National Aeronautics and Space Administration

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Big Data Analytics and Visualization to Monitor Sea Level Rise

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Data Scientist @NASA/JPL

- **Principal Investigator** for NASA AIST OceanWorks
- **Project Technologist** for the NASA's Physical Oceanography Distributed Active Archive Center (PO.DAAC) – http://podaac.jpl.nasa.gov
- **Co- Investigator and Architect** for the NASA Sea Level Change Portal – https://sealevel.nasa.gov
- **Architect** for Tactical Data Science Framework for Naval Research
- **Chair** for The Federation of Earth Science Information Partners (ESIP) Cloud Computing Cluster
- **Previously Principal Investigator / Co-Investigator** in several NASA-funded Big Data Analytic Projects
  - OceanXtremes: Oceanographic Data-Intensive Anomaly Detection and Analysis Portal – https://oceanxtremes.jpl.nasa.gov
  - Distributed Oceanographic Matchup Service (DOMS) – https://doms.jpl.nasa.gov
  - Mining and Utilizing Dataset Relevancy from Oceanographic Datasets (MUDROD)
  - Enhanced Quality Screening for Earth Science Data – https://vqss.jpl.nasa.gov
  - NEXUS - Big Data Analytic on the Cloud

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NASA Sea Level Change Portal – *https://sealevel.nasa.gov*

Goal for the NASA Sea Level Change Team

- Determine how much will sea level rise by [2100]?
- What are the key sensitivities?
- Where are the key uncertainties? Observables? Model Improvements

Goals for the NASA Sea Level Change Portal

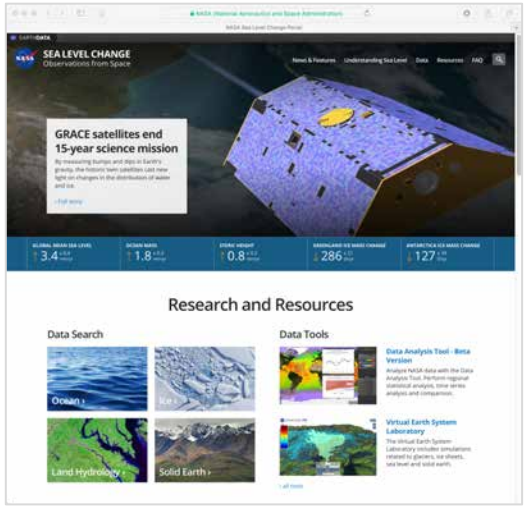
- Provide scientists and the general public with a “one-stop” source for current sea level change information and data
- Provide interactive tools for analyzing and viewing regional data
- Provide virtual dashboard for sea level indicators
- Provide latest news, quarterly report, and publications
- Provide ongoing updates through a suite of editorial products

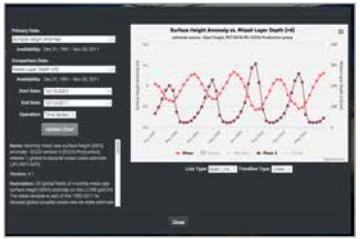
Requires

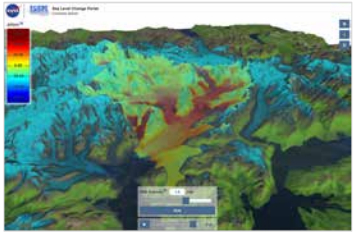
- Interdisciplinary collaboration
- Connect disciplines and evaluate dependencies

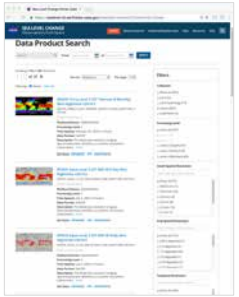
Sea Level Change Portal facilitates

- Easy interdisciplinary data comparison
- Access to latest news and information
- Collaboration (data and information exchange)









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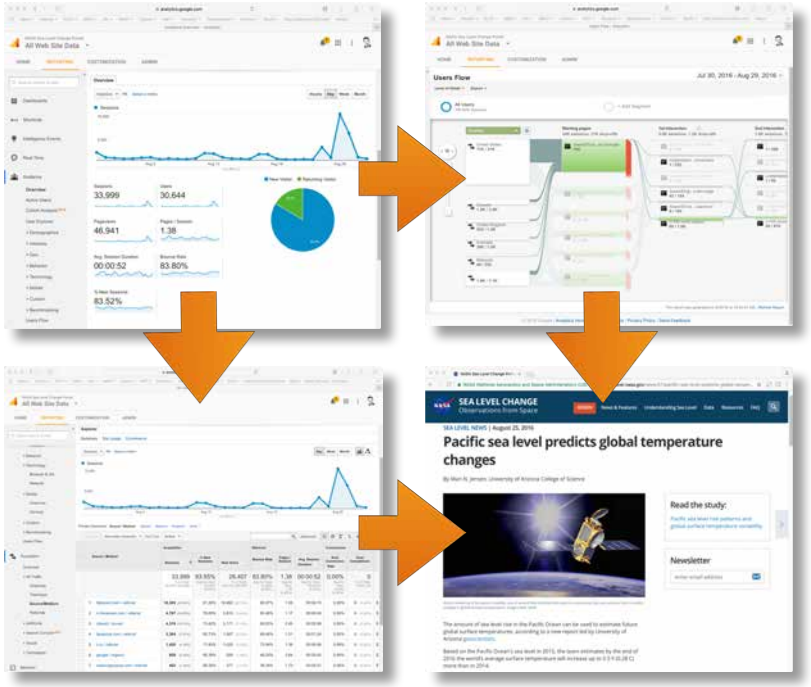
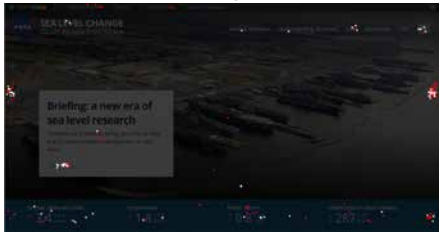
Analyze User Interactions

- Guide website layout
- Determine effectiveness of articles and contents
- Identify popular media outlines
- New and returning users

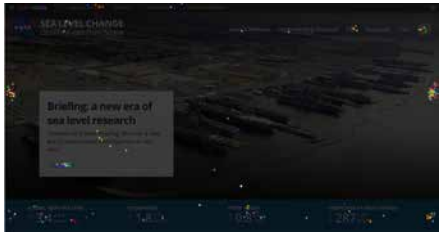


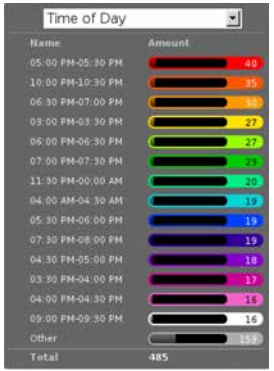
New vs. Returning



Referrer (Media Outlets)

Time to Click





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Web, Social Media, and Headliners

- 373K monthly page views
- 172K sessions
- 143K users
- **Social Media**

  Twitter: @NASASeaLevel has over 23K followers

  Facebook: over 31K followers

TECH HEADLINES

"NASA Sea Level Change Website Offers Everything You Need to Know About Climate Change"
http://www.techtimes.com/articles/147210/20160405/nasa-sea-level-change-website-offers-everything-need-know-climate.htm

"NASA's New Sea Level Site Puts Climate Change Papers, Data, and Tools Online"
http://techcrunch.com/2016/04/04/nasas-new-sea-level-site-puts-climate-change-papers-data-and-tools-online/

