Appendix S

Dynamic Thermal Spacecraft Simulator based on nodal mathematical model

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(Thales Alenia Space, France)

François Brunetti
(Dorea, France)

Abstract

To improve the quality and reliability of the dynamic spacecraft simulator, Thales Alenia Space Cannes asked DOREA to implement the thermal real-time simulator based on the thermal mathematical model (TMM) provided by thermal analysis team.
Both SYSTEMA/Thermisol (from EADS Astrium) and ETHERM (from Thales Alenia Space) nodal models have been converted and integrated into a new DSS product line called SCSIM (SpaceCraft SIMulator). A set of ESA tools were used in an industrial context to solve this technical challenge: reduction tool TMRT (without reduction) has been used to convert TMM from SYSTEMA/Thermisol nodal definition; STEP-TAS and TASverter to convert geometrical model from THERMICA and thermal post processing tool ESATAP for thermal model comparison and debugging.
Ray-tracing calculator and temperatures resolution from internal ETHERM core module (former CORATHERM) have been successfully improved to fit the real-time constraints. Parallelisation has been largely used to make the calculation most reactive in order to fit as much as possible the physics behaviour.
New SCSIM based on TMM has been successfully validated on Alphasat (@bus platform) and O3B Networks satellite.


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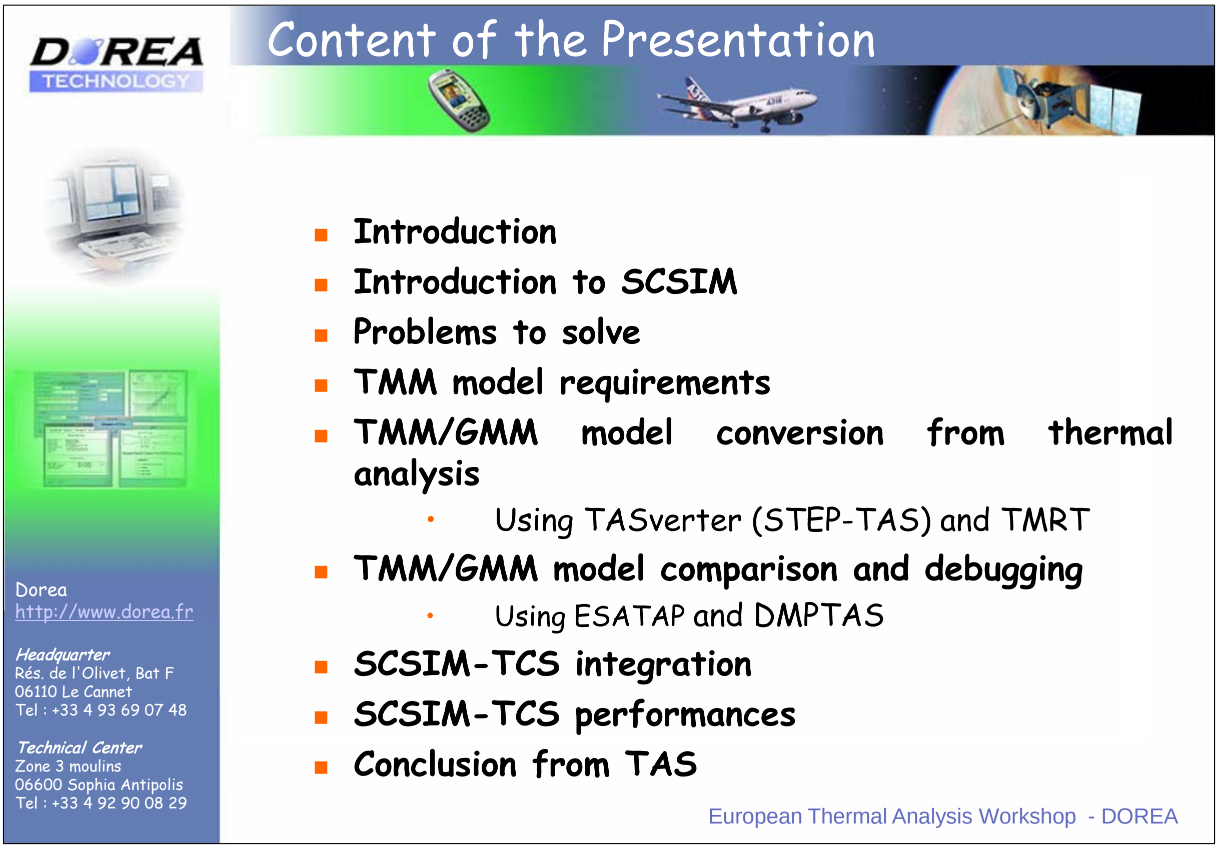
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Content of the Presentation
Introduction
Introduction to SCSIM
Problems to solve
TMM model requirements
TMM/GMM model conversion from thermal analysis
Using TASverter (STEP-TAS) and TMRT
TMM/GMM model comparison and debugging
Using ESATAP and DMPTAS
SCSIM-TCS integration
