Petascale Design Optimization of Space-based Precipitation Observations to Address Floods and Droughts

<u>Principal Investigators</u>

Patrick Reed, Cornell University

Matt Ferringer, The Aerospace Corporation

Eric Wood, Princeton University

Petascale Track 1 OCI 1144212

Image courtesy ESA-AOES Medialab.

Key Challenges

The NRC (2007, 2012) have highlighted a legitimate concern that we are reaching a tipping point where our key Earth Science space infrastructure could collapse.

- Task #1: Demonstrate the implications of vulnerabilities to our precipitation observing space infrastructure
- Task #2: Discover transformative satellite architectures that dramatically reduce costs, increase life cycle sustainability, and maximize coverage

Why it Matters:

Move towards long term space-based integrated global water cycle observatory long sought by World Climate Research Programme

Fundamentally change cost, life cycle sustainability, and global coverage capabilities in next generation Earth observing architectures

The Economist

Log in | Register | Subscribe | Digital & mobile

World politics | Business & finance | Economics | Scienc

Current issue | Previous issues | Special reports | Politics t

Earth-observation satellites

Something to watch over us

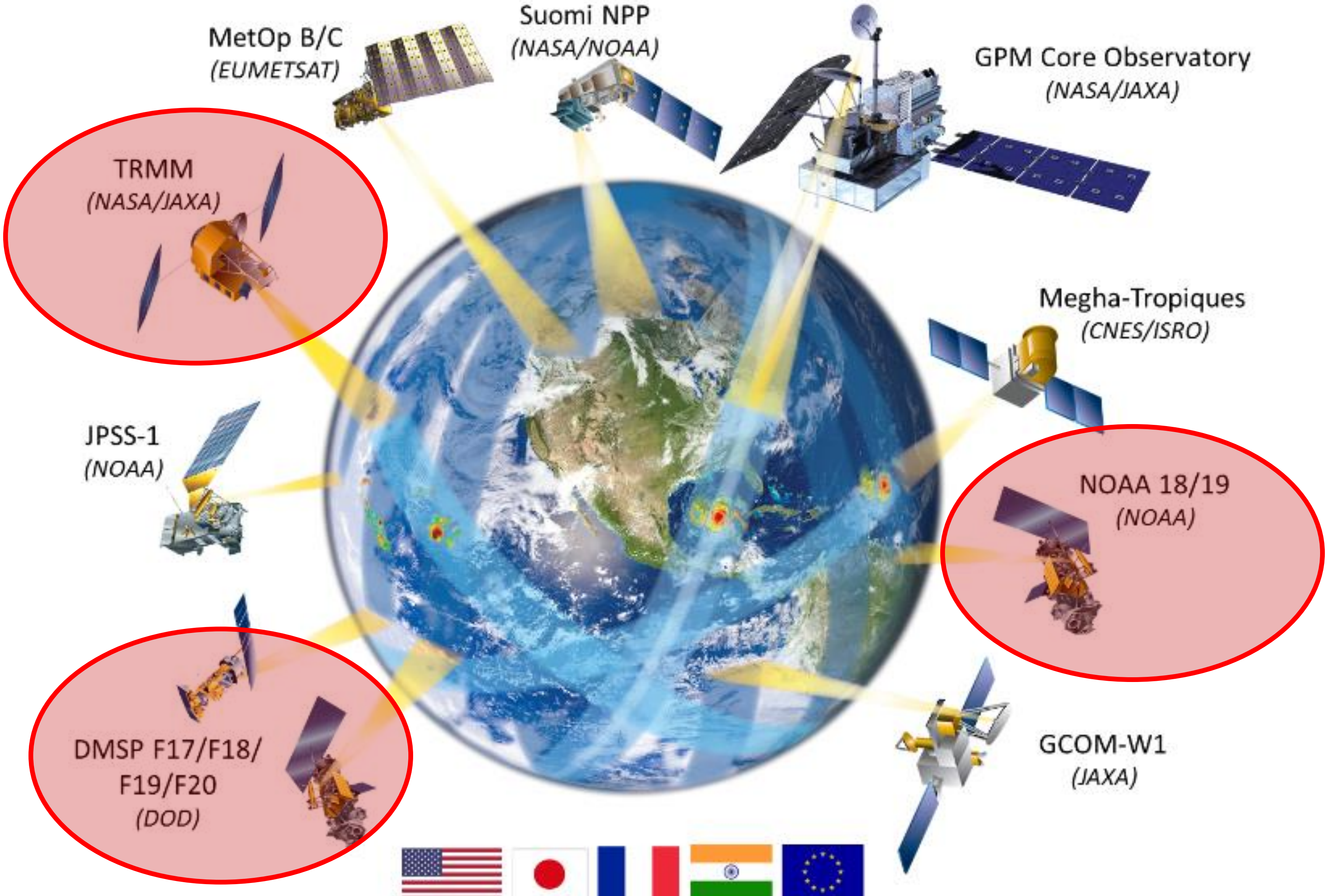
The Earth should be monitored more carefully

May 12th 2012 | from the print edition

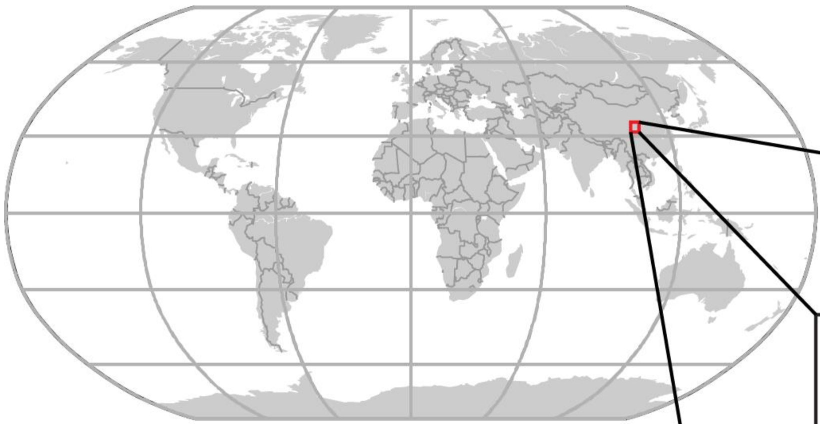
What are the implications of our aging precipitation observing space infrastructure?

