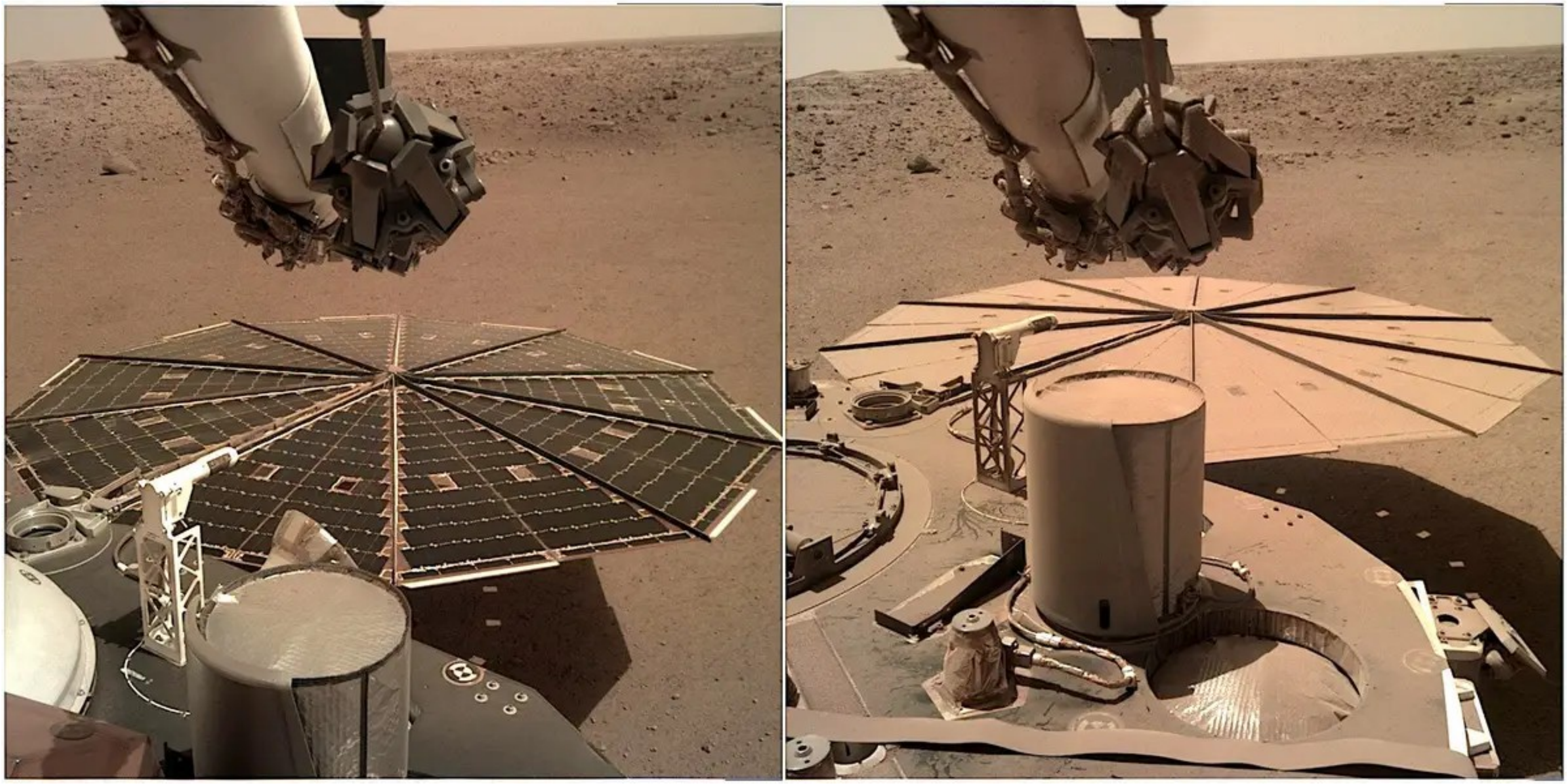
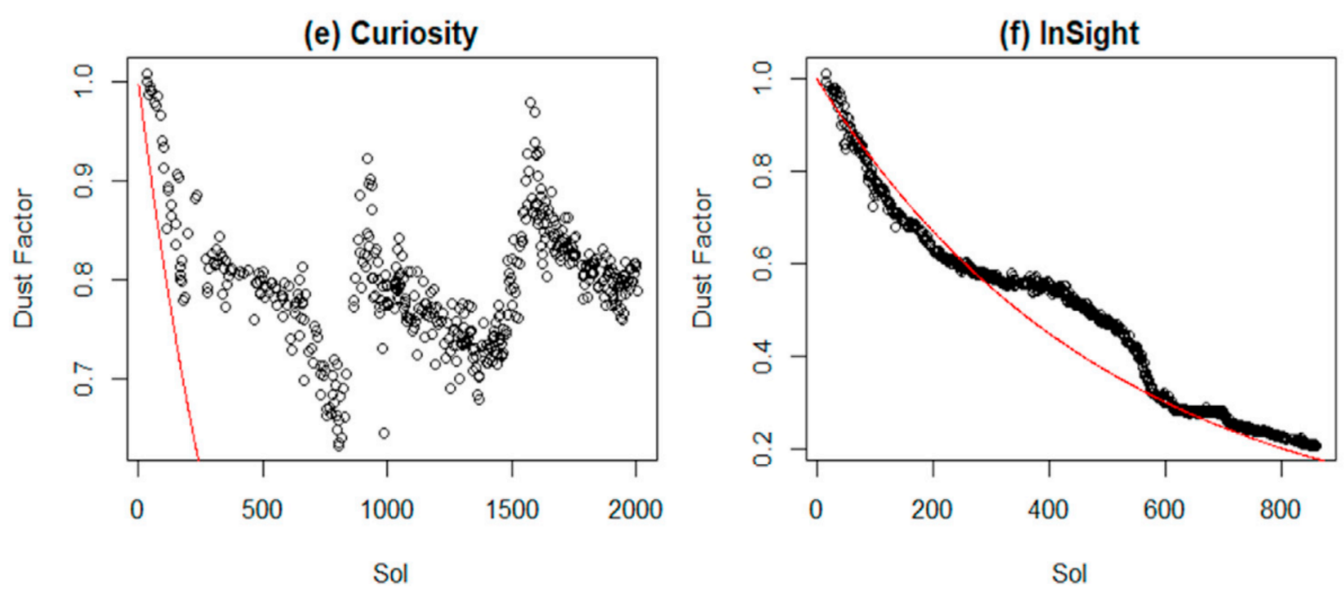
POWER ATTENUATION OF MARTIAN ROVERS AND LANDERS SOLAR PANELS DUE TO DUST DEPOSITION

T. Pierron, F. Forget, E. Millour, Laboratoire de Météorologie Dynamique (LMD), IPSL, Sorbonne Université, CNRS, Paris, France



EXISTING MODELS FOR POWER ATTENUATION DUE TO DUST

- Knowing the amount of **available electrical power** produced by solar panels for **future missions** on Mars is **mandatory** to prepare as best possible the operations.
- **Several studies have already been conduced** to try to model the dust accumulation on solar panels.
- One of the most accurate model so far is the **empirical** one described in *Lorenz et al. (2021)* which considers **a simple attenuation factor of 0.2%/sol**.



