Assessment of possible Mars landing site for Mars-EDL

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Japanese-French model studies
of planetary atmospheres
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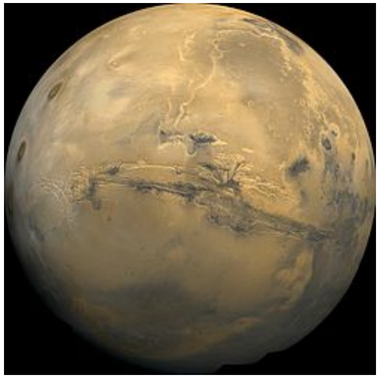
Introduction

- 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.



Models

- 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).

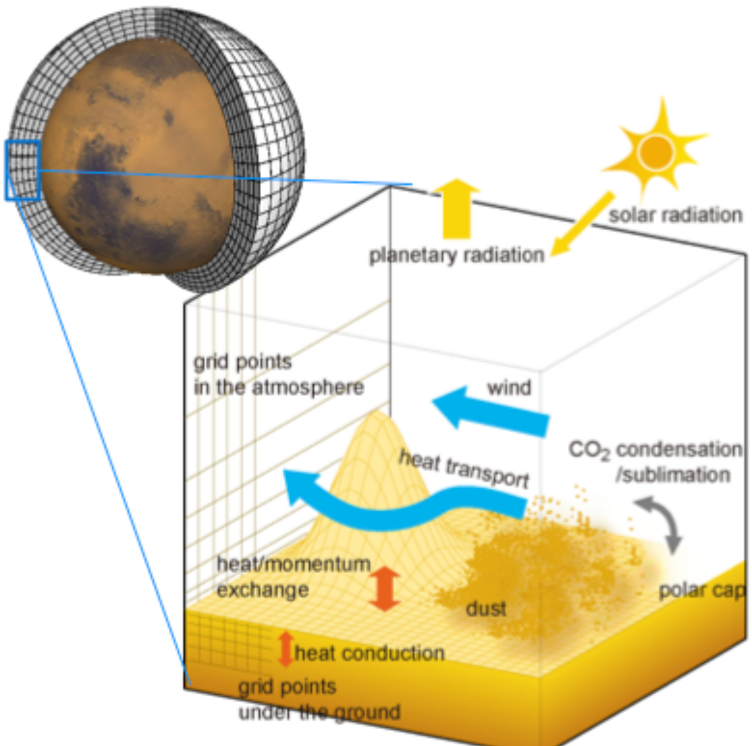


Figure: Schematic figure of DCPAM

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).

