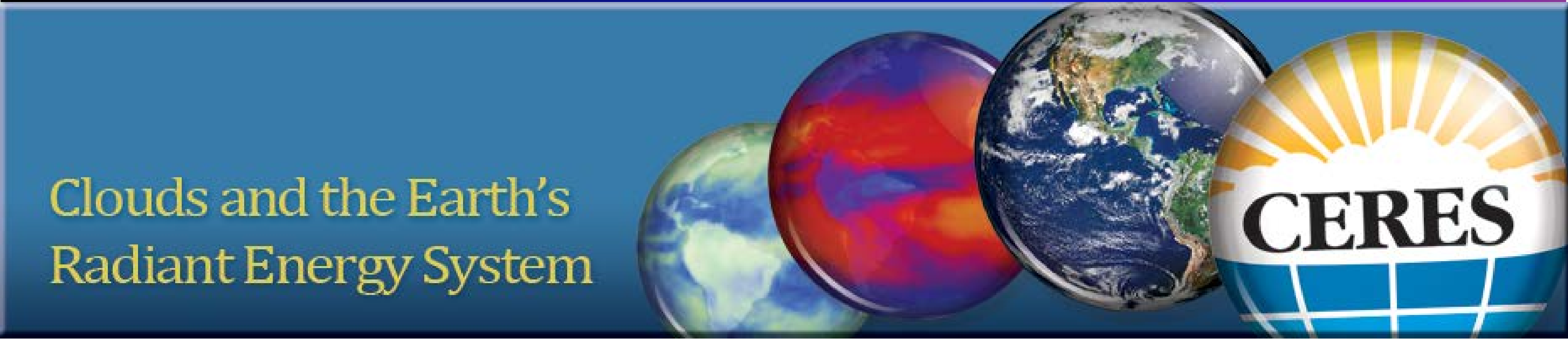



# Production of a Multi-decadal Earth Radiation Budget Climate Data Record: Balancing Accuracy, Precision, and Data Availability to Meet the Needs of the Community

**Kory Priestley**

**Johnathon Gleason, Kathleen Moore, Anum Ashraf**

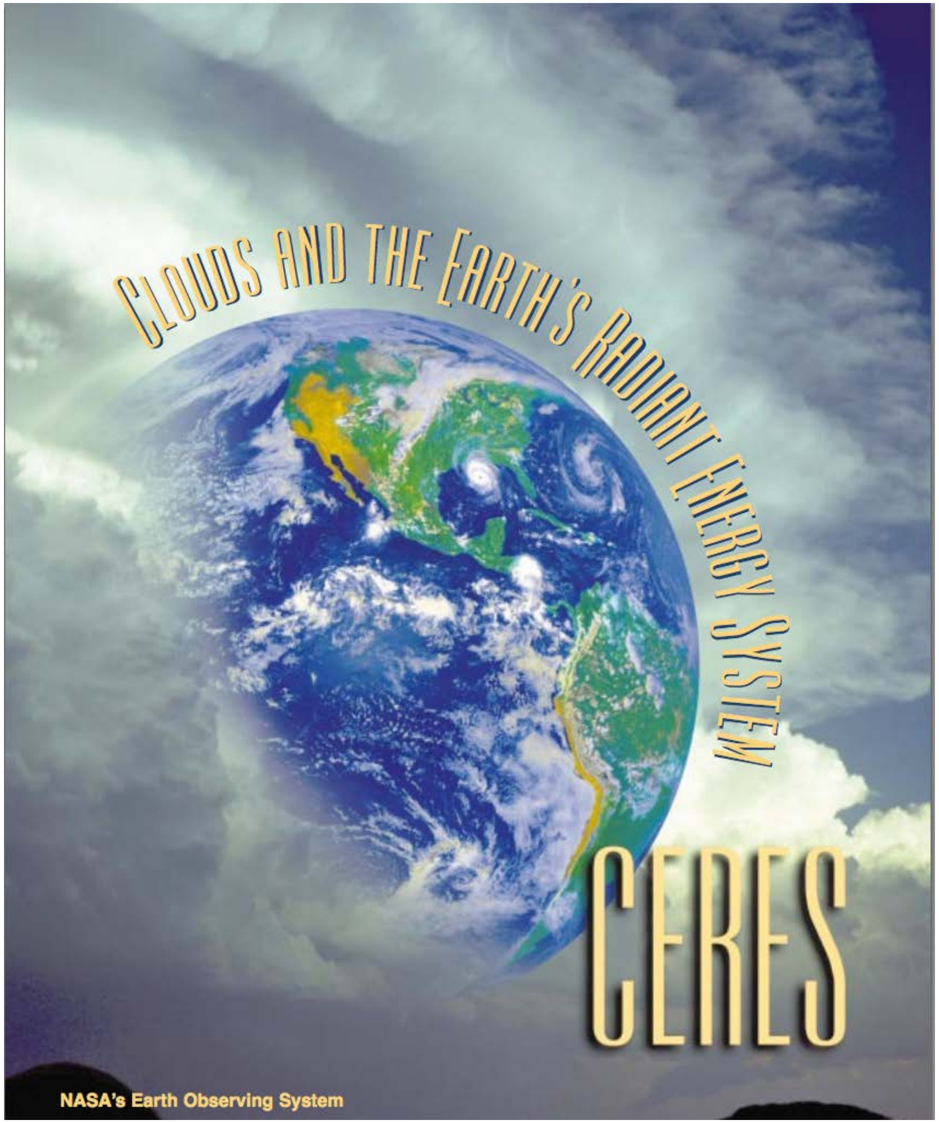
**NASA Langley Research Center**

**CalCon 2018**
**Utah State University**
**June 19, 2018**

www.calcon.sdl.usu.edu

# Discussion Topics






- **ERB Overview**
  - Introduction
  - Science
  - Production Streams
  - Products
  - Dependencies
- **Summary**

**C**heap
**E**lectronics
**R**eally
**E**xpensive
**S**oftware

# Introduction



**NASA's Earth Radiation Budget Science Team, ERB-ST, (CERES Science Team) has the responsibility for governance of the nation's multi-decadal Earth Radiation Budget Climate Data Record (ERB CDR).**

- Processing System is highly complex, producing Level 1 through 4 products.
- The system ingests data from 16 unique instruments on 9 different spacecraft (5 GEO and 4 LEO) as well as other ancillary information, producing 25 + different products with consistent TOA, Surface, and atmospheric radiative fluxes, cloud and aerosol properties on multiple spatial and temporal scales.
- Spatial scales vary from instantaneous/pixel (25 km), 1-deg grid, zonal, regional and global means
- Temporal scales vary across instantaneous, hourly, 3 hourly to monthly scales.
- Accuracy and precision values vary across the various spatial and temporal scales, with the long-term goal of measuring decadal trends of better than 0.3 W/m^2 per decade.

