Modelling Martian and Lunar Environments Using the GRAPPA with GRAS

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What is GRAPPA?

- GRAS Preprocessor for Planetary bodies and Asteroids
- Creates GDML geometry representations of Mars and Moon so that ESA's GRAS/Geant4 may be used for 3D particle simulation
- Planar and spherical geometries
  - Simple 1D geometries, or
  - 3D geometries with XY (latitude/longitude) dependence
- Can be used at local scales (~ several metres) to planetary scales
- Treatment of:
  - Atmosphere composition and density as function of altitude
  - Soil as function of depth
  - Precipitates (CO_2 & H_2O)
  - Magnetic fields (for Mars)
- Geometry defined based on a user-selected point on Mars/Moon
  - Can be extended to Phobos and Deimos
- Part of ESA Human Interplanetary Exploration Radiation Risk Assessment System (***HIERRAS***) Project

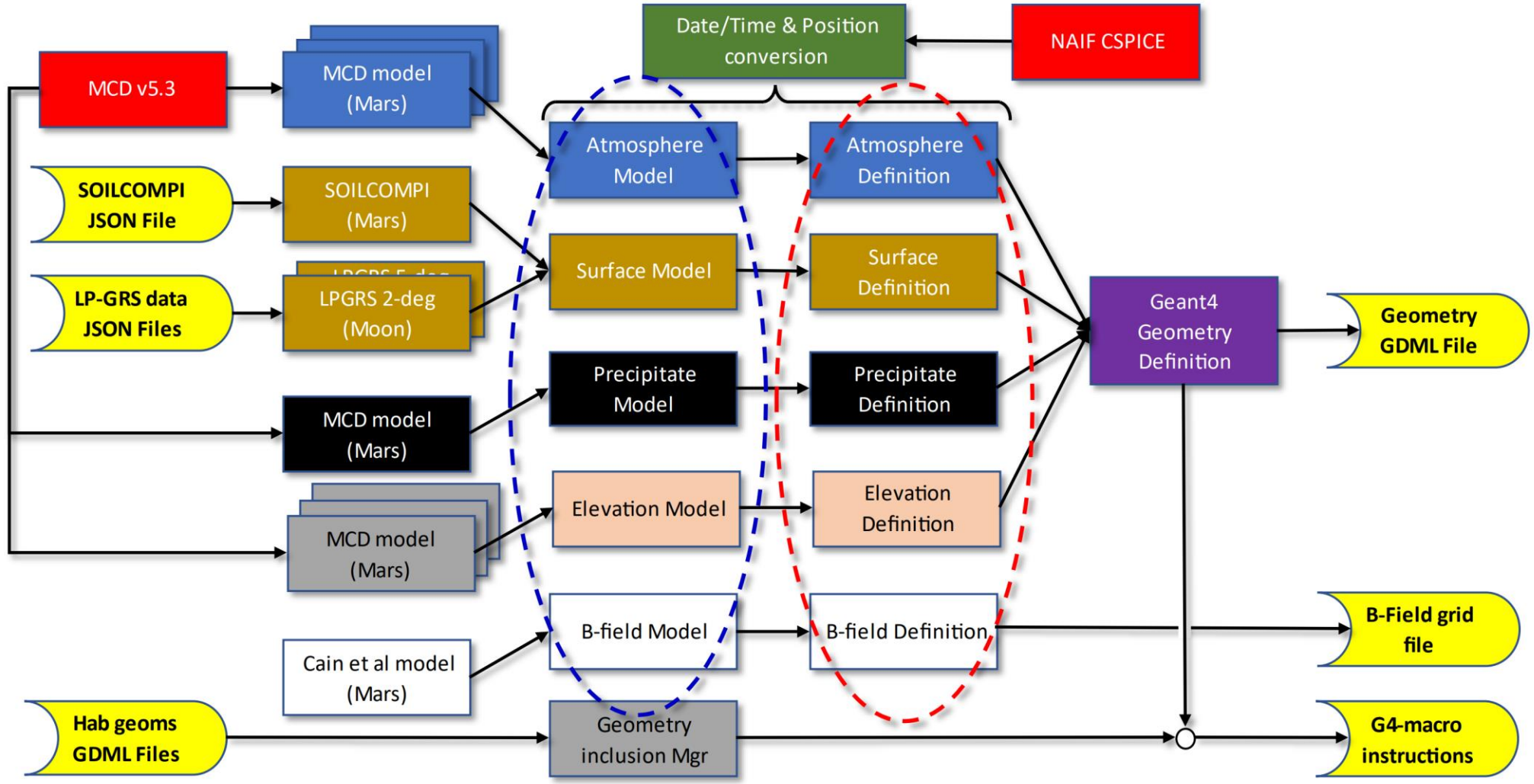
Why use GRAS & Why Create a Geometry Preprocessor? - Maintainability

