The Assimilation of Satellite Observations for the U.S. Navy's Operational Forecast Models

Nancy L. Baker[1], Clay Blankenship[1], Bill Campbell[1], Rolf Langland[1], Steve Swadley[2]

[1]Naval Research Laboratory, Monterey, CA
[2] METOC Consulting, Monterey, CA

Naval Research Laboratory

- *Monterey – Marine Meteorology Division*
  - Research and development of global, mesoscale and shipboard atmospheric analysis and prediction systems
  - Coupled atmosphere-ocean modeling
  - Development of forecaster aids and automated weather interpretation system
- *Washington, D.C. – Remote Sensing Division*
  - Design and build satellites (Windsat, POAM)
  - GPS and ozone assimilation
- *Stennis Space Center, MS – Ocean Division*
  - Ocean data assimilation and modeling

Customers

- *Fleet Numerical Meteorology and Oceanography Command (FNMOC)*
  - produces and distributes products from numerical prediction models of the ocean and atmosphere
  - ocean modeling
- *Other Customers*
  - Navy and Marine Corps, Air Force and other DoD activities
  - Civilian - US Coast Guard search and rescue planners
- *Objective*
  - Provide the best global and/or regional analysis at any time,
    - from upper levels (for ballistic missile support),
    - to lower levels for EM/EO support, visibility, winds for flight operations, etc.
    - Analysis variables are temperature, humidity and winds
  - Provide the best initial conditions for the NWP model forecasts

NRL/FNMOC Forecast Suite

- *NOGAPS - Navy Operational Global Atmospheric Prediction System*
  - Spectral T239, L30
  - NAVDAS – NRL Atmospheric Variational Atmospheric Variational Analysis System (3DVAR) operational October 1, 2003
- *COAMPS[TM] - Coupled Ocean/ Atmosphere Mesoscale Prediction System*
  - Nonhydrostatic; globally relocatable, nested grids; explicit prediction of moisture variables
  - NAVDAS will replace soon the multivariate optimum interpolation (MVOI) system

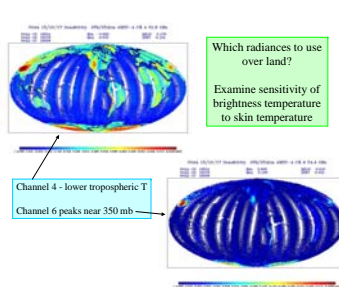*COAMPS[TM] is a trademark of the Naval Research Laboratory, Monterey, CA.*

NAVDAS Features

$$(1) \quad \mathbf{z} = \left[\mathbf{H}\mathbf{P_b}\mathbf{H}^T + \mathbf{R} \right]^{-1} \left[\mathbf{y} - H(\mathbf{x_b}) \right] \qquad \text{Solver}$$

$$(2) \quad \mathbf{x_a} - \mathbf{x_b} = \mathbf{P_b}\mathbf{H}^T \mathbf{z} \qquad \text{Post-multiplier}$$

- $\mathbf{y}$ - observation vector
- $\mathbf{x_b}$ - the background vector
- H – forward or observation operator
- $\mathbf{P_b}$ – background error covariance
- $\mathbf{x_a}$ – analysis vector
- $\mathbf{R}$ – observation error covariance
- $\mathbf{H}$ – observation operator linearized about the background

- *Formulates the solution in observation space (not model space)*
  - Applicable to any model or grid projection (global or mesoscale)
  - Computes the solution much faster for data-sparse areas/ dense grids
  - Runs on mainframes or workstations (uses MPI and standard Fortran)
  - Cost is proportional to the number of observations assimilated
- *Provides flexibility in specifying background errors*
  - Eigenvector decomposition is used in the vertical
  - This provides an enormous computational advantage (factor of 25) for the assimilation of profile observations (i.e. radiosondes, radiances).
  - Equally importantly, it permits a non-separable formulation of the background error correlation.
    - Shorter horizontal correlations for temperatures and shorter vertical correlations for winds than for geopotentials.
    - The horizontal correlation length can vary vertically (increasing in the stratosphere) and modally (increasing for deep modes).
    - Tropical vertical correlation lengths can be different (shorter) than in high latitudes.
    - Divergent and rotational winds can have different structures.
  - Adapts easily to flow-dependent background errors
    - A straightforward transformation to isentropic coordinates (based on the background state estimate) can be easily incorporated. The background error correlations then become sensitive to frontal structures, static stability, marine boundary layers, the tropopause and the jet streams.
- *Supports nested grids*
  - Analyzes all simultaneously
  - Assures complete coupling between all of the nests
- *Direct assimilation of radiances, SSM/I TPW and wind speeds; nonlinear for wind speed*
- *NAVDAS adjoint*
  - Useful diagnostic tool that provides sensitivity of forecast aspect (e.g., error) to the observations.
- *Lays the foundation for cycling representer algorithm*
- *Designed by Roger Daley with Edward Barker, Keith Sashegyi, Patricia Pauley, James Goerss, Nancy Baker, Tom Rosmond, Tim Hogan, Bill Campbell, Clay Blankenship, Liang Xu, Randal Pauley, Peter Steinle, Tom Lougheed*
- *Sponsors: NRL, ONR, SPAWAR*

