# Optimizing Earth-Observing Systems

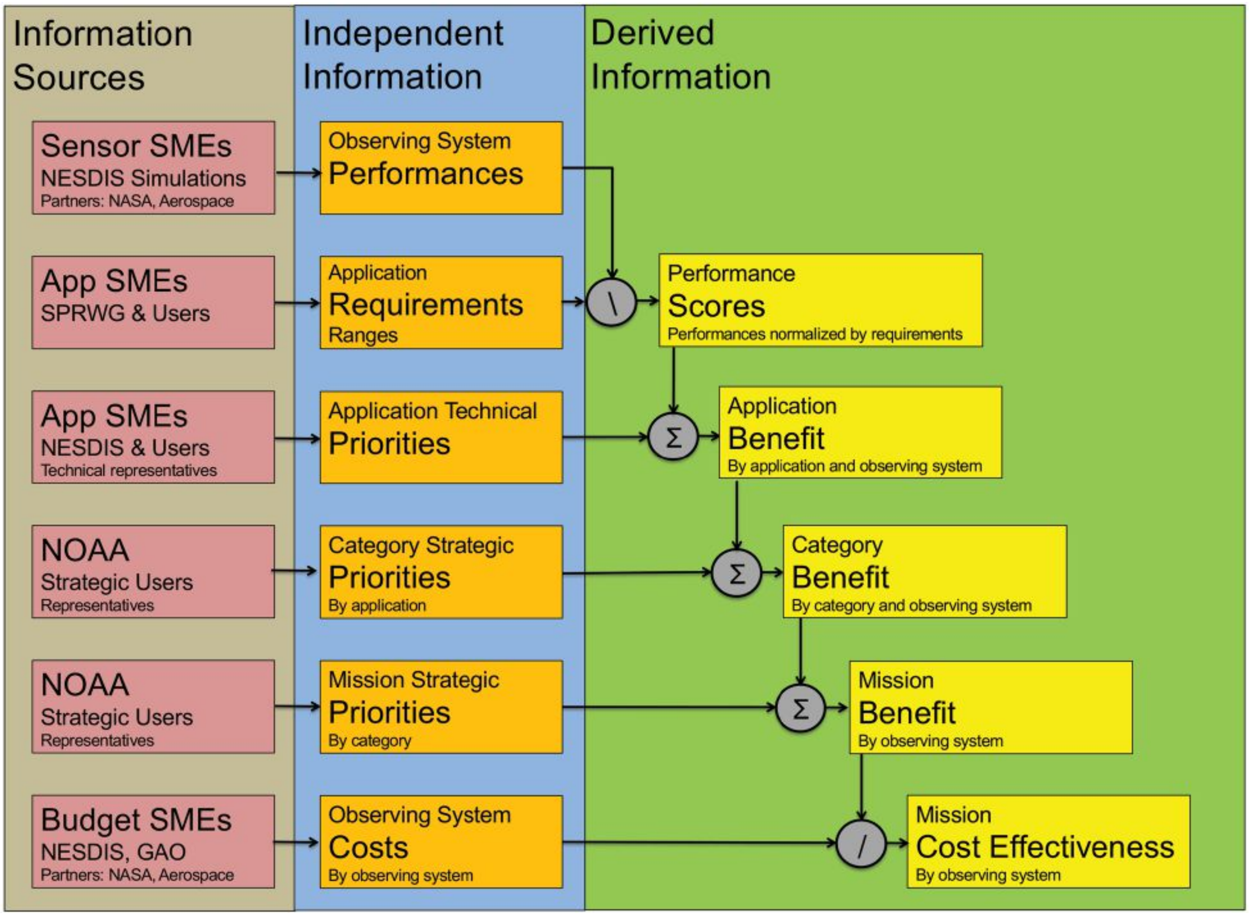
## Using ASPEN to Meet Diverse Evolving User Needs and Priorities

**Key messages from** "Optimizing Observing Systems Using ASPEN: An Analysis Tool to Assess the Benefit and Cost Effectiveness of Observations to Earth System Applications," by **Sid-Ahmed Boukabara** (NOAA/NESDIS) and **Ross N. Hoffman**. Published online in *BAMS*, October 2022. For the full, citable article, see **https://doi.org/10.1175/BAMS-D-22-0004.1**.

The Advanced Systems Performance Evaluation tool for NOAA (ASPEN) is designed to measure *the degree to which one or more observing systems are able to satisfy the needs of one or more environmental applications*. Its goal is to support the design and evaluation of existing and planned observing systems in terms of comparative assessment, cost effectiveness, tradeoffs analysis, and design optimization studies whether in planning the next generation space architectures or in negotiating international agreements to optimize international satellite sensor constellations. ASPEN is a dynamic tool that rapidly assesses the benefit and cost effectiveness of environmental data obtained from any set of observing systems, whether ground-based or space-based, and whether an individual sensor or a collection of sensors. ASPEN accounts for the level of ability to measure the environment, the cost(s) associated with acquiring these measurements, and the degree of usefulness of these measurements to users and applications. It computes both the use benefit, measured as a requirements-satisfaction metric, and the cost effectiveness (equal to the benefit-to-cost ratio).

In the past, the evolution of the Earth-observing satellite constellation (EOSC) was gradual and technology driven. Now there are additional driving factors that add significant complexity to planning and designing the next-generation EOSC. Besides the rapid advances in sensor technology in the recent past, these factors include 1) the expected revolution of medium to very small size satellites that will provide slightly degraded, similar, or even better performance, for a fraction of the cost of traditional platforms; 2) the large array of environmental applications, all vying for even more and better environmental data; 3) the multiplication of observing methods and technologies that have varying error characteristics and resolutions; 4) the emergence of the private sector as a viable source of environmental data; and 5) the increasing number of new space-faring nations with ambitious space programs that have significant potential to enhance the EOSC.

