U.S. Navy Earth System Prediction System (ESPC) Development from R&D to Operations

Ocean Predict Symposium - OP'24
Paris, France
18-22 November 2024

E. Joseph Metzger[1]
Richard Allard[1], Charlie Barron[1], Jonathan Christophersen[2], William Crawford[2], Maria Flatau[2], Deborah Franklin[4], David Hebert[1], Gregg Jacobs[1], Matthew Janiga[2], Tommy Jensen[1], David Kuhl[3], Fei Liu[5], Justin McLay[2], Michael Phelps[3], Alex Reinecke[2], Carolyn Reynolds[2], James Ridout[2], Erick Rogers[1], Clark Rowley[1], Jay Shriver[1], Gerhard Theurich[5], Prasad Thoppil[1], Marcela Ulate[6], Timothy Whitcomb[2], Luis Zamudio[7], Jake Zapalla[4]

[1]U.S. Naval Research Laboratory, Stennis, MS;
U.S. Naval Research Laboratory, Monterey, CA;
[3]U.S. Naval Research Laboratory, Washington, DC;
[4]Peraton, Inc. Herndon, VA; [5]Science Applications International Corporation/Cherokee Nation Business;
[6]University Corporation for Atmospheric Research, Boulder, CO; [7]Florida State University, Tallahassee, FL

ESPC Development from R&D to Operations

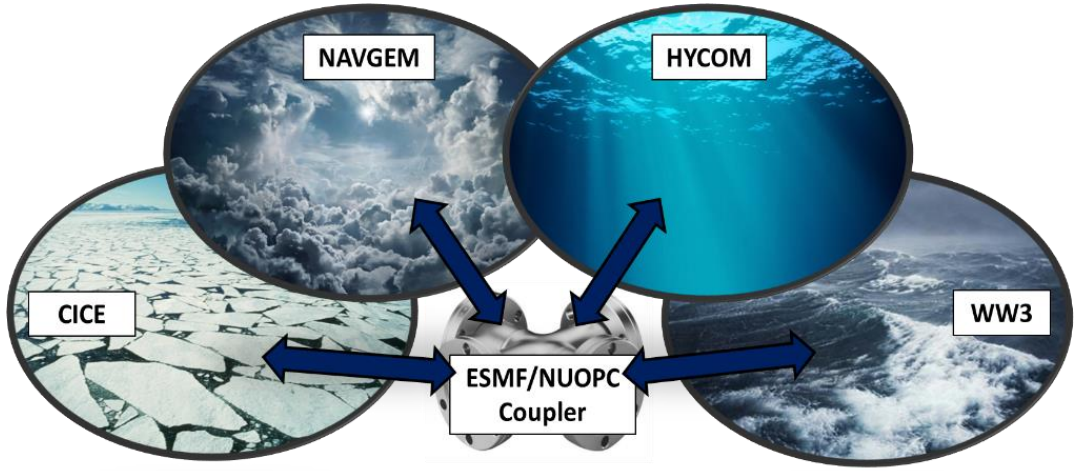
A historical perspective on US Navy environmental prediction

- The Navy DoD Supercomputing Resource Center (DSRC) dedicates a portion of the total cpu cycles (15%) to operational meteorology/ oceanography applications run by FNMOC
- All operational forecast systems must fit with this 15%
  - Atmosphere, ocean, sea ice and wave models – stand-alone and coupled
  - Global, regional and coastal domains
- This controls what can be accepted into operations
  - Governs the horizontal and vertical resolution of the prediction systems
  - Governs the complexity of the physics within the models and the associated data assimilation

ESPC Development from R&D to Operations

Move toward a whole Earth prediction via coupling

- Earth System Prediction Capability (ESPC) is the development of a whole Earth prediction system with coupling between the atmosphere, ocean, cryosphere and waves via the Earth System Modeling Framework
- Prediction from the top of the atmosphere to the bottom of the ocean
- Extending the forecast lead times from weekly to subseasonal (45 days)



Models

NAVGEM: NAVy Global Environmental Model
HYCOM: HYbrid Coordinate Ocean Model
CICE: Community Ice CodE
WW3: WAVEWATCH III®

