(Compute) Cloud Research in VISAGE:
Visualization for Integrated Satellite, Airborne and Ground-based data Exploration

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PI:	Helen Conover, UAH
Co-Is:	Todd Berendes, Aaron Naeger, UAH
	Manil Maskey, Patrick Gatlin, MSFC
	Stephanie Wingo, USRA/NPP
Technical Team:	Ajinkya Kulkarni, Charles Collins, UAH
Students:	Sriraksha Nagaraj, Shivangi Gupta, UAH
Collaborators:	David Wolff, GSFC/WFF
	Walt Petersen, MSFC

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INFORMATION TECHNOLOGY AND SYSTEMS CENTER

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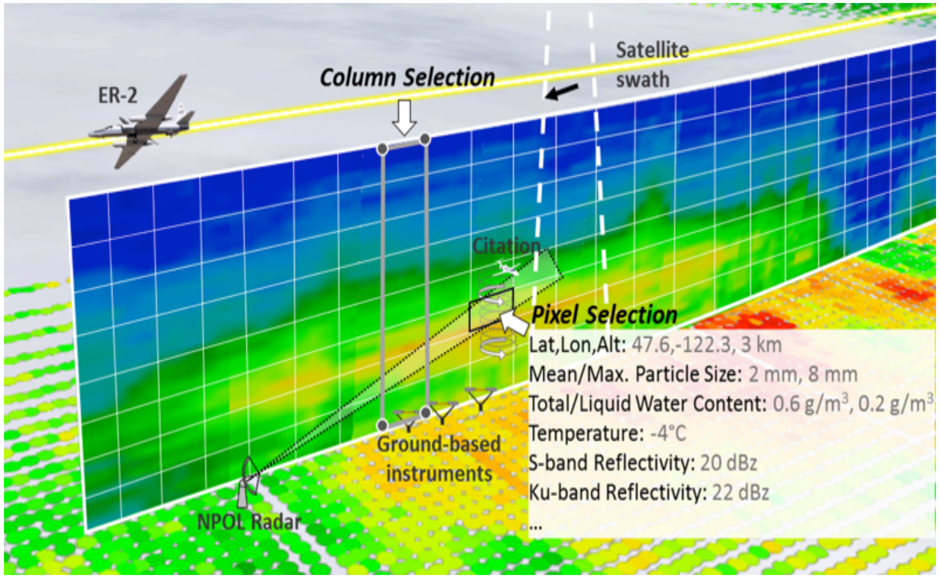
Introduction

- VISAGE is a data exploration tool that will facilitate ***more efficient Earth Science investigations*** by providing visualization and analytic capabilities for diverse coincident datasets, with a focus on airborne field campaigns



VISAGE concept to visualize and interrogate diverse, fused field campaign datasets

- Expected outcomes:
  - Interactive user interface for visualization and analytics
  - VISAGE repository containing data specific to the selected use cases
  - Support for target user community – NASA Precipitation Measurement Mission Science Team
  - *Long term vision – a robust multi-sensor, multi-format integration system suitable for a wide array of applications*

Science Value

- Proof-of-concept to be centered around the ***GPM Ground Validation program***
  - Valuable source of intensive, coincident observations of atmospheric phenomena
  - Data from a wide variety of ground-based, airborne and satellite instruments
  - Diversity in spatial and temporal scales, variables, formats, etc., makes these data difficult to use together
- VISAGE can bring together these diverse measurements into a common framework to
  - facilitate selection of weather events or features for study
  - improve the data discovery process
  - assist with both qualitative and quantitative analysis of the measurements
  - facilitate more efficient research and analysis
- Focus on "golden cases" where most ground instruments were in operation and multiple research aircraft sampled a significant weather event, ideally while the GPM Core Observatory passed overhead

Science Use Cases from the GPM GV Program

Olympic Mountains Experiment (OLYMPEX) - Rain & snow in extreme coastal & topographic gradients (NW Washington, Nov 2015 – Feb 2016)

- *Use Case: complex baroclinic system with orographic enhancement on 3 Dec 2015; excellent sampling coordination with simultaneous satellite, airborne, & ground-based*

Integrated Precipitation and Hydrology Experiment (IPHEX) - Warm season precipitation and hydrologic processes in complex terrain (W North Carolina, April – June 2014).

- *Use Case: warm-season convective storm with severe hail on 23-24 May 2014; observations from ground-based radars, two aircraft, and GPM Core satellite with very good GMI and DPR coverage*

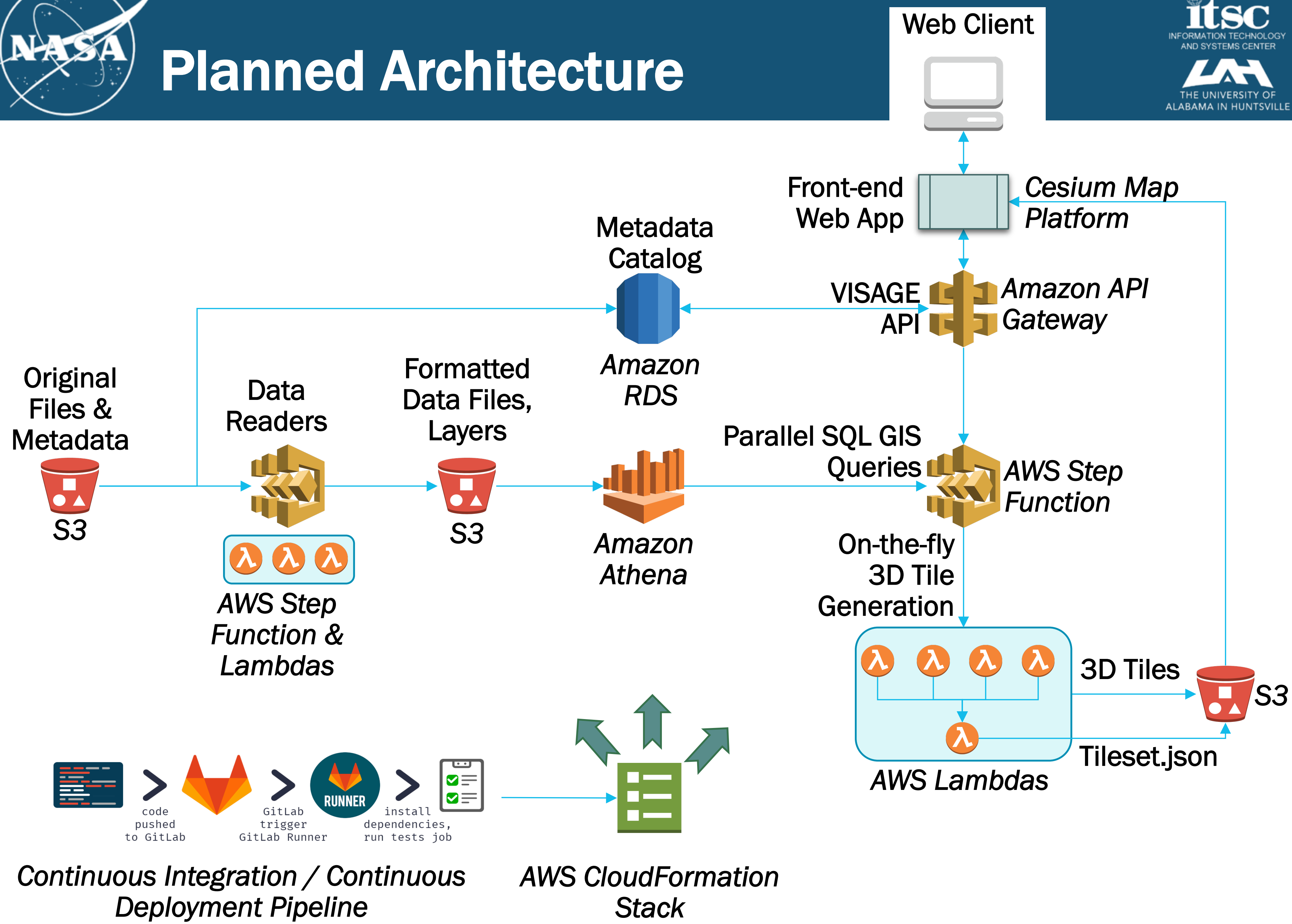
GPM Cold season Precipitation Experiment (GCPEX) - Microphysical properties of precipitating snow (Ontario, Canada, Jan – Feb 2012)

- *Use Case: Microphysical observation & simulation of the entire life cycle of a significant precipitation band along a warm front; multiple airborne and ground observations on 18 Feb 2012 (before GPM Core satellite launch in Feb 2014)*

Technical Approach

- Key Technical Challenges
  - *3D data rendering and visualization* of multiple diverse datasets on a web-based platform
  - Data interrogation via map user interface, especially 3D data
  - Temporal alignment of data with diverse time scales and resolutions
  - Computations on data fields across instruments and platforms
- Current Research Areas
  - **Serverless Cloud-Native Technologies**
    - Amazon Web Service (AWS) Athena stateless query service for searching data stored in S3 buckets
    - AWS Step Functions and Lambdas to orchestrate and run data processing and rendering code without provisioning or managing servers, automatically scaling resources as needed
  - **3D tiles for data visualization and exploration**
    - Cesium open source geospatial 3D mapping platform
    - Point clouds, a proposed OGC community standard, to render millions of data points.
    - Experimentation with numbers of points, 3D tiles, and tileset hierarchy for efficient generation and rendering of tiles for visualization

