Examining effect of TPW-classified a priori error and quality control on atmospheric temperature and water vapor sounding retrieval

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Introduction

In the typical atmospheric profile retrieval methods, a priori error is used to specify the ranges within which the retrieved atmospheric state departs from the first-guess to match the satellite radiance observations. An incorrect error can constrain the solution inappropriately, and thus it could result in unstable or largely biased solution. Considering the importance of a priori errors in the inverse problem, we suggest to use a priori errors classified by atmospheric moistness as an alternative to a fixed a priori error in the temperature and water vapor profile retrievals.

It is also valuable to assign appropriate quality control (QC) flags in the retrieval process. Under some conditions, such as an incorrect specification of cloud, measurement error, surface information, etc., the inverse of satellite radiance measurements to the atmospheric state cannot be performed well and thus can result in divergence of the solution or convergence to an unrealistic solution. Also, poor performance of atmospheric temperature and moisture retrievals was reported over high terrain and desert. Since those poor retrievals can have a substantial negative impact on their applications, assigning QC flags is necessary so that users can appropriately select good retrievals depending on their purpose.

This study investigates the use of dynamic a priori error information according to atmospheric moistness and the use of quality controls in temperature and water vapor profile retrievals from hyperspectral infrared (IR) sounders. In doing so, temperature and water vapor profiles are retrieved from AIRS radiance measurements using the retrieval algorithm which is a physical iterative approach using the regression retrieval as the first-guess.

Methodology & Data

"Inverse problem"

$$\mathbf{Y}^m = \mathbf{F}(\mathbf{X}) + \sigma$$

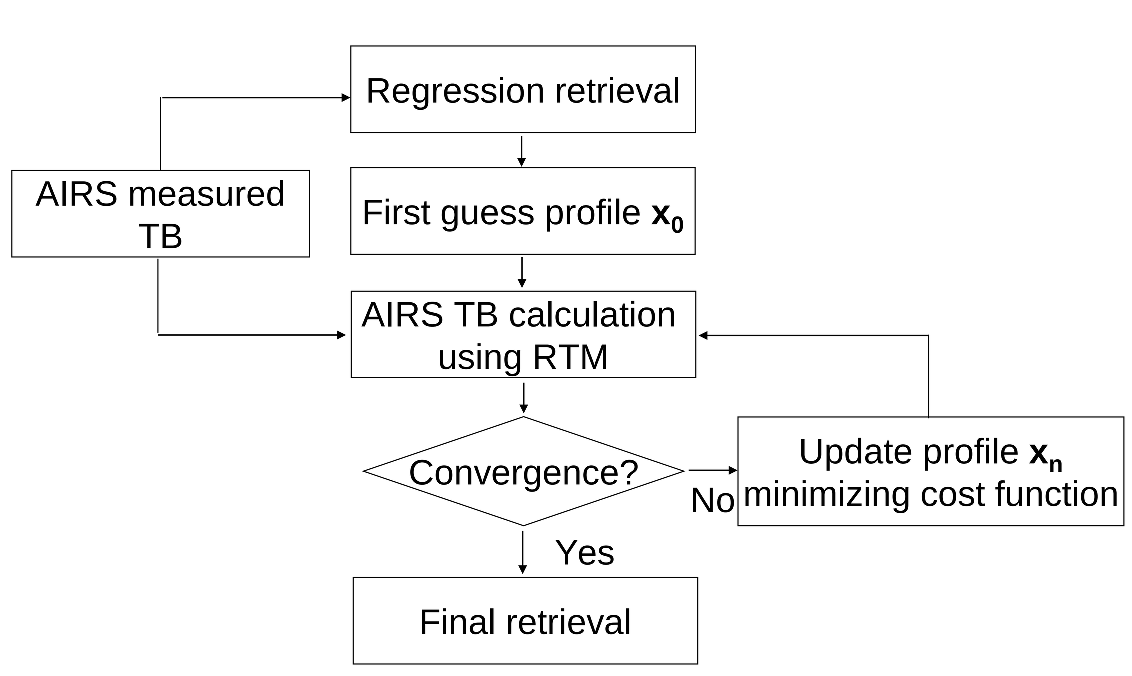
- $\mathbf{Y}^m$: satellite radiance measurement
- **X**: atmospheric state {T(p), Q(p), O_3(p), Ts, ε(ν)}
- **F**: forward model
- σ: measurement error

