An Earth System Data Record (ESDR) Atmospheric Profiling Algorithm for Suomi-NPP CrIMSS and Other Sensors

Jean-Luc Moncet, Alan E. Lipton,
Richard Lynch, Yuguang He

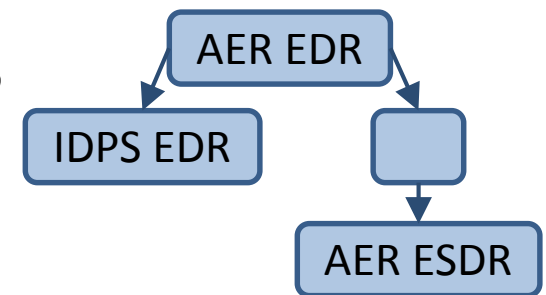Atmospheric and Environmental Research, Inc.

Outline

- Algorithm purpose, requirements, and heritage

- Modular software approach overview

- Terrain-following coordinates for retrieval

- Alternative basis functions for profile regularization

- Fidelity of climate change signals   ← main focus here

  - Impacts of background and basis functions
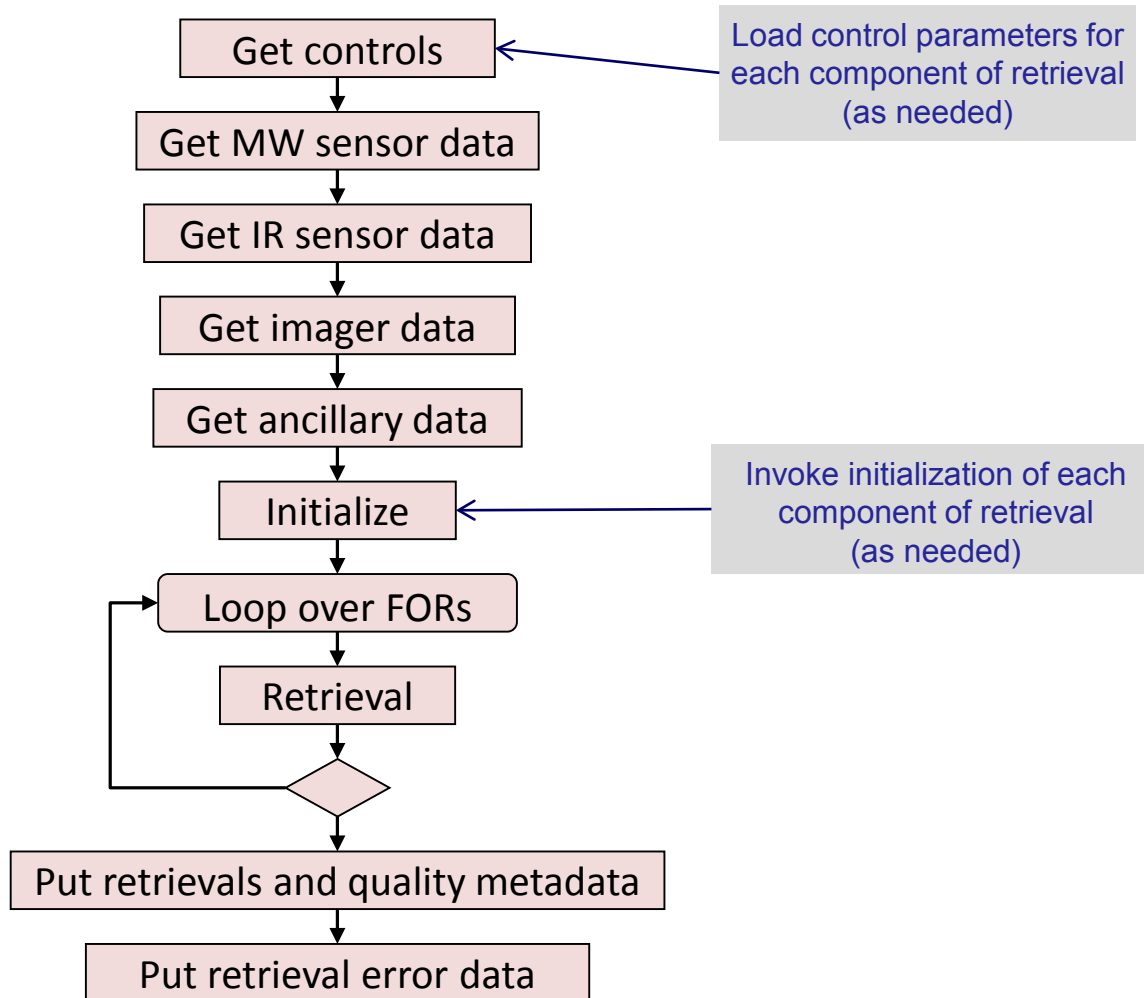
aer
**Atmospheric and
Environmental Research**
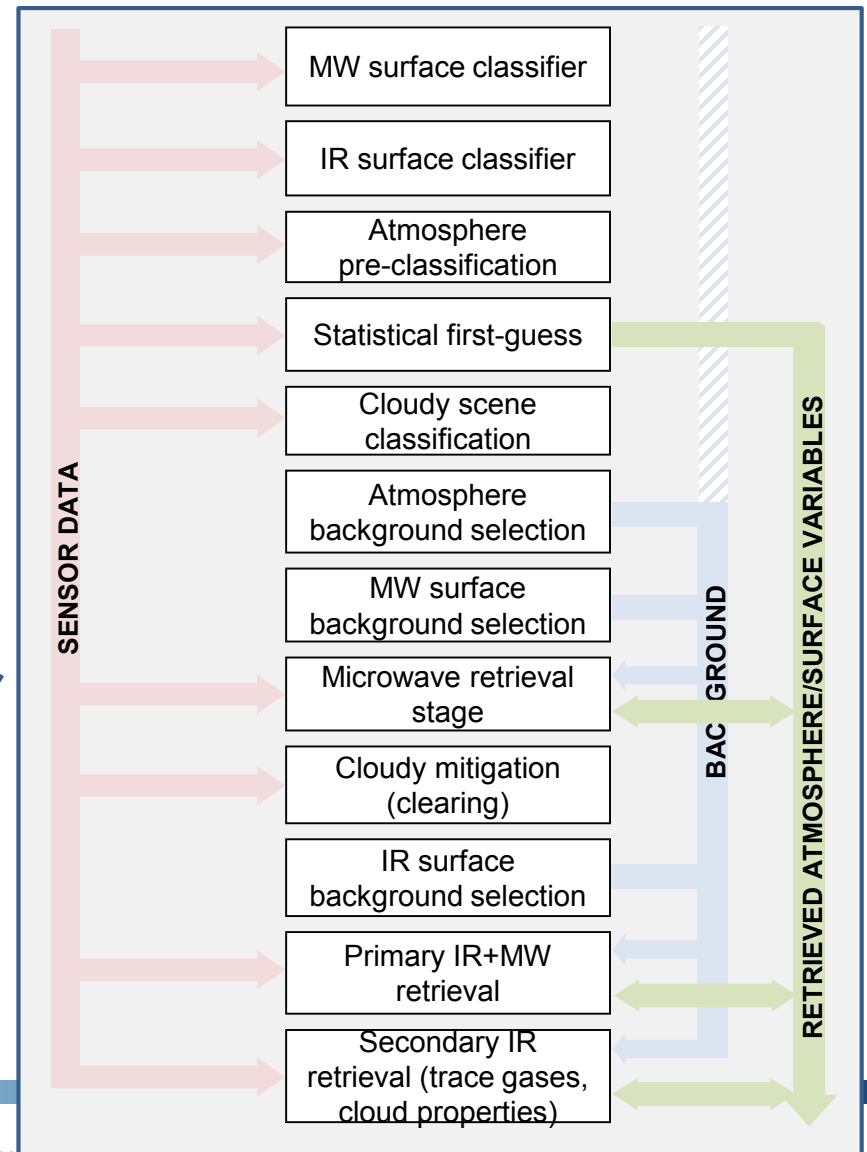
Purpose / Requirements and Heritage

