Using NASA Remote Sensing Data for Multiscale Air Quality Models

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Presentation Purpose

- To discuss the availability and usefulness of NASA remote sensing data, and data discovery and access services, in support of air quality research and modeling for public health studies

- To discuss data usability issues and potential solutions that enable the use of remote sensing data in air quality modeling and research

Environmental Health

Environmental health is **that branch of public health** that is concerned with all aspects of the natural and built environment that may affect human health. The field of environmental health is closely related to environmental science and public health as environmental health is **concerned with environmental factors affecting human health**.

World Health Organization:

(http://www.who.int/topics/environmental_health/en)

Environmental health addresses all the physical, chemical, and biological factors external to a person, and all the related **factors** impacting behaviours. It encompasses the assessment and control of those **environmental factors that can potentially affect health**. It is targeted towards preventing disease and creating health-supportive environments. This definition excludes behaviour not related to environment, as well as behaviour related to the social and cultural environment, and genetics

Remote Sensing Data and Public Health

Key information required by epidemiological studies is the spatial and temporal distributions of **environmental factors** and their proximity to concerned cohorts.

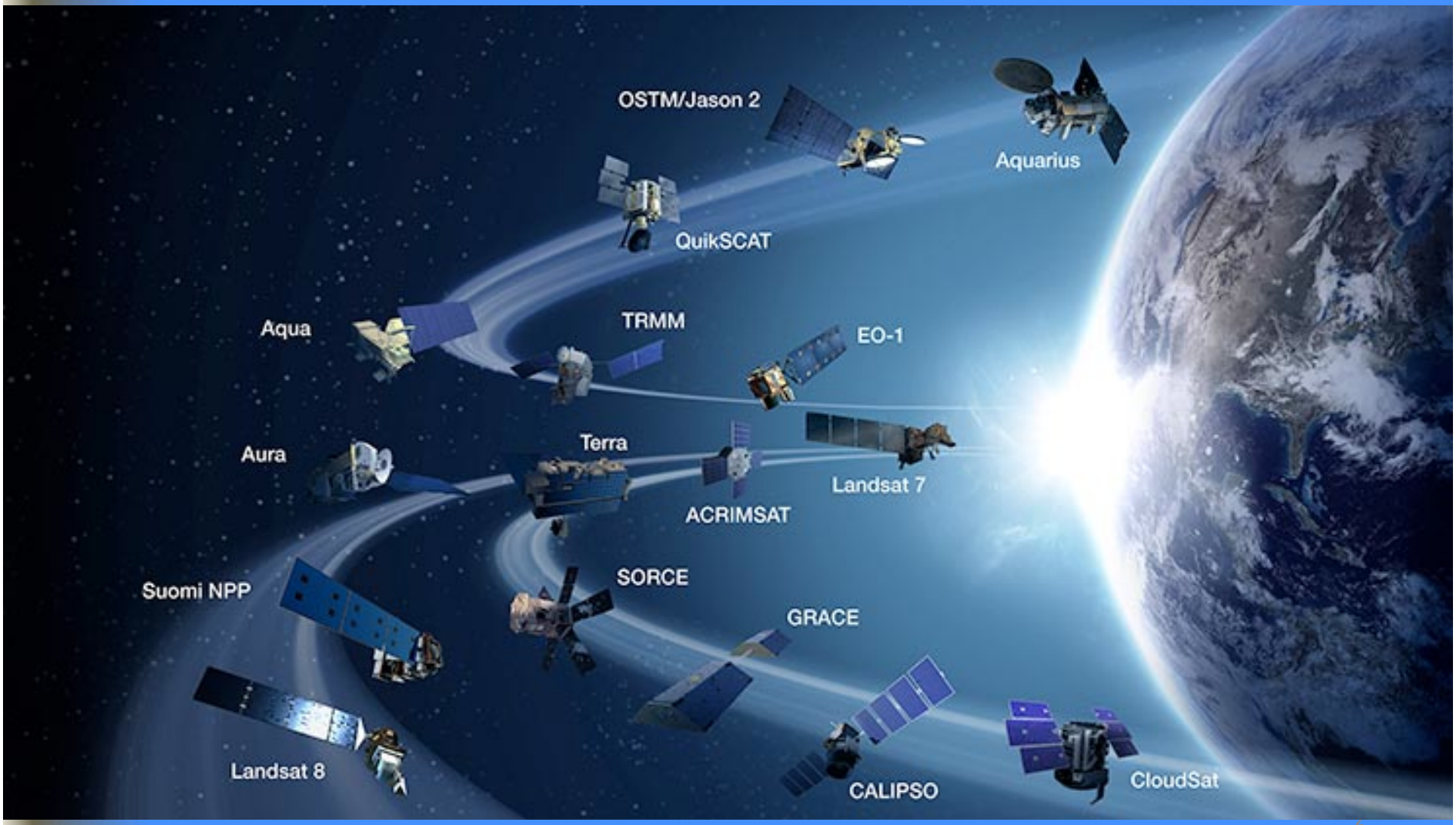
- Remote sensing data provides evenly gridded spatial coverage
- Collection is quick and systematic
- Provides global coverage

Remote Sensing Data, Environmental Health, and Public Health

The potential of Remote Sensing data to contribute measureable Environmental Health factors to Public Health research is evident, if not fully realized

NASA's Earth Observing System Operating Missions

EOS Science Project Office, Image by Jenny Mottar



Remote Sensing Measurements Found Useful for Air Quality Modeling and Related Disease Research

(not exhaustive)

- Aerosol
- Atmospheric Chemistry components
- Normalized Difference Vegetation Index (NDVI)
- Surface Temperature
- Solar Insolation
- Relative Humidity

