Appendix O

Implementation of the Equation of Time in Sun Synchronous Orbit Modelling and ESARAD Planet Temperature Mapping Error at the Poles

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Abstract

The Equation of Time describes the change of the solar reference vector causing a virtual sun movement (i.e. noon point) due to orbital effects. This has effects on the difference between True and Mean Local Solar Time causing inaccuracies of up to 16 minutes Local Solar Time or $\backsim 4^\circ$ of Ω (RAAN).
In the course of the MIPAS instrument thermal analysis (ENVISAT Mission Extension) it showed how important it is to know the exact angle of the Solar Vector because it had to be assessed if optical components inside of baffles and radiators have solar incidence, due to the degraded ENVISAT orbit. For this reason the Equation of Time had to be considered. It showed that the thermal software did not consider this virtual sun movement. For this reason a workaround had to be established considering the date dependant Equation of Time and the resulting difference between Mean and True Local Solar Time. In the course of the presentation the Equation of Time will be explained, as well as the mission related problems caused by the non-consideration of the EoT. The workaround will be presented, related to the different thermal software tools THERMICA and ESARAD.
Additionally to this issue a problem will be presented related to mapping of planet temperature and its effect on sun synchronous dawn/dusk orbits. Due to the variation of distance between longitudes from pole to pole and the circular pole elements, the planet temperatures are mapped to varying element surfaces, causing erroneous flux variations along a dawn/dusk orbit with a local minimum at the poles. This problem will be presented accompanied with the workaround to minimize the flux error.

Implementation of the Equation of Time in Sun-Synchronous Orbit Modelling

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Overview

- Implementation of the Equation of Time in Sun-Synchronous Orbit Modelling
  - The Equation of Time and Analemma
  - The MIPAS Mission Analysis Specifics (Importance of an accurate Local Solar Time)
  - Workaround to implement the Equation of Time in current Thermal Software

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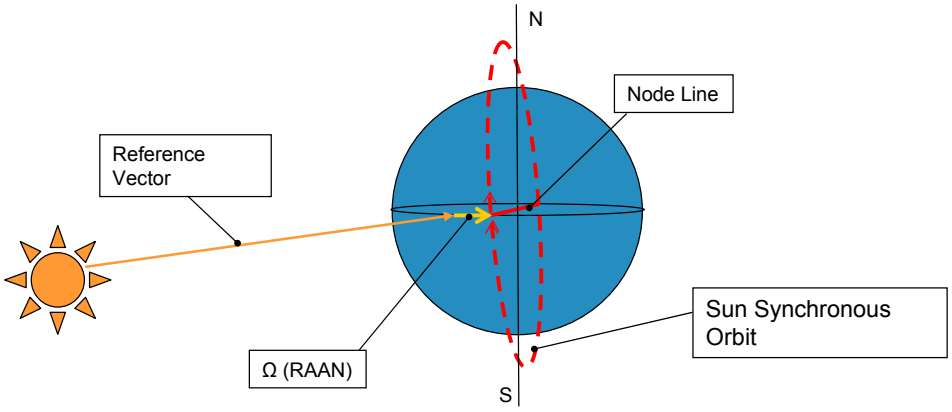
Implementation of the Equation of Time in Sun-Synchronous Orbit Modelling

- The Equation of Time
  - Describes the virtual sun movement concerning the Solar Reference Vector
  - Reference Vector is not constant due to physical effects
  - Shifting of the Reference Vector around a Mean Reference Vector
  - Causes difference between True Local Solar Time and Mean Local Solar Time



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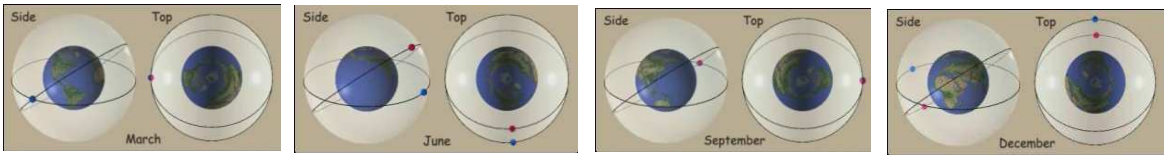
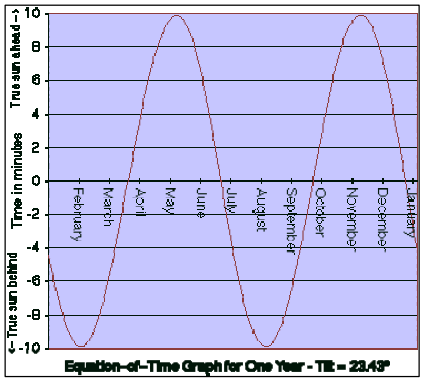
Implementation of the Equation of Time in Sun-Synchronous Orbit Modelling

