Monitoring the Antarctic Ozone Hole with IASI: Simultaneous Retrieval of O_3 and HNO_3 in Cloudy and Clear-Sky Conditions

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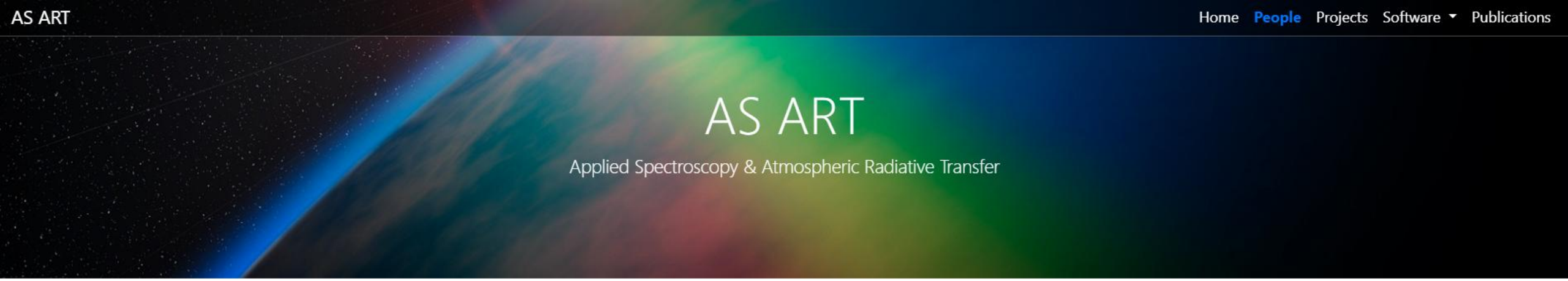

People

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Role: Associate Professor

Head of AS-ART at University of Basilicata, leading expert in atmospheric radiative tranfer

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Role: Associate Professor

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World-l

AS ART Group

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Outline

DATA & METHOD

RESULTS

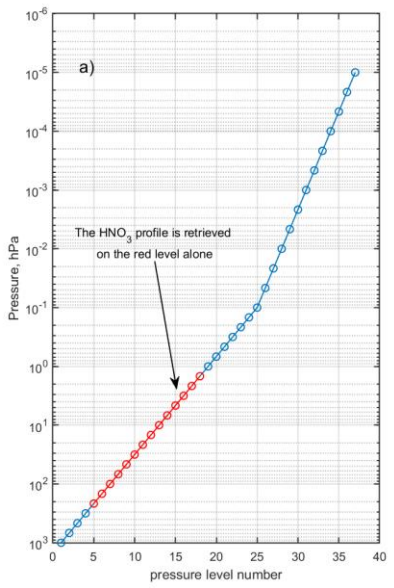
CONCLUSIONS

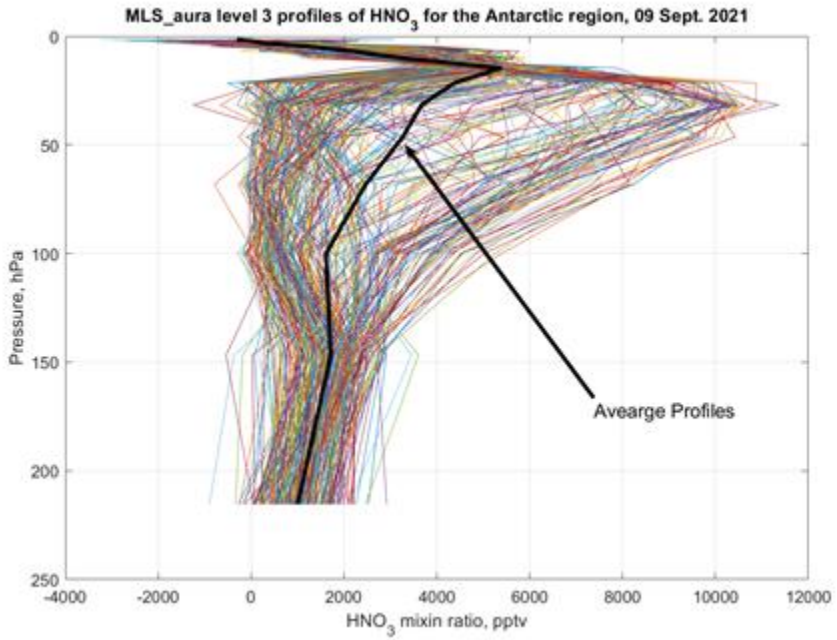
The “Ingredients” of the Ozone Depletion

	TROPOMI	OMI	IASI	MLS-AURA
Ozone	X	X	X	
HNO3			X	X
Temperature			X	
Water Vapour			X	

We collect data for the 9th of July, Sept and Oct 2021 and 2023 -90°<Lat<-60°

Microwave Limb Sounder (MLS) on NASA's EOS AURA Satellite





- Level 3 observations of the HNO3 profiles for MLS.
- https://disc.gsfc. nasa.gov/
- Sept. 9, 2021, and 2023.
- Level 3 data available on a 4°×5° longitude/latitude grid
- pressure range: 215–1.5 hPa.
- HNO3 Profiles-> Columnar Amount

$$\bar{X}_{HNO_3} = \frac{1}{p_u - p_l} \int_{p_l}^{p_u} q(p)\,dp$$

TROPOMI and OMI

TROPOspheric Monitoring Instrument (TROPOMI) Level 2 data (flag q <0.75)

