THE NASA MASS CHANGE DESIGNATED OBSERVABLE STUDY: OVERVIEW, PROGRESS, AND FUTURE PLANS

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ABSTRACT

The 2017-2027 US National Academy of Sciences Decadal Survey for Earth Science and Applications from Space classified mass change as one of five designated observables having the highest priority in terms of Earth observations required to better understand the Earth system over the next decade. In response to this designation, NASA initiated multi-center studies with an overarching goal of defining observing system architectures for each designated observable. Here, we discuss the progress made and future plans for the Mass Change Designated Observable study. Progress includes the development of a Science and Applications Traceability Matrix, as well as the definition of different architectural classes from which mass change can be measured. The development of a Value Framework is in progress to assess and evaluate each observing system architectural option.

Index Terms**—** mass change, gravity, water storage change, geopotential, decadal survey

1. INTRODUCTION

In 2018, the US National Academies of Sciences, Engineering, and Medicine released the 2017-2027 Decadal Survey for Earth Science and Applications from Space (ESAS 2017), which is designed to help shape science priorities and guide agency investments over the next decade [1]. One outcome of this report was the creation of a class termed Designated Observables (DOs), which define the highest priority geophysical observables to be measured over the next decade; this designation was given to five geophysical observables. From this set of five DOs, NASA initiated four multi-center studies to evaluate potential observing system architectures for each DO (two DOs were combined into a single study). The four studies currently underway are: Aerosols, Clouds, Convection, and Precipitation (ACCP), Mass Change (MC), Surface Biology and Geology (SBG), and Surface Deformation and Change (SDC). Each study is synonymous with one or more of the geophysical observables identified as DOs. The focus of this paper is on the MC DO study, as we describe an overview of the study, progress made to date, and future plans.

The primary goals of the MC DO Study are to identify and characterize a diverse set of high value MC observing system architectures that are responsive to the Decadal Survey, assess the cost effectiveness of each of the studied architectures, and then perform a sufficient in-depth design of one or two of the selected architectures to enable a rapid initiation of a Phase A study (the phase of "Concept and Technology Development", see https://www.nasa.gov/seh/3-project-life-cycle). To achieve these goals, we have focused efforts over several fronts: 1) The development of a Science and Applications Traceability Matrix (SATM), 2) identification of architectural classes from which MC can be measured, 3) the development of methods from which to assess viable architectural options and quantitatively measure science value in relation to the SATM, and 4) the development of a Value Framework from which the science value of an architecture can be assessed against cost and risk, among other criteria. Each of these will be discussed in more detail below.

2. SCIENCE AND APPLICATIONS TRACEABILITY MATRIX

The development of a Science and Applications Traceability Matrix is paramount to the success of the study. We identified fifteen unique science and application objectives listed in the Decadal Survey relevant to Mass Change. These fifteen objectives span three unique panels: Global Hydrological Cycle and Water Resources, Earth Surface and Interior, and Climate Variability and Change.

The science and applications objectives are fairly evenly distributed with six from Climate Variability and Change, four from the Global Hydrological Cycle and Water Resources, and five from Earth Surface and Interior. In addition, each objective has an associated Importance factor which is prescribed in the Decadal Survey, being listed as either Most Important (MI), Very Important (VI), or Important (I). MC has 8 MI, 2 VI, and 5 I objectives.

Each of these fifteen objectives was then translated into measurement objectives in terms of a targeted spatial resolution, temporal resolution and accuracy. Further, the Utility of MC in achieving each objective was assessed, ranking from either High, Medium, or Low. Both the translation of the objectives into measurement targets as well as the assessment of Utility is fundamentally a value judgement; hence, it necessitates inputs from the larger scientific community. To facilitate this process, we hosted one community workshop, and three separate community telecons (one for each thematic panel), to come to community agreement on these parameters. The outcome of this exercise is the full development of an SATM for the MC DO, with community input, where each scientific objective is assigned an Importance, Utility, as well as targeted measurement parameters (spatial resolution, temporal resolution, and accuracy). The full SATM is available for download here: https://science.nasa.gov/earth-science/decadal-mc. We note that there is significant diversity in the targeted measurement parameters dependent on the objective; this necessitates the development of a flexible framework from which these diverse targets can be quantitatively assessed (Section 4).

3. ARCHITECTURAL CLASSES FOR MEASURING MASS CHANGE

We identified five separate classes of architectures from which mass change within the Earth system can be measured. These are: 1) Ground networks of GPS receivers, oceanic ARGO floats (coupled with satellite altimeter measurements), and in-situ gravimeters; 2) Precisely measuring time either with a distributed network of in-situ clocks or clocks onboard spacecraft; 3) Precisely measuring the absolute position of one or more satellites as they orbit the Earth (i.e. Precise Orbit Determination (POD)); 4) Precisely measuring the intersatellite distance between a pair or multiple pairs of satellites as they orbit the Earth (i.e. Satellite-Satellite Tracking (SST)); 5) Measuring the free-fall of an atom cloud in space (i.e. Atomic Interferometry Gravity Gradiometry (AIGG)). 1) and 2) are not being considered in this study due to cost and technical implementation/readiness constraints. We are, however, assessing a variety of architectural concepts that utilize POD, SST, and AIGG measurement concepts.

