The NASA Mass Change Designated Observable Study: Progress and Future Plans

The Mass Change Designated Observable Study Team[1,2,3,4,5]

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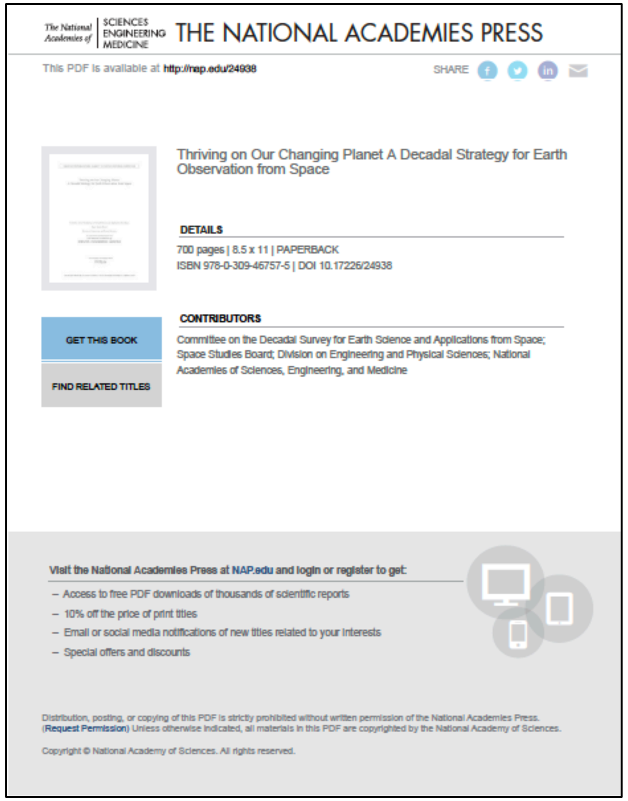
The cost information contained in this document is of a budgetary and planning nature and is intended for informational purposes only. It does not constitute a commitment on the part of JPL and/or Caltech.

Mass Change Introduction

- 2017 Decadal Survey released in January 2018
- Identified five Designated Observables, organized as 4 studies
  - Aerosols
  - Cloud, Convection, and Precipitation

    } Combined as ACCP
  - **<u>Mass Change (MC)</u>**
  - Surface Biology and Geology (SBG)
  - Surface Deformation and Change (SDC)
- Mass change is determined by measuring gravitational changes over set time periods
- Link to the MC study is at

  https://science.nasa.gov/earth-science/decadal-mc



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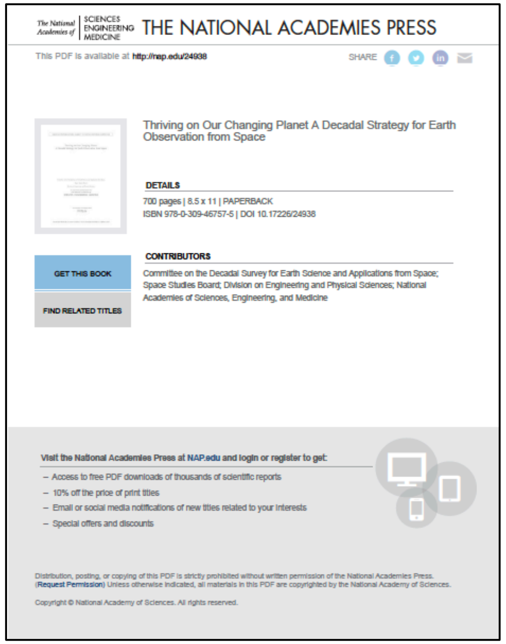
Study Process Overview

