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Interactive comment on "An intercomparison of Large-Eddy Simulations of the Martian daytime convective boundary layer" *by* Tanguy Bertrand et al.

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Review of:

Journal: GMD Title: An intercomparison of Large-Eddy Simulations of the Martian daytime convective boundary layer Author(s): Tanguy Bertrand et al. MS No.: gmd-2016-241 MS Type: Methods for assessment of models

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manuscript overview: This manuscript endeavors to accomplish two goals: 1) perform an intercomparison of the dynamical cores of the LMD and SwRI LES models, and 2)

provide a high-resolution LES assessment of the turbulent convective boundary layer for the ExoMars Schiaparelli lander during its afternoon EDL. The first of these goals is the primary one; the second was never directly addressed since no mesoscale forecasts for the landing site were considered/compared with the LES results.

review overview: I found that a good effort was put into this work by the authors; I'm encouraged to see a manuscript with a model intercomparison focus (this speaks to the awareness of what I believe is an important issue in our community). However, with only one simulation from the SwRI LES model to examine, accomplishing the stated goals is unlikely no matter the effort involved. Moreover, there is one overarching problem with this study: the grid used is entirely inappropriate in consideration of typical afternoon mixed layers on Mars (as based on the body of literature regarding LES). Thus, I must recommend rejection, although I enthusiastically recommend the authors redo the modeling on an appropriate grid, and the resubmit the manuscript upon consideration of my comments in 2) and 3) below.

ISSUES IDENTIFIED IN THIS REVIEW:

1) the horizontal size of the modeling domain used in this study (a fatal problem):

When performing LES studies of the convective boundary layer (CBL), it is imperative that the horizontal size of the domain is large enough so the periodic boundary conditions cannot influence/contaminate the solution computed for the domain interior. The authors suggest that they have followed the guidance of Mason (1989) to achieve this, but they haven't. For typical square LES domains, a generalized "rule of thumb" (as was used, if not clearly stated, by Mason (1989)) is to design the grid so the length of the domain side is ~3x the size of the largest eddy that will be resolved by the simulation. For an afternoon Mars EDL related investigation, the size of the largest eddy scales as the maximum depth of the CBL, which can reach ~10 km (thus, ~30 km would be an appropriate lateral size). It's an unfortunate reality of LES for Mars that, to sufficiently resolve the range of smaller eddies and the complexity of convective structures (with the underlying desire being to capture the energy spectrum), a grid-spacing of ∼50 m (as was used here) is needed. For a square LES domain with a 50 m grid-spacing, the number of computational locations would then be 600x600. In this work, with only 145x145 computational locations, the lateral size of the domain is just 7.25 km (this is far too small), and the problems that will be created in this approach will contaminate the analysis and intercomparisons that could be performed at a time of day with a deep CBL. For Mars, especially once any wind profile is introduced to force the simulation, this ∼3x aspect ratio rule likely should be considered a minimum, and this is due to dramatic variations seen across the diurnal cycle of the scale of convective structures as a function of time and height in the domain. this poses a real problem for LES of the Martian atmosphere, and any study desiring a high-quality LES model intercomparison should err on the side of having completely eliminated the possibility of a contaminated simulation due to a very deep CBL that will interact with the periodic boundary conditions. Most certainly, the top of the modeling domain should also be well above the top of the CBL. As used here, a top of 12 km is probably sufficient, although a few km higher would be preferred. For the goals of this manuscript, the 145x145 number of computational locations, with a grid spacing of 50 m, is a fatal problem. It's easy to see that LES studies involving the CBL on the planet Mars almost certainly require the use of massively parallel architectures.

2) dust used during the intercomparison phase (thoughts/suggestion):

As described by the authors, without managing the issue of dust and its differing treatments between the two models, an intercomparison of LES models could reduce itself to an 'intercomparison of radiation schemes', not of the dynamical cores as is desired (this is also true for mesoscale and global climate model intercomparisons). The authors did put effort into getting the LMD model to show an improved agreement with the SwRI model to facilitate their intercomparison, although I wasn't fully convinced this effort was actually successful. From a perspective of do it as simply as possible, it's unclear why the authors didn't just run/compare the two models (the primary focus of this

manuscript) with no dust loading at all, a dust-free atmosphere. Even with dust properties modified so ground temperatures come into far better agreement, there was no discussion about heating rate profiles, that they had also come into better agreement as a result. It is much easier (and more straightforward) to use a dust-free atmosphere for the intercomparison focus of this effort, eliminating the complication of the radiative properties of dust in the atmosphere, and the probable non-linear response to this change the the heating rates as a function of height. For the secondary aspect of this effort (the prediction of the EDL environment for the Sciaparelli spacecraft), dust would be reintroduced in both models, and LES results would need to be compared with mesoscale model results (presumably form both of the parent models). Most certainly, a primary reason to use LES is to both improve and qualify our confidence in (and understanding of) the results from mesoscale models, specifically the performance of PBL schemes being used (since there is no PBL scheme in LES). Moreover, and I believe this is important, the use of mesoscale model results would allow the ability to characterize the larger-scale environment in which the LES was being performed. It's important because the larger-scale regional/local circulation can dramatically affect the evolution of the CBL. Careful consideration of this for site-specific LES is not addressed by any authors to date, whereas local strong subsidence has been shown by Tyler and Barnes (2015) to be very important to the development of the CBL, with actual evidence of this (Moores et al., 2015). How can this reality be incorporated into LES, and is it even possible? For Mars, LES has unique challenges, and a manuscript sufficiently well thought-out, that addresses some of these issues head-on with some new approaches would be most-welcomed and likely important to the community.

