NGGPS

UNIFIED GLOBAL COUPLED SYSTEM (UGCS) FOR WEATHER AND CLIMATE PREDICTION

"A good prediction system incorporates both a good data assimilation (DA) system and a good forecast model."

TOWARDS BUILDING A PROTOTYPE OF THE NEXT GENERATION UNIFIED GLOBAL COUPLED ANALYSIS AND FORECAST SYSTEM AT NCEP (UGCS)

UNIFIED GLOBAL COUPLED SYSTEM
DATA ASSIMILATION

Atmosphere, Land, Ocean, Seaice, Wave, Chemistry, Ionosphere

- Data Assimilation cycle

➢ Analysis frequency	Hourly
➢ Forecast length	9 hours
➢ Resolution	10 km
➢ Ensemble members	100
➢ Testing regime	3 years (last 3 years)
➢ Upgrade frequency	1 year

UNIFIED GLOBAL COUPLED SYSTEM
WEATHER FORECASTS

Atmosphere, Land, Ocean, Seaice, Wave, Chemistry, Ionosphere

- Weather Forecasts
  - Forecast length — 10 days
  - Resolution — 10 km
  - Ensemble members — 10/day
  - Testing regime — 3 years (last 3 years)
  - Upgrade frequency — 1 year

UNIFIED GLOBAL COUPLED SYSTEM
SUB-SEASONAL FORECASTS

Atmosphere, Land, Ocean, Seaice, Wave, Chemistry, Ionosphere

- Sub-seasonal forecasts
  - Forecast length: 6 weeks
  - Resolution: 40 km
  - Ensemble members: 20/day
  - Testing regime: 20 years (1999-present)
  - Upgrade frequency: 2 year

UNIFIED GLOBAL COUPLED SYSTEM
SEASONAL FORECASTS

Atmosphere, Land, Ocean, Seaice, Wave, Chemistry, Ionosphere

- Seasonal Forecasts

➢ Forecast length	9 months
➢ Resolution	60 km
➢ Ensemble members	40 (lagged)
➢ Testing regime	40 years (1979-present)
➢ Upgrade frequency	4 year

UNIFIED GLOBAL COUPLED SYSTEM NEW PARADIGM

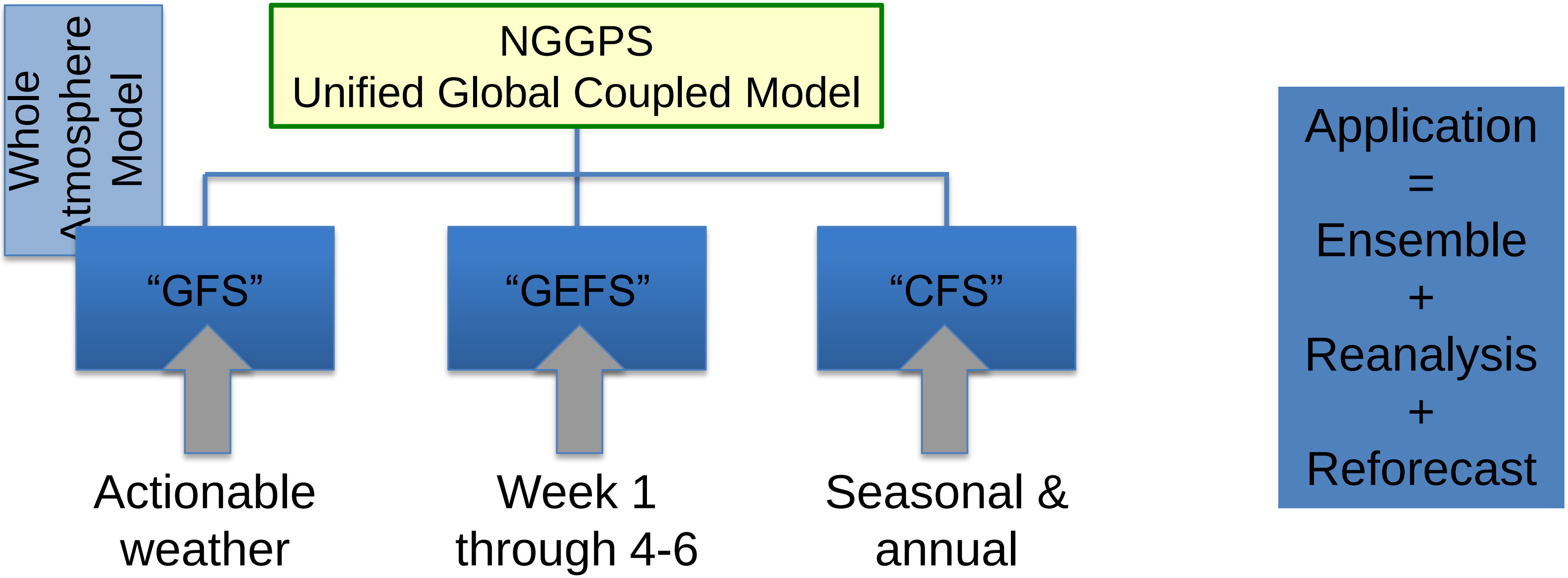
Atmosphere, Land, Ocean, Seaice, Wave, Chemistry, Ionosphere

- Predictions for all spatial and temporal scales will be ensemble based.
- There will be a ***continuous*** process of making ***coupled Reanalysis*** and Reforecasts for every implementation (weather, sub-seasonal and seasonal)
- Since the resolution of all parts of the system is usually increased with every new implementation (in proportion to the increased computing power currently available), we need to explore cheaper cloud computing and storage options for making these reanalysis/reforecasts.

