Variability of the Martian upper atmosphere

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Upper atmosphere (UA)

- UA: mesosphere + mesopause + thermosphere + ionosphere
- Interface with UV solar activity + solar wind
- Transition between gravitationally bound atmosphere and escaping exosphere
Mars climate: a complex system

Atmospheric circulation

Dust cycle

Water cycle

CO₂ cycle

Photochemical cycle

Upper atmosphere processes and ionosphere
Tools

Observations

- Mars Express Interdisciplinary Scientist
- Collaborator of MAVEN/IUVS
- NOMAD/ExoMars TGO science team

Modeling

Development and application of LMD-Mars Global Climate Model
Basic characteristics of the LMD Mars Global Climate Model:

1) LMDZ final Dynamical Core (Grid point Model)

2) Radiative transfer:
   - TIR CO2 wide band model (Hourdin 1991) + NLTE model (Lopez-Valverde 2011)
   - NIR CO2 (NLTE)
   - EUV absorption
   - Aerosols: Toon et al. 1989

3) Subgrid scale dynamics
   - Turbulence: Mellor and Yamada 2.5 Scheme
   - Convection:
   - Gravity waves (orographic) + low level drag: Parametrisation of impact on the main flow

4) Surface and subsurface thermal balance

5) Volatile:
   - CO2 cycle: see below
   - H2O cycle: see below

6) Dust transport and distribution: see below
The LMD/IPSL « Mars system simulator »

- **CO₂ Cycle** (LMD, Latmos, IDES)
- **Atmospheric Dynamics, T structure**
- **Exosphere Atm. Escape** (Latmos, LMD)
- **Thermosphere Ionosphere** (IAA, LMD, Latmos)
- **Dust cycle** (Oxford U., LMD, LISA, Latmos)
- **Mesoscale Model / LES** (LMD)
- **Mars GCM**
- **Photo-Chemistry** (Latmos, IAA)
- **Water Cycle** (LMD, Latmos)
- **Climate variations & paleoclimates** (LMD, Brown U, IDES)
- **Radon Cycle** (LMD, Latmos)
- **Ancient Mars** (- 3 à - 4 Gyr (with Harvard University Obs. Royal de Belgique))
- **Volcanic eruption simulations** (with Brown University)
- **Meteorological Data assimilation**: Optimal combination of data and model information to create the best climatology (as on Earth)

« Mars Climate database »
- Reference tool for the Scientific and Space Engineer community
- Version « pro » on DVD-ROM ordered by ~250 teams from ~22 countries
- Interactive website
# The Mars Climate Database

## Beginners' column (1-click presets)

1. **LANDING DATE**
   - Curiosity
   - Phoenix
   - Opportunity
   - Spirit
   - Pathfinder
   - Viking 2
   - Viking 1

2. **TIME**
   - Morning
   - Afternoon
   - Evening
   - Night

3. **ALTITUDE**
   - Near-surface
   - Boundary layer
   - Troposphere
   - Mesosphere
   - Thermosphere

4. **INTEREST**
   - Atmosphere
   - Winds
   - Weather
   - Water cycle
   - Chemistry
   - Landing engineering
   - Glaciology
   - Surface meteorology
   - Radiative balance

## Regular users' column

- **MARS date**
  - Solar longitude: 41.2 degrees
  - Local Time: 12 Martian hour
  - Write a value (or a range 'val1 val2' or 'all')

- **EARTH date**
  - YY / MM / DD @ hh:mm:ss UTC
  - 2015 / 9 / 14 @ 7:15:10

- **CUSTOMIZE COORDINATES ON MARS**
  - Latitude: all degree North
  - Longitude: all degree East
  - Altitude: 200000 m above surface

- **CUSTOMIZE VARIABLE(S) TO BE DISPLAYED**
  - Variable 1: Temperature (K)
  - Variable 2: [C] vol. mixing ratio (mol/mol)
  - Variable 3: Horizontal wind (m/s)
  - Variable 4: [Ar] vol. mixing ratio (mol/mol)

## Advanced settings and information

- If longitude is a free dimension, local time value is:
  - at longitude 0
  - fixed for the whole planet