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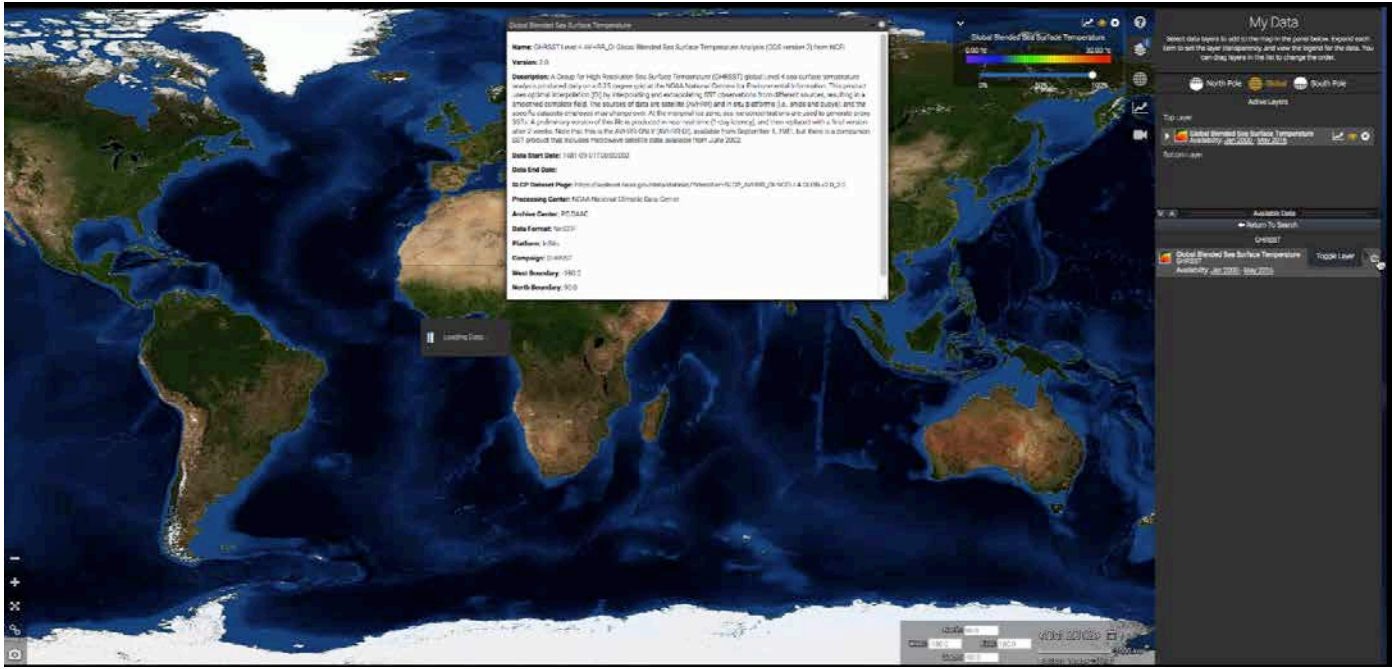
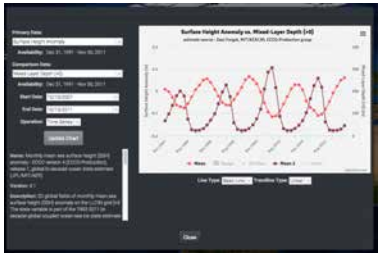
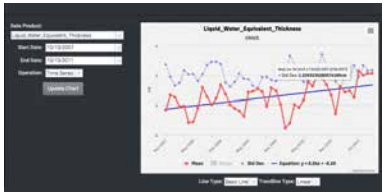
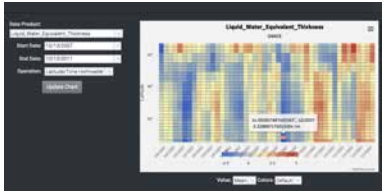
Analyze Sea Level On-The-Fly *https://sealevel.nasa.gov*









Sea Level Change - Data Analysis Tool

Visualizations | Hydrological Basins | Time Series | Deseason | Data Comparison | Scatter Plot | Latitude/Time Hovmöller | Etc.

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Big Data and Data Centers

- **Increasing "big data" era is driving needs to**
  - Scale computational and data infrastructures
  - Support new methods for deriving scientific inferences
  - Shift towards integrated data analytics
  - Apply computation and data science across the lifecycle
- **For NASA Data Centers, with large amount of observational and modeling data, downloading to local machine is becoming inefficient**
- **Reality with large amount of observational and modeling data**
  - Downloading to local machine is becoming inefficient
  - Search has gotten a lot faster. Too many matches
  - Finding the relevant measurement has becoming a very time consuming process "*Which SST dataset I should use?*"
  - Analyze decades of regional measurement is labor-intensive and costly
- **Limitations**
  - Little to no interoperability between tools and services: metadata standard, keyword, spatial coverage (0-360 or -180..180), temporal representation, etc.
  - Making sure the most relevant measurements return first
  - Visualization is nice, but it doesn't provide enough information about the event/phenomenon captured in the image.
  - With large amount of observational data, data centers need to do more than just storing bits

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NASA's Upcoming Big Data Mission: Surface Water and Ocean Topography (SWOT)

Oceanography: Characterize the ocean mesoscale and sub-mesoscale circulation at spatial resolutions of 10 km and greater.

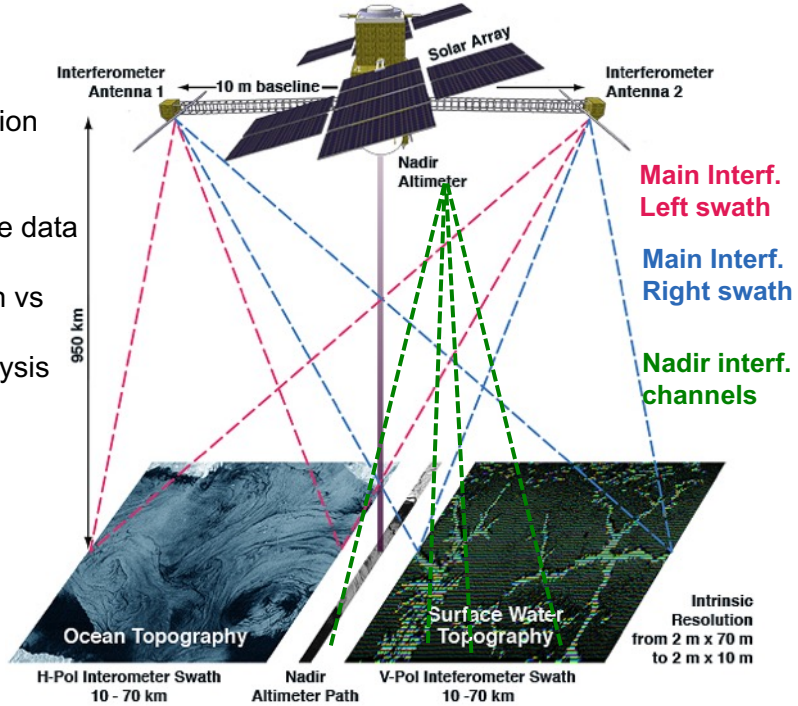
Hydrology: To provide a global inventory of all terrestrial water bodies whose surface area exceeds $(250m)^2$ (lakes, reservoirs, wetlands) and rivers whose width exceeds 100 m (requirement) (50 m goal) (rivers).

- To measure the global storage change in fresh water bodies at sub-monthly, seasonal, and annual time scales.
- To estimate the global change in river discharge at sub-monthly, seasonal, and annual time scales.

