APPLICATIONS USING THE ATMOSPHERIC DATA OF THE PACE MISSION

Ali H. Omar (NASA)
Maria Tzortziou (CCNY), Woody Turner (NASA)

Groups/Subgroups: Atmospheric Correction, Applications, Atmospheric by-products

PACE Science Team Meeting, Pasadena, CA, Jan 20-22, 2016

PACE

Proposed Activities

- ❖ Identify existing applications that can be augmented by the PACE measurements
- ❖ Determine new applications that can be developed using PACE measurements
- ❖ Quantify the uncertainties of the data that will be used for these applications
- ❖ Assess and interpret the impact on applications of resolution, latency and accuracy requirements of the PACE data
- ❖ Facilitate collaboration between science team members and the applications user community
- ❖ Provide data to early adopter communities to test their applications prior to the launch of PACE
- ❖ Achieve consensus on the applications outcomes of the proposed activities
- ❖ Estimate of the value of PACE data to society

PACE

Activities (2015)

- **Identify key stakeholders and engage them in decisions about data, availability, and formatting within the parameters of mission capabilities**
  - **EPA, NOAA, NRL, NASA**

- **Develop communication plans and tools (e.g., website, early adopter workshops). Present material on key applications areas at meetings relevant to PACE mission**
  - **Applications Content for the PACE Website**
  - **Applications Traceability Matrices**
  - **Applications White Papers**
  - **Air and Waste Management Association Annual Meeting**
  - **AGU Ocean Sciences Meeting (PACE+HyspIRI)**

- **Foster the capacity building geared toward the use of PACE data and successor missions**
  - **Develop course content for ARSET to use PACE data**

- **Develop Application Traceability Matrices and White Papers for Applied Sciences Program Applications areas (HABs and Air Quality Applications)**
  - **Air Quality, Volcanic Ash Hazard Warning (+HyspIRI)**

PACE Aerosol Measurements

OCI Only

Aerosol Optical Depth (τ_λ)
Aerosol Optical Depth Angstrom Exponents [$\alpha = -\log(\tau_{\lambda 1} / \tau_{\lambda 2}) / \log(\lambda_1/\lambda_2)$]
NO2 from OCI Hyperspectral measurements

Main Applications: Particulate Material (PM) concentrations –Air Quality Indices (PM)
Limited information about aerosol type – Air Quality Forecasting
Some information about aerosol transport – Exceptional Event Flagging

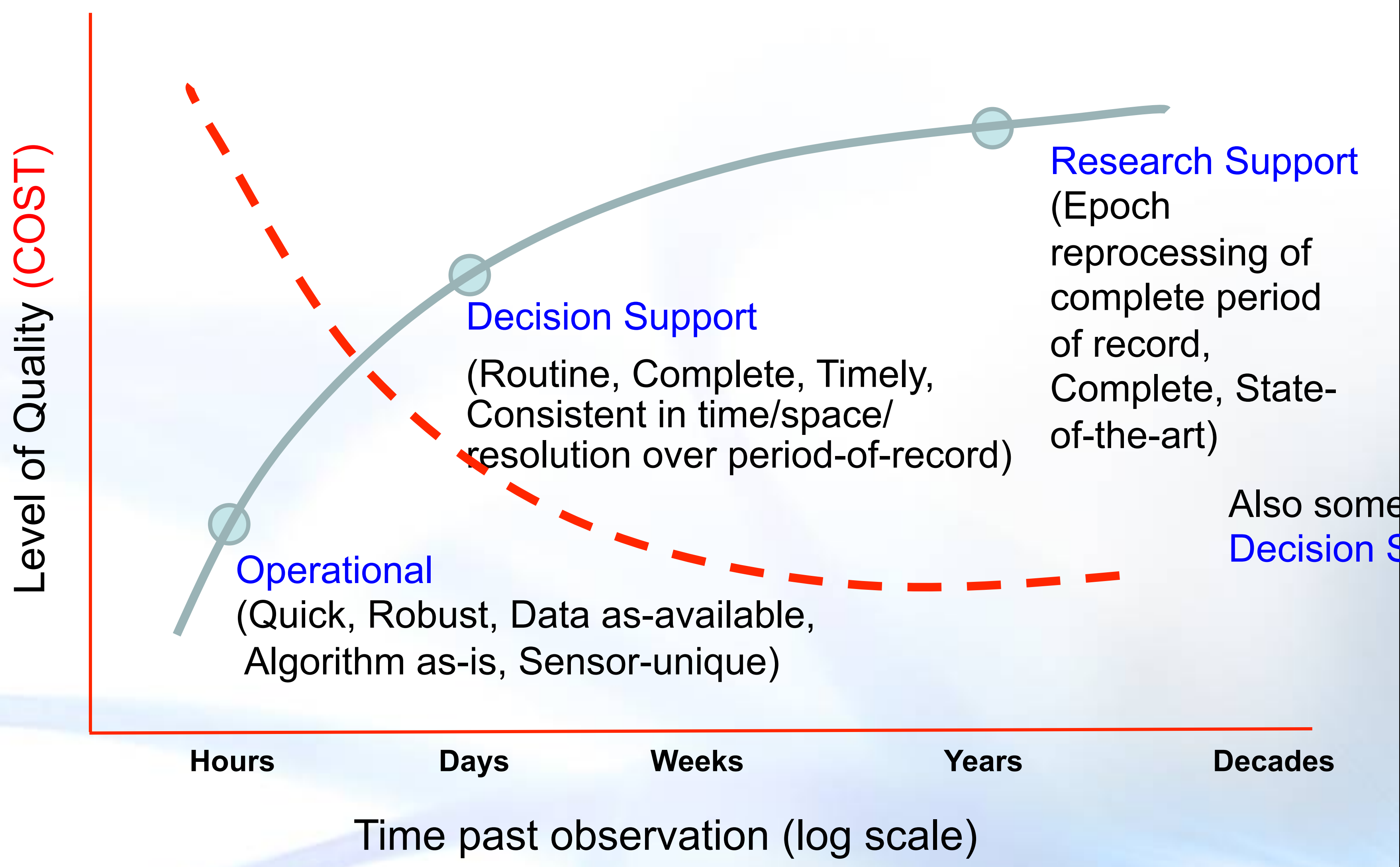
OCI + Polarimeter (Multi-directional, Multi-spectral, Multi-polarization)