Decadal Survey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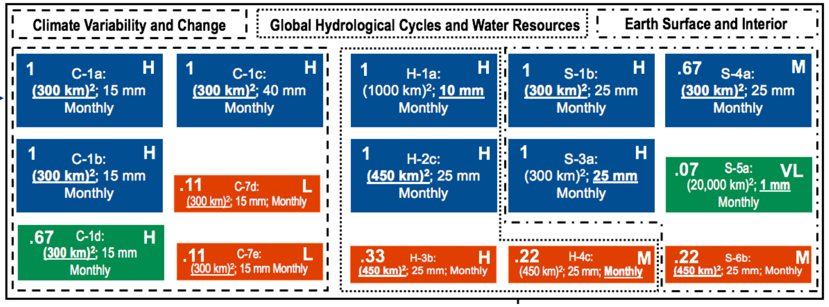
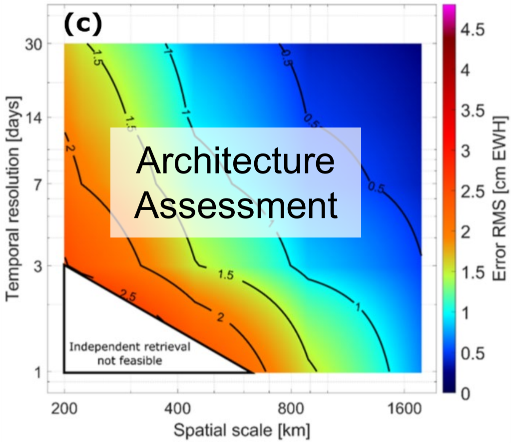
Science and Applications Traceability Matrix vetted by the community



Science value metrics directly relate the capability of an observing system architecture to achieving science and application targets relevant to MC in the Decadal Survey

The process has been presented to the community for input and is successful in discriminating between architectures

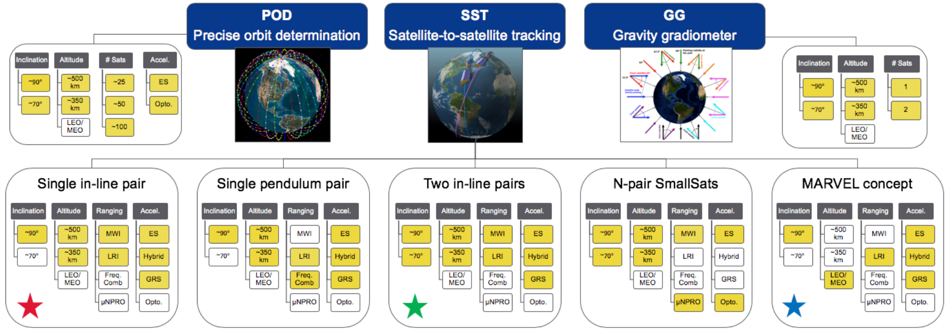


Hauk and Wiese, 2020

Science Value

$$SV(a) = \frac{\sum_{n=1}^{15}(W_n)P_n}{\sum_{n=1}^{15}(W_n)}$$

Architecture Tree



Decadal Survey Science and Application Objectives for Mass Change

A Diverse Set of Objectives Spanning Three Panels

Climate Variability and Change

- 1 — C-1a: (300 km)^2; 15 mm Monthly — H
- 1 — C-1c: (300 km)^2; 40 mm Monthly — H
- 1 — C-1b: (300 km)^2; 15 mm Monthly — H
- .11 — C-7d: (300 km)^2; 15 mm; Monthly — L
- .67 — C-1d: (300 km)^2; 15 mm Monthly — H
- .11 — C-7e: (300 km)^2; 15 mm Monthly — L

Global Hydrological Cycles and Water Resources

- 1 — H-1a: (1000 km)^2; 10 mm Monthly — H
- 1 — H-2c: (450 km)^2; 25 mm Monthly — H
- .33 — H-3b: (450 km)^2; 25 mm; Monthly — H
- .22 — H-4c: (450 km)^2; 25 mm; Monthly — M

Earth Surface and Interior

- 1 — S-1b: (300 km)^2; 25 mm Monthly — H
- .67 — S-4a: (300 km)^2; 25 mm Monthly — M
- 1 — S-3a: (300 km)^2; 25 mm Monthly — H
- .07 — S-5a: (20,000 km)^2; 1 mm Monthly — VL
- .22 — S-6b: (450 km)^2; 25 mm; Monthly — M

DS Prescribed Weights [Importance]

Most Important Highest weight	Very Important Medium weight	Important Lower Weight
1.0	0.67	0.33

