Fault Tolerance and Scaling in e-Science Applications: Observations from the Continuing Development of MODIS Azure

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Global and Regional Eco-Science

- A major shift is happening in the way eco-science is done.

  - Moving from individual studies of local processes to collaborative studies of regional and global processes. (e.g. studying the impact of climate change)

- Studying global scale environmental processes requires:

  - Integration of local, regional, and global spatial scales.

  - Integration across disciplines, e.g., climatology, hydrology, forestry, etc., and across methodologies (field observations, remote sensing, and modeling).
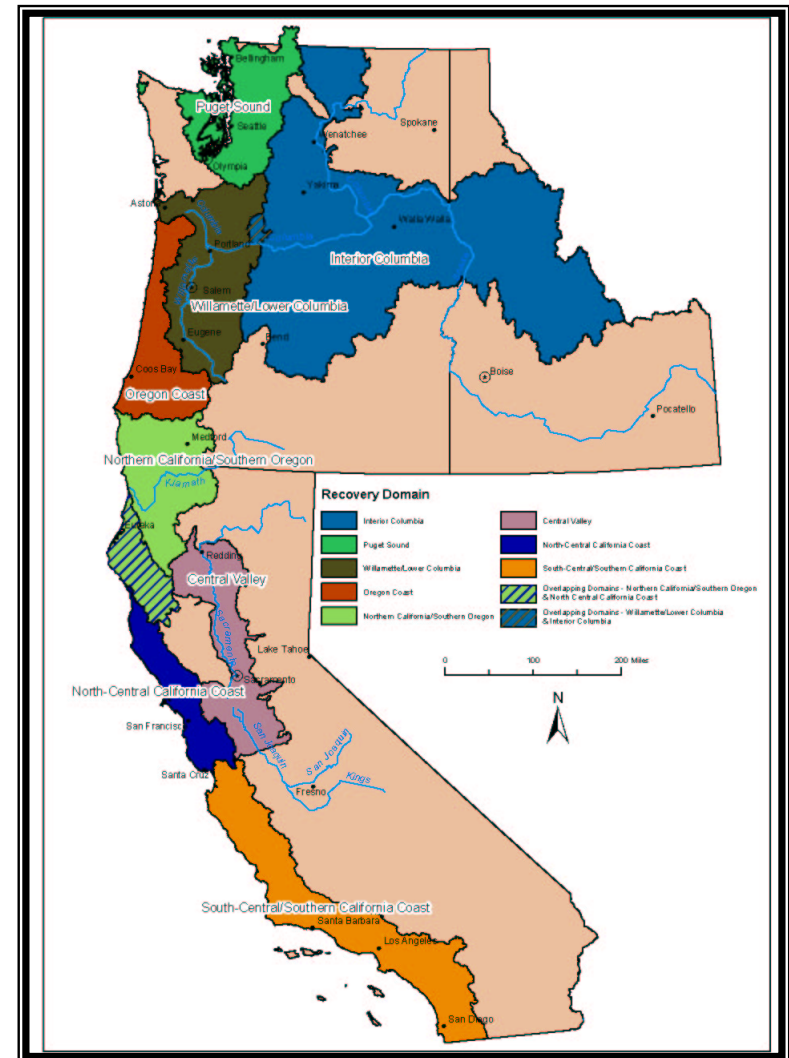
Global and Regional Eco-Science
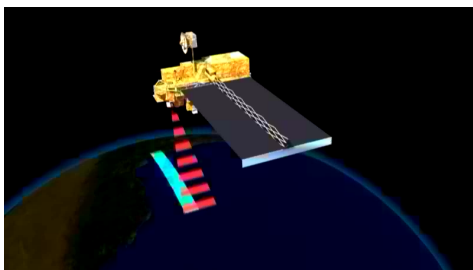

