A Scalable, Flexible Instrument Simulation (OSSE) Toolkit for Mission Design

PI: Brian D. Wilson (398M)

Co-I's: Derek Posselt (329E), Rachel Storer (329), Ethan Nelson (329E), Noppasin Niamsuwan (334), and Benyang Tang (398)

Program: Topic

Project Objective:

Observing System Simulation Experiments (OSSE's) are used to design mission & instrument constellations and evaluate the science return by simulating the instrument "looks" and retrievals. Candidate measurement configurations may span a large trade-space (set of parameters), including: # of spacecraft, orbits, instrument type and sensitivity, instrument scans/footprints, retrieved variables, retrieval fidelity, observation repeat times, overlaps with complementary platforms, etc. **We propose to develop a fast-turnaround, scalable OSSE Toolkit that can support both "quick look" instrument simulation at lower fidelity, as well as full-scale, high-fidelity simulations using state-of-the-art simulators and radiative transfer codes, by integrating capabilities as pluggable modules. The toolkit will automate the entire mission simulation workflow and scale to large analyses by parallelizing most operations, including the search of the parameter space by an ensemble of runs and simulating each radar "look", using cluster computing and GPU computing.**

Objective 1. Assemble and parallelize (PySpark) a simple OSSE Pipeline using QuickBeam low-fidelity and NEOS3 high-fidelity radar simulators.

Objective 2. Conduct a set of test OSSE experiments using the parallel OSSE Pipeline and an existing suite of numerical simulations of deep convection.

FY18/19 Results:

The accomplishments / milestones included:

- Interfaced outputs from ensemble of 75 RAMS model runs.
- Integrated latest version of QuickBeam radar simulator, with Python binding.
- Authored first Spark Map codes to execute a set of forward model runs on the compute cluster.
- Educated science team in the use of PySpark Map-Reduce computing.
- Performed parallel forward model runs: QuickBeam low-fidelity simulator on RAMS nature runs.
- Developed Python thin client to call NEOS3 full-fidelity radar simulator running in a Docker container.
- Integrated Hogan and Battaglia medium-fidelity radar simulator (extra credit)
- Performed parallel analysis runs for simulated reflectivity and attenuation (see Figure 2).
- Infusion: Submitted an expanded proposal to the NASA ROSES AIST 2018 call (see Figure 1).

Parallel Workflow: **Figure 2** below depicts the OSSE workflow for the analysis of a parameterized ensemble: first, many forward model executions are run in parallel (the Map), and then metrics are aggregated comparing the ensemble members (the Reduce step). There is a lot of independent, parallel work available by segmenting over time (each instrument "look") and the ensemble of parallel runs needed to search and characterize the mission parameter space to evaluate tradeoffs. The Toolkit is being exercised on two high-importance mission simulations that are currently of interest: the 2017 Earth Science Decadal Survey directed Clouds, Convection, and Precipitation (CCP) mission, and a constellation of small radars designed to measure convective storm dynamics.

Analysis Results: **Figure 3** below depicts a sample analysis in which QuickBeam was used to compute simulated reflectivity measurements from the RAMS atmosphere. The hail mass-diameter relationship assumed for the forward model was varied to gather statistics about the uncertainty of the resulting reflectivity measurement. A calculation of path integrated attenuation (PIA) was used as a stand-in for a simple geophysical variable retrieval. Results demonstrate the sensitivity of PIA to the choice of hail parameter.

