Advanced σ Radiative Transfer Model: Enhancing Atmospheric Remote Sensing for Earth and Planetary Exploration

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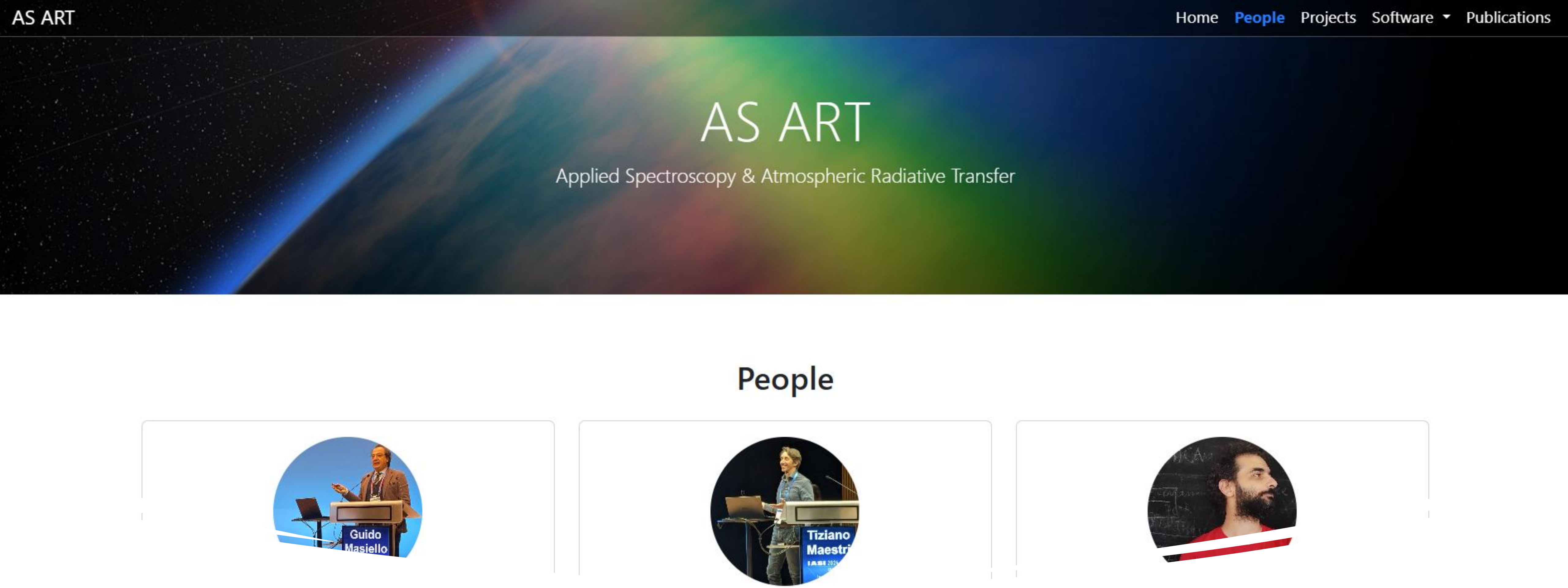

