Data Assimilation of Satellite Observations

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Motivation and Outline

- Satellite data assimilation is a big topic!

- Satellite observations provide critical information over the entire globe

- Talk will focus on topics where significant efforts are still required to fully utilize the information content in satellite observations

    - All-sky observations sensitive to clouds and water vapor

    - Atmospheric motion vectors

    - Land surface variables (soil moisture)

All-Sky Satellite Brightness Temperatures

- Focus has been primarily on all-sky microwave observations within the operational community, but more attention is being directed toward the assimilation of all-sky infrared observations

- Uncertainties and errors in the assimilation of all-sky observations

    - NWP model errors (biases, timing and placement of clouds)

    - Forward radiative transfer model assumptions

    - How to handle observation errors?

    - How to handle bias corrections?

Radiative Transfer Model Errors and Uncertainties

- Significant progress in recent years such that it is now possible to work on all-sky data assimilation activities

- Cloud, precipitation, and aerosol single-scattering properties

    - Function of particle size, shape, composition, and roughness

    - Errors are more important for some channels than for others, and also depend upon the cloud scene

    - Inconsistencies between assumptions made in the NWP cloud microphysics scheme and the lookup tables used by the RTM

    - Errors are smaller for liquid droplets and largest for ice particles (up to several degrees)

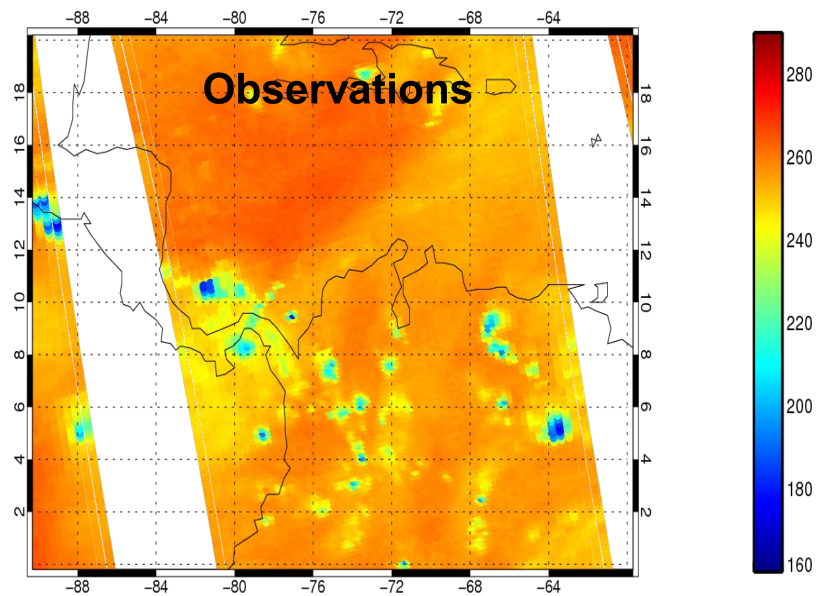
Courtesy of Tom Greenwald (CIMSS)

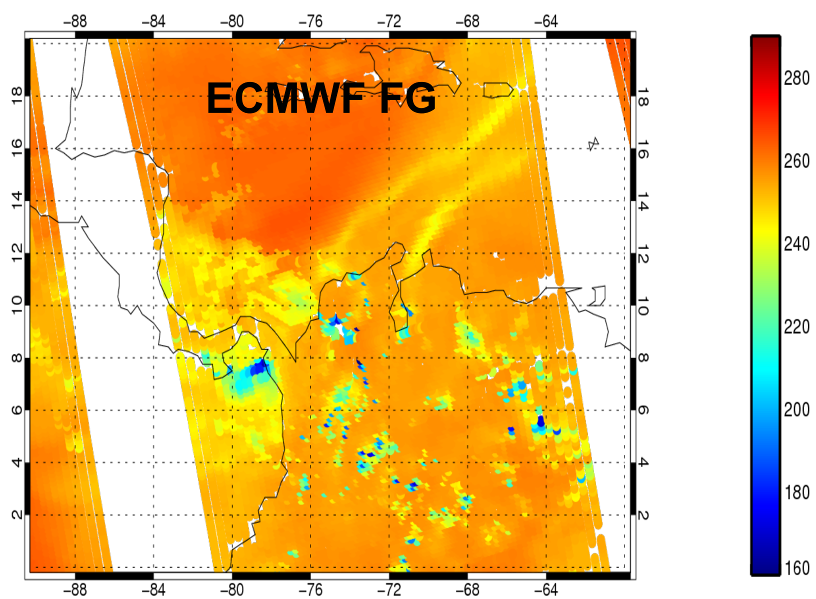
Radiative Transfer Model Errors and Uncertainties

