The role of ocean heat transport versus surface heat fluxes in driving Arctic warming and sea-ice decline

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Claude Frankignoul
Gokhan Danabasoglu
Stephen Yeager
Who Kim

Motivation

- Arctic Ocean warming has been linked to enhanced ocean heat convergence (e.g. Bitz et al. 2006, Årthun et al. 2012, Smedsrud et al. 2013, Onarheim et al. 2015; Polyakov et al. 2017; Auclair and Tremblay 2018; Stroeve and Notz 2018; Wang et al. 2020; Shu et al. 2022)

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Presentation Outline

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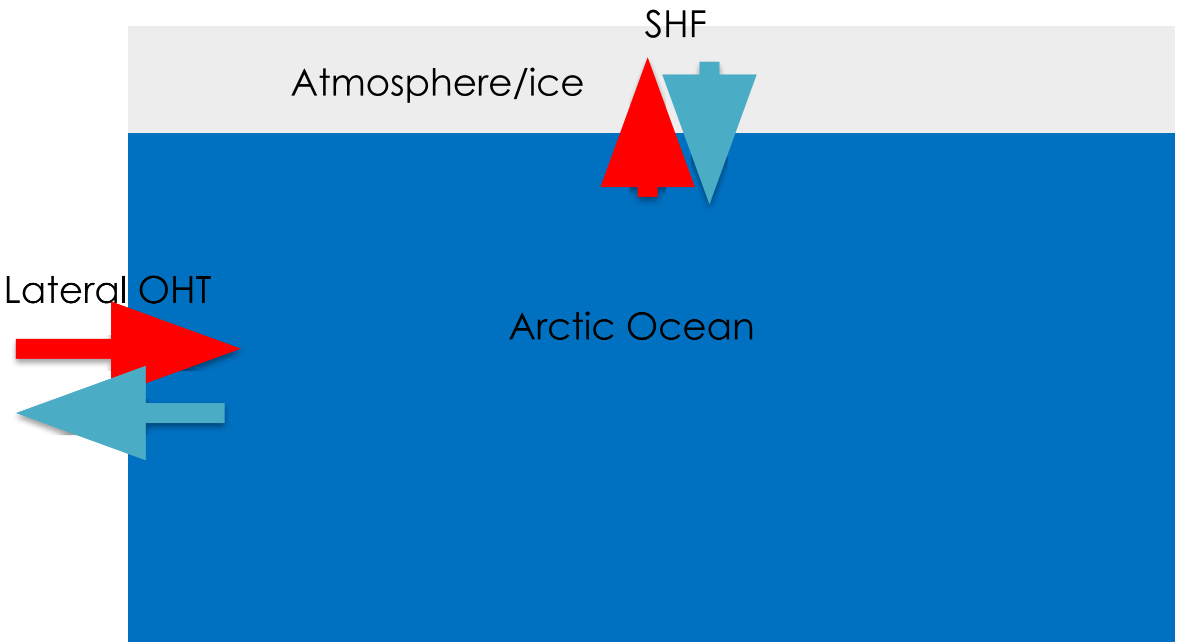

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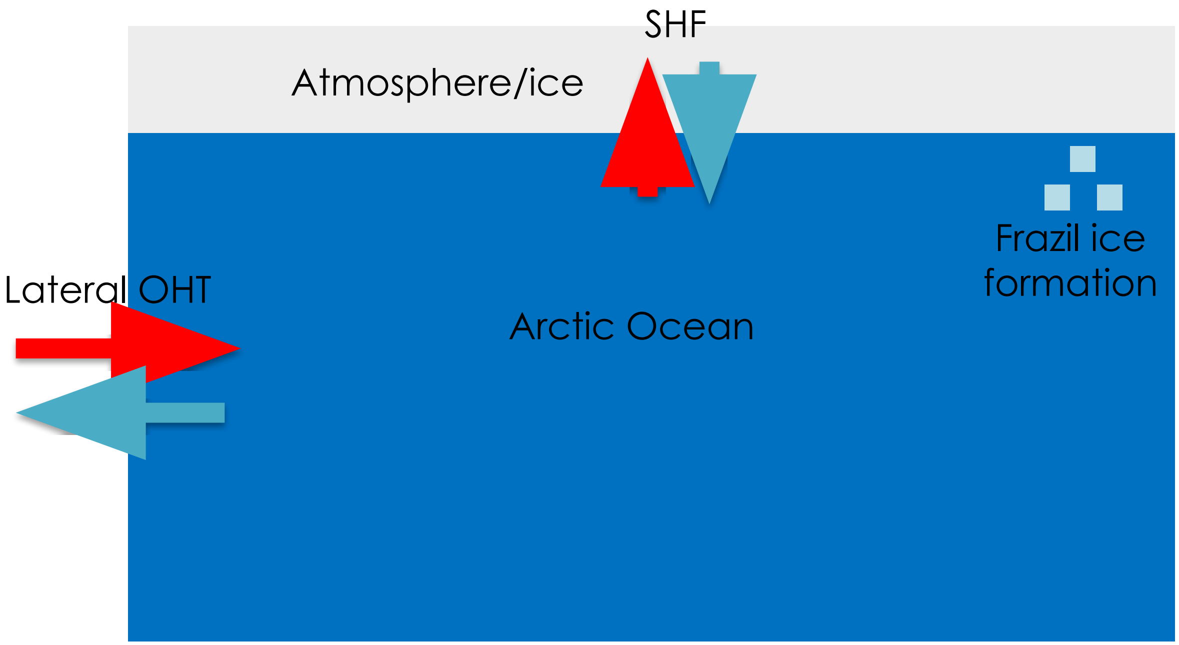

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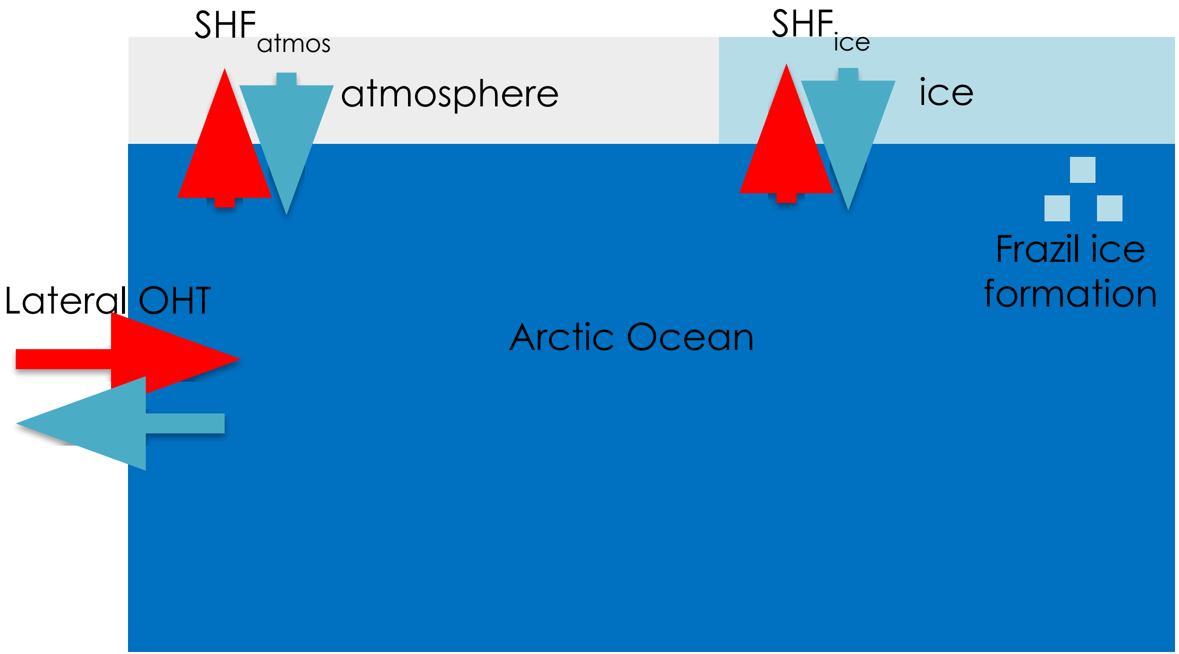

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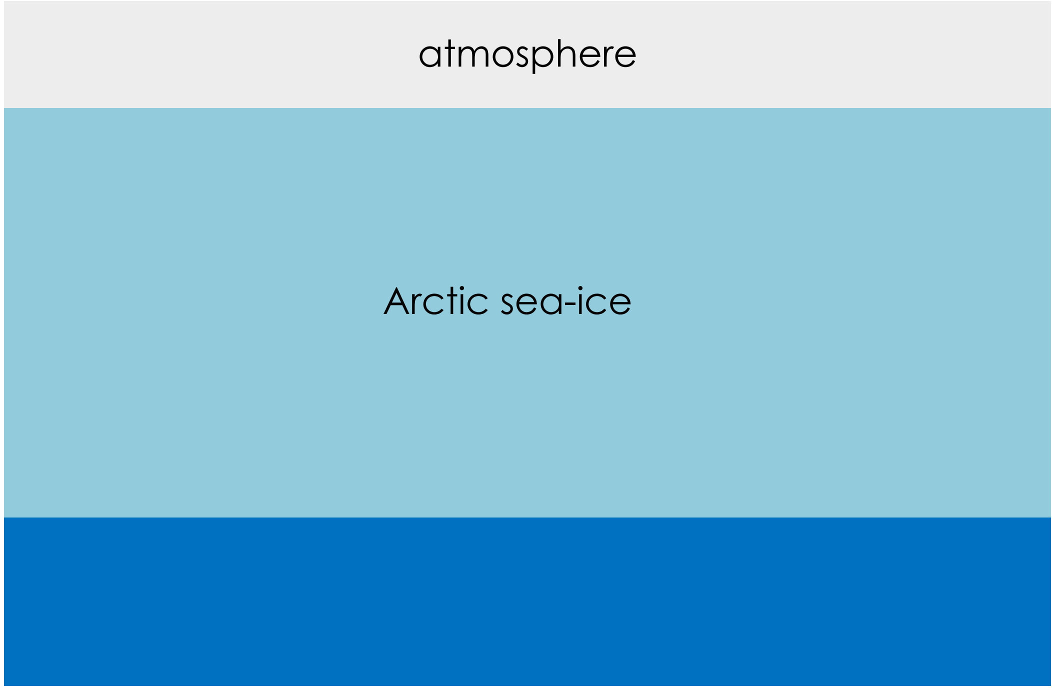

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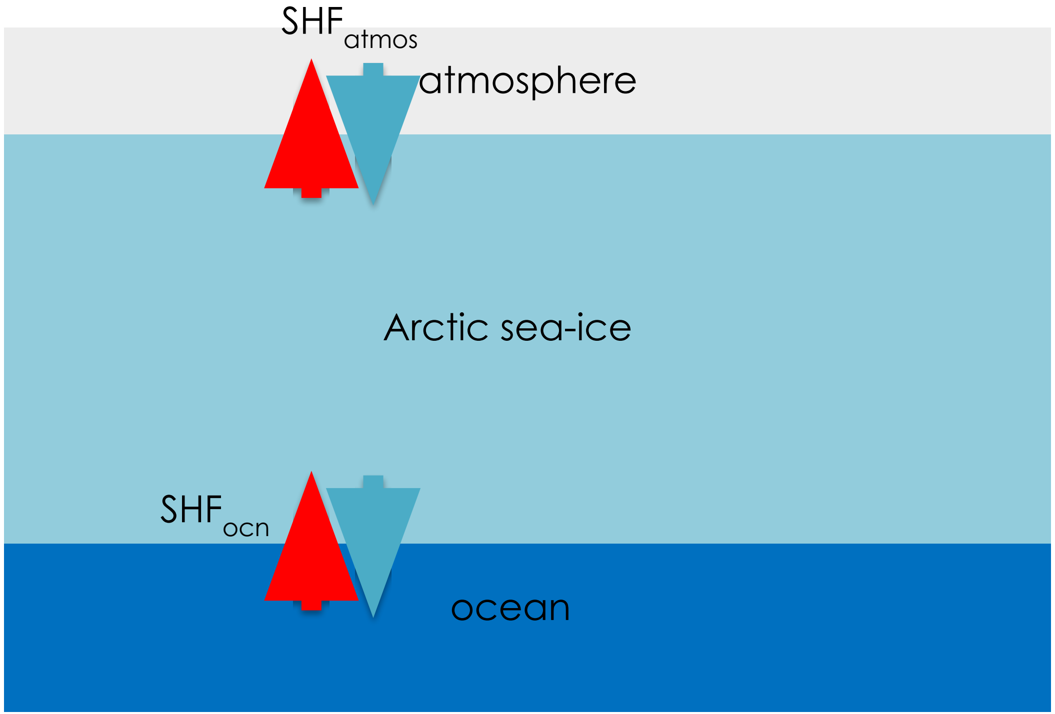

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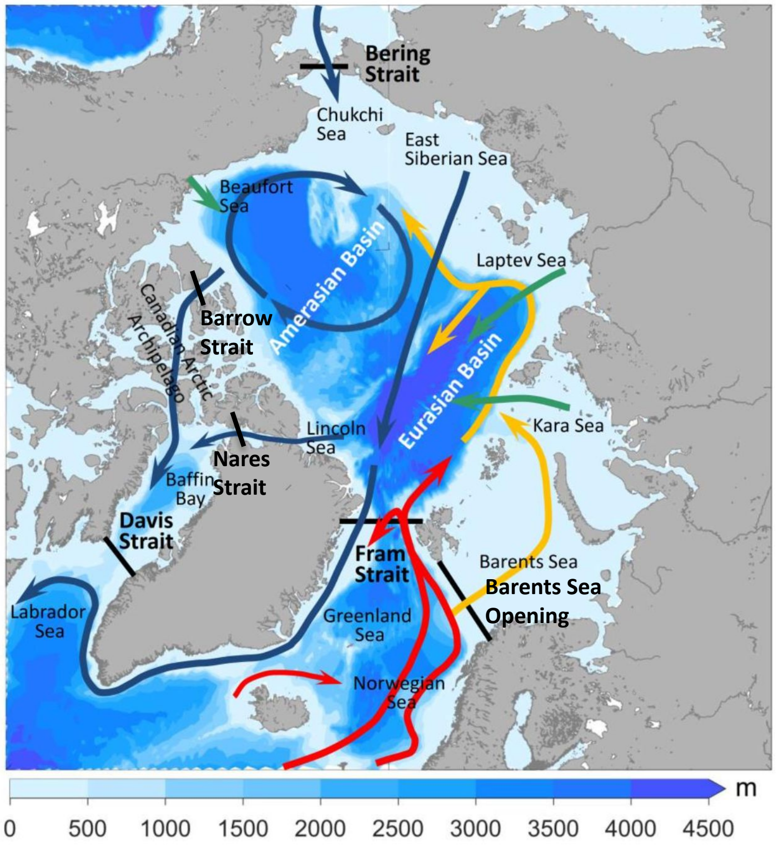

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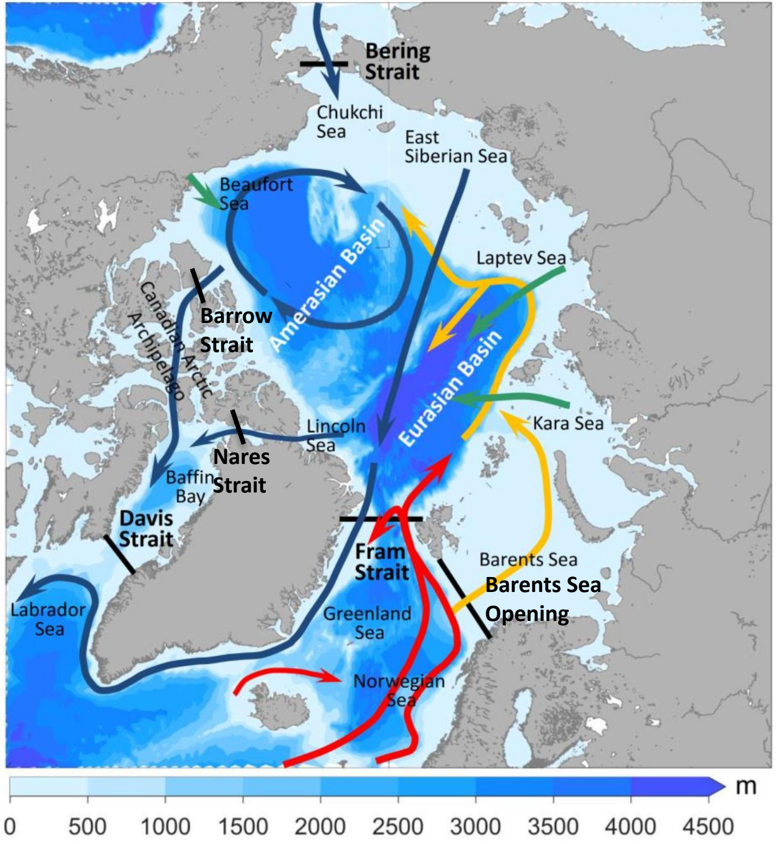
$$\mathrm{OHT_{tot}}(t) = \rho c_p \int_{x_1}^{x_2} \int_{z_{bot}}^{0} \overline{v\theta}\, dz\, dx$$



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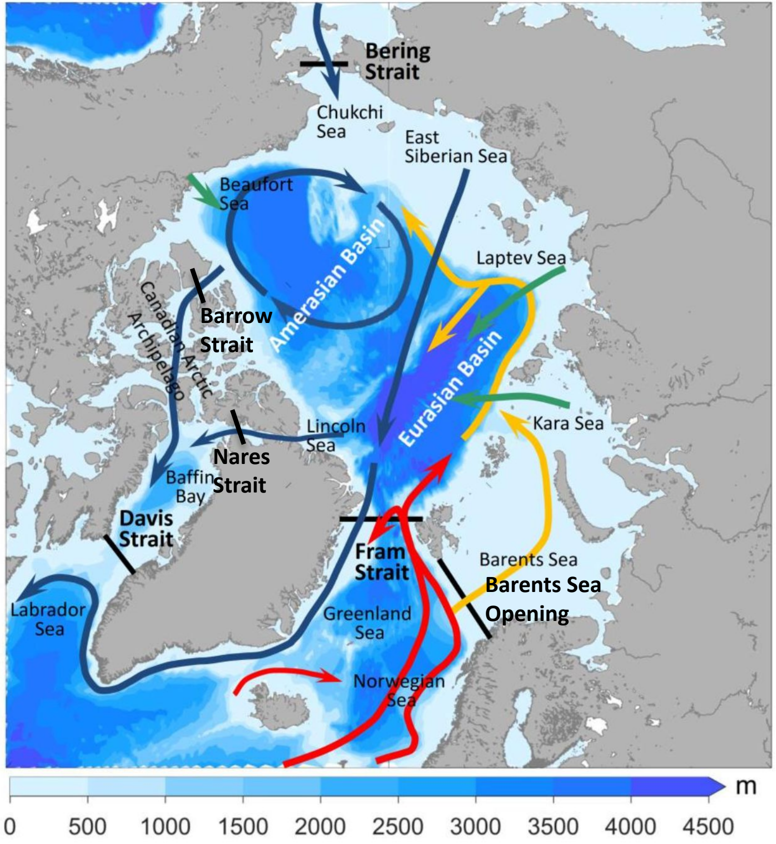

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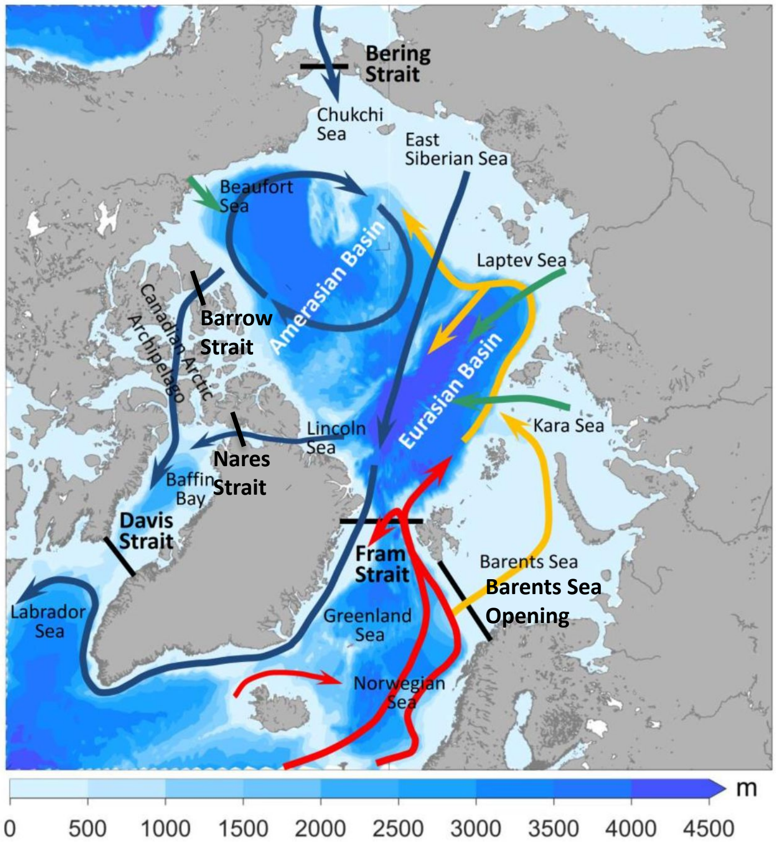
$$\mathrm{OHT_{subm}} = \mathrm{OHT_{tot}} - \mathrm{OHT_{Eul}}$$



