Implementation Martian dust lifting scheme into DCPAM, and a diagnosis experiment of surface dust flux

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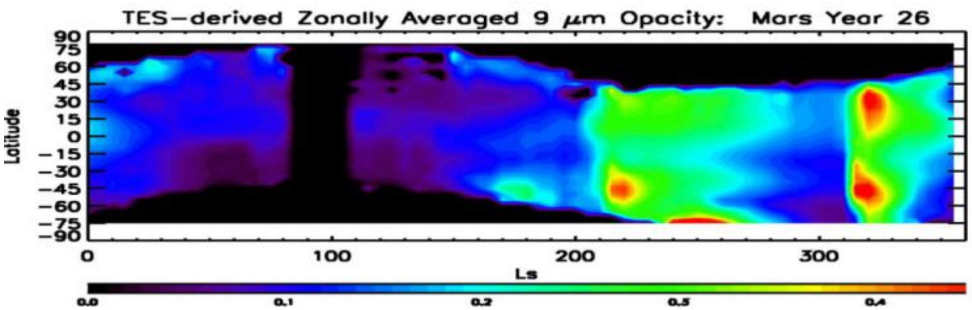
Martian dust

- Dust plays a critical role in the thermal and dynamical state of the Martian atmosphere
  - Dust distribution variabilies
    - Seasonal change

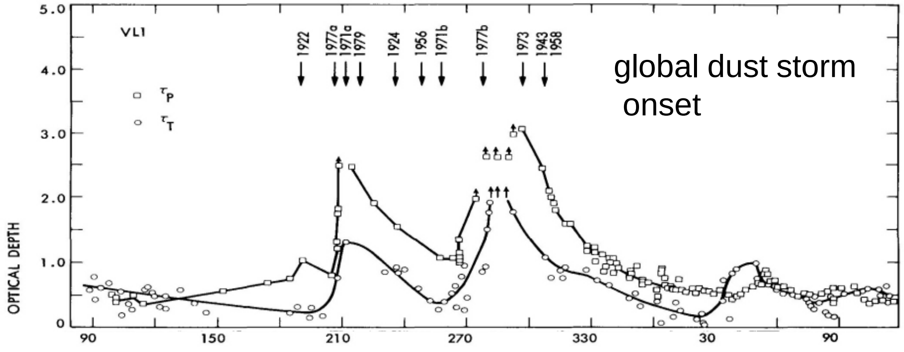
Observed seasonal change of infrared (9 μm) opacity



TES for Mars year 26
(Kahre et al., 2006)

- Interannual variability : global dust storm

Observed interannual variability of visible opacity



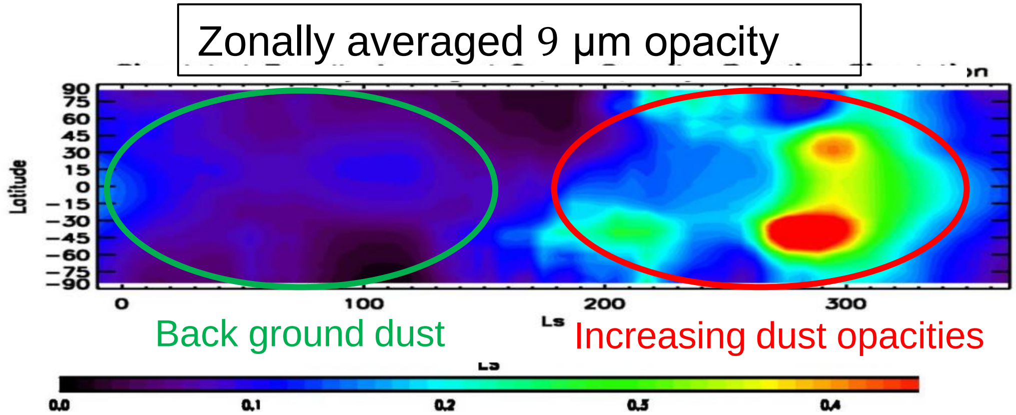
Viking Lander 1 imaging data for
Viking year 1(Zurek, 1982)

Modeling of dust processes

- Dust processes which should be implemented
  - lifting processes
    - wind stress lifting
    - dust devil lifting
  - transport processes
    - turbulent mixing
    - advection
    - gravitational sedimentation
  - radiative processes
    - absorption and scattering by dust
- Some research groups have performed the Martian dust cycle experiments with those processes
  - Newman et al., 2002; Basu et al., 2004; Kahre et al., 2006

