COUPLED DATA ASSIMILATION AND FORECASTING AT NCEP

THE NCEP CLIMATE FORECAST SYSTEM

Suru Saha

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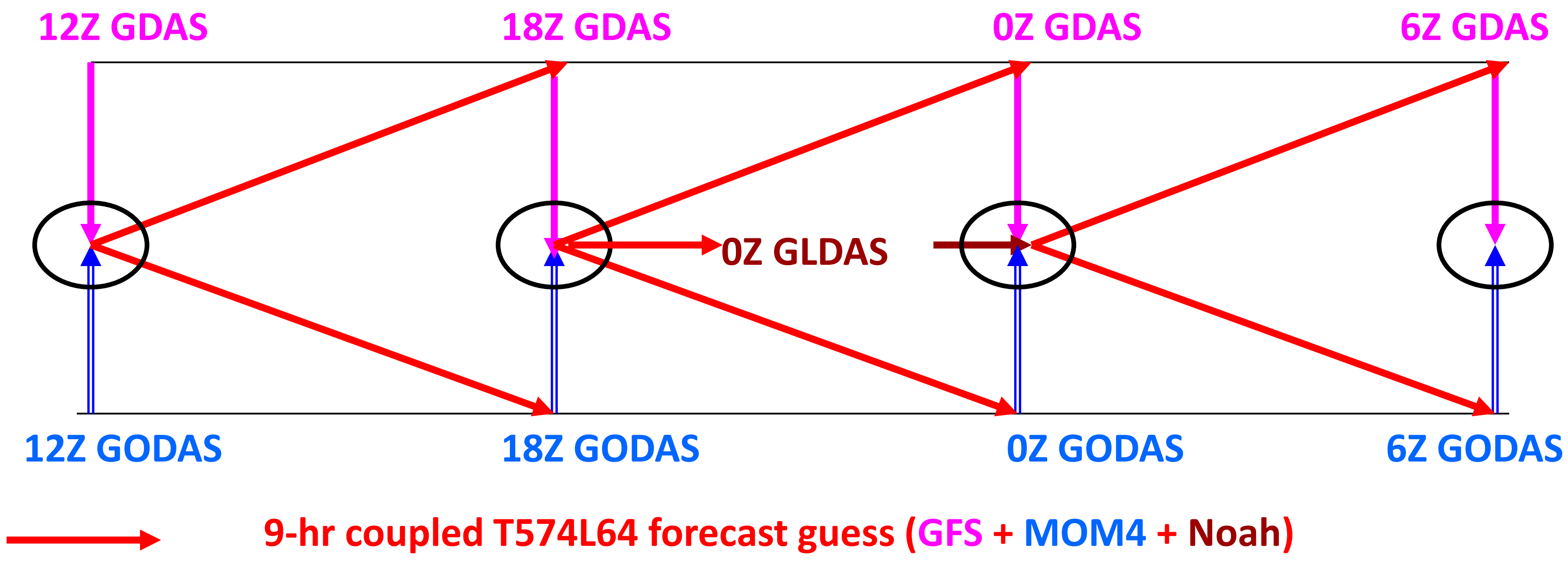
"A good prediction system incorporates both a good data assimilation (DA) system and a good forecast model."

In this workshop, focus has been mainly on the forecast models –here we'll also discuss DA.

A Historical Perspective

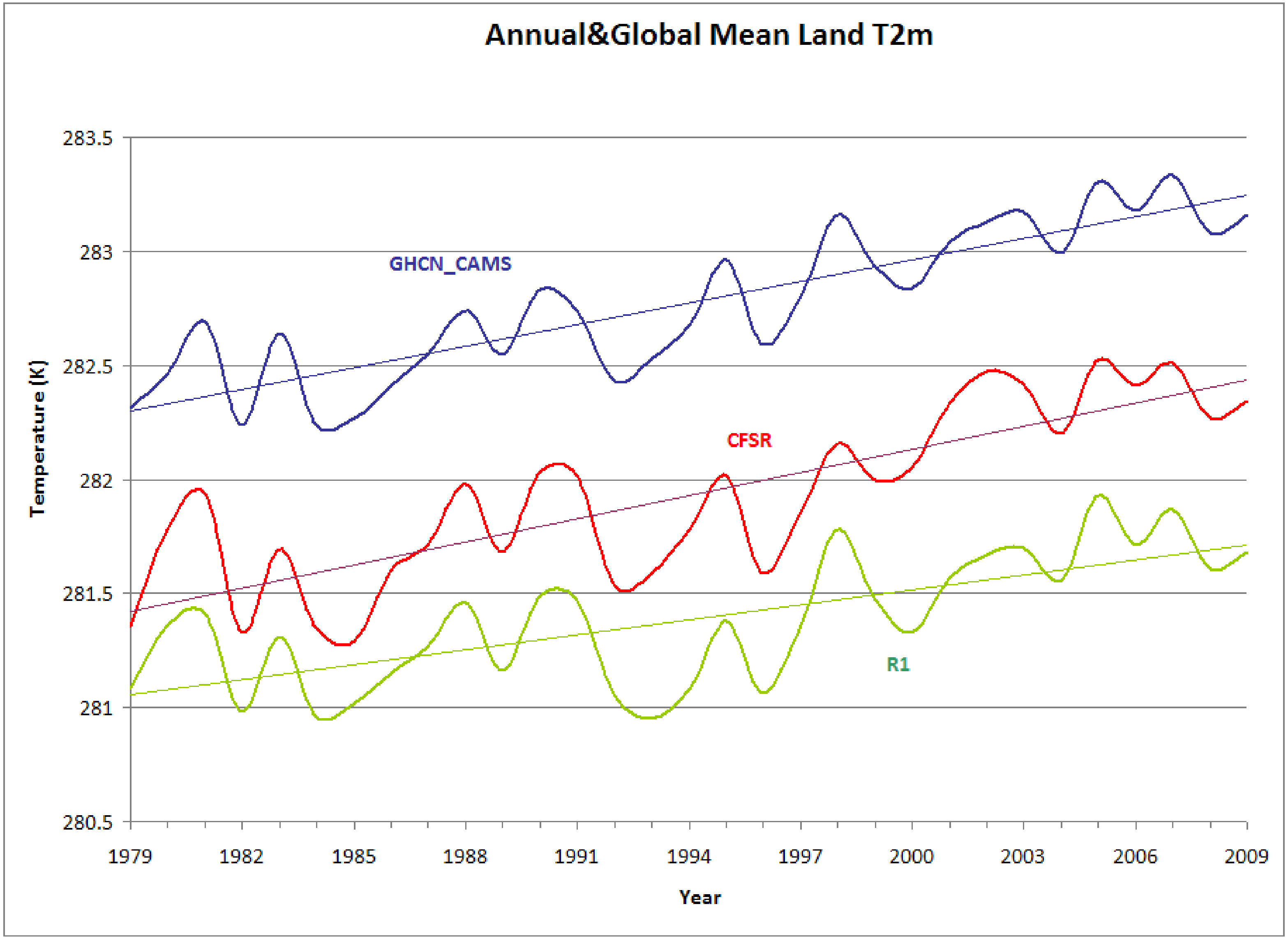
ONE DAY OF CFSR



Another innovative feature of the CFSR GSI is the use of the historical concentrations of carbon dioxide when the historical TOVS instruments were retrofit into the CRTM.

Satellite Platform	Mission Mean (ppmv)b
TIROS-N	337.10
NOAA-6	340.02
NOAA-7	342.96
NOAA-8	343.67
NOAA-9	355.01
NOAA-10	351.99
NOAA-11	363.03
NOAA-12	365.15
GEOS-8	367.54
GEOS-0	362.90
GEOS-10	370.27
NOAA-14 to NOAA-18	380.00
IASI METOP-A	389.00
NOAA-19	391.00

