The FIT-FORUM project: status and perspectives

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FIT-FORUM project

FIT-FORUM – **Forward and Inverse Tool for FORUM** is a research project developed within an Implementation Agreement (n. 2023-23-HH.0) between ASI and the University of Bologna which coordinates 5 more teams with specific expertise on rt modelling and remote sensing.

FIT-FORUM contributes to the "Scientific activities to support the development of Earth Observation missions", promoted by ASI.

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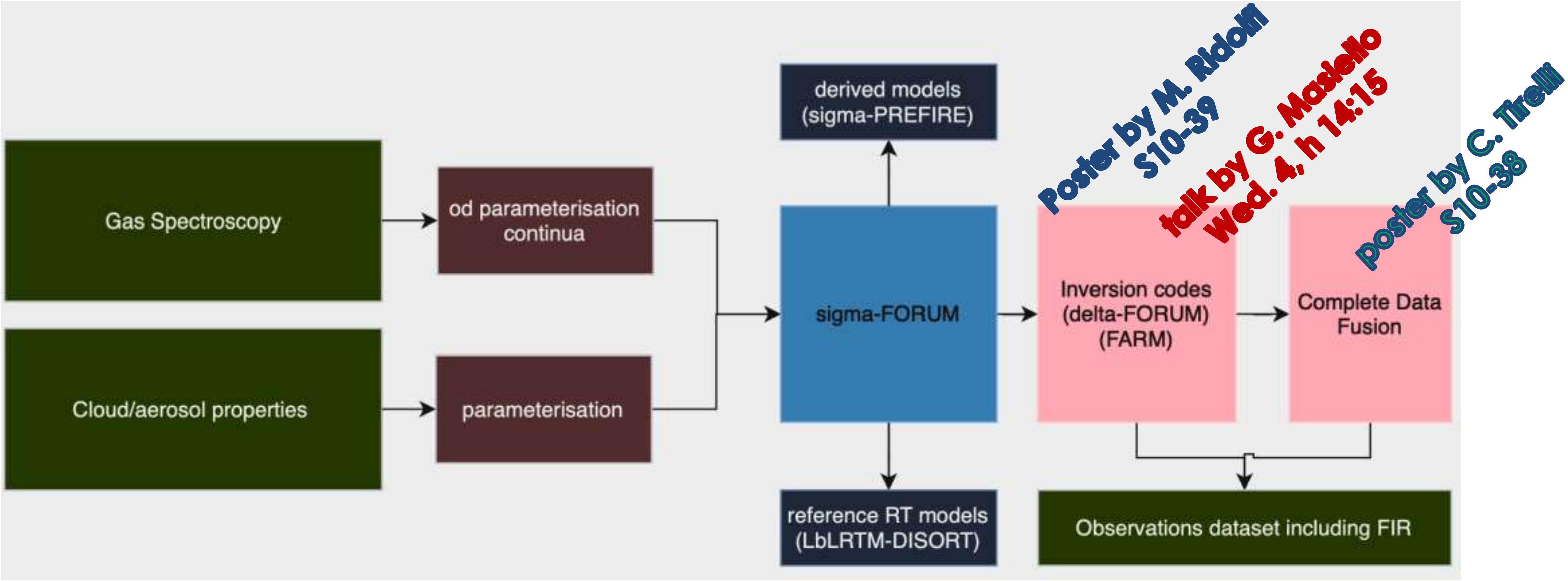
FIT-FORUM Goal