Aerosol Optical Depth, α, Absorption
Aerosol Type - Aerosol Size/Shape, Refractive Indices, Number
Aerosol Vertical Resolution – Plume height
NO, NO_2, O_3 from OCI Hyperspectral measurements (< 350 nm)

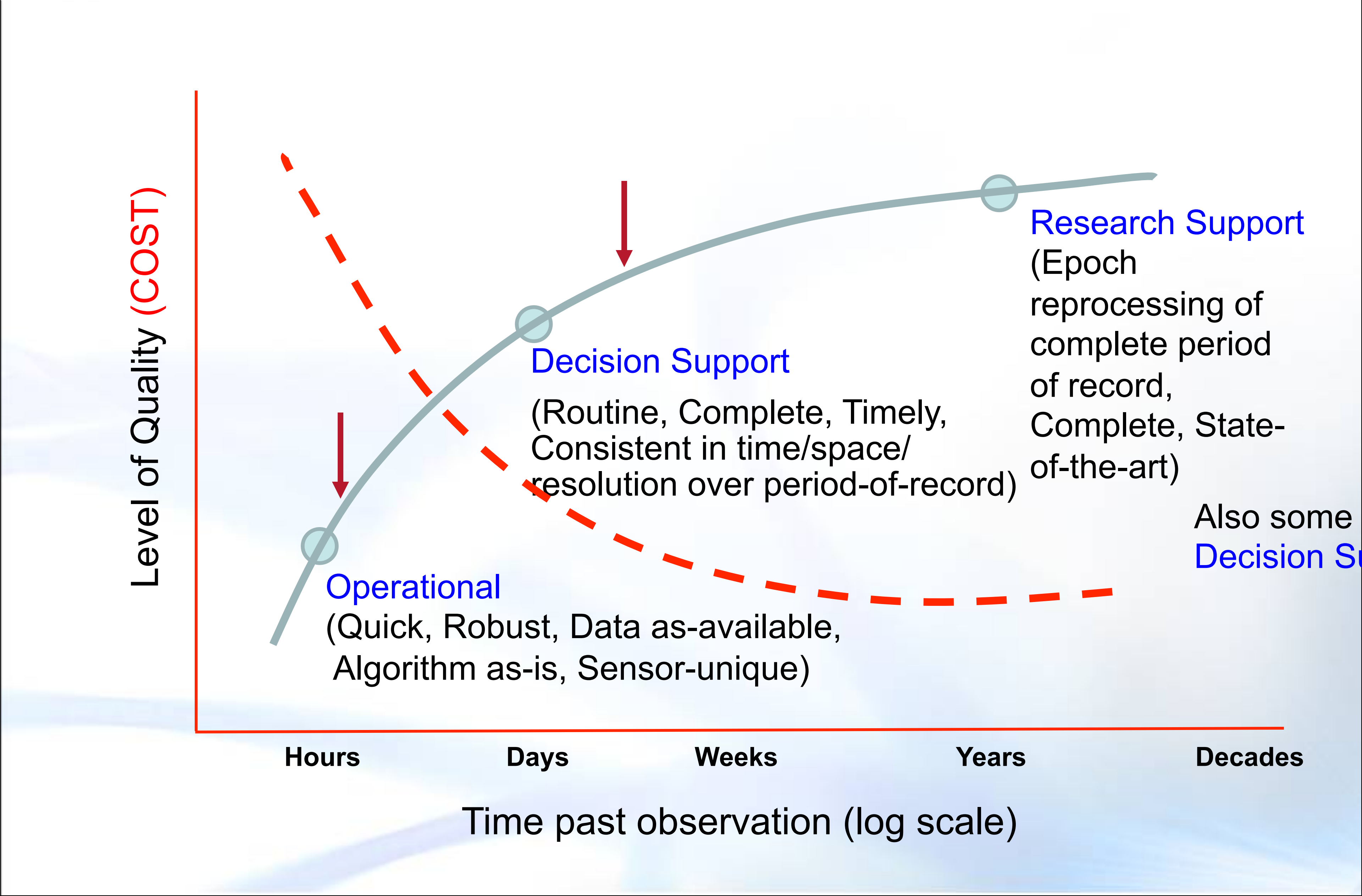
Main Applications: Air Quality Indices (PM)
Air Quality Forecasting
Regional and Inter-hemispheric Transport– Exceptional Event Flagging and Demonstration
Disaster Monitoring – Extreme events, Wildfires, Volcanoes, Dust Storms

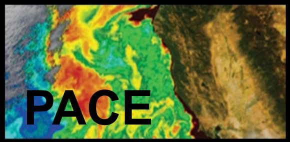
(cf. Waquet et al, 2010; Dubovik et al, 2011; Hasekamp et al, 2011)