- **Data Volume:**
  - 17PB of original data
  - 6 PB of reprocessed data
- **Total of about 23PB for a nominal 3-year mission**
- **Add roughly 450TB/month for any mission extension**

SWOT changes how PO.DAAC operates

- Infrastructure
- Cloud storage selection (Object store, AWS Glacier)
- Interface with science data system
- On-the-fly generation vs long-term store
- Distribution and analysis services



Launches April of 2021
https://swot.jpl.nasa.gov

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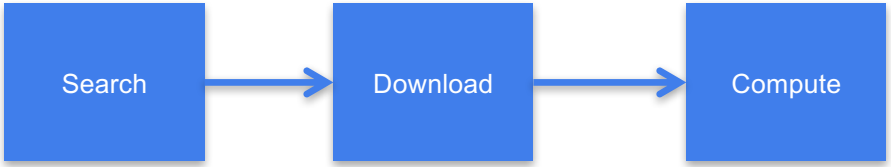
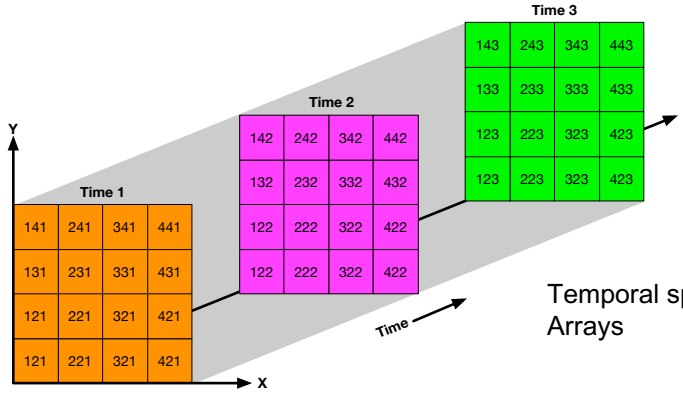
Traditional Method for Analyze Satellite Measurements



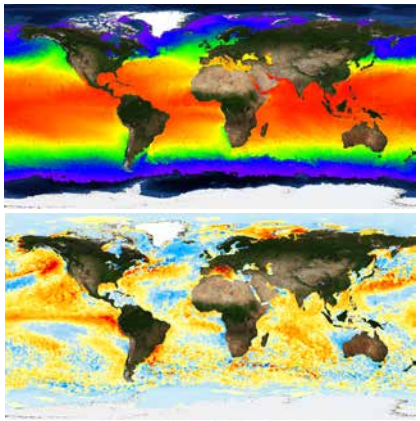


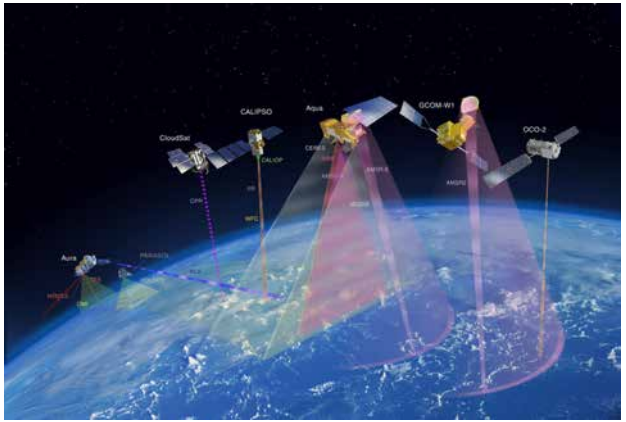
Temporal spatial Arrays

- Depending on the data volume (size and number of files)
- It could take many hours of download – (e.g. 10yr of observational data could yield thousands of files)
- It could take many hours of computation
- It requires expensive local computing resource (CPU + RAM + Storage)
- After result is produced, purge downloaded files

Observation

- Traditional methods for data analysis (time-series, distribution, climatology generation) can't scale to handle large volume, high-resolution data. They perform poorly
- Performance suffers when involve large files and/or large collection of files
- A high-performance data analysis solution must be free from file I/O bottleneck





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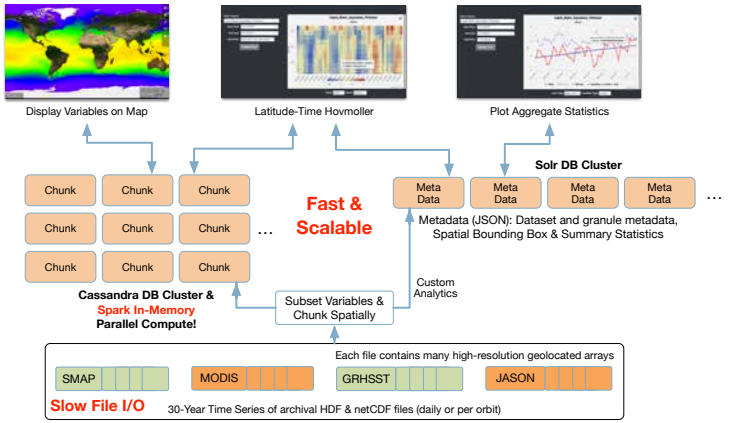
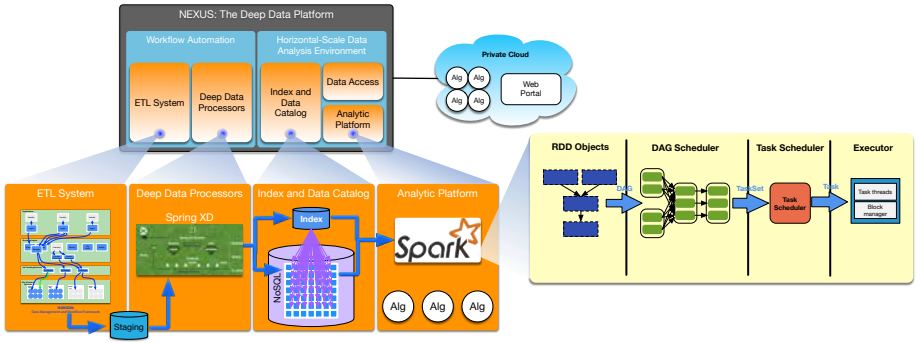
NEXUS: Scalable Data Analytic Solution

- NEXUS is a data-intensive analysis solution using a new approach for handling science data to enable large-scale data analysis
- Streaming architecture for horizontal scale data ingestion
- Scales horizontally to handle massive amount of data in parallel
- Provides high-performance geospatial and indexed search solution
- Provides tiled data storage architecture to eliminate file I/O overhead
- A growing collection of science analysis webservices using Apache Spark: parallel compute, in-memory map-reduce framework
- Pre-Chunk and Summarize Key Variables
  - Easy statistics instantly (milliseconds)
  - Harder statistics on-demand using Spark (in seconds)
  - Visualize original data (layers) on a map quickly (Cassandra store)
- **Algorithms** – Time Series | Latitude/Time Hovmöller| Longitude/Time Hovmöller| Latitude/Longitude Time Average | Area Averaged Time Series | Time Averaged Map | Climatological Map | Correlation Map | Daily Difference Average



Two-Database Architecture



Open Source: Apache License 2
https://github.com/dataplumber/nexus

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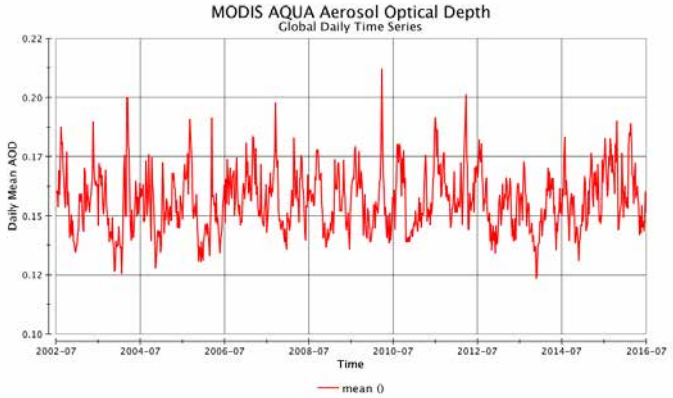
NEXUS Performance: Custom Spark vs. AWS EMR

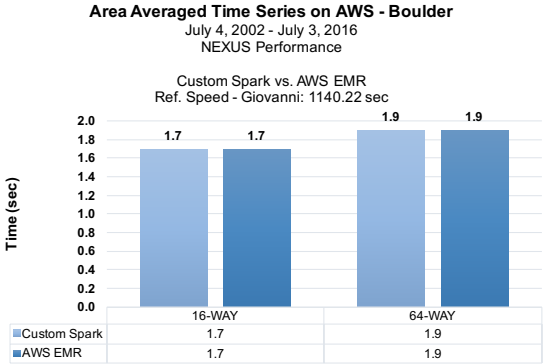
Dataset: MODIS AQUA Daily
Name: Aerosol Optical Depth 550 nm (Dark Target) (MYD08_D3v6)
File Count: 5106
Volume: 2.6GB
Time Coverage: July 4, 2002 – July 3, 2016

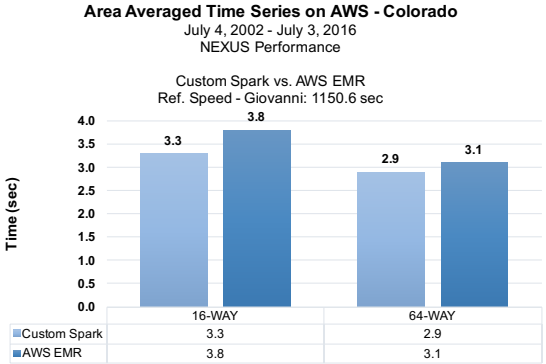
Giovanni: A web-based application for visualize, analyze, and access vast amounts of Earth science remote sensing data without having to download the data.

