Resolving turbulence in the boundary layer of Titan to interpret Cassini-Huygens measurements and to prepare Dragonfly explorations

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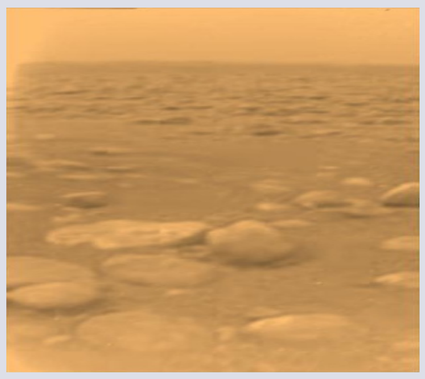
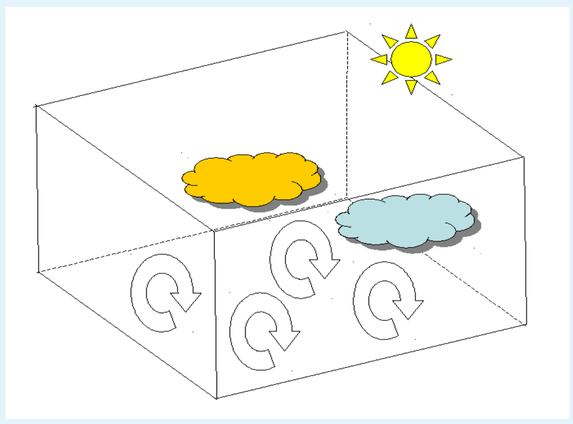
Goal and motivation

Characterizing the dynamics of Titan's Planetary Boundary Layer by turbulence-resolving modeling is a means to broaden the knowledge on this key part of the atmosphere in contact with the surface and to bridge the gap from the environmental conditions unveiled during the Huygens descent twenty years ago to the atmospheric diversity to be experienced and explored by Dragonfly about ten years from now.

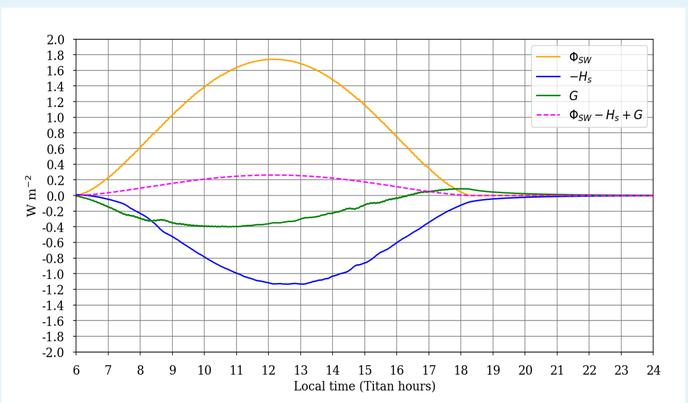


Large-eddy simulations

We leverage large-eddy simulations for Titan in which turbulent dynamics in the Planetary Boundary Layer is resolved (using the WRF hydrodynamical solver). The horizontal resolution used is 100 m on a double-periodic domain.

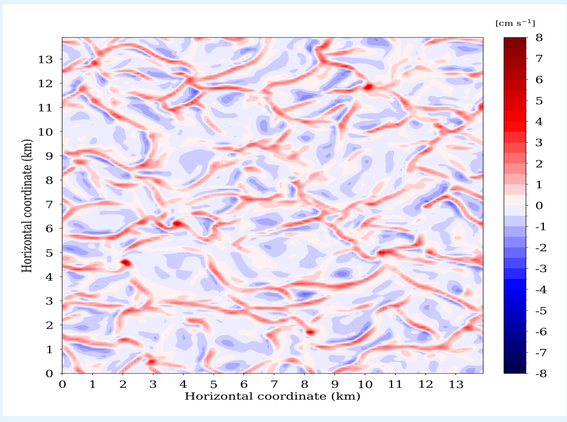


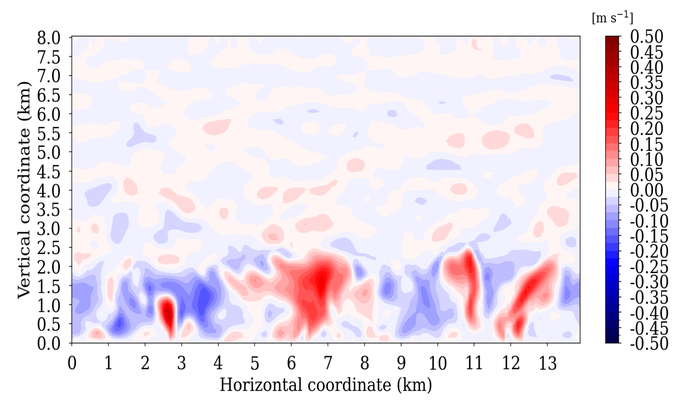
The full daytime cycle of Titan environmental conditions represented by online radiative transfer and soil modeling from Titan global-climate modeling (Titan PCM) is included.