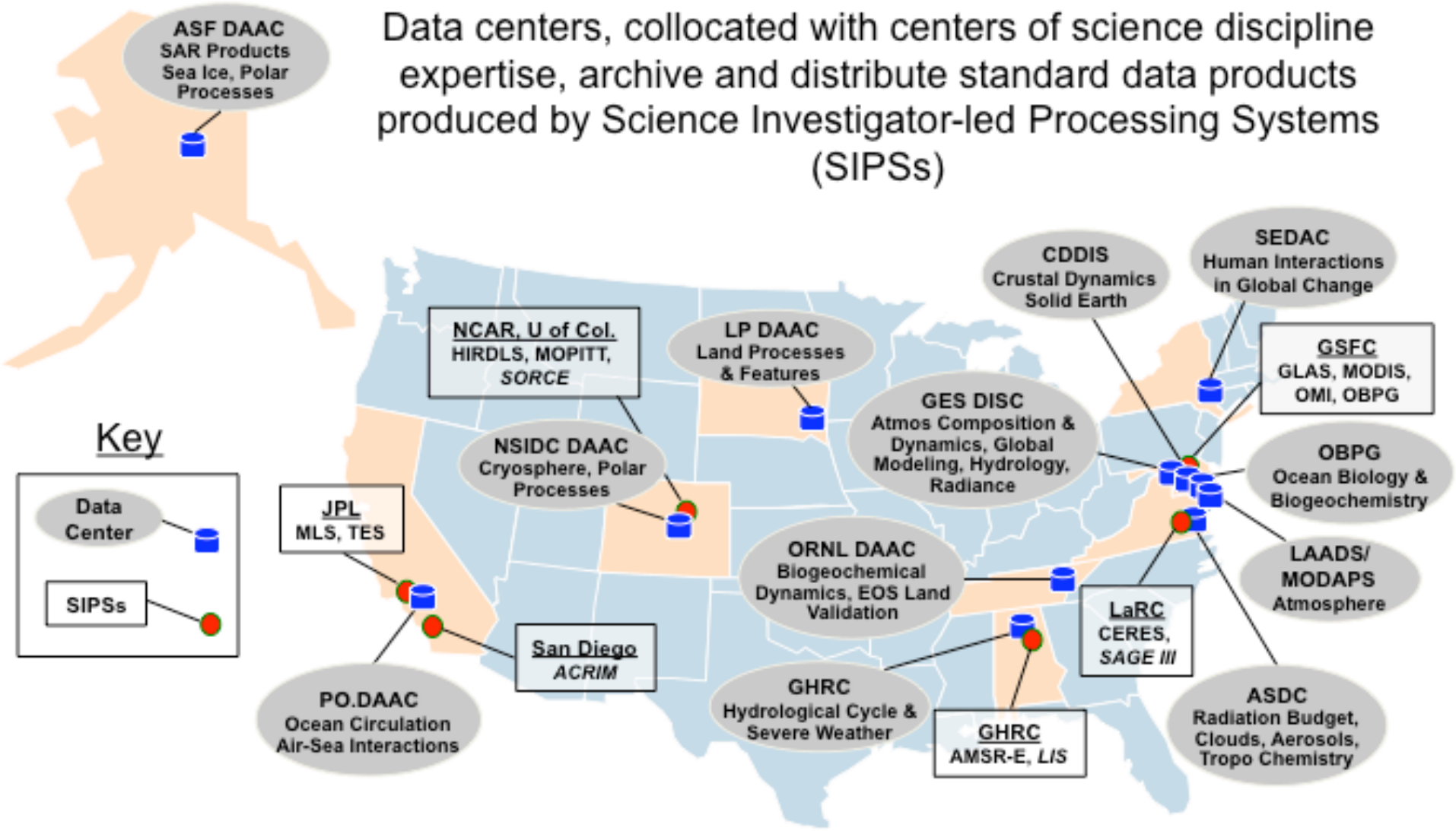
Exemplary NASA Air Pollution Related Disease Research Using Remote Sensing Data

- *Yang Liu*/Harvard School of Public Health, Enhancing Environmental Public Health Tracking with Satellite-Driven Particle Exposure Modeling and Epidemiology
- *Jeffrey Luvall*/NASA Marshall Space Flight Center, Integration of Airborne Dust Prediction Systems and Vegetation Phenology to Track Pollen for Asthma Alerts in Public Health Decision Support Systems
- *Leslie McClure*/University of Alabama at Birmingham, Linking NASA Environmental Data with a National Public Health Cohort Study to Enhance Public Health Decision Making
- *Stanley Morain*/University of New Mexico, Adding NASA Earth Science Results to EPHTN via the NM/EPHT System
- *Amy Huff*/Battelle Memorial Institute, Using NASA Satellite Aerosol Optical Depth Data to Create Representative PM2.5 Fields for Use in Human Health and Epidemiology Studies in Support of State and National Environmental Public Health Tracking Programs

EOSDIS Facilities

https://earthdata.nasa.gov/data/data-centers

Data centers, collocated with centers of science discipline expertise, archive and distribute standard data products produced by Science Investigator-led Processing Systems (SIPSs)



EOSDIS – Earth Observing System Data and Information System
DAAC – Distributed Active Archive Center

NASA's Earth Science Data Centers	Discipline
Alaska Satellite Facility SAR Data Center (ASF SDC) website: http://www.asf.alaska.edu	• Synthetic Aperture Radar (SAR) • Sea Ice • Polar Processes • Geophysics
Crustal Dynamics Data Information System (CDDIS) website: http://cddis.gsfc.nasa.gov/	• Space Geodesy
Global Hydrology Resource Center (GHRC) website: http://ghrc.msfc.nasa.gov/	• Hydrologic Cycle • Severe Weather Interactions • Lightning • Atmospheric Convection
Goddard Earth Sciences Data and Information Services Center (GES DISC) website: http://disc.sci.gsfc.nasa.gov/	• Global Precipitation • Solar Irradiance • Atmospheric Composition • Atmospheric Dynamics • Global Modeling
Land Processes (LP) DAAC website: https://lpdaac.usgs.gov/	• Surface Reflectance • Land Cover • Vegetation Indices
Level 1 Atmosphere Archive and Distribution System (MODAPS LAADS) website: http://ladsweb.nascom.nasa.gov/	• Radiance • Atmosphere

NASA Langley Research Center Atmospheric Science Data Center (LaRC ASDC) website: http://eosweb.larc.nasa.gov/	• Radiation Budget • Clouds • Aerosols • Tropospheric Chemistry
National Snow and Ice Data Center (NSIDC) DAAC website: http://nsidc.org/	• Snow • Ice • Cryosphere • Climate
Oak Ridge National Laboratory (ORNL) DAAC website: http://daac.ornl.gov/	• Biogeochemical Dynamics • Ecological Data • Environmental Processes
Ocean Biology Processing Group (OBPG) website: http://oceancolor.gsfc.nasa.gov/	• Ocean Biology • Ocean Color • Biogeochemistry • Sea Surface Temperature
Physical Oceanography (PO) DAAC website: http://podaac.jpl.nasa.gov/	• Sea Surface Temperature • Ocean Winds • Circulation and Currents • Topography and Gravity
Socioeconomic Data and Applications Data Center (SEDAC) website: http://sedac.ciesin.columbia.edu/	• Human Interactions • Land Use • Environmental Sustainability • Geospatial Data • Multilateral Environmental Agreements

At the GES DISC …

- The GES DISC specializes in serving and supporting atmospheric, hydrologic, and precipitation remote sensing, and remote sensing based assimilated data
- The GES DISC provides data access, discovery, visualization, retrieval, and analysis services to glean information from data
- Many GES DISC datasets are useful for air quality research, modeling, surveillance, and decision support systems
- **The GES DISC is one of several NASA data archives containing data useful for air quality research**

Relating Remote Sensing Data to Air Quality Research

Temporal Coverage, Temporal Resolution, Spatial Resolution Considerations:

- Measurements with long temporal coverage are useful for long term studies and health trend relationships.
- High temporal resolution measurements support short term health variability studies.
- High spatial resolution measurements are used for relating to local, small region health studies.
- Lower resolution remote sensing measurements are sufficient for wider, regional public health studies

GES DISC Data Holdings Relevant to Air Quality Research and Modeling

(See backup slides for spatial resolution, temporal coverage, usage, and health relevance… and acronym list)

	Remote Sensing Data	Assimilated Data
Aerosol	OMI, TOMS, HIRDLS	GOCART
Atmospheric Composition	AIRS, OMI, MLS, HIRDLS	MERRA
Vegetation Index		GLDAS, NLDAS, MERRA
Surface Air Temperature	AIRS, TOVS	GLDAS, NLDAS, MERRA
Insolation	SORCE	
Relative Humidity	AIRS, OMI, MLS, TOMS	MERRA, NLDAS

