Appendix B

OrbEnv
A tool for Albedo/Earth Infra-Red environment parameter determination

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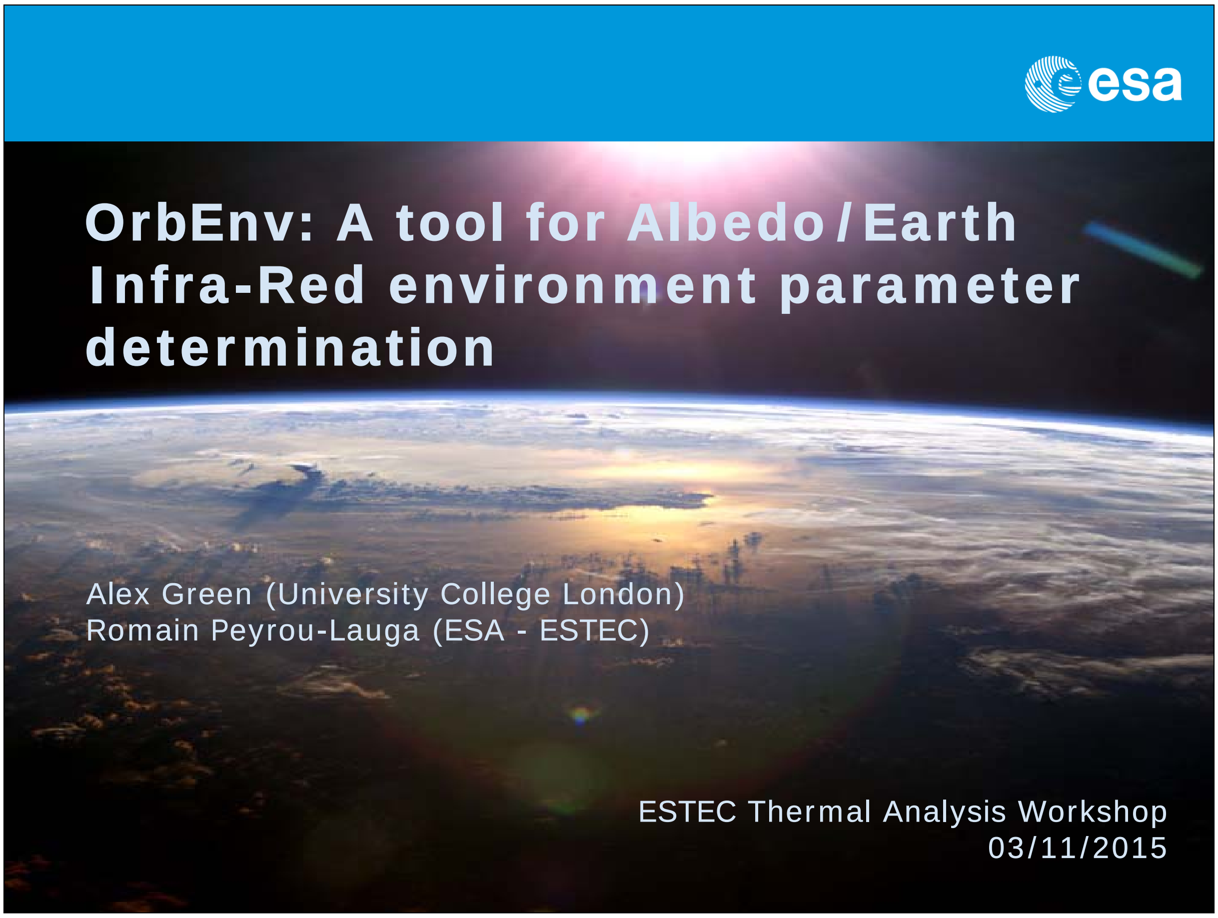
Abstract

OrbEnv is a tool developed for ESA missions to provide realistic and less enveloping albedo coefficient and Earth temperature range for an orbit using data measured by satellites. The tool is able to treat the most common orbit types (LEO, SSO, HEO, MEO...) and is able to calculate impinging albedo and Earth fluxes for several basic geometries and several time steps. Data comes from the CERES instrument on NASA's Terra satellite and covers more than 6 years of measurement.


esa
OrbEnv: A tool for Albedo/Earth Infra-Red environment parameter determination
Alex Green (University College London)
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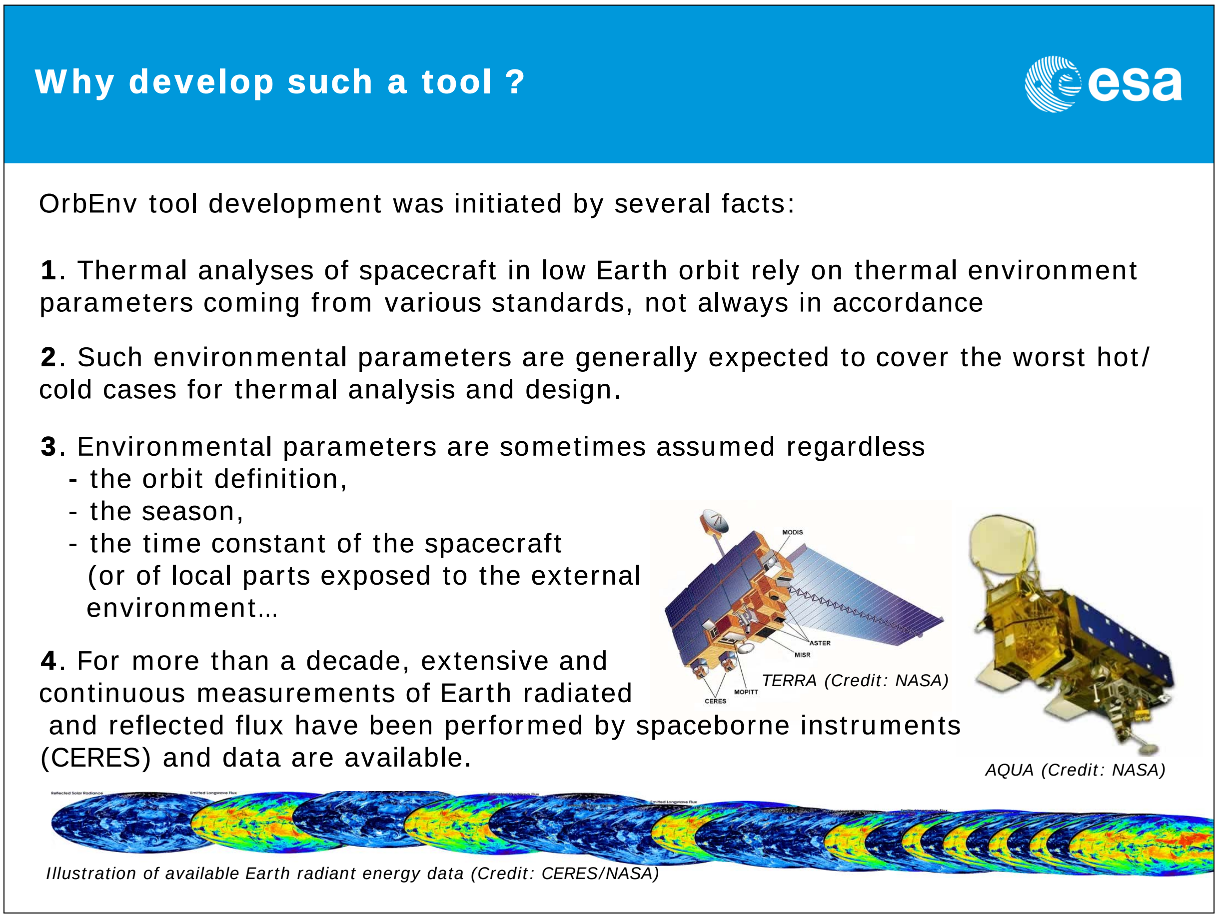
ESTEC Thermal Analysis Workshop
03/11/2015


Why develop such a tool ?
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OrbEnv tool development was initiated by several facts:
1. Thermal analyses of spacecraft in low Earth orbit rely on thermal environment parameters coming from various standards, not always in accordance
2. Such environmental parameters are generally expected to cover the worst hot/cold cases for thermal analysis and design.
3. Environmental parameters are sometimes assumed regardless
- the orbit definition,
- the season,
- the time constant of the spacecraft (or of local parts exposed to the external environment…
4. For more than a decade, extensive and continuous measurements of Earth radiated and reflected flux have been performed by spaceborne instruments (CERES) and data are available.
MODIS
ASTER
MISR
MOPITT
CERES
TERRA (Credit: NASA)
AQUA (Credit: NASA)
Illustration of available Earth radiant energy data (Credit: CERES/NASA)

Objectives of OrbEnv tool

OrbEnv activity and tool development objectives:

1. Understanding CERES data (albedo, IR flux) and compare them with existing standards

2. Find a method to use CERES data and determine albedo / IR flux depending on:
- the orbit definition,
- the season,
- the time constant of the spacecraft

(or of local parts exposed to the external environment.

3. Develop a tool to determine albedo / IR flux for any Earth orbit with several options:
- basic geometry of the spacecraft (plane, sphere, cube)
- time step

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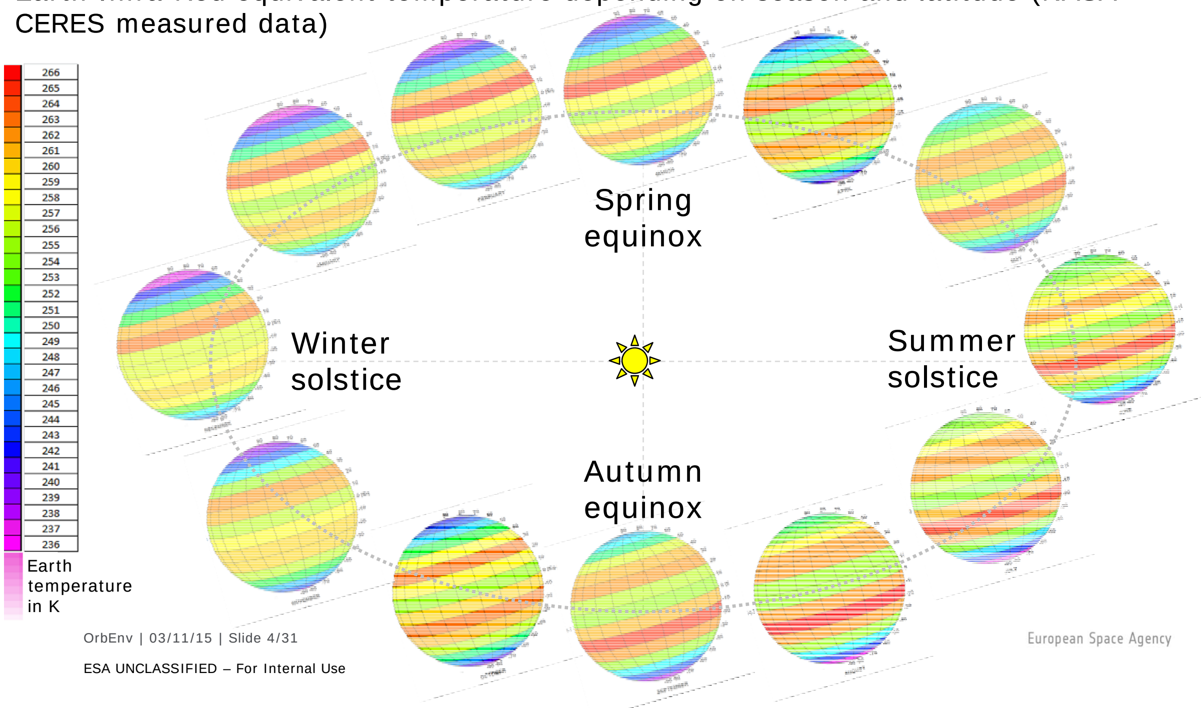
Earth Infra-Red equivalent temperature depending on season and latitude (NASA CERES measured data)

Earth Infra-Red equivalent temperature depending on season and latitude (NASA CERES measured data)