# Reprocessing Considerations



- Many considerations drive the decision to reprocess including but not limited to:
    - Removal of instrument artifacts (cal/val)
    - Validation and instantiation of new Scientific algorithms ***(Science Evolves)***
    - Outside teams reprocessing the products we ingest
    - Launch of new instrumentation to sustain observations at EOL
    - Updates to processing hardware and programming languages
    - Resource availability
    - User community desires new data product formats

- Current re-processing capability of 30X once all inputs are available and staged

**These all need to be managed in order to provide the global community products of sufficient accuracy and precision on a time-scale which allows continued advancement and discovery of key scientific questions such that policy makers may make informed decisions.**

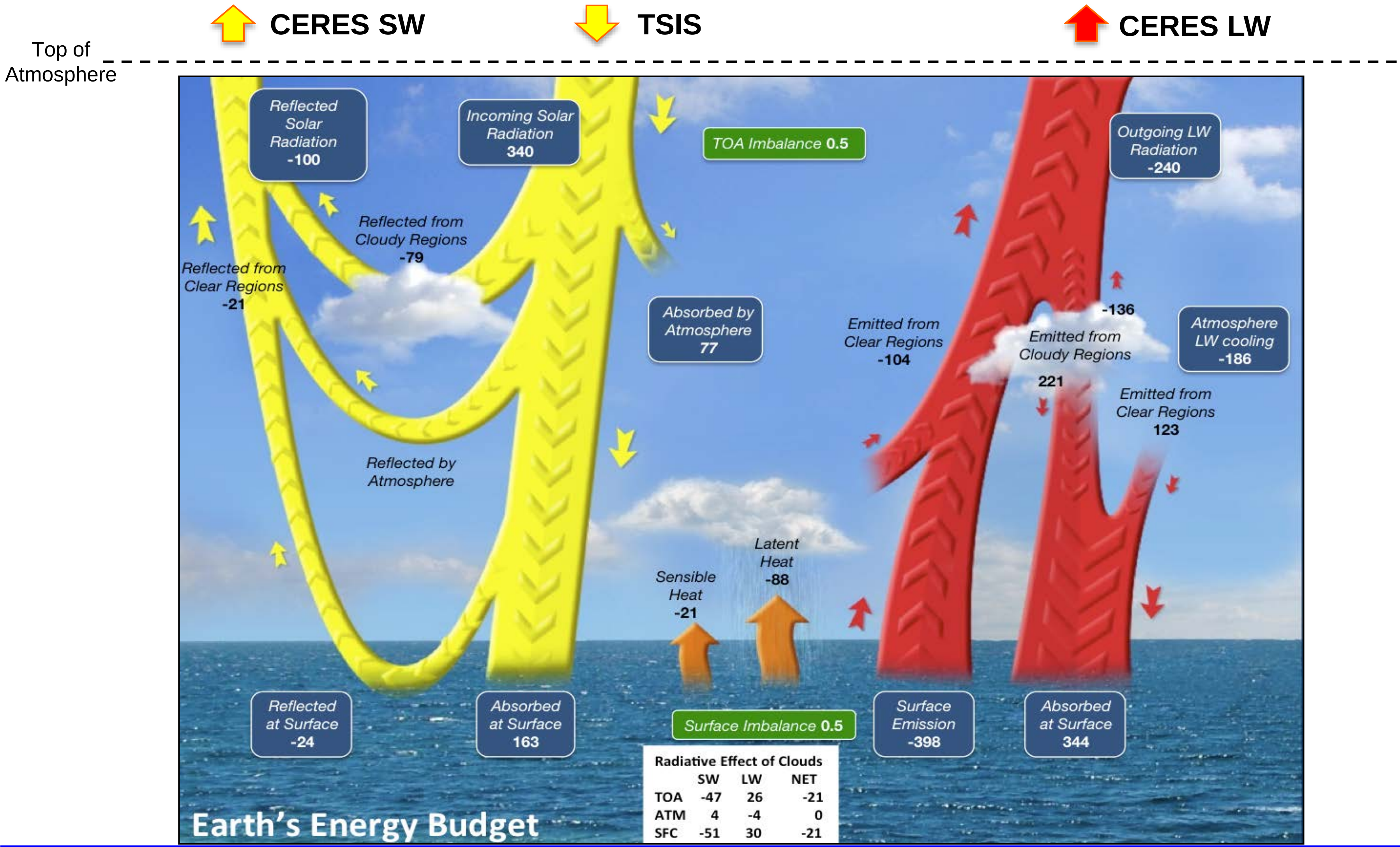
# Earth Radiation Budget Science Needs



- ***Accurate*** **observation-based data products for climate model evaluation and improvement.**
- ***Precise*** **observations to enable improved understanding of the variability in Earth's radiation budget over multiple decades.**
- ***Continuous*** **long-term global Earth radiation budget observations at the top-of-atmosphere, within-atmosphere and surface together with coincident cloud, aerosol and meteorological data.**

