Adaptive Targeting Schemes and Their Technology Implications

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SWA

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Outline

- Targeting objectives
- Targeting techniques
- Technology implications

Targeting Objectives

- Concentrate limited platform resources to achieve maximum data utility
  - Who’s utility?
  - Metrics
- Avoid nighttime operations
  - Battery issues
  - Background issues
- Selective use of instrument to increase on-orbit lifetime
- Avoid interference with other instruments on same platform
- Optimize sampling pattern for Targets of Opportunity

Primary Targets for Hybrid/AT*

- Significant Shear regions
  - Requires contiguous observations in the vertical. Thus both direct and coherent detection technologies are needed.
- Divergent regions
  - Requires some cross track coverage. Identified by NCEP adaptive targeting scheme(s)
- Partly cloudy regions
  - Requires measurement accuracy weakly dependent upon shot integration (i.e., coherent detection).
- Tropics
  - Tropical cyclones (in particular, hurricanes & typhoons). Requires penetration of high clouds and partly cloudy scenes.

*AT: Adaptive Targeting

The Adaptive Targeting Mission

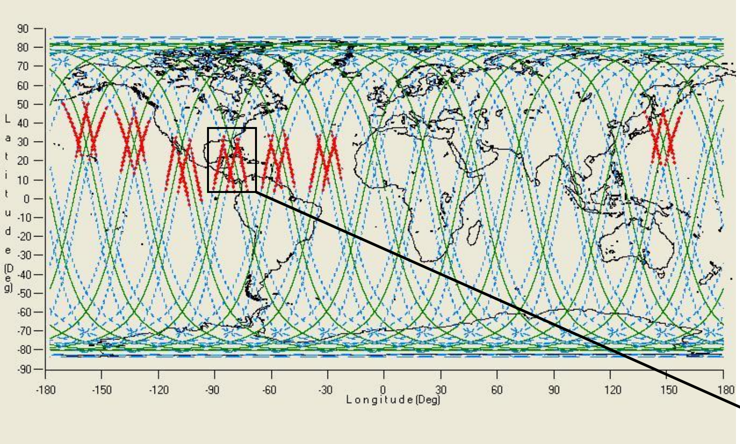
- Adaptive targeting of tropospheric wind profiles for high impact weather situations
  - Hurricanes/typhoons (Navy)
  - Air quality “episodes” (Army)
  - Mid and high latitude cyclones (DoD)
  - Civilian and military aircraft operations (DoD)
  - Stratospheric/Tropospheric Exchange (USAF)
- Coherent detection sub-system (wedge scanner or HOE)
  - 100% duty cycle
  - Lower tropospheric and enhanced aerosol/cloud winds
  - CMV height assignment
    - Reduce DAS observation error by ~2-3 m/s
  - Depth of PBL
  - Initial Condition Adaptive Targeting (ICAT) for managing direct detection
- Direct detection (molecular) sub-system (using HOE)
  - 10-15% duty cycle (aperiodic, i.e. adaptively targeted)
  - Cloud free mid-upper tropospheric/ lower stratospheric winds

Evaluation of adaptive targeting of DWL observations

- IPO has funded AT studies at NOAA/NCEP and NASA/GSFC that have shown that adaptive targeting (10-15% duty cycles) can produce impacts that rival 100% duty cycle operations.
- IPO and the THORPEX are currently funding OSSE*s at NCEP and GSFC to better quantify the AT impacts and evaluate methods of identifying targets.
- Field programs such as NASA's CAMEX and NOAA's WSR have field demonstrated the value of adaptive targeting.
- Many military needs would be met with targeted wind observations.

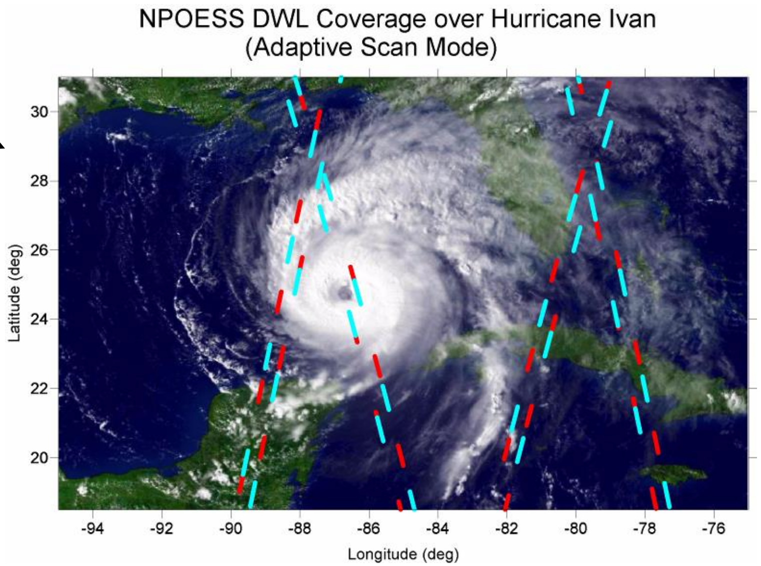
* OSSE: Observing System Simulation Experiment

