UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL ENVIRONMENTAL SATELLITE, DATA, AND INFORMATION SERVICE
Office of System Architecture and Engineering
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4 August 2023

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SUBJECT: Assessment of Solution-Agnostic Observational Needs for Atmospheric Composition in Climate Monitoring

1. Scope:
   This memo provides background information and recommendations and guidance for solution-agnostic observational needs for Atmospheric Composition in Climate Monitoring.

2. Background:

   NESDIS has to regularly assess the user mission needs for environmental observations. This is important in order to (1) remain cognizant 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 or reduce existing observation gaps. It is important to note that these needs are expressed from a relatively wide community of observational users, but it is important to highlight they do not constitute requirements for NOAA. An internal NOAA process exists to define observational requirements. This effort is one part of the overall NESDIS user engagement process.

   Atmospheric composition in climate monitoring is important for understanding and predicting changes to local and global climate. The SAT subcommittee on atmospheric composition (see List of Contributors) focused on several application areas where satellite data is a main source of observational data. A panel of expert reviewers (see List of Contributors) reviewed the needs, attributes, and their priorities, following which observational needs for these applications were briefed to the SAT where representatives from academia, the private sector, NASA, DoD, and NOAA Cooperative Institutes were participating. There were also several representatives from all NOAA Line Offices, including representatives from the NESDIS flight programs, who ultimately will be charged with developing the components of the space architecture (LEO, GEO, SWO). The OSAAP/TPIO (Technology, Planning and Integration for Observation) team has the responsibility of stewarding and updating the Consolidated Observational User Requirements List (COURL). All participants were given opportunities to provide comments and feedback on the observational needs.

It is the purpose of this memo, compiled by the SAT subcommittee on atmospheric composition and reviewed by the Government-only Core-SAT team, to document and establish the needs for atmospheric composition in climate monitoring by assessing the users' needs from many sources. 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.

3. Facts and Findings:

a. Facts

(1) Atmospheric chemistry species were selected from a subset of chemical species that are included in state-of-the-art global atmospheric chemical transport models, such as the Real-time Air Quality Modeling System (RAQMS).

(2) Long-term global monitoring of greenhouse gases is needed for atmospheric composition forecasting and tracking expected carbon-climate feedback mechanisms.

(3) Accurate representation of carbon-climate feedbacks in climate models is critically needed to inform policies aimed at limiting future climate change.

(4) Comprehensive monitoring of greenhouse gases is particularly important for assessing progress towards achieving the goals of the Paris Agreement and meeting other carbon reduction targets (e.g. the Global Methane Pledge).

b. Findings

(1) The SAT developed a list of solution-agnostic atmospheric composition in climate monitoring observational needs and assembled them into several tables. The tables summarize those observational needs and were determined as part of the overall NESDIS user engagement process that consisted of deliberations with experts, established expert groups, published documentation, and NOAA Line Office experts. The list was consolidated, reviewed, and approved by the Government-only Core-SAT committee.

4. Recommendation:

The SAT recommends that NOAA use the following solution-agnostic atmospheric composition in climate monitoring observational needs, as shown in the tables below, as an input to the establishment of the NOAA observational requirements for atmospheric composition needs. These tables include variable names, attributes' ranges of these variables, as well as associated prioritizations. These recommendations should be considered as part of the planning and development of next-generation space architecture and product development.

Table Descriptions

Table 1. Describes the list of variables needed for the atmospheric composition in climate monitoring application, why they are important for the application, and whether they are already identified as an existing variable in the TPIO databases (e.g., COURL).

Table 2. Identifies geophysical variable priorities for the atmospheric composition in climate monitoring application as reviewed by the Core-SAT using the inputs from the subcommittee for atmospheric composition as an input. The recommendations from other user needs activities (TPIO, NASA-NOAA, XORWG, etc.) were considered, and included by OSAAP/TPIO as appropriate.

Table 3. Shows the variable performance ranges for the atmospheric composition in climate monitoring application, as determined by the Core-SAT. These data are based on the input from the subcommittee for atmospheric composition as well as input from the OSAAP Analysis Team, and other sources, as mentioned previously. The data ranges, shown as triplets, are defined as "minimally useful or Threshold," "Expected [performance in the 2030-time frame]," and "Maximum Effective." The current geophysical variable performance ranges are listed as well.

