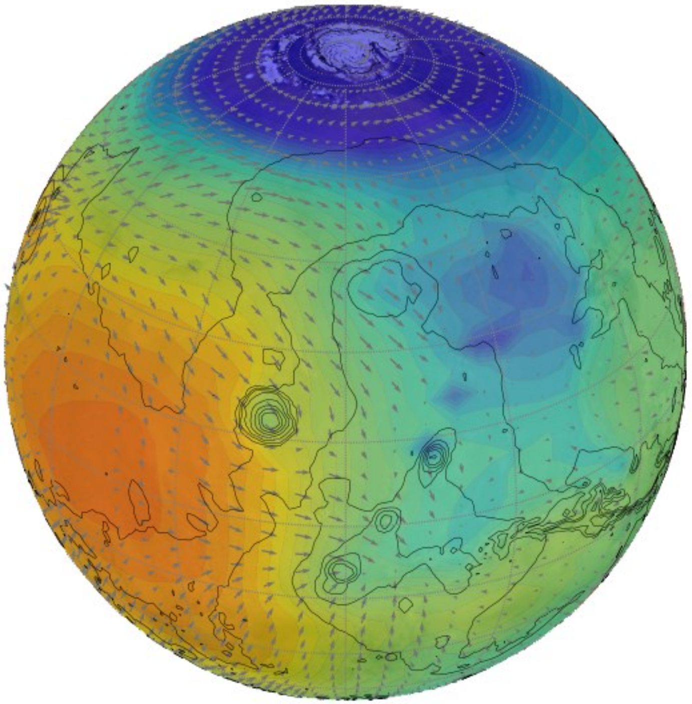
Mars Climate Database Training day May 26th 2016

MCD full version, detailed description



E. Millour, F. Forget and the MCD team

Why use the Mars Climate Database full version ?

- To interface with your favorite tool for interactive queries.
- To efficiently retrieve the needed data and available output variables.
- To be able to use the added variability options to have access to more than just climatological values.

MCD full version software

MCDv5.2 includes the following documents:

1. MCDv5.2 User Guide :
   - How to install and use the MCD software.
   - Details on the software input/outputs.

2. MCDv5.2 Detailed Design Document :
   - Technical details concerning how data is stored and processed. For users who need to know in details how things are done in the MCD.

3. Validation document : Ideally we should provide one; not yet the case for MCDv5.2

MCD full version software

MCDv5.2 includes the following tools:

1. call_mcd : the main Fortran subroutine to extract values from the MCD.
2. julian : a subroutine to convert a Gregorian date to a Julian date (input Earth date for call_mcd).
3. heights : a routine to convert heights above areoid to height above surface or distance to center of planet or vice-versa.
4. pres0 : a (redundant wrt call_mcd) routine to estimate surface pressure with high accuracy, using high resolution (32pix/deg.) MOLA topography.

call_mcd inputs and outputs

- A call to subroutine call_mcd :

Inputs

```
 call_mcd(zkey,xz,xlon,xlat,hireskey,
&           datekey,xdate,localtime,dset,scena,
&           perturkey,seedin,gwlength,extvarkeys,
&           pres,dens,temp,zonwind,merwind,
&           meanvar,extvar,seedout,ier)
```

Outputs

call_mcd inputs

zkey: Key for the type of vertical coordinates :

- *zkey=1* : xz is the radial distance from the center of the planet (m)
- *zkey=2*: xz is the altitude above the Martian zero datum (Mars geoid or “areoid”)
- *zkey=3*: xz is the altitude above the local surface (m)
- *zkey=4*: xz is the pressure level (Pa)
- zkey=5: xz is altitude (m) above ref. radius of $3.396\ 10^6$m

xz : Vertical coordinate of the requested point. Its definition depends on the value of zkey.

xlat : Planetocentric latitude in degrees

xlon : Planetocentric EAST longitude in degrees

call_mcd inputs

highreskey: Flag to switch to high horizontal resolution

- hireskey=0: use GCM resolution (lonxlat = 5.625°x3.75°)
- hireskey=1: use high-resolution post-processing (i.e: Adapted and consistent with the MOLA 1/32 degree 3.75° topography)

call_mcd inputs

datekey: Flag to select the input date type

- datekey=0: Earth date; xdate given as an Earth Julian date (in days). This is where routine Julian (convert Gregorian date to Julian date) can be handy.
- datekey=1: Mars date; xdate given as Mars solar longitude Ls (in degrees).

xdate: Earth Julian date or Solar Longitude; **DOUBLE PRECISION** number

localtime: Local time at longitude xlon (in martian hours). Valid ONLY IF datekey=1.

call_mcd inputs

dset: Path to the directory where mcd data is located

scena: dust and EUV scenario

1 = Climatology dust scenario, average solar EUV conditions

2 = Climatology dust scenario, minimum solar EUV conditions

3 = Climatology dust scenario, maximum solar EUV conditions

4 = Dust storm scenario, minimum solar EUV conditions

5 = Dust storm scenario, average solar EUV conditions

6 = Dust storm scenario, maximum solar EUV conditions

7 = Warm dust scenario, maximum solar EUV conditions

8 = Cold dust scenario, minimum solar EUV conditions

24 to 31 = dust scenario reconstructed from Mars Year 24 to 31 observations, with similarly realistic solar EUV conditions

call_mcd inputs

perturkey: Type of perturbation to add to the retrieved climatological values in order to simulate any possible realistic atmosphere at a given time.

1 : no perturbation

call_mcd inputs

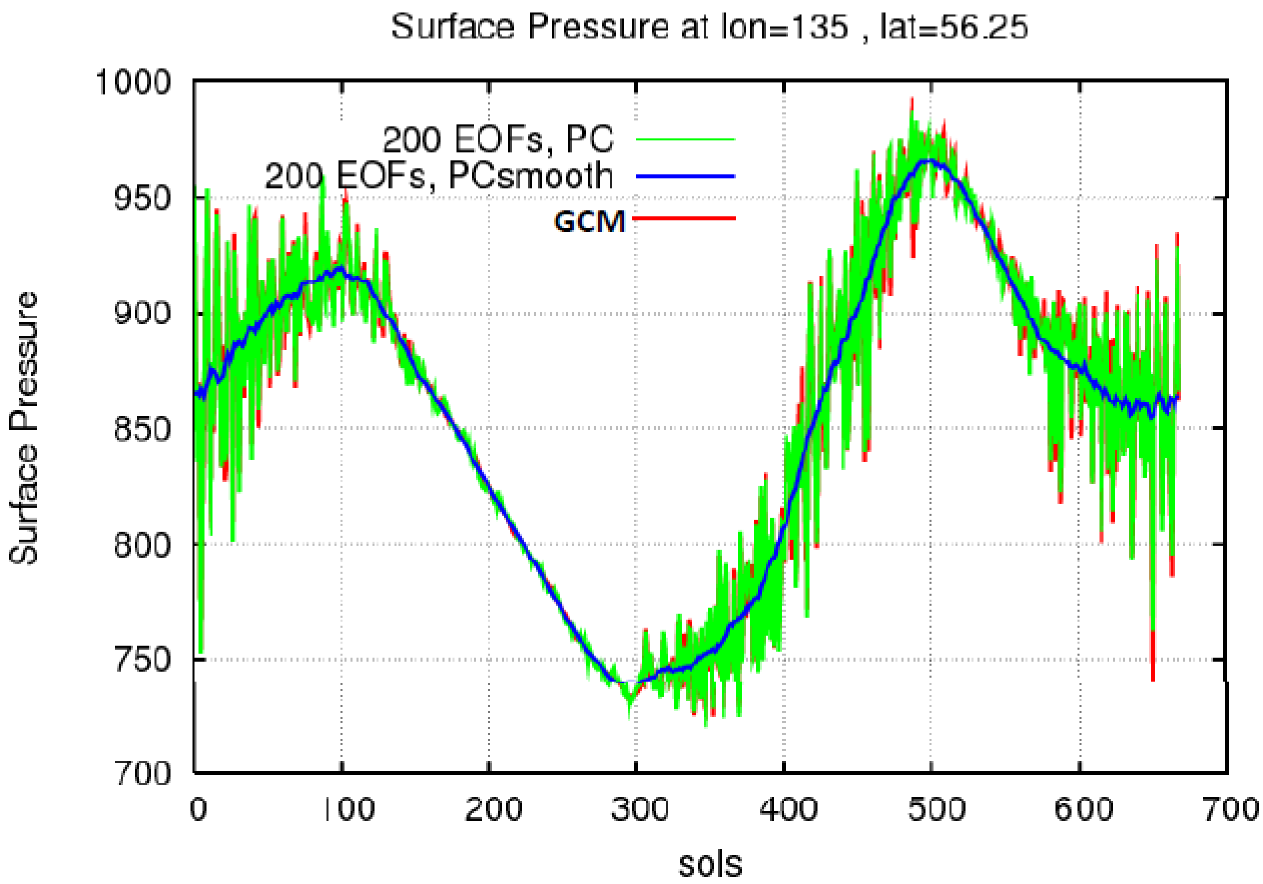
perturkey: Type of perturbation to add to the retrieved climatological values in order to simulate any possible realistic atmosphere at a given time.