Surface energy budget obtained in our Titan LES (incoming solar flux Φ_{SW}, sensible heat flux H_{S}, ground flux G)

Our Titan LES reveal both the horizontal and vertical structure of PBL daytime mixing: strong narrow vertical updraft forms the walls of convection cells with broad downdraft in the middle.

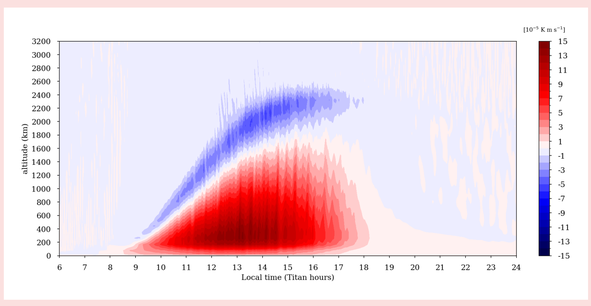




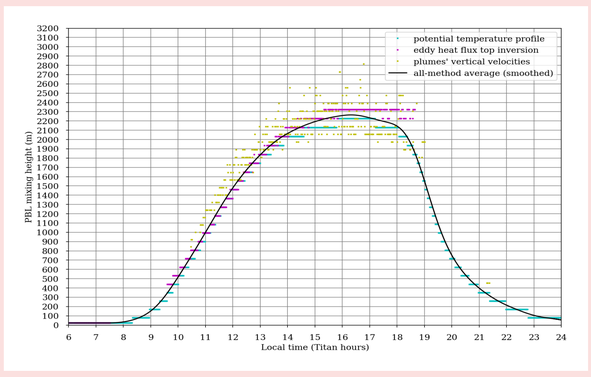
(top) Horizontal field of vertical wind speed about 20 m from the surface (LT 14:40); (bottom) Typical horizontal-vertical cross-sections of vertical wind speed

Gravity wave activity is also found above the top of the mixed PBL, with wave packets propagating above the mixing layer as a result of perturbations caused by convective plumes.

Height of Planetary Boundary Layer mixing

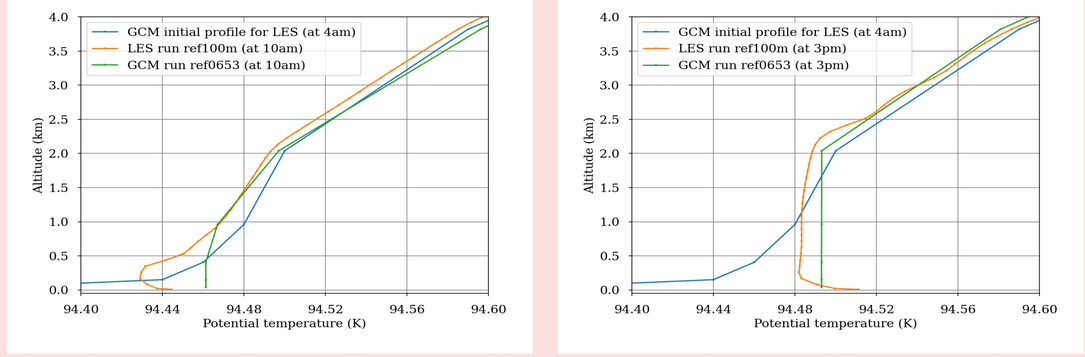


Growth of the Titan convective PBL on the temporal (local time in Titan hours) and vertical (altitude in meters) dimensions. Domain-averaged vertical eddy heat flux $\overline{w'\theta'}$.



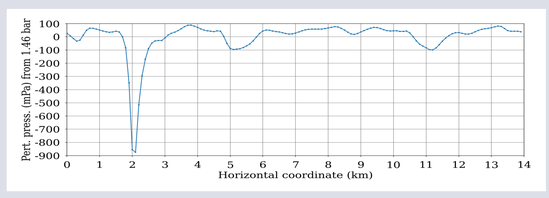
Growth of the Titan convective PBL: altitude (meters) of the top of the convective Titan PBL as a function of local time (Titan hours) diagnosed by three distinct methods.

