CHARACTERISATION OF POTENTIAL LANDING SITES FOR THE EUROPEAN SPACE AGENCY'S LUNAR LANDER PROJECT. Diego De Rosa[1], Ben Bussey[2], Joshua T. Cahill[2], Tobias Lutz[3] , Ian Crawford[4], Terence Hackwill[4], Stephan van Gasselt[5], Gerhard Neukum[5], Lars Witte[6], Andy McGovern[2] and James D. Carpenter[1], [1]European Space Agency, [2]The Johns Hopkins University Applied Physics Laboratory, [3]Astrium ST, [4]Birkbeck College London, [5]Freie Universität Berlin, [6]DLR Space Systems.

Introduction: The Human Space Flight and Operations directorate of the European Space Agency is conducting a mission and system study for a Lunar Lander targeting a launch date in 2018 and landing in the South Polar Region, at latitudes 85 to 90 degrees south [1]. The mission objectives are to demonstrate technologies for soft-precision landing with hazard avoidance and to conduct surface investigations in preparation for future robotic and human exploration. A parallel presentation provides a detailed description of the science and payload activities performed in support of the mission [2].

The landing sites currently envisaged for the mission have been identified based on the favourable illumination conditions found at some locations near the lunar South Pole [3]. At these locations, due to the combination of highly variable terrain and the small inclination of the Moon's axis of rotation with respect to the ecliptic, the Sun is visible for periods of several months, which are interrupted only by short periods of darkness, of the duration of few tens of hours. Landing at these locations allows a surface mission duration of more than 14 days (potentially several months) with highly optimised but conventional power and thermal control subsystems, capable of enduring short periods of darkness, instead of utilising Radioisotope Heating Units (RHU).

In order to assess the feasibility of a mission scenario without RHU and to evaluate the impacts on the mission and system design of the environment at the provisional polar landing sites, a thorough characterization of the illumination conditions and hazard distributions at these sites is being carried out.

Characterization of the illumination conditions: The illumination conditions of the potential landing sites are being characterised through computer simulations based on topographic data from the Lunar Orbiter Laser Altimeter (LOLA), using independent tools at Astrium Space Transportation, Bremen; The John Hopkins Applied Physics Laboratory and ESA. These tools simulate the illumination conditions at desired locations over one year, in terms of visible Sun fraction. The visible Sun fraction time history at a given site is converted to a binary illumination/darkness pattern by applying a threshold (which is roughly proportional to the power needed to operate the surface payload) and short periods of darkness, resulting from shadowing by horizon topography, are filtered out. This gives the duration of the Longest Quasi-Continuous Illumination Period (LQCIP) for each point of interest. LQCIP maps are built following this procedure for several points within the Regions of Interest (Fig. 1), varying mainly the duration of the darkness periods and the height above the surface at which the illumination is computed (corresponding to the height of the solar arrays). These maps are used to determine the possible duration of the surface mission and, more importantly, the size of the landing areas, which must be compatible with the system's landing dispersions.

Conditions of direct communications to Earth are simulated in a similar manner, using the Earth centre or a ground station as sources. Combined illumination and communication patterns are used to establish possible landing dates and a mission timeline, including surface operations.

The described simulation tools are being validated through comparison of their outputs with real images, with support from Freie Universität Berlin (FUB) and through the comparison between the outputs of the various tools. The limitations of these analyses are linked to the spatial density and accuracy of the available measurements of surface topography [4]. These limitations are being addressed by FUB (based on Lunar Reconnaissance Orbiter Camera products) through the analysis of images and the generation of Digital Terrain Models (DTM) from stereo images, with resolution better than LOLA products.

Characterization of the hazard distributions: Landing hazards can exist at the sites identified by the illumination analyses. With the current lander design, hazards are defined as slopes steeper than 15° and surface features (e.g. boulders) higher than 50 cm. The lander must also touch down on terrain which is not in shadow. The lander carries an on-board autonomous Hazard Detection and Avoidance system, capable of identifying surface hazards and performing a retargeting manoeuvre if necessary.