Adaptive Targeting For NPOESS

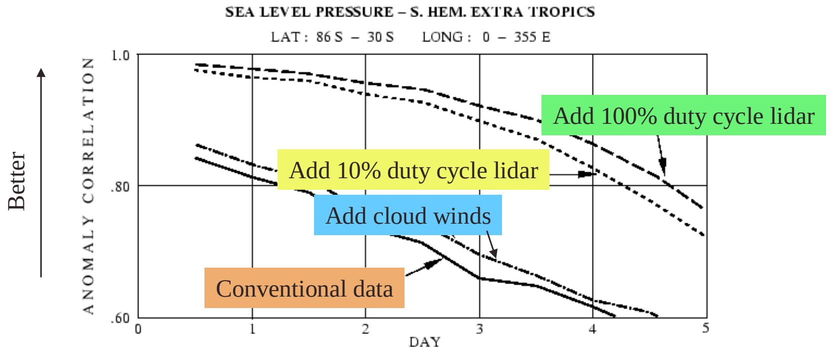


Adaptive targeting with emphasis on CONUS interests

(Blue is coherent coverage
Red is both coherent and direct)



Adaptive Targeting Experiments



Model: GEOS-2 Recon.
Verification: ECMWF Nature Run

Control: - Conventional Data + Perfect TOVS
CTW - Control + Cloud Tracked Winds
1 m/s Wind - Control + Doppler Wind Lidar (RMSE = 1 m/s)
Adaptive Targeting - Control + Adaptive Targeting of DWL Observations (~10% duty cycle)

Example of targeting a hurricane as it approaches the Gulf coast. (blue segments: forward looks; Red segments: aft looks; Blue plus red Provide full horizontal wind vector)

