The AURORA Project: Taking Hyper-spectral Data Inversion and Assimilation to a New Limit

Kat Giamalaki · Paolo Antonelli · Tiziana Cherubini · Frederike Monte · Steven Businger

University of Hawai‘i at Mānoa | AdaptiveMeteo

2026 AR Recon Workshop · ECMWF Reading

Supported by ONR grant N000142412764

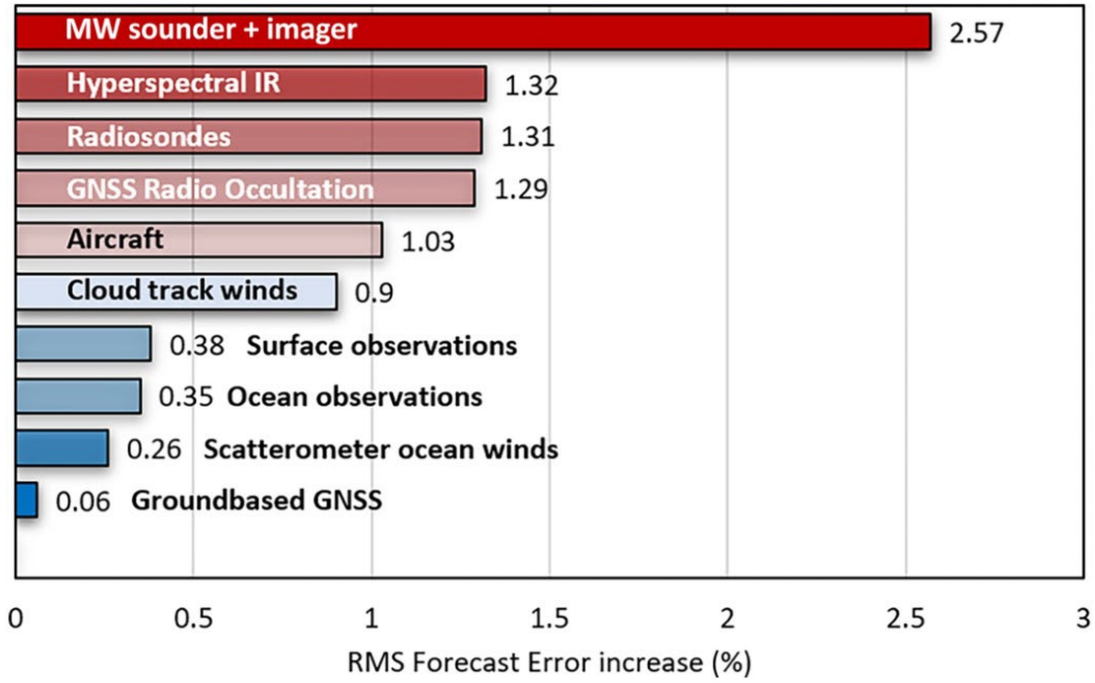
Motivation: The Atmospheric River (AR) Forecast Problem

ARs drive extreme precipitation along the U.S. West Coast — high societal impact

Forecast errors trace back to poor moisture initialization over the data-sparse Pacific

Hyper-spectral IR is the 2nd most impactful observation type — yet most is discarded under cloud cover

Cloud cover blocks up to 70–80% of potential IR observations over the Pacific



Saunders R., 2021: https://doi.org/10.1002/wea.3913

Overall Goal:

Recover moisture information lost to cloud cover by assimilating transformed hyper-spectral retrievals into MPAS-JEDI for improved atmospheric river forecasts.

What are Transformed Retrievals?

Retrieval assimilation: first-guess prior contaminates the solution, especially where observation information is weak