Courtesy: http://gaw.kishou.go.jp

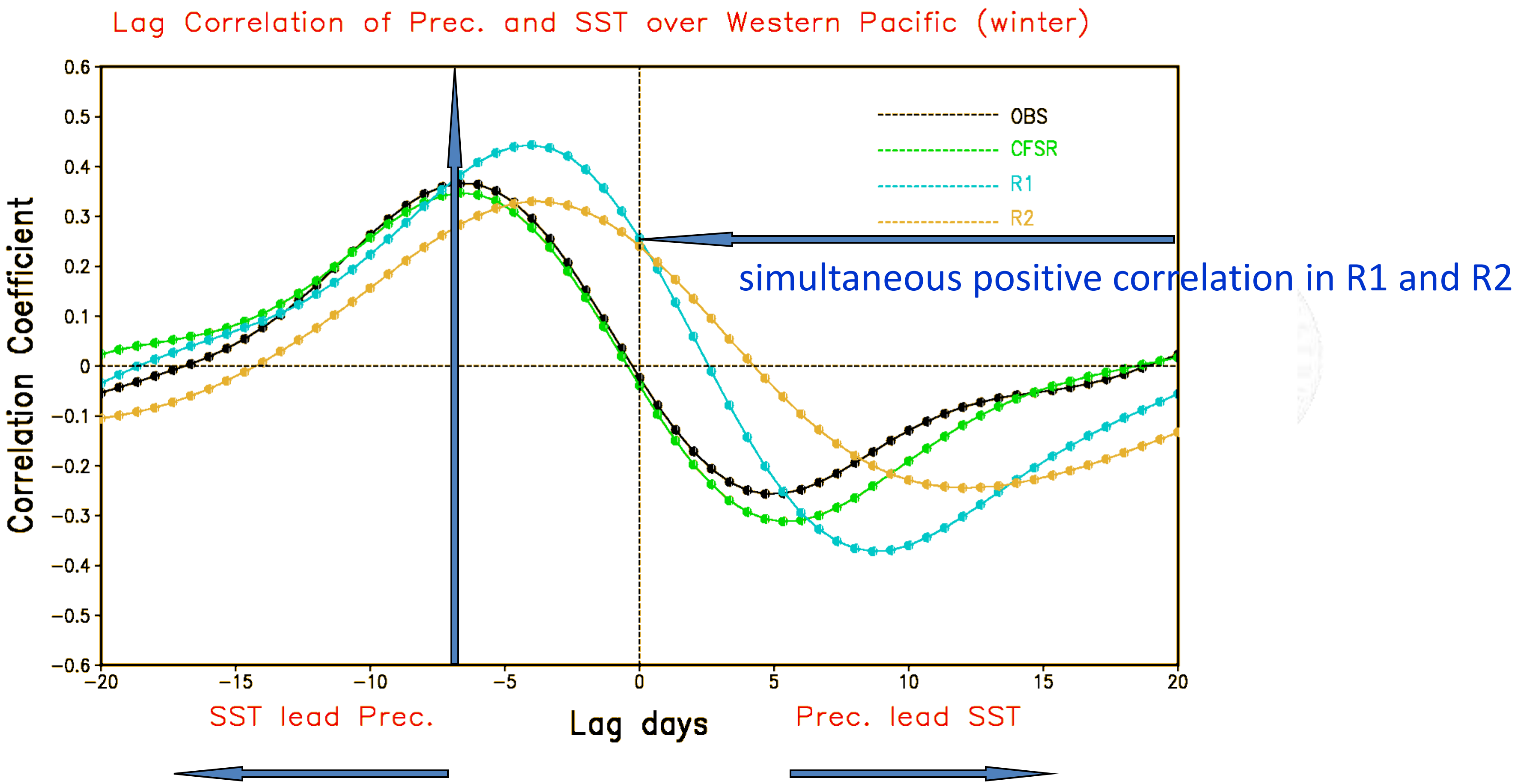


The linear trends are 0.66, 1.02 and 0.94K per 31 years for R1, CFSR and GHCN_CAMS respectively. (Keep in mind that straight lines may not be perfectly portraying climate change trends).

Huug van den Dool

SST-Precipitation Relationship in CFSR

Precipitation-SST lag correlation in tropical Western Pacific



Response of Precip to SST warming is too quick in R1 and R2

Jiande Wang

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

UNIFIED GLOBAL COUPLED SUITE
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 SUITE
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 SUITE
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 SUITE
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 SUITE
NEW PARADIGM

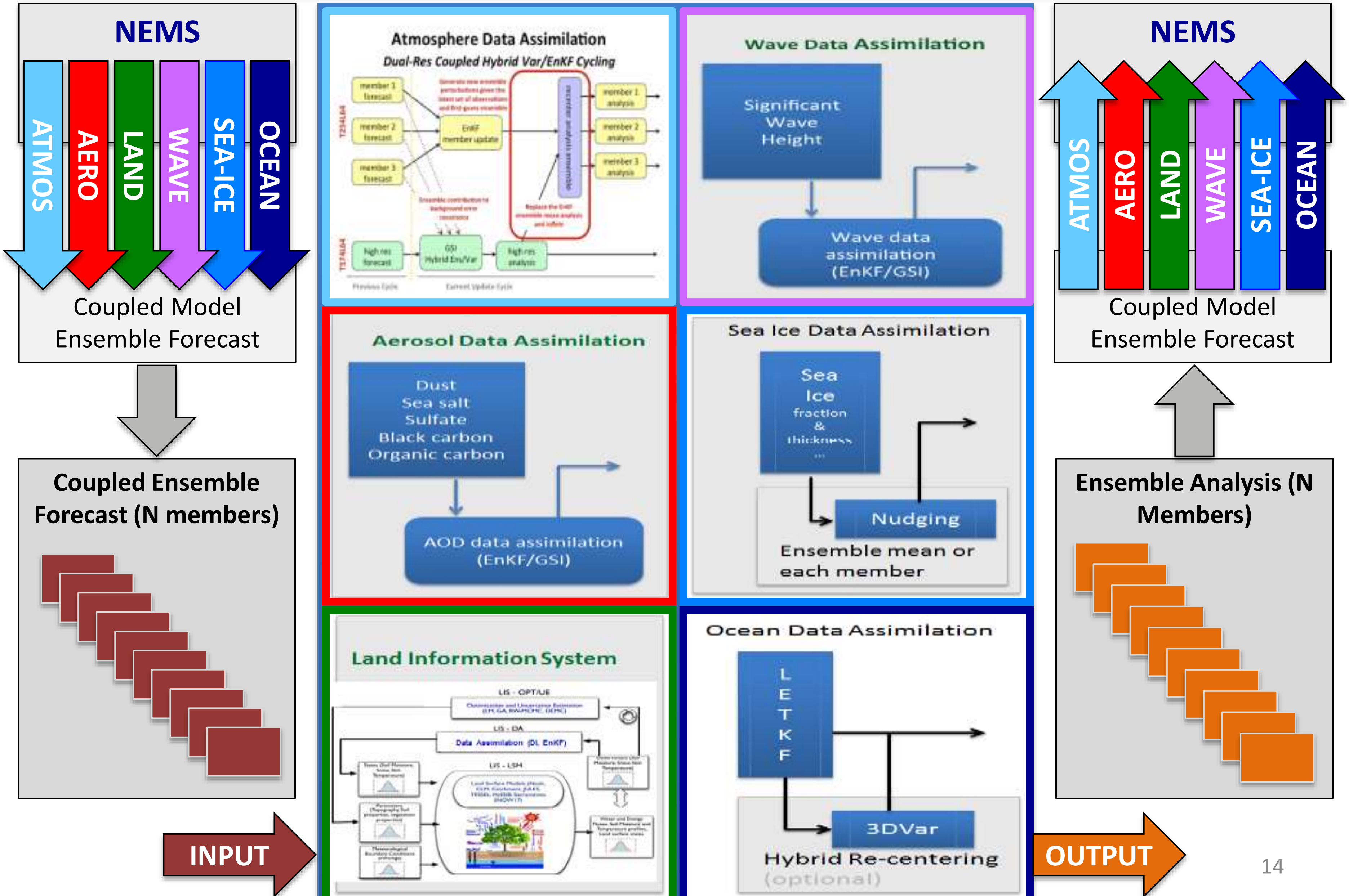
Atmosphere, Land, Ocean, Seaice, Wave, Chemistry, Ionosphere

- 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), there is the possibility of exploring 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 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.