Data Assimilation

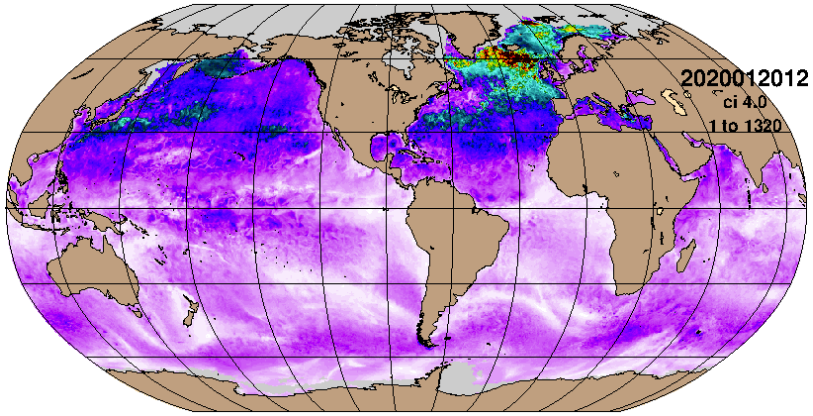
NAVDAS: NRL Atmospheric Variational Data Assimilation
NCODA: Navy Coupled Ocean Data Assimilation

ESPC Development from R&D to Operations

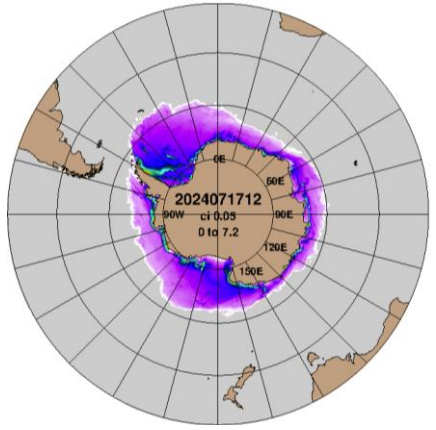
ESPC development - version 1

- Two-way coupled NAVGEM, HYCOM and CICE
- ESPC-D: Deterministic system
  - T359L60 NAVGEM - 1/25° HYCOM - 1/25° CICE
  - A single daily 16-day forecast
  - Did not outperform the corresponding stand-alone uncoupled forecast systems
- ESPC-E: Ensemble system
  - 16-member ensemble, perturbed observations
  - T359L60 NAVGEM - 1/12.5° HYCOM - 1/12.5° CICE
  - Every Sunday, 45-day subseasonal forecasts
  - Declared operational in August 2020
  - First eddy-resolving ensemble ocean/sea ice forecasts for US Navy use