- Mathematically ill-posed problem → need a priori constraint
- Constrained retrieval methods find an optimal solution which is consistent with both satellite-measured radiances and a priori information (first-guess and a priori first-guess error)

Cost function: $[\mathbf{Y}^m - \mathbf{F}(\mathbf{X})]^T \mathbf{E}^{-1} [\mathbf{Y}^m - \mathbf{F}(\mathbf{X})] + [\mathbf{X} - \mathbf{X}_0]^T \gamma \mathbf{S}_a^{-1} [\mathbf{X} - \mathbf{X}_0]$

Iterative solution: $\mathbf{X}_{n+1} = \mathbf{X}_0 + [\mathbf{K}_n^T \mathbf{E}^{-1} \mathbf{K}_n + \gamma \mathbf{S}_a^{-1}]^{-1} \mathbf{K}_n^T \mathbf{E}^{-1} [\mathbf{Y}^m - \mathbf{F}(\mathbf{X}_n) + \mathbf{K}_n(\mathbf{X}_n - \mathbf{X}_0)]$

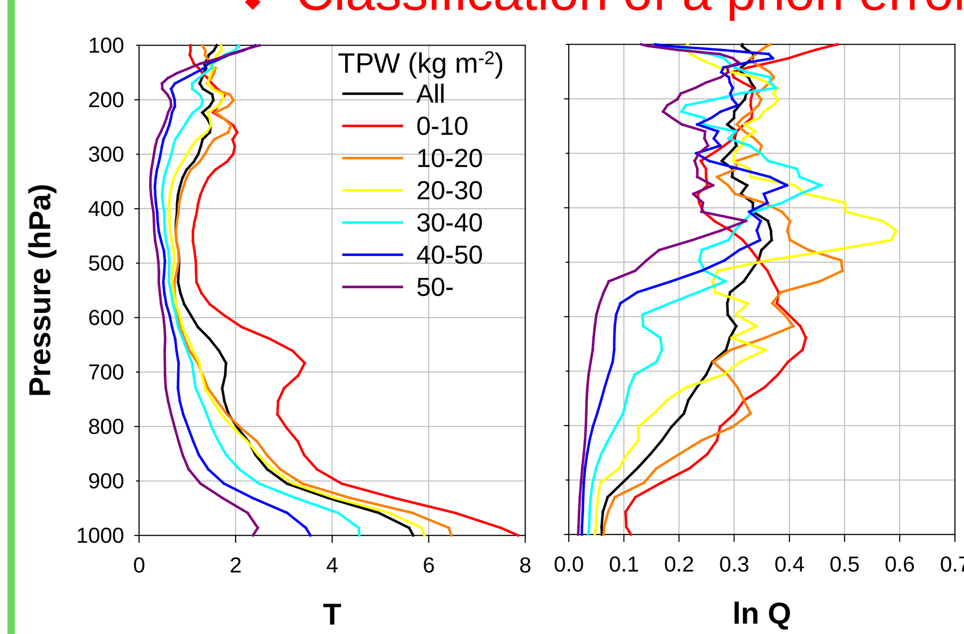
$\mathbf{X}_0$: first-guess of atmospheric state; **K**: Jacobian (weighting function) matrix of **F**; **E**: measurement error covariance matrix; $\mathbf{S}_a$: a priori first-guess error covariance matrix



