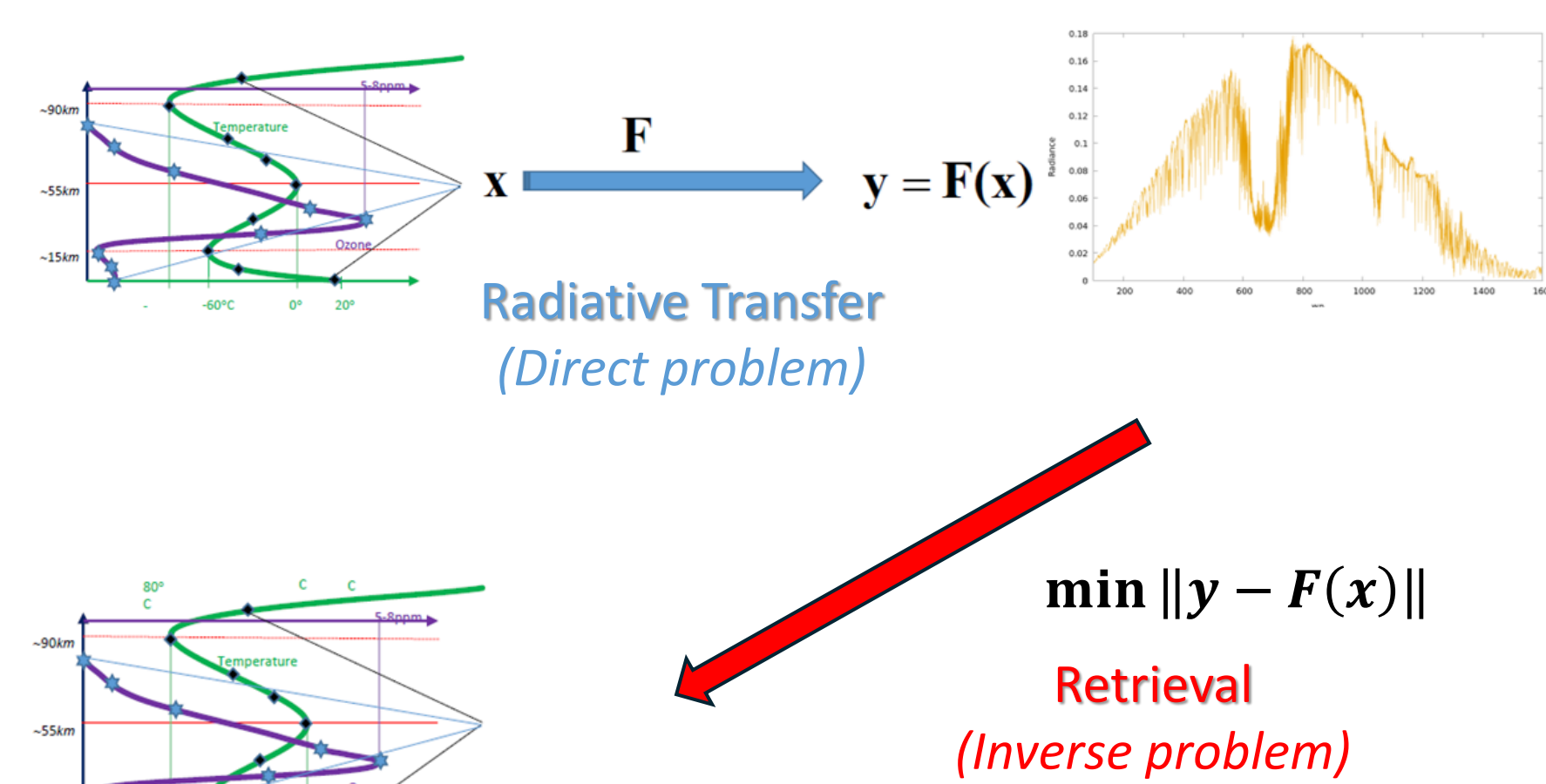


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INTRODUCTION AND ARCHITECTURE

FORUM MISSION

- FORUM (Far-infrared Outgoing Radiation Understanding and Monitoring) is a Fourier Transform Spectrometer selected as the ninth Earth Explorer mission by the European Space Agency in 2019.
- It will provide interferometric measurements in the Far-Infrared (FIR) spectrum (100-1600 cm⁻¹ region), constituting 50% of Earth's outgoing longwave flux.
- Accurate Top Of the Atmosphere measurements in the FIR are crucial for improving climate models.



