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HiLAT RASM

Understanding Radiative Feedbacks and Arctic Warming Trend in Recent Decades

Hailong Wang

Rudong Zhang, Qiang Fu, Philip Rasch

DOE RGMA program, HiLAT-RASM project

U.S. DEPARTMENT OF ENERGY BATTELLE

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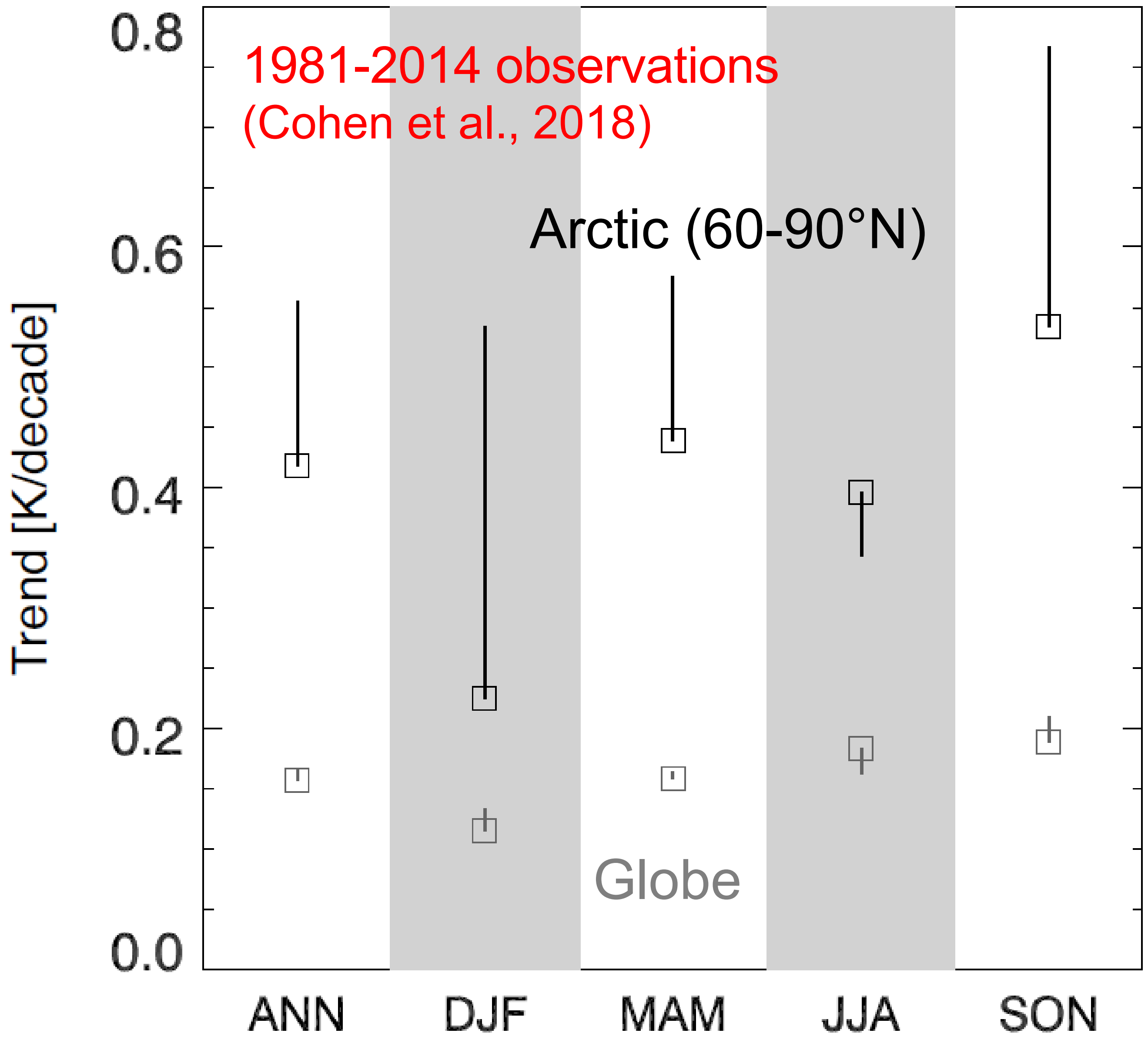
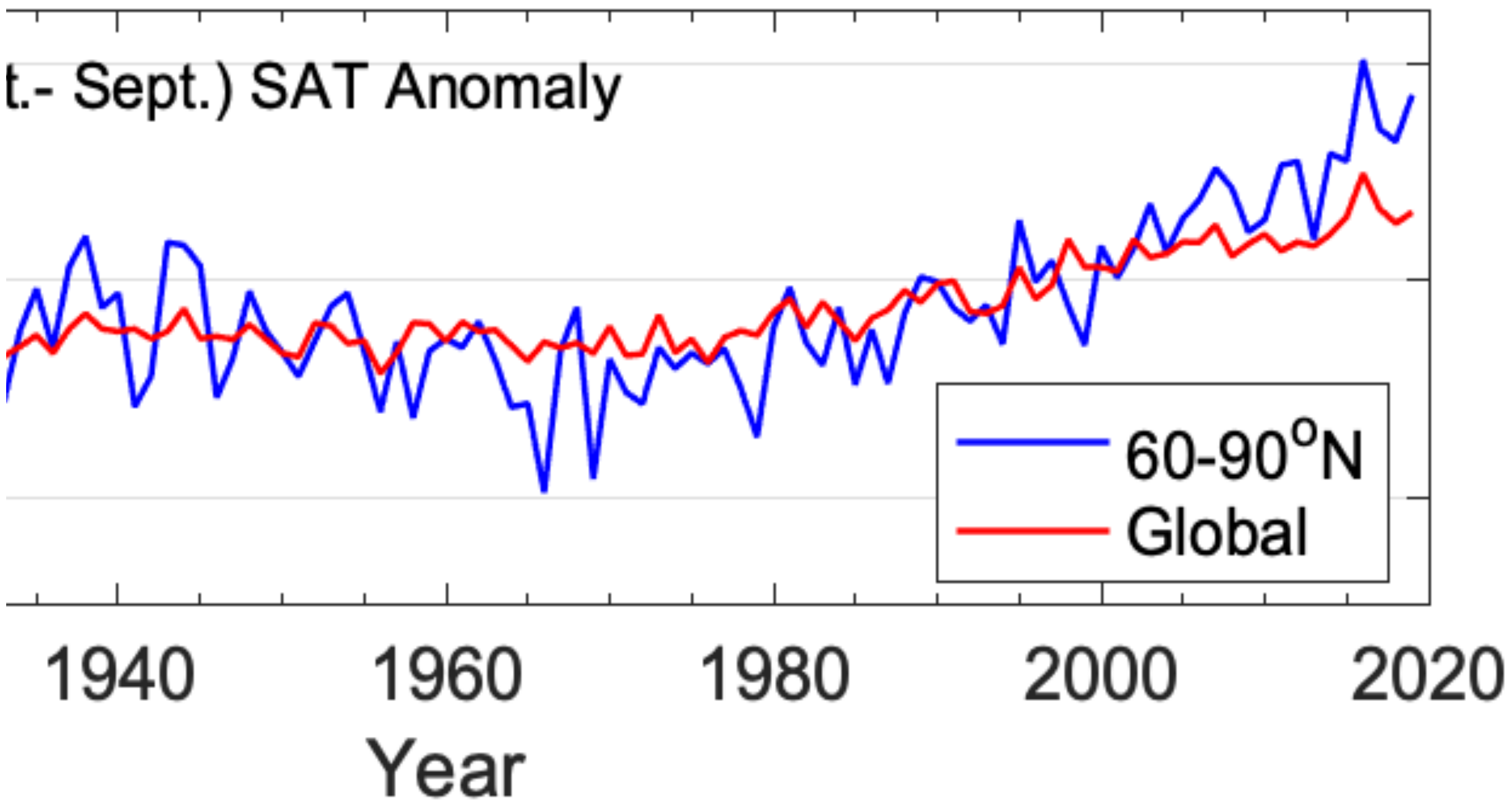