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Conclusion from TAS
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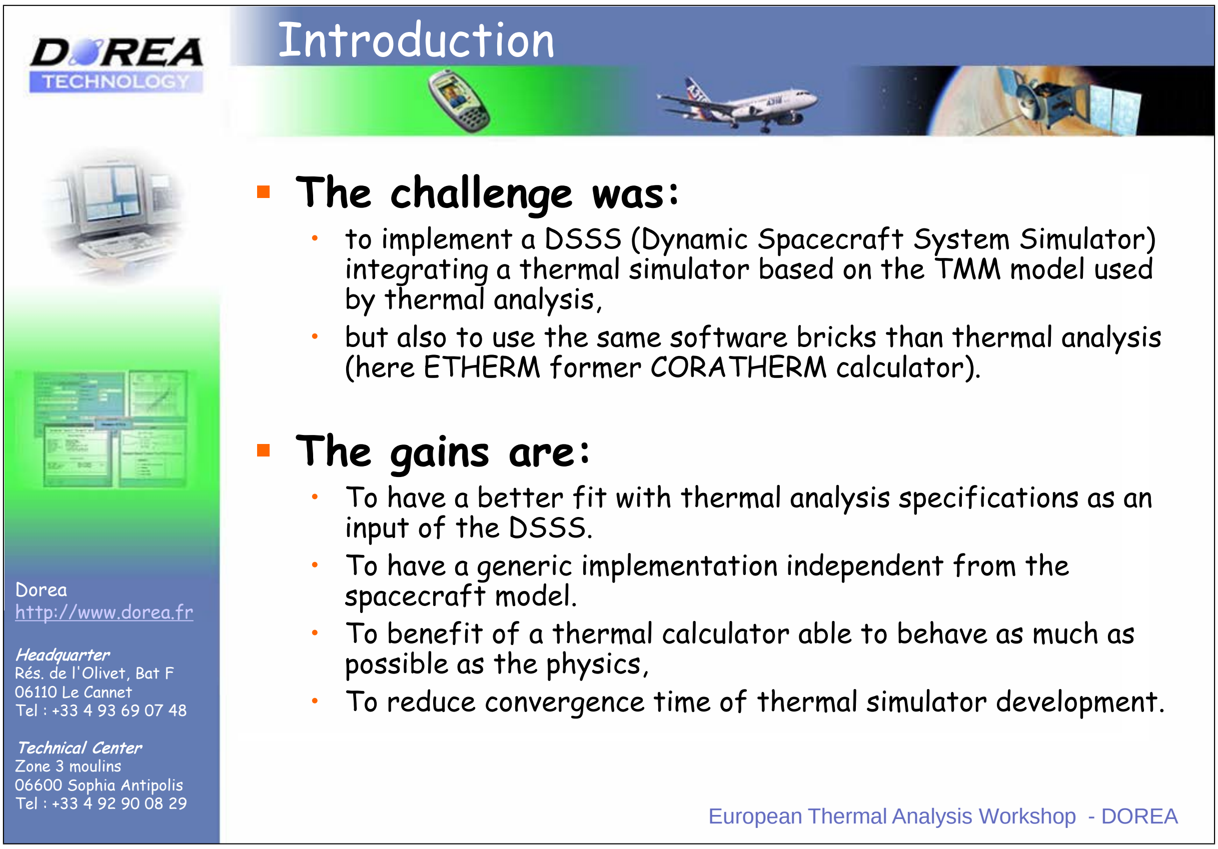
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Introduction
The challenge was:
to implement a DSSS (Dynamic Spacecraft System Simulator) integrating a thermal simulator based on the TMM model used by thermal analysis,
but also to use the same software bricks than thermal analysis (here ETHERM former CORATHERM calculator).
The gains are:
To have a better fit with thermal analysis specifications as an input of the DSSS.
To have a generic implementation independent from the spacecraft model.
To benefit of a thermal calculator able to behave as much as possible as the physics,
To reduce convergence time of thermal simulator development.
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SCSIM Simulation Platform
Template reference : 100182079N-EN
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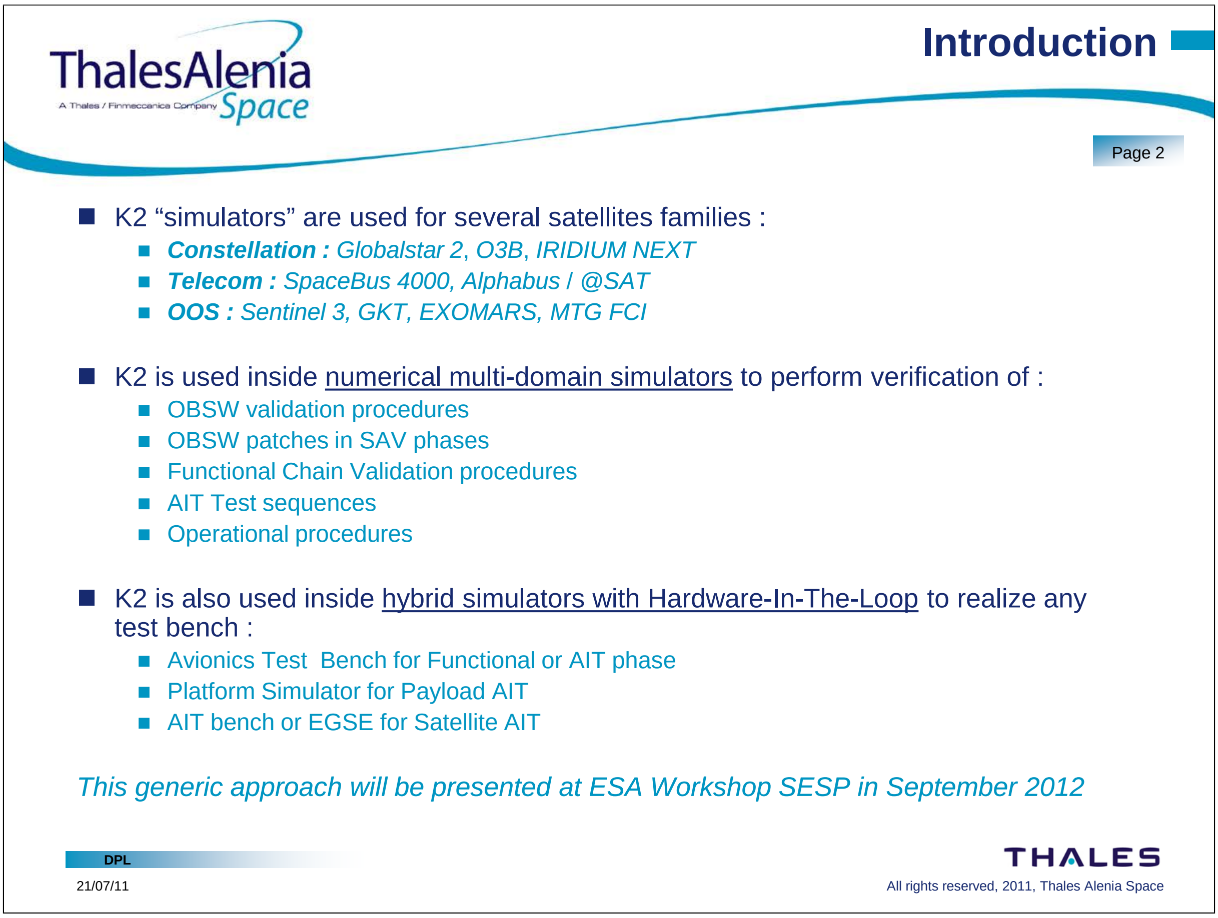
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Introduction
Page 2
K2 “simulators” are used for several satellites families :
Constellation : Globalstar 2, O3B, IRIDIUM NEXT
Telecom : SpaceBus 4000, Alphabus / @SAT
OOS : Sentinel 3, GKT, EXOMARS, MTG FCI
K2 is used inside numerical multi-domain simulators to perform verification of :
OBSW validation procedures
OBSW patches in SAV phases
Functional Chain Validation procedures
AIT Test sequences
Operational procedures
K2 is also used inside hybrid simulators with Hardware-In-The-Loop to realize any test bench :
Avionics Test Bench for Functional or AIT phase
Platform Simulator for Payload AIT
AIT bench or EGSE for Satellite AIT
This generic approach will be presented at ESA Workshop SESP in September 2012
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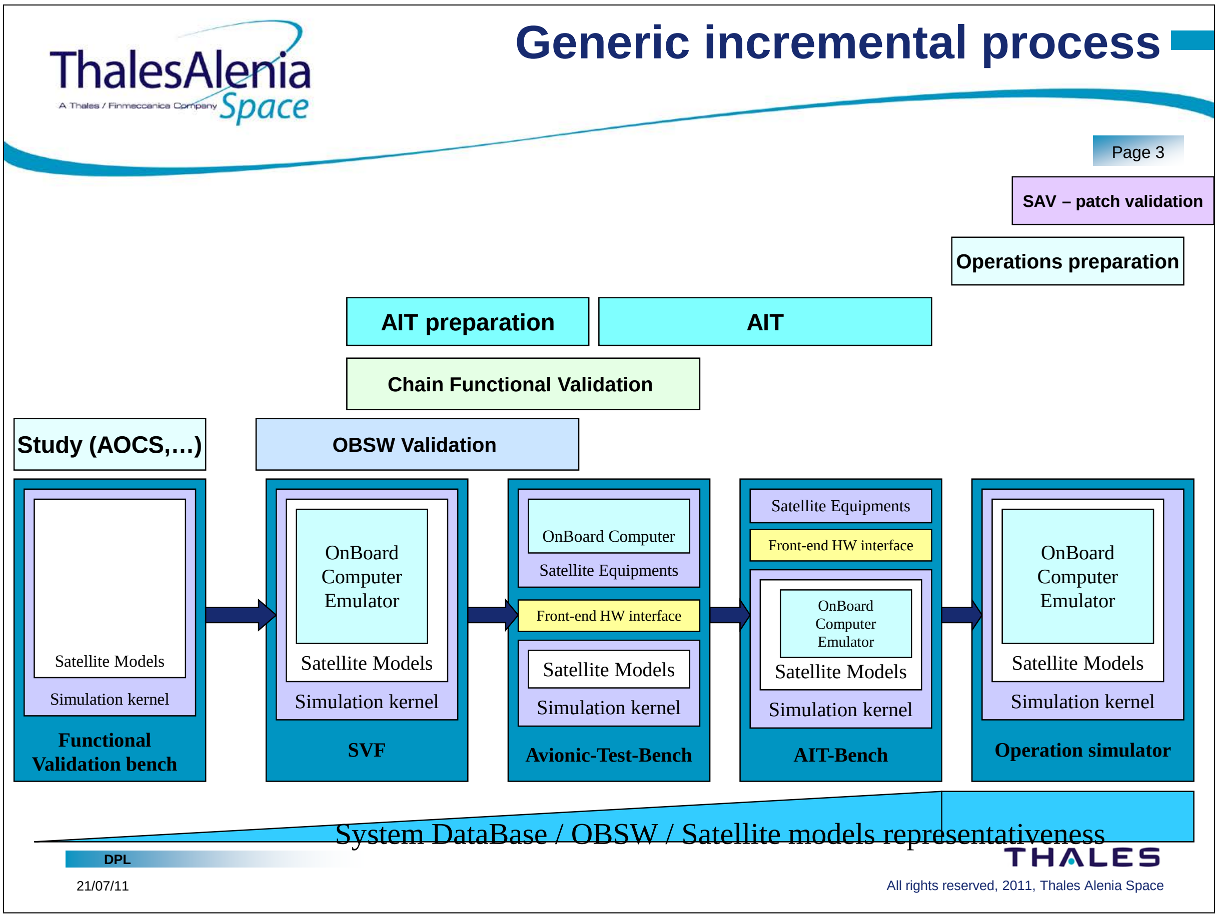