- Designed for Earth System Data Records
  - "Climate quality" profiling products
  - Stability and response to Earth system change
    - Minimal dependence on NWP models
  - Same algorithm applicable to multiple sensors in a series (e.g., AIRS, CrIS)
  - Modular to support experimentation and collaboration
  - Applicable to trace gas profiling
- Shared lineage with Suomi-NPP IDPS EDR algorithm
  - All use optimal estimation (1Dvar)

AER EDR

IDPS EDR

AER ESDR

aer

Atmospheric and Environmental Research

Top-level organization is modular

Get controls → Load control parameters for each component of retrieval (as needed)

Get MW sensor data

Get IR sensor data

Get imager data

Get ancillary data

Initialize → Invoke initialization of each component of retrieval (as needed)

Loop over FORs

Retrieval

Put retrievals and quality metadata

Put retrieval error data

aer
Atmospheric and
Environmental Research

Top-level organization is modular


```
Get controls
    ↓
Get MW sensor data
    ↓
Get IR sensor data
    ↓
Get imager data
    ↓
Get ancillary data
    ↓
Initialize
    ↓
Loop over FORs
    ↓
Retrieval
    ↓
◇
    ↓
Put retrievals and quality metadata
    ↓
Put retrieval error data
```

SENSOR DATA

- MW surface classifier
- IR surface classifier
- Atmosphere pre-classification
- Statistical first-guess
- Cloudy scene classification
- Atmosphere background selection
- MW surface background selection
- Microwave retrieval stage
- Cloudy mitigation (clearing)
- IR surface background selection
- Primary IR+MW retrieval
- Secondary IR retrieval (trace gases, cloud properties)