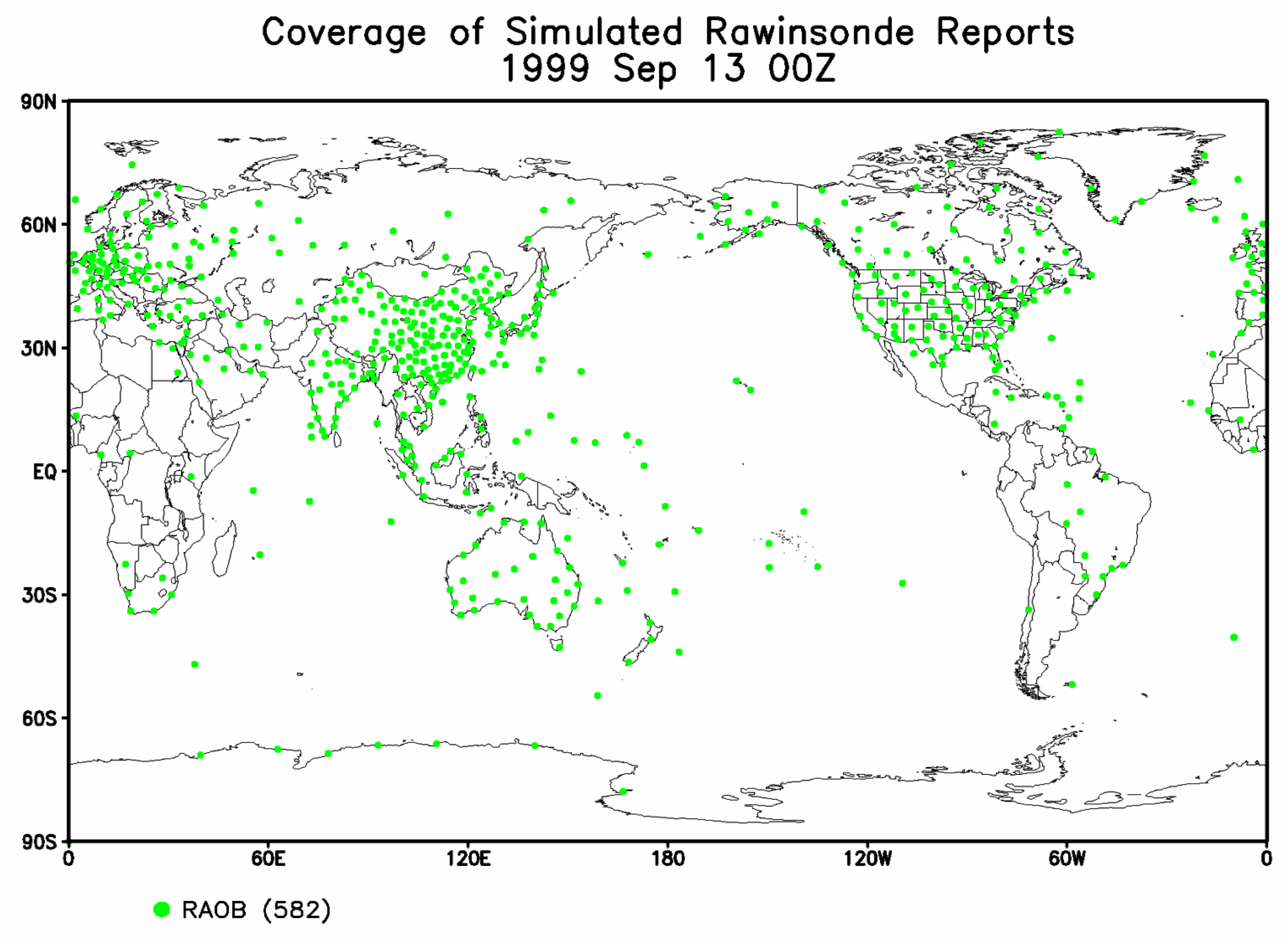
Targeting Options

- Operate at high/low PRF
- Operate instrument in on/standby modes
  - Short standby (< 1 minute)
  - Long standby (> 30 minute)
- Rotate FOR to obtain enhanced coverage of targets that are off center from the satellite ground track
- Vary dwell times to achieve improved accuracy or cloud penetration probabilities
- Vary timing of individual “shots” to target cloud gaps

Target Selection Schemes

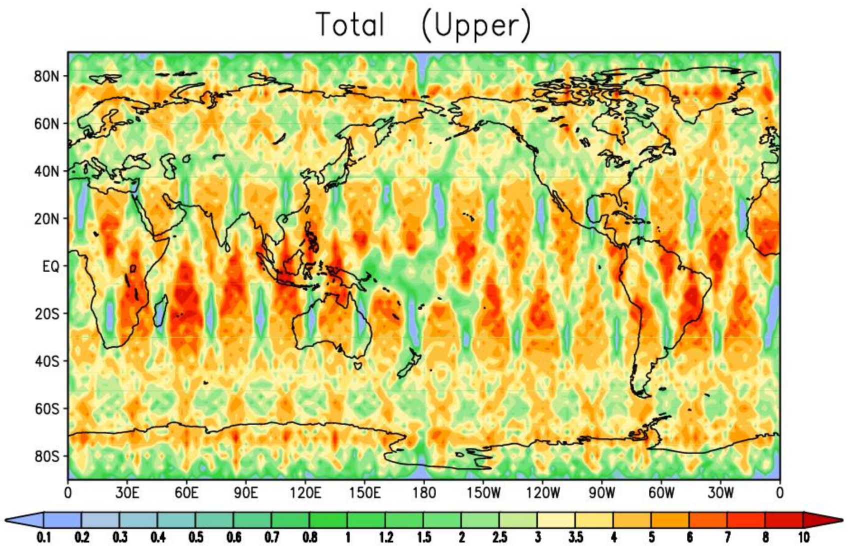
- Pre-launch target definition
  - Fixed on/standby program (e.g. on only over Tropics, only between 20N and 60N, only over water)
- Post-launch target selection
  - Ground based target selection; uploaded to satellite
  - On-board target selection

