NASA Earth Observing System Simulator Suite (v 2.0)

https://**NEOS3**.jpl.nasa.gov

(NEE-os)

N. Niamsuwan[1], S. Tanelli[1] (PI), M. P. Johnson[1], D. Dao[1], J. Jacob[1], S. Jaruwatanadilok[1], S. Oveisgharan[1], M. Simard[1], F. J. Turk[1], N. Majurec[1], and L. Tsang[2]

[1]Jet Propulsion Laboratory, California Institute of Technology
[2]University of Washington

Earth Science Technology Forum
Oct 29, 2014

NASA Earth Observing System Simulator Suite (v 2.0)

https://**NEOS3**.jpl.nasa.gov

(NEE-os)

supercomputing facility

cloud computing

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S. Jaruwatanadilok[1], S. Oveisgharan[1], M. Simard[1], F. J. Turk[1], N. Majurec[1], and L. Tsang[2]

sea ice · snowpack · forest · land · ocean · vegetation · snow/ground

[1]*Jet Pro… aborato… ia… of T… y*
[2]*University of Washington*

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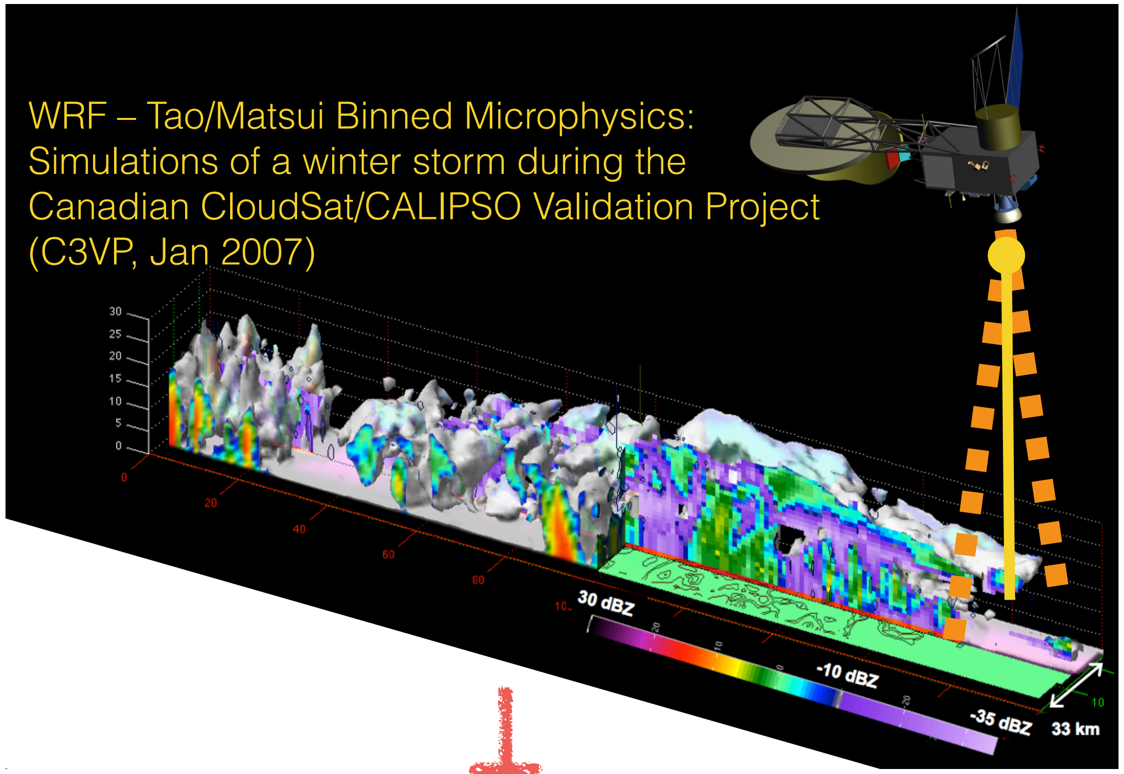
Introduction: What is NEOS^3 ?

- Produce simulated satellite observables based on given a 3D field of geophysical description of the Earth's atmosphere and surface as provided by weather and climate models



Physical Properties of the Target
(at all 3D grid-points in a domain)

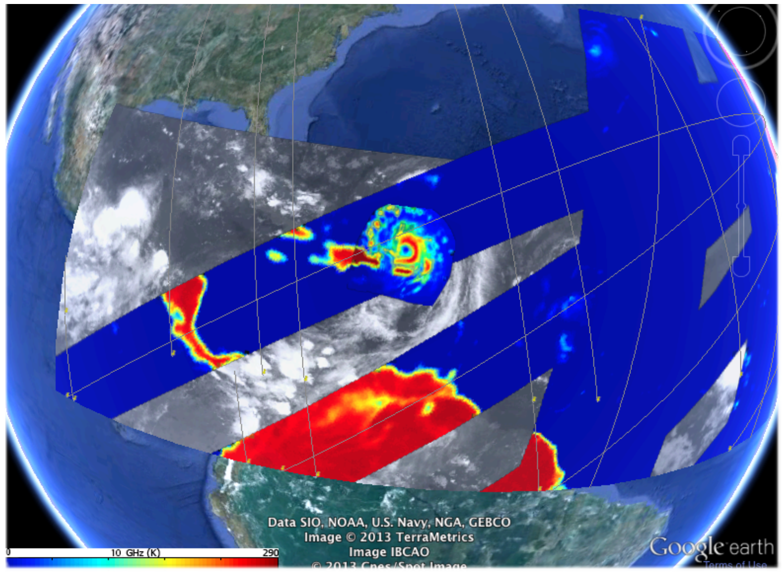
↓

NEOS^3

↓

Observables
(e.g. brightness temperature map, radar reflectivity profile)

Simulated Brightness Temperature
(89 GHz)



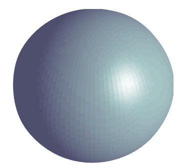
[Tropical Cyclone Information System, *S. Hristova-Veleva*]

Motivation: Role of NEOS^3

Simplified Models ⟷ **Complex**

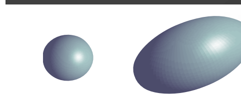
General ⟷ Specific

COSP
(A. Bodas-Salcedo, et al.)
SDSU
(H. Masunaga, T. Matsui, et al.)



. . . .

[SnowFake database: K.-S. Kuo]



NEOS^3

- Examples of NEOS^3 alternatives are shown
  - Each of these 4 corners addresses specific need of the community
- NEOS^3 was designed to fill the one corner that was previously unavailable: *a framework to produce a simulation of a complex observation*

J-SIM
(T. Hashino, et al.)
CRTM
(Y. Han, et al.)

ECSIM
(D. Donovan, et al.)

Image credit: http://gpm-gv.gsfc.nasa.gov/img/GPM_constellation.png

Chronicle of NEOS^3

- 2009—2012 (AIST'08)
  Instrument Simulator Suite for Atmospheric Remote Sensing (ISSARS)

S. Tanelli	PI
W. Tao	Atmospheric Modeling
T. Matsui	SDSU
C. Hostetler	Lidar, HSRL
J. Hair	
C. Butler	
N. Niamsuwan	Architecture and Interface
M. P. Johnson	Processor and IO
J. C. Jacob	High Performance Computing
J. Kwan	System Administrator
K.-S. Kuo	DDSCAT database

Additional contributors: , O. Sy[1], T. Clune[2], A. Battaglia[5], D. J. Diner[1], D. Donovan[6], S. L. Durden[1], A. J. Heymsfield[7], T. L'Ecuyer[8], T. Nakajima[9], G. L. Stephens[1], A. Ackermann[10], R. Bennartz[11], K. Bowman[1], A. B. Davis[1], G. DeBoer[12], A. Fridlind[10], S. Ghan[13], T. Hashino[14], J. T. Johnson[1], O. V. Kalashnikova[1], S. Kneifel[16], P. Kollias[17], S. Kreidenweis[8], S. Krueger[18], M. Kulie[11], S. Kumar[2], L. Liao[2], G. Liu[19], N. Majurec[15], J. V. Martonchik[1], D. Mueller[20], A. Parodi[21], W. Szyrmer[17], A. Tatarevic[17], G. Tripoli[11], J. Turk[1], G.-J. Van Zadelhoff[6], F. Weng[22]

- 2012—present (AIST'11)
  Unified Simulator for Earth Remote Sensing (USERS)

+++

D. Dao	Cloud Computing
S. Jaruwatanadilok	Sea Ice Scattering Model
S. Oveisgharan	Snow Scattering Model
M. Simard	Forest Scattering Model
J. Turk	Land Scattering Model
L. Tsang	Vegetation Scattering Model
N. Majurec	Ocean Scattering Model

Additional contributors: W. Chang[23], T.-H. Liao[23], G.-F. Sacco[1], J. Parker[1], Q. Chau[1]

1 - JPL; 2 – NASA/Goddard Space Flight Center; 3 – NASA/Langley Research Center; 4 - Caelum Research Corporation, Rockville, MD, USA; 5 – Univ. of Leicester, Leicester, UK; 6 - Royal Netherlands Meteorological Institute, De Bilt, Netherlands; 7 - National Center for Atmospheric Research; 8 – Colorado State Univ.; 9 – Tokay Univ., Tokyo, Japan; 10 – NASA/Goddard Institute for Space Studies; 11 – Univ. of Wisconsin; 12 – Laurence Berkley National Laboratory; 13 – Pacific Northwest National Laboratory; 14 – Univ. of Tokyo, Tokyo, Japan; 15 – Ohio State University; 16 - Institute for Geophysics and Meteorology, Univ. of Cologne, Germany; 17 – McGill University, Montreal, CA; 18 – Univ. of Utah. Salt Lake City, UT, USA; 19 – FSU, Tallahassee, FL; 20 - Gwangju Institute of Science and Technology (GIST), Gwangju, South Korea and Leibniz Institute for Tropospheric Research, Leipzig, Germany; 21 – CIMA Research Foundation, Savona, Italy; 22 - NOAA/STAR; 23 — U. of Washington

Chronicle of NEOS³

version 1.0

- 2009—2012 (AIST'08)
  Instrument Simulator Suite for Atmospheric Remote Sensing (ISSARS)

S. Tanelli	PI
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NEOS³

version 2.0

- 2012—present (AIST'11)
  Unified Simulator for Earth Remote Sensing (USERS)

+++

D. Dao	Cloud Computing
S. Jaruwatanadilok	Sea Ice Scattering Model
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Outline

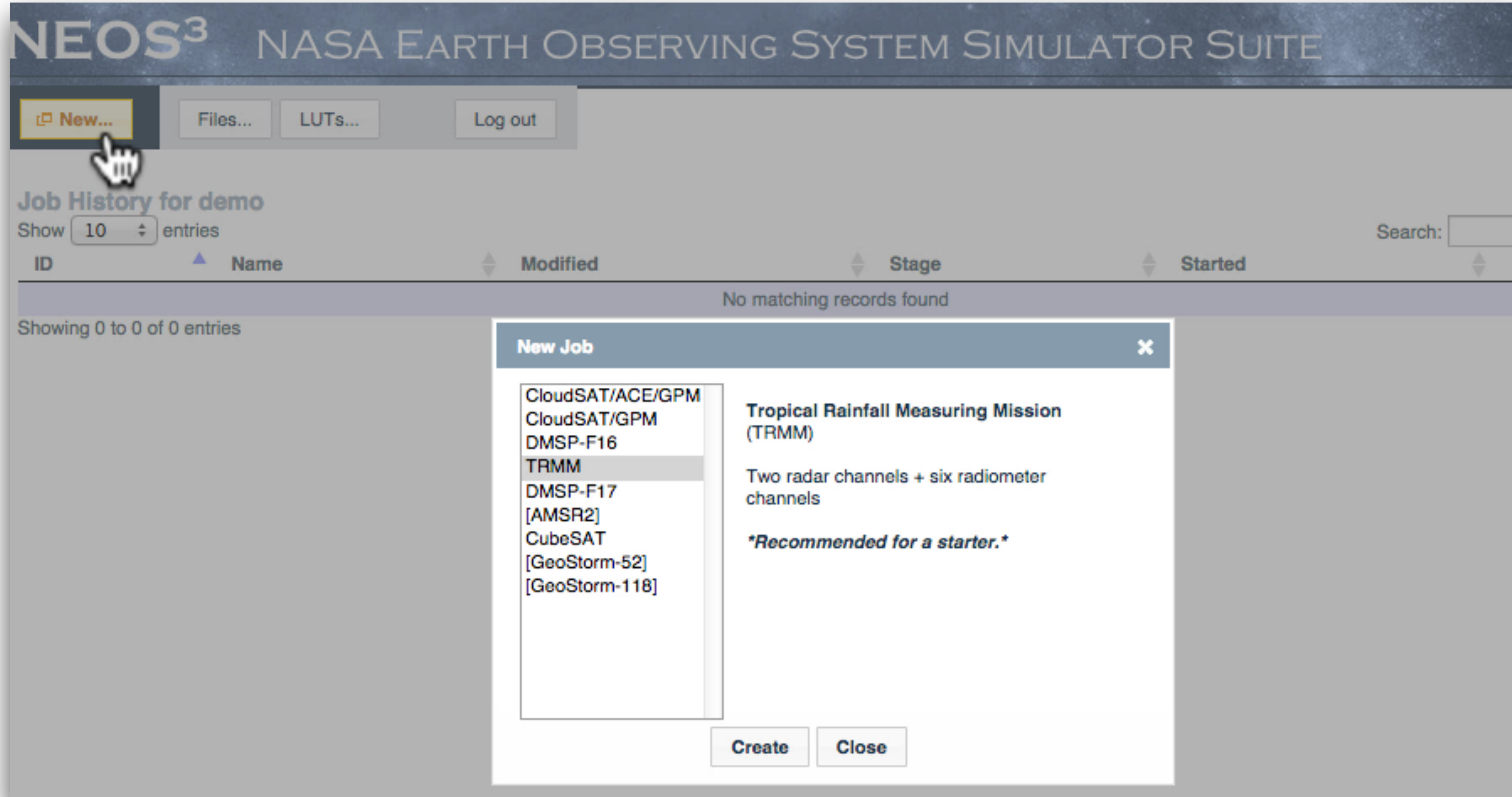
- Overview: demo, input, output
- Sample Applications
- Features
- Architecture
- Collaboration

