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

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SUBJECT: Assessment of Solution-Agnostic Observational Needs for Nowcasting Applications of Dense Fog and Ceiling Monitoring and Forecasting

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 dense fog and ceiling monitoring and forecasting, which is the focus of this memo.

- ***Fact:*** Nowcasting for dense fog and ceiling in the 0-6 hour range is important for safe air and ground transportation.
- ***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:*** Multispectral satellite imagery is useful in the detection of low cloud and fog.
- ***Fact:*** Fog observations are used by NWS forecasters and aviation forecasters
- ***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 dense fog and ceiling 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 dense fog 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 dense fog and ceiling and the impacts to aviation. It is important to be able to accurately forecast dense fog and ceiling since low visibilities make safe air and ground travel difficult. 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 dense fog and ceiling nowcasting, 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 of dense fog and ceiling 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 dense fog and ceiling 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.

Importance of this Application (Dense Fog and Ceiling Monitoring and Forecasting):

This application serves the following communities: aviation and ground transportation. It produces the following important outputs used by a number of users including dense fog forecasts that can make travel conditions difficult. The table 1 below summarizes the importance of the individual measurements that this application needs, along with the reason why these are important.

Sources of Dense Fog and Ceiling observational Needs:

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 dense fog and ceiling 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 Dense Fog and Ceiling:

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 dense fog and ceiling forecasting 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 dense fog and ceiling 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 dense fog and ceiling 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 dense fog and ceiling 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 dense fog and ceiling monitoring and forecasting 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 dense fog and ceiling: J. Gerth, M. Sporer, J. Zvolensky, T. Humphrey, J. Rabinowitz, J. Michael, A. Edwards, D. Zaff, S. Bunin

Table 1. Dense Fog and Ceiling Monitoring and Forecasting Variable Needs: List of the variables needed by the dense fog monitoring and forecasting 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	Can help determine where fog will form, especially when used in conjunction with air temperature	E
Cloud Cover	Can be an indicator of low level dense fog and can help determine the likelihood of fog forming	E
Cloud and Moisture Imagery	High resolution datasets are used in visualization systems to monitor hazards	E
Air Temperature: Profiles	Can help determine where fog will form, especially when used in conjunction with relative humidity	E
Water Vapor: Boundary Layer Depth	The amount of moisture at the boundary layer can help determine fog formation and extent	N
Specific Humidity	Can help determine where fog will form, especially when used in conjunction with air temperature	N
Hydrometeor Size	Reduction in visibility depends on the structure of the fog, and especially on the density and size distribution of the droplets	N
Land Surface Temperature	Can help determine where fog will form, especially when used in conjunction with relative humidity	E
Snow Cover	Moist air over snow cover can be an indicator of the formation of fog	E
Cloud Liquid Water Path	The amount of liquid water in the atmosphere can be an indicator of fog formation	N
Cloud Top Temperature	Important for fog formation, particularly with low lying clouds	E
Cloud Base Height	Helps with understanding of fog extent with low lying clouds	E
Sea Surface Temperature	Warm moist air over cooler water can help with fog formation over water	E
Wind Speed Profile: Eastward, Planetary Boundary Layer	Higher wind speeds can mix the air and reduce the density of fog	E
Wind Speed Profile: Northward, Planetary Boundary Layer	Higher wind speeds can mix the air and reduce the density of fog	E

<u>Table 2. Geophysical Variable Priorities for Nowcasting Dense Fog and Ceiling:</u> List of the geophysical information and their prioritization (based on a scale from 0: non-important to 1: critically important), needed for current dense fog and ceiling 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 Cover	CC	Fraction	0.8
Cloud and Moisture Imagery	CMI	NA	0.9
Air Temperature: Profiles	T(z)	K	0.7
Water Vapor: Boundary Layer Depth	WV_BLD	km	0.8
Specific Humidity	q	g/kg	0.8
Hydrometeor Size	HST_LCF	%	0.7
Land Surface Temperature	LST	K	0.6
Snow Cover	SC	%	0.6
Cloud Liquid Water Path	LWC	g/m2	0.5
Cloud Top Temperature	CTT	K	0.5
Cloud Base Height	CBH	km	0.6
Sea Surface Temperature	SST	K	0.7
Wind Speed Profile: Eastward, Planetary Boundary Layer	u, PBL	m/s	0.8
Wind Speed Profile: Northward, Planetary Boundary Layer	v, PBL	m/s	0.8

