End-to-End Design and Objective Evaluation of Sensor Web Modeling and Data Assimilation Architectures: Phase II

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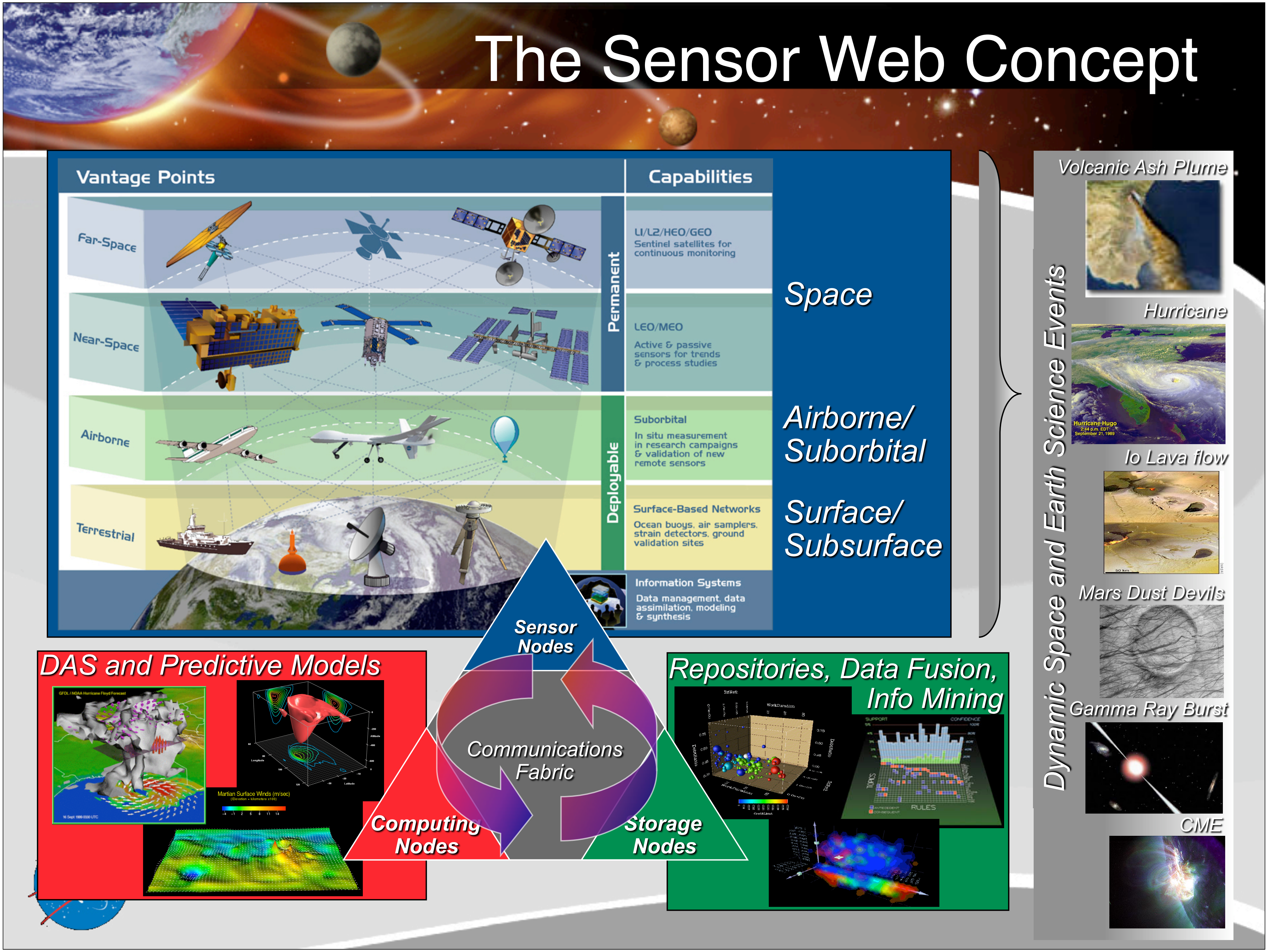


