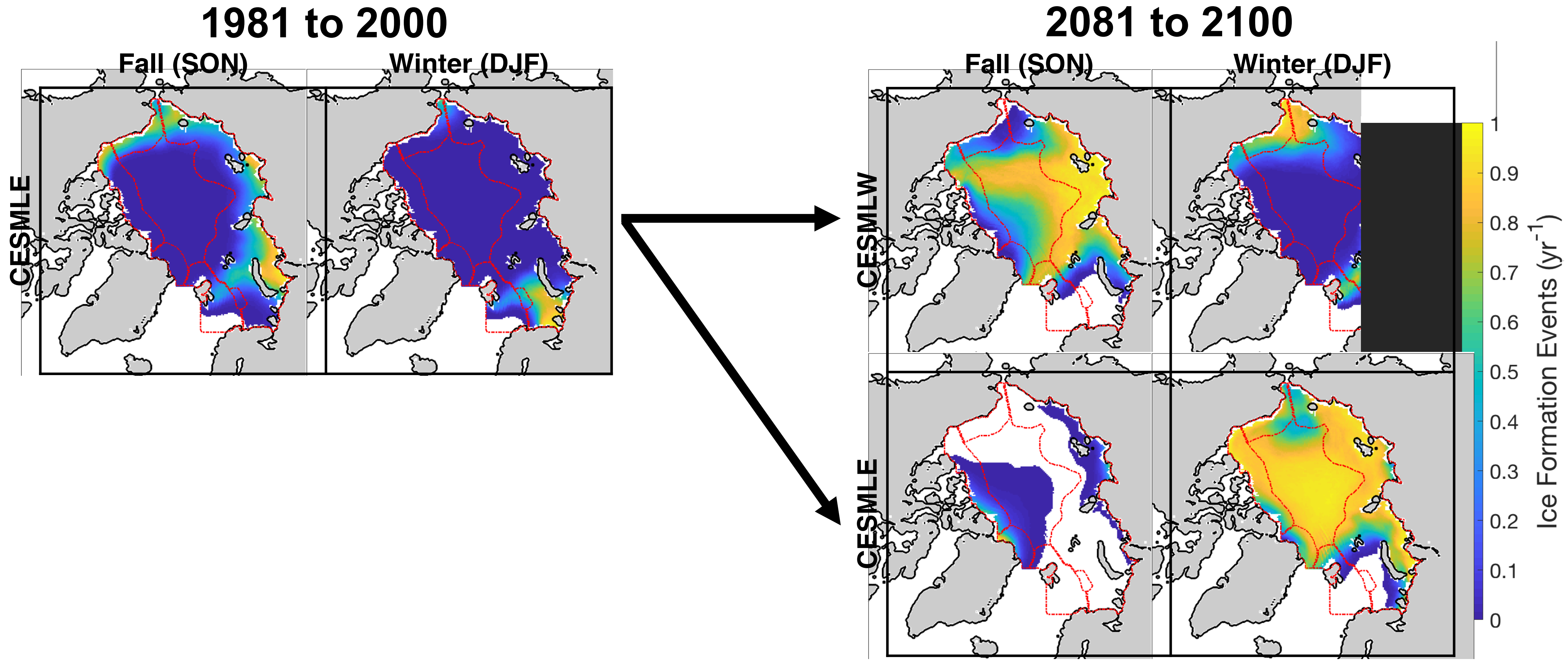


Russia & Central Arctic Dominate Transnational Ice Exchange

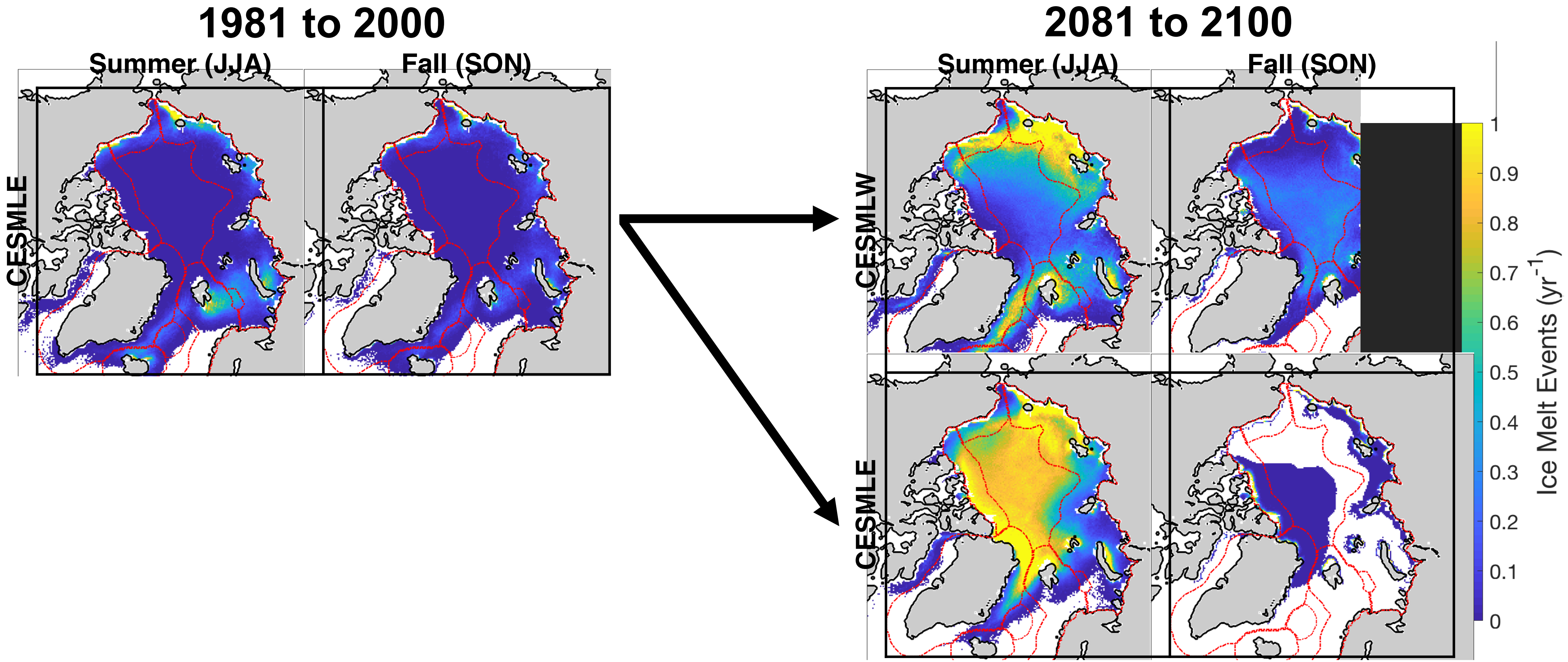
Figure: Annual transnational ice exchange for CESMLE [*left*] and CESMLW [*right*] for the time periods of 1981-2000 [*top*], 2031-2050 [*middle*] and 2081-2100 [*bottom*]