Demo

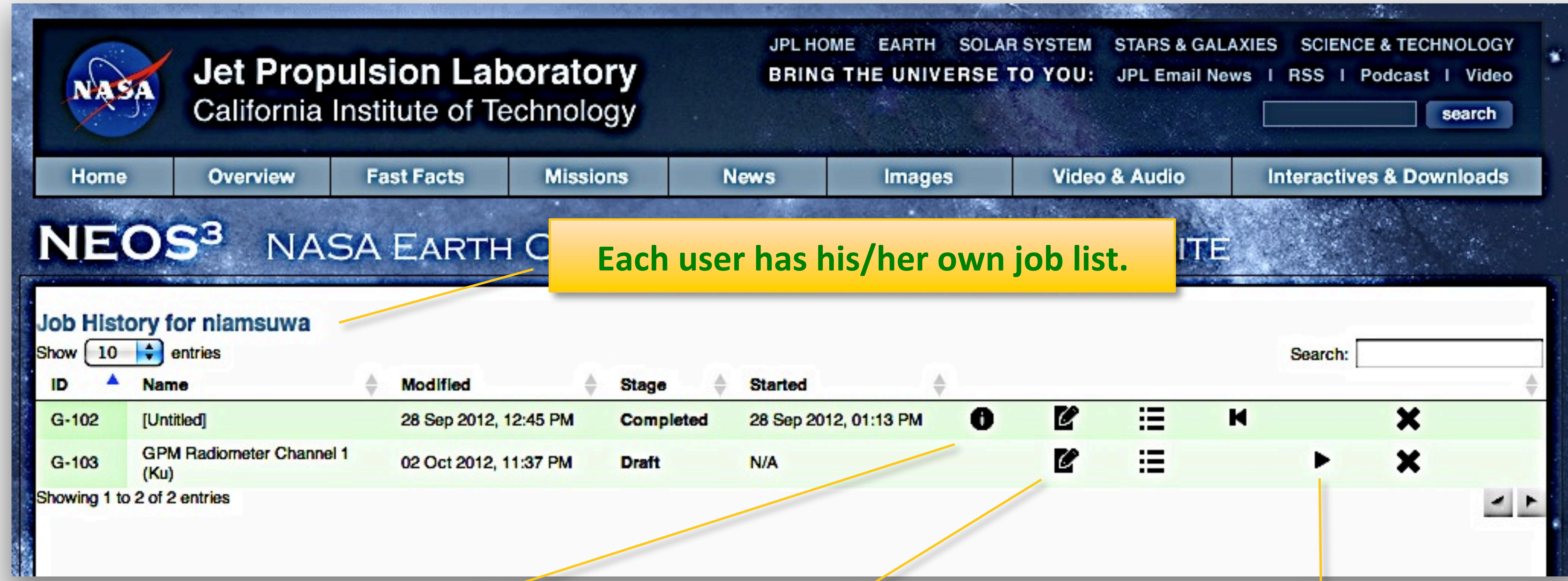
- This video shows how to create a new simulation "job"; (~~set up parameters~~); start a simulation "run"; and view/download the output


Starting a Default Simulation

Creating a New Job



Job Manager



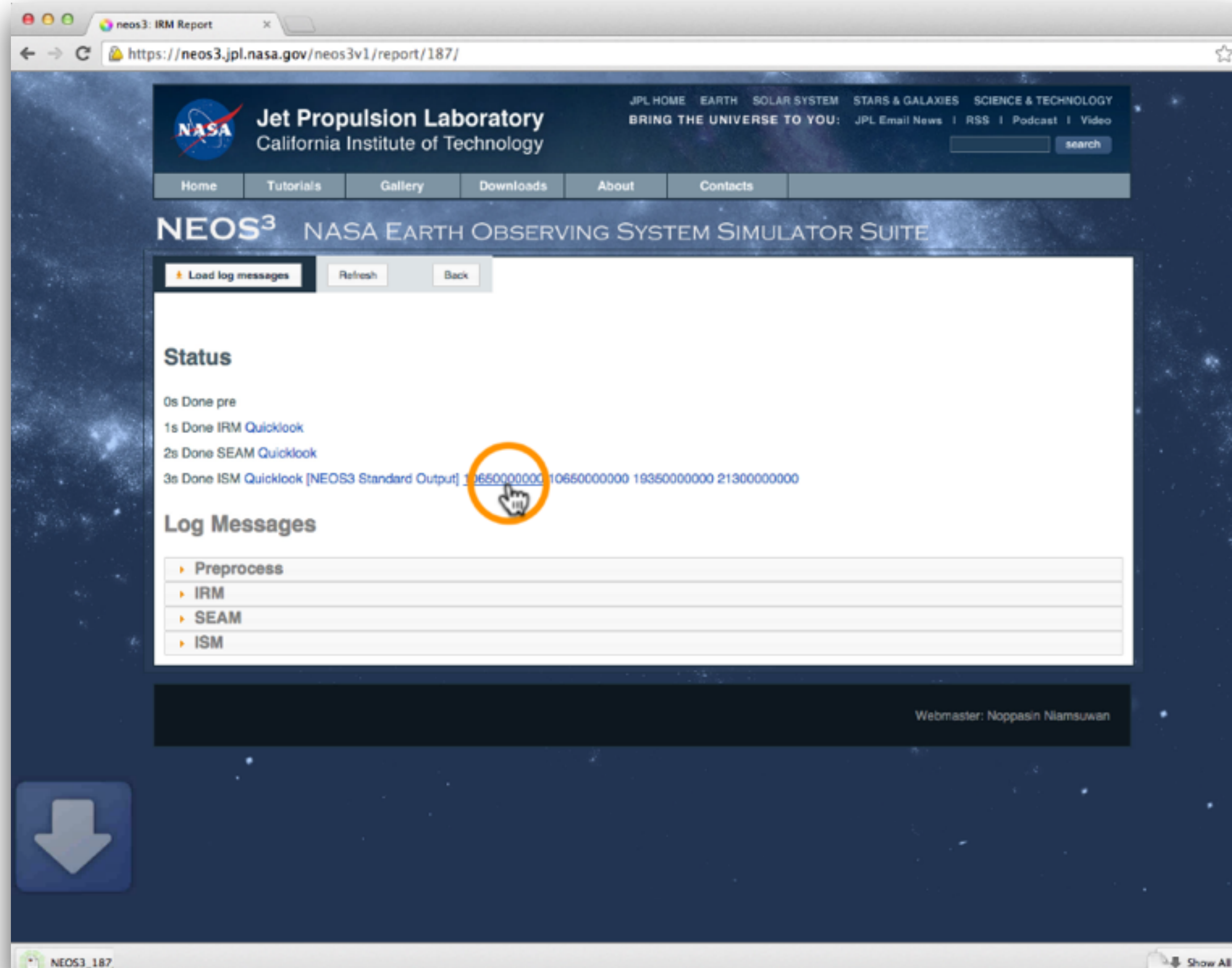
Each user has his/her own job list.

(3) Check
status

(1) Edit
job description

(2) Submit
when ready

Job Report


neos3: IRM Report
https://neos3.jpl.nasa.gov/neos3v1/report/187/
Jet Propulsion Laboratory
California Institute of Technology
JPL HOME EARTH SOLAR SYSTEM STARS & GALAXIES SCIENCE & TECHNOLOGY
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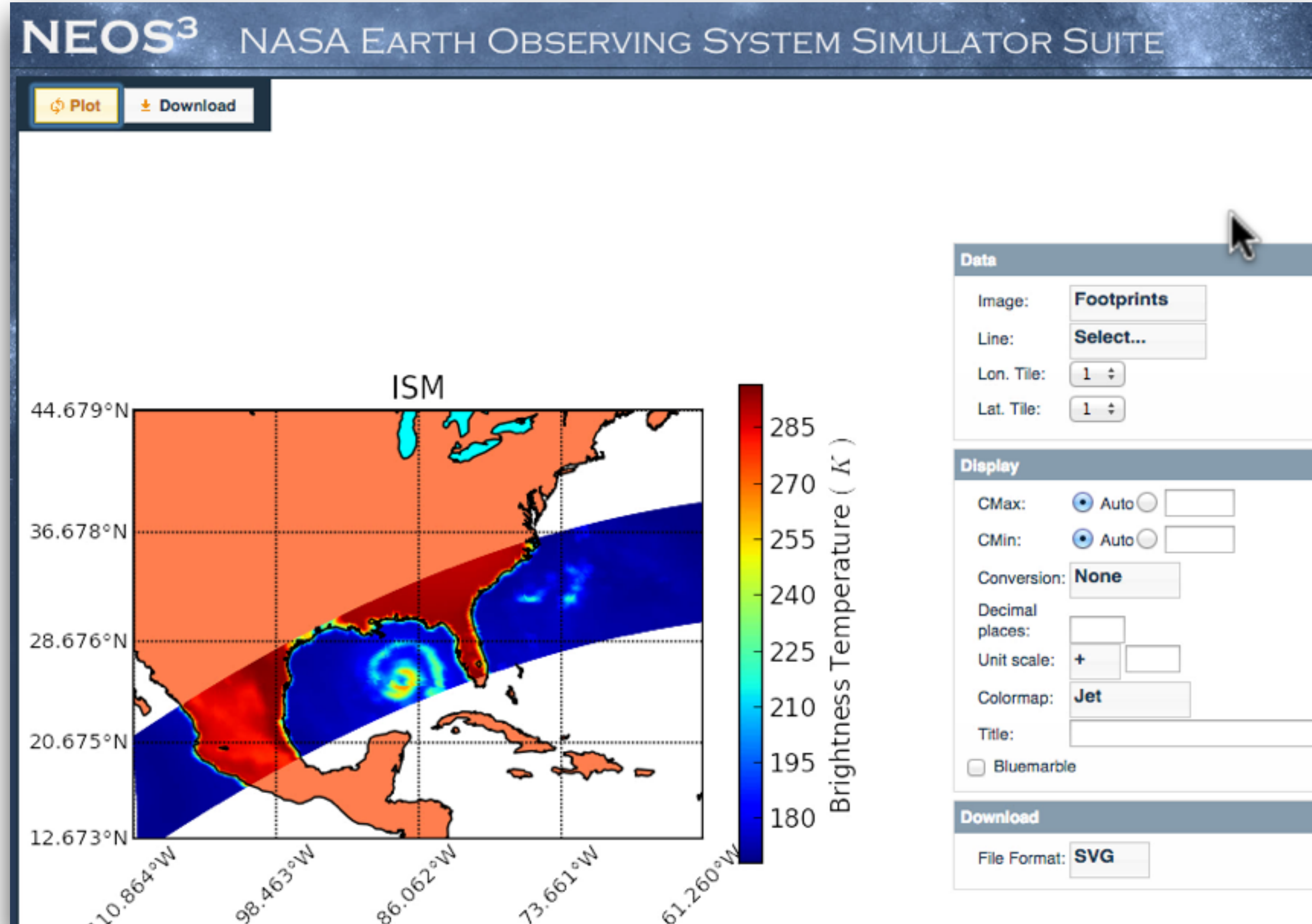
NEOS3 NASA EARTH OBSERVING SYSTEM SIMULATOR SUITE
Load log messages Refresh Back
Status
0s Done pre
1s Done IRM Quicklook
2s Done SEAM Quicklook
3s Done ISM Quicklook [NEOS3 Standard Output] 10650000000 19350000000 21300000000
Log Messages
Preprocess
IRM
SEAM
ISM
Webmaster: Noppasin Niamsuwan
NEOS3_187
Show All

Quicklook


NEOS3 NASA Earth Observing System Simulator Suite
Plot
Download
ISM
44.679°N
36.678°N
28.676°N
20.675°N
12.673°N
110.864°W
98.463°W
86.062°W
73.661°W
61.260°W
285
270
255
240
225
210
195
180
Brightness Temperature (K)
Data
Image: Footprints
Line: Select...
Lon. Tile: 1
Lat. Tile: 1
Display
CMax: Auto
CMin: Auto
Conversion: None
Decimal places:
Unit scale: +
Colormap: Jet
Title:
Bluemarble
Download
File Format: SVG

Input

- 3D Geophysics Description of the Atmosphere

Regional CRM (Cloud Resolving Model)

- NASA-Unified WRF (Weather Research & Forecasting)
- NCAR's Advanced Research WRF
- WRF-Chem (WRF with chemistry coupling)
- HWRF (Hurricane WRF)
- RAMS (Regional Atmospheric Modeling System)

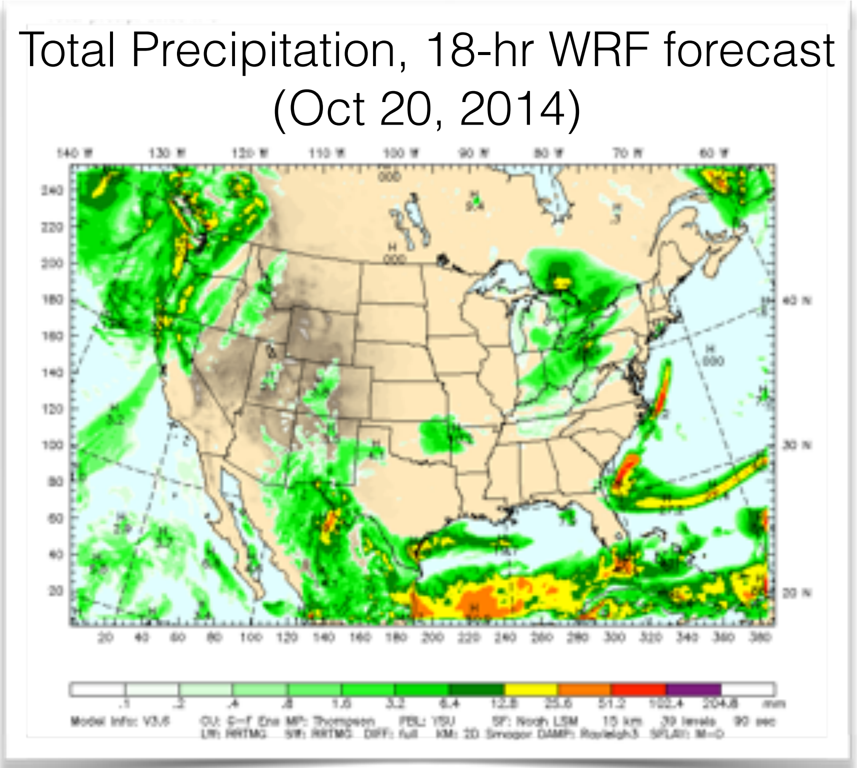
GCM (Global Circulation Model)

- GFS (Global Forecast System)
- ECMWF (European Center for Medium range Weather Forecasting)

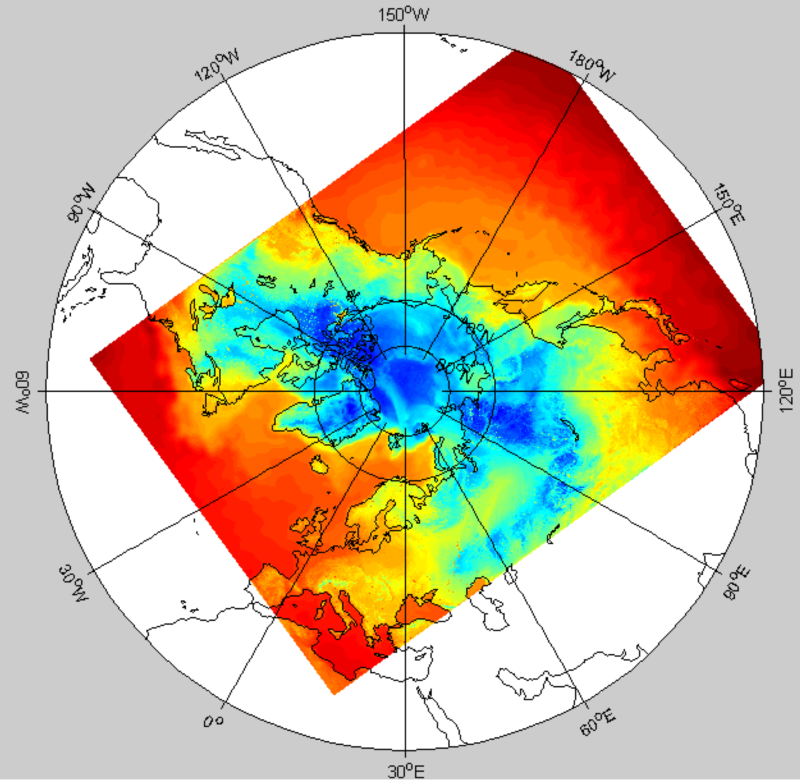
New entries (integration is in progress)