BAC GROUND

RETRIEVED ATMOSPHERE/SURFACE VARIABLES

aer
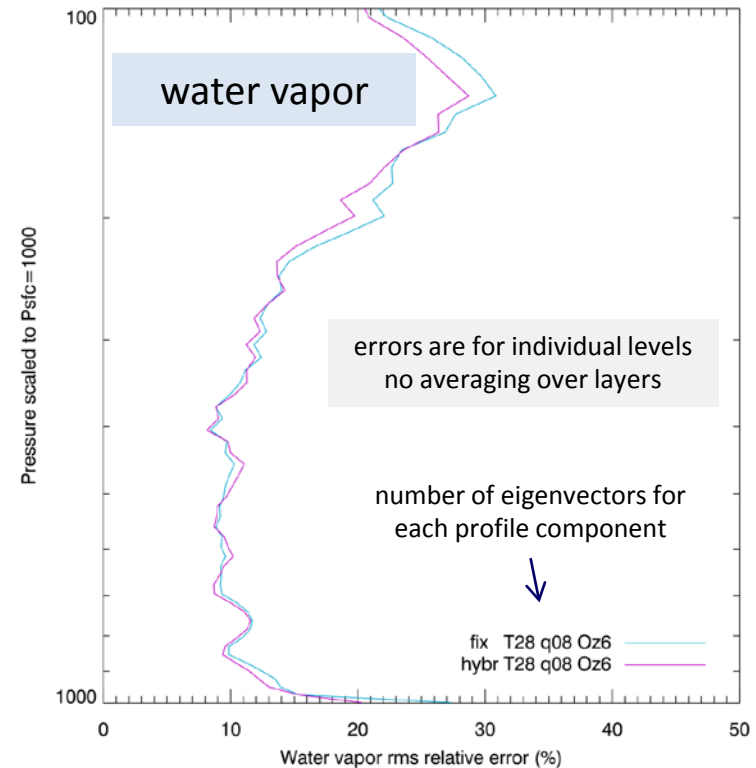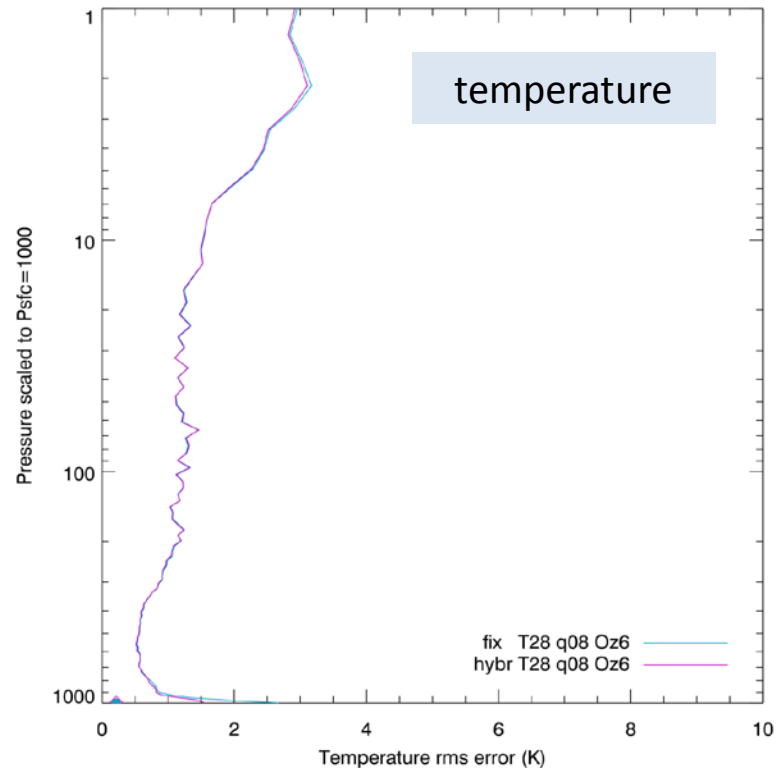**Atmospheric and Environmental Research**

Vertical coordinates for retrieval

- Heritage algorithm retrieves on fixed 101-level vertical pressure grid covering 0.05–1100 mb
  - Drawback of fixed grid:
    - Profile vertical structure is strongly affected by the proximity of surface
    - Background error covariance on fixed levels does not well represent profile structures when applied to diverse surface pressures

- ESDR algorithm can retrieve on a vertical grid that follows the terrain (σ or hybrid pressure-σ)
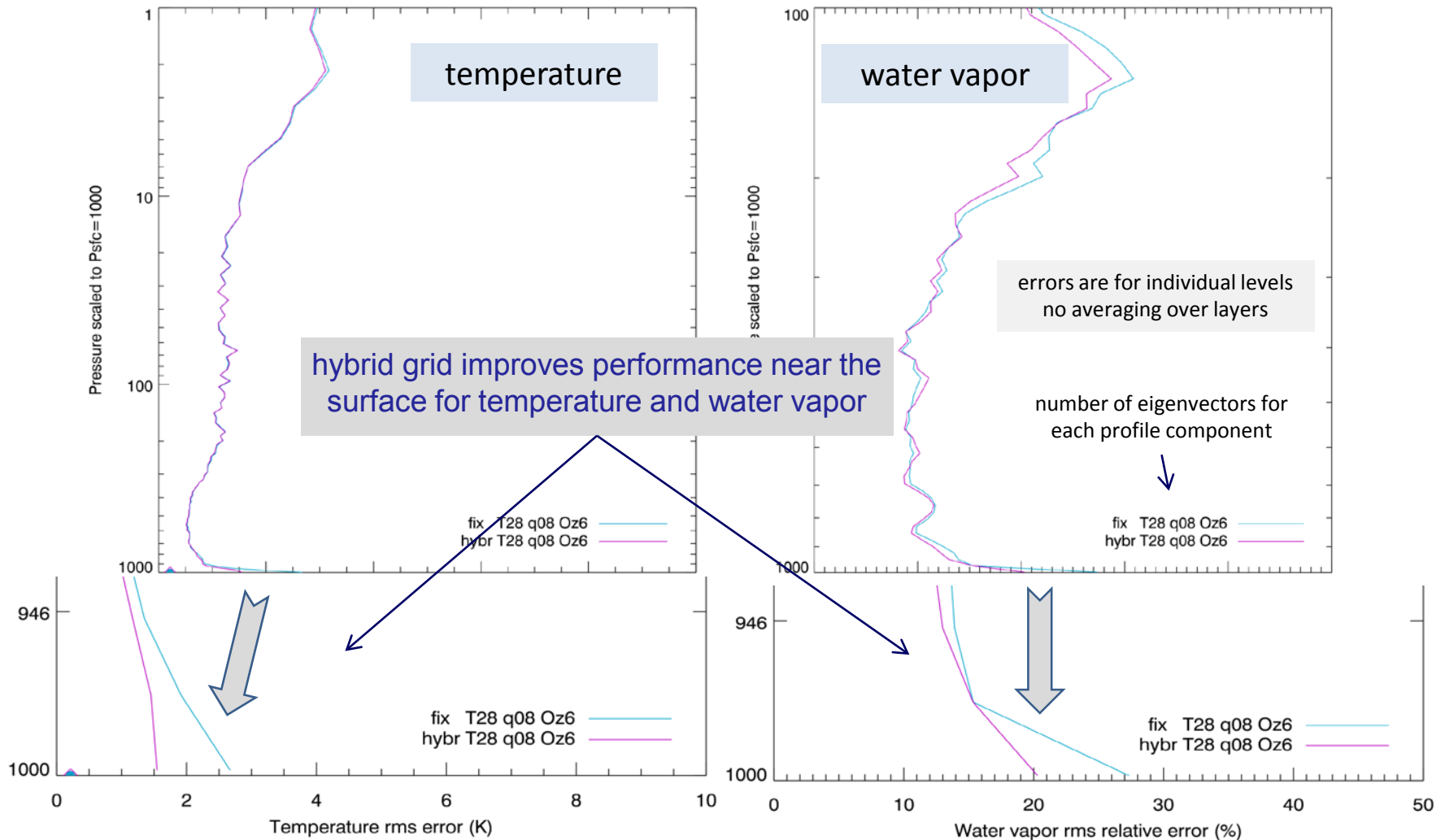 - Error covariance at near-surface levels accounts for the proximity of the surface