# Earth’s Energy Budget

***Clouds and the Earth’s Radiant Energy System***



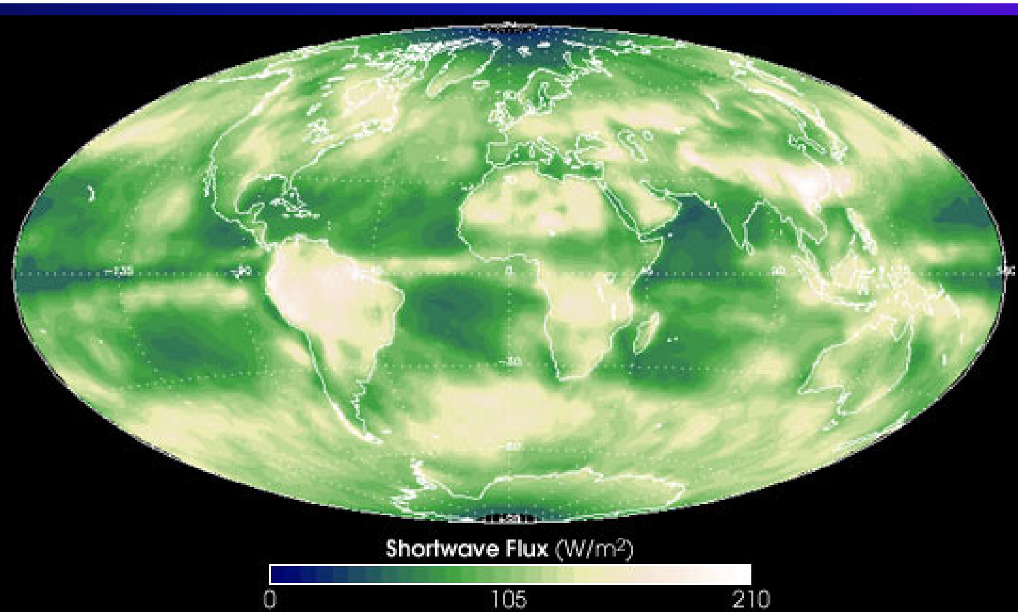

**Radiative Effect of Clouds**

| | SW | LW | NET |
|---|---|---|---|
| TOA | -47 | 26 | -21 |
| ATM | 4 | -4 | 0 |
| SFC | -51 | 30 | -21 |

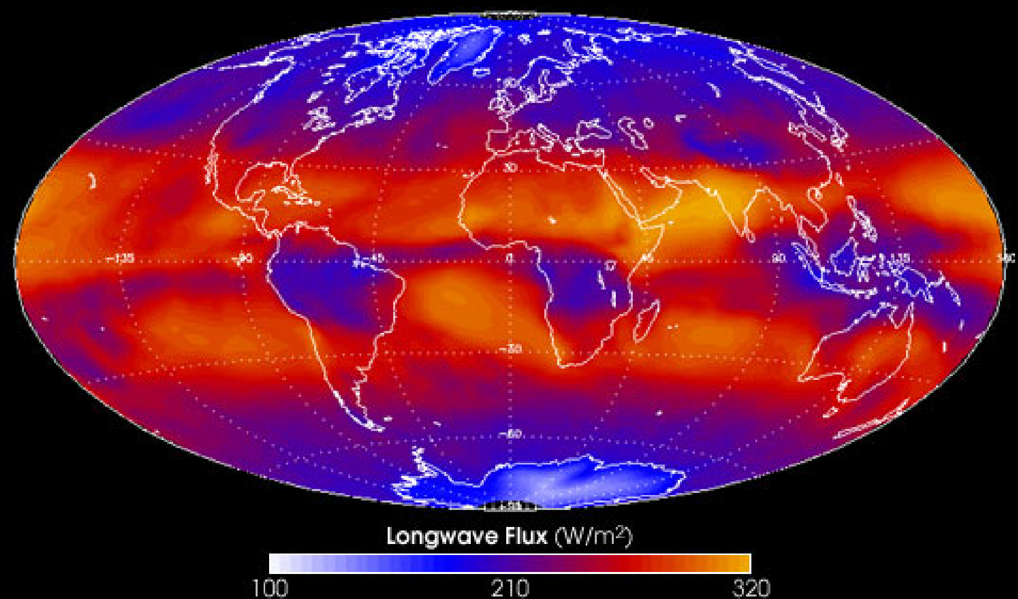
The radiative imbalance between the surface and atmosphere determines how much energy is available to drive the hydrological cycle and the exchange of sensible heat between the surface and atmosphere.

