Take Home Message

- Arctic tundra continues to ‘green’ over most areas but not all.
- Sea ice retreat is extensive as summer open water grows.
- Summer Warmth has increased more over Eurasia than North America.
- Summer precipitation has increased more over N. American than Eurasia and is still weakly correlated with NDVI.
- Snow-off is happening earlier particularly over Eurasia.

Revisiting Climate Drivers of Arctic Tundra Variability and Change with a View to the Future

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Session: 2.8 Building a time machine out of a Delorean: Observing, reconstructing, and predicting vegetation change in the Arctic

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What do we know about *climate drivers* of tundra vegetation?

- More summer warmth correlates with higher NDVI
- Less sea ice along the coasts correlates with more summer warmth
- The sea-ice link to tundra NDVI operates on interannual to multidecadal time scales
- As sea ice continues its decline the correlations with NDVI have weakened

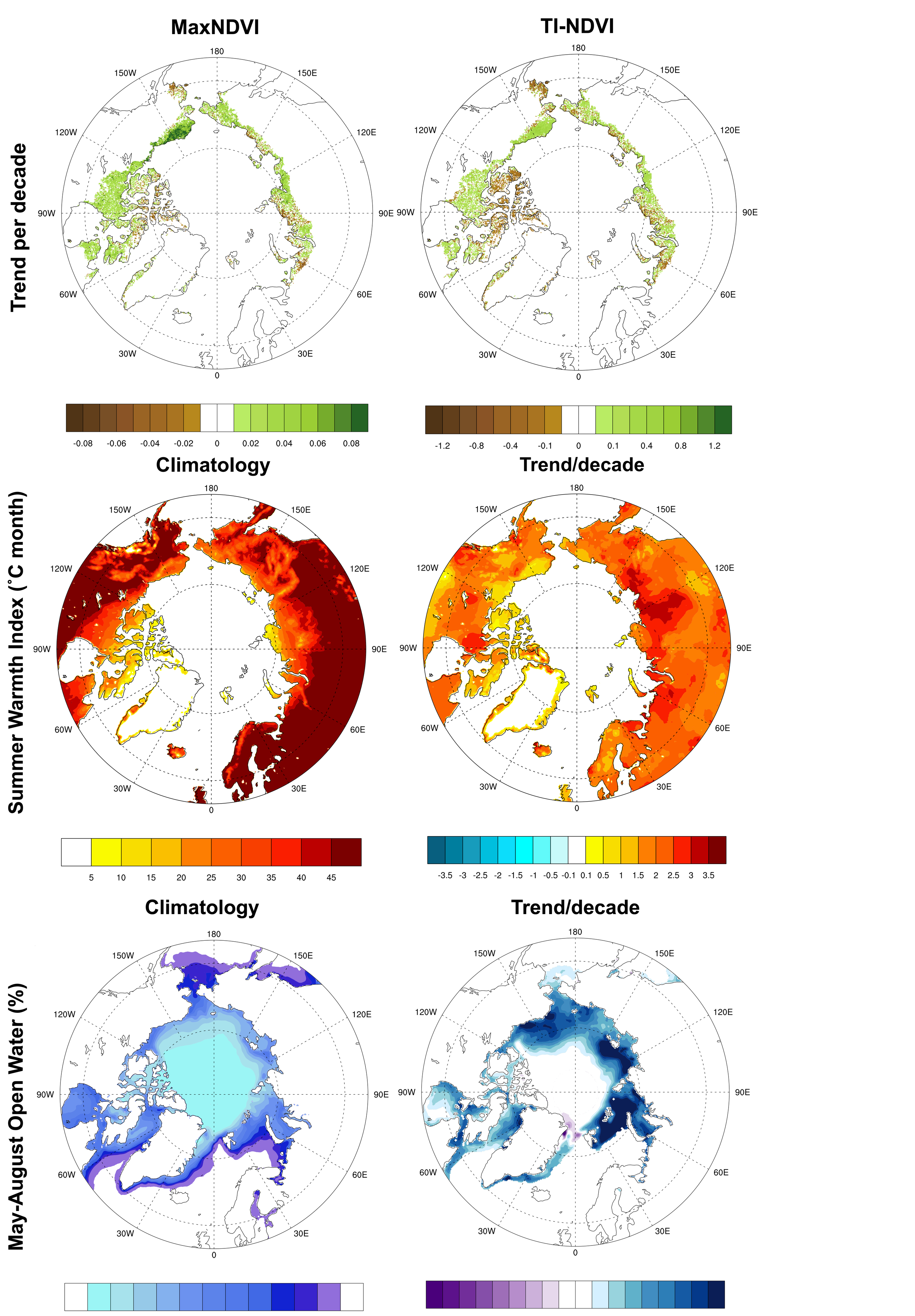

Figure 1. Decadal trends in Maximum NDVI (top left) and Time integrated NDVI (top right). Climatology (middle left) and decadal trend of Summer Warmth Index (SWI: sum of the degree months above freezing between May and September) (middle right). Climatology (bottom left) and decadal trend of summer open water (OW) (bottom right).

- **Yukon-Kuskokwim NDVI declines closely associated with decadal variations in sea ice in the Bering Sea (Hendricks et al. 2023, Frost et al. 2021)**
- **Multi-decadal NDVI variations are closely associated with low-frequency sea ice variability driven by the Arctic Dipole, atmospheric circulation pattern (Polyakov et al. 2025).**
- **There is extensive summer sea ice retreat in the Laptev and Beaufort Seas.**

Is moisture now an important driver of NDVI? Will it’s importance increase?

- What does earlier snow-off mean for Arctic tundra? Earlier start to growing season (MaxNDVI reaches higher values?) but that could also foster an earlier fire season.
- North America displays a greater absolute increase in precipitation than Eurasia during the summer.

