Ice supersaturated regions: properties and validation of ERA-Interim reanalysis with IAGOS in situ water vapour measurements

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Philipp Reutter, Patrick Neis, Susanne Rohs, Bastien Sauvage, Peter Spichtinger and Andreas Petzold

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Motivation (i)

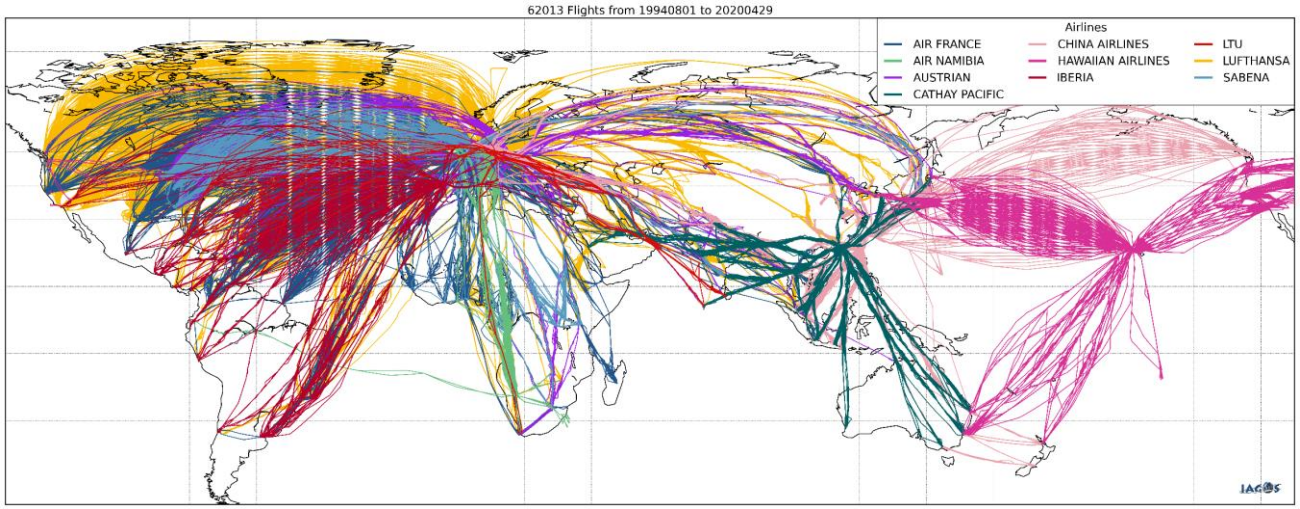
Cirrus clouds and their potential formation regions, so-called ice supersaturated regions (ISSRs), with values of relative humidity with respect to ice exceeding 100 %, occur frequently in the tropopause region. It is assumed that ISSRs and cirrus clouds can change the tropopause structure by diabatic processes, driven by latent heating due to phase transition and interaction with radiation.

For many research questions, a three-dimensional picture including a sufficient temporal resolution of the water vapour fields in the tropopause region is required. This requirement is fulfilled nowadays by reanalysis products such as the European Centre for Medium-Range Weather Forecasts (ECMWF) ERAInterim reanalysis.

Motivation (ii)

However, for a meaningful investigation of water vapour in the tropopause region, a comparison of the reanalysis data with measurement is advisable, since it is difficult to measure water vapour and to assimilate meaningful measurements into reanalysis products.

Source: www.iagos.org



More than 60 000 flights since 1994.
Source: www.iagos.org

Here, we present an intercomparison of high-resolution in situ measurements aboard passenger aircraft within the European Research Infrastructure IAGOS (In-service Aircraft for a Global Observing System; www.iagos.org) with ERA-Interim.

Temperature and humidity data over the North Atlantic from 2000 to 2009 are compared relative to the dynamical tropopause.

