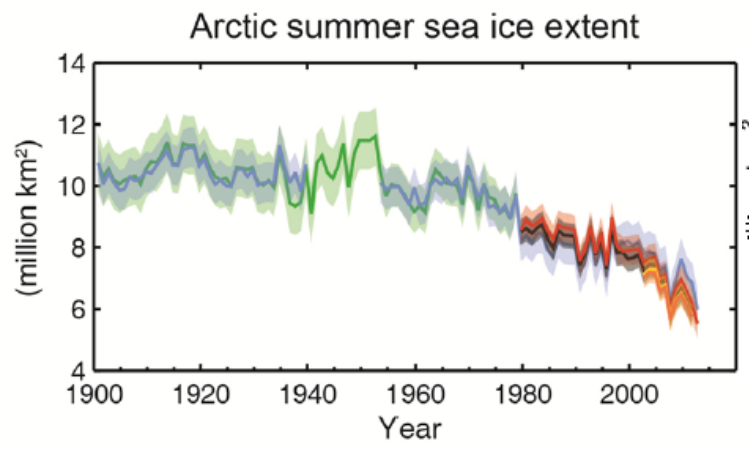
# Can regional Geoengineering save the Arctic Sea-ice?

*Simone Tilmes, Alexandra Jahn, Jennifer E. Kay, Marika Holland, Jean-François Lamarque*

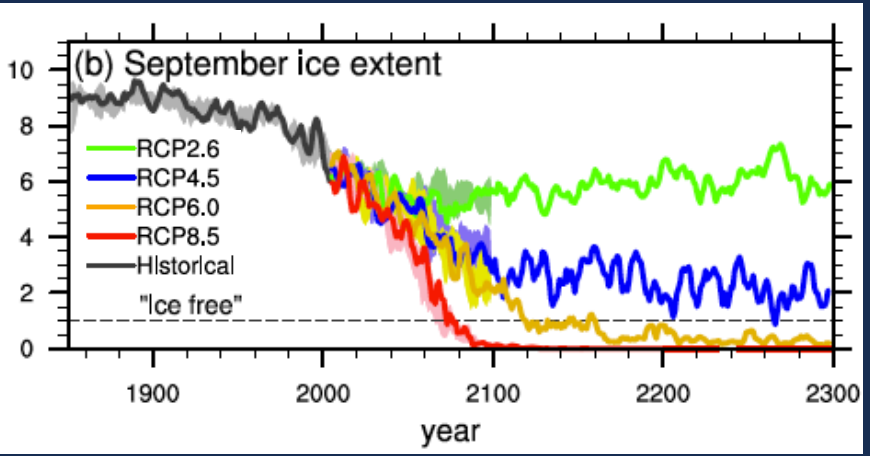
**An Energy Budget Perspective**

Observations




*IPCC 2013*

CCSM4 Model Projections



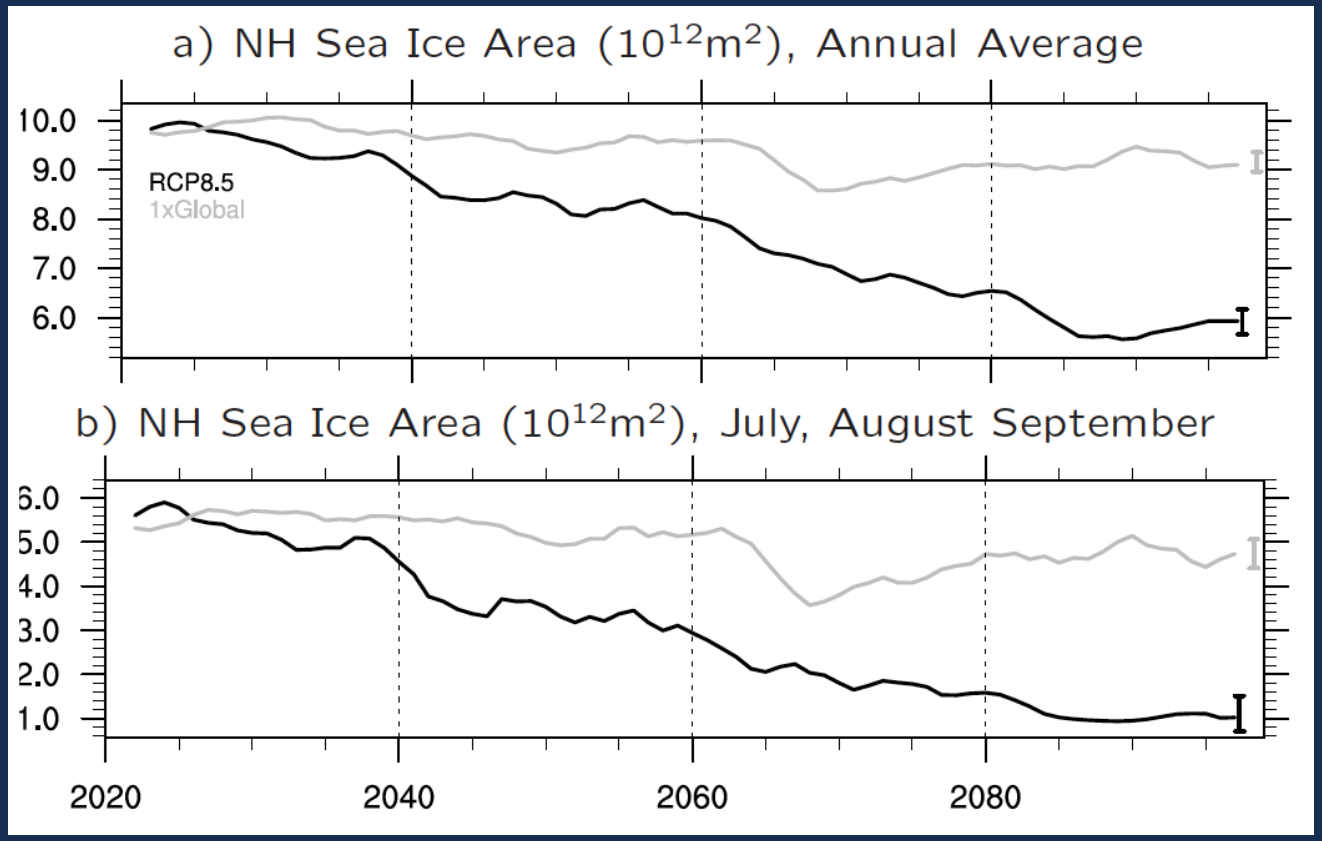

*Jahn and Holland, 2013*

# Why do we want to save the Arctic Sea-ice?

- Arctic is an important climate driver
- Potential release of carbon in Arctic shelve seas and permafrost -> acceleration of climate change
- Large impact on the Arctic Ecosystem
- Arctic dimming may be most effective (MacCracken et al.,2013)
- Less intrusive than a global approach?