PROOF OF CONCEPT

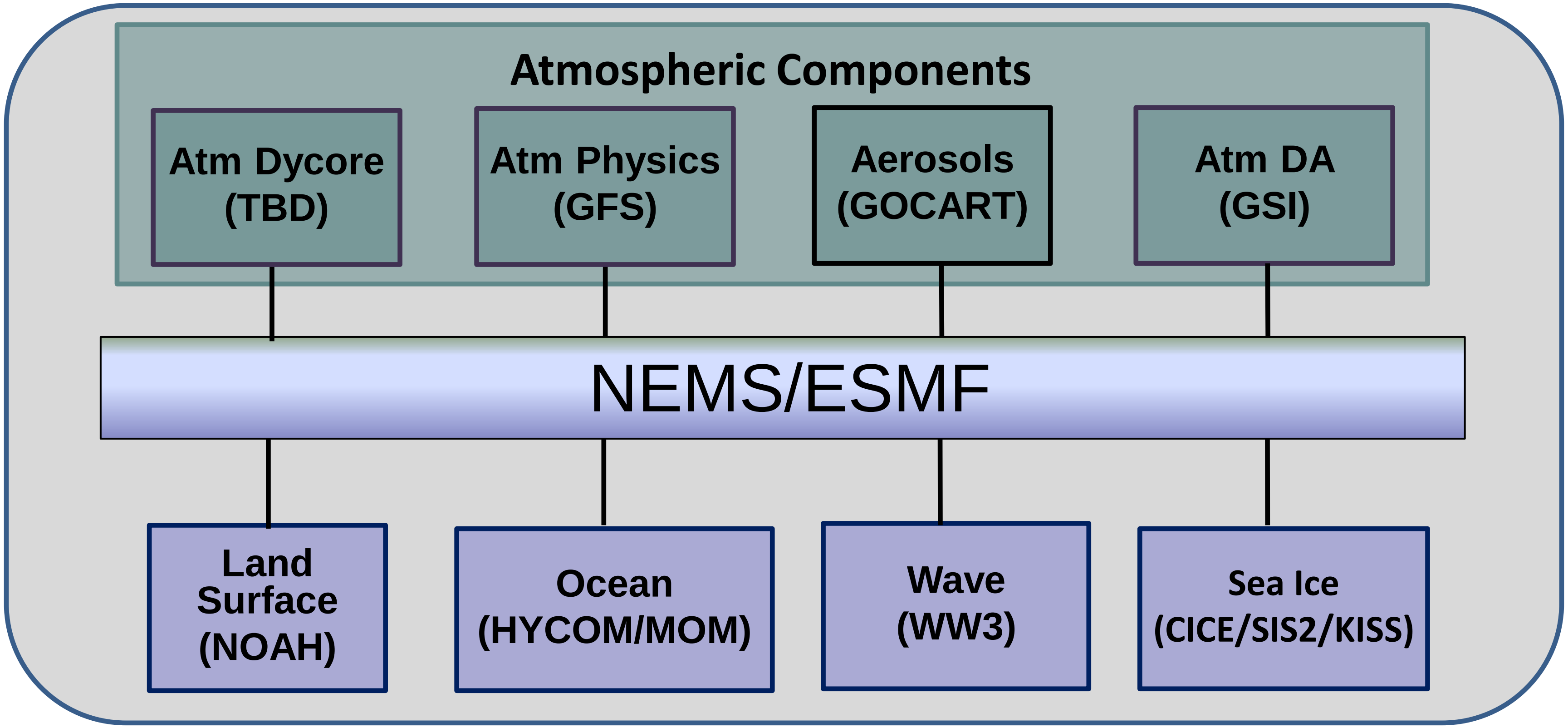
- Atmosphere: Hybrid 4D-EnVAR approach using a 80-member coupled forecast and analysis ensemble, with Semi-Lagrangian dynamics, and 128 levels in the vertical hybrid sigma/pressure coordinates.
- Ocean/Seaice: GFDL MOM5.1/MOM6 and/or HYCOM for the ocean and CICE/SIS2/KISS for sea-ice coupling, using the NEMS coupler.
- Aerosols: Inline GOCART for aerosol coupling.
- Waves: Inline WAVEWATCH III for wave coupling.
- Land: Inline Noah Land Model for land coupling.
- Ionosphere: Inline Whole Atmosphere Model (WAM) –up to 600km.

NGGPS Unified Global Coupled Model

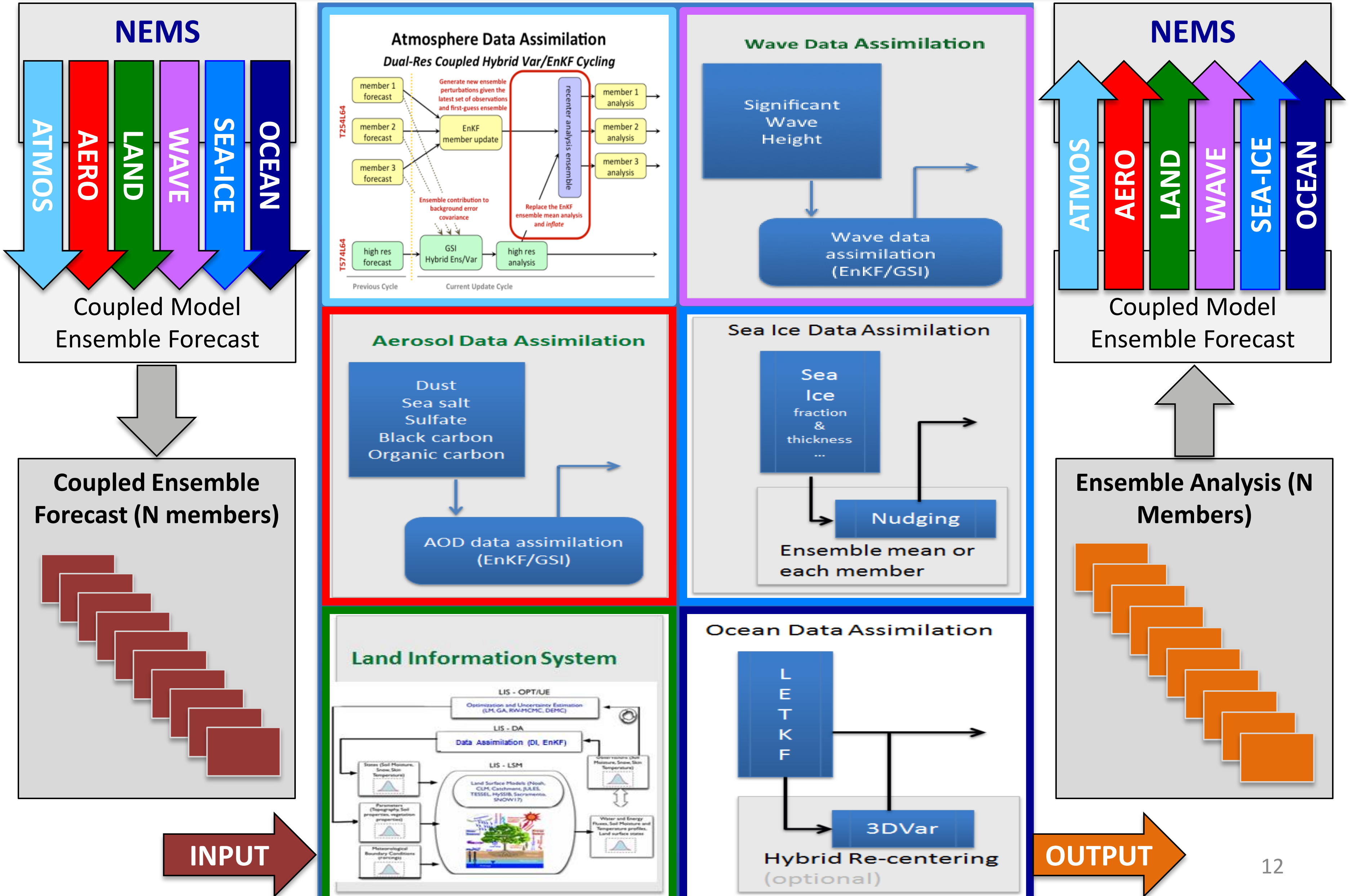


1 y	2 y	4 y	**Update cycle**
3 y	1999 - present	1979 - present	**Reanalysis**
6h	6h	6h	**cycling**
WCOSS	WCOSS	WCOSS	**where**

NGGPS Planned Components



NCEP Coupled Hybrid Data Assimilation and Forecast System



NEMS

- The NOAA Environmental Modeling System is being built to unify operational systems under a single framework, in order to more easily share common structures/components and to expedite interoperability.
- The first two systems under NEMS (NAM/NMMB and GOCART) have been implemented into NCEP operations with others to follow in the next few years, such as the GFS, etc.
- The NUOPC (National Unified Operational Prediction Capability, NOAA, Navy and Air Force) layer will be used to make collaboration with other groups less difficult, when building/coupling modeling systems.
- Incorporation of a NUOPC physics driver can help standardize the often complex connections to physics packages, thereby enhancing their portability.

