Moving Objects Database Technology for Ad-Hoc Querying and Satellite Data Retrieval of Dynamic Atmospheric Events

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Presentation Outline

- Motivations and Objectives
  - Application
  - System
- Review: Moving Objects Database Concepts
- System Overview and Status
  - Software Architecture
  - Demo I – Web-based Trajectory Query
  - Demo II – Matlab-based Satellite Data Retrieval
- Future Work

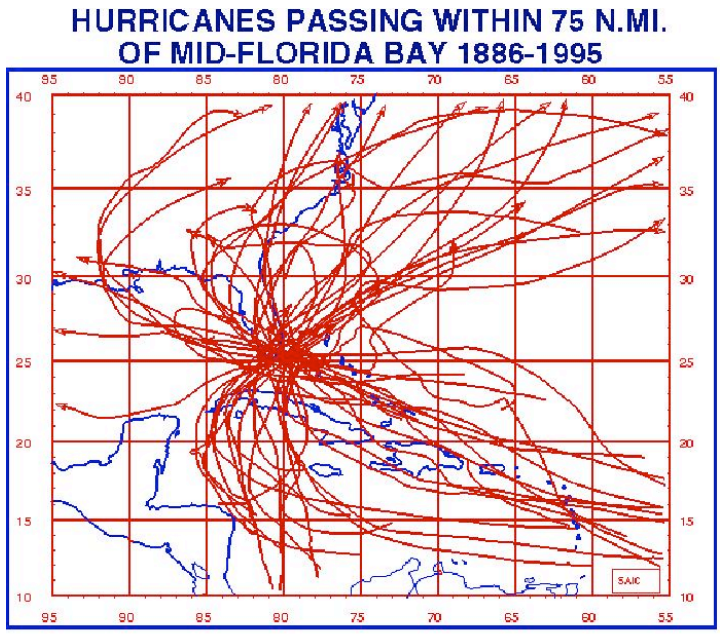
ESTO
Earth Science Technology Office

Motivations and Objectives

Application Objectives (I)

- Provide the NASA workforce with previously unavailable data(base) management, analysis, and query capabilities that will advance the research and understanding of dynamic weather events based on data derived from the NASA mission sensor measurements
- Focus on tropical cyclone events
- Our technology will provide both Earth Science researchers and non-scientist decision makers with the capability to
  - ad-hoc query for dynamic atmospheric events and their related information, and
  - easily retrieve satellite data for scientific analysis.

Application Objectives (II)

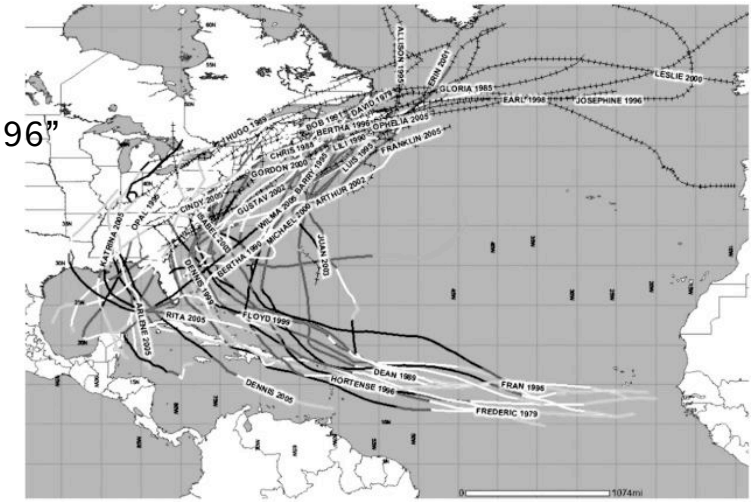


Ad-hoc Trajectory Query

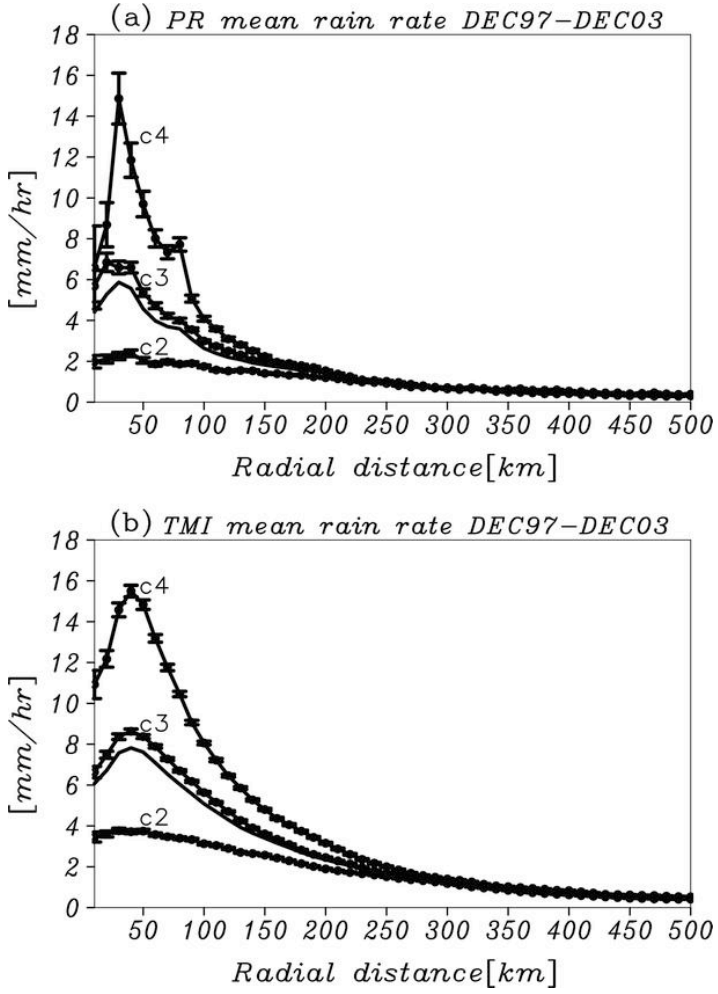
``List all tropical cyclones that starts from Windsor, Ontario, to St. John's, Newfoundland from 1979 to 2005. Retrieve NCEP-NCAR global reanalysis data and the NCEP NARR data'' and data from 40 tropical cyclones were collected.

Shawn M. Milrad, Eyad H. Atallah, and John R. Gyakum, ``Dynamical and Precipitation Structures of Poleward-Moving Tropical Cyclones in Eastern Canada, 1979--2005'', Monthly Weather Review, vol. 137, pp. 836-851, Mar. 2009.

A visualization for the query "List the best tracks of the hurricane passing within 75 nautical miles of mid-Florida Bay from 1886 to 1996" (http://www.aoml.noaa.gov/hrd/Storm_pages/fl_track_red.html)



Application Objectives (III)



1-D Composite Data Analysis

"List all tropical cyclones from December 1997 to December 2003. Retrieve related TRMM 2A25 and 2A12." and 563 tropical cyclones retrieved with 3703 TRMM satellite data snapshots.

Radial distributions of mean rain rates (derived from (a) PR and (b) TMI) at the ``mature'' stage. (Chie Yokoyama and Yukari N. Takayabu, ``A Statistical Study on Rain Characteristics of Tropical Cyclones using TRMM Satellite Data'', Monthly Weather Review, vol. 136, pp. 3848--3862, Oct. 2008.

