The assimilation of water vapor information from satellite observations and the choice of the analysis variable

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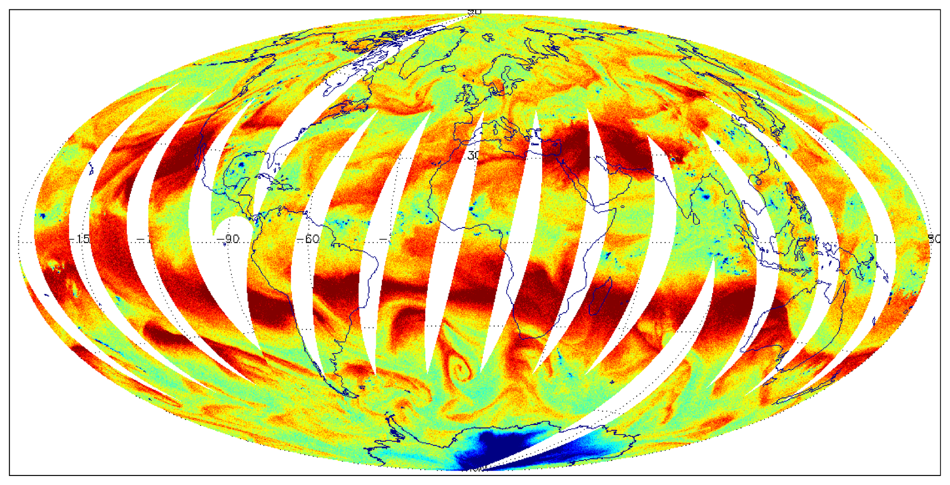


DMSP F-18 SSMIS TDR ch 11 183.3+/- 3.0. GHz
dtg = 2010063012+/- 6hrs

Assimilation of Water Vapor Information

- **NAVDAS-AR use pseudo-relative humidity (PRH) as the analysis moisture variable, following Dee and daSilva (2003)**
- **PRH is defined as the mixing ratio scaled by the saturation mixing ratio computed using the background temperature and pressure fields**
- **In the troposphere, PRH has advantages over specific humidity (the forecast model variable)**
  - ➢Smaller dynamic range
  - ➢More gaussian error characteristics
- **However, PRH has unexpected consequences for the assimilation of moisture information (e.g. radiances or GPS bending angles) with non-zero sensitivity in the stratosphere**

Why PRH Creates Problems for Water Vapor Radiance Assimilation

- **We use the Joint Center for Satellite Data Assimilation (JCSDA) Community Radiative Transfer Model (CRTM) to compute brightness temperatures and Jacobians corresponding to the background fields**
- **CRTM Jacobians are computed with respect to mixing ratio, and then converted to Jacobians with respect to PRH**
- **In the stratosphere, the combination of warm temperatures and low pressures produce extremely small PRH values and lead to assimilation difficulties**
- **These PRH values can also exhibit large vertical and horizontal gradients that are controlled primarily by the non-linear sensitivity of saturation mixing ratio to temperature change, even when the ambient water vapor abundance is nearly constant**
- **Unrealistic values of saturation mixing ratio tend to produce sensitivities to moisture (large Jacobian values) in the upper atmosphere, even when the satellite sensor has peak sensitivity in the troposphere.**
- **The magnitudes of the PRH Jacobians in the upper atmosphere may be as large as those in the troposphere, and can produce unrealistic increments of moisture in the stratosphere.**
- **The Jacobians are used to compute the background radiance and GPS error covariances. Computed background error variances may be much larger than appropriate.**
  - ➢Values up to 100K for MHS were noted, which are larger than the assumed observation errors of 1-2K.

Possible Solutions

- **Change moisture variables for the entire assimilation system**
  - ➢In the stratosphere, mixing ratio (or specific humidity), is a better behaved control variable and is commonly used in chemical data assimilation systems
- **The quick solution - set the CRTM jacobians to zero above some arbitrary pressure level**
  - ➢Reduces the maximum background errors for MHS to around 10K
  - ➢Solution is only partially satisfactory, as GPS bending angle jacobians are also affected by this issue.