aer

**Atmospheric and
Environmental Research**

Hybrid vertical grid performance test

- Hybrid pressure-σ coordinate: $p_l = a_l + b_l\,p_{sfc}$
- 101-level hybrid grid was adapted from the 60-level hybrid grid used for the Navy NAVGEM model
  - Coefficients a and b defined so the grid is on fixed pressure levels in 0.05–100 mb range and gradually transitions to terrain-following
  - Hybrid grid is identical the fixed grid for the special case where p_{sfc} = 1102 mb
- Background estimate and error covariance produced on hybrid grid
- Retrieval experiments with 500 profiles having various surface pressures (low and high elevations)
  - Independent of set used for covariance
- Errors analyzed on the hybrid grid to show error in relation to surface proximity

aer
Atmospheric and
Environmental Research

Hybrid versus fixed grid performance

temperature

water vapor

errors are for individual levels
no averaging over layers

number of eigenvectors for
each profile component

Hybrid versus fixed grid performance

temperature

water vapor

errors are for individual levels
no averaging over layers

hybrid grid improves performance near the
surface for temperature and water vapor

number of eigenvectors for
each profile component

fix   T28 q08 Oz6
hybr T28 q08 Oz6

fix   T28 q08 Oz6
hybr T28 q08 Oz6

fix   T28 q08 Oz6
hybr T28 q08 Oz6

fix   T28 q08 Oz6
hybr T28 q08 Oz6

Temperature rms error (K)

Water vapor rms relative error (%)

Pressure scaled to Psfc=1000

scaled to Psfc=1000

aer

**Atmospheric and
Environmental Research**

# Alternative basis functions for profile regularization

- The departure of the profile state from an initial background state can be projected on a set of basis functions, and retrieval is done in the transformed space
  - The number of elements representing the state is thus reduced to be more commensurate with the information content of the observations
  - This is one aspect of the regularization of the inversion
- After inversion, the retrieval increments are transformed to the original geophysical space for input to the radiative transfer model in preparation for the next iteration
- Heritage code uses the first eigenvectors of the atmospheric profile and emissivity covariance matrices to transform to retrieval space
  - With eigenvectors, retrieval is done in principal component (PC) space
  - Eigenvectors are a special case where forward and reverse transforms are transpose of each other
- ESDR algorithm is generalized to use any suitable basis functions
  - Allows tests of algorithm with basis functions used by other algorithms

