# Processing NASA Earth Science Data on Nebula Cloud

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# Goddard Earth Science DISC

- NASA GES DISC offers atmospheric related observation and model data and applied services.
- Data in missions:
  - TRMM (PR, TMI, VIRS ),
  - Terra (MODIS, ASTER),
  - Aqua (AIRS, MODIS, AMSU-A, HSB ),
  - Aura (MLS, HIRDLS, OMI, TES ),
  - CloudSat,
  - CALIPSO, etc.
- Services and Tools:
  - **Mirador**,
  - **Giovanni**,
  - OPeNDAP,
  - GrADS,
  - OGC WMS,
  - FTP, etc.

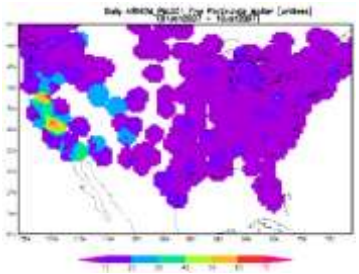
# Goddard Earth Science DISC - Mirador

# Goddard Earth Science DISC -Giovanni

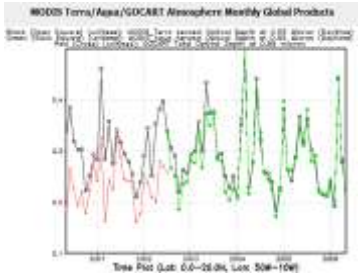
**Data Inputs**

- AIRS
- MODIS
- MISR
- Parasol
- CloudSat
- CALIOP
- TOMS
- OMI
- MLS
- HIRDLS
- HALOE
- TRMM
- AMSR-E
- SeaWiFS
- Models
- and more…