- NICAM Global cloud resolving model
- JPL LES

- Additional 2D Geophysics Description of the Surface
    - LIS (Land Information System)



[The Weather Research & Forecasting Model, http://wrf-model.org]



Output

Simulated observation for active and passive instruments

- Microwave radiometers and doppler radars (mature)
- Lidars, including hyper-spectral resolution (validation in progress)
- Polarimeters (development in progress)

Multiple degrees of realism

- **Ideal** quantities from radiative transfer
- Observations affected by **real**istic limitations of actual instruments (e.g. sampling time, thermal noise)

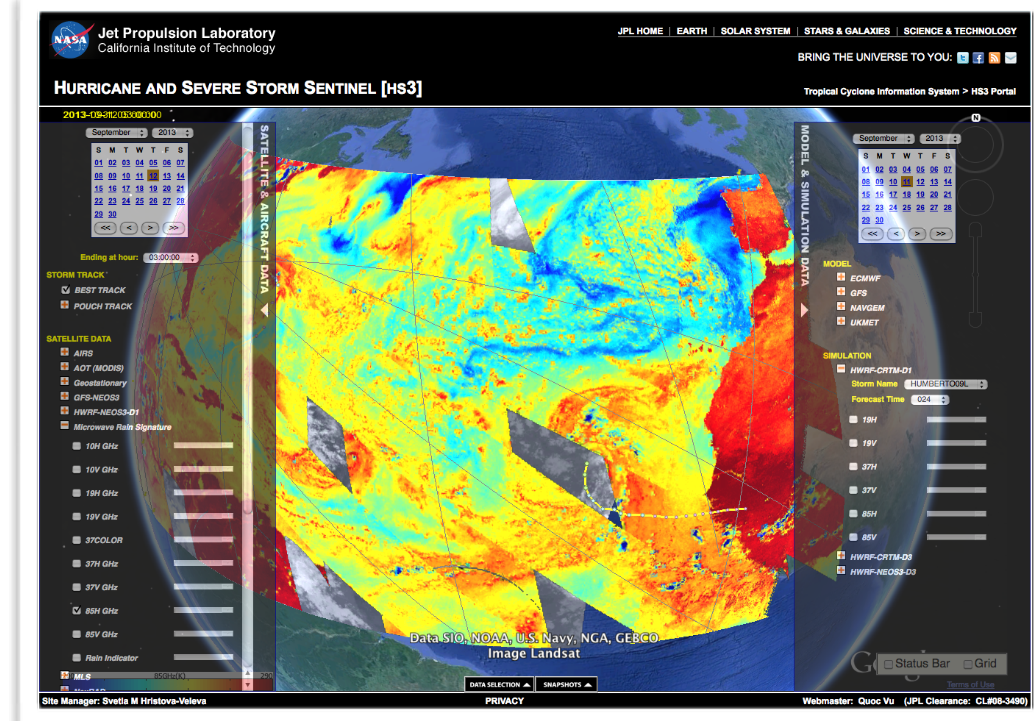
Format

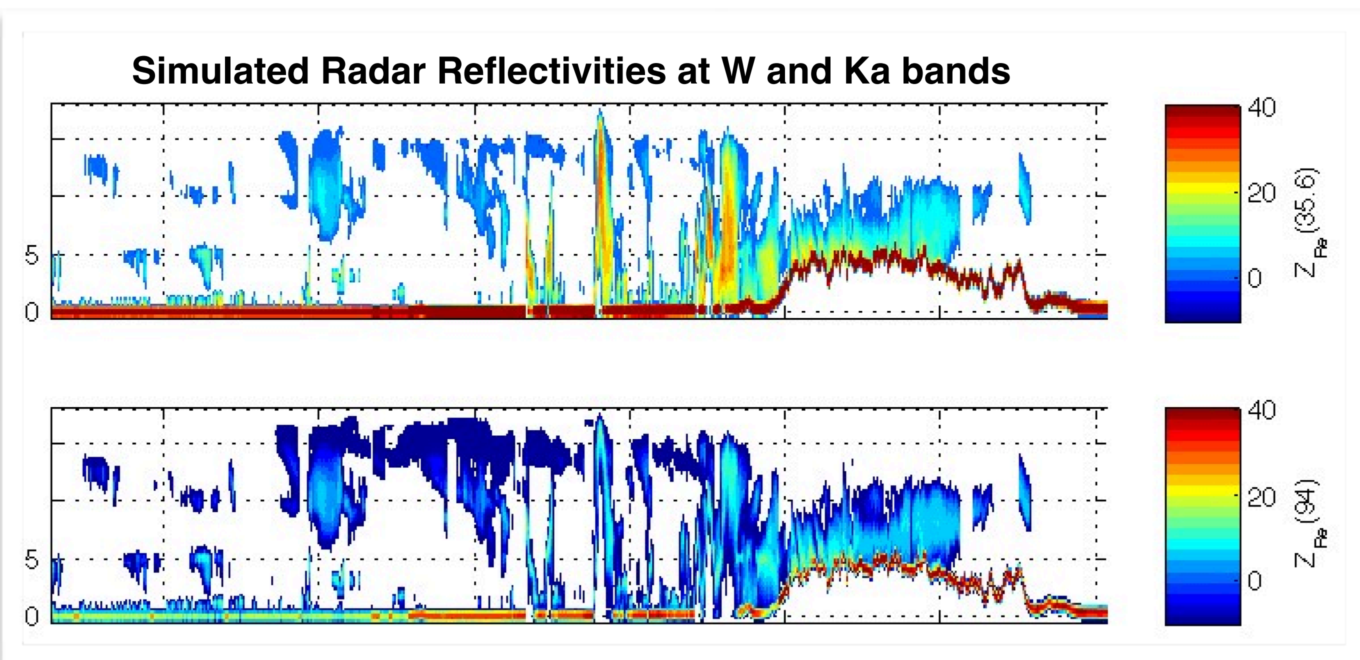
- Standard NEOS^3 binary: Python and MATLAB readers for internal use
- NetCDF4 (HDF5) for external use
  - Self explanatory: name, value, unit, dimension
  - MATLAB (built-in), Python (h5py), Fortran/C/Java (officially supported)
  - NEOS3-Complete, NEOS3-Compact, and some custom contents

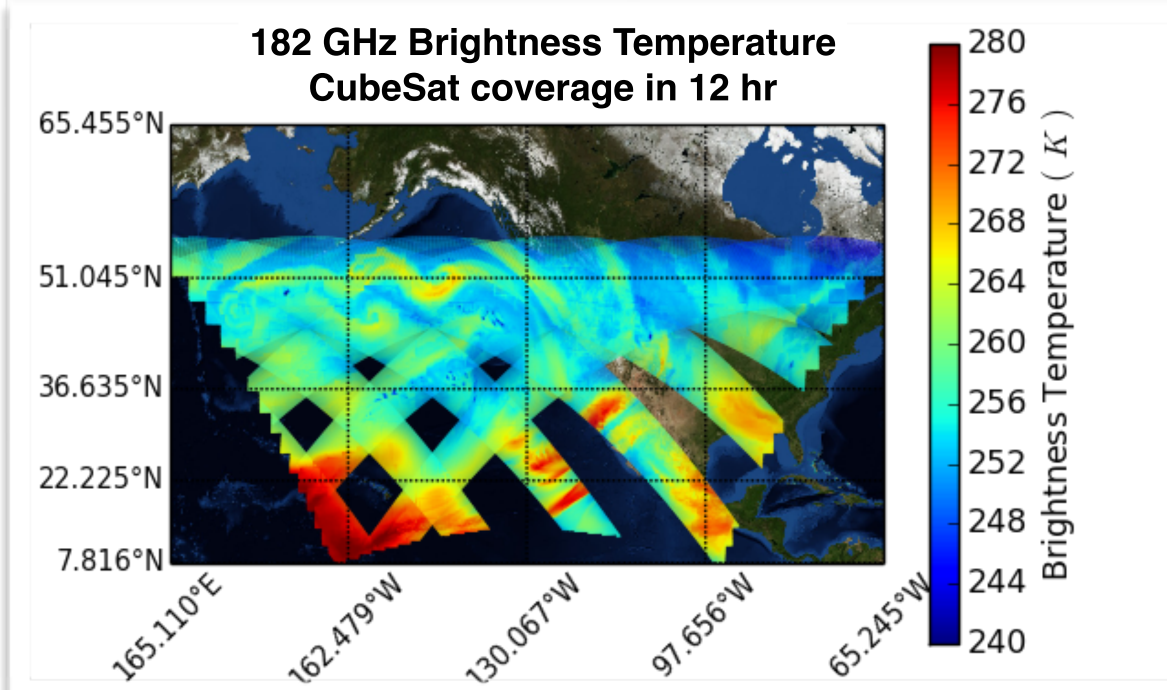
Sample Applications

- **Model evaluation**
  Tropical Cyclone Information System
- **Trade Studies**
  CubeSat and ACE
- **Analysis via IDE (Integrated Development Environment)**
  Collaborative Workbench

[http://**hs3**.jpl.nasa.gov]





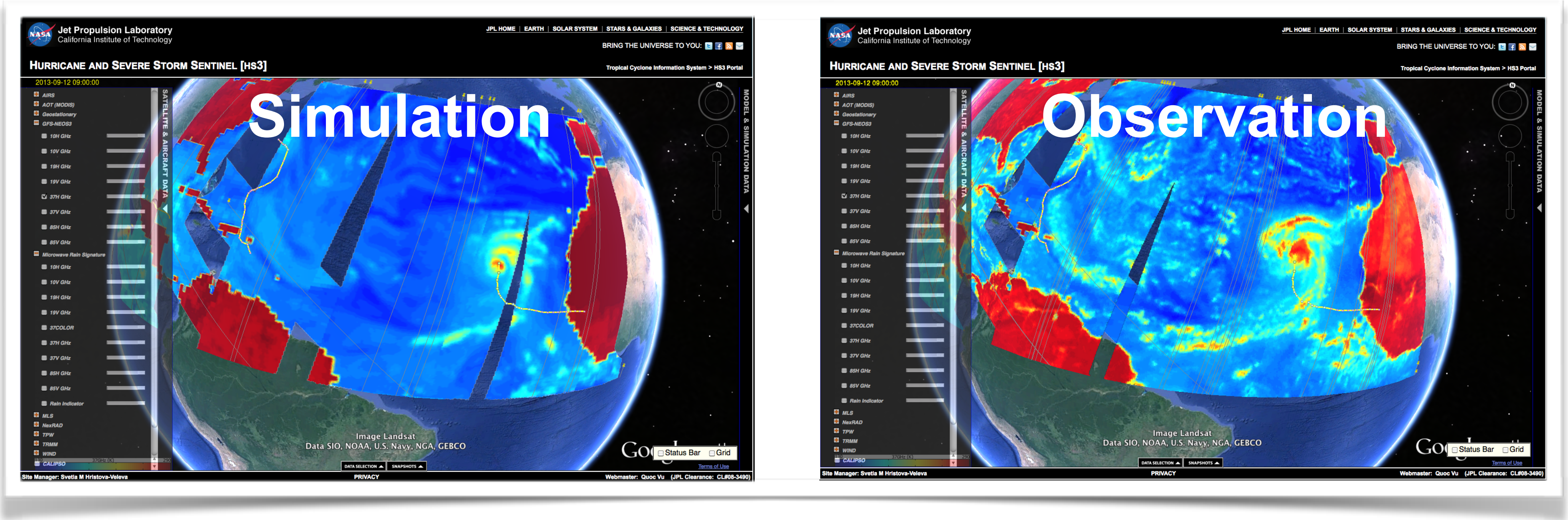


[Courtesy: L. Wu, S. Padmanabhan, and H. Su; JPL

1. Tropical Cyclone Information System (TCIS)

1st Beta User!

- Extensively used by TCIS for simulating brightness temperature observed by multiple instruments: TMI, AMSR2, SSMI, and SSMI/S