- Plane-parallel assumption
    - Effects are spatial resolution dependent – a few K for larger resolutions, but can be in excess of 10-20 K at high spatial resolutions
    - Most important for high-resolution model domains where parallax affects can lead to large displacement errors
- Strong error correlations between different channels need to be accounted for when assimilating observations from multiple channels
    - Largest correlations generally between channels that have the most scattering

Courtesy of Tom Greenwald (CIMSS)

Representing Clouds and Precipitation in Models





Why such large errors?

- Limited predictability of clouds and precipitation, particularly in convective situations
- Accuracy of the model's cloud and precipitation parameterization
- Accuracy of the observation operator (radiative transfer simulations)

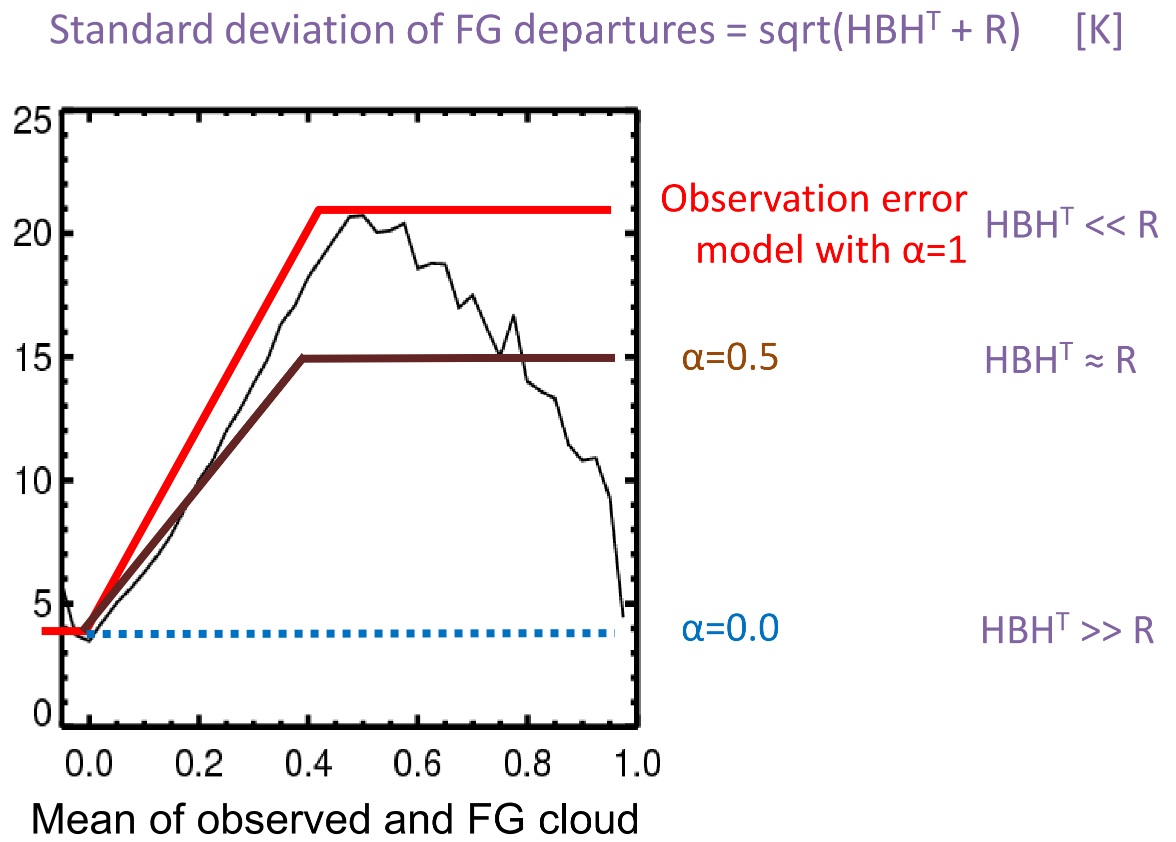
Courtesy of Alan Geer (ECMWF)