The Sensor Web Concept
Vantage Points
Capabilities
Far-Space
Near-Space
Airborne
Terrestrial
Permanent
Deployable
L1/L2/HEO/GEO
Sentinel satellites for continuous monitoring
LEO/MEO
Active & passive sensors for trends & process studies
Suborbital
In situ measurement in research campaigns & validation of new remote sensors
Surface-Based Networks
Ocean buoys, air samplers, strain detectors, ground validation sites
Information Systems
Data management, data assimilation, modeling & synthesis
Space
Airborne/ Suborbital
Surface/ Subsurface
Dynamic Space and Earth Science Events
Volcanic Ash Plume
Hurricane
Hurricane Hugo
Io Lava flow
Mars Dust Devils
Gamma Ray Burst
CME
DAS and Predictive Models
Martian Surface Winds (m/sec)
Sensor Nodes
Communications Fabric
Computing Nodes
Storage Nodes
Repositories, Data Fusion, Info Mining
RULES

Why Build a Sensor Web Simulator?

- Investing in the development and deployment of such large complex systems would be costly and involve significant risk
- Facilitates detailed studies of proposed sensor web observing systems before large investments are made to deploy them
- Objectively evaluate how predictive skill is affected by combinations of assets, instruments and measurement strategies

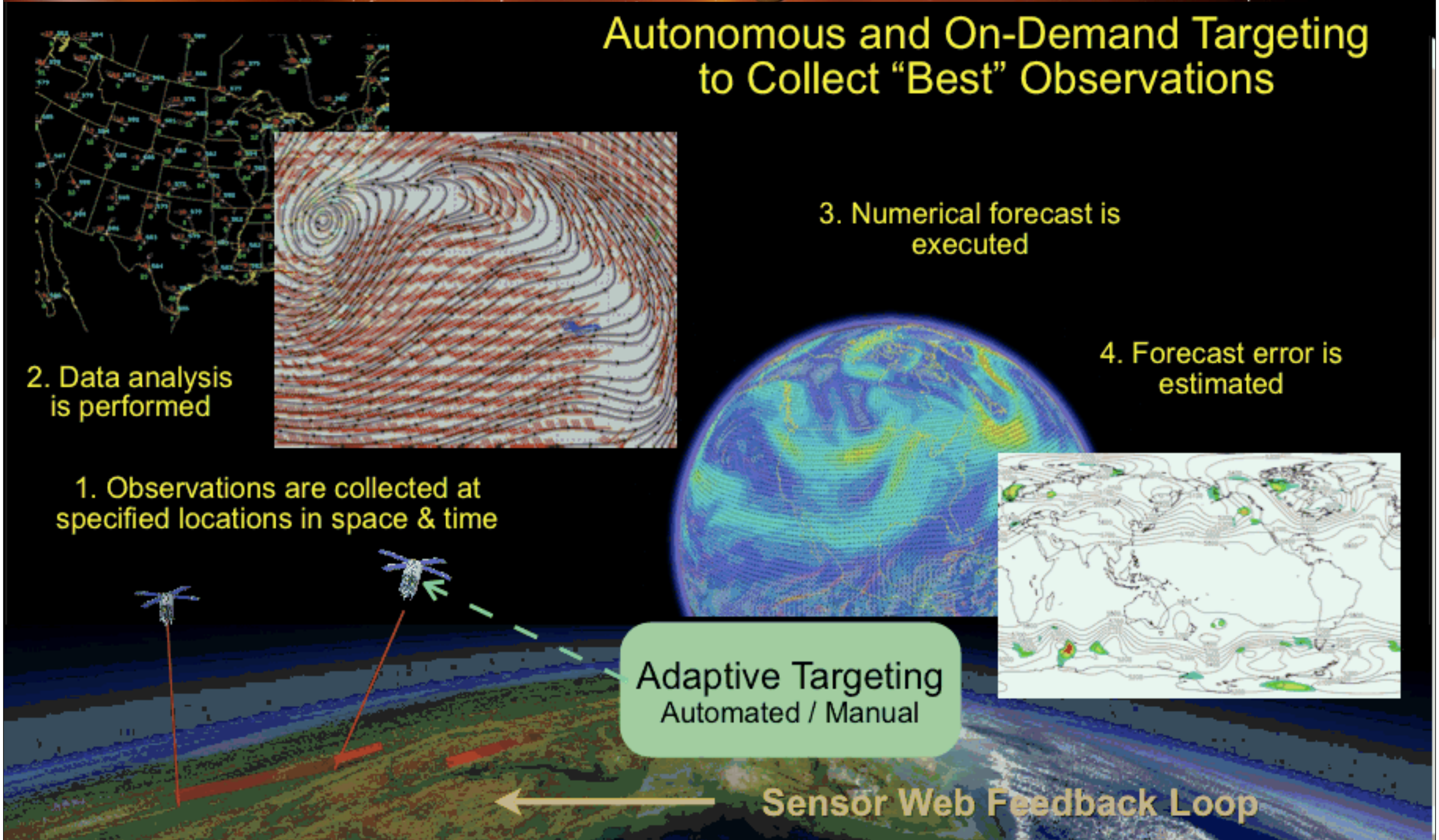
Project Goals

Demonstrate the value of implementing <u>model-driven sensor web</u> concepts for <u>meteorological use cases</u>

Quantify improvement in achieving science goals

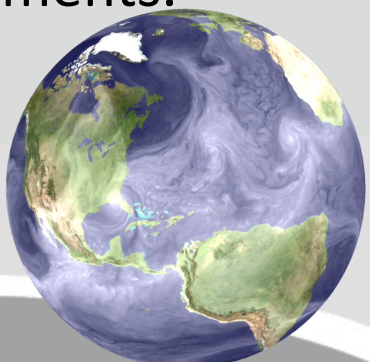
Design and Build an integrated simulator with functional elements that will allow multiple "What if?" scenarios in which different configurations of sensors, communication networks, numerical models, data analysis systems, and targeting techniques may be tested and evaluated

Model-driven Adaptive Targeting



Key Concepts

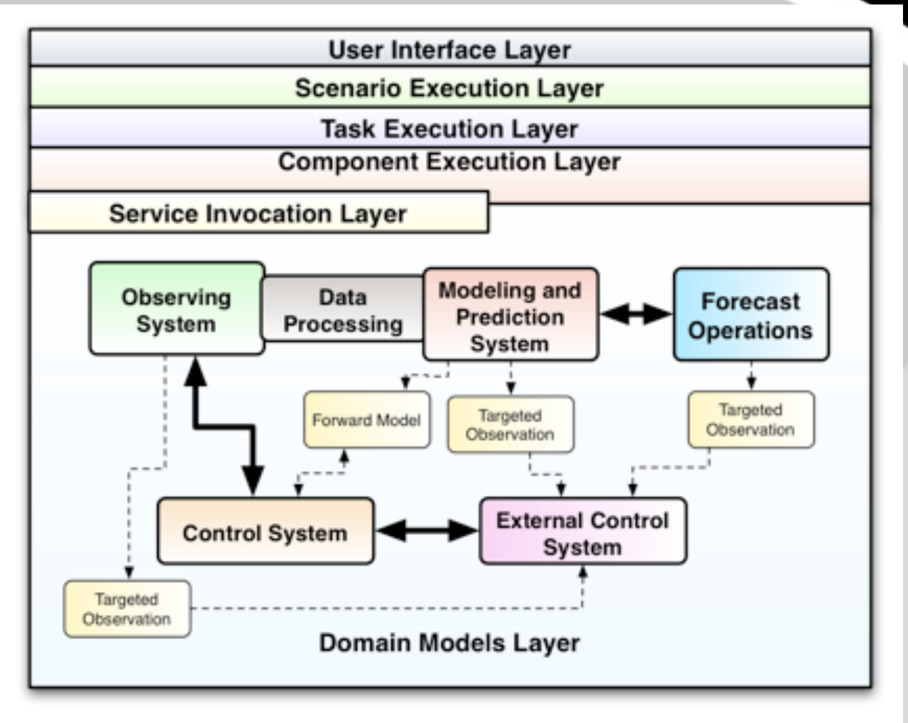
- Observing System Simulation Experiment (OSSE)
  - An experiment designed to assess the potential impact of a planned mission on Numerical Weather Prediction.
- Nature Run (NR)
  - A high resolution long integration from a state-of-the-art numerical weather prediction model.
  - A proxy atmosphere for OSSE's to derive synthetic observations from existing and future observing systems.
- Data Assimilation System (DAS)
  - Assimilates observations and generating forecasts. It is the mechanism for conducting observing system experiments.
  - e.g., GEOS-5, WRF, NCEP GDAS



