# Water vapor, ice supersaturation, and stratospheric mixing in TORERO

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# NSF Gulfstream-V VCSEL hygrometer in TORERO

VCSEL = vertical cavity surface emitting laser hygrometer for NSF Gulfstream-V

*(Zondlo et al., 2010)*

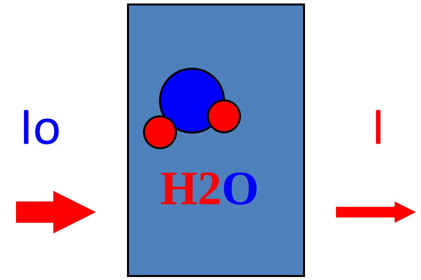
1854 nm fiberized VCSEL, located on top, right aperture plate in TORERO

Open-path avoids sampling biases (moderate/heavy icing can be an issue)

| Parameter | Specifications |
|---|---|
| Dew point range | -110°C to +30°C |
| Mixing ratio range | 1-35,000 ppmv |
| Sensitivity (SNR=1) | 0.05 ppmv |
| Frequency | 25 Hz |
| Accuracy | ≤ 5% |
| Precision | ≤ 3% |
| Power | 10 W |
| Weight | 5 kg |
| Size | 25 cm × 16 cm × 5 cm |
| Operation | unattended |

# Beer-Lambert law

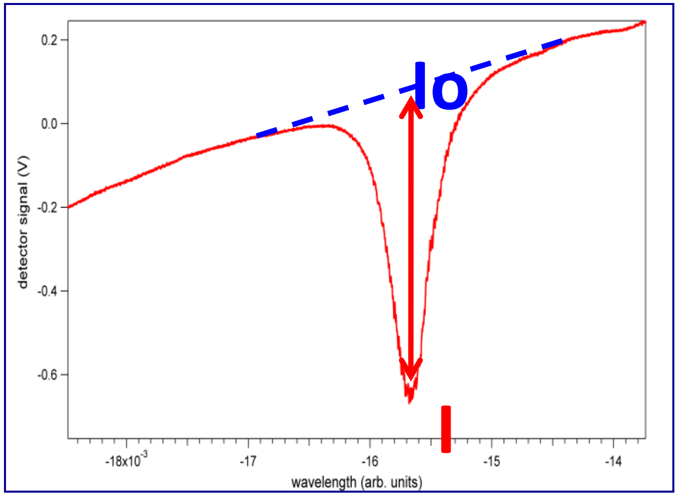
$$\frac{I(\lambda)}{Io(\lambda)} = \exp(-\alpha(\lambda))$$




where: $I(\lambda)$ is light intensity after absorption

$Io(\lambda)$ is incident light intensity

$\alpha(\lambda)$ is absorbance




$$a(\lambda) = S(T)\, g(\lambda,T,P)\, N\, l$$

$\sigma$ = cross section

where: $S(T)$ is the linestrength

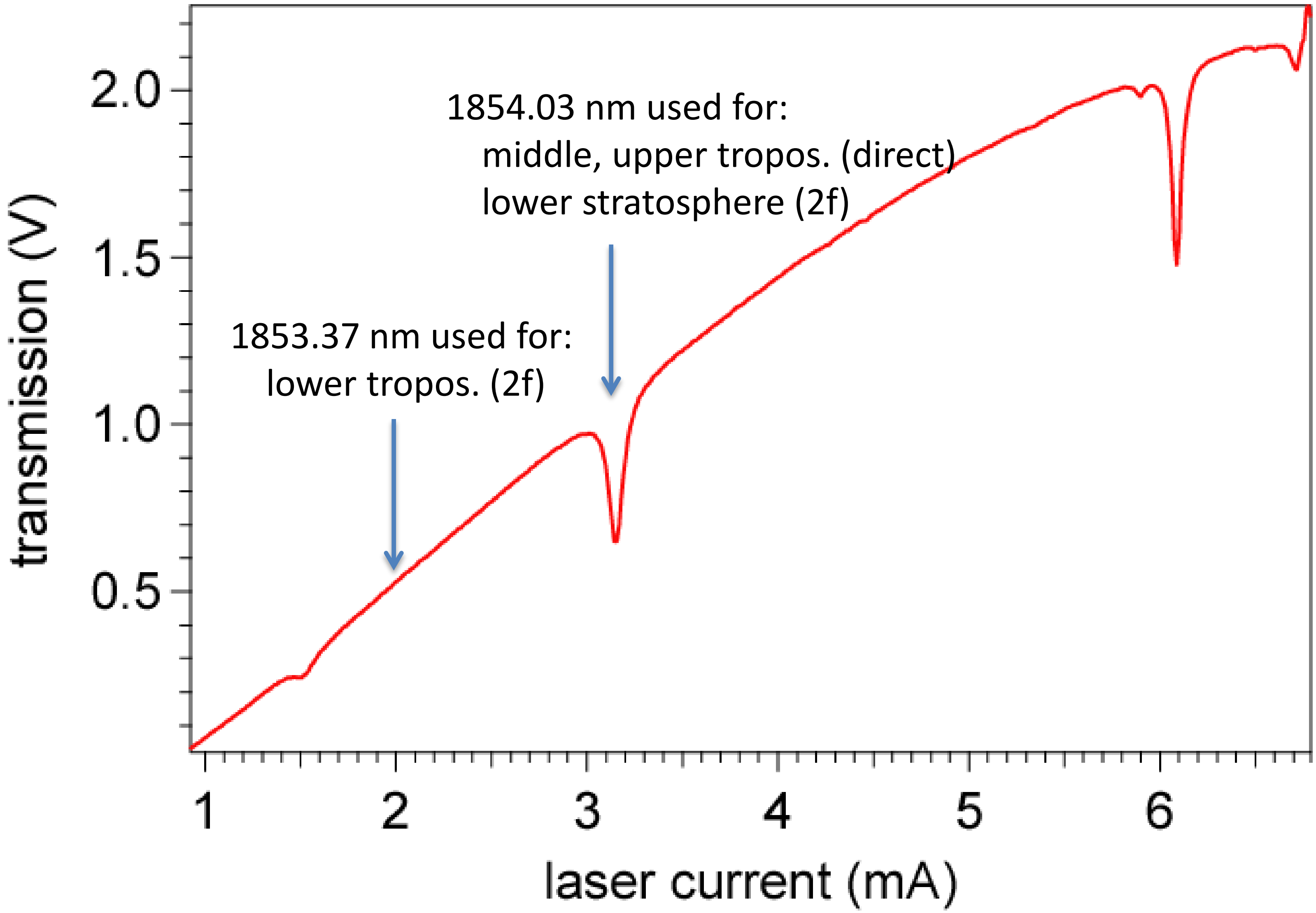
$g(\lambda,T,P)$ is the normalized Voigt lineshape function

$N$ is the absolute concentration

$l$ is the pathlength

We use direct absorption and a derivative technique, wavelength modulation spectroscopy, for high sensitivity

# current tuning capabilities




Switch absorption lines around -15º to -30ºC dewpoints (1000-3000 ppmv) depending upon pressure and temperature

# VCSEL status in TORERO

- Performed well for all flights, >98.5% data coverage

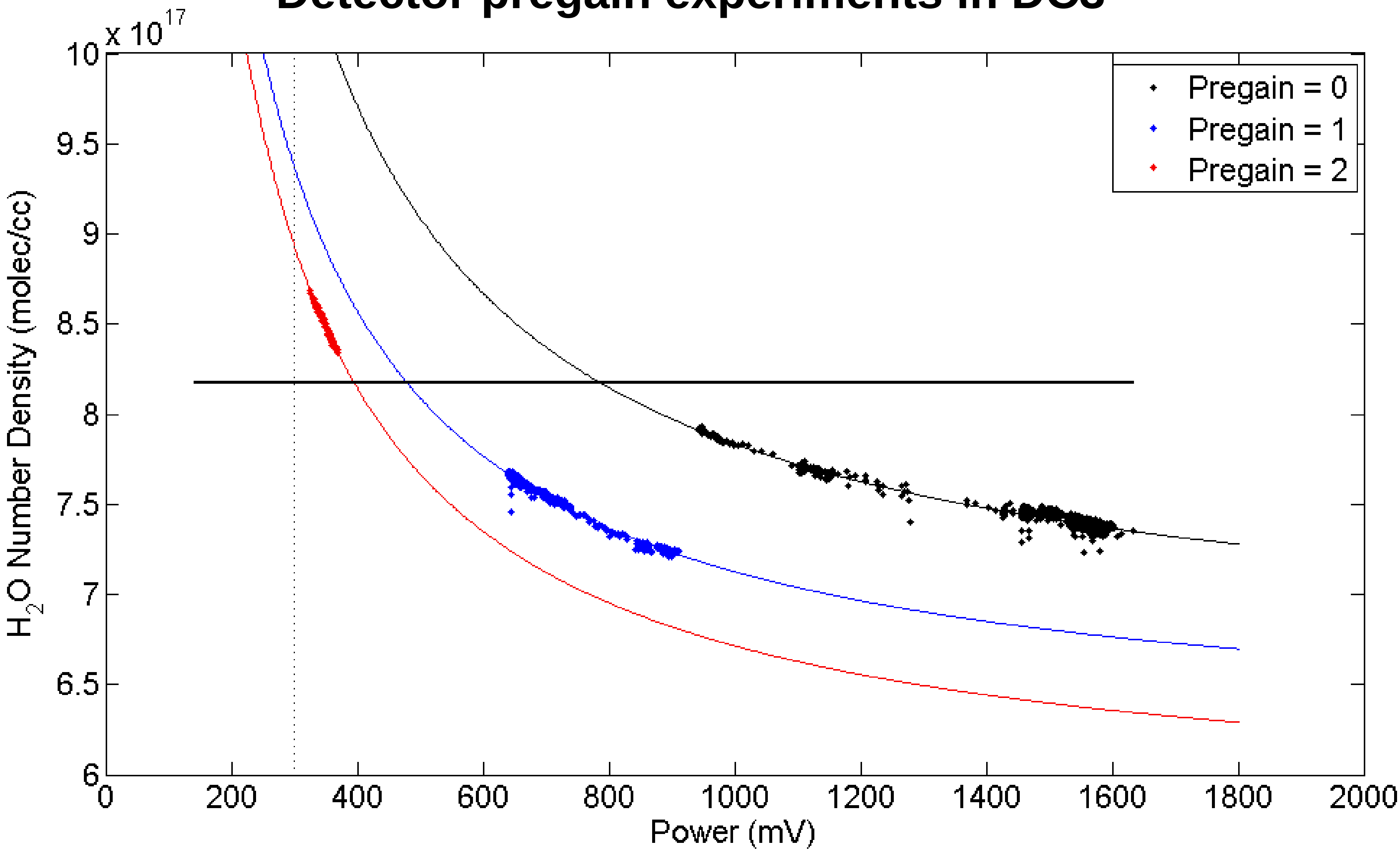
- QC/QA of data ongoing, expected by end of August (final accuracy ±5%)
  (possible high bias in submitted data at dewpoints > -20ºC)

- Accuracy of raw data ±20%

- Normal data anomalies (transitions between absorption lines, icing, linelocking issues) will be removed in final dataset