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Generic incremental process
Page 3
SAV – patch validation
Operations preparation
AIT preparation
AIT
Chain Functional Validation
Study (AOCS,…)
OBSW Validation
Satellite Models
Simulation kernel
Functional Validation bench
OnBoard Computer Emulator
Satellite Models
Simulation kernel
SVF
OnBoard Computer
Satellite Equipments
Front-end HW interface
Satellite Models
Simulation kernel
Avionic-Test-Bench
Satellite Equipments
Front-end HW interface
OnBoard Computer Emulator
Satellite Models
Simulation kernel
AIT-Bench
OnBoard Computer Emulator
Satellite Models
Simulation kernel
Operation simulator
System DataBase / OBSW / Satellite models representativeness
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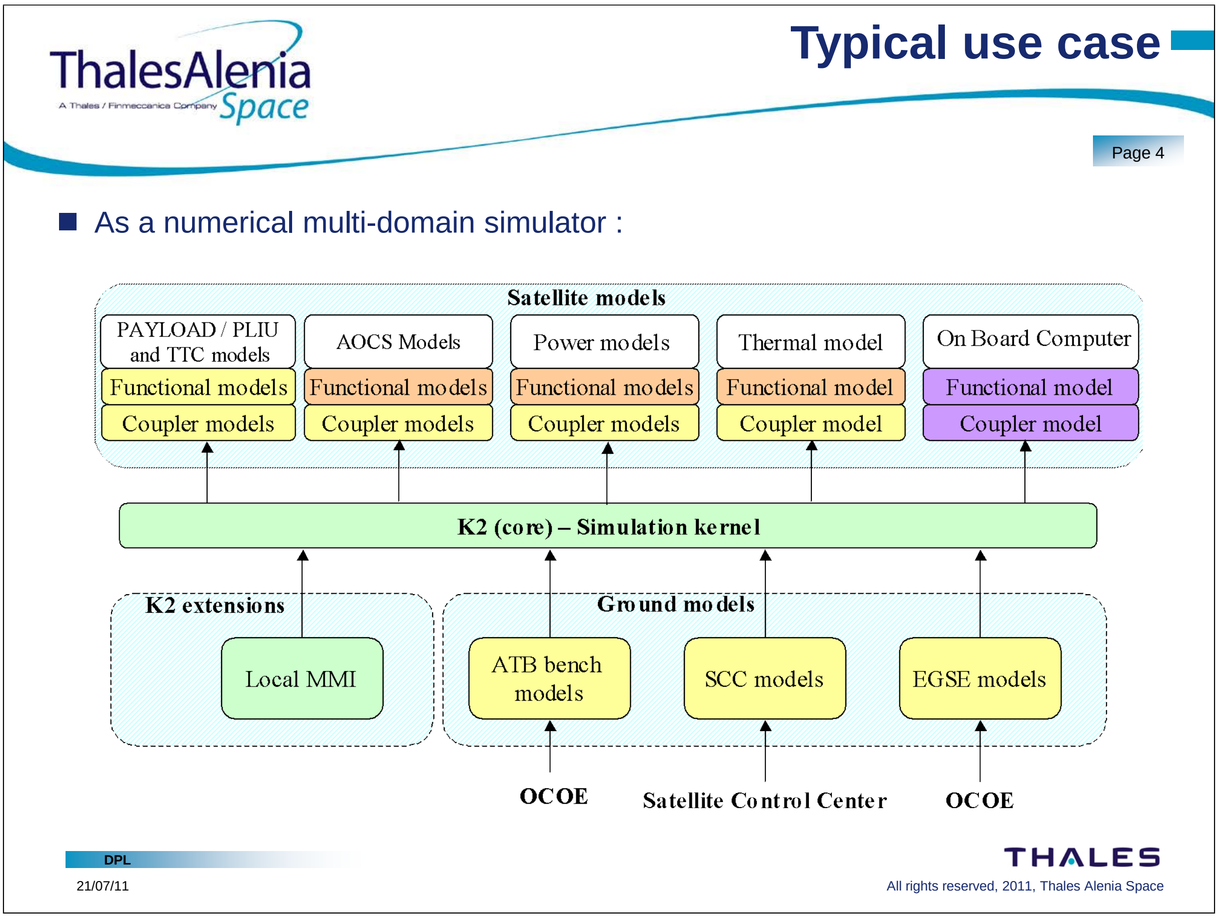