Application Objectives (IV)

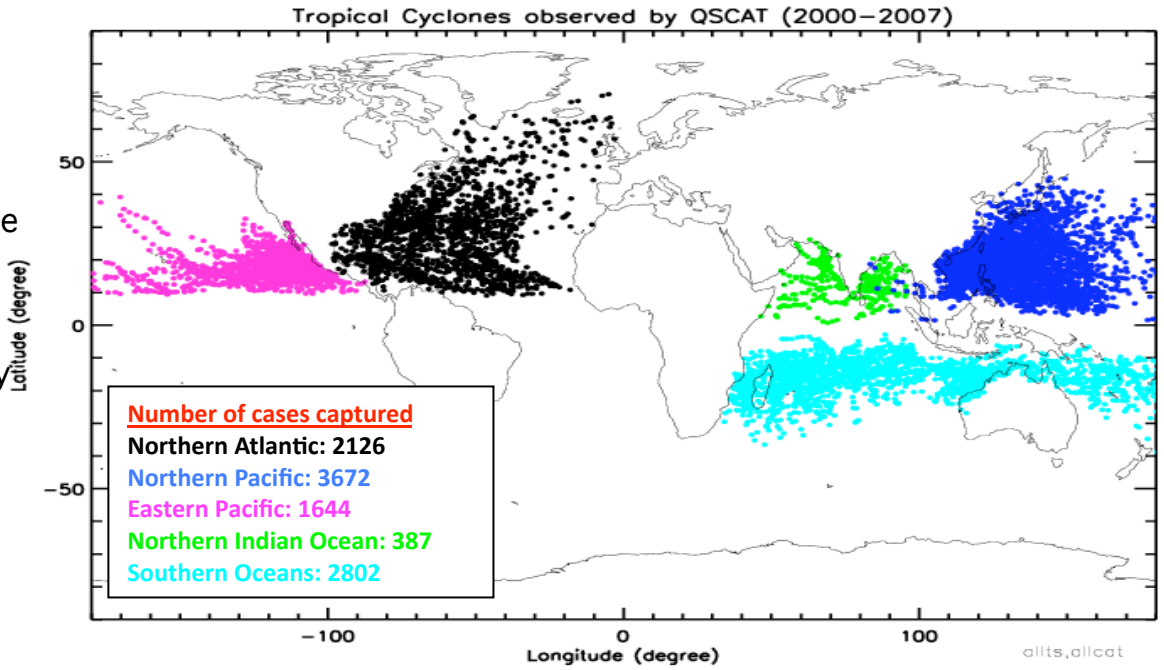
Tang, W. and W. T.Liu, 2010: Effect of Wind Stress Asymmetry in Typhoon Intensity Changes. *2010 Ocean Science Meeting*, February 19-24, 2010, Portland, Oregon.

Liu, W.T. and W. Tang, 2009: Hurricane Asymmetry Revealed by a Decade of Spacebased Measurements. *2nd International Summit on Hurricanes and Climate Change.* Corfu, Greece, May 31 - June 5, 2009.

Tang, W., and W. T. Liu, 2009: Dependence of Hurricane Asymmetry and Intensification on Translation Speed Revealed by a Decade of QuikSCAT Measurements. *NASA Ocean Vector Wind Science Team Meeting*, Boulder, Colorado, May 18-20, 2009.

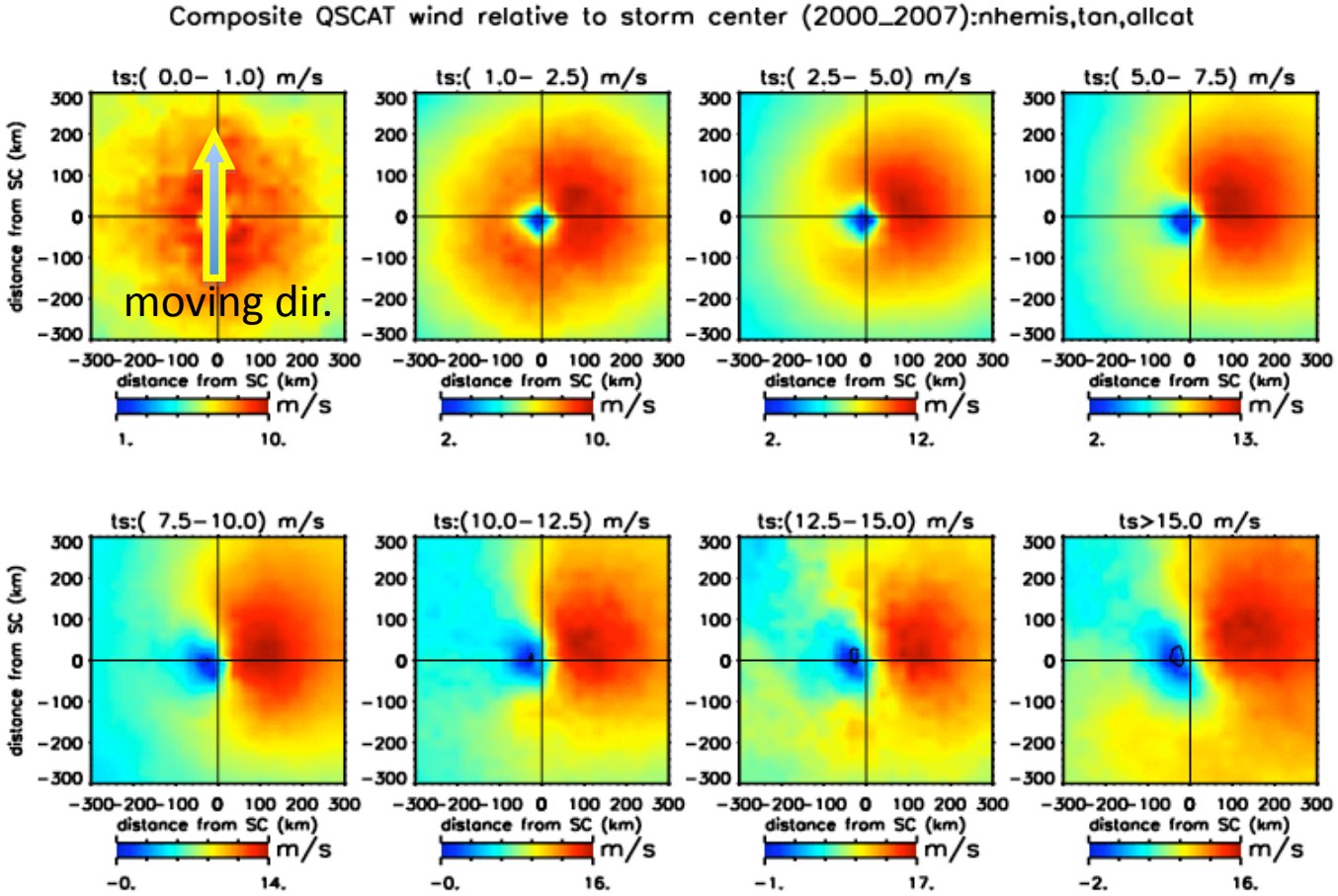
Tang, W. and W. T. Liu, 2008: Surface Wind/Stress Structure under Hurricanes, *SeaWinds Science Working Team meeting*, Seattle, Washington, November 2008.

"Retrieve QuikSCAT wind vectors and TRMM precipitation data for all tropical cyclones with translation speed faster than 15 meter/second".