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Outline

The Model

Lines

Aerosols

Applications

Polar Stratospheric Clouds

Mars

Future Developments

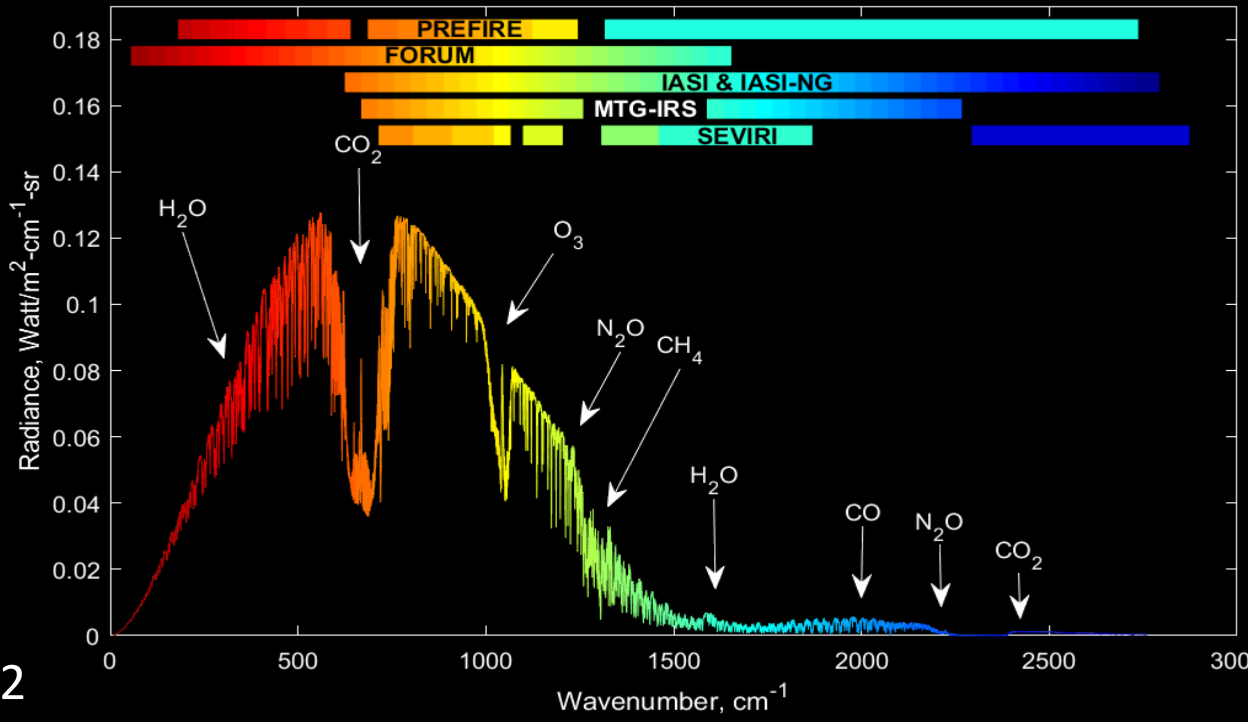
σ-IASI/F2N, → σ

The RTM developed in the framework of EUMETSAT programs

- Assessment of IASI data for the Atmosphere (1996-2004) grants
  - EUM/CO/96/407/DD, EUM/CO/99/688/DD, EUM/CO/02/1053/PS
- Italian Space Agency ASI programs (2019-Now)
  - FORUM-Scienza Program of Italian Space Agency (Contract No. 2019-20-HH.0, P.I. CNR-INO)
  - FIT-FORUM (contract n. 2023-23-HH.0, CUP F33C23000240005, P.I. DIFA, University of Bologna),
  - MC-FORUM (contract n. 2023-23-HH.0, CUP F93C2300046000, P.I. IBE-CNR)
- Pseudo-monochromatic
- OD databases (parametrized in T and ρ)
- Clouds and aerosols properties (parametrized in ρ and r_{eff})
- Analytical Derivatives in clear and clouds
- Masiello, G., Serio, C., Liuzzi, G., Venafra, S., Maestri, T., Martinazzo, M., Amato, U., & Grieco, G. (2023). σ-IASI (2.4). Zenodo. https://doi.org/10.5281/zenodo.8152674
- Masiello et al 2024, doi:10.1016/j.jqsrt.2023.108814

More details about Radiative Transfer Calculations

- Spectral Range : 5-3000 cm^{-1}
- Surface Type: Lambertian or Specular
- Radiance
- Jacobian with respect to
  - Temperature,
  - H2O, HDO, CO2, O3, N2O, CO, CH4, SO2, NH3, HNO3, OCS, CF4, CFC11, CFC12, HFC22,CCL4 concentrations
  - Surface Temperature and Emissivity
  - Liquid cloud re, and concentrations
  - Ice cloud re, and concentrations
  - Aerosols re, and concentrations
  - H2O self and foreign continua coefficients, CO2 foreign continuum coefficients
- High resolution 10^{-2} cm^{-1}



Spectral coverage of FORUM,PREFIRE, IASI-NG and MTG-IRS

Gases OD Look-Up-Table: Parametrization

Low order (2) Polynomial Interpolation

1) For the trace gases (*N*)

$$\tau_{i,N,\sigma} = \rho_{i,N}\left(C_{0,i,N,\sigma} + C_{1,i,N,\sigma}\Delta T_i + C_{2,i,N,\sigma}\,\Delta T_i^2\right)$$

- $\rho_{i,N}$ is the mixing ratio of the species *N* at layer *i*,
- ΔT_i is the difference between the actual and reference temperature
- $C_{0,i,N,\sigma}$, $C_{1,i,N,\sigma}$, $C_{2,i,N2,\sigma}$, parabolic fit coefficients

2) For main radiatively Active species (H2O Earth, CO2 Mars and Venus, CH4 Uranus…)

$$\tau_{i,W,\sigma} = \rho_{i,W}\left(C_{0,i,W,\sigma} + C_{1,i,W,\sigma}\Delta T_i + C_{2,i,W,\sigma}\,\Delta T_i^2 + C_{3,i,W,\sigma}\,\Delta\rho_{i,W}\right)$$

- $\rho_{i,W}$ is the water vapour mixing ratio ,
- $\Delta\rho_{i,W}$ is the difference between the actual and reference water vapour profiles
- $C_{3,i,N,\sigma}$, Takes into account self broadening of Water Vapour

Clouds and Aerosols OD parametrization

- According the Chou approximation (Chou et al 1999), particles scattering contribution is accounted for by replacing the optical depth with an apparent optical depth for extinction:

$$\tau = \frac{3}{4}\frac{x_{pc}}{r_e \rho_p}\tilde{\beta}\Delta z$$

$$\tilde{\beta} = \beta[(1-\omega) + b\omega]$$

β, b, ω are parametrized as a function of r_e , if Y is one among β, b, ω

$$Y = \sum_{i=1}^{7} P_i x^{i-1}; \quad x = \frac{1}{r_e + t}$$

With P_i, t function of wavenumber

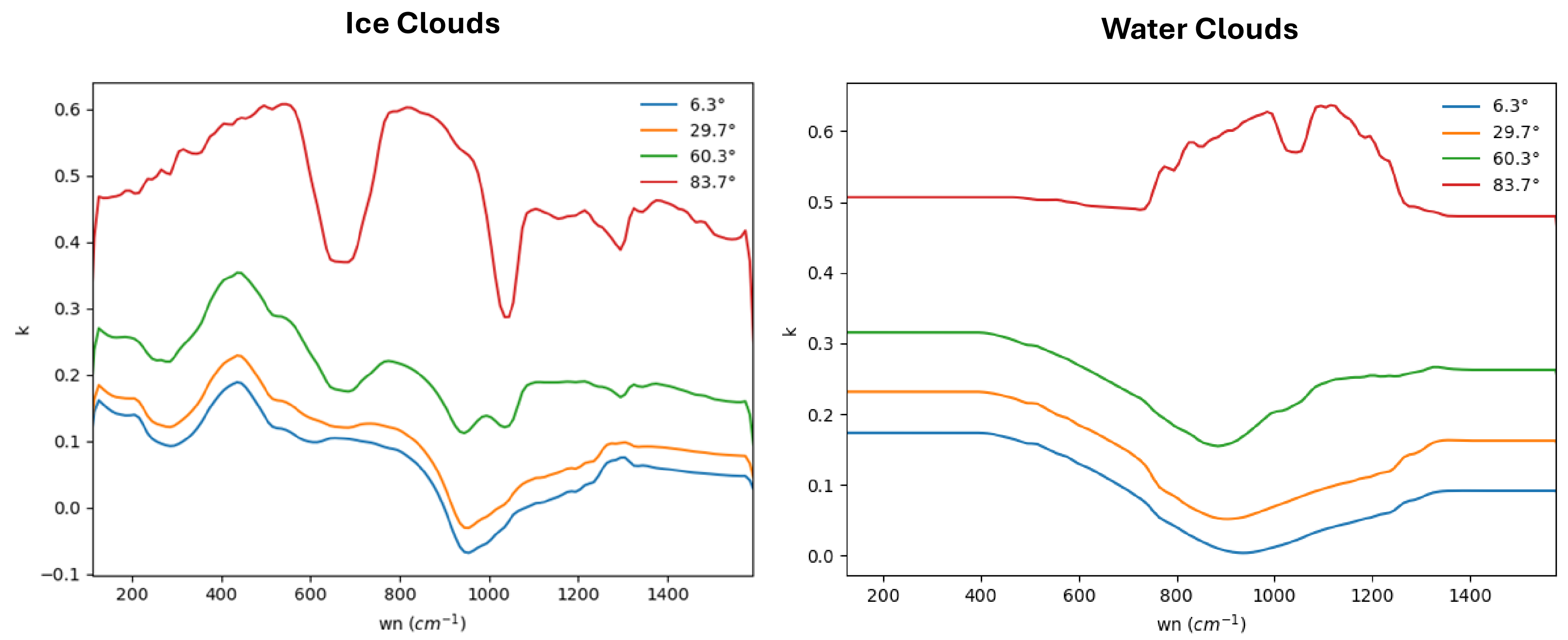
From Chou to Tang to k-Tang

- The application of scaling methodologies introduces errors that are generally acceptable in the MIR for most realistic cloud scenarios. On the other hand, when simulations of ice clouds in the FIR are considered, accurate results are obtained only in the case of optically thin clouds (OD < 0.1-1).
- A possible way to improve the scaling method proposed by Chou is described in the work by Tang et al. 2018

$$I_{tang}^{n} = \boldsymbol{k}_{tot} \frac{\omega_{tot} b_{tot}}{[1 - \omega_{tot}(1 - b_{tot})]} \left[\left(I_n^{\downarrow} - B_n \right) - \left(I_n^{\downarrow} - B_n \right) e^{-2\tau_n^*} \right]$$

Our *K*-Tang Methodology

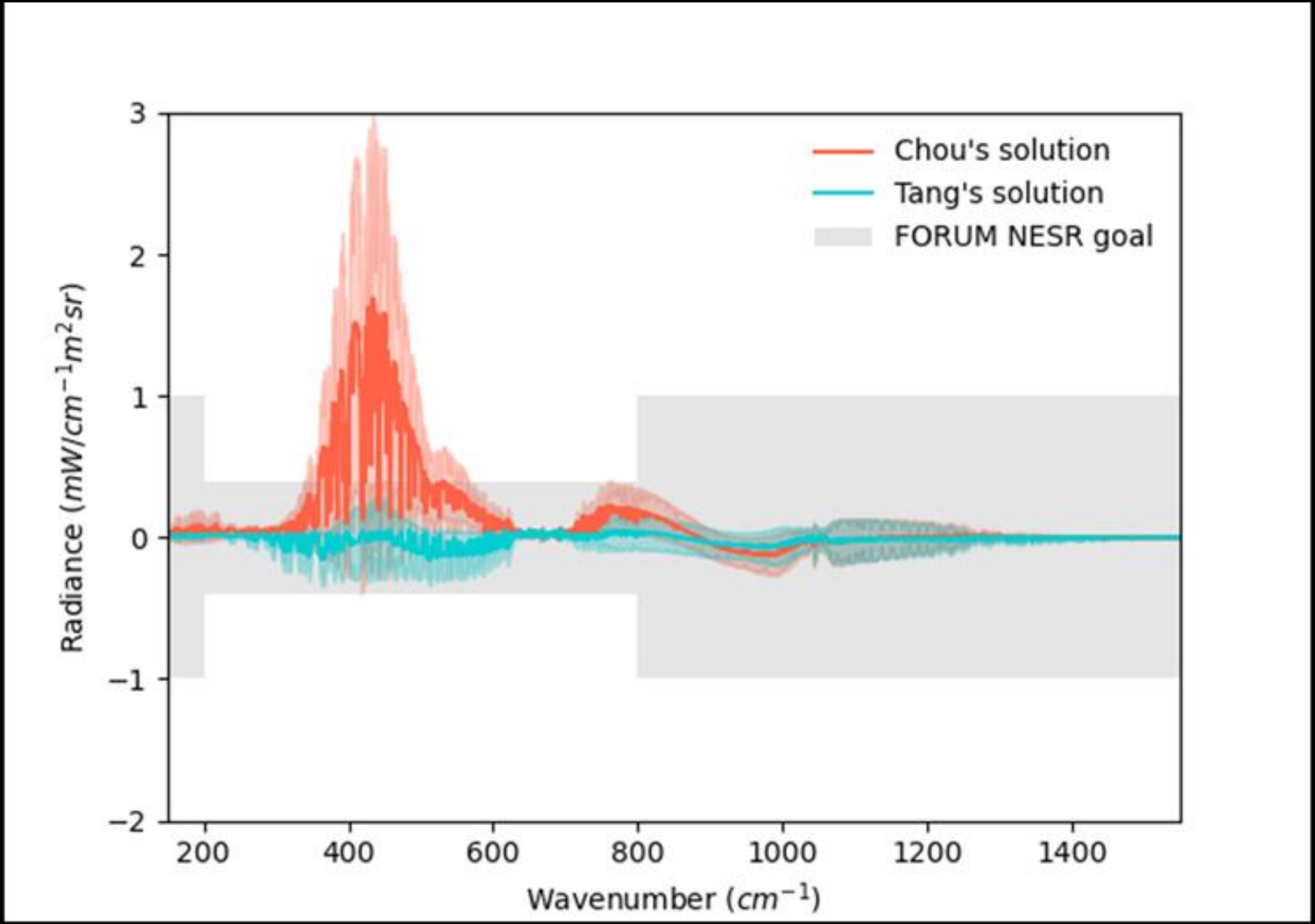
- Tang's correctional coefficients are provided at nadir and at for 4 gaussian angles after a smoothing filtering procedure.
- The k(μ) values are produced from accurate simulations obtained with the DISORT model for four gaussian angles (6.3°, 29.7°, 60.3°, and 83.7°).