# Experiments: CCSM4, 1degree

Business-as-usual scenario RCP8.5



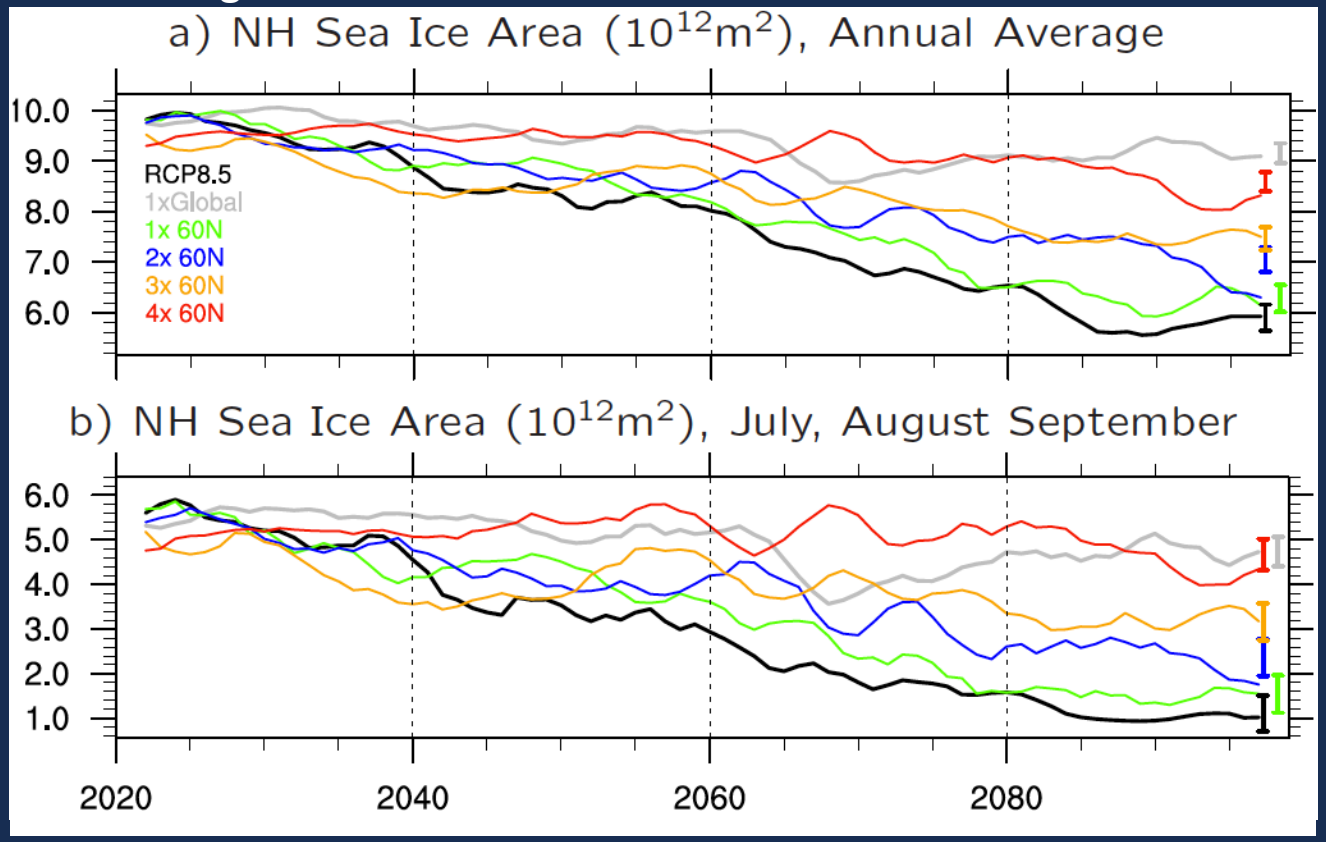

Global solar dimming: ~45W/m$^2$ for RF=8.5Wm$^2$ (about 3.3% from 1361 W/m$^2$)

- ~8% increase in 1 billion years,
- 11-year cycle is 0.1%

Global dimming: Steadily increasing amount of global dimming to balance the top of the atmosphere energy budget

# Regional Solar Dimming Experiments

Dimming of the Arctic: northward 60°N

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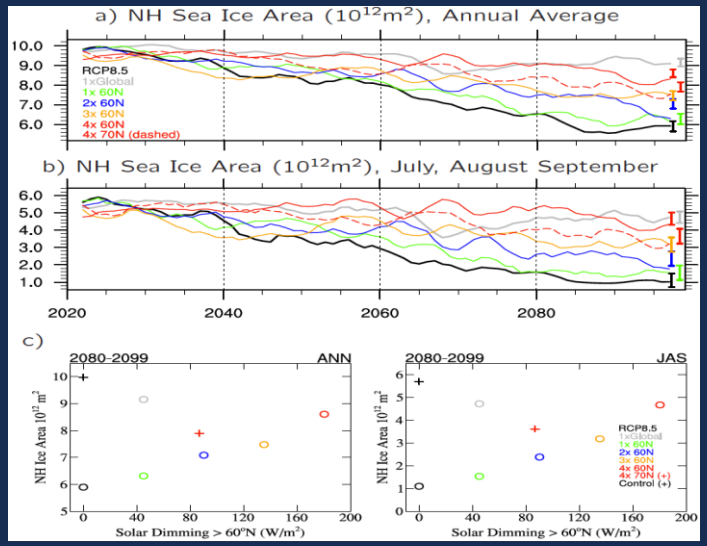
- ~8% increase in 1 billion years,
- 11-year cycle is 0.1%

**4x solar dimming: 180 W/m², 13%**

How much regional dimming is necessary?

# Correlation: NH Ice Area and Solar Dimming




Why do we need so much dimming ?

What are the Processes?

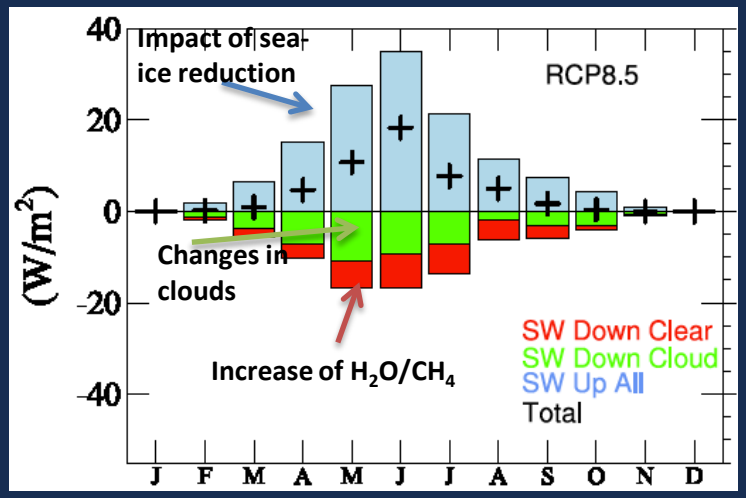
What are the consequences for climate, and the meridional overturning circulation?

**July/August/September**

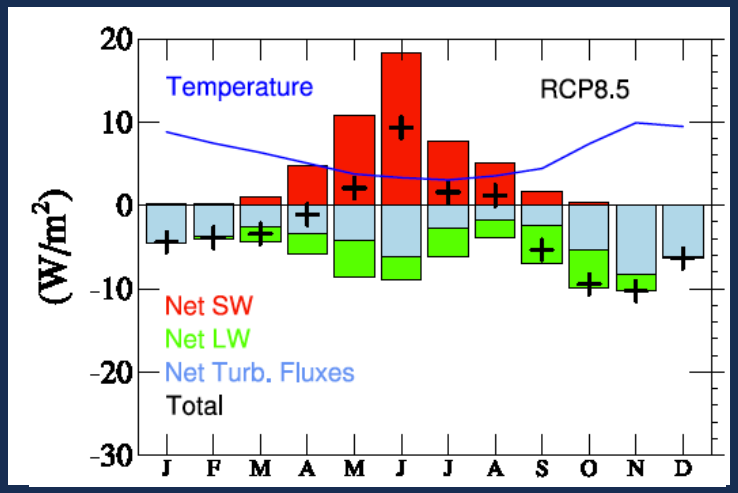
| | Control | RCP8.5 | 1xglobal | 1x60N | 2x60N | 3x60N | 4x60N | 4x70N |
|---|---|---|---|---|---|---|---|---|
| Amount Dimming ($W/m^2$) | 0 $W/m^2$ | 0 $W/m^2$ | 45 $W/m^2$ | 45 $W/m^2$ | 90 $W/m^2$ | 135 $W/m^2$ | 180 $W/m^2$ | 180 $W/m^2$ 87 $W/m^2$ (60°N equivalent) |
| Sea Ice Area | 5.69 $10^{12}m^2$ | 19% | 83% | 27% | 42% | 56% | 82% | 64% |
| Sea Ice Volume | 1.60 $10^{13}m^3$ | 10% | 60% | 15% | 25% | 38% | 66% | 45% |
| Snow Volume | 0.043 $10^{13}m^3$ | 5% | 70% | 9% | 21% | 54% | 151% | 76% |