Current tropospheric wind profiles from rawinsondes

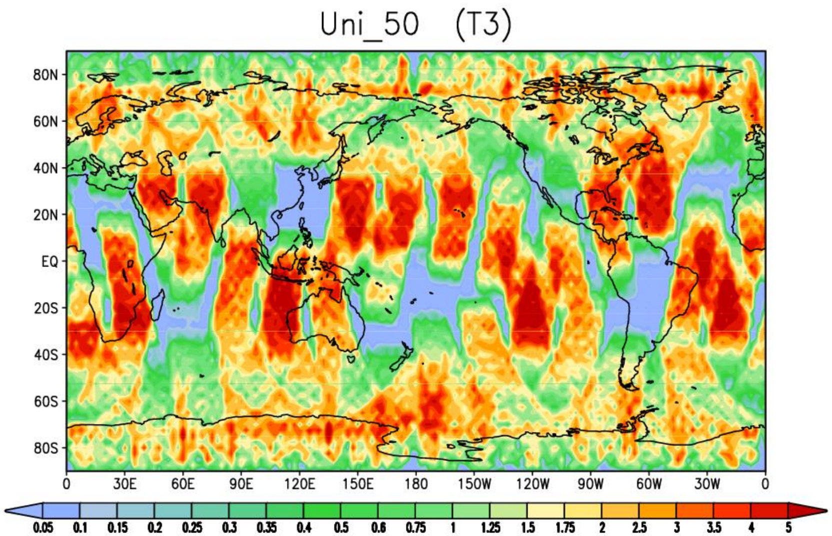


Data selection Cases

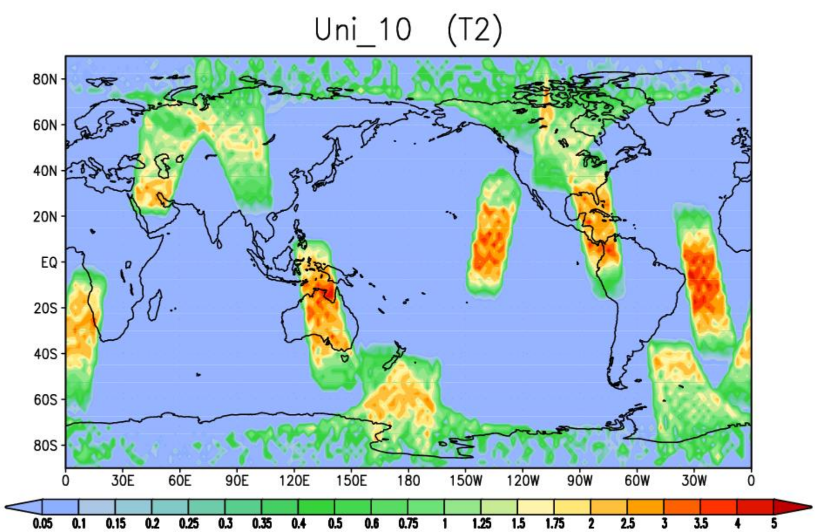
(200mb Feb13 - Mar 6 average)