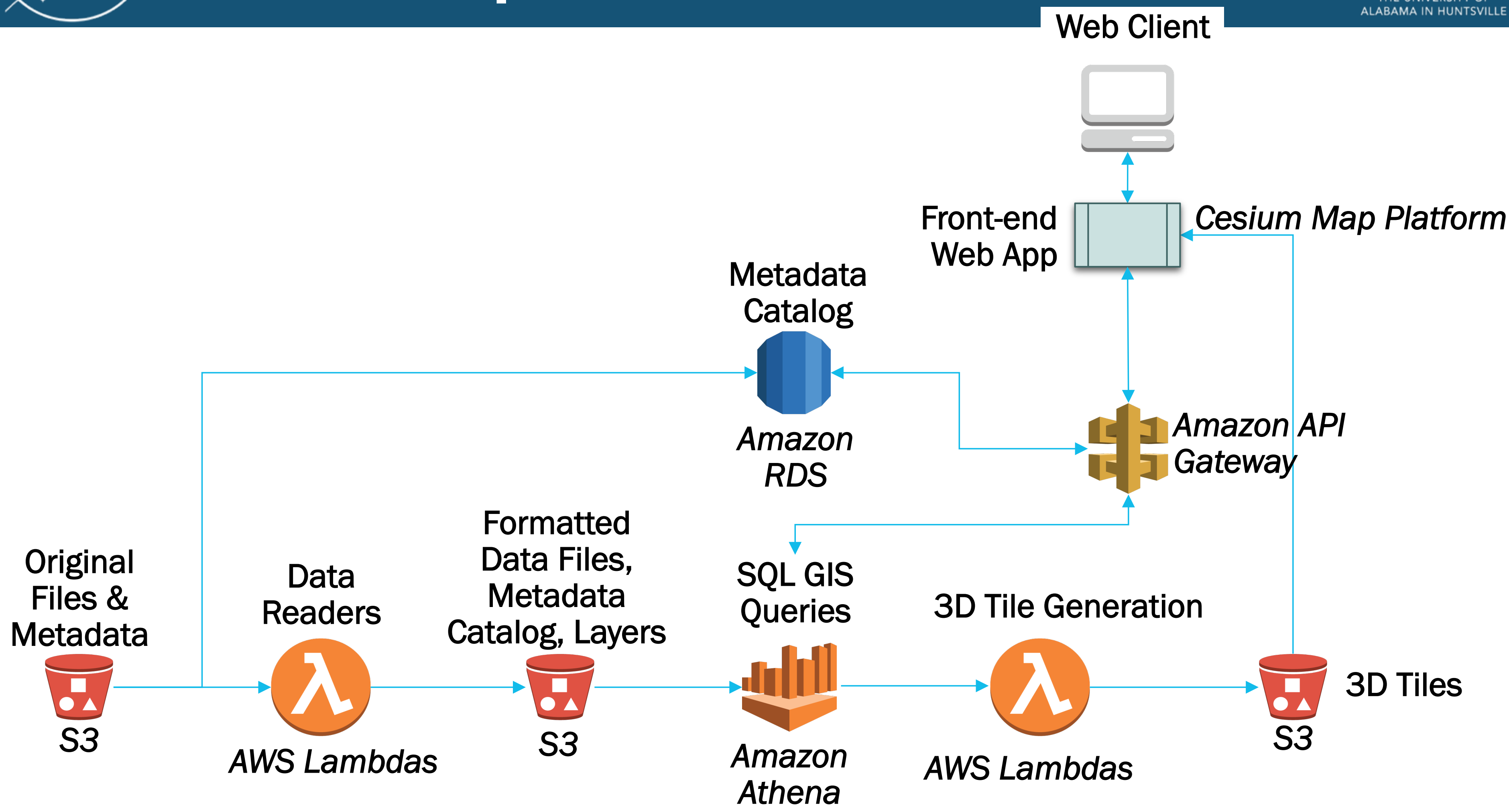
Planned Architecture



Cloud Native Technologies: AWS (mostly) Serverless Platform

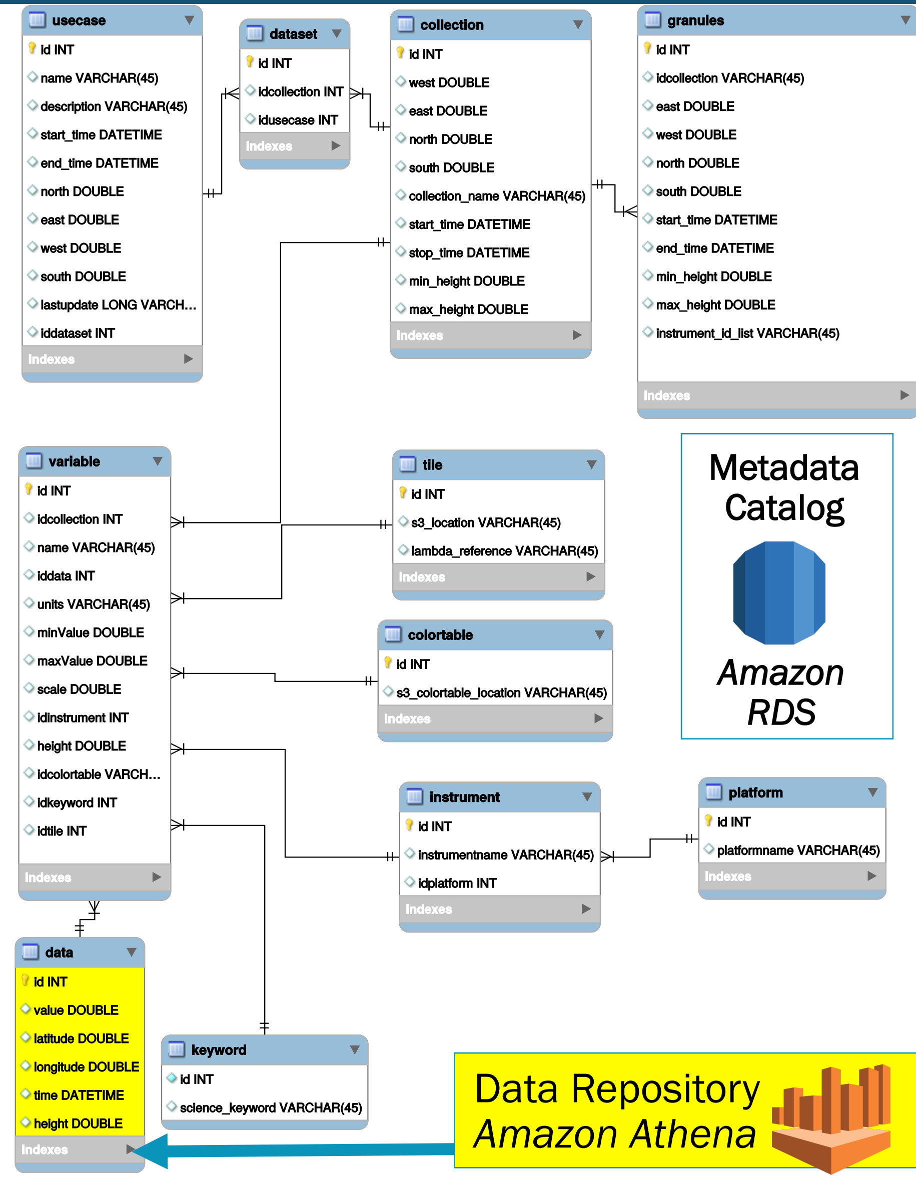
- **S3** – Simple Storage Service - within S3, data objects are stored in buckets
- **Lambda** – provides capability to run code without provisioning or managing servers, with automatic scaling
- **Step Functions** – used to coordinate components and step through the functions of an application, e.g., to orchestrate Lambda functions
- **Athena** – serverless, interactive query service analyze data in S3 using standard SQL
- **Amazon API Gateway** – service to create, publish, maintain, monitor, and secure APIs
- **AWS CloudFormation** – tools to describe and provision all the infrastructure resources in the cloud environment
- **AWS RDS** – Relational Database Service supporting different database engines

Current Implementation



Metadata Catalog (RDS)

- Initial basic metadata
  - VISAGE use cases
  - Data collections and granules
  - Information about variables, mapped to
    - GCMD science keywords
    - Instruments and platforms
    - Color tables
  - Index of 3D tiles
- Relationship to CMR/UMM*
  - Subset of CMR metadata for *collections* and *granules*
  - Metadata for *variables* as needed for VISAGE, but should be compatible; will evaluate against UMM-Var and UMM-Vis as these models evolve
  - Metadata for *use cases* specific to VISAGE, comparable to *events*



