Preliminary Observing System Simulation Experiments for Doppler Wind Lidars Deployed on the International Space Station

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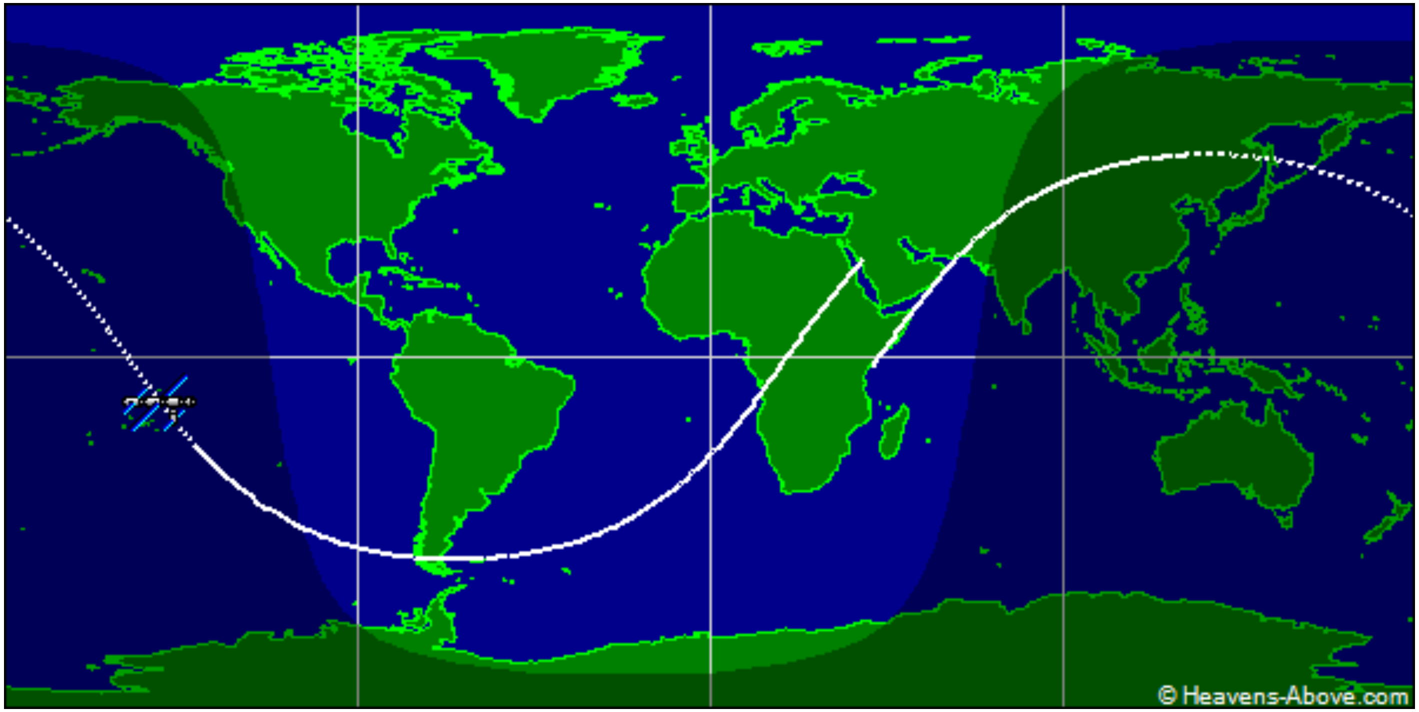
Introduction

- Multi-agency group studying benefits of deploying **OAWL/DE** or **WISSCR** wind lidars on International Space Station and assimilating observations
- ISS orbit would provide observations in tropical and mid-latitude belt, roughly 4 orbits in 6-hour synoptic period
- Deployment would be consistent with NASA strategic goals:
  - Expanding use of ISS for scientific and technological purposes
  - Advancing Earth system science
  - Engaging in partnerships with other government agencies (e.g., NOAA) to generate US commercial activity and other public benefits
- Benefits quantified using Observing System Simulation Experiments (OSSEs)
  - NASA GSFC performing preliminary OSSEs using **GEOS-DAS/fvGCM**