Temporal Scales for Decision Support Applications



Temporal Scales for Decision Support Applications





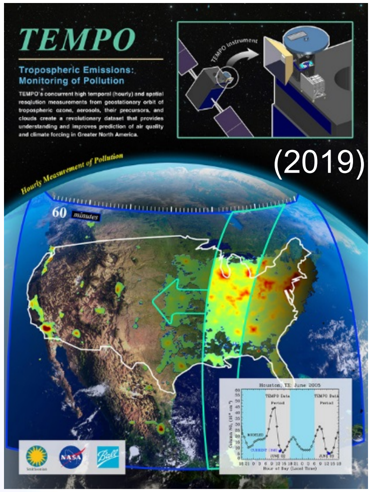
Increasing the Value of PACE Products

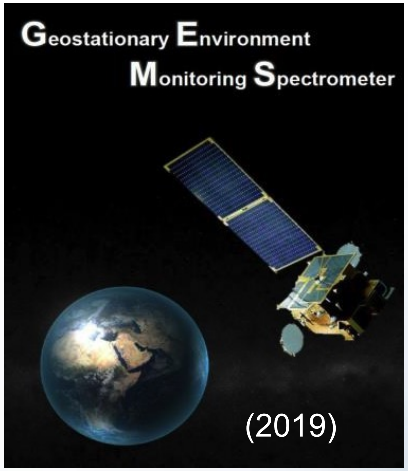
- To maximize attractiveness of any PACE aerosol product, **it should look as *close to MODIS as possible and be available from LANCE or similar access/ latency*.** Temporal/spatial resolutions should mimic MODIS products as best as a product development team could do under the parameters of the mission
- The assimilation community would like aerosol products as soon as possible (3 hours) at the highest resolution (1 km) but would find products with a data latency of 12 hours and 10 km resolution very useful (NASA, NOAA, NRL, EPA)
- The lowest acceptable latency for Chemical Weather Forecasting (NOAA) is daily (24 hours). The preference is a latency of 6 hours (they conduct 4 assimilation/ forecast cycles per day)
- Disaster Monitoring / Response to Wildfires, Volcanic Eruptions – 3 hour latency is preferred

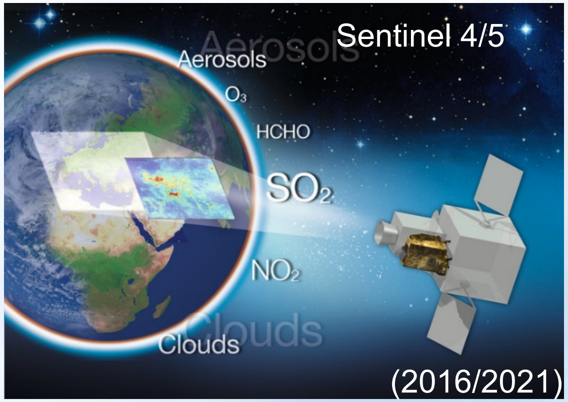
Increasing the Value of PACE Products

- The impact and attraction of upcoming geostationary satellites will change the way applications users rely on sun synchronous measurements. Geostats at 15-60 min resolution, will provide such new and novel data density that <u>regional models</u> will become highly dependent upon them very quickly
- Polarimetric measurements, especially
  - retrievals of species composition and vertical extent
  - <u>global measurements</u>

are unique and would still be very important even in the context of high density column measurements from geostationaries



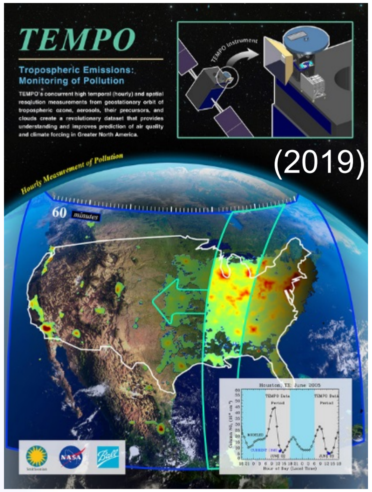


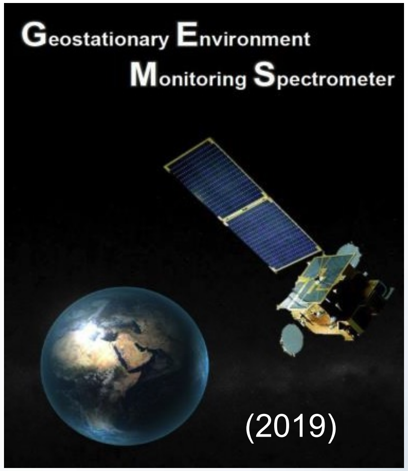


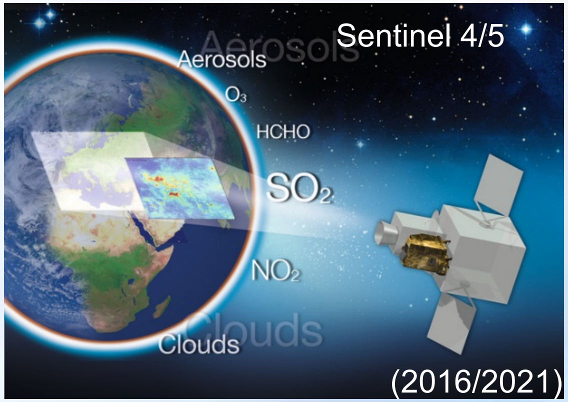
Increasing the Value of PACE Products

- The impact and attraction of upcoming geostationary satellites will change the way applications users rely on sun synchronous measurements. Geostats at 15-60 min resolution, will provide such new and novel data density that regional models will become highly dependent upon them very quickly

- Polarimetric measurements, especially retrievals of species composition and vertical extent are unique and would still be very important even in the context of high density column measurements from geostationaries
- The advent of geostats will make polarimetric measurements event more imperative as composition and vertical resolution of aerosol layers become the main missing pieces.



