Atmospheric Data Assimilation

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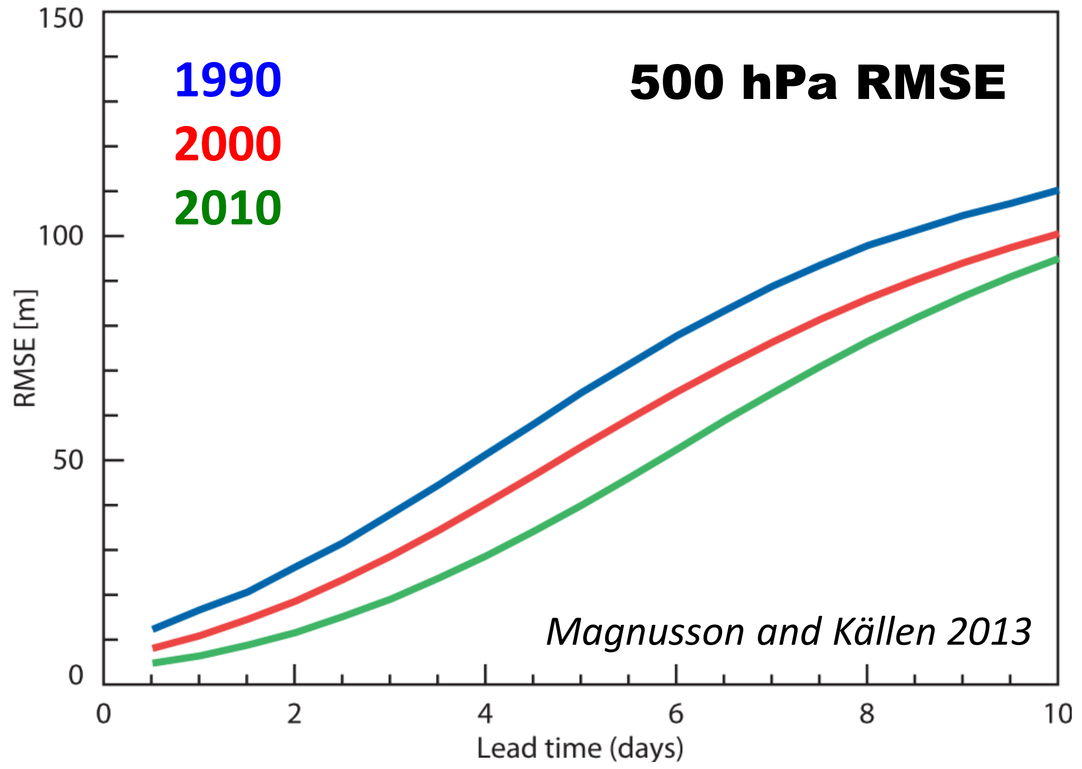
Motivation

- Initial conditions for Numerical Weather Prediction (NWP)
- Calibration and validation
- Observing system design, monitoring and assessment
- Reanalysis
- Better understanding (Model errors, Data errors, Physical process interactions, *etc*.)