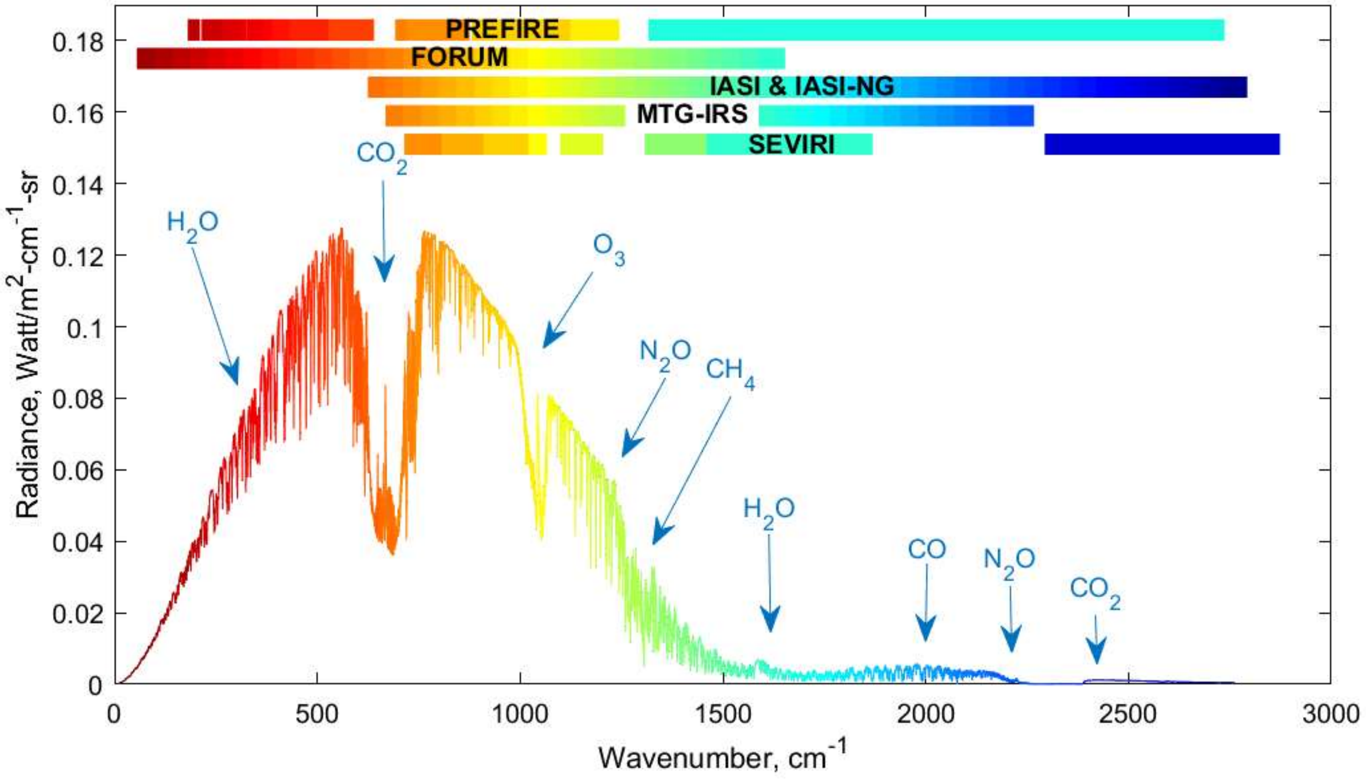
The FIT-FORUM general goal is **to develop a set of advanced and innovative tools along the entire radiative transfer chain at far and thermal infrared.**



The Forward model: σ-FORUM (σ-IASI/F2N)

The forward model is a **fast, accurate physical rt model** derived from σ-IASI (developed by Unibas it in the framework of EUMETSAT programs starting about 25 years and then in activities supported by ASI and related to the FORUM mission).

σ-FORUM (https://zenodo.org/record/7019991#.Y3ns-S8w1B3) is a fortran modular code which is under continuous upgrade in each one of its modules.



Pseudo-monochromatic rt on the 5-3000 cm-1 spectral range

- OD databases (parametrized)
- Clouds and aerosols properties (parametrized)
- In presence of scattering layer the code accounts for a Chou+Tang solution
- Analytical Derivatives
- SW radiation

Why a physical RT model for the analysis of FORUM observations?

The FORUM mission will observe the FIR part of the spectrum which has never been observed spectrally from space before with the same accuracy.

Our knowledge of some important processes is still poor, such as the characterization of the related physical parameters.

Two examples:

Spectroscopy

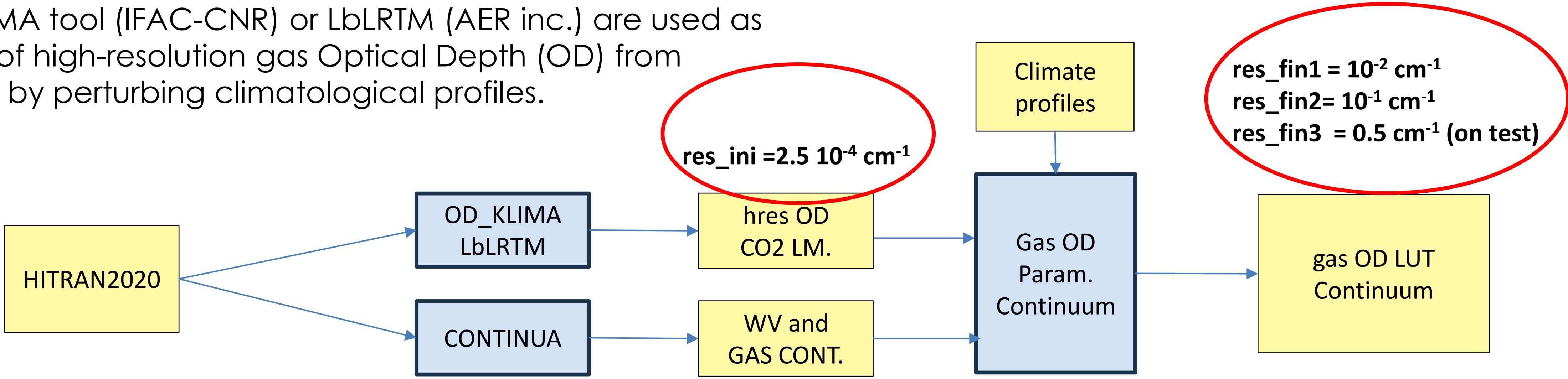
- The water vapor continuum absorption is still subjected to large uncertainties (especially at low temperatures and low pressure)

Cloud microphysics and optics

- The minimum in the imaginary part of the refractive index of ice enhances the role of scattering at FIR. Cirrus clouds scattering properties at FIR are strongly dependent on crystal shape.
- Ice refractive index at FIR are dependent on temperature. This dependency is not accounted for in our current reference database.