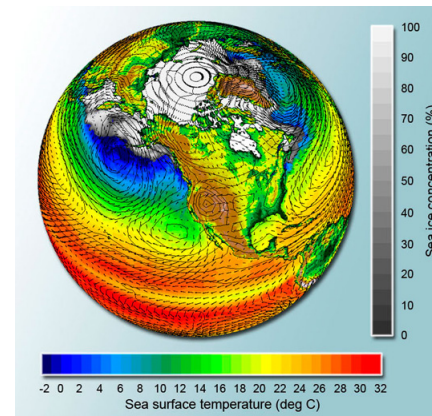Manual Measurement

Automated Measurement

Sample Collection

Typing

Satellite

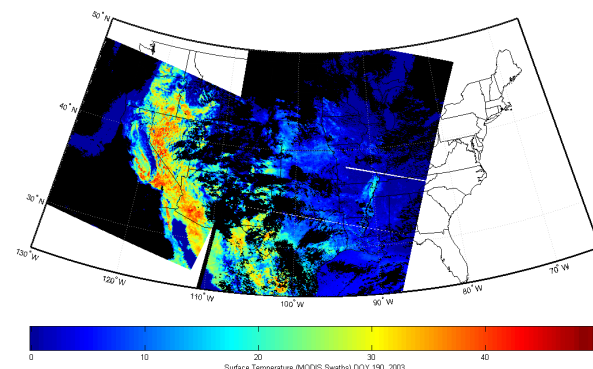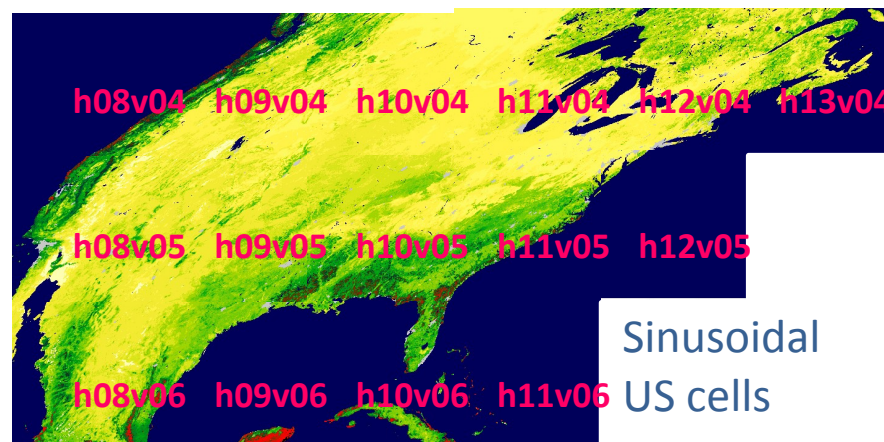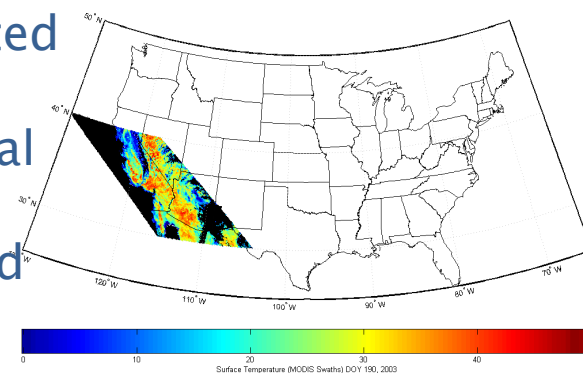Aircraft Surveys

Model Output

Counting

CS Grunge

- Data download

  - Locate download site for each data product

  - Validate your download

- Reprojection

  - Converts one geo-spatial representation to another.

  - Example: latitude-longitude swaths converted to sinusoidal cells.

- Spatial & Temporal resampling

  - Converts one spatial resolution to another.

  - Example is converting from 1 KM to 5 KM pixels.

- Gap filling

  - Assigns values to pixels without data either due to inherent data issues such as clouds or missing pixels.

Source Data (Swath format)

Reprojected Data (Sinusoidal format – equal land area pixel)

h08v04 h09v04 h10v04 h11v04 h12v04 h13v04

h08v05 h09v05 h10v05 h11v05 h12v05

h08v06 h09v06 h10v06 h11v06

Sinusoidal US cells

Evapotranspiration

- Evapotranspiration (ET) is the release of water to the atmosphere by evaporation from open water bodies and transpiration, or evaporation through plant membranes, by plants.

- Climate change isn't just about a change in temperature, it's also about a change in the water balance and hence water supply critical to human activity.
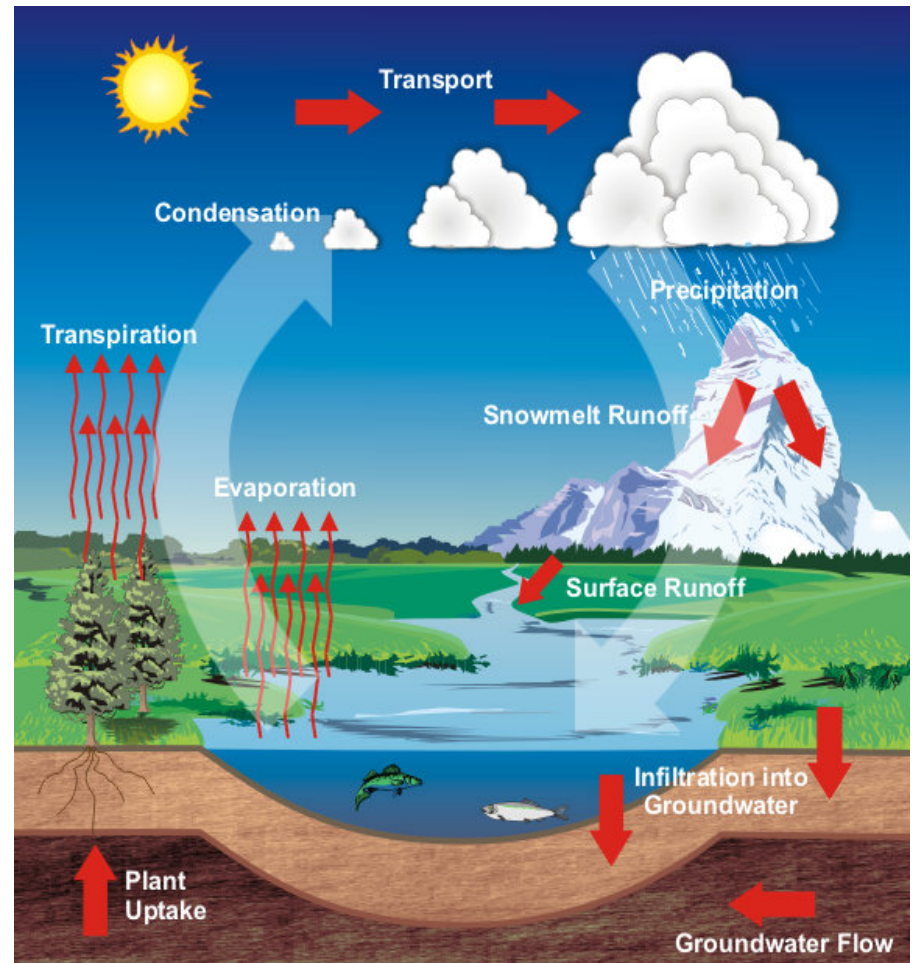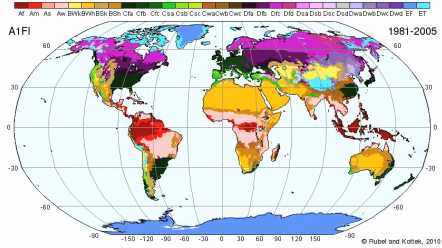