- No obvious problems occurred during TORERO

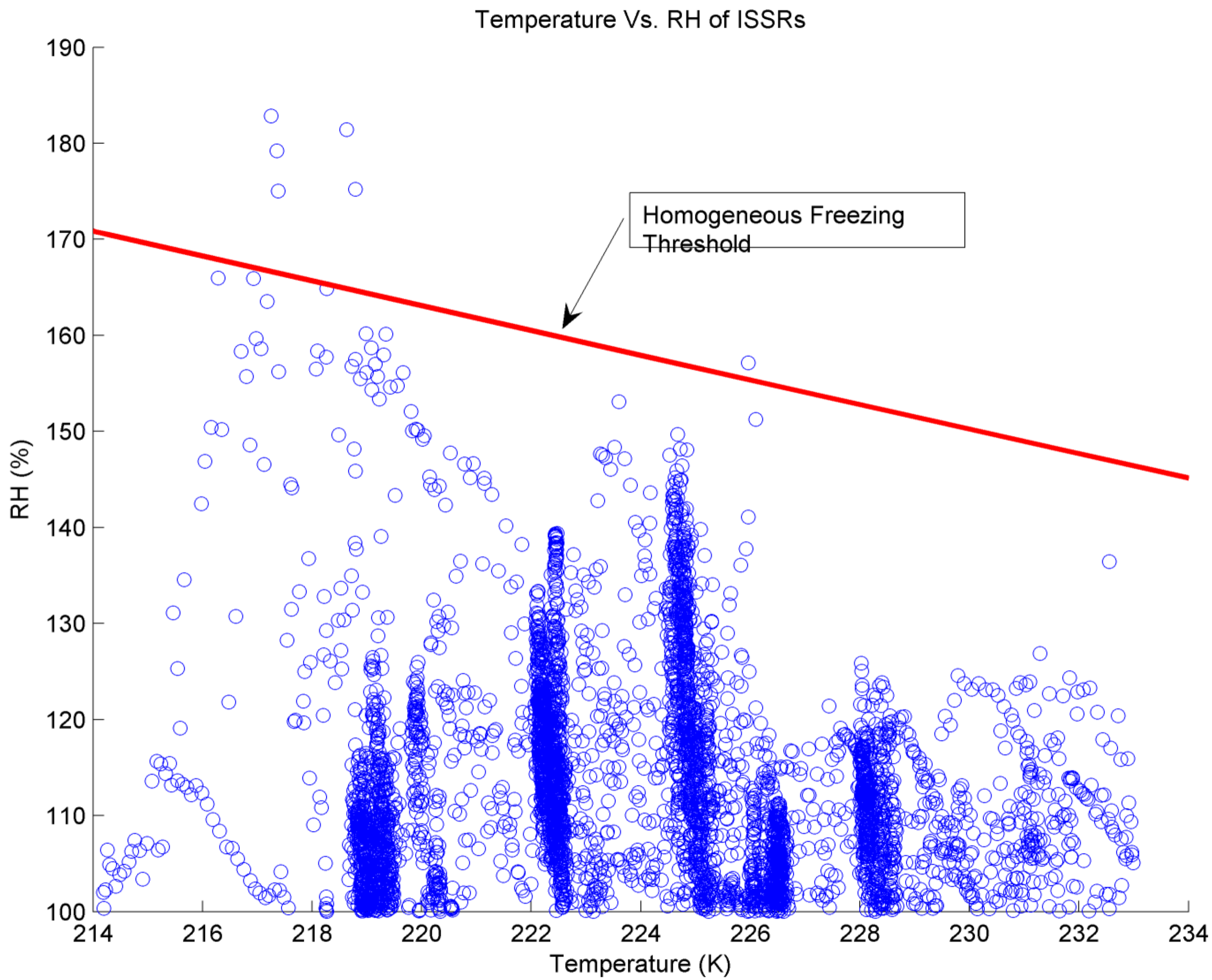
# Detector pregain experiments in DC3




Uncertain if these data (gain problems) impact TORERO
Need to examine pre-, post- calibrations and compare to DC3 results
Well-defined response if this requires correction

# Ice supersaturation in TORERO

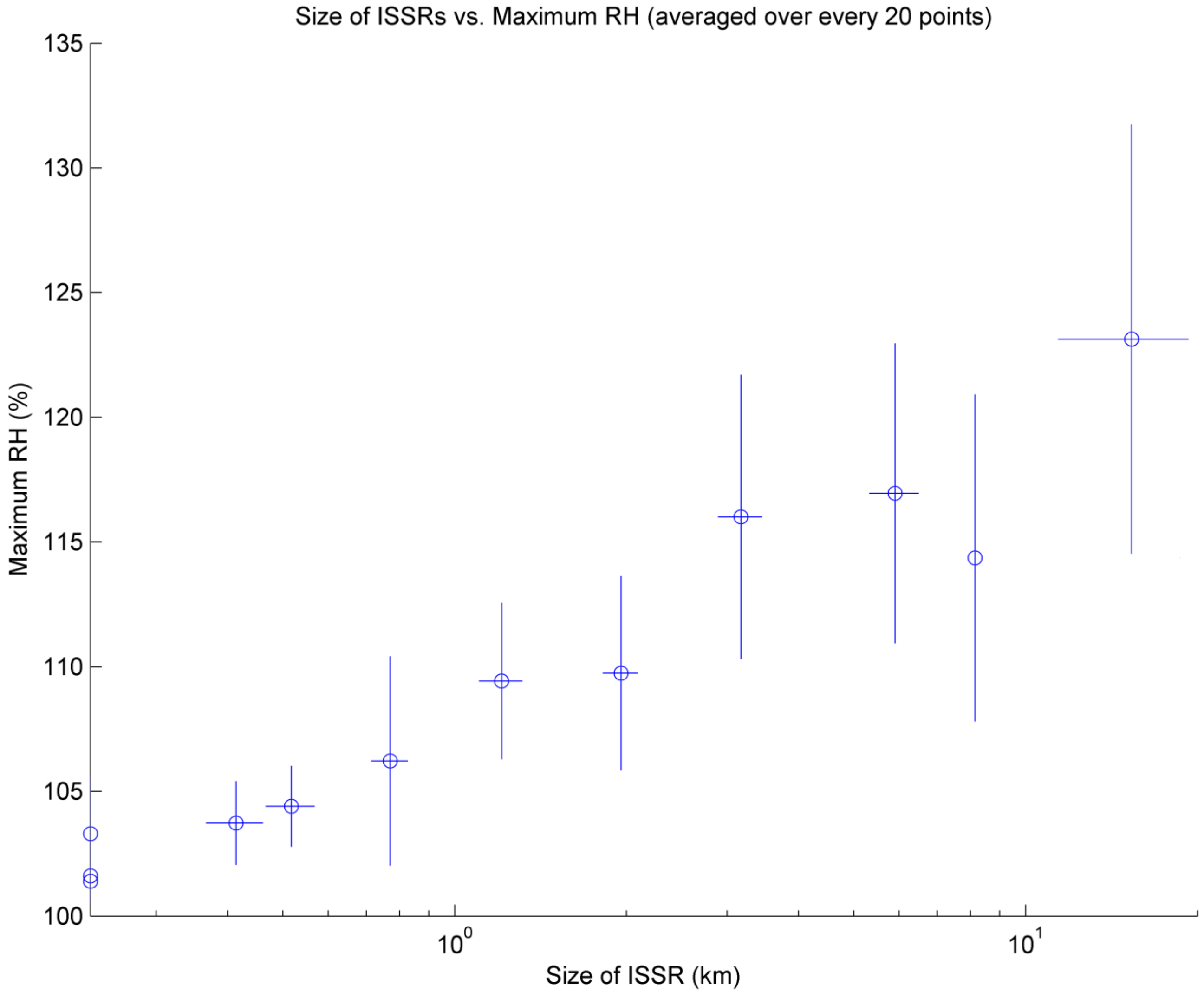
(all analyses shown herein are restricted to T≤-40ºC to ensure ice phase)




N=235 ice supersaturated regions in TORERO at T≤-40ºC

Most well below the homogeneous ice nucleation (Koop et a., 2000)

# Horizontal chord lengths of ISSRs in TORERO




Median ISSR lengths:

TORERO: 1.0 km

Compare to:

PREDICT: 0.7 km
(tropical, western Atl.)

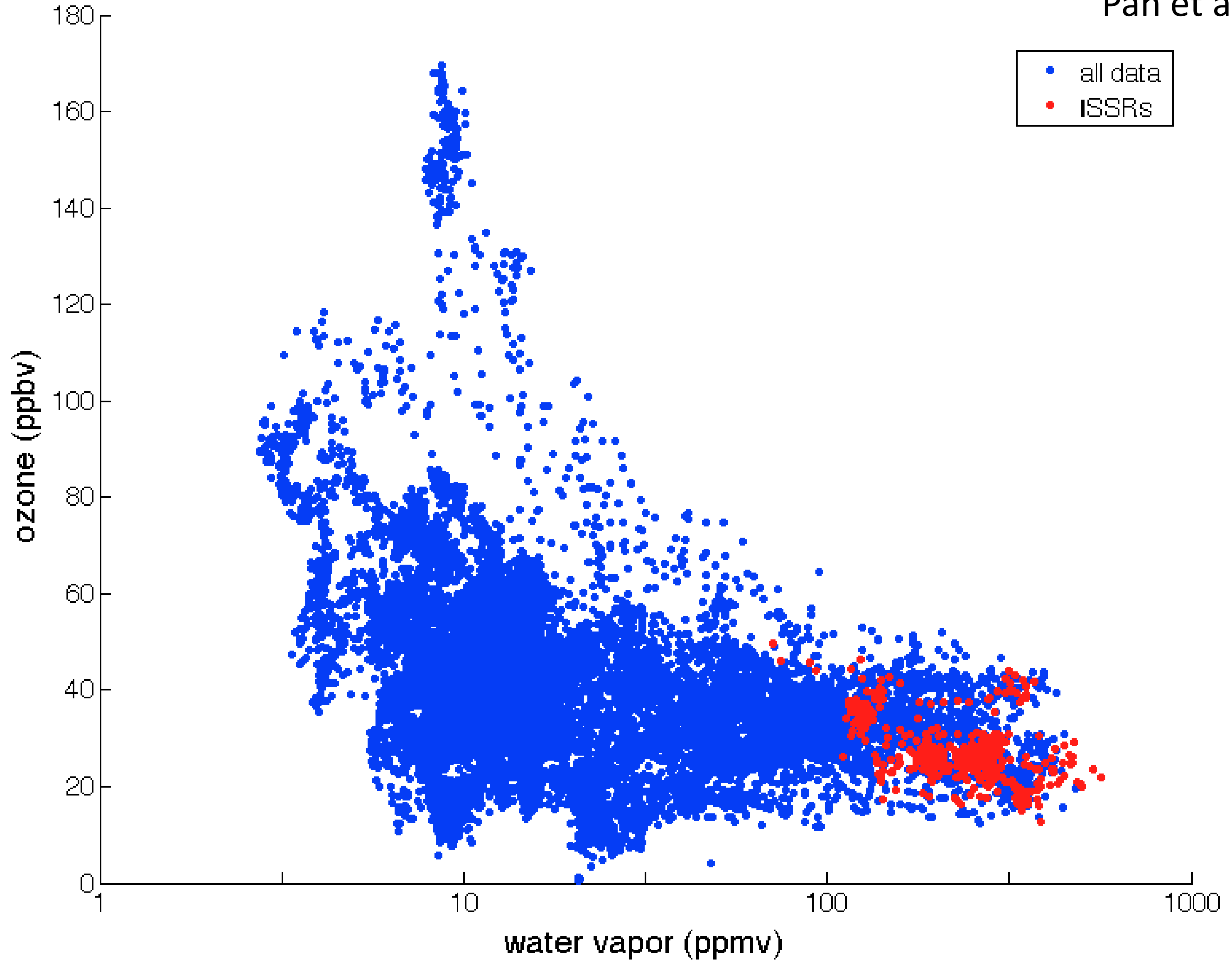
HIPPO: 0.9 km
(Pacific, 67ºS to 87ºN)

START08: 0.9 km
(North America)

Higher max (mean) RHi observed as ISSR horizontal length increases
Sizes very consistent with previous field campaigns

