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**Mission Science Goals & Impact Proposal**

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| For HQ use only: | |
| Decision | Accepted                      Rejected |
| If Rejected: | First Rejection              Final Rejection (penalty fee) |

**Proposal Approval Sheet**

|  |  |  |  |
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**1. Abstract**

The Ice, Cloud, and Land Elevation Satellite-II (ICESat-II), is a satellite mission whose goal is to characterize the change in ice sheets, glaciers, and sea ice as a result of climate changes, and how this impacts sea level, as outlined in the 2007-2017 Earth science Decadal Survey (2007). ICESat-II will be utilizing the Advanced Topographic Laser Altimeter System (ATLAS) to gather elevation data on all topographical regions of the Earth. ICSat-II will be launched in 2018 into a near-polar, processing orbit, and will have a projected mission duration of three years before being decommissioned (Pearce, Purification, & NASA). The largest risks to the mission have been addressed and mitigated to the point where the value of the data to be collected is more valuable. Calibration and validation of the data will ensure the quality of the data, which will be released to the public and global scientific community for analysis. This paper further outlines the mission details of the ICESat-II mission.

**2.0 Introduction**

According to the 2007 Earth Science Decadal Survey, understanding how the cryosphere is changing as a result of rapid climate changes is vital for the improvement of the future wellbeing of society. One of the more paramount cryosphere questions concerns whether there will be a catastrophic collapse of the major ice sheets, how rapidly this will occur, and how will time patterns of sea-level rise as a result (2007). The topographic data obtained by ICESat-II will allow for studying ice sheet volume change and characterizing sea ice freeboard; sea ice freeboard data characterizes sea ice thickness change, which is then “used to estimate the flux of low-salinity ice out of the Arctic basin into the marginal seas,” thus assisting in sea level rise prediction estimations (ESA). Previous missions studying the cryosphere are only capable of measuring in two dimensions, thus lacking the capability to measure the full extent of global ice formations (Pearce, Purification, & NASA). In addition to having three-dimensional data collection capabilities, ICESat-II will obtain a higher quantity of data over the same area as its predecessor, ICESat; this improvement upon the original ICESat mission follows the Decadal Survey request that a new mission should “build upon the current fleet of space-based instruments” (Pearce, Purification, & NASA). The ICESat-II mission will study how ice sheet changes directly affect global sea levels. Understanding this connection will assist in advancing ice sheet, glacier, and sea ice prediction capabilities in the future; collaboration with relevant policy makers and communities will mitigate the negative effects caused by sea-level changes such as infrastructural and economic damage. Further understanding how ice sheets are responding to climate changes will allow for improved preparedness to coastal sea-level change, which will advance local mitigation of the resulting detrimental impact upon economic, infrastructural, and environmental systems.

**3.0 Mission Science Goals**

The main objective of the ICESat-II mission is to better understand why, and how much, the cryosphere is changing in a warming climate to investigate how this affects sea level rise through the study of mass and thickness changes of ice sheets, glaciers, and sea ice. The following traceability matrix outlines the vital mission characteristics.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Mission Goals** | **Science Objectives** | **Science Measurement Requirements** | | **Instruments Requirements** | **Mission Function Requirements** |
| **Physical Parameters** | **Observables** |
| **To better understand why, and how much, the cryosphere is changing in a warming climate to investigate how this affects sea level rise** | Measure the changes in mass of ice sheets and glaciers | Terrain elevation | Returned 532 nanometer photons,  Return time of photons | Advanced Topographic Laser Altimeter System *(*ATLAS*)* | Near-polar, processing orbit |
| X-band downlink |
| Onboard GPS |
| Launch site: Vandenberg |
| Estimate and study sea ice and glacier thickness |  |
| Measure sea level changes |  |
|  |  |

The mission goal of ICESat-II specifically addresses the Decadal Survey question concerning the collapse of ice sheets and how sea-levels will change as a result. More specifically, ICESat-II will obtain global terrain elevation data, which will indicate ice sheet mass and thickness, two critical indicators of ice sheet collapse likelihood. ATLAS will detect terrain elevation through the measurement of the time it takes lasers emitted from the instrument to return to the detector telescope. In order to measure globally while focusing on the Arctic and Antarctic ice sheets, ICESat-II will be launched from Vanderberg Air Force Base and maintain a near-polar, processing orbit. To ensure the proper altitude and calibration of the satellite, ICESat-II will be equipped with an onboard Global Positioning System (GPS). Once the data has been collected, the X-band Downlink system will send the data to Earth-based data management stations.