Image courtesy of the
National Oceanic and Atmospheric Administration

Data Inputs

Climate classification ~1MB (1file)

J.M. Chen et al. / Remote Sensing of Environment 97 (2005) 447–457
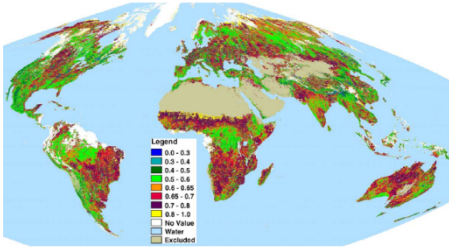
Vegetative clumping ~5MB (1file)

NASA MODIS imagery archives 5 TB (600K files)

Sizes given are 1 US year 20 US year ~ 1 global land surface year

FLUXNET Curated sensor dataset 30GB (960 files)

FLUXNET curated field dataset 2 KB (1 file)

The Resource Barrier

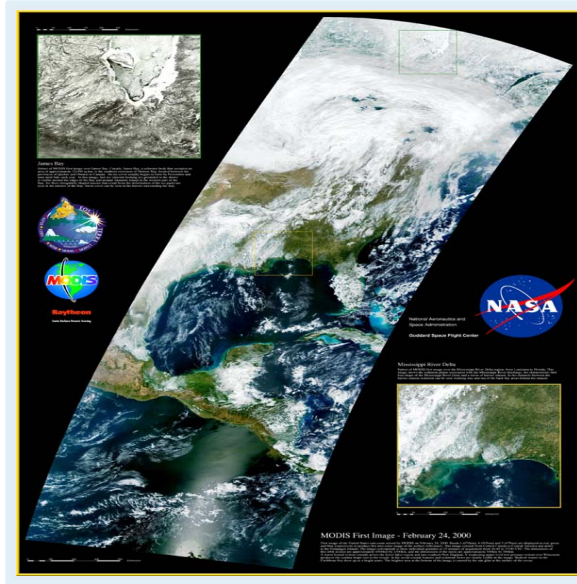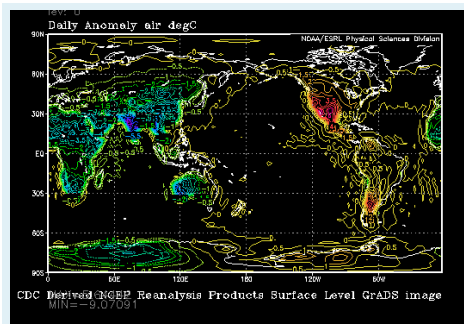|	#Source Files	Source Size	# Result Files	Result Size
USA (18)	21850	238 GB	27375	261 GB
FluxTower (3)	80670	993 GB	58400	210 GB
Global (3)	152670	2414 GB	352225	630 GB

1 Global year

▸ **~ 9000 hours or 375 days**
  ◦ 1 year takes 1 year !
  ◦ With 200 cpus, that's > 2 days

▸ **8 TB download reduced to 2.4 TB by reprojection**
  ◦ How to know which are missed (and why) among 350K files?
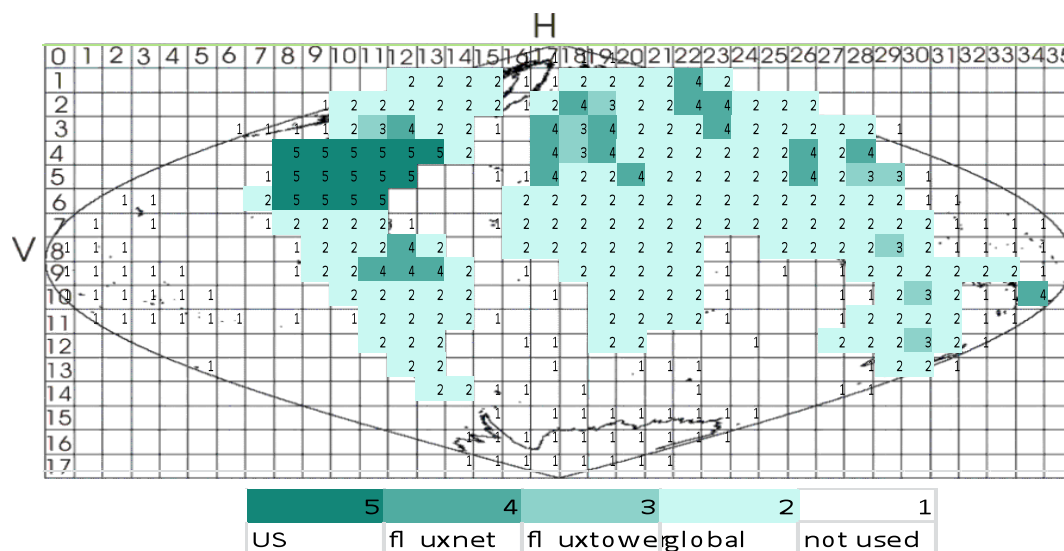
US: 15 tiles   FluxTower: 32 tiles   Global: 194 tiles

A Cloud-based Solution

- A MODIS Data Reprojection and Reduction Pipeline in Microsoft Windows Azure cloud computing platform

  - Lower resource entry barriers

  - Hide the complexities in data collection, reprojection and management from domain scientists

  - A generic Reduction Service for scientists to upload arbitrary executables to perform scientific analysis on reprojected data.