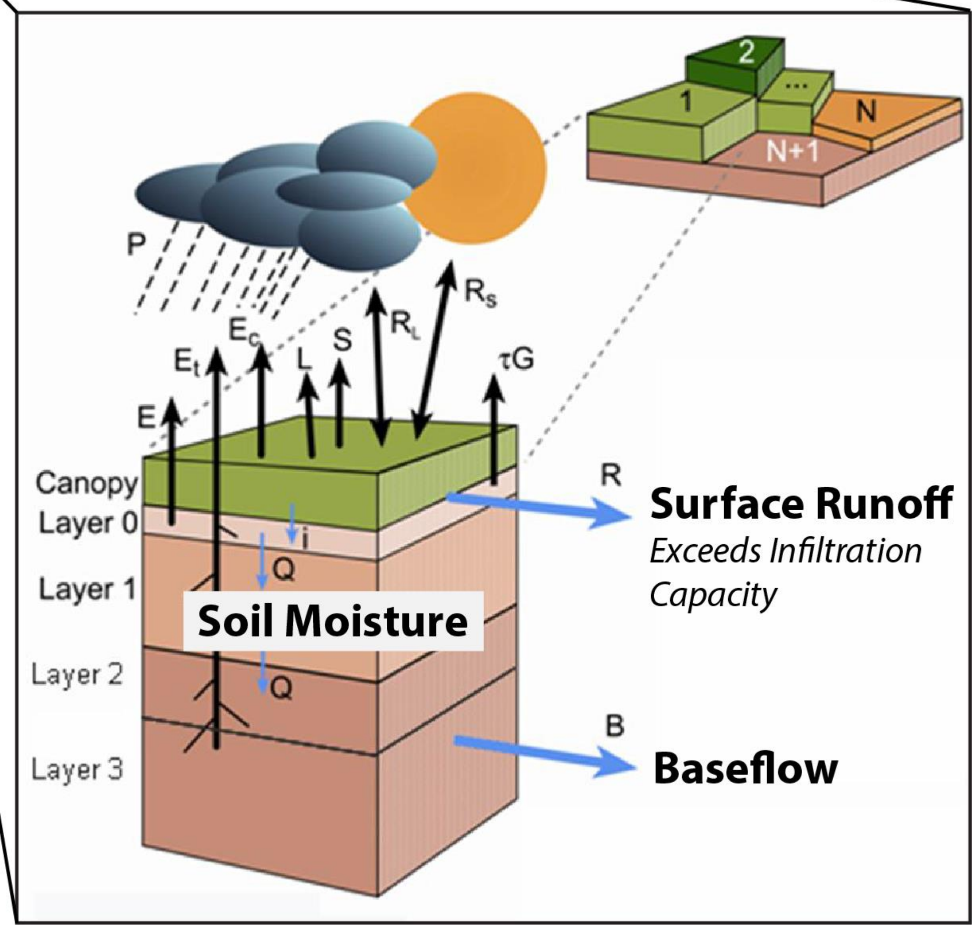
Reed, P. M., Chaney, N., Herman, J., Ferringer, M., and Wood, E. F., "Internationally Coordinated Multi-Mission Planning Is Now Critical to Sustain the Space-based Rainfall Observations Needed for Managing Floods Globally", Environmental Research Letters, 10, (024010), 2015.

Risks of Aging Space-based Infrastructure?



Variable Infiltration Capacity (VIC) Model
(Liang et al., 1994)





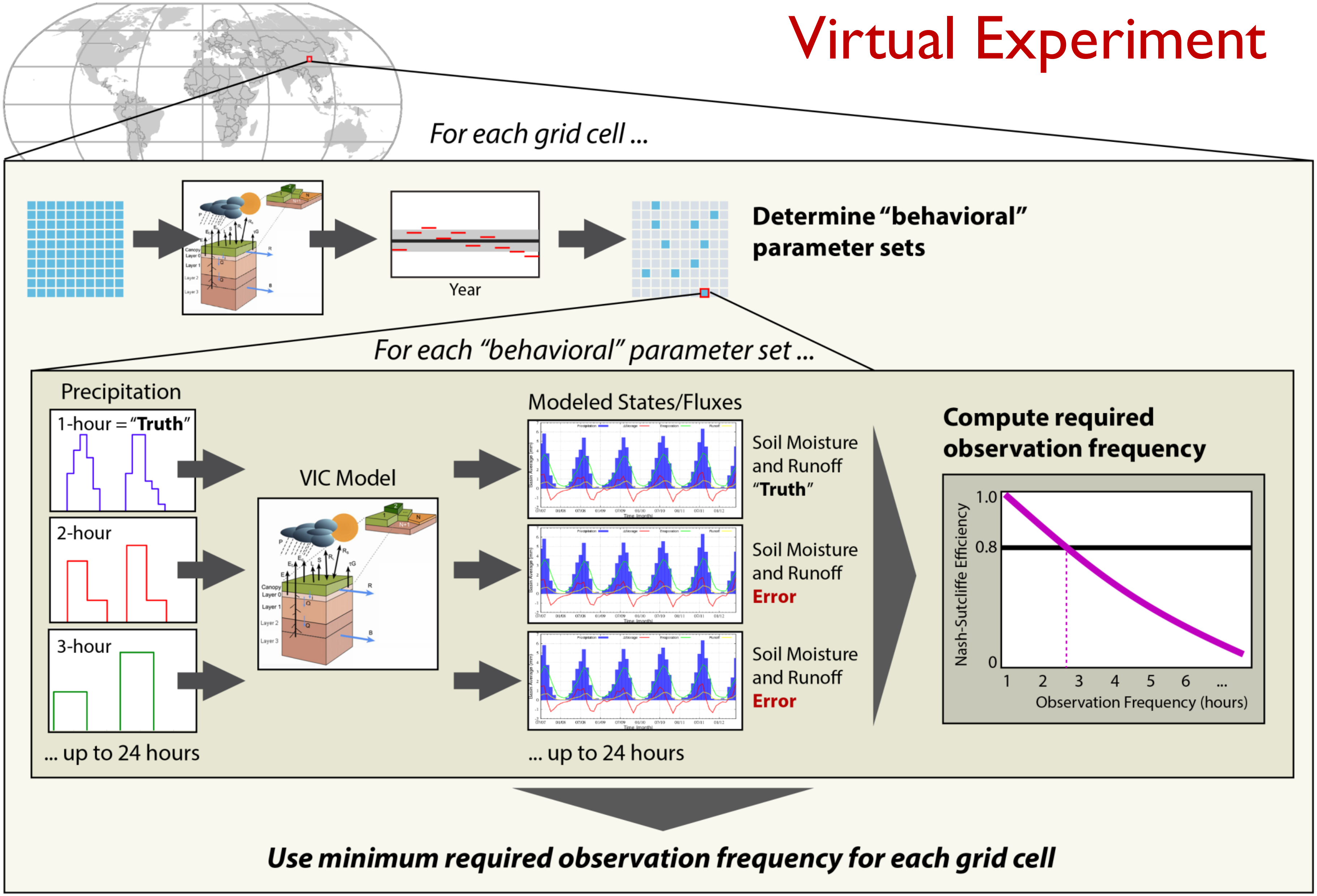
Sub-grid heterogeneity handled by statistical distributions

Inputs: sub-daily precipitation, air temp., wind speed, etc.