*ESDIS Common Metadata Repository and Unified Metadata Model

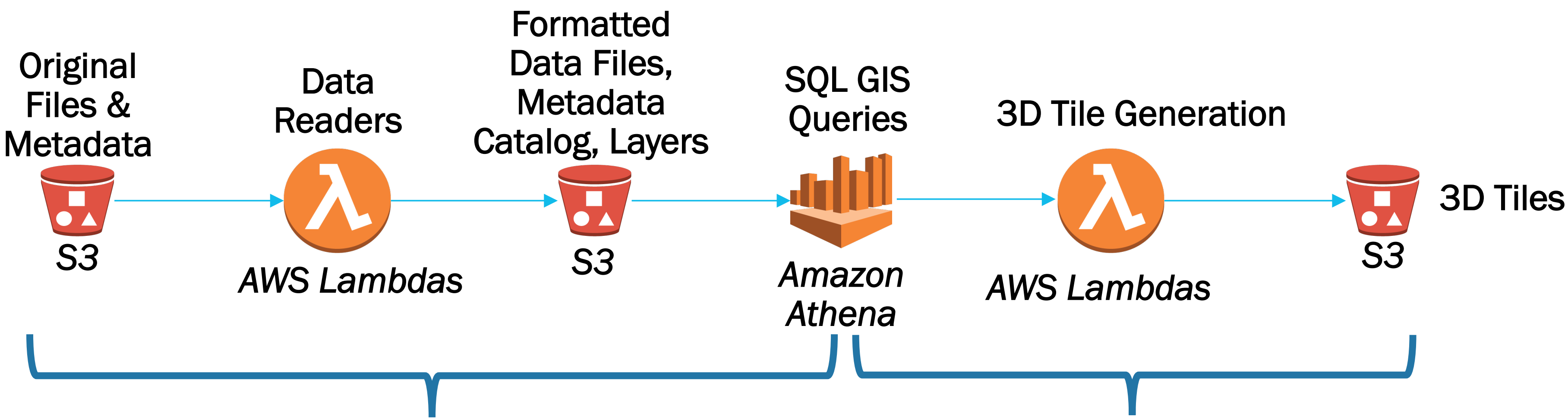
Interactive Data Repository (Athena Query Service)

- Stateless query service provides cost efficiency for VISAGE database (i.e., charged only for queries, not to maintain database uptime)
- Data files stored as comma separated value (CSV) files in S3 buckets. Athena "tables" support SQL queries to select data by time, location or value.
  - Common structure for all variables (time, location, value) in Athena data repository
  - Variable metadata (name, units, scale, range) in RDS metadata catalog
- Data is partitioned based on most commonly used query fields for better cost efficiency and response time

Data Repository
Amazon Athena

visage-db
- vn
  - campaign/year/month/day/hours/minutes/seconds
- simba
  - campaign/year/month/day/hours/minutes/seconds
- rain-gauge
  - campaign

Data Transformations



Original data files to Athena database

- Native data files are converted to CSV (and compressed)
  - Dataset specific code to translate to CSV
  - Possibility of using OPeNDAP server for translation

Athena to 3D tiles

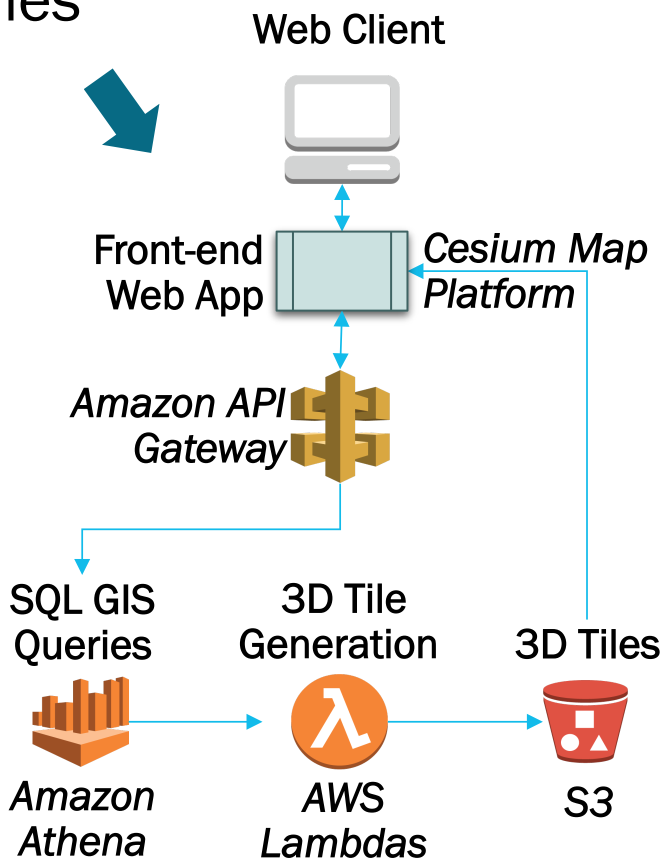
- Common, reusable Lambda functions
- Working toward on-the-fly generation using parallel Lambda functions

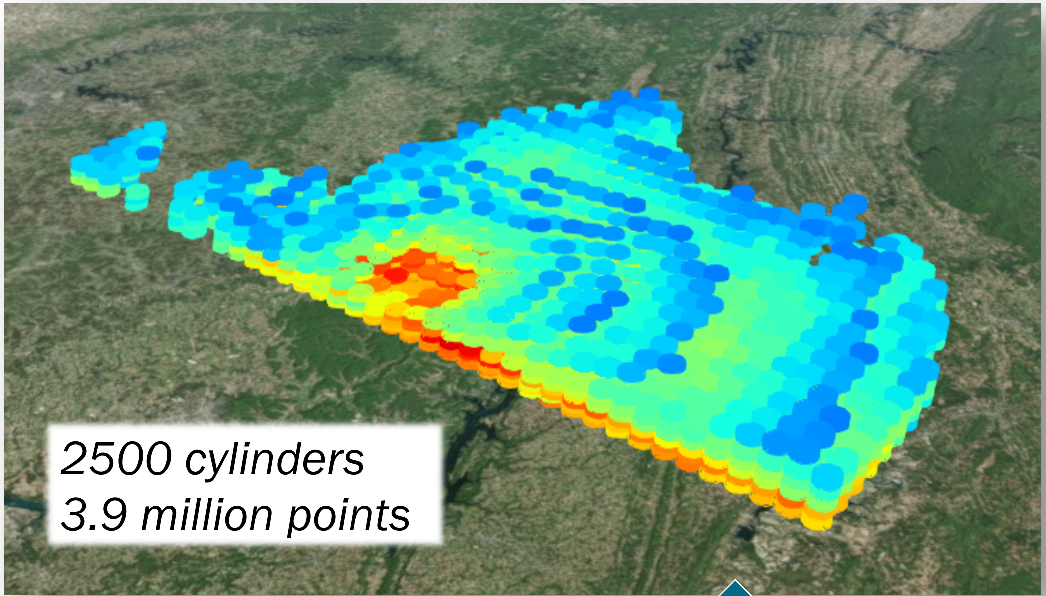
3D Data Rendering and Visualization

- *Why 3D tiles?*
  - Designed for streaming massive heterogeneous 3D geospatial datasets
  - Natively supported by Cesium map visualization user interface
  - Supports several data models
    - Batched 3D Model - Textured terrain and surfaces, 3D building exteriors and interiors, massive models
    - Instanced 3D Model - Trees, windmills, bolts
    - ➢ *Point Cloud - Massive amount of points*
      - **Point cloud density can be adjusted to render solid or semi-transparent appearance**
      - **Proposed OGC Community Standard**
    - Vector Data - Polygons, polylines, and placemarks (draft spec only)
    - Composite - Combine heterogeneous tile formats
    - Declarative Styling - Style features using per-feature metadata

Experiments in Making 3D Tiles

Goal: on-the-fly generation and display of data as 3D tiles





Sample dataset: GPM Validation Network of coincident satellite and ground radar reflectivity averages within a cylindrical GPM view volume were rendered as cylindrical volumes using an adjustable spatial density of points in Cesium 3D tile point cloud files.

Evolution of 3D Tile Software

Dec 2017 — Mar 2018 — June 2018

py3dtiles – public domain Python module to create point cloud 3dTiles

https://github.com/Oslandia/py3dtiles

CesiumTiles – locally developed Java function implements additional features of the point cloud 3dTile

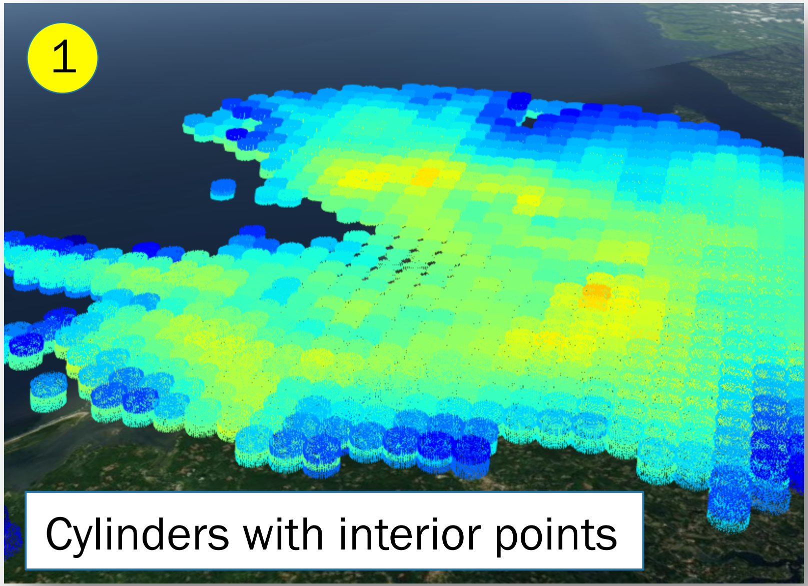
VisageTiles – lambda function to generate 3D tiles on-the-fly and render them in Cesium. Multiple VisageTiles lambdas can be invoked in parallel

	py3dtiles	CesiumTiles	VisageTiles
# points	3.9 million	3.9 million	3.9 million
# tiles	2500	1	4
Time to create	13+ min	11 sec	6 sec total elapsed time
Time to display	30+ min	<1 sec	

