What processes drive Southern Ocean sea ice variability and trends? Insights from the interannual variability of the energy budget

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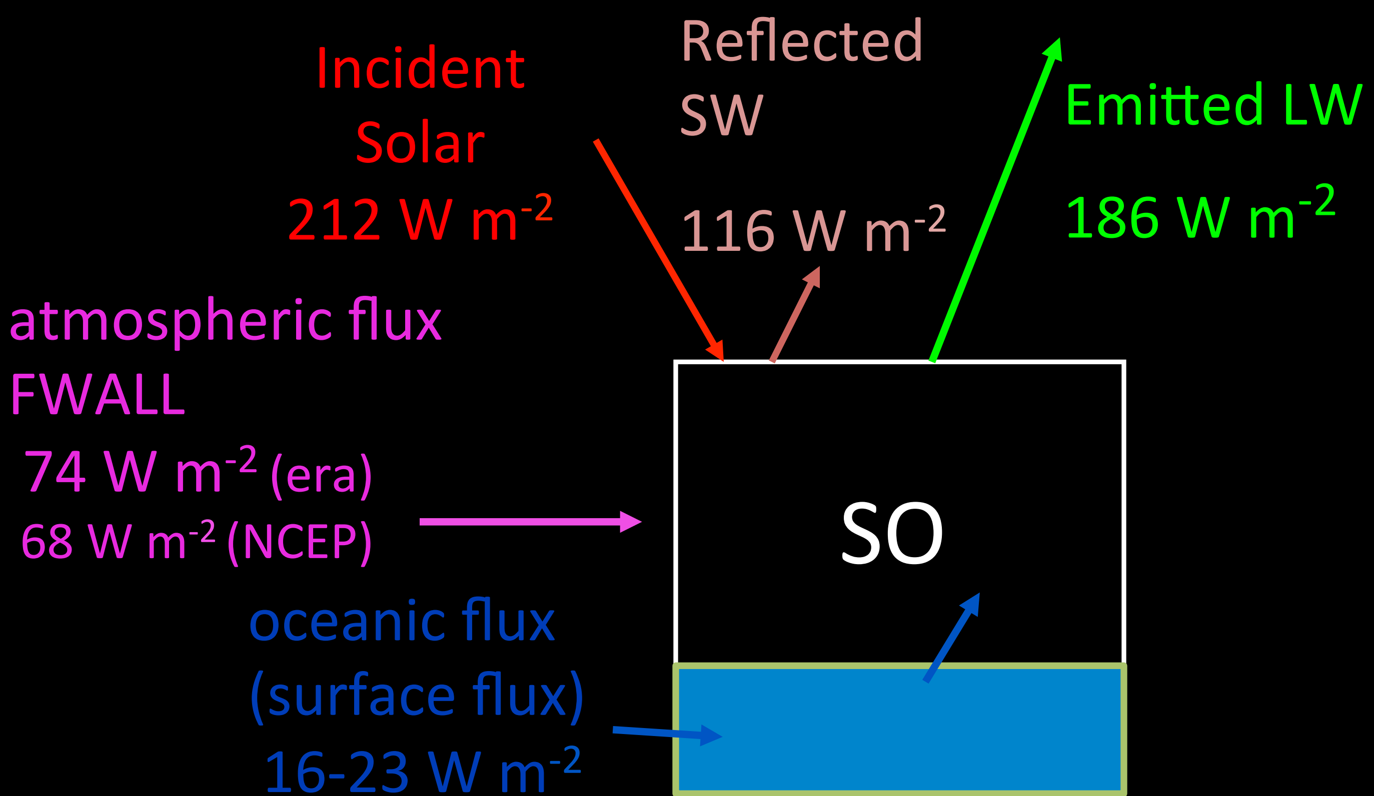
- Southern Ocean Climatological energy budget (poleward of 55S)

Radiative loss = Energy Import

- (Incident – Reflected) + Emitted = Ocean flux + atmospheric flux

90 W m^{-2}



Ar n
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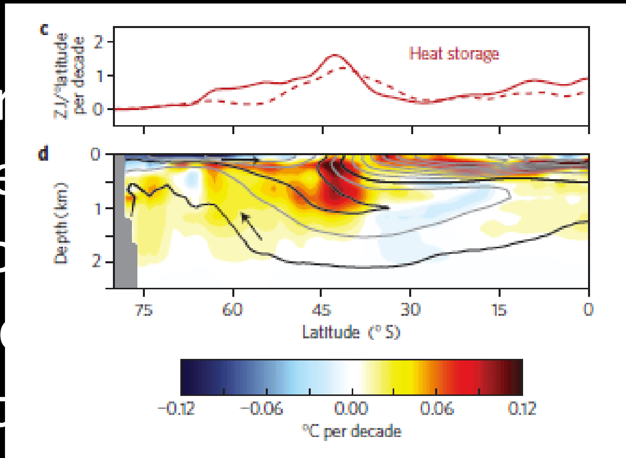
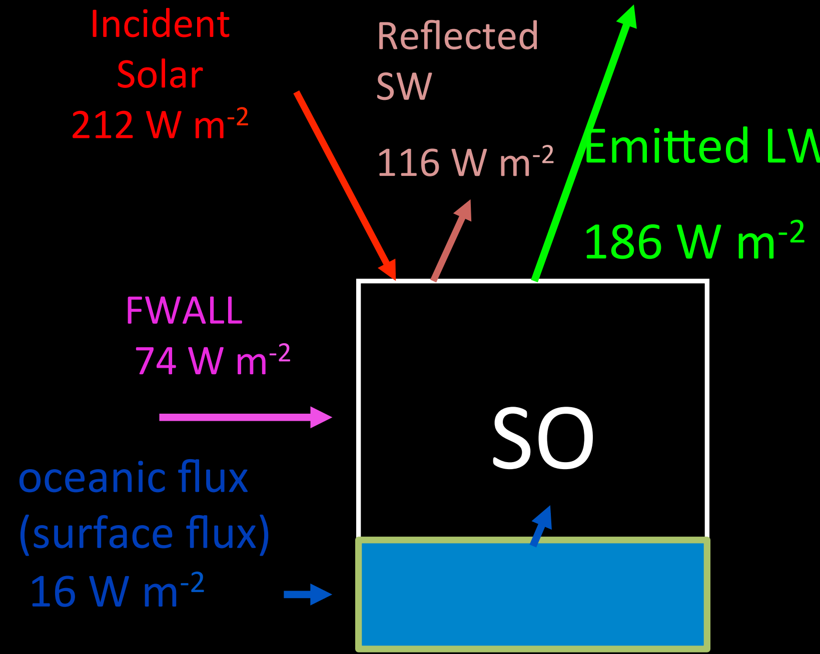
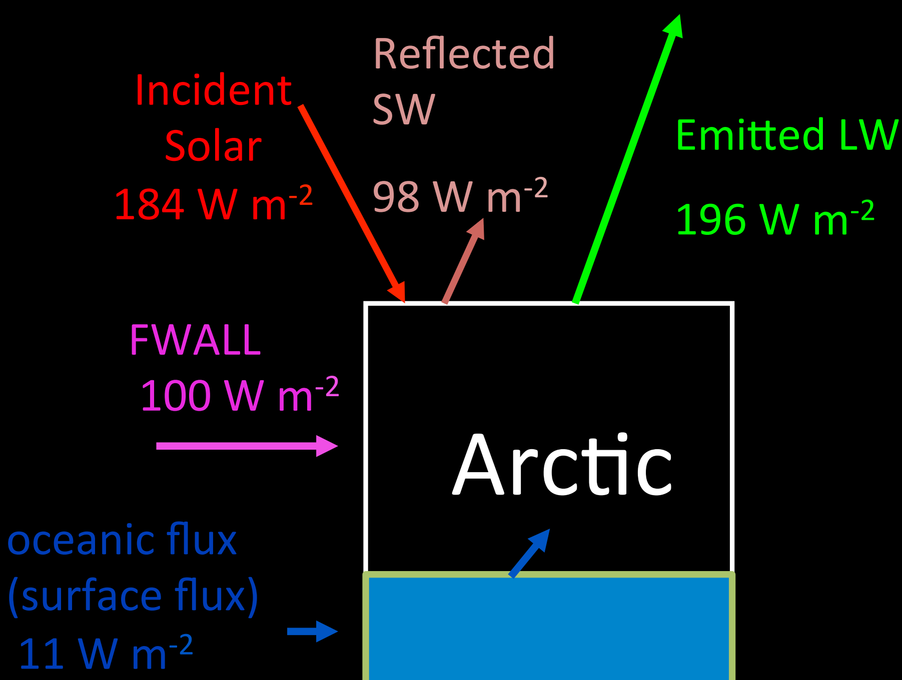


--Role of ocean heat storage over satellite era (< 1 W m^{-2})

