# EDDY DIFFUSIVITY MASS FLUX PARAMETERIZATION FOR NON-DUSTY MARTIAN BOUNDARY LAYERS: A PROGRESS REPORT

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**Introduction:**

Planetary and regional atmospheric models of the Earth and Mars (global climate models: GCMs; numerical weather models: NWMs etc,) simulate the transport of quantities like heat, momentum, mechanical energy, aerosols, and trace gases (hereafter "variables") both horizontally and vertically. Horizontal advection is usually well represented regardless of model resolution, but vertical transport is largely carried out by turbulence and eddies that cannot be explicitly resolved in a model and thus need to be parameterized. Vertical mixing of variables at scales below the horizontal resolution of the model is typically parameterized by two different schemes: (1) an eddy diffusivity (ED) scheme that models vertical transport of variables diffusively along local gradients; and (2) a mass flux (MF) scheme that models transport due to convective updrafts and/or downdrafts. Typically, models employ the ED scheme for dry turbulence and the MF scheme for moist convection. In other words, various atmospheric regimes are addressed independently with separate schemes. Such an approach is often acceptably accurate and generally quite appealing due to its simplicity. However, it lacks physical consistency by introducing arbitrary divisions in the atmosphere. Furthermore, it usually fails to seamlessly resolve transitions between boundary layer regimes and to simulate more extreme cases, such as, for example, strong thermal convection.

A typical daytime planetary boundary layer (PBL) structure exhibits a superadiabatic surface layer forced by surface heating; a well-mixed interior with a constant potential temperature profile; and a capping inversion at the top that limits vertical extent of turbulent eddies. An ED parameterization often struggles to resolve such conditions due to the lack of vertical gradients in the well-mixed layer. The resulting boundary layer is too stable near the surface, too unstable in the interior, and the thermal structure at the top of the boundary layer is usually incorrect as well [1].

Solutions to this problem have been suggested, all of which assume some form of a nonlocal turbulent transport that is insensitive to the neutral stratification. In particular, a combination of the ED scheme with the MF scheme offers a computationally efficient and physically consistent approach for dealing with convective boundary layers.

In recent years, there have been efforts to improve simulation of vertical mixing in Earth models by combining ED and MF-based convection schemes into a single parameterization [e.g., 1,2]. These eddy diffusivity mass flux (EDMF) parameterizations have proven quite successful for reducing model biases in the PBL. The ED part depends on local gradients and accounts for transport by smaller eddies. The MF-based convection accounts for vertical transport by one or more convective updrafts and/or downdrafts occupying a small portion of the grid cell but extending through the whole depth of the boundary layer. They typically make use of probability distribution of updrafts and/or downdrafts to improve accuracy without sacrificing computational efficiency. One such scheme, a thermal plume model, has been developed for dry convection on Mars, but this scheme relied on coupling to a separate ED boundary layer routine [3]

Dry convective activity is very common in the Martian PBL. Large numbers of dust devils have been observed on Mars from both orbit and the surface [e.g., 4, 5], while relatively strong and brief fluctuations in atmospheric pressure and/or wind speed are often observed by surface meteorological package, even in settings where visible dust devils are not observed [e.g., 6,7]. Dust devils and the analogous dustless circulations are interpreted as dry convective helical vortices, whose formation is associated with strong updrafts in the PBL resulting from the instability of the superadiabatic layer. This instability is a daily occurrence on much of the Martian surface, so representing vertical transport by dry convection is essential to accurate modeling of vertical transport on Mars.

The purpose of this work is to develop an EDMF parameterization appropriate for non-dusty boundary layers. The term non-dusty is used analogously to dry. By non-dusty, we refer to cases where the effects of the radiative heating of dust negligibly impacts the vertical transport at the scales being parameterized, not cases where dust is completely absent.