1 : no perturbation

2 : large scale perturbations (weather systems)

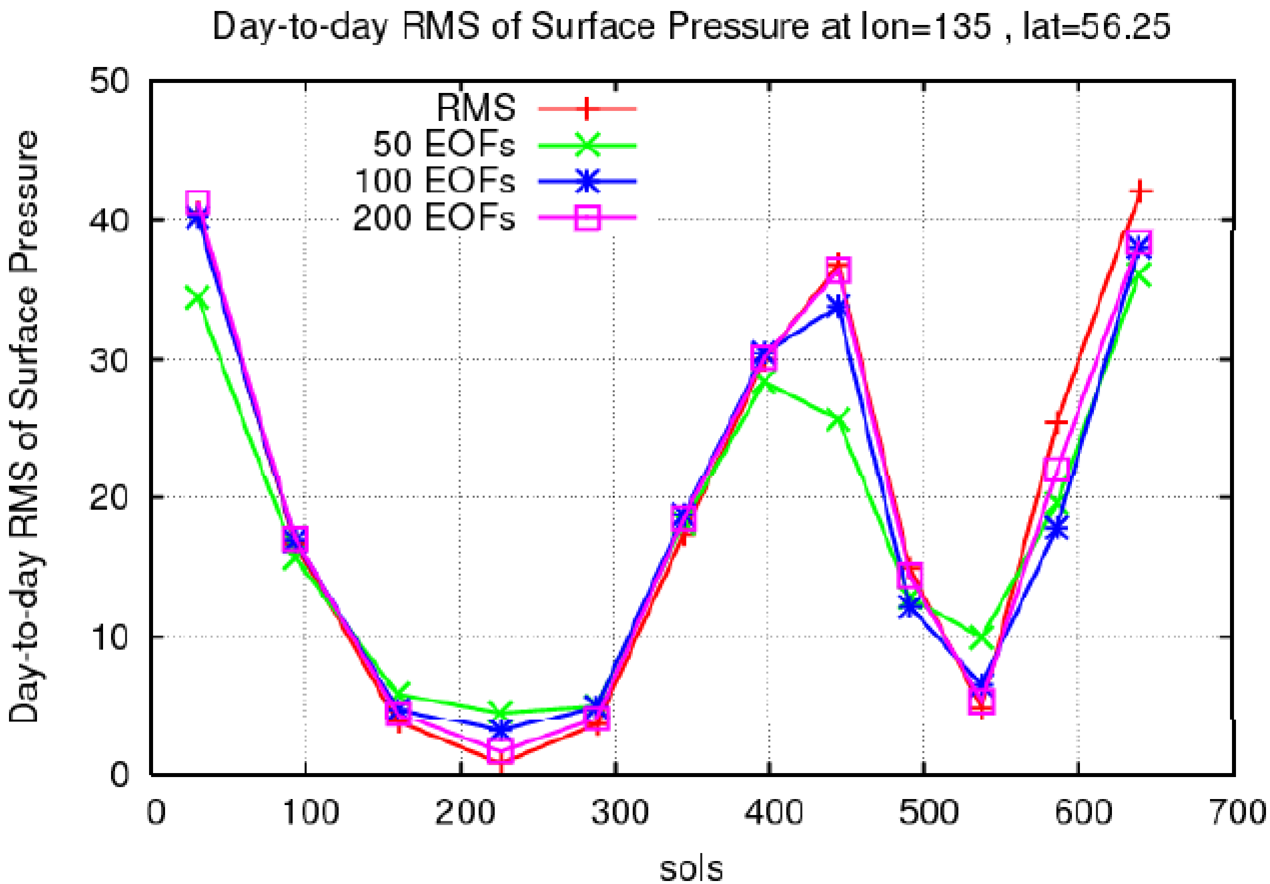
- To enable the reconstruction of day to day and year to year variability as simulated in the GCM.
- Key fields variations are stored using 200 EOFs which contain the correlation of fields with location and time.
- The phase of the reconstructed fields is set by input seedin which should remain unchanged as long as one works with the same correlated perturbed atmosphere.

Large scale perturbations



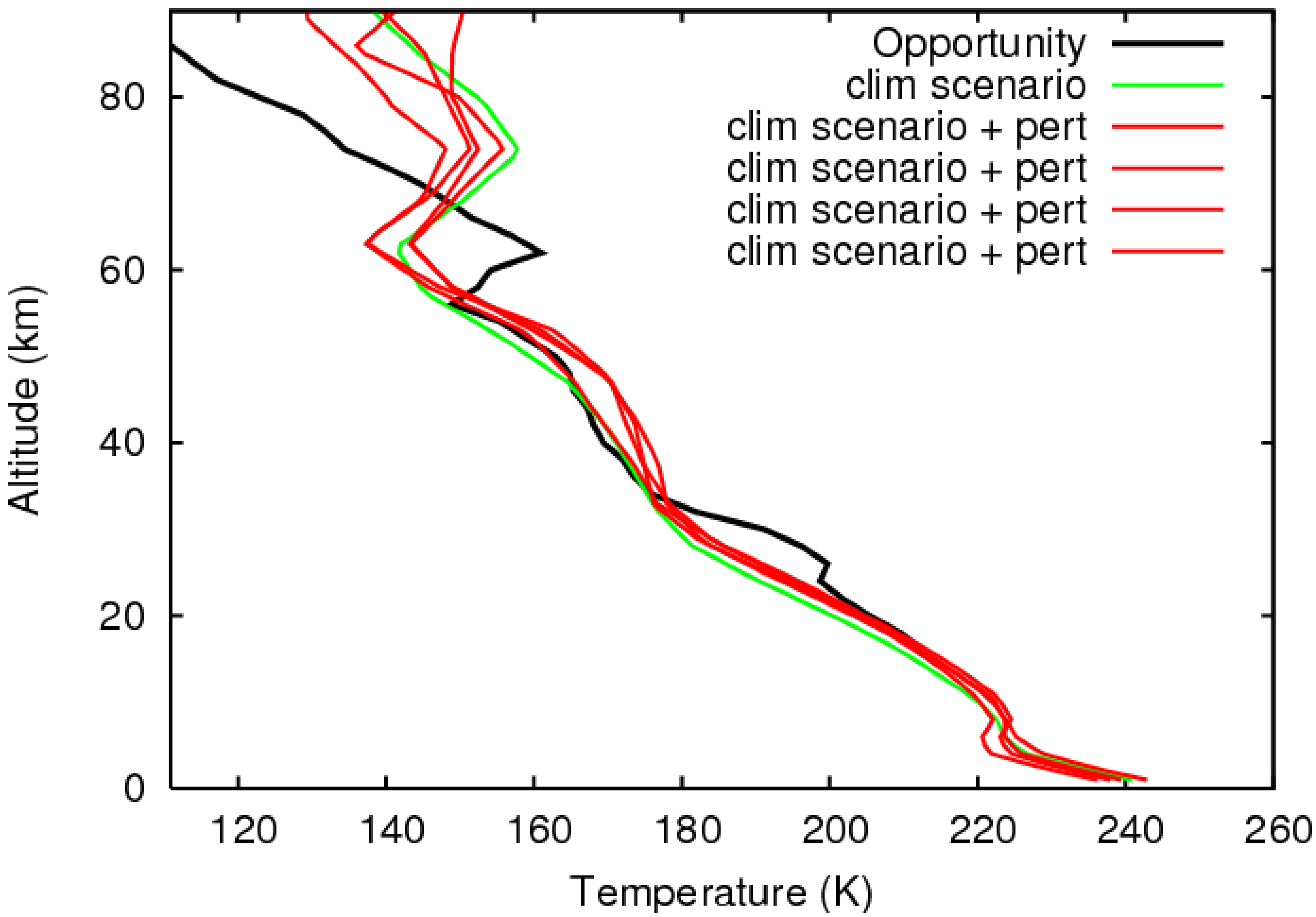
Illustrative example of EOF decomposition enabling to reconstruct the daily variations and thus deviations to general trend of a variable.

Large scale perturbations



Illustration, on the same example as before, that with a sufficient number of EOFs (~200 here) the actual variability is well represented.

Large scale perturbation example



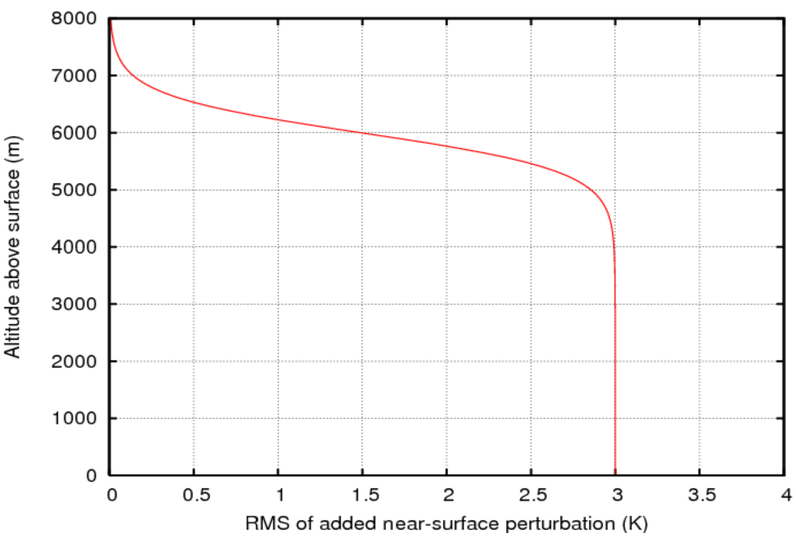
Opportunity entry profile along with perturbed (using large scale scheme) clim scenario predictions.

Near-surface variability

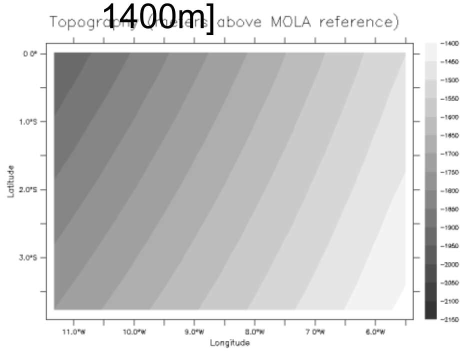
- Included in large scale perturbations and added to account for (GCM) unresolved sub-gridscale spatial variability:
  - A random Gaussian perturbation of 1% RMS of unperturbed value is added to surface pressure.
  - A random Gaussian perturbation of temperature is added, with a vertically varying RMS:

$$RMS(z) = T_{pert\_level} .(1.0 – \tanh[6.(z-z_{mid})/z_{delta}]) / 2$$

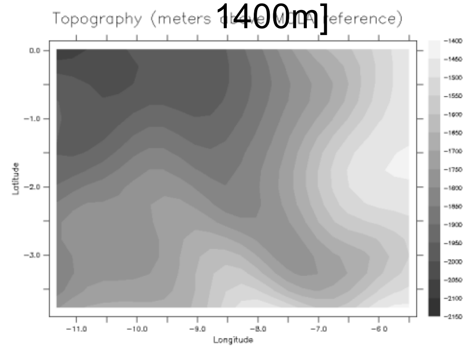
$$z_{mid} = 6000 \text{ m},\ z_{delta} = 4000 \text{ m},\ T_{pert\_level} = 3 \text{ K}$$



GCM topography [-1950m:-1400m]



Mesoscale topography [-2150m:-1400m]



call_mcd inputs

perturkey: Type of perturbation to add to the retrieved climatological values in order to simulate any possible realistic atmosphere at a given time.