Given these trends, there is an increasing need to quantify the value and impact of observing systems. A number of techniques including the Observing System Simulation Experiment (OSSE) and Forecast Sensitivity to Observation Impact (FSOI) methods are well




**ASPEN provides rapid computations of relative benefits (hereafter benefits), based on the scoring (or normalization) and prioritization (or weighting) of observing systems' performance by the application requirement ranges and priorities, respectively. The observing systems performance and the application requirements ranges and priorities are all independent information (center column) in the form of input tables derived from information sources (left column), including expert elicitation and calculations conducted for maturity reviews of existing sensors, simulation studies, or sensitivity. This approach allows us to compare benefits across many possible observing systems, including, for example, multiple permutations of constellations of Earth-observing satellites. Given costs (or relative costs) of the observing systems that are compared, ASPEN also calculates cost effectiveness as the ratio of benefit to cost (illustrated only at the mission level in the figure). ASPEN calculates the derived information metrics (benefit and cost effectiveness, right column) over a wide range of granularity. Benefits at one level of granularity are combined (rolled-up) to the next (less granular) level by means of weighted averages. Figure acronyms: SMEs are subject matter experts. NESDIS is the National Environmental Satellite, Data, and Information Service. GAO is the Government Accountability Office.**

developed for assessing impacts on global NWP skill. But these are expensive and time-consuming. As an alternative, a number of projects collect and compare observing system capabilities and application requirements. These include the Space Platform Requirements Working Group (SPRWG), the Consolidated Observing User Requirements List (COURL), the WMO Observing Systems Capability Analysis and Review (OSCAR) database, the GeoXO Requirements Working Group (XORWG), and the NOAA Observing System Integrated Analysis (NOSIA). These types of studies can apply to a wide range of applications, can be done quickly, and can optimize the return-on-investment for new capabilities. However, these methods are somewhat subjective, user-dependent, and limited to the applications studied, and have not been transparent nor extensible. Furthermore, they are not easily generalizable.

ASPEN, on the other hand, has been designed to be an extensible, repeatable, and explainable system that could answer a wide range of questions. Some of these questions involving global observing systems include: What observations provide the best return on investment? What combination of observing systems is optimal? What is the best allocation of resources between ground-based and space-based observing systems? What is the cost effectiveness of commercial data? How well will today's observing systems satisfy the requirements of tomorrow's applications? Other questions that involve a finer level of granularity include: How should a particular observing system be designed to satisfy the requirements of multiple users and applications? How should an individual sensor be designed to maximize its cost effectiveness? How should a set of sensors be distributed on a number of orbital platforms to optimally satisfy the requirements?

Considering the above list of desired ASPEN use cases, our design of ASPEN was driven by three challenges. First, achieving a fair comparison between different observing systems solutions requires truly solution-agnostic metrics. Second, there is a need for a comprehensive and inclusive assessment using an Earth system approach and recognizing the many different applications and users supported by Earth observations. While global NWP is a critical application that indeed supports many other applications, it is not the whole story. Third, there is a need for granularity in an assessment approach so that impacts can be traced back to fine details in observing system design.

ASPEN introduces two novel concepts for capabilities/requirements assessments. First, ASPEN provides a uniform interface to compare the performance of different observing systems and to capture the requirements and priorities of applications. This interface describes the environment in terms of geophysical observables and their attributes. Second ASPEN requirements are matched to priorities. This is a way to capture and apply the knowledge that satisfying some requirements is more valuable than satisfying others.

ASPEN has several advantages. ASPEN is:

- Comprehensive. ASPEN can be applied to all Earth science applications and users and all Earth-observing systems.
- Efficient and interactive. ASPEN is implemented as an interactive, web-based tool.
- Flexible. ASPEN is dynamically adaptable—changing one or a few table entries is all that is required to perform "what if" scenarios.
- Transparent. ASPEN metrics are automatically linked to more granular metrics and ultimately to the ASPEN inputs, thereby providing traceability and interpretability.

ASPEN is a work in progress. There are many possible extensions and enhancements to it. A current focus of the ASPEN team is collecting and validating the observing system capabilities, application requirements, and application priorities. This is critical because ASPEN results are limited by the quality of its inputs. With further advances, we expect ASPEN will become an increasingly valuable addition to the observing systems assessment toolbox.

## METADATA

**BAMS:** What would you like readers to learn from this article?

***Ross Hoffman [NOAA/NESDIS/Center for Satellite Applications and Research (STAR), and University of Maryland]:*** *Earth-observing systems are expensive and have long lifetimes. Investment decisions in these systems are fraught but can be supported by ASPEN. This is the case because ASPEN collects and validates information from multiple sources and experts, yet provides traceability from the ASPEN-calculated benefits to the validated information.*

**BAMS:** How did you become interested in the topic of this article?

***RH:*** *Decades of experience on teams conducting observing system experiments (OSEs) and observing system simulation experiments (OSSEs) led us to conceptualize simpler, more generic, and more efficient approaches to estimating the benefits of observing systems for applications.*

**BAMS:** What surprised you the most about the work you document in this article?

***RH:*** *Initially we knew that the quality of ASPEN inputs would impact the quality of ASPEN results. I was surprised what a challenge it is to capture high-quality ASPEN inputs (that describe observing system capabilities and application requirements and priorities). I was also surprised how valuable these inputs themselves are.*

**BAMS:** What was the biggest challenge you encountered while doing this work?

***RH:*** *Avoiding overcomplicating the ASPEN method while at the same time capturing the full realistic complexity to satisfy all involved communities.*