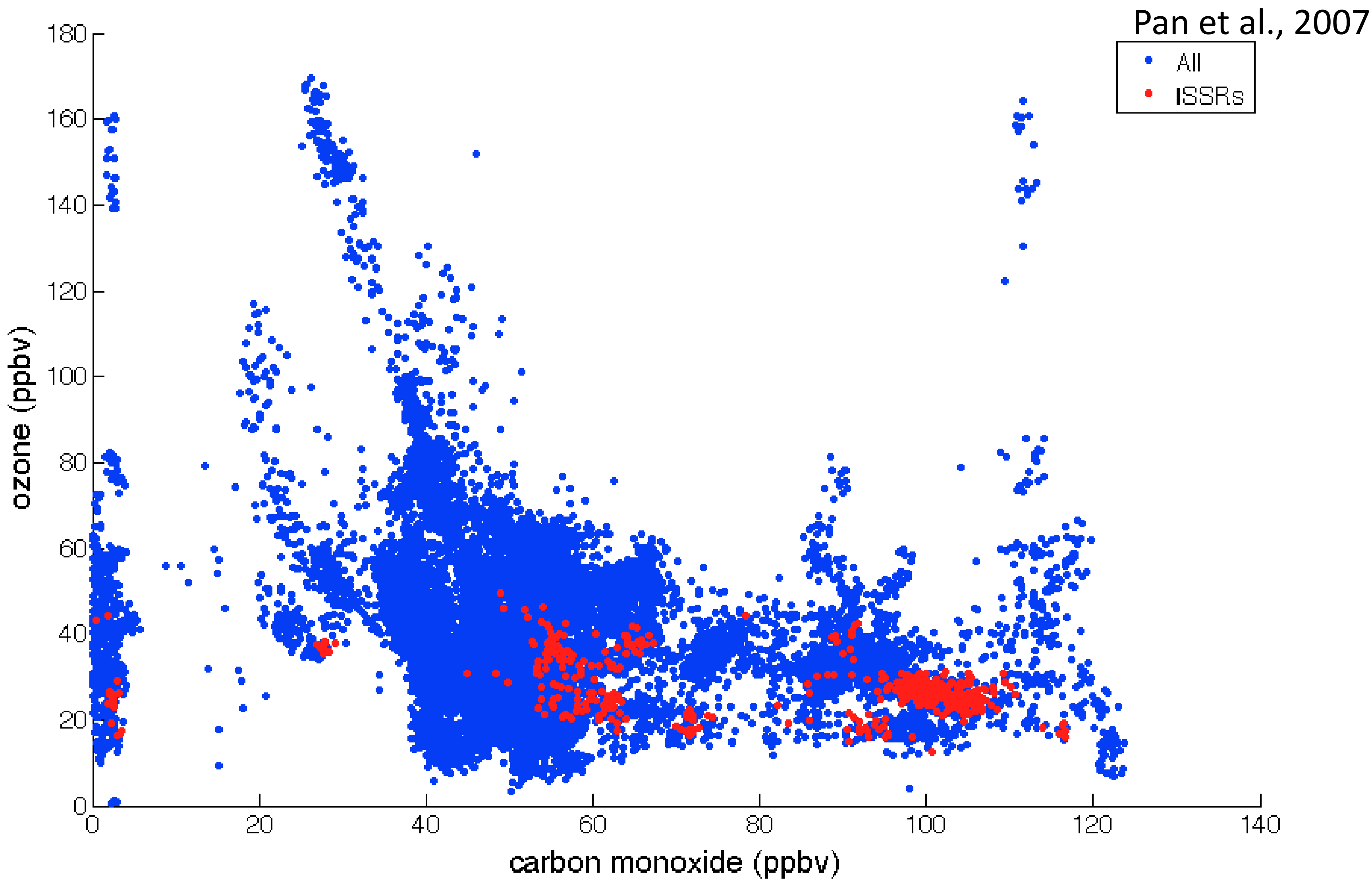
# Strat.-trop. mixing: Ozone vs. $H_2O$

Pan et al., 2007



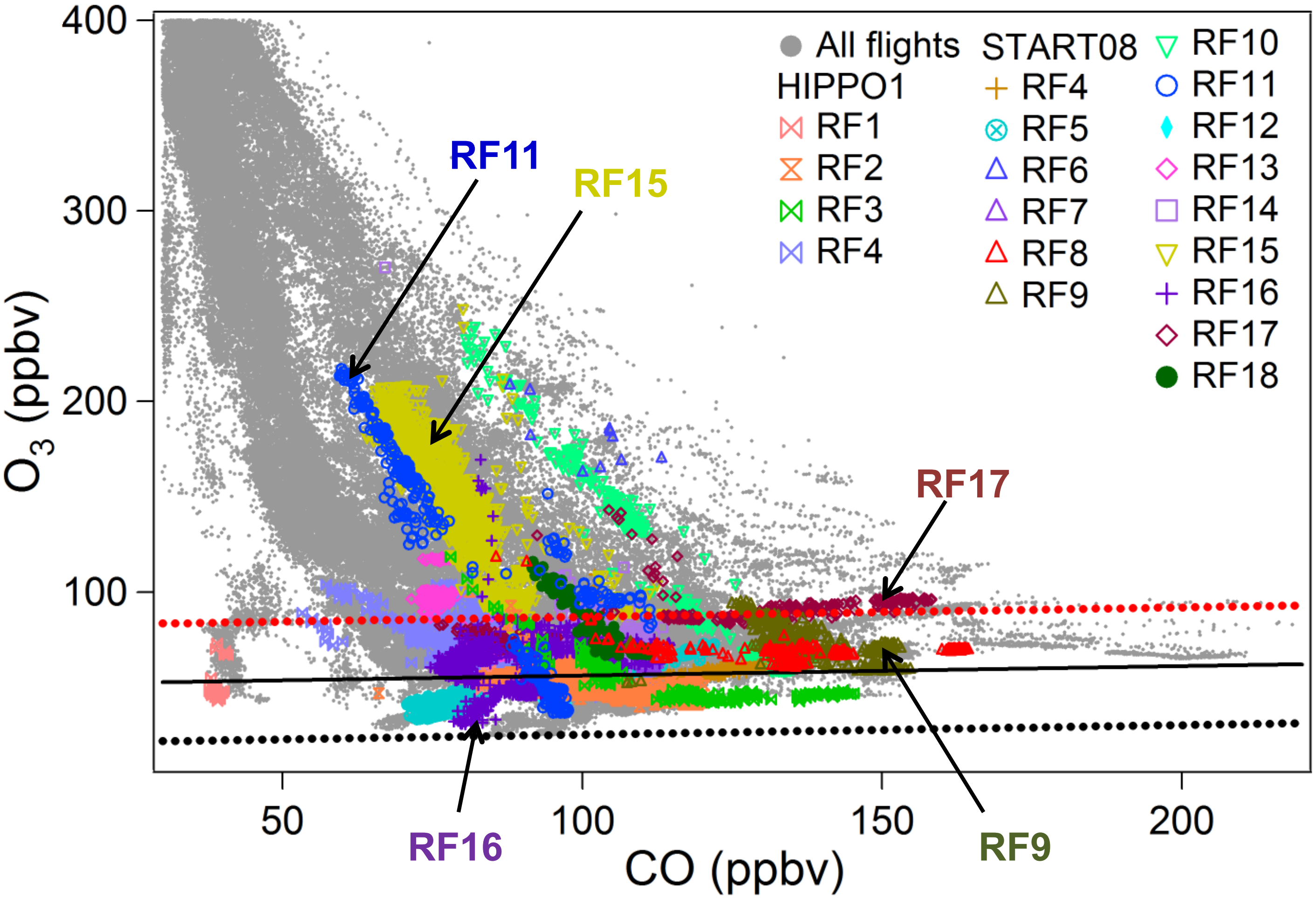

ISSRs largely forming along tropospheric-tropospheric mixing lines

# Strat.-trop. mixing: Ozone vs. CO



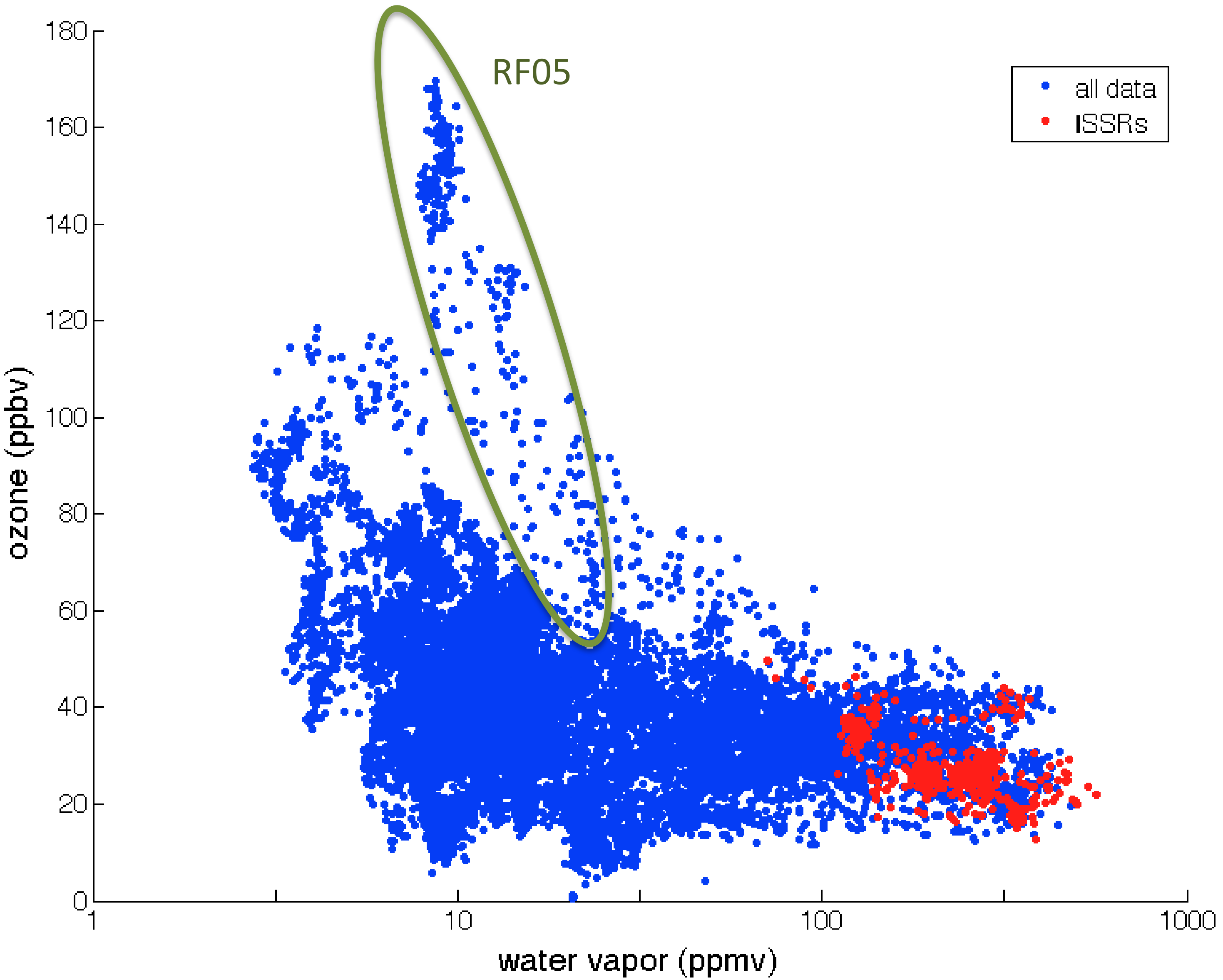

ISSRs largely forming along tropospheric-tropospheric mixing lines

# START08: ISSRs also along strat.-trop. mixing lines

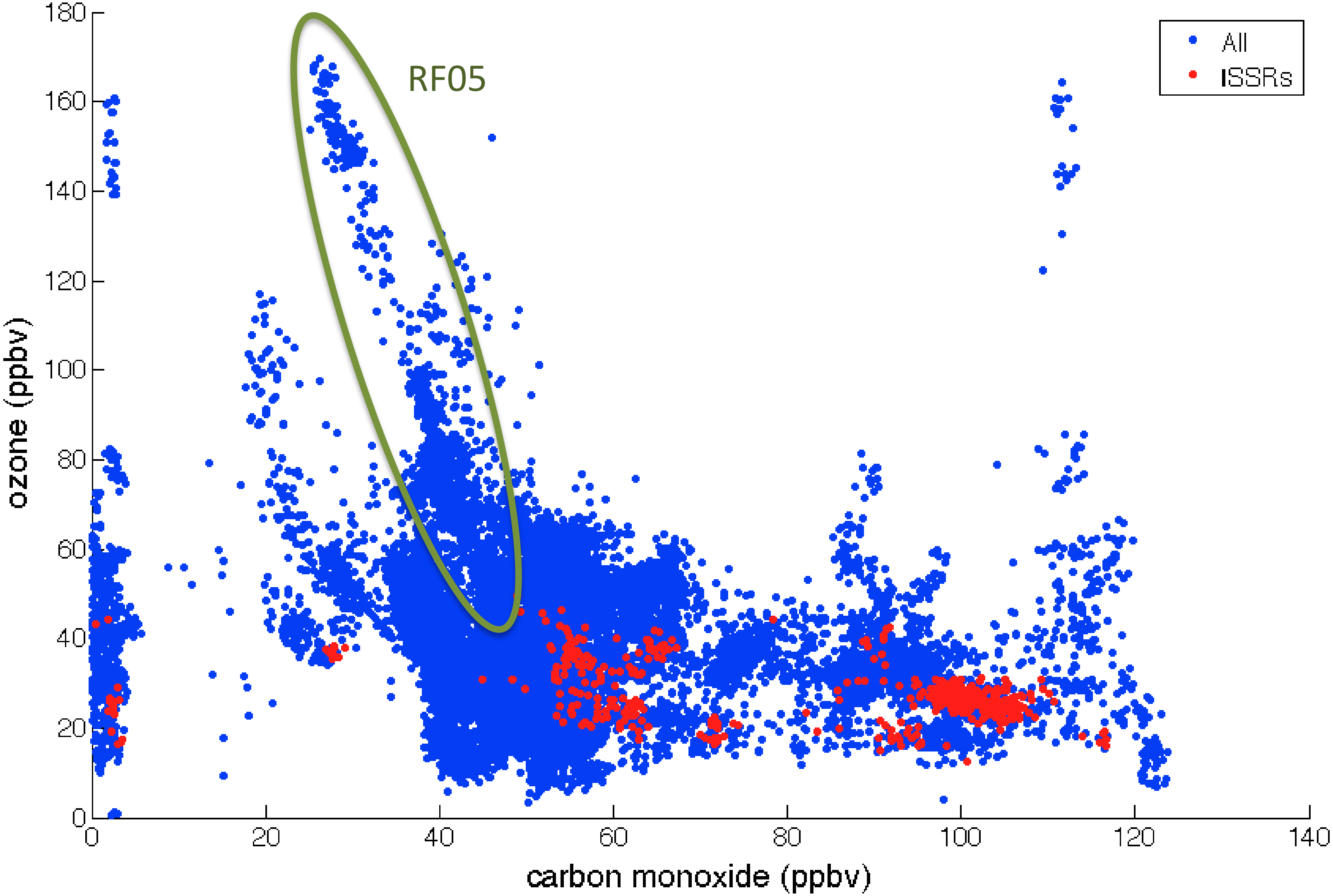



Ice supersaturated regions in extratropics often seen along stratosphere-troposphere mixing lines