Lidar on ISS

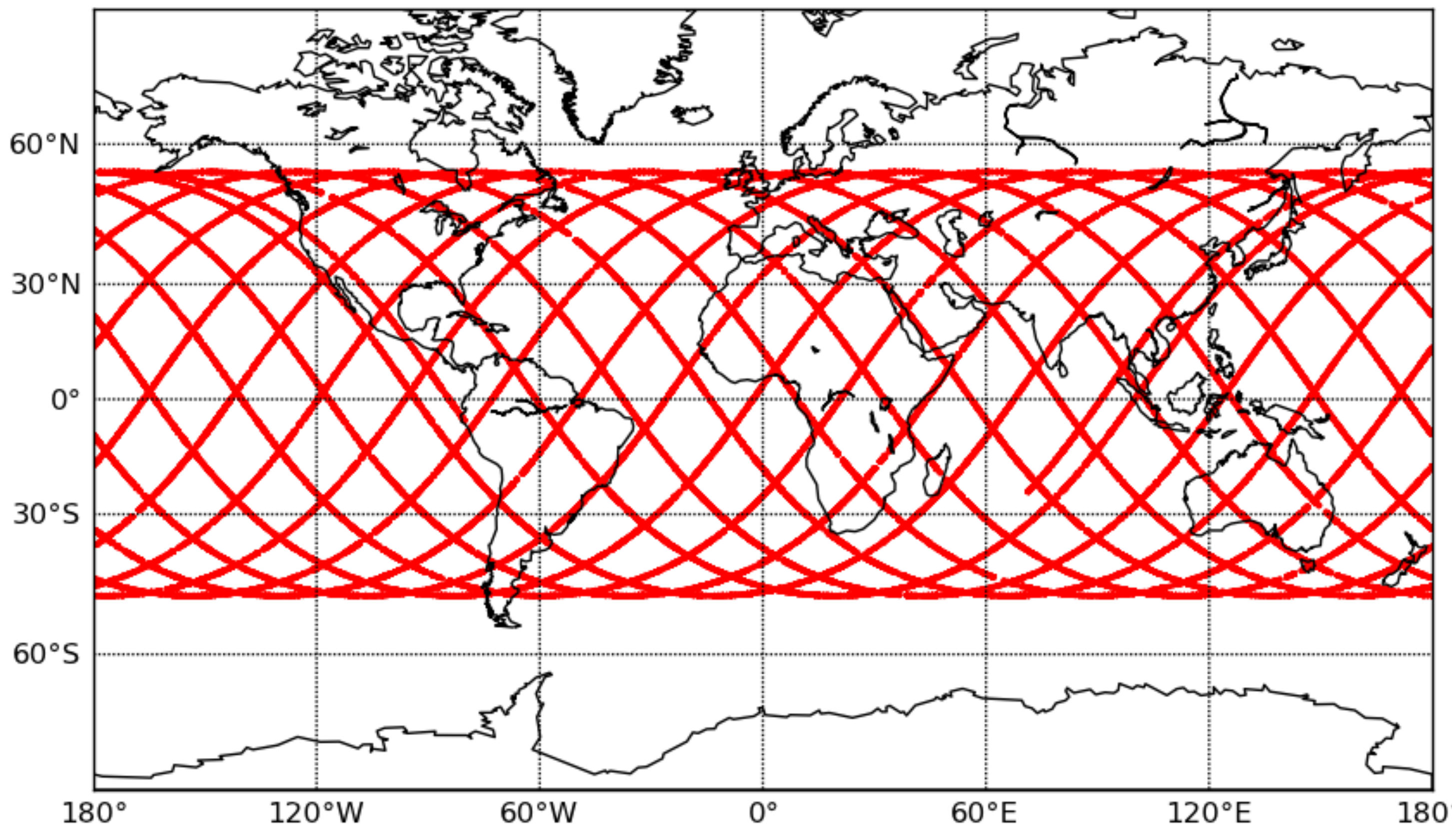


- ISS single orbit time ~92 min; ~15 orbits a day
- Altitude: ~400 km
- Assume two lasers on port side of ISS
- 90 deg separation between forward and aft lasers
- Nadir angle is 40 deg

Lidar Observation Positions

- Use AGI Satellite Tool Kit to model ISS orbit and calculate 100 Hz line-of-sight and day/night time series
  - Separate time series for GSFC and JCSDA/AOML OSSEs
- Stitch time series to mimic OAWL/DE and WISSCR
  - WISSCR: 10 Hz/100 Hz coherent/direct detection, 12 s dwell, 1.3 s gap
  - OAWL/DE: 100 Hz, oscillates forward and aft between each shot (equivalent to 50 Hz for each laser)
- Provide time series to Simpson Weather's Doppler Lidar Simulation Model (DLSM)