Result of Kahre et al. (2006)

- One of previous simulation of Martian dust cycle
  - Model: NASA Ames GCM with dust as a radiatively active tracer
- Result
  - Observed seasonal variation of dust is almost reproduced.
    - Low dust opacity in Northern summer, Increasing dust opacity in Northern winter
    - The atmospheric dust load increase during northen fall and winter



Simulation by Kahre et al. (2006) .
Opacity have been scaled to
the 6.1 mbar presure level

- Unresolved problem
  - Interannual variability of global dust storms can not be simulated

Aims of this work

- Present state of our model
  - Dust cycle parametarization schemes have not been implemented
- Goal
  - Implementing dust cycle parametarization schemes into DCPAM
  - Numerical experiments on dust variability with dust cycle model
- In this work
  - Implementing a dust lifting scheme(Kahre et al., 2006) into DCPAM
  - diagnosing surface dust flux
    - Radiatively active dust is given, and dust lifting scheme lifts only radiatively inactive dust
  - Comparing our model's results with Kahre et al. (2006)

Model

- DCPAM: general circulation model of planetary atmosphere (http://www.gfd-dennou.org/arch/dcpam/index.htm.en)
  - Dynamical core
    - Three dimentional primitive equation system
  - Radiation
    - Mars radiation model based on Takahashi et al. (2003, 2006)
      - Effects of absorption and scattering by CO_2 and dust are considered
  - Turbulent mixing
    - Mellor and Yamada (1974, 1982) level 2 scheme
    - Bulk formulae based on Louis et al. (1982) is used to estimate surface flux
  - Dry convective adjustment
    - Dry convective adjustment scheme based on Manabe et al. (1965)
  - Surface CO_2 ice phase change process

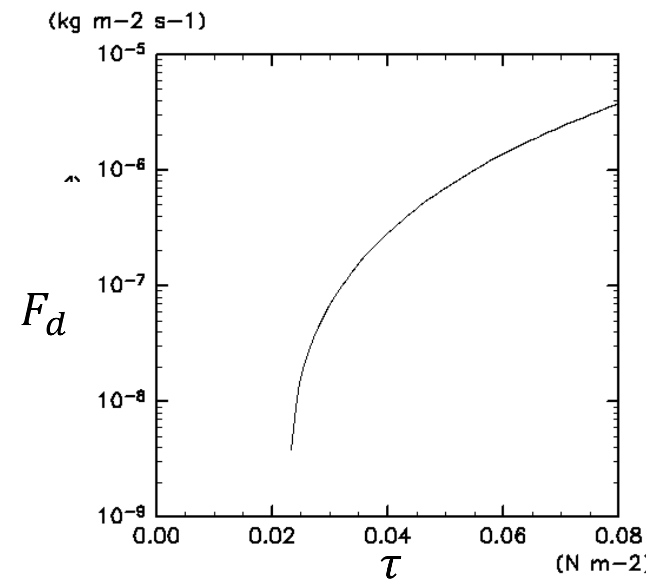
Wind stress lifting scheme

- KMH scheme (Kahre et al., 2006)
  - Dust lifting scheme by using model resolved near surface wind stress

$$F_d = \alpha R \tau^2 \left(\frac{\tau - \tau^*}{\tau^*} \right)$$

F_d: vertical dust flux
α :efficiency factor
R : empirically coefficient
τ : surface stress
τ^* : threshold stress required for lifting

$\tau - F_d$ Relation



- Vertical dust flux is zero, unless surface stress exceeds threshold stress required for lifting
- This scheme is based on that of terrestrial dust lifting
  - Westphal et al., 1987;Haberle et al., 2003

Experimental setup

- Dust distribution for radiative scheme is given
  - Horizontally and temporally uniform
  - The dust optical depth at 0.67 μm is set to be 0.2
  - Vertical distribution is determined on the based of Pollack et al. (1990) and Forget et al. (1999)
- Surface dust flux is diagnosed
  - parameters of KMH scheme
    - $\alpha = 0.1$
    - $\tau^* = 0.00225 \mathrm{Nm^{-2}}$
    - $R = 0.0023$
  - Lifted dust are radiatively inactive and not advected

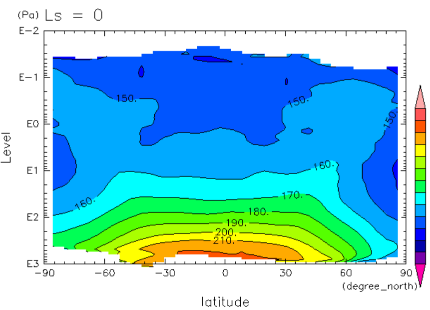
Experimental setup (cont.)