aer

**Atmospheric and
Environmental Research**

Trapezoid basis functions test

- Trapezoid basis functions as are used in a stage of the AIRS Science Team (AST) algorithm
  - Transform from retrieval space to geophysical space
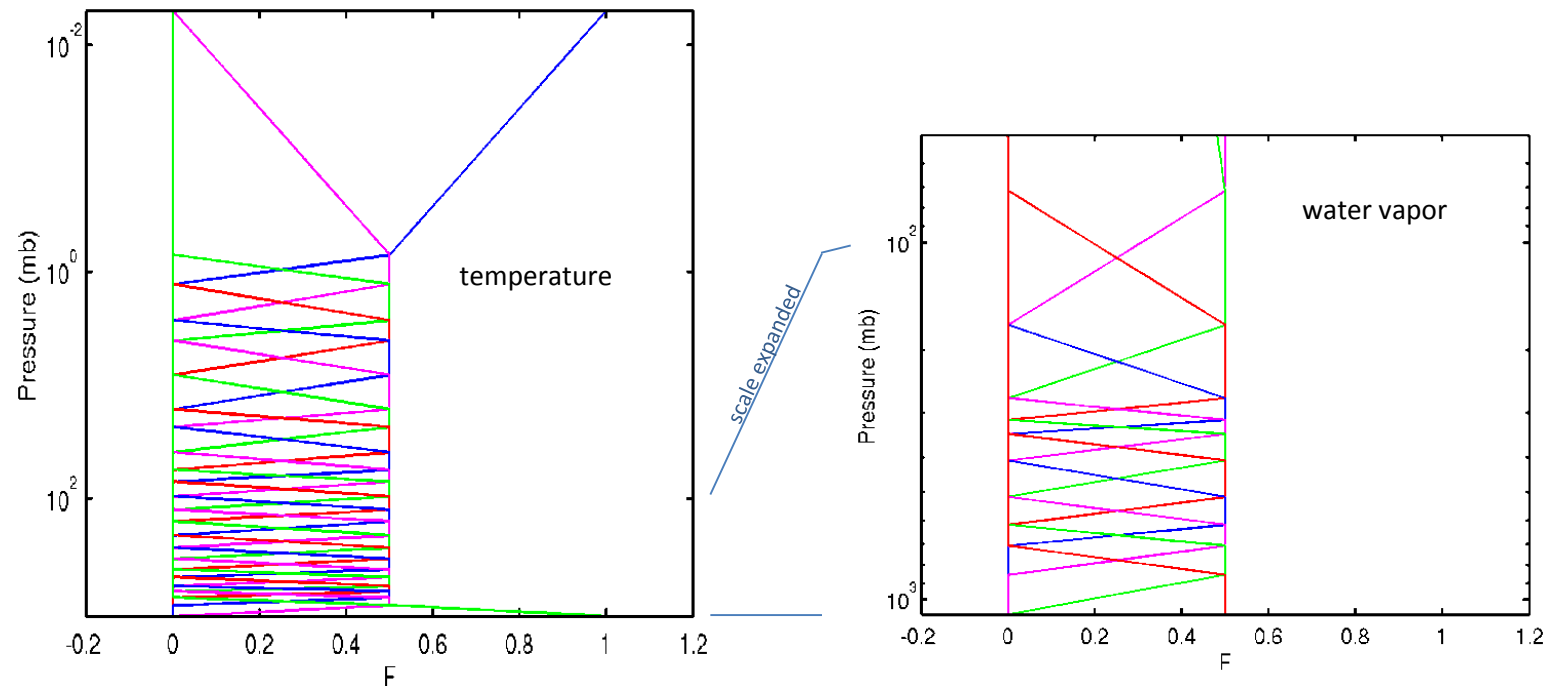
Performance test with trapezoid and eigenvector basis functions
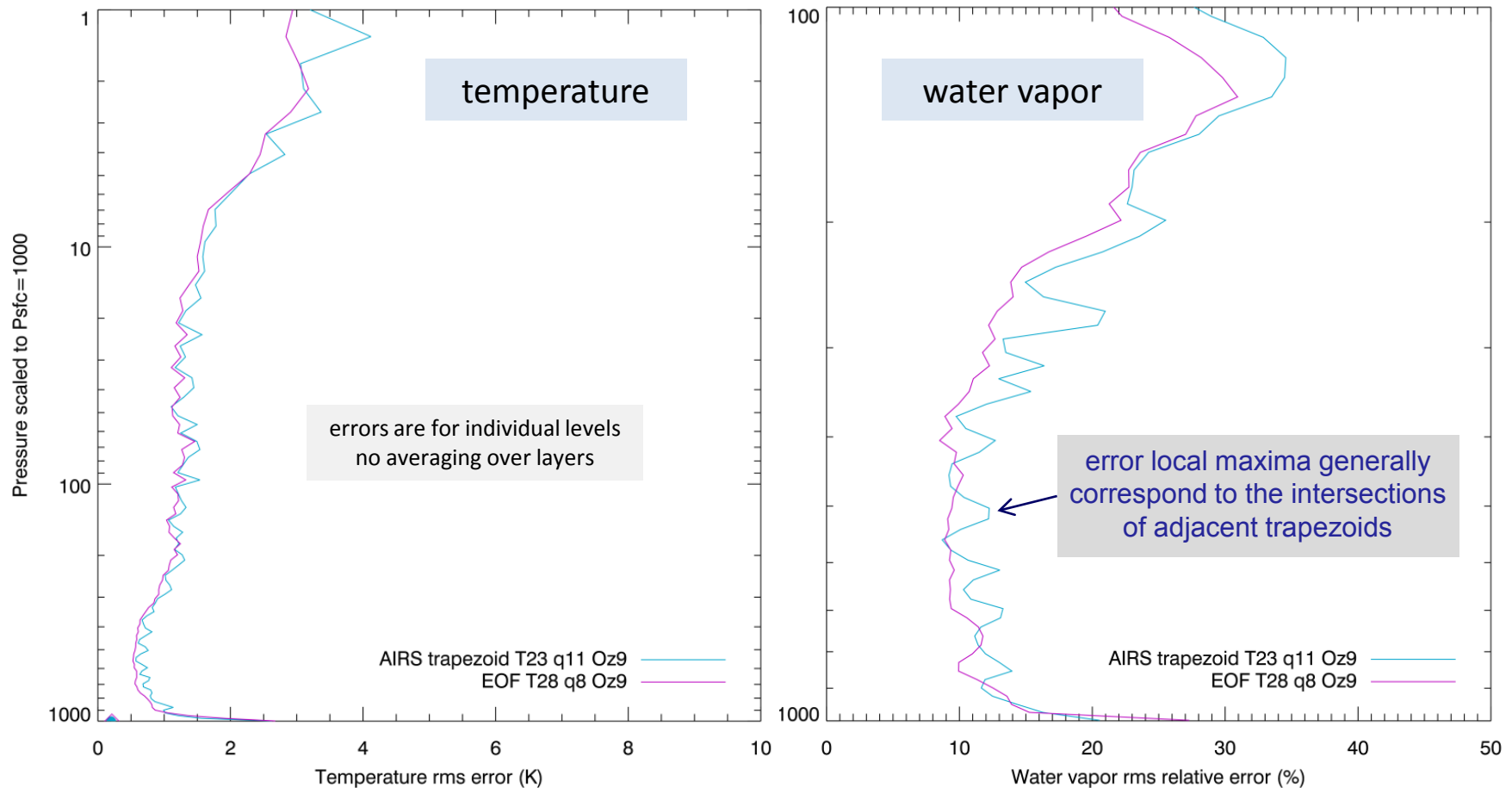
Performance of ESDR optimal estimation algorithm with trapezoids is not indicative of performance of AST algorithm, due to algorithm differences in many other aspects

Outline

- Algorithm purpose, requirements, and heritage
- Modular software approach overview
- Terrain-following coordinates for retrieval
- Alternative basis functions for profile regularization
- Fidelity of climate change signals
  - Impacts of background and basis functions

aer
**Atmospheric and
Environmental Research**

Response of retrievals to climate change: background dependence

- Impact of using a static climatological background in retrievals when the real climate is changing
  - With optimal estimation, impact of background estimate on retrievals depends on its error covariance and on information content of sensor measurements
- Would the algorithm respond inadequately to climate change if it uses a static background?
  - Would retrievals underestimate secular changes and become biased toward an outdated climatology?
- Experimental approach:
  - 30-year climate change (2006 to 2036) simulated by GISS-E2-R for CMIP5 RCP4.5
  - Take one sample of profiles from 2006 and another from 2036 and use covariance from each sample to make separate backgrounds
  - Take independent samples from each to use in retrieval experiments
    - Simulated CrISS and ATMS measurements

aer
Atmospheric and Environmental Research

Impact of eigenvector basis functions (1/2)

