EPIC L2 Cloud Products Update

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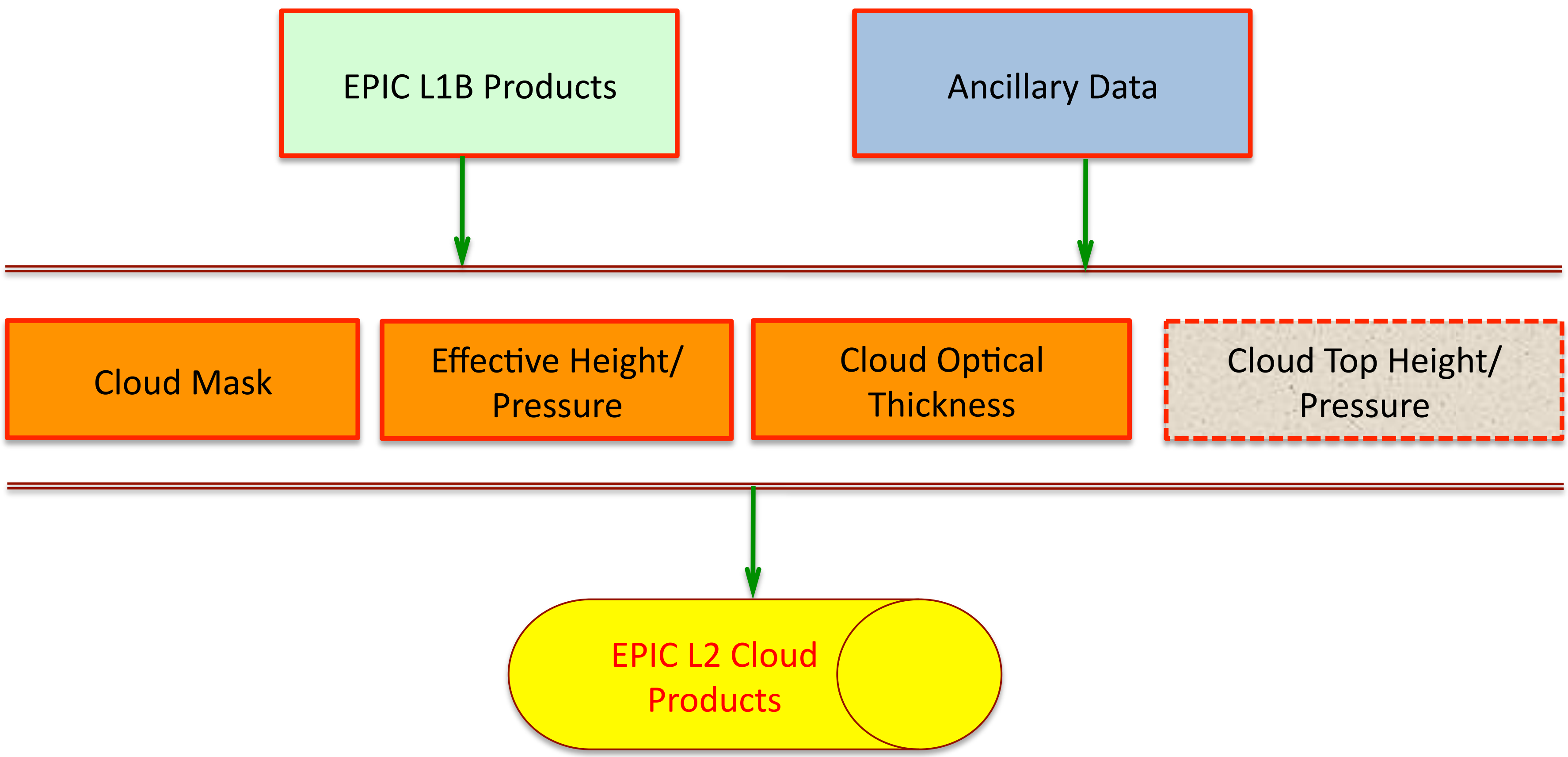
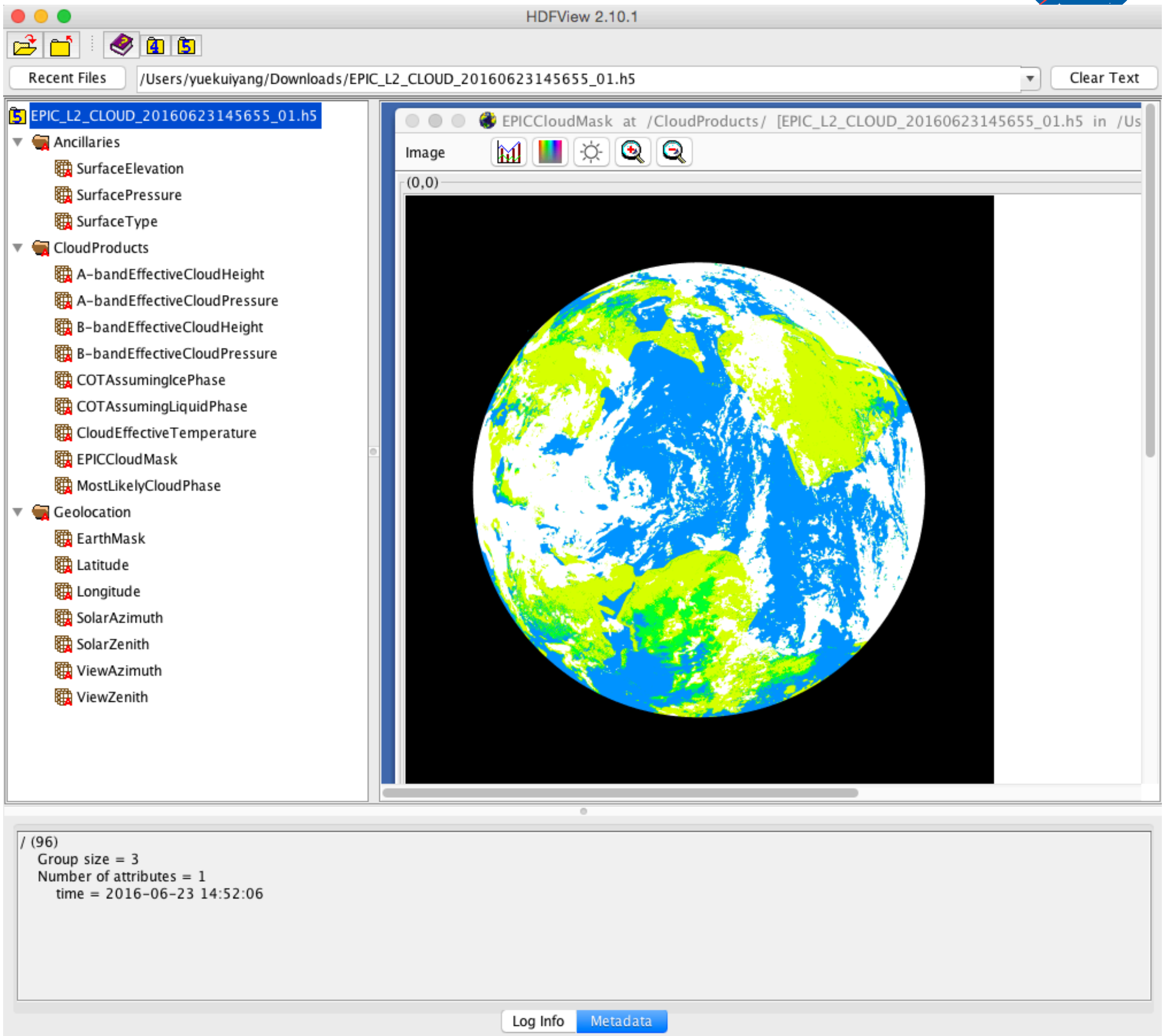
Cloud Product System



Current Status

1. Cloud mask, cloud effective height and cloud optical thickness subsystems running.
2. Cloud mask subsystem improvements undergoing.
3. Cloud effective height/pressure subsystem implemented and running.
4. Cloud optical thickness: single channel retrieval using MODIS infrastructure.
5. Theoretical studies published (no DSCOVR data involved): 1) potential uncertainties in EPIC cloud optical thickness retrieval (*Meyer, Yang and Platnick, 2016, AMTD*); 2) EPIC temporal sampling effect study with GEOS-5 Nature Run (*Holdaway and Yang, 2016a, 2016b, Remote. Sens.*)

L2 Cloud Product File Overview



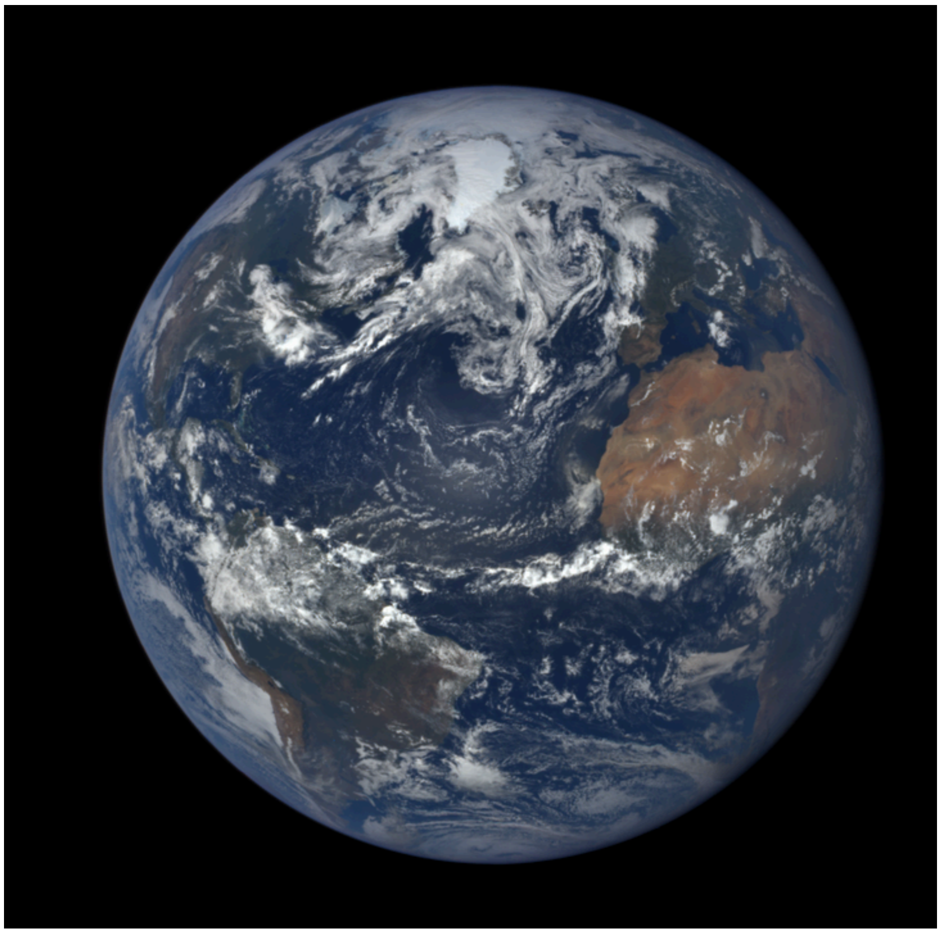
EPIC Channels Currently Used for Cloud Products

λ (nm)	$\Delta\lambda$ (nm) FWHM	Purpose
317.5±0.1	1±0.2	Ozone
325±0.1	2±0.2	Ozone
340±0.3	3±0.6	Ozone, Aerosols
388±0.3	3±0.6	Aerosols, Clouds
443±1	3±0.6	Aerosols
551±1	3±0.6	Aerosols, Vegetation
680±0.2	2±0.4	Aerosols, Vegetation, Clouds, O_2 B-Band Reference
687.75±0.2	0.8±0.2	O_2 B-Band Cloud Height
764.0±0.2	1±0.2	O_2 A-Band Cloud Height
779.5±0.3	2±0.4	O_2 A-Band Reference, Vegetation

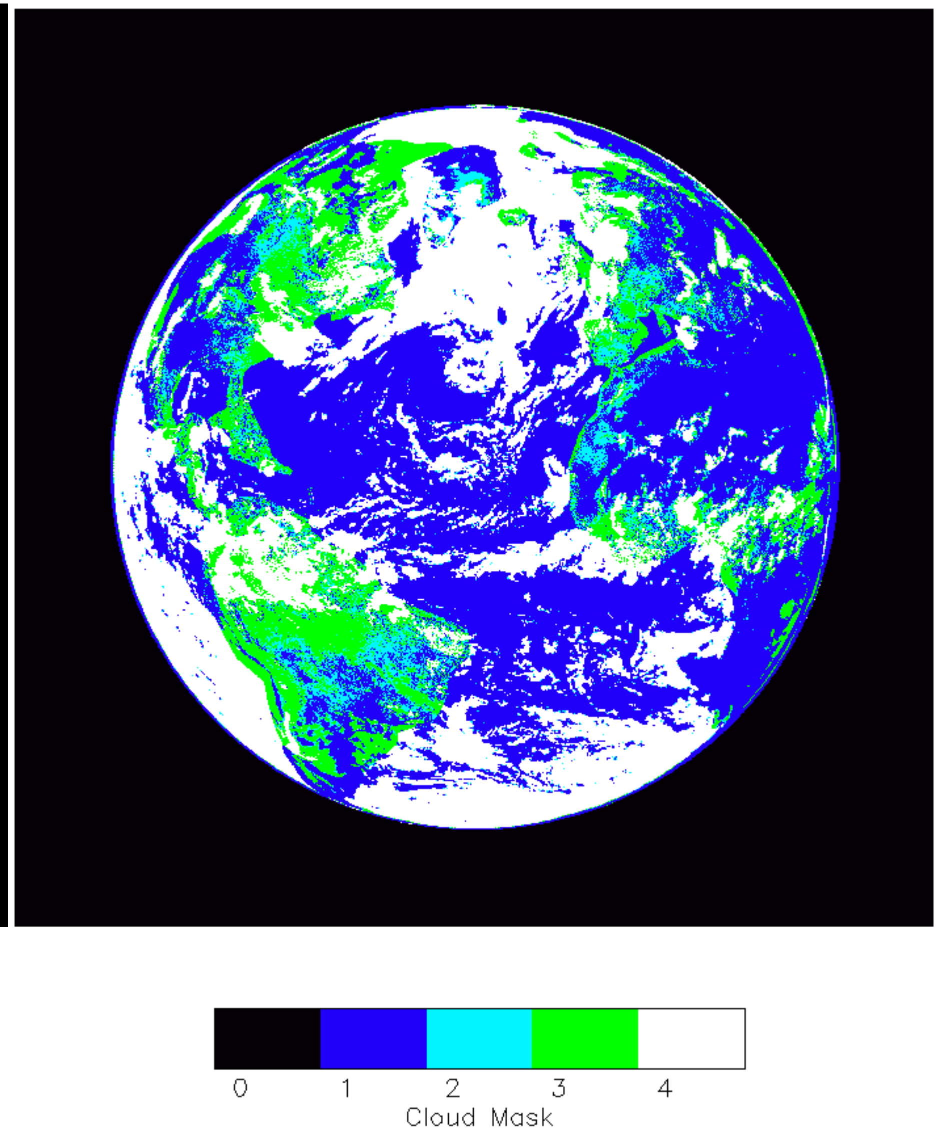
1. Cloud Mask

Test	Ocean	Land	Snow/Ice
388 nm		Y	
680 nm	Y		
780 nm	Y		
Ratio: 688 nm / 680 nm			Y
Ratio: 764 nm / 779.5 nm		Y	Y