Simulated Clouds from the fvGCM Nature Run

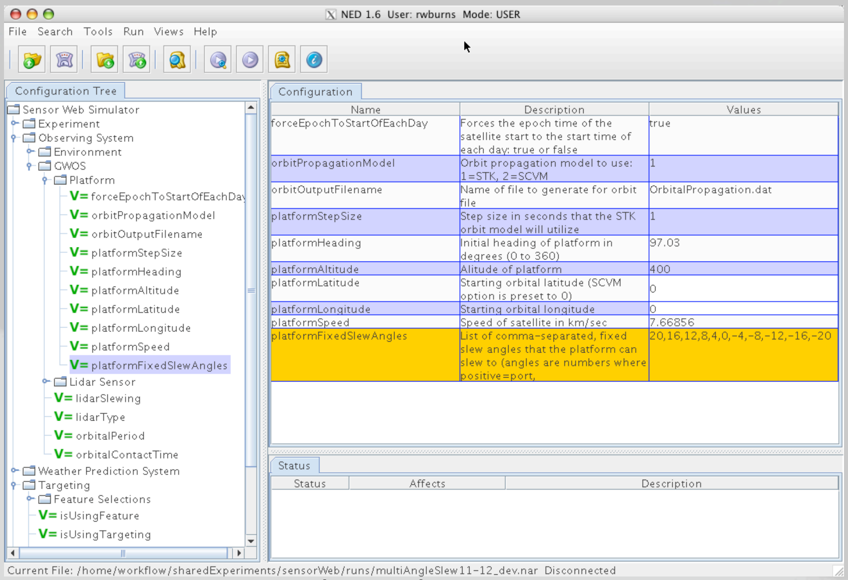
Phase I Summary

- Phase I ~2006 - 2008
- Developed SWS software architecture
- Designed & implemented initial core suite of software to perform preliminary "proof-of-concept" testing
- Designed and tested preliminary use case scenarios for a single spacecraft mission – GWOS (aka Decadal Survey "3D Wind Lidar Mission")

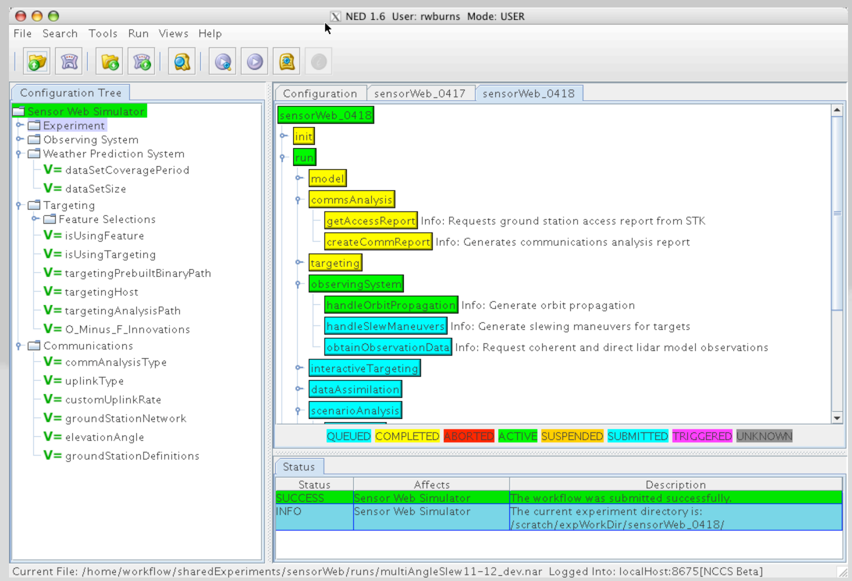


Sensor Web Simulator layered architecture:
- user interface
- scenario execution
- science and engineering models

User Interaction and Simulation Monitoring



Work Flow Tool (WFT) setup for GWOS. The user can modify these settings and then launch a new simulation.