Methodology

- Aircraft-based measurements of atmospheric state variables and chemical composition usually refer to the aircraft flight altitude or pressure level, respectively.
- In the present work, the humidity data will be separated relative to the tropopause height (dynamical tropopause @ 2 PVU) in order to study the humidity in the tropopause region.
- **The vertical data will be distributed into three main layers: upper troposphere (UT), tropopause layer (TP) and lower stratosphere (LS) in accordance with Thouret et al. (2006). Furthermore, UT and LS are each separated into three subclasses (Table 1).**
- Focus on the North Atlantic region (40 to 60° N and −65 to 5° E)

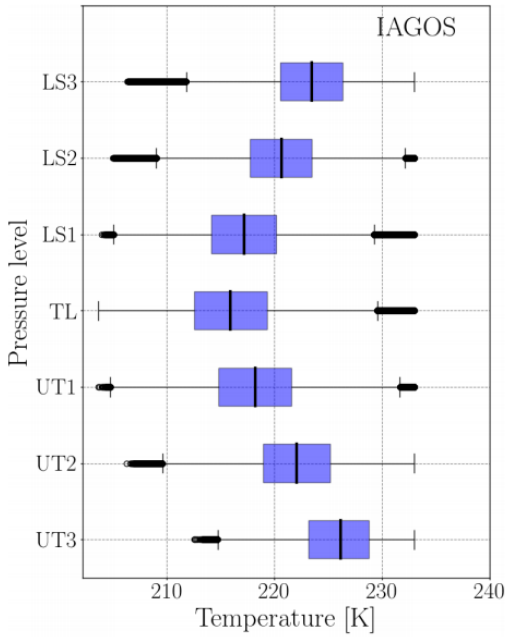
Region	Short name	$p_{ap} - p_{tph}$ (hPa)	Number of measurements
Lowermost stratosphere	LS3	−90	3 203 483
	LS2	−60	4 237 245
	LS1	−30	5 268 138
Tropopause layer	TL	0	5 643 057
Uppermost troposphere	UT1	+30	4 649 883
	UT2	+60	2 647 935
	UT3	+90	909 120

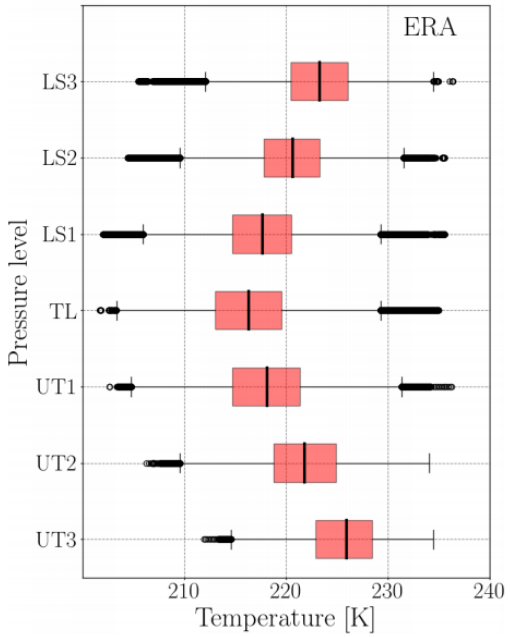
Table 1: The data set is distributed into three main layers: the upper troposphere, tropopause layer and lowermost stratosphere. The outer layers are additionally subdivided into three sublayers. The distribution criterion is the pressure difference between aircraft pressure pac and the tropopause pressure ptph with the range of ±15 hPa. Additionally, for every flight layer, the number of IAGOS measurements between 2000 and 2009 is presented.

