Ocean Data Assimilation for Operational Hurricane Forecast Systems at NWS/NCEP: Current Status and Future plans

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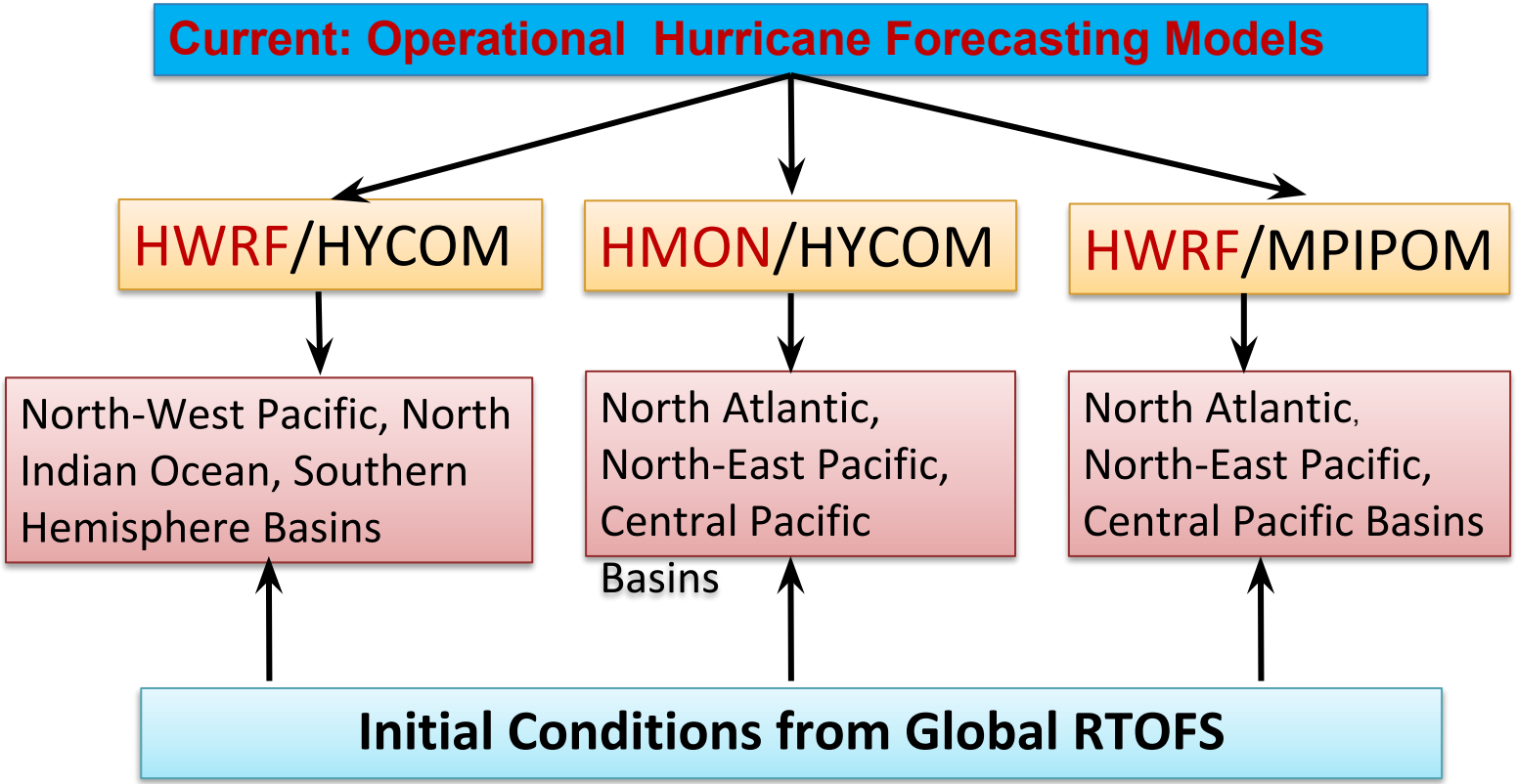
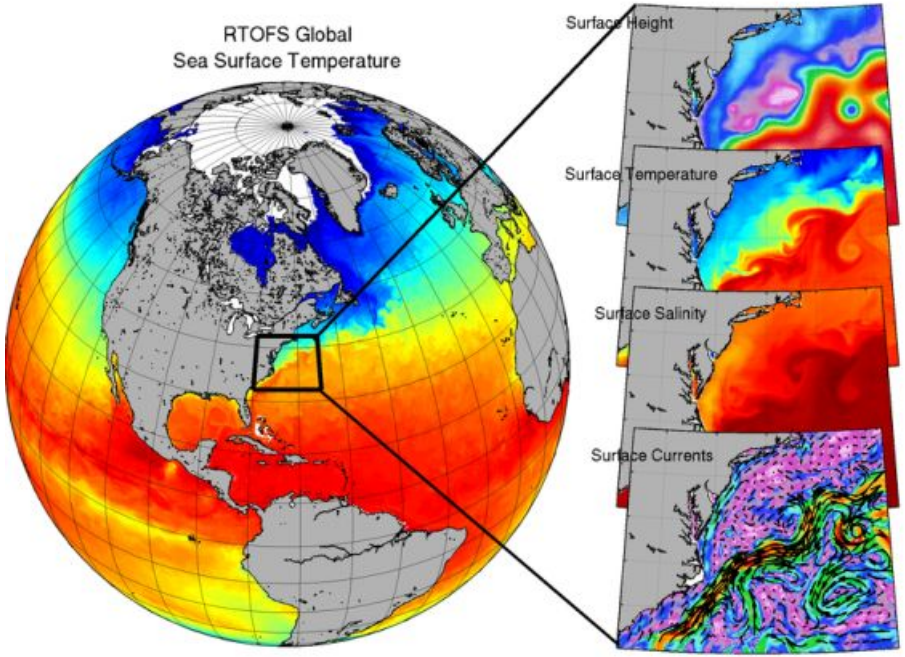
Outline

- Current Status
- Near-term upgrades
- Future plans
  - HAFS
  - JEDI
  - HSUP-2 FL-4 Project



Adapted from Maria Vargas (Rutgers Univ)