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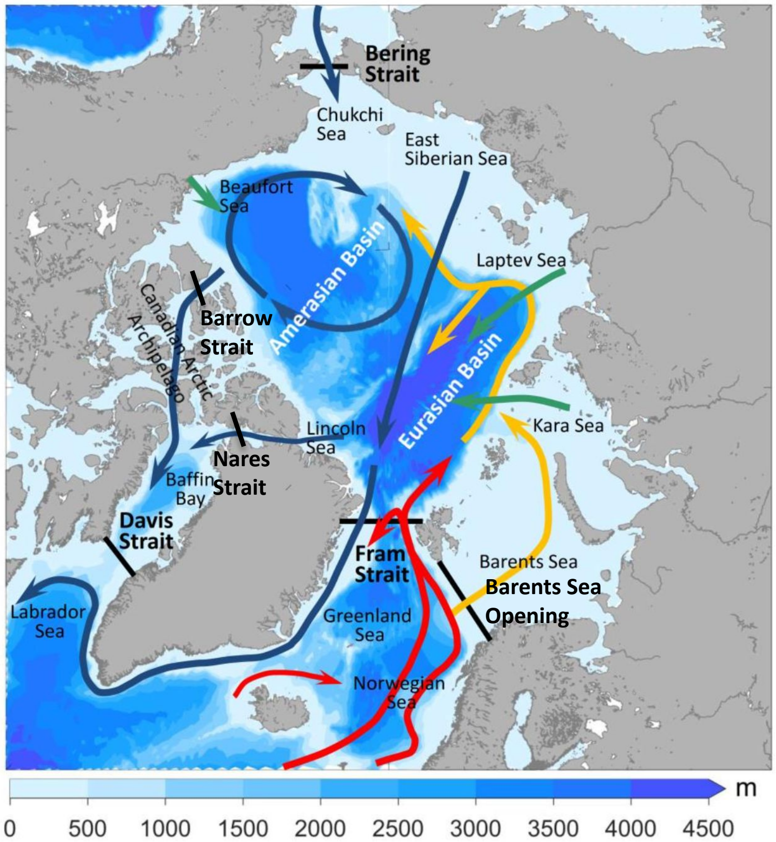
$$\mathrm{OHT_{subm}} = \mathrm{OHT_{tot}} - \mathrm{OHT_{Eul}}$$

$$\mathrm{F_{residual}} = \frac{d}{dt}\mathrm{OHC} - \mathrm{OHT_{tot}} - \mathrm{Frazil} - \mathrm{SHF}$$



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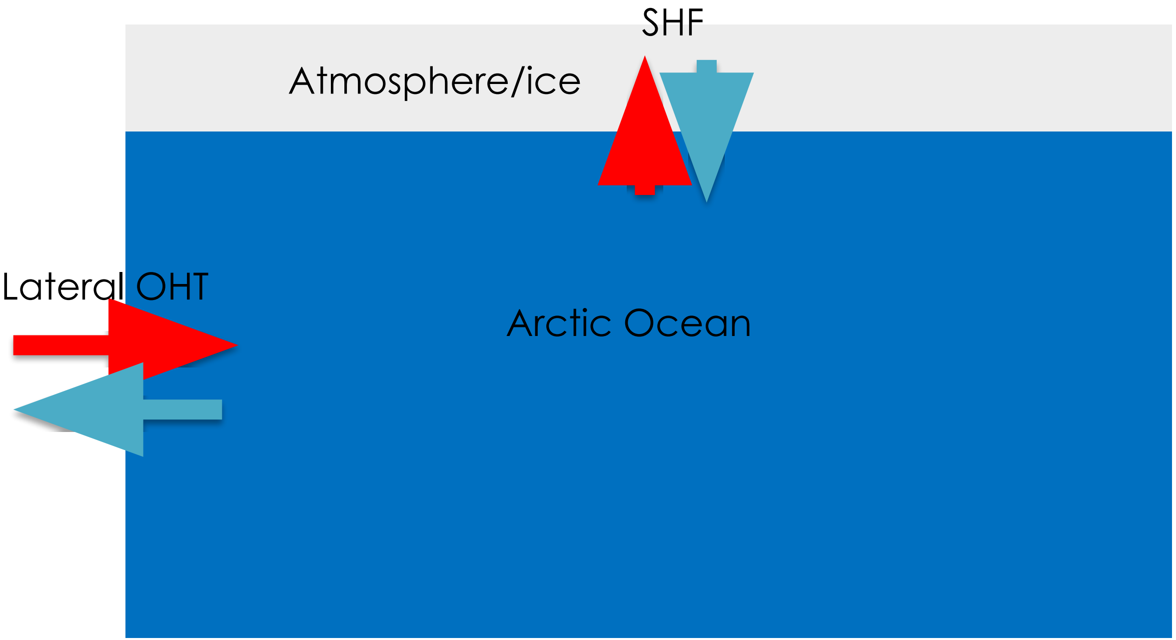

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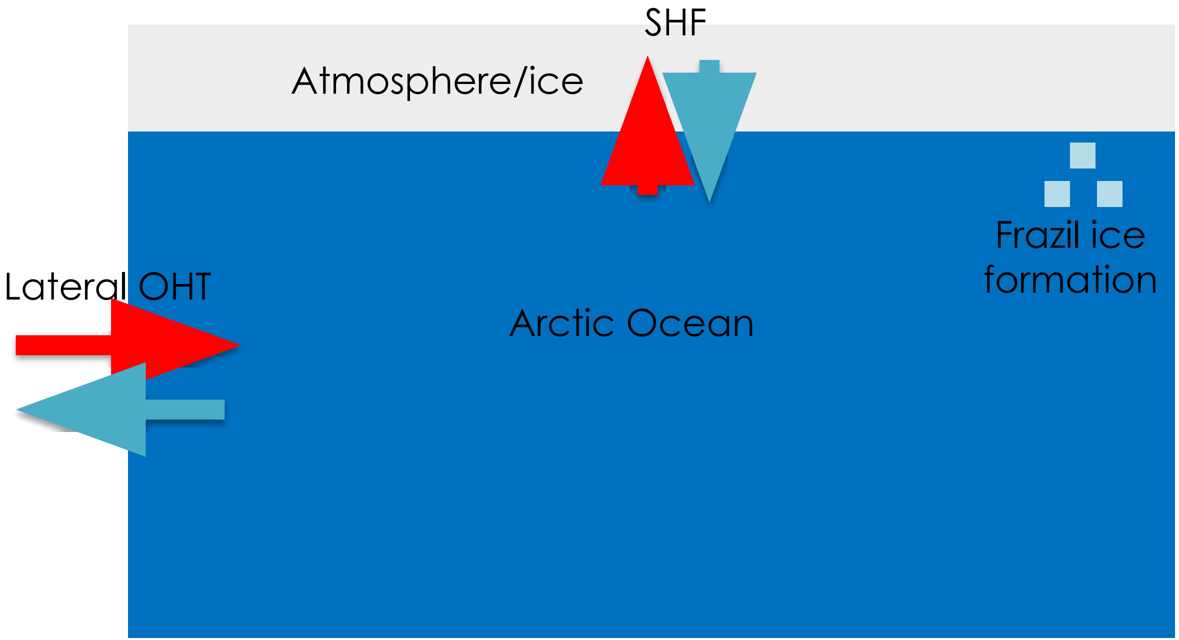
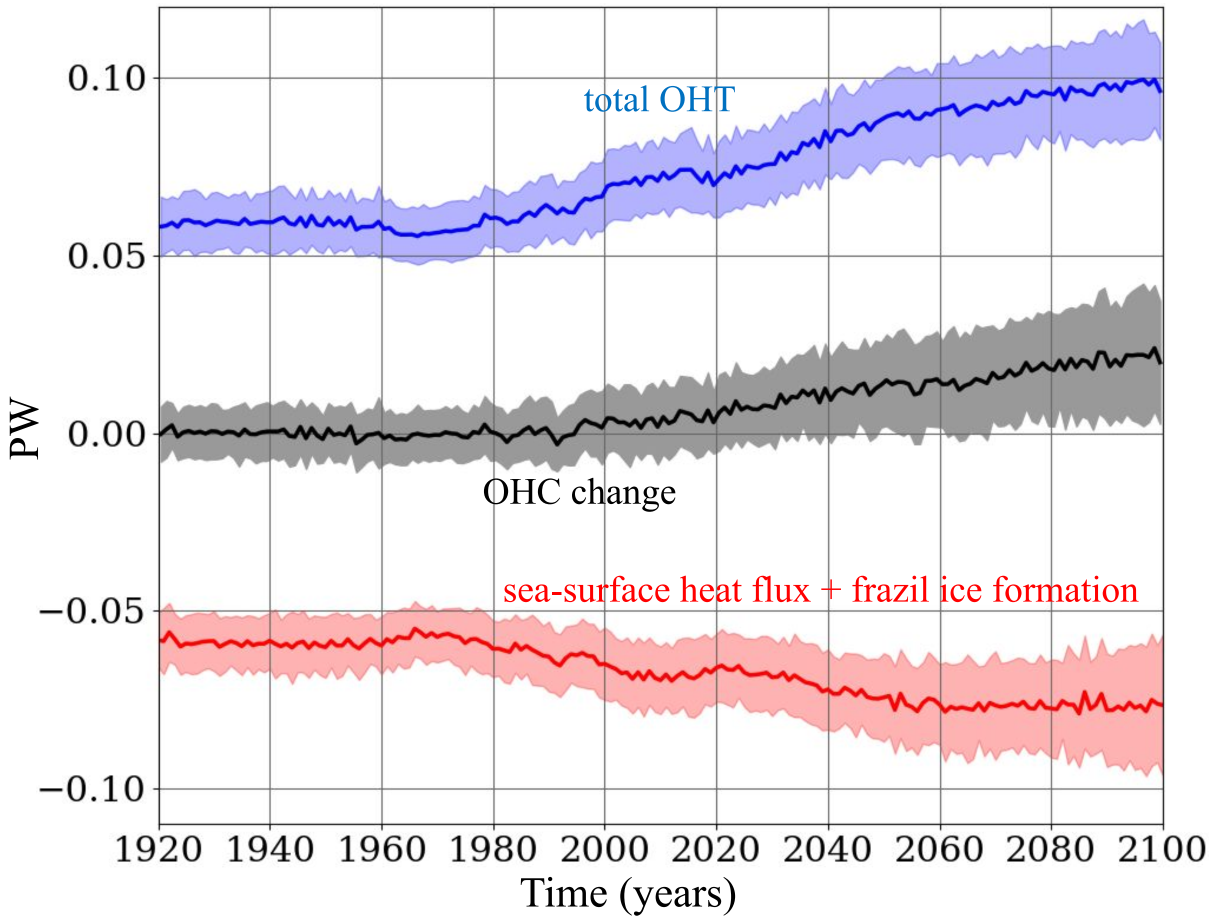


OHT increase drives warming, overwhelms increase in surface heat loss



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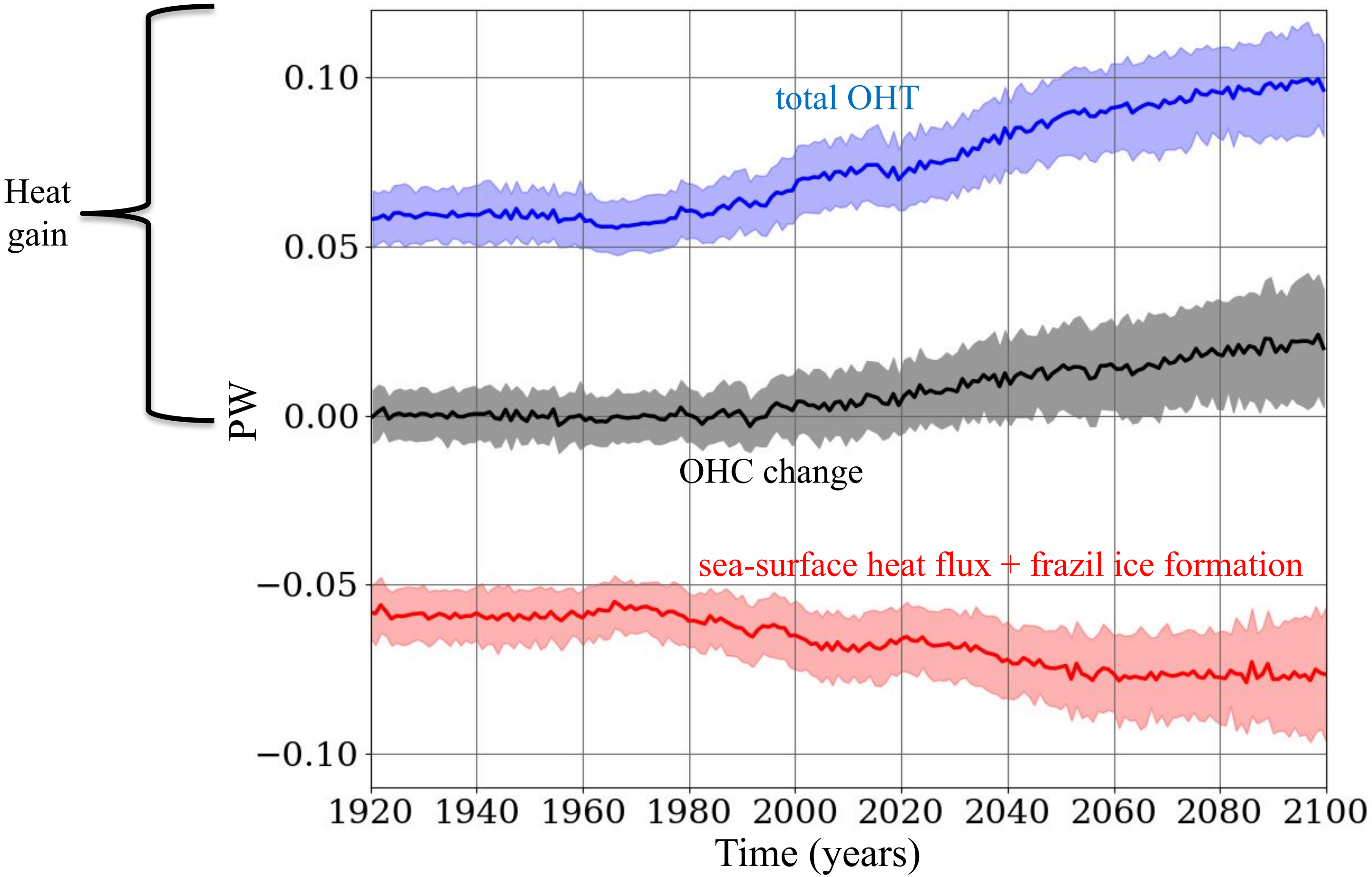

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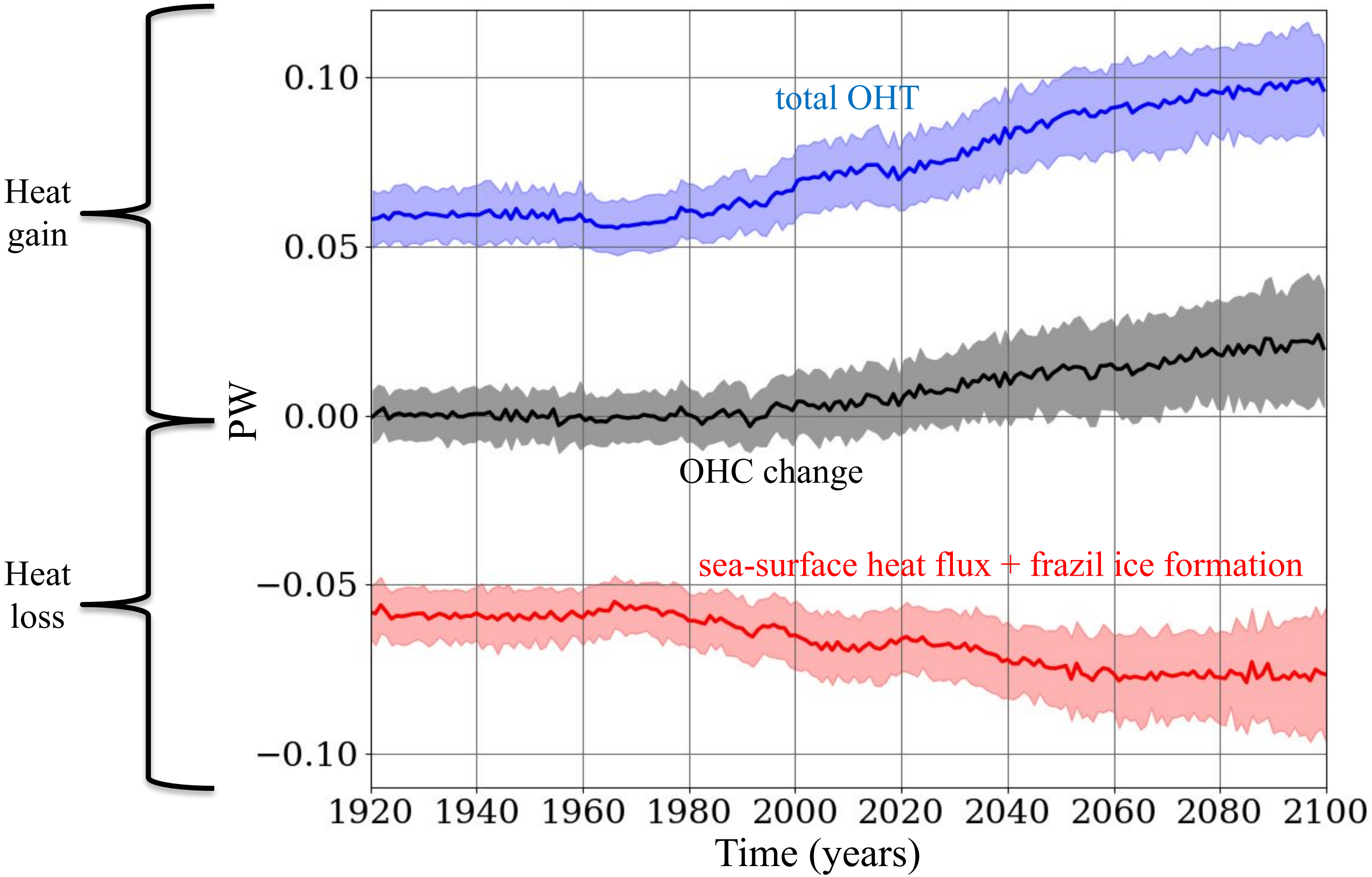

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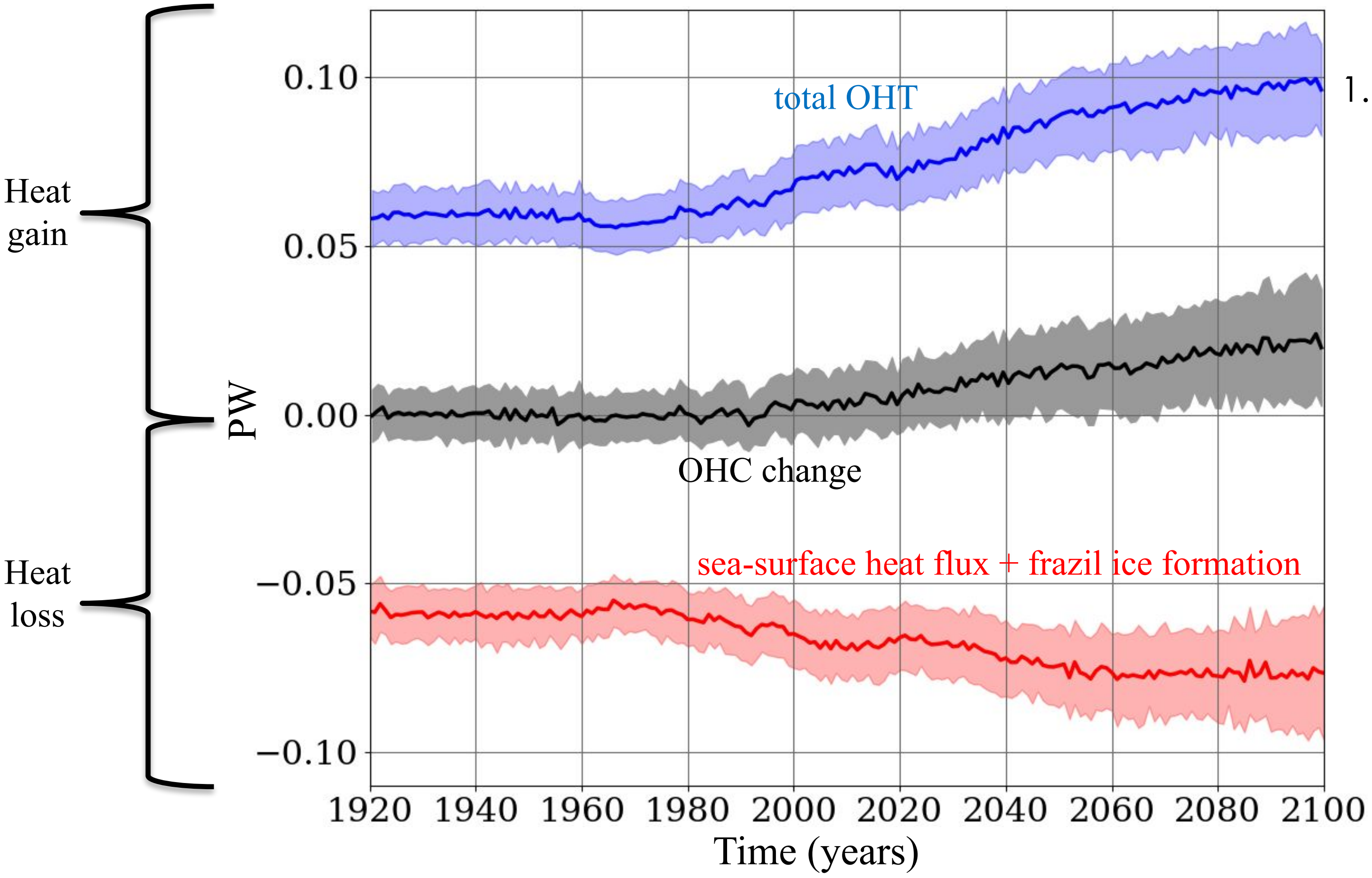
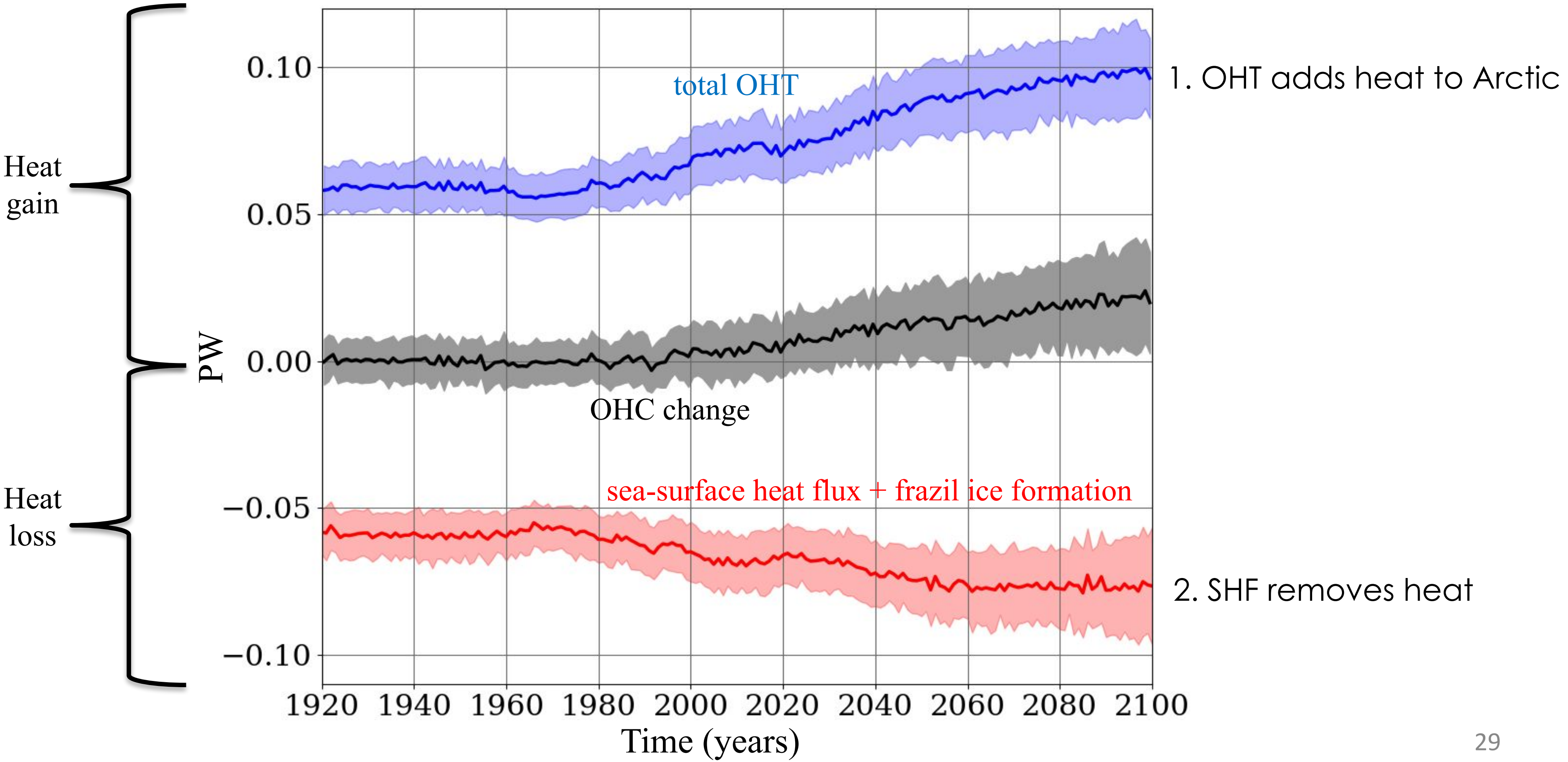