Symmetric Observation Error Model

- Use a variable obs error to account for uncertainty in the first guess departures

- Symmetric cloud amount has been shown to work well

- Smallest standard deviations where both observations and model background are clear or cloudy

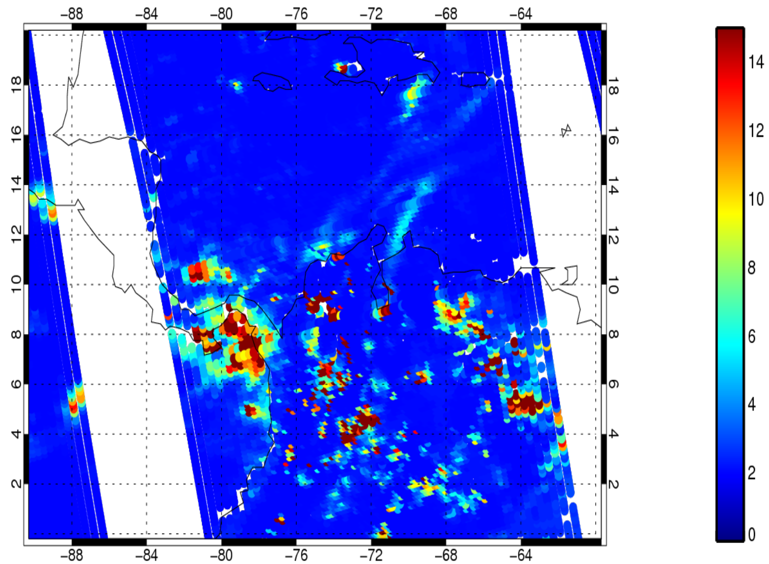


- Okamoto et al. (2014) and Harnisch et al. (2016) have developed similar observation error models for infrared brightness temperatures

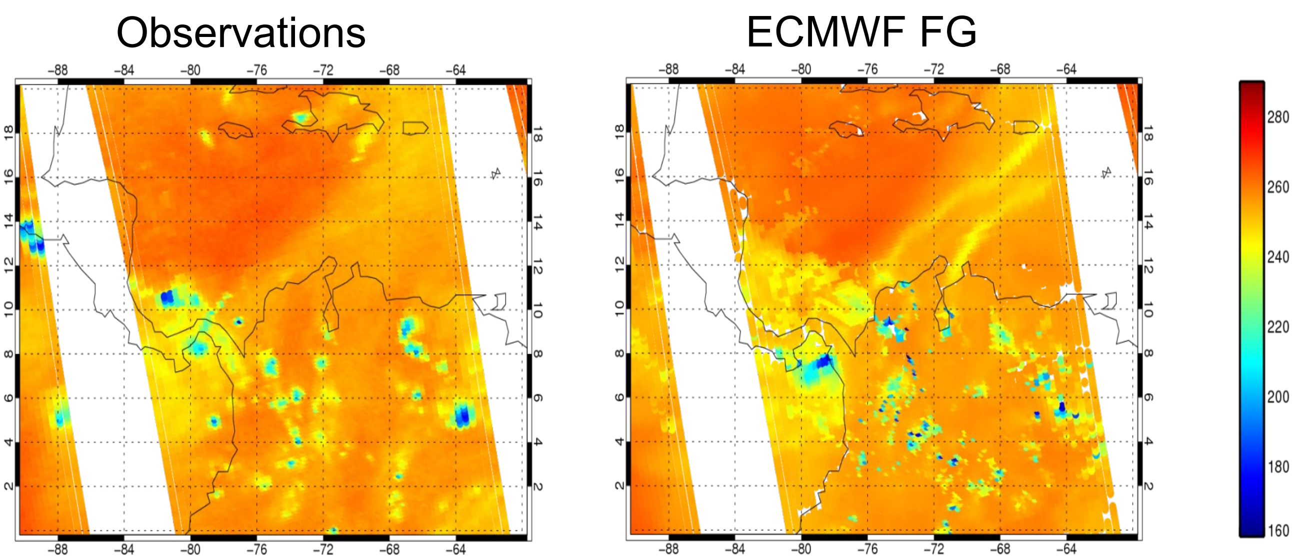
Courtesy of Alan Geer (ECMWF)

