Earth Radiation Budget Continuity

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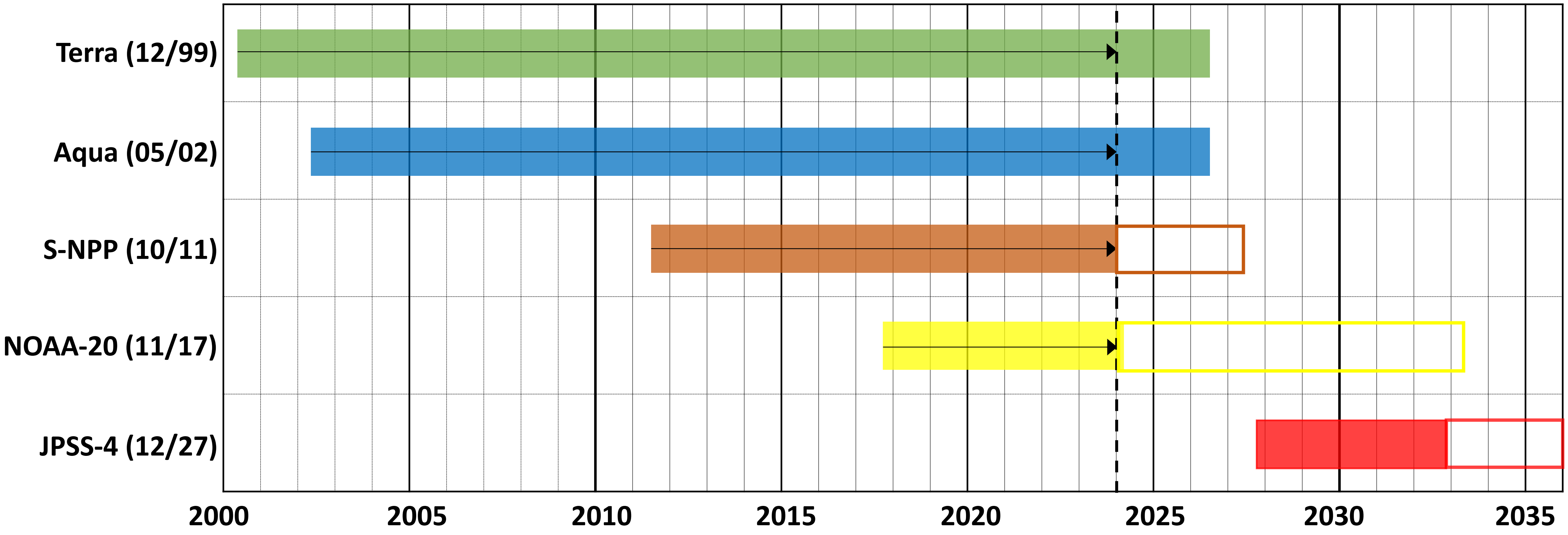
Outline

- **Ensuring Seamless Continuity in ERB Record Across Multiple Overlapping Satellites**