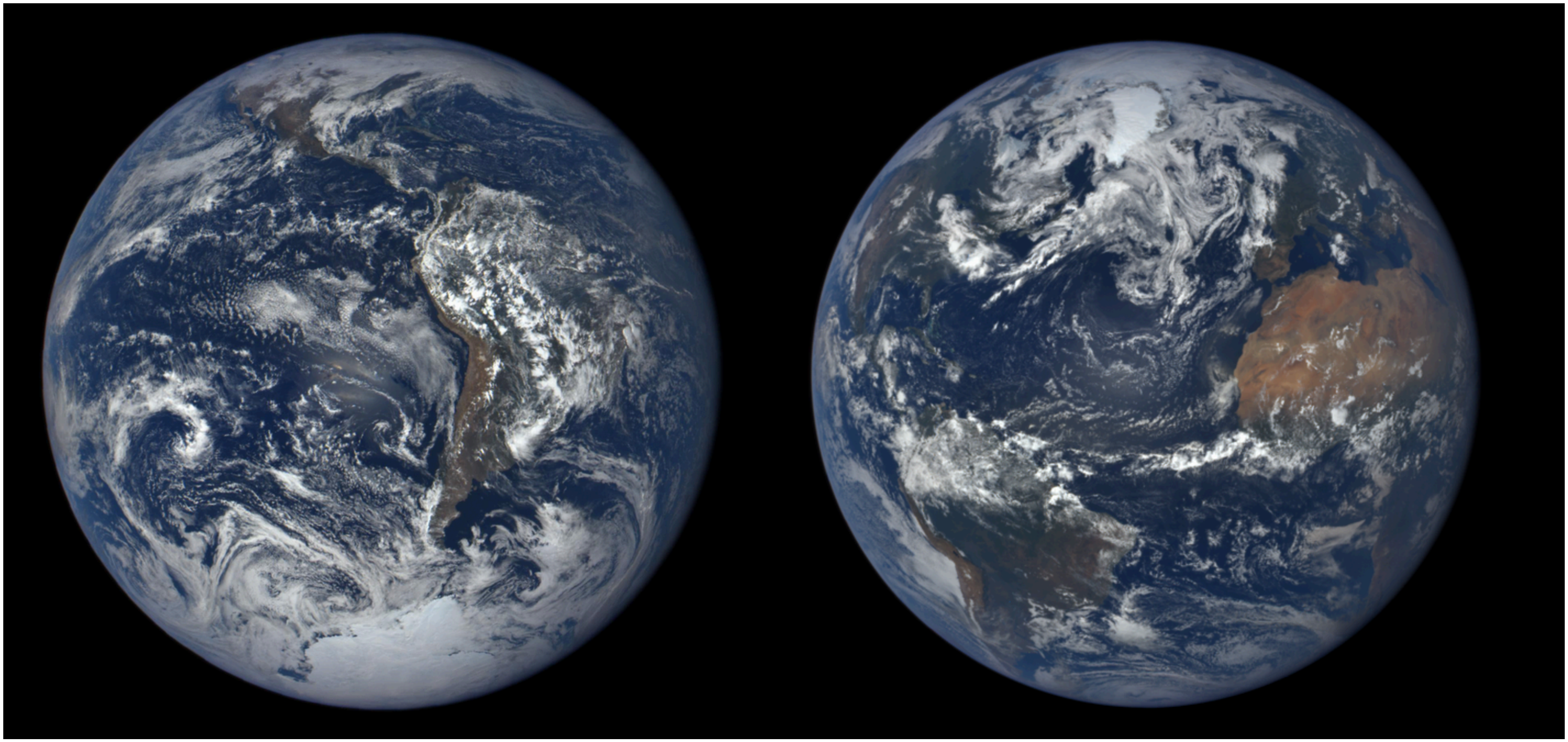
Cloud mask example



epic_1b_20160623145655_01.h5

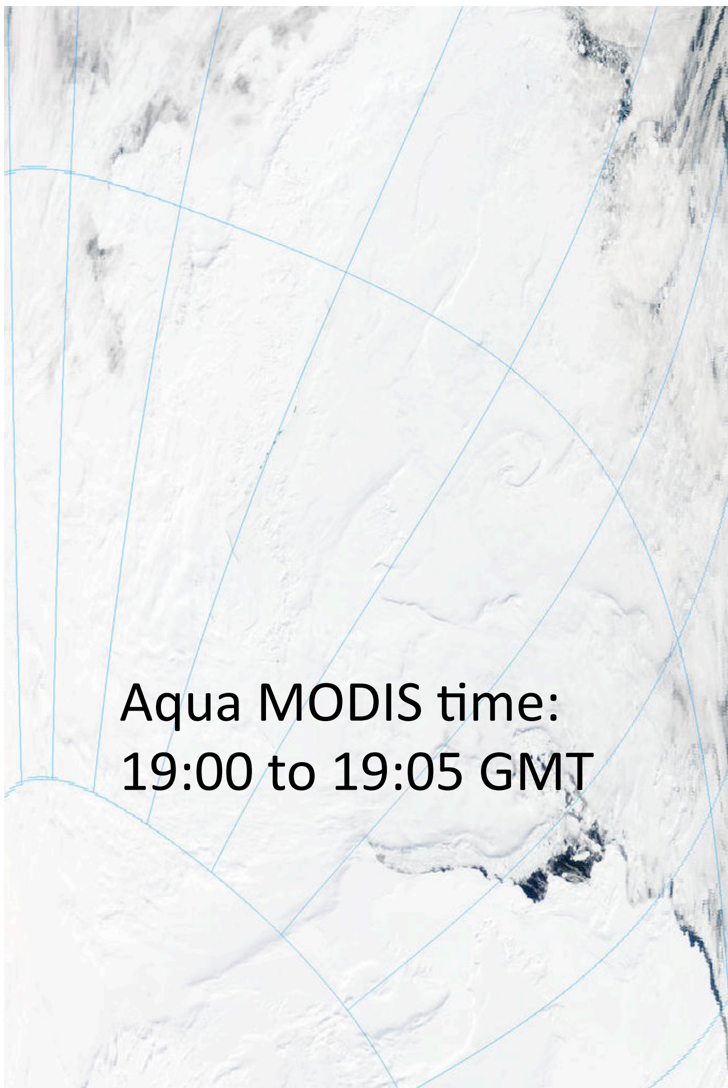


Difficulties in cloud detection with only shortwave channels, especially over ice/snow