Ozone Measurements Instruments (OMI) Level 3 gridded data

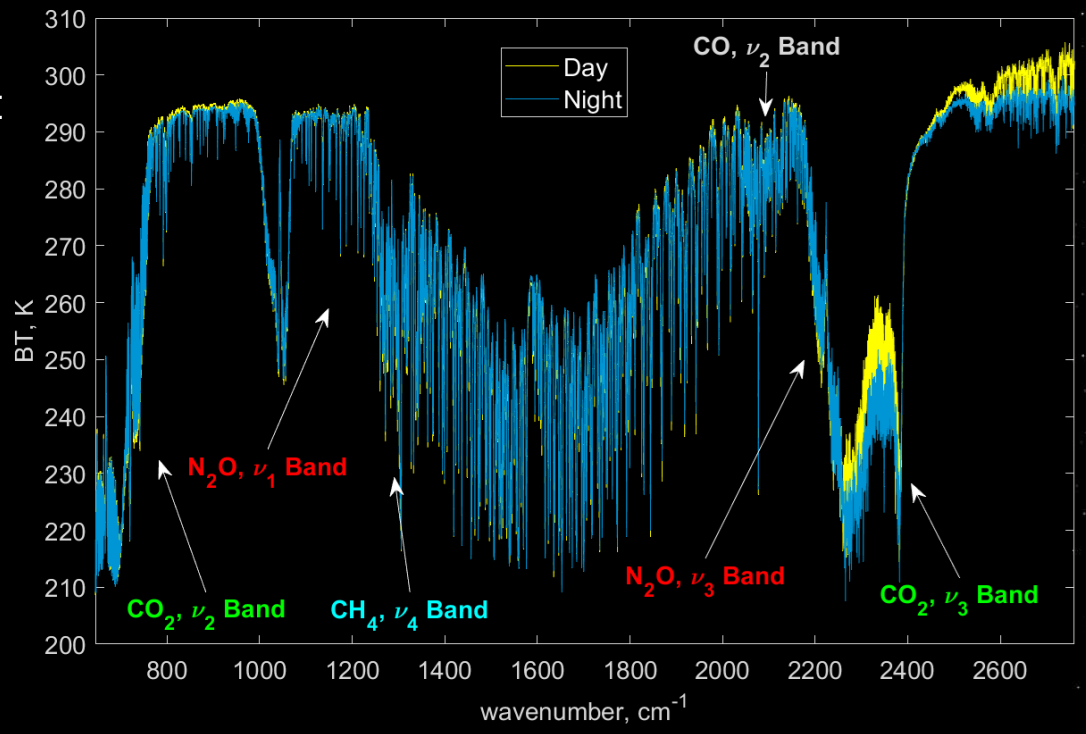
IASI (Infrared Atmospheric Sounding Interferometer)

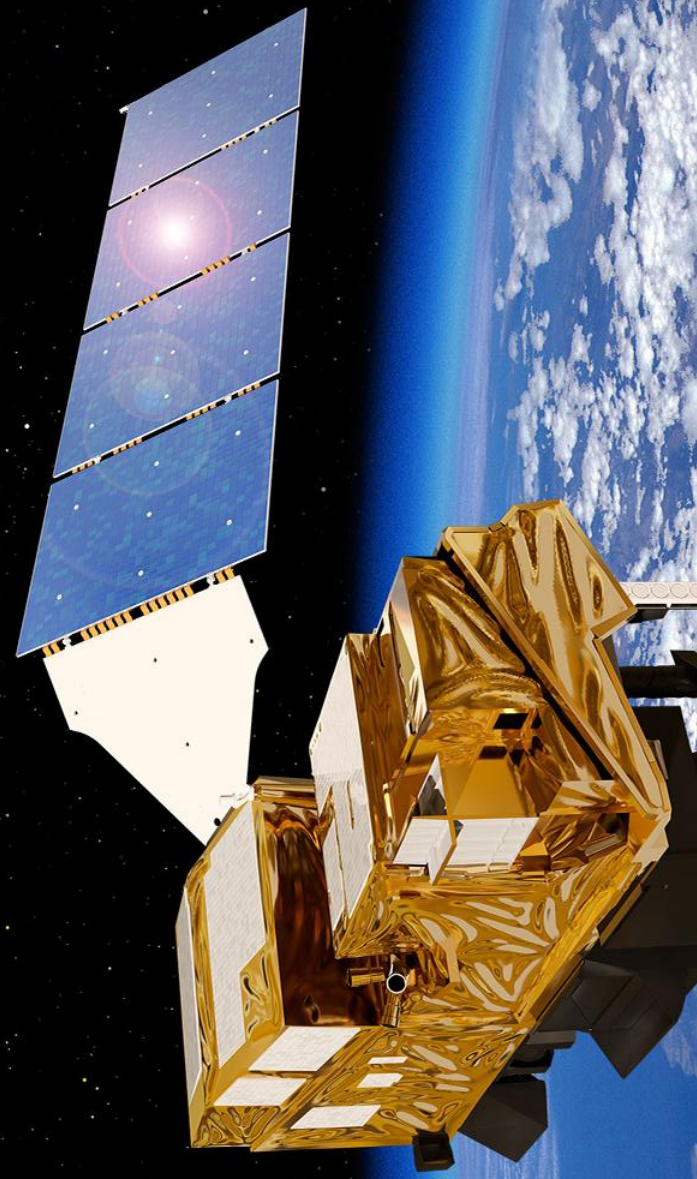
IASI is a Michelson Interferometer, developed at CNES/EUMESAT, measuring the spectral distribution of the atmospheric radiation covering the Spectral range 15.5 to 3.62 micron with a sampling rate of 0.25 cm^{-1}