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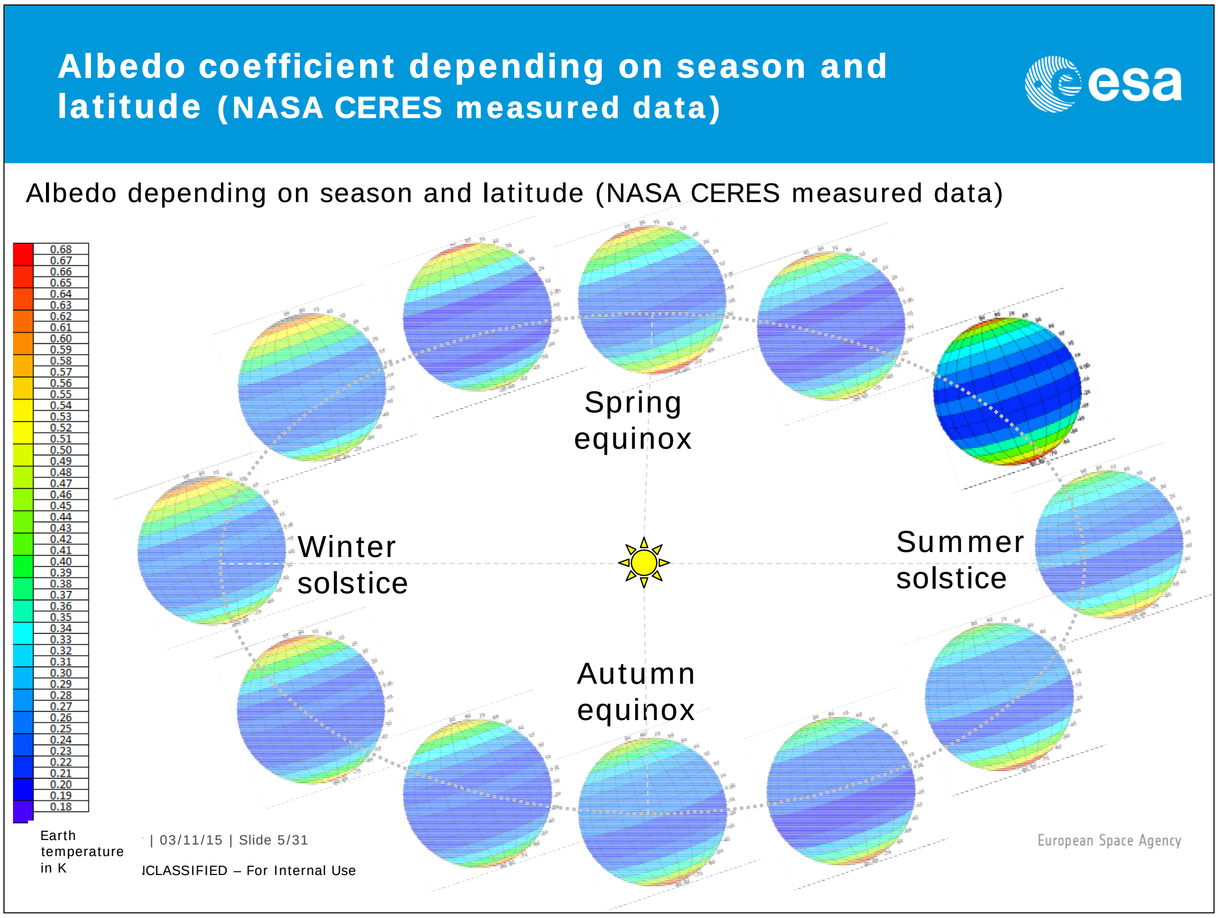
Albedo coefficient depending on season and latitude (NASA CERES measured data)
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Albedo depending on season and latitude (NASA CERES measured data)
0.68
0.67
0.66
0.65
0.64
0.63
0.62
0.61
0.60
0.59
0.58
0.57
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0.23
0.22
0.21
0.20
0.19
0.18
Earth temperature in K
Spring equinox
Winter solstice
Summer solstice
Autumn equinox
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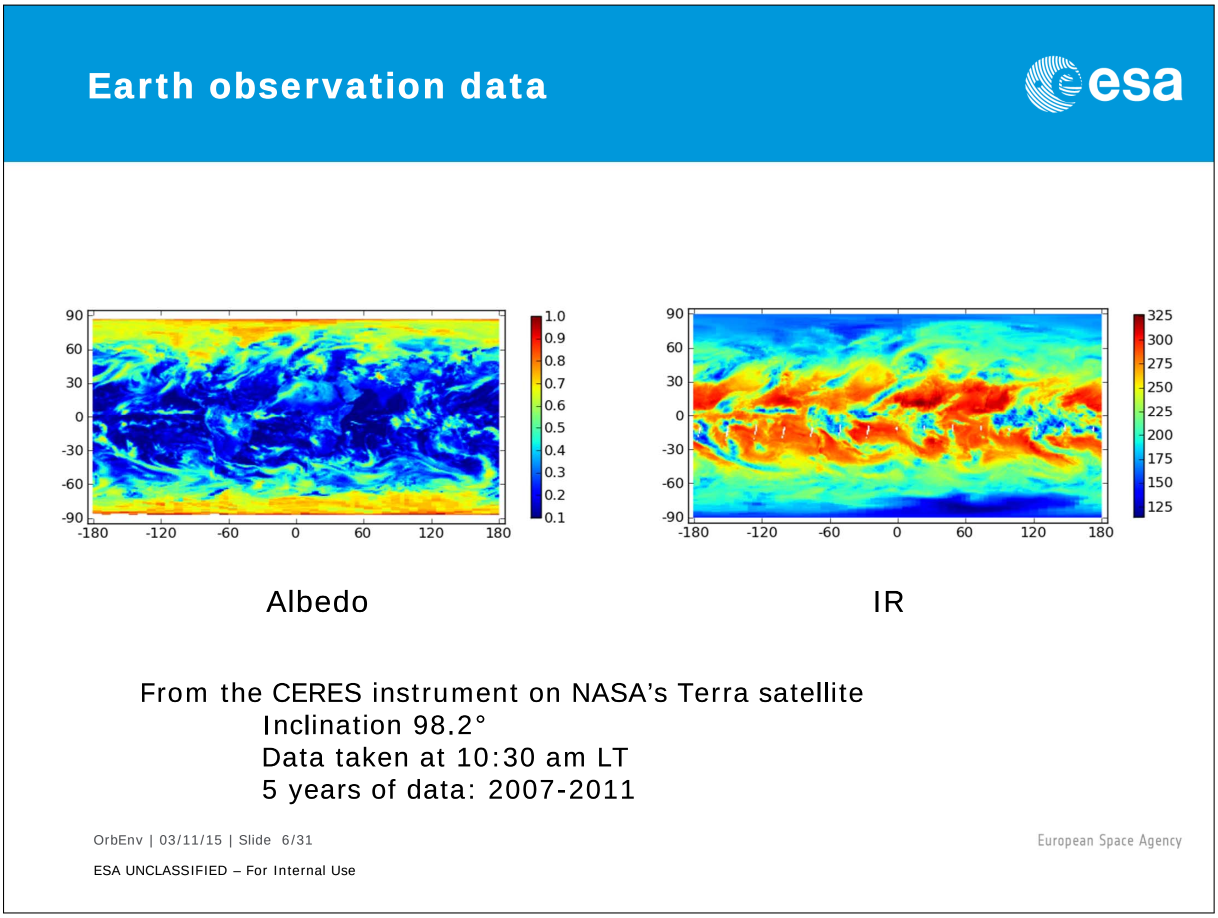
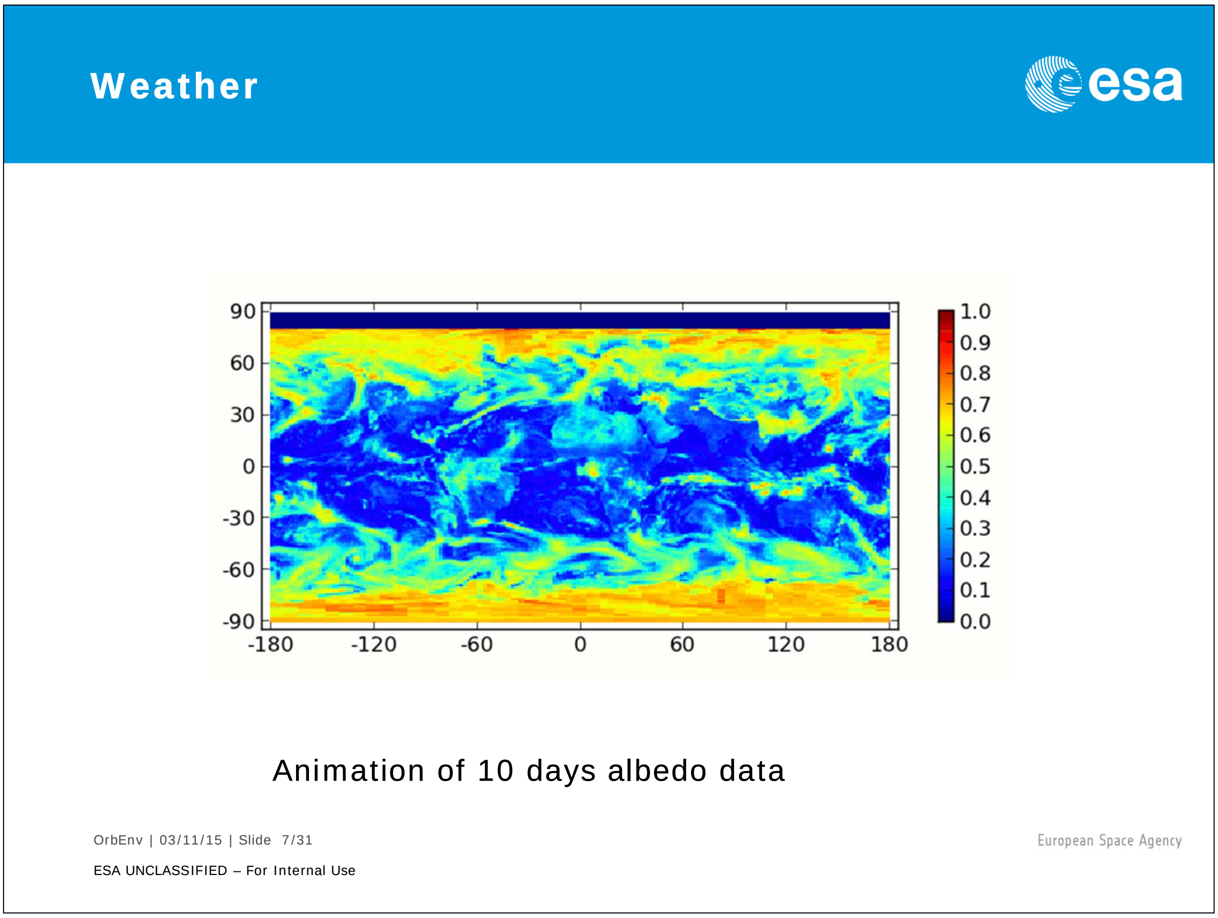
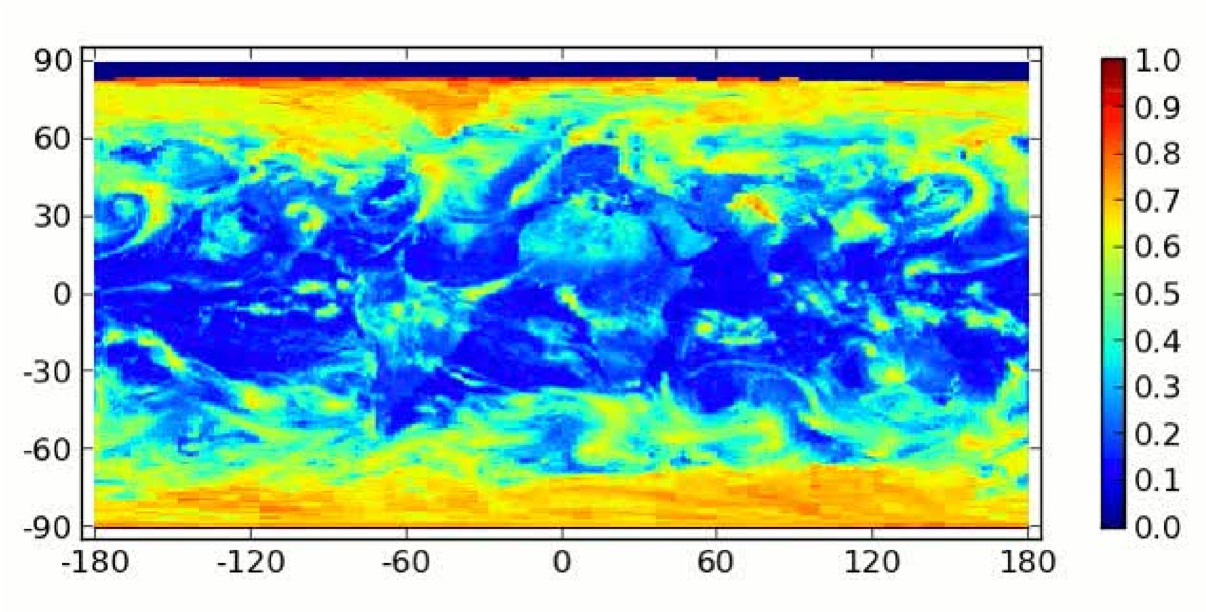


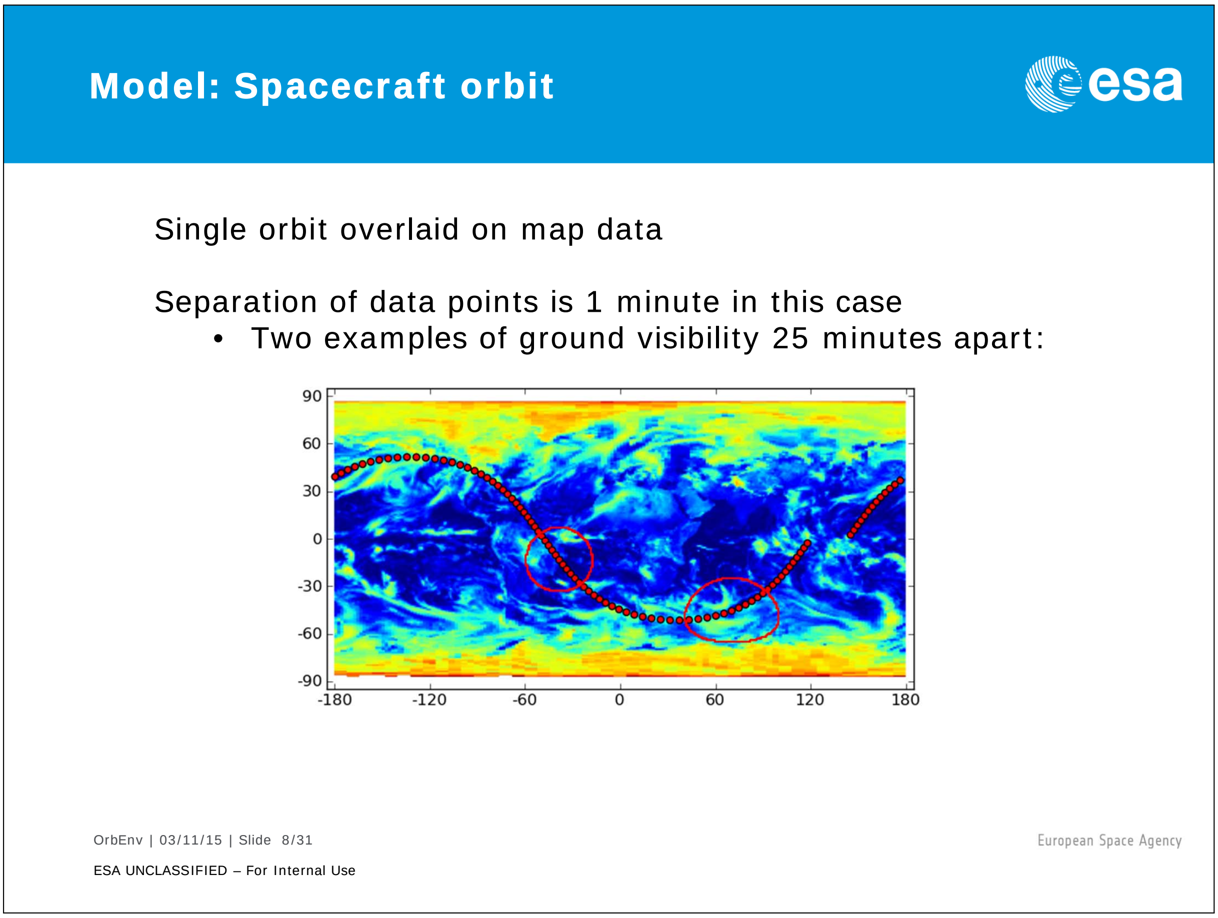
Real data was obtained for every day during the period of interest. Given as a map with 1 degree by 1 degree grid points. The planetary IR emission is given in W/m^2. The same features can be seen in both maps, for example clouds tend to be more reflective than land so have a higher albedo, but are colder so have lower thermal IR emission.