THE MODEL USED :
LM1D THERMAL MODEL

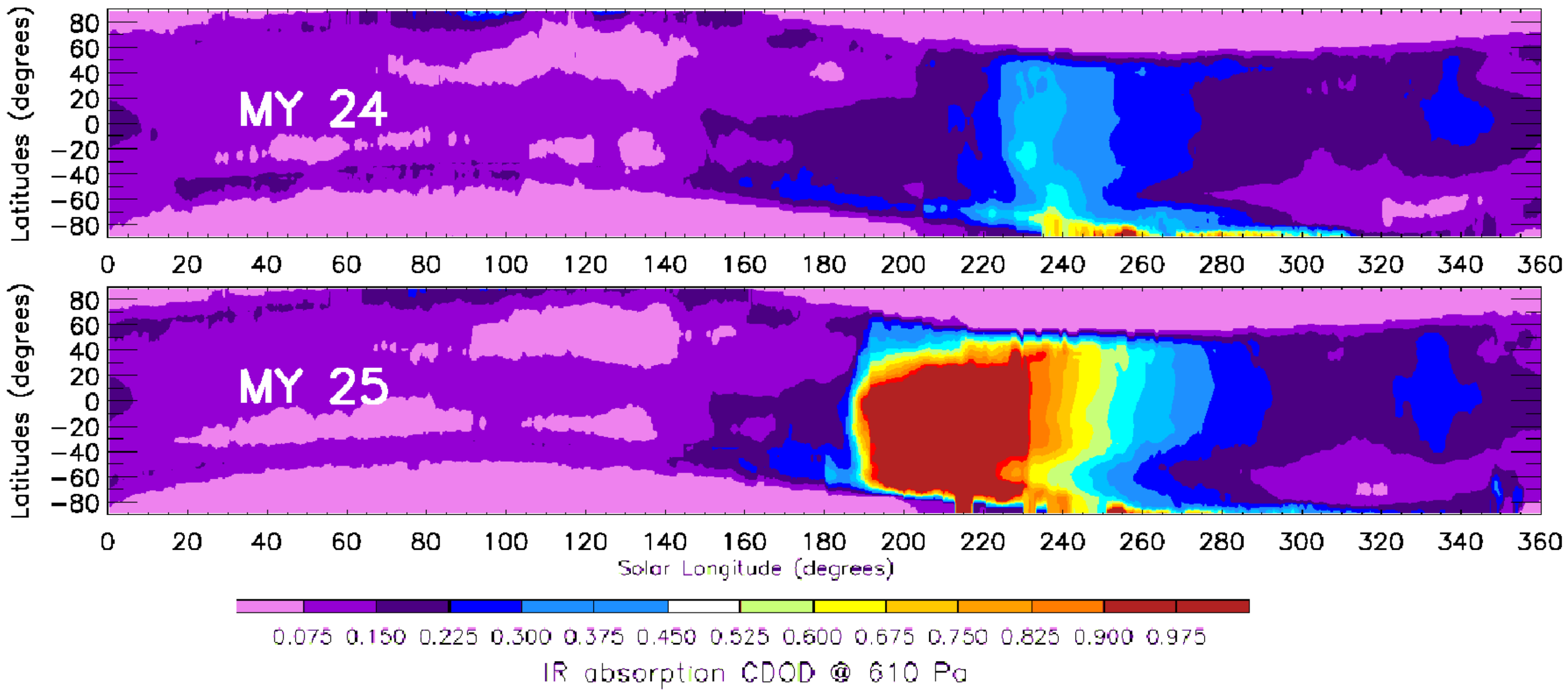
A 1D radiative convective model derived from a full 3D General Circulation Model

- Ls_{start}
- Local $\text{Time}_{\text{start}}$
- Duration (sols)
- Longitude, Latitude, Altitude
- Surface Pressure
- Dust optical depth scenario
- Bare ground Albedo
- Thermal Inertia soil/ subsurface
- Slope inclination/orientation

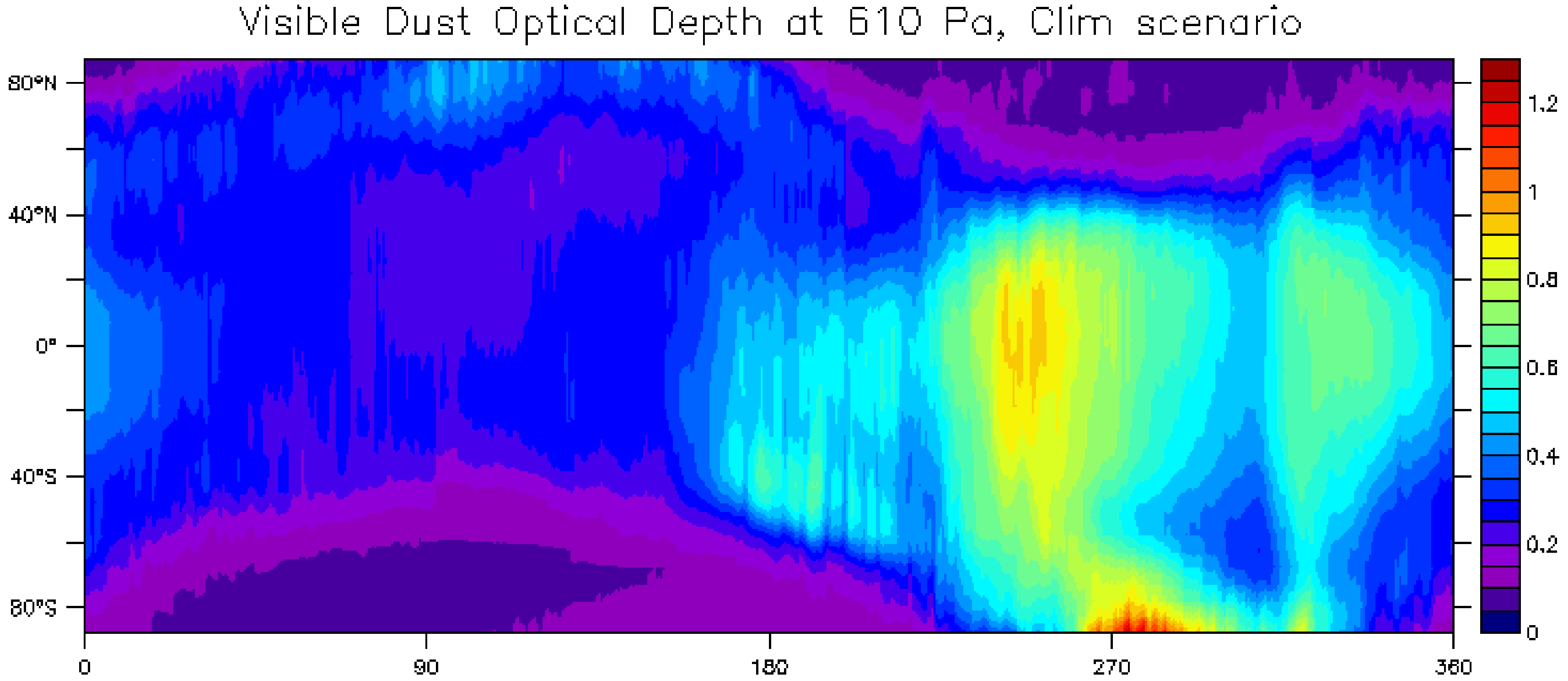
→ LMD1D Thermal Model →

- Downward solar flux on surface
- Reflected solar flux on surface
- Downward thermal IR flux
- Ground temperature
- Atmospheric temperature
- Dust deposition rate
- Solar flux received by surface covered by dust
- Visibile extinction optical depth