Gas OD Parameterization

The OD_KLIMA tool (IFAC-CNR) or LbLRTM (AER inc.) are used as generators of high-resolution gas Optical Depth (OD) from HITRAN2020 by perturbing climatological profiles.



- Gas OD are parameterized as **second order polynomials** of layer Temperature and concentration
- **OD polynomial fits** are first obtained on the High-Resolution OD and then fitted on the final desired resolution.
- For the CO_2 we use the **Line-Mixing** (LM) package provided by HITRAN2020: Full diagonalization LM function (Gordon et al., JQSRT 2021).
- the **continuum absorption** can be either computed using the MT_CKD method or by inquiring look-up tables for CIAs coefficients (created for each pair of collisional partners)

Fitted OD:

- H2O,
- CO2,
- O3,
- N2O,
- CO,
- CH4,
- SO2,
- HNO3,
- NH3,
- OCS,
- HDO,
- CF4

Grouped OD:

- O2
- NO
- NO2
- OH
- HF
- HCL
- HBR
- HI
- CLO
- H2CO
- HOCL
- N2
- HCN
- CH3CL
- H2O2
- C2H2
- C2H6
- PH3
- CCL3F (CFC-11)
- CCL2F2 (CFC-12)
- CCL4
- CHCLF2

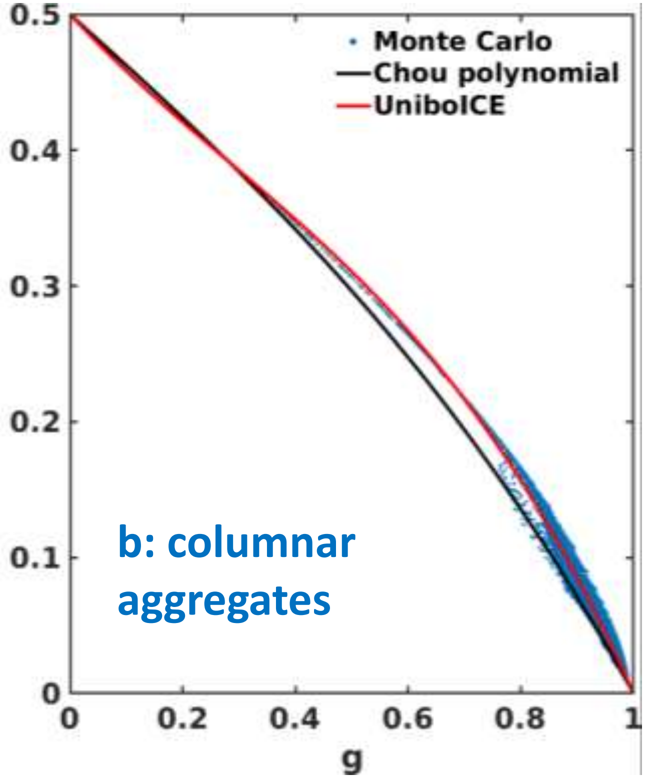
Cloud and aerosols Properties

The optical properties comprise accurate computations of the Chou parameters, b, and Tang adjustments coefficients, k(μ) for multiple sets of PSDs

PSDs types	LBLDIS	σ-FORUM	Comments
Liquid water clouds (Downing and Williams, 1975)	**Tested**	**Tested**	
Columnar Aggregates (Ping Yang, 2013)	**Tested**	**Tested**	
Hexagonal plates (Ping Yang, 2013)	**Tested**	**Testing phase**	
Hexagonal columns (Ping Yang, 2013)	**Tested**	**Testing phase**	
Bullet rosettes (Ping Yang, 2013)	**Tested**	**Testing phase**	
Mixed phase clouds (Warren and Brandt, 2008)	**Tested**	**Testing phase**	Coated spheres.
Volcanic dust (HITRAN database)	**Tested**	**Testing phase**	Extended to 100 cm^{-1} using liquid water refractive index.
Mineral transported (HITRAN database)	**Tested**	**Testing phase**	Extended to 100 cm^{-1} using liquid water refractive index.
Black carbon (HITRAN database)	**Tested**	**Testing phase**	Extended to 100 cm^{-1} using liquid water refractive index.
PSC type II (Ice) (Warren and Brandt, 2008)	**Tested**	**Testing phase**	Hexagonal columns and small ice droplets for D<2 microns.

talk by L. Cassini Wed. 4, h 11:55

$$b = \frac{1}{2}\int_0^{2\pi}\frac{1}{2\pi}d\phi\int_0^{2\pi}\frac{1}{2\pi}d\phi'\int_0^{1}d\mu\int_{-1}^{0}P(\mu,\phi,\mu',\phi')d\mu'$$



