# Optimizing Earth Observing Constellations of Satellite Sensors Using ASPEN: A Proof-of-Concept Study for Global NWP and Nowcasting Applications


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## Introduction

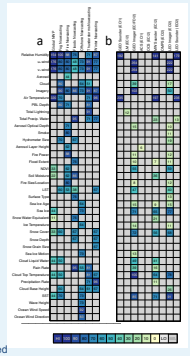
In this proof-of-concept study, ASPEN calculates the efficient frontier (EF) in the space of constellation cost vs. benefit

– ASPEN = Advanced Systems Performance Evaluation tool for NOAA

- ASPEN is used to calculate the cost and benefits of all possible combinations within two design ensembles of sensors
- The benefit vs. cost plot visualizes an efficient frontier (EF) of the optimal constellations-the constellations that maximize benefit for a given cost
- The optimal constellation depends strongly on the budget, the applications considered, and the design ensemble
- Thus, the optimal constellations for Global NWP are different from those for nowcasting

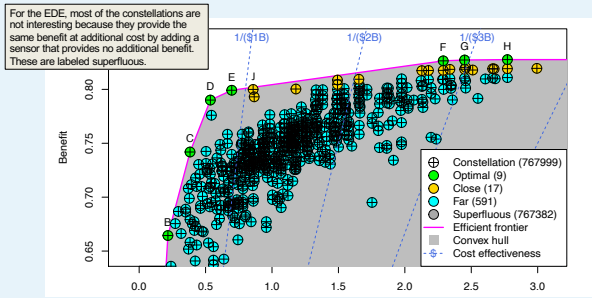
## Applications

- For Global NWP, the Systems performance Assessment Team (SAT) study was led by Dr. Rick Anthes and included representatives from NOAA, NASA, DoD, and academia
- For the nowcasting applications, the SAT study was led by Dr. Jordan Gerth who conducted surveys of the front-line operational forecasting staff
- We converted the results of these studies to the needed ASPEN requirements and (technical) priority tables
- ASPEN weights benefits of different applications by strategic priorities. In this study the nowcasting applications were weighted equally
- The figure shows the application priorities and sensor capabilities, i.e., which variables are required by which applications and which variables are observed by which sensors



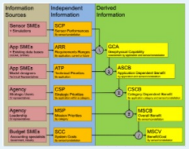

– (a) plots for each variable, for each application, the total priority (% x 10); (b) plots for each variable, for each EC sensor, the total ASPEN benefit (scaled so that a value of 0.035 is plotted as 100).

## EF, Global NWP, Enhanced Design Ensemble




## ASPEN Approach

- ASPEN compares obs systems capabilities to applications requirements ranges and their priorities, and associates a score to these obs systems: based on their degree of users/application satisfaction metric (in %)
- ASPEN also accounts for the associated costs of obs systems & computes their benefit/cost ratios
- ASPEN was developed following the NSOSA methodology, expanded to be able to assess all solutions, and to account for all applications and uses
- A major criterion for ASPEN's trustworthiness is the trustworthiness of its inputs: (1) observing systems detailed capabilities and costs, and (2) users' observational requirements ranges, priorities
- ASPEN assumes that satisfying users needs close to the maximum level, will lead to maximizing systems skills and performances.
- Similarly, satisfying users needs at the minimum level will lead to minimum levels of performance and skills of those systems



## Sensor design ensembles

**Each design ensemble lists all possible constellations under consideration**

- The simple design ensemble (SDE) has all the EC sensors and each is in a predetermined orbital configuration
  - In the SDE every constellation includes the MW LEO Sounder and VIS IR GEO Imager sensors.
  - All LEO sensors if present are in a 2-orbit configuration
  - The GEO sensors orbital configuration follows GeoXO plans
    - + The VIS IR GEO Imager, the LM, and the OCS if present are on GOES East and West
    - + The IR GEO Sounder and ACS if present are on the Central platform
  - The SDE has 128 members
- The enhanced design ensemble (EDE) allows choices from all classes of sensors and several LEO orbital configurations
  - The LEO sensors if present may be in a 1-, 2-, or 4-orbit configuration
  - The GEO sensors orbital configuration follows GeoXO plans as in the SDE
  - In each constellation a single class and single orbital configuration may be included
  - The EDE has approximately 3/4 of a million members.