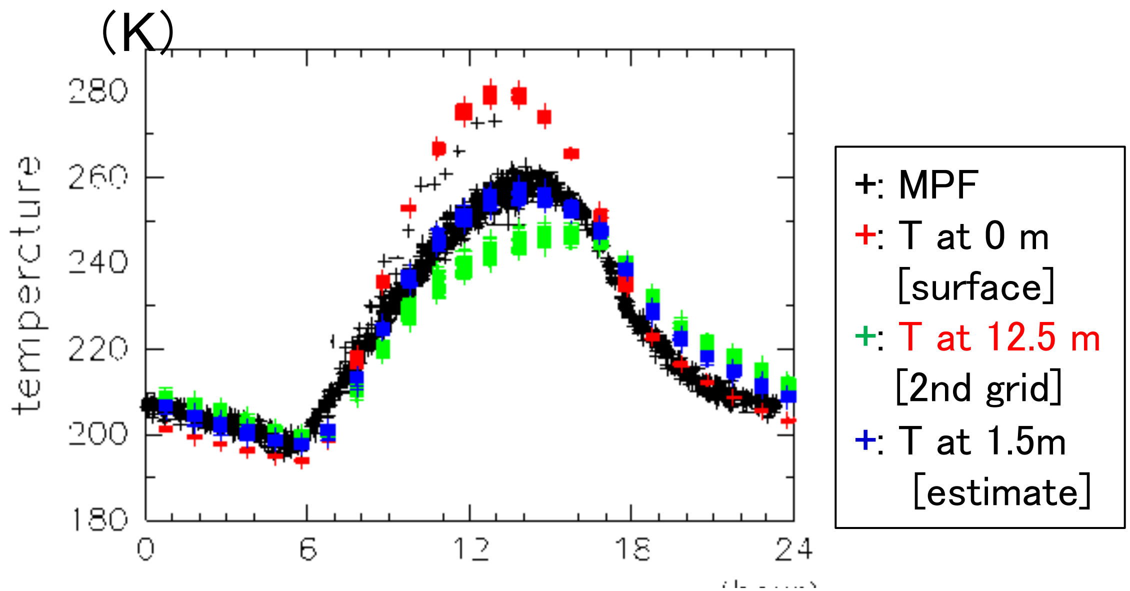
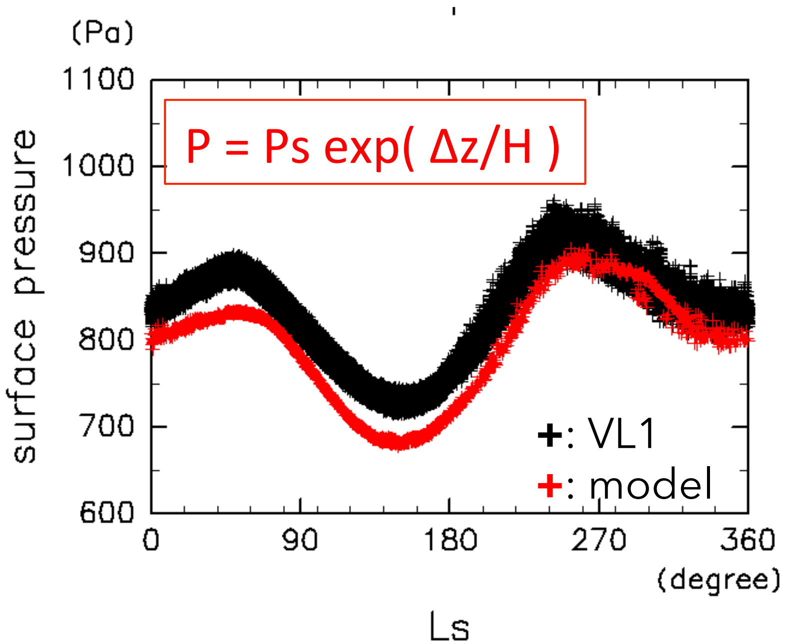


Figure: Diurnal variation of ground and atmospheric temperatures

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.



