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Development of Multi-Sensor Global Cloud and Radiance Composites for DSCOVR EPIC Imager with Subpixel Definition

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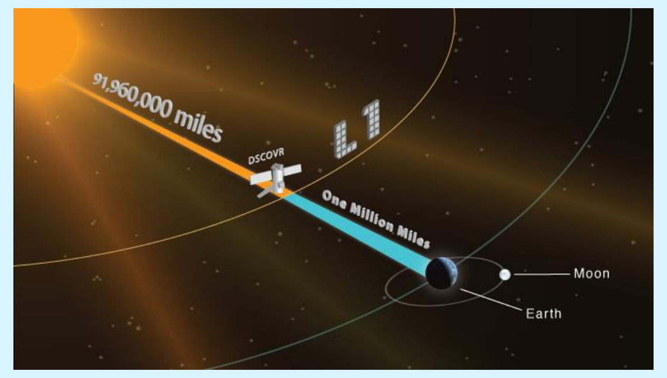
Introduction

The Deep Space Climate Observatory (DSCOVR) enables analysis of the daytime Earth radiation budget via the onboard Earth Polychromatic Imaging Camera (EPIC) and National Institute of Standards and Technology Advanced Radiometer (NISTAR). EPIC delivers adequate spatial resolution imagery but only in shortwave bands (317–780 nm), while NISTAR measures the top-of-atmosphere (TOA) whole-disk radiance in shortwave and longwave broadband windows. Accurate calculation of albedo and outgoing longwave flux requires a high-resolution scene identification such as the radiance observations and cloud properties retrievals from low earth orbit (LEO, including NASA *Terra* and *Aqua* MODIS, Suomi-NPP VIIRS, and NOAA AVHRR) and geosynchronous (GEO, including GOES east and west, METEOSAT, INSAT-3D, MTSAT-2, and Himawari-8) satellite imagers. The cloud properties are derived using the Clouds and the Earth's Radiant Energy System (CERES) mission Cloud Subsystem group algorithms. These properties have to be co-located with EPIC pixels to provide the scene identification and to select anisotropic directional models (ADMs), which are then used to adjust the NISTAR-measured radiance and subsequently obtain the global daytime shortwave and longwave fluxes.

This work presents an algorithm for optimal merging of selected radiance and cloud property parameters derived from multiple satellite imagers to obtain seamless global hourly composites at 5-km resolution. Selection of satellite data for each 5-km pixel is based on an aggregated rating that incorporates five parameters: nominal satellite resolution, pixel time relative to the EPIC time, viewing zenith angle, distance from day/night terminator, and probability of sun glint. To provide a smoother transition in the merged output, in regions where candidate pixel data from two satellite sources have comparable aggregated rating, the selection decision is defined by the cumulative function of the normal distribution so that abrupt changes in the visual appearance of the composite data are avoided. Higher spatial accuracy in the composite product is achieved by using the inverse mapping with gradient search during reprojection and bicubic interpolation for pixel resampling.

DSCOVR Earth Science Instruments



Earth Polychromatic Imaging Camera (EPIC)

2048×2048 CCD Camera
Nominal resolution 7.8 km (some channels 15.6 km)
Spectral bands from 317 to 780 nm

NIST Advanced Radiometer (NISTAR)

Measures the total Earth disk TOA radiance in 3 broad-band spectral windows: 0.2–100, 0.2–4, and 0.7–4 μm

Lack of IR channels and insufficient resolution make it difficult to retrieve cloud properties and scene IDs

Proposed calculation of fluxes from DSCOVR

1. Use scene identification from LEO/GEO cloud retrieval and EPIC or LEO/GEO radiance I_j (visible or IR) to determine anisotropic factor for NISTAR view:

From EPIC

ADMs from the combo of TRMM & Terra/Aqua models

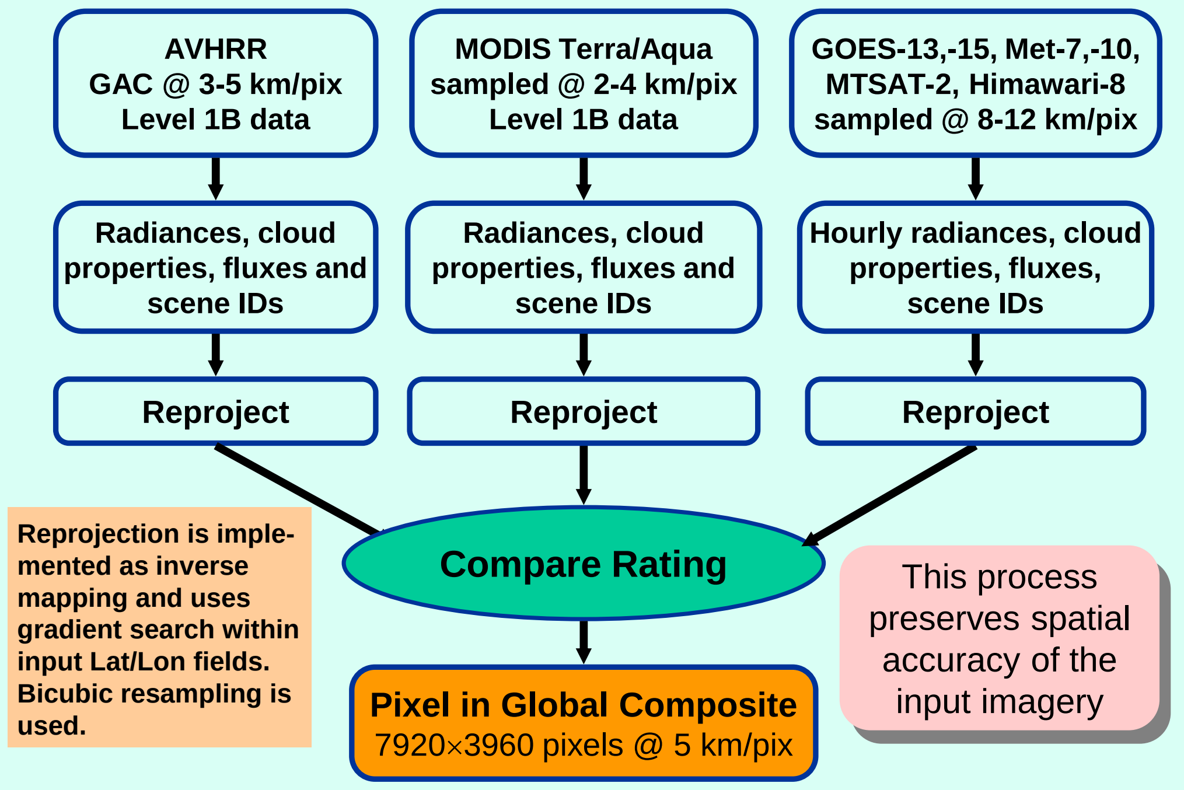
$$\overline{R}_{\mathrm{LW}} = \frac{\sum_j w_j I_j(11\mu\mathrm{m}) R_j^{\mathrm{CLW}}(\theta_0, \theta_D, \phi_D, \mathrm{SceneID})}{\sum_j w_j I_j(11\mu\mathrm{m})}$$