Why not use dedicated Geant4 applications PLANTOCOSMICS (Uni Bern/ESA) or dMEREM (LIP/ESA)?

- GRAS application performs full 3D particle transport with nuclear & EM interactions
- GRAS is well maintained, well structured, and frequently updated:
  - Use more recent version of Geant4 (v10.7 patch 3) – more up-to-date physics
  - New analysis modules – GRAS v6.0 includes human exposure quantities, incl. ICRP-123 coefficient based
  - Multithreaded – GRAS v6.0
  - Two-stage simulation to resample ("split") particles nearer habitats
  - User-added magnetic fields
  - Reverse MC for ions in future?
- GRAS being used for 3D radiation analysis of spacecraft modules
- Use GRAS as "Geant4 simulation engine" for interactions with planet/moon structure
- Geant4 GDML file reader – other Geant4 applications may be used
- Note: FLUKA can also simulate particle interactions in GDML geometries

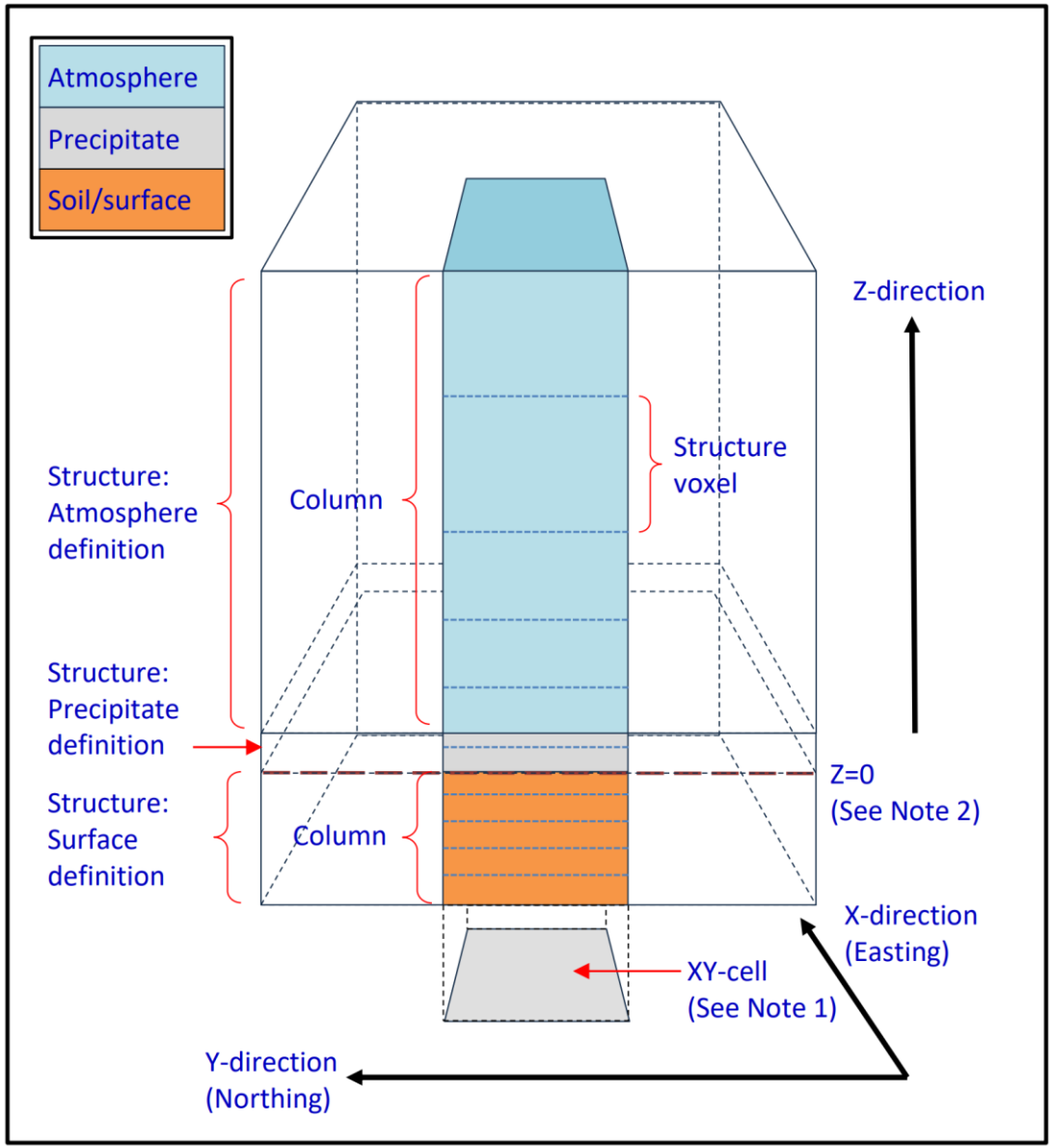
GRAS on ESA ESSR