RETRIEVAL: classical method

- Find the atmospheric parameters x (surface temperature, temperature, water vapor, ozone, surface spectral emissivity, liquid and ice water content, liquid and ice particle radius) that best reconstruct the measured spectrum y .

! VERY ILL-CONDITIONED PROBLEM

- Formulated as a Bayesian inference problem and solved using the OPTIMAL ESTIMATION METHOD:

$$x = \arg \min_{\xi} \frac{1}{2} \|L_y(y - F(\xi))\|_2^2 + \frac{1}{2} \|L_a(\xi - x_a)\|_2^2,$$

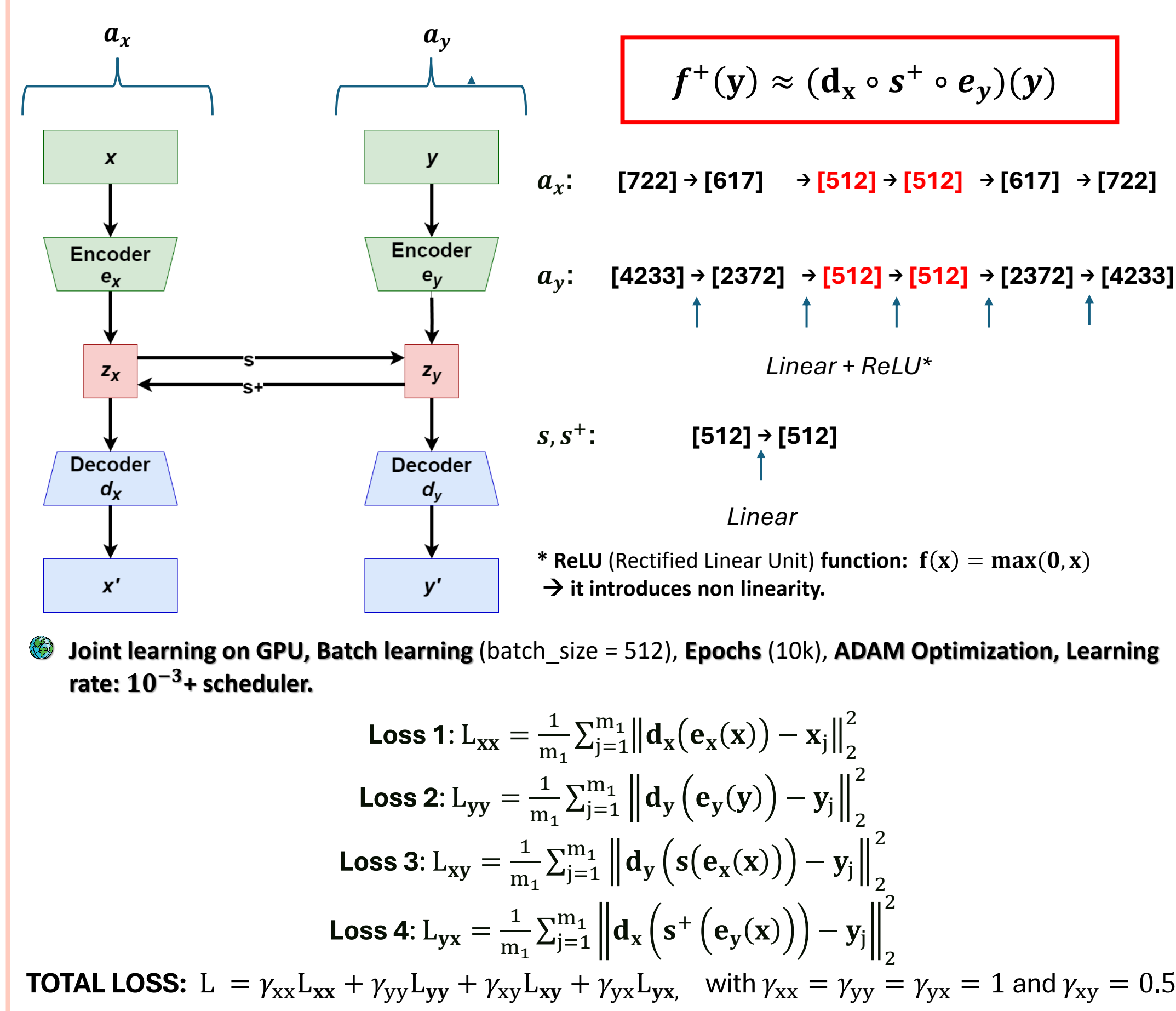
where $S_y^{-1} = L_y^T L_y$ and $S_a^{-1} = L_a^T L_a$ are the inverses of the Variance-Covariance Matrices of the measurements y and the a priori information x_a , respectively.