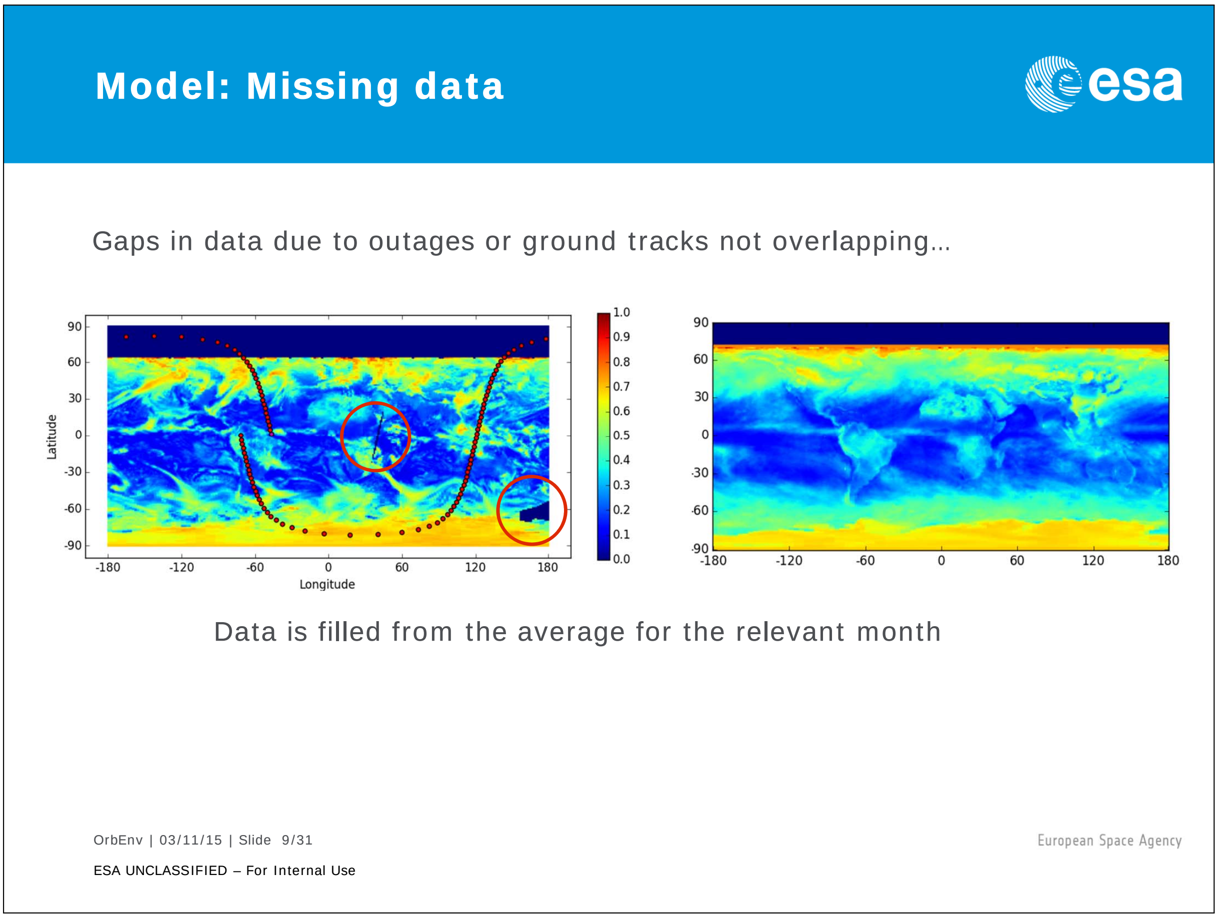
The movement of cloud features can be seen in this 10 day period. The lack of sunlight at the pole due to the northern hemisphere winter can be also be seen.



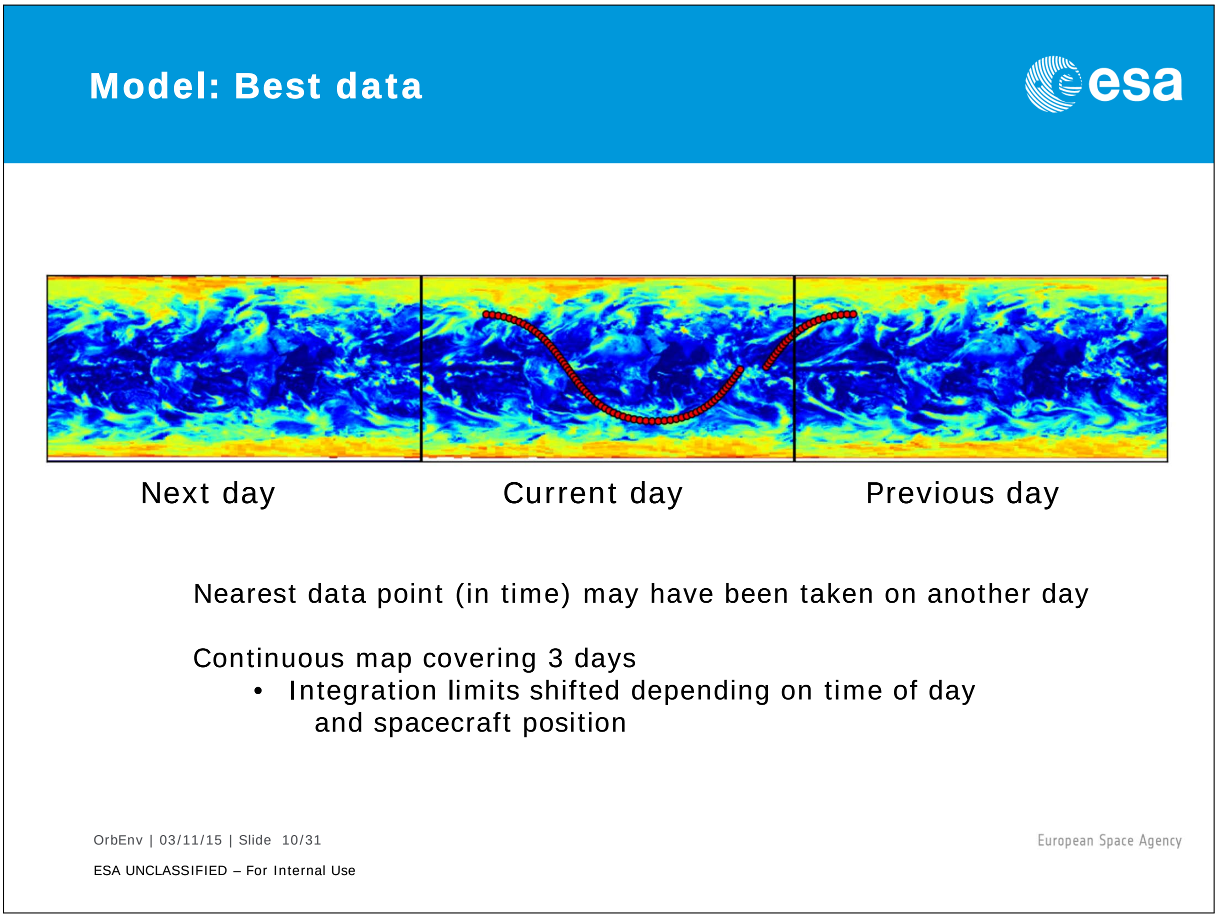
Save the attachment to disk or (double) click on the picture to run the movie.



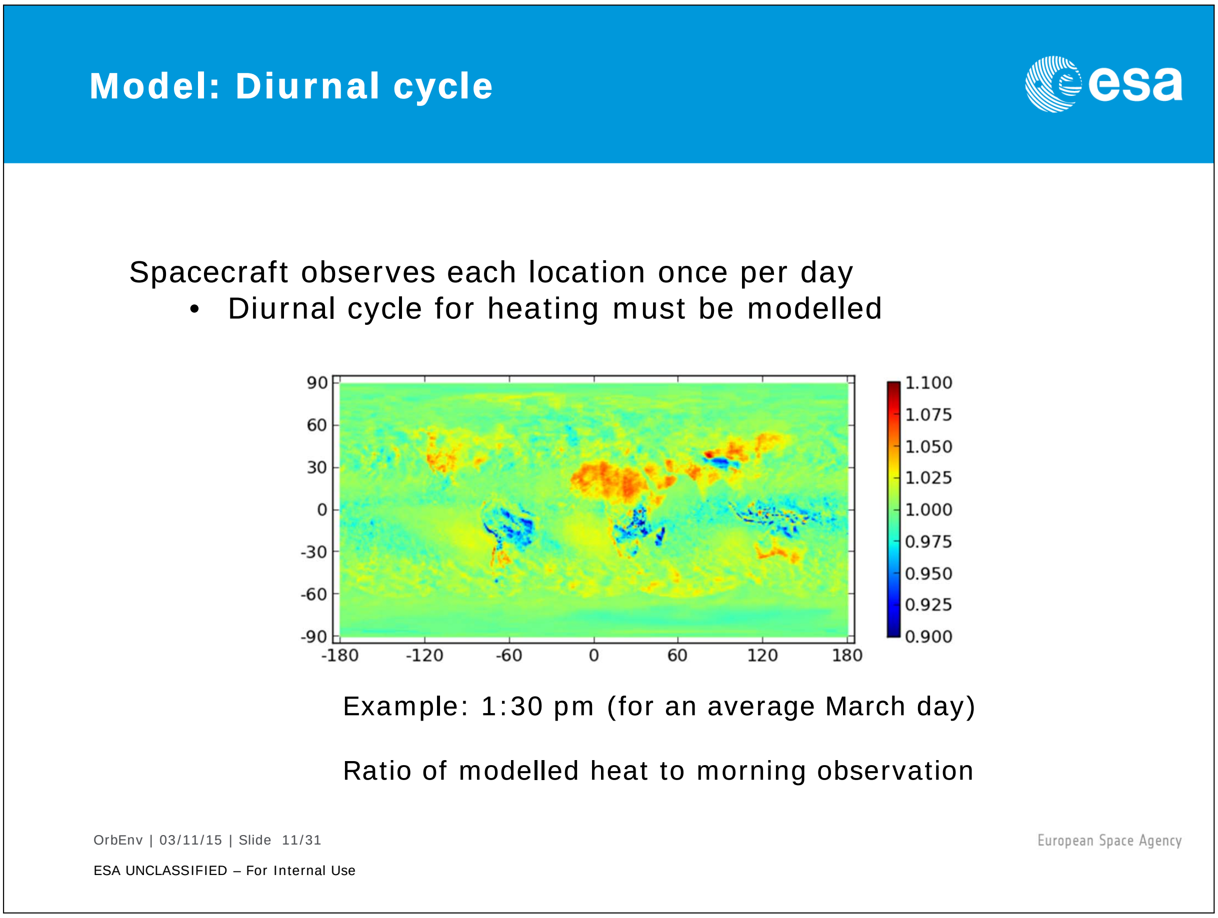
The flux received at each point of the orbit varies according the features visible at each instant. In one of these two examples the spacecraft is over the coast of Brazil and sees mainly low albedo ocean and forest, but later is over ocean with lots of cloud cover and thus a much higher average albedo.



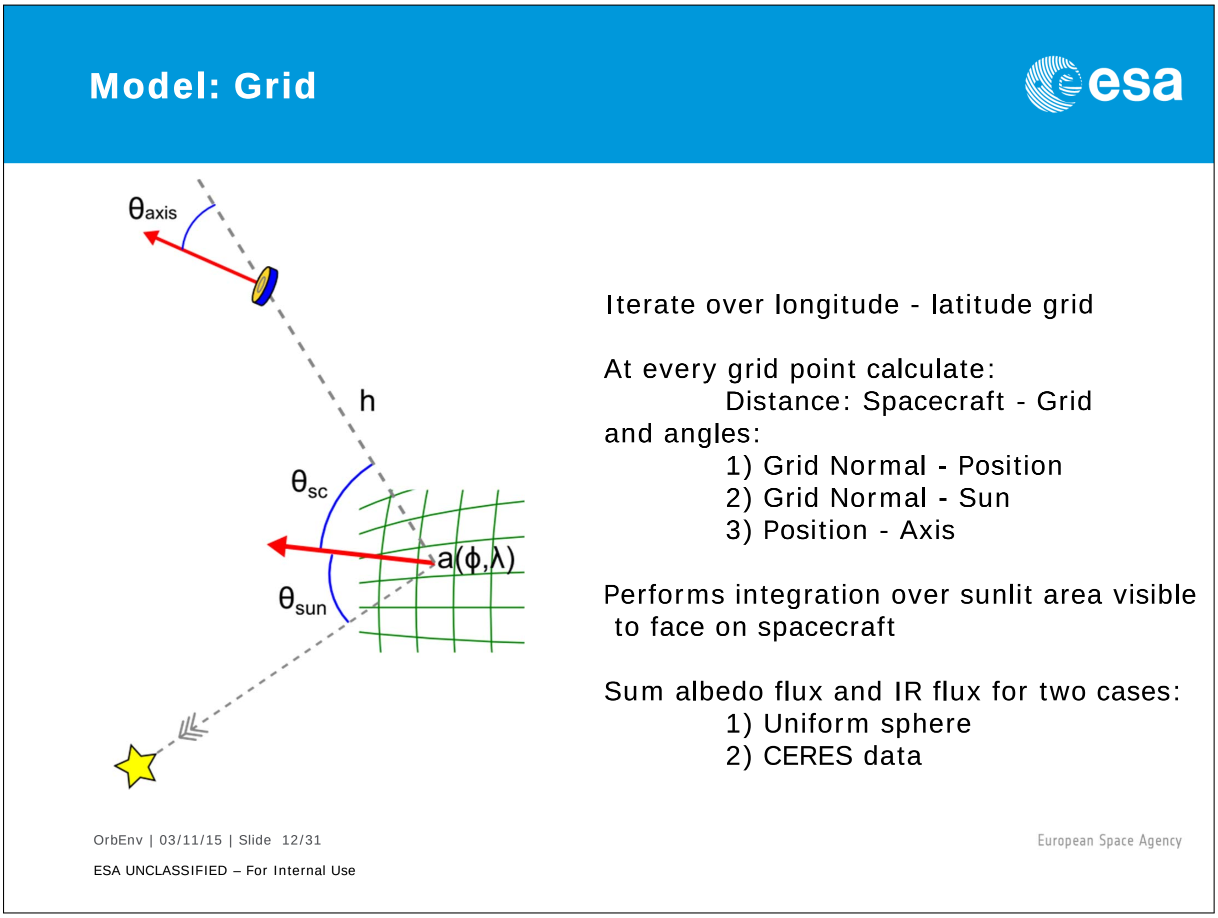
Where there is missing data the average value for the month is used. If a time period outside the data range is requested then the date can be be mapped around into the range, or average values can also be used.