Mark Iredell, EMC

Atmospheric Data Assimilation Upgrades

- Develop prototype, Hybrid 4D-EnVAR data assimilation system using the GSI and a NEMS-based GSM at SL T670/L64 resolution and an 80 member ensemble at T254L64 resolution for Hybrid DA.

- Test and validate system using UGCS coupled model as background for atmospheric DA. Determine impacts of each domain for atmospheric prediction and DA.

- Prototype system will be initial NEMS-based code set for atmospheric component of NGGPS and CFSv3 development. System will generate more accurate background field for the atmosphere and other domains.

Daryl Kleist, UMD and NCEP

CONVECTION

- Improve the representation of small-scale phenomena by implementing a scale-aware PDF-based subgrid-scale (SGS) turbulence and cloudiness scheme replacing the boundary layer turbulence, the shallow convection, and the cloud fraction schemes in the GFS and CFS.
- Improve the treatment of deep convection by introducing a unified parameterization that scales continuously between the simulation of individual clouds when and where the grid spacing is sufficiently fine and the behavior of a conventional parameterization of deep convection when and where the grid spacing is coarse.
- Improve the representation of the interactions of clouds, radiation, and microphysics by using the additional information provided by the PDF-based SGS cloud scheme.
- Alternatively, upgrade the clouds and boundary layer parameterization, using the approach of moist Eddy Diffusion and Massflux (EDMF) approach by considering several microphysics schemes available in WRF package and a simple pdf based clouds and improved scale aware convection by extending SAS.

S. Moorthi, EMC

Atmospheric Model Physics Upgrades

RADIATION AND OTHER:

- Improve cloud radiation interaction with advanced radiation parameterization based on the McICA-RRTMG from AER Inc. with interactive aerosol (both direct and indirect) affects.
- Include radiative effects due to additional (other than CO2) green-house gases from near real-time observations.
- Improve the representation of aerosol-cloud-radiation interaction in the model. Implement a double-moment cloud microphysics scheme and a multimodal aerosol model. Develop an interface to link cloud properties and aerosol physiochemical properties, consistent coupling of cloud micro and PDF-based macro physics, and the modification of RRTM to support the new cloud-aerosol package.

Consistent clouds, convection, radiation and microphysics interactions

- Enhance the parameterization of gravity wave drag, particularly the non-stationary, propagating type. As shown by ECMWF, this is important for the proper simulation of QBO in the stratosphere.

Yu-Tai Hou, Sarah Lu

Hybrid GODAS

- Hybrid Method:
  The **Hybrid-Gain** method of *Penny (2014)*
- EnKF Component:
  The **Local Ensemble Transform Kalman Filter (LETKF)** developed by *Hunt et al. (2007)* at the University of Maryland (UMD)
- Variational Component:
  NCEP's **operational 3DVar** used in the Global Ocean Data Assimilation System (GODAS) described by *Derber and Rosati (1989)* and *Behringer (2007)*

Penny, S.G., 2014: The Hybrid Local Ensemble Transform Kalman Filter. *Mon. Wea. Rev.*, **142**, 2139–2149. doi: http://dx.doi.org/10.1175/MWR-D-13-00131.1

Hunt, B.R., E.J. Kostelich, and I. Szunyogh, 2007: Efficient Data Assimilation for Spatiotemporal Chaos: A Local Ensemble Transform Kalman Filter. *Physica D*, **230**, 112-126.

Derber, J. D., and A. Rosati, 1989: A global oceanic data assimilation system. *J. Phys. Oceanogr.*, **19**, 1333–1347.

Behringer, D. W., 2007: The Global Ocean Data Assimilation System at NCEP. Preprints, 11th Symp. on Integrated Observing and Assimilation Systems for Atmosphere, Oceans and Land Surface, San Antonio, TX, *Amer. Meteor. Soc.*, 14–18.

Hybrid 3DVar/LETKF GODAS

- The following slide shows the results from an 8-year Reanalysis using temperature and salinity profile data as used in the CFSR.
- All experiment conditions are identical except for the DA system (3DVar vs. Hybrid)
- The Hybrid-GODAS eliminates growing biases in temperature and salinity, and gives an overall reduction in RMSD and BIAS.
- This ocean data assimilation approach is also being tested with the HYCOM ocean model