- Radiative transfer model: Stand-alone AIRS Radiative Transfer Algorithm (SARTA)
- Simultaneous retrieval of temperature, water vapor, ozone, surface skin temperature, and surface emissivity (over land)
- Retrieved vertical levels: 101 pressure levels
- Vertical atmospheric structure and surface emissivity spectrum are represented by a few EOF coefficients (15 for temperature, 6 for water vapor, 3 for ozone, and 6 for emissivity). 101*3+2378+1 = 2682 → 31 unknowns
- The maximum number of successful iterations is set to be six.
- Exclude SW channels >2240 cm^{-1} during day.
- Atmospheric clear-sky sounding retrievals are performed from AIRS radiance measurements by applying a physical iterative approach (Li et al., 2000) using the regression retrieval (Weisz et al., 2007) as the first-guess.
  -Domain: East Asia (0 – 55°N, 90 – 150°E) -Period: July 20 ~July 24, 2009
- Collocated ECMWF analysis data is used as a reference for the evaluation of AIRS retrievals

Results

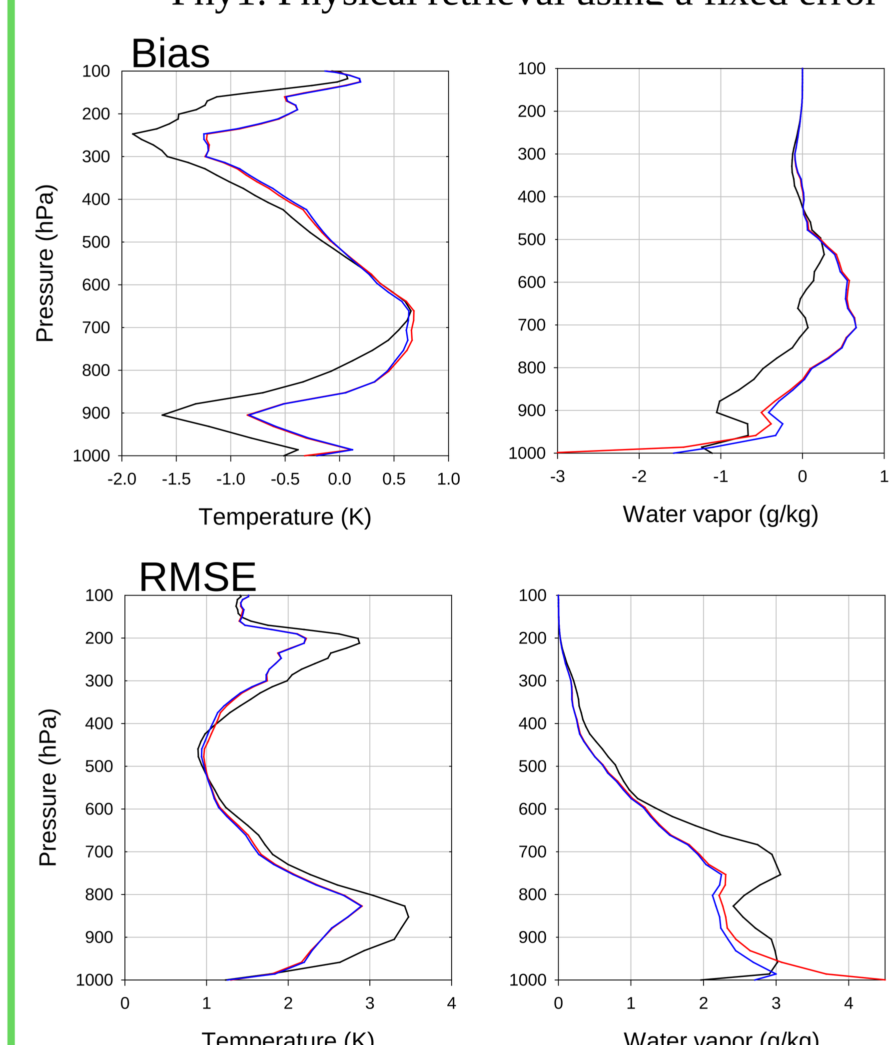
❖ Classification of a priori errors by total precipitable water (TPW)