MC Utility Score

H: High	1.0
M: Medium	0.67
L: Low	0.33
VL: Very Low	0.10

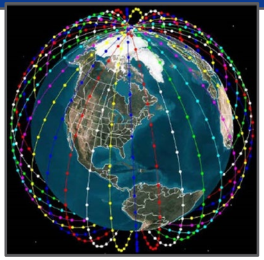
→ Science Performance Targets

Architecture trade space

Highlighted boxes = Orbit & technology trade space

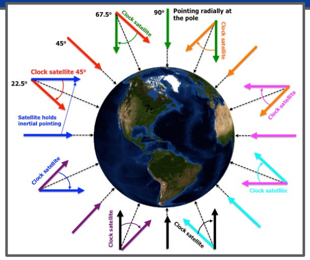
POD
Precise orbit determination

- Inclination: **~90°**, **~70°**
- Altitude: **~500 km**, **~350 km**, LEO/MEO
- # Sats: **~25**, **~50**, **~100**
- Accel.: **ES**, **Opto.**



SST
Satellite-to-satellite tracking

GG
Gravity gradiometer



- Inclination: **~90°**, **~70°**
- Altitude: **~500 km**, **~350 km**, LEO/MEO
- # Sats: **1**, **2**

Single in-line pair ★ (red)
- Inclination: **~90°**, ~70°
- Altitude: **~500 km**, **~350 km**, LEO/MEO
- Ranging: **MWI**, **LRI**, Freq. Comb, µNPRO
- Accel.: **ES**, **Hybrid**, **GRS**, Opto.

Single pendulum pair ★ (blue)
- Inclination: **~90°**, ~70°
- Altitude: **~500 km**, **~350 km**, LEO/MEO
- Ranging: MWI, **LRI**, **Freq. Comb**, µNPRO
- Accel.: **ES**, **Hybrid**, **GRS**, Opto.

Two in-line pairs ★ (green)
- Inclination: **~90°**, **~70°**
- Altitude: **~500 km**, **~350 km**, LEO/MEO
- Ranging: **MWI**, **LRI**, Freq. Comb, µNPRO
- Accel.: **ES**, **Hybrid**, **GRS**, Opto.

N-pair SmallSats
- Inclination: **~90°**, **~70°**
- Altitude: **~500 km**, **~350 km**, LEO/MEO
- Ranging: **MWI**, LRI, Freq. Comb, **µNPRO**
- Accel.: **ES**, Hybrid, GRS, **Opto.**

MARVEL concept ★ (blue)
- Inclination: **~90°**, ~70°
- Altitude: ~500 km, ~350 km, **LEO/MEO**
- Ranging: MWI, **LRI**, Freq. Comb, µNPRO
- Accel.: **ES**, **Hybrid**, **GRS**, Opto.

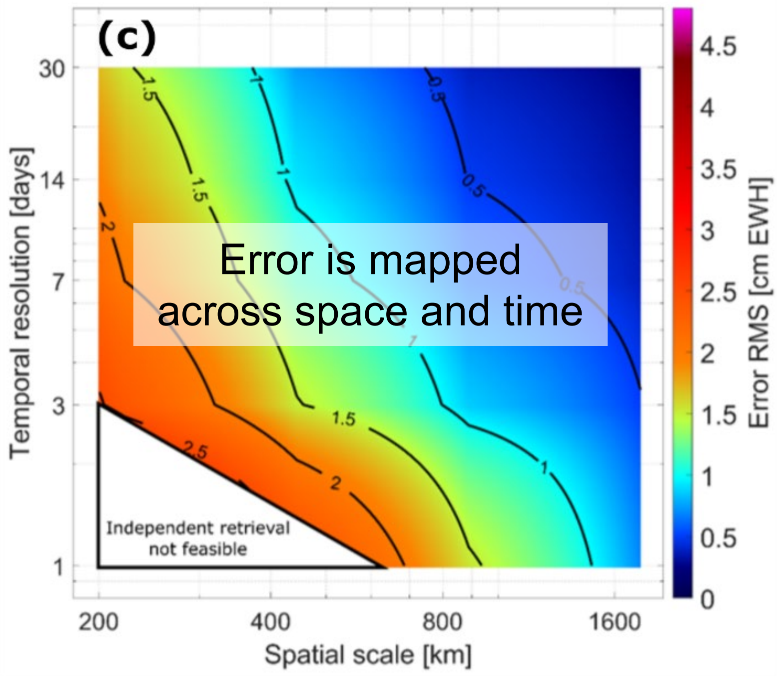
★ Discussions in Germany
★ Favored by ESA
★ Favored by CNES

