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National Oceanic and Atmospheric Administration
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Workshop on Hyperspectral Sensor Greenhouse Gas (GHG) and Atmospheric Soundings from Environmental Satellites

Co-organizers: NOAA and NASA civilian space agencies of the Government of the U.S. and EUMETSAT, the European Organization for the Exploitation of Meteorological Satellites (serving 26 member states)

Prospectus for Workshop

This workshop will assess current and future user requirements and technology readiness for improved greenhouse gas measurements and atmospheric soundings from space-based hyperspectral sensors on future potential operational missions.

Hyperspectral remote sensing from satellites is becoming increasingly capable of providing information rich atmospheric measurements for operational meteorology, chemistry, and climate monitoring. There are two classes of hyperspectral IR sensors that have emerged as alternatives to address historical operational meteorology needs, the Fourier Transform Spectrometer (FTS) and the dispersive (slit/grating) spectrometer. When used for operational meteorology, to measure vertical profiles of atmospheric temperature and moisture, they are termed "Sounders". The spectral range of these sensors and the classical definition of their place in the electromagnetic spectrum begins at 0.77 micron wavelength (the dividing point between the visible and IR parts of the electromagnetic spectrum) extending out today to about 15 microns wavelength for operational meteorology and greenhouse gas monitoring.

EUMETSAT launched the Infrared Atmospheric Sounding Interferometer (IASI) hyperspectral sensor (an FTS), in polar orbit in 2006, for atmospheric soundings and chemistry. The NOAA-NASA Joint Polar Satellite System (JPSS) Preparatory Project (NPP) satellite (to be launched in the next two years) and the follow-on satellites will carry the FTS class Cross-track Infrared Sounder (CrIS) to meet NOAA's requirements for highly accurate vertical profiles of temperature, moisture, and pressure profiles. CrIS will have the potential to provide NOAA users with improved operational capabilities to monitor the Earth's atmosphere, ocean and land for assessing and predicting weather, climate, and environmental conditions well into the next decade (2020's). The Atmospheric Infrared Sounder (AIRS) launched in 2002 by NASA and JPL, a dispersive (slit/grating) spectrometer hyperspectral sensor is still operating today. It has been a pioneer for the U.S. and world nations on the application of hyperspectral sensor soundings for operational meteorology, chemistry, and climate monitoring and in particular most recently mid troposphere carbon emission trace gases. NASA will launch the Orbiting Carbon Observatory-2 (OCO-2 mission) in February 2013 with a dispersive (slit/grating) hyperspectral sensor to make global measurements of atmospheric carbon dioxide (CO₂). And, JAXA, the Japanese Aerospace Exploration Agency, launched its GOSAT satellite in 2009, with the TANSO FTS to measure CO₂ and CH₄. Planning operational remote sensing satellite missions be it for POLAR, MEO, or geo orbits requires considerable preparation related to user requirements and technology assessments. Since operational missions for a particular class of sensors are sustained for many years, generally at least 15 years, it is very important that both user requirements and potential technologies that can be used for a long and sustained operational mission be carefully assessed. With these recent advances the time is now to formulate requirements for future needs. In addition to the discussion of current and future needs, this



workshop will explore the potential technology and design concept readiness of hyperspectral sensors that can be used to improve vertical and spatial/sampling resolution of atmospheric temperature and water vapor profiles, to provide GHG products capable of monitoring sources and sinks, and atmospheric

Questions the workshop will help to answer are:

1. How are current hyperspectral IR sounders such as the NASA JPL AIRS and CNES & EUMETSAT IASI used?
 - What are the deficiencies?
 - What improved information is needed by the user?

2. What are the U.S. NWS Weather Research and Forecast (WRF) / North American Mesoscale (NAM) and Global Forecast System (GFS) models' forecast needs for IR hyperspectral soundings ((i.e. model forecast accuracy improvements, horizontal spatial resolution, temperature and moisture profile requirements (over land, over water).

3. With respect to the EUMETSAT/CNES Meteorological Operational satellite program (METOP-A), the hyperspectral IASI FTS sensor was designed for operational meteorological soundings with high level of accuracy (specifications on Temperature accuracy: 1K for 1 km and 10 % for humidity) being devoted to improved medium range weather forecast; and atmospheric chemistry at estimating and monitoring trace gases like ozone, methane or carbon monoxide on a global scale:
 - What are the experiences with its use?
 - What is the status of operational applications (e.g. weather forecasting, atmospheric chemistry)?
 - What are limitations and / or problems in its performance?
 - What are plans for its next generation (IASI NG)?