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.



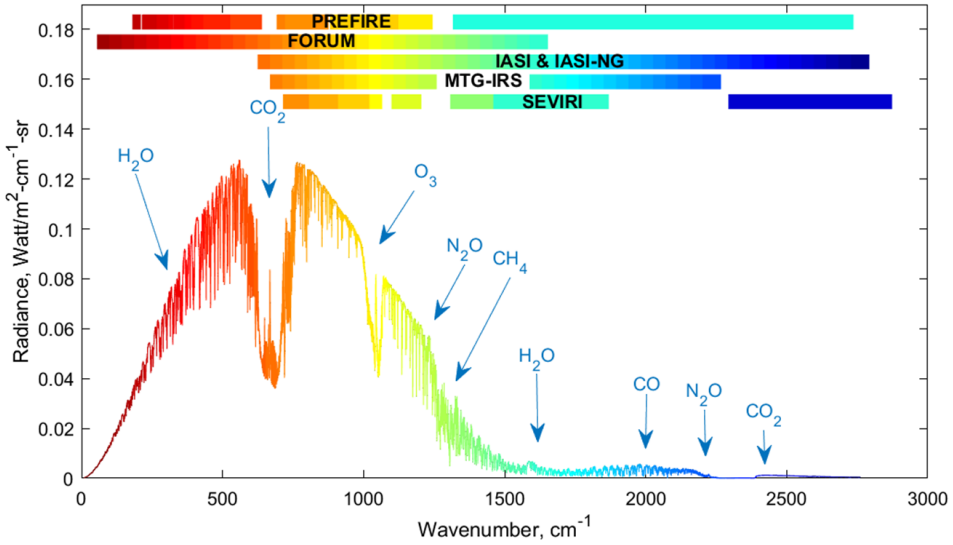


σ-IASI/F2N, → σ

Sigma stands for Spectral Infrared Generation, Modeling and Analysis
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 (0.01 cm-1)
- 5-3000 cm-1 spectral range
- OD databases (parametrized in T and ρ)
- Clouds and aerosols properties (parametrized in ρ and r_{eff})
- In presence of scattering layers, the code accounts for a Chou+Tang solution
- Analytical Derivatives in clear and clouds
- Masiello et al 2024, doi:10.1016/j.jqsrt.2023.108814



σ State Vector

Surface	Atmosphere (Profiles of size nl=60)			
	Gases		Aerosols	
Temperature (K)	q_H2O (g/kg)	q_NH3 (ppv)	q_LW kg/kg)	re_LW (μm)
Emissivity(σ)	q_HDO (ppv)	q_HNO3 (ppv)	q_IW (kg/kg)	De_IW (μm)
Cloud Fraction	q_CO2 (ppv)	q_CF4 (ppv)	q_Volc. Dust (kg/kg)	re_Volc.Dust (μm)
	q_O3 (ppv)	q_OCS (ppv)	q_Min.Tran (kg/kg)	re_Min.Tran (μm)
	q_N2O (ppv)	q_CFC11 (ppv)	q_Blk.Car (kg/kg)	re_Blk.Car (μm)
	q_CO (ppv)	q_CFC12 (ppv)		
	q_CH4 (ppv)	q_HFC22 (ppv)	Temperature (K)	
	q_SO2 (ppv)	q_CCL4 (ppv)		

Our Retrieval Scheme

It is based on Optimal estimation with a compression of both radiances and State vector

State vectors simultaneously retrieved

$$\mathbf{V} = (T_S, \mathbf{T}, \mathbf{Q}, \mathbf{O}, \mathbf{D}, \mathbf{q_{LWC}}, \mathbf{r_e}, \mathbf{q_{IWC}}, \mathbf{D_e}, \mathbf{q_{CO_2}}, \mathbf{q_{OCS}}, \mathbf{q_{N_2O}}, \mathbf{q_{CO}}, \mathbf{q_{CH_4}}, \mathbf{q_{SO_2}}, \mathbf{q_{HNO_3}}, \mathbf{q_{NH_3}}, \mathbf{q_{CF_4}}, pc_\epsilon)$$

- Surface temperature, (Ts), Atmospheric profiles of Temperature, Water vapour, Ozone, HDO, CO_2, OCS, CO, N_2O, CH_4, SO_2, HNO_3, NH_3, and CF_4, liquid and ice water clouds and related effective dimension;
- PC scores for surface emissivity

