# Improving our Craftmans of Mars Global Climate Models Tuning: Future Directions?

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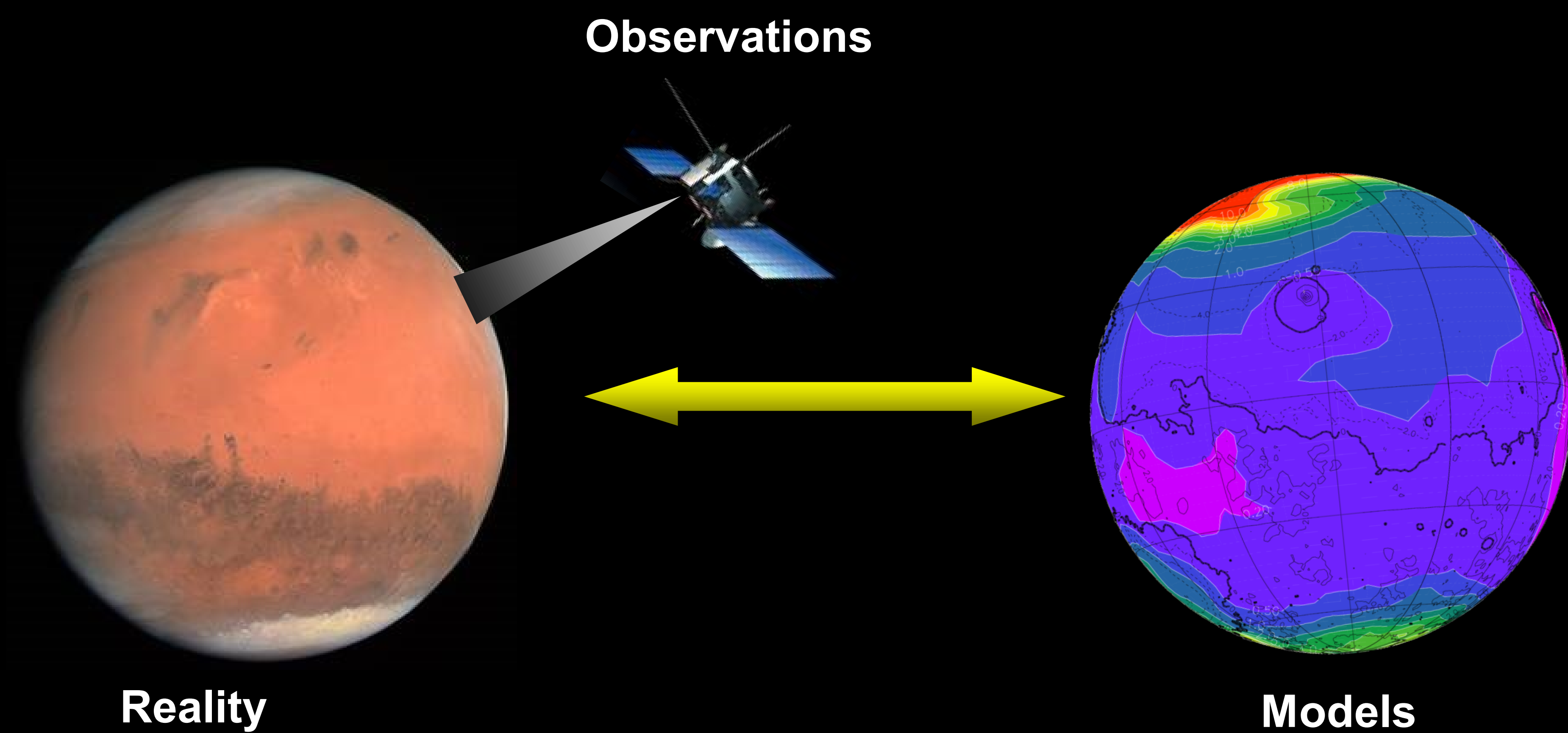
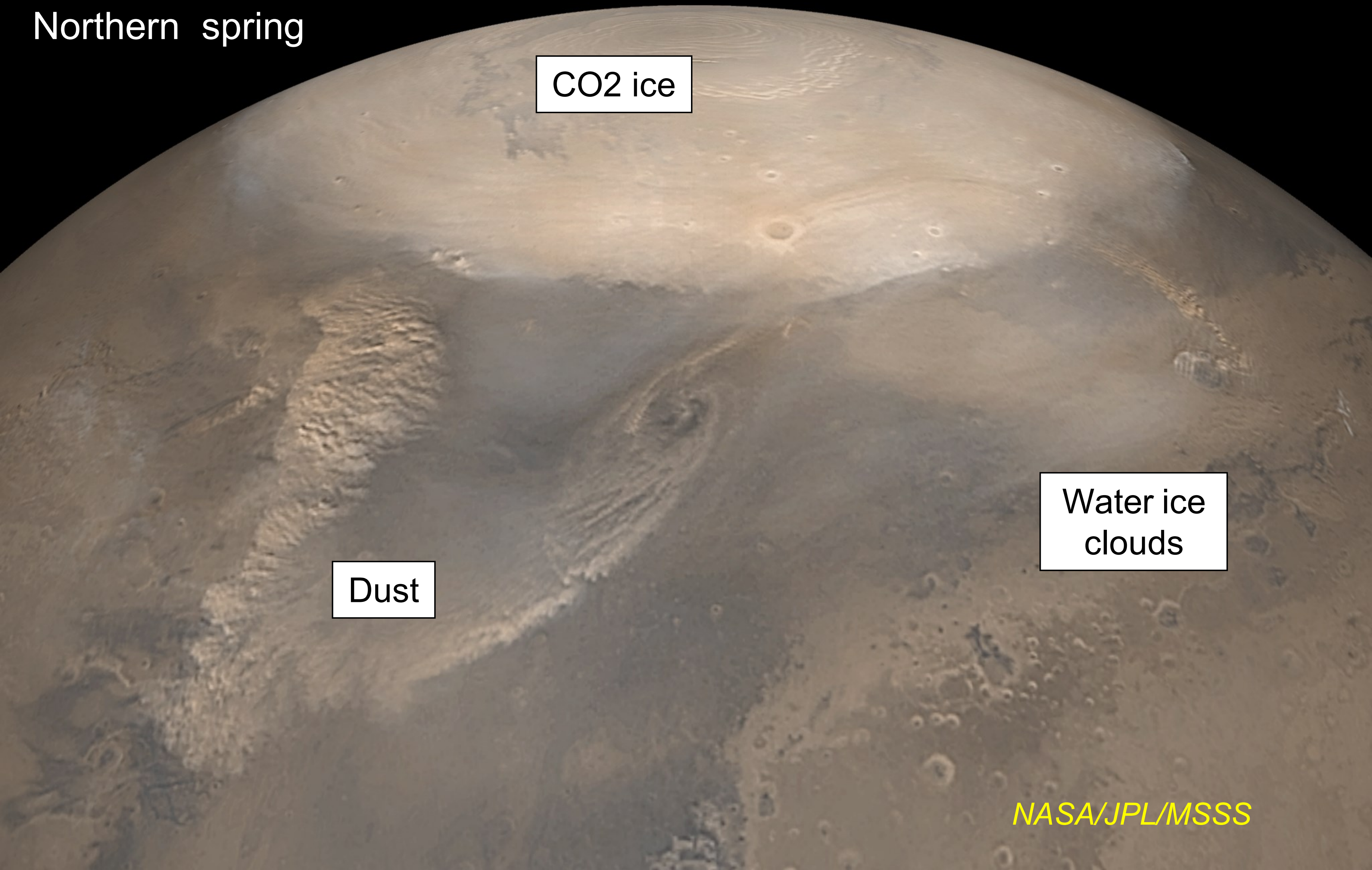
LMD

