A Simple SW TOA and Surface Flux Decomposition Method for Evaluating Model Variability

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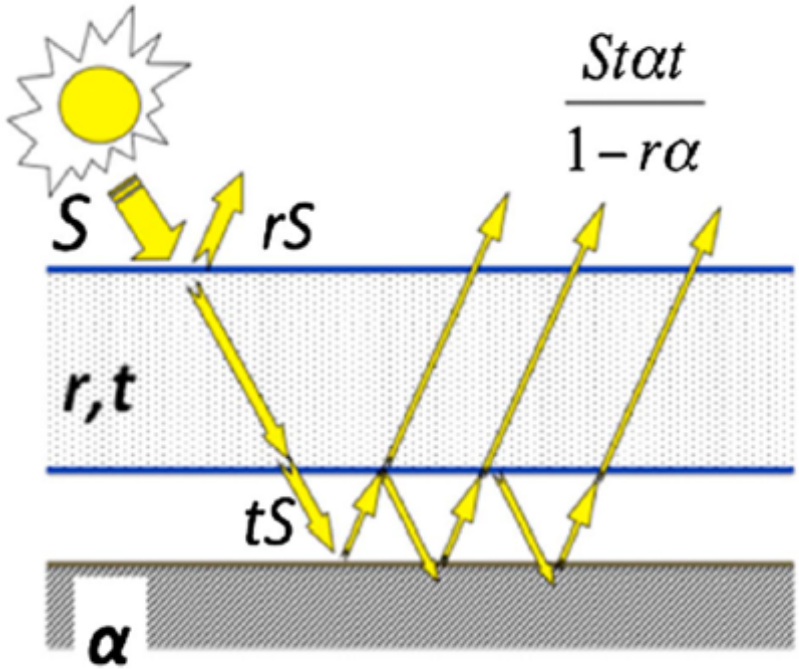
Diagnostic Framework for Atmosphere-Only and Atmosphere-Surface Contributions to SW TOA Flux



- Single scattering and absorbing layer of atmosphere over a reflecting surface of albedo α.
- The total reflected flux of the system is given by the sum of the reflected energy from the layer plus the multiple scattering between the surface and atmosphere:

$$F_T^{\uparrow} = rS + T\left(\frac{1-\alpha R}{1-\alpha^2 T^2}\right) F_S^{\uparrow}$$

$$r = R - t\alpha T$$

$$t = T\frac{1-\alpha R}{1-\alpha^2 T^2}$$

Stephens et al., Rev. Geophys. 2015

SW TOA Flux Decomposition in Terms of TOA and Surface Contributions

$$F\downarrow T\uparrow = rS + tF\downarrow S\uparrow$$

$$\delta F\downarrow T\uparrow = [r\,\delta S + \delta r S + \delta r \delta S - \delta r \delta S] + [t\,\delta F\downarrow S\uparrow + \delta t F\downarrow S\uparrow + \delta t \delta F\downarrow S\uparrow - \delta t \delta F\downarrow S\uparrow]$$

(1)

$$\delta F\downarrow T\uparrow (ATM) = [r\,\delta S + \delta r S + \delta r \delta S - \delta r \delta S] + [t\,\delta G\downarrow S\uparrow + \delta t G\downarrow S\uparrow + \delta t \delta G\downarrow S\uparrow - \delta t \delta G\downarrow S\uparrow]$$

(2)

where $\delta G\downarrow S\uparrow$ is the anomaly in upward flux @ surface due to atmos. variations only (determined using climatological surface albedo).

From (1) minus (2):

$$\delta F\downarrow T\uparrow (SFC) = t\,(\delta F\downarrow S\uparrow - \delta G\downarrow S\uparrow) + \delta t(\delta F\downarrow S\uparrow - \delta G\downarrow S\uparrow) - (\delta t \delta F\downarrow S\uparrow - \delta t \delta G\downarrow S\uparrow)$$

(3)

Net Downward SW Flux at Surface Decomposition

$$F\downarrow S\uparrow\downarrow = tS + rF\downarrow S\uparrow\uparrow$$

$$\delta F\downarrow S\uparrow\downarrow (ATM) = [t\,\delta S + \delta t S + \delta t \delta S - \delta t \delta S] + [r\,\delta G\downarrow S\uparrow\uparrow + \delta r G\downarrow S\uparrow\uparrow + \delta r \delta G\downarrow S\uparrow\uparrow - \delta r \delta G\downarrow S\uparrow\uparrow]$$

where $\delta G\downarrow S\uparrow\uparrow$ is the anomaly in upward flux @ surface due to atmos. variations only (determined using climatological surface albedo).

$$\delta(F\downarrow S\uparrow\downarrow - F\downarrow S\uparrow\uparrow)(ATM) = (1-\alpha)\,\delta F\downarrow S\uparrow\downarrow (ATM)$$

$$\delta(F\downarrow S\uparrow\downarrow - F\downarrow S\uparrow\uparrow)(SFC) = \delta(F\downarrow S\uparrow\downarrow - F\downarrow S\uparrow\uparrow) - \delta(F\downarrow S\uparrow\downarrow - F\downarrow S\uparrow\uparrow)(ATM)$$

