UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL ENVIRONMENTAL SATELLITE, DATA AND INFORMATION SERVICE

May 1, 2024

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**SUBJECT: Assessment of Solution-Agnostic Observational Needs for Nowcasting Applications of Fire Monitoring**


**Executive Summary:**

The NESDIS next-generation space architecture planning and development process requires a thorough understanding of the observational needs (current and expected in the future) by the major users and their applications, in order to better design data acquisition projects and programs of the future. These user needs have to be captured at a high level of granularity to provide useful information for the design of the next generation architecture (in terms of design of sensors, antennas, and constellations' orbits, swaths, etc). For example, knowing the relative importance of the spatial resolution and precision of a variable needed by the users will help in the relative importance of designing a sensor with the optimum combination of antenna size, number of channels, and associated noise levels. One of the major applications using satellite data is nowcasting applications of fire monitoring, which is the focus of this memo.

- ***Fact:*** Accurate forecasts and up-to-date weather information are critical to fire fighting agencies. Forecasters use a variety of sources, including those from satellites, to aid in the safety of fire management teams and to monitor rapid changes in individual fires.
- ***Fact:*** In order to design the highest value cost-effective constellation of space satellites and sensors, it is important to capture the observational needs in a solution-agnostic fashion, balancing the ranges of the required observations and their relative priorities.
- ***Fact:*** Users of satellite fire observations include NOAA/NESDIS hazard mapping system, NOAA's air quality product suite, NWS fire weather program, USDA Forest Service, and international users.
- ***Fact:*** While satellite data is important for nowcasting applications, it is not the only observing source used.
- ***Findings:*** The tables presented in this memo summarize the nowcasting for fire monitoring observational needs, as found through multiple deliberations with nowcasting experts, several prior established expert groups, and Line Offices, and consolidated and adjudicated through the Government-only Core-SAT.
- ***Recommendation:*** We recommend that NOAA use these solution-agnostic nowcasting fire monitoring observational needs (outlined in the tables below) as an input to the establishment of the NOAA observational requirements for nowcasting. These include variables, attributes' ranges of these variables, as well as associated prioritizations. These should also be considered as part of the planning and development of next-generation requirements, space architecture, and products development.


## Background:

NESDIS has to regularly assess the user mission ***needs*** for environmental observations. This is important in order to (1) remain in tune with the evolution of these needs and to (2) better plan for the next-generation architecture, and in particular, the space-based architecture. To achieve this goal, these needs have to be collected from a broad community, in a solution-agnostic fashion, in order to provide a reference for multiple observing systems solutions that will be able (1) to meet these needs now and in the future, (2) to look at innovative ways to meet all needs cost-effectively, and (3) to potentially fill existing gaps or reducing them. It is important to note that these needs are expressed from a relatively wide community of observations' users, but it is important to highlight they do not constitute ***requirements*** for NOAA. An internal NOAA process exists to define observational requirements.

Nowcasting is forecasting for the following six hours. The Nowcasting subcommittee focused on six application areas where satellites would play a major role as an observational source. Surveys were sent to NWS forecasters and the results of those surveys were used to come up with the initial observation ranges. In order to perform the assessment of observational needs for nowcasting, a series of SAT meetings took place over the spring and summer of 2022. These purposefully included representatives from academia, private sector and NASA, all members of the SAT, and in NOAA, from line offices, and the SAE Analysis Team (TPIO) in charge of stewarding and updating the *COURL*, as well as representatives from the major programs, who ultimately will be charged with developing the components of the space architecture (both LEO and GEO).

The first of the nowcasting meetings aimed at identifying the observational needs for fire monitoring for wildfires and urban fires. It is important to be able to accurately monitor and forecast fires so that the fire management teams can make the best decisions about fire containment, develop fire control strategies, and manage activities aimed at protecting life and property. An SAT subgroup was established to determine these observational needs. The team was led by Jordan Gerth and made up of subject matter experts in nowcasting for fire monitoring, with representatives from NOAA/NWS. The overall goals of the group included determining which variables and what attributes of those variables are expected to be most important for nowcasting for fire monitoring in the 2030 timeframe. For example, NOAA needs to understand what are the realistic performance ranges of these needs and what are their associated NOAA priorities. The group also reviewed many previous impact and requirements studies to aid their development of the needs list.