# An ambitious goal : Building a “virtual” Mars behaving like the real one, on the basis of universal equations

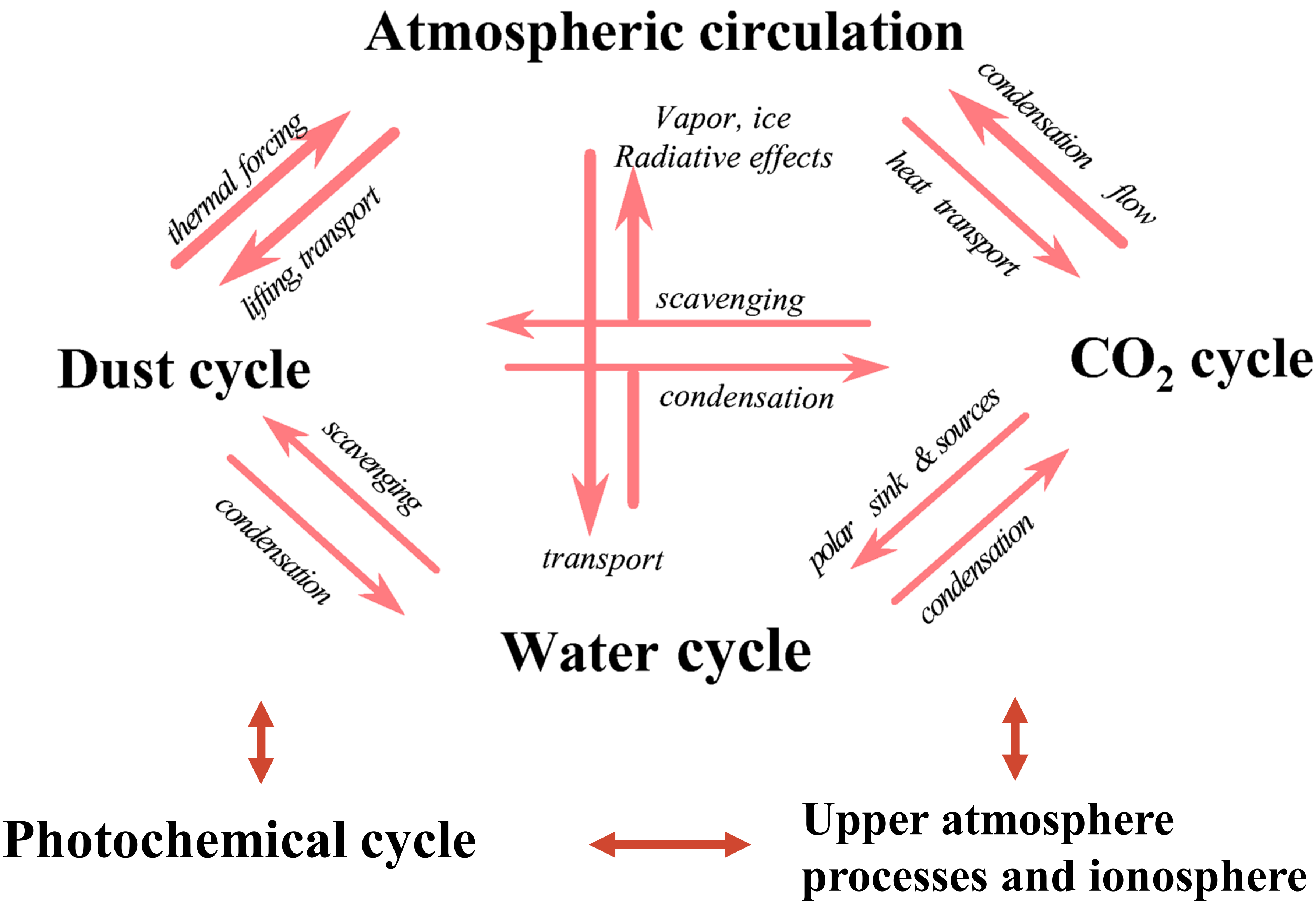


# **The Mars cycles :** CO2, dust, and water

Northern spring



## *Mars climate : a complex system*

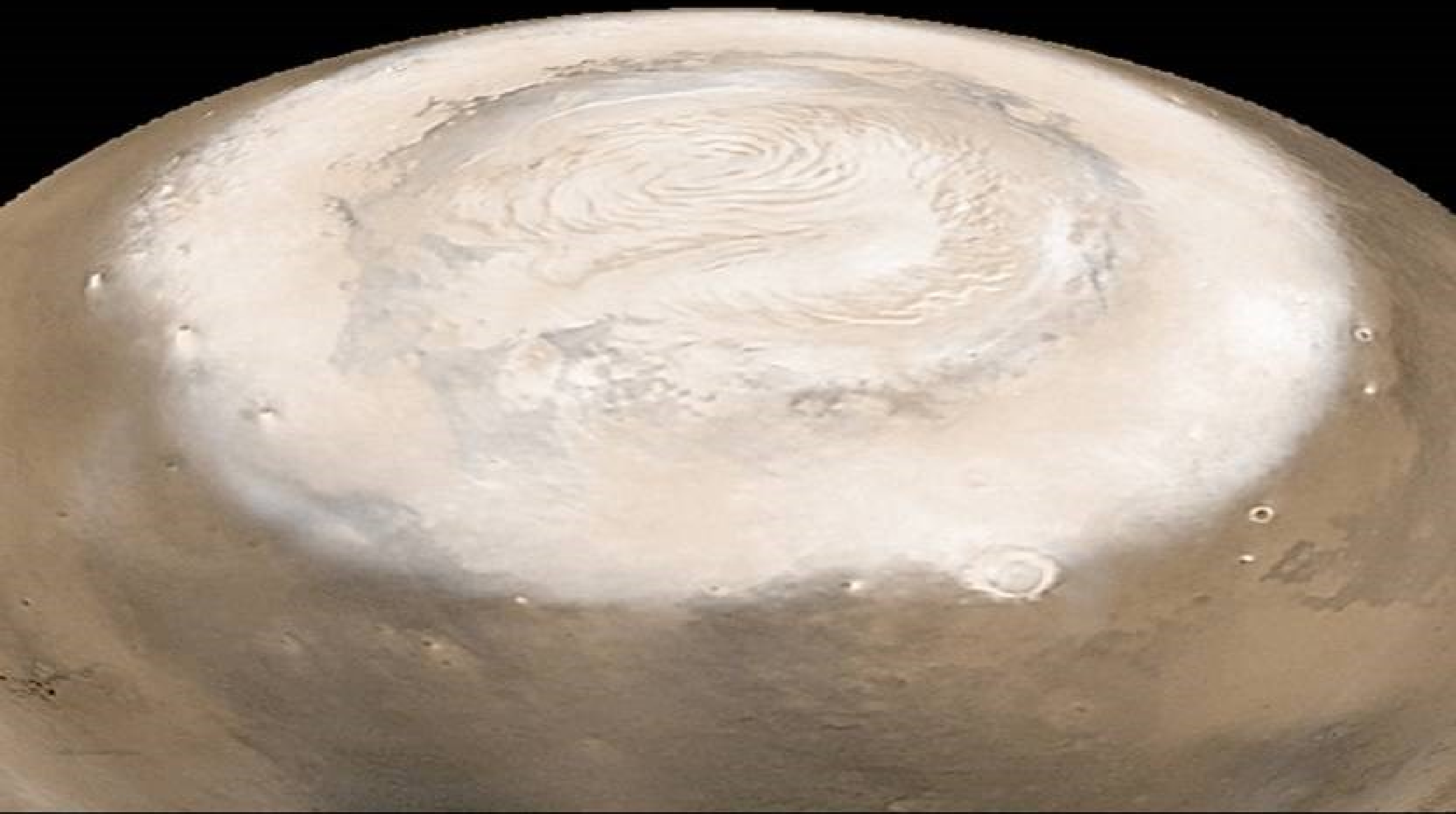


# Global Climate Model Tuning

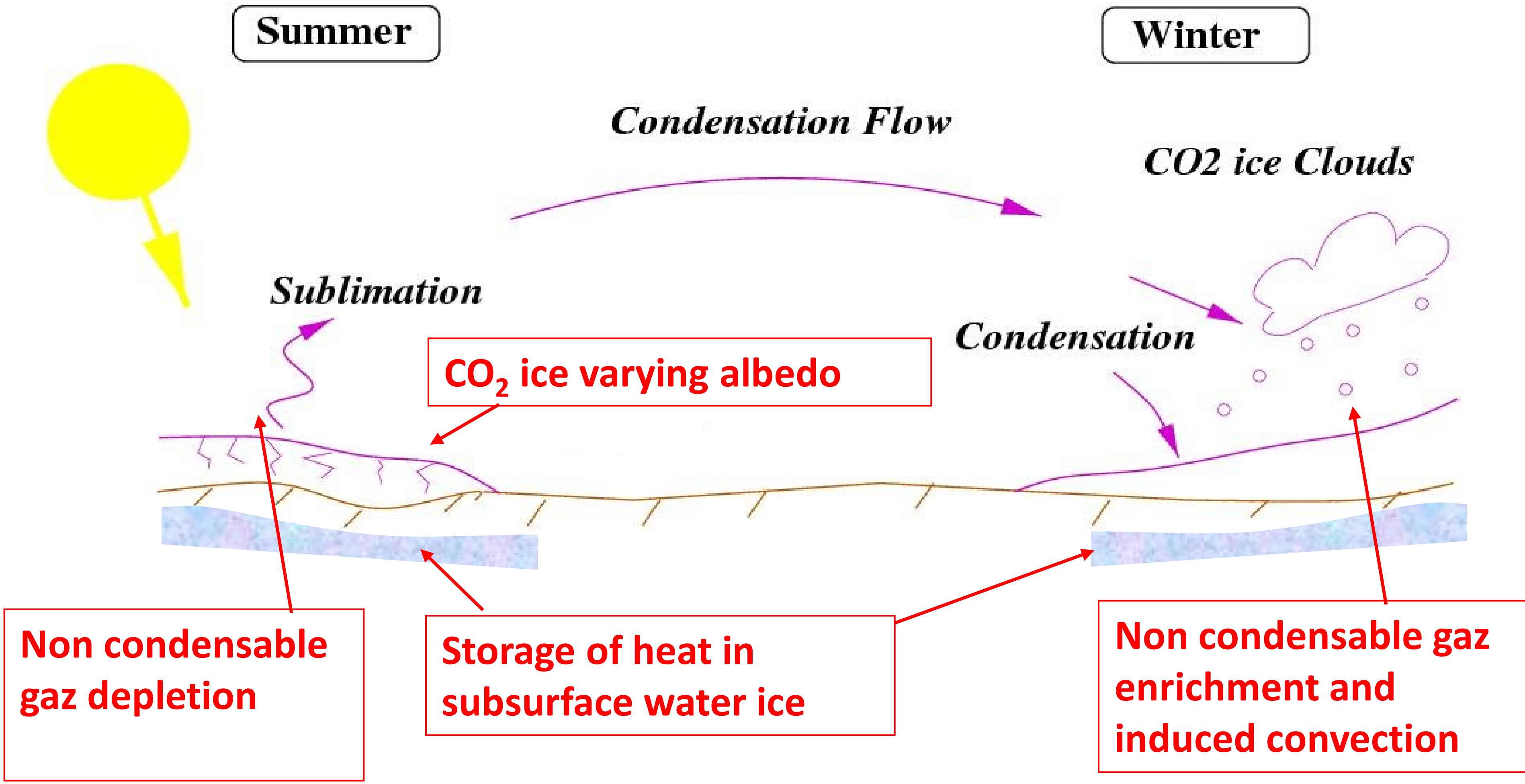
- GCMs rely on parametrizations, which attempt to summarize complex or multiscale processes through idealized and approximate representations.
- Parametrizations rely on sets of internal equations and depend on parameters which can be poorly constrained by observations
- Tuning : estimating the uncertain parameters in order to reduce the mismatch between specific observations and model results.