ning and amplification

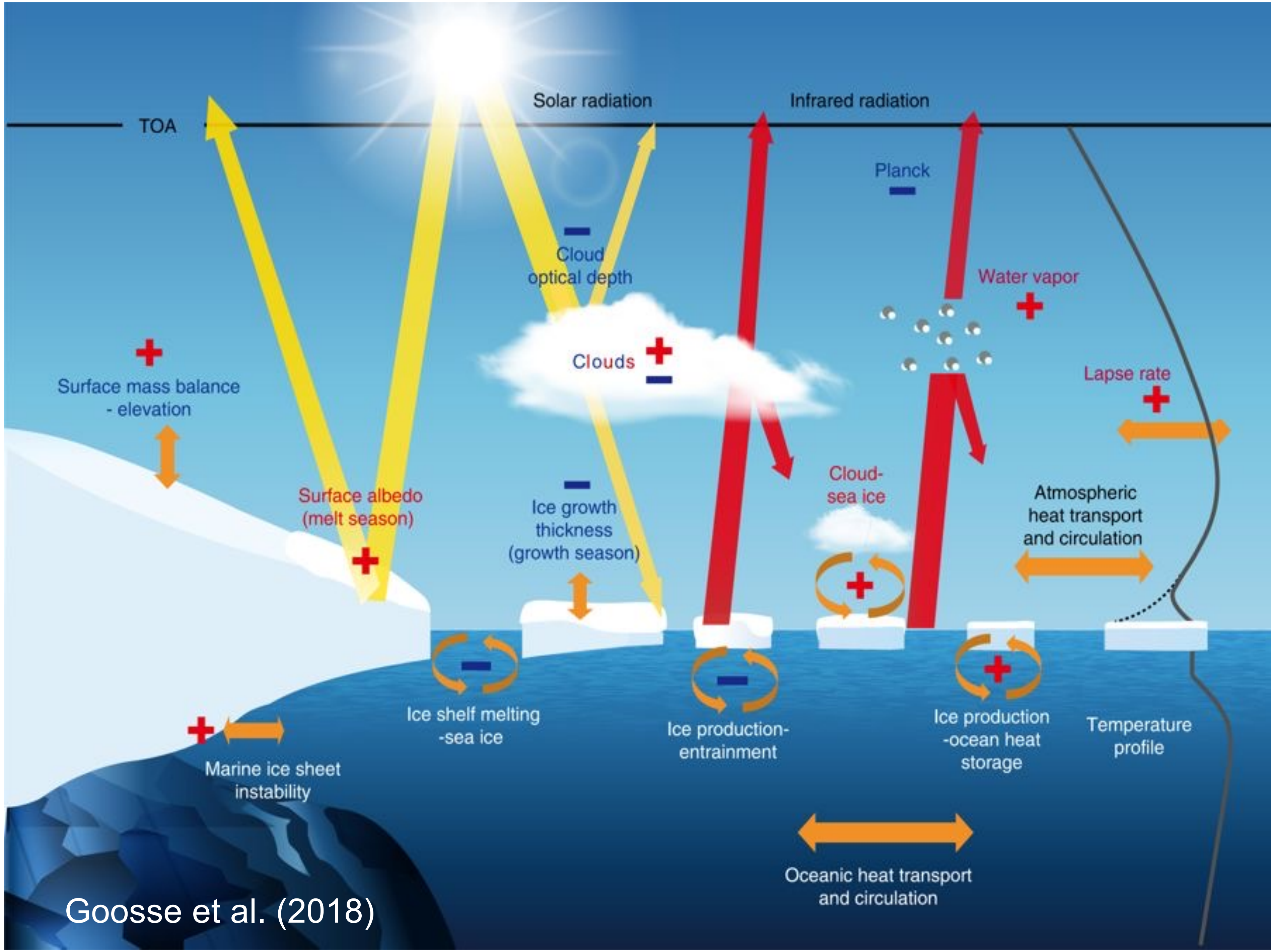
(Overland et al. 2019)