$$k\left(r_{eff},\mu\right) = P_0(\mu) + P_1(\mu)\frac{1}{r_{eff}} + P_2(\mu)\frac{1}{r_{eff}^2}$$

Comparison with line-by-line and multiple scattering

ESA FORUM (Far-infrared Outgoing Radiation Understanding and Monitoring) is the **9th Earth Explorer mission** and the **first satellite** dedicated to measuring Earth's **far-infrared** energy.
It will provide critical insights into the greenhouse effect and heat loss.
Scheduled for Launch **2027**.

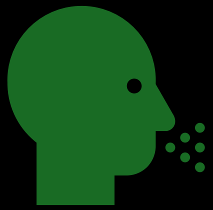


Fast models: parameterizations

Gases

Polynomial with respect

- concentration
- Temperature

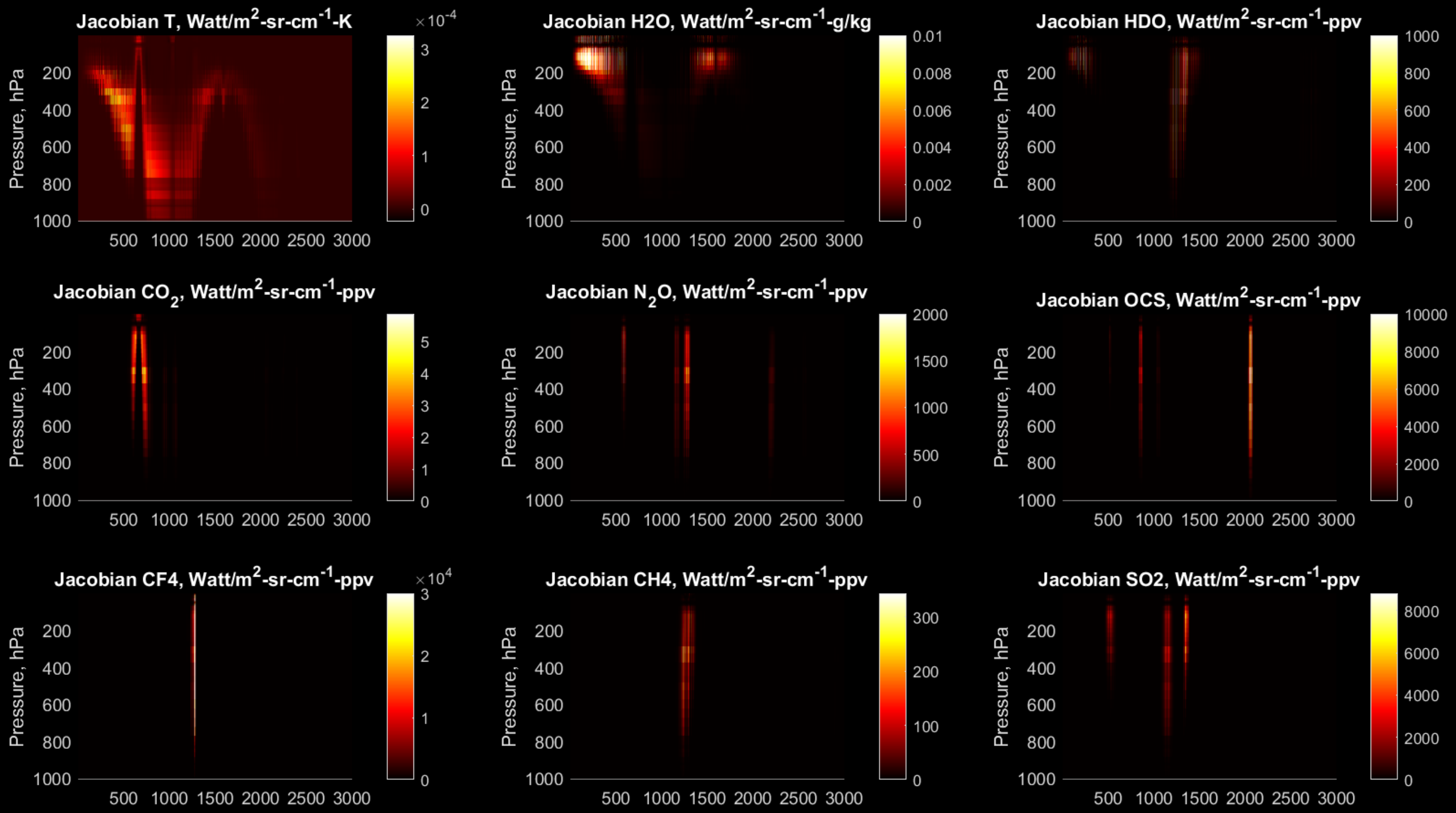


Aerosols

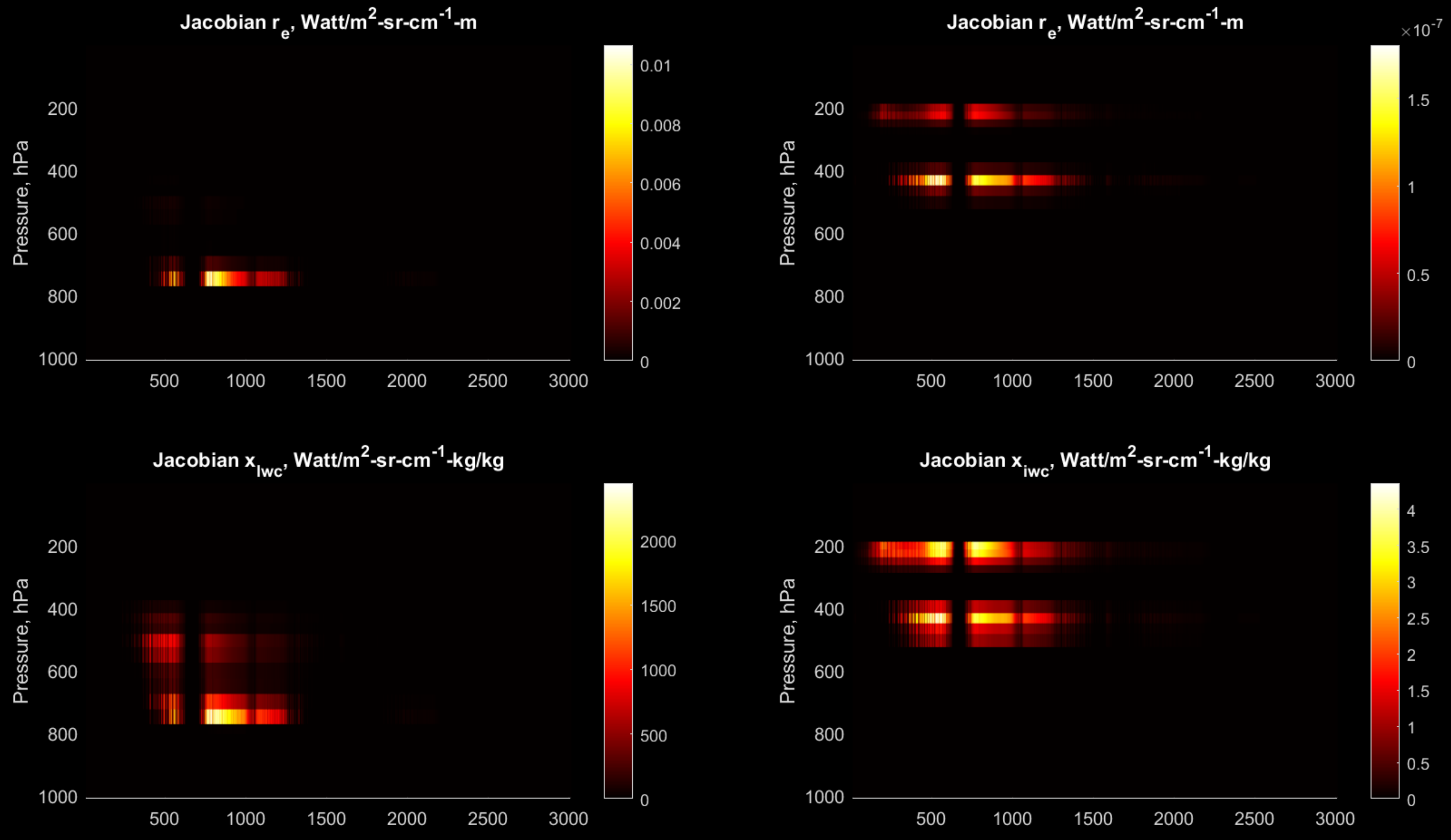
Polynomial with respect to

- concentration
- effective dimensions

Gases and Temperature Jacobians



Clouds and Aerosols Jacobians