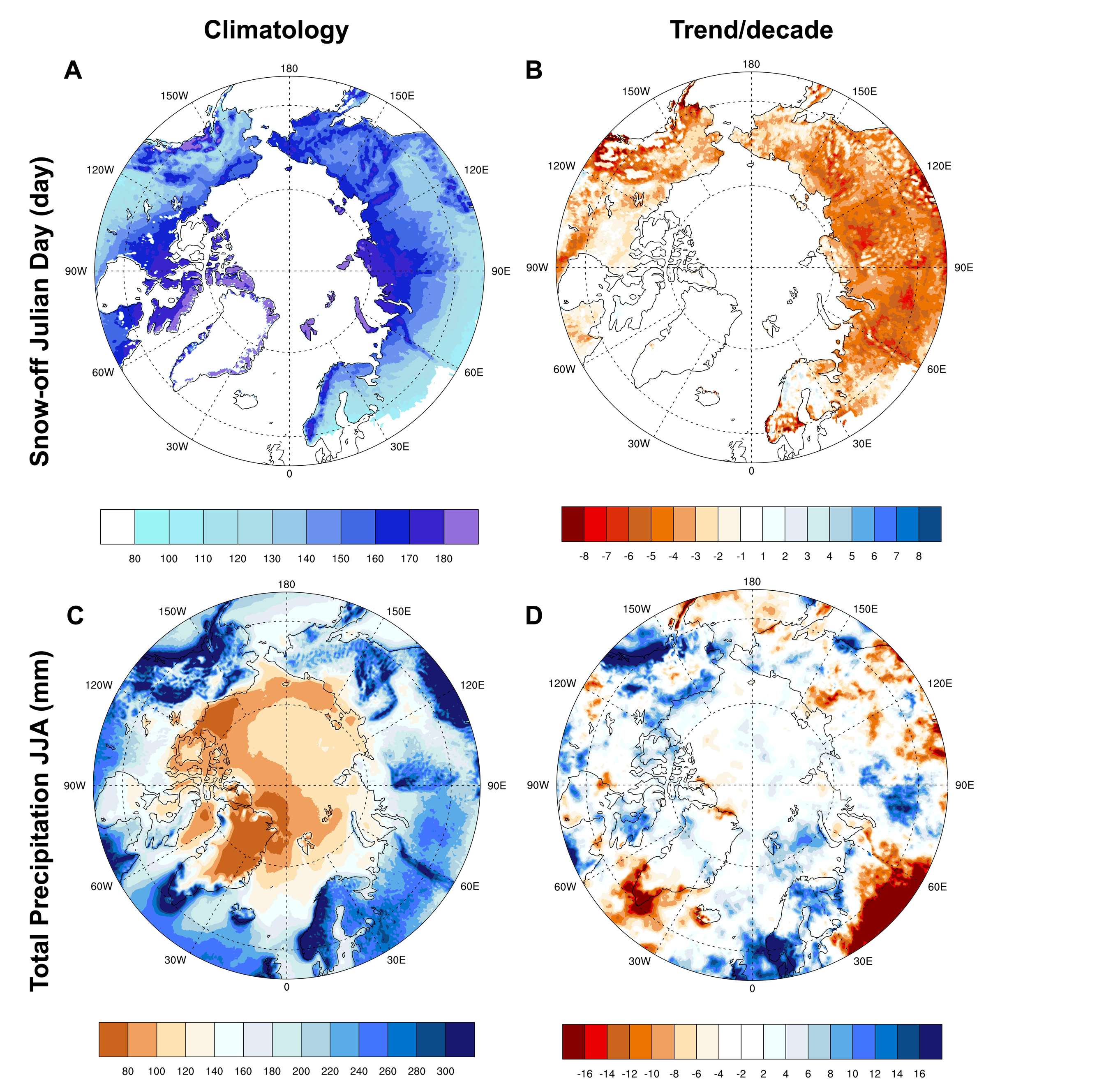

Figure 2. Climatology (top left) in Julian day and decadal trend in days/decade of snow-off (last day of snow in spring) (top right). Climatology (bottom left) in mm and decadal trend in mm/decade of summer precipitation (TP) (bottom right).