It is the purpose of this memo, drafted and reviewed by the Government-only Core-SAT team, to document and establish the needs of nowcasting applications by assessing the users' needs for fire monitoring products from many sources.

***Note:*** It is important to note that the information captured is in geophysical space which is consistent with the international standard established by the WMO (e.g., the OSCAR database). This means that what is captured here is the information content needed for the observations. It does not mean that the user systems will assimilate those products. This exercise captured user needs in a solution-agnostic fashion.

## <u>Importance of this Application (Fire Monitoring):</u>

This application serves the following communities: forestry management, wildfire management, incident command centers, emergency personnel, public safety officials, etc. It produces the following important outputs used by a number of users including real-time fire weather forecasts to support tactical firefighting decisions. The table 1 below summarizes the importance of the individual measurements that this application needs, along with the reason why these are important.

## <u>Sources of Fire Monitoring observational Needs:</u>

The Core-SAT team, composed of federal employees from NOAA (including representatives from the NWS, NOAA SAE Analysis Team, and the NOAA LEO and GEO Programs) reviewed the nowcasting for fire monitoring observational needs by assessing the users' needs as developed by this SAT subgroup mentioned previously, but also with the findings from the following sources:

- "Guidelines for Nowcasting Techniques." World Meteorological Organization, 2017 edition. https://library.wmo.int/doc_num.php?explnum_id=3795.
- Nowcasting needs identified by the Space Platform Requirements Working Group (SPRWG)
- Nowcasting needs identified by the GeoXO Requirements Working Group (XORWG)
- User engagement events by the LEO program
- Incorporating work done by SAE Analysis Team
- Community of Practice, product baseline, and user value chain coordination through the User Engagement Council

All these needs were incorporated into a single document, using a prioritized, vetted list of variables with an agreed upon format (e.g., choice of units, etc.). This will allow for a better understanding of the overall nowcasting needs, a streamlining of the process to collect observational needs, and minimizing the outreach to users. The requirements ranges, and their associated priorities, will also serve as an input to the ASPEN tool, which is used to assess potential future architecture solutions and their abilities to meet users needs.

**Observational Needs and Associated Priorities for Nowcasting Fire Monitoring:**

The following tables represent the main findings, as summarized by the Core-SAT team, based on all the inputs mentioned above, including the sub-committee findings.

**Table 1.** Describes the list of variables needed for the fire monitoring application, why they are important for the application, and whether they are already identified as an existing variable in the TPIO databases.

**Table 2.** Identifies geophysical variable priorities for the nowcasting fire monitoring application as reviewed by the Core-SAT using the inputs from the nowcasting survey of NWS meteorologists as an input, as well as considering other sources (TPIO, NASA-NOAA, XORWG, etc.), and harmonized by SAE Team Analysis.

**Table 3.** Shows the variable performance ranges for the nowcasting fire monitoring application, as determined by the Core-SAT. These data are based on the input from the nowcasting survey of NWS meteorologists as well as input from the SAE Analysis Team, and other considerations/sources, as mentioned above. Data ranges, shown as triplets, are defined as "minimally useful.", "expected [in the 2030 time frame]," and "maximum effective,"values. Current geophysical variable performance ranges are listed as well.

**Table 4.** Includes nowcasting fire monitoring application attribute priorities, per variable, including horizontal and vertical resolution, temporal resolution, error standard deviation, and data latency. This table was provided by the SAE Analysis Team based on differential attribute change per unit time in the vertical and horizontal dimensions. Current attribute weights per geophysical variable are listed.

**Conclusions:**.

The observational needs for the fire monitoring application have been collected in the past by different groups in NESDIS, in various ways, using different definitions, different variables, different units, etc. This was partly because it was done through different mechanisms over the last few years, including through SAE Analysis Team interactions with direct NOAA users, etc. This latest round of observational needs collection was designed to consolidate the set of needs, defined in a way that helps the design and evaluation of the next-generation space architecture, but also to serve as a reference for all those interested in these needs in the near future. This was done as part of the Systems performance Assessment Team (SAT), and, in particular, the government-only Core-SAT. As stated previously, the collection of user needs was developed and reviewed by a variety of different sources that included representatives from the SAE Analysis Team, SAE/TPIO, the LEO and GEO programs, and representatives from the NOAA LOs, NASA, DoD, and academia, but the final determination of the list of user needs and attributes was conducted by the Core-SAT. This exercise of collecting observational needs should be refreshed regularly, to maintain an up to date awareness of the observational needs.