Monthly Data Products

- CERES EBAF-TOA & EBAF-SFC Ed4.0
- MERRA-2
- ERA-Interim

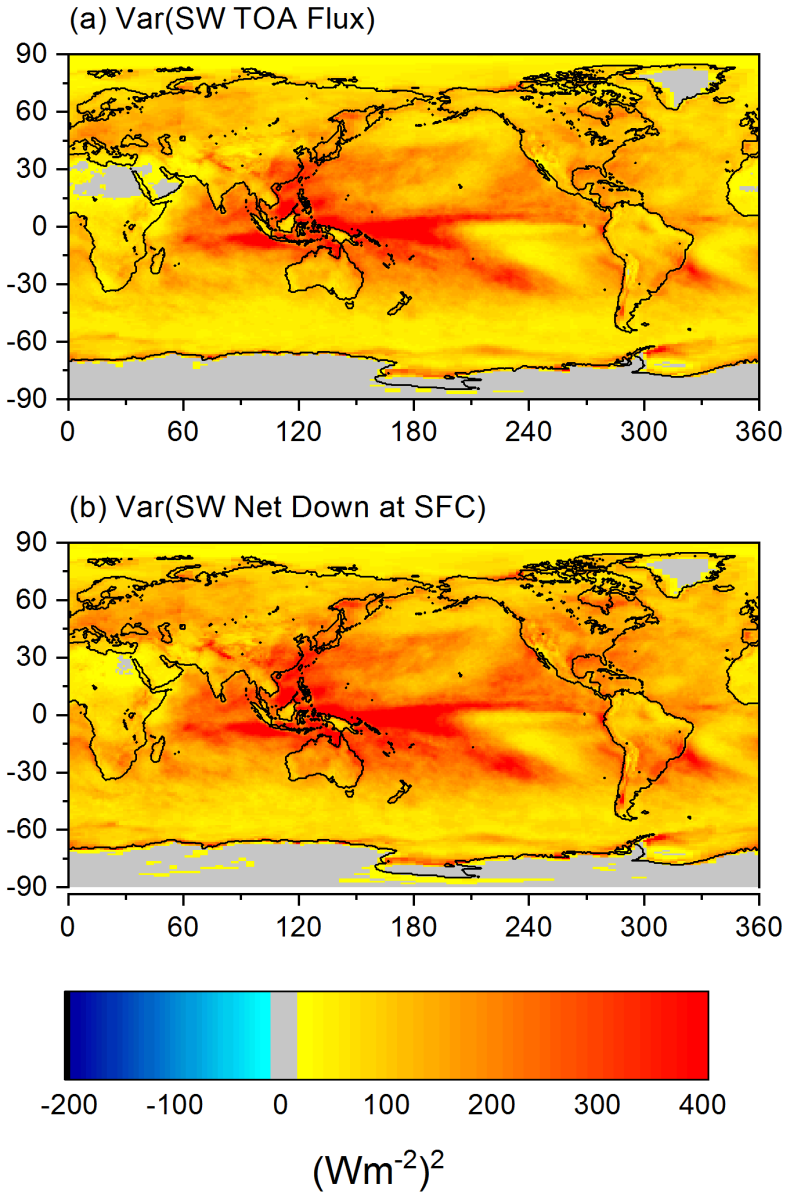
Variables

- TOA: Incoming solar flux, SW up
- Surface: Upward SW, Downward SW

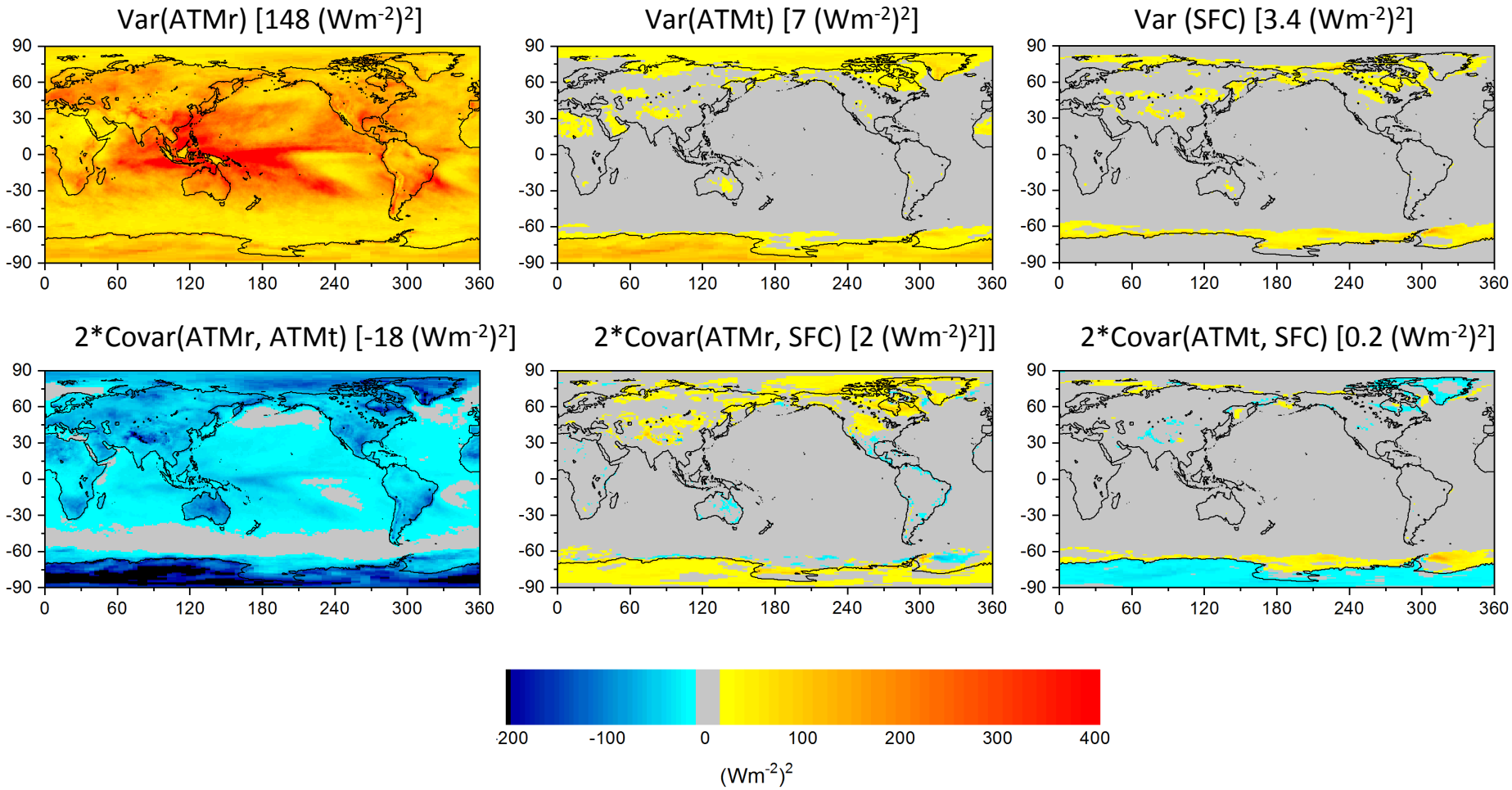
Time Range

- March 2000 – October 2017.

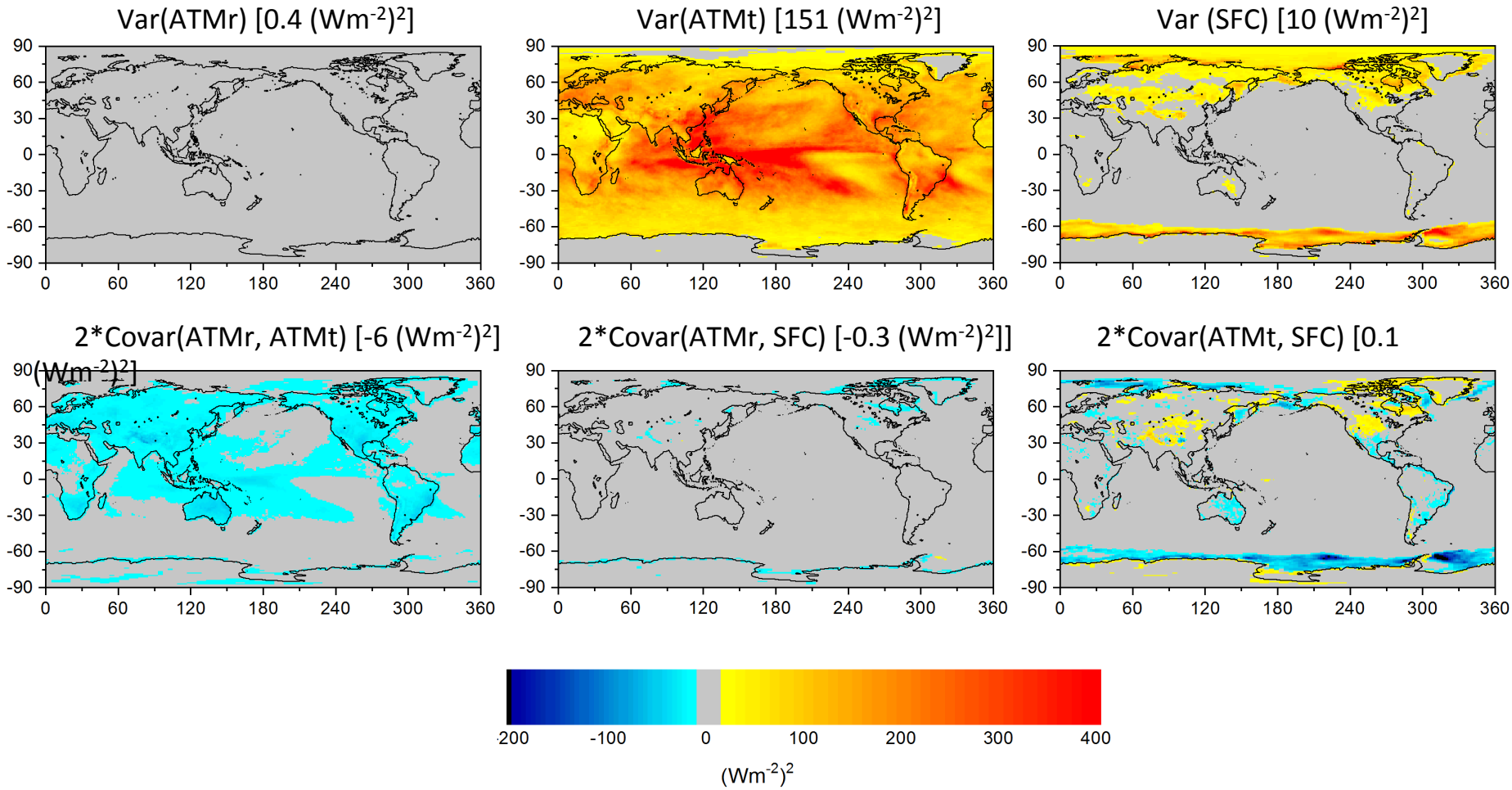
Variance in Monthly Outgoing TOA and Net Surface Downward SW Flux Anomalies (EBAF Ed4.0; March 2000-October 2017)