Results

Comparison between IAGOS and ERA

Temperature





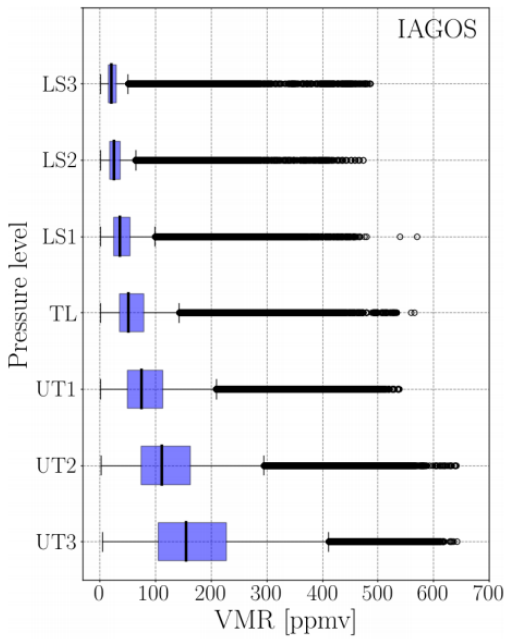
Vertical profile of temperature

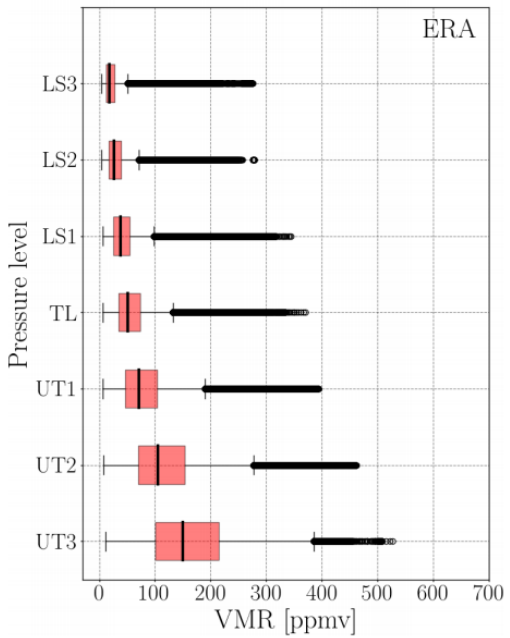
- As expected by definition, the tropopause layer shows the coldest mean temperatures, with 216.1 and 216.5 K for IAGOS and ERA, respectively
- Overall, the comparison between IAGOS and ERA shows a very good.

Vertical profile of water vapour

- The comparison between IAGOS and ERA shows a good overall agreement
- A clear dependence of the distribution with height is visible. The lowest median values of the water vapour VMR are observed, as expected, in the uppermost layer (LS3). In contrast, the lowermost level (UT3) shows the largest mean values of the water vapour mixing ratio.

Water vapour volume mixing ratio

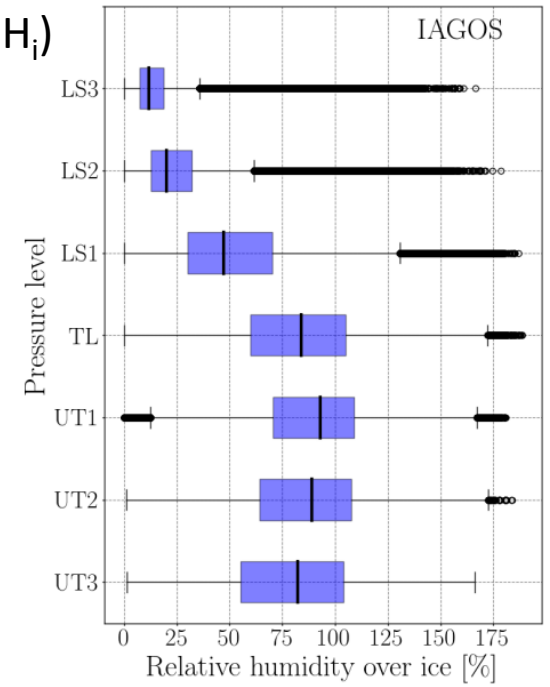




Results

Comparison between IAGOS and ERA

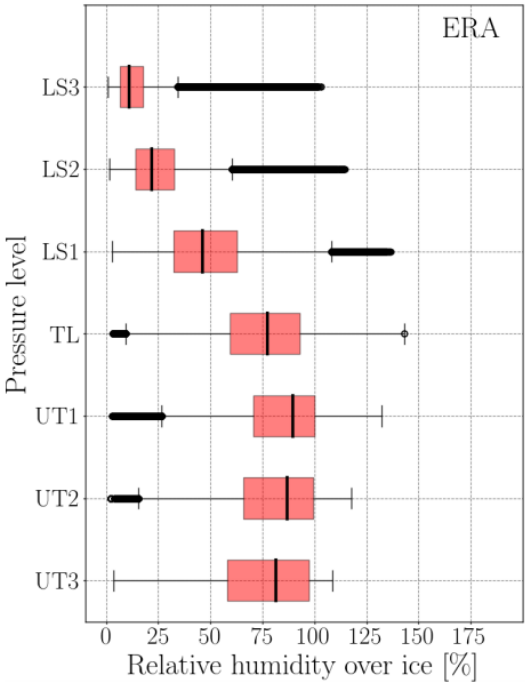
relative humidity with respect to ice (RH_i)



- Since cloud formation is governed by the relative humidity rather than the water vapour mixing ratio, the relative humidity with respect to ice RHi is investigated.

- The overall results show two different regimes. In the troposphere, up to the tropopause layer, the statistics cover the whole range of possible saturation values.