Table 4. Includes atmospheric composition in climate 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 OSAAP/TPIO Team based on "differential attribute change per unit time" in the vertical and horizontal dimensions. Current attribute weights, per geophysical variable, are listed.

<u>Conclusions:</u>

This is the first comprehensive catalog of observational needs for atmospheric composition in climate monitoring that has been collected by NOAA. This 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. As stated previously, the collection of user needs was developed and reviewed by a variety of different sources that included representatives from the OSAAP/TPIO, the LEO and GEO programs, and representatives from the NOAA Line Offices and Centers (OAR/CSL, OAR/GML,

OAR/ARL, NWS/EMC, NESDIS/STAR, OAR/CPO), NASA, DoD, and academia. The final determination of the list of user needs and attributes was assembled and confirmed by the Core-SAT. The collection of observational is part of the on-going user engagement process and needs should be refreshed regularly in order to maintain an up to date list of users' observational needs.

Table 1. Atmospheric Composition in Climate Monitoring Variable Needs: Table 1 is a list of the variables needed by the atmospheric composition in climate 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)
O_3 – Ozone	Climate forcer	E
N_2O – Nitrous Oxide	Climate forcer	E
CH_4 – Methane	Climate forcer	E
CO_2 – Carbon Dioxide	Climate forcer	E
$CFCl_3$ (F11) – Trichlorofluoromethane	Climate forcer	N
CF_2Cl_2 (F12) – Dichlorodifluoromethane	Climate forcer	N
CH_3Br – Bromomethane	Climate forcer	N
CF_3Br (H1301) – Bromotrifluoromethane	Climate forcer	N
CF_2ClBr (H1211) – Bromochlorodifluoromethane	Climate forcer	N

Table 2. Geophysical Variable Priorities for Atmospheric Composition in Climate Monitoring: This table includes the list of the geophysical information and their prioritization, based on a scale from 0 (non-important) to 1 (critically important), needed for atmospheric composition in climate monitoring 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 Advanced Systems Performance Evaluation tool for NOAA (ASPEN) tool.

Geophysical Variable	Short Name	Units	Priority
O_3 – Ozone	O_3	ppmv	1.0
N_2O – Nitrous Oxide	N_2O	ppbv	0.8
CH_4 – Methane	CH_4	ppb	0.9
CO_2 – Carbon Dioxide	CO_2	ppm	1.0
$CFCl_3$ (F11) – Trichlorofluoromethane	$CFCl_3$	pptv	0.5
CF_2Cl_2 (F12) – Dichlorodifluoromethane	CF_2Cl_2	pptv	0.5
CH_3Br – Bromomethane	CH_3Br	pptv	0.3
CF_3Br (H1301) – Bromotrifluoromethane	CF_3Br	pptv	0.5
CF_2ClBr (H1211) – Bromochlorodifluoromethane	CF_2ClBr	pptv	0.5

Table 3. Atmospheric Composition in Climate Monitoring Observational Need Attribute Performance Ranges: List of observational needs of the current systems for atmospheric composition in climate monitoring in NOAA. These needs are expressed in terms of ranges between minimally useful (Threshold), expected level of performance in 2030 (Expected) and the maximum effective usefulness level beyond which there is no incentive to improve performance (Maximum Effective). These are written as [Threshold, Expected, Maximum Effective]. The attributes include the following:

- Geographic Coverage: The geographic region needed for observations.
- Horizontal resolution: The ground projected instantaneous field of view.
- Temporal refresh: Time between observations at a location, i.e., time to observe the geographic coverage region.
- Data Latency: Time from 'image taken' to full relay of data to a ground station.
- Vertical Resolution (when appropriate): The average vertical distance between observations in degrees of freedom.
- Precision: Error standard deviation under clear/cloudy conditions and over land/ocean.
- Accuracy: Mean absolute non-random error.
- Validity Range: The low and high values that can be observed.
- Long term stability of the measurement: Long term changes in precision (noise).
- Robustness: The number of sources needed to make the observation.
- Continuity: Period in years for which the observations are required.

