

Appendix B

A proposition for updating the environmental standards using real Earth Albedo and Earth IR Flux for Spacecraft Thermal Analysis

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Abstract

This presentation aims at recreating a link between real Earth Albedo and Earth IR Flux measurement (by CERES instruments) and Earth environment assumptions used for Earth orbiting spacecraft thermal analysis. It will compare the common Earth albedo and Earth Infrared flux hypotheses (coming from the standards, and past or current projects) with the real measured Earth radiated energy. From such comparison, one can assess if the current hypotheses cover properly the reality or how to quantify the margin potentially contained in these usual assumptions. As an ultimate goal, this presentation will open the discussion whether the usual hypotheses need to be updated.




Using real Earth Albedo and Earth IR Flux for Spacecraft Thermal Analysis

Romain Peyrou-Lauga

ESA UNCLASSIFIED - For Official Use

ESTEC Thermal Workshop, 24 Oct. 2017

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Introduction

- The reasons of such an approach...
 - *curiosity...*
 - *variations of assumptions* found on projects thermal analysis, standards (ECSS, NASA...), handbooks...
 - *track of their origin* difficult to find
 - *recent Earth observations* have been providing invaluable data about Earth radiated energy measured from Space
- NASA's CERES (Clouds and Earth Radiant Energy System) experiment
 - Terra (1999...)
 - Aqua (2002...)
 - Suomi NPP (2011...)

☞ what is the link between albedo/Earth temperature assumptions and the reality (clouds, continents, oceans...)?

☞ who's right ? Who's wrong ?

☞ Is there hidden margin ?

☞ with an increased accuracy and a continuous improved Earth surface coverage

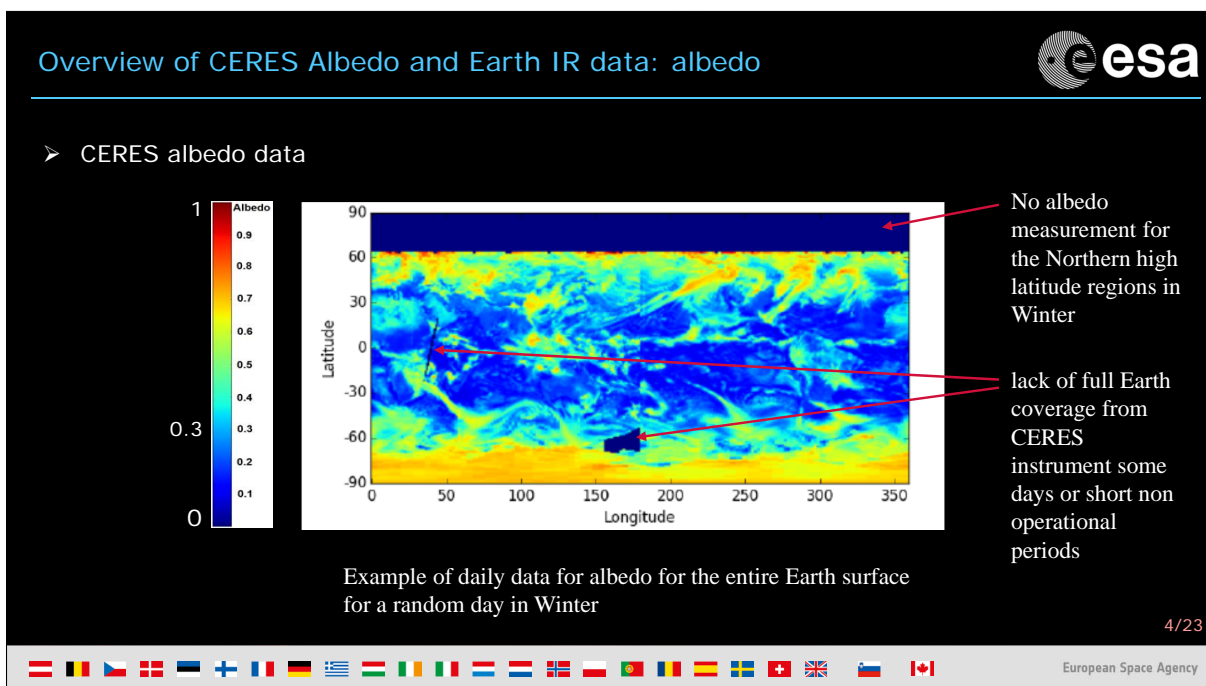
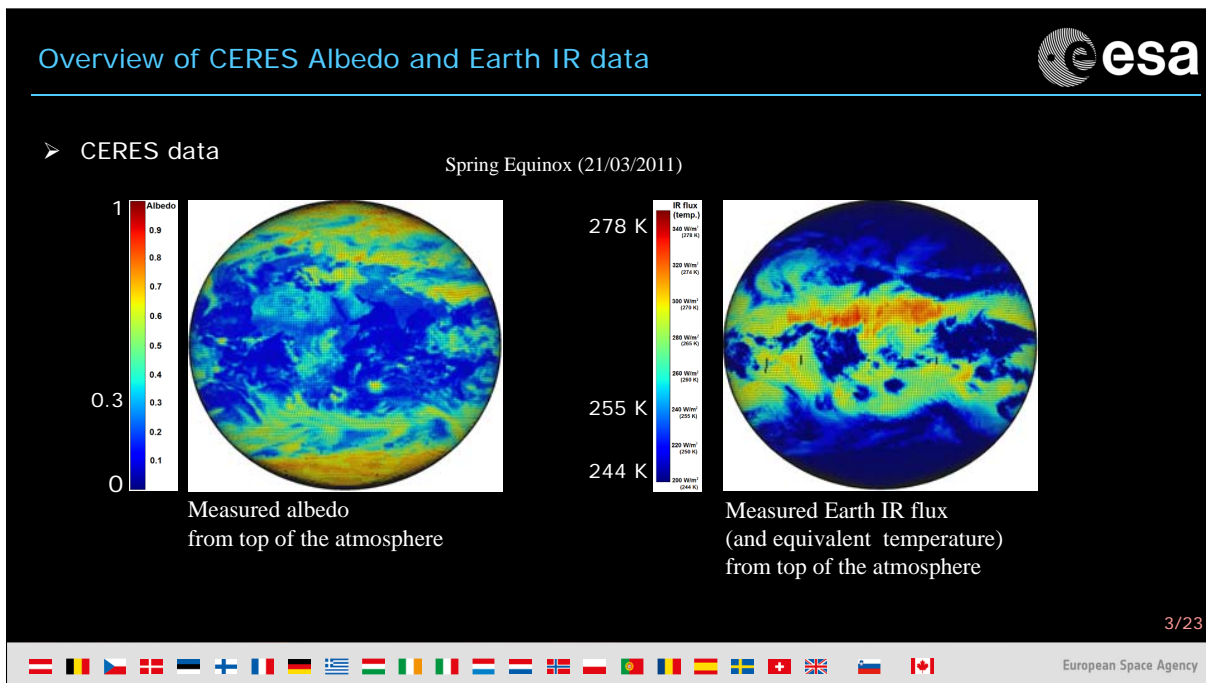
Min Albedo	Max Albedo	Min Earth T	Max Earth T
0.2	0.4	245 K	265 K
0.19	0.41 (sensitivity)	244 K	260 K
0.14	0.36	244 K	265 K
0.2	0.4	240 K	261 K
0.2	0.4	240 K	260 K
0.25	0.35	248 K	262 K

