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

E. Kemp, J. Jacob
SSAI/NASA GSFC

R. Rosenberg, J. C. Jusem
SAIC/NASA GSFC

G. D. Emmitt, S. Wood, S. Greco L. P. Riishojgaard, M. Masutani, Z. Ma
Simpson Weather Associates JCSDA

S. Tucker
Ball Aerospace

R. Atlas, L. Bucci
NOAA AOML

M. Hardesty
NOAA ESRL

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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)
• 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

Pre-Existing Synthetic Observations From Goddard

GSFC software
Surface Observations
Upper-Air Observations
Retrievals

New Synthetic Observations (1) From Simpson Weather Associates

Doppler Lidar Simulation Model
Lidar winds

GSFC software
QuikSCAT winds

GOES-R CMW Simulator
CMW vector data

fvGCM Nature Run
Used as “Truth” for our Experiments

Calculate Forecast Performance Metrics
Forecast

GEOS-5 DAS
Used to produce a “Forecast” for our Experiments
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”)

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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 ($\sigma_m$) provided with each observation
  – GSI uses pressure-dependent look-up tables of observation error ($\sigma_o$) which also consider scale of observation versus scale of analysis
  – Establishment of lidar $\sigma_o$ and binning of observations by error are required
Lidar Observation Errors and Binning

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

<table>
<thead>
<tr>
<th></th>
<th>OAWL HWVs: 1383913</th>
<th>DE HWVs: 2295609</th>
</tr>
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<tbody>
<tr>
<td>Tier 1 Subset:</td>
<td>593730 (42.9%)</td>
<td>77741 (3.4%)</td>
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<tr>
<td>Tier 2 Subset:</td>
<td>451379 (32.6%)</td>
<td>2011274 (87.6%)</td>
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</table>

<table>
<thead>
<tr>
<th></th>
<th>WISSCR coherent HWVs: 148388</th>
<th>WISSCR DD HWVs: 1012038</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tier 1 Subset:</td>
<td>100756 (67.9%)</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>Tier 2 Subset:</td>
<td>38892 (26.2%)</td>
<td>901289 (89.1%)</td>
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</tbody>
</table>

## Enhanced Aerosol Model

<table>
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<tr>
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<th>OAWL HWVs: 1558290</th>
<th>DE HWVs: 2178510</th>
</tr>
</thead>
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<tr>
<td>Tier 1 Subset:</td>
<td>748075 (48.0%)</td>
<td>62637 (2.9%)</td>
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<td>Tier 2 Subset:</td>
<td>476125 (30.6%)</td>
<td>1914173 (87.9%)</td>
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<table>
<thead>
<tr>
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<th>WISSCR coherent HWVs: 295345</th>
<th>WISSCR DD HWVs: 957346</th>
</tr>
</thead>
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<tr>
<td>Tier 1 Subset:</td>
<td>168612 (57.1%)</td>
<td>0 (0%)</td>
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<tr>
<td>Tier 2 Subset:</td>
<td>108514 (36.7%)</td>
<td>854615 (89.3%)</td>
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</table>

- 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

Disclaimer: Results are preliminary and represent work in progress

Iterations of this approach may be required
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 $\sigma_o$ and $\sigma_r$ (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