ABSTRACT
Rocket exhaust clouds are composed by hazardous pollutants, e.g. alumina, carbon monoxide and dioxide, and hydrogen chloride, which are generated during the burning of rocket engines. In the case of vehicle launching, huge and hot clouds are generated near the ground level and are composed by the byproducts exhausts particles, which will expand, stabilize, entrain the ambient air, and will be dispersed according to the atmospheric conditions. This process takes a couple of minutes to occur, and generally human receptors located in populated areas nearby the launching center may be exposed to high levels of concentrations within a few to tens of minutes, up to less than one hour. Also, these pollutants may be carried further due atmospheric dispersion, and chemically interact with other atmospheric compounds, forming new pollutants, reaching and impacting other populated areas located in farther distances. The launch centers around the globe, like spaceports, need to operationally assess the impact of rocket launching events in the environment, requiring both short and long range models prior to launching through meteorological and air quality modeling. In general, however, air quality models do not account for calculating vertical and horizontal plume evolution from minutes to one hour. In addition, there is the fact that modeling rocket exhaust clouds forms due rocket vehicular landing is quite a uncertain and affected problem, hence name: MISTED. For long range assessment, we chose the CMAQ modeling system, since it represents the state-of-the-art in regional and chemical transport in air quality modeling, and due to its capability to deal with complex terrains - which is a considerable part of rocket exhaust clouds. In order to couple both models, the MISTED code is being rewritten using the I/O API library, making it feasible for MISTED to generate the initial conditions as input to CMAQ model. Thus, it forms the basis for a hybrid, modern and multidisciplinary system which, in conjunction with the WRF model, can be operationally used in different missions at the Alcântara Launching Center (ALC), the Brazilian gate to the space, as planning activities and environmental assessments, pre-and-post-launching forecasts of the environmental effects of rocket operations.

INTRODUCTION
Although the assumption regarding the formation of the ground and contrail cloud (see Figure 1) is a major concern in rocket exhaust cloud modeling, it is also important to predict weather and air quality conditions in short and long range terms in order to operationally assess the impact in the normal and abnormal landing events. Recently, the REEDM model [1] has been used in a hybrid system, in conjunction with other modeling tools to simulate the weather and the dispersion of toxic gases in launch operations. The French Space Agency (CNES) conducts simulations of the impact of rocket exhaust pollutants using a model called SARRFRM (Stratified Atmospheric Radiation Range Impact Model), during normal or abnormal landing operations in the European Space Agency (ESA). However, more recent works present the idea of using a (50 km) high, multidisciplinary and hybrid approach in order to achieve the goal of assessing the impact of effluents released from landing operations for the European Space Agency (ESA), and the work presented in [4] presents a first step effort for the Indian Space Agency to evaluate a hybrid approach in the assessment of the impact of rocket exhaust pollutants during launch operations.

Unfortunately, there is no model fully operational to meet these demands in ALC, the Brazilian Spaceport. Currently, a more complete, multidisciplinary, modern and hybrid approach is under development, which will be not only adapted to the Brazilian site characteristics, but will be also applicable to any spaceport site in the world wide. This work reports the first results of the application of this system to a hypothetical rocket launch event in the ALC region (see Figure 2).

THE SHORT RANGE DISPERSION MODEL - MISTED
A modern approach has been developed by [2] called “Modelo Simulador de Dispersion de Eluentes de Fugas”, in Portuguese, which stands for “Simulation Model of Rocket Efferent Dispersion”. It applies a stepwise approach in the definition of toxic pollutants’ eddy diffusivity and wind speed. The Lagrangean formulation in the diffusion-adiabatic equation, a semi-analytical solution of the linear ordinary set resulting in the Laplace transform application, the construction of the dispersion by the Laplace Transform via application of the Gaussian quadrature scheme, the computation of first-order chemical reactions, and the discretization and the parameterization of the atmospheric boundary layer (ABL). Such as in the REEDM model, the MISTED model can represent the start and end of a rocket launch, and the cloud formed during the rocket landing, given the environmental conditions that can be used. The model remains as a single cloud during the formation of its ascending phase (see Figure 3). Thus, the discretization of the ABL is done with the parameterization of the atmospheric boundary layer, with the use of both short and long range models. The vertical diffusion at different altitudes, each one having a single wind speed and direction that moves the plume into the atmosphere. The hypothesis of transport in a strict horizontal transport process, the presence of a horizontal and vertical well-mixed layer, and the complex terrain may evolve during the passage of a sea breeze front or greater scale.