☞ How do standards correlate with real values ?

☞ Do standards need to be updated ?

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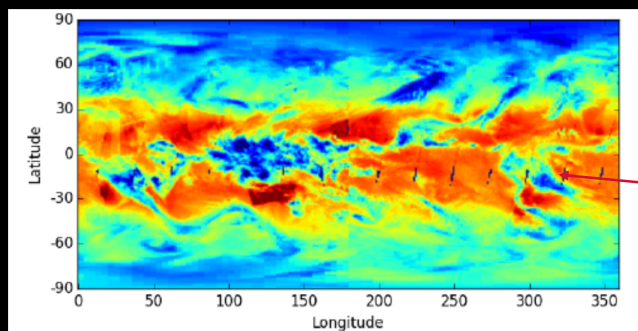
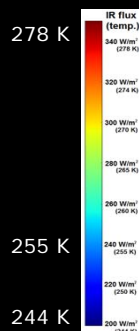
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Overview of CERES Albedo and Earth IR data: albedo



➤ CERES Infra-Red flux data



Example of daily data for Infra-Red for the entire Earth surface for a random day in Winter

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1st step: Average monthly albedo and Earth IR flux: albedo



- 5 years of data (from 01/01/2007 to 31/12/2011)
- Repeatability from a year to another can be checked

Average Latitude	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave. over 2007	Ave. over 2008	Ave. over 2009	Ave. over 2010	Ave. over 2011	Average over 5-year
85°	nan	nan	0.64	0.62	0.62	0.57	0.50	0.52	0.58	0.65	nan	nan	0.59	0.58	0.59	0.59	0.58	0.59
75°	nan	0.66	0.62	0.60	0.58	0.49	0.43	0.44	0.49	0.57	0.65	nan	0.55	0.55	0.55	0.55	0.55	0.55
65°	0.59	0.55	0.53	0.51	0.45	0.38	0.36	0.38	0.42	0.50	0.56	0.59	0.49	0.49	0.48	0.48	0.49	0.49
55°	0.50	0.48	0.44	0.39	0.37	0.35	0.35	0.36	0.37	0.41	0.48	0.51	0.42	0.42	0.42	0.42	0.42	0.42
45°	0.45	0.42	0.38	0.34	0.33	0.32	0.31	0.30	0.30	0.34	0.40	0.45	0.36	0.36	0.36	0.37	0.36	0.36
35°	0.36	0.35	0.32	0.30	0.28	0.27	0.25	0.24	0.26	0.28	0.32	0.36	0.30	0.29	0.30	0.30	0.30	0.30
25°	0.28	0.26	0.25	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.26	0.28	0.25	0.25	0.25	0.25	0.25	0.25
15°	0.22	0.20	0.20	0.20	0.21	0.23	0.25	0.25	0.25	0.23	0.23	0.23	0.22	0.22	0.22	0.22	0.23	0.22
5°	0.24	0.22	0.22	0.23	0.25	0.26	0.26	0.25	0.25	0.24	0.25	0.25	0.24	0.24	0.24	0.25	0.25	0.24
-5°	0.24	0.23	0.22	0.22	0.21	0.21	0.21	0.21	0.21	0.22	0.23	0.23	0.22	0.22	0.22	0.22	0.22	0.22
-15°	0.23	0.23	0.21	0.20	0.20	0.21	0.21	0.21	0.21	0.22	0.23	0.23	0.22	0.21	0.22	0.22	0.22	0.22
-25°	0.22	0.21	0.22	0.23	0.25	0.26	0.25	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.24	0.23	0.23
-35°	0.24	0.25	0.26	0.29	0.31	0.33	0.32	0.30	0.29	0.27	0.27	0.26	0.28	0.28	0.28	0.28	0.28	0.28
-45°	0.32	0.33	0.35	0.37	0.40	0.41	0.40	0.37	0.35	0.33	0.33	0.33	0.36	0.36	0.36	0.36	0.36	0.36
-55°	0.40	0.40	0.42	0.45	0.48	0.51	0.49	0.46	0.44	0.41	0.41	0.40	0.44	0.44	0.44	0.44	0.44	0.44
-65°	0.49	0.49	0.51	0.55	0.60	0.61	0.64	0.63	0.61	0.59	0.55	0.51	0.56	0.57	0.57	0.57	0.57	0.57
-75°	0.62	0.64	0.65	0.68	0.74	nan	nan	0.73	0.70	0.69	0.66	0.64	0.68	0.67	0.68	0.67	0.67	0.68
-85°	0.67	0.68	0.69	0.74	nan	nan	nan	0.72	0.70	0.68	0.67	0.69	0.69	0.69	0.69	0.69	0.69	0.69
Total	0.32	0.32	0.32	0.31	0.31	0.30	0.30	0.30	0.31	0.31	0.32	0.32	0.31	0.31	0.31	0.31	0.31	0.31