Our Solution

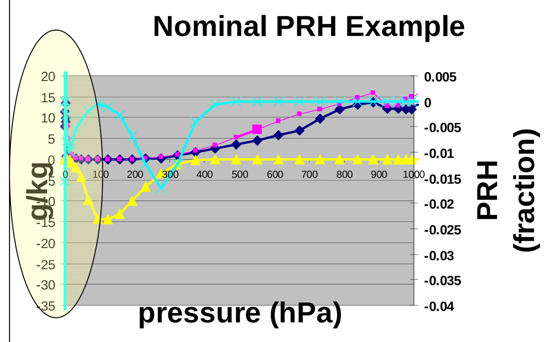
- **Hybrid PRH variable transformation for radiance and GPS bending angle assimilation**
  - ➢Modify PRH variable by replacing the saturation mixing ratio at low pressures with a constant mixing ratio that is larger than the maximum water abundance observed in the stratosphere
  - ➢Hybrid-PRH is proportional to mixing ratio in the stratosphere, with values in the normal PRH range of 0-100%
  - ➢Hybrid-PRH smoothly transitions from PRH to scaled-mixing ratio in the upper troposphere/lower stratosphere.
  - ➢Computer code changes are trivial, and used only in conjunction with the satellite observation processing

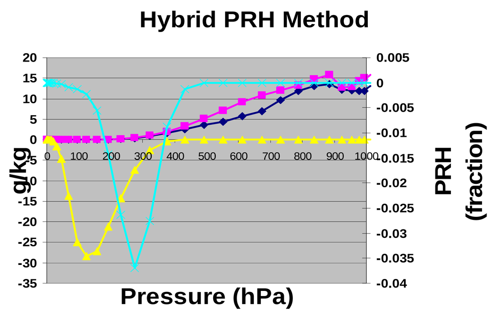
Experiment Design

- **Experiments**
  - •**Nominal:** computes PRH jacobians with no modifications
  - •**Zero:** PRH jacobians are set to zero above 20 hPa
  - •**Zero w/limits:** PRH jacobians are set to zero above 20 hPa, and qsat is limited to 0.001 above 20 hPa.
  - •**Hybrid:** Uses hybrid moisture transformation for radiance/gps jacobians
- **Approach**
  - •**Assimilate MHS channels 3,4,5 with an assumed ob error of 4K**
    - •**NOAA 18, NOAA 19 and METOP-A**
    - •**NOAA 19 Ch 3 not assimilated due to high noise levels**
  - •**At the end of a 60-day assimilation run using the hybrid method, experiments #1, 2, 3 were computed for one update cycle only**
  - •**The resulting output from the update cycles were analyzed, and are displayed in the following plots for MHS channels 3 and 4**
- **NRL/FNMOC Analysis Systems**
  - •**NAVDAS-AR – NRL Atmospheric Variational Data Assimilation System-Accelerated Representer**
  - • Operational at FNMOC September 23, 2009
  - –Full 4D-VAR algorithm solved in observation space using representer approach
  - –T319L42, model top at 0.04 hPa
  - –Adjoint developed for observation impact with real-time web monitoring capability
- **MHS Sensor**
  - •MHS provides information on atmospheric humidity at various altitudes, cloud properties and precipitation (liquid, ice, snow, etc.), surface temperature and emissivity

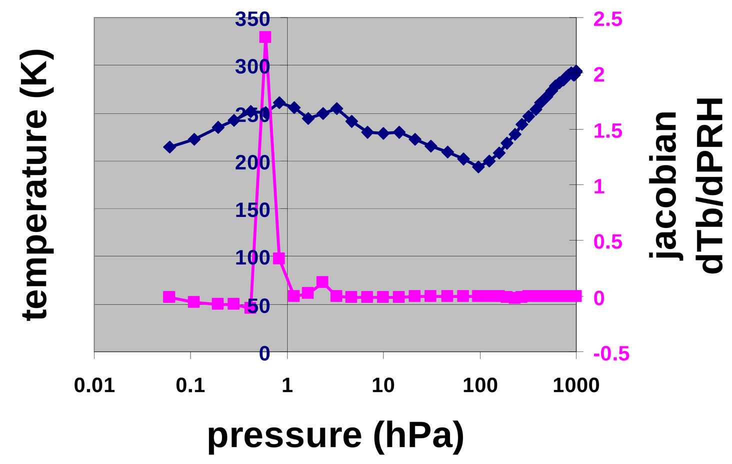
Results

Examples of Profiles for METOP-A ch 3
lat = -0.53, lon = 276.71,`dtg = 2010063012