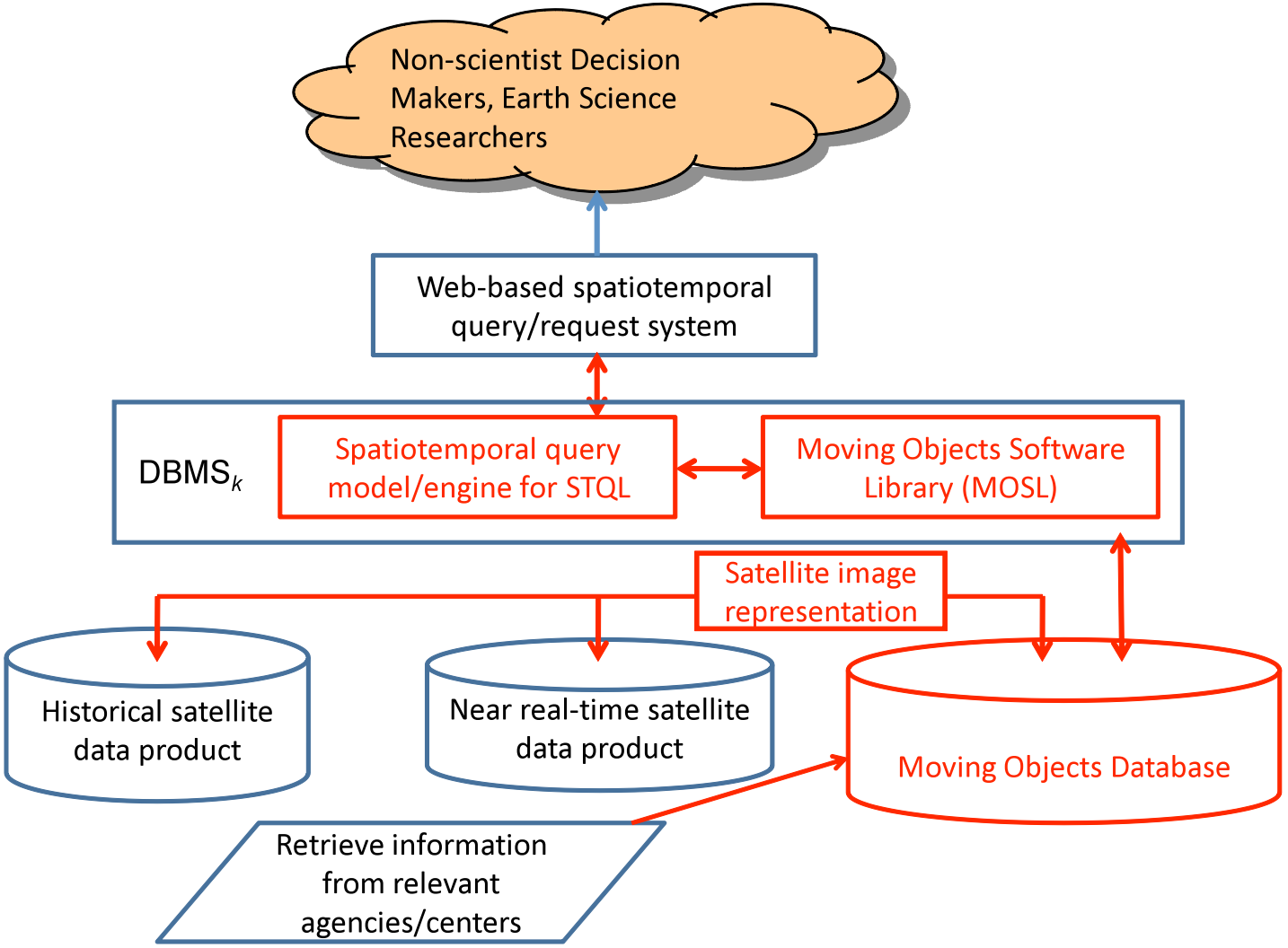
Application Objectives (V)

2-D Composite Data Analysis



The tangential component is near symmetric for slow-moving storms. The left-right asymmetry induced by and becomes stronger for fast-moving storms. Asymmetry increases with translation speed and is associated with the weakening of tropical cyclones

System Objectives (I)



System Objectives (II)

Moving Objects Database (MOD)

- keeps tropical cyclone and hur ricane data provided by public sources and web sites in a centralized repository.
- is a full-fledged database with additional s upport for spatial and spatiotemporal data in its data model and query language
- requires an extensible database system

Moving Objects Software Library (MOSL)

- provides the functionality (in terms of types, operations, predicates) that can be deployed by users/scientists in ad hoc queries and in database applicatio n programs (C++, Java, Matlab, etc.) to retrieve and derive tropical cyclone data
- provides a spatiotemporal data type system together with a large number of operations (e.g., *Intersection*, *Union*, *Difference*) an d predicates (*Inside*, *Meet*, *Disjoint*, *Overlaps*; *Enters*, *Leaves*, *Crosses*, *Bypasses*)
- provides historical spatiotemporal data types like *hmpoint*, *hmline*, and *hmregion*
- can be integrated into *extensible databases*
- is *database-independent* and *application-neutral*

System Objectives (III)

Spatiotemporal Query Language (STQL)

- provides the communication interface
  betwe
  en the moving objects database for tropical cyclone data and the user/scientist
- enables users to pose ad hoc
  spatiotem
  p
  oral queries on moving objects in general and tropical cyclone data in particular
- allows users to obtain immediate response

Satellite Data Retrieval (SDR)

- take
  s
  ou
  tput trajectory information from user queries as input for satellite data retrieval
- Enable users to manipulate satellite data for future data analysis

Review: Moving Objects Database Concepts

Review: Moving Objects Database Concepts (I)

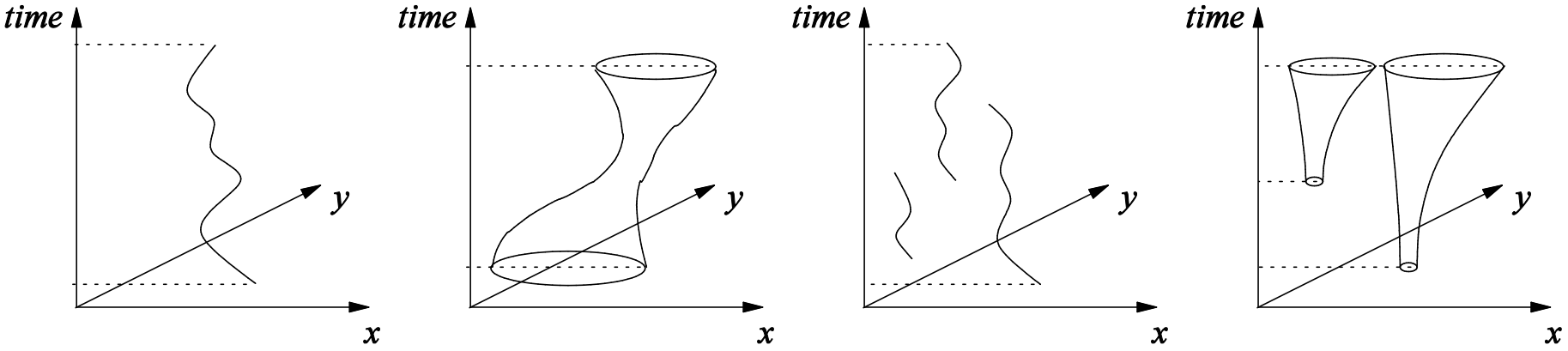
A moving object represents the *continuous* evolution of a spatial object over time.

Classification of moving objects

- Category 1: Moving points
  - Only time-dependent location is of interest
  - Examples: cell phone users, cars, terrorists, whales
- Category 2: Moving region
  - Also the time-dependent shape and/or areal extent is of interest
  - Examples: hurricanes, forest fires, oil spills, diseases, glaciers
- Category 3: Moving line
  - the time-dependent shape and/or linear extent is of interest
  - Examples: traffic jam, front of an army; boundary of any moving region

Review: Moving Objects Database Concepts (II)

- Formally: Let $\alpha \in$ {*point*, *line*, *region*}. Then a moving object *m* is a function of a spatiotemporal data type $\iota(\alpha) = time \to \alpha$.
  - $mpoint = \iota(point) = time \to point$
  - $mline = \iota(line) = time \to line$
  - $mregion = \iota(region) = time \to region$



Review: Moving Objects Database Concepts (III)

- Spatiotemporal operations and spatiotemporal pr edicates embedded into a Spatiotemporal Query Language called STQL

- Query 1: “Determine the t otal size of the forest areas destroyed by the fire called “The Big Fire”.

- ```
  forest(forestname:string, Territory:hmregion)
  forest_fire(firename:string, Extent:hmregion)
  ```

- ```
  SELECT sum(size) FROM
     (SELECT size AS area(traversed(
                  Intersection(Territory, Extent)))
      FROM   forest fire, forest
      WHERE  firename = "The Big Fire" AND
             Ever(Intersects(Territory, Extent)))
  ```

- In database terms: spatiotemporal join

Review: Moving Objects Database Concepts (IV)

- Query 2: “Find all planes that ran into a hurricane.”

- ```
  flights(id:string, Route:hmpoint)
  weather(kind:string, Extent:hmregion)
  ```

- ```
  SELECT id
  FROM   flights, weather
  WHERE  kind = "hurricane" AND
         Route Disjoint>>meet>>Inside Extent
  ```

Review: Moving Objects Database Concepts (V)

Why Moving Objects Database?