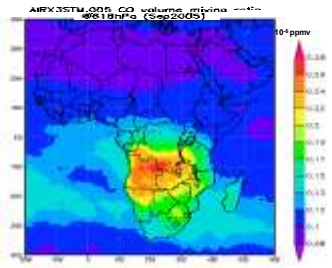
Giovanni Instances



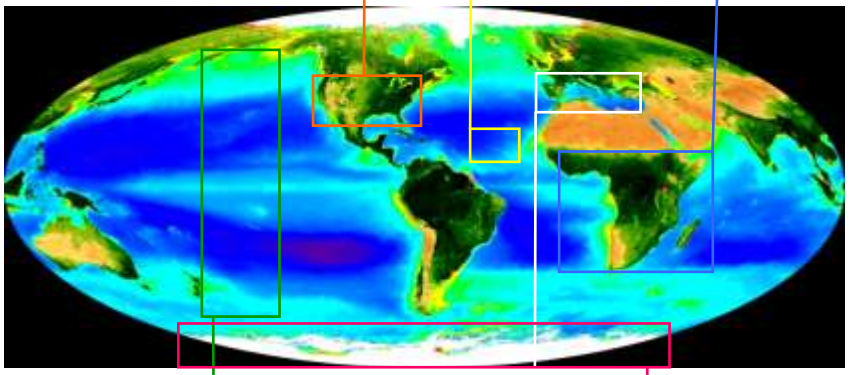
Particulate Matter (PM 2.5) from AIRNow

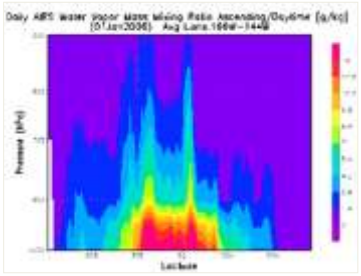


Aerosol from MODIS and GOCART model

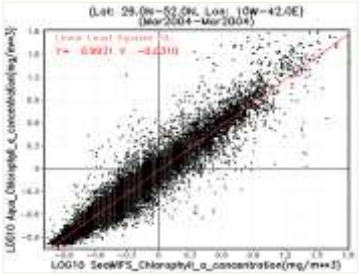


Carbon Monoxide from AIRS

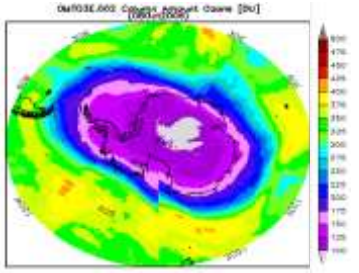




Water Vapor from AIRS



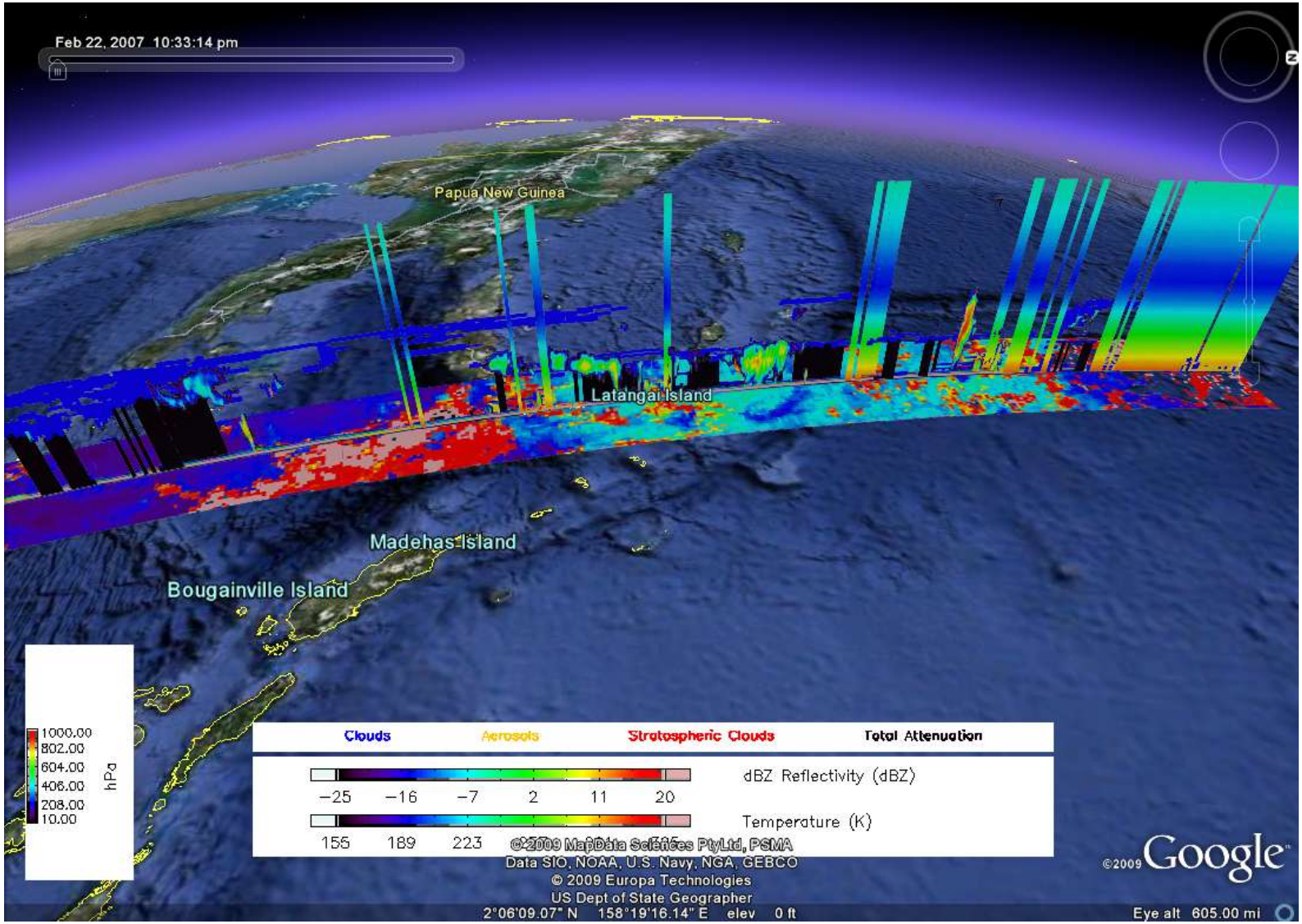
MODIS vs SeaWiFS Chlorophyll



Ozone Hole from OMI

Courtesy of Suhung Shen, NASA GES DISC

# Goddard Earth Science DISC - Visualization



# Goddard Earth Science DISC

**http://disc.gsfc.nasa.gov**

# Outline

- Background
- The migrating procedure
- Performance estimation, comparison, and analysis
- Costs estimation and comparison
- Output verification
- Advantages of Nebula Cloud
- Challenges and Lessons Learned
- Summary

# Background -1

- Cloud Computing has been implemented and used by quite a few commercial companies (e.g. Amazon EC2 [SaaS, 2006], Google App Engine [PaaS, 2008], Microsoft Azure [PaaS, 2008], etc.).
- NASA Launched Nebula in 2008 to provide Infrastructure as a Service (IaaS).

a) Make NASA realize significant cost savings through efficient resource utilization, reduced energy consumption, and reduced labor costs.
b) Provide an easier way for NASA scientists and researchers to efficiently explore and share large and complex data sets.
c) Allow customers to provision, manage, and decommission computing capabilities on an as-needed bases.

NASA Nebula: http://nebula.nasa.gov/

# Background -2

- GES DISC has been evaluating feasibility and suitability of migrating GES DISC's applications to the Nebula platform by porting following projects.

**a) Using Nebula Cloud to run scientific data processing infrastructure**

**S4PM** is an open source data processing infrastructure. Based on S4PM, scientific data processing algorithms can be run to efficiently process large volumes of satellite data. http://sourceforge.net/projects/s4pm/

**b) Using Nebula Cloud to run scientific data processing workflow**

The Atmospheric Infrared Sounder (AIRS) focuses on supporting climate research and improving weather forecasting. Based on S4PM, the **AIRS Level 1 & Level 2 algorithms workflow,** consisting of many of sub-algorithms (executables), processes large volumes of AIRS Level 0 data to produce Level 1 data as intermediate results, and finally outputs Level 2 data products.

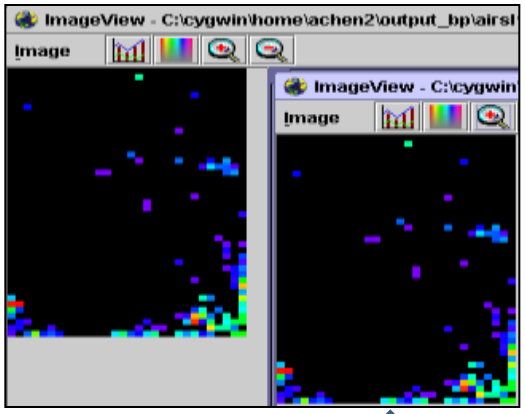
# Background -3

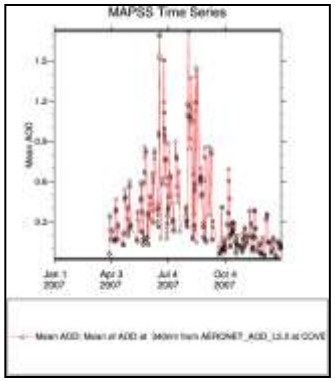
**c) Porting a Web-based scientific data processing application to Nebula Cloud**

**Giovanni** is a Web-based application which offer online visualization and analysis of vast amounts of Earth science data. The **Giovanni MAPSS** (Multi-sensor Aerosol Products Sampling System) portal focuses on visualizing aerosol relationships among ground-based data and satellite data.

- The experiences, lessons learned, and tutorials will expedite our future efforts to utilize Nebula/Cloud computing technologies to process Earth Science data.