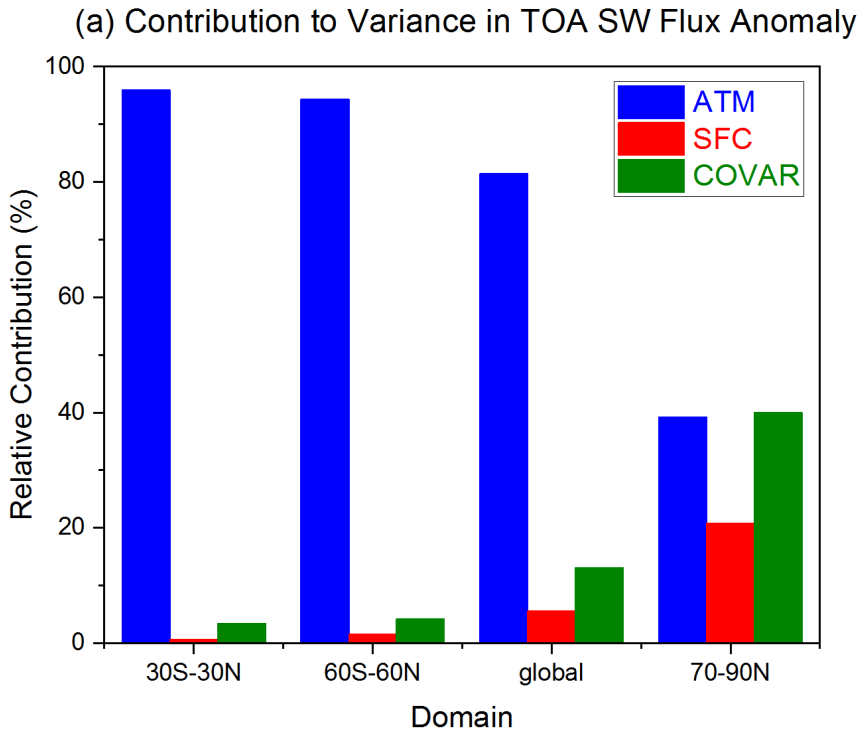
Decomposition of Variance in SW TOA Flux Anomaly

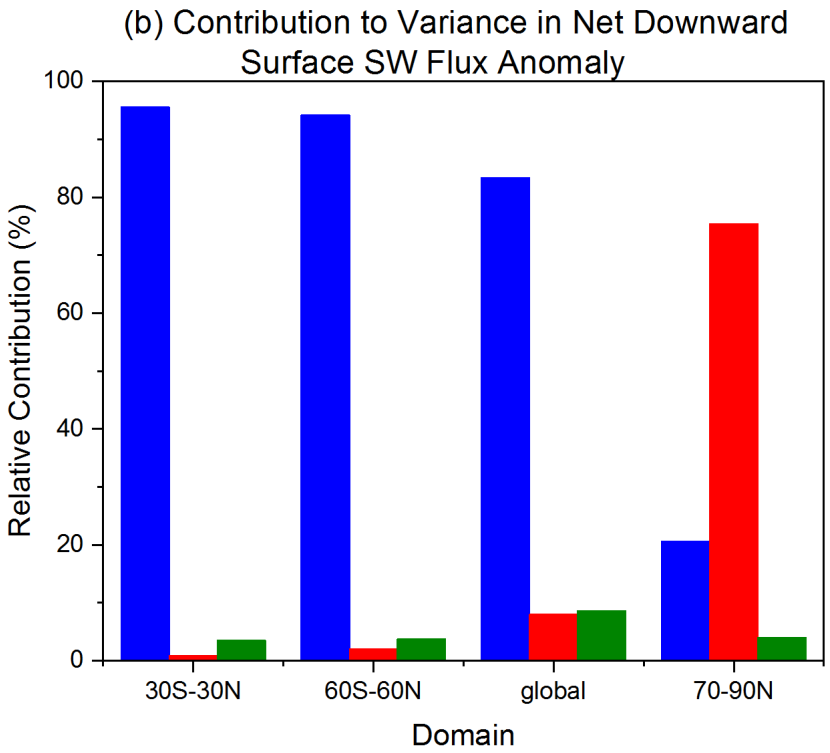


Decomposition of Variance in Net Downward Surface SW Flux Anomaly



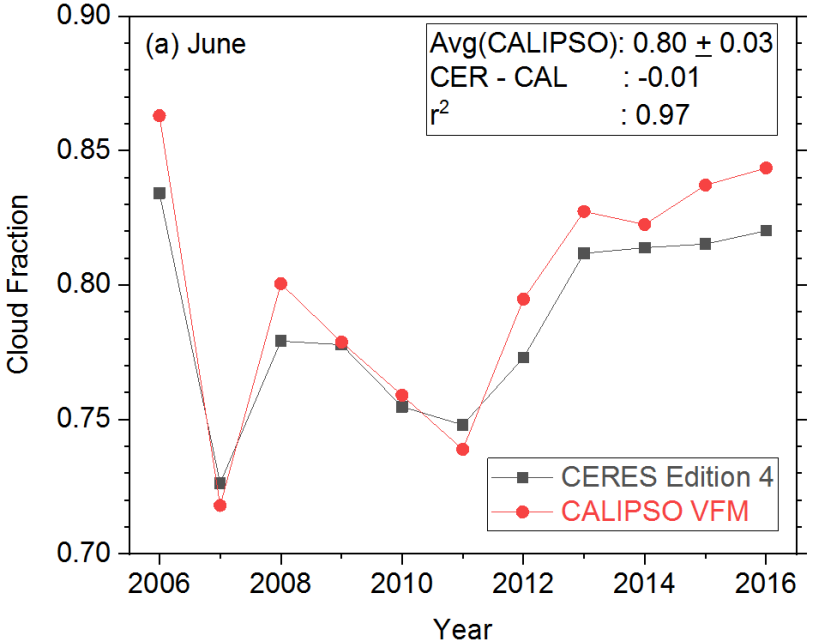
Relative Contributions to Variance in TOA SW Flux Anomaly and Net Downward Surface SW Flux Anomaly

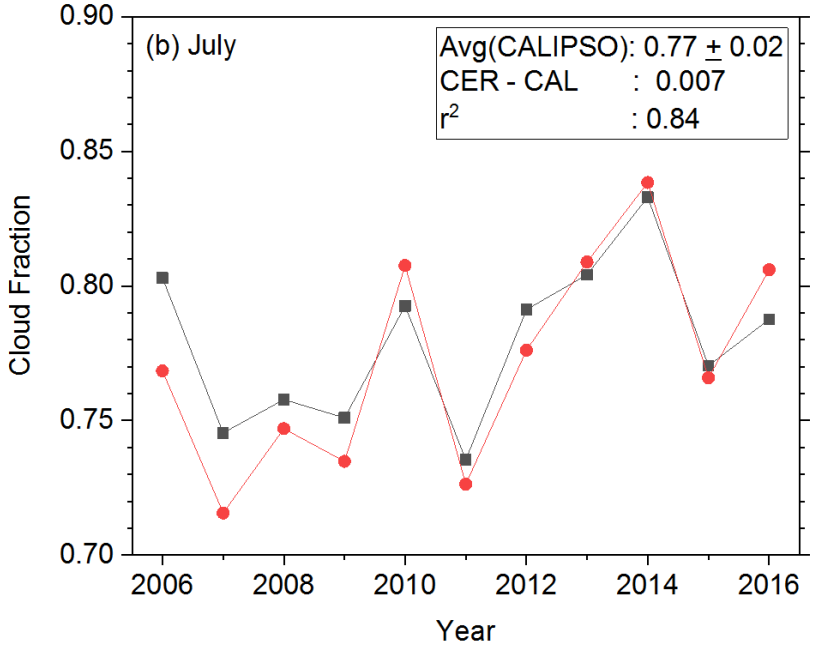


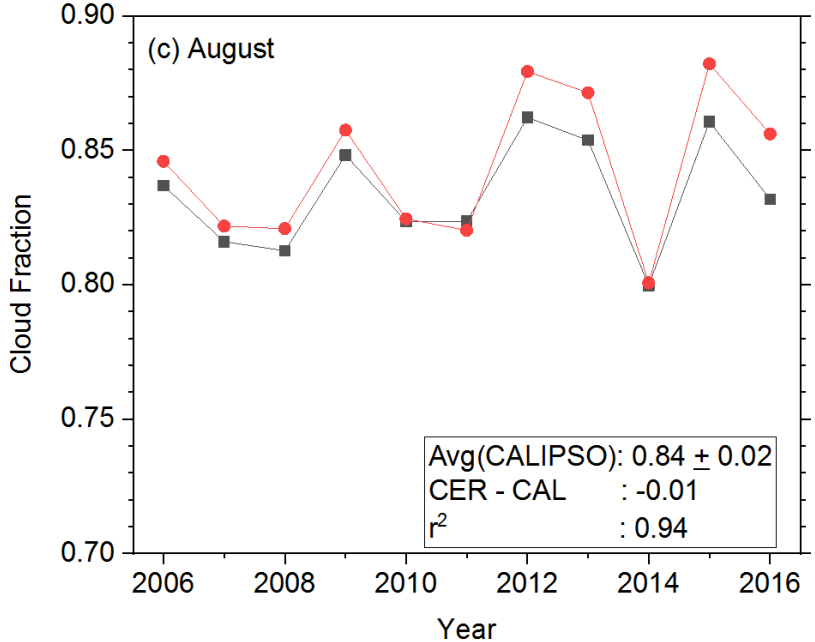


- All months are used for 30°S-30°N, 60°S-60°N and global.
- Only June, July and August are used for 70-90°N.