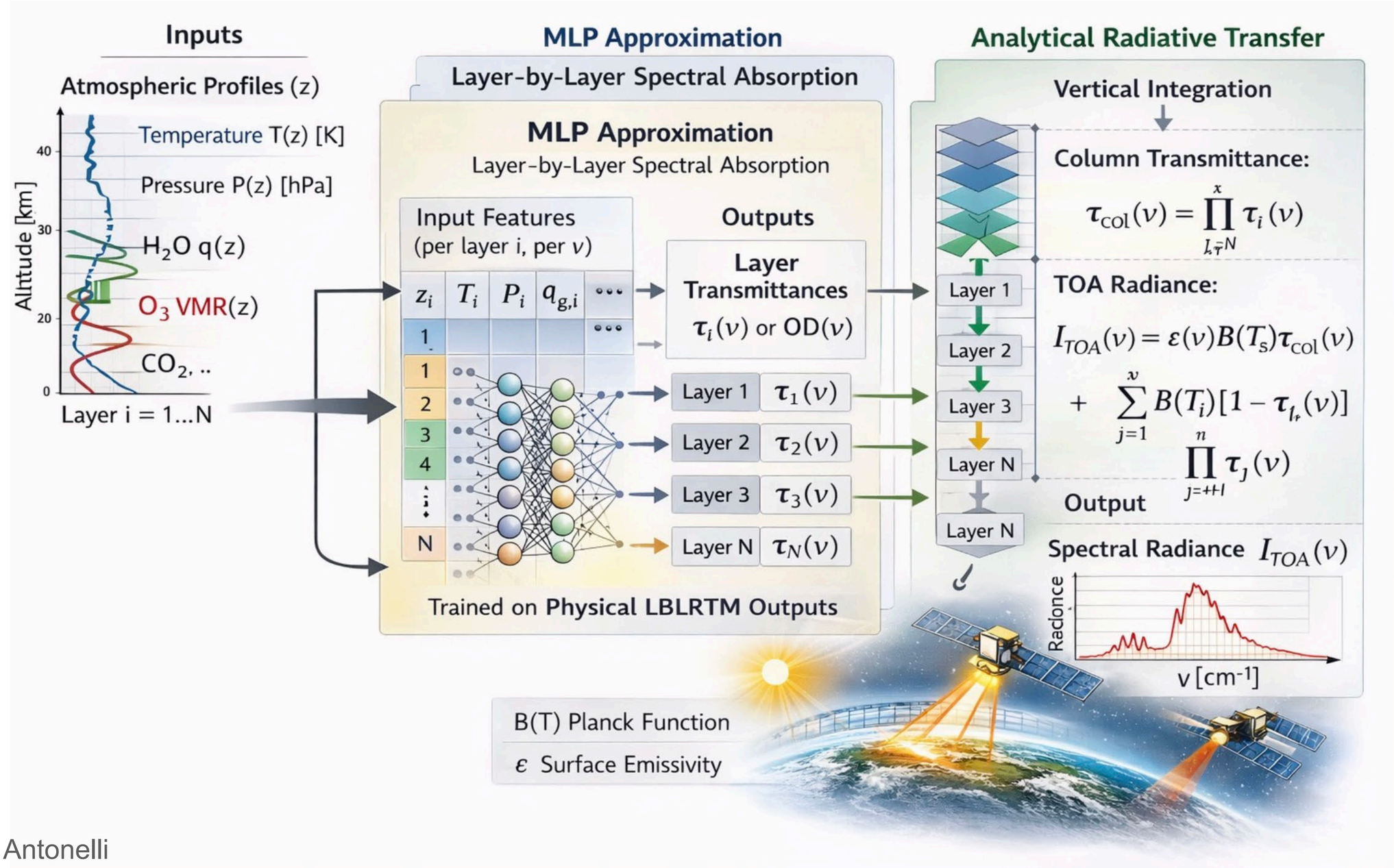
Radiance assimilation: traditionally restricted to clear sky, with channel selection for tractability

Transformed Retrievals (TRs — Migliorini, 2008; Migliorini, 2012):

- Satellite retrievals projected into eigenvector space
- Proper observation error covariance (diagonal in transformed space)
- Full spectral information content,
- First-guess contamination is greatly mitigated through a comparison between observation error covariance matrix and B-matrix
- Equivalent to radiance assimilation when all eigenvectors retained

Task 1: Retrieval System
HELIOS-RT · AMETHYST

HELIOS-RT: ML-Based Forward Model

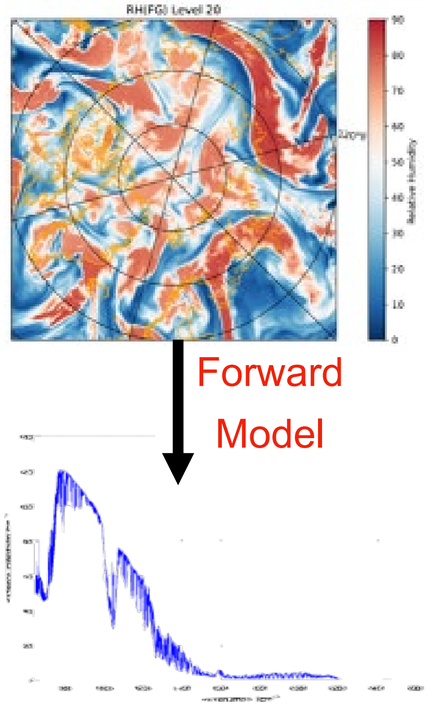


Dr. Paolo Antonelli

Benefits of Machine Learning (ML) based Forward Model (FM)

- A ML FM is well suited to solving the Radiative Transfer Equation (Artificial Neural Networks are Universal Approximators of Functions).
- ML FMs, once trained are extremely fast.
- ML FMs allows different types of observations (hyperspectral IR and MW) to be combined within a single system.