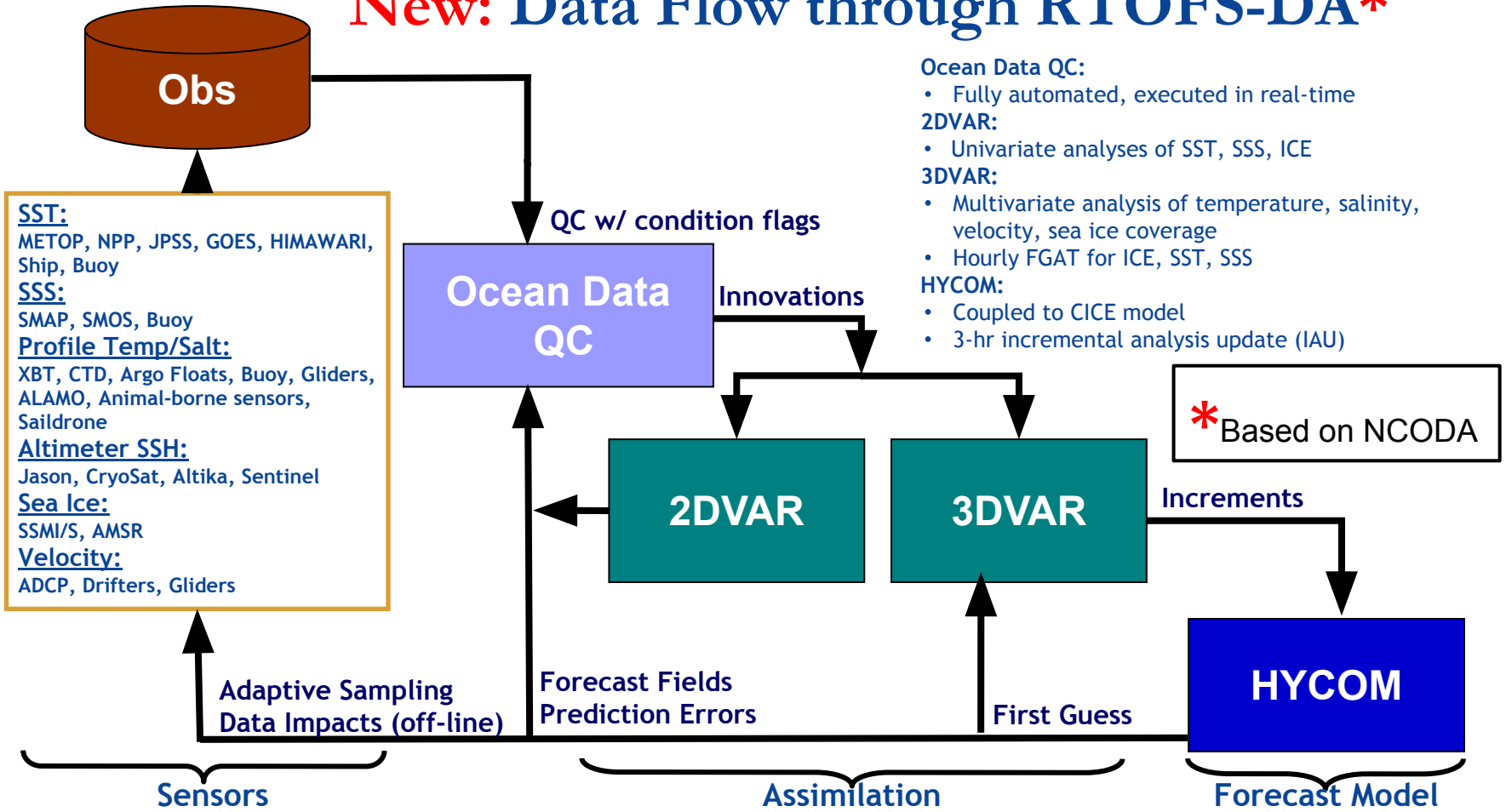
Current: Real Time Ocean Forecast System (RTOFS) at NWS/NCEP



- Eddy Resolving Ocean Modeling and Initialization
- Coupled Modeling for Hurricanes (Air- Sea- Wave flux interactions, mixing)
- Inputs to operational Global (GFS v16) and Coastal (NWPS) wave models to allow for wave-current interactions.
- Coupled Ecosystem Forecasting (Biogeochemical, NPZD, tracers)
- RTOFS presently based on **HYCOM**

Strong collaboration with US Navy, leveraging core HYCOM and ocean data assimilation developments at NRL.

New: Data Flow through RTOFS-DA*



Ocean Data QC:
- Fully automated, executed in real-time

2DVAR:
- Univariate analyses of SST, SSS, ICE

3DVAR:
- Multivariate analysis of temperature, salinity, velocity, sea ice coverage
- Hourly FGAT for ICE, SST, SSS

HYCOM:
- Coupled to CICE model
- 3-hr incremental analysis update (IAU)

*Based on NCODA

New: Q1FY21 RTOFS-DA Implementation Timeline

Dates	Milestone
May 1, 2020	Retrospective T&E at EMC
July 20, 2020	Real time T&E at EMC
July 23, 2020	External Evaluation
July 24, 2020	Approval from EMC Director
August 7, 2020	Approval from NCEP Director's Office
August 31, 2020	Submission of Codes to NCO
October-November 2020 (tentative)	NCO IT Testing completed
November 2020 (tentative)	IT briefing to NCEP Director's Office
December 2020 (tentative)	Operational implementation by NCO

Future: Hurricane Analysis and Forecast System (HAFS): A collaborative Project in UFS Framework