# An example: Tuning the $CO_2$ cycle

*Seasonal CO2 ice cap in spring (mosaic)*

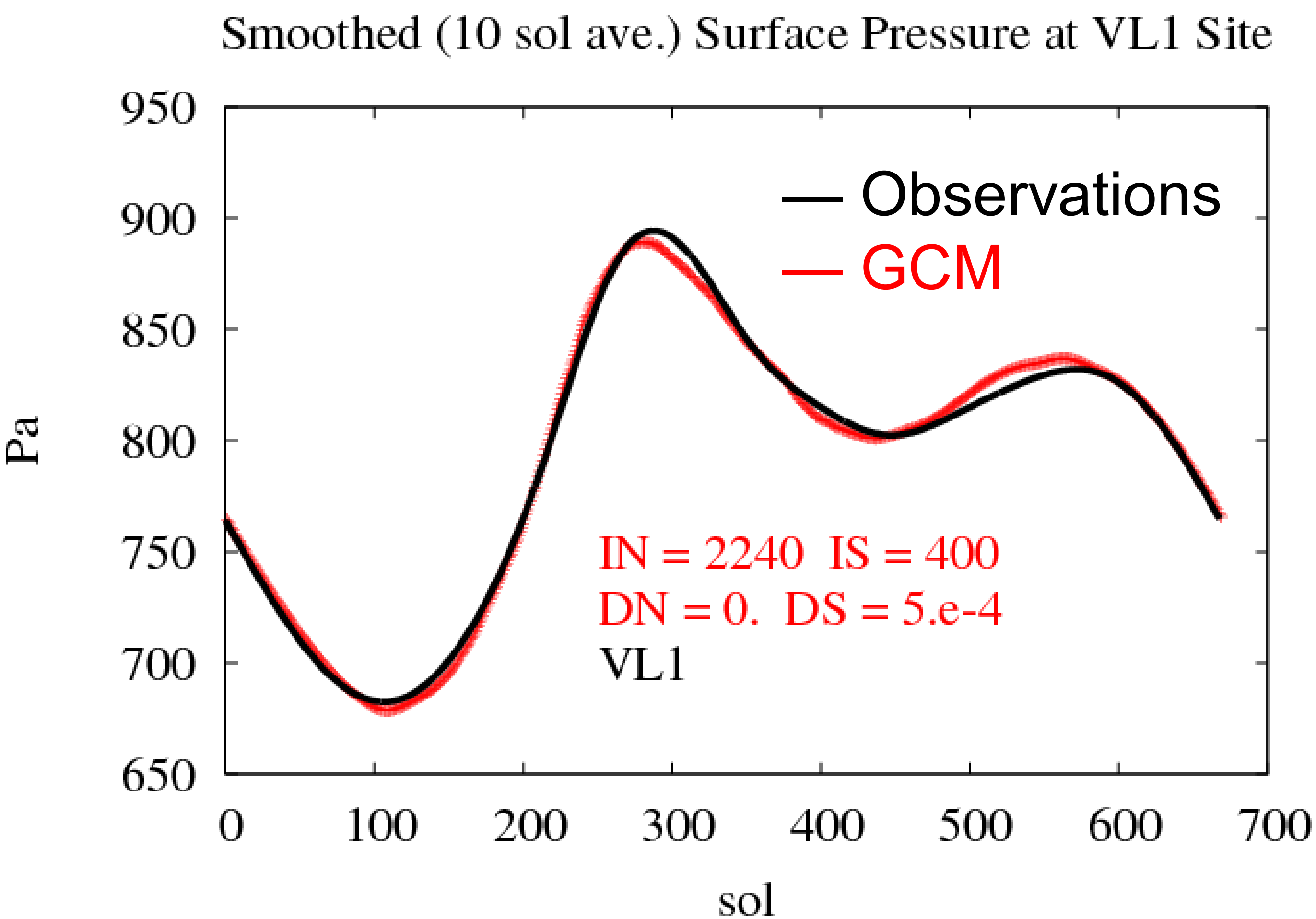


# Modeling the $CO_2$ cycle in the LMD GCM



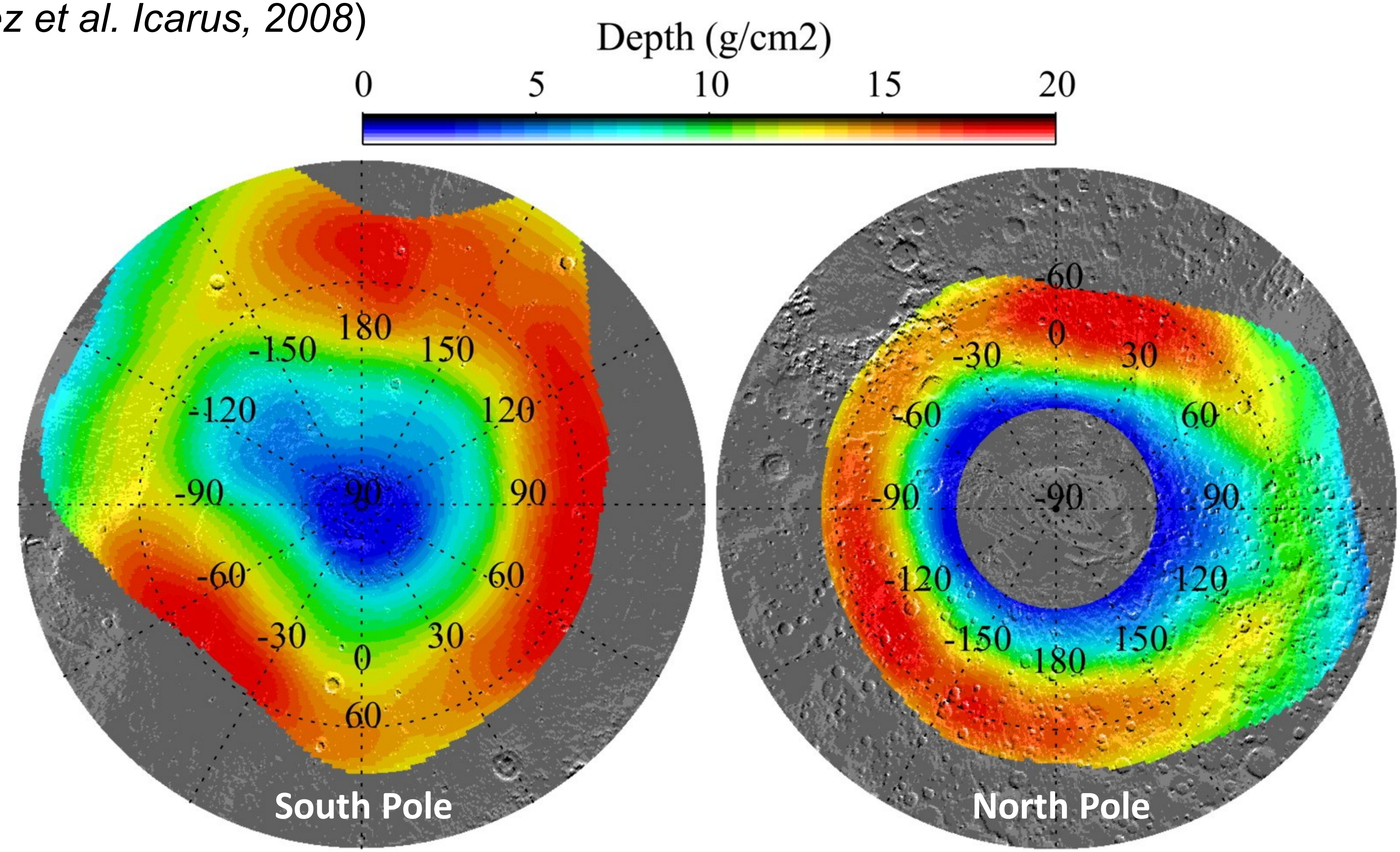
# Modelling Surface Pressure Evolution

Fitting Viking Lander 1 pressure measurements
with subsurface ice depth driven by Mars Odyssey Neutron Spectrometer ice depth measurements
(adjusting dry layer properties and subsurface ice thermal inertia)



# Taking into account subsurface Ice thermal inertia

(Water Ice table depth taken from Mars Odyssey Neutron spectrometer data)
(*Diez et al. Icarus, 2008*)




True depth depends on dry soil layer density and composition
⇨ **Tunable parameter**

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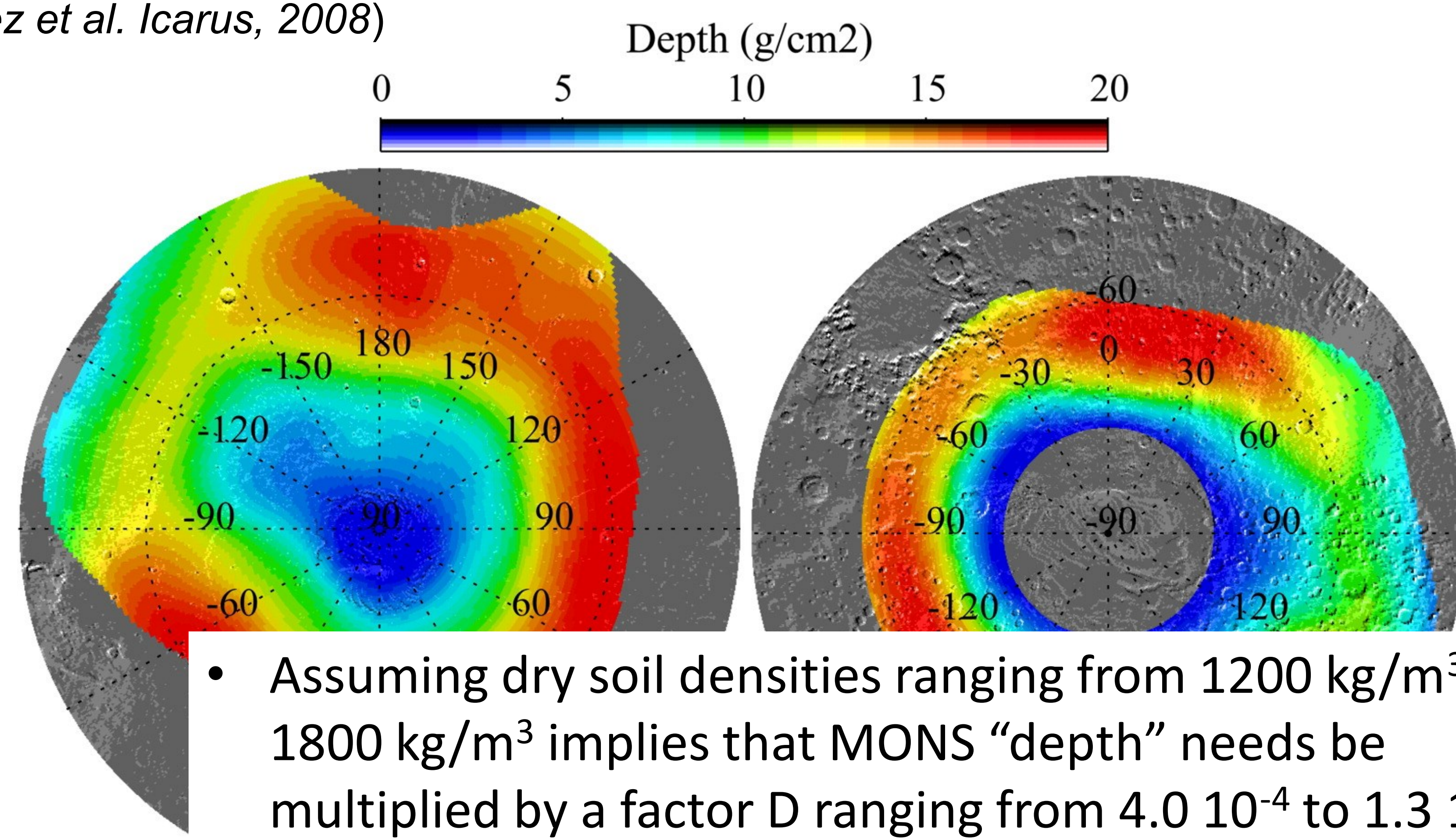
(*Diez et al. Icarus, 2008*)




- Assuming dry soil densities ranging from 1200 kg/m$^3$ to 1800 kg/m$^3$ implies that MONS "depth" needs be multiplied by a factor D ranging from 4.0 10$^{-4}$ to 1.3 10$^{-3}$.

  Decreasing D ⇔ Ice table rising to the surface

  Increasing D ⇔ Ice table sinking away

- Value of the thermal Inertia I of the water ice table?

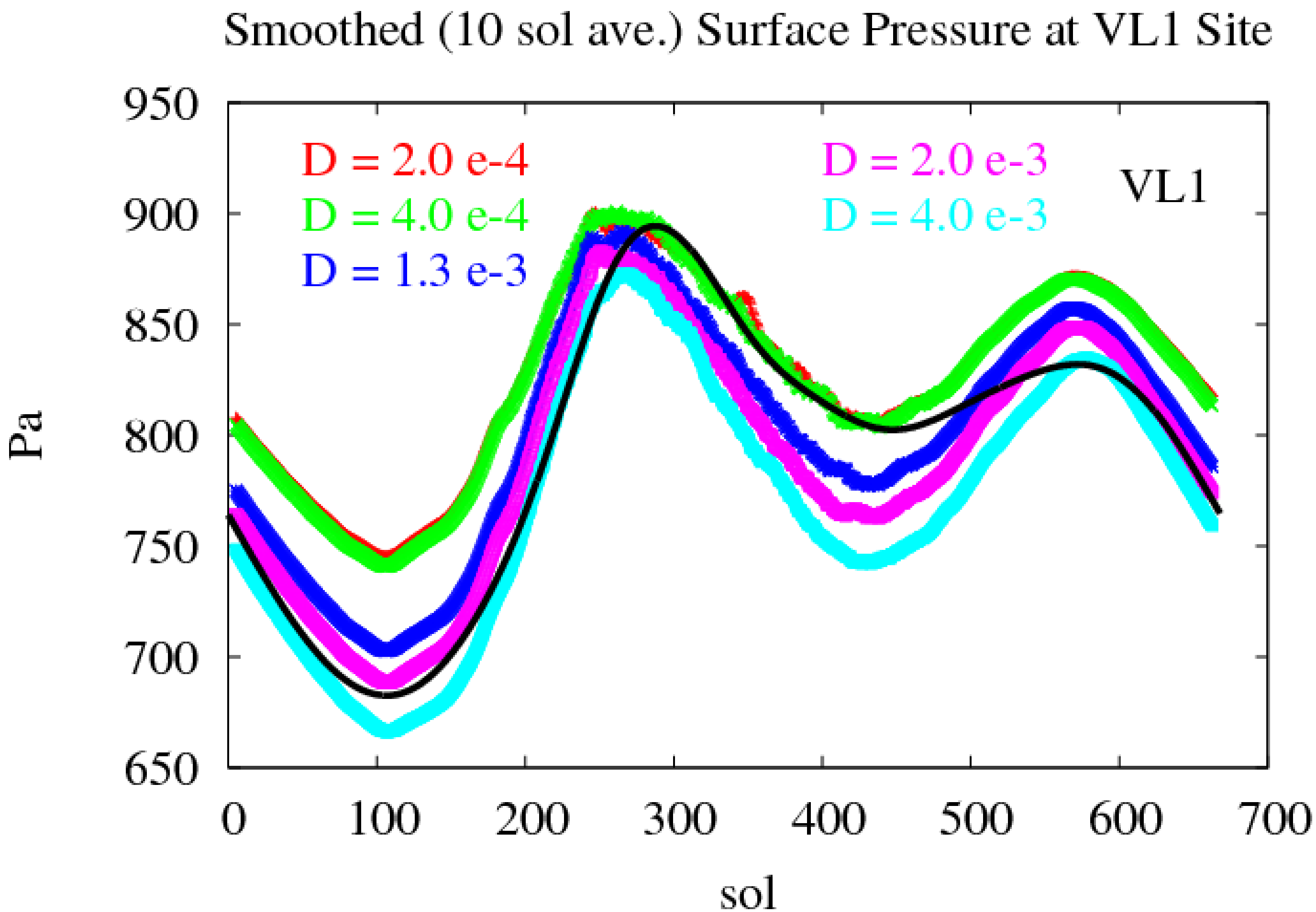
  Inertia likely between 400 and 4000 SI