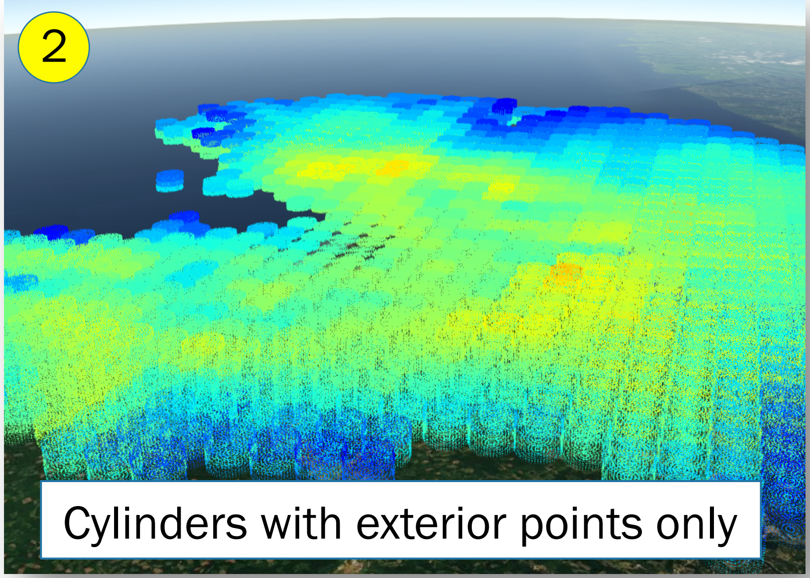
Note: time to create 3D tiles is related to number of points, while time to display depends more on number of tiles

Experiments in Point Cloud Density

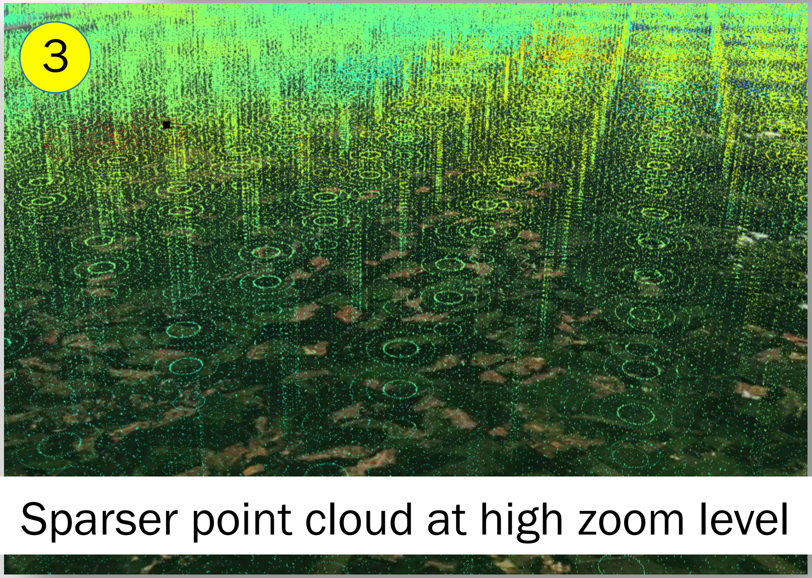
1. Denser point clouds can appear opaque
2. Fewer points can be rendered more quickly, and provide for better user interface performance
3. Sparser point clouds provide some transparency, allowing users to see into the data.