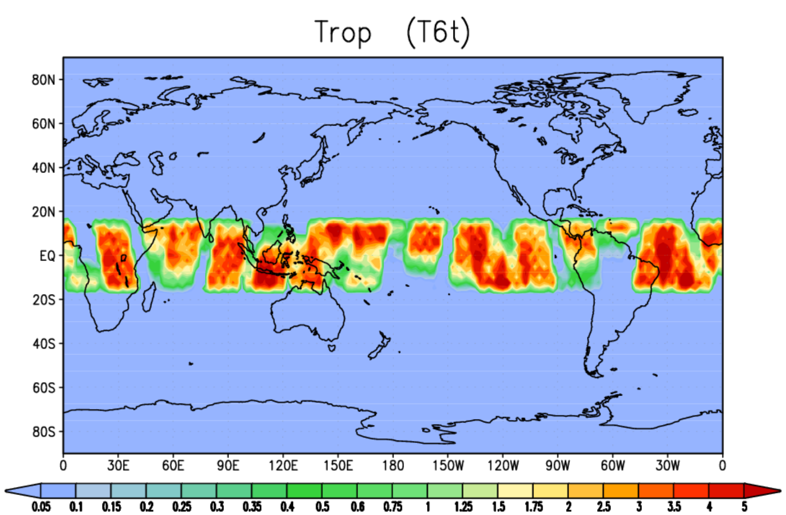
100% Upper Level



50% Upper Level regular sampling

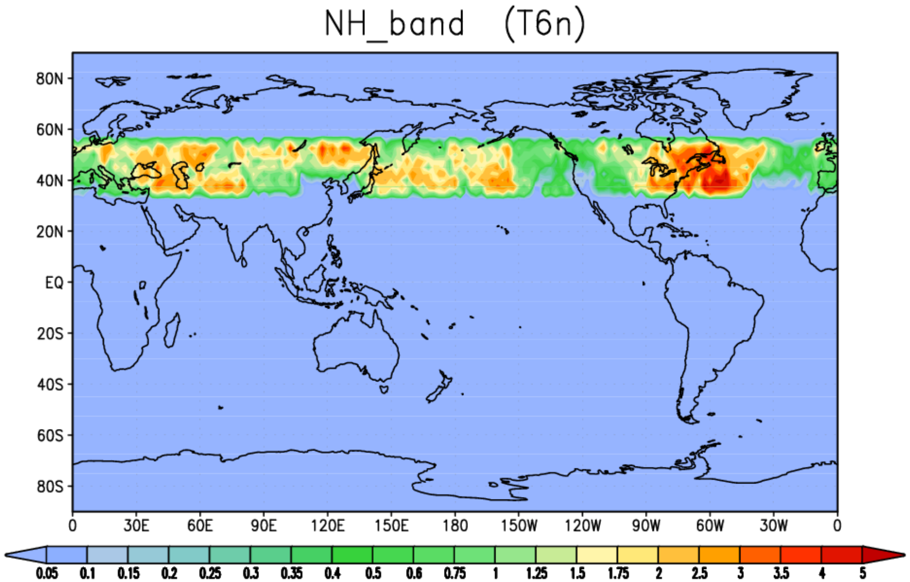


10% Upper Level

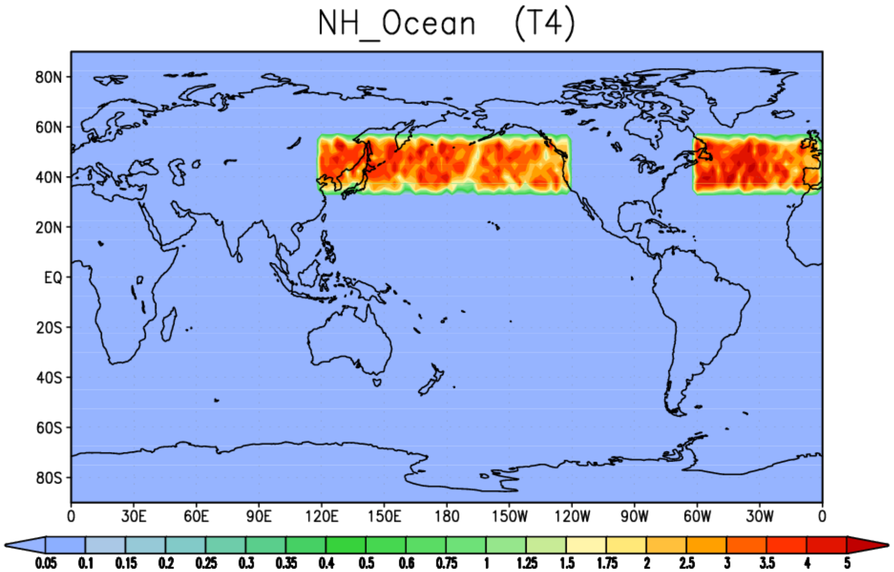


10% Upper Level tropics

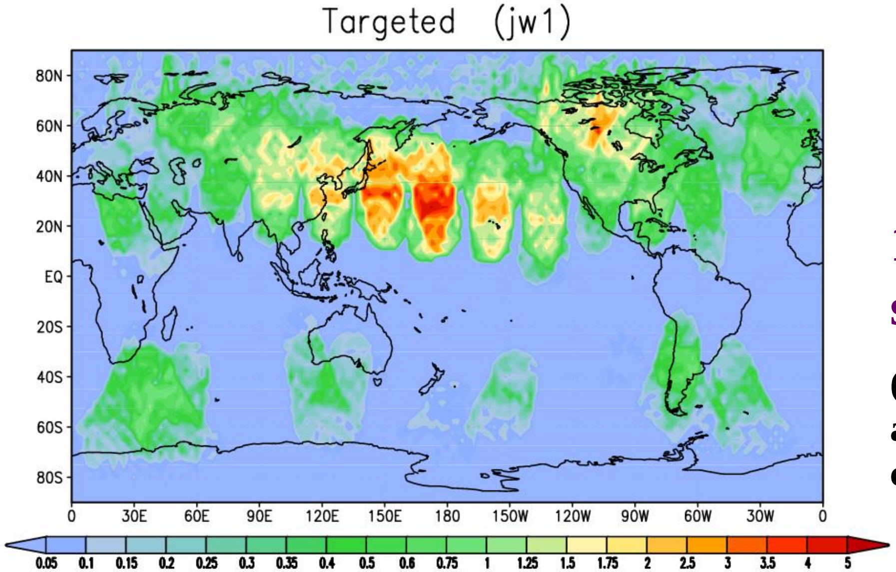
Courtesy of Y. Song



10% Upper Level NH band



10% Upper Level NH Ocean

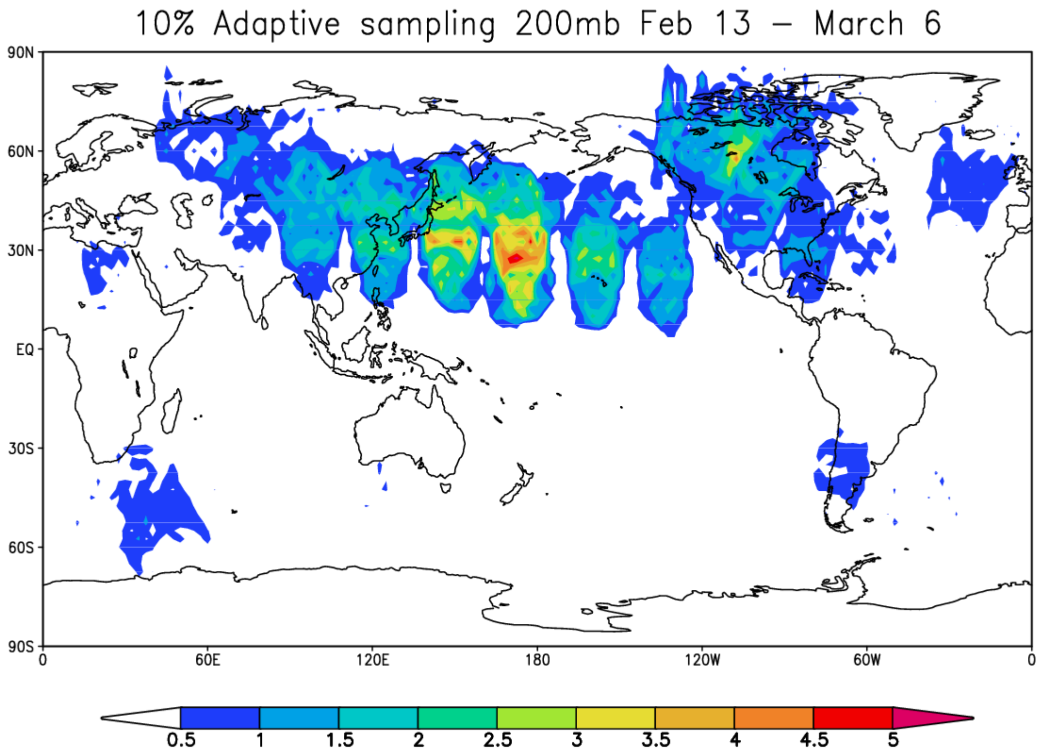


10% Upper Level Adaptive sampling

(based on the difference of first guess and NR, three 3mins of segments are chosen – the other 81 mins discarded)

Courtesy of Y. Song

Adaptive sampling based on error level



The values are number of selected data within a 2.5 by 2.5 degree box

Courtesy of Y. Song

Targeting Criteria

- Climatologic basis
  - IPO project
- Realtime identification of data sensitive regions
  - General Adjoint technique (NCEP)
  - LETKF (Kalnay)
  - ICAT (Initial Condition Adaptive Targeting/Emmitt, Toth and Kalnay)
- Phenomenological
  - Hurricanes
  - Jets
  - Fronts

Adaptive Targeting Study for DWL Operations*

D. Emmitt (SWA)

Z. Toth (NCEP)

E. Kalnay (UMd)

R. Atlas (GSFC)

April, 2003