NCEP Coupled Hybrid Data Assimilation and Forecast System

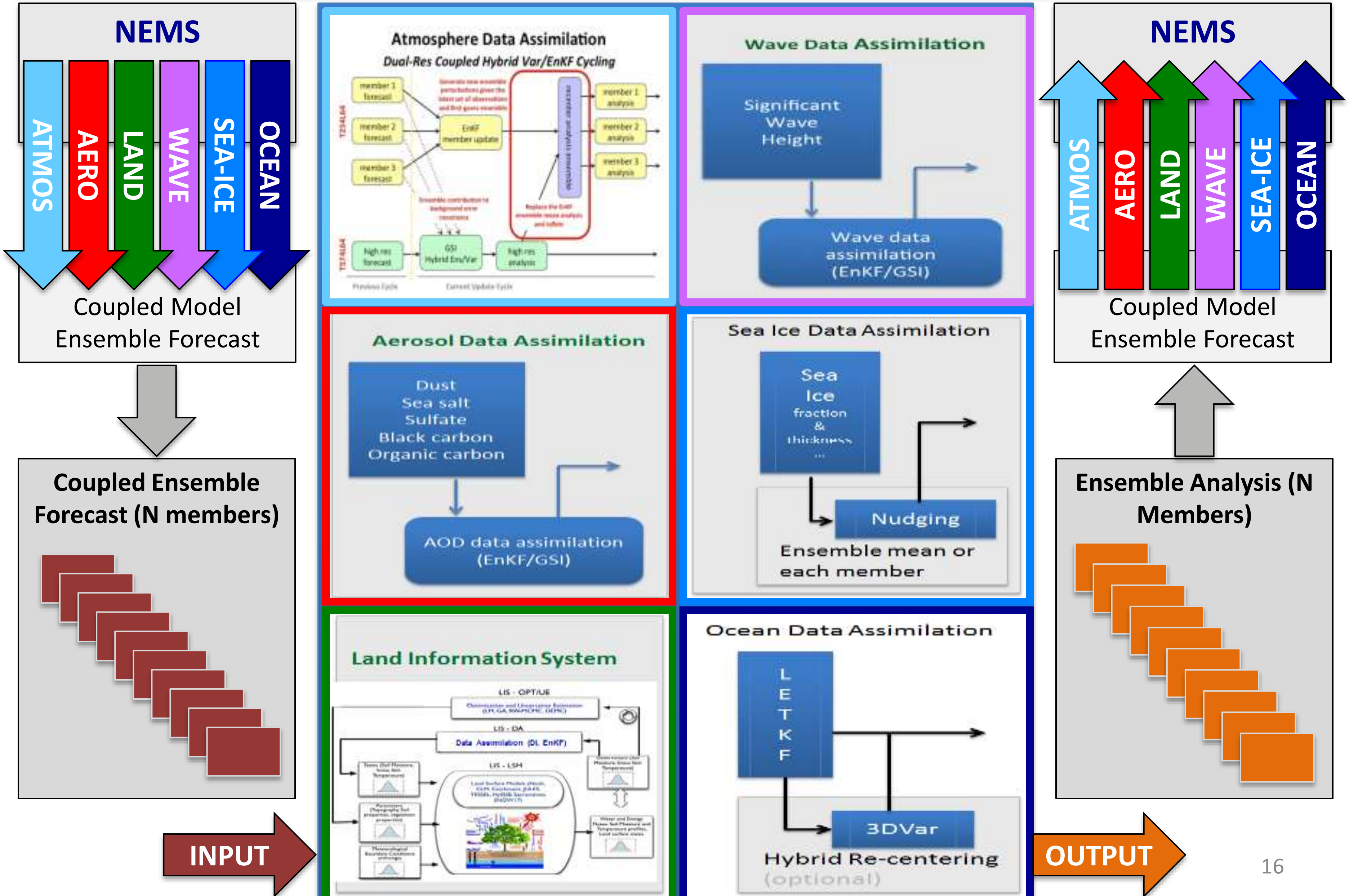


NEMS

- 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

NCEP Coupled Hybrid Data Assimilation and Forecast System



Data Assimilation Upgrades

- Stochastic physics to replace additive inflation
- New (totally) inline automated bias correction for satellite data (making reanalysis using radiances more straightforward and accurate)
- The system will be upgraded to a Hybrid 4D-EnVAR, which is not the traditional 4D-VAR, ie. no tangent linear or adjoint model is used.
- Can still perform an outer loop, as in the traditional 4DVAR
- Potentially improved initialization of the forecast, due to 4D IAU (incremental analysis update) , which allows for the prescription of an incremental 4D trajectory, instead of a single time-level of analysis increment.

Daryl Kleist

Atmospheric Model Physics Upgrades

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

Atmospheric Model Physics Upgrades

RADIATION AND OTHER:

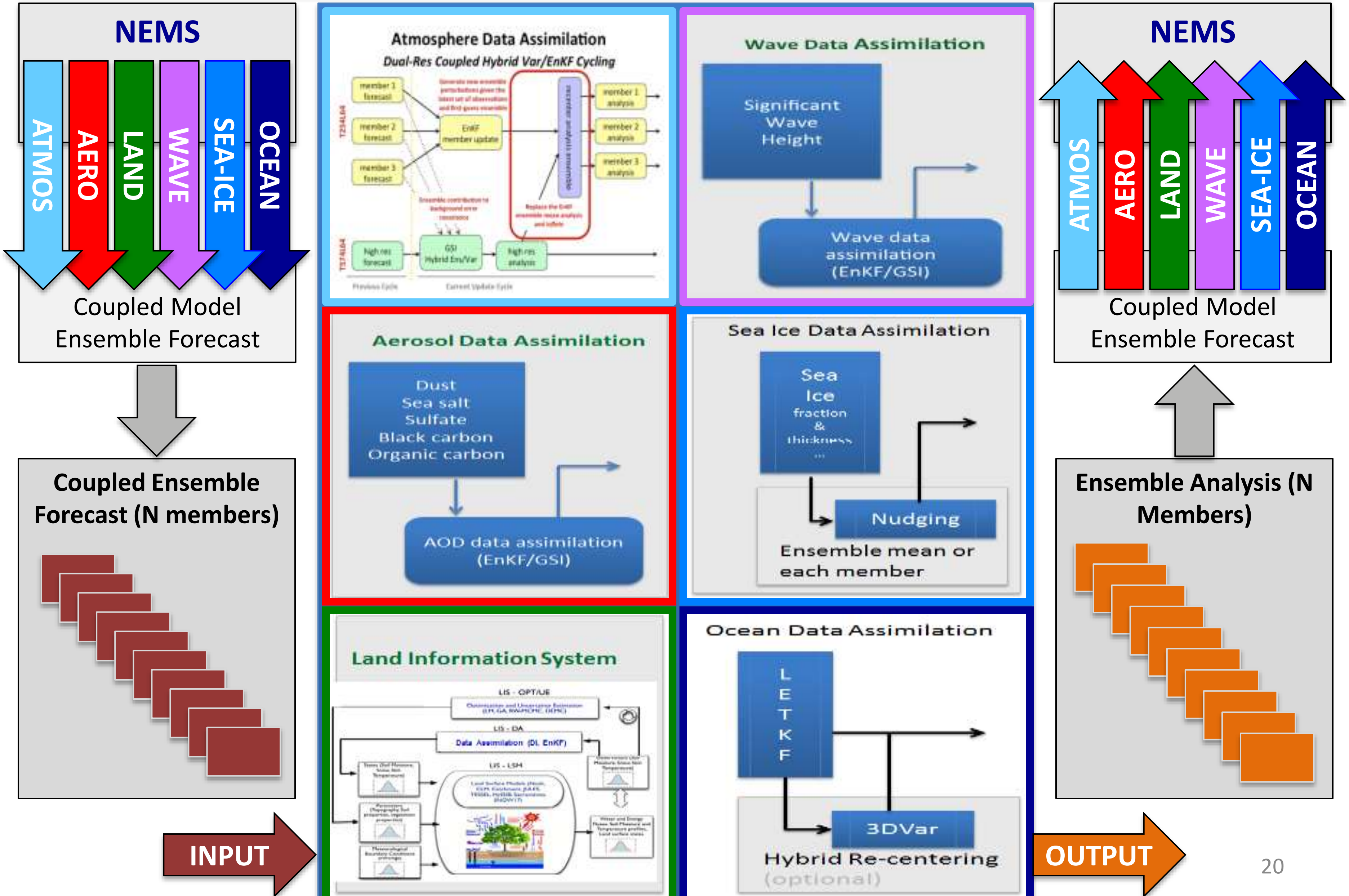
- Improve cloud radiation interaction with advanced radiation parameterization based on the McICA-RRTMG from AER Inc. with interactive aerosol (both direct and indirect) affects.
- Include radiative effects due to additional (other than CO2) green-house gases from near real-time observations.
- Improve 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

NCEP Coupled Hybrid Data Assimilation and Forecast System



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.

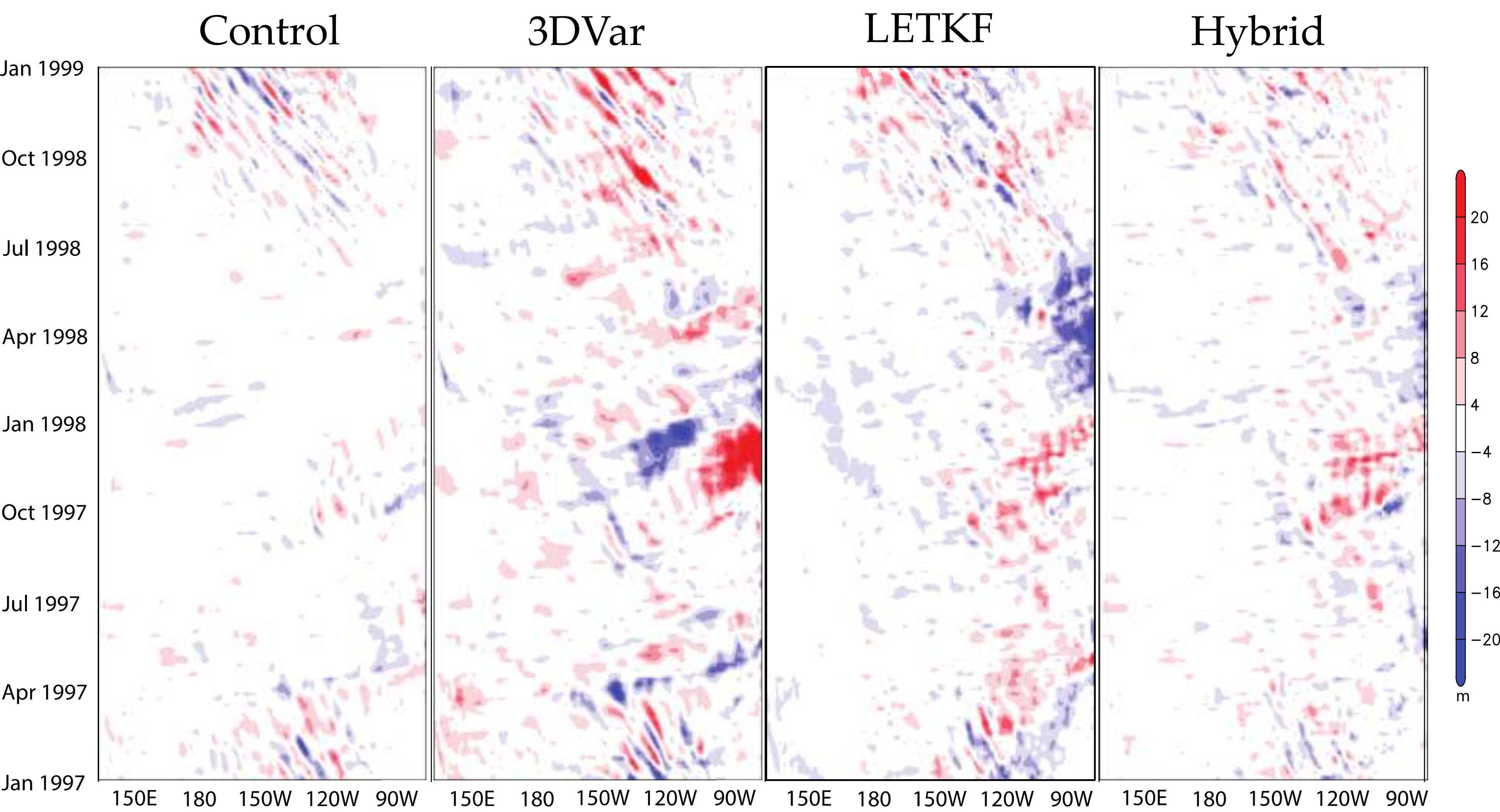
Behringer, D. W., 2007: The Global Ocean Data Assimilation System at NCEP. Preprints, 11th Symp. on Integrated Observing and Assimilation Systems for Atmosphere, Oceans and Land Surface, San Antonio, TX, *Amer. Meteor. Soc.*, 14–18.