**3.1 Mission Science Measurements**

ATLAS will measure the elevation of the Earth’s terrain to gather data concerning global ice sheets to better understand how climate changes affect sea level rise. The change in ice sheet, glacier, and sea ice mass and thickness over time is indicative of the effects of climate and oceanic temperature changes. Moreover, measuring such characteristics assists in tracking and predicting sea level rise, leading to improved advanced warning for coastal communities negatively impacted by such changes. In addition to the ice sheet data collected by ATLAS, data gathered on the height of vegetation will improve predictions of global carbon exchanges concerning the biosphere (Pearce, Purification, & NASA). The resulting improvement in quantifying carbon exchange processes will aid policy makers in mitigating the negative effects of such carbon such as global warming.

**3.2 Mission Timeline & Operation**

The production of ICESat-II will begin in February 2014. Testing of ATLAS will begin in February 2015, and will continue until June of 2018 when the satellite will be prepared for launch. ICESat-II will be housed in the LEOStar-3 bus and launch on the tentative date of September 15th, 2018 from Vanderberg Air Force Base on a Delta II launch vehicle. ICESat-II will acquire a near-polar orbit, angled at 92 degrees, at an altitude of approximately 500 kilometers above the surface in Low Earth Orbit (LEO). As a result, ICESat-II will repeat its orbit every 91 days. The life duration of ICESat-II is three years, with a goal of five years, putting decommission in 2023. In the event that the mission duration exceeds five years, seven years of propellant is available for orbital maneuvers and positioning adjustments (Northrop Grumman, 2018). Upon decommission, an orbital maneuver will advance the satellite into the atmosphere; any remaining materials that are not destroyed by re-entry will splash-down in the “satellite graveyard” in the Pacific Ocean.

**3.3 Calibration/Validation**

The satellite altitude and orientation, along with the alignment of the laser and telescope receiver, must be calibrated constantly to ensure the reliability of the collected data. Before launch, ATLAS will be calibrated and tested for a maximum of three years by reflecting the emitted lasers back into the telescope to ensure correct distance calculations (ESA). During operation, the altitude will be measured through the use of the onboard GPS. The orientation of the satellite and the alignment of the laser and telescope system will be measured through the onboard Laser Reference System (LRS) (Pearce, Purification, & NASA). The orientation will be measured by using the star-facing telescope to detect constellations; the LRS will also measure the relative orientation of the laser and telescope to allow for adjustments. Satellite maneuvering will be accomplished through the use of four blowdown hydrazine thrusters.

The data collected by ICESat-II will primarily be validated by comparing select data points to those of ICESat. Periodic ground measurements at National Aeronautics and Space Administration (NASA) ground stations across the United States will provide additional validation.

**3.4 Risk Assessment**

ICESat-II will face many risks to the mission; understanding and mitigating those risks is vital to the success of the mission. Hereafter is a Mission Risk Assessment Matrix detailing the most critical risks to the mission. The letter “a” indicates pre-mitigation risk, while the letter “b” indicates post mitigation risk.