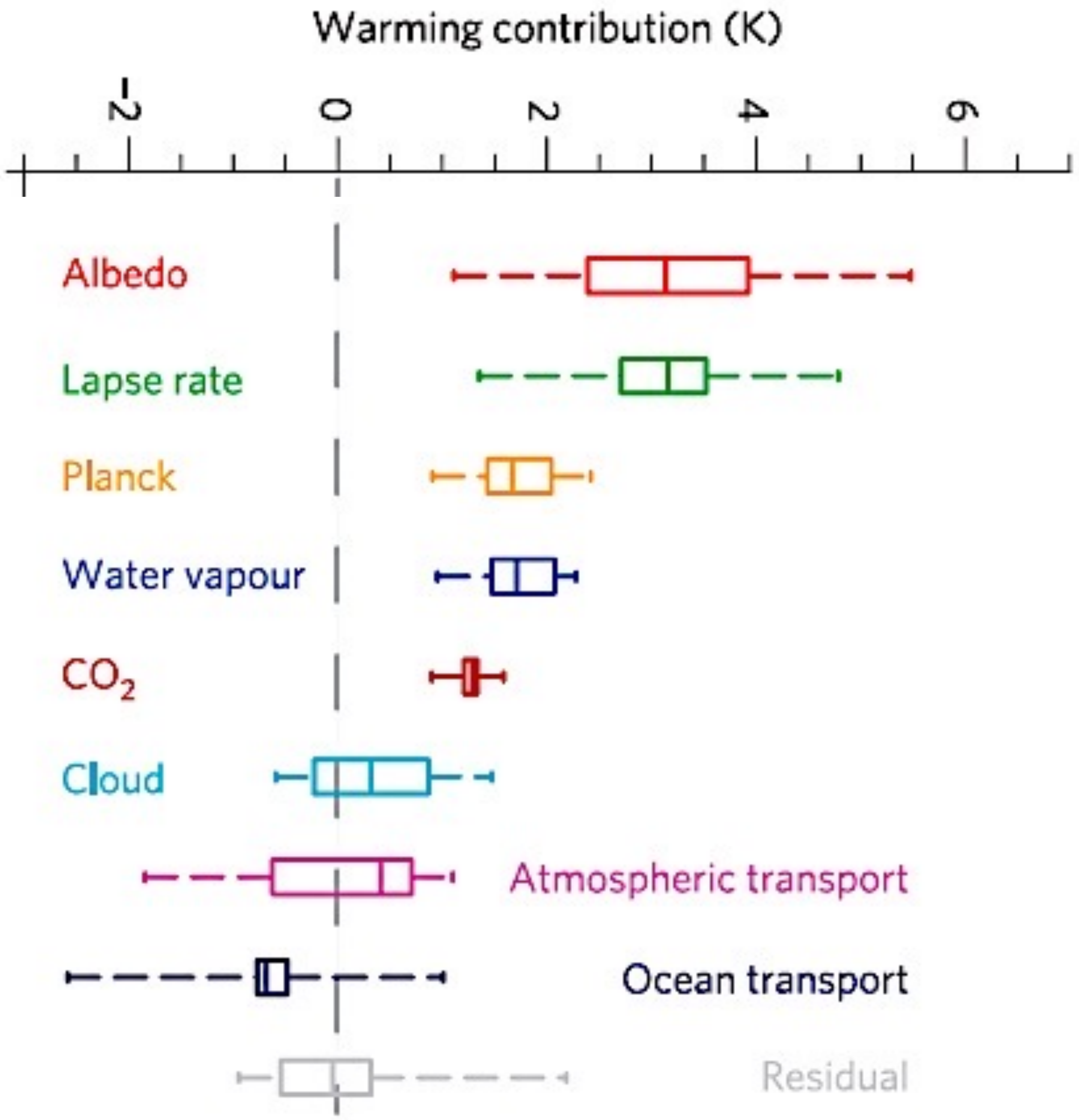
- Land stations for 60-90°N; SAT anomaly relative to 1981-2010 mean
- The Arctic has now warmed more than twice as much as the globe—a phenomenon known as Arctic amplification

Causes of Arctic warming and/or amplification

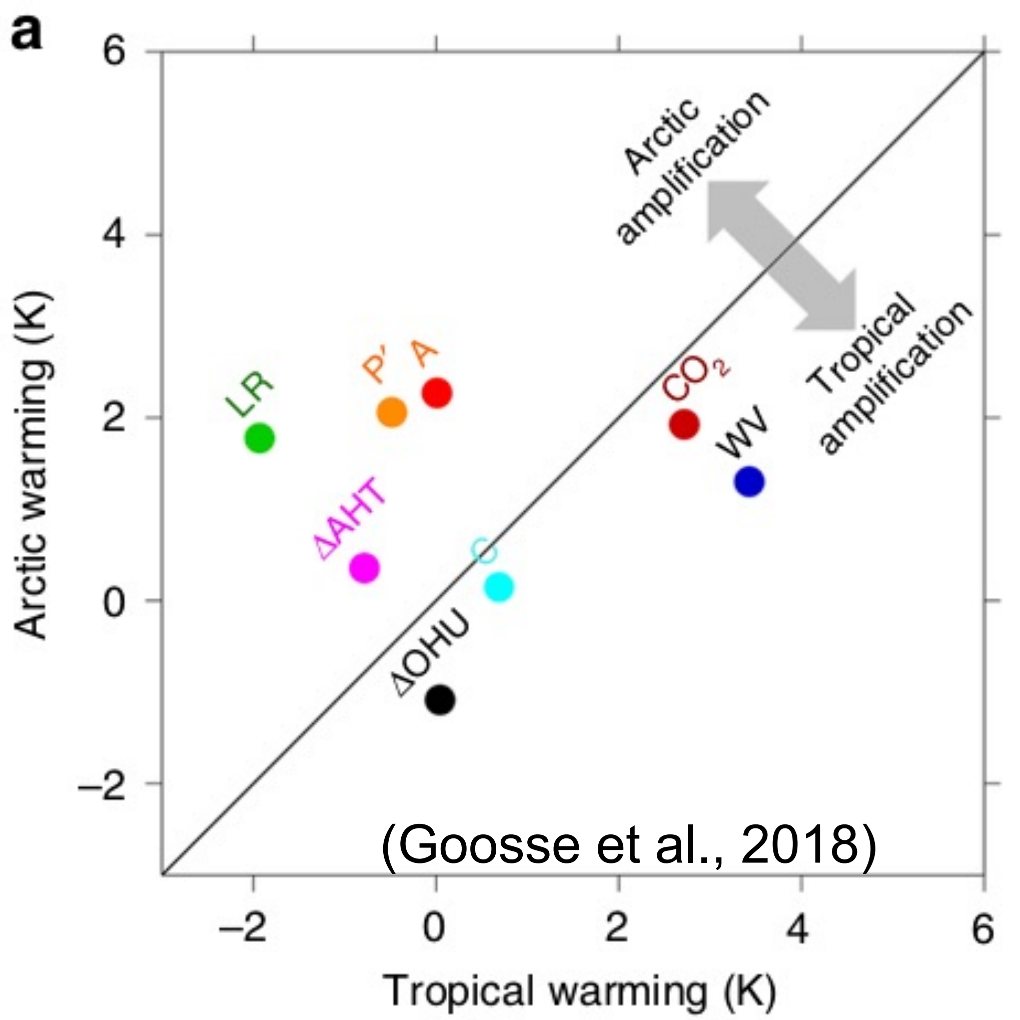
- Radiative feedbacks
  - Reduced surface albedo
  - Increase of water vapor and clouds
  - Lapse rate feedback
  - Planck feedback
- Poleward energy transport
- Changes in aerosols



Quantitative importance of warming factors (CMIP5)



(Pithan and Mauritsen, 2014)



(Goosse et al., 2018)