- **Probability of a Data Gap in ERB Record**

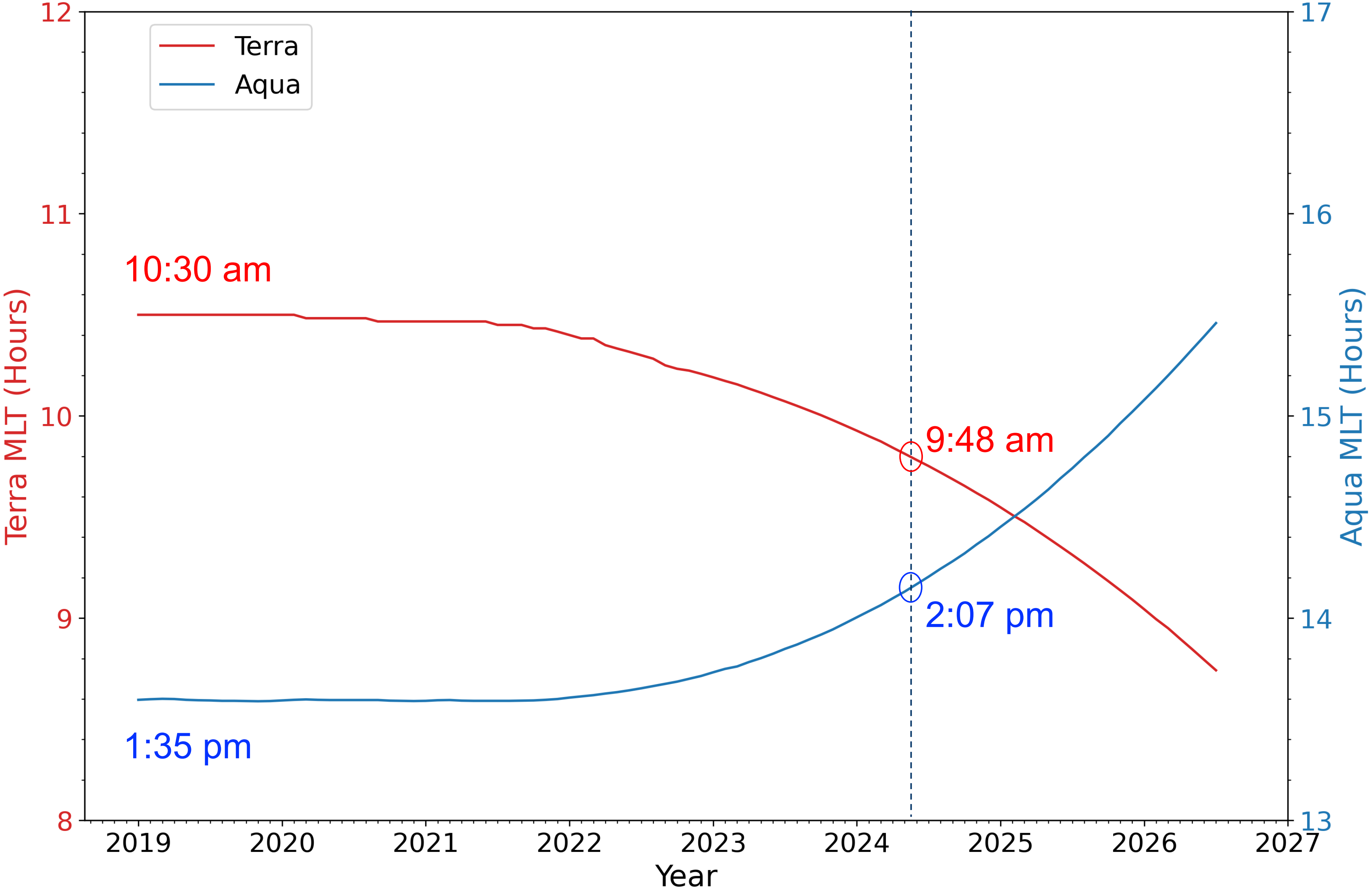
- **Impact of a Data Gap: Case Study**

Flight Schedule of Satellites Carrying Earth Radiation Budget Instruments



Within the next 10 years, we're going from four missions down to one, and the one remaining will be past its prime

Terra and Aqua Mean Local Equatorial Crossing Times (MLTs)



- **MLT updates available at: https://terra.nasa.gov & https://aqua.nasa.gov**

CERES EBAF Timeline

Terra-Only	→	Terra+Aqua	→	NOAA20
(03/2000-06/2002)		(07/2002-03/2022)		(04/2022-onwards)

- **How can we ensure a seamless climate data record across these satellite transitions?**

1) First step is to ensure that radiance measurements from instruments on different satellites are on the same radiometric scale.
   - All CERES instruments are anchored to FM1 instrument via intercalibration using coincident data (Shankar et al., 2020).
   - All LEO and GEO imager radiances are placed on the same radiometric scale using a combination of ray-matching and invariant targets (Doelling et al., 2015, 2018).

