

# **Bi-modal Distribution of Tropical Tropospheric Ozone**

## **over the Western Pacific from CONTRAST Observations**

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Kinnison, J-F Lamarque, A. Saiz-Lopez, R. J. Salawitch, and  
A. J. Weinheimer**

CT3LS Meeting, Boulder, July 22, 2015

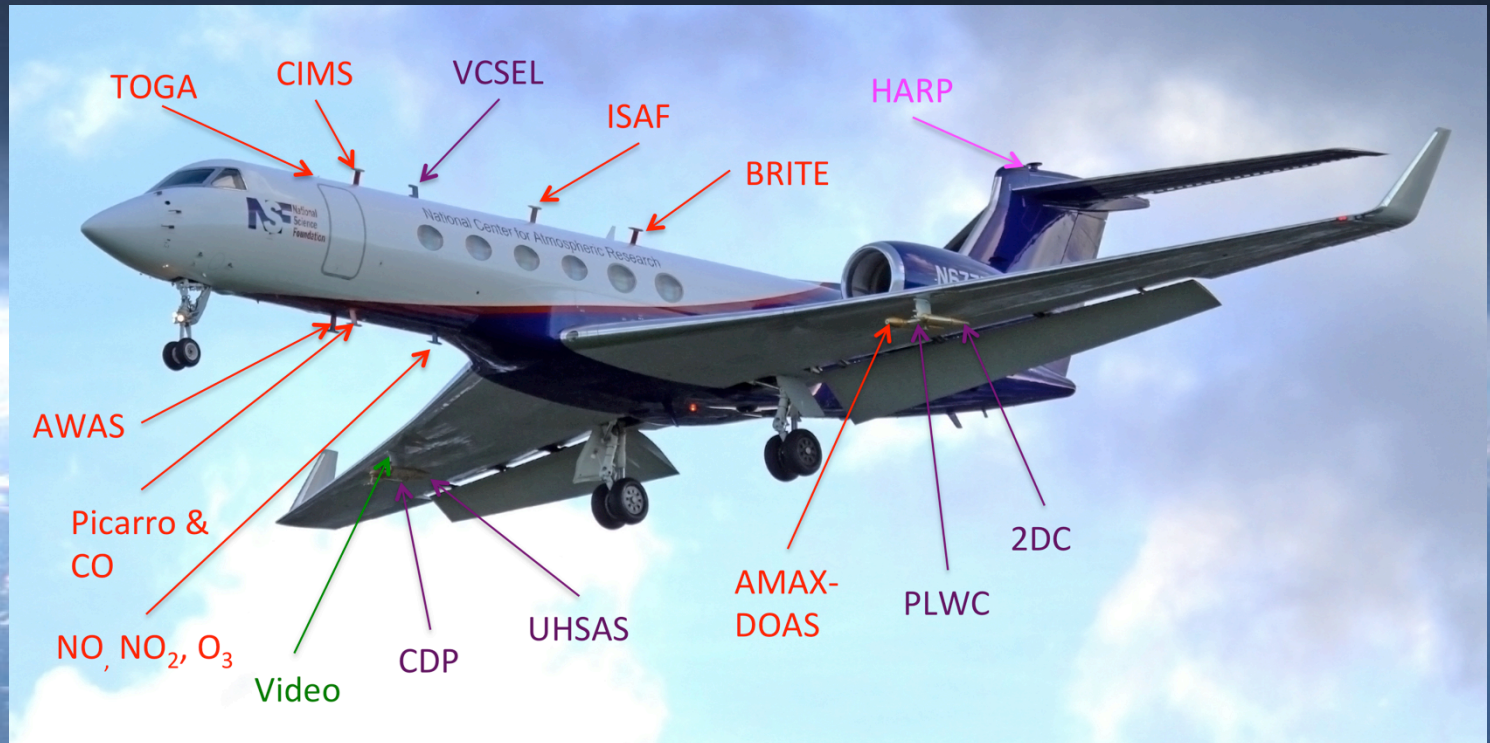
# CONTRAST: Convective Transport of Active Species in the Tropics