True deptl
⇨ **Tunabl**

# Influence of ice table depth on the CO2 cycle

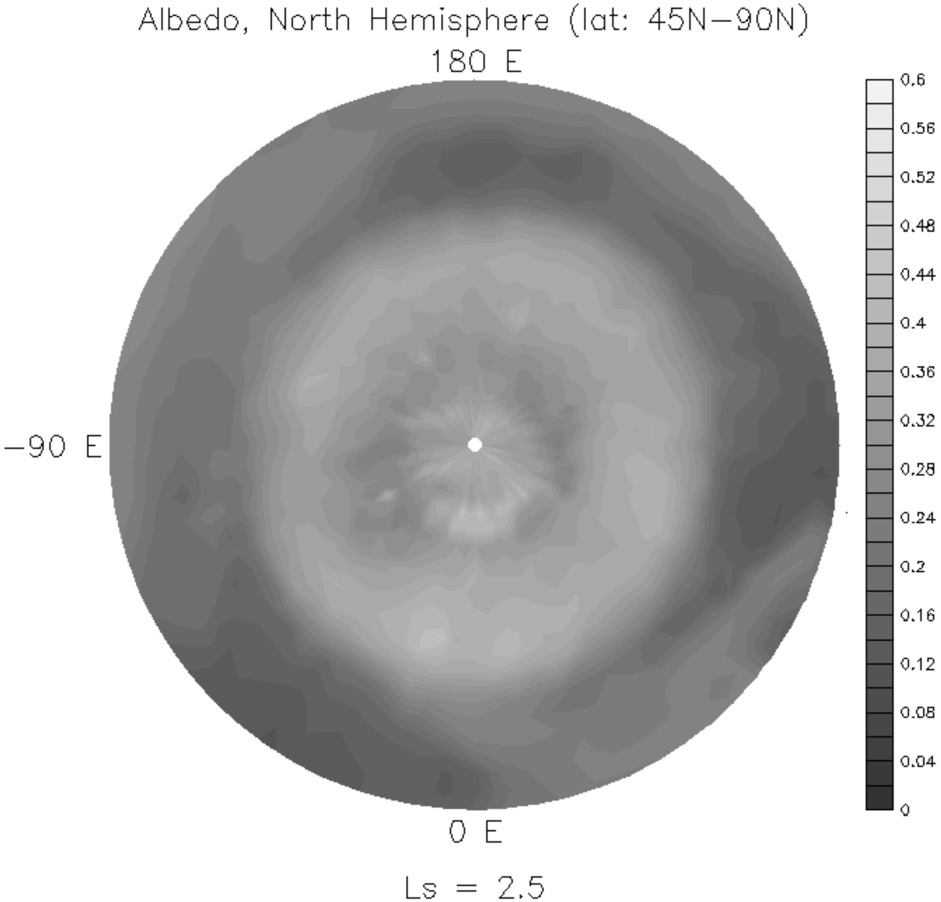
- Illustrative example:

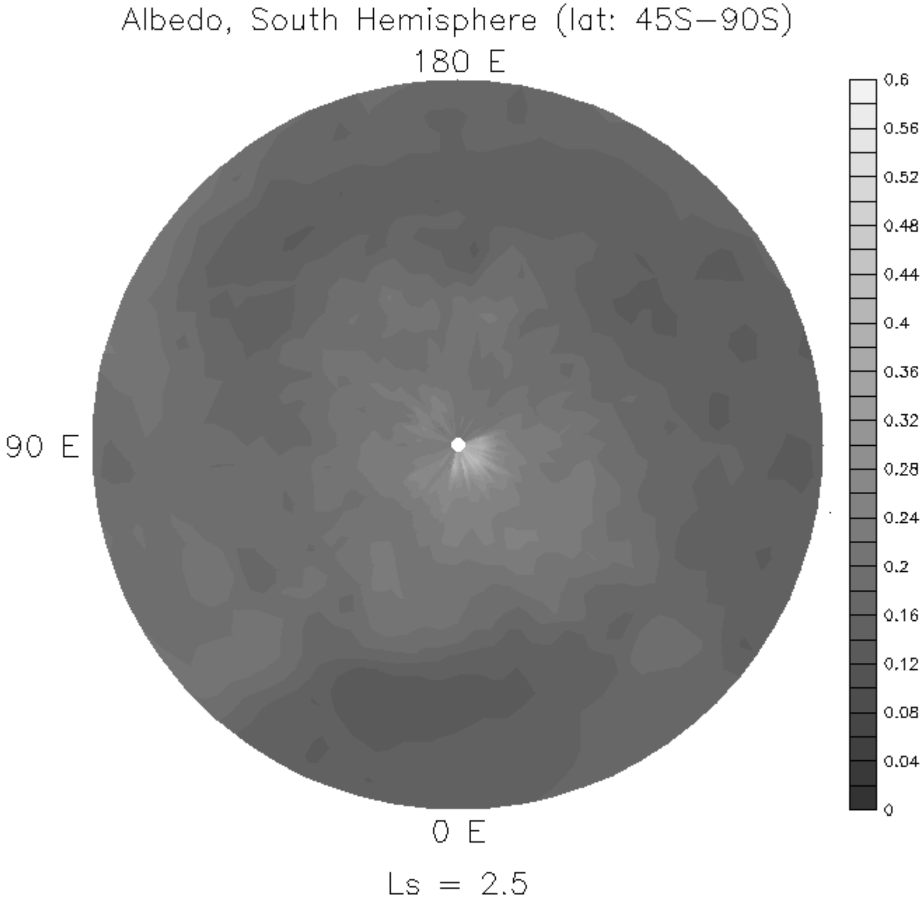
  - fixed (North&South) CO2 cap albedoes (A=0.4)



# TES Polar Cap albedoes

- Kindly provided by T. Titus
- Values (45° and poleward) used in the GCM when there is $CO_2$ ice, eventually with a multiplicative coefficient



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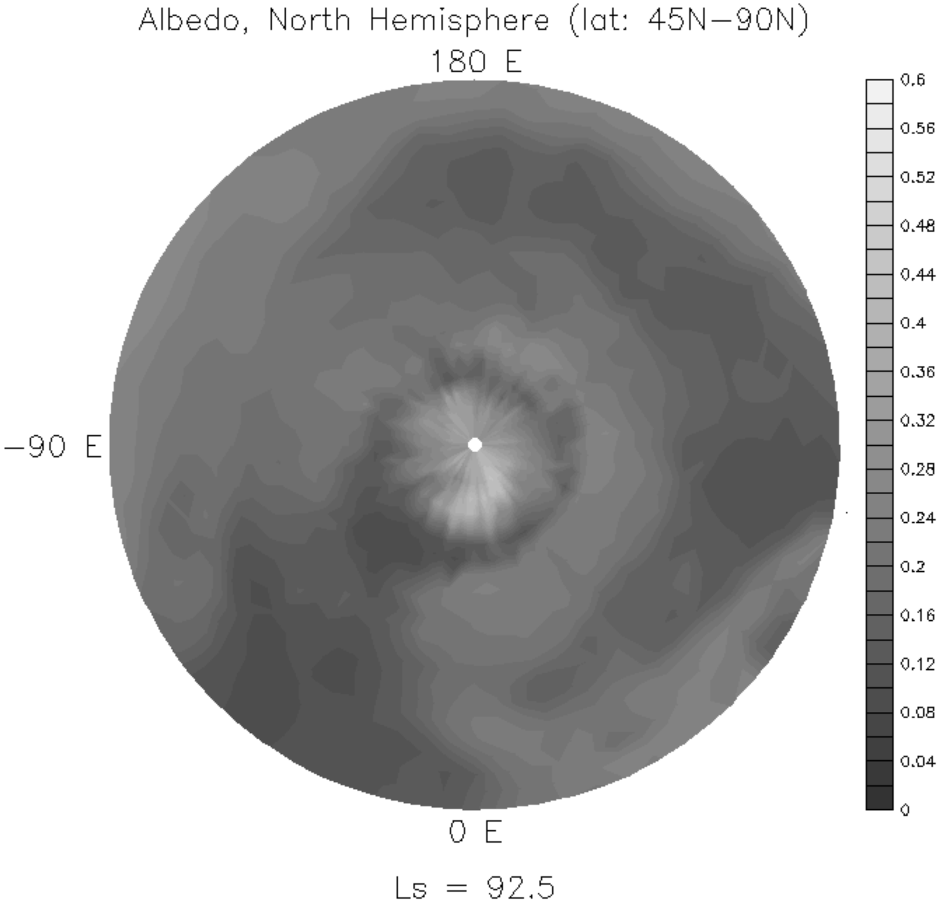