Water and energy balances simulated at sub-daily timescale

Adapted from http://web.hwr.arizona.edu/~surface/files/research/grace3.jpg

Virtual Experiment

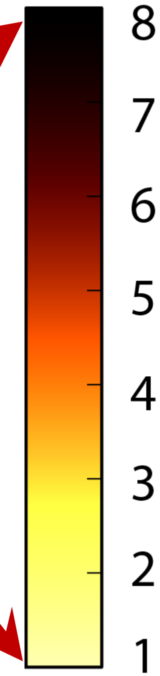


Data Gaps for Floods Exist Even Using All Missions

Surface Runoff: Coverage Deficit

Full Constellation

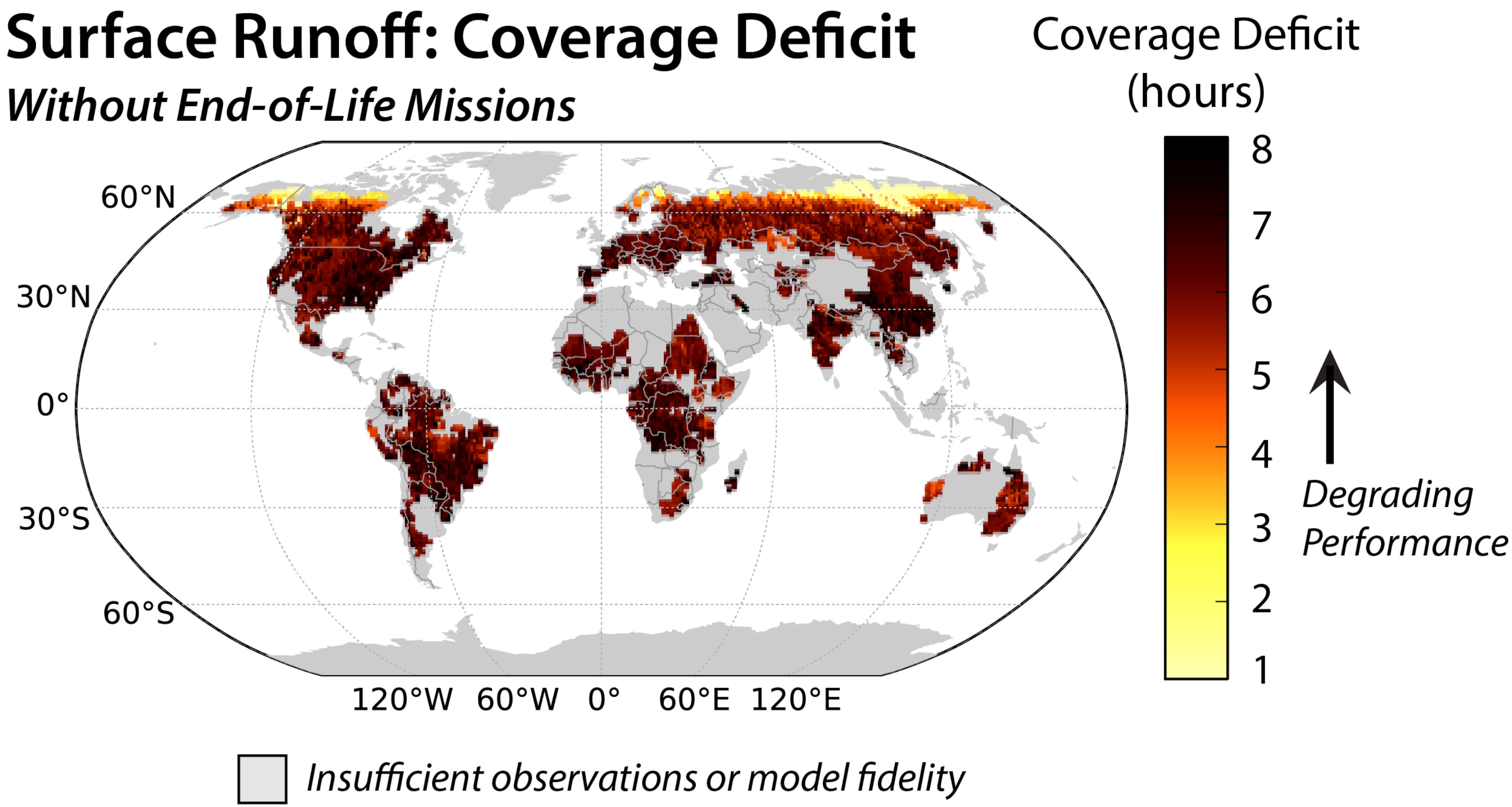
Coverage Deficit (hours)



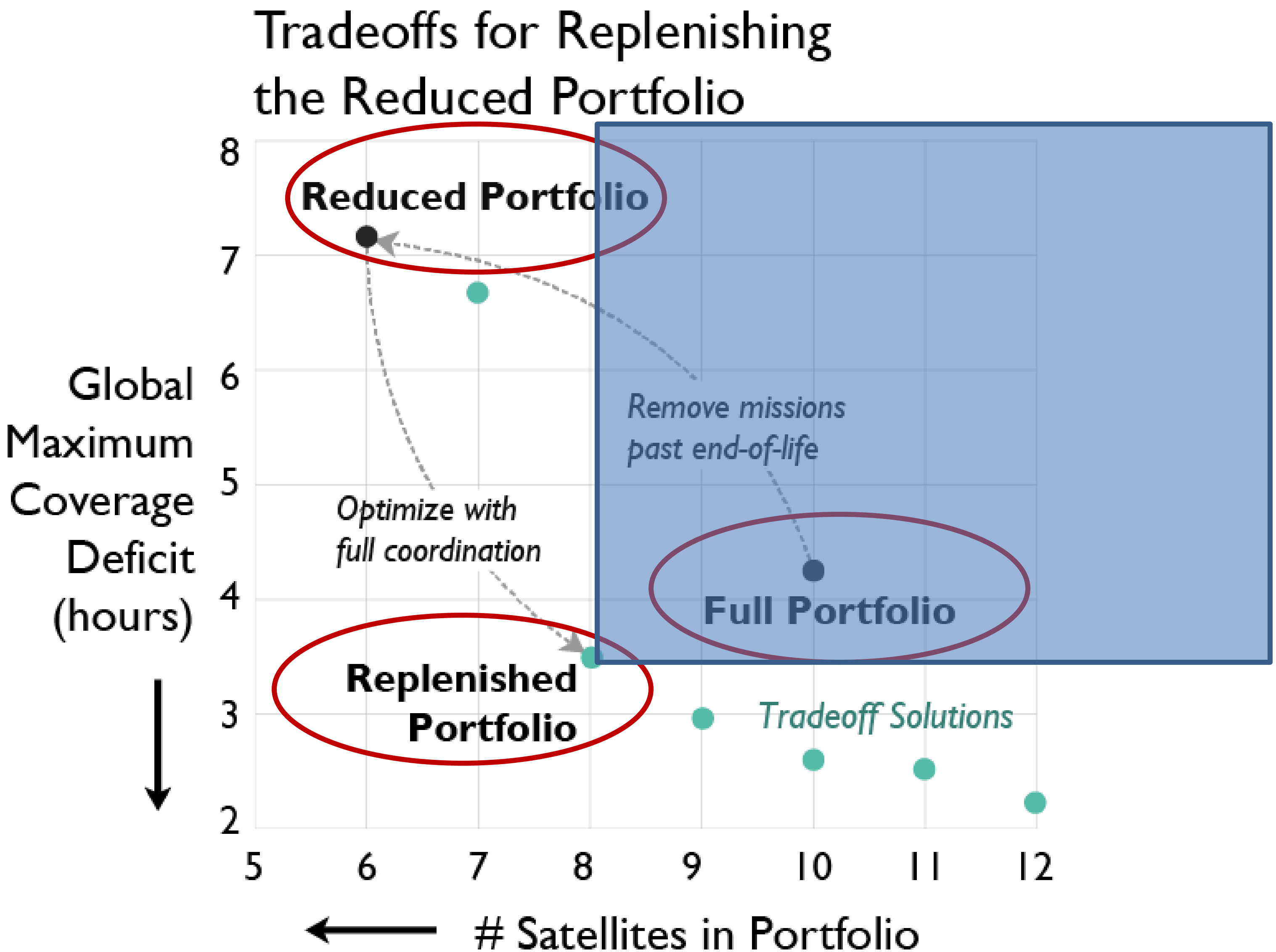
Degrading Performance

Time delay between rainfall data we need and what we can get

Vulnerabilities from Losing End-of-Life Missions



Tradeoffs & the Value of Coordination



A nudge in a global dialogue…

Shanghai Sun

Call of the Orient

Shanghai Sun http://www.shanghaisun.com 10:37 AM Monday 23 February 2015

Shanghai News | Breaking International News | Breaking Entertainment News | International Business News | Property Nev
Retail News | Music News | Breaking Media News | Books News | Shanghai News | Animals News

Facebook Tweet Email ShareThis

Global rainfall satellites need massive overhaul: Study

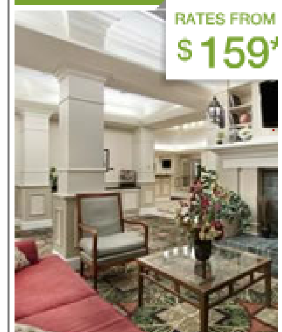
Shanghai Sun (IANS) Friday 13th February, 2015

A new collaborative study warns that the existing system of space-based rainfall observation satellites requires a serious overhaul.