CC:
*Core-SAT Members relevant to this memo:*

*SAT sub-committee on Nowcasting for fire monitoring: J. Gerth, M. Sporer, T. Humphrey, J. Rabinowitz, J. Michael, S. Stearns, D. Zaff, C. Jones, S. Bunin*

**<u>Table 1. Fire Monitoring Variable Needs:</u>** List of the variables needed by the fire monitoring application, the importance of these variables, and a notation about the variable status in the TPIO databases.

| Geophysical Variable | Variable Importance | TPIO Database (Existing/ New) |
|---|---|---|
| Relative Humidity | Impacts fire behavior by increasing or decreasing fuel moisture, which can affect flame length, rate of spread, energy released, and amount of smoke produced | E |
| Cloud and Moisture Imagery | High resolution datasets are used in visualization systems to monitor hazards | E |
| Aerosol Concentration | Helps to determine the amount of smoke in the vicinity of the fire | N |
| Water Vapor: Boundary Layer Depth | Knowledge of atmospheric moisture helps understanding of the dryness of the air for fueling the fire | N |
| Aerosol Optical Depth/Thickness | Helps to show the amount of direct sunlight prevented from reaching the ground due to aerosol particles, including smoke | E |
| Smoke | Helps to show the extent and potential movement of the fire | E |
| Aerosol Layer Height | Regulates the transport of aerosol particles, it can be useful for air quality forecasting related to wildfires | N |
| Fire Radiative Power | The rate of emitted radiative energy by the fire shows the strength of the fire. | N |
| NDVI | The amount of greenness in vegetation can be an indicator of fire spread | E |
| Soil Moisture: Surface Wetness | The amount of moisture in the soil can be an indicator of fire spread | E |
| Fire Size | Provides an understanding of the size of the fire | N |
| Land Surface Temperature | Can be used to monitor the temperature of active fires | E |
| Wind Speed: Planetary Boundary Layer | Can be an indicator of the movement of fire | E |
| Wind Direction: Planetary Boundary Layer | Can be an indicator of the direction of fire movement | E |
| Smoke Injection Height | Can impact smoke dispersion and environmental impact | N |

**Table 2. Geophysical Variable Priorities for Nowcasting Fire Monitoring:** List of the geophysical information and their prioritization (based on a scale from 0: non-important to 1: critically important), needed for current fire monitoring nowcasting as determined by the Systems performance Assessment team (SAT). This list was consolidated using a multitude of sources and follows the variables definition and units used in the ASPEN tool.

| Geophysical Variable | Symbol / Abbreviation | Units | Priority |
|---|---|---|---|
| Relative Humidity | RH | % | 1.0 |
| Cloud and Moisture Imagery | CMI | unitless | 0.9 |
| Aerosol Concentration | n_A | /m3 | 0.5 |
| Water Vapor: Boundary Layer Depth | WV_BLD | km | 0.8 |
| Aerosol Optical Depth/Thickness | AOT | unitless | 0.8 |
| Smoke | Smoke_night | unitless | 0.9 |
| Aerosol Layer Height | ALH | km | 0.7 |
| Fire Radiative Power | FRP | MW/km2 | 1.0 |
| NDVI | NDVI | unitless | 0.7 |
| Soil Moisture: Surface Wetness | W | m3/m3 | 0.7 |
| Fire Size | fire_size | km | 0.9 |
| Land Surface Temperature | LST | K | 0.6 |
| Wind Speed: Planetary Boundary Layer | u | m/s | 0.9 |
| Wind Direction: Planetary Boundary Layer | v | deg | 0.9 |
| Smoke Injection Height | SIH | km | 0.8 |