# Surface Heat Budget Change: 60-90°N between 2080-2099 and present (2004-2020)

Net Shortwave Surface Fluxes:RCP8.5




Net Surface Fluxes: RCP8.5 -present




Positive Downward

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Positive Downward

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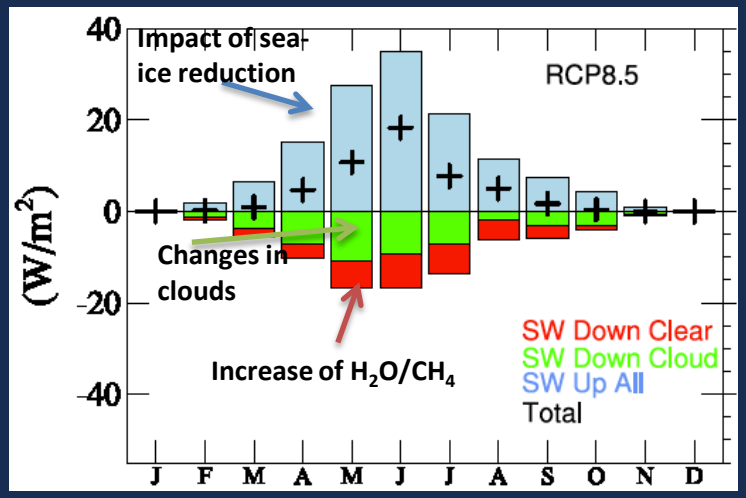
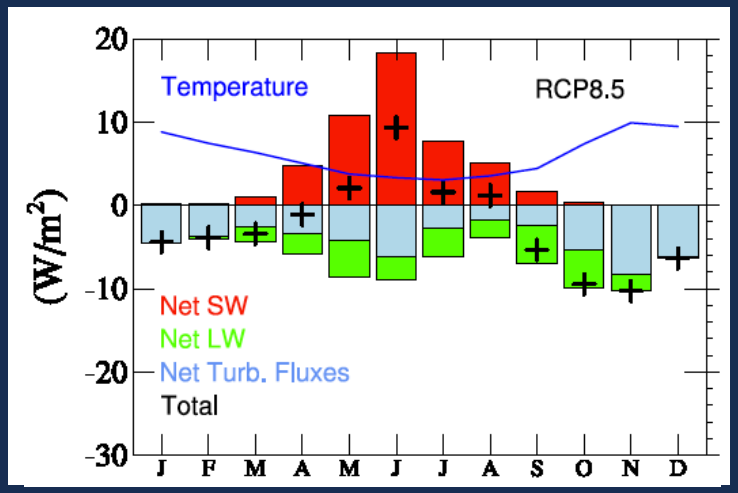
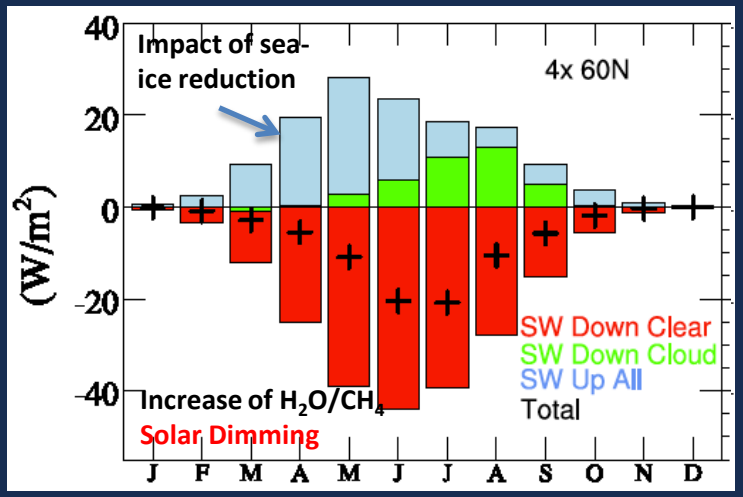