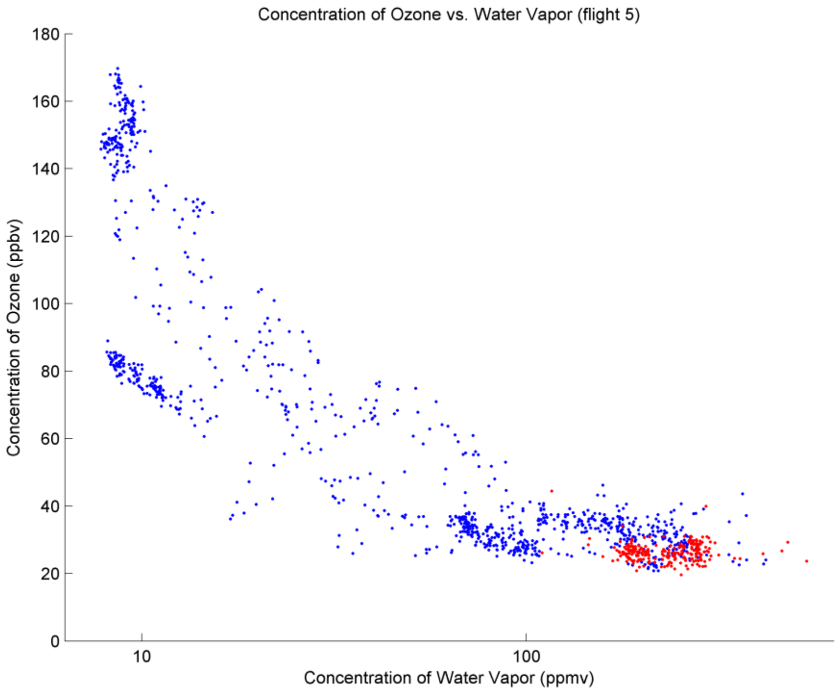
# Ozone vs. $H_2O$: TORERO

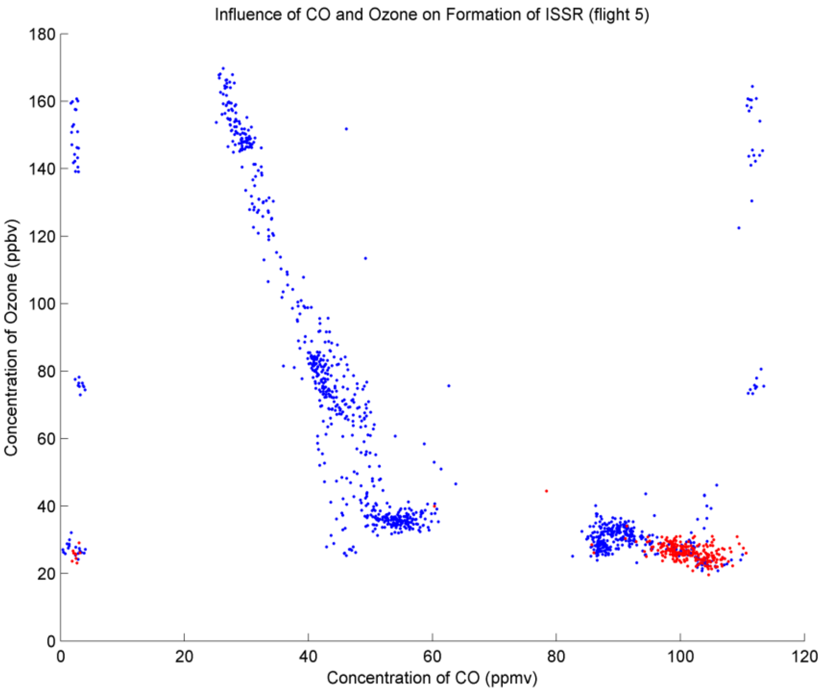


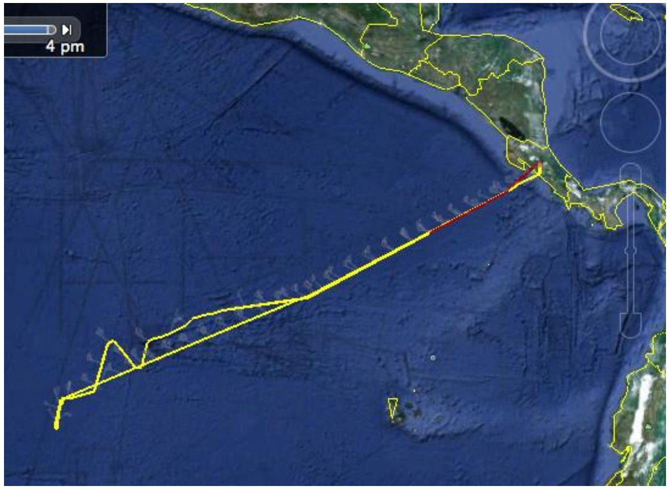
# Ozone vs. CO:  TORERO



# Stratosphere-troposphere tracers: RF05

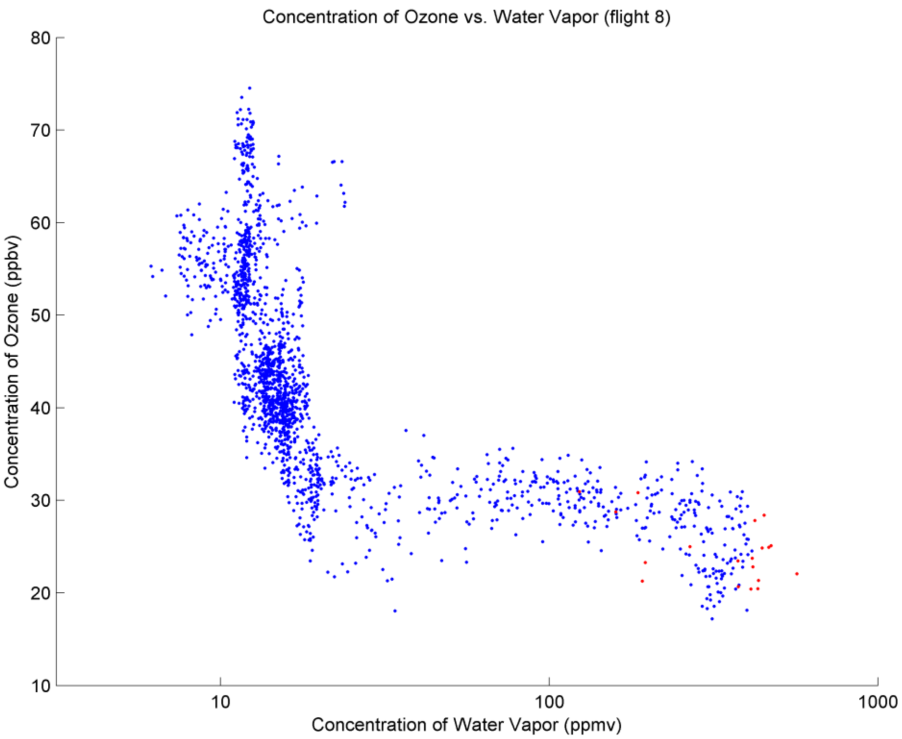


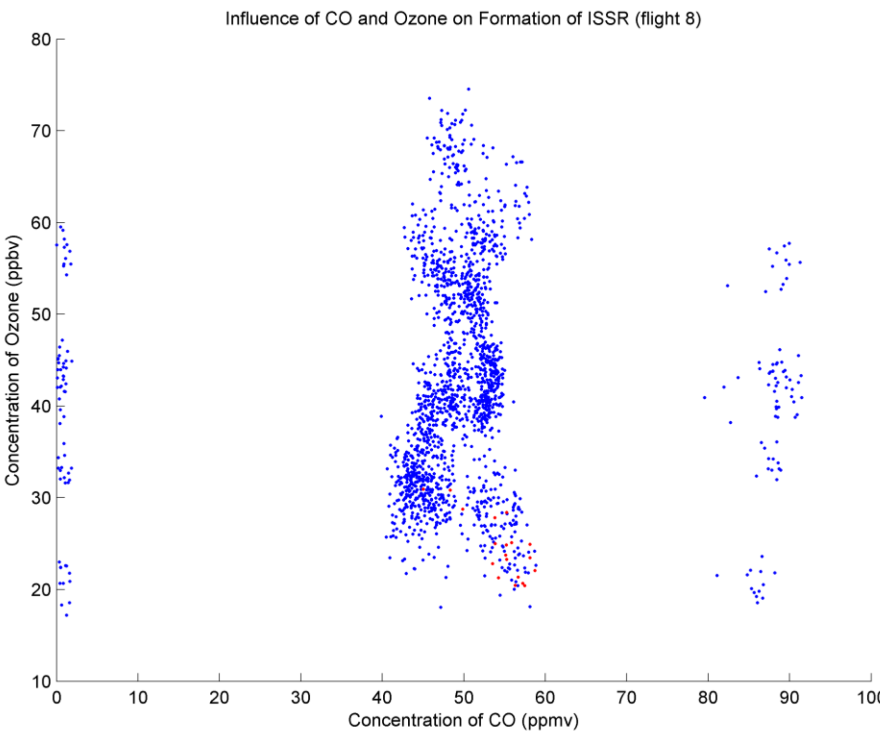



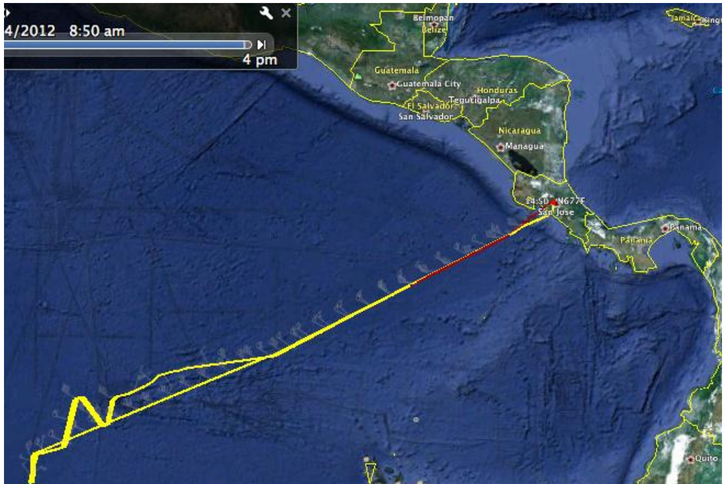




Both pairs of tracers show evidence of strat.-trop. mixing

# Stratosphere-troposphere mixing: RF08

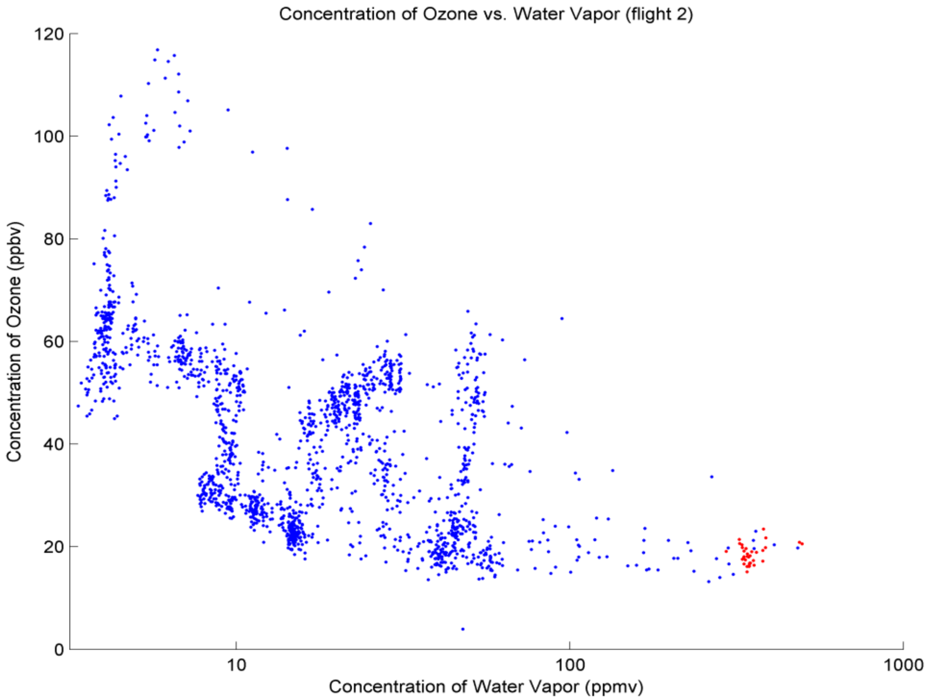


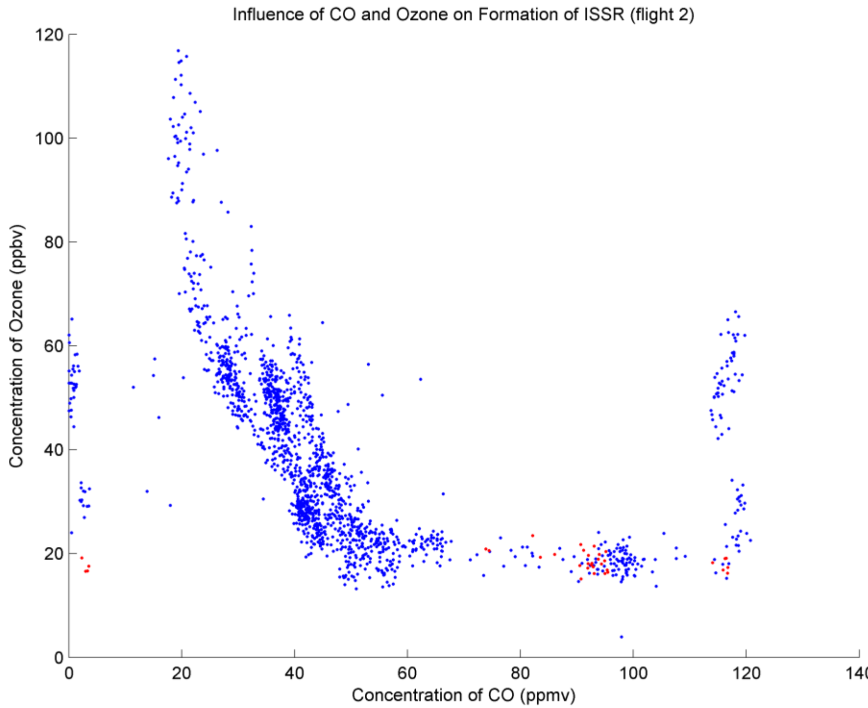




$O_3/H_2O$ more clearly shows evidence of stratospheric influence

# Stratosphere-troposphere mixing: RF02





$O_3$/CO more clearly shows evidence of mixing than $O_3/H_2O$

# Summary

• VCSEL performed well in TORERO, need to analyze esp. low/mid tropospheric data for potential biases in calibrations

• Ice supersaturated regions in TORERO:

small median size (1 km)

larger sized regions also have higher humidities

ISSRs mostly intra-tropospheric mixing (entrainment/detrainment?)