Steve Penny, UMD

Ocean OSSE Configuration

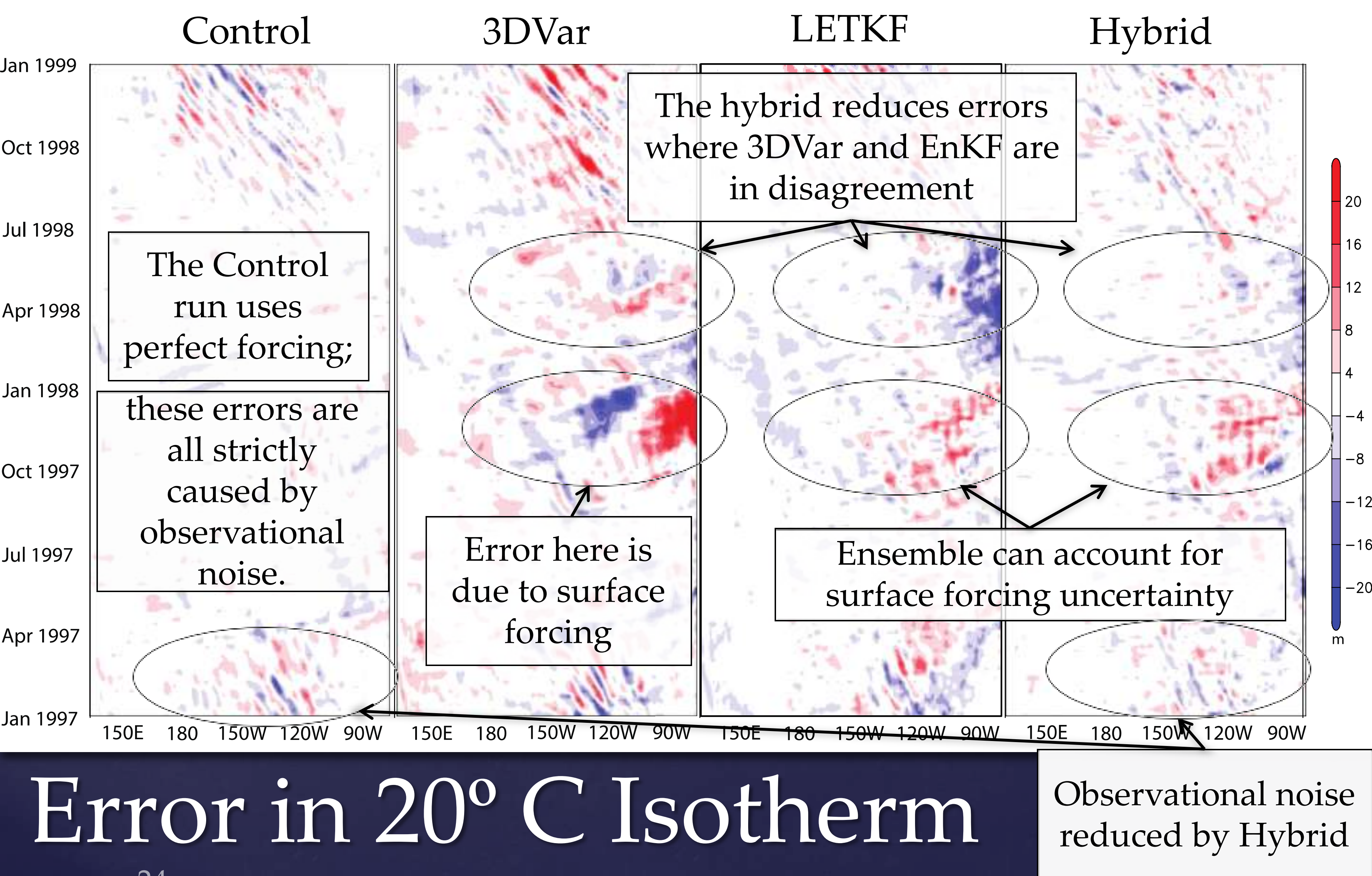
- <u>Purpose:</u>
  Evaluate effectiveness of the Hybrid-GODAS in a **controlled environment**
- <u>Duration</u>:
  8 Years (Jan. 1991- Dec. 1998)
- <u>Model</u>:
  GFDL MOM4p1, 1/2º-1/4º, 40-vertical level
- <u>Observations</u>:
  Synthetic Temperature and Salinity profiles (**XBT/CTD historical locations**) with realistic magnitude observation errors (representativeness + instrument errors)
- <u>Surface forcing</u>:
  28-member 20th Century Reanalysis (20CRv2: *Compo et al. 2011*)**,**
  re-centered at NCEP R2 (members 1-28 selected from 56 after re-centering)
- <u>Inflation</u>:
  none
- <u>Horizontal Localization</u>:
  Latitude dependent: 720km at Eq. down to 200km at poles
- <u>Vertical Localization</u>:
  none (=> more accurate, computationally faster, & facilitates use of satellite data)
- <u>Initialization</u>:
  6-year spinup from Jan 1st 1985 CFSR ocean state (same for all 56 members), forced by re-centered 56-member 20CRv2

Steve Penny, UMD



Error in 20º C Isotherm Eq. Pacific 97-98 ENSO

(analysis - nature)
(averaged 5ºS to 5ºN)

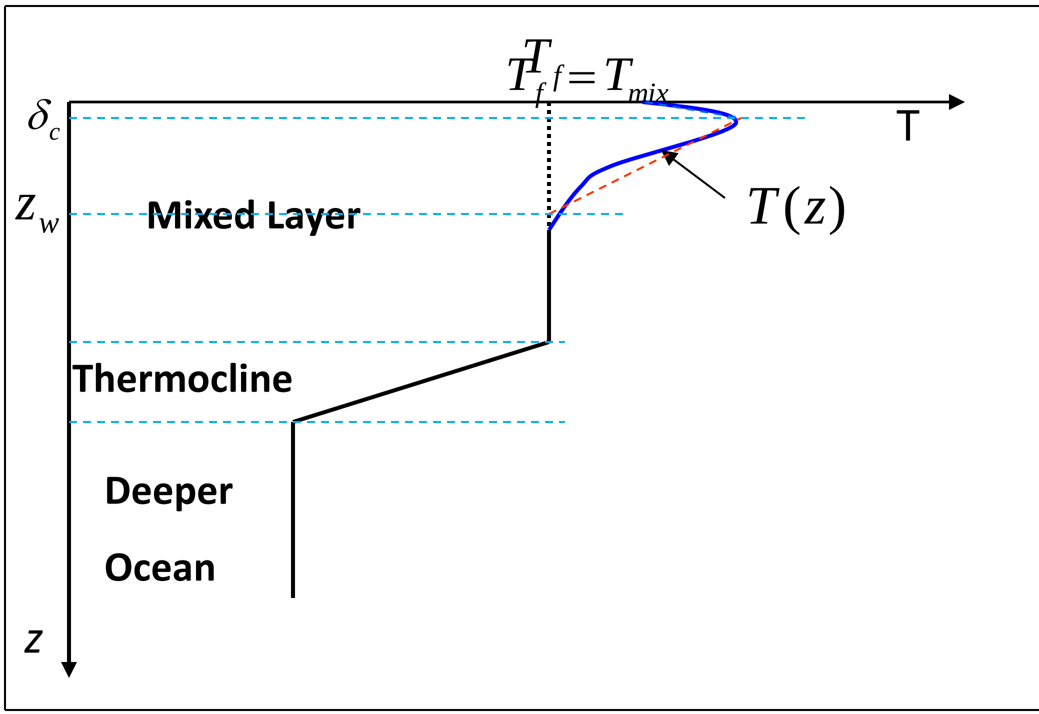


Error in 20° C Isotherm Eq. Pacific 97-98 ENSO

(analysis - nature)
(averaged 5ºS to 5ºN)

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**.