AMSU-A Radiance Assimilation for NOGAPS and COAMPS

- **Approach:** Assimilate radiances directly using NAVDAS
  - Use channels 4-11; screen land/ice/snow observations depending upon whether channels "sees" the surface
  - Every 4th observation; additional thinning to remove overlapping passes/satellites; final spacing ~ 150 km
  - QC removes sporadic bad data, and radiances affected by cloud liquid water, precipitation, surface ice or land
  - Bias corrections are an essential component, modified Harris and Kelly approach
- **Results**
  - Modifications to bias correction method led to excellent improvements in forecast skill and quality of the assimilated radiances
  - Radiances strengthen circulation in SH; better fit with radiosondes and other observations; improved tropical cyclone track predictions
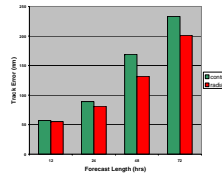

Which radiances to use over land?

Examine sensitivity of brightness temperature to skin temperature

Channel 4 - lower tropospheric T

Channel 6 peaks near 350 mb

NAVDAS/NOGAPS Forecast Impact
AMSU-A Radiances vs. NESDIS Retrieval Assimilation
500 mb Height Anomaly Correlation
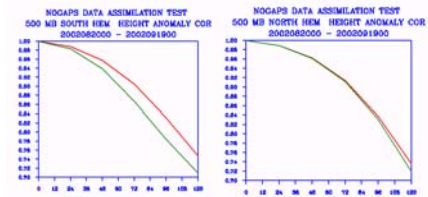
Tropical Cyclone Track Improvement
(May 1, 2002 to June 15, 2002)

	Tau 12	Tau 24	Tau 48	Tau 72
Western N. Pacific	13	13	10	7
Eastern N. Pacific	11	9	6	5
S. Hemisphere	16	14	11	8
Total	40	36	27	20

Number of Cases

Bias Correction Method

- Most weather centers predict (and correct) bias statistically via multiple linear regression, using either actual satellite radiances or NWP model variables as predictors.
- *Any* approach runs the risk of either throwing out signal with bias, or not throwing out enough bias, although careful choice of time scales can mitigate this risk.
- NRL is investigating hybrid approaches, which use both satellite radiances and NWP model variables as bias predictors.
- Three bias correction schemes are compared offline, using two weeks of data to construct regression coefficients, which are then applied to the next two weeks of data.
- Harris and Kelly (HK) method
  - Latitude band regression (18 separate zonal regressions)
  - Model predictors (tropospheric and stratospheric thicknesses, TPW, and SST)
- NRL test method (based on suggestions by J. Derber)
  - Global regression
  - Model predictors (latitude-modulated tropospheric and stratospheric thicknesses, TPW, SST, and cloud liquid water)
- Campbell global and latitude band hybrids
  - Global or latitude band regressions
  - All NRL test predictors, plus radiances from all AMSU-A channels *except* the channel being evaluated
- Channel 4 (52.8 GHz) has some sensitivity to moisture, so cloud liquid water as predictor in the NRL test method helps it to have a lower RMS error than the HK method.
- The Campbell hybrid methods have the lowest RMS in all channels (except for the global hybrid method in Channel 10).
- Note that both latitude band methods, but in particular the Harris and Kelly method, show a discontinuity in the bias correction along latitude band boundaries (every 10 degrees). This may cause their performance in an assimilation run to suffer, despite lower RMS error in offline tests.
- In preliminary testing, the NRL test method significantly improved both NOGAPS forecast skill, quality of radiances, and stability of bias corrections over time.

NOAA-16 AMSU-A Channel 4 data from 0Z 4/15/01 to 18Z 4/25/01
Bias-corrected innovations (°C)