Motivation



$$dE/dt = (\alpha E + \beta)(1 - E/E_\infty)$$

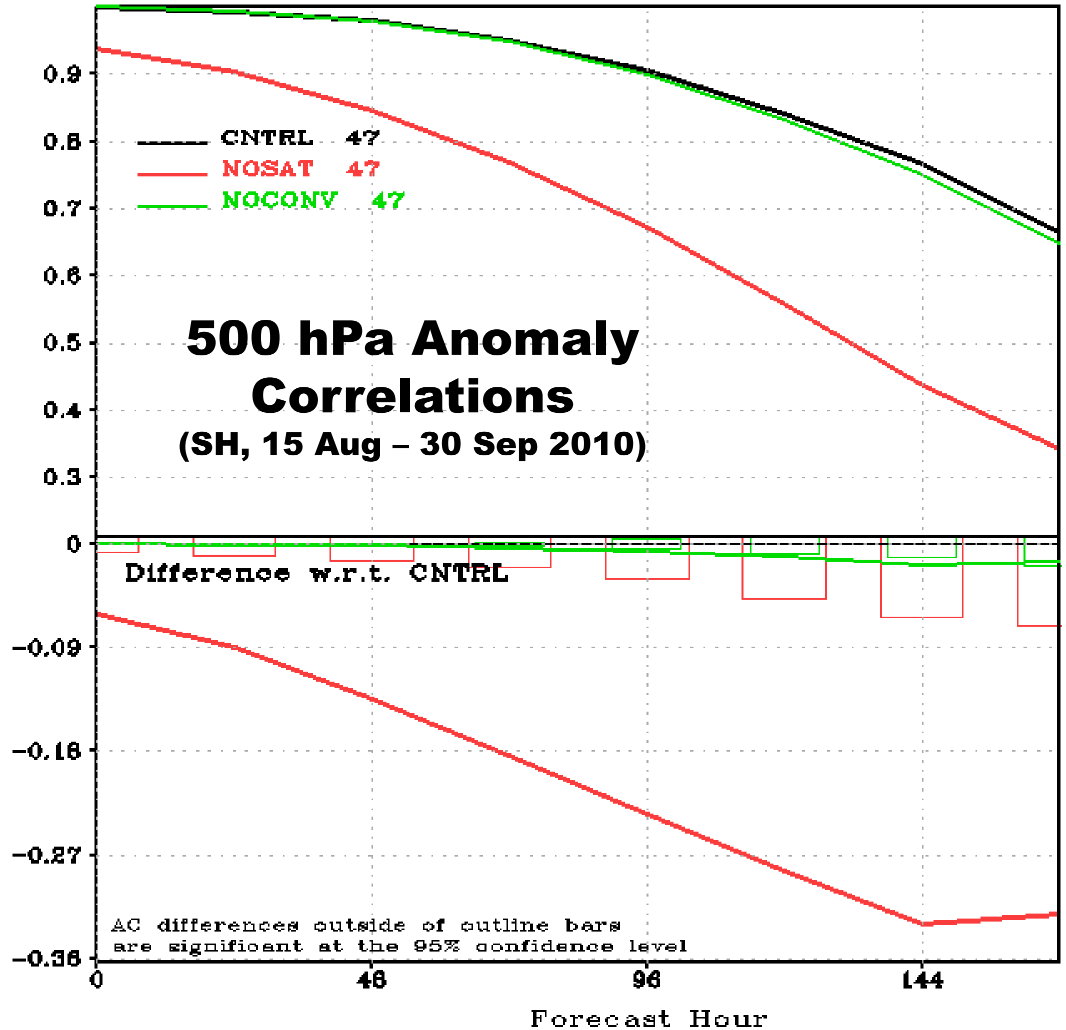
Chaotic ~ **Model error** contribution

α ~ 0.4/day

β ~ 2.4m/day

E_∞ ~ 115m

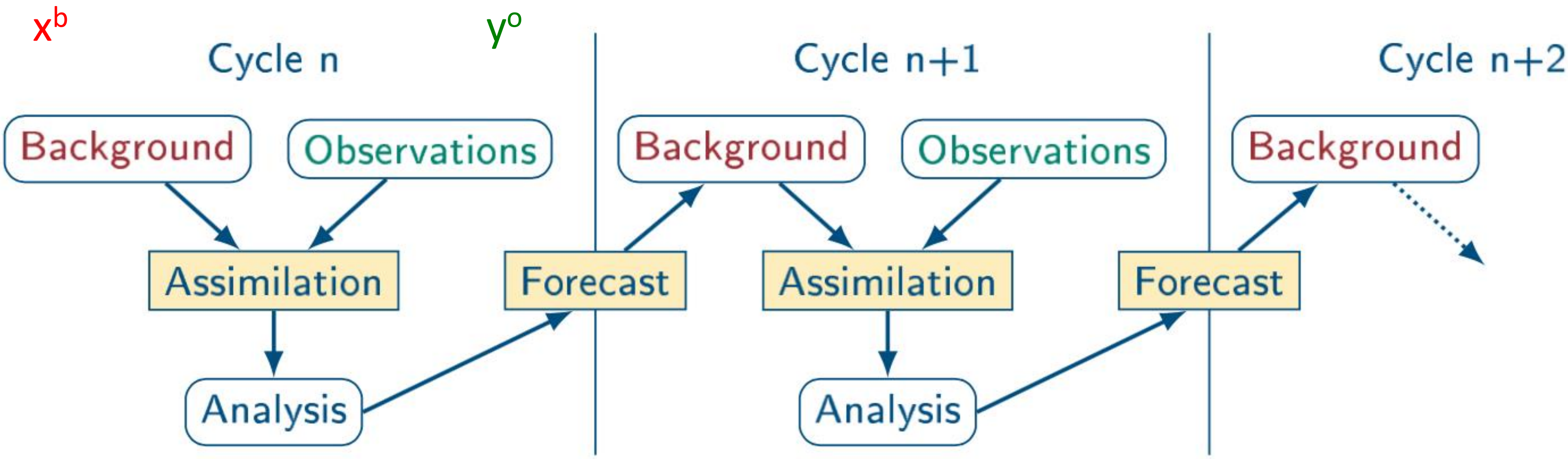
Motivation



Source: Jung (2012)

Introduction

Modern data assimilation systems combine together information from a short term forecast, a set of observations and possibly other information to estimate the most probable state of atmosphere.

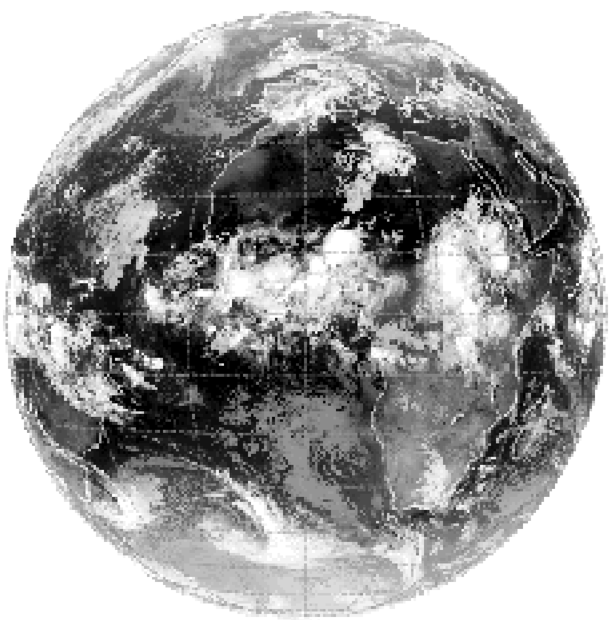


Courtesy: Ménétrier

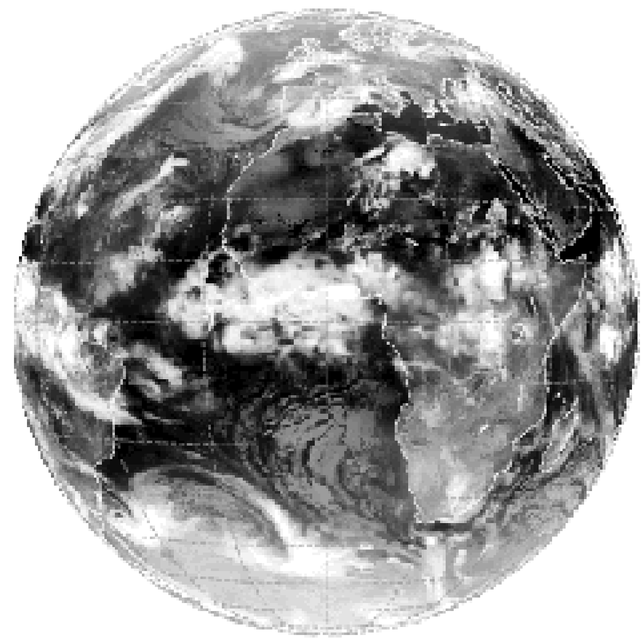
Introduction

- Compute observation operator $H: x \rightarrow y$ $d = y^o - Hx^b$

Meteosat 9 IR10.8 20080525 0 UTC



ECMWF Fc 20080525 00 UTC+0h:



Source: ECMWF

Introduction

- Compute observation operator $H: x \rightarrow y$ $\quad d = y^o - Hx^b$

Hypotheses: Background and observation errors are uncorrelated, unbiased, normally distributed, with known covariances **B** and **R**

- (Extended) Kalman Filter analysis:

  $x^a = x^b + \mathbf{K}d \qquad \mathbf{A} = (\mathbf{I} - \mathbf{KH})\mathbf{B}$