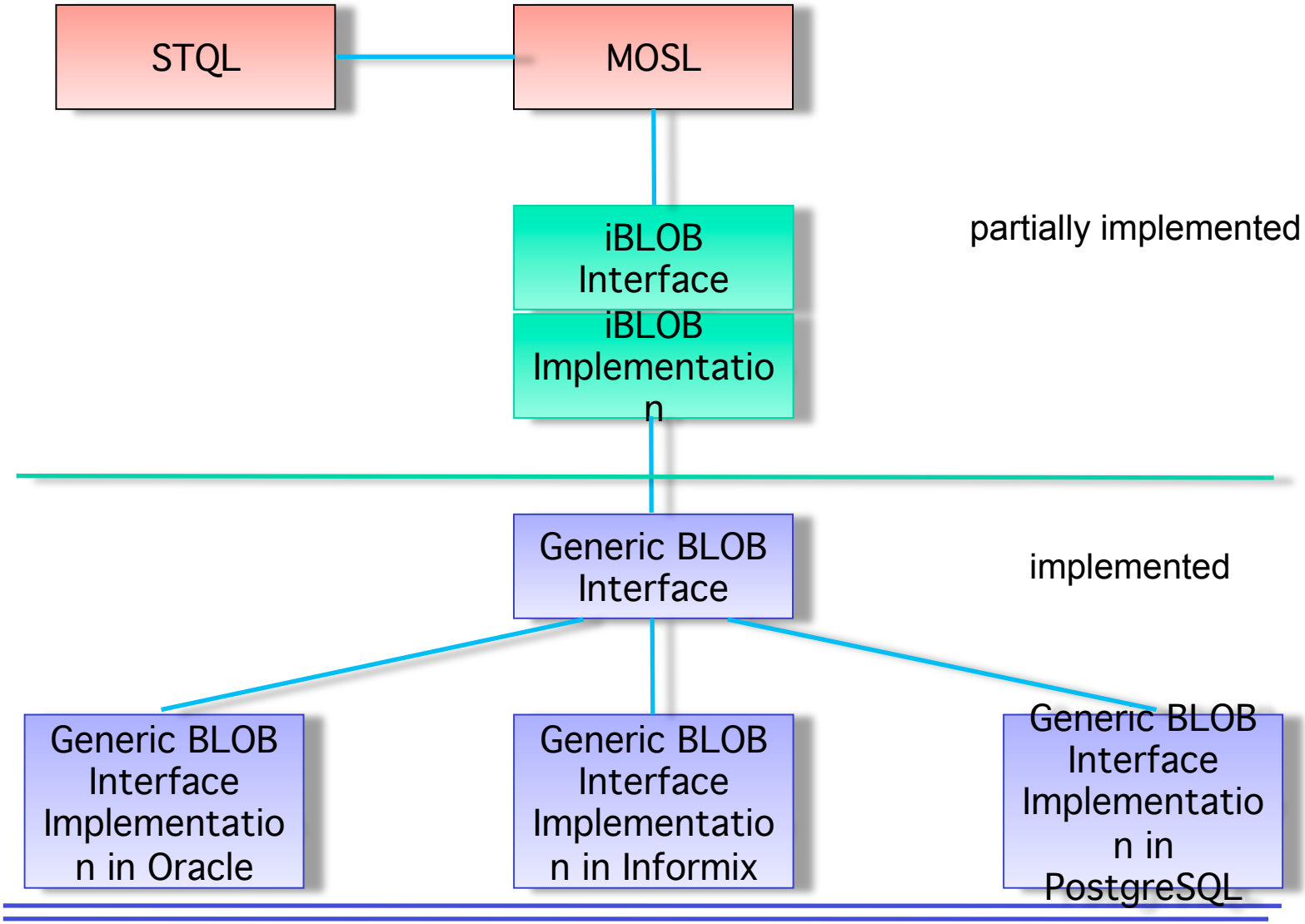
- Representing and storing moving entities in (standard) database system using spatiotemporal data types
- A collection of comprehensive spatiotemporal operations and predicates to query moving entities.
- Efficient ad-hoc query on moving entities.

System Overview and Status

Sys
tem Overview and Status (I) - Software Architecture

- Exploration of database
  systems
  w
  ith extensibility features appropriate and needed for implementing MOSL
  - Needed features
    - B
      LO
      B
      (Binary Large Object) data type for representing values/objects of arbitrary length
    - UDTs and UDFs for the
      specificatio
      n
      and external binding of user-defined data types and functions implemented in MOSL
  - Appropriate DBS: Oracle, Informix; PostgreSQL
- BLOB data type
  - is
    a
    bu
    ilt-in data type in SQL and represents arbitrarily long, finite *byte strings* (4GB)
  - is used for representing complex application objects
    of
    lar
    g
    e and/or varying length (e.g., spatial, image, DNA, video, multimedia objects)

System Overview and Status (II) - Software Architecture



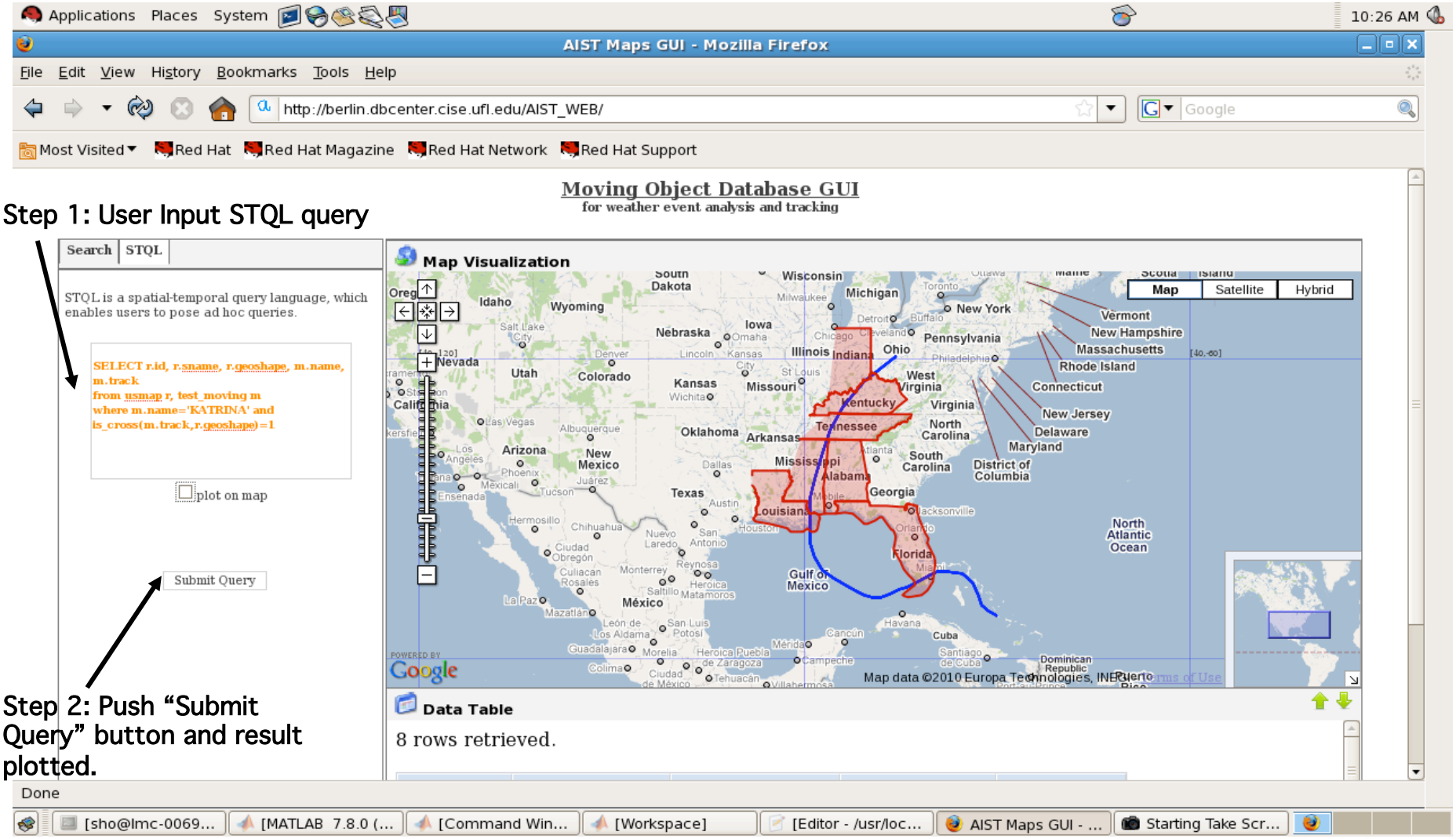
System Overview and Status (III) - Software Architecture