1 : no perturbation

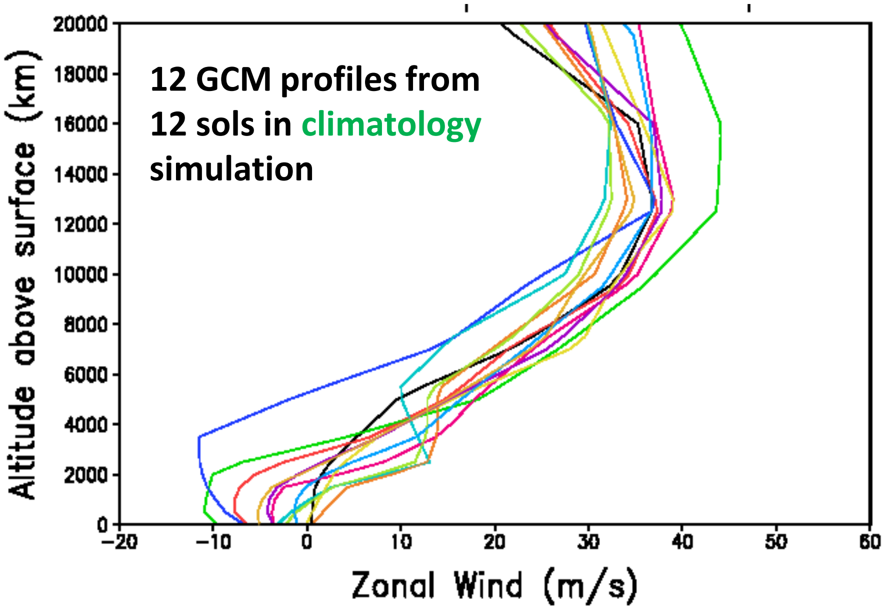
2 : large scale perturbations (weather systems)

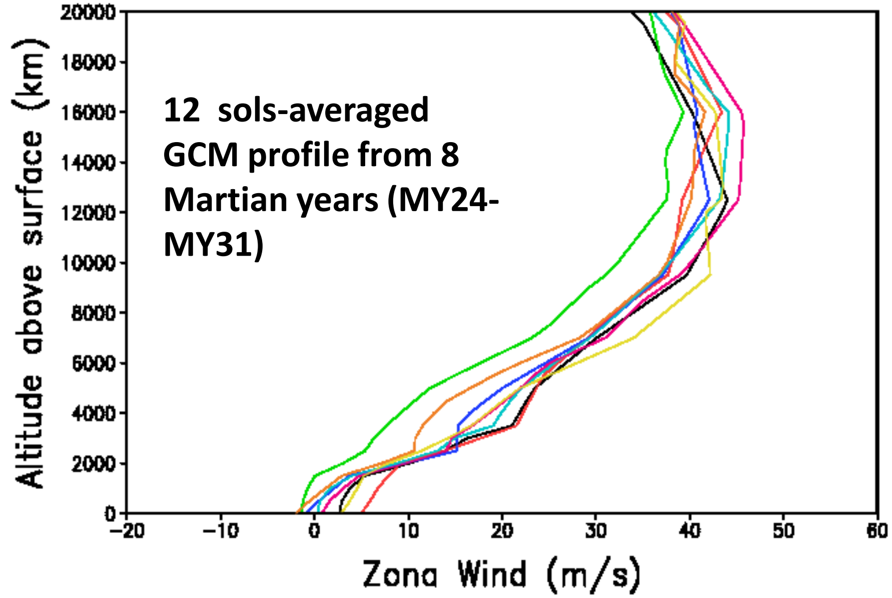
- The phase of the reconstructed fields is set by input seedin which should remain unchanged as long as one works with the same correlated perturbed atmosphere.
- For the climatology scenario case, used EOFs come from simulations of MY24 to MY31 scenarios **to better account for year to year variability**.

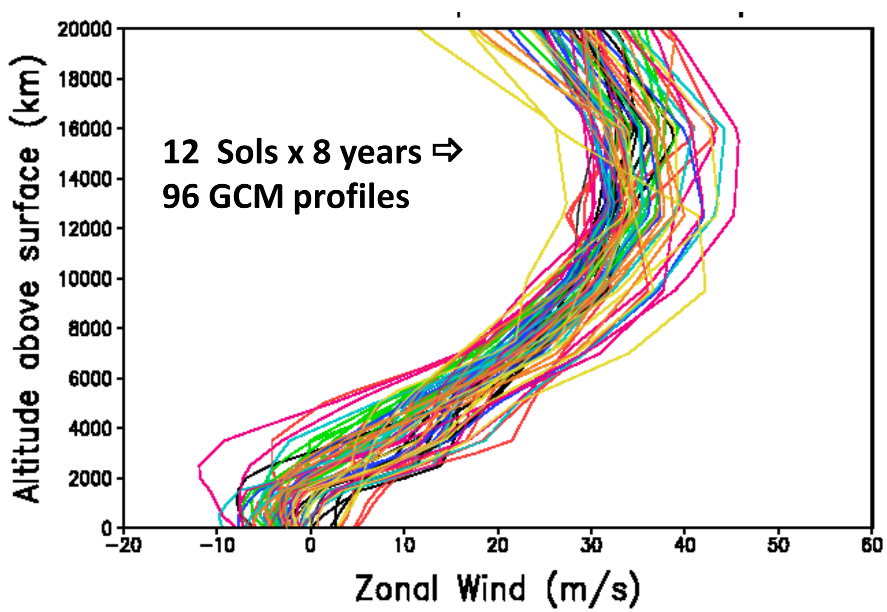
seedin: random number seed and flag.

Combining day-to-day variability with year-to-year variability

Illustrative example: Oxia Planum, Ls=324°, LT = 10.5







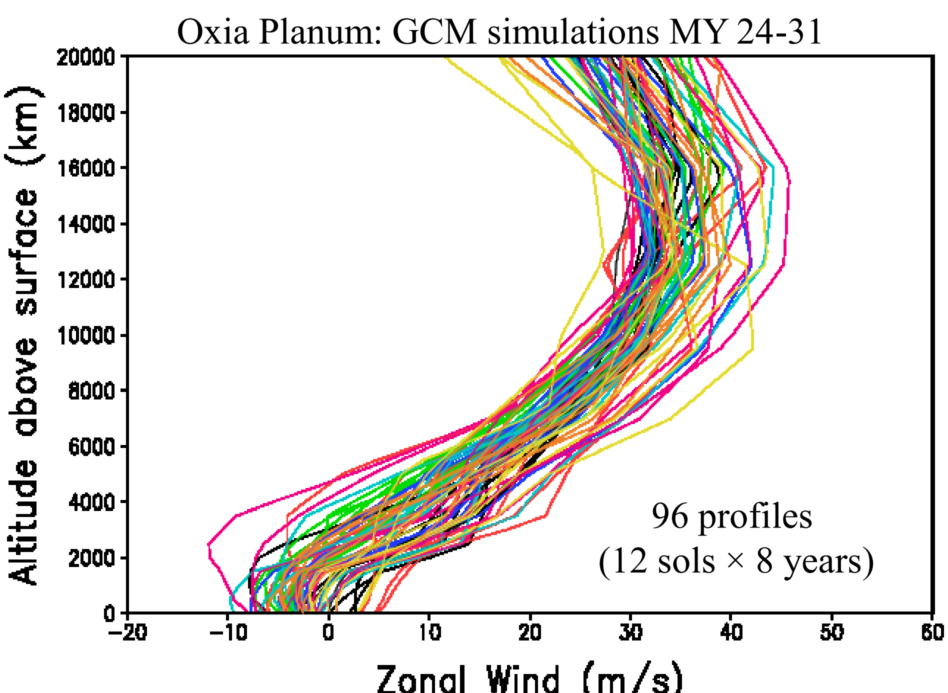
Combined day-to-day and year-to-year variability

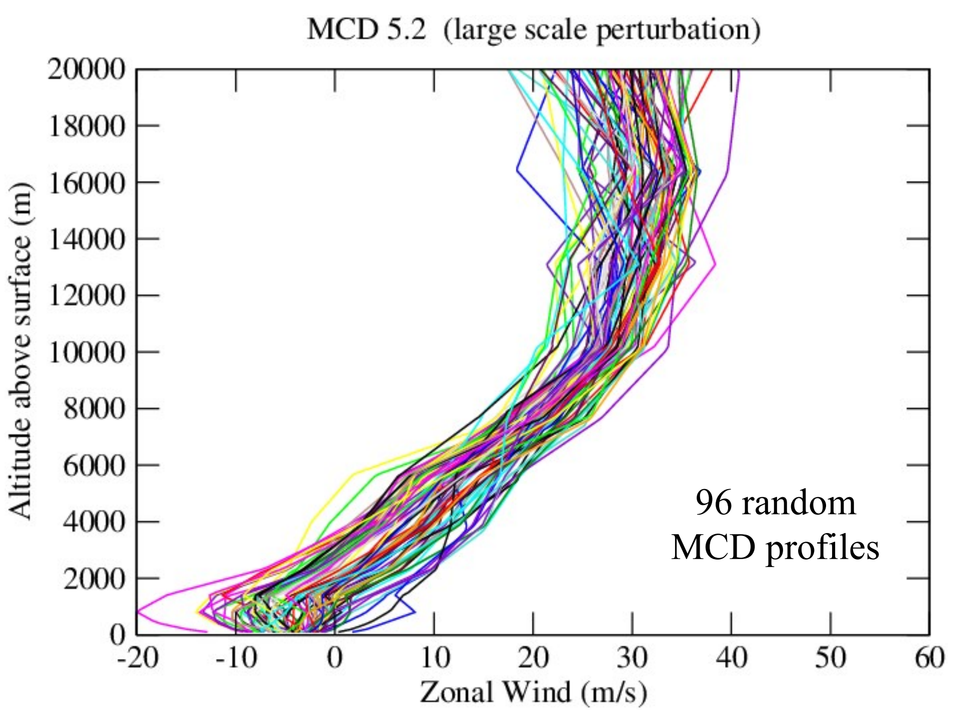
Combining day-to-day variability with year-to-year variability

Illustrative example: Oxia Planum, Ls=324°, LT = 10.5

96 profiles (12 sols x 8 years) from original GCM runs

96 profiles randomly generated by MCD large scale perturbation scheme for the climatology scenario





call_mcd inputs

perturkey: Type of perturbation to add to the retrieved climatological values in order to simulate any possible realistic atmosphere at a given time.