OAWL/DE Time Series for 1 day

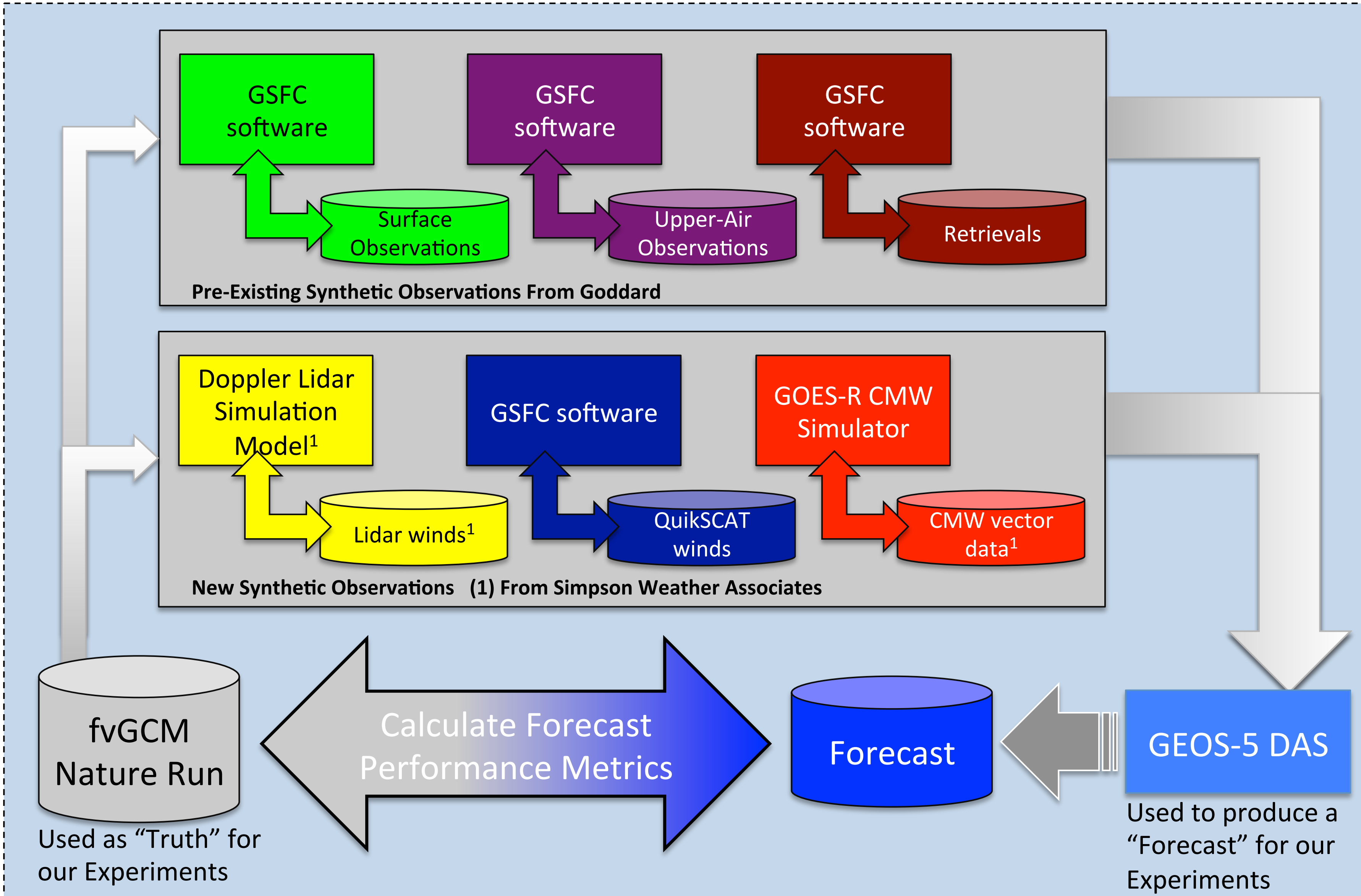


- Observation gaps may occur depending on atmospheric conditions

OSSE Concept

- Use a model simulation (called a Nature Run) as a “virtual atmosphere” to create synthetic observations
  - Critical for Nature Run to simulate weather systems in a realistic manner
- Assimilate observations into separate prediction model to simulate forecasts
  - Control run only assimilates existing or planned observing systems (e.g., GOES-R); hypothetical systems (e.g., lidars) added in separate runs
- Compare the “forecasts” with the Nature Run to assess errors; statistics estimate real-world impact of assimilating the observations
  - **Critical for Control run observation types to be calibrated to mimic real world statistics when assimilated**, otherwise conclusions for new observing systems will be questionable

