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Genetic Algorithms assisted ESATAN Modelling for automatic test verification and other scientific uses of ESATAN modeling at DLR Berlin

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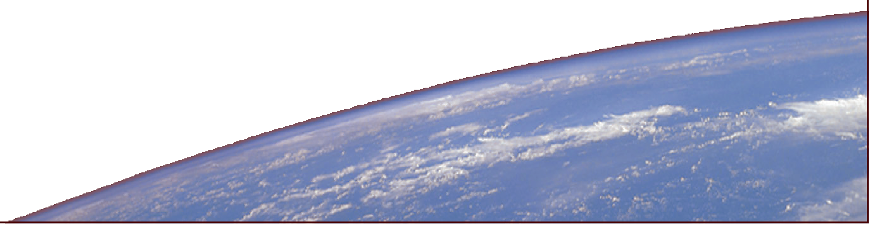

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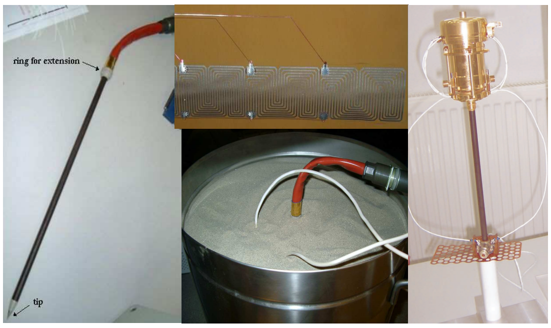
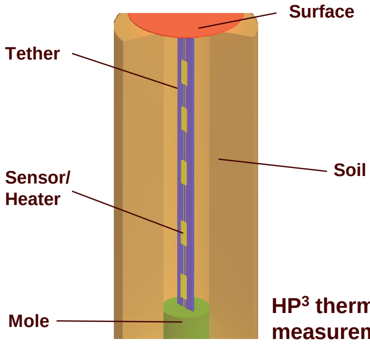
Summary

- Thermal Probes overview
- The inversion Problem
- Inversion by Modelling
- Parameter search with Genetic Algorithms
- Details of the process
- Other scientific uses of ESATAN
- Ongoing and Future Developments

Thermal Properties Probes



Extase and MUPUS (GRM) probes



HP³ thermal measurements concept

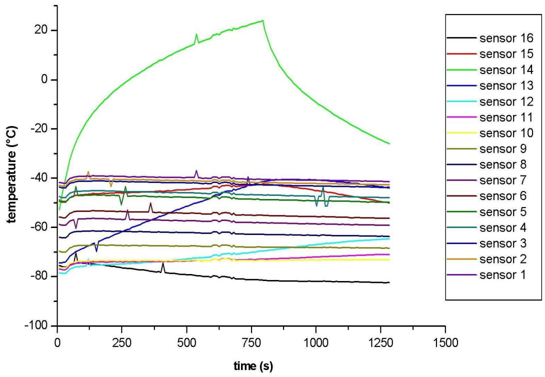
Various probes for heat-related experiments are under study:

- MUPUS (Rosetta Lander)
- Extase (terrestrial applications)
- HP³ (planetary and asteroidal heat flow and thermal physics)

All share common characteristics

- Shape (long thin "rods")
- Condition (surrounded by investigated material)
- Operation mode (temperature monitored while heating and cooling of the material occurs)
- Aim (measure of T and thermal properties)

Inversion



Example of measurement (Extase)

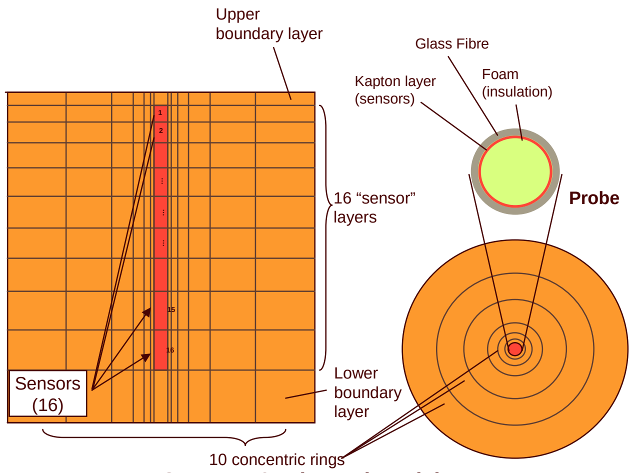
To get the desired information (C_p, k) from a measurement an inversion is required.