GRAPPA Functions



The GRAPPA Geometry Structure

- The modelled geometry comprises Atmosphere, Precipitate and Surface layers
- Sub-divided into columns delimited in XY
  - Relative to user reference point
  - Flat geometries: XY are displacements in length
  - Spherical: XY are in degrees
- Each of these is segmented into voxels based on user-supplied Z-grids
- Grid XY resolution can be different between Atmosphere, Precipitate and Surface



GRAPPA Models Currently Implemented

Atmosphere:
- Mars Climate Database (MCD) v5.3
- User defined composition and $\rho(H)$
- User defined fixed composition and scale Height

Precipitate:
- Mars Climate Database (MCD) v5.3 for CO_2 & H_2O ice
- User defined composition and $\rho(H)$

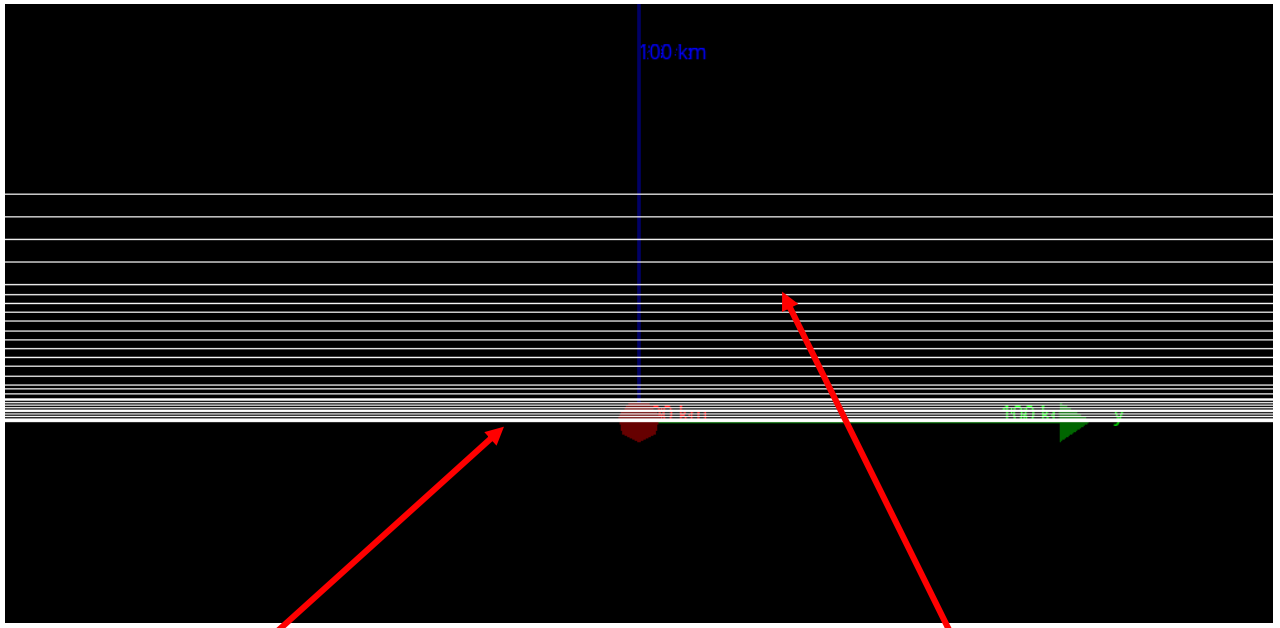
Surface:
- SOILCOMPI based on Mars Odyssey's MGRS; from LIP's dMEREM code (ESA MarsREM Project)
- Lunar Prospector GRS (2-deg) based composition model
- User defined composition and $\rho(H)$