# System Architecture





MAPSS

Kepler Workflow Engine

aGiovanni

HDF4/HDF5

AIRS L1/L2 Algorithms workflow

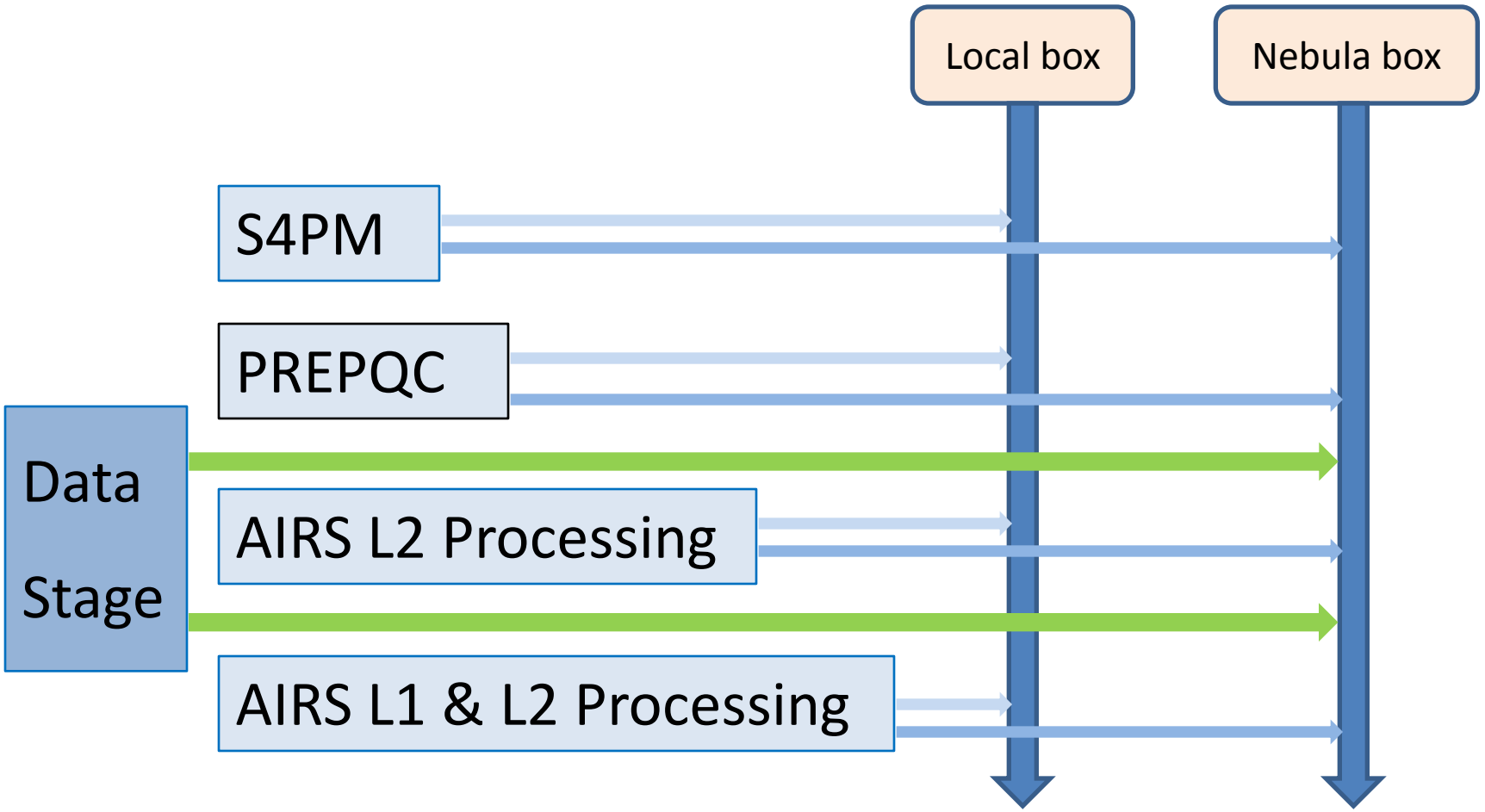
AIRS L1 Processing

HDF-4.2/SDPTK_5.2.12

GES DISC S4P/S4PM

NASA Nebula Cloud

# The Migrating Procedures



# Performance Estimation -1

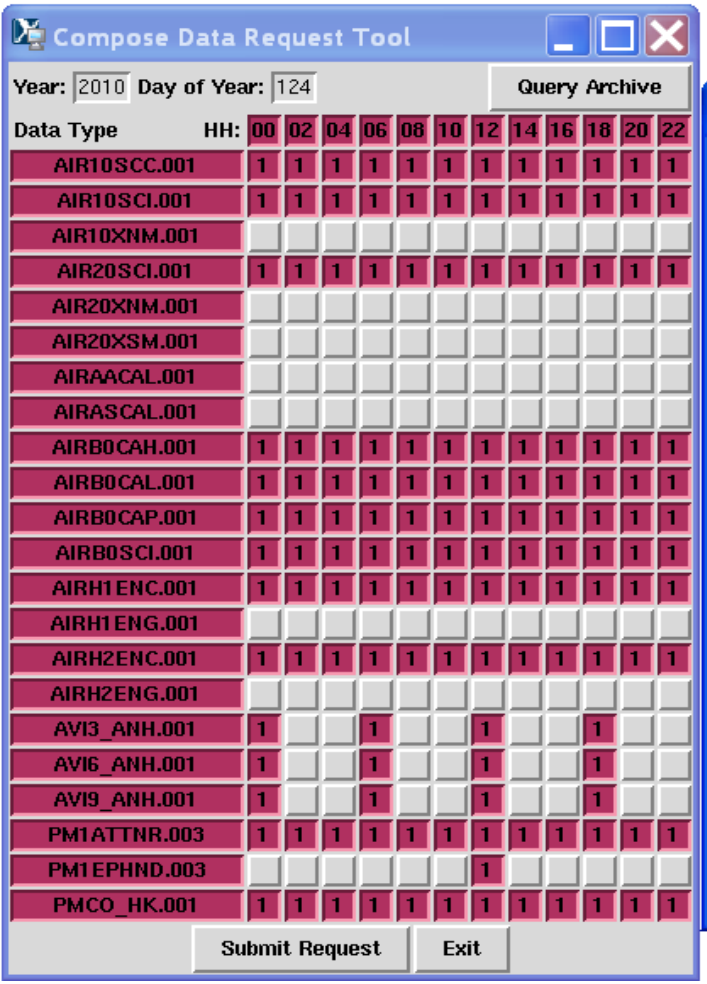
-- Hardware Information

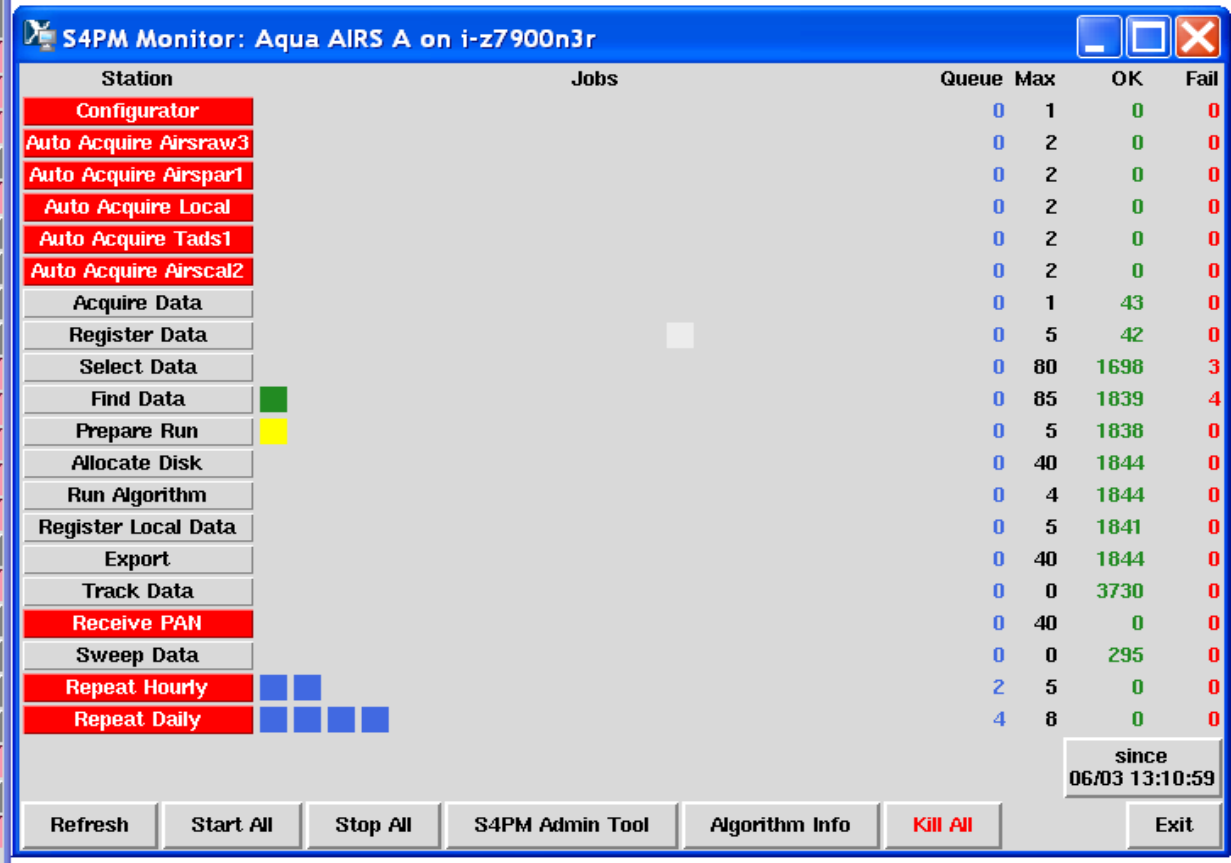
| | Local Real Linux box | Nebula virtual Linux Box |
|---|---|---|
| Hardware | DELL PowerEdge 6800 with Xeon Processor 7100 series | DELL PowerEdge c2100 with Xeon Processor 5500 series |
| CPU (GHz) | 8 cores * 3.16 | 4 cores * 2.8 |
| RAM (GB) | 16 | 8 |
| L2 Cache Size (MB) | 1 | 4 |
| Storage | 11TB | 300GB (200GB in default) |
| CPU Microarchitecture | 65nm NetBurst | 45nm Nehalem / 32nm Westmere |