# Primary CERES Climate Data Records

**Reflected Solar Energy**

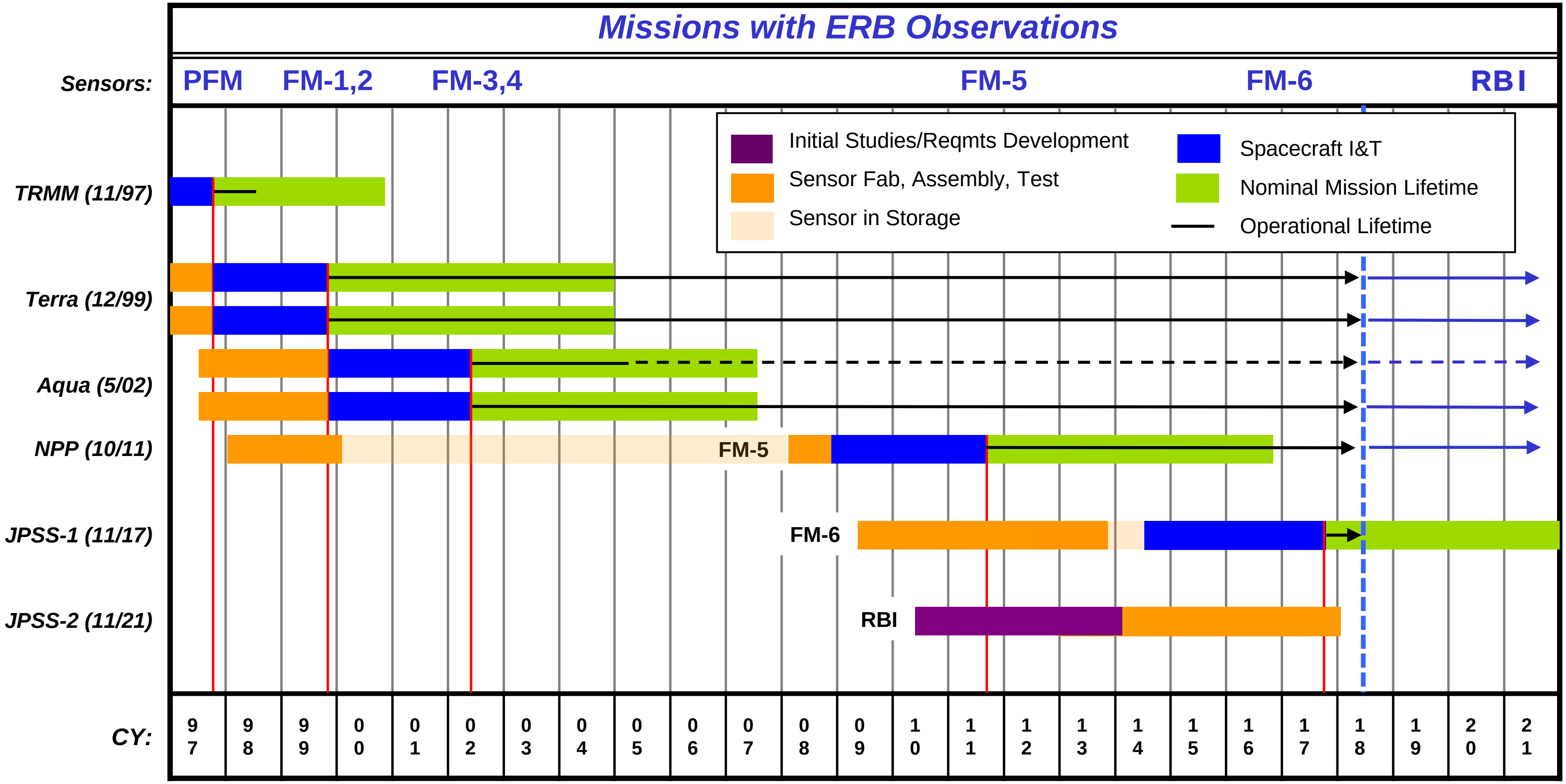



**Emitted Thermal Energy**



# Enabling Climate Data Record Continuity

## CERES Flight Schedule




***We now have over 51 years of flight experience with the CERES instruments and simulators***

# Radiometric Performance Requirements



**CERES is defined as a class 'B' Instrument**

**5-year design Lifetime**

| Spectral Regions | Reflected Solar | | Emitted Thermal | | Atmospheric Window |
|---|---|---|---|---|---|
| Wavelengths | 0.3 - 5.0 μm | | 5.0 - 200 μm | | 8 - 12 μm |
| Scene levels | <100 $w/m^2$-sr | >100 $w/m^2$-sr | <100 $w/m^2$-sr | >100 $w/m^2$-sr | All Levels |
| Accuracy Requirements | 0.8 $w/m^2$-sr | 1.0 % | 0.8 $w/m^2$-sr | 0.5 % | 0.3 $w/m^2$-sr |
| SOW Stability Requirements | | < 0.14%/yr | | < 0.1%/yr | |
| Climate Stability Goals | | < 0.6 $w/m^2$/dec<br>< 0.03 %/yr | | < 0.2 $w/m^2$/dec<br>< 0.02%/yr | |

- **Requirements for CERES are more stringent than ERBE's by a factor of 2**
- **Requirements per Ohring et. al. are more stringent than CERES by a factor of 3-5**

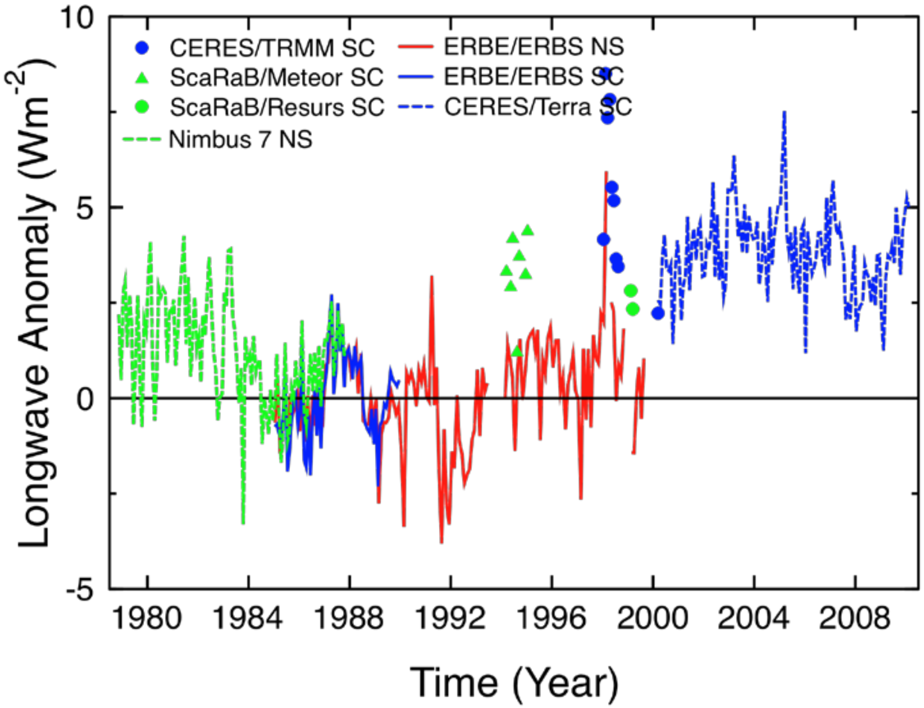
***Calibrate, Calibrate, Calibrate….***

***Evolve Observational Strategies via FSW Modifications***

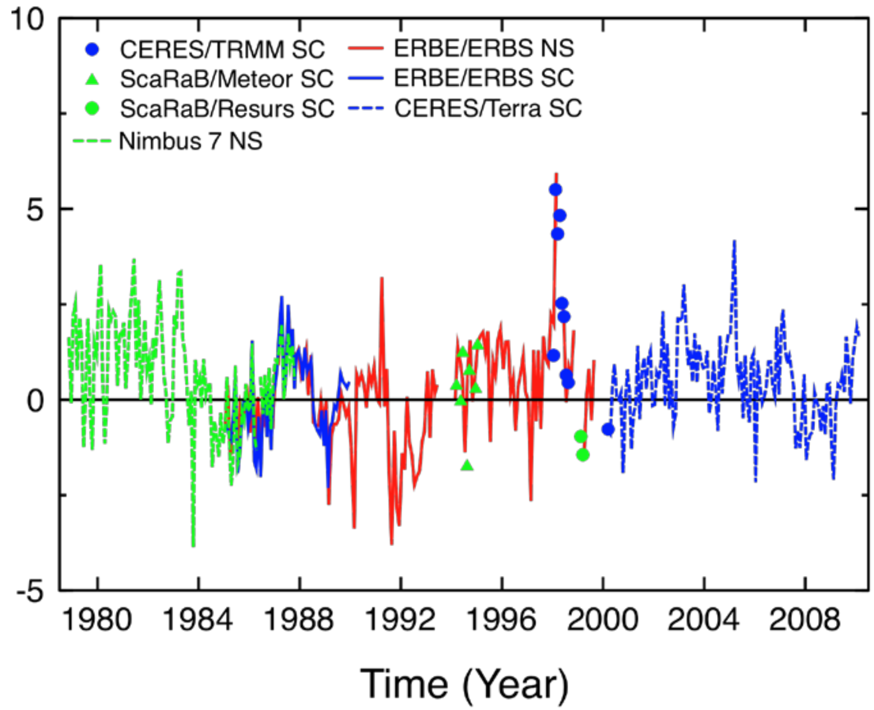
# Tropical Mean Outgoing Longwave Radiation (20°S-20°N)



Without Overlap Adjustment




With Overlap Adjustment




- Instrument-to-instrument absolute calibration differences are 1 to 4 Wm$^{-2}$
  - ⇒ Absolute accuracy alone is insufficient to detect climate change at required accuracy
- Overlapping observations allows use of instrument stability instead of absolute accuracy to constrain decadal climate change.