4. With respect to the industry research and studies on requirements, technology, trades, led by U.S. NOAA NESDIS for the GOES R satellite series: what was learned about hyperspectral sensor availability, performance, minimized risks, and costs?
 - One of the outcomes of the last phase of NESDIS GOES R led study with industry were hyperspectral sensor concepts minimized in performance to constrain costs for a very limited budget, directed to meeting operational meteorology forecast needs of the NWS (highly accurate vertical profiles, and 1hr 67o LZA Earth scanning radius).
 - What did this GOES R minimized study sensor (s) look like?
 - What can such a sensor look like?
 - What could be a very limited core basic list of operational meteorology/weather forecasting algorithms/products to minimize initial acquisition ground system costs yet still meet core NWS forecast product needs:
 - What was the initial EUMETSAT IASI product/algorithm list?
 - What could an initial minimal list of algorithm/products be to meet weather forecast needs such as by NOAA NWS?
 - What could be added at minimum design, cost, risk burden for atmospheric chemistry, and GHGs?
 - What can be said about the state of available hyperspectral sensor technology for satellite applications (e.g. LEO, GEO orbits)
 - Is there a role for GHG measurements in GEO Orbit?

5. What role can satellites take, as a complement to ground based measurement systems, to provide sustained observations to monitor GHG emissions (e.g. CO₂, CH₄, O₃, N₂O, CFC's, NH₃, NF₃) that contribute to global warming?
6. What are the GHG (e.g. CO₂, CH₄, O₃, N₂O, CFC's, NH₃, NF₃) and chemical agent sensing capabilities of hyperspectral satellite sensors?
7. Can one hyperspectral instrument (FTS or dispersive) satisfy both operational weather sounding and GHG requirements (at least CO₂ and CH₄)?
8. With respect to Japan's JAXA Greenhouse Gases Observing Satellite (GOSAT) and its FTS IR hyperspectral sensor in measuring CO₂ and CH₄; (The GOSAT sensor has three narrow IR bands 0.76, 1.6, and 2 micron and a wide IR band (5.5-14.3 micron) with 0.2 cm⁻¹ spectral resolution). The 3 narrow bands are the same as the NASA JPL OCO satellite.
 - What was its intended range of applications
 - How well has it performed?
 - What are the experiences with its operations?
 - What are the future plans?
9. With respect to the NASA JPL Atmospheric Infrared Sounder -AIRS (dispersive) and Tropospheric Emission Spectrometer- TES (FTS) hyperspectral sensors:
 - What are the applications and experiences with the TES use?
 - What have been the ranges of applications for both sensors (e.g. weather forecasting, atmospheric chemistry)?
 - What is the latest status of new JPL research in applying AIRS to GHG measurement?
 - What do AIRS & TES show for future atmospheric measurements?
 - The next GEN AIRS?
10. With respect to the NASA JPL OCO (CO₂) GHG directed satellite mission:
 - What does NASA consider as its capabilities?
 - Operational uses by NOAA?
 - What does NASA consider as an appropriate NOAA operational follow-on mission from this validation (e.g. should OCO follow-on include CH₄ as does GOSAT satellite)?
11. What are Canada's and Europe's Plans and Activities relative to GHG Satellite Sensing?
12. With respect to the current ESA SCIAMACHY capabilities to measure GHGs:
 - What does the European community consider as its capabilities? operational uses?
 - What does European community consider as an appropriate follow-on mission (e.g. CarbonSat?) which will further improve precision, accuracy, global coverage?
 - What does Europe community consider as a sensor for future operational missions?
13. What are the views of NOAA Research on the role of present, emerging, and future hyperspectral sensing from satellite for operational meteorology, atmospheric chemistry,

and climate monitoring (in particular trace gases) ?

- 14** What role can, should Observing System Simulation Experiments-OSSE's (e.g. use of models such as NAM/WRF, GFS to examine the impact of the new observations) and Observing System Experiments-OSE's play in enhancing validation of NOAA acquisition requirements for future hyperspectral sensor satellite capabilities in NOAA forecast operations. What are the views of NOAA OAR AOML, NOAA NWS NCEP?
- 15** What are some of the new sensor concepts for satellite hyperspectral sensors emerging to deal with operational meteorology with finer spatial resolution, atmospheric chemistry, and climate monitoring including greenhouse gas monitoring to ground level point sources.
- One such new hyperspectral concept is JPL's Advanced Remote-sensing Imaging Emission Spectrometer (ARIES) reflecting an integration into one sensor, abilities of both the Moderate-Resolution Imaging Spectroradiometer (MODIS) 36 band multispectral Imager and AIRS (2378 spectral bands) hyperspectral grating spectrometer
 - Do such concepts from a NOAA perspective of being an operational monitoring agency (versus science research, and technology and acquisition system development) represent an advance so great beyond current generation sensors (AIRS, IASI, CRIS, TES, OCO, GOSAT) that a NASA development mission would first be advisable?
 - Can such sensors meet the core requirements of NOAA such as rapid earth view scanning in geostationary orbit?