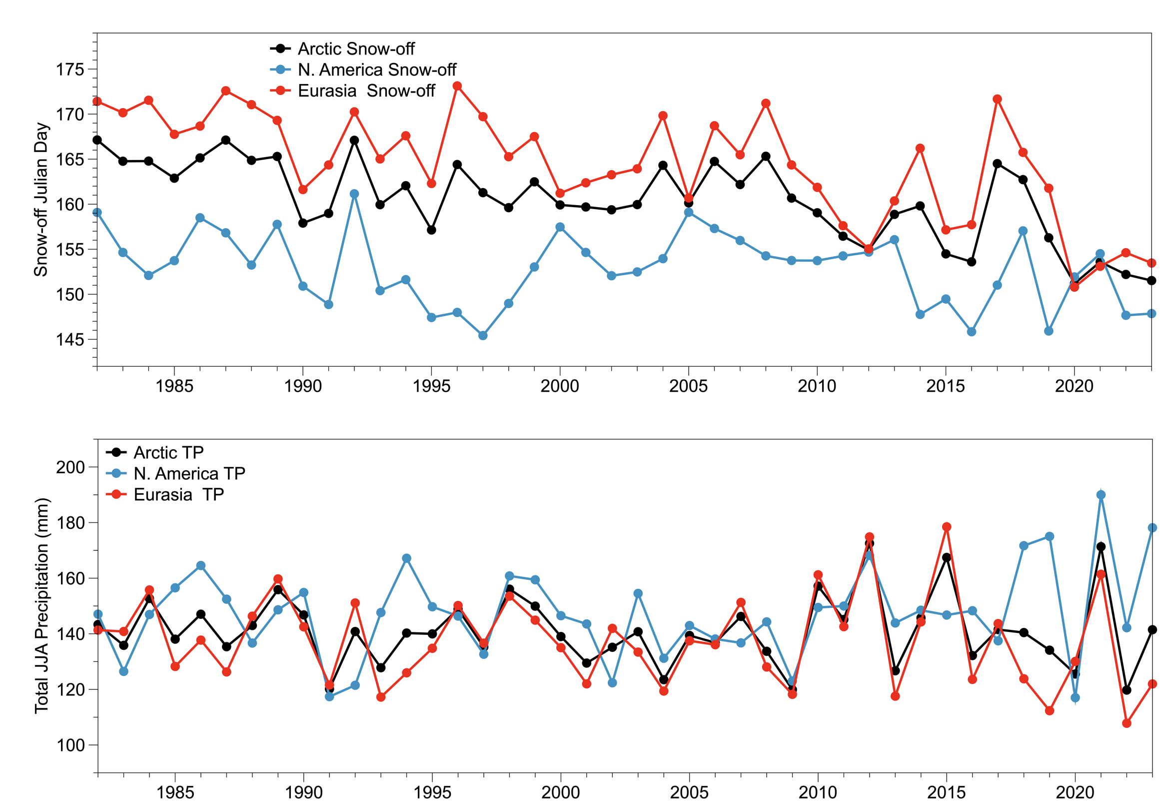

Figure 3. Timeseries of snow-off (top) and total summer precipitation in June-August (bottom) for Arctic (black), N. America (blue) and Eurasia (red) tundra as defined by Treshnikov zones (Bhatt et al. 2021).

- **The gap in snow-off timing between North America and Eurasia has narrowed, with Eurasia transitioning from significantly earlier snow-off to dates now more closely aligned with those in North America.**
- **Total summer precipitation and its variability has increased in North America during last 15 years.**

Correlation Compared 1982-24 (1982-2003/2004-2023)

Arctic

Arctic	SWI	Snowoff	MaxNDVI	TINDVI	CI	PCP
OW	**0.52 (0.58/0.58)**	**0.33** (0.32/0.34)	0.14 (0.23/0.25)	*0.27* **(0.45/0.46)**	-0.01 (0.24/0.25)	0.07 (0.22/0.25)
SWI	1	-0.03 (0.15/0.19)	**0.37** (0.28/0.35)	**0.33 (0.69/0.73)**	0.19 (0.25/0.27)	0.06 (0.22/0.3)
Snowoff		1	0.05 (0.01/-0.01)	*0.29* (0.14/0.13)	-0.05 (0.17/0.17)	0.11 (-0.22/-0.27)
MaxNDVI			1	**0.78 (0.74/0.76)**	*0.26* **(0.55/0.58)**	0.06 (0/-0.08)
TINDVI				1	0.23 **(0.49/0.49)**	0.14 (0.12/0.12)