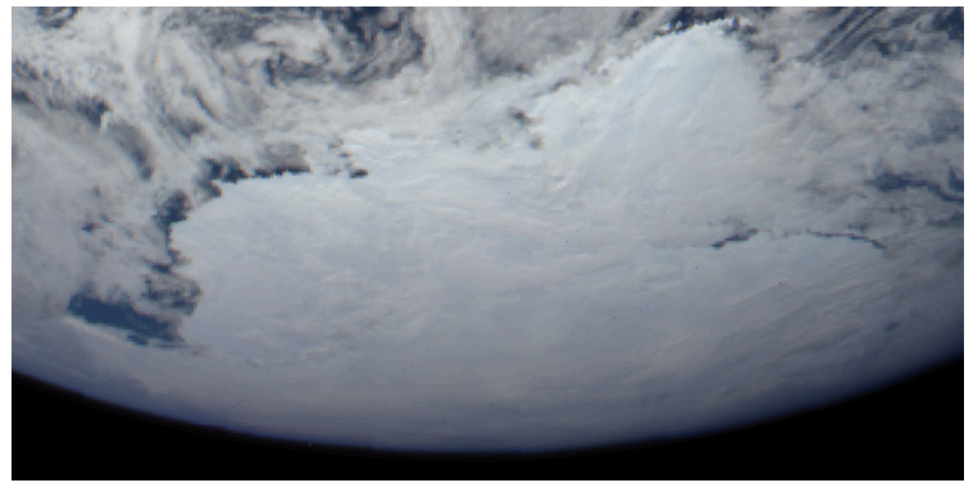


No IR channels; no SWIR channels

Difficulties in cloud detection over ice/snow

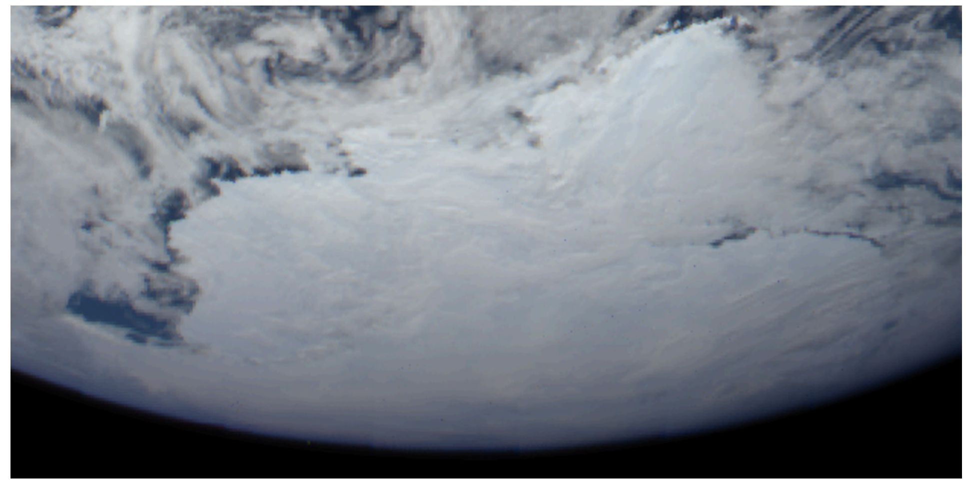


EPIC image time: 12/29/2015 18:27 GMT

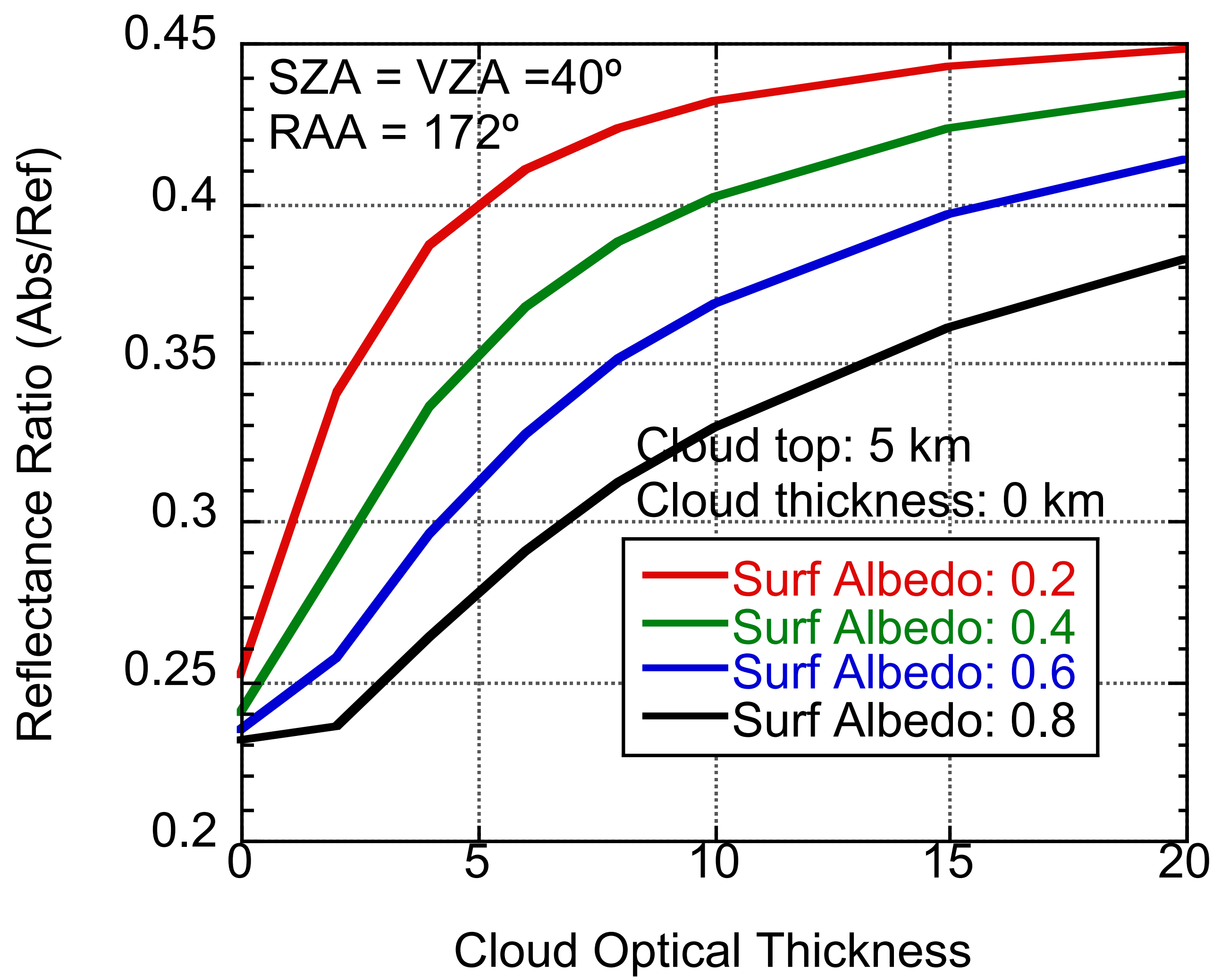


Difficulties in cloud detection over ice/snow

EPIC image time: 18:27 GMT

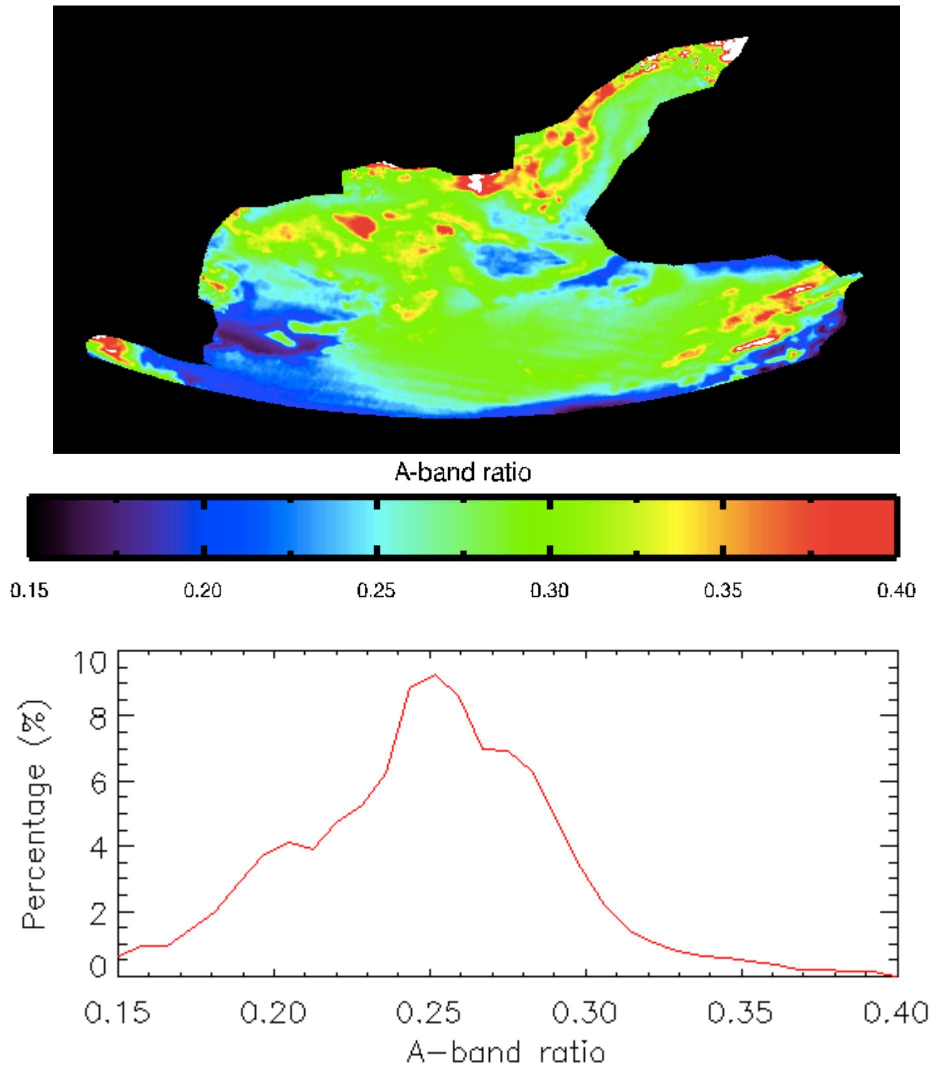


Cloud signal in EPIC A-band over different surface types

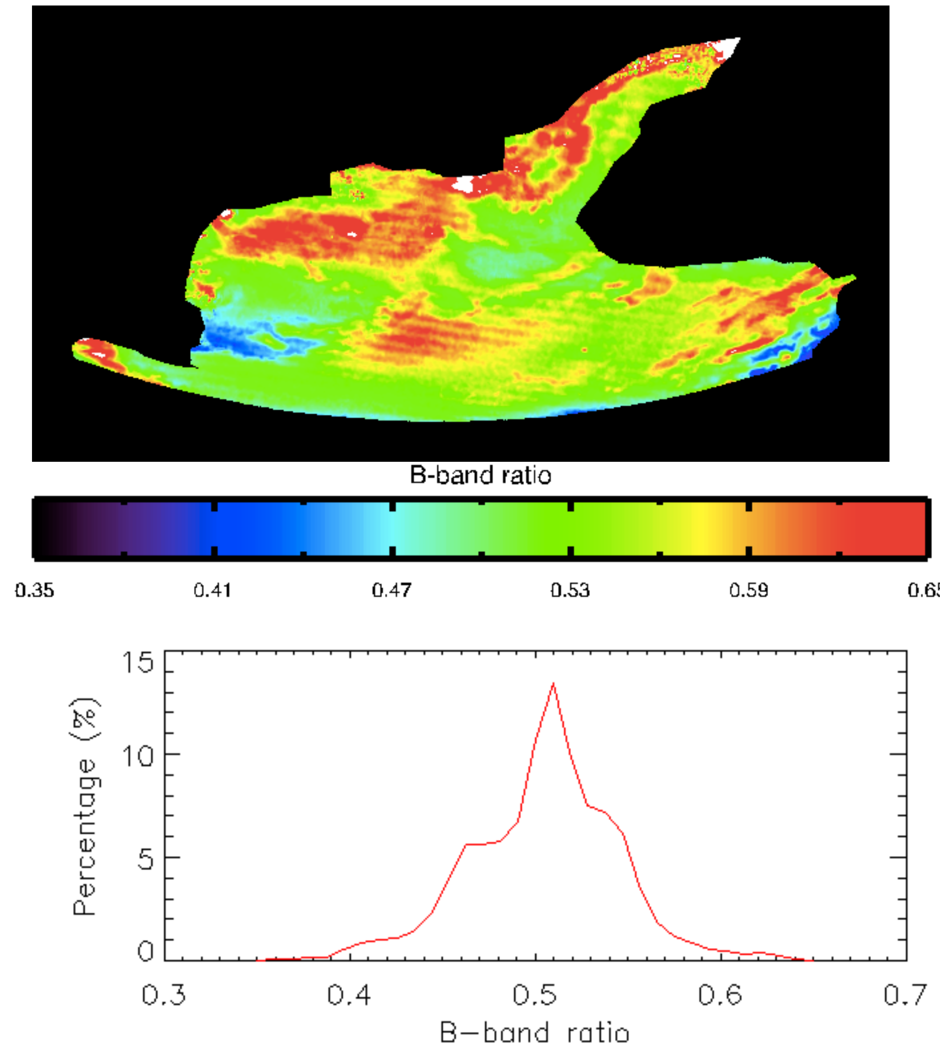


Cloud signal in EPIC A- and B-bands over ice/snow

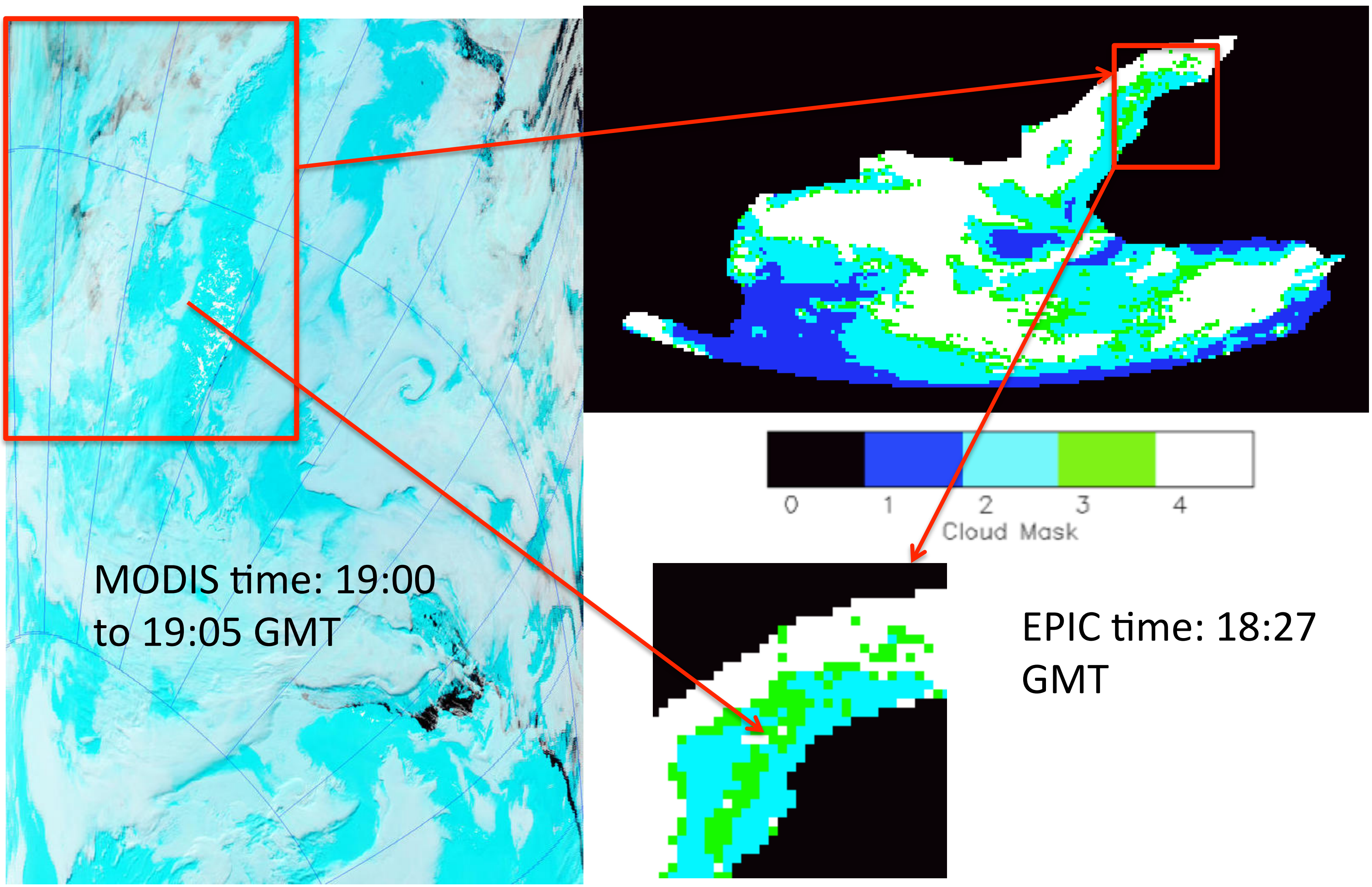
A-band Ratio



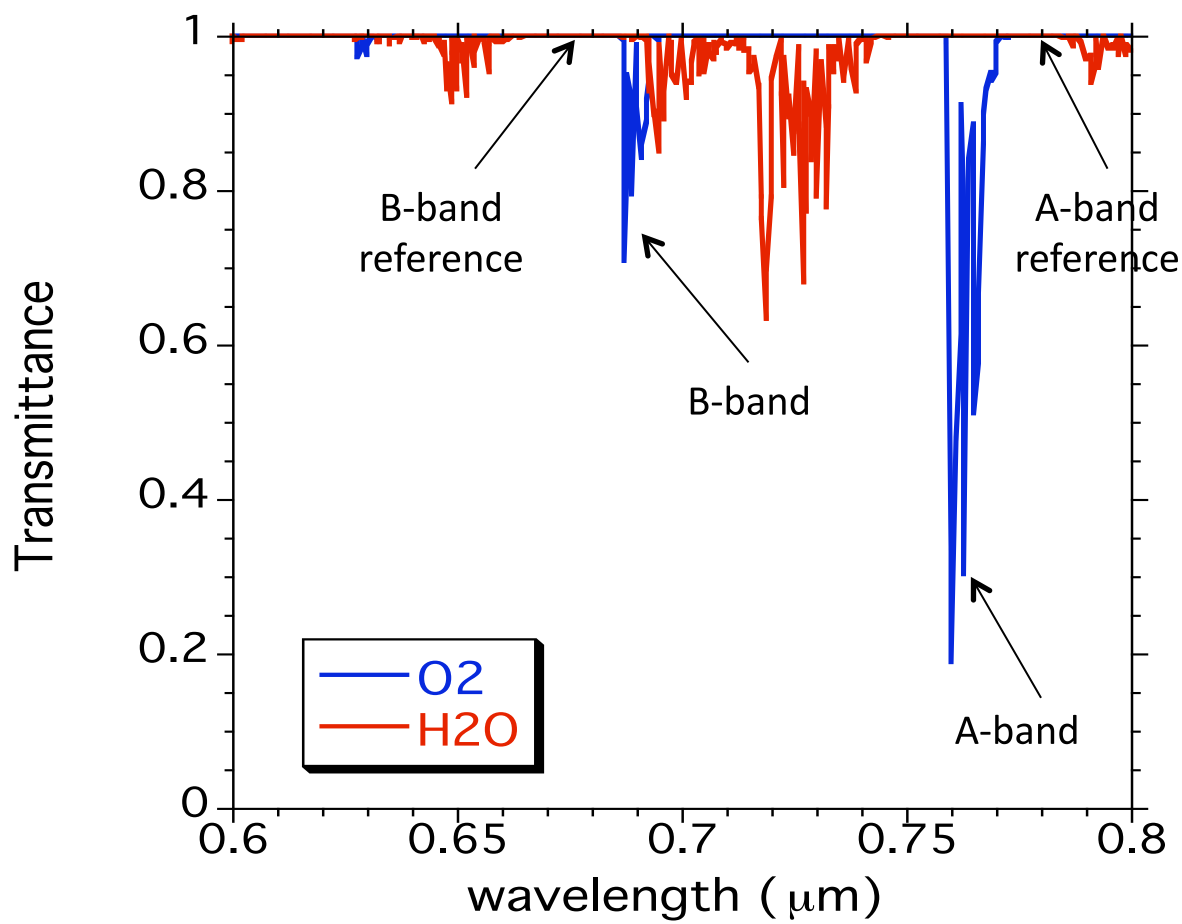
B-band Ratio



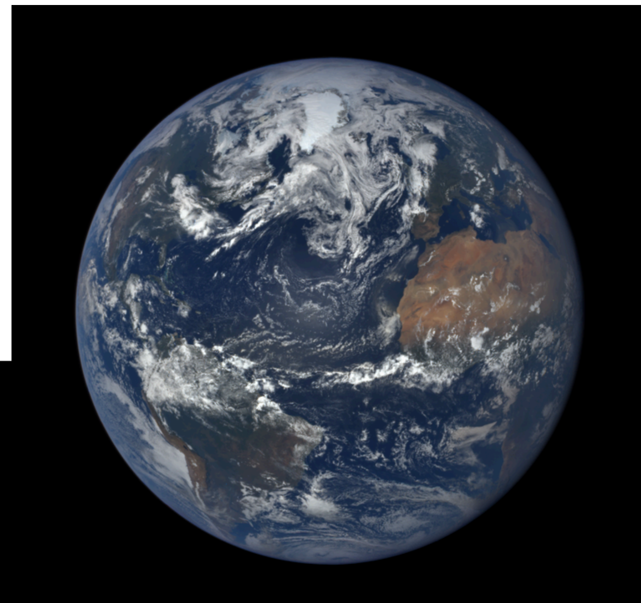
Cloud Mask from A- and B-bands

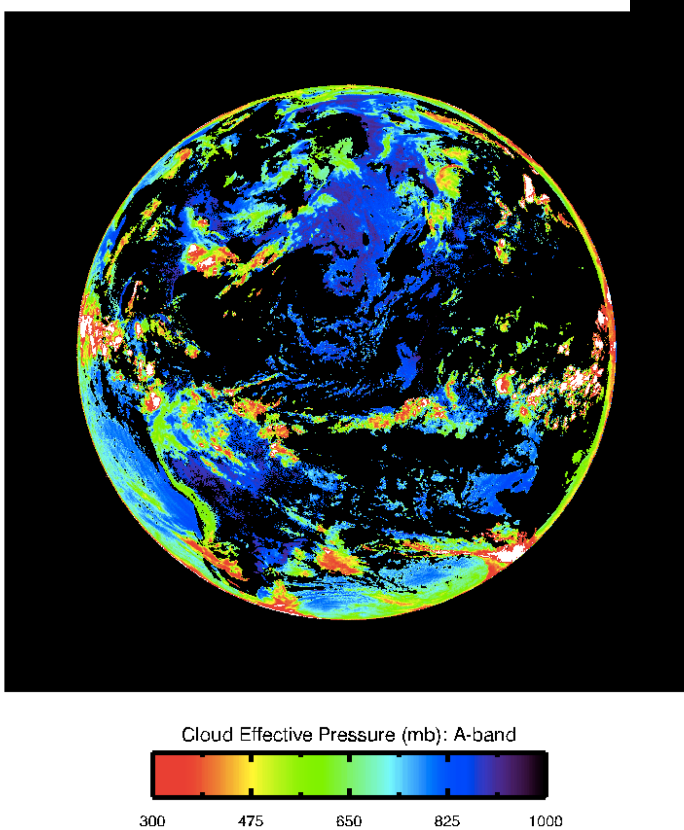


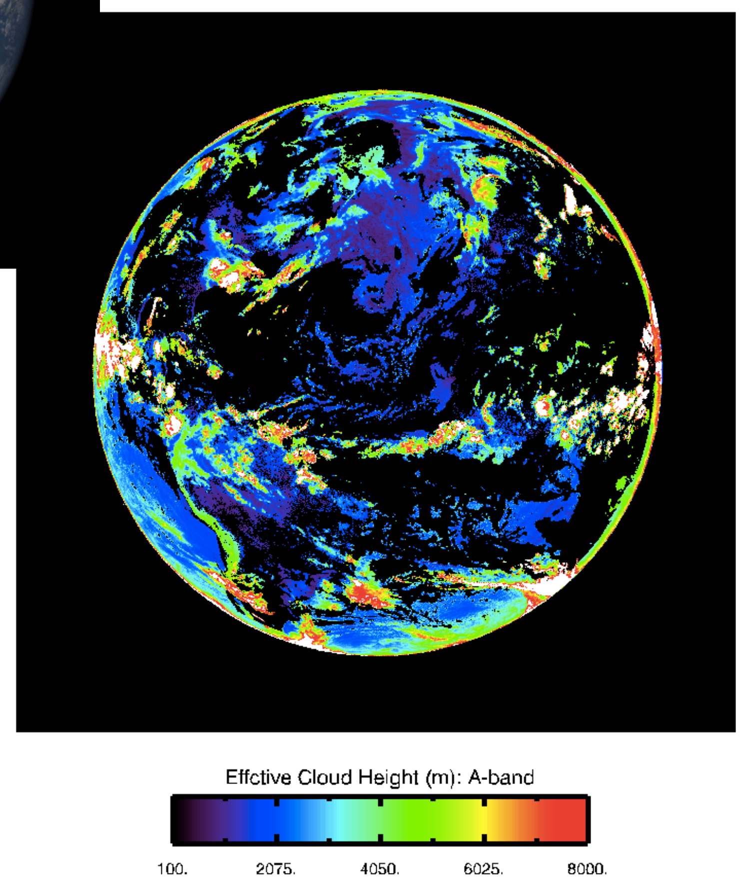
2. Cloud Effective Height/Pressure



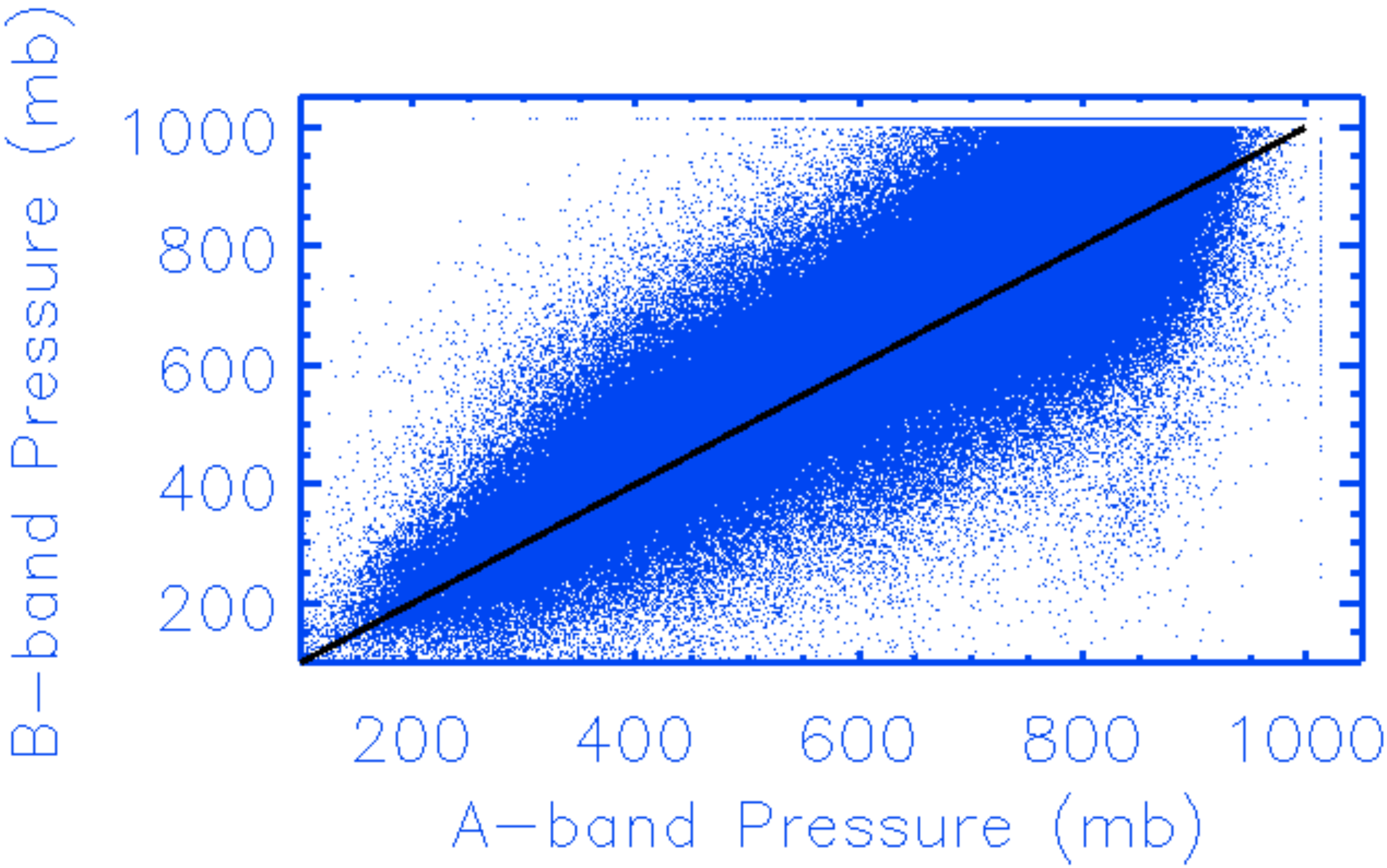