Change in Ice Formation Distribution

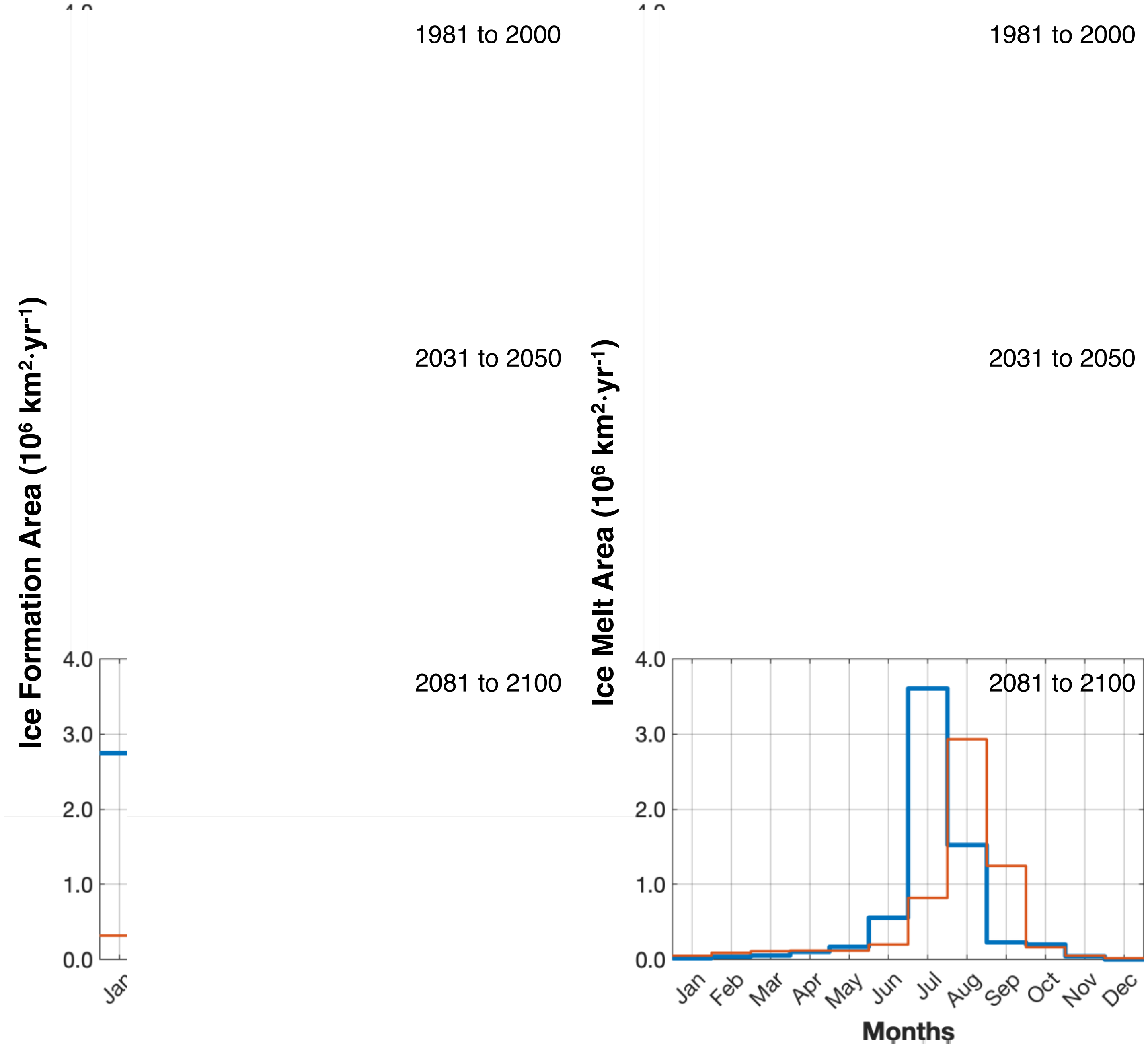


Change in Ice Melt Distribution



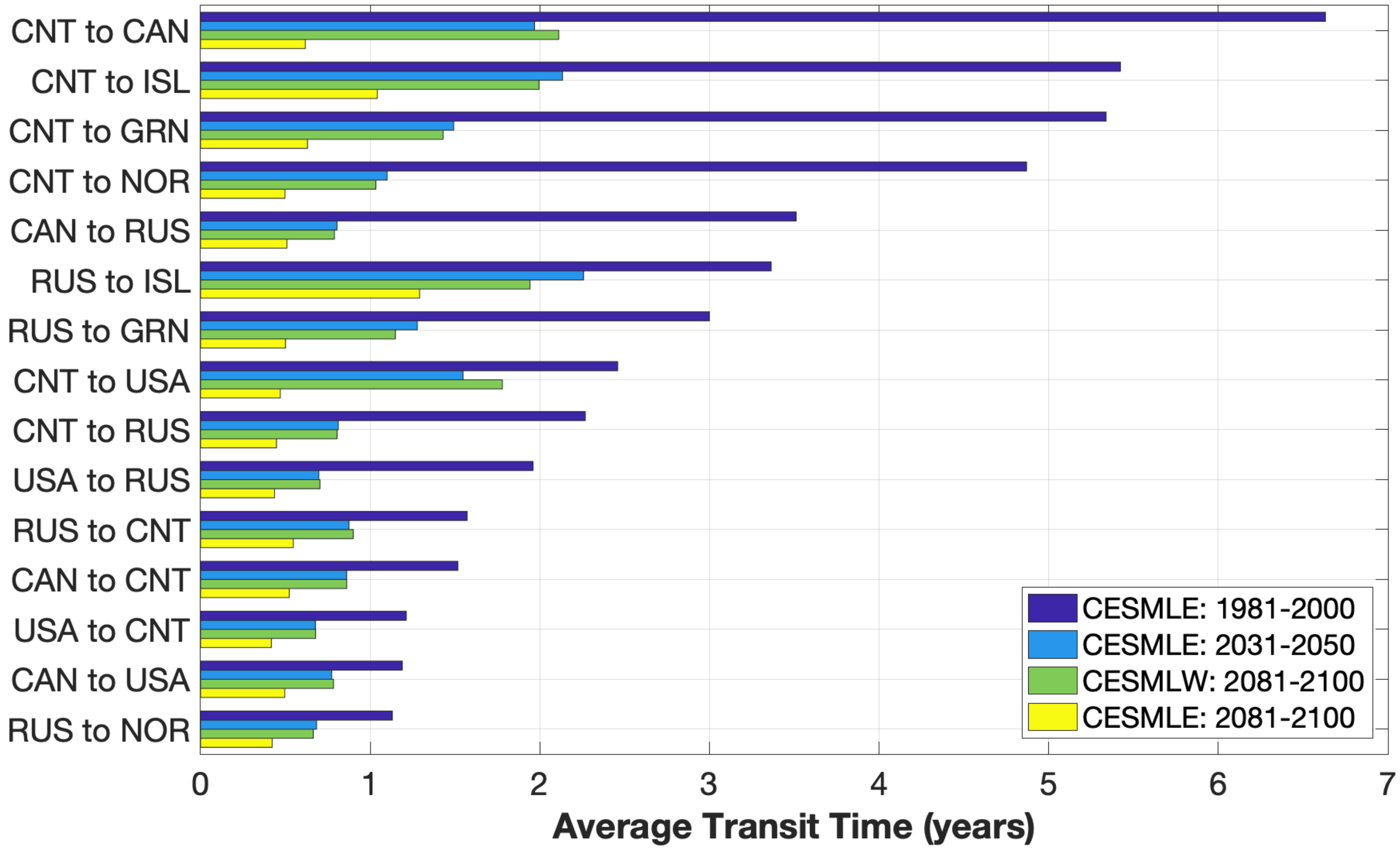
Longer Melt Season Length

Figure: Annual cycle of ice formation [*left*] and melt [*right*] for the time periods of 1981-2000 [*top*], 2031-2050 [*middle*] and 2081-2100 [*bottom*] for both CESMLE and CESMLW



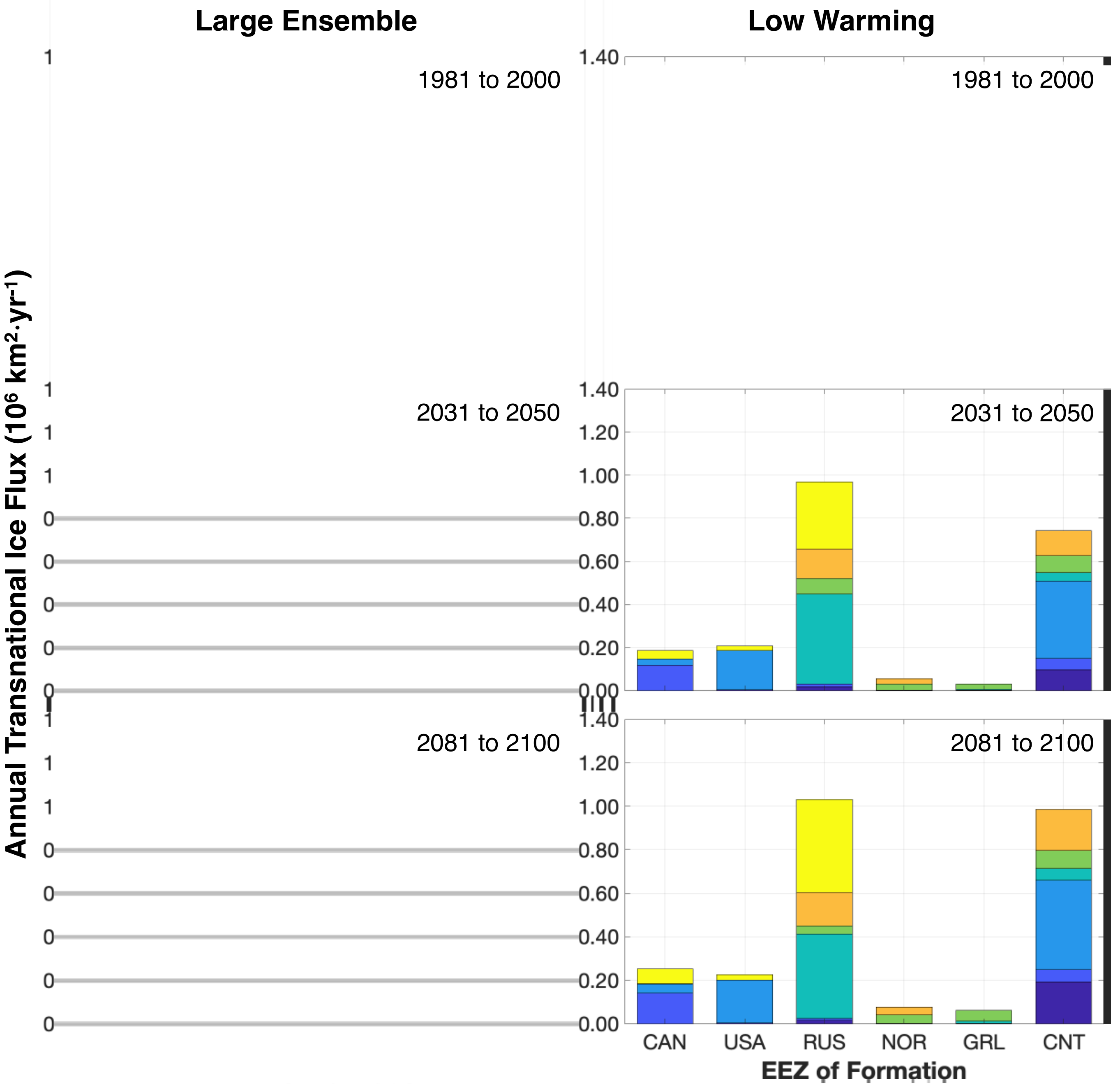
Decrease in Average Transit Time

Figure: Average transit time in years for the 15 pathways exchanging the largest area flux of ice between all 3 time periods