1. OHT adds heat to Arctic

OHT increase drives warming, overwhelms increase in surface heat loss



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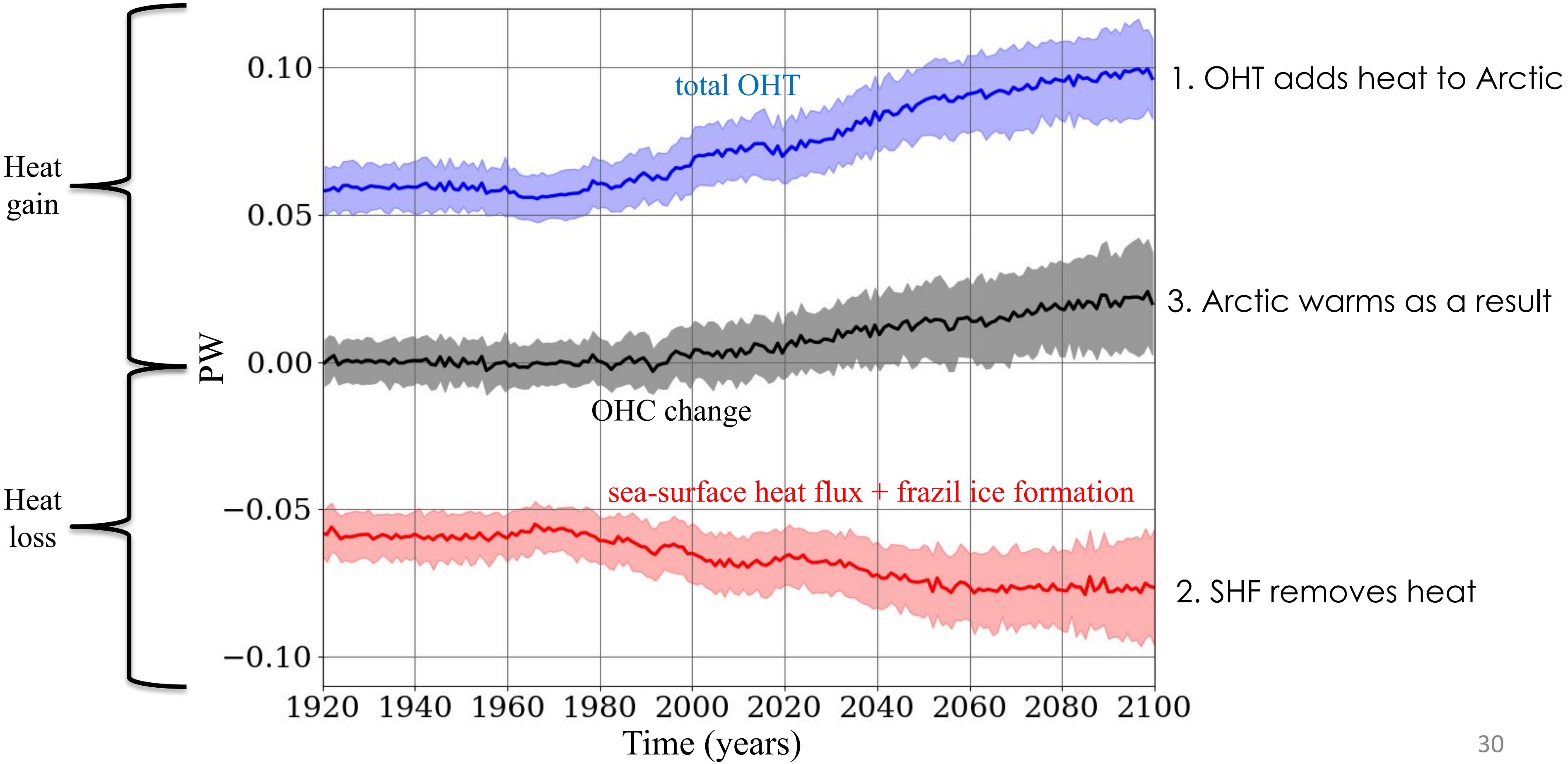

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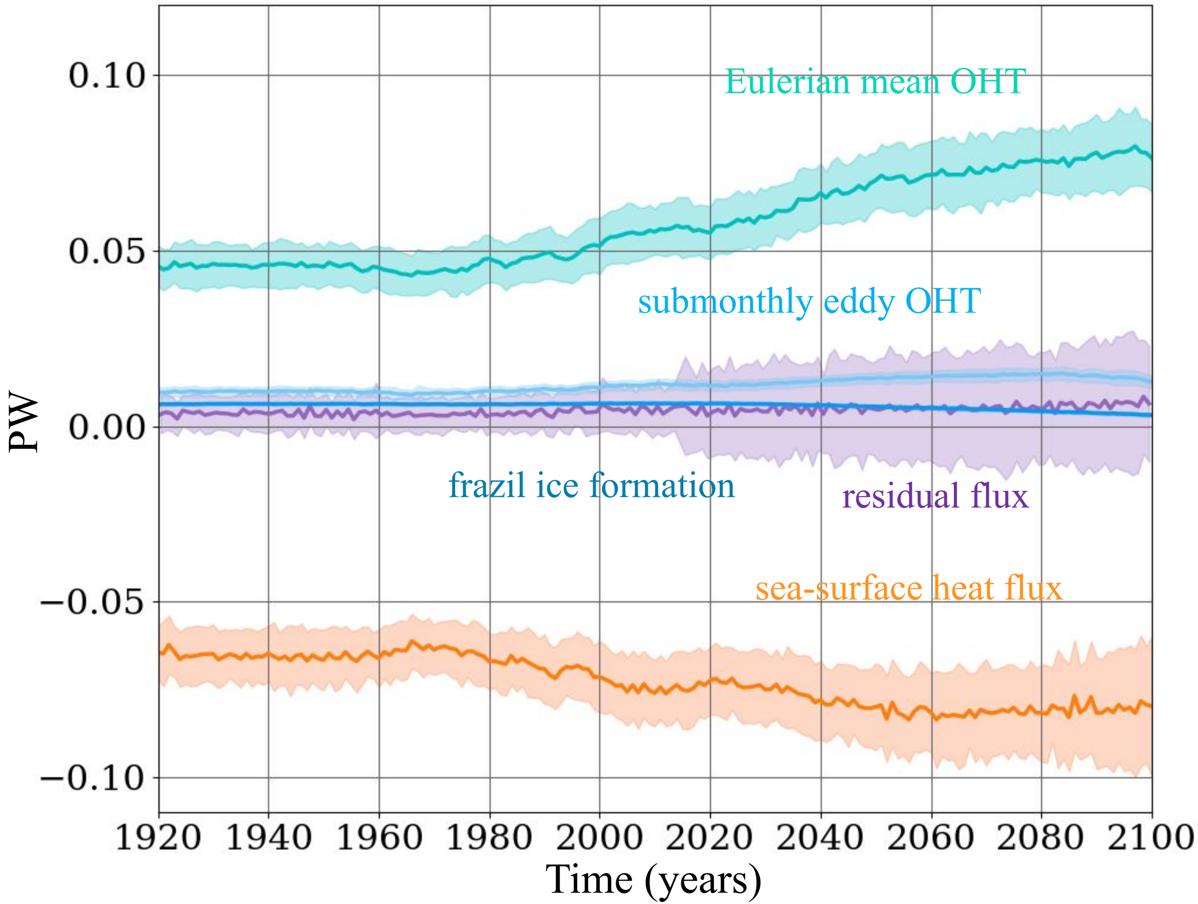

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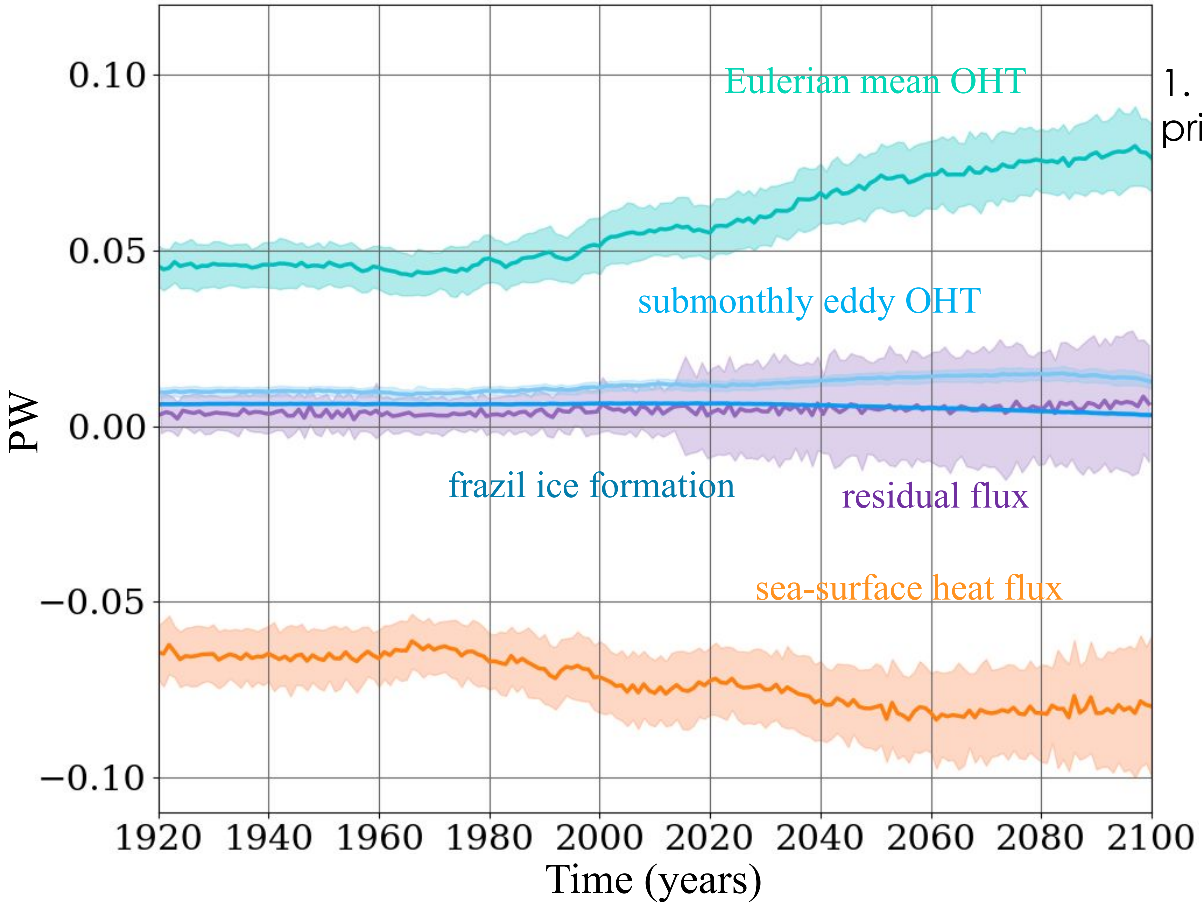
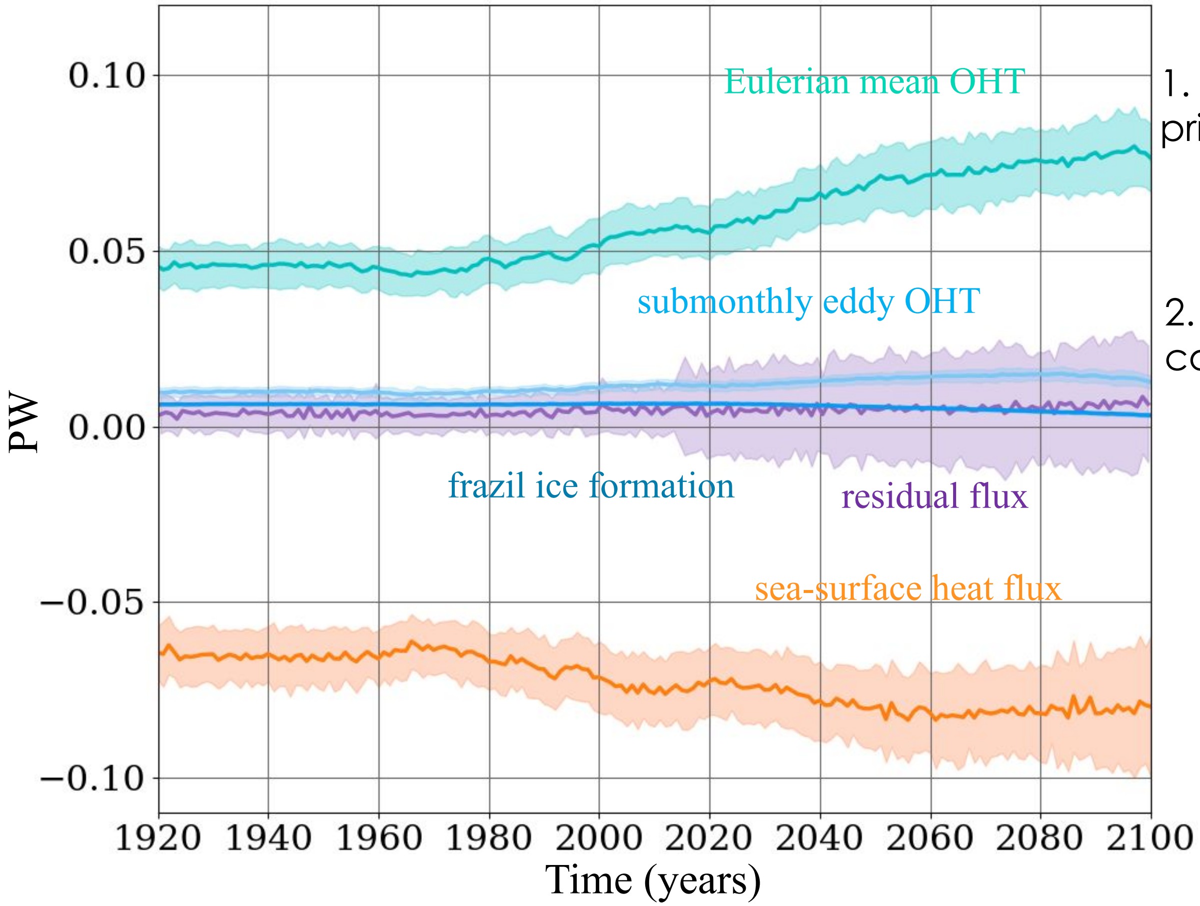


1. Eulerian-mean OHT primary driver of heat gain

OHT increase drives warming, overwhelms increase in surface heat loss



1. Eulerian-mean OHT primary driver of heat gain

2. Submonthly/residual also contribute to heat gain

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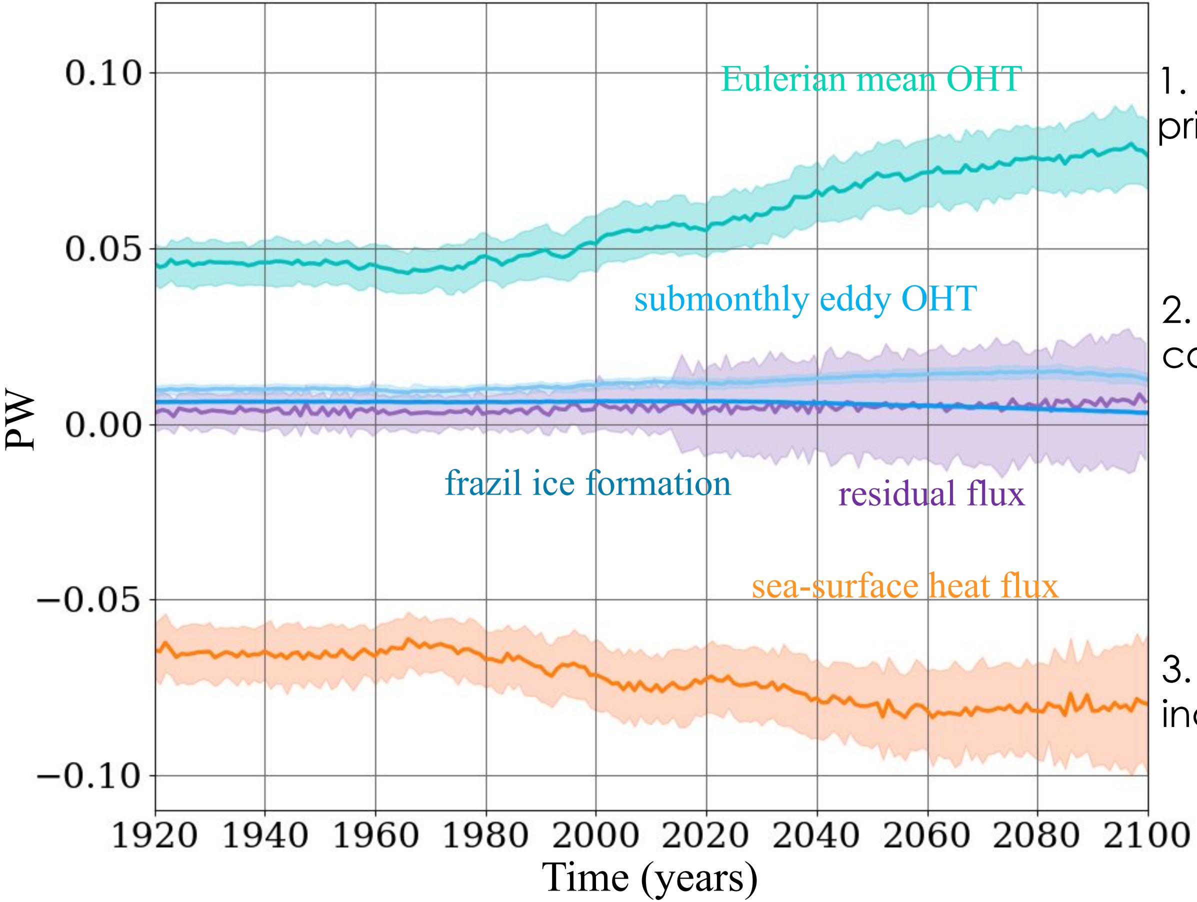