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Typical use case
Page 4
As a numerical multi-domain simulator :
Satellite models
PAYLOAD / PLIU and TTC models
Functional models
Coupler models
AOCS Models
Functional models
Coupler models
Power models
Functional models
Coupler models
Thermal model
Functional model
Coupler model
On Board Computer
Functional model
Coupler model
K2 (core) – Simulation kernel
K2 extensions
Local MMI
Ground models
ATB bench models
SCC models
EGSE models
OCOE
Satellite Control Center
OCOE
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Typical use case

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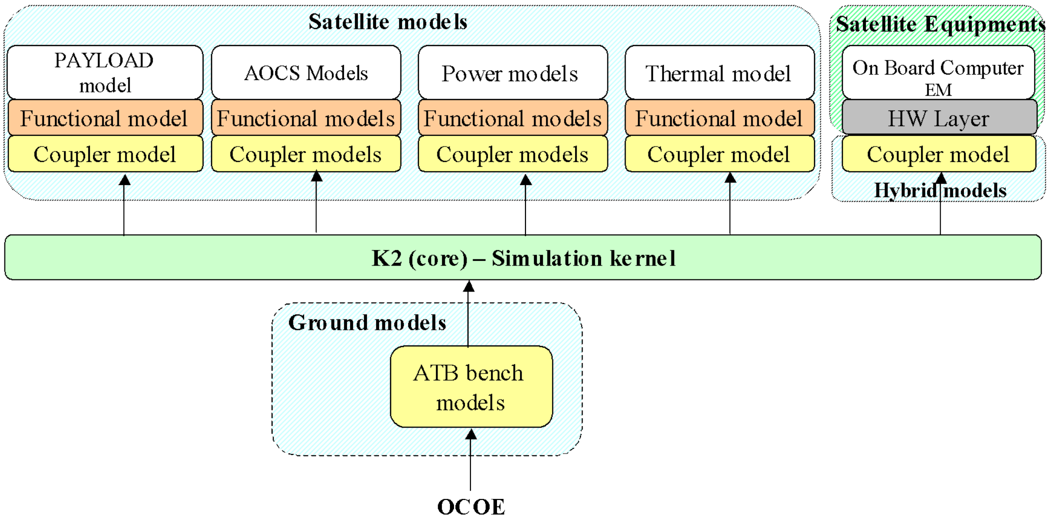
- As a hybrid simulator with real OBC :



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K2 Software Development Kit content

Page 6

Different software of the K2 product line :

- **K2 platform library**
  - API for models development (C++)
  - Integration and test API (python), also known as Control of Test
- **MMI** (Man Machine Interface)
  - Command and control a simulator
  - Optionally add the **daemon** to enhance MMI services and functionalities
- Development assistance (**datassim**) : model template generation, variant (integrated simulator) generation, documentation generation
- Bridges :
  - **lucassim** (data generation from lucile SDB to simulator)
  - **Matlab** (encapsulate Matlab models into K2 platform)
  - **Smp2** (encapsulate SMP2 models into K2 and vice-versa)

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Simulator building

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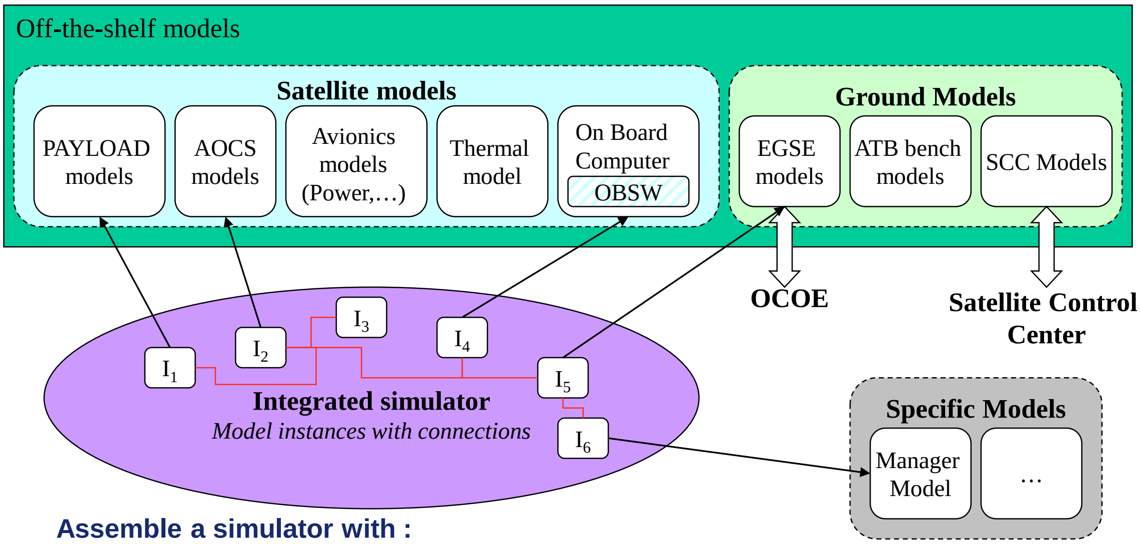

Assemble a simulator with :

- off-the-shelf model instances (ie shared by several programs)
- model instances specific to the program
- connections between model instances

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K2 platform – Core description

Page 8

- The K2 Core platform offers different kind of services
  - **Data exchange** : as shown
  - **Scheduler** : is responsible for the co-ordination and processing of all events within the Simulation Kernel. An event on the schedule identifies an action that needs to be performed at a specified time in simulated time
  - **Time Keeper** : is responsible for maintaining and providing models and the MMI with the correct simulation-Time. It provides time in four formats, Simulation-Time, Epoch-Time, Zulu-Time and Correlated Zulu-Time. this is a family of SIMSAT compatible models enabling a realistic simulations
  - **Data explorer** : is responsible for making the values of both model and Kernel data items available for display in an MMI.