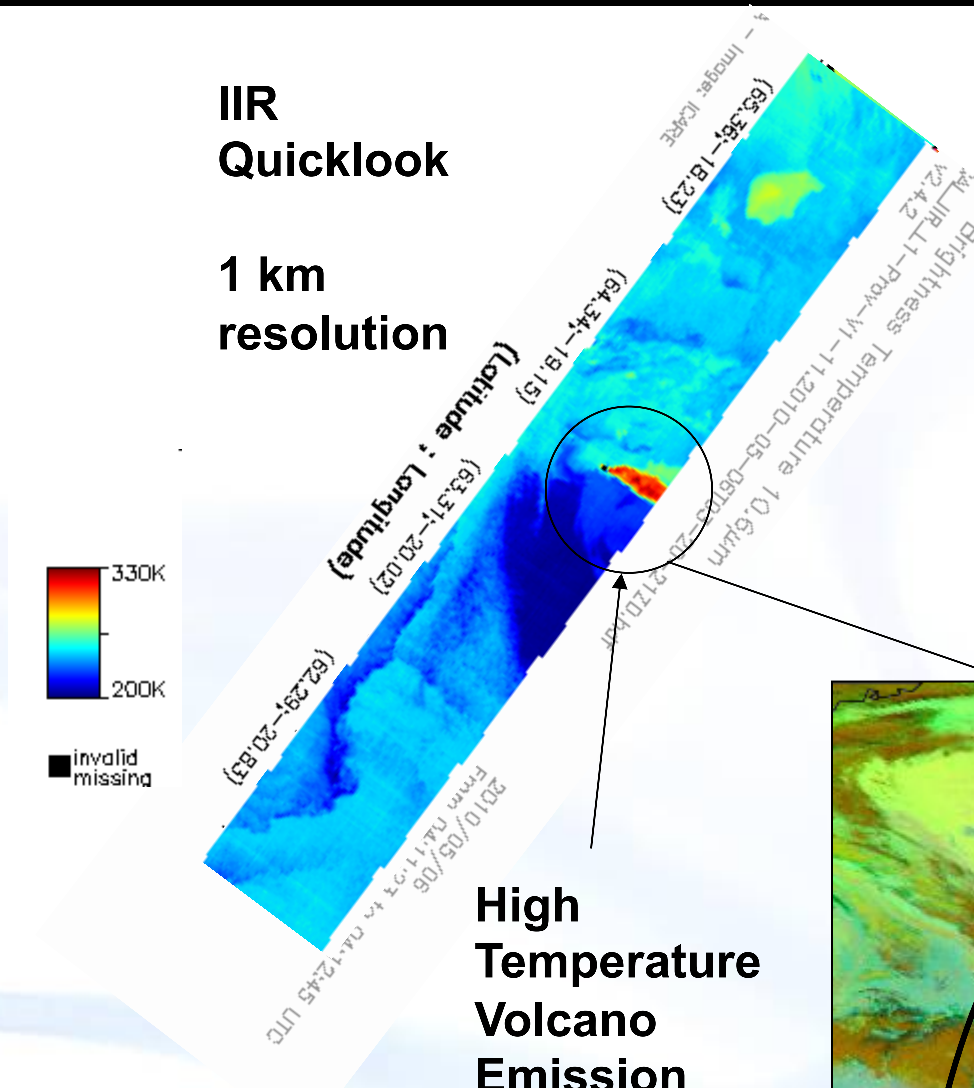




EYJAFJALLAJOKULL ERUPTION 6 MAY 2010

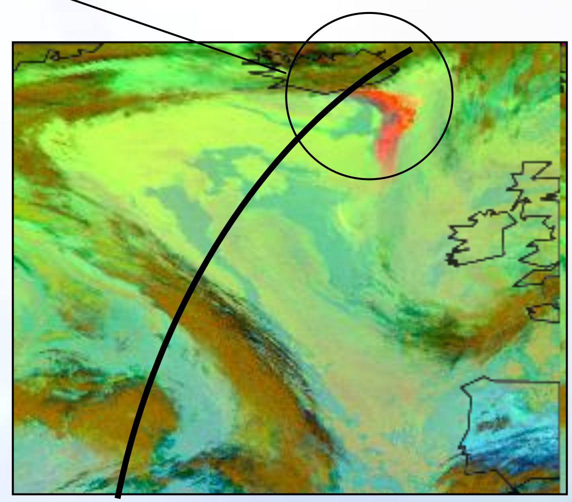
IIR Quicklook

1 km resolution



Observation of volcanic emission soon after the May 6 eruption : IIR onboard CALIPSO at 04:11 UTC (left) and MSG/SEVIRI at 13:00 UTC (below)

High Temperature Volcano Emission point



SO2 : BTD 10 - 8
Ash : BTD 12-10

Analog: OCI + HyspIRI

Development of PACE Applications White Papers

PACE MISSION APPLICATIONS – ATMOSF

Figure 1. The concentration of particulate material (PM) from ground monitors (the small
satellite data, the area of coverage would be limited only to the areas shaded green. The MODIS
the gaps (but not all). The next columns show MODIS image of a typical air quality situa
solution (PM2.5 from ground based data), and NASA's contribution (PM2.5 from Ground + Sa
because the ground monitors in this region are very few, the interpolated PM2.5 data shows rela
4). The addition of satellite data shows that the Air Quality as a result of the fires is poorer a
value in producing an Air Quality Index that actually protects the public from harm. If the sat
be no indication of this poorer air quality.

Application Question/Issue

The main application question is: What is the air quality forecast of particulate matter concentration (PM, an indication of the extent of air pollution) predicted from *satellite* measurements of the aerosol optical depth (AOD) in regions where there are no *ground* measurements of PM? Figure 1 is an illustration of such an application.

Who Cares and Why?

In regions where there are no ground measurements of PM, the EPA and thus the public has no indication of the extent of air pollution, a situation that has deleterious public health implications. Satellite measurements of AOD can be used to estimate PM in such areas. The Environmental Protection Agency (EPA) produces a daily air quality index (AQI) which comprises both the ozone and particulate matter concentrations. The latest surveys show 75 -80% of the public are aware of AQI and 50% report taking action based on the AQI.

Needed Measurement[s]

The accuracy of the daily (and forecast) AQI depends on the spatial resolution, latency and accuracy of the satellite-observed AOD and the validity of the relationship between column AOD and surface PM. To meet the needs of the public, the satellite measurements of AOD must be produced at spatial resolutions of less than 1 km at a latency not exceeding 1 hour and at an

accuracy of ±0.05. Th
PM using the colur
measurements must b

The NASA Response

The PACE mission wil
accuracy of ± 0.02 at a
250-500 m. It is expec
broadcast PACE data v
the Land Atmosphere I
Capability for EOS (LA
modis.eosdis.nasa.gov
AOD products current
minutes for the Level 2
Additional capabilities
layers (these are aeroso
detached from the surf
lidars, sondes or mode
HYSPLIT
http://ready.arl.noaa.go
chemical transport mo
PACE will measure wh
air quality concern is o
surface. The availabili
will significantly reduc
based measurements a
predicted PM.