From GEO/LEO

2. Convert the NISTAR measured radiance to flux:

$$F_{\mathrm{NLW}} = \frac{\pi I_{\mathrm{NLW}}}{R_{\mathrm{LW}}}$$

Global GEO/LEO composites



AVHRR GAC @ 3-5 km/pix Level 1B data → **Radiances, cloud properties, fluxes and scene IDs** → **Reproject**

MODIS Terra/Aqua sampled @ 2-4 km/pix Level 1B data → **Radiances, cloud properties, fluxes and scene IDs** → **Reproject**

GOES-13,-15, Met-7,-10, MTSAT-2, Himawari-8 sampled @ 8-12 km/pix → **Hourly radiances, cloud properties, fluxes, scene IDs** → **Reproject**

Compare Rating → **Pixel in Global Composite** 7920×3960 pixels @ 5 km/pix

Reprojection is implemented as inverse mapping and uses gradient search within input Lat/Lon fields. Bicubic resampling is used.

This process preserves spatial accuracy of the input imagery

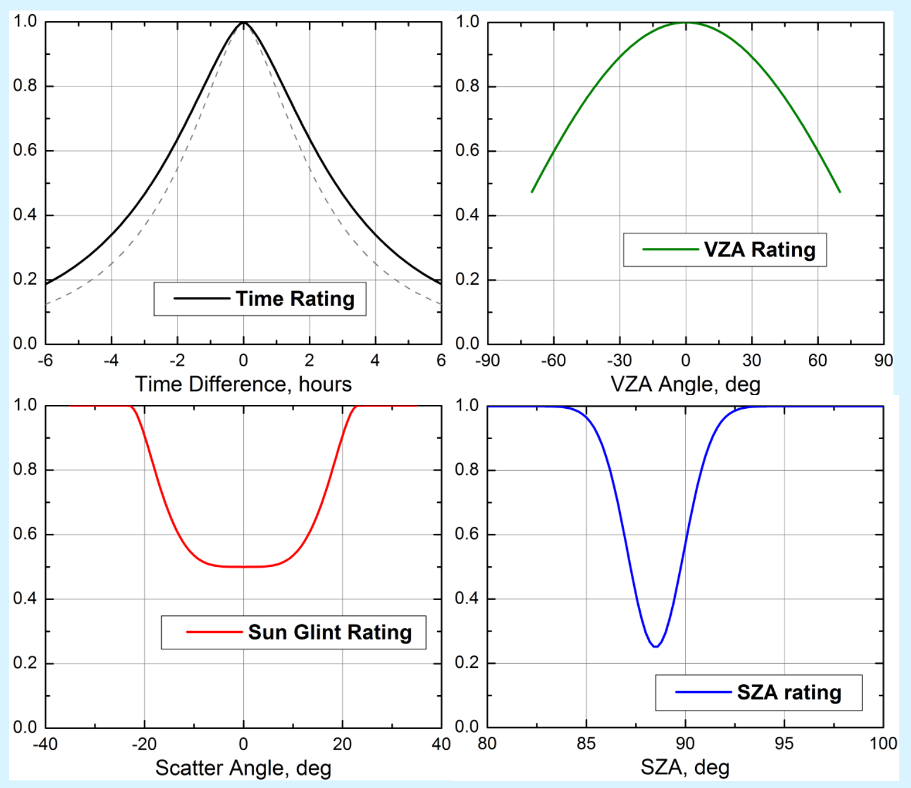
Aggregated rating

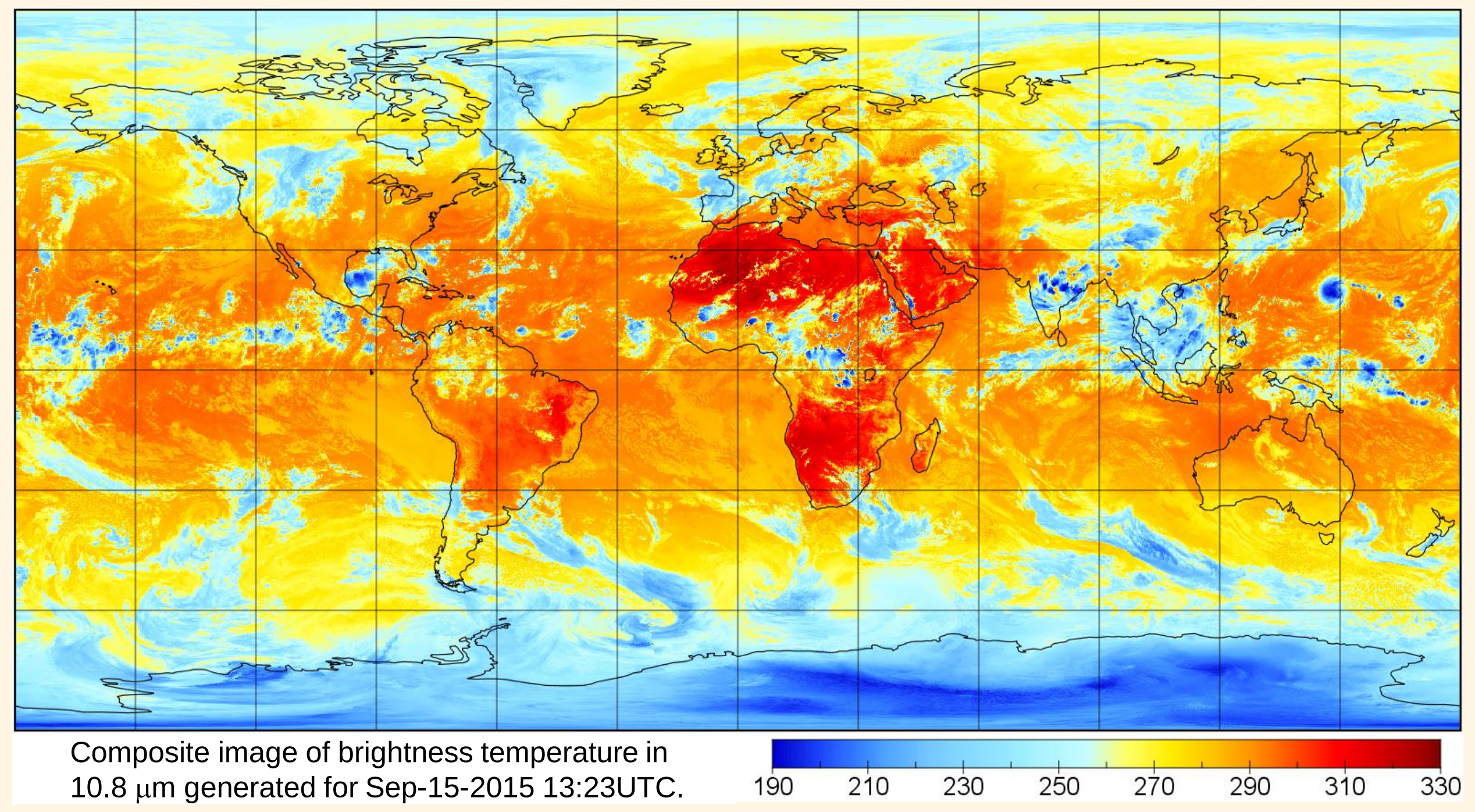
$$R = F_{\mathrm{resolution}} \; F_{\mathrm{terminator}} \; F_{\mathrm{glint}} \frac{F_{\mathrm{VZA}}}{\left(1 + (\Delta t / \tau)^{1.5}\right)^2}$$

$F_{\mathrm{resolution}}$ describes our subjective preference in choosing a particular satellite:

100 – Met-7
220 – MTSAT-2 and Himawari-8
210 – All other GEOs
185 – MODIS Terra and Aqua
140 – All NOAA satellites

This rating approach allows merging of multiple input factors into a single number to be compared and enables higher flexibility in choosing between two candidate pixels.





Composite image of brightness temperature in 10.8 μm generated for Sep-15-2015 13:23UTC.

The composite image presents a continuous coverage with no gaps and no artificial breaks or disruptions in the temperature data

Parameters included in global composite:

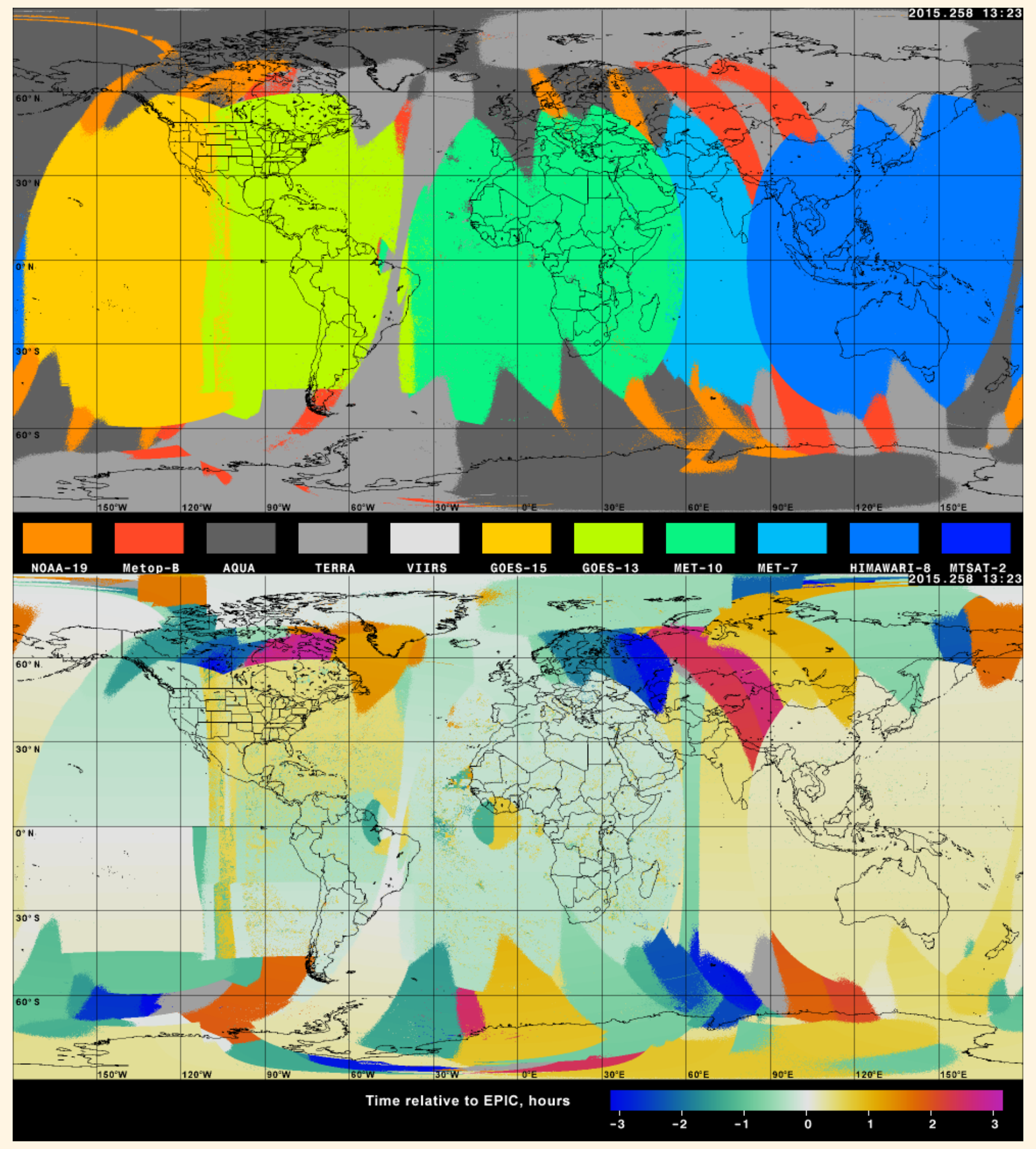
AVHRR is missing the water vapor band, so it is assigned a lower initial rating.

Cloud properties are retrieved by using the CERES Cloud Subsystem group algorithms.

Radiative properties are derived from GEO and MODIS to calculate broadband shortwave albedo, and following a modified version of the radiance-based approach to calculate broadband longwave flux.

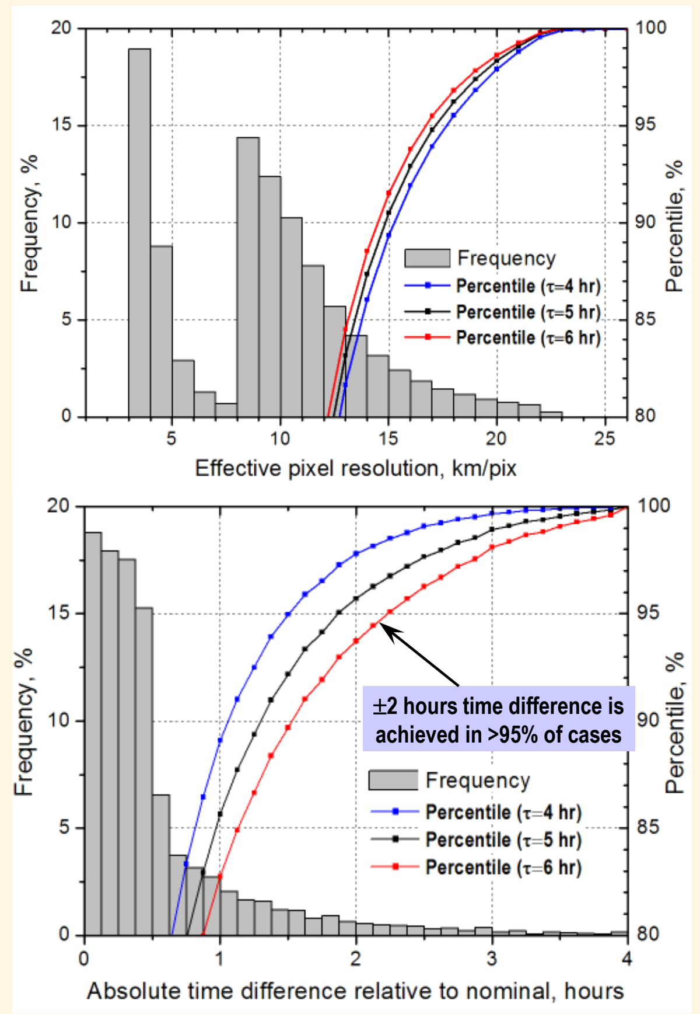
	Parameter	AVHRR	MODIS	GEOs	Global Composite
1	**Latitude**	✓	✓	✓	✓
2	**Longitude**	✓	✓	✓	✓
3	**Solar Zenith Angle**	✓	✓	✓	✓
4	**View Zenith Angle**	✓	✓	✓	✓
5	**Relative Azimuth Angle**	✓	✓	✓	✓
6	**Reflectance in 0.63um**	0.63 um	0.63 um	0.65 um	✓
7	**Reflectance in 0.86um**	0.83 um	0.83 um	—	✓
8	**BT in 3.75um**	3.75 um	3.75 um	3.9 um	✓
9	**BT in 6.75um**	—	6.70 um	6.8 um	✓
10	**BT in 10.8um**	10.8 um	10.8 um	10.8 um	✓
11	**BT in 12.0um**	12.0 um	11.9 um	12/13.5	✓
12	**SW Broadband Albedo**	✓	✓	✓	✓
13	**LW Broadband Flux**	✓	✓	✓	✓
14	**Cloud Phase**	✓	✓	✓	✓
15	**Cloud Optical Depth**	✓	✓	✓	✓
16	**Cloud Effective Particle Size**	✓	✓	✓	✓
17	**Cloud Effective Height**	✓	✓	✓	✓
18	**Cloud Top Height**	✓	✓	✓	✓
19	**Cloud Effective Temperature**	✓	✓	✓	✓
20	**Cloud Effective Pressure**	✓	✓	✓	✓
21	**Skin Temperature (retrieved)**	✓	✓	✓	✓
23	**Surface Type**	from IGBP + snow/ice flags			✓
24	**Time relative to EPIC**	± 3.5 hours maximum			✓
25	**Satellite ID**				✓