Our Retrieval Scheme

It is based on Optimal estimation with a compression of both radiances and State vector

State vectors simultaneously retrieved (this work)

$$\mathbf{V} = (T_S, \mathbf{T}, \mathbf{Q}, \mathbf{O}, \mathbf{D}, \mathbf{q_{LWC}}, \mathbf{r_e}, \mathbf{q_{IWC}}, \mathbf{D_e}, \mathbf{q_{CO_2}}, \mathbf{q_{OCS}}, \mathbf{q_{N_2O}}, \mathbf{q_{CO}}, \mathbf{q_{CH_4}}, \mathbf{q_{SO_2}}, \mathbf{q_{HNO_3}}, \mathbf{q_{NH_3}}, \mathbf{q_{CF_4}}, pc_\epsilon)$$

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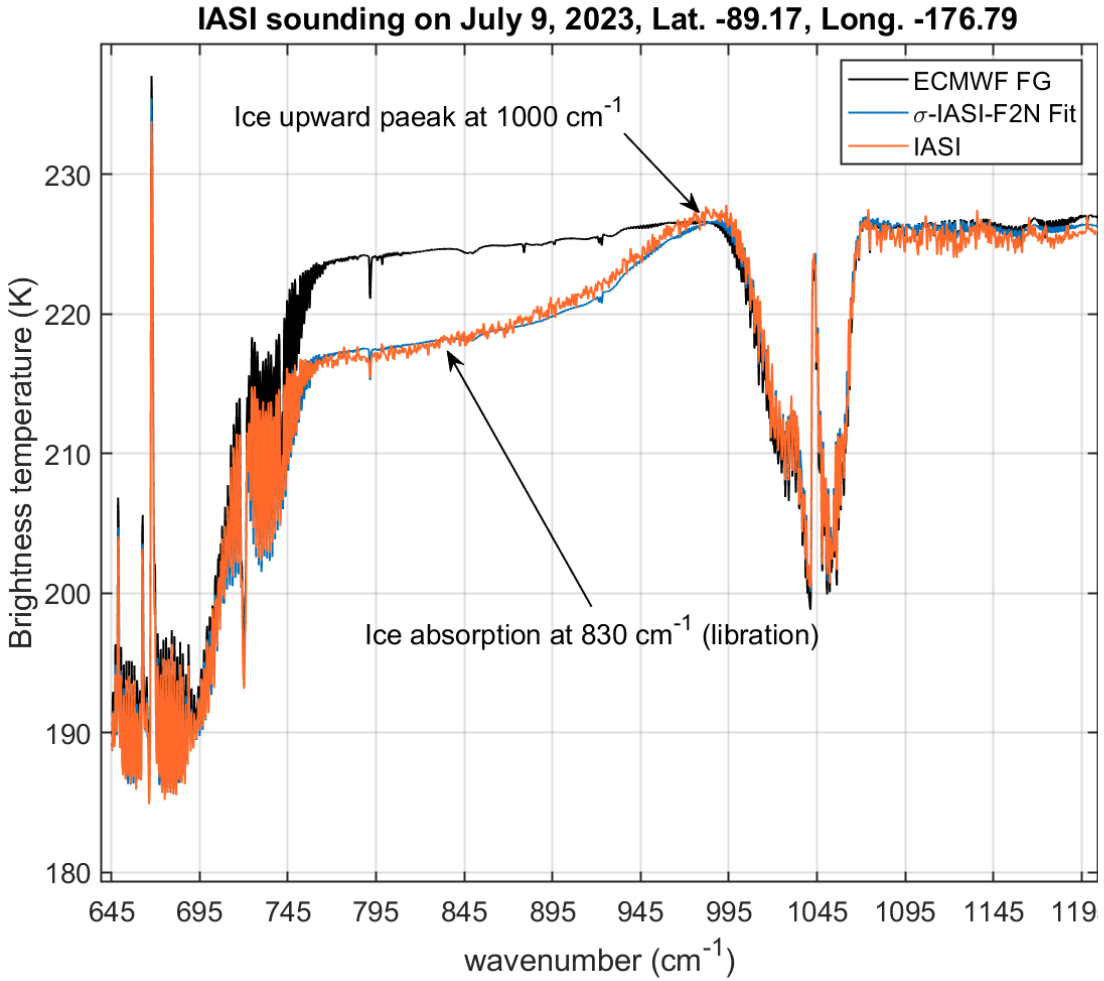
- PC scores for surface emissivity