MODIS Source Data

Windows Azure
Cloud Computing Platform

Data Processing Pipeline

Scientific Results
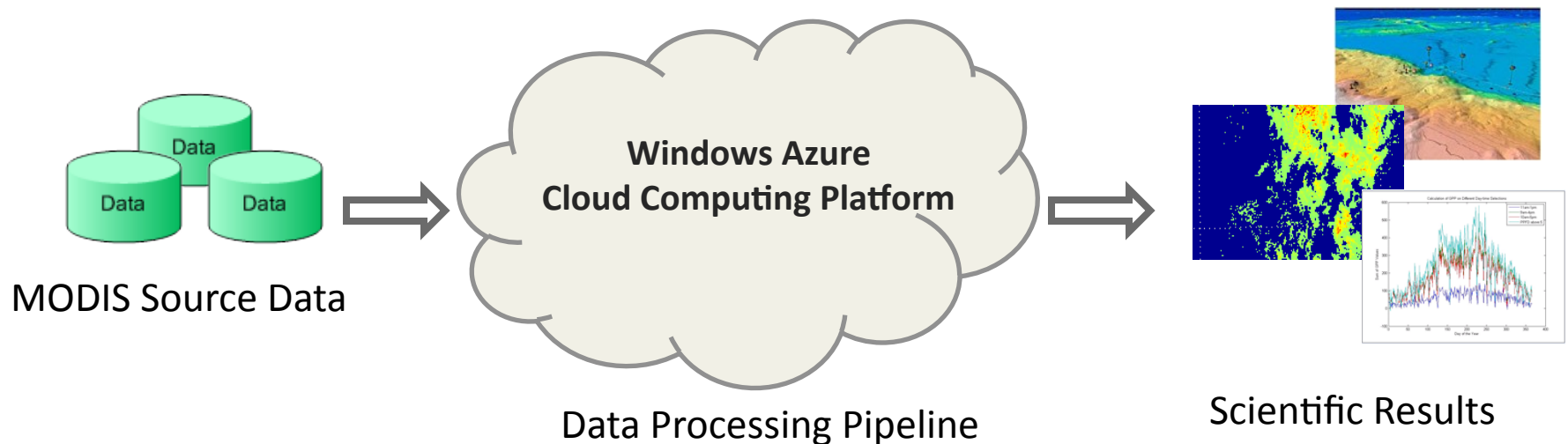
Windows Azure Basics

- Hosted Services

  - Web Role: A Web application accessible via an HTTP and/or an HTTPS endpoint

  - Worker Role: A background processing application

  - Dynamic scalability of role instances

- Storage Services

  - Blob service: Storage for entities such as binary files and data files

  - Queue Service: A reliable, persistent queue model for messaging within and between hosted services

  - Table Service: Structured storage in the form of tables, with simple query support