# Measurement to CDR



- **Does CERES measure Climate Data Records directly?**
  - No, CERES measures instantaneous TOA broadband radiances
    - SW channel - Reflected Solar
    - TOT channel - Reflected Solar + Emitted Thermal
    - LW channel - Emitted Thermal
- **How do we get CDR's from instantaneous Radiance measurements?**

***Thermal Energy → Electrical Signal → Radiance → TOA flux → Surface and Atmospheric Flux → Gridding → Spatially Averaged → Temporal Interpolation → Temporal Averaging***

- **In addition to CERES instrument data, this process requires:**
  - Cloud Imager Data
  - Aerosol Optical Depth
  - Atmospheric State Data
  - Surface Temperatures
  - Geostationary imager data for diurnal interpolation

**High level of data fusion; up to 16 instruments on 9 spacecraft all integrated to obtain climate accuracy in TOA to surface fluxes ~8-dimensional radiative assimilation**

# Why is CERES Climate Quality Trend Detection so Difficult?



**A question of time scales, experience and balancing accuracy with providing data products to the community.**

- *Calibrated Radiances have been released on ~6 month centers*
- *6 months is just a blink of an eye when analyzing decadal trends…*

**Same time scale as phenomena which influence instrument response**

- *Beta Angle*
- *Solar Zenith Angle*
- *Earth Sun Distance*
- *Solar Cycle*
- *Orbital shifts*
- *Instrument Operational modes (e.g. RAPS vs. Xtrack)*

**Design weaknesses and anticipated failures in onboard calibration hardware**

- *full spectral range of observations not covered by cal subsystems*

***Complicates separation of instrument 'artifacts' from natural variability.***

# CERES Processing Level Descriptions

*Clouds and the Earth's Radiant Energy System*

**Level 0**: **Raw digitized** instrument data for all engineering and science data streams in Consultative Committee for Space Data Systems (CCSDS) packet format.

**Level 1B**: **Instantaneous filtered** broadband **radiances** at the CERES **footprint** resolution, geolocation and viewing geometry, solar geometry, satellite position and velocity, and all raw engineering and instrument status data.

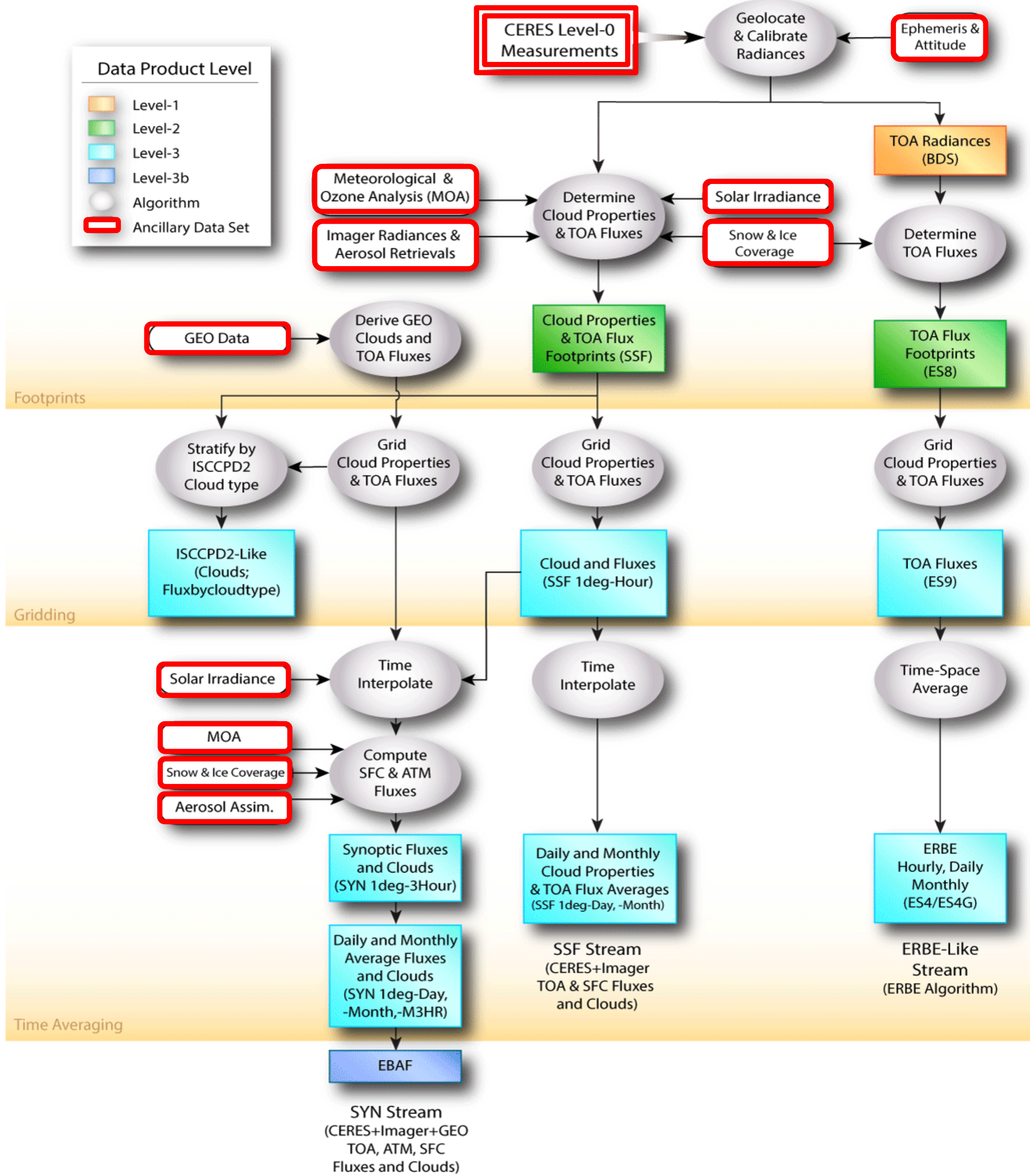
**Level 2**: **Instantaneous geophysical variables** at the CERES **footprint** resolution. Includes some Level 1B parameters and retrieved or computed geophysical variables. (e.g., filtered and unfiltered radiances, viewing geometry, radiative fluxes, imager cloud and aerosol properties).