Symmetric Observation Error Model

MHS 183±3 GHz adaptive observation error from a "symmetric error model"



If you can describe the observation error correctly, and the observations are unbiased, you can assimilate them



Courtesy of Alan Geer (ECMWF)

Nonlinear Bias Correction Method

- Linear bias corrections have been shown to work well for clear-sky satellite observations that have Gaussian error characteristics

- Nonlinear error dependencies are more likely to occur when cloudy observations are assimilated

    - Complex nonlinear cloud processes in the NWP model

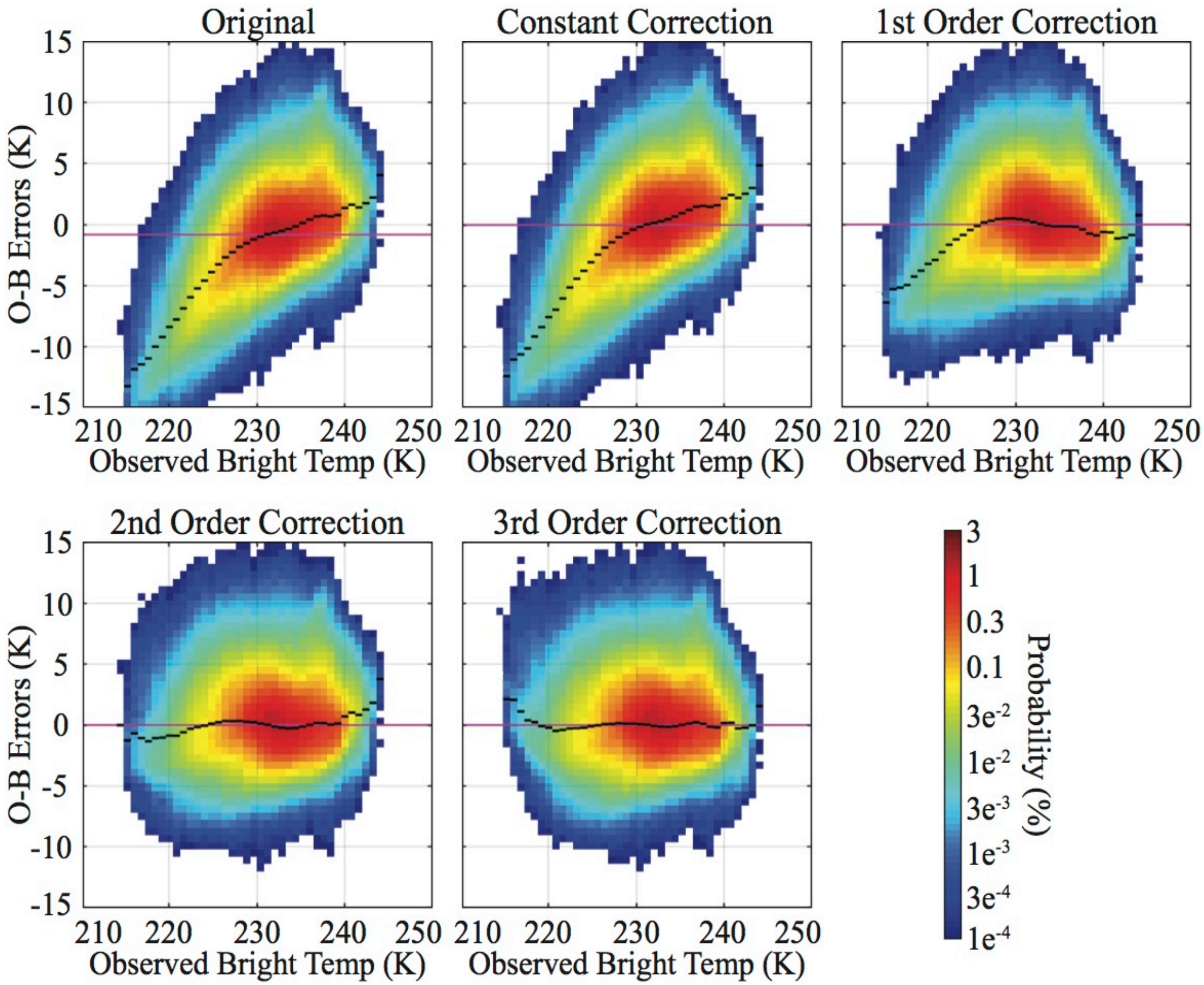
    - Errors in the forward radiative transfer model used to compute the model-equivalent brightness temperatures