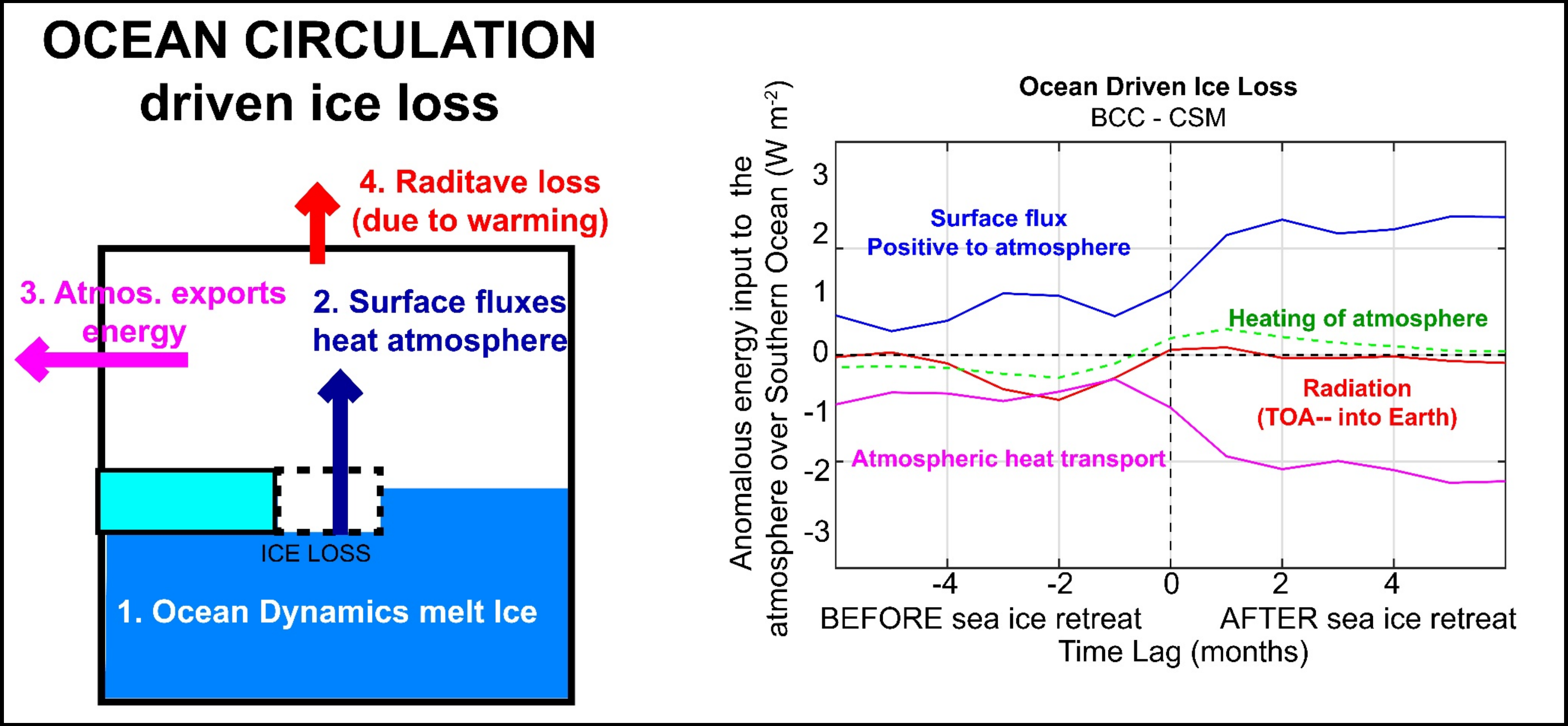




Serreze et al. (2007) closed the Arctic energy budget (poleward of 70N)

110 W m^{-2} = 111 W m^{-2}

Possible Mechanisms of sea ice loss: Energetic perspective



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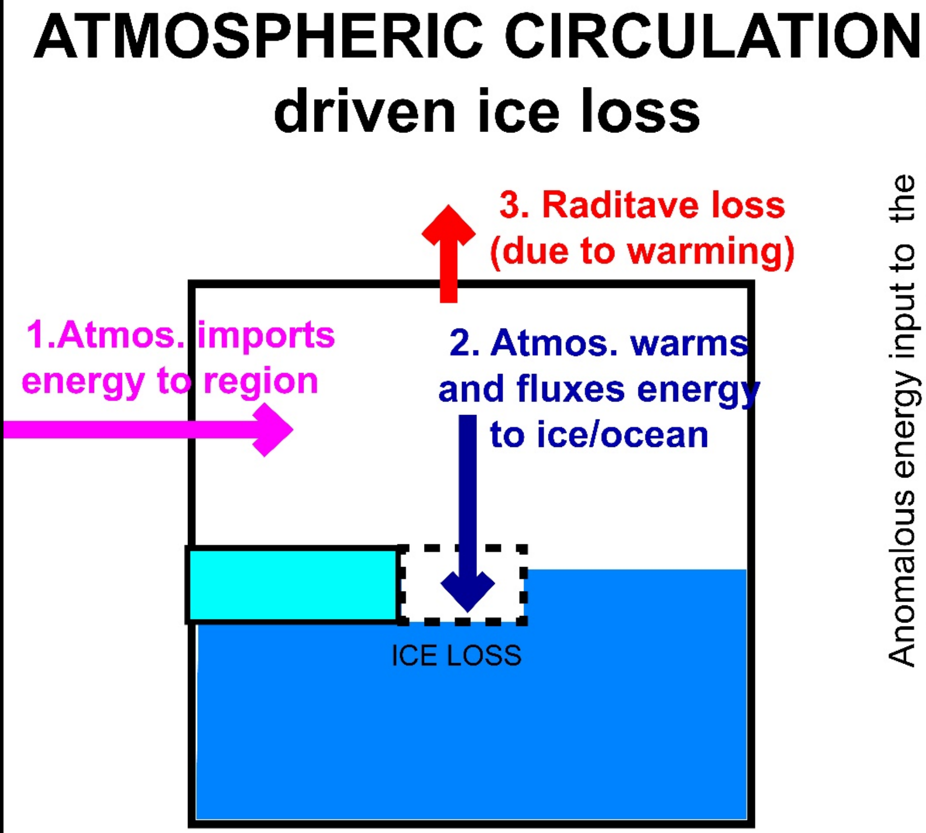