CI					1	**-0.32 (-0.43/-0.44)**

Eurasia

Arctic	SWI	Snowoff	MaxNDVI	TINDVI	CI	PCP
OW	**0.54 (0.52/0.55)**	0.11 (0.08/0.06)	0.2 (0.17/0.24)	*0.27* **(0.43/0.45)**	-0.12 (-0.03/-0.05)	0.05 (0.02/0.22)
SWI	1	-0.1 (0.03/0.06)	*0.26* (0.12/0.27)	**0.44 (0.71/0.79)**	0.12 (0.24/0.26)	-0.06 (0.15/0.27)
Snowoff		1	0.09 (0.07/0.11)	*0.27* (0.17/0.18)	-0.04 (0.2/0.17)	-0.08 (-0.27/-0.31)
MaxNDVI			1	**0.55 (0.61/0.63)**	0.05 (0.32/**0.45**)	0.07 (0.22/0.11)
TINDVI				1	0.09 *(0.41/0.44)*	0.02 (0.23/0.2)
CI					1	*-0.28* **(-0.46/-0.49)**

N. America

Arctic	SWI	Snowoff	MaxNDVI	TINDVI	CI	PCP
OW	**0.52 (0.59/0.61)**	0.02 (0.1/0.08)	0.13 *(0.37/0.39)*	**0.35 (0.54/0.57)**	0.04 (0.29/0.28)	0.18 (0.14/0.1)
SWI	1	-0.14 (-0.24/-0.26)	**0.39** (0.33/0.33)	**0.48 (0.64/0.65)**	*0.28* (*0.37*/0.37)	0.16 (0.24/0.25)
Snowoff		1	0.1 ((-0.11/-0.11)	0.1 (-0.22/-0.2)	-0.13 (-0.34/*-0.39*)	0.02 (-0.22/-0.27)
MaxNDVI			1	**0.82 (0.84/0.84)**	**0.43** *(0.4/0.41)*	0.04 (-0.22/-0.22)
TINDVI				1	**0.31 (0.42/0.44)**	0.17 (-0.1/-0.08)
CI					1	0.14 (-0.02/-0.04)