- Generic BLOB Interface
  - is database system independent
  - makes all components built on top of it database system independent
- User-defined data type iBLOB
  - iBLOB = Intelligent Binary Large Object
  - implemented on top of the generic BLOB interface
  - enables *random read access* to the conceptual components of a *complex application object* without understanding their meaning
  - enables *random updates* of application objects
  - Not necessary to load a complex application object completely into main memory
  - Two main parts
    - Structure index represents the hierarchical structure of the application object
    - Sequence index maintains the logical sequential order of components stored in the structure index and supports updates

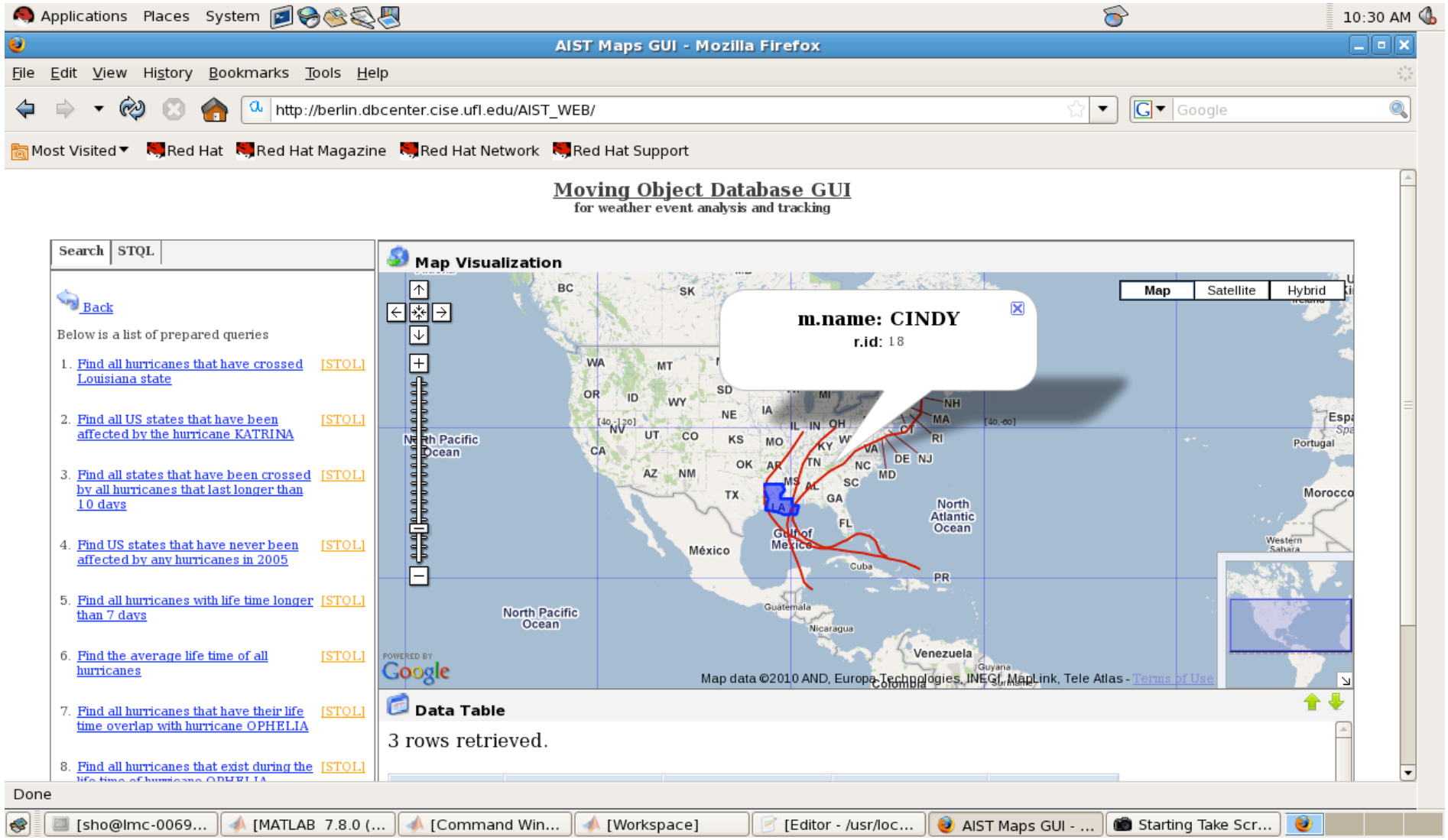
System Overview and Status (IV) - Demo I

- Moving Objects Software Library (MOSL)
  - provides a first implementation of the data type hmpoint for historical moving point objects
  - offers a few spatiotemporal operations on historical moving point objects
- Spatiotemporal Query Language (STQL)
  - enables the embedding of spatiotemporal operations and predicates into an extension of SQL
  - allows the execution of spatiotemporal queries
- Simple Query Tool and Visualization Tool
  - Query tool for posing STQL queries
  - Web-based and Google Map-based visualization tool
    - ❖ for showing the results of STQL queries (trajectories) with Google maps as background
    - ❖ providing the full functionality of Google maps like zooming, tagging, etc.