NASA GEOS-DAS/fvGCM OSSE System



fvGCM Nature Run

- Produced by NASA Global Modeling and Assimilation Office in early 2000's
- 0.5 degree global domain, 3-hourly output
  - Sufficient to simulate synoptic weather systems and crudely simulate tropical cyclones
- Period of interest: **24 Sep – 9 Oct 1999**
- Caveat: Synthetic observations do not include satellite radiances (instead uses retrievals)

Aerosol Distribution

- fvGCM Nature Run does not include aerosols
- Simpson Weather tested two aerosol distribution functions
  - *Background*: Most applicable with no anthropogenic sources or deserts (e.g., South Pacific)
  - *Enhanced*: Higher aerosol counts
- Lidar observations simulated from **both** functions will be tested in separate experiments (as “brackets”)

GEOS-DAS

- Global system developed by NASA GMAO with components from NOAA NCEP
  - Using GEOS-DAS 2.1.4 (released c. 2009)
- 3DVAR global data assimilation performed by NASA/NOAA GSI program at 00, 06, 12, 18 UTC
- Global simulations performed using NASA GEOS-5 model
  - 1/2 deg by 2/3 deg lat/lon grid
  - Short-range forecasts produced at 00, 06, 12, 18 UTC as first guess for subsequent GSI analysis
  - 5-day forecasts launched at 00 UTC

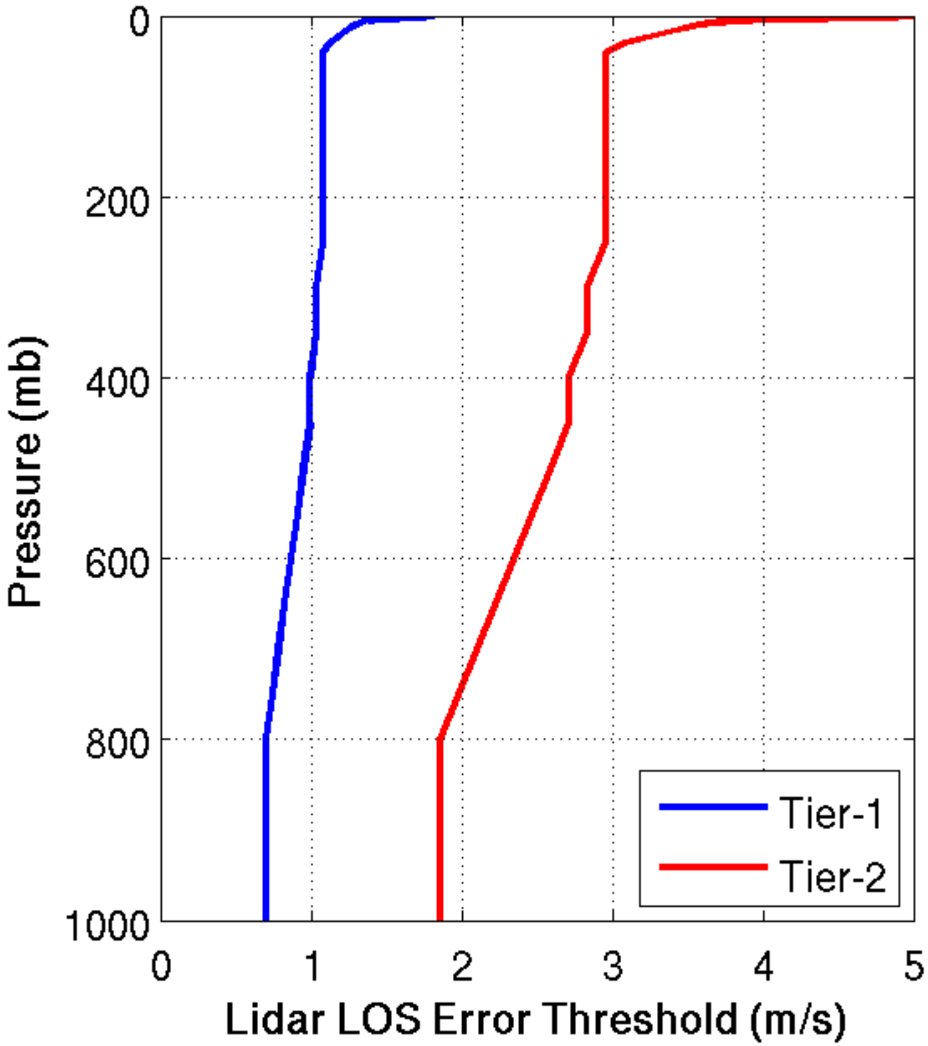
GEOS-DAS Caveats

- Cannot assimilate raw lidar line-of-sight observations
  - **Assimilate horizontal wind vectors (HWVs) derived from co-located forward and aft lidar shots**
  - Unmatched forward or aft shots are tossed
- Difficult to use unique *measurement errors* (σ_m) provided with each observation
  - GSI uses pressure-dependent look-up tables of *observation error* (σ_o) which also consider scale of observation versus scale of analysis
  - **Establishment of lidar σ_o and binning of observations by error are required**

Lidar Observation Errors and Binning

- Proposed by D. Emmitt
- Observation error defined as $\sigma_o^2 = \sigma_m^2 + \sigma_r^2$
  - σ_r is "error of representativeness," partially a function of data assimilation system
- We divide the lidar HWVs into two **quality tiers**:
  - $\boldsymbol{(\sigma_o)_{tier1} = (\sigma_o)_{raob}}$ ("raob" stands for radiosondes)
  - $\boldsymbol{(\sigma_o)_{tier2} = 2(\sigma_o)_{raob}}$
- We assume $(\sigma_r)_{tier1} = (\sigma_r)_{tier2} = 0.75(\sigma_r)_{raob}$ ← **First guess**
- Solve for $(\sigma_r)_{raob}$ using specified $(\sigma_o)_{raob}$ and constant $(\sigma_m)_{raob}$ = 0.5 m/s (WMO reference measurement error)
- With HWV σ_o and σ_r known, calculate σ_m threshold for each tier
- Set line-of-sight σ_m proportional to HWV σ_m
- **Use line-of-sight $\boldsymbol{\sigma_m}$ thresholds to bin the lidar observations into the tiers**

Measurement Error Thresholds



- Lowest thresholds below 800 mb
- Increasing to 250 mb
- Sharp increase at 40 mb

- **Both** LOS σ_m must be left of blue threshold for Tier-1 assignment; otherwise **both** must be left of red threshold for Tier-2

- **Iterations of this approach may be required**

Observation Counts

Background Aerosol Model

OAWL HWVs: 1383913 Tier 1 Subset: 593730 (42.9%) Tier 2 Subset: 451379 (32.6%)	DE HWVs: 2295609 Tier 1 Subset: **77741 (3.4%)** Tier 2 Subset: 2011274 (87.6%)
WISSCR coherent HWVs: 148388 Tier 1 Subset: 100756 (67.9%) Tier 2 Subset: 38892 (26.2%)	WISSCR DD HWVs: 1012038 **Tier 1 Subset: 0 (0%)** Tier 2 Subset: 901289 (89.1%)

Disclaimer: Results are preliminary and represent work in progress

Iterations of this approach may be required

Enhanced Aerosol Model

OAWL HWVs: 1558290 Tier 1 Subset: 748075 (48.0%) Tier 2 Subset: 476125 (30.6%)	DE HWVs: 2178510 Tier 1 Subset: **62637 (2.9%)** Tier 2 Subset: 1914173 (87.9%)
WISSCR coherent HWVs: 295345 Tier 1 Subset: 168612 (57.1%) Tier 2 Subset: 108514 (36.7%)	WISSCR DD HWVs: 957346 **Tier 1 Subset: 0 (0%)** Tier 2 Subset: 854615 (89.3%)

- Significantly less WISSCR coherent HWVs than other three types
- Roughly twice as many DE HWVs as WISSCR direct detection
- **No Tier 1 WISSCR direct detection HWVs; few DE Tier 1 HWVs**
- Enhanced aerosol model increases OAWL and WISSCR coherent HWV counts, decreases DE and WISSCR direct detection

Current Experiments

- **Control** – radiosondes, surface observations, aircraft reports, ship reports, retrievals, scatterometer, GOES-R cloud drift winds
- **OWLB** – Control plus OAWL/DE (both tiers) using "background" aerosols
- **OWLE** – Similar to OWLB but using "enhanced" aerosols
- **WISB** – Control plus WISSCR (both tiers) using "background" aerosols
- **WISE** – Similar to WISB but using "enhanced" aerosols

Status

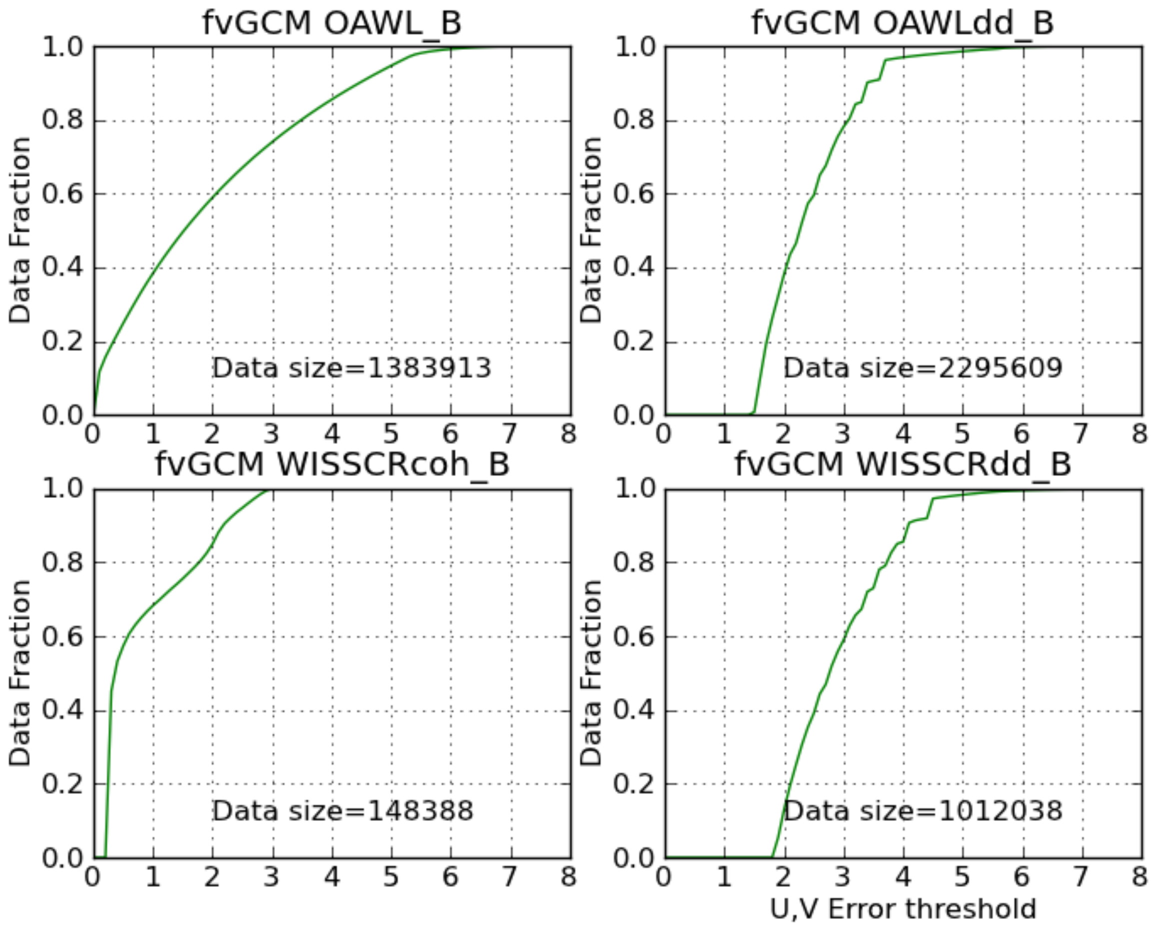
- First set of runs completed early this week
- Evaluating anomaly correlations and root-mean-square errors by hemisphere and region (tropical versus extratropical), including:
  - 500 mb height
  - Mean sea level pressure
- Will also evaluate cyclone forecast tracks
- Reruns may occur with different observation errors and binning

Summary

- Constructed set of synthetic **OAWL/DE** and **WISSCR** shots for instruments based on ISS
- Simpson Weather simulated HWVs using fvGCM Nature Run and two assumed aerosol distributions
- Partitioning HWV observations into two tiers with assumed σ_o and σ_r (proportional to radiosonde values)
  - Some iterations of this approach may occur
- Performing OSSEs with NASA GEOS-DAS
  - Will compare with JCSDA and AOML OSSEs

Backup Slides

Observation error Vs data fraction: Background aerosols



Direct detection – more data, less accuracy ?

Recommendations:

Separate obs based on obs error to tier-1 and tier-2

Used RAWSONDE error tables for tier-1 and twice that for tier-2

Observation error Vs data fraction: Enhanced aerosols