Comprehensive Analysis of Antarctic Ozone Hole Dynamics Using Day-Night IASI Infrared Observations

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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.

Outline

DATA & METHOD

RESULTS

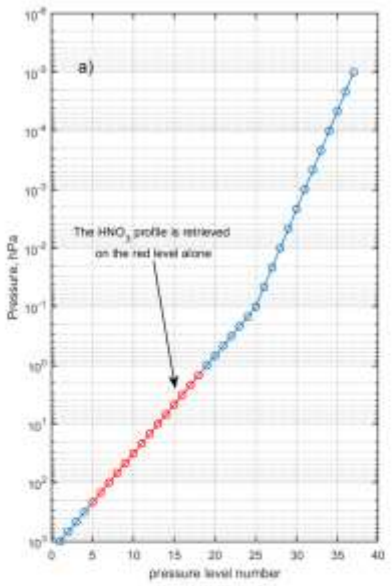
CONCLUSIONS

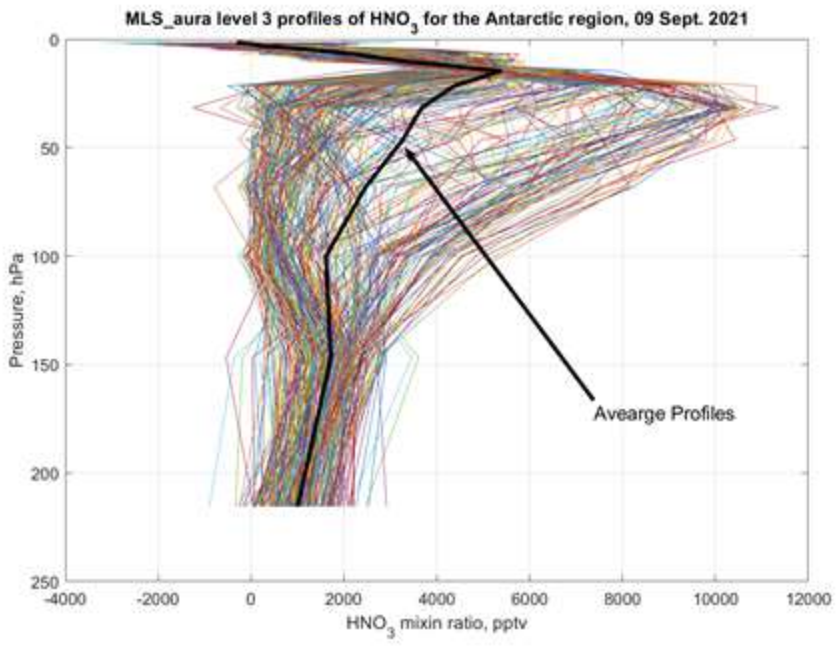
The “Ingredients” of the Ozone Depletion

	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

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

OMI and TROPOMI

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

Ozone Measurements Instruments (OMI) Level 3 gridded data

φ-IASI-F2N: forward/inverse package from the far to near infrared

φ-IASI-F2N is a forward/inverse for all-sky (clear and cloudy conditions) calculations of forward (L1) and inverse (L2) products

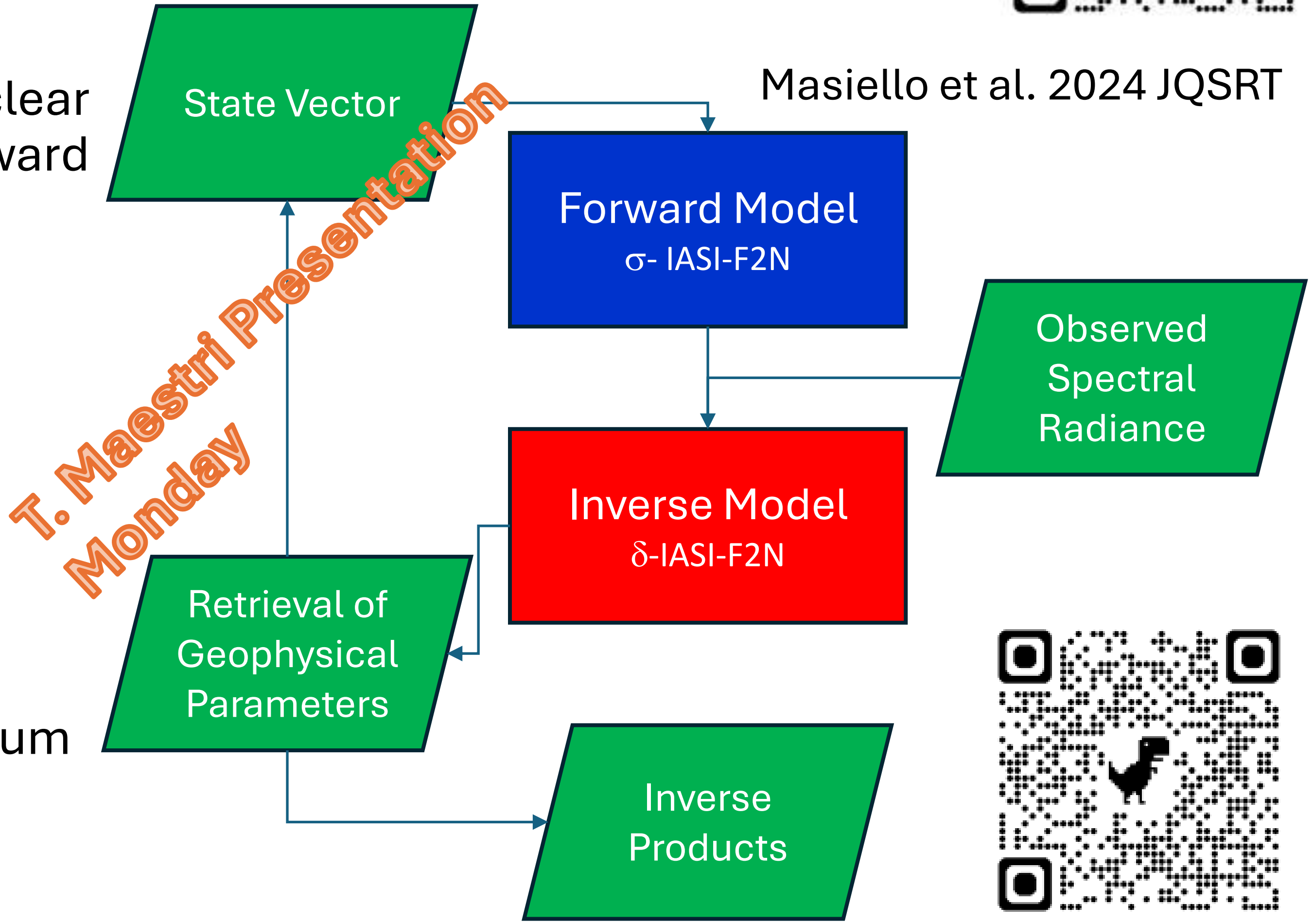
The system includes

- σ- IASI-F2N
- δ-IASI-F2N

To sum up

- φ stands for φυσικά physical
- σ stands for wavenumber and for s - Spectrum
- δ stands for increment