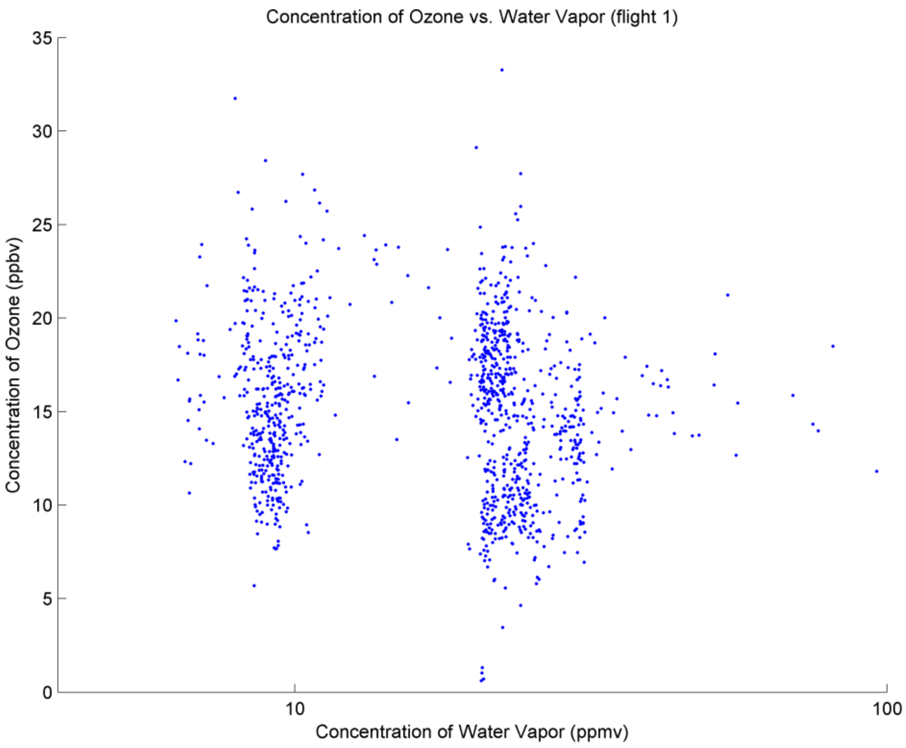
• Examine both $O_3/H_2O$ and $O_3/CO$ tracers to assess stratospheric influence

• Most evident strat.-trop. mixing observed in:

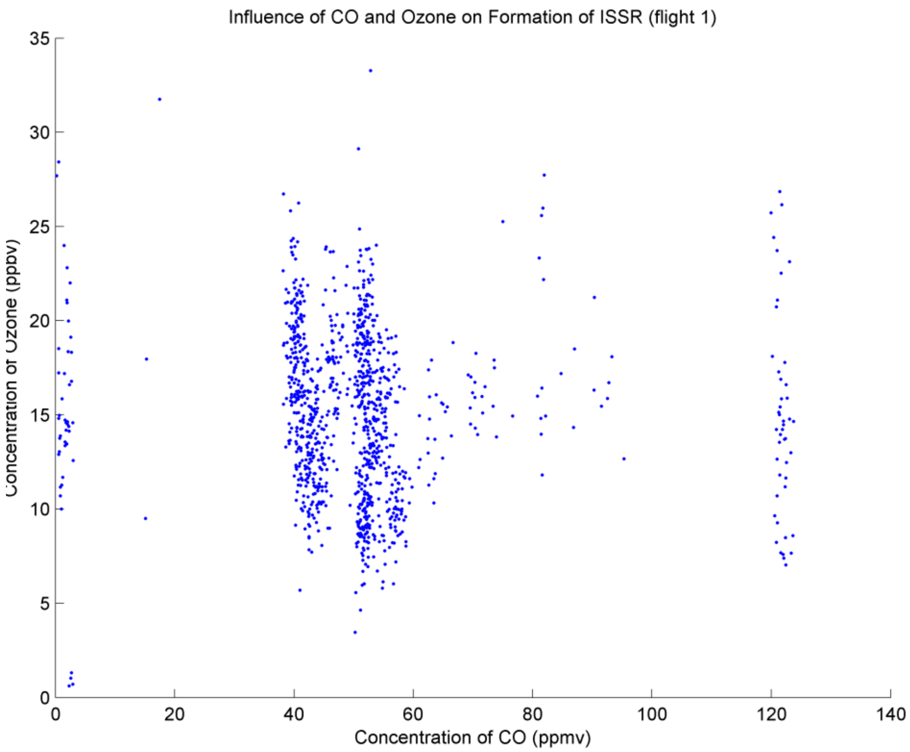
RF 02, 03, 04, 05, 07, 08, 09, 15, 17

• Future work: deep convection/entrainment/detrainment processes through tracers and moist adiabatic ascent / adiabatic descent model

# RF01

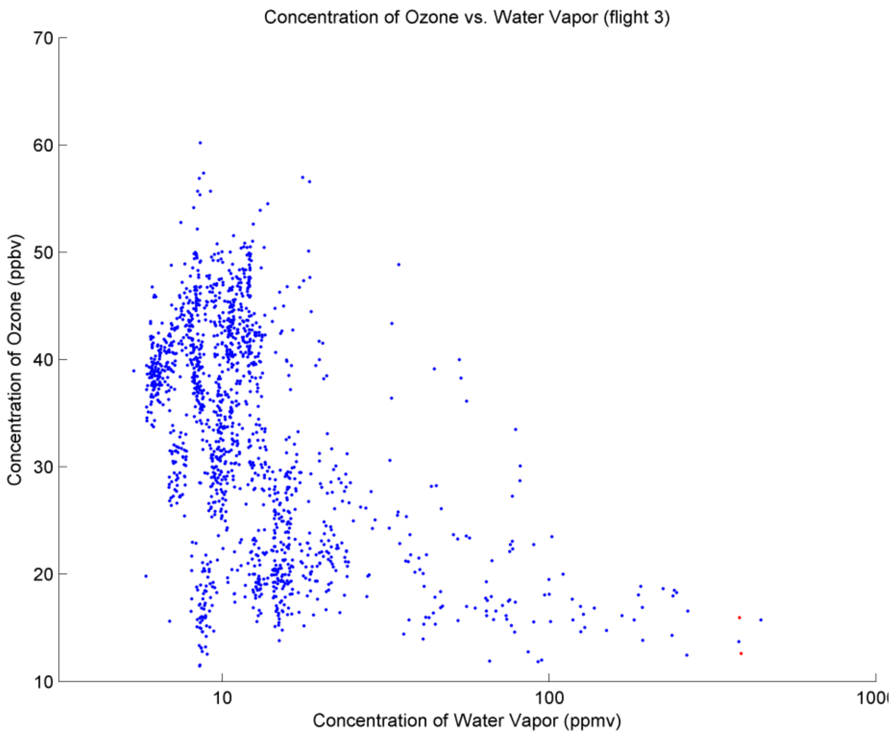


Concentration of Ozone vs. Water Vapor (flight 1)
Concentration of Ozone (ppbv)
Concentration of Water Vapor (ppmv)
0
5
10
15
20
25
30
35
10
100

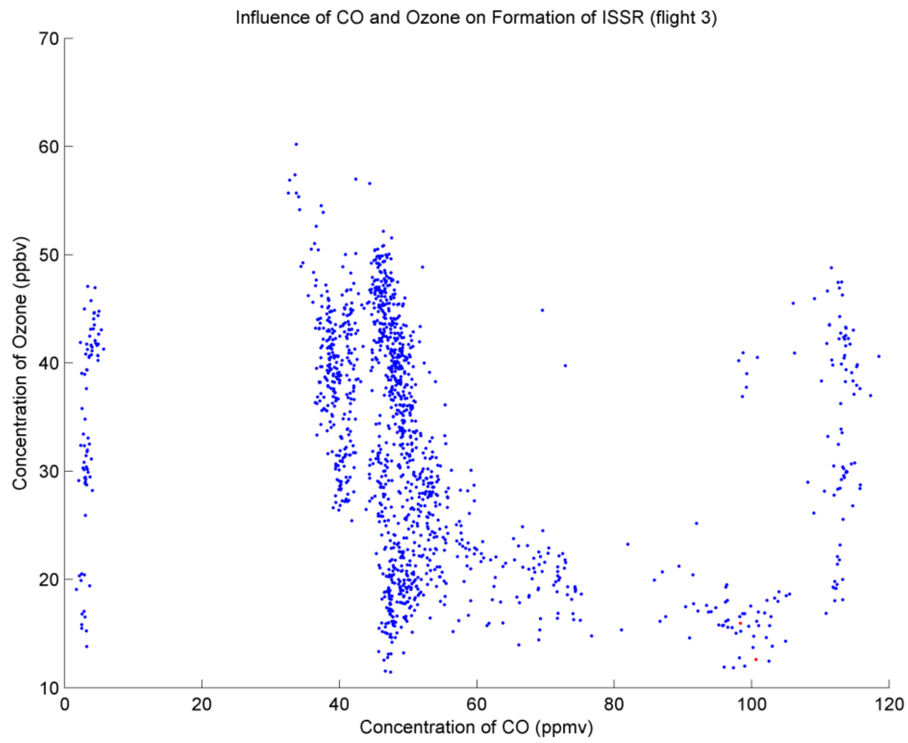



Influence of CO and Ozone on Formation of ISSR (flight 1)
Concentration of Ozone (ppbv)
Concentration of CO (ppmv)
0
5
10
15
20
25
30
35
0
20
40
60
80
100
120
140