Magnetic Field (crustal models for Mars):
- Cain et al, n=50
- Cain et al, n=90 (2003)
- Purucker et al (2001)
- Alternatively, user-defined field can be added in GRAS simulation

- Software OO-design allows easy extension of GRAPPA to treat additional models
  - Can be interfaced to external software library or data-file based model
- Potential to extend to Earth or other planets and moons

Simple Mars Case (Flat geometry)

```
/GRAPPA/setPlanet MARS
/GRAPPA/setReferenceDate 2004 1 4 4 35 0.0
/GRAPPA/setReferencePosition 175.48 -14.57 deg
/GRAPPA/structure/setShape FLAT
/GRAPPA/listPlanet
/GRAPPA/structure/createAtmosphereStructure
/GRAPPA/structure/createSurfaceStructure
/GRAPPA/structure/createElevationStructure
/GRAPPA/preConstructGeometry
/GRAPPA/constructGeometry
/GRAPPA/saveGeometry test_01_00_1_out.gdml
```



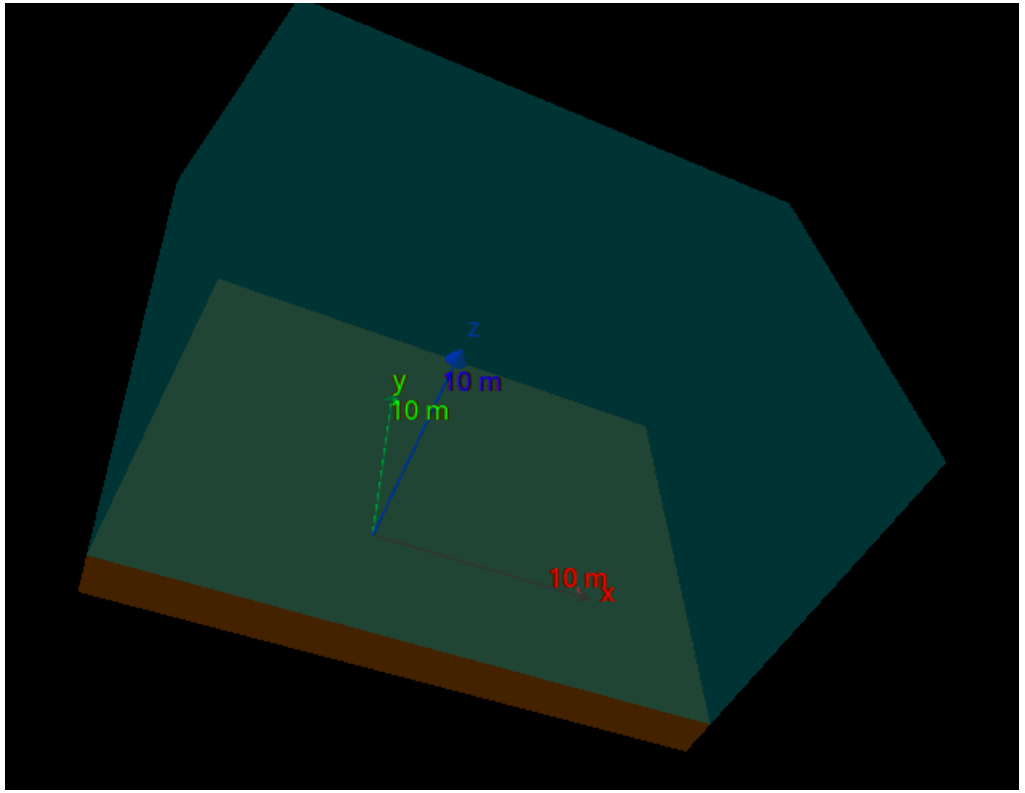

```
Solar system body       :                    MARS
NAIF SPICE ID for body  :                     499
Date/time         [UTC] : 2004-01-04T04:35.00.00
Date/time ET        [s] :       126462964.184004
MJD 1950           [dy] :       19726.1909719999
Longitude         [deg] :                175.480
Latitude          [deg] :                -14.570
Z-datum type (default)  :     ORIGIN_CELL_GROUND
Models used
Elevation      :                   ZERO
Atmosphere     :        MCD_ATMOSPHERE
Precipitate    :       MCD_PRECIPITATE
Surface        :              SOILCOMPI
Magnetic field :                 (none)
```