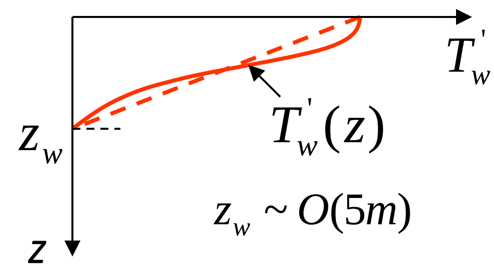
$$T(z,t) = T_f(z_w,t) + T'(z,t),$$

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

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

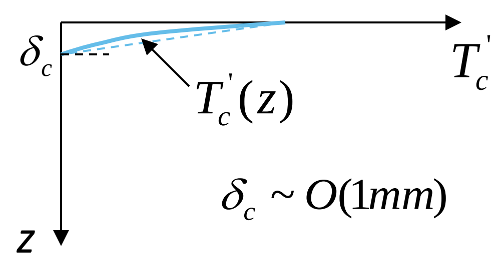
Diurnal Warming Profile

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



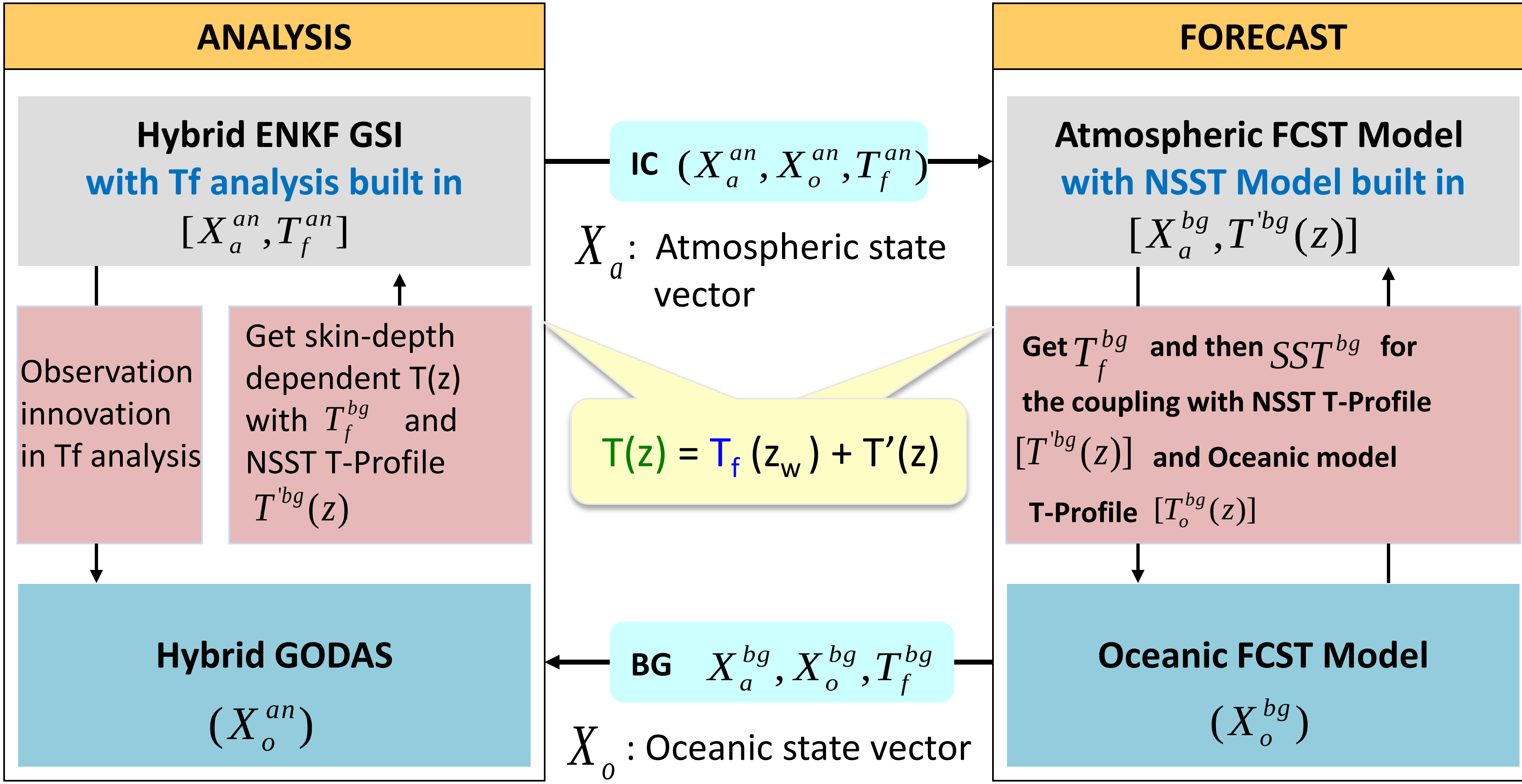
Skin Layer Cooling Profile

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



Xu Li, EMC

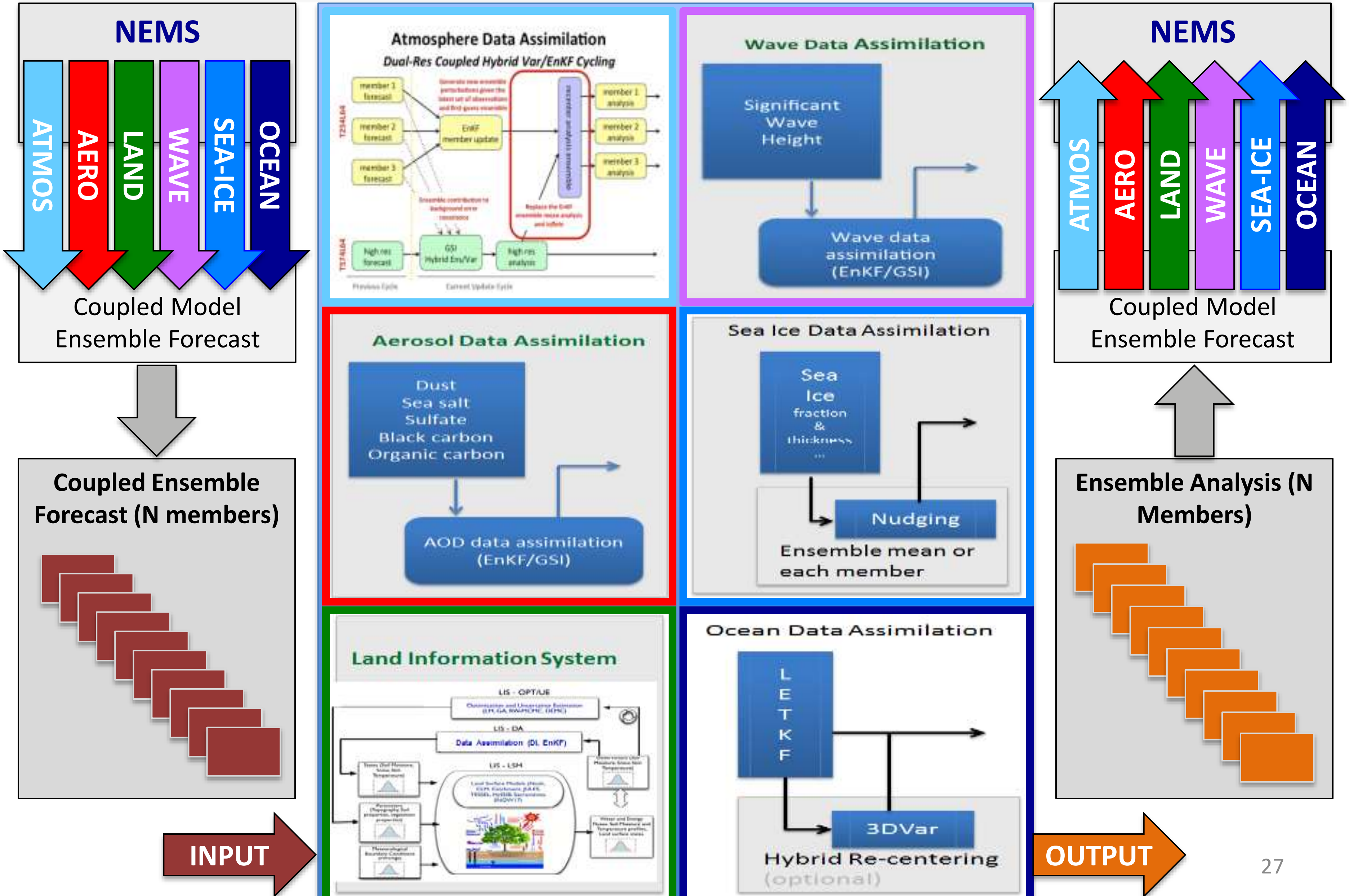
Incorporation of the NSST into an air-sea coupled data assimilation and prediction system



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.

Xu Li, EMC

NCEP Coupled Hybrid Data Assimilation and Forecast System



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, CO_2-based photosynthesis, groundwater, multi-layer snow pack, river routing).