  $\mathbf{K} = \mathbf{BH}^T(\mathbf{HBH}^T + \mathbf{R})^{-1}$

- Model forecast:

  $x^b \leftarrow M(x^a) \qquad \mathbf{B} \leftarrow \mathbf{MAM}^T + \mathbf{Q}$

State of the Art

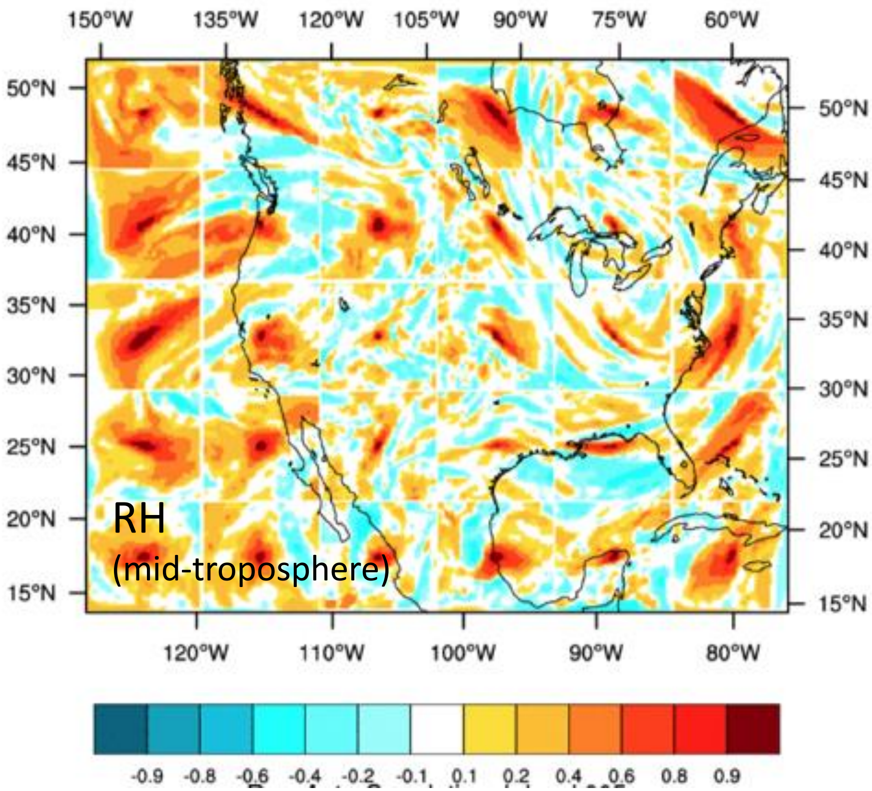
- Good estimates of the observational AND forecast error structure are necessary. Much of our effort is directed towards improving the specification of these error structures.

- In addition, determining the set of observations to use in an analysis is very important.
  - Quality control
  - Forward models (go from analysis variables to observed variables)

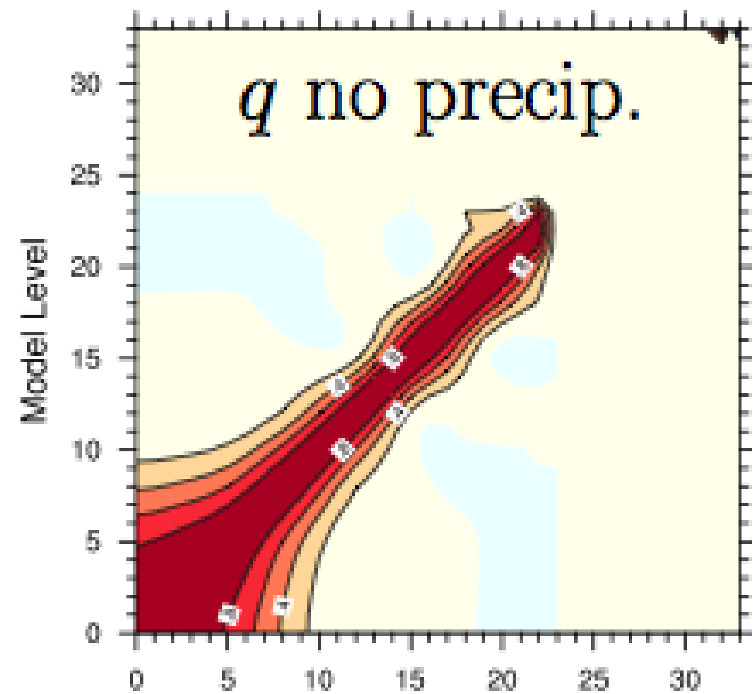
- Also, assimilation system must be efficient enough to complete in operational time window (~20 minutes for current global system).
  - Approximations necessary.