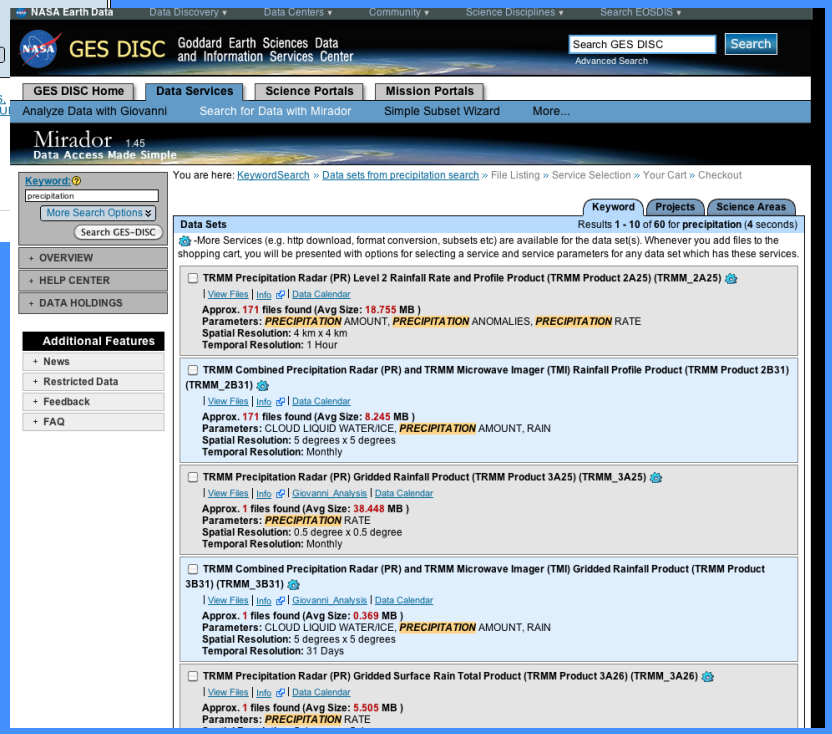
GES DISC Data Search and Access Services

Mirador
http://mirador.gsfc.nasa.gov

Choose:
Keyword search, Time
Location…

or Project…

or Science Area



Other Services:

- OPenDAP
http://disc.sci.gsfc.nasa.gov/services/opendap/
- GrADS Data Server (GDS)
http://disc.sci.gsfc.nasa.gov/services/grads-gds
- Web Map Service (WMS)
http://disc.sci.gsfc.nasa.gov/services/ogc_wms
- Simple Subset Wizard (NASA Earth science data-wide data subsetting service)
http://disc.gsfc.nasa.gov/SSW/

Giovanni Data Discovery and Exploration Allows Researchers to Concentrate on the *Research*

The Old Way:

Pre-Science

- Find data
- Retrieve high volume data
- Learn formats and develop readers
- Extract parameters
- Perform spatial and other subsetting
- Identify quality and other flags and constraints
- Perform filtering/masking
- Develop analysis and visualization
- Accept/discard/get more data (sat, model, ground-based)

DO SCIENCE

- Exploration
- Initial Analysis
- Use the best data for the final analysis
- Derive conclusions
- Write the paper
- Submit the paper

Jan
Feb
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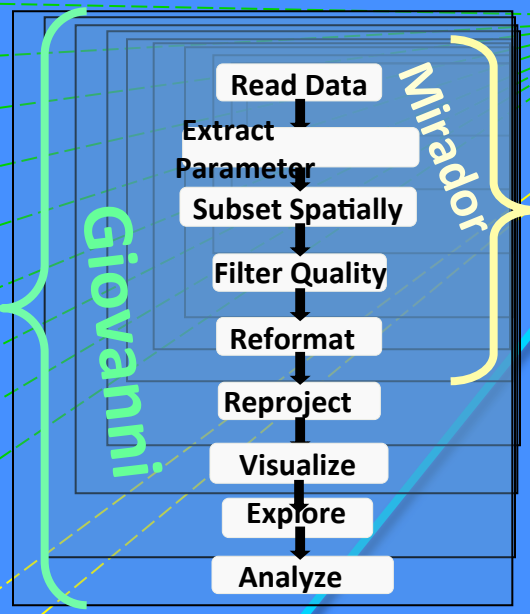
Web-based Services:



The Giovanni Way:

- Minutes
- Days for exploration

- Use the best data for the final analysis
- Derive conclusions
- Write the paper
- Submit the paper

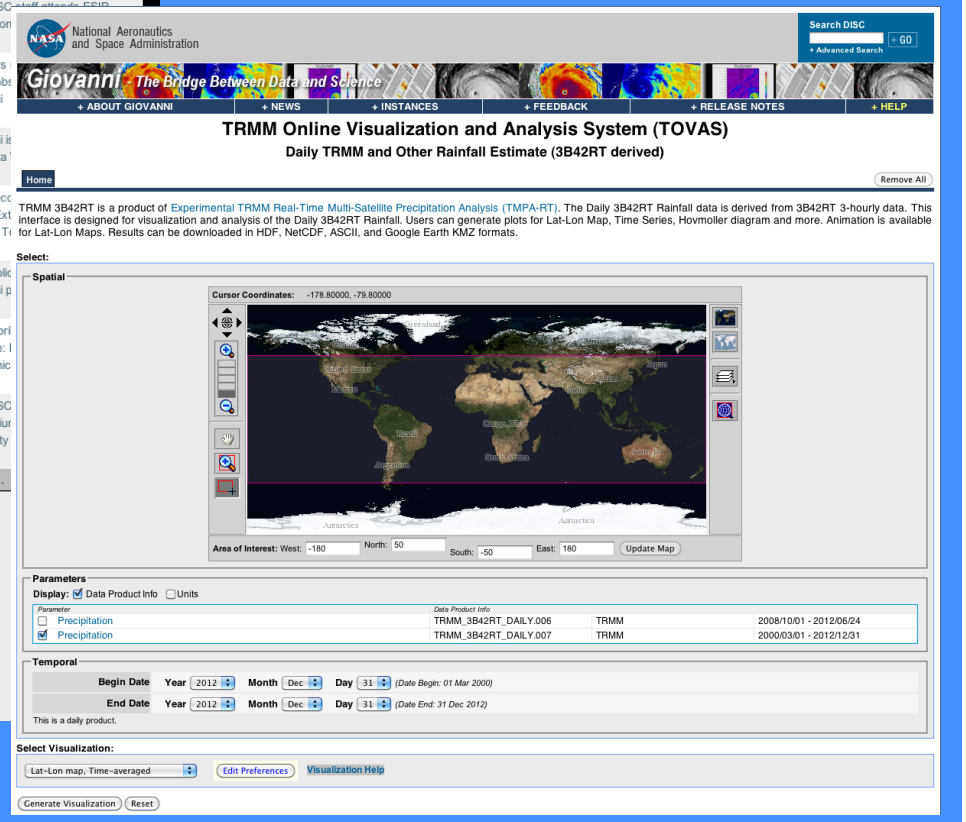
DO SCIENCE

Giovanni and other web-based tools allow scientists to ***compress*** the time needed for pre-science preliminary tasks: *data discovery, access, manipulation, visualization, and basic statistical analysis.*