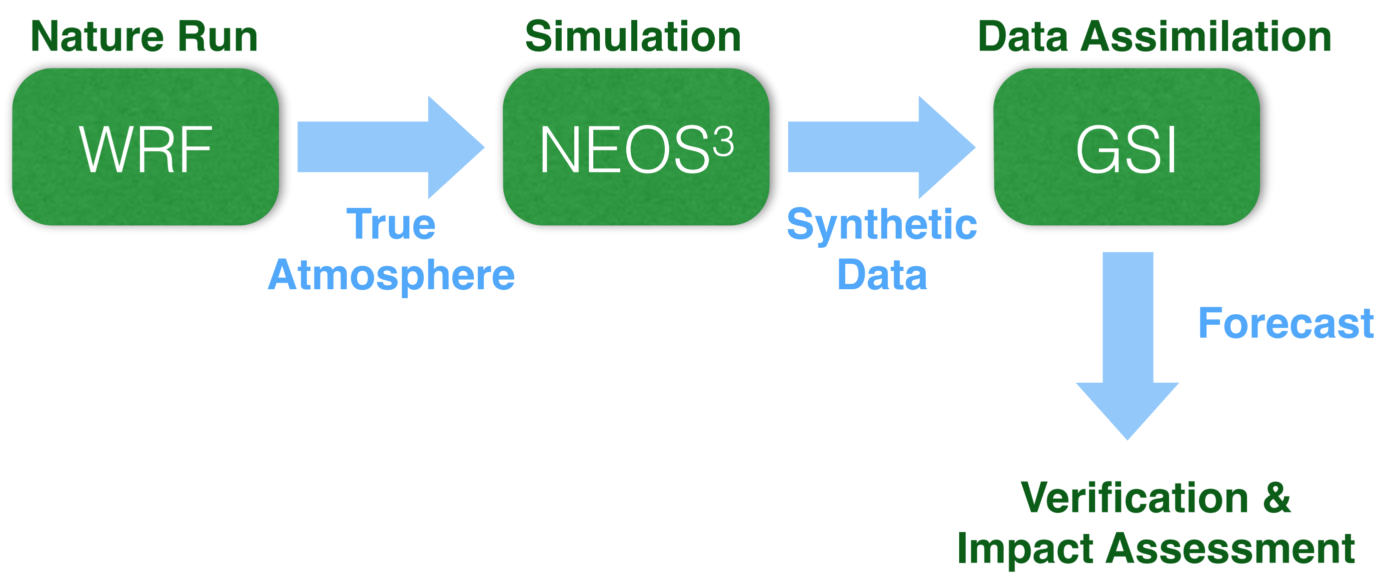


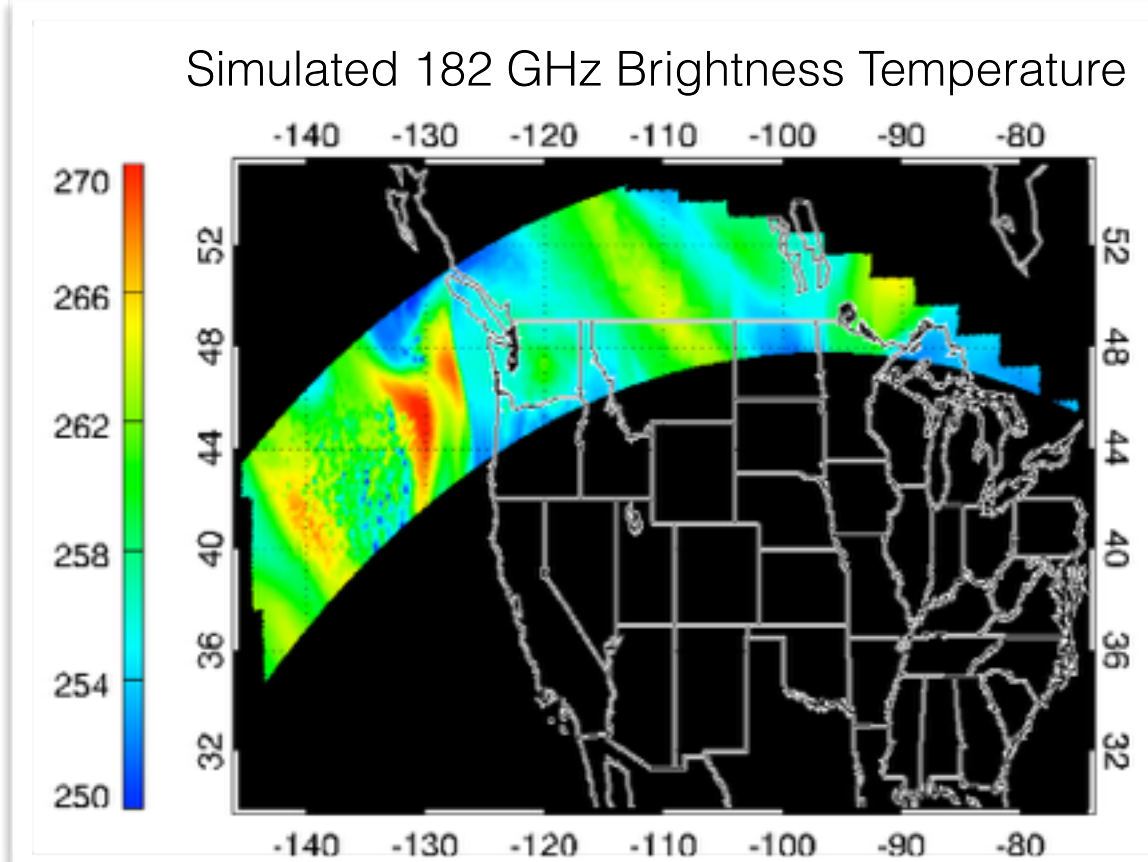
[S. Hristova-Veleva, P. Li, B. Knosp, Q. Vu; JPL]

- Adjust simplifying model assumptions and evaluate its impact (NEOS³ ensures the assumptions are consistent throughout the simulation)
- “Heavy” use of web service capability (manage simulation without web interface)
- Submit a request for simulations (~100s jobs of a few hours each), polling for the status, transfer the output when ready
- Constant demand for NEOS³ to be optimized for speed

2. OSSE for CubeSat

- Evaluate potential impact of CubeSat sounders on extreme weather forecasts
- NEOS^3 serves as a forward simulator producing an “ideal” synthetic observations with and without CubeSat
- Forward simulator in the GSI (Gridpoint Statistical Interpolation) data assimilation system is much cruder, generally uses different and more approximated sets of assumptions)

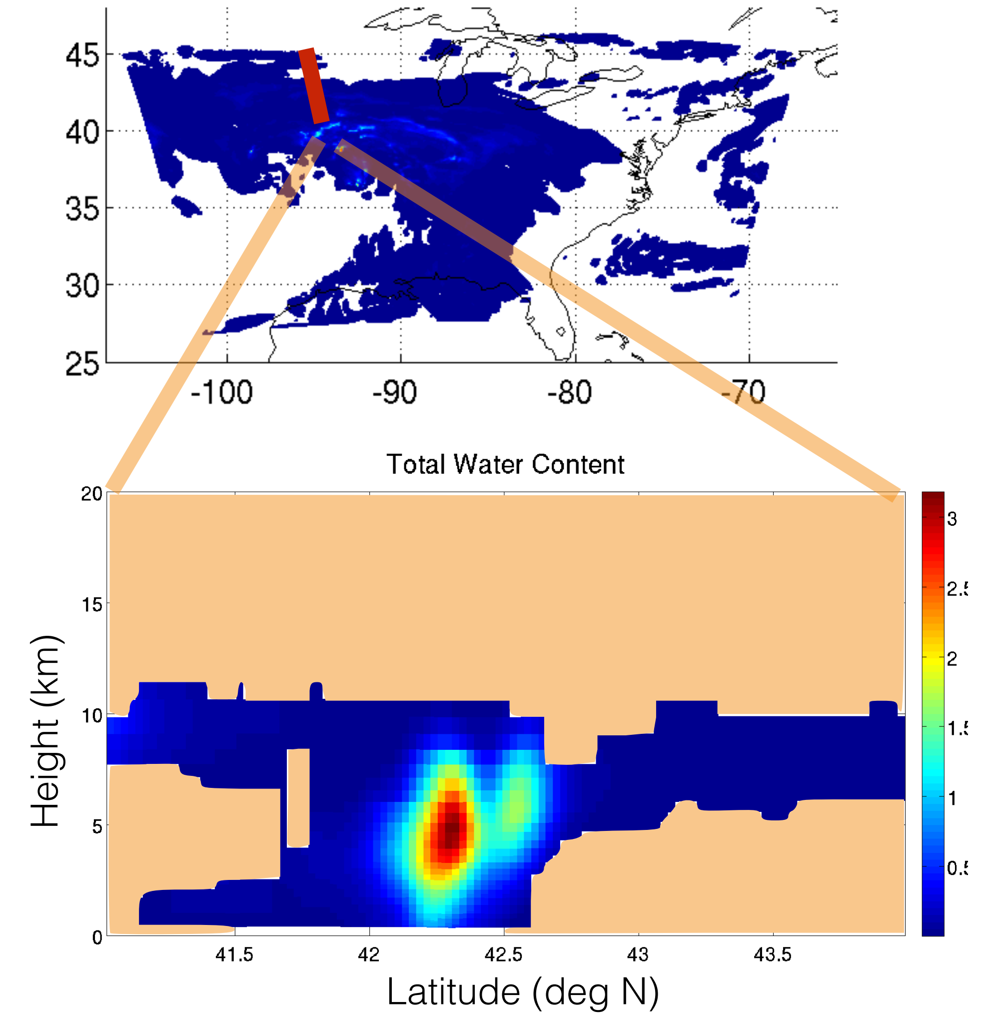


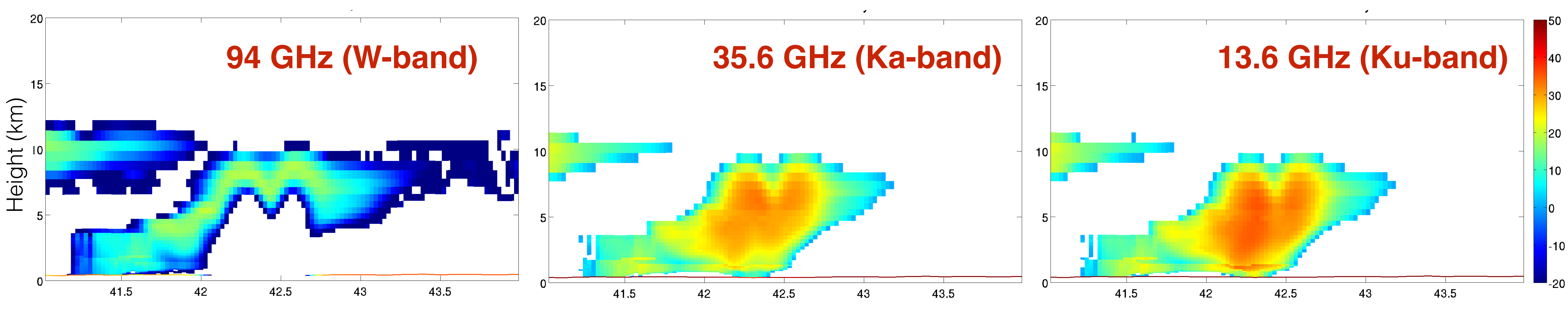


[Courtesy: H. Su, S. Padmanabhan, and L. Wu; JPL]

3. Definition of Requirements for Future Satellite Missions

- Currently used by ACE and CaPPM* definition working groups to define mission requirements
- One example of ongoing trade studies is shown below (courtesy T. L'Ecuyer and E. Nelson, U. of Wisc)
    - What Doppler radar characteristics are sufficient to observe the atmospheric phenomena of interest to the minimum accuracy required to address science questions?
    - How much information is gained by improving these characteristics beyond the sufficient level?
- NEOS[3] provides the necessary and consistent framework to translate model simulations to satellite observations with prescribed instrument configurations
- Synthetic algorithmic retrievals and information content analyses can then be performed to answer our questions.



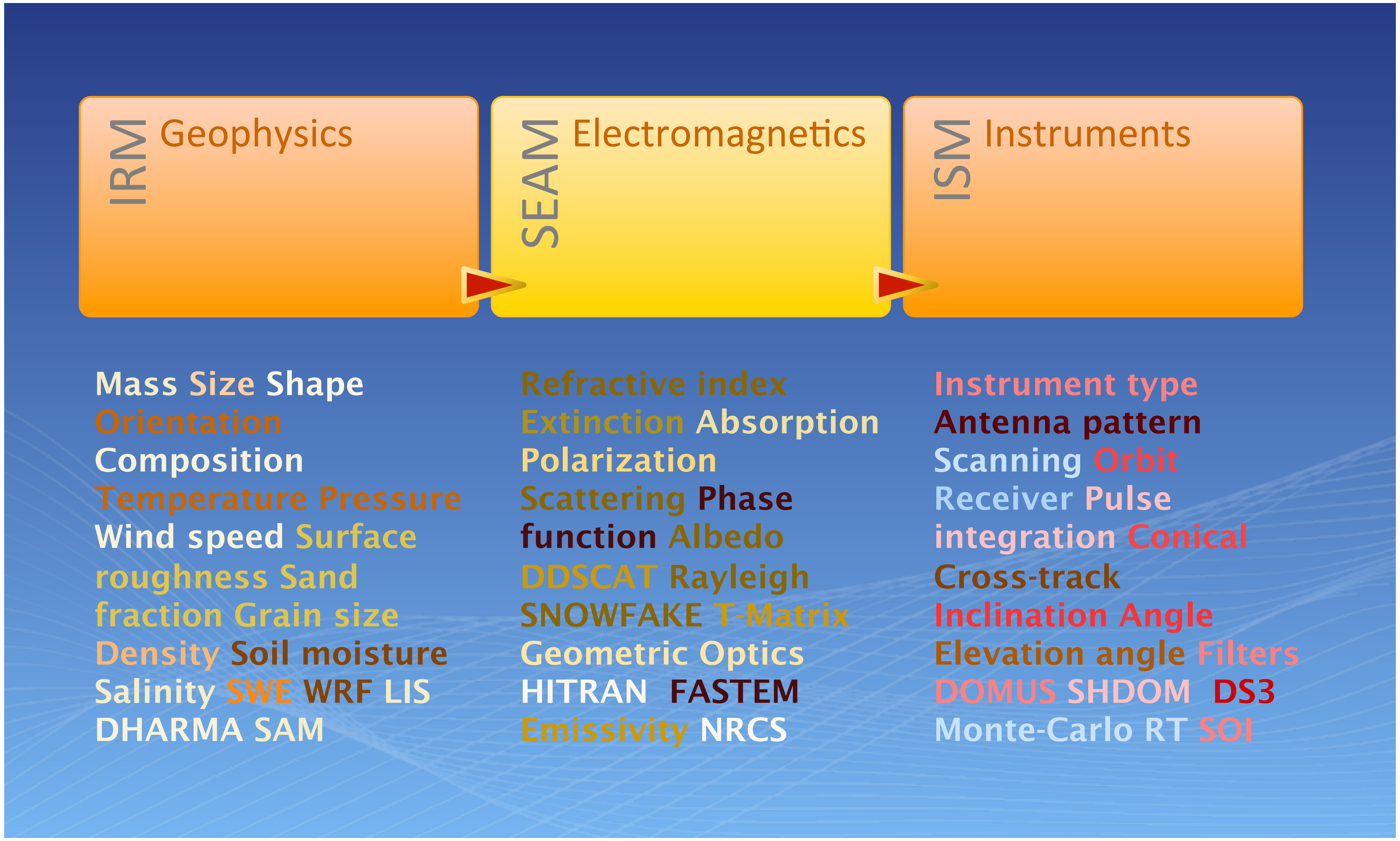


Latitude (deg N)

*Cloud and Precipitation Processes Mission

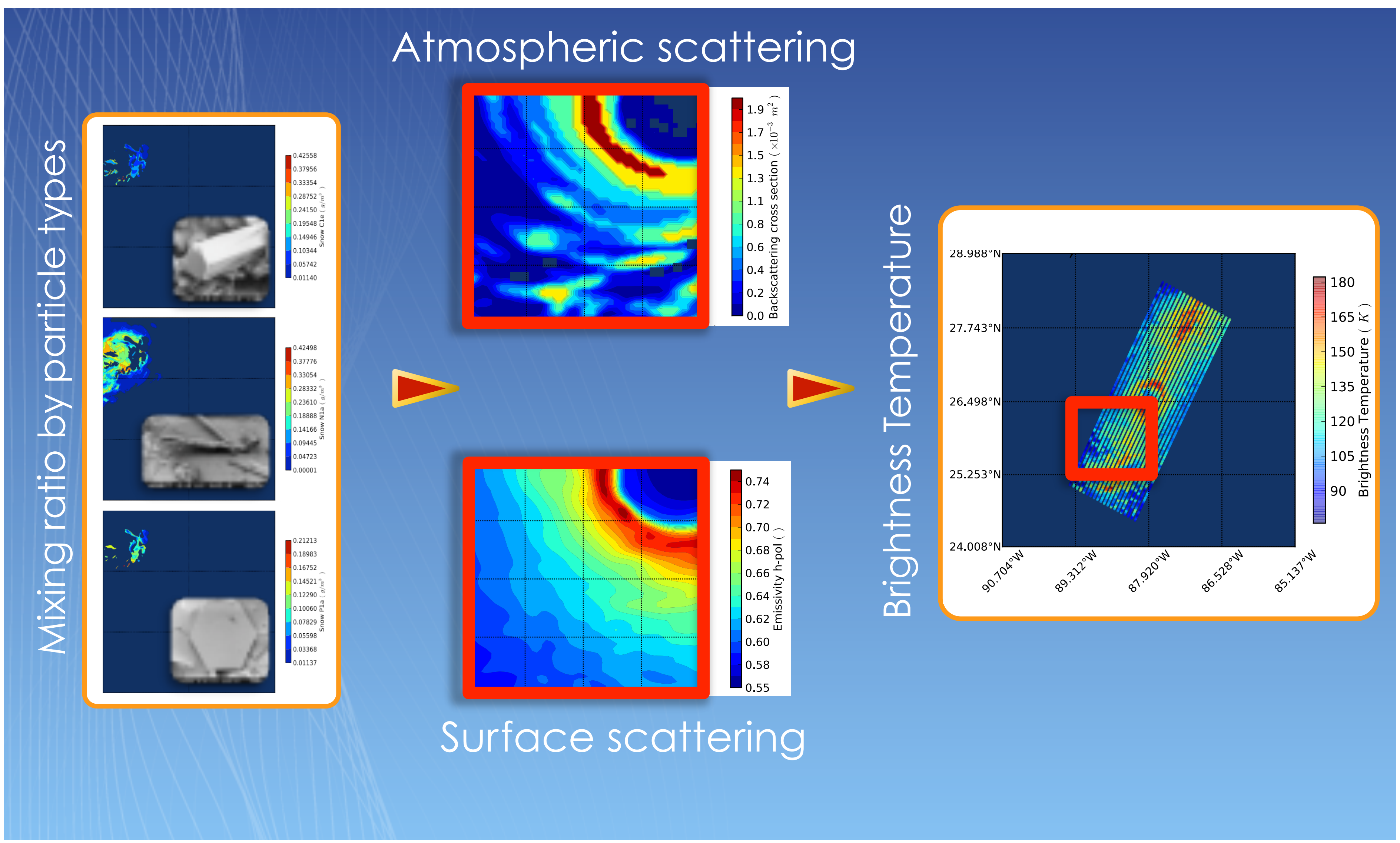
3-Stage Processing

- Simulation is completed in 3 stages
- Parameters are also grouped into 3 categories
- Possible to repeat only later stage(s) of simulation where the parameters have been updated