The data is taken by the satellite in a sun-synchronous orbit by building up ground tracks that have an equator crossing at 10:30 am local time. When integrating over the area visible to the satellite the data for the grid point should therefore be the one taken closest to 10:30 am local time even if it was taken on the previous or next calendar day according to UTC.

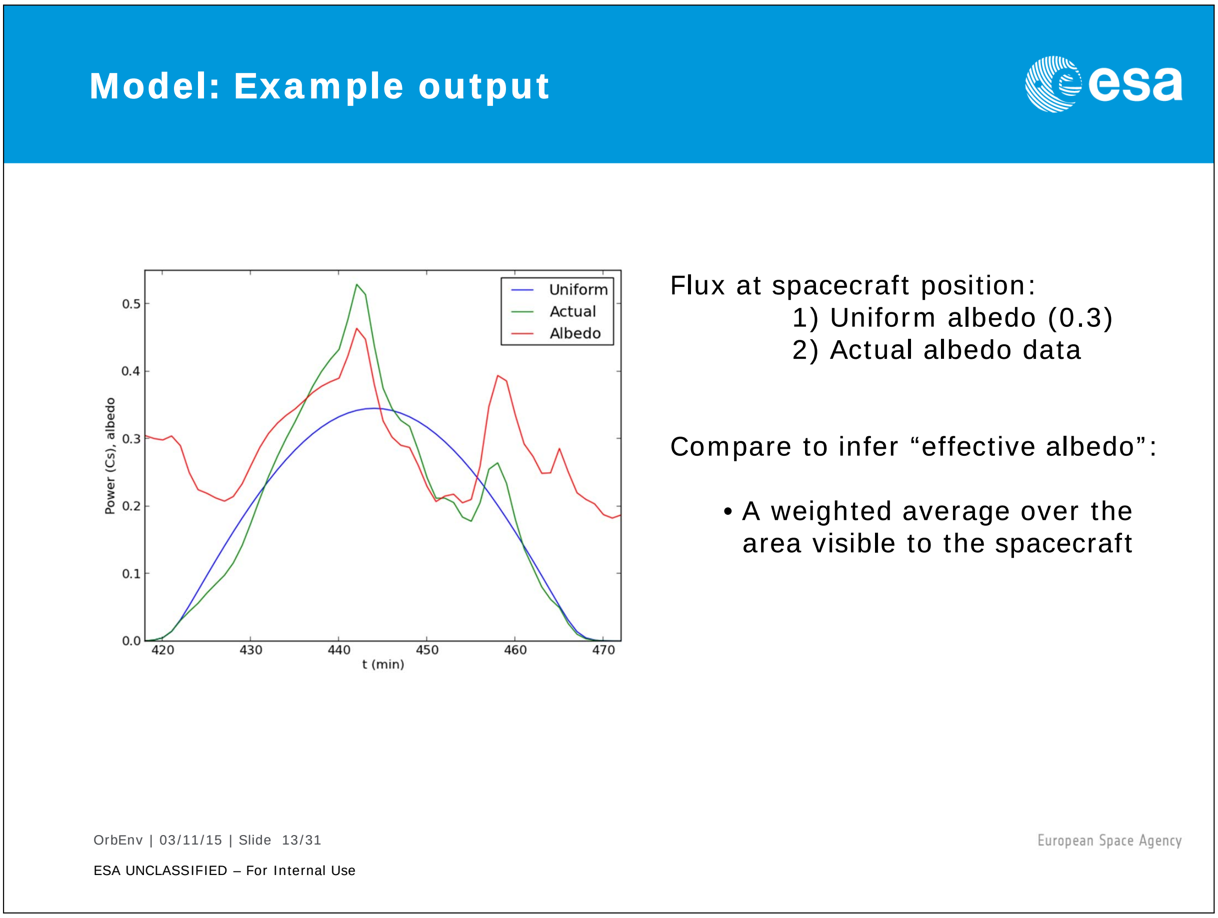


The data is provided as a single value for each day, but thermal IR emission has a strong variation during the day which must be allowed for. This also depends on location; ocean sees little variation due to the large thermal inertia of water, while desert sees a much bigger cycle. Also some areas experience different cycles due to cloud cover changes, e.g. clouds tend to form over rainforests in the afternoon, reducing IR emission. To estimate this cycle, data was processed that shows how IR emission varies during the day for each grid point, by each month of the year. So for example we can say that on a typical March day the IR emission from a grid point in the Sahara is 5% greater at 1:30 pm than at 11:30 am when the satellite data was taken. This is combined with the satellite data for that day to provide an estimate of the emission at any time during the day in question.



At every grid square on the map the contribution to the flux received at the spacecraft location is calculated if the spacecraft is visible (the angle between the grid point normal and the grid-to-spacecraft vector is < 90 deg). Both albedo and IR fluxes are calculated for each face on the spacecraft. In addition the flux is calculated for two cases:

1. If the Earth had a uniform value for albedo/IR
2. With the real, varying albedo/IR values measured by satellite.



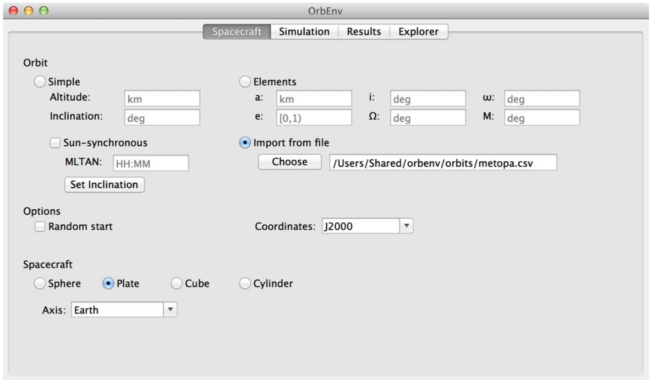
The sunlit portion of one orbit is shown. The albedo flux (in units of the solar constant) at the spacecraft position is shown for two cases:

1. Earth has a uniform albedo value of 0.3
2. An actual flux with albedo varying according to satellite measurements for the relevant day.

By comparing the two we can calculate an effective albedo value at each point - a uniform value for the earth that would produce the same heating as predicted using the varying albedo data. For example if the predicted (actual) flux at the spacecraft position is higher than the calculation for the uniform (0.3) case then we can infer that the effective albedo at that moment must have been proportionally greater than 0.3. It can be seen that on this orbit the effective albedo during the orbit is around 0.3 on average, with some variation between 0.2 and 0.4 due to the features the spacecraft passes over.

Program: Orbits

Front end written in Python, user interface in wxPython (platform independent)



Ability to specify orbit:
- Simple circular
- Keplerian elements
- Import from file

Select sun-synchronous orbit

Select spacecraft geometry

Select spacecraft orientation

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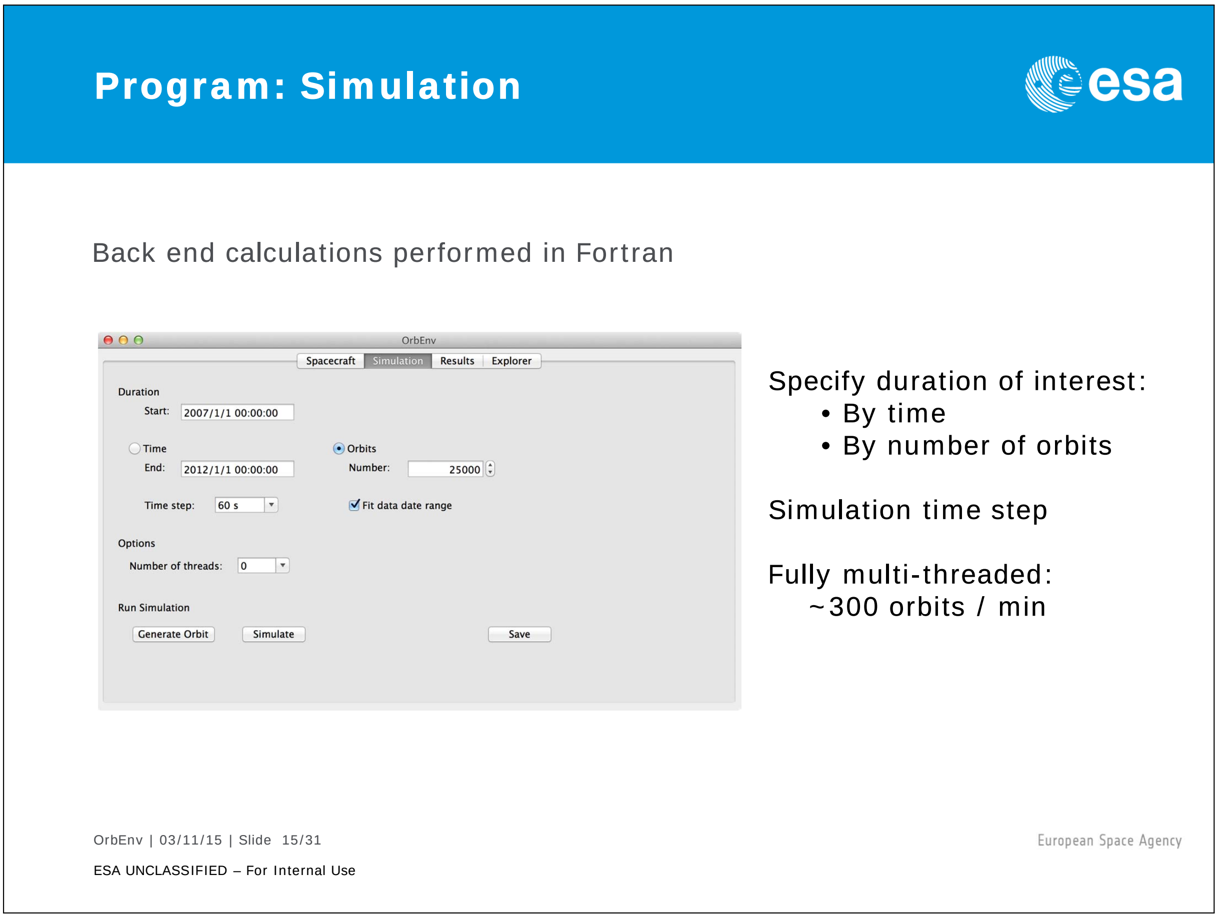
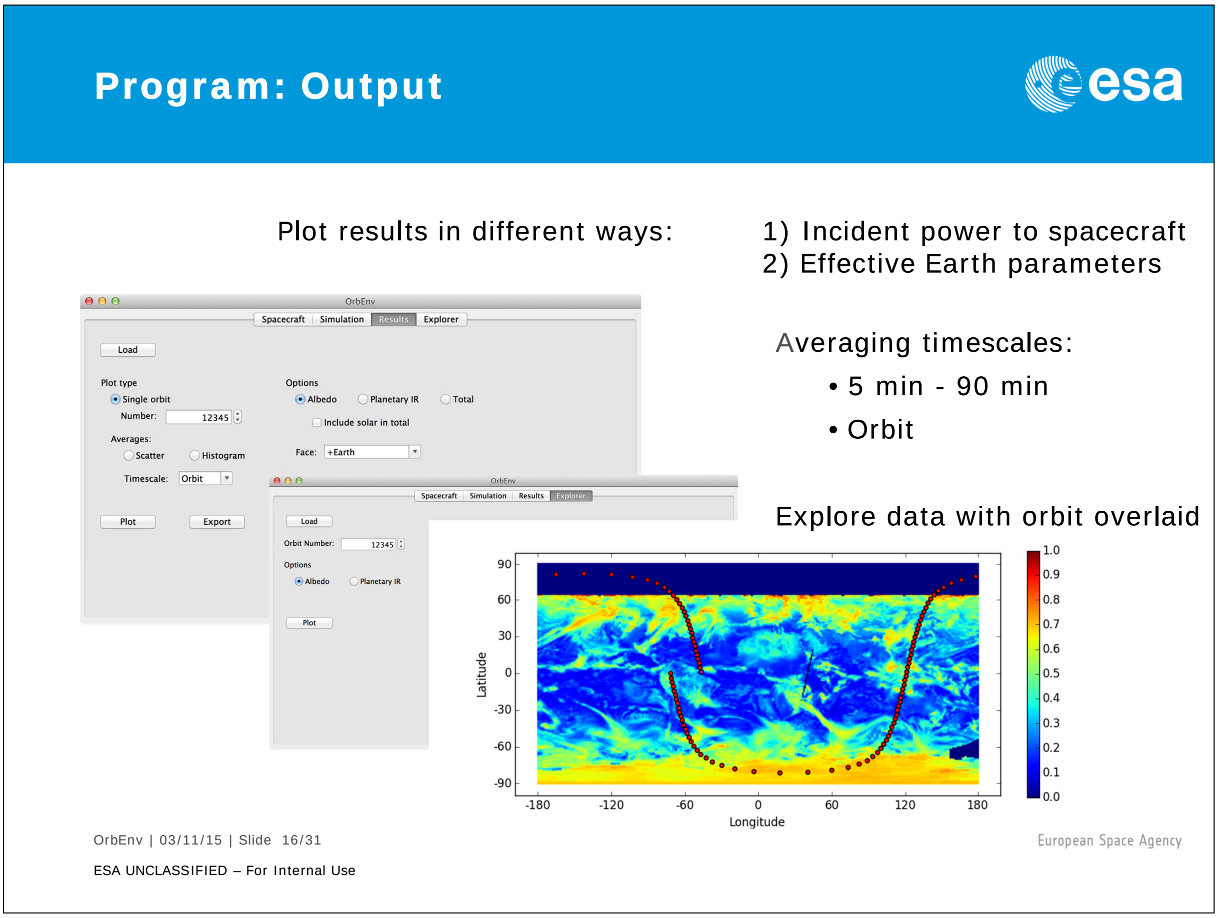
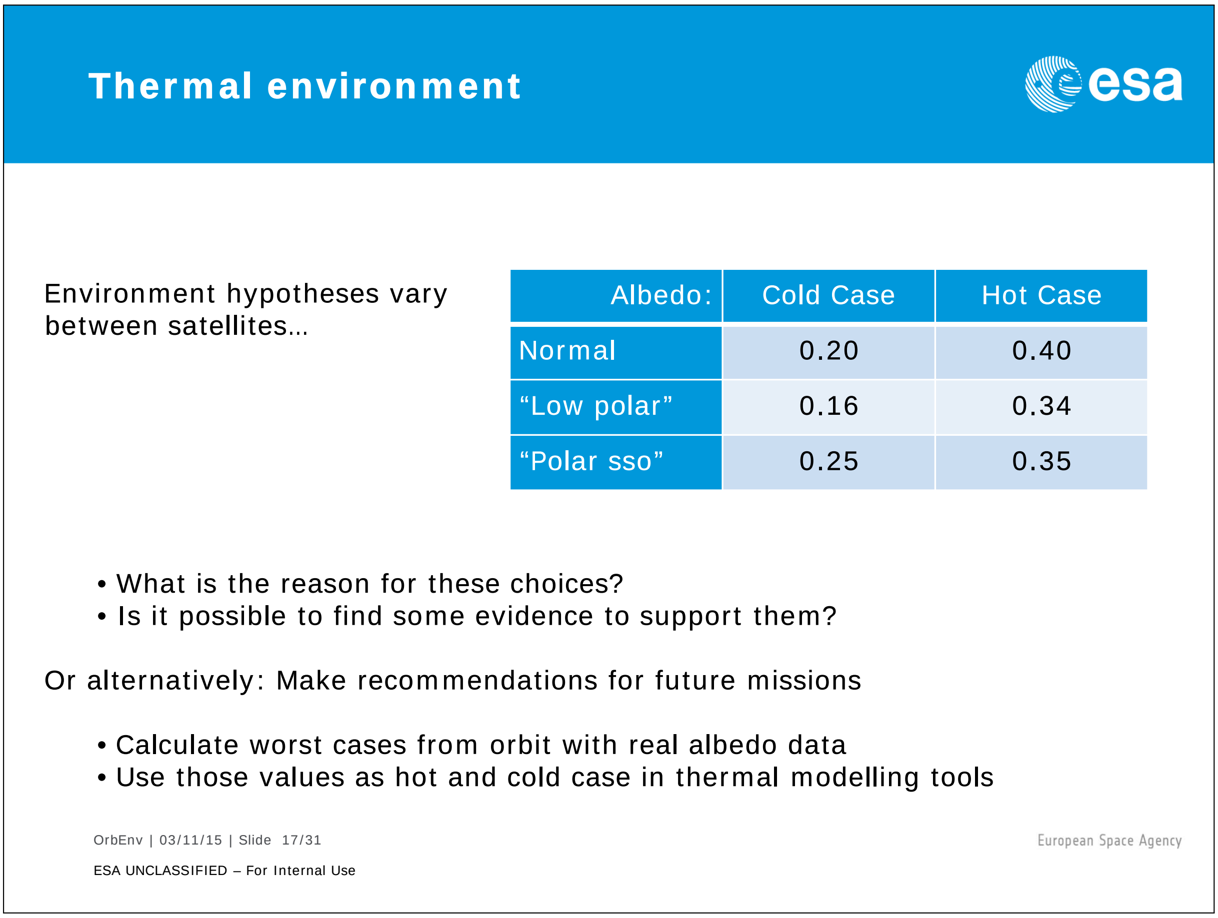
A front end for the model has been written to make it easy for engineers to set up and study cases of interest. The orbit can be specified in several ways, or imported from a file (e.g. output from STK). The spacecraft geometry and orientation (earth/velocity/sun/polar/ecliptic) can also be specified.



