Quantifying Sensor Web Capabilities Through Simulation: Recent Results

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Project Goals

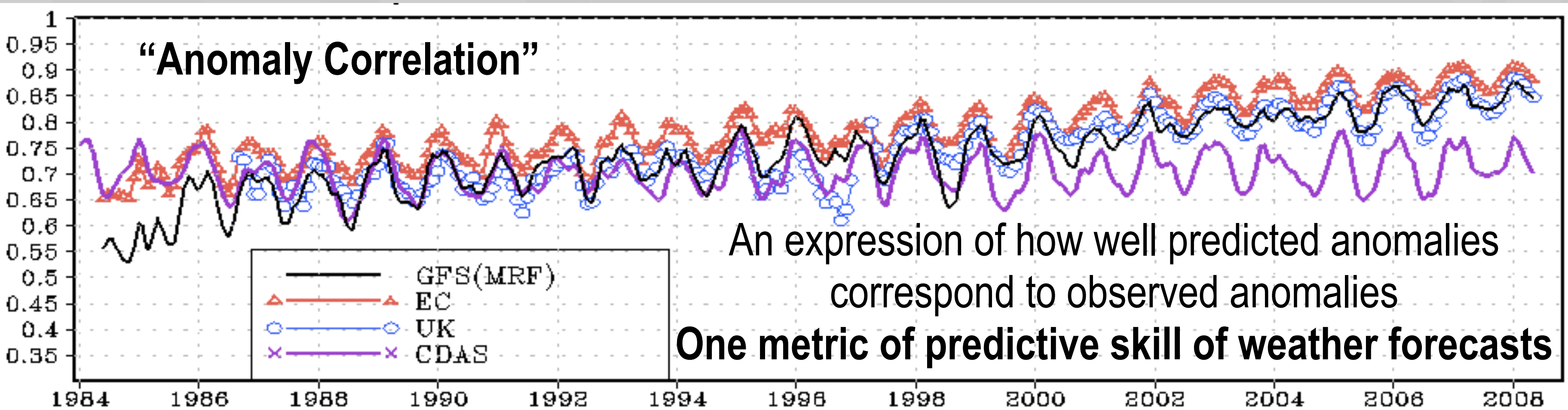
Demonstrate the value of implementing sensor web concepts for meteorological use cases

- **Quantify** cost savings to missions
- **Quantify** improvement in achieving science goals

Design and Build an 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

Evolution of Weather Forecast Predictive Skill

TIME SERIES of monthly mean anomaly correlations for 5-day forecasts of 500hPa heights for various operational models (CDAS frozen as of 1995) - Northern Hemisphere



Improvements in predictive skill over the past several decades have been gradual; the sensor web provides an opportunity for a "revolutionary" impact

Source: Fanglin Yang, Environmental Modeling Center, National Centers for Environmental Prediction, NOAA

Example: Societal Impact and Predictive Skill

Errors in temperature forecasts lead to errors in the prediction of electrical loads for large utilities

San Francisco, May 28, 2003

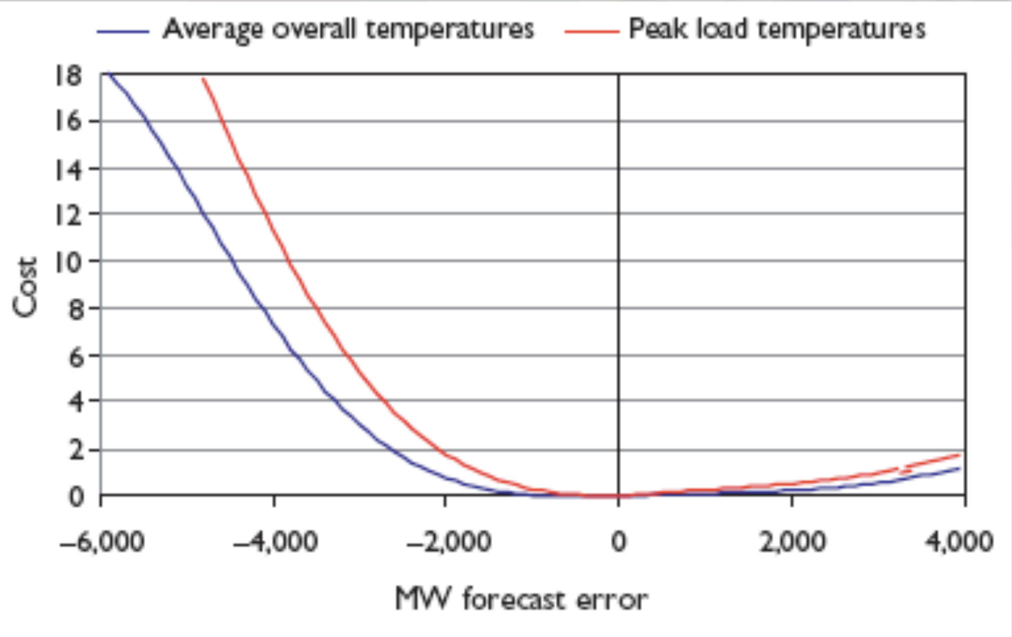
Temperature forecast error of 5ºC (five day forecast)

↓

Electrical load underestimated by 4.8GW

↓

“On the spot” energy purchase required



Source: Mary G. Altalo (SAIC, Inc) and Leonard A. Smith (London School of Economics): “Using Ensemble Weather Forecasts to Manage Utilities Risk”, *Environmental Finance*, October 2004