Retrieval of Polar Stratospheric Cloud



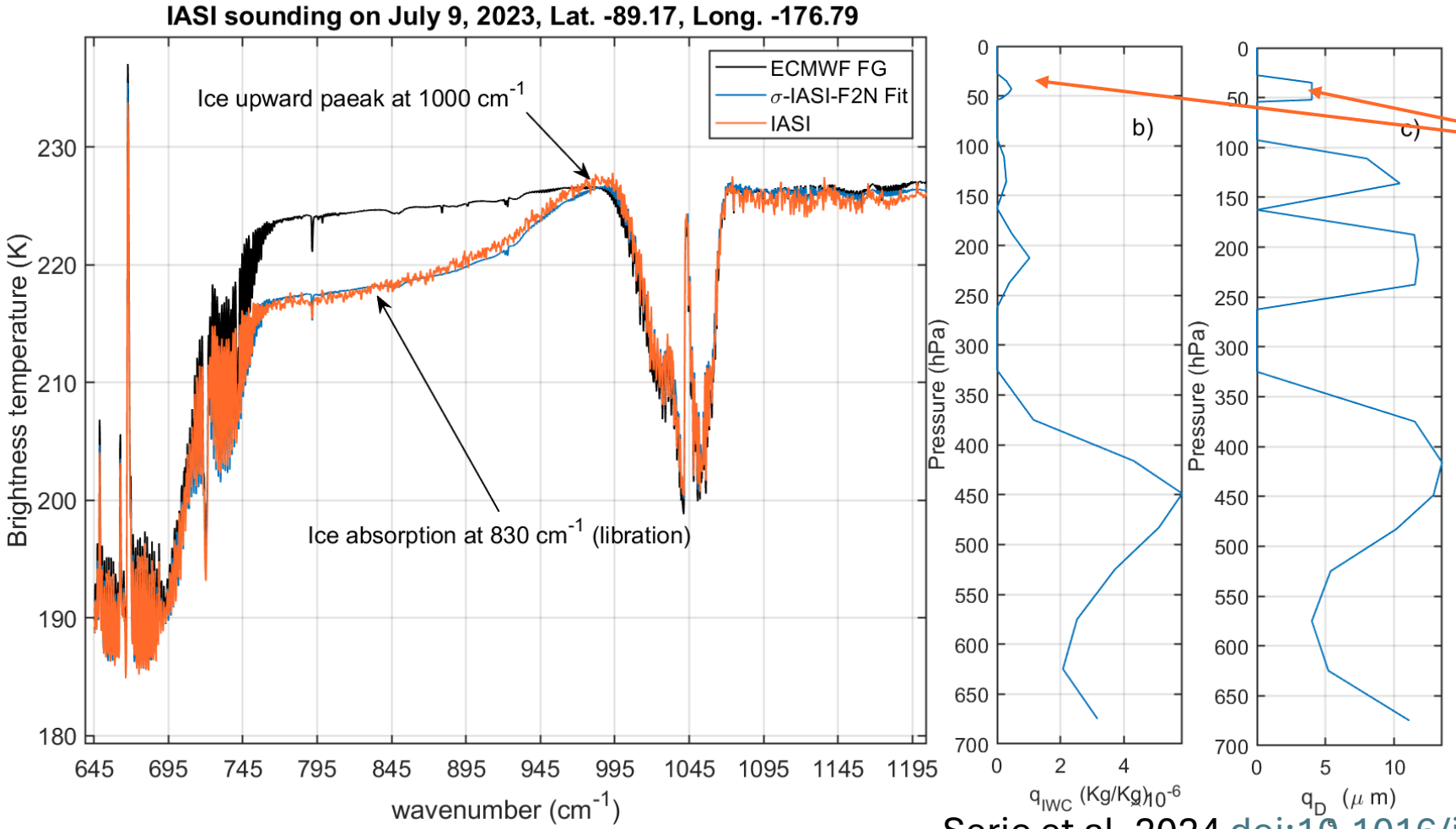
Orange – IASI Measurement

Black – Computed with ECWMF profile

Blue – Computed with IASI retrieved profile

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

Retrieval of Polar Stratospheric Cloud



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

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

Retrieval of Ozone, 09/09/2021 (Clear and Cloudy)

a) O3 map from ECMWF (background),

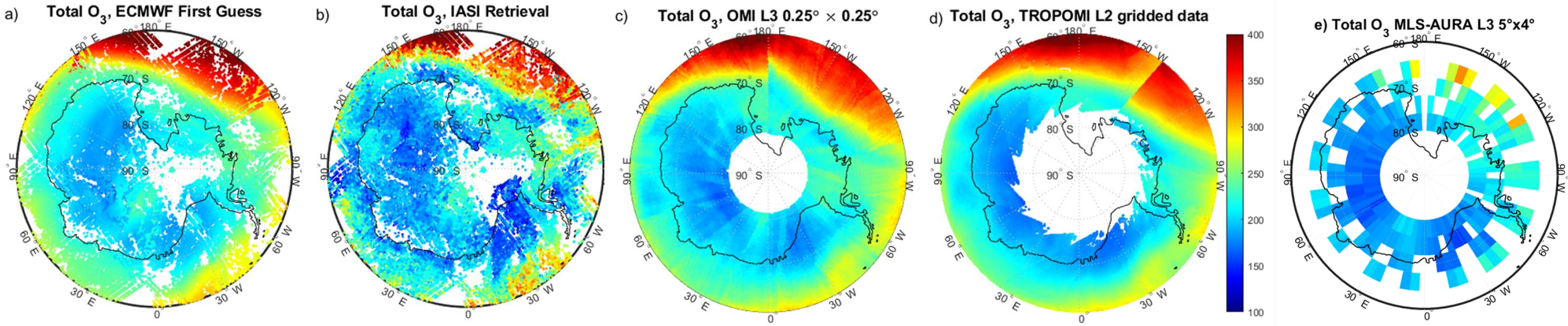
b) O3 map retrieved by IASI data (un-gridded level 2 product)

c) OMI level 3 gridded and smoothed product.