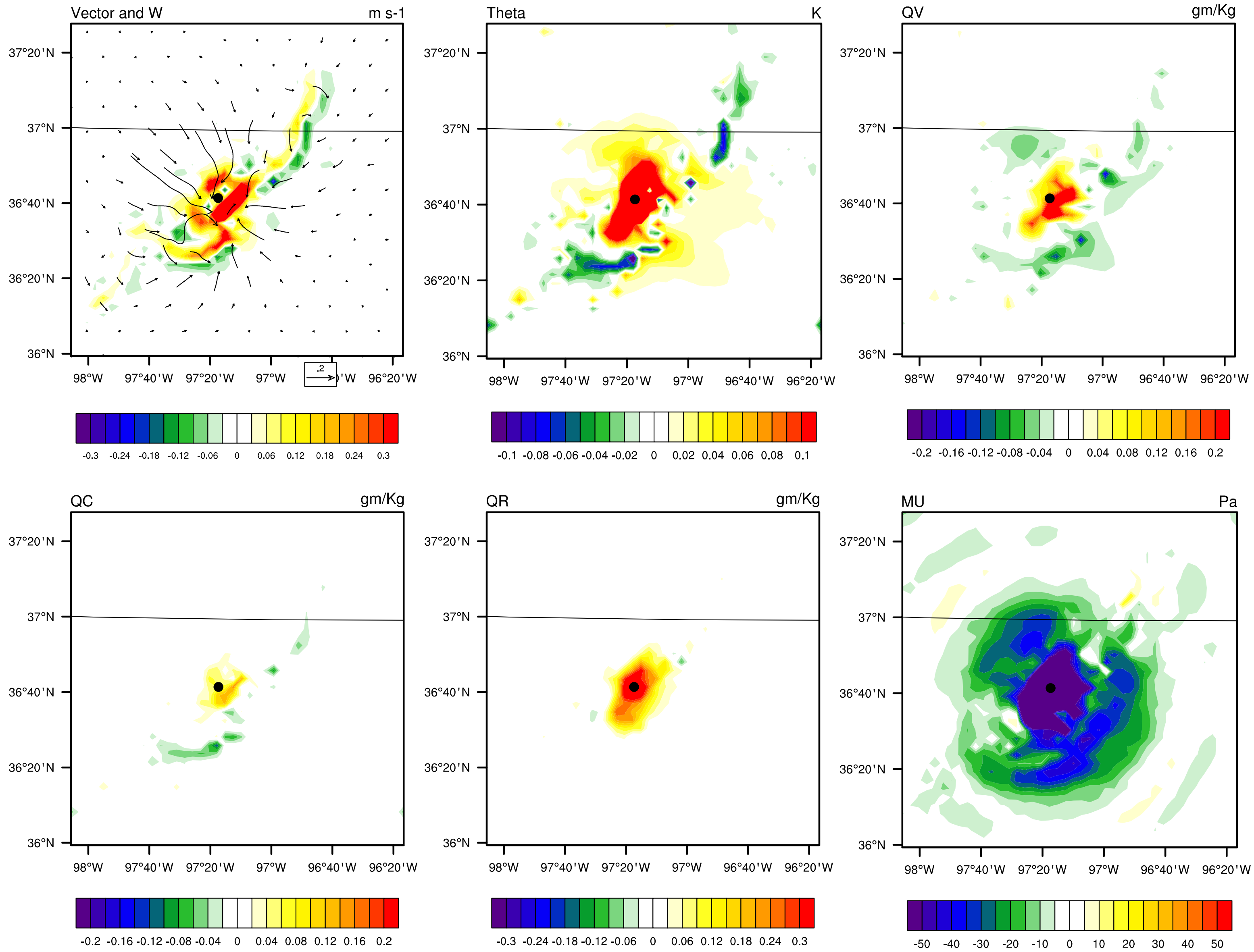
State of the Art

Horizontal autocorrelations



Vertical auto-correlation





Mini-4DVar (10min)

Wang, Sun, Zhang, Huang and Auligné (MWR 2013)

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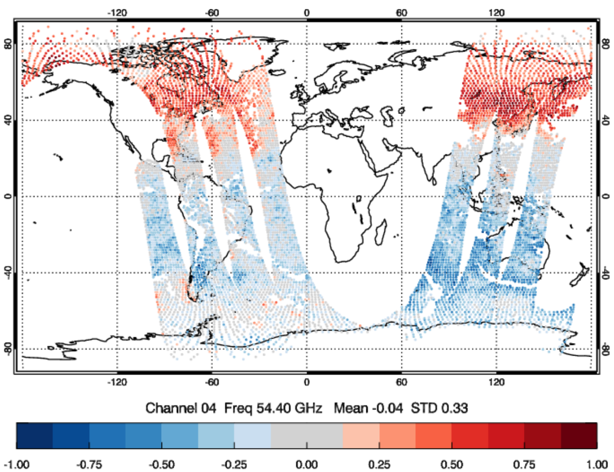
State of the Art

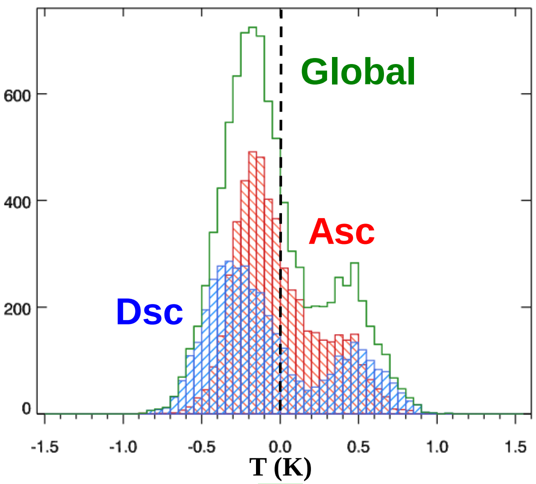
- Technique
  - 3D/4D-Var
  - Ensemble
  - Hybrid – Ensemble used to specify part of model error covariance
    - Current NCEP operational system is 3D Hybrid EnVar
    - Upgrade to 4D Hybrid EnVar under final testing
- Observations
  - Conventional
  - Satellite instruments
  - Bias correction – currently aircraft satellite radiances, radiosondes (radiation correction).
- Many other details (the devil is in the details)