The model calculations are implemented in Fortran for speed. The simulation can be completed in under an hour on a reasonably powerful computer, so does not have a significant impact on workflow.

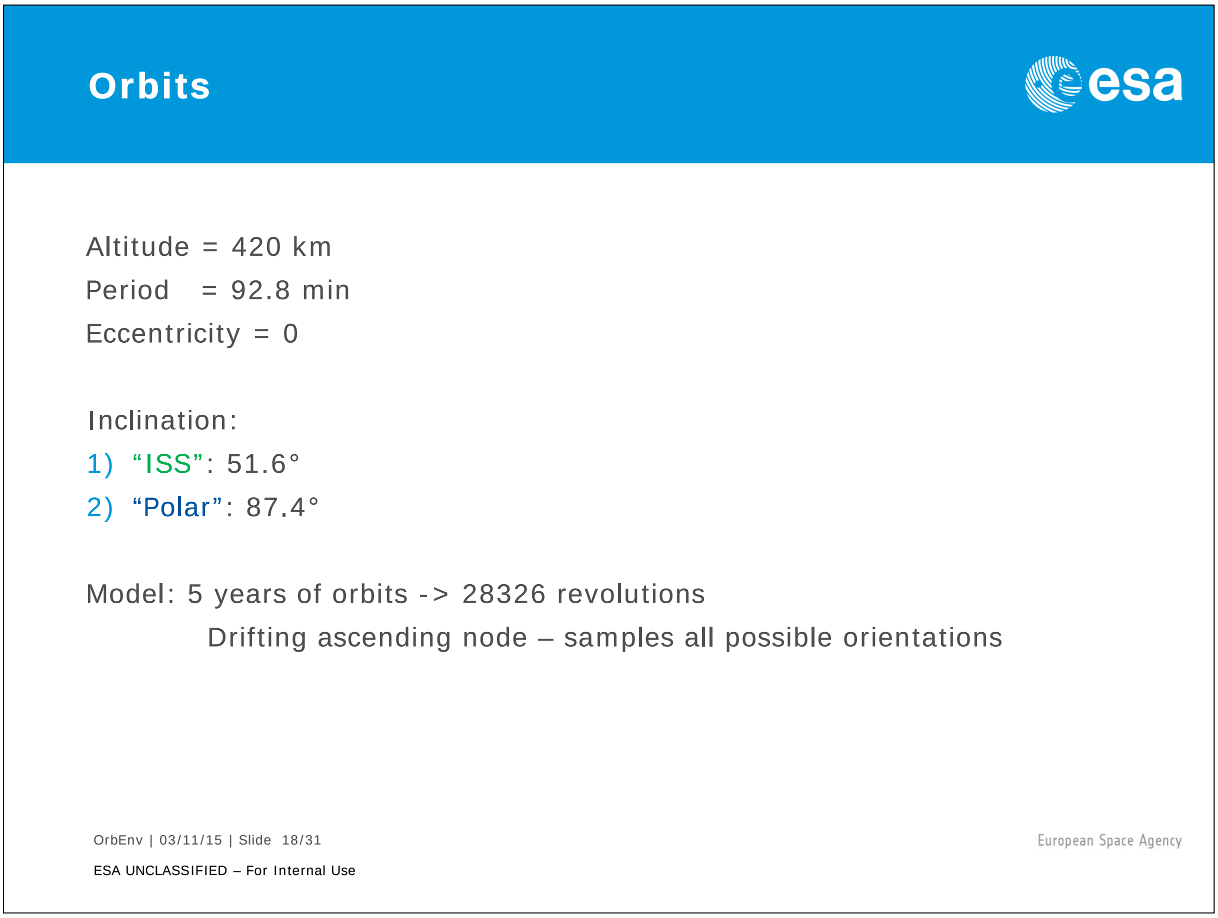


The results can be explored graphically or exported to file for further study.

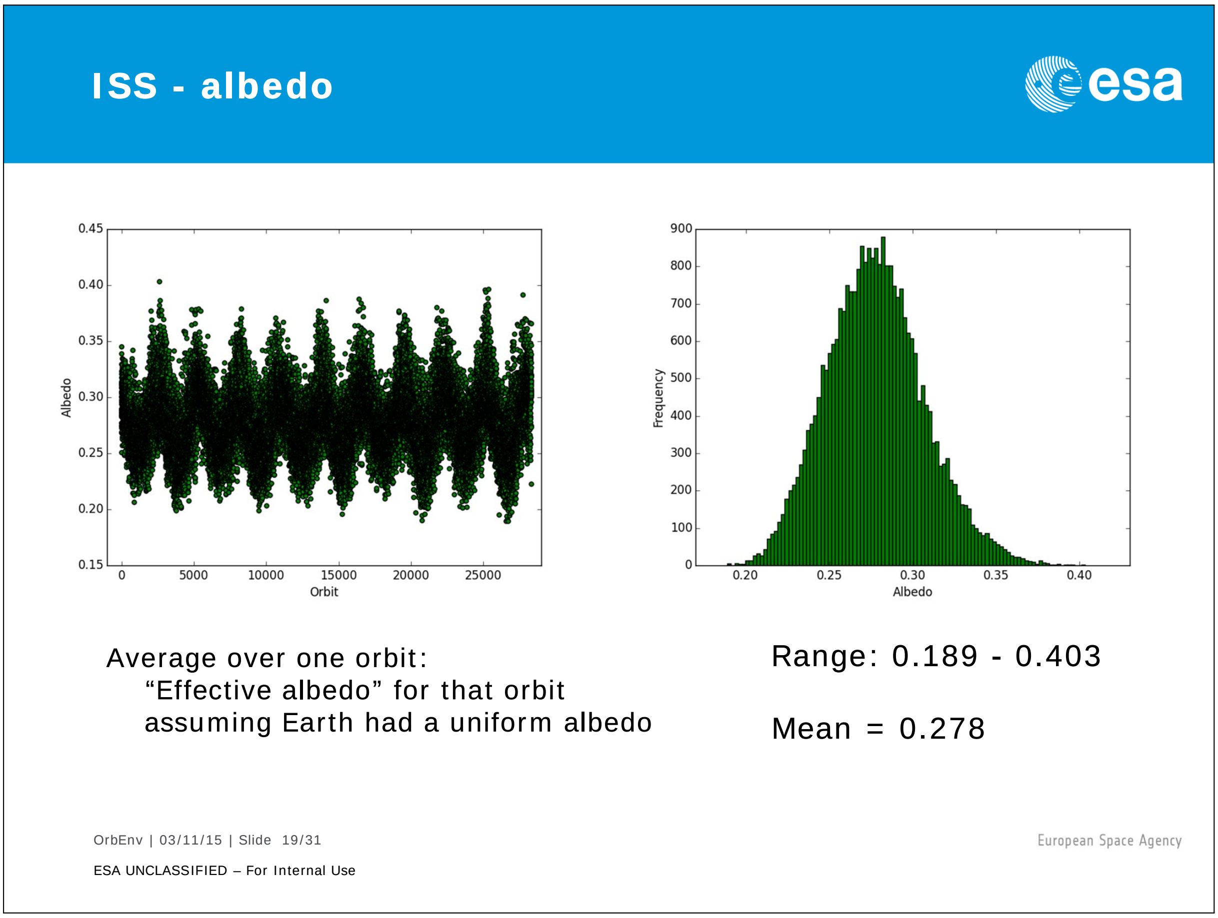


The issue has been raised lately of why certain values for Earth's thermal environment are used; why the chosen values are not consistent, and what justifies the choices. Earth's albedo is approximately 0.3 when averaged over the entire globe, so values of 0.2 - 0.4 are common choices for the cold and hot cases. But for example, in the case of some polar spacecraft, flying over areas with greater albedo on average, we see lower values are chosen, why?

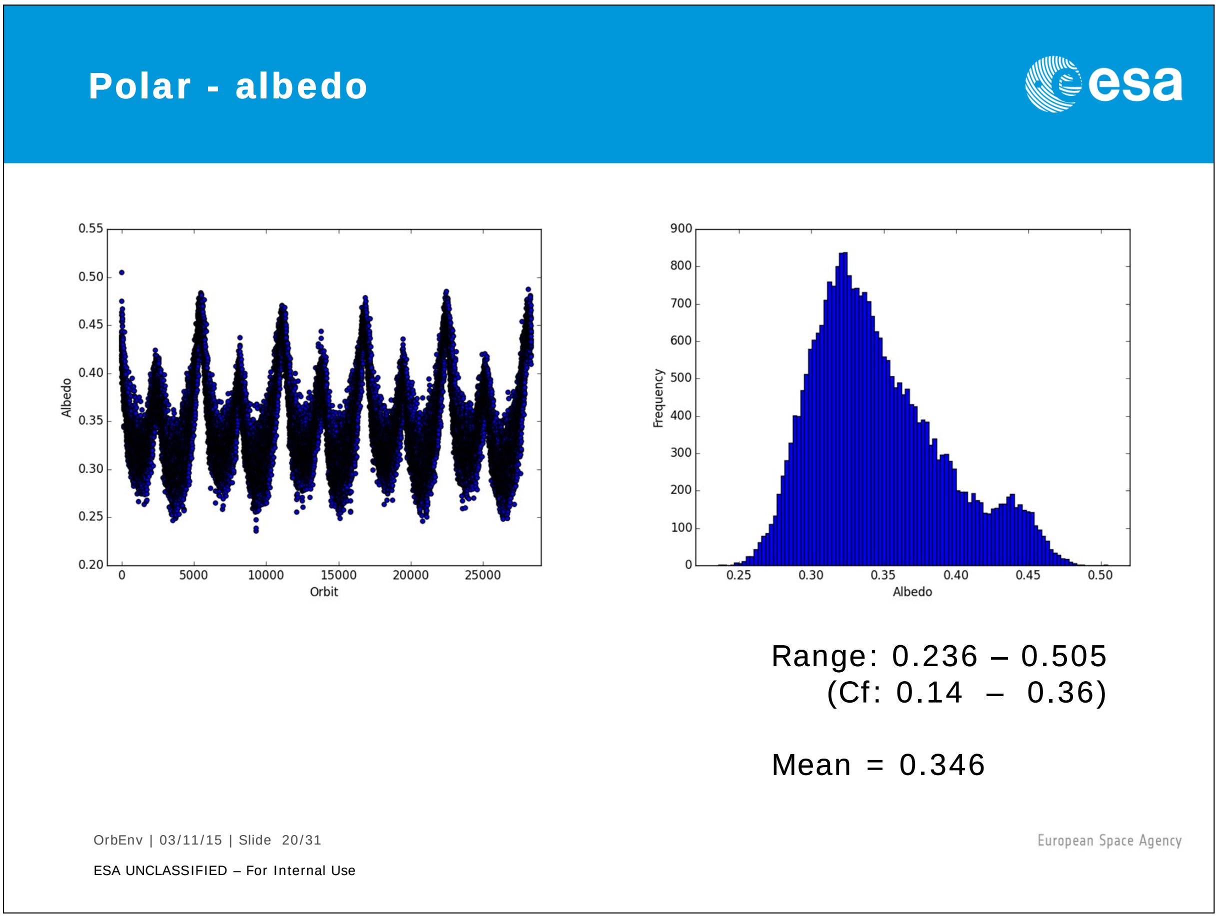
Instead the model that has been developed can be used to combine spacecraft orbits with real Earth observation data to estimate the range of environment variables that would have been experienced in reality. This can provide evidence to support the choice of values for thermal modelling.