Mission Risk Assessment Matrix

Likelihood of Occurrence

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 5  (Very High) |  |  |  |  | **1a** |
| 4  (High) |  |  |  | **4a & 3a** | **2a** |
| 3  (Medium) |  |  |  |  |  |
| 2  (Low) |  | **1b** | **2b, 3b & 4b** |  |  |
| 1  (Very Low) |  |  |  |  |  |
|  | 1  (Very Low) | 2  (Low) | 3  (Medium) | 4  (High) | 5  (Very High) |

Consequences of Occurrence

Key:

1. Atomic Oxygen                2. Contamination by Outgassing

  3.  Radiation            4. Orbital Debris

ICESat-II has four main risks: atomic oxygen, outgassing, weather occurring on Earth which would block the lasers from ATLAS, and orbital debris. Atomic Oxygen (ATOX), present in the Low Earth Orbit of ICESat-II, is highly damaging to particular materials present on satellites (Schulberg, Krech, Lauten, Gordon, & Hock, 2010). Without mitigation of the damage caused by ATOX, the likelihood of occurring is extremely high, while the consequences of occurring may cause mission failure over time (Dunbar & Woods, 2011). Outgassing, when materials on the satellite release molecules into the surrounding space, may contaminate ICESat-II’s telescope optics, causing false data to be collected, and in severe cases, the failure of the instrument. Without mitigation, outgassing is likely to occur and may cause mission critical damage. Radiation may cause electronic malfunctions within the satellite, possibly causing mission failure; in a precessing LEO, ICESat-II will experience constant, and variable radiation from solar wind and from Galactic Cosmic Radiation (GCR), and is therefore very likely to occur (Mars, 2017). Lastly, orbital debris in LEO is a critical issue for the continual success of ICESat-II; colliding with any size debris may cause mission failure, and LEO contains a significant amount of catalogued and uncatalogued debris.

**3.4a Post-Mitigation Plans**

The risks to ICESat-II posed by ATOX will be mitigated mainly by coating the satellite in ATOX-resistant films such as silicon dioxide for the solar arrays, and through Atomic Layer Deposition (ALD) (Schulberg, Krech, Lauten, Gordon, & Hock, 2010). After mitigation, the likelihood of exposure to ATOX reduces dramatically. Outgassing may be mitigated through management of the materials used in manufacturing, and precision cleaning, baking, and applying primer to various components of the satellite; components manufactured with adhesives and tapes will be prioritized for baking and outgassing mitigation. For radiation, all pertinent electronic components will be radiation hardened to reduce the likelihood of malfunctions (Keys & Watson, 2019). Lastly, for orbital debris mitigation, strategic shielding will assist in protecting against uncatalogued debris, and the onboard thrusters will allow for avoidance when necessary, decreasing the likelihood of occurrence. After mitigation, the most critical risks to ICESat-II are within ranges sufficient for mission continuation.

**3.4b Contamination**

The contamination of ICESat-II is when any substance, either from Earth, the materials on the satellite itself, or from other sources in space, affix to the satellite and negatively affect its operation. The two main types of contamination, particulate and molecular, may be experienced by the satellite during pre-launch and operation. Particulate contamination, visible conglomerates upon any surface of the satellite, pose the largest threat to the optics systems, and may be caused by outgassing, ATOX degradation, or other satellite decomposition events. Particulate contamination may limit the view of ATLAS or disrupt the detection of photons, causing the collection of incorrect or incomplete data. Mitigation for particulate contamination includes cleaning materials and components to high International Organization for Standardization (ISO) cleanliness levels and managing the materials which the satellite is manufactured with to reduce outgassing. Molecular contamination is when vapors or aerosols form residue on satellite components, causing detrimental effects. Mitigating molecular contamination pre-launch includes maintaining clean-room quality and performing cleaning techniques to remove any contaminants that may be present. During operation, the main protection against molecular contamination is prevention; therefore, baking systems to prevent outgassing will be utilized to lower the risk of such contamination events.

**3.5 Stakeholder Value**

The stakeholders for ICSat-II primarily include international policy-making entities, the international scientific community, entities operating near coastlines, and the general public. The data collected by ICESat-II will assist policy-making entities by informing them of estimated sea-level changes, river and reservoir heights, and even vegetation growth rates and CO2 exchange data; having more accurate information concerning vital issues may lead to more prudent and effective solutions. The international scientific community will benefit from the data from ICSat-II because of the improved understanding of how climate changes are affecting the cryosphere, and how that affects sea-level rise; higher of these processes and interactions will allow scientists to improve predictive capabilities concerning cryosphere changes in the future. Peoples, organizations, and governments operating near coastlines will be impacted greatly by the arrival of the data from ICESat-II because of the risk of sea-level rise and coastline movement as a result. Rising sea levels have the potential to damage infrastructure, increase storm surge regions, change fishing grounds, and adjust extreme storm paths. Coastal economies may be severely damaged due to such changes, and that may impact the general public through the rise in prices of food products, shipping services, and coastal activities. Ultimately, the understanding and prediction of ice sheets, glaciers, and sea ice will provide the global community with the means to prepare for sea level rise and topographic changes, thus mitigating the negative effects of such events.

