Recent Developments in Ensemble Research

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- **Navy Global Ensemble Forecast System Overview**
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- **Validation of NAVGEM Ensemble System**
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Navy Global Ensemble Forecast System

- **Current system:**
  - **NOGAPS T159L42**
    - **80-mem, 4 times per day, to 6h**
    - **20-mem, 2 times per day, to 16 days**
  - **Banded ET initial perturbations, no model uncertainty**
  - **Used to force surface wave ensemble**

- **2014 Upgrade:**
  - **NAVGEM T239L50, 20-mem, 2 times per day, to 16 days**
  - **ET with improved (scaled) analysis error variance estimates**

- **Upgrades for 2014-2015:**
  - **Incorporation of model uncertainty.**
    - **SST initial perturbations, diurnal cycle, persistent anomaly capability**
    - **Stochastic forcing (SKEB)**
  - **T359L50 run in support of the NOAA HIWPP program**

Navy Global Environmental Model (NAVGEM)

Data Assimilation

- NAVDAS-AR 4D-Var with variational bias correction

Dynamics

- SL/SI scheme
- T359L50 (Δx=37km, top at 0.04 hPa or ~70 km)
- Time step = 360 sec

New Physics

- Simplified Arakawa-Schubert scheme
- Shallow convection
- Prognostic cloud scheme with two species
- RRTMG 4-stream radiation
- Modified cloud fraction scheme
- Modified turbulent mixing scheme

NAVGEM replaced NOGAPS for deterministic run in FEB 2013

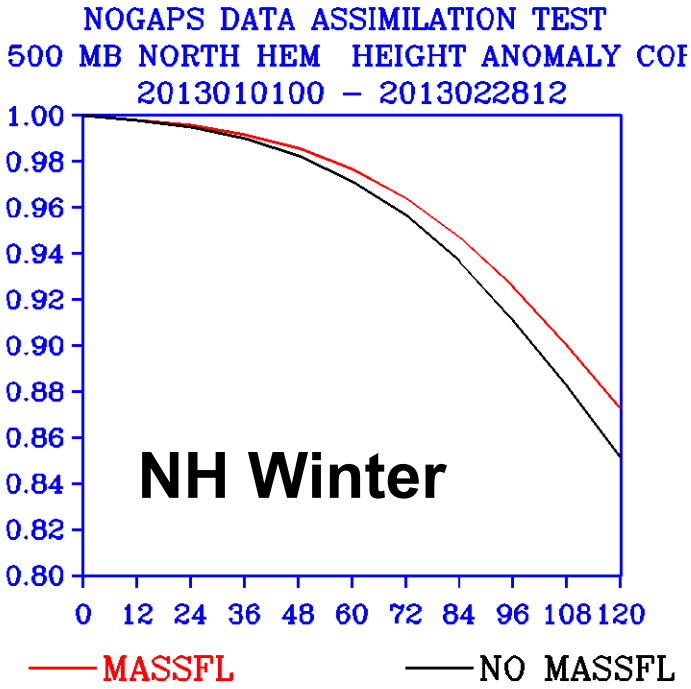
NAVGEM 1.1 FNMOC Operational Scorecard
(Comparison between NOGAPS and NAVGEM)