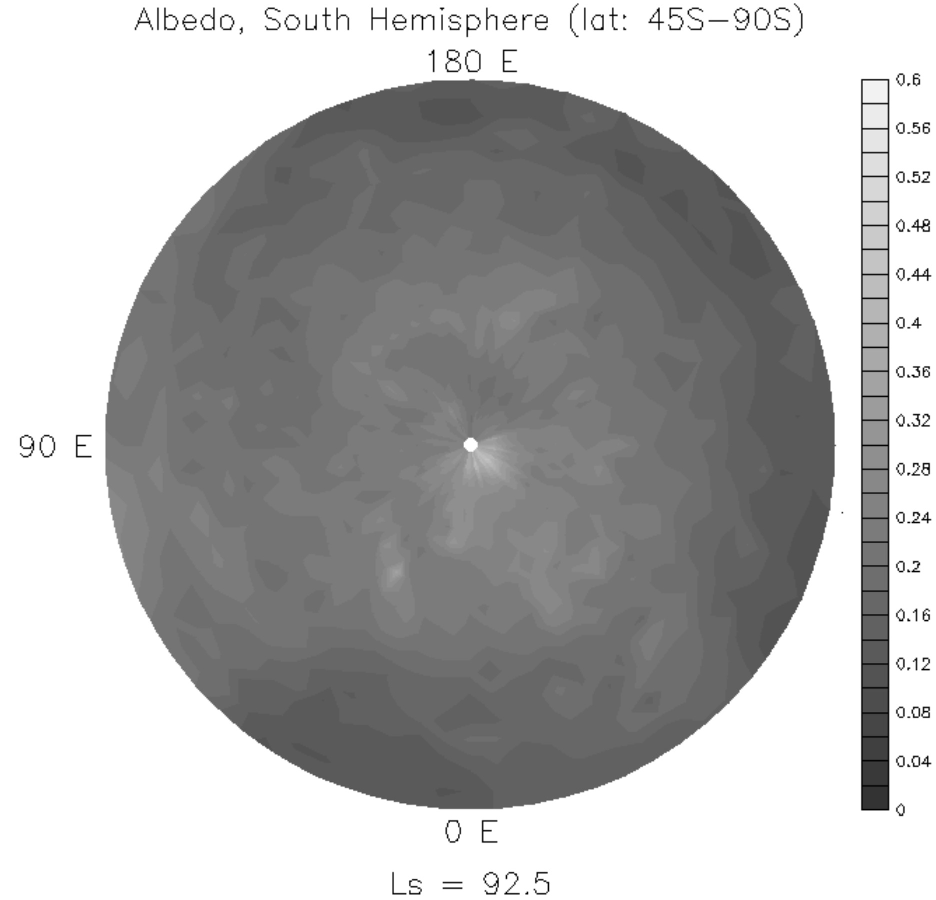

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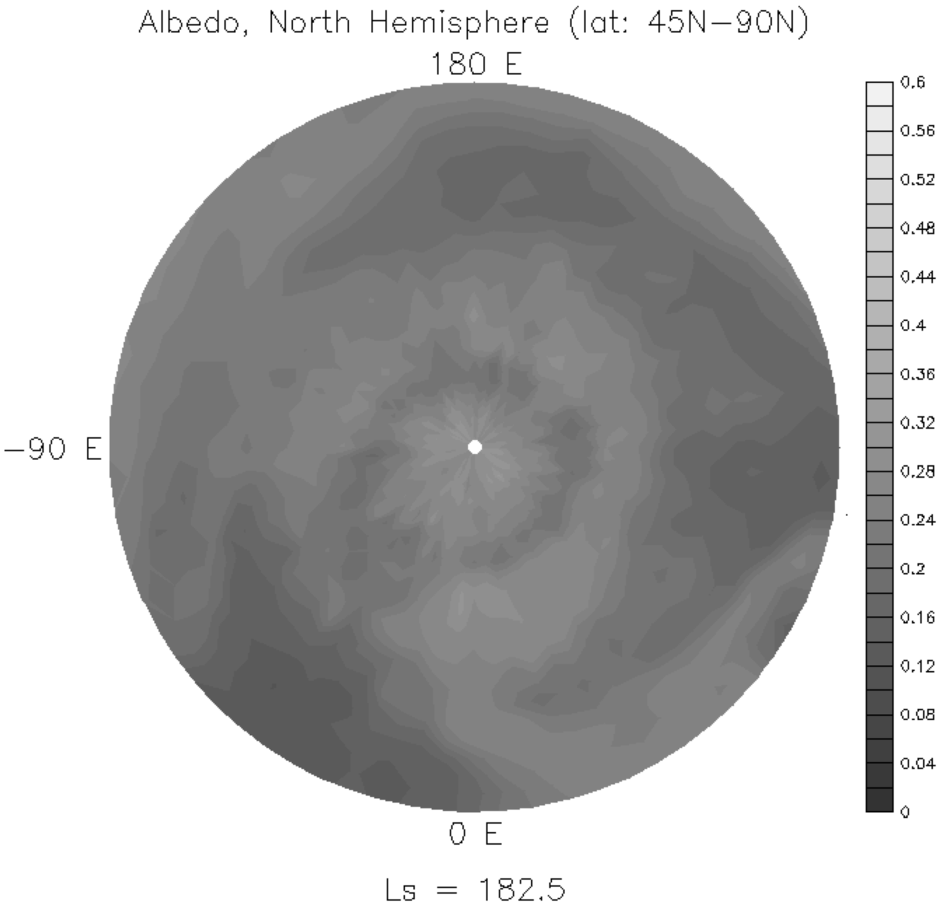


