Perspectives on Maintaining High-quality Global Precipitation Records

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(Thanks to George Huffman, Bob Adler, and several other colleagues/students)

Acknowledgments:

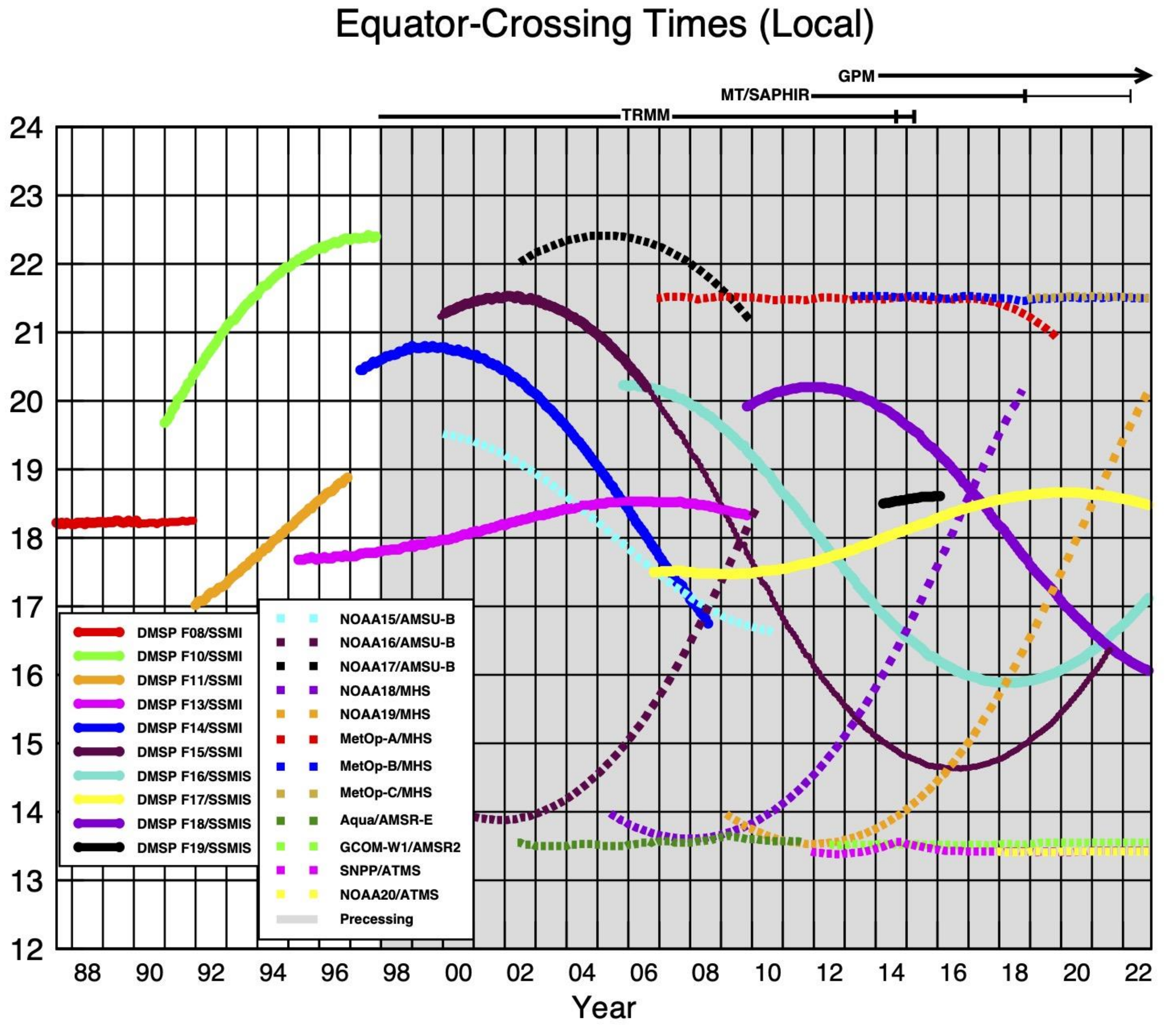
NASA MEaSUREs program

NASA PMM

Virtual Workshop on "Precipitation Estimation from LEO Satellites: Retrieval and Applications," March 1-2, 2023

Tucson, AZ, March 2, 2023

1 hour ago

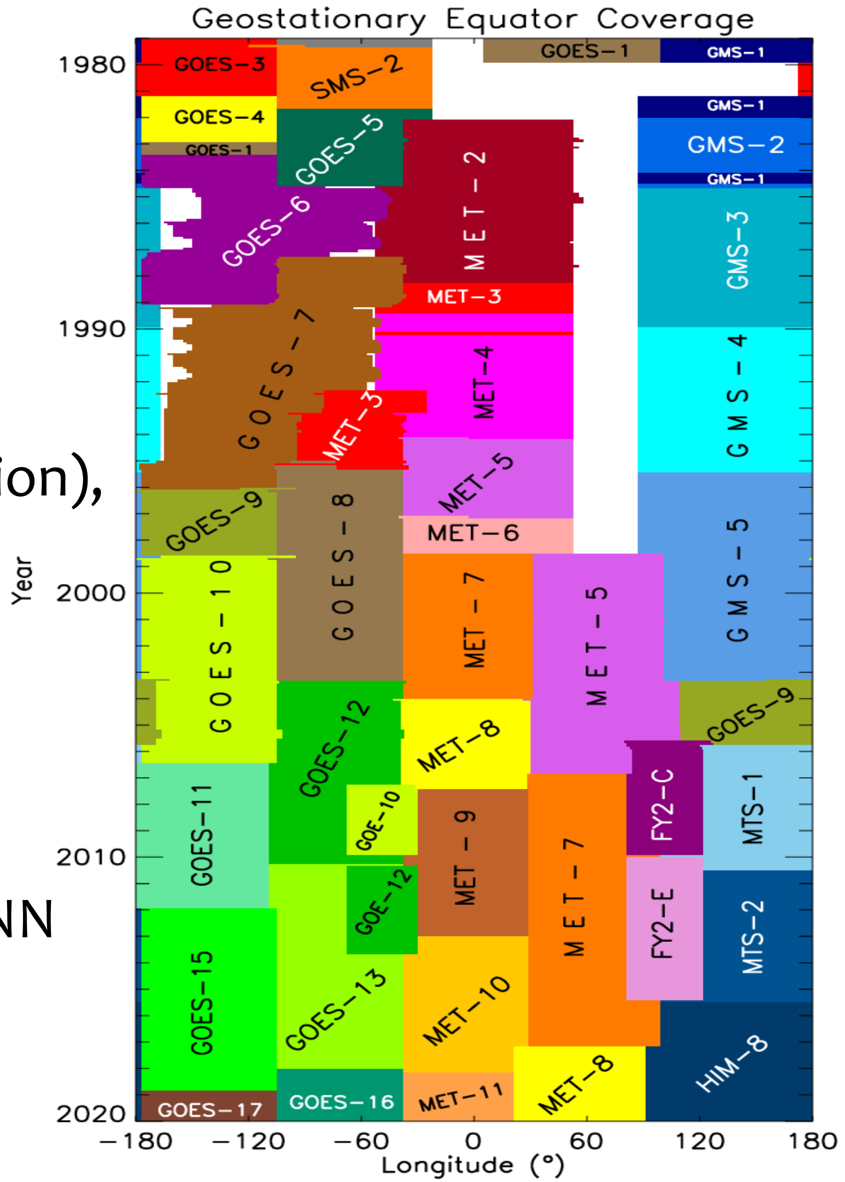


Ascending passes (F08 descending); satellites depicted above graph precess throughout the day.
Image by Eric Nelkin (SSAI), 29 November 2022, NASA/Goddard Space Flight Center, Greenbelt, MD.

Important points to consider for weather and climate products:

- Local time observation continuity/consistency
- Diurnal cycle sampling
- Satellite/Orbit Drift
- Sensors quality (spatial, temporal, spectral density)
- Sensors Density
- Sensors coverage

Geostationary IR observations remain critical for precipitation products (High spatiotemporal Res., long record)



Current IR data used by precipitation products:

(1) NOAA Gridded Satellite (GridSat) B1 data

for CDR . E.G.,PERSIANN-CDR , GPCP

- Going back to 1980
- Covering 70 deg. S/N
- 0.07x0.07 deg. lat/lon

- **VIS,**
- **IR (window)** – CDR (more extensive calibration),
- **IR WV**

Reference:

Knapp, K. R., 2008: Scientific data stewardship of International Satellite Cloud Climatology Project B1 global geostationary observations. *Journal of Applied Remote Sensing*, 2, 023548, doi:10.1117/1.3043461.