**Level 3**: Radiative fluxes and cloud properties **spatially averaged** onto a **uniform grid**. Includes either **instantaneous** averages sorted by local/GMT hour (e.g., SSF1deg–Hour) or **temporally interpolated** averages at 3–hourly, daily, monthly or monthly hourly intervals (e.g., SSF1deg–Month).

**Level 4**: Level 3 data products **adjusted within their range of uncertainty to satisfy known constraints** (e.g., consistency between average global net TOA flux imbalance and ocean heating rate from in-situ ocean measurements like Argo).

# CERES Processing Streams

*Clouds and the Earth's Radiant Energy System*



# Products and Parameters : Level 2 and 3



| Product | TOA Fluxes | Surface Fluxes | In-Atmospheric Fluxes | Cloud Properties | Aerosols | Atmosphere |
|---|---|---|---|---|---|---|
| **Level 3B**: Consistency between TOA global net flux and ocean heat storage. | | | | | | |
| EBAF-TOA | CERES/GEO net balanced | | | | | |
| EBAF-Surface | | Computed | | | | |
| **Level 3**: Spatial and temporally (daily, monthly, etc) averaged fluxes and cloud properties. | | | | | | |
| SYN1deg | CERES/GEO & Computed | Computed | Computed | MODIS & GEO | MODIS & MATCH | GMAO GEOS |
| SSF1deg | CERES | Parameterized | | MODIS | MODIS | GMAO GEOS |
| AVG | CERES/GEO & Computed | Computed | Computed | MODIS & GEO | MODIS & MATCH | GMAO GEOS |
| ZAVG | CERES/GEO & Computed | Computed | Computed | MODIS & GEO | MODIS & MATCH | GMAO GEOS |
| SYN | CERES/GEO & Computed | Computed | Computed | MODIS & GEO | MODIS & MATCH | GMAO GEOS |
| SRBAVG | CERES | Parameterized | | MODIS & GEO | | GMAO GEOS |
| SFC | CERES | Parameterized | | MODIS | MODIS | GMAO GEOS |
| FSW | CERES & Computed | Computed | Computed | MODIS | MODIS | GMAO GEOS |
| ISCCP-D2like | | | | MODIS & GEO | | |
| FLASH_TISA | CERES | Parameterized | | MODIS | | GMAO GEOS |
| ES4/ES9 | CERES-ERBElike | | | | | |
| **Level 2**: CERES instantaneous footprint level fluxes and cloud properties. | | | | | | |
| CRS | CERES & Computed | Computed & Parameterized | Computed | MODIS | MODIS | GMAO GEOS |
| FLASH_SSF | CERES | Parameterized | | MODIS | MODIS | GMAO GEOS |
| SSF | CERES | Parameterized | | MODIS | MODIS | GMAO GEOS |
| ES8 | CERES-ERBElike | | | | | |
| **Level 2**: CERES instantaneous footprint level fluxes and cloud properties. | | | | | | |
| BDS | CERES filtered radiances | | | | | |

***Monthly Data Product Volume ~400GB***

**GMAO GEOS 5.4.1 Merra**: temperature, humidity, pressure, and ozone used as input to cloud retrieval and radiative transfer calculation.

**NOAA CLASS:** SSM/I passive microwave sensor data. Need for aerosol calc.

**SORCE**: total solar irradiance, which provides solar incoming. One value per day from U of Colorado/LASP.

**NSIDC NISE** : used for snow and ice scene identification. ~64 Mb/month

**MODAPS and Land SIPS:** MODIS or VIIRS aerosols, radiances, and geolocation from MODAPS and LandSIPS. ~6.5 Tb/month

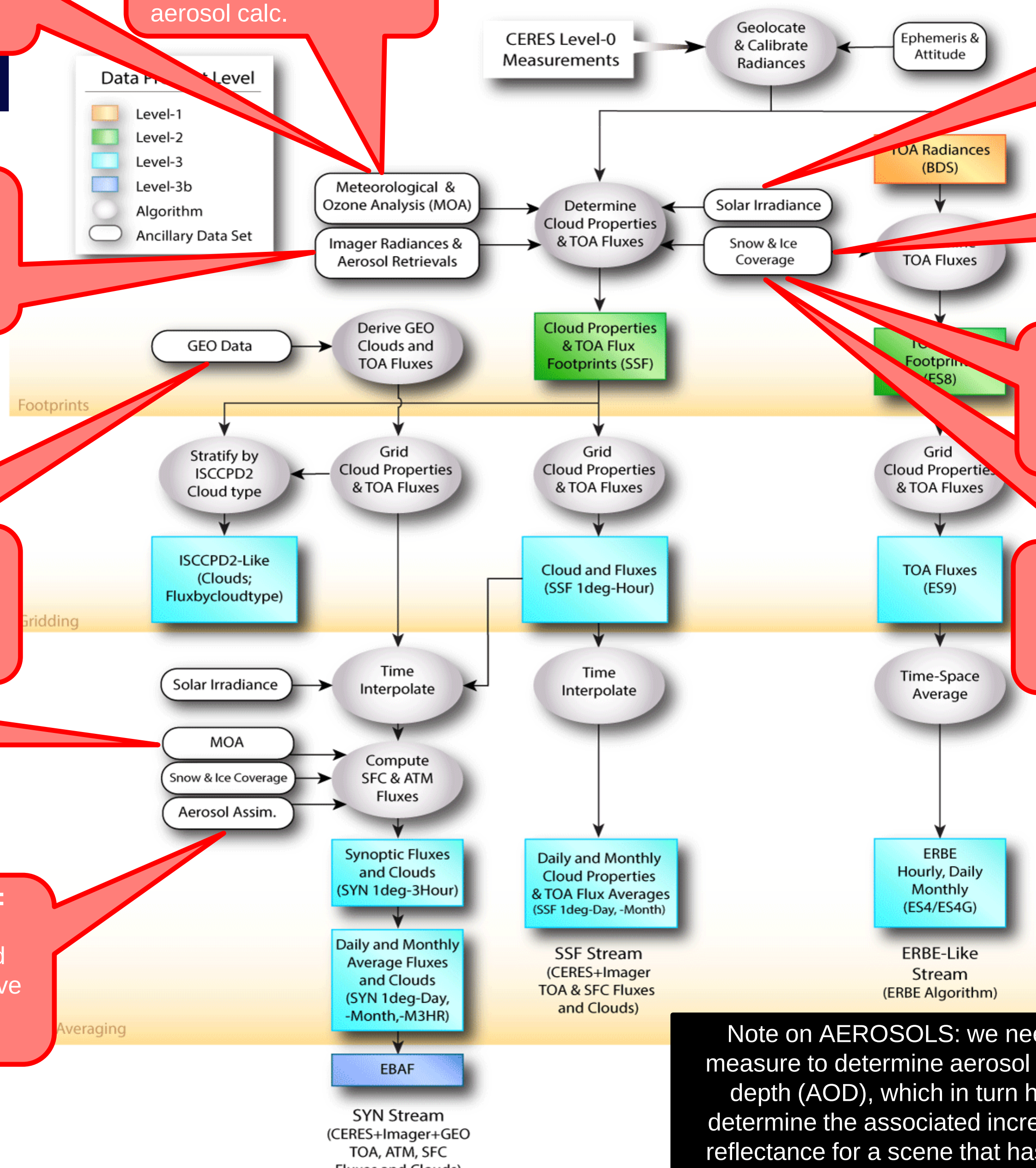
**NOAA CLASS**: Snow/ice map from SSM/I supplement to NISE in SSF stream determines *where* there is snow or ice. ~2.3 Gb/month