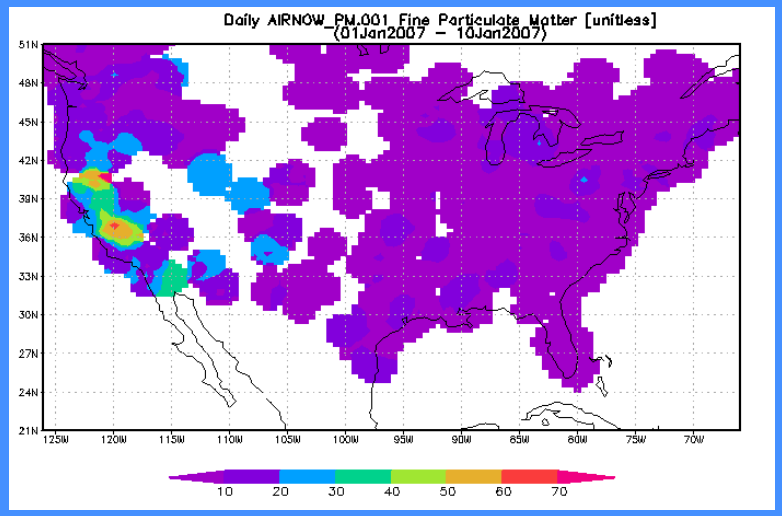
disc.sci.gsfc.nasa.gov/giovanni

Choose Giovanni instance…

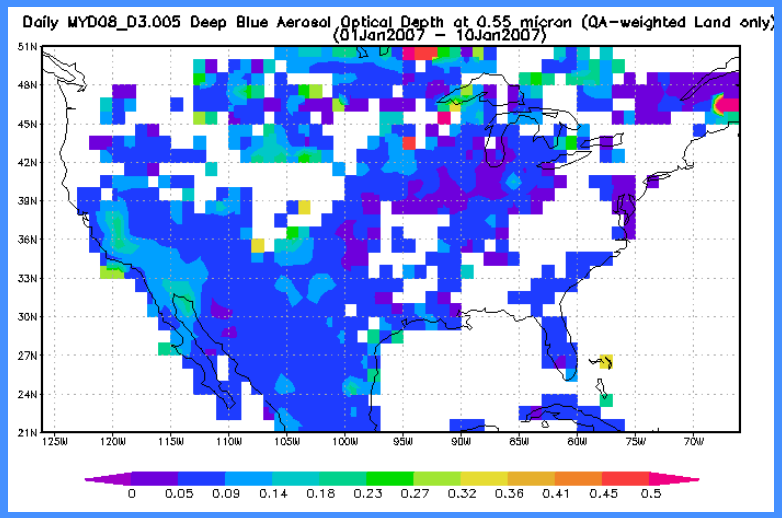
select location, time, measurement, and visualization



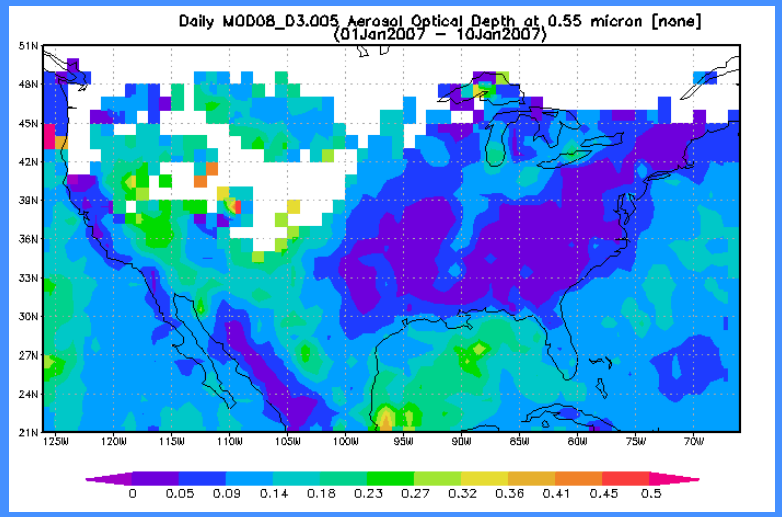
PM2.5 data in Giovanni



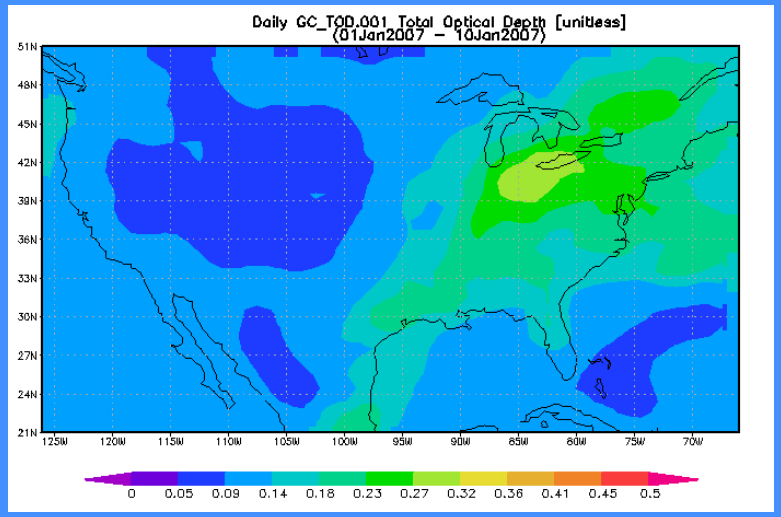
PM2.5 (EPA→ DataFed → Giovanni)



Deep Blue MODIS Aerosol Optical Depth



The standard MODIS AOT



GOCART AOT

Let's talk about NASA Remote Sensing Data Usability for Air Quality Research and Modeling

- Remote Sensing provides a significant resource in producing Environmental Health measurements valuable in studying Public Health, and specifically Air Quality
- Please note: NASA data is typically created to address specific science research questions, but broader use in science applications research is proven and effective
- When utilizing remote sensing data for science applications research, a very good understanding of the data is needed, as well as how the data needs to be made usable (interpreted) for the specific application research
- Time investment is needed… but worth it.