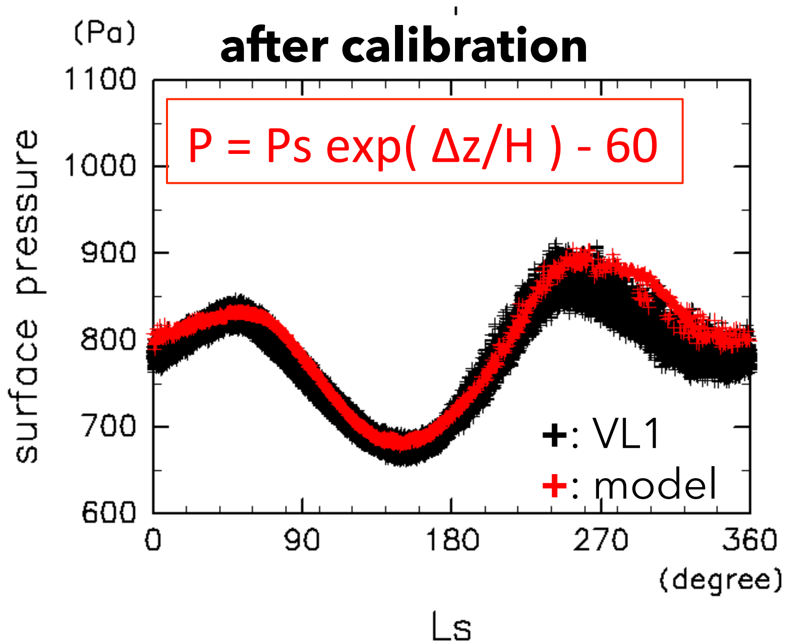
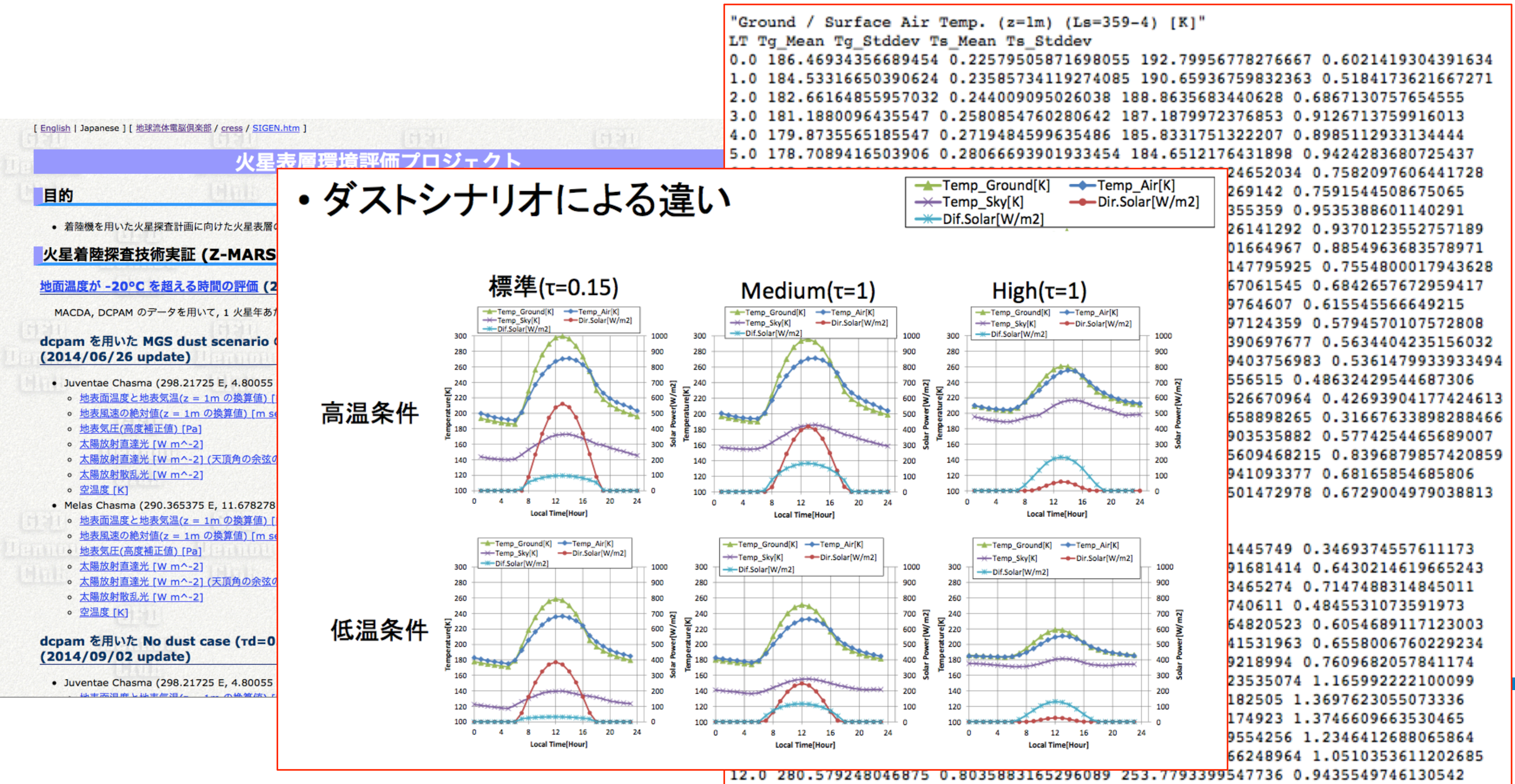


Figure: Seasonal variation of surface pressure at Viking Lander 1 site:

Contribution to MARS-EDL

- Based of 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)
    - CO_2 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.