Increase in Transnational Ice Exchange

Figure: Annual transnational ice exchange for CESMLE [*left*] and CESMLW [*right*] for the time periods of 1981-2000 [*top*], 2031-2050 [*middle*] and 2081-2100 [*bottom*]

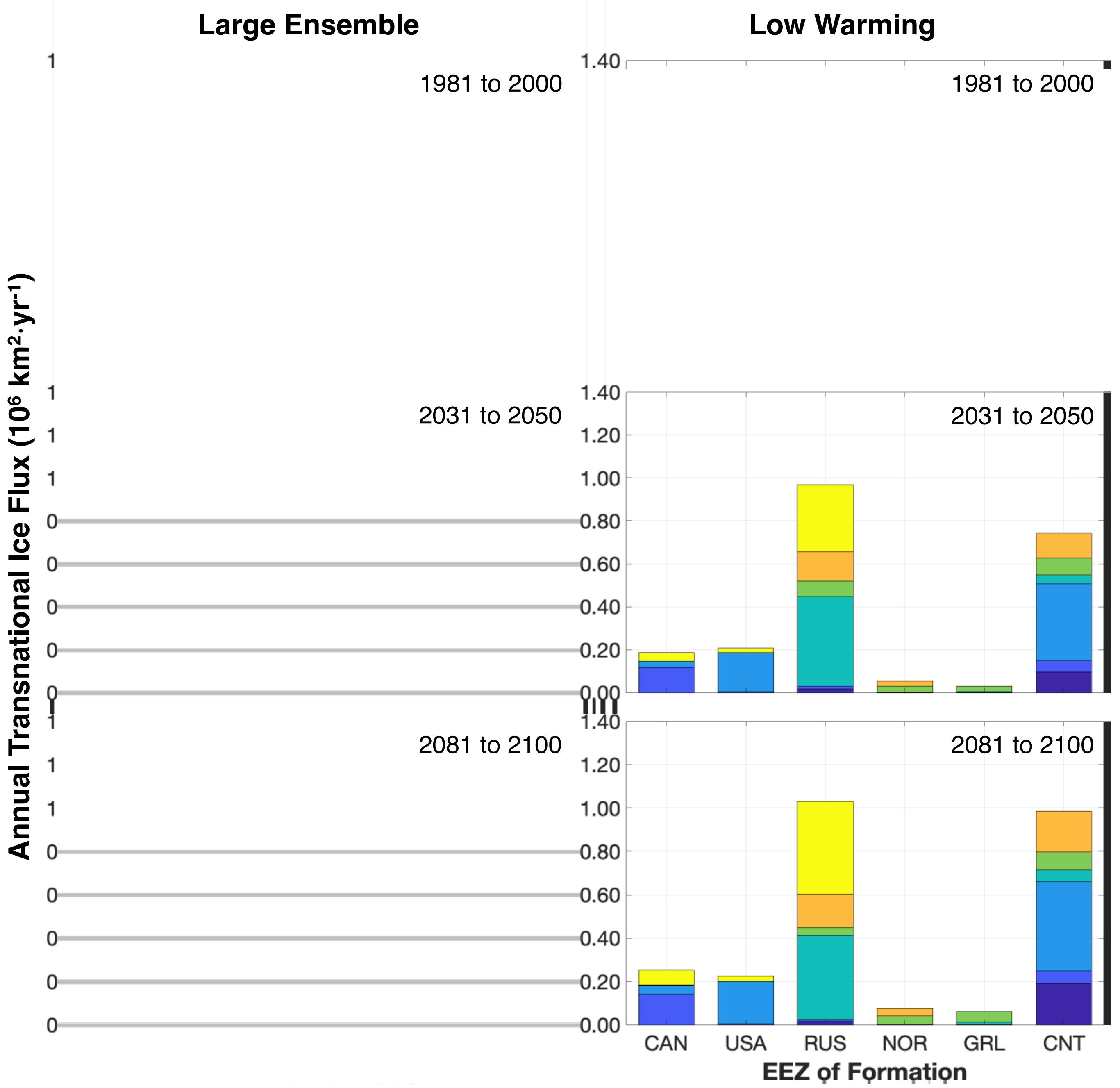


Increase in Transnational Ice Exchange

→ Long distance pathways disappear in favor of exchange between neighboring EEZs

→ Fraction of Transnational Ice Exchange = $\frac{transnational}{transnational+domestic}$

- CESMLW: 46.4% → 47.8% → 48.9%
- CESMLE: 46.1% → 47.3% → 43.7%



Conclusions

- Sea-ice retreat leads to growing transnational ice exchange over the 21^{st} century due to a larger seasonal ice zone
- By mid-century, Russia and the Central Arctic increasingly dominate transnational ice exchange
- Long distance ice transport pathways disappear by the end of the 21^{st} century due to a longer melt season and a decrease in transit times
- By the end of the century, consistent ice-free summers in CESMLE act to reduce the fraction of transnational ice exchange, whereas CESMLW continues to see an increase


Thank you!
Questions?