Weather satellites that are constantly working to provide rainfall data, that are key for flood prediction.

But such satellite-based flood prediction has weak points, which could lead to major flooding that catches people by surprise.

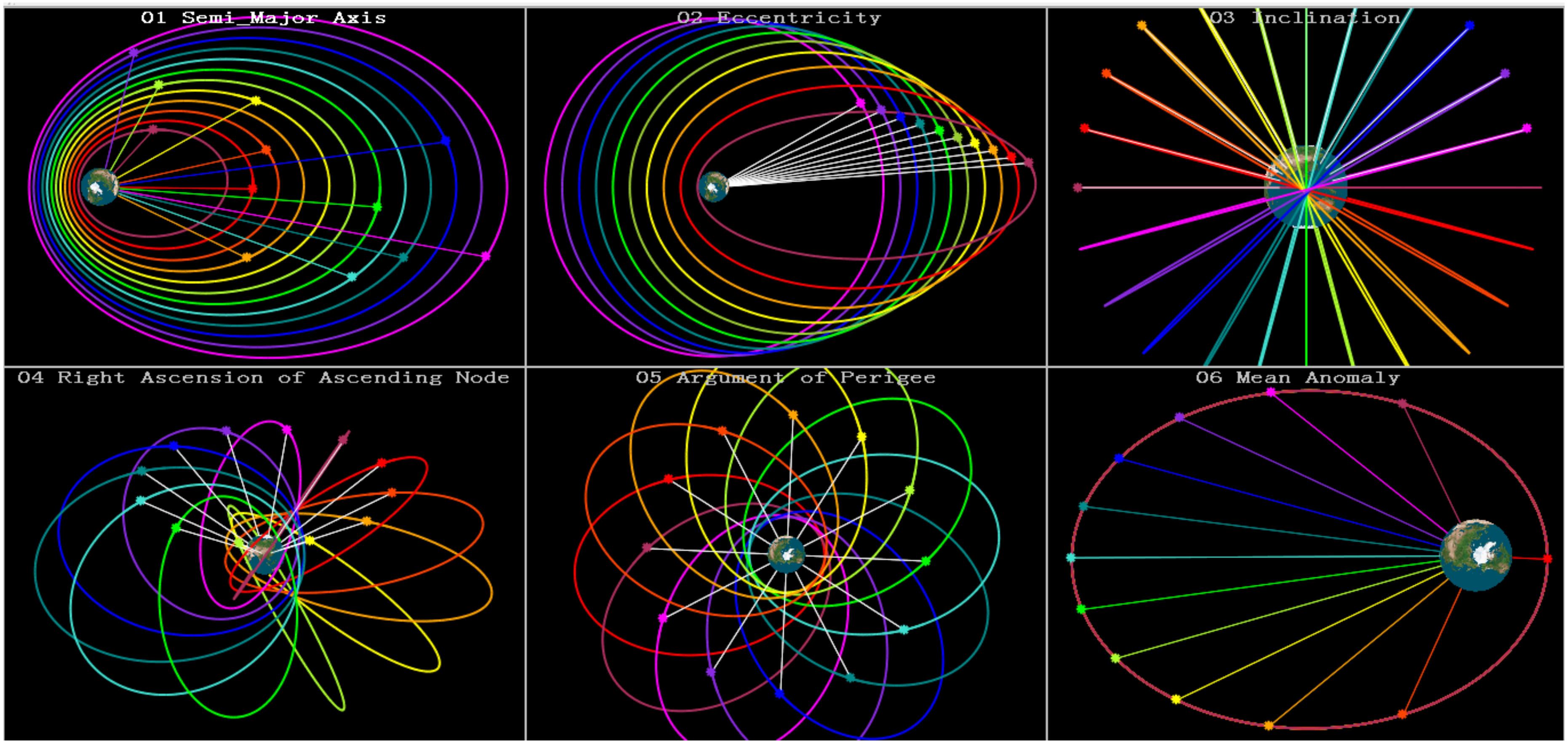
Moreover, four of the 10 dedicated rainfall satellites are past their warranty, further increasing risk of disaster.



Latest Shangh

Higgins wins snool
Welsh Open

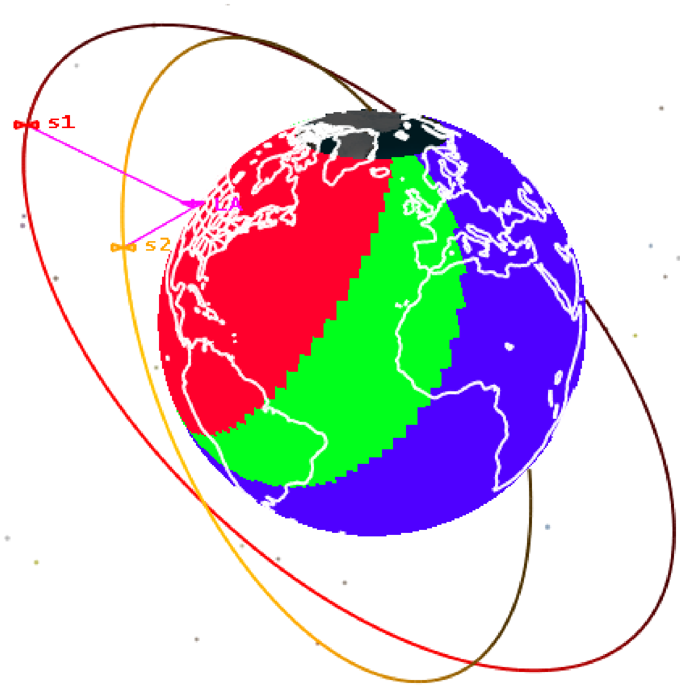
Satellites: Nonlinear, Interdependent Dynamics

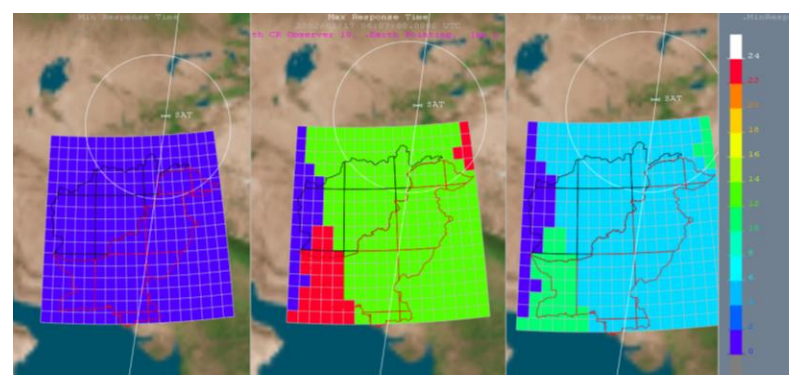


A satellite constellation is a group of satellites that collaborate to provide one or more services

Satellite Constellation Basics—Evaluating Access Globally

- Maximum revisit time: largest gap in coverage for a particular location over a given time period
- Average response time: the statistical average amount of time to the next access at any moment in time
- Many other access metrics
  - *Minimum daily accesses*
  - *Daily visibility time*
  - *Cumulative accesses*
  - …
- Figures of merit are not analytical and often conflicting or competing with each other





Many-Objective Design Analytics: Bridging Astrodynamics & Earth Science

Stakeholder Interviews

Identify Design Parameters

Identify Key Objectives

Identify Constraints

Variables
Assumptions
Constants
…

Requirements
Goals
…

Application Program Interfacing (API)

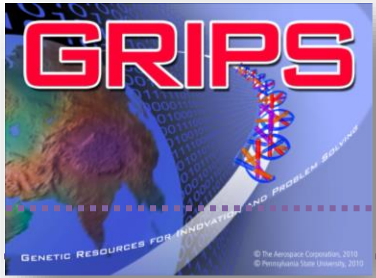
Identify existing Aerospace tools that model:

- Design Parameters
- Key Objectives
- Constraints

Assess feasibility for GRIPS integration via the API

Build new models if necessary

Wrap models into GRIPS via API



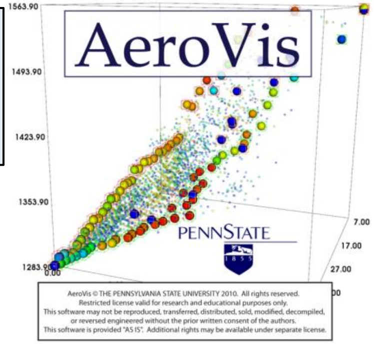
Multi-objective optimization

Massively parallel search using Multi-objective Evolutionary Algorithms (MOEAs)

Explore, Visualize, Communicate

Watch architectures "evolve" and identify key interactions between design parameters, objectives, and constraints

Provide an accessible visualization roadmap of key tradeoffs to Decision Maker

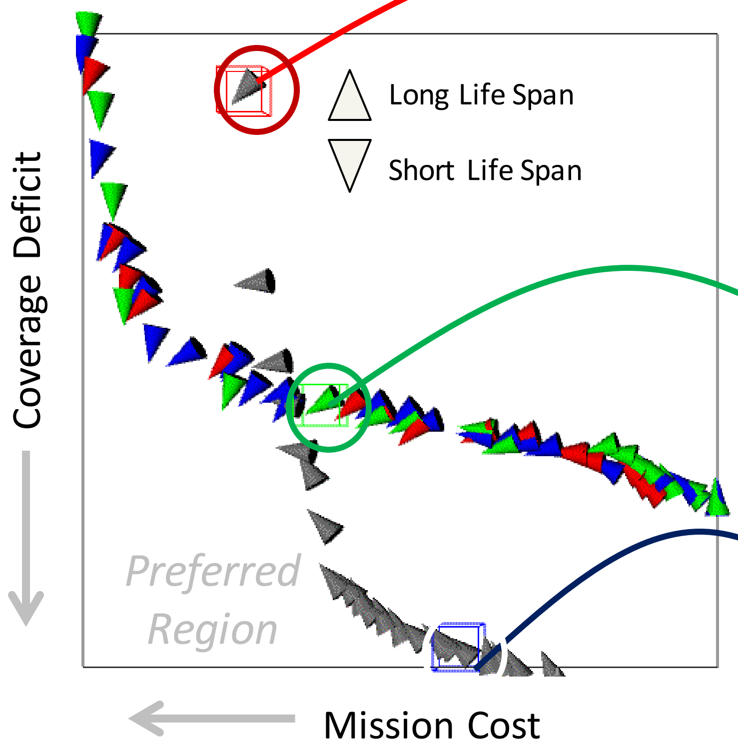


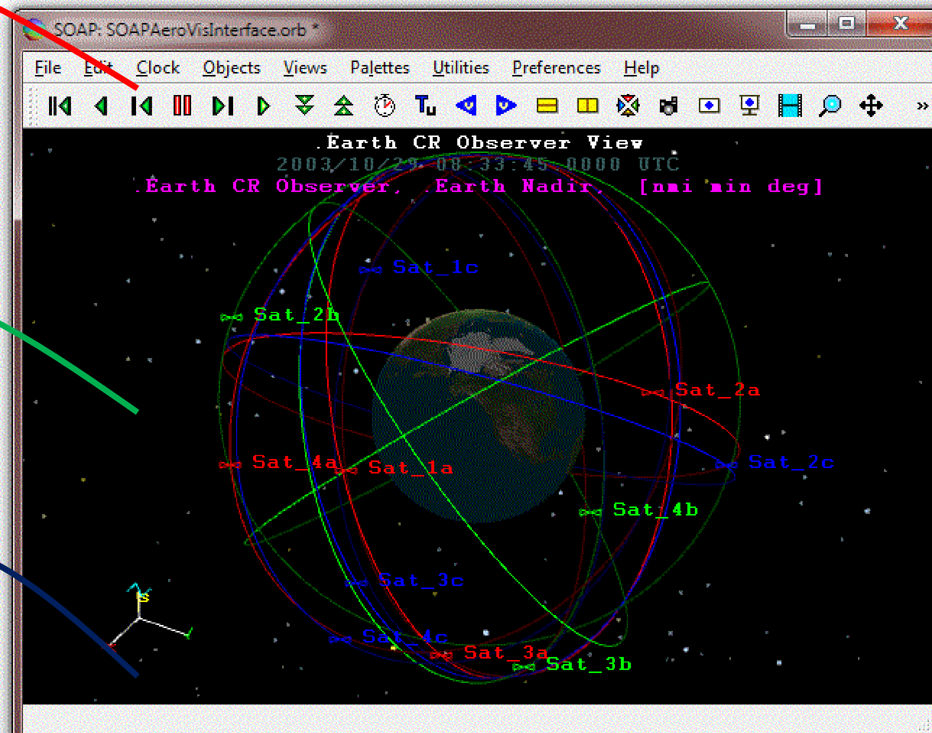
Discovering Tradeoffs for Candidate Constellations (Illustrative Example)

Innovating the design of precipitation missions

Transformative exploration of candidate designs

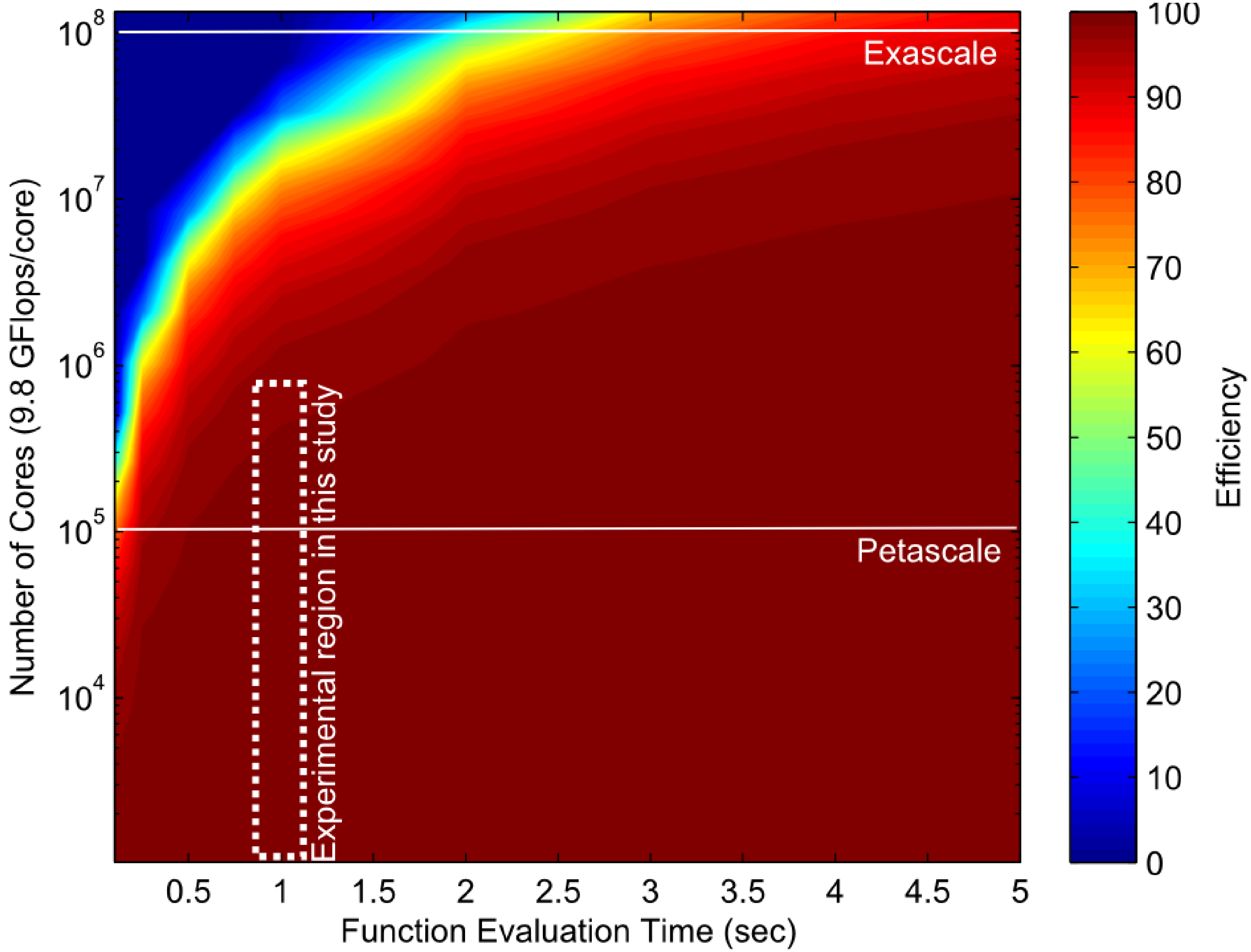
- Click on the red, green, and blue solutions to visualize their designs