HYCOM Mixed Layer Depth



CICE Sea Ice Thickness

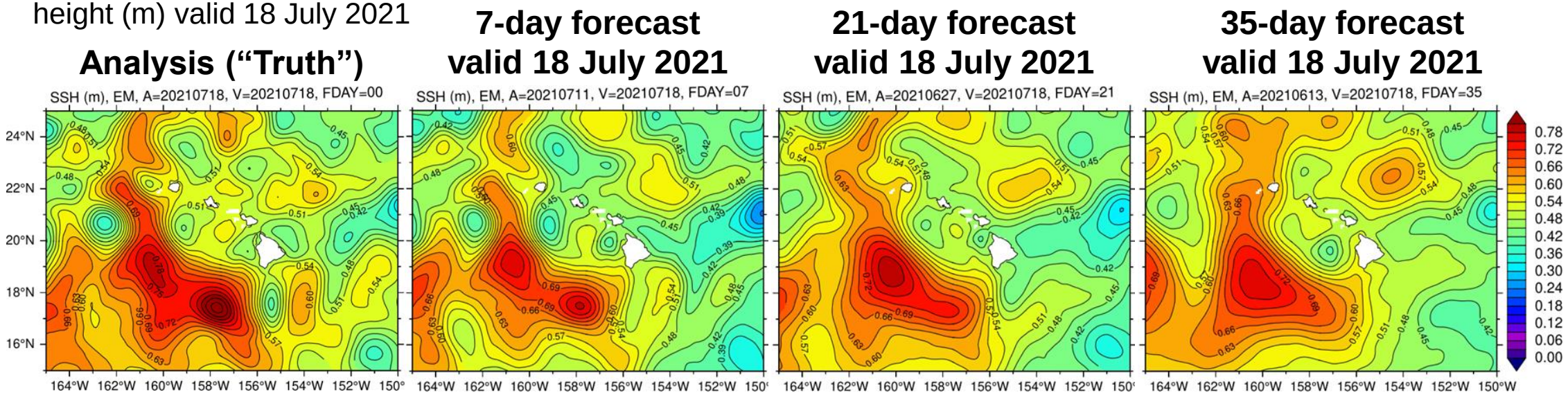


ESPC Development from R&D to Operations

US Navy use of ESPC-E v1 ocean products

Ocean: Long range prediction of mesoscale ocean eddies for RIMPAC 22

Ensemble mean sea surface height (m) valid 18 July 2021

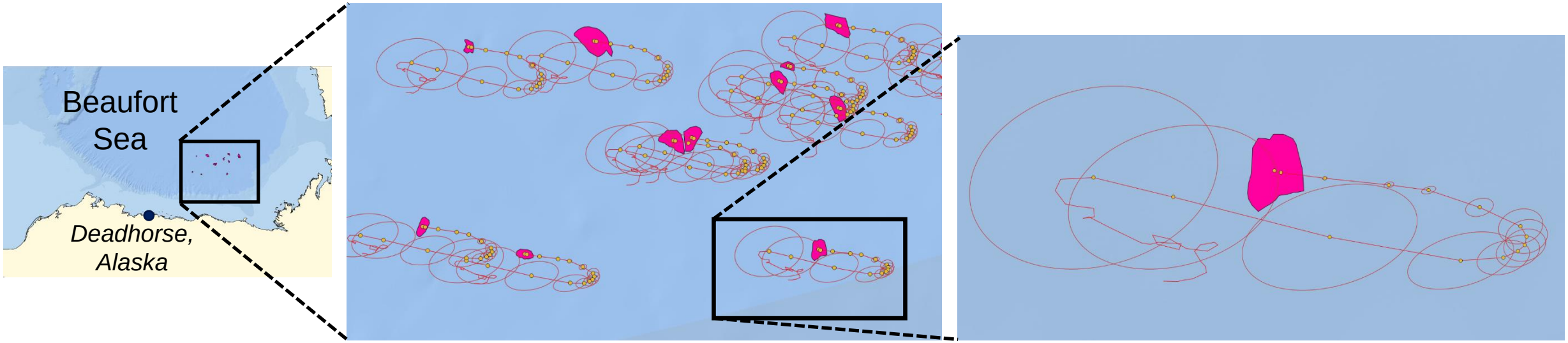


- Skill in predicting ocean mesoscale features up to six weeks in advance
- Mesoscale eddies impact ocean acoustics
- Planners can direct exercises to the most favorable regions of the RIMPAC domain

ESPC Development from R&D to Operations

US Navy use of ESPC-E v1 sea ice products

- US National Ice Center assists in ice floe selection for ICEX: US Navy ice camp in the Beaufort Sea
- Operational ESPC-E v1 was used to provide forecast track and uncertainty estimates
  - Both prior to floe selection and during the exercise
- Floe must remain within a flyable distance of Deadhorse, AK
- Magenta shapes show various ice floes that may host the ice camp
- Yellow dots are ensemble mean forecast every 24 hours out to 14 days
- Circles represent uncertainty (standard deviation) of sea ice drift