Application of NWP Bias Correction for SSMIS F18

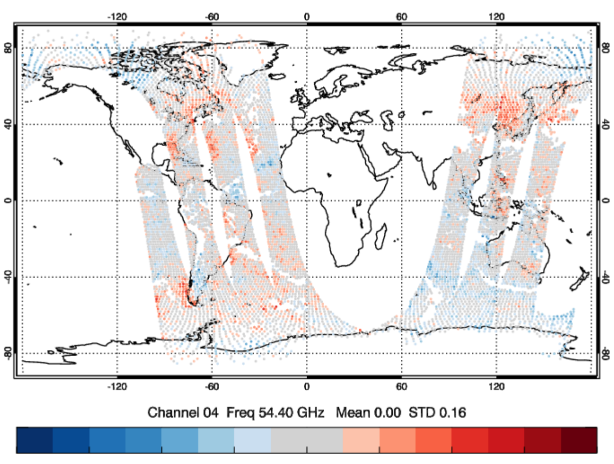
O-B Before Bias Correction



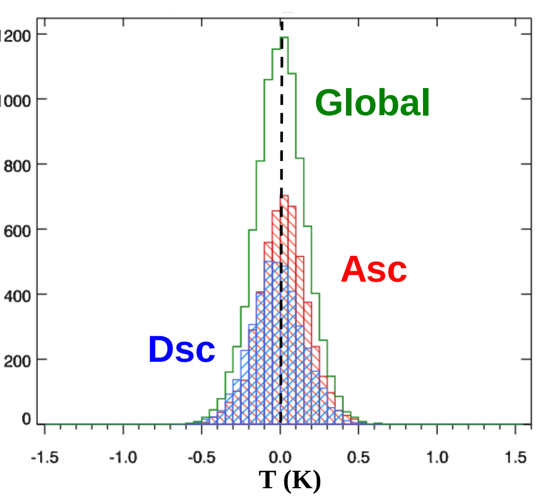
O-B Before Bias Correction



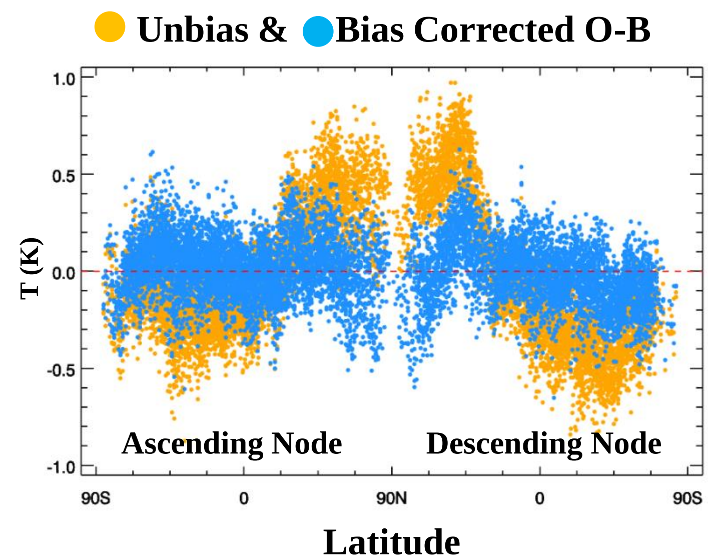
O-B After Bias Correction



O-B After Bias Correction



Using Met Office SSMIS Bias Correction Predictors



Courtesy: Andrew Collard

Priorities

- Upgrade and maintain use of current observations
- Continue to develop GSI Hybrid
- Enhance use of cloud-impacted (“all sky”) radiances
- Improve specification of observation errors
  - Error variances
    - Increased granularity (station/instrument type statistics)
  - Correlated errors

Priorities

- Improve hydrological and dynamical balance in analysis increments
- Improve stochastic physics in ensemble members
- Add new satellite instruments/channels
- Improve scalability and efficiency of GSI code

Priorities

- Improve quality control and bias correction of conventional data
- Enhanced variational quality control for all observations
- Bias correction of background field
- Assimilation of aerosol and trace gas information

Priorities

- Improve static background error in GSI hybrid
- Increase resolution for data assimilation ensemble members

Externally Funded Projects

1. Improved tropical cyclone initialization for NCEP operations through direct assimilation of storm information.
   PI Daryl Kleist

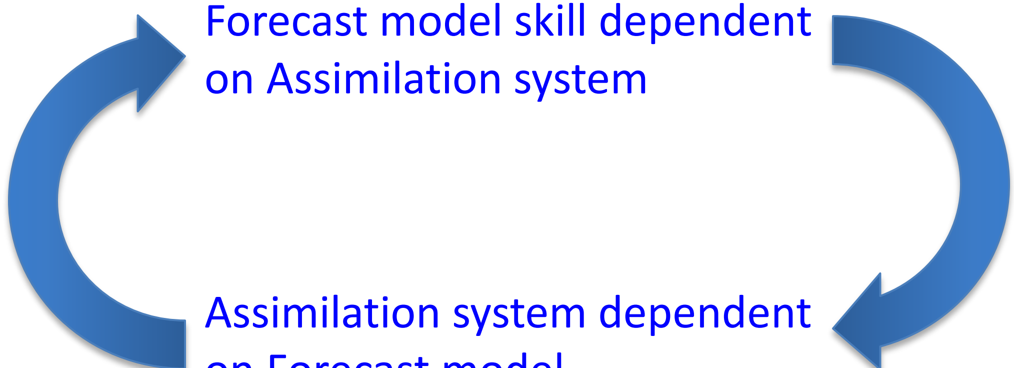
1. Testing and implementation of a cycling ensemble data assimilation system for operational hurricane prediction.
   PI Jeff Whitaker

2. Development of Advanced Data Assimilation Techniques for Improved use of Satellite-Derived Atmospheric Motion Vectors.
   PI James Jung

3. Improving Global and Hurricane Prediction by Using Minimum-Cost Large Ensemble in GFS 4DEnVar Hybrid Data Assimilation System.
   PI Xuguang Wang