Net Surface Fluxes: RCP8.5 -present




Net Shortwave Surface Fluxes: 4x60N

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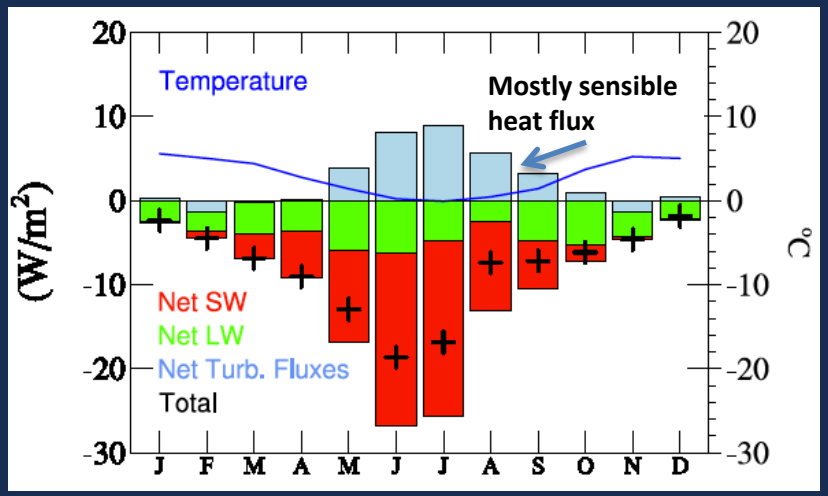
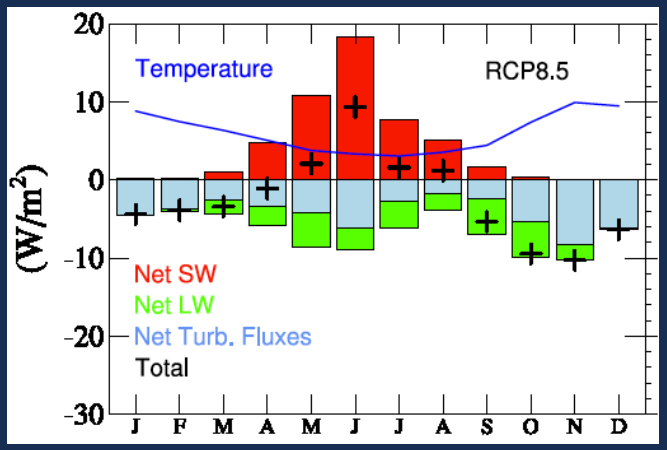
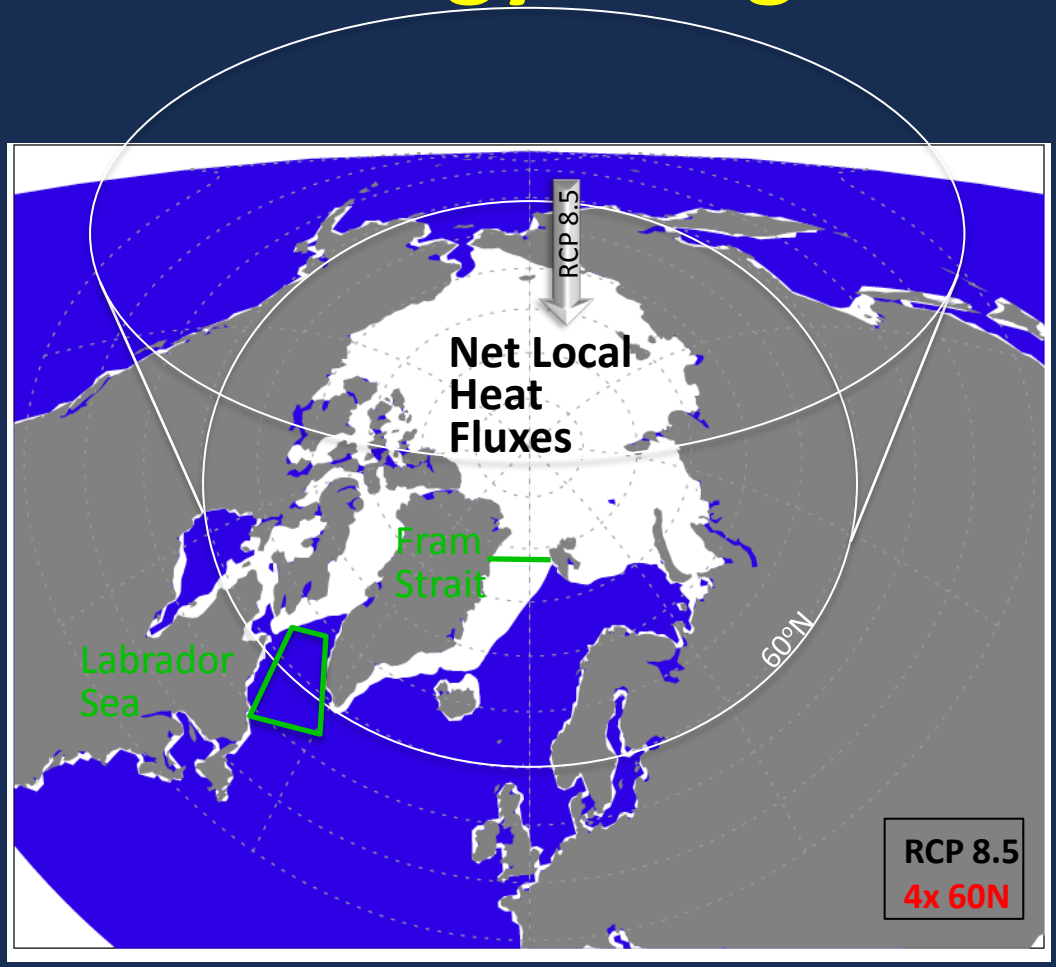


# Arctic Energy Budget

RCP8.5 – present (2005-2024)
Net Surface Fluxes Changes




Positive Downward




Heat Flux ( ) and Water Transport ( ) Changes to Present Day

Shortwave (SW) fluxes:

Summer:

- Increase in downward heat flux, mostly controlled sea-ice reduction (counteracted by increase in clouds, greenhouse gases)

Winter:

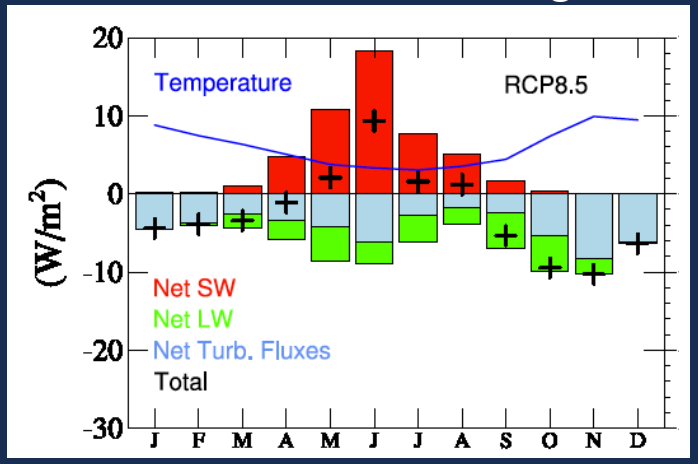
- Decrease in downward heat flux, controlled by turbulent fluxes