Windows Azure

MODISAzure: Four Stage Image Processing Pipeline

Source Imagery Download Sites

Download Queue

Source Metadata

MODIS Data Reduction Service

Request Queue

Scientists

Data Collection Stage

AzureMODIS Service Web Role Portal

Reprojection Queue

Science results

Reprojection Stage

Derivation Reduction Stage

Analysis Reduction Stage

Reduction #1 Queue
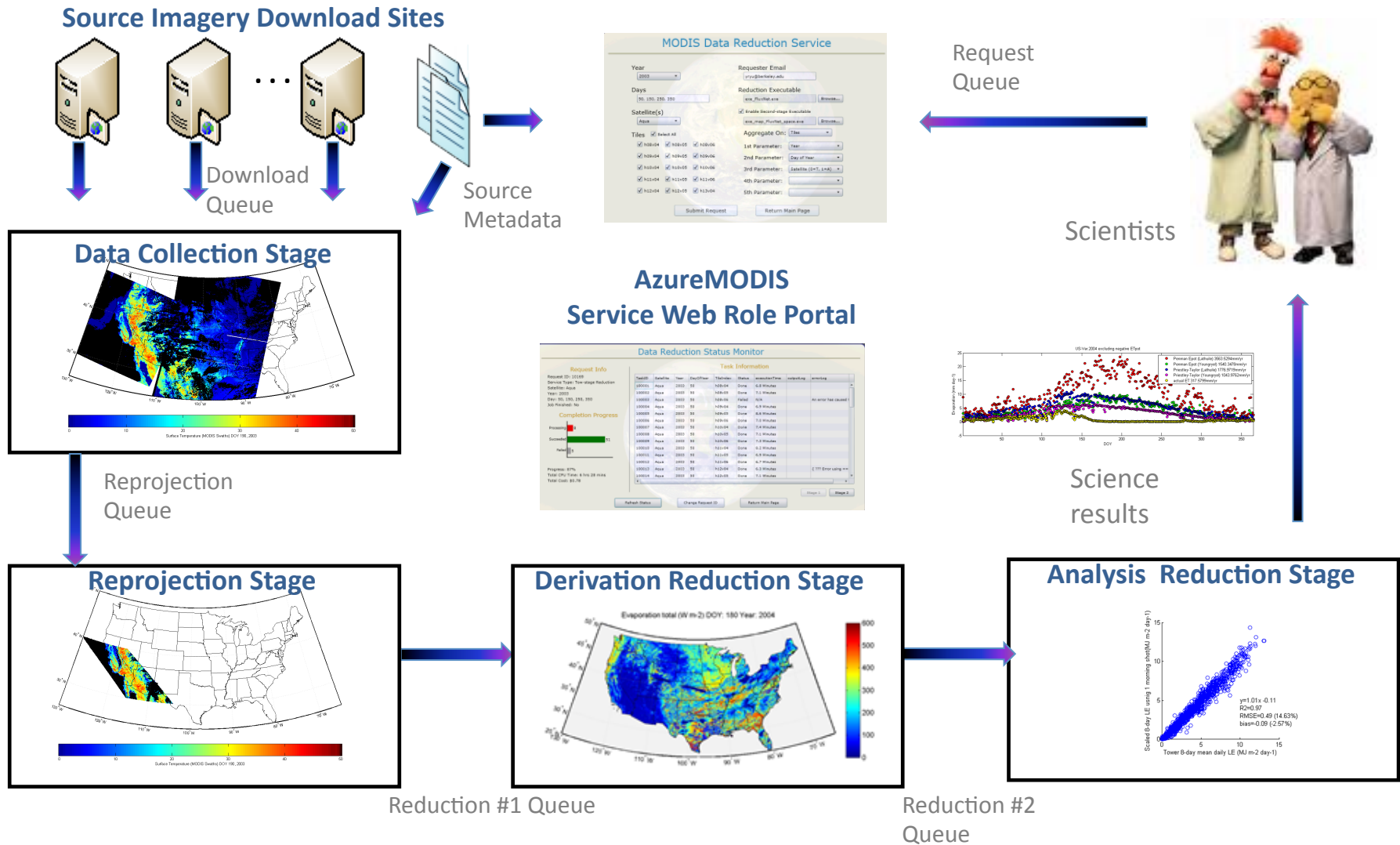
Reduction #2 Queue

MODISAzure: Architecture

<PipelineStage>Request   **<PipelineStage>JobQueue**   **<PipelineStage>JobStatus**

Persist

MODISAzure Service
(Web Role)

Service Monitor
(Worker Role)

Parse & Persist   **<PipelineStage>TaskStatus**

Dispatch

<PipelineStage>Task Queue

Generic Worker
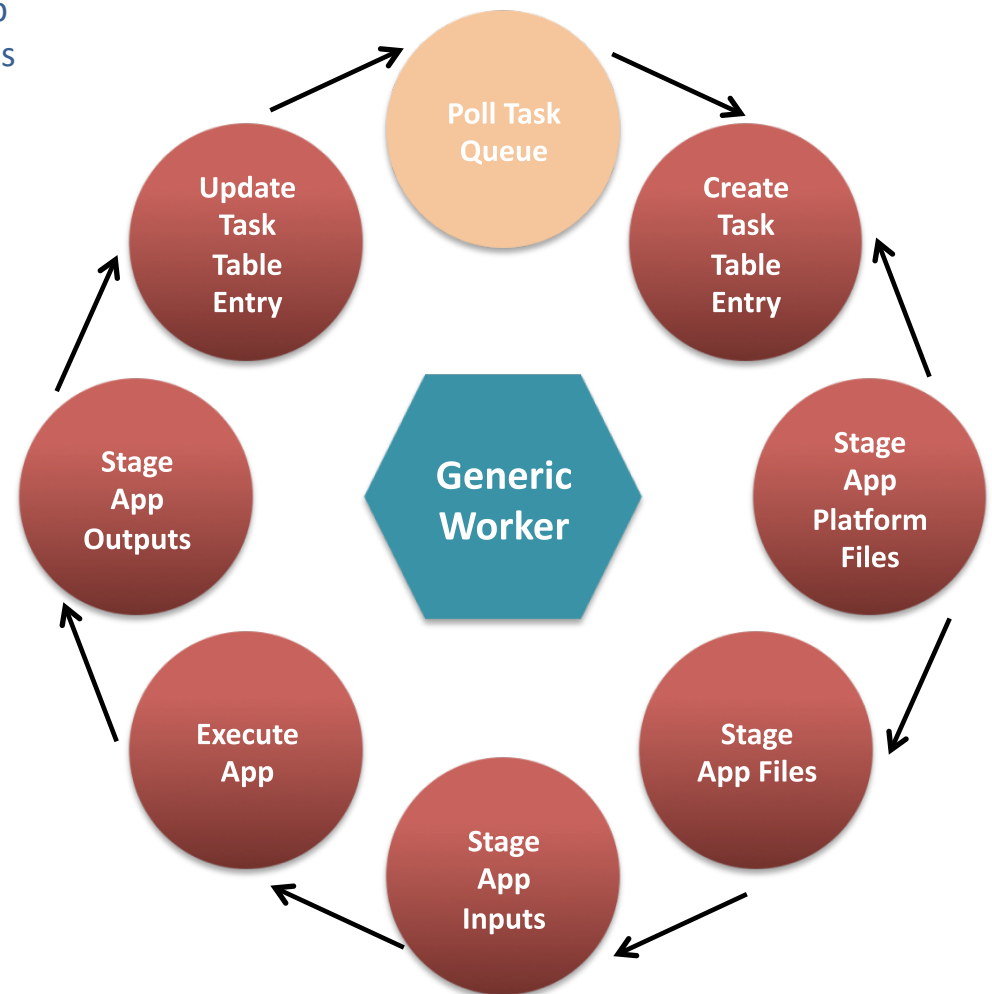(Worker Role)
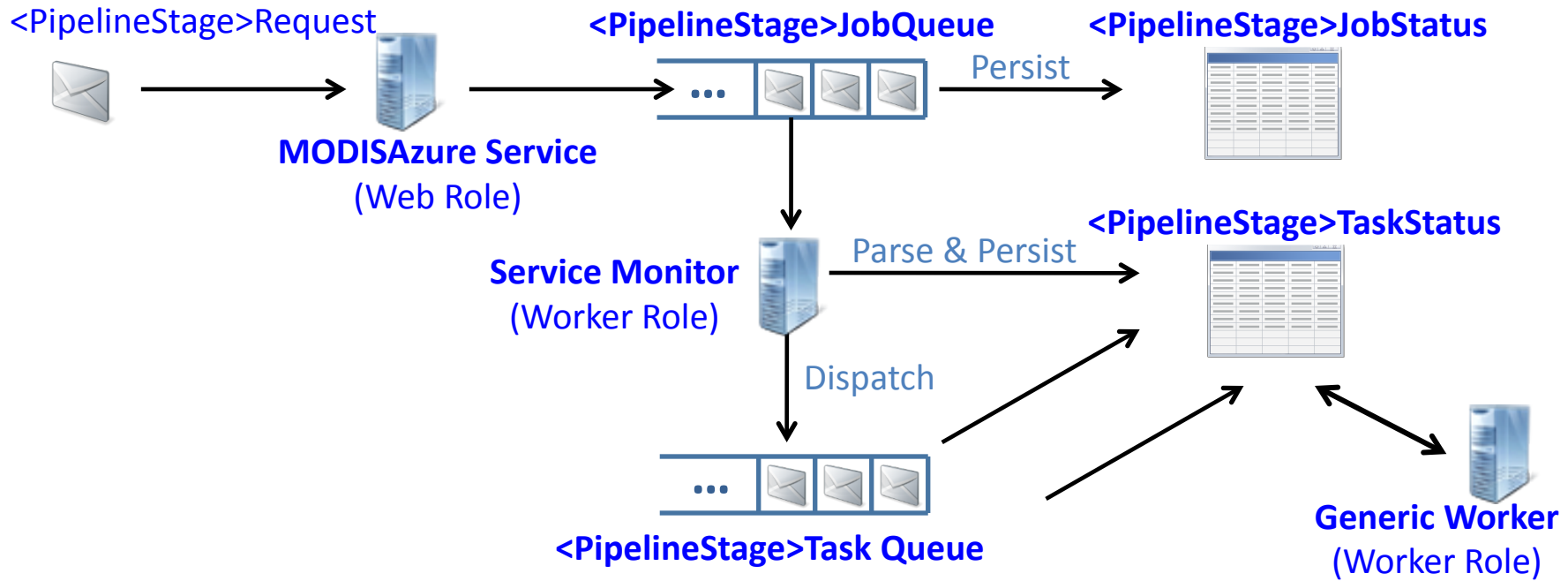
- **ModisAzure Service** is the Web Role front door
  - Receives all user requests
  - Queues request to appropriate Download, Reprojection, or Reduction Job Queue