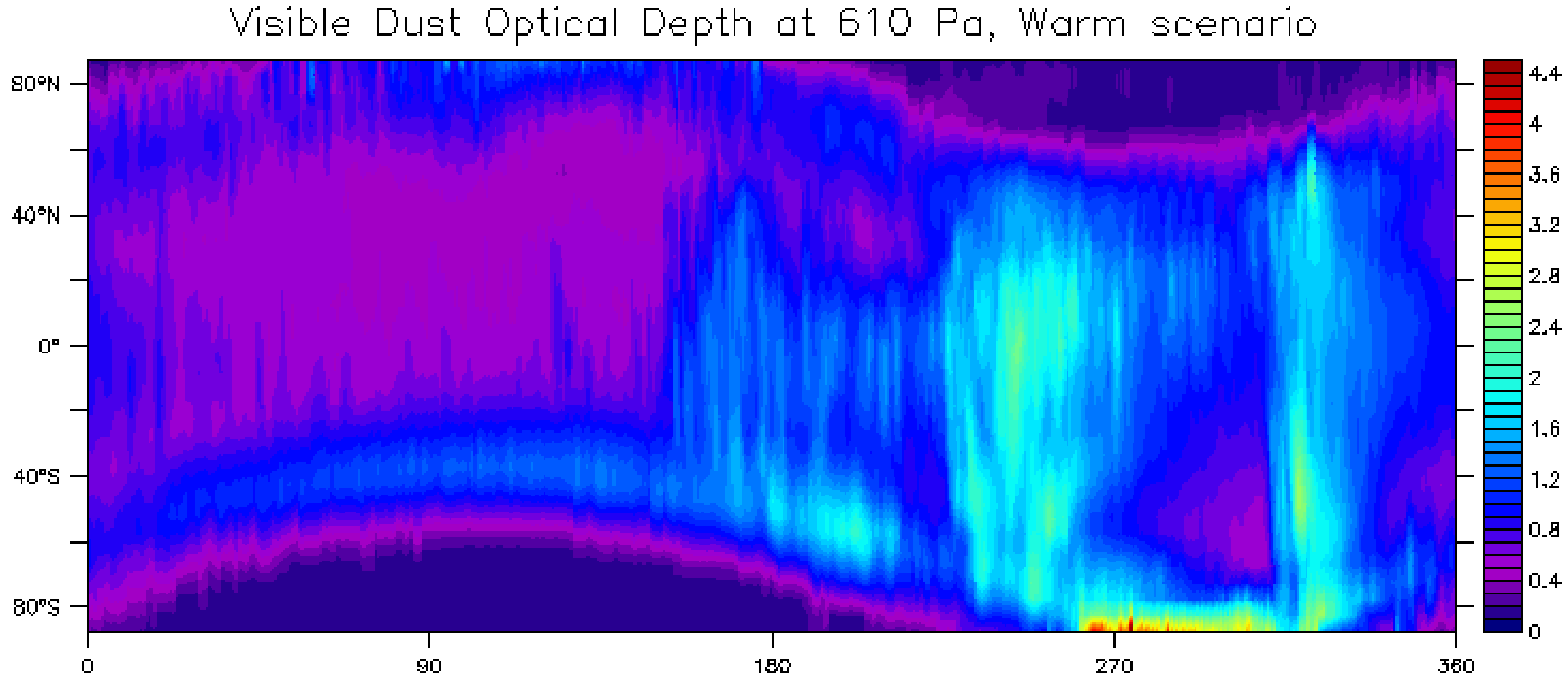
IMPLEMENTATION OF DUST SCENARIOS IN LMD1D MODEL



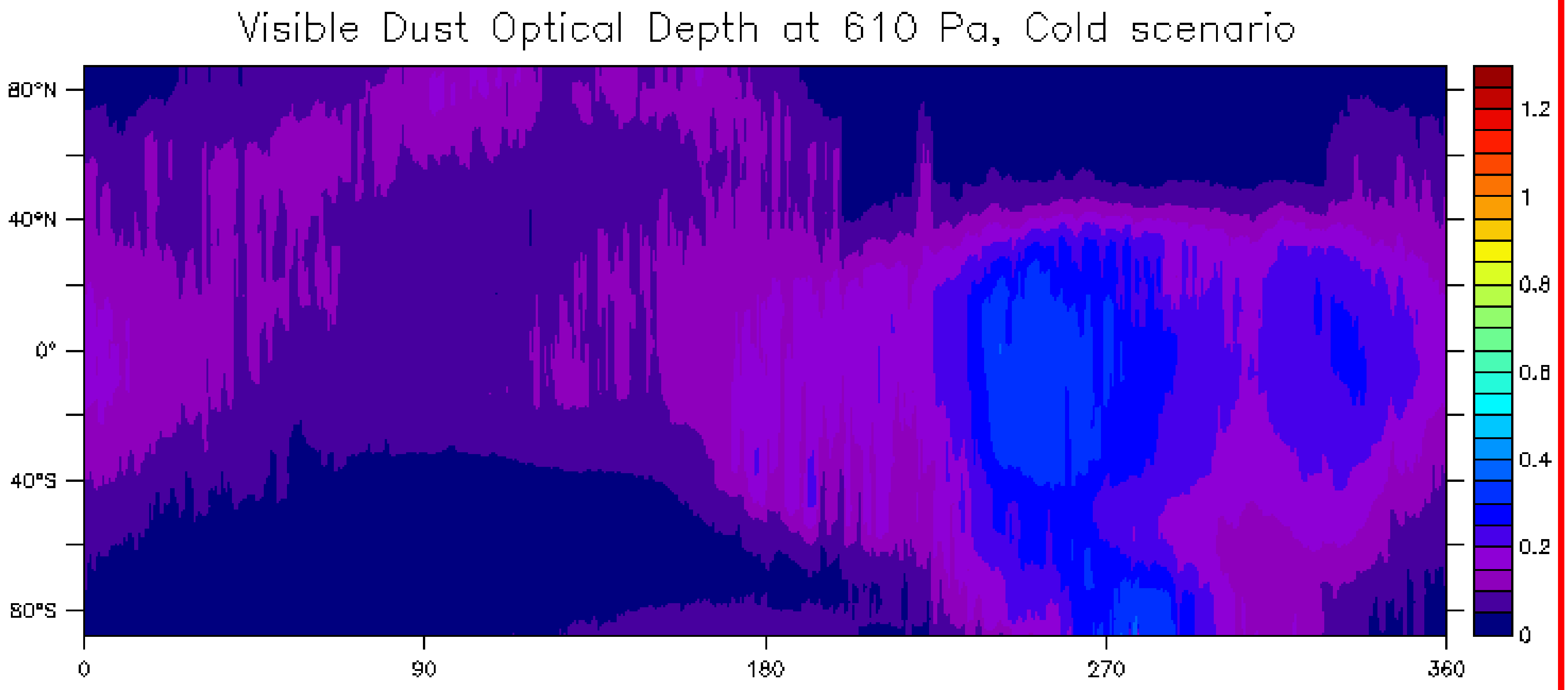
IMPLEMENTATION OF DUST SCENARIOS IN LMD1D MODEL



IMPLEMENTATION OF DUST SCENARIOS IN LMD1D MODEL



IMPLEMENTATION OF DUST SCENARIOS IN LMD1D MODEL



DESIGN OF DUST ACCUMULATION MODEL
DUST DEPOSITION RATE

- **Calculation of the dust deposition rate :**

$$R_{\text{dust}} = mmr \times \rho \times W_{\text{s}}$$

- **Depends on the Sotckes speed at which the dust falls :**

$$W_{\text{s}} = \frac{2}{9}\frac{\rho g}{\mu} r_{\text{sed}}^2 \left(1 + \beta \frac{4}{3} a \frac{T}{P_{\text{surf}} \times r_{\text{sed}}}\right)$$

- **The average particle radius r$_{\text{sed}}$** and the **sphericity coefficient β** play a key role in the amount of depositied dust.

