Preparing for GPM: Inclusion of Linearized Moist Physics in NASA's Data Assimilation Tools

Dan Holdaway, Ron Errico and Ron Gelaro
E-mail to dan.holdaway@nasa.gov

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Introduction

- GPM (Global Precipitation Measurement) is a constellation of moisture measuring satellites providing regular global coverage.

- The GPM core observatory (lead by Goddard) launches on Feb. 27th.

- On board is GMI (GPM Microwave Imager), providing next-generation observations of clouds and moisture.

We would like to assimilate information about clouds from GPM into GEOS-5.

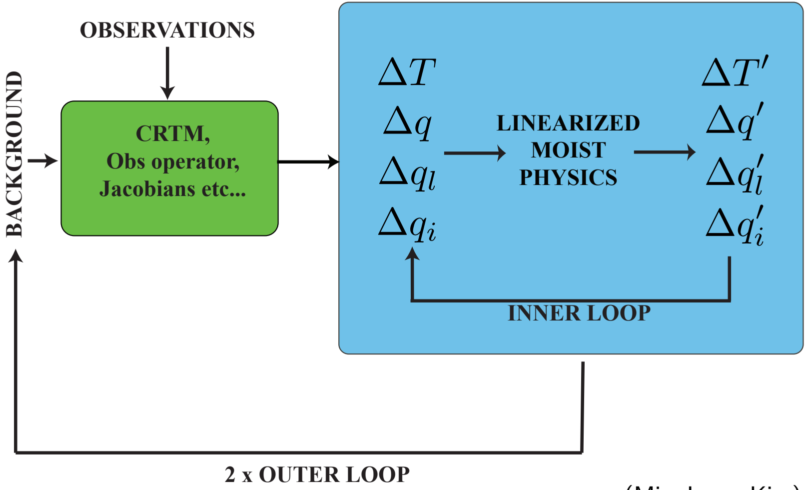
Clear-Sky to All-Sky

There are a number of challenges involved when developing an 'all-sky' assimilation (Bauer et al, 2011 QJRMS**137**).

- Convert from total cloud water to cloud liquid water and ice.
- Compute covariances for cloud variables.
- Estimate model bias and error growth for moisture variables.
- **Model is assumed to be linear for the assimilation window.**
- **Assimilating cloud variables requires some dynamical feedback (ideally we would like to use 4DVAR).**

Currently GEOS-5 has a 'clear-sky' assimilation system using GSI.

3DVAR + Linearized Physics



(Min-Jeong Kim)

Linearized Moist Physics

We require linearized versions of the convection and large scale condensation schemes, including cloud perturbations q_l' and q_i'.

Moist physics schemes suffer from the following:

- Behavior can be very nonlinear.
- Gradients of the underlying functions can be very steep.
- They use piecewise functions, e.g. convection on/off.

Left unchecked these issues will cause **massive problems**. The approach to linearizing moist physics usually involves redeveloping the schemes to something simpler and more linear.

Controlling the schemes

However, we would like to keep the linear schemes as close to the nonlinear schemes as possible. The tangent linear model is,

$$\mathbf{y}' = \mathbf{M}\mathbf{x}'.$$

If nonlinearity or instability occurs it can be understood by examining **M** and how **M** changes with respect to model inputs.

For the RAS and Bacmeister prognostic cloud scheme **M** has relatively straightforward structure. After very careful analysis, problems can be related to the inputs through the behavior of **M**.

Approach

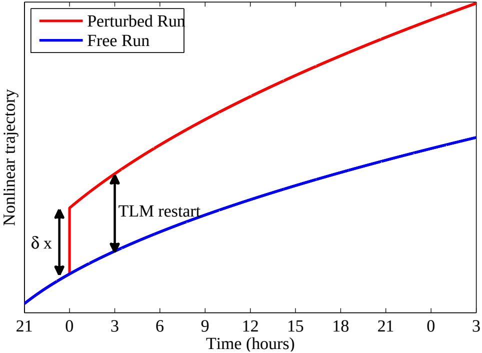
- Linearize the schemes (pretty much) exactly.
- On the fly compute parts of $\mathbf{M}$ that correspond to problem areas. This must:
  - Be very efficient.
  - Capture all instability.
  - Control worst nonlinearity.
  - Be better than substituting the scheme.
- Filter but mostly keep some percentage of the linear perturbation tendency.