- The Equation of Time
  - Effects causing the Equation of Time:
    - Varying Solar Declination over the Year





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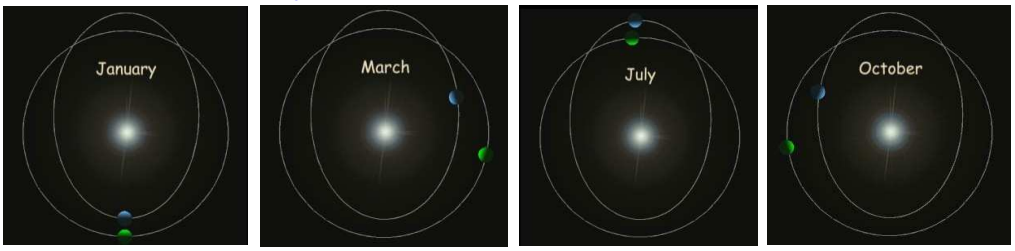
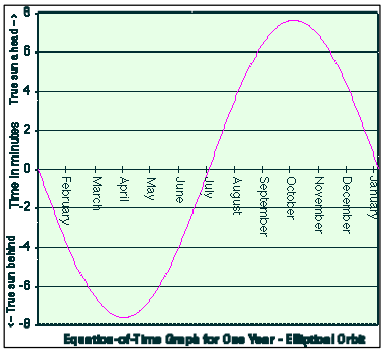
Implementation of the Equation of Time in Sun-Synchronous Orbit Modelling

- The Equation of Time
  - Effects causing the Equation of Time:
    - Eccentricity of Earths Orbit around the Sun



- Mean Sun (Circular Earth-Orbit around the Sun)
- True Sun (Elliptic Earth-Orbit around the Sun)



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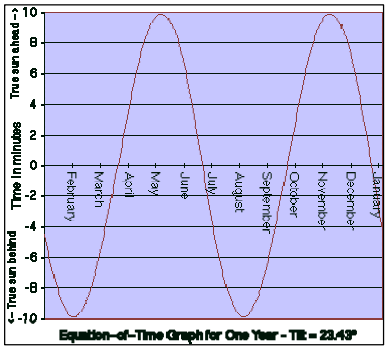
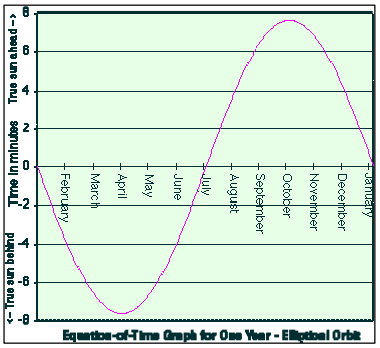
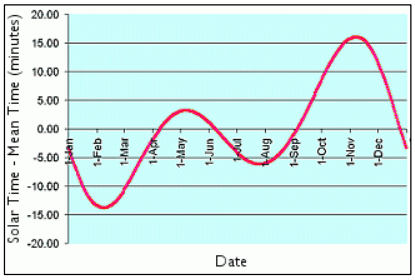
Implementation of the Equation of Time in Sun-Synchronous Orbit Modelling

- Impact on Local Solar Time
  - Causes Differences between Mean and True Local Solar Time (Up to 16 minutes of Local Solar Time – Corresponds to about 4° in Beta-Angle)







$$E = 9.87\sin(2B) - 7.53\cos(B) - 1.5\sin(B)$$

with:

$$B = 2\pi(N - 81)/364$$

N = Days (1.Jan. = 1)

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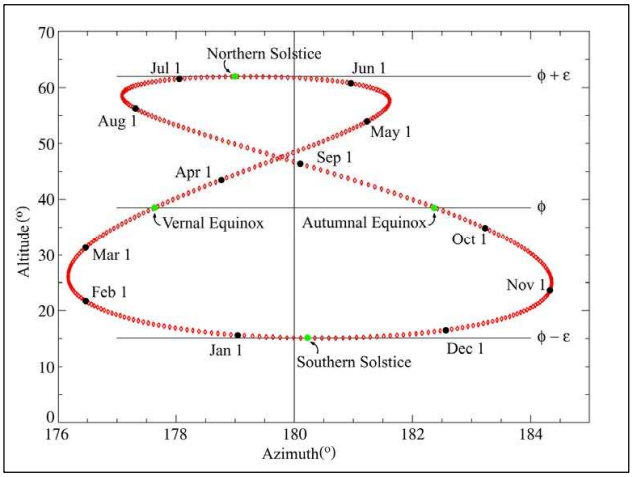
Implementation of the Equation of Time in Sun-Synchronous Orbit Modelling