- Minimization carried out using Gauss Newton + Levenberg-Marquardt technique.

OBJECTIVE

- Innovative data-driven techniques for fast, near real-time analysis, overcoming the limitations of full-physics methods and exploiting large data.

LATENT TWINS FRAMEWORK AND TRAINING



CORRECTION: ADDITIONAL TRAINING

- Retrieved c_{liq} , c_{ice} , r_{liq} , r_{ice} are not physically consistent \rightarrow second training phase! Independent, autoencoder & latent networks frozen.

- 4 Feedforward neural networks (MLP, fully-connected):

[4] \rightarrow [16] \rightarrow [8] \rightarrow [1]

LINEAR + SOFTPLUS

INPUT: $(c^i)^{inp}$ or $(r^i)^{inp}$, p^i , T^i , w_{vap}^i OUTPUT: $(c^i)^{new}$ or $(r^i)^{new}$

- Training: entire training set; Inference: applied only on inconsistent points.

- Loss function:

$$L = \underbrace{L_{T_{liq}}^{MSE} + L_{T_{ice}}^{MSE} + L_{p_{liq}}^{MSE} + L_{p_{ice}}^{MSE}}_{\text{global MSE over all points}} + \gamma_c \underbrace{\frac{1}{N_{liq}} \sum_{i \in M_{liq}} (c_{liq}^i)^2 + \frac{1}{N_{ice}} \sum_{i \in M_{ice}} (c_{ice}^i)^2}_{\text{penalty on inconsistencies only}}$$

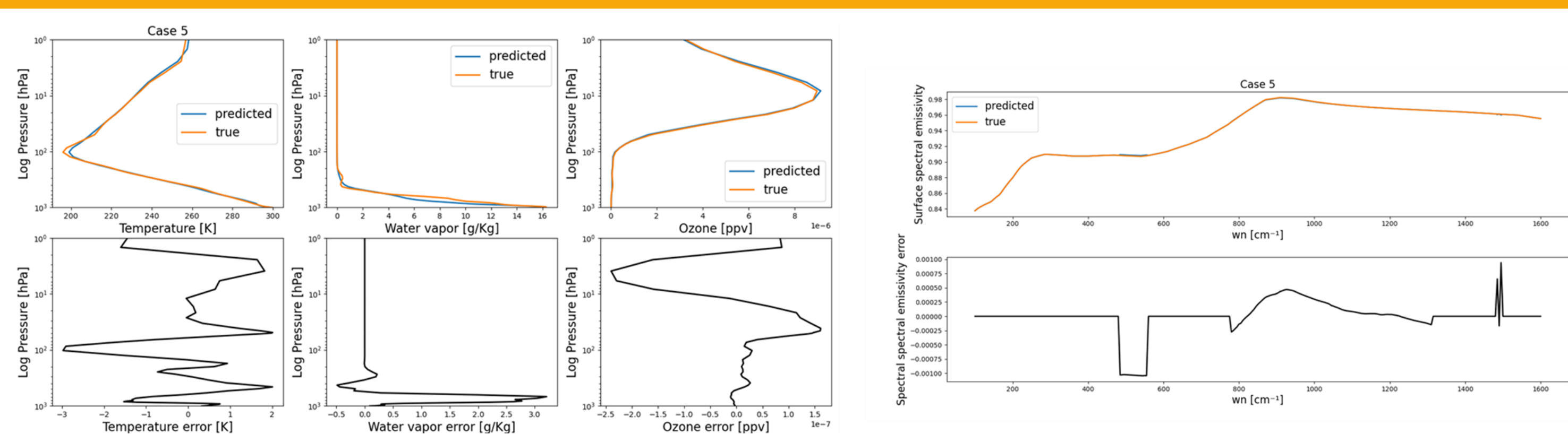
- Batch size: 512, Adam optimizer.