**Core** (65nm) /**Penryn** (45nm)

# Performance Estimation -2

## S4PM/GUI for PREPQC, AIRS L1 & L2 Processing

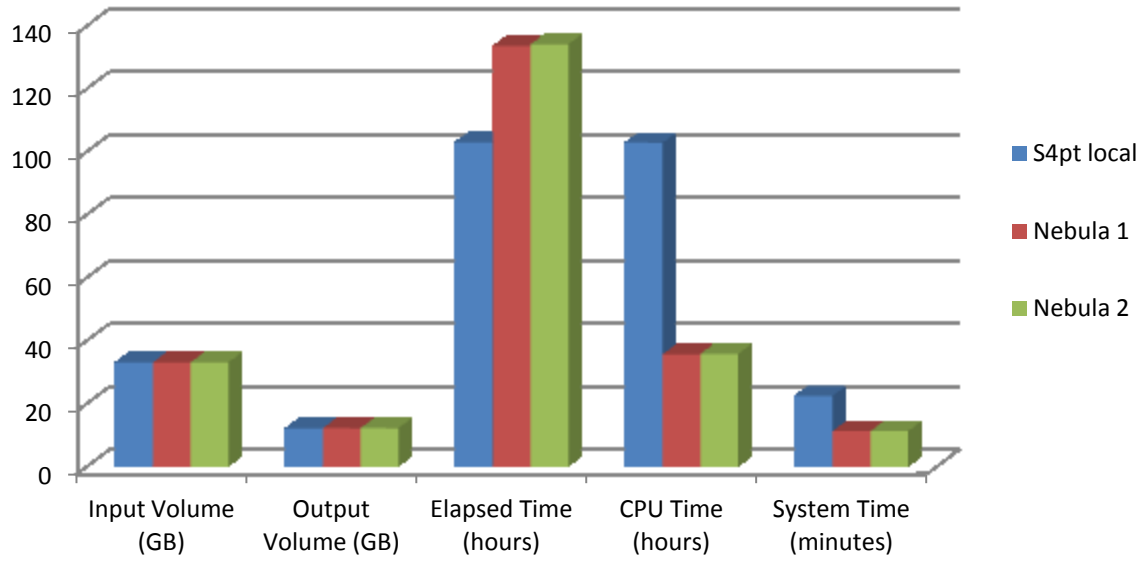


# Performance Comparison -1

## --Two-day AIRS L2 Processing at Nebula box and Local box

| Two days (2010.123-124) | Local Server | Nebula 1 | Nebula 2 |
|---|---|---|---|
| Input Volume (GB) | 33.1 | 33.1 | 33.1 |
| Output Volume (GB) | 12.16 | 12.2 | 12.2 |
| Elapsed Time (hours) | 103.05 | 133.60 | 134.13 |
| **CPU Time (hours)** | **102.90** | **35.67** | **35.80** |
| System Time (minutes) | 22.47 | 11.27 | 11.27 |




**Input Data (L1):** Calibrated and geolocated radiance in physical units, e.g. brightness temperature in Kelvin (K).

**Output Data (L2):** Retrieved physical variables, e.g. temperature, humidity and ozone profiles, total precipitable water, cloud top height.

# Performance Comparison -2

--Stable and consistent processing at Nebula box and Local box

**AIRS L2 processing at s4pt and Nebula box**

| One day (2010.123) | Local Server | Nebula 1 | Nebula 2 |
|---|---|---|---|
| Input Volume L1 data (GB) | 15.3 | 15.3 | |
| Output Volume L2 data (GB) | 6.06 | 6.11 | |
| Elapsed Time (hours) | 52.47 | 17.76 | |
| **CPU Time (hours)** | **52.34** | **17.76** | |
| System Time (minutes) | 10.5 | 4.34 | |

| Two days (2010.123-124) | Local Server | Nebula 1 | Nebula 2 |
|---|---|---|---|
| Input Volume L1 data (GB) | 33.1 | 33.1 | 33.1 |
| Output Volume L2 data (GB) | 12.16 | 12.2 | 12.2 |
| Elapsed Time (hours) | 103.05 | 133.60 | 134.13 |
| **CPU Time (hours)** | **102.90** | **35.67** | **35.80** |
| System Time (minutes) | 22.47 | 11.27 | 11.27 |

| Three days (2010.123-125) | Local Server | Nebula 1 | Nebula 2 |
|---|---|---|---|
| Input Volume L1 data (GB) | 48.8 | 48.8 | 48.8 |
| Output Volume L2 data (GB) | 18.3 | 18.3 | 18.3 |
| Elapsed Time (hours) | 154.39 | 207.84 | 207.83 |
| **CPU Time (hours)** | **154.14** | **55.31** | **55.32** |
| System Time (minutes) | 32.87 | 17.23 | 17.30 |