The PACE website is d
engage the community
and process feedbac
interactive workshop
tutorials and other per

PACE/HyspIRI COMPLEMENTARY MISSION APPLICATIONS:
Improving Hazard Assessment and Aviation Safety

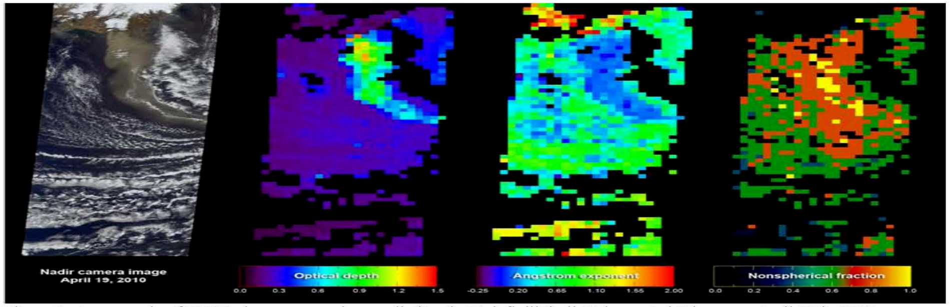


Figure 1. An example of MISR air mass mapping applied to the Eyjafjalljökull Volcano Ash Plume on April 19th, 2010. The four panels show successive information content (true color, optical depth, size, and sphericity) obtained from retrievals using multi-spectral, multi-angle MISR data (courtesy of Ralph Kahn and the MISR Team). This is similar to the information content of the multi-angle multi-spectral polarimeter planned for PACE.

Application Question/Issue

Aviation operations can be significantly impacted by volcanic ash as evident from the recent Eyjafjallajökull volcano in Iceland (April 2010). Knowledge of the location, amount, and evolution of the volcanic plume and its ash content will enable timely and accurate hazard assessment/avoidance and enhance aviation safety after volcanic eruptions.

Who Cares and Why?

Volcanic plumes consist of Sulfur Dioxide (SO_2) and volcanic ash which is predominantly composed of silicates with a melting point (~1100°C) far below the turbine engine full thrust temperature of 1400°C. Aircraft flight through high concentrations of volcanic ash will fuse molten silicate on to turbine blades and guide vanes leading to transient flame out, and possibly engine failure. According the International Civil Aviation Organization (ICAO) Journal Issue 1 (2013), more than 100,000 commercial flights were cancelled during the Eyjafjallajökull's 2010 volcanic eruption and over $5 billion in global GDP was lost due to what eventually became the largest shut-down of European air traffic since World War II.

Needed Measurements

An ICAO task force recommended the use of satellite-based observations to guarantee safety while avoiding the unnecessary closure of immense portions of airspace. The closure of air space during the 2010 eruption of Eyjafallajökull was based on forecasts rather than satellite observations of ash. Satellite measurements will help to initialize and/or validate such forecasts. Measurements of volcanic plumes, plume height, ash and SO_2 concentrations, and the ability to discriminate between clouds of volcanic ash and meteorological (water/ice) clouds are needed. Some of these measurements are needed both day and night for the development of advisories directly or as inputs to model simulations from which such advisories will be developed.

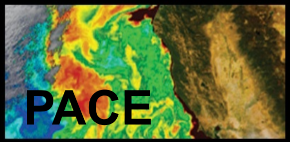
The NASA Response

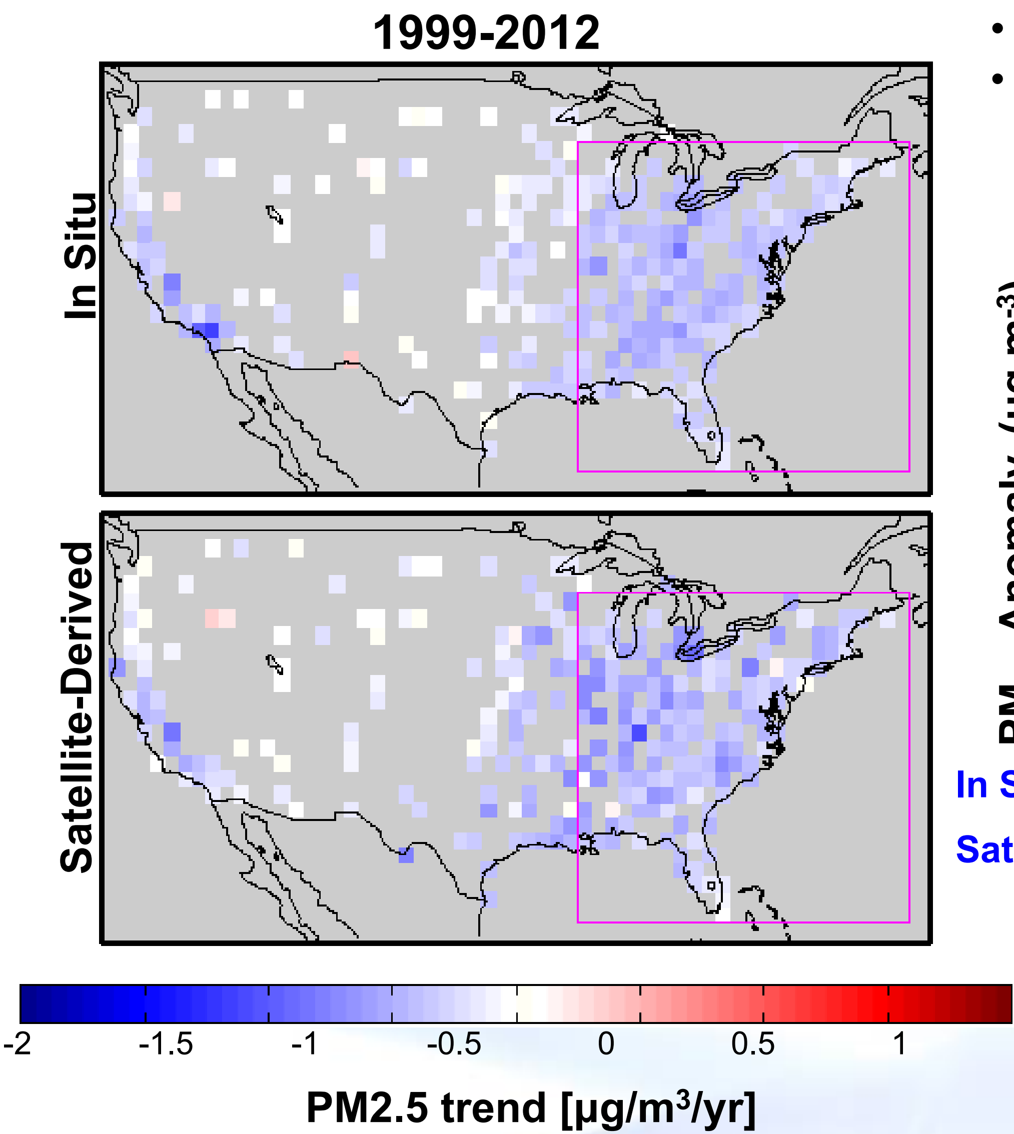
Measurements, similar to the information content of Figure 1 above, that would identify the ash particle size and concentration (from a **Multi-angle Multi-spectral Polarimeter on PACE**), and the ability to discriminate between water/ice clouds and volcanic plumes (from **HyspIRI**) would form **a complementary data** set and provide the relevant Volcanic Ash Advisory Centers (VAACs) **sufficient actionable information** for hazard avoidance during volcanic eruptions. The Eyjafjallajökull plume was observed by many satellites sensors including OMI, MISR, MODIS, SEVIRI, ASTER, AIRS, and CALIPSO. The MODIS instruments (in low earth orbit on the Terra and Aqua satellites) and the SEVIRI instrument (on METEOSAT in geostationary orbit) tracked the geographic transport of the ash plume and estimated its height and ash particle size, and HyspIRI TIR measurements will provide us with similar capabilities. The MISR instrument on the Terra satellite, provided critical information that allowed mapping the height of distinct plumes over the North Atlantic. Multi-angle aerosol measurements on board PACE would enable plume heights to be derived in a manner similar to those employed using MISR. Additionally polarization measurements aboard PACE would enable separation of volcanic ash from sulfate aerosols. The ability to obtain these data results in direct societal benefit.

