September, 2009

Ice Supersaturations from the VCSEL Hygrometer in HIPPO Global and START08 Campaigns

Minghui Diao, *Princeton University*
Mark A. Zondlo, *Princeton University*

Ice Supersaturations from the VCSEL Hygrometer in HIPPO Global and START08 Campaigns

Minghui Diao and Mark A. Zondlo

Department of Civil and Environmental Engineering, Princeton University

Center for Mid-Infrared Technologies for Health and the Environment

National Science Foundation; NASA NESSF Fellowship
HIPPO Global Science Team;START08 Science Team

• Water vapor and Ice Supersaturations

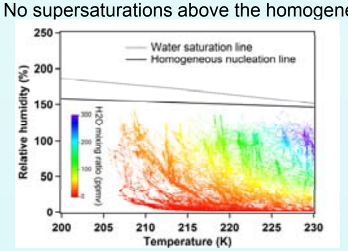
• **Water vapor** is the most important greenhouse gas in the atmosphere. Accurate measurements of water vapor are critical for predicting future climate. Based on the high resolution water vapor data, we examine the climatology of ice supersaturations of water vapor (relative humidity over ice (RHi) is above 100%) in the upper troposphere (UT) from 100% to homogeneous thresholds. We analyze the magnitude, frequency, distribution and location of the ice supersaturated regions. [1][2][3]

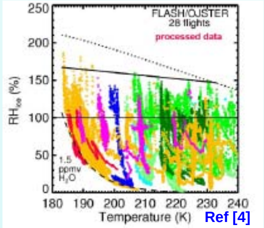
•Ice Supersaturations in the Upper Troposphere in START08 Campaign

•**1. START08 Campaign** is the Stratosphere -Troposphere Analyses of Regional Transport campaign, which includes 18 flights from 21 April 2008 to 28 June 2008. During this campaign we analyze ice supersaturated regions (ISSRs) in the midlatitudinal upper troposphere (UT) over North America, where ice supersaturations are common according to satellite data from the Atmospheric Infrared Sounder (AIRS) [3].

•**2. Magnitude of ice supersaturations in field campaigns**

Below and to the left is the 98 hrs VCSEL data of relative humidity (RHi) vs. temperature with the black line as the homogeneous nucleation line and the dotted line is the liquid water saturation line. In the right graph green dots represent midlatitudinal RHi data from FLASH and OJSTER hygrometers. No supersaturations above the homogeneous nucleation line are observed.

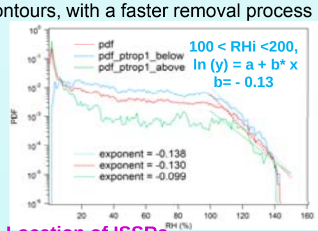


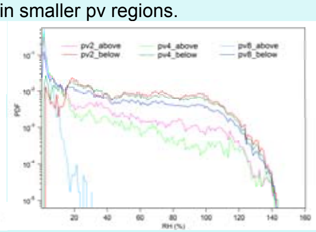


Ref [4]

•**3. Probability distribution functions (PDFs) of ice supersaturations**

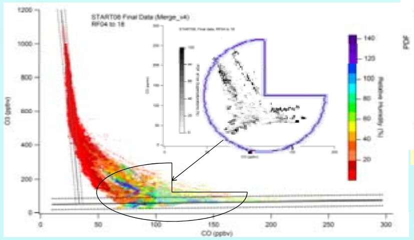
In the lower left graph, PDF of all RHi is in red with an exponent of -0.13 by an exponential fit from RHi of 100 to 200. In Ref [3], AIRS data have an exponent of -0.06. CAM3 modeling data do not show supersaturations. A faster exponential decay in *in situ* measurements may be a result of the high resolution measurements of small scale ISSRs which tend to have lower RHi than large scale ISSRs. Blue and green lines show PDFs of RHi below and above the GFS pressure tropopause, respectively. The right graph shows PDFs of ice supersaturations below and above potential vorticity (pv) 2, 4, 6 contours, with a faster removal process in smaller pv regions.