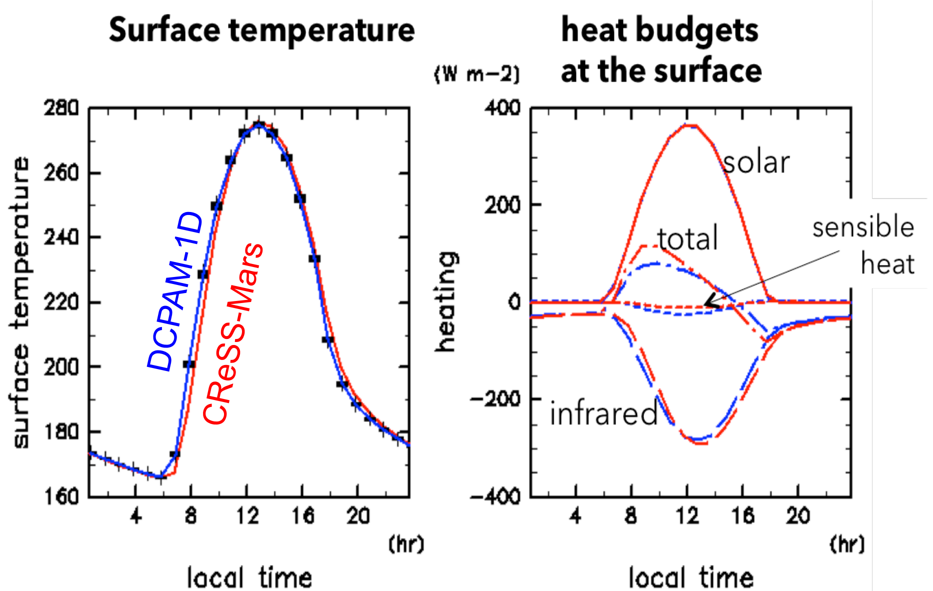
2D experiment with idealized boundary condition

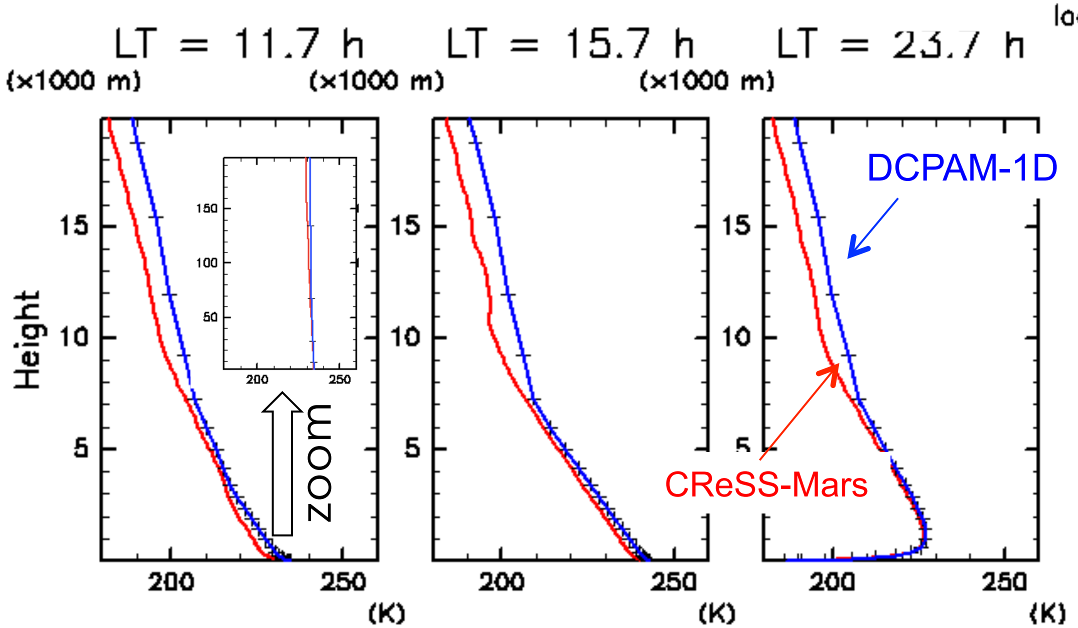
- Location: Spirit landing site (14.6 S, 175.5 E)
- Dust opacity: $\tau = 0.3$
- No topography
- Cyclic condition (Horizontal)
- Grid size: 250 x 200 (2-dimensional)
- Resolution: $\Delta x = 200$ m, Δz (mean) = 200 m, Δz (min) = 2 m
- Initial temperature profile: calculated by DCPAM-1D.
- Integral time: 6 days.
- In order 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: $1/l = \boxed{1/\kappa z} + 1/l_0(z)$ (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