1 : no perturbation

2 : large scale perturbations

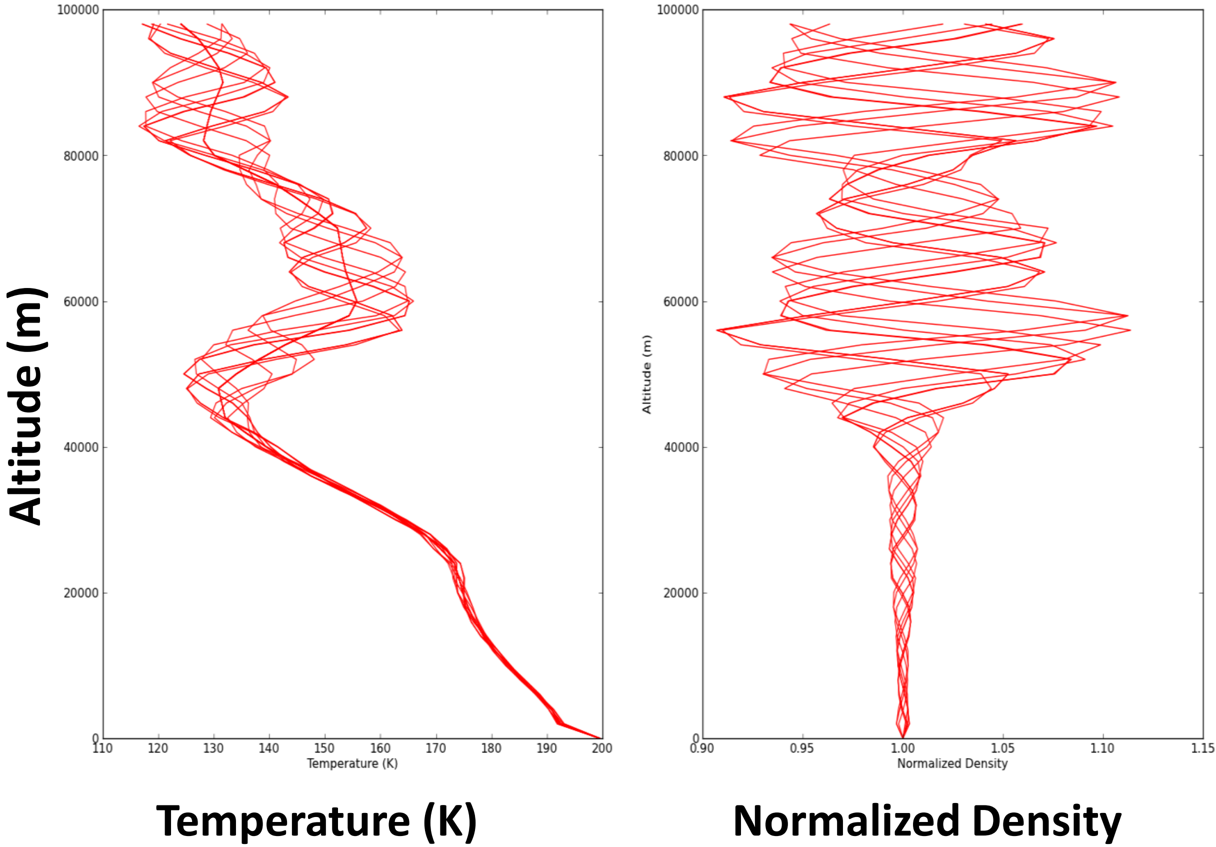
3 : small scale perturbations (gravity waves)

seedin: random number seed and flag.

gwlength: wavelength (m) of the gravity wave. Must be between 2km and 30km, default is 16000m.

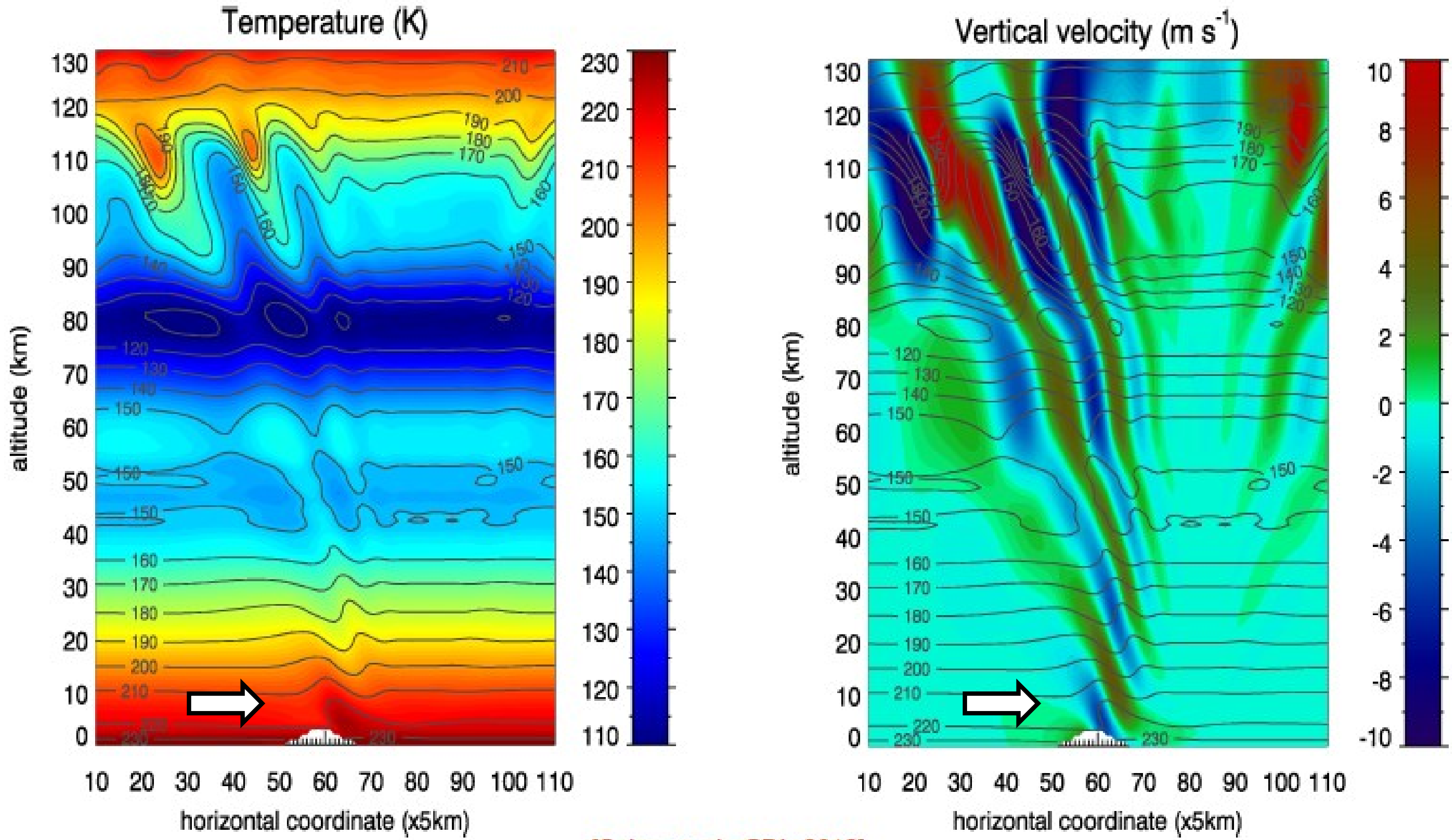
Small scale perturbation model

- Simulate **gravity waves** not represented in the GCM simulation (sub-grid scale)
- Source intensity depends on low-level wind and sub-grid scale topography
- Tunable vertical wavelength (2 to 30 km; default : 16 km)
- Constant amplitude above 100 km