d) TROPOMI level 2 gridded product,(QF>0.75)

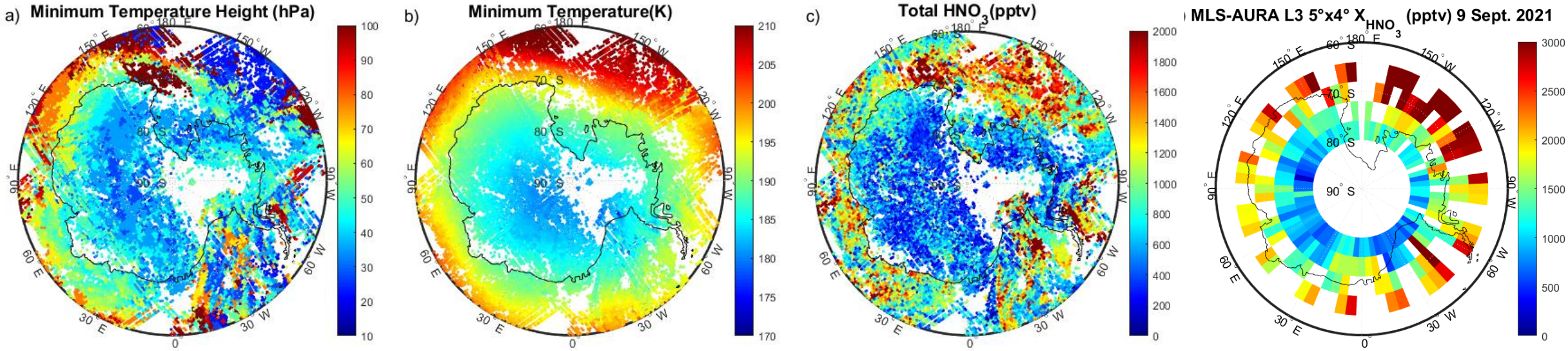
e) MLS-AURA level 3 Data (5°x4°)

- IASI see a deeper and wider Ozone hole (**<220 DU**) with respect ECMWF
- OMI, and TROPOMI don't cover the pole (Night)