Cloud Fraction Comparison (70°-90°N; Ocean Only; Daytime Only)



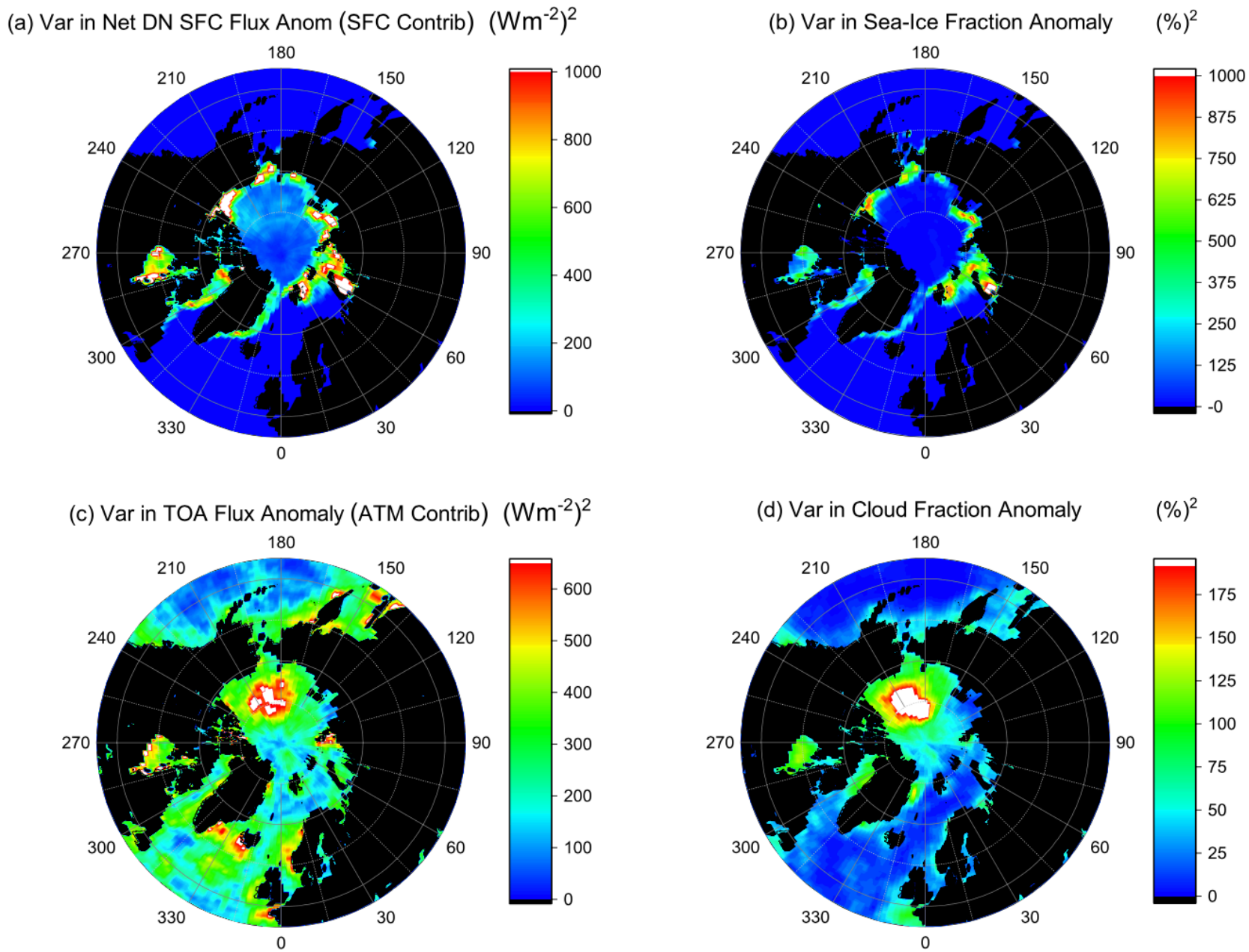




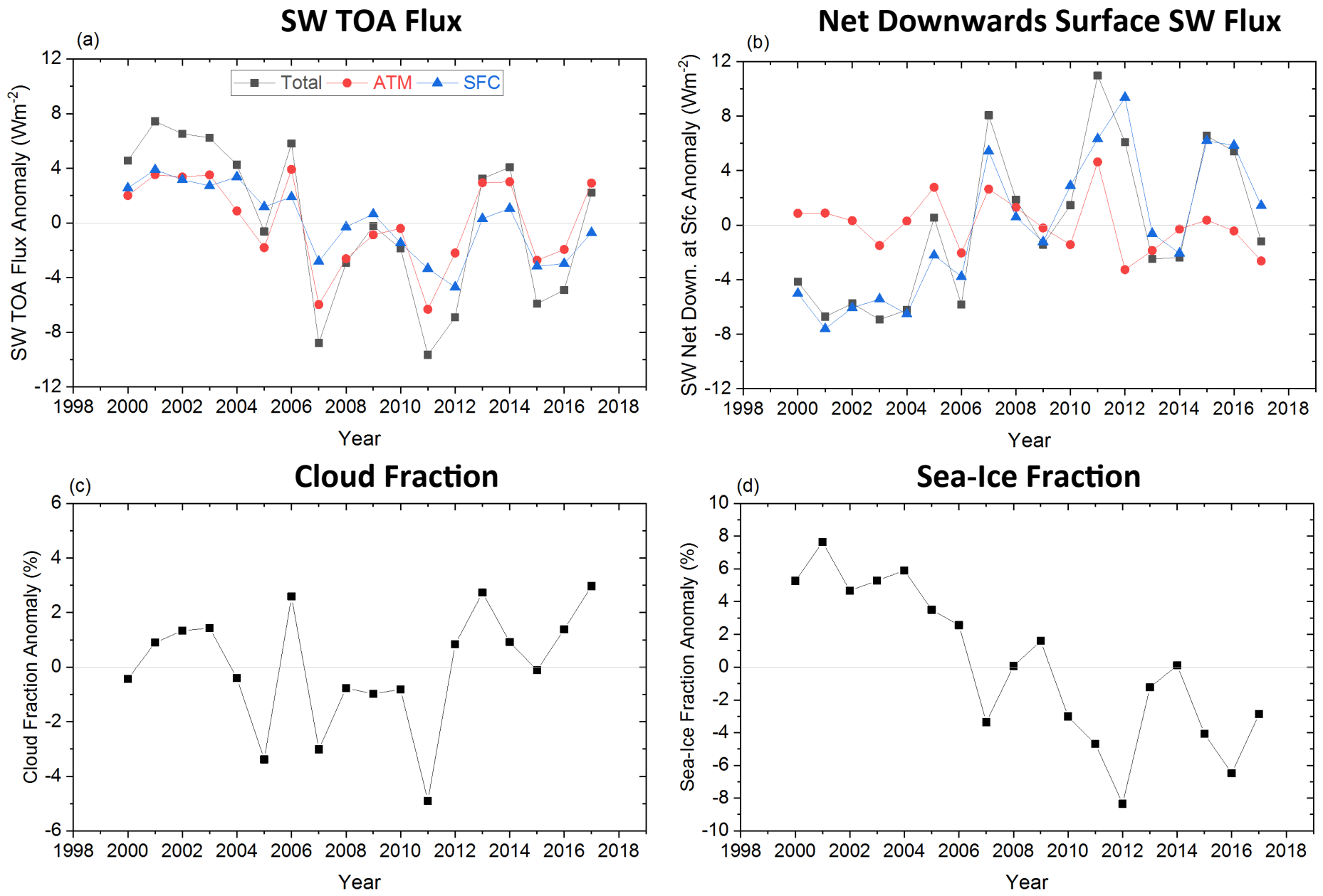
Details of Comparison:

- Ed4 MODIS Aqua is from swath data, but restricted to VZA < 5°.
- CALIPSO selected only for high conference clouds.
- Remove CALIPSO clouds only detectable with 80 km resolution.