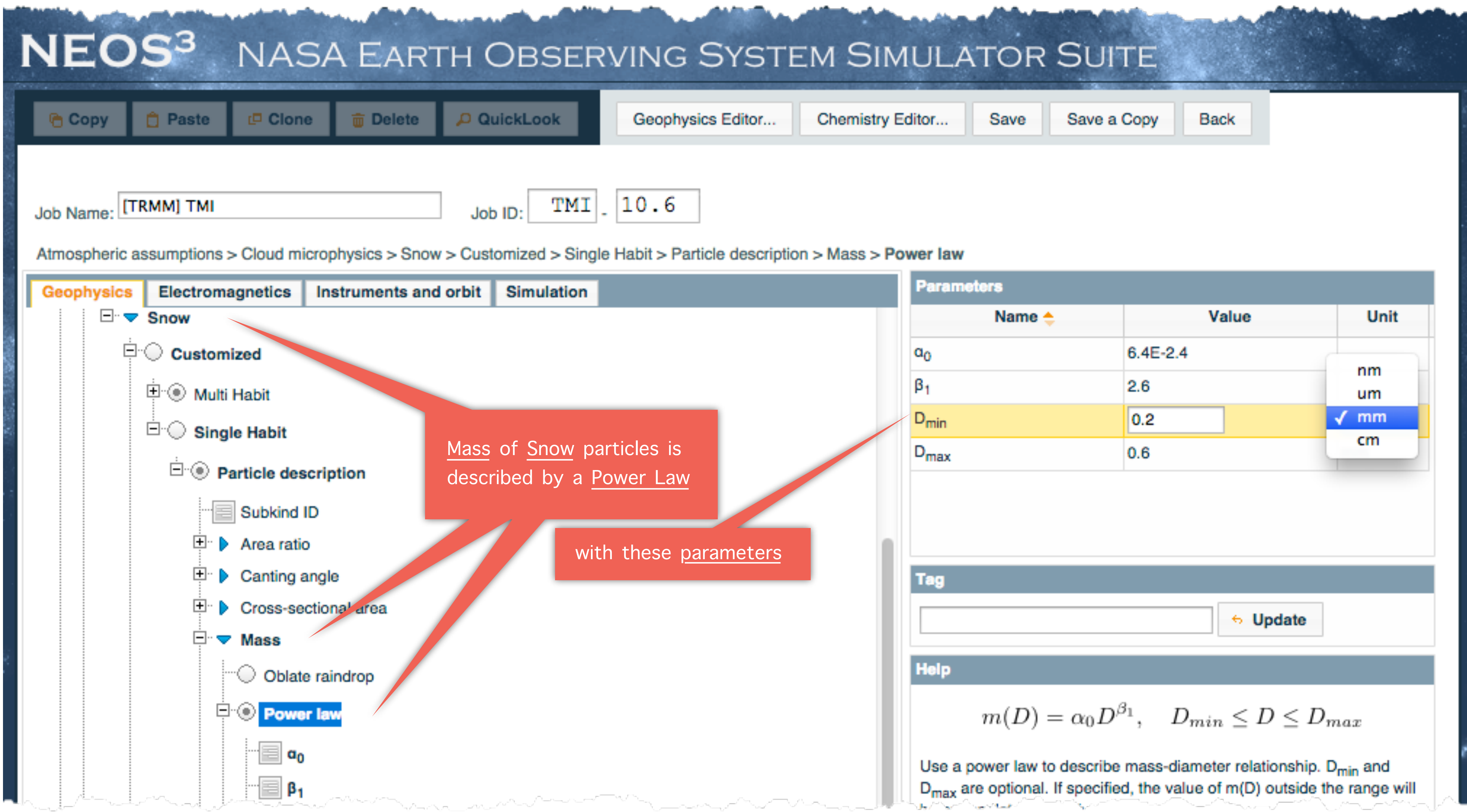
Sample Output of Each Stage

1. **IRM** reads the quantities of each type of particle from the file and splits them into subtypes (shown are 3 different snow crystal shapes)
2. **SEAM** applies scattering models to each grid points in the atmosphere and surface
3. **ISM** then solves the radiative transfer problem and produces the final product



Editing Parameters

- Parameters are organized in a tree structure



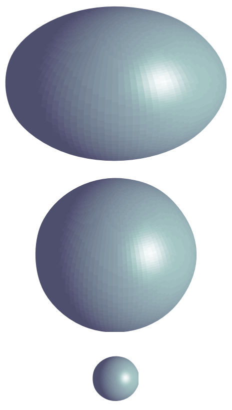
Atmosphere

Particles

- Selectable models (Speed vs. Accuracy)
- Pre-made lookup tables for scattering properties (Speed w/o scarifying accuracy)

Gases

- **MPM** for Microwave
- **HITRAN** for UV/IR:
  w/ clustering algorithm to reduce redundant calls



ISSARS HITRAN Query Filters:

molecule = 2
isotope = 1
4870.0 <= trans_wavenum <= 4880.0
line_intensity >= 1e-26

Matching HITRAN 2008 absorption lines:

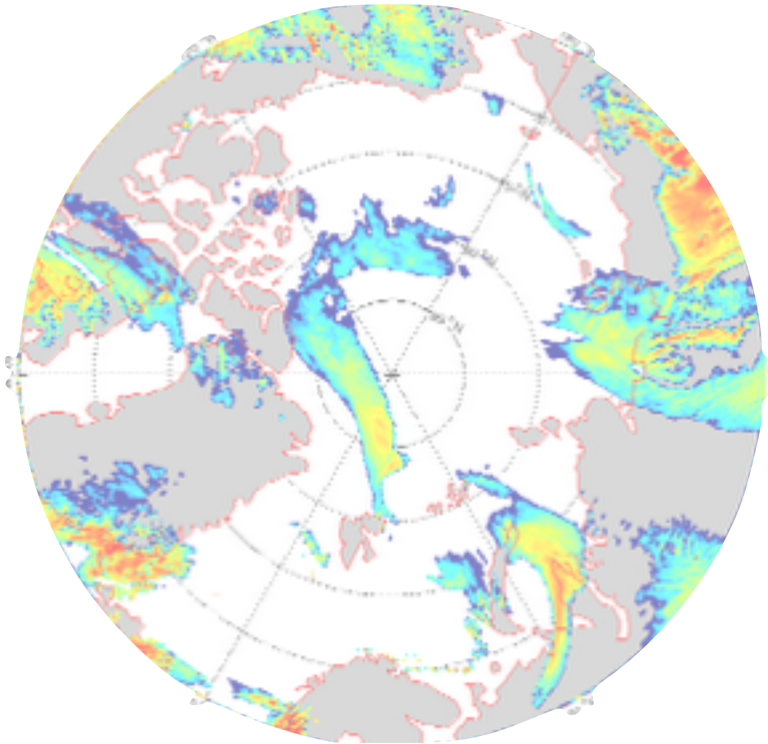
Show 10 entries

Molecule Number	Isotope Number	Transition Wavenumber (cm-1)	Line Intensity	Einstein A-Coefficient	Air-Broadened Width	Self-Broadened Width	Lo St: En
2	1	4870.23	4.623e-26	1.462e-05	0.0727	0.096	19
2	1	4870.44	2.416e-22	0.06993	0.072	0.098	19
2	1	4870.63	1.772e-26	0.1364	0.0696	0.071	24
2	1	4871.35	1.241e-26	0.1381	0.0692	0.069	25
2	1	4871.79	2.214e-22	0.07062	0.071	0.095	23

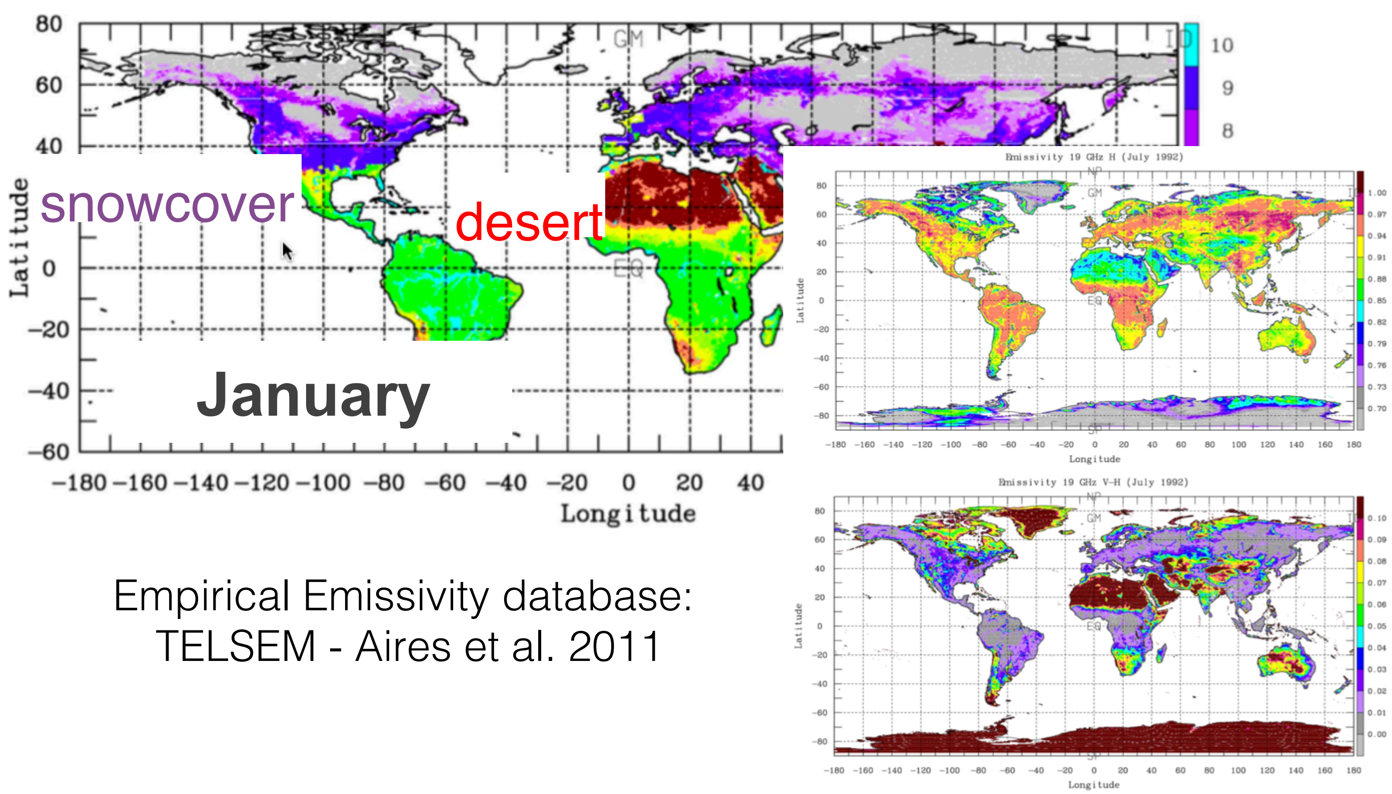
Surface

Surface Properties are imported from

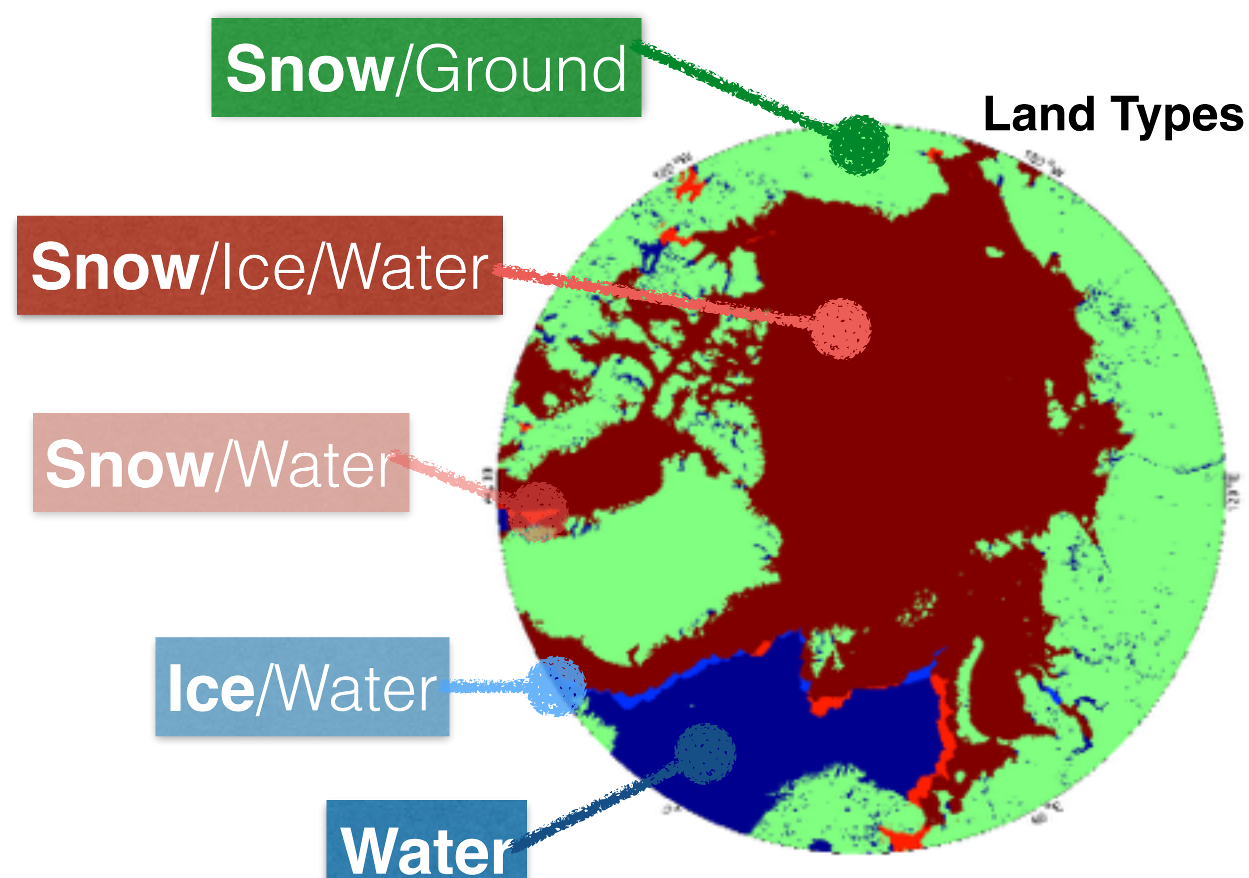
- The atmospheric models themselves
- The Land Information System
- Empirical Databases