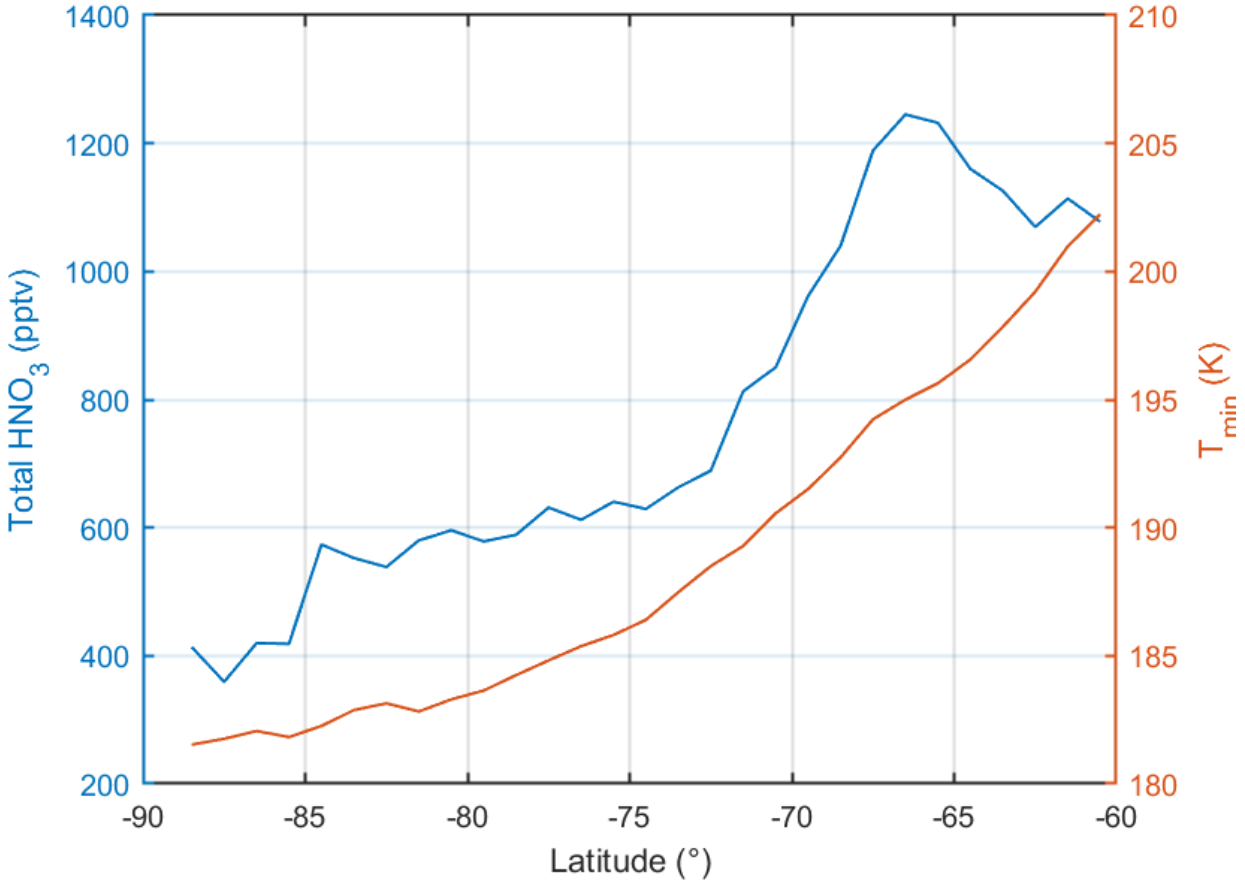


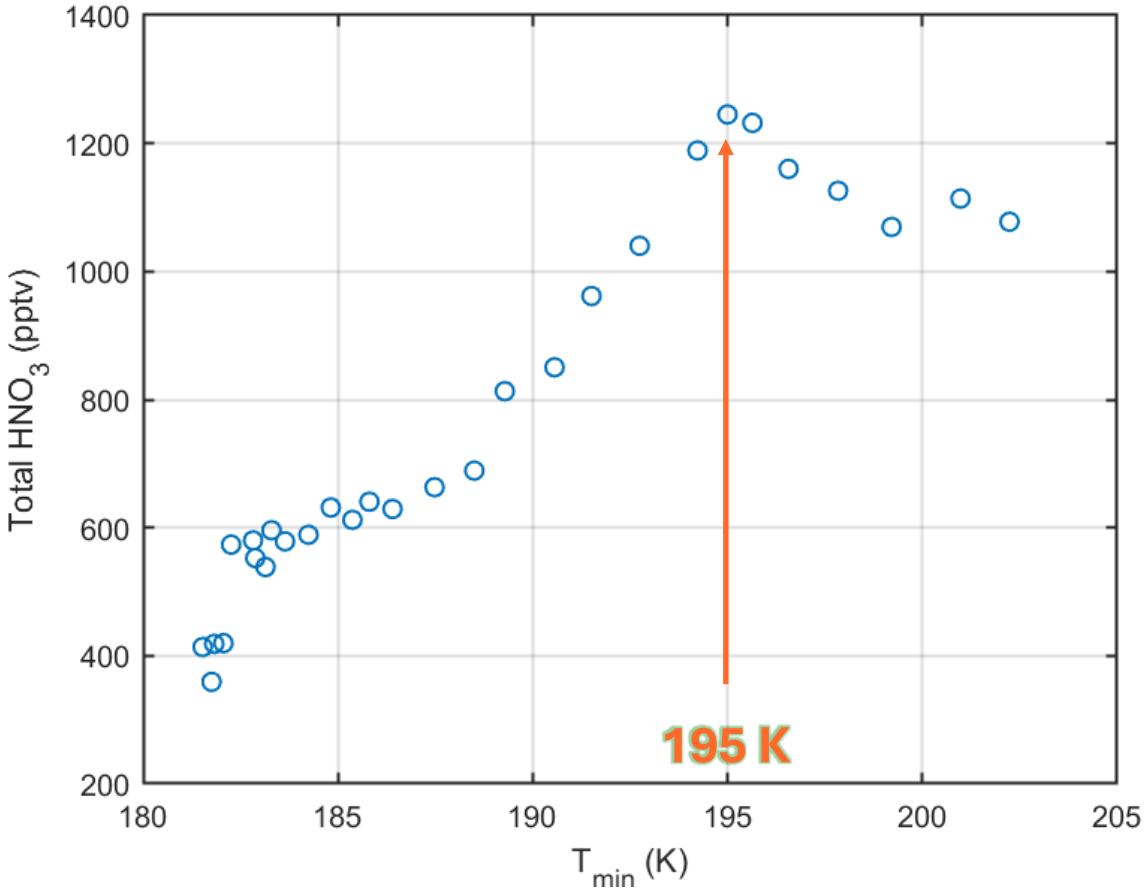
P_{min}, T_{min} & HNO_3

- In the inner continent, the temperature is well below **195 K** (b)
- Pressure at Temperature inversion ranges 30-60 hPa (a)
- Low amount of HNO_3 < 500 pptv in the inner continent (c)
- PSCs formation may lead to the removal of nitric acid from the gas phase.
- Good Comparison IASI-MLS-AURA



Zonal Mean of T_{min} & HNO_3





Key Points

- **Ozone Hole and Denitrification**: The onset of the ozone hole in September 2021 and 2023 was accompanied by significant denitrification of the polar atmosphere.
- **Instrument Agreement**: Both IASI (infrared) and MLS_aura (microwave) instruments observed this denitrification, despite their different viewing geometries and spectral ranges.
- **NAT PSC Clouds**: NAT PSC clouds catalyzed ozone destruction, contributing to the overall ozone hole.
- **Infrared Instrument Importance**: Infrared instruments like IASI are crucial for improving the night/day coverage and spatial resolution of trace gases, enhancing our understanding of ozone depletion in the polar atmosphere.