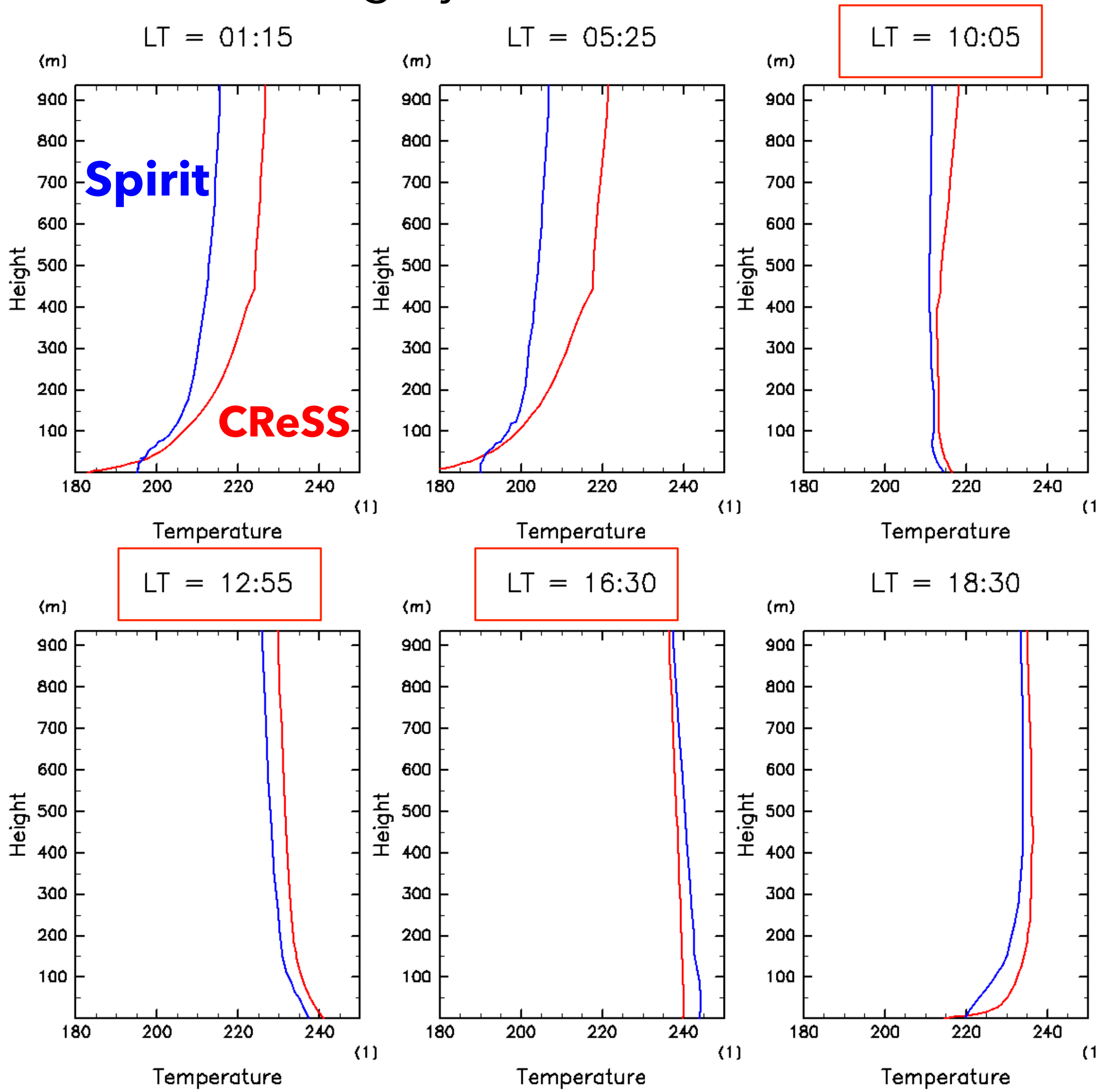
- The results are almost consistent with those obtained by 1D convective-radiative model (DCPAM-1D).
  - Same source code of radiative transfer equation is used.