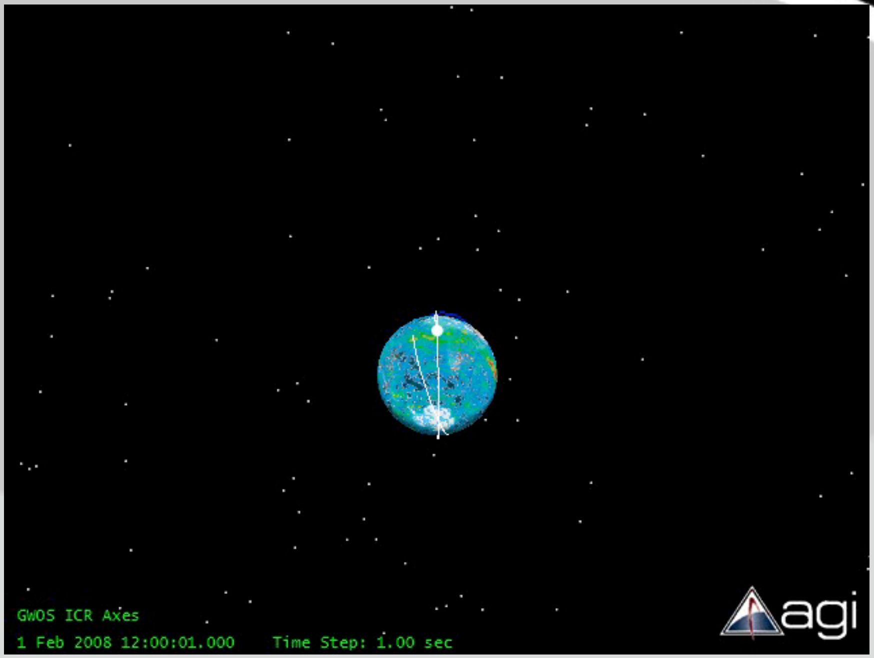
WFT monitor mode shows a simulation in progress. The green task shows it is currently computing the orbit for the GWOS platform.

Phase I: Use Case Mission
Decadal Survey Mission *3D Wind Lidar*

- Global Wind Observing Sounder (GWOS)
- Doppler Wind Lidar (DWL) mission.
- Launch: ~2020
- Orbit: 400km, sun synchronous polar orbit
- Instrument: Direct detection and coherent detection lidars.
- Generate vertical profiles of the horizontal wind field
  - A global 3-D picture of the dynamical atmospheric state.

Use Case #1
Extend Mission Life via Power Modulation

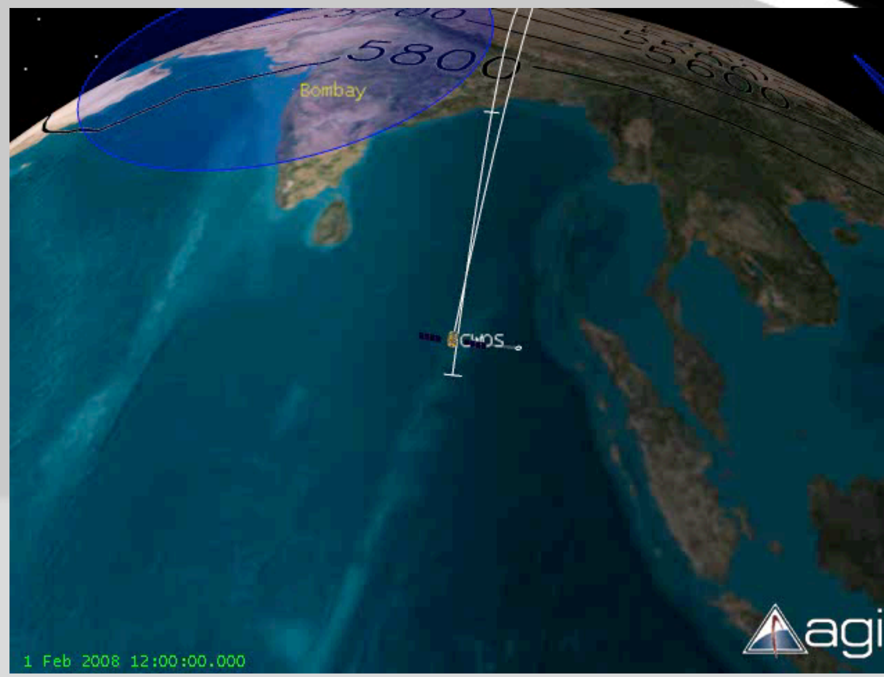
- Conserve power / extend instrument life by using aft shots only when there is "significant" disagreement between model first guess line-of-sight winds and winds measured by fore shots
- Model's first guess fields must be uplinked and stored on board the spacecraft