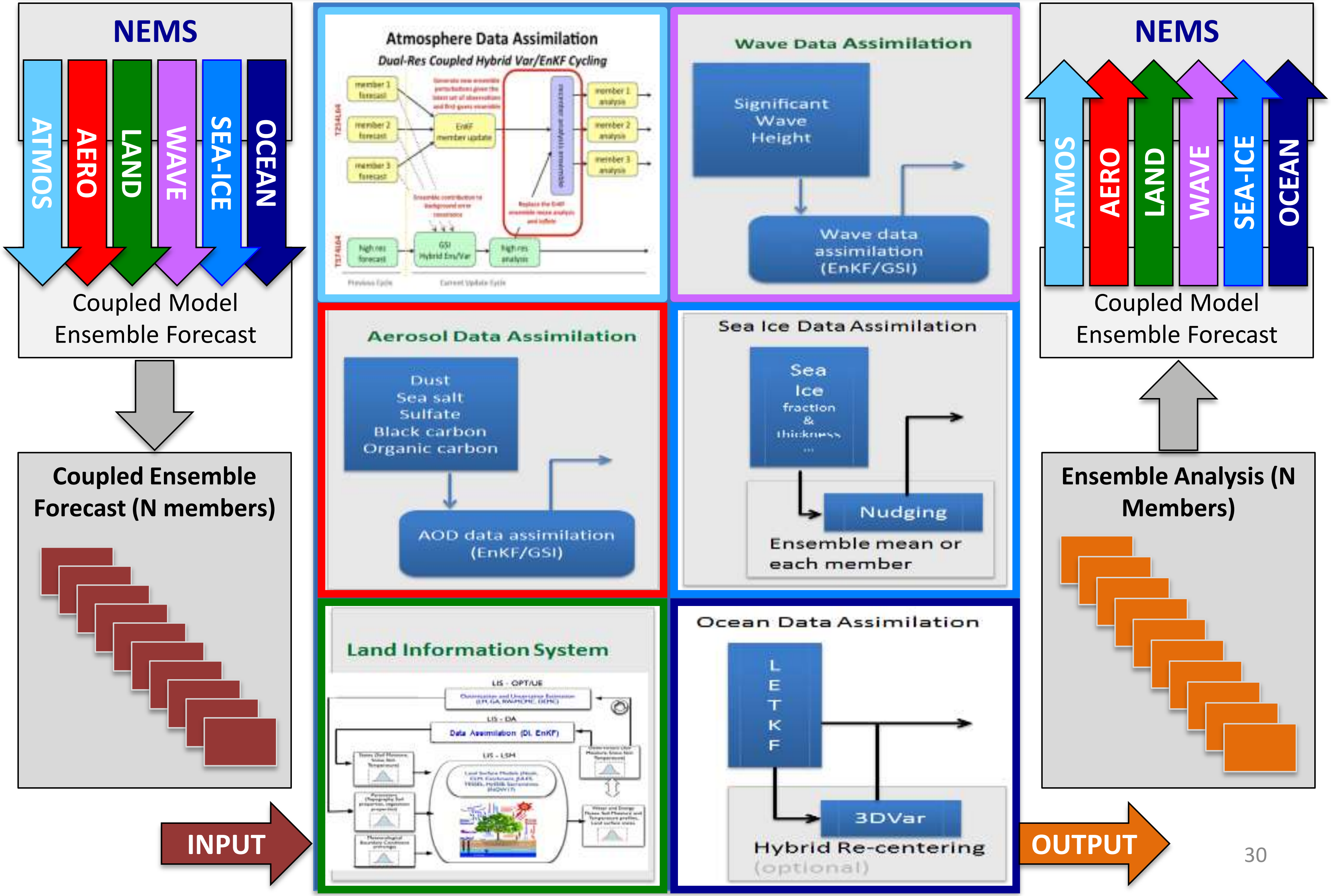
J. Dong, M. Ek, H. Wei, J. Meng

Proposed Upgrades to Land Surface (cont.)

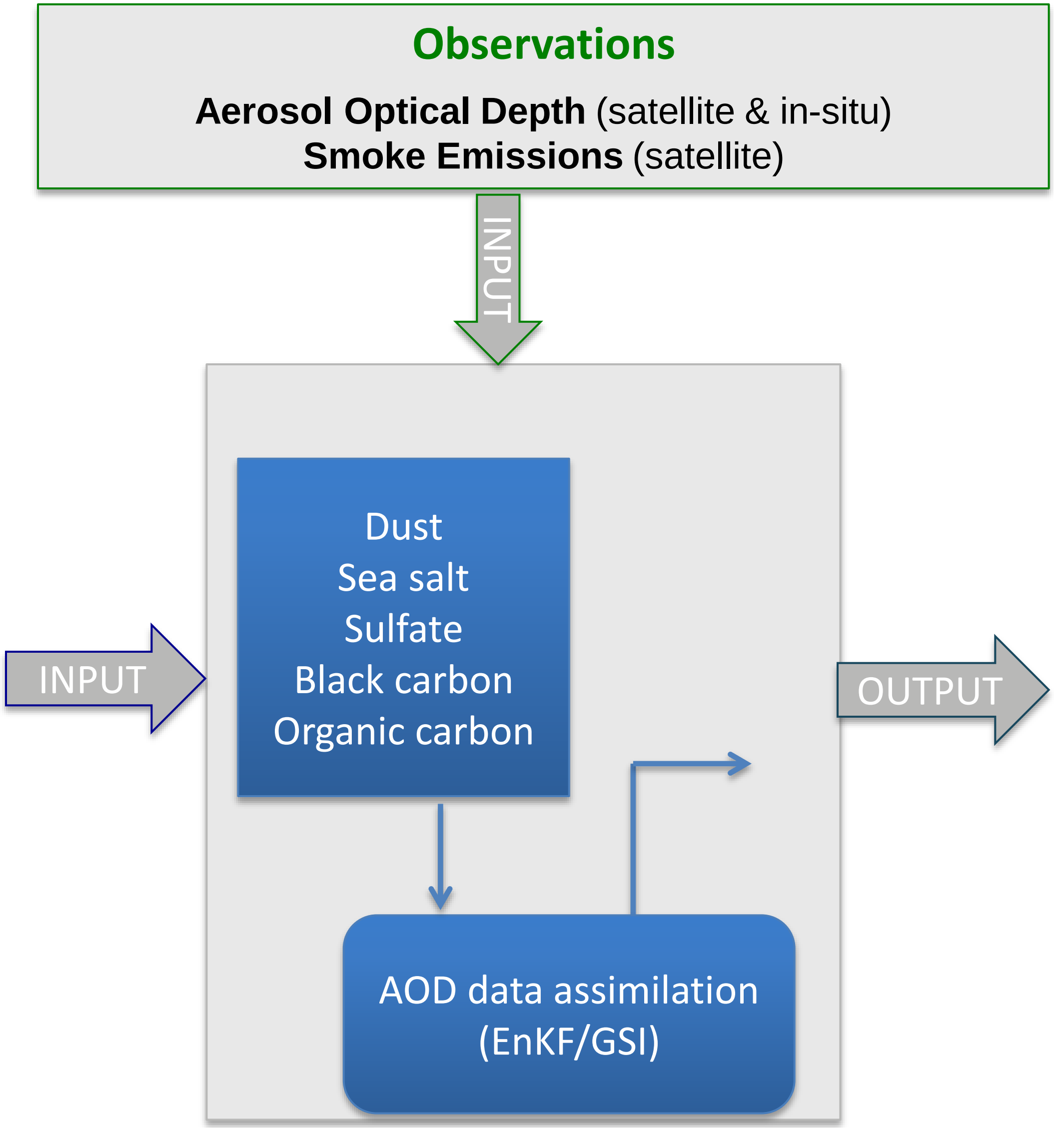
- Land use dataset upgrades:
  - Near-realtime GVF (global 16-km, 1981-present, and 25-year climatology), land-use/vegetation (IGBP-MODIS, global 1km), soil type (STATSGO-FAO, global 1km), MODIS snow-free albedo (global 5km), maximum snow albedo (U. Arizona, global 5km).
  - SMOPS soil moisture (AMSR-E (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

NCEP Coupled Hybrid Data Assimilation and Forecast System



Aerosol Data Assimilation



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, 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.