Scalability of Search

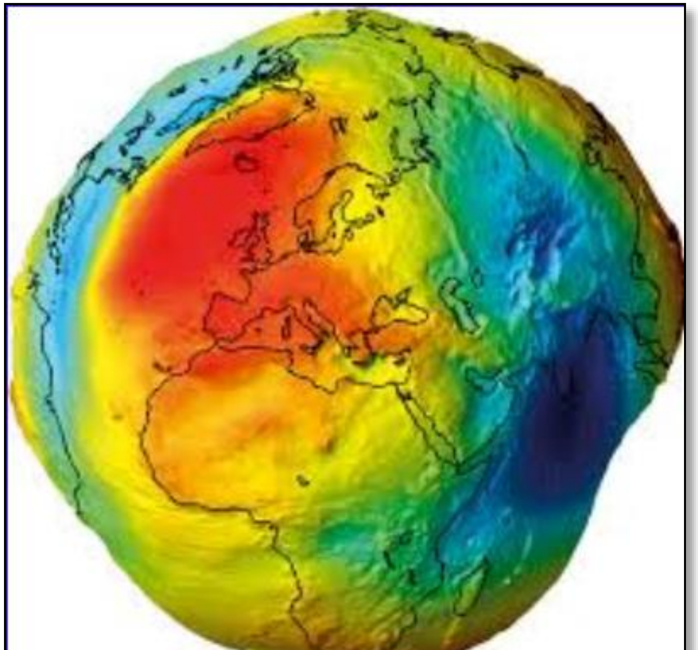
Theoretical Scaling from Discrete Event Simulation (accurate to within 0.1%)



Reed, P.M. and Hadka, D., "Evolving Many-Objective Water Management to Exploit Exascale Computing", Water Resources Research, v50, n10, 8367–8373, 2014.

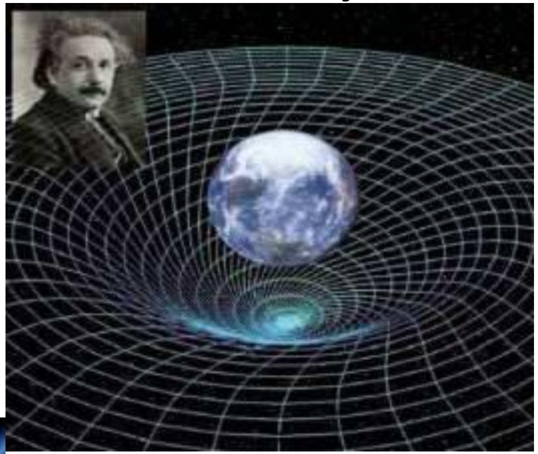
Exploring Big Opportunities Hidden in Small Errors