White ellipses: Forward LOS lidar shots
Yellow ellipses: Model LOS <> Measured LOS
Red ellipses: Aft LOS lidar shot required/taken

Use Case #2
Better Science via Targeted Observations

- Studies have shown that targeted observations can improve predictive skill*
- Goal - target features to help improve predictive skill:
  - "Sensitive regions" of the atmosphere where the forecast is highly sensitive to analysis errors
  - Features outside of instrument's nominal attitude field of view (e.g.,)
    - Tropical cyclones
    - Jet streaks
    - Rapidly changing atmospheric conditions
- Targeting optimization algorithms needed to choose between multiple targets



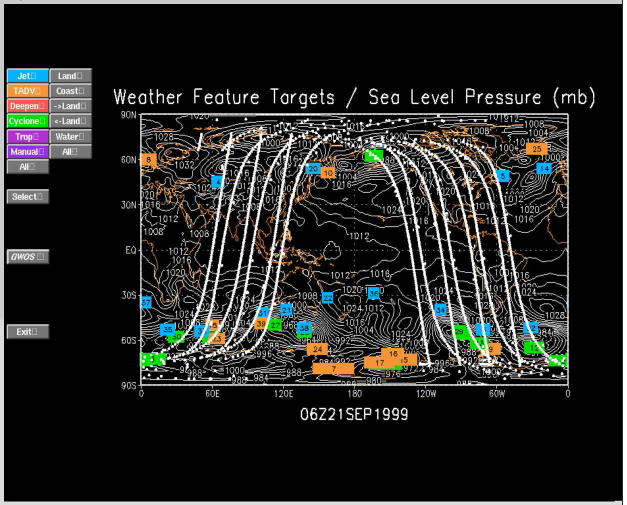
* **Source: D. Emmitt and Z. Toth, 2001: Adaptive targeting of wind observations: The climate research and weather forecasting perspectives. Preprints, 5th Symposium on Integrated Observing Systems, AMS.**

Phase I: Preliminary Results Use Case 1

- We set up:
  - A control case (i.e., no lidar data used)
  - Test case in which lidar data used only where there was "significant" disagreement with the forecast winds
  - A case with all lidar data used
- 80% of the lidar wind profiles compared favorably with the model first guess and were withheld from the data assimilation cycle.
- Realized a duty cycle reduction of about 30%.
- The simulation of a reduced lidar duty cycle (i.e. targeted observations only) was similar to the full lidar results in the Northern Hemisphere.
- Results for the Southern Hemisphere were more difficult to interpret.

Phase I: Preliminary Results
Use Case 2

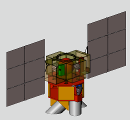
- Experiments examined impact of slewing GWOS for adaptive targeting.
  - Identifying "sensitive regions" in the atmosphere
  - Autonomously detect features of interest (e.g., tropical cyclones)
  - Features of interest identified by meteorologist
- Targets were prioritized
  - Feature is over land
  - Feature is over the coastline
  - Feature is over ocean but is approaching land
  - Feature is over ocean and is moving away from land
  - Feature is over ocean and is far from land (> 1000km)
- Calculated difference between a 12-and 36-hour forecast of 500-hPa heights valid at the same time.



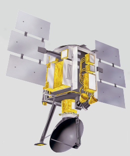
- Areas of large differences are identified as targets. GWOS is then tasked to observe these targets and may have to perform a roll maneuver (i.e., slew).
- Approximately 33% additional data were captured over the targeted features.