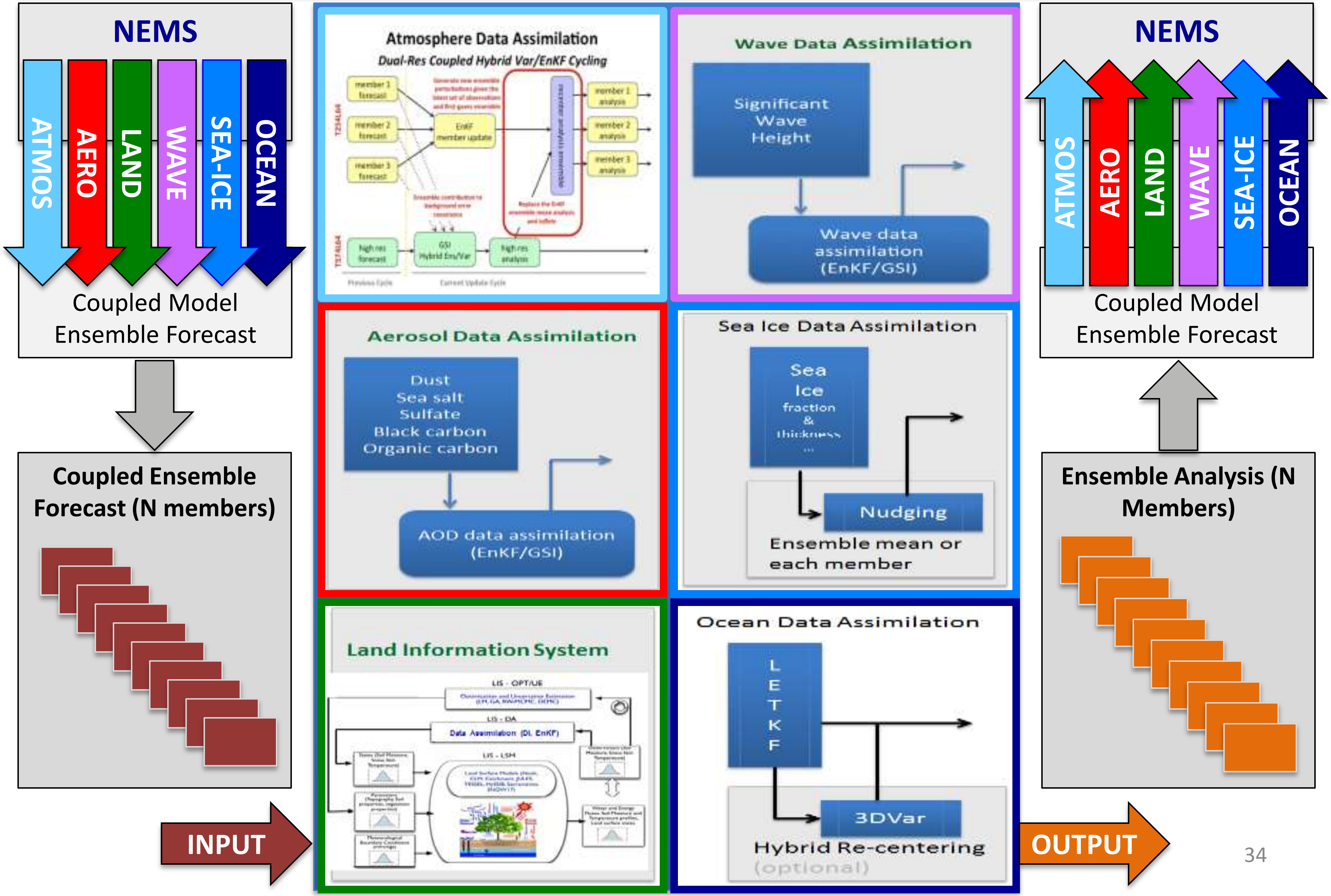
- Data assimilation upgrades:

  The AOD observations will be from MODIS (satellite) and AERONET (in-situ).

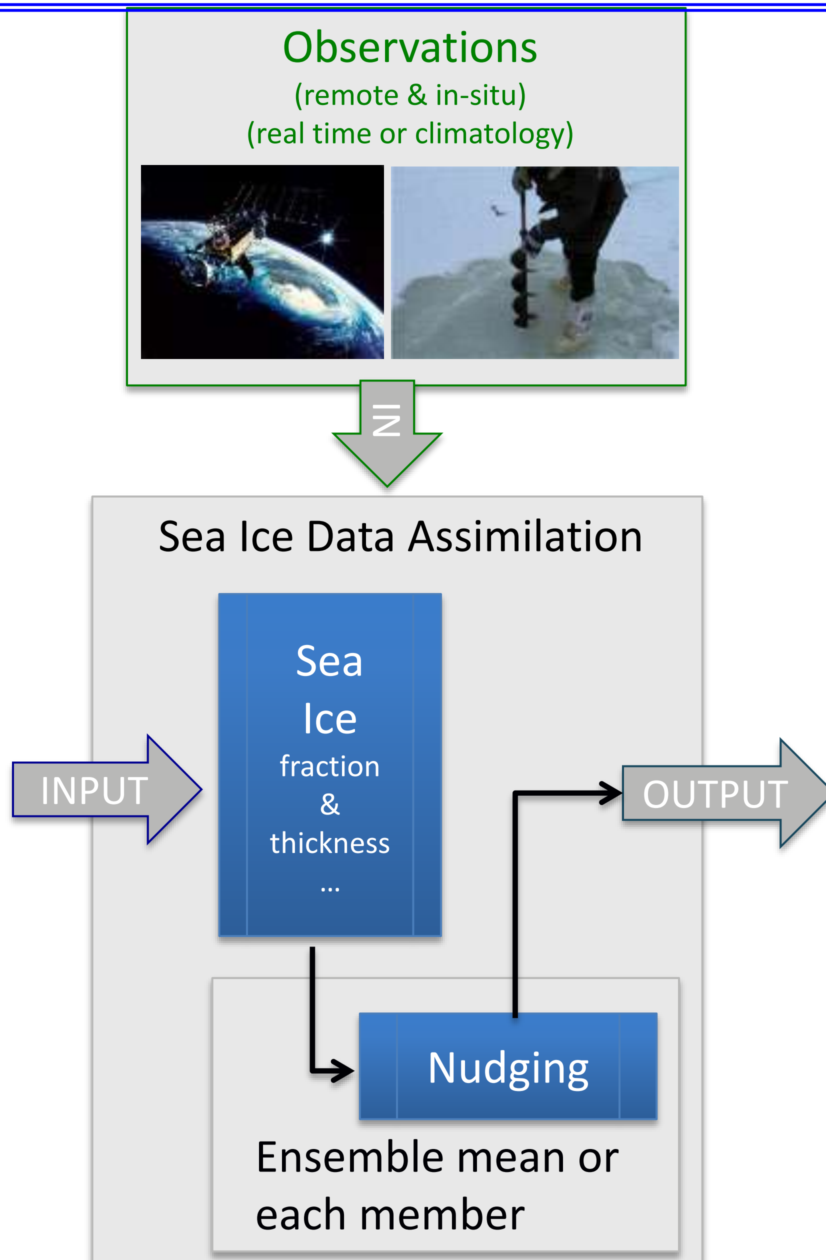
  Aerosol data assimilation is proposed for the EOS era (2002 to present).