Earth's Actual Mass Distribution



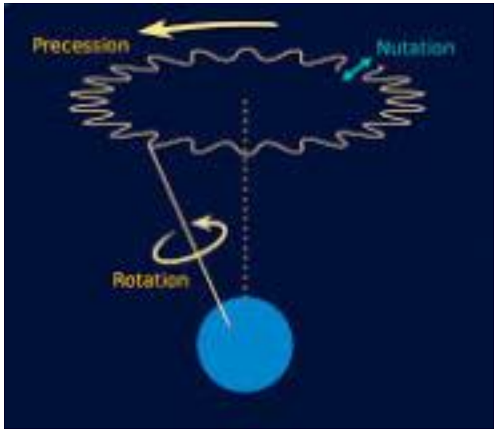
Tides

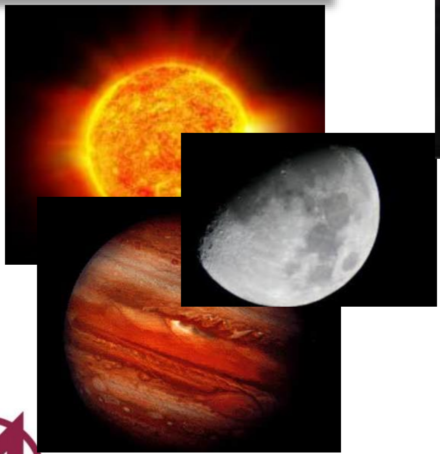
Relativity



Drag

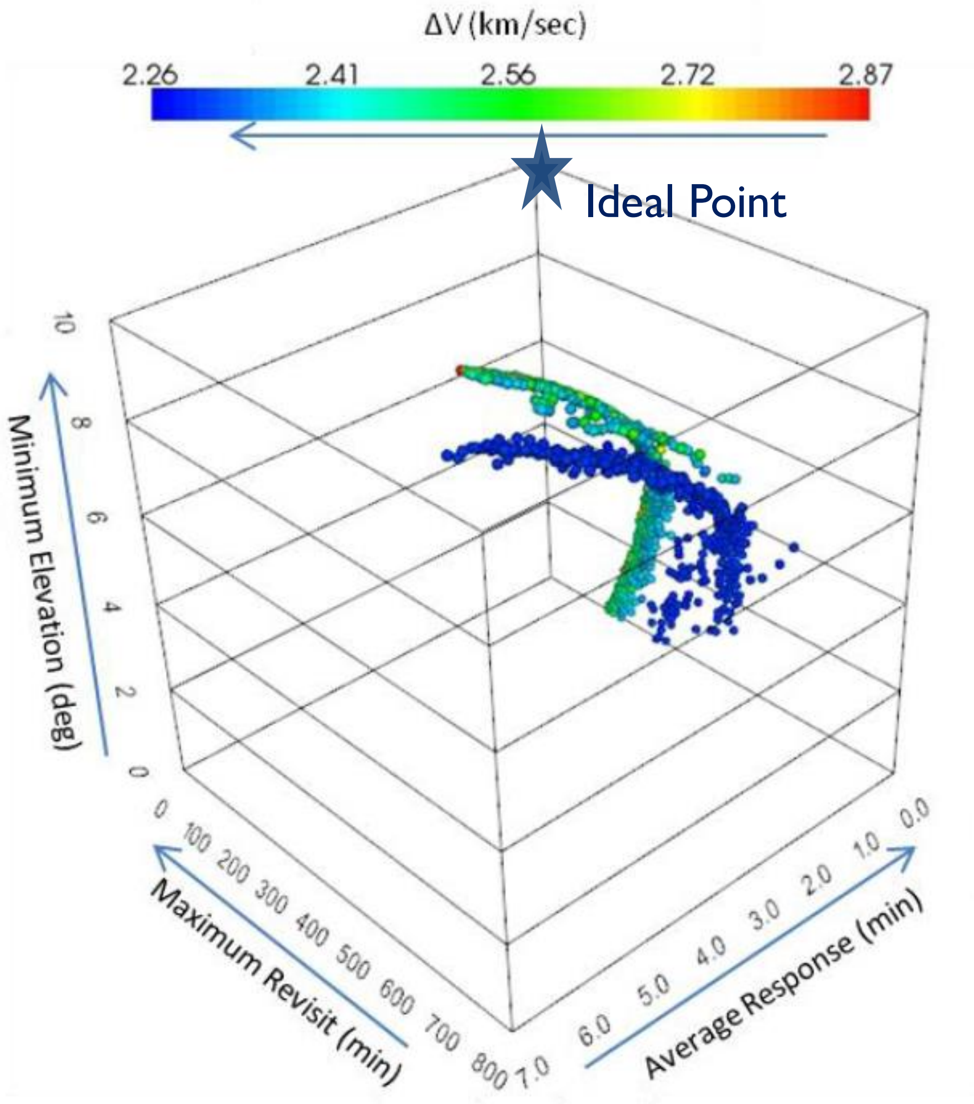
Nutation, precession



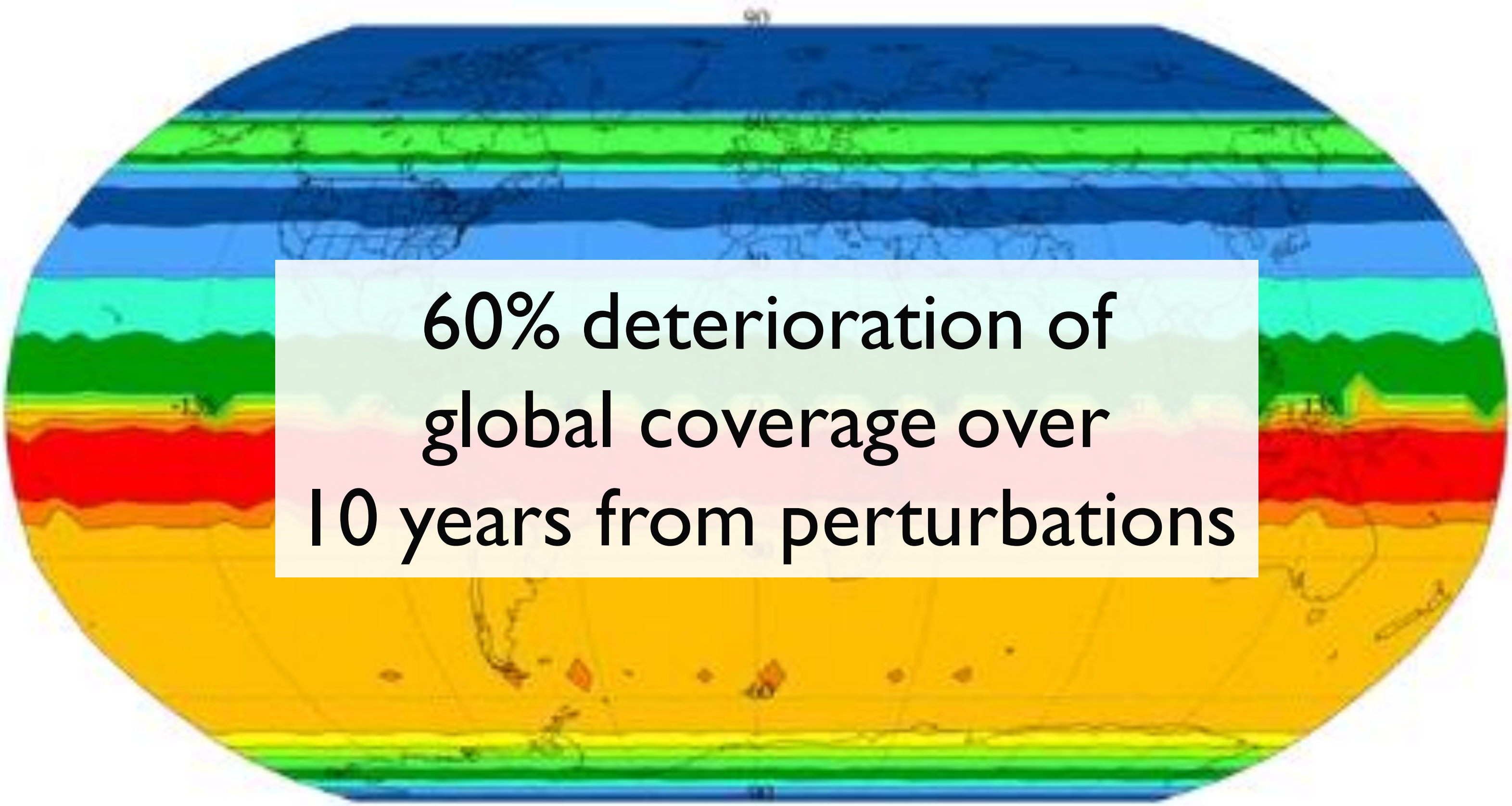


Third-body effects

Example Tradeoffs When Exploiting Perturbations



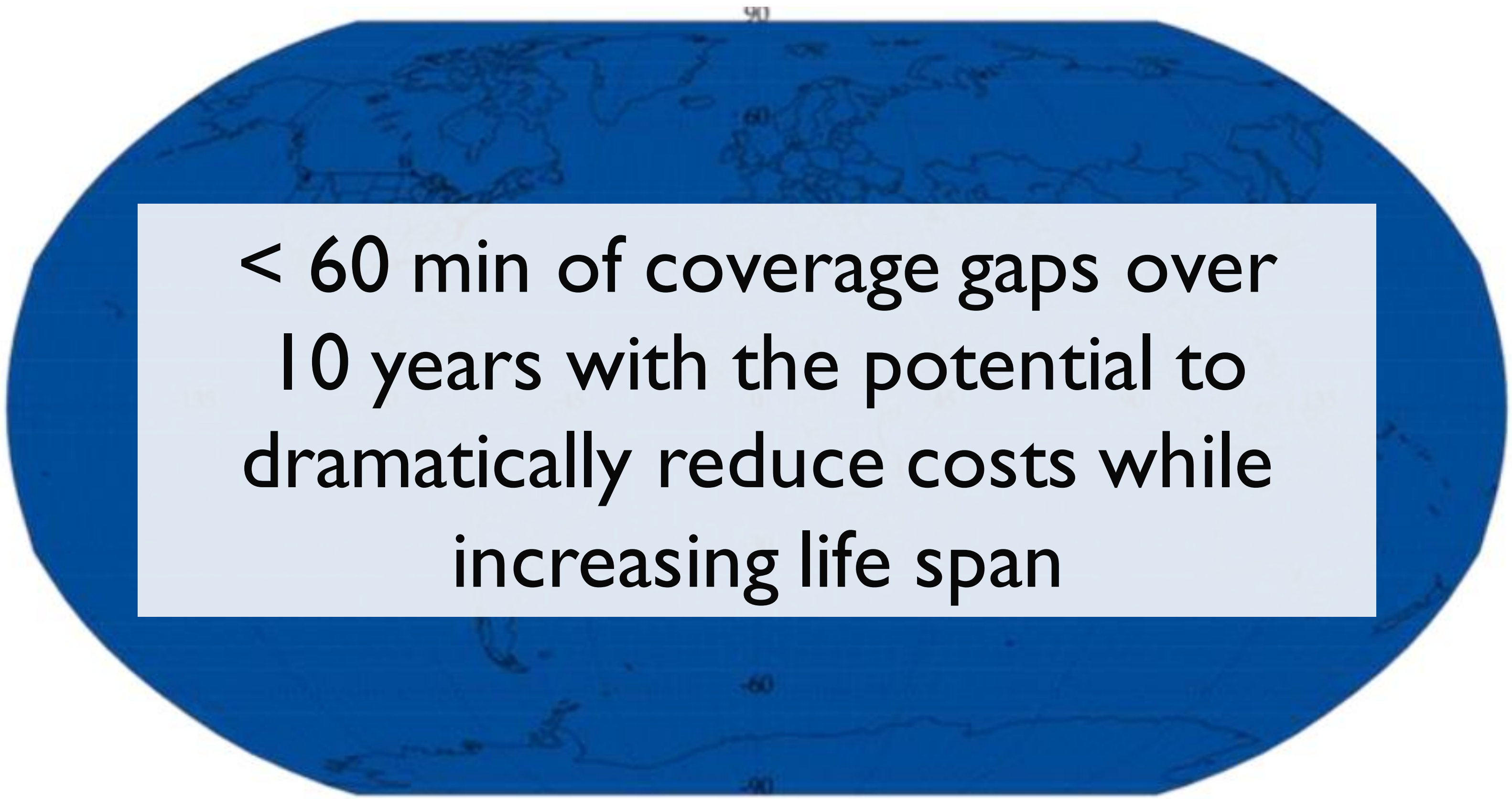
DRAIM 4 Satellite Global Coverage Results