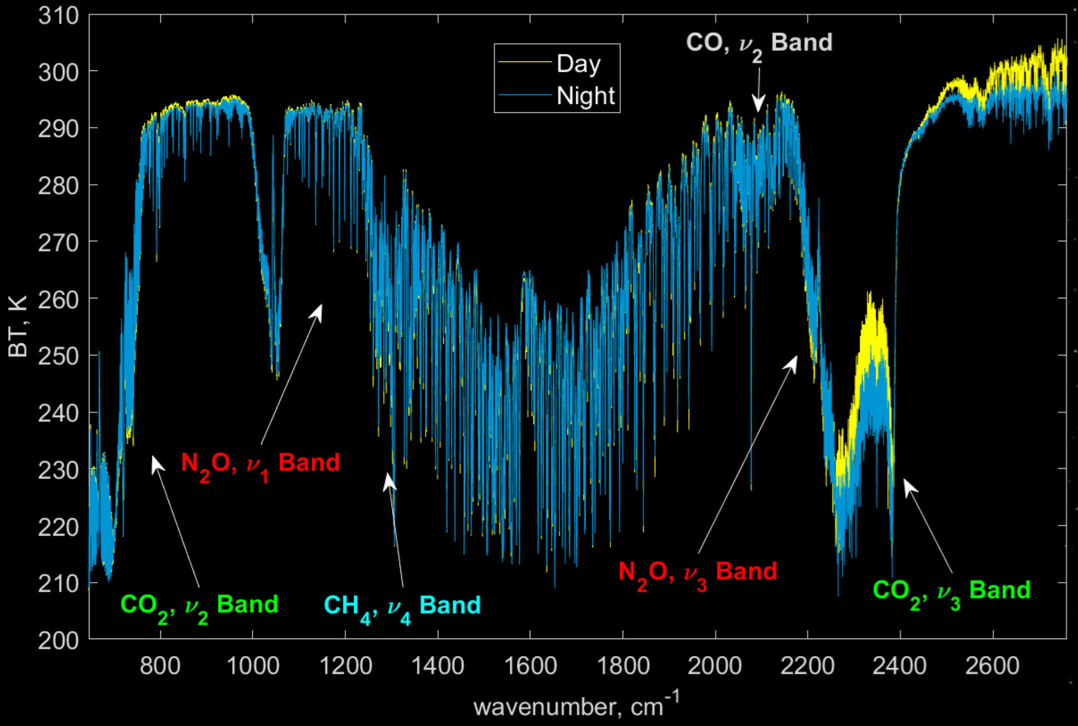


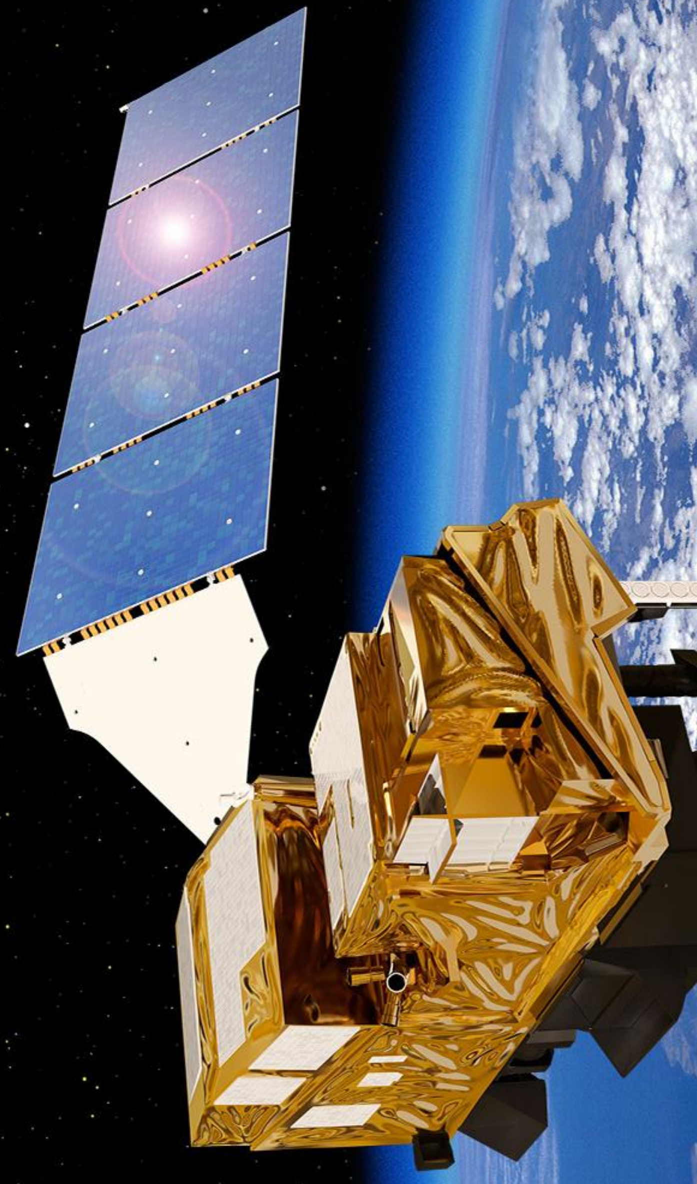
Applications

Retrieval of Polar Stratospheric Cloud

IASI (Infrared Atmospheric Sounding Interferometer)

IASI is a Michelson Interferometer, developed at CNES/EUMESAT, measuring the spectral distribution of the atmospheric radiation covering the Spectral range 15.5 to 3.62 micron with a sampling rate of 0.25 cm^{-1}