References

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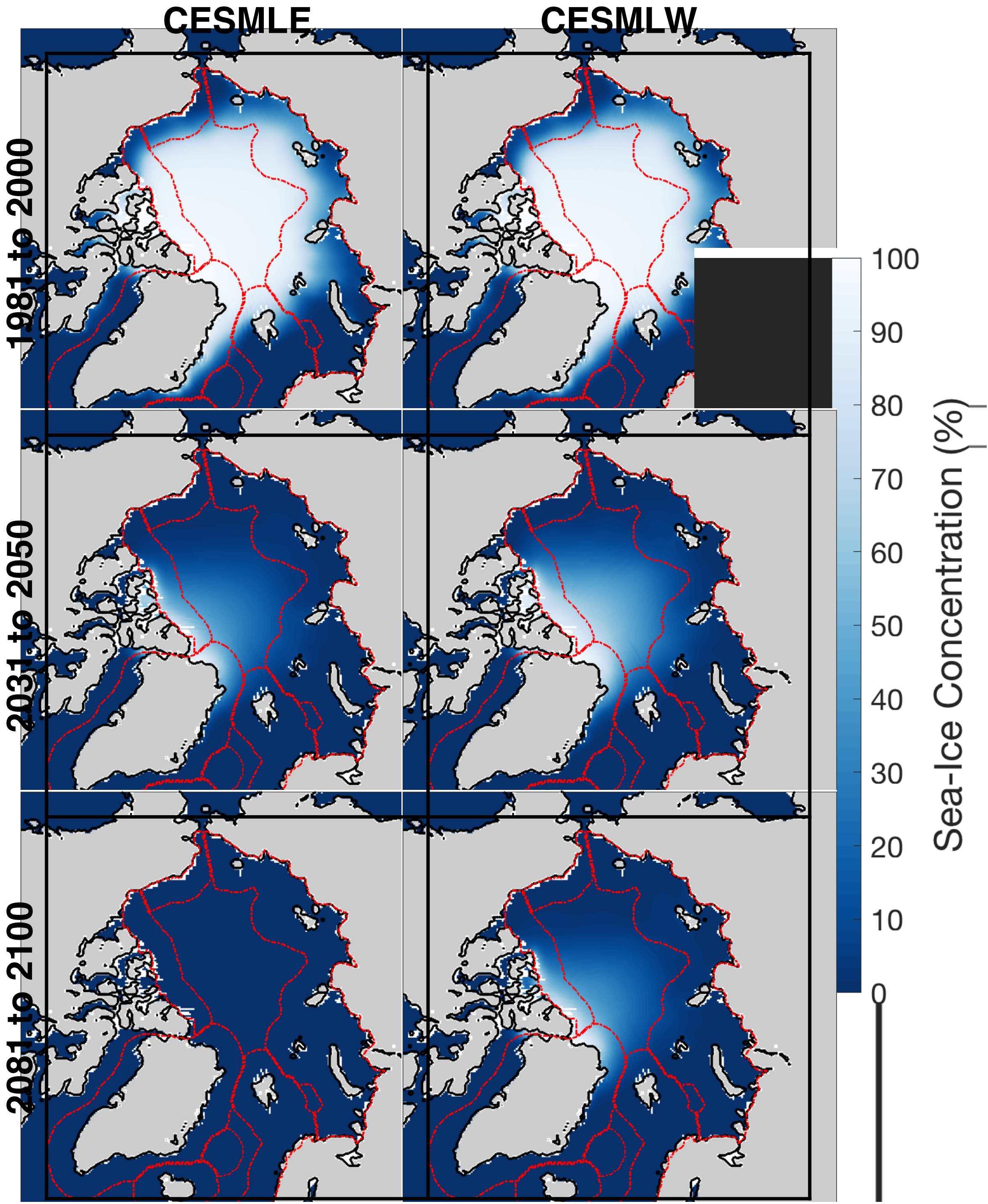
Time Periods

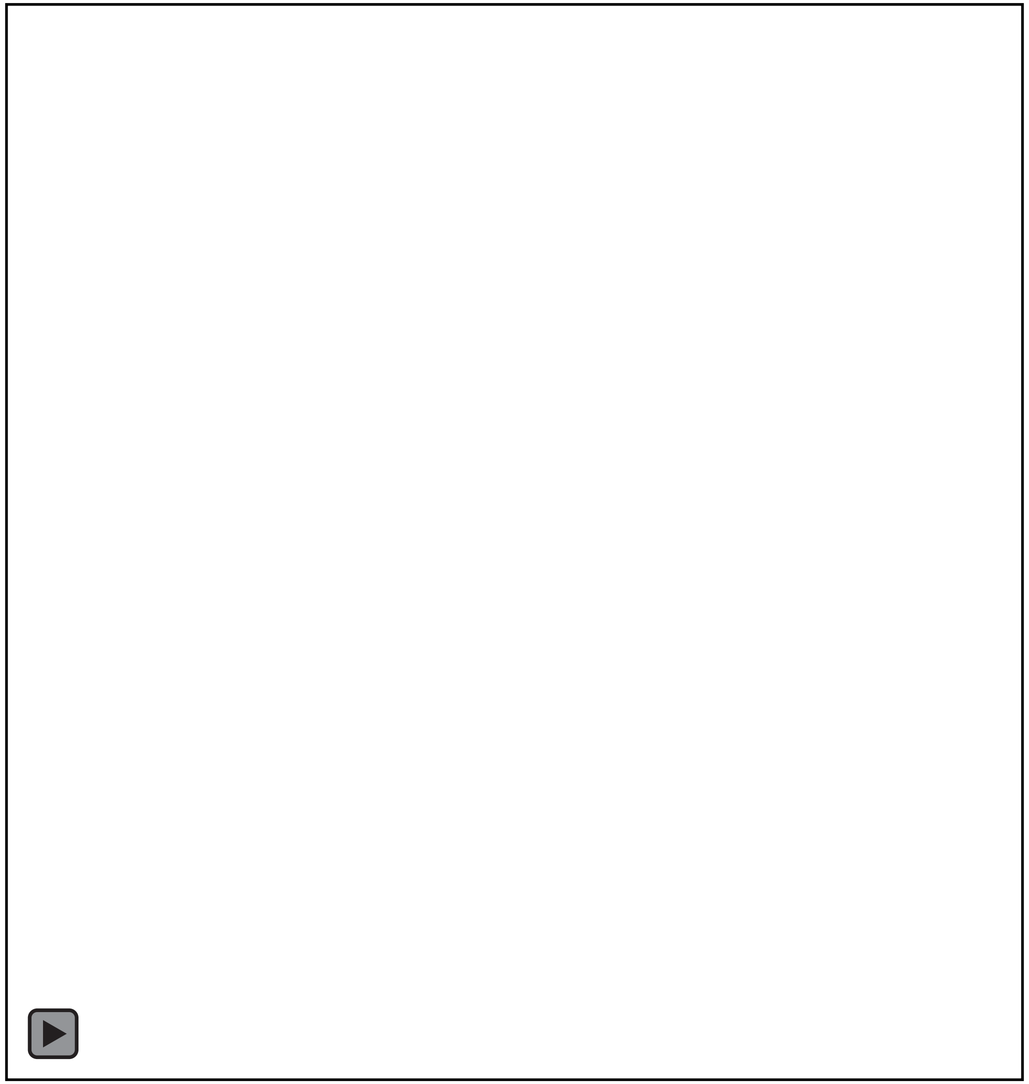
1. 1981-2000: Representative of the state of the Arctic before the start of the observed series of record low minima in September sea-ice extent of under $6x10^6$ km^2.
2. 2031-2050: Representative of a fragile and dynamic ice pack, mostly consisting of first-year ice.
3. 2081-2100: Representative of a fully seasonal ice cover for CESMLE, with an ice-free Arctic over 3-4 months for all 40 members, and a partial seasonal ice cover for CESMLW due to less sea-ice loss and a shorter (max. 1 month) ice-free season (*Jahn, 2018*).