# RF03

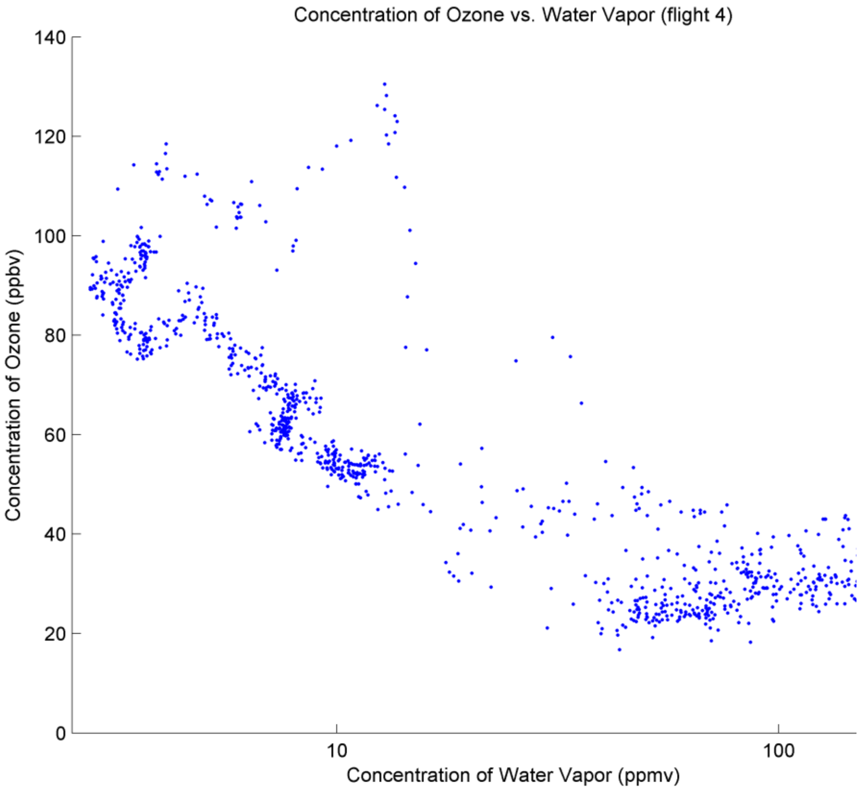


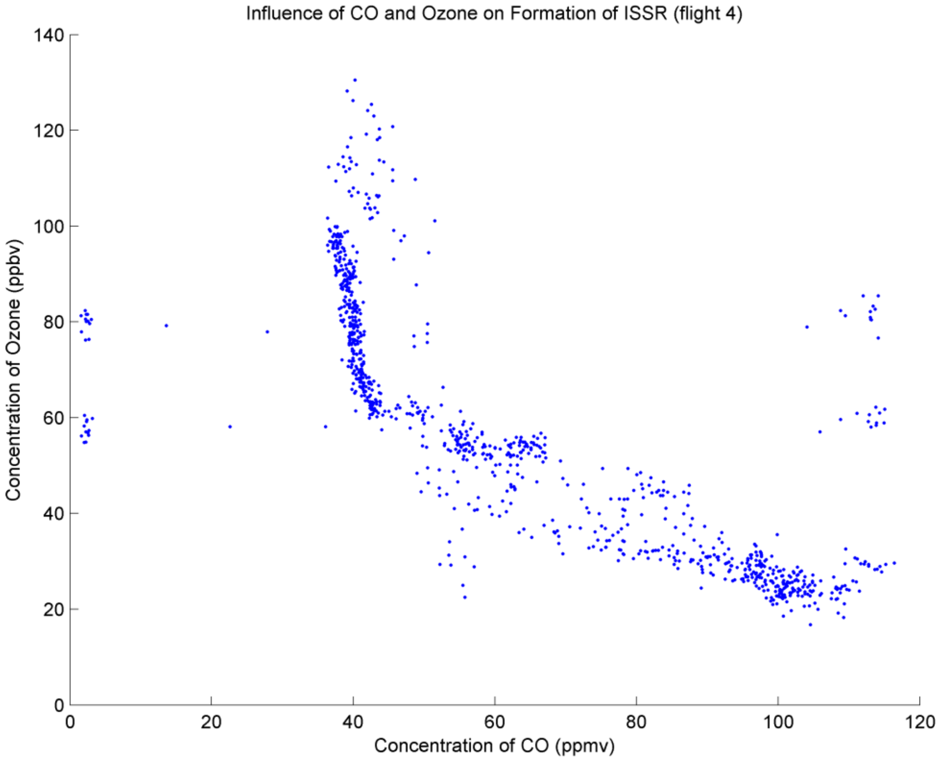
Concentration of Ozone vs. Water Vapor (flight 3)
Concentration of Ozone (ppbv)
Concentration of Water Vapor (ppmv)
10
20
30
40
50
60
70
10
100

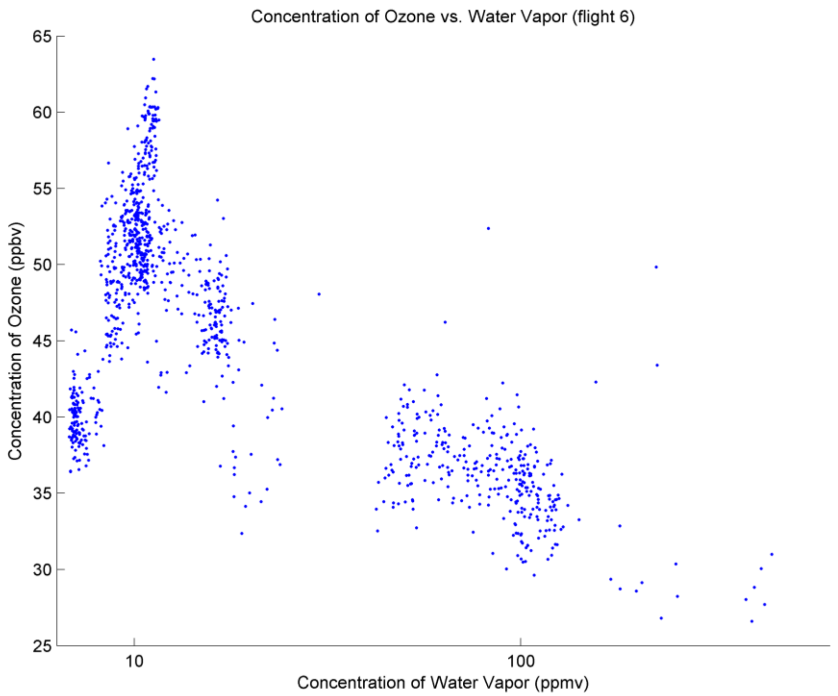
Influence of CO and Ozone on Formation of ISSR (flight 3)
Concentration of Ozone (ppbv)
Concentration of CO (ppmv)
10
20
30
40
50
60
70
0
20
40
60
80
100
120

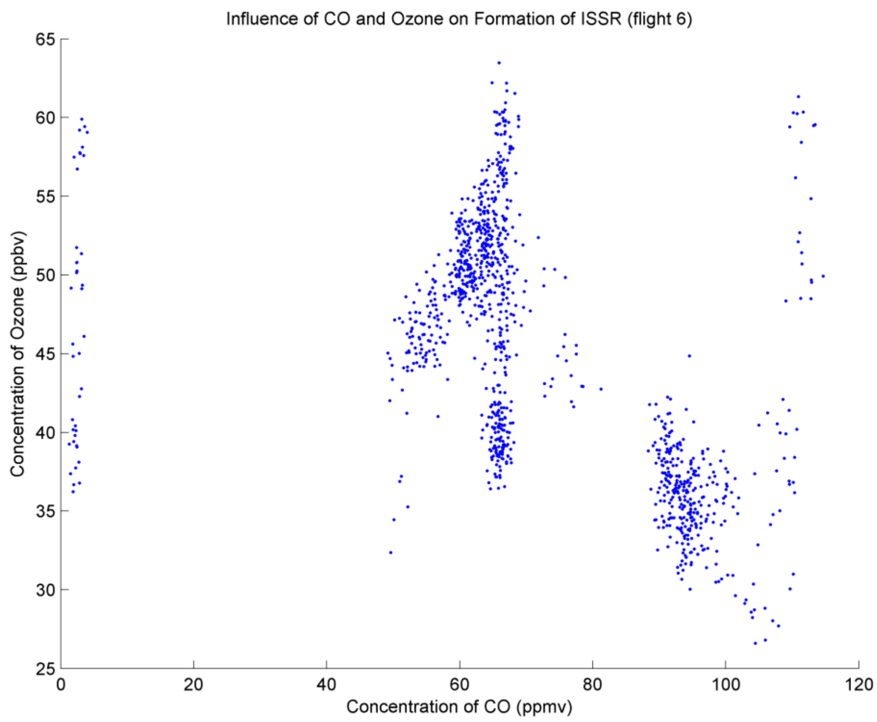
# RF04


Concentration of Ozone vs. Water Vapor (flight 4)
Concentration of Ozone (ppbv)
Concentration of Water Vapor (ppmv)
0
20
40
60
80
100
120
140
10
100

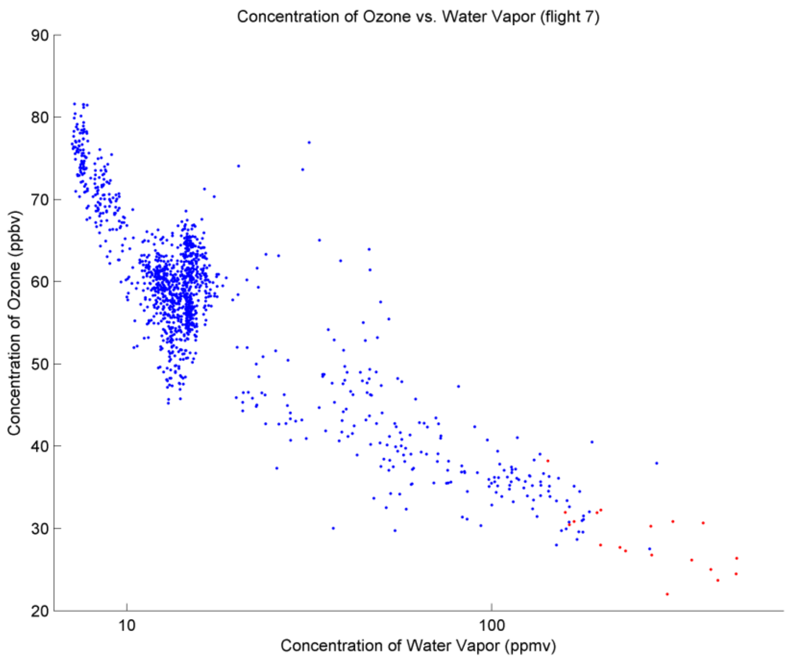

Influence of CO and Ozone on Formation of ISSR (flight 4)
Concentration of Ozone (ppbv)
Concentration of CO (ppmv)
0
20
40
60
80
100
120
140

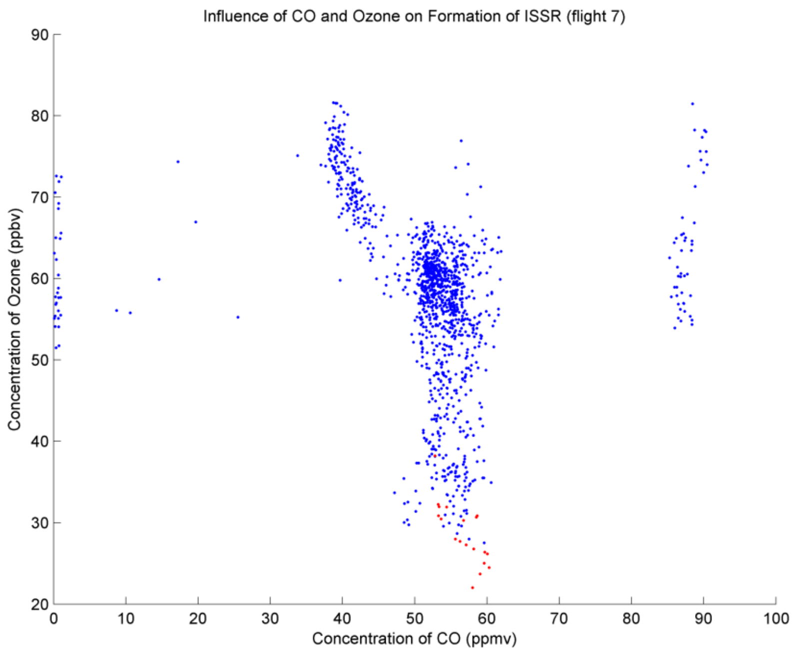
# RF06


Concentration of Ozone vs. Water Vapor (flight 6)
Concentration of Ozone (ppbv)
Concentration of Water Vapor (ppmv)
65
60
55
50
45
40
35
30
25
10
100

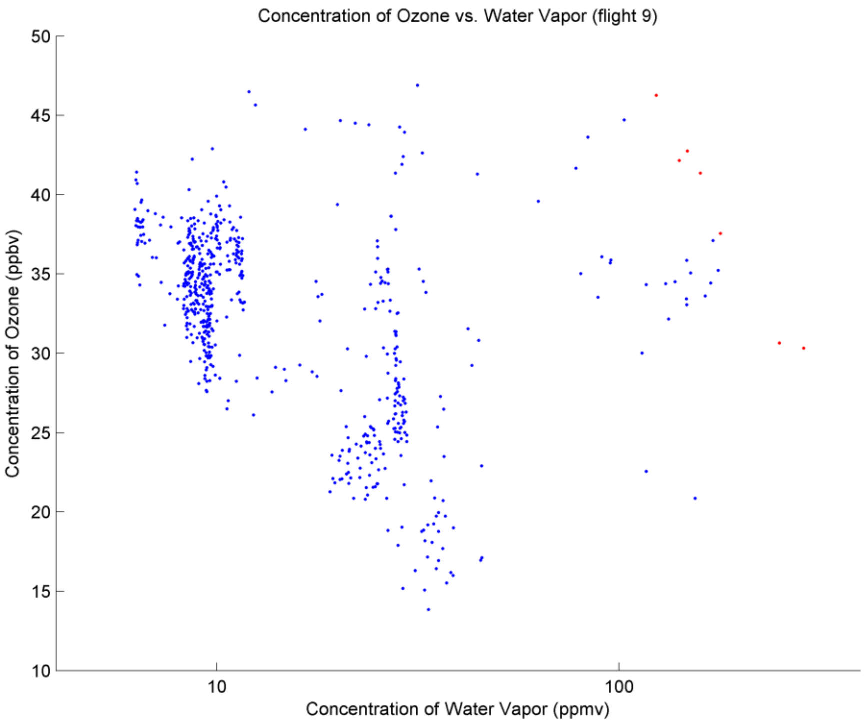

Influence of CO and Ozone on Formation of ISSR (flight 6)
Concentration of Ozone (ppbv)
Concentration of CO (ppmv)
65
60
55
50
45
40
35
30
25
0
20
40
60
80
100
120