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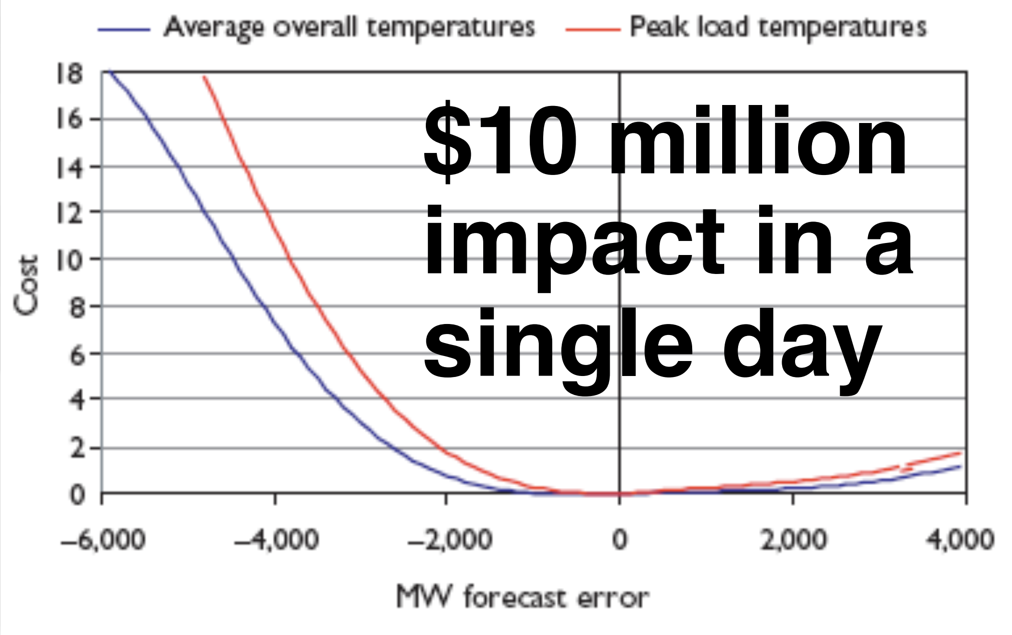
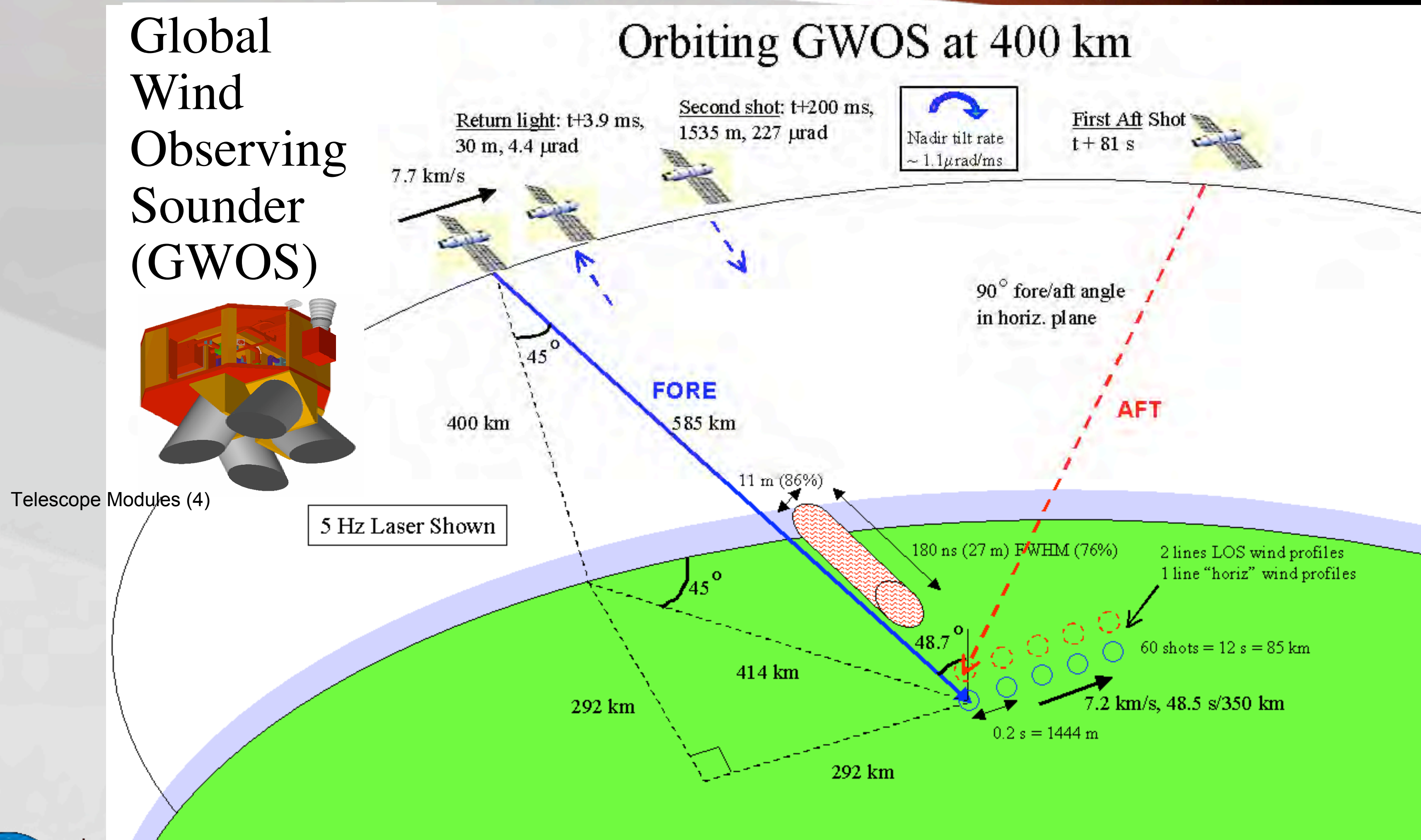


$10 million impact in a single day

Source: Mary G. Altalo (SAIC, Inc) and Leonard A. Smith (London School of Economics): "Using Ensemble Weather Forecasts to Manage Utilities Risk", *Environmental Finance*, October 2004

Use Case: Decadal Survey Mission 3D Wind Lidar

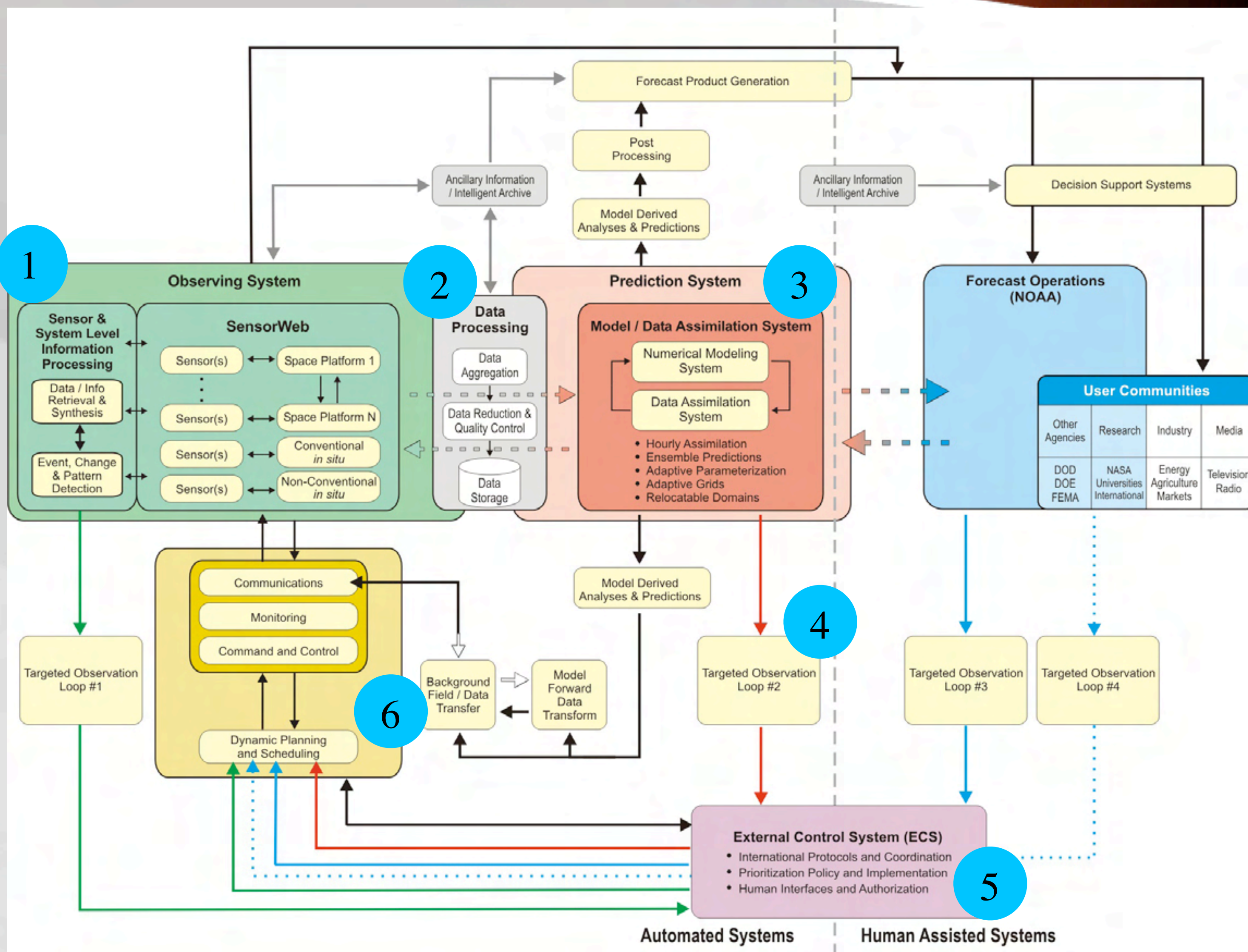


Source: Kakar, R., Neeck, S., Shaw, H., Gentry, B., Singh, U., Kavaya, M., Bajpayee, J., 2007: "An Overview of an Advanced Earth Science Mission Concept Study for a Global Wind Observing Sounder".

