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Coupled data assimilation at the US Navy

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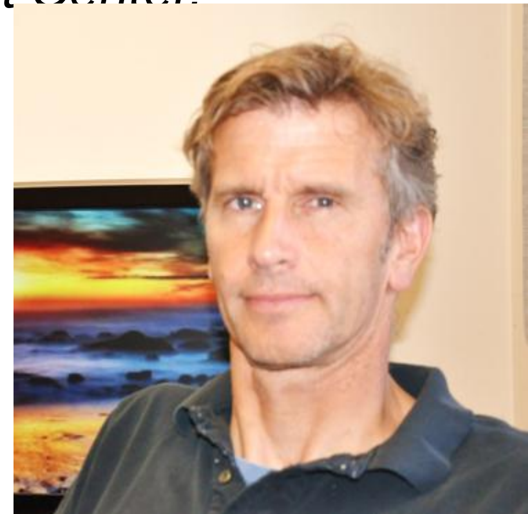

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Background

- Analysis and prediction of ocean, ice, waves, surf, river flow, land-surface, clouds, precipitation, aerosols, ionosphere and space weather are all of interest to the Navy.
- Navy sub-models are gradually being coupled and there is high interest in coupled DA methods that could be used to initialize them.

Challenges

- Ocean is undersampled compared to atmosphere
- Time scale of ocean much slower than atmosphere
- Arrival time of ocean observations is delayed compared with that of atmospheric obs.
- Compromise between long ocean DA and much shorter atmospheric DA windows?
- How to build on top of existing useful single fluid DA schemes?
- How to build and maintain TLM/adjoints of complex coupled systems?
- Non-Gaussian errors in ice assimilation
- Managing complexity (OOPS, JEDI, etc)

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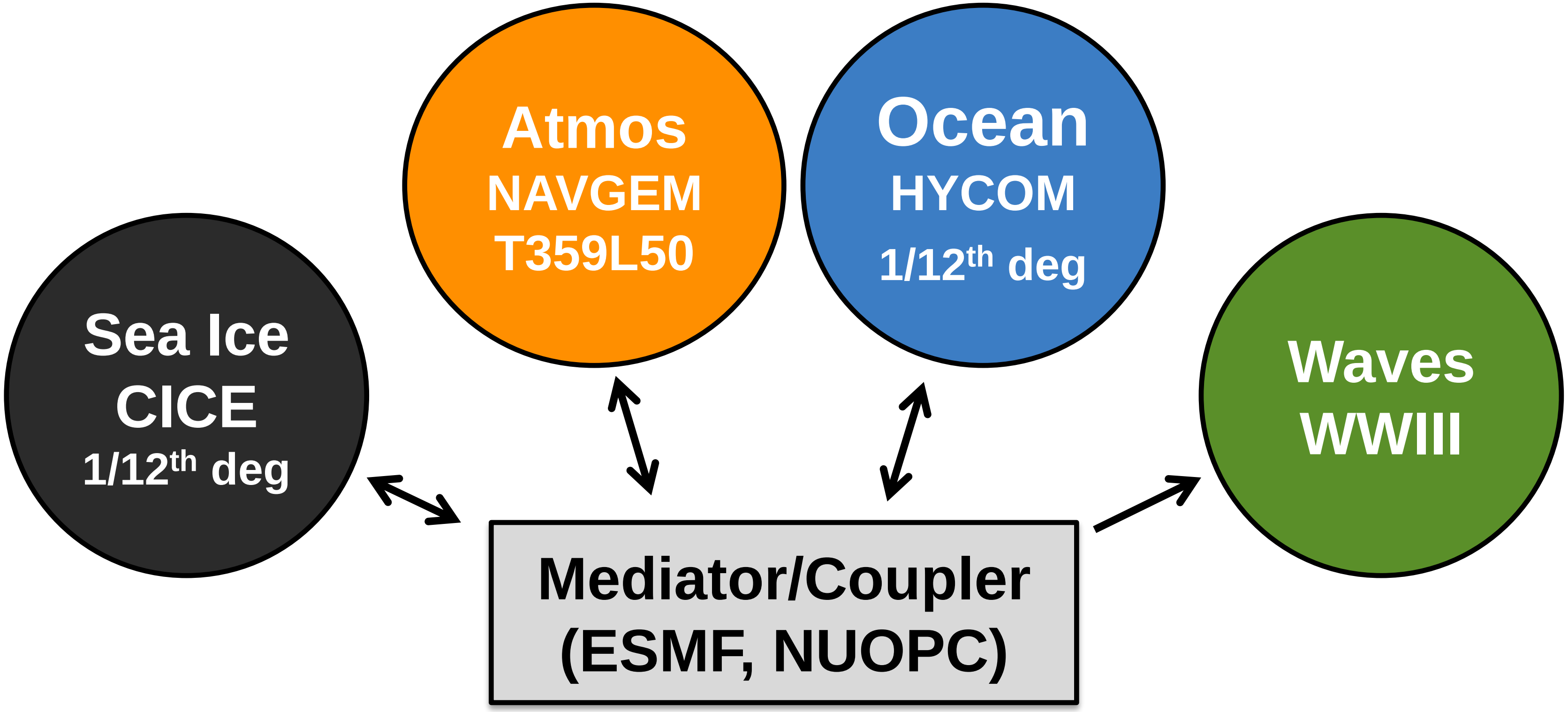
Global Coupled Model (current state)