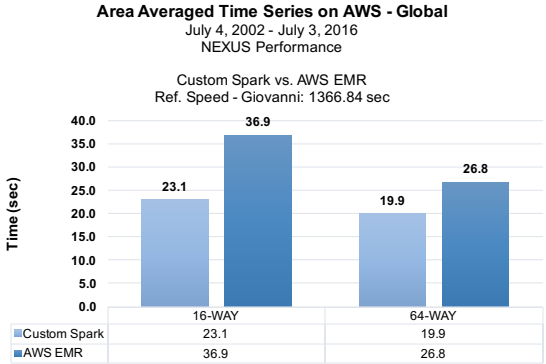
- Represents current state of data analysis technology, by processing one file at a time
- Backed by the popular NCO library. Highly optimized C/C++ library

AWS EMR: Amazon's provisioned MapReduce cluster









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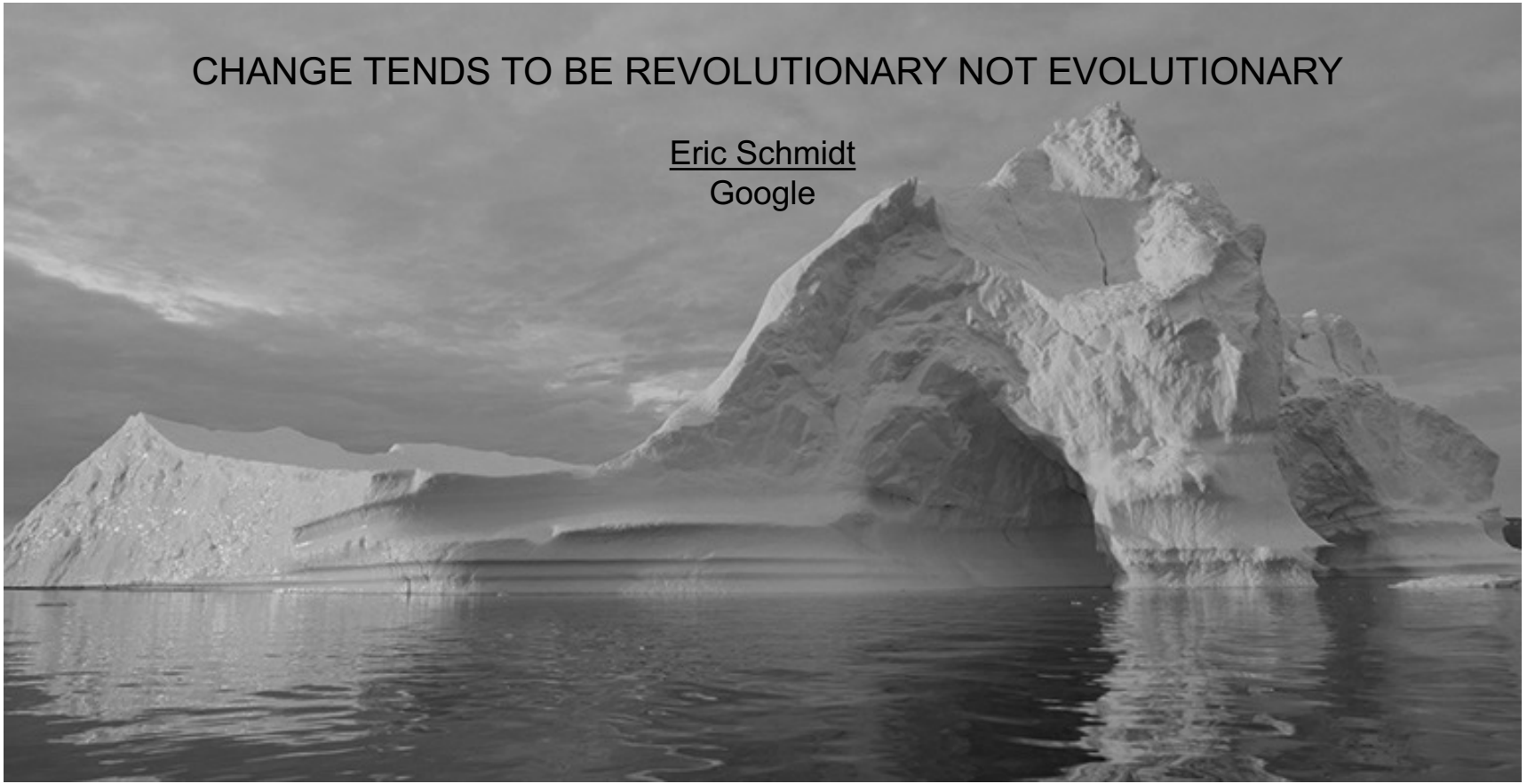

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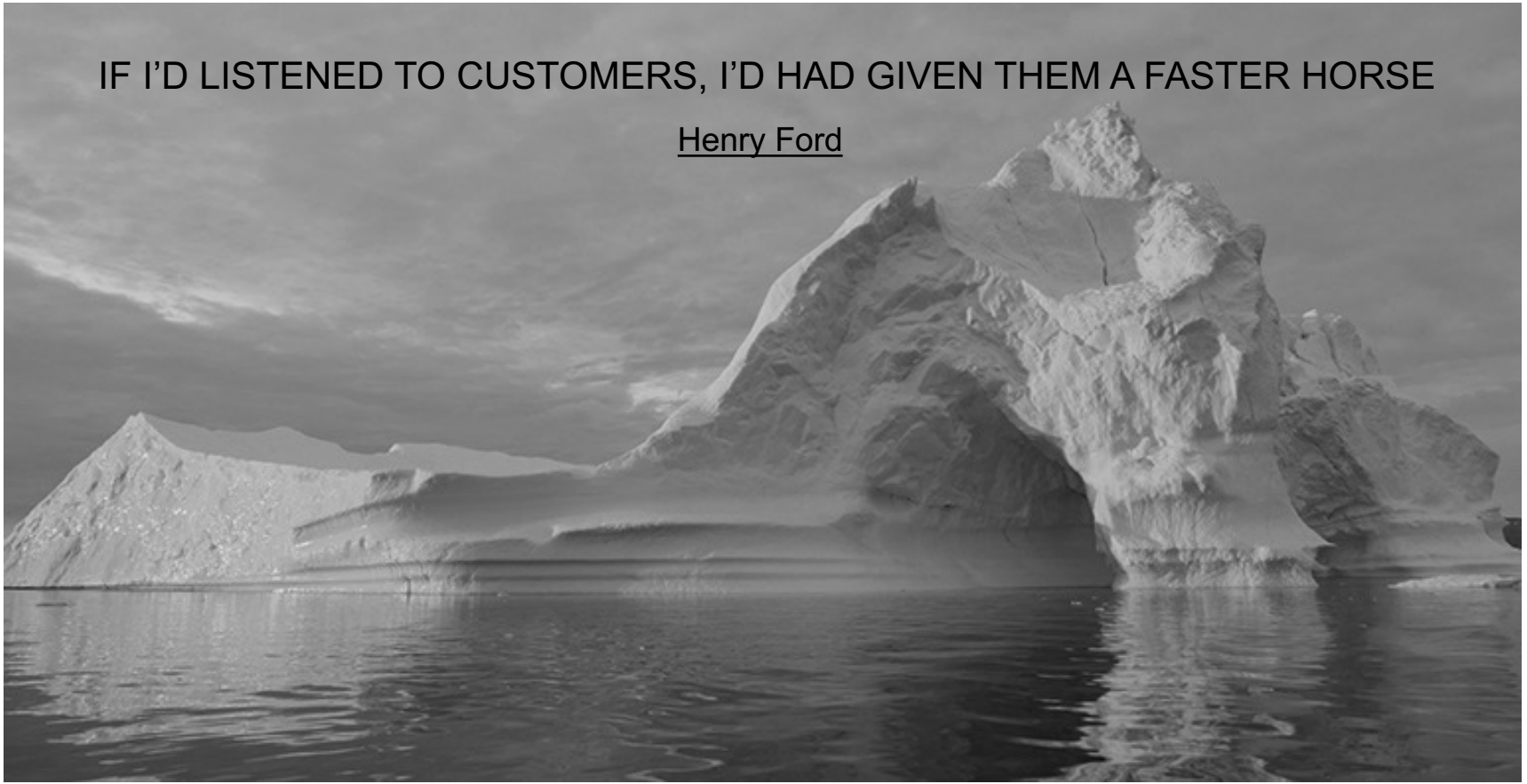