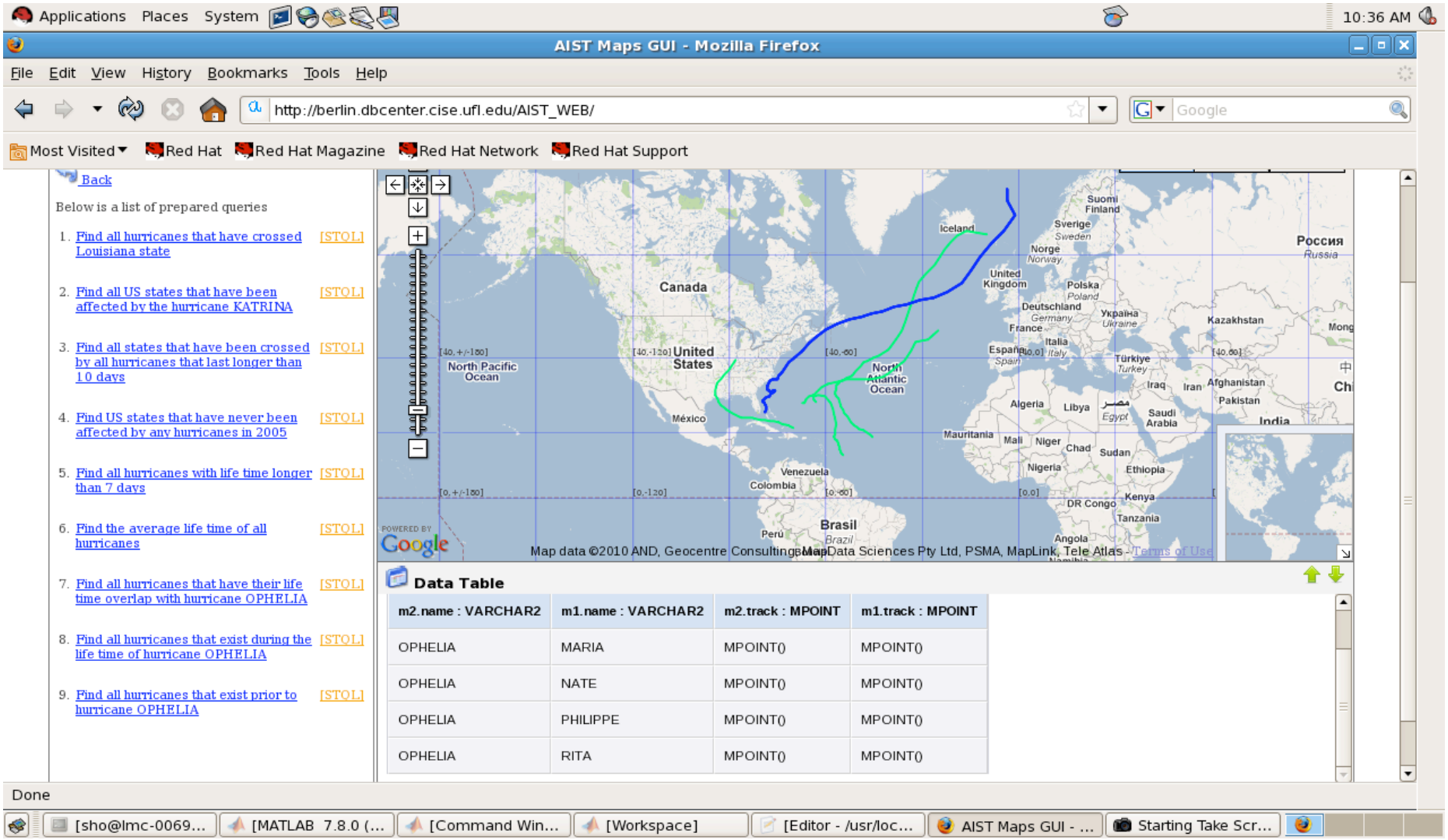
System Overview and Status (V) - Demo I



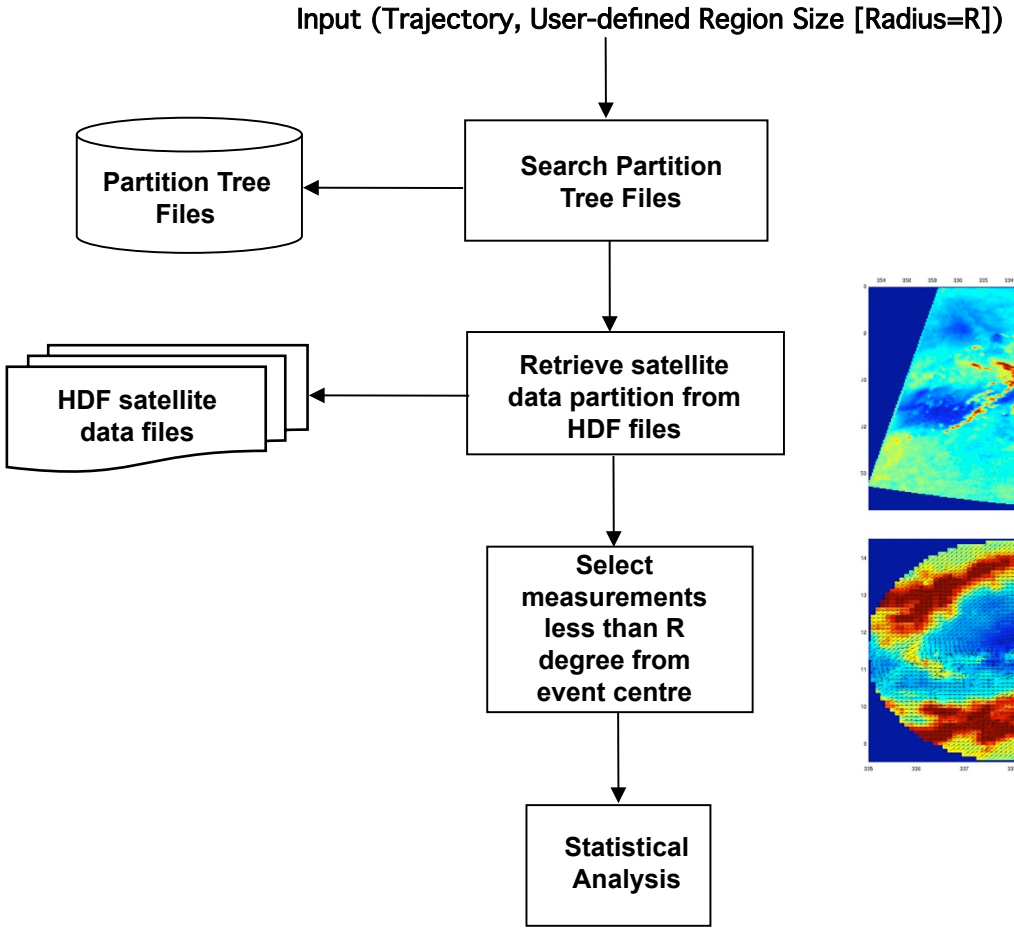
System Overview and Status (VI) - Demo I

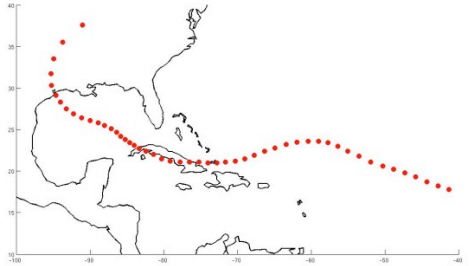


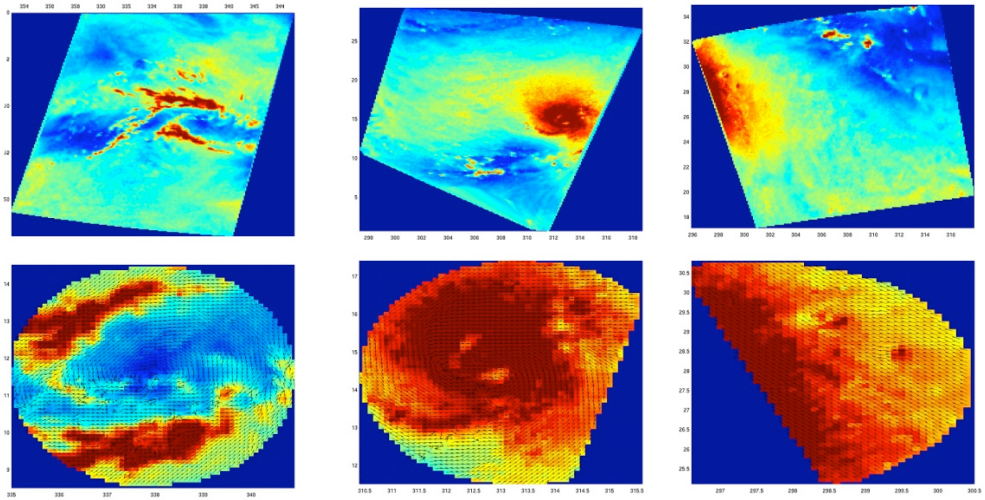
System Overview and Status (VII) - Demo I