Data published:

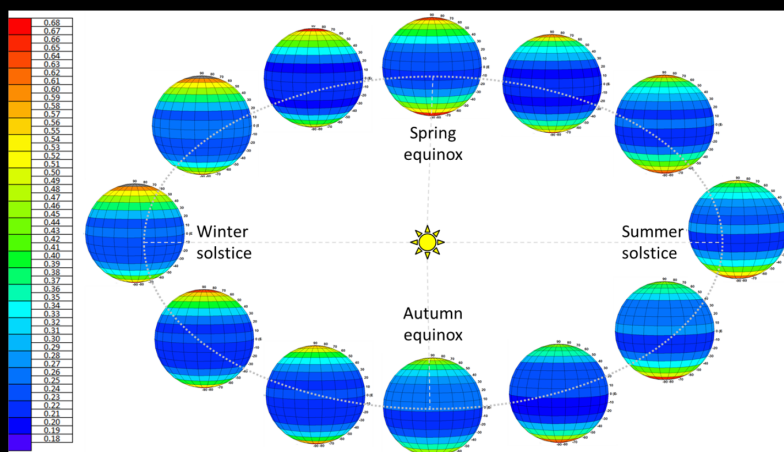
Ref. : Earth Albedo and Earth IR Temperature definition based on CERES measurements (ESA-TECMTT-TN-001975)

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1st step: Average monthly albedo and Earth IR flux: albedo



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1st step: Average monthly albedo and Earth IR flux: Earth temperature



- 5 years of data (from 01/01/2007 to 31/12/2011)
- Repeatability from a year to another can be checked

Average Latitude	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave. over 2007	Ave. over 2008	Ave. over 2009	Ave. over 2010	Ave. over 2011	Average over 5-year
85°	233	236	235	241	247	251	252	250	245	240	236	234	242	242	242	242	242	242
75°	235	236	237	242	248	251	253	251	247	242	238	236	243	243	243	244	243	243
65°	237	238	241	245	249	253	254	252	249	244	240	237	245	245	245	245	245	245
55°	241	242	244	248	251	253	255	254	251	248	244	242	248	248	248	248	248	248
45°	245	246	247	250	253	256	258	259	257	252	249	246	252	252	251	251	252	252
35°	251	251	253	254	257	259	262	262	261	258	255	252	257	257	256	256	256	256
25°	261	261	262	262	262	262	262	262	262	263	262	261	262	262	262	262	262	262
15°	264	265	265	263	261	258	256	255	256	259	261	263	261	261	261	261	260	261
5°	258	259	258	255	254	254	254	255	255	255	256	257	256	255	256	256	256	256
-5°	255	255	255	256	259	261	261	262	261	260	258	257	258	258	258	258	259	258
-15°	257	257	259	262	264	265	265	266	265	263	260	258	262	262	262	262	262	262
-25°	261	262	262	261	261	260	262	262	262	261	260	260	261	261	261	261	261	261
-35°	260	260	259	257	255	254	254	255	255	256	256	256	258	257	256	256	257	257
-45°	254	254	253	251	250	249	248	249	249	251	252	253	253	251	251	251	251	251
-55°	249	249	248	246	245	244	243	243	244	246	247	249	246	246	246	246	246	246
-65°	247	246	244	241	239	237	237	236	238	241	244	246	242	241	242	241	241	241
-75°	244	240	235	230	228	225	224	224	226	231	238	243	233	232	233	232	233	233
-85°	242	236	229	224	222	219	218	216	219	226	235	242	228	228	228	228	228	228
Average	254	254	254	254	255	255	256	256	255	255	254	254	255	255	255	255	255	255

☞ Data published:

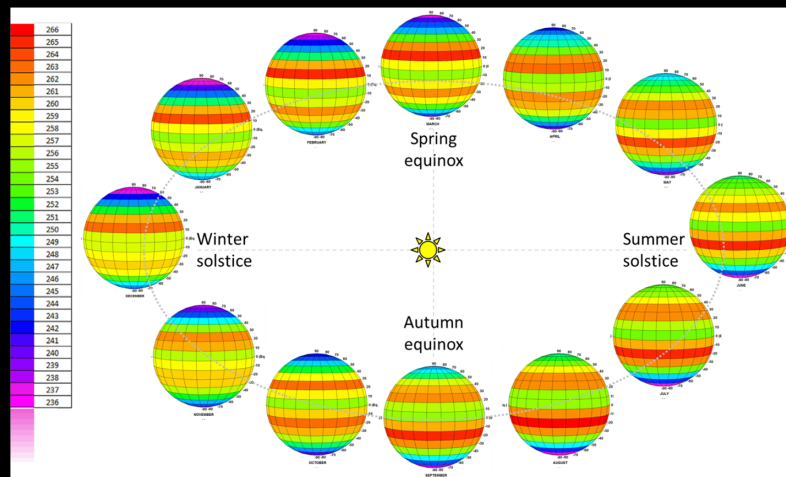
Ref. : Earth Albedo and Earth IR Temperature definition based on CERES measurements (ESA-TECMTT-TN-001975)

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1st step: Average monthly albedo and Earth IR flux: Earth temperature



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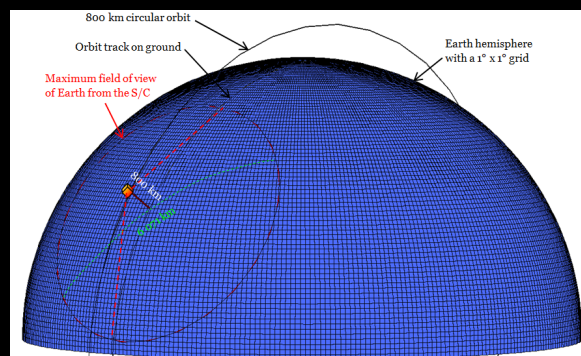
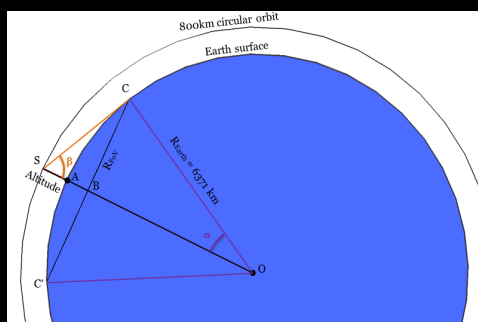


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2nd step: Effective albedo / Effective Earth IR flux



- Effective albedo = perceived albedo from Earth orbit
- Effective Earth IR flux = perceived Earth IR flux from Earth orbit
- But first, what's the Earth field of view from orbit ?



Earth field of view from a spacecraft on a 800 km Low Earth circular orbit

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2nd step: Effective albedo / Effective Earth IR flux



➤ From CERES data... to effective albedo

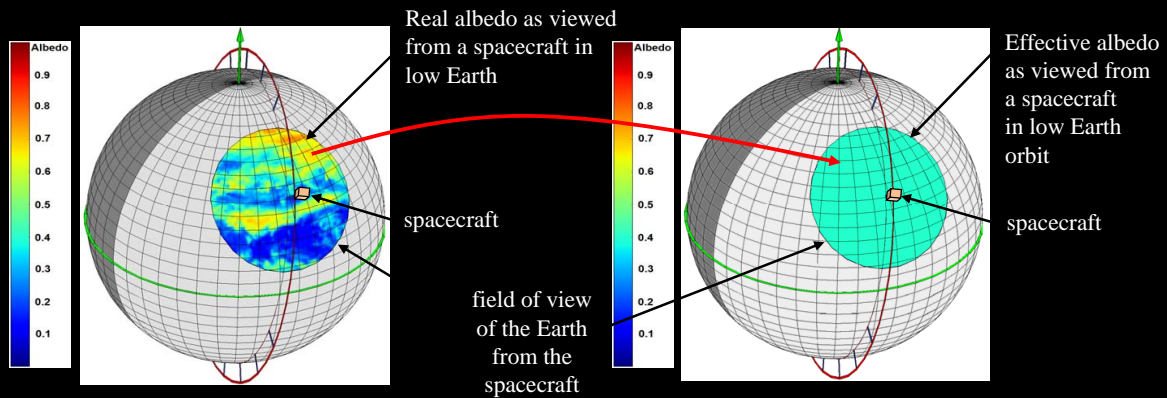


Illustration of effective albedo at any instant as perceived by an Earth orbiting spacecraft

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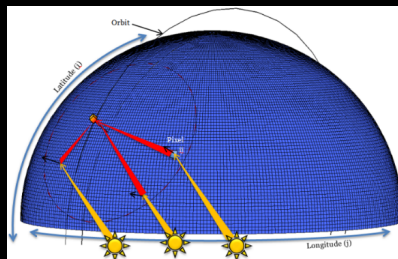


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Calculating effective albedo / effective Earth temperature



⇒ How is the instantaneous received albedo flux calculated ?