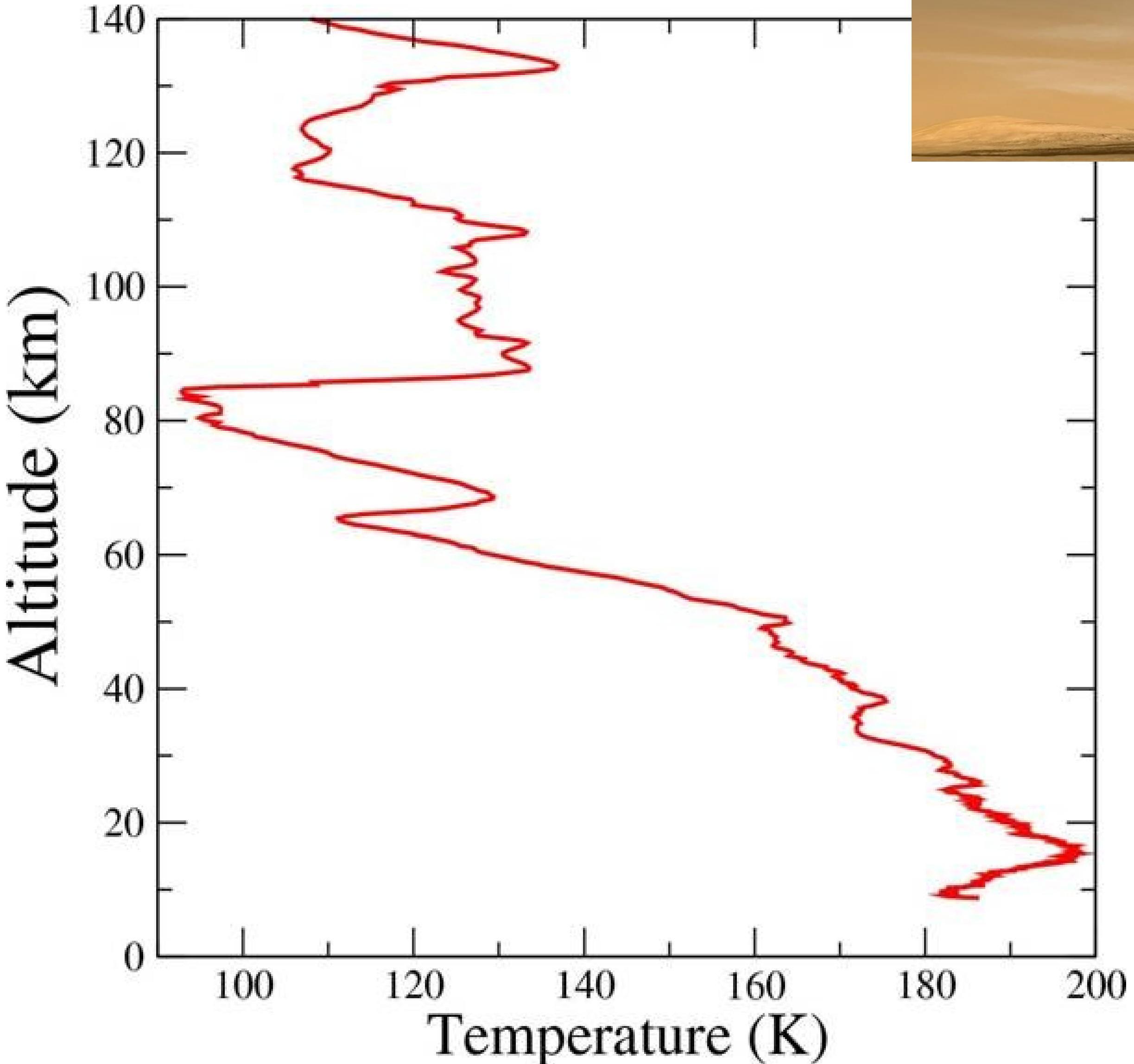
Simulation with a mesoscale model able to resolve the waves

$\delta x = 5km$, $\delta z \sim 1km$, model top 180 km with 50-km sponge layer

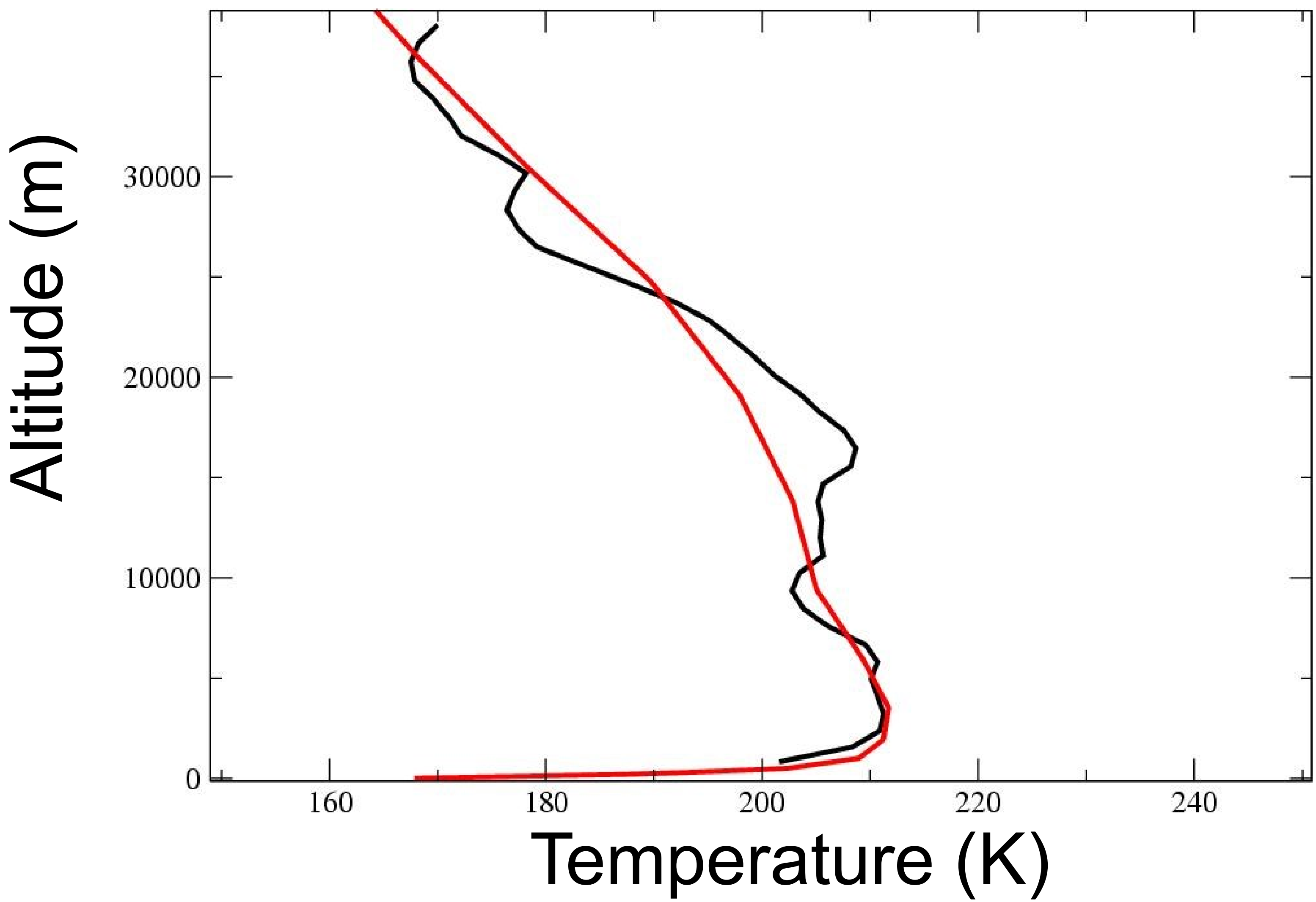


[Spiga et al. GRL 2012]

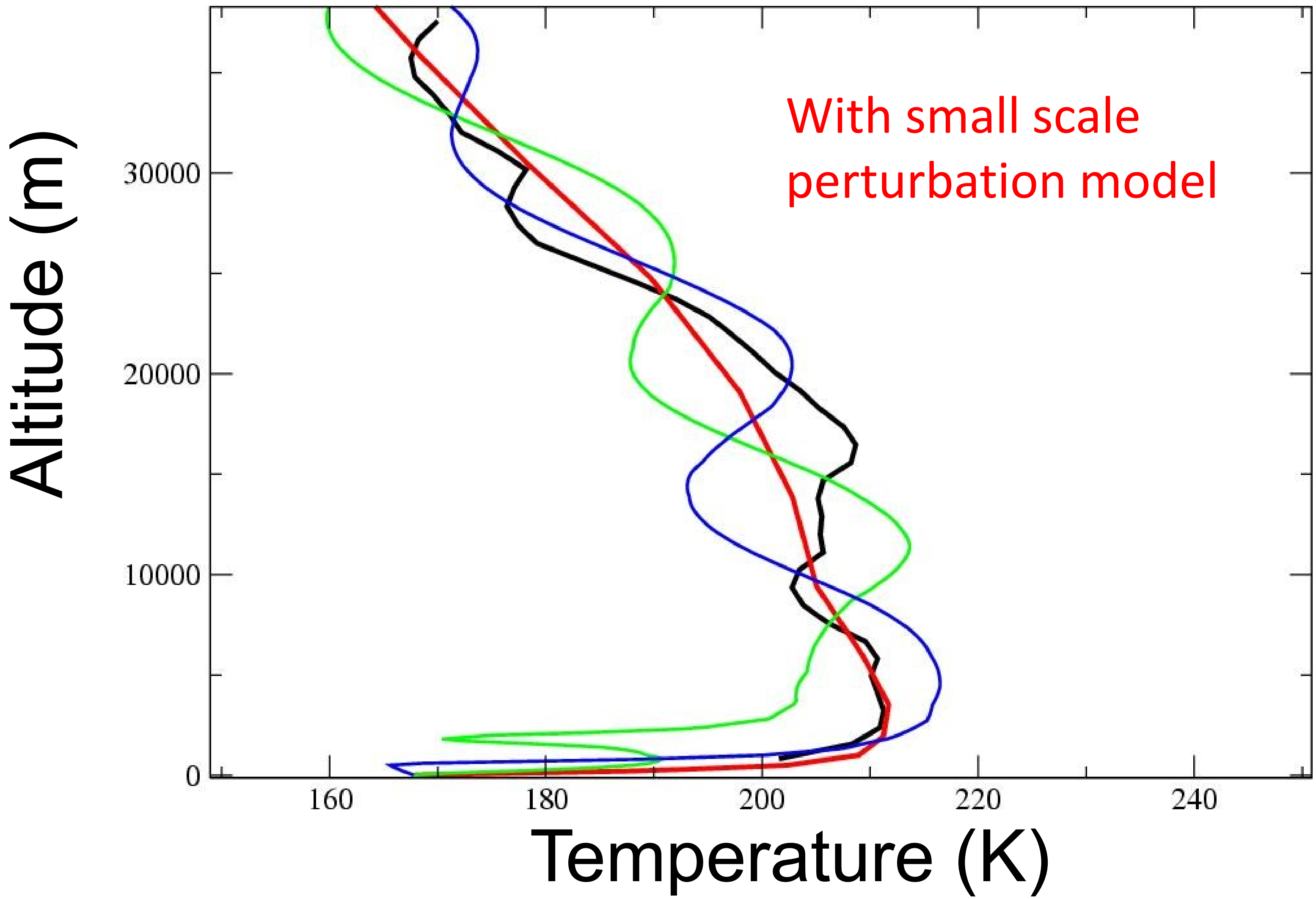
Gravity waves in Pathfinder entry profile