Testing

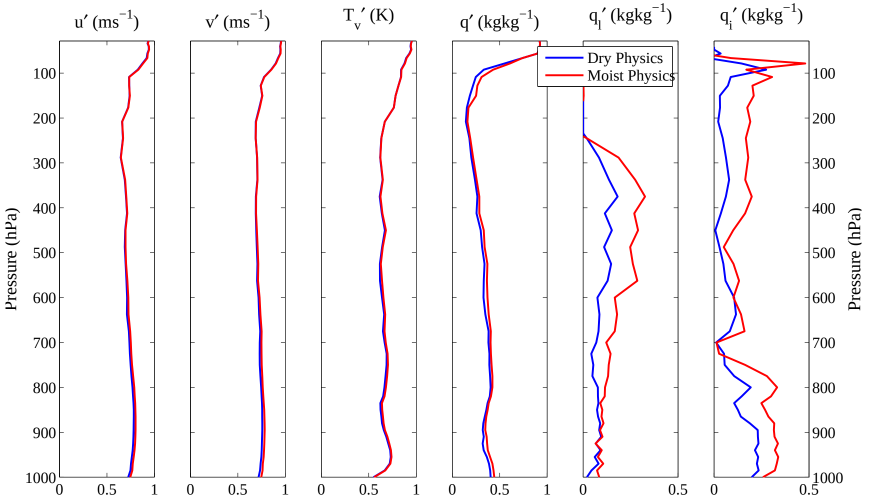
The tangent linear model is compared to the nonlinear model:

$$\lim_{\delta \mathbf{x} \to 0} \frac{\mathbf{m}(\mathbf{x} + \delta \mathbf{x}) - \mathbf{m}(\mathbf{x})}{\mathbf{M} \delta \mathbf{x}} = 1.$$

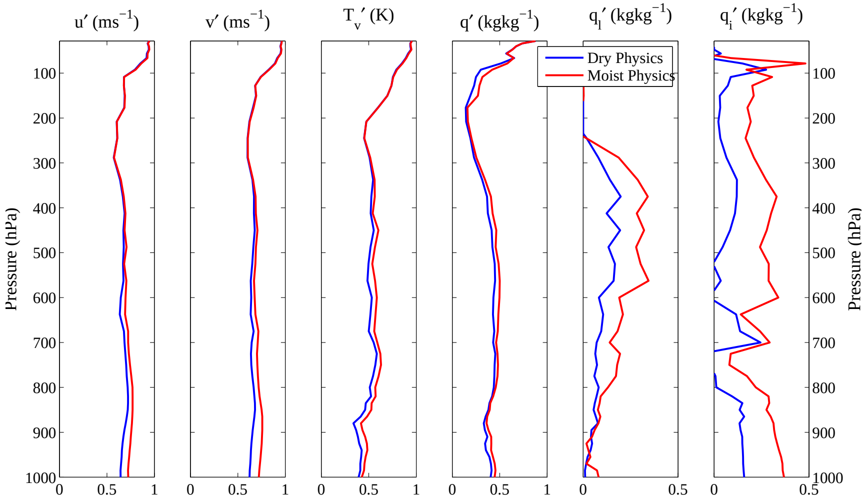
The initial conditions are chosen from ‘spun up’ NLM.



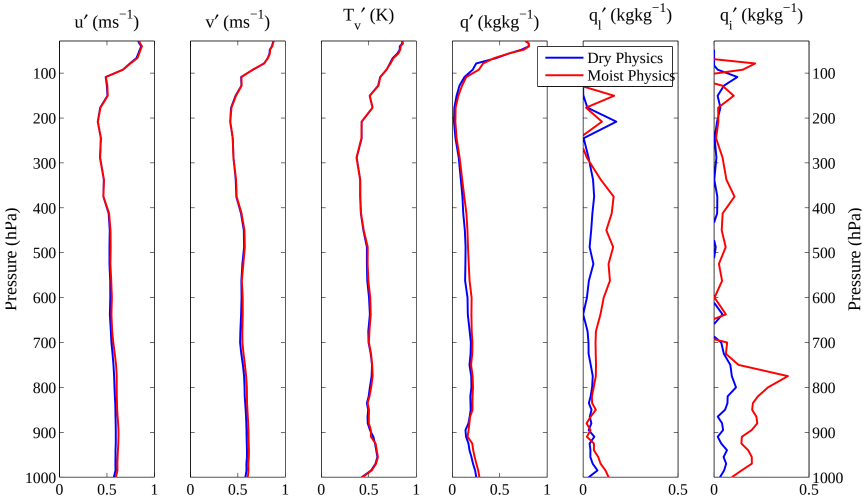
12 Hour Spatial Correlations - Global



12 Hour Correlations - Tropics (23°S to 23°N)



24 Hour Spatial Correlations - Global



Summary

- Use of linearized moist physics gives good improvement to the perturbation trajectory.
- Uses an efficient filtering that allows for use of the actual model.
- Convection is more linear than large scale condensation.
- The cloud scheme has good linearity and is stable.
- Good linearity in clouds, especially high clouds.

Next...

- Test 3DVAR+linearized physics with proxy GPM data.
- Test within a 4DVAR system.
- Sensitivity studies and moist singular vectors.

Questions