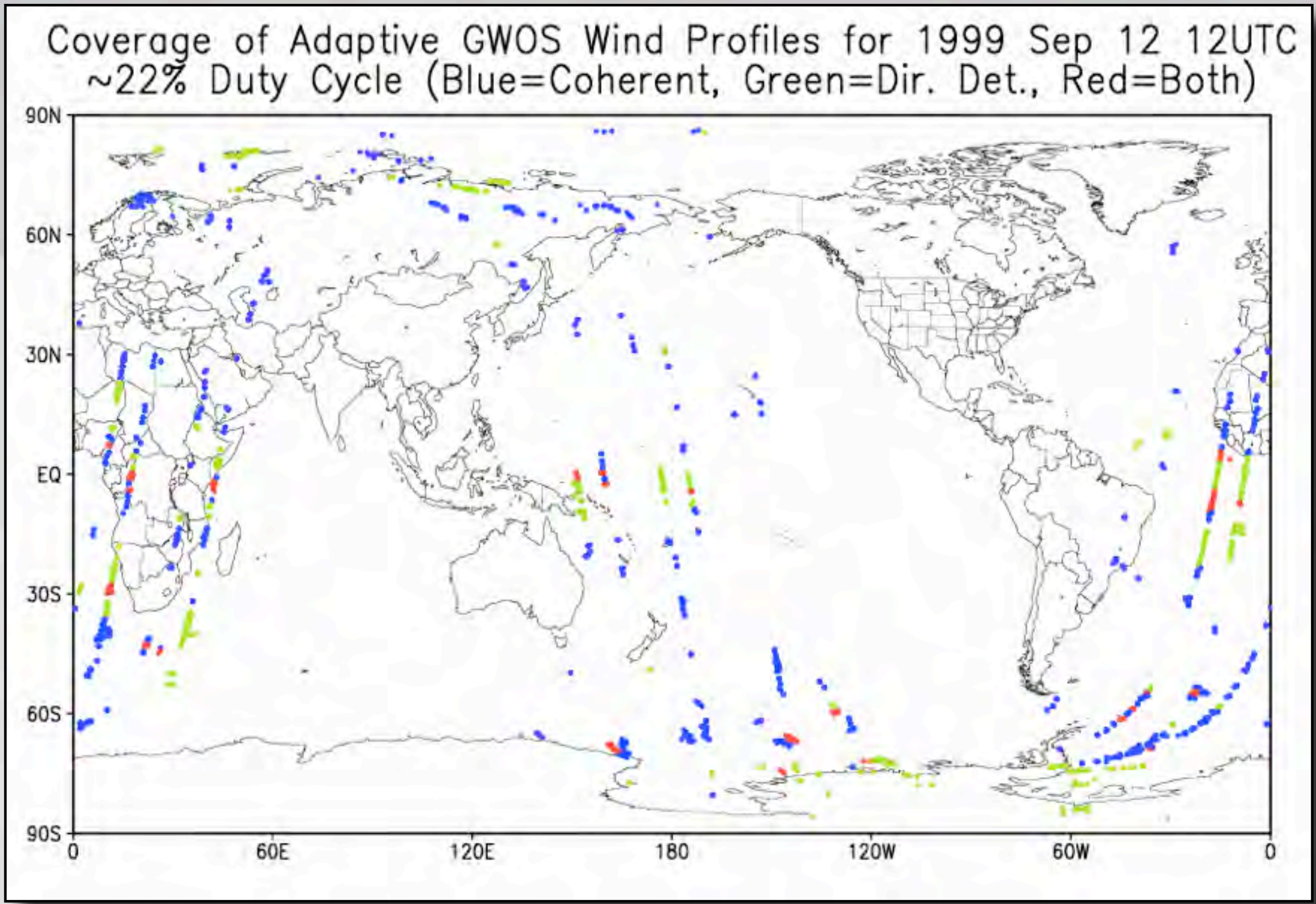
Application of Sensor Web Concepts

- **Simulation 1: <u>Extend Mission Life</u> via Power Modulation**
  - 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 minutes “on” and 80 minutes “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

Main Architecture ("Science Layer")



Simulation 1 Results

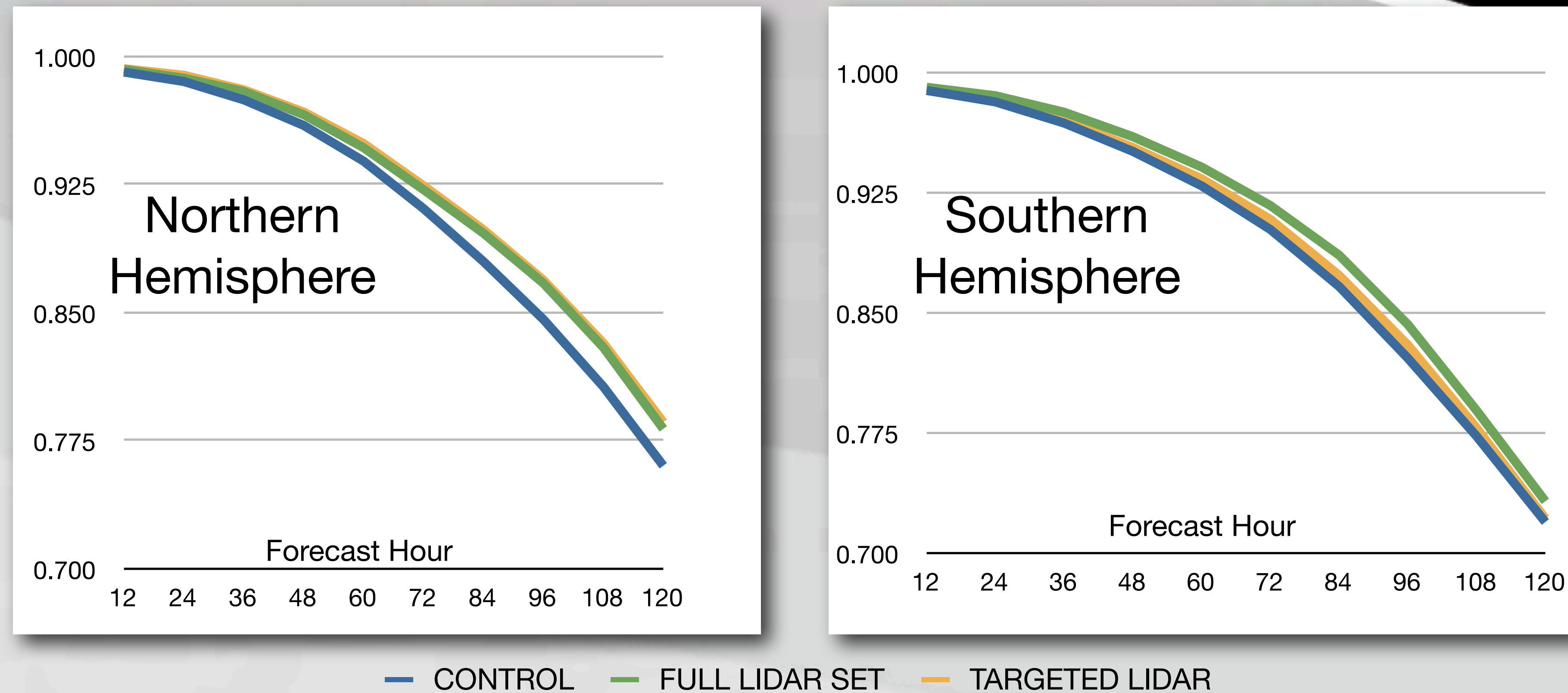


Lidar data deleted when there is "adequate" agreement with the numerical model's first guess wind fields