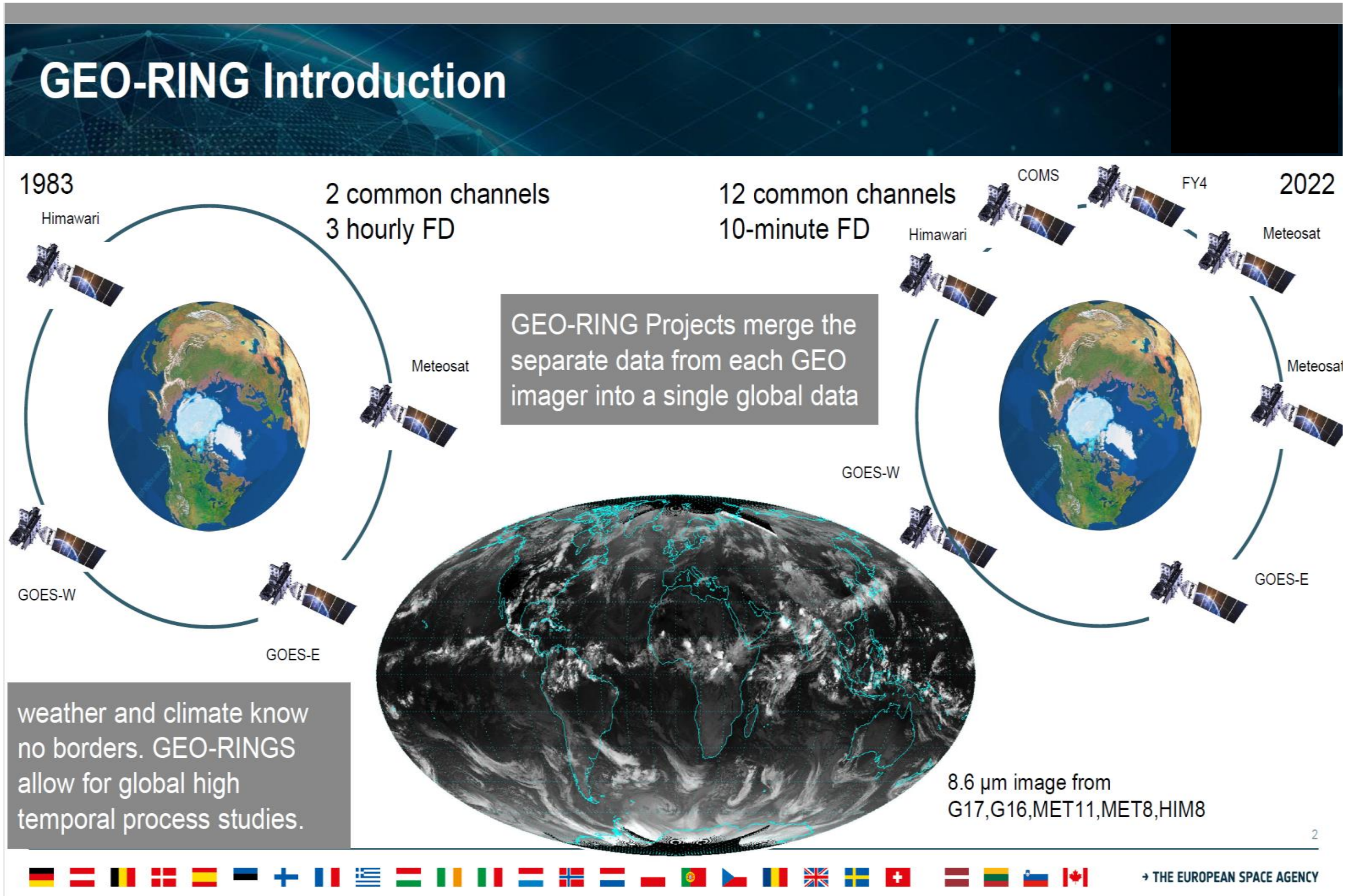
(2) NOAA CPC IR

for multi-sensor precipitation products CMORPH, IMERG, PERSIANN

- Higher resolution (4km, 30 min)
- Going back to 2000
- Only 1 channel (IR-window)

Reference: Joyce, R., J. Janowiak, and G. Huffman, 2001: Latitudinally and Seasonally Dependent Zenith-Angle Corrections for Geostationary Satellite IR Brightness Temperatures. *Journal of Applied Meteorology*, **40,** 689-703.

GEO-RING & ISCCP-NG



Slide from Andrew Heidinger NOAA/NESDIS

- In 2009 GEWEX initiated ISCCP-NG to exploit the new GEO-RING.
- ISCCP-NG will extend the capabilities:
  (a) 2 spectral bands→ ~16 bands,
  (b) 3 hrs -> 10 mn
  (Merged global product is needed)
- We are hoping for quasi-global multi-spectral precipitation estimation
- How far can we cover higher latitudes given the higher resolution of newer Geostationary sensors? (70 deg?)
- For CDR still consistency matters: spatial res. , temporal res. , spectral res. , and latitudinal extent

Multispectral data can improve precipitation estimate

JOURNAL OF HYDROMETEOROLOGY VOL

PERSIANN-MSA: A Precipitation Estimation Method from Satellite-Based Multispectral Analysis

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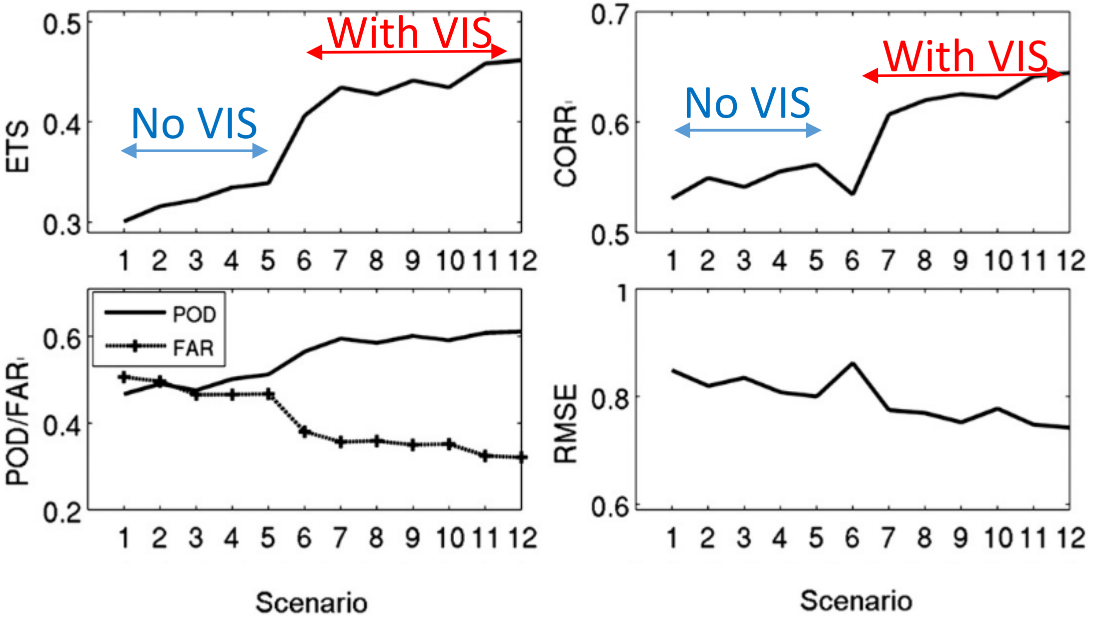
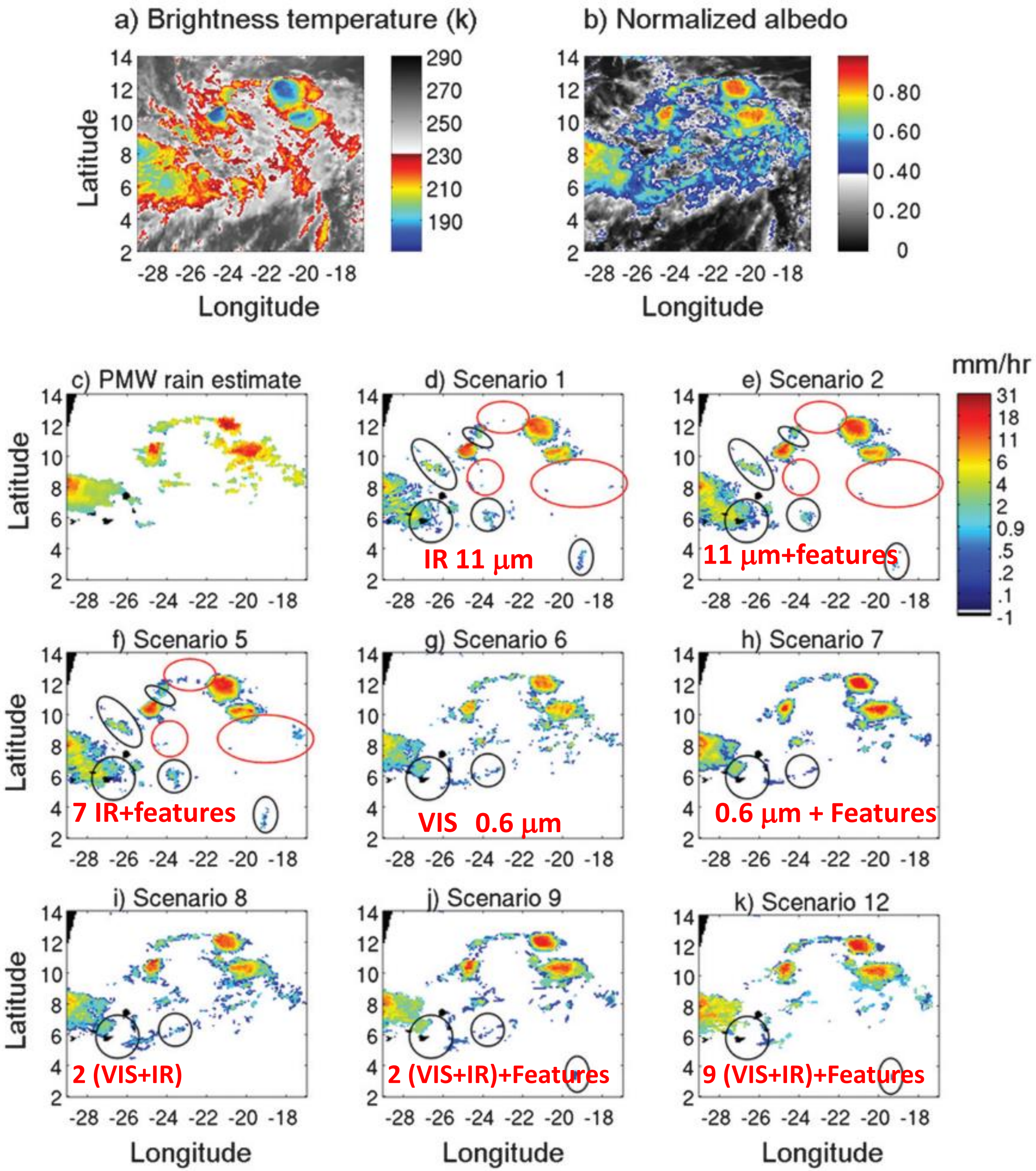
(Manuscript received 16 December 2008, in final form 3 June 2009)