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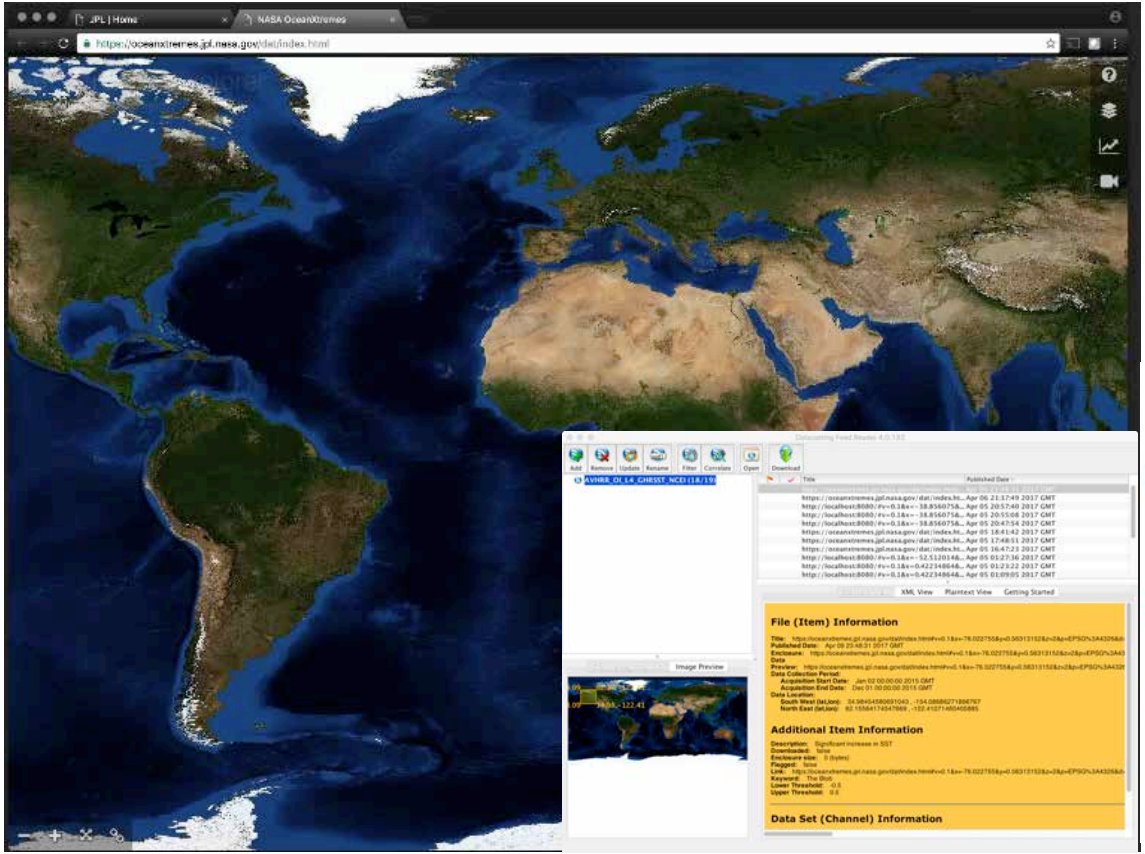
Analyze Ocean Anomaly – “The Blob”



- **Visualize** parameter
- **Compute** daily differences against climatology
- **Analyze** time series area averaged differences
- **Replay** the anomaly and visualize with other measurements
- **Document** the anomaly
- **Publish** the anomaly

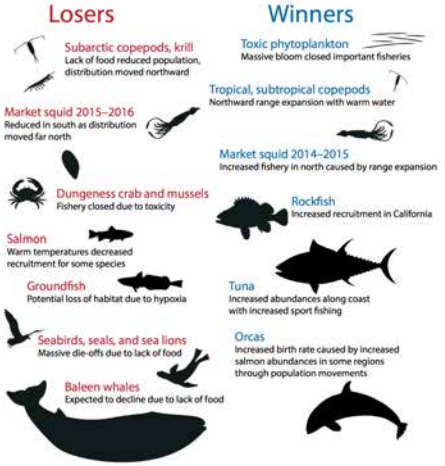


Figure from Cavole, L. M., et al. (2016). "Biological Impacts of the 2013–2015 Warm-Water Anomaly in the Northeast Pacific: Winners, Losers, and the Future." Oceanography 29.

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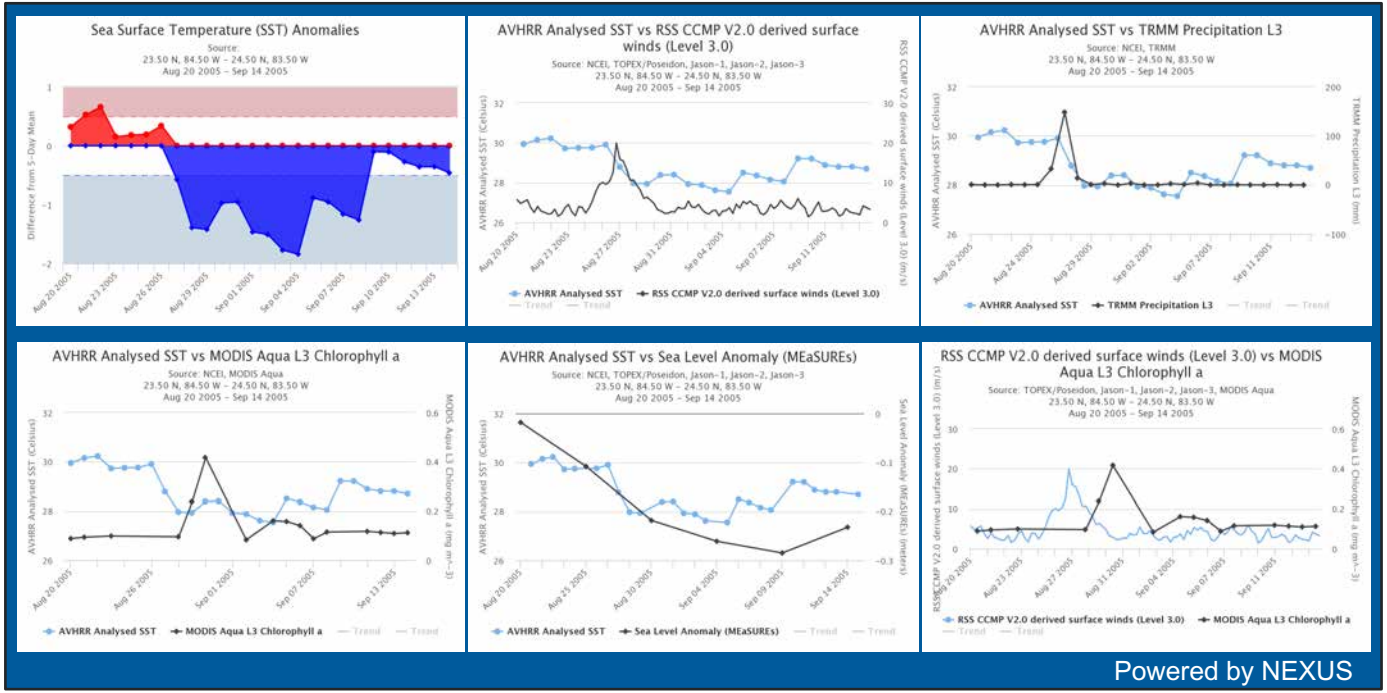
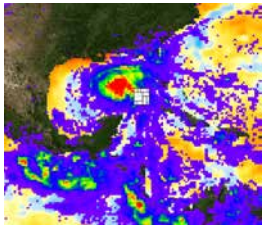
Hurricane Katrina Study