- **Correlations do not reveal notable differences between the first and second halves of the 1982-2023 record.**
- **OW & SWI are positively correlated at the Pan-Arctic scale as well as regionally (regional correlations not shown).**
- **MaxNDVI & TINDVI are correlated with SWI with TINDVI more strongly, consistent with both TI & SWI being summer measures.**
- **Continentaliy Index (CI, Annual monthly maximum minus minimum T) positively correlated with TINDVI (i.e., warm summers).**
- **CI is negatively correlated with precipitation (TSP) and this relationship is stronger in Eurasia than North America. Low CI means a more maritime climate and consistent with reduced continentality.**
- **Snowoff (last day of snow) is positively correlated with TINDVI in Eurasia but not North America (later showoff higher TINDVI?).**

CMIP6 Projections indicate warming and wetting over Y-K Delta

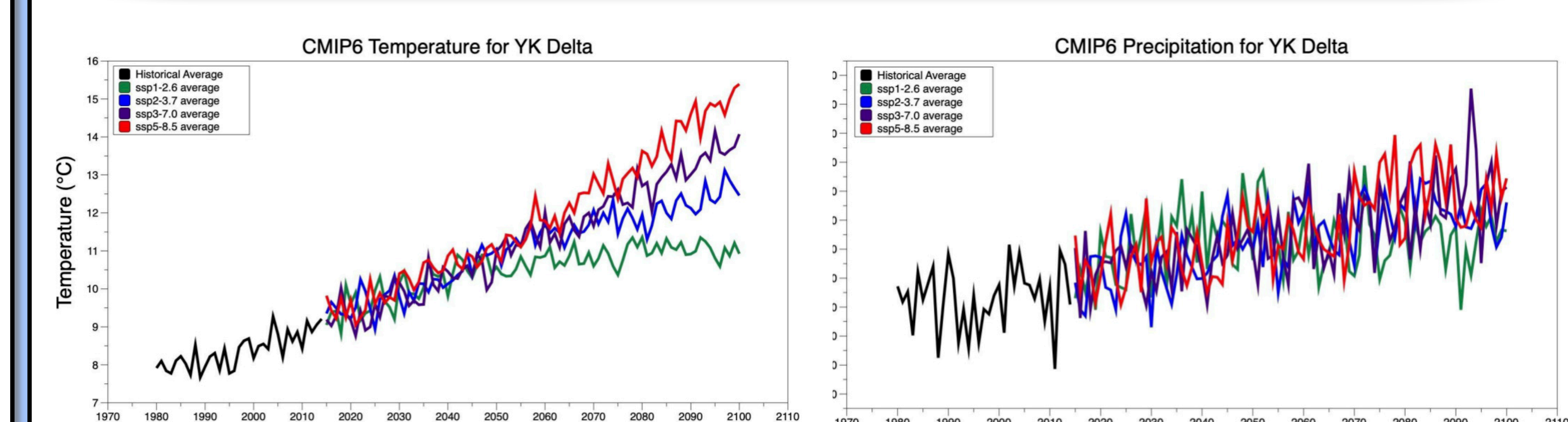

Figure 4. CMIP6 multi-model ensemble projections for summer (May-August) (left) average temperature and (right) total precipitation. Colors represent representative concentration pathways (see key). The multi-model ensemble consists of twelve model averages for each scenario except SSP2-3.7 and SSP4-7.0 which averaged eleven and ten models, respectively. This is figure 9 from Hendricks et al. (2025).

- **Temperature projections for the Yukon-Kuskokwim increase depending on scenario (Hendricks et al. 2025) with higher emissions decreasing more. The scenarios separate starting around 2050-2060.**
- **Precipitation increases in all scenarios but displays large interannual variability and starting in 2080 ssp1-2.6 has less precipitation than higher scenarios.**

Data and Methods

Data

- GIMMS3g AVHRR-based Max NDVI and Time Integrated NDVI (TI-NDVI) (Pinzon et al. 2023) for 1982-2023.
- SSMI/SSMR Passive microwave sea ice concentration 1982-2023.
- ECMWF ERA5 Reanalysis air temperature (SWI & CI), snow-off, and total precipitation for 1982-2023 (Hersbach et al. 2020).

Methods

- Conventional climate statistical analysis: correlation, regression, trend, statistical significance etc.

References

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Acknowledgements

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