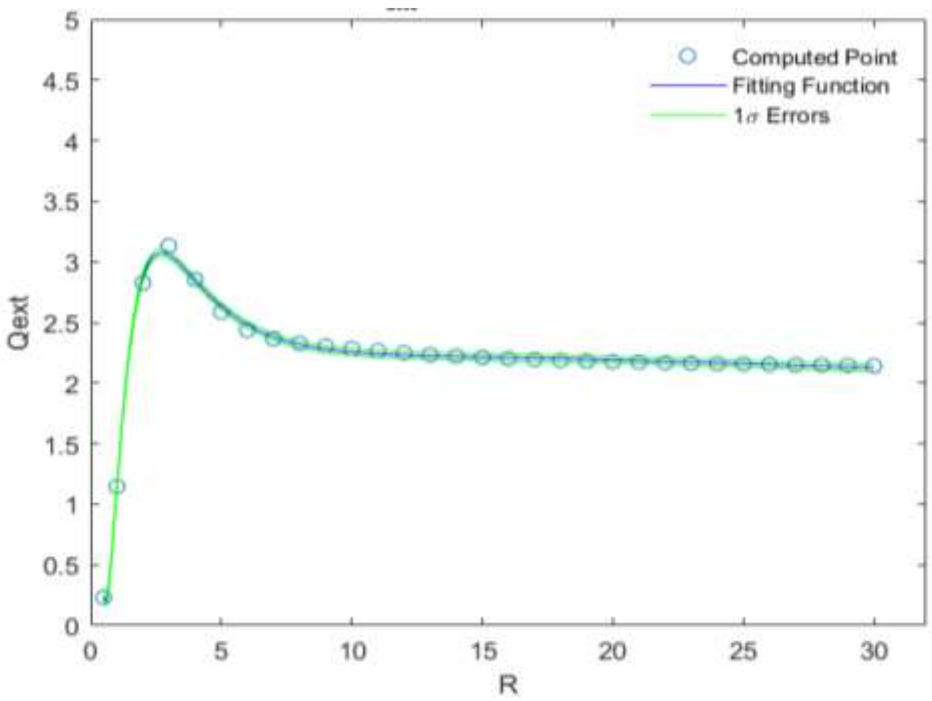
σ-FORUM cloud and aerosol parameterisation

Main optical parameters are parameterized as function of the inverse of the effective radius.
A variable scaling term is used to obtained an accurate fit (relative rmse about 10^{-4})

- Extinction efficiency Q_{ext}
- Single scattering albedo ω_0
- Asymmetry parameter g
- Chou parameter b
- …

$$Property = \alpha_0 + \alpha_1 x + \cdots + \alpha_6 x^6,$$

$$x = \frac{1}{r_{eff} + t}$$



Ice column aggregate parameterization **RMSE**s

Parameter	Q_{ext} (k_{ext} for Chia–pang)	ω_0	g	b
RMSE	$\sim 10^{-3} - 10^{-4}$	$\sim 10^{-3} - 10^{-4}$	$\sim 10^{-4}$	$\sim 10^{-4}$
Chia-Pang RMSE	$\sim 10^{-2} - 10^{-3}$	$\sim 10^{-3} - 10^{-4}$	$\sim 10^{-4}$	/

Tang’s adjustment term

The Tang’s adjustment term is independently calculated and linearly added to the final solution as follow:

$$I_v = \underbrace{\boxed{\epsilon_{g,v} B_v(\theta_g) T_{0,v} + \int_0^{\infty} B_v(\theta) \frac{\partial T_v}{\partial z} dz + (\epsilon_{g,v} - 1) T_{0,v} \int_0^{\infty} B_v(\theta) \frac{\partial {T_v}^*}{\partial z} dz + \frac{1 - \epsilon_{g,v}}{\pi} T_{s,v} \mu_s U_s}}_{\text{σ-FORUM original routine}} + \underbrace{\boxed{I_{tang}}}_{\text{Tang adjustment routine}}$$

Where:

$$I_{tang} = \sum_{n=1}^{N\,layer} I_{tang}^{n} T(z_n, z_{top}) \qquad \text{and} \qquad I_{tang}^{n} = \boldsymbol{k}_{tot} \frac{\omega_{tot} b_{tot}}{[1 - \omega_{tot}(1 - b_{tot})]} \left[(I_n^{\downarrow} - B_n) - (I_n^{\downarrow} - B_n) e^{-2\tau_n^*} \right]$$

- $T(z_n, z_{top})$ the transmissivity from the level n to the TOA
- τ_n^* the scaled optical depth of the n-th layer.

Tang's adjustment scheme implementation and multiple scatterers in the layer

The contribution from a single layer is given by:

$$I^n_{tang} = \boldsymbol{k}_{tot} \frac{\omega_{tot} b_{tot}}{[1-\omega_{tot}(1-b_{tot})]} \left[\left(I^{\downarrow}_n - B_n\right) - \left(I^{\downarrow}_n - B_n\right) e^{-2\tau^*_n} \right]$$