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K2 Components Off-the-shelf

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- K2 simulator target : Linux 64 bits and 32 bits
- MMI target : full java program, can run on JRE 6 supported platform.
- K2 3rdparty components : mostly based on open source software
  - Gcc 4.3.3
  - Python 2.6
  - Swig 1.3
  - Java 6
  - …

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MMI

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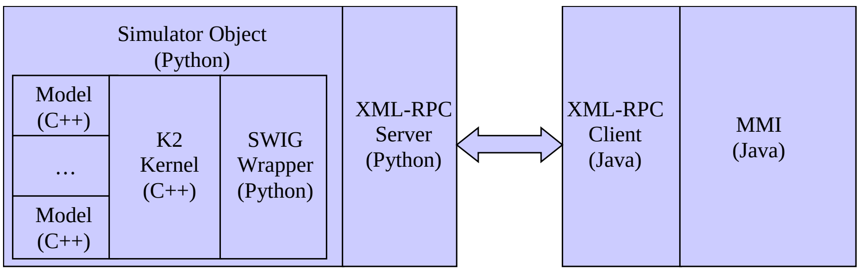
- The Man-Machine Interface (MMI) is the part of the simulation infrastructure that provides the graphical, user-friendly, configurable interface to any simulator.
- Local MMI are in charge of :
  - **initialization**
  - **simulation control**
  - **events activation**
  - **failures activation**
  - **internal variables control**
  - **Satellite Database control and command**
  - **Mimics display**
  - **Graph display**
- Design :



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MMI

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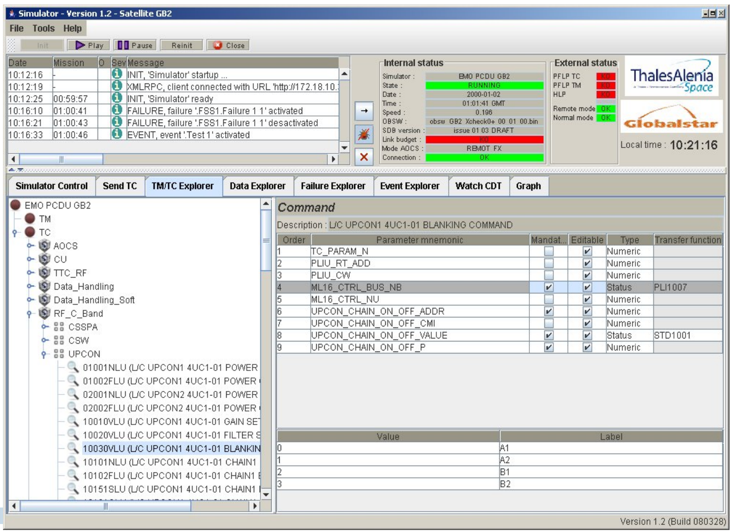
- **The “SDB explorer” panel provides the following features:**
  - Quick access to SDB TM / TC data sorted by subsystem / equipments
  - Perform SDB TC send
  - Perform SDB TM decommutation



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Problems to solve

- **DSSS has to compute in real time:**
  - to take care of equipement powers as input,
  - the solar, albedo and IR earth fluxes depending on the spacecraft attitude,
  - the temperatures based on a static conductive and radiative matrices, updated according to external fluxes,
  - the SA movements.
- **DSSS requirements:**
  - Performances have to be improved, ray tracing and temperatures recalculation based on geometry and nodal model, especially during SHM or spin.
- **TMM and GMM conversion:**
  - TMM models come from THERMISOL, ESATAN and ETHERM
  - GMM models come from ESARAD, THERMICA and ETHERM.