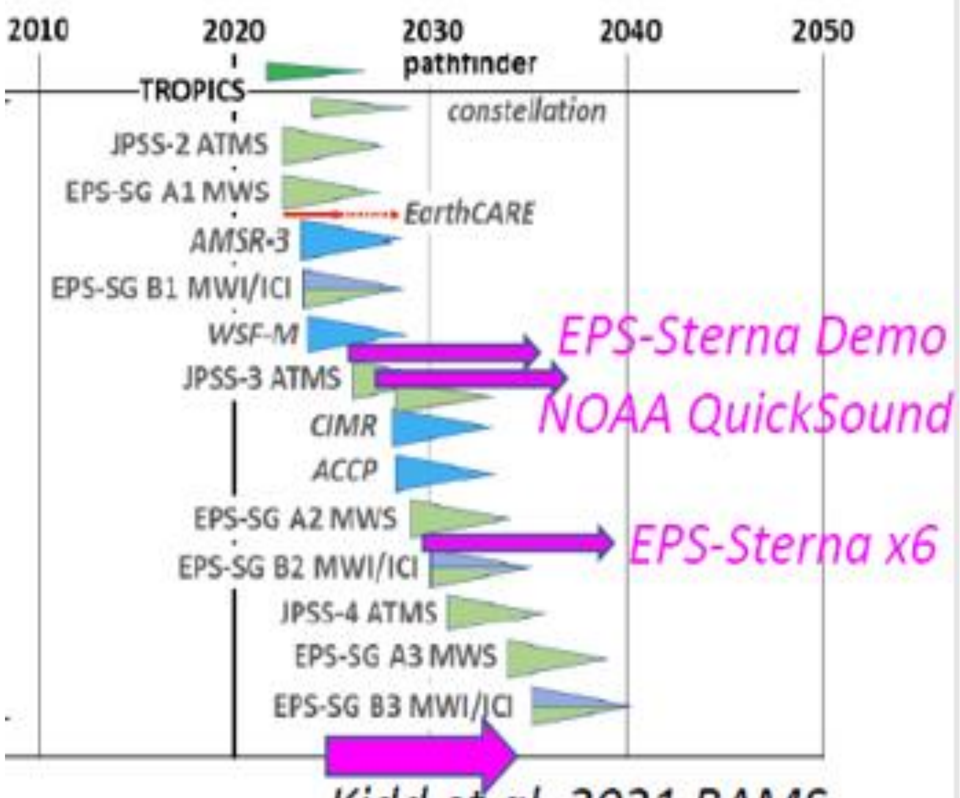




Behrangi et al. 2009

PMW precipitation products

- PMW precipitation products have been critical to provide often more accurate precipitation estimate than IR data. They have been used to improve GEO-Based precipitation products. E.g. of PMW sensors used in the products (SSMI/S, AMSU/MHS, AMSR, TMI, GMI, ATMS, TROPICS, …)
- Among those SSMI/SSMIS have been important to their long-record.
- After 35 years of SSMI/SSMIS, DMSP will continue with the **Weather System Follow-on Microwave (WSF-M). This is important for consistency of data record.** E.g., GPCP has used 6 a.m./p.m. SSMI/SSMIS for long-term continuity/consistency.
- **Several other missions will continue PMW obs.** E.g., JPSS, EPS-SG, AMSR3, AOS, tomorrow.io sounders, …
- Using these products may not be too difficult in the merged precipitation products (although controlling the jumps as one sensor shows up and disappear might be important), but it not often straightforward to satisfy CDR standards of consistency



Kidd et al. 2021 BAMS

tomorrow.io
10 radars &
18 PMW sounders

Radar precipitation products

- They are important to inform PMW precipitation products
- TRMM PR, CloudSat, and DPR have played critical roles in advancing precipitation products
- However, they have been limited in their temporal resolution and consistency
- Future missions EarthCARE , AOS radars, other resources (e.g., Tomorrow.io Ka radars) will be critical to inform both modeling and remote sensing communities.

How the new instruments can be used in long-term precipitation products?

- Advanced sensors show up at certain time and may or may not last long. This can include both GEO and LEO satellites.

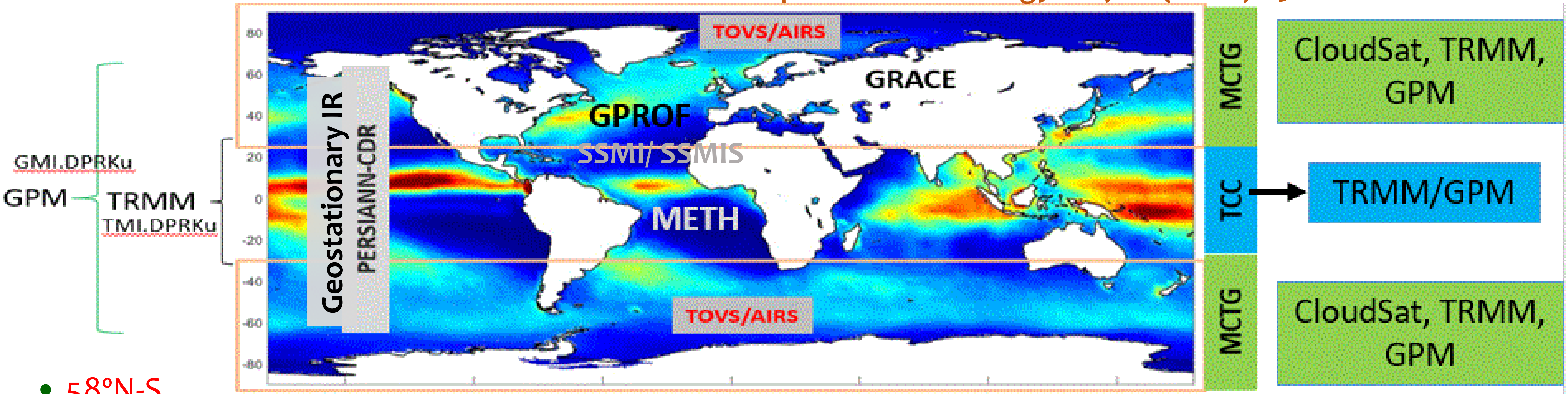
- How can we benefit from them, considering all important features of long-term precipitation records (e.g., consistency, accuracy, spatiotemporal resolution, timeliness, etc.)?

- One way is to improve retrieval data base (e.g., GPROF). How about other ways?

Example: Global Precipitation Climatology Project (GPCP)

- In light of new estimates (TRMM, GPM, CloudSat, GRACE), GPCP was updated in V3
- Enhanced resolution from 2.5° monthly and 1.0°-deg daily to 0.5° monthly and daily.

Main satellites used in the Global Precipitation Climatology Project (GPCP) V3.2

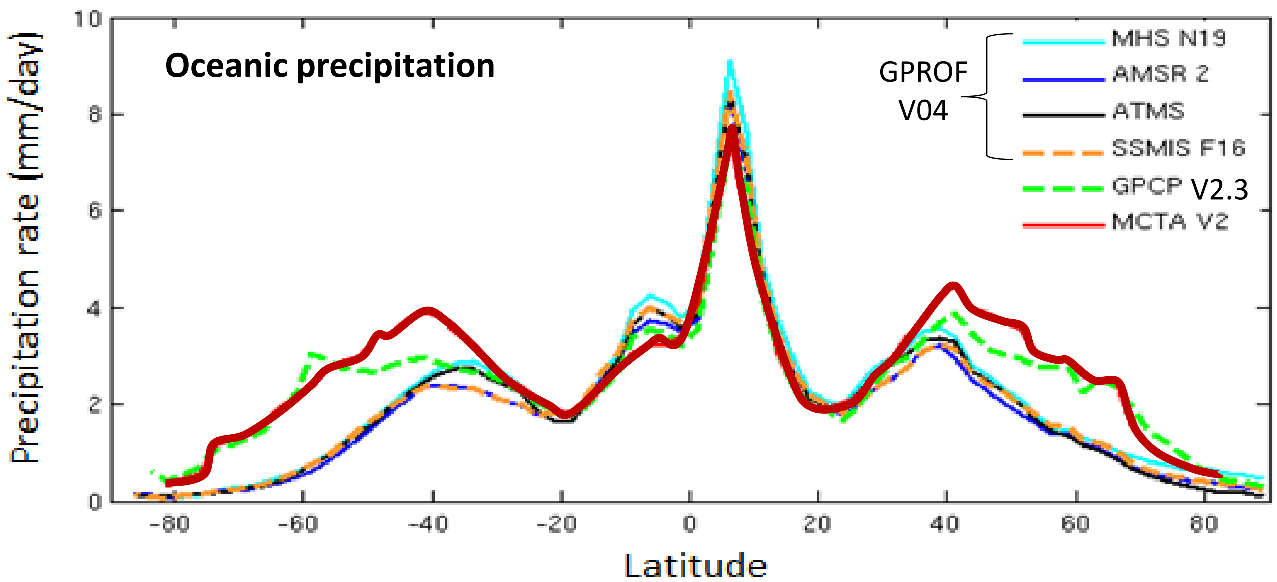


- 58°N-S
  - 1992-present: GEO IR precip histogram-adjusted using GPROF (SSMI /SSMIS) at the 3-hourly scale, calibrated to monthly METH (SSMI/SSMIS), then calibrated with TCC/MCTG climatology blend
  - 1983-1991: GEO IR precip adjusted using monthly climatological (1993-2008) GPROF relationship
- higher latitudes
  - calibrated TOVS/AIRS-IR (globally) adjusted to the MCTG

TCC: Tropical Composite Climatology – Adler et al. MCTG: Merged CloudSat/TRMM/GPM climatology – Behrangi et al.