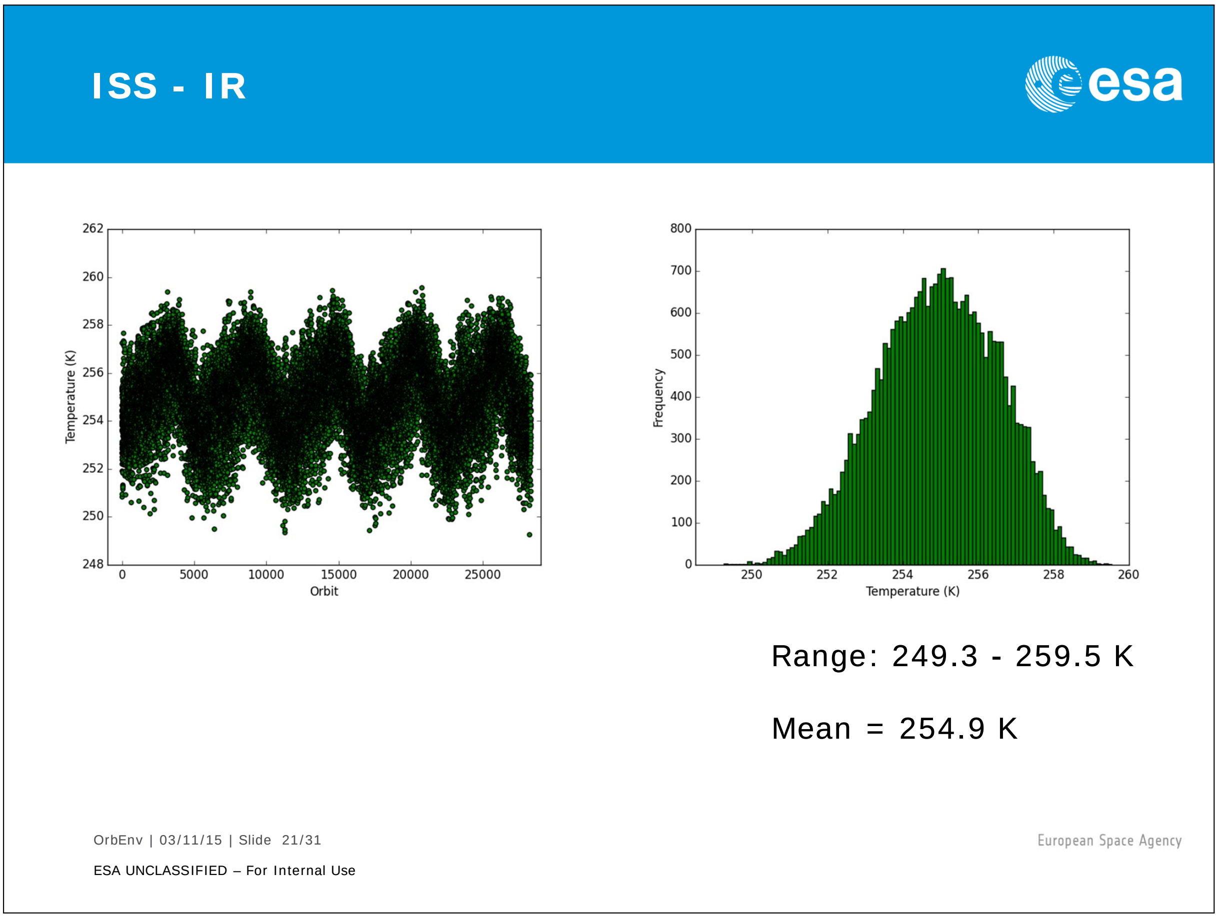
Two orbits have been chosen for comparative purposes; one orbit similar to the ISS, and one with the same altitude but in a polar orbit. Five years are modelled, providing a large number of revolutions to give a large statistical sample.



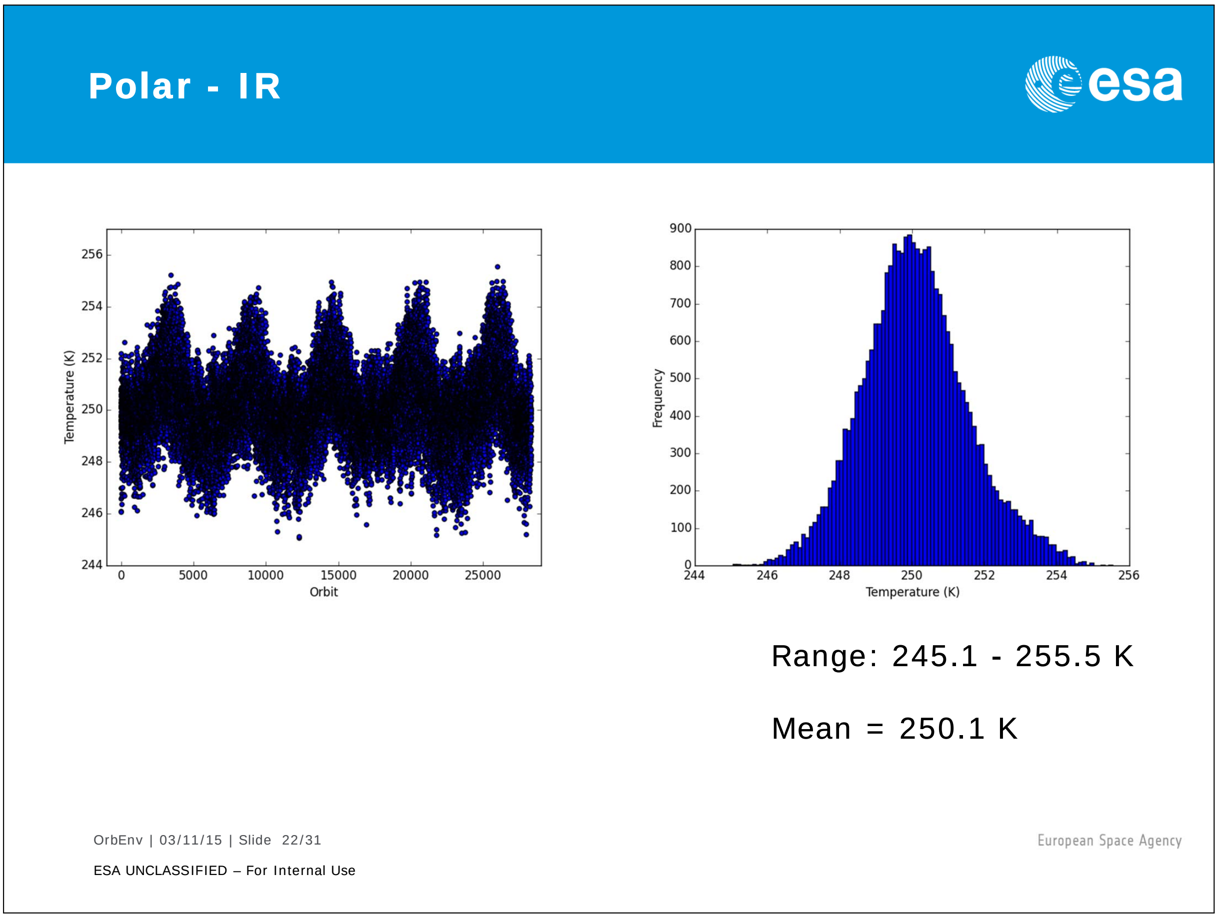
The data can be averaged over different timescales, here an average over one orbit is calculated. This shows what uniform value of albedo the earth would have needed for the spacecraft to receive the same energy over one orbit as it does in the case when actual albedo data is used. For the ISS orbit a range of 0.2 - 0.4 appears sensible for the extreme cases. There are appear to be two peaks of albedo per year.



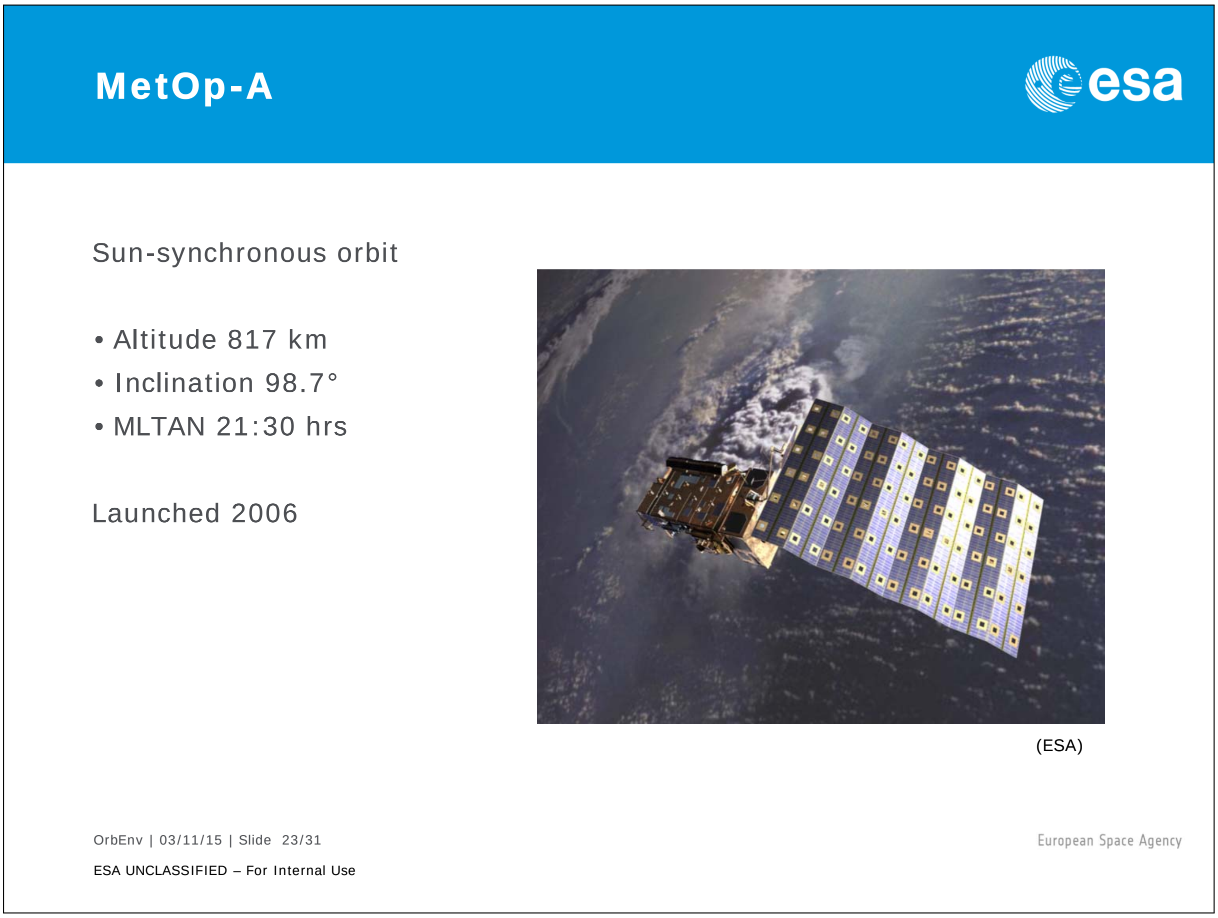
In the polar case the effective albedo range observed is much higher, the ranges assumed for polar spacecraft earlier does not appear to be appropriate. The distribution also appears to be somewhat bimodal.