Lagrangian Ice Tracking System (LITS)

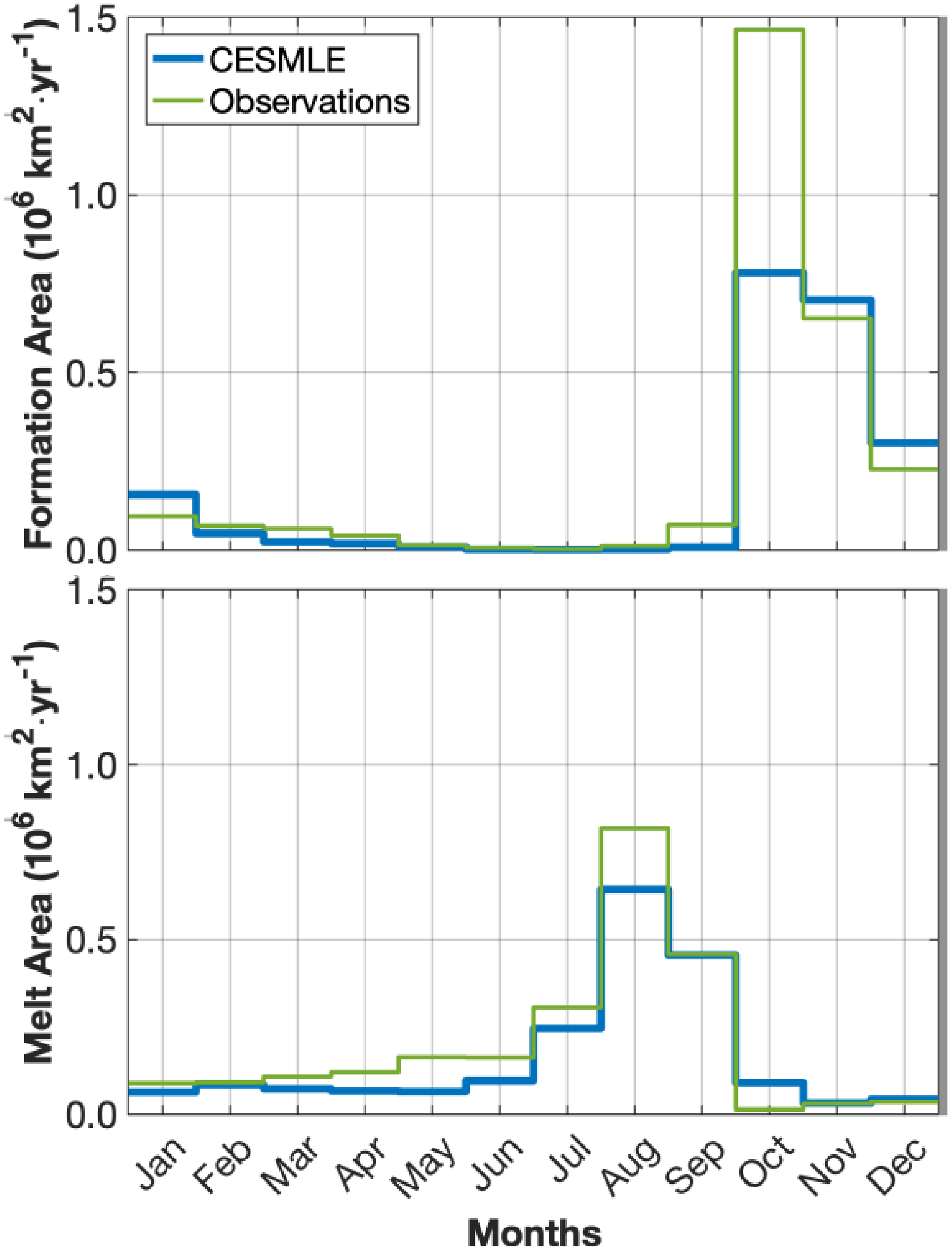
1) Identify all ice formation events → need to distinguish between ice formation (freeze) and ice that arrives as a result of advection
   - Find each month's ice edge (t_1)
   - Track each month's ice edge for one time step ($t_{1+1} = t_2$)
   - Compare with the ice edge of the following month (t_2)
   - Ice-covered grid points that were ice free at t_1 and didn't receive ice from advection between t_1 and t_2 are marked as formation events
2) Track all parcels found in 1) until they melt
   - Track each formation event from the time when it formed (t_2) for one time step and verify if the new position ($t_{2+1} = t_3$) is covered by ice
   - If so, repeat the process until the parcel melts

Lagrangian Ice Tracking System (LITS)