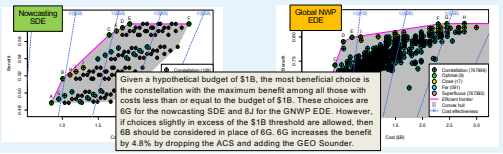
## With a hypothetical budget of $1B

Which constellation maximizes the benefit

| DE | | ⊕ | ID | Benefit | Cost | Cost Effectiveness | Distance to EF | GEO Sounder | LM | GEO Imager | ACS | OCS | MW Sounder | OMPS | LEO Imager | LEO Sounder |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SDE | Nowc. | 4A | EF.128 | 0.710 | 0.850 | 0.835 | 0.0000 | | | EC/2 | | | EC/2 | | | |
| | | 4B | EF.1 | 0.744 | 1.007 | 0.738 | 0.0000 | EC/1 | | EC/2 | | | EC/2 | | | |
| | | 6A | EF.128 | 0.488 | 0.850 | 0.575 | 0.0000 | | | EC/2 | | | EC/2 | | | |
| | | 6G | CF.4 | 0.493 | 0.951 | 0.518 | 0.0134 | | | EC/2 | EC/1 | | EC/2 | | | |
| | | 6B | EF.1 | 0.517 | 1.007 | 0.513 | 0.0000 | EC/1 | | EC/2 | | | EC/2 | | | |
| | | 6H | CN.5 | 0.521 | 1.108 | 0.470 | 0.0036 | EC/1 | | EC/2 | EC/1 | | EC/2 | | | |
| EDE | NWP | 8E | EF.32088 | 0.799 | 0.697 | 1.147 | 0.0000 | | | TC/2 | | | MC/1 | | TC/1 | |
| | | 8J | CN.39768 | 0.800 | 0.858 | 0.932 | 0.0020 | | | TC/2 | | | MC/1 | | TC/1 | |
| | Nowc. | 9G | EF.9050 | 0.572 | 0.937 | 0.611 | 0.0000 | EC/1 | | TC/2 | | | MC/1 | | EC/1 | |
| | | 9T | CN.9058 | 0.577 | 1.038 | 0.556 | 0.0001 | TC/1 | | TC/2 | EC/1 | | MC/1 | | EC/1 | |

Nowcasting SDE

Global NWP EDE

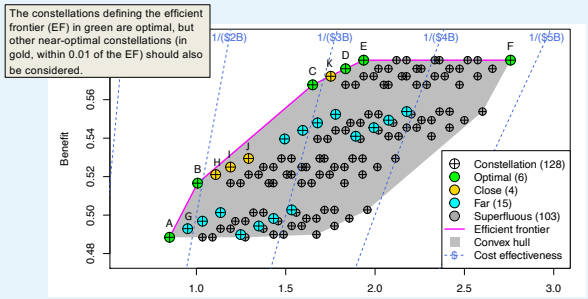



## Sensors and costs

- For each of 9 types of sensors there are up to 3 versions—from three sensor classes: the threshold class (TC), the expected class (EC) and the maximal class (MC)
- Costs for EC sensors with legacy equivalents in the JPSS and GOES-R program are those total program's costs allocated to each sensor based proportionally to each sensor's build costs. Costs for other sensors are based on simple scaling arguments
- The constellation cost model simply sums the annualized per sensor allocation of the total system costs. By construction, this method reproduces the JPSS and GOES-R program costs for identical EC constellations

| Sensor Type | Legacy | TC (M) | EC (M) | MC (M) |
|---|---|---|---|---|
| IR **GEO Sounder** | GEO-CrIS | 79 | 157 | 314 |
| Lightning Mapper (**LM**) | GLM | | 92 | 184 |
| VIS IR **GEO Imager** | ABI | 157 | 314 | 628 |
| Atmospheric Composition Sensor (**ACS**) | ACX | | 101 | |
| Ocean Color Sensor (**OCS**) | OCX | | 92 | |
| **MW LEO Sounder** | ATMS | 56 | 111 | 222 |
| Ozone Mapper Profile Sensor (**OMPS**) | OMPS | | 120 | |
| VIS IR **LEO Imager** | VIIRS | 161 | 322 | 644 |
| VIS IR **LEO Sounder** | CrIS | 100 | 199 | 398 |

## EF, Nowcasting, Simple Design Ensemble




## Last Thoughts

### Limitations and caveats

- We only considered the Global NWP and nowcasting applications and only some of the NOAA GEO and LEO sensors
- We used the curretn version of ASPEN and the current ASPEN data bases
- ASPEN reliability depends on trustworthiness of its inputs (performances and costs of the observing systems, and requirements ranges and priorities of the applications)

### ASPEN evolution

- Earth observing systems are expensive and have long lifetimes
- Investment decisions in these systems can be supported by ASPEN
- ASPEN is a work in progress, and we welcome community collaboration and coordination
- With further advances we expect ASPEN will become an increasingly valuable addition to the observing systems assessment toolbox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*Journal article: ASPEN is described in our October 2022 BAMS paper @ doi:10.1175/bams-d-22-0004.1*




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