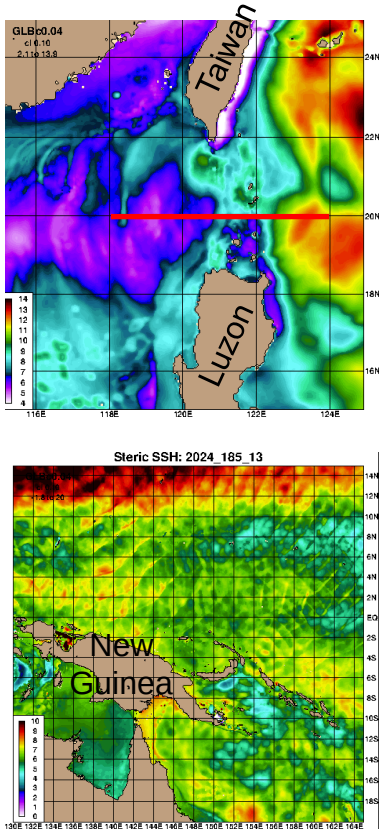


ESPC Development from R&D to Operations

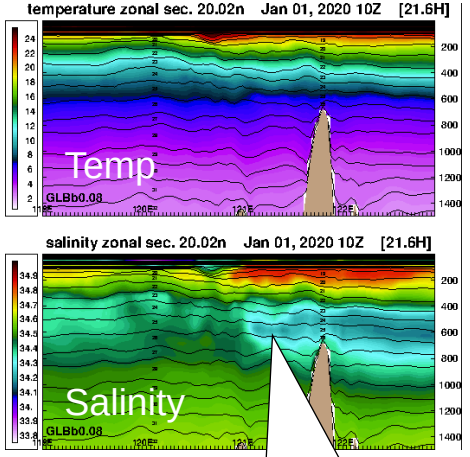
ESPC development - version 2

- ESPC-D v2
  - T681L143 NAVGEM - 1/25° HYCOM - 1/25° CICE - 1/8° WW3 - operational August 2024
  - Higher resolution atmosphere, ocean and sea ice models than ESPC-E v1 and the addition of wind waves
  - Deterministic - daily 16-day forecast
  - Two-way coupling between NAVGEM, HYCOM and CICE; one-way coupling to WW3
  - Astronomical tidal forcing in HYCOM produces internal waves at tidal frequencies
    - Internal waves can be of order 100 m at depth and are reflected in the sea surface height
    - Internal waves are important for underwater operations

Internal tidal signature in steric sea surface height



Internal tidal on model interfaces



Internal tides appear as interface deviations

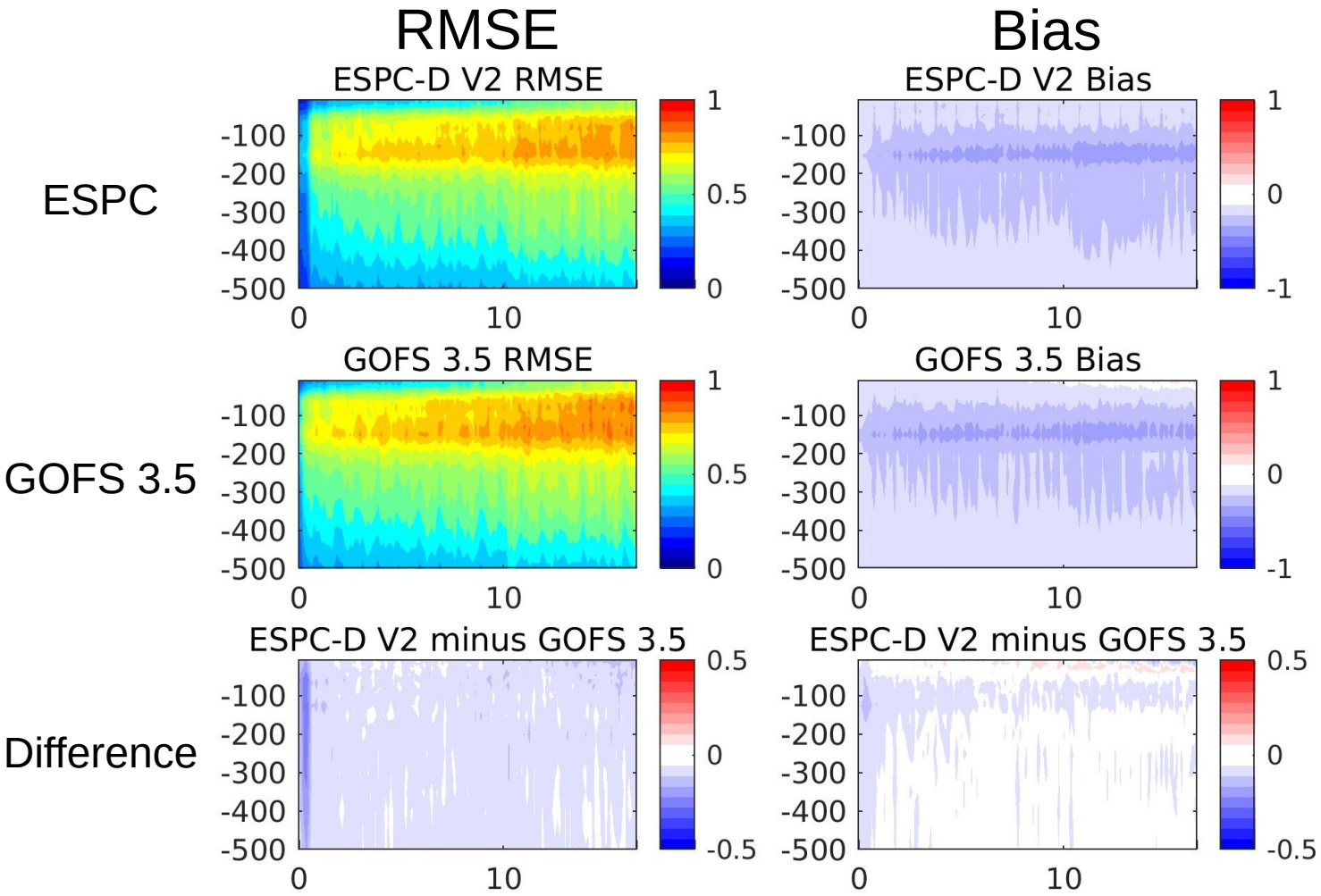
ESPC Development from R&D to Operations

Verification and Validation (V&V)