- Desirable to develop bias correction methods that can remove both the linear and nonlinear bias components from the observation departures

- Remove linear and nonlinear conditional biases from all-sky satellite observations using a Taylor series expansion of the OMB departures

Otkin et al. (2018; MWR)

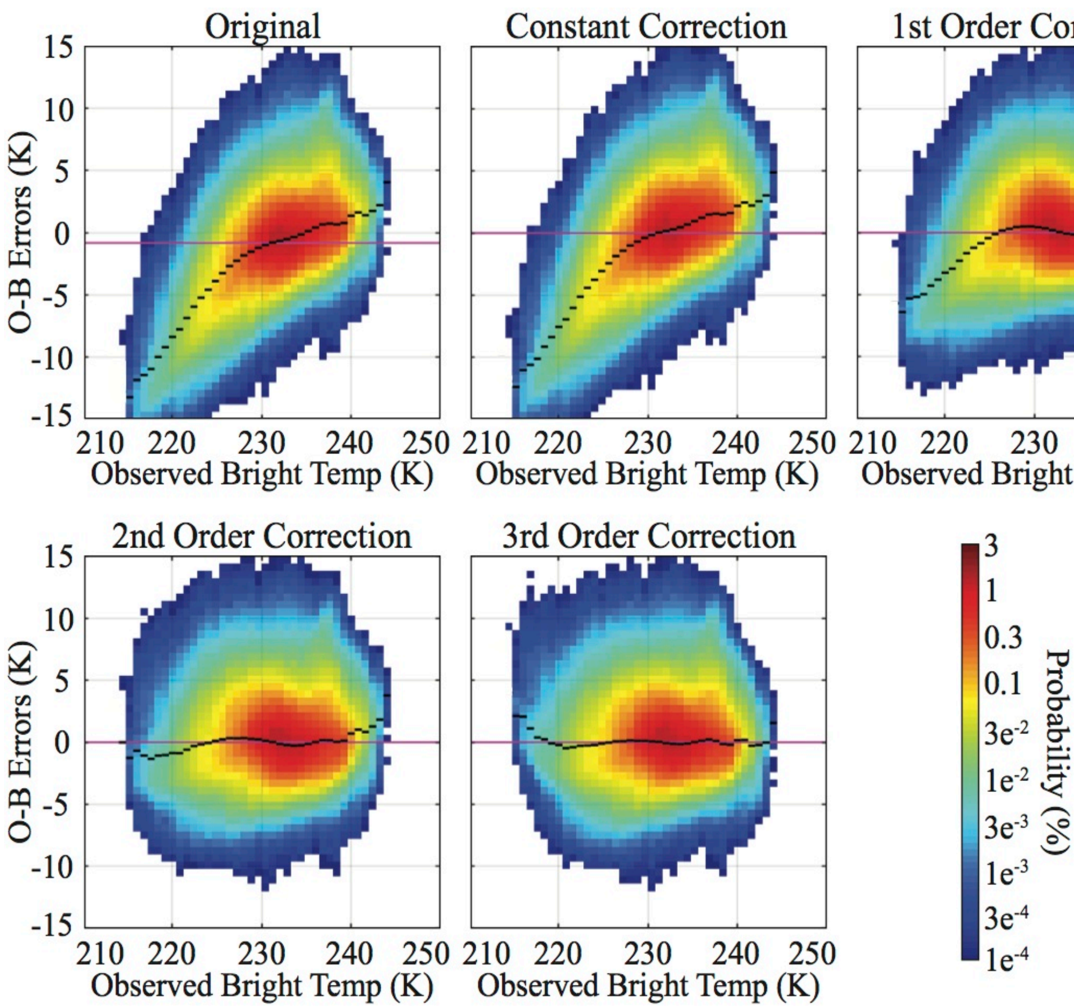
Observed 6.2 μm Brightness Temperature Predictor