Masiello et al. 2024 JQSRT



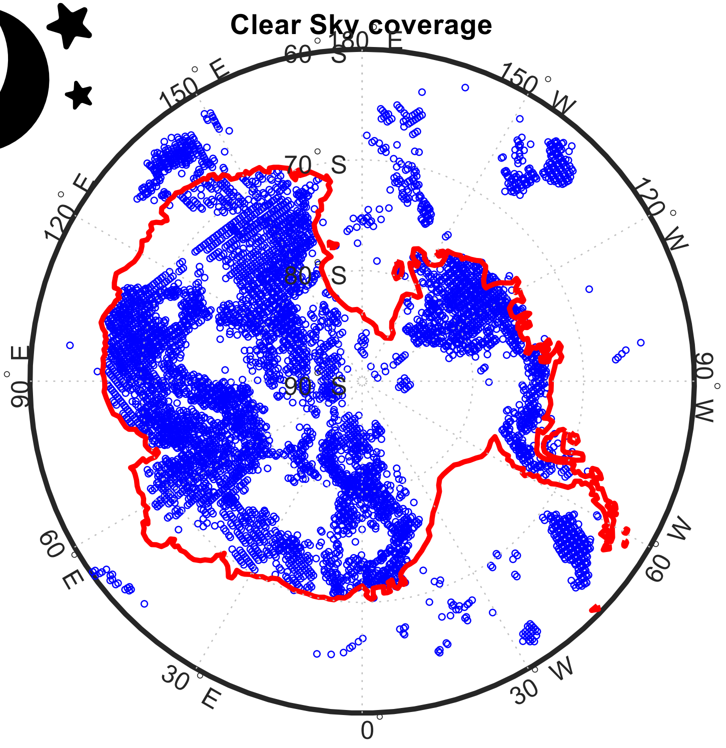
Serio et al. 2024 JQSRT

δ-IASI/F2N State Vector

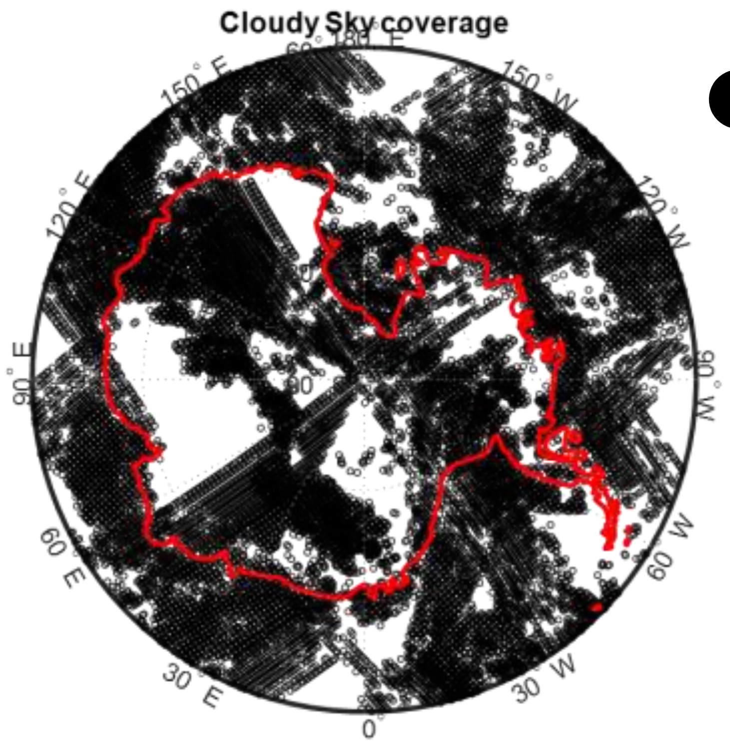
Atmosphere (profiles of size N_L=60)		Surface
• Temperature (K)	• CH_4 (ppv)	• Ts (scalar, K)
• H_2O (g/kg)	• SO_2 (ppv)	• Emissivity spectrum, $\varepsilon(\sigma)$
• HDO (ppv)	• NH_3 (ppv)	Cloud parameters (profiles of size, N_L=60)
• CO_2 (ppv)	• HNO_3 (ppv)	• LWC (kg/kg)
• O_3 (ppv)	• CF_4 (ppv)	• IWC (kg/kg)
• N_2O (ppv)	• OCS (ppv)	• r_e (μm)
• CO (ppv)		• D_e (μm)
		• Cloud fraction, cf (scalar)

$$\mathbf{v} = \left(\begin{array}{c} \varepsilon(\sigma), cf, T_s, \mathbf{T}, \mathbf{Q}, \mathbf{O}, \mathbf{HDO}, \mathbf{q}_{CO_2}, \\ \mathbf{q}_{CH_4}, \mathbf{q}_{N_2O}, \mathbf{q}_{CO}, \mathbf{q}_{SO_2}, \mathbf{q}_{NHO_3}, \mathbf{q}_{HNO_3}, \mathbf{q}_{OCS}, \mathbf{q}_{CF_4}, \\ \mathbf{q}_{LWC}, \mathbf{q}_{IWC}, \mathbf{q}_{r_e}, \mathbf{q}_{D_e}, w \end{array} \right)$$