07 NCAR/DTC

06 OFCM/AOC

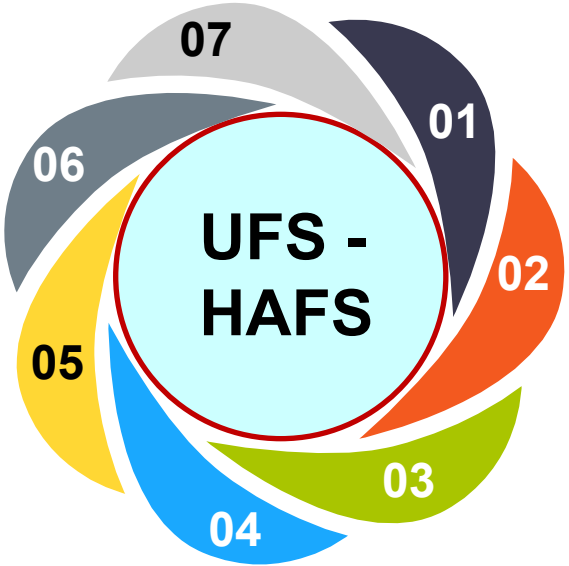
05 CIRES/NESII

04 ESRL/GSD

NCEP/EMC 01

AOML/HRD 02

GFDL 03



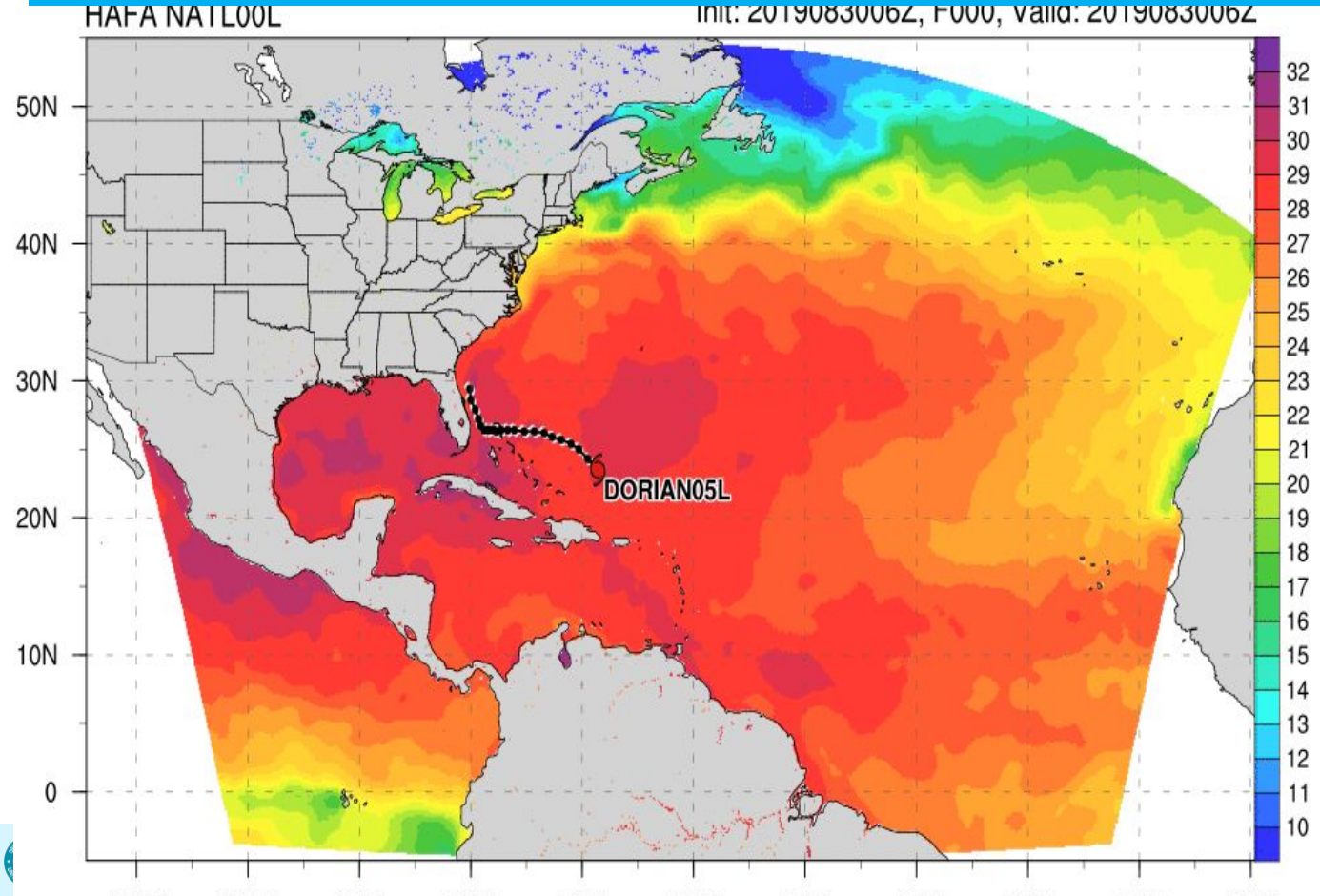
HAFS Overview and Objectives

- As a Unified Forecast System (UFS) application, HAFS is an FV3 (Finite Volume Cubed-Sphere Dynamical Core) based multi-scale model and data assimilation system capable of providing Tropical Cyclone (TC, including Hurricanes and Typhoons) analyses and forecasts of the inner core structure and the large-scale environment.

- The HAFS development targets an operational analysis and forecast system for Hurricane forecasters with reliable, robust and skillful guidance on TC track and intensity (including rapid intensification), storm size, genesis, storm surge, rainfall and tornadoes associated with TC's.

- HAFS will provide an advanced analysis and forecast system for cutting-edge research on modeling, physics, data assimilation, and coupling to earth system components for high-resolution TC predictions within the outlined Next Generation Global Prediction System (NGGPS)/Strategic Implementation Plan (SIP) objectives of the Unified Forecast System (UFS).

2019 Season: Regional HAFSv0.A Configuration



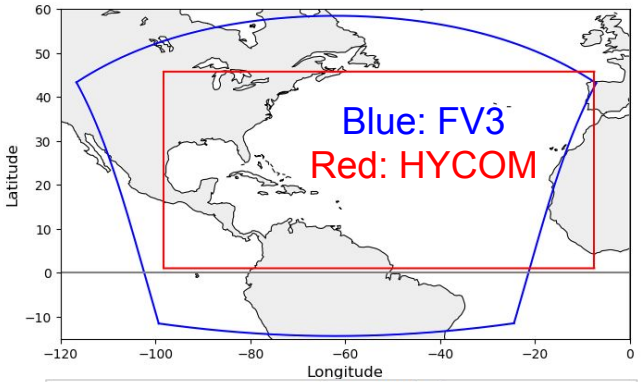
Hurricane Dorian forecasts using the HAFSv0.A configuration from HFIP real-time experiments.

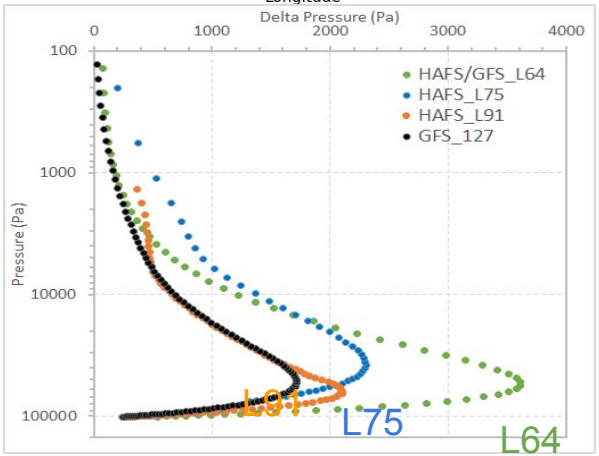
Dorian track forecasts from HAFS picked up on the right turn before the operational models.