Compare to Spirit observation

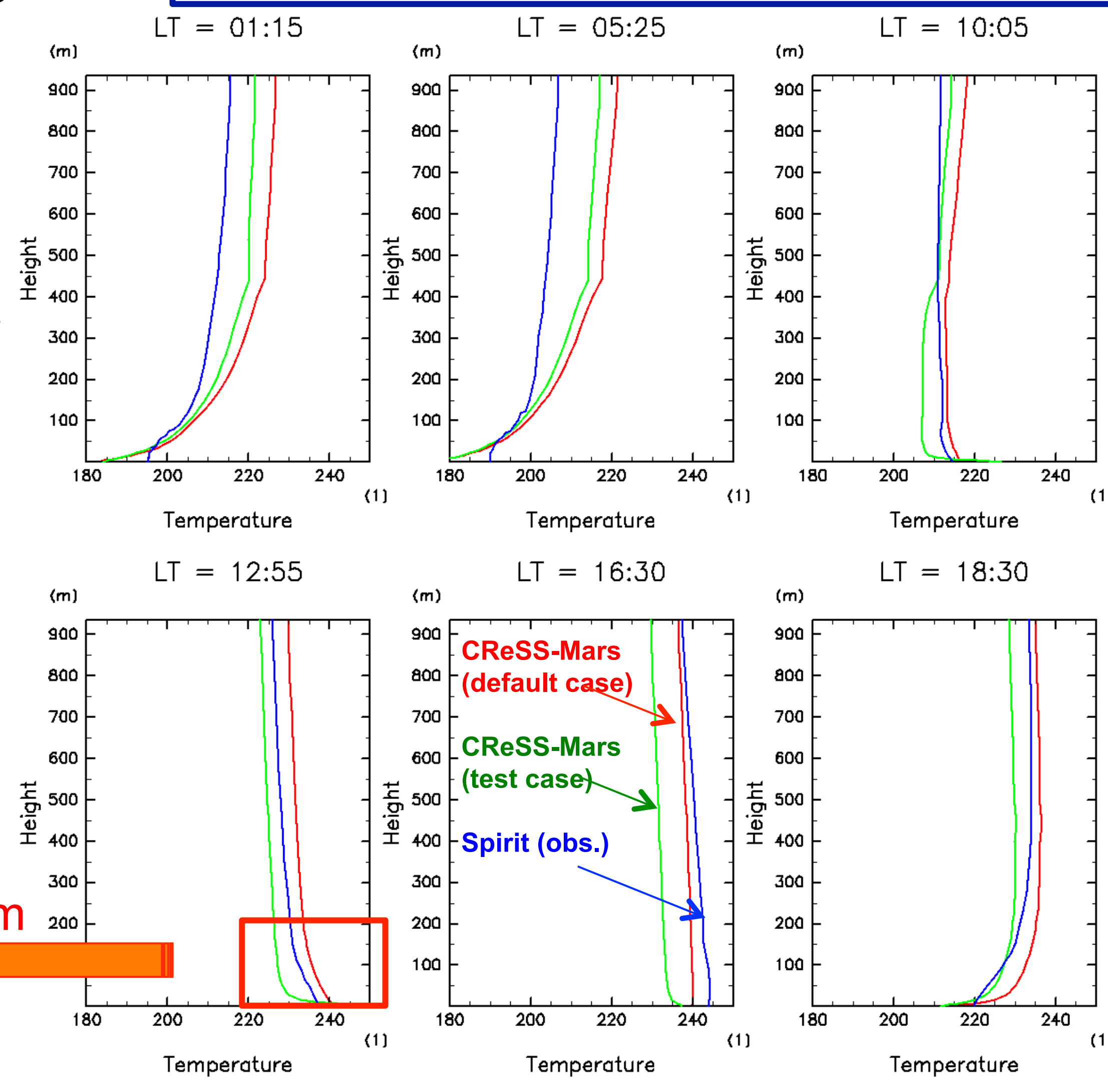
- At daytime (LT=10:05, 12:55, 16:30), temperature lapse rate near the surface is roughly consistent with the observation.