Interpreting NASA Remote Sensing Data for Air Quality Research and Modeling

Popular Air Quality Models:

- Community Multiscale Air Quality (CMAQ) model, developed jointly by the US Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA)
- NASA-Unified Weather Research and Forecasting (NU-WRF) model. The NU-WRF modeling system has explicit land-cloud-aerosol-precipitation interactions

Interpreting NASA Remote Sensing Data for Air Quality Research and Modeling

Technical Challenges:

- Having specialized data access services for Level 2 data: Regional modelers prefer high resolution satellite data, while most data services provide merged Level 3 products
- Obtaining quality filtered data: Data quality filtering requires in-depth understanding of the specific data product, and knowledge of common practices by the air quality and remote sensing communities
- Acquiring proper horizontal projections: Regional modelers define their own horizontal gridding with regular spacing in distance, not necessarily following latitude/longitude lines
- Acquiring data in formats that are model ready: Data needs to be converted into formats compatible with air quality models

Interpretation of NASA Remote Sensing Data for Air Quality Research and Modeling: **Proof of Concept**

The NASA Remote Sensing Data Interpretation for Air Quality Research and Modeling includes the following features:

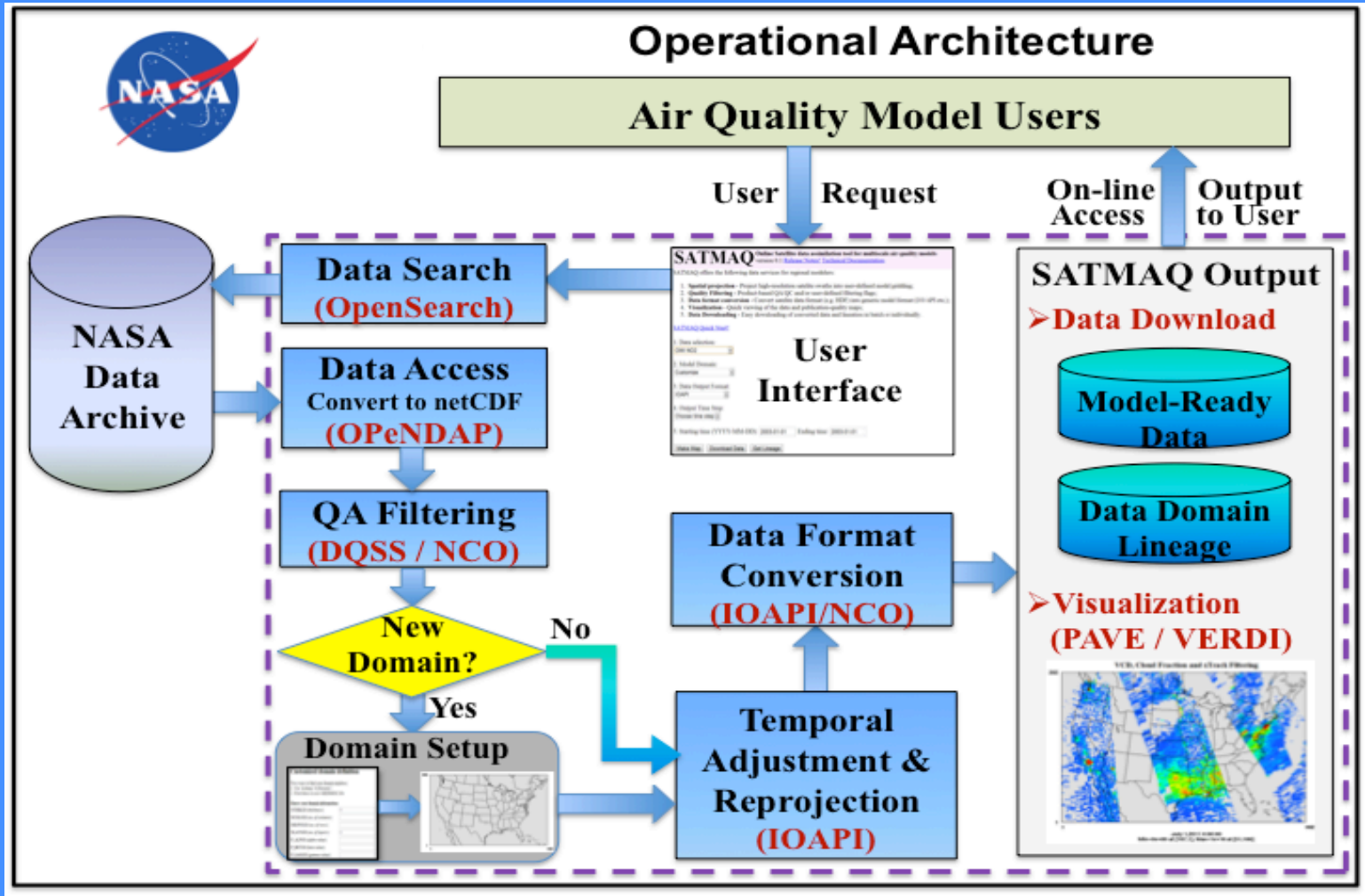
- **Spatial projection** - Cast high-resolution Level 2 satellite data directly into dynamically generated user-defined regional model gridding.
- **Format conversion** - Convert HDF or netCDF data into model specific formats.
- **Quality filtering** - Apply quality control flags to filter data.
- **Temporal resolution adjustment** – Adjust desired data to extract data coincident with model requirement.
- **Model ready output** – Provide modelers output files in specific format and projection directly usable in their model, consistent with other model inputs.
- **Domain Definition** – Allow modelers to dynamically define their own domain
- **Browse images**– Allow quick look at domain data results
- **Expandability** – Provide capabilities that can be reused/adapted for other models.

Interpretation of NASA Remote Sensing Data for Air Quality Research and Modeling: **Proof of Concept**

- Learn from previously developed interpreters: Wisconsin Horizontal Interpolation Program for Satellites (WHIPS) (Holloway, Univ. of Wisconsin)
- Utilize existing components for interpreting data:

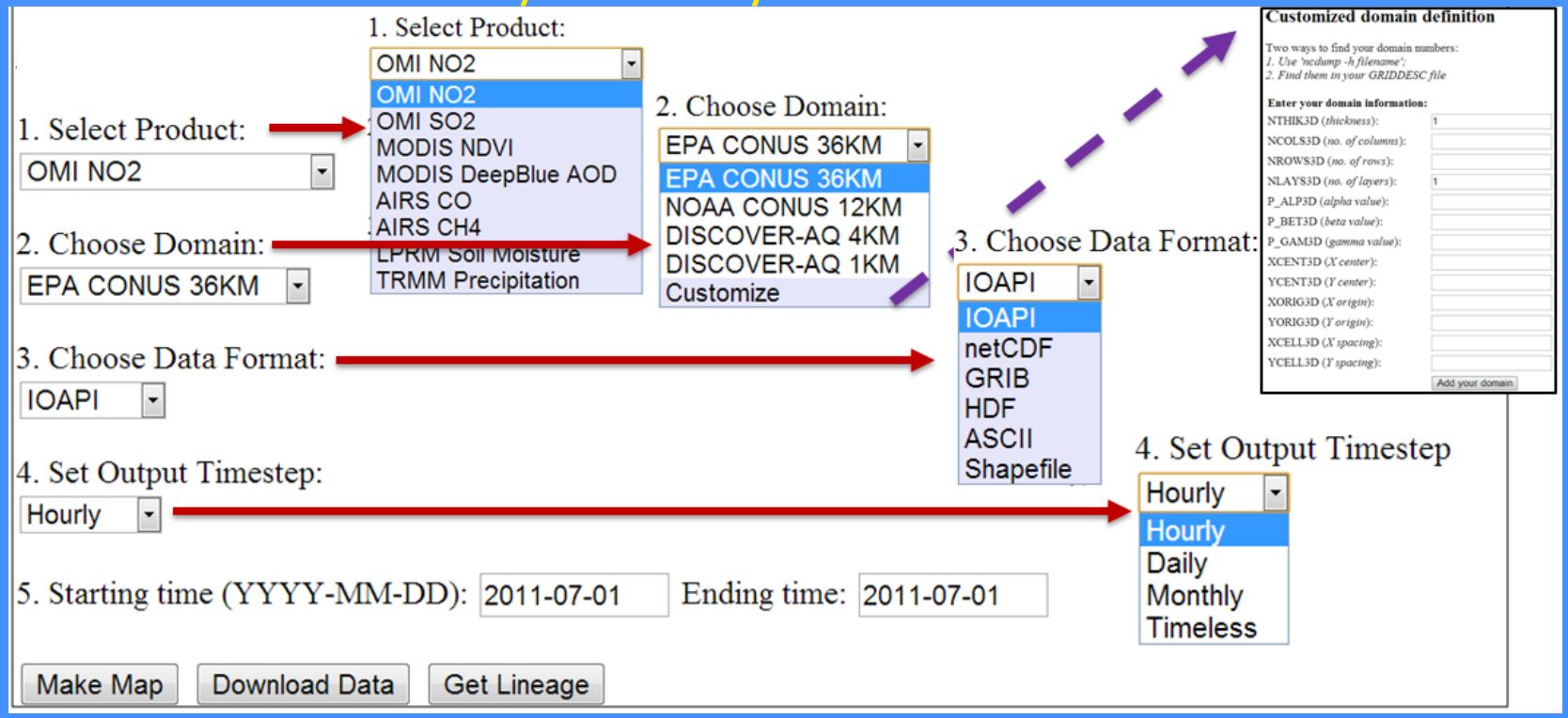
Component	Technical Approaches	Usage
Search NASA data	OpenSearch Services (OSS)	Use OpenSearch implementation to download distributed data location search result
Access and convert data to netCDF	OpenDAP	Coupled with OpenSearch, use the popular OpenDAP protocol for common data conversion.
Perform data quality screening	DQSS (Data Quality Screening Service); Alternative: NCO (netCDF Operators)	Use operational quality screening code to provide users with highly desired quality assessment.
Horizontal reprojection	IOAPI (Input/Output Application Programming Interface)	Open Source IOAPI provides reprojection routines tailored for AQ modeling
Convert data to IOAPI file format	IOAPI or NCO	IOAPI routines convert data into the specific output format, required for CMAQ modelers; Reusing Open Source NCO may require less overhead
Visualize data	PAVE (Package for Analysis and Visualization of Environmental data) and VERDI (Visual Environment for Rich Data Interpretation)	Used by AQ modelers, both PAVE and VERDI are flexible and distributable applications to visualize, specifically, environmental data.

Interpretation of NASA Remote Sensing Data for Air Quality Research and Modeling: **Proof of Concept**



Interpretation of NASA Remote Sensing Data for Air Quality Research and Modeling: **Proof of Concept**

User interface to dynamically select data and domain:



Interpretation of NASA Remote Sensing Data for Air Quality Research and Modeling: **Proof of Concept**

Exemplary Remote Sensing Data Products:

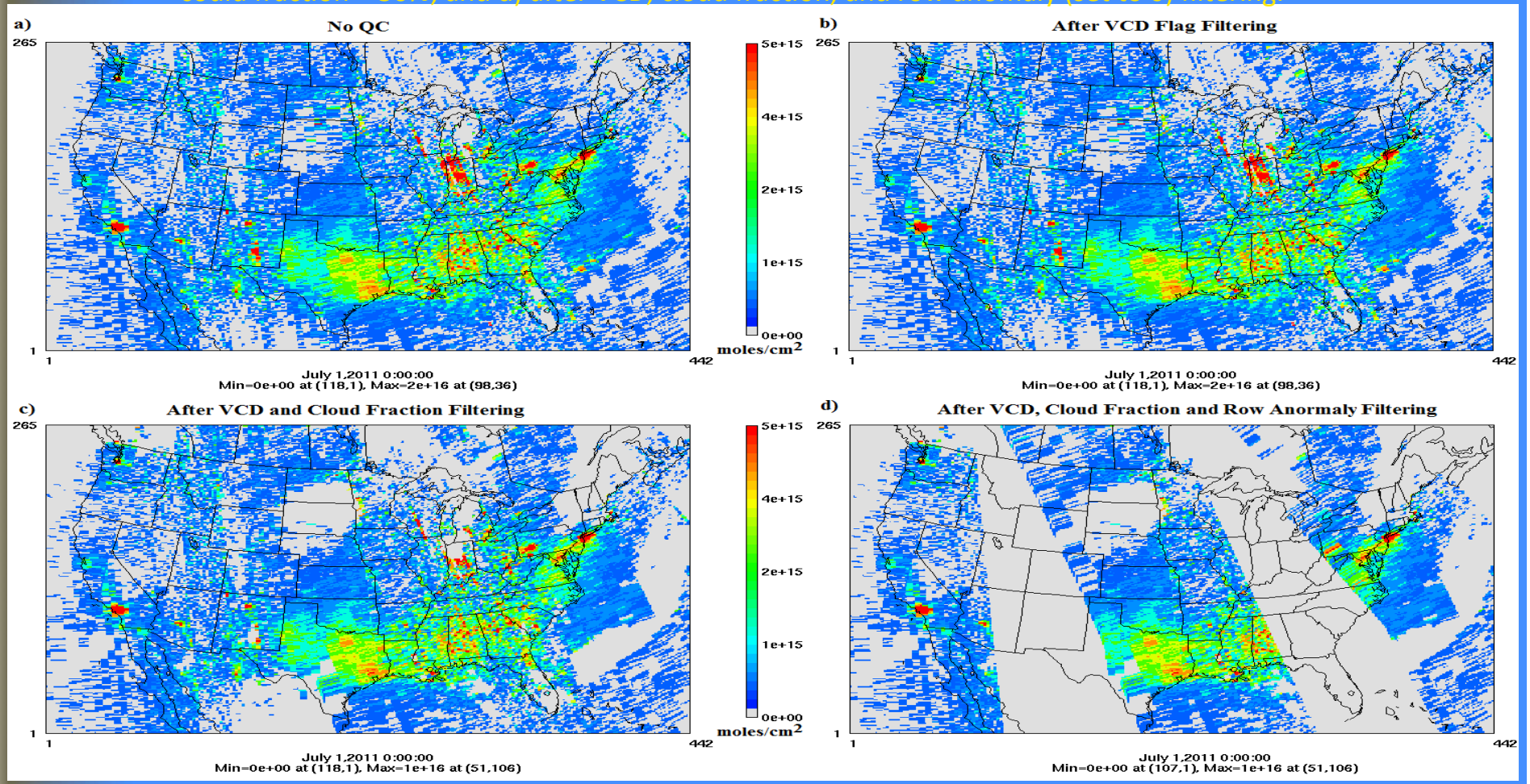
Instrument/Model Parameter	Spatial Coverage	Temporal Coverage	Expected End Users
OMI NO2 (Aura)	Global	2004-Present	NASA/NOAA
OMI SO2 (Aura)	Global	2004-Present	NOAA
MODIS Deep Blue AOD (Aqua)	Global	2002- Present	NASA/NOAA/CMAS
MODIS NDVI (Aqua)	Global	2002-Present	NOAA
LPRM Soil Moisture (AMSR-E)	Global	2002-Present	NOAA
AIRS Carbon Monoxide (Aqua)	Global	2002-Present	NASA/CMAS
MOPITT Carbon Monoxide (Terra)	Global	2000-Present	NASA/CMAS
TRMM Precipitation	Global	1998-Present	NASA/NOAA