2020 Season: The regional HAFSv0.1A Configuration

- The FV3 component (based on 2019 HAFS.v0.0A)
  - FV3 model domain (~85x72 deg)
  - 91 vertical leves from
  - Use the HAFS_V0_gfdlmp_nocpnsstugwd physics suite
    - GFDL microphysic; RRTMG radiation; No CP; Noah LSM; GFS surface layer with HWRF exchange coefficients; GFS EDMF PBL with HWRF modification; Both convective and orographic GWD are turned off; Turning off the NSST component
  - GFS NEMSIO file for IC; 3-hrly GFS grib2 files for LBC

- The HYCOM ocean model component
  - Cover NATL basin (1-45.78N, 261.8-352.5E) at a 1/12-degree resolution with 41 vertical layers
  - Ocean IC from RTOFS nowcast and/or forecasts
  - Use persistent oceanic LBC
  - Atmospheric forcing from 0.25-degree GFS grib2 files to cover non-overlapped area





Future: Unified DA Effort - JEDI

- The Joint Effort for Data assimilation Integration (JEDI) is a collaborative development spearheaded by the JCSDA
  - Next generation unified data assimilation system
    - For research and operations (including R2O/O2R)
    - For various components of the earth system, including coupled
    - Mutualize as much as possible without imposing single approach
  - Collaborative teams – NOAA, NASA, US NAVY
- The Marine JEDI DA system for NOAA/NCEP is through SOCA (Sea-ice Ocean Coupled Assimilation)

Courtesy of JCSDA

Future: Benefits of Using JEDI

- **Reduce duplication of effort between JCSDA partners**
  - Adding new observations (UFO and IODA)
  - Implementation of new DA algorithms (OOPS)

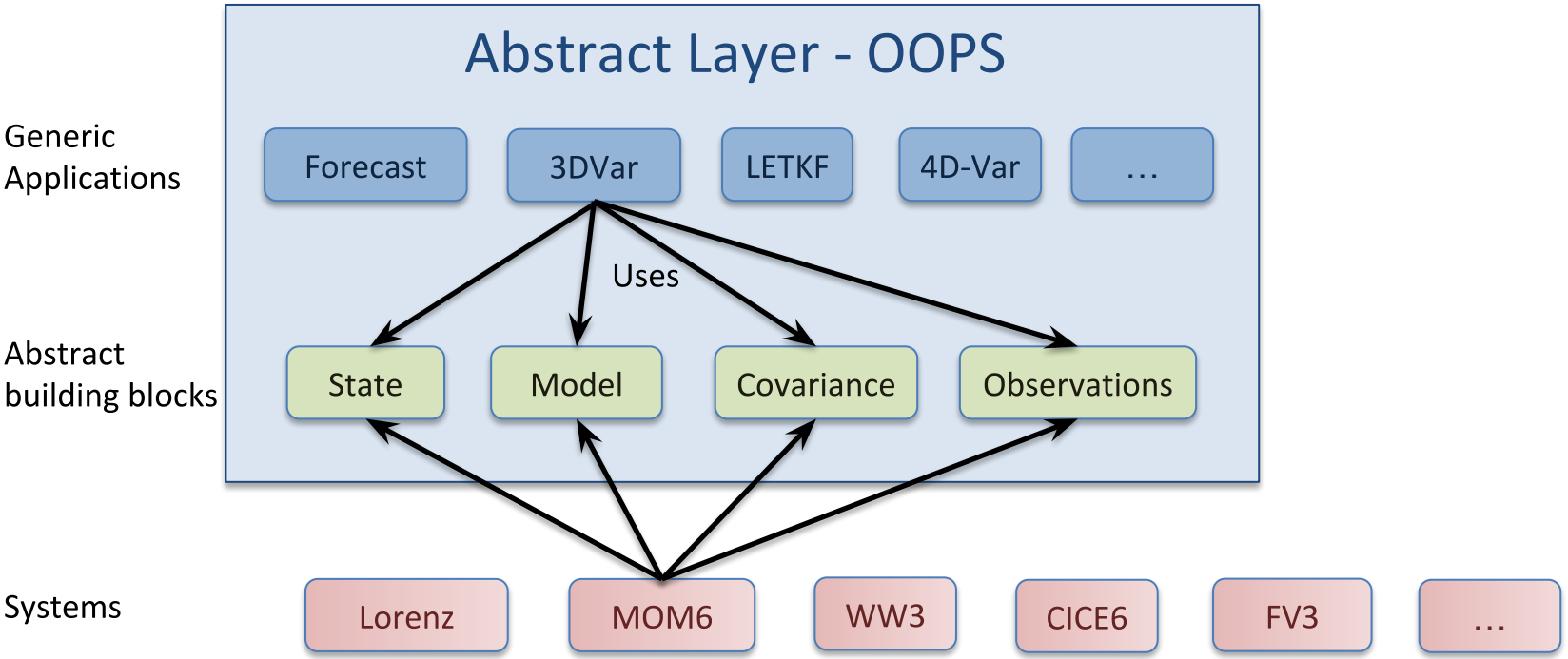
- **Bring all components of Earth-system in one DA system**
  - Develop DA once for all components (OOPS)
  - Enable future coupled DA developments (OOPS)

- **Modern DA systems are too complex for one person to grasp**
  - Collaborative developments
  - Separation of concerns

- **Modernize software**
  - Speed-up future developments
  - Ease maintenance
  - Increase portability and efficiency

Courtesy of JCSDA

Future: Unified DA Effort - JEDI



Abstract interfaces are the most important aspect of the design

Courtesy of JCSDA

Project HSUP-2/DRA-2: FL-4

Title: Advance ocean data assimilation and coupling of air-sea models in the NOAA UFS in support of improved flood and inundation forecasting through coordination with NWS and NOS

Objectives:

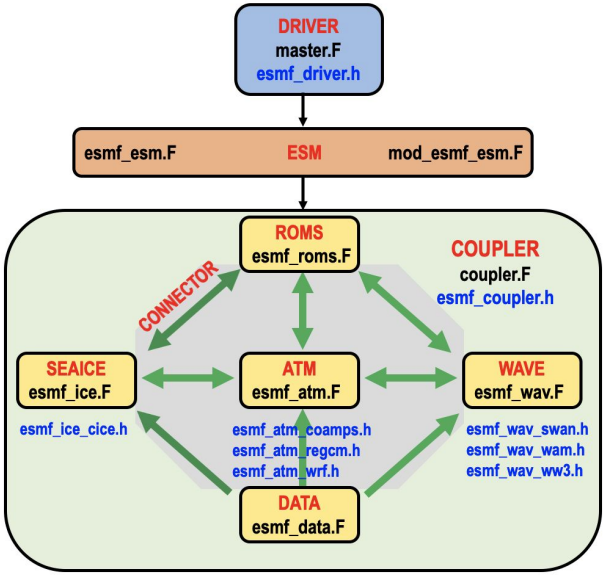
- Coupled model development within the UFS framework with regional FV3
- Transition NWS and NOS ocean data assimilation efforts toward a common infrastructure (JEDI) and incorporate currently unused high-resolution ocean observations
- Enable comparison of ocean models and DA methods, and future leveraging of research activities for improved coupled Hurricane forecasts
- Establish capabilities of air-sea interface modeling and gaps that must be addressed for future coupled DA and explore strongly coupled DA for Hurricane applications