Phase II Overview

- Phase II March 2009 – Feb 2012
- Expanding capabilities and flexibility
  - 2 GWOS satellites in different orbits
  - Add new types of sensors
  - Add new spacecraft
- Selected 3 missions for our next use case



Global Wind Observing Sounder (GWOS): 3D wind profiles

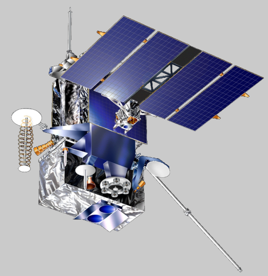


Extended Ocean Vector Winds Mission (XOVWM) or similar mission such as the Dual Frequency Scatterometer (DFS): 10-meter winds over the oceans.

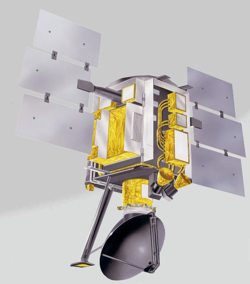
Geostationary Operational Environmental Satellite “R” Series (GOES-R): High resolution visible/infrared imagery, cloud track winds

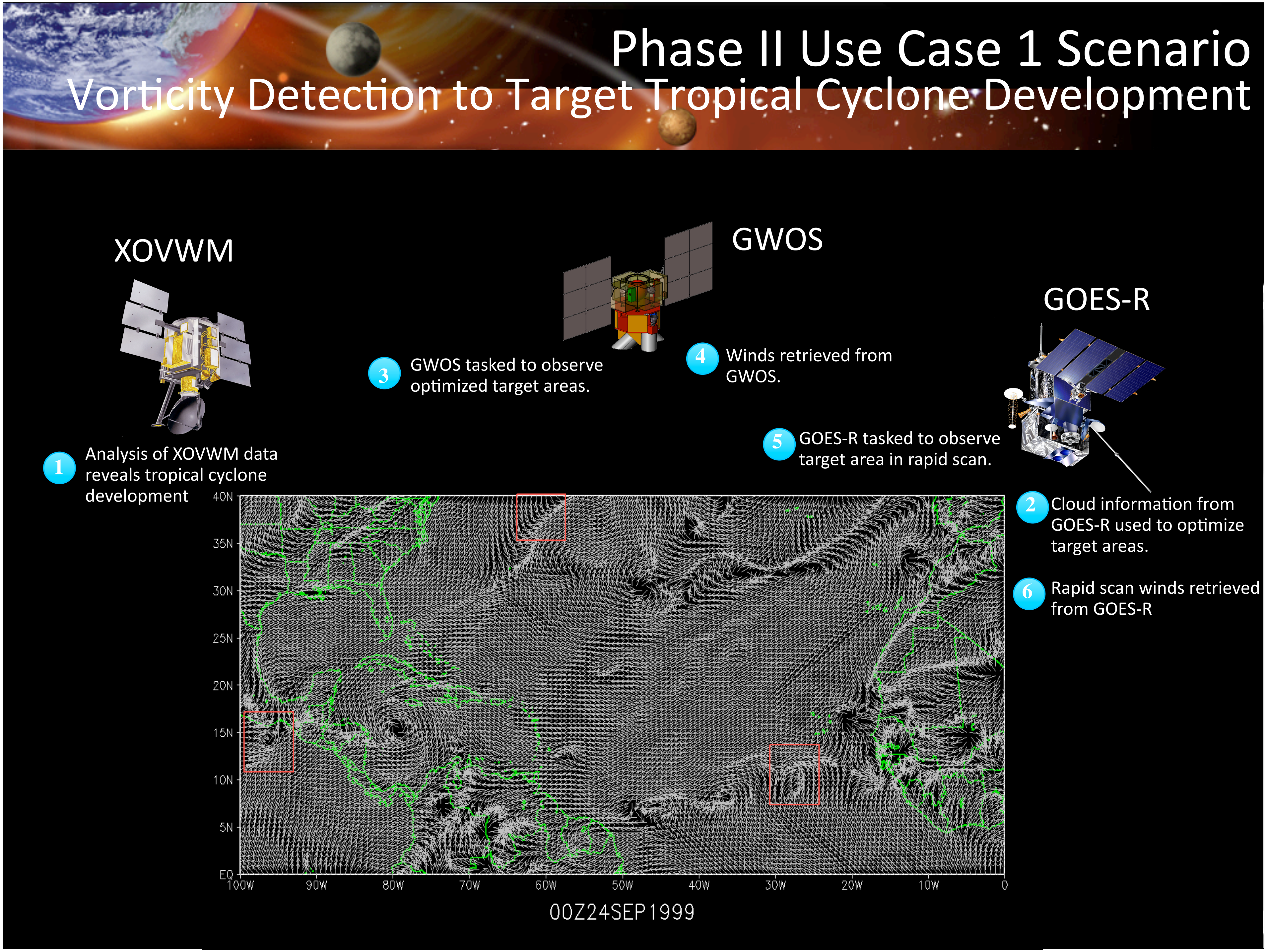
Phase II
Use Case 1 Missions

- Geostationary Operational Environmental Satellite-R Series (GOES-R)
- Launch: ~2015
- Orbit: Geosynchronous
- Instruments
  - 16 channel Advanced Baseline Imager
  - Spatial resolution: 0.5 km visible; 1 km near-IR; 2 km IR
  - Full earth disc every 15 mins (“Flex” Mode 3) or every 5 minutes (“Continuous” Mode 4)
  - CONUS every 5 minutes
  - Mesoscale frame every 30 secs.



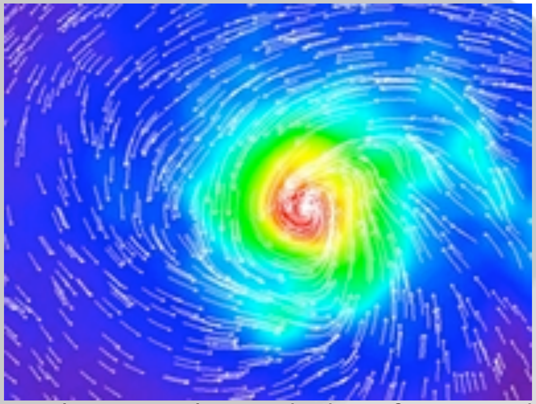
- Extended Ocean Vector Winds Mission (XOVWM)
- Proposed QuikSCAT follow-on
  - All-weather, high horizontal spatial resolution measurements of global ocean surface wind speed & direction
- Launch: 2013 - 2016
- Orbit: 800 km altitude, sun synchronous, polar orbit
- Instruments