* Funded by the IPO (S. Mango)

Specific tasks

- Zoltan work on the target selection strategy(s) (LEKF?); Dave has suggested a strategy summarized in the next slide.
- Zoltan has conducted some OSEs using WSRP data. Winds make more impact than temperatures but both combined clearly the best solution.
- Eugenia has offered to have a student develop a target climatology that can be used in instrument design and operations (based upon what targeting technique?).
- Dave will prepare a simulated DWL data set using an adaptive targeting scheme and the DAO Nature Run.
- Bob will conduct the OSSEs using the “models of the day”.

General Plan

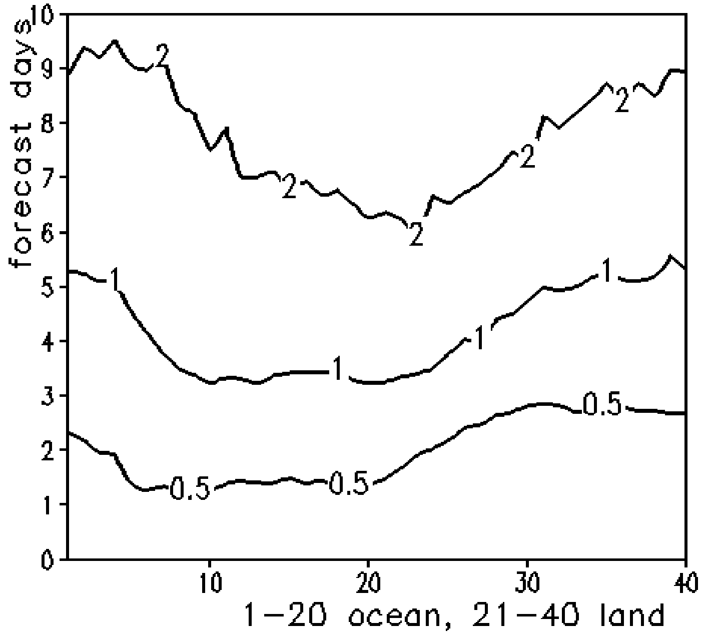
- Develop a climatology of data targets based upon a year's worth of NCEP model runs
  - target locations
  - areal size
  - persistence
  - cloud coverage
- Using OSEs, assess potential advantages of adaptive targeting of specific atmospheric phenomenon
- Design and execute an OSSE to test several adaptive targeting strategies (Observation Scheduling Algorithms)
- Relate results to DWL (or other sensors) design and operations