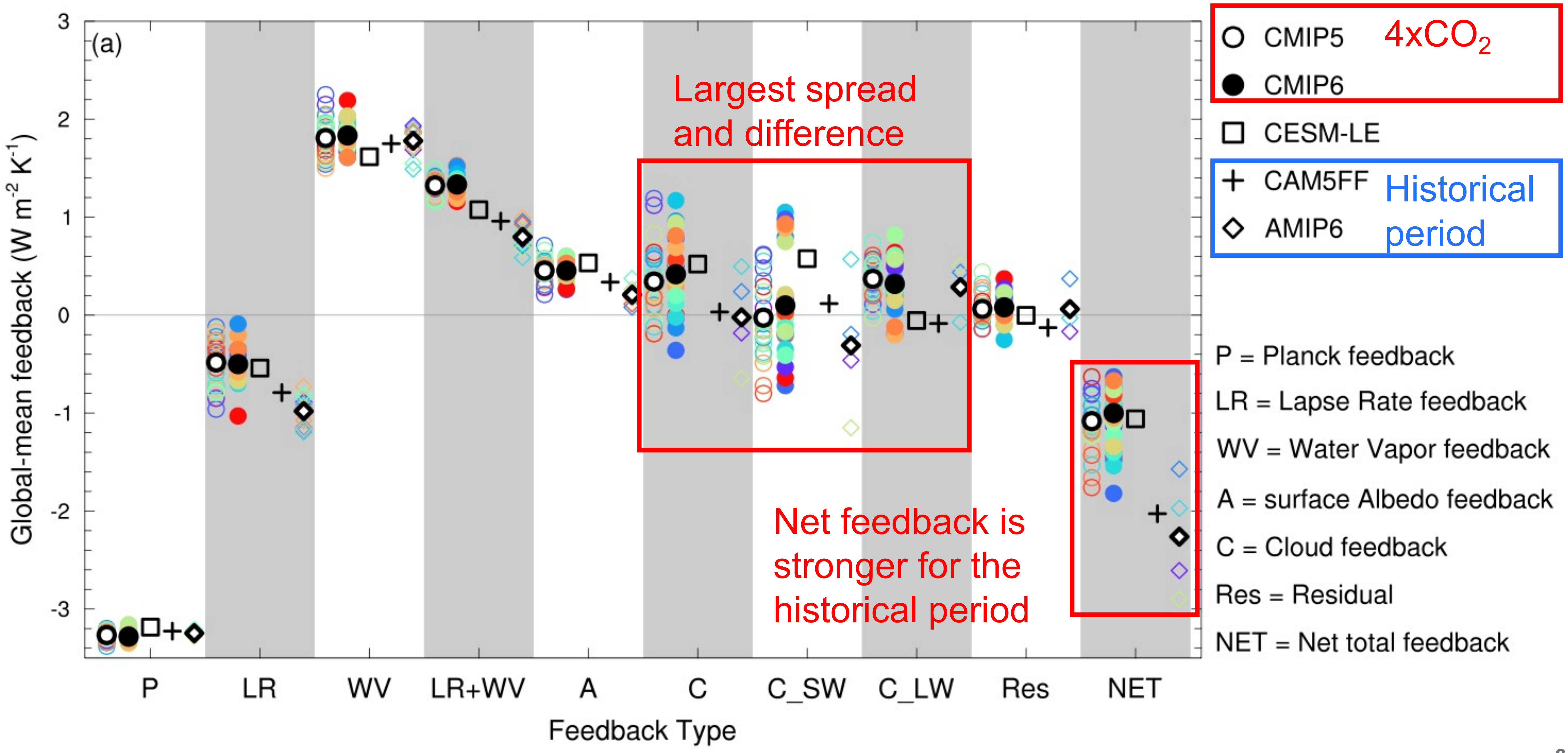
Contributions to Arctic warming by feedback and transport processes in CMIP5 4×CO_2 experiments

Model and data used for Arctic feedback quantification

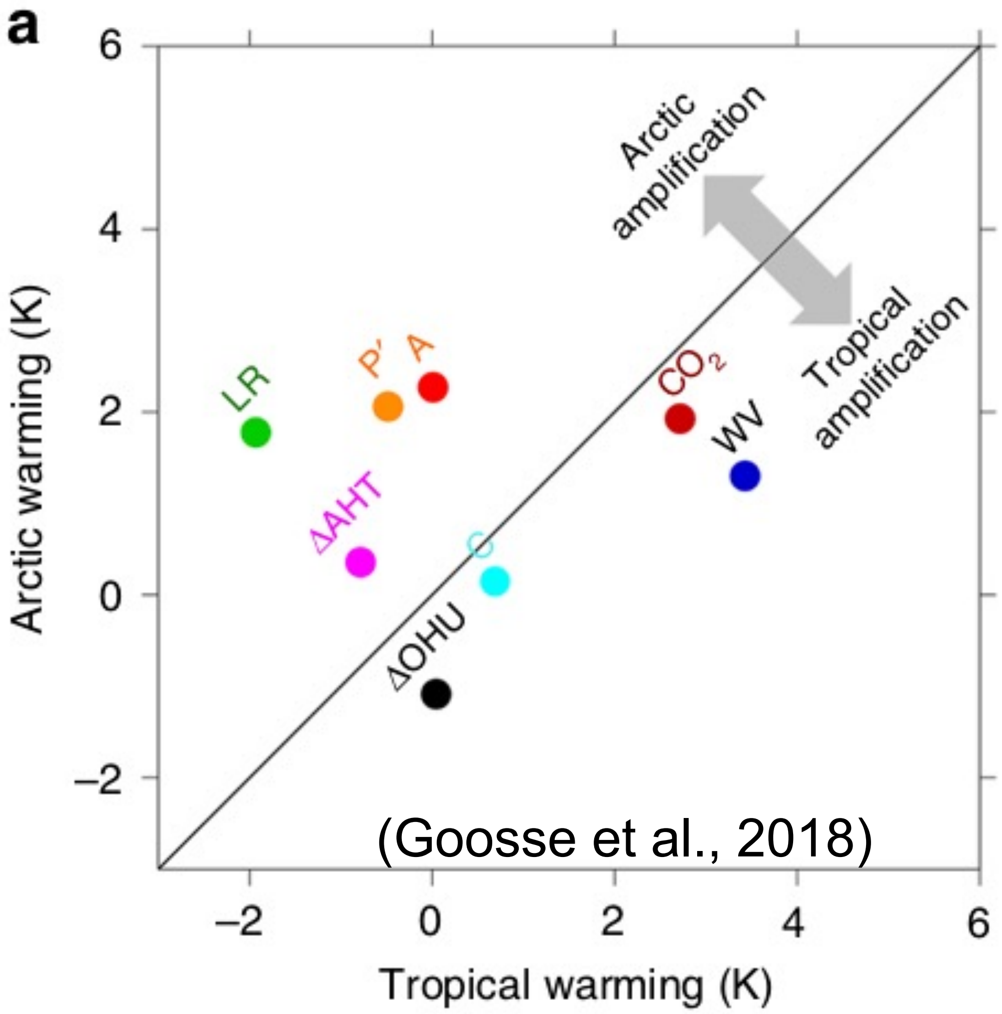
- Model simulation using CAM5
  - 1979, 1980−2017
  - 0.9°×1.25° horizontal grid; 30 vertical layers
  - Prescribed SST and sea ice; nudged wind (u, v)
  - **Fixed forcing at the year-2000 levels** (CAM5FF)
- Available AMIP6 models (1980−2014)
  - *piClim-control*: 30 years with constant preindustrial forcing agents
  - *piClim-histall*: transient simulation with time-varying forcing agents
- Other data sets
  - CMIP5/6 model results for comparison
  - Radiative kernels based on CESM Large Ensemble Simulations