- Before a forecast system is declared operational by FNMOC, it must undergo a thorough V&V process relative to the existing operational system
- Validation Test Panel comprised of NRL, FNMOC and independent representatives agree upon a series of validation metrics for each model component
- NRL runs a year-long reanalysis and sequence of forecasts and computes forecast system error between the two systems, then writes a Validation Test Report (VTR)

ESPC Development from R&D to Operations

HYCOM V&V - Temperature error (°C) vs forecast length

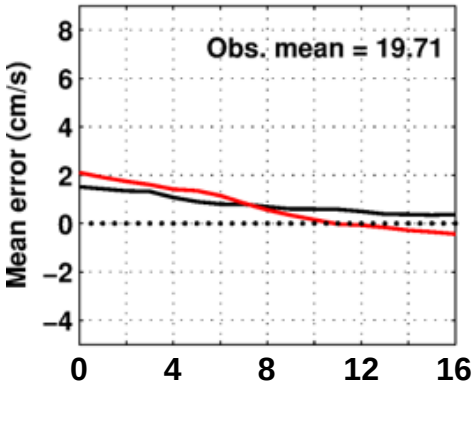


- Slightly improved performance in ESPC-D v2 compared to the stand-alone Global Ocean Forecast System (GOFS) 3.5
- Highest error in the depth range of the thermocline
- Bottom row: blue means ESPC-D v2 has lower error than GOFS 3.5