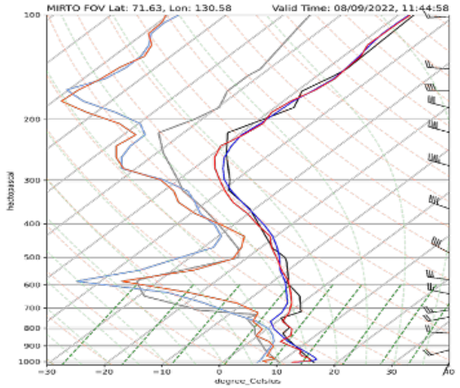
AMETHYST: From Radiances to Transformed Retrievals



Forward Model

A-priori NWP model knowledge regarding the atmospheric state + hyper-spectral space-borne observations

Data Inversion



Physical Retrievals provide updated knowledge of the atmospheric state

Migliorini Transformation

Transformed Retrievals in clear skies and without a priori feeding data assimilation frameworks.

The AMETHYST produced an initial dataset used previously in WRF-DA, used here as an input for MPAS-JEDI DA.

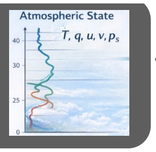
Dr. Paolo Antonelli

Task 2: Data Assimilation
MPAS-JEDI TR Operator

The MPAS-JEDI data assimilation workflow

2 months
12-24h forecasts

MPAS-A
x_b



Background

Observation Streams · Forward Operators

Conventional

AMSU-A
Ch 5-9 · VarBC

TR profiles

H_conv
Interpolation

CRTM
Radiance Model

TR Operator
H_tr · [T, ln q]

B Matrix
Background errors

O-B
y-H(x_b)

3DVar cost function J(x)
$1/2(x-x_b)^T B^{-1}(x-x_b) + 1/2\sum_i (y-H_i x)^T R_i^{-1}(y-H_i x)$

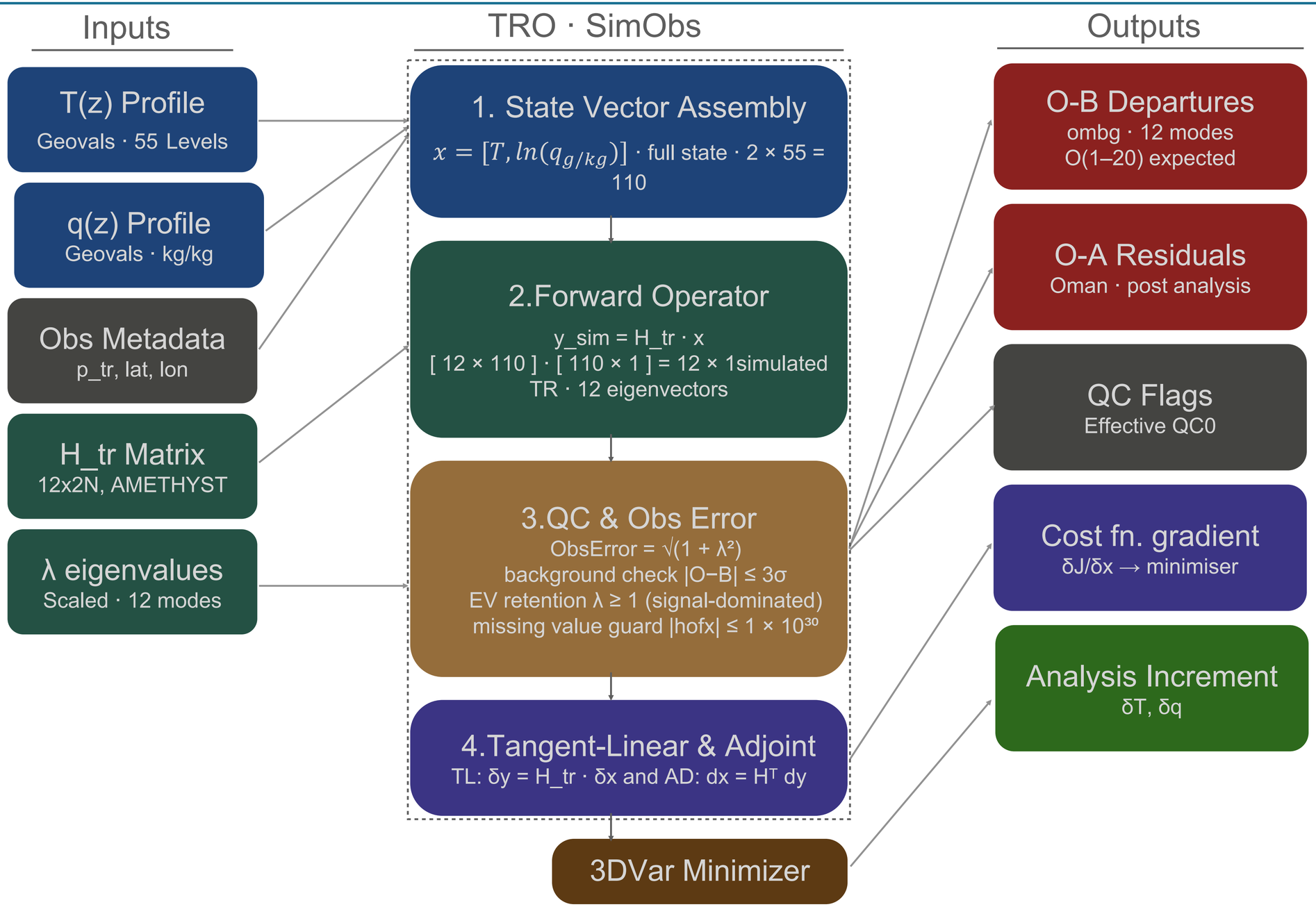
Minimizer
TL/AD · $\partial J/\partial x \rightarrow \delta x$