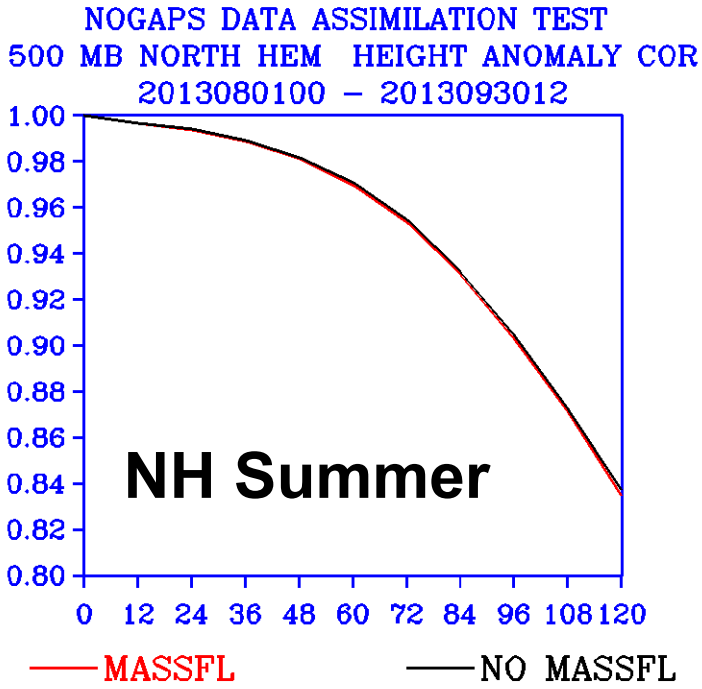
Field	Surface	Tropics	Tropical cyclone	Track error	96 hrs	+4
Field	500 mb	N Hem	Height	AC	96 hrs	+4
Field	1000 mb	N Hem	Height	AC	96 hrs	+1
Field	500 mb	S Hem	Height	AC	96 hrs	0
Field	1000 mb	S Hem	Height	AC	96 hrs	+1
Field	850 mb	Tropics	Wind	RMS	72 hrs	0
Field	250 mb	Tropics	Wind	RMS	72 hrs	0
Field	850 mb	N Hem	Wind	RMS	72 hrs	+1
Field	250 mb	N Hem	Wind	RMS	72 hrs	+1
Buoy Data	Surface	Global	Wind	Speed Error	72 hrs	0
Raob Data	850 mb	Global	Wind	RMS	72 hrs	0
Raob Data	250 mb	Global	Wind	RMS	72 hrs	0
Raob Data	850 mb	Global	Temperature	RMS	72 hrs	+1
Raob Data	250 mb	Global	Temperature	RMS	72 hrs	+1
Raob Data	500 mb	Global	Height	RMS	72 hrs	+1
Raob Data	100 mb	Global	Height	RMS	72 hrs	-1

Total Score: +14 out of a possible +24
Highest score in past 20 years

NAVGEM 1.2 - Operational in October 2013

Eddy Diffusivity Mass Flux (EDMF) boundary layer mixing scheme (*Sušelj et al. 2013 MWR*)





NAVGEM 1.2 T239L50 ensemble currently being tested by FNMOC for operational implementation (M. Sestak presentation)

NAVGEM 1.3 Planned Upgrades - FY14

- T425L60 (31km, 0.04mb~71km)
- P-theta dynamic core
- Revised EDMF boundary layer mixing scheme
- Reduced Gaussian Grids
- New Gravity Wave Drag Scheme
- Water Vapor Chemistry

NAVGEM currently being coupled to HYCOM (ocean) and CICE (sea ice)

NAVGEM 1.2 Ensemble Verification

- **Old system: NOGAPS T159L42, banded ET**
- **New system: NAVGEM T239L50, banded ET with improved (scaled) analysis error variance estimate**
- **Test periods: January 2013 and August 2013**

Variables	**Surface wind speed (V_{sfc})** **500 hPa geopotential height ($Ø_{500}$)** **Surface air temperature (T_{sfc})** ***850 hPa temperature (T_{850})*** ***250 hPa wind speed (V_{250})***
Regions	**Tropics (TR)** **Southern Hemisphere (SH)** **Northern Hemisphere (NH)**
Lead times	**24h, 48h, 120h, 240h**
Metrics	**RMSE, CRPS, Binning (ens var vs. fcst error var)**
Significance	**95% threshold, 5% difference**

NAVGEM 1.2 Ensemble: By Region

- T_{sfc} and V_{sfc} verified against land surface stations/buoys and analyses
- $Ø_{500}$ verified against analyses

Region	Verif. type	Winter	Summer	Possible range of score	Both seasons	Possible range of score
TR	ANL	+16	+14	[-20,+20]	+30	[-40,+40]
	OBS	-2	+1	[-32,+32]	-1	[-64,+64]
SH	ANL	+11	+15	[-32,+32]	+26	[-64,+64]
	OBS	0	-3	[-32,+32]	-3	[-64,+64]
NH	ANL	+23	+18	[-32,+32]	+41	[-64,+64]
	OBS	+6	-1	[-32,+32]	+5	[-64,+64]

$Ø_{500}$ not considered in the tropics. Suface and buoy stations considered separately.

Most improvement in NH. Large improvements for analysis verification.
Near neutral for land surface/buoy verification.