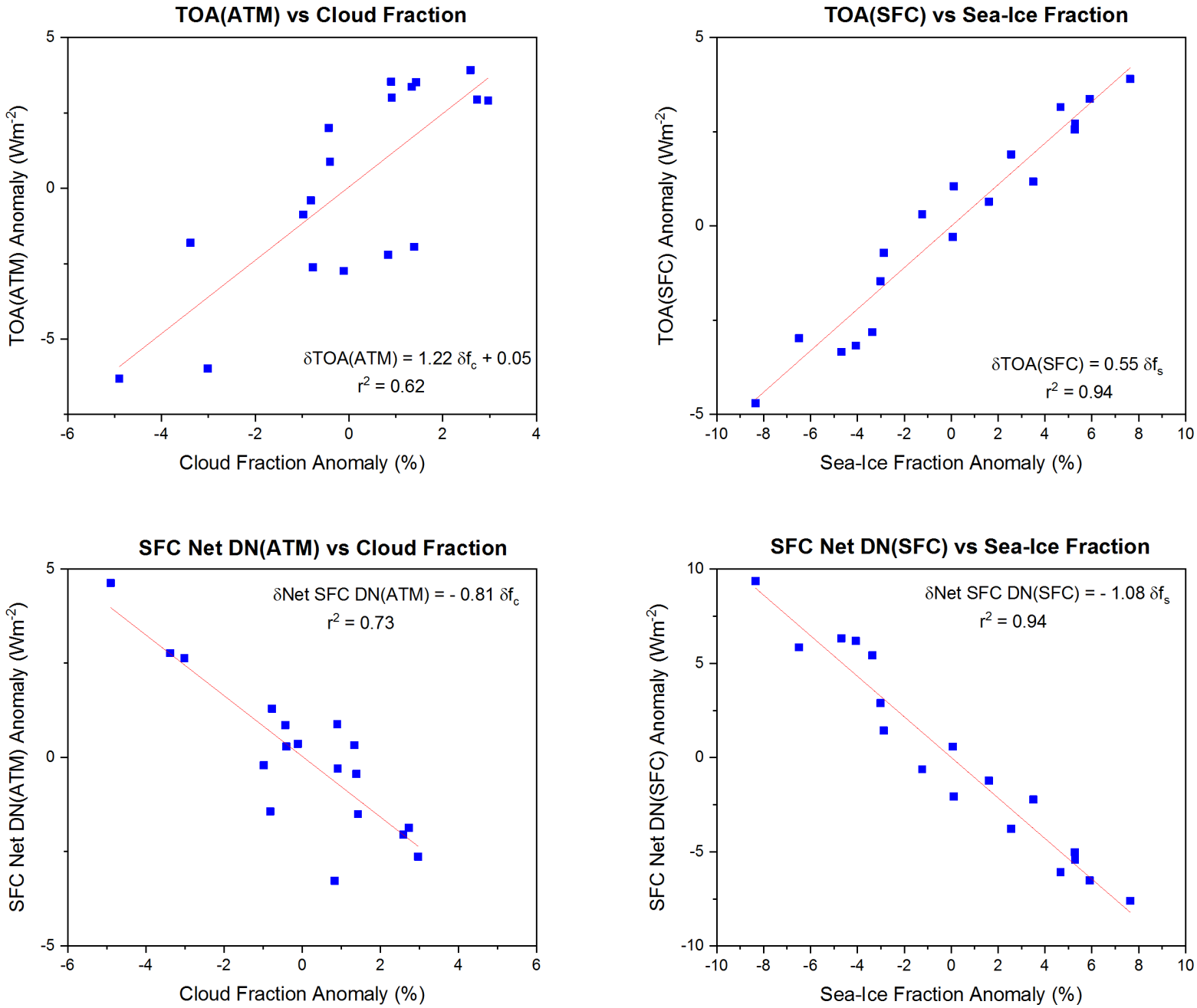
Variance in Net DN SFC SW Flux, Sea-ice Fraction, TOA SW Flux and Cloud Fraction



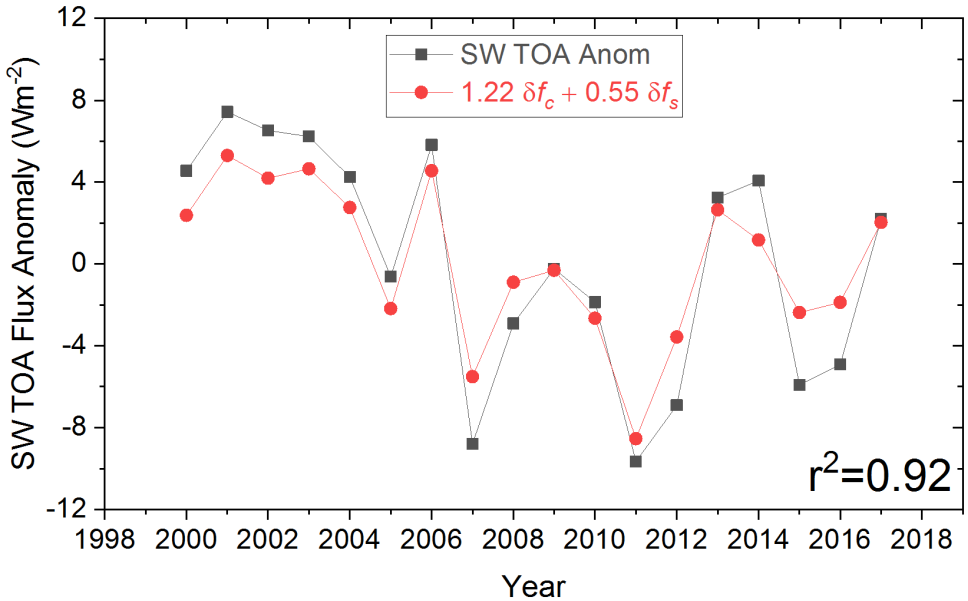
Anomalies for 70°-90°N (Ocean Only)

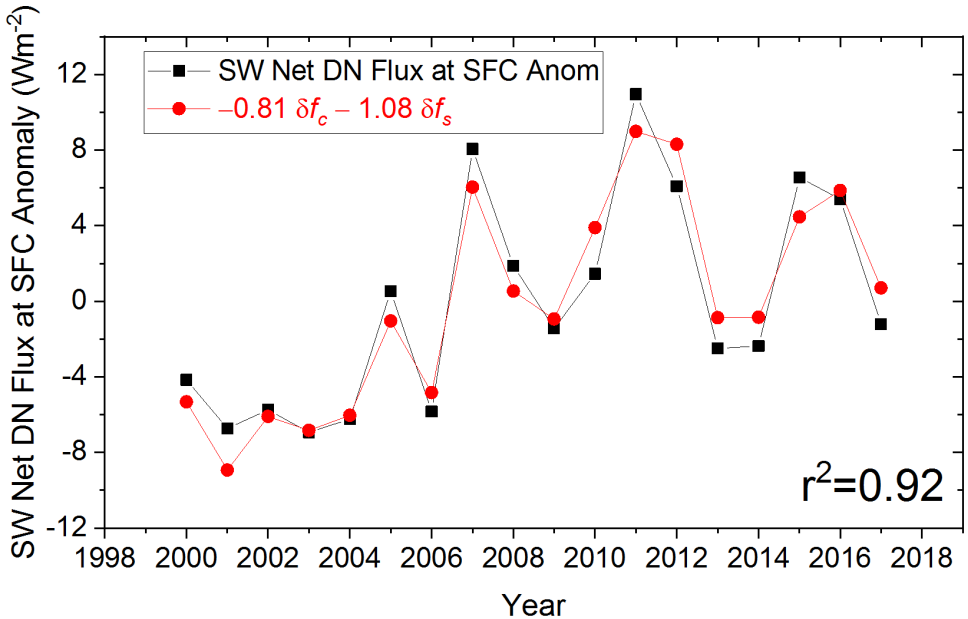


Regression Fits for ATM & SFC Contributions vs Cloud Fraction and Sea-Ice Anomalies