Analysis Increment δx
$x_a = x_b + \delta x,\ \delta x = (\delta T, \delta q, \delta u)$

Merge into MPAS IC
$T \rightarrow \theta \cdot q \rightarrow qv$ · init file

MPAS forecast
+2 day · IVT, PW

The TR Observation Operator (TRO) in MPAS-JEDI



AR Case Studies to test TRO

Dec 17 & Dec 21 2020 AR Events

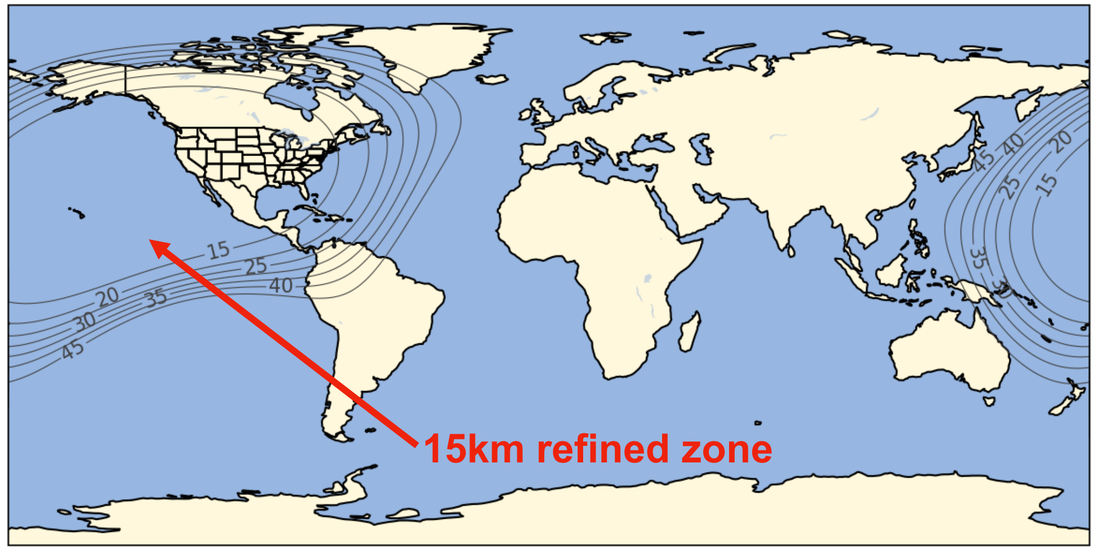
Two landfalling AR cases, Pacific Northwest.

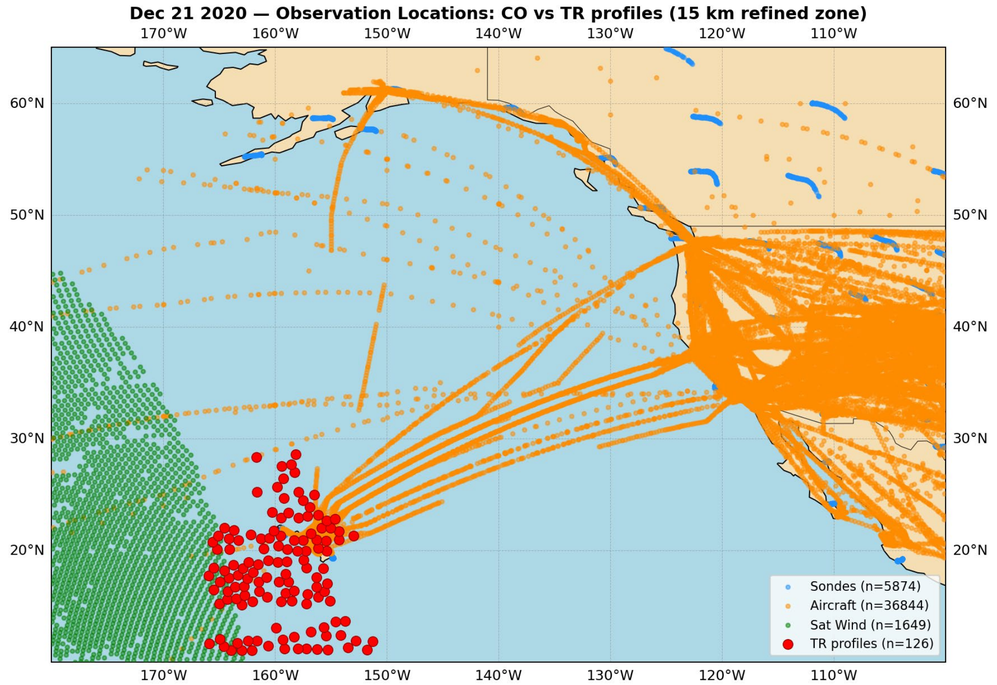
Available TRs from initial AMETHYST output.