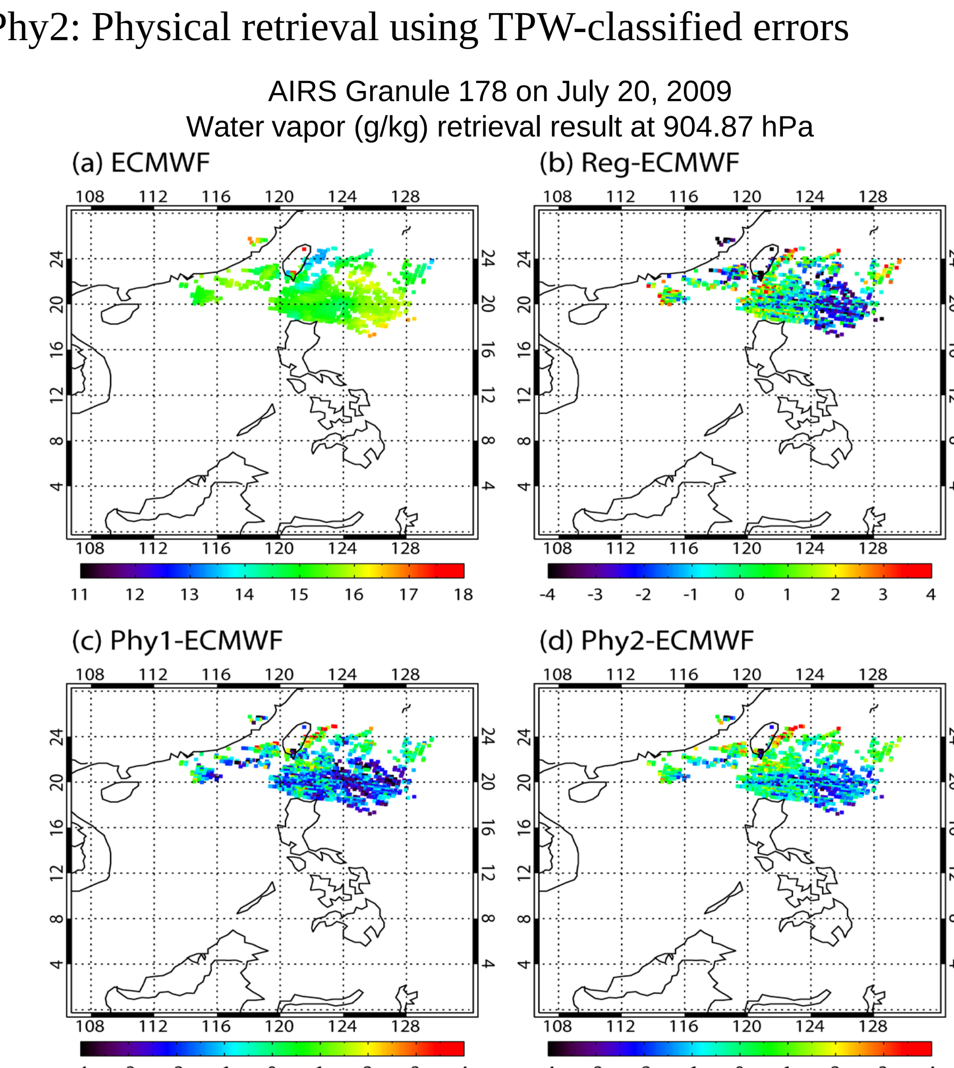


- Calculated from 15704 atmospheric profiles and corresponding simulated AIRS radiances using the difference between first guess (regression retrieval) and true profile
- The first-guess errors coming from the regression retrieval depend on the atmospheric moistness.
- Applying the a priori first-guess error values classified by TPW in the physical inverse procedure will result in more weight to the first guess for moist cases and less weight to the first guess for dry cases.