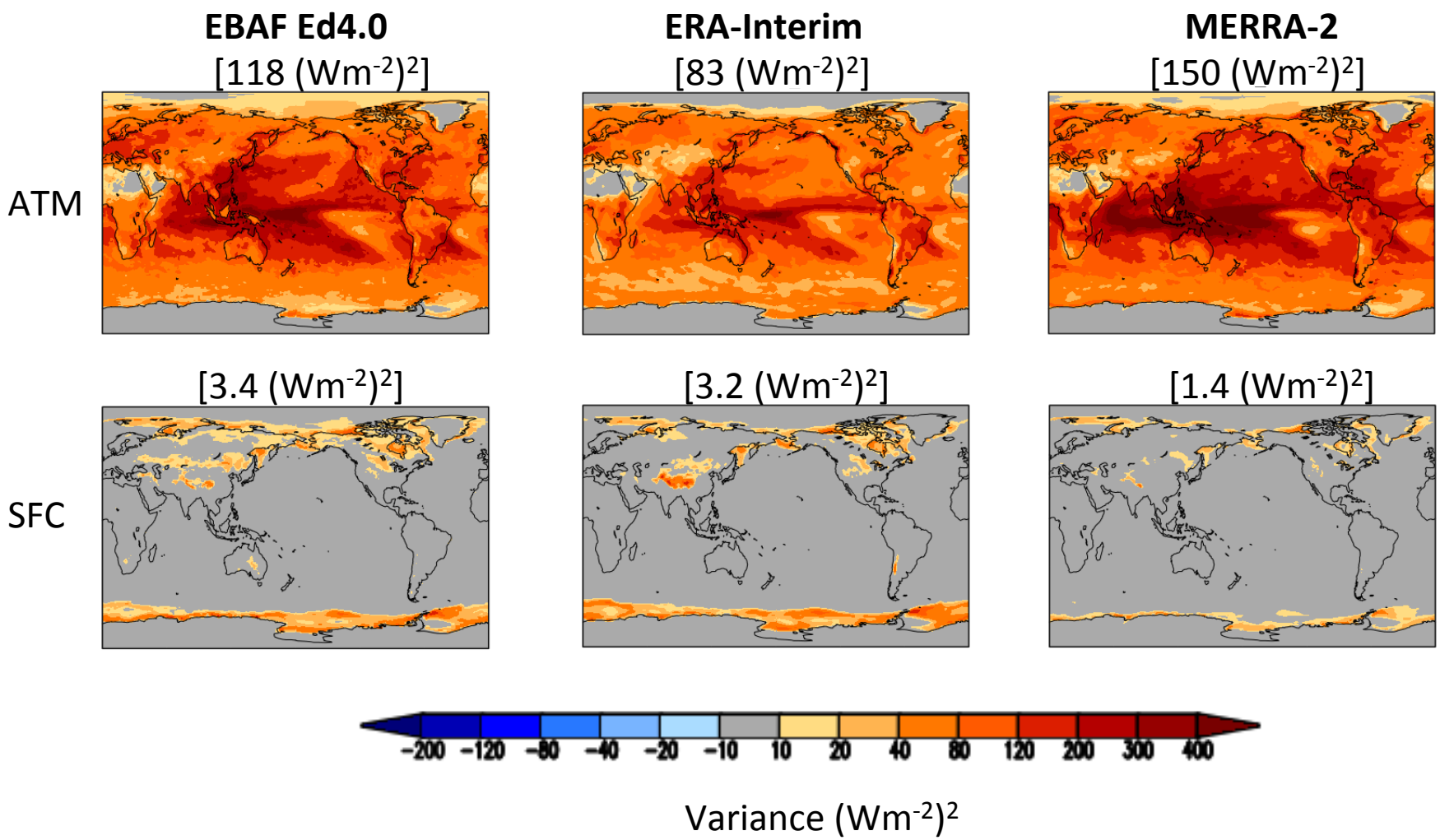


SW TOA Flux and Net Downward Surface SW flux Anomalies (Ocean-Only 70˚N-90˚N) Regression Fit vs Actual