- The Analemma
  - Caused by the Equation of Time
  - Describes the movement of a virtual position of the sun at one certain time of day
  - Solar Reference Vector (i.e. Noon Point) changes thus over the Year:



12:00 Analemma (Source: Greenwich Observatory)

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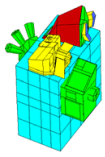
Implementation of the Equation of Time in Sun-Synchronous Orbit Modelling

- The MIPAS Mission Analysis Specifics



  - ENVISAT Mission Extension (Analysis of the Impact of the Degraded Orbit)
    - ENVISAT Mission Extension Scenario comprises modification of orbit altitude
    - Loss of Altitude causes turning of Nodeline of the Sun-Synchronous ENVISAT Orbit
    - Turning of Nodeline causes Change of Local Solar Time
      - Originally MLST 22:00 hrs Ascending Node
      - Worst Case + 10 minutes (22:10 LST)
  - Analysis to determine Impact of worst case Local Solar Time on Baffles and Radiators
    - Incident Solar Flux on Optical Components ?
    - Major Temperature Raise on Radiators?
  - For this Analysis the use of the exact Angle of the Sun to the Satellite is essential!
  - Analysis was decided to do with an existing and running Thermal Model to save effort
  - Results based on used Thermal Software Version do not consider Equation of Time
  - Consideration of a constant Local Solar Time over the year (Corresponding to MLST – Not Realistic)
  - Error was confirmed by means of Beta-Angle check at the Equinoxes
  - Error caused by constant coupling between Solar Reference Vector and Nodeline

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Implementation of the Equation of Time in Sun-Synchronous Orbit Modelling

- Workaround to implement the Equation of Time in current Thermal Software:
  - THERMICA:
    - Mission Modelling of THERMICA considers Solar System Physicality (Date Dependant Sun / Earth Positions and attitudes)
    - Definition of Date changes automatically Orbital Parameters (Solar Declination, Solar Constant, etc…)
    - Implementation of Season Dependant True Local Solar Time into the Software is thus possible by means of decoupling the Solar Reference Vector of the Nodeline
    - Only MLST would have to be supplied, Equation of Time is calculated by Software depending on Date
    - Until Implementation of Equation of Time in Software: Workaround as in ESARAD
  - ESARAD:
    - No automatic Change of Orbit Parameters with Season Change is considered (“Snapshot” Mission Modelling), all Parameters have to be supplied for specific Date
    - Direct manual implementation of True Local Solar Time (Ω)
    - Utilisation of a table showing Date dependant True Local Solar Time based on Mean Local Solar Time and Equation of Time

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Implementation of the Equation of Time in Sun-Synchronous Orbit Modelling

- Workaround Table
  - Date Dependant True Local Solar Time (MLST + EoT)

Mean Local Solar Time: 22:10			$E = 9.87\sin(2B) - 7.53\cos(B) - 1.5\sin(B)$ $B = 2\pi(N-81)/364$			
Date	Day (N)	B	EoT (min)	Real True Local Solar Time (min)	EoT (h)	Real True Local Solar Time (h)
1.1.08	1	-1.381	-3.607	22:06	-0.060	22.1066
2.1.08	2	-1.364	-4.054	22:05	-0.068	22.0991
3.1.08	3	-1.346	-4.496	22:05	-0.075	22.0917
4.1.08	4	-1.329	-4.932	22:05	-0.082	22.0845
5.1.08	5	-1.312	-5.364	22:04	-0.089	22.0773
6.1.08	6	-1.295	-5.789	22:04	-0.096	22.0702
7.1.08	7	-1.277	-6.208	22:03	-0.103	22.0632
8.1.08	8	-1.260	-6.620	22:03	-0.110	22.0563
9.1.08	9	-1.243	-7.025	22:02	-0.117	22.0496
10.1.08	10	-1.226	-7.423	22:02	-0.124	22.0430
11.1.08	11	-1.208	-7.813	22:02	-0.130	22.0365
12.1.08	12	-1.191	-8.194	22:01	-0.137	22.0301
13.1.08	13	-1.174	-8.567	22:01	-0.143	22.0239
14.1.08	14	-1.157	-8.932	22:01	-0.149	22.0178
15.1.08	15	-1.139	-9.287	22:00	-0.155	22.0119
16.1.08	16	-1.122	-9.632	22:00	-0.161	22.0061
17.1.08	17	-1.105	-9.968	22:00	-0.166	22.0005
18.1.08	18	-1.087	-10.294	21:59	-0.172	21.9951
19.1.08	19	-1.070	-10.610	21:59	-0.177	21.9898
20.1.08	20	-1.053	-10.914	21:59	-0.182	21.9848
21.1.08	21	-1.036	-11.208	21:58	-0.187	21.9799
22.1.08	22	-1.018	-11.491	21:58	-0.192	21.9751
23.1.08	23	-1.001	-11.763	21:58	-0.196	21.9706
24.1.08	24	-0.984	-12.023	21:57	-0.200	21.9663
25.1.08	25	-0.967	-12.272	21:57	-0.205	21.9621