MCTG: Merged CloudSat, TRMM, GPM climatology

- The heritage of MCTG goes back to MCTA
- MCTA is ***Merged CloudSat CPR, TRMM PR, and AMSR-E*** climatology to account for the entire precipitation histogram from drizzle, light rain, and snow fall (from CloudSat) to intense precipitation from TRMM PR and AMSR-E when TRMM has no coverage.
- The outcomes of MCTA was insightful to GPCP development.
- With the Emergence of GPM, the combined GMI.DPRku was used instead of AMSR-E, the product was named **MCTG: Merged CloudSat (CPR), TRMM(PR), GPM (DPR.GMI)-** (Behrangi et al. 2021)
- The estimate matched the water budget studies

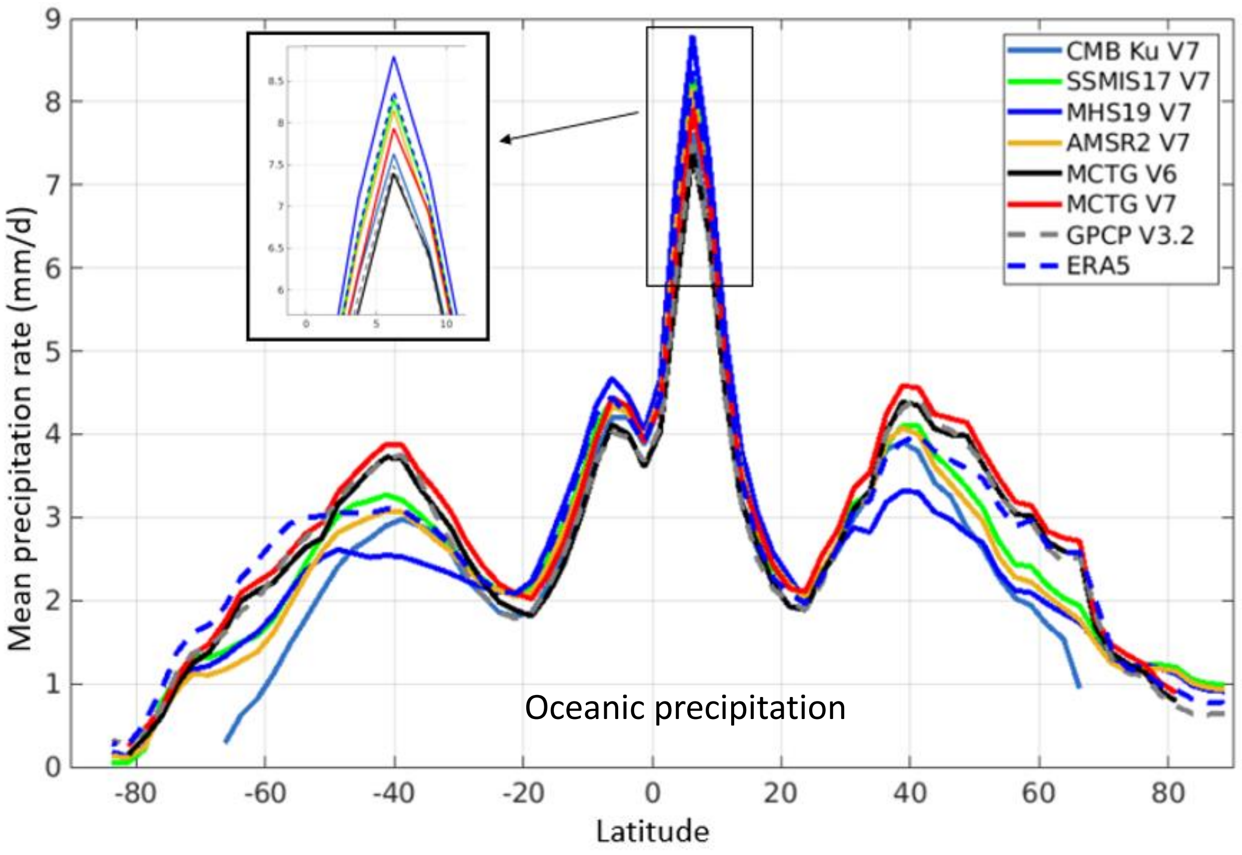


Behrangi et al. (2012, 2014)

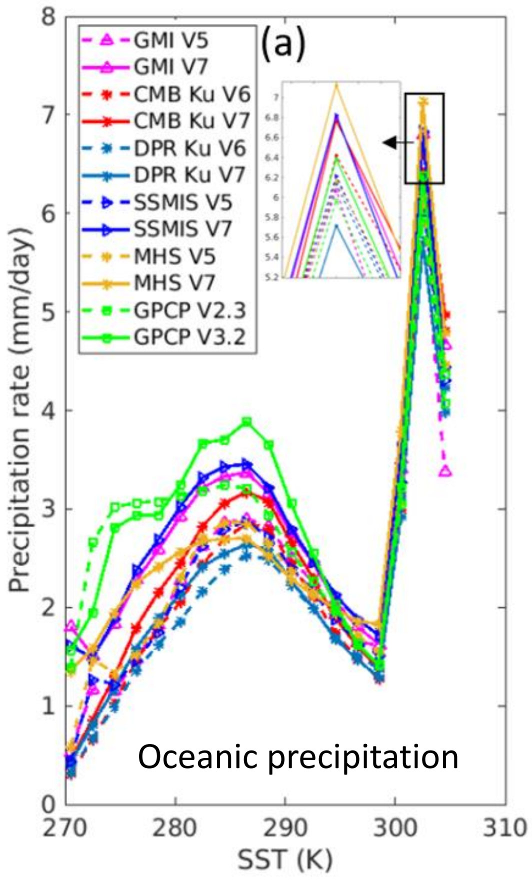
Spread of precipitation products over oceans: Uncertainty?

- Can the spread of the products give us an insight on the uncertainty range?

