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The Unique Contribution to Understanding Antarctic Ozone Hole Dynamics of Infrared Sounder Measurements

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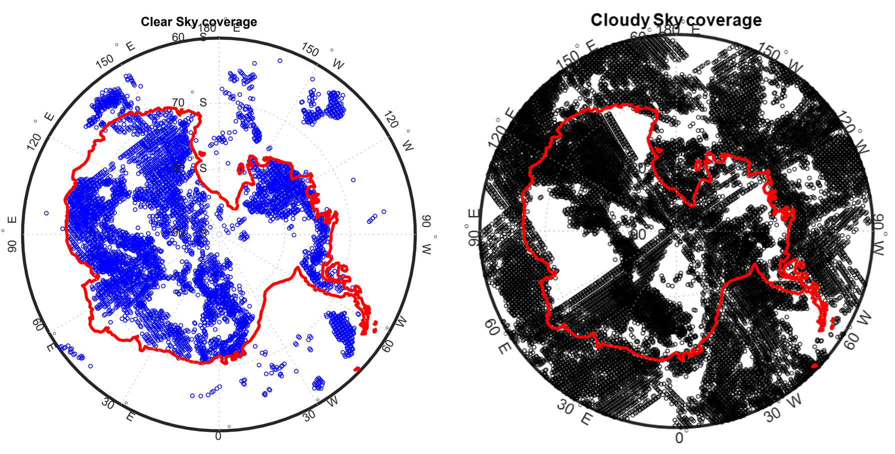
The problem: Antarctica Ozone hole and the importance of Polar Stratospheric Clouds

Years 2021 and 2023 witnessed the most spatially extensive, deep ozone hole. Formation of Polar stratospheric clouds (PSCs) is the fundamental catalytic mechanism that accelerates ozone destruction. PSC formation initially involves HNO3 and H2O in the gas phase, which condenses into the solid phase (giving rise to crystals of HNO3-3H2O or NAT) at T < 195 K. The phenomenon is continuously monitored by satellite instruments (Ozone Monitoring Instrument, OMI, TROPOspheric Monitoring Instrument, TROPOMI). Unfortunately, these instruments need daylight to properly function. Moreover, 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.

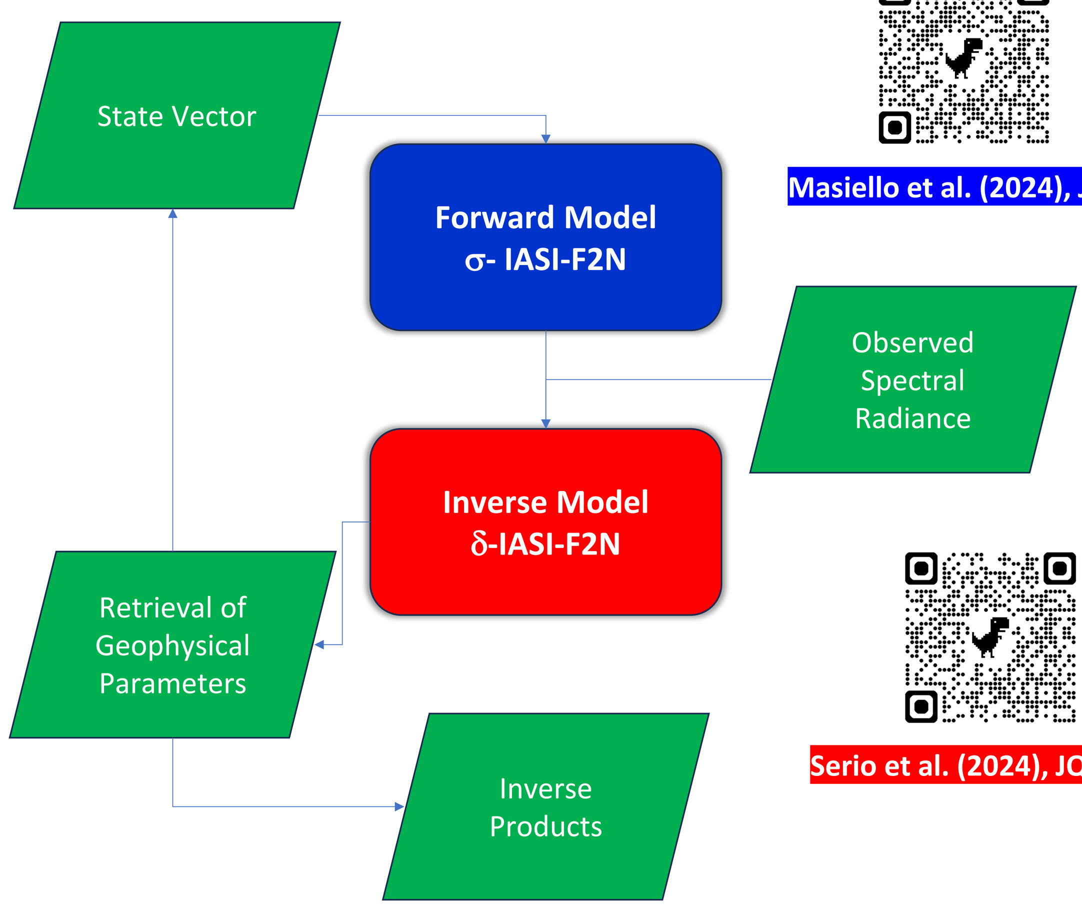
The "Ingredients" of the Ozone Depletion