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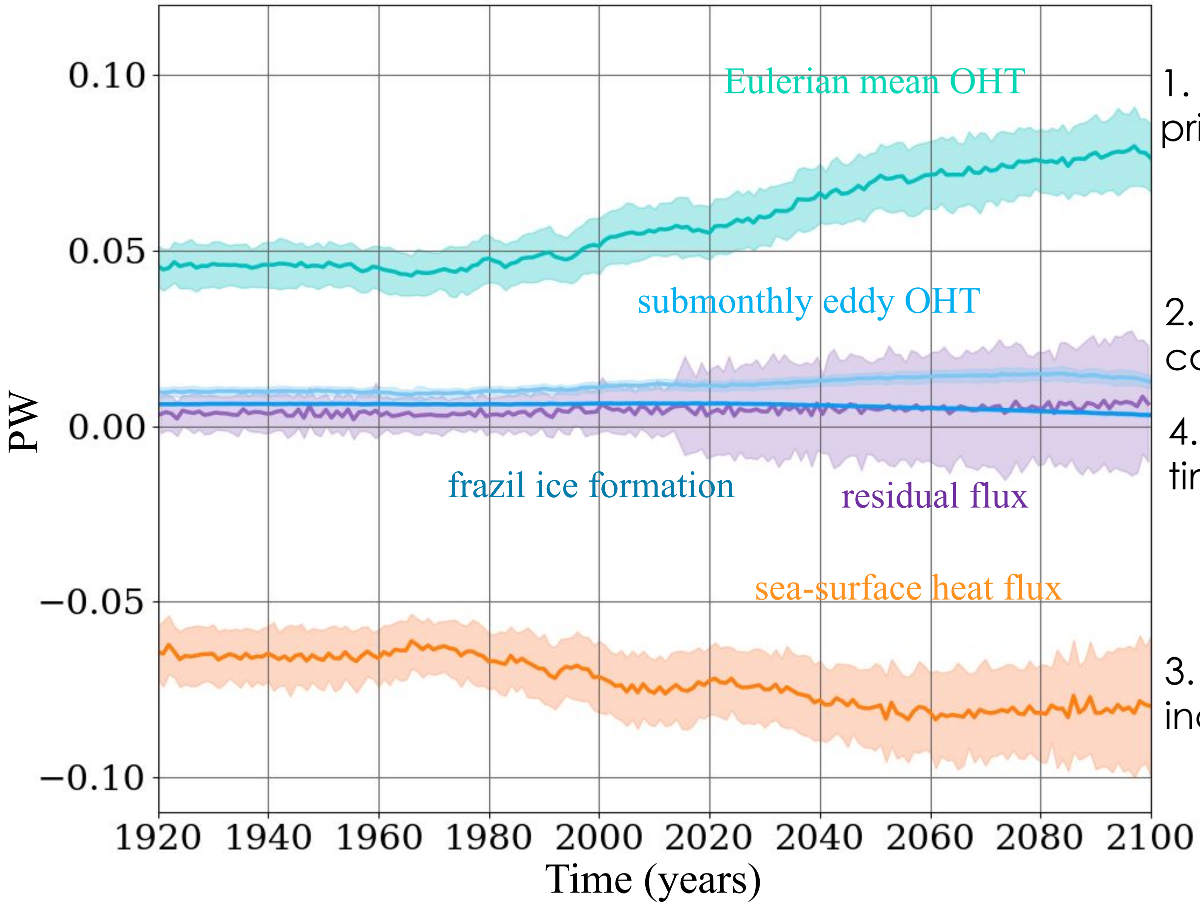
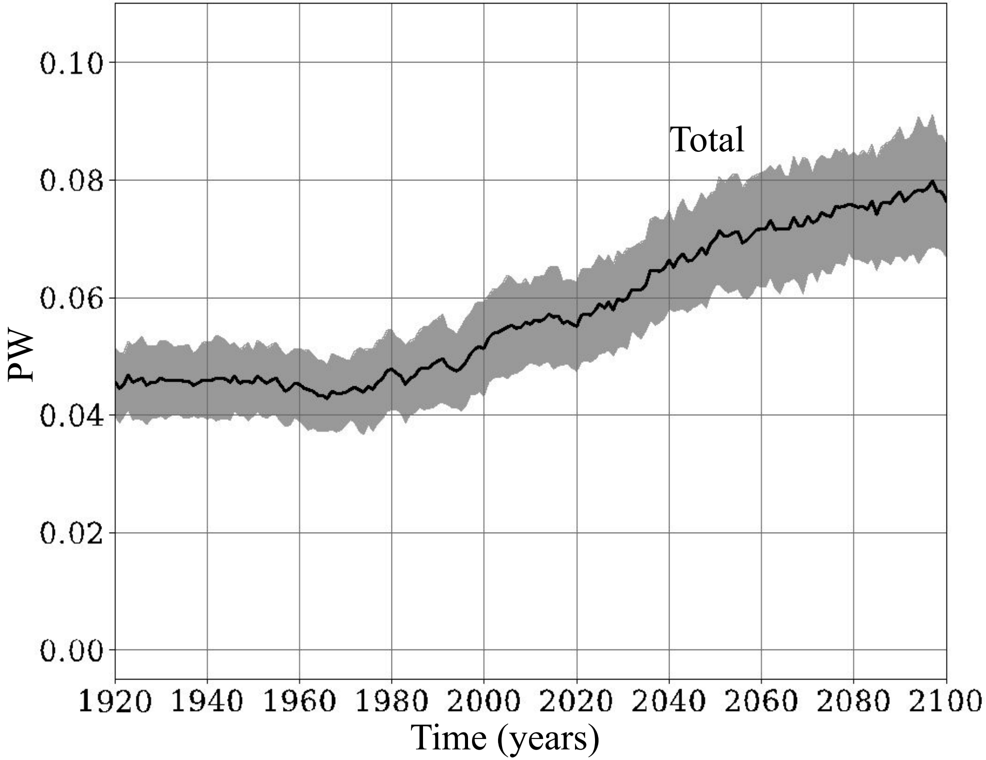


1. Eulerian-mean OHT primary driver of heat gain
2. Submonthly/residual also contribute to heat gain
4. Frazil heat gain declines o time
3. Enhanced SHF drives increased heat loss

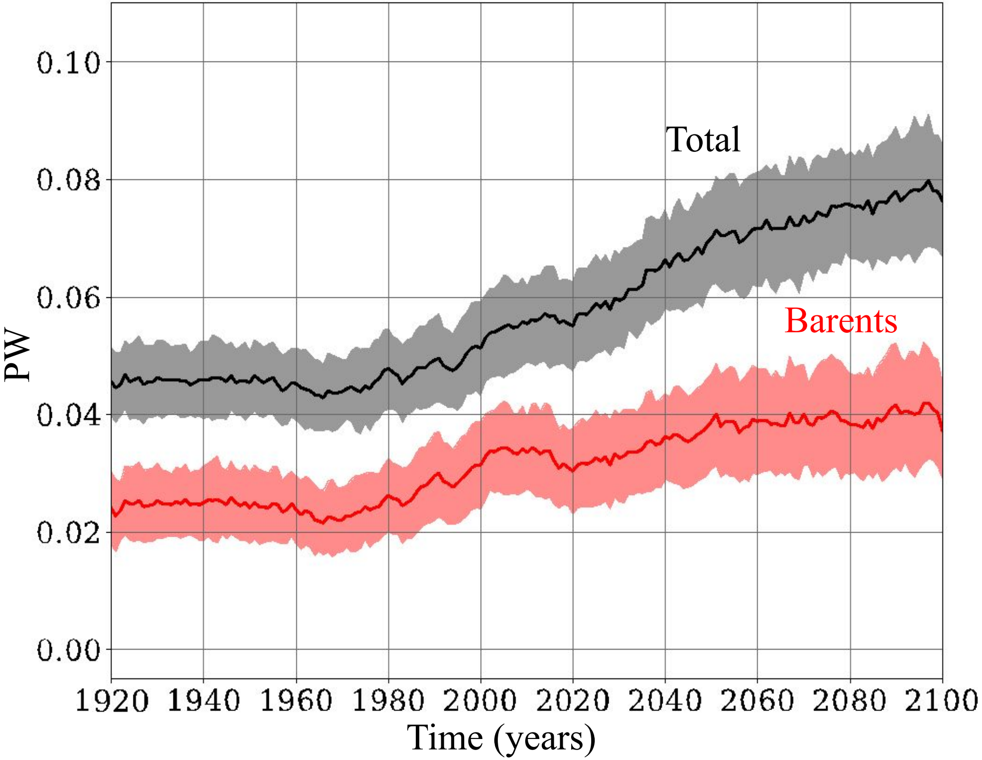
Which Arctic gateways drive OHT increase?

Eulerian-mean OHT



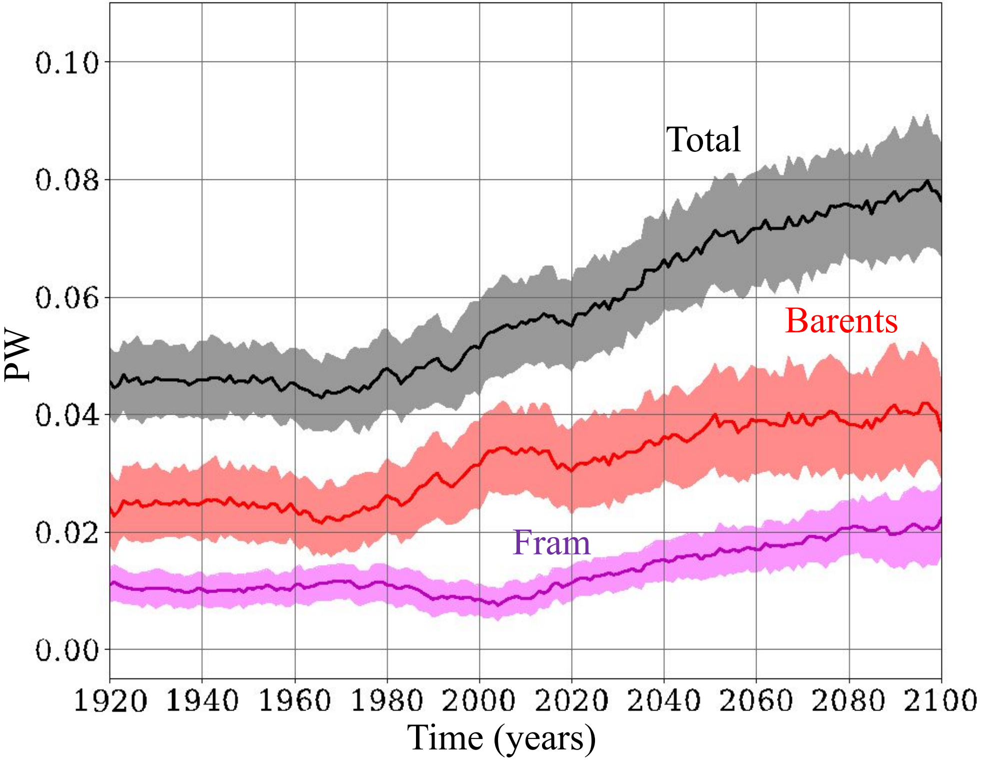
Barents Sea Opening contributes substantially to OHT increase

Eulerian-mean OHT



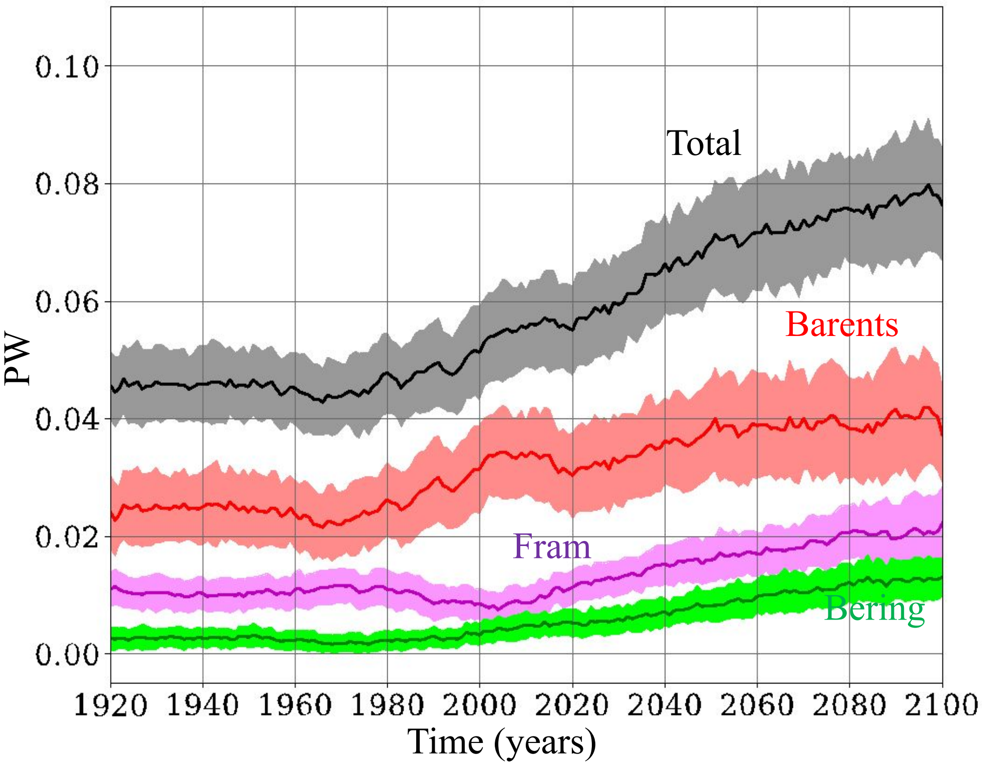
Fram Strait also contributes to OHT increase

Eulerian-mean OHT



OHT increase driven by changes in Barents, Fram and Bering Straits

Eulerian-mean OHT



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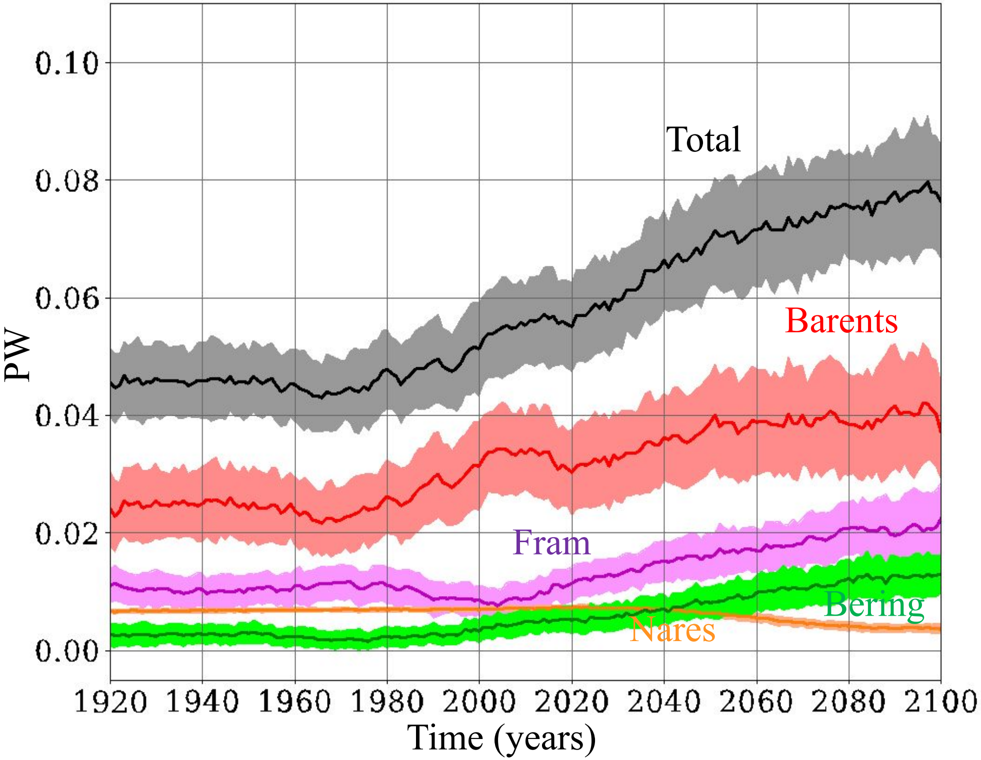

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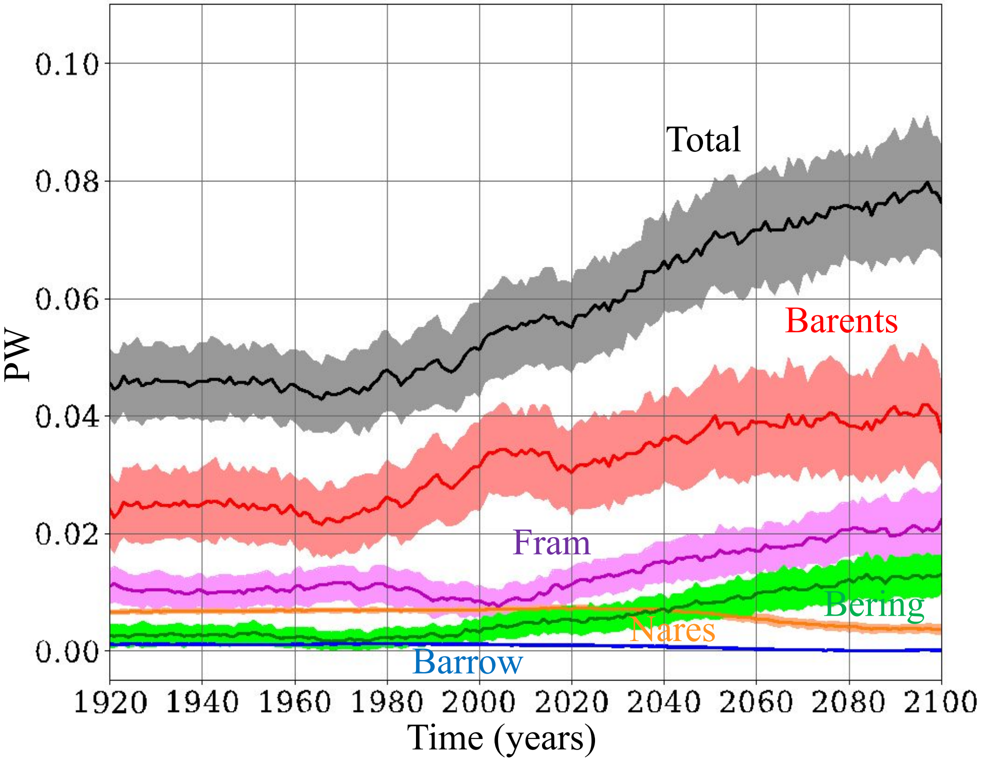
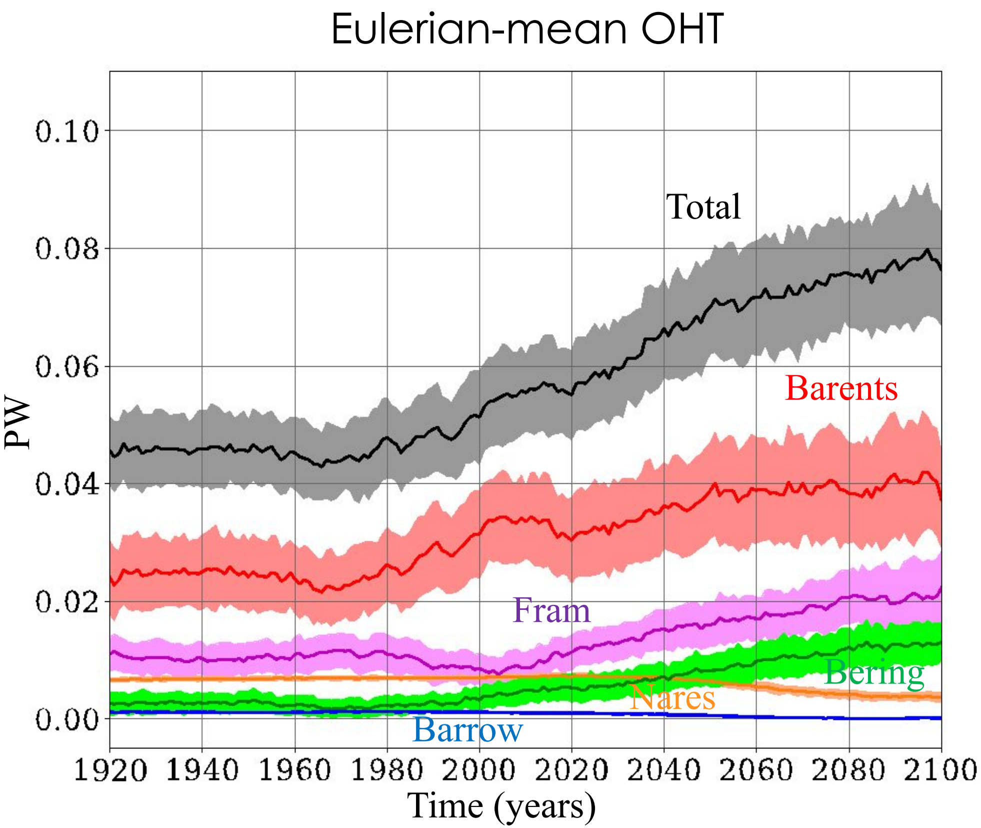
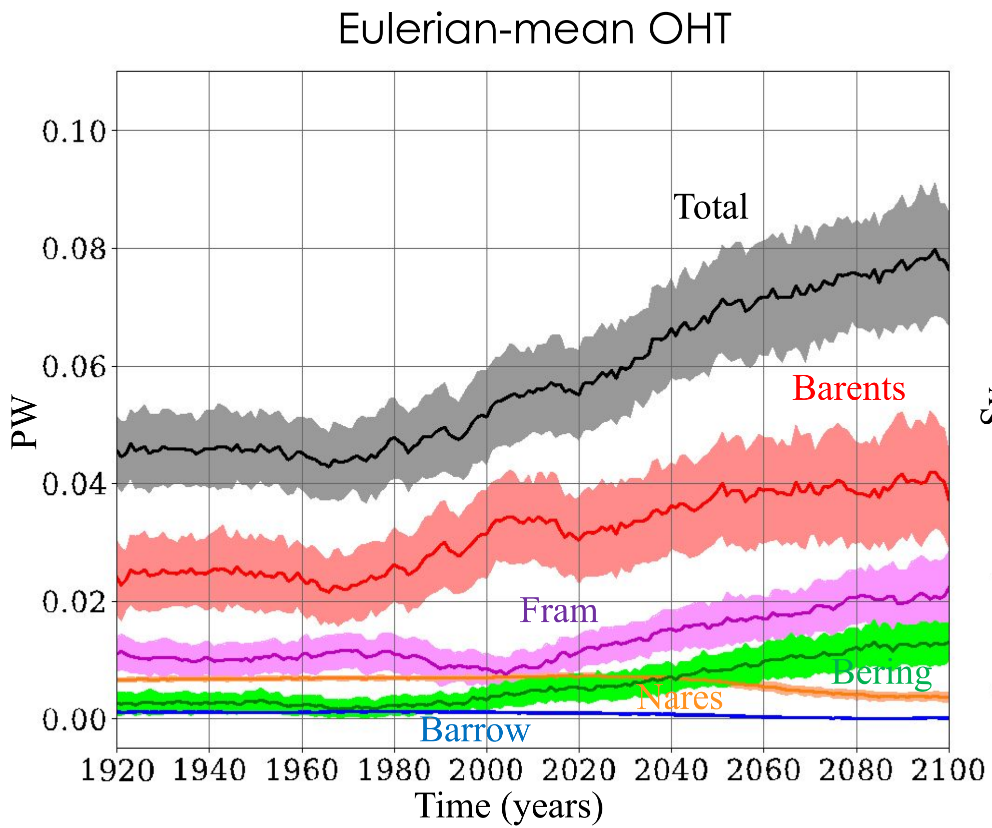
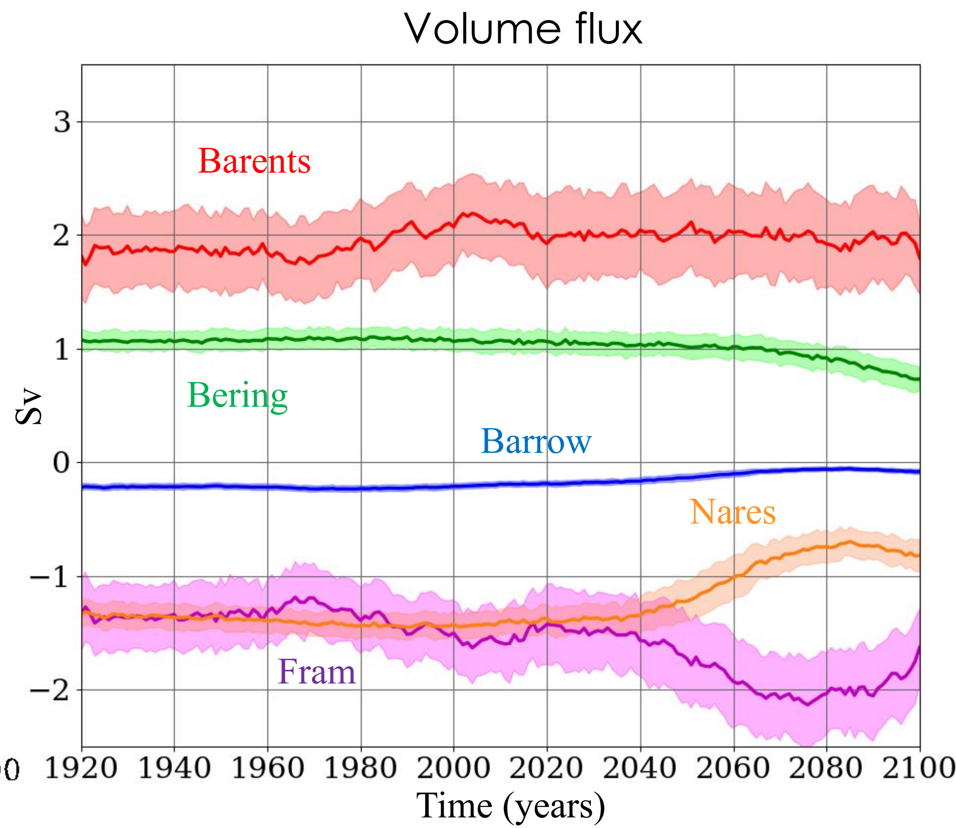