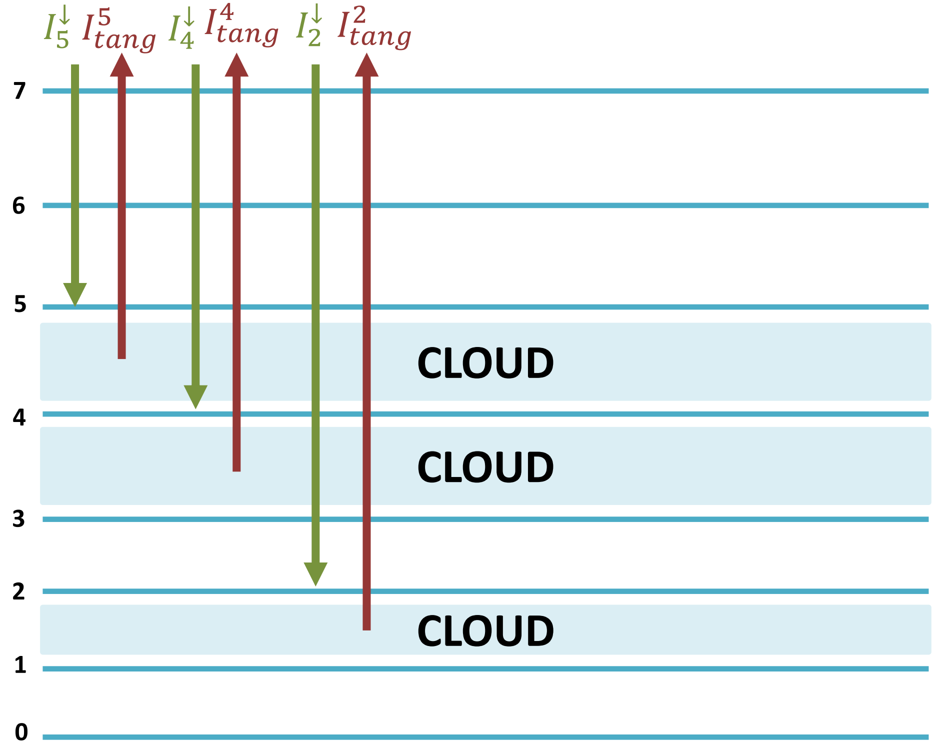
Where the optical depth of the layer is:

$$\tau^*_n = [1-\omega_{tot}(1-b_{tot})]\tau_n$$

And the optical properties τ_n, b_{tot}, ω_{tot} and k_{tot} are calculated for the whole layer (particles and gas).
In case of liquid and ice phase in the same layer:

$$\omega_{tot} = \frac{\beta^{sca}_{ice} + \beta^{sca}_{wat}}{\beta^{ext}_{ice} + \beta^{ext}_{wat} + \beta^{ext}_{gas}} \qquad b_{tot} = \frac{b_{ice}\beta^{sca}_{ice} + b_{wat}\beta^{sca}_{wat}}{\beta^{sca}_{ice} + \beta^{sca}_{wat}}$$

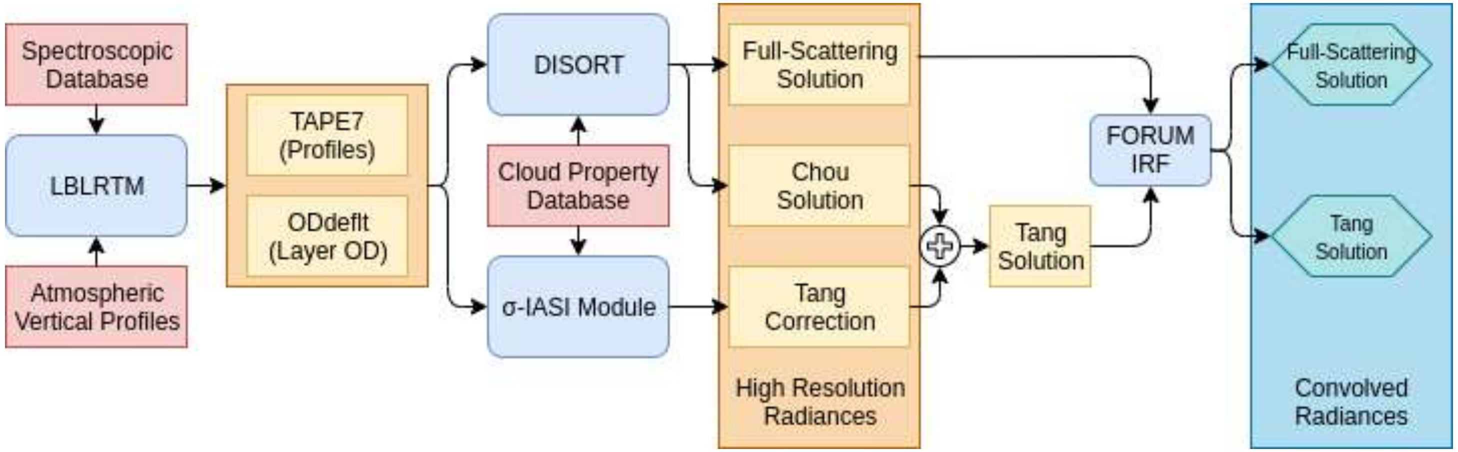
With β is the ext/scatt/abs coefficient [1/m].



New quantities computed by σ-FORUM.