*** Current Geophysical Variable Need**

Table 3. Nowcasting Dense Fog and Ceiling Observational Need Attribute Range: List of observational needs of the current nowcasting systems for dense fog and ceiling 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	[2, 0.5, 0.25]	[25, 400, 1600]	[1 h, 5 m, 1 m]	[1, 0.5, 0.1]	[10, 5, 2]	[15 m, 1 m, 0.5 m]
Cloud Cover	fraction	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]
Cloud and Moisture Imagery	unitless	TRUE	CONUS+AK+HI+US Territories	[5, 1, 0.25]	[4, 100, 1600]	[1 h, 5 m, 1 m]	NA	NA	[15 m, 1 m, 0.5 m]
Air Temperature: Profiles	K	TRUE	CONUS+AK+HI+US Territories	[5, 1, 0.25]	[4, 100, 1600]	[1 h, 5 m, 1 m]	[1, 0.5, 0.1]	[5, 2, 1]	[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]
Specific Humidity	g/kg	TRUE	CONUS+AK+HI+US Territories	[10, 2, 0.5]	[1, 25, 400]	[1 h, 5 m, 1 m]	[2, 1, 0.2]	[2, 1, 0.5]	[15 m, 1 m, 0.5 m]
Hydrometeor Size	%	TRUE	CONUS+AK+HI+US Territories	[5, 1, 0.25]	[4, 100, 1600]	[3 h, 15 m, 2 m]	NA	[25, 10, 5]	[1 h, 5 m, 1 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]
Snow Cover	%	TRUE	CONUS+AK+HI+US Territories	[5, 1, 0.25]	[4, 100, 1600]	[6 h, 1 h, 15 m]	NA	[20, 10, 5]	[3 h, 15 m, 2 m]
Cloud Liquid Water Path	g/m2	TRUE	CONUS+AK+HI+US Territories	[10, 2, 0.5]	[1, 25, 400]	[3 h, 15 m, 2 m]	[2, 1, 0.2]	[50, 20, 10]	[1 h, 5 m, 1 m]
Cloud Top Temperature	K	TRUE	CONUS+AK+HI+US Territories	[10, 2, 0.5]	[1, 25, 400]	[3 h, 15 m, 2 m]	NA	[5, 2, 1]	[1 h, 5 m, 1 m]
Cloud Base Height	km	TRUE	CONUS+AK+HI+US Territories	[10, 2, 0.5]	[1, 25, 400]	[1 h, 5 m, 1 m]	NA	[0.5, 0.25, 0.1]	[15 m, 1 m, 0.5 m]
Sea Surface Temperature	K	TRUE	CONUS+AK+HI+US Territories	[100, 50, 1]	[0.01, 0.04, 100]	[12 h, 1 h, 5 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 Profile: Eastward, Planetary Boundary Layer	m/s	TRUE	CONUS+AK+HI+US Territories	[20, 5, 1]	[0.25, 4, 100]	[3 h, 15 m, 2 m]	NA	[5, 2, 1]	[1 h, 5 m, 1 m]
Wind Speed Profile: Northward, Planetary Boundary Layer	m/s	TRUE	CONUS+AK+HI+US Territories	[20, 5, 1]	[0.25, 4, 100]	[3 h, 15 m, 2 m]	NA	[5, 2, 1]	[1 h, 5 m, 1 m]

<u>Table 4. Nowcasting Dense Fog and Ceiling Observational Need Attribute Priority</u>: List of the nowcasting dense fog and ceiling 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	1.0	1.0	0.9	0.9	0.5	1.0
Cloud Cover	1.0	0.8	0.9	0.9	0.9	NA	0.5	1.0
Cloud and Moisture Imagery	1.0	0.8	0.9	0.9	0.9	NA	NA	1.0
Air Temperature: Profiles	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
Specific Humidity	0.5	0.8	0.7	0.7	0.9	0.8	0.5	1.0
Hydrometeor Size	1.0	0.8	0.9	0.9	0.9	NA	0.5	1.0
Land Surface Temperature	1.0	0.8	0.9	0.9	0.7	NA	0.5	1.0
Snow Cover	1.0	0.8	0.9	0.9	0.7	NA	0.5	1.0
Cloud Liquid Water Path	0.5	0.8	0.7	0.7	0.9	0.8	0.5	1.0
Cloud Top Temperature	1.0	0.8	0.7	0.7	0.9	NA	0.5	1.0
Cloud Base Height	1.0	0.8	0.7	0.7	0.9	NA	0.5	1.0
Sea Surface Temperature	1.0	0.8	0.5	0.5	0.7	NA	0.5	1.0
Wind Speed Profile: Eastward, Planetary Boundary Layer	1.0	0.8	0.5	0.5	0.9	NA	0.5	1.0
Wind Speed Profile: Northward, Planetary Boundary Layer	1.0	0.8	0.5	0.5	0.9	NA	0.5	1.0

*** Current Geophysical Variable Need**