Comments? Thoughts?

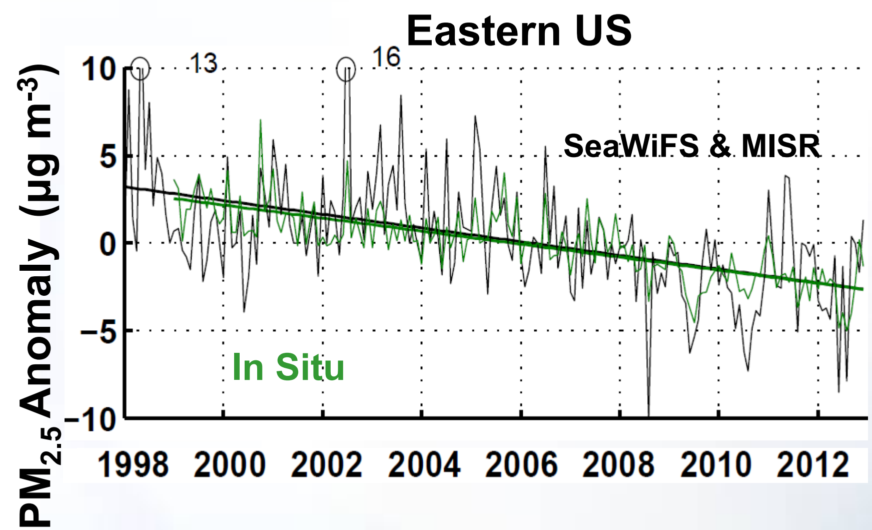
The PACE and HyspIRI websites are designed engage the community of practice (CoP), accept and process feedback and queries, support interactive workshops and disseminate user tutorials and other pertinent information. A list of contacts and a page for comments can be found at http://decadal.gsfc.nasa.gov/pace.html.

SeaWiFS and MISR AOD give insight into $PM_{2.5}$ trend





- Both instruments radiometrically stable
- CALIOP unavailable before 2006
  - cannot use on long-term AOD-$PM_{2.5}$ relationship



In Situ (1999-2012): 0.37 ± 0.06 μg m^{-3} yr^{-1}

Satellite-Derived (1999-2012): 0.36 ± 0.13 μg m^{-3} yr^{-1}

- Apply relative change to 2001-2010 mean $PM_{2.5}$ → consistent magnitude and trend