(Zhang et al., 2020)

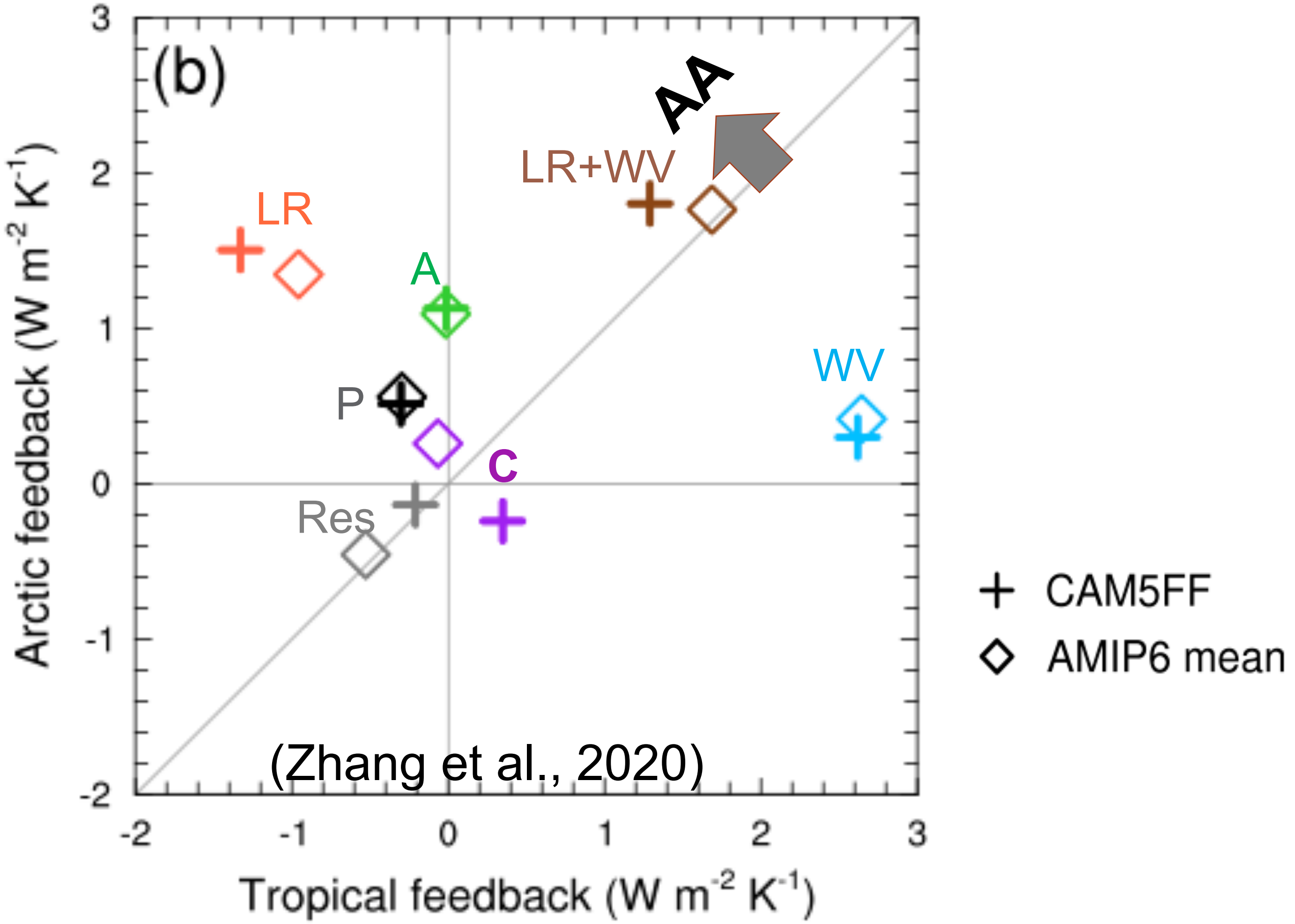
Comparison of global mean feedbacks between CMIP5/6 and recent historical simulations



Lapse rate, Planck and surface albedo feedbacks are top factors contributing to AA



Contributions to Arctic warming by feedback and transport processes in CMIP5 4×CO_2 experiments



- Lapse rate, albedo and Planck feedback deviation are major contributors to AA in the recent decades
- Arctic **cloud feedback** is negative in CAM5FF but positive in AMIP6 (and CMIP5) ***ensemble mean***

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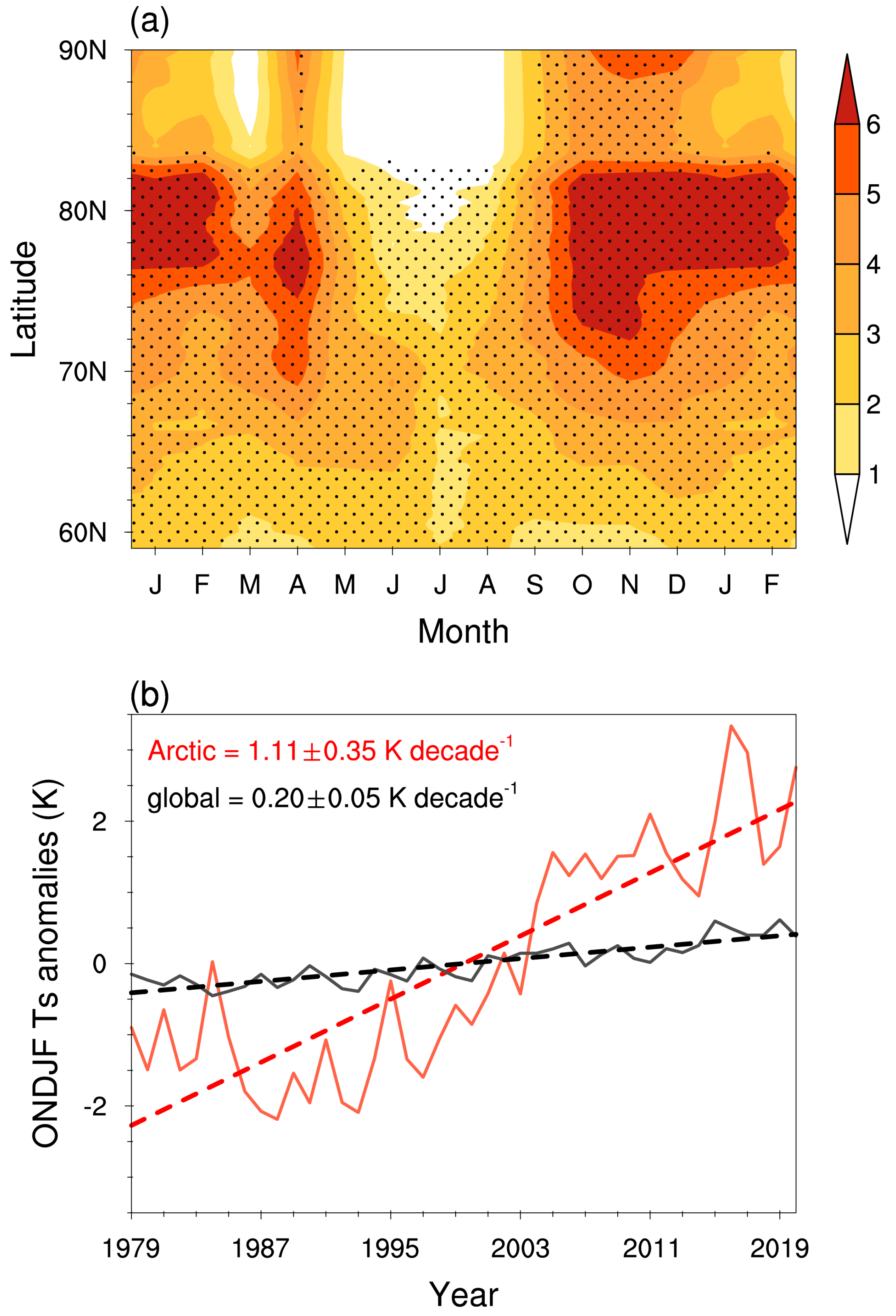
Strong cold season amplified Arctic warming