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Conclusion

- For certain Mission Profiles the exact Angle to the Sun is essential to be modelled
- Equation of Time is not considered in used Thermal Software versions, due to constant coupling between Solar Reference Vector and Nodeline over the Year
- EoT – Error was confirmed by checking the THERMICA generated Beta-Angle at the Equinoxes and comparing it to the hand-calculated Beta-Angle considering all Date dependant orbit data including the EoT
- In THERMICA an implementation of the EoT should be feasible due to the consideration of Solar System Physicality by decoupling the Solar Reference Vector from the Nodeline
- For ESARAD due to “Snapshot” Modelling of the Mission, the True Local Solar Time has to be provided for the specific Date to be taken for the Load Case (using EXCEL-Table)
- Workaround accuracy was checked by Beta-Angle comparison between the THERMICA generated Beta-Angle and the hand-calculated Beta-Angle for each Load Case based on orbit data (EXCEL-Table with Date dependant Solar Declination and Equation of Time resulting in the Date dependant Beta-Angle)
- MIPAS Analysis Experience showed Importance of Maintenance of a Thermal Model throughout the Mission

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Sources

- Greenwich Observatory Homepage (Status: 07/2008)
  - http://www.nmm.ac.uk/server/show/conWebDoc.351
- www.analemma.com (Status: 07/2008)
- MIPAS Mission Document

ESARAD Planet Temperature Mapping Error at the Poles

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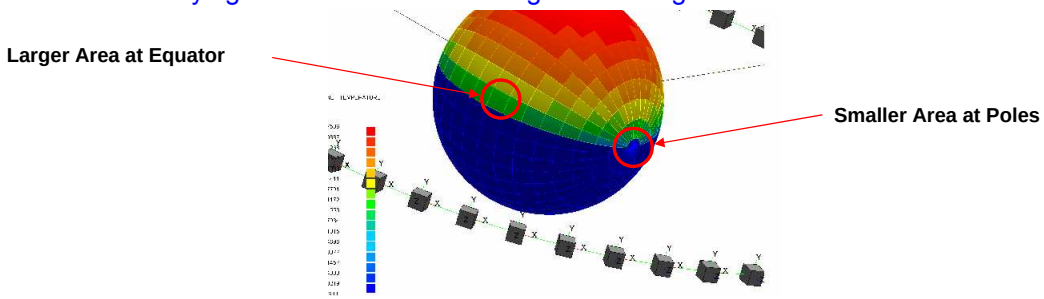
Planet Temperature Mapping Error at the Poles

- Planet Temperature Mapping Error at the Poles
  - planet_temperature_method = "CALCULATED„
    - Cold Side of the Planet is User Defined
    - ESARAD calculates the Temperature on Hot Side automatically based on User Information
    - Temperatures are assessed on Latitude and Longitude Intersections and interpolated on Intersection Areas
  - Problem
    - Varying Distances between Longitudes along Latitudes



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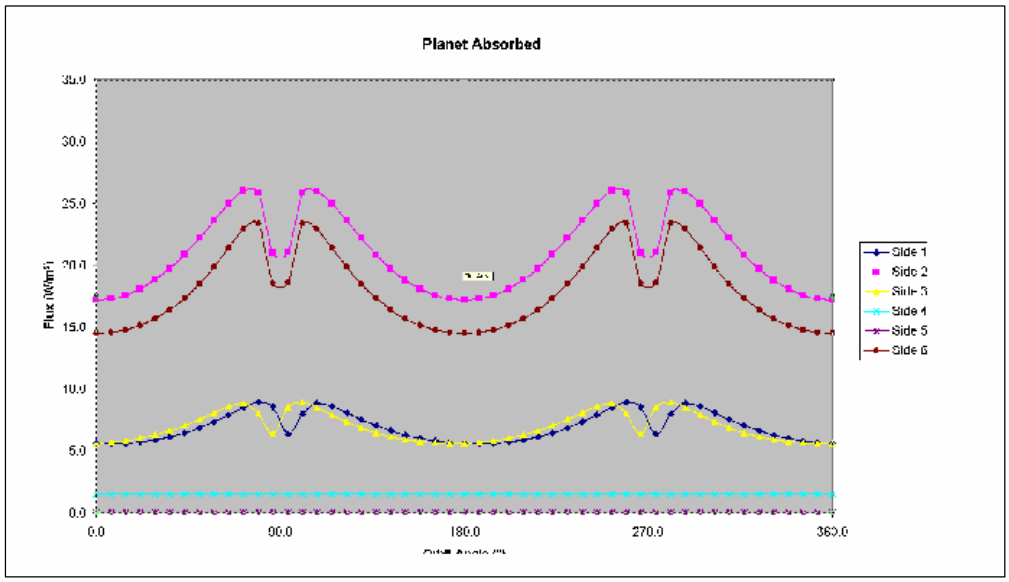
Planet Temperature Mapping Error at the Poles