Snow water content at 750 mbar altitude



Empirical Emissivity database:
TELSEM - Aires et al. 2011



Radiative Transfer

(Currently integrated models)

Time independent (for passive instruments)

- **SOI**: Successive Order of Interaction
  (A. Heidinger, C. O'Dell, R. Bennartz, and T. Greenwald; U. of Wisconsin)
- **SHDOM**: Spherical Harmonic Discrete Ordinate Method
  (R. Pincus and K. F. Evans; NOAA/ U. of Colorado)
- **SOS**: Successive Order of Scattering
  (Pengwang Zhai; NASA Langley)
- **MC3D**: Monte Carlo 3D Radiative Transfer
  (A. Battaglia, U. of Leicester)

Time dependent (for active instruments)

- **DS3**: Doppler Simulator 3D (S. Tanelli, et al.; JPL)
- **DOMUS2**: Monte Carlo Polarimetric Doppler Radar Simulator
  (A. Battaglia, U. of Leicester, and S. Tanelli, JPL)
- **Quick1D**: 1D single-scattering non-doppler model (similar to Quickbeam and SDSU radar and lidar)

Observer Placement

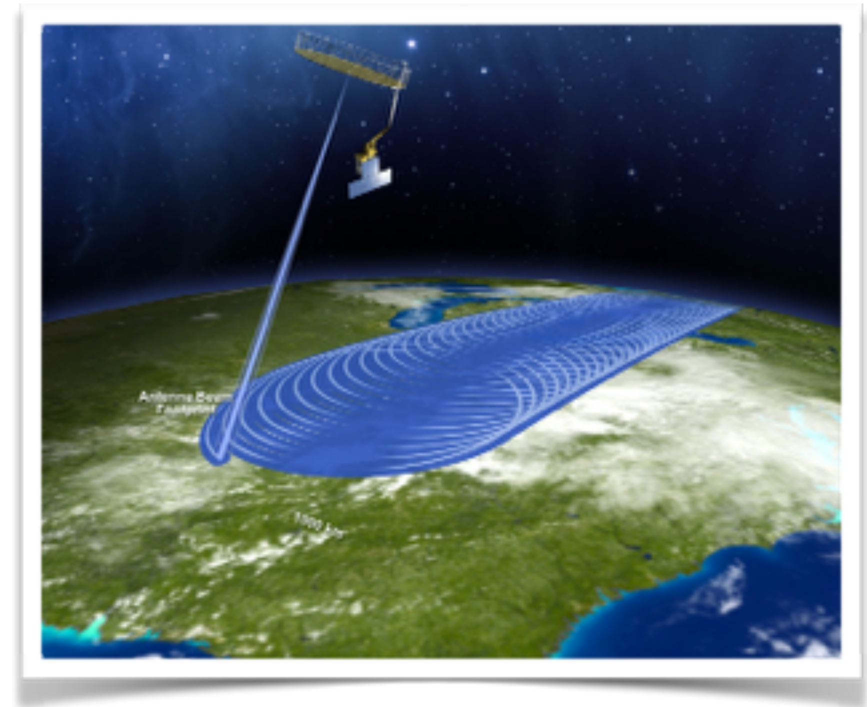
Orbit simulator

(Current method)

- Specify 5 Keplerian elements and position of the satellite at 0-sec simulation time
- Specify start and stop simulation time

(To be added)

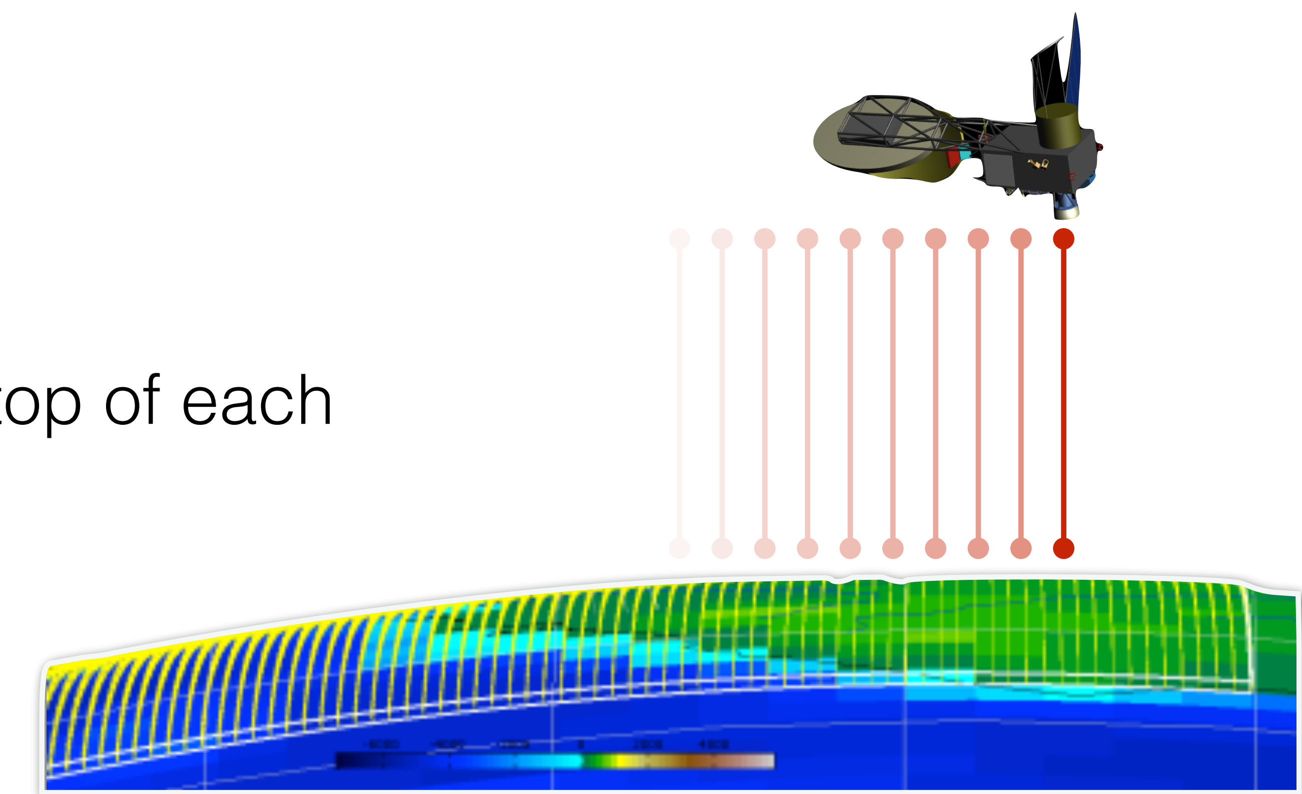
- Two-Line Element (TLE) and STK (Systems/Satellite ToolKit)



Domain sampling (current method)

(Current method)

- Place observing instrument at the top of each column of the atmosphere
- Simulate the observation at nadir, ignoring antenna's beam and pointing parameters
- Specifically added to satisfy custom requests

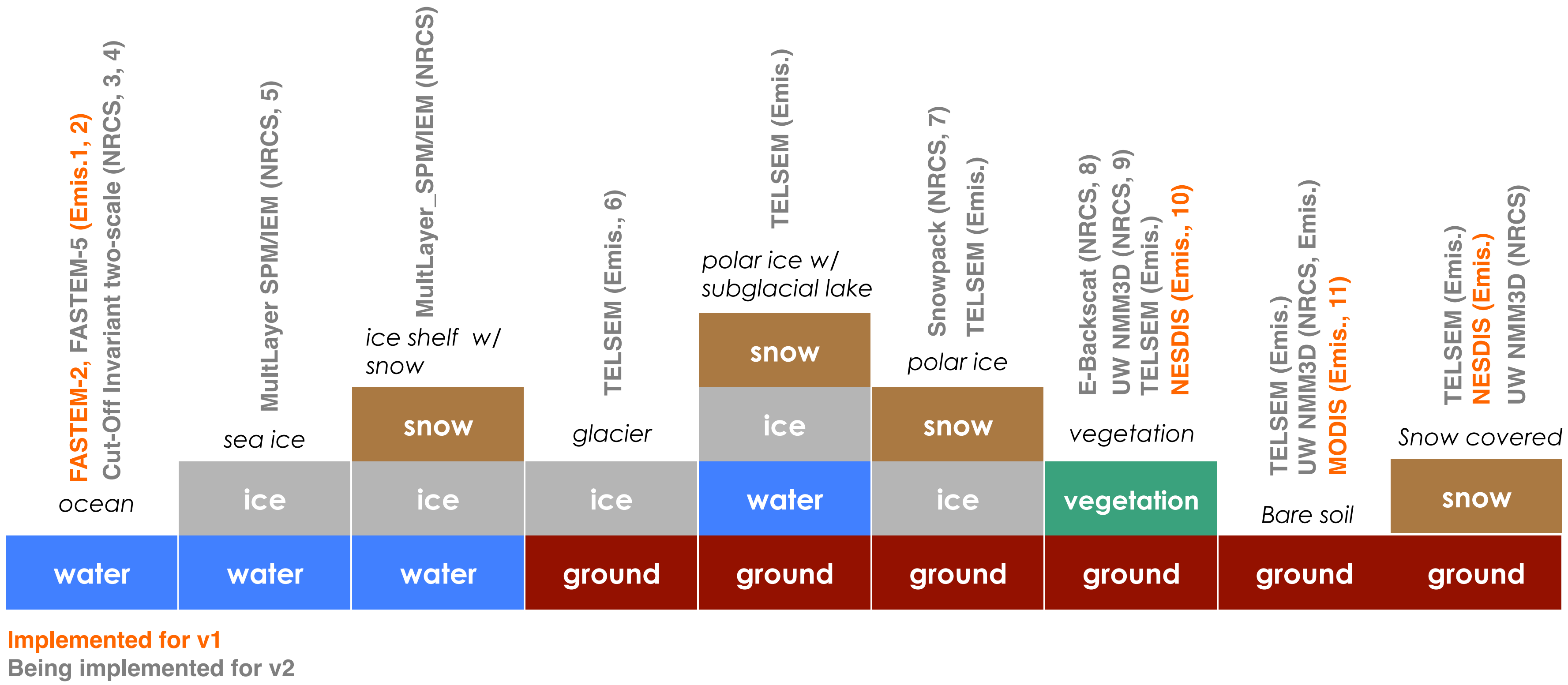


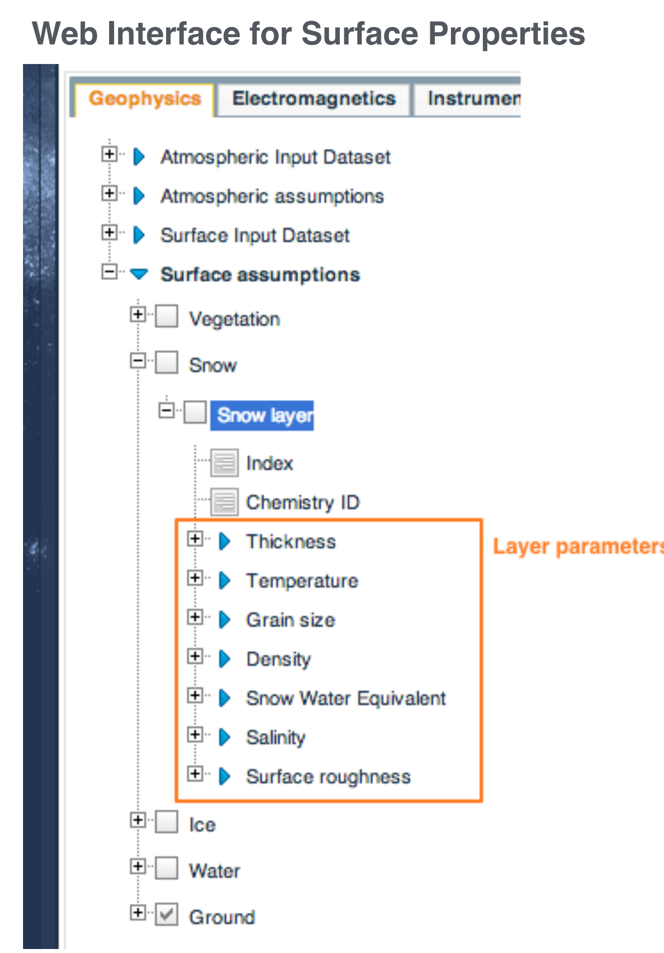
NEOS^3 2.0 (ETA 2015)

- Main areas of improvement
  - Surface Scattering Models ↔ **Physics**
  - Web service/ OSSE Interface ↔ **Analysis**
  - Cloud Computing ↔ **Performance**

New Surface Scattering Models

- **Version 1.0**: Earth's surface has no sub layer
- **Version 2.0**: Layered surface can be specified.
  Scattering Models that can support layered surface have been integrated





(1) English, S., and T. Hewison, 1998: A fast generic millimeter-wave emissivity model, Proceedings of SPIE, 3503, 288-300.
(2) Liu, Q., F. Weng, and S. English, 2011: An improved fast microwave water emissivity model. IEEE TGRS, 49, 1238-1250.
(3) Majurec, N. ; Johnson, J.T. ; Tanelli, S. ; Durden, S.L., (2014) Comparison of Model Predictions With Measurements of Ku- and Ka-Band Near-Nadir Normalized Radar Cross Sections of the Sea Surface From the Genesis and Rapid Intensification Processes Experiment, IEEE TGRS, Volume: 52 , Issue: 9, Page(s): 5320 – 5332
(4) Majurec, N., Johnson, J. T., Tanelli, S., & Durden, S. (2012). Near-nadiral normalized radar cross section of the SEA surface at Ku, Ka, and W-Bands: comparison of measurements and models. (http://trs-new.jpl.nasa.gov/dspace/handle/2014/42527).
(5) Sermsak Jaruwatanadilok; JPL
(6) Aires, F., Prigent, C., Bernardo, F., Jiménez, C., Saunders, R. and Brunel, P. (2011), A Tool to Estimate Land-Surface Emissivities at Microwave frequencies (TELSEM) for use in numerical weather prediction. Q.J.R. Meteorol. Soc., 137: 690–699. doi: 10.1002/qj.803
(7) Shadi Oveisgharan; JPL
(8) Marc Simard; JPL
(9) L. Tsang, W. Chang, T.-H. Liao; University of Washington
(10) Weng, F, B. Yan, and N.C. Grody, 2001: A microwave land emissivity model. J. Geophys. Res., D17, 20115-20123.
(11) MODIS derived emissivity model