- AA is a distinct feature all over the NH high latitudes, especially in the cold season (ONDJF) over ocean/ice areas
- The trend over 70-90N is over five times higher than global mean during ONDJF (1979-2020)
- What contributes to this amplified warming trend?

(Zhang et al., 2021)



Data and Methodology

- ERA5 reanalysis gridded data
  - January 1979 to February 2021
  - 0.25° x 0.25° horizontal resolution and 37 pressure levels
- Surface energy budget equation $G = rsns + rlds - rlus - SH - LE$
  - Net absorption shortwave radiation: rsns
  - Downward longwave radiation: rlds (rldsclr + rldscld)
  - Upward longwave radiation: $rlus = \varepsilon\sigma T_s^4$
  - Sensible heat: SH
  - Latent heat: LE
  - Net gain underneath the surface through transport: G
- Surface radiative-kernel method $\Delta R_x = K_x \Delta x$
  - Contribution of T and Q to downward longwave radiation at the surface

(Zhang et al., 2021)

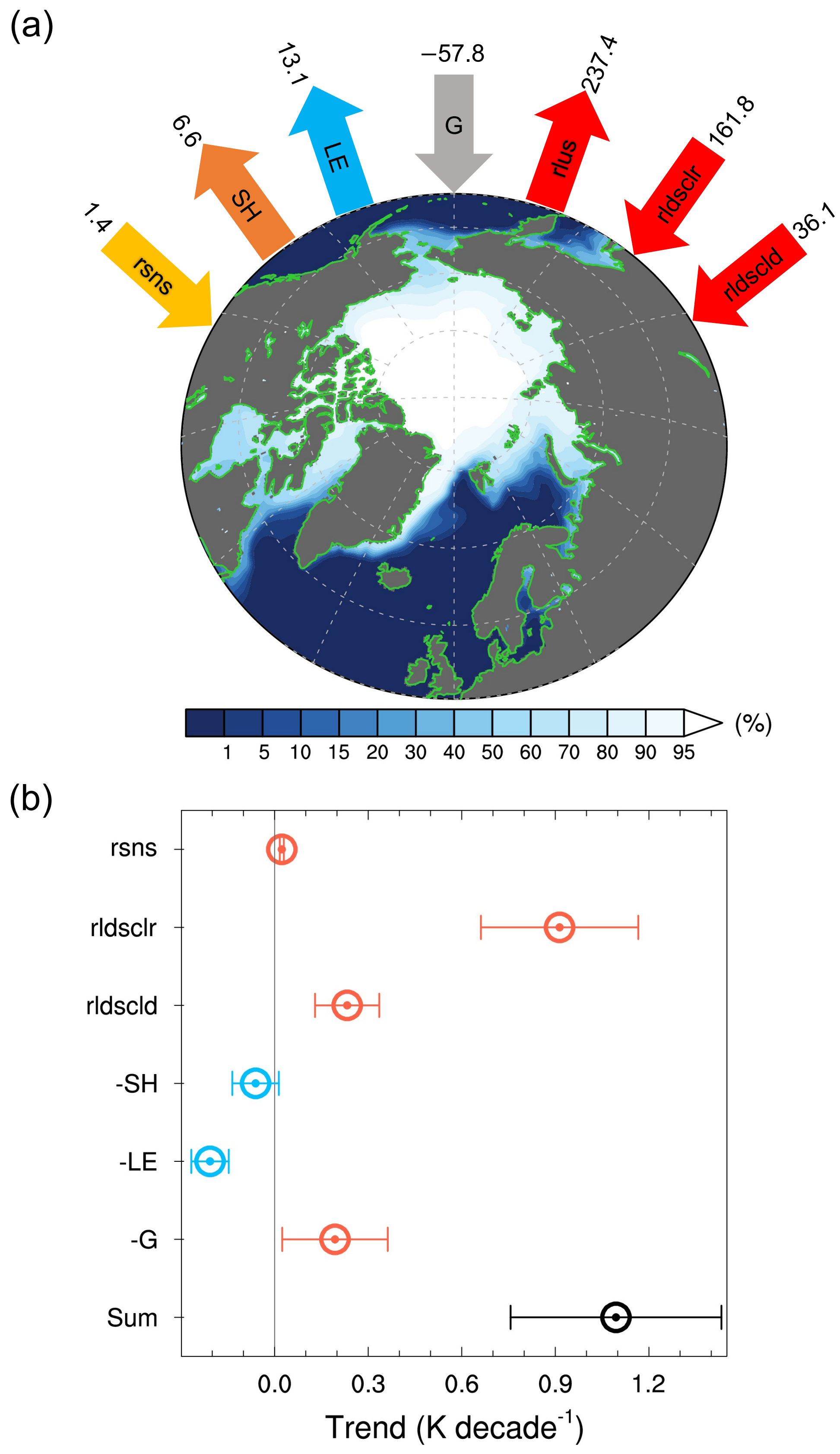
Source attribution of surface warming based on energy budget

$$G = rsns + rlds - rlus - SH - LE$$

$$\frac{\Delta T_s}{\Delta t} = \frac{\Delta}{\Delta t}\left[\frac{rsns + rldsclr + rldscld - SH - LE - G}{4\sigma\overline{T_s}^3}\right] + \gamma$$