- Results: Loss: 5.6 \rightarrow 0.05

- Inconsistent points: 401,681 (train), 71,048 (test) \rightarrow All inconsistencies corrected

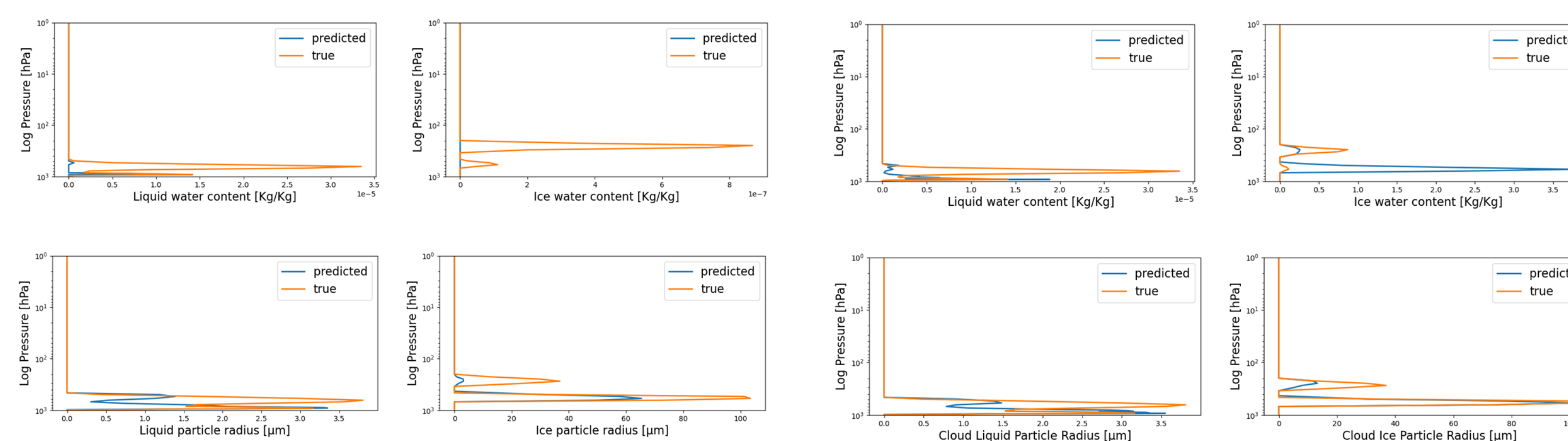
* SoftPlus function: $f(x) = \ln(1 + e^x) \rightarrow$ it avoids discontinuity

SINGLE CASE RESULTS



BEFORE CORRECTION

AFTER CORRECTION



COMPUTATIONAL TIME

- Training the first 4 models \rightarrow it depends on the epochs and laptops \rightarrow some hours
- Training the last 4 networks \rightarrow it depends on the epochs and laptops \rightarrow some minutes
- Testing \rightarrow Total time taken for all predictions (4862): 2.06 seconds
- Average time per batch (512): 0.21 seconds