- Results in incorrect Representation of Planet Fluxes, particularly at the Poles
- For a 6:00/18:00 Orbit (Dawn/Dusk) the Fluxes should be constant



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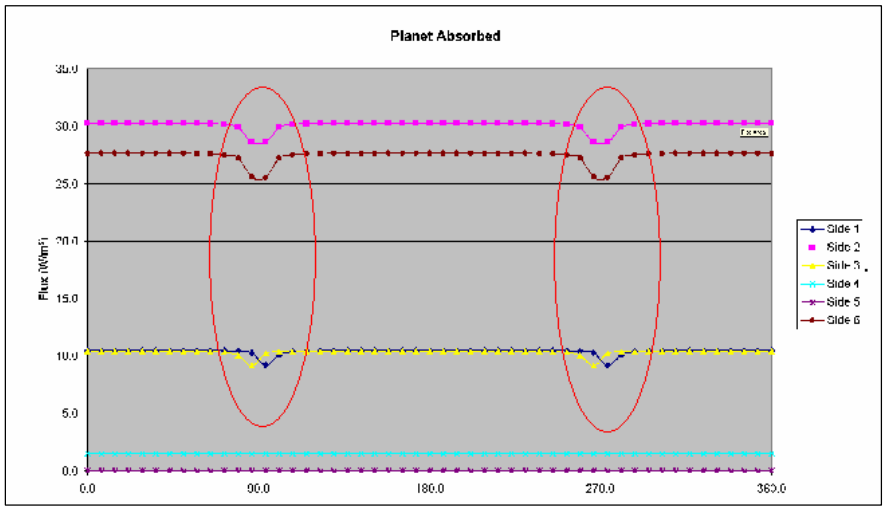
Planet Temperature Mapping Error at the Poles

- Results are more accurate when increasing the Latitude/Longitude Resolution
  - Recommended Resolution : 181 Latitudes and 360 Longitudes
    - Odd number of Latitudes in order to have a Sub-Solar Point at Cell Intersection to consider maximum Temperature



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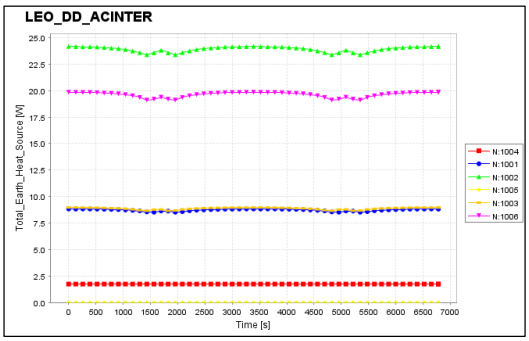
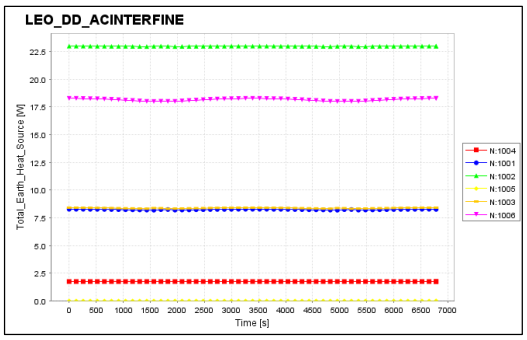
Planet Temperature Mapping Error at the Poles

- Interpolation Routine has been improved for next ESARAD Version

50000m, 90 deg Inclination, RA 90 deg, interpolate temperatures = TRUE - **[LATEST RESULTS]**



Coarse mesh: 19 lat x 36 long mesh



Fine mesh 73 lat x 720 long mesh