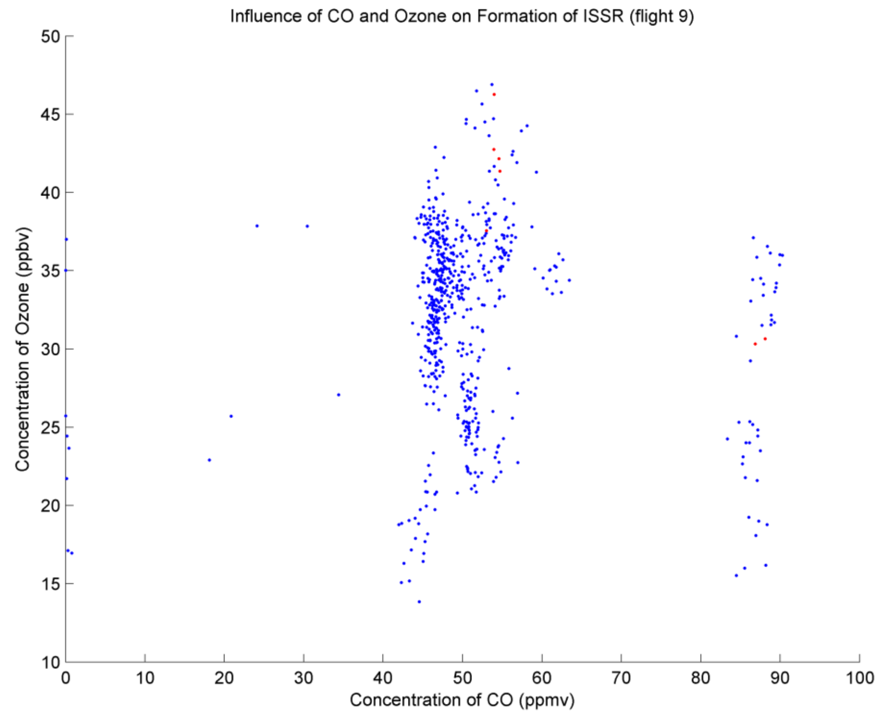
# RF07


Concentration of Ozone vs. Water Vapor (flight 7)
Concentration of Ozone (ppbv)
Concentration of Water Vapor (ppmv)
90
80
70
60
50
40
30
20
10
100


Influence of CO and Ozone on Formation of ISSR (flight 7)
Concentration of Ozone (ppbv)
Concentration of CO (ppmv)
90
80
70
60
50
40
30
20
0
10
20
30
40
50
60
70
80
90
100

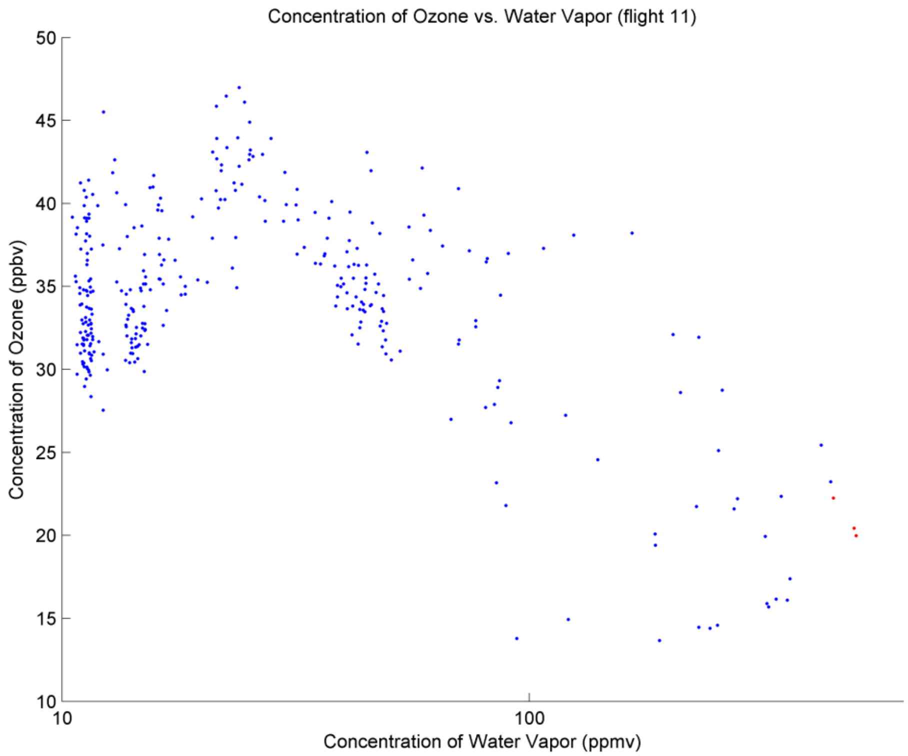
# RF09

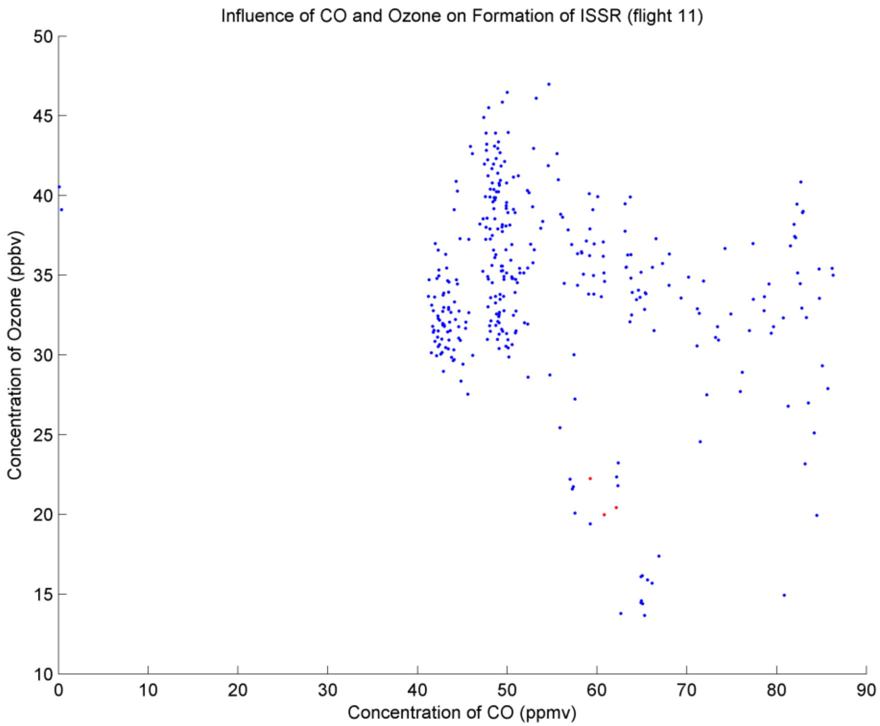

Concentration of Ozone vs. Water Vapor (flight 9)
Concentration of Ozone (ppbv)
Concentration of Water Vapor (ppmv)
10
15
20
25
30
35
40
45
50
10
100


Influence of CO and Ozone on Formation of ISSR (flight 9)
Concentration of Ozone (ppbv)
Concentration of CO (ppmv)
10
15
20
25
30
35
40
45
50
0
10
20
30
40
50
60
70
80
90
100

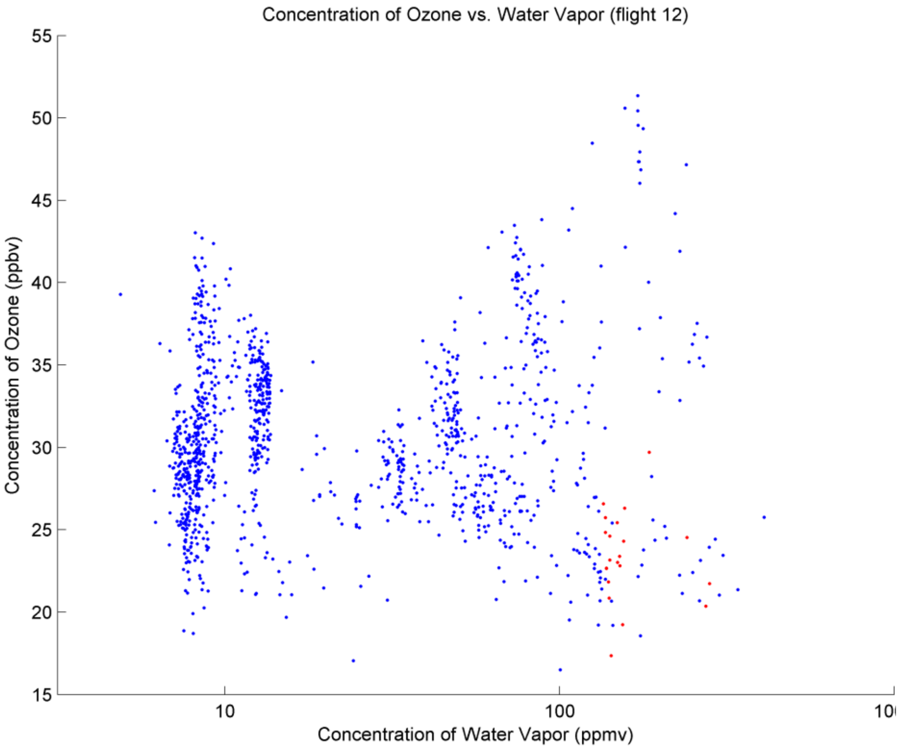

4 pm
Nicaragua
Managua
San Jose
Panama
Quito
Ecuador

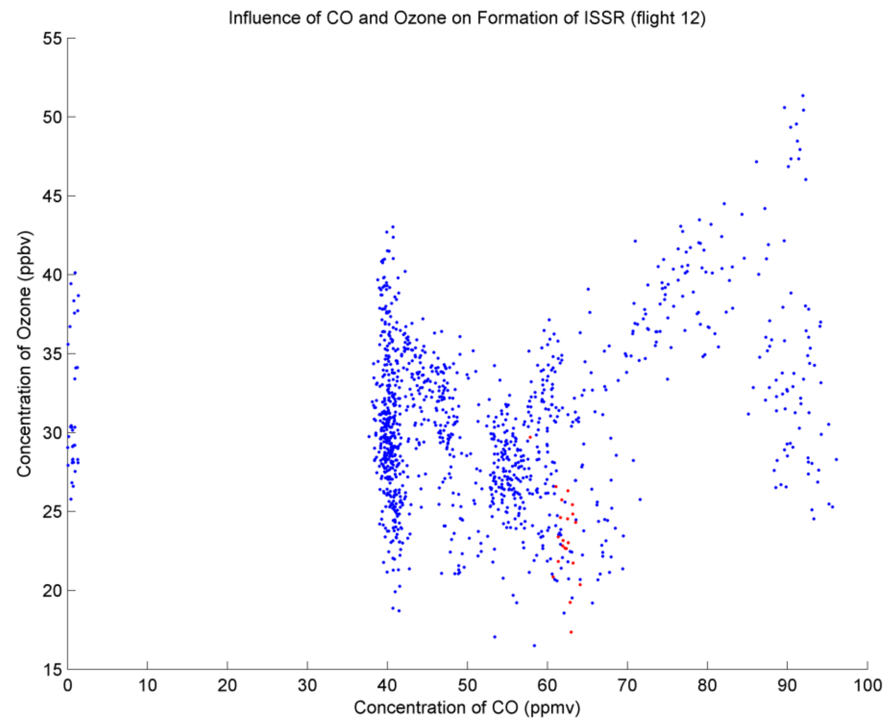
# RF11


Concentration of Ozone vs. Water Vapor (flight 11)
Concentration of Ozone (ppbv)
Concentration of Water Vapor (ppmv)
50
45
40
35
30
25
20
15
10
10
100