Adaptive observations with LETKF

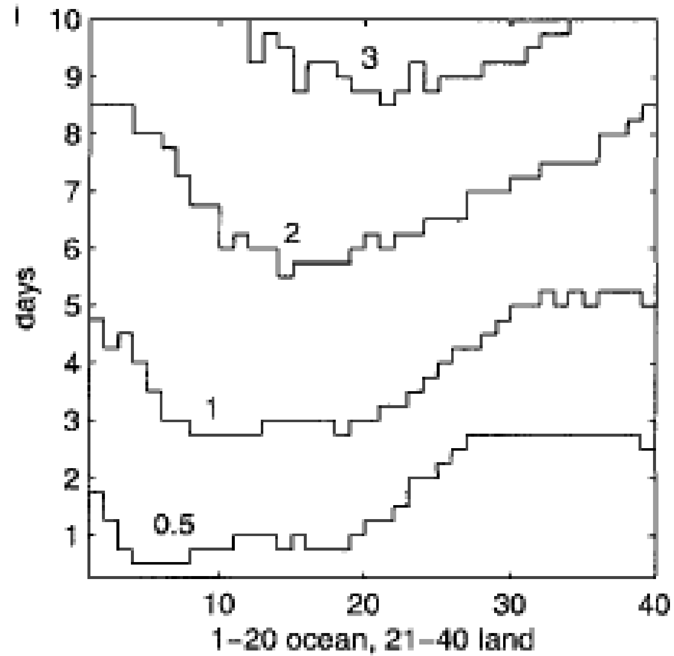
Junjie Liu and Eugenia Kalnay (U. of MD at College Park)

- We developed at UMD the Local Ensemble Transform Kalman Filter (LETKF) method (Ott et al, 2004, Hunt et al, 2004, Szunyogh et al, 2005, Liu et al, 2005, Hunt, 2005).
- LETKF should be faster, cheaper and better than 4D-Var.
- LETKF has been shown to be much better than PSAS, a 3D-Var data assimilation system.
- LETKF provides analysis and forecast error covariances from the ensembles for all variables, all levels, all times.
- We can use the forecast ensemble spread (estimate of error variance) to optimally choose adaptive observations.
- We tested this with the Lorenz-Emanuel 40-variable model, and the results are very encouraging, better than all other published results.

RMS forecast errors for 10 day-forecasts with the Lorenz-Emanuel 40-variables model



Adaptive observation chosen with the LETKF spread (15-ensemble members)



Adaptive observation chosen with Singular Vectors in EnKF (1024-ensemble members)

Tests with the Lorenz 40-variable model show that using the 15-member LETKF spread to choose the adaptive observations (left) gives results better than the best method tested (Hansen and Smith, 2000, right), using singular vectors within a 1024-member ensemble Kalman Filter. But the LETKF is computationally feasible!

Summary

- The Local Ensemble Transform Kalman Filter (LETKF) method developed at UMD promises to be better (and cheaper) alternative to 4D-Var.
- LETKF gave much better results than PSAS using the NASA fvGCM. It is very fast (a few minutes per analysis step with millions of observations)
- Unlike 4D-Var, LETKF provides analysis and forecast error covariances for every variable, every level.
- We tested it with the Lorenz-Emanuel 1998 setup and found that using forecast ensemble spread (an estimate of the error variance) to choose the location of adaptive observations gave excellent results, better than the <u>much</u> more expensive approach of Hansen and Smith (2000)
- We will test adaptive observations next with the SPEEDY global primitive equations model, a fast but fairly realistic model.

Initial Condition Adaptive Targeting (ICAT)

- Argues that if the models “first guess” is correct, then the initial conditions for the longer range forecasts are as good as they can be.
- DWL operates in a coarse (modest resolution) mode with an onboard current model analyses or next time step forecast. Observations are compared with a forward modeled value. If comparison is good, no special action.
- If comparison “fails”, then DWL goes into high resolution mode during the current orbit and several subsequent orbits.
- Additional targets may also be identified by schemes such as the LEKF.