MGS Radio occultation compared to MCD prediction

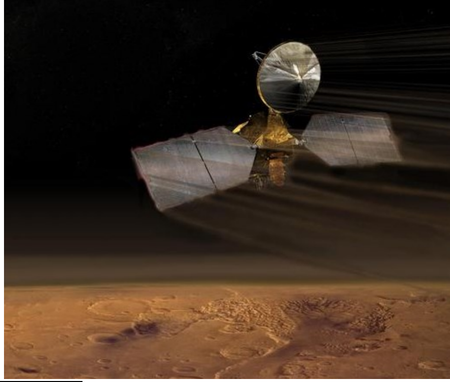


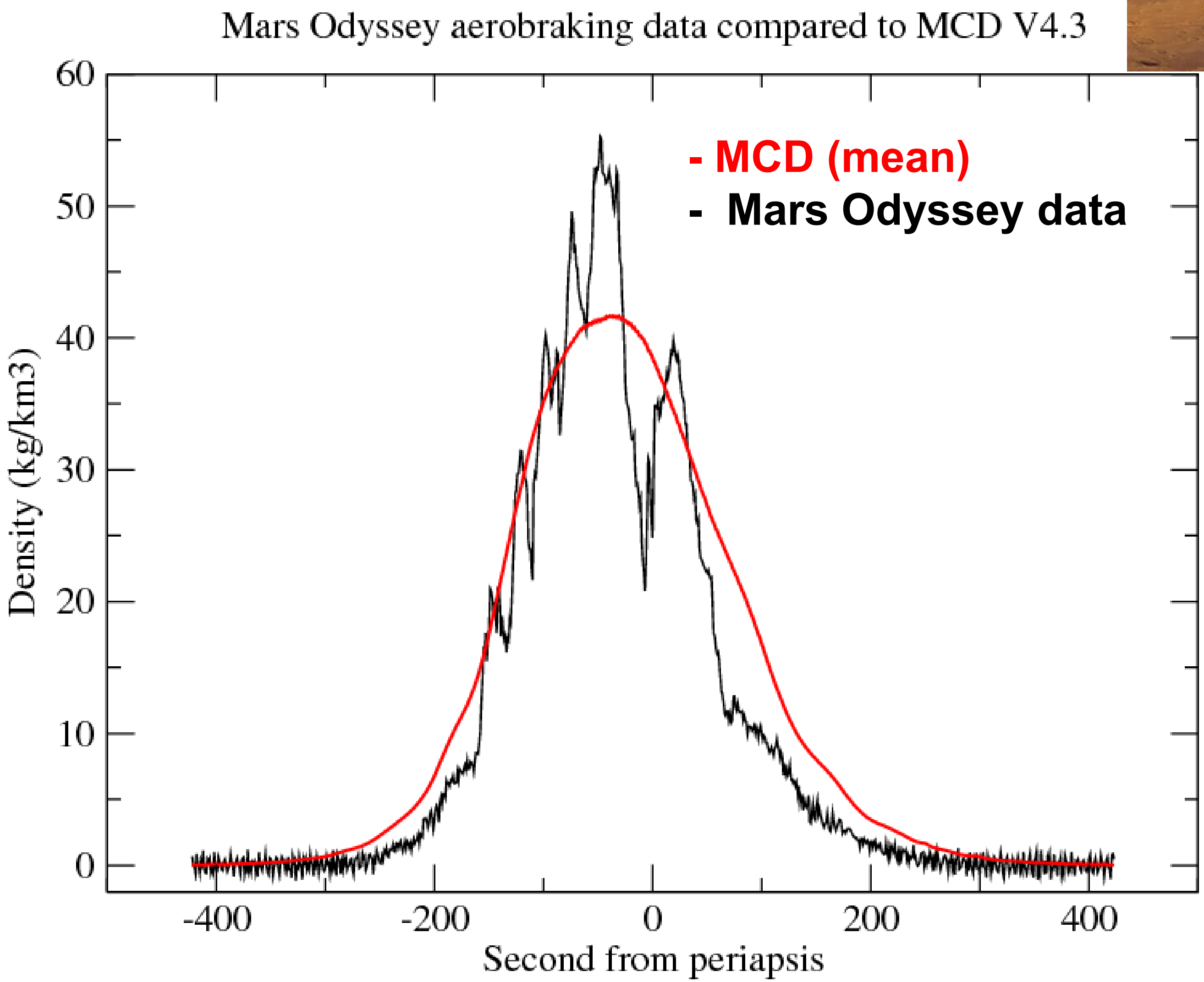
MGS Radio occultation compared to MCD prediction



Aerobraking observations:

Mars Odyssey, orbit 199 (Ls=302°)