Legend:
(% Earth)
(min)

0 60 120 180 240 300 360 420 480 540

Discovered 4 Satellite Passive Control Results



< 60 min of coverage gaps over 10 years with the potential to dramatically reduce costs while increasing life span

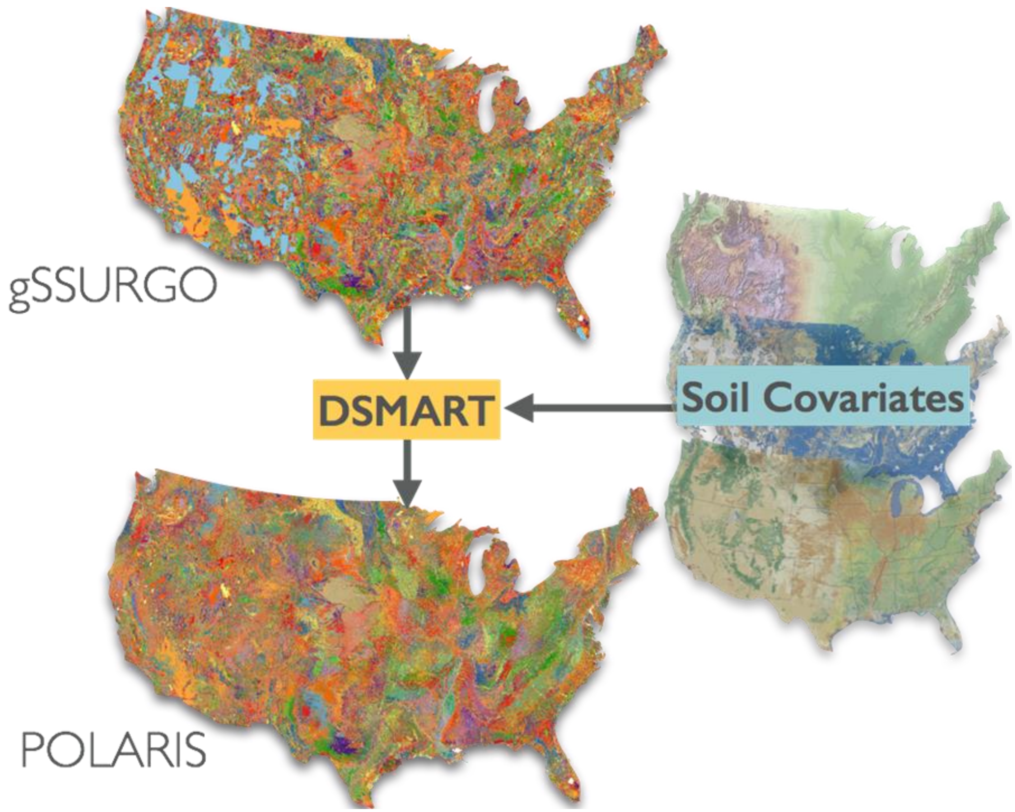
Legend:
(% Earth)
(min)

0 60 120 180 240 300 360 420 480 540

Ferringer, M., M. DiPrinzio, T. Thompson, K. Hanifen, W. Whittecar, and P. Reed (2014), A Framework for the Discovery of Passive-Control, Minimum Energy Satellite Constellations, Space 2014 AIAA/AAS American Institute of Aeronautics and Astronautics, San Diego, CA.

Next Steps for Our Team

POLARIS database—Improve Soil Survey Geographic (SSURGO) database assembled from 100+ years via machine learning, vegetation, elevations, and geology (2 TB reference dataset)



Next Steps for Our Team

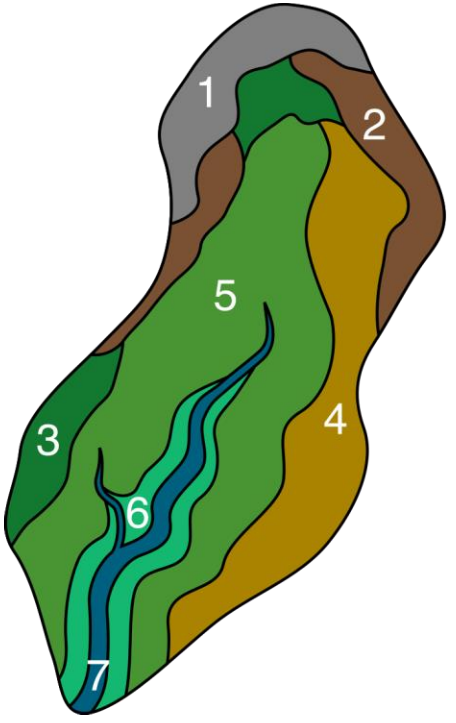
High Resolution Hydrology—move toward 30m CONUS and 100m global ensembles

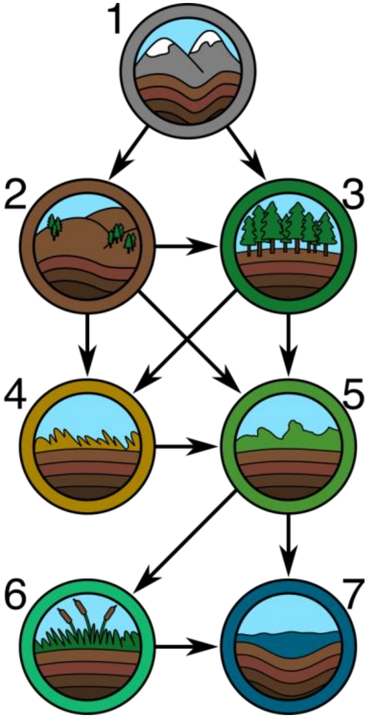
HydroBloks

Build HRUs on drivers of spatial heterogeneity

Coupling:

- Noah-MP
- Dynamic TOPMODEL





Next Steps for Our Team

New baselines for space-based observation system simulation experiments (e.g., next generation NOAA architectures)

Reduced 700,000 grid cells to 393 HRUs

Exploiting mixed OpenMP and MPI parallelization of HRUs

Future work will link to WRF