High Fidelity Numerical Simulations

- Numerical simulations are run that include realistic measurement system errors as well as dynamic force model errors to quantify the expected performance of each architectural variant
- Simulations mimic processing of real GRACE and GRACE-FO data
- Analytic partial derivatives relate the simulated observations to the state parameters of interest – this allows for a quantitative metric of performance.
- Numerically intensive: ~300,000 CPU hours
- Performance is analyzed across space and time

Dynamic force models used in simulations

	Truth Model	Nominal Model
Static Gravity Field	gif48	gif48
Ocean Tides	GOT4.8	FES2004
Atmosphere/Ocean (AOD)	AOD RL05	AOerr + DEAL (Dobslaw et al., 2016)
Hydrology + ICE	ESA Earth System Model	



Quantitatively Determining Science Value

$$SV(a) = \frac{\sum_{n=1}^{15}(W_n)P_n}{\sum_{n=1}^{15}(W_n)} = \frac{\sum_{n=1}^{15}(W_n)\frac{Spatial\_Res_n}{Spatial\_Res(a)}\frac{Temporal\_Res_n}{Temporal\_Res(a)}\frac{Accuracy_n}{Accuracy(a)}}{\sum_{n=1}^{15}(W_n)}$$

Assessing value against spatial resolution

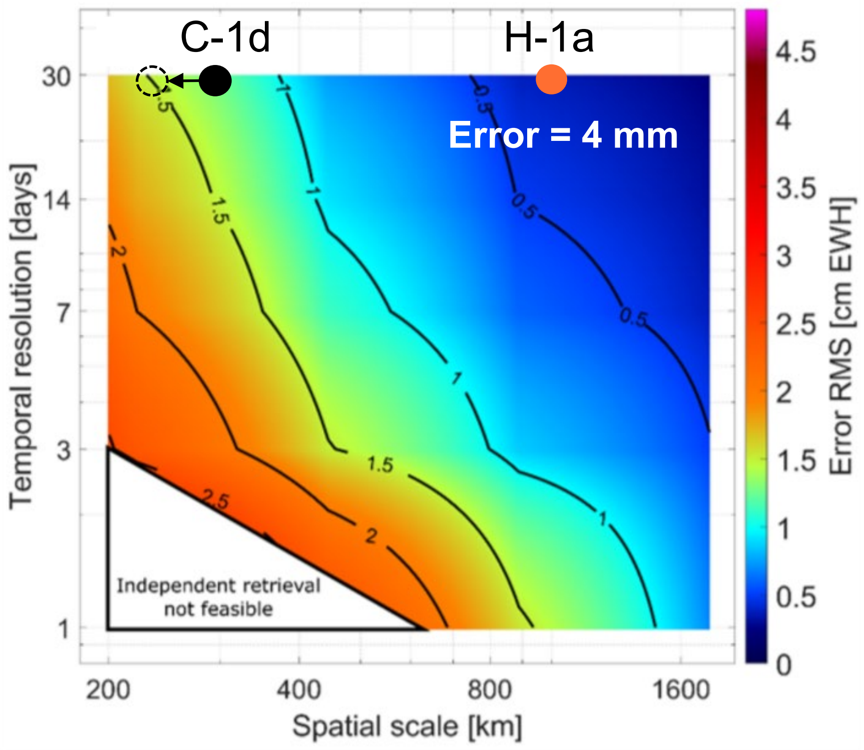
C-1d:
(300 km)^2; 15 mm
Monthly

Medium – High Weight

$SV_{C\text{-}1d} = 0.67 * (300/225)^2 = 1.2$

W = Importance * Utility

Architecture *a*



Hauk and Wiese, Earth and Space Science, 2020.