January 11 – March 2, 2014, Guam

ATTREX/GH



CAST/BAe146

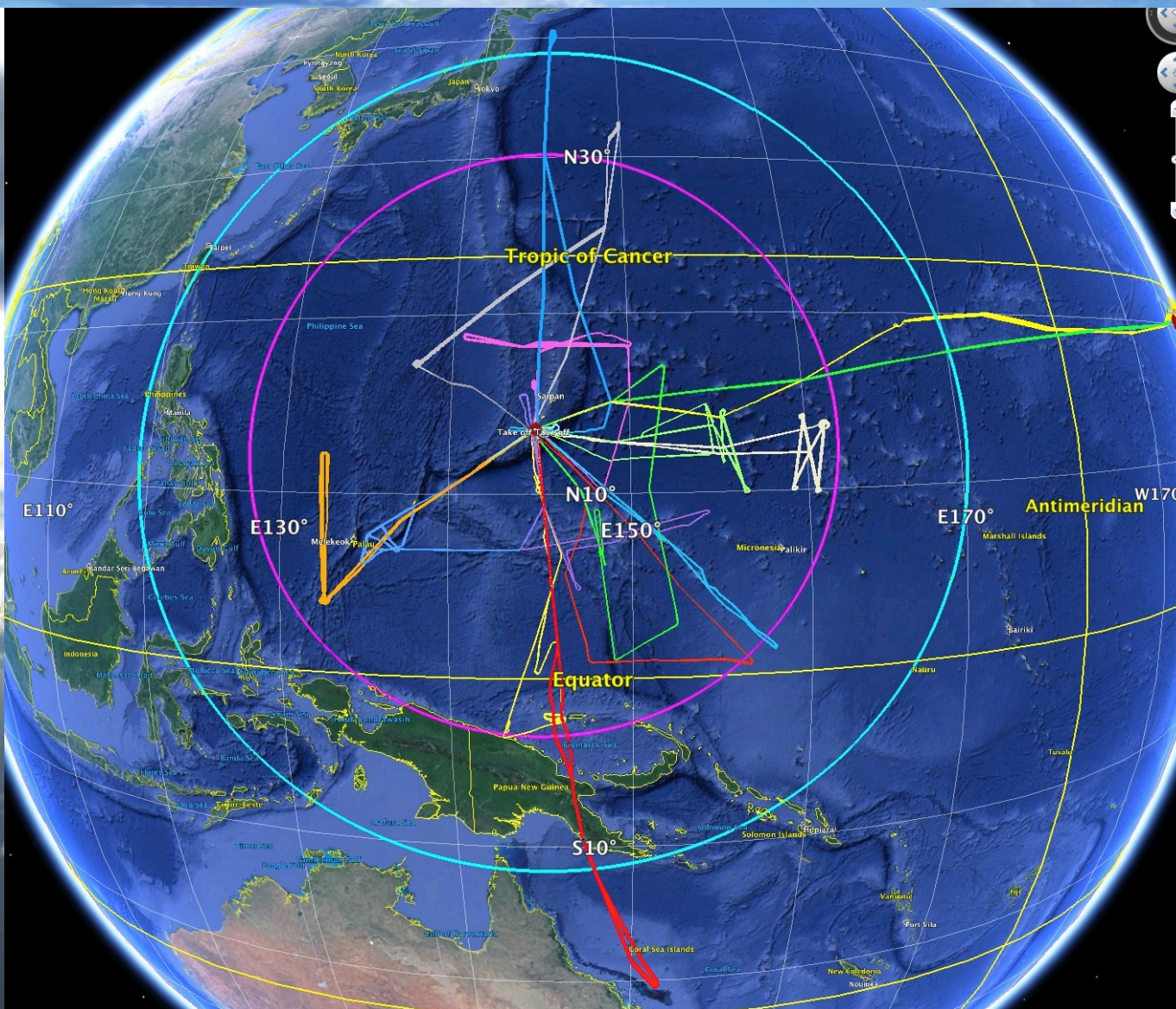


NSF/NCAR Research Aircraft Gulfstream V (GV)