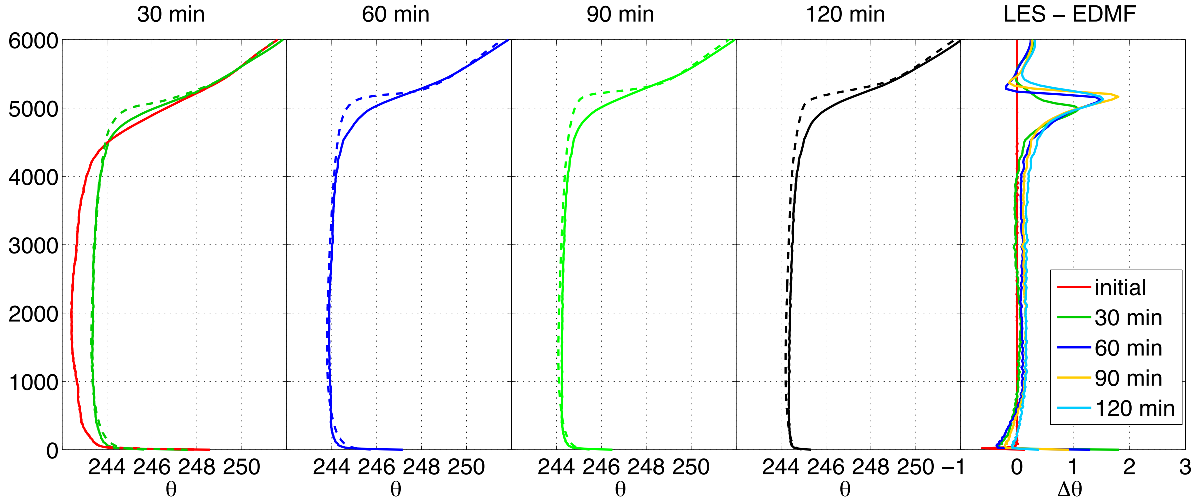


**Figure 1.** *Potential temperature (θ) profiles at different time steps from LES-WRF (solid lines) and 1D EDMF (dashed lines) simulations (four left panels). Also shown is the difference between LES and EDMF (right panel)*