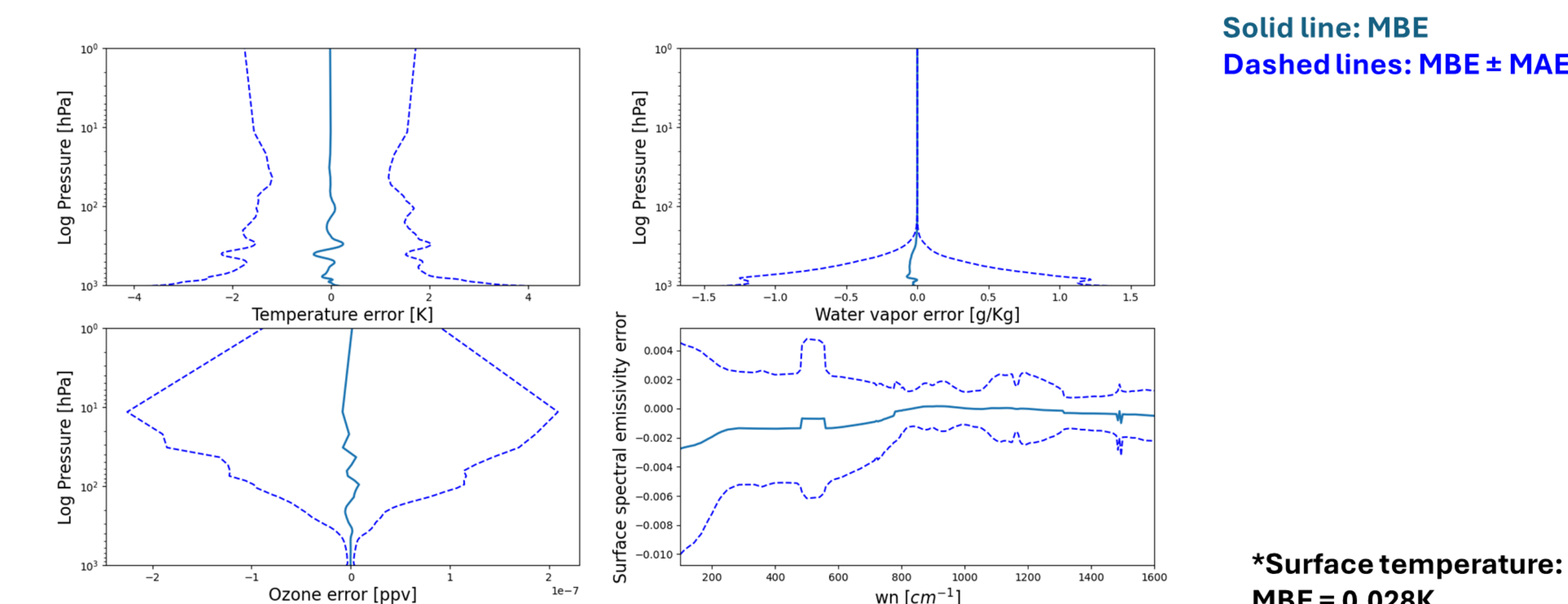
CONCLUSIONS

- Latent-twin architecture successfully reconstructs atmospheric profiles and cloud properties.
- Additional neural networks and physical constraints improve the cloud-property retrieval.
- Optical depth retrieval enables accurate scene recognition.
- Retrievals are instantaneous, suitable for real-time applications but still require further improvement.
- Ongoing work aims to apply this architecture to clear-sky retrievals using real IASI measurements and to perform a comprehensive error and robustness analysis of the method.

AVERAGE RESULTS

- Data collected at 12:00 UTC, covering entire globe on a 2°x2° lat-lon grid, January and July 2021.