Some Selected Surface Models

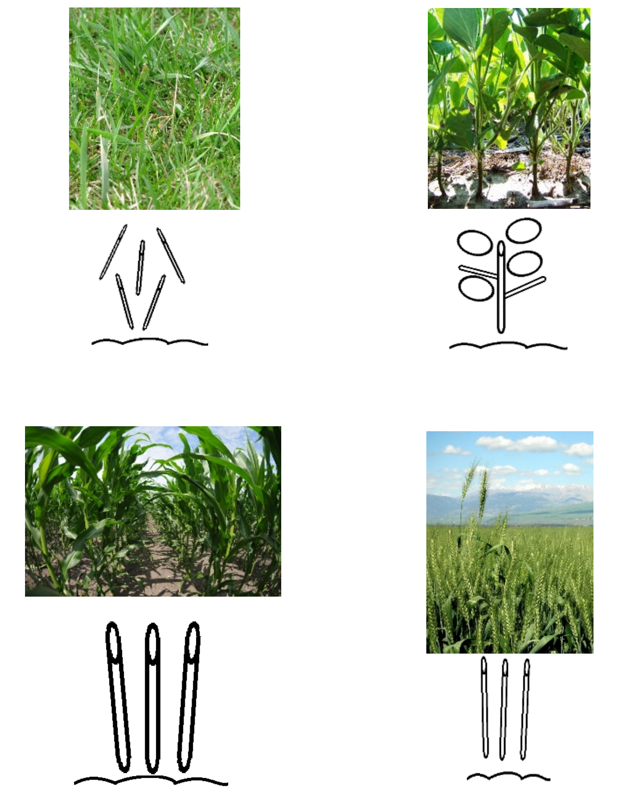
U. of Washington Vegetation Model

- Modeled as cylinders for different types of vegetation
- Numerical Maxwell Equation Model (NMM3D)
- SMAP, AMSR-E, GPM, GCOM-W satellites

U. of Washington Snow Model

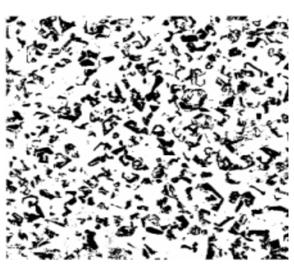
- GCOM-W, TRMM, SnowSAR (ESA aircraft), SCLP, GPM
- Validated with SnowScat measurement

Grassland Soy bean

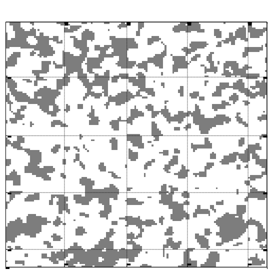


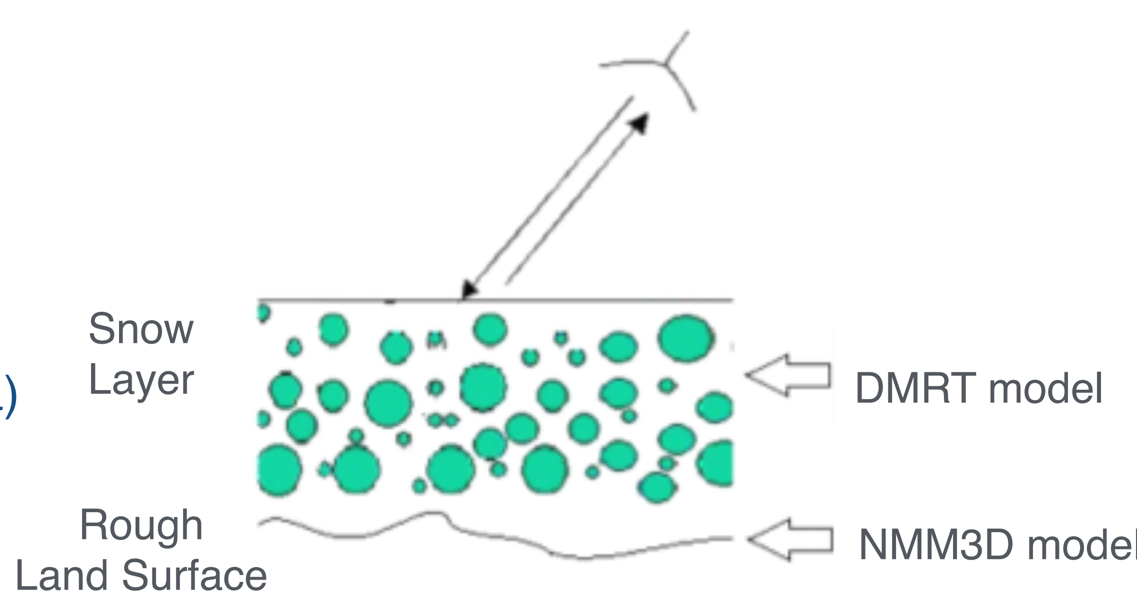
Corn Wheat

Real Snow

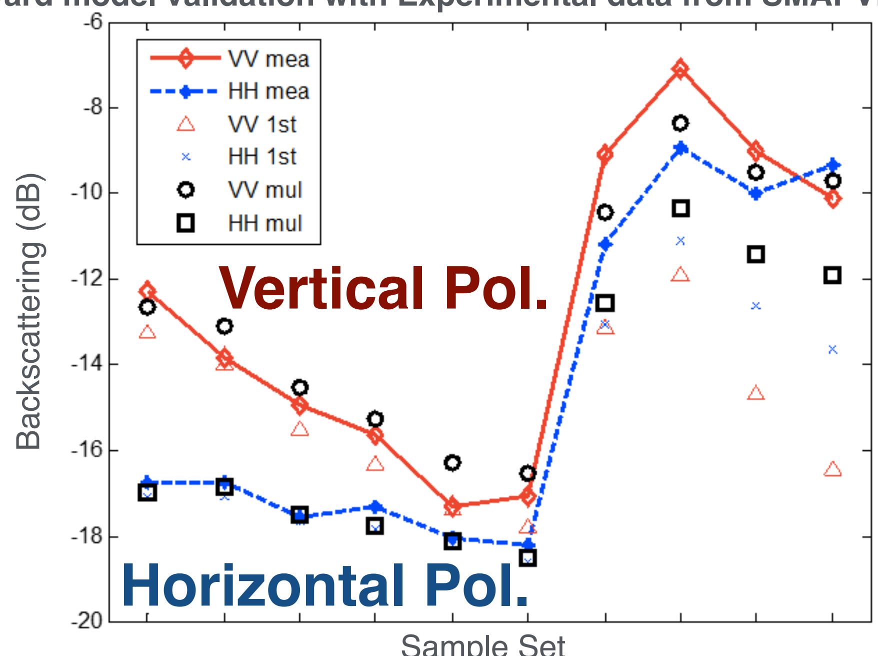


Model
(Bi-continuous media)





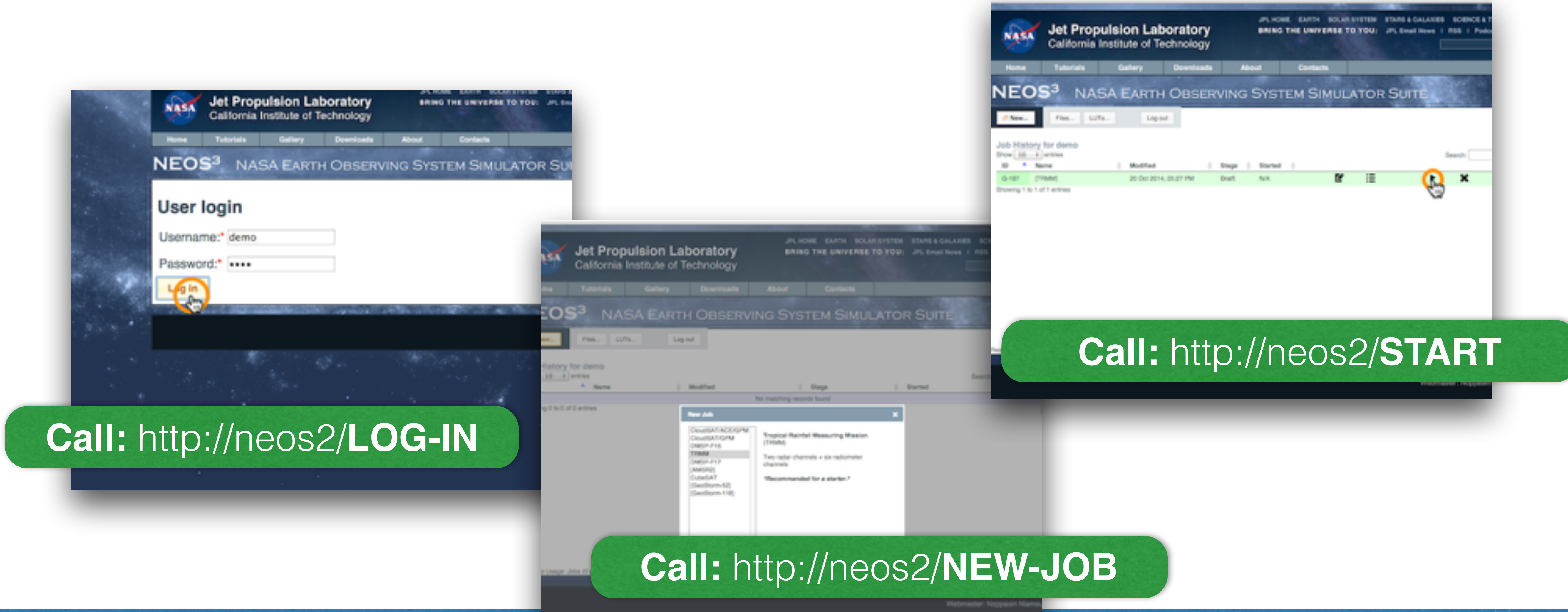
Forward model validation with Experimental data from SMAPVEX12



[Leung Tsang, Tien-Hao Liao; U. of Washington]

Web Service

- Simulation process can also be controlled via web service calls
- Especially useful for repeating simulation while varying certain sets of parameters:
  - Running simulation for comparison with actual observations
  - OSSE: perturb a parameter over a range of interest and observe the impact



Updating Simulation Parameters via Web Service

- **Version 1.0**: Update a complete set of simulation configuration

```
…
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      <_tag>KuPR</_tag>
        <_selected/>
        <frequency description=“Frequency" units=“MHz,GHz,nm,um”>
                <_decimal>13.8</_decimal>
                <_unit>GHz</_unit>
        </frequency>
        …
</channel>
…
```

21,335 lines

NEOS^3 Job

- **Version 2.0**:
  - Only send updated values
  - Recognize a list input and automatically generate multiple jobs
  - Reuse intermediate outputs from similar jobs

```
<task>
      <FREQUENCY> 13.8 : 0.1 : 14.0 </FREQUENCY>
      <BEAMWIDTH> 0.45 : 0.1 : 0.55 </BEAMWIDTH>
</task>
```