1 day IASI B & C Antarctica overpasses

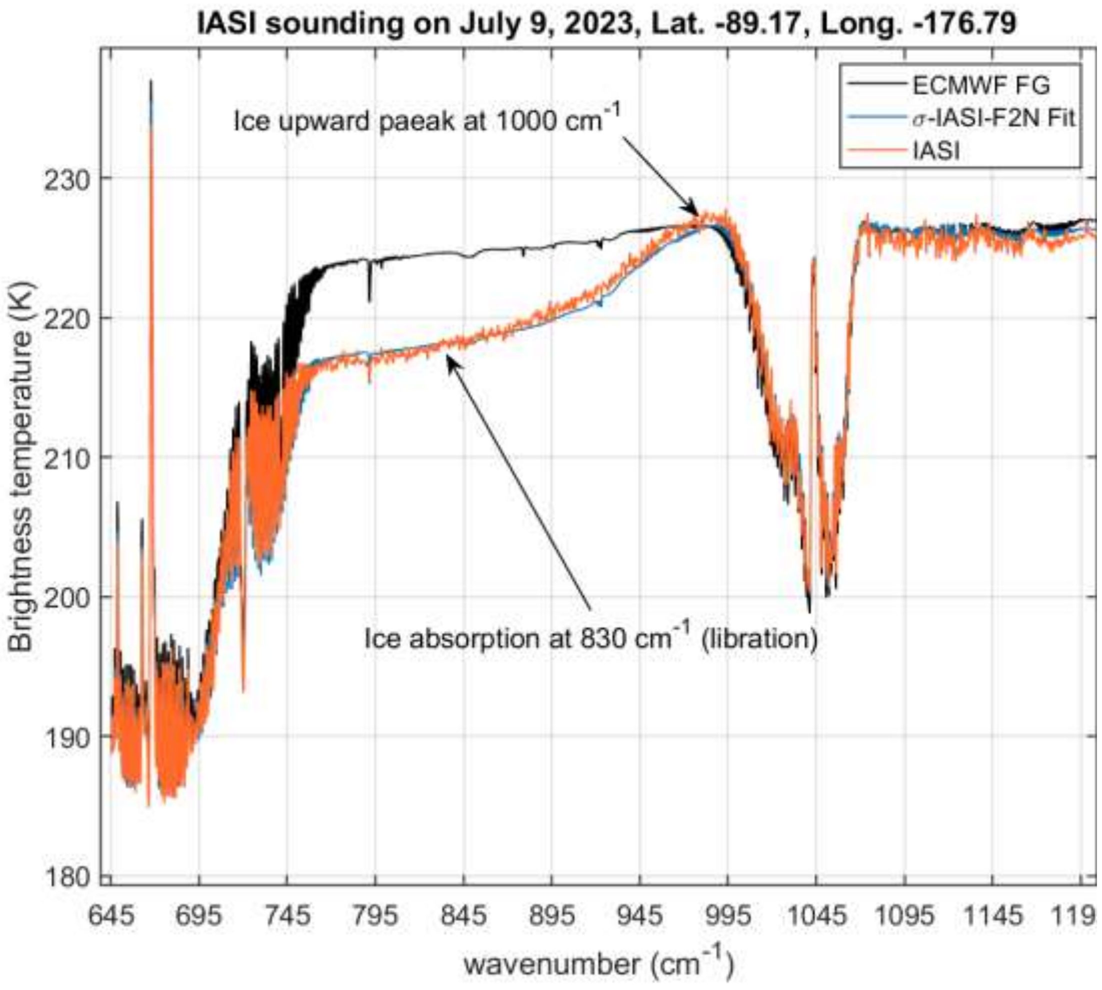


Clear Sky



Cloudy Sky

Retrieval of Polar Stratospheric Cloud

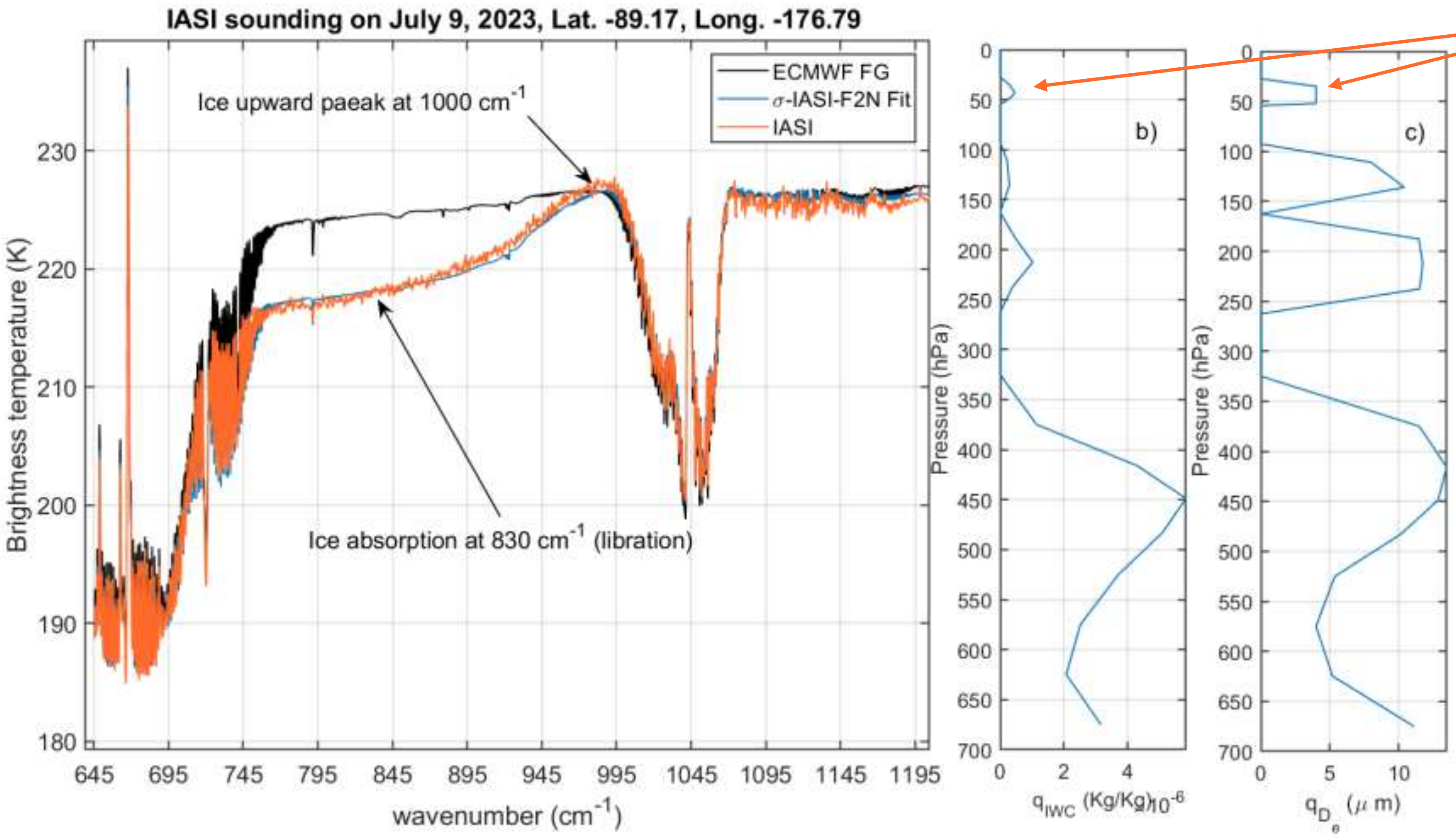