- **Service Monitor** is a dedicated Worker Role
  - Parses all job requests into tasks – recoverable units of work
  - Execution status of all jobs and tasks persisted in Tables

Generic Worker

- Manages application sandbox

  - Ensures all application binaries such as the MatLab runtime are installed for "known" application types

  - Stages all input blobs from Azure storage to local files

  - Passes any marshalled inputs to uploaded application binary

  - Stages all output blobs to Azure storage from local files

  - Preserves any marshalled outputs to the appropriate Task table

- Manages all task status

  - Dequeues tasks created by the Service Monitor

  - Retries failed tasks 3 times

  - Maintains all task status

Pipeline Scaling & Interactions

- The Web Portal Role, Service Monitor Role and 5 Generic Worker Roles are deployed at most times

  - 5 Generic Workers are sufficient for reduction algorithm testing and development ($20/day)

  - Early results returned to scientist while deploying up to 93 additional Generic Workers; such a deployment typically takes 45 minutes

  - Deployment taken down when long periods of idle time are known

  - Heuristic for scaling number of Generic Workers up and down

- Download stage runs in the deep background in all deployed generic worker roles

  - IO, not CPU bound so no competition

- Reduction tasks that have available inputs run preferentially to Reprojection tasks

  - Expedites interactive science result generation

  - If no available inputs and a backlog of reprojection tasks, number of Generic Workers scale up naturally until backlog addressed and reduction can continue

  - Second stage reduction runs only after all first stage reductions have completed

Resource Utilization

- Fine scale computation expanded to cover more of the globe: 2x compute requirements and 2x (transient) storage requirements

- Lower resolution global computation added: .5x compute requirements and 2x (transient) storage and higher IOP/cpu reprojection