The datasets used for this study are listed in the table below. Data were collected for the 9th of July, September, October 2021 and 2023, with latitude spanning from -90° to -60° over the Antarctica region.

Sensor / Variable	TROPOMI	OMI	IASI	MLS-AURA
Ozone	X	X	X	X
HNO3			X	X
Temperature			X	
Water Vapor			X	



1 day IASI B & C Antarctica overpasses



Masiello et al. (2024), JQSRT

Serio et al. (2024), JQSRT

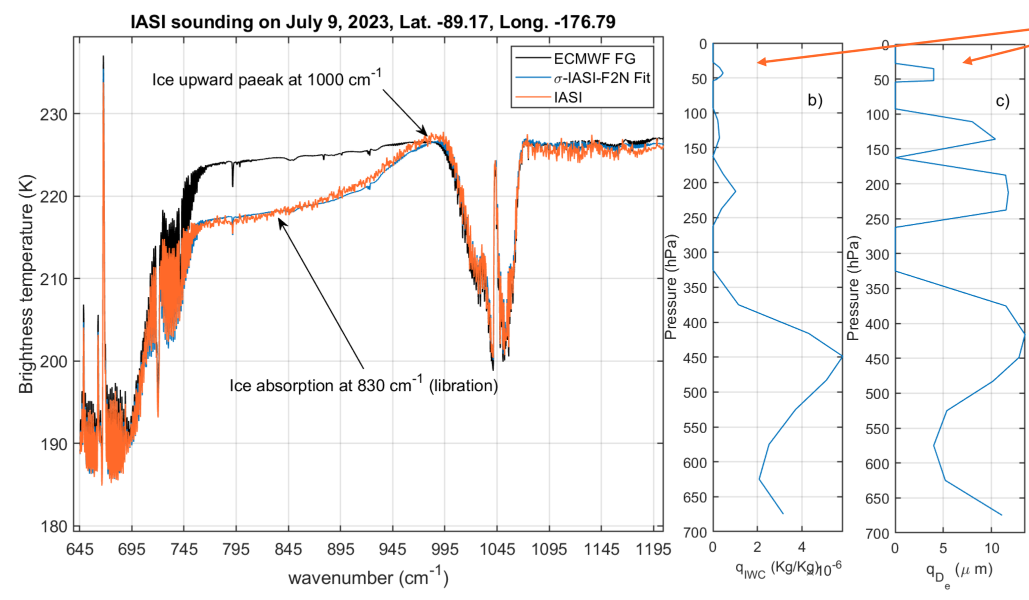
The ϕ-IASI-F2N Model

Developed in the framework of several projects to support IASI mission, 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 a forward model, σ-IASI-F2N, and an inverse one, δ-IASI-F2N:

- the σ-IASI module is a monochromatic radiative transfer model based on a look-up table of optical depths parametrized as a polynomial concerning the atmospheric temperature and constituents. The look-up table is built based on the current LBLRTM (Line-By-Line Radiative Transfer Model) version, but the model can use other line-by-line models and different spectroscopic parameters (e.g. KLIMA). The strategy enables fast, accurate radiance and analytical derivatives calculations preserving the model flexibility that can be applied straightforwardly to all the hyperspectral instruments in Thermal Infrared. The model has been improved by representing ice and water clouds and aerosols multiple scattering and absorption properties with an improved, analytical parameterization of the so-called Chou approximation.
- the delta-IASI module implements an iterative algorithm for the optimal estimation of the thermodynamic state of the atmosphere. The retrieval algorithm follows Rodgers optimal estimation method and uses an additional regularization parameter which improves the retrieval accuracy and convergence rate of the inverse scheme. It is able to estimate the following atmospheric state vector:

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

Retrieval of Polar Startospheric Clouds

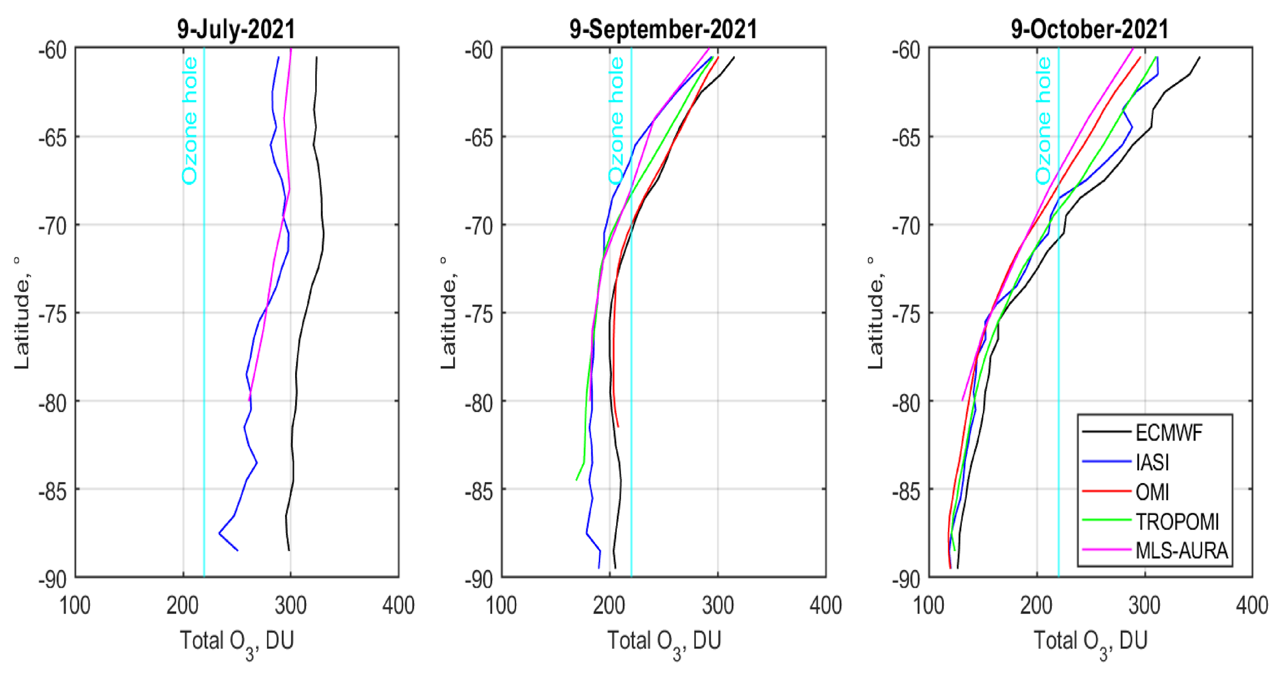


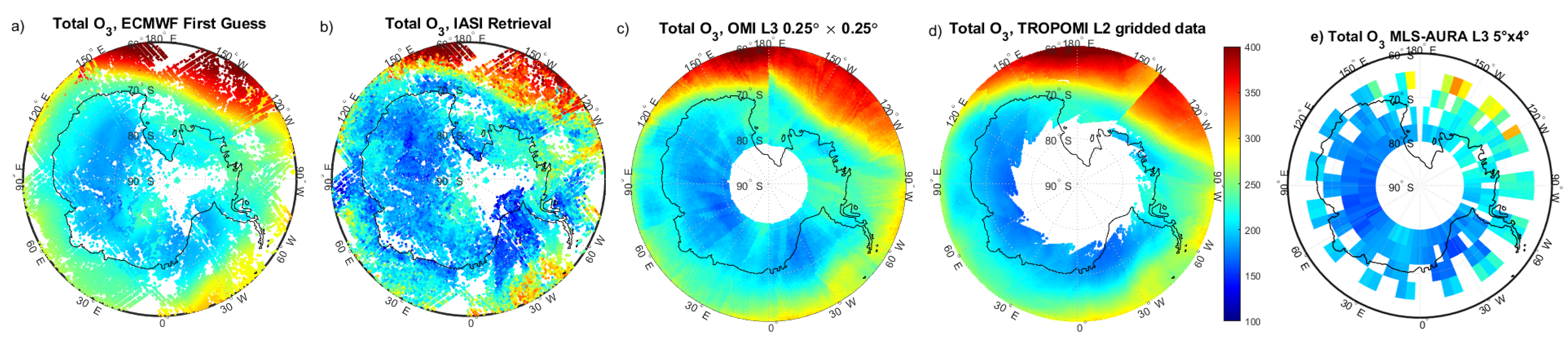
P=43 hPa (~20 km)
T=182 K
IWC=4.5 10^{-7} kg/kg
D_e=4 um

Orange – IASI Measurement
Black – Computed with ECMWF profile
Blue – Computed with IASI retrieved profile

Retrieval of Ozone

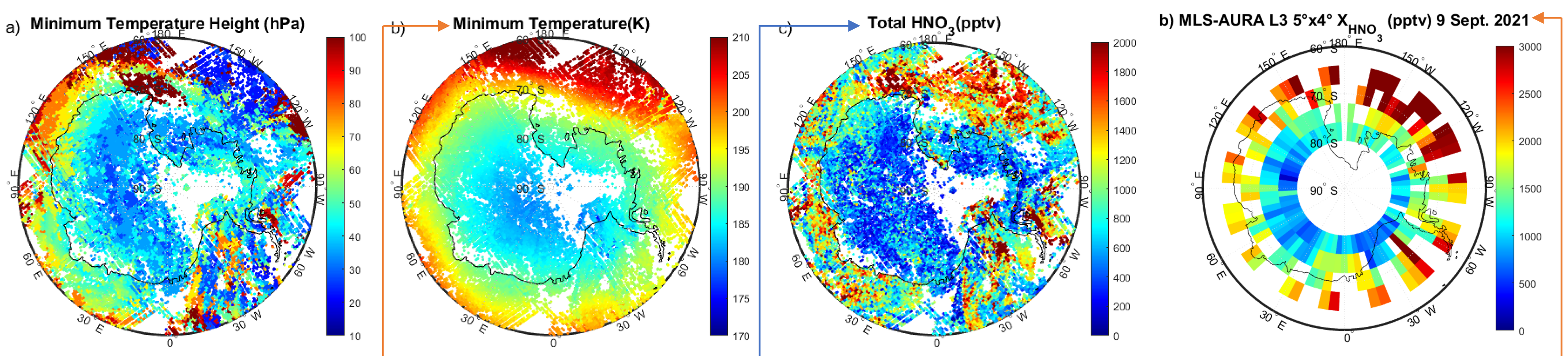
Looking at the plots of IASI-based ozone against other ozone products, it can be observed how IASI data actually show a deeper and wider ozone hole with respect to ECMWF, and this is true for both the total ozone column and the profile. MLS-AURA captures the same features as IASI, despite its coarser spatial resolution. Overall, it can be stated that our IASI L2 data compare better with TROPOMI and MLS-AURA , while OMI tends to be more coherent with the ECMWF analysis (which could just be a result of OMI data being L3).