IASI | CriS, clear-sky, TRs:

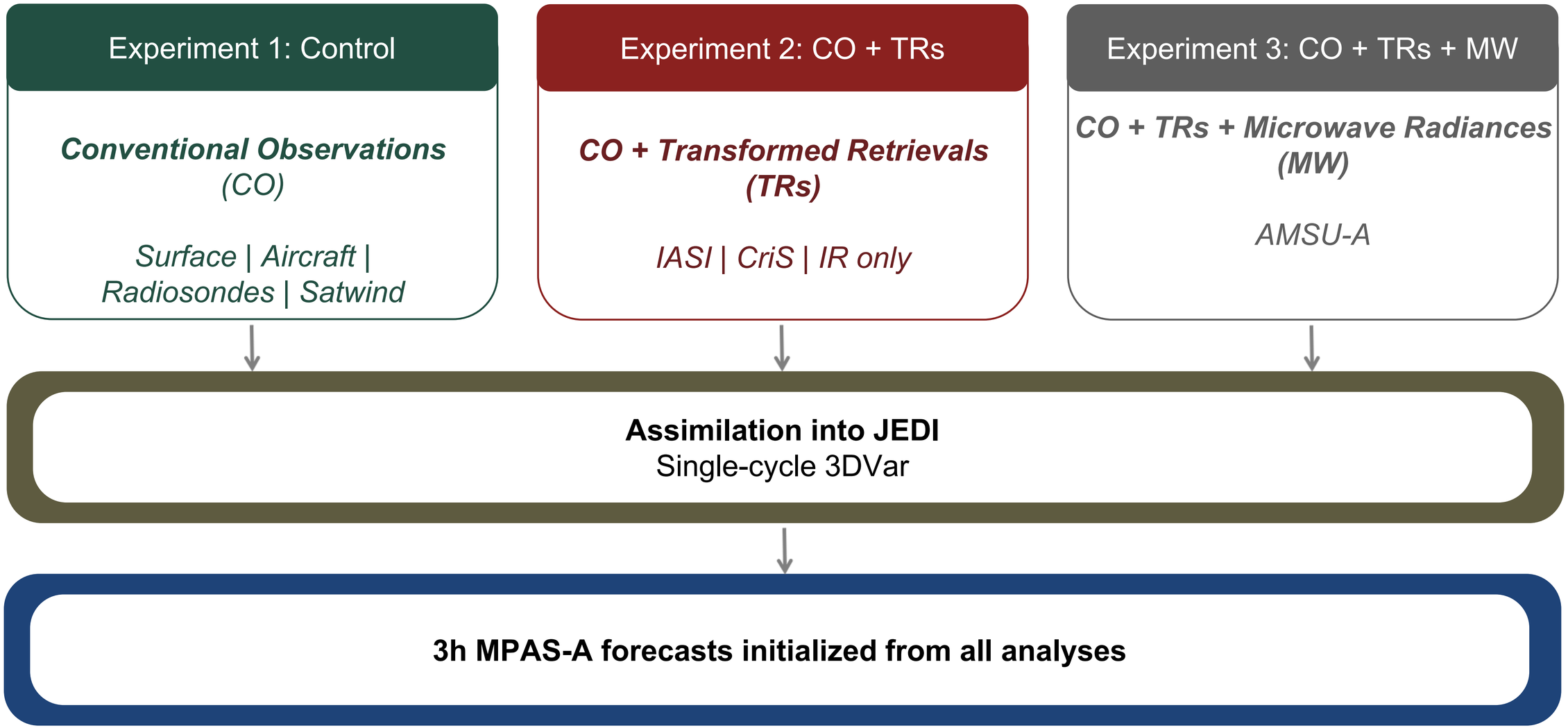
76 profiles (Dec 17) and

126 profiles (Dec 21)