Sarah Lu, EMC

NCEP Coupled Hybrid Data Assimilation and Forecast System



Sea Ice Data Assimilation

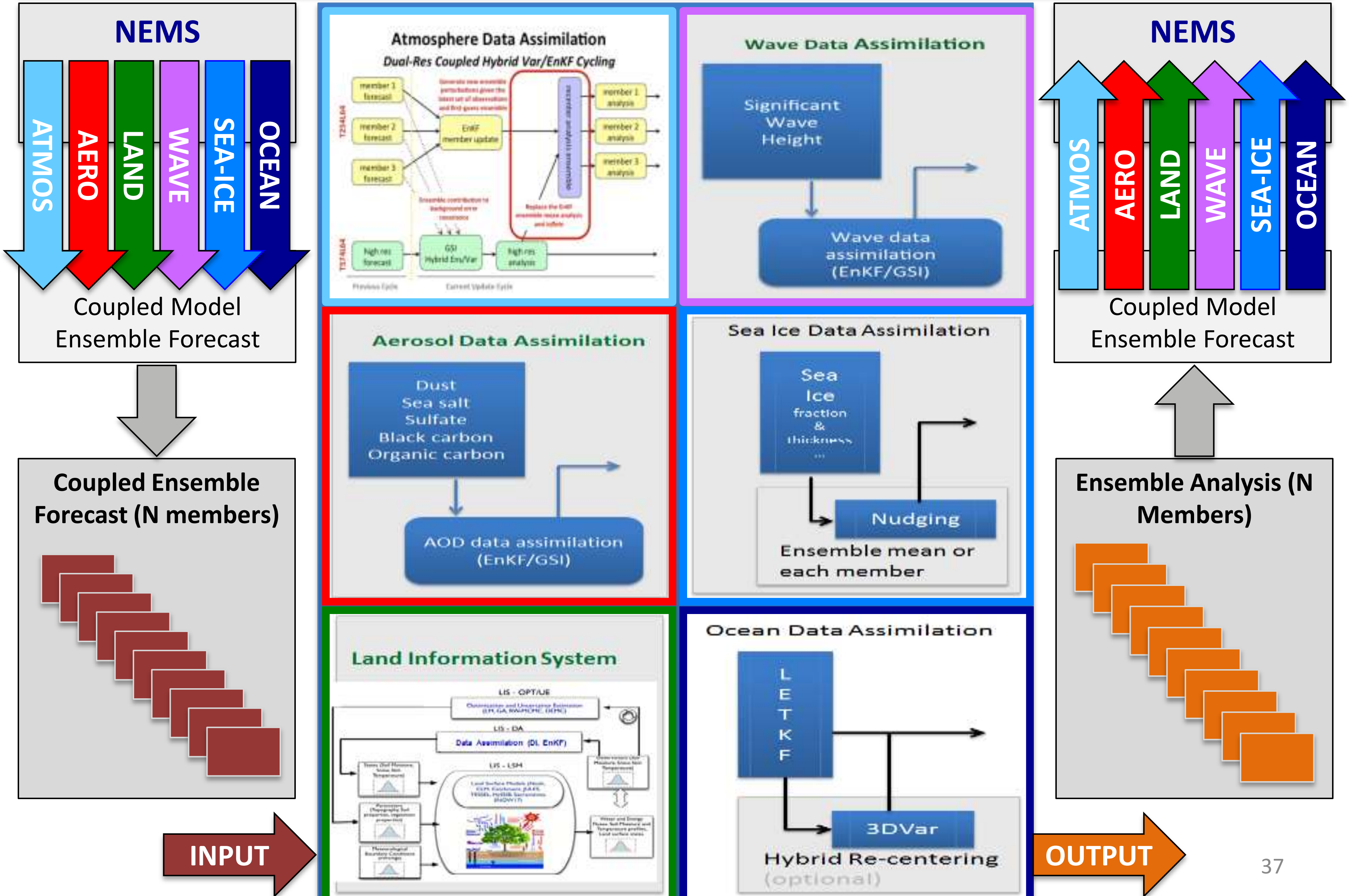


Xingren Wu, EMC

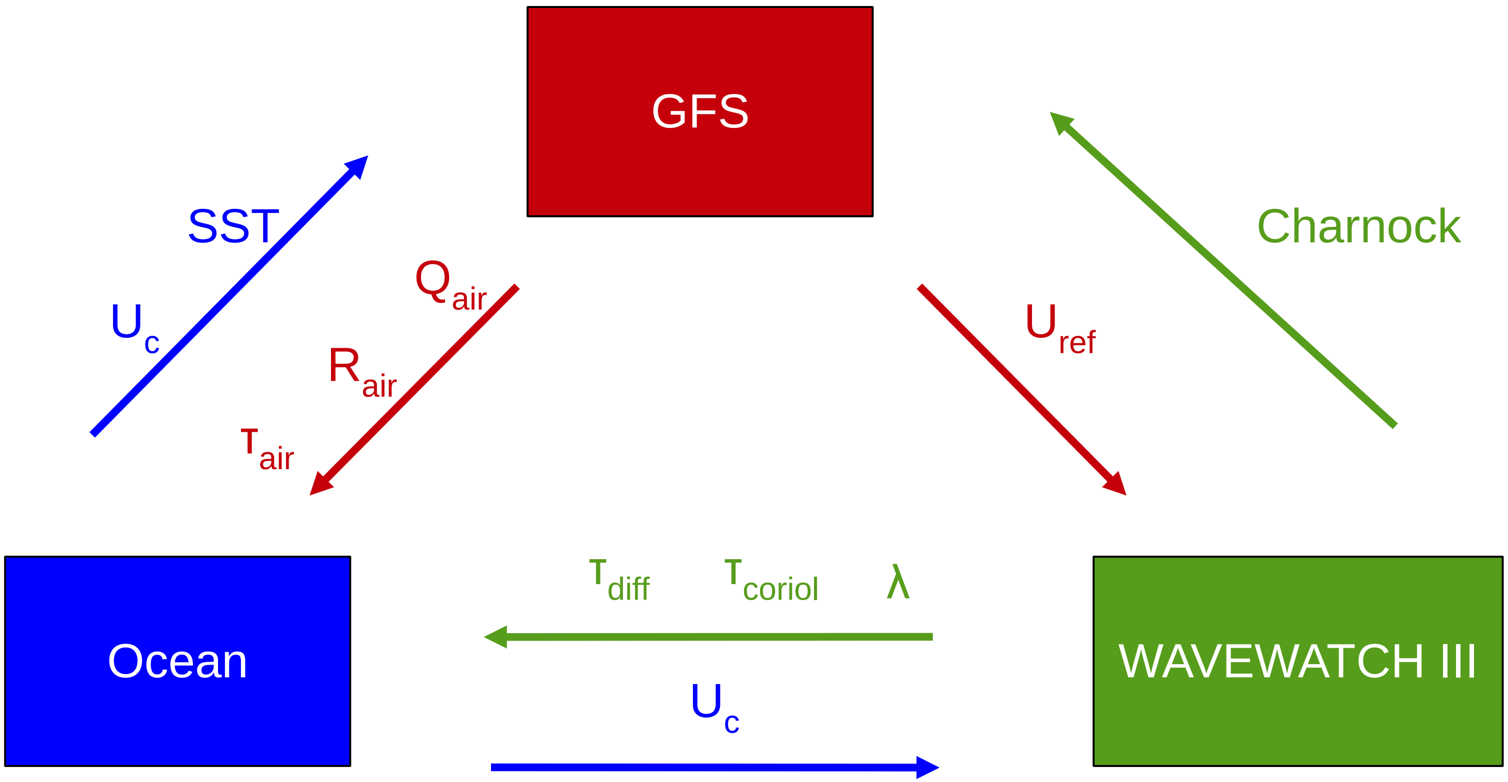
Sea Ice Data Assimilation

- 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).

NCEP Coupled Hybrid Data Assimilation and Forecast System



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**.**

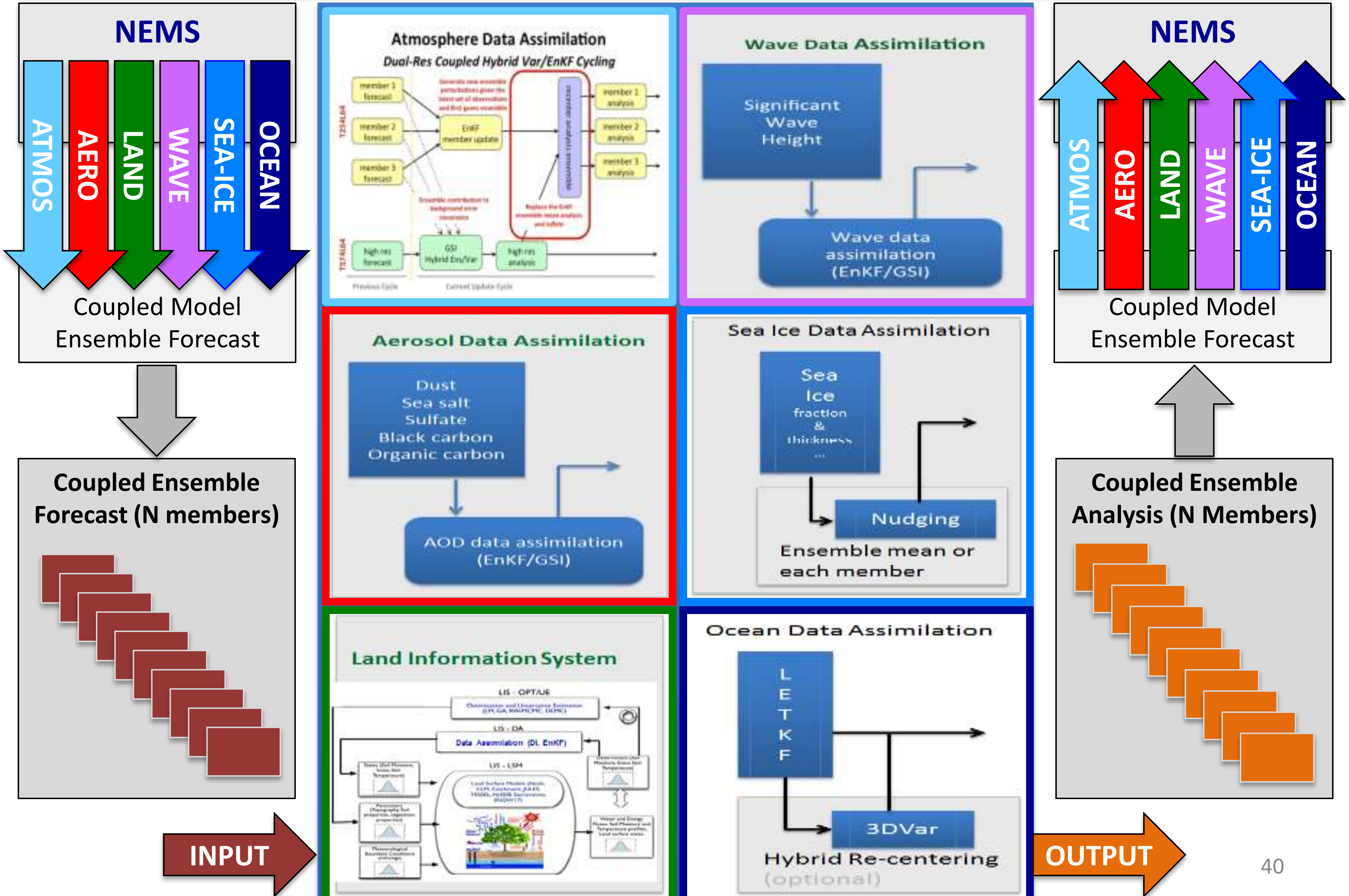
Ocean model forced by **heat flux**, sea state dependent **wind stress** modified by **growing or decaying wave fields and Coriolis-Stokes effect.**

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

Arun Chawla, Henrique Alves, Hendrik Tolman, EMC

NCEP Coupled Hybrid Data Assimilation and Forecast System



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.

THANK YOU