Two possibilities exist:

- Analytical (or direct), by use of heat transfer equations
  - Low resources
  - Well designed for ideal cases, very difficult to deal with losses and disturbances
- Numerical, by simulation of the experiment with a thermal model
  - Model verification needed
  - Requires modeller and computation time

Thermal Modelling (1)

Purpose: simulate experiments with a certain combination of physical characteristics. If simulation fits the experimental reality, the characteristics of the material (C_p, l,r, G_{surf}) are determined



MUPUS-Extase 2D thermal model

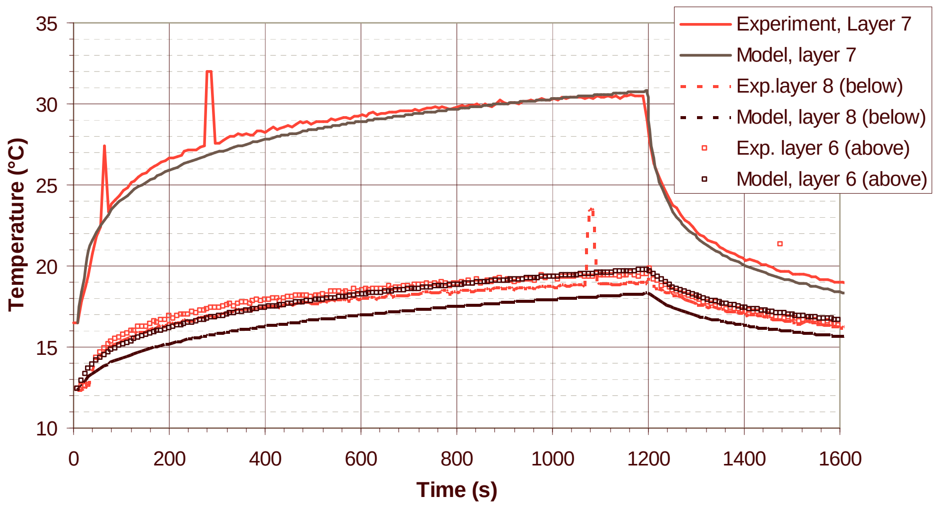
Model characteristics:

- Bi-dimensional (axial symmetry)
- Parameters included as nodal properties:
  - Density (variable)
  - Cp (constant)
  - Conductivity (variable)
  - Contact resistance (constant)
  - Depth
  - Axial distance

Thermal Model (2)

Results of first Phases

- Model vs. experiment, Manual Fit (3 layers)
- Satisfactory fit



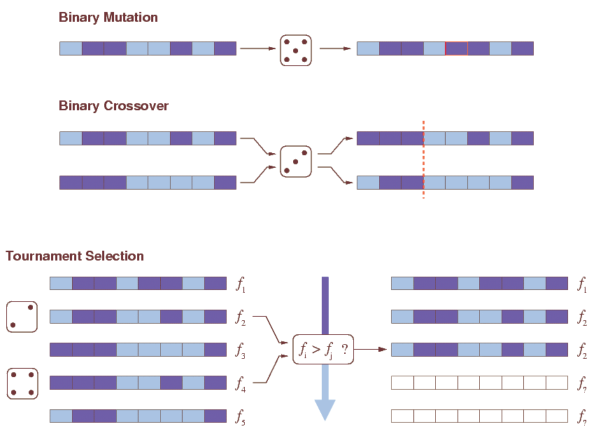
Open Issues

Even if the thermal model approach proves effective, some outstanding issues remain with a manual fit approach:

- No certainty that the solution is optimal and unique
- Extremely long and tedious procedure (trial and error) to find the “right” set of parameters
- Limited number of parameters (no more than 4-5)

Necessity of automating the process

Genetic Algorithms



Genetic algorithms are the best known method to create original set of parameters, to be then used in thermal models

GA mimic biology:

- Parameter = gene
- Set of parameters = chromosome
- Fit to environment = error fit
- Survival of the most fit = selection of the smallest error