- Surface properties(topography, albedo, thermal inertia)
  - Data observed by Mars Global Serveyor
- Other parameters are those commonly used for Mars simulation
- Resolution
  - T21L32
    - $5.625° \times 5.625°$ longitude-latitude grid
    - 32 vertical levels
- Initial state
  - motionless and isothermal(200K) state with small temperature disturbances
- Integration time
  - Three Mars years
  - The last year is used for analysis

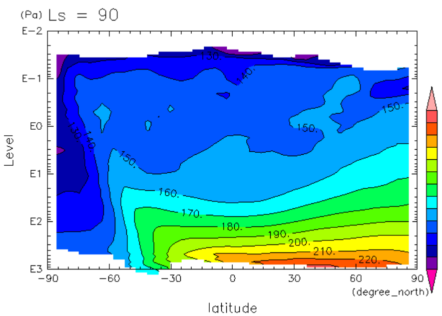
Model performance test

- Simulated temperature distribution is similar to observation result
  - northern spring and fall: temperature distribution is equatorially symmetric
  - northern summer and winter: temperature distribution is equatorially asymmetric
    - low tropospheric temperature rapidly decreases from near $40°$ latitude toward pole in the winter hemisphere

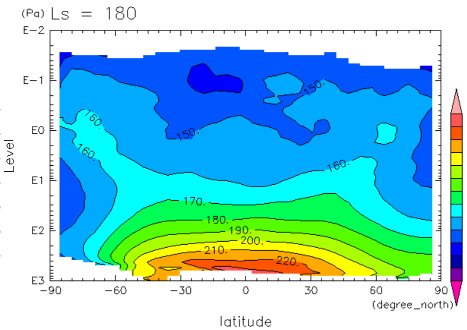
Zonal mean temperature



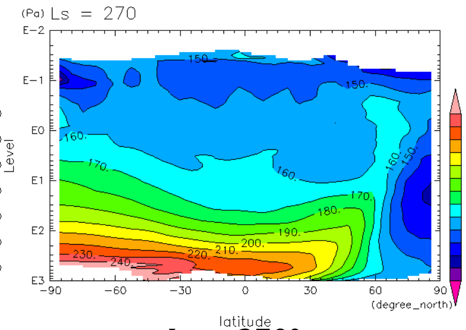
$L_s = 0°$
(northern spring)



$L_s = 90°$
(northern summer)



$L_s = 180°$
(northern fall)

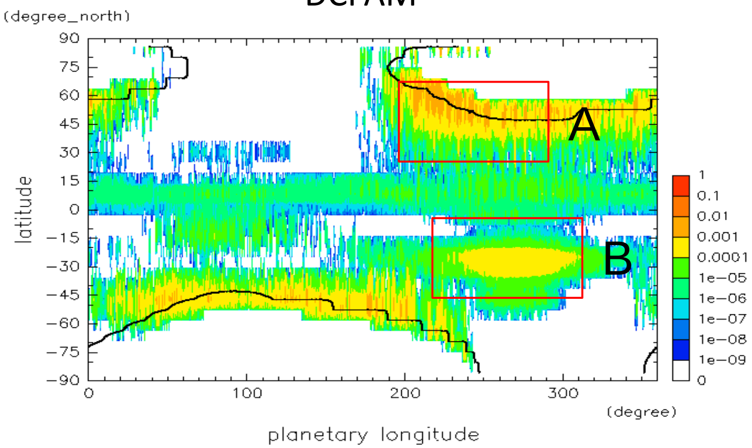


$L_s = 270°$
(northern winter)

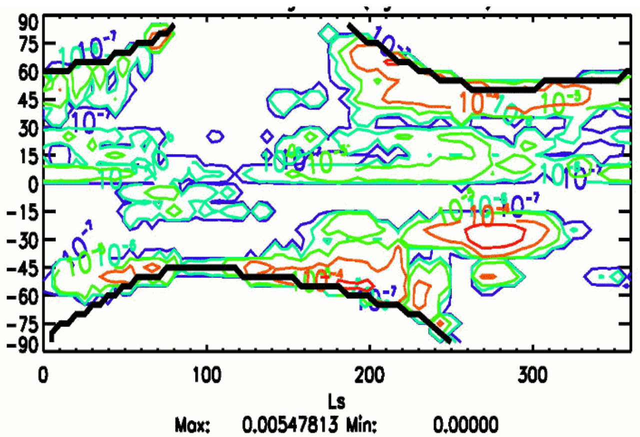
Results of diagnosed surface dust flux

seasonal change of zonal mean surface dust flux

DCPAM



Kahre et al, (2006)