Analog: OCI + Polarimeter

Boys et al., ES&T, 2014

PACE MISSION APPLICATIONS – AIR QUALITY

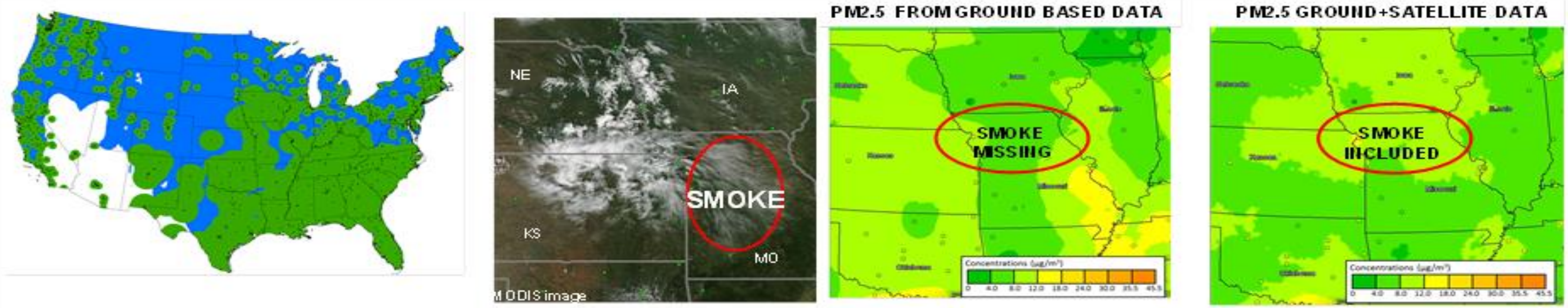


Figure 1. Ground monitors (denoted by small dots) for measuring the concentration of particulate material (PM). Without satellite data, the area of coverage would be limited only to the areas shaded green. The MODIS Satellite data is used to fill most of the gaps (but not all). The next columns show MODIS image of a typical air quality situation resulting from fires, the nominal solution (PM2.5 from ground based data), and NASA's contribution (PM2.5 from Ground + Satellite Data). In the nominal solution because the ground monitors in this region are very few, the interpolated PM2.5 data shows relatively good Air Quality (AQI of 0 – 4). The addition of satellite data shows that the Air Quality as a result of the fires is poorer at AQI = 4-8.0. Satellite data has real value in producing an Air Quality Index that actually protects the public from harm. If the satellite data were not there, there would be no indication of this poorer air quality (Images courtesy of the AirNow Group)

Application Question/Issue

What is the air quality forecast of particulate matter concentration (PM, an indication of the extent of air pollution) predicted from *satellite* measurements of the aerosol optical depth (AOD) in regions where there are no *ground* measurements of PM? Figure 1 is an illustration of such an application.

Who Cares and Why?

In regions where there are no ground measurements of PM, the EPA and thus the public has no indication of the extent of air pollution, a situation that has deleterious public health implications. Satellite measurements of AOD can be used to estimate PM in such areas. The Environmental Protection Agency (EPA) produces a daily air quality index (AQI) which comprises both the ozone and particulate matter concentrations. The latest surveys show 75 -80% of the public are aware of AQI and 50% report taking action based on the AQI.

Needed Measurement(s)

The accuracy of the daily (and forecast) AQI depends on the spatial resolution, latency and accuracy of the satellite-observed AOD and the validity of the relationship between column AOD and surface PM. To meet the needs of the public, the satellite measurements of AOD must be produced at spatial resolutions of less than 1 km at a latency not exceeding 1 hour and at an accuracy of ±0.05. The predicted PM using the column AOD and auxiliary measurements must be within ±(1 μg/m^3+42%)[c.f. van Donkelaar 2012]

The NASA Response

The PACE mission will produce AOD at an accuracy of ± 0.02 at a horizontal resolution of 250-500 m. It is expected that the latency of the broadcast PACE data will be at least as good as the Land Atmosphere Near Real-Time Capability for EOS (LANCE, http://lance-modis.eosdis.nasa.gov/data_products/) MODIS AOD products currently available in less than 90 minutes for the Level 2 10 km Swath AOD. Additional capabilities such as ground-based lidars, sondes or models of trajectories (e.g., HYSPLIT http://ready.arl.noaa.gov/HYSPLIT.php), and chemical transport models are required to identify elevated layers. This is because PACE will measure whole column AOD and the air quality concern is only the layer closest to the surface. The availability of a PACE Polarimeter will significantly reduce reliance on ground- based measurements and enhance accuracy of the predicted PM.

Comments? Thoughts?

The PACE website is designed engage the community of practice (CoP), accept and process feedback and queries, support interactive workshops and disseminate user tutorials and other pertinent information. Comments and feedback can be posted at http://decadal.gsfc.nasa.gov/pace.html where there is also a list of contacts.

PACE

Available LANCE NRT Products

Instrument	Product Categories	Average Latency
Atmospheric Infrared Sounder (AIRS)	Radiances, Temperature, Moisture Profiles, Precipitation, Dust, Clouds and Trace Gases	75 - 140 minutes
Advanced Microwave Scanning Radiometer 2 (AMSR2)	Global Total Precipitation, Global Rainfall, Total Precipitable Water (TPW), Ocean Wind Speed (OWS), Columnar Cloud Liquid Water (CLW) over ocean, Columnar Water Vapor (CWV) over ocean, Snow Water Equivalent (SWE), Sea Ice Concentration, Brightness Temperature (Tb)	75 – 165 minutes
Microwave Limb Sounder (MLS)	Ozone, Temperature, Carbon Monoxide, Water Vapor, Nitric Acid, Nitrous Oxide, Sulfur Dioxide	75 - 140 minutes
Moderate Resolution Imaging Spectroradiometer (MODIS)	Radiances, Clouds/Aerosols, Water Vapor, Fire, Snow Cover, Sea Ice, Land Surface Reflectance, Land Surface Temperature	60 - 125 minutes
Ozone Monitoring Instrument (OMI)	Ozone, Sulfur Dioxide, Aerosols, Cloud Top Pressure	100 - 165 minutes

Mission Applications Value of PACE

FACTORS THAT WILL INCREASE THE VALUE OF PACE MEASUREMENTS

Inclusion of a polarimeter would allow enhanced measurements of atmospheric composition and pollutants and would increase the value of applications relevant to air-quality & public health

Increased spatial resolution (better than 1 km at nadir) would improve coverage of urban, coastal and estuarine areas, increasing applications value relevant to air and water quality

Low latency (~6hrs) would allow for faster satellite data product distribution to end users, near-real time applications, and increased mission applications value