Ground thickness 1m (default)

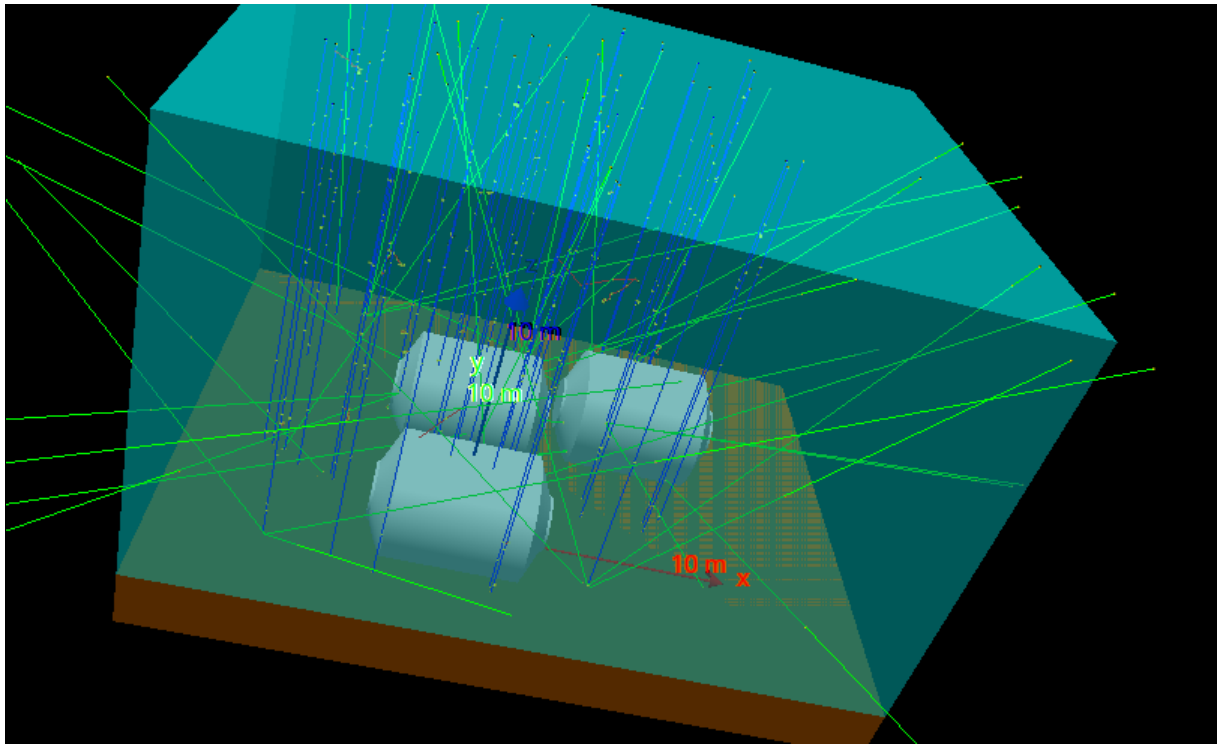
Atmosphere thickness 50km (default)
Intervals ≅ dMEREM default

Note: To change the atmosphere / surface model etc:
/GRAPPA/structure/setAtmosphereModel <MODEL_NAME>
/GRAPPA/structure/setSurfaceModel <MODEL_NAME>
Etc …