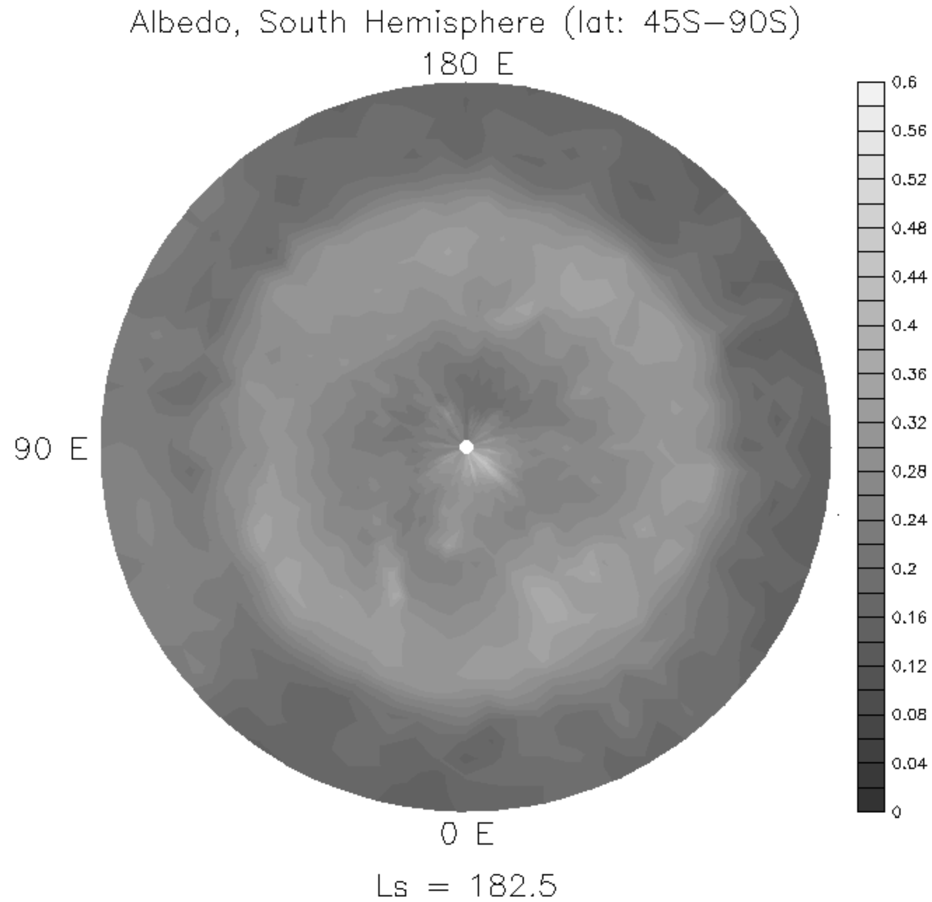

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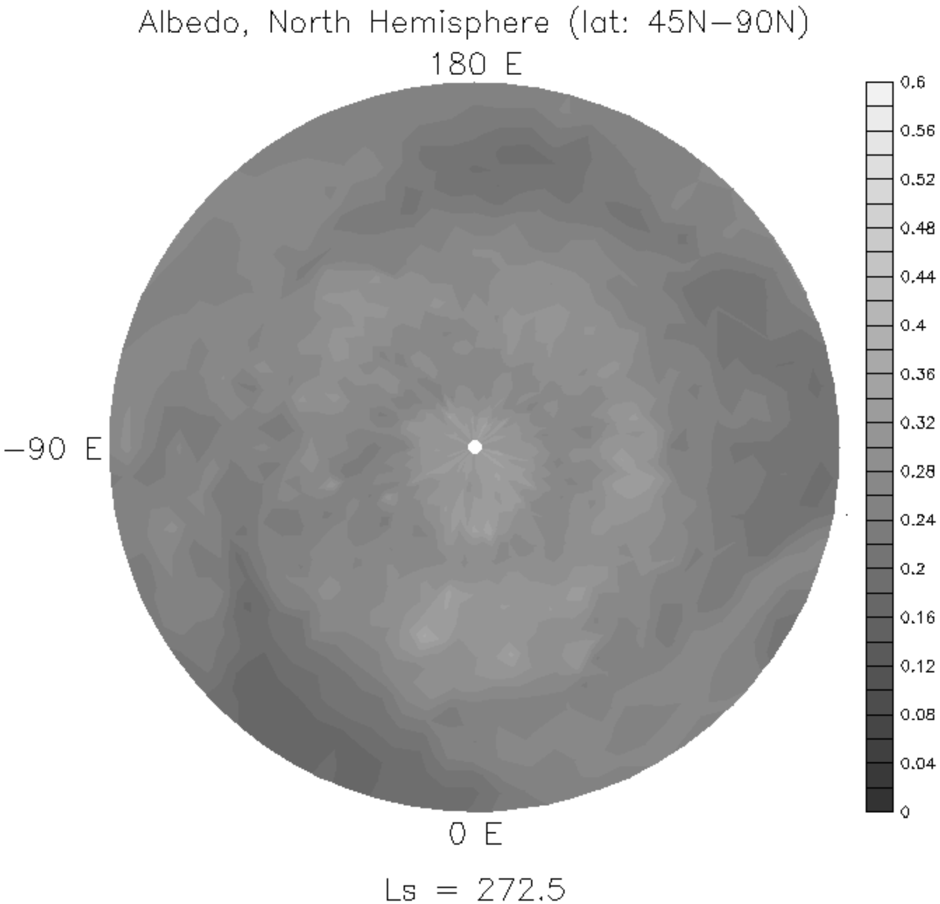
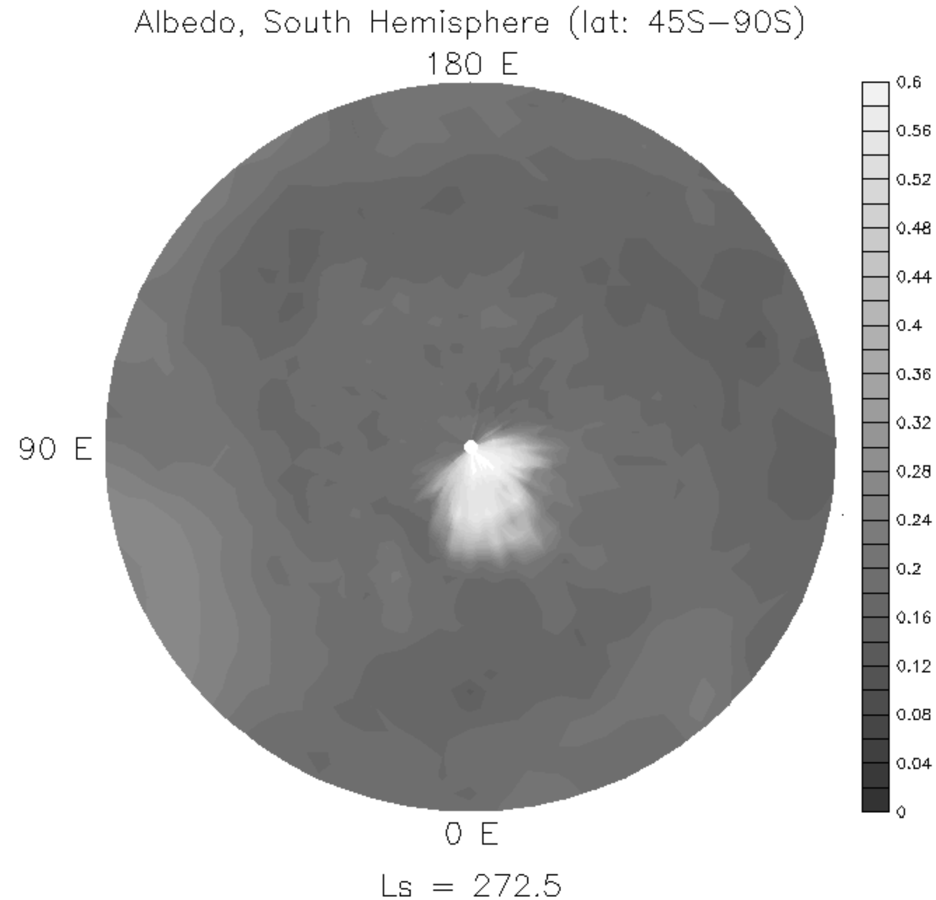
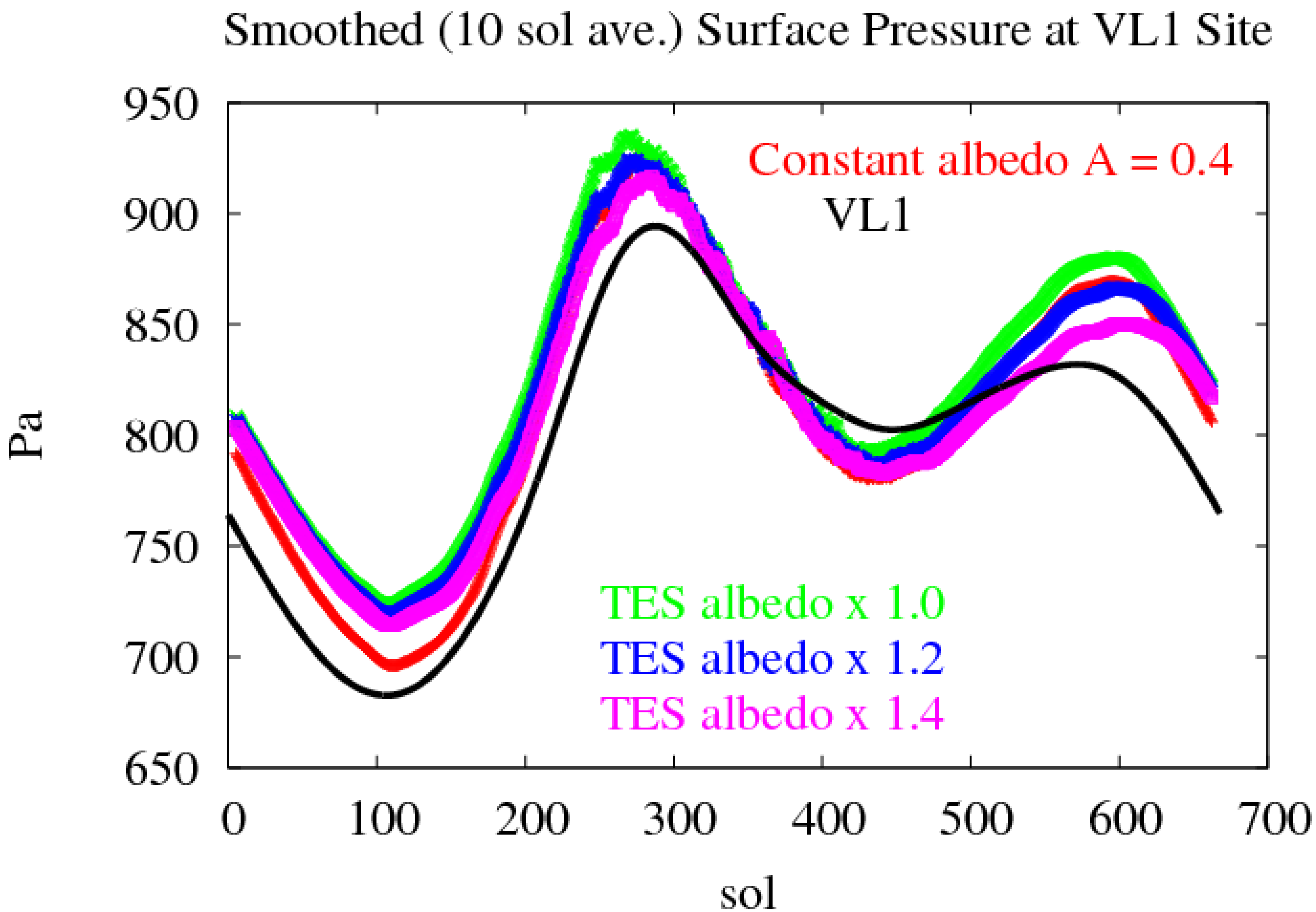


# Impact of TES cap albedoes on CO2 cycle

- Illustrative example:
  - No subsurface ice tables

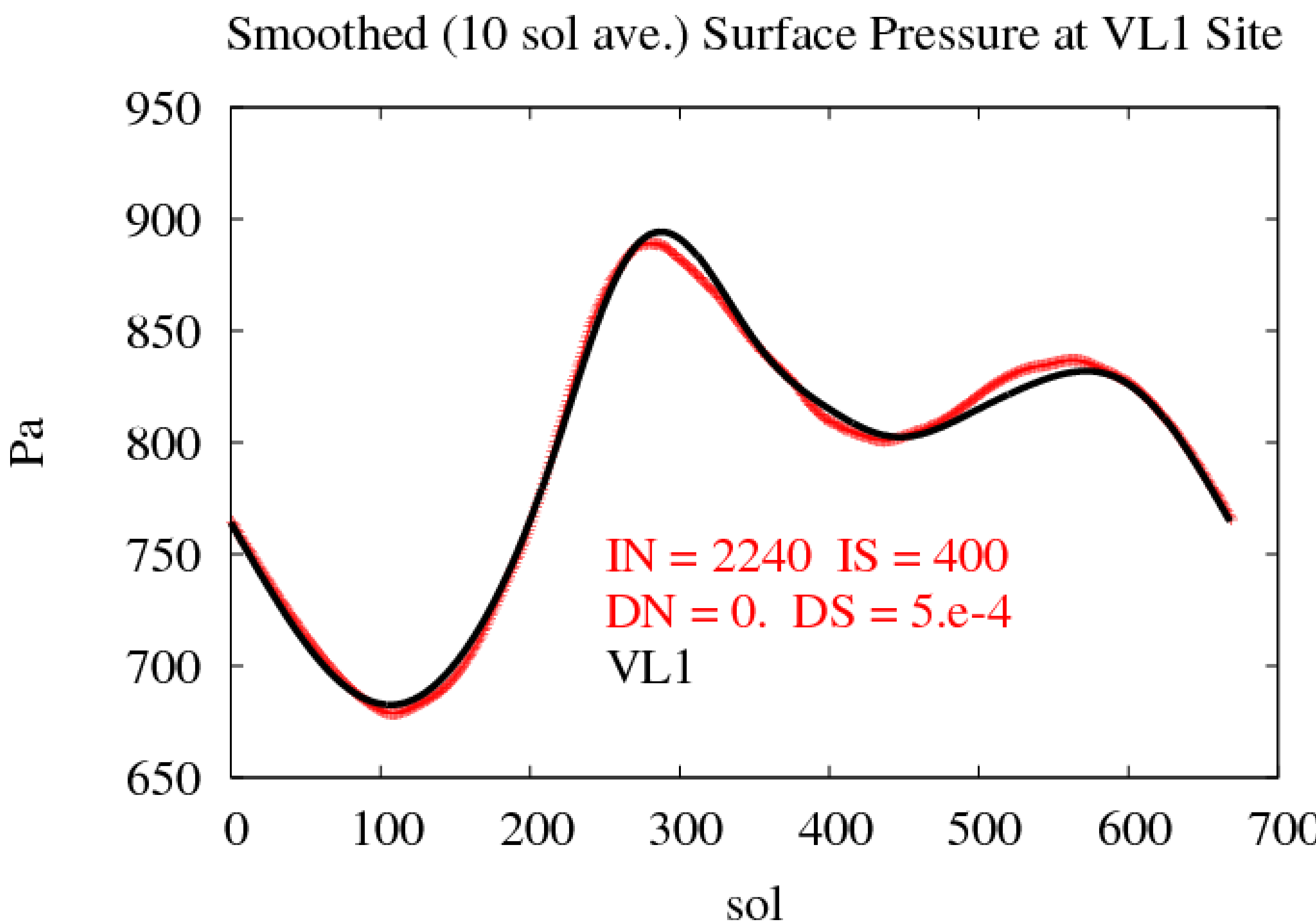


# Varying MONS ice depth and ice thermal inertia

- Encompassing model runs with extreme values of:

- MONS ice table depth (DN, DS): 0 and 1.3 $10^{-3}$

- MONS ice table thermal inertia (IN, IS): 400 and 4000 $J.s^{-1/2}.m^{-2}.K^{-1}$




Results with TES albedo factor 1.4

(and CO2 cap ice emissivity of 0.90 )

Best fit parameters:

IN = 2240

IS = 400

DN = 0

DS = 5.0 $10^{-4}$

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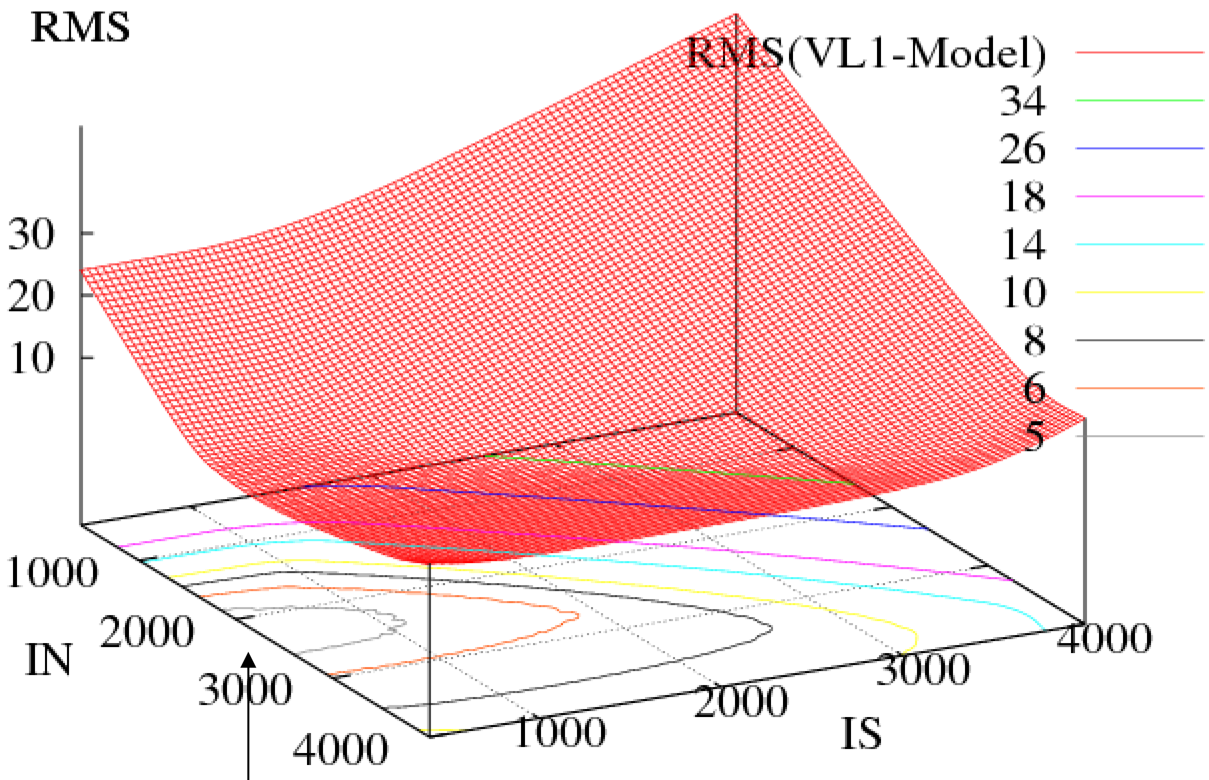