In this sense, the model does forecast concentration ranging from 5 to 10 km from the launch pad. The model makes predictions of instantaneous and average concentration in time (typically 10 min and hourly average). A shorter average time is appropriate for exposure to the cloud of the rocket, because the source (cloud) typically goes on a receiver with a time scale of tens of minutes before the hour.

MISTED needs a single layered profile of meteorological information such as wind speed and direction. It can be achieved through a short-range meteorological model. There are at least two options for the WRF model (WRF) [9]. Recently [5] validated WRF for the ALC region using radiosonde data collected during launch events for the environment, required to evaluate both short and long range models. The geometry of WRF-LES is quite interesting, since it provides very high resolution information about the atmospheric turbulence and terrain evolution. This allowed a vertical air quality assessment for a number of pollutants, including hydrogen chloride. The domains were configured and modeled using WRF 3.6 model. The horizontal resolutions of the nested grids was 4.1 km, 2.5 km, 900 m, 300 m and 100 m, with values of 40, 40, 40, 40, 40, 90, 76, 76, and 112 grid cells for domain 1 to 6, respectively. It was necessary to process 3° terrain resolution from USGS into WRF in order to provide higher resolution to the model. The episodes range from Mar’ 18, 2013 to Mar’ 22, 2013. WRF 3.6 was run with the large eddy simulation (LES) option enabled for real cases (WRF-LES), and its output was used as input to MISTED (domain 5). Two hypothetical simulation of rocket launch cases were atmospheric conditions, and the other for slightly neutral conditions, with the launching events at Mar’ 18, 2013, 17:00h (07:00h GMT+3), respectively. The emission rate value for each case was 1,000 kg/s.

After MISTED execution, its output was then post-processed in order to generate background concentrations as initial conditions for CMAQ. For this end, an IDON file has been produced for each case for the domain 3. The IDON file contains the 3-D data for each hour of simulation, data generated for each grid cell, vertical layers, merging of vertical layers, computation of concentration values from the finest domain (10 m) to the largest coarser domain (300 m), and IDAPI programming, and so on.

Finally, CMAQ 5.0.2 was executed using the domain 3 configuration, with no emissions from any other source. The boundary conditions was also set out, with only the initial concentrations computed by MISTED being used, as initial conditions to CMAQ.

RESULTS
Figure 4 and 5 show a plot of HCl concentrations computed by MISTED for one hour after the launching for each convective and neutral conditions, respectively, for the domain 5. Figures 6 and 7 present the scenario of HCl concentrations computed by CMAQ using the initial conditions from the MISTED output, two hours after the launching.

CONCLUSIONS AND FUTURE WORK
The results show the importance of a hybrid and multidisciplinary approach in order to evaluate the impact of rocket exhaust clouds in the environment. While the MISTED, acting as the short range dispersion model, provides a fast and affordable tool to evaluate the concentrations of the first minutes after the rocket landing at different vertical levels, the CMAQ, acting as the long range transport model, provides a more robust way for computing the concentrations of the very first minutes after the rocket landing at different vertical levels. It is also important to realize that for the entire domain, the CMAQ model deals with the simulation of horizontal transport process in larger space and time scales. Although this is a qualitative work, it presents the basis of a framework, which is under development, that can represent the state of the art in the assessment of the regional impacts of rocket exhaust clouds in the environment.

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REFERENCES