Project HSUP-2/DRA-2: FL-4

1. Integrate ROMS within UFS
2. Implement ROMS 4D-Var in JEDI
3. Ingest high resolution ocean observations in JEDI
4. Build Hybrid ODA for HAFS
5. Explore coupled DA using ocean observations

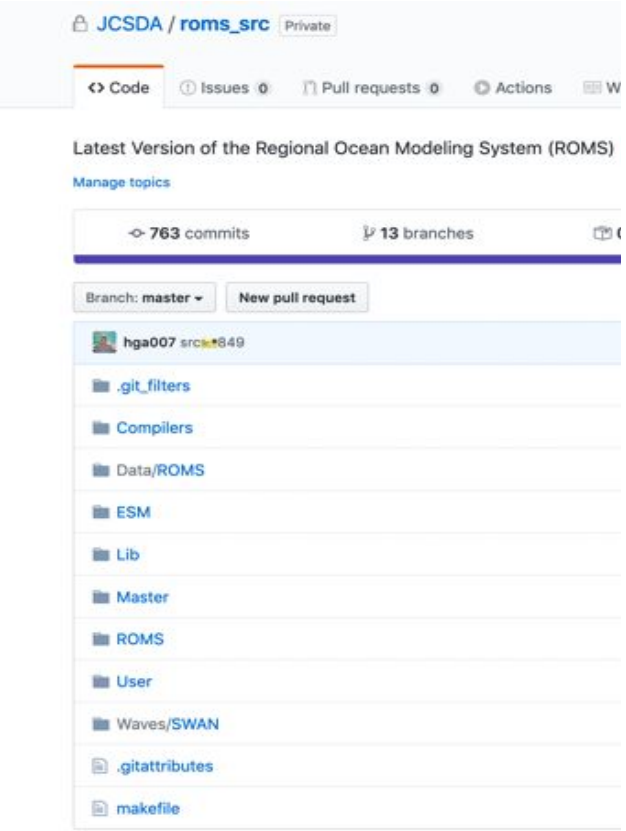
Integrate ROMS within UFS (Rutgers)

- Updated to ESMF/NUOPC version 8.0
  - New extrapolation options improve land/sea mask reconciliation during regridding
- Redesign of nesting - elegant and flexible
  - NUOPC now allows coupling sets in the import/export states of ESM components
  - Nested grids represented as ESMF_Grid object; coupled models can have telescoping meshes of increasing resolution.
- Presently using connectors not mediators
  - NUOPC connector exchanges directly between different grids of ESM components
  - Connections possible: nest-to-nest, fine-to-coarse, or coarse-to-fine. User decides which nested grids to connect.
- The RunSequence is now specified from an input configuration script



Implementing ROMS 4D-Var in JEDI (Rutgers & JCSDA)

- Completed loading ROMS into JCSDA's GitHub repository (JCSDA/roms_src)
- Completed separation of ROMS sequential 4D-Var into phases for background, increment and analysis
- Established how to encapsulate ROMS Fortran Code into OOPS C++ classes (with M. Chrust ECMWF)
- Formulated incremental strategy to use UFO and IODA in existing ROMS 4D-Var (H. Arango and G. Verniers) prior to full ROMS in JEDI
- Testing migration of ROMS build process to use Cmake to meet JEDI requirements to use shared libraries, Cmake, and eckit (cross-platform C++ toolkit)



Towards Marine DA for HAFS (JCSDA-EMC)

Applications Status

✓ Implemented

❌ Not implemented

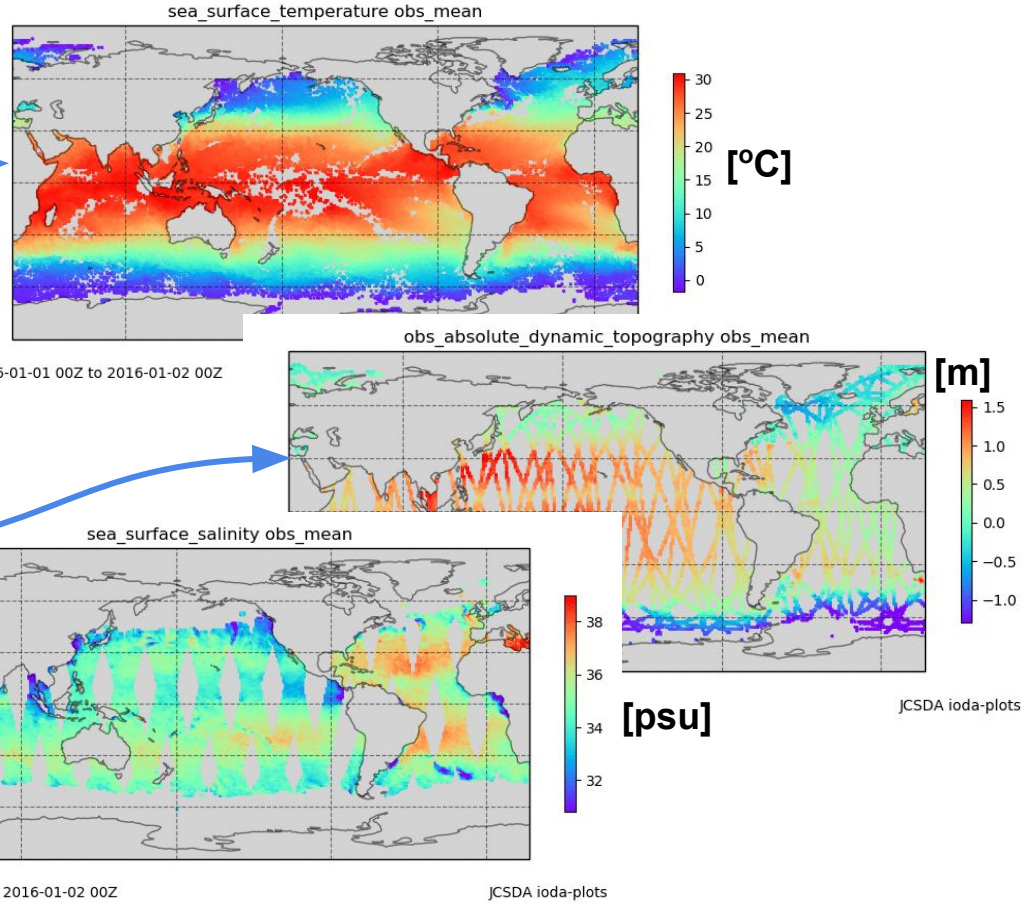
	Global UFS (MOM6-CICE)	Global MOM6	Regional MOM6
h(x) (forecast + observation simulation & innovation)	✓	✓	❌
3DVAR	✓	✓	❌
LETKF	✓	✓	❌
Hybrid-EnVAR	✓	✓	❌