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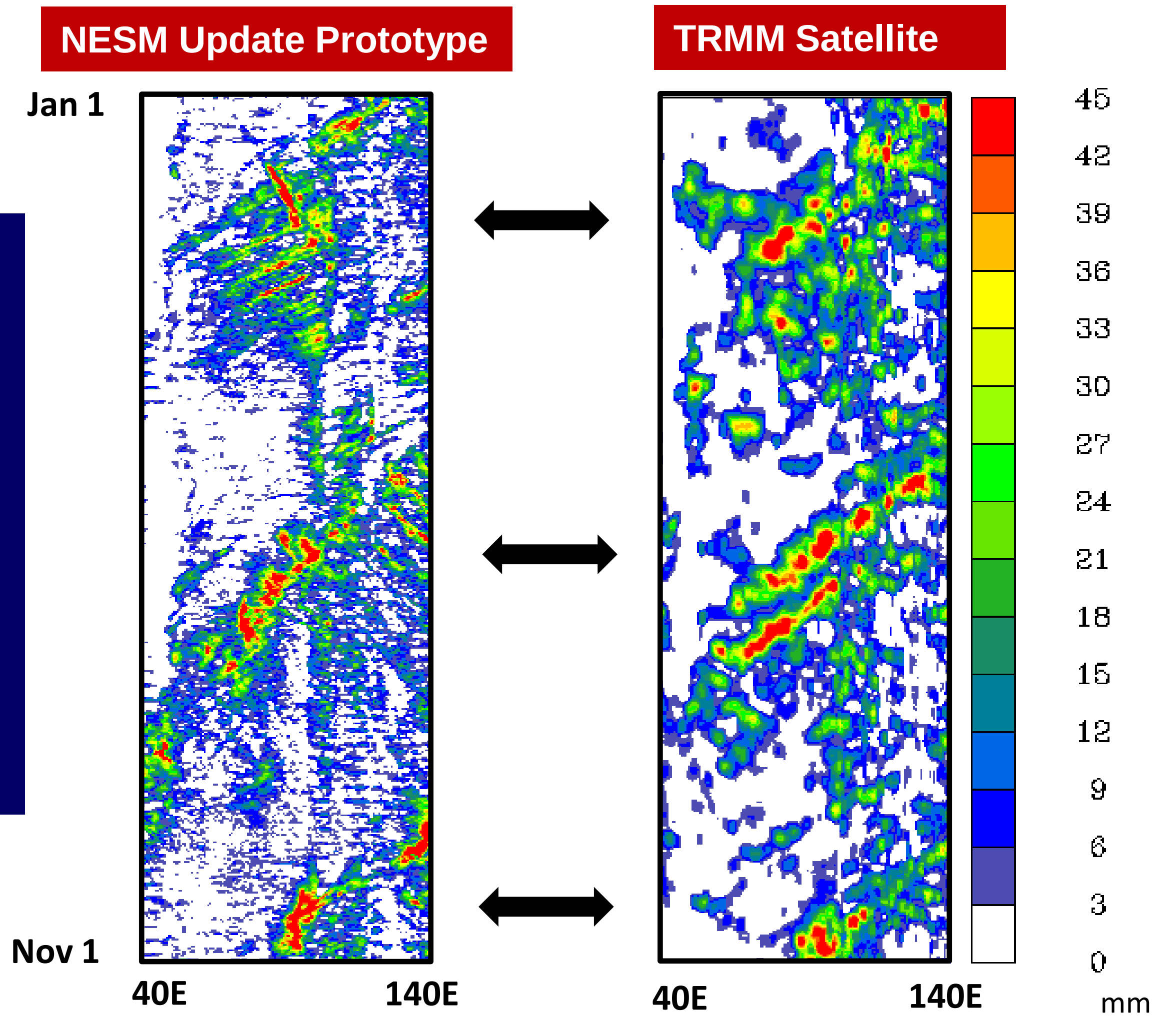
Skill of the pre-operational forecast system: MJO