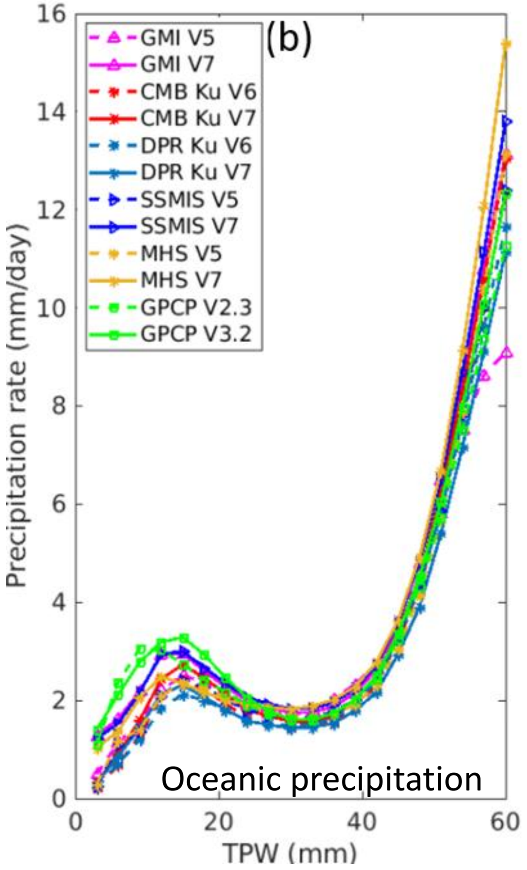
Average versus **Latitude**



Average versus **SST**



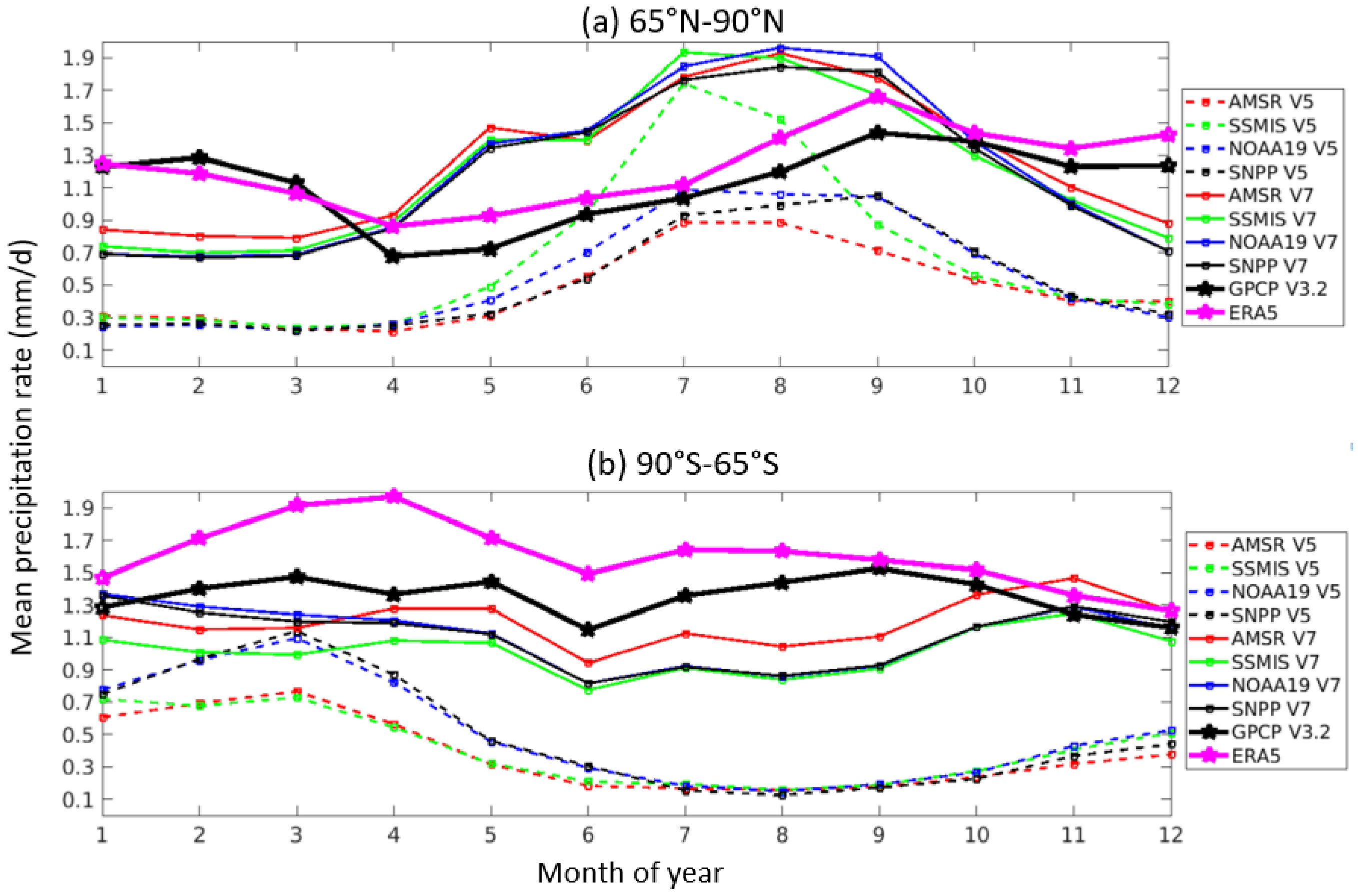
Average versus **TPW**



The Southern Oceans show large spread among the satellite products:
both precipitation magnitude and location of precipitation peak

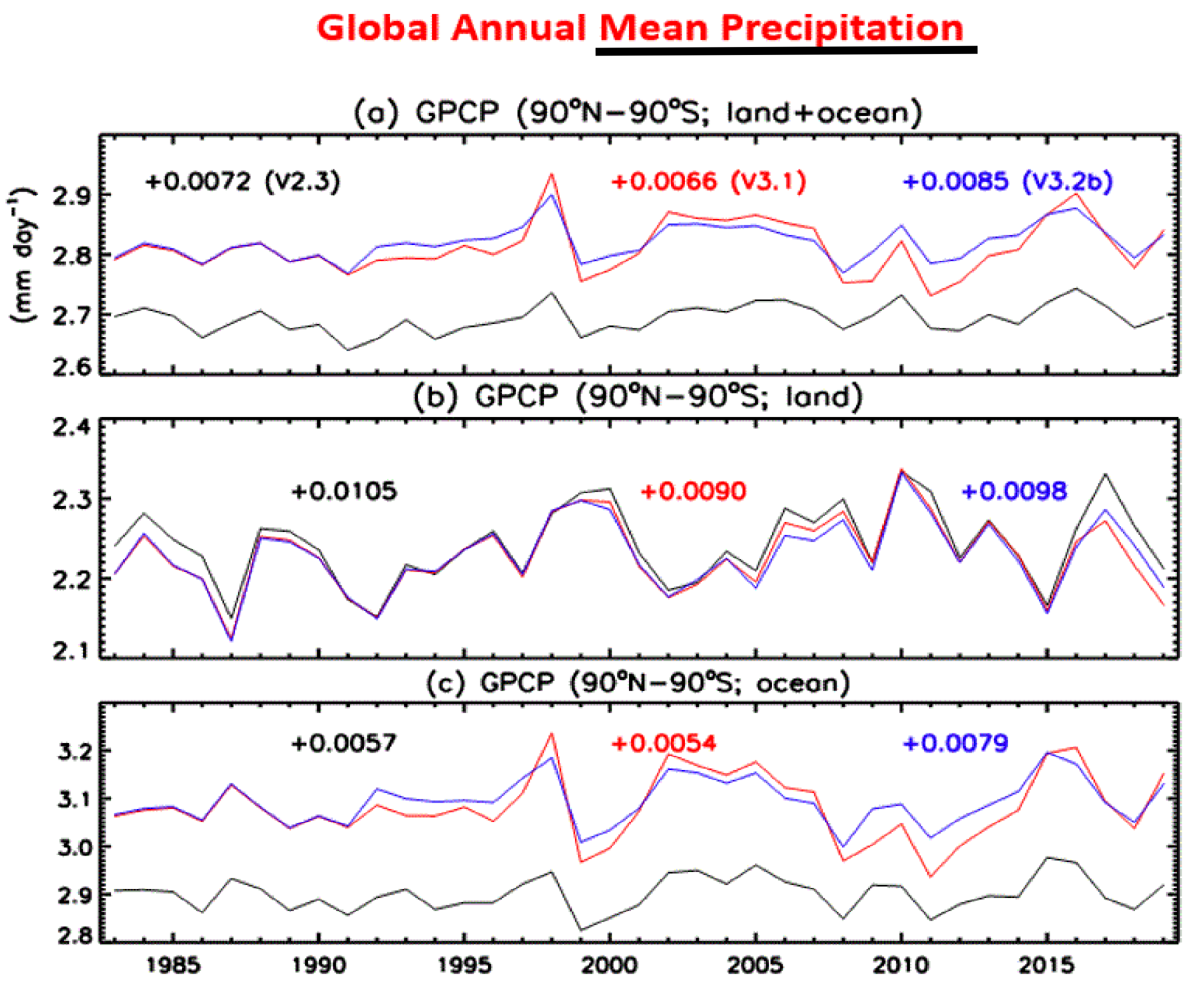
Spread among precipitation products can be seasonal dependent: Uncertainty?

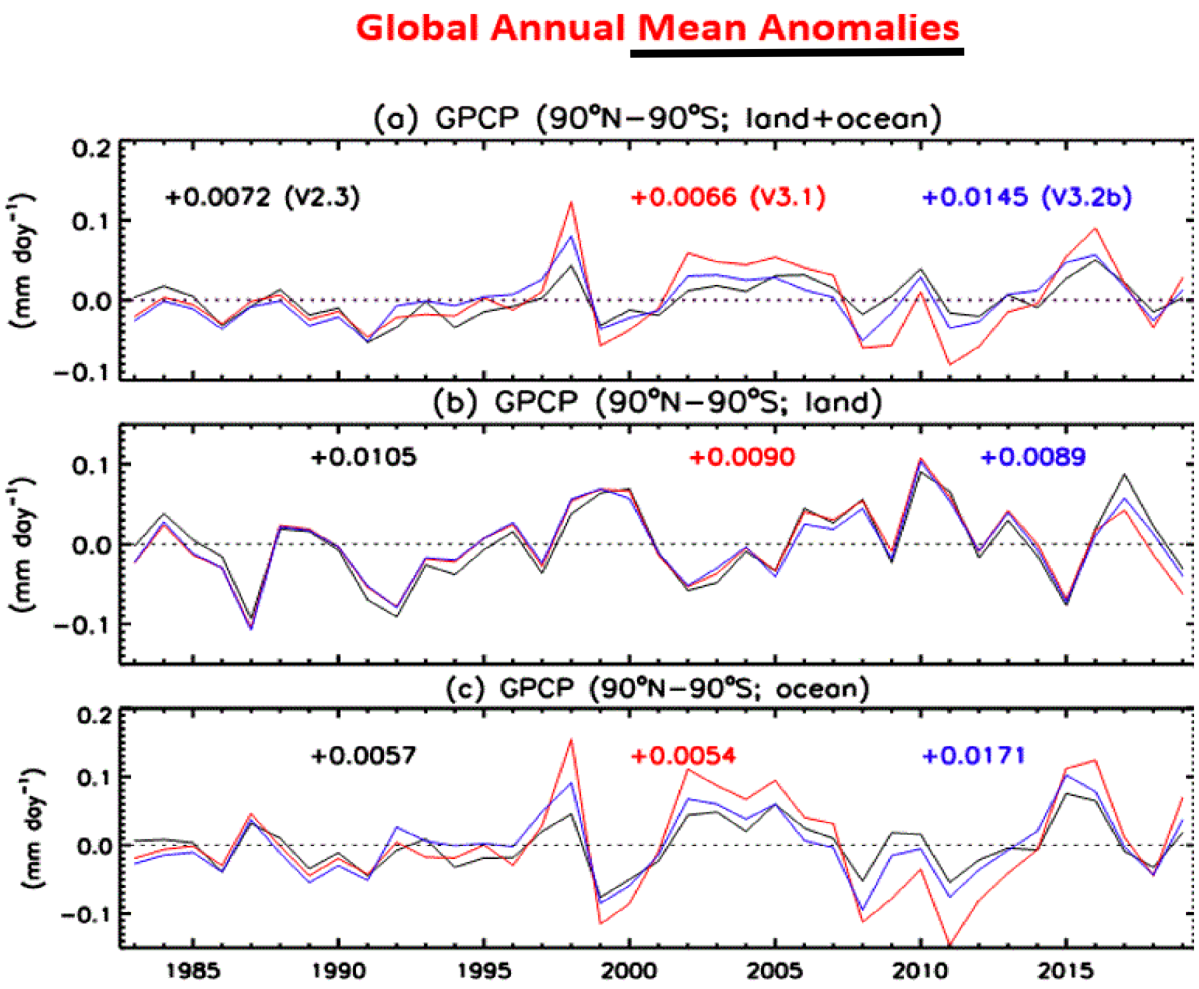
- Inconsistency in capturing precipitation monthly variation exists among satellite precipitation products and reanalysis. It is larger in high latitudes.