The Tang adjustment coefficient

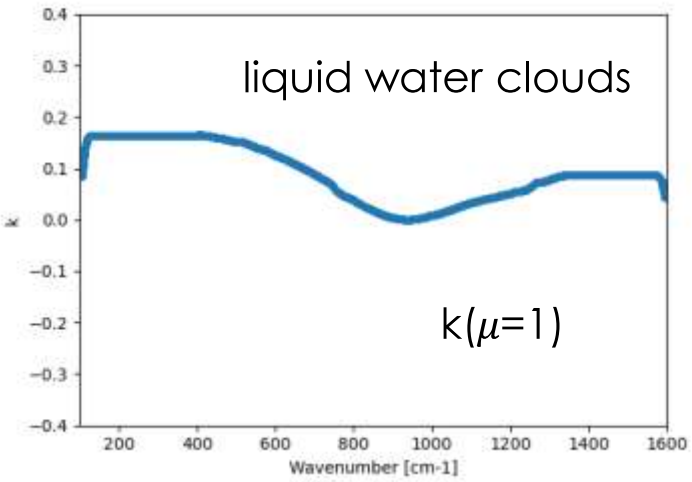
The Tang coefficients is spectrally derived for a set of observational angles for a large set of climatological atmospheric conditions and cloud properties



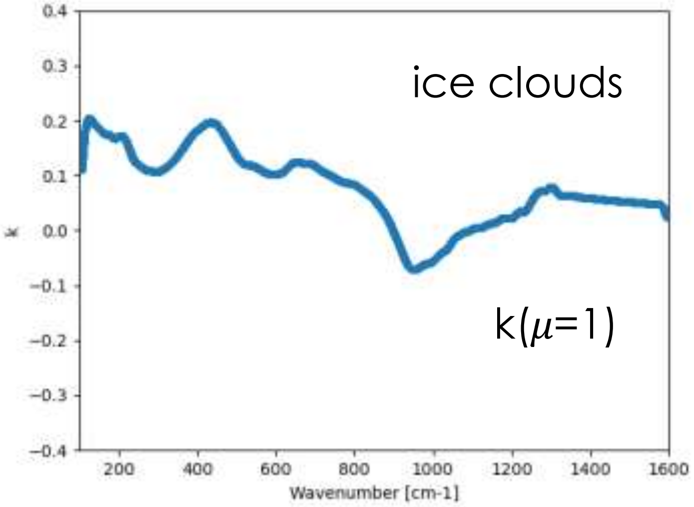
Chou's differences with respect to full-scattering solution

$$k_{\square}(\mu) = F_2 \; \frac{1}{2} \frac{F_1\left(\Delta I_{\square}(\mu)\right)}{F_1\left(I^{ss}_{\square,tot}(\mu)\right)}$$