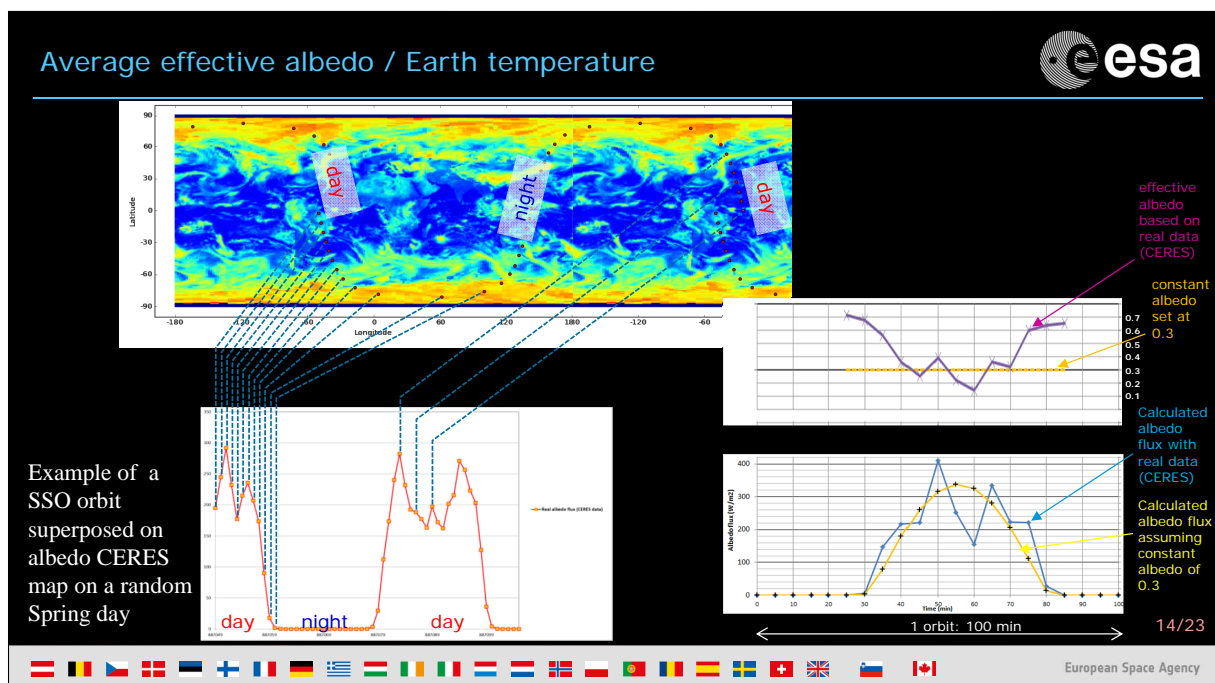
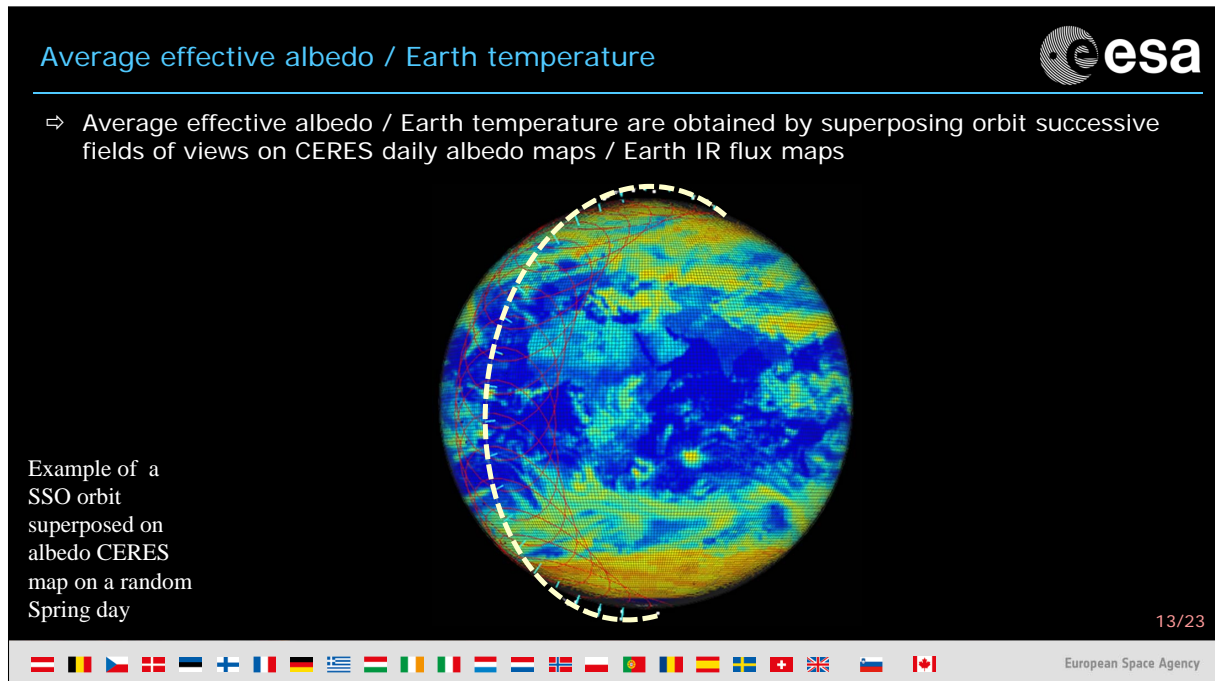
It takes into account:

- the spacecraft position and attitude on its orbit,
- the view factor between spacecraft surface and each visible pixel of daily CERES albedo grid
- the Sun illumination (or not) of the pixel
- the albedo value of the pixel

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Average orbital effective albedo and Earth IR flux for various orbits



⇒ Synthesis of average effective albedo / Earth temperature over an orbit for several LEO orbits