Composite maps of satellite ID and time difference from EPIC



- Most of the regions corresponding to GEO satellites (between 50°S and 50°N) have a low time difference, in the range of ±30 minutes;
- The polar regions are also covered very well by the polar orbiters, which help to decrease the time difference to less than an hour;
- The mid-latitude regions present most of the problem: they are out of reach for GEO satellites and are observed only twice a day by the polar orbiters. Still, most of the observations in the mid-latitudes fall within the Δt range of ±3 hours.

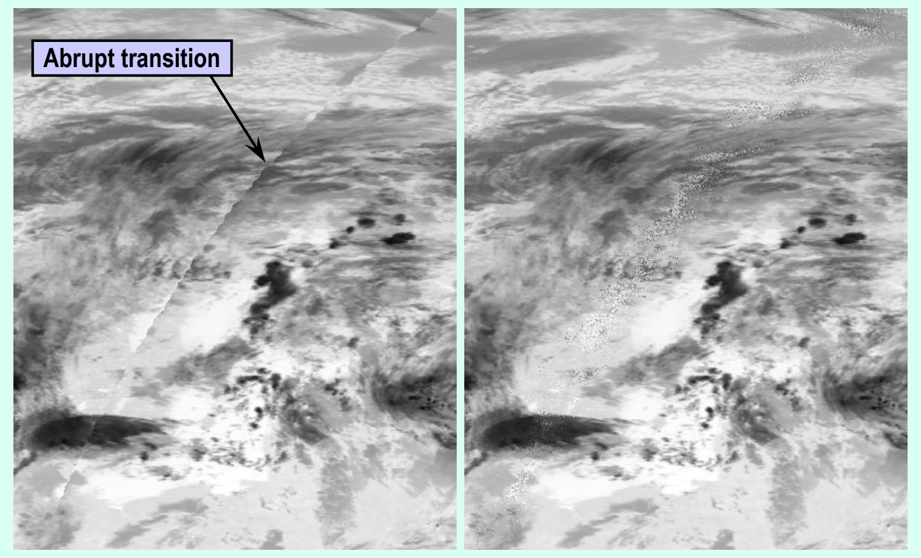
Balance between resolution and time difference



Smaller τ shifts the balance towards larger VZA, which lowers the resolution. We can introduce effective pixel resolution as the nominal pixel resolution (specific to each satellite) adjusted to the pixel-to-satellite distance and local viewing zenith angle.

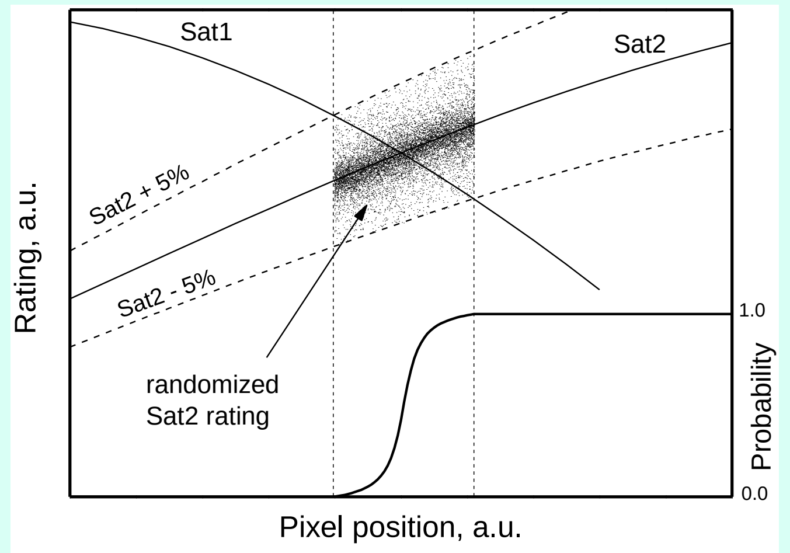
The characteristic time τ is set to 5 hours in order to limit the time difference to ±2 hours in about 96% of the composite coverage.

Transition between composite data



1. Uneven transitions can cause biases in regional statistics.
2. Data from different sources cannot be blended.

Allow a certain amount of randomness when comparing the rating *R*

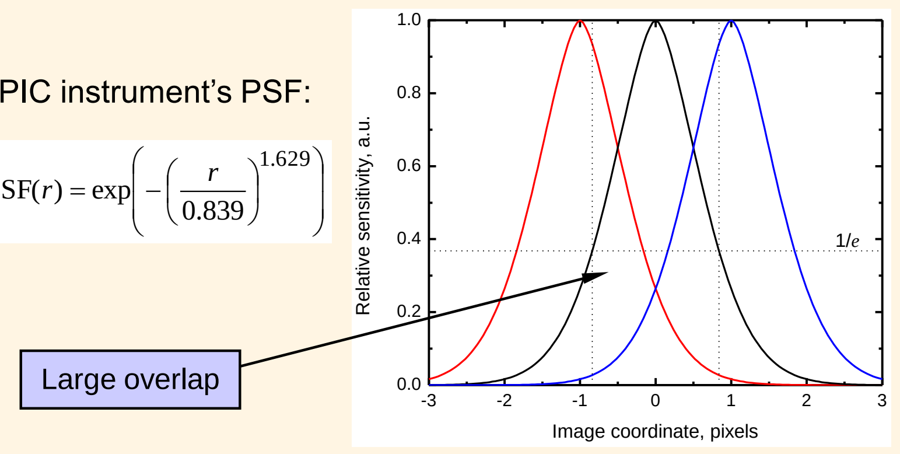


Requirement to select Sat2 data: $R_1 < R_2 \cdot (1 + r)$

EPIC-view composites

EPIC instrument's PSF:

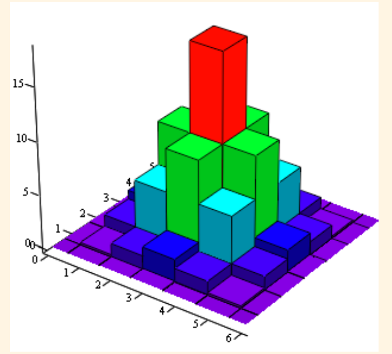
$$\mathrm{PSF}(r) = \exp\left(-\left(\frac{r}{0.839}\right)^{1.629}\right)$$



Effective FOV is ~13.2 km

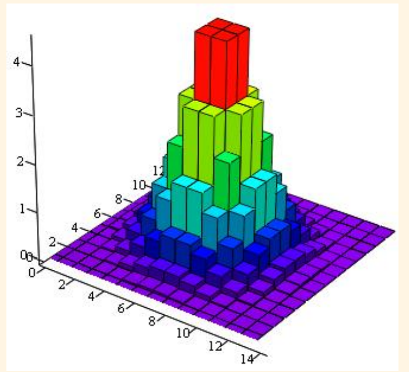
Our goal is an accurate collocation of cloud and radiances data with EPIC measurements

To minimize under-sampling of the global composite data and to improve the accuracy of PSF sampling we convert the original EPIC Lat/Lon grid 2048×2048 (7.8 km/pix at nadir) to Virtual grid of Lat/Lon 4096×4096 (3.9 km/pix at nadir)

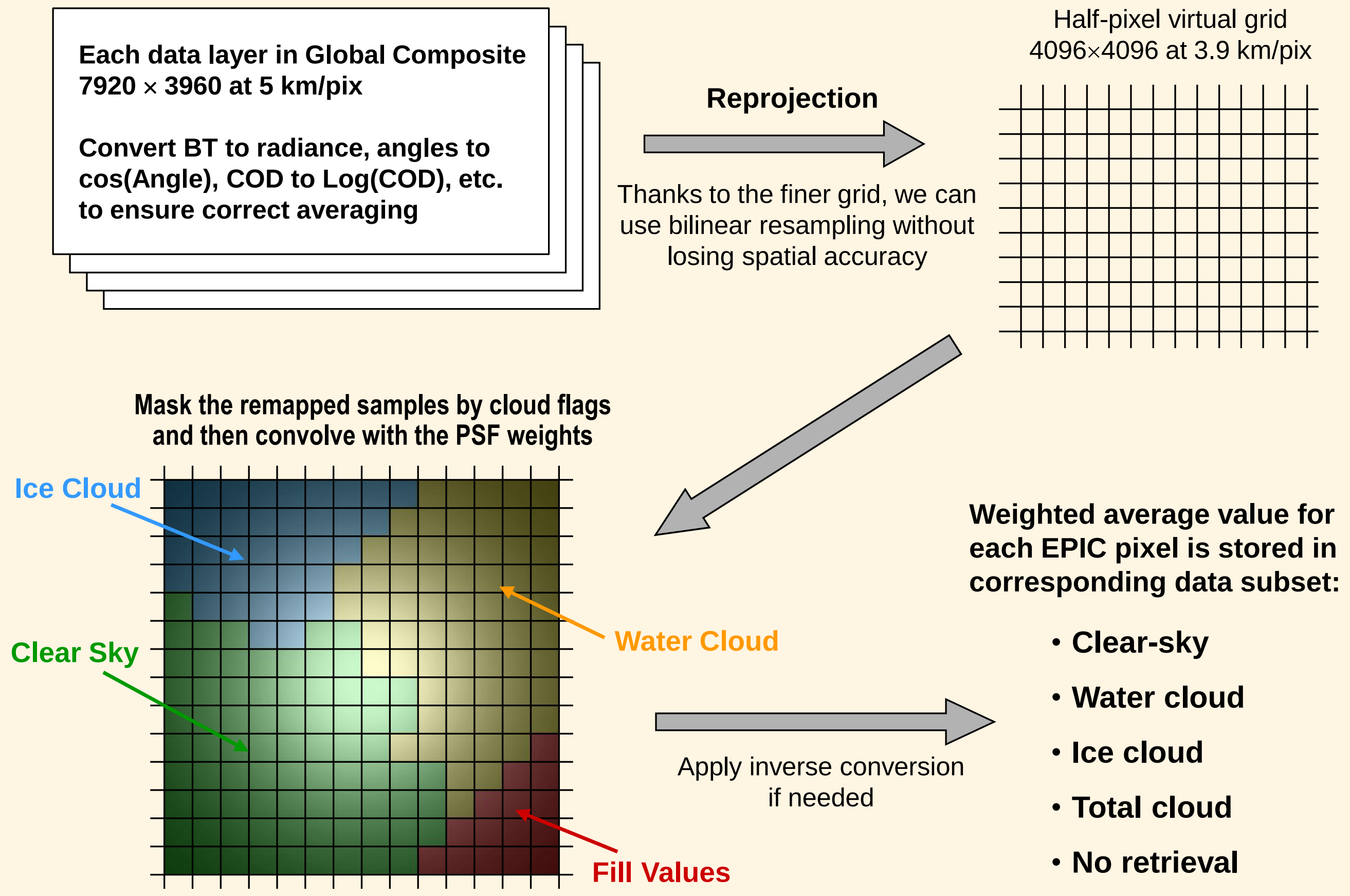


PSF weights, %

- **Half-pixel weights are more accurate**
- **Sub-pixel grid preserves spatial resolution of the global composite**
- **More precision when computing fractional FOV coverage**
- **16 times computational complexity**