61-Day MJO Reforecasts from 1 Nov, 2011 (DYNAMO* period)

Equatorial Zonal Propagation of Rainfall (5°N - 5°S)



Recent runs with improved convective physics suggest MJO prediction skill at the frontiers of current global models.

* DYNAMO (Dynamics of t Madden-Julian Oscillation)

J. Ridout

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Global Coupled Model (initial operating capability 2018)

Forecast	Time Range, Frequency	Atmosphere NAVGEM	Ocean HYCOM	Ice CICE	Waves WW3[3]	Land-Surface NAVGEM-LSM	Aerosols
Deterministic short term	0-16 days, Daily	T681L80 (19 km) 80 levels	1/25° (4.5 km) 41+ layers	1/25° (4.5 km)	1/8° (14 km)	Module within NAVGEM	Module within NAVGEM
Probabilistic long term	0-30 days, Daily 15 members	T359L60 (37 km) 60 levels	1/12° (9 km) 41 layers	1/12° (9 km)	1/4° (28 km)	Module within NAVGEM	Module within NAVGEM

- **IOC Data Assimilation will be weakly coupled (independent DA systems but coupled forecast for first guess)**
- **Final Operational Capability: FY22**
  - **Seasonal (90-day) ensemble forecasts**
  - **Coupled data assimilation**
  - **Interactive ocean surface waves**

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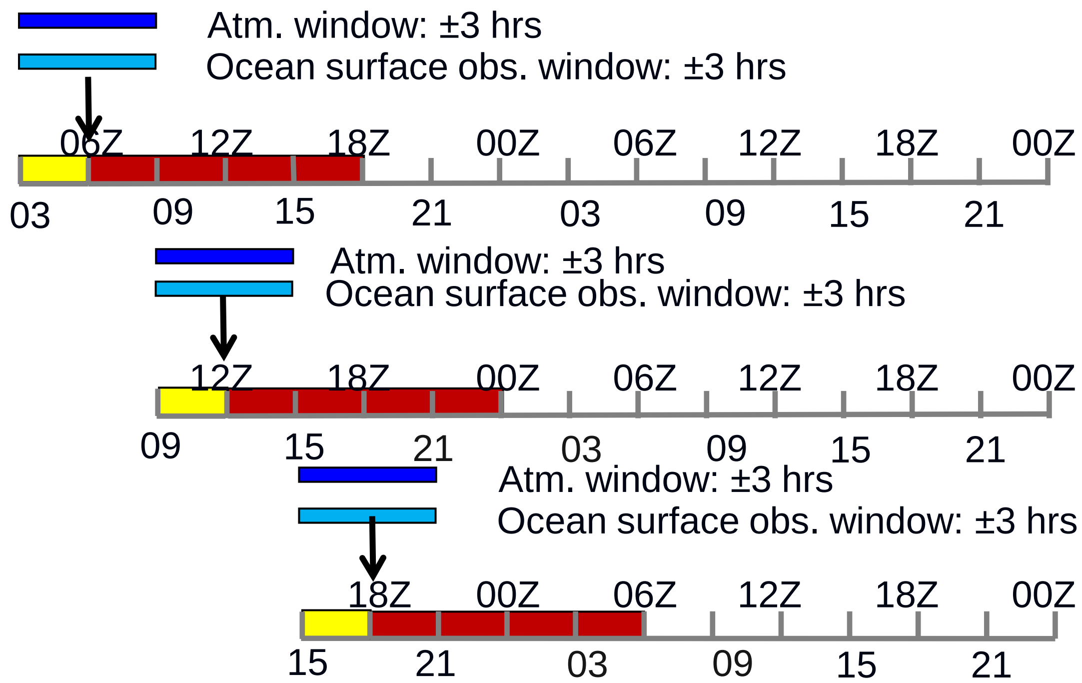
Current uncoupled Global DA