-> heating of the atmosphere

# Arctic Energy Budget

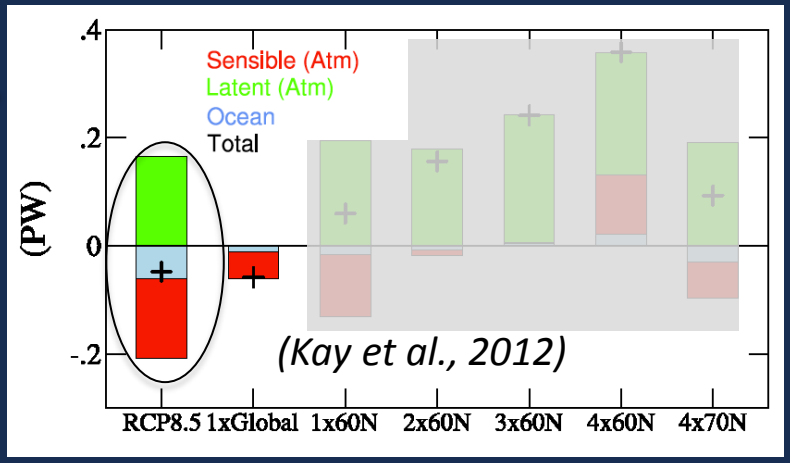
RCP8.5 – present

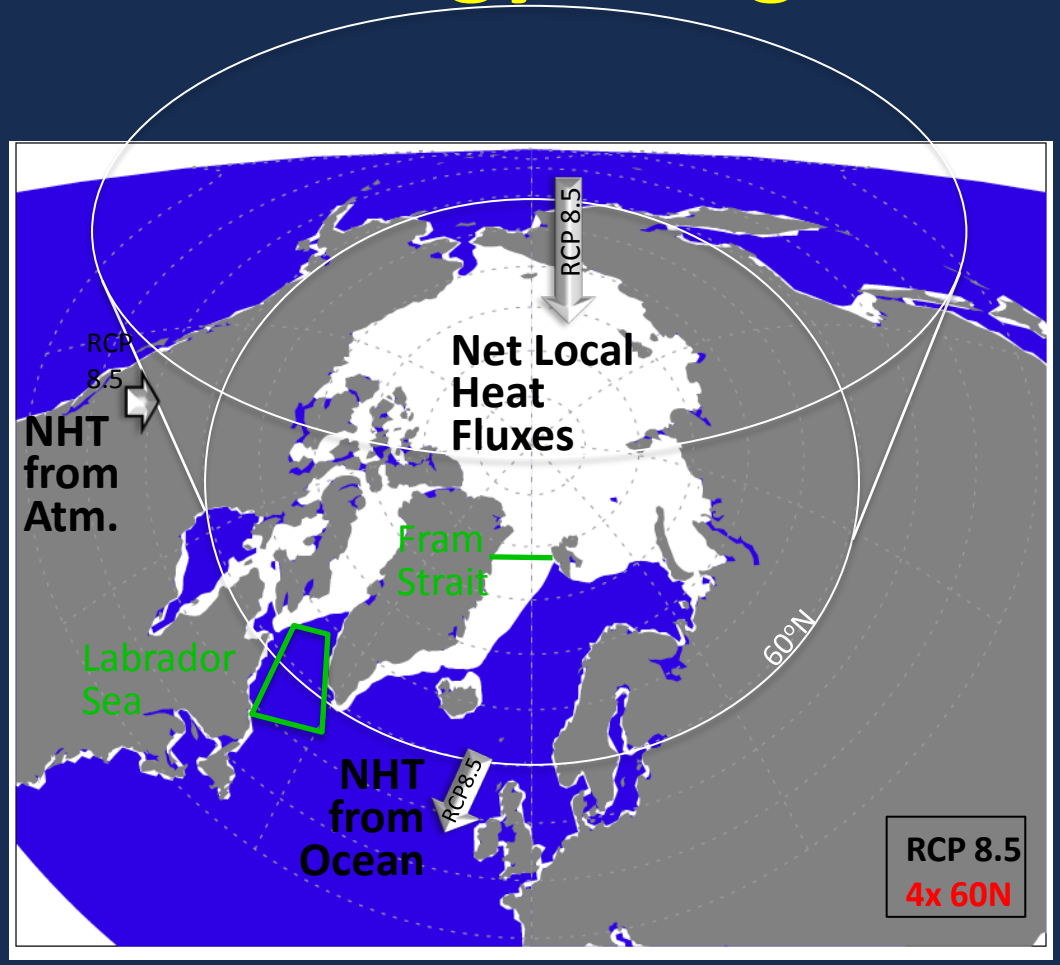
Net Surface Fluxes Changes




Positive Downward

Northward Heat Transport Changes




Heat Flux ( ) and Water Transport ( ) Changes to Present Day

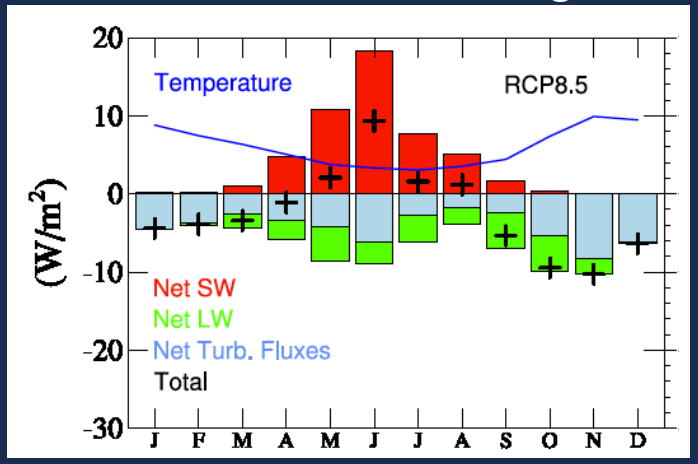
NHT Latent Heat increased: increase in global temperatures

NHT Sensible Heat decreased: reduction of the temperature gradient

# Arctic Energy Budget

RCP8.5 - present

Net Surface Fluxes Changes

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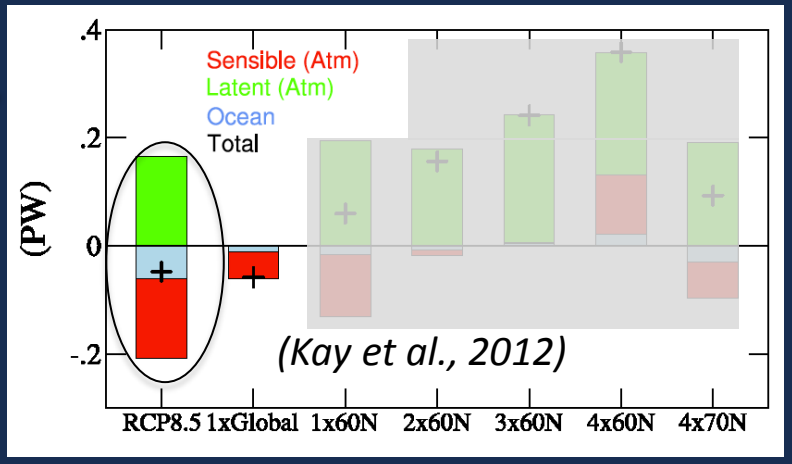
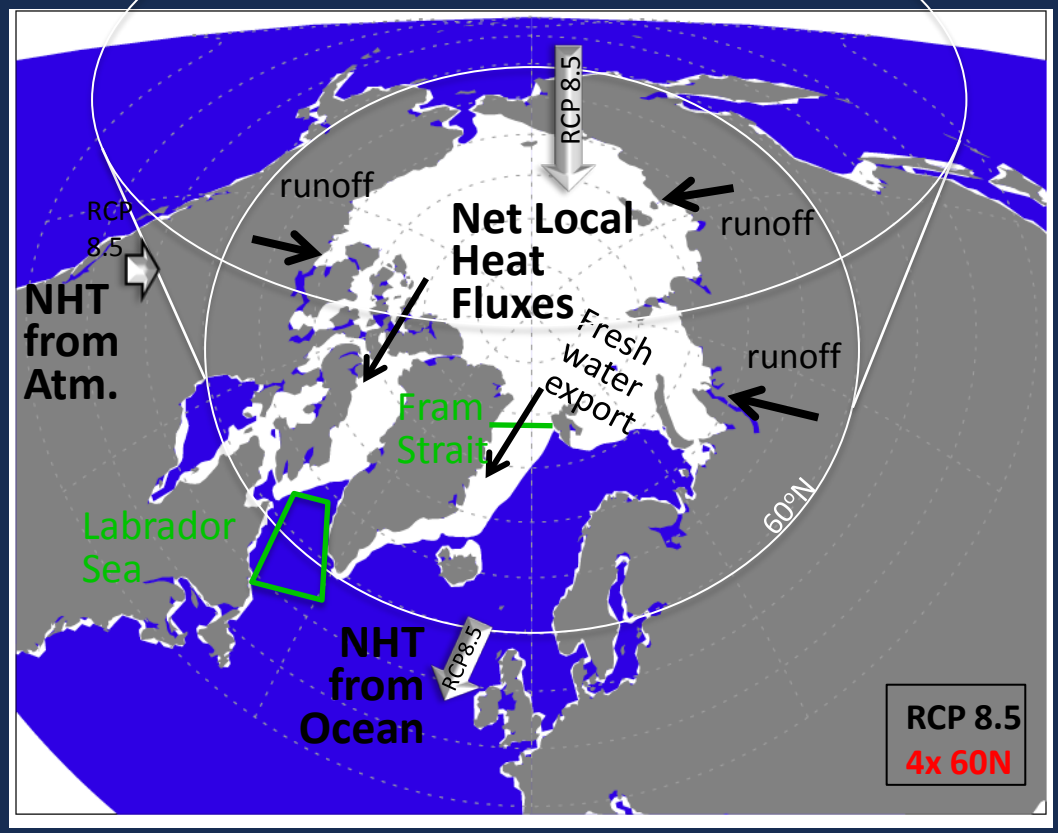
Northward Heat Transport Changes