3) subgrid mixing parameterizations (thoughts/suggestion):

Upon looking at the results provided, it's easy to agree with the authors that subgrid mixing in the LMD model is much stronger than it is in the SwRI model. A short section in the manuscript suggested the authors did experiment with the subgrid mixing strength in the LMD model. Unfortunately no results were shown to indicate the degree of change seen towards what I would expect to be a much more 'noisy' solution (more like that in the SwRI model). Were such changes seen in that exercise, and if not did the authors try to completely disable the subgrid mixing to insure it had indeed been modified? Analogously, subgrid mixing schemes are to LES as PBL schemes are to mesoscale models; and, both are fundamentally untested in regard to being used in atmospheric modeling for Mars (designed for and tested in terrestrial modeling). I believe we should have a bit more trust in the subgrid mixing scheme of LES (as being fundamental) than the PBL scheme of a mesoscale model, although doubt must still be raised in regard to the isotropic nature of vertical mixing compared to horizontal in a deep and energetic CBL. How do individual schemes address this? The results here serve to elucidate the central importance of subgrid mixing schemes in LES model intercomparisons, where a thorough intercomparison would investigate a wide range of strengths of subgrid mixing. We should be able to show that results become 'smooth' on one hand (as in the LMD results) and very 'noisy' on the other hand (as in the SwRI results) with variations in the strength of this mixing. The idea would be to investigate the point at which the energy spectrum became sufficiently corrupted and/or modified. Possibly, a balancing of the subgrid mixing schemes between the two models, in a no-dust scenario such that the energy spectra became more similar, would be a logical framework from which to begin this intercomparison. This has never even been tried by investigators, and as so clear in the results presented, it's a central question that was not sufficiently addressed.

MINOR THOUGHTS/ISSUES:

The vertical grid of the SwRI model is actually quite different, with heights fixed above ground in a sigma z (not sigma p) formulation, quite different form the vertical grid used in the LMD model. It actually leads to a "pressure cooker" effect in MRAMS. For comparison of these two models, it is worth acknowledging that there shouldn't be any surface pressure variation in the LMD model, while there should be in the SwRI model.

Without a doubt, spacecraft payloads are only going to get more massive, which ren-

ders the sensitivity of any spacecraft to atmospheric turbulence quantified during the EDL phase by LES in the CBL (such as for Phoenix or Insight) a moot point. The LES modeling that was done for Phoenix was driven by the possibility of oscillations in the parachute/lander system that (according to my understanding) are not problematic for either the MSL or the Mars 2020 spacecraft. I'm unaware of any LES modeling being requested/performed for Insight. In the near future, SpaceX and others will be landing massive payloads; and, the EDL trajectories for such payloads will cause the spatial variation of the CBL depth (as modified by topographic circulations) to be far more important during the final phase of 'flight' (quite low for large horizontal distances to make the greatest use of larger air densities). Results from LES are likely to provide the turbulence spectra that turns out to be crucial for autonomous navigation software, etc… My sense at this point is that the reason for high-resolution LES modeling may have much more to do with autonomous robotic flying exploration vehicles, such as Mars Helicopter: http://www.jpl.nasa.gov/news/news.php?feature=4457

The manuscript was not clear on whether the surface layer scheme truly only acts on the lowest model layer acting with the ground for turbulence closure. I know this is the case for the OSU Mars LES model and believe it must also be so for the LMD and SwRI LES model. It's a point worth making, especially since the authors see differences in the near surface wind and/or temperature profiles. The structure near the surface is quite possibly another means through which the subgrid mixing can be examined in an intercomparison.

The authors certainly recognize that systematic intercomparisons between mesoscale and/or LES models have not been carried out, possibly because no funding entity seems to think that such intercomparisons are important. I acknowledge and appreciate that this work has tried to remedy this situation. Since atmospheric dynamics are actually so much more important on Mars in relation to physical processes than they are on the Earth, raising awareness here is important. Possibly, we are stuck in a terrestrial modeling paradigm that we need to escape to improve our mesoscale and

LES modeling of the Martian atmosphere.

Finally, even though it only leads to greater computational burden, it is definitely worth considering the value of running the LES model through one full diurnal cycle before examining results from the second full diurnal cycle. Such 'spin-up' does affect the results, with the second diurnal period quite different. When background forcing is added, the second diurnal cycle can be quite different from the first, where the morning air temperature profiles (before the onset of convection) differ significantly, which noticeably affects the growth/evolution of the CBL. In the diurnal cycle, there is another weakness of LES (the highly stable regime, even more stable in the atmosphere of Mars) to investigate and better understand. We strive for the most realistic/honest results from our models; and, in this, intercomparison is an art form that I hope efforts such as this convince us to practice more enthusiastically.

Dan Tyler

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