Cylinders with interior points



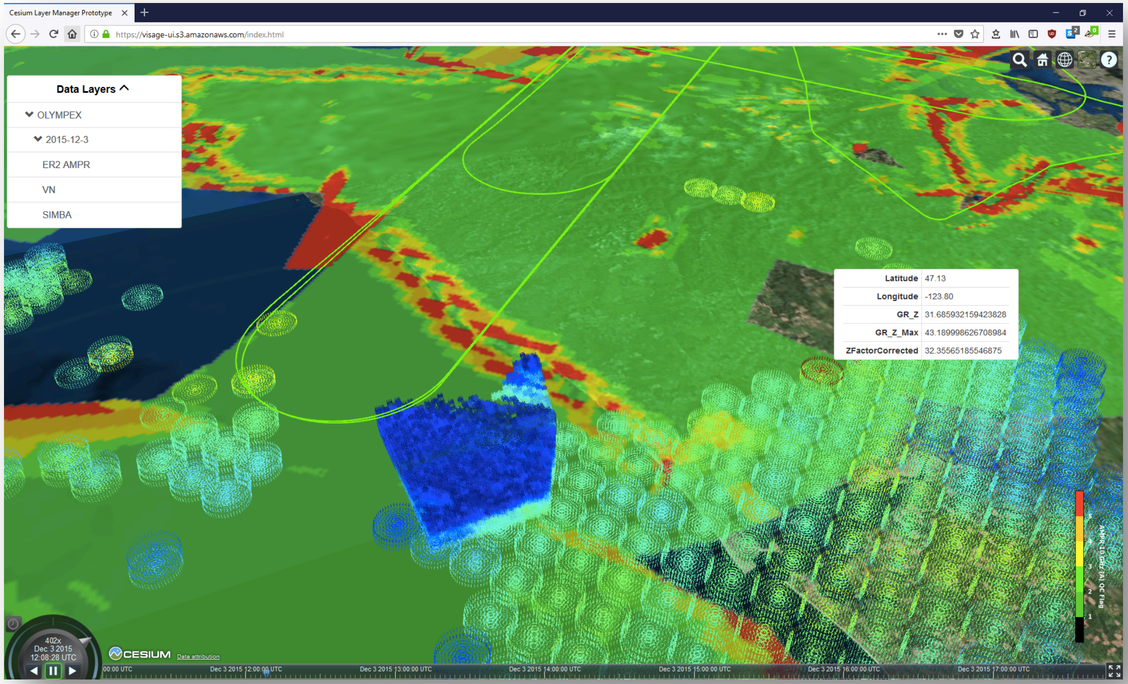
Cylinders with exterior points only



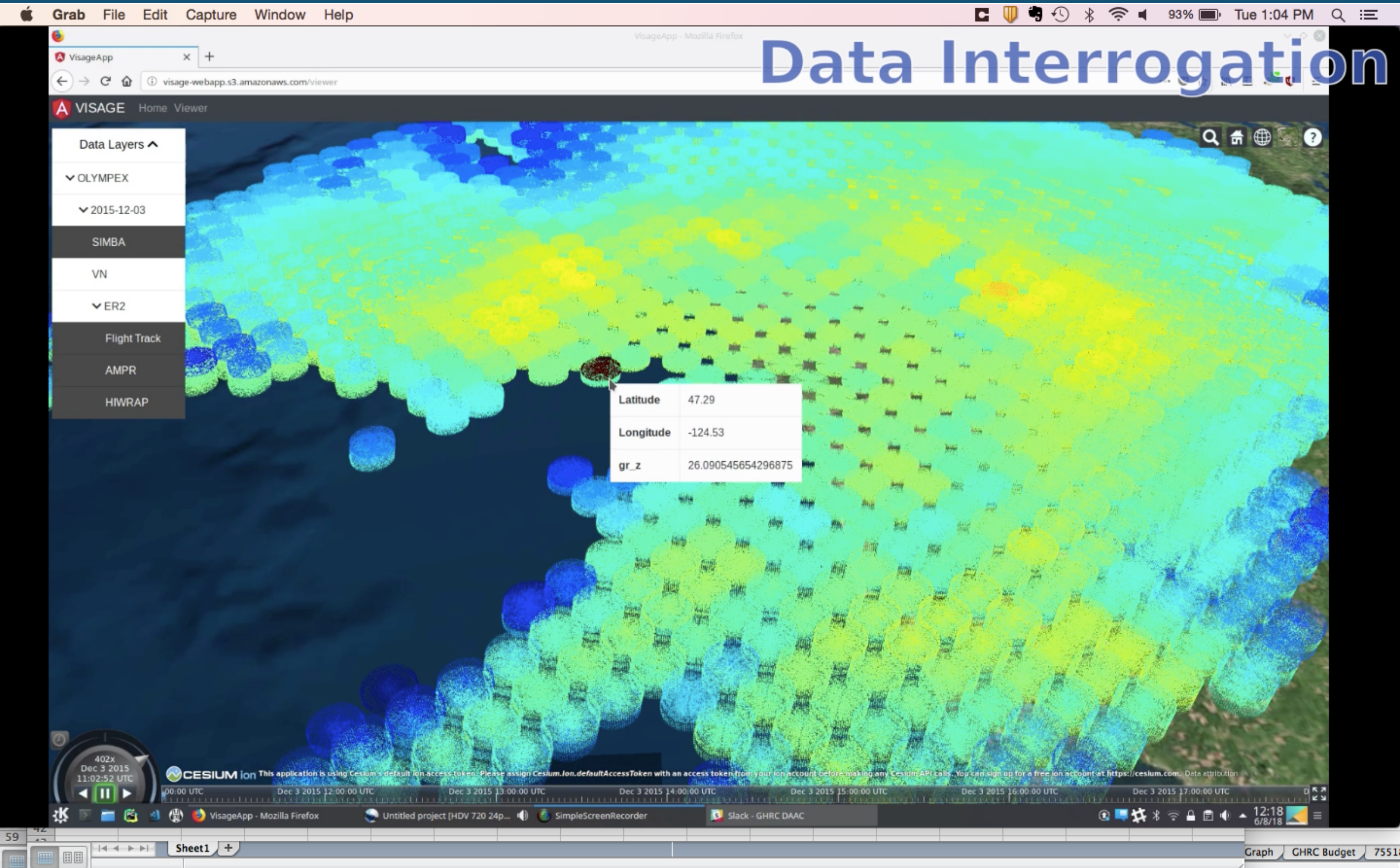
Sparser point cloud at high zoom level

User Interface – Web Application

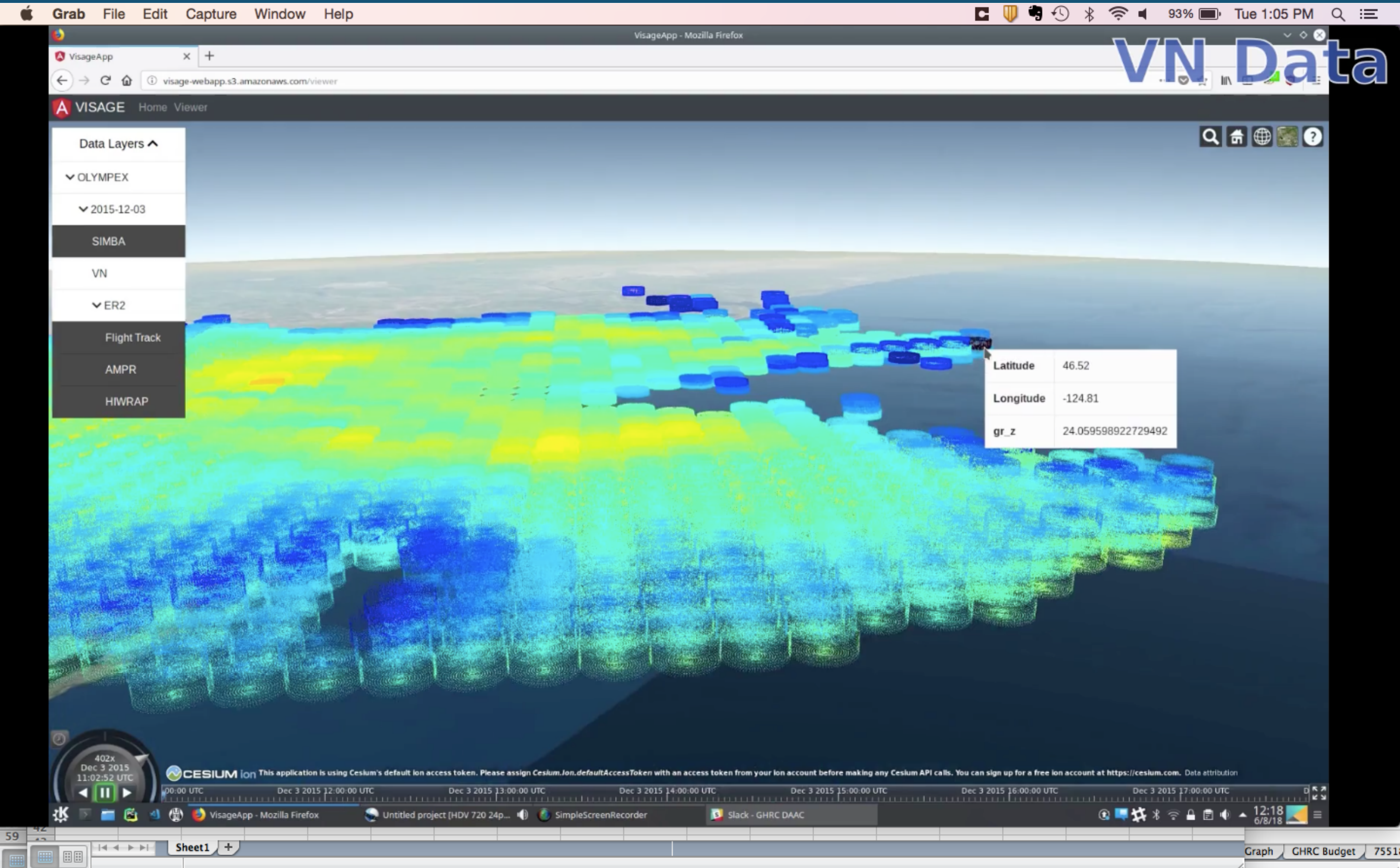
- VISAGE is a serverless web application hosted on an AWS S3 bucket. The VISAGE API is developed in .NET Core using AWS API Gateway and AWS Lambda functions.
- Cesium JavaScript library is used for data and map visualization
- A layer manager, to allow users to manipulate datasets loaded in Cesium, is being developed using the Angular framework. The web application also allows for mouse-over data interrogation.
- Most data is in point cloud format from the 3D tiles specification
- Simpler datasets, such as navigation data and flight paths, are visualized using CZML, a JSON-based format designed specifically for use with Cesium



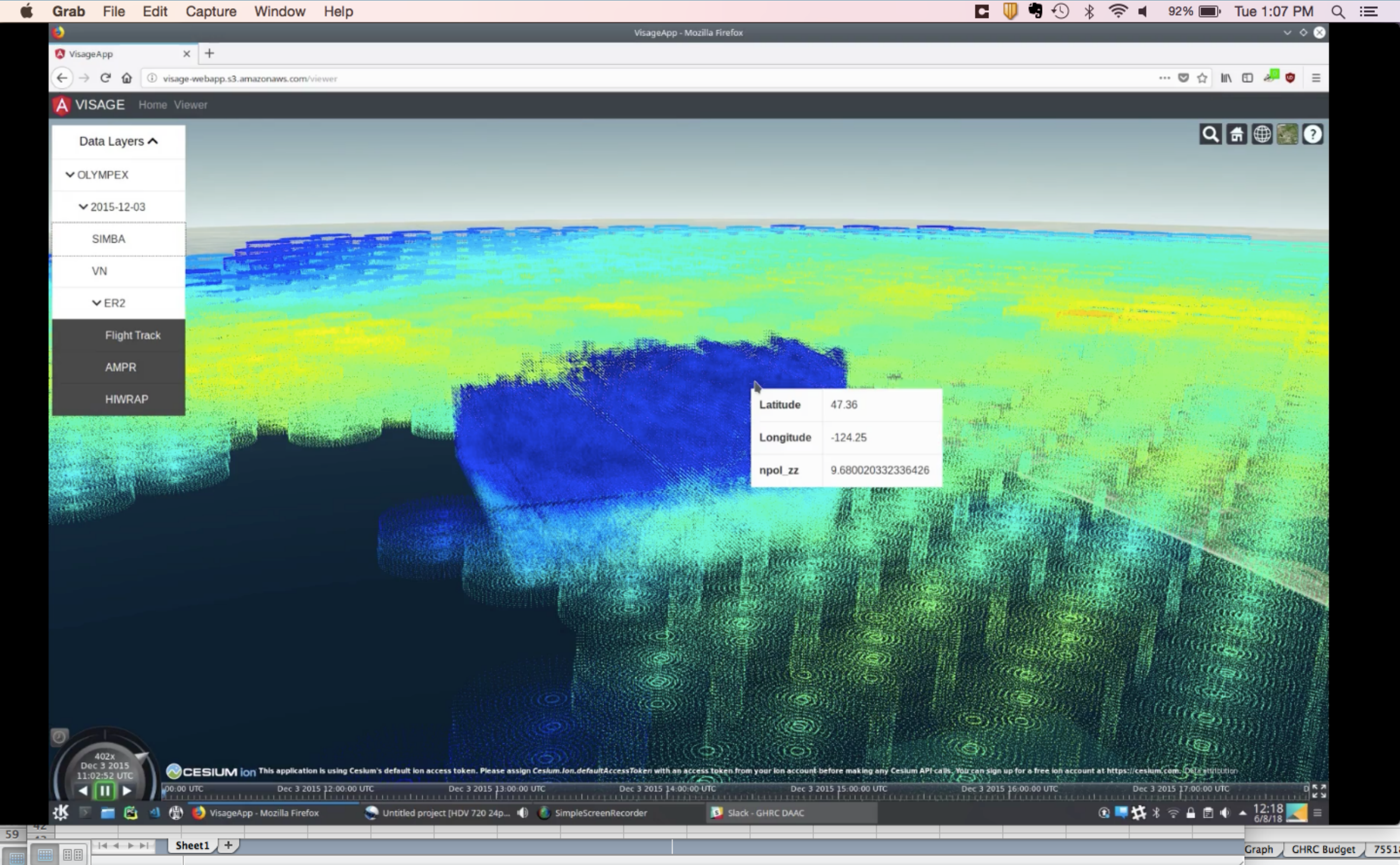
User Interface – Merged GPM and Ground Radar