Heat Flux ( ) and Water Transport ( ) Changes to Present Day

NHT Latent Heat increased: increase in global temperatures

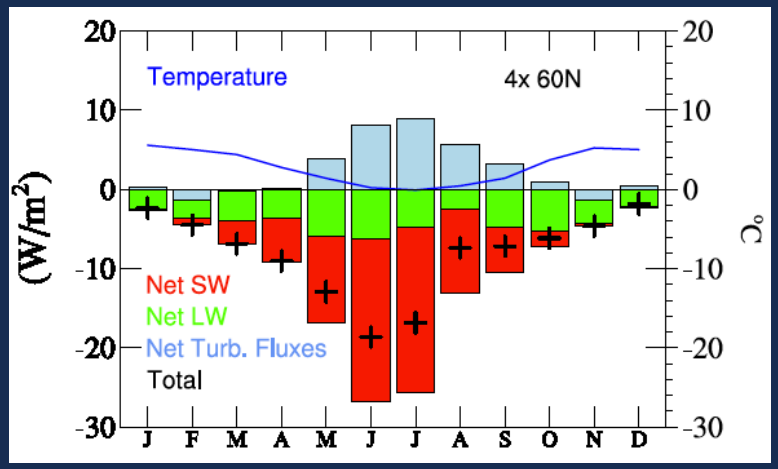
NHT Sensible Heat decreased: reduction of the temperature gradient

Ocean transport reduced: less salinity with increased fresh water from run off, sea-ice reduction

Reduction in the Labrador Sea convection, MOC is strongly reduced

# Arctic Energy Budget

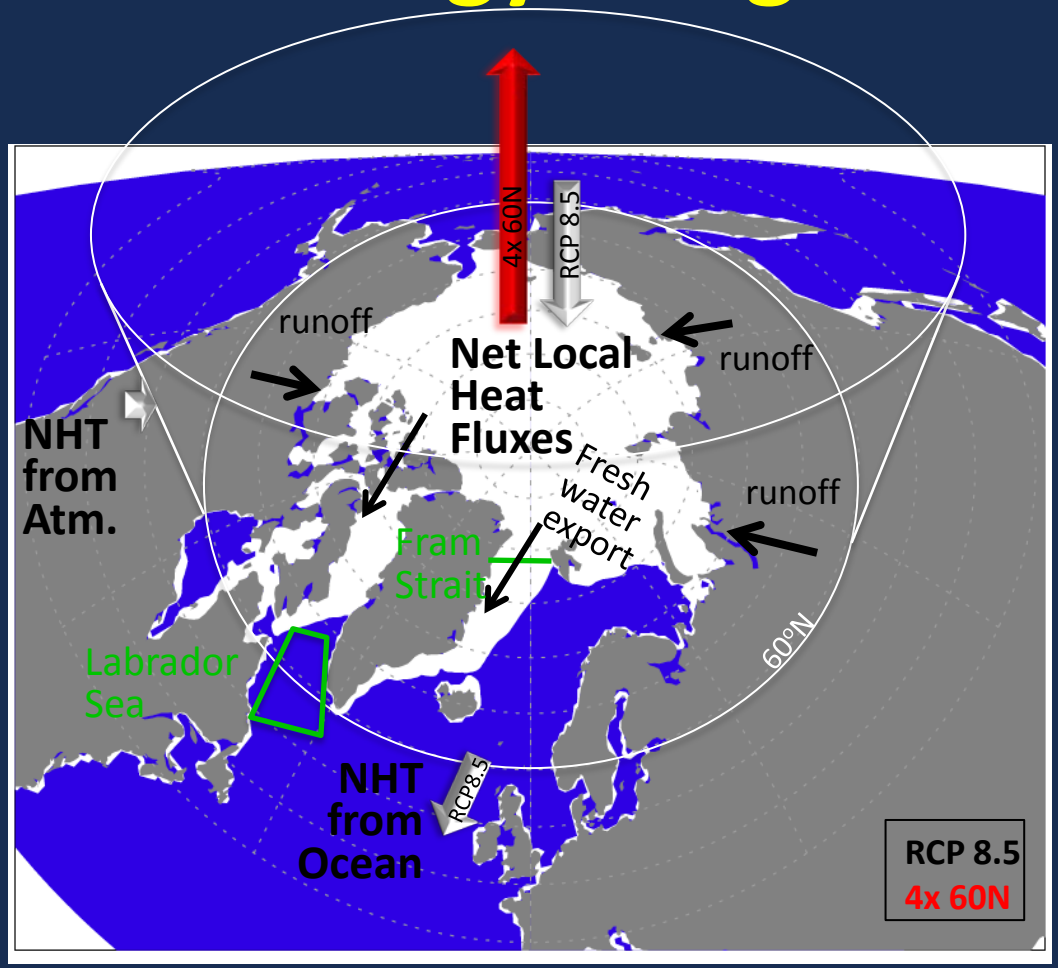
4x60N - present
Net Surface Fluxes Changes