Orange – IASI Measurement

Black – Computed with ECWMF profile

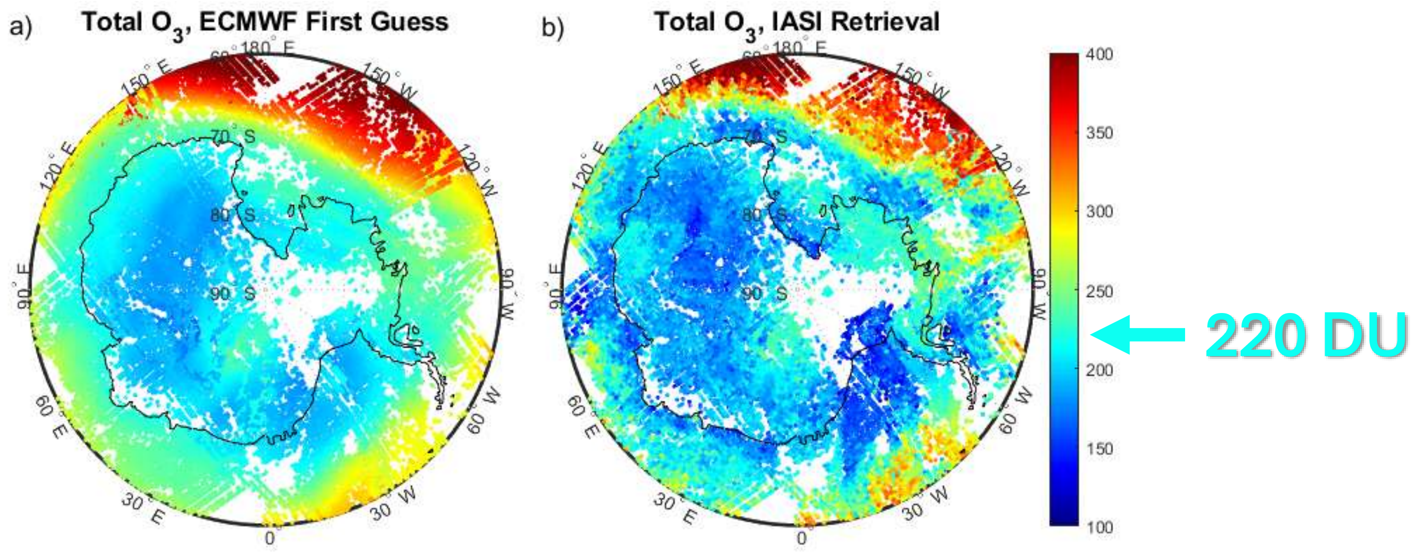
Blue – Computed with IASI retrieved profile