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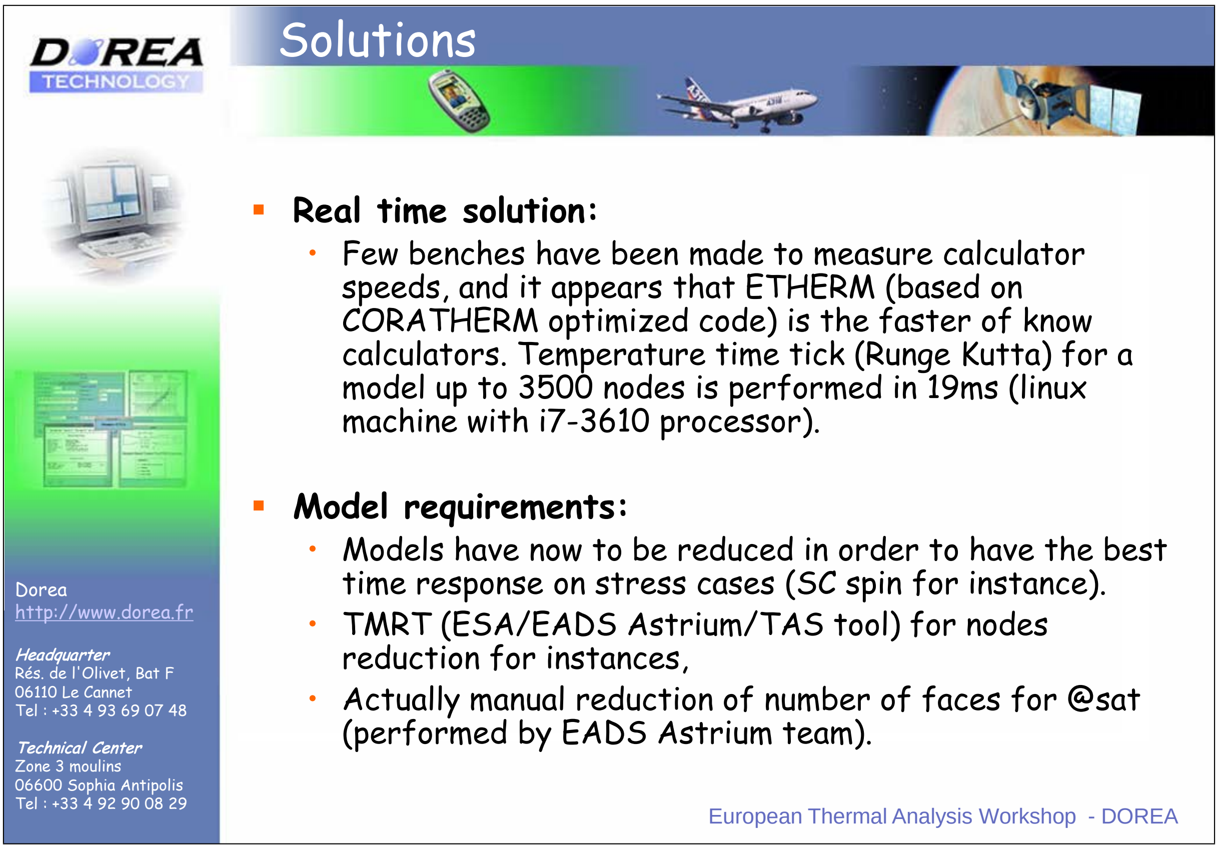
Solutions
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Real time solution:
Few benches have been made to measure calculator speeds, and it appears that ETHERM (based on CORATHERM optimized code) is the faster of know calculators. Temperature time tick (Runge Kutta) for a model up to 3500 nodes is performed in 19ms (linux machine with i7-3610 processor).
Model requirements:
Models have now to be reduced in order to have the best time response on stress cases (SC spin for instance).
TMRT (ESA/EADS Astrium/TAS tool) for nodes reduction for instances,
Actually manual reduction of number of faces for @sat (performed by EADS Astrium team).
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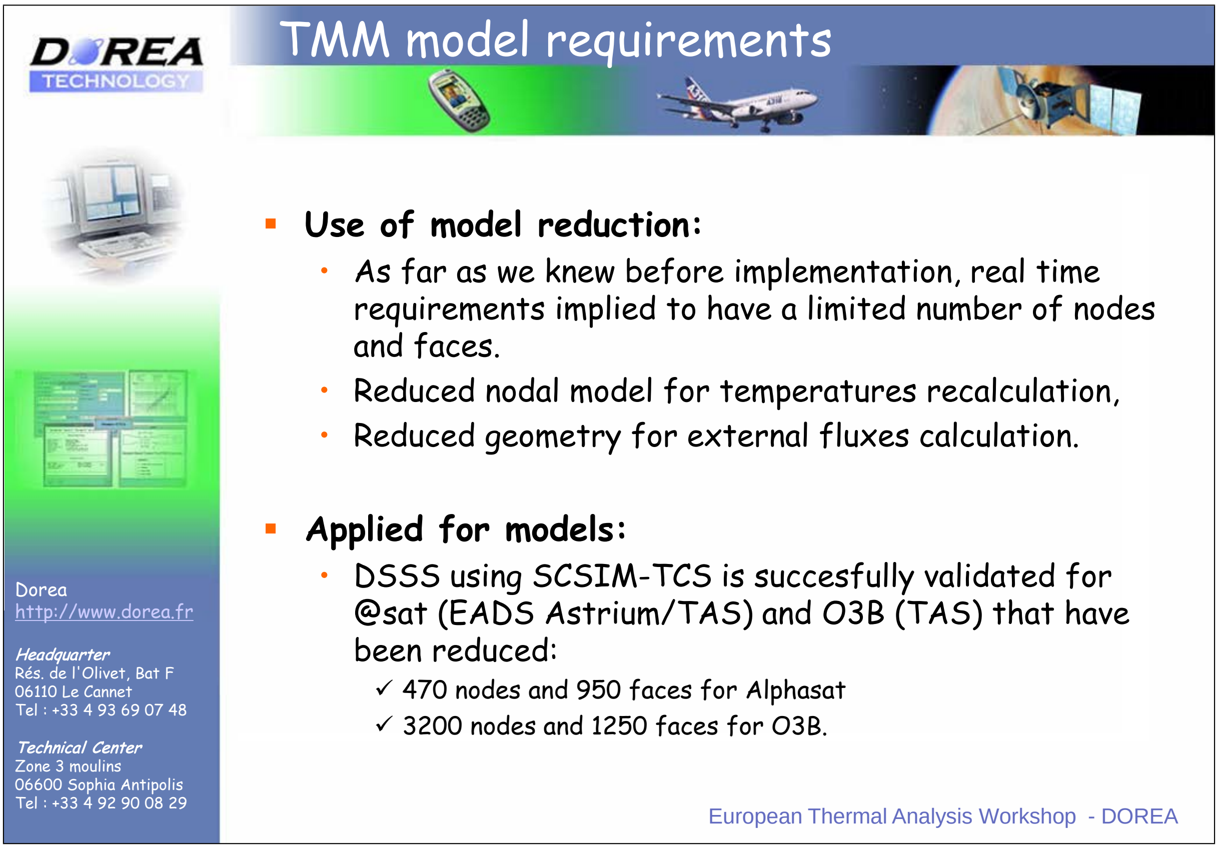
TMM model requirements
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Use of model reduction:
As far as we knew before implementation, real time requirements implied to have a limited number of nodes and faces.
Reduced nodal model for temperatures recalculation,
Reduced geometry for external fluxes calculation.
Applied for models:
DSSS using SCSIM-TCS is succesfully validated for @sat (EADS Astrium/TAS) and O3B (TAS) that have been reduced:
✓ 470 nodes and 950 faces for Alphasat
✓ 3200 nodes and 1250 faces for O3B.
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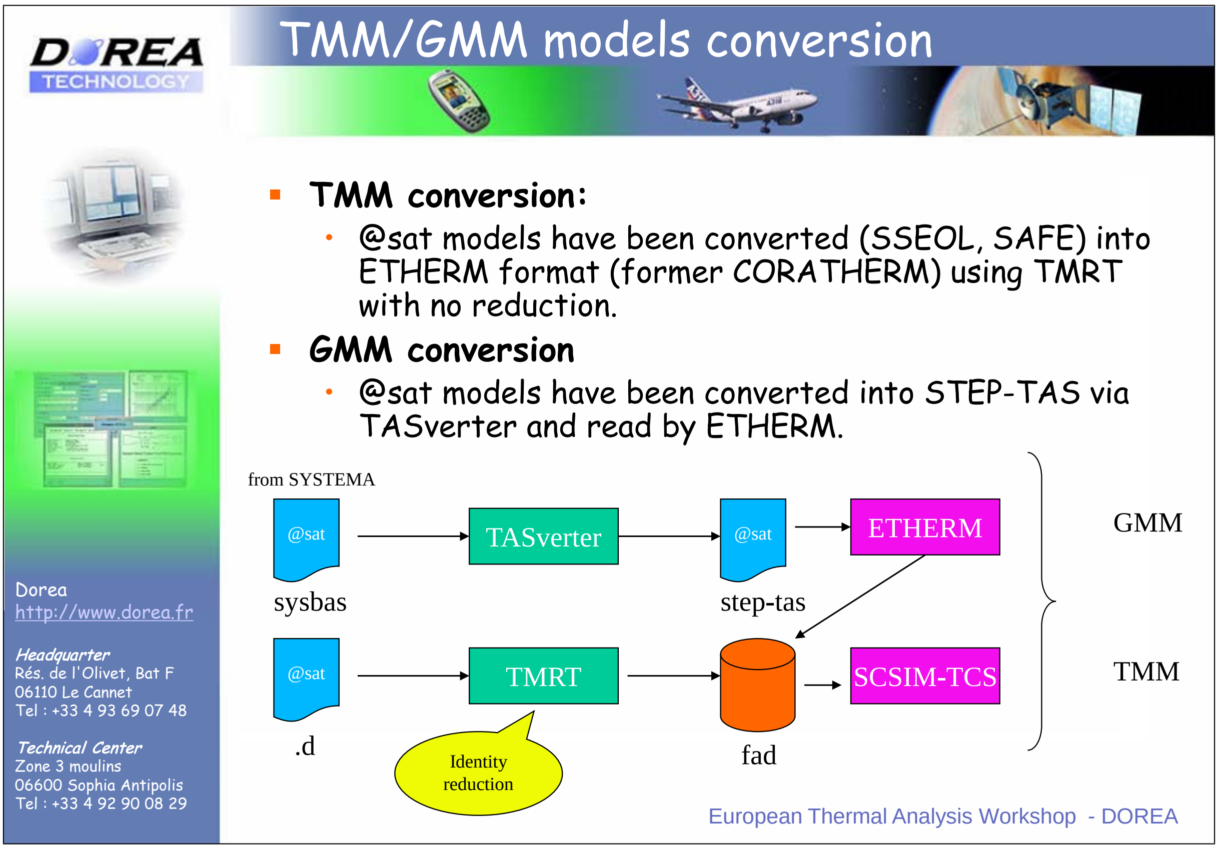
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TMM/GMM models conversion
TMM conversion:
@sat models have been converted (SSEOL, SAFE) into ETHERM format (former CORATHERM) using TMRT with no reduction.
GMM conversion
@sat models have been converted into STEP-TAS via TASverter and read by ETHERM.
from SYSTEMA
@sat
sysbas
TASverter
@sat
step-tas
ETHERM
GMM
@sat
.d
TMRT
Identity reduction
fad
SCSIM-TCS
TMM
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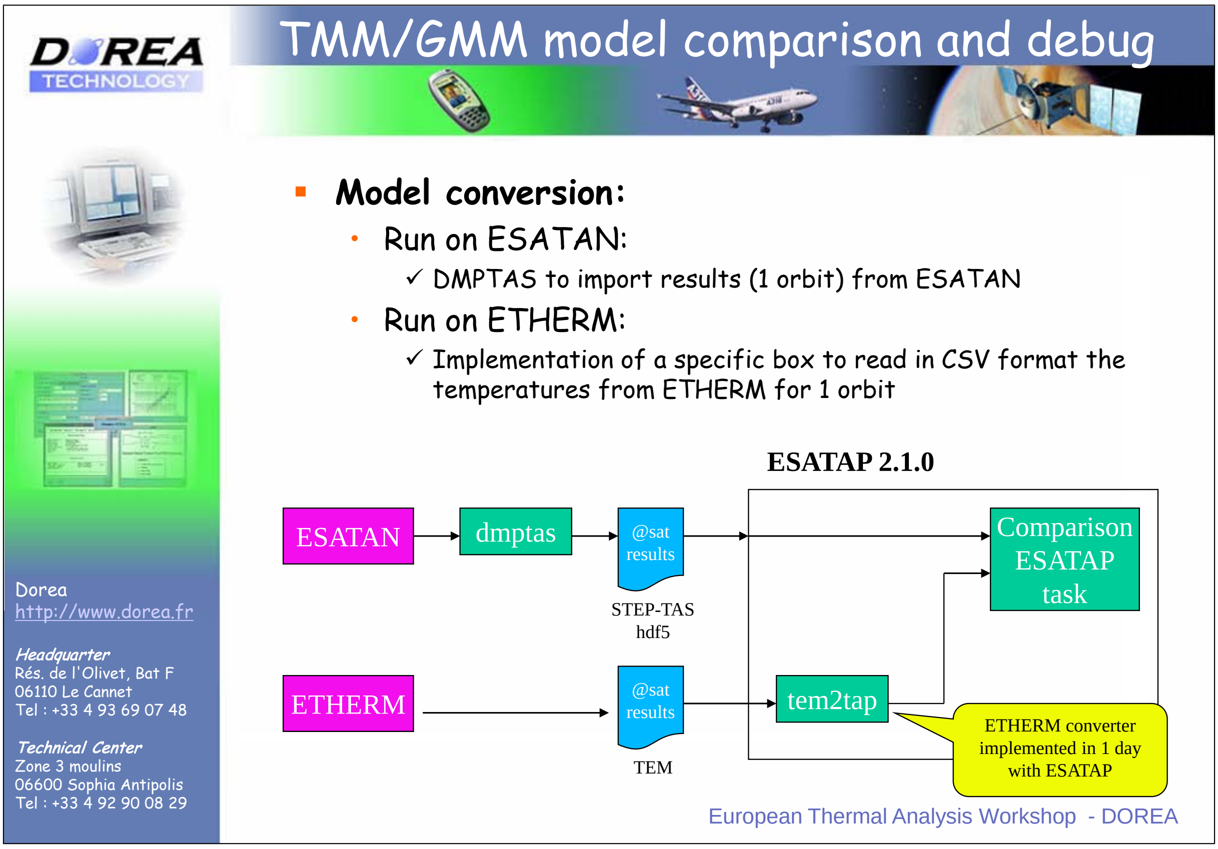
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TMM/GMM model comparison and debug
Model conversion:
Run on ESATAN:
✓ DMPTAS to import results (1 orbit) from ESATAN
Run on ETHERM:
✓ Implementation of a specific box to read in CSV format the temperatures from ETHERM for 1 orbit
ESATAP 2.1.0
ESATAN
dmptas
@sat results
STEP-TAS hdf5
Comparison ESATAP task
ETHERM
@sat results
TEM
tem2tap
ETHERM converter implemented in 1 day with ESATAP
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TMM/GMM model comparison and debug