Hurricane Katrina passed to the southwest of Florida on Aug 27, 2005. The ocean response in a 1 x 1 deg region is captured by a number of satellites. The initial ocean response was an immediate cooling of the surface waters by 2 ℃ that lingers for several days. Following this was a short intense ocean chlorophyll bloom a few days later. The ocean may have been "preconditioned' by a cool core eddy and low sea surface height.

The SST drop is correlated to both wind and precipitation data. The Chl-A data is lagged by about 3 days to the other observations like SST, wind and precipitation.



Hurricane Katrina TRMM overlay SST Anomaly

A study of a Hurricane Katrina–induced phytoplankton bloom using satellite observations and model simulations
Xiaoming Liu, Menghua Wang, and Wei Shi
JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 114, C03023, doi:10.1029/2008JC004934, 2009

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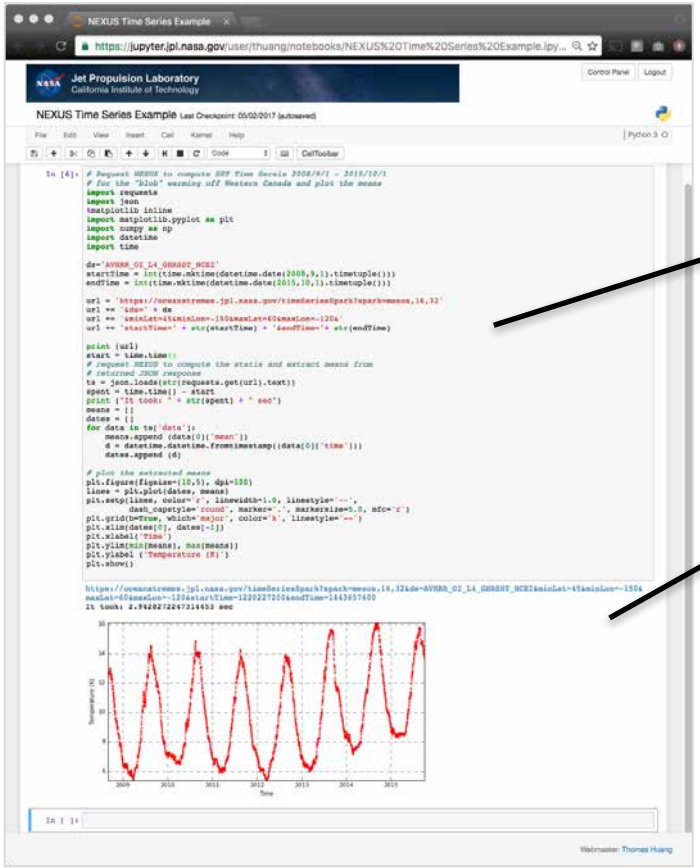
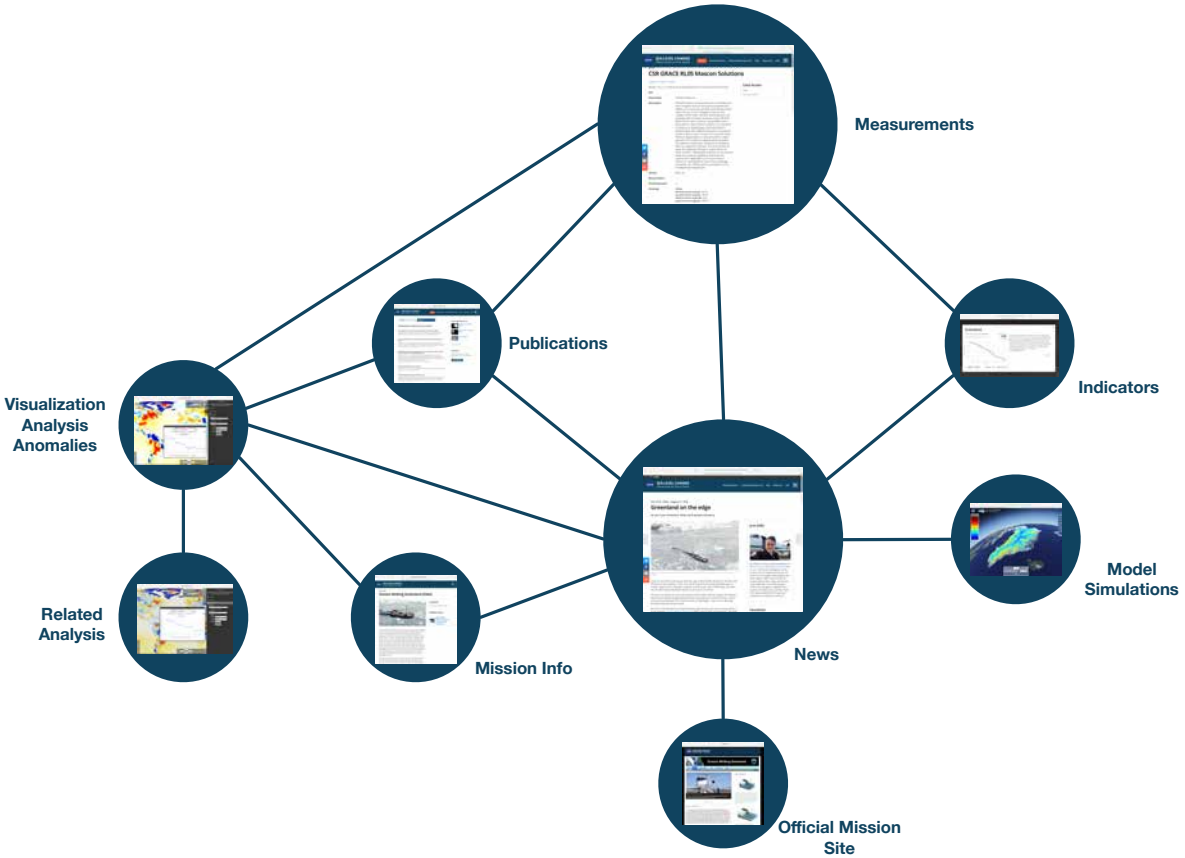
Enable Science without File Download




```
# Request NEXUS to compute SST Time Series 2008/9/1 - 2015/10/1
# for the "blob" warming off Western Canada and plot the means
…
ds='AVHRR_OI_L4_GHRSST_NCEI'

url = … # construct the webservice URL request


# make request to NEXUS using URL request
# save JSON response in local variable
ts = json.loads(str(requests.get(url).text))

# extract dates and means from the response
means = []
dates = []
for data in ts['data']:
    means.append (data[0]['mean'])
    d = datetime.datetime.fromtimestamp((data[0]['time']))
    dates.append (d)

# plot the result
…
```

```
https://oceanxtremes.jpl.nasa.gov/timeSeriesSpark?spark=mesos,16,32&ds=AVHRR_OI_L4_GHRSST_NCEI&minLat=45&minLon=-150&maxLat=60&maxLon=-120&startTime=1220227200&endTime=1443657600

It took: 2.9428272247314453 sec
```