Retrieval of HNO3

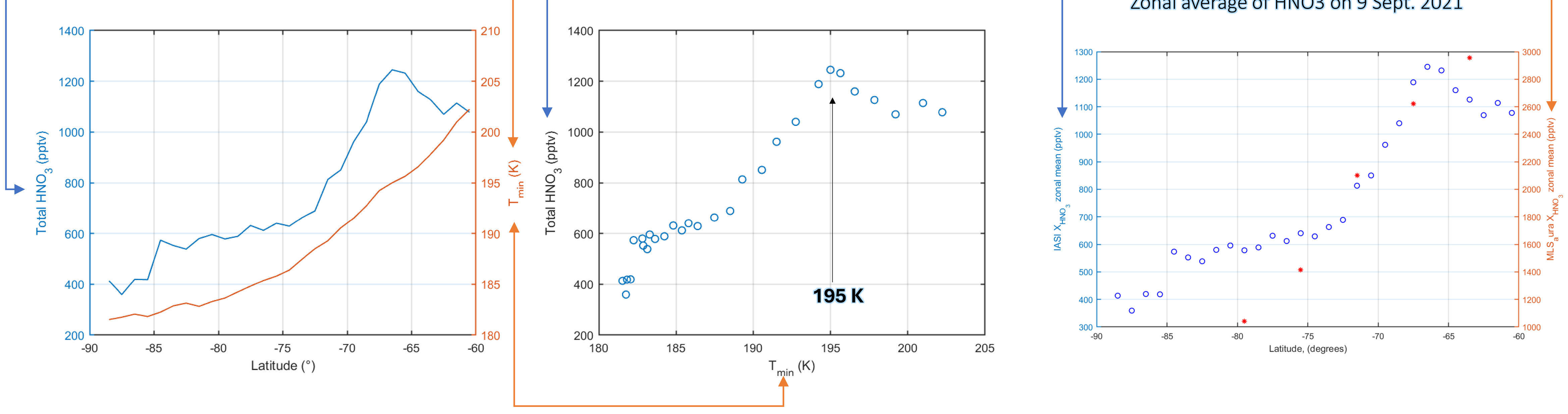
In the inner Antarctic continent, temperatures were found to be well below 195 K, with temperature inversion layers occurring at pressures between 30 and 60 hPa, and low concentrations of HNO_3 (< 500 pptv). These conditions are favorable for the formation of polar stratospheric clouds (PSCs), which can lead to the removal of nitric acid from the gas phase through heterogeneous reactions.



Key Points

- We developed ϕ-IASI-F2N, a system integrating a direct and an inverse model. The scheme simultaneously retrieves cloud optical properties, the atmosphere's thermodynamic, and composition state for the clear-cloudy sky.
- 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.
- The onset of the ozone hole in September 2021 and 2023 (not shown here) was accompanied by significant denitrification of the polar atmosphere.
- Both IASI (infrared) and MLS-AURA (microwave) instruments observed this denitrification, despite their different viewing geometries and spectral ranges.
- PSCs catalyzed ozone destruction, contributing to the overall ozone hole.

Zonal average of HNO3 on 9 Sept. 2021



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