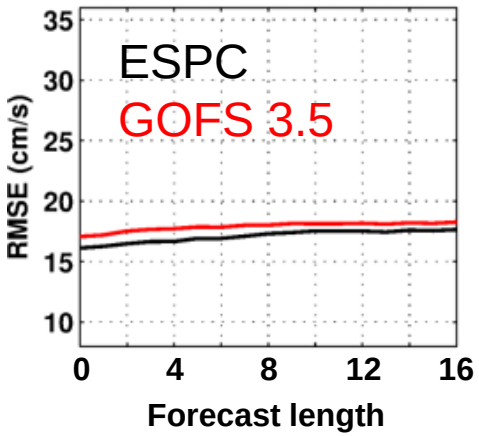
ESPC Development from R&D to Operations

HYCOM V&V - Near surface currents vs forecast length

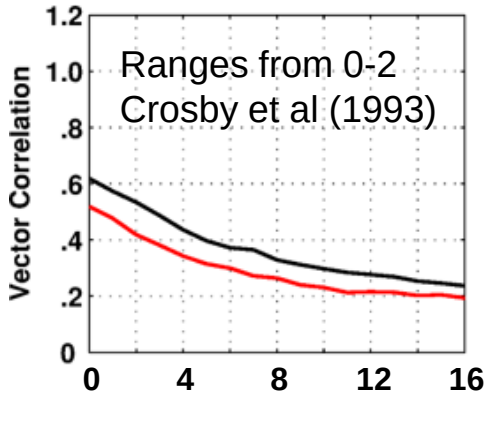
Bias



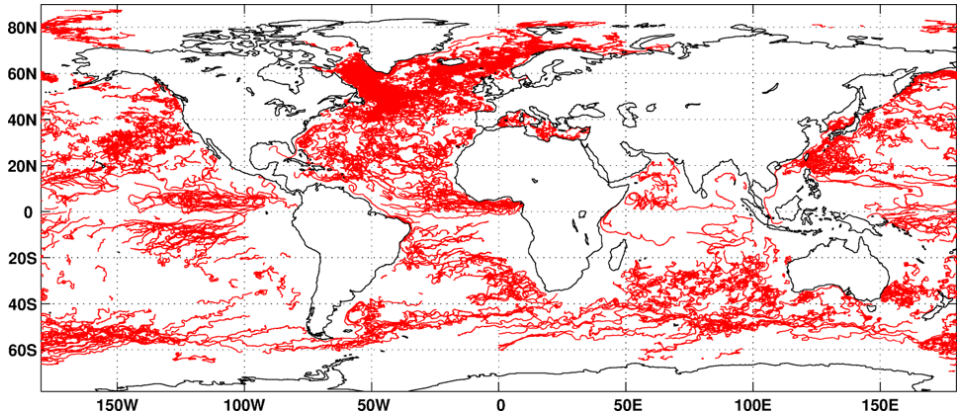
RMSE



Vector Correlation



NOAA Global Drifter Program buoy paths
1 Sep 2020 - 31 Aug 2021

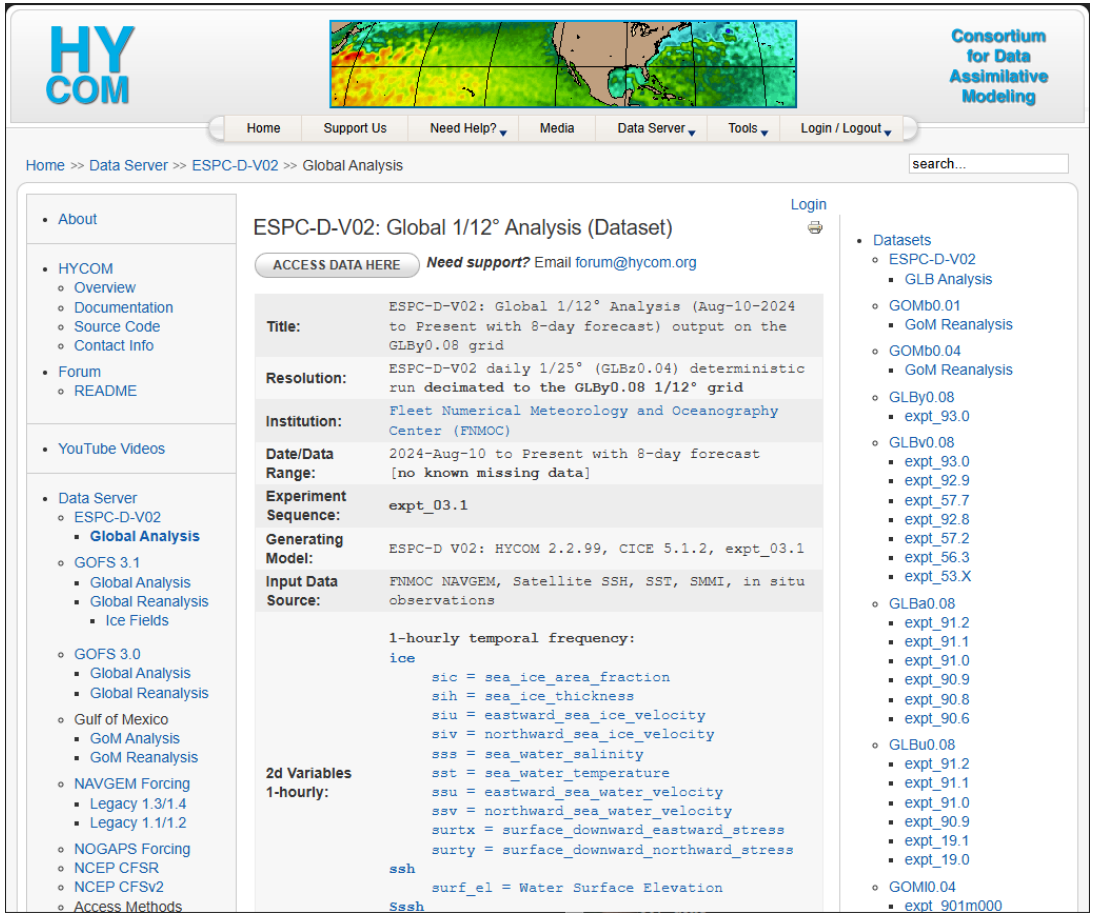


- Slow error growth with increasing forecast length
- Speed bias is small, less than 10% of observed mean speed
- Slightly lower RMSE and higher directional correlation for ESPC, indicates the two-way coupling between the atmosphere and ocean improves near surface current prediction

ESPC Development from R&D to Operations

Dissemination of ESPC-D output

- US Navy presently allows public release of ESPC-D ocean output, but on a decimated grid - 0.08° longitude x 0.04° latitude
- 1-hourly 2D fields: sea ice fraction, thickness, velocity; sea surface salinity, temperature, velocity; surface downward stress
- 3-hourly 3D fields: T, S, U and V
- Served on hycom.org by Florida State University
- https://www.hycom.org/dataserver/espc-d-v02/global-analysis



ESPC Development from R&D to Operations

Questions?

Contact: e.j.metzger.civ@us.navy.mil