Example of satellite observing systems available through the existing workflow

	sensor	satellite
SST-IR	AVHRR	NOAA-19
SST-MW	GMI	GPM
	AMSR2	GCOM-W1

	sensor	satellite
Absolute Dynamic Topography	Poseidon-3, AMR, DORIS, GPSP, LRA	Jason-2
	SIRAL, DORIS, LRR	Cryosat-2
	Altika, DORIS, LRL	SARAL
	SRAL	Sentinel-3

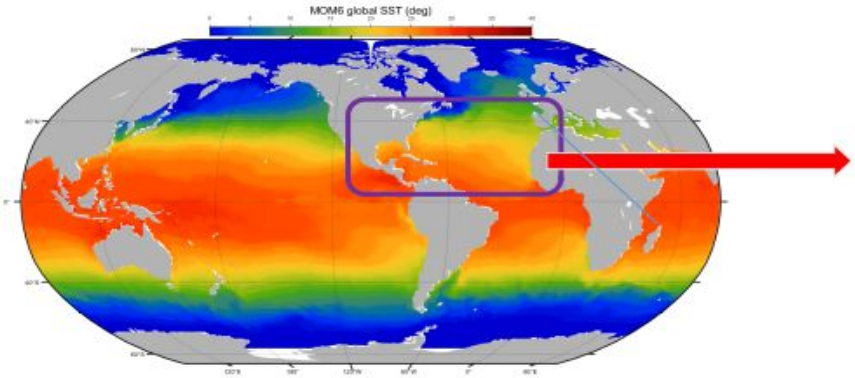
	sensor	satellite
SSS	SMAP	SMAP



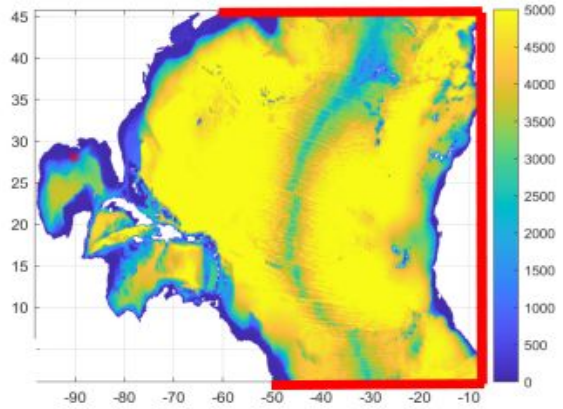
Regional ODA Implementation

- Established regional ODA capability in the UFS-GODAS/JEDI-SOCA system
  - Implemented global-to-regional state converter and linked to DA workflow

Global MOM6



Regional MOM6 (HAT10)

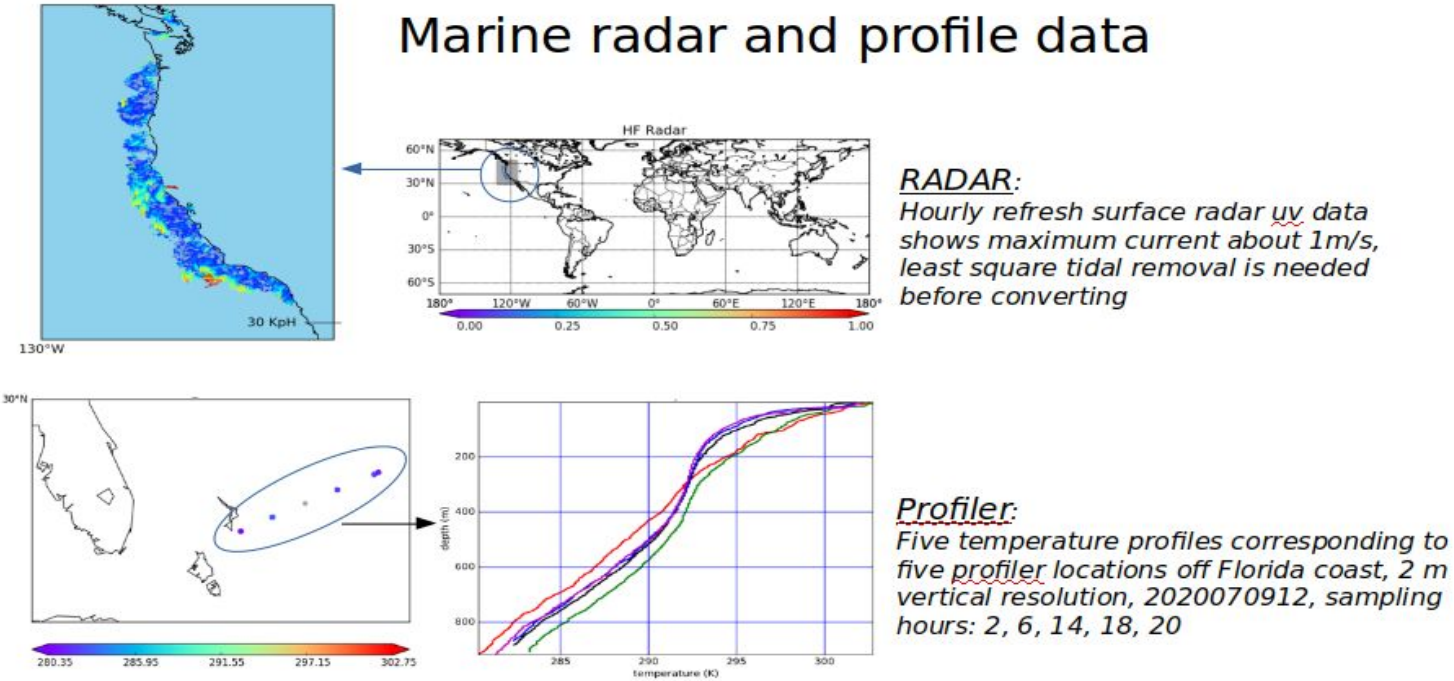


Goal:
provide best estimate ocean IC & BC for coupled Hurricane forecast system

Current Experiment configuration: 1/12-degree resolution
Forcing: CORE/JRA55
IC & BC: Climatology from SODA3, Rutgers-developed OBC options

Establishing Observation Data Workflow

- Work-in-progress to implement JEDI-based obs operators
  - Staging obs data in NOAA HPCs and on-going JEDI UFO code development



On-going SOCA/JEDI Marine DA Updates

- DA system development
  - Global and regional DA applications with multiple model resolution options (1°, 1/4°, 1/12°)
  - BGC DA capability: observation workflow, JEDI/UFO obs operator, 3DVAR test phase
  - Tuning and optimization of LETKF and hybrid EnVar DA options