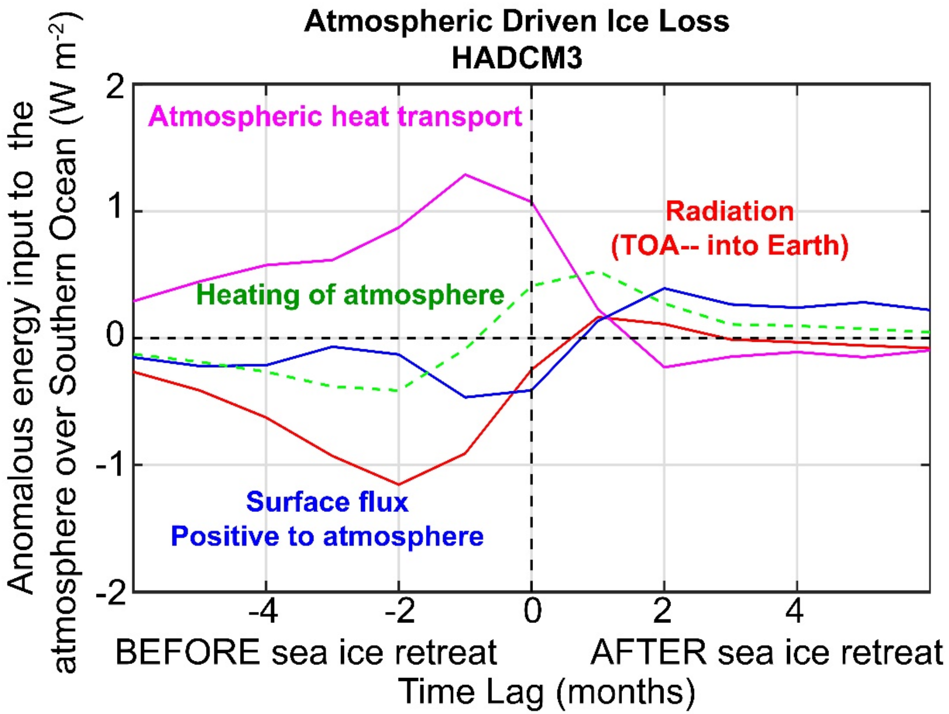

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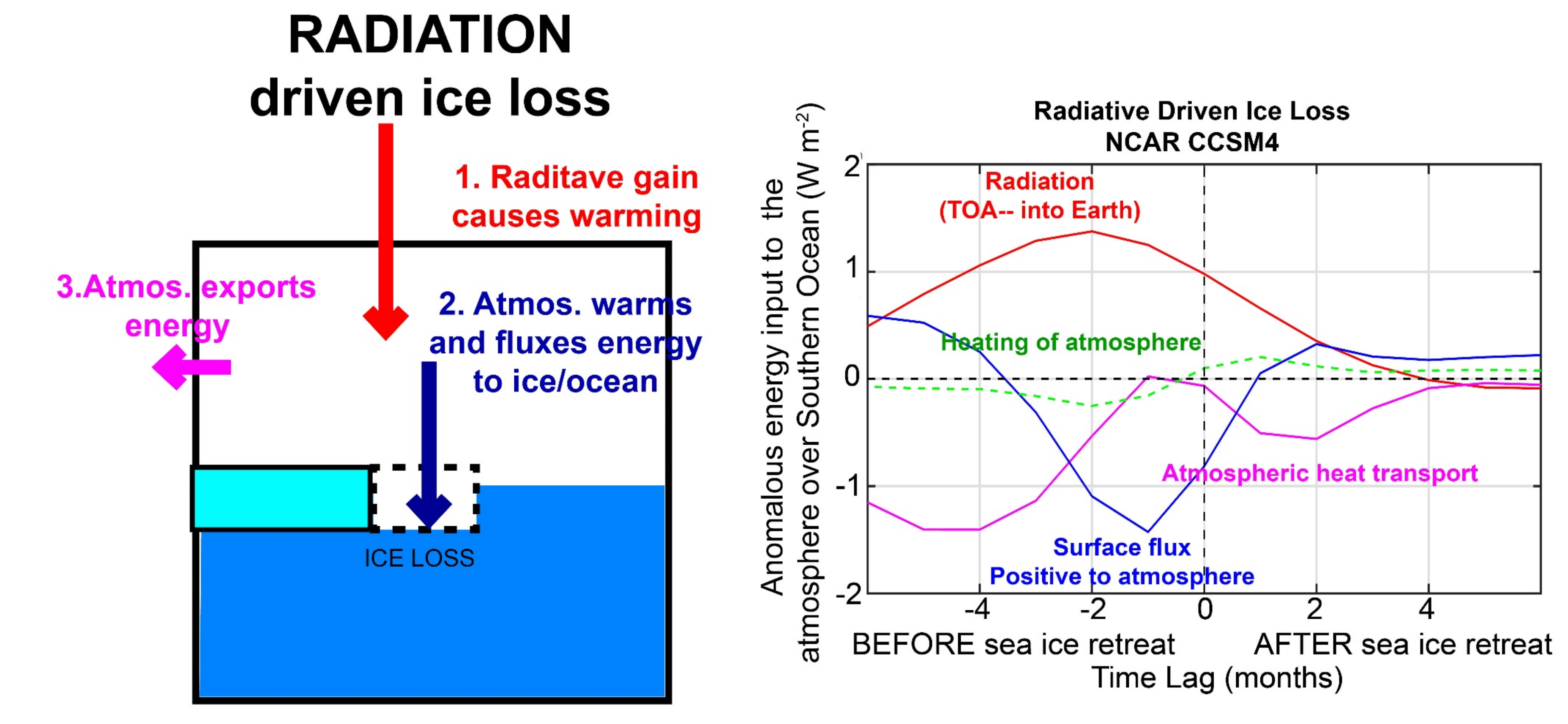
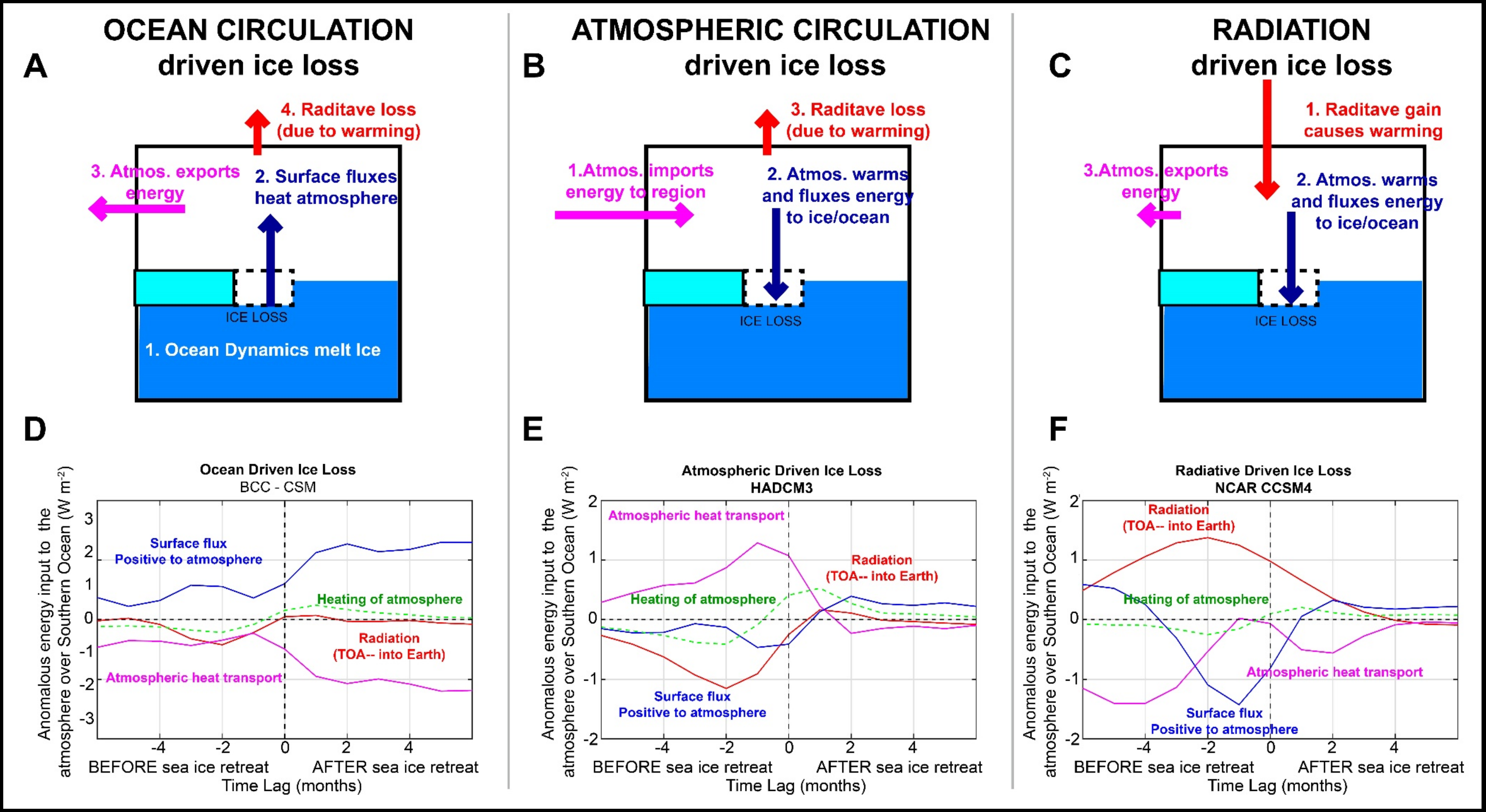
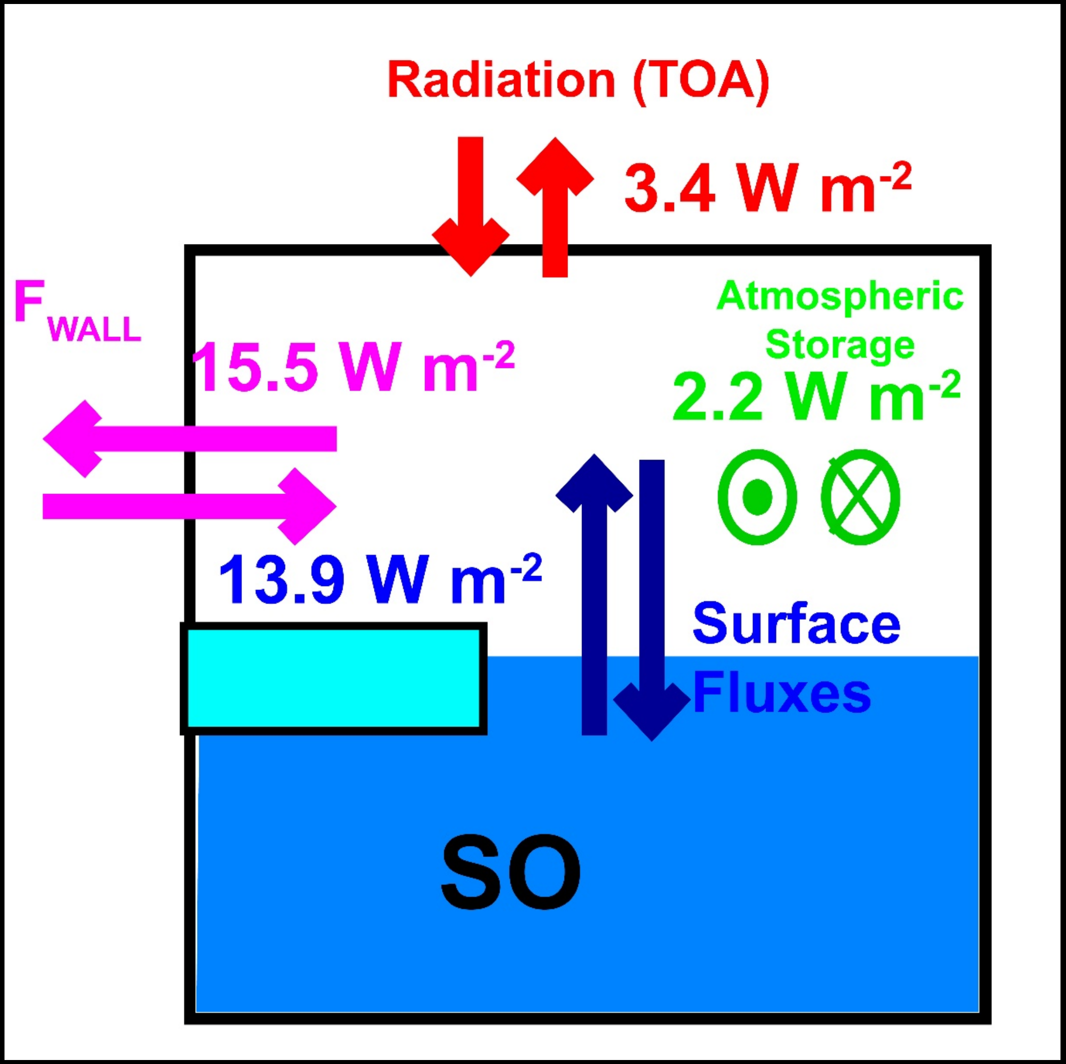




All three mechanisms (ocean driven, atmospheric driven and radiatively driven) of SO sea ice loss is exhibited in the diversity of coupled climate models

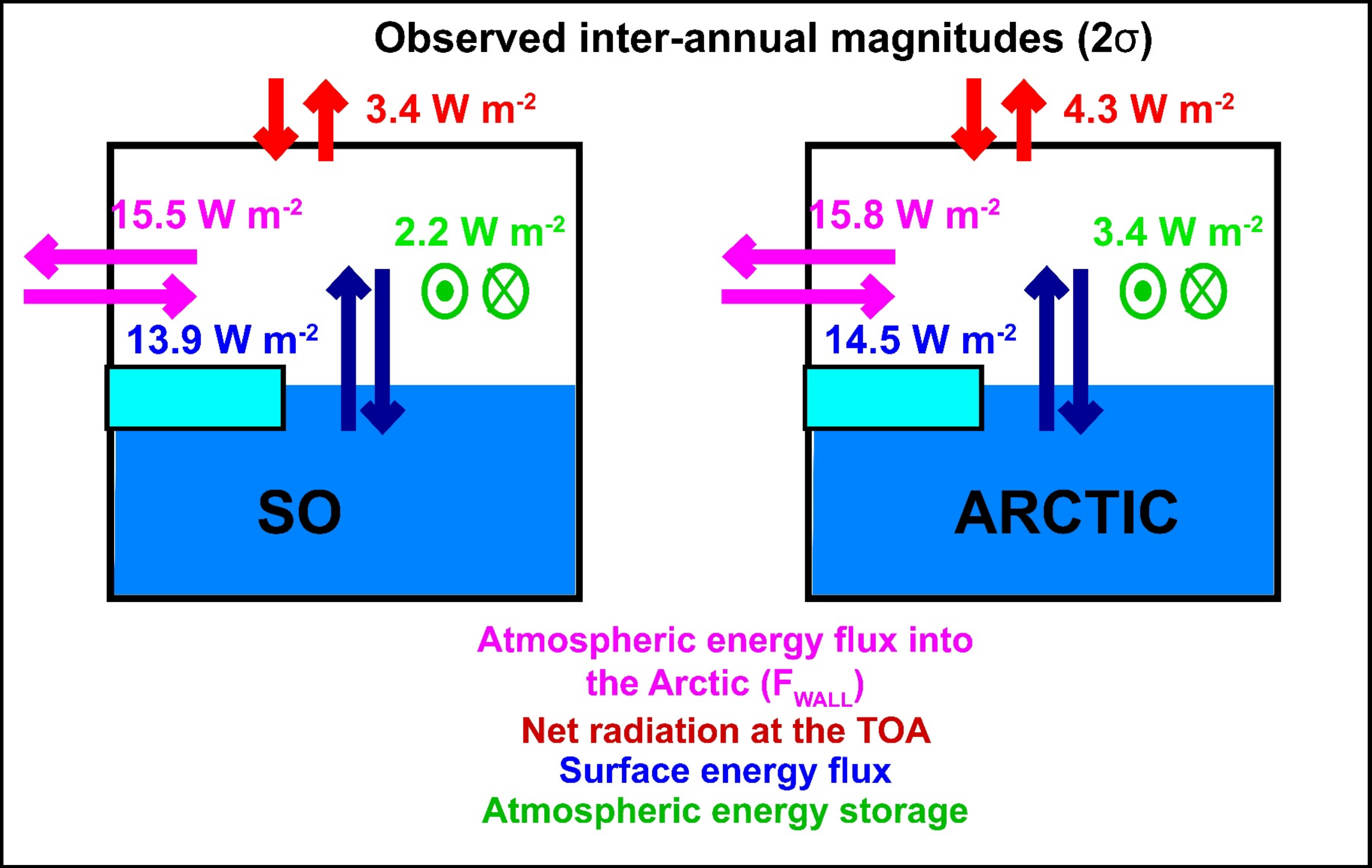
→ Can observations constrain the models that adequately represent the relevant physics?