Tang correction to spectral radiance

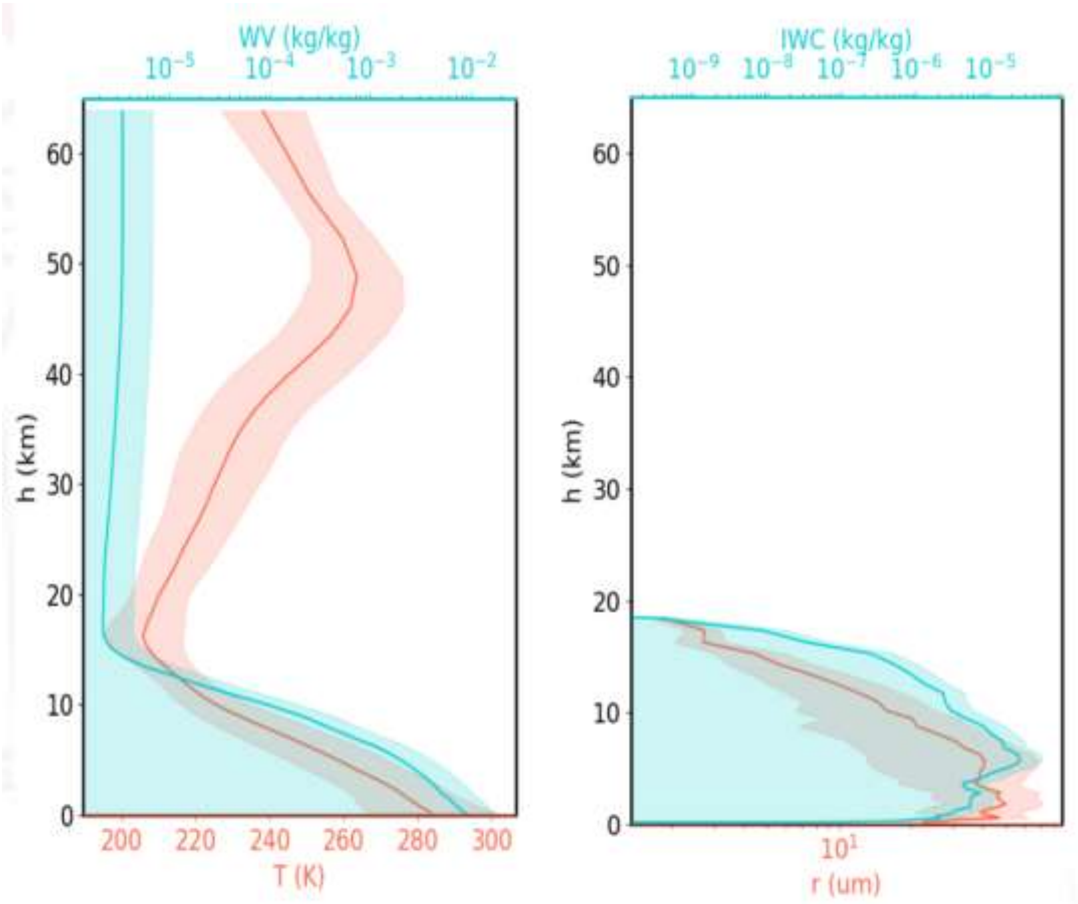


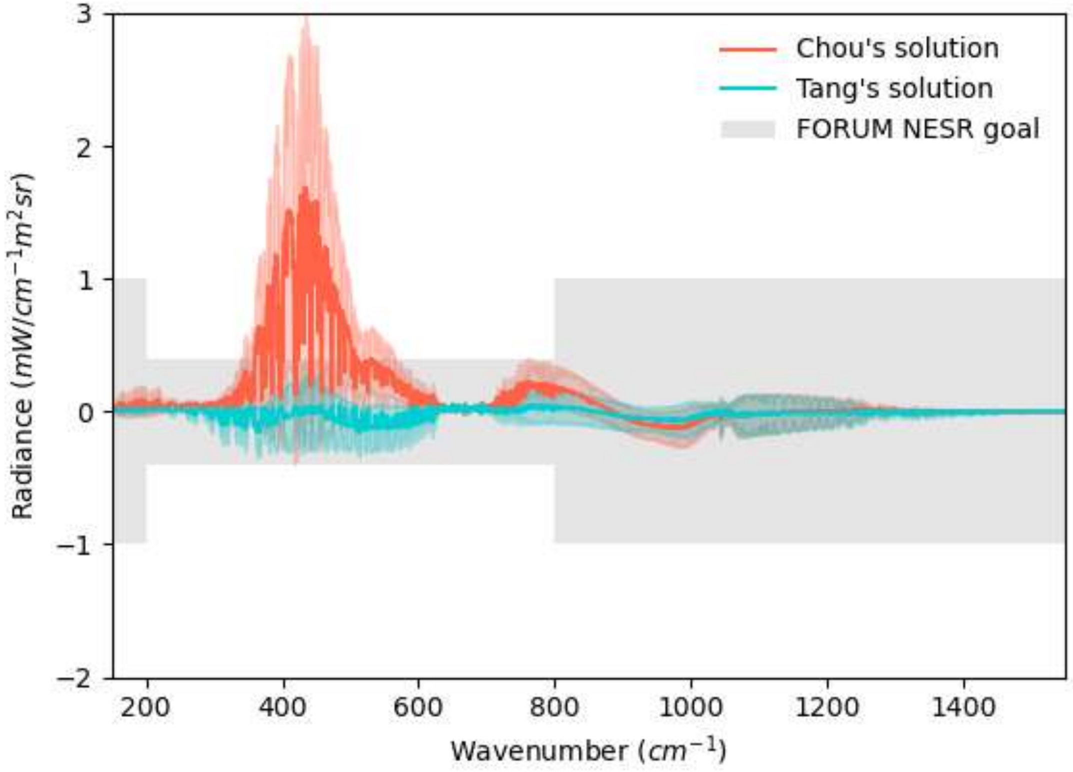
$$k_{tot} = \frac{k_{ice} b_{ice} \beta^{sca}_{ice} + k_{wat} b_{wat} \beta^{sca}_{wat}}{b_{ice} \beta^{sca}_{ice} + b_{wat} \beta^{sca}_{wat}}$$



Application to SAF reduced dataset

Average differences between approximate methodologies (Chou and Tang) and a reference model (DISORT 32 streams) computed for the NWP SAF reduced set database (60 levels).





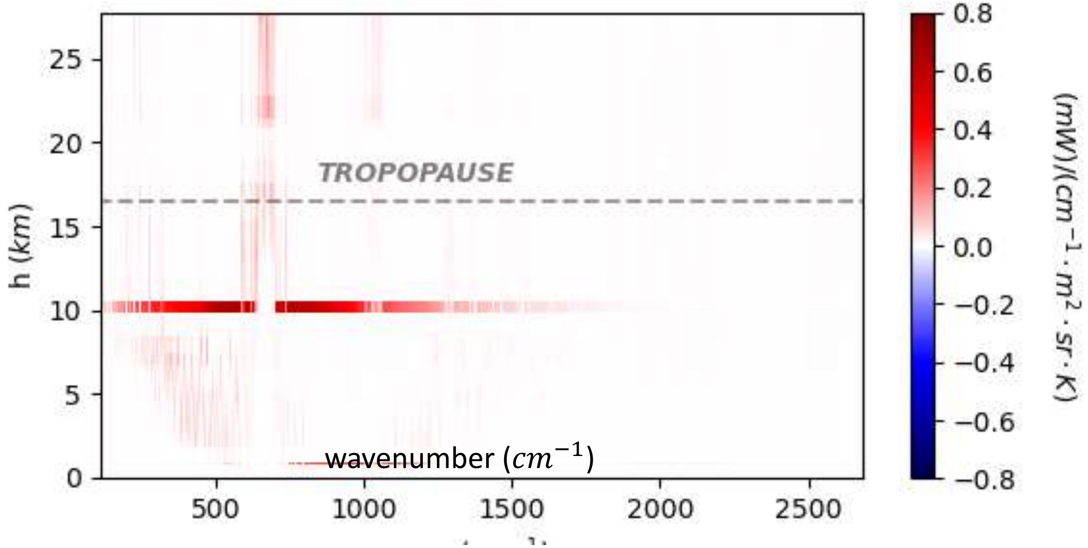
Only cloudy scenes are considered (54 scenes).