Steve Penny, UMD and EMC

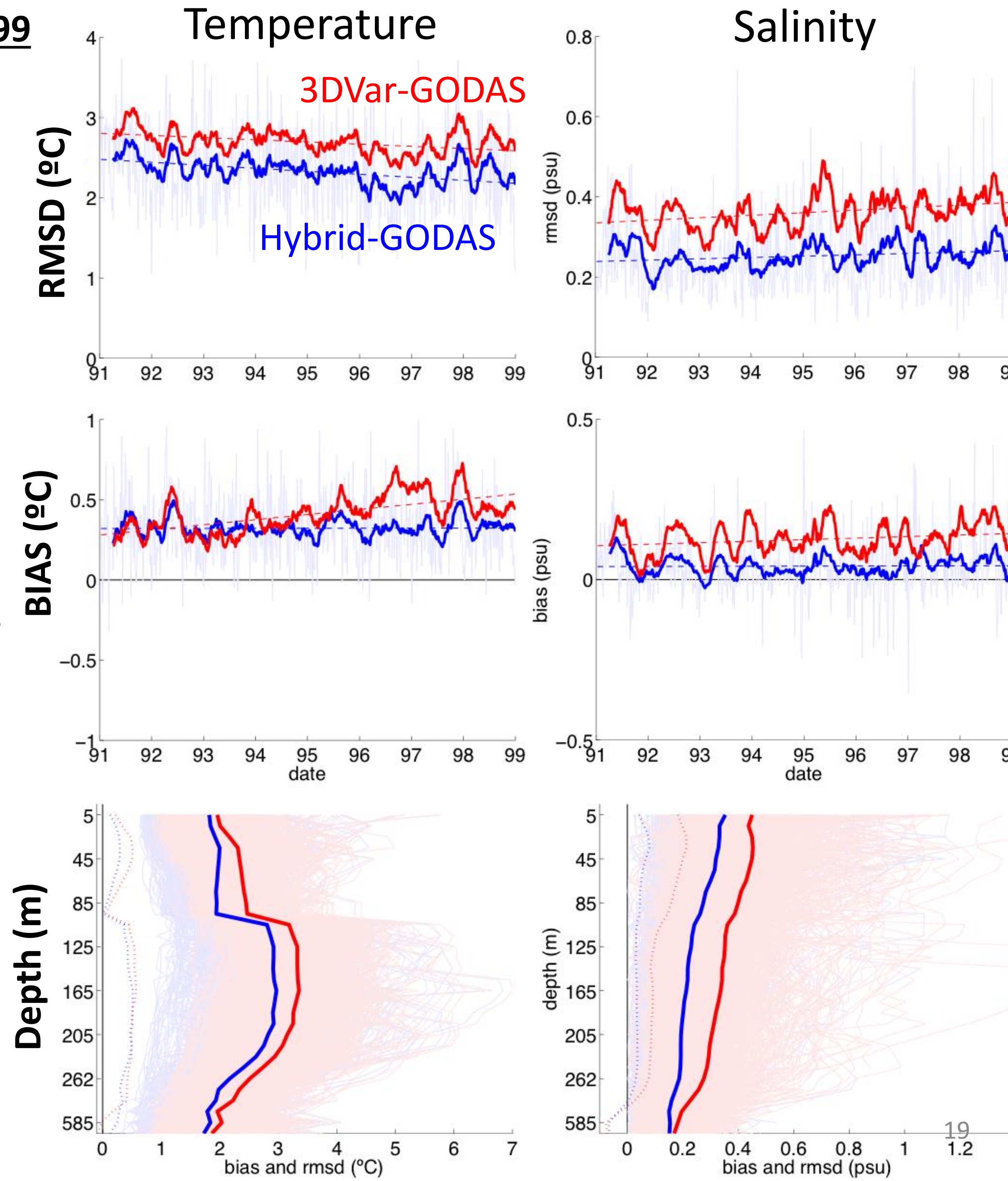
Historical Reanalysis, 1991-1999

RMS Deviations are reduced uniformly by the hybrid, for both temperature and salinity (solid line = 3 mo. moving ave. dashed line = linear regression)

Growth in temperature and salinity **biases** using 3DVar **are eliminated** by the Hybrid

The magnitude of all **biases are generally reduced**

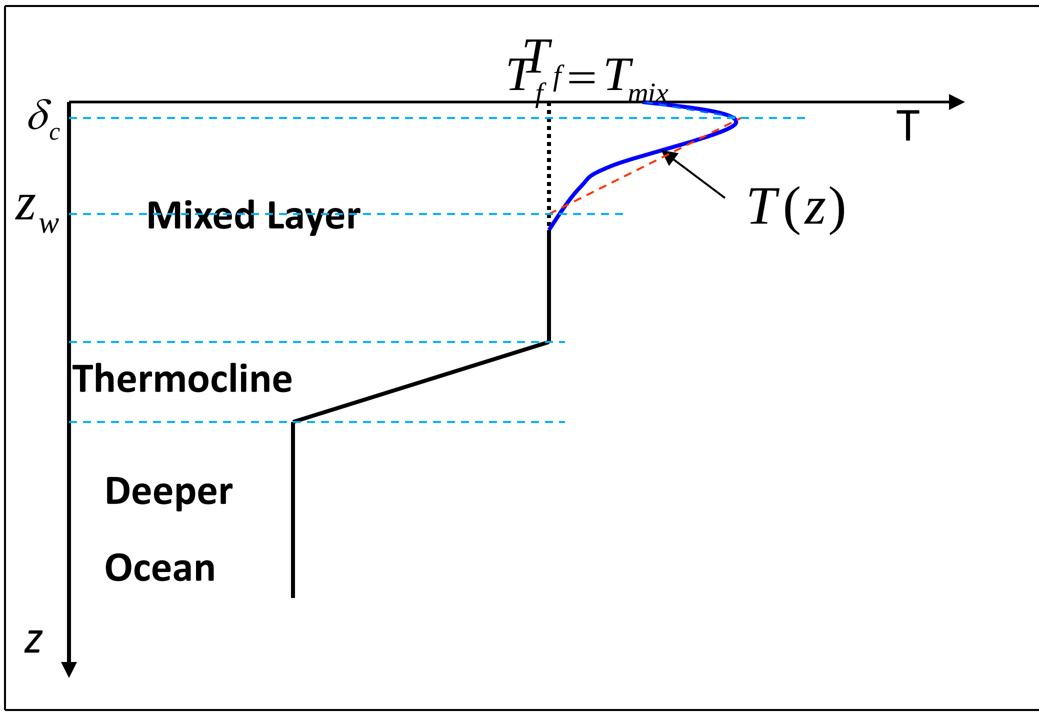
The reduction in RMS deviations for temperature and salinity are fairly **uniform throughout the upper ocean**



Steve Penny, UMD

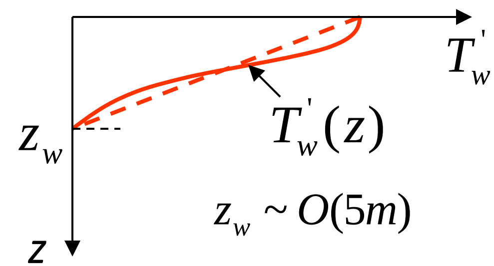
NSST (Near-Surface Sea Temperature)

The ocean model does not produce an actual SST. The **NSST** determines a **T-Profile** just below the sea surface, where the vertical thermal structure is due to **diurnal thermocline layer warming** and **thermal skin layer cooling**.