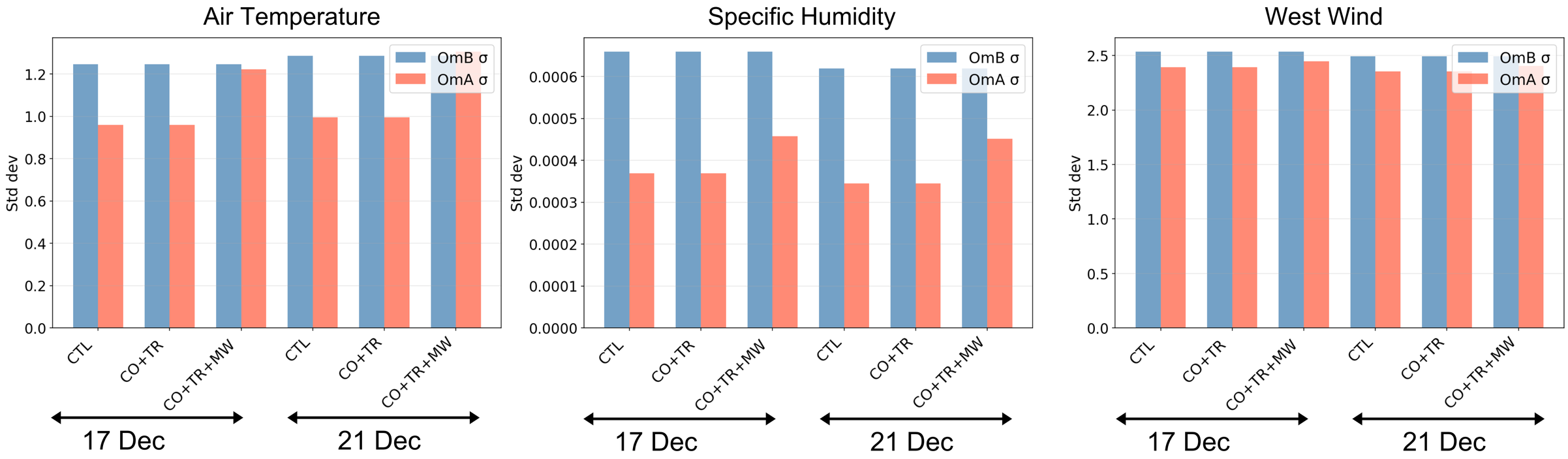


DA Experiment Design



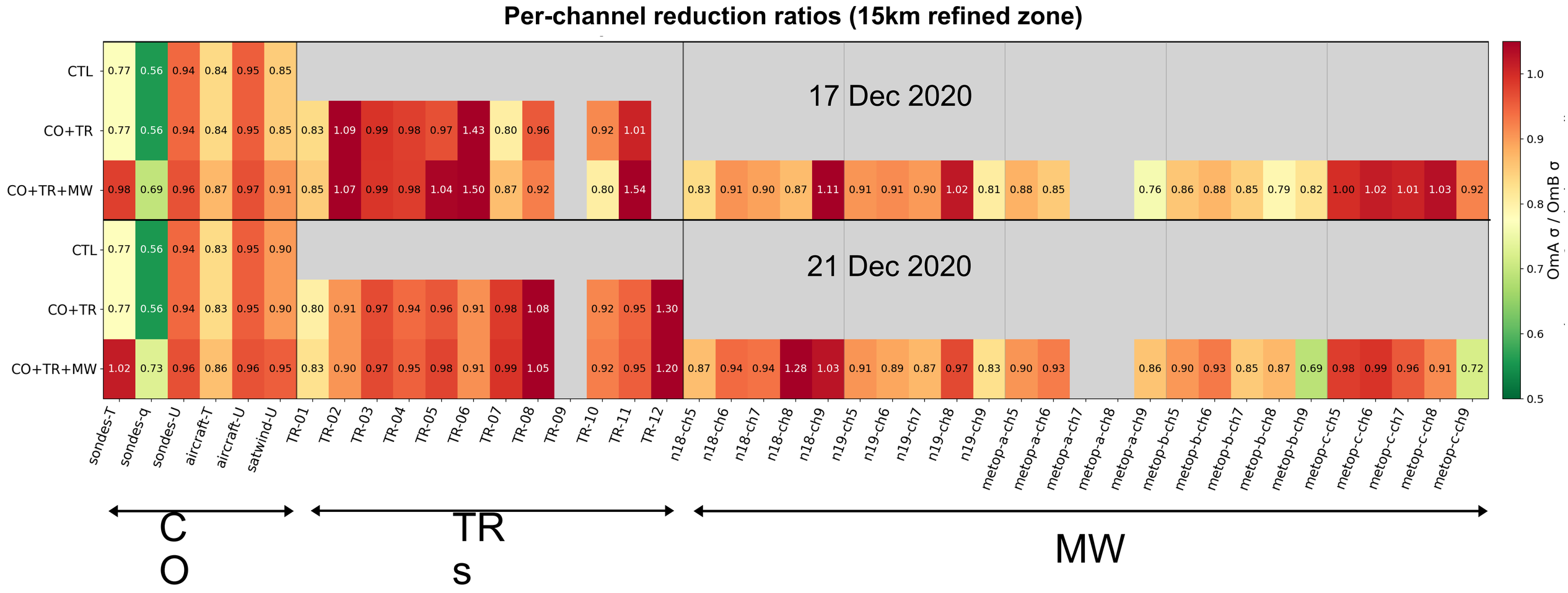
Assimilation Efficiency

Observations minus Background (OmB) σ and Observations minus Analysis (OmA) σ by experiment on CO only



CO+TR reduces **specific humidity** departures by **~44%** relative to background (both cases).