- Results evaluated for original, 0th (constant), 1st (linear), 2nd (quadratic), and 3rd (cubic) order Taylor series expansions
- Purple line shows mean bias of the distribution
- Short black lines show conditional bias in each vertical column
- Used to assess how the bias varies as a function of the predictor value

- Each error distribution (except for the original) has zero overall bias; however, the conditional biases strongly vary as a function of the predictor value

Observed 6.2 μm Brightness Temperature Predictor



- Nonlinear conditional bias error pattern in the original distribution
- Constant and linear BC terms unable to remove all of the conditional bias
- Asymmetric arch shape in the conditional biases after 1st order BC, which is removed after applying the 2nd order BC
- Most of the remaining bias is removed after the 3rd order BC is applied

- Though each departure distribution has zero overall bias, the conditional biases are much smaller when using higher order, nonlinear bias correction terms

Atmospheric Motion Vectors (AMVs)

- AMVs derived from infrared brightness temperatures have long been an important source of information for some data assimilation systems

- Upgraded capabilities on modern sensors (GOES-16 ABI) such as more frequent scanning, higher spatial resolution, and improvements in signal quality all translate to enhanced AMV quality and capabilities

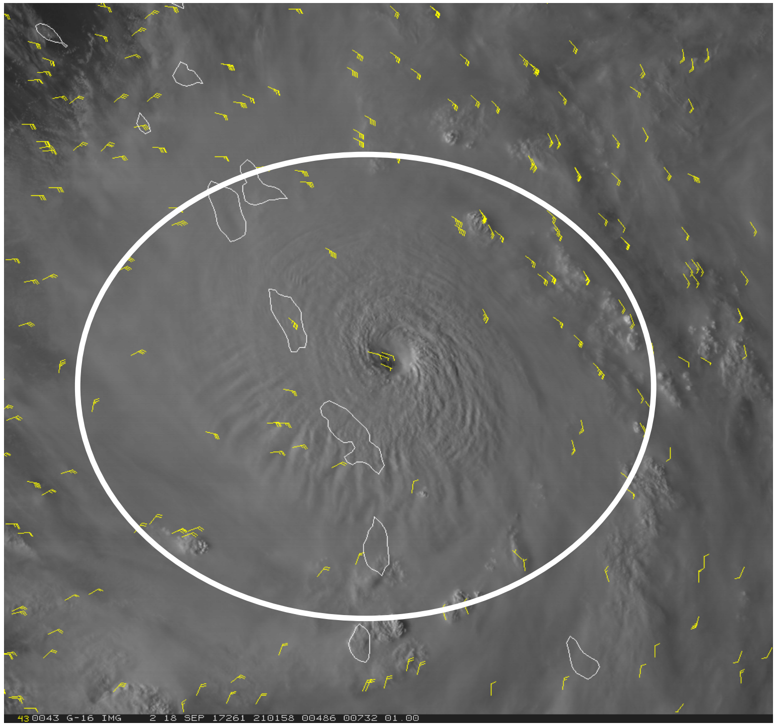
- Prudent to seek optimal methods to fully exploit information content of enhanced AMVs in high-impact weather events where high resolution observations are needed to resolve small-scale features

- Retrieving AMVs in mesoscale flow environments is challenging, but these are often dynamic regions where high-resolution data assimilation systems require more information

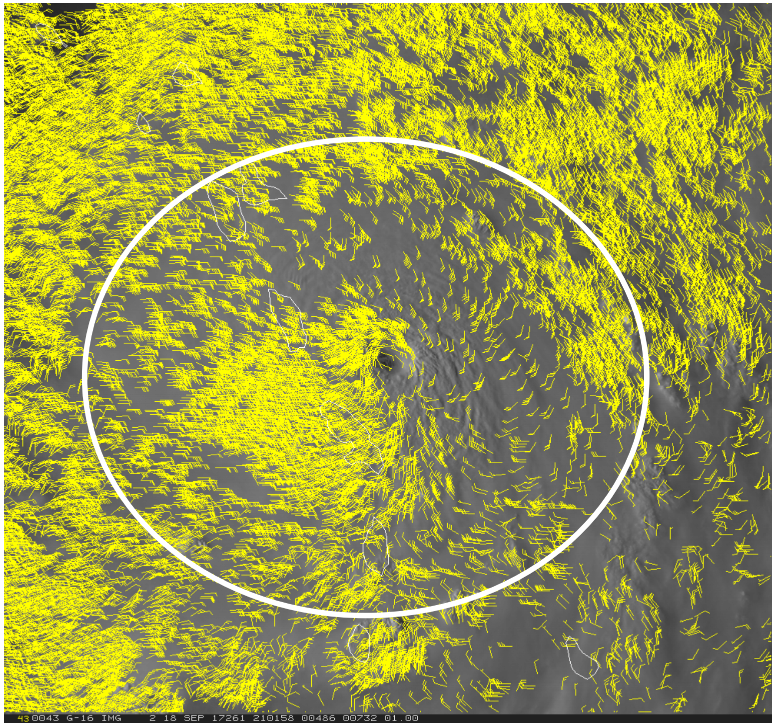
Courtesy of Chris Velden (CIMSS)

