Assessment of possible Mars landing site for Mars-EDL

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Japanese-French model studies of planetary atmospheres
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Introduction

• A Mars surface exploration program is discussed by space engineering and planetary science communities in Japan (MARS-EDL).

• Evaluation of plausible range of meteorological conditions at landing site is required.
  - To support designing the landing module and observation instruments and ensure safety mission operation

• We join MARS-EDL working group, because it is a good chance to improve our models and to get experience of performing assessment for exploration program.
Our research group now progress to assess the Mars surface environment by using following numerical models results.

- **General Circulation Model (GCM):**
  - DCPAM (developed by GFD_Dennou_Club)

- **Cloud Resolving models (CRM):**
  - CReSS-Mars (developed by Nagoya U.)
  - deepconv (developed by GFD_Dennou_Club)

- **a Large Eddy Simulation (LES) model**
  - SCALE-LES (developed by RIKEN AICS)
Models: summary of our status

- **DCPAM [GCM]** (developed by GFD_Dennou_Club)
  - Proper calibration for assessment of Mars surface environment is established.
  - The calibrated data are used in Mars-EDL working group.

- **CReSS-Mars [CRM]** (developed by Nagoya U., Japan)
  - As a preparation, a lot of numerical experiments are performed in order to examine performance of CReSS-Mars

- **deepconv [CRM]** (developed by GFD_Dennou_Club)
  - Topography is not considered.
  - We are planning to perform comparative experiments between CReSS-Mars and deepconv with idealistic condition.

- **SCALE-LES [LES]** (developed by RIKEN)
  - Some idealistic experiments are performed (see presentation of Dr. Nishizawa)
Assessment of Mars surface environment using Planetary General circulation model, DCPAM

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We show:

• Comparison between simulation results of DCPAM and observations
• Proper calibration for assessment of Mars surface environment by using DCPAM data.
• Contribution to MARS-EDL
Model and Simulation setup

- DCPAM is a planetary atmospheric general circulation model developed by GFD Dennou Club (Takahashi et al. 2012).
  - A spectral GCM designed by using primitive equation system.
  - Physical processes are included
    - subgrid scale turbulence
    - CO$_2$ condensation/sublimation
    - atmospheric and dust radiation
    - surface process
  - The topography, surface albedo and thermal inertia in the model are based on observation results obtained by Mars Global Surveyor (MGS).

Figure: Schematic figure of DCPAM
Model and Simulation setup

• Simulation setup is as follows.
  - Resolution
    • The horizontal truncation wave number is 31 (dx ~ 200 km).
    • The number of vertical layer is 36 and the height of lowest level is about 3 m.
  - Dust opacity
    • MGS senario [default]
    • constant opacity (τ = 0, 1, 3, 5)
  - Numerical integration is performed for 7 Mars years with isothermal no motion initial condition.
    • The data of last two years are used for analysis.
Comparison results:
Surface atmospheric temperature

- Diurnal variation of atmospheric temperature at 1.5 m height observed by MPF is well reproduced.
  - Logarithmic wind and temperature profiles under neutral stratification are assumed.
  - Interpolating with ground temperature and atmospheric temperature at 2nd model level (about 12.5 m height).

Figure: Diurnal variation of ground and atmospheric temperatures
Comparison results:
Surface atmospheric pressure

- The seasonal variation of surface pressure observed by Viking Lander 1 (VL1) is almost represented by the model with some calibrations
  - a height difference between the model grid and actual landing site by using a scale height at 10th model level
  - uncertainty of global mean atmospheric mass by subtracting 60 Pa.

\[ P = P_s \exp\left(\frac{\Delta z}{H}\right) \]

\[ P = P_s \exp\left(\frac{\Delta z}{H}\right) - 60 \]

Figure: Seasonal variation of surface pressure at Viking Lander 1 site:
Contribution to MARS-EDL

- Based on the calibration, assessment of surface environment at proposed landing sites is published on a Web.
- This data is used in Mars-EDL working group.
Assessment of Mars surface environment using Cloud Resolving Model, CReSS-Mars

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• 2D experiment with idealized boundary condition
  • We examine whether the obtained diurnal change of temperature is consistent with the data obtained by DCPAM-1D and NASA's Mars lander, Spirit.

• 3D experiment using DCPAM data
  • We examine whether CReSS-Mars successfully run when considering very steep slope and using DCPAM data as initial and boundary conditions.
Model description

- We apply CReSS to Martian atmosphere since April 2013
  - CReSS is a well-developed cloud resolving model used in studies of terrestrial mesoscale phenomena (Tsuboki and Sakakibara, 2002).