- In the tropopause layer, still a significant amount of the data is exceeding values of RHi > 100 %, both in the in situ data as well as in the ERA data set. However, the whisker in Figure indicates that ERA has less data points with a higher supersaturation compared to IAGOS.

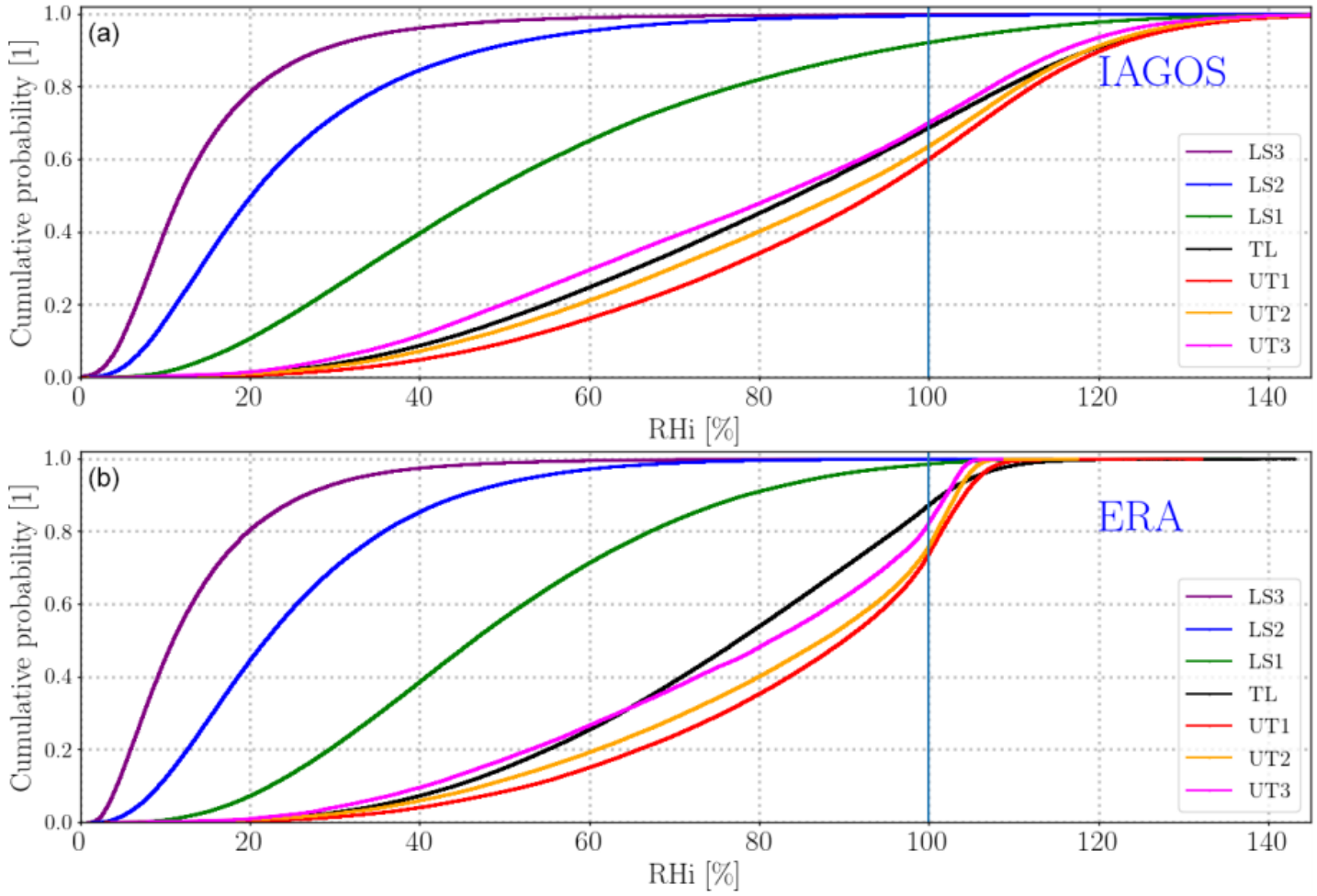


- In the stratospheric layers, the median of the RHi values is decreasing strongly. However, ice supersaturation is still possible, especially in the lowest stratospheric layer (LS1). **The statistics of ISSRs in higher levels provided by the ERA data set show clearly less occurrence of this feature compared to IAGOS.**

- Since ISSRs are an important factor for the formation and lifetime of contrail cirrus (Kärcher, 2018), a good model representation of the abundance of ice supersaturation in this region is important for an adequate description of the Earth's radiative budget.