Impact of New Retrieval Methods – Hurricane Maria

Baseline Algorithm



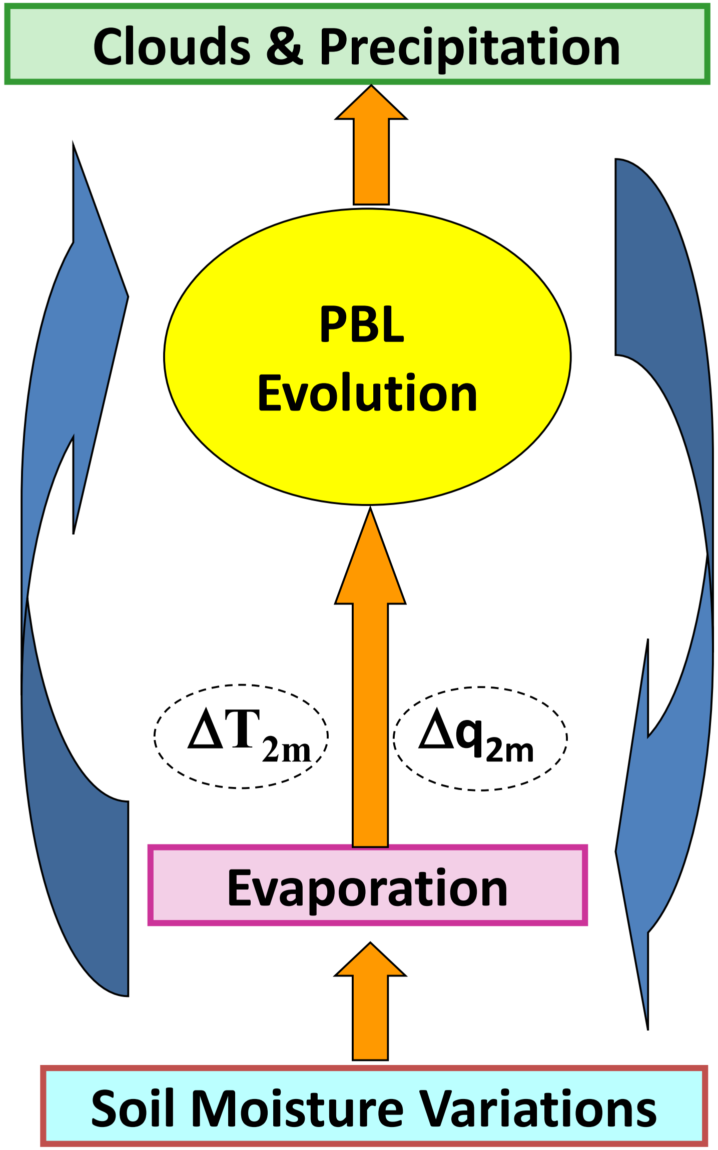
Enhanced Algorithm



- Baseline image is similar to what is used in current operational DA systems
- Much denser retrievals with the enhanced algorithm
- Could be very useful for high-resolution assimilation systems

Courtesy of Chris Velden (CIMSS)

Soil Moisture Assimilation



- Challenging topic because the land surface has traditionally been viewed as a sink within model and DA system