Observed Interannual Variability of SO Energy budget



Shown is the magnitude of month-to-month variability of energy fluxes into the Southern Ocean (poleward of 60N) over the 2000-2017 period from the following sources:

- F_{WALL} is from NCEP and ERA reanalysis (V, T, Q and Z)
- TOA radiation from CERES EBAF
- Atmospheric energy storage from NCEP and ERA reanalysis
- Surface fluxes from the RESIDUAL of the atmospheric energy budget

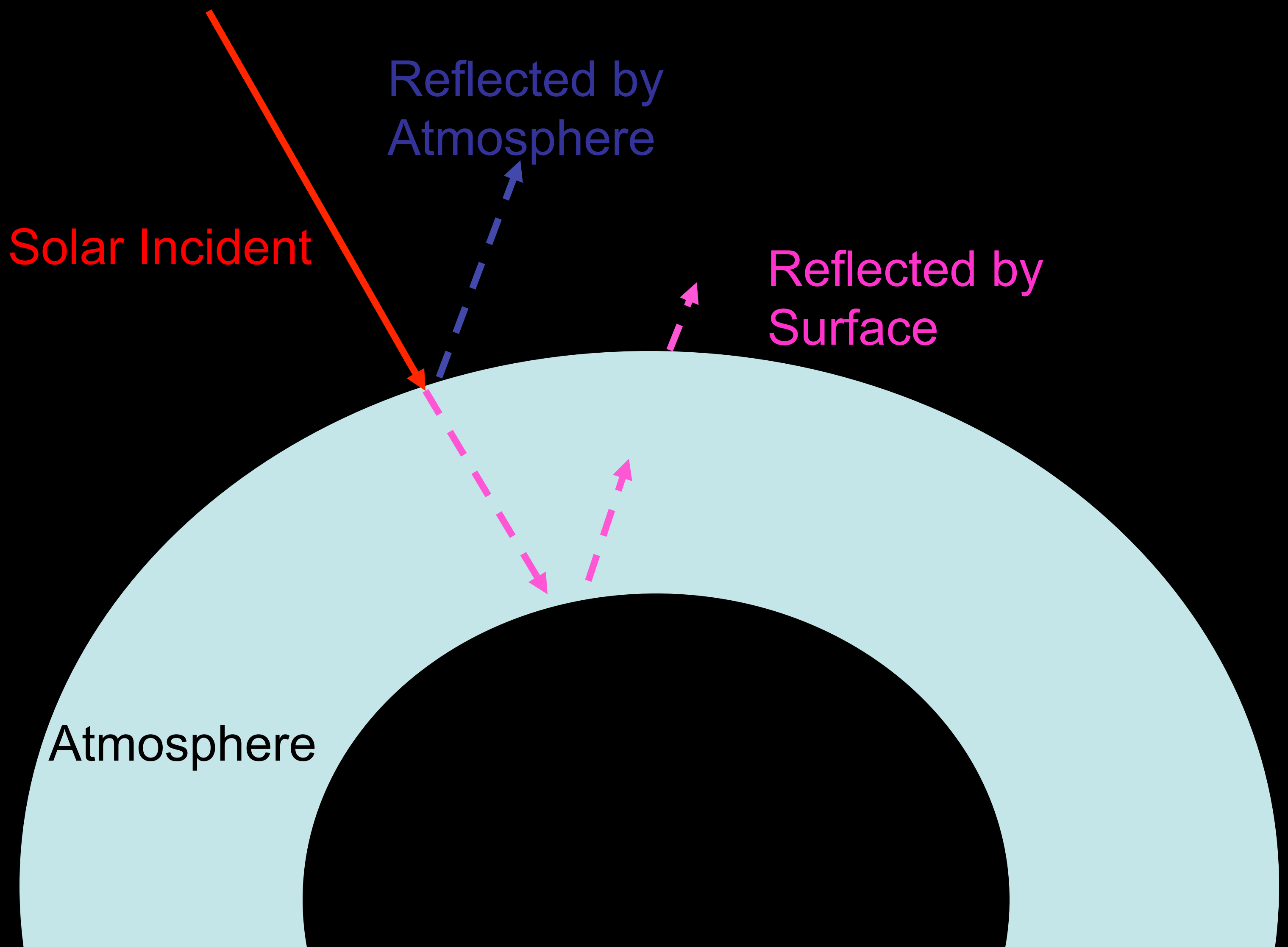


In both the SO and Arctic, radiative variability is small compared to the variations in atmospheric energy fluxes into the region

→ Dominate balance between surface fluxes and lateral atmospheric energy flux (with unknown causality)

→ Atmospheric energy storage is non-negligible

How much solar radiation does sea ice reflect?