Retrieval of Polar Stratospheric Cloud



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

Retrieval of Ozone, 09/09/2021

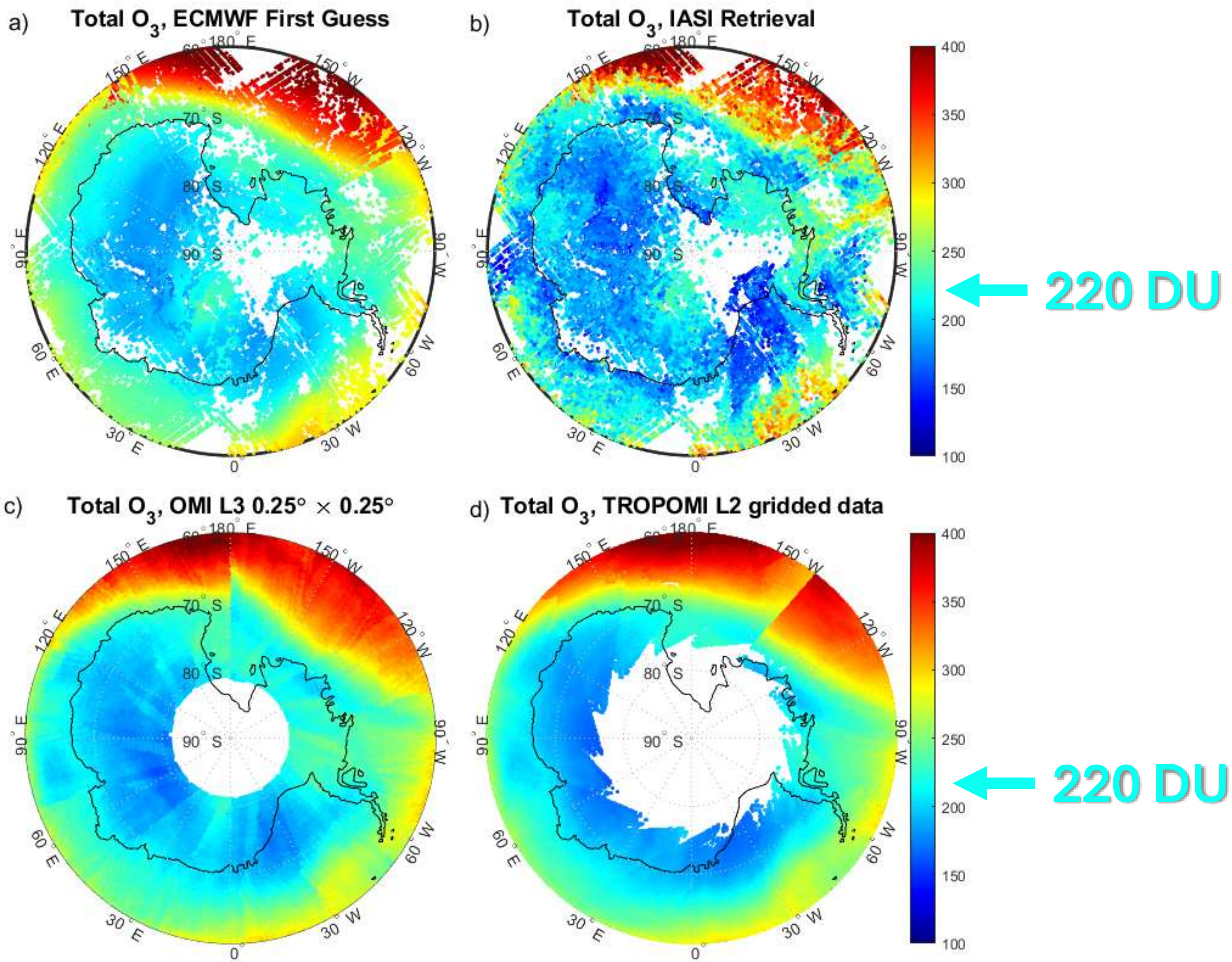


a) O3 map from ECMWF (background),

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

- IASI see a deeper and wider Ozone hole with respect ECMWF

Retrieval of Ozone, 09/09/2021



a) O3 map from ECMWF (background),

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

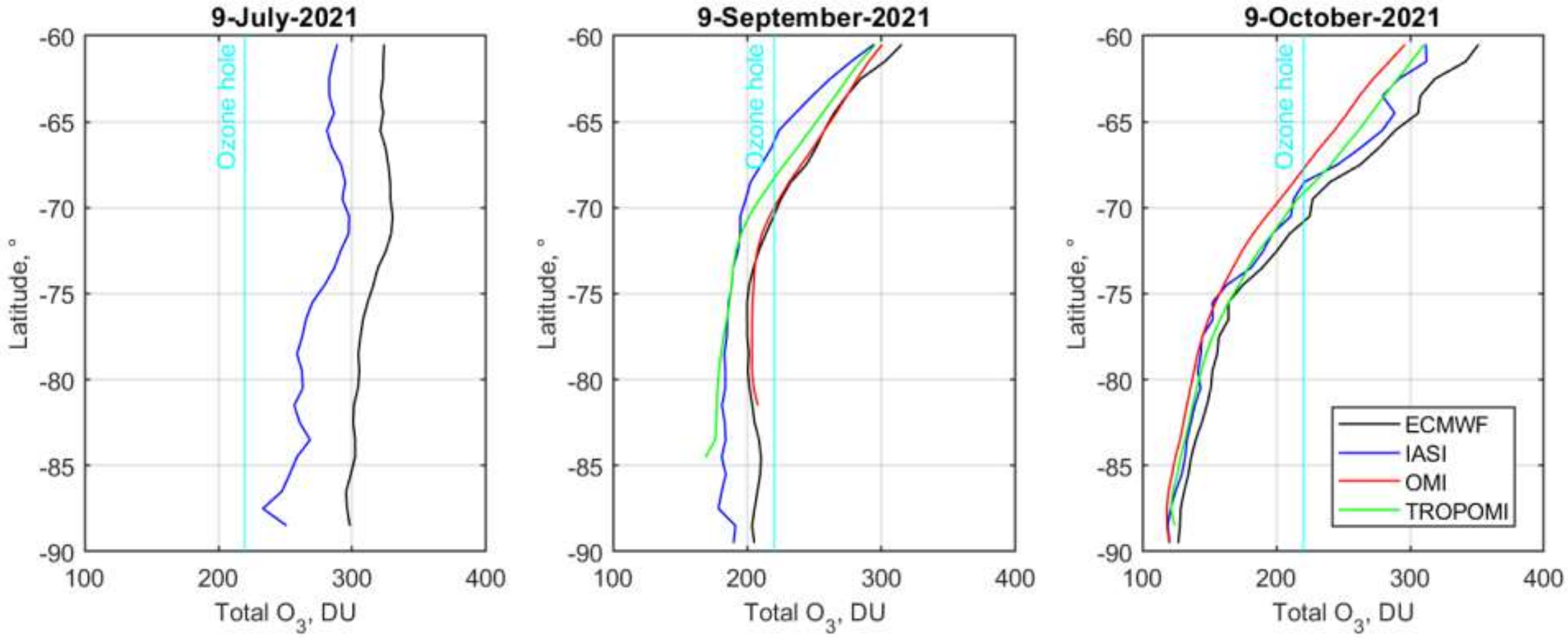
c) OMI level 3 gridded and smoothed product.

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

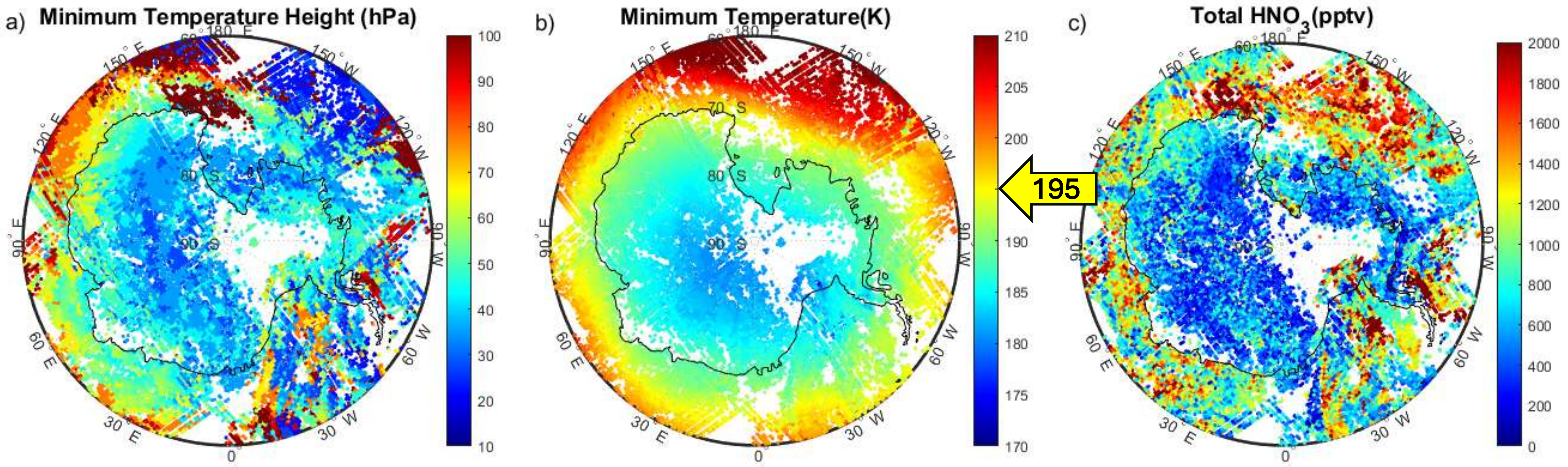
- IASI see a deeper and wider Ozone hole with respect ECMWF
- OMI and TROPOMI don't cover the pole (Night)