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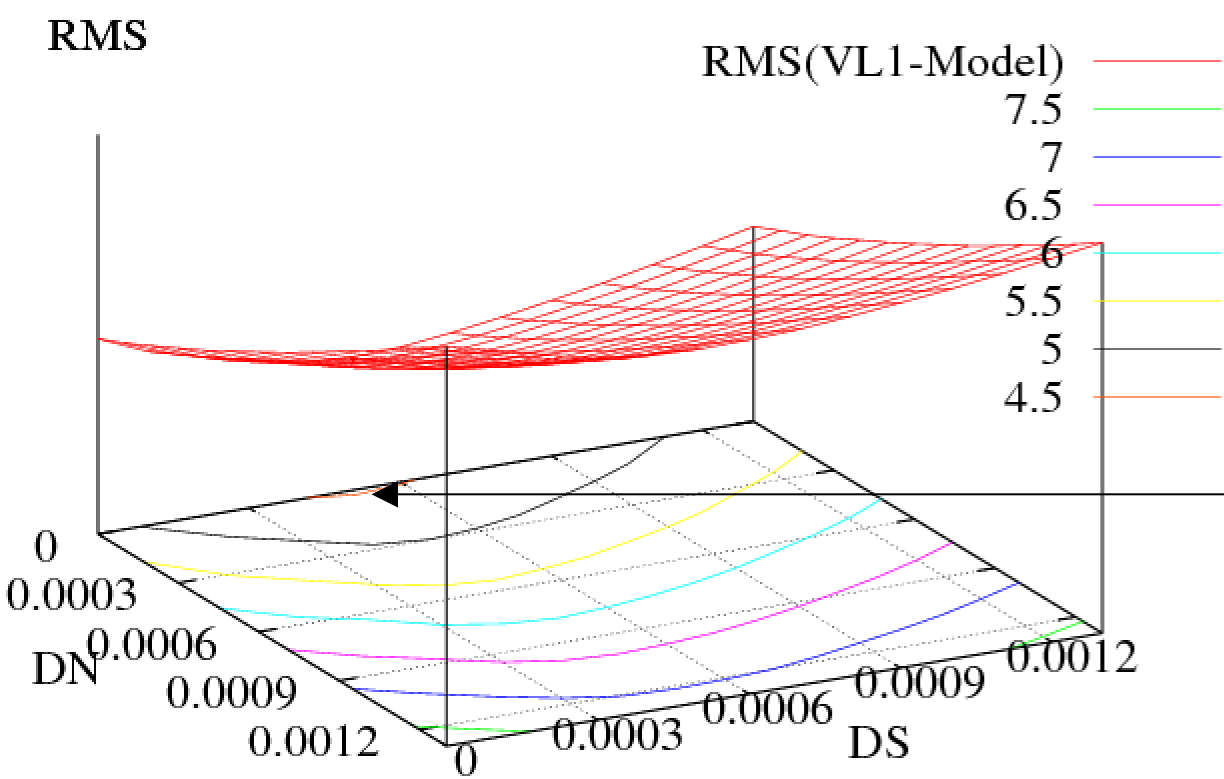


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<u>Best fit parameters</u>:

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IS = 400

DN = 0

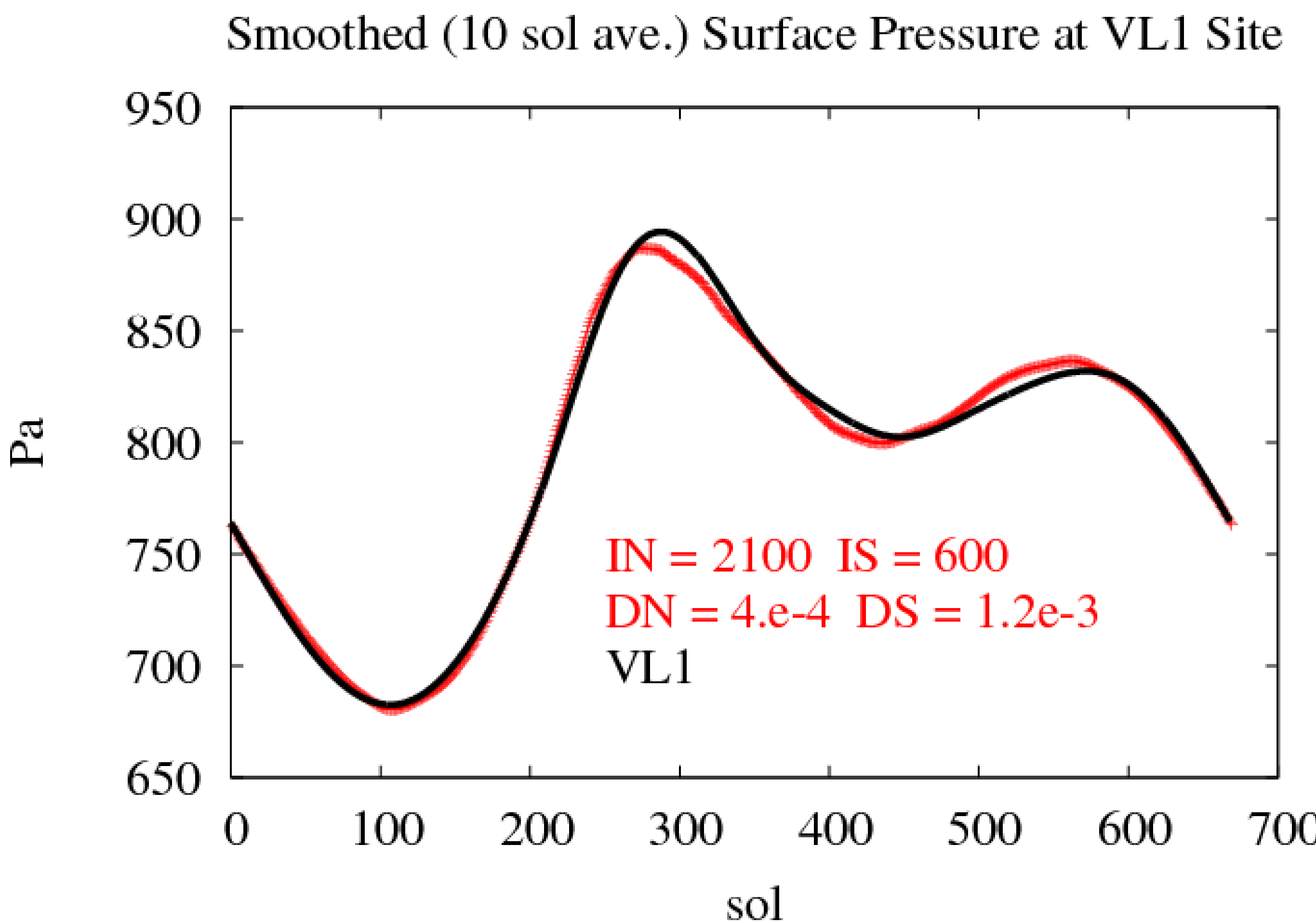
DS = 5.0 $10^{-4}$

# Many “equally reasonable” possibilities…

- Encompassing model runs with extreme values of:

- MONS ice table depth (DN, DS): $4.0\ 10^{-4}$ and $1.3\ 10^{-3}$

- MONS ice table thermal inertia (IN, IS): 600 and 3000 $J.s^{-1/2}.m^{-2}.K^{-1}$




Results with TES albedo factor 1.4

(and CO2 cap ice emissivity of 0.85 )

Best fit parameters:

IN = 2100

IS = 600

DN = $4.0\ 10^{-4}$

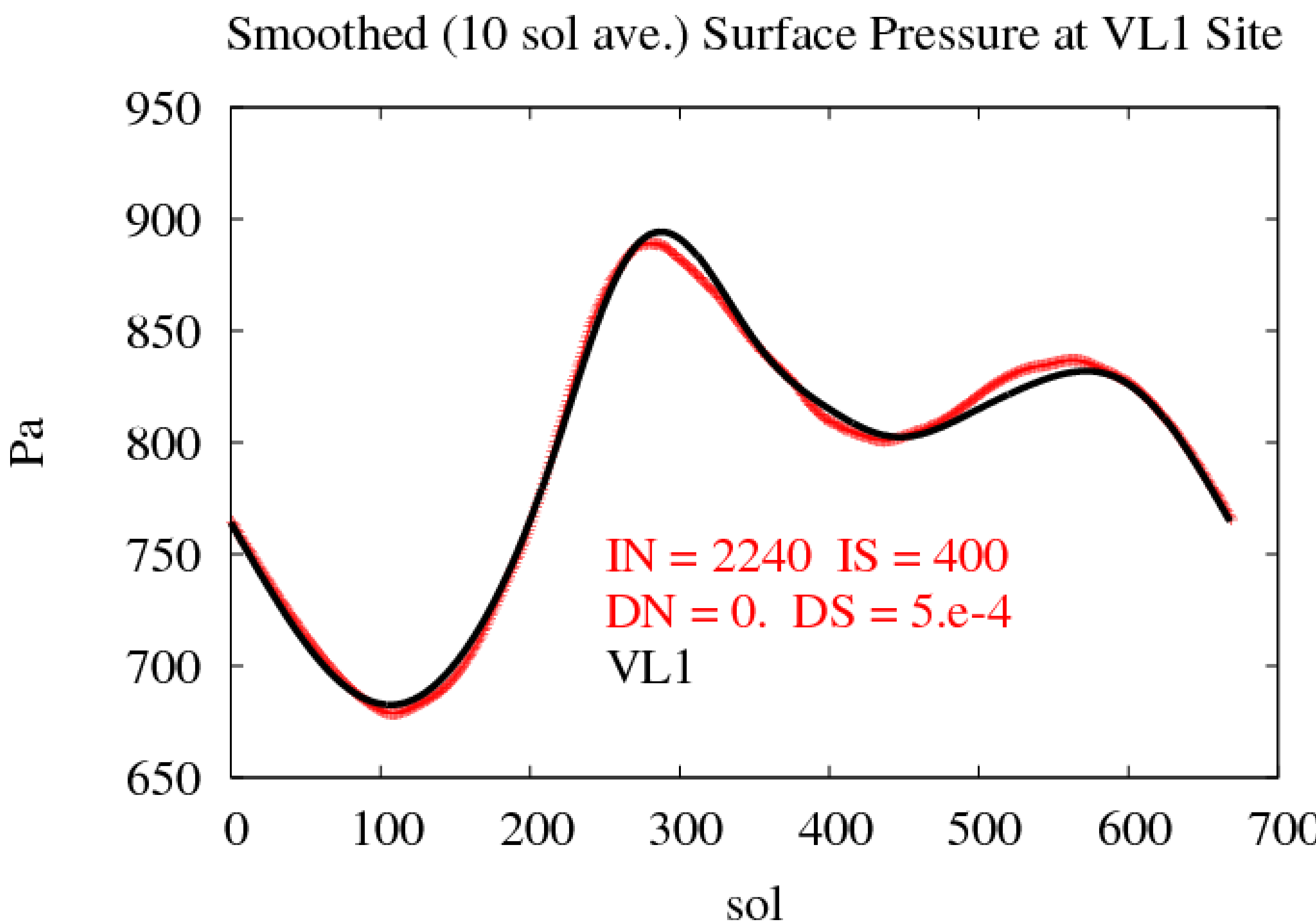
DS = $1.2\ 10^{-3}$

# Varying MONS ice depth and ice thermal inertia

- Encompassing model runs with extreme values of:

  - MONS ice table depth (DN, DS): 0 and 1.3 $10^{-3}$

  - MONS ice table thermal inertia (IN, IS): 400 and 4000 $J.s^{-1/2}.m^{-2}.K^{-1}$




Results with TES albedo factor 1.4

(and CO2 cap ice emissivity of 0.90 )

<u>Best fit parameters</u>:

IN = 2240

IS = 400

DN = 0

DS = 5.0 $10^{-4}$

# Global Climate Model Tuning Strategies

- As the GCMs becomes more advanced , i.e. include new additional parametrizations, some advocate to "*make the process of model tuning more explicit and transparent*" F. Hourdin et al., "The art and Science of Climate Model Tuning", BAMS, 2017.
- Most often parametrizations are tuned one at a time, even though they are coupled and subject to feedback from the whole system.
- Beyond just documenting the tuning strategies that were used for isolated parametrizations, arises the question of **tuning a GCM as a whole**, and how **UQ** (Uncertainty Quantification) methods or **DA** (Data Assimilation) may help.