Mars Case: Local Environment Model & Addition of Mission Equipment

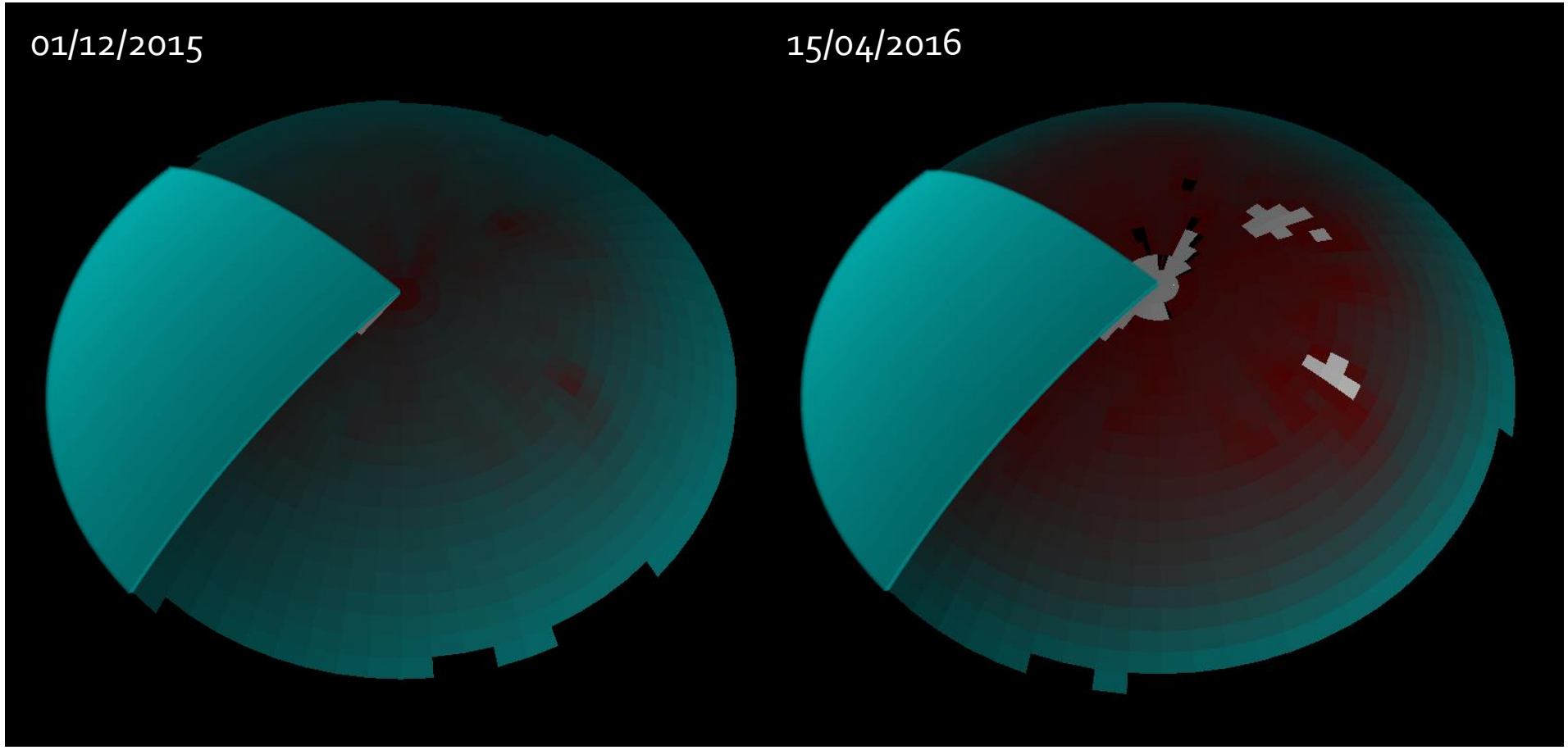


Local environment with partially-buried habitat modules (additional GDML files) included in GRAS simulation