β is the one with most incertitudes → tuned to fit with observations

$$\beta = 0.5 \quad r_{\text{eff}} = 2.0\ 10^{-6}\text{m}$$

DESIGN OF DUST ACCUMULATION MODEL
DUST DEPOSITION RATE

We assume that the **dust is well mixed** in the atmosphere :
True in the Planetary Boundary Layer where the bulk of the dust loading

→ We can assume that the **near surface dust mass mixing ratio is a function of the column dust opacity** of the atmosphere :

$$mmr = \frac{4}{3}\frac{\rho r_{\mathrm{eff}}\tau}{Q_{\mathrm{ext}}}\frac{g}{P_{\mathrm{surf}}}$$

The dust opactity is the daily mean value derived from the scenarios converted in visible extinction

$$\begin{cases} \tau_{\mathrm{ext}}(9.3\mu\mathrm{m}) = 1.3 \times \tau_{\mathrm{abs}}(9.3\mu\mathrm{m}) \\ \tau_{\mathrm{ext}}(0.67\mu\mathrm{m}) = 2 \times \tau_{\mathrm{ext}}(9.3\mu\mathrm{m}) \end{cases}$$

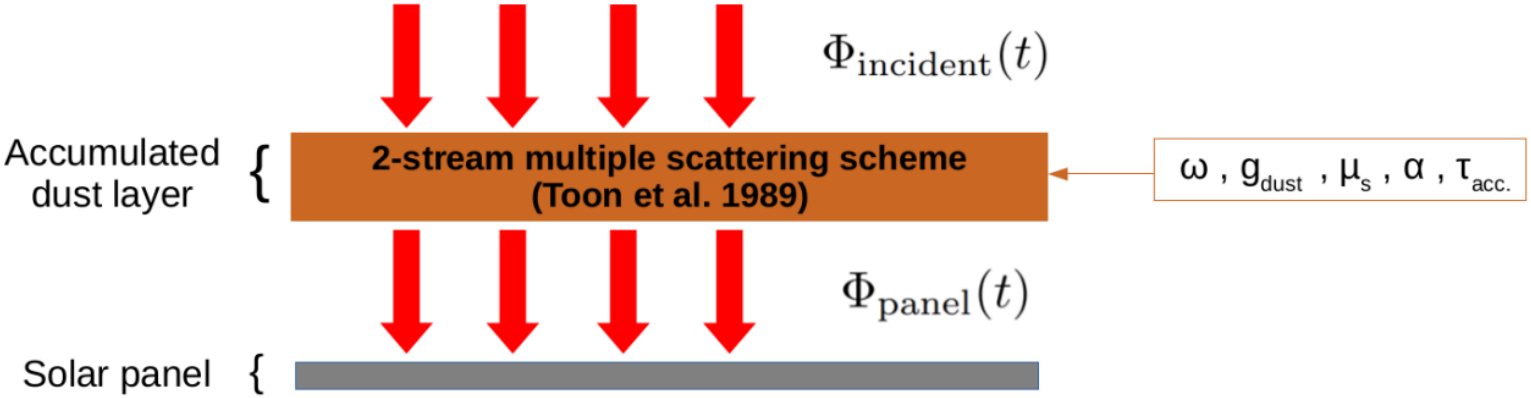
At each time step, we integrate the rate to calculate the amount of dust accumulated

$$M_{\mathrm{dust}}(t) = \int_0^t R_{\mathrm{dust}}(t')\,\mathrm{d}t'$$

DESIGN OF DUST ACCUMULATION MODEL

RADIATIVE TRANSFER
IN THE ACCUMULATED DUST LAYER

- We calculate the **attenuation of the solar flux due to the atmosphere** using the model from *Spiga and Forget 2008.*
- The incident solar flux is calculated **on the slope**
- The solar flux under the accumulated dust layer is calculated using the **2-stream multiple scattering scheme from Toon et al. 1989**



DESIGN OF DUST ACCUMULATION MODEL

RADIATIVE TRANSFER
IN THE ACCUMULATED DUST LAYER

The 2-stream multiple scattering scheme from Toon et al. 1989 takes as **inputs :**

- The single scattering albedo ω
- The asymetry parameter g_{dust}
- The cosine of the solar zenith angle on the local slope μ_s
- The albedo of the solar panel α
- **The dust optical depth of the accumulated dust τ_{acc}**

$$\tau_{\mathrm{acc}} = \frac{3M_{\mathrm{dust}}Q_{\mathrm{ext}}}{4\rho r_{\mathrm{acc}}}$$

DESIGN OF DUST ACCUMULATION MODEL

RADIATIVE TRANSFER
IN THE ACCUMULATED DUST LAYER

The dust optical depth of the accumulated dust τ_{acc} depends on the **effective radius of the dust particles deposited on the panel r_{acc}**.

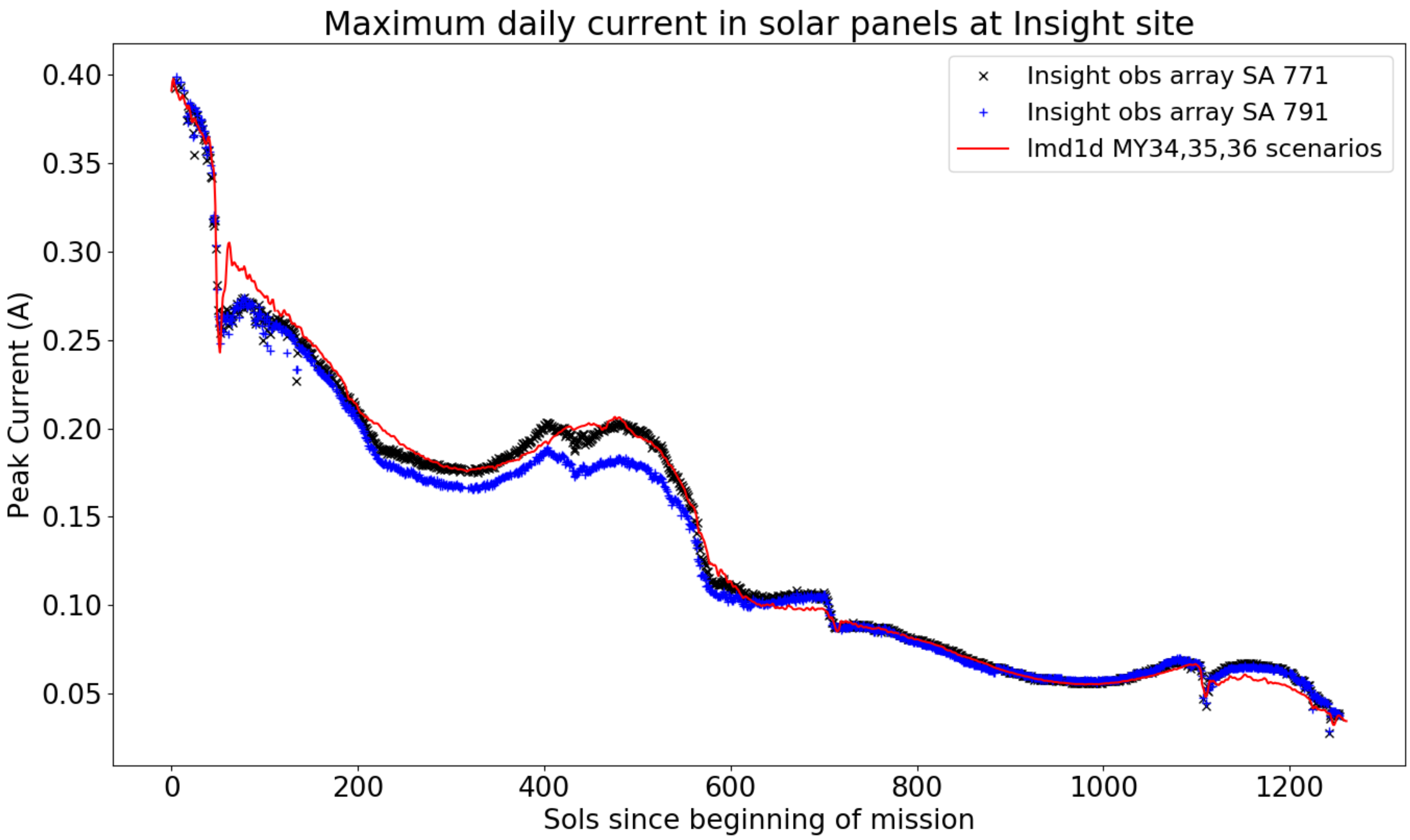
It defers from the one in the atmosphere r_{eff} because of the aggregation of the dust particles accumulating on the panel.