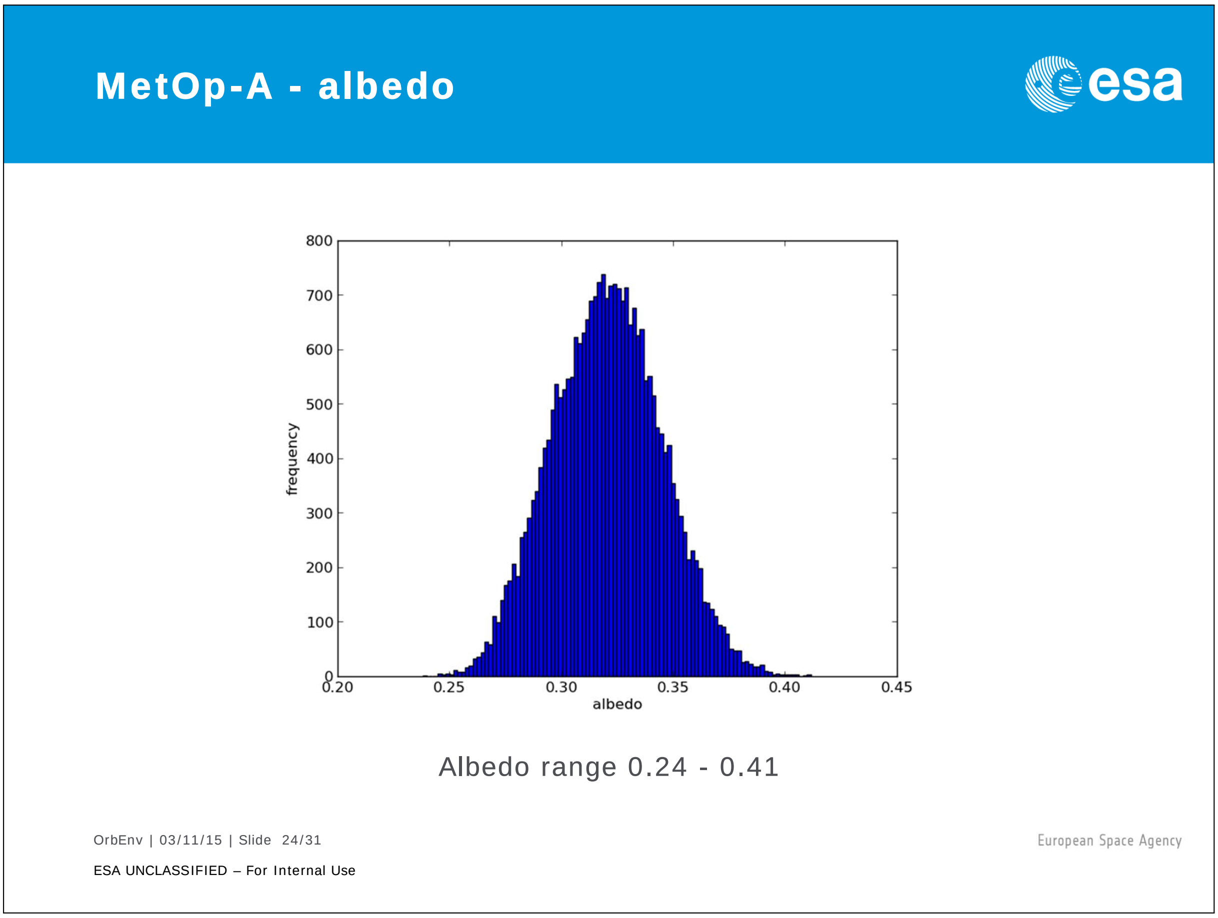
The same calculations can be done for thermal IR emission in the ISS case. There is only one peak per year.



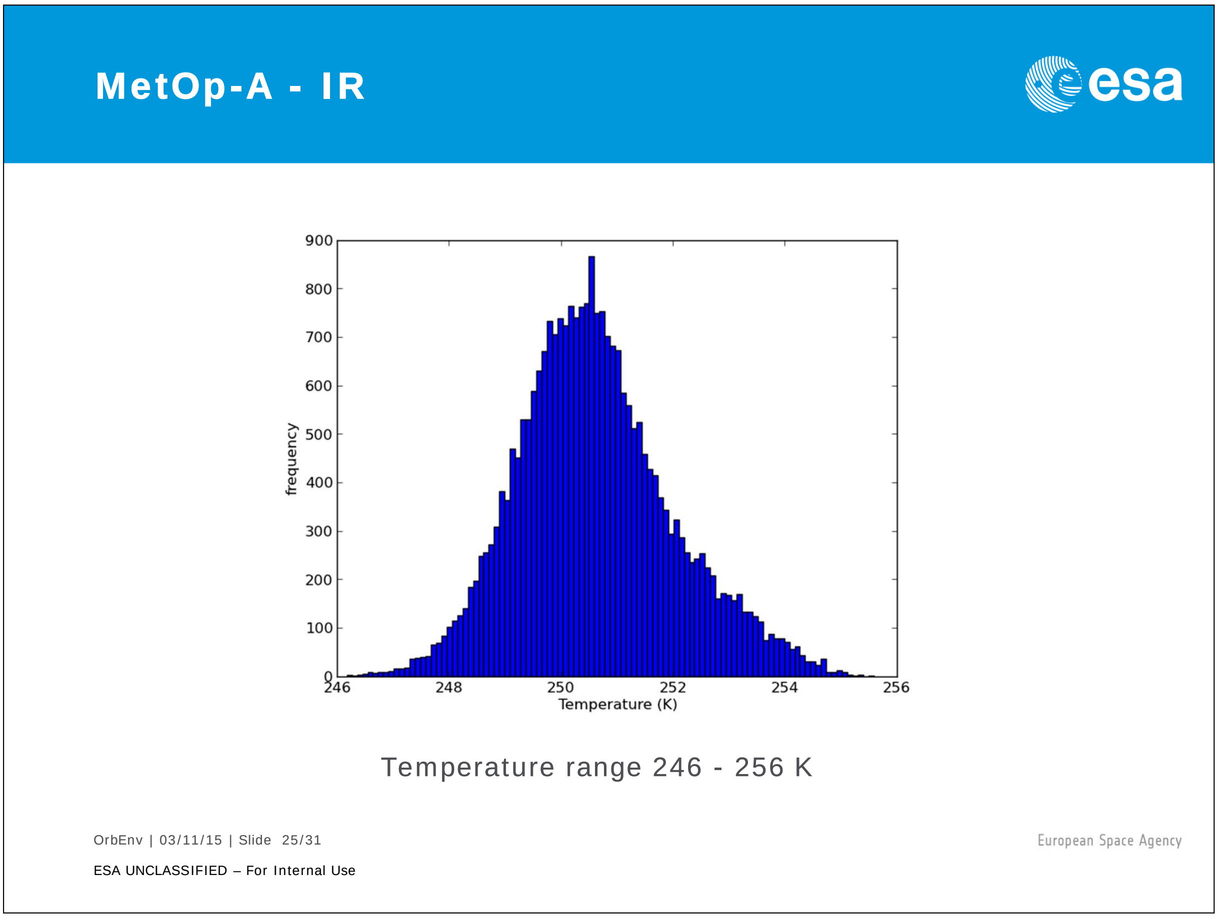
Polar orbit, IR.



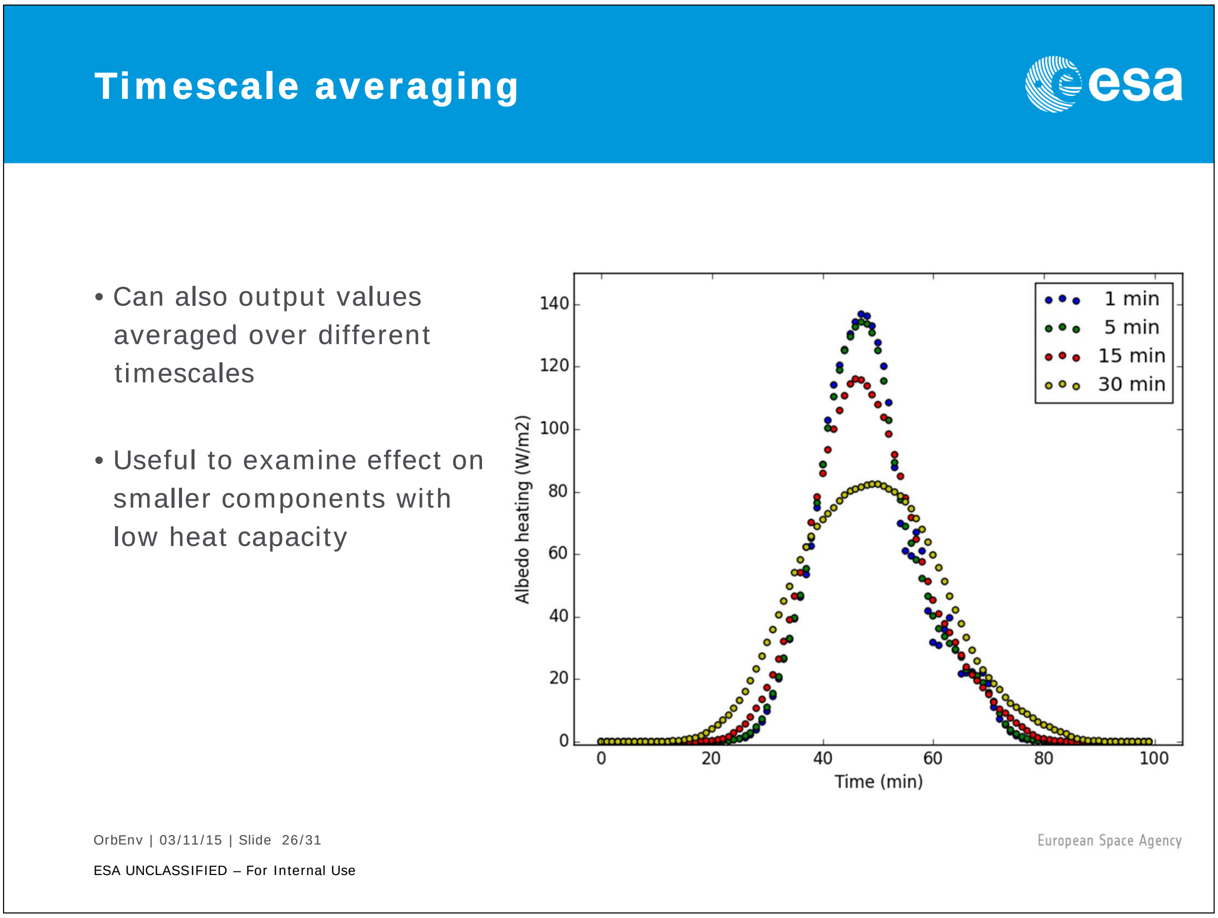
MetOp-A has an orbit typical of sun-synchronous earth observation satellites. It was launched in 2006 so here the real spacecraft position data for the period 2007-2011 could be imported into the simulation. This allows us to observe the actual features/weather the spacecraft flew over.



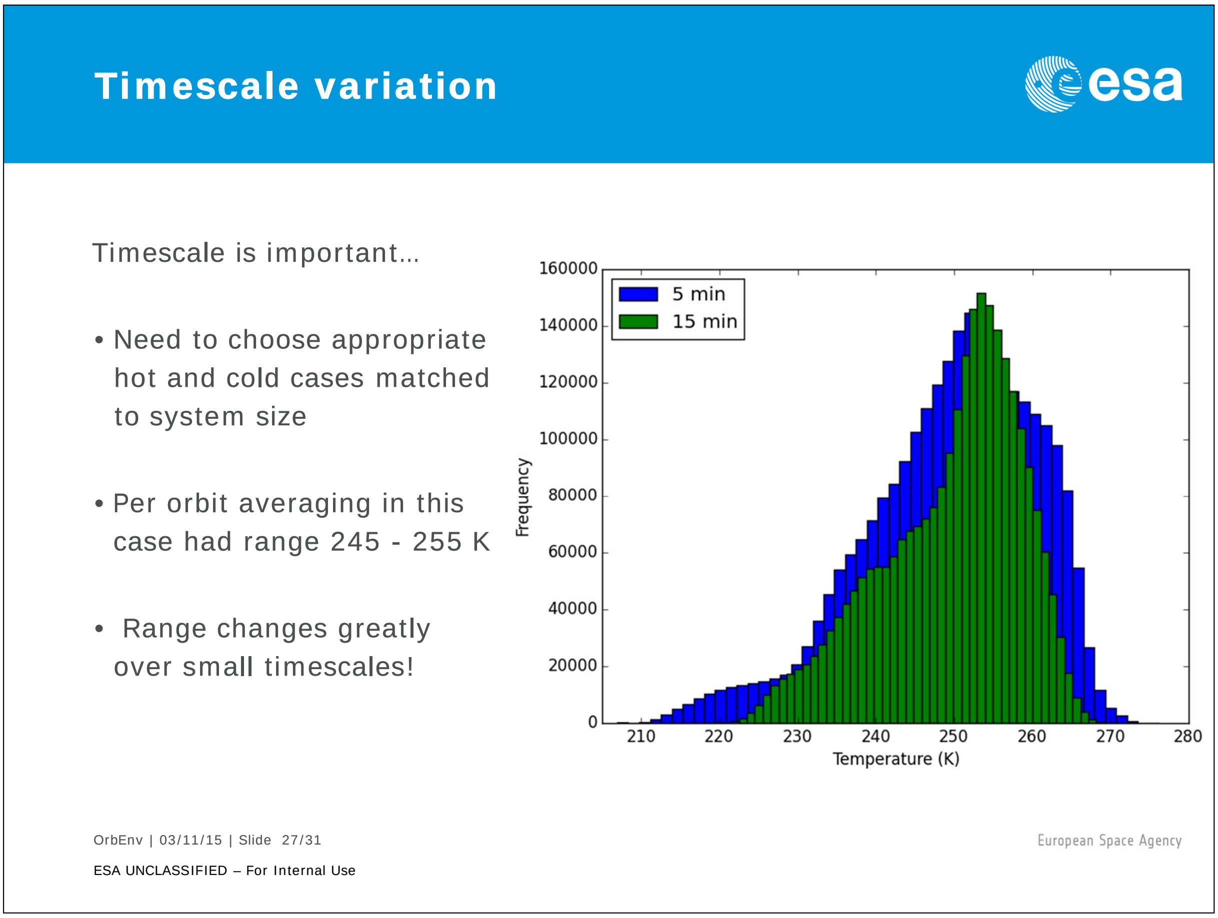
The range of effective albedo averaged over one orbit is observed to vary between 0.24 and 0.41. We can see that the normal range of 0.2 - 0.4 would perhaps be a little too conservative in the cold case.