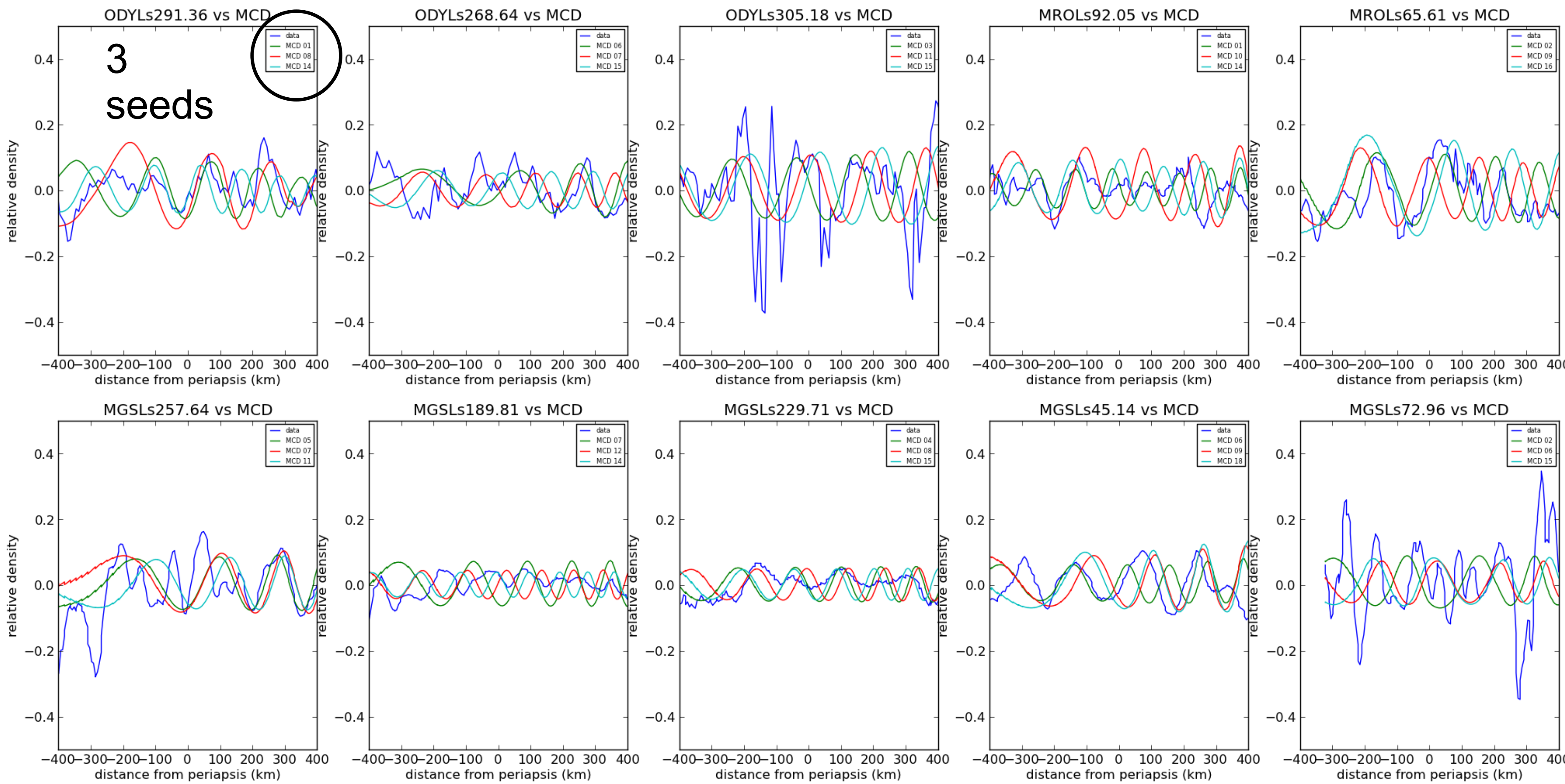




New ! MCD V4.21: include a parametrization of horizontal wave structure

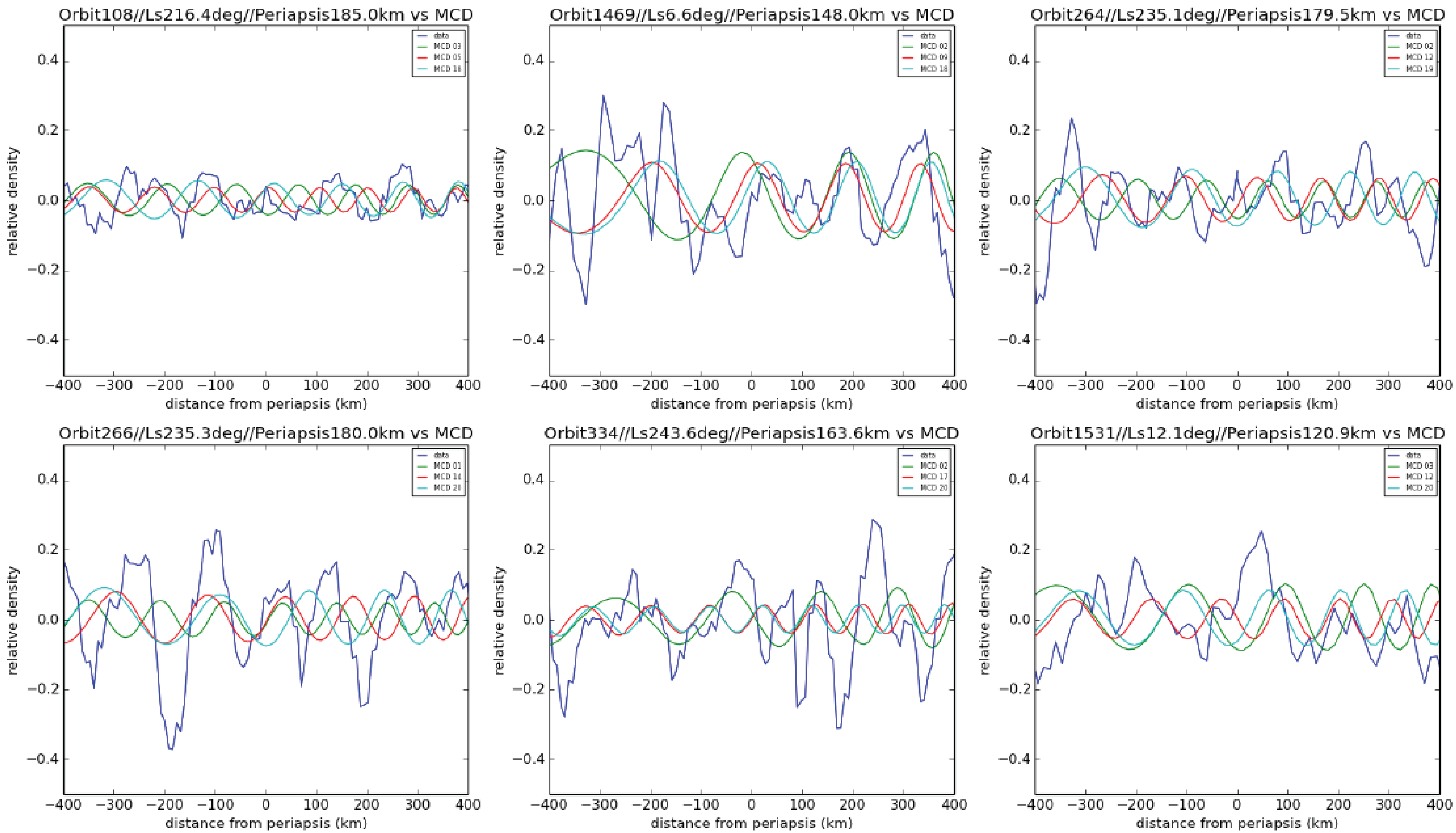
MCD	Improved MCD
Random phase Φ0	Random phase Φ0
Vertical wavelength λ=16km	Vertical wavelength λ=16km
Amplitude wave saturation limit dzmax=λ/2π	Random amplitude wave saturation limit dzmax ([0.5,1.5]λ/2π)
No gravity wave horizontal variation term	Gravity wave horizontal variation term Dist
-	Random λDist ([100,250]km)

New ! MCD V4.21: include a parametrization of horizontal wave structure



Relative density towards distance from periapsis for 10 selected orbits gathered from ODY, MGS and MRO versus MCD results with same polar characteristics

Simulation of MAVEN NGIMS Mass spectrometer density measurements



ive density towards distance from periapsis for 6 selected orbits gathered from MAVEN, compared to MCD results generated with the same polar and for many different seeds. Only three of the best fitting seeds are displayed on the figure for the sake of clarity. For all simulations λ=16km, nly generated between 100 and 250km and saturation dz_{max} between $\frac{1}{2}\frac{\lambda}{2\pi}$ and $\frac{3}{2}\frac{\lambda}{2\pi}$

call_mcd inputs

perturkey: Type of perturbation to add to the retrieved climatological values in order to mimic a realistic atmosphere.

1 : no perturbation

2 : large scale perturbations

3 : small scale perturbations (gravity waves)

4 : large scale and small scale perturbations

- Combines the previous cases by using both schemes. Again, as long as input seedin remains fixed, one is investigating a spatiotemporally coherent atmosphere.

call_mcd inputs

perturkey: Type of perturbation to add to the retrieved climatological values in order to mimic a realistic atmosphere.

1 : no perturbation

2 : large scale perturbations

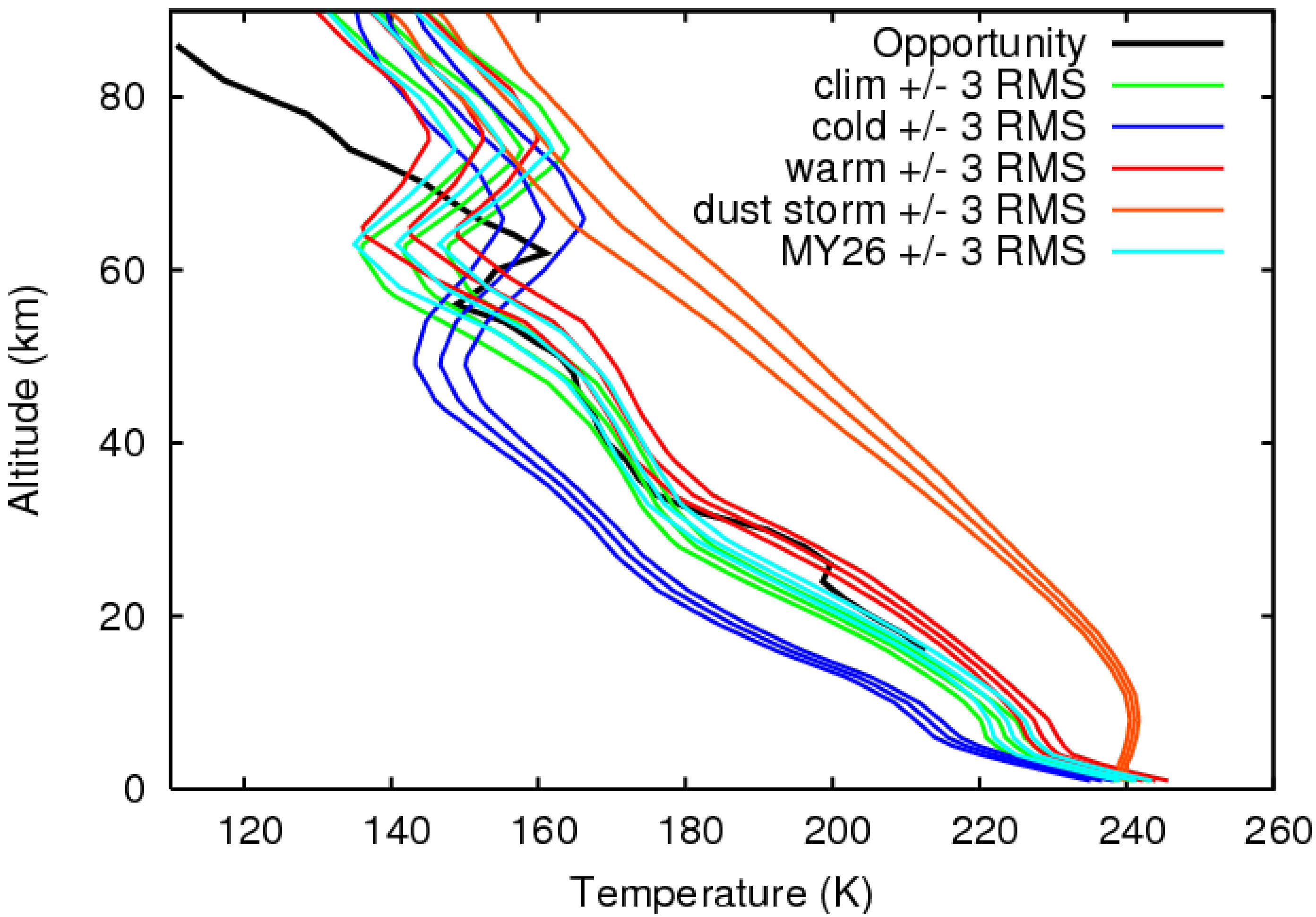
3 : small scale perturbations (gravity waves)

4 : large scale and small scale perturbations

5 : add seedin times the day-to-day variability

- In this case seedin is not a random number seed and should not be more/less than +4/-4.
- Useful to get envelopes of variability.

Adding day-to-day RMS example



Opportunity entry profile along with unperturbed scenarios and envelopes of +/- 3 day-to-day RMS.

call_mcd inputs

extvarkeys: Flag to request computation of extra output variable. Array of 100 elements.