Cloud Effective Pressure/Height



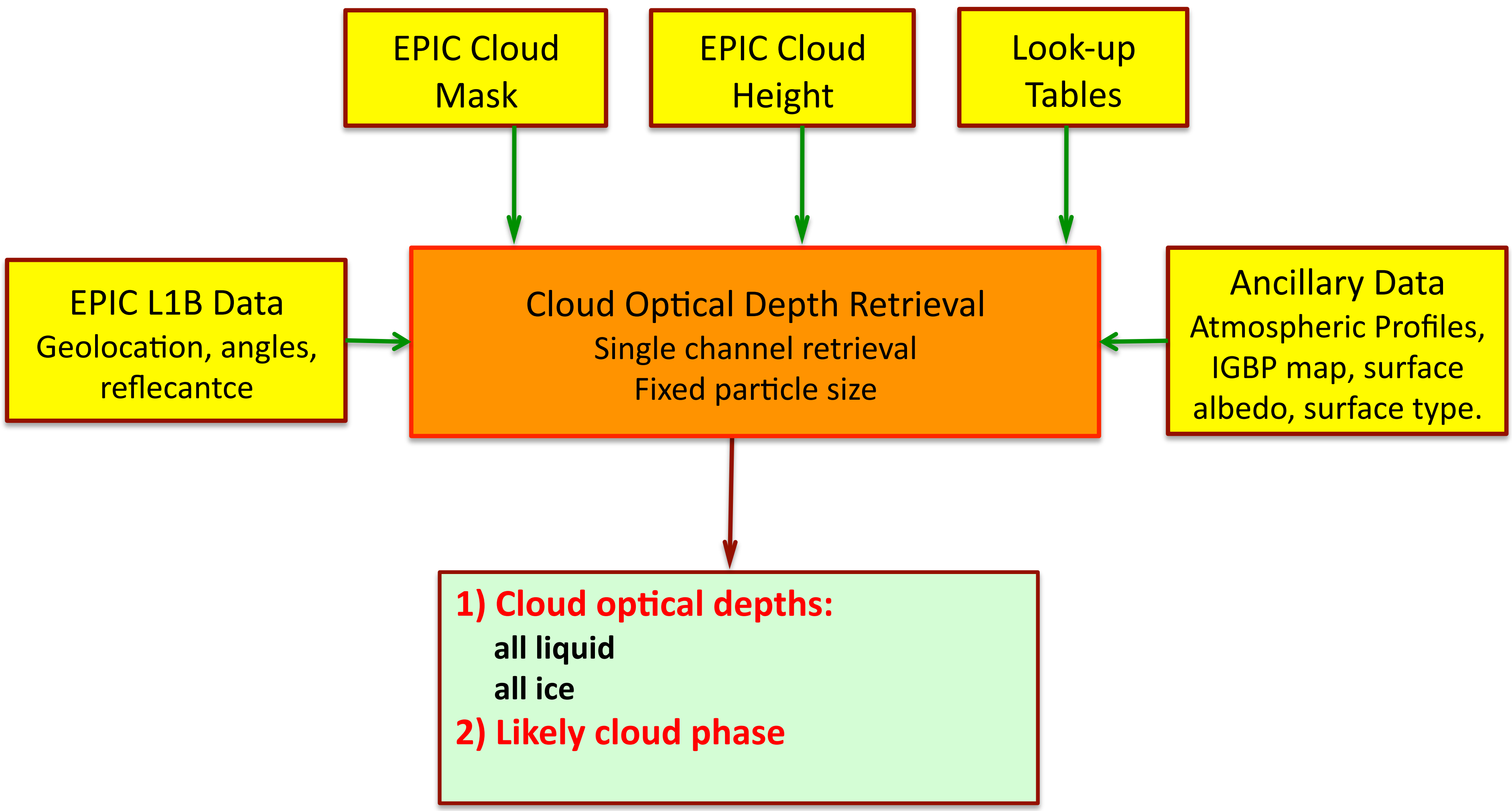




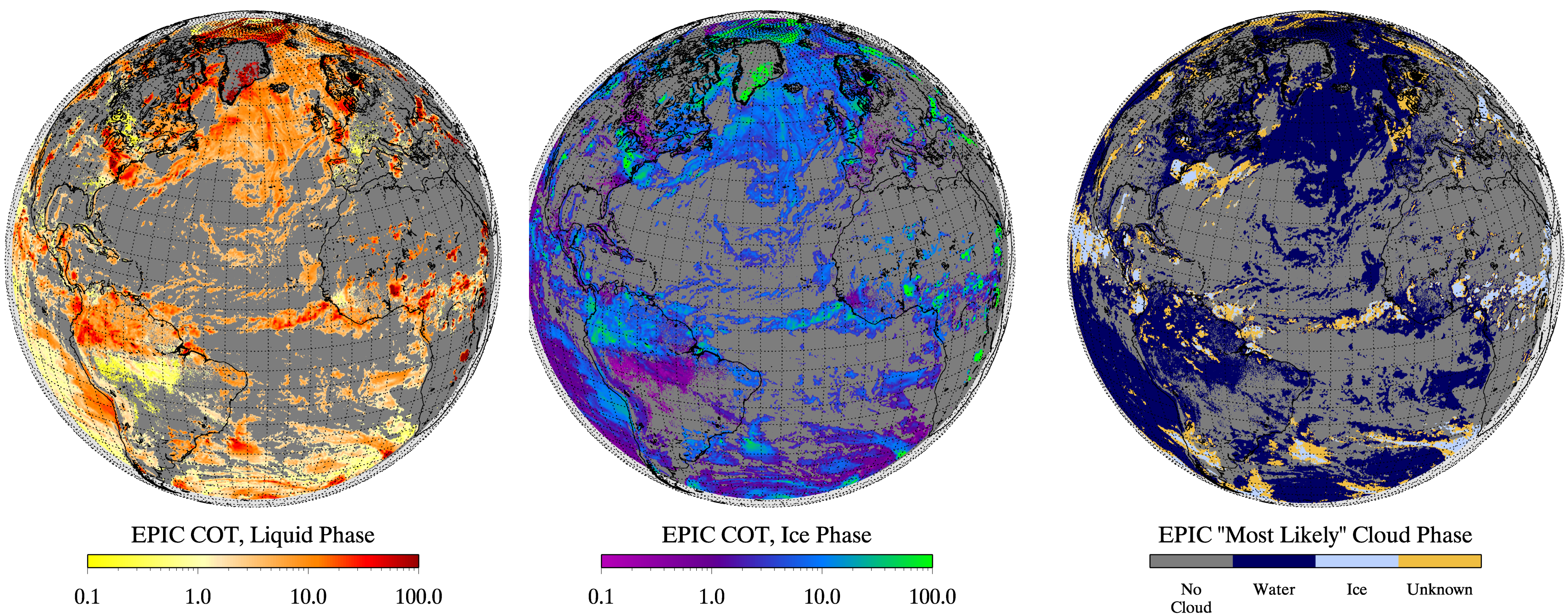
A-band vs B-band



3. Cloud Optical Thickness Retrieval

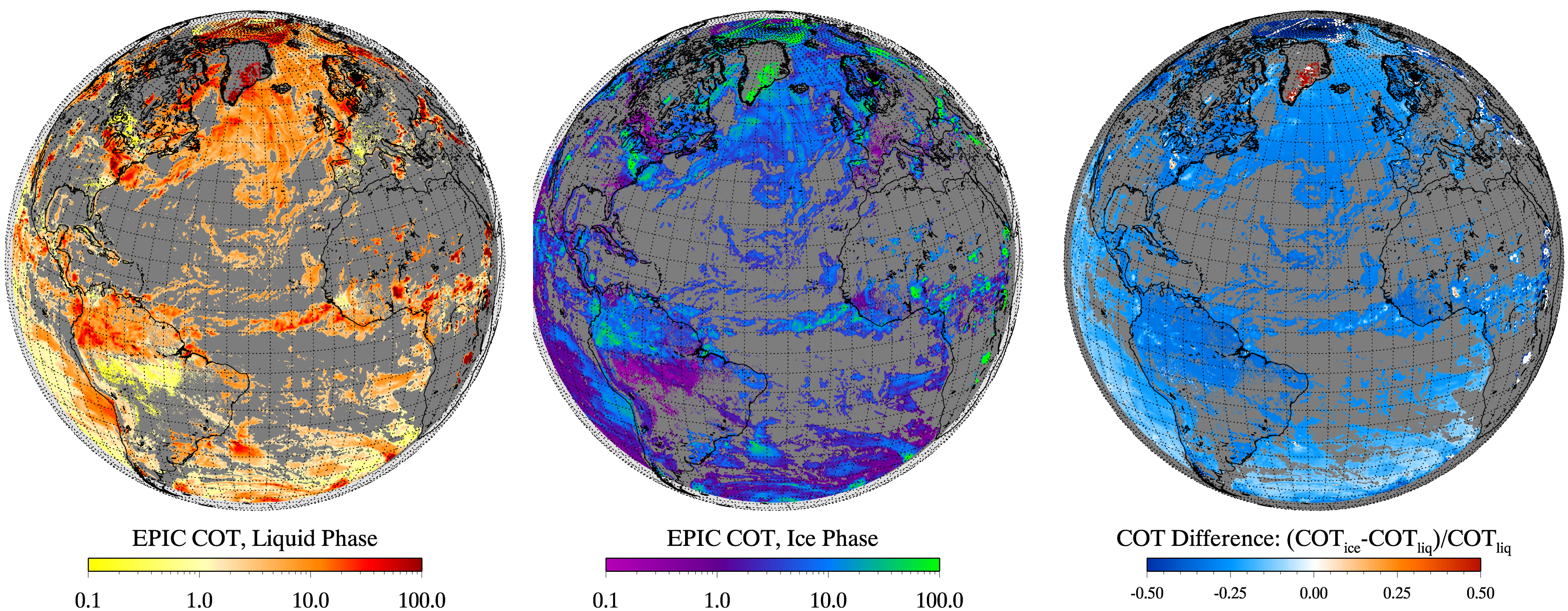


Cloud optical thickness retrievals



- Cloud phase determination is based on the cloud temperature converted from the EPIC cloud height retrievals, which has large uncertainty.
- L2 cloud products include COT assuming liquid phase, COT assuming ice phase and the likely cloud phase.

Cloud optical thickness retrievals



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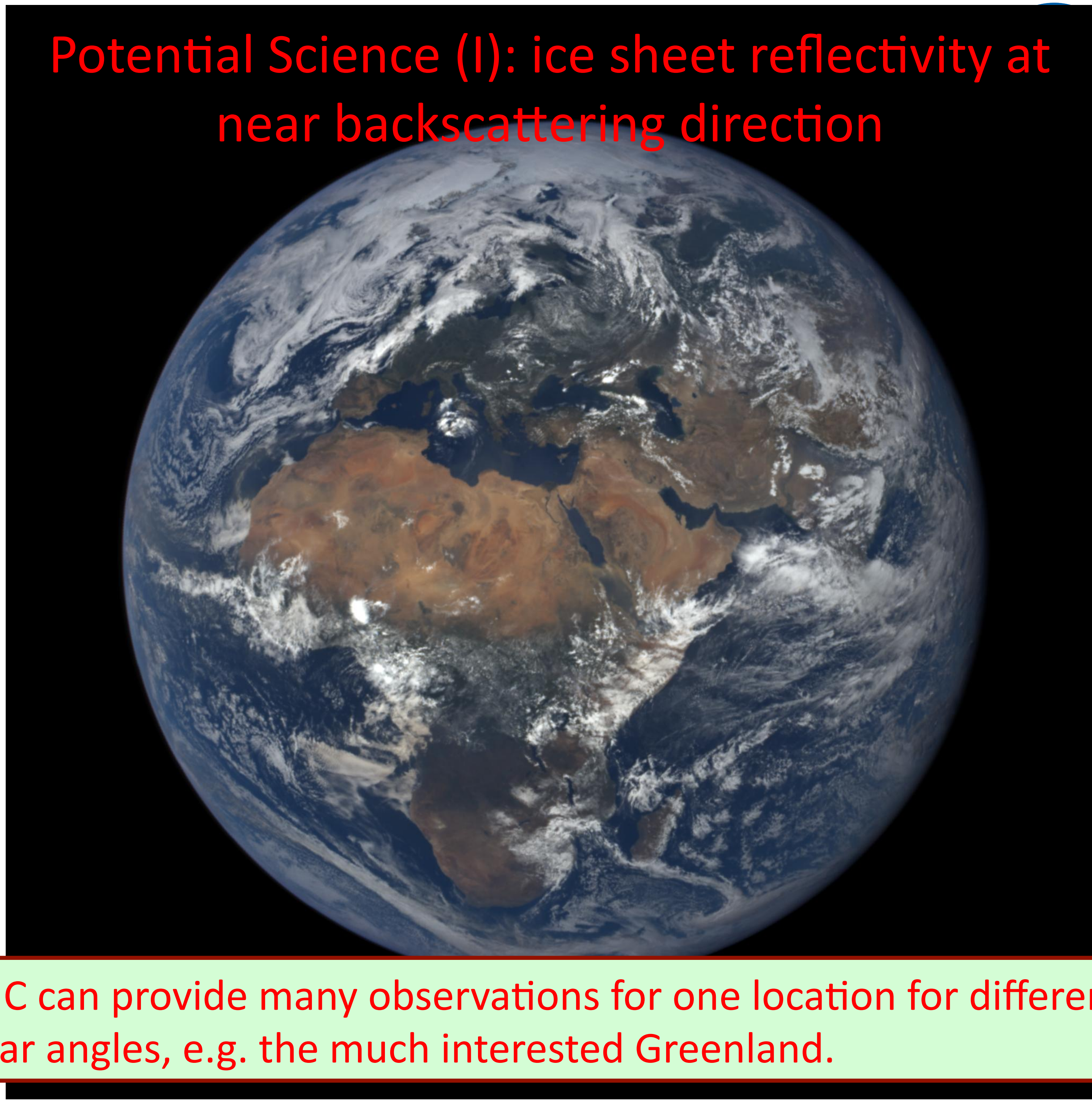
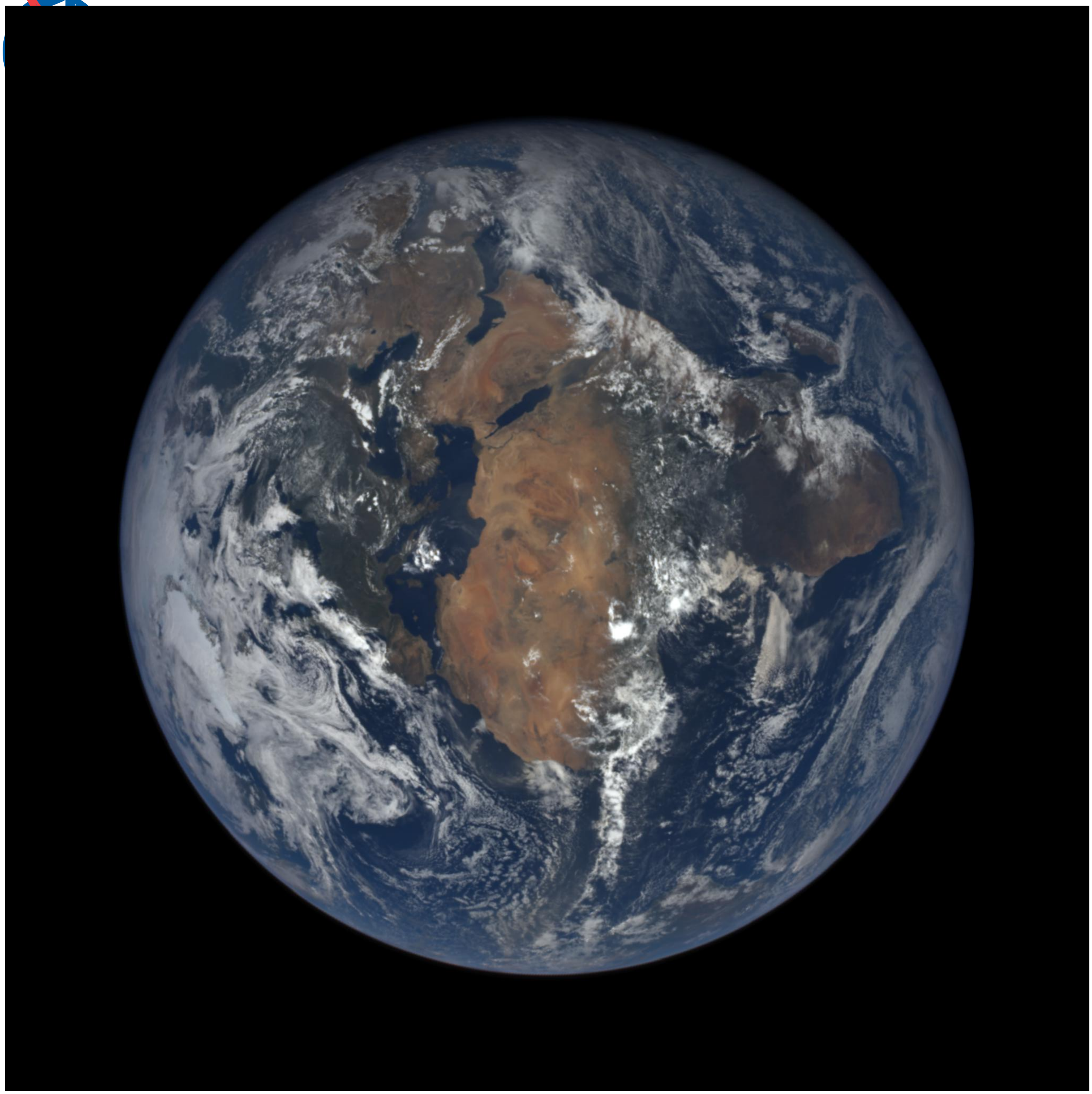
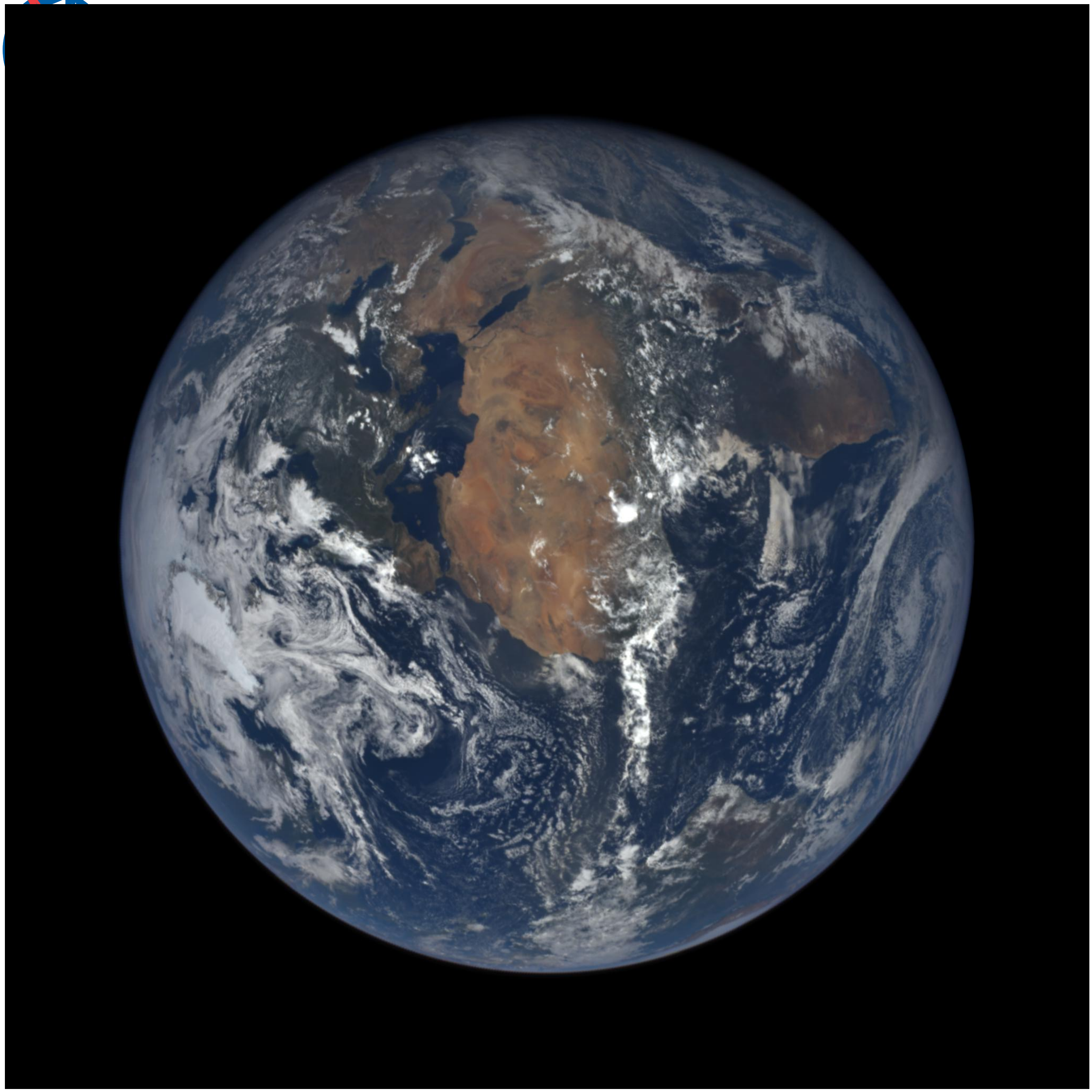
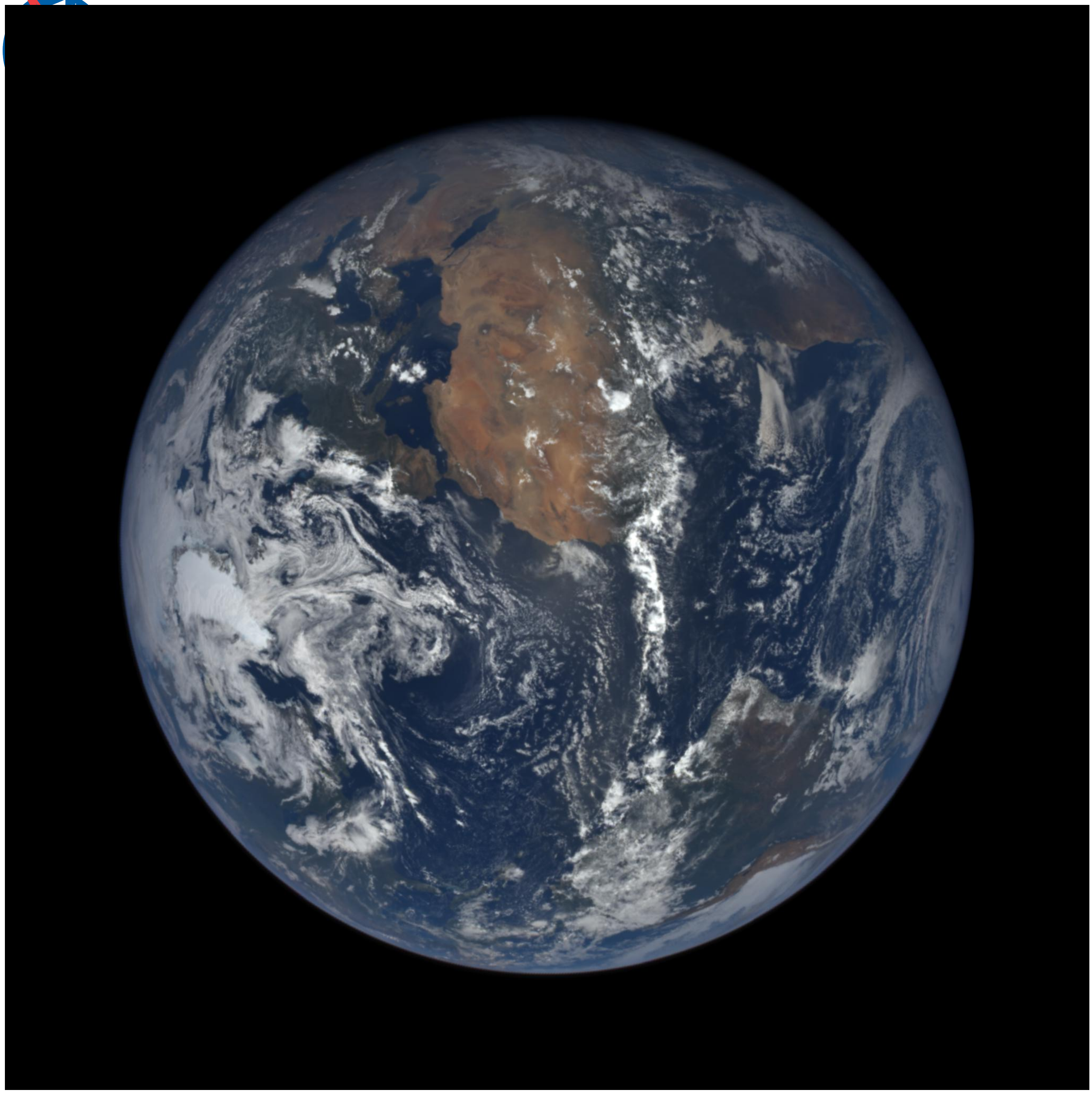
Potential Science (I): ice sheet reflectivity at near backscattering direction