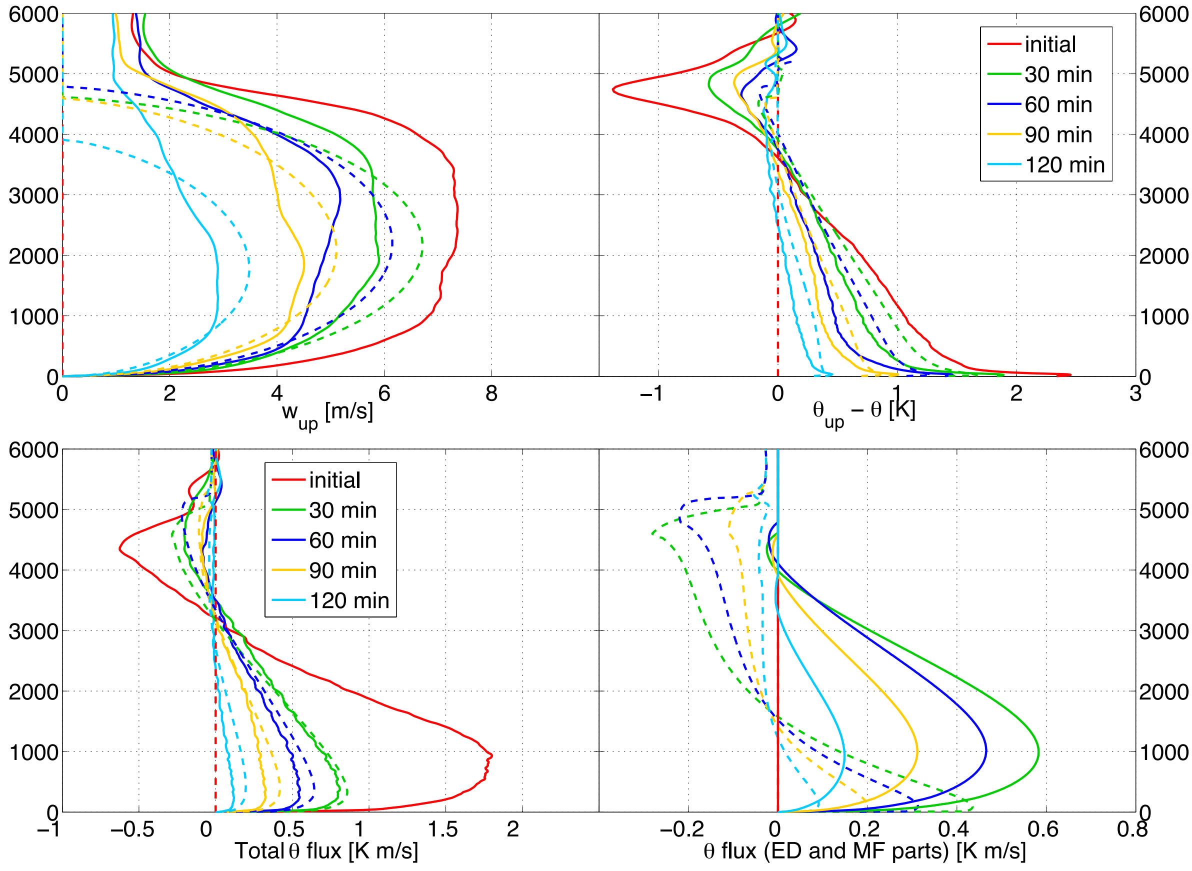


**Figure 2.** *EDMF performance assessment at different time steps: LES-WRF (solid lines) vs. 1D EDMF (dashed lines). (top left) Updraft vertical velocity; (top right) potential temperature excess inside updrafts* $\left(q_{up} - \bar{q}\right)$*; (bottom left) turbulent flux of potential temperature* $\left(\overline{w'q'}\right)$*; (bottom right) turbulent flux partitioning in the 1D model: the eddy-diffusivity part (dashed lines) and the mass-flux part (solid lines).*

**Methods:**

Parameterization formulation and design is based on large eddy simulations (LES) in the Planetary Weather Research and Forecasting model (planetWRF) [8]. These simulations provide the information necessary to force the EDMF scheme as well as the information necessary to validate it. The ideal simulation is one in which the surface heat flux is uniform, but this condition only can be approximated by planetWRF LES simulations.

**Results:**

Initial results indicate that the EDMF for Martian conditions agrees well with the LES with respect to potential temperature structure (Fig. 1). It also exhibits good behavior with respect to turbulent fluxes and turbulent kinetic energy (Fig. 2), although more work is needed to address existing discrepancies.

**Discussion:**

The EDMF parameterization has so far required three improvements that are either unique to Mars and/or often neglected for parameterizing dry convection on the Earth. First, the scheme accounts for mixing of downdrafts. Second, [2] showed that vertical transport of turbulent kinetic energy is often underestimated in models of terrestrial dry convection. This result appears to hold for Mars as well. Agreement with the LES is only possible if non-local transport is accounted for in the EDMF parameterization. Third, a unique feature of the Martian lower atmosphere is the importance of long-wave (IR) radiative heating on temperature profiles in the surface layer. This is due to the fact that the Martian atmosphere consists mostly of $CO_2$, which readily absorbs IR radiation. As a result, the sensible heat flux from the surface as a source of atmospheric heating is outweighed by the IR radiation flux. This has an impact on the way updrafts are initialized close to the surface, as was realized by [9]. An updraft initialization that accounts for the impact of IR heating in the surface layer thus has been developed.

This work also has suggested the need for some improvements to the planetWRF LES, particularly with respect to the model top and the radiative transfer scheme. These improvements have been incorporated into a new set of LES simulations/EDMF comparisons that is now in progress.

**Summary:**

An EDMF scheme for Martian dry convective boundary layers is currently under development. This scheme looks promising for translating insights from microscale/mesoscale modeling into simulations of the global atmosphere.

**Acknowledgements:**

This work is supported by NASA's Solar System Workings program (NNX15AI33G). Computational resources supporting this work were provided by the NASA High-End Computing (HEC) Program through the NASA Advanced Supercomputing (NAS) Division at Ames Research Center.

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