Half-pixel weights, %



Each data layer in Global Composite 7920 × 3960 at 5 km/pix

Convert BT to radiance, angles to cos(Angle), COD to Log(COD), etc. to ensure correct averaging

Reprojection

Thanks to the finer grid, we can use bilinear resampling without losing spatial accuracy

Half-pixel virtual grid 4096×4096 at 3.9 km/pix

Mask the remapped samples by cloud flags and then convolve with the PSF weights

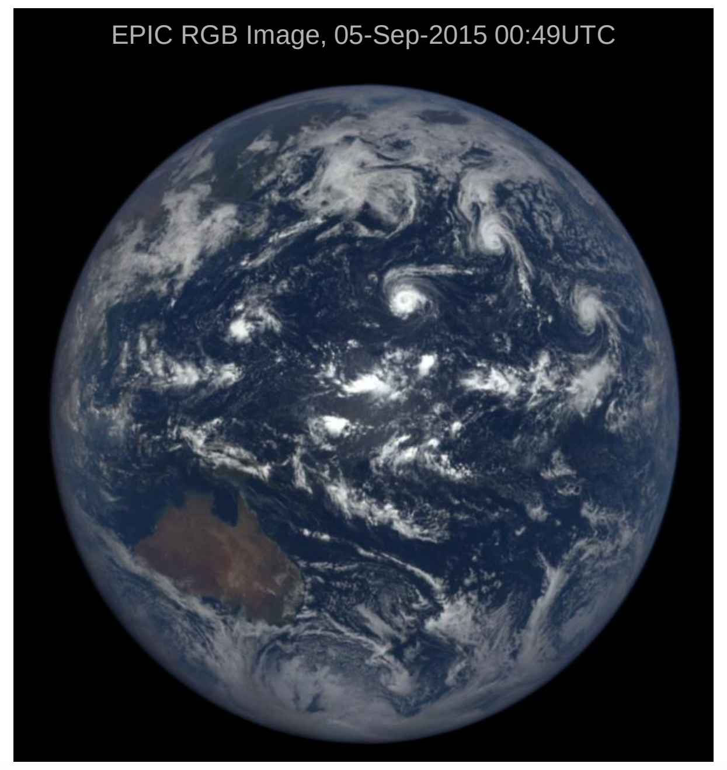
Apply inverse conversion if needed

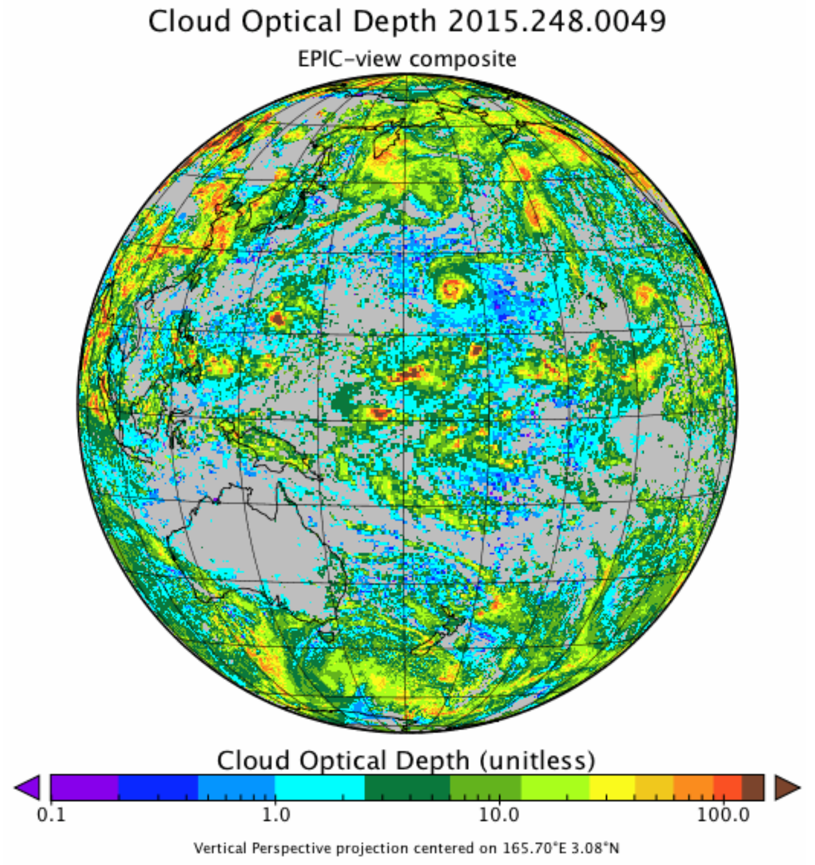
Weighted average value for each EPIC pixel is stored in corresponding data subset:

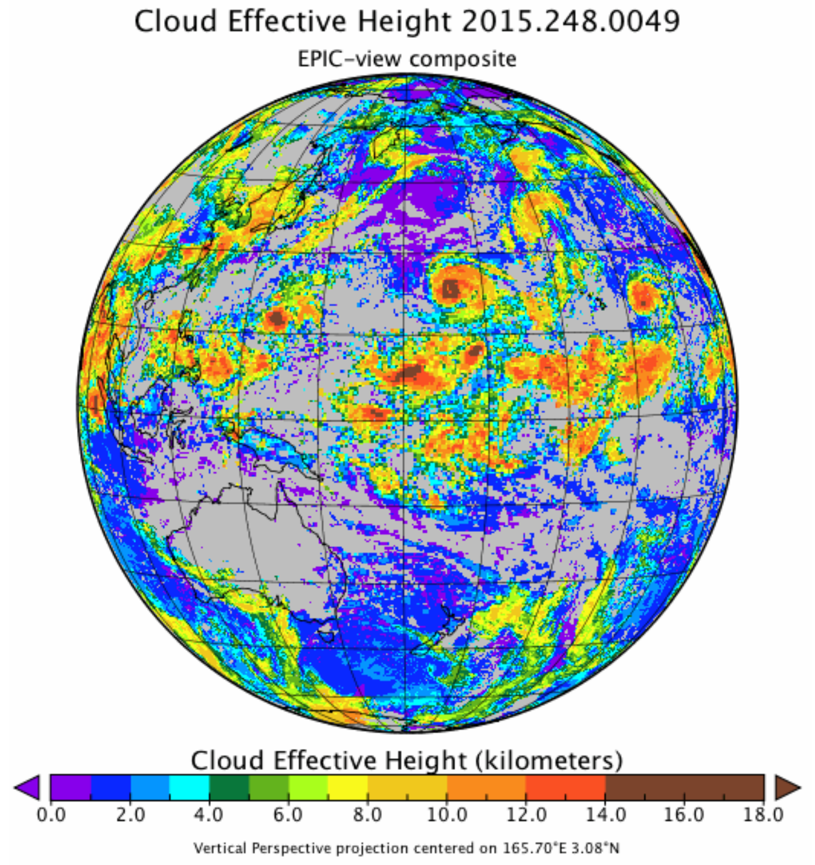
- **Clear-sky**
- **Water cloud**
- **Ice cloud**
- **Total cloud**
- **No retrieval**

Parameters included in EPIC-view composites:

	Parameter	Converted	Remapped	EPIC view composite (7.8 km/pix)					
				general	Clear sky	Ice Cloud	Water Cloud	Total Cloud	No retrieval
1	**Latitude**		EPIC orginal	2D					
2	**Longitude**		EPIC orginal	2D					
3	**Solar Zenith Angle**	cos()	bilinear	✓					
4	**View Zenith Angle**	cos()	bilinear	✓					
5	**Relative Azimuth Angle**	cos()	bilinear	✓					
6	**Reflectance in 0.63um**		bilinear		✓	✓	✓	✓	✓
7	**Reflectance in 0.86um**		bilinear		✓	✓	✓	✓	✓
8	**BT in 3.75um**	radiance	bilinear		✓	✓	✓	✓	✓
9	**BT in 6.75um**	radiance	bilinear		✓	✓	✓	✓	✓
10	**BT in 10.8um**	radiance	bilinear		✓	✓	✓	✓	✓
11	**BT in 12.0um**	radiance	bilinear		✓	✓	✓	✓	✓
12	**SW Broadband Albedo**		bilinear		✓	✓	✓	✓	✓
13	**LW Broadband Flux**		bilinear		✓	✓	✓	✓	✓
14	**Cloud Phase**		N.N.		FOV fraction	FOV fraction	FOV fraction	FOV fraction	FOV fraction
15	**Cloud Optical Depth**		bilinear			✓	✓	✓	
		log()	bilinear			✓	✓	✓	
16	**Cloud Effective Particle Size**		bilinear			✓	✓	✓	
17	**Cloud Effective Height**		bilinear			✓	✓	✓	
18	**Cloud Top Height**		bilinear			✓	✓	✓	
19	**Cloud Effective Temperature**	radiance	bilinear			✓	✓	✓	
20	**Cloud Effective Pressure**		bilinear			✓	✓	✓	
21	**Skin Temperature (retrieved)**	radiance	bilinear		✓				
23	**Surface Type**		N.N.	**Surface Types** (4 predominant types per EPIC pixel) **Surface Type Fraction** (percent coverage)					
24	**Time relative to EPIC**		N.N.	✓					
25	**Satellite ID**		N.N.	✓					
				Precipitable Water (from MOA) **Skin Temperature** (from MOA) **Vertical Temp. Change** = SkinTemp - MOA Temp @300mB above surface **Surface Wind Speed (east-west)** (from MOA) **Surface Wind Speed (north-south)** (from MOA)					







Conclusion

For accurate spatial matching between EPIC measurements and the high-resolution cloud properties in the global composite, the composite data have been remapped into the EPIC-view domain by using geolocation information supplied in EPIC Level 1B data. This step includes convolution of the composite pixels with the EPIC point spread function (PSF) defined with a half-pixel accuracy. Within every EPIC footprint, the PSF-weighted average value of each radiance and cloud property parameter is computed for each cloud phase based on the cloud mask from the global composite. The obtained values are then stored within five data subsets (clear-sky, water cloud, ice cloud, total cloud, and no retrieval) for each pixel in EPIC domain.

Spatial variability and continuity of the global composite data have been analyzed to assess the performance of the merging criteria. The proposed algorithm has demonstrated contiguous global coverage for any requested time of day with a temporal lag of under 2 hours in over 95% of the globe. Overall, the composite product has been generated for every EPIC observation from June 2015 to February 2017, typically 300-500 composites per month, which makes it useful for many climate applications.

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