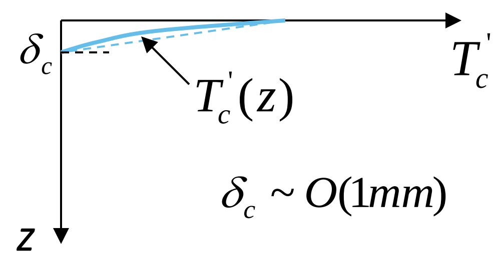
Diurnal Warming Profile

$$T_w'(z) = (1 - z/z_w)T_w'(0)$$



Skin Layer Cooling Profile

$$T_c'(z) = (1 - z/\delta_c)T_c'(0)$$



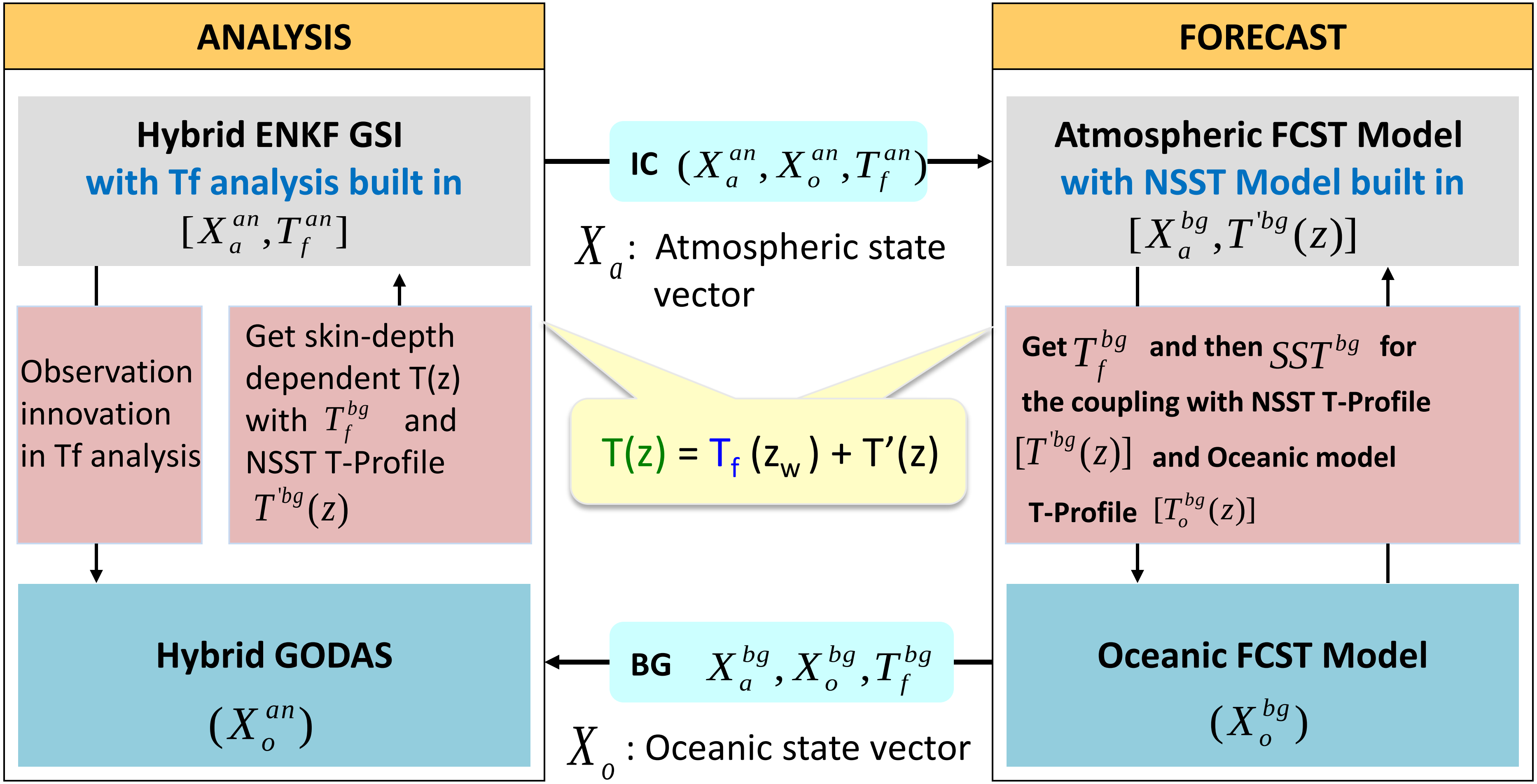
$$T(z,t) = T_f(z_w,t) + T'(z,t),$$

$$T'(z,t) = T_w'(z,t) - T_c'(z,t)$$

$$z \in [0, z_w]$$

Xu Li, EMC

Incorporation of the NSST into an air-sea coupled data assimilation and prediction system



NSST algorithm is part of both the analysis and forecast system. In the analysis, the NSST provides an analysis of the the interfacial temperature ("SST") in the hybrid ENKF GSI using satellite radiances. In the forecast, the NSST provides the interfacial temperature (SST) in the free, coupled forecast instead of the temperature at 5-meter depth that is predicted by the ocean model.

Proposed Upgrades to Land Surface

- Methodology upgrades: NASA's Land Information System (LIS) integrates NOAA NCEP's operational land model, high-resolution satellite and observational data, and land DA tools (EnKF).

- Global observed precipitation forcing from 0.5^o to 0.25^o resolution (CPC daily, 1979-present).

- Model upgrades: Noah 3.x, Noah-MP (e.g, dynamic vegetation, explicit canopy, CO2-based photosynthesis, groundwater, multi-layer snow pack, river routing).

