

DWL operations within a sensor web concept

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Project Goals

Design a sensor web architecture that couples current & future Earth observing systems with atmospheric, chemical, and oceanographic models and data assimilation systems

Build an end-to-end sensor web simulator (SWS) based upon the suggested architecture to enable objective scientific evaluation of a fully functional model-driven sensor web for a numerical weather forecasting application

End Product: Fully integrated simulator with functional elements that will allow multiple “what if” scenarios in which different configurations of sensors, communication networks, numerical models, data analysis systems, and targeting techniques may be tested

Project began October, 2006

Primary Findings / Technical Status

Predictive Skill of Weather Forecasts

“Anomaly Correlation”
Departure of observed
500hPa height fields from
climatological mean
**One metric of predictive
skill of weather forecasts**

Correlation less than 0.6 is
indicative of “no skill”

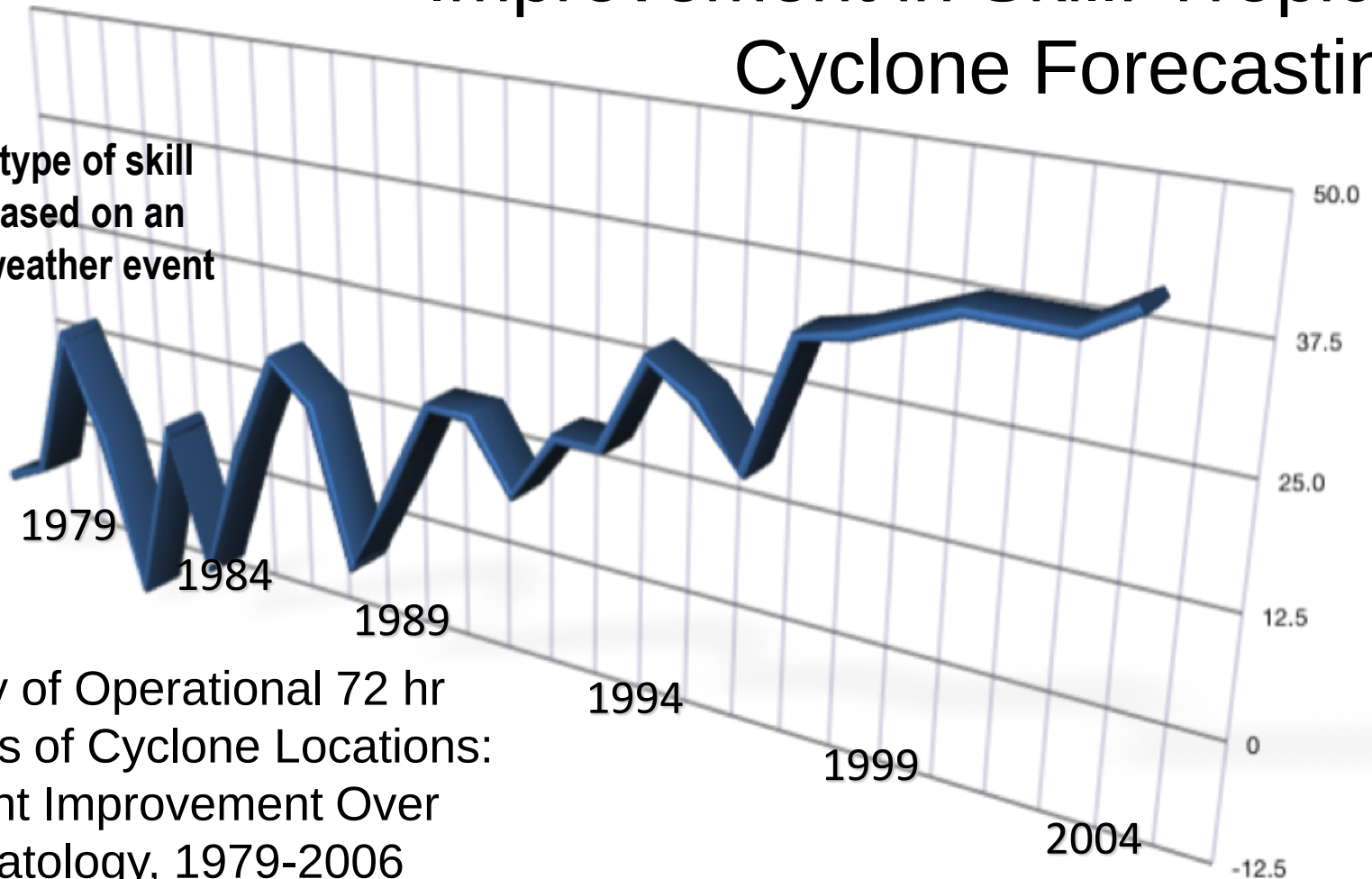


The Overarching Goal of this project:

***Quantify weather forecast skill impact of using operational meteorological data
assimilation system results to drive dynamic targeted measurements by sensor assets***

Improvement in Skill: Tropical Cyclone Forecasting

Another type of skill metric based on an extreme weather event



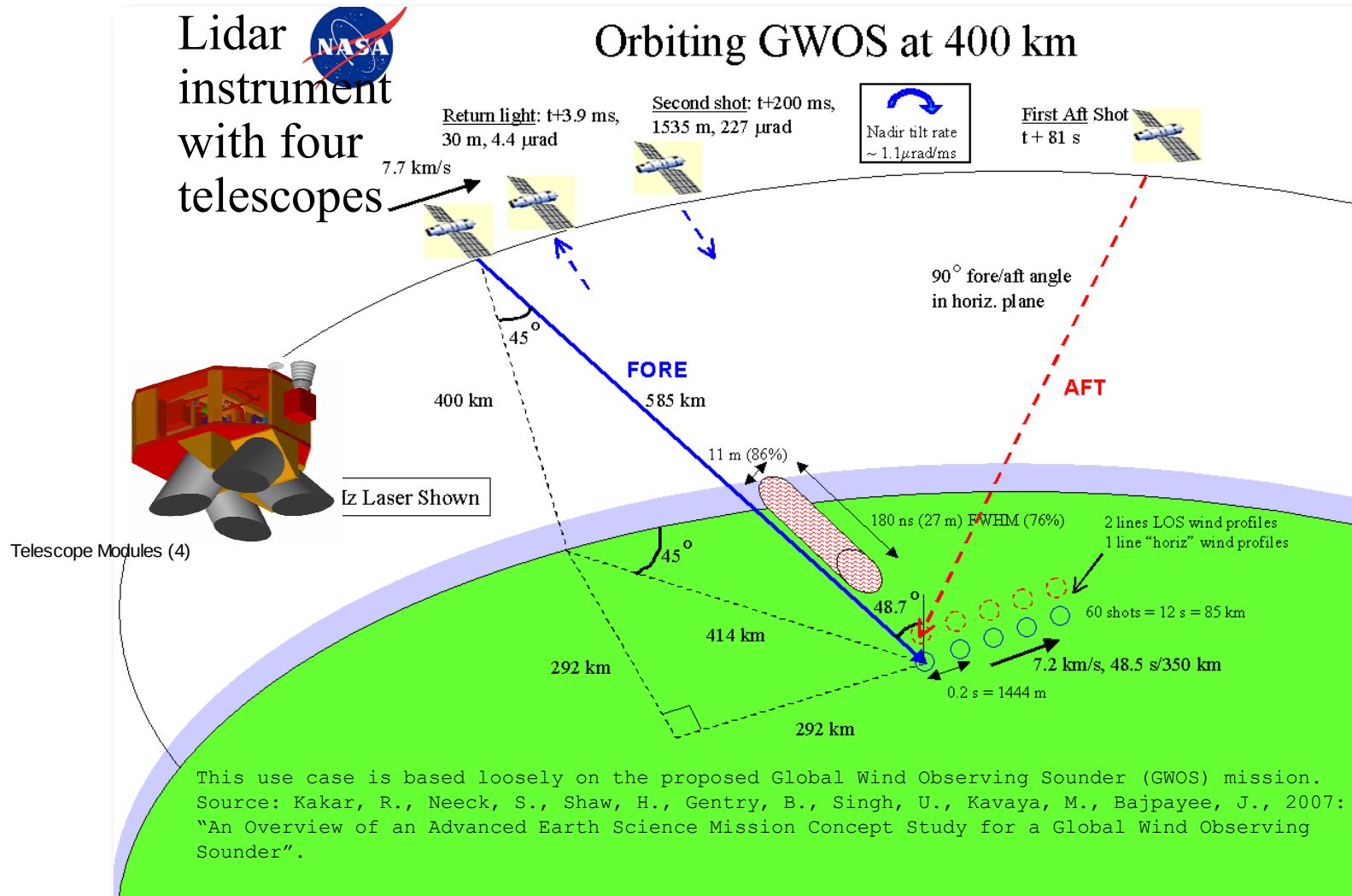
History of Operational 72 hr
Forecasts of Cyclone Locations:
Percent Improvement Over
Climatology, 1979-2006