  - C-band scatterometer
  - Ku-band SAR
- Possible 2 spacecraft constellation to meet NOAA coverage needs




Phase II Use Case 1 Scenario
Vorticity Detection to Target Tropical Cyclone Development
XOVWM
GWOS
GOES-R
1 Analysis of XOVWM data reveals tropical cyclone development
2 Cloud information from GOES-R used to optimize target areas.
3 GWOS tasked to observe optimized target areas.
4 Winds retrieved from GWOS.
5 GOES-R tasked to observe target area in rapid scan.
6 Rapid scan winds retrieved from GOES-R
40N
35N
30N
25N
20N
15N
10N
5N
EQ
100W
90W
80W
70W
60W
50W
40W
30W
20W
10W
0
00Z24SEP1999

Phase II Status

- In progress or completed
  - Developed hurricane use case
  - Selected two Decadal Survey missions + GOES-R
  - Selected TC development period (24Sep99 – 09Oct99)
  - Selected and tested vorticity algorithm
  - Approximated XOVWM using QuikSCAT data
  - Generated XOVWM targets
  - Simulated GOES-R cloud motion winds
  - Simulating GWOS LOS and full vector winds
- Conduct use case experiments (July/August)
  - Run GEOS-5 DAS for TC development period and initiate 5-day forecasts every 6 hours
  - Run control experiment
  - Run control + different combinations of XOVWM, GWOS, GOES-R
  - Compute statistics (TC track/intensity errors) for each forecast



QuikSCAT color coded surface wind speed and direction vectors of hurricane Dora (Credit: NASA)

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