# Example of parameter estimation using DA

- From Schirber et al, “*Parameter estimation using data assimilation in an atmospheric general circulation model: From a perfect toward the real world*”, J. Adv. Model. Earth Syst., 2013.
- Test (in an Earth GCM) the evaluation of 4 closure parameters of a cumulus-convection scheme:

**Table 1.** List of Closure Parameters With the Corresponding Default Values for ECHAM6 at T31L19[a]

| Parameter | Acronym | Range | Default Value | Unit |
|---|---|---|---|---|
| Entrainment rate for shallow convection | $\epsilon_s$ | $3 \times 10^{-4}$ to $1 \times 10^{-3}$ | $3 \times 10^{-4}$ | $m^{-1}$ |
| Entrainment rate for penetrative convection | $\epsilon_p$ | $3 \times 10^{-5}$ to $5 \times 10^{-4}$ | $1 \times 10^{-4}$ | $m^{-1}$ |
| Cloud mass flux above level of nonbuoyancy | $\beta$ | 0.1–0.3 | 0.27 | $m^{-1}$ |
| Conversion rate from cloud water to rain | $\gamma$ | $1 \times 10^{-4}$ to $5 \times 10^{-3}$ | $4 \times 10^{-4}$ | $s^{-1}$ |

[a]The range of parameter values is chosen by expert elicitation and has been used in parameter perturbation experiments by *Klocke et al.* [2011] with ECHAM5.

- These scalar parameters are moreover expanded to 2D spatial arrays (=> yields a posteriori information about possible geographical distributions thereof)

# Example of parameter estimation using DA

- 2 parameters end up with values compatible with the literature, one to a different value, and one does not converge.

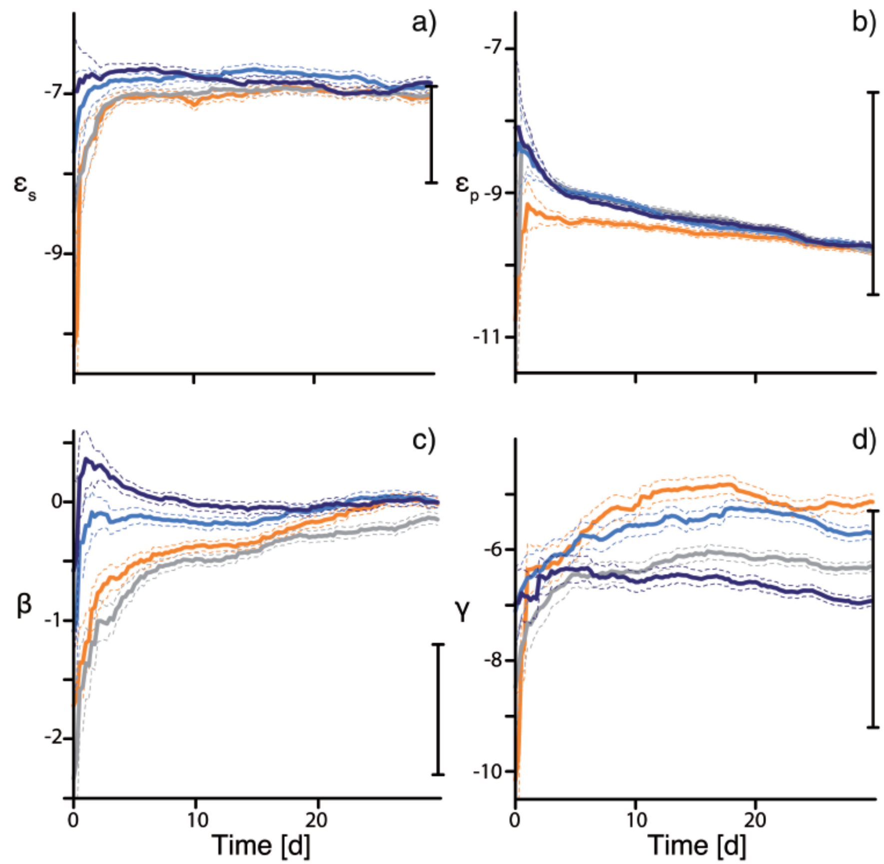



**Figure 6.** Evolution of four closure parameters (a–d) with assimilation of real observations showing the distribution mean (solid lines) and spread (dashed lines) for different initial parameter distributions (colors). The parameter values are shown in log space, and the vertical black range displays possible parameter values chosen by expert elicitation.

# Example of global tuning using UQ

- From Williamson et al, "*History matching for exploring and reducing climate model parameter space using observations and a large perturbed physics ensemble*", Clim. Dyn., 2013.
- Because the multidimensional parameter space to explore is too huge to be systematically explored with GCM runs, only a small (~O(100)) subset of simulations are run and an "emulator" (which includes information on uncertainty in the GCM predictions) is generated to explore parameter space and "*rule out regions of the parameter space that are inconsistent with observations given the relevant uncertainties*".

# Example of global tuning using UQ

- 2D projections of NROY (Not Ruled Out Yet) densities for the chosen tuning parameters.
- Having identified an NROY subspace one may generate new emulators to explore it.

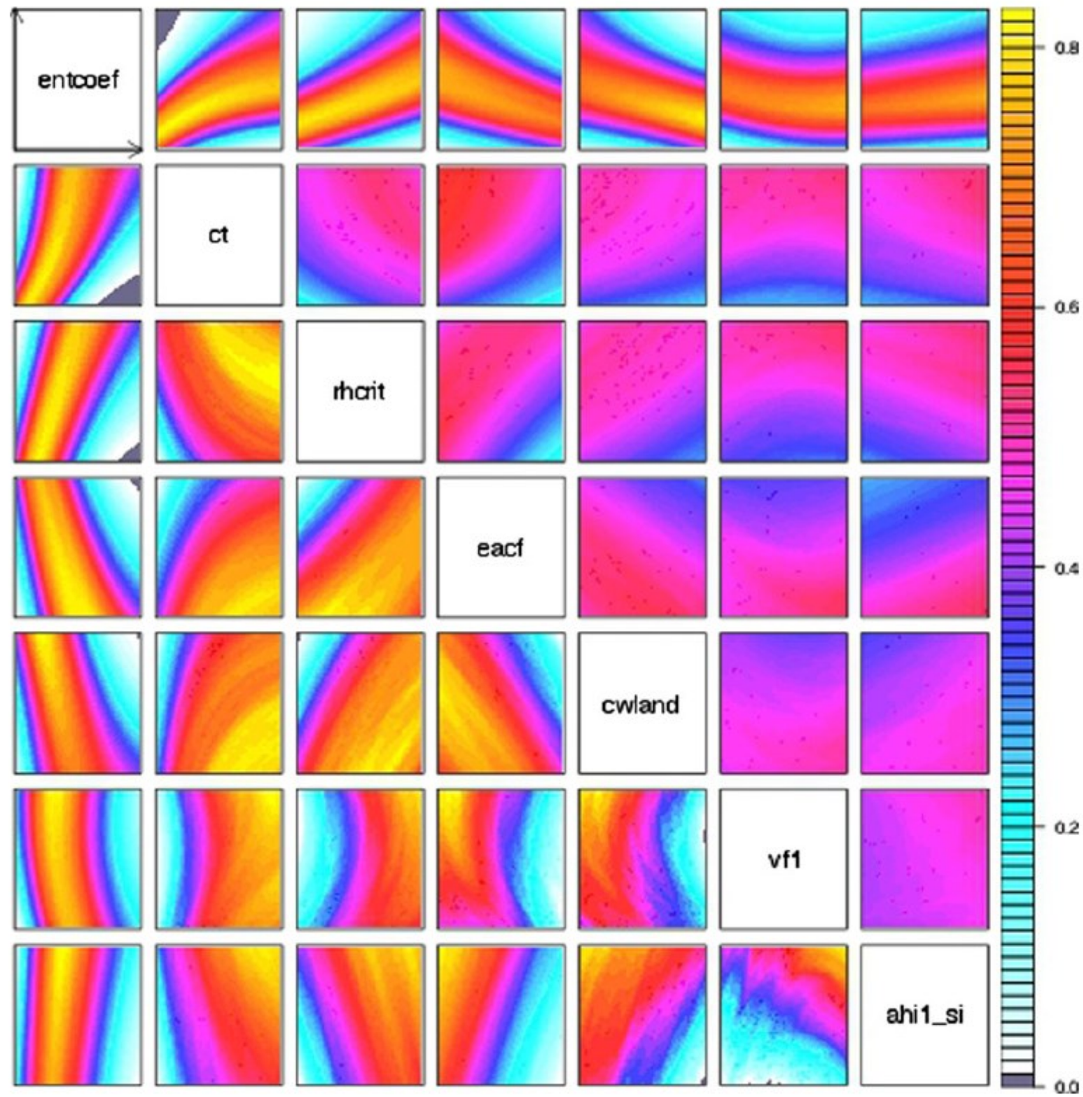



**Fig. 3** NROY densities. The *scale* on the *right* applies only to the plots on the *upper triangle* of this *matrix*. Each plot on the *lower triangle* has its own relative scale so that any unusual shapes can be more readily seen and interpreted. Each point in each image represents the density of points in NROY space projected onto the relevant two dimensions within their standard ranges and with the *colour scale* defining the proportion of points in NROY space at that location throughout the other dimensions. The parameter cwland determines another parameter, cwsea (see Appendix C)

# Global Climate Model Tuning Discussion

- Can we (should we?) agree on the decisive metrics which should clearly be used when tuning a GCM?
- Should the goal be to reach only one set of optimal values for parameters? Or can we foresee that there will be multiple sets (e.g. depending on the GCM resolution, or choice of parametrizations), and how should one investigate and document this?
- What strategy should be employed for a better "global" tuning of a GCM? Old-school iterative tuning of individual parametrizations? Global Uncertainly Quantification methods? Can data assimilation also be successfully used to constrain unknown parameters?