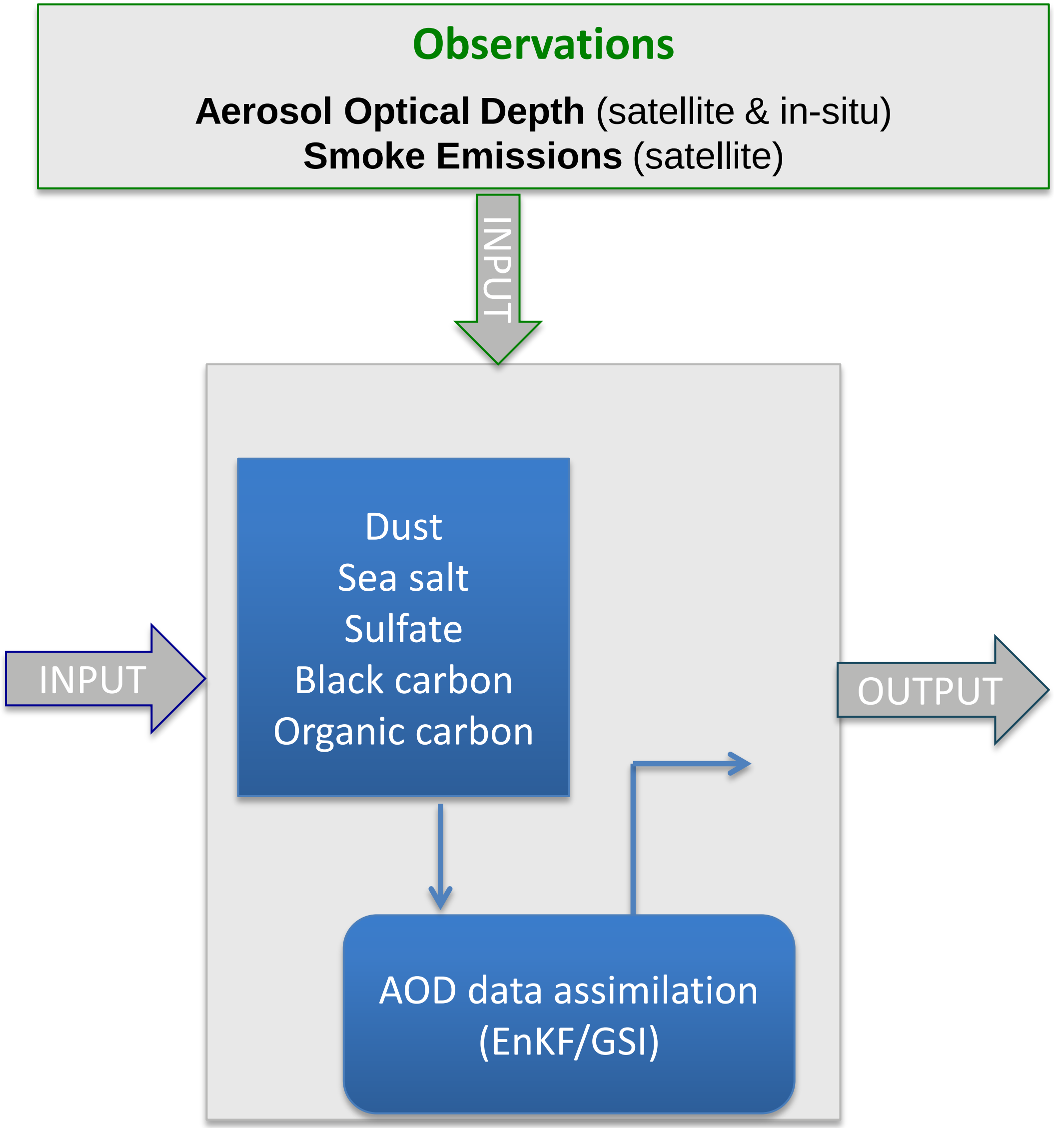
J. Dong, M. Ek, H. Wei, J. Meng, EMC

Proposed Upgrades to Land Surface (cont.)

- Land use dataset upgrades:
  - Near-realtime GVF (global 16-km, 1981-present, and 25-year climatology), land-use/vegetation (IGBP-MODIS, global 1km), soil type (STATSGO-FAO, global 1km), MODIS snow-free albedo (global 5km), maximum snow albedo (U. Arizona, global 5km).
  - SMOPS soil moisture (AMSR-E (2002-2011), SMOS (2010-present), ASCAT, AMSR2 (2012-present), SMAP (launched 2014).
  - Snow cover: IMS (global 24km (1997-present) & 4km (2004-present).
  - Snow water equivalent: SMMR (1978-1987), SSM/I (1987-2007), AMSR-E (2002-2011), AMSR2 (2012-present).

J. Dong, M. Ek, H. Wei, J. Meng, EMC

Aerosol Data Assimilation



Sarah Lu, SUNY Albany and EMC

Proposed upgrades to data assimilation and modeling of aerosols

The Goddard Chemistry Aerosol Radiation and Transport (GOCART) model simulates major tropospheric aerosol components, including sulfate, dust, black carbon (BC), organic carbon (OC), and sea-salt aerosols. GOCART considers emission, wet removal and dry removal processes and simple sulfate chemistry.

- Model upgrades:

    To introduce aerosol-cloud interaction (indirect effect) in the GFS

- Methodology upgrades

    To use much higher resolutions for NGAC (NEMS GFS Aerosol Component (NGAC) to couple with higher resolution of the GFS.

    Upgrade the Hybrid DA system to enable assimilation of AOD observations.

Sarah Lu, SUNY Albany and EMC

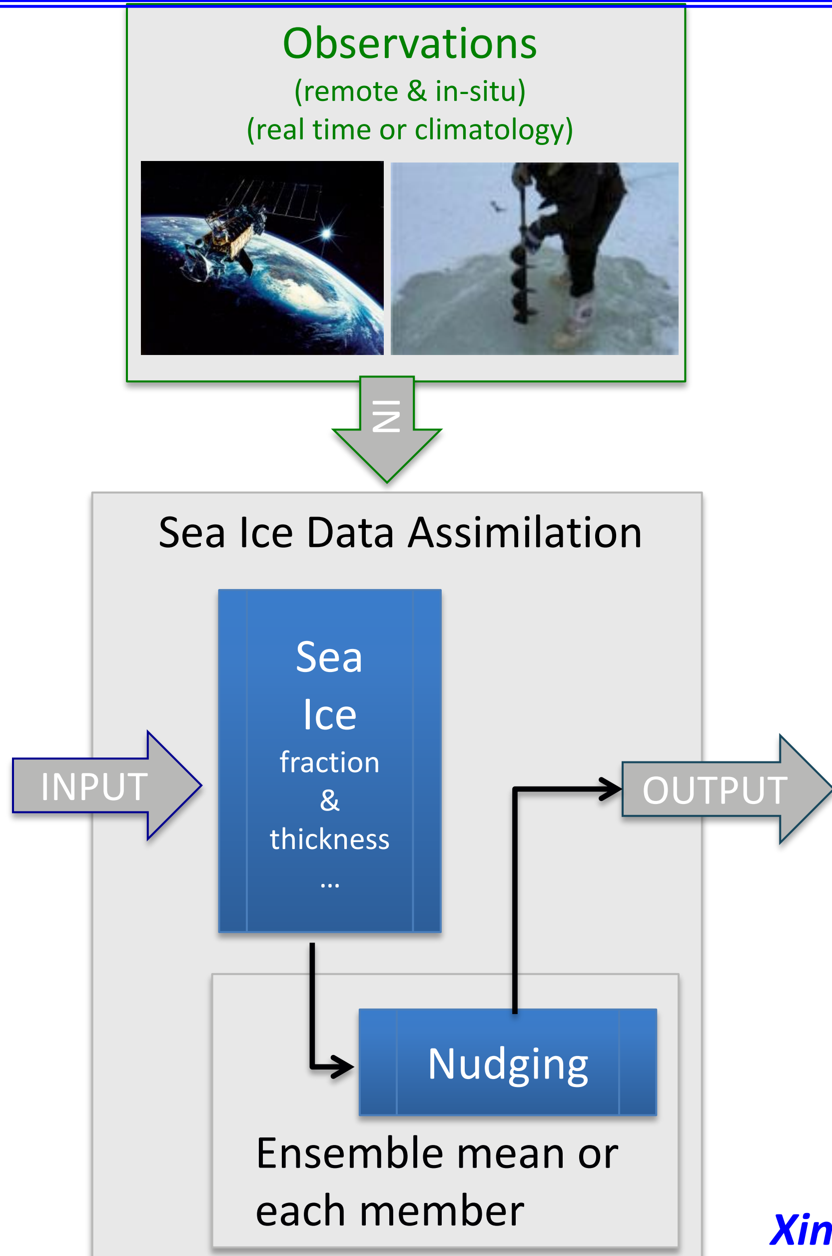
Proposed upgrades to data assimilation and modeling of aerosols (contd)

- Emissions dataset upgrades:
  Use satellite-based smoke emissions (MODIS fire radiative power) for organic carbon, black carbon and sulfate.