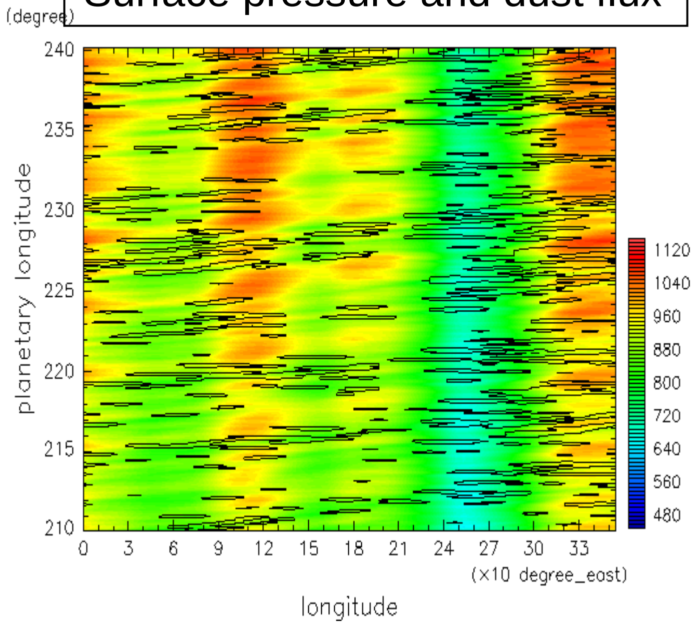


- Season and location of intense dust lifting are similar to Kahre et al. (2006).
  - the edge of polar caps, regions in the southern mid-latitudes
- The order the magnitude of dust flux is larger
  - maximum of daily mean value: 0.026 kg m^{-2} s^{-1}(DCPAM), 0.005 kg m^{-2} s^{-1}(Kahre et al., 2006)
  - It might be caused by differences in vertical level setting and turbulent mixing scheme

Details of dust lifting near the edge of northern polar caps

- latitude $50°$N, $L_s = 210° - 240°$ (region "A")
- Dust lifting occurs in low pressure region.
- Pressure variation shows eastward propagating wave-like structure
  - wavenumber 1 and period of 6 Mars days
  - it is considered to be baroclinic wave(Briggs et al., 1979).

Surface pressure and dust flux

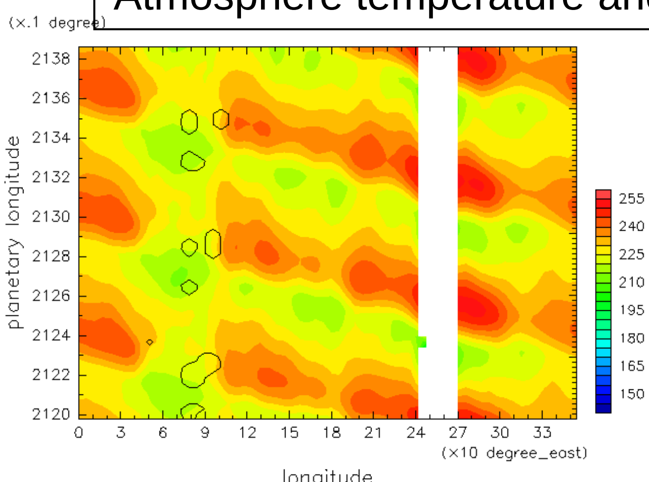


X-T diagram at 50°N,
color tone indicates surface pressure.
The contour indicates dust flux.