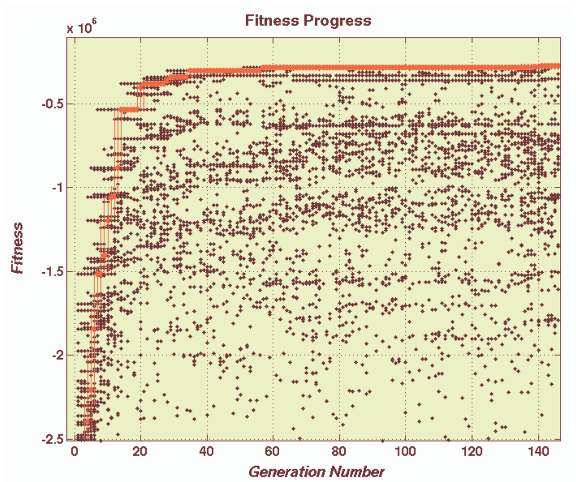
Disadvantages

- Complex to implement
- Computation intensive

Advantages

- Automatic
- Reach Optimal solution
- Allows tens of parameters

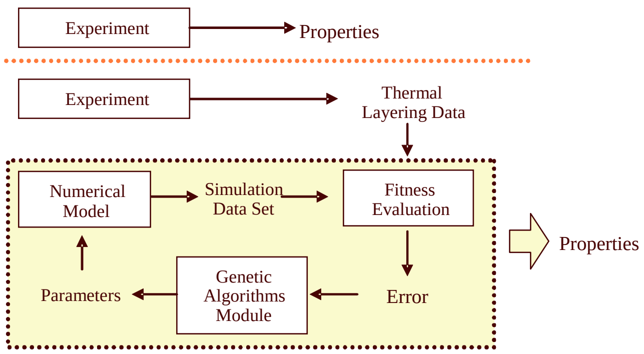
GA fitness



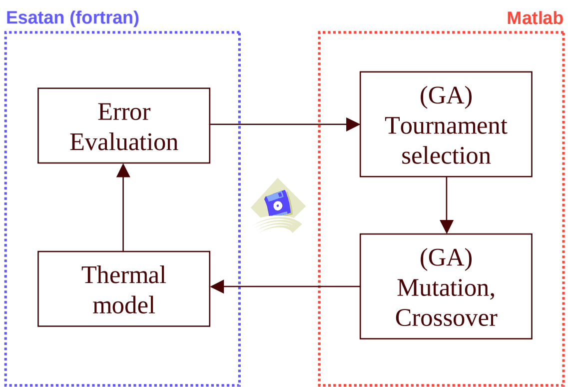
Genetic Algorithms fitness evolution example: individual model fitness (black), population median (red)

- The median fitness increases quickly at first but slows down approaching the optimum
- The complete parameter space is explored, no local optimum limitation (as per gradient method)
- CPU time for GA (mutation, crossover, selection) depends on parameter set characteristic.
- The error function must be accurately selected

GA and thermal modelling



A recursive process is implemented between the model (with an internal error function between simulation and experiment) and the Genetic Algorithms Module



At the programming level, the error evaluation is implemented INSIDE the ESATAN model, while the GA module is in MATLAB.

The two programs exchange data through ASCII text files

Scientific Uses of ESATAN

In addition to evaluation of experiments, additional scientific simulations are run at DLR Berlin

- Environmental definition
  - Orbiter-mounted instruments (e.g. Bepi-Colombo Laser Altimeter)
  - Surface and subsurface probes (HP^3, IR radiometry)
- Scientific Simulation
  - Mercury surface conditions
  - Mars subsurface conditions
  - Mars subsurface long term (climate) simulations
  - Asteroid surface and subsurface simulations

Mercury Soil Model (1)

1D soil model (purely conductive, no ESARAD)

Parameters included as nodal properties:

- Physical parameters (r,C_p, conductivity)
- Radiative transmission factor
- Location (longitude, latitude) and surface inclination
- Node geometric dimensions

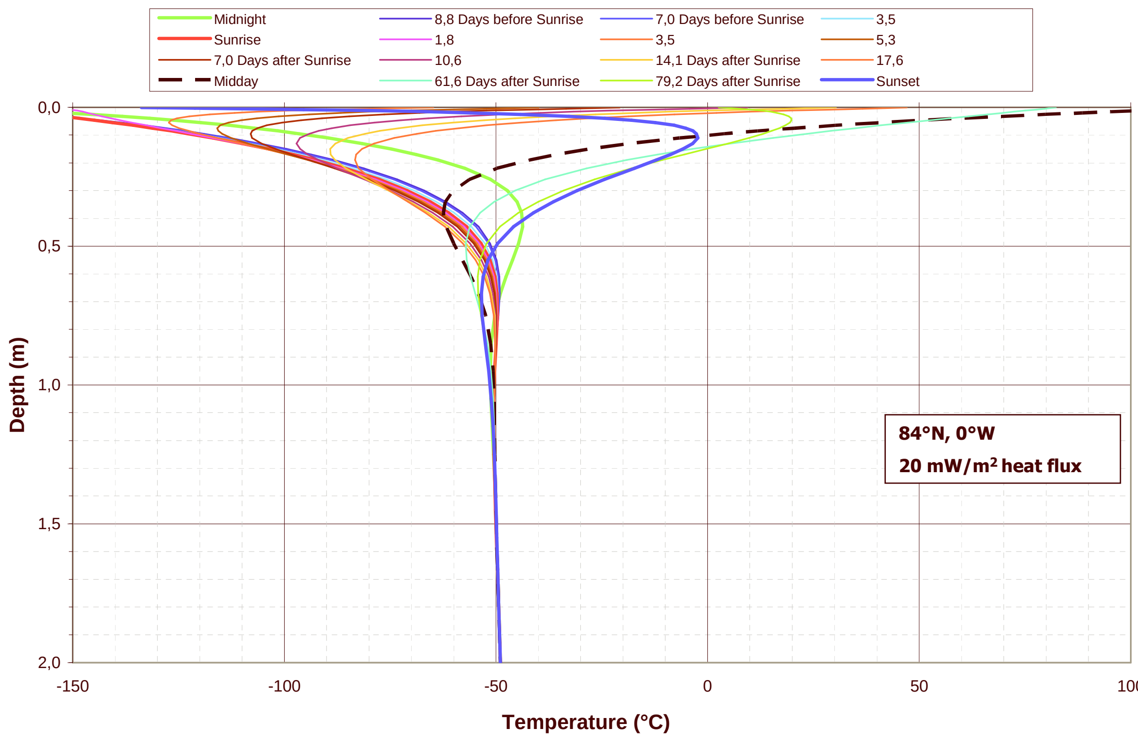
Solar flux is calculated directly in ESATAN (Fortran)