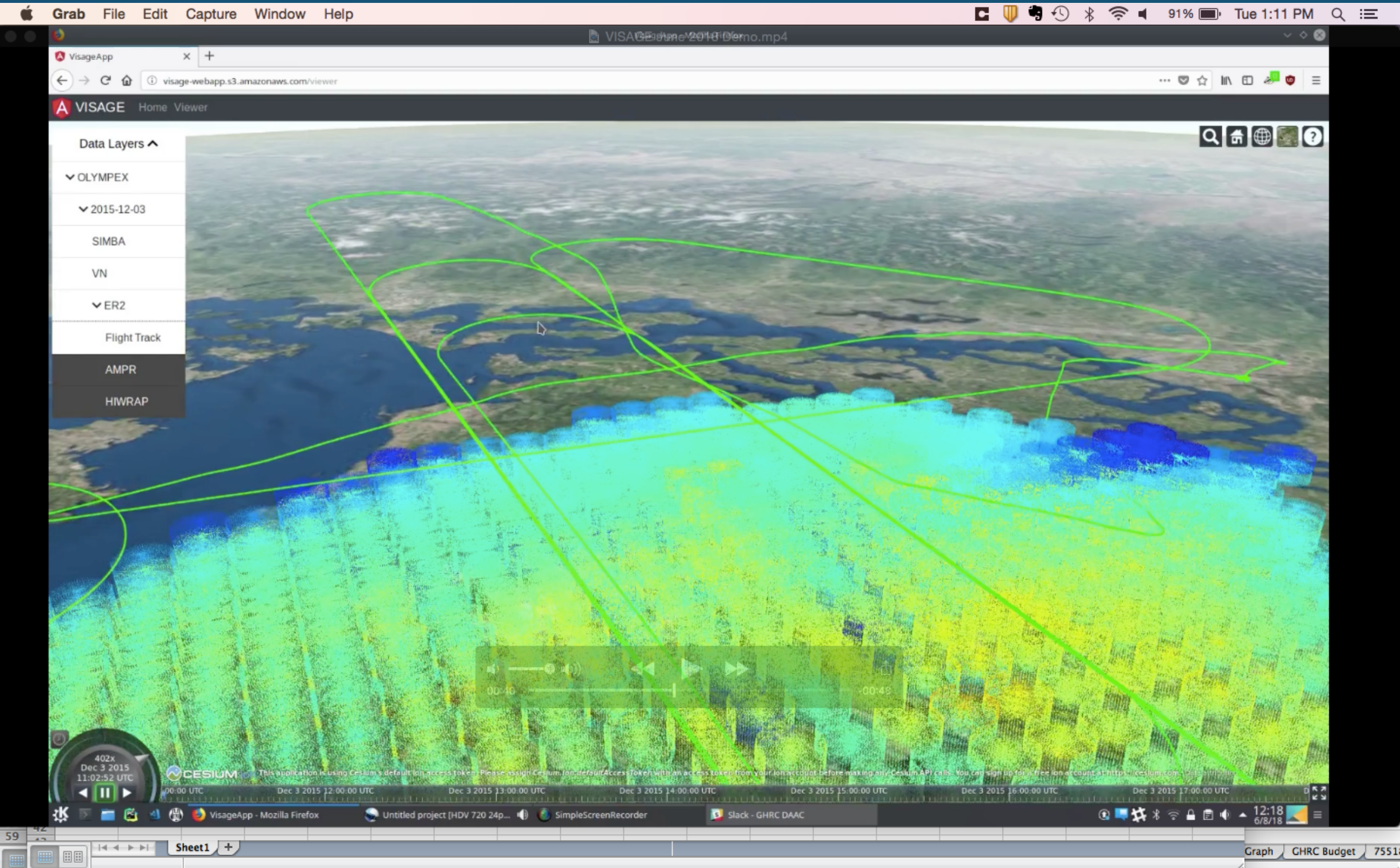
User Interface – Merged GPM and Ground Radar



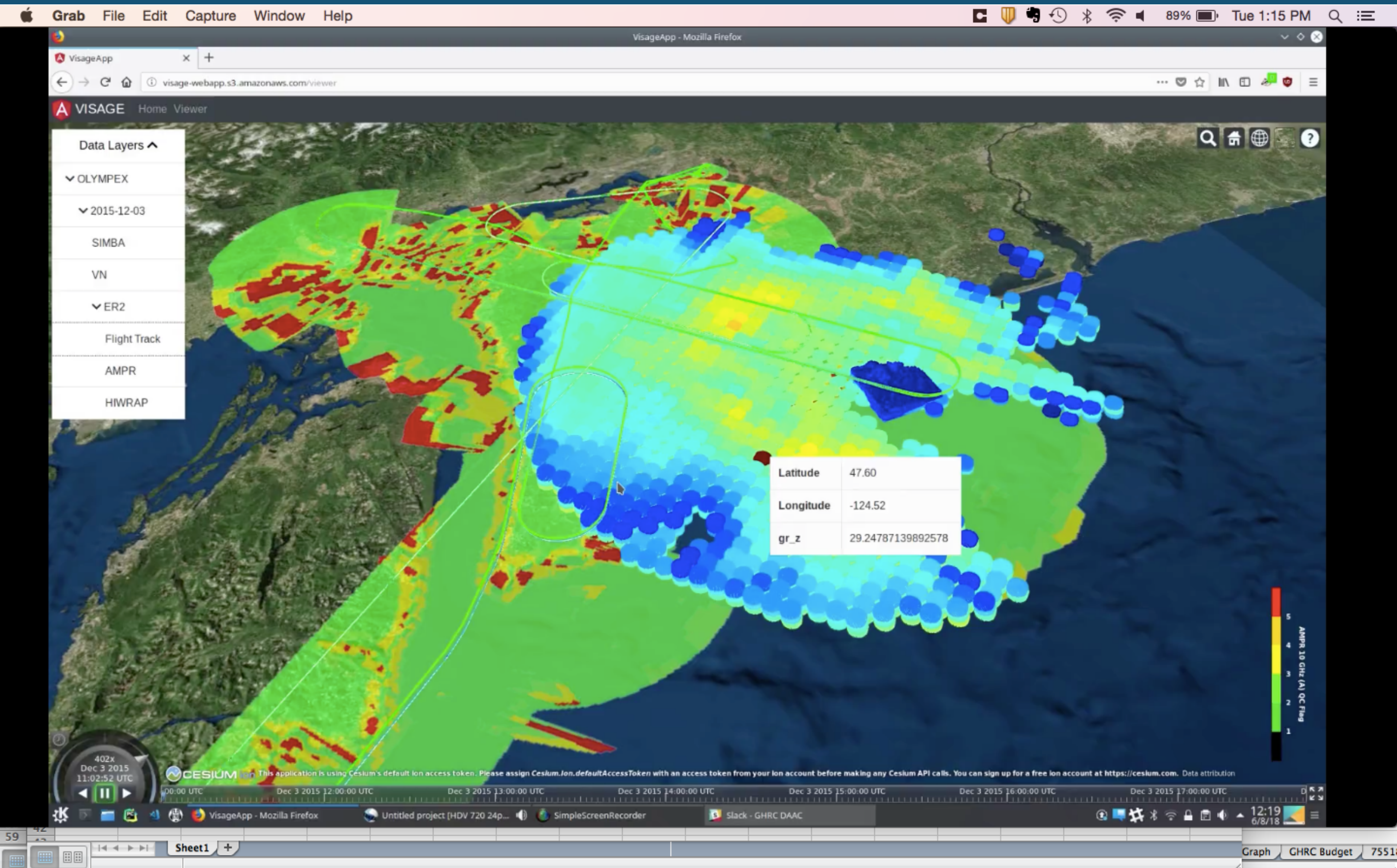
User Interface – NPOL radar



User Interface – ER-2 Flight Track



User Interface – Radars and Flight Observations



VISAGE demo:
https://youtu.be/B60b_IbAE4A

Issues and Planned Mitigations

- Data processing and volume
  - Balancing processing and performance requirements for on-demand 3D tile generation against cost of pre-generating and storing 3D tiles for all datasets
  - ➢ Continued experimentation with cloud native approaches, such as using multiple Lambdas orchestrated with Step Functions to generate many 3D tiles in parallel
- Need for custom software to handle diversity of data types
  - ➢ Store all data as CSV files in Athena database
    - Common software to generate data visualizations
    - Common tools for basic analytics such as differences and ratios across data products fields
  - ➢ Use OPeNDAP services for data in standard formats and write custom handlers for others

Plan Forward – Data Services

- Import additional field campaign data into Athena database
  - Experiment with OPeNDAP as common service to convert many target data types to CSV
  - Experiment with Lambda functions to convert data files to CSV files on demand
- Continue experiments with configuration of parallel Lambda functions for 3D tile generation to increase performance and avoid memory and/or timeout problems
- Continue experiments with composition of 3D tiles to increase performance
  - Increase size of individual points to improve display quality
  - Experiment with styling to resize tiles as user zooms in and out
  - Find optimal combination of tile resolutions for best display quality and interactivity
- Experiment with additional 3D visualization approaches such as volume rendering with ray casting

Plan Forward – UI Features

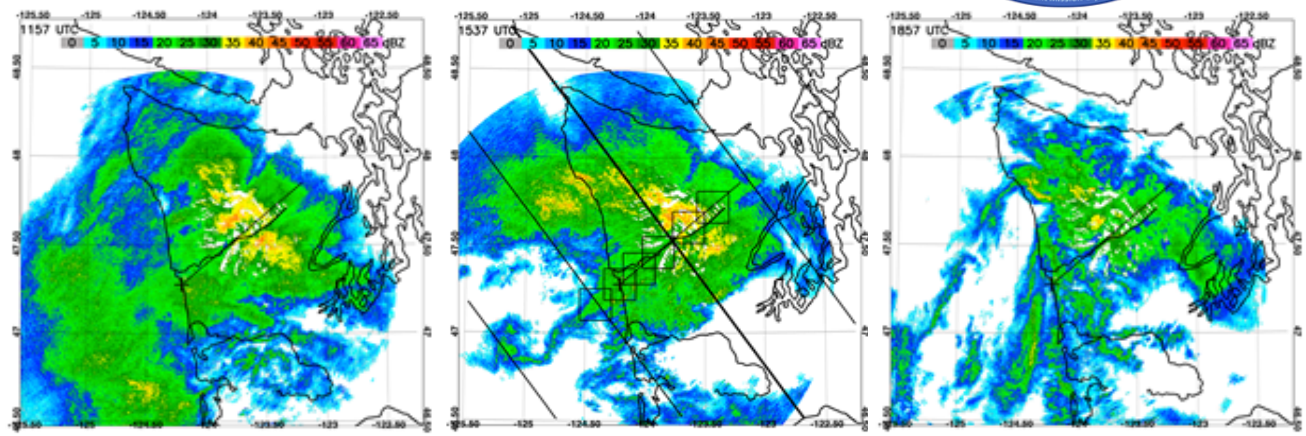
- Provide better support for interactive data interrogation
  - Help user select specific points to interrogate in the 3D point cloud
  - Determine whether to store data point location and values in 3D tiles, or query source data file
- Investigate methods for temporal alignment of data with diverse time scales and resolutions
- Allow user to access metadata and download data associated with on-screen visualizations
- Prototype cloud-native data services for subsetting and computations on data fields across instruments and platforms