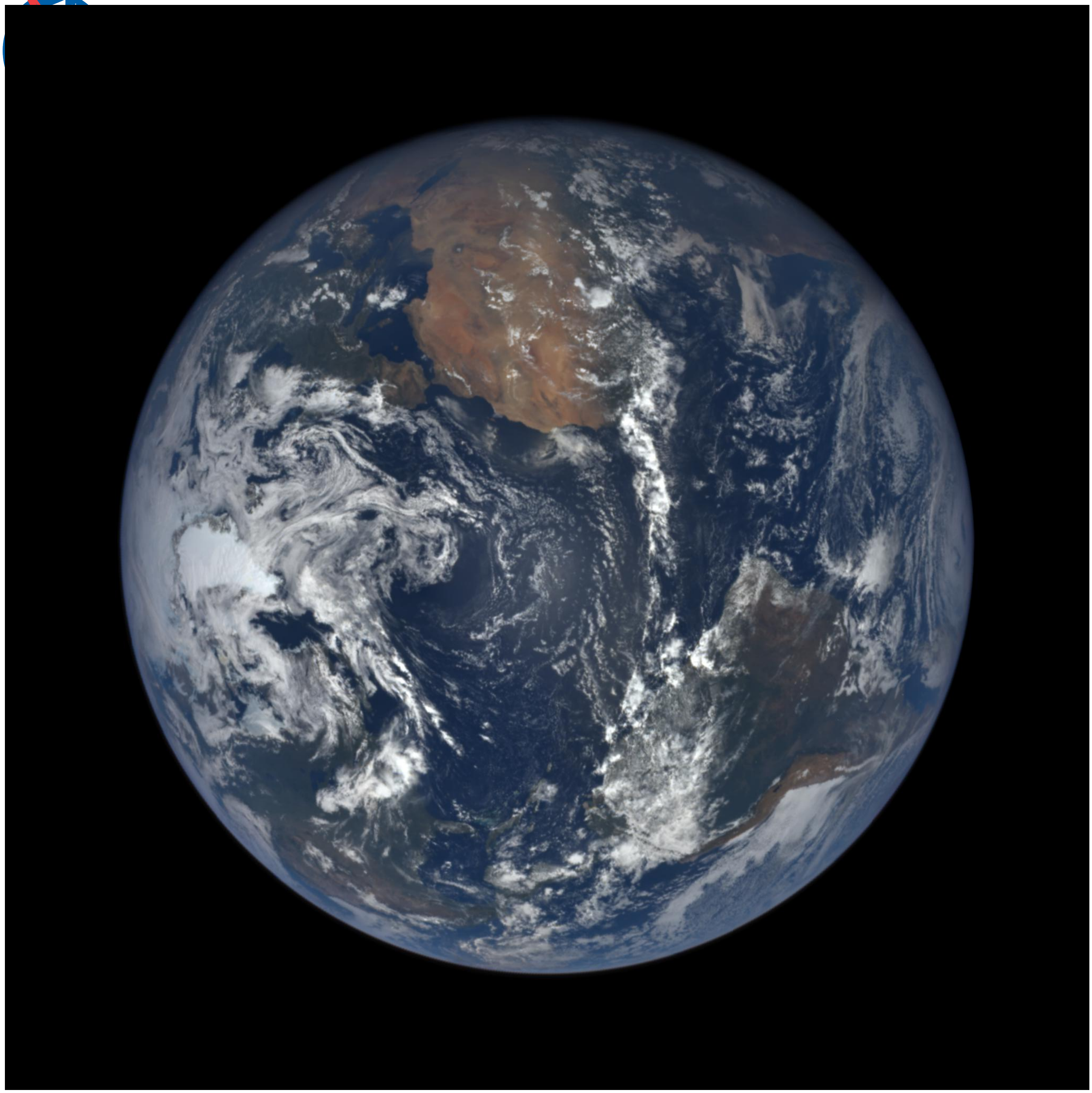


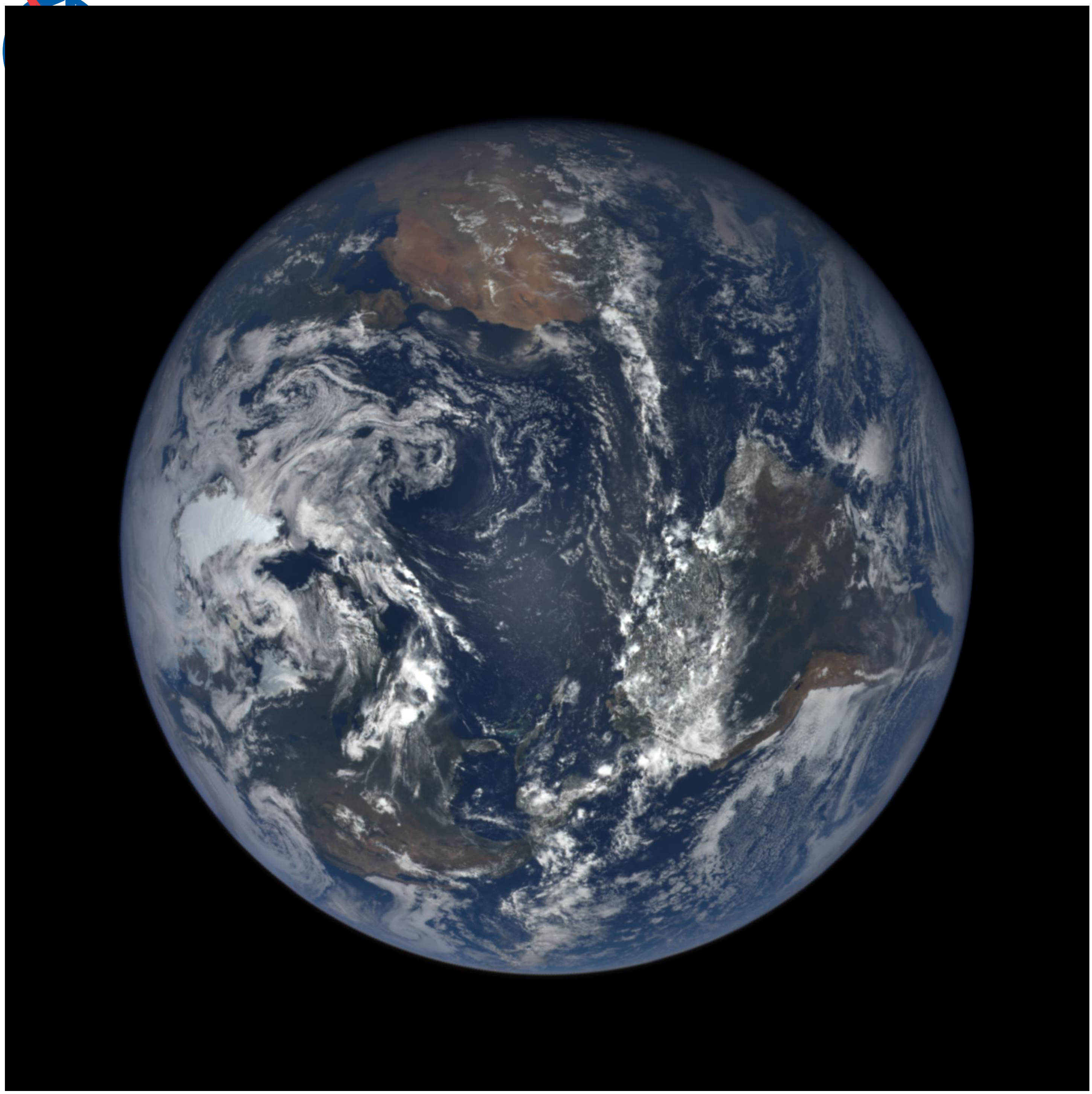
EPIC can provide many observations for one location for different solar angles, e.g. the much interested Greenland.