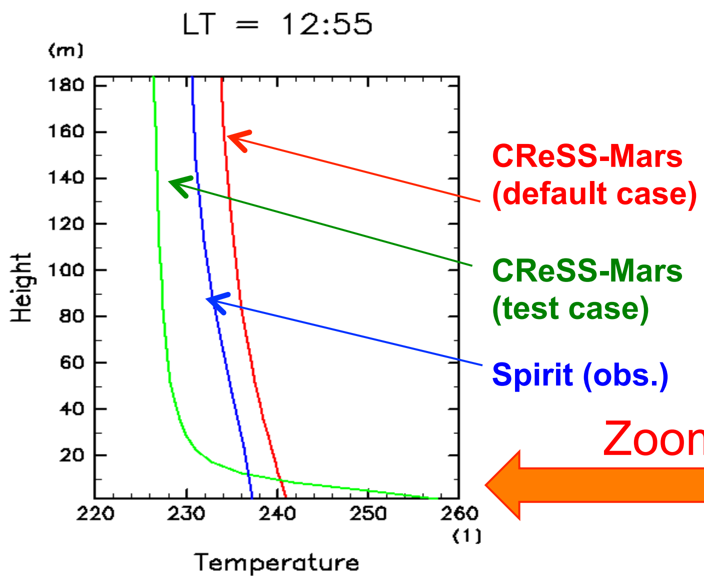


Dependency on the mixing length

- The mixing length of the turbulence process is one of the major problem, which effects 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)





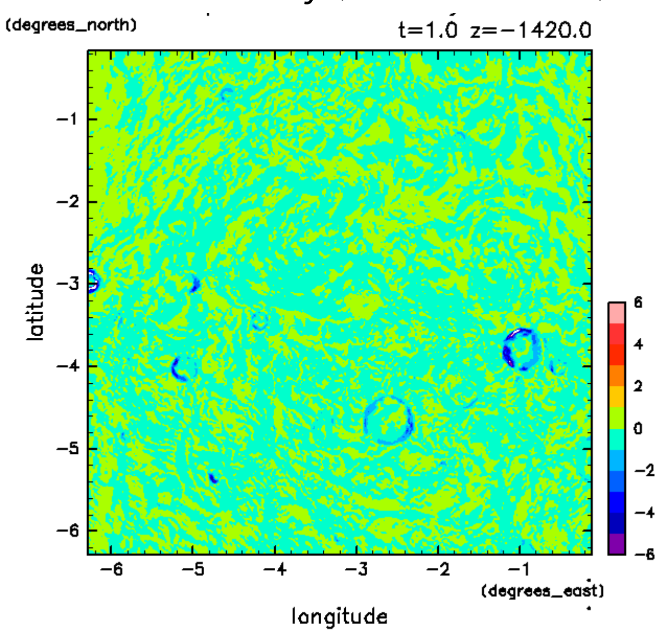
3D experiment using DCPAM data

- Location:
  Opportunity landing site (1.9S, 2.5W)
- Grid size: 750 x 500 x 64
- Resolution:
  $\Delta x = \Delta y = 0.012°$ (~700 m),
  Δz (mean) = 500m, Δz (min) = 20 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)

