An Earth System Approach for NOAA’s Next-Generation Observation System Architecture

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Introduction

There is a continuing and growing need to take a comprehensive view of how we assess the value and impact of observing systems. This is important in many areas, including prioritizing investments in the observing systems portfolio, ensuring cost-effectiveness, optimizing system performance, and planning next generation space architectures.

Having a standard description and definitions of the Earth system, including domains, variables, and attributes, is necessary for capturing observational needs in a solution-agnostic manner. This helps to provide a framework to facilitate fair comparisons of the information content of individual geophysical variables provided by observing systems or required by applications/users. It also allows for ranking existing and proposed observing systems in terms of their information content and benefit to national and international agency missions and their costs.

Earth System Domains and Subdomains

Environmental Domain	Atmosphere	Land/Hydrology	Cryosphere	Ocean	Space Weather
Environmental Subdomains	Atmospheric Composition	Fire	Glaciers, Ice Caps, Ice Sheets	Bathymetry/ Seafloor Topography	Solar
	Clouds	Inland Waters	Iceberg	Coastal	Heliosphere
	Neutral Atmosphere	Surface Geophysical Properties	Lake Ice and River Ice	Ocean Composition and Optical Properties	Magnetosphere
	Precipitation	Surface Radiative Properties	Permafrost	Open Ocean	Ionosphere
	TOA Earth Radiation	Vegetation	Sea Ice		Upper Atmosphere
			Snow		

Types of Attributes

Spatial	Temporal	Vertical	Angular and Spectral	Data Type	Data Quality	System
Resolving Power	Revisit Time	Vertical Extent	Angular Resolution	Classification Scheme	Accuracy	Continuity
Spatial Coverage	Sampling Rate	Vertical Resolution	Spectral Range	Images	Exclusion Fraction	Data Latency
Spatial Density	Temporal Coverage Fraction		Spectral Resolution		Measurement Resolution	Long Term Accuracy
Spatial Resolution	Time of Day				Precision	Long Term Precision
Spatial RMSE					Validity Range	Prior Data
						Robustness

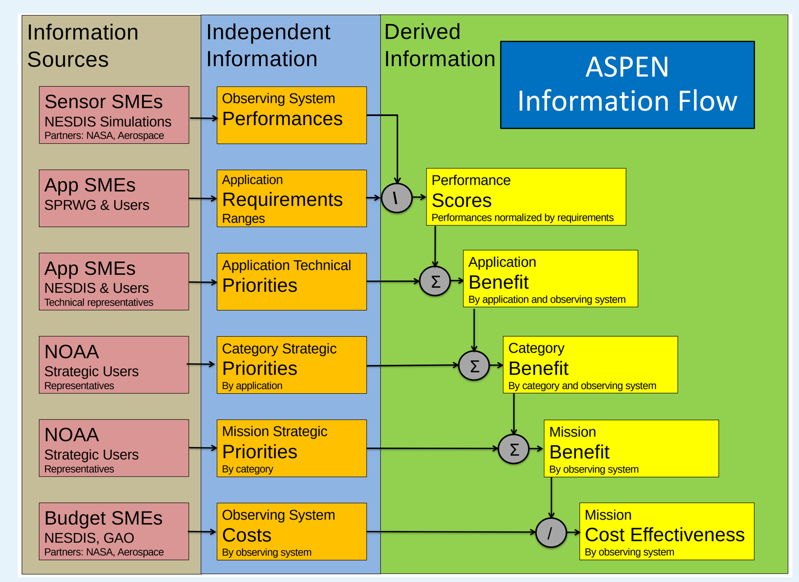
Use and Benefits

Providing a definition of the Earth system environment can have benefits and uses to many downstream uses including:

- To support NOAA’s move toward an Earth system approach for observations.
- To provide an infrastructure reference for observations, modeling, digital twins, and user needs for monitoring and prediction.
- To add the optimization of the next-generation observation system architecture to meet the needs of multiple applications that require different observations of the Earth system.
- To provide definitions for the Advanced Systems Performance Evaluation tool for NOAA (ASPEN), a dynamic and user-friendly tool that rapidly assesses the value of environmental data obtained from observing systems.