Type of orbit	Altitude	Inclination	LTAN	Range of average albedo over 1 orbit	Range of average Earth temperature over 1 orbit
SSO	800 km	98.6°	06:00	0.25 – 0.40	246 K – 256 K
			12:00	0.25 – 0.40	246 K – 256 K
			18:00	0.25 – 0.40	246 K – 256 K
			20:00	0.24 – 0.40	246 K – 256 K
			21:00	0.25 – 0.40	246 K – 256 K
			22:00	0.25 – 0.40	246 K – 256 K
ISS	400 km	51.6°	drifting	0.19 – 0.40	250 K – 260 K
Tropical	800 km	20°	drifting	0.16 – 0.34	253 K – 264 K
Equatorial	800 km	6°	drifting	0.15 – 0.31	253 K – 260 K

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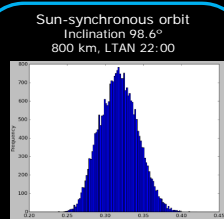


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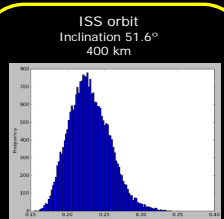
Statistical distribution of average orbital albedo and Earth temperature over an orbit for several LEO orbits



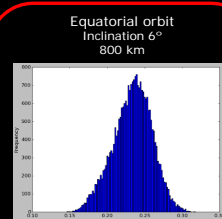
Albedo



Range: 0.25 - 0.40
Mean: 0.31

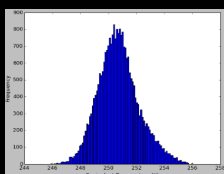


Range: 0.16 - 0.34
Mean: 0.23

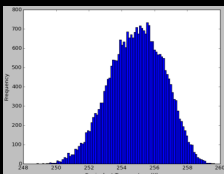


Range: 0.15 - 0.31
Mean: 0.24

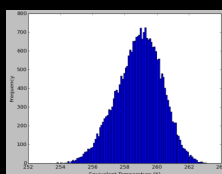
Earth temperature



Range: 246–256 K
Mean: 250 K



Range: 250–260 K
Mean: 255 K

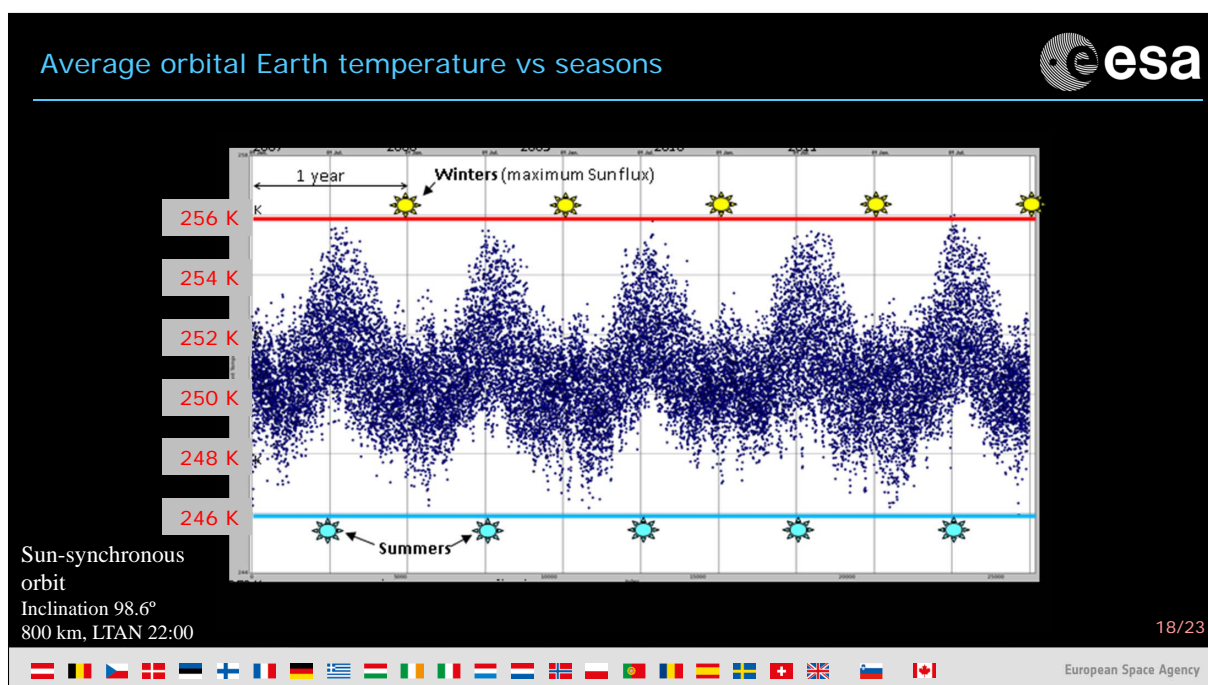
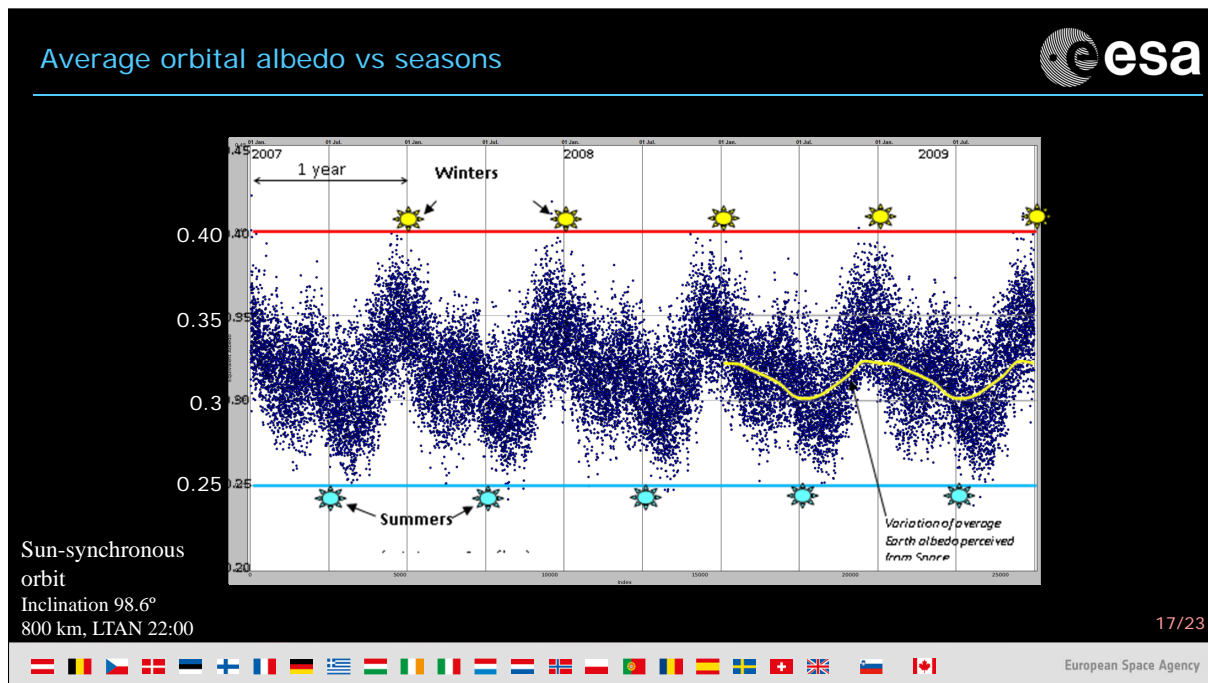