Are these OHT changes driven by volume flux variability?

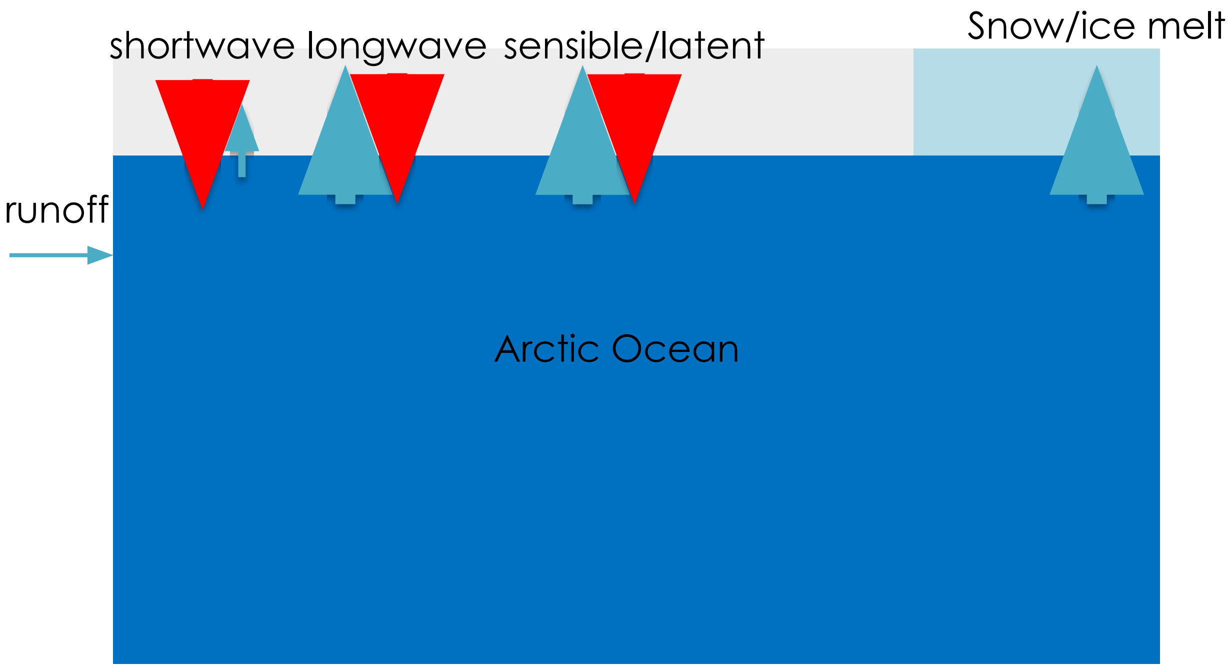


Volume fluxes not primary driver of OHT changes

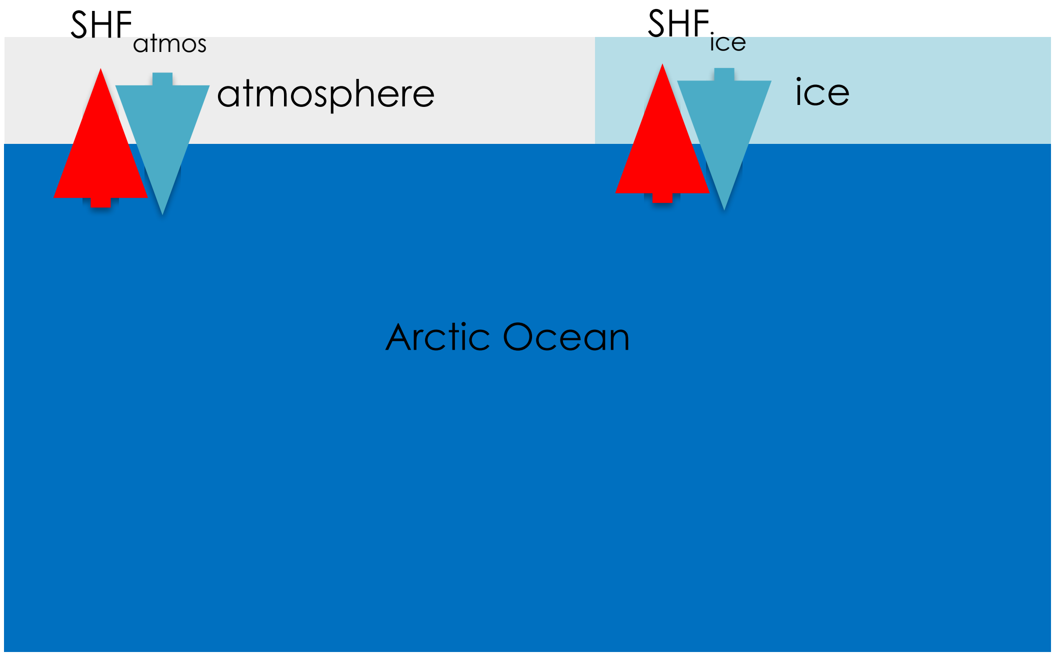




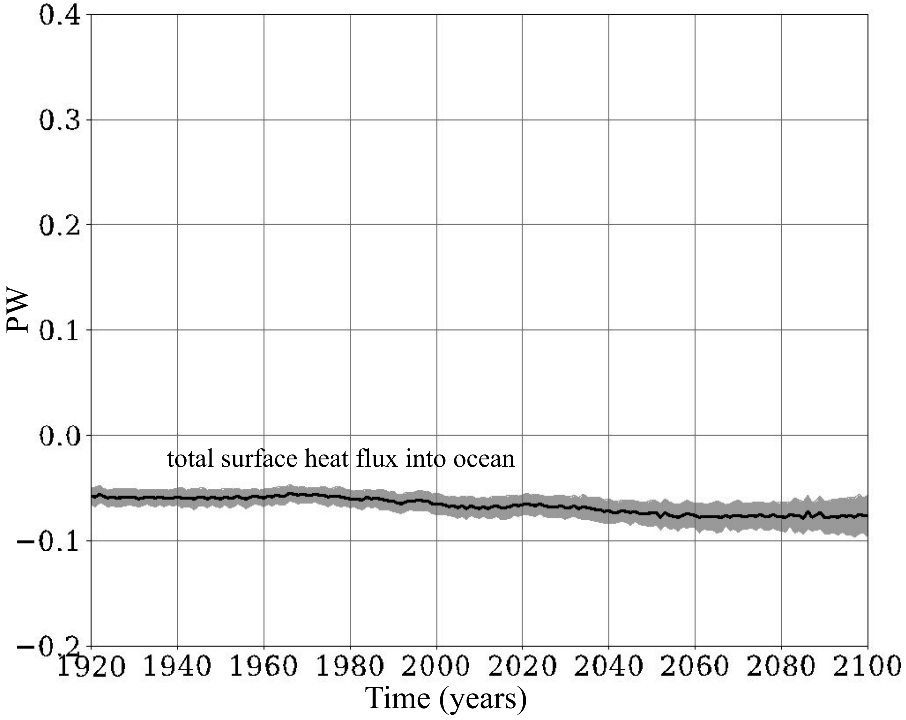
How much do the different surface heat flux components contribute to Arctic Ocean heat gain/loss?



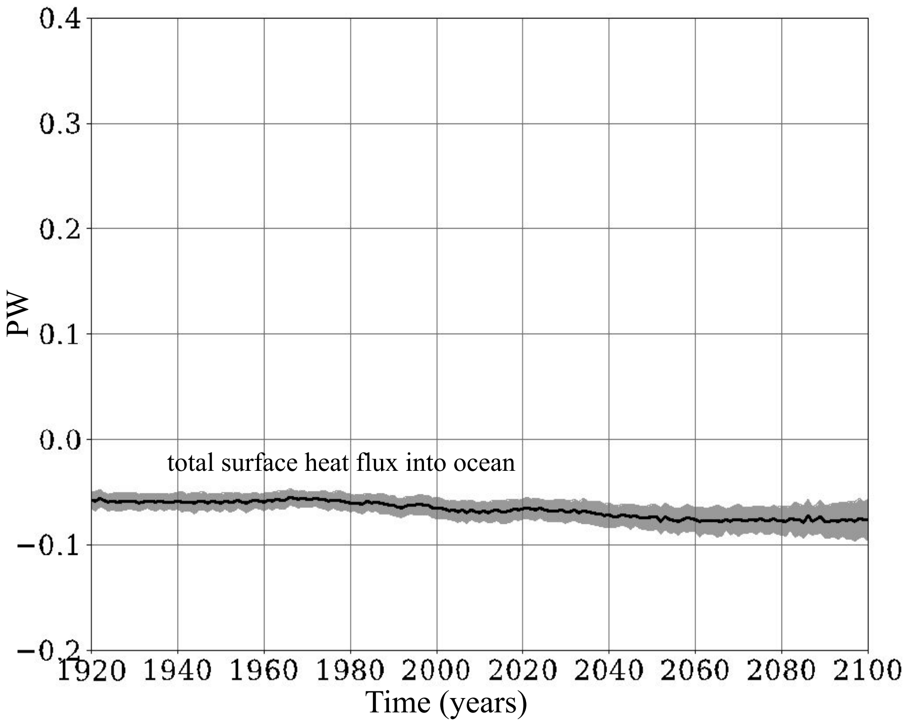
How much heat is exchanged with ice vs. atmosphere?

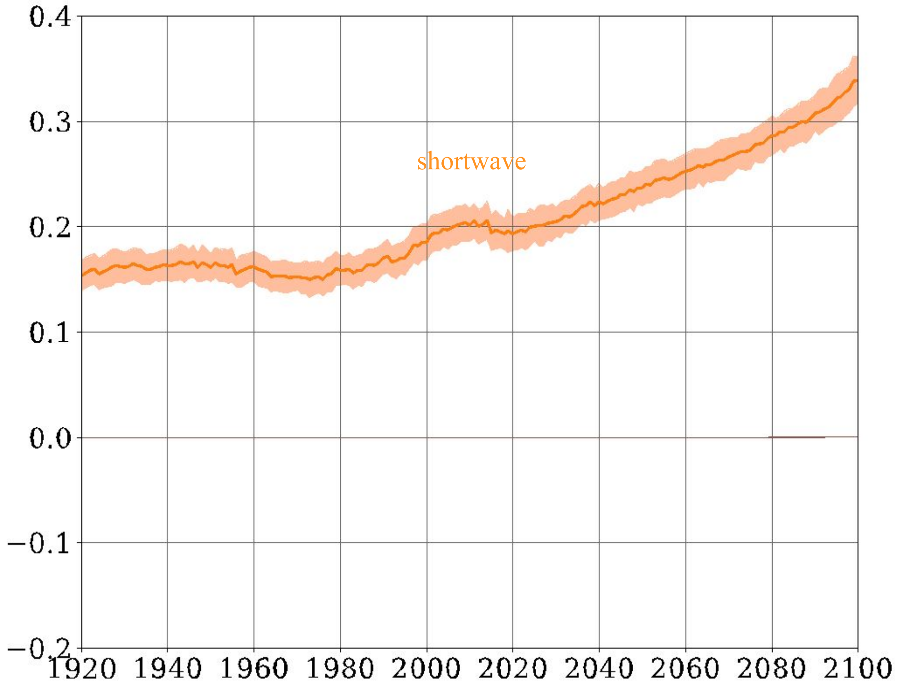


What drives sea-surface heat loss?

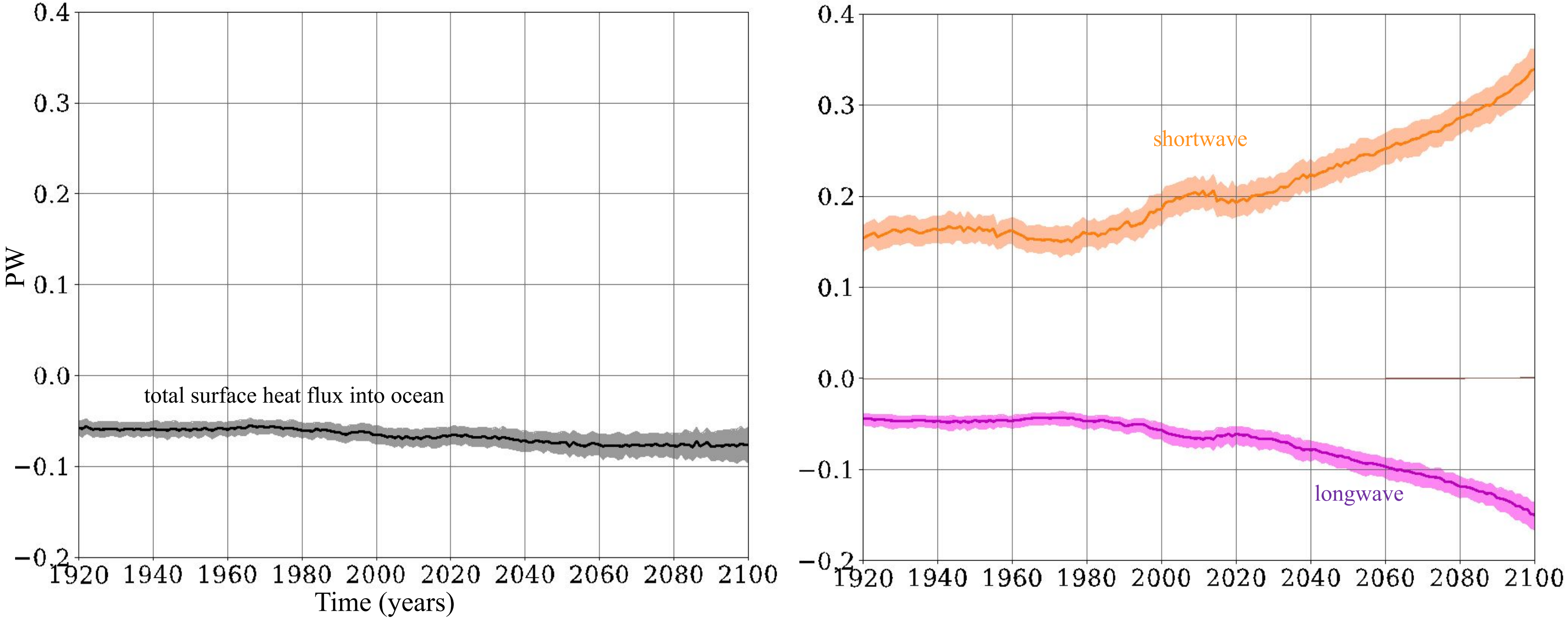


Shortwave radiation increases over time

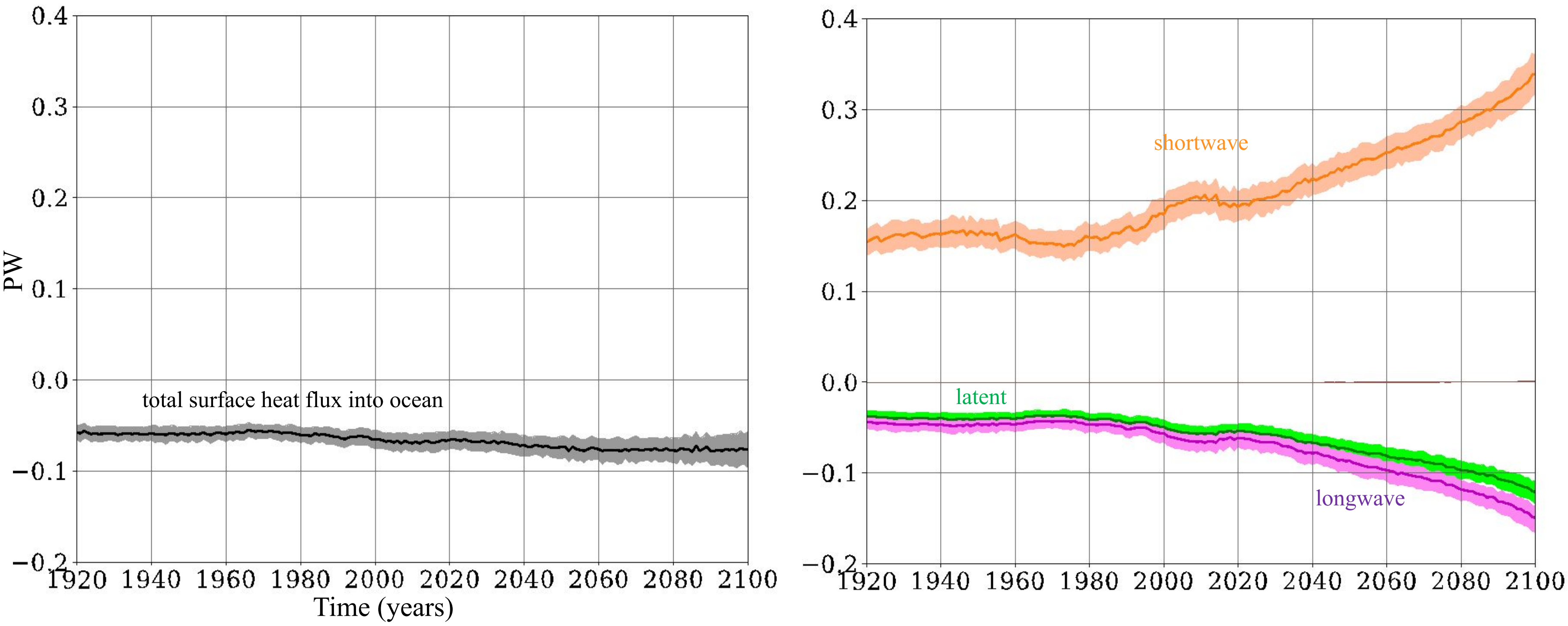




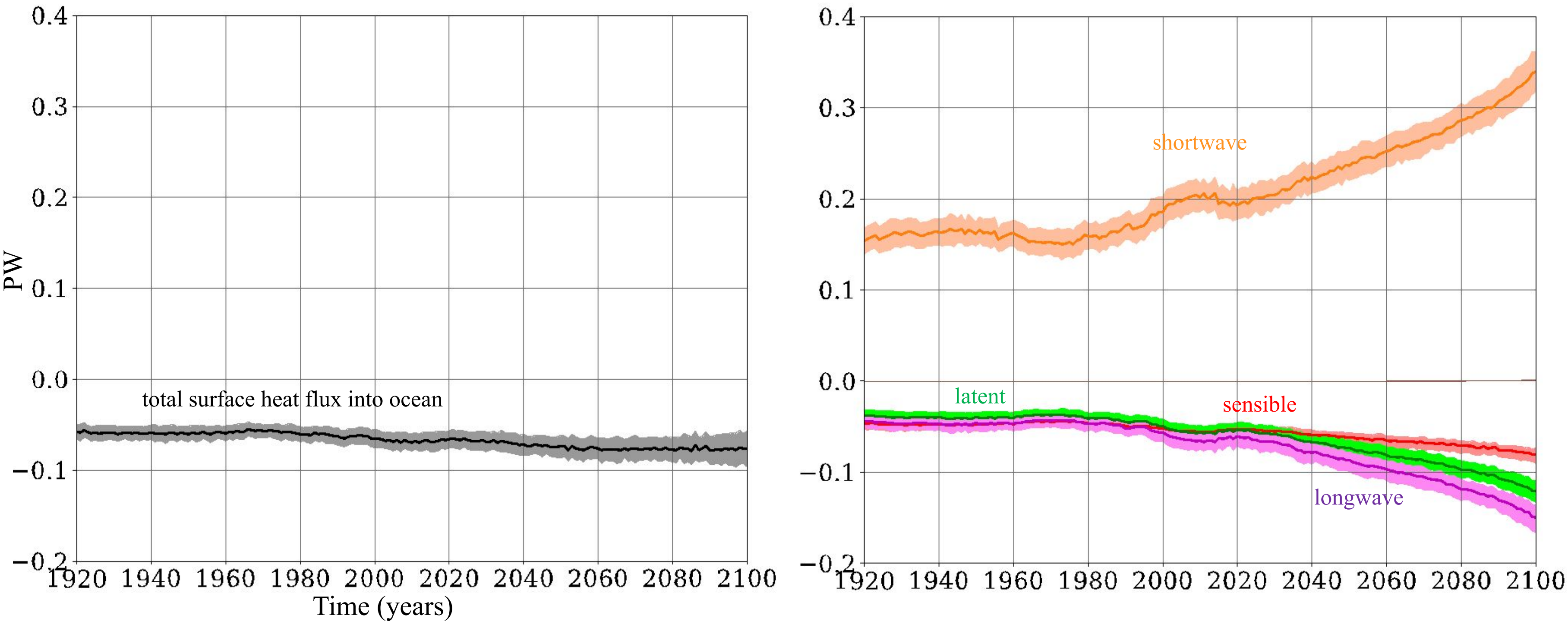
Longwave radiation becomes more negative