System Overview and Status (VIII) - Demo II

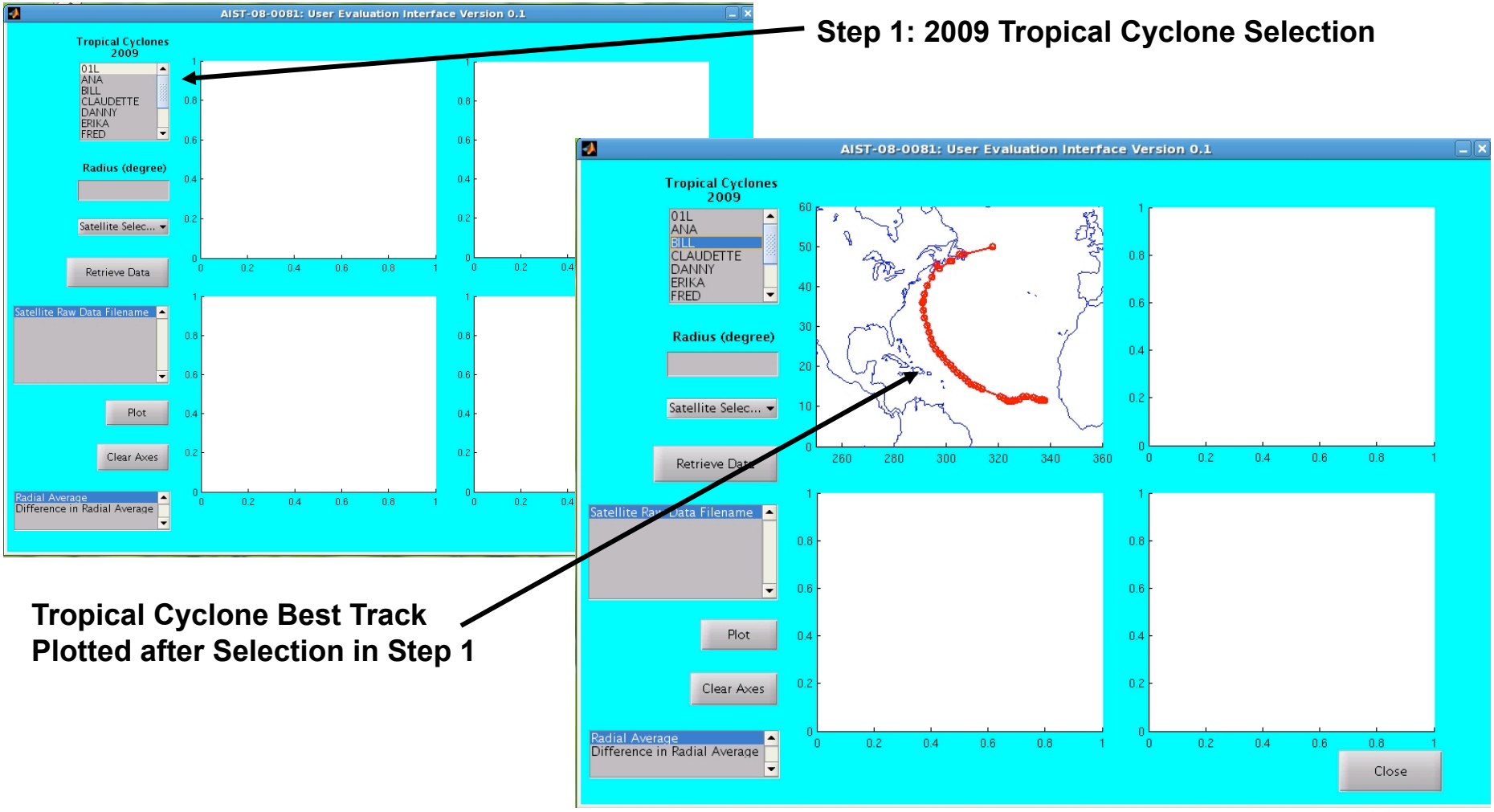






System Overview and Status (IX) - Demo II

GUI DEMO Snapshots



Step 1: 2009 Tropical Cyclone Selection

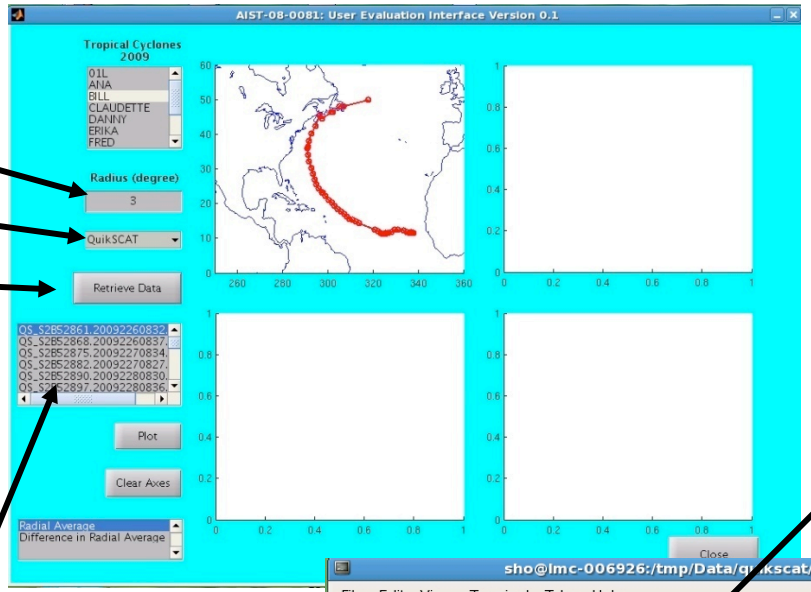
Tropical Cyclone Best Track Plotted after Selection in Step 1

System Overview and Status (X) - Demo II

Step 2: User Specifies Radius in degree

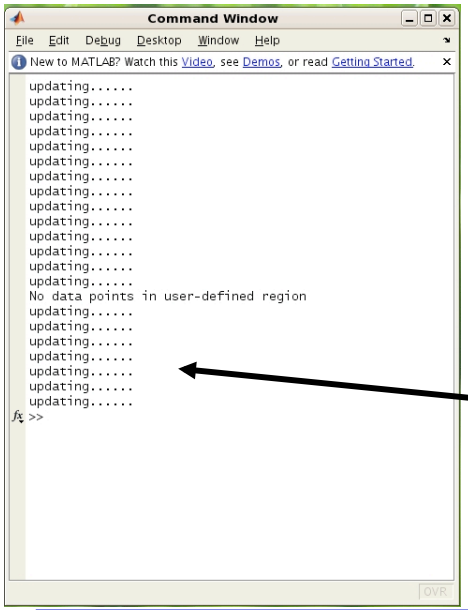
Step 3: User Specifies Mission (Satellite)

Step 4: Push "Retrieve Data" Button to retrieve data based on user-defined tropical cyclone trajectory and radius parameter

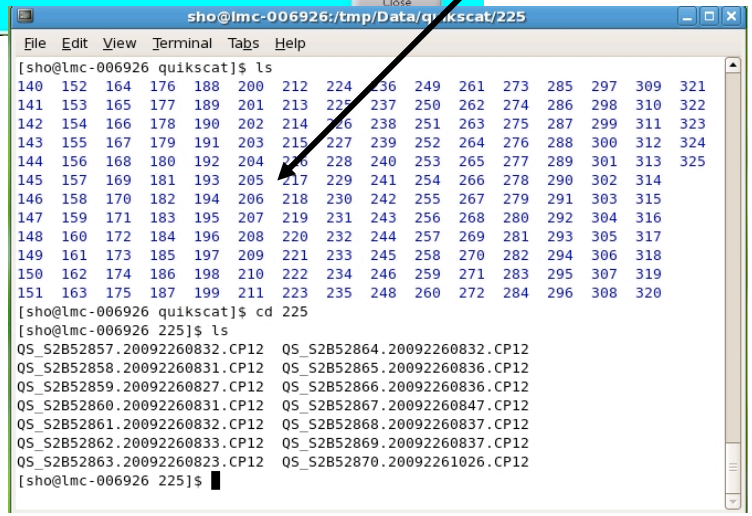


Satellite Data (HDF format) stored in local file systems

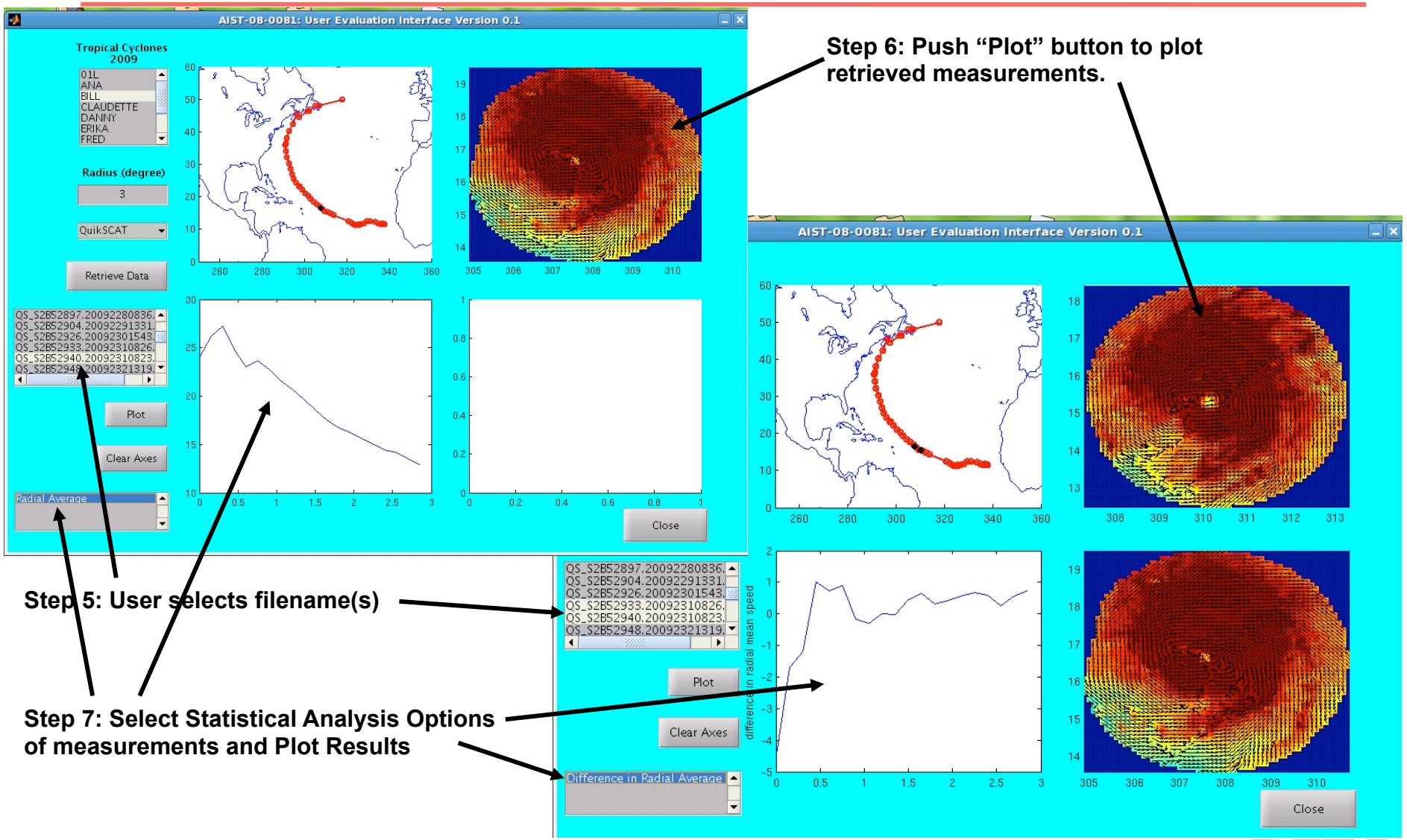
Filenames corresponding to retrieved data.