- Eigenvector (EOF) basis functions are derived from same covariance as background
- How accurately can 2036 profiles be reconstructed after projecting on truncated sets of EOFs derived from 2006 profiles (outdated era) versus 2036 profiles (same era)?
  - Transformation to retrieval space and then back to geophysical space acts as a filtering operation

    $\Delta \mathbf{x}_r = \mathbf{F}(\mathbf{F}^+ \Delta \mathbf{x})$

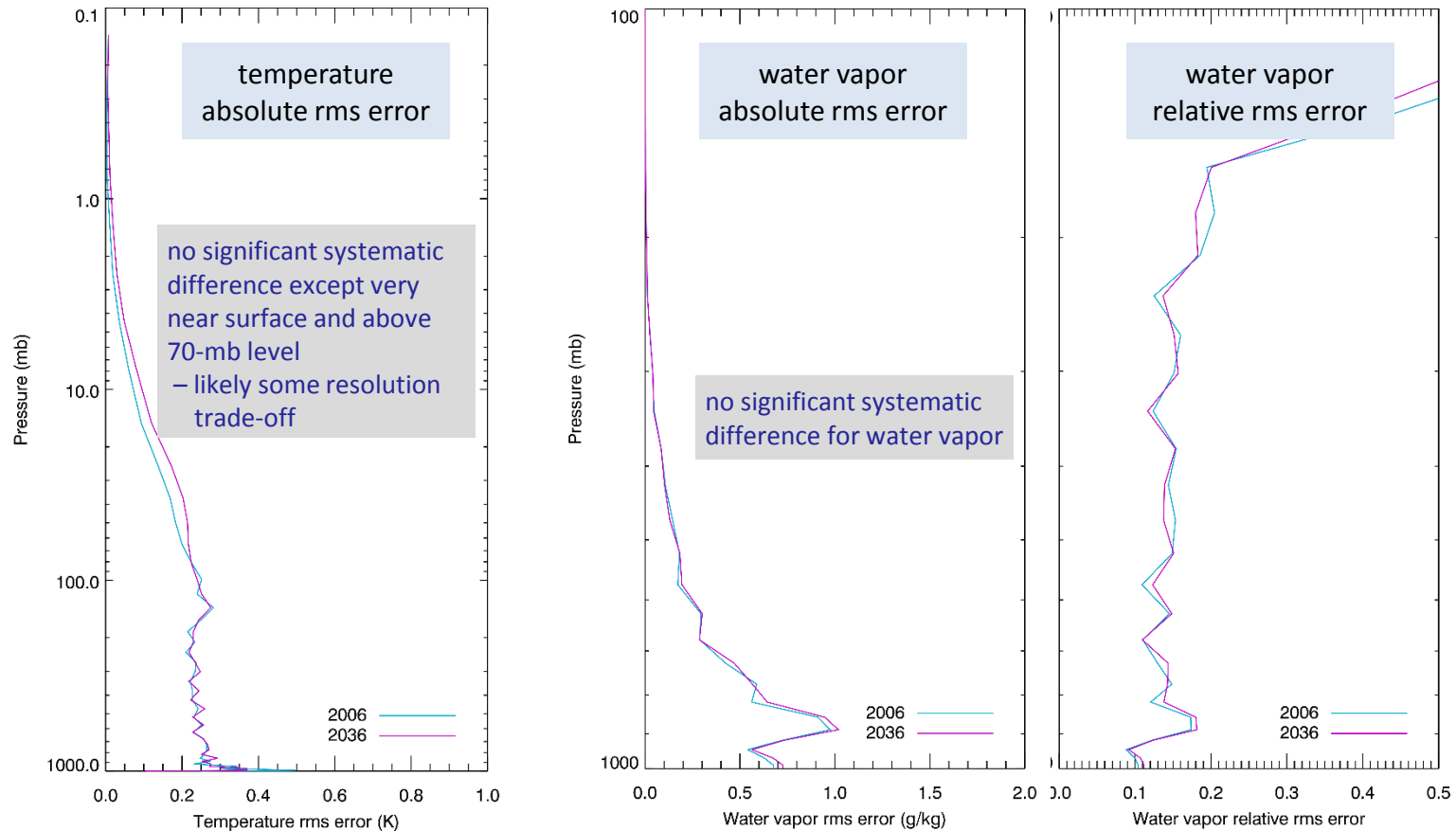 $\Delta \mathbf{x}$ is the original profile (as departure from the background)