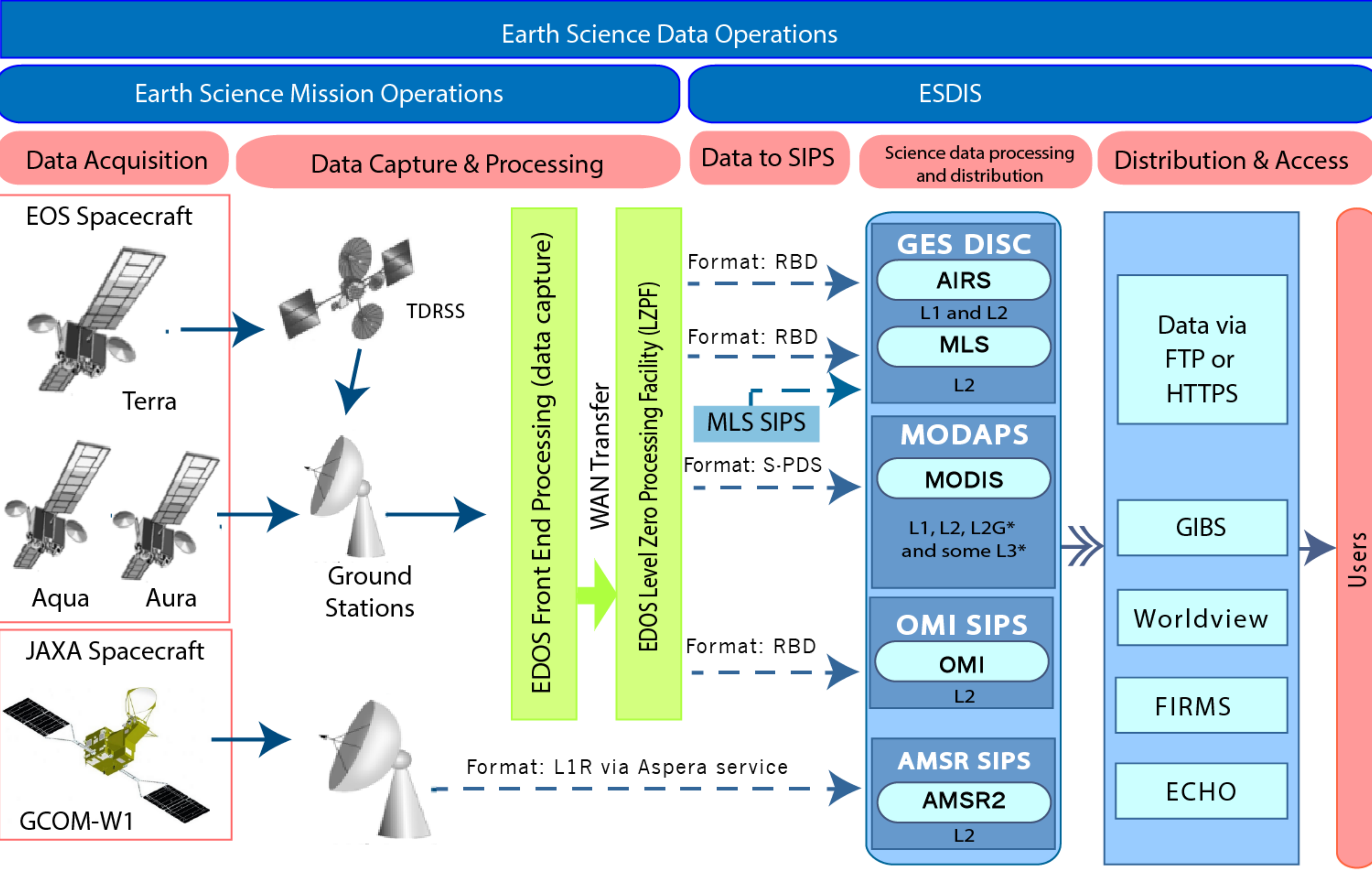
Synergy with other contemporaneous/co-located measurements

Applications Traceability Matrix

PACE

Application Question	Application Concept	Application Measurement Requirements	Applied Sciences Category	Potential Host Agency	Mission Data Product	Projected Mission Performance (SDR)	ARL	Ancillary Measurements
What is the air quality forecast of particulate matter (PM) predicted from PACE aerosol optical depth (AOD) in regions where there are no direct measurements of PM	In regions where there are no direct measurements of PM, satellite measurements of AOD can be used to estimate PM. The EPA produces a daily air quality index which comprises both the ozone and particulate matter concentrations	Multi- spectral observations of AOD at spatial resolutions of less than 1 km and latency of 3 hours	Public Health and Air Quality	Environmental Protection Agency [James Szykman - EPA]	Multi-spectral AOD	AOD to ± 0.02 at a horizontal resolution < 1km	3	Aerosol vertical distributions Surface PM concentrations at a few locations
Volcanoes: What is the volcanic ash concentration during and after a volcanic eruption? Is there an impact on air quality as a result of a volcanic material deposited in coastal/populated regions?	Quantify concentration using measurements collected to support PACE atmospheric corrections and useful data to enable prudent aviation volcanic ash hazard mitigation policy and advisories?	Observations of AOD at spatial resolutions of less than 1 km and latency of 3 hours	Disaster Mitigation Health and Air Quality	Federal Aviation Administration (FAA), US EPA, NOAA, International Civil Aviation Organization, Volcanic Ash Advisory Centers [Shobha Kondragunta- NOAA]	Multi-spectral AOD	AOD within ± 0.02 at a horizontal resolution of < 1km	3	Aerosol vertical distributions Sulfur dioxide concentrations

Applied Sciences Category:	Disaster Mitigation, Ecological Forecasting, Health and Air Quality, Water Management, Agriculture, Climate, Energy, Oceans, and Weather
Justification for Application Readiness Level 3: Proof of Application Concept (Viability Established) Feasibility studies to assess the potential viability of and provide a proof-of-concept for the application have been conducted.	



RBD: Rate Buffered Data
S-PDS: Session Based Production Data Set
*L2G and L3 products have a latency of 27 - 48 hours
SIPS:Science Investigator-led Processing Systems
TDRSS: Tracking and Data Relay Satellite System

ACE/PACE Applications Concepts

Some Application Concepts identified as most critical/relevant to ACE/PACE mission, by the PACE Science Team (January 2015 Meeting):

- HAB monitoring
- Fisheries
- Fire monitoring
- Smoke monitoring
- Volcanic ash
- Freshwater applications/ water quality
- Sea Ice
- Trichodesmium blooms
- Coral reefs / habitat management
- Overlap with GEO-CAPE to track plumes and blooms
- Land products, NDVI etc
- Sediment products, particle size, particle type
- Air quality, type, plumes