Back-up Slides

Initial Focus Use Case: 3 Dec 2015 from the OLYMPEX Field Campaign

Complex baroclinic system with orographic enhancement; excellent sampling coordination with simultaneous satellite, airborne, & ground-based observations

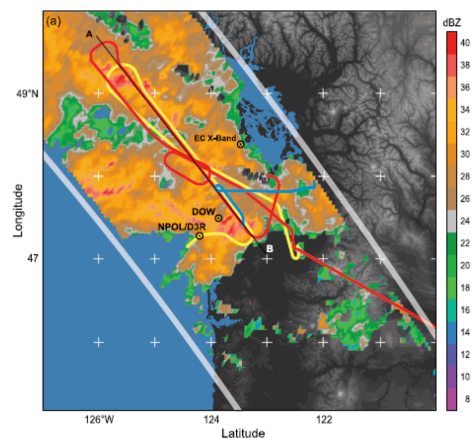
- Evolving shortwave trough with shallow, developing frontal boundary
- Southerly flow & widespread stratiform precipitation with embedded variability
- Stacked aircraft observations within GPM satellite coverage
- Post-frontal behind wind shift later after GPM overpass



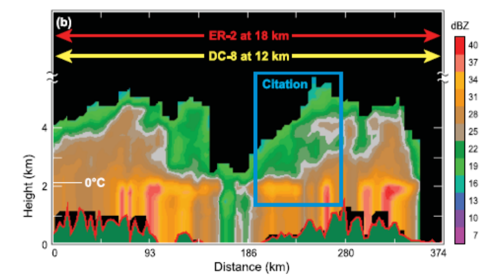
3 Dec NPOL reflectivity, middle panel shows GPM DPR and GMI overpass swaths (bold line is nadir track) and select SIMBA column locations

Data Available:

- Most ground instruments, including:
  - Radars: NPOL, KLGX, D3R, DOW
  - Disdrometers, gauges, profilers, soundings
- ER-2, DC-8, and Citation aircraft:
  - AMPR, CRS, APR-3, CoSMIR, microphysics probes, etc
- GPM overpass at 15:22 UTC
  - Both GMI & DPR swaths
- Select SIMBA columns
- DPR and ground radar match-ups
- Select WRF model subsets



Locations of stacked ER-2, DC-8, and Citation flights within GPM DPR Ku-band swath for ~1 h centered on the GPM overpass time, DPR Ku reflectivity shown



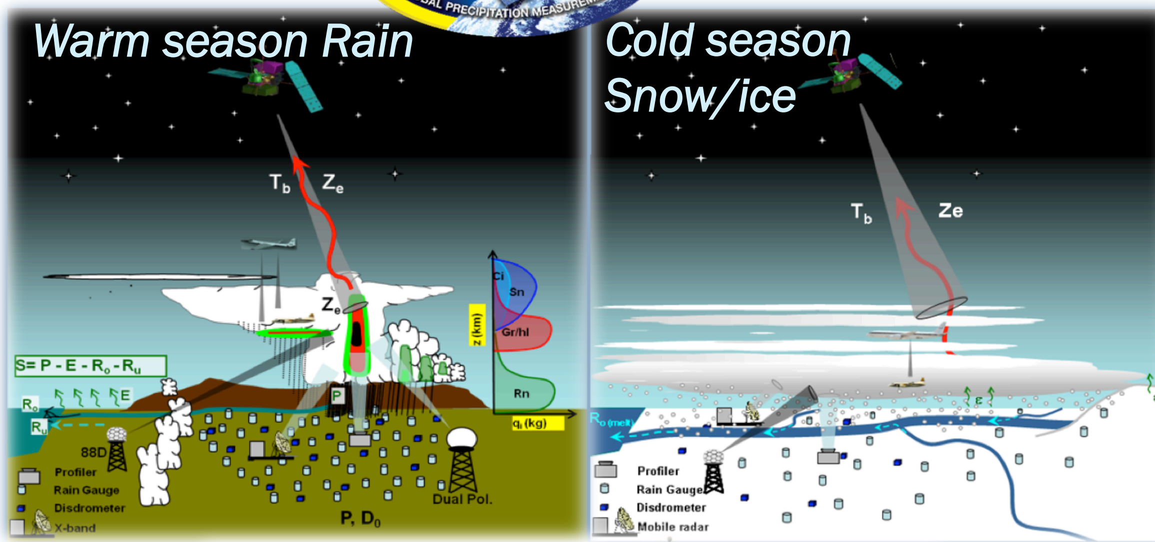
Relative nominal aircraft altitudes shown on cross section of DPR Ku reflectivity

Houze et al. (2017)

Targeted Data Products: GPM Ground Validation Archive

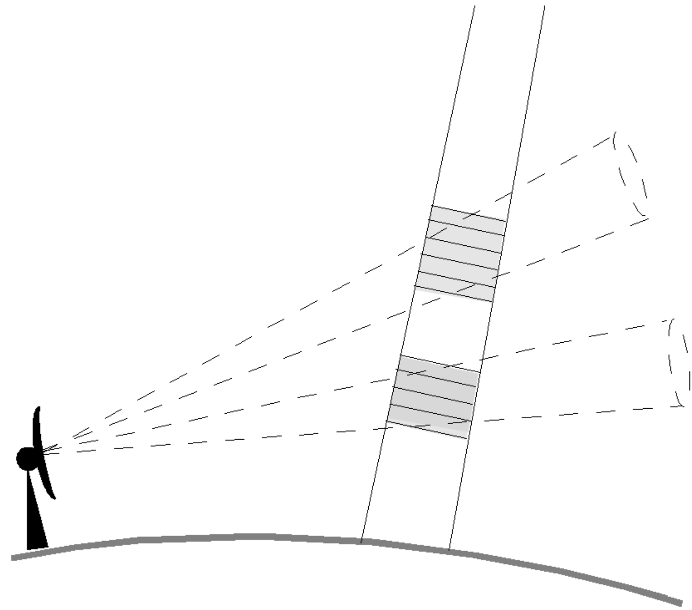
GPM GV data are archived at the GHRC DAAC. Dataset publication is ongoing. This collection includes:

- Series of field campaigns collecting detailed measurements of precipitation and related physical processes in a variety of diverse metrological regimes
- Ground and airborne precipitation datasets supporting validation of satellite-based precipitation retrieval algorithms
- Related extended observations from additional sites



Targeted Data Products: GPM Validation Network (VN)

- Compares data from satellite radars (GPM DPR, TRMM PR) and microwave imagers (GMI, TMI and others) to ground-based scanning weather radar observations
- Subsets satellite and ground radar (GR) data for coincident observations of precipitation
- Generates vertical profiles with matching coincident DPR and GR data for precipitation events



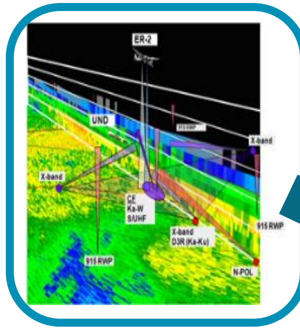
Example of DPR gate averaging at GR sweep intersections. Shaded areas show individual DPR gates intersecting the vertical extent of two GR sweeps (dashed) at different elevation angles. The reflectivity values of the individual DPR gates are averaged over the vertical extent of the GR sweeps, resulting in two matching volumes for the single DPR ray shown in this case.