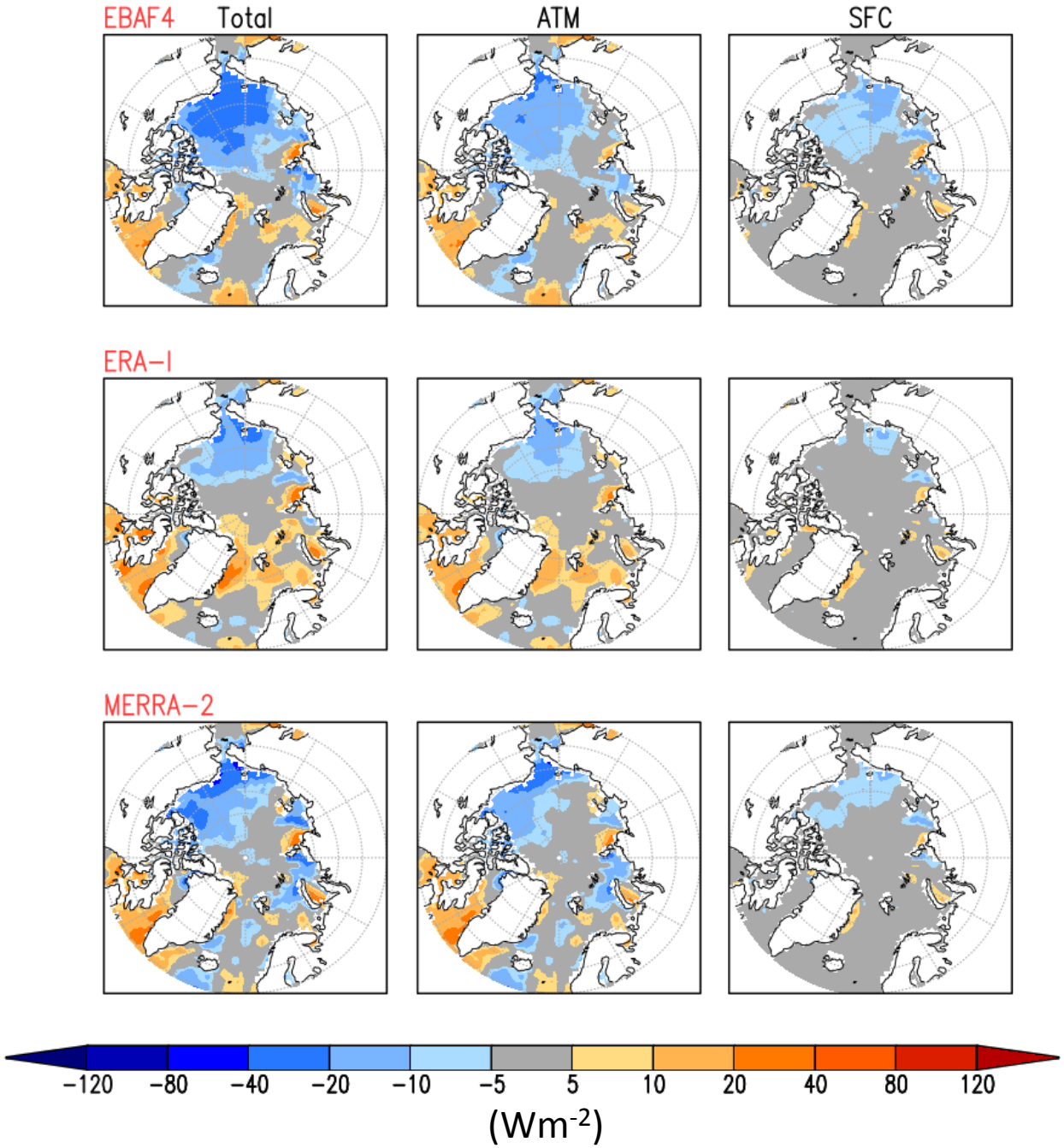




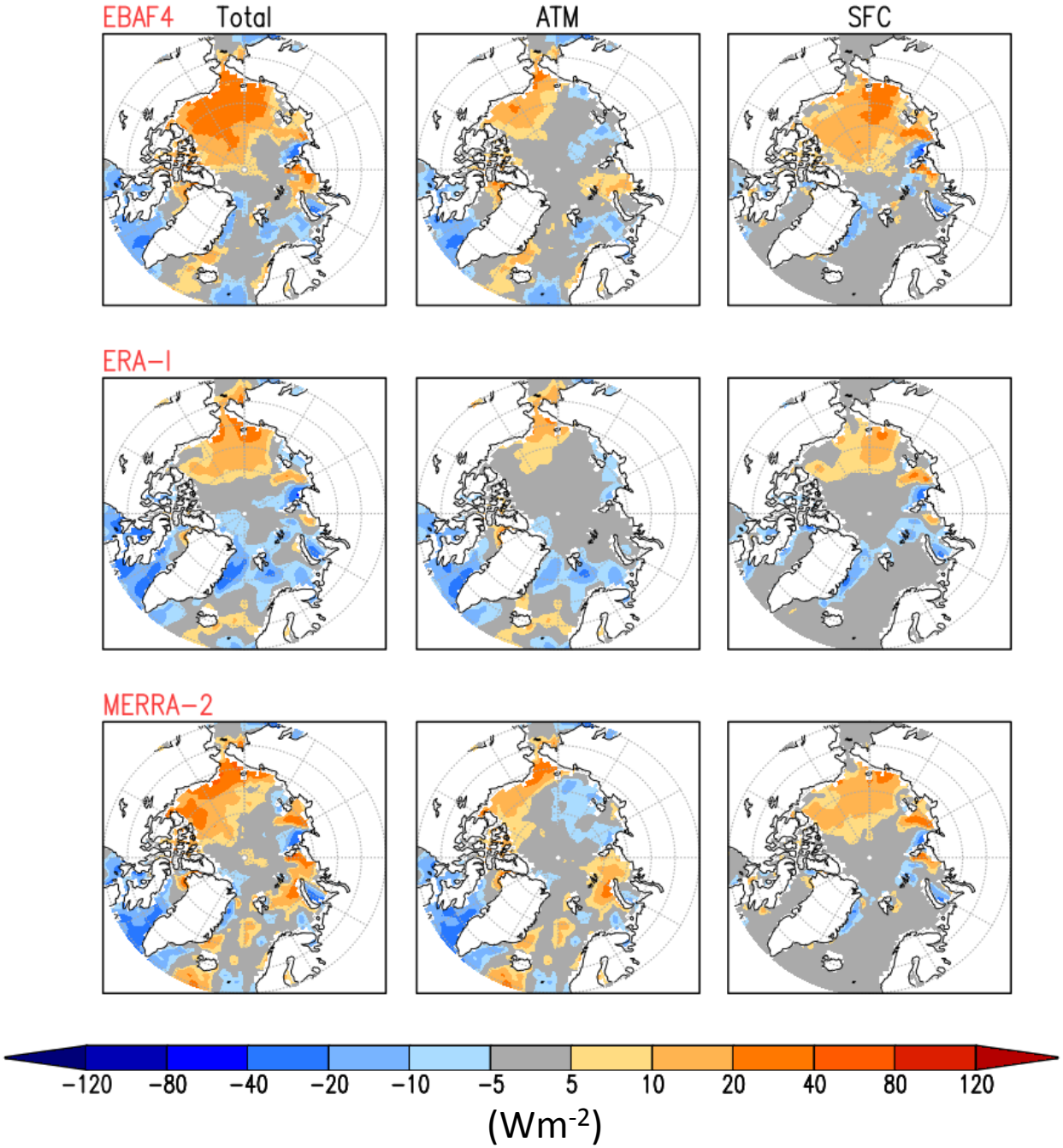
ATM and SFC Contributions to SW TOA Flux Variance



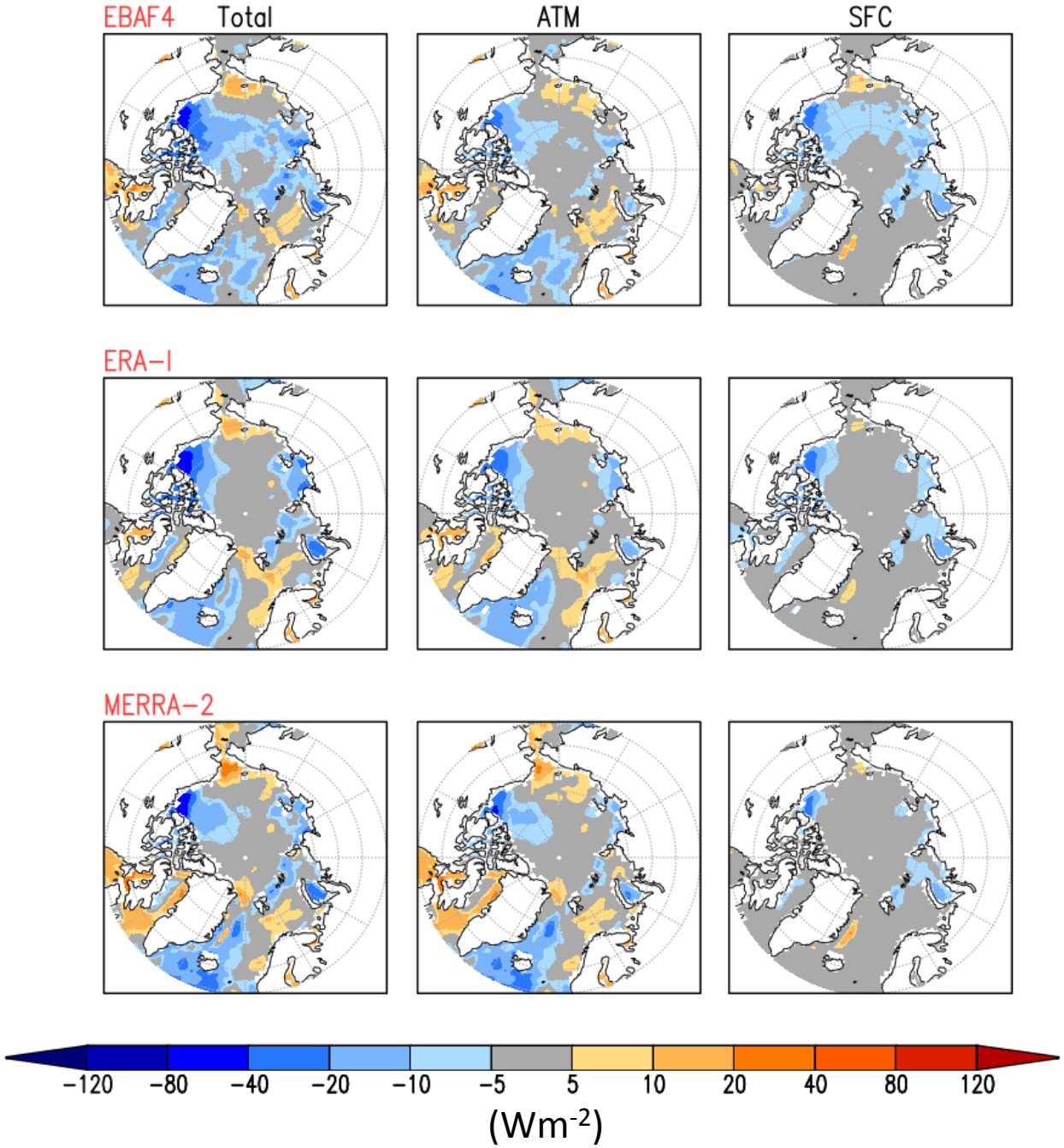
SW TOA Flux Anomalies: CERES EBAF4.0 vs ERA-I & MERRA-2 (JJA 2007)