- Unified observation workflow with JEDI-IODA/UFO
  - Updated buf2ioda converters to process all marine data available in WCOSS data tanks
  - Enhanced DA capability for CryoSat2 seaice freeboard thickness data
  - On-going implementation of IODA/UFO codes for the observation of regional DA applications
  - Glider (extended application of in-situ marine UFO interfaces) and HF-Radar (new implementation)
  - Cross model validation of Hurricane applications: HYCOM/MOM6 and high-density obs

- Added DA workflow options
  - Switched from rocoto-based DA woflow to soca-science/JEDI-ewok (Rapids) system
  - Reanalysis intercomparion experiments underway (EMC/JCSDA/GMAO)
  - Comparison of UFS-DATM-MOM6-CICE5/MOM6-SIS2/GEOS reanalysis results

Supplementary Slides

Ocean Data Quality Control: Stages and Outcomes

Stage 1 – sensibility checks

- land/sea boundaries, location (speed) test, exact/near duplicate, future observation time test

Stage 2 – error checks:

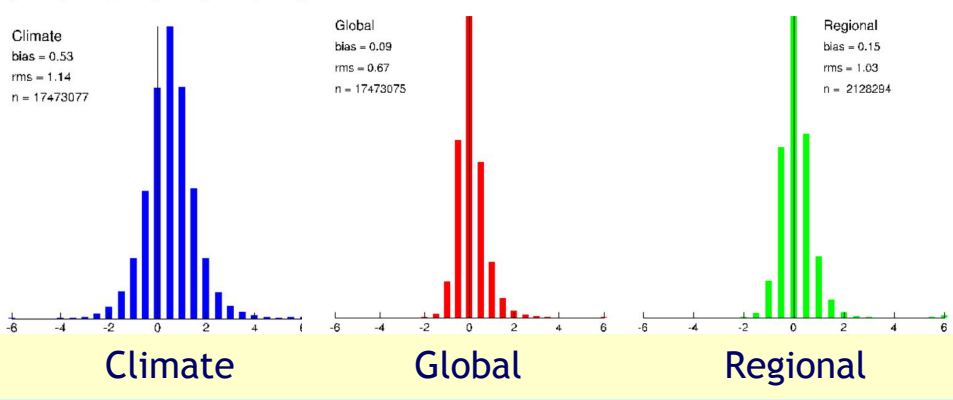
- instrumentations failure modes, vertical gradients, static stability
- cross validation, background fields (climate, forecast)

Stage 3 – consistency checks:

- reject if global 3DVAR solution is not converging at observation location
- innovation error checks performed during the variational minimization

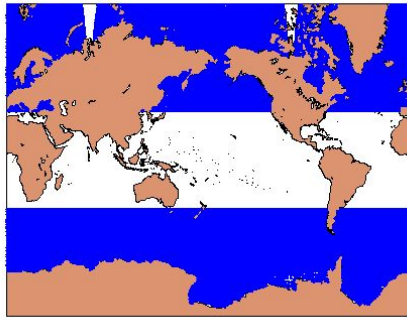
Anomaly histograms of JPSS-VIIRS SST vs. various SST backgrounds

- QC outcomes: likelihood observation contains an error plus condition flags
- All QC tests performed before a QC decision is made: accept, reject, correct
- Decision making algorithm is used to resolve multiple background field checks
  - climate, cross validation analysis, forecast
- QC outcomes and flags used to select valid observations for the analysis

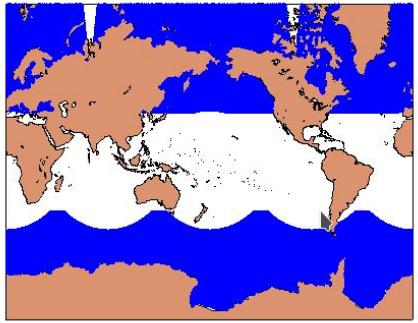


RTOFS v2 Ocean Observing Systems: 28 July 2020

Sea Ice Coverage



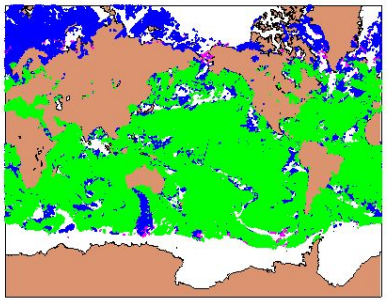
SSMI/S

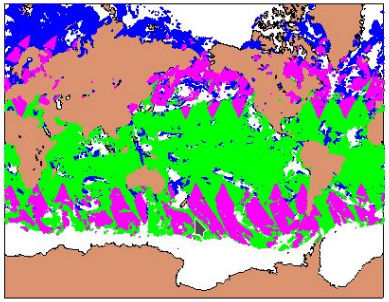


AMSR

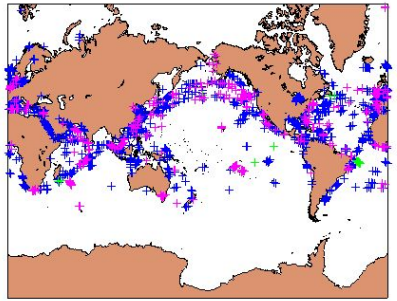
ICE obs: 14,407,462
SST obs: 26,897,764

Satellite and In situ SST

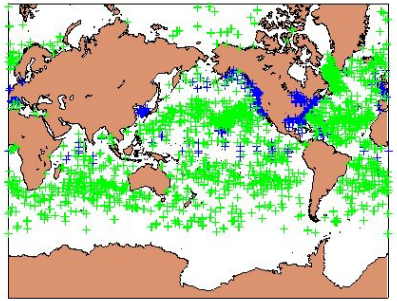




METOP-A



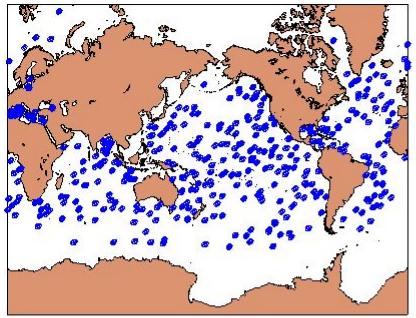
Sfc SHIP



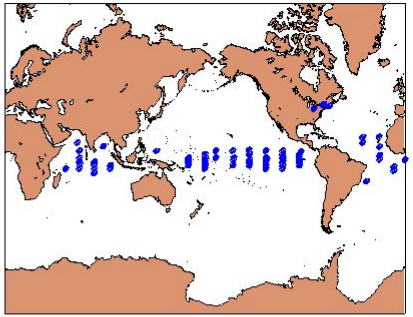
Fixed/Drifting Buoy

RTOFS v2 Ocean Observing Systems: 28 July 2020

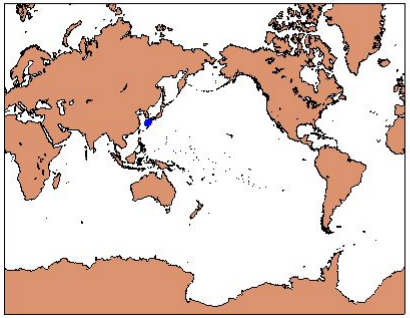
Profile Observations: # profiles: 3677 # profile obs: 226,150