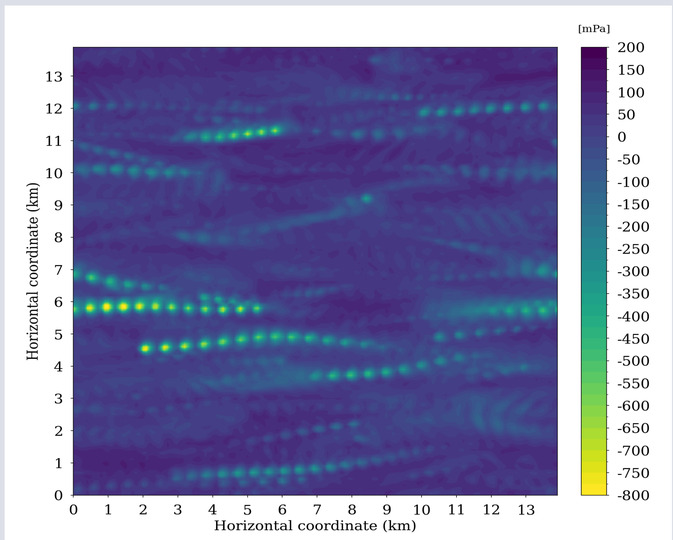
While our large-eddy simulations reproduce the correct vertical extent of the mixed PBL estimated by Huygens instruments during the descent of the probe in the morning, the mixed PBL is predicted to extend up to 2.2 km above the surface in the afternoon, close to the largest possible values reported in the literature based on dune spacing and interpration of the Huygens descent profile (including recent revisit of the dataset). This value is compliant with the profile obtained by global-climate modeling in similar conditions



Potential temperature profile both in LES and in the GCM shown at the Huygens landing time (left) and in the middle of the afternoon (right). The GCM profil at 4am used as initialization in the Titan LEs is also shown.

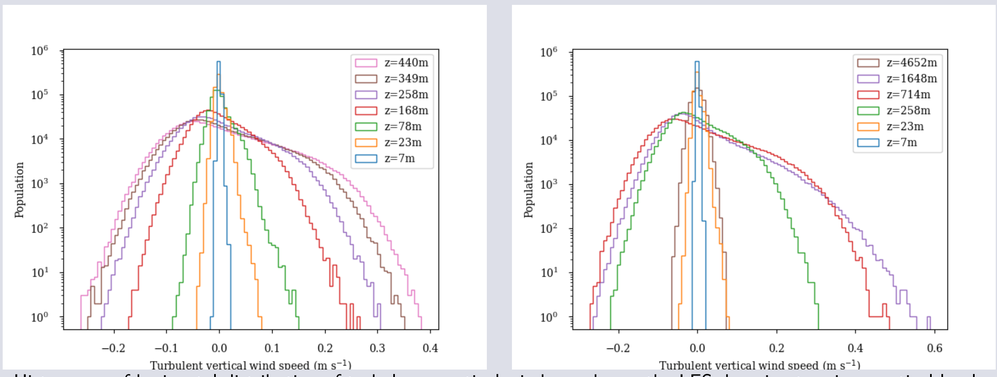
Dragonfly perspective





Surface pressure field simulated in the Titan LES : (top) an example of strong convective vortex showing as a pressure drop ; (bottom) cumulative horizontal map of surface pressure over a simulated Titan half-hour.

Large-eddy simulations offer a good plateform to explore the plausible atmospheric dynamics to be experienced by Dragonfly. Turbulent variability of wind and temperature, vertical variations of turbulent kinetic energy and vertical eddy heat flux, possible occurrence of convective vortices – all within reach of Dragonfly's measurements which, we are able to argue using large-eddy simulations as illustrative predictions, would be particularly interesting to perform during flights.



Histograms of horizontal distribution of turbulence vertical wind speed over the LES domain at various vertical levels

Conclusions and future work

The reference large-eddy simulation showcased here is performed at the Huygens landing site at the season of landing. It represents realistic conditions to consider for Dragonfly, keeping in mind that the predicted PBL depth trends towards the highest values observed. More detailed diagnostics, as well as specifically designed simulations tailored for Dragonfly (both global climate modeling and large-eddy simulations) will be needed to better investigate the environment to be met by the rotorcraft when landing and operating on Titan.

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