Developing Information Discovery Solutions



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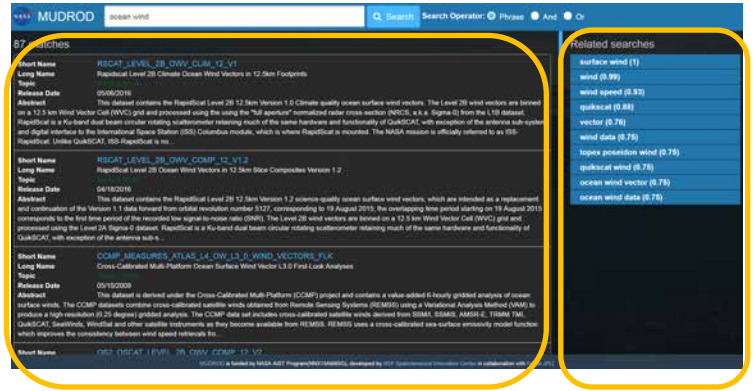
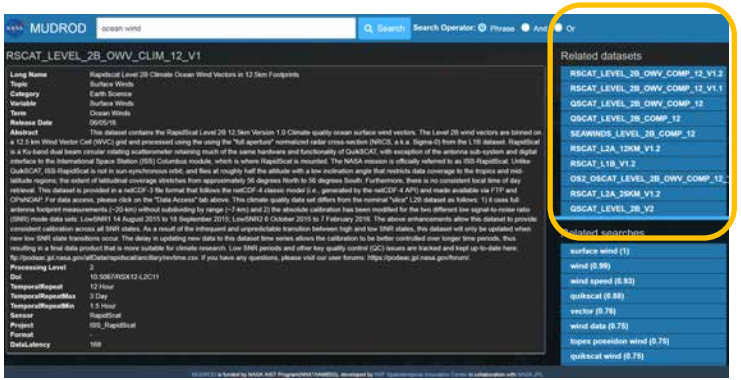
Search and Discovery

- **Search** – look for something you expect to exist
  - Information tagging
  - Indexed search technologies like Apache Solr or ElasticSearch
  - The solution is pretty straightforward
- **Discovery** – find something new, or in a new way
  - This is non-trivial
  - Traditional ontological method doesn't quite add up
  - The strength of semantic web is in inference
  - What happen when we have a lot of `subClassOf`, `equivalentClassOf`, `sameAs`?
  - How wide and deep should we go?
- **Relevancy**
  - It is domain-specific
  - It is personal
  - It is temporal
  - It is dynamic



Search Ranking
Based on a machine learning model (RankSVM) which takes a number of features, such as vector space model, version, processing level, release date, all-time popularity, monthly-popularity, and user popularity.



Search Recommendation
Based on dataset metadata content and web session co-occurrence

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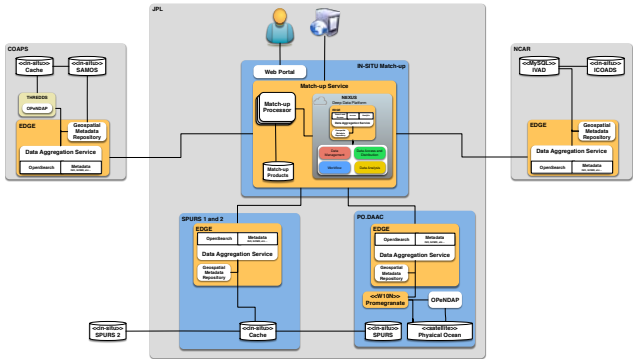
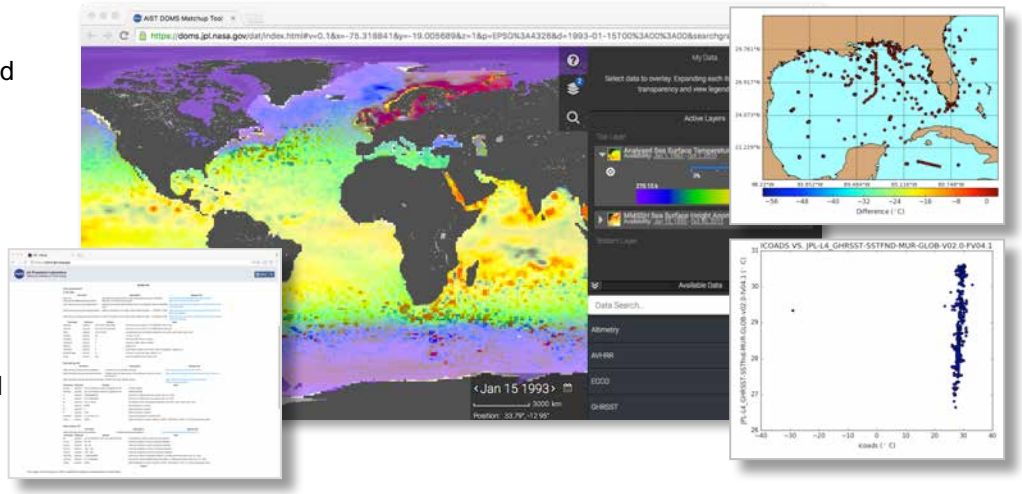
In Situ to Satellite Matchup

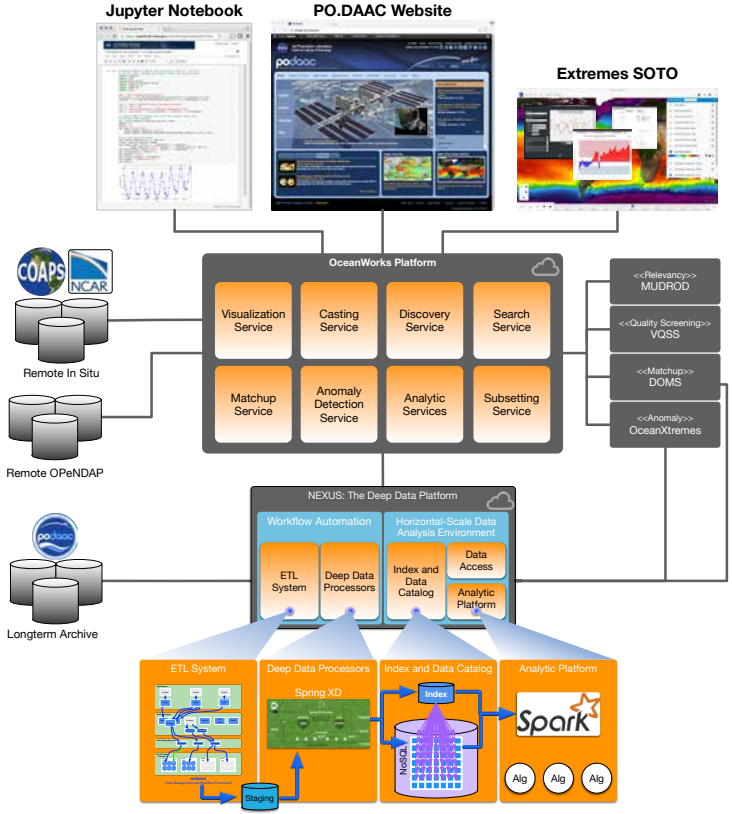
- Distributed Oceanographic Matchup Service
- Typically data matching is done using one-off programs developed at multiple institutions
- A primary advantage of DOMS is the reduction in duplicate development and man hours required to match satellite/in situ data
  - Removes the need for satellite and in situ data to be collocated on a single server
  - Systematically recreate matchups if either in situ or satellite products are re-processed (new versions), i.e., matchup archives are always up-to-date.
- In situ data nodes at JPL, NCAR, and FSU operational.
- Provides data querying, subset creation, match-up services, and file delivery operational.
- Prototype graphical user interface (UI) and APIs accessible for external users.
- Plugin architecture for in situ data source using EDGE
  - Extensible Data Gateway Environment is an Apache License 2 open source technology
  - https://github.com/dataplumber/edge
- Defined specification for packaging matchup results. Working with Unidata and ESDSWG's data interoperability and standard groups