Monthly mean oceanic precipitation rates in high latitudes, separately for the Northern and Southern Hemispheres

Annual precipitation variations



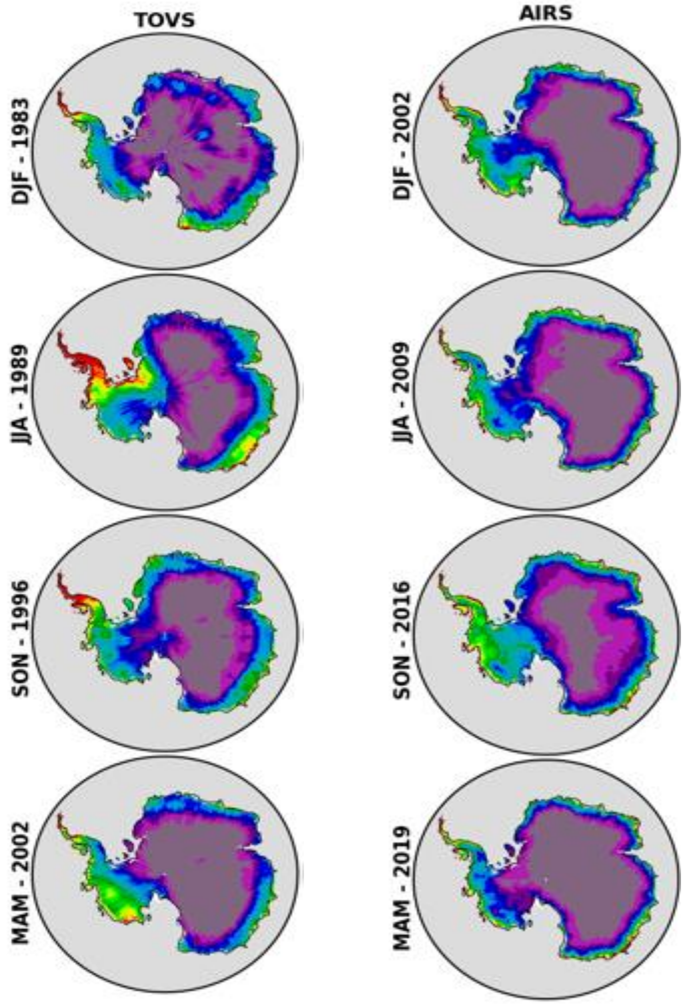


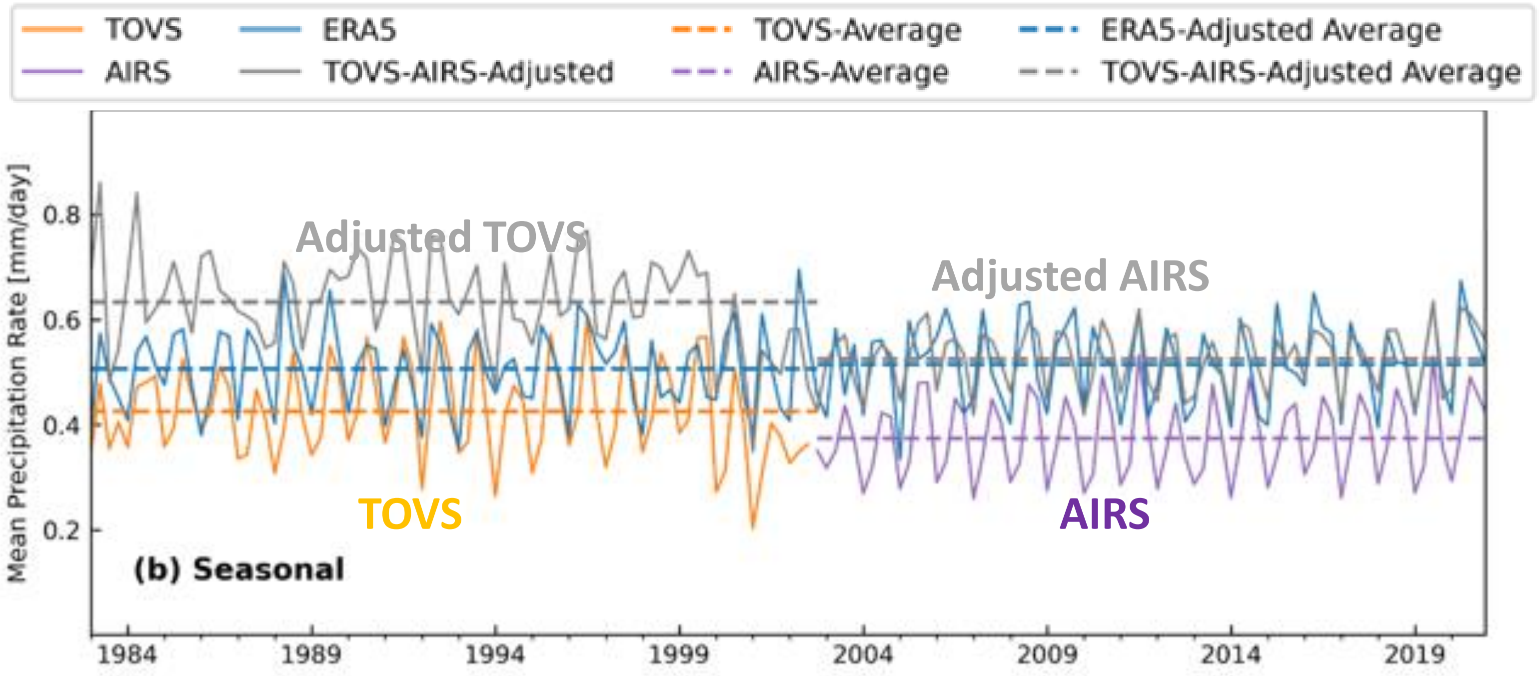
- calibration by TCC and MCTG sets the mean increase in V3.2 relative to V2.3
- near zero trend in global total precipitation
- V3.2 mitigates the large interannual variation that observed in V3.1 (see the anomaly plots; right side)

[Adler et al. ; UMD]

Bias adjustment of time series (long-term data record)

- Bias adjustment may not improve time series unless the time series is consistent
- Adjusting old records (TOVS/AIRS) using higher quality (CloudSat) over Antarctica was found challenging. However, we were able to find a solution.





Time series of Antarctic mean precipitation from TOVS, AIRS, ERA5, their long-term averages (dashed lines), and TOVS-AIRS adjusted by static correction factors. There is a significant difference between TOVS and AIRS averages while ERA5 averages do not indicate any considerable difference between the two periods.

Ehsani M., A. Behrangi, G. Huffman, R. Adler (to be submitted)

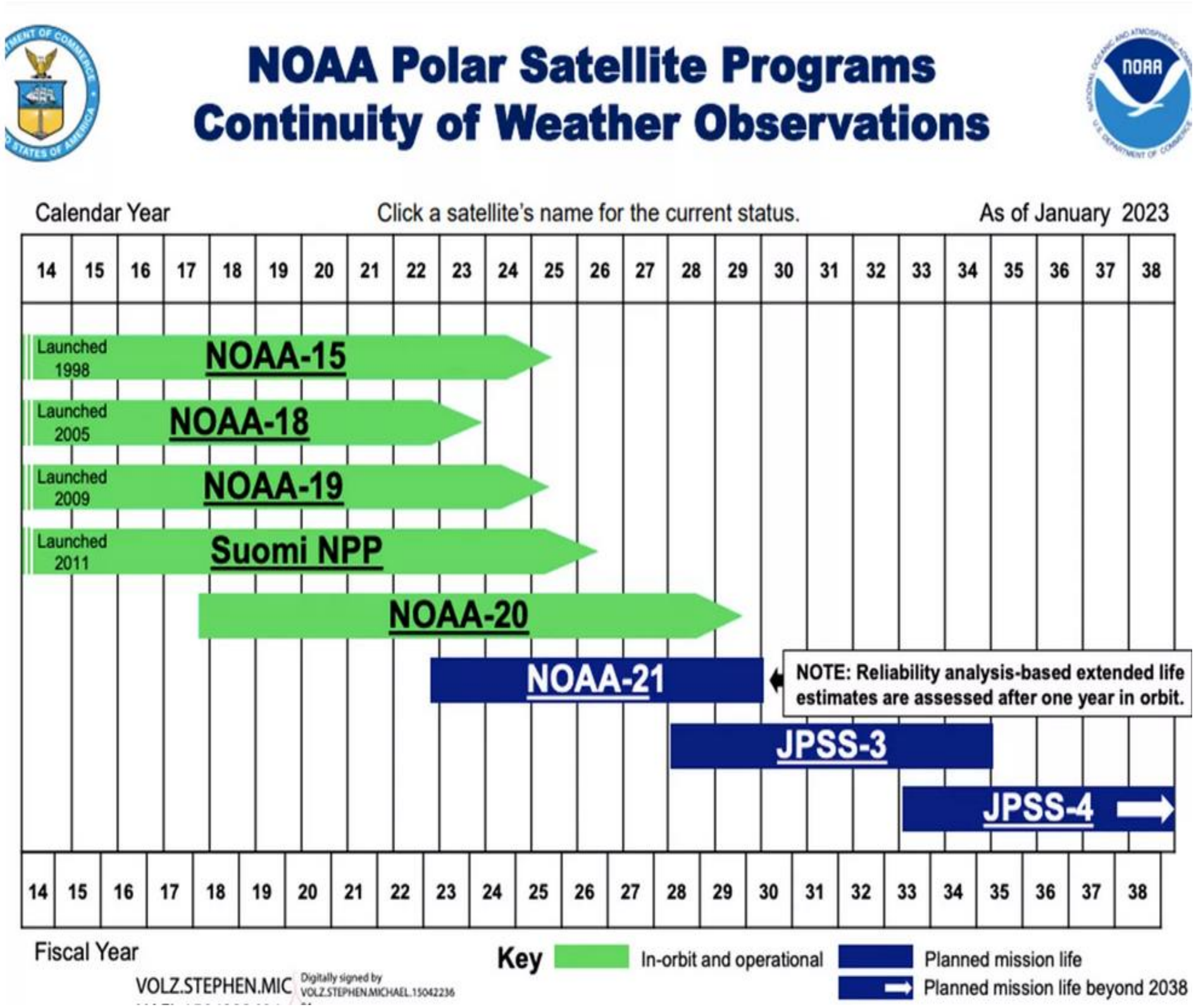
CrIS to continue AIRS and VIIRS to continue AVHRR