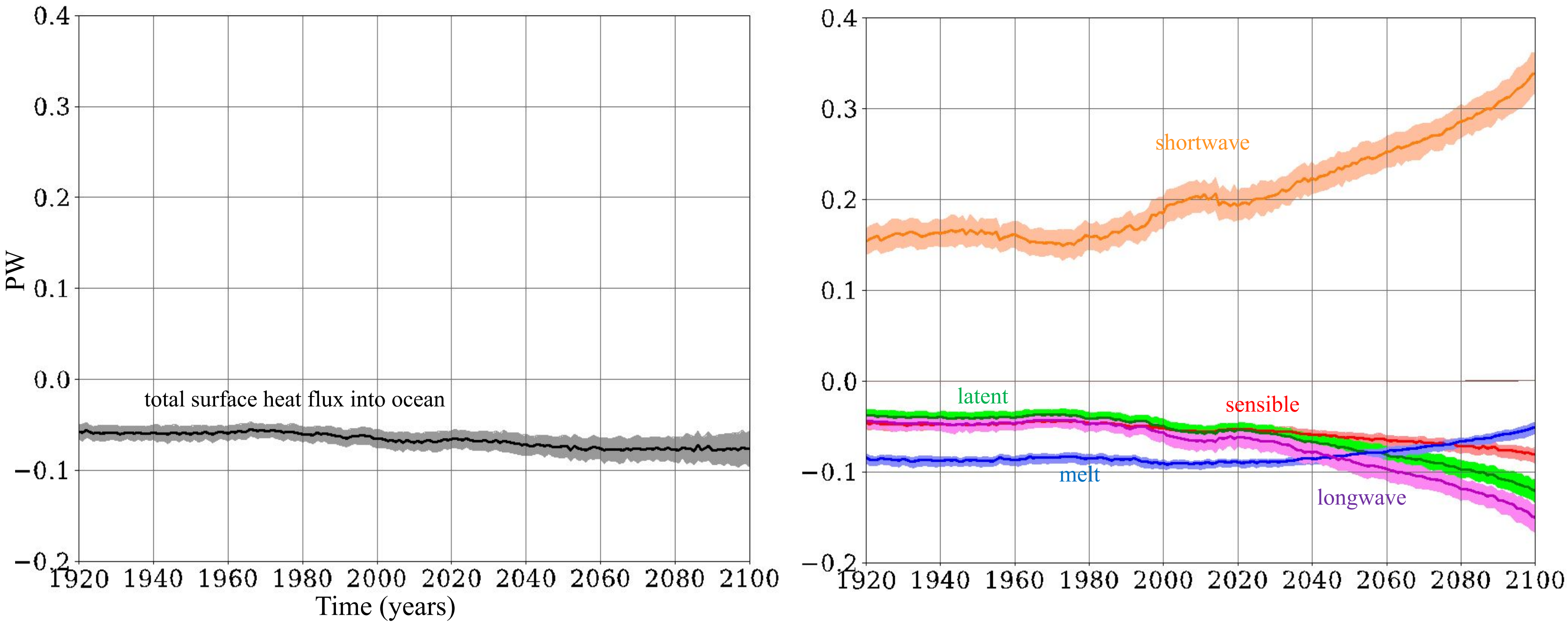
Latent heat flux also increases in magnitude



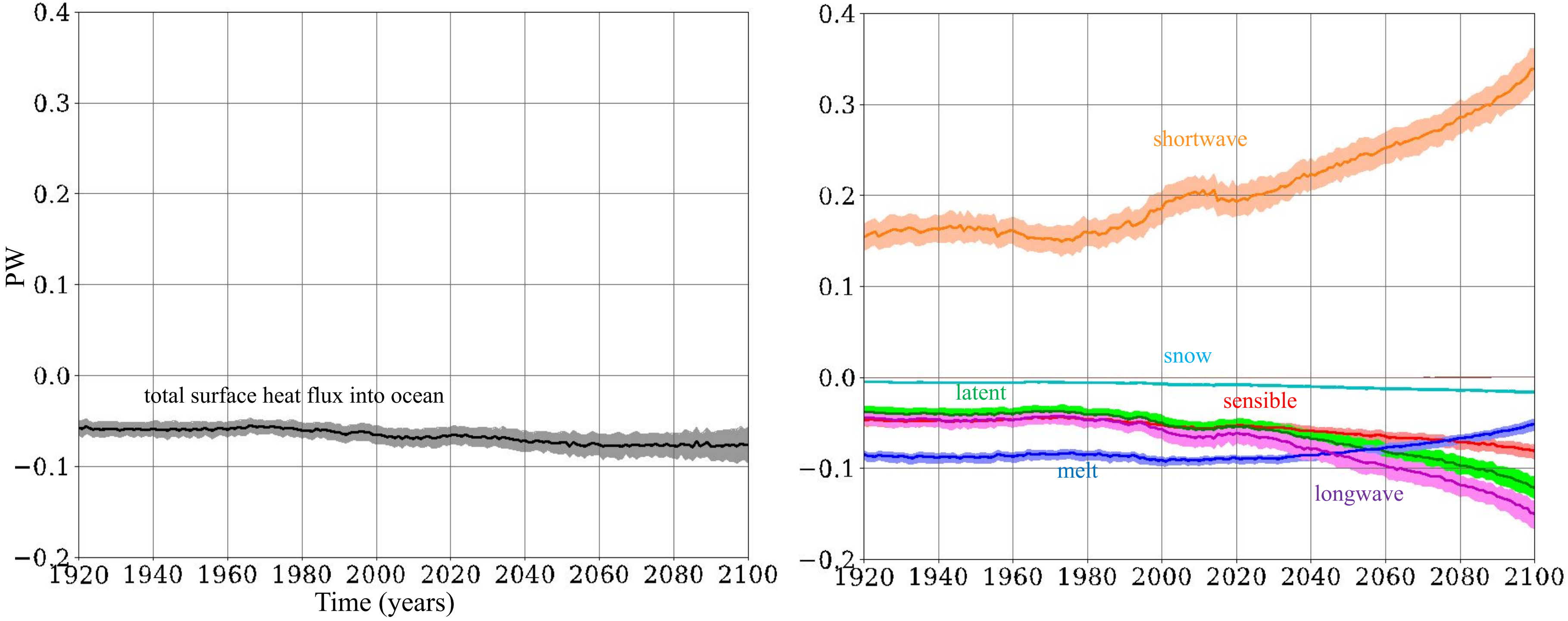
Sensible heat fluxes also increase in magnitude



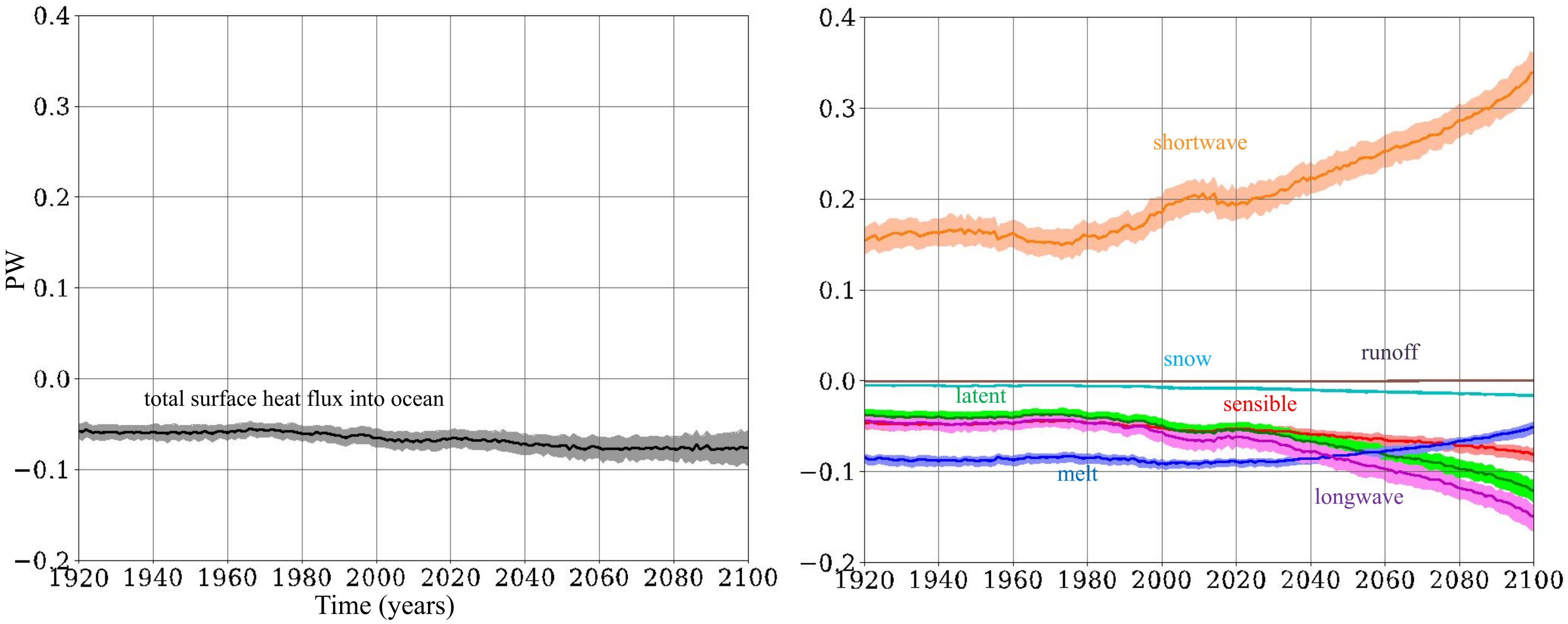
Melt heat flux decreases due to sea-ice decline



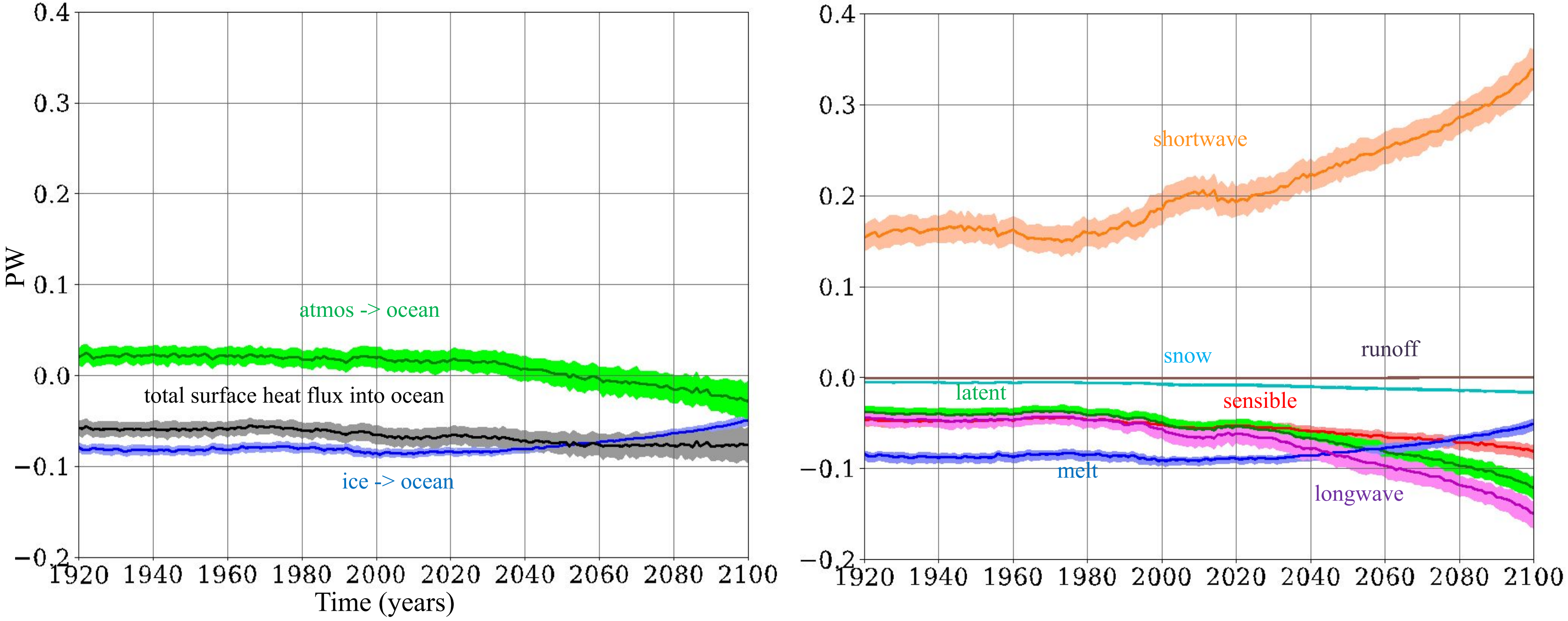
Increased heat loss from snow melt



Runoff component negligible



Ocean heat loss increases due to enhanced sensible, latent and longwave fluxes



Part II: Arctic sea-ice heat budget

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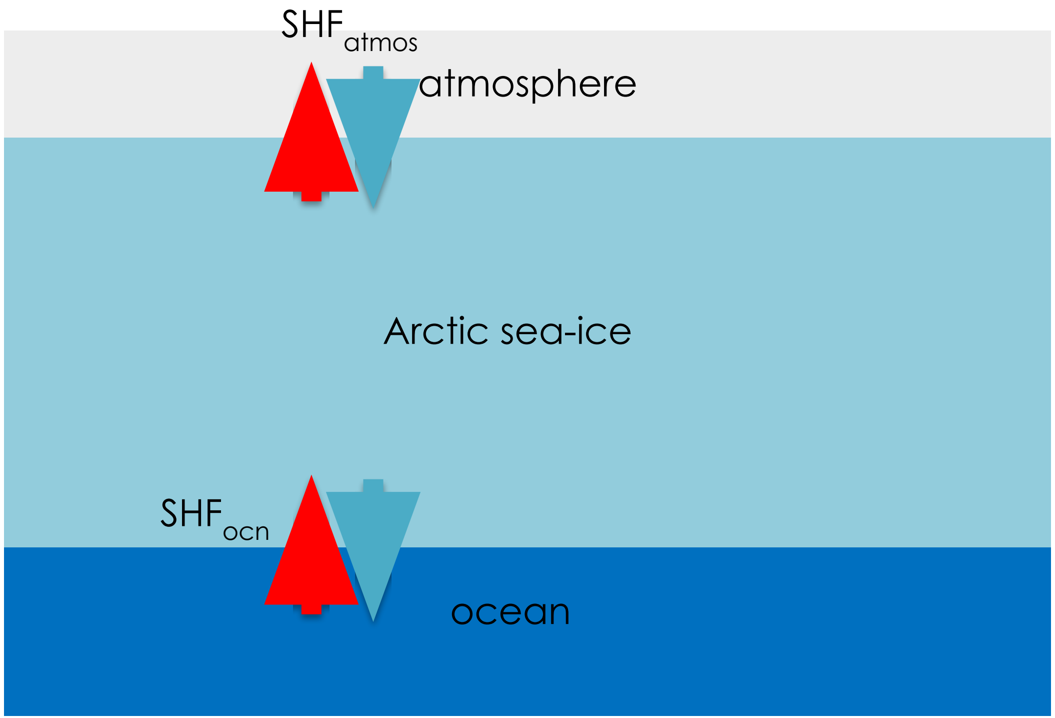
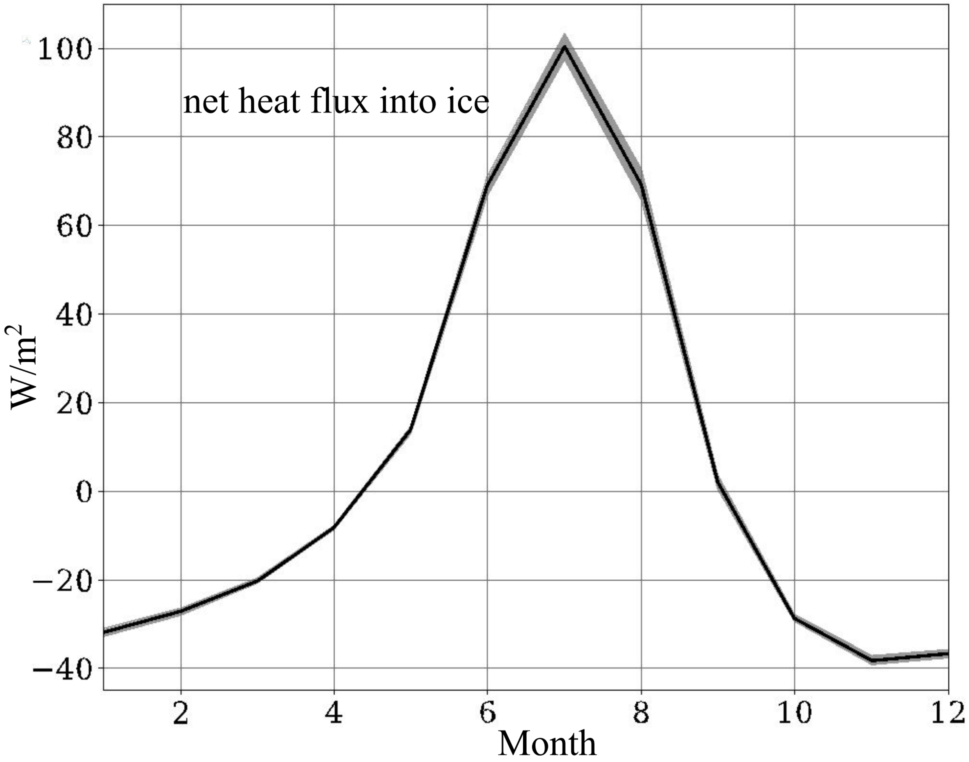


Both ocean and atmosphere provide heat to ice in summer

Seasonality 1920-1940

Arctic ice heat fluxes



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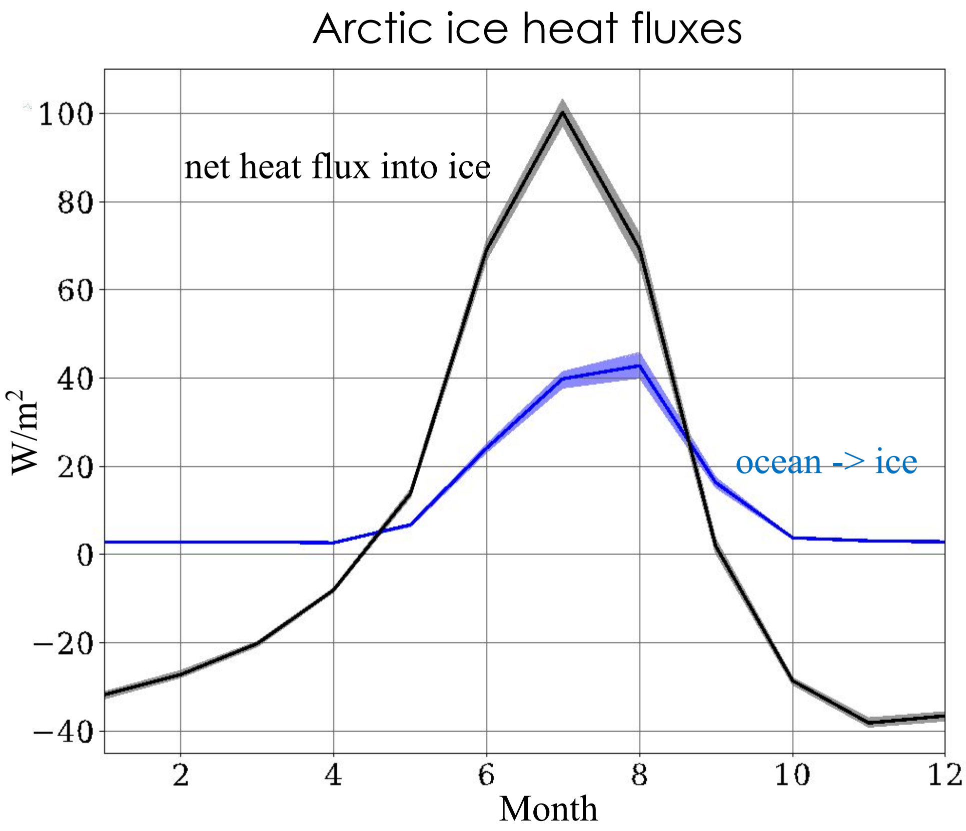