2) Use overlap between successive missions to anchor Level-3 data products from different satellites to a common reference.
   - Mitigates cross-platform differences between satellite orbits, differences in instrument characteristics and the ancillary input data used to generate higher-level data products.

Terra-Only & NOAA20-Only Climatological Adjustment

- **Terra-Only**: Use 5-year overlap with Terra+Aqua (07/2002-06/2007) to anchor Terra-Only period (03/2000-06/2002) to Terra+Aqua.
- **NOAA20-Only**: Use 4-year overlap with Terra+Aqua (05/2018-03/2022) to anchor NOAA20-Only period (04/2022-onwards) to Terra+Aqua.

$$F_T'(\lambda,\phi;yr,mn) = F_T(\lambda,\phi;yr,mn) + \{\bar{F}_{TA}^O(\lambda,\phi;mn) - \bar{F}_T^O(\lambda,\phi;mn)\}$$

$$= F_T(\lambda,\phi;yr,mn) + \bar{\Delta}^O(\lambda,\phi;mn)$$

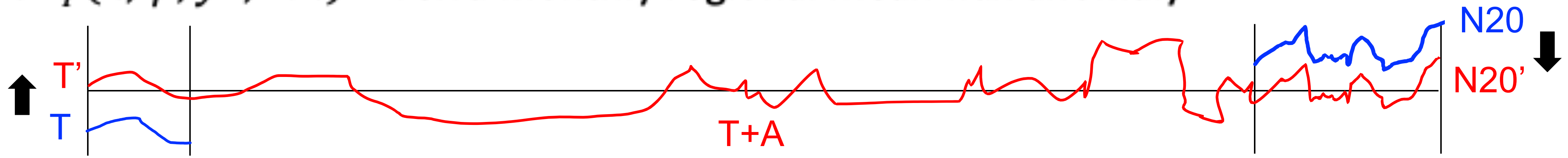
By definition: $\delta F_T'(\lambda,\phi;yr,mn) = \delta F_T(\lambda,\phi;yr,mn)$

$F_T(\lambda,\phi;yr,mn)$ = Terra monthly regional mean flux

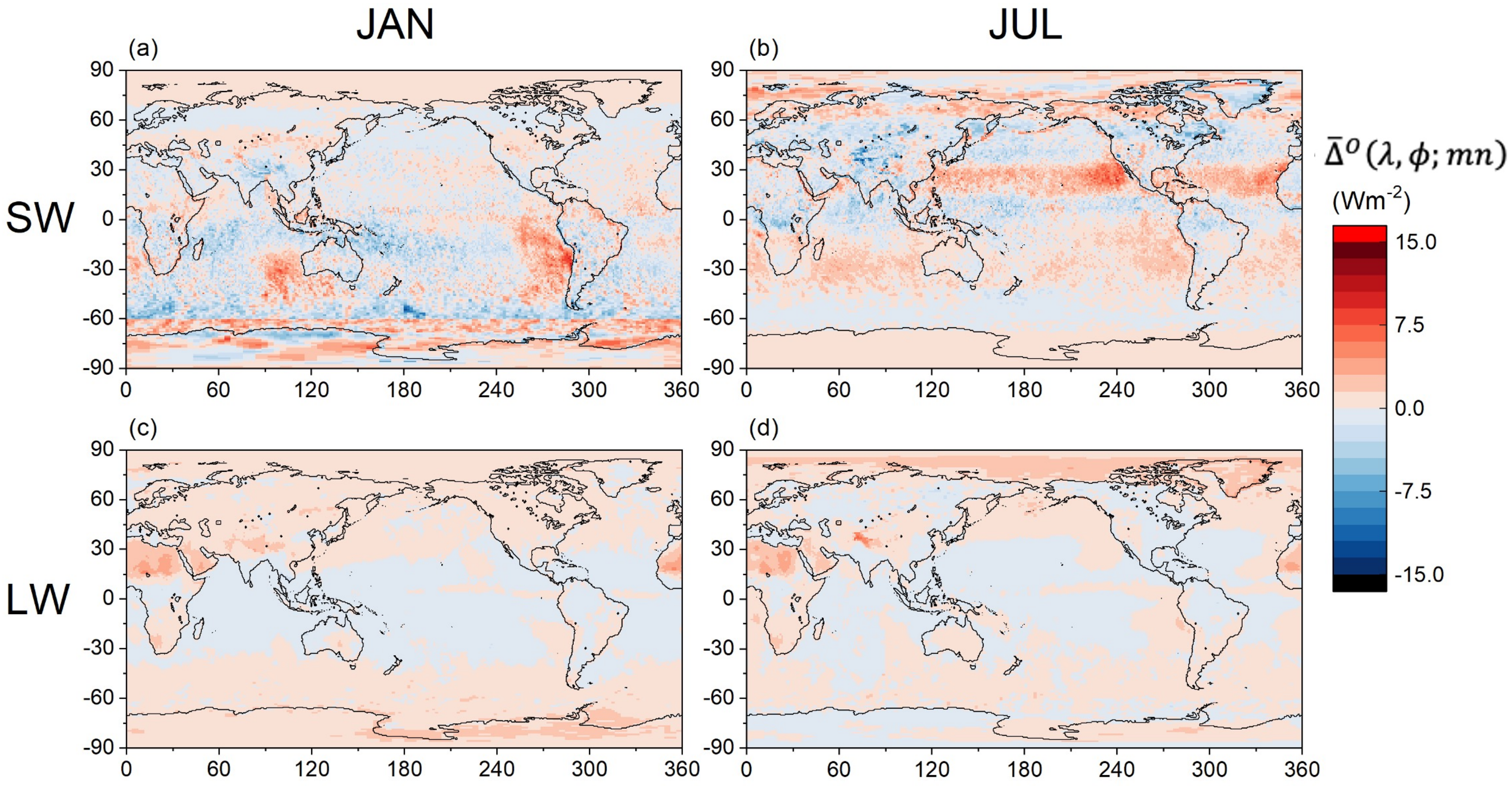
$\bar{F}_T^O(\lambda,\phi;mn)$ = Terra climatological monthly regional mean flux for overlap period