2021 Total Ozone zonal mean

- OMI and TROPOMI don’t cover the pole (Night)
- IASI see a deeper and wider Ozone hole with respect ECMWF.
- Overall, our IASI level 2 data compare better with TROPOMI than OMI.
- OMI tends to be more coherent with the ECMWF analysis, could be just the results that OMI total ozone is of the level 3 type.

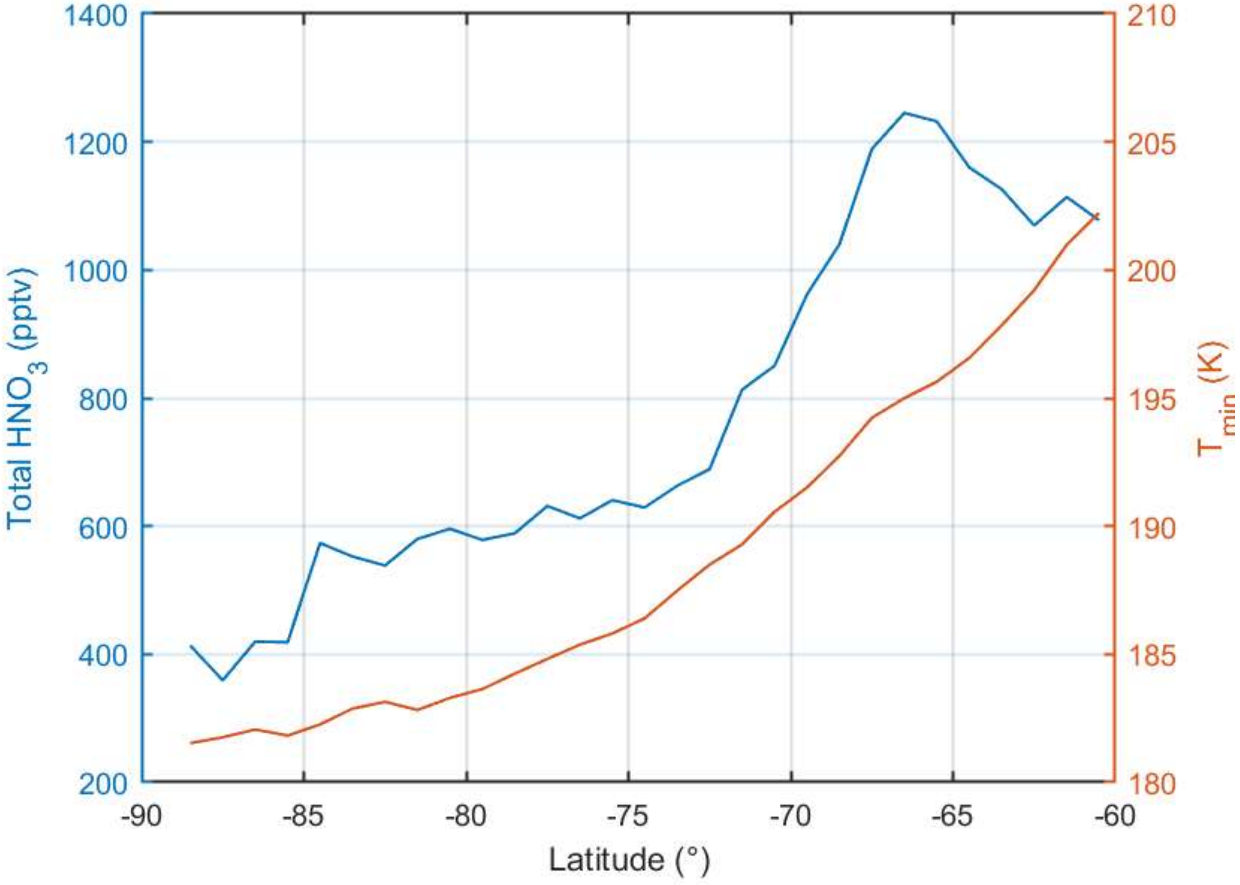