- Now underway: geo-spatial validation with yearly aggregate: shifts reduction to IO intensive
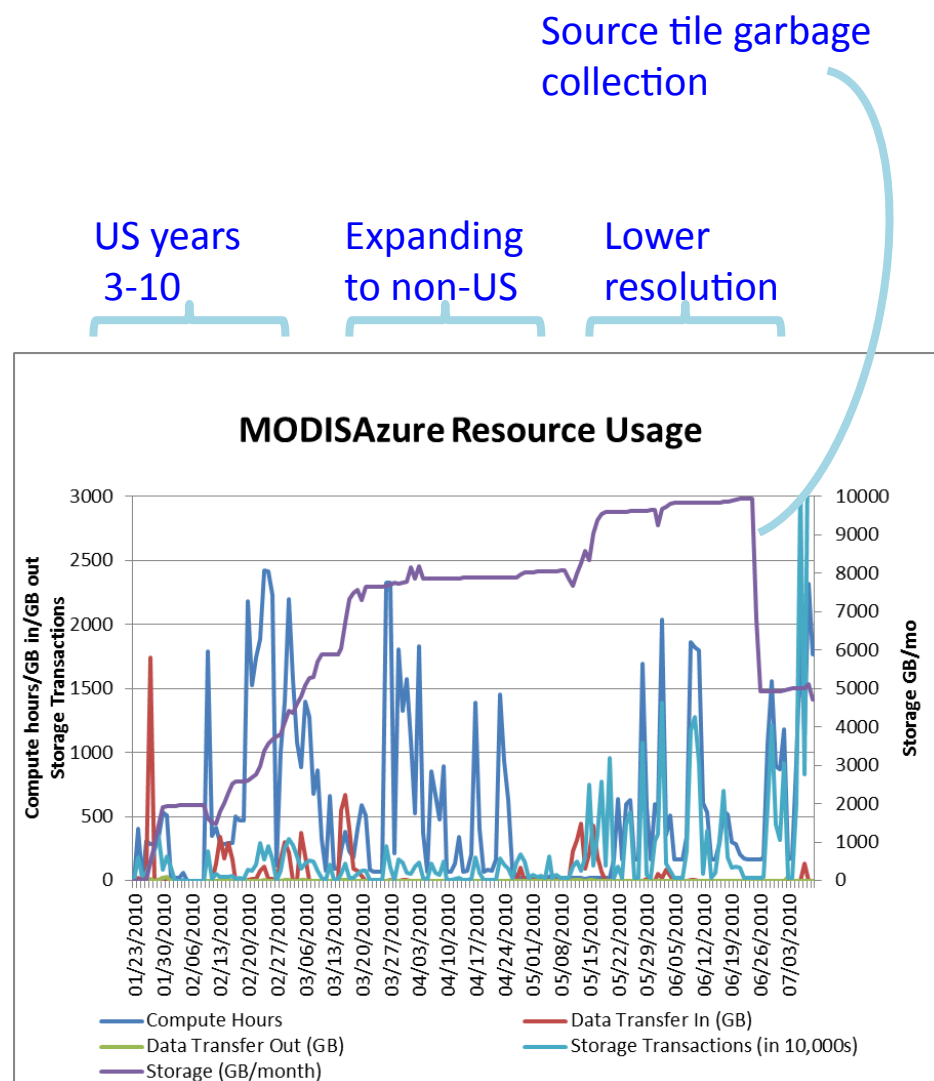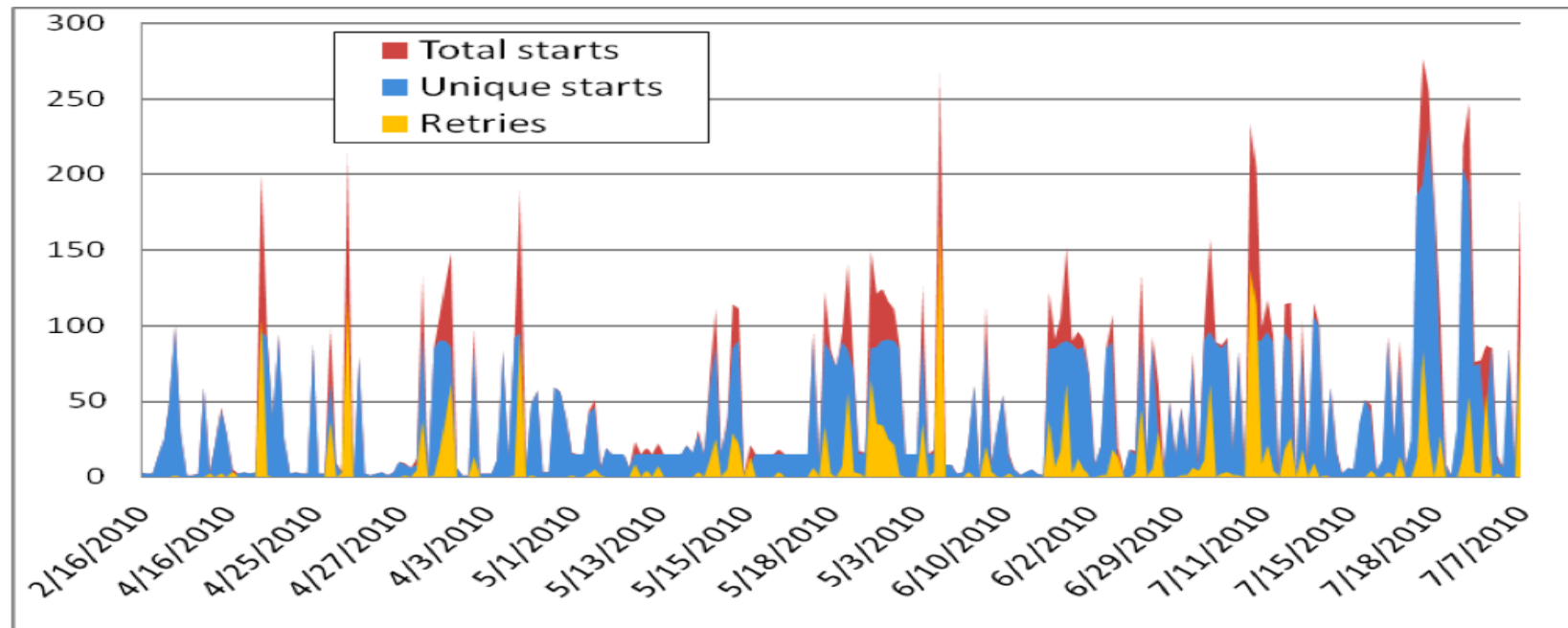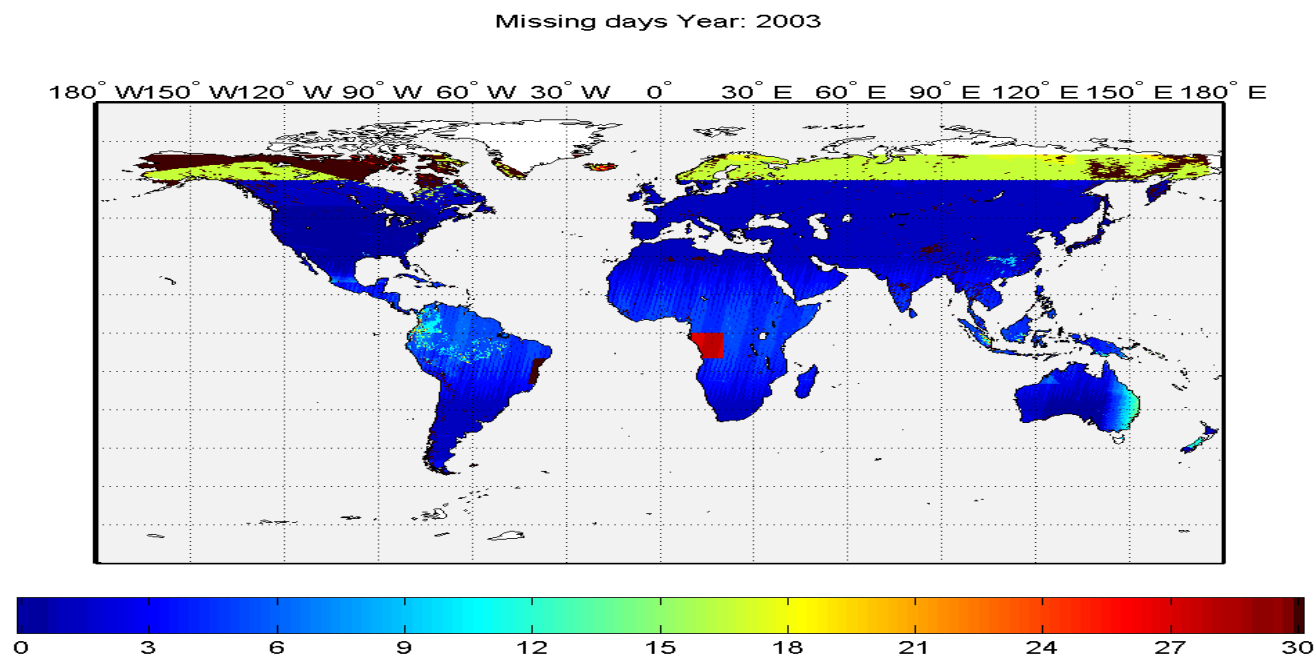
Performance Variability
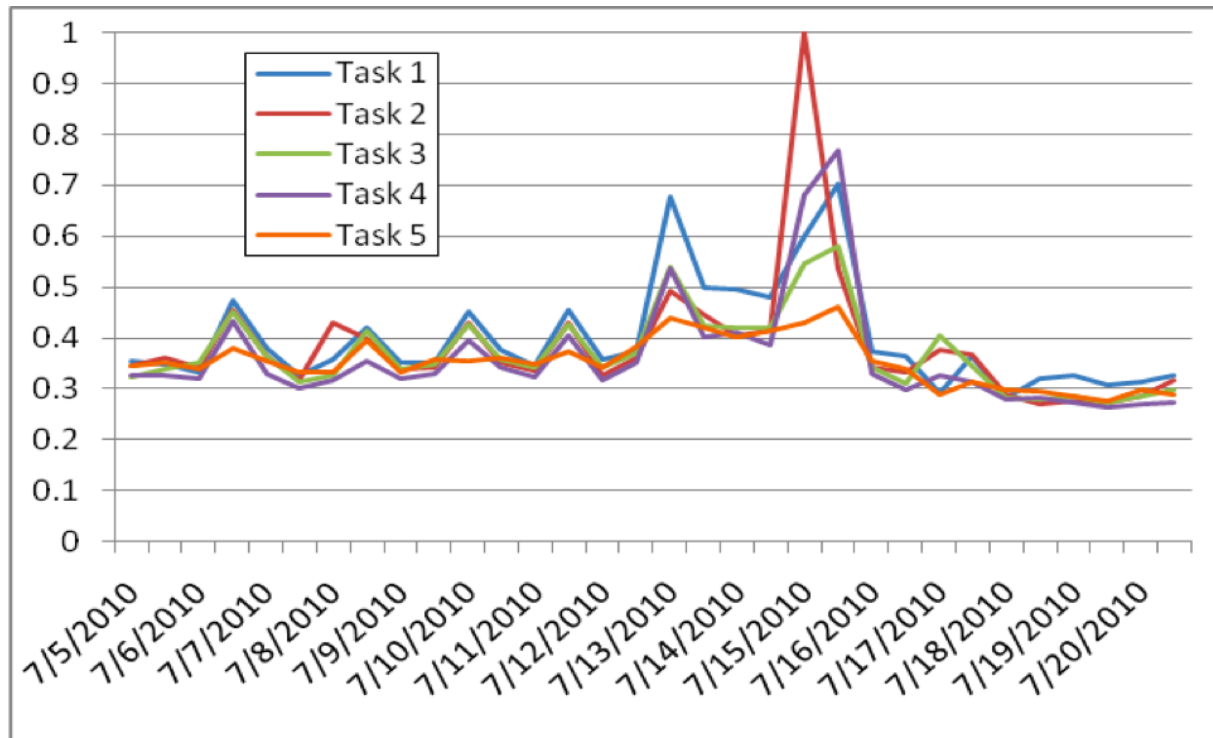
- Run the same 5 reduction tasks twice a day for 15 days

- The difference between the best performance and the worst can be as large as 350%

Infrastructure Reliability

- Instances fail to boot properly

- Temporary storage request failures

- Instances restarted

Data Reliability

Missing days Year: 2003

- When running hundreds of thousands to millions of tasks, even 99.999% reliability is not enough!

  - 1-2% of MODISAzure tasks fail, but succeed on retry.

Architectural Lessons

- Assume failures

    - Failures can occur at all levels

    - Log task start and end events

        - Logs must be minable

    - Tasks should be idempotent

        - Much easier failure/restart behavior

    - Simple retry behavior can be very effective

- Decouple components and communicate via reliable message queues

Conclusions

- Clouds like Windows Azure provide a set of building blocks for building scalable, reliable, distributed data-intensive e-Science applications

- Clouds can lower the barriers to doing science

    - Remove CS grunge work

    - Provide access to significant amounts of storage and compute resources

    - Provide Software-as-a-Service web interfaces to scientific data processing

Acknowledgments

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