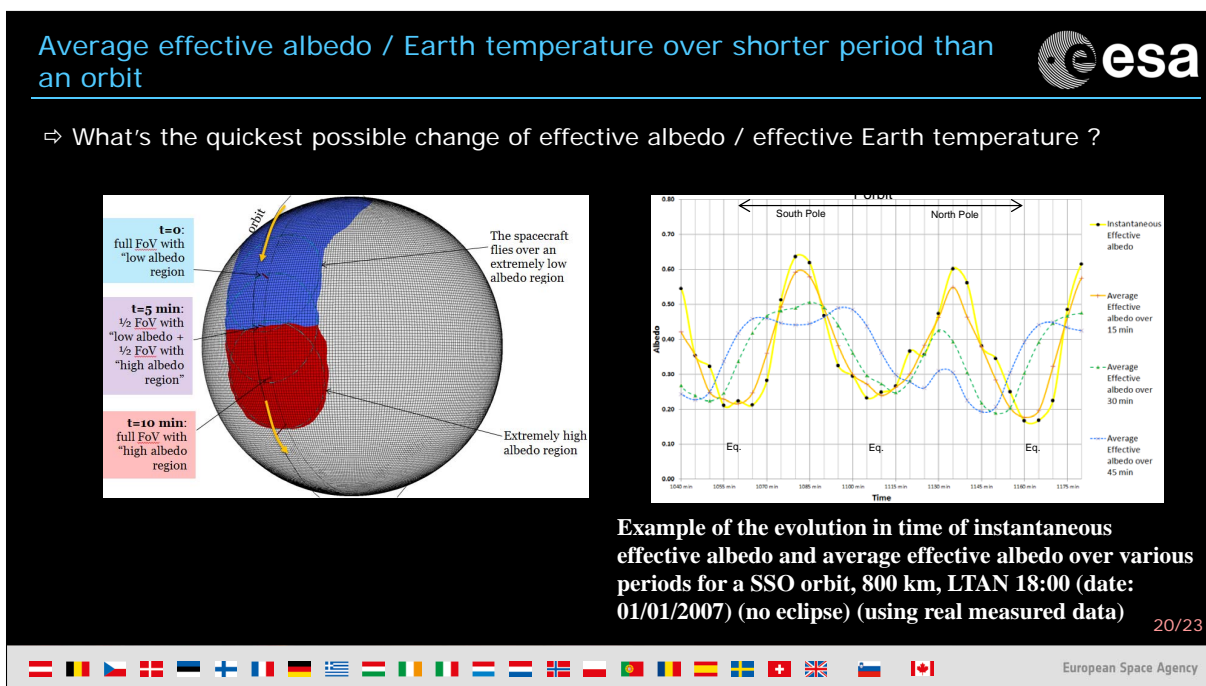
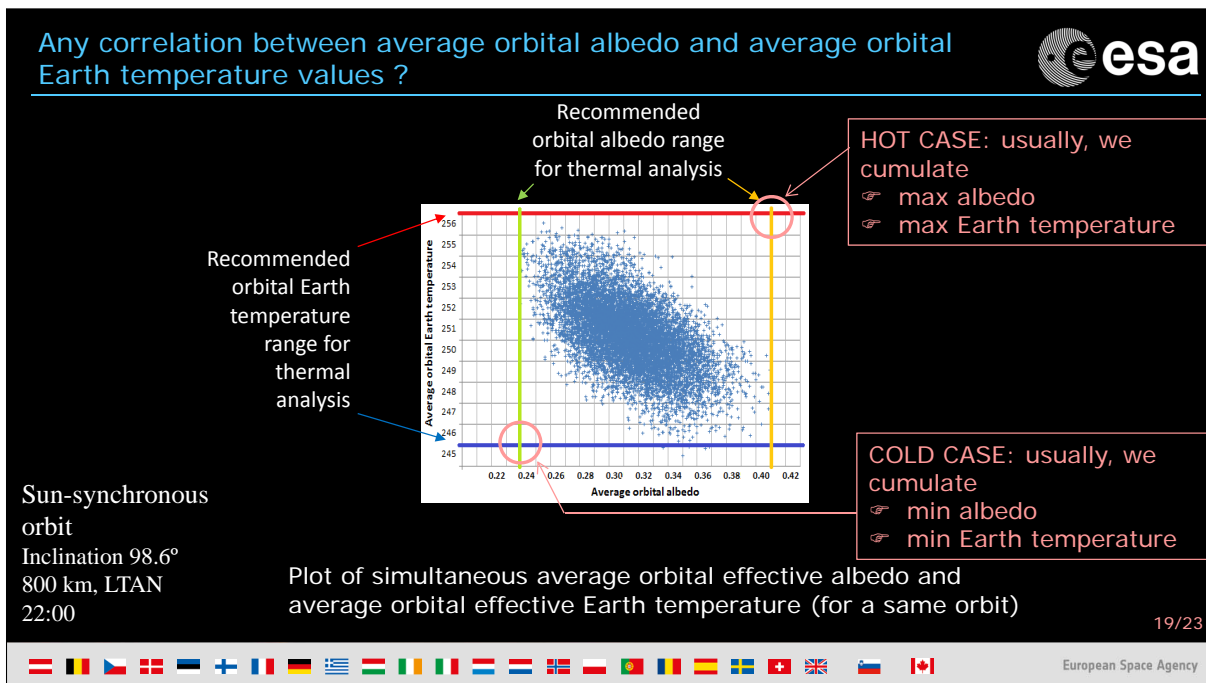
Range: 253–260 K
Mean: 259 K