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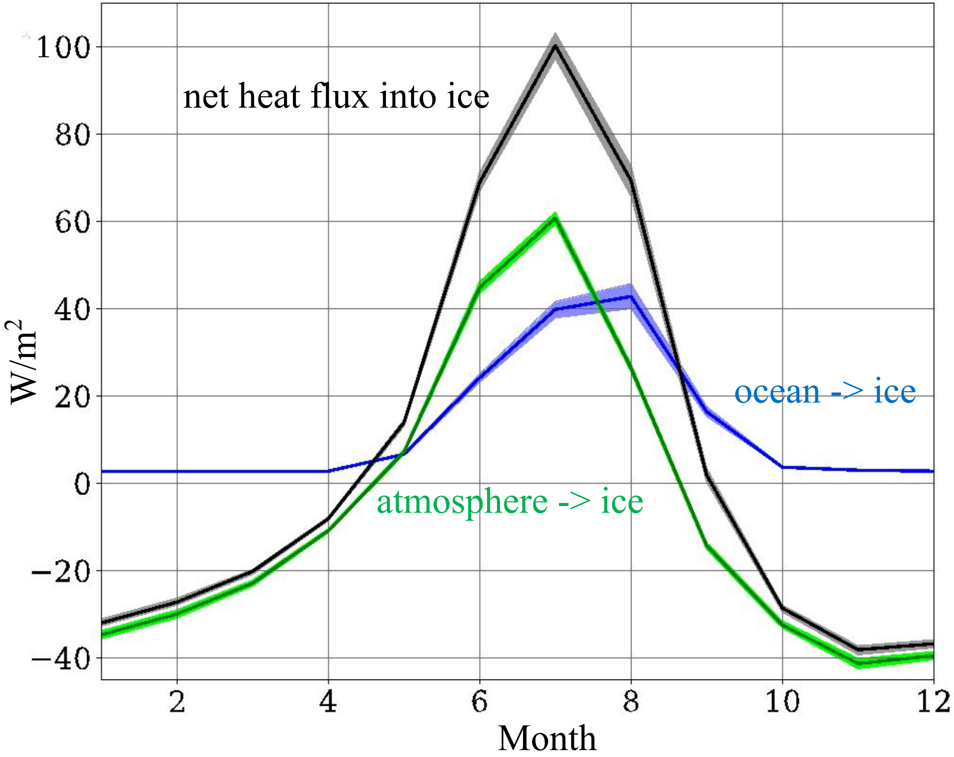
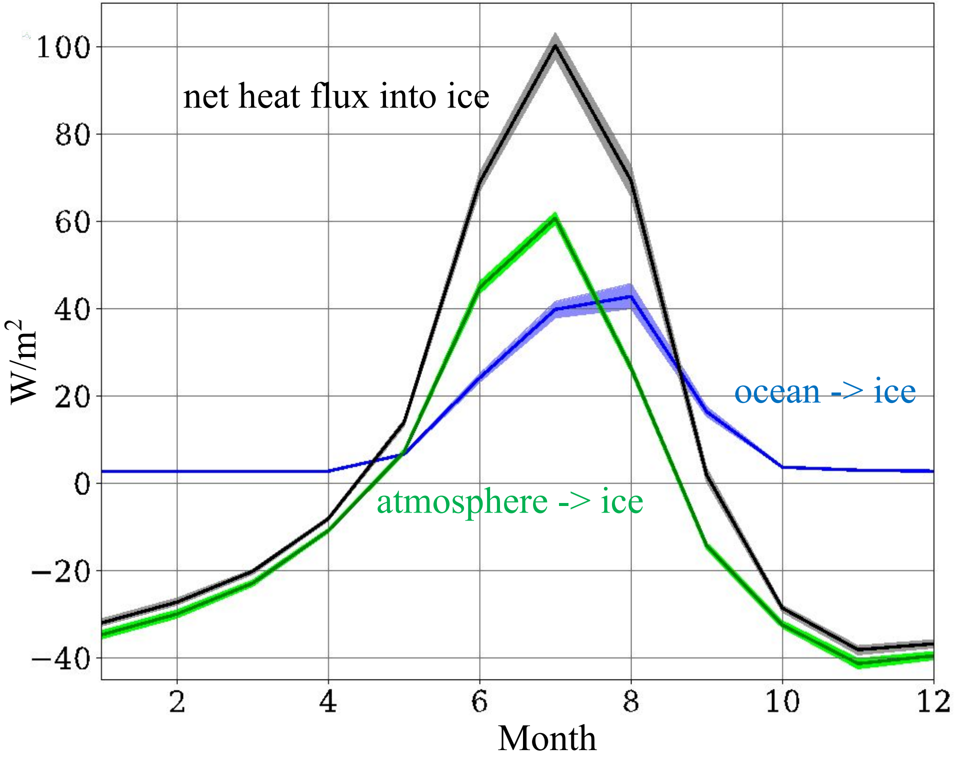


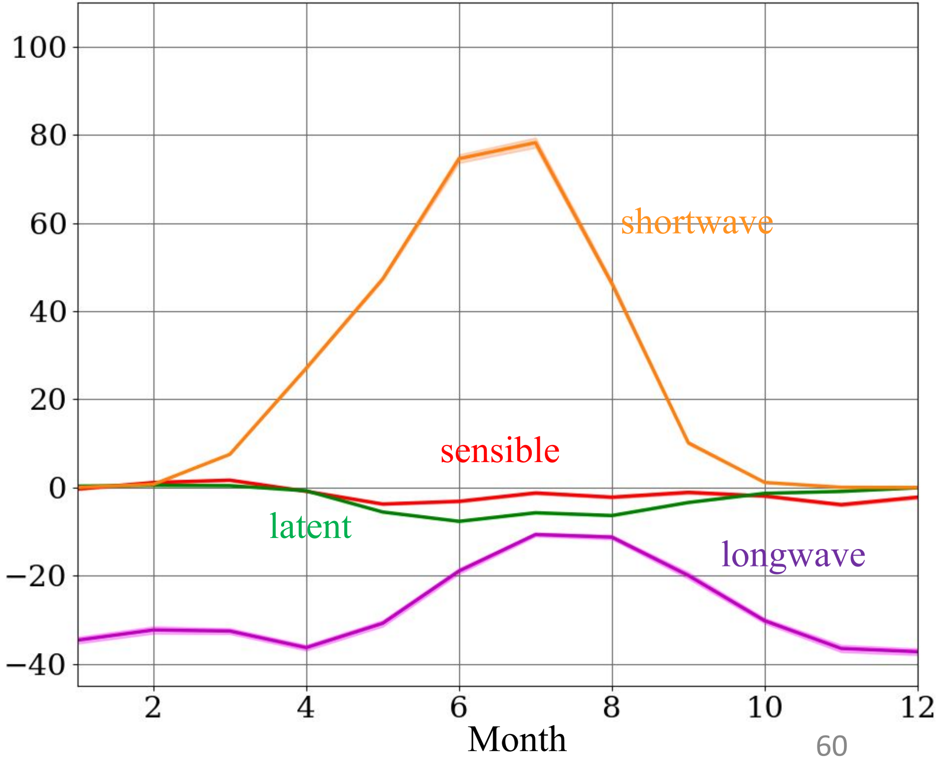
Shortwave drives ice heat gain in summer, longwave drives heat loss in winter

Seasonality 1920-1940

Arctic ice heat fluxes



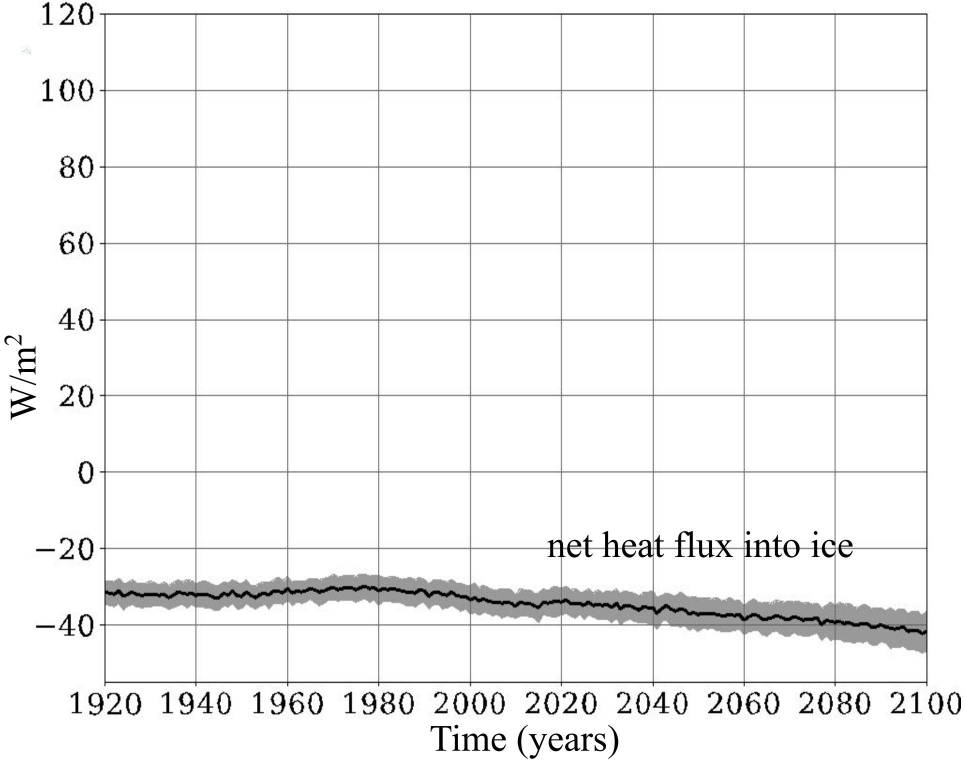
Arctic ice-atmosphere heat fluxes



How do these heat fluxes change over time?

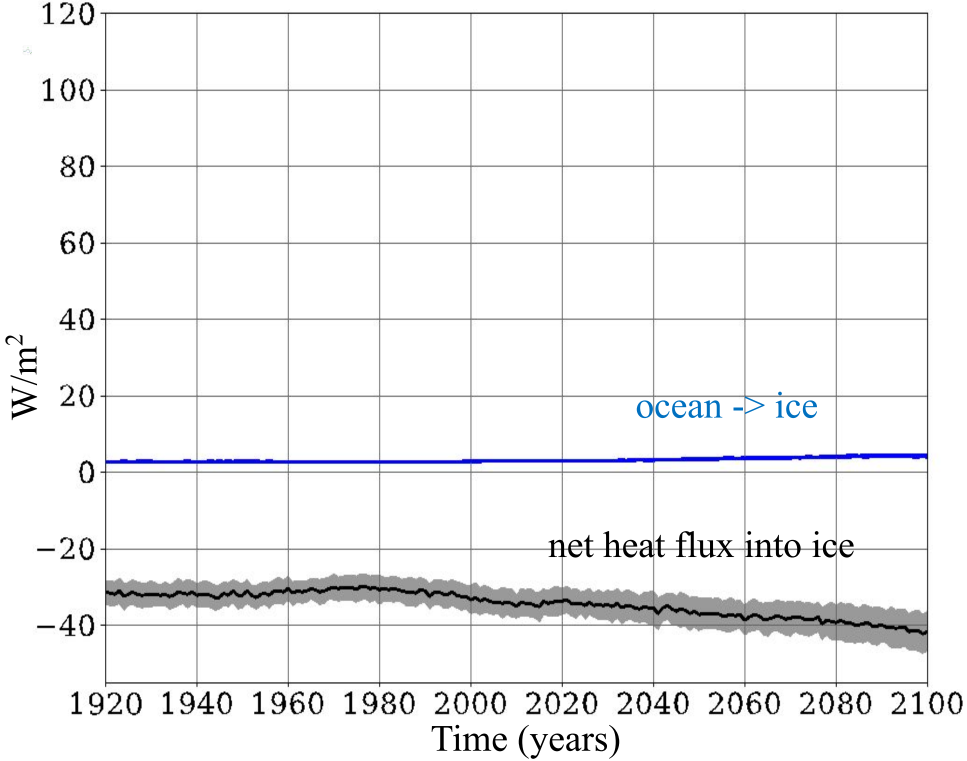
In winter, total ice heat loss increases