Simplified (isotropic) shortwave radiation model

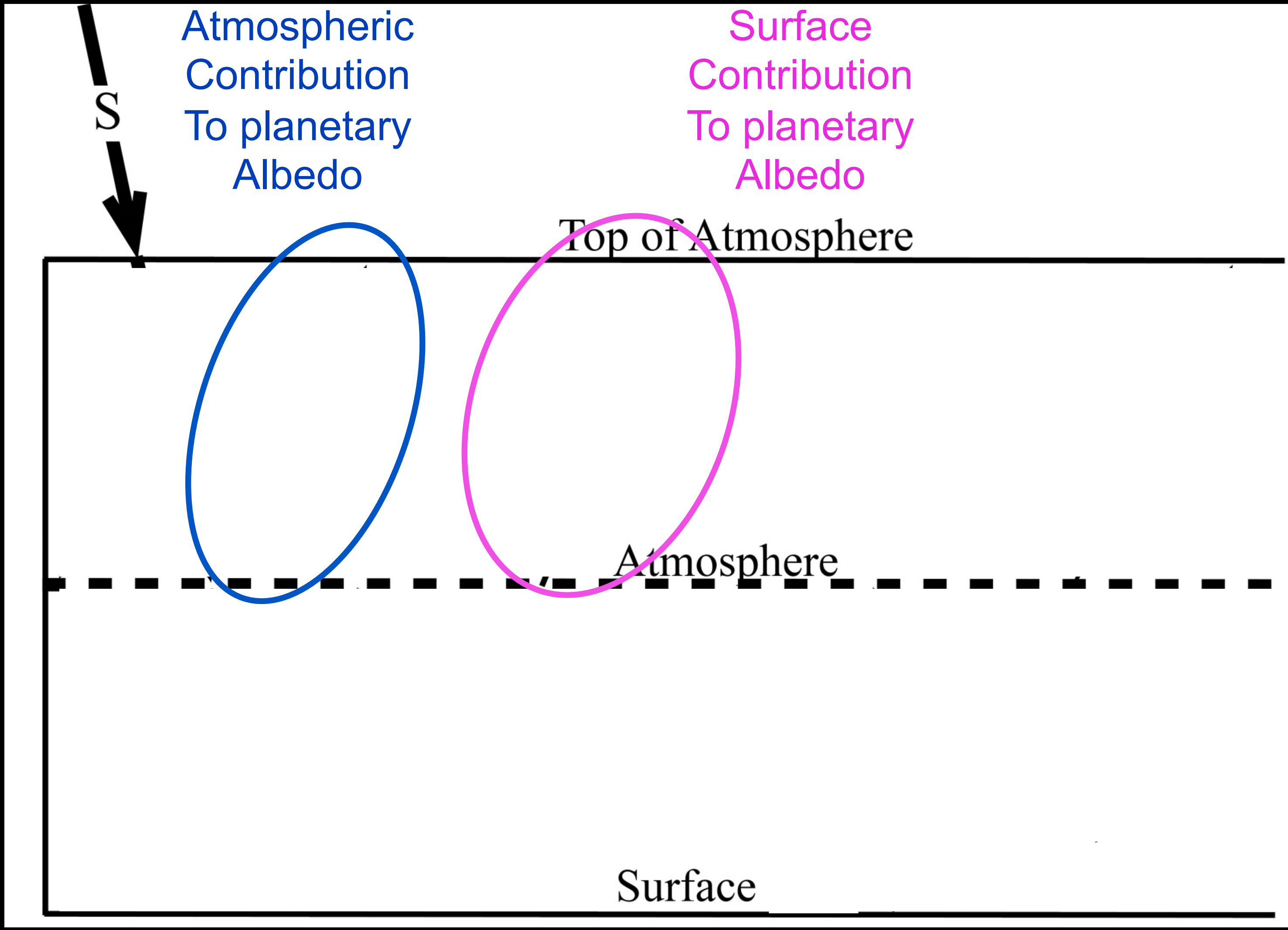
S = incident

R = cloud reflection

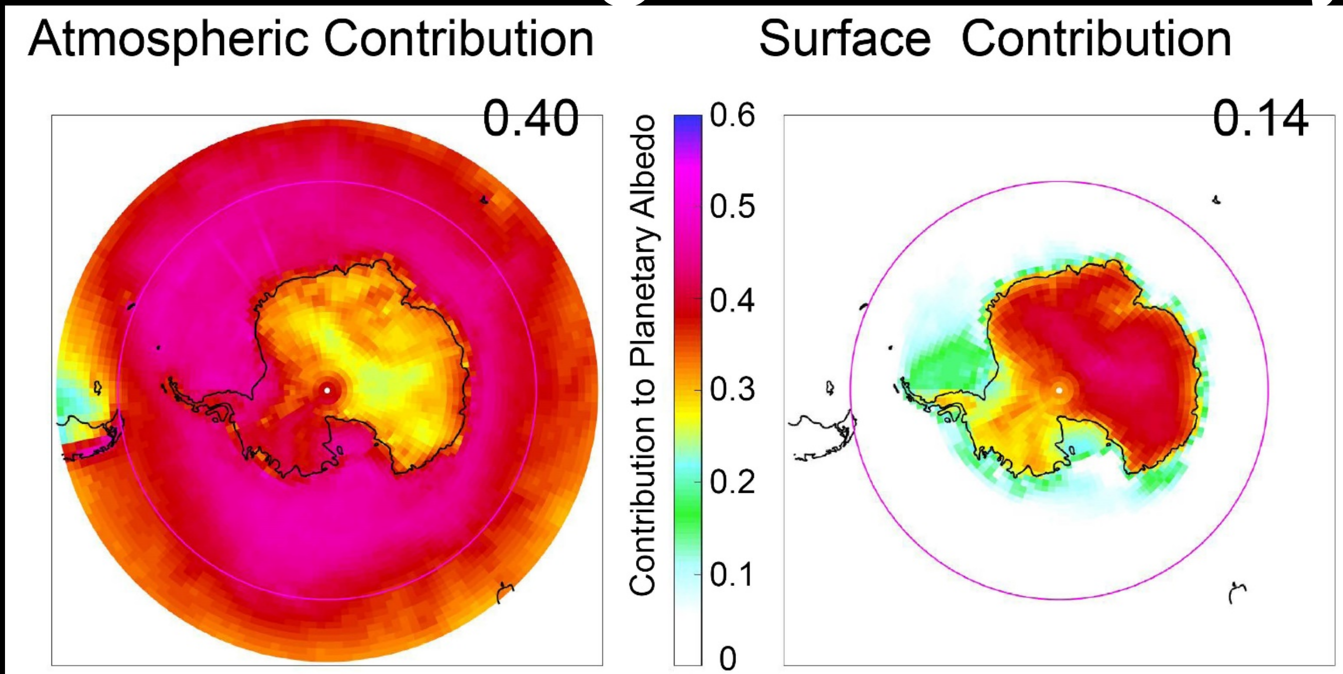
A = absorption

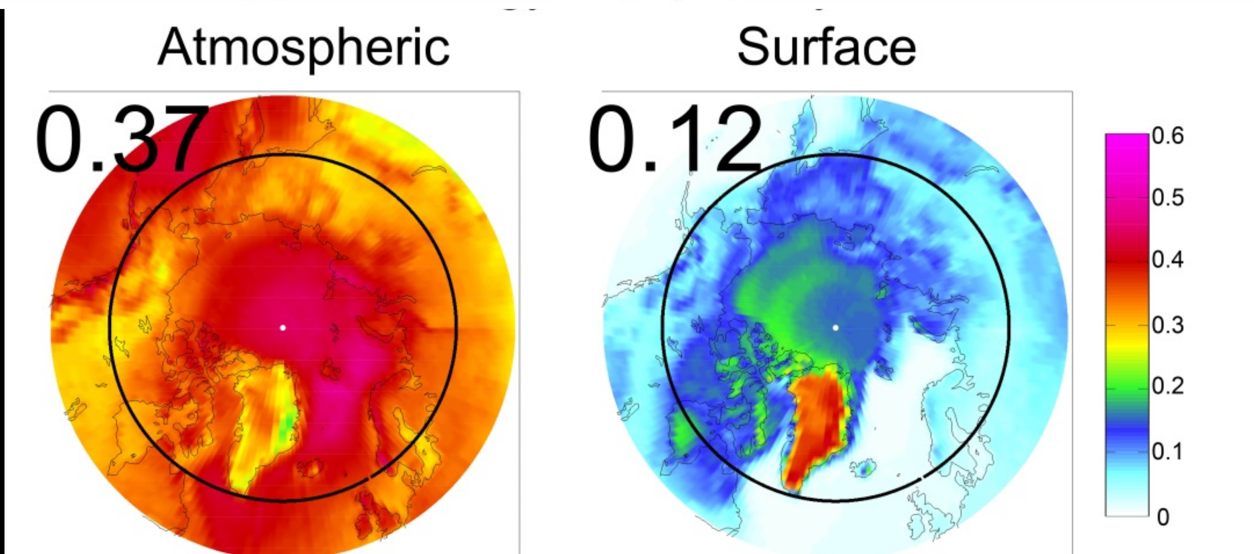
α = surface albedo

(UNKNOWNS)

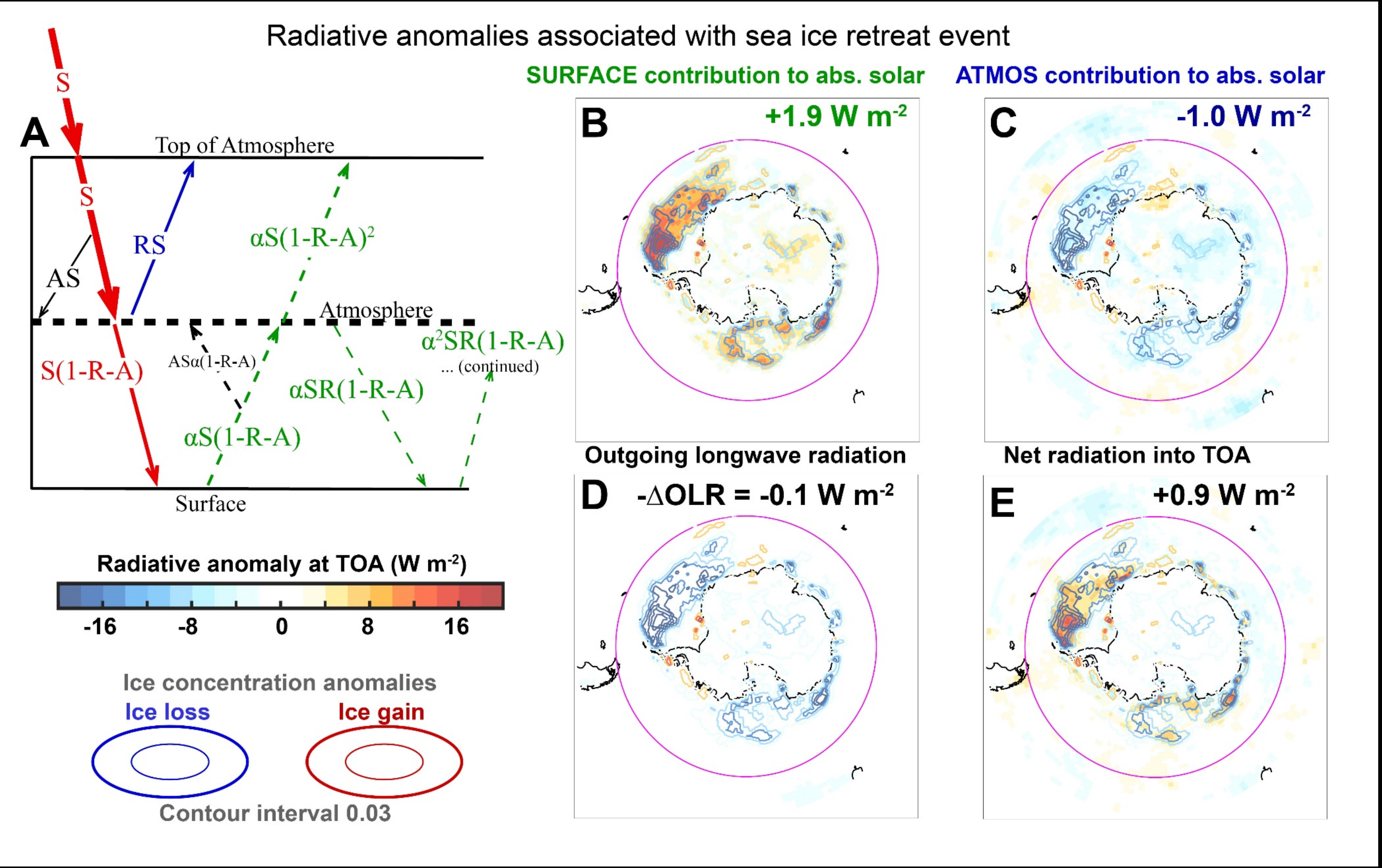


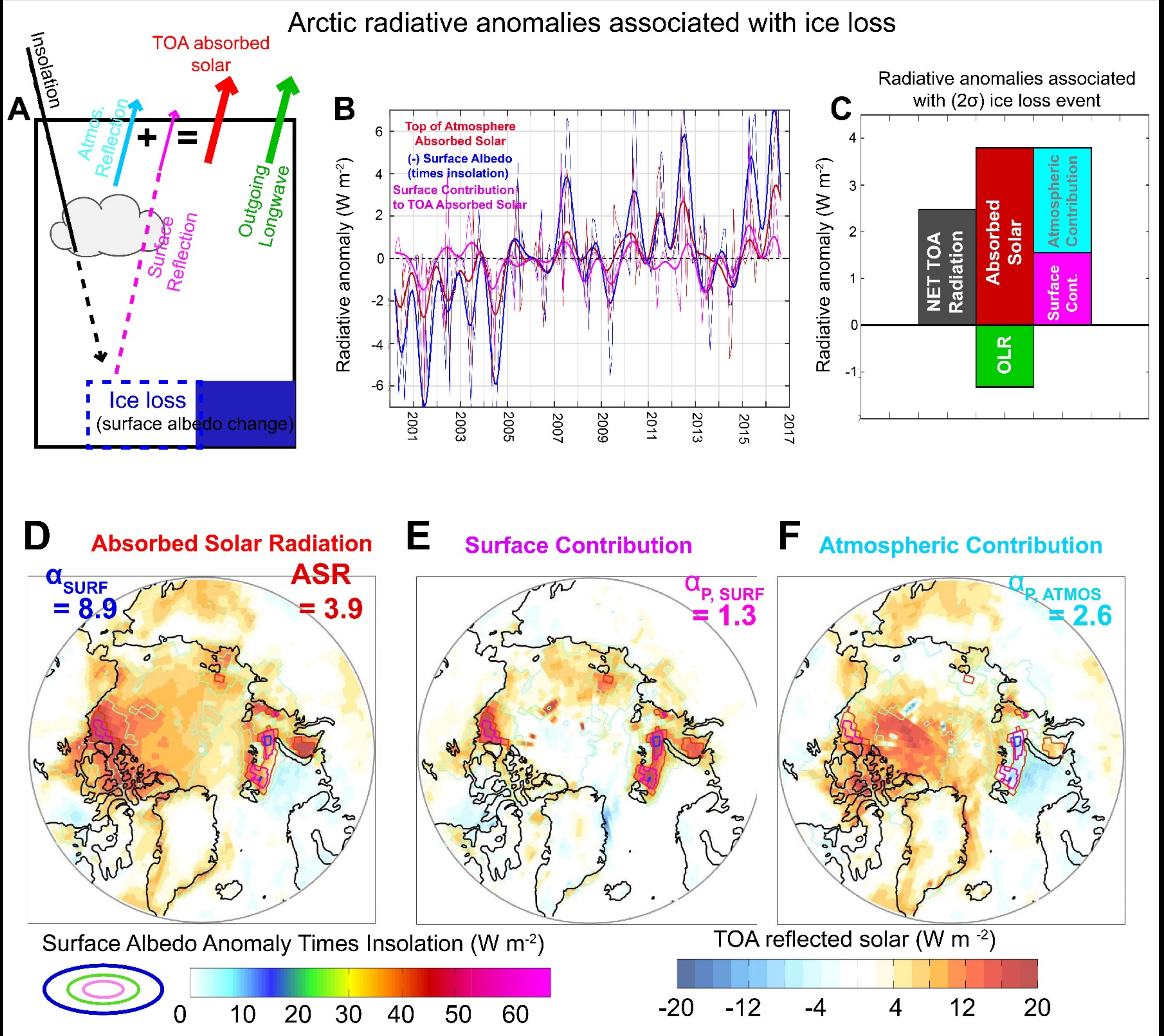
Climatological Planetary Albedo





Radiation Associated with SO ice loss





Arctic radiative anomalies associated with ice loss
A
Insolation
TOA absorbed solar
Atmos. Reflection
+
=
Outgoing Longwave
Surface Reflection
Ice loss
(surface albedo change)
B
Top of Atmosphere Absorbed Solar
(-) Surface Albedo (times insolation)
Surface Contribution to TOA Absorbed Solar
Radiative anomaly (W m-2)
C
Radiative anomalies associated with (2σ) ice loss event
NET TOA Radiation
Absorbed Solar
Atmospheric Contribution
Surface Cont.
OLR
Radiative anomaly (W m-2)
D
Absorbed Solar Radiation
αSURF = 8.9
ASR = 3.9
E
Surface Contribution
αP, SURF = 1.3
F
Atmospheric Contribution
αP, ATMOS = 2.6
Surface Albedo Anomaly Times Insolation (W m-2)
TOA reflected solar (W m -2)