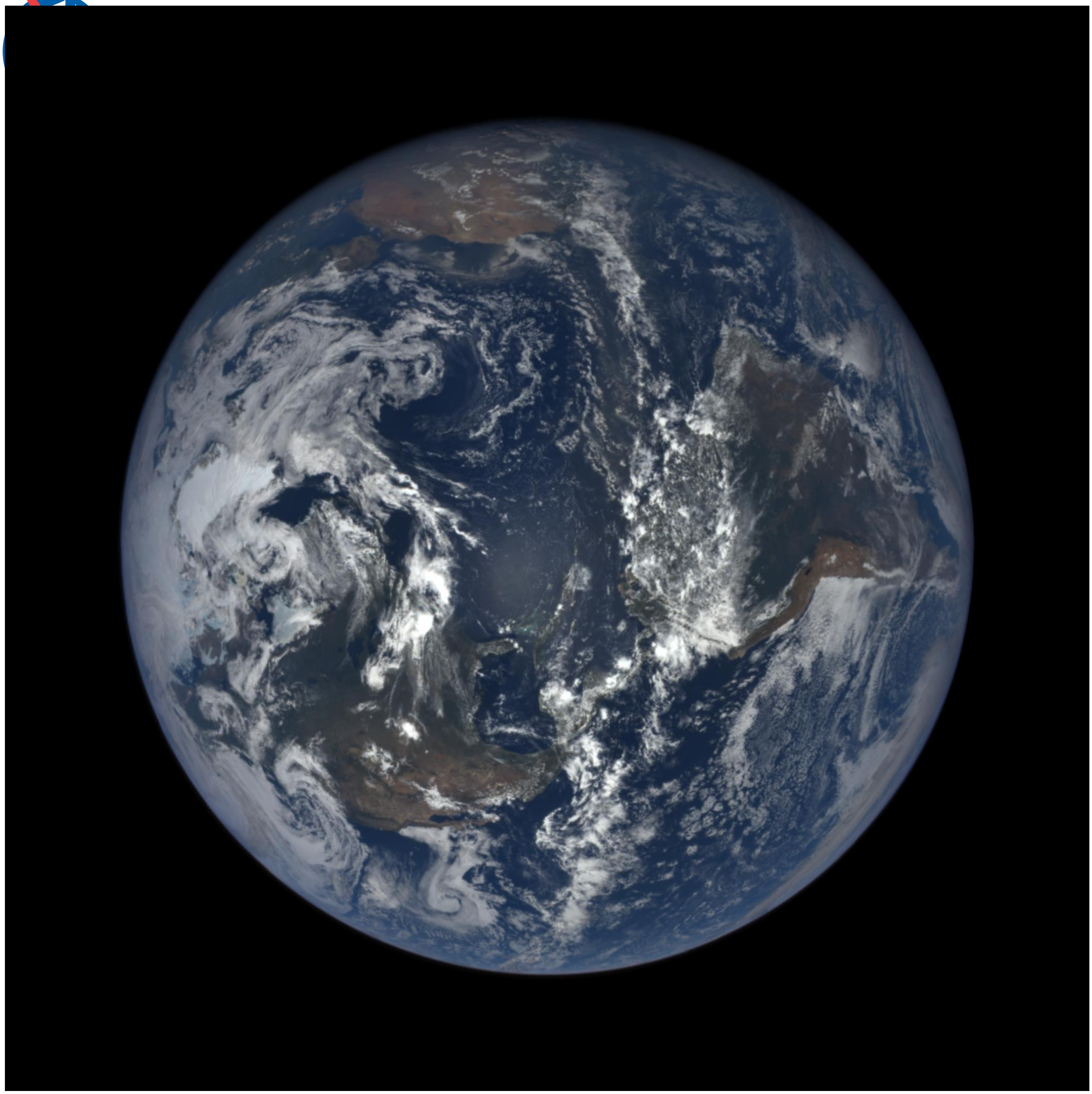


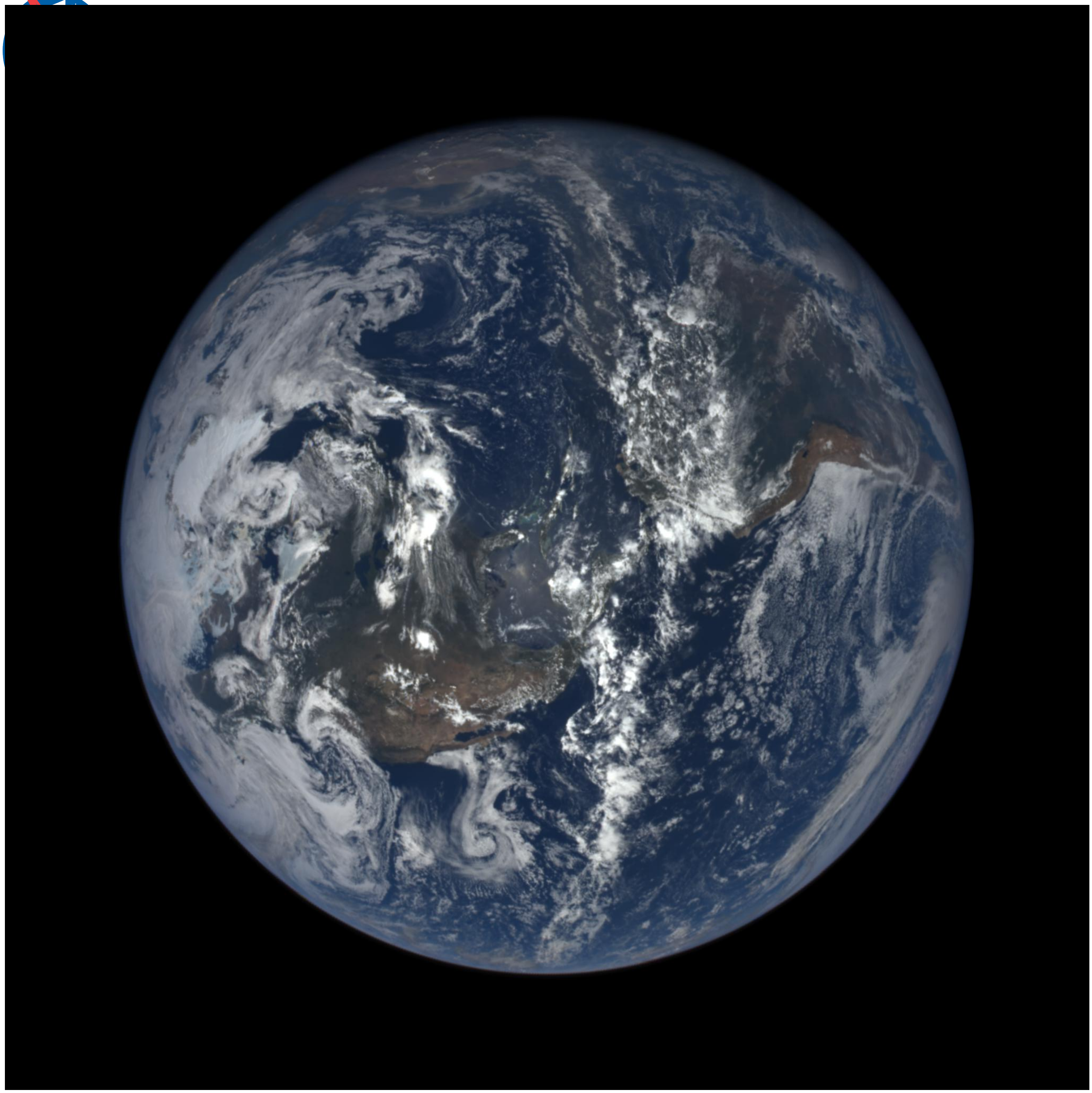


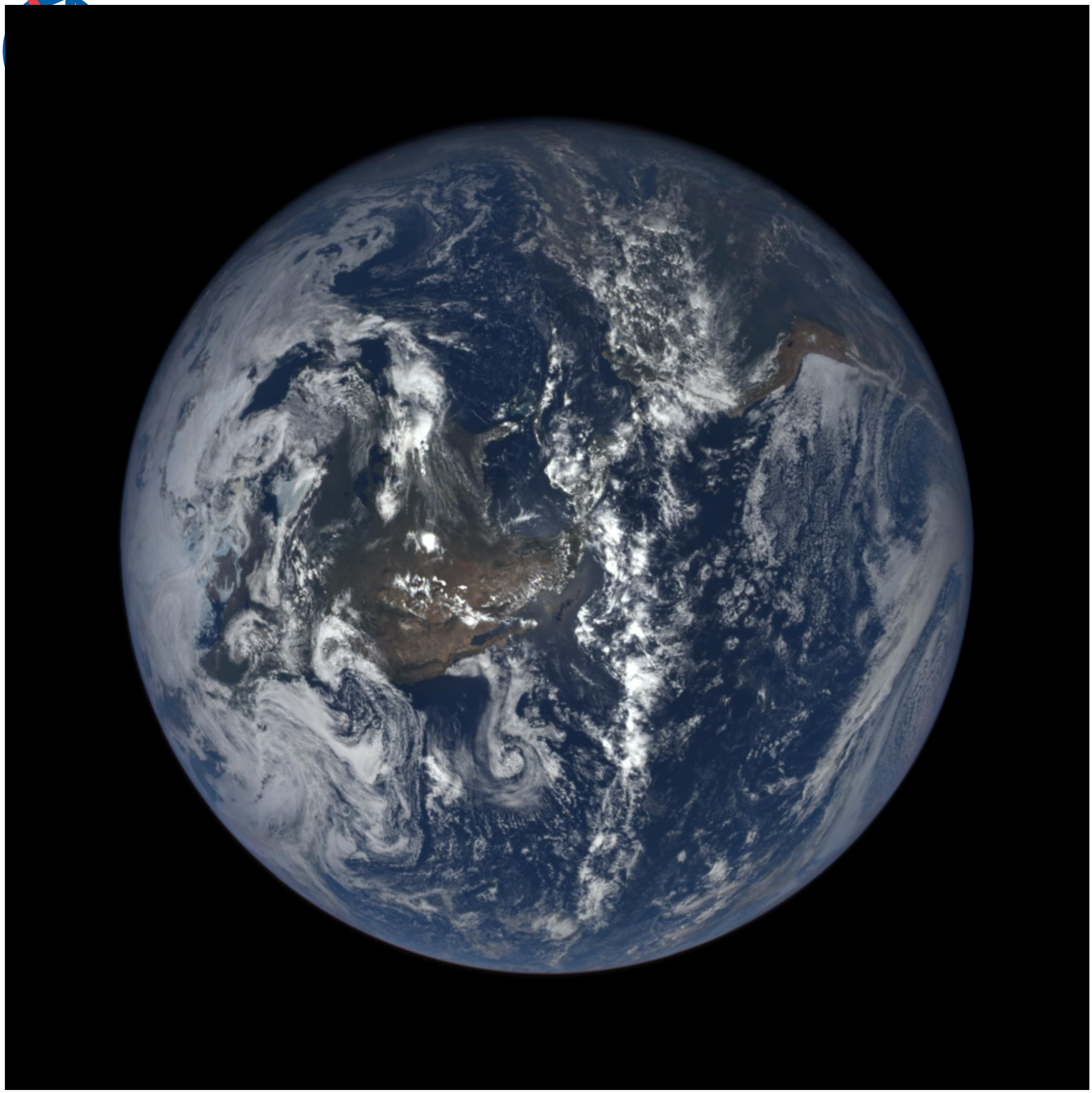


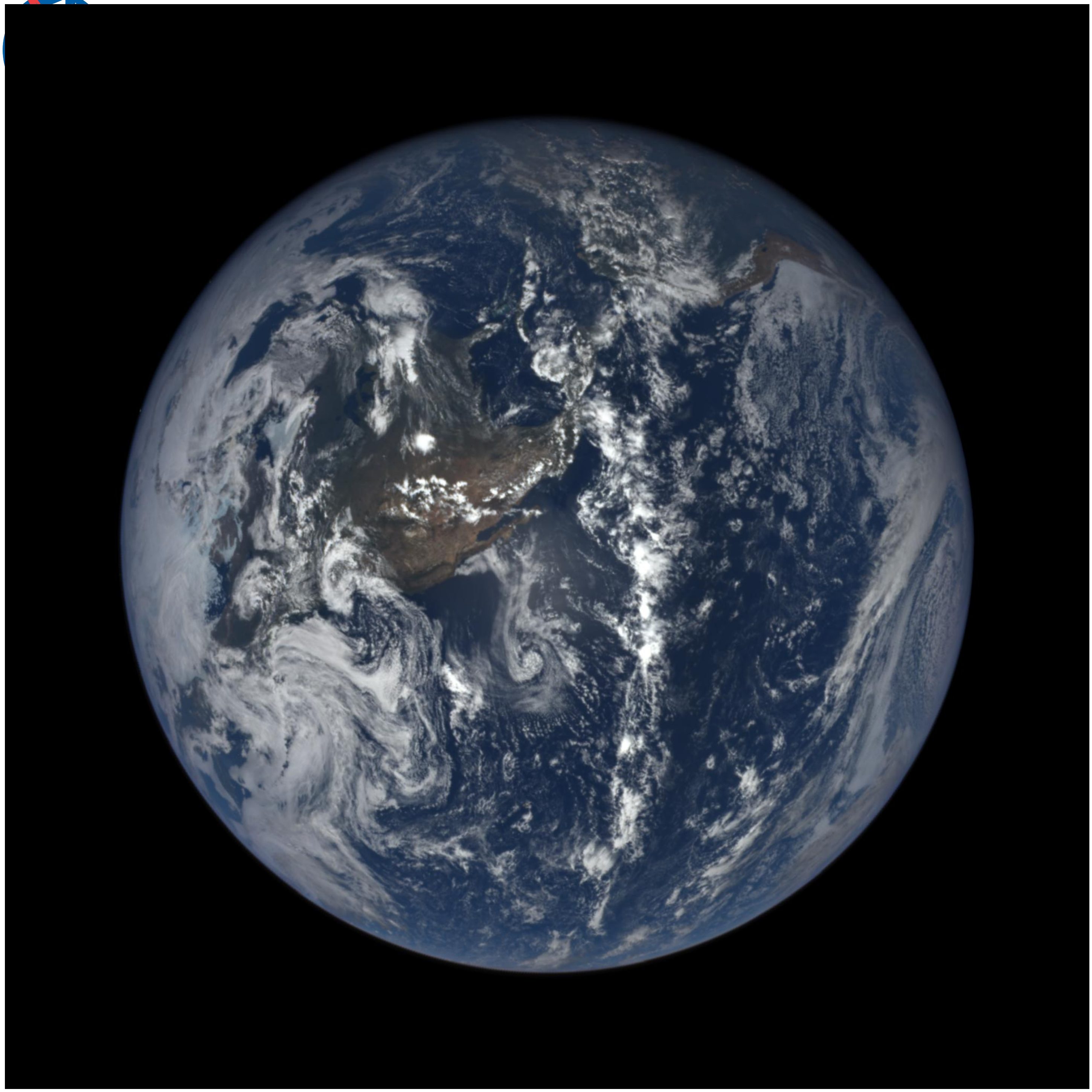




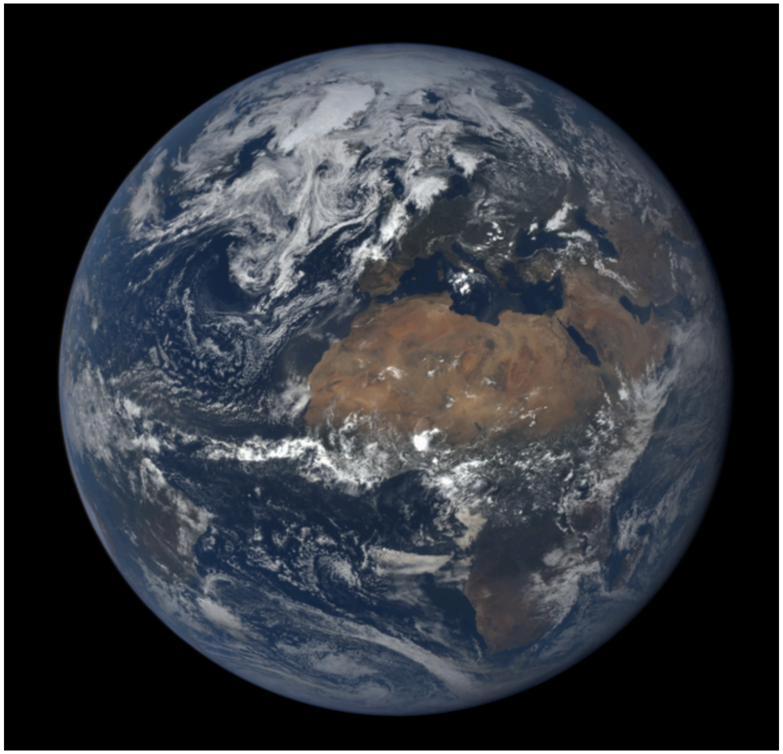


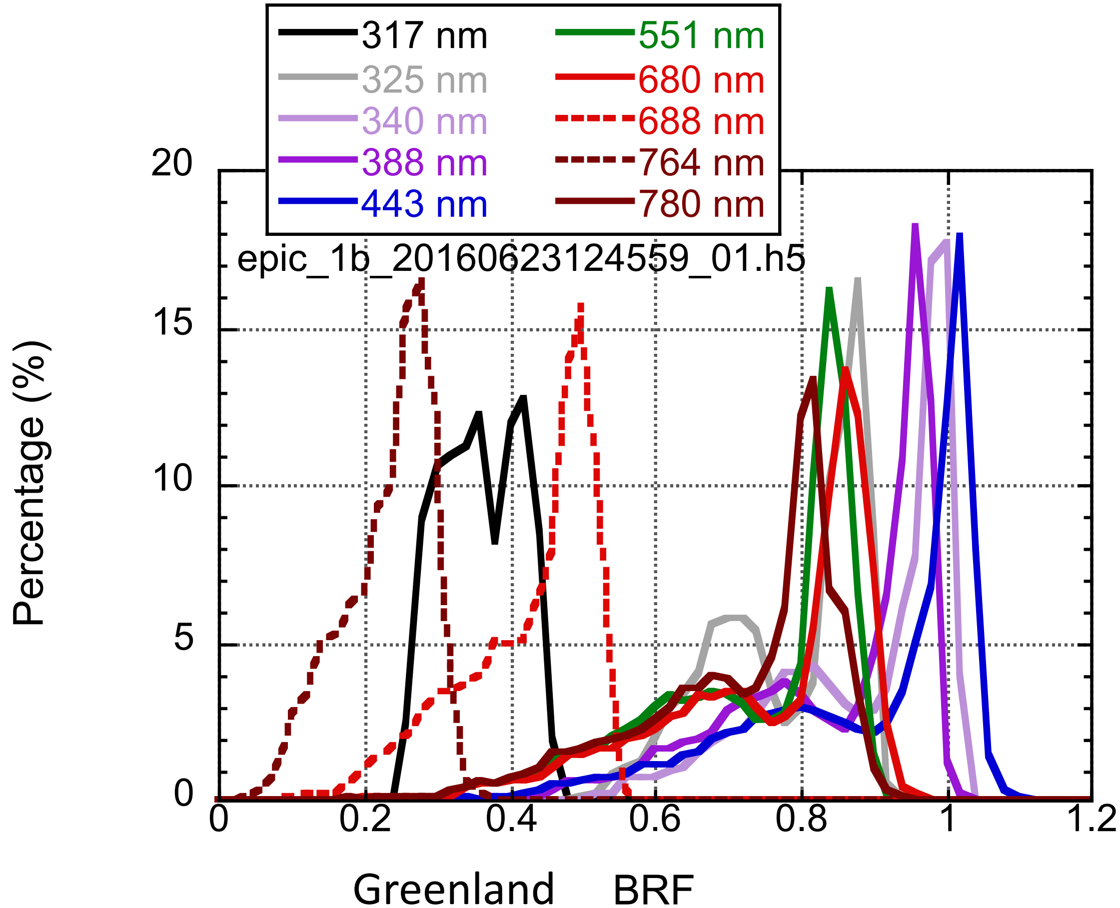






Potential Science (I): ice sheet reflectivity at near backscattering direction

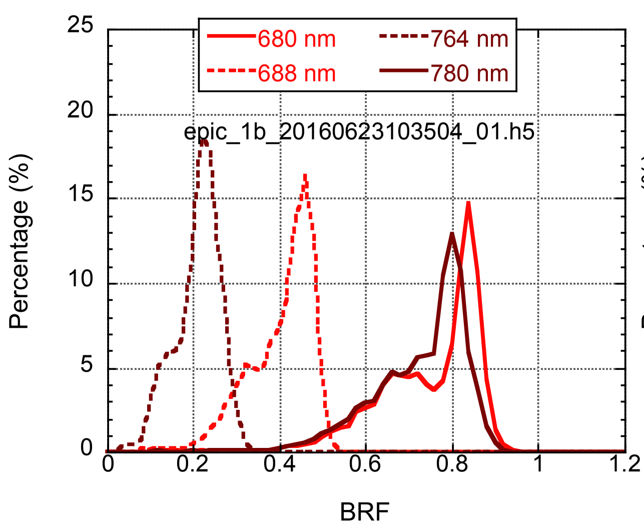




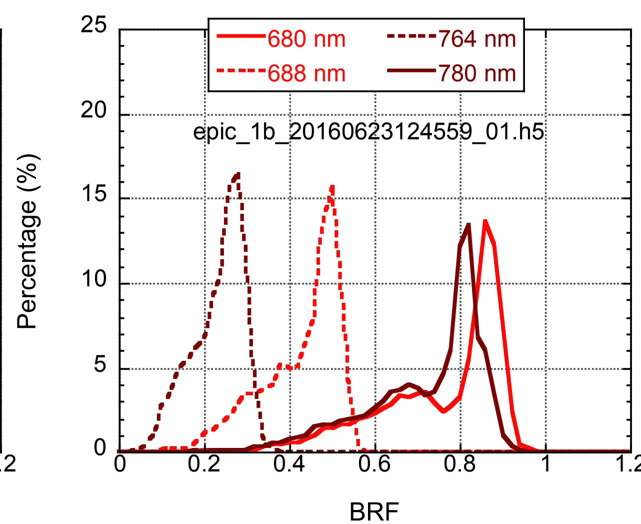
- Compensates other sensors in providing ice sheet reflectivity at unique scattering angles multiple times within a day.
- Can be helpful in improving the ice/snow BRDF model and polar radiation budget calculations.