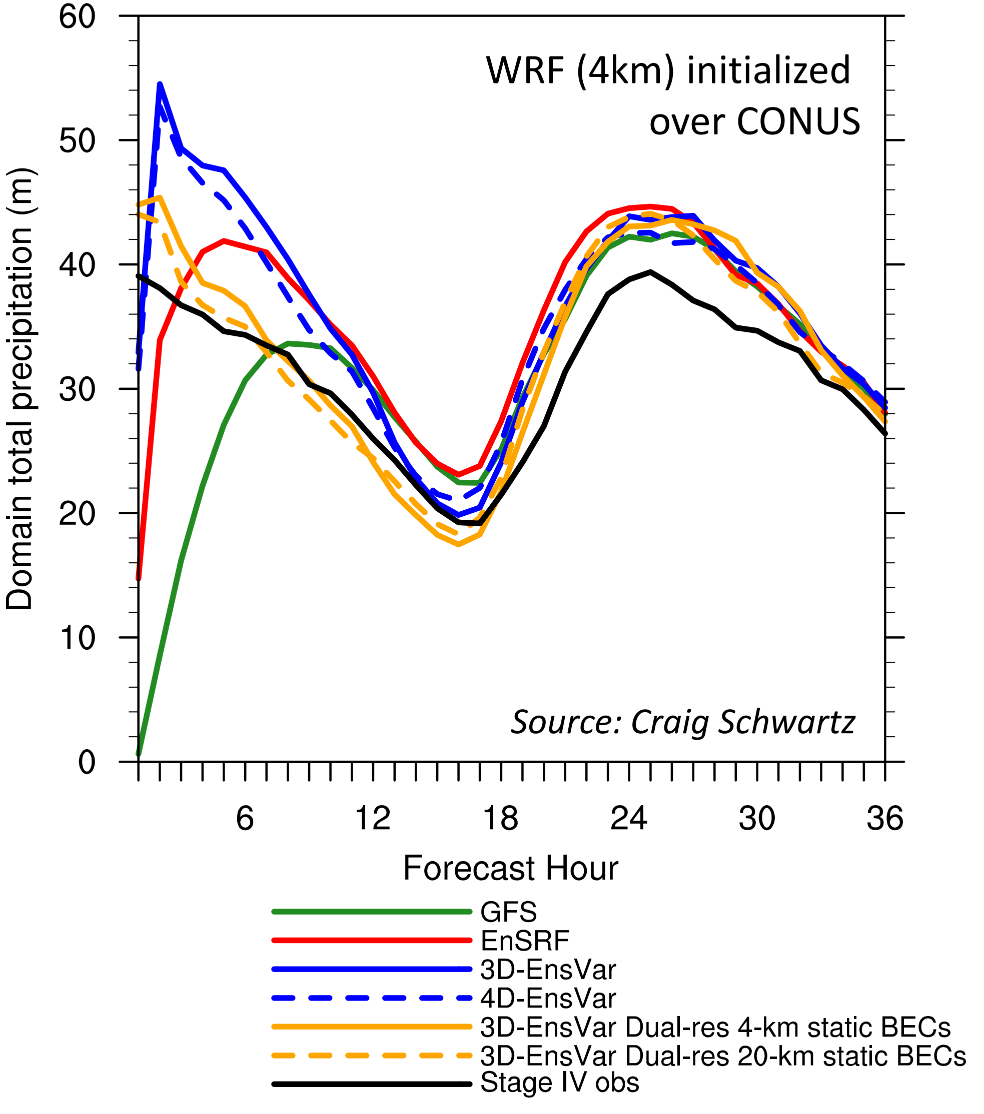
Interaction with other projects

- Some people would argue that greatest improvement in forecast skill has been due to improvement in assimilation systems



- To properly evaluate a forecast system, must include data assimilation
  - Corollary: Details of assimilation system may be different for different forecast models. Significant effort necessary to ensure appropriate assimilation system for individual model.

Examples of DA details important for evaluation of Forecast system



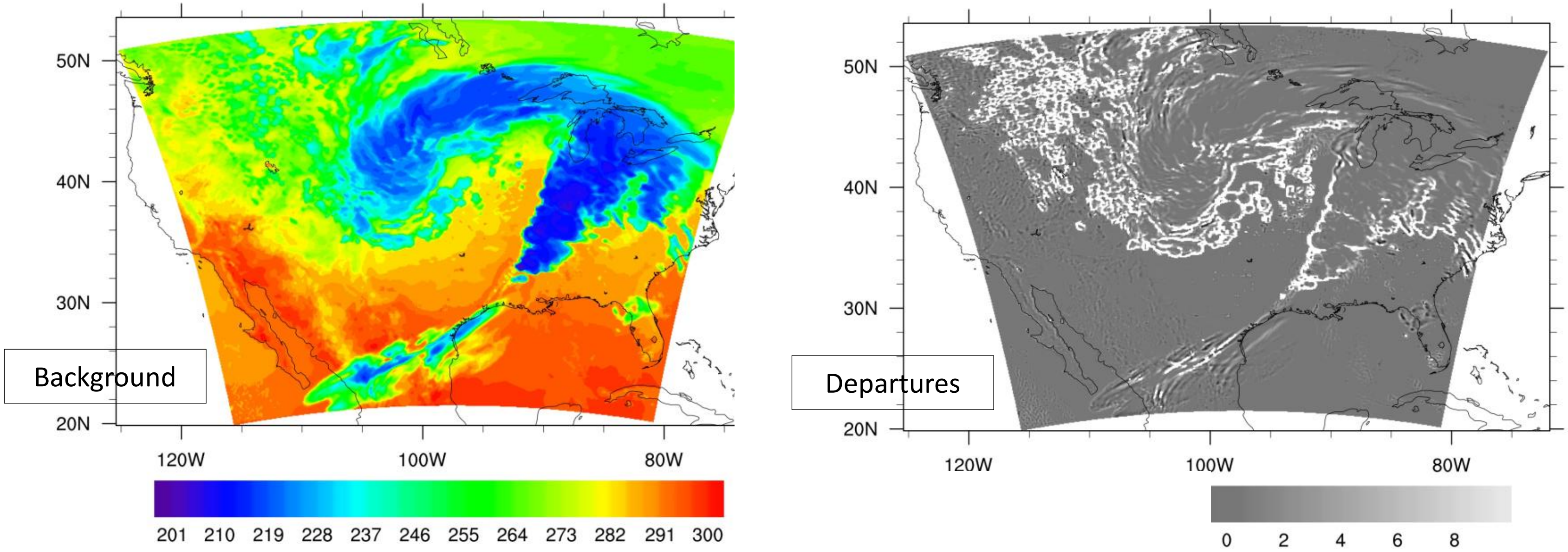
Examples of DA details important for evaluation of Forecast system

- Model error. If two models have different forecast error characteristics, different background error covariances will be necessary to project information on proper scales
- Vertical coordinate. Background error covariances can be very sensitive to the vertical coordinate used. Should be defined in same vertical coordinate as forecast model.
- Grid. Ideally analysis is performed on same grid as forecast model. For non-uniform grids not straightforward to do analysis. Possibilities:
  - Calculate O-B directly from model solution, then calculate increment and interpolate to non-uniform grid. (More accurate)
  - Interpolate forecast from non-uniform grid then calculate O-B, then calculate increment and interpolate to non-uniform grid. (Easier – more common)