Geophysical Variable	Geophysical Variable Units	Geographic Coverage (dimensionless)	Horizontal Resolution (km)	Temporal Refresh (h)	Data Latency (h)	Vertical Resolution (dof)	Precision: Clear/ Cloudy, Land/ Ocean (%)	Accuracy (%)	Validity Range (Same Units as Variable)	Long- term Stability (%)	Robustness (unitless)	Continuity (yr)
O_3 – Ozone	ppmv	Network, CONUS, Global	[50, 5, 1]	[24, 12, 1]	[3, 1, 0.5]	[1*, 5, 120]	[20,5,1]%	0.001+[10, 5, 1]%	0.001- 15	[5,2,0.5]%/ decade	[2, 3, 6]	7/1 (life/ overlap)
N_2O – Nitrous Oxide	ppbv	Network, CONUS, Global	[50, 5, 1]	[24, 12, 1]	[3, 1, 0.5]	[1, 5, 120]	1+[10, 5, 1] %	1+[10, 5, 1] %	1-400	[10,5,1]%/ decade	[2, 3, 6]	10/2 (life/ overlap)
CH_4 – Methane	ppbv	Network, CONUS, Global	[50,5,1]	[24, 12, 1]	[72,24,1]	[1**,5,120]	[5, 2.5, 1]	[12,6,2]	1000-2000	[12,6,2]/ decade	[2, 3, 6]	10/2 (life/ overlap)
CO_2 – Carbon Dioxide	ppmv	Network, CONUS, Global	[10,3,0.5]	[24, 12, 1]	[72,24,1]	[1**,5,120]	[3,1,0.5]	[0.4,0.2,0.1]	250-500	[0.4,0.2,0.1] ppm/decade	[2, 3, 6]	20/2 (life/ overlap)
$CFCl_3$ (F11) – Trichlorofluoromethane	pptv	Network, CONUS, Global	[200, 100, 20]	[72, 24, 12]	[36, 12, 6]	[1, 5, 120]	[20, 10, 1] %	1+[10, 5, 1] %	1-300	[10, 5, 1] %/ decade	[2, 3, 6]	10/2 (life/ overlap)

Geophysical Variable	Geophysical Variable Units	Geographic Coverage (dimensionless)	Horizontal Resolution (km)	Temporal Refresh (h)	Data Latency (h)	Vertical Resolution (dof)	Precision: Clear/ Cloudy, Land/ Ocean (%)	Accuracy (%)	Validity Range (Same Units as Variable)	Long- term Stability (%)	Robustness (unitless)	Continuity (yr)
CF_2Cl_2 (F12) – Dichlorodifluoromethane	pptv	Network, CONUS, Global	[200, 100, 20]	[72, 24, 12]	[36, 12, 6]	[1, 5, 120]	[20, 10, 1] %	1+[10, 5, 1] %	1-600	[10, 5, 1] %/ decade	[2, 3, 6]	10/2 (life/ overlap)
CH_3Br – Bromomethane	pptv	Network, CONUS, Global	[50, 5, 1]	[24, 12, 1]	[3, 1, 0.5]	[1, 5, 120]	[40, 10, 5] %	[40, 10, 5] %	1-20	[40, 10, 5] %/ decade	[2, 3, 6]	10/2 (life/ overlap)
CF_3Br (H1301) – Bromotrifluoromethane	pptv	Network, CONUS, Global	[200, 100, 20]	[72, 24, 12]	[36, 12, 6]	[1, 5, 120]	[20, 10, 1] %	[10, 5, 1] %	1-10	[10, 5, 1] %/ decade	[2, 3, 6]	10/2 (life/ overlap)
CF_2ClBr (H1211) – Bromochlorodifluoromethane	pptv	Network, CONUS, Global	[200, 100, 20]	[72, 24, 12]	[36, 12, 6]	[1, 5, 120]	[20, 10, 1] %	[10, 5, 1] %	1-10	[10, 5, 1] %/ decade	[2, 3, 6]	10/2 (life/ overlap)

* Surface to 60 km

** Must include surface

<u>Table 4. Atmospheric Composition in Climate Monitoring Observational Need Attribute Priority</u>: List of the atmospheric composition in climate monitoring variables as prioritized in Table 1. This table contains the relative importance of the attributes for each of the variables. This provides engineers and designers of sensors and constellations the ability to assess where emphasis should be put when performing trade studies. For each row (variable), the weights between 0 (no importance) and 1 (highest importance) is assigned to the individual attributes described in the columns. NA indicates not applicable.