- **A dedicated ESATAP component and task has been implemented to calculate time constants for each node (formula taken from ETHERM / RPT):**
  - calculated from temperatures, capacitances, GR and GL for each nodes, for model on ESATAN format.

ESATAP =>

- **ESATAP was an asset to:**
  - 1) Reduce temperature calculation time by analysing and tuning the time constants for temperature cycles convergence,
  - 2) Identify the nodes with very small capacitances (near to zero) and fix some capacitances in the original model.

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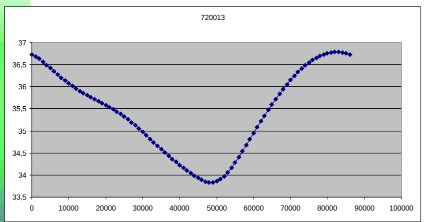
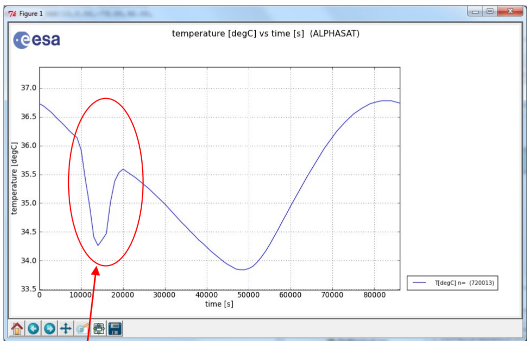
TMM/GMM model comparison and debug

- **Another problem was detected by ESATAP when comparing temperatures on thermistances during 1 orbit:**



from EADS Astrium, node 214



Anomaly

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TMM/GMM model comparison and debug

- **Investigation:**
  - A dedicated ESATAP component has been implemented in order to calculate all the conductive and radiative (internal and external) paths to nodes with powers.
- **Given result after analysis all the leaf nodes that have powers:**
  - A difference is noted for a power (QS) from some external nodes during a short period of time.
  - The decrease of the temperature for these nodes is due to the shadow of the reflector.
  - After having analysed the GMM, we found that transmissivity was not correctly set on the GMM.