- **Atmospheric DA**
  - Hybrid 4DVAR with 80 member ensemble no outer loop. Resolution of first guess trajectory is T425L60. Resolution of inner loop T119L60.
- **LSM DA**
  - LIS/NASA
- **Aerosol DA**
  - 3DVAR
- **Wave DA**
  - none operationally (2DVAR in research)
- **Ocean DA**
  - 3DVAR for ocean with no outer loop. Resolution of first guess trajectory is 1/12th degree. Altimeter data assimilated through a synthetic profile generating intermediator. Correction is coarser resolution than first guess.
- **Ice DA**
  - Strongly nudged towards blend of US National Ice Center analysis and satellite (SSMIS) ice concentration at beginning of forecast.

Planned mixed window length weakly coupled DA



In the first three 6-hour cycles:

- Use traditional 6-hour 4DVAR window in atm.
- Use 6-hour 3DVAR in the ocean but only for surface ocean obs.
- Use 3-hour IAU to initialize coupled forecast

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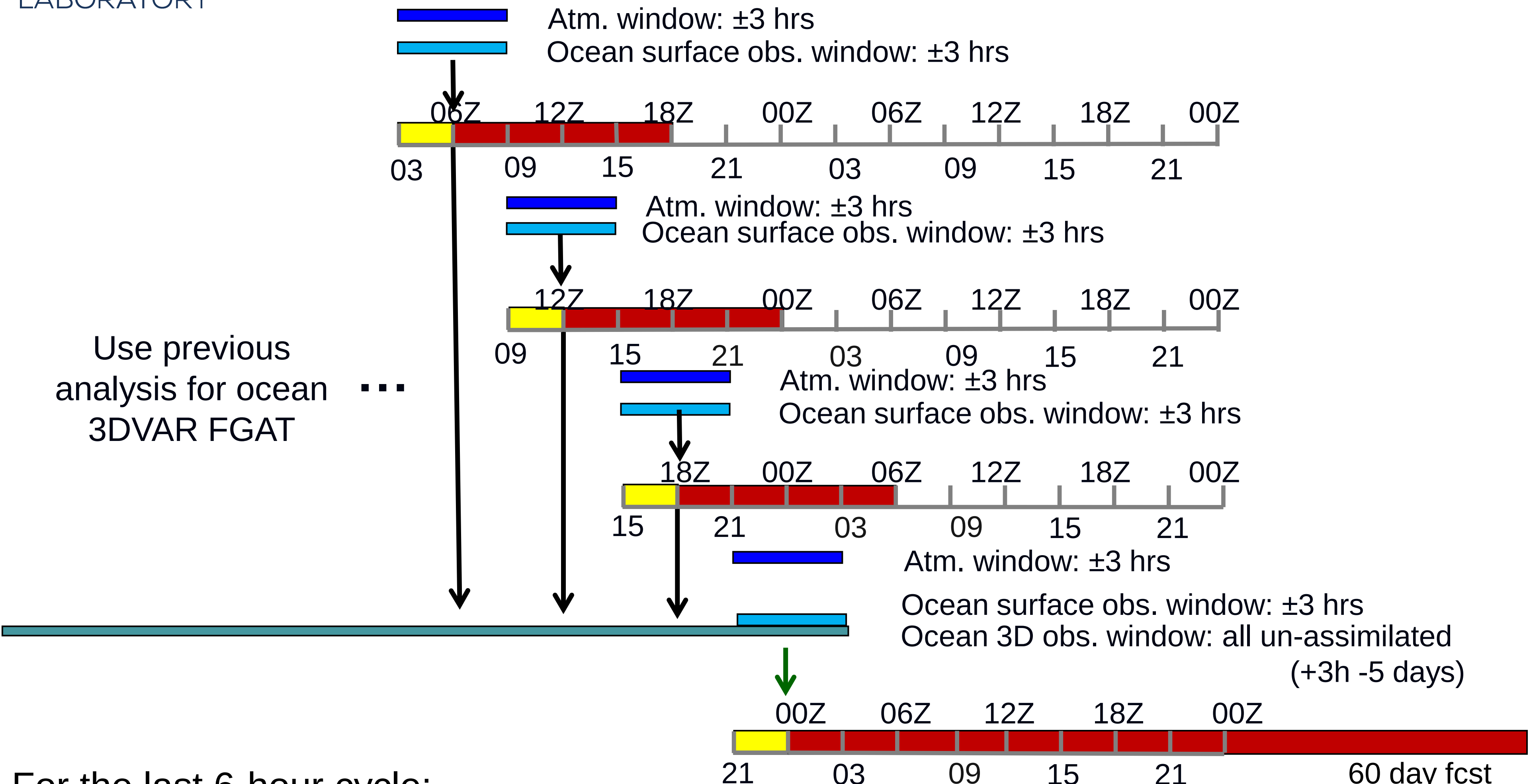
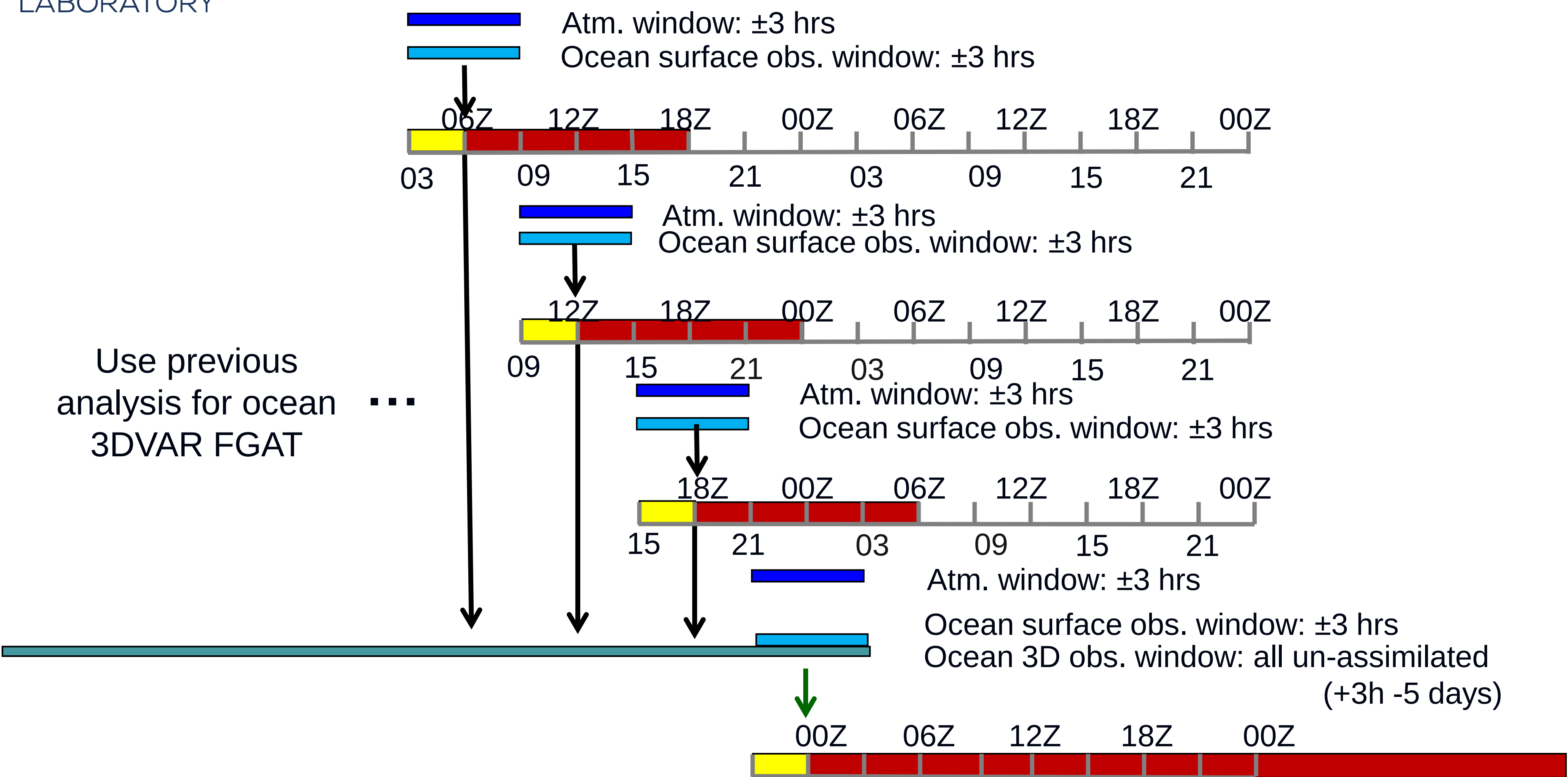
Planned mixed window length weakly coupled DA