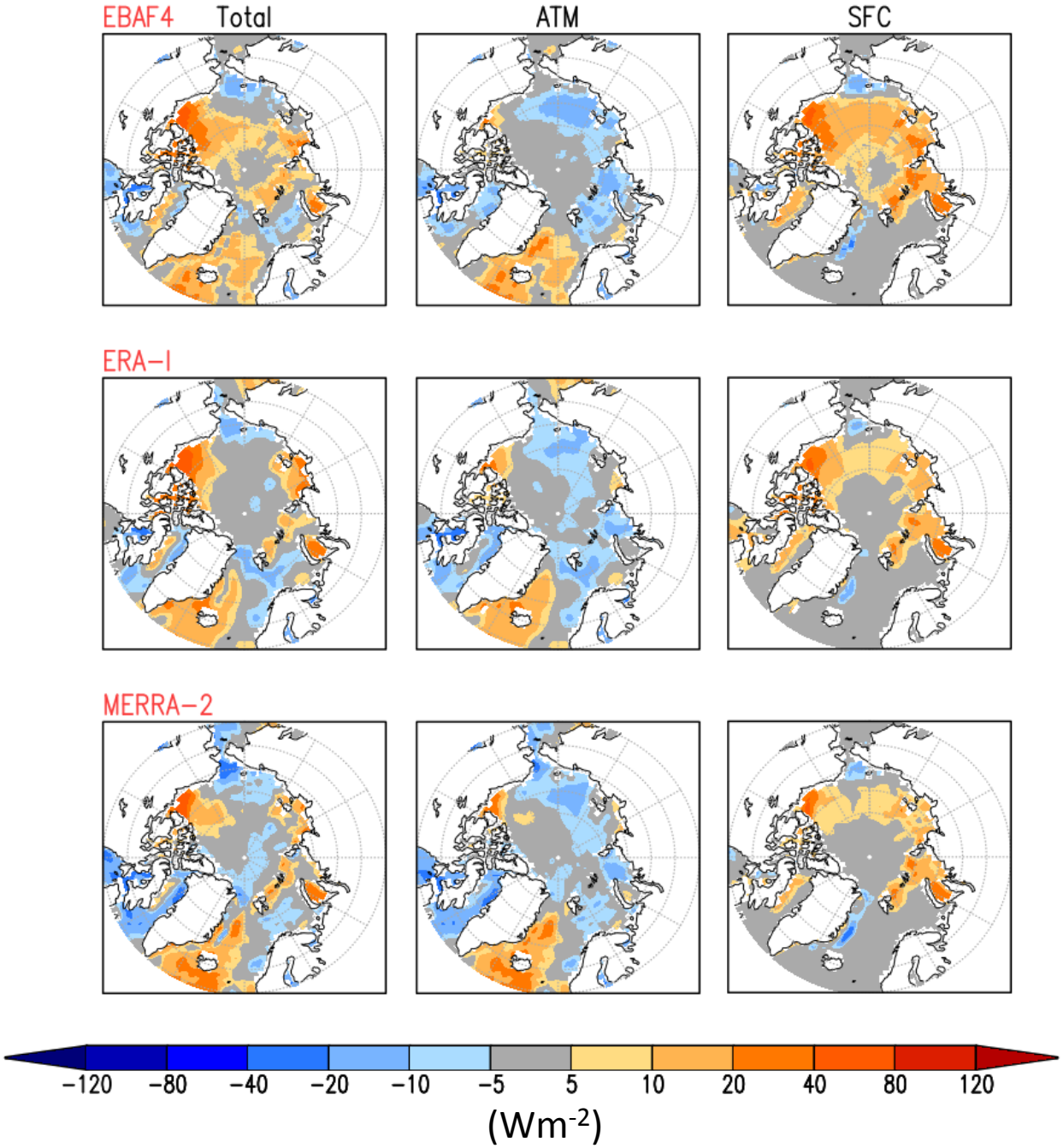
Net Downward Surface SW Flux Anomalies: CERES EBAF4.0 vs ERA-I & MERRA-2 (JJA 2007)



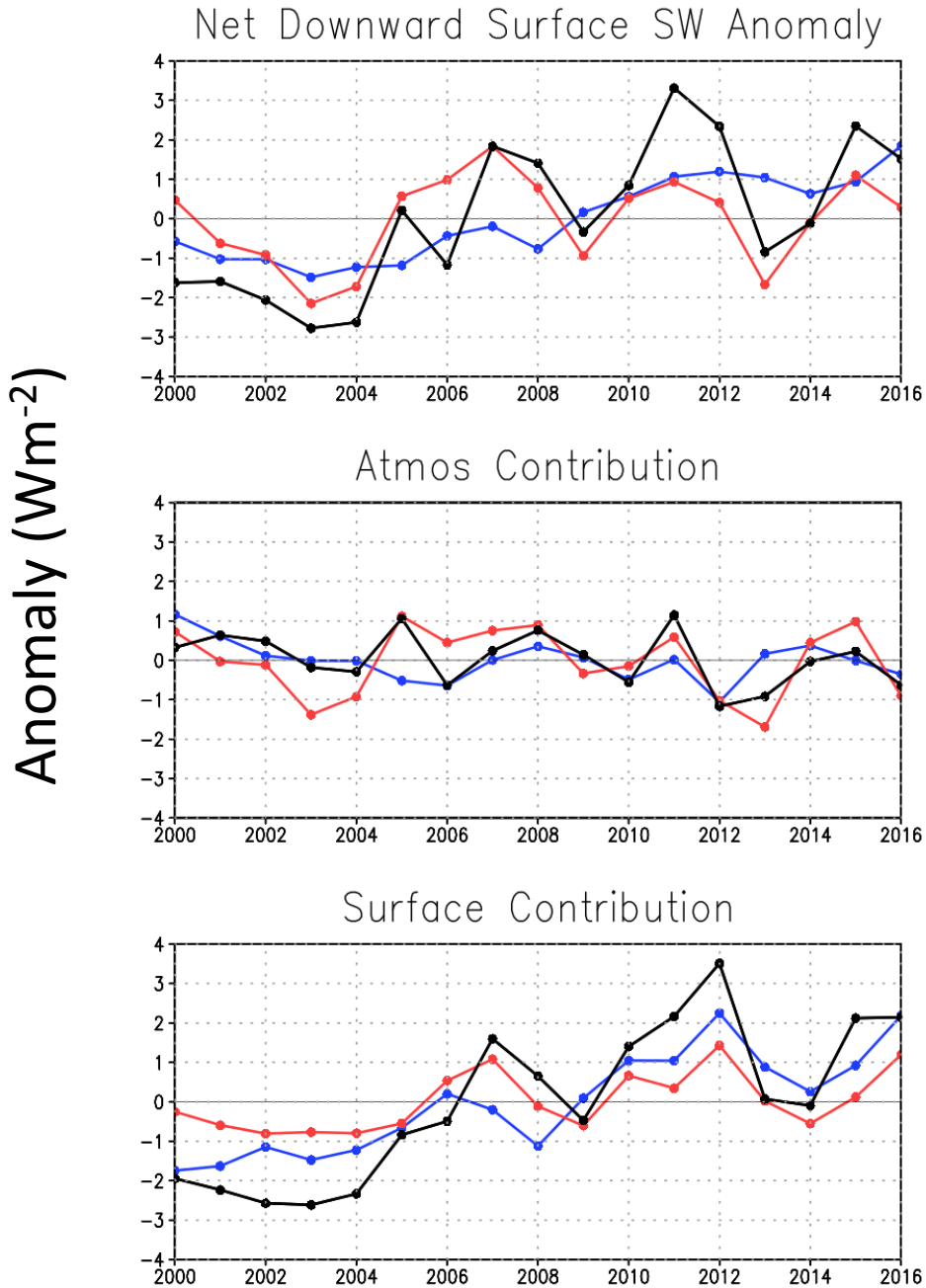
SW TOA Flux Anomalies: CERES EBAF4.0 vs ERA-I & MERRA-2 (JJA 2012)



Net Downward Surface SW Flux Anomalies: CERES EBAF4.0 vs ERA-I & MERRA-2 (JJA 2012)



Net Downward Surface SW Flux Anomalies (70-90N; Ocean Only)



EBAF4
ERA-I
MERRA-2

Conclusions

- The CERES TOA and surface radiative fluxes are used to derive a diagnostic tool to determine surface and atmospheric contributions to SW TOA flux and net surface downward SW flux variability.
- At global scale, the atmosphere contributes most of the variability (81%). Surface contribution (4%) is mainly from polar regions.
- Over the Arctic Ocean, most of the variability in TOA and surface radiation can be explained by cloud fraction and sea-ice variations alone.
- ERA-I and MERRA-2 both underestimate the surface contribution to TOA flux variability. ERA-I underestimates the atmospheric contribution while the opposite is true for MERRA-2.