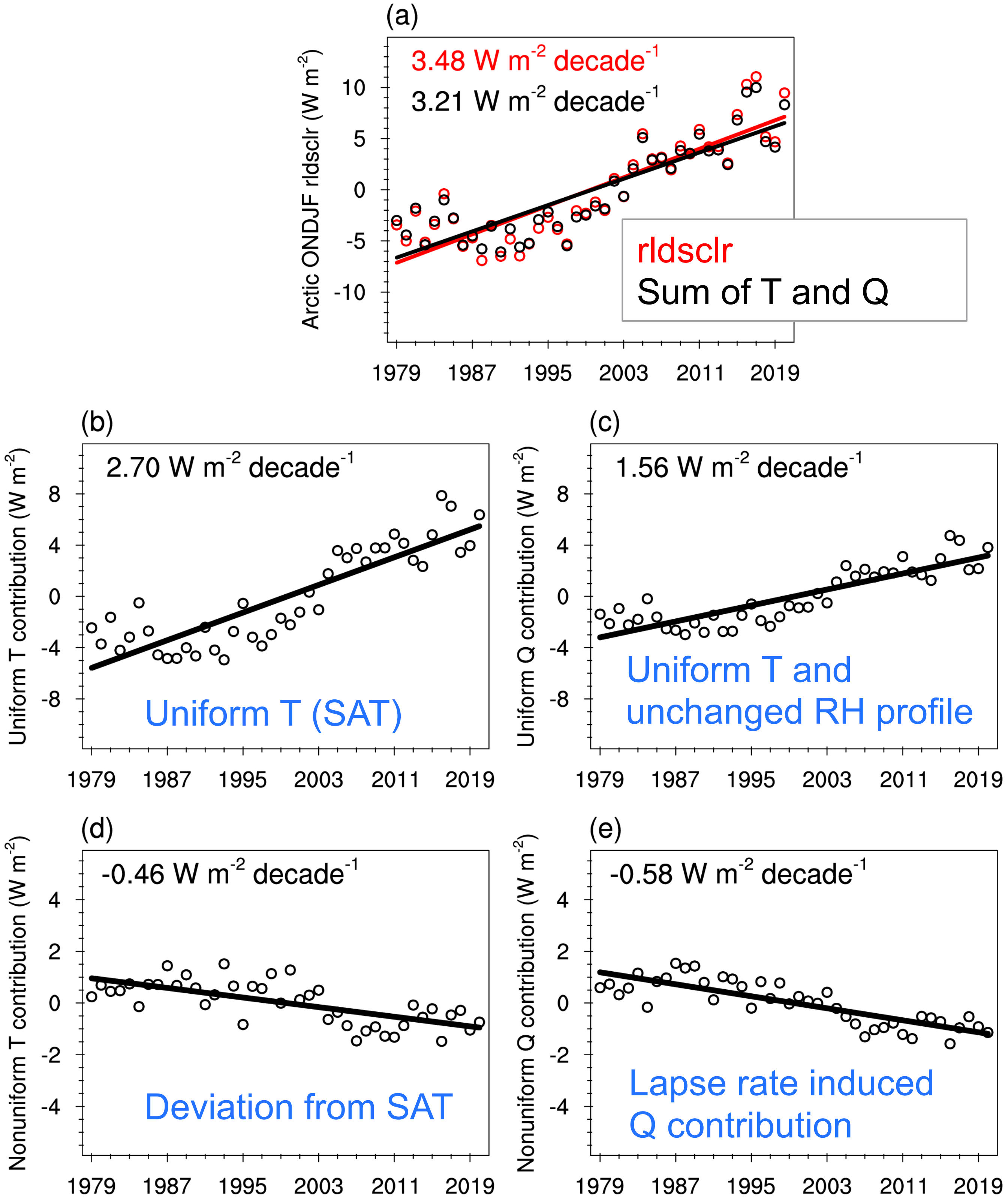
- Longwave radiation and surface gain/loss are the primary terms of cold season surface energy budget
- Clear-sky downward longwave radiation represents the largest contributor to the Arctic surface warming trend, followed by cloud forcing and G

(Zhang et al., 2021)



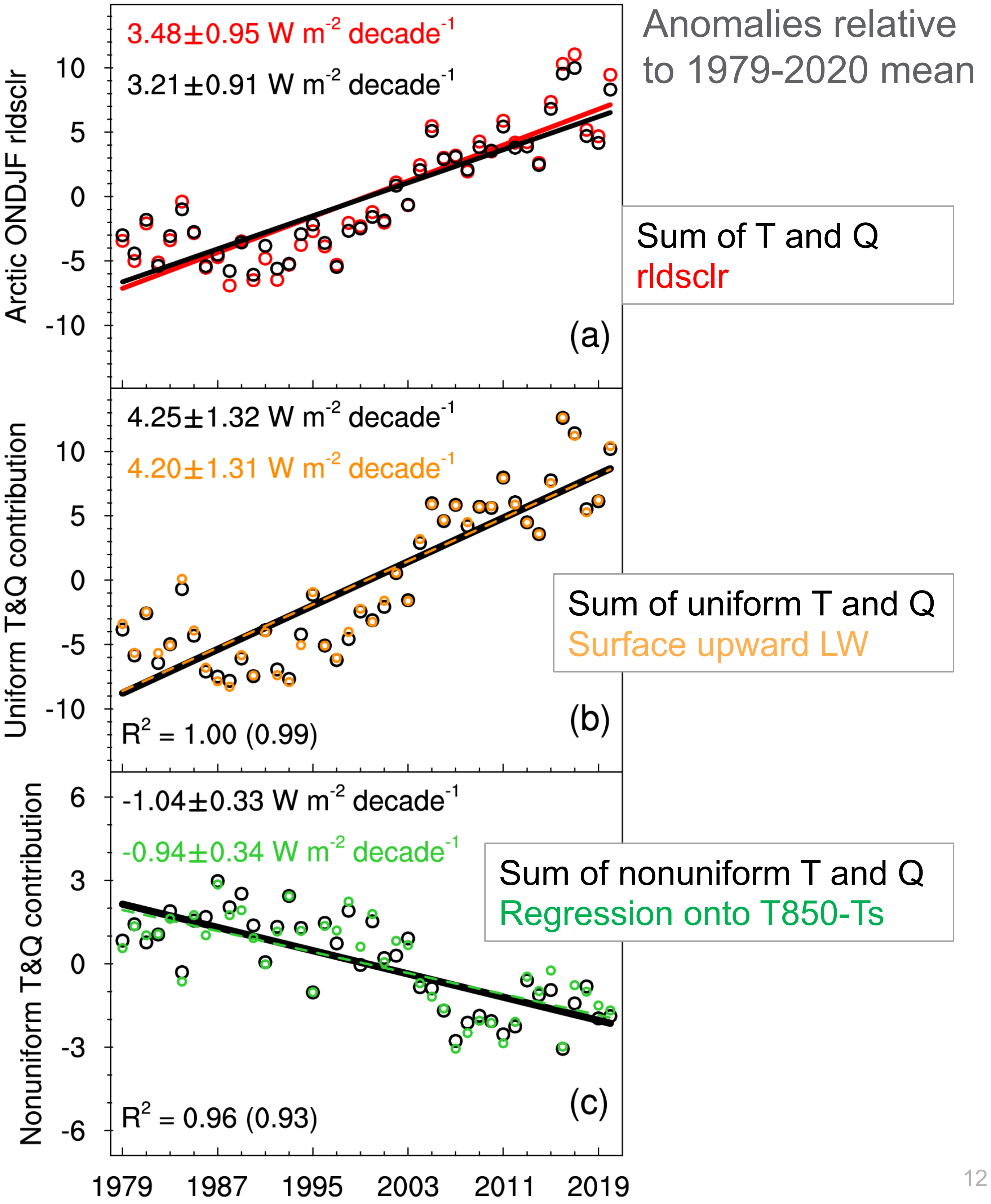
Attribution of clear-sky surface downward longwave radiation