$\bar{F}_{TA}^O(\lambda,\phi;mn)$ = Terra+Aqua climatological monthly regional mean flux for overlap period

$\delta F_T(\lambda,\phi;yr,mn)$ = Terra monthly regional mean flux anomaly

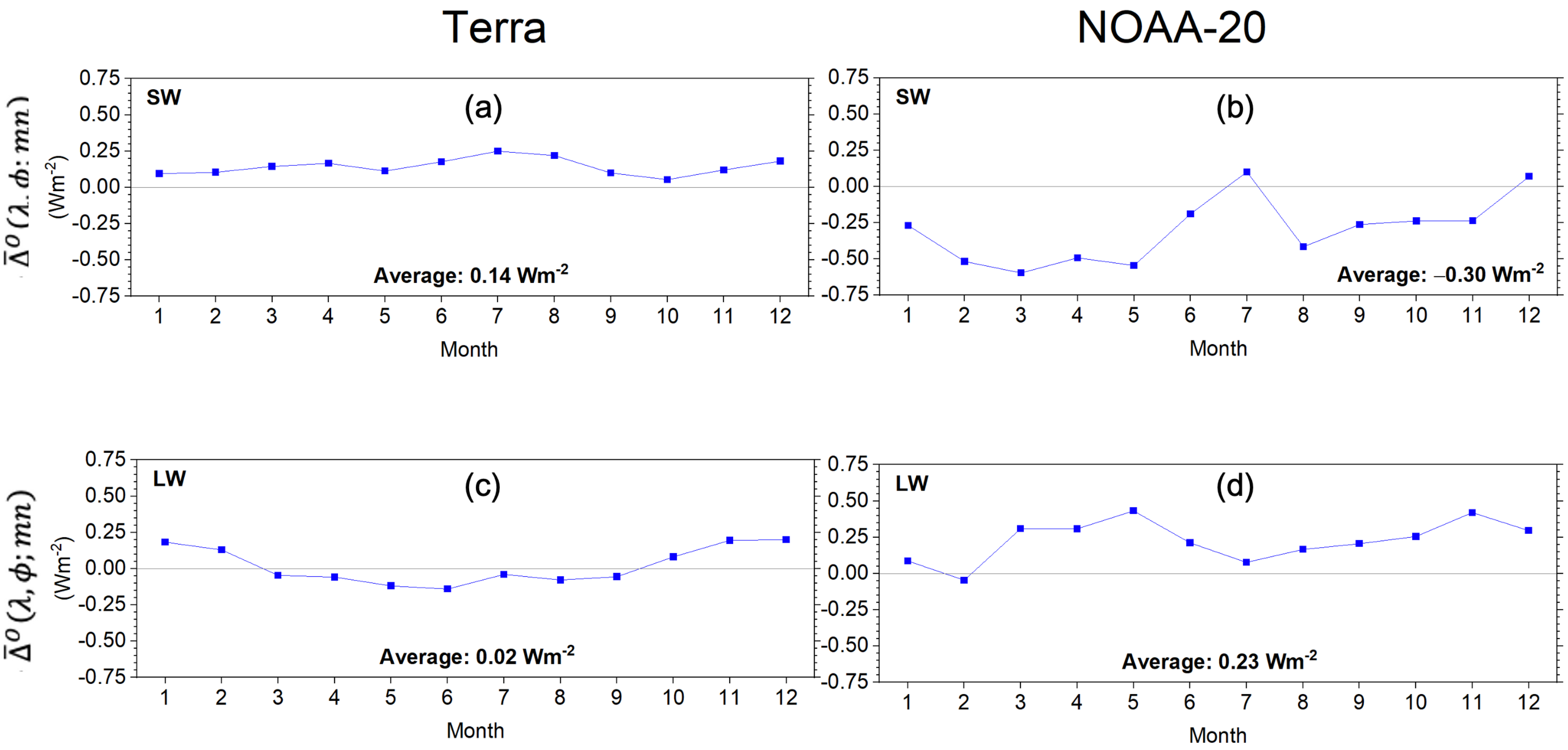


NOAA-20 All-Sky SW and LW TOA Flux Climatological Adjustments



RMS of monthly regional values: ≈2 Wm^{-2} for SW and ≈0.7 Wm^{-2} for LW

Global Average Climatological Adjustments for Terra and NOAA-20



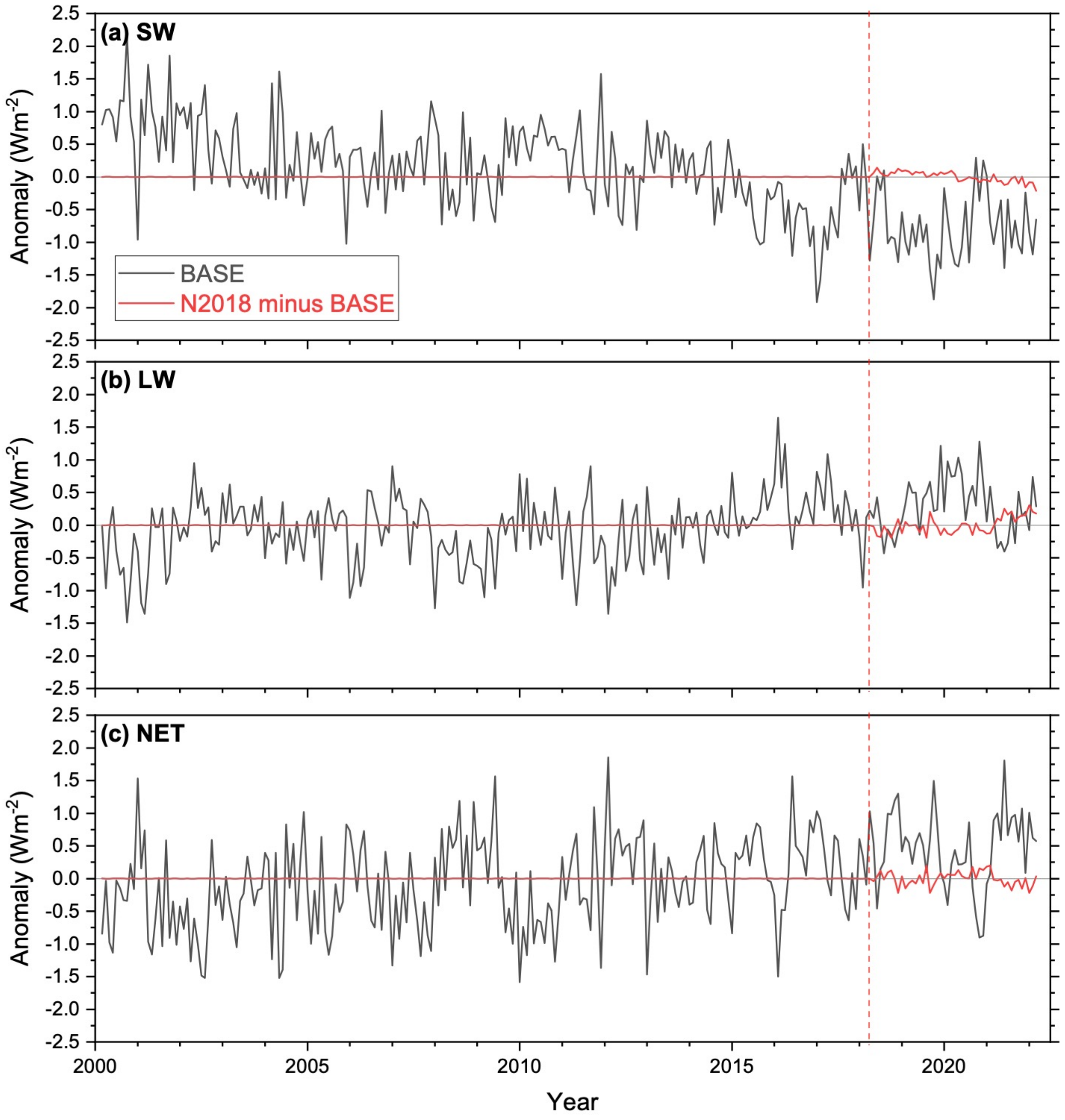
Validation of Methodology

- Focus on the transition from Terra+Aqua to NOAA-20 (all-sky)
- Assume the transition to NOAA-20 occurs in 05/2018 instead of 04/2022 used in the official EBAF Edition 4.2 product.
- Compare time series of anomalies from:

BASE: Terra (03/2000-06/2002) ➜ Terra+Aqua (07/2002-03/2022)

N2018: Terra (03/2000-06/2002) ➜ Terra+Aqua (07/2002-04/2018) ➜ NOAA-20 (05/2018-03/2022)