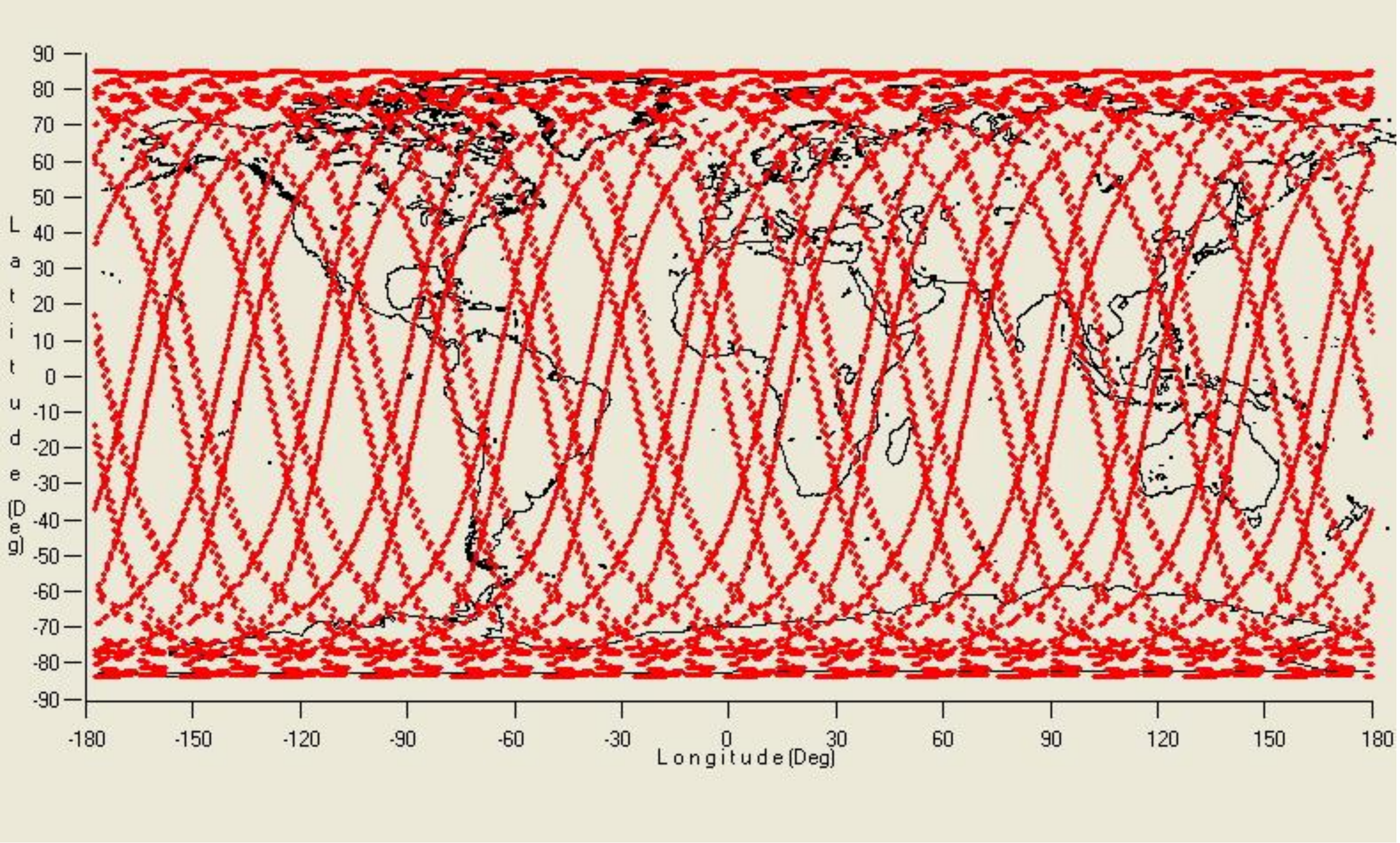
Technology Enablers

- On/off switches
- 2 – 3 DOF beam pointing
- Variable PRF lasers
- Look ahead imager or other companion sensor
- On-board autonomous or commanded reconfiguration
  - On-board data processing and condition recognition software

Technology Issues

- Power management
  - Batteries
- Thermal management
  - Laser stability
  - Heat rejection
- Laser lifetimes
- Beam pointing mechanics
  - Platform rotation?
  - Variable nadir angle?
  - Momentum compensation
  - Fugitive vibrations

Global coverage of lower tropospheric wind profiles, clouds and elevated aerosol layers using 100% duty cycle of coherent subsystem



Full tropospheric/lower stratospheric wind soundings
using 10% duty cycle with direct detection subsystem
combined with the coherent detection coverage of lower troposphere