Strongest dimming case (13%)
Artificial SW reduction counteracted by

- continuous sea-ice reduction
- reduction in clouds
- sensible heat flux

Net SW fluxes are strongly reduced to balance surface temperatures

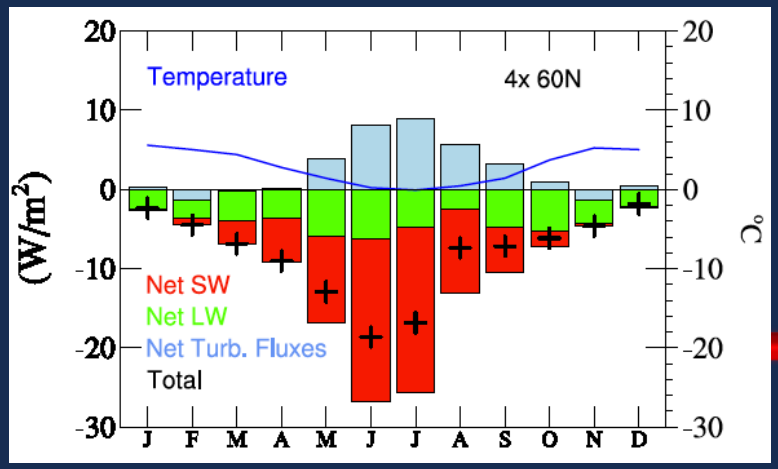



Heat Flux ( ) and Water Transport ( ) Changes to Present Day

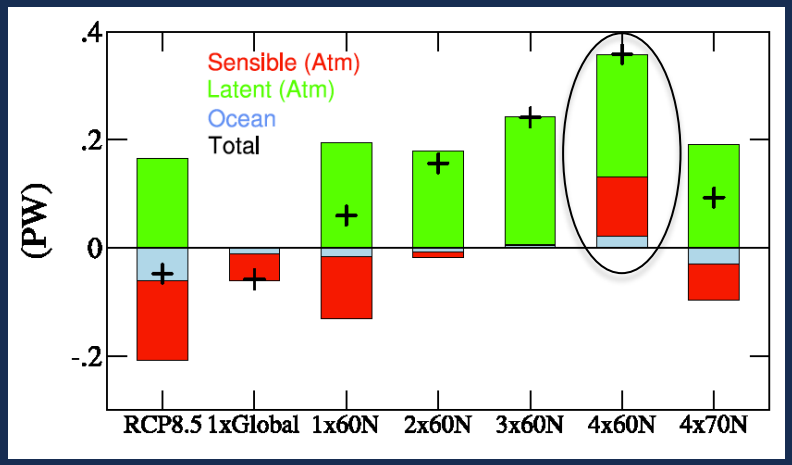
# Arctic Energy Budget

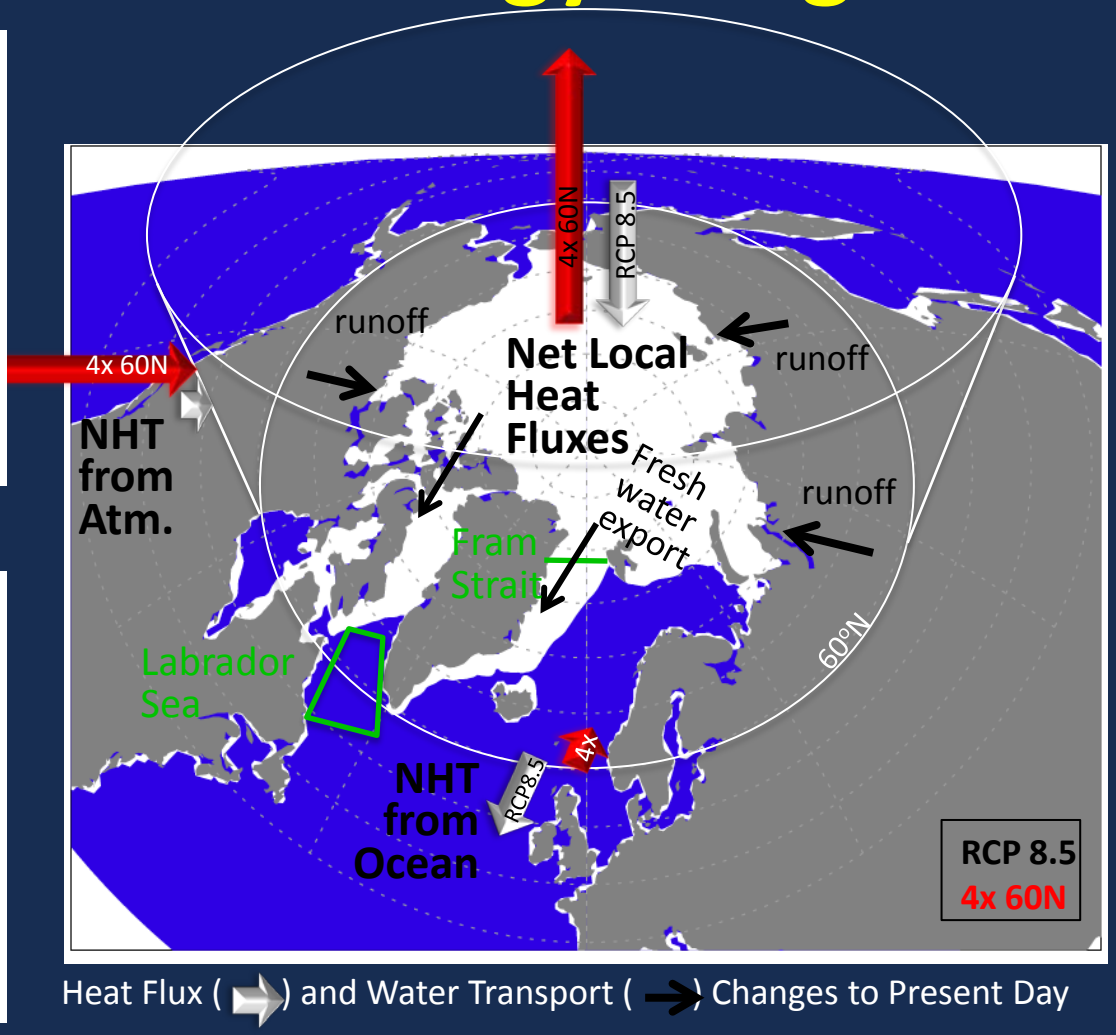
4x60N - present

Net Surface Fluxes Changes




Northward Heat Transport Changes




Heat Flux ( ) and Water Transport ( ) Changes to Present Day

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Ocean Heat Transport increased: similar salinity, stronger temperature gradient

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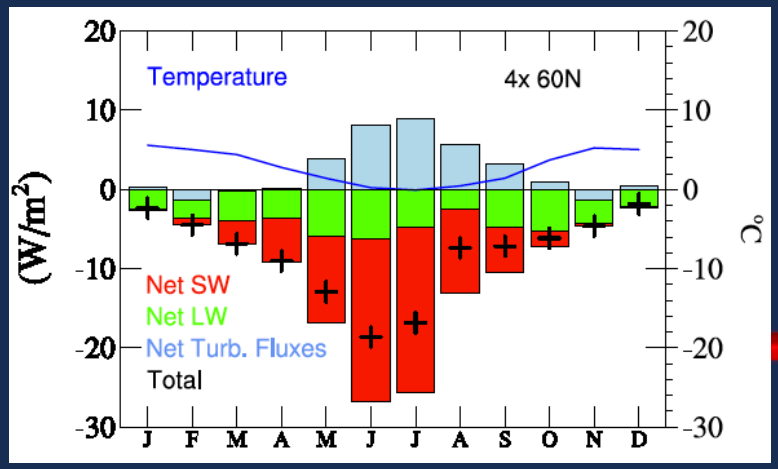


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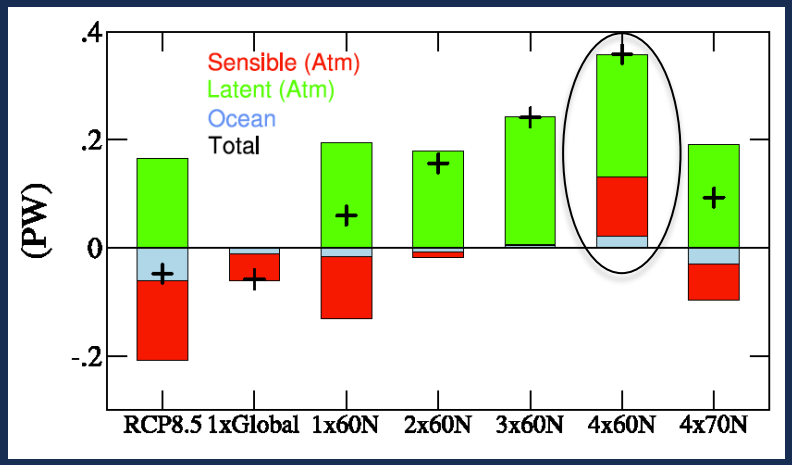