F WALL

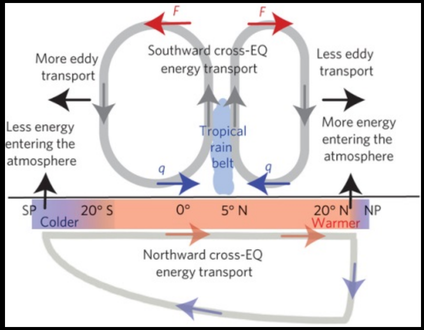
$$AHT(\phi) = -\frac{2\pi a\cos(\phi)}{g}\int_{p_s}^{0} \underbrace{[\bar{V}][\overline{MSE}]}_{MOC} + \underbrace{\overline{[V]'[MSE]'}}_{TOC} + \underbrace{[\overline{V^{*}MSE^{*}}]}_{Stat.eddy} + \underbrace{[\overline{V^{*\prime}MSE^{*\prime}}]}_{Trans.eddy}\, dp$$

* = Departure from zonal mean -- [ ]

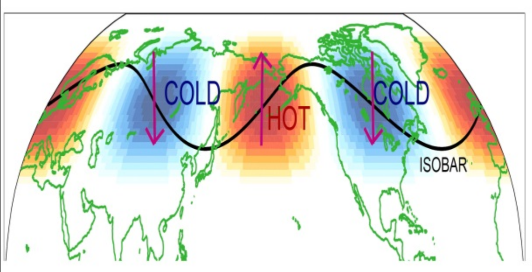
' = Departure from time mean -- ¯

MSE = moist static energy
= CpT + LQ +gZ

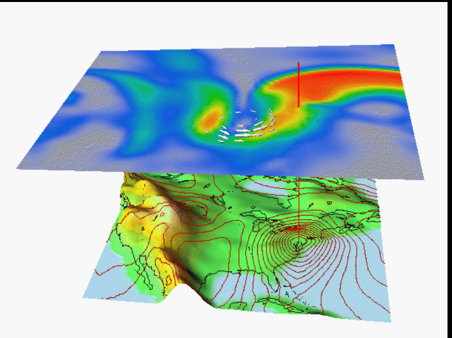
MOC
Overturning

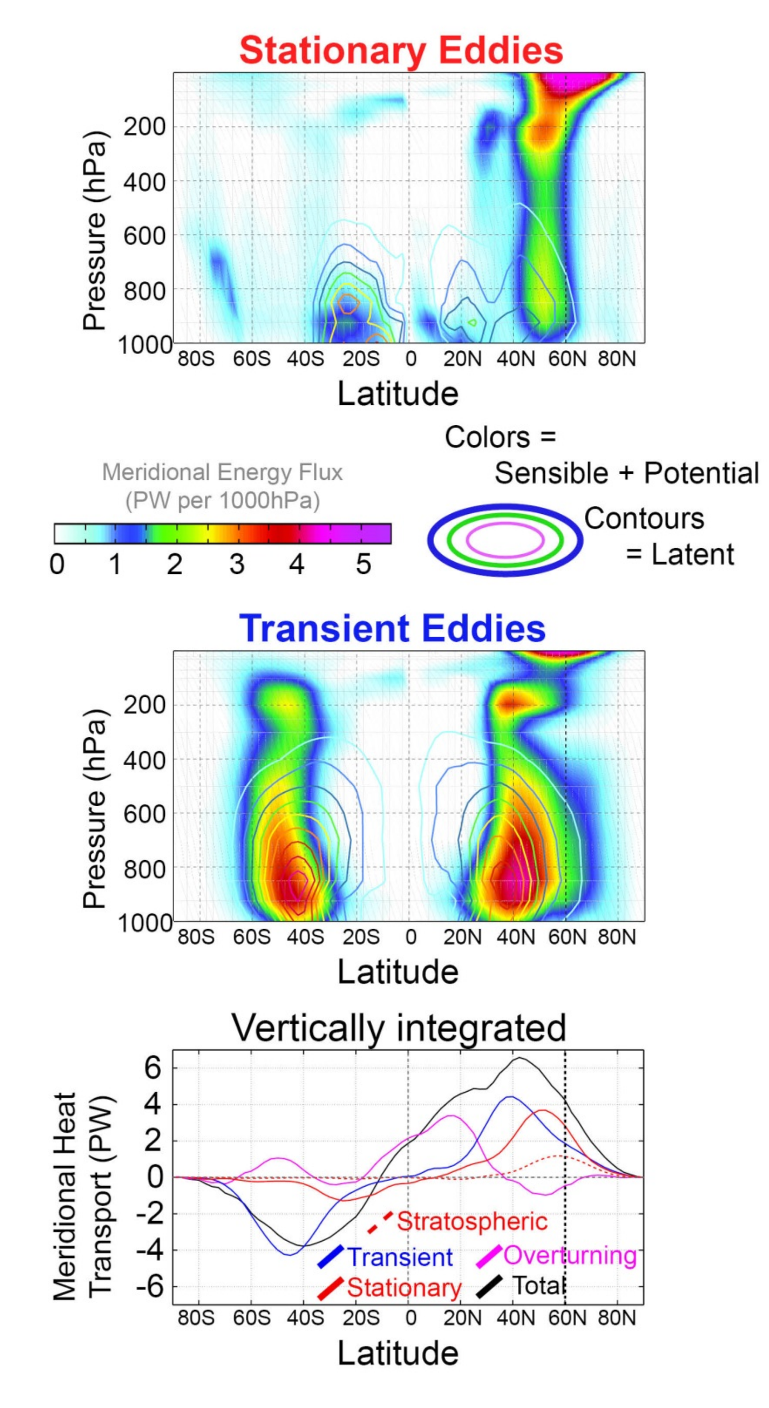


Stationary



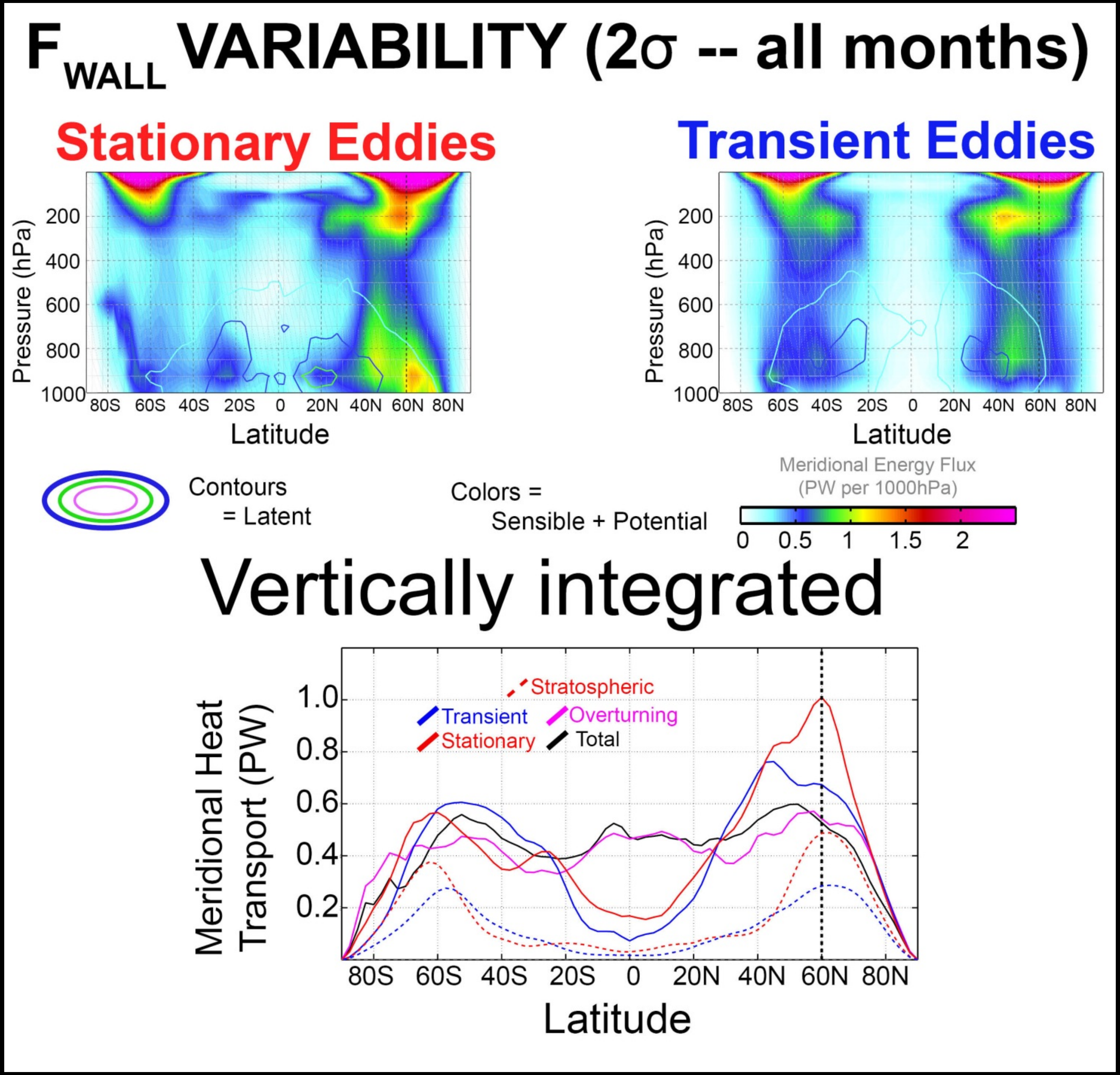
Transient



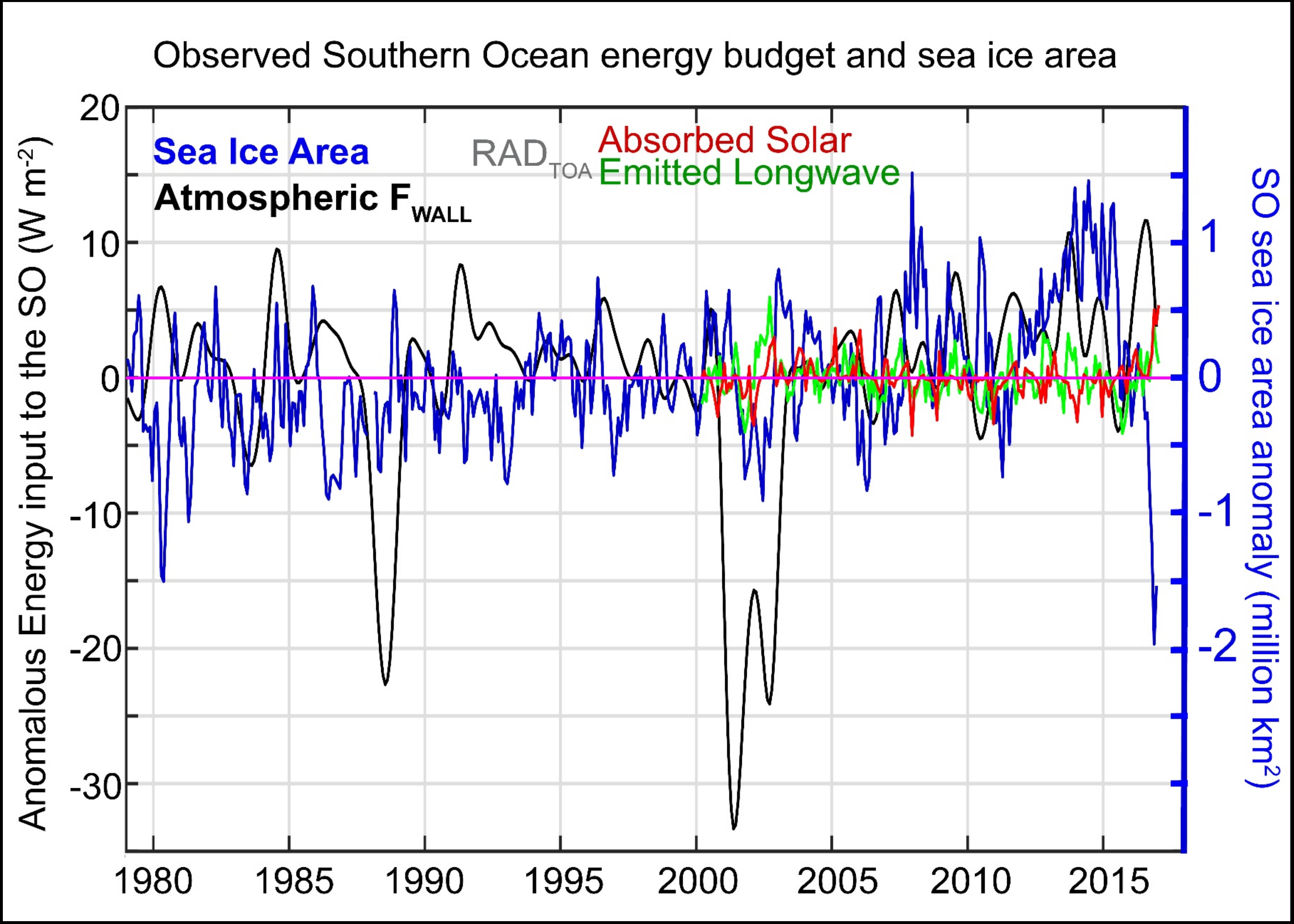