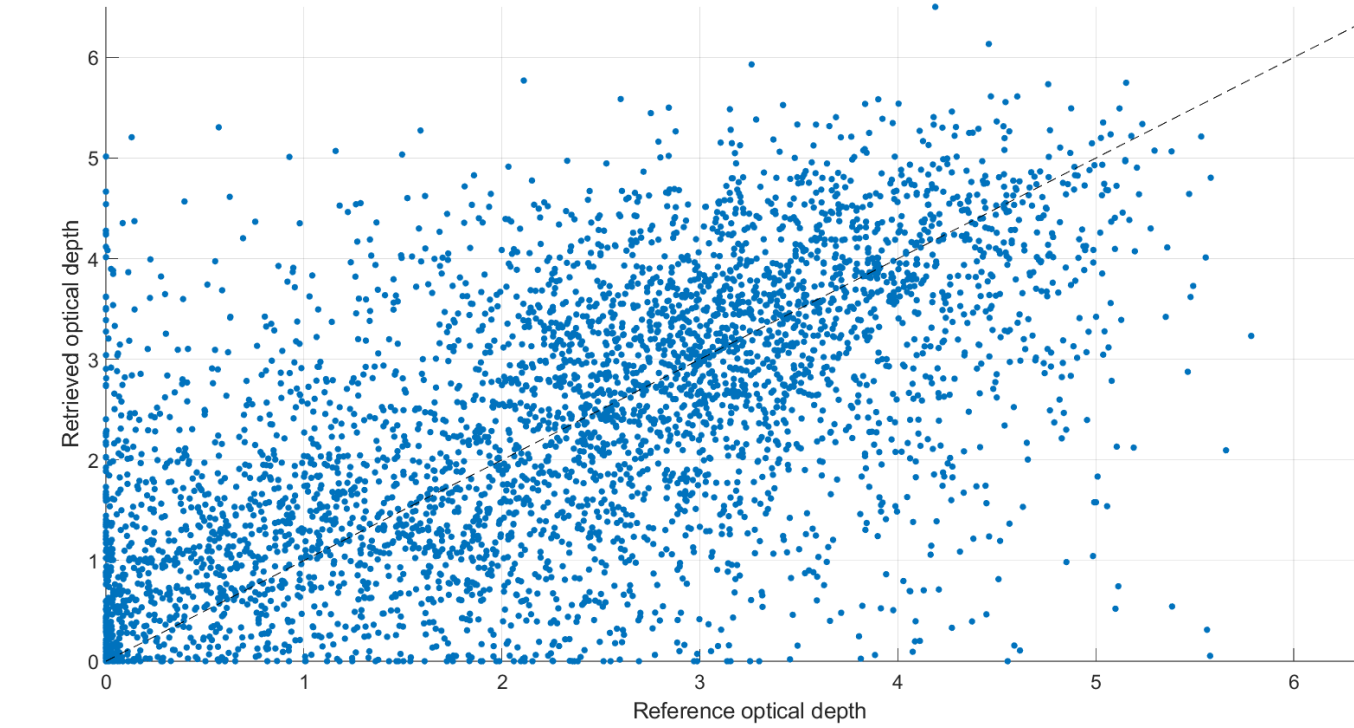
- Total cases: $m = 31,862 \rightarrow$ Training set: $m_1 = 27,000$ (~85%), uniformly sampled from $\{1 \dots m\}$.
- \rightarrow Test set: $m_2 = 4,862$ (~15%), complementary subset.



OPTICAL DEPTH RECONSTRUCTION

$$\tau_{ice} = \frac{3}{2} \sum_i \frac{Q_{ext}^i c_{ice}^i \rho_{air}}{r_{ice}^i \rho_{ice}} \Delta z_i^i,$$

with i layer, ρ_{air} and ρ_{ice} air and ice density, respectively, Δz_i^i geometric thickness and Q_{ext}^i . The same for τ_{liq} .

MBE = 3.40
MAE = 20.12

* Logarithmic scale with a unit offset

SCENE CLASSIFICATION PERFORMANCE

 $\tau = \tau_{liq} + \tau_{ice}$ used to assess the scene classification between clear and cloudy conditions.

CATEGORY	DEFINITION	ACCURACY
Binary: Clear / Cloudy	Clear if $\tau \leq 0.03$, Cloudy if $\tau > 0.03$	94.82 %
Three classes: Clear / Thin / Thick	Clear: $\tau \leq 0.03$ • Thin: $0.03 < \tau \leq 1$ • Thick: $\tau > 1$	82.91 %

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⁹ C. Sgaton, L. Sgheri and M. Chung. "A physics-aware data-driven surrogate approach for fast atmospheric radiative transfer inversion". *Living Planet Symposium 2025*, Vienna.

¹⁰ Matthias Chung et al. *Latent Twins*. Submitted on 24 September 2025. arXiv:2509.20615

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