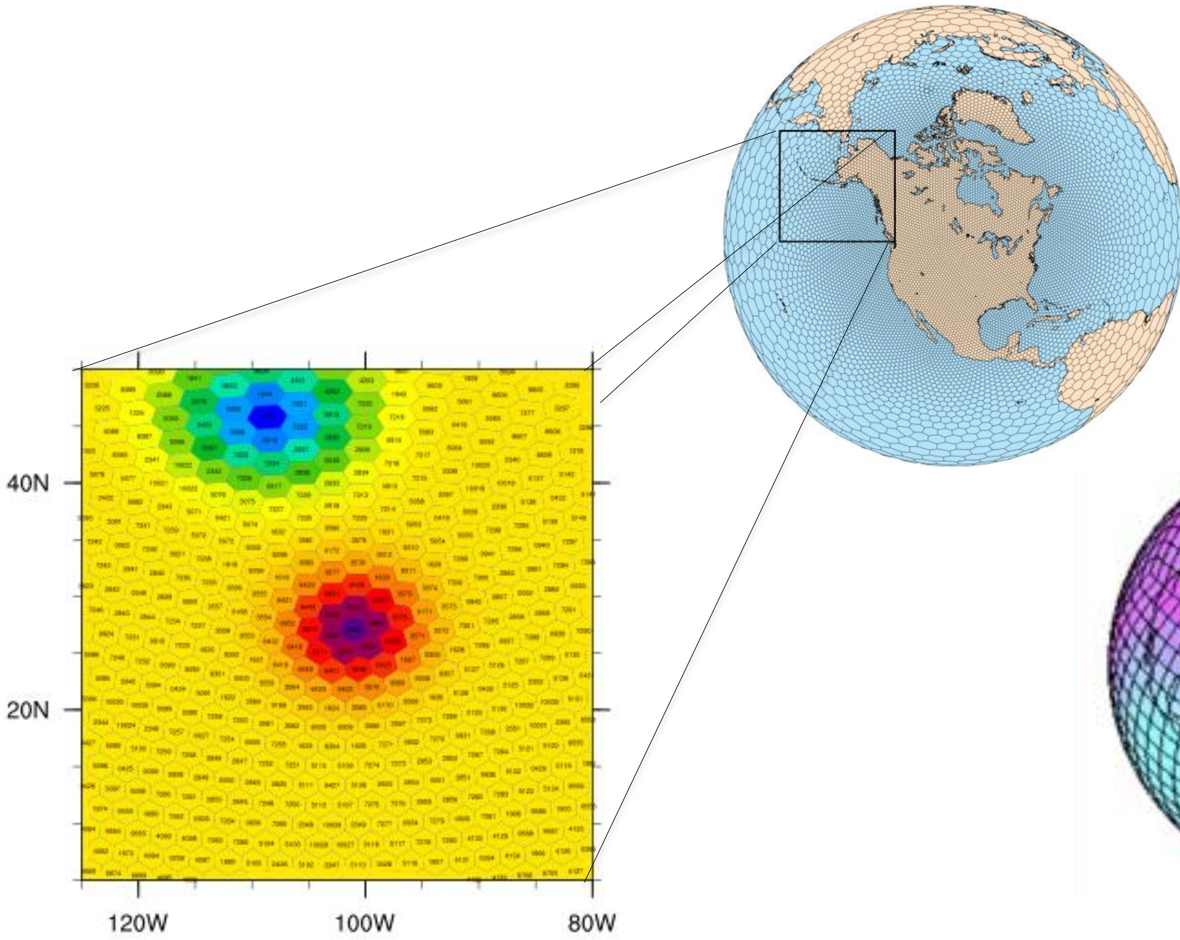
Examples of DA details important for evaluation of Forecast system

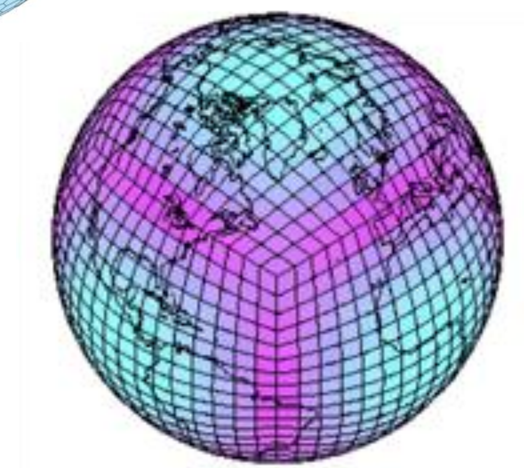
<u>Simulated mismatch in resolution:</u> (Daley 1993, Liu and Rabier 2002, Waller et al. 2014)

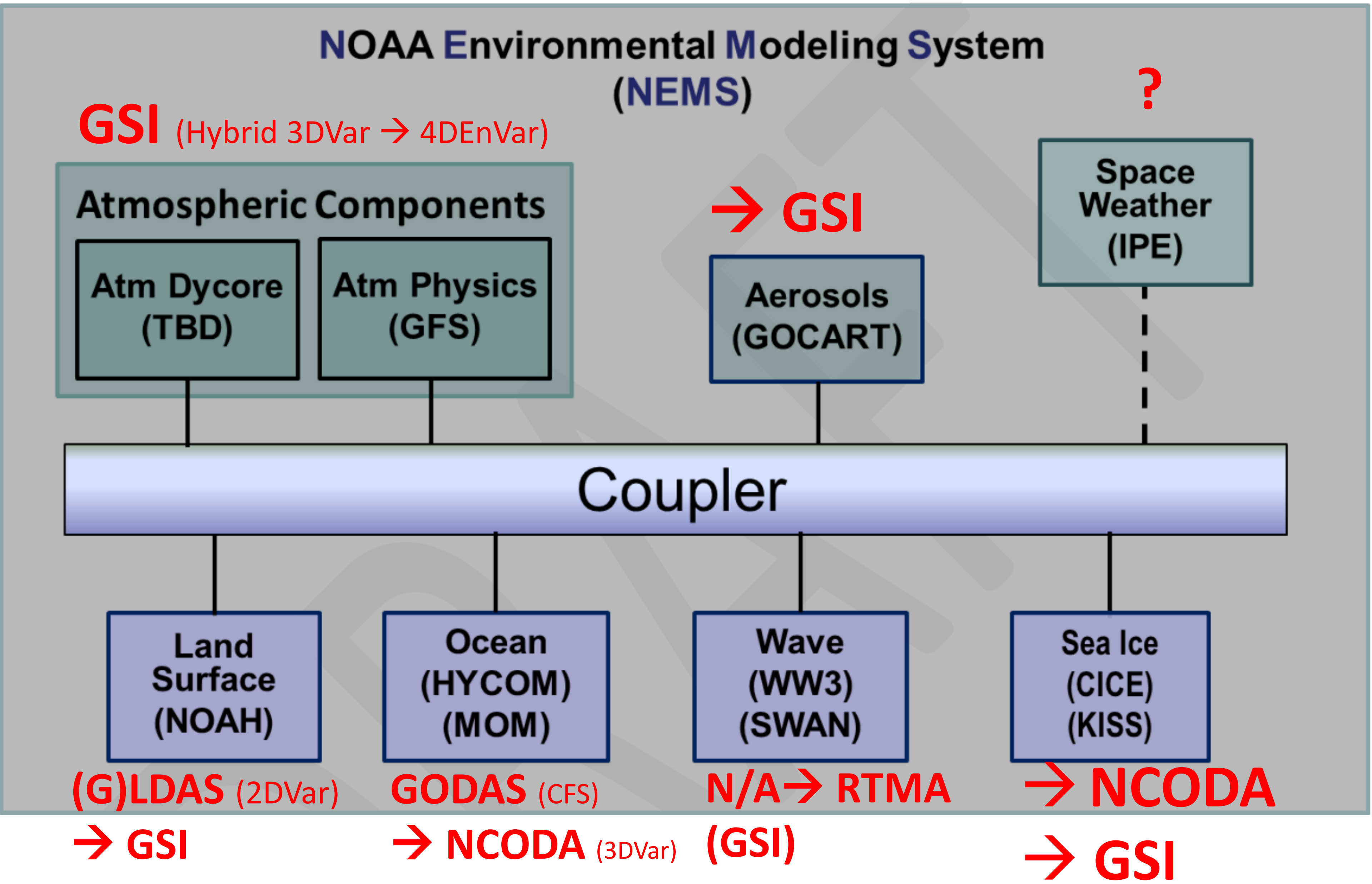
Perfect observations (high resolution), perfect Background (lower resolution)