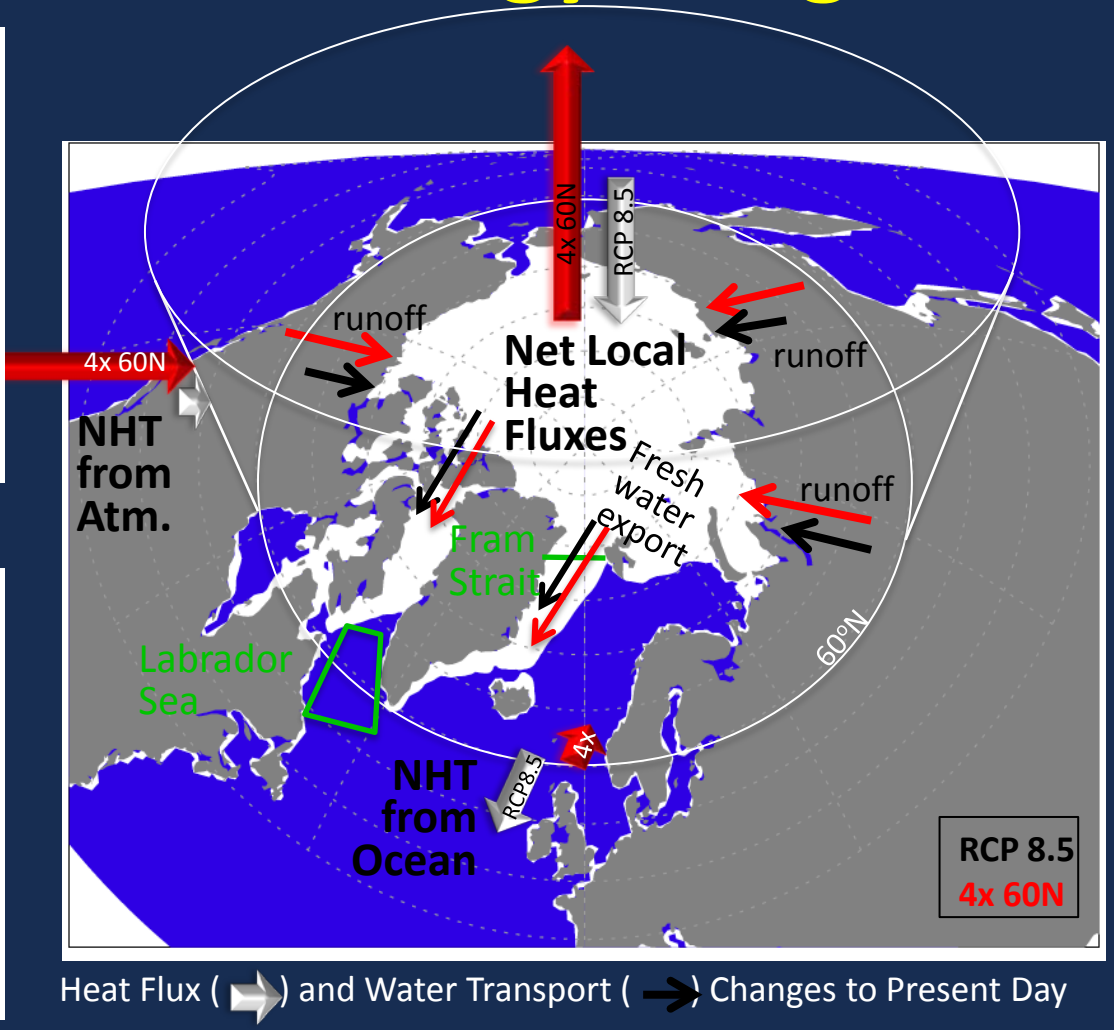


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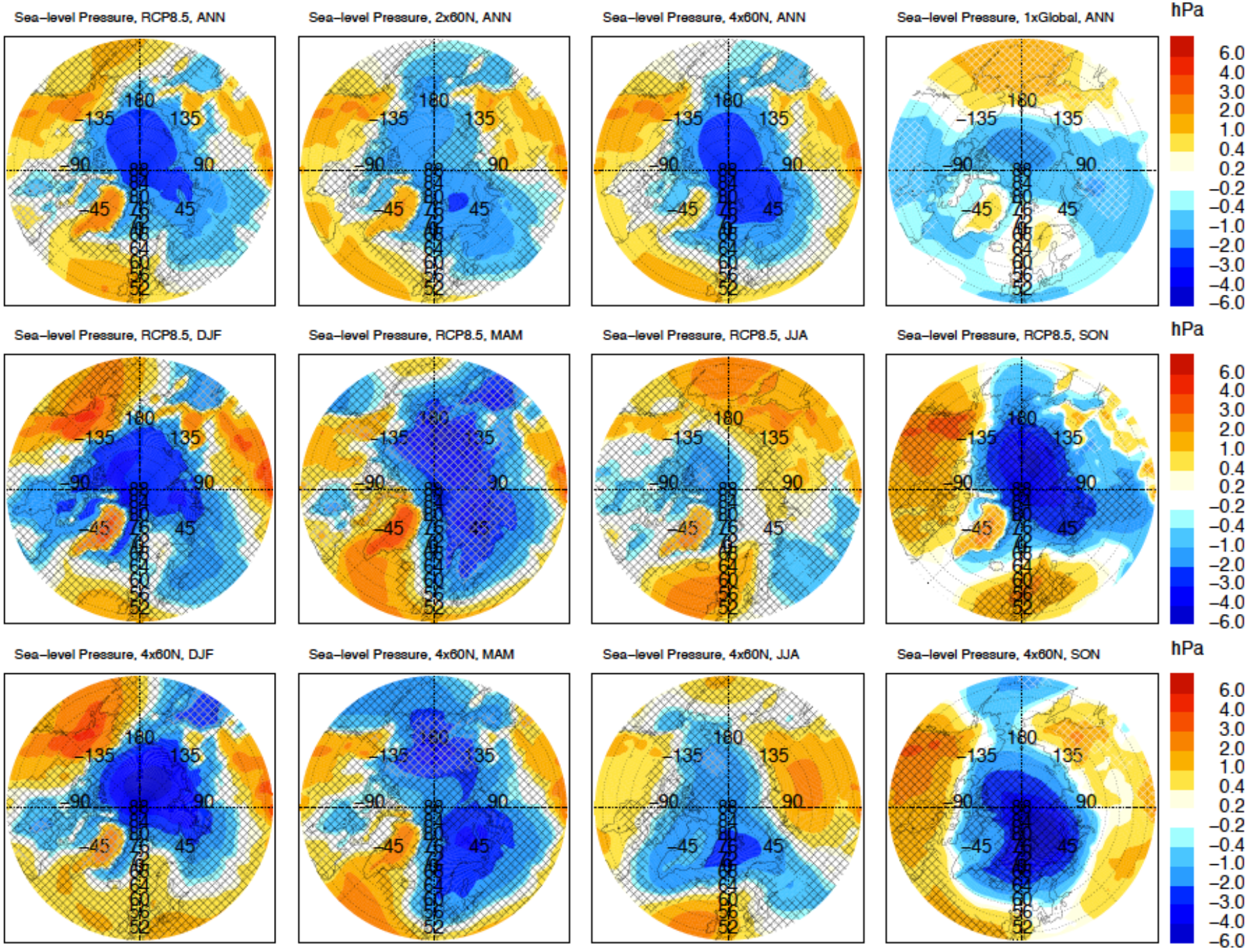
Ocean Heat Transport increased: similar salinity, stronger temperature gradient

MOC still strongly reduced, larger fresh water export, increased runoff from lower latitudes

# Conclusions

- Four times the amount of global dimming required to preserve summer Arctic sea-ice area, volume still reduced, 180Wm$^2$, 13% reduction, ~10 times more than currently technically possible
- Changes of local surface fluxes and Northward Heat Transport important
- Counteracting processes to solar dimming:
  - More dimming, more energy transport from lower latitudes
  - More dimming, SW flux increase due to clouds
- MOC still reduced
- Precipitation pattern likely to shift ITCZ away from the NH
- Large impact on the Ecosystem possible

Regional Arctic dimming not an option in RCP8.5


Sea–level Pressure, RCP8.5, ANN
Sea–level Pressure, 2x60N, ANN
Sea–level Pressure, 4x60N, ANN
Sea–level Pressure, 1xGlobal, ANN
Sea–level Pressure, RCP8.5, DJF
Sea–level Pressure, RCP8.5, MAM
Sea–level Pressure, RCP8.5, JJA
Sea–level Pressure, RCP8.5, SON
Sea–level Pressure, 4x60N, DJF
Sea–level Pressure, 4x60N, MAM
Sea–level Pressure, 4x60N, JJA
Sea–level Pressure, 4x60N, SON
hPa
6.0
4.0
3.0
2.0
1.0
0.4
0.2
−0.2
−0.4
−1.0
−2.0
−3.0
−4.0
−6.0
180
−135
135
−90
90
−45
45