    $\Delta \mathbf{x}$ is the reconstructed profile

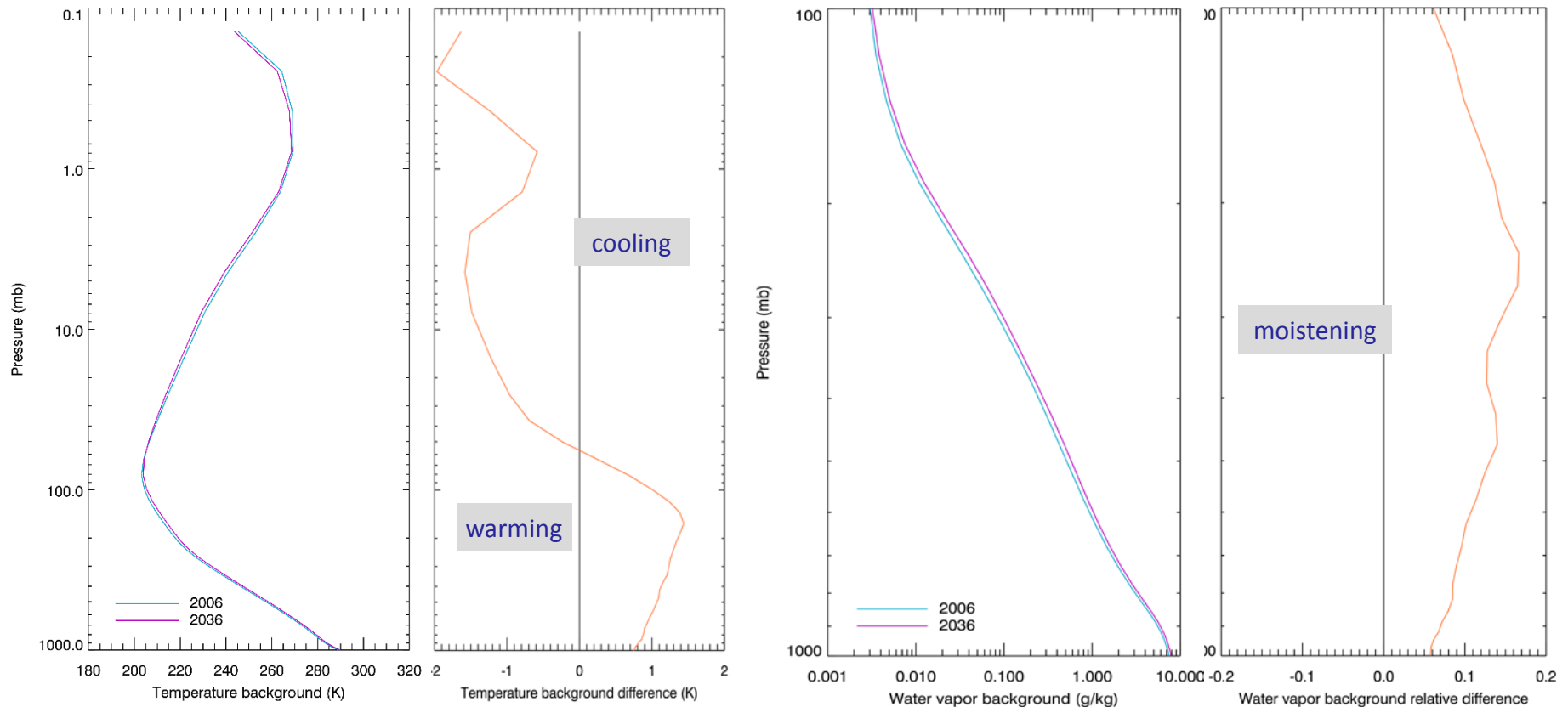 $\mathbf{F}^+$ is the truncated EOF matrix that transforms into PC space

    $\mathbf{F}$ is the matrix that transforms from PC space to geophysical space (transpose of $\mathbf{F}^+$)

- Experiment used 28 EOFs for temperature and 8 EOFs for water vapor
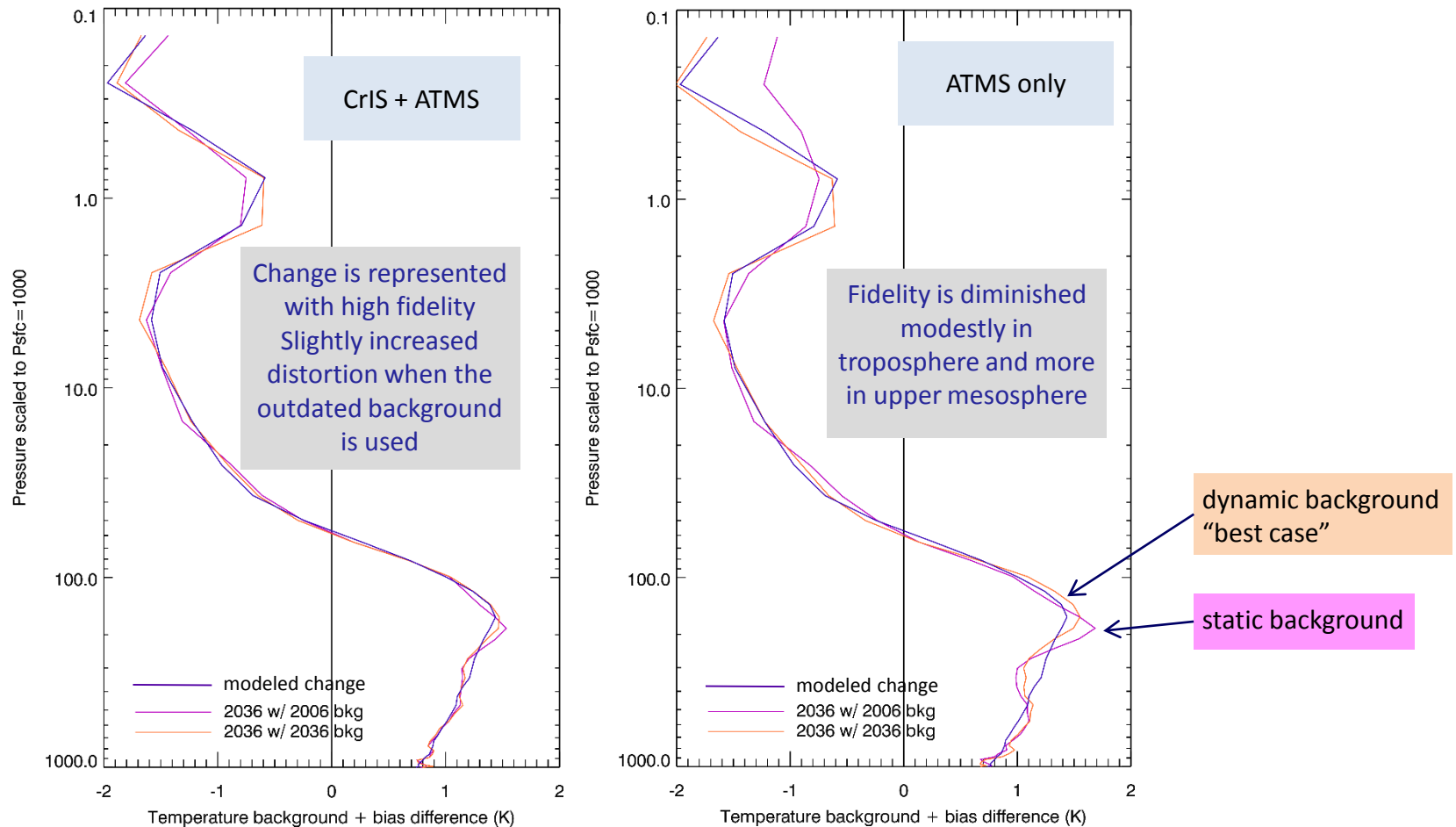 - Based on prior experiments varying numbers of EOFs