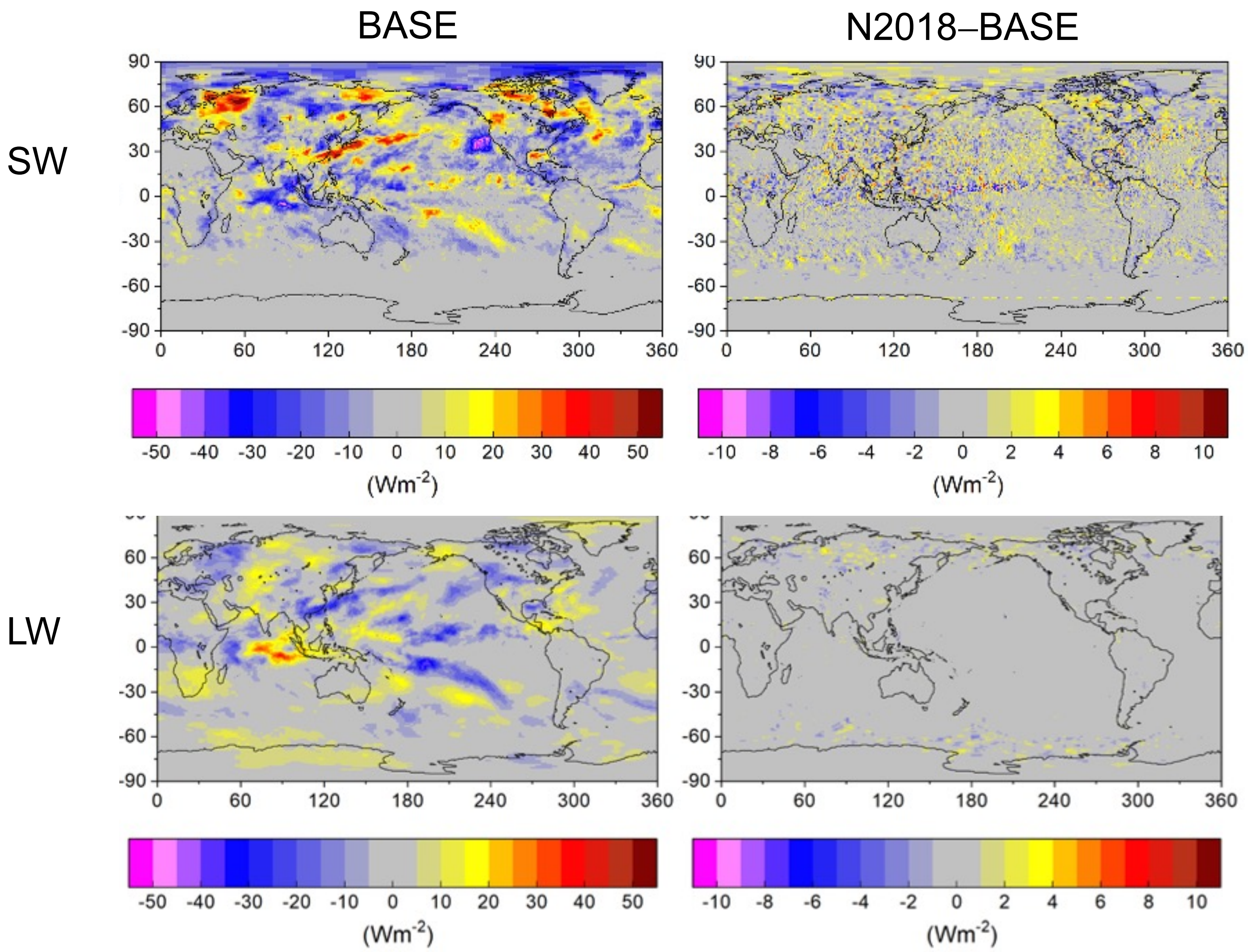
Global All-Sky TOA Flux Anomalies: BASE vs N2018 (03/2000-03/2022)



Trends and Standard Deviations for BASE and N2018−BASE

		Trend (03/2000-03/2022) (Wm^{-2} per decade)		Anomaly Std (05/2018-03/2022) (Wm^{-2})	
		BASE	N2018–BASE	BASE	N2018–BASE
Global All-Sky	SW	-0.73	0.003	0.49	0.078
	LW	0.27	0.004	0.43	0.13
	NET	0.44	-0.0008	0.57	0.11
Peruvian Stratus	SW	0.60	0.01	8.2	0.63
	LW	0.13	0.002	4.8	0.24
	NET	-0.76	-0.01	7.3	0.71
Global Clear-Sky	SW	-0.37	0.008	0.33	0.08
	LW	-0.11	0.005	0.34	0.11
	NET	0.45	-0.014	0.50	0.14

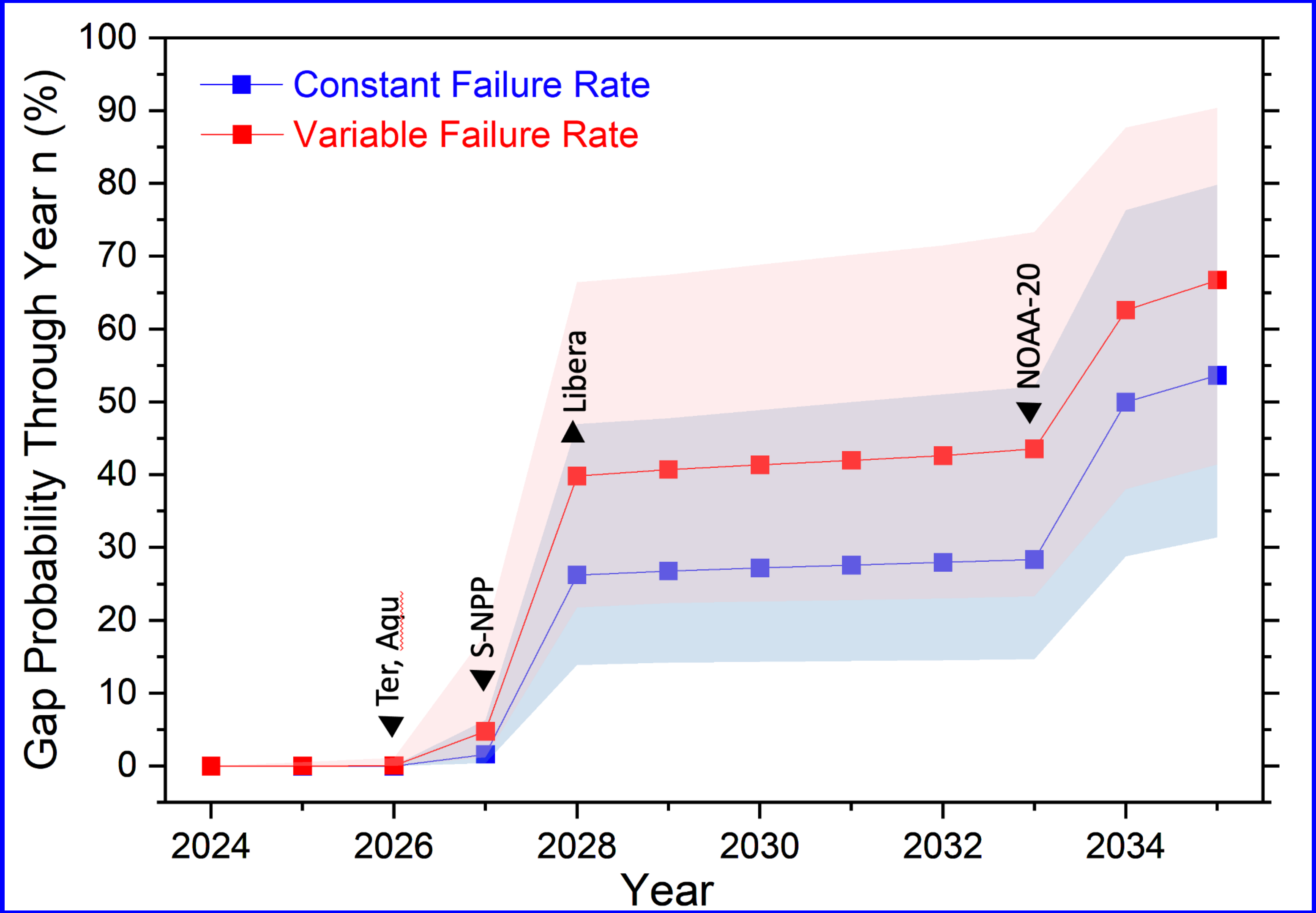
Regional Monthly TOA Flux Anomalies for BASE and N2018−BASE (July 2019)