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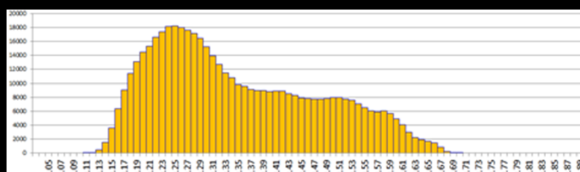


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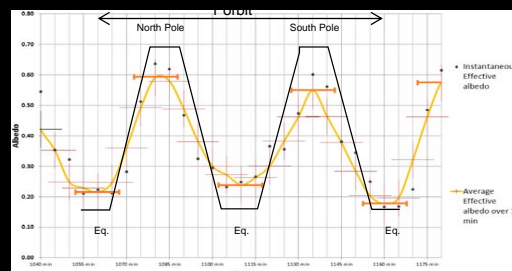




Variation of short term average albedo / Earth temperature values



Distribution of average effective albedo over a period of 15 min for a SSO orbit, 800 km, LTAN 18:00 (using real measured data from 2007 to 2011 (CERES mission))



Worst case profile of the evolution of average effective albedo over various periods for an SSO orbit, 800 km, LTAN 18:00

☞ Already used

Ref. : Definition of Earth thermal environment for TIRI (Thermal Infra-Red Instrument) mission (ESA-TECMITT-TN-004247)

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Conclusion



- clear link between real observations and assumptions used for spacecraft thermal analysis.
- provide useful and realistic inputs to simulate Earth environment, including finding worst cases of thermal conditions changes, which are mainly needed for temperature stability of sensitive instrument or radiators.

- Recommended albedo and Earth temperature over an orbit for the main LEO orbits:

Type of orbit	Altitude	Inclination	LTAN	Range of average albedo over 1 orbit	Range of average Earth temperature over 1 orbit
SSO	650 km - 850 km	~98-99°	any	0.24 – 0.40	246 K – 256 K
ISS	400 km	51.6°	drifting	0.19 – 0.40	250 K – 260 K
Tropical	800 km	20°	drifting	0.16 – 0.34	253 K – 264 K
Equatorial	800 km	6°	drifting	0.15 – 0.31	253 K – 260 K

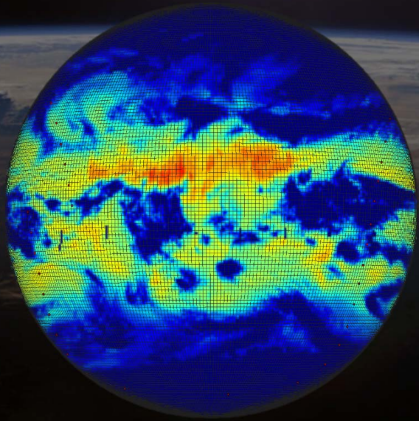
- Future activities: developing the tool with a more statistical approach covering a larger range of orbits
- Proposing standard update for albedo and IR Earth temperature

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Questions...



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Flags of participating countries: Germany, Belgium, Czech Republic, Denmark, France, Finland, Germany, Greece, Hungary, Italy, Italy, Netherlands, Norway, Poland, Portugal, Romania, Spain, Sweden, Switzerland, United Kingdom, Russia, Canada.