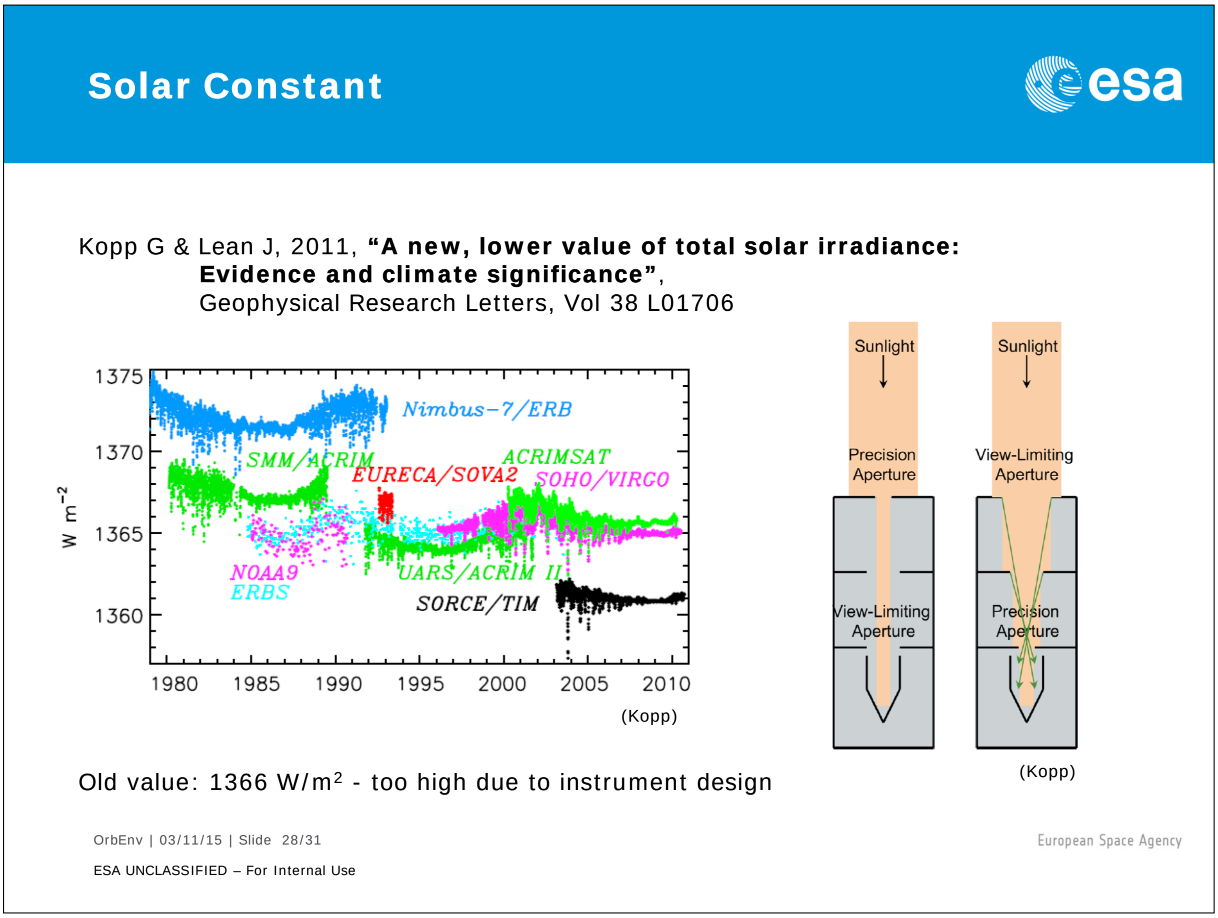
For IR emission the effective surface temperature varies between 246 and 256 K.



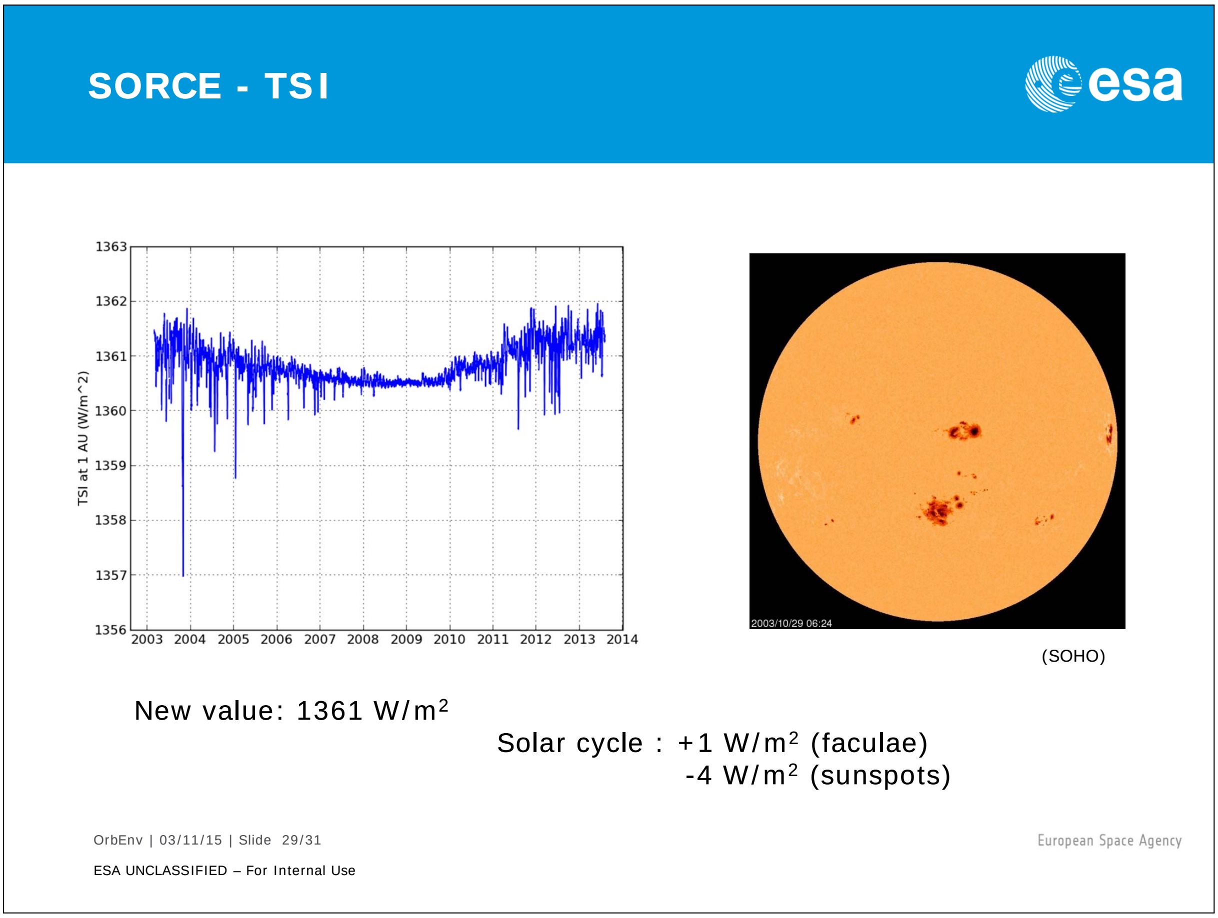
The results so far have shown effective surface parameters when averaged over a single orbit. The model can also output the instantaneous albedo/IR heating received by the spacecraft, and perform averaging over different timescales.



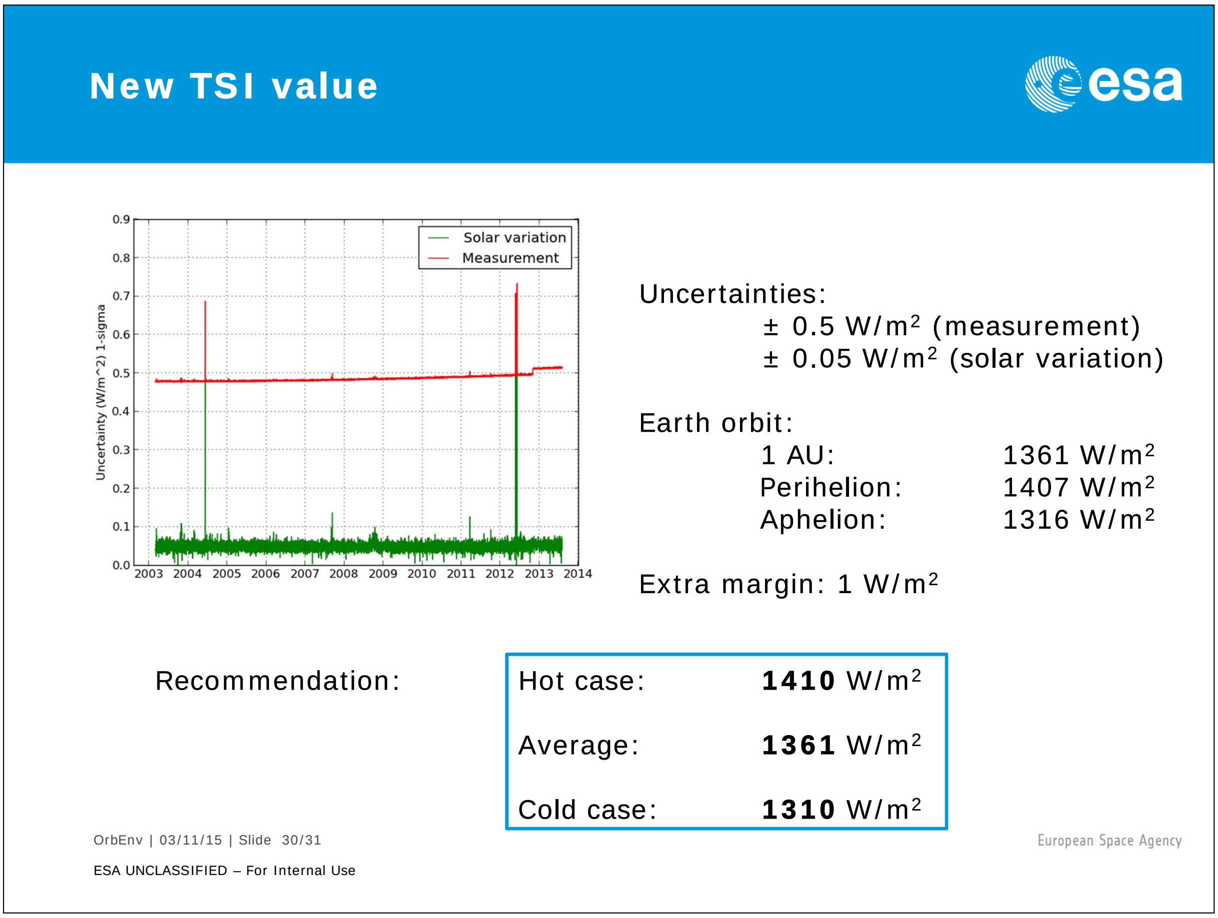
It can be seen that the variations are much greater when averaged over smaller timescales.



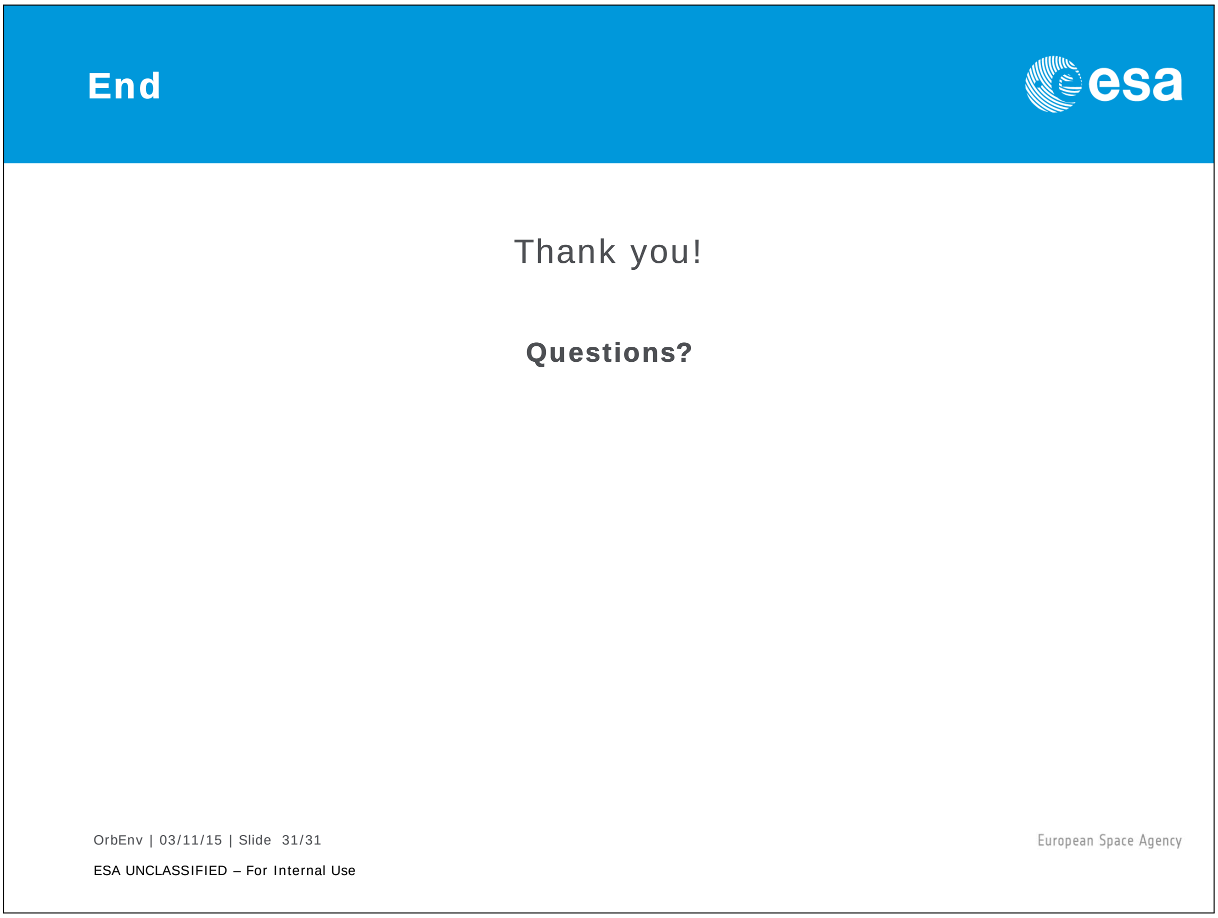
In addition to albedo and planetary IR, the other major parameter of the orbital thermal environment is direct solar heating. In recent years the value of solar "constant" has been questioned due to new measurements. The commonly employed, old values of solar irradiance appear to be in error due to scattering and diffraction internal to the instruments used.



The Total Irradiance Monitor on NASA's SOlar Radiation and Climate Experiment satellite measures the Total Solar Irradiance much more accurately and gives a new lower figure. This value is now accepted by climate scientists and is recommended in the latest report from the United Nations Intergovernmental Panel on Climate Change.



When taking into account Earth's orbit, the solar cycle, and the uncertainties, then new values of solar heating for hot and cold cases are recommended for a spacecraft in orbit around the Earth.



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