- Noisy spatial pattern primarily due to sampling differences between Terra+Aqua and NOAA-20
- Std Dev of 1°×1° regional anomalies for N2018-BASE:

  SW: 1.6 Wm^{-2}
  LW: 0.4 Wm^{-2}

Probability of a Data Gap Through January 1 of Year n



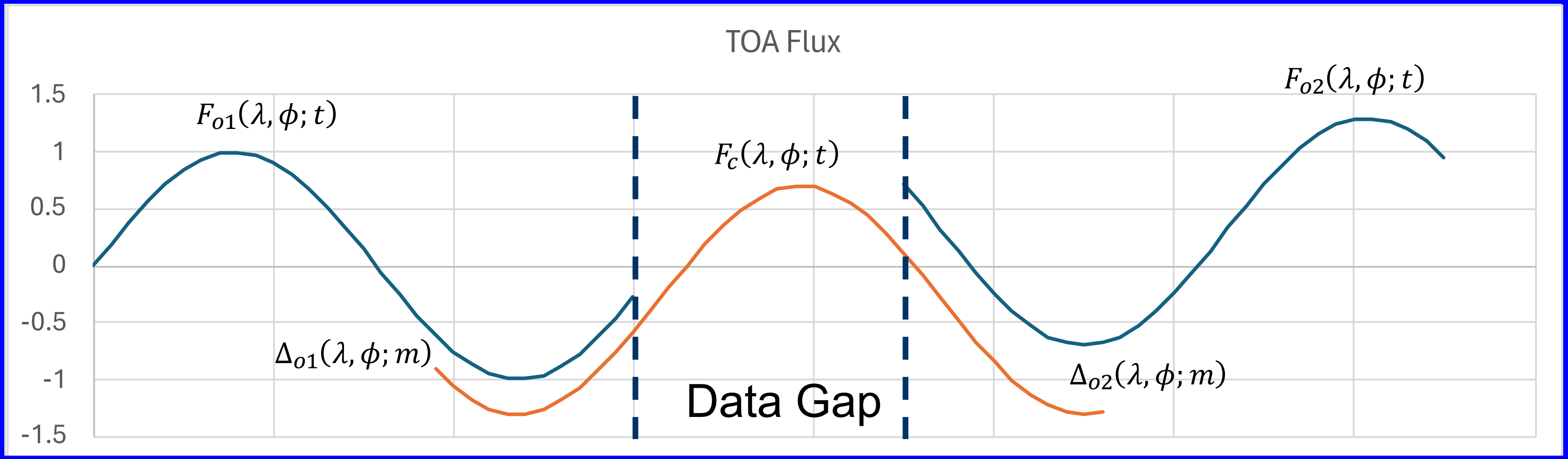
- Probability of a data gap remains less than 5% through January 2027, but then increases sharply to 26% for the constant FR case and 40% for the variable FR case in 2028.
- Avoiding a data gap requires that NOAA-20 survives long enough to ensure sufficient overlap with JPSS-4.

Impact of a Data Gap in the ERB Record

Can we use computed TOA Fluxes to “Bridge” a Data Gap in the ERB Record?

Simulation:

- Introduce an artificial 1-year data gap in the EBAF Ed4.2 time series and use either computed TOA fluxes in SYN1deg Ed4.1 or ERA5 to place the pre- and post-gap periods on the same scale.