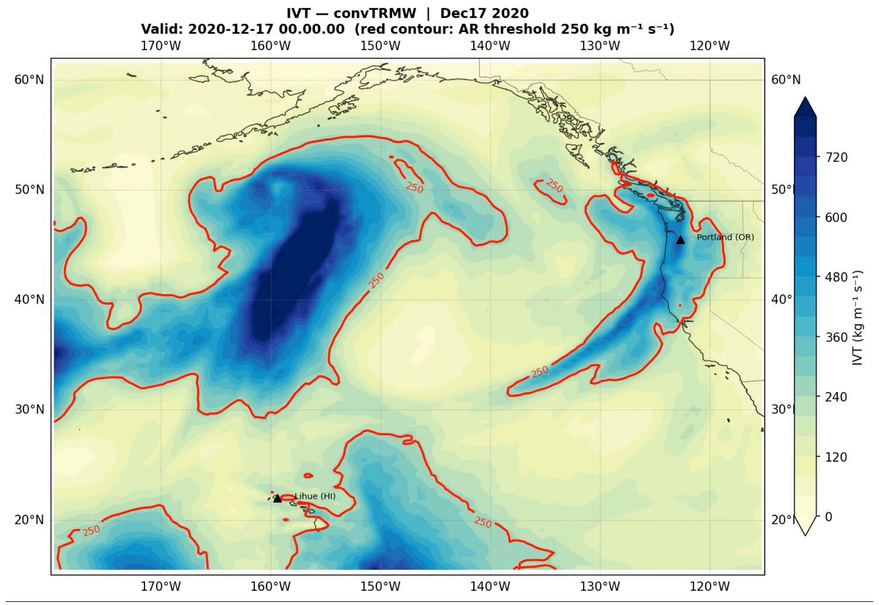
Analysis Skill: OmA σ /OmB σ Ratio

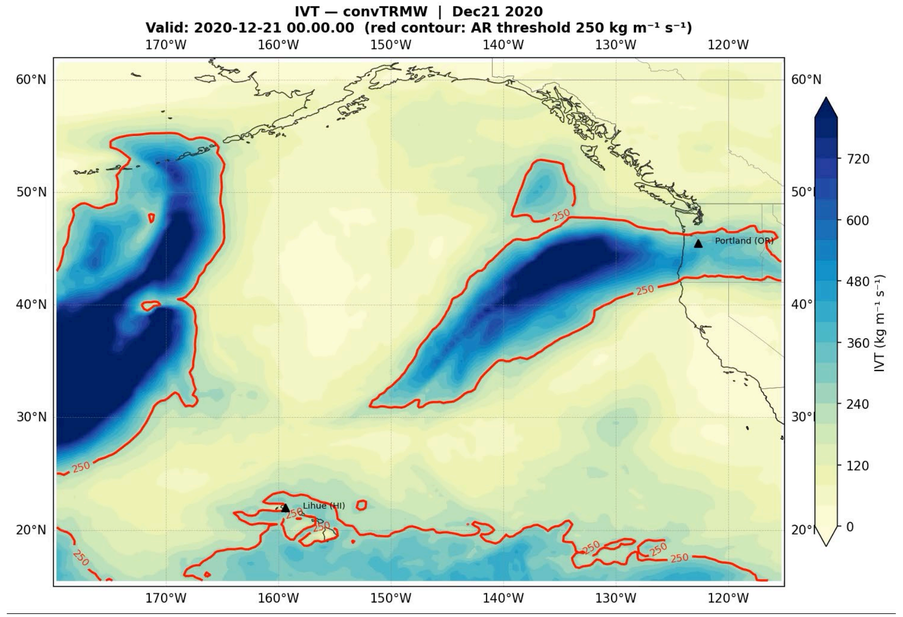


Green < 1 = analysis fits the observations **better** than the background

Red ≥ 1 = analysis did **not improve** on the background

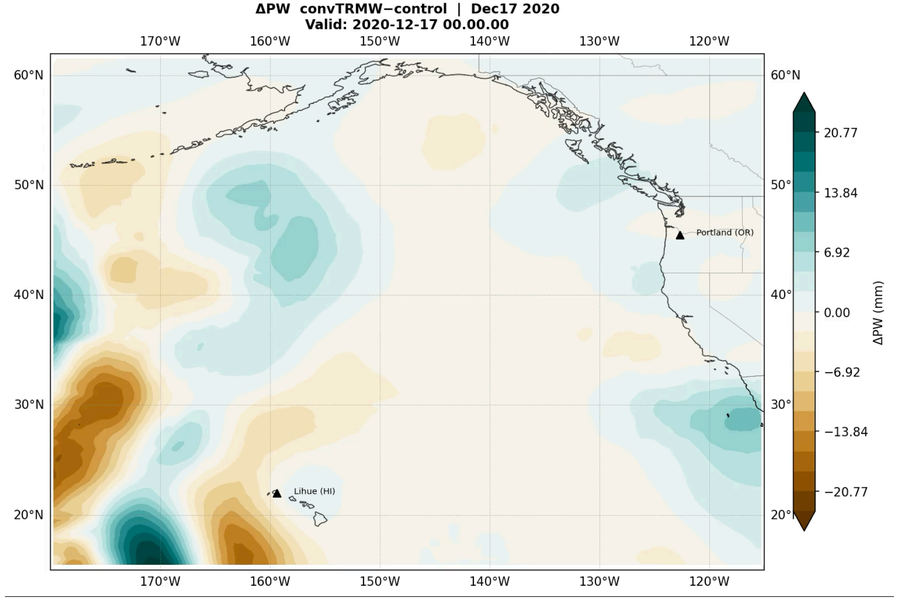
Forecast Impact

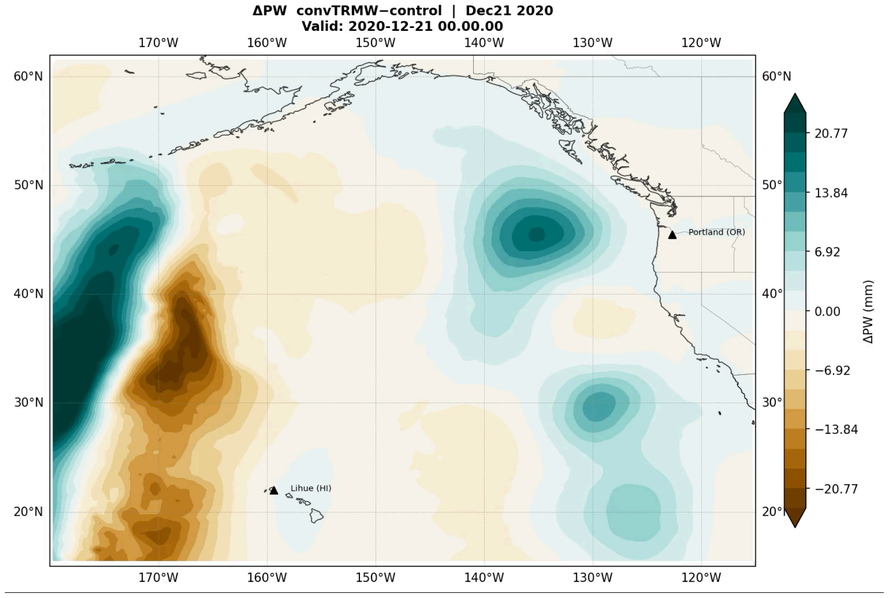




IVT

CO+TR+MW





ΔPW

(CO+TR+MW) - CO

Summary & Road Ahead

Retrieval system:

- HELIOS-RT ML forward model under active development
- AMETHYST to produce new batch of TRs

Data assimilation:

- TR operator is validated and produces consistent analysis improvements in MPAS-JEDI
- Data Assimilation under active development

Next step:

- Complete spectral forward model and data retrieval will allow cloudy-sky TR assimilation in MPAS-JEDI

Submit an Abstract to our AGU26 Session!

NH027 - Extreme Atmospheric Rivers and Compound Hazard Risk: Advances in Modeling, Data Assimilation, and AI

Katerina Giamalaki (University of Hawai‘i at Mānoa),
Anna Wilson (CW3E, Scripps, UC San Diego),
Minghua Zheng (CW3E, Scripps, UC San Diego),
Yang Zhou (Lawrence Berkeley National Laboratory),
Frederike Monte (University of Hawai‘i at Mānoa)


Thank you!
giamalak@hawaii.edu