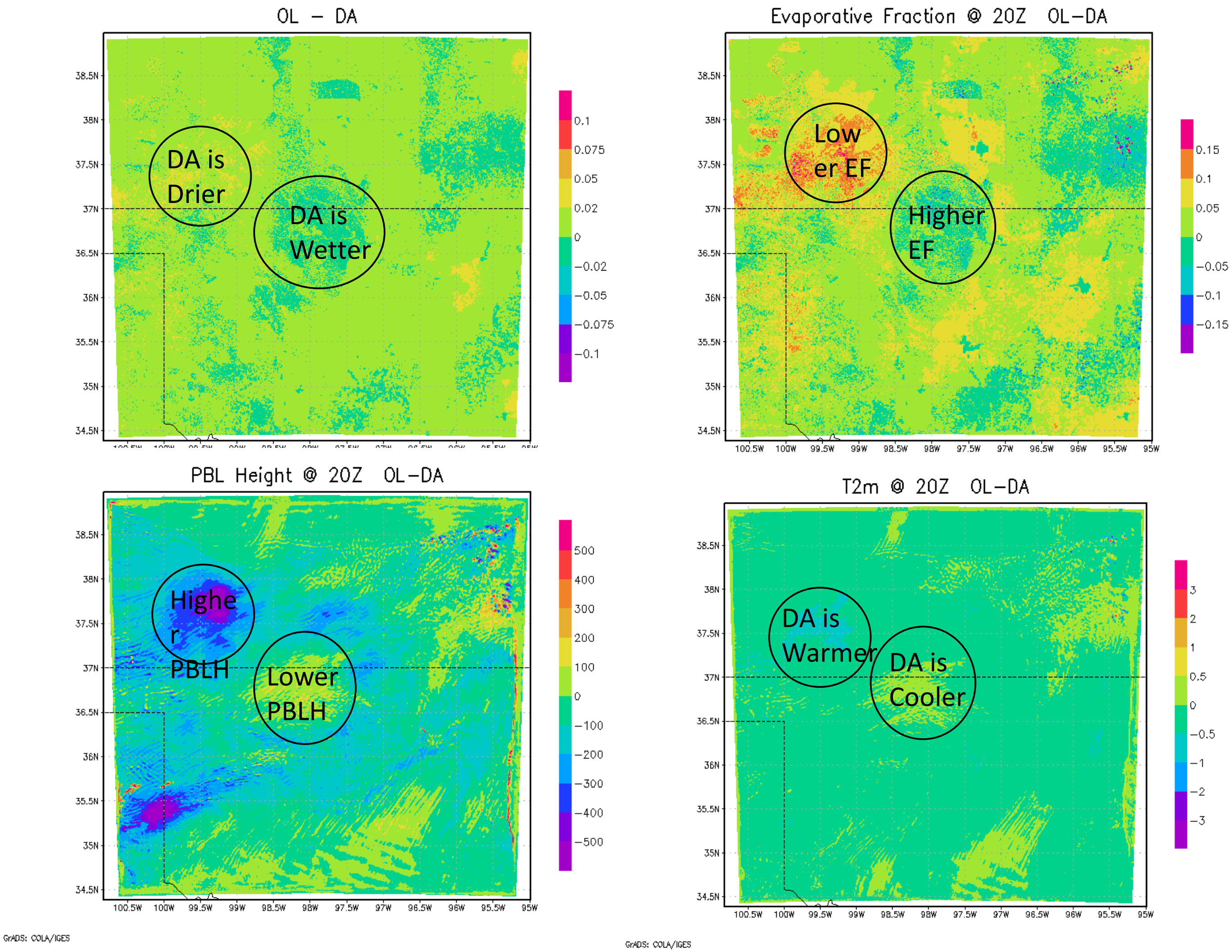
- Several sensors (SMAP, SMOS, etc.) provide useful information about topsoil moisture over the entire globe, albeit with coarse spatial resolution

- Soil moisture impacts surface energy flux partitioning (latent, sensible heat), which then impacts planetary boundary layer growth

- Can lead to changes in atmospheric stability and convective cloud growth

Courtesy of Sujay Kumar (NASA)

Impact of Soil Moisture Assimilation on Land-Atmos Coupling



- This example illustrates how changes in soil moisture lead to changes in the evaporative fraction and then to changes in the PBL height and 2-m temperatures

Courtesy of Sujay Kumar (NASA)

Thank you for your attention!