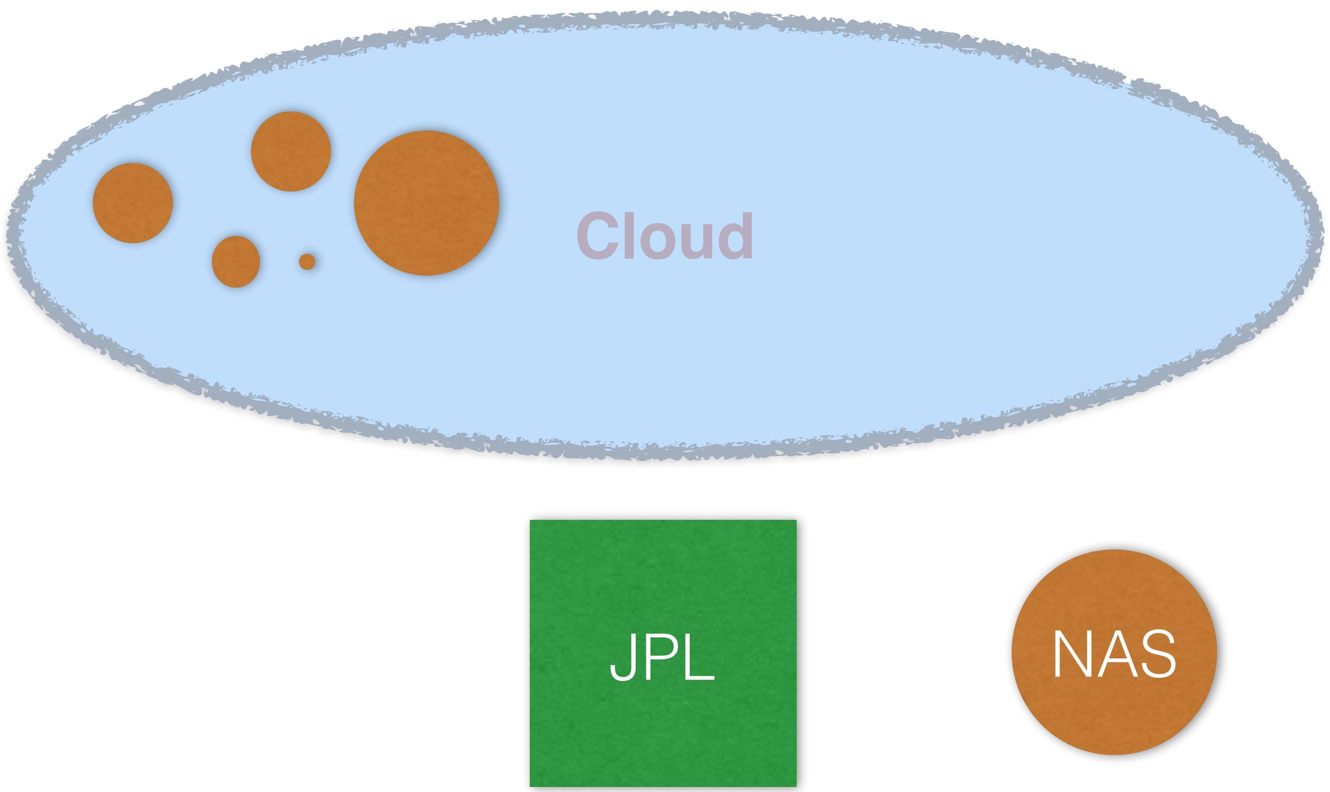
NEOS^3 Job

Processing Options

- **Local**
  neos3.jpl.nasa.gov, 16 CPUs, 128GB memory

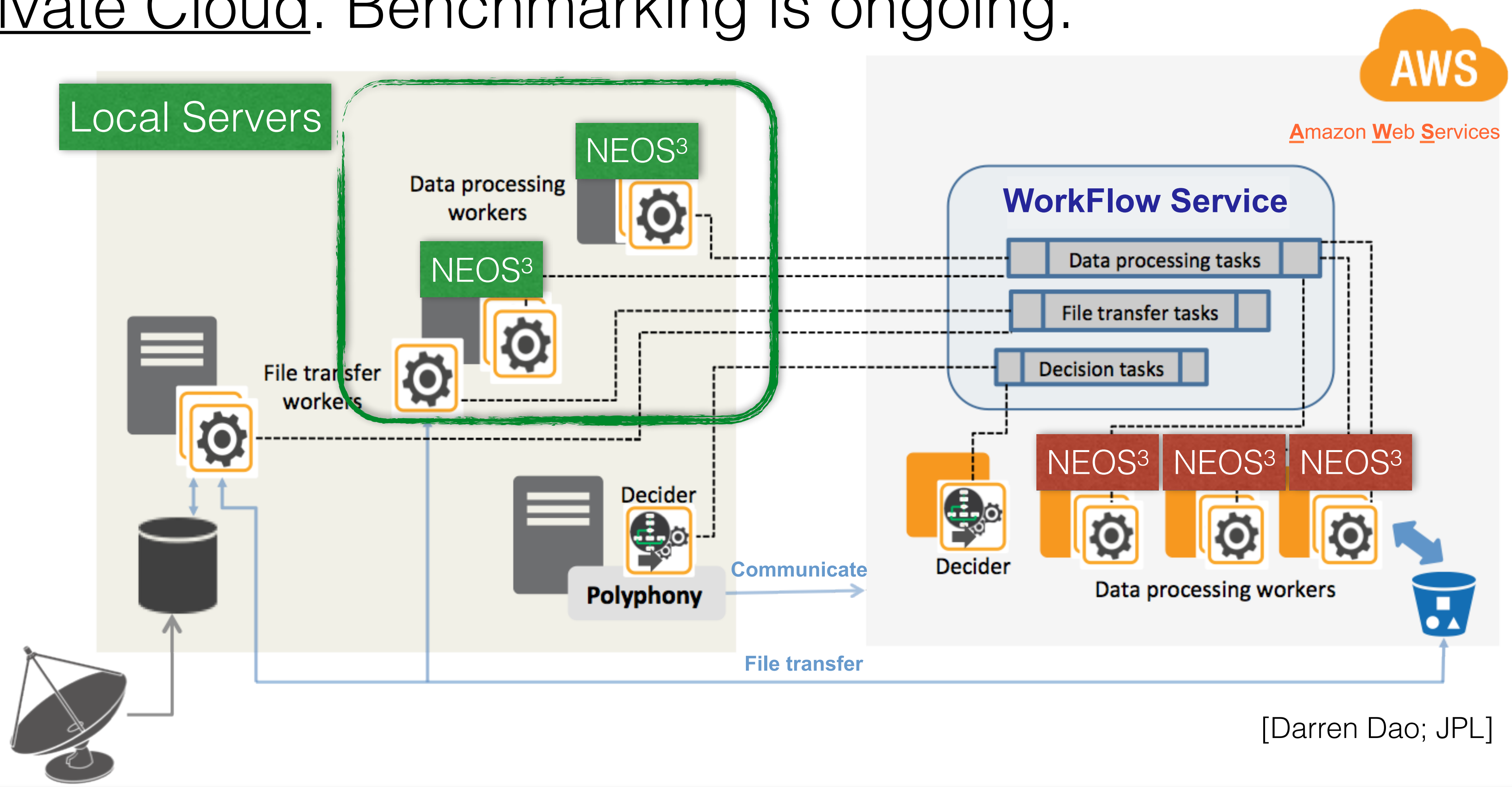
- **Remote**
  NASA's Advanced Supercomputing (NAS) Division

- **Cloud**
  New in Version 2.0 !



Cloud Computing

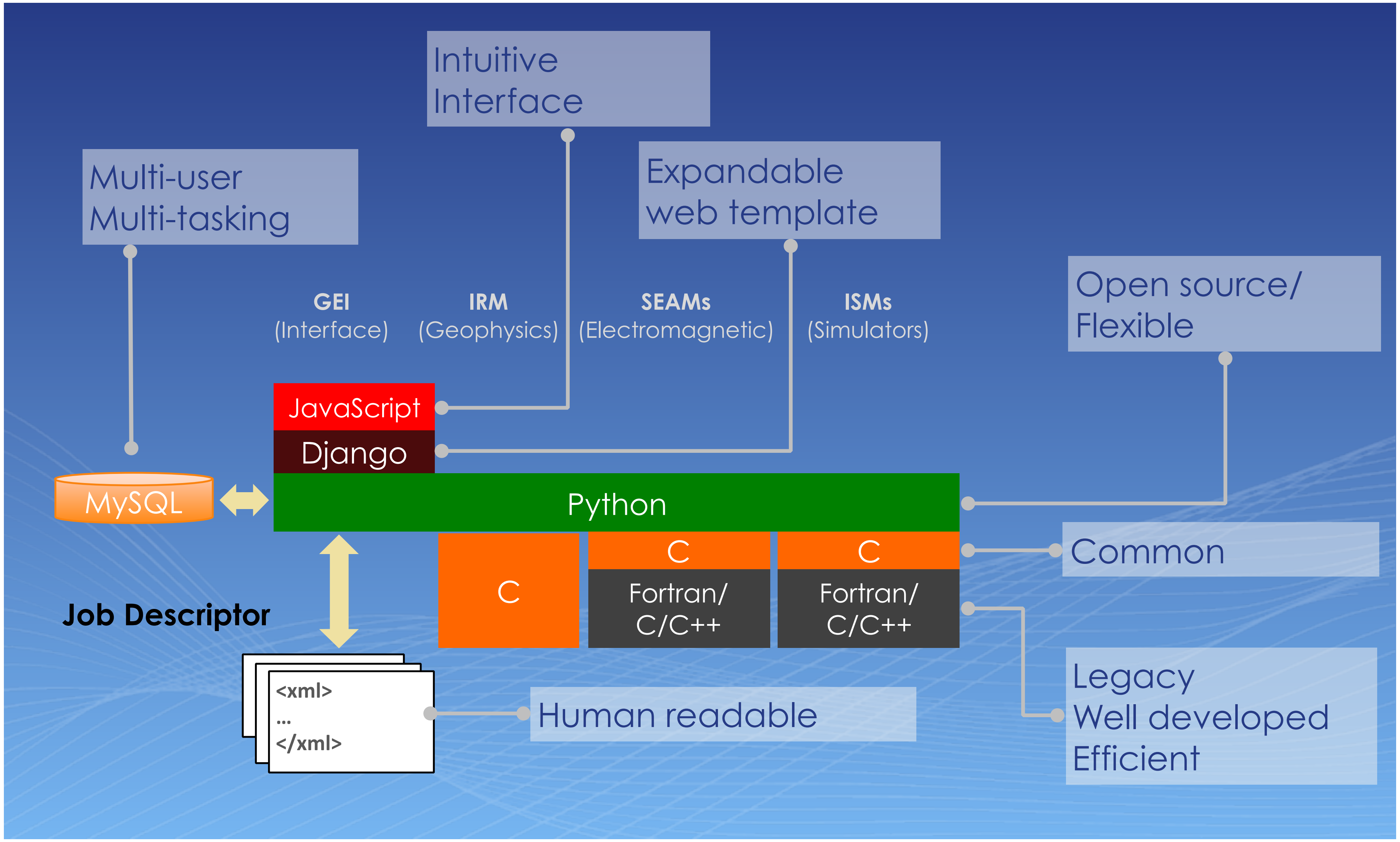
- Automatically adapt to workload changes
- Implemented JPL Polyphony, a resilient, scalable, and modular workflow orchestration framework for Cloud Computing
- Private Cloud. Benchmarking is ongoing.



[Darren Dao; JPL]

Architecture

- **NEOS³ developer**: Adaptable to future technology changes. Thanks to modularity of the design and the software frameworks
- **Contributors**: minimal change is required. No code restructuring needed (w/ some exceptions)

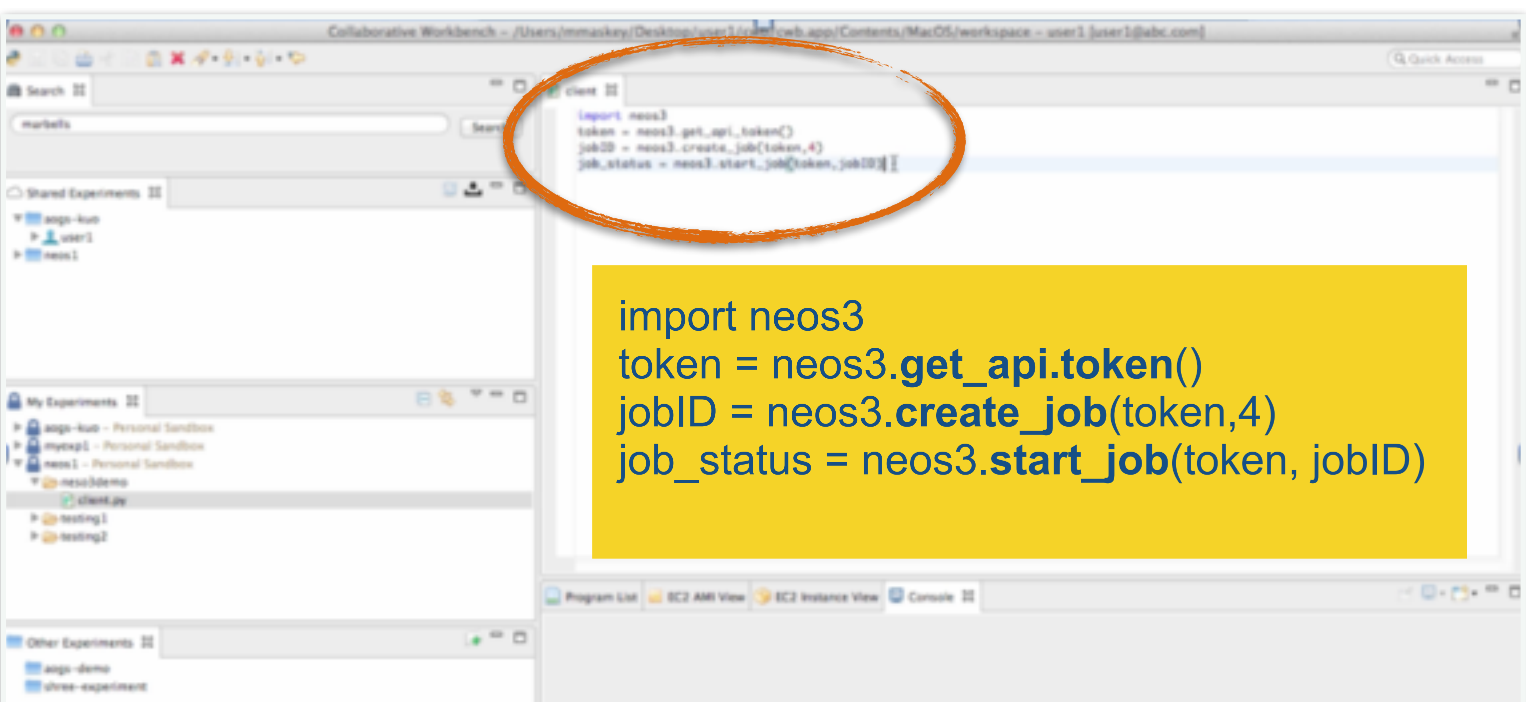


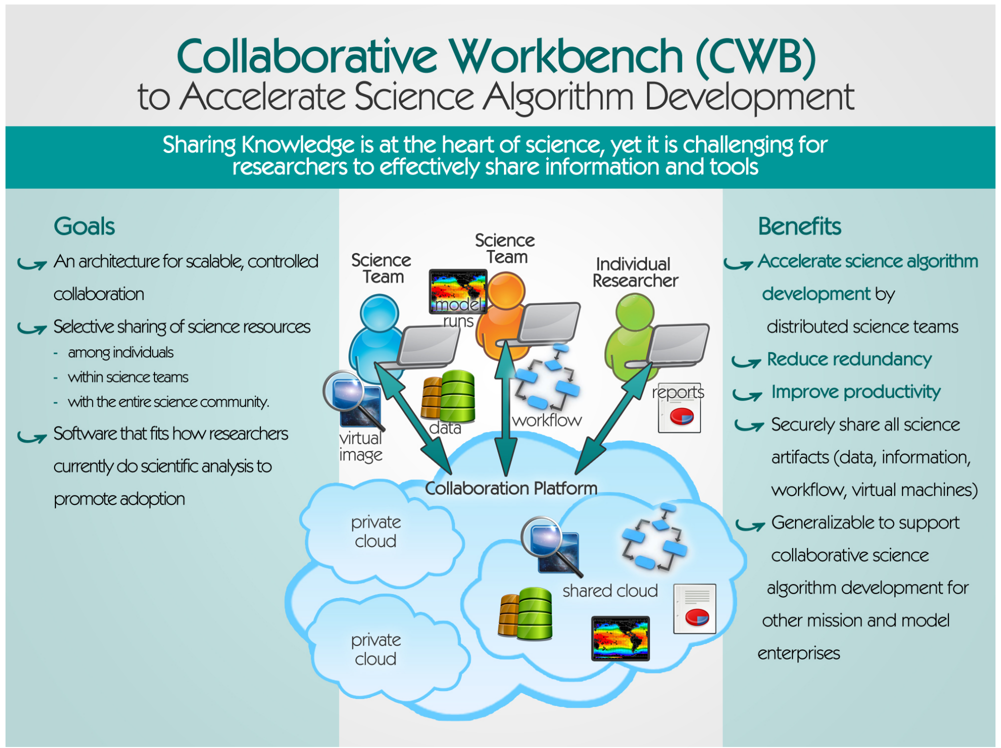
Collaboration

- **Request** for NEOS[3] account or suggestion: Noppasin.Niamsuwan@jpl.nasa.gov
- **Contributing** a model
  - Source code is revision controlled (git) and hosted by our server
  - Minimal change is required: interface compliance, unit tests
  - Alternative: Contribute a lookup table for more complex algorithm
  - The approach has been successfully demonstrated for internal (JPL) and external (university partner) code contributors.

Collaborative Workbench (CWB)

- CWB (R. Ramachandran[1], M. Maskey[2], C. Lynnes[3], K.-S. Kuo[3,4]) is a framework for facilitating science algorithm development
- Eclipse based IDE (Integrated Development Environment)
- NEOS^3 contributed to CWB development by serving as a practical example of an external tool integrated in CWB via web services (i.e. users run NEOS^3 from Eclipse editor)
- CWB will facilitate user access, further development, and expansion of NEOS^3





[1]NASA Marshall Space Flight Center, [2]University of Alabama-Huntsville, [3]NASA Goddard Space Flight Center, [4]Bayesics, LLC

Summary

- NEOS³ was developed to fulfill the need of generalized observing system simulators
  - Web-based and web-service enabled
  - State-of-the-art models
  - Modular and extensible infrastructure
  - Local and remote (including Cloud) processing options
- Possible applications include model evaluation, trade studies
- Collaboration is encouraged: Use it or help us improving it