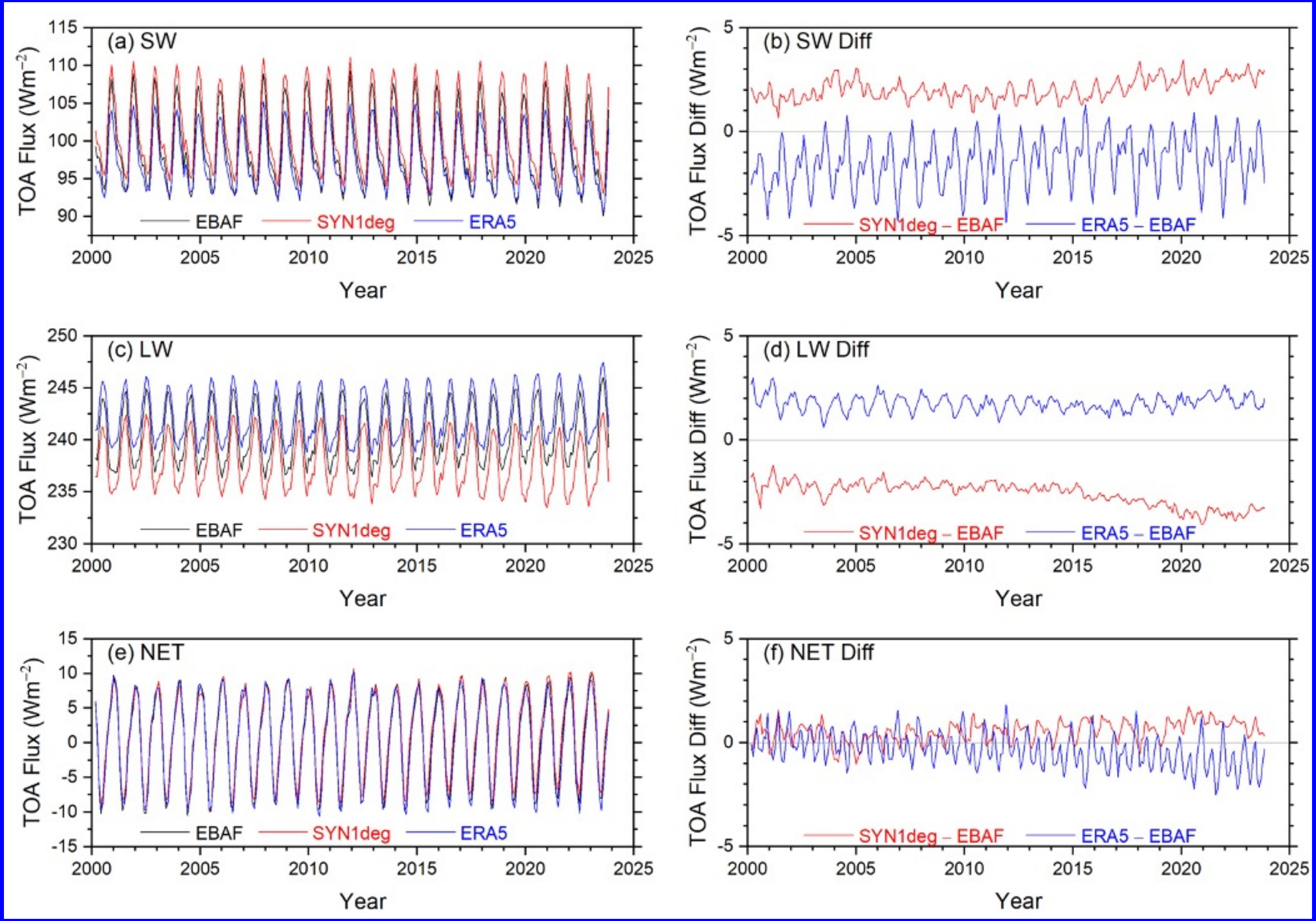


$$\Delta_{o1}(\lambda,\phi;m) = F_{o1}(\lambda,\phi;t) - F_c(\lambda,\phi;t) \qquad \Delta_{o2}(\lambda,\phi;m) = F_c(\lambda,\phi;t) - F_{o2}(\lambda,\phi;t)$$

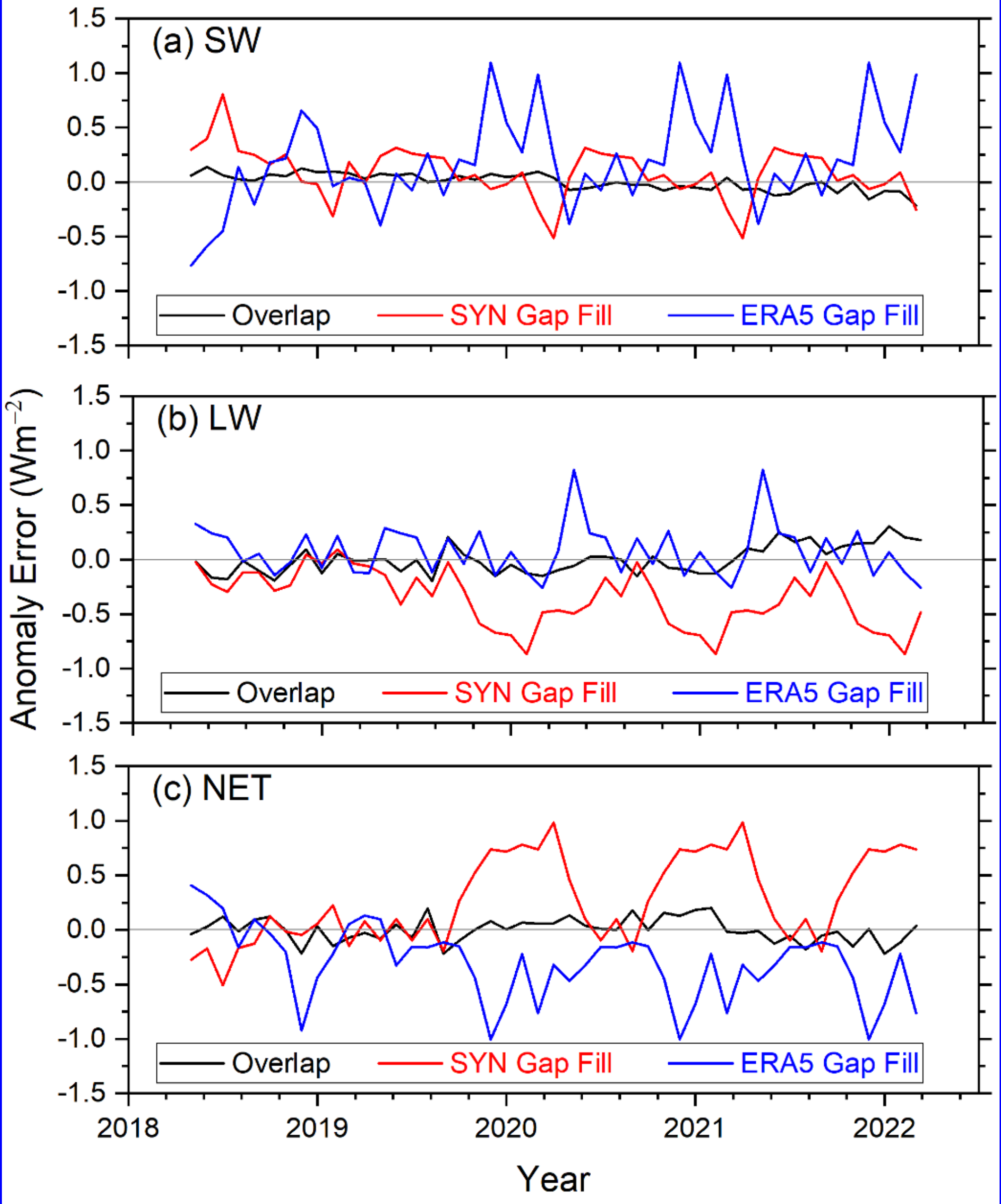
$$F'(\lambda,\phi;t) = \quad F_{o1}(\lambda,\phi;t) \qquad F_c(\lambda,\phi;t) + \Delta_{o1}(\lambda,\phi;m) \qquad F_{o2}(\lambda,\phi;t) + \Delta_{o1}(\lambda,\phi;m) + \Delta_{o2}(\lambda,\phi;m)$$