**McIDAS**: geo radiances. These raw images come from McIDAS. Then run with cloud retrieval ~85 Gb/month

**AFWA:** SNODEP Snow/ice map supplement to NISE in SSF stream determines *where* there is snow or ice. ~0.2 Gb/month

**MOA**: included temperature profile can determine cloud height

**MATCH (LaRC, run-offline):** modeled aerosols using MODIS inputs. Coverage and properties are used in radiative transfer calc. ~5.4 Mb/month




Note on AEROSOLS: we need to measure to determine aerosol optical depth (AOD), which in turn helps determine the associated increase in reflectance for a scene that has been determined to include aerosols.

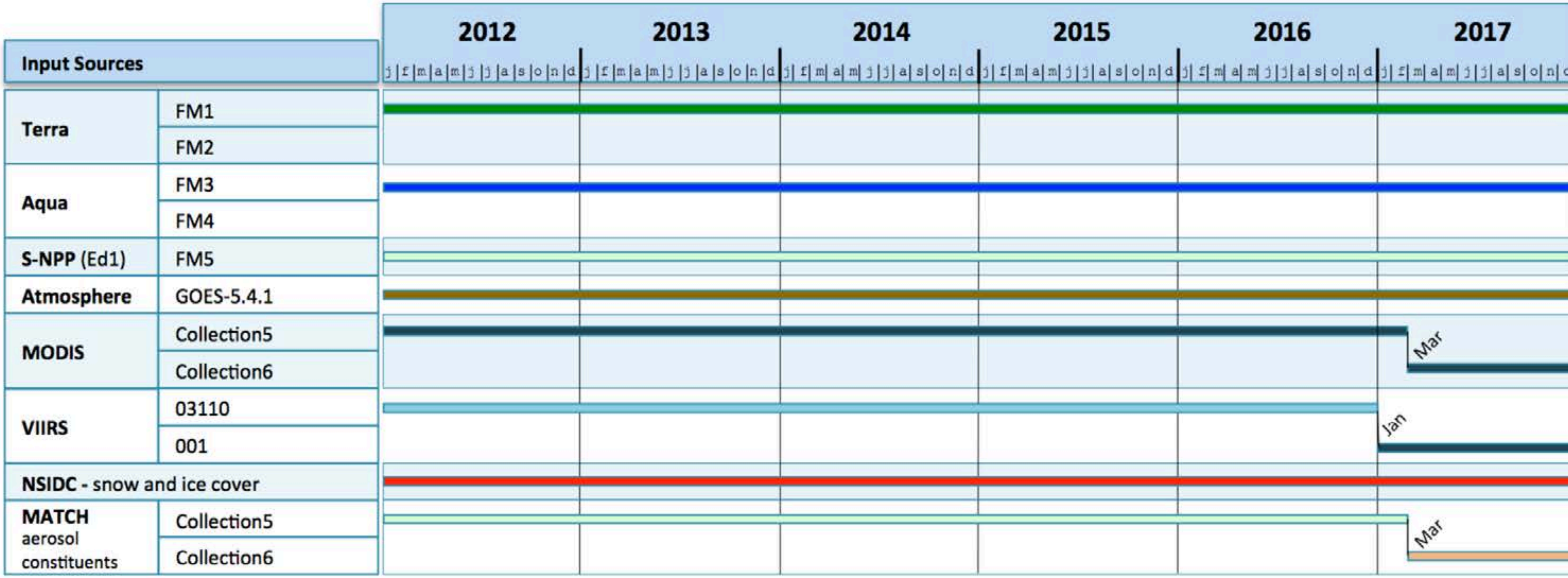
# Data Ingest Sources

*Clouds and the Earth's Radiant Energy System*

## CERES Input Data Sources

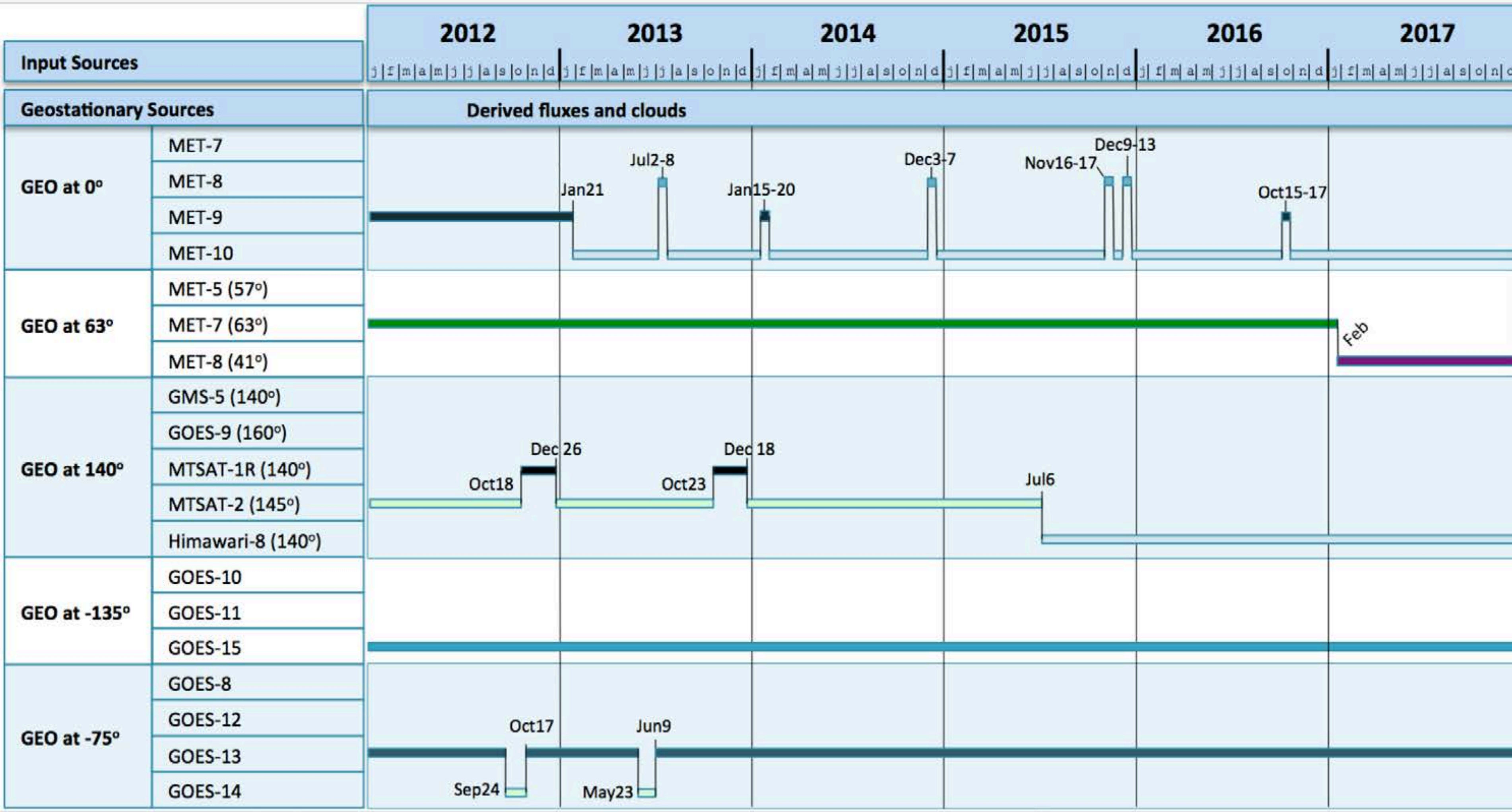
Edition3 | **Edition4**

2000-2005 | 2006-2011 | **2012-2017** | 2018-2023



# Data Ingest Sources – Cont'd





# INTERFACES & DEPENDENCIES

# CERES Instrument Monthly Data Volume

*Clouds and the Earth's Radiant Energy System*

## CERES Instrument Data from EDOS

| Product | Granule Size (MB) | Number of Granules Per Day | Average Volume per Month (MB) |
|---|---|---|---|
| Terra Level 0 | 88.00 | 2 (FM1 and FM2) | 5,354 |
| Terra Ephemeris | 0.46 | 12 | 168 |
| Terra Attitude | 0.88 | 12 | 321 |
| Aqua Level 0 | 88.00 | 2 (FM3 and FM4) | 5,354 |
| Aqua Ephemeris | 5.30 | 1 | 161 |
| Aqua Attitude | 0.46 | 12 | 168 |
| NPP Level 0 | 88.00 | 1 | 2,677 |
| NPP Ephemeris and Attitude | 0.50 | 12 | 178 |
| JPSS-1 Level 0 | 88.00 | 1 | 2,677 |
| JPSS-1 Ephemeris and Attitude | 0.50 | 12 | 178 |
| | | **Total :** | **17,236** |

# Imager Monthly Ingest Data Volume



## MODIS & VIIRS Data

| Source | Product | Granule Size (MB) | Number of Granules Per Day | Average Volume per Month (MB) |