**4.0 Impact**

Sea level ri se as a result of global ice melting events can have severe impacts on global economies and communities in addition to forcing events in all four of the Earth’s main spheres. Concerning anthropomorphic effects, sea level rise mainly poses a risk to infrastructure, economies, and lives. For example, coastline changes may cause businesses and families to move to higher ground, away from the impeding water. As opposed to shifting coastlines, a more impactful scenario is larger areas prone to periodic flooding and storm surges; increased flooding lowers the value of property and decreases the economic productivity of the area. In response to flooding, local and national governments may use resources to build protective structures such as flood walls and may be required to rebuild key facilities and communities in new locations. Similarly, higher intensity storms as a result of the increased water in the area may lead to property damage, loss of life, shipping and commerce route decreases, and less investment in communities and businesses within the area. Further, flooding may contaminate local water supplies with salt water, leading to communal water shortages, and crop production facilities, leading to higher food prices for trade partners and international buyers. According to some estimates, sea level rise could cost up to fourteen trillion dollars by the year 2100 (Institute of Physics, 2018).

As for natural impacts, the loss of ice volume and mass will affect all four spheres. For the atmosphere, ice melting will lead to lower water and air temperatures in the local surroundings. Additionally, higher humidity will lead to more intense storms. Concerning the hydrosphere, those storms will lead to increased water displacement such as storm surges, runoff events, and changing river and lake water levels. Ice melt will also serve to change pH levels for the surrounding areas. For the lithosphere, more intense storms bring about increased mass wasting events such as erosion. Moreover, sea level rise may submerge banks and sand bars that were previously exposed. The various elements of the biosphere such as plants and wildlife will also be impacted by the original and subsequent forcings. Coastal habitats will be damaged or lost by storm surges, altering coastlines, and changing river levels, more intense runoff may expose and unearth roots leading to slower mature plant growth rates, local wildlife may begin to migrate into new territories as a result of changing rainfall patterns. On the other hand, some areas may experience higher plant growth rates and more prosperous ecosystems as a result of increased rainfall.

The data from ICESat-II will bring about a higher understanding of how changing climates are affecting the cryosphere, and how melting events are affecting sea level rise. Furthermore, more accurate data on how that ice is melting will better inform policy-makers on decisions concerning topics such as water resource control, coastline protection, and agricultural and water-supported industry management. ICESat-II’s data on the height of tree tops and the subsequent CO2 exchange cycle of topographical regions will also better inform the scientific community and policy makers on how to assist in improving the health of the global ecosystem. Overall, ICESat-II may bring about informed changes which protect from global infrastructural, economic, environmental, and anthropogenic damages.

**5.0 Conclusion**

As outlined in the decadal survey, and as experienced currently by global policy makers and communities, understanding how the cryosphere is changing as a result of climate changes is crucial to tracking and predicting sea level rise, a primarily detrimental event occurring on a global scale. The ICESat-II satellite mission, launching in 2018 and having a projected decommission date of 2023, will collect a higher quantity and quality of elevation data than previous missions through use of ATLAS. ICESat-II will use such elevation data to not only study ice mass and volume changes, but also the heights of forested areas. Gathering data on the changes in ice structures will assist in achieving such an understanding of melting events and sea level rise that policy-makers may bring about the prevention of economic, infrastructural, and environmental damage. The cost of, and risks to, the ICESat-II mission are outweighed by the possibility that the data collected may serve to improve the wellbeing of both anthropogenic organizations and communities, and the global environment.

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