Interpretation of NASA Remote Sensing Data for Air Quality Research and Modeling:

Proof of Concept

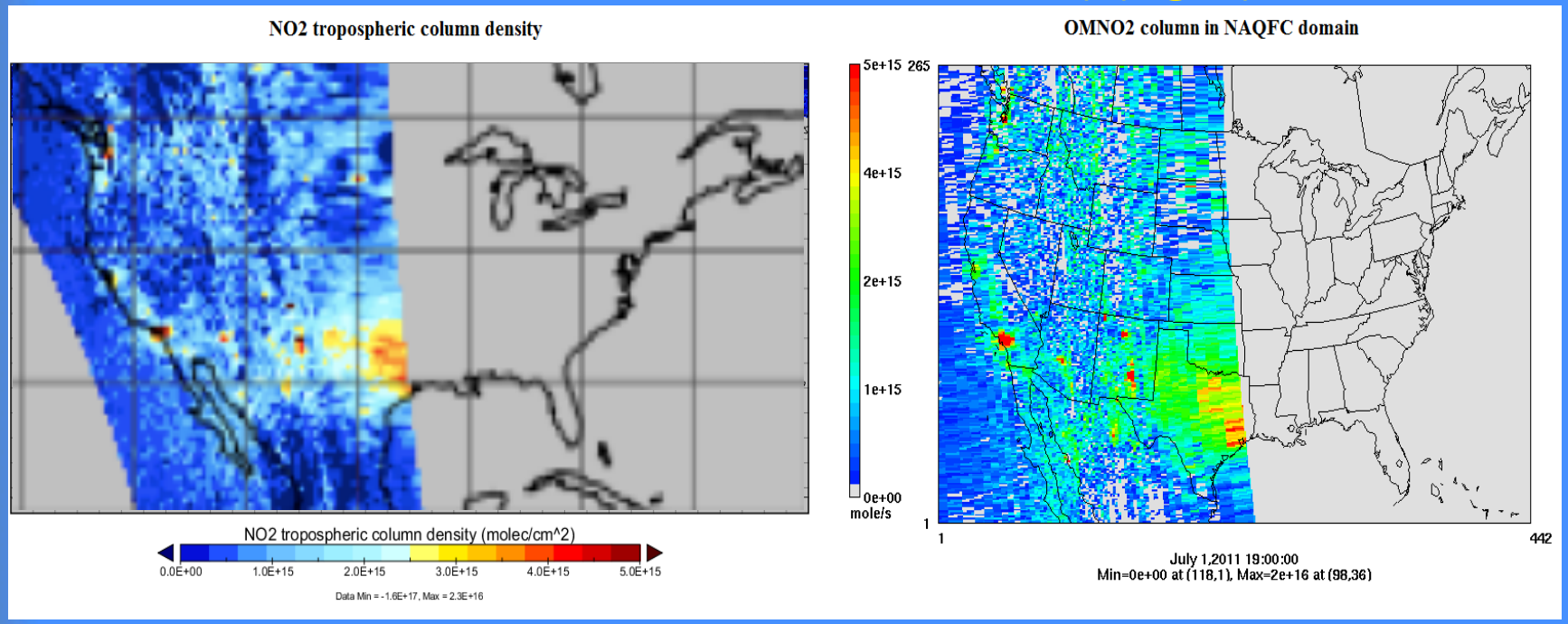
Sample Results:

Comparison of daily OMI tropo. NO2 vertical column density (VCD) before and after quality control: a) no quality control; b) VCD quality flag set to zero; c) additional filtering with could fraction < 50%; and d) after VCD, cloud fraction, and row anomaly (set to 0) filtering.



Interpretation of NASA Remote Sensing Data for Air Quality Research and Modeling: **Proof of Concept**

Sample Results: Spatial projection of OMI NO2 Level 2 swath (left) into a Lambert Conformal CMAQ domain (12km x 12km over the continental United States) (right)



Conclusions

- Satellite remote sensing data and services hold great promise to alleviate limitations of monitor-based environmental data collecting
- Obstacles such as uncertainties in methodology, data accessibility (for epidemiologists) and data quality are being addressed
- Numerous community efforts are addressing these issues on local and global levels
- Interpreting remote sensing data to address the specific needs of end user communities, such as air quality modelers and health impact studies, can be done, and should be further pursued to facilitate data usability by these communities

Thank You

Backup…

Exemplary NASA Vector Borne Disease Research Using Remote Sensing Data

- *Jorge Pinzon*/Science System and Applications, Inc (SSAI), Predicting Zoonotic Hemorrhagic Fever Events in Sub-Saharan Africa using NASA Earth Science Data for DoD - Global Emerging Infections Surveillance and Response System
- *Benjamin Zaitchik*/Johns Hopkins University, Development of a Detection and Early Warning System for Malaria Risk in the Amazon
- *Daniel Irwin and John Kessler*/NASA Marshal Space Flight Center, SERVIR Africa
- *Sue Estes*/NASA/USRA, Investigating the Potential Range Expansion of the Vector Mosquito Aedes aegypti in Mexico with NASA Earth Science Remote Sensing Results.
- *Michael Wimberly*/South Dakota State University, Enhanced Forecasting of Mosquito-Borne Disease Outbreaks Using AMSR-E
- *Richard Kiang*/NASA Goddard Space Flight Center, Modeling Global Influenza Risks using NASA Data
- *Richard Kiang*/NASA Goddard Space Flight Center, Avian Influenza Risk Prediction in Southeast Asia and Early Warning of Pandemic Influenza
- *Xiangming Xiao*/University of Oklahoma, Integrating Earth observations and satellite telemetry of wild birds for decision support system of avian influenza
- *Katia Charland*/Children's Hospital Boston, Application of NASA Data to Develop an Influenza Forecasting System

Exemplary NASA Water Borne Disease Research Using Remote Sensing Data

- *Richard Stumpf and Timothy Wynne*/National Oceanic Atmospheric Administration Ocean Service, Monitoring and Forecasting Cyanobacterial Blooms for Public Health Protection and Response
- *Zhiqiang Deng*/Louisiana State University, Feasibility Study of Satellite-Assisted Detection and Forecasting of Oyster Norovirus Outbreak
- *Charles Tilburg*/University of New England, Influence of Land-Use and Precipitation on Regional Hydrology and Public Health

GES DISC Data Useful for Public Health Research Activities

Measurement	GES DISC Dataset*	Spatial Resolution	Temporal Coverage	Current Usage/ Potential Usage	Health Relevance
Precipitation	TRMM	1/4 deg - 1 deg	1997 - present	See Pinzon, Zaitchik, Kiang, Tilburg	Vector Borne Diseases; Water Borne Diseases
	GPM	1/4 deg X 1/4 deg	Starting 2013		
	GLDAS	1/4 deg X 1/4 deg; 1 deg X 1 deg	1979 - present	GLDAS, MERRA NLDAS are of comparable resolution to TRMM	
	NLDAS	1/8 deg X 1/8 deg	1979 - present North America		
	MERRA	1.25 deg X 1.25 deg	1979 - present		
Water Runoff	*Non*	*GES DISC product*	*often used*	USGS derived products (Tilburg)	Vector Borne Diseases; Water Borne Diseases
	GLDAS	1/4 deg X 1/4 deg; 1 deg X 1 deg	1979 - present	GLDAS, MERRA NLDAS provide assimilated alternatives	
	MERRA	2/3 deg X 1/2 deg	1979 - present		
	NLDAS	1/8 deg X 1/8 deg	1979 - present North America		
Vegetation Index	*Non*	*GES DISC product*	*often used*	MODIS derived data has set the standard (Ponzon, Estes, Kiang)	Vector Borne Diseases; Air Pollution
	NLDAS	1/8 deg X 1/8 deg	1979 - present North America	NLDAS, MERRA provide alternatives with higher temporal resolution	
	MERRA	2/3 deg X 1/2 deg	1979 - present		