Data based on user-defined trajectory and radius parameters retrieved on-demand from local file system

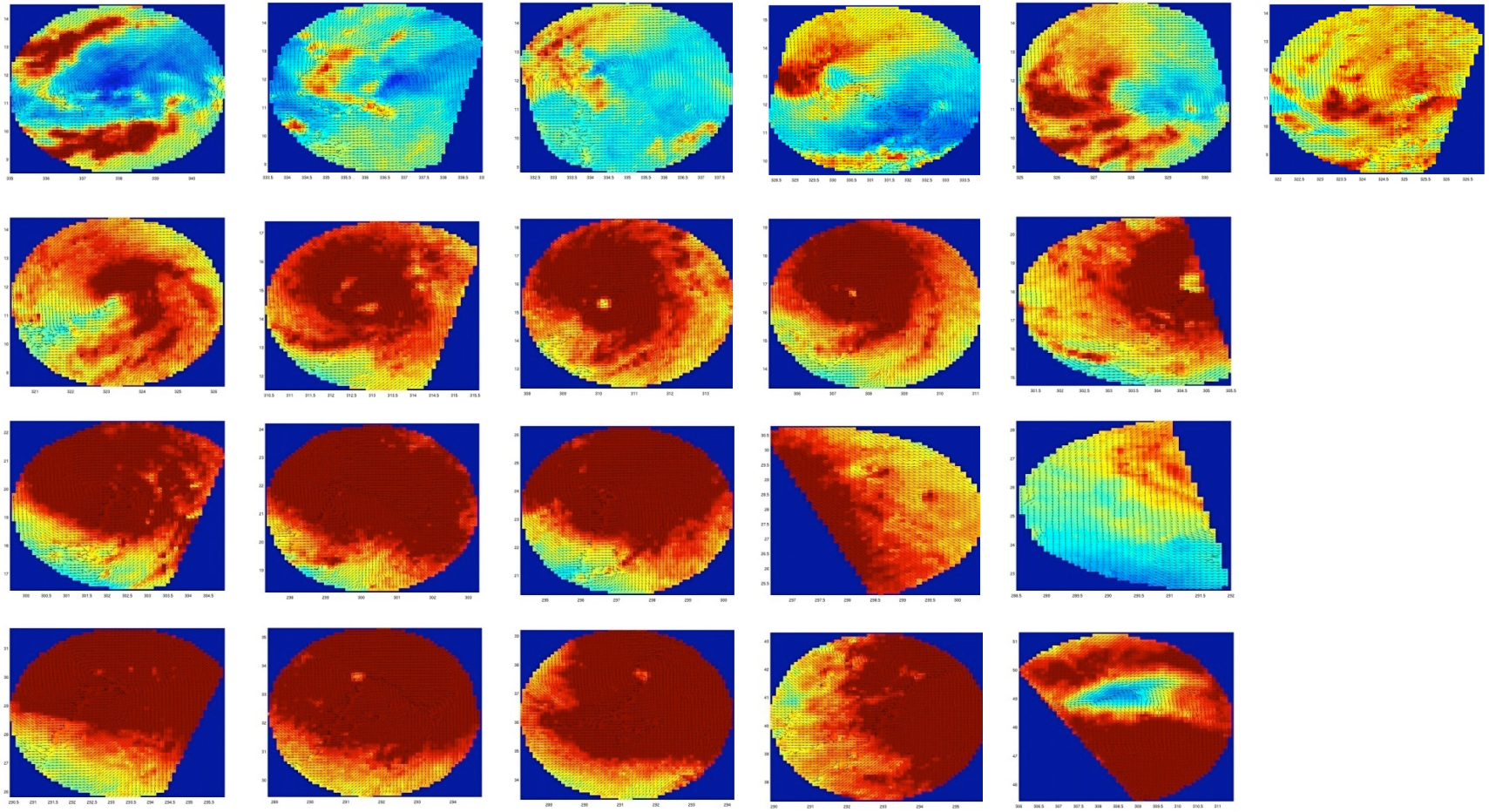


System Overview and Status (XI) - Demo II



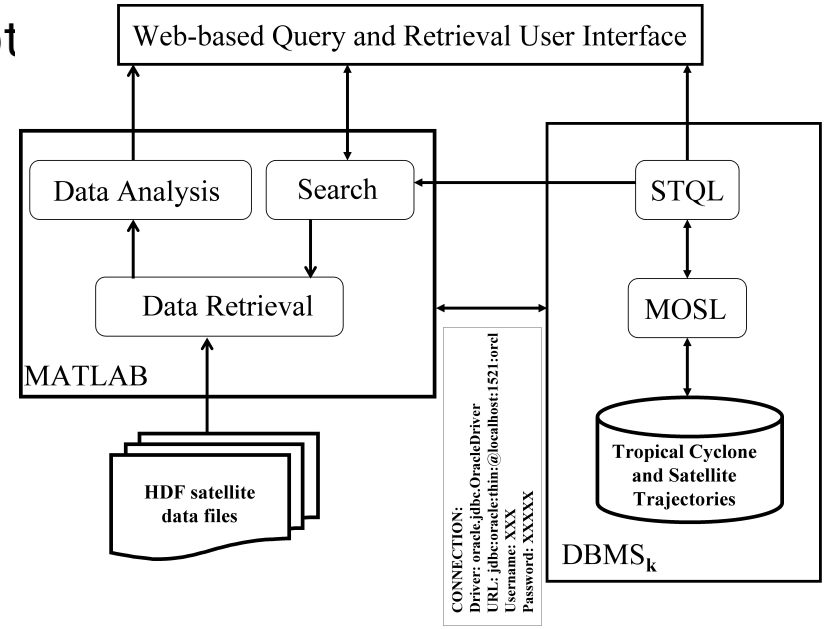
System Overview and Status (XII) - Demo II

QuikSCAT Data Retrieved for Hurricane Bill 2009 and R = 3



Future Work

- Populating the Moving Objects Database with global tropical cyclone trajectories from 2000-2009, QuikSCAT and TRMM trajectory data
- Integrating/Connecting Satellite Data Retrieval on Matlab to Oracle-based moving objects database.
- Exploration of other integration alternatives
- Continuation of MOSL and STQL development
- Implementation of a prototype



Publications

- Shen-Shyang Ho, Wenqing Tang, W. Timothy Liu, and Markus Schneider. A Framework for Moving Sensor Data Query and Retrieval of Dynamic Atmospheric Events. *22 nd Int. Conf. on Scientific and Statistical Database M a nagement* (*SSDBM*), Heidelberg, Germany, June 30-July 2, 2010.
- Shen-Shyang Ho, Wenqing Tang, and W. Timothy Liu. Tropical Cyclone Event Sequence Similarity Search via Dimensionality Reduction and Metric Learning, *16th ACM SIGKDD Int. Conf. on Knowledge Disco very and Data Mining (KDD),* Washington, DC, July 25-28, 2010.
- Reference: R. Guting and M. Schneider, Moving Objects Databases. Morgan Kaufmann Publications, 2005.