Cross-track Infrared Sounder (CrIS)

- CrIS will continue AIRS. CrIS is a key instrument currently flying on the Suomi NPP, NOAA-20 and NOAA-21 satellites. CrIS will also fly on the JPSS-3 and -4 satellites.
- CrIS works in tandem with the Advanced Technology Microwave Sounder (ATMS)

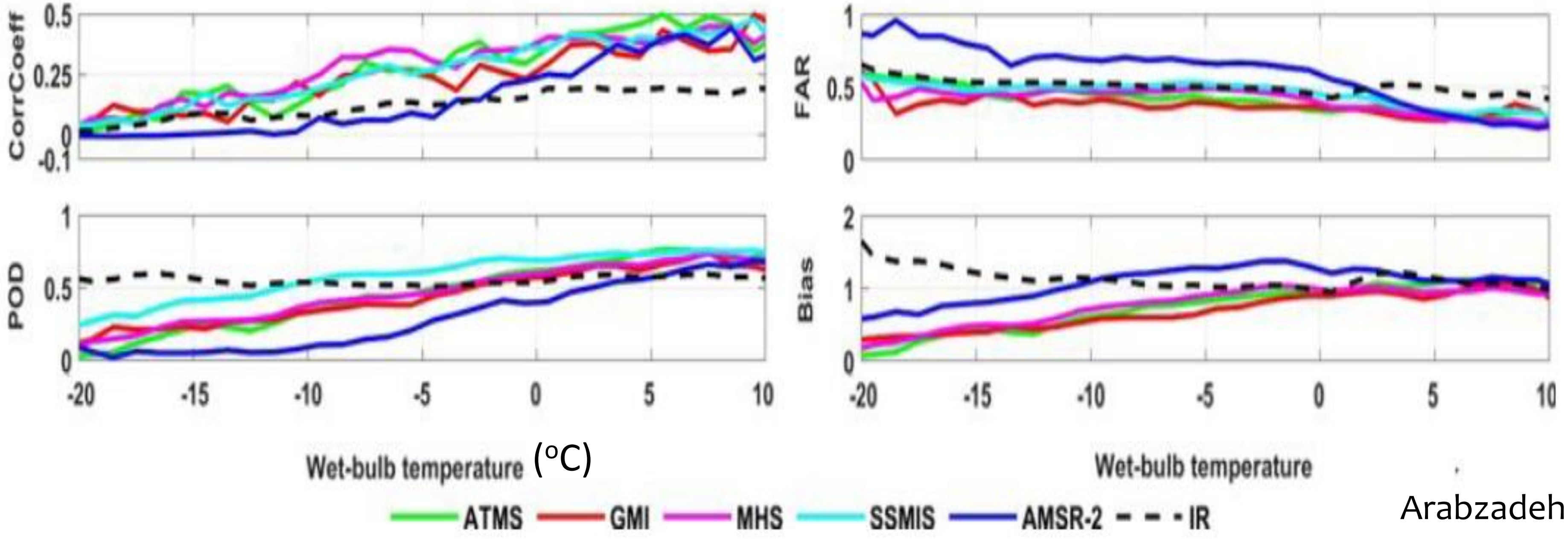
The Visible Infrared Imaging Radiometer Suite (VIIRS)

- VIIRS flying on the Suomi NPP, NOAA-20 and NOAA-21 satellites. VIIRS will also fly on the JPSS-3 and -4 satellites.
- VIIRS will continue AVHRR on NOAA series and MetOps (A,B,&C); METimage on EPS-SG
- GPCP team is actively working on **using AVHRR** with some auxiliary data sets **instead of TOVS/AIRS** to improve consistency



Precipitation estimation skill as a function of regime/surface condition

- Regime dependent error analysis is important. Different variables or combination of variables can be used (near surface temperature, soil moisture, TPW, etc.). An example of surface wetbulb temperature is presented here.
- Clearly as we approach colder temperatures and drier atmosphere both PMW and IR products show lower skill.
- Unfortunately, "high quality" reference observations are often very limited over snow/ice surfaces and at colder temperatures. So considering the length of record AIRS/TOVS/AVHRR are still important options for long-term CDR.



Arabzadeh and Behrangi (2021)

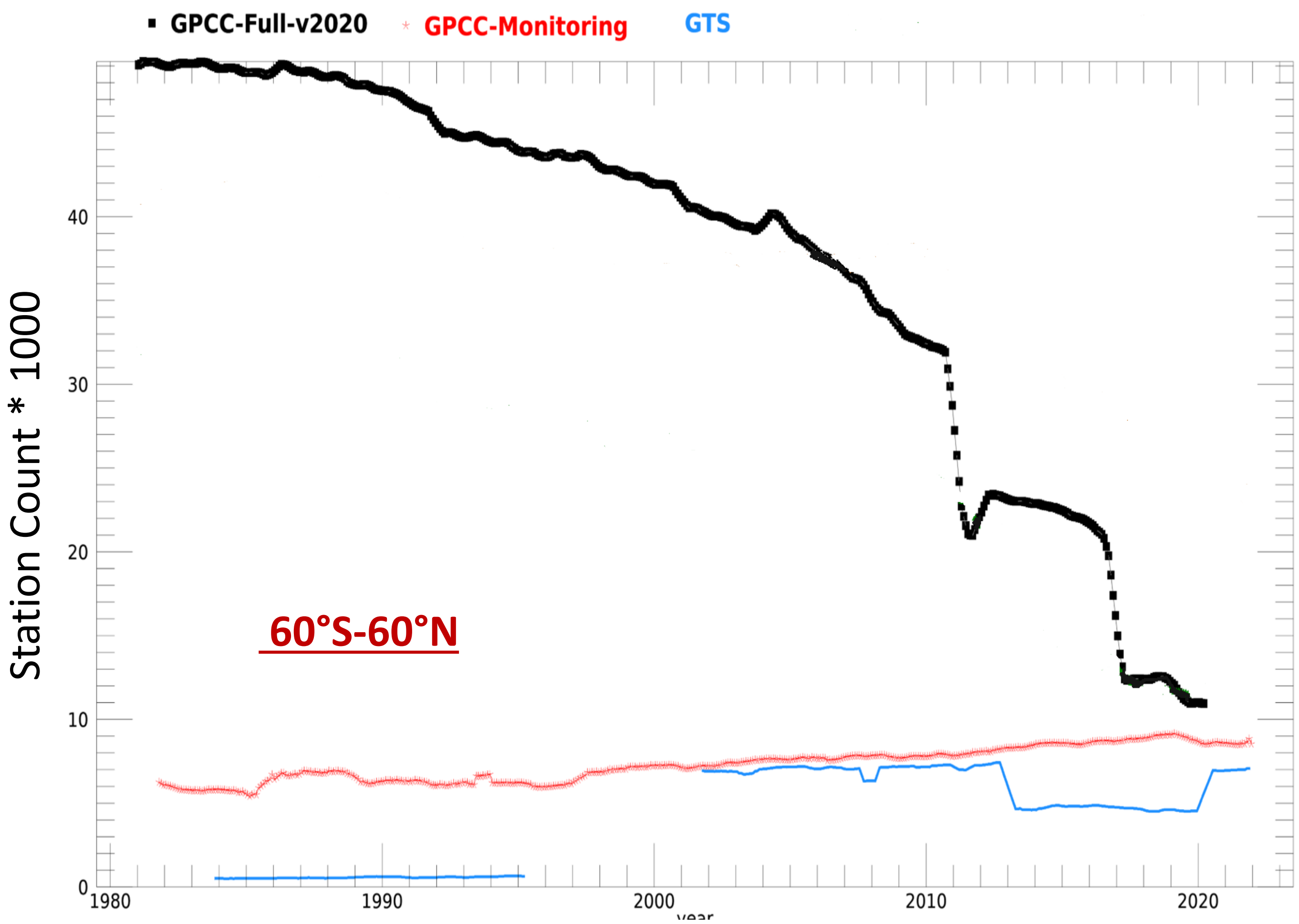
Fig. Assessment of precipitation estimates from IR and various PMW sensors used in IMERG using Stage IV **over snow and ice surfaces** in CONUS. The skill scores are calculated versus wetbulb temperature. Bias score 1 is ideal. AMSR2 clearly shows lower skill than other PMW sensors. The analysis are based on GPROF V05 and PERSIANN-CCS retrievals used in IMERG.

Precipitation estimation over land and bias adjustment using rain gauges

Over land, several challenges exist: (**topography, snow/ice surfaces, land-surface interaction with precipitation**)

However, satellite products heavily rely on rain gauges to reduce their biases.