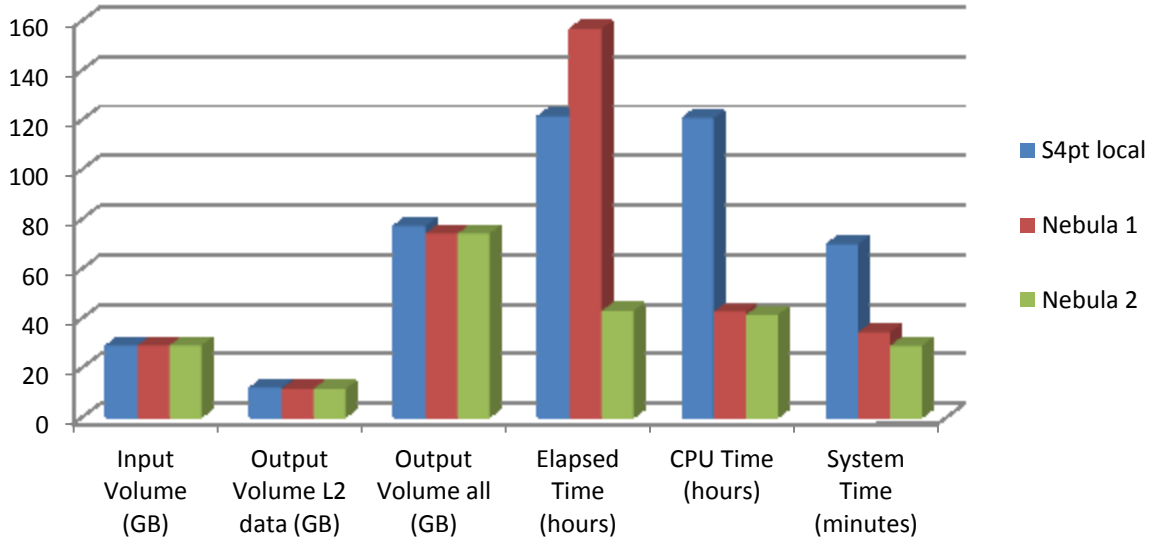
**Input Data (L1):**
Calibrated and geolocated radiance in physical units, e.g. brightness temperature in Kelvin (K).

**Output Data (L2):**
Retrieved physical variables, e.g. temperature, humidity and ozone profiles, total precipitable water, cloud top height.

# Performance Comparison -3

## -- Two-day AIRS L1 & L2 Processing at Nebula box and Local box

| Two days (2010.123-124) | Local Server | Nebula 1 | Nebula 2 |
|---|---|---|---|
| Input Volume (GB) | 29.11 | 29.11 | 29.11 |
| Output Volume L2 data (GB) | **12.14** | **11.61** | **11.64** |
| Output Volume all (GB) | 77.47 | 74.37 | 74.35 |
| Elapsed Time (hours) | 121.70h | 157.00h | 43.11h |
| CPU Time (hours) | **120.98h** | **42.80h** | **41.52h** |
| System Time (minutes) | 70.02m | 34.43m | 29.04m |




**Input Data (L0):**
Raw data from AIRS, AMSU-A1, AMSU-A2 instruments, and data about the spacecraft.

**Output Data (L2):**
Retrieved physical variables, e.g. temperature, humidity and ozone profiles, total precipitable water, cloud top height.

# Hardware Performance Analysis

| | Local Real Linux box (s4pt) | Nebula virtual Linux Box |
|---|---|---|
| Hardware | DELL PowerEdge 6800 with Xeon Processor 7100 series | DELL PowerEdge c2100 with Xeon Processor 5500 series |
| CPU (GHz) | 8 cores * 3.16 | 4 cores * 2.8 |
| Microarchitecture | 65nm NetBurst | 45nm Nehalem / 32nm Westmere |

| | NetBurst Microarchitecture | Nehalem/Westmere Microarchitecture |
|---|---|---|
| Cache L3 | N/A | 2 MB/core |
| FSB | Dual Independent 800MHz | QPI=6.4GT/s (Quick Path Interconnections) |
| Memory | DDR-2 400 ECC SDRAM (double channel) | DDR-3 (triple channel) |

**Netburst** (65nm) --> **Core** (65nm) /**Penryn** (45nm) --> **Nehalem** (45nm)/**Westmere** (32nm)

Core = *2.5 x* NetBurst[1]

Penryn = 1.8 x Core[2]

Nehalem/Westmere=*(1.2-2.0) x* Penryn[3]

⇒ Nehalem/Westmere=*(5.4-9.0)x* NetBurst

[1]Intel, white paper, Introducing the 45nm Next-Generation Intel® Core™ Microarchitecture.2007