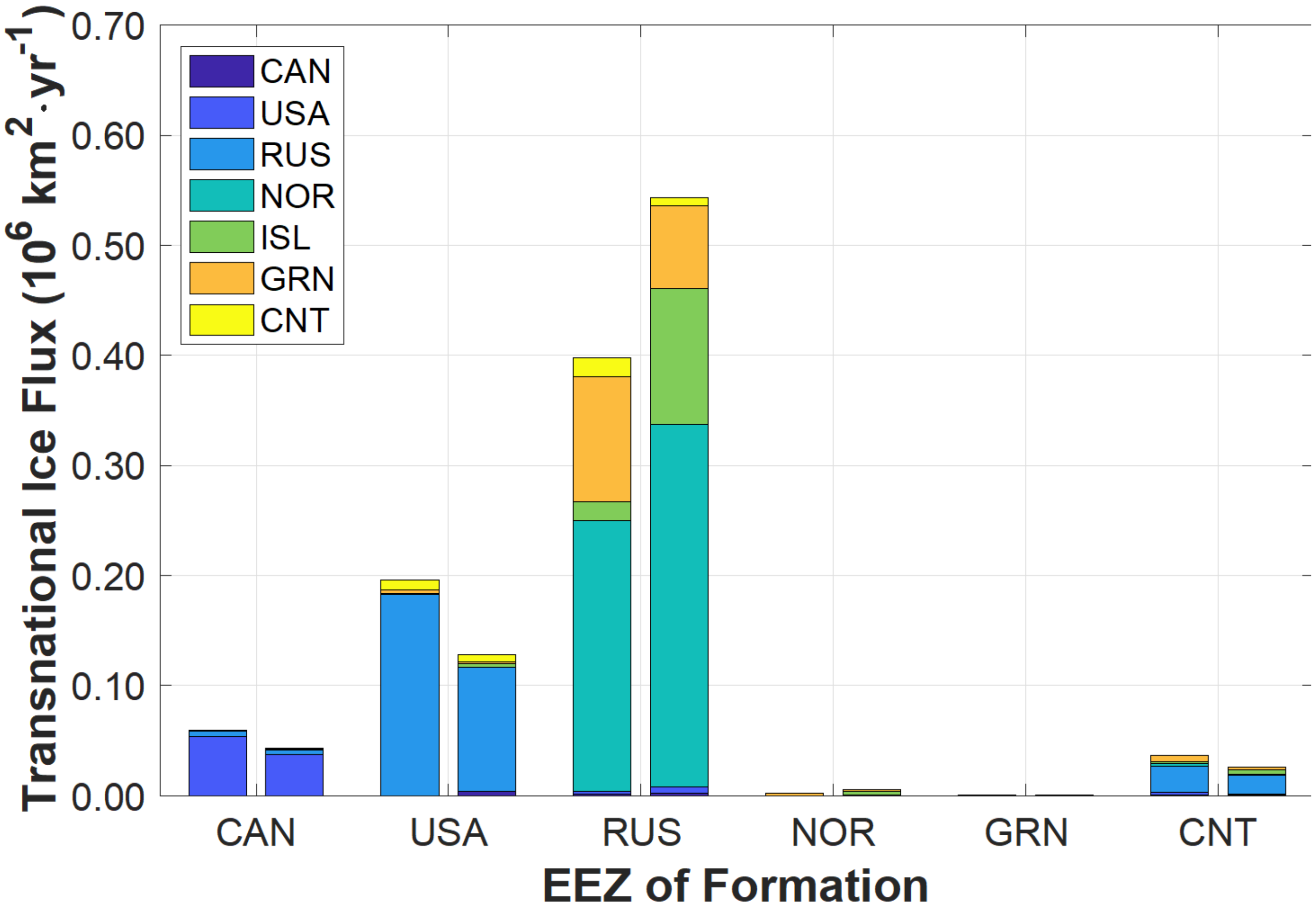
Comparison with Observations

Figure: Annual cycle of ice formation [*top*] and melt [*bottom*] for the observations and CESMLE over the period of 1989 to 2008