Designed to simulate suppression of the aft shot of the lidar

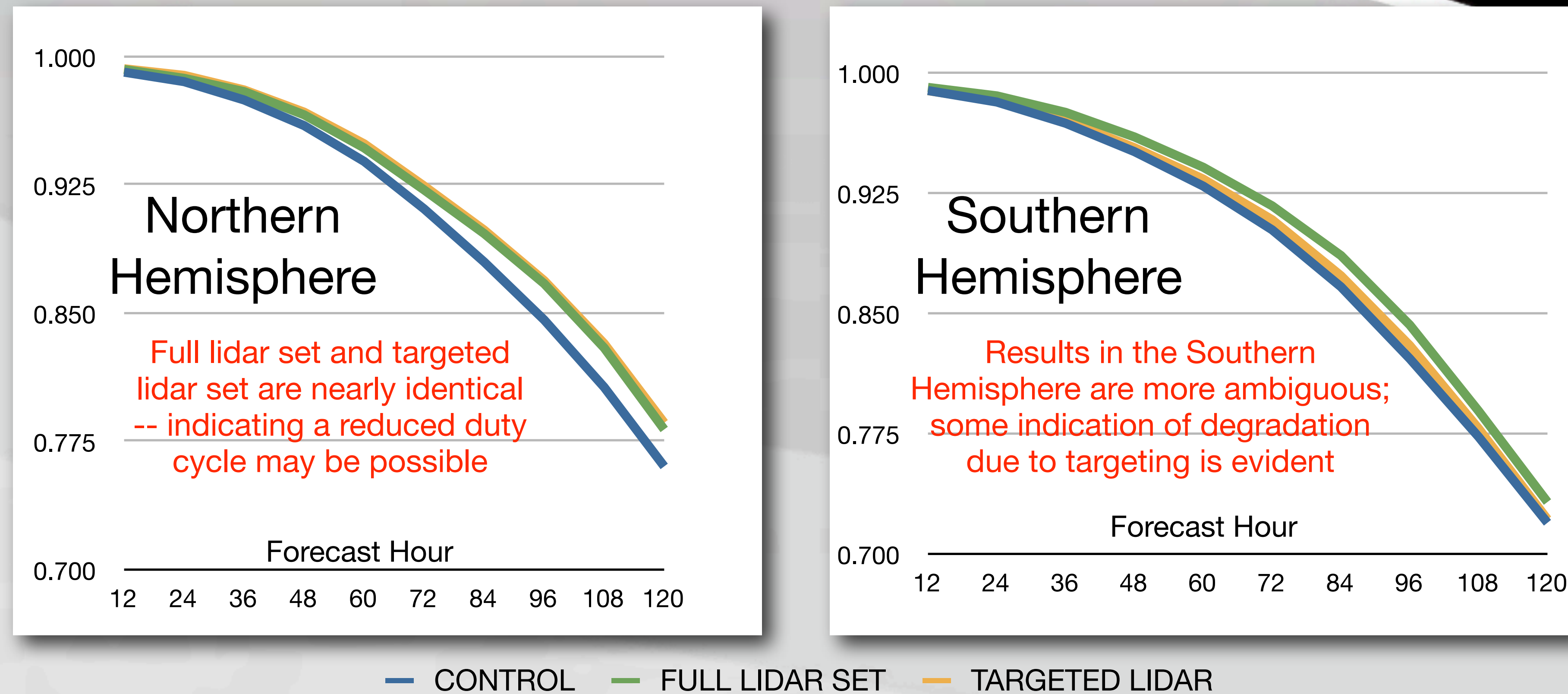
Result: Nearly 30% of the lidar's duty cycle may be reduced -- IF there is no discernible impact to forecast skill!

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

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

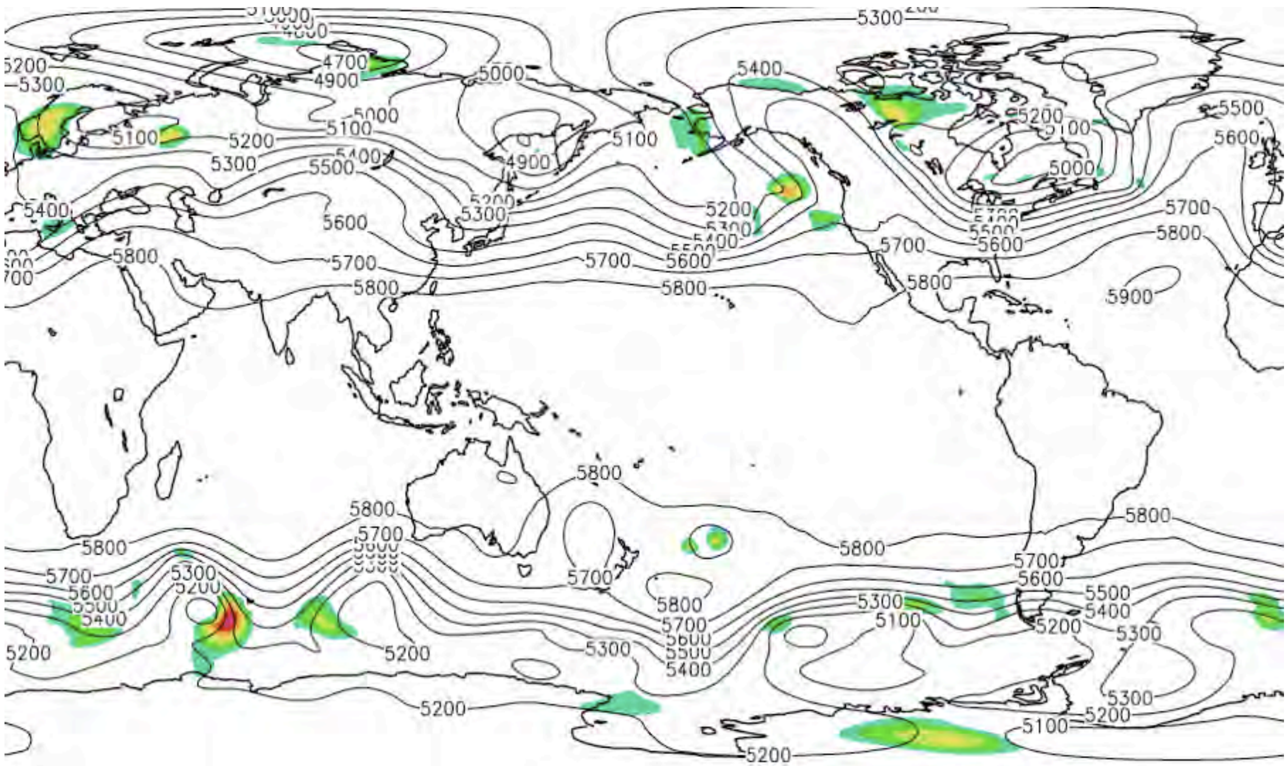
Application of Sensor Web Concepts

- **Simulation 2: <u>Better Science</u> via Targeted Observations**
  - Goal is to target two types of features to help improve predictive skill:
    - "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 require slewing
  - Would require optimization to choose between multiple targets
  - Studies have shown that targeted observations can improve predictive skill (difficult to implement operationally)

Source: D. Emmitt and Z. Toth, 2001: Adaptive targeting of wind observations: The climate research and weather forecasting perspectives. Preprints, 5th Symposium on Integrated Observing Systems, AMS.

Calculating "Sensitive Regions"