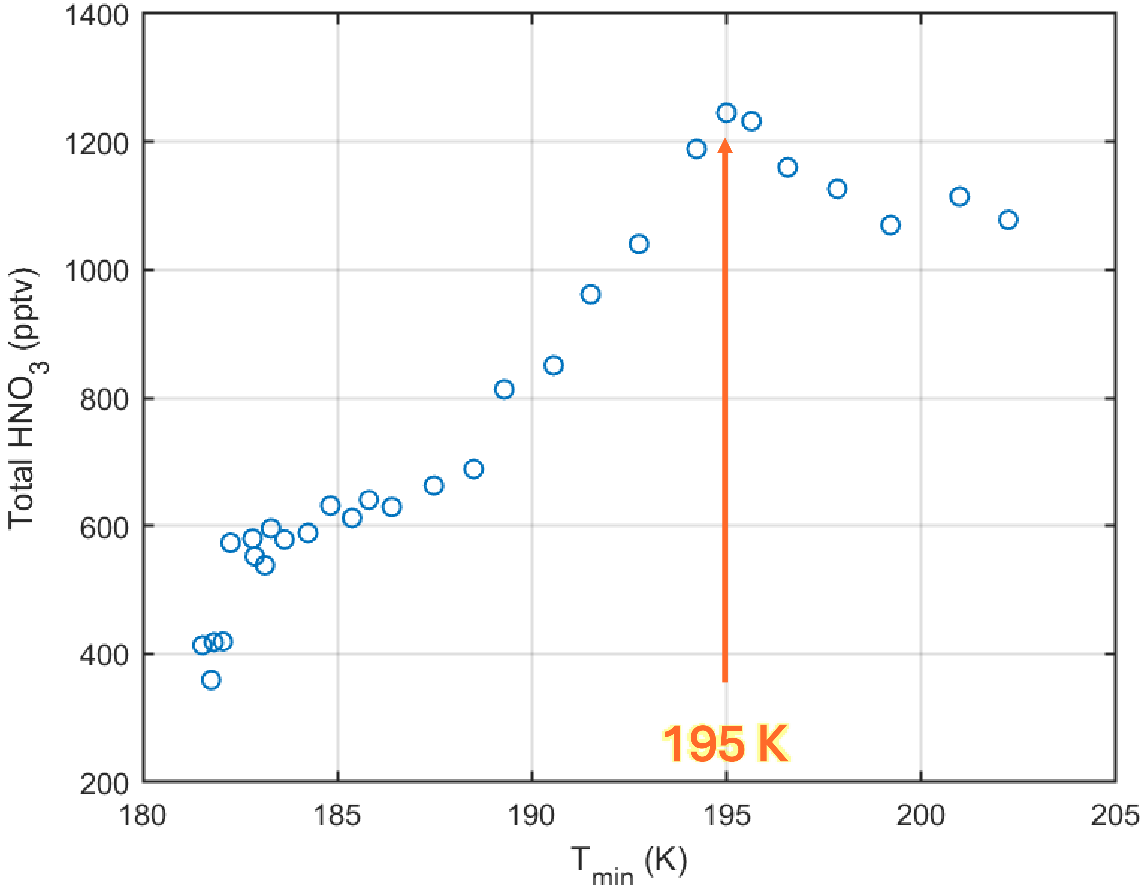
P_{min}, T_{min} & HNO_3



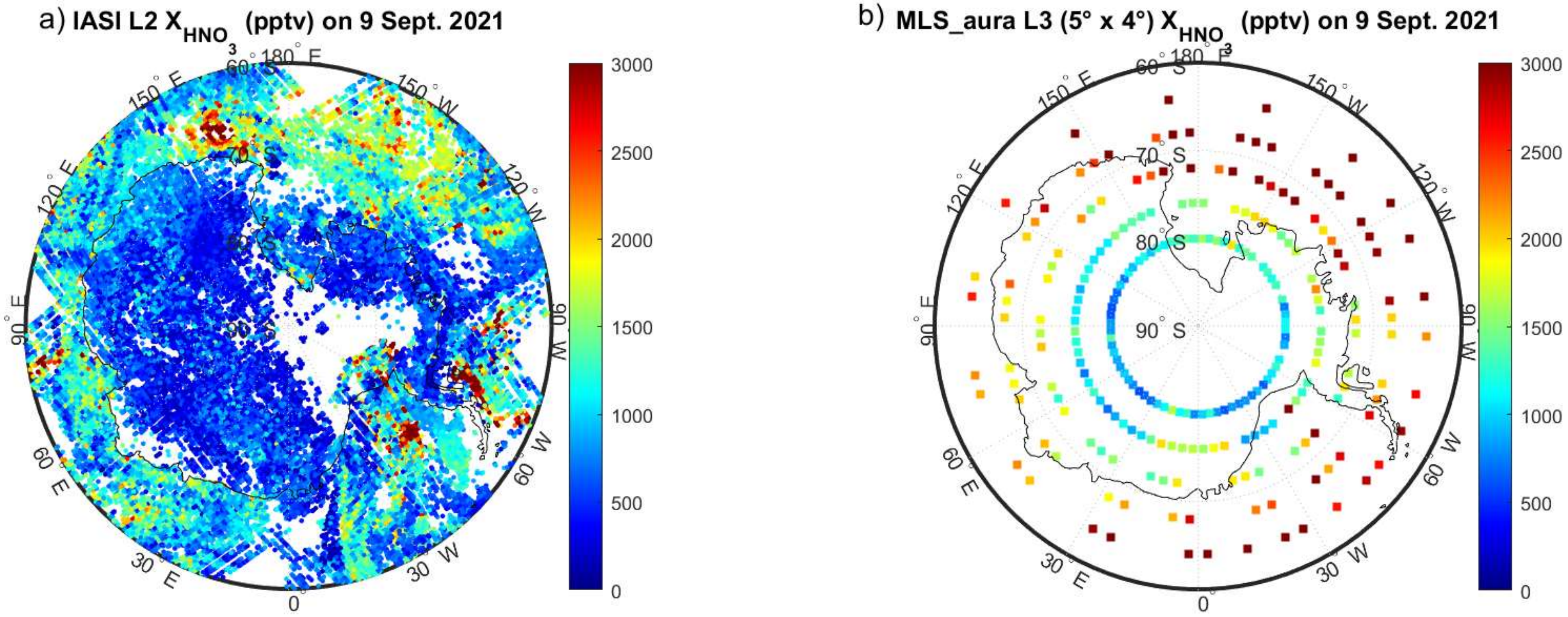
- In the inner continent, the temperature is well below **195 K** (b)
- Pressure at Temperature inversion ranges 30-60 hPa (a)
- Low amount of HNO_3 < 500 pptv in the inner continent (c)
- PSCs formation may lead to the removal of nitric acid from the gas phase.