- Data assimilation upgrades:
  The AOD observations will be from MODIS (satellite) and AERONET (in-situ).
  Aerosol data assimilation is proposed for the EOS era (2002 to present).

Sarah Lu, SUNY Albany and EMC

Sea Ice Data Assimilation

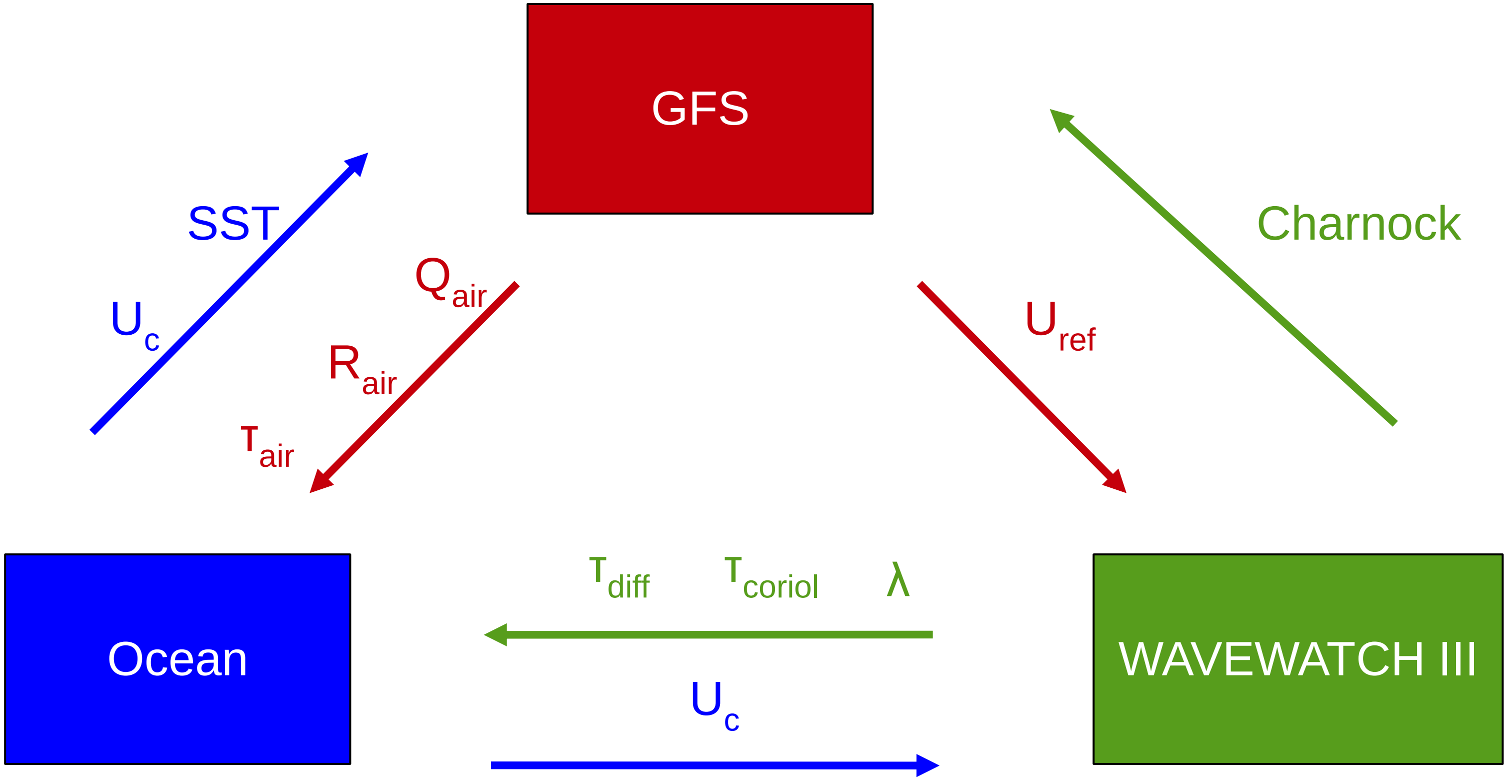


Xingren Wu, EMC

Sea Ice Data Assimilation

- Among the toughest problems is the analysis of sea-ice. The period 1979-2020 offers hitherto hard to explain, variations in the extent and thickness of the sea-ice in both polar regions.
- The modeling of sea ice, shelf ice, sheet ice and glacial ice needs to improve.
- Special attention has to be given to the coupling of seaice to fresh water from atmosphere and continental runoff, and its interaction with meridional overturning currents in all ocean basins (especially the North Atlantic) and marginal seas (Mediterranean, Baltic etc).

Wave Coupling



GFS model air-sea fluxes depend on **sea state** (roughness -> Charnock).

WAVEWATCH III model forced by **wind** from GFS and currents from Ocean**.**

Ocean model forced by **heat flux**, sea state dependent **wind stress** modified by **growing or decaying wave fields and Coriolis-Stokes effect.**

WAVEWATCH III

- Planned Upgrades
  - Drive the wave model in a coupled mode with atmospheric winds (for wave dependent boundary conditions in atmospheric models)
  - Include wave - ocean coupling (currents from ocean model to wave model and wave induced langmuir mixing and Stokes drift from wave model to ocean model)
  - Data assimilation of significant wave heights to develop a wave analysis
    - GSI approach
    - LETKF approach
  - Planned sources of data
    - Spectral data from ocean buoys
    - Satellite data from altimeters

A. Chawla, H. Alves and H. Tolman, EMC

IMPROVE ANALYSIS COUPLING

The operational CFSR uses a coupled atmosphere-ocean-land-sea ice forecast for the analysis background but the analysis is done separately for each of the domains.

In the next reanalysis, the goal is to increase the coupling so that, e.g., the ocean analysis influences the atmospheric analysis (and vice versa). This will be achieved mainly by using a coupled ensemble system to provide the background and the EnKF to generate structure functions that extend across the sea-atmosphere interface.

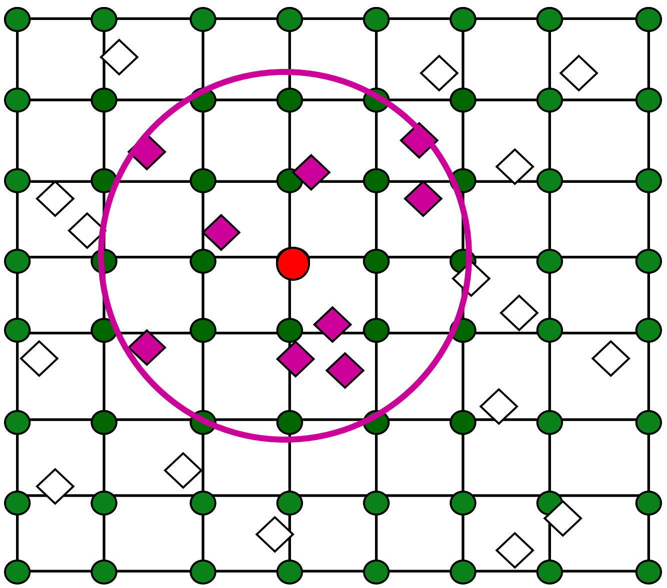
The same can be done for the atmosphere and land, because assimilation of land data will be improved for soil temperature and soil moisture content.