For the last 6-hour cycle:

- Use traditional 6-hour 4DVAR window in atm.
- Ocean 3DVAR assimilates all unassimilated 3D obs. the last 6 hours of surface obs.
- A long forecast is launched

Planned mixed window length weakly coupled DA



- This system mimics sequential assimilation of observations in a Kalman filter (e.g. update of previous analysis with new obs.)
- Preserves capability of the ocean DA to use long window for assimilation of sparse, delayed 3D obs.

R&D for future Global DA

- **Mixed window length DA for weakly and (eventually) strongly coupled DA**
- **4DVAR**
- **Hybrid 3DVAR DA for ocean with coupled model perturbed observations ensemble**
- **Interface Solver (see Sergey's talk for details)**
  - Extend atmospheric domain into upper ocean to allow ocean obs to affect atmosphere
  - Extend oceanic domain into the atmosphere to allow atmospheric obs to affect ocean
  - Same idea for other sub-components

Regional Coupled Model

Operational:

- Coupled Ocean Atmosphere Model Prediction System
  - COAMPS atmosphere, NCOM ocean, SWAN/WW3 waves, CICE ice

R&D (early work):

  - COAMPS atmosphere, ROMS ocean, DART data assimilation

Regional Coupled model DA (current)

- Option 1: Cold start off uncoupled global model analyses (operational for TC forecasting)
- Option 2: Weakly coupled 3DVAR data assimilation in ocean and atmosphere.

Research Activities

- Fully coupled ocean-wave-atmosphere 4DVAR (see Hans Ngodock's talk)
- Hybrid 3DVAR
- Strongly coupled EnKF

Summary

- Observation latency and time scale differences will be addressed using a mixed DA window length approach.

- Strongly coupled DA structure for ocean and atmosphere will be obtained using interface solver (global system) or coupled 4DVAR (regional) and coupled EnKF (regional).

- Still need to develop ensemble forecasting systems that accurately sample both initial condition and model error essential to the improvement of coupled DA and Hybrid error covariance models.

Concluding Remarks

- The Navy is very interested in the coupled DA problem.
- Visits from coupled DA experts to the Naval Research lab are welcome!
- Looking for help from community.

Planned mixed window length weakly coupled DA