4. Location of ISSRs

The bigger graph represents the relationship between RHi and O_3 / CO mixing. The inside graph shows PDF of ISSRs with higher PDF inside and below extratropical transition layer (ExTL), which is described by the 3σ dotted lines based on curve fitting of CO<25ppbv and O_3<70ppbv.

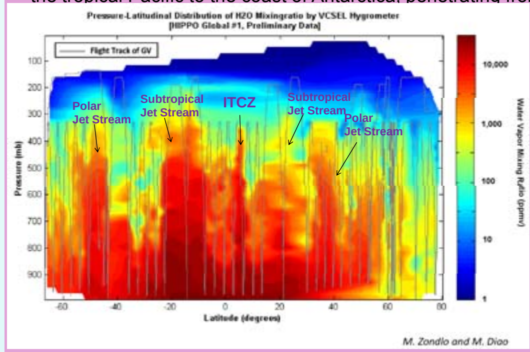


• HIPPO Global # 1 Campaign

•**1.** The *HIAPER Pole-to-Pole Observations (HIPPO)* of Carbon Cycle and Greenhouse Gases field experiment is the first ever, most comprehensive, seasonal global survey of trace gases from the Arctic to the Antarctica and from the Earth's surface to the lower stratosphere. These preliminary data are from the first deployment of HIPPO Global in January, 2009.

•**2. "Snapshots" of water vapor in the from Pole-to-Pole**

The graph below is the first high-resolution "snapshot" of water vapor concentration in the atmosphere from Pole to Pole. The black line shows the flight track of the aircraft as it made vertical profiles every 3.5 degrees from the Arctic Ocean to the tropical Pacific to the coast of Antarctica, penetrating from the Earth's surface to the lower stratosphere.

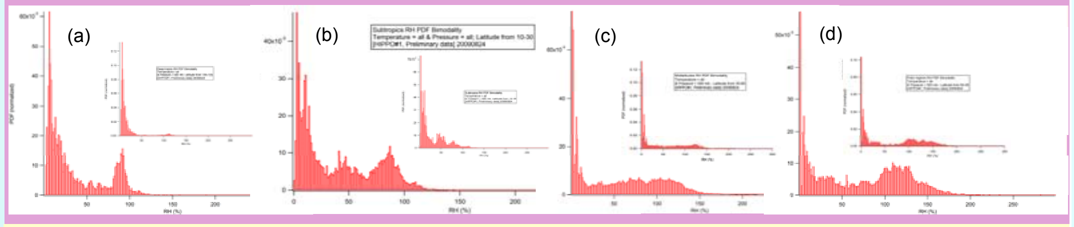


•Global distribution of water vapor

•In the left picture surprisingly large horizontal gradients of water vapor exist, and well-defined plumes of moist air transport the air vertically into the dry upper troposphere. A large plume of water vapor around the Equator depicts the Intertropical Convergence Zone (ITCZ), which continuously pumps up moist air from the Equator into higher altitudes. Other plumes of moisture include areas near the subtropical (20°) and polar (40°) jet streams that are marked also by strong horizontal gradients in water vapor.