❖ The effect of TPW-classification of a priori errors

- Phy1: Physical retrieval using a fixed error
- Phy2: Physical retrieval using TPW-classified errors

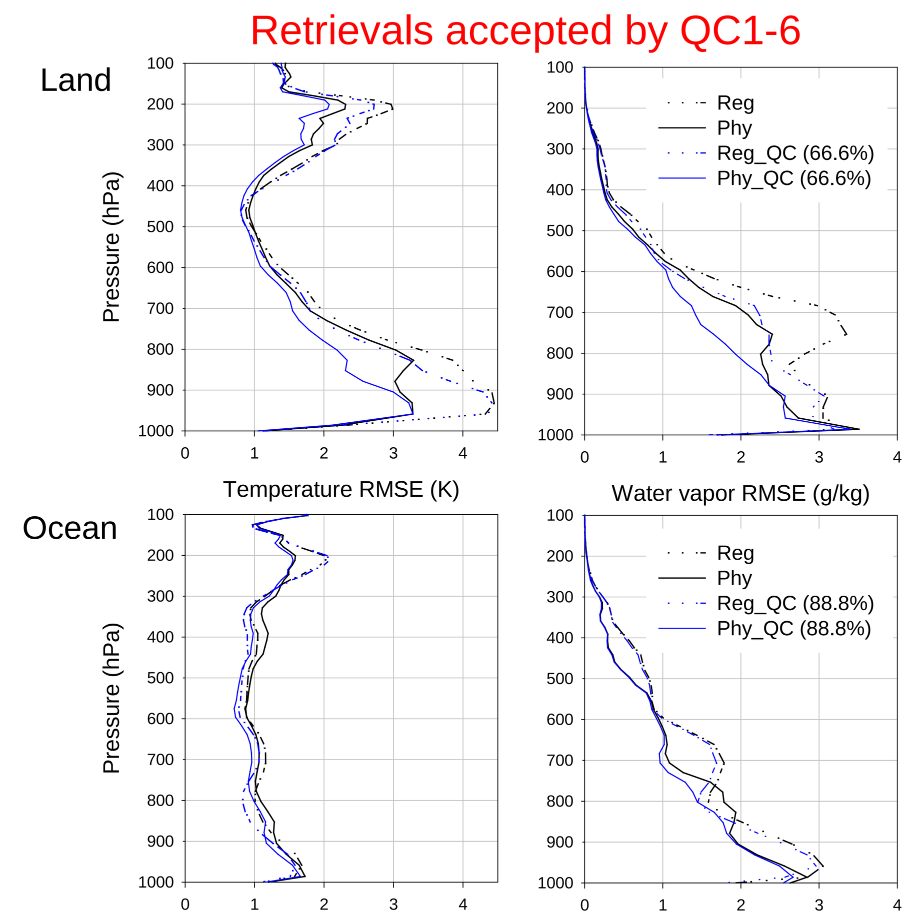




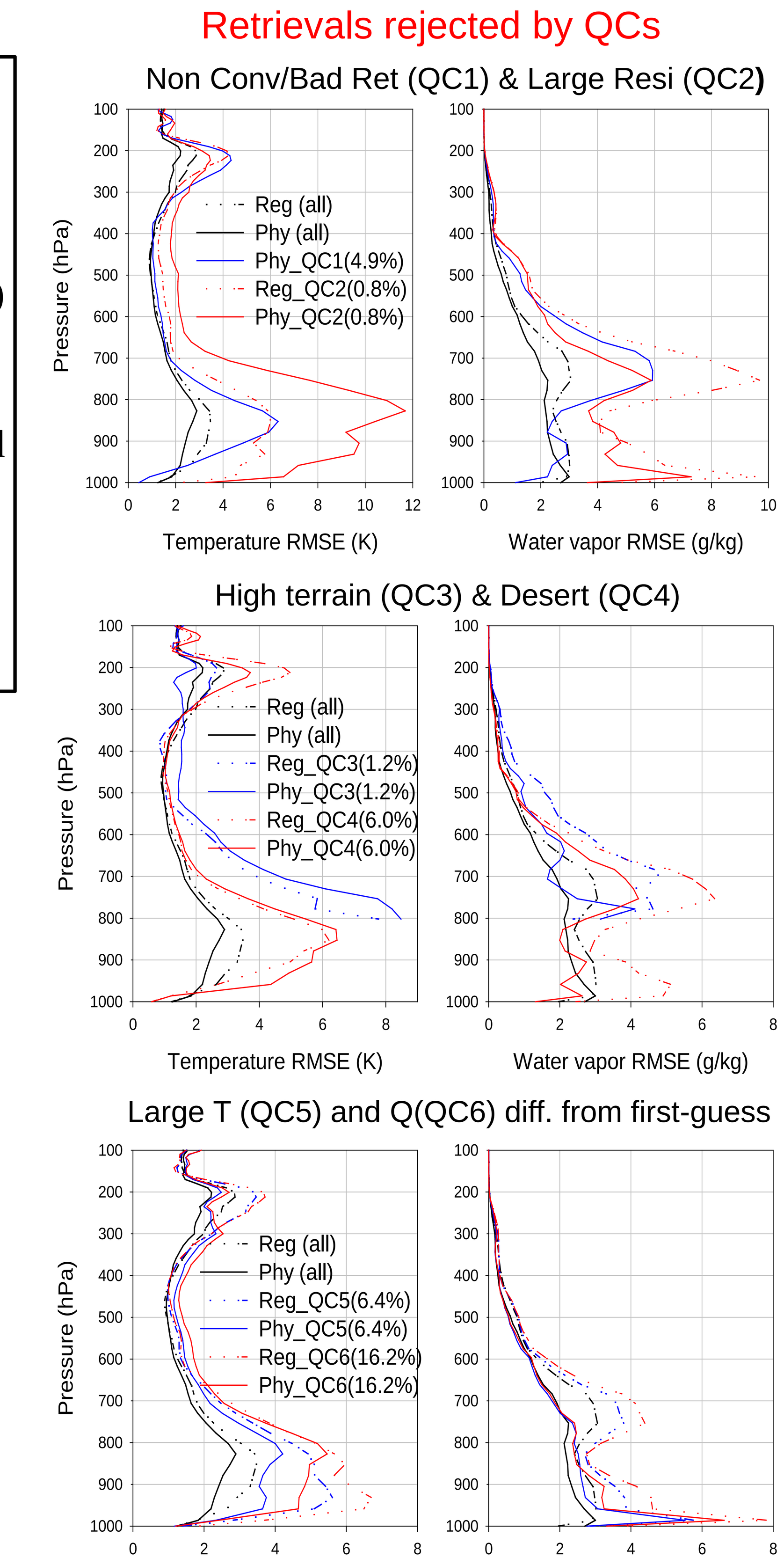
❖ Quality control tests

QC1	Non-convergence or bad physical retrieval
QC2	Large residual (> 1K)
QC3	High terrain (Ps < 750 hPa)
QC4	Desert (using IGBP surface type)
QC5	Large temperature difference between first-guess (T_g) and physical retrieval (T_r) $\lvert T_g - T_r \rvert$ > 5K (at any level below 100 hPa)
QC6	Large moisture difference between first-guess (Q_g) and physical retrieval (Q_r) $\lvert Q_g - Q_r \rvert / Q_g > \alpha$ where, α varies depending on the magnitude of Q_g and the sign of $Q_g - Q_r$

Retrievals accepted by QC1-6



Retrievals rejected by QCs



Conclusions

- A priori first-guess error variances for each TPW class are significantly different indicating that the first-guess errors coming from the regression retrieval depend on the atmospheric moistness.
- In the physical retrieval results from AIRS measurements over East Asia, the use of a priori first-guess errors classified by TPW, rather than a fixed error, appears to improve water vapor retrievals in the boundary layer.
- The six QCs tested here can be appropriately used to rule out the retrievals with large errors. The use of QCs for the temperature and water vapor soundings has more impact over land than over ocean.
- The use of dynamic a priori error information according to atmospheric moistness, and the use of appropriate QCs dealing with the geographical information and the deviation from the first-guess as well as the conventional inverse performance are suggested to improve temperature and moisture retrievals and their applications.