To model the **dust aggregation** on the panel, we made the effective radius of dust particles on the panel evolve linearly with accumulated dust mass.

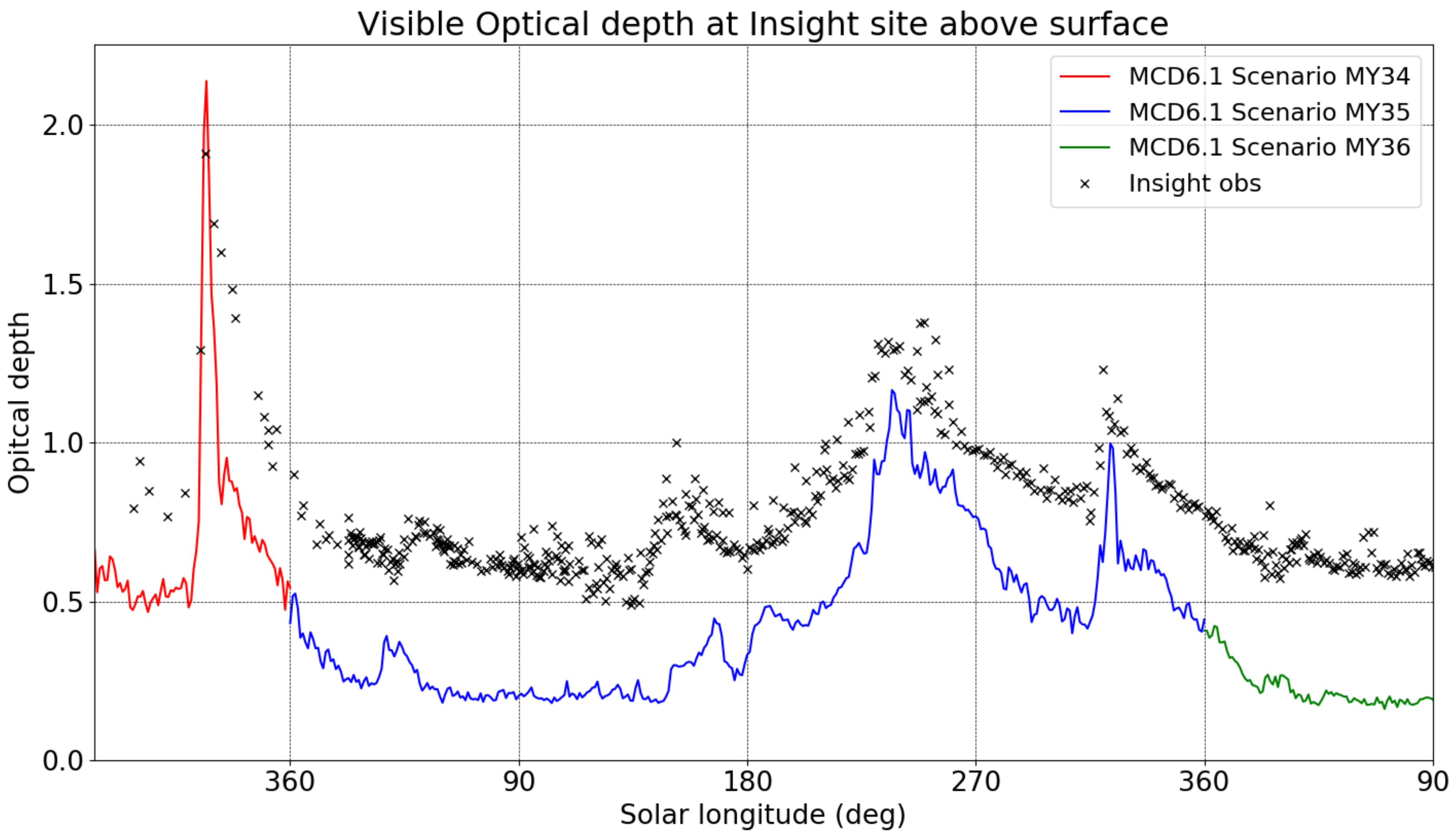
$$r_{\mathrm{acc}}(t) = r_{\mathrm{acc}_{\mathrm{init}}} + \lambda M_{\mathrm{dust}}(t)$$