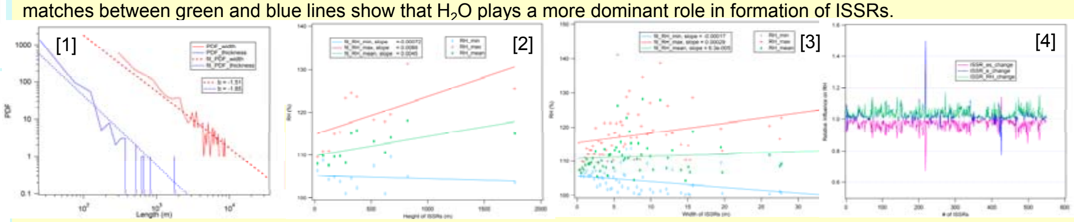
•Multimodalities of Relative Humidity

•Graphs below show PDFs of RHi in different latitudinal ranges: deep tropics, subtropics, midlatitudes and polar regions. Deep tropics (a) and polar regions (d) show bimodality in the distribution of RHi; Subtropics show trimodality (b); Midlatitudes show unimodality (c), which agrees with the RHi unimodal distribution in midlatitudes in START08 campaign. The difference between PDFs of RHi in different latitudinal regions may be a result of different mechanisms in H_2O removal process. However, the PDFs may bias towards lower H_2O removal rates in large scale measurements of satellites. Similar analyses for pressure < 500 mb (UT) (inside graphs) in each region all show less clear modality of RHi distribution, which reveals that one of the mechanisms may mainly happen < 500 mb, while the other ones may happen in all pressures.



• Ice Supersaturated Regions in the UT in START08 Campaign

Fig 1. below shows the geometric curve distribution of thickness and width of ISSRs, log (PDF) = a + b*log (Length), with b of -1.85 and -1.51, respectively. This demonstrates the importance of high resolution *in situ* measurements of small scale ISSRs which have much larger numbers than large scale ISSRs. Fig. 2 and 3 reveal that small scale ISSRs tend to have smaller average (green line) and maximum (red line) RHi, which would be averaged out in satellite data. Fig. 4 shows the relative influences from H_2O mixing ratio (blue line) and temperature (pink) on the RHi increase over 100% (green). The matches between green and blue lines show that H_2O plays a more dominant role in formation of ISSRs.



References:

[1] T. Peter et al., When dry air is too humid. *Science*, 314,1399-1402, 2006.

[2] A. Gettelman and D. E. Kinnison. The global impact of supersaturation in a coupled chemistry-climate model. *Atmos. Chem. Phys*., 7, 1629–1643, 2007.

[3] A. Gettelman. The Global Distribution of Supersaturation in the Upper Troposphere from the Atmospheric Infrared Sounder. *Journal of Climate*, 19, 6089-6103, 2006.

[4] M. Kramer, et al. Ice supersaturations and cirrus cloud crystal numbers. *Atmos. Chem. Phys. Discuss.*, 8, 21089–21128, 2008.

VCSEL hygrometer on the NSF plane

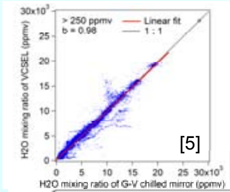
1. How do we measure water vapor?

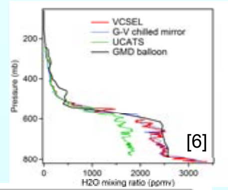
2. What are the challenges in water vapor measurements?

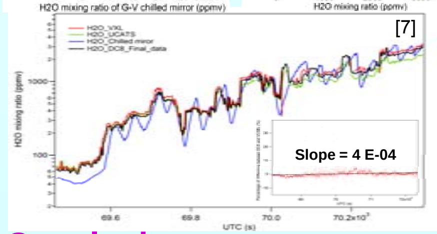
Challenges	Solutions of VCSEL
Broad Dynamic Range from 4 to 40,000 ppmv	1854.03 nm (strong) + 1853.37 nm absorption lines for entire range
High affinity to surfaces	Open Path

3. How well is the VCSEL compared with other hygrometers?

During the START08 Campaign, the VCSEL hygrometer (red) agrees well with all other hygrometers in their working ranges, including chilled mirror hygrometer (Fig. 5) and UCATS (Fig. 6 green) on NSF G-V plane, NOAA balloon hygrometer (Fig. 6 black) and NASA DC8 hygrometer (Fig. 7 black).







Conclusions:

1) In START08 Campaign RHi is below 150% in the upper troposphere with a PDF exponent of - 0.13.
2) ISSRs happen inside and below ExTL, with a geometric curve distribution of both thickness and width. RHi of small scale ISSRs are smaller than bigger ISSRs. H_2O mixing ratio plays a more dominant role in ISSRs than temperature does.
3) In HIPPO data there are multimodalities of RHi distributions in different latitudinal regions, which reveal different H_2O removal process mechanisms.
4) In START08 campaign the VCSEL agrees well with all other hygrometers in their working ranges.