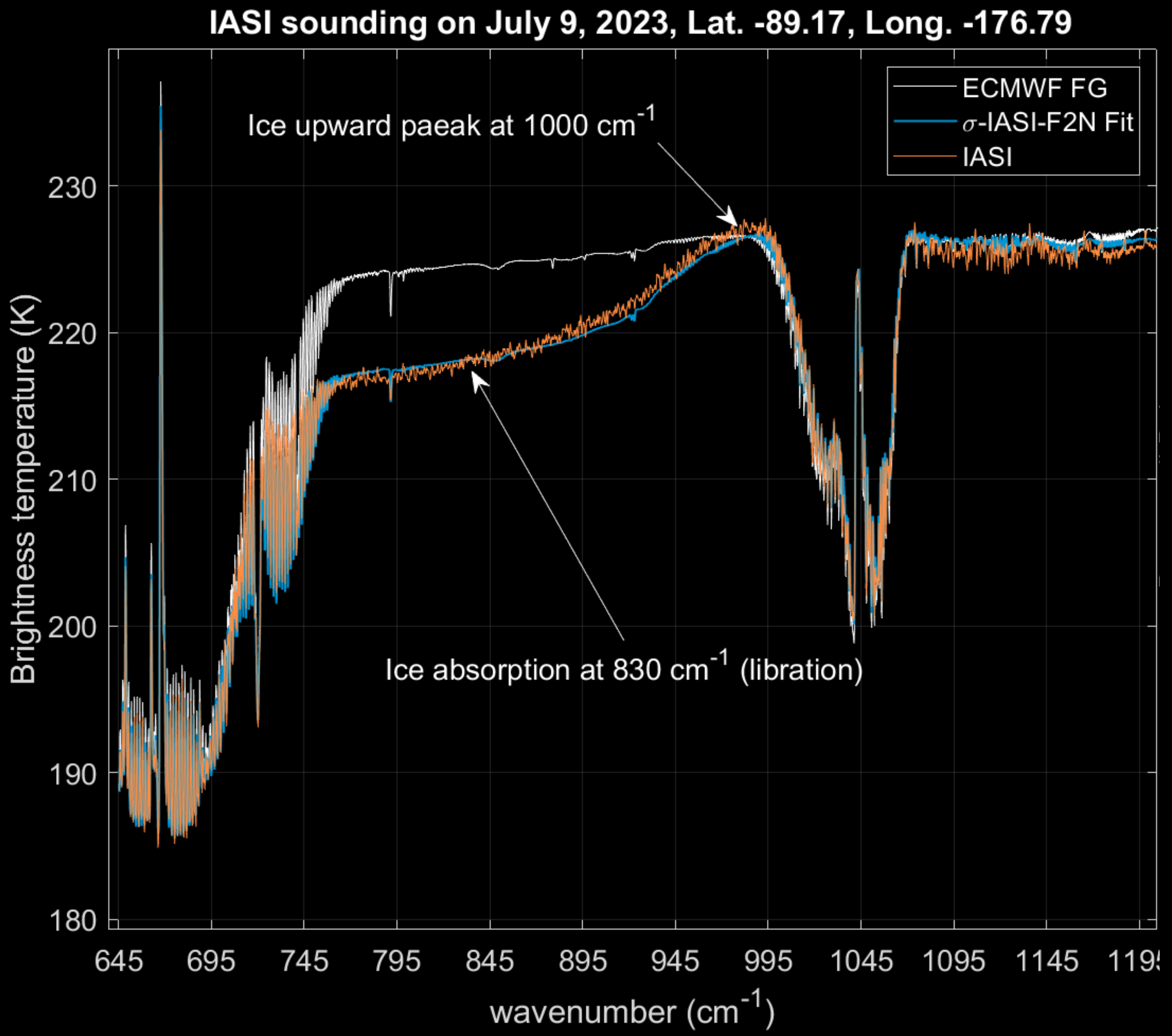
MetOp-A (2006 -2021)
MetOp-B (2012-Now)
MetOp-C (2018-Now)

http://smsc.cnes.fr/IASI/

Next generation of IASI has been launched on August 13 2025.

Retrieval of Polar Stratospheric Cloud

P=43 hPa (~20 km)
T=182 K
IWC=4.5 10^{-7} kg/kg
D_e=4 um



Orange – IASI Measurement

White – Computed with ECWMF profile

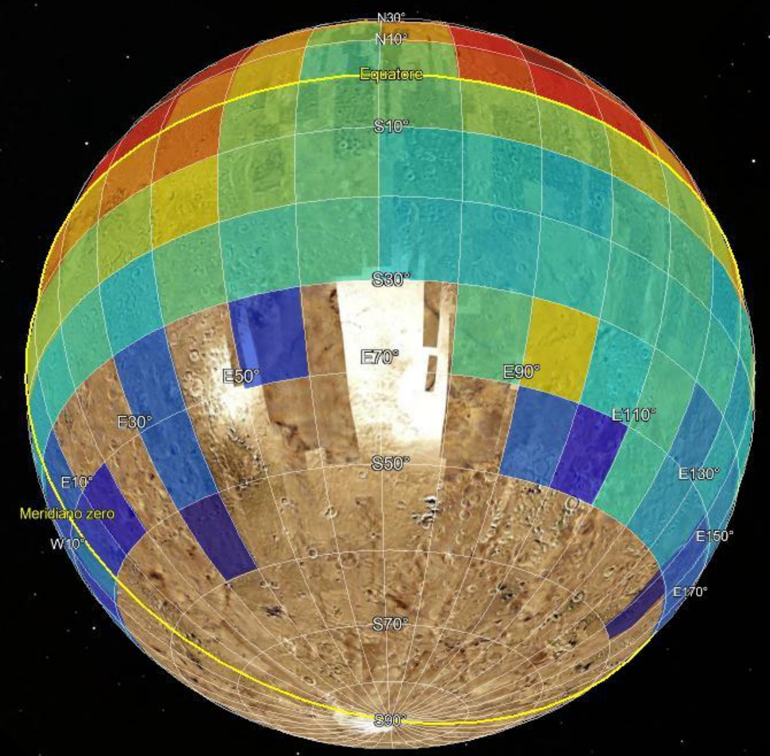
Blue – Computed with IASI retrieved profile