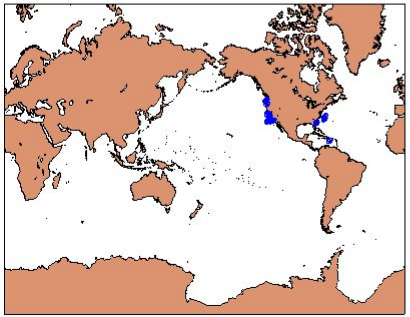
Argo



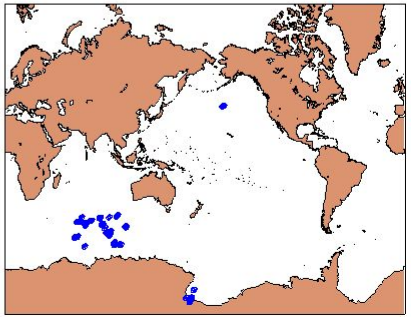
Fixed Buoy



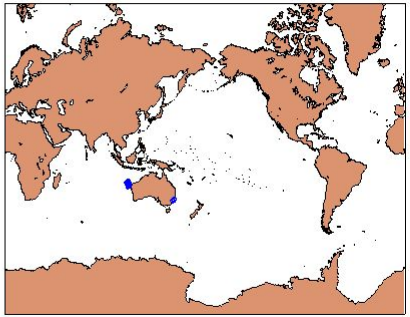
TESAC



Glider



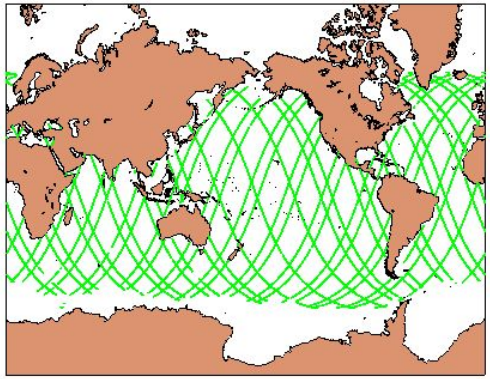
Animal Sensor



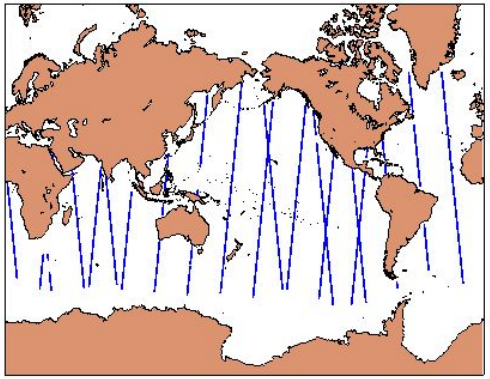
XBT/XCTD

RTOFS v2 Ocean Observing Systems: 28 July 2020

Altimeter SSH

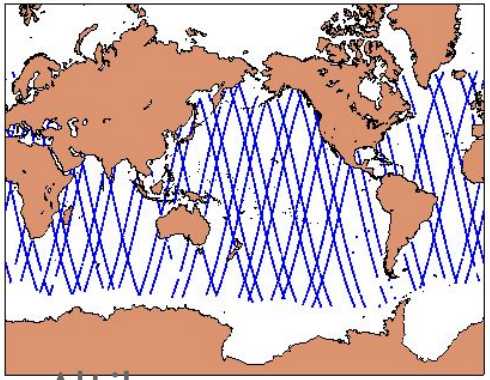


Jason-3

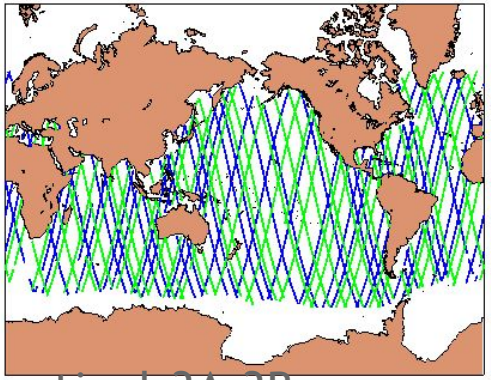


CryoSat-2

SSH obs: 232,429



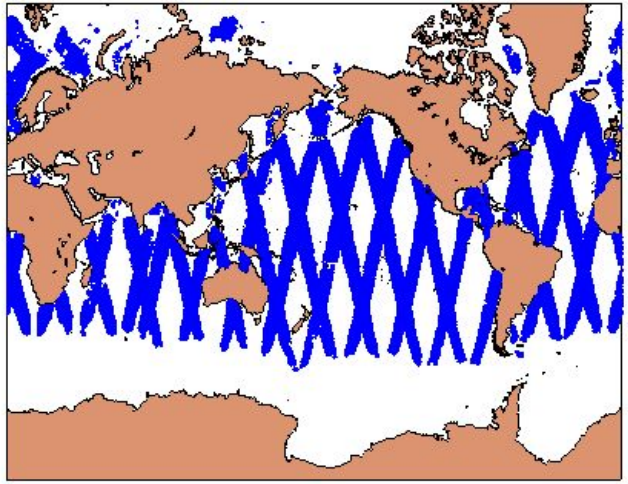
Altika



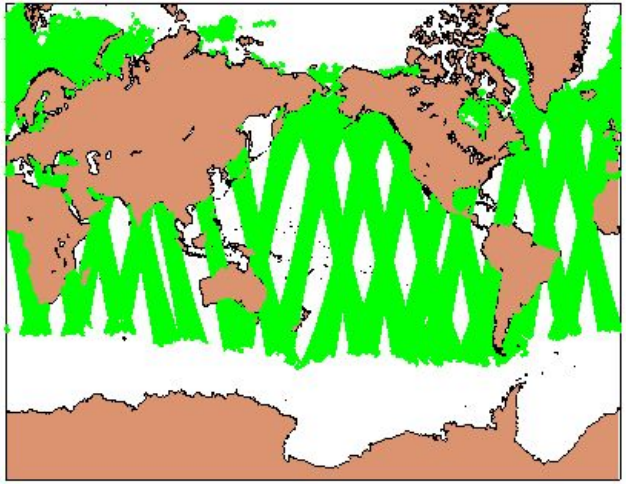
Sentinel-3A,3B

RTOFS v2 Ocean Observing Systems: July 28 2020

Satellite Sea Surface Salinity



SMOS



SMAP

SSS obs: 964,536