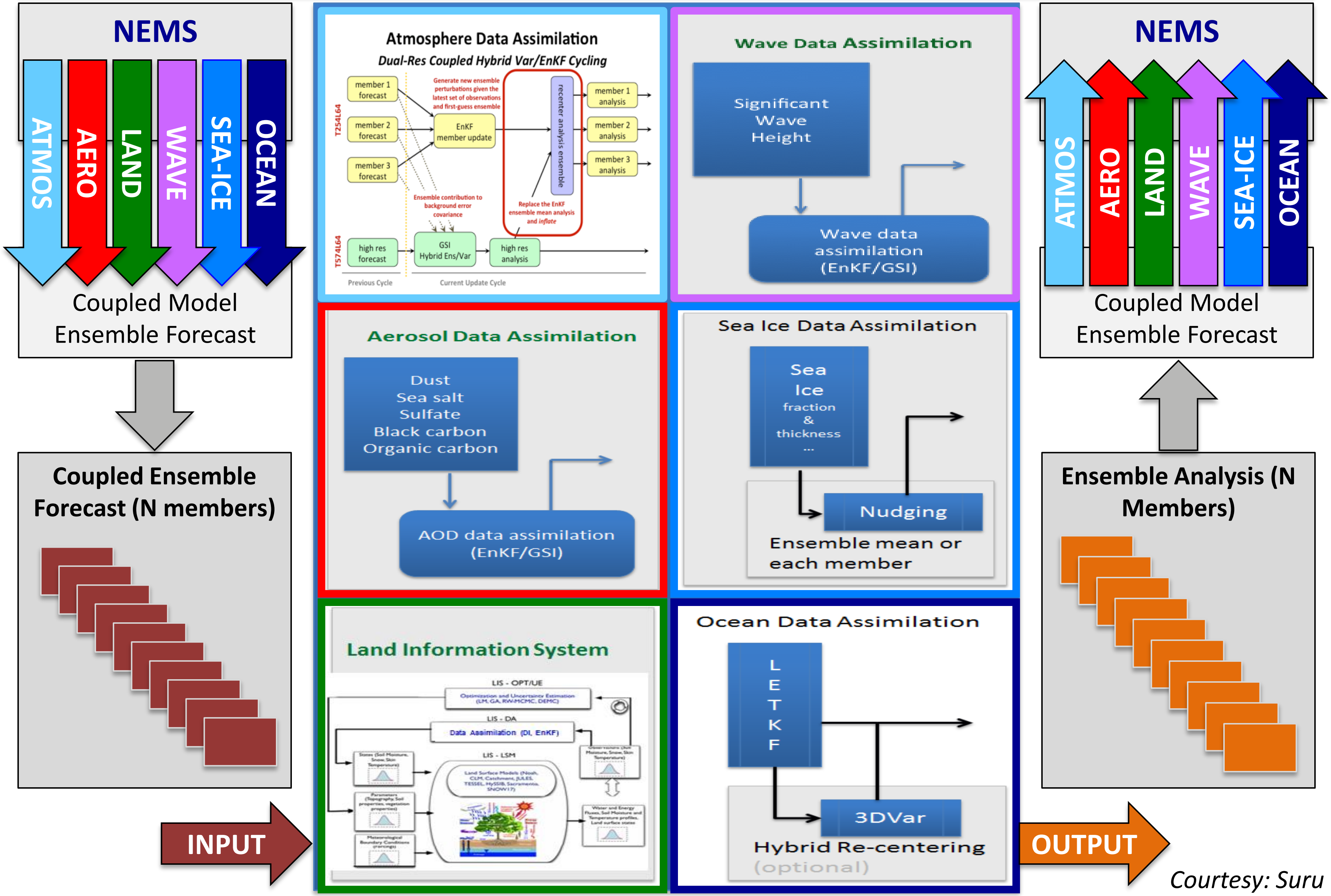
Examples of DA details important for evaluation of Forecast system






NOAA Environmental Modeling System
(NEMS)
GSI (Hybrid 3DVar → 4DEnVar)
Atmospheric Components
Atm Dycore
(TBD)
Atm Physics
(GFS)
→ GSI
Aerosols
(GOCART)
?
Space
Weather
(IPE)
Coupler
Land
Surface
(NOAH)
Ocean
(HYCOM)
(MOM)
Wave
(WW3)
(SWAN)
Sea Ice
(CICE)
(KISS)
(G)LDAS (2DVar)
→ GSI
GODAS (CFS)
→ NCODA (3DVar)
N/A→ RTMA
(GSI)
→ NCODA
→ GSI

NCEP Coupled Hybrid Data Assimilation and Forecast System



Joint Effort for Data assimilation Integration (JEDI)

- Modular, flexible, object-oriented code
- Improved readability, maintenance and testing
- Collaborative operation & research applications
- Model-agnostic DA components
  → strongly coupled Data Assimilation