- extvarkeys[i] = 0 : don’t compute output extvar[i]
- extvarkeys[i] = 1 : compute output extvar[i]
- This has been set up to avoid unnecessary computations, and make call_mcd as fast as possible

Additional features (not call_mcd arguments!):

- ``silent mode’’ by setting common flag output_messages to false in constants_mcd.inc
- ``standard output’’ unit number is a parameter `out’ defined in constants_mcd.inc (default: out=6).

call_mcd inputs and outputs

- A call to subroutine call_mcd :

Inputs

```
 call_mcd(zkey,xz,xlon,xlat,hireskey,
&        datekey,xdate,localtime,dset,scena,
&        perturkey,seedin,gwlength,extvarkeys,
&        pres,dens,temp,zonwind,merwind,
&        meanvar,extvar,seedout,ier)
```

Outputs

call_mcd outputs

pres: Atmospheric pressure (Pa)

dens: Atmospheric density (kg/m3)

temp: Atmospheric temperature (K)

zonwind: zonal wind component (Eastward) in m/s

merwind: meridional wind component (Northward) in m/s

meanvar : array of 5 elements; same as above, but unperturbed:

meanvar(1) = mean pressure

meanvar(2) = mean density

meanvar(3) = mean temperature

meanvar(4) = mean zonal wind component

meanvar(5) = mean meridional wind component

call_mcd outputs

Extvar: array of 100 elements

The first 7 are always provided :

- extvar(1) = Radial distance from planet center (m)
- extvar(2) = Altitude above areoid (Mars geoid) (m)
- extvar(3) = Altitude above local surface (m)
- extvar(4) = orographic height (m) (surface altitude above areoid)
  - NOTE: Depending on hireskey references to areoid and topography are with respect to GCM grid resolution or high resolution MOLA data
- extvar(5) = Ls, solar longitude of Mars (deg)
- extvar(6) = LST local solar time (hours = 1/24 of a mars day)
- extvar(7) = Universal solar time (LST at longitude=0) (hrs)

call_mcd outputs

Extvar: array of 100 elements

- extvar(8) = Cp: Air specific heat capacity ($J.kg^{-1}.K^{-1}$).
- extvar(9) = γ = Cp/Cv ratio of specific heats.
- extvar(10) = density RMS day to day variations (kg/m3); pressure-wise (if zkey =4) or altitude-wise (other values of zkey)
- extvar(11) = LMT: Local Mean Solar Time at longitude xlon (in martian hours = 1/24th of a Mars day).
- extvar(12) = Sun-Mars distance (in Astronomical Units AU).
- extvar(13) = atmospheric scale height H(p) (km)
- extvar(14) = GCM orography (m) (will be equal to extvar(4) if input parameter hireskey=0).

N.B. Provided for specialist interested in the differences between low resolution (i.e.: the GCM resolution) and high resolution MOLA topography.

call_mcd outputs

Extvar: array of 100 elements

- extvar(15) = surface temperature (K)
- extvar(16) = daily maximum mean surface temperature (K)
- extvar(17) = daily minimum mean surface temperature (K)
- extvar(18) = surf. temperature RMS day to day variations (K)

- extvar(19) = surface pressure (Pa) (high resolution if hireskey=1, GCM if hireskey=0)
- extvar(20) = GCM surface pressure (Pa)
- extvar(21) = Atmospheric pressure RMS day to day variations (Pa) (if zkey = 1,2, 3 or 5)
- extvar(22) = surface pressure RMS day to day variations (Pa)

call_mcd outputs

Extvar: array of 100 elements

- extvar(23) = atmospheric temperature RMS day to day variations (K) *
- extvar(24) = zonal wind RMS day to day variations (m/s) *
- extvar(25) = meridional wind RMS day to day variations (m/s) *
- extvar(26) = vertical wind component (m/s) (**positive when downwards**)
- extvar(27) = vertical wind RMS day to day variations (m/s)*

* (pressure-wise if zkey = 4 , altitude-wise if zkey = 1, 2, 3 or 5)

call_mcd outputs

Extvar: array of 100 elements

- extvar(28) = small scale density perturbation (gravity wave) (kg/m3)
- extvar(29) = surface roughness length z_0 (m)

- extvar(30) = solar flux reflected to space (W/m2)
- extvar(31) = thermal IR (λ>5µm) flux to surface (W/m2)
- extvar(32) = solar flux (λ<5µm) to surface (W/m2)
- extvar(33) = thermal IR flux to space (W/m2)

- extvar(34) = Surface H_2O ice (seasonal frost) layer (kg/m^2). In areas covered by perrenial H_2O ice deposits, this seasonal frost layer is limited to maximum value 0.5 kg/m^2 .
- extvar(35) = Surface CO_2 ice layer (kg/m^2).

call_mcd outputs

Extvar: array of 100 elements

- extvar(36) = DOD: Dust column visible optical depth (from local surface to top of atmosphere, at 0.67µm)
- extvar(37) = Dust Optical Depth RMS day to day variations
- extvar(38) = Dust mass mixing ratio (kg/kg_{air})
- extvar(39) = Dust effective radius (m)
- extvar(40) = Dust deposition rate on a flat horizontal plane at the surface of Mars ($kg.m^{-2}.s^{-1}$)

- extvar(41) = water vapor column ($kg.m^{-2}$)
- extvar(42) = water vapor vol. mixing ratio (mol/mol).
- extvar(43) = water ice column ($kg.m^{-2}$)
- extvar(44) = water ice vol. mixing ratio (mol/mol).
- extvar(45) = water ice effective radius (m) Bugged in MCD5.2!!

call_mcd outputs

Extvar: array of 100 elements

- extvar(46) = Convective planetary boundary layer (PBL) height (m).
- extvar(47) = Maximum upward convective wind (m/s) within the planetary boundary layer (PBL).
- extvar(48) = Maximum downward convective wind (m/s) within the planetary boundary layer (PBL).
- extvar(49) = Convective vertical wind variance ($m^2.s^{-2}$) at input altitude xz.

  This quantity has only a meaning inside the PBL; it is set to zero if the sought input xz altitude is above the PBL.
- extvar(50) = Convective eddy vertical heat flux ($m.s^{-1}.K^{-1}$) at input altitude xz.

  This quantity has only a meaning inside the PBL; it is set to zero if the sought input xz altitude is above the PBL.

call_mcd outputs

Extvar: array of 100 elements

- extvar(51) = Surface wind stress ($kg.m^{-1}.s^{-2}$).
- extvar(52) = Surface sensible heat flux ($W.m^{-2}$).

Negative when the flux is from the surface to the atmosphere

- extvar(53) = R: Reduced Molecular gas constant ($J.kg^{-1}.K^{-1}$) at altitude xz.
- extvar(54) = Air viscosity ($N.s.m^{-2}$) at altitude xz.

- extvar(55) = Not used. Set to zero.
- extvar(56) = Solar zenith angle (degrees).

call_mcd outputs

Extvar: array of 100 elements

- extvar(57) = CO_2 volume mixing ratio (mol/mol_{air}).
- extvar(58) = N_2 volume mixing ratio (mol/mol_{air}).
- extvar(59) = Ar volume mixing ratio (mol/mol_{air}).
- extvar(60) = CO volume mixing ratio (mol/mol_{air}).
- extvar(61) = O volume mixing ratio (mol/mol_{air}).
- extvar(62) = O_2 volume mixing ratio (mol/mol_{air}).
- extvar(63) = O_3 volume mixing ratio (mol/mol_{air}).
- extvar(64) = H volume mixing ratio (mol/mol_{air}).
- extvar(65) = H_2 volume mixing ratio (mol/mol_{air}).
- extvar(66) = electron number density (cm^{-3}). Values are only given for pressures higher than 5 10−6 Pa (roughly up to ~200 km); i.e. the “chemistry ionosphere”.

call_mcd outputs

Extvar: array of 100 elements (used up to 76)

- extvar(67) = CO_2 column ($kg.m^{-2}$).
- extvar(68) = N_2 column ($kg.m^{-2}$).
- extvar(69) = Ar column ($kg.m^{-2}$).
- extvar(70) = CO column ($kg.m^{-2}$).
- extvar(71) = O column ($kg.m^{-2}$).
- extvar(72) = O2 column ($kg.m^{-2}$).
- extvar(73) = O3 column ($kg.m^{-2}$).
- extvar(74) = H column ($kg.m^{-2}$).
- extvar(75) = H2 column ($kg.m^{-2}$).
- extvar(76) = Total Electronic Content (TEC) (m^{-2}). As computed using electron content from the ”chemistry ionosphere”, i.e. from the surface to 5 10−6 Pa.

call_mcd outputs

seedout: current index of random number generator (can be used to change seedin value to generate a new set of perturbations).

ier: returned call_mcd status

ier = 0 : everything OK

ier = 1, 20 : error codes (see documentation for details), e.g. if wrong values for some call_mcd input arguments.

Some technical aspects

- Installing the MCD:
  - You need to have a Fortran compiler, and also to have downloaded and installed the NetCDF library.
  - It works on Linux systems and Windows (we have much less experience on the later).
  - Don’t hesitate to ask us for help/advice!
  - We have set up an FAQ page that you might find useful:

    http://www-mars.lmd.jussieu.fr/mars/mcd_faq/faq.html

Some technical aspects

- The MCD interfaces:
  - Provided illustrative examples in C, C++, python, IDL, Matlab and Scilab.
  - In some cases (C/C++/python) these are “true” interfaces (i.e. directly and interactively call the call_mcd Fortran routine), and in others (IDL/Matlab/Scilab) “brute force” examples of obtaining chunks of data via a system call to a Fortran program (i.e. non-interactive). Feel free to improve these!

Using the MCD efficiently

- Taking into account the MCD resolution:

  Even in high resolution mode, some fields (e.g. winds) are at GCM (5.625°x3.75°) resolution.

- Being aware of potential interpolation issues:

  The software uses linear interpolations between 12 monthly (range of 30° in Ls) records to compute sought values. This implies that abrupt changes will not be rendered correctly (e.g. the presence and evolution of clouds over a few days).

Using the MCD efficiently

- Getting the MCD to load and reload datafiles as little as possible:

  To compute values for a given date, the MCD uses datasets from two encompassing “months” (30° of Ls), which are kept in memory.

  Loading the two input datafiles takes some time (a few seconds) and it is thus advised to use a querying strategy that minimizes reloading datafiles (i.e. for multiple queries, a loop on dates should be as external as possible).

Using the MCD efficiently

- Using the seedin (and seedout) arguments correctly when adding perturbations:

  As large scale and small scale perturbations are spatiotemporally coherent structures, as long as one investigates a given perturbed atmosphere (e.g. to compute an EDL trajectory) seedin should be fixed.

  When moving on to investigate a different case (e.g. another EDL trajectory for Monte Carlo analysis), switch to a different value of seedin (e.g. the seedout returned by previous calls).