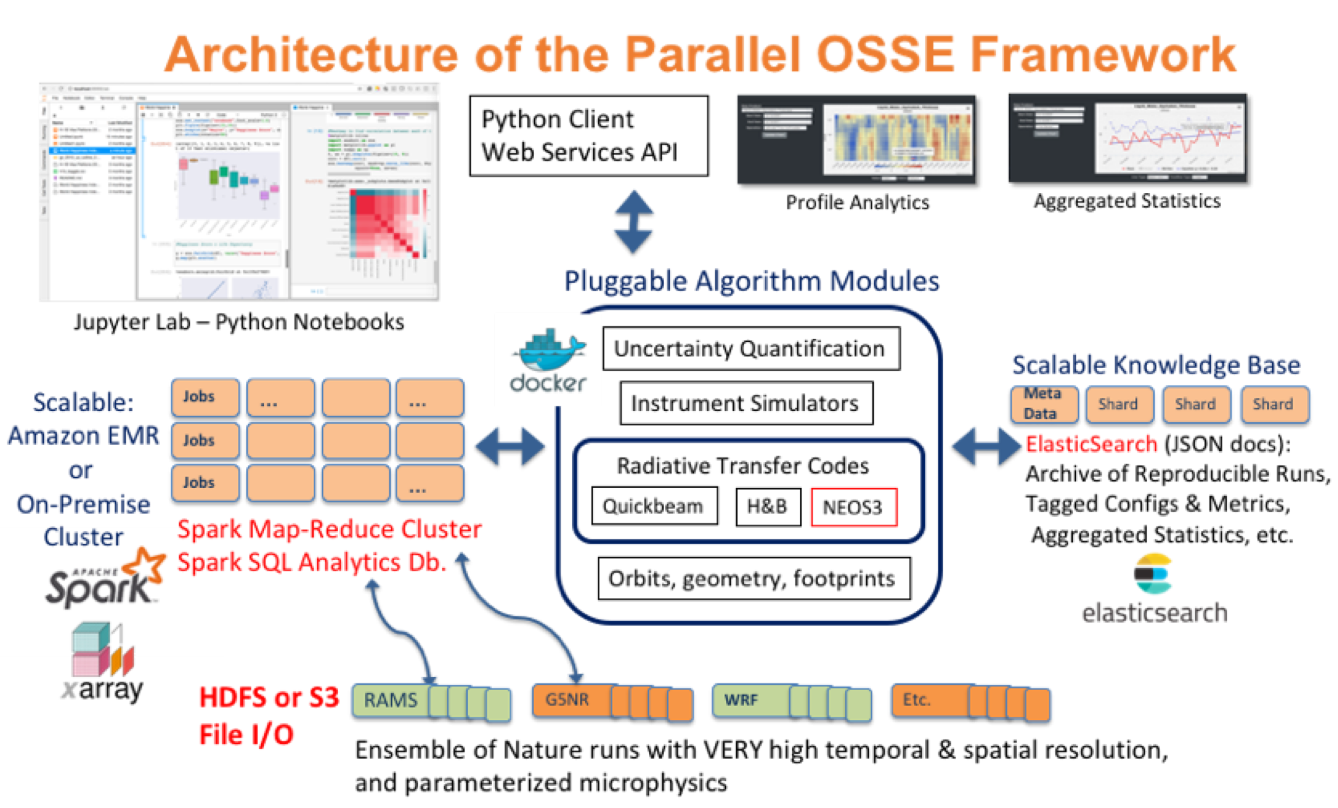


Figure 1. The architecture of the full parallel OSSE system as proposed to the NASA AIST call. Includes the Map-Reduce compute cluster (Apache PySpark & xarray), the scalable Knowledge Base (ElasticSearch) of ensemble runs, a set of "pluggable" code modules (e.g. radar simulators), and python Live Notebooks as one of several front-ends.

Figure 2. A schematic of the OSSE Workflow: forward model runs through an ensemble of model atmospheres yield simulated measurements (e.g. reflectivity), retrievals then yield estimates of geophysical variables (attenuation), and statistical analysis over all of the instantiations characterize the science return. Each of the three steps (blue) are parallelized (over ensemble members and radar "looks") executing on a Spark Map-Reduce compute cluster.