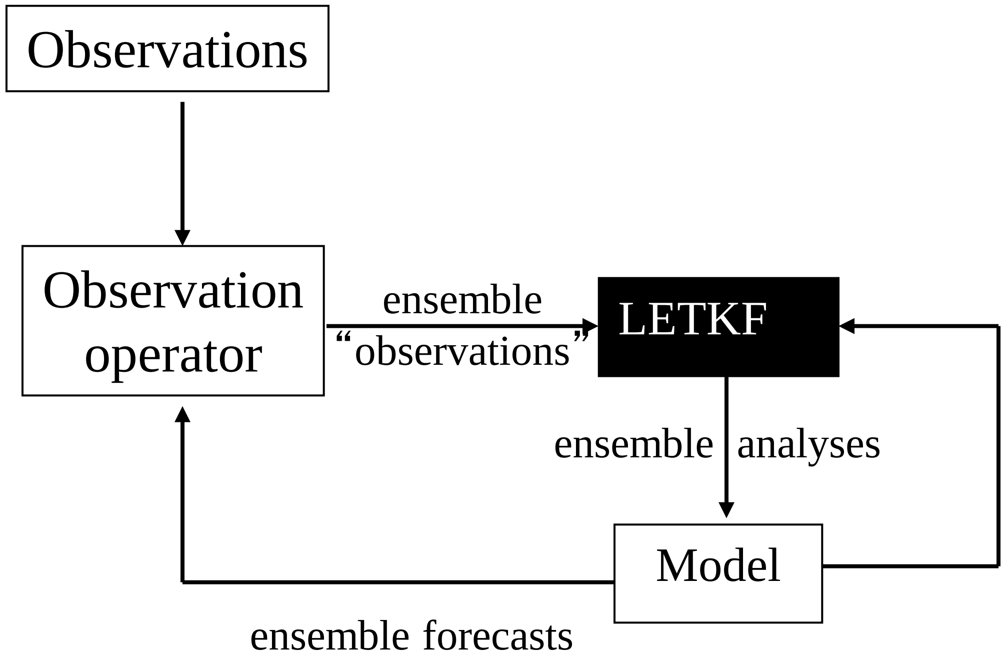
LETKF: Perform assimilation locally at each point

Courtesy: University of Maryland

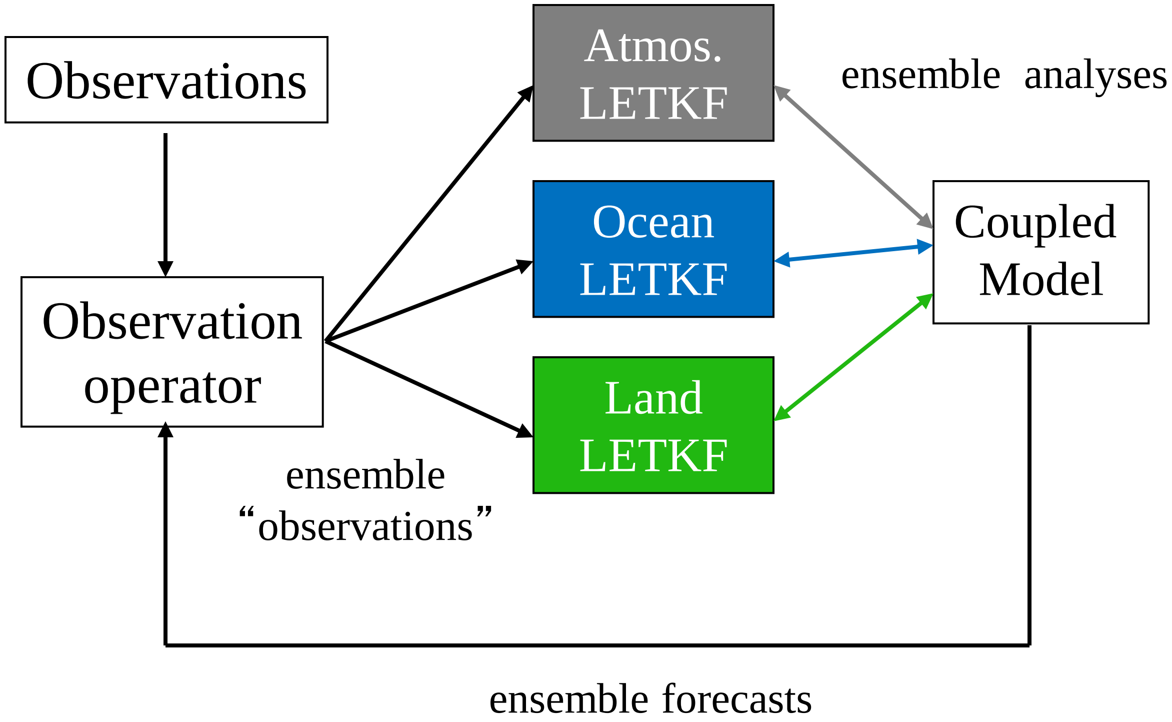
The state estimate is updated at the central grid red dot

All observations (purple diamonds) within the local region are assimilated





Coupled LETKF: Sharing of Departures



Each grid point is solved independently, so by passing observation departures (O-F) and model sub-state (land, ocean, atmosphere), one can solve LETKF equations independently (on different grids if desired) and decide (spatial/variable localization) how "strongly" to couple. For example, can pass atmospheric O-F to ocean LETKF! Equivalent to "strong coupling".

Status Report

Thanks to Cecelia DeLuca's group for the

initial delivery of the UGCS, consisting of the

GSM atmospheric model coupled to MOM5.1

ocean model and CICE1 seaice model.

Status Report

Current status and future plans:

1. Work being done to add cold start and restart capabilities.
2. Merge of this system to the GSM/NEMS/NUOPC trunks.
3. NEMS/GSM parallel scripts to be modified to add coupling options.
4. Begin testing for forecast-only runs for weather, sub-seasonal and seasonal runs, using CFSR initial conditions.
5. Begin testing for data assimilation using the coupled model to generate coupled 9-hour forecasts as background guess for separate atmospheric, land, ocean, seaice, aerosols and wave DA.
6. Test inline WWIII in the GSM, until NEMS version is ready.
7. Adapt the NEMS-based NGAC-GOCART system to the UGCS.
8. Begin work with offline non-NEMS version of MOM6 ocean model and SIS2 seaice model, prior to coupling them in NEMS.

THANK YOU!