NAVGEM 1.2 Ensemble: By Metric

- T_{sfc} and V_{sfc} verified against land surface stations/buoys and analyses
- $Ø_{500}$ verified against analyses

Metric	Verif. type	Winter	Summer	Possible range of score	Both seasons combined	Possible range of score
RMSE	ANL	+22	+23	[-32,+32]	+45	[-64,+64]
	OBS	+1	-5	[-48,+48]	-4	[-96,+96]
CRPS	ANL	+22	+23	[-32,+32]	+45	[-64,+64]
	OBS	+3	+2	[-48,+48]	+5	[-96,+96]
Binning	ANL	+6	+1	[-24,+24]	+7	[-48,+48]

The small negative summer RMSE score reflects verification against tropical land-station wind-speed obs. and SH buoy air temperature obs.

Large improvements for RMSE and CRPS for analysis verification. Larger improvements for CRPS than for RMSE for verification against surface stations/buoys.

NAVGEM 1.2 Ensemble: By Variable

- T_{sfc} and V_{sfc} verified against land surface stations/buoys and analyses
- $Ø_{500}$ verified against analyses

Variable	Verif. type	Winter	Summer	Possible range of score	Both seasons combined	Possible range of score
V_{sfc}	ANL	+21	+14	[-36,+36]	+35	[-72,+72]
	OBS	-5	-2	[-48,+48]	-7	[-96,+96]
T_{sfc}	ANL	+22	+24	[-24,+24]	+46	[-48,+48]
	OBS	+9	-1	[-48,+48]	+8	[-96,+96]
$Ø_{500}$	ANL	+7	+9	[-24,+24]	+16	[-48,+48]

T_{sfc} : small negative summer score reflects verification against SH buoy obs.
V_{sfc}: small negative winter score reflects verification against tropical buoy obs., small negative summer score reflects verification against tropical land-station obs.

Larger improvements for T_{sfc} than for V_{sfc}.

NAVGEM 1.2 Ensemble: V_{250} and T_{850}

- **V_{250} and T_{850} verification against analyses and radiosondes**

Variable	Verif. type	Winter	Summer	Possible range of score	Both seasons	Possible range of score
V_{250}	ANL	+11	+6	[-24,+24]	+17	[-48,+48]
	OBS	+8	+3	[-24,+24]	+11	[-48,+48]
T_{850}	ANL	+22	+22	[-24,+24]	+44	[-48,+48]
	OBS	+6	+13	[-24,+24]	+19	[-48,+48]

Upper-air verification not included in score card.

Improvements seen for both V_{250} and T_{850} for verification against analyses and radiosondes.

NRL COAMPS Ensemble Forecast System

- **Ensemble transform with perturbed physics parameters**
- **ESRF (DART) for COAMPS-TC (27, 9, 3 km, 80-mem DA, 10-mem long forecasts)**
- **EnKF for RADAR data assimilation**
- **Applications:**
  - **Coupled dispersion modeling (Fukushima)**
  - **Coupled atmosphere-ocean ensembles (Hydrological cycle in the Mediterranean Experiment)**
  - **Tropical Cyclone applications (NOAA HFIP, ONR)**
  - **DoD tactical applications (refractivity)**

NRL Global Ensemble Research Topics

- **Ensemble Design**
  - Scaling factors based on innovation statistics to improve analysis error variance estimates and ensemble performance (Satterfield)
  - Real-time TC track bias correction/TC Brownian Motion research (Hodyss, McLay)
  - Stochastic Kinetic Energy Backscatter (Hodyss, McLay)
  - Parameter variation ensemble experiments (McLay, Liu)
  - SST initial perturbations, diurnal cycle (McLay et al.)
  - Methods to combine global and regional ensembles (Rainwater et al.)
- **Ensemble Post Processing, Diagnostics, and Products**
  - Lagrangian bias correction applied to wave height forecasts (Satterfield, Hansen)
  - Accounting for varying variances in ensemble post processing (Satterfield, Bishop)
  - Objective Probabilistic Aid for TC Sortie Decisions (Hansen, Sampson, Peak et al.)
  - Linear diagnostics to assess multi-model ensemble predictability (Satterfield et al.)
  - Ensemble sensitivity to explore phenomenological uncertainty (Hansen et al.)
- **Data Assimilation**
  - Hybrid Data Assimilation (Kuhl, Rosmond, Bishop, McLay, Baker)
  - Static vs. flow dependent error covariance optimal weighting in Hybrid DA (Bishop, Satterfield)
  - Ensemble variance smoothing (Bishop et al.)
- **NUOPC/NAEFS/HIWPP (Hansen, Doyle, Whitcomb, et al.)**