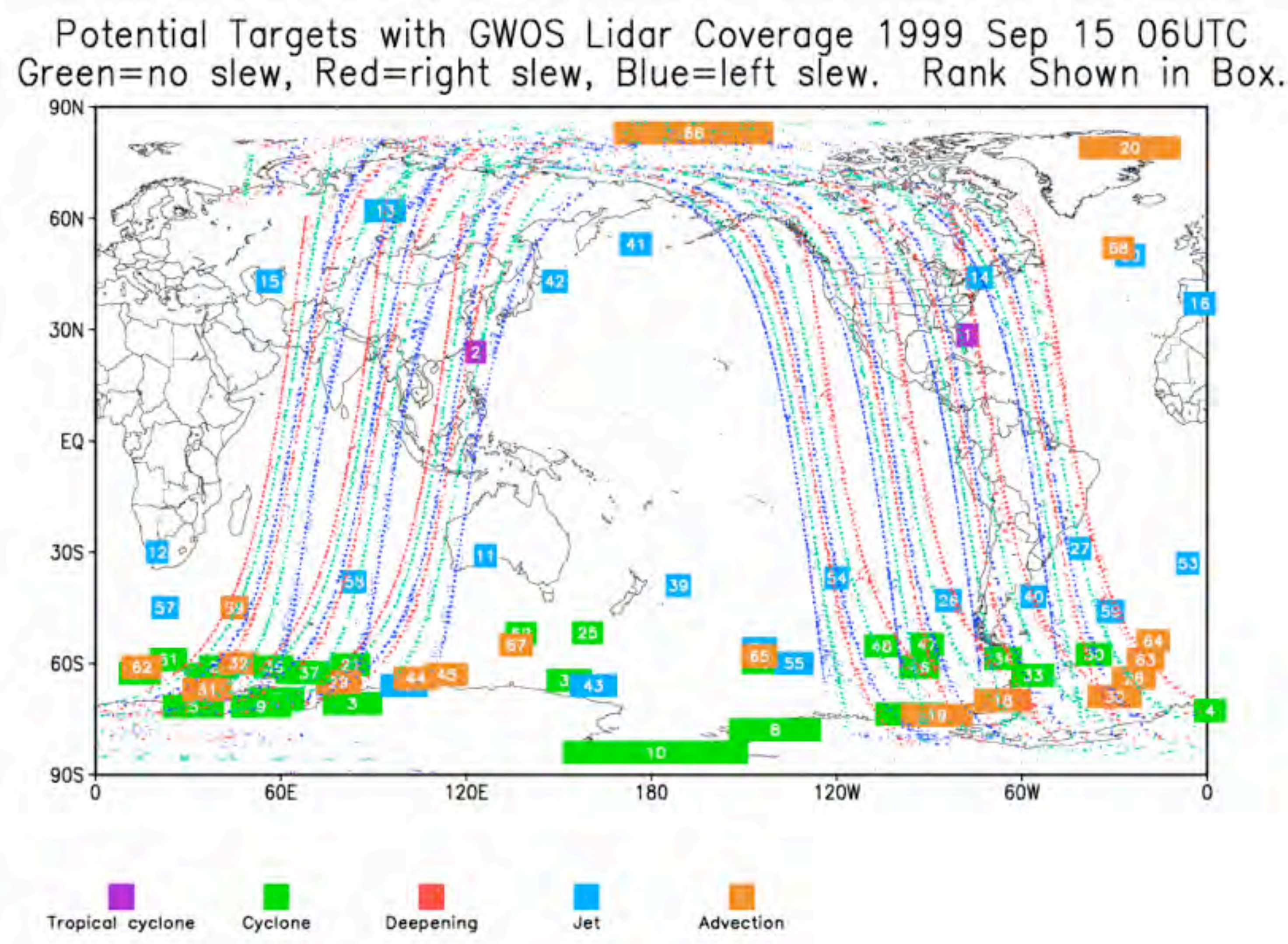
Differences between two forecasts launched 72 hours apart and valid at the same forecast hour. Largest differences ("sensitive regions") depicted in colored shading.



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 NASA's Global Modeling & Assimilation Office.

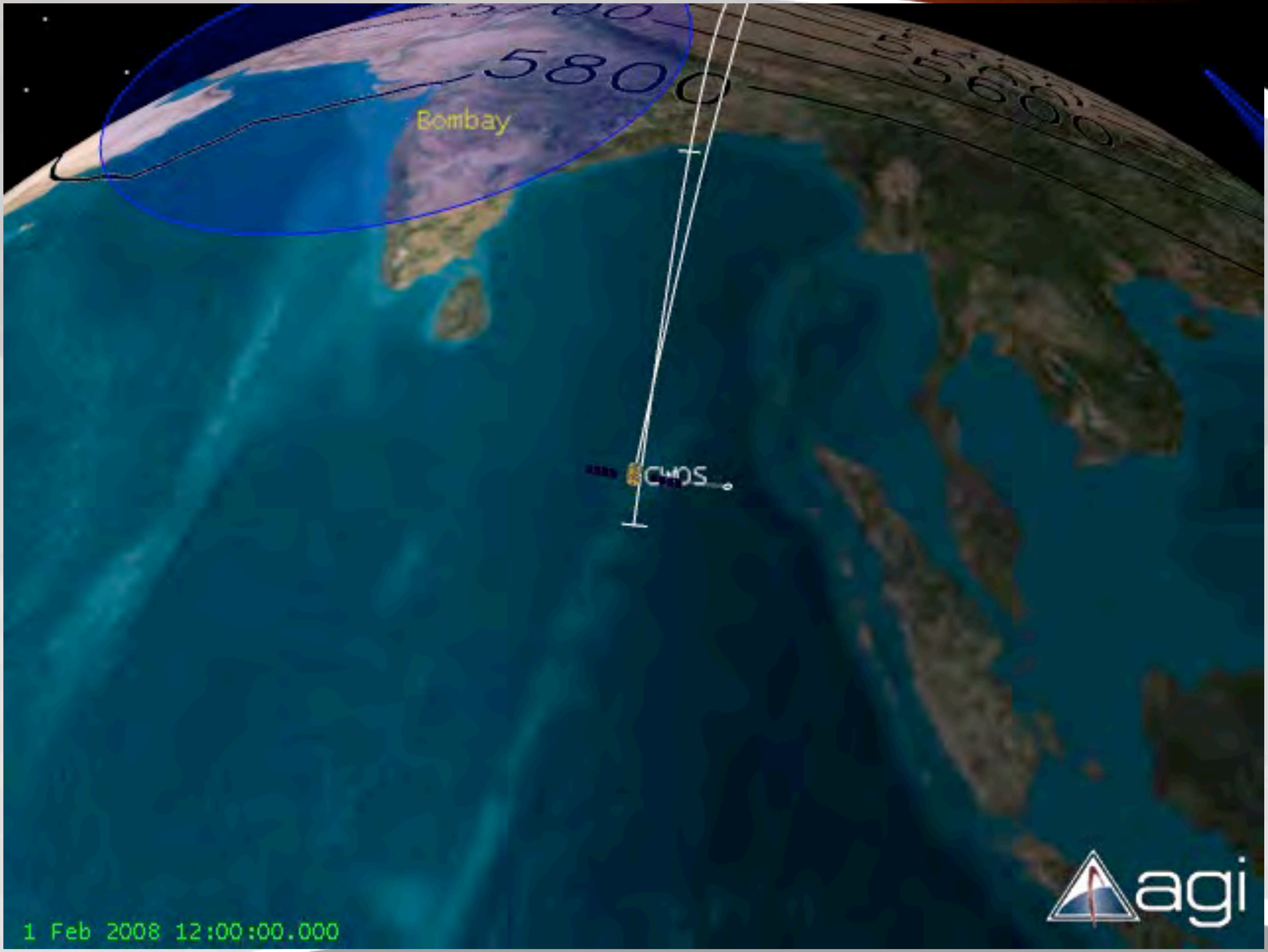
†Leutbecher, M., and A. Doerenbecher, 2003: Towards consistent approaches of observation targeting and data assimilation using adjoint techniques. Geophysical Research Abstracts, Vol. 5, 06185, European Geophysical Society.

Selecting Specific Targets



Simulation 2: Adaptive Targeting

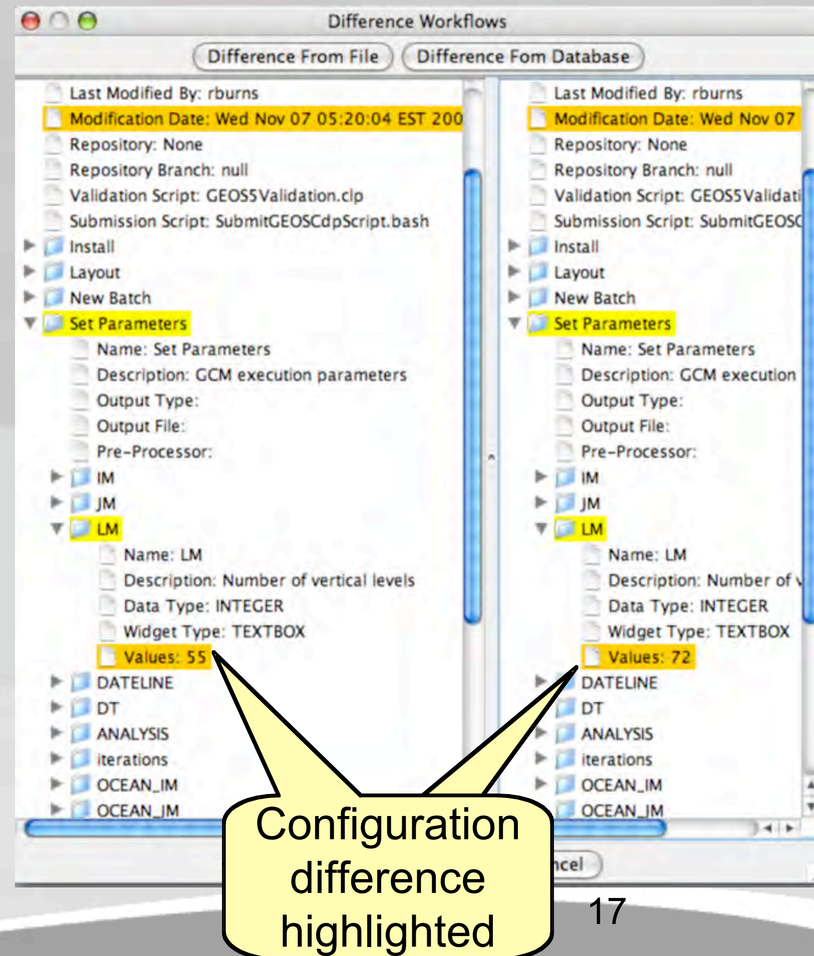
- [Click here to play movie]