Soil Moisture	NEESPI – AMSR-E	1 deg X 1 deg	2002 - present	See Zaitchik, Estes, Wimberly (uses AMSR-E)	Vector Borne Diseases
	LPRM using AMSR-E	25 km X 25 km	2002 - present	LPRM provides higher spatial resolution based on AMSR-E	
	NLDAS	1/8 deg X 1/8 deg	1979 - present North America	GLDAS, MERRA NLDAS provide higher temporal resolution	
	GLDAS	1/4 deg X 1/4 deg; 1 deg X 1 deg	1979 - present		
	MERRA	2/3 deg X 1/2 deg	1979 - present		
Surface Air Temperature	*Non*	*GES DISC product*	*often used*	MODIS generated data has set the standard (Pinzon, Zaitchik, Estes, Kiang, Stumpf, McClure, Ceccato)	Vector Borne Diseases; Air Pollution
	AIRS	1 deg X 1 deg	2002 - present	See reference: Wallace	
	TOVS	1 deg X 1 deg	1984 - 1995	TOVS: Historical data	
	MERRA	2/3 deg X 1/2 deg; 1.25 deg X 1.25 deg	1979 - present	GLDAS, MERRA NLDAS provide higher temporal resolution data	
	GLDAS	1/4 deg X 1/4 deg; 1 deg X 1 deg	1979 - present		
	NLDAS	1/8 deg X 1/8 deg	1979 - present North America		

Aerosols	*Non*	*GES DISC product*	*often used*	MODIS generated data (Liu, Morain)	Air Pollution
	OMI	24 km X 13 km; 1/4 deg X 1/4 deg	2004 - present	OMI is useful for low resolution applications	
	TOMS	1.25 deg X 1.0 deg	1978 - 2005	TOMS: Historical data	
	MERRA	2/3 deg X 1/2 deg; 1.25 deg X 2.0 deg	1979 - present	MERRA, GOCART provide higher temporal resolution	
	GOCART	2.5 deg X 2.0 deg	2000 - 2007		
Wind	Non	GES DISC product	often used	Local records used (Kiang)	Vector Borne Diseases; Air Pollution
	MERRA	2/3 deg X 1/2 deg; 1.25 deg X 1.25 deg	1979 - present	See reference: Lau	
	GLDAS	1/4 deg X 1/4 deg; 1 deg X 1 deg	1979 - present	GLDAS, NLDAS, GSSTF2b provide assimilated alternatives	
	NLDAS	1/8 deg X 1/8 deg	1979 - present North America		
	GSSTF2b	1 deg X 1 deg	1988 - 2008		
Solar Irradiance	*Non*	*GES DISC products*	*often used*	Local records used (Kiang); TOPS (Charland)	Air Pollution; Vector Borne Diseases
	SORCE		2003 - present	SORCE, OMI provide alternative global measurements	
	OMI	1/4 deg X 1/4 deg; 1 deg X 1 deg	2004 - present		

* Acronyms:
- AIRS - The Atmospheric Infrared Sounder
- AMSR-E - Advanced Microwave Scanning Radiometer-Earth Observing System
- GLDAS - Global Land Data Assimilation System
- GOCART - The Goddard Chemistry Aerosol Radiation and Transport model
- GPM - The Global Precipitation Measurement
- GSSTF2b - Goddard Satellite-based Surface Turbulent Fluxes Version-2b (Produced through a NASA MEaSURES funded project led by Dr. Chung-Lin Shie, UMBC/GEST, NASA/GSFC)
- LPRM - Land Parameter Retrieval Model
- MERRA - Modern Era Retrospective-Analysis for Research and Applications
- MISR – Multi-angle Imaging Specroradiometer
- MLS - Microwave Limb Sounder
- MODIS - Moderate Resolution Imaging Spectroradiometer
- NEESPI - Northern Eurasia Earth Science Partnership Initiative (Provided through a NASA MEaSURES funded project led by Dr. Gregory Leptoukh, NASA/GSFC)
- NLDAS - North American Land Data Assimilation System
- OMI - Ozone Monitoring Instrument
- SORCE- The Solar Radiation and Climate Experiment
- TES – Troposheric Emission Spectrometer
- TOMS - Total Ozone Mapping Spectrometer
- TOPS - Terrestrial Observation and Prediction System
- TOVS - TIROS Operational Vertical Sounder
- TRMM - Tropical Rainfall Measuring Mission

Customized domain definition

Two ways to find your domain numbers:
1. Use 'ncdump -h filename';
2. Find them in your GRIDDESC file

Enter your domain information:

NTHIK3D (*thickness*):	1
NCOLS3D (*no. of columns*):	
NROWS3D (*no. of rows*):	
NLAYS3D (*no. of layers*):	1
P_ALP3D (*alpha value*):	
P_BET3D (*beta value*):	
P_GAM3D (*gamma value*):	
XCENT3D (*X center*):	
YCENT3D (*Y center*):	
XORIG3D (*X origin*):	
YORIG3D (*Y origin*):	
XCELL3D (*X spacing*):	
YCELL3D (*Y spacing*):	

Add your domain

Interpreting NASA Remote Sensing Data for Air Quality Research and Modeling

- Popular Air Quality Models:
  - Community Multiscale Air Quality (CMAQ) model, developed jointly by the US Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA)
  - NASA-Unified Weather Research and Forecasting (NU-WRF) model. The NU-WRF modeling system has explicit land-cloud-aerosol-precipitation interactions
- Interested Air Quality Projects:
  - Deriving Information on Surface Conditions from Column and Vertically-Resolved Observations Relevant to Air Quality (**DISCOVER-AQ**) field campaigns. Designed to improve the interpretation of satellite observations to diagnose near-surface conditions relating to air quality. (Dr. Ken Pickering, DISCOVER-AQ Project Scientist)
  - **Air quality forecasting research** and integration into the NOAA air quality forecasting model system, lead by Dr. Pius Lee, NOAA Air Resources Laboratory (ARL).
  - **Community Modeling and Analysis System (CMAS)** center for air quality modeling community, directed by Dr. Adel Hanna. Distributes and supports air quality modeling, analysis, and decision support tools, including the CMAQ model, to over 5000 registered users.
  - University of Wisconsin (Tracy Holloway, also deputy leader of NASA's Air Quality Applied Science Team [AQAST]) projects **to analyze NO2 trends** from hydrofracturing over North Dakota, isolating truck emissions on rural highways, and evaluating lightning NOx in CMAQ.