Targeted Data Products: SIMBA

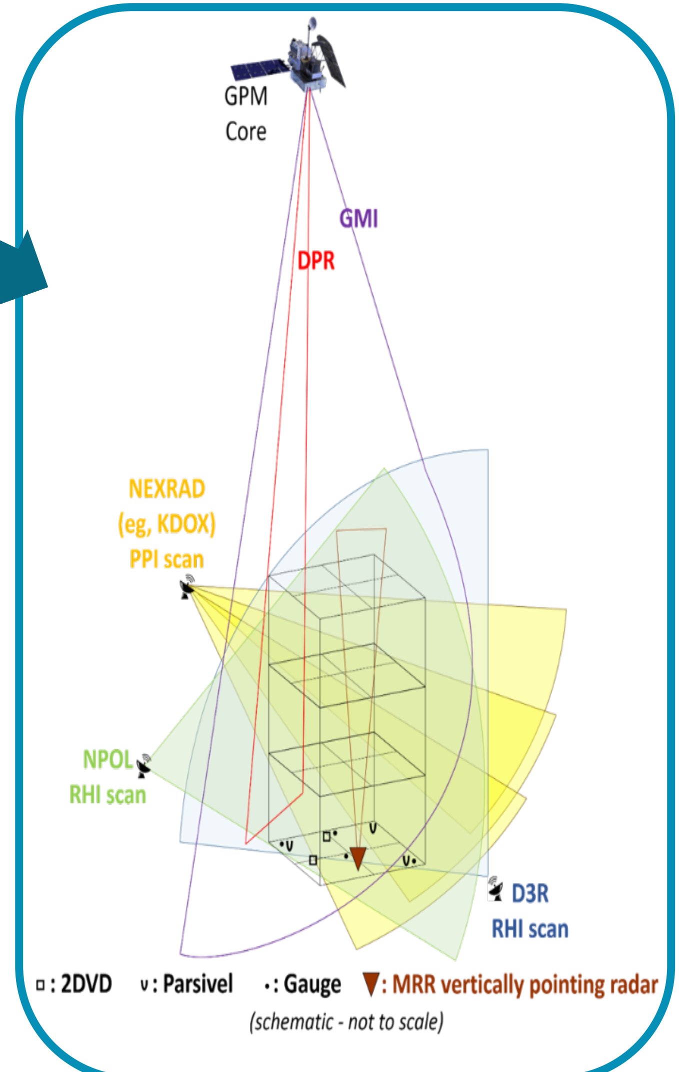
System for Integrating Multi-platform data to Build the Atmospheric column

- Higher-level data product, fusing **GPM satellite and ground-based observations** into a gridded atmospheric column data file
- Interpolates and/or resamples observations from various scales to set data into a common, **user-specified 3D grid**
- Encodes observations from diverse data formats into unified **netCDF file**
- **Attributes** preserve key operation parameters for each sensor
  - Location, operation mode, timestamps, algorithms, product versions, etc.

Wingo et al. – in review (JTECH)

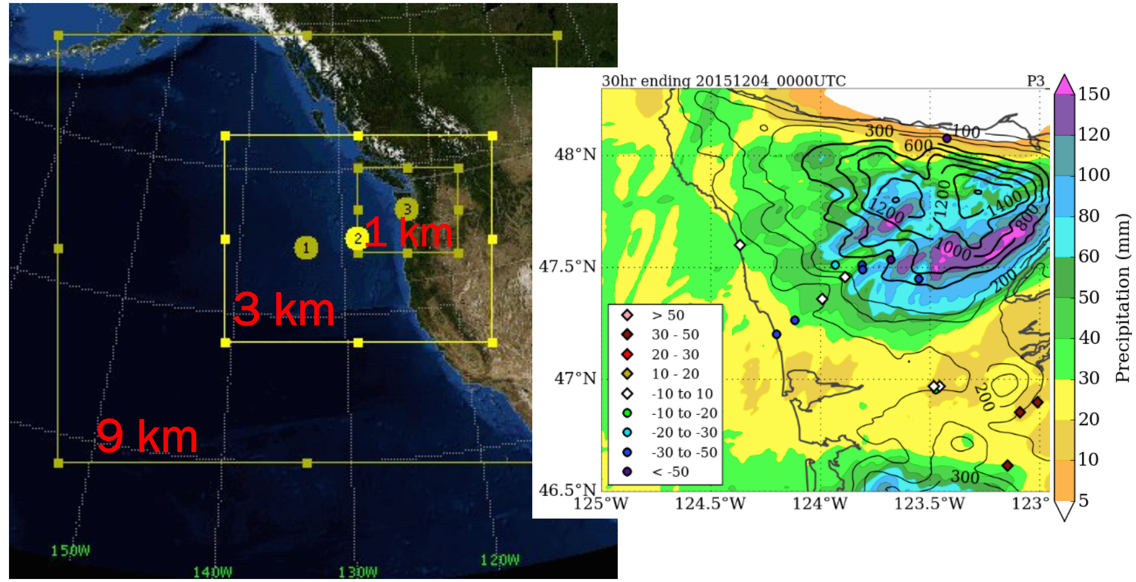


SIMBA fuses targeted satellite- and ground-based observations collected in various formats & coordinate systems to a single, used-defined 3D column grid

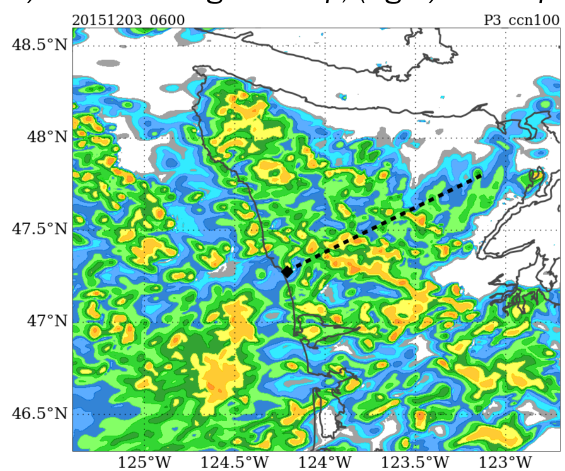


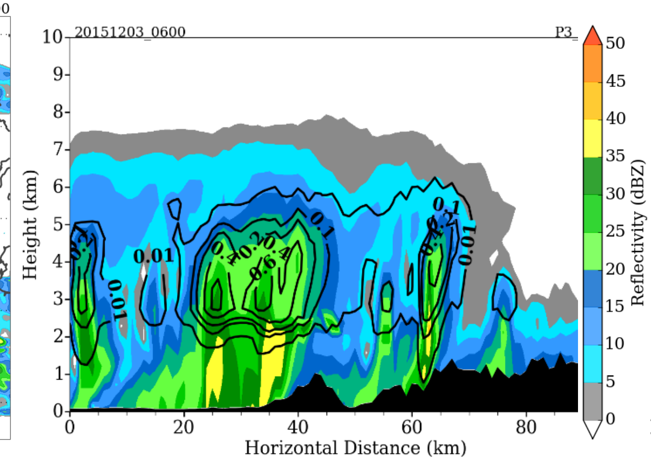
WRF Model Simulations

- Triple-nested 9, 3, and 1 km grid setup with high-resolution innermost nest over OLYMPEX field site
- Cloud microphysical schemes in WRF model can lead to large uncertainties in the precipitation forecasts
- Field campaign data can help intensively validate cloud microphysical schemes, but collecting/analyzing the large amount of field and model data can be tedious
- VISAGE will help promote more efficient model validation work, which can ultimately help improve precipitation forecasts



(left) WRF model grid setup, (right) model precipitation versus ground-based observations





(left) WRF model reflectivity at lowest level over the Olympic peninsula, (right) WRF model reflectivity (shaded) and rime mass (solid black) along NPOL RHI scan (black dashed)

Entry and Exit TRL

- *Entry TRL: This new capability is still in the concept phase, **TRL 2***
- *Current TRL: We are currently researching technical feasibility of 3D Tiles / Point Clouds and Amazon Athena database with representative data, **TRL 3**. However, proposed analytics functions remain at concept phase, **TRL 2**, until Year 2.*
- *Exit TRL: During the two-year VISAGE project, we expect to advance FCX to **TRL 4**, a standalone implementation using full-scale data and providing the functionality needed to address the selected use cases*

VISAGE component	TRL	Comment
Amazon Cloud services	8	Fully operational with most, but not all, documentation
Cesium platform	7	Operational but with limited documentation
Data readers	3	Native data files to CSV, for representative data
3D tile generators	3	Athena to point cloud, for representative data
3D vis web app	3	Proof of concept demonstration
Data interrogation function	3	Proof of concept demonstration
Basic analytics functions	2	Concept only

Acronyms

AIST	Advanced Information Systems Technology
AMCE	AIST-managed Cloud Environment
AMS	American Meteorological Society
API	Application Programming Interface
AWS	Amazon Web Services
CMR	Common Metadata Repository
CSV	Comma Separated Value
DAAC	Distributed Active Archive Center
DPR	Dual-frequency Precipitation Radar (on GPM)
ESDIS	Earth Science Data and Information System
FCX	Field Campaign Explorer
GCPEX	GPM Cold-season Precipitation Experiment
GHRC	Global Hydrology Resource Center
GMI	GPM Microwave Imager
GPM	Global Precipitation Monitoring
GPM GV	GPM Ground Validation
GR	Ground Radar
GRA	Graduate Research Assistant
GSFC	Goddard Space Flight Center
IPHEX	Integrated Precipitation and Hydrology Experiment
HAMSR	High Altitude Monolithic microwave integrated circuit (MMIC) Sounding Radiometer
HS3	Hurricane and Severe Storm Sentinel
MSFC	Marshall Space Flight Center
netCDF	network Common Data Form
NPP	NASA Postdoctoral Program
OLYMPEX	Olympic Mountain Experiment
OPeNDAP	Open-source Project for a Network Data Access Protocol
PPS	Precipitation Processing System
PR	Precipitation Radar (on TRMM)
S3	Simple Storage Service
SIMBA	System for Integrating Multi-platform data to Build the Atmospheric column
SQL	Structured Query Language
TMI	TRMM Microwave Imager
TRL	Technology Readiness Level
TRMM	Tropical Rainfall Measurement Mission
UAH	The University of Alabama in Huntsville
UI	User Interface
UMM	Unified Metadata Model
USRA	Universities Space Research Association
VISAGE	Visualization for Integrated Satellite, Airborne and Ground-based data Exploration
VN	Validation Network (for GPM)
WFF	Wallops Flight Facility
WRF	Weather Research and Forecasting