Source: M. Fiorino, National Hurricane Center

Use Case Scenarios

- **Use GEOS5 model to command a future wind lidar instrument & feed observations to next analysis cycle**
 - Goals: Acquire high fidelity wind measurements to improve predictive skill in numerical model forecasts and conserve power and extend longevity of the instrument
 - Method: Perform optimal targeting for specific atmospheric events, intelligent use of lidar capabilities (e.g., telescope sequencing, slewing)
- **Follow-on use case will apply GEOS5 model to command GOES-R (planned for 2014) & feed observations to next analysis cycle**
 - Goal: Acquire high resolution cloud motion winds to better identify regions of tropical and extratropical cyclone genesis/intensification
 - Method: Place Advanced Baseline Imager (ABI) into rapid scan mode for targeted regions -- would make use of John Moses cloud motion wind algorithm

Lidar Use Case



Lidar Use Case: Adaptive Targeting Modes

- **Simulation 1: Power Modulation**

- Goal is to conserve power / extend instrument life by using aft shots only when there is “significant” disagreement between model first guess line-of-sight winds and winds measured by fore shots
 - Lidar engineers have recently suggested reduced duty cycles may increase laser lifetimes
 - Duty cycles that are on the order of 10 mins “on” and 80 mins “off” may be very beneficial to mission lifetime
- Will require model’s first guess fields be made available on board the spacecraft -- requires engineering trades be performed for on-board processing, storage, power, weight, communications

Lidar Use Case: Adaptive Targeting Modes

■ **Simulation 2: Targeted Observations**

- Goal is to target two types of features:
 - “Sensitive regions” of the atmosphere: those regions where the forecast is highly responsive to analysis errors
 - Features of interest that may lie outside of the instrument’s nadir view
 - Tropical cyclones
 - Jet streaks
 - Rapidly changing atmospheric conditions
- Would make use of reaction wheels to change angular momentum
- Would require optimization to choose between multiple targets
- Studies have shown that targeted observations can improve predictive skill, but implementation of an operational system using such data is not straightforward

Data Assimilation Methodology

- Simulator will make use of existing 3D Var techniques
- NASA / GMAO GEOS5 - DAS
- NOAA GDAS

General Analysis Equation

$$\mathbf{x}_a = \mathbf{x}_b + \mathbf{K} (\mathbf{y} - \mathbf{H}\mathbf{x}_b)$$

$\mathbf{x}_a$: optimal analysis

$\mathbf{x}_b$: model first guess

$\mathbf{K}$: gain matrix (applies appropriate weighting)

$\mathbf{y}$: observations

$\mathbf{H}$: interpolator

- For sensitivity analysis, adjoint techniques will likely be employed

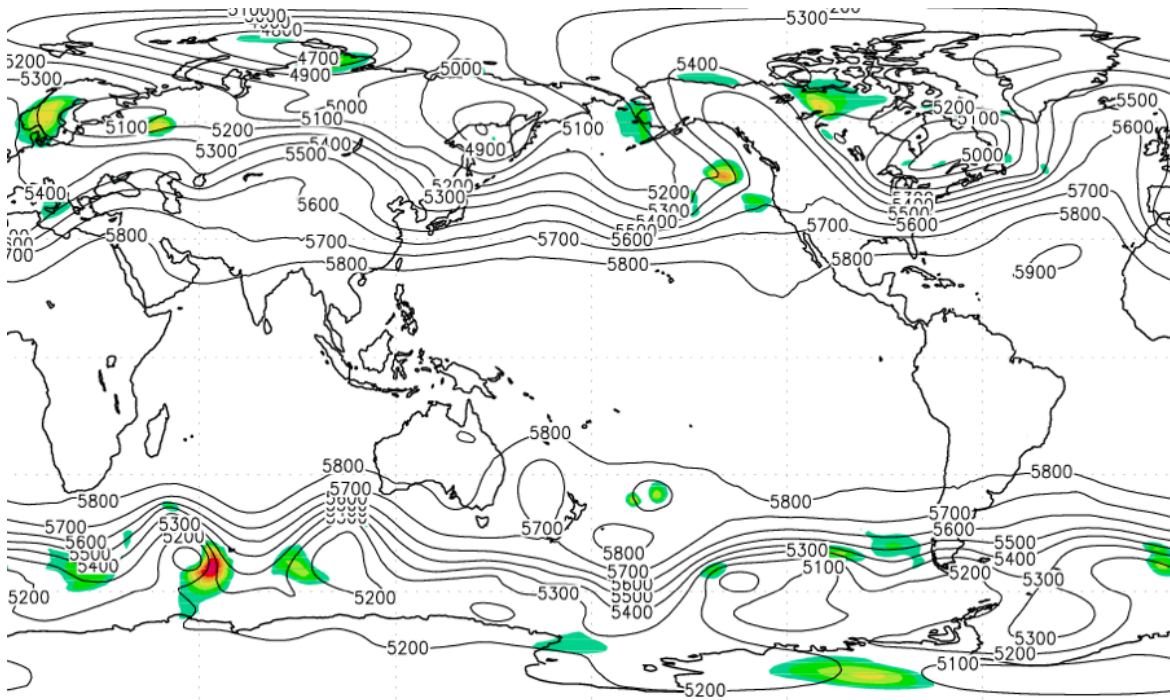
$$\frac{\partial J}{\partial \mathbf{y}} = \mathbf{K}^T \frac{\partial J}{\partial \mathbf{x}_a}$$

Estimate of the sensitivity of the forecast error J to the observations $\mathbf{y}$

- Studies at NASA, NOAA, and the Naval Research Laboratory have shown sensitivity can occur where observations are in data-sparse regions, where there are gradients/discontinuities, and where the observation density changes

Calculating “Sensitive Regions”

Differences between two forecasts launched 72 hours apart and valid at the same forecast hour. Largest differences (“sensitive regions”) depicted in colored shading.



Studies have shown the adjoint technique to be effective for adaptive targeting†.

Testing with this technique will occur during years 2-3 in coordination with the GMAO.

Prior to the implementation of the adjoint technique we calculate forecast sensitivity by a simple differencing of 72 hour forecasts that are valid at the same synoptic time.

Large differences are selected as the “sensitive regions” for adaptive targeting.

†Leutbecher, M., and A. Doerenbecher, 2003: Towards consistent approaches of observation targeting and data assimilation using adjoint techniques. Geophysical Research Abstracts, Vol. 5, 06185, European Geophysical Society.

Autonomous Feature Detection (for Experiment 2)

- **Software has been augmented to autonomously detect meteorological features of interest from the data assimilation system (credit: Joe Terry, SAIC)**
- Consolidation of existing feature identification software into an application driver -- will be very important for extending capabilities for addition of new feature detection elements
- Prioritization scheme was introduced to ingest a user-specified template of the desired ranking of 25 categories of features (5 major categories each with 5 subcategories)

Autonomous Feature Detection (for Simulation 2)

- **“Major” categories**

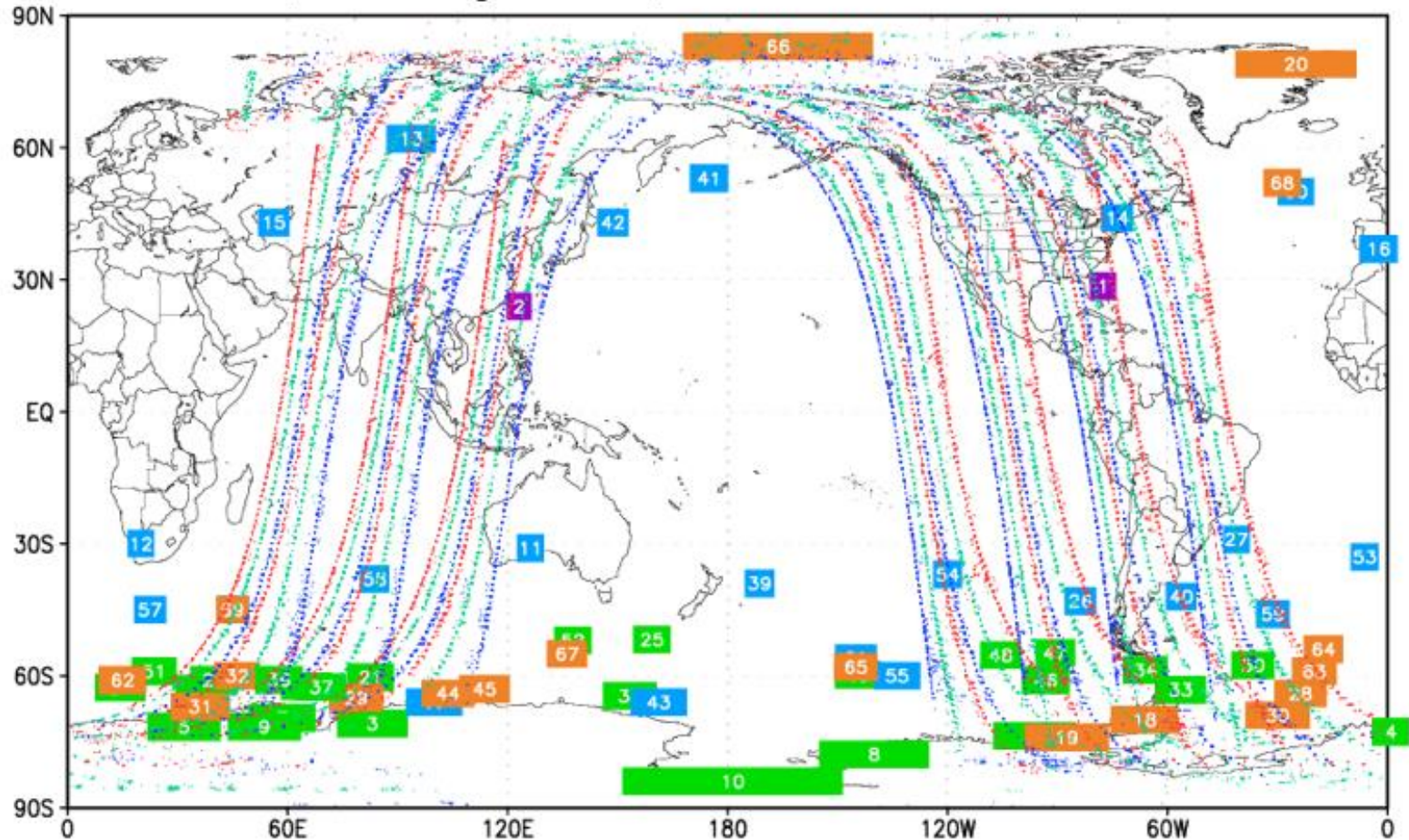
- Tropical cyclones (all that are discernable)
- Extratropical cyclones (threshold $<980\text{hPa}$)
- Thermal advection centers ($>0.25\text{ K/hr}$ at 850hPa)
- Jet centers ($>50\text{m/s}$ above 500hPa ; $>35\text{m/s}$ below 500hPa)
- Deepening centers ($>0.5\text{hPa/hr}$)

- **Subcategories**

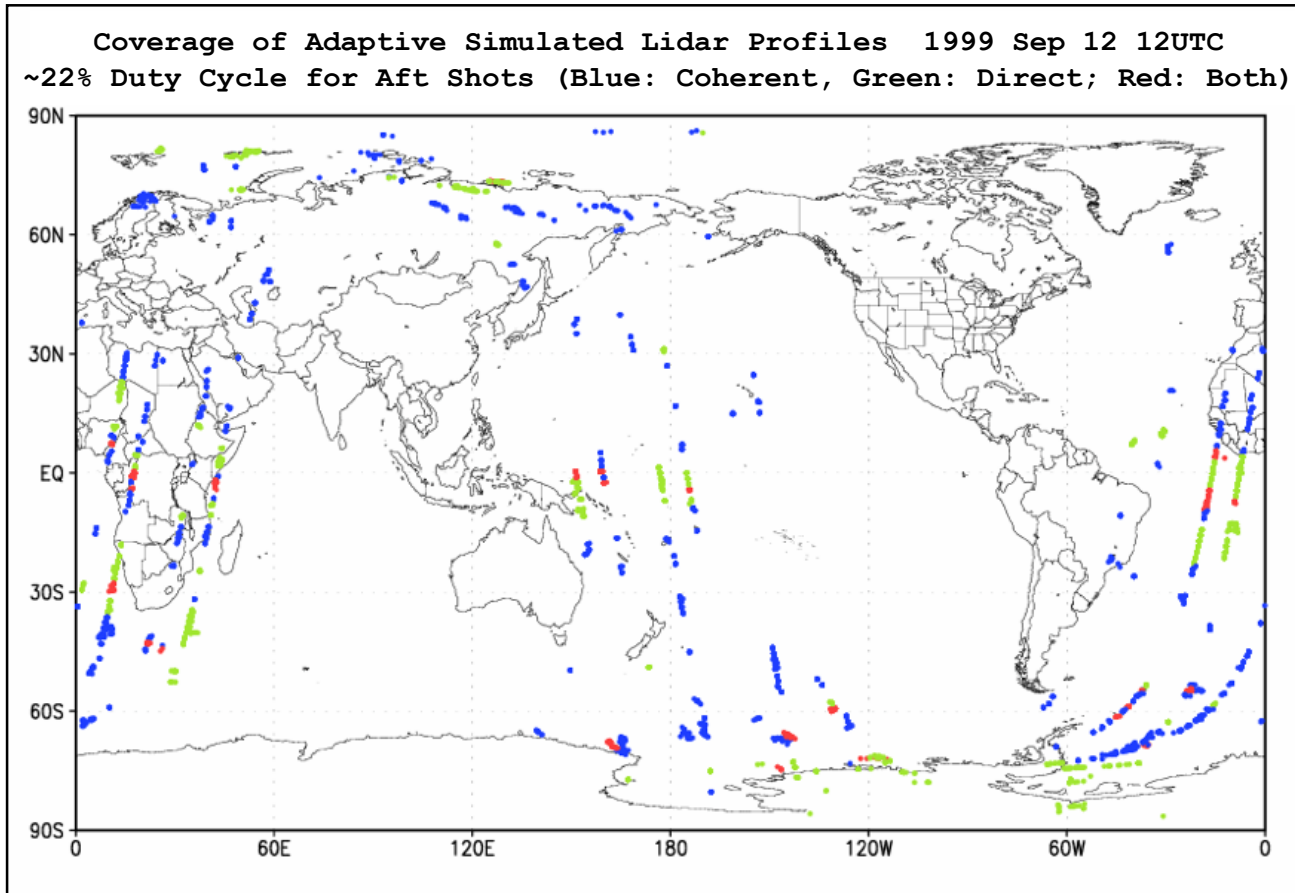
- Feature over land
- Feature over coast
- Feature over water but approaching land
- Feature over water but moving away from land
- Feature over water and far from land ($>1000\text{km}$)

Potential Targets with Simulated Lidar Coverage 1999 Sep 15 06UTC
 Green= No Slew, Red= Right Slew, Blue= Left Slew, Target Rank Shown in Box

Potential Targets with GWOS Lidar Coverage 1999 Sep 15 06UTC
 Green=no slew, Red=right slew, Blue=left slew. Rank Shown in Box.



Simulation 1 Results



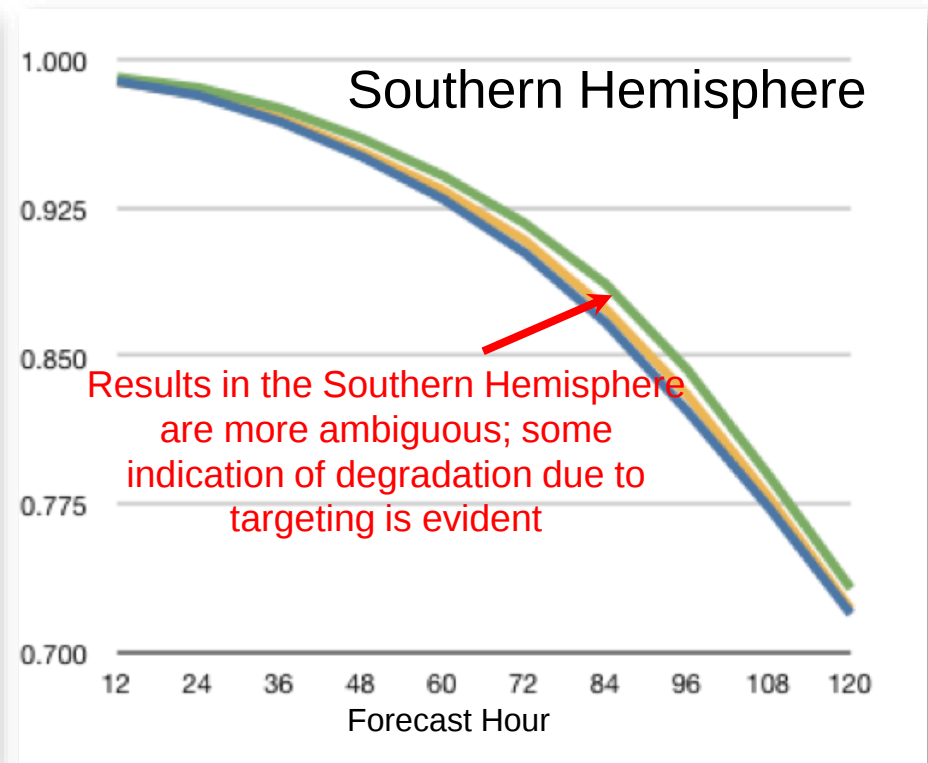
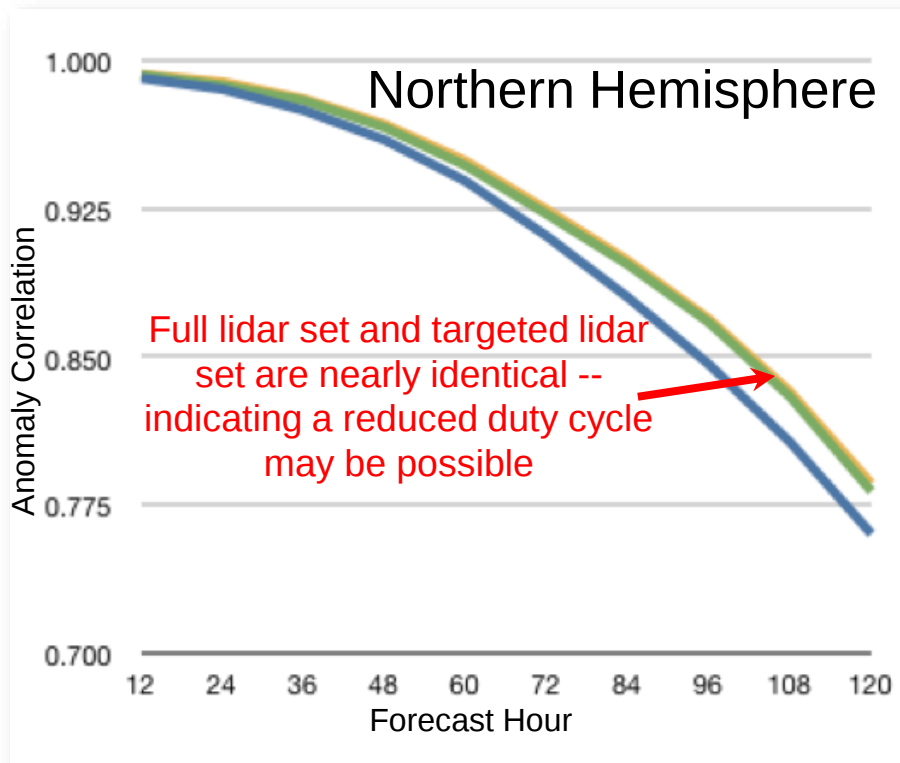
Lidar data deleted when there is “adequate” agreement with the numerical model’s first guess wind fields

Designed to simulate suppression of the aft shot of the operational lidar

Result: Nearly 30% of the lidar’s duty cycle may be reduced -- IF there is no discernable impact to forecast skill!

Simulation 1 Results

Impact of duty cycle reduction on forecast skill, 20 day assimilation with 5-day forecasts launched at 00z each day. Results represent an aggregate over all forecasts



— CONTROL — FULL LIDAR SET — TARGETED LIDAR

Simulation 2 - Preliminary Results

Targeted Lidar Profiles using Objective Targeting 1999 Sep 15 06UTC
Satellite Orientation: Blue= left slew; Green= no slew; Red= right slew)

Targeted GWOS Profiles using Objective targets (1999 Sep 15 06UTC)
Satellite Orientation: Green=no slew, Red=right slew, Blue=left slew

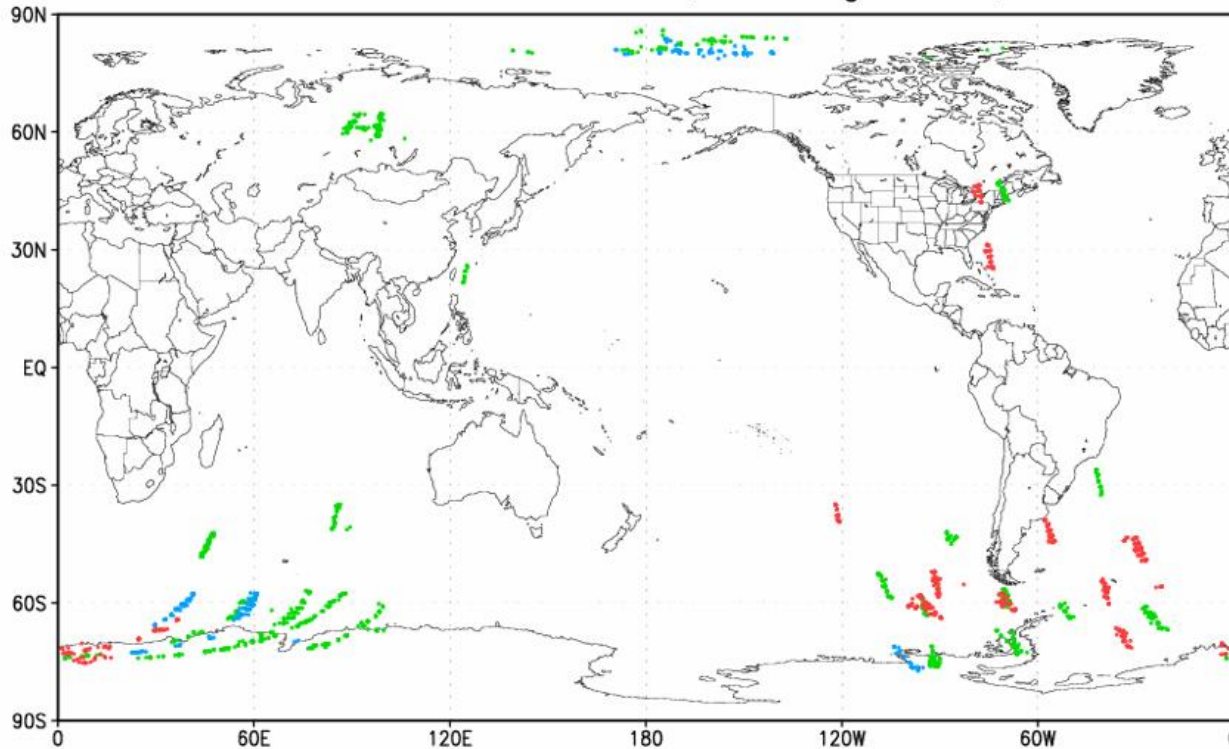


Figure indicates lidar profiles that would result from slewing the spacecraft to capture features of interest

Assimilation & forecasts to be executed during the second period of performance

Preliminary results indicate a nearly 30% increase in adaptive targets is possible!

Considerations for the Simulator

- **Establishment of Service Architecture**

- Simulator will be designed for extensibility -- the project will be successful if science / mission questions can be quickly posed and trade studies completed in a cost-effective manner with the simulator used as a tool
- Will accommodate rapid reconfiguration of major elements (1 - 6) of the science layer without re-engineering
- Elements to be hosted as independent services
 - All elements are mature but none are designed to be operated in a service-oriented architecture
 - Use of OSSE method to generate synthetic observations is especially challenging to make generic -- will be emphasized by this project

Next Steps

- **Simulation of Command & Control Elements**

- Will incorporate work performed under Dan Mandl's sensor web activity

- **Simulation of Observations**

- Will incorporate use of SensorML (Michael Goodman & Michael Botts team)
- Simulation of wind lidar data to begin this summer; ECMWF T511 Nature Run to be used

- **Testing of Optimization Techniques**

- Will examine genetic algorithms, use of Objectively-Optimized Observation Direction System (OOODS, David Lary team), use of Earth Phenomena Observing System (Steve Kolitz team)

- **Acquisition and Testing of Adjoint Algorithm**

- Will coordinate with Global Modeling & Assimilation Office, make use of existing algorithm by Ron Gelaro

The DLSP Component