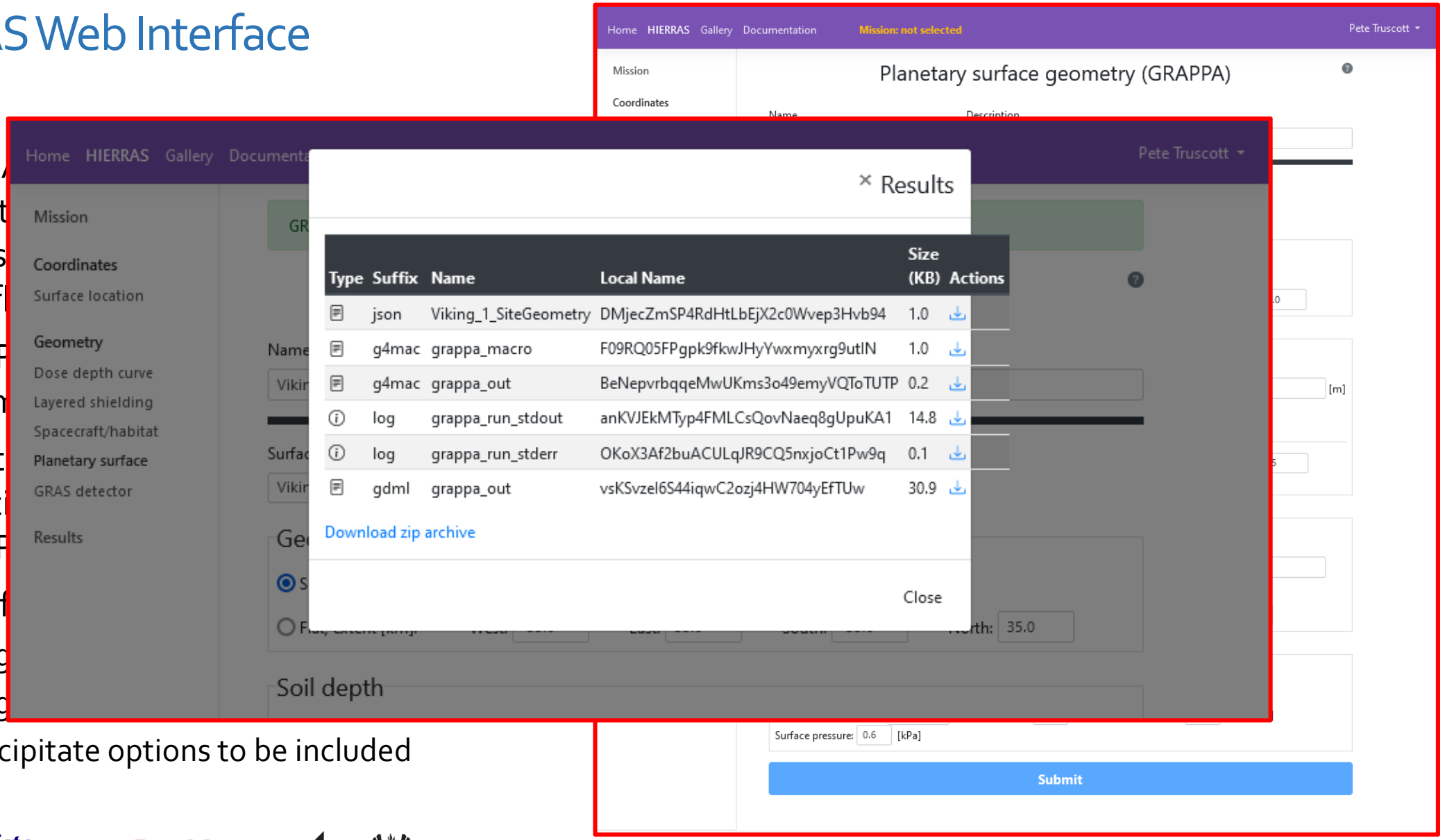
Local environment 25 x 20 x 17 m^3

Spatial Dependence of CO_2 and H_2O Ice (MCD v5.3)