We use λ=30 μm/(kg.m^{-2}) to fit the best the observations from Insight

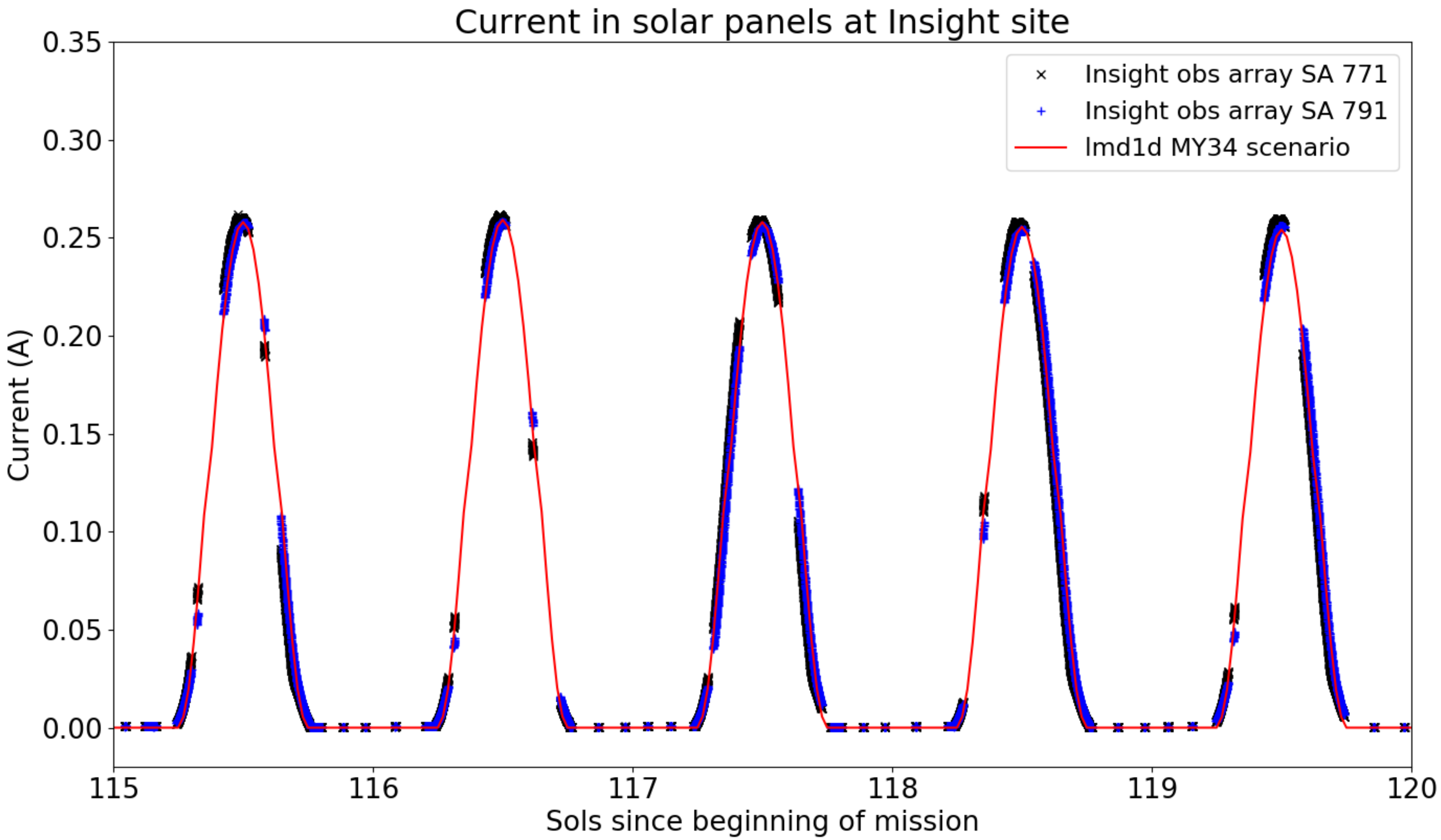
VALIDATION OF THE MODEL
INSIGHT



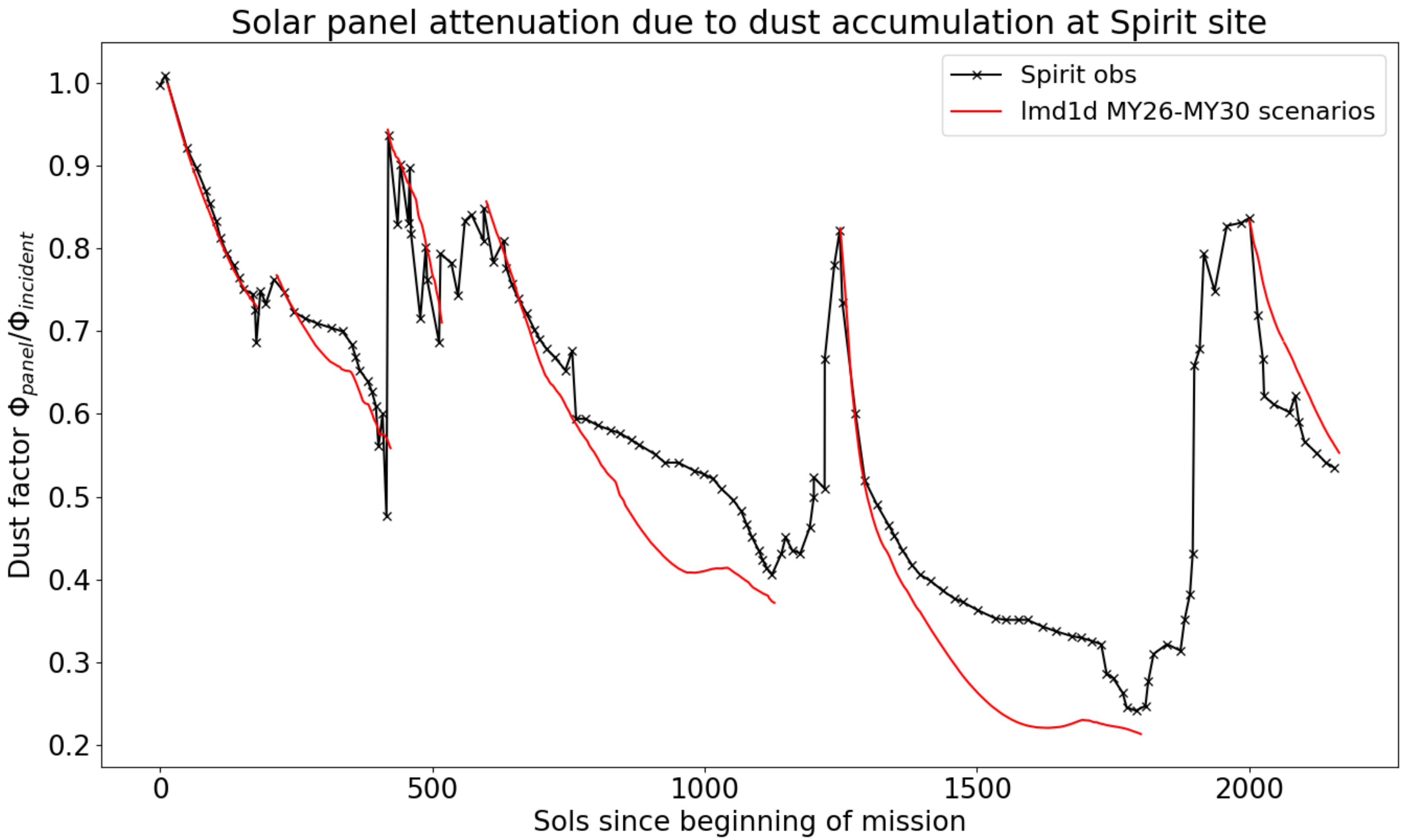
VALIDATION OF THE MODEL
INSIGHT



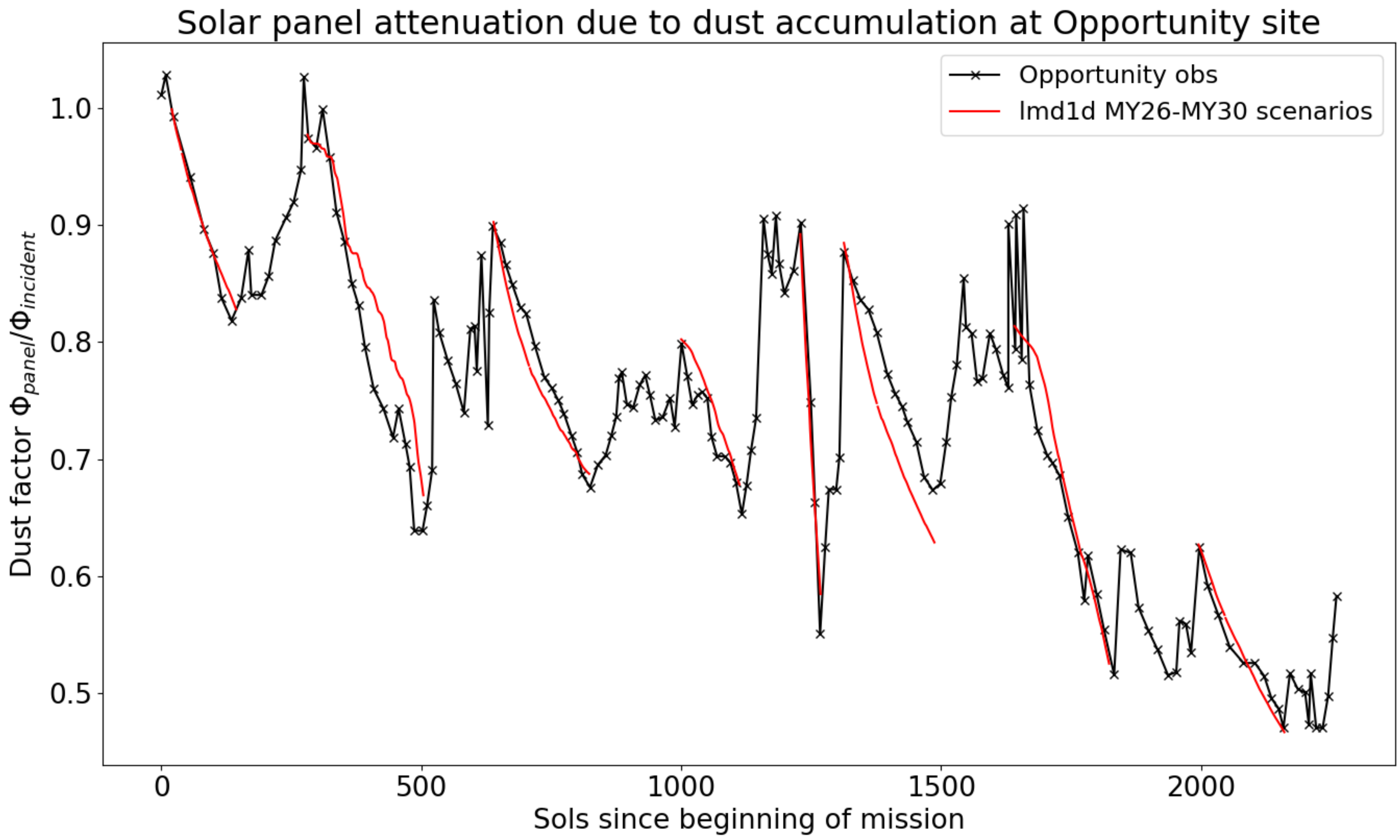
VALIDATION OF THE MODEL
INSIGHT



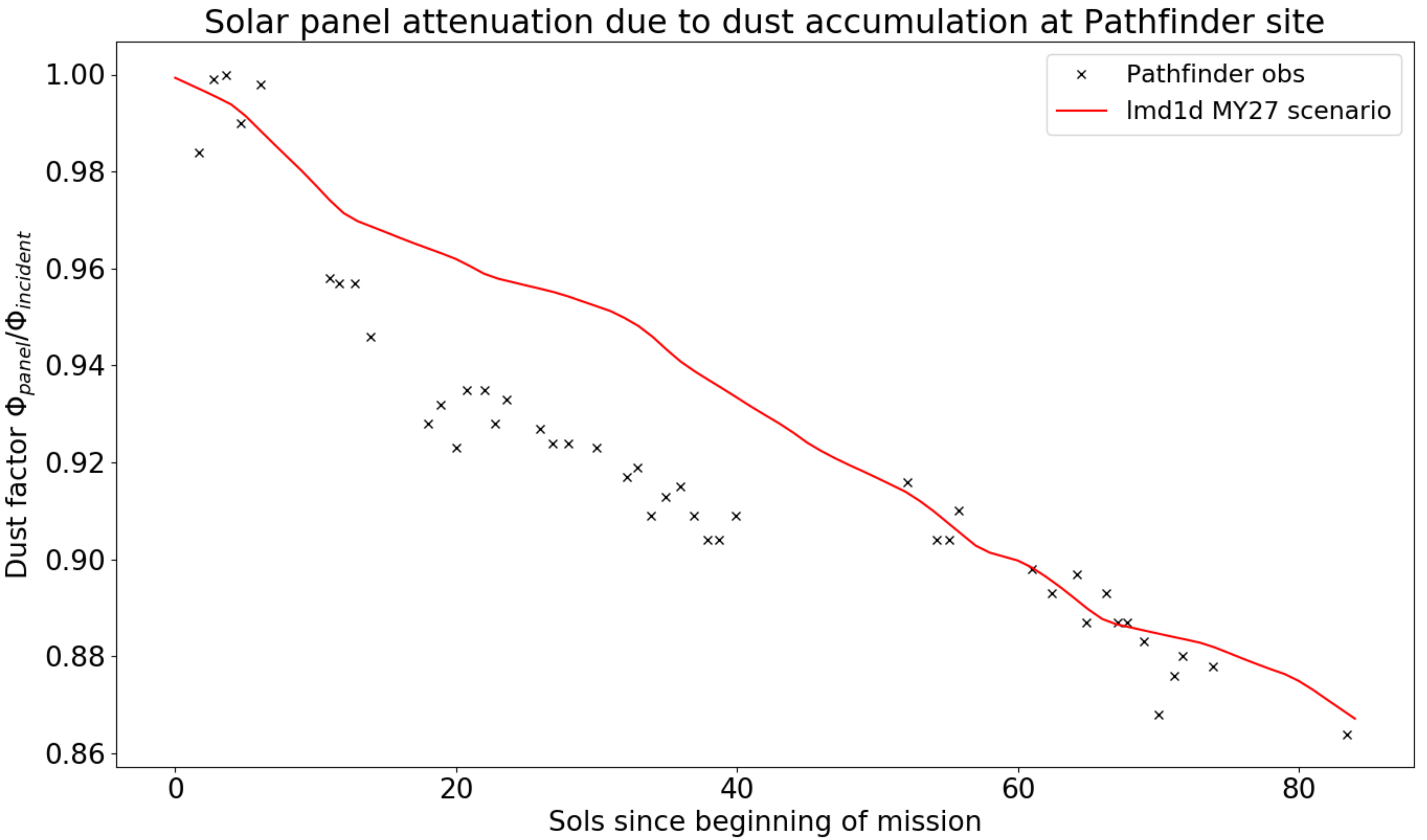
VALIDATION OF THE MODEL
SPIRIT



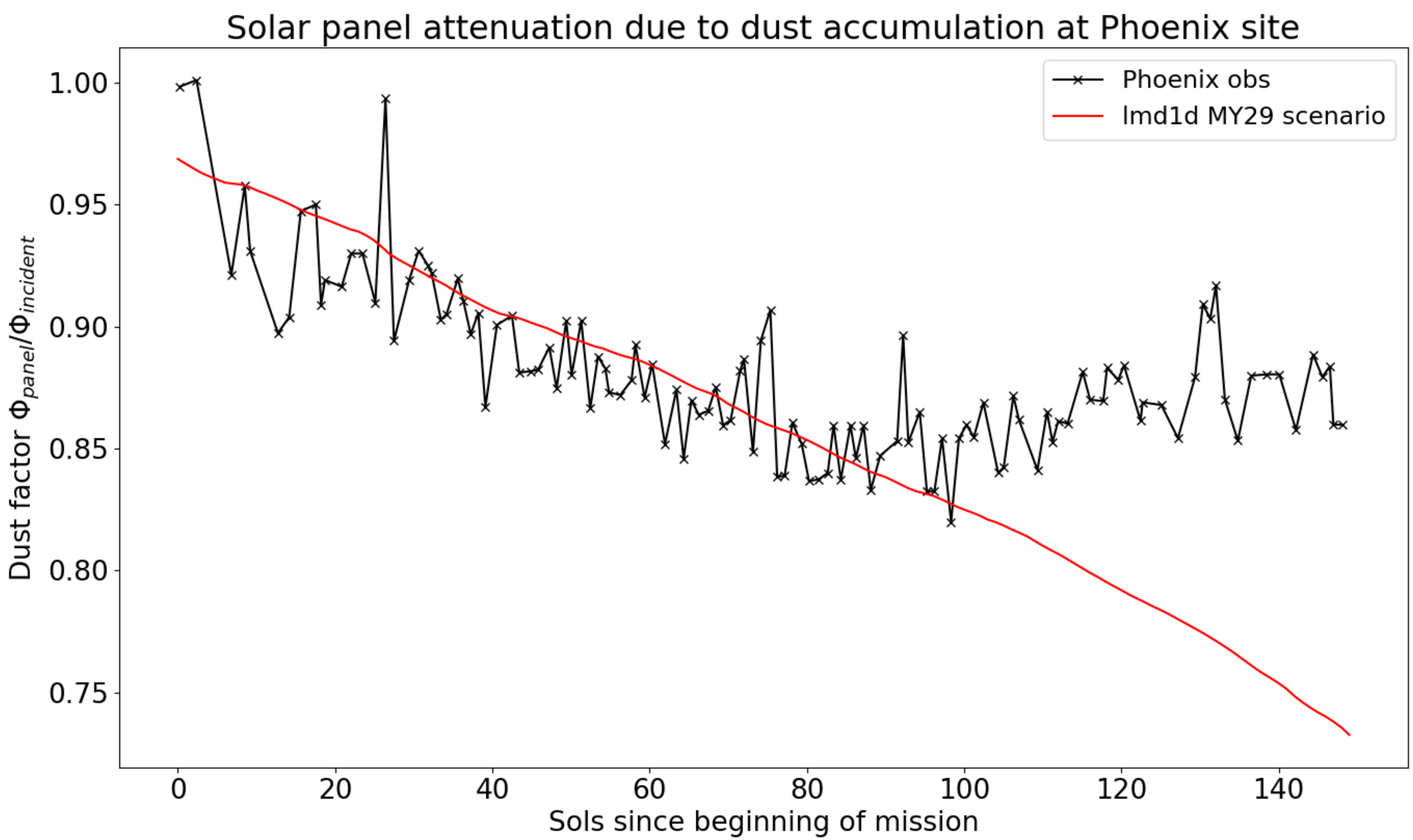