[2]Intel, http://en.wikipedia.org/wiki/Intel_Core_%28microarchitecture%29

[3]Intel, http://en.wikipedia.org/wiki/Nehalem_%28microarchitecture%29

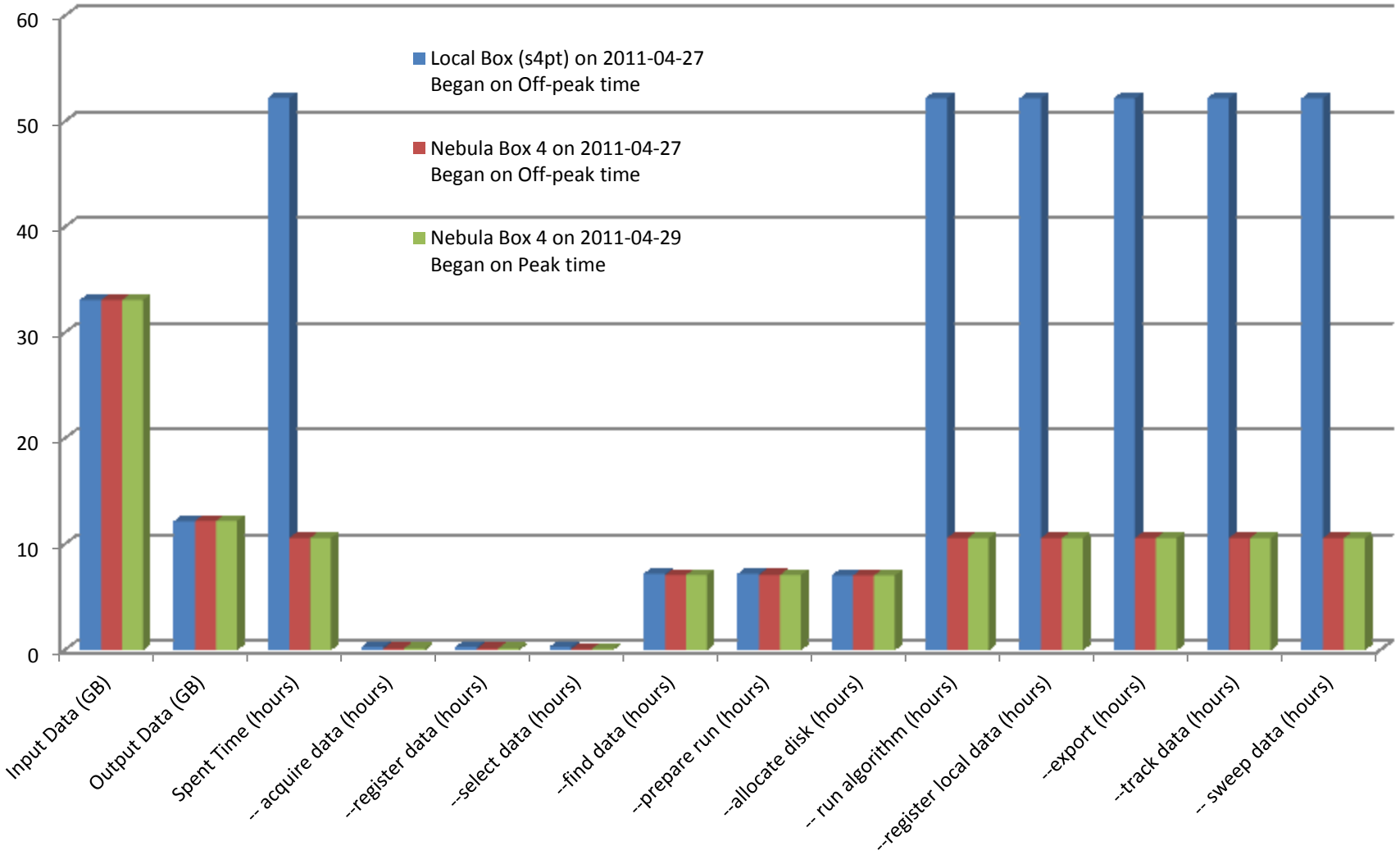
# Performance Analysis -1

## Two-day AIRS L2 Processing at Nebula box and Local box

| | Local Box<br>On Off-peak time | Nebula Box 4<br>On Off-peak time | Nebula Box 4<br>On Peak time |
|---|---|---|---|
| **Data Date** | 2010.123-124 (2010.05.02-03) | 2010.123-124 (2010.05.02-03) | |
| Input Data | ~33.1GB | ~33.1GB | ~33.1GB |
| Output Data | ~12.16 GB | ~12.2GB | 12.2~ GB |
| **Spent Time** | **52h 11m 58s** | **10h 34m 50s** | **10h 33m 43s** |
| -- acquire data | 17m 14s (**21:36:33** - 21:53:47) | 6m 33s (**14:01:25** - 14:07:58) | 6m 34s (**07:58:32** - 08:05:06) |
| --register data | 17m 21s (21:36:35 - 21:53:56) | 6m 32s (14:01:28 - 14:08:00) | 6m 43s (07:58:34 - 08:05:17) |
| --select data | 16m 5s (21:36:36 - 21:52:41) | 4m 26s (14:01:31 - 14:06:57) | 5m 36s (07:58:37 - 08:04:13) |
| --find data | 7h 10m 58s (21:36:37 - 4-28 04:47:35 | 7h 5m 12s (14:01:34 - 21:06:46) | 7h 4m 54s (07:58:40 - 15:03:34) |
| --prepare run | 7h 10m 59s (21:36:38 - 04-28 04:47:37) | 7h 5m 18s (14:01:37 - 21:06:55) | 7h 4m 56s (07:58:43 - 15:03:39) |
| --allocate disk | 7h 1m 39s (21:46:16 - 04-28 04:47:55) | 7h 1m 50s (14:05:26- 21:07:16) | 7h 1m 13s (08:02:32 - 15:03:45) |
| ***-- run algorithm*** | ***52h 11m 34s (04-27 21:36:40 - 04-30 01:48:14)*** | ***10h 34m 23s (14:01:40 - 04-28 00:36:03)*** | ***10h 34m 15s (07:58:46 - 18:32:01)*** |
| --register local data | 52h 10m 40s (21:36:41 - 04-30 01:48:21) | 10h 34m 27s (14:01:44 - 04-28 00:36:11) | 10h 33m 16s (07:58:49 - 18:32:05) |
| --export | 52h 10m 40s (21:36:42 - 04-30 01:48:22) | 10h 34m 23s (14:01:46 - 04-28 00:36:09) | 10h 33m 17s (07:58:52 - 18:32:09) |
| --track data | 52h 10m 47s (21:36:44 - **04-30 01:48:31**) | 10h 34m 25s (14:01:50 - **04-28 00:36:15**) | 10h 33m 15s (07:58:55 - 18:32:10) |
| -- sweep data | 52h 10m 40s (21:36:46 - 04-30 01:48:25) | 10h 34m 1s (14:02:12 - 04-28 00:36:13) | 10h 33m 10s (07:59:05 - **18:32:15**) |