Geophysical Variable	Images	Geographic Coverage	Horizontal Resolution	Temporal Refresh	Data Latency	Vertical Resolution	Precision: Clear/Cloudy, Land/Ocean	Accuracy	Validity Range	Long-term Stability	Robustness	Continuity
O_3 – Ozone	0.8	1	0.8	0.3	0.3	1	0.8	1	1	1	1	1
N_2O – Nitrous Oxide	0.8	1	0.5	0.5	0.5	0.8	1	1	1	1	1	1
CH_4 – Methane	1	1	1	0.8	0.3	0.8	1	1	1	0.5	1	1
CO_2 – Carbon Dioxide	0.8	1	0.8	0.8	0.3	0.8	1	1	1	0.5	1	1
$CFCl_3$ (F11) – Trichlorofluoromethane	0.5	1	0.5	0.5	0.5	0.5	0.8	1	1	1	1	1
CF_2Cl_2 (F12) – Dichlorodifluoromethane	0.5	1	0.5	0.5	0.5	0.5	0.8	1	1	1	1	1
CH_3Br – Bromomethane	0.5	1	0.5	0.5	0.5	0.5	1	1	1	1	1	1
CF_3Br (H1301) – Bromotrifluoromethane	0.5	1	0.5	0.5	0.5	0.5	0.8	1	1	1	1	1
CF_2ClBr (H1211) – Bromochlorodifluoromethane	0.5	1	0.5	0.5	0.5	0.5	0.8	1	1	1	1	1

Sources of Atmospheric Composition in Climate Monitoring Observational Needs:
The Core-SAT team, composed of federal employees from NOAA (including representatives from the NWS, NOAA OSAAP Analysis Team, and the NOAA LEO and GEO Programs), reviewed the atmospheric composition in climate 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:

- "A Value Assessment of an Atmospheric Composition Capability on the NOAA Next-Generation Geostationary and Extended Orbits (GEO-XO) Missions." DOI: https://doi.org/10.25923/1s4s-t405, https://repository.library.noaa.gov/view/noaa/27224
- "Chemical data assimilation estimates of continental U.S. ozone and nitrogen budgets during the Intercontinental Chemical Transport Experiment–North America." DOI: https://doi.org/10.1029/2006JD007722
- "A revised linear ozone photochemistry parameterization for use in transport and general circulation models: multi-annual simulations." DOI: https://doi.org/10.5194/acp-7-2183-2007
- "Tropospheric chemistry in the Integrated Forecasting System of ECMWF." https://doi:10.5194/gmd-8-975-2015
- "Global Atmospheric Composition Needs from Future Ultraviolet–Visible–Near-Infrared (UV–Vis–NIR) NOAA Satellite Instruments" https://journals.ametsoc.org/view/journals/bams/104/3/BAMS-D-22-0266.1.xml

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 needs for the atmospheric composition in climate monitoring application, 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.

Important note: This memo was developed by the Subcommittee and approved after deliberations and discussions among the core-SAT, which consist of federal employees only. These recommendations were made following extensive scientific fact-finding, review of the scientific literature, and SAT discussions with scientific experts and others knowledgeable in the field.

List of Contributors to Observational Needs

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List of Acronyms

Abbreviation	Definition
ARL	Air Resources Laboratory
ASPEN	Advanced Systems Performance Evaluation tool for NOAA
BAMS	Bulletin of the American Meteorological Society
COURL	Consolidated Observational Users Requirements List
CPO	Climate Program Office
CSL	Chemical Sciences Laboratory
DAAS	Deputy Assistant Administrator for Systems
DoD	Department of Defense
ECMWF	European Centre for Medium-Range Weather Forecasts
EMC	Environmental Monitoring Center
EPA	[U.S.] Environmental Protection Agency
GEO	Geosynchronous Earth Orbit
GeoXO	Geostationary Extended Observations (Previously GEO-XO)
GML	Global Monitoring Laboratory
IR	Infrared
LEO	Low Earth Orbit
NASA	National Aeronautics and Space Administration
NESDIS	National Environmental Satellite, Data, and Information Service
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
OAR	Office of Oceanic and Atmospheric Research
OBS	NWS Office of Observations
OSAAP	Office of System Architecture and Advanced Planning (NOAA/NESDIS)
OSCAR	Observing Systems Capability Analysis and Review tool
RAQMS	Real-time Air Quality Modeling System
SAT	System performance Assessment Team
STAR	Center for Satellite Applications and Research
SWO	Space Weather Office
TPIO	Technology, Planning and Integration for Observation
UV	Ultraviolet
Vis	Visible
WMO	World Meteorological Organization
XORWG	GeoXO Requirements Working Group

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