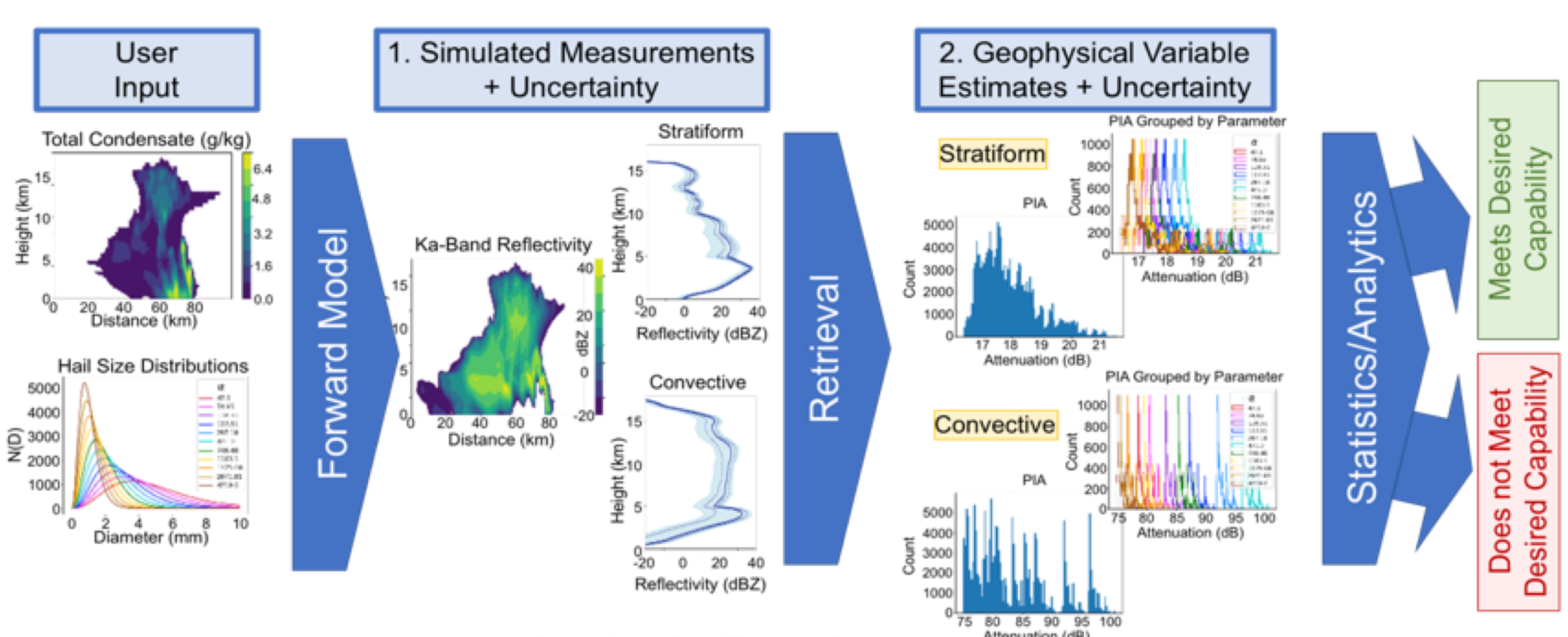
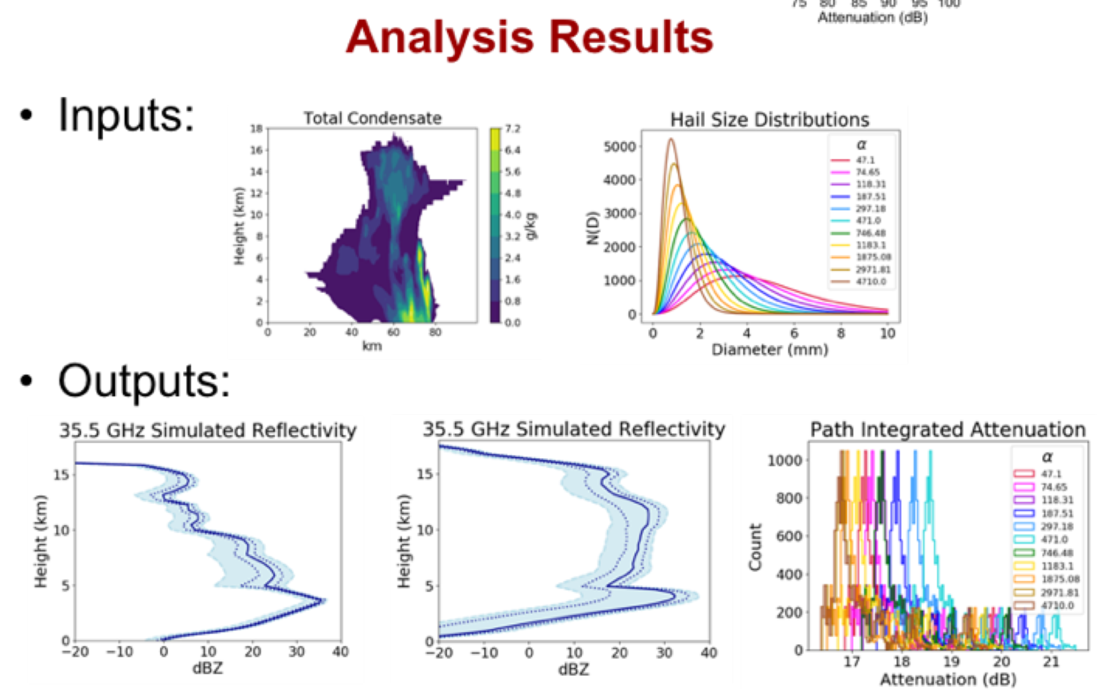