# Performance Analysis -2

## Two-day AIRS L2 Processing at Nebula box and Local box

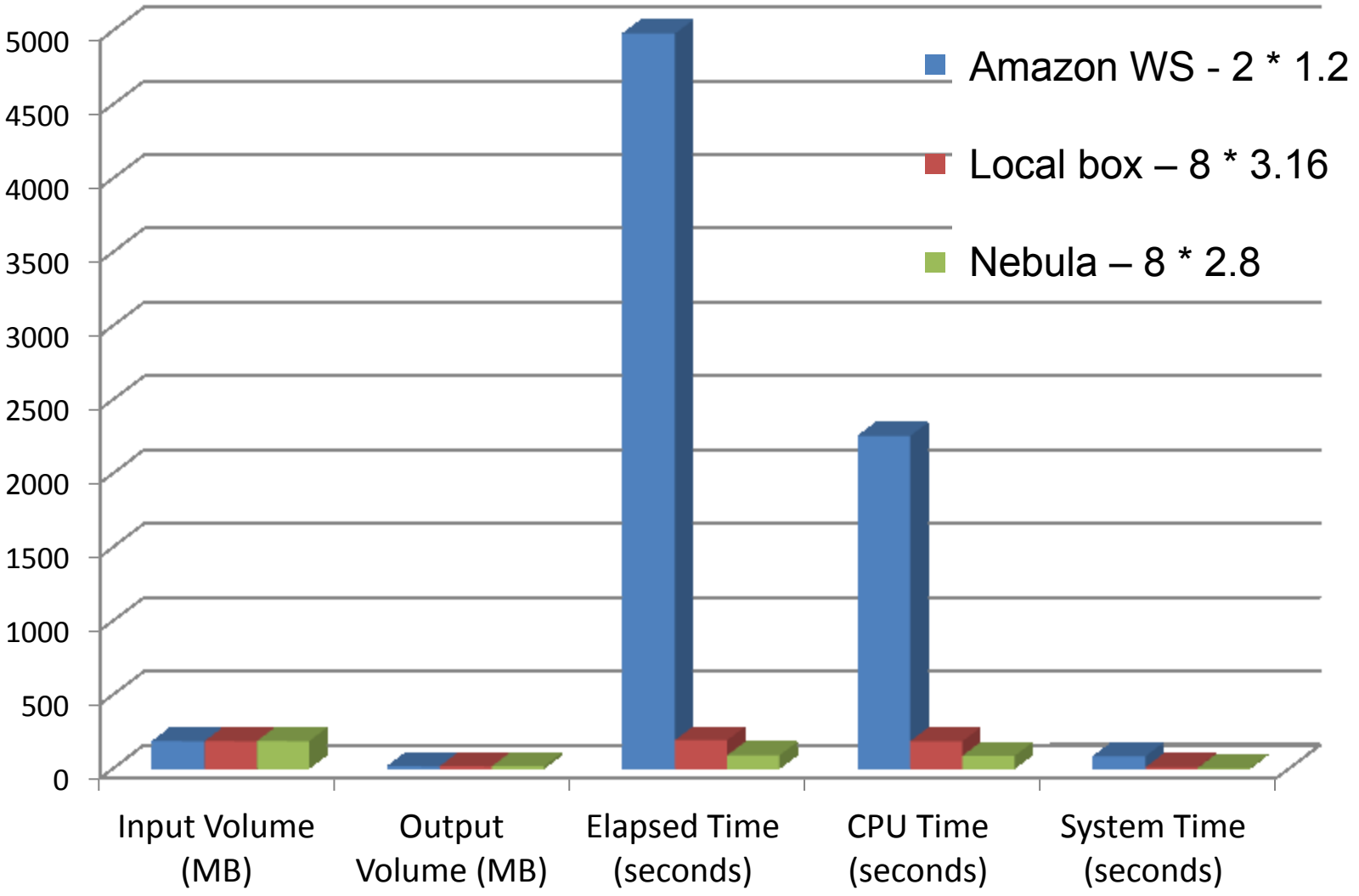


# Performance comparison: AWS, Nebula, and local

## PREPQC 2011-111 (one-day)

| One day (2011.111) | Amazon WS | | Local Linux box | Nebula |
|---|---|---|---|---|
| Hardware Information | **t1.micro**: 613MB RAM Up to 2 * 1.2GHz Nehalem-based processor | | 16GB RAM, 4 * 3.16GHz NetBurst-based dual-core processor (8 cores) | 8GB RAM, 2 * 2.8GHz Nehalem-based quad-core processor (8 cores) |
| Input Volume (MB) | 184.67 | | 184.67 | 184.67 |
| Output Volume (MB) | 14.89 | | 14.95 | 15.01 |
| Elapsed Time (seconds) | 4980.25 | 5745.15 | 191.05 | 88.83 |
| **CPU Time (seconds)** | 2253.23 | 2395.79 | 184.21 | 85.51 |
| System Time (seconds) | 82.29 | 99.42 | 7.58 | 3.16 |

# Performance comparison: AWS, Nebula, and local



# Cost Estimation and Comparison -1

-- Nebula charge policies

## ❖ CPU charges

-- $0.12 per CPU-hr.

-- $0.48 per hour for an m1.large instance, which uses 4 CPUs.

-- The charge applies whenever an instance is running, whether or not it is processing.

-- Cloud applications should be designed to terminate non-processing instances wherever possible.

## ❖ Storage charges

-- $0.15 per GB-month apply to Volume storage and to Object Store storage.

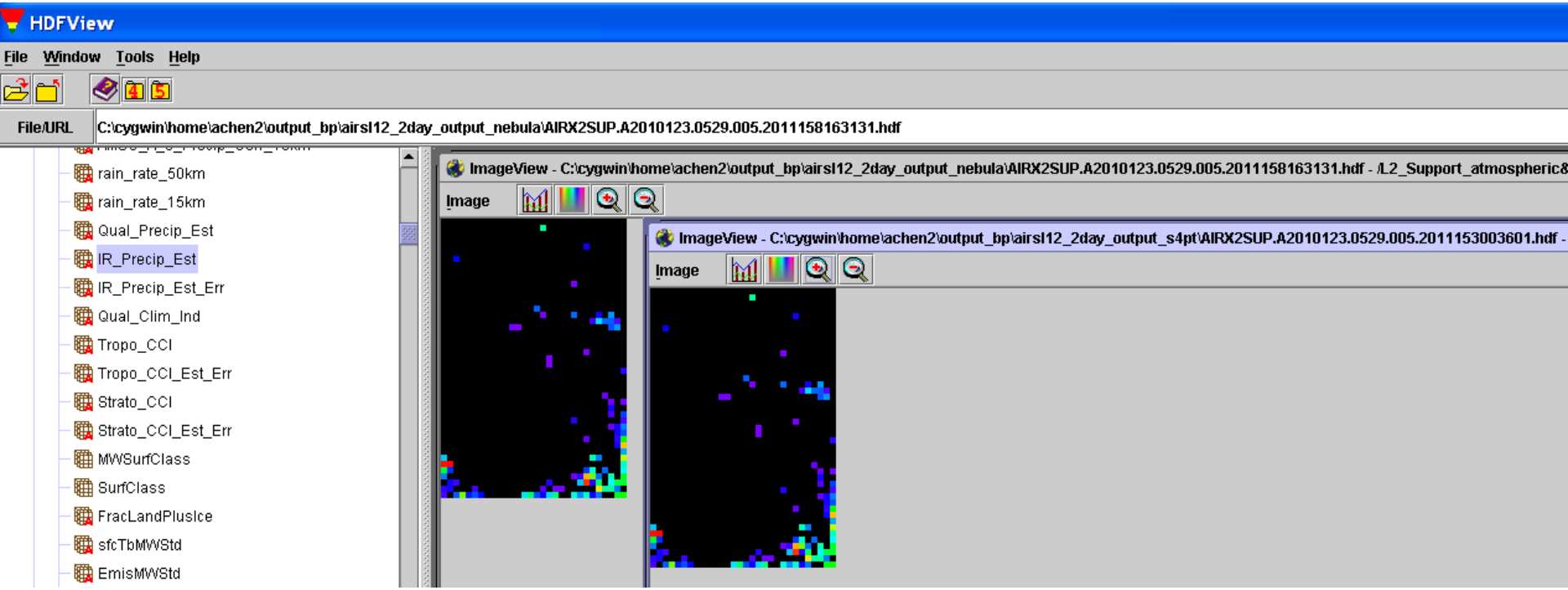
-- No charge for internal storage which comes within an instance (100GB) .

-- Nebula does not charge for the storage used for your images themselves.