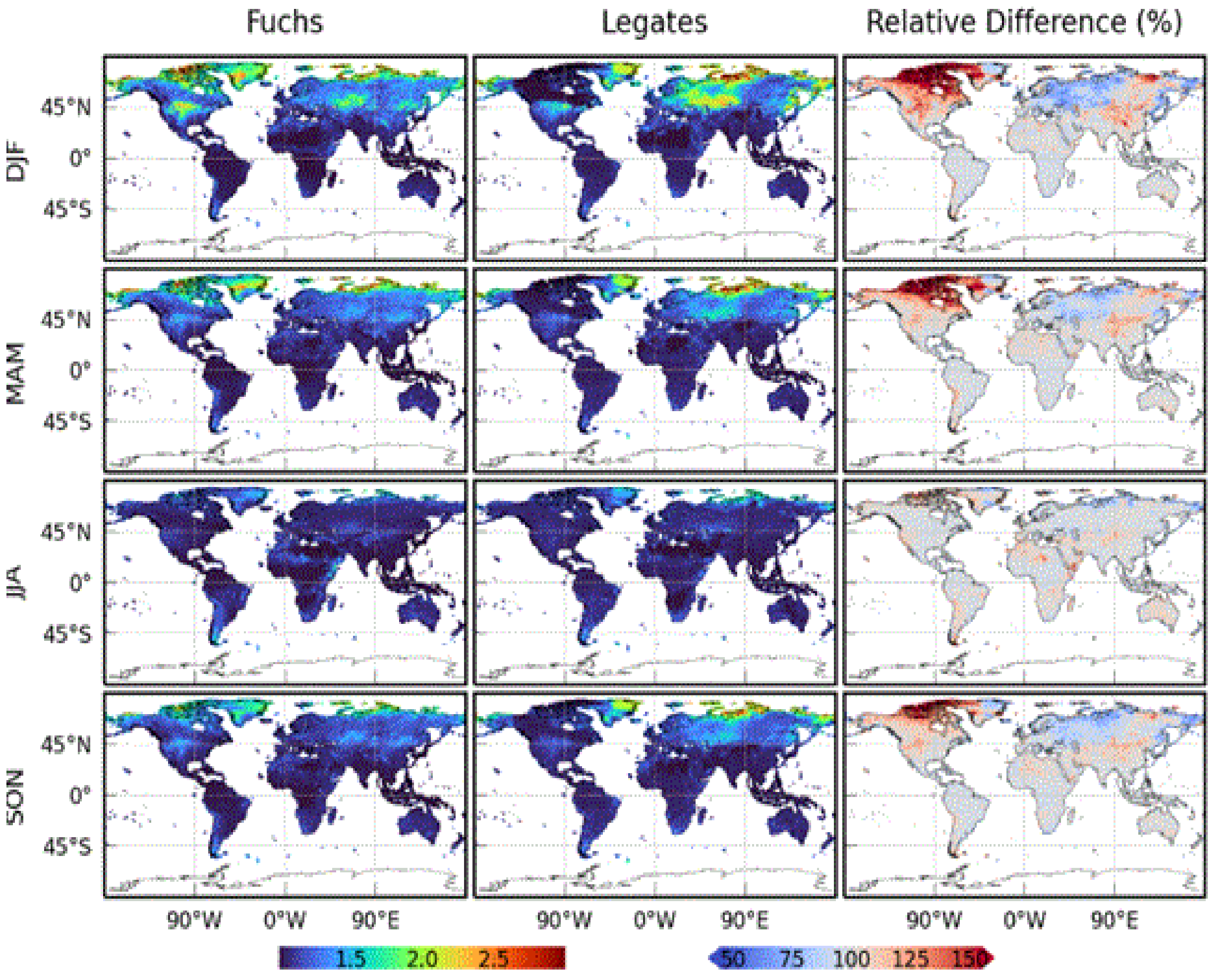
- Satellite product often are bias-adjusted using in situ observations (mainly rain gauges).
- After bias-adjustment products tend to be more consistent over land
- **Number of rain gauges has been reduced** rapidly in recent years !
- We are planning to work with other groups (e.g., UCSB) to supplement GPCC data.
- There are also the **gauge-undercatch** issue that must be considered
- Rain gauge uncertainties need to also be considered.



From Dr. Chris Funk

Gauge undercatch correction:

- **Annual precipitation estimate from gauges (with no correction) can be biased by ~ 7% in boreal summer to more than 12% in boreal winter).**
- **The choice of CF can lead to ~4 % difference in the global land precipitation estimate**
- Two methods are popular for global application: Fuchs (2001) and Legates and Willmott (1990).
- **Major differences exist between the two methods that seems seasonal dependent can exceed 100%.**
- The correction factors (CFs) for gauge undercatch are generally bigger for snow than rainfall.
- We modified corrections factors in **GPCP V3.2** over Eurasia and Northern Asia based on mass balance analysis of snowfall accumulation.



asonal maps of CF-F (left column) and CF-L (middle column), and relative differences between the two e., $\frac{100 \times CF-F}{CF-L}$, right column) calculated from monthly CF-L and 38 years (1982-2019) of monthly CF-. From top to bottom, rows show winter, spring, summer, and fall, respectively. The maps are produced at 1-degree spatial resolution.

Reference:
Ehsani and Behrangi (2022), J of hydrology

CF-L is correction factor based on Legates and Willmott (1990)
CF-F is correction factor based on Fuchs et al. (2001)

GPCP Uncertainty estimate

- The current V3.2 Monthly product has random uncertainty estimates attached to each grid based on an adaption of the Huffman (1997) technique.
- It takes into account algorithm random errors (from validation data), sampling error, and precipitation magnitude.
- In the future versions we will also include bias uncertainty based on Adler et al. (2012), which varies by location and precipitation magnitude and is based on inter-comparison of various satellite estimates of precipitation.
- The total uncertainty or error is a sum of squares of the bias and random estimates.
- While the Huffman (1997) scheme works relatively well at monthly scales because the histograms are somewhat Gaussian, at finer time scales the baseline approach currently in IMERG (at half-hourly timescale) is relatively primitive (namely downscaling the monthly estimate assuming that each gridbox error is independent).
- Factors that we are planning to examine include the space–time-average precipitation estimate, shape of the probability distribution of precipitation, the frequency of nonzero precipitation, and the number of independent samples. At a minimum, the coefficients used in these error formulas will have to be converted to the finer spatial scale.

Summary:

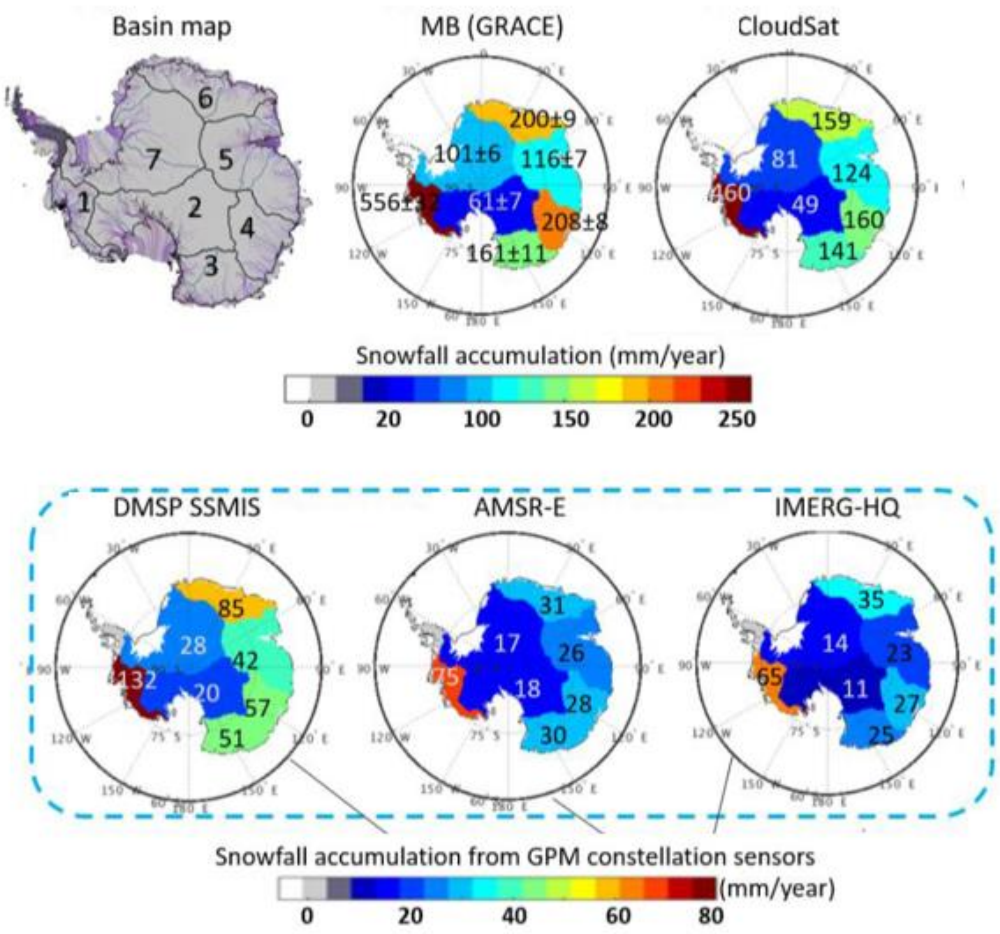
- Continuity and consistency of precipitation sensors are important for developing high quality climate data record.
- As advanced sensors become available (higher spatial and spectral resolutions), an important question is how the new sensors can help improve the entire precipitation record.
- GPCP V3.2 initiated to use some of the new sensors to adjust precipitation records.
- Over ocean we still see large spread among the satellite products, that could be linked to large uncertainties
- We need error estimators appropriate to sub-daily, daily, and monthly at high resolution (e.g., 0.1 deg.), and ways for users to aggregate to even coarser scales
- Rain gauges are often used as a reference to quantify or correct bias in satellite products. However, besides the point versus areal issues and the decline in the number of gauges, rain – gauges can also have large biases due to their biased location (often in valleys and populated areas) and undercatch (critical for snowfall).
- Regime dependent error/uncertainty quantification seems important as they can also provide useful feedback to the product developers. This is where numerical models/reanalyses are helpful.

Thank you

Contact: Behrangi@Arizona.edu

Backup slides

Assessment of precipitation estimates over Antarctica using mass-change analysis (GRACE)



Behrangi et al. (2020)

- Mass balance analysis at basin scale suggests that **CloudSat** and **Reanalysis** are doing reasonable over Antarctica
- GPM V05 and IMERG MW V06 showed Large underestimation (e.g., 1/3 of CloudSat)
- GPCP (AIRS/TOVS) is doing reasonable but needs tuning.
- Can we learn from CloudSat to improve our CDR