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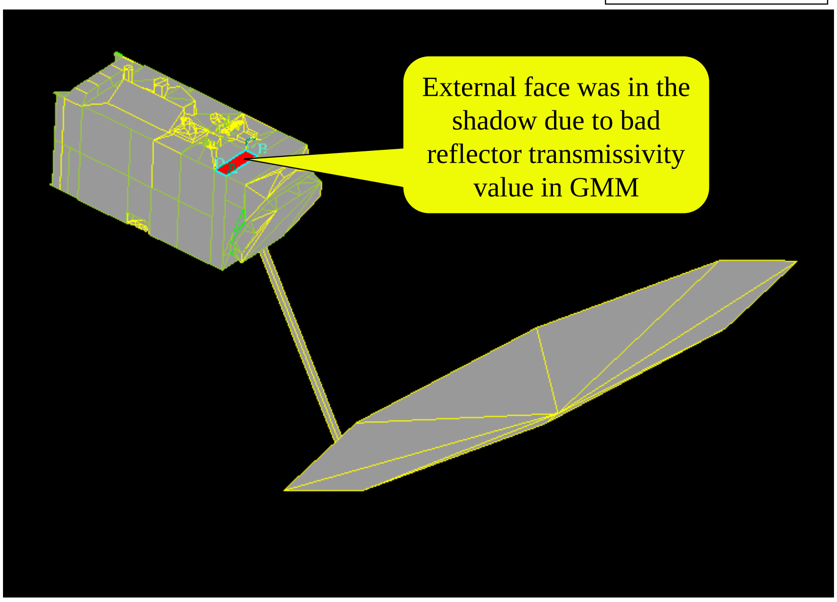
TMM/GMM model comparison and debug

ETHER 3D View



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SCSIM-TCS integration

- **SCSIM-TCS:**
  - Standalone thermal simulator connected via TCP-IP with the SCSIM scheduler,
  - Multi-threading has been largely used for communication process but also to separate external fluxes and temperatures calculations.
- **ETHERM modules integration:**
  - ETHERM 1.3 view surfaces, solar and albeo flux, earth IR calculator (SV) and temperatures calculator (RPT) have been integrated into SCSIM-TCS.
- **Capabilities:**
  - Temperatures recalculation according to equipment power real-time settings (from OBS) including regulation,
  - Solar, earth vector and fluxes handling in real time and thresholds handling,
  - Multi-configurations (new GMM/TMM) is handled and conf switches are taken into account in less than 1 s,
  - Regulation can be switched on/off for debugging.

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SCSIM-TCS performances

- **Size of the reduced models:**
  - @sat: 470 nodes, 956 faces
  - Stress test model: 3500, 1300 faces
- **Measured at DOREA, from a dedicated stress test:**
  - Initialisation : 110 ms (loading ETHERM model)
  - Solar + Albedo + IR recalculation : 23s of CPU
  - T° calc in 1 loop of 80 iterations : 1500ms of CPU
- **Measured from Alphasat model:**
  - Initialisation : 110 ms (loading ETHERM model)
  - Solar flux calculation : 6.8s of CPU
  - T° calc in 1 loop of 32 iterations : 500 ms of CPU
- **Precision:**
  - Compared to @sat thermal analysis results, SCSIM-TCS temperatures restitution confidence is from +/- 0.1 degC to +/- 1.7 degC for the max on thermistances.

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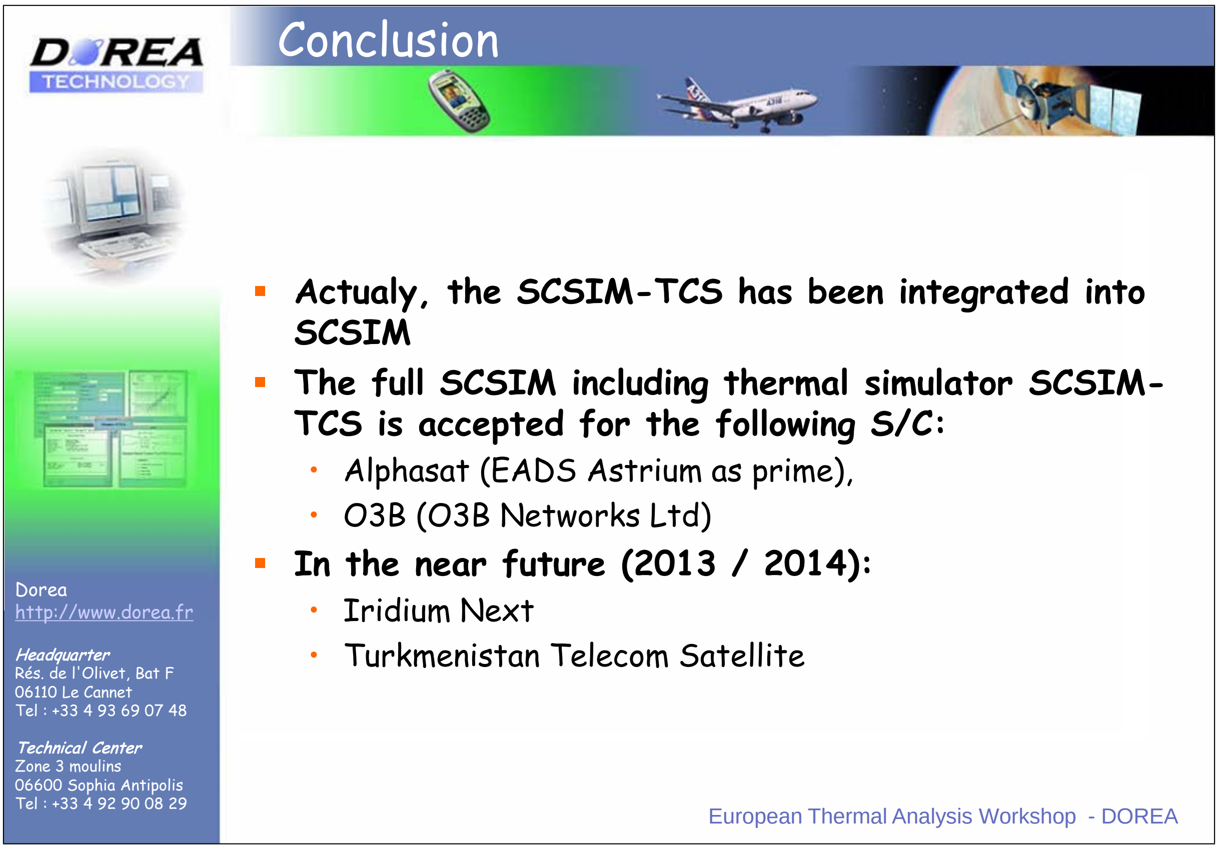
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Conclusion
Actualy, the SCSIM-TCS has been integrated into SCSIM
The full SCSIM including thermal simulator SCSIM-TCS is accepted for the following S/C:
Alphasat (EADS Astrium as prime),
O3B (O3B Networks Ltd)
In the near future (2013 / 2014):
Iridium Next
Turkmenistan Telecom Satellite
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