Potential Science (I): ice sheet reflectivity at near backscattering direction

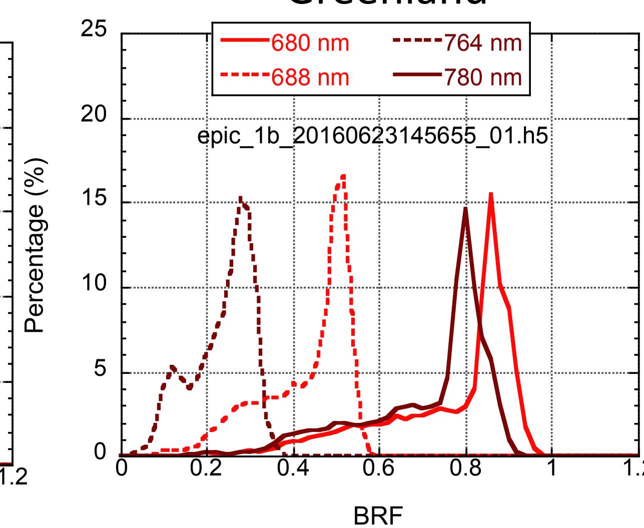
Greenland

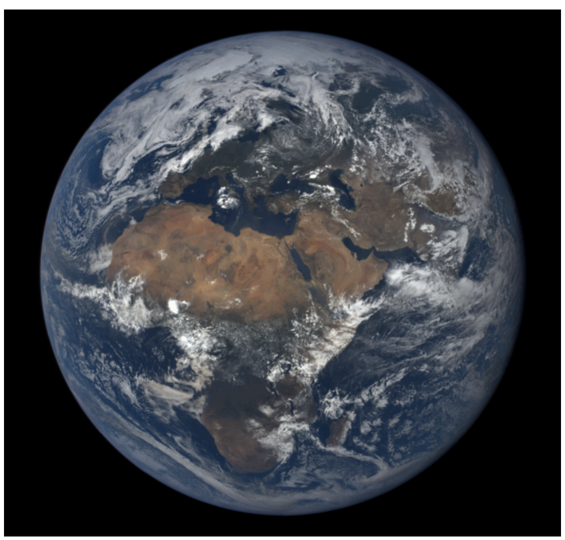


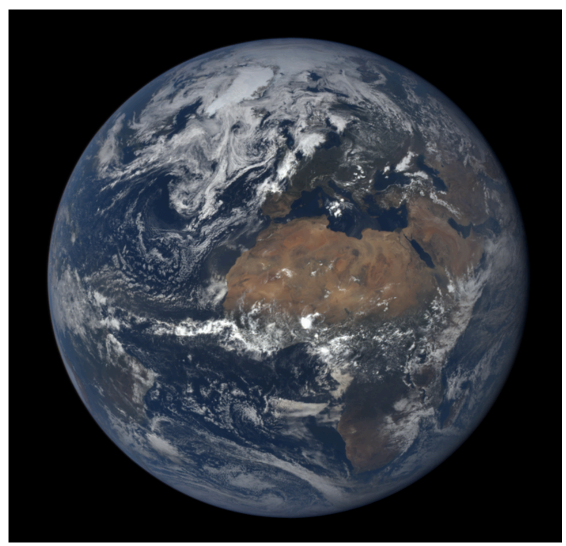
Greenland

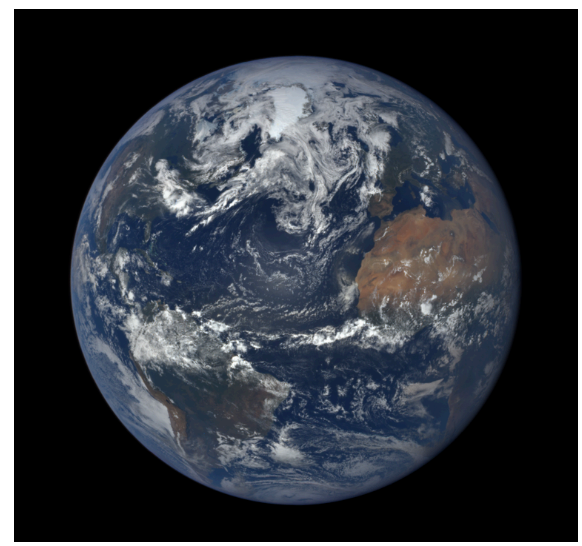


Greenland

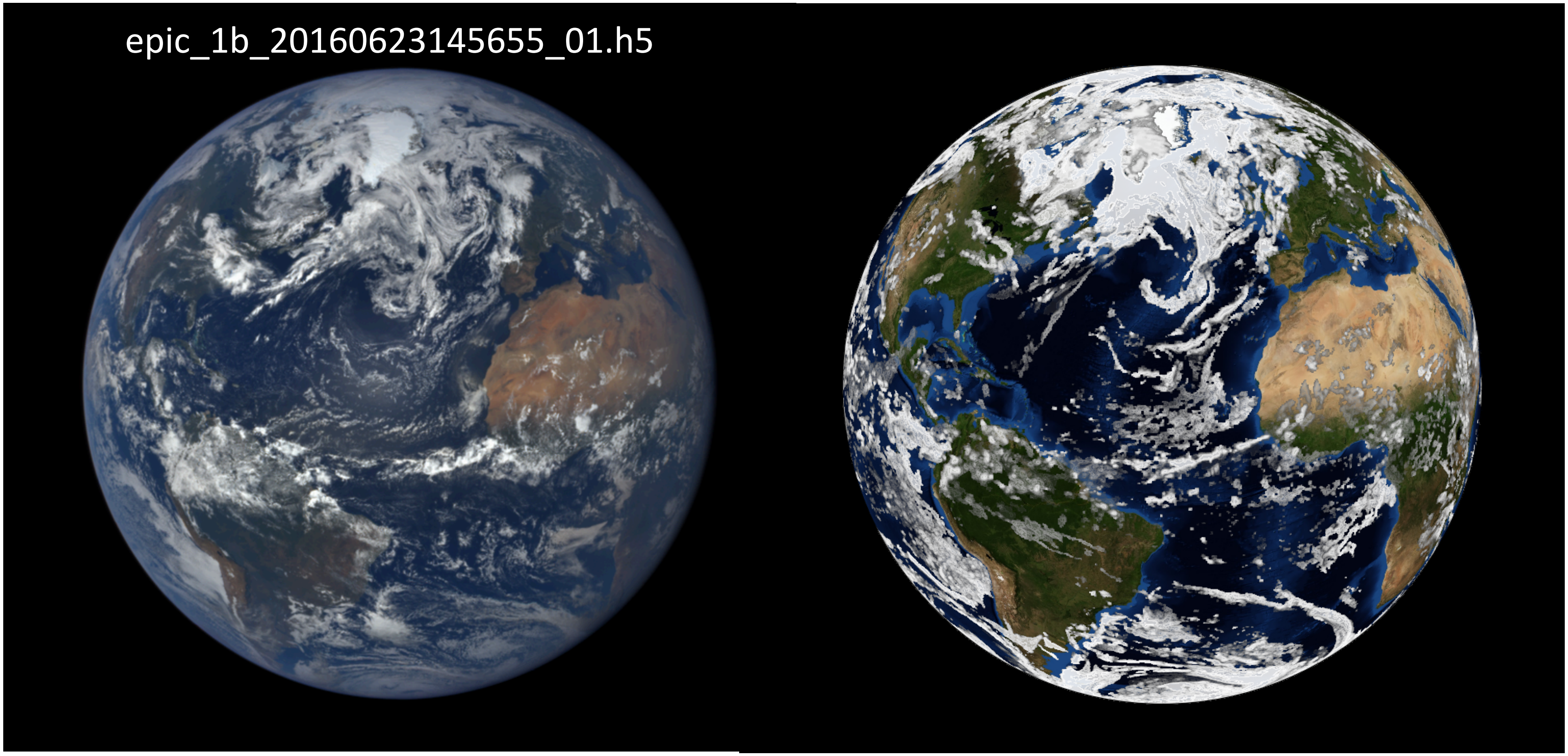








Potential Science (II): helping in understanding climate model cloud fields



EPIC RGB

Cloud field simulated by GEOS-5

- Once validated, EPIC cloud mask can be helpful to the understanding the GEOS-5 cloud simulations.

Summary

1. Cloud mask, cloud effective height and cloud optical thickness subsystems running.
2. Cloud mask subsystem improvements undergoing.
3. Cloud effective height/pressure subsystem implemented and running.
4. Cloud optical thickness: single channel retrieval using MODIS infrastructure.

Next Step

1. Cloud mask threshold selection procedure improvement.
2. Integrating GOES-5 atmosphere profiles, and surface type classification.
3. Cloud mask validation.

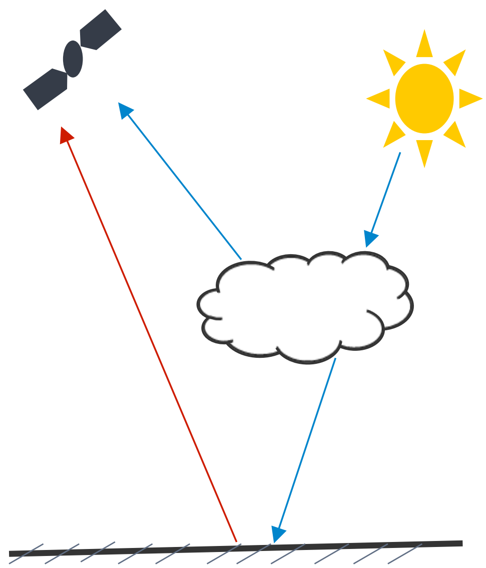
Cloud Top Pressure Retrievals:
EPIC oxygen A- & B-bands Issues

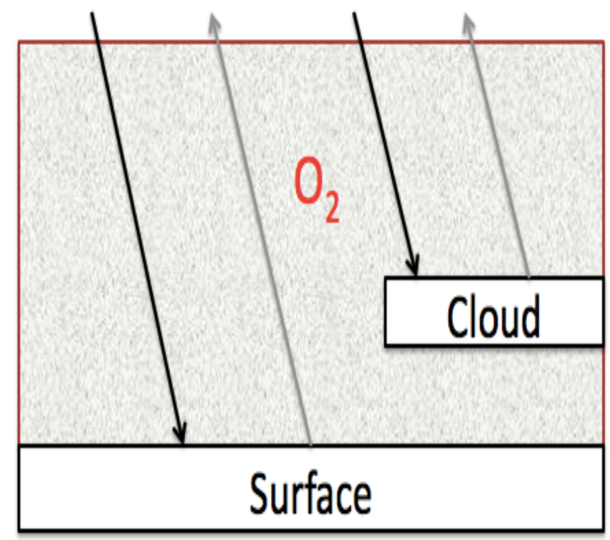
Qilong Min
State University of New York at Albany

EPIC Cloud algorithm team

Cloud Top Information:

oxygen A- and B-bands and photon path length

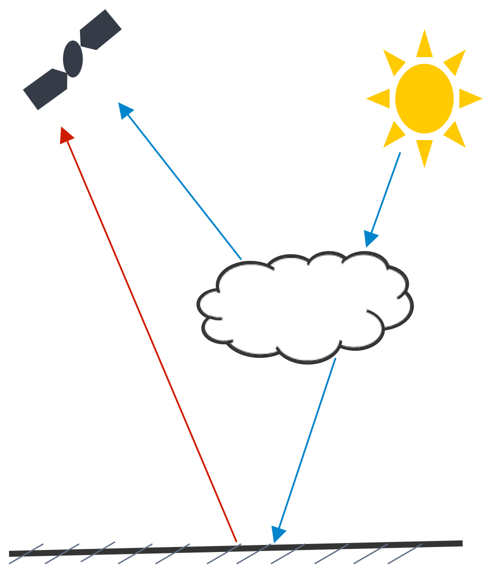




Mixed Lambertian
Equivalent Reflectivity
(MLER) Model

Cloud Top Information:

oxygen A- and B-bands and photon path length



- Clouds:
  - Cloud Top Pressure (Height)
  - Cloud Optical Property
  - Cloud Thickness
  - Cloud Faction
- Atmospheric Profiles

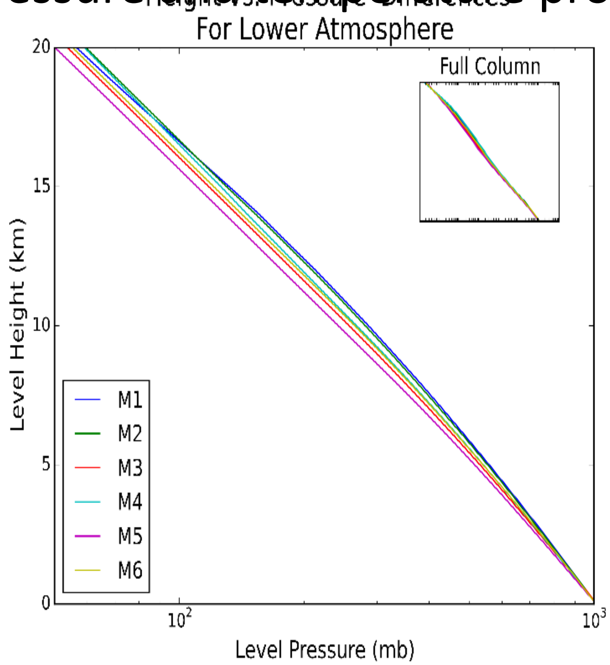
✓ Maximizing information content

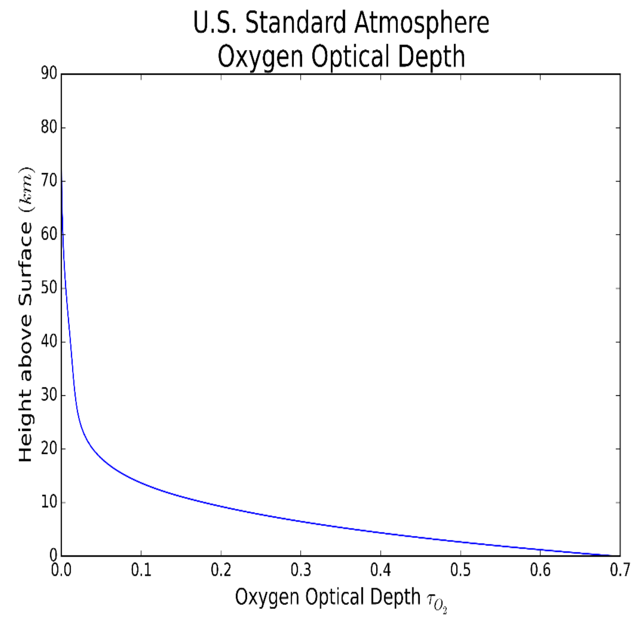
✓ Minimizing inconsistent assumptions for all cloud retrieva

Oxygen Absorption Optical Depth Coordinate (pressure):

a simple/fast conversion function from pressure to altitude

- All information retrieved from oxygen A- and B-bands are in terms of pressure, as oxygen absorption coefficients are pressure and temperature dependent (or pressure square for absorption depth).
- For the cloud level at the same pressure, the cloud height (km) can be substantial different for different atmospheric profiles
- LBLRTM (time consuming) for each atmospheric profile: different pressure and temperature profile

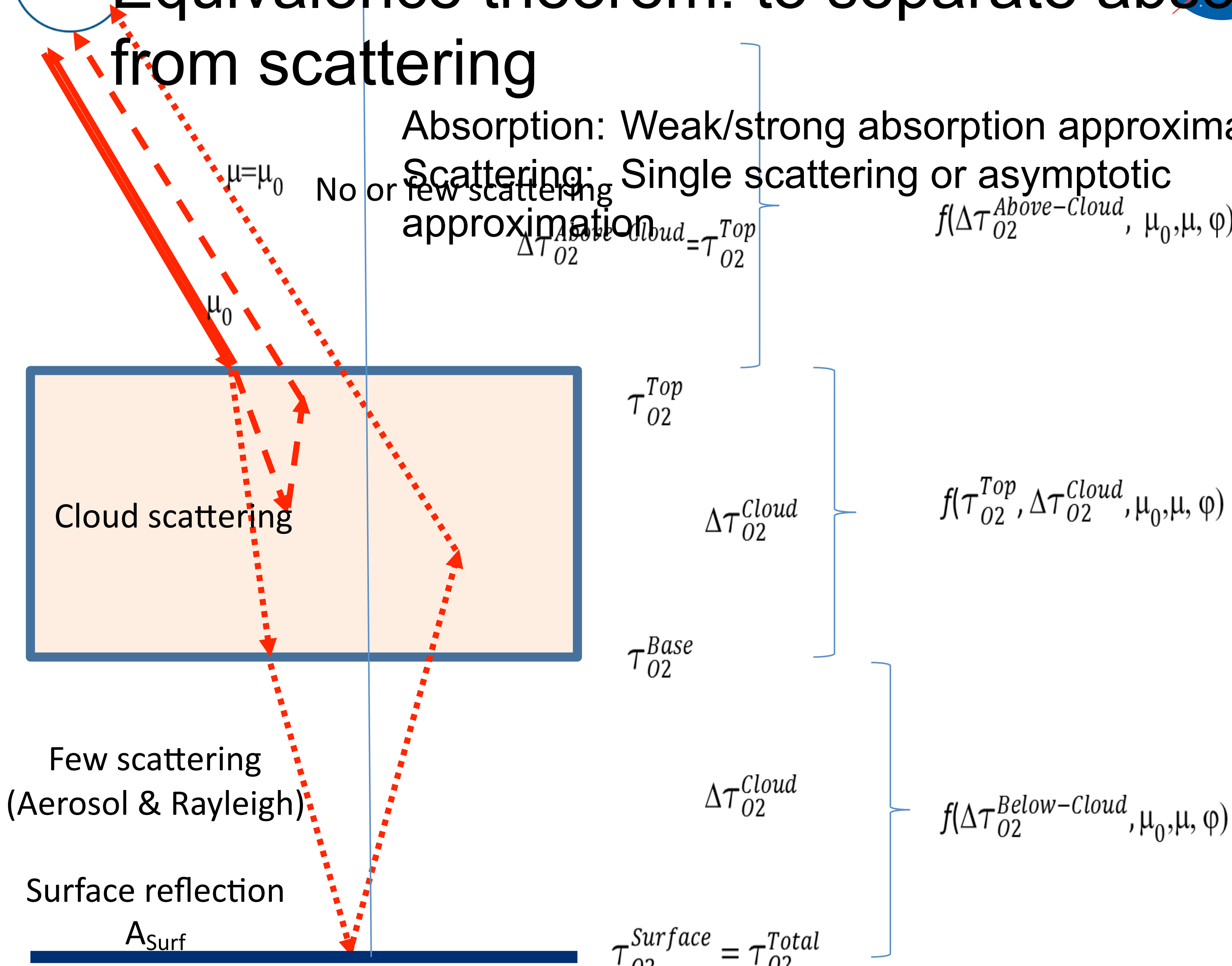




Equivalence theorem: to separate absorption from scattering

Absorption: Weak/strong absorption approximation

Scattering: Single scattering or asymptotic approximation



Above Cloud:

- Equivalence theorem to separate absorption from scattering

$$f(\Delta\tau_{02}^{Above-Cloud}, \mu_0,\mu,\varphi) = f(\Delta\tau_{02}^{Above-Cloud}) f(\mu_0,\mu,\varphi) = \tau_{02}^{Top}(\frac{1}{\mu}+\frac{1}{\mu_0}) = \frac{2}{\mu_0}\tau_{02}^{Top}$$

Within Cloud:

- Due to photon penetration, two oxygen parameters influence the enhanced path length absorption:

$$\frac{\partial(\tau_{02}^{Top})}{\partial\tau} \sim \tau_{02}^{Top}; \Delta\tau_{02}^{Cloud} = \tau_{02}^{Base} - \tau_{02}^{Top}$$

- Equivalence theorem to separate absorption from scattering

$$f(\tau_{02}^{Top}, \Delta\tau_{02}^{Cloud}, \mu_0,\mu,\varphi) = f(\tau_{02}^{Top}, \Delta\tau_{02}^{Cloud}) f(\mu_0,\mu,\varphi)$$
$$= f(\tau_{02}^{Top}) f_1(\mu_0,\mu,\varphi) + f(\Delta\tau_{02}^{Cloud}) f_2(\mu_0,\mu,\varphi)$$

- The Fourier expansion decouples zenith angle from azimuthal dependence; And only the azimuth dependence of singly scattered light plays a primary role in the overall azimuthal dependence
- For EPIC view geometry, the azimuthal dependence is just a constant

$$f(\tau_{02}^{Top}, \Delta\tau_{02}^{Cloud}, \mu_0,\mu,\varphi) = f(\tau_{02}^{Top}, \Delta\tau_{02}^{Cloud}) f(\mu_0,\mu)$$
$$= f(\tau_{02}^{Top}, \Delta\tau_{02}^{Cloud}) f(\mu_0)$$
$$= f(\tau_{02}^{Top}) f_1(\mu_0) + f(\Delta\tau_{02}^{Cloud}) f_2(\mu_0)$$

Within Cloud:

- Strong (~ $\sqrt{\tau_{O2}^{Top}}$) and weak (~ τ_{O2}^{Top}) absorption dependences

$$f(\tau_{O2}^{Top}) = a1\sqrt{\tau_{O2}^{Top}} + b1\,(\tau_{O2}^{Top})$$

- Based on asymptotic approximation,

$$R(\tau,\mu_0,\mu,\varphi) = R_\infty(\tau,\mu_0,\mu,\varphi) - TK(\mu)K(\mu_0)$$
$$= R_\infty(\tau, f_1(\mu_0)) - Tf_2(\mu_0)$$

Where $T = \frac{1}{0.75\tau(1-g)+1.072}$ and both functions have quadratic form

$$f(\tau_{O2}^{Top}, \Delta\tau_{O2}^{Cloud}, \mu_0, \mu, \varphi) = (a1\sqrt{\tau_{O2}^{Top}} + b1\,(\tau_{O2}^{Top}))(a2{*}T + b2{*}\mu_0 + c2{*}T{*}\mu_0 + d2\mu_0\mu_0)$$
$$+\ \Delta\tau_{O2}^{Cloud}(a3{*}T + b3{*}\mu_0 + c3{*}T{*}\mu_0 + d3\mu_0\mu_0)$$

Below Cloud:

- Similar reasoning as to within cloud

$$f(\Delta\tau_{O2}^{Below-Cloud}, \mu_0, \mu, \varphi) = \Delta\tau_{O2}^{Below-Cloud} * \frac{A_{Surf}}{1+(e4*T+f4)*A_{Surf}} * (a4{*}T + b4{*}\mu_0 + c4{*}T{*}\mu_0 + d4\mu_0\mu_0)$$

The analytical EPIC model:

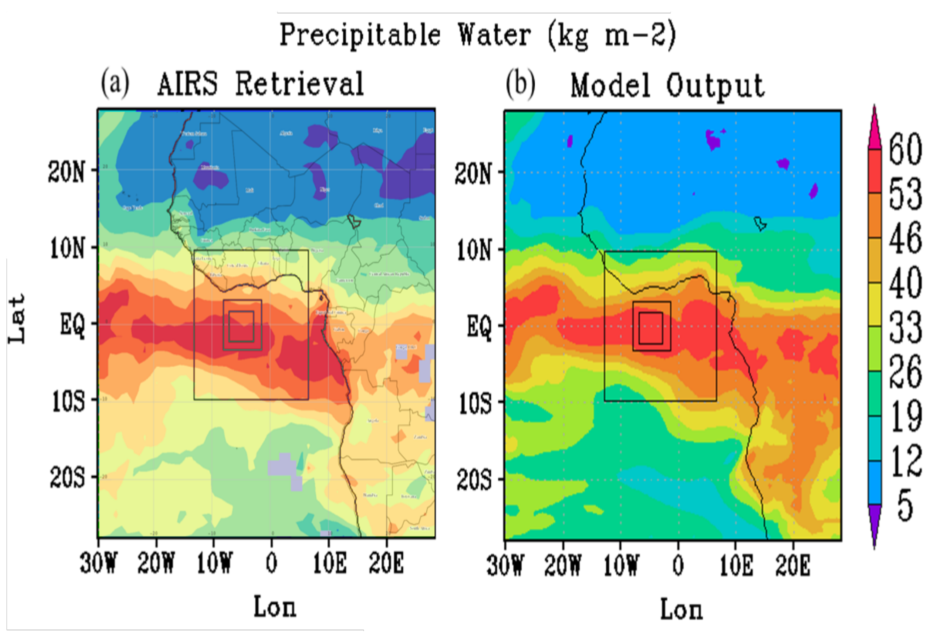
$$
\begin{aligned}
-\log\left(\frac{R_A}{R_f}\right) = {} & \frac{2}{\mu_0}\tau_{O2}^{Top} \\
& +\left(a1\sqrt{\tau_{O2}^{Top}} + b1\left(\tau_{O2}^{Top}\right)\right)\left(a2*T+b2*\mu_0+c2*T*\mu_0+d2\mu_0\mu_0\right) \\
& + \Delta\tau_{O2}^{Cloud}\left(a3*T+b3*\mu_0+c3*T*\mu_0+d3\mu_0\mu_0\right) \\
& + \Delta\tau_{O2}^{Below-Cloud}\frac{A_{Surf}}{1+(e4*T+f4)*A_{Surf}}\left(a4+b4*\mu_0+c4*T*\mu_0+d4\mu_0\mu_0\right)
\end{aligned}
$$

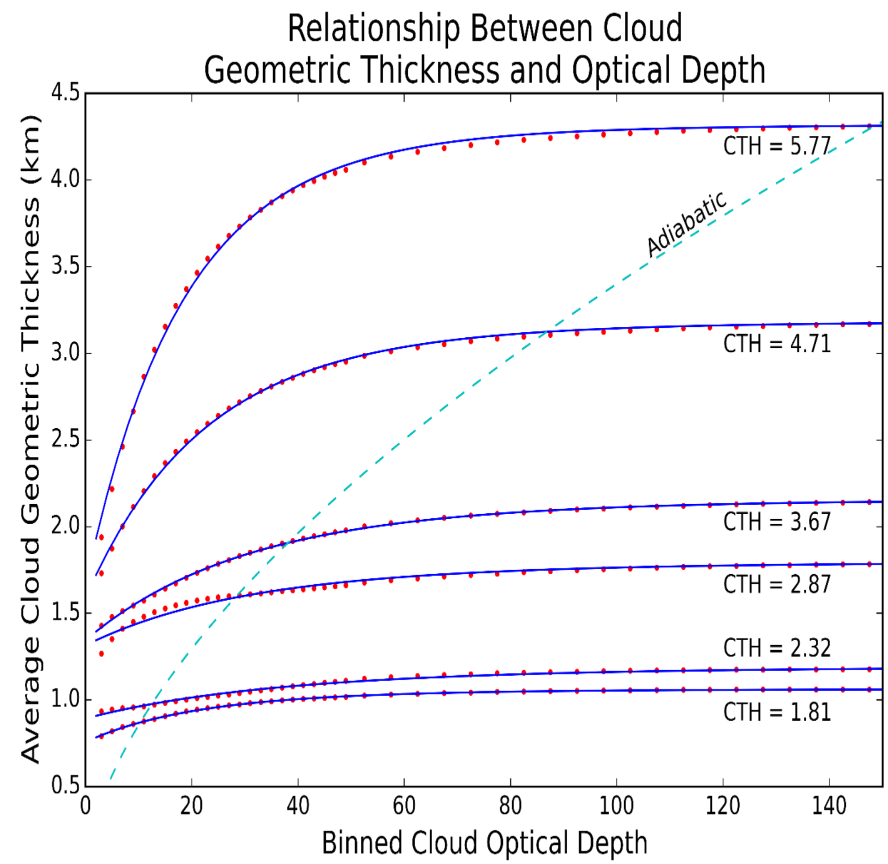
The coefficients are determined through nonlinear regression.

- A fast forward model
- A analytical retrieval algorithm

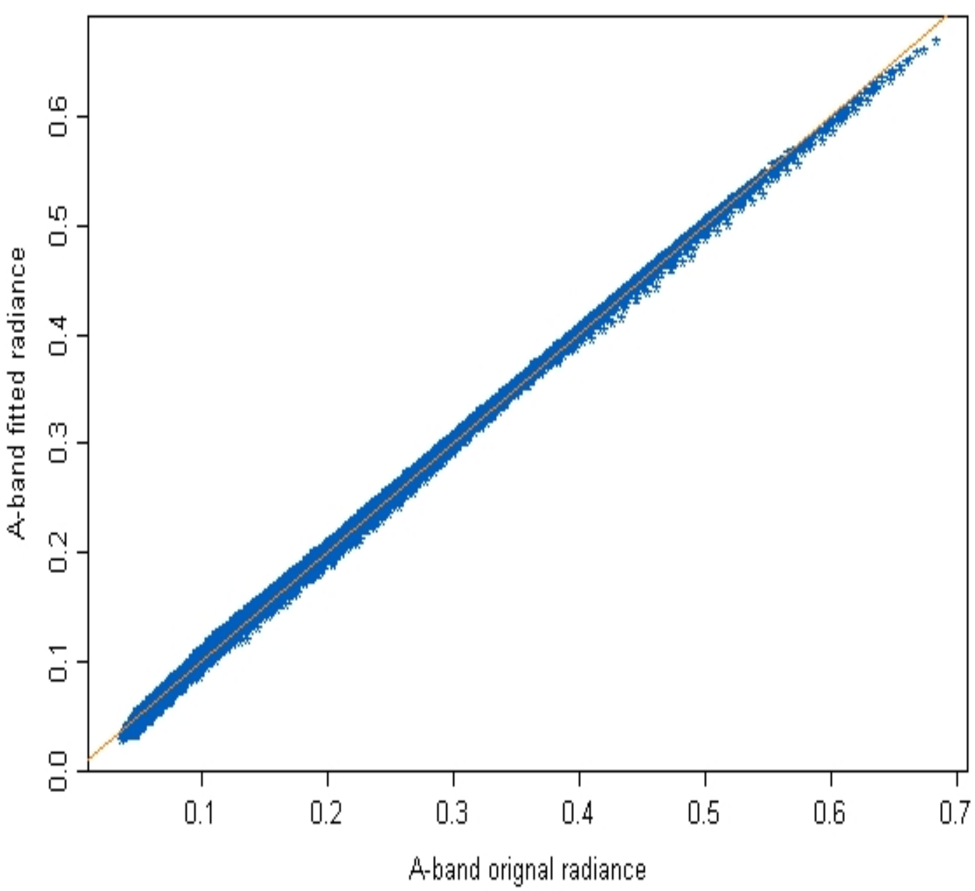
$\Delta\tau_{O2}^{Cloud} = \tau_{O2}^{Base} - \tau_{O2}^{Top}$, e.g. Cloud Geometric Thickness: inferring from cloud optical thickness

- WRF-SBM (Spectral Bin Model) simulation

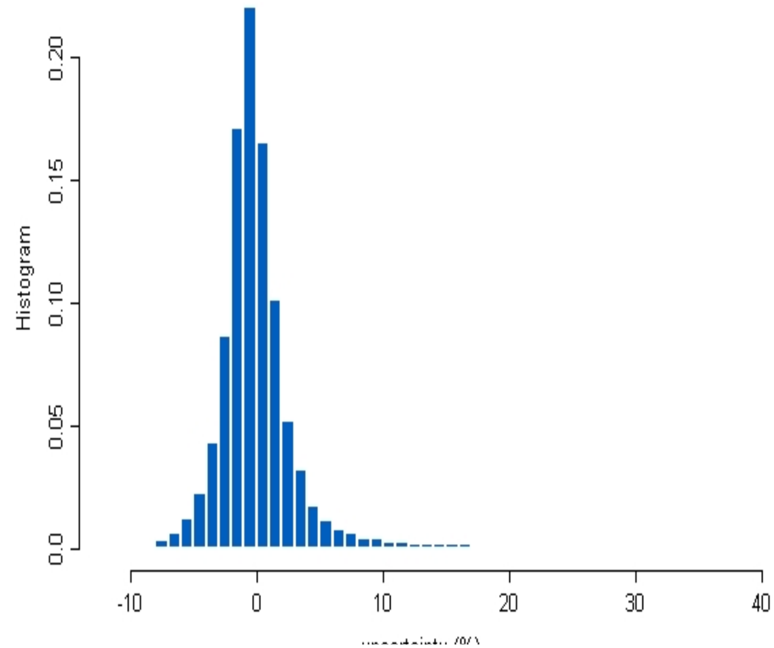




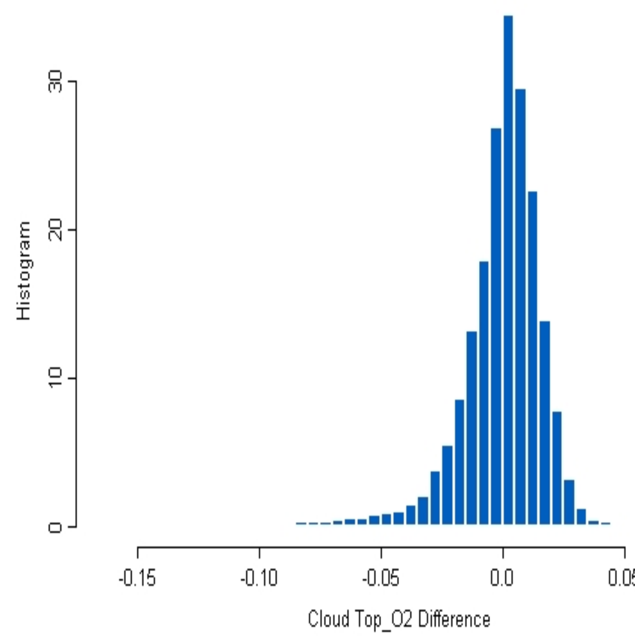
Results:



A-band fitted radiance
A-band orignal radiance
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7



Histogram
0.0
0.05
0.10
0.15
0.20
-10
0
10
20
30
40



Histogram
Cloud Top_O2 Difference
0
10
20
30
-0.15
-0.10
-0.05
0.0
0.05

The analytical EPIC model:

$$-\log\left(\frac{R_A}{R_f}\right) = \frac{2}{\mu_0}\tau_{O2}^{Top}$$
$$+\left(a1\sqrt{\tau_{O2}^{Top}} + b1\left(\tau_{O2}^{Top}\right)\right)\left(a2*T+b2*\mu_0+c2*T*\mu_0+d2\mu_0\mu_0\right)$$
$$+\ \Delta\tau_{O2}^{Cloud}\left(a3*T+b3*\mu_0+c3*T*\mu_0+d3\mu_0\mu_0\right)$$
$$+\ \Delta\tau_{O2}^{Below-Cloud}\frac{A_{Surf}}{1+(e4*T+f4)*A_{Surf}}\left(a4+b4*\mu_0+c4*T*\mu_0+d4\mu_0\mu_0\right)$$

The coefficients are determined through nonlinear regression.

- A fast forward model
- A analytical retrieval algorithm