- CReSS-Mars is based on CReSS ver.3.4.
  - Dynamical core: quasi-compressible system (Klemp and Wilhelmson, 1978).
  - Sub-grid scale turbulence: Deardorff (1980).
    - also used by Spiga et al. (2010)
  - Radiation: Takahashi et al. (2003, 2006)
    - CO₂ gas and dust are considered.
    - The source code of DCPAM is installed
  - Surface momentum and heat fluxes: Louis et al. (1982).
  - The surface and ground temperature are calculated by using one-dimensional thermal diffusion equation.
2D experiment with idealized boundary condition

- **Location:** *Spirit* landing site (14.6 S, 175.5 E)
- Dust opacity: $\tau = 0.3$
- No topography
- Cyclic condition (Horizontal)
- Grid size: 250 x 200 (2-dimensional)
- Resolution: $\Delta x = 200$ m, $\Delta z$ (mean) = 200 m, $\Delta z$ (min) = 2 m
- Initial temperature profile: calculated by DCPAM-1D.
- Integral time: 6 days.
- In order to check variability, other mixing length of unstable layer included turbulence parameterization is also used.
  - default: $l = l_0(z)$ (Deardorff, 1980)
    - suggested by Spiga et al. (2010)
    - where $l_0 = (\Delta x \Delta y \Delta z)^{1/3}$, $\kappa = 0.4$
  - test case: $1/l = 1/\kappa z + 1/l_0(z)$ (CReSS original)

This follows Prandtl's mixing theory near the surface. Its origin is a forecast model of Japan Meteorological Agency.
Compare to DCPAM-1D

- The results are almost consistent with those obtained by 1D convective-radiative model (DCPAM-1D).
  - Same source code of radiative transfer equation is used.

LT = 11.7 h  LT = 15.7 h  LT = 23.7 h
(×1000 m)    (×1000 m)    (×1000 m)

Surface temperature

heat budgets at the surface

DCPAM-1D  CReSS-Mars

solar  total  sensible heat
infrared

zoom
Compare to Spirit observation

- At daytime (LT=10:05, 12:55, 16:30), temperature lapse rate near the surface is roughly consistent with the observation.
Dependency on the mixing length

- The mixing length of the turbulence process is one of the major problems, which affects temperature profile near the surface.
  - Surface temperatures of both cases are almost the same.

Parameter: the mixing length of unstable layer.
- default: \( l = l_0(z) \) (Deardorff, 1980)
- test case: \( 1/l = 1/\kappa z + 1/l_0(z) \) (CReSS original)
3D experiment using DCPAM data

- **Location:** Opportunity landing site (1.9S, 2.5W)
- **Grid size:** 750 x 500 x 64
- **Resolution:**
  \[ \Delta x = \Delta y = 0.012^\circ (\sim 700 \text{ m}), \]
  \[ \Delta z (\text{mean}) = 500 \text{ m}, \Delta z (\text{min}) = 20 \text{ m} \]
- **Dust opacity:** \( \tau = 0.3 \)
- **Season:** Ls = 0 (the vernal equinox day)
- **Simulation data of DCPAM is used as initial and boundary conditions in order to consider the large-scale effect.**
- **Topography are considered**
- **Integral time:** 2 days (177600 sec)
Results

- The temporal variation of convective activity is successfully calculated.
  - Small-scale circulation in daytime is similar to that obtained LES calculation.

Vertical velocity (above ~10m)

Vertical velocity (above ~430m)

Topography
Other sites …

- At Opportunity landing site, CReSS-Mars successfully run using DCPAM data as initial and boundary conditions.

- However, CReSS-Mars can not run when considering very steep slope such a possible landing site of MARS-EDL.

  - One of the reasons may be grid interval of DCPAM and CReSS-Mars
    - DCPAM: $dx \sim 200$ km
    - CReSS-Mars: $dx \sim 500 - 1000$ m
      (domain size : $L \sim 300 - 500$ km)

- We will try to change nesting DCPAM ($dx \sim 200$ km)
  $\Rightarrow$ CReSS-Mars ($dx \sim 10$ km)
  $\Rightarrow$ CReSS-Mars ($dx < 1$ km)
Summary

• Some numerical experiments are performed in order to examine performance of CReSS-Mars

• 2D experiment with idealized boundary condition
  - The obtained diurnal change of temperature is consistent with the data obtained by DCPAM-1D and NASA's Mars lander, Spirit.
  - The mixing length of the turbulence process is one of the major problem, which effects temperature profile near the surface.

• 3D experiment using DCPAM data
  - In some cases, CReSS-Mars successfully run using DCPAM data as initial and boundary conditions.
  - We will try to change nesting in order to perform simulation with very steep slope such a possible landing site of MARS-EDL.