Serio et al. 2024 doi:10.1016/j.jqsrt.2024.109211

Applications

Application to MARS

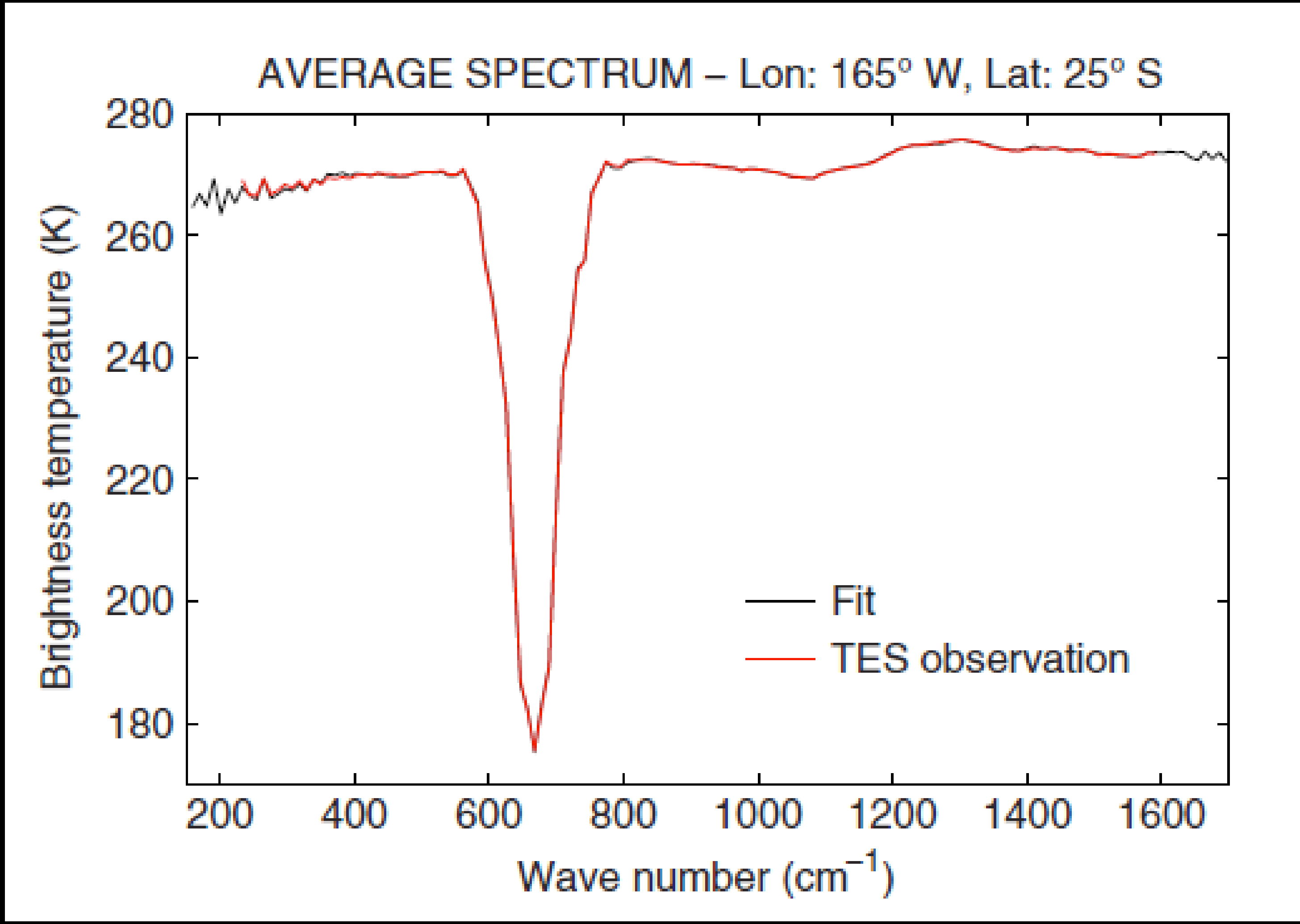
- Thermal Emission Spectrometer (TES) spectra
- We applied the same methodology to Martian atmosphere and surface
- Liuzzi et al. (2015) doi:10.1364/AO.54.002334



Martian Spectra and Geophysical Parametrs

We retrieved from TES spectrum

- Profile of Temperature
- dust aerosol mass mixing ratios
- Ice mass mixing ratios
- surface skin temperature
- Emissivity coefficients
- water vapor integrated columnar amount



Future developments

- **Application to Mars**
  - Lorenzo Buriola
    Poster 47
- **Implementation of NLTE**
  - Lorenzo Cassini
    Poster 52

Conclusions

We developed a fast RTM that enables

Retrieval of physical parameters

Assessment spectroscopy

Consider both gases and particles

It can be applied to planetary atmosphere

More information and Contact

https://www.as-art.it/

Special Issue

Advances in Far-to-Near Infrared Quantitative Spectroscopy and Application to Remote Sensing, in Honor of Prof. Carmine Serio

Guest Editors

Dr. Guido Masiello
Dr. Tiziano Maestri
Dr. Giuliano Liuzzi

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remote sensing

IMPACT FACTOR 4.1

CITESCORE 8.6