→Variability of energy transport is due to both stationary and transient eddies and is very large at high latitudes

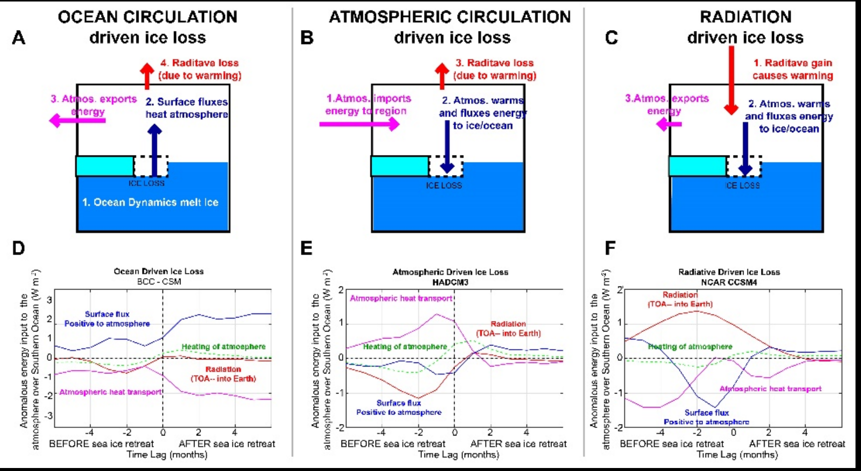
→Substantial signal in the upper atmosphere



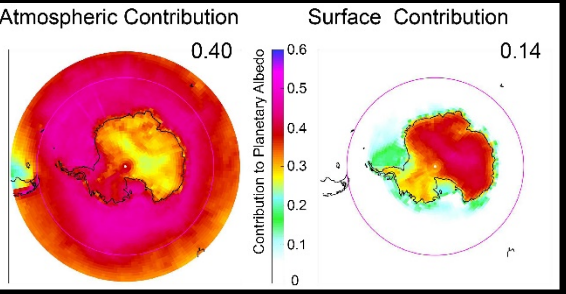
Attempt to relate energetics to sea ice variability



Conclusions



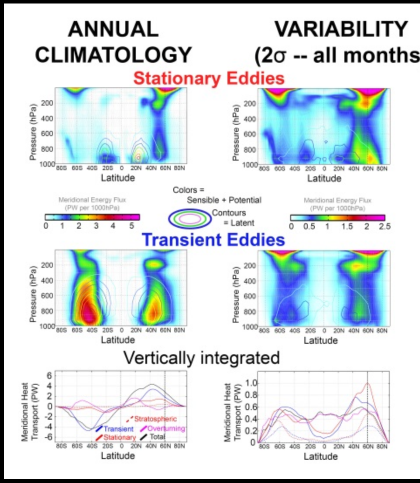
Radiative processes, oceanic processes, and atmospheric dynamics all contribute to Southern Ocean sea ice loss events in the diversity of CMIP5 climate models

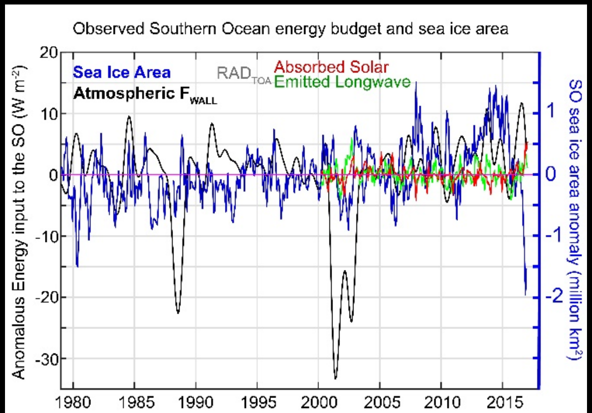


Observations suggest that:

→ FWALL into the polar latitudes is incredibly variable (14 W m^{-2})

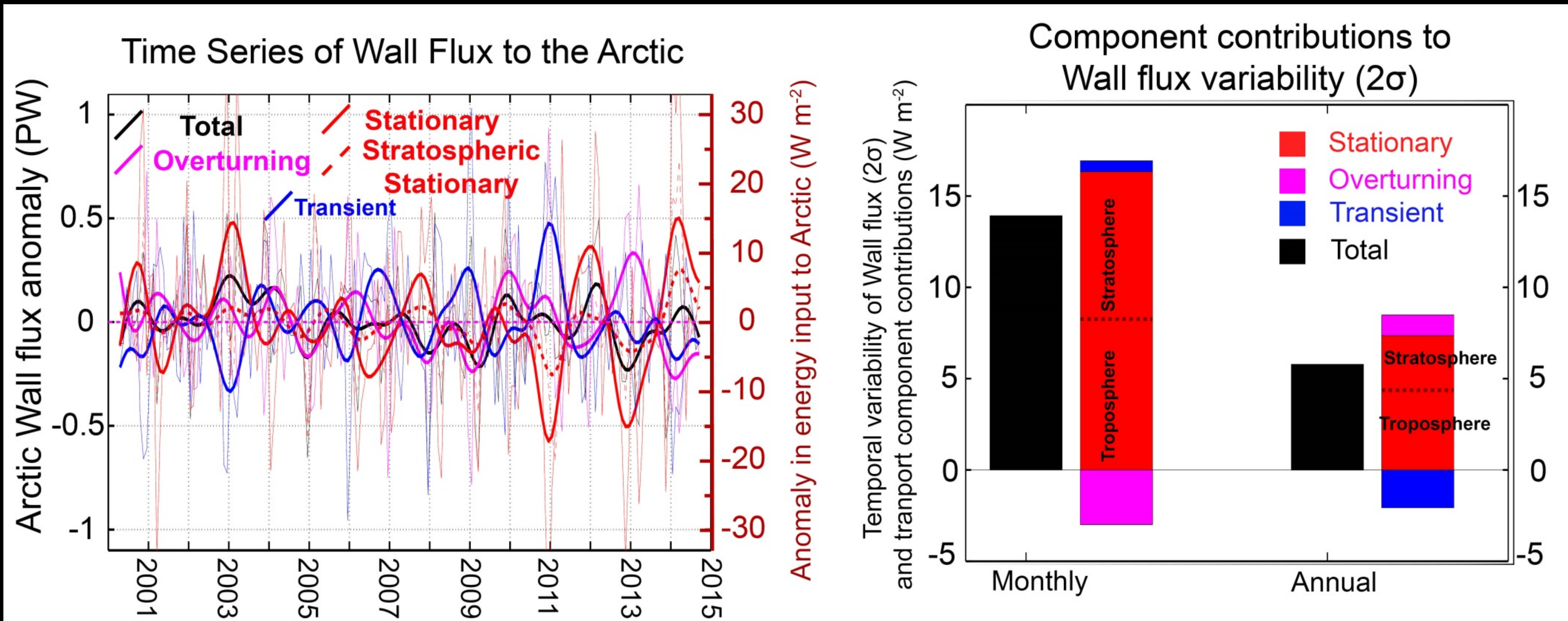
→ Radiative anomalies associated with ice loss are small because the atmosphere is opaque