- Earth Julian Date: 2457279.80219

- Mars MY: 03 - MM: 2 - DD: 12 - sol: 86

- MCD version: 5.2
- Dust/EUV scenario: Martian Year 25
- Interpolate using MOLA topography
- Zonal averaging (only lat/alt plot): off/on
- Picture resolution: medium/high/eps

- [1D] Log(values): off/on
- [2D] Colormap: blue, green, yellow, red
- [2D] Bounds: min/max
- [2D map]: flat/lat/lon
- [2D map]: Transparency (%)
- [2D map]: Wind vectors: off/on

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Mars Climate Database (c) LMD/OU/IAA/ESA/CNES.
Open source python interface by A. Spiga (LMD).
Javascript time conversion by E. Millour (link).
Motivation

- Geological records on Mars show evidence of wetter, denser atmosphere in the past
- Where did that atmosphere go?
- Atmospheric escape is a key process to understand Mars atmospheric evolution
Motivation

- Escape variability strongly affected by temperature/density variability in UA
Motivation

- Good knowledge of UA structure and variability essential for aerobraking manoeuvres
Sources of variability in UA

- Solar UV variability
  - 11-year cycle
  - 27-sols
  - Flares
  - Orbital eccentricity
  - Latitudinal/LT due to insolation variations

- Atmospheric waves
  - Tides (migrating/non migrating)
  - Transient waves
  - Gravity waves

- Dust load in the lower atmosphere
Solar UV variability
Results: temperature variability

González-Galindo et al., JGR 2015
Results: temperature variability

González-Galindo et al., JGR 2015
Results: Hydrogen escape

Chaufray, González-Galindo et al., submitted

Chaffin et al., GRL 2014
Summary and future work

- Mars upper atmosphere strongly affected by variability
- We have characterized the temperature variability in the UA during the last 10 MYs
  - Strong seasonal variability
  - Important solar cycle variability
- Strong H escape rate variability
  - x10 seasonal, good agreement with MEx and MAVEN
  - x2-5 solar cycle
- Future directions:
  - Study temperature/escape rate at past solar conditions, to provide estimates of accumulated H loss
SPICAM Ultra-Violet observations, orbit #17
13 Jan. 2004

Spectrum of the star:
- outside the atmosphere
- through the atmosphere
  altitude: 750 km

Atmospheric Transmission
- altitude: 50 km

Mars Express spacecraft
Line of sight
Star
Mars
Atmosphere
LMD GCM Zonal mean exobase temperatures at noon and lat=50S

Gonzalez-Galindo et al. (2015)
The Mars Climate Database

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   - Pathfinder
   - Viking 2
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   - Winds
   - Weather
   - Water cycle
   - Chemistry
   - Landing engineering
   - Glaciology
   - Surface meteorology
   - Radiative balance

### Regular users' column
- **MARS date**
  - Solar longitude: **41.2** degrees
  - Local Time: **12** Martian hour
  - Earth date: **2015/9/14 12:15 UTC**

### Advanced settings and information
- If longitude is a free dimension, local time value is:
  - **0** at longitude 0
  - Fixed for the whole planet

- Earth Julian Date: **2457279.80219**
- Mars MY: **33**
- Dust/EUV scenario: **Martian Year 25**
- Interpolate using MOLA topography
- Zonal averaging (only lat/alt plot): **off**
- Picture resolution: **medium**
- High: **high**
- Eps: **eps**

### Customize coordinates on Mars
- Latitude: **all** degree North
- Longitude: **all** degree East
- Altitude: **200000** m above surface

### Customize variable(s) to be displayed
- **Variable 1**: Temperature (K)
- **Variable 2**: [O] vol. mixing ratio (mol/mol)
- **Variable 3**: Horizontal wind (m/s)
- **Variable 4**: [Ar] vol. mixing ratio (mol/mol)

### Additional notes
- [1D] Log(values) **off** **on**
- [2D] Colormap: **blue green yellow red**
- [2D] Bounds: **min** **max**
- [2D map] **lat** **lon**
- [2D map] Transparency (%)
- [2D map] Wind vectors: **off** **on**

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The Mars Climate Database

MCD v5.2 with Martian Year 25 scenario, Ls 41.2 deg.
Altitude 200000.0 m ALS Local time 12.0h (at longitude 0)

Mars Climate Database (c) LMD/QUIAA/ESA/CNES