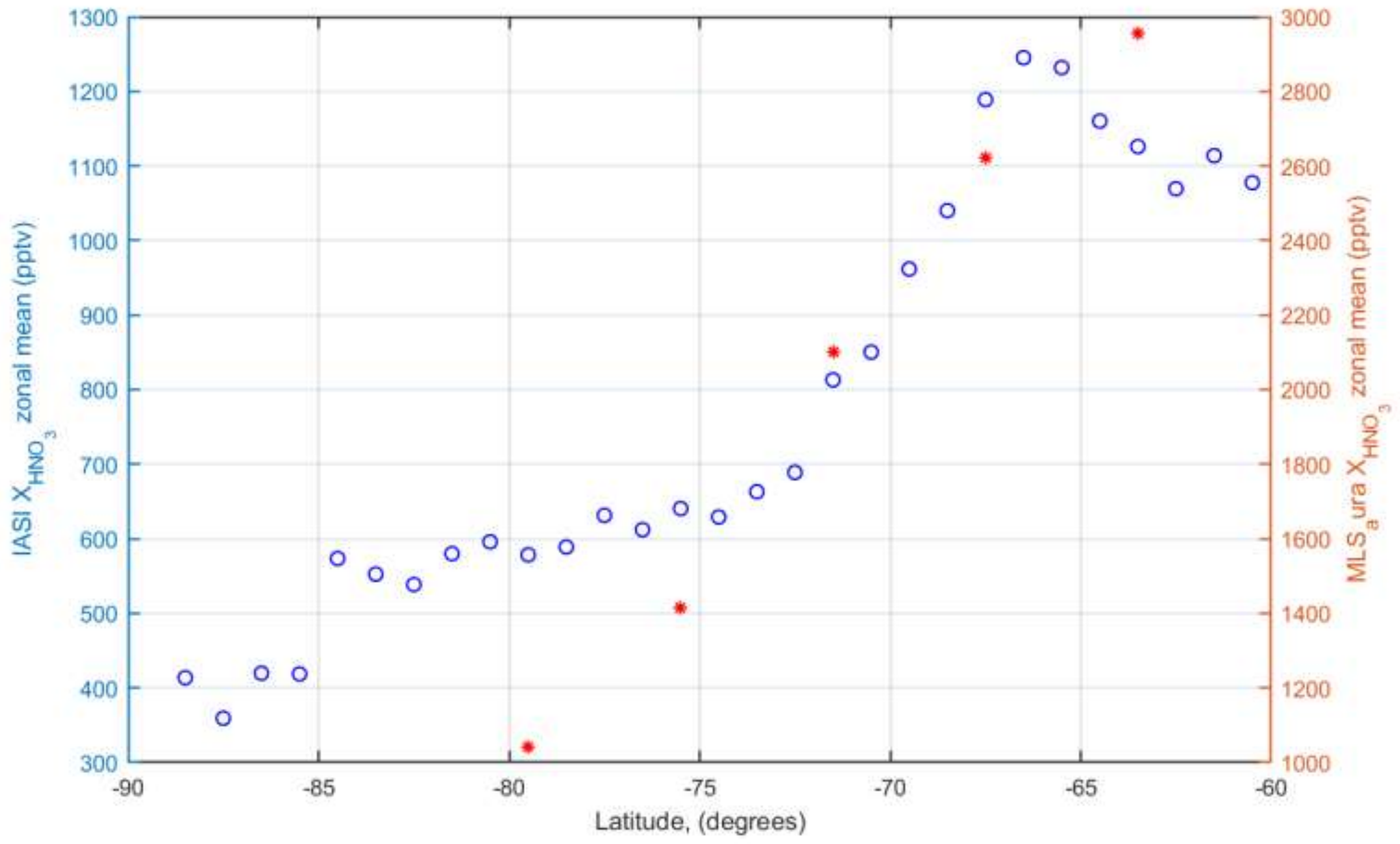
Zonal Mean of T_{min} & HNO_3





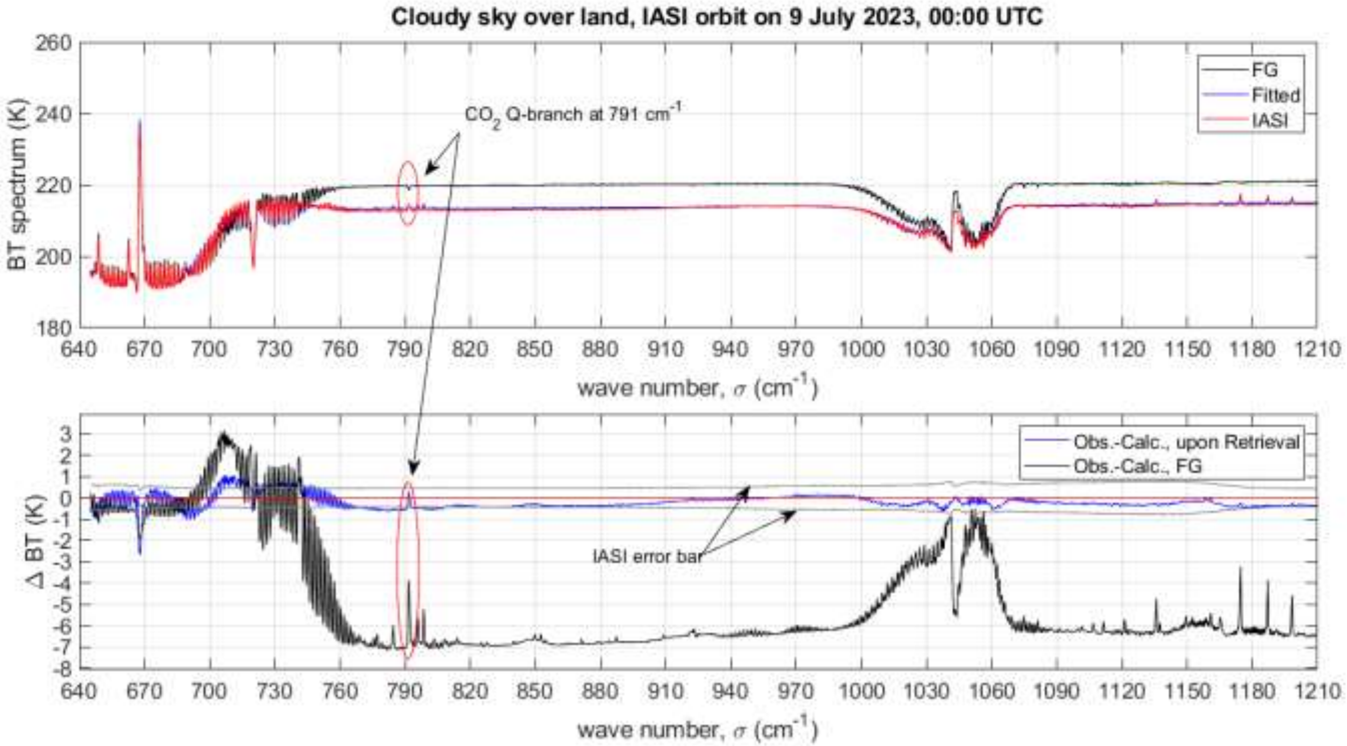
HNO3 (IASI v/s MLS)





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

Red – IASI
Blue – FIT
Black -FG



Magenta–noise
Blue – FIT
Black - FG

Spectral Residuals: Cloudy over Land

Key Points

- **ϕ-IASI-F2N:** we developed a system integrating a direct and inverse models. The scheme simultaneously retrieve cloud optical properties, the atmosphere's thermodynamic, and composition state for the clear-cloudy sky
- **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.
- **Ozone Hole and Denitrification**: The onset of the ozone hole in September 2021 and 2023 (not shown here) 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.