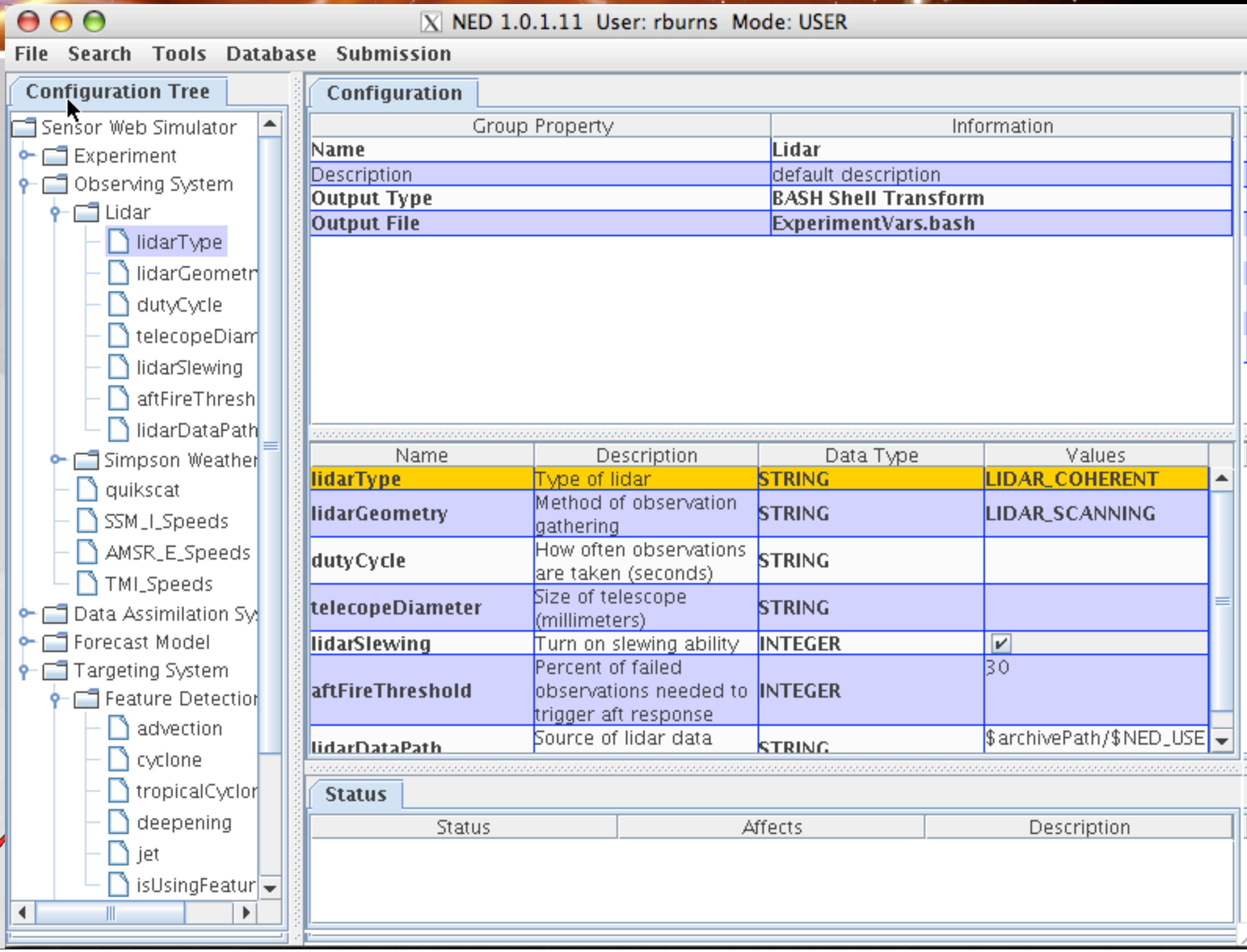
NASA Experiment Design (NED)

NED Features

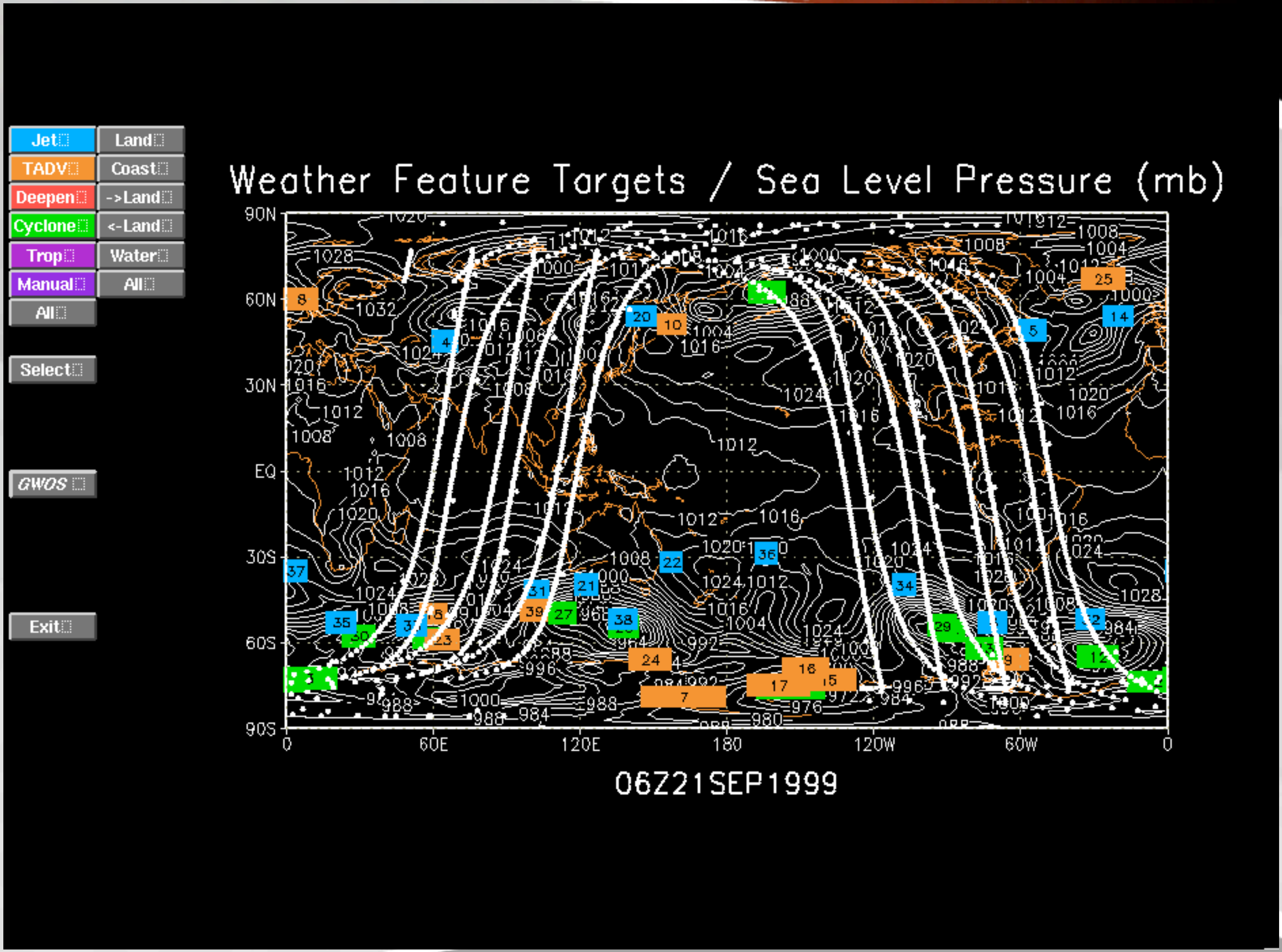
- GUI allows simple configuration of experiment workflow variables
- "Design-mode" to create **templates** for new experiment configurations
- **Save configured experiments** to files or a searchable database
  - Re-run past experiments
  - Share with other users
- **Compare experiment configurations** for changes
- **Version-controlled scripts**
  - Offer development branches
  - Automatic workflow updates