AIST OceanWorks

- **OceanWorks** is to establish an **Integrated Data Analytic Center** at the NASA Physical Oceanography Distributed Active Archive Center (PO.DAAC) for Big Ocean Science
- Focuses on technology integration, advancement and maturity
- Collaboration between JPL, FSU, NCAR, and GMU
- Bringing together PO.DAAC-related big data technologies
  - **OceanXtremes –** Anomaly detection and ocean science
  - **NEXUS –** Big data analytic platform
  - **Data Container Studies**
  - **DOMS –** Distributed in-situ to satellite matchup
  - **MUDROD –** Search relevancy and discovery – linking datasets, services, and anomalies through recommendations
  - **VQSS –** Virtualized Quality Screening Service



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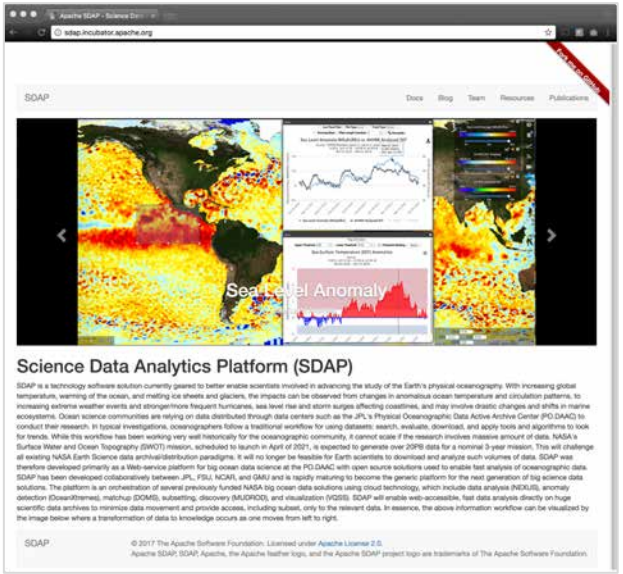
Open Source

- Technology sharing through Free and Open Source Software (FOSS)
- Further technology evolution that is restricted by projects / missions
- **Science Data Analytic Platform (SDAP)**, the implementation of **OceanWorks**, in **Apache Incubator**
  - Cloud platform
  - Analyzing satellite and model data
  - In situ data analysis and coordination with satellite measurements
  - Fast data subsetting
  - Mining of user interactions and data to enable discovery and recommendations
  - Streamline deployment through container technology

THE APACHE SOFTWARE FOUNDATION

http://sdap.incubator.apache.org



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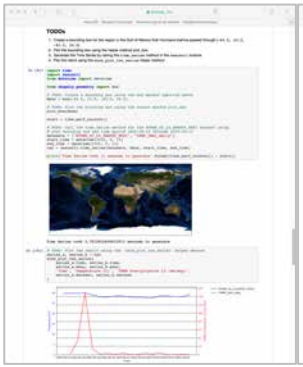
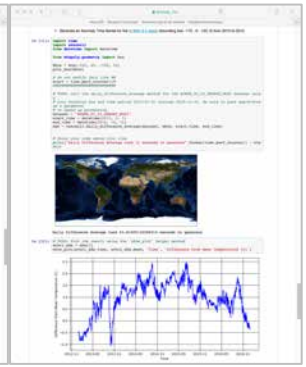
Community Engagement and Support

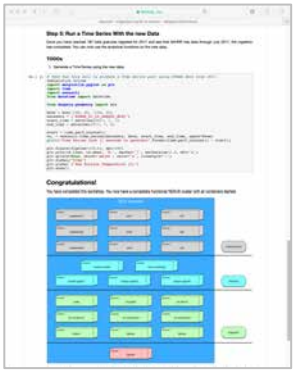
- Develop in the open
- Working with Apache Incubator
- Target Apache top-level project by 2019.
- Public hands-on workshops
- Organize technical sessions at conferences
- Invited speaker and panelist
- Lead Editor: 2018 Wiley Book on **Big Earth Data Analytics in Earth, Atmospheric and Ocean Sciences**



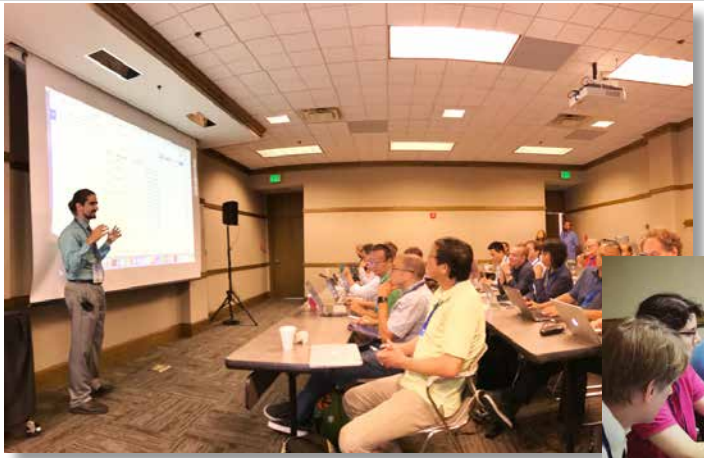
Analyze Hurricane Katrina by comparing SST and TRMM time series



Generate daily difference average
"The Blob" is an oceanographic anomaly



Each participant deployed 3 computing clusters, a total of 24 containers on EC2



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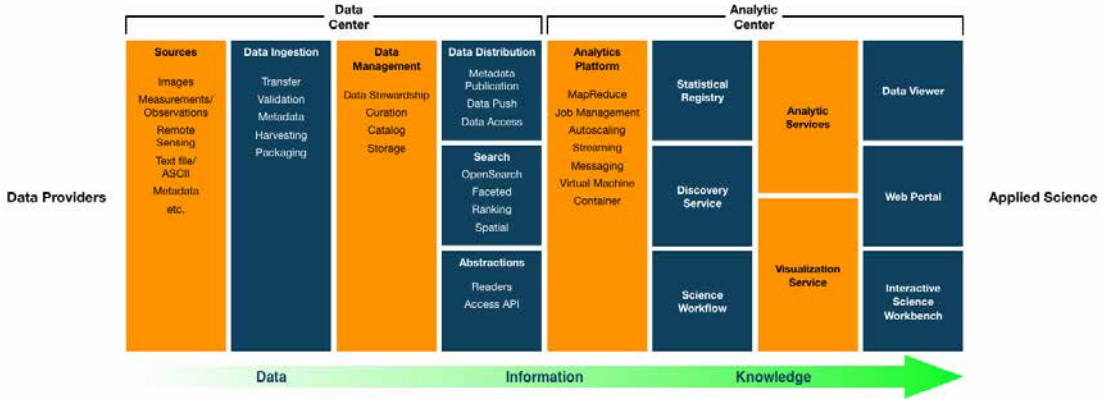
In Summary

- Traditional method for scientific research (search, download, local number crunching) is unable to keep up
- Think beyond the archive
- Connected information enables discovery
- Community developed solution through open sourcing
- Thanks to the NASA ESTO/AIST and Sea Level Rise programs, and the NASA ESDIS project
- Investment in data and computational sciences
- Data Centers need to be in the business of Enabling Science!
- OceanWorks infusion 2018 – 2019
  - Watch for changes to the Sea Level Change Portal
    - Even faster analysis capabilities
    - More variety of measurements – satellites, in situ, and models
    - Event more relevant recommendations
  - NASA's Physical Oceanography Distributed Active Archive Center (PO.DAAC)

Transforming Data to Knowledge



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"Without counsel plans fail, but with many advisers they succeed." – Proverbs 15:22

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