January Arctic ice heat fluxes

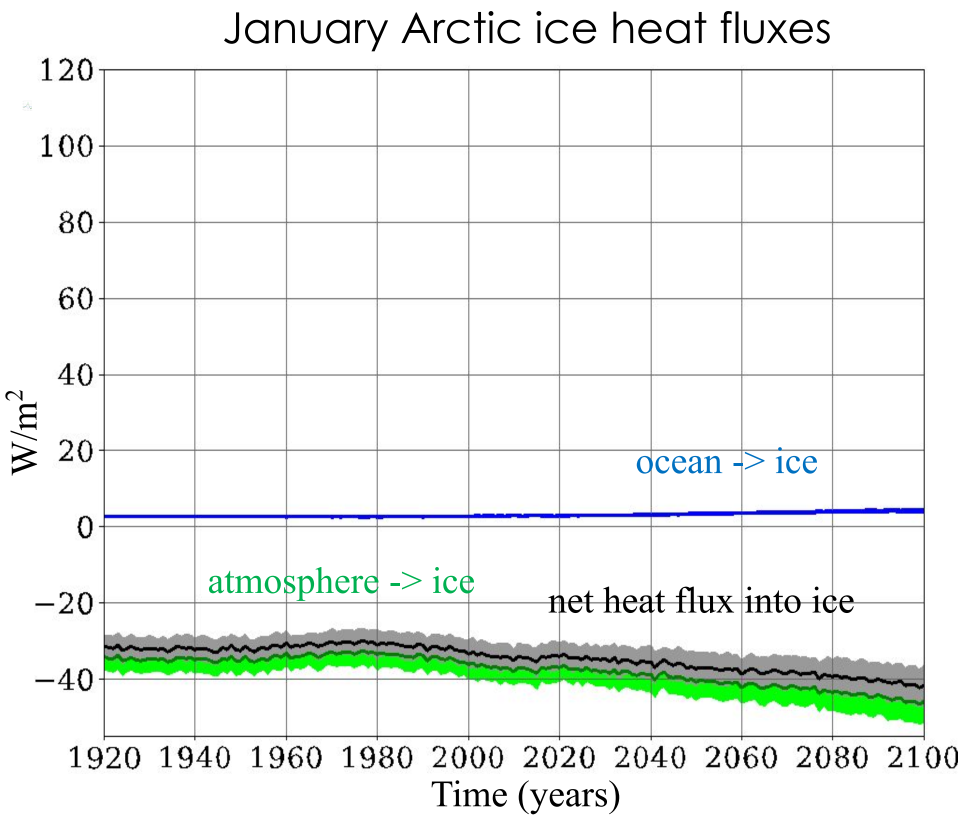


Heat gain from ocean increases slightly

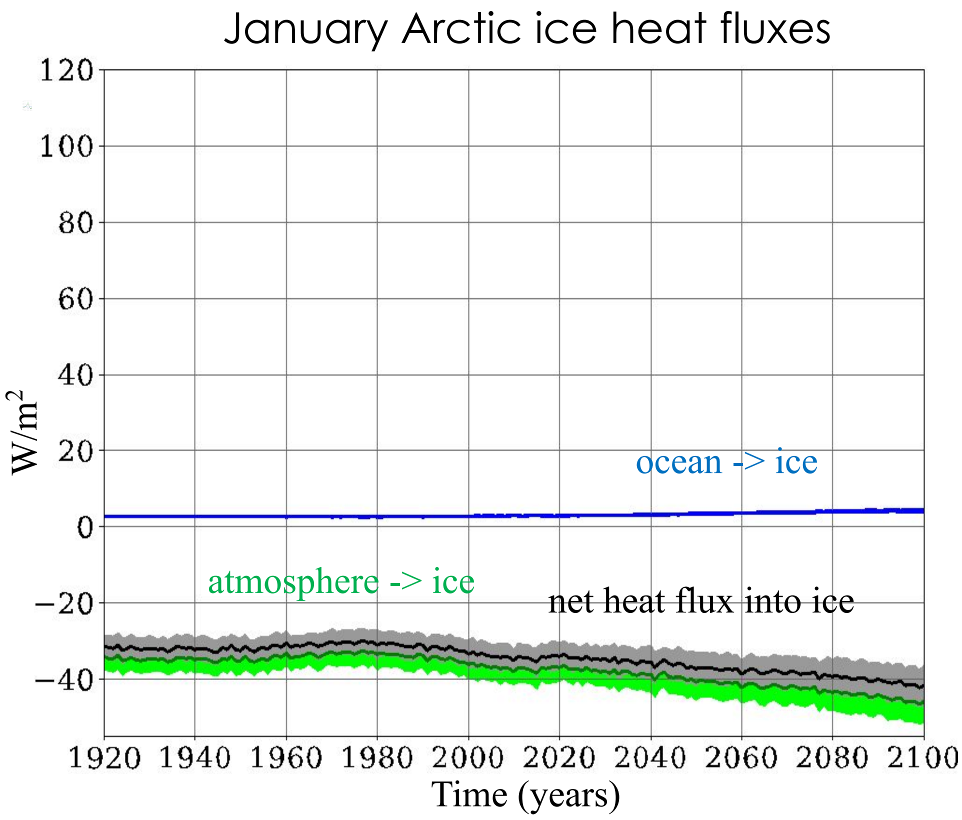
January Arctic ice heat fluxes

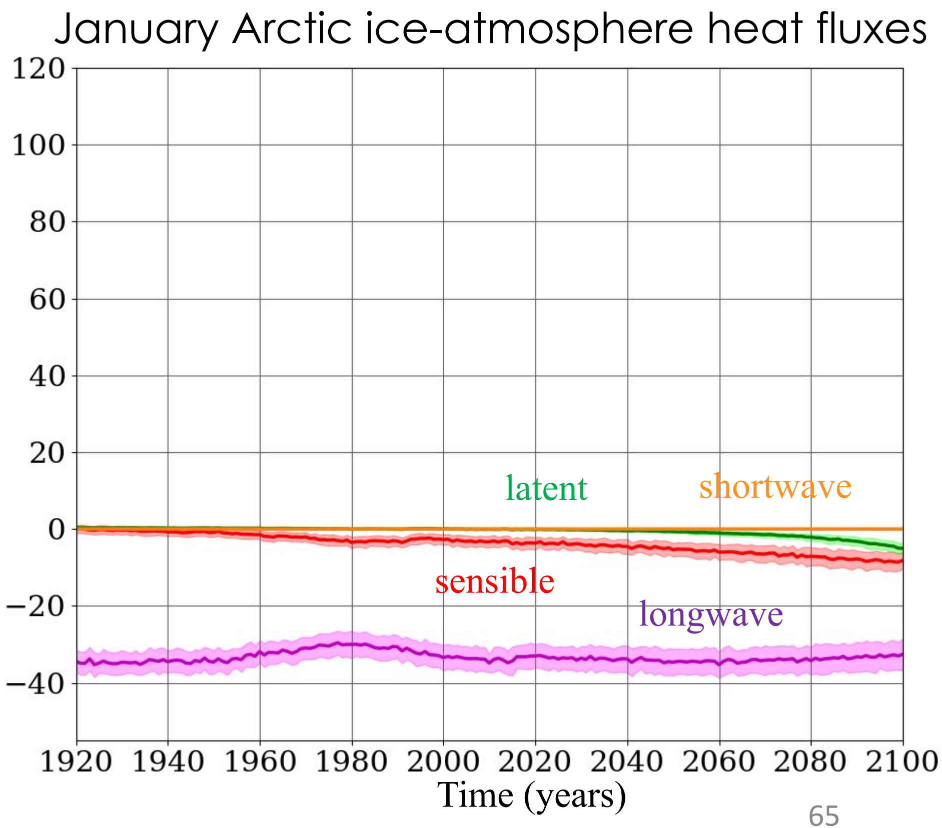


Increased heat loss to atmosphere over time

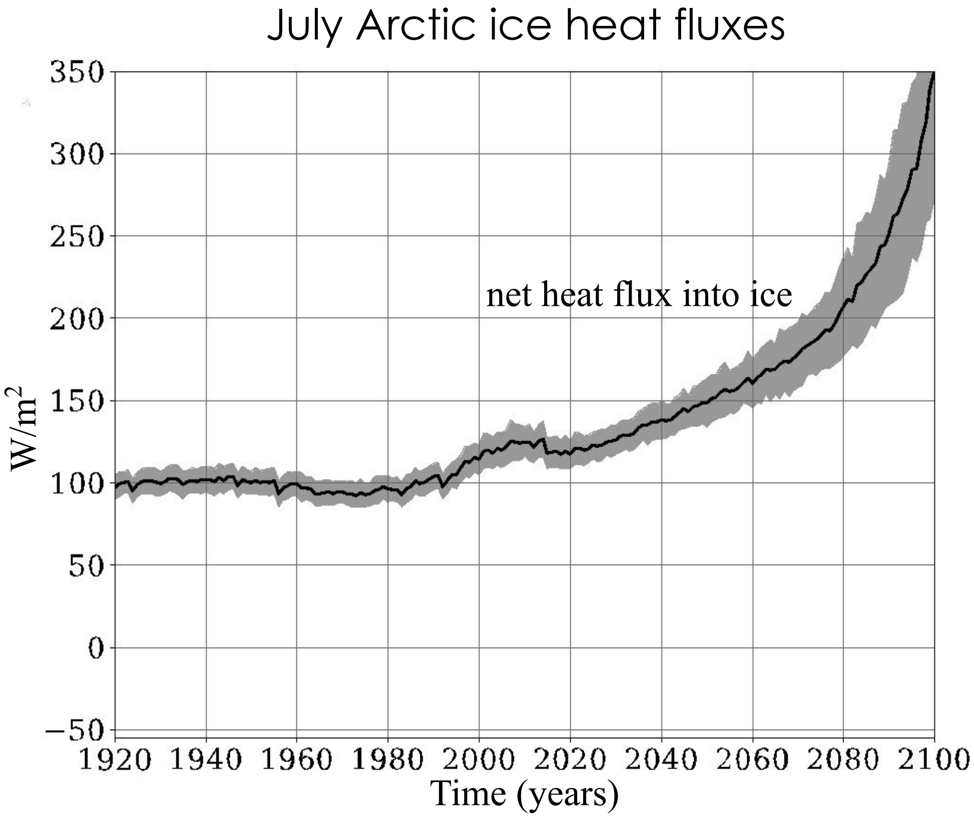


Increased heat loss to atmosphere due to enhanced sensible, latent heat loss

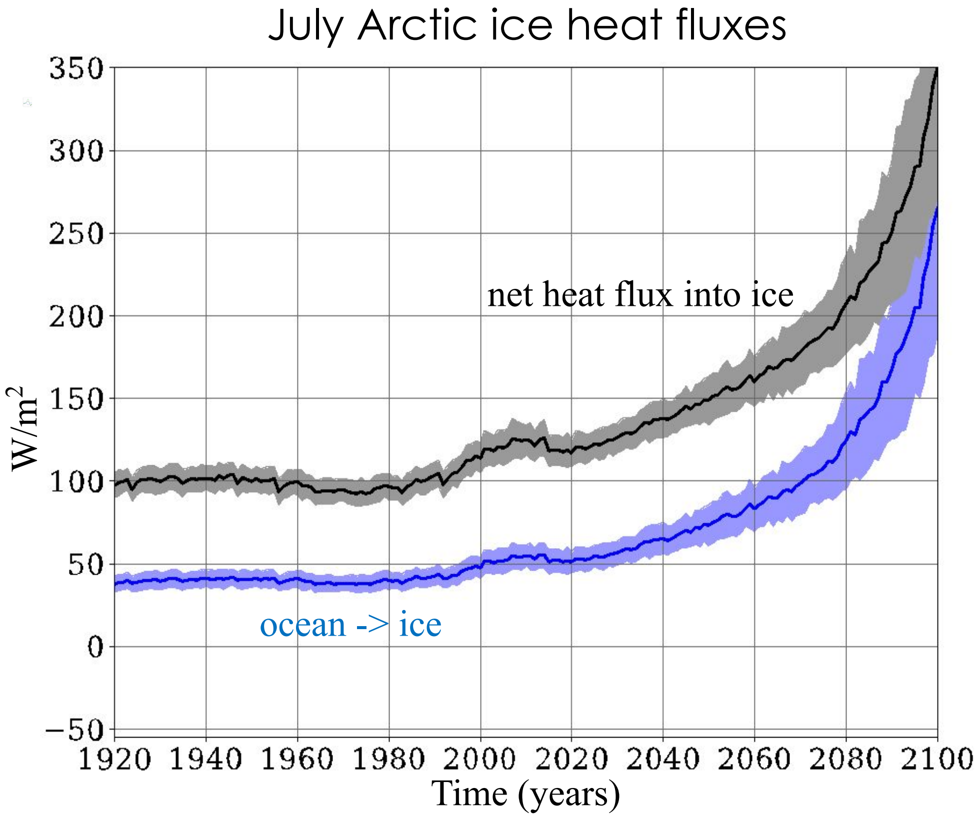




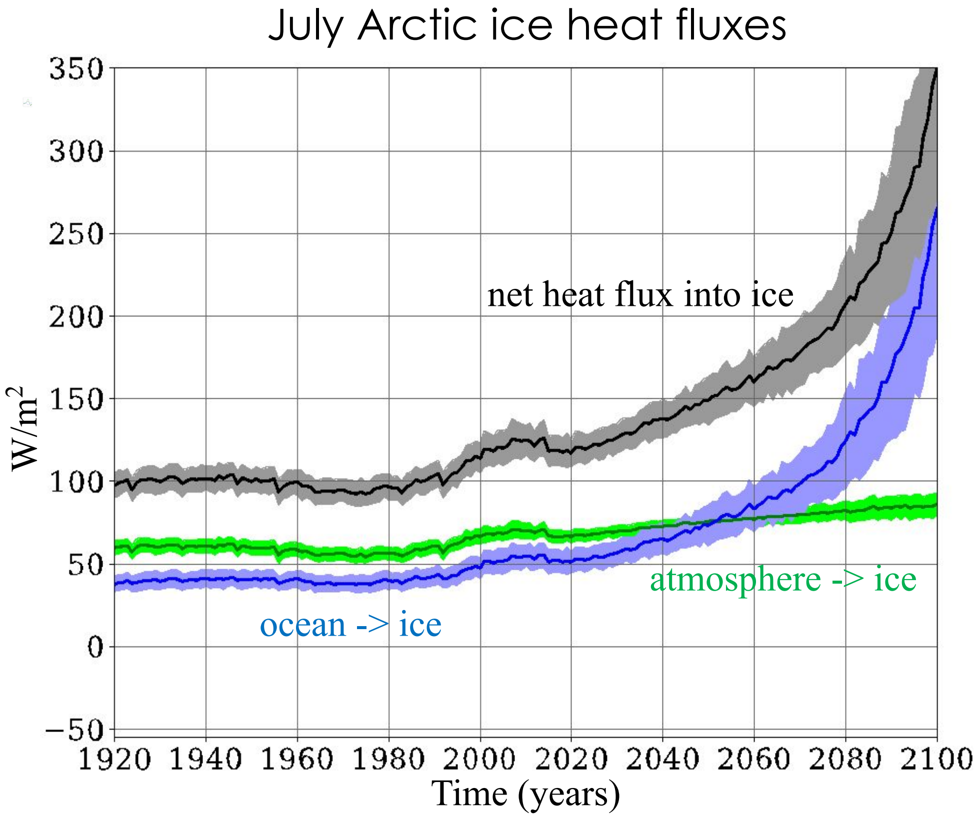
In summer, flux per unit area increases over time, blowing up as ice disappears



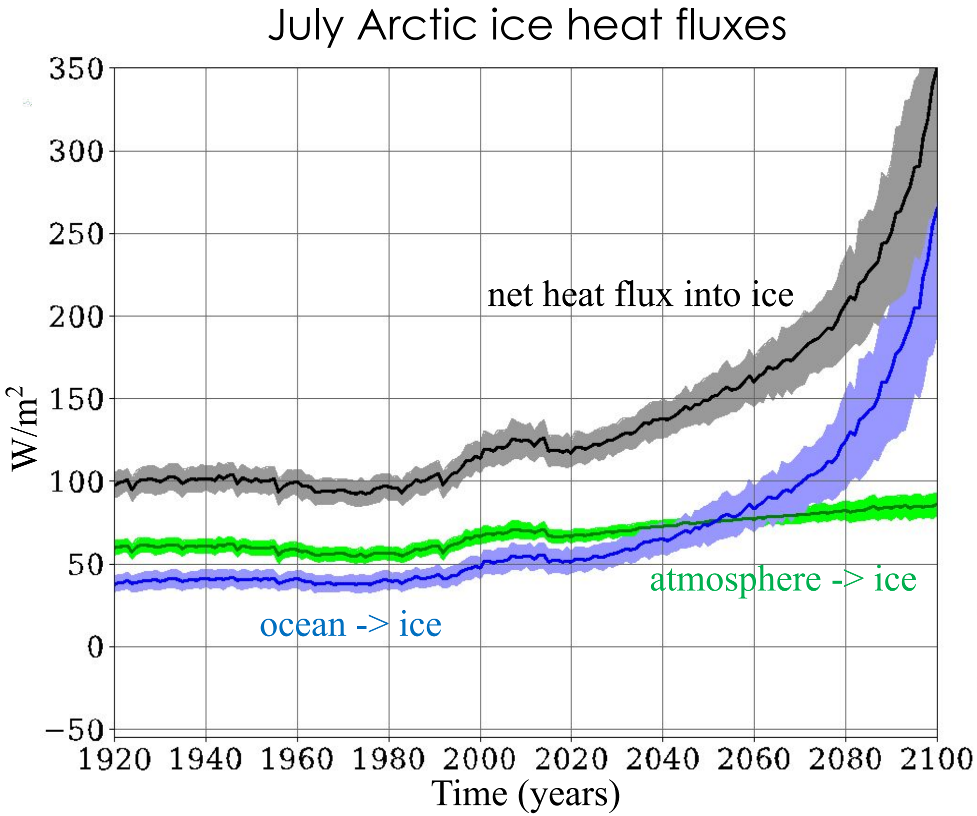
Ocean heat flux also increases dramatically

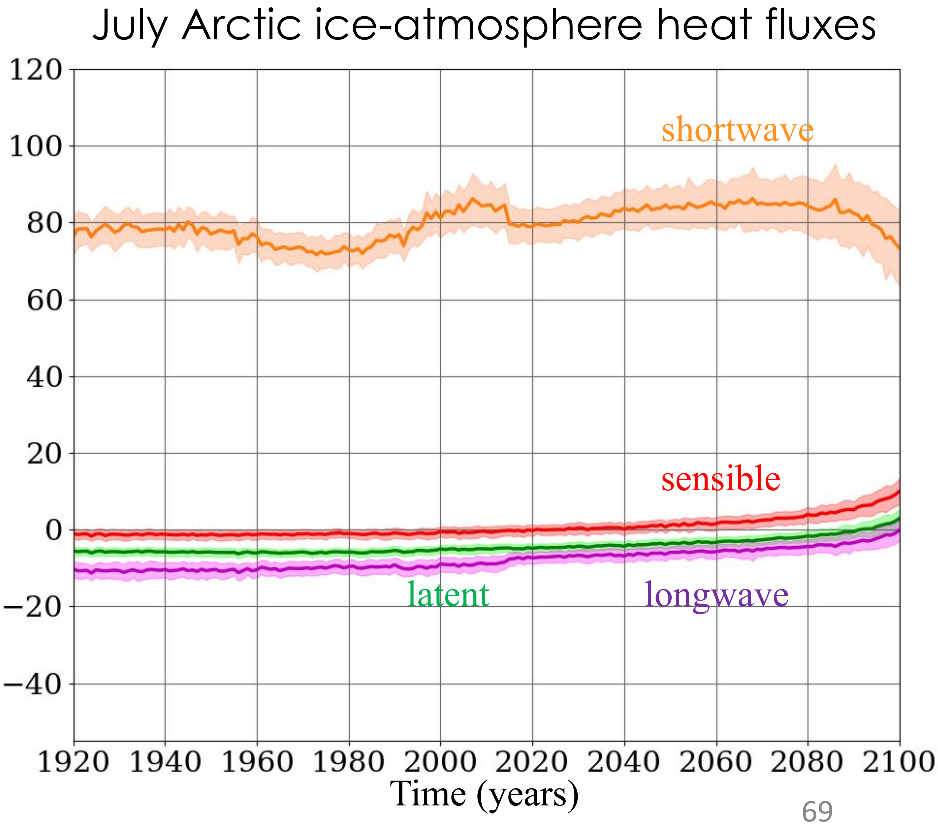


Heat flux from atmosphere main source of heat until around 2050



Increase in atmospheric heat gain largely due to strengthened incoming longwave radiation





Conclusions

- Arctic Ocean warming driven by increased OHT through Fram, Bering Straits, Barents Sea Opening

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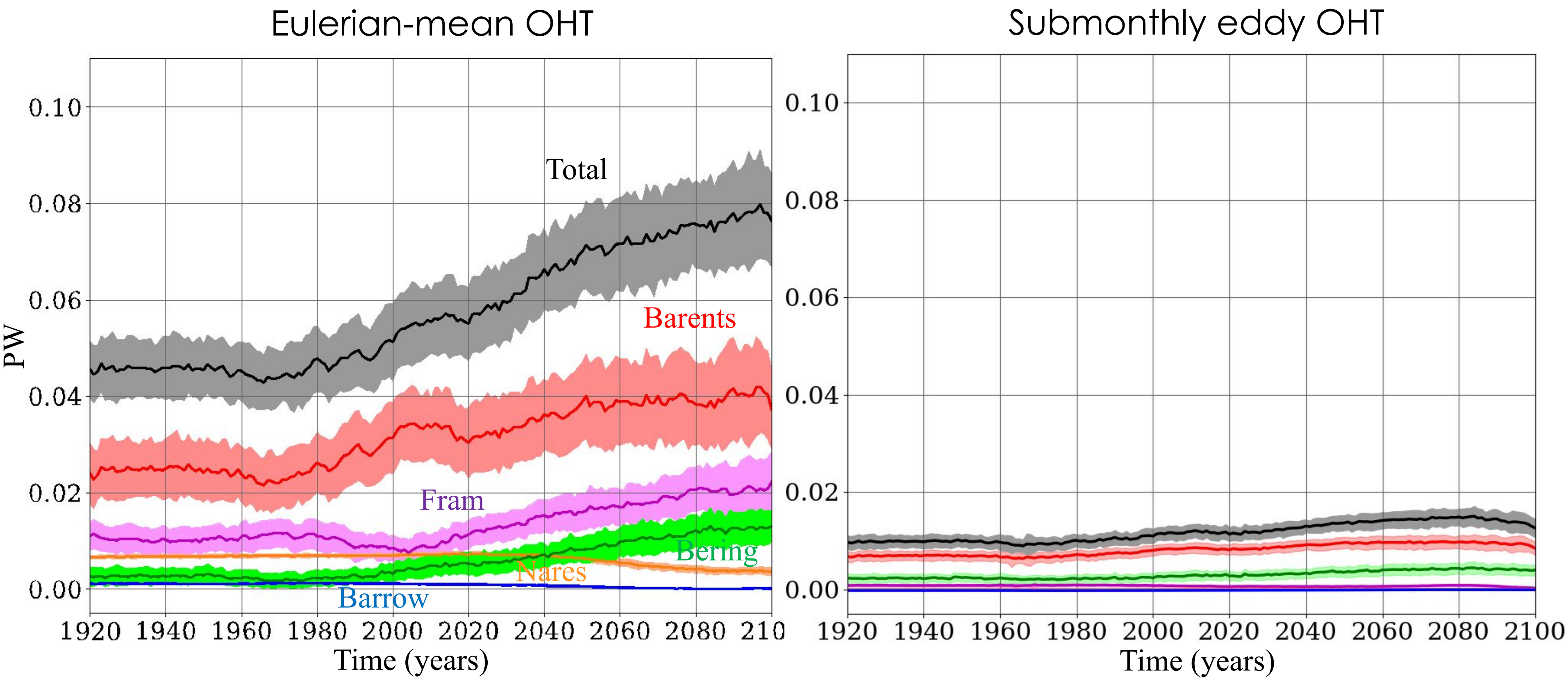
- OHT increase largely due to passive temperature changes
- Sea-surface heat loss increases due to enhanced longwave radiation and latent, sensible heat loss
- Atmosphere is initially main heat source for ice in summer. Ocean starts to become main heat source over time

The end

- Thank you!

Submonthly OHT increase driven by changes in Barents and Bering Straits



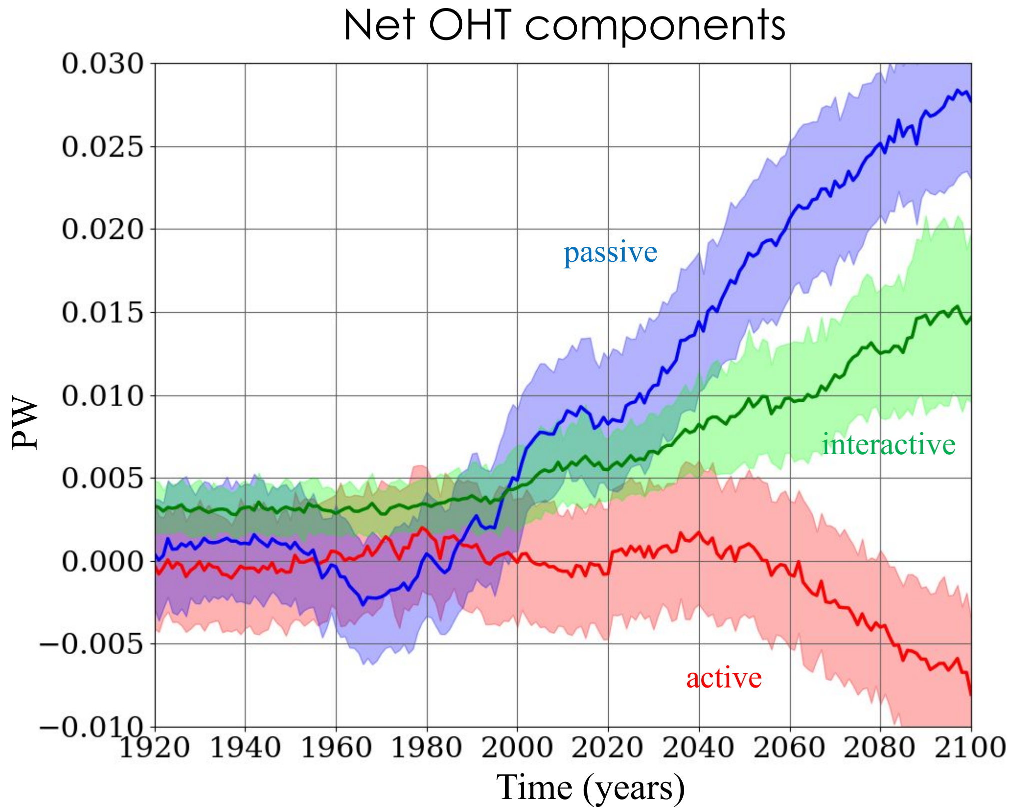
OHT anomalies split into active and passive components

$$\mathrm{OHT}'(y,t) = \rho c_p \int_{x_1}^{x_2} \int_{z_{bot}}^{0} \overline{v}\theta' dz dx \quad \text{(passive)}$$

$$+ \rho c_p \int_{x_1}^{x_2} \int_{z_{bot}}^{0} v'\overline{\theta} dz dx \quad \text{(active)}$$

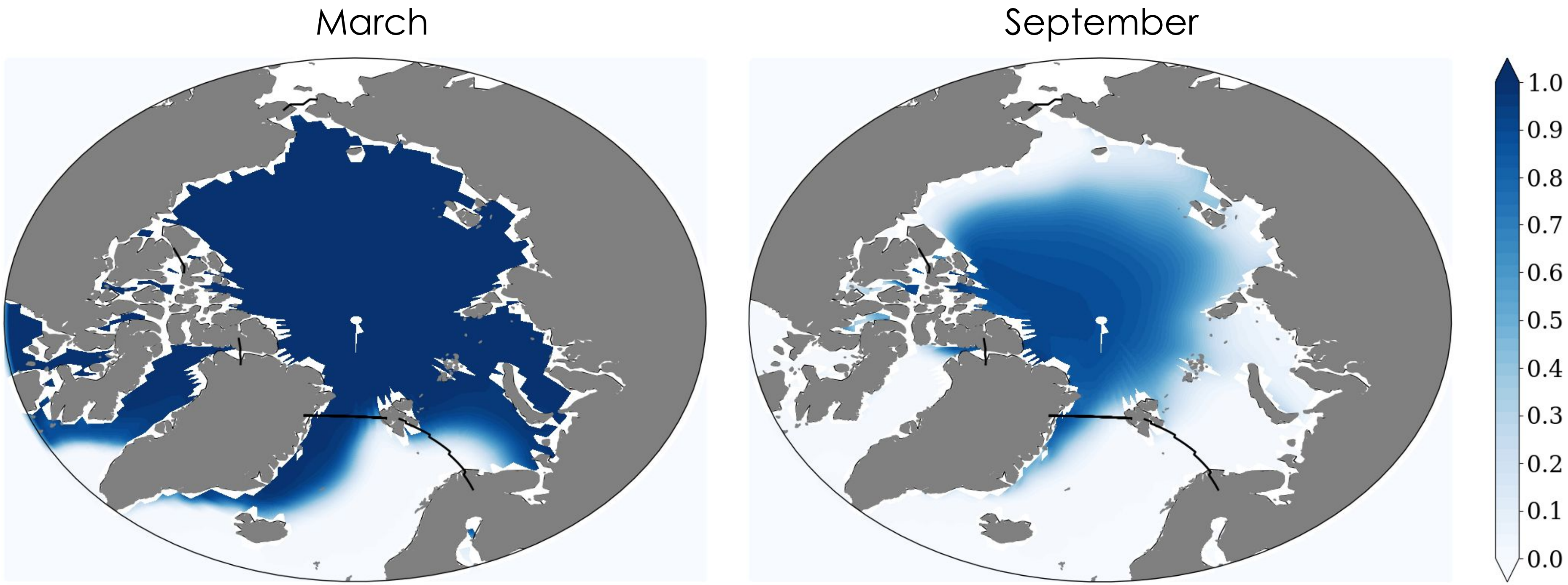
$$+ \rho c_p \int_{x_1}^{x_2} \int_{z_{bot}}^{0} v'\theta' dz dx \quad \text{(interactive)}$$

OHT increase driven by passive and interactive changes



Part II: Arctic sea-ice heat budget

Sea-ice concentration 1920-1940



Arctic becomes ice-free in September

Sea-ice concentration change 2080-2100 – 1920-1940

March | September