Global Mean TOA Flux

Global Mean TOA Flux Diff



Error in Global Mean Monthly Anomalies: With and Without Overlap (1-Year Data Gap Starting in May 2018)

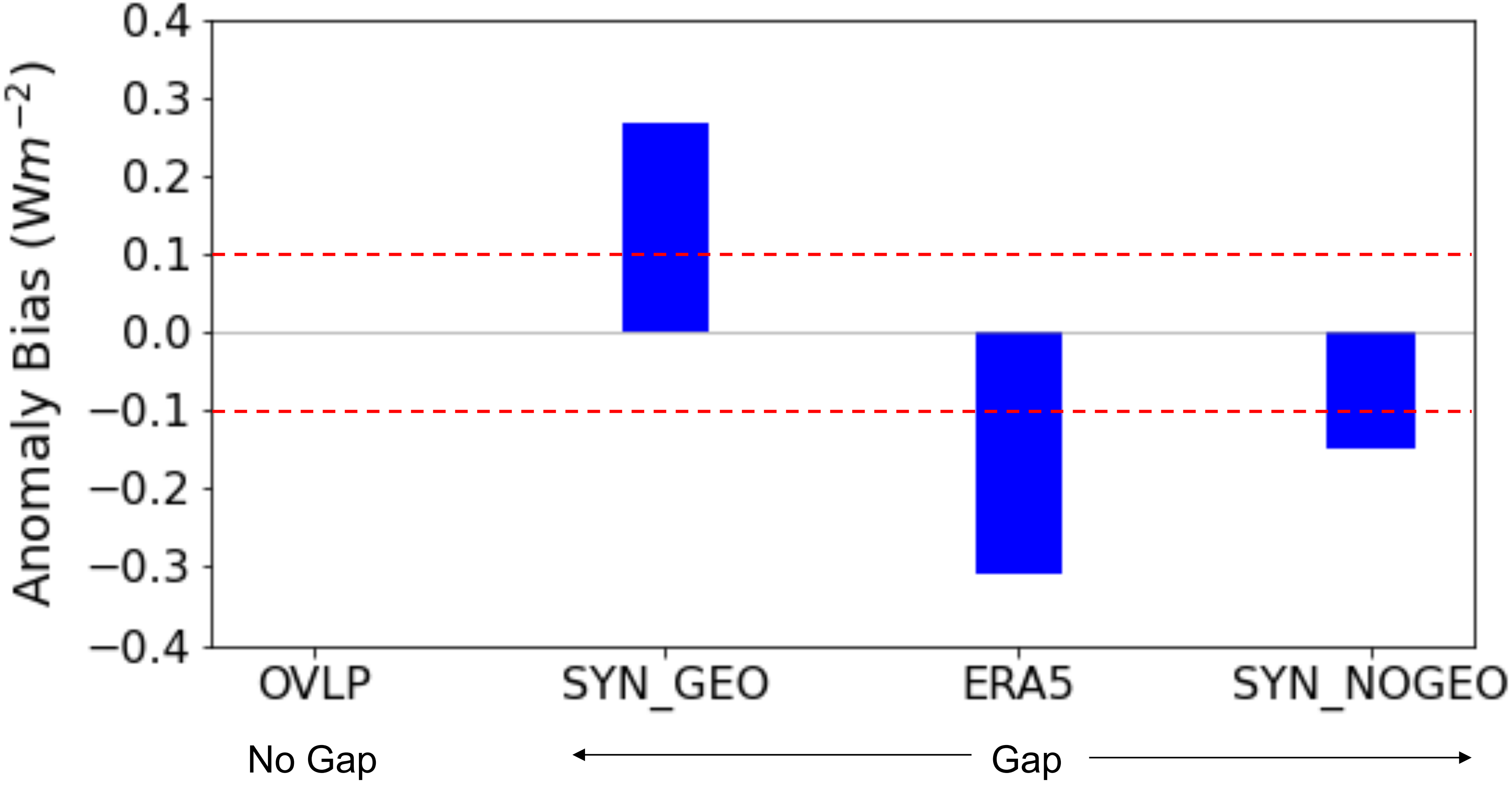


Average and RMS Error in Global Monthly Mean Anomaly for 05/2018-03/2022

	Average Error (Wm^{-2})		
	Overlap	SYN Gap Fill	ERA5 Gap Fill
SW	0.0	0.088	0.20
LW	0.0	−0.36	0.08
NET	0.0	0.27	−0.31
	RMS Error (Wm^{-2})		
	Overlap	SYN Gap Fill	ERA5 Gap Fill
SW	0.078	0.25	0.48
LW	0.13	0.44	0.24
NET	0.11	0.48	0.45

- Compared to the overlap case, bridging the data gap with computed fluxes results in RMS errors in global monthly mean anomaly that are factors of 3-6 larger for SW, 2-3 larger for LW, and 4 times larger for NET.
- Furthermore, a substantial portion of the error is systematic, implying that a discontinuity in the ERB record would be introduced in addition to random error.

Bias in Global Mean NET TOA Flux Anomaly During and Following Data Gap (05/2018-03/2022)



- When a data gap occurs, it is exceedingly difficult to avoid a discontinuity in NET TOA flux CDR

Conclusions

- **Can we ensure a seamless climate data record across satellite transitions?**
  - ➢ Yes, but only if we have overlap between successive missions.
  - ➢ Long-term trends are not impacted; Avoids discontinuity in the record; However, transition can introduce noise not removed by applying climatological adjustment (0.1 Wm^{-2} global; 0.5–1 Wm^{-2} regional)
- **There is a 1 in 3 chance of a data gap in the ERB record in 2028**
  - ➢ Requires that FM6 remains healthy and provides sufficient overlap with Libera
  - ➢ Gap probability grows to 60% by 2035 when Libera is the solo ERB instrument
- **Can we use computed TOA Fluxes to “Bridge” a Data Gap in the ERB Record?**
  - ➢ None of the methods considered here avoid a discontinuity in NET TOA flux CDR, despite near “ideal” case where VIIRS imager is known to be stable across data gap.
  - ➢ Introduces multi-year delay in ERB data product release.
  - ➢ Since there is no “truth”, the actual uncertainty associated with a data gap will never be known.