VALIDATION OF THE MODEL
OPPORTUNITY



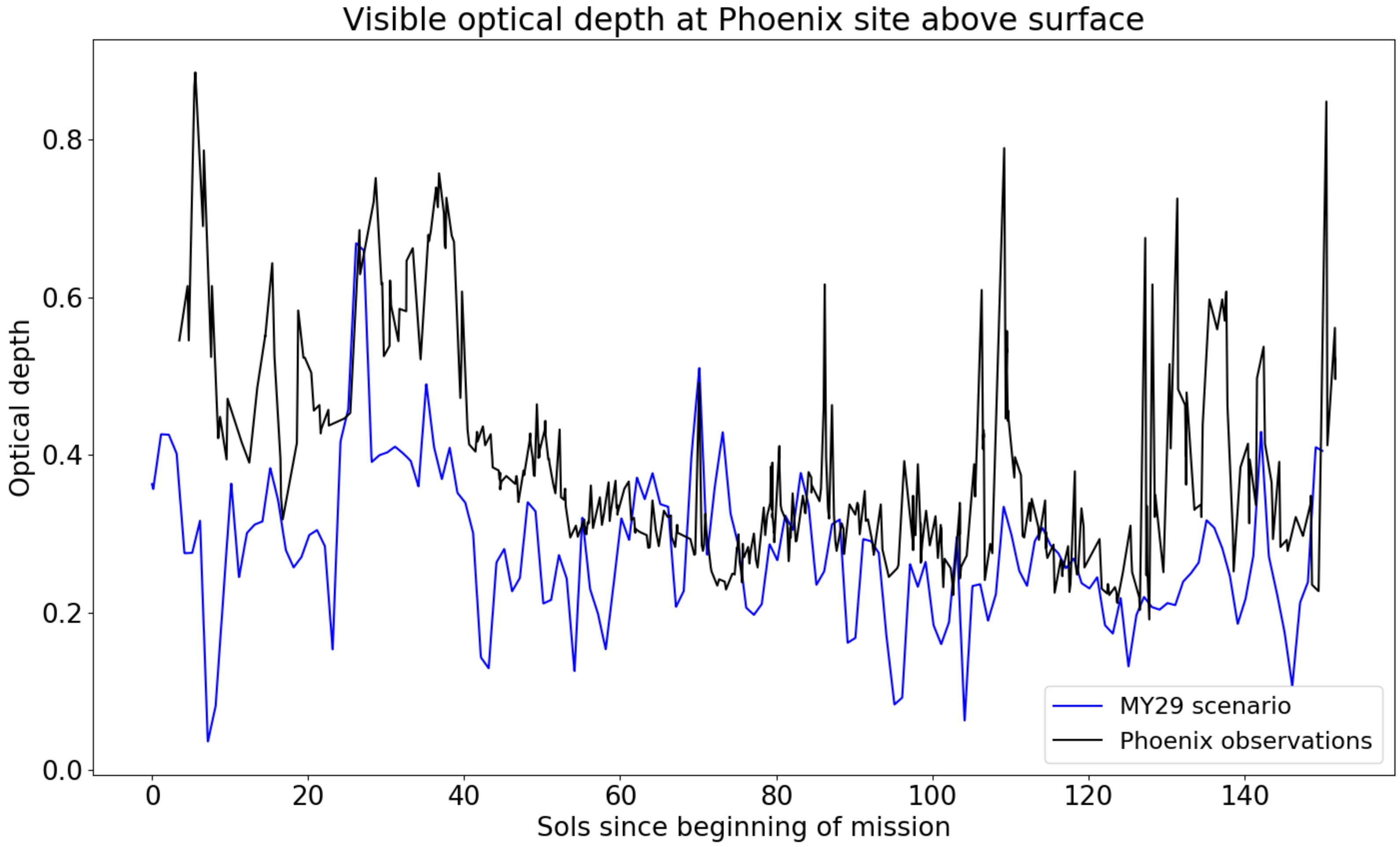
VALIDATION OF THE MODEL
PATHFINDER



VALIDATION OF THE MODEL
PHOENIX



VALIDATION OF THE MODEL
PHOENIX



CONCLUSION

- New tool allows a **good physical prediction** of the surface power in $W.m^{-2}$ received by a surface such as a solar panel
- **Inclination and orientation of the panel** is taken into account and can be specified as inputs of the model
- **Does not take into account any dust cleaning events** → pessimistic → good tool for future missions
- Comparisons with available observations satisfying
- Especially Insight : most consistent since **direct comparison between the model and the electrical current**
- For other missions : **only the dust factor** available (semi-observational semi-theoretical)