For POD architectures, we are primarily interested in the performance of large constellations. To date, the performance of time variable gravity fields using strictly POD has not been sufficient to satisfy the measurement targets in the SATM [2]. However, with large commercial constellations coming onboard in the next decade, this option is worthy of consideration.

SST measurement concepts have significant heritage with the pioneering Gravity Recovery and Climate Experiment (GRACE) mission, as well as the GRACE Follow-On mission, both utilizing this measurement concept [3]. In this study, we will assess a variety of formation types as well as a number of satellite-pairs [4]. Further, there are a range of instruments that will be assessed in the study, including different types of accelerometers, ranging systems, etc.

AIGG concepts are significantly less mature than either POD or SST concepts; however, past simulations have shown this to be an extremely promising technology. We will assess this concept, and in particular focus on the Technology Readiness Level (TRL) of the measurement technique as it relates to this study and potential future observing systems for MC.

4. QUANTITATIVELY DETERMINING SCIENCE VALUE FOR MASS CHANGE ARCHITECTURES

The evaluation of multiple architectural observing system concepts against a diversity of science and applications objectives necessitates a framework from which science value for each architecture can be quantified in an obvious, relatable manner. To this end, we have developed a framework we term Space-Time-Accuracy-Grids (STAG) analysis [5]. In STAG analysis, we use a full-scale numerical simulation framework to simultaneously map the expected accuracy of a particular observing system architecture across space (200 km to 1800 km spatial

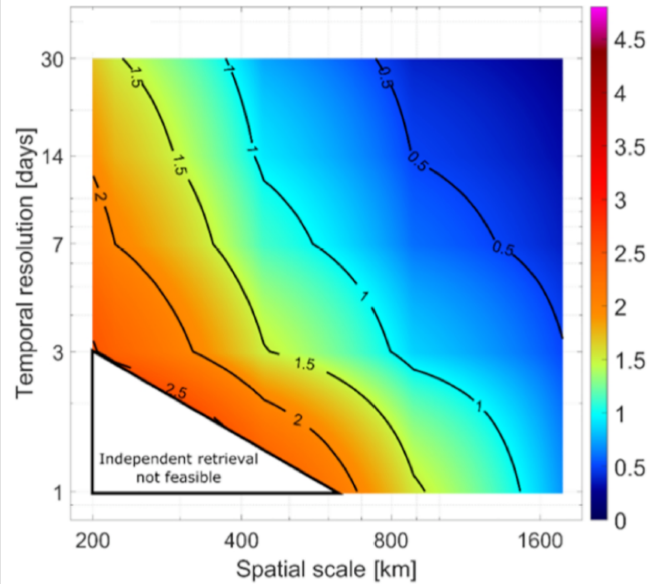

Figure 1: Example of STAG analysis assessing the error of a particular observing system architecture across space and time.

scales) and time (daily to monthly scales). Figure 1 illustrates an example of STAG analysis. This framework includes the integrated effect of the accuracies of the error of different measurement system components, as well as that introduced due to inaccuracies in geophysical models that are relied upon during the data processing, such as models of ocean tides and high frequency atmosphere and ocean mass redistributions [6]. Further, state-of-the art post-processing algorithms can be included in STAG analysis, such as removing predictable correlated error structure that is routine practice when dealing with GRACE and GRACE-FO data [7]. For a complete description about how the expected error is mapped across space and time, the reader is referred to [5]. This framework then easily allows for the performance of an observing system architecture to be assessed at the space/time scales of interest for each science and application objective in the SATM. Using this assessment of performance, along with the Importance and Utility of each science and application objective, a quantitative formula for determining science value for each architecture can be derived.

5. VALUE FRAMEWORK AND FUTURE PLANS

The final stages of assessing the full range of potential observing system architectures for mass change relies on the development of a value framework. The output of the Value Framework is a plot that assesses science value (Section 4) of each architecture on the y-axis against cost/risk of the architecture on the x-axis. Cost will be assessed using calibrated cost models with significant heritage. Risk involves many aspects, including heritage of components, TRL levels, potential mission lifetimes as well as launch dates, etc. At this stage in the MC DO study, the full development of the Risk component of the Value Framework is still under assessment.

Our study team aims to have a full assessment of potential observing system architectures complete in the Value Framework by summer 2020. At this time, we would recommend notionally three architectures for further consideration, and in coordination with NASA Headquarters, would then decide which of these architectures necessitate further in-depth study over the next year to enable a rapid transition to a Phase A study of a future Mass Change observing system architecture.

6. ACKNOWLEDGEMENTS

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