*** Current Geophysical Variable Need**

**<u>Table 3. Nowcasting Fire Monitoring Observational Need Attribute Range:</u>** List of observational needs of the current nowcasting systems for fire monitoring in NOAA. These needs are expressed in terms of ranges between minimally useful, expected level and maximum usefulness level. These attributes include the spatial coverage, the horizontal resolution, the temporal refresh, the uncertainty (in standard deviation) and the latency and when appropriate the vertical resolution, for all the variables listed in table 1.

| Geophysical Variable | Units (Accuracy) | Images | Geographic Coverage (dimensionless) | Horizontal Resolution (km) | Horizontal Density (100 km-2) | Temporal Refresh (h) | Vertical Resolution (km) | Error Standard Deviation | Data Latency (h) |
|---|---|---|---|---|---|---|---|---|---|
| Relative Humidity | % | TRUE | CONUS+AK+HI+US Territories | [5, 2, 1] | [4, 25, 100] | [1 h, 5 m, 1 m] | [1, 0.5, 0.1] | [10, 5, 2] | [15 m, 1 m, 0.5 m] |
| Cloud and Moisture Imagery | unitless | TRUE | CONUS+AK+HI+US Territories | [2, 0.5, 0.25] | [25, 400, 1600] | [15 m, 2 m, 0.5 m] | NA | NA | [2 m, 1 m, 0.5 m] |
| Aerosol Concentration | /m3 | TRUE | CONUS+AK+HI+US Territories | [5, 1, 0.25] | [4, 100, 1600] | [1 h, 5 m, 1 m] | [1, 0.5, 0.1] | [25, 10, 5] | [15 m, 1 m, 0.5 m] |
| Water Vapor: Boundary Layer Depth | km | TRUE | CONUS+AK+HI+US Territories | [5, 1, 0.25] | [4, 100, 1600] | [1 h, 5 m, 1 m] | NA | [0.5, 0.25, 0.1] | [15 m, 1 m, 0.5 m] |
| Aerosol Optical Depth/Thickness | unitless | TRUE | CONUS+AK+HI+US Territories | [5, 1, 0.25] | [4, 100, 1600] | [1 h, 5 m, 1 m] | NA | [0.2, 0.1, 0.05] | [15 m, 1 m, 0.5 m] |
| Smoke | unitless | TRUE | CONUS+AK+HI+US Territories | [2, 0.5, 0.25] | [25, 400, 1600] | [1 h, 5 m, 1 m] | NA | [0.2,0.1,0.05]* | [15 m, 1 m, 0.5 m] |
| Aerosol Layer Height | km | TRUE | CONUS+AK+HI+US Territories | [5, 1, 0.25] | [4, 100, 1600] | [1 h, 5 m, 1 m] | NA | [0.5, 0.25, 0.1] | [15 m, 1 m, 0.5 m] |
| Fire Radiative Power | MW/km2 | TRUE | CONUS+AK+HI+US Territories | [2, 0.5, 0.25] | [25, 400, 1600] | [15 m, 2 m, 0.5 m] | NA | [2, 1, 0.5] | [2 m, 1 m, 0.5 m] |
| NDVI | unitless | TRUE | CONUS+AK+HI+US Territories | [10, 2, 0.5] | [1, 25, 400] | [6 h, 1 h, 15 m] | NA | [0.2, 0.1, 0.05] | [3 h, 15 m, 2 m] |
| Soil Moisture: Surface Wetness | m3/m3 | TRUE | CONUS+AK+HI+US Territories | [5, 1, 0.25] | [4, 100, 1600] | [6 h, 1 h, 15 m] | NA | [0.2, 0.1, 0.05] | [3 h, 15 m, 2 m] |
| Fire Size | km | TRUE | CONUS+AK+HI+US Territories | [2, 0.5, 0.25] | [25, 400, 1600] | [15 m, 2 m, 0.5 m] | NA | [25, 10, 5] | [2 m, 1 m, 0.5 m] |
| Land Surface Temperature | K | TRUE | CONUS+AK+HI+US Territories | [5, 1, 0.25] | [4, 100, 1600] | [6 h, 1 h, 15 m] | NA | [5, 2, 1] | [3 h, 15 m, 2 m] |

