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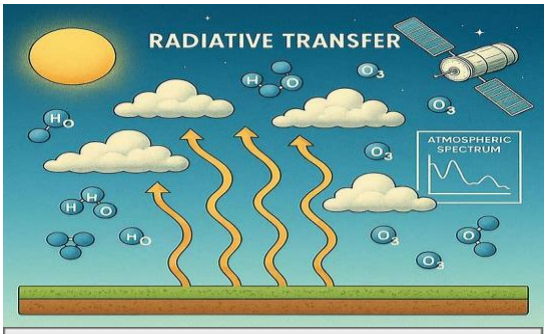
PNRR Project EMM – Task 1500-02

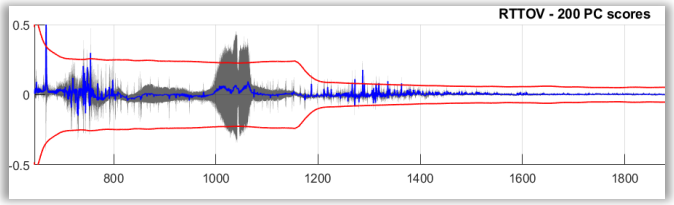
Fast radiative transfer method



Application		
Retrieval	Metereology	Climatology
10's	100's to 1000's	millions
Number of RT needed for a single run		

Radiative transfer (RT) is governed by an equation that describes the propagation of radiation through the atmosphere and predicts the spectrum measured by satellite instruments. Using full-physics methods, the computation of a single clear-sky scene may take several minutes, while for cloudy scenes it may require hours due to the additional complexity introduced by scattering.

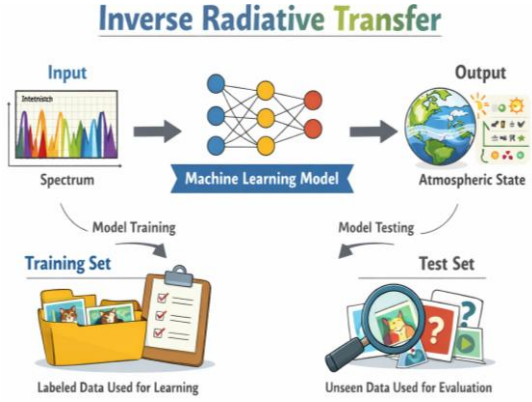
The inversion of the RT is required to analyze satellite observations; this process is known as retrieval. The number of RT simulations required operationally (e.g. IASI-NG produces approximately one million spectra per day) is not compatible with real-time constraints if full-physics models are used.



RTTOV [1] and SIGMA [2] are examples of fast RT models. For meteorological and climatological applications, RTTOV is particularly suitable because it allows efficient computation of radiances at individual frequencies or channels.

RTTOV can be further accelerated using the Matricardi technique [3], which reduces the number of monochromatic RT calculations using Principal Component Analysis (PCA). For an IASI spectrum (~4000 channels), the error obtained using 200 PCA-based RT calculations instead of the full set of monochromatic calculations is typically smaller than the instrument random noise (see red curves).

AI Methods for Radiative Transfer: Studies performed, Opportunities and Challenges



- **Clear/cloudy scene identification**. Classification of scenes prior to retrieval is essential for selecting the appropriate forward model and inversion strategy. IASI scene classification with 90% accuracy [4].
- **Direct radiative transfer problem**. Issue: ***dimensionality curse***. The output consists of thousands of spectral radiances, while the input atmospheric state vector includes hundreds of variables. This high-dimensional mapping is challenging for machine learning models.
- **Inverse radiative transfer problem.** Issue: ***ill-posedness***. Multiple atmospheric states may produce very similar spectra. Regularization techniques are therefore required, typically incorporating prior information. Inverse RT with FORUM simulations for clear-sky [5], and all-sky case [6]. The latter uses latent-twins architecture and a classifier with 94% accuracy.

AI-based methods are significantly faster: after the training phase, a single retrieval typically requires only seconds. They can also estimate parameters that are not directly observable, such as atmospheric properties below cloud layers (through learned statistical correlations). However, the final accuracy and physical consistency are generally lower. The main challenge for the coming years is to improve the robustness, interpretability, and precision of AI-based methods, narrowing the performance gap with physically based approaches.

[1] Saunders, R., Hocking, J., Turner, E., Rayer, P., Rundle, D., Brunel, P., Vidot, J., Roquet, P., Matricardi, M., Geer, A., Bormann, N., and Lupu, C., 2018: An update on the RTTOV fast radiative transfer model (currently at version 12), Geosci. Model Dev., 11, 2717-2737 (2018)
[2] Masiello G., Serio C., Maestri T., Martinazzo M., Masin F., Liuzzi G., Venafra S., The new σ-IASI code for all sky radiative transfer calculations in the spectral range 10 to 2760 cm-1: σ-IASI/F2N, Journal of Quantitative Spectroscopy and Radiative Transfer, 312, 108814 (2024)
[3] Matricardi, M.: A principal component based version of the RTTOV fast radiative transfer model, Q. J. Roy. Meteor. Soc., 136, 1823–1835, (2010)
[4] Zugarini C., Sgattoni C., Sgheri L.: Machine Learning for Cloud Detection in IASI Measurements: A Data-Driven SVM Approach with Physical Constraints, arXiv:2508.10120 (2025)
[5] Sgattoni C., Sgheri L. and Chung M.: A data-driven approach for fast atmospheric radiative transfer inversion, Inverse Problems 41, 085006 (2025)
[6] Sgattoni C., Sgheri L. Chung M., Martinazzo M.: Latent Twins: A Framework for Scene Recognition and Fast Radiative Transfer Inversion in FORUM All-Sky Observations, arXiv:2512.24865 (2025)