Details of dust lifting in the southern mid-latitudinal region

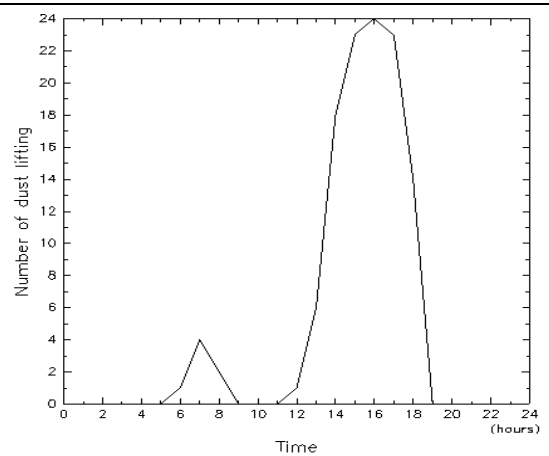
- latitude $30°S$, $L_s = 210° - 240°$ (region "B")
- Dust lifting occurs at around longitude $80°E$ (Hellas basin)
  - Onset of dust lifting seems to be triggered propagating high temperature region
- Temperature variation shows westward propagating wave-like structure
  - wavenumber 1 and period of 1 Mars day
  - it is considered to be diurnal thermal tide (Joshi et al., 1997)

Atmosphere temperature and dust flux



X-T diagram at $50°N$, color tone indicates temprerature on 400 Pa pressure level. The contour indicates dust flux.

Duurnal change of dust lifting at $(30°S, 90°E)$



Summary

- Implemented wind stress lifting scheme into DCPAM
  - KMH scheme(Kahre et al., 2006)
- Performed a diagnostic experiment of surface dust flux
  - Seasonal variation of dust lifting
    - Our results are similar to those of Kahre et al. (2006)
  - In region at latitude $50°$N, $L_s = 210° - 240°$
    - Dust lifting occurs in low pressure region. Baroclinic wave ?
  - In region at latitude $30°$S, $L_s = 210° - 240°$
    - Dust lifting occurs at around longitude $80°$E (Hellas basin). Diurnal thermal tide?
- Next step
  - Implementing dust devil lifting scheme, advective scheme and gravitational sedimentation scheme

Ongoing model development: implementation of dust devil lifting scheme

- Implementing dust devil lifting scheme into DCPAM
- Dust devil lifting scheme is a scheme for sub-grid scale
  - This is based on the thermodynamics of dust devils (Rennó et al., 1998)

$$F_d = \alpha F_s \eta$$

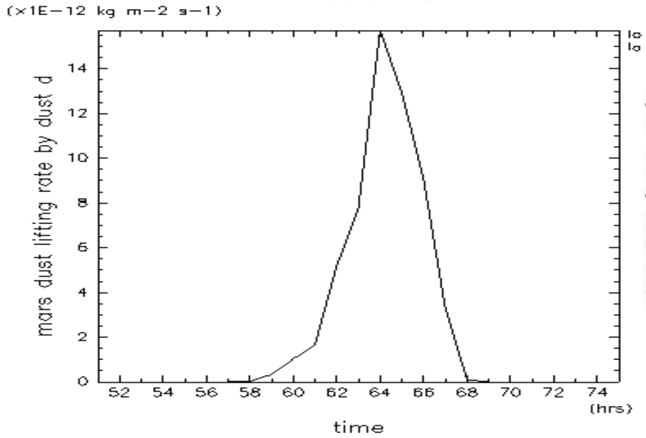
F_d : vertical dust flux
α : efficiency factor
F_s : vertical sensible heat flux
η : thermodynamic efficiency

Test experiment for dust devil scheme with 1D model

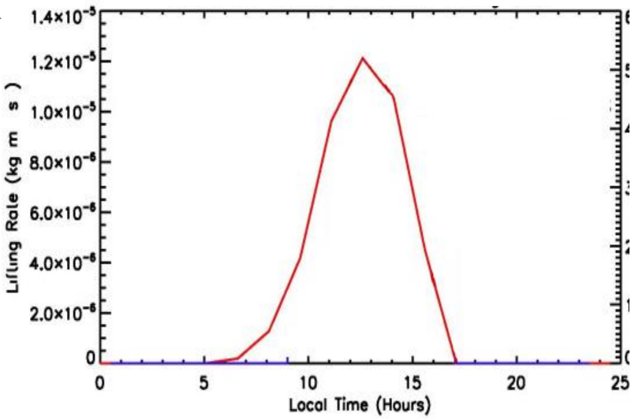
- We are performing 1 dimentional numerical experiments for dust devil lifting scheme

Diurnal variation of dust flux

1D model DCPAM



GCM Kahre et al. (2006)



under the condition Mars Pathfinder landing site(19N, 34W)

- Our result is qualitatively similar to Kahre et al. (2006)
  - Peak of dust flux appears at local time 12:00
- The order of magnitude of dust flux is larger
  - Is parameter value used by Kahre et al. (2006) correct ?