Simulator Example



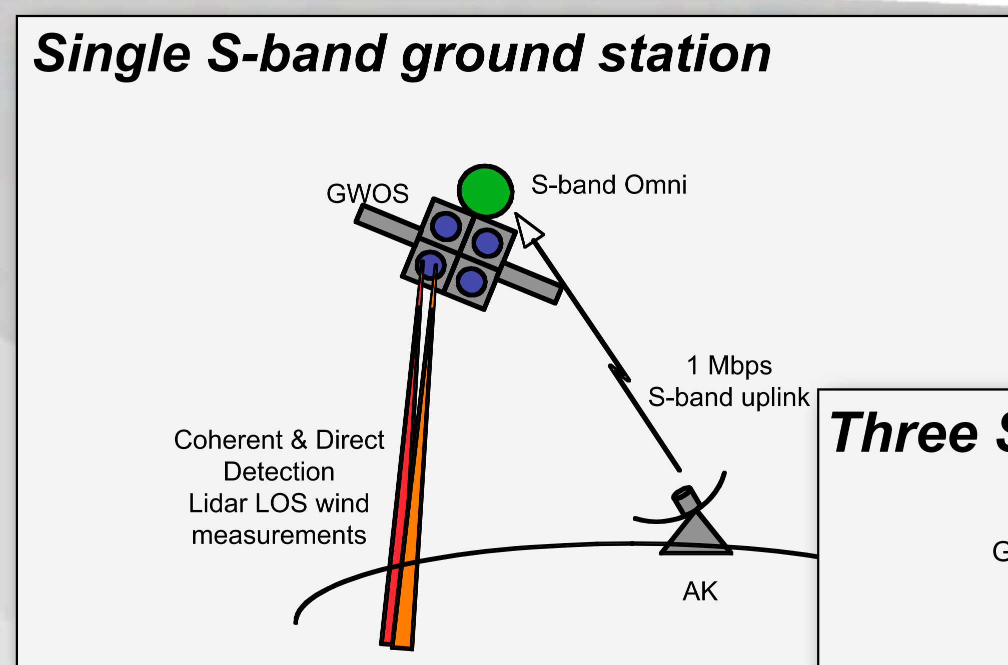
User-Directed Targeting

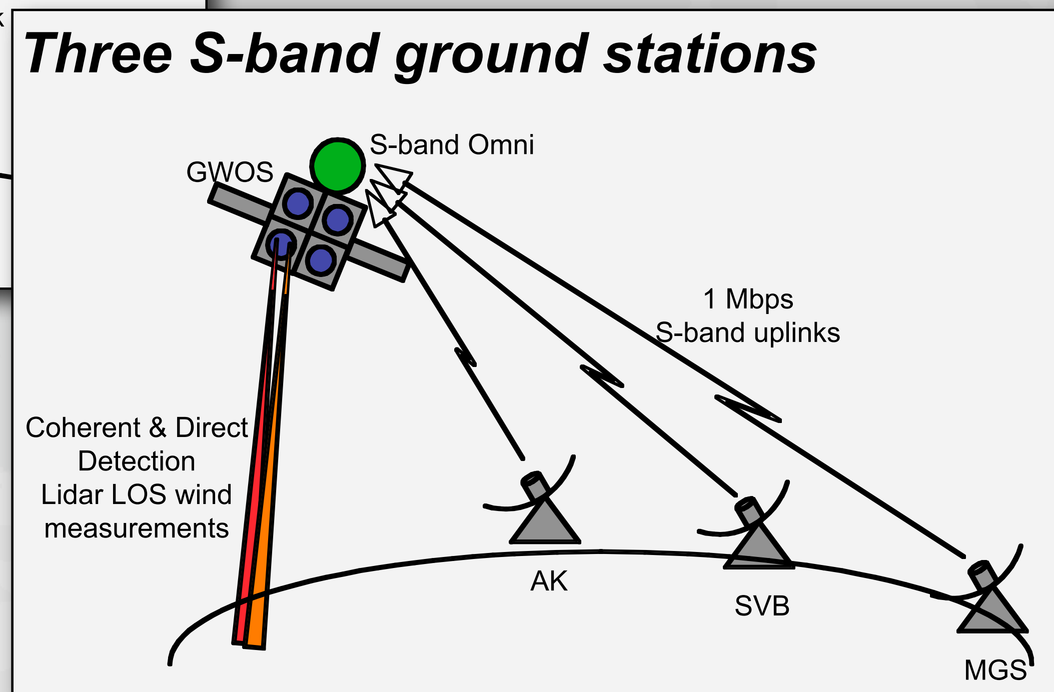


Options for Uplink Comms Requirements

Class	*Architecture*	*Forward Link Capacity*
Non-TDRS	S-band; AK ground station	1 Mb/s
	S-band; AK, SVB, MGS ground stations	1 Mb/s
	SafetyNet S-band Augmentation	1 Mb/s
	SafetyNet Ka-band Augmentation	25 Mb/s
TDRS	SSA	300 Kb/s, 1Mb/s
	SSA, KaSA	7 Mb/s
	KaSA	25 Mb/s
Hybrid	RF uplinks, Optical Cross Links	100-200 Mb/s

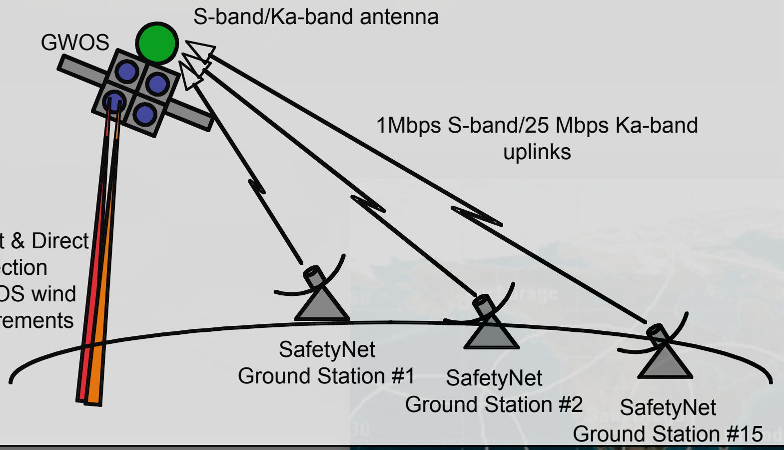
Non-TDRS "Classical" Ground Stations





Non-TDRS “Classical” Ground Stations

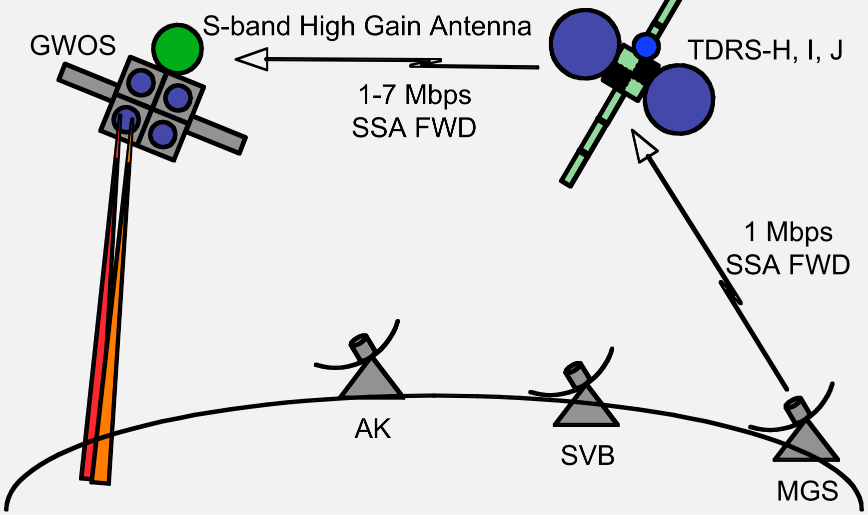
15 NPOESS SafetyNet ground stations S-band/Ka-band