ASPEN Overview

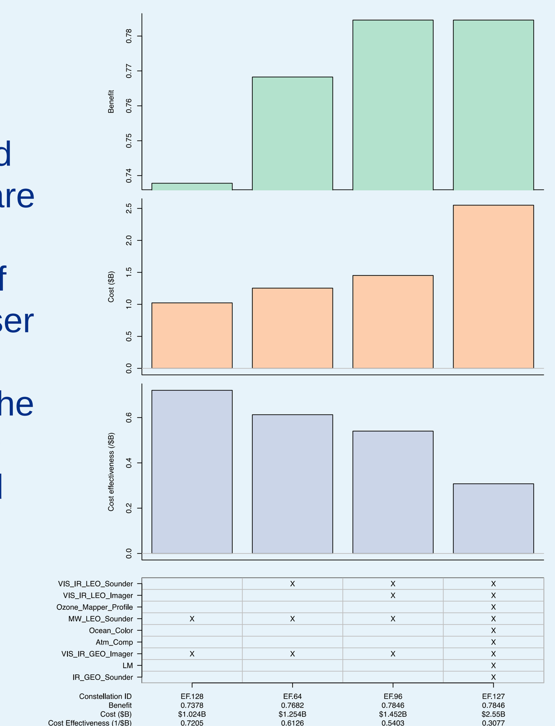
- ASPEN is a dynamic and user-friendly tool that can quickly answer a wide variety of questions about optimizing systems and satisfying requirements, thereby rapidly assessing the value of environmental data obtained from observing systems.
- It uses an interface based on Earth system variables and attributes to better describe the sensor capabilities and user needs.
- ASPEN is designed to support the decision process that leads to the design, selection and ultimately deployment of new space asset in a way that can be clearly communicated.



ASPEN Output

- Permutations of constellations of ASPEN sensors were compared against Global NWP.
  - **(1)** MW sounder on LEO + IR imager on GEO
  - **(2)** Same as (1) + VIS/IR Sounder on LEO
  - **(3)** Same as (2) + VIS/IR LEO Imager
  - **(4)** Same as (3) + LM+OC+AC+Ozone+GEO IR sounder
- True assessment of optimal LEO+GEO configuration would need to extend to many more applications, including Ocean, Atmosphere, Land/Hydrology, etc.
- Sensors adding the most additional benefit are IR_LEO_Sounder and VIS/IR_LEO_Imager because global coverage is so important to Global NWP.
- The LM, IR_GEO_Sounder, Atm_Comp, Ozone_Mapper_Profiler, and Ocean_Color sensors provide no significant benefit in this analysis (as expected since the reference here is Global NWP only).

ASPEN-based scores, which are based on satisfaction of Global NWP user needs. This analysis used the Earth system variables and attributes.



What about other databases?

It is important to note that the Earth system is defined in other databases. As part of this effort, we mapped the proposed Earth system variables to other similar databases. There is a wide variety of ways to define the variables as shown in the small sample below.

Geophysical Variable	GCMD ID (TPIO COURL)	NASA GCMD Variable	Link to NOAA Level Requirements	Product Baseline	CF Mapping	WMO OSCAR
Carbon Dioxide/CO2	CO2_Profile	Atmospheric Carbon Dioxide	Atmosphere/Atmospheric Composition and Air Quality	Trace Gases Product Suite	atmosphere_mass_content_of_carbon_dioxide	CO2
Green Vegetation Fraction	Veg_Fraction	Vegetation Fraction: Green	Land & Surface Hydrology/Vegetation	Green Vegetation Fraction	vegetation_area_fraction	Fraction of vegetated land
Sea Ice Age	Sea_Ice_Age	Sea Ice Age	Cryosphere/Lake & Sea Ice	Ice Age	age_of_sea_ice	NA
Ocean color: Chlorophyll-a Concentration	Chlorophyll	Chlorophyll Concentration: Aquatic	Oceans, Freshwater and Coasts/Biology and Biogeochemistry	Chlorophyll-a Concentration	mass_concentration_of_chlorophyll_a_in_sea_water	Ocean chlorophyll concentration
Auroral Imagery	Supra_thermal_Auroral_Ion	Aurorae	Space/Solar	NA	NA	Aurora

Future Uses

Having an understanding of the full Earth system and performing assessments with the ASPEN tool will help management and scientists answer questions about future architectures and their benefits to user applications. Potential future uses include:

- Determining the benefits of:
  - Addition of Smallsat constellations.
  - Quantity of Smallsats in each constellation.
  - Addition of new sensors, such as hyperspectral microwave or 3D winds.
  - Optimal LEO, GEO, or space weather constellations.
- Expanding observational needs for specific user applications.

References

Over 400 Earth system variables were compared to other existing databases, both for definition and naming convention. These included:

- Climate and Forecast (CF) Standard Name Table: https://cfconventions.org/Data/cf-standard-names/current/build/cf-standard-name-table.html
- NASA GCMD: https://gcmd.earthdata.nasa.gov/KeywordViewer/scheme/all?gtm_scheme=all
- WMO OSCAR: https://space.oscar.wmo.int/
- NESDIS Integrated Product List, May 2019 update
- NESDIS Product Baseline, September 2021: https://www.nesdis.noaa.gov/s3/2022-05/NESDIS-REQ-1002-1.pdf
- The Technology Planning and Integration for Observations (TPIO) value tree
- NOAA Level Requirements