-- Nebula does not charge for inputs and outputs, puts and gets, or network bandwidth usage.

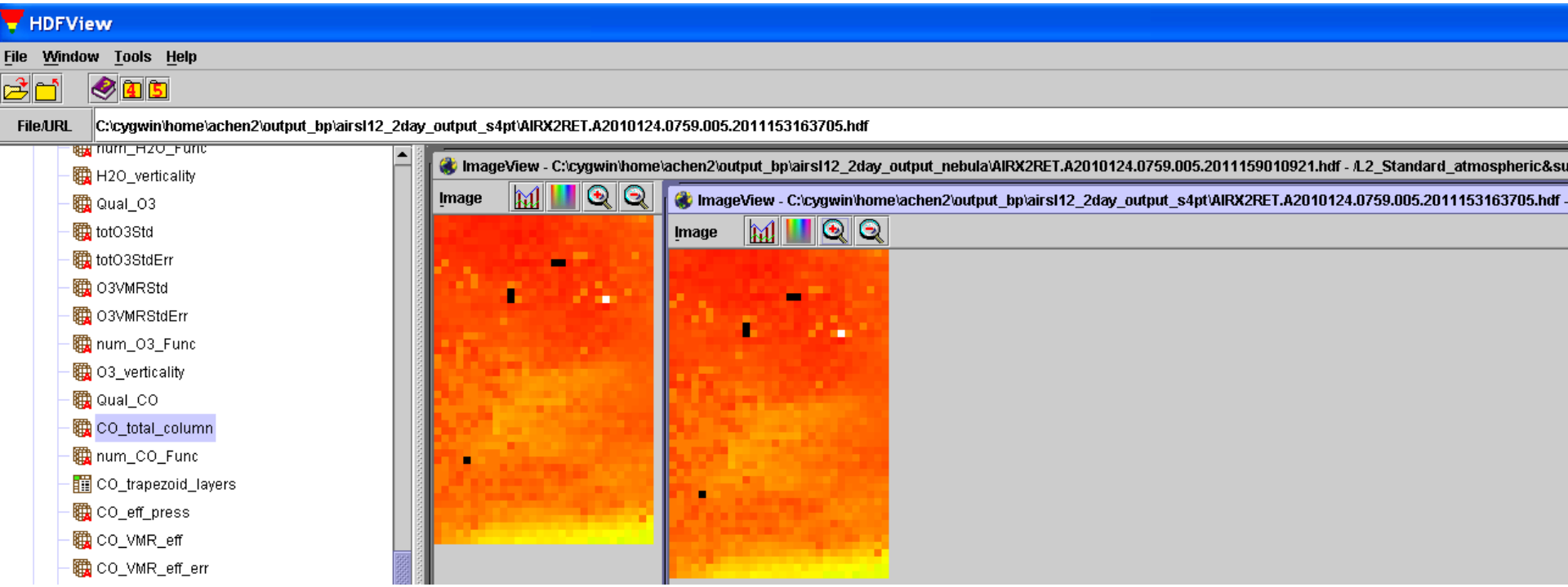
# Output Verification -1

## AIRX2SUP (AIRS L2 Products)



# Output Verification -2

## AIRX2RET (AIRS L2 Products)



# Advantages -1

- User Friendly interface, access to and manage Nebula resources
  - -- dashboard: simple and convenient web interface
  - -- Euca2ools: fast and powerful command line tools
- Better Performance, compared with local box (details in appendix C)
- Lower cost, only pay for used time and resources (details in appendix C)
- Scalability, on-demand provisioning of resources in near real time and without users involvement for peak loads.
- Cloning, simple bundling process to save a modified/improved image. This is an excellent feature to maintain, back up, and mirror the systems; hence, increasing reliability.

# Advantages -2

- VPN-based high security (1024 bit private and public key and X509 Cert.), easy login using private keys.
- Knowledge base:

  -- Detailed how-to instructions for using Nebula via Dashboard and Euca2ools.

  -- Fairly comprehensive FAQ, covering most common questions.

  -- Helpful tutorial video for getting started.
- Nebula Forum, good venue for additional materials, user encountered bugs, solutions, and discussion.
- Nebula team support, responsive and eager to help; prompt response to general questions and resolving commonly encountered problems.

# Challenges -1

## ❖ Stability

-- Instances are not stable, operational access maybe lost and instances have to be rebooted. Before rebooting an instance, all attached volumes have to be detached.
-- Network (FTP/wget) between Nebula and local machines is slow and not stable. Complications may arise from users attempting to ssh into Nebula instances during data transfers via FTP/wget (e.g. login failure, frequent FTP timeout, and throughput stalls).

## ❖ Under Developed

-- Object Store not yet available
-- Lack of tools for managing and monitoring running instances (e.g. Elastic Load Balancing, CloudWatch, Auto Scaling, etc.).

## ❖ Images, Volumes & Bundles

-- Bare-bone images lacking trivial software packages (e.g. gcc, x11).
-- When volume is attached, the specified location maybe not necessarily correspond to the entered location (e.g. /dev/vdh may end up as /dev/vdg).
-- Any defects in the image you start with will be bundled up with your instance into your resulting image. (Defects in CentOS images result in bundling issues).

# Challenges -2

- Gaps in Knowledge Base
  - -- Lack of information on Nebula provided images.
  - -- No troubleshooting tools.
  - -- Details on hardware and basic software used by Nebula?
- Communication Concerns
  - -- **Telecon**: Nebula used to have periodic telecon for end users to discuss problems needs, defects. These would be beneficial if they would return
  - -- **Technical support**: Faster and more efficient technical support is needed
  - -- **Forum**: Turn around for technical questions is long. Some posts are not responded to
- Size Limitation
  - -- Instances: Maximum of 5 instances per project
  - -- Volumes: 100GB volume storage per project (**exceptions can be requested directly)*
  - -- CPUs: 16 cores.
- Commercial Software
  - -- Uncertainty about 3rd-party commercial software installation on Nebula (e.g. licenses issues using instances with 3rd-party software in other projects, etc.).

# Summary

- Three applications were successfully migrated to Nebula, including S4PM, AIRS L1/L2 algorithms, and Giovanni MAPSS.
- Nebula has some advantages compared with local machines (e.g. performance, cost, scalability, bundling, etc.)
- Nebula still faces some challenges (e.g. stability, object storage, networking, etc.).
- Migrating applications to Nebula is feasible but time consuming.
- Lessons learned from our Nebula experience will benefit future Cloud Computing efforts at GES DISC.

# Team Members

**Long Pham**

**Aijun Chen**

**Steven Kempler**

**Christopher Lynnes**

**Michael Theobald**

**Esfandiari Asghar**

**Jane Campino**

**Bruce Vollmer**

Thank You for your attention !

# Any Questions ?