The risk associated with landing at the provisional sites is being assessed by independent studies carried out by DLR, Birkbeck College and FUB. LOLA products are used to assess slopes on a long baseline. Craters and boulders are detected, visually and using computer tools, in LROC images, down to a size of less than 2 m. Size-frequency distributions are generated, when enough samples are available. Dispersions are also estimated, and the sensitivity of the determined crater and boulder size to terrain slope and illumination angles is analysed. Shadow hazards are assessed via LROC images at times equivalent to those of the expected landing in terms of illumination angles. Hazard distributions are combined to generate risk maps (including uncertainties) and to derive the engineering parameters of interest (safe to total area ratio, separation between safe areas etc). Hazard distributions, including uncertainties, are also used in simulations to validate the Hazard Detection and Avoidance system and the landing systems.

Results: The preliminary results of the illumination analyses show that a number of areas with LQCIP duration of several months exist. The most promising areas are on the connecting ridge between the Shackleton crater and de Garlache crater, on the Leibnitz-β plateau, on the Shackleton and de Garlache rims and on the Malapert massif peaks. The results also show that, as expected, the size of the areas with long LQCIP duration is small (in the order of few hundreds of metres) and the LQCIP duration drops quickly to less than one month outside the areas. It was also found that some areas present gaps with short LQCIP durations. The size of the areas with favourable illumination conditions and the duration of the LQCIP are very sensitive to the height above the surface and to a lesser extent to the duration of the short periods of darkness. Direct to Earth communication windows generally follow a regular pattern of 14 days.

The derived hazard distributions reveal that slopes are shallow over a ~50 m baseline (few degrees), based on LOLA analysis. At the scale of the lander footprint (~5 m) slopes are dominated by craters, which are expected to be (geologically) mature and therefore shallow (11° maximum slope), although this should be confirmed by a more detailed analysis. Boulders in the detectable range are sparse at most sites, and for some sites no boulders were detected. Boulder distributions below the detectable size are extrapolated with conservative assumptions. The preliminary conclusion is that the hazard distributions at the prospective landing sites are well within the capabilities of the Lander design.

Future work: The site characterisation work is being currently performed for landing sites identified as having the most favourable illumination conditions. Further modelling and analysis along with validation of the tools will continue in parallel. We foresee the use of a stereo image based DTM, if possible, in order to reduce the uncertainties in the illumination simulations and to improve knowledge of slopes at small scales. More extensive work will also be performed on crater size-frequency distributions and on crater and boulder modelling. Shadow hazard distributions will also be modelled using dedicated simulations. The framework for the combination of the hazard distribution into risk maps will also be finalised. Detail models of the landing sites will be produced and used in end-to-end landing simulations, in order to validate and verify the performance of the system in a realistic environment, including the Hazard Detection and Avoidance system).

References: [1] Pradier A. et al. (2011) *IPPW8.* [2] Carpenter J.D. et al. (2012) *LPSC.* [3] Vanoutryve B. at al. (2010) *IPPW7* [4] Mazarico E. et al. (2011) *JG*

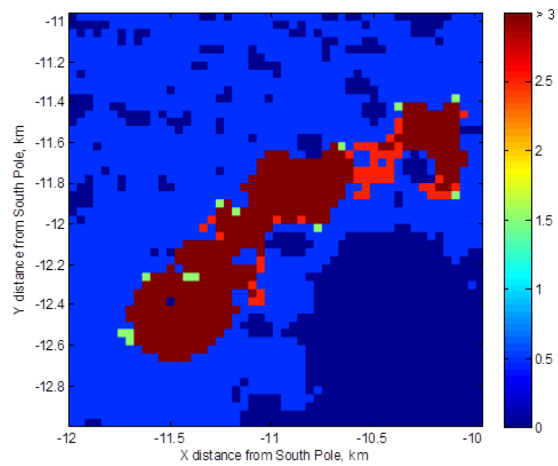

Fig 1: Map showing the LQCIP duration (in months) at the Connecting Ridge, simulated for year 2009, at 3 m height and for 100 hour night survivability. Grid spacing is 40 m. Coordinates are in polar stereographic projection. Note that the areas in red have LQCIP duration longer than 3 months.