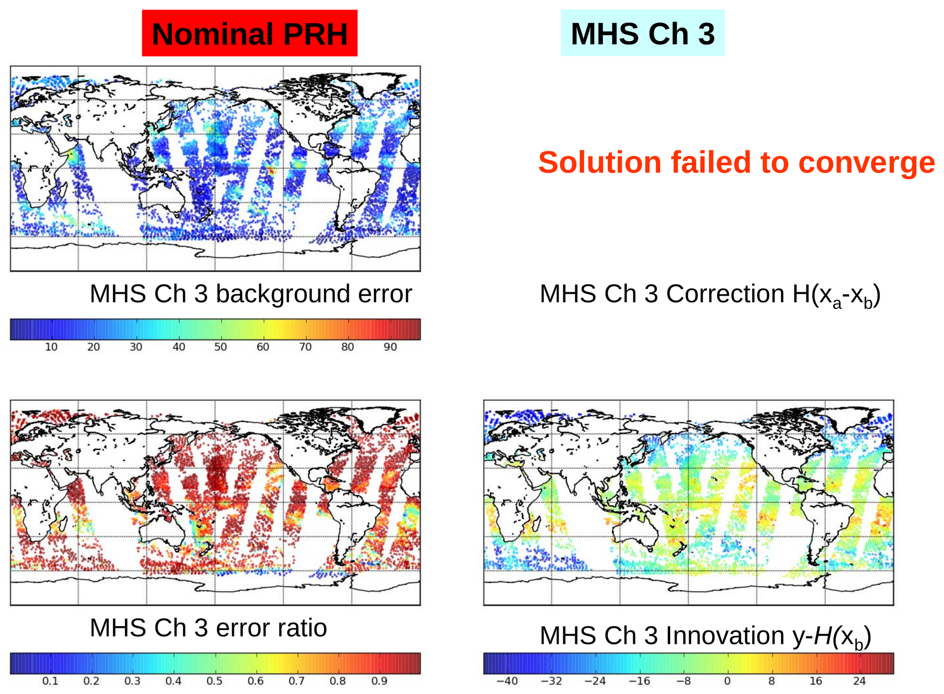


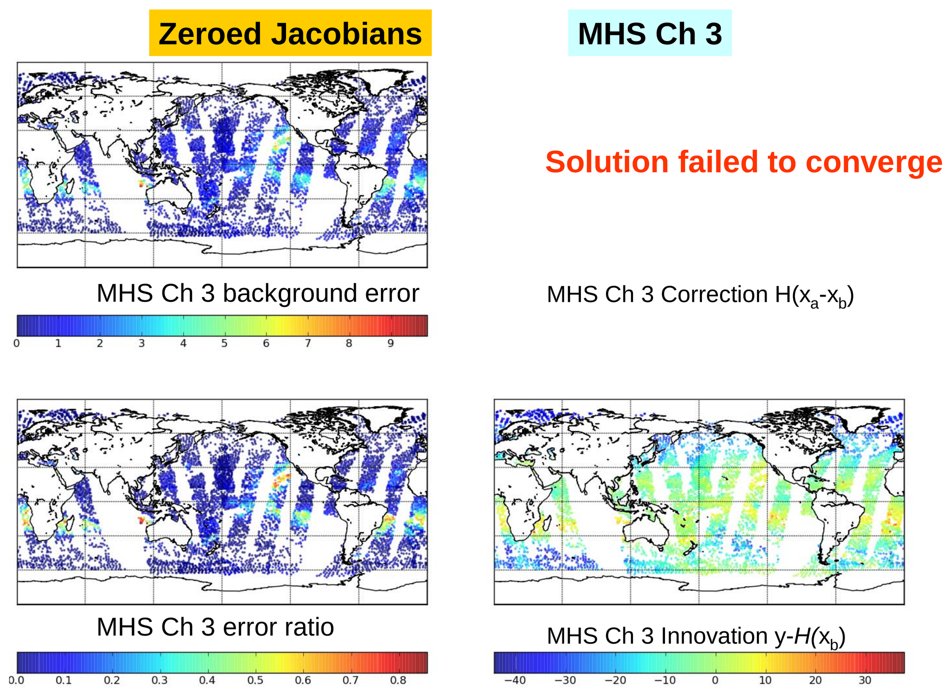
Mixing ratio (dark blue), saturation mixing ratio (magenta), mixing ratio jacobian returned from CRTM (yellow), and PRH jacobian (cyan), computed for the background temperature and pressure profiles. The magnitudes and peak levels for the jacobians differ dramatically for the two variables. Note the anomalous behavior above 100 hPa.