Results

- For a more distinct look at the occurrence of ISSR, we illustrate the statistic evaluation with cumulative probability.
- Each layer is depicted with its own colour. It is clearly visible that ERA and IAGOS behave differently for RHi > 100 %, especially for the tropospheric layers.
- ERA deviates from the IAGOS measurements concerning values larger than RHi = 100 % by showing less data points and weaker supersaturations.
- **This is an important finding, because it points to a misrepresentation in ERA of ice supersaturation in the UT and tropopause region, which is the formation region of in situ cirrus.**



Cumulative distribution of RHi for every height level in the IAGOS (a) and ERA (b) data sets. The vertical blue line denotes saturation with respect to ice.

more and detailed information can be found in the recently published manuscript:

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unless otherwise indicated, all figures and tables from Reutter et al., 2020

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Ice supersaturated regions: properties and validation of ERA-Interim reanalysis with IAGOS in situ water vapour measurements

Philipp Reutter[1], **Patrick Neis**[1,2,a], **Susanne Rohs**[2], **and Bastien Sauvage**[3]

[1]Institute for Atmospheric Physics, Johannes Gutenberg University Mainz, Mainz, Germany
[2]Institute of Energy and Climate Research Troposphere (IEK-8), Forschungszentrum Jülich, Jülich, Germany
[3]Laboratoire d'Aerologie, Université de Toulouse, CNRS, UPS, Toulouse, France
[a]now at: CGI Deutschland B. V. & CO. KG, Frankfurt, Germany

Correspondence: Philipp Reutter (preutter@uni-mainz.de)

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Abstract. Cirrus clouds and their potential formation regions, so-called ice supersaturated regions (ISSRs), with values of relative humidity with respect to ice exceeding 100 %, occur frequently in the tropopause region. It is assumed that ISSRs and cirrus clouds can change the tropopause structure by diabatic processes, driven by latent heating due to phase transition and interaction with radiation. For many research questions, a three-dimensional picture including a sufficient temporal resolution of the water vapour fields in the tropopause region is required. This requirement is fulfilled nowadays by reanalysis products such as the European Centre for Medium-Range Weather Forecasts (ECMWF) ERA-Interim reanalysis. However, for a meaningful investigation of water vapour in the tropopause region, a comparison of the reanalysis data with measurement is advisable, since it is difficult to measure water vapour and to assimilate meaningful measurements into reanalysis products. Here, we present an intercomparison of high-resolution in situ measurements aboard passenger aircraft within the European Research Infrastructure IAGOS (In-service Aircraft for a Global Observing System; http://www.iagos.org, last access: 15 January 2020) with ERA-Interim. Temperature and humidity data over the North Atlantic from 2000 to 2009 are compared relative to the dynamical tropopause. The comparison of the temperature shows good agreement between the measurement and ERA-Interim. While ERA-Interim also shows the main features of the water vapour measurements of IAGOS, the variability of the data is clearly smaller in the reanalysis data set. The combination of temperature and water vapour leads to the relative humidity with respect to ice (RH_i). Here, ERA-Interim deviates from the measurements concerning values larger than $RH_i = 100$ %, both in number and strength of supersaturation. Also, pathlengths of ISSRs along flight tracks are investigated, representing macrophysical properties as linked to atmospheric flows. The comparison of ISSR pathlengths shows distinct differences, which can be traced back to the spatial resolution of both data sets. Also, the seasonal cycle and height dependence of pathlengths changes for the different data sets due to their spatial resolution. IAGOS shows a significantly greater amount of smaller ISSRs compared to ERA-Interim. Good agreement begins only at pathlengths on the order of the ERA-Interim spatial resolution and larger.

1 Introduction

Water vapour is the most important greenhouse gas in the atmosphere and therefore plays a major role in the Earth's radiative balance (Myhre et al., 2013). Especially in condensed form, water is also of large significance for planetary radiation. Clouds can reflect incoming solar radiation while absorbing and re-emitting longwave radiation from the Earth. Particularly the effect of cirrus clouds is still challenging. Whether a cirrus cloud has a net warming or cooling effect on the Earth's atmosphere depends strongly on altitude, avail-

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