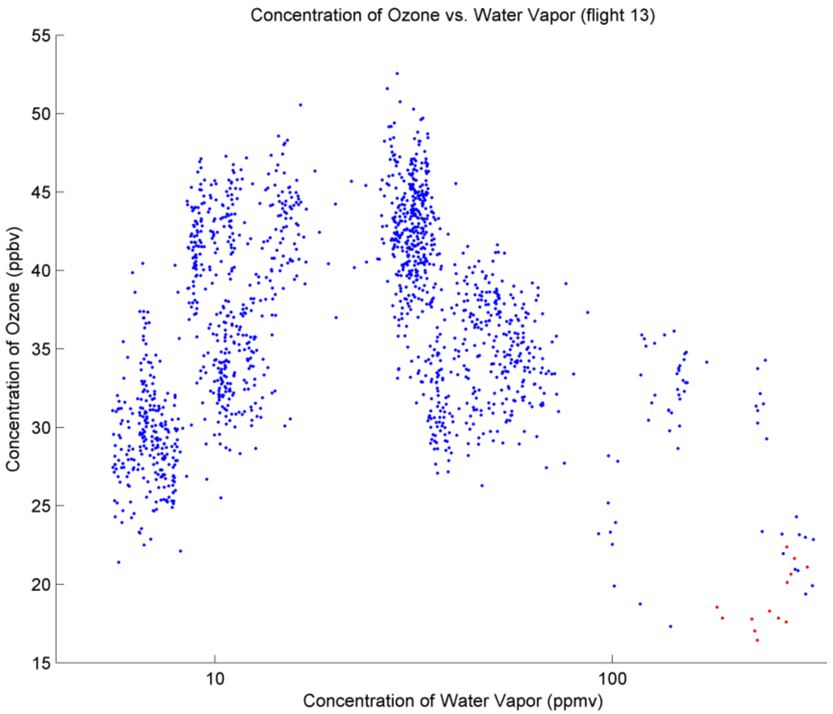

Influence of CO and Ozone on Formation of ISSR (flight 11)
Concentration of Ozone (ppbv)
Concentration of CO (ppmv)
50
45
40
35
30
25
20
15
10
0
10
20
30
40
50
60
70
80
90

# RF12

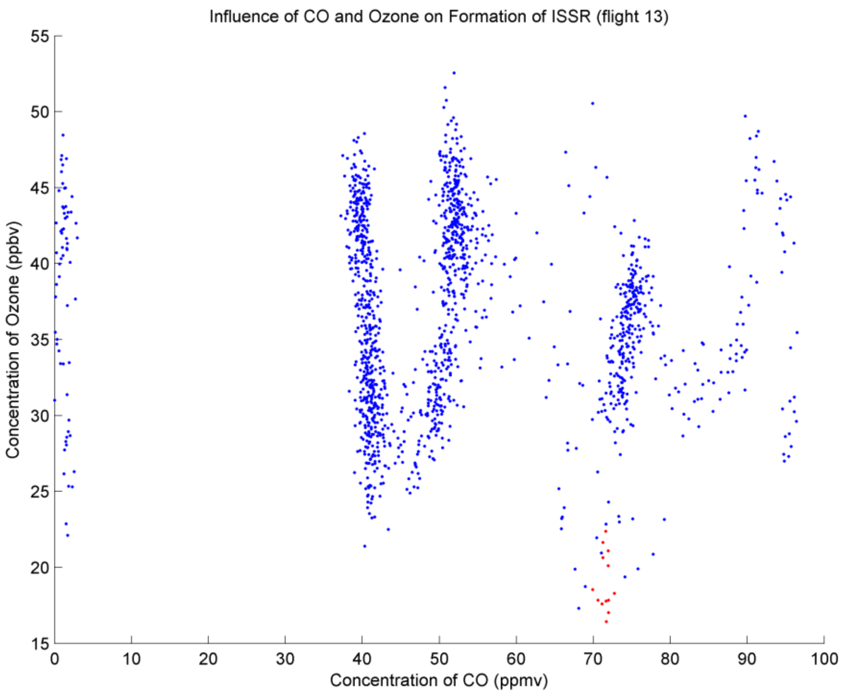

Concentration of Ozone vs. Water Vapor (flight 12)
Concentration of Ozone (ppbv)
Concentration of Water Vapor (ppmv)
15
20
25
30
35
40
45
50
55
10
100


Influence of CO and Ozone on Formation of ISSR (flight 12)
Concentration of Ozone (ppbv)
Concentration of CO (ppmv)
15
20
25
30
35
40
45
50
55
0
10
20
30
40
50
60
70
80
90
100

# RF13

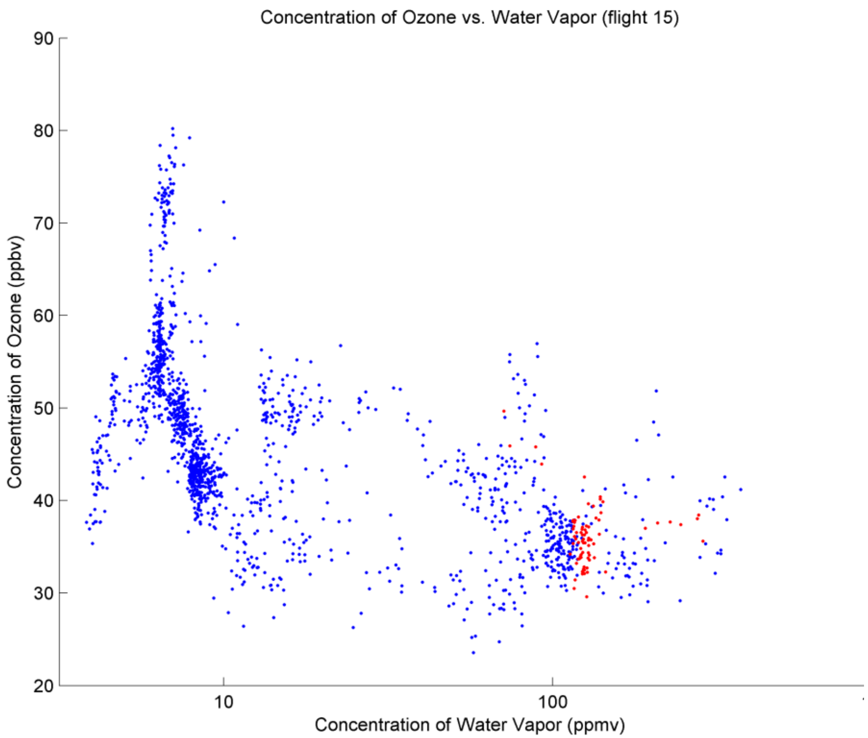


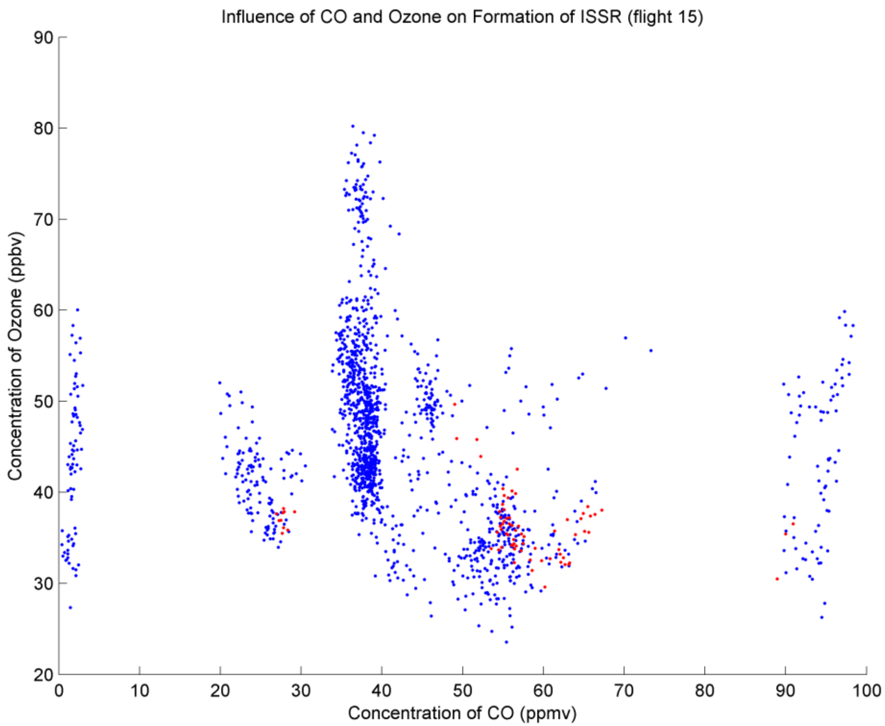
Concentration of Ozone vs. Water Vapor (flight 13)
Concentration of Ozone (ppbv)
Concentration of Water Vapor (ppmv)
55
50
45
40
35
30
25
20
15
10
100

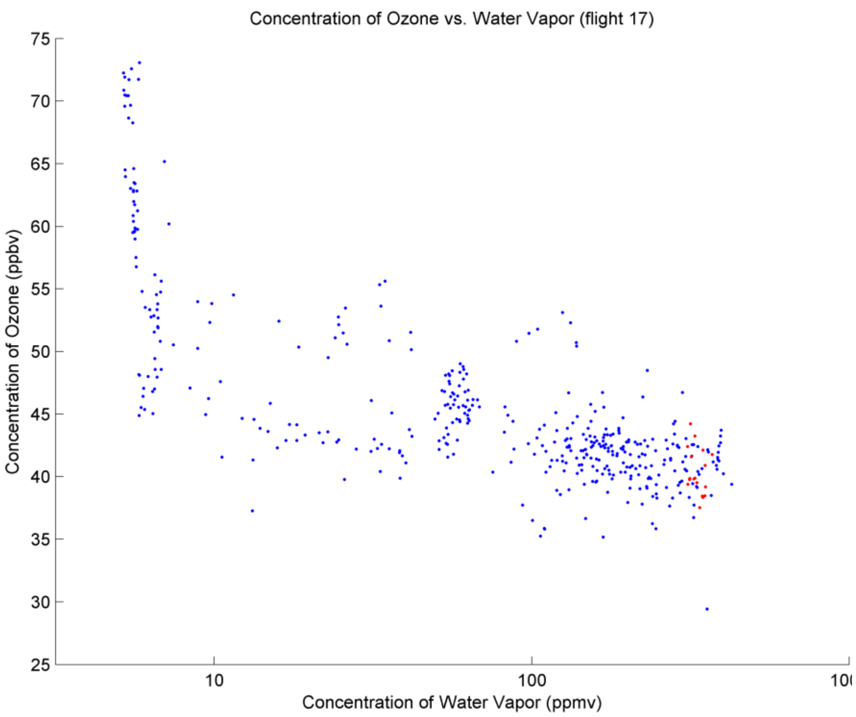
Influence of CO and Ozone on Formation of ISSR (flight 13)
Concentration of Ozone (ppbv)
Concentration of CO (ppmv)
55
50
45
40
35
30
25
20
15
0
10
20
30
40
50
60
70
80
90
100

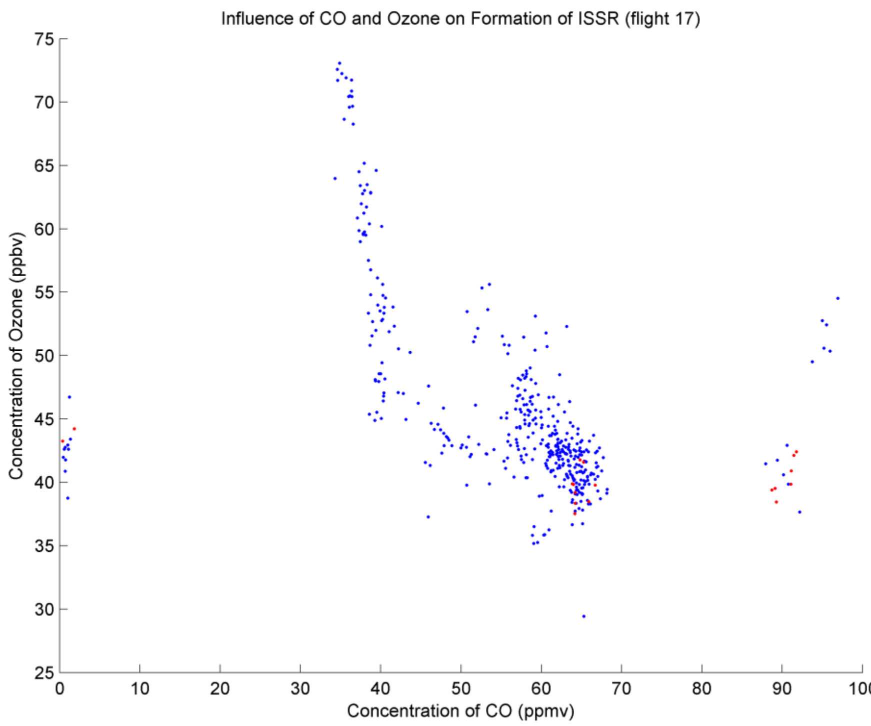
# RF15


Concentration of Ozone vs. Water Vapor (flight 15)
Concentration of Ozone (ppbv)
Concentration of Water Vapor (ppmv)
90
80
70
60
50
40
30
20
10
100


Influence of CO and Ozone on Formation of ISSR (flight 15)
Concentration of Ozone (ppbv)
Concentration of CO (ppmv)
90
80
70
60
50
40
30
20
0
10
20
30
40
50
60
70
80
90
100

# RF17


Concentration of Ozone vs. Water Vapor (flight 17)
Concentration of Ozone (ppbv)
Concentration of Water Vapor (ppmv)
75
70
65
60
55
50
45
40
35
30
25
10
100


Influence of CO and Ozone on Formation of ISSR (flight 17)
Concentration of Ozone (ppbv)
Concentration of CO (ppmv)
75
70
65
60
55
50
45
40
35
30
25
0
10
20
30
40
50
60
70
80
90
100