aer
**Atmospheric and
Environmental Research**

2036 profiles filtered with outdated 2006 EOFs and with 2036 EOFs

temperature
absolute rms error

no significant systematic
difference except very
near surface and above
70-mb level
 – likely some resolution
   trade-off

water vapor
absolute rms error

no significant systematic
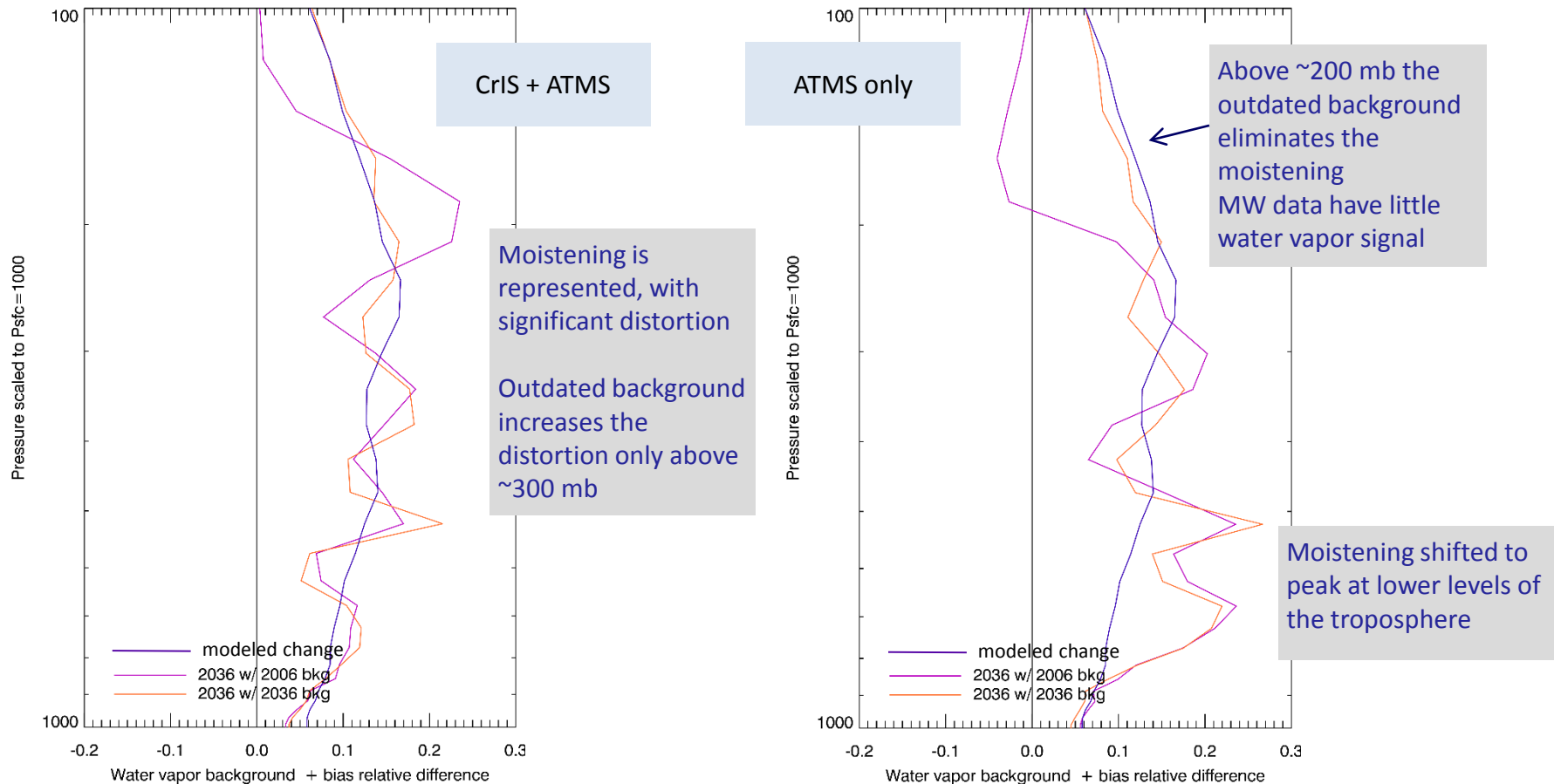difference for water vapor

water vapor
relative rms error

Modeled climate change 2006 to 2036

Fidelity of climate change in retrievals: temperature

Fidelity of climate change in retrievals: water vapor

CrIS + ATMS

ATMS only

Above ~200 mb the outdated background eliminates the moistening
MW data have little water vapor signal

Moistening is represented, with significant distortion

Outdated background increases the distortion only above ~300 mb

Moistening shifted to peak at lower levels of the troposphere

modeled change
2036 w/ 2006 bkg
2036 w/ 2036 bkg

ATMS-only results simulate what would happen if it were necessary to rely on ATMS-only retrievals *globally*, but global change assessment would rely on CrIS+ATMS retrievals substantially

aer
Atmospheric and
Environmental Research

Alternatives

- Use atmosphere pre-classification to define background and to select background
  - Radiance-based microwave and IR
    - primarily stratospheric channels
  - To reduce dependence on background
    - Primary change expected to be in % occurrence of each class and not in the composition of the classes themselves
  - Next step is testing this

- Update background periodically
  - Need to use consistent methodology for each update

aer
Atmospheric and Environmental Research