- Orbit and rotation dependent
- Solar disk effect

Mercury Soil Model (2)

- Stability over 1 cycle (for Mercury 1 solar day = 176 Earth days) is obtained automatically by using SOLCYC
  - Stability is ~0.001K
- Conditions over entire planet are obtained with a REPEAT … UNTIL cycle calling the solution routine with different parameters
- Results are stored in custom files
- Custom ASCII files are also used to store conditions in case of an interruption
- 1 global map of Mercury Temperature (0 to 6m depth, 5°x5° grid, over 1 solar day) is obtained in 30-36 hours of calculation.

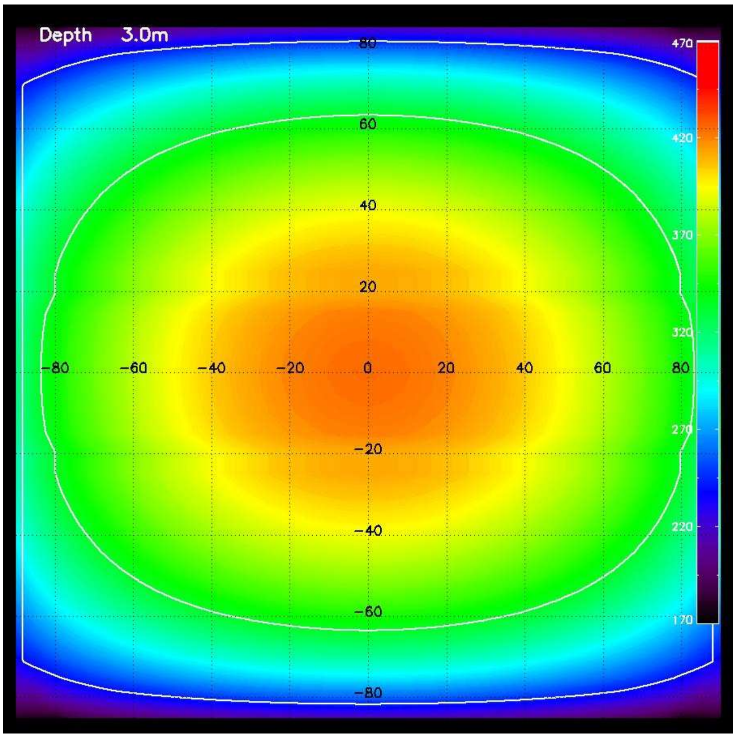
Temperature Curves



Temperature Maps

Global Result

- 1 hemisphere
- Temperature at **3m depth**
- Relevant contours
  - Cold (~233K)
  - Hot (~313K)
- "Asymmetric" conditions due to Mercury orbit/rotation
- Some mild regions to be found



Mars Models

To deal with the Mars case, an expansion of the Mercury Soil Model is required, and many modifications must be added:

- Humidity and Volatile contents parameters
- Two phase behaviour (condensation and sublimation of H_2O and CO_2 ices)
- Interaction with atmosphere
- Boundary condition come from Mars climate database, not from internal calculations
- Higher Spatial resolution

Ongoing & future developments (1)

IN the Genetic Algorithms assisted modelling field, the following activities are or will be addressed:

- Implementation of different models
- Recoding of Genetic Algorithms from Matlab to Fortran
- Alternative languages for thermal models (FEM based, Femlab, MATLAB)
- Additional thermal models
- Investigation on the possible use of the Genetic Algorithms approach also for automatic verification of engineering tests (e.g. STM tests, material tests)

Ongoing & future developments (2)

In the scientific applications field the following actions are or will be implemented

- Implementation of Mars models
- Extended sensitivity analyses on Mercury surface/underground relations
- Investigation on parallelization
- Solution of licensing issues

Acknowledgments

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