|---|---|---|---|---|
| MODAPS | MOD02_SS | 12 - 65 | 288 | 340,300 |
| MODAPS | MOD03 | 28 | 288 | 245,150 |
| MODAPS | MOD04 | 1.5 | 130 | 6,000 |
| MODAPS | MYD02_SS | 12 - 65 | 288 | 340,300 |
| MODAPS | MYD03 | 28 | 288 | 245,150 |
| MODAPS | MYD04 | 1.5 | 130 | 6,000 |
| Land SIPS | VIMD_SS | 160 - 360 | 288 | 2,141,000 |
| Land SIPS | VAOT_L2 | 0.8 | 288 | 7,000 |
| Land SIPS | VNP0203IMD_SS | 300 - 415 | 240 | 2,736,000 |
| Atmosphere SIPS | VAERDT* | 38 | 130 | 150,000 |
| Atmosphere SIPS | VAERDB* | 15 | 130 | 59,280 |
| | | | **Total:** | **6,276,180** |

# Ancillary Monthly Ingest Data Volume



## Other Ancillary Data

| Source | Product | Granule Size (MB) | Number of Granules Per Day | Average Volume per Month (MB) |
|---|---|---|---|---|
| NSIDC | NISE | 2.1 | 1 | 64 |
| CLASS | 1/8th mesh Snow/Ice (DMSP EDR) | 9.6 | 8 (NH and SH) | 2,335 |
| AFWA | 1/16th mesh Snow/Ice (SNODEP) | 2.3 | 2 (NH and SH) | 140 |
| GMAO | GEOS 5.4.1 Met-Reanalysis | | 8 files / day | ~83,000 |
| U. of Wisc SSEC | Geostationary Weather Satellite (area files) (from McIDAS) | 5 – 37 | 120 (5 GEO) | ~84,000 |
| SSAI | MATCH Model Aerosols | | 2 files / day | 5.3 |
| | | | **Total :** | **169,544** |

# Summary



- Many considerations drive the decision to reprocess including but not limited to:
    - Removal of instrument artifacts (cal/val)
    - Validation and instantiation of new Scientific algorithms ***(Science Evolves)***
    - Outside teams reprocessing the products we ingest
    - Launch of new instrumentation to sustain observations at EOL
    - Updates to processing hardware and programming languages
    - Resource availability
    - User community desires new data product formats

**These all need to be managed effectively….**

**C**heap
**E**lectronics
**R**eally
**E**xpensive
**S**oftware