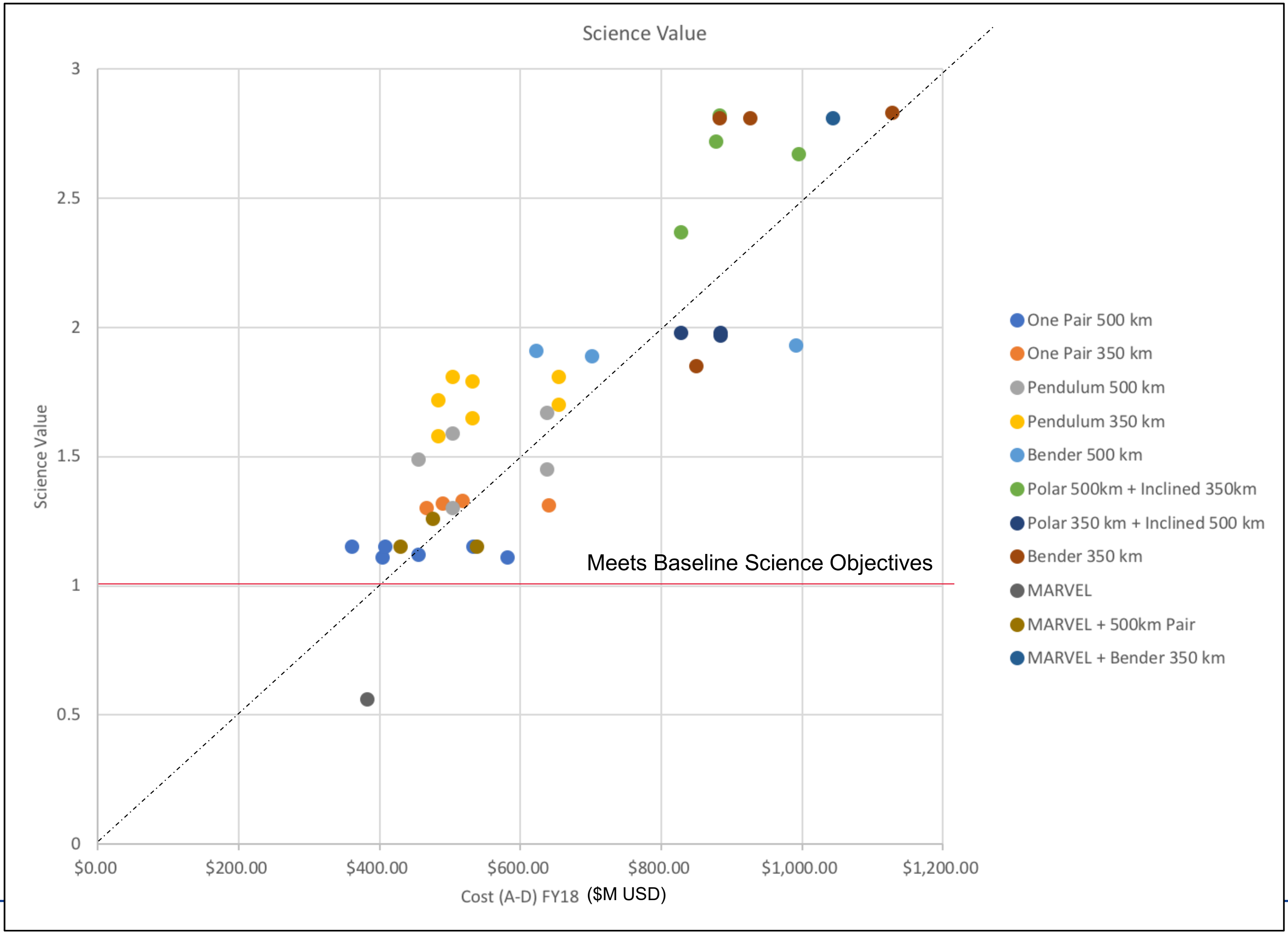
Assessing value against accuracy

H-1a:
(1000 km)^2; **10 mm**
Monthly

Highest Weight

$SV_{H\text{-}1a} = 1 * 10/4 = 2.5$

Value Framework – Preliminary Results



Concurrent Engineering Model is used to design and size each architecture. These designs then drive a validated cost model that has been calibrated against heritage missions.

This value framework allows for discrimination between architectural options on science value vs. cost.

We find an extremely linear relationship between science value and cost in this framework.