| Geophysical Variable | Units (Accuracy) | Images | Geographic Coverage (dimensionless) | Horizontal Resolution (km) | Horizontal Density (100 km-2) | Temporal Refresh (h) | Vertical Resolution (km) | Error Standard Deviation | Data Latency (h) |
|---|---|---|---|---|---|---|---|---|---|
| Wind Speed: Planetary Boundary Layer | m/s | TRUE | CONUS+AK+HI+US Territories | [2, 0.5, 0.25] | [25, 400, 1600] | [1 h, 5 m, 1 m] | NA | [5, 2, 1] | [15 m, 1 m, 0.5 m] |
| Wind Direction: Planetary Boundary Layer | deg | TRUE | CONUS+AK+HI+US Territories | [2, 0.5, 0.25] | [25, 400, 1600] | [1 h, 5 m, 1 m] | NA | [25, 10, 5] | [15 m, 1 m, 0.5 m] |
| Smoke Injection Height | km | TRUE | CONUS+AK+HI+US Territories | [5, 1, 0.25] | [4, 100, 1600] | [1 h, 5 m, 1 m] | NA | [0.5, 0.25, 0.1] | [15 m, 1 m, 0.5 m] |

*Error metric for category variables is probability of misclassification.

**Table 4. Nowcasting Fire Monitoring Observational Need Attribute Priority**: List of the nowcasting fire monitoring needed variables as prioritized in table 1. This table contains the relative importance of the attributes or each of the variables. This is important for allowing the engineers and designers of sensors and constellations, to assess where emphasis should be put when performing trade studies. The way to read this table: for each row (variable), the weights between 0 (no importance) and 1 (highest importance) is assigned to the individual attributes such as temporal refresh, horizontal resolution, uncertainty standard deviation), etc.

| Geophysical Variable | Images | Geographic Coverage | Horizontal Resolution | Horizontal Density | Temporal Refresh | Vertical Resolution | Error Standard Deviation | Data Latency |
|---|---|---|---|---|---|---|---|---|
| Relative Humidity | 0.5 | 0.8 | 0.7 | 0.7 | 0.9 | 0.9 | 0.5 | 1.0 |
| Cloud and Moisture Imagery | 1.0 | 0.8 | 1.0 | 1.0 | 1.0 | NA | 0.5 | 1.0 |
| Aerosol Concentration | 0.5 | 0.8 | 0.9 | 0.9 | 0.9 | 0.9 | 0.5 | 1.0 |
| Water Vapor: Boundary Layer Depth | 1.0 | 0.8 | 0.9 | 0.9 | 0.9 | NA | 0.5 | 1.0 |
| Aerosol Optical Depth/Thickness | 1.0 | 0.8 | 0.9 | 0.9 | 0.9 | NA | 0.5 | 1.0 |
| Smoke | 1.0 | 0.8 | 1.0 | 1.0 | 0.9 | NA | 0.5 | 1.0 |
| Aerosol Layer Height | 1.0 | 0.8 | 0.9 | 0.9 | 0.9 | NA | 0.5 | 1.0 |
| Fire Radiative Power | 1.0 | 0.8 | 1.0 | 1.0 | 1.0 | NA | 0.5 | 1.0 |

| Geophysical Variable | Images | Geographic Coverage | Horizontal Resolution | Horizontal Density | Temporal Refresh | Vertical Resolution | Error Standard Deviation | Data Latency |
|---|---|---|---|---|---|---|---|---|
| NDVI | 1.0 | 0.8 | 0.7 | 0.7 | 0.7 | NA | 0.5 | 1.0 |
| Soil Moisture: Surface Wetness | 1.0 | 0.8 | 0.9 | 0.9 | 0.7 | NA | 0.5 | 1.0 |
| Fire Size | 1.0 | 0.8 | 1.0 | 1.0 | 1.0 | NA | 0.5 | 1.0 |
| Land Surface Temperature | 1.0 | 0.8 | 0.9 | 0.9 | 0.7 | NA | 0.5 | 1.0 |
| Wind Speed/Direction: Planetary Boundary Layer | 1.0 | 0.8 | 1.0 | 1.0 | 0.9 | NA | 0.5 | 1.0 |
| Smoke Injection Height | 1.0 | 0.8 | 0.9 | 0.9 | 0.9 | NA | 0.5 | 1.0 |

*** Current Geophysical Variable Need**