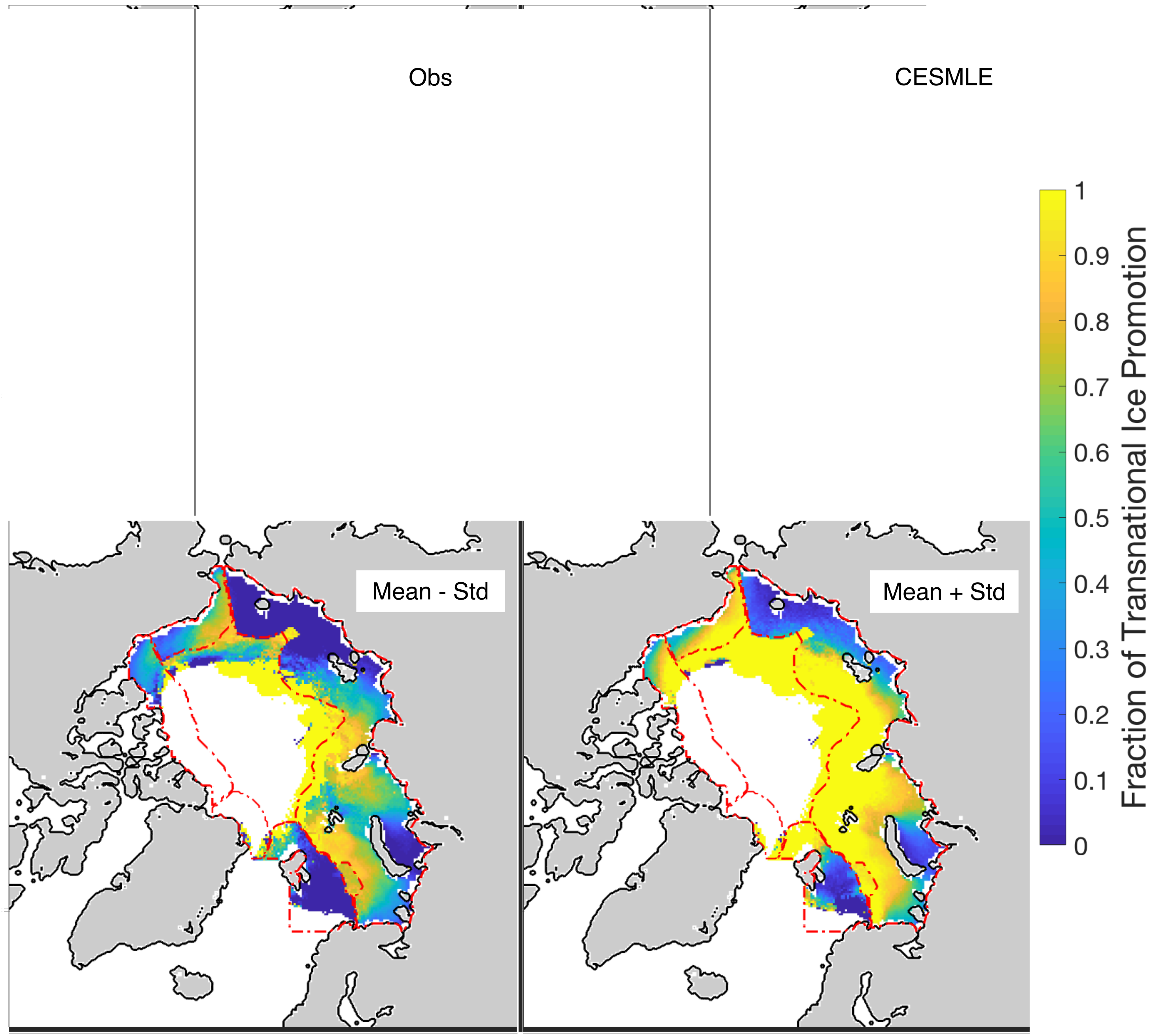
Comparison with Observations

Figure: Annual transnational ice exchange for the observations [*left bars*] and CESMLE [*right bars*] for the period of 1989 to 2008



Comparison with Observations

Figure: Fraction of transnational ice promotion for the observations [*top left*], the mean of all CESMLE members [*top right*] as well as the mean ± 1 std for CESMLE [*bottom*] over the period of 1989 to 2008



Comparison with Observations

Figure: Winter (Nov–May) mean sea ice velocity field (arrows) and sea level pressure contours (red) for years of sea-level pressure anomalies [*left*] greater or [*right*] lesser than 1 std from the mean during the 1990–99 period for (a,b) observations & (c,d) CESMLE

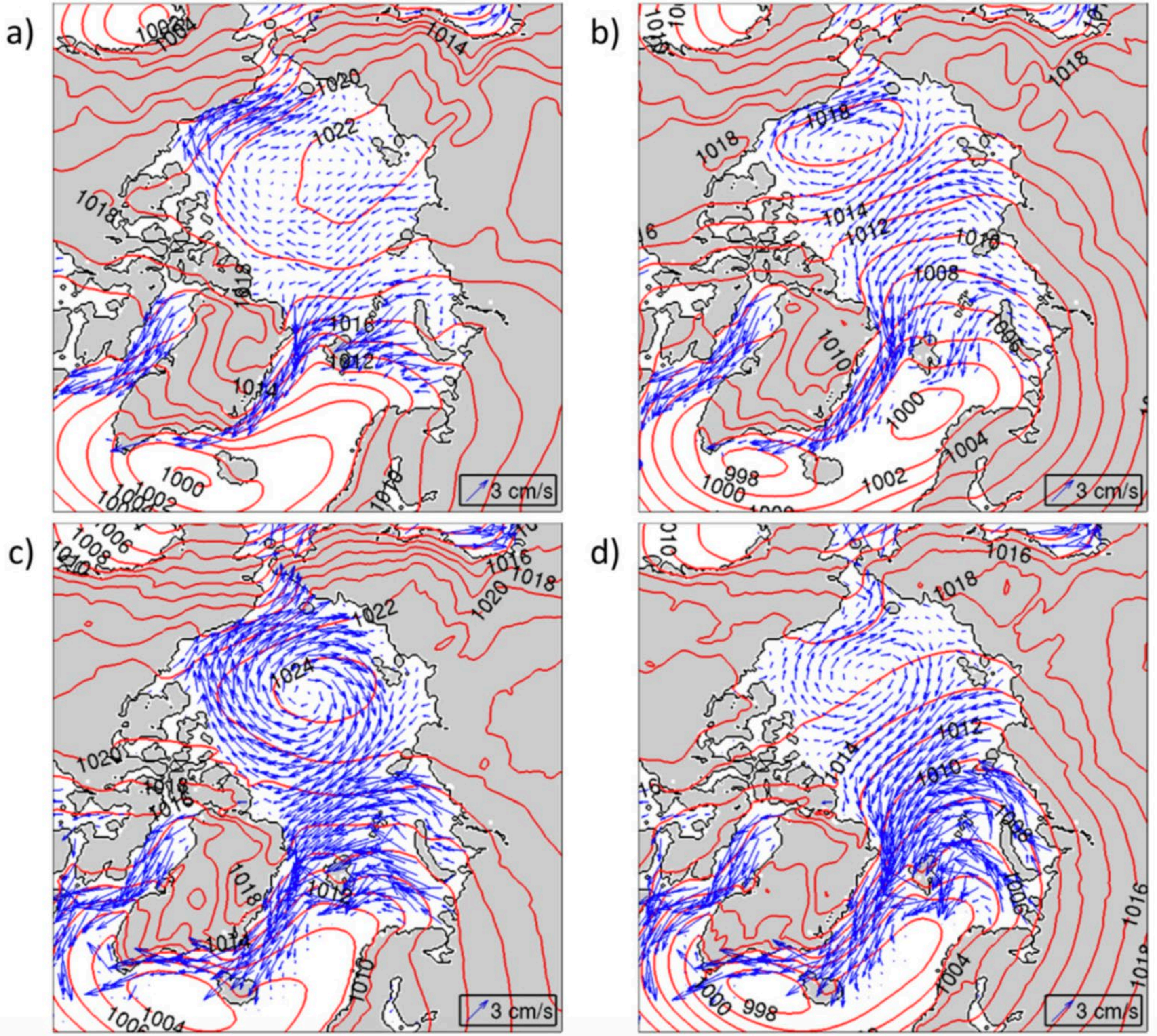


Figure from *DeRepentigny et al., 2016*