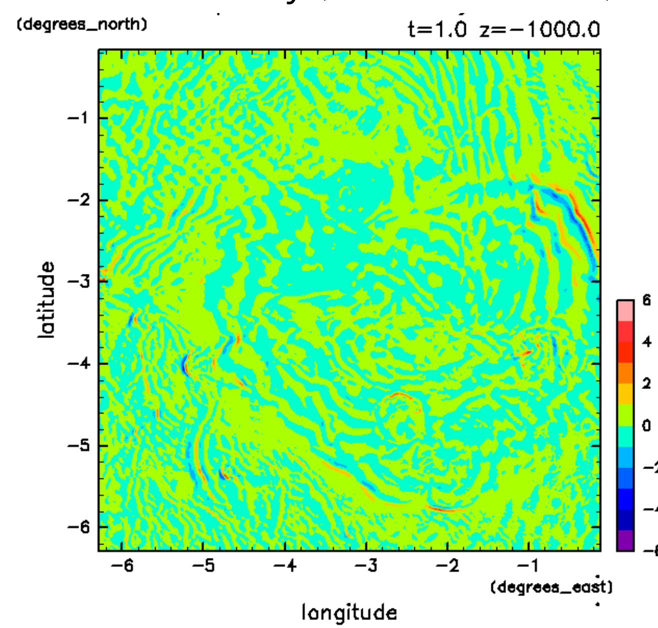
Results

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

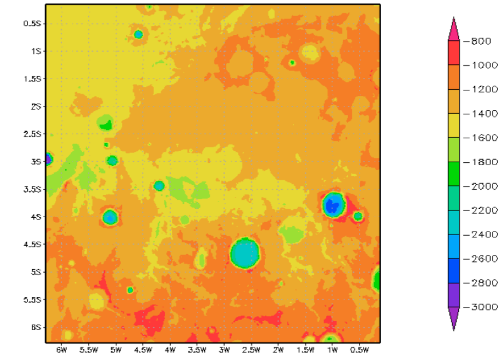
Vertical velocity (above ~10m)



Vertical velocity (above ~430m)

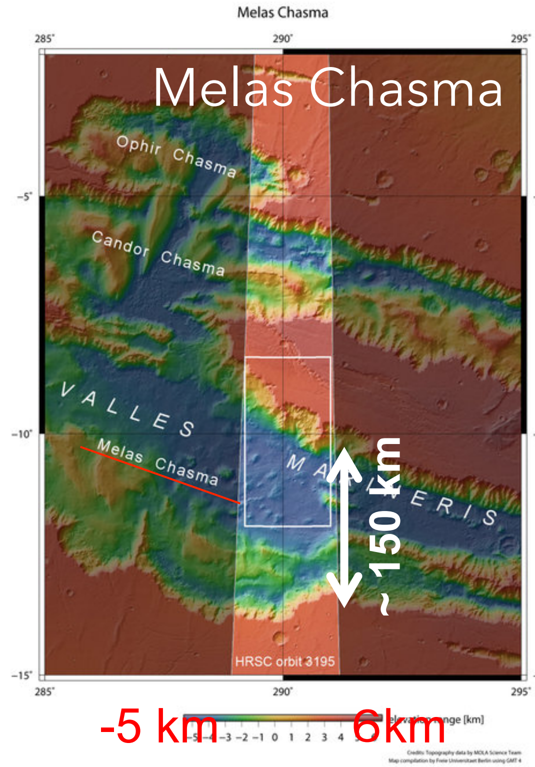


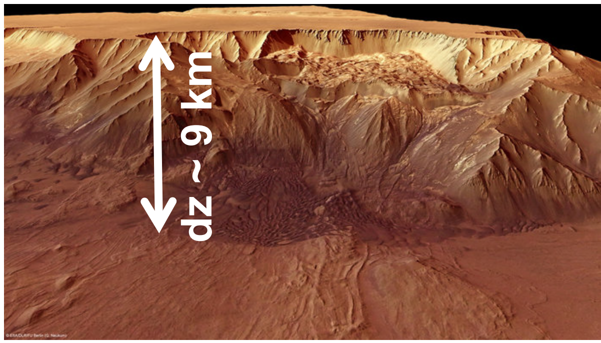
Topography



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 ~ 200 km
        - CReSS-Mars: dx ~ 500 – 1000 m (domain size : L ~300 - 500 km)
    - We will try to change nesting DCPAM (dx ~ 200 km) => CReSS-Mars (dx ~ 10 km) => 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.