# CONTRAST



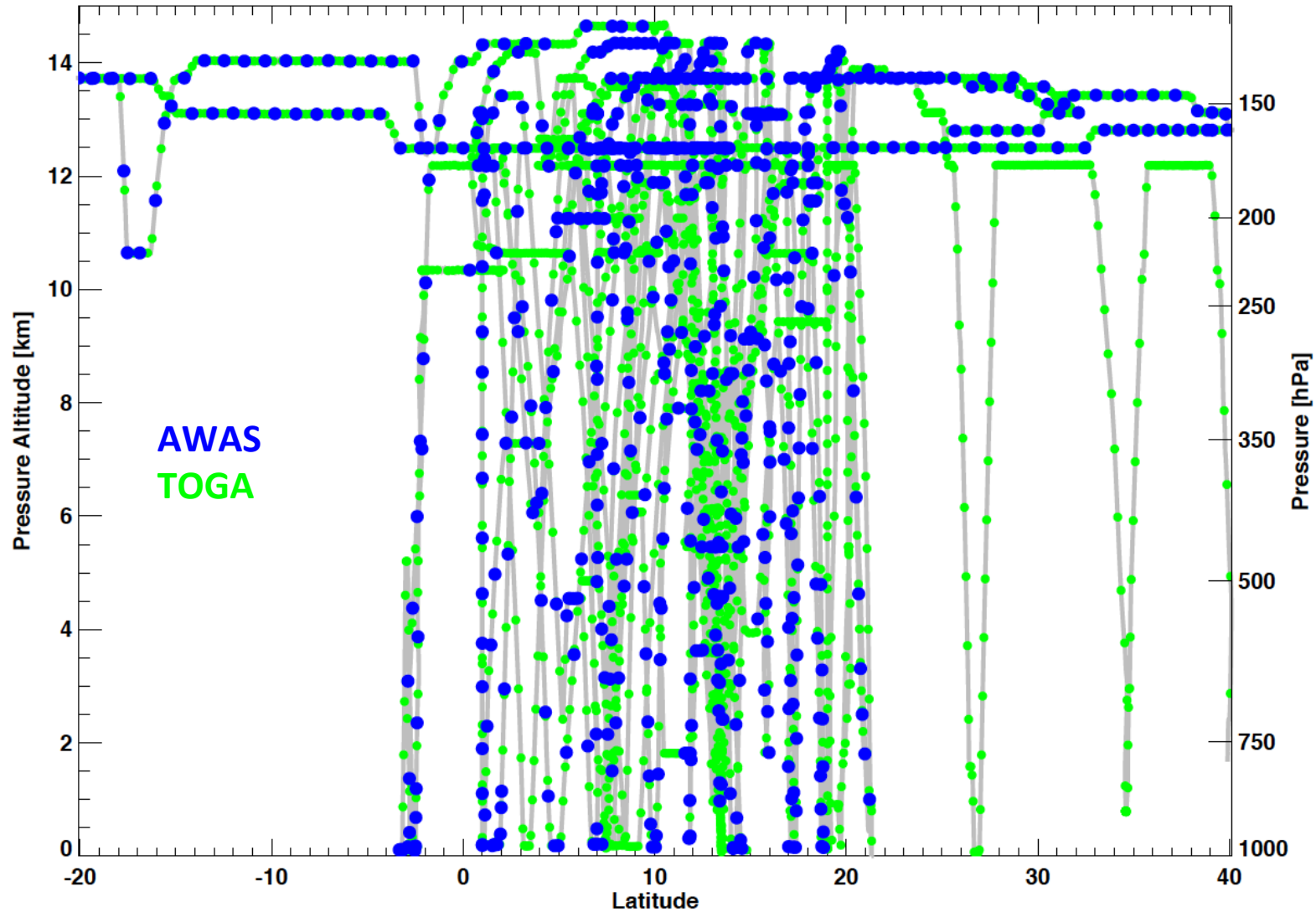
Guam, Jan-Feb 2014



- 16 Research Flights, 20°S -40°N



- Near 100 profiles, 92 m – 15.3 km