- Attributing rldsclr trend to T and Q changes using surface radiative kernels
- Unexplained (0.26 W m^{-2} $decade^{-1}$) rldsclr is attributed to GHGs increases
- Change in T (Q) profile contributes 2.24 (0.98) W m^{-2} $decade^{-1}$ to the total rldsclr trend
- Nonuniform changes in T and Q profiles have a 1.04 (30%) less contribution than a uniform T change profiles to the Ts warming



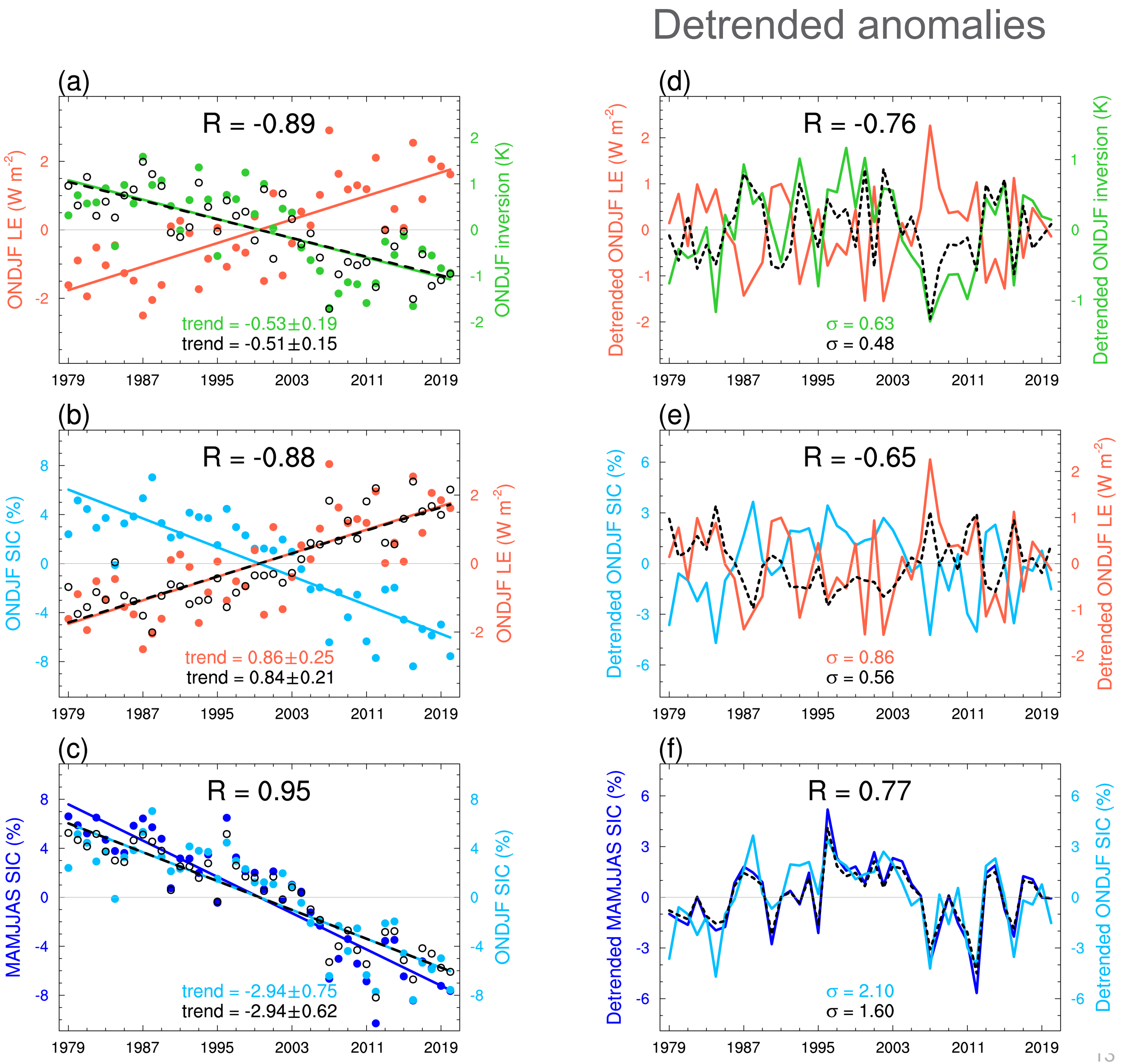
Combined contributions from changes in T and Q profiles to rldsclr

- Vertically uniform T and associated Q changes result in 4.25 W m^{-2} decade^{-1}, close to the surface upward LW trend that can be reconstructed from Ts changes (orange circles and line)
- The nonuniform part (−1.04 W m^{-2} decade^{-1}) is close to the regression onto the lower-tropospheric inversion (T850−Ts) (green circles and line)
- This role of inversion is unique to the Arctic cold season (insignificant over the tropics or Arctic summer)



Changes in the cold season Arctic temperature inversion

- T850−Ts has a good correlation with latent heat (LE)
- Sea ice cover in the cold season and the preceding warm season has an important role in regulating LE (panel b)
- SIC in cold season and SIC in the preceding warm season are highly correlated



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Summary

- Lapse rate feedback is the largest contributor to AA among all feedbacks, followed by albedo feedback and Planck feedback; Water vapor feedback is positive but doesn’t contribute to AA
- Arctic cloud feedback, including its sign, has large uncertainties; Cloud feedback likely makes an important difference in the global total feedback between the recent past and a much warmer long-term future
- The largest contributor to the cold season Arctic Ts trend is connected to a trend in clear-sky downward LW radiation at the surface that is sensitive to the lower-tropospheric temperature inversion.
- Trends in Arctic inversion strength influence the downward longwave radiation trends through the vertically nonuniform temperature and associated moisture changes.
- Lapse rate feedback in the Arctic cold season is likely a consequence of sea-ice albedo feedback during the preceding warm season

Thank you

hailong.wang@pnnl.gov

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Zhang R, Wang, H., Fu, Q., and Rasch, P.J. (2020). Assessing global and local radiative feedbacks based on AGCM simulations for 1980–2014/2017. Geophys. Res. Lett., 47, e2020GL088063. DOI: 10.1029/2020GL088063