Figure 3. QuickBeam analysis results using RAMS simulations of deep convection. In this example the radar simulator was used to compute simulated reflectivity as inputs: 1. Model output and 2. A series of possible values for a parameter in the assumed hail mass-diameter relationship. The parallel OSSE system produces as outputs: 1. Profiles of simulated reflectivity with their variability and 2. Retrieved path integrated attenuation, with statistics about the variability with regard to the choice in hail parameter.



Benefits to NASA and JPL:

JPL needs a fast, automated, and flexible OSSE Toolkit that leverages parallel computing architectures, and enables users to easily test new measurement configurations. Our toolkit will allow scientists to quickly and efficiently identify suitable candidate observing strategies. It will include both simple low-order measurement simulators, as well as high complexity realistic simulators. This enables a two-tiered strategy, in which measurement concepts can be first rapidly evaluated, followed by a detailed examination using a sophisticated (more computationally complex) simulator. D. Posselt's team is currently simulating proposed W- and Ka-band radar instruments in support of the Clouds, Convection, and Precipitation (CCP) mission designated in the 2017 Earth Science Decadal survey. They are also evaluating the science potential of a constellation of radars for observations of convective storm dynamics. To date, they have been able to perform a limited set of OSSEs using just a few candidate measurement configurations. The OSSE toolkit will enable evaluation of a much larger set of candidate radar configurations, and will position JPL strategically to be competitive for participation in the CCP mission.

Impacts: Development of an OSSE toolkit will enable JPL to rapidly narrow the trade space of possible measurement configurations to just a select few. It will also provide the capability to quickly and easily evaluate the uncertainty introduced by an engineering design change. Both of these make the process of mission design more efficient by enabling faster iterations and broader exploration of the trade space. **Pervasive parallel computing, from instrument / radar "looks" to huge ensemble analyses including parallel aggregation of statistical metrics, has never been systematically applied to evaluating science return as a function mission design.**

Publications:

No publications submitted the first year; there will be several in the 2nd year.

Expanded proposal submitted to the 2019 NAST AIST call: "A Science-Focused, Scalable, Flexible Instrument Simulation (OSSE) Toolkit for Mission Design"

PI Brian D. Wilson:

Brian.Wilson@jpl.nasa.gov

818-726-4383

Poster RPC-047