Analytical derivatives

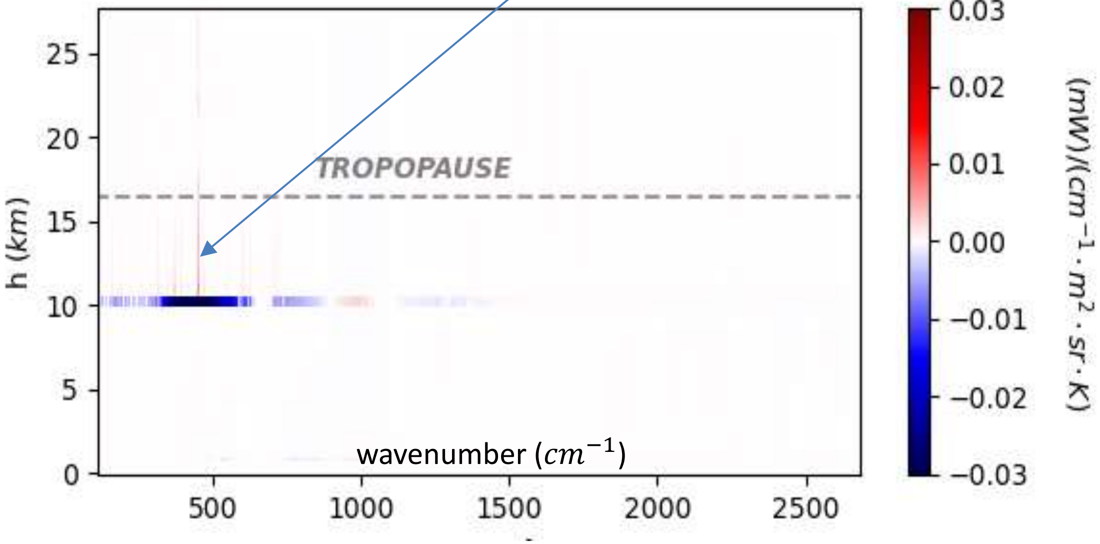
The analytical Jacobian for the Tang adjustment term is computed:

$$\boldsymbol{J}\left(\sum_{n=1}^{N}\left[k_{tot,n}\frac{\omega_{tot,n}b_{tot,n}}{[1-\omega_{tot,n}(1-b_{tot,n})]}\left[(I_n^{\downarrow}-B_n)-(I_n^{\downarrow}-B_n)e^{-2\tau_n^*}\right]\right]T_n\right)$$

Tang solution accounts for interaction between clouds and layers above



$$\frac{\partial I_v^{Tang}}{\partial T}$$



$$\frac{\partial I_v^{Tang}}{\partial T}-\frac{\partial I_v^{Chou}}{\partial T}$$

Values for the Temperature Jacobians in presence of a thin ice cloud (OD=0.5 z=11 km) and a low-level liquid water cloud

Summary of the objectives of the FIT-FORUM project

The FIT-FORUM aims at providing an innovative scientific tool consisting in a calculation and analysis code with a modular structure that brings together unique features:

- ***Pseudo-Monochromatic IR spectrum*** → *applicable to any type of measurement in the IR (IASI, IASI-NG, …);*
- ***Easy to upgrade in spectroscopy*** → *analysis of the continuum of **water vapor** and trace gas concentrations;*
- ***Accurate in simulating MS effects*** → *study of **cirrus clouds** at FIR;*
- ***Solutions for multiple viewing angles*** → *Off nadir IASI observations, computations of TOA spectral and total **fluxes**;*
- ***Platform independency*** *(ground, balloon, plane, satellite)* → *data analysis of experimental campaigns (calibration/validation);*
- ***Parameterised for the T, ρ, reff*** → *explicit treatment of clouds microphysics and analytical Jacobians*

*The model is **characterized in its accuracy** to properly analyse the FORUM observations and be applied for the derivation of L2 (and L3) products.*

The possibility to derive a **radiative operator** to be used in the data assimilation phase is investigated in the **MC-FORUM** project (PI: A. Ortolani, CNR) also supported by ASI.

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Training Schools

1st **Training Staff School** (02/2024) at the Univ. of Bologna

2nd **Training Staff School** (date tbd) at the Univ. of the Basilicata Potenza: open to visitors

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