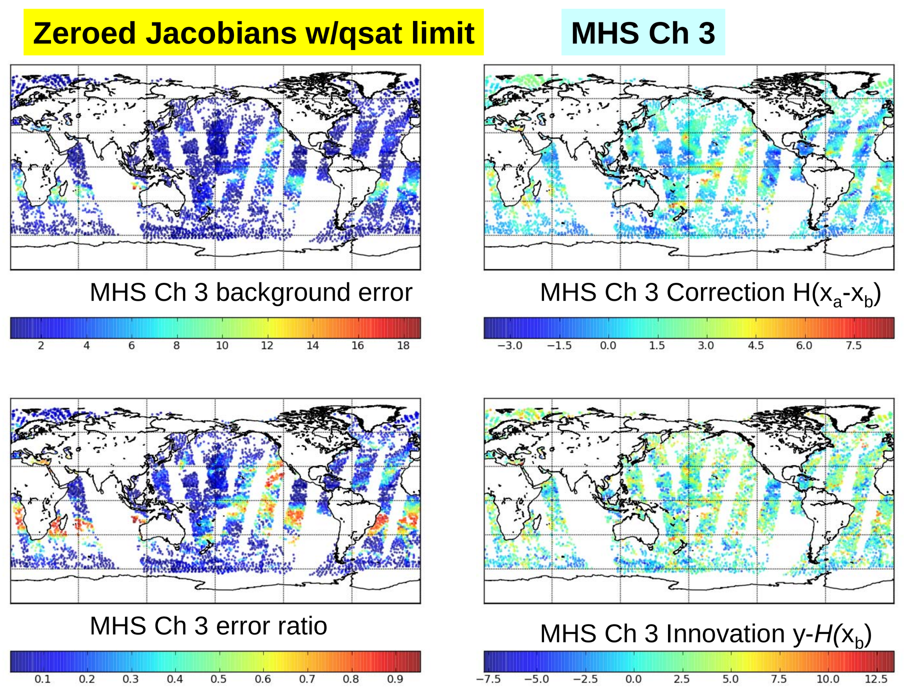


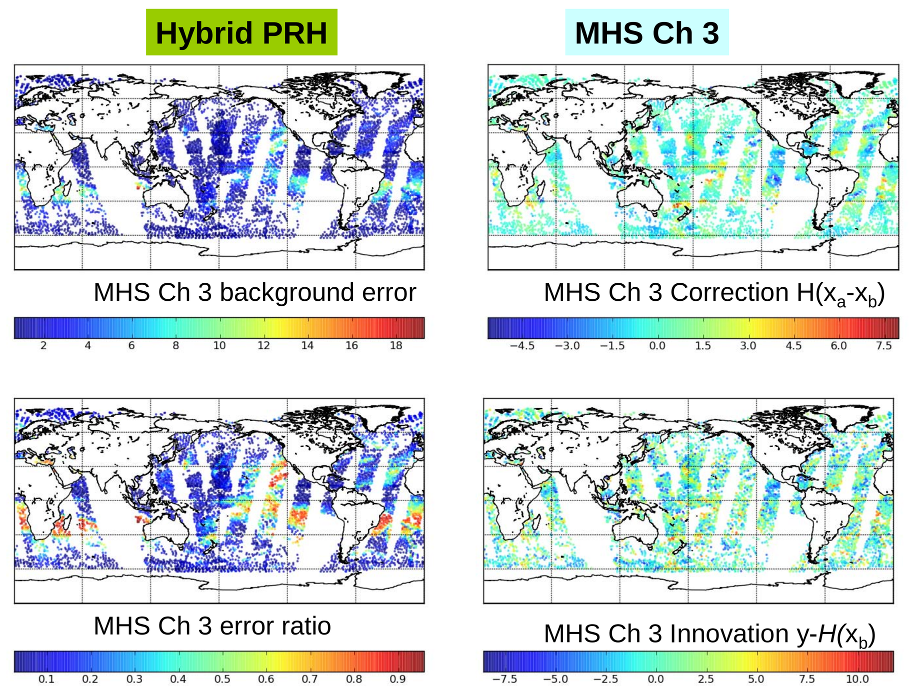
Warm Stratospheric Temperatures (blue line) at low pressures lead to spike in PRH jacobian (magenta)

Experiment Name	MHS Channel Number
Background error = **HBH**^{T} **B** = background error covariance **H** = jacobian for each x_b profile	Correction = **H**$(x_a - x_b)$ x_a = analysis **H** = jacobian x_b = background
Error Ratio = $\varepsilon_b^2/(\varepsilon_b^2 + \varepsilon_o^2)$ Ratio ~ 1 ➔ large background errors (draws to observations) Ratio ~ 0.5 ➔ equal weighting of ob and bkgd Ratio ~ 0 ➔ small background errors (draws to background)	Innovation = y – $H(x_b)$ y = observation H = forward operator x_b = background









Conclusions

- **New moisture variable transformation has the following properties**
  - –Eliminates unrealistically large brightness temperature and bending angle background error variances
  - –It is no longer necessary to zero out the MHS Jacobians at the top levels.
  - –Moisture contributions from the Jacobians at low pressures are naturally very small.
- **Assimilation forecast results are positive (beneficial)**

References

Dee, D.P. and A.M. da Silva, 2003: The choice of variable for atmospheric moisture analysis. *Mon. Wea. Rev.*, **131**, 155-171.

Acknowledgement

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