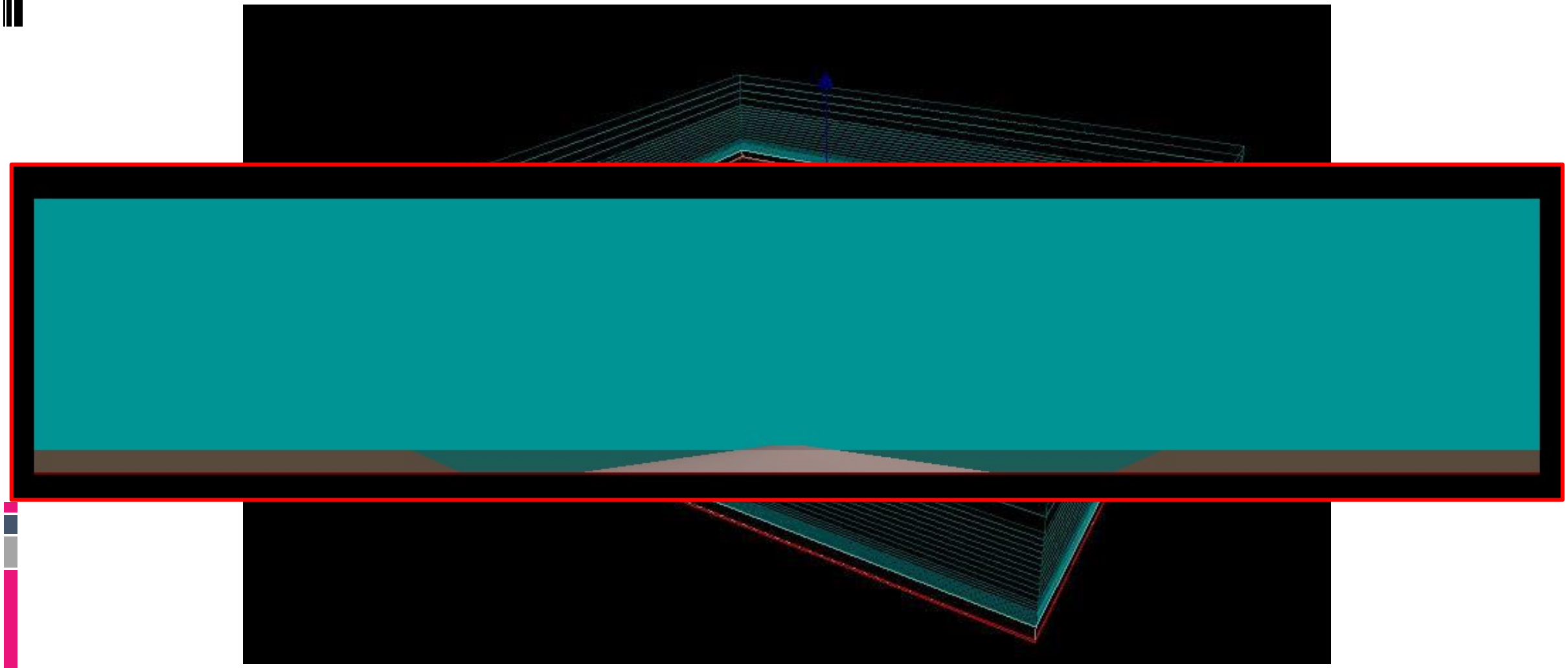


HIERRAS Web Interface

- HIERR
  toolset
  effects
  spacef
- GRAPP
  implen
- Permit
  definit
  GRAPP
- Simplif
  - Sing
  - Sing
  - Precipitate options to be included



GDML Gale Crater Representation easily created using G4 Parallel Mass World features in GRAS



Dockerization of Geant4 – g4_space_apps Features

- G4 v10.7 patch 03 is required together with GRAPPA and GRAS
- Installing and maintaining installations of Geant4 can be very problematic for user if they're not experts
- A docker image has been created for HIERRAS containing Geant4 with:
  - GRAS
  - MULASSIS
  - SSAT
  - CIRVis
  - GRAPPA
  - MAGNETOCOSMICS
- Portable between Linux and Windows
  - Need OS specific batch files, bash scripts or alias commands to help invoke functions
- Status
  - Not currently released
  - Expected Docker build scripts to be available under ESSR Open Worldwide licence

Summary

- GRAPPA is a new ESA tool to help predict radiation environments near/on planets & moons:
  - Allows easy creation of Mars and Moon geometries for 3D GRAS-Geant4 simulations
  - Treats local to planetary scales
  - From simple 1D case to complex 3D (longitude/latitude/altitude) spatial dependency
  - Position-dependent compositions for atmosphere, soil, precipitate are possible at different resolutions
  - Includes crustal magnetic field models
- Allowing GRAS to be used for particle simulation and analyses
  - More efficient to maintain ESA Geant4-based planetary radiation analysis capability
- Applications:
  - Analyses for radiation effects for human interplanetary spaceflight
  - Can be extended to treat other planets with/without large-scale magnetic fields: Earth, Jupiter, Saturn, etc.
  - Scientific analyses: interpretation of data from airborne/space-borne instruments