There is no clear relationship between FWALL and sea ice extent in the observational record – In both hemispheres

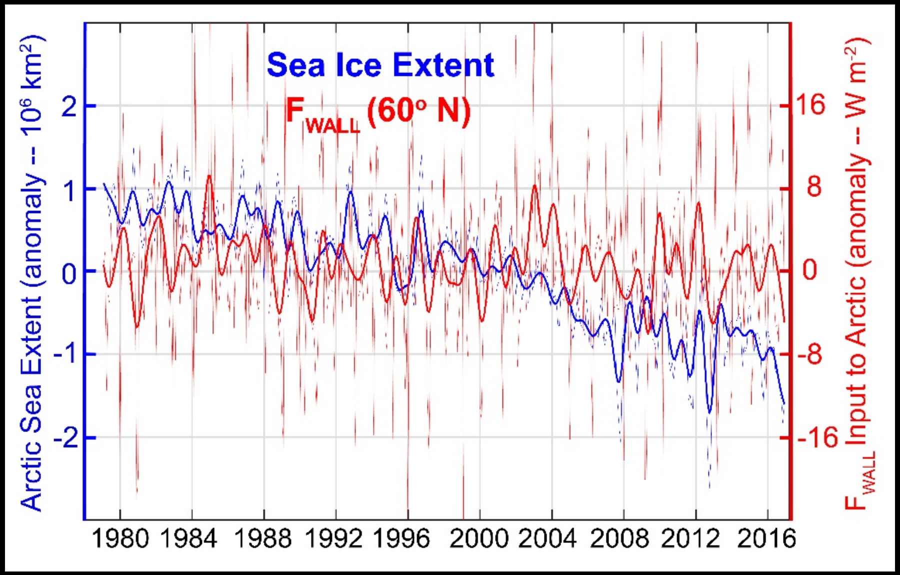
Extras



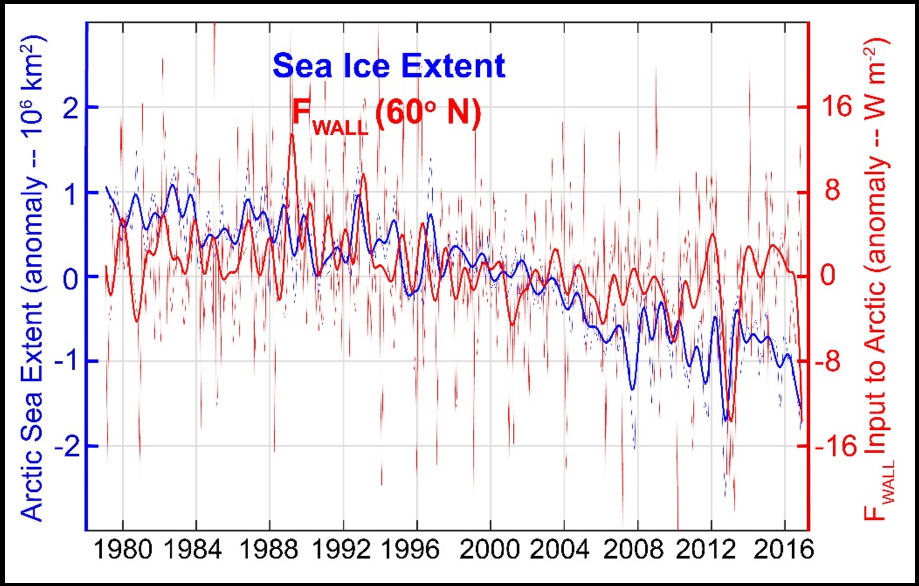
- Variability of Atmospheric energy flux into the Arctic is large
    - 6 W m^{-2} at the annual time scale, 12 W m^{-2} at the monthly time scale
- Primarily due to stationary waves and compensated by overturning (short timescale) and transient eddies (annual timescale)
    - Nearly equal contributions from the stratosphere and troposphere

F_{WALL} and sea ice extent

Full atmosphere

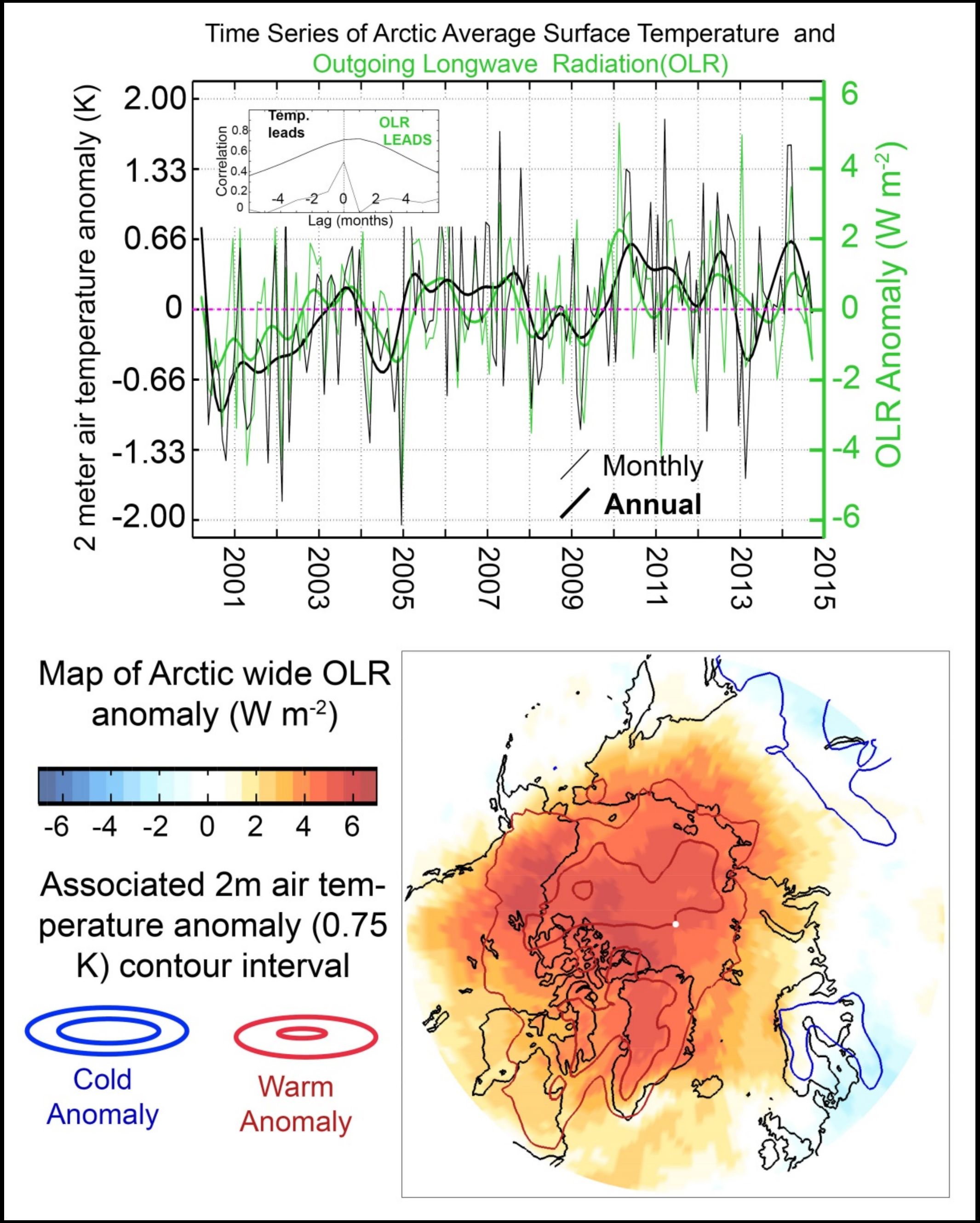


Troposphere only

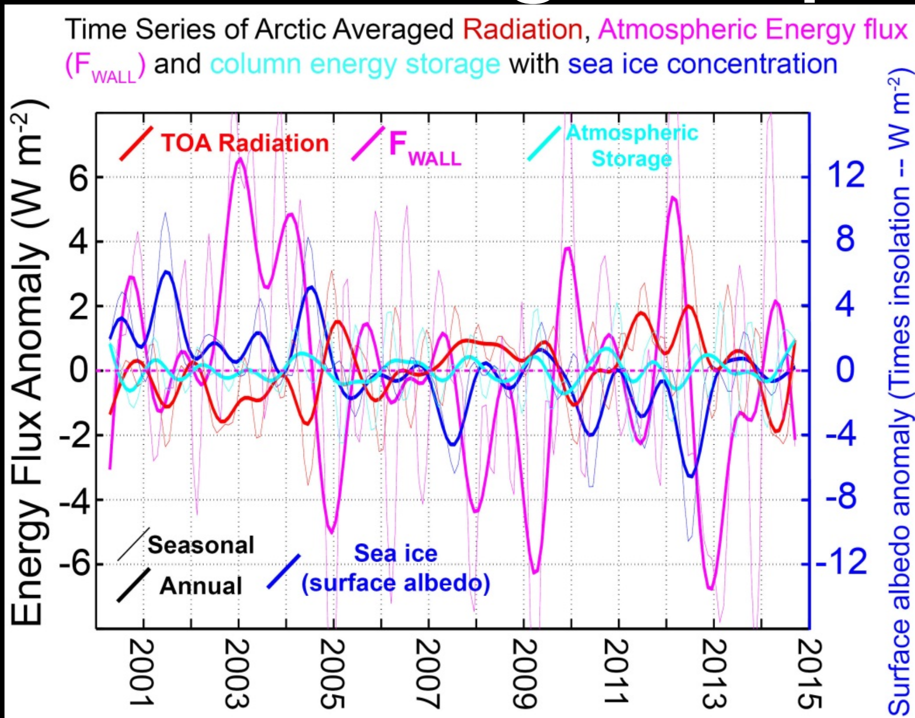


Arctic emits more OLR to space when the surface warms – basin wide

Consistent with a climate feedback parameter of 1.5 W m^{-2} K^{-1}



Putting the pieces together



Relative variances of terms in W m^{-2} per 2σ– annual (seasonal)

→ FWALL 5.7 (8.5)

→ RADIATION 1.8 (2.7)

→ TENDENCY 0.7 (1.8)

Hint that enhanced F_{WALL} precedes sea ice anomaly and decreases afterward