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

Deadline

20 November 2026

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remote sensing

IMPACT FACTOR 4.1

CITESCORE 8.6

Foreword

- 2021 and 2023 have been two years with the most spatially extensive, and deep ozone hole.
- Formation of Polar stratospheric clouds (PSCs) is the fundamental catalytic mechanism that accelerates ozone destruction
- PSC formation involves HNO_3 and H_2O initially in the gas phase, which condenses into the solid phase (giving rise to crystals of HNO_3-$3H_2O$ or NAT) at T<195 K
- The phenomenon is continuously monitored by satellite instruments, (Ozone Monitoring Instrument, OMI, TROPOspheric Monitoring Instrument, TROPOMI)
- They need daylight
- They have no sensitivity to the thermodynamic conditions of UT/LS region, and they don’t sense nitric acid and water in the gas phase.

Anknowledgements

- This work is supported by Italian Space Agency in the framework of the following project
  - FORUM-Scienza (contract n-2018-6-Q.0, consortium leaded by CNR-INO Florence),
  - Fit-FORUM (contract n. 2023-23-HH.0, CUP F33C23000240005, consortium leaded by DIFA, University of Bologna),
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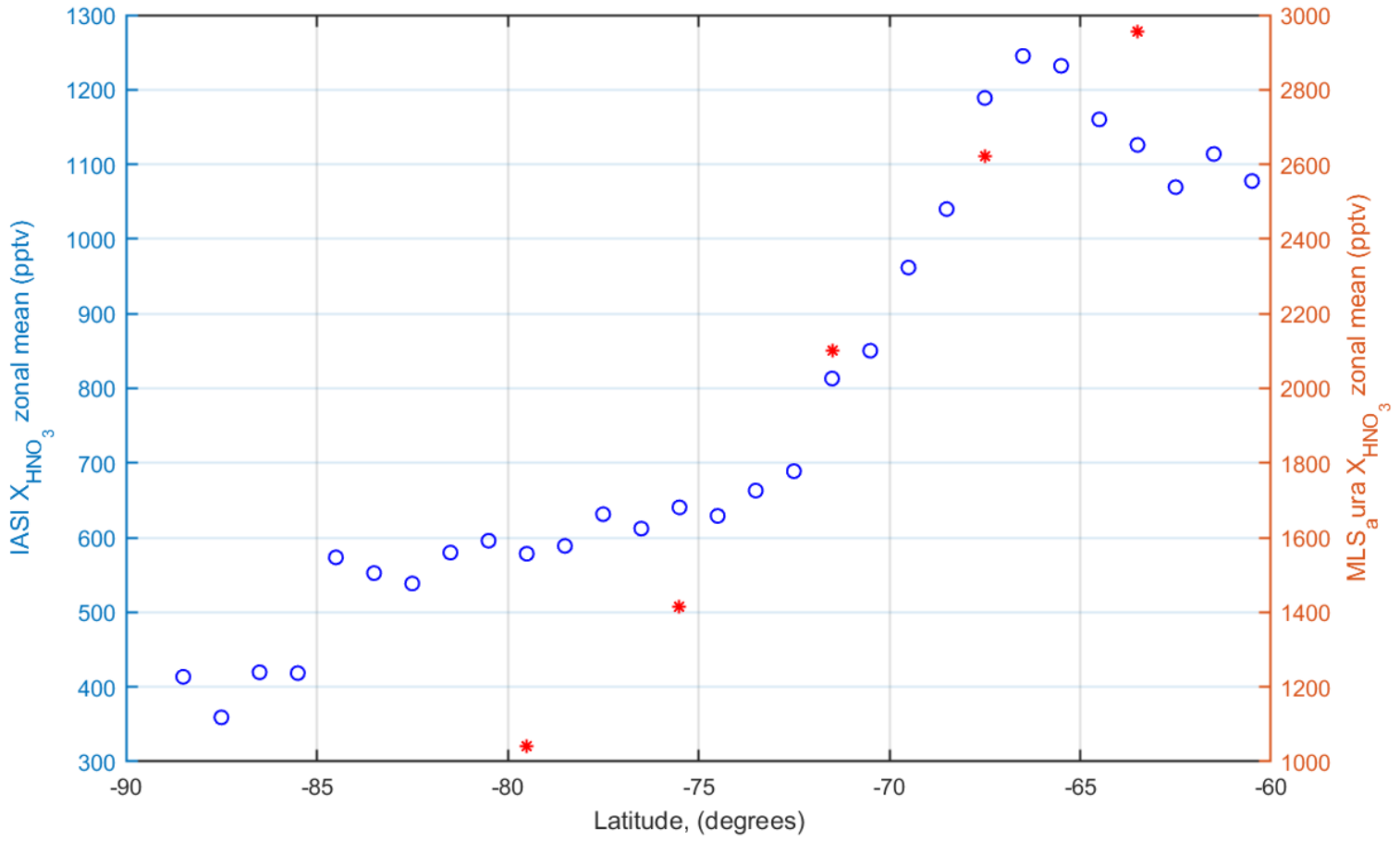
Agenzia Spaziale Italiana



Zonal average of on 9 Sept. 2021;
left y-axis IASI;
right y-axis MLS_aura