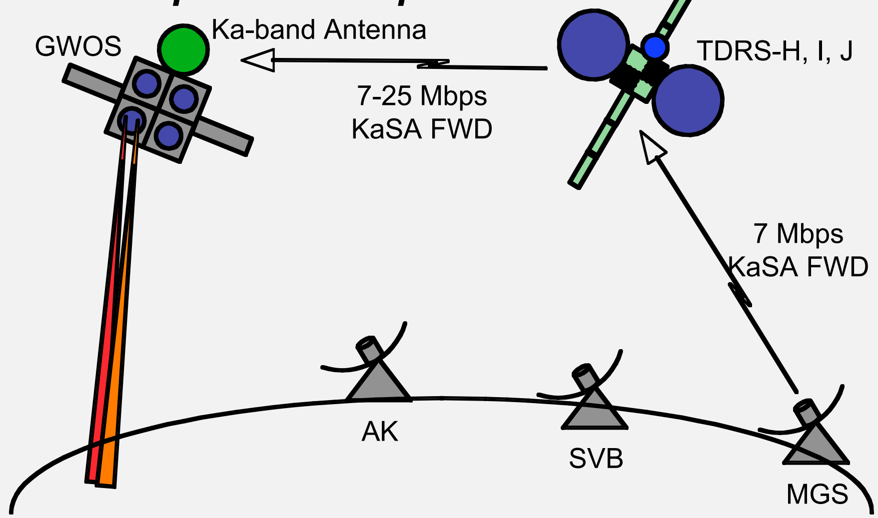
NPOESS SafetyNet Ground Stations

TDRS Forward Link Architectures

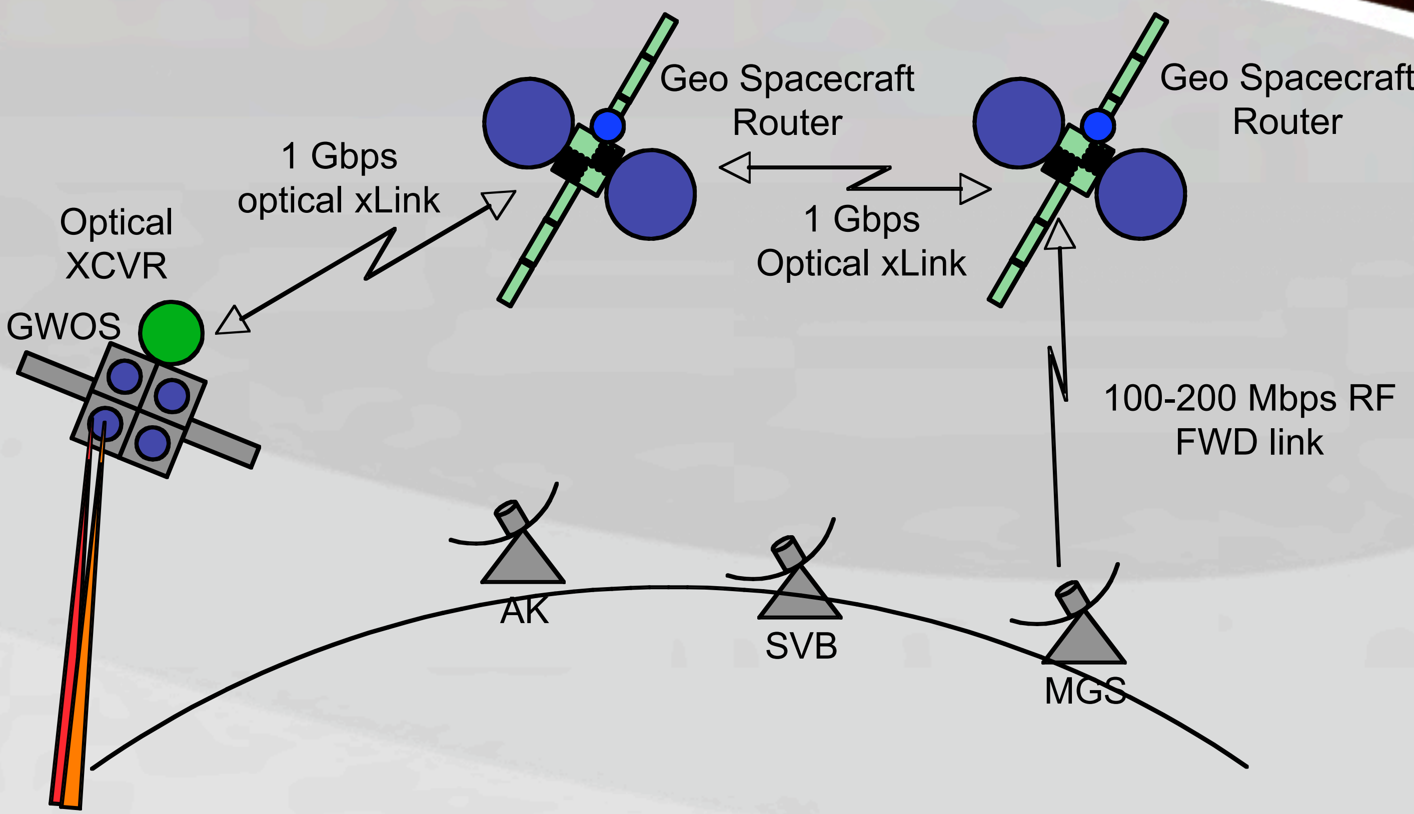
Current capability: 1Mbps
TDRS capable: 7Mbps



Current capability: 7Mbps
TDRS capable: 25Mbps



2030 Architecture



RF Uplinks and Optical Crosslinks (100-200 Mb/s)

Acronym List

ABI	Advanced Baseline Imager
DAS	Data Assimilation System
ECS	External Control System
EPOS	Earth Phenomena Observing System
FTE	Full Time Equivalent
GEOS5	Fifth-Generation Goddard Earth Observing System (numerical model)
GOES-R	Geostationary Operational Environmental Satellite “R” Series
GMAO	Global Modeling & Assimilation Office
GSI	Gridpoint Statistical Interpolation
GWOS	Global Wind Observing System
NHC	National Hurricane Center
NOAA	National Oceanic & Atmospheric Administration
OSSE	Observing System Simulation Experiment
SAIC	Science Applications International Corp
TEC	Targeting & External Control
UTC	Coordinated Universal Time

Approach

- **Sensor Web Simulator Design**
  - During 2007 most elements of the lidar use case (1-5) were executed “by hand” to help aid in the design of the simulator prototype
  - Five separate Observing System Simulation Experiments (OSSEs) were conducted that concluded:
    - Under certain situations[1], the lidar duty cycle may be reduced 30% without impacting forecast skill
    - Under certain situations, having the model task the lidar to perform a roll maneuver improves detection of features of interest 30% (tropical cyclones, jet streaks, rapidly changing atmospheric conditions)
- **SIVO Workflow Tool (“NASA Experiment Design”)**
  - Selected as the “glueware” to sequentially execute components 1-6 and manage data flow

1 The OSSEs performed were based upon a 20 day assimilation cycle during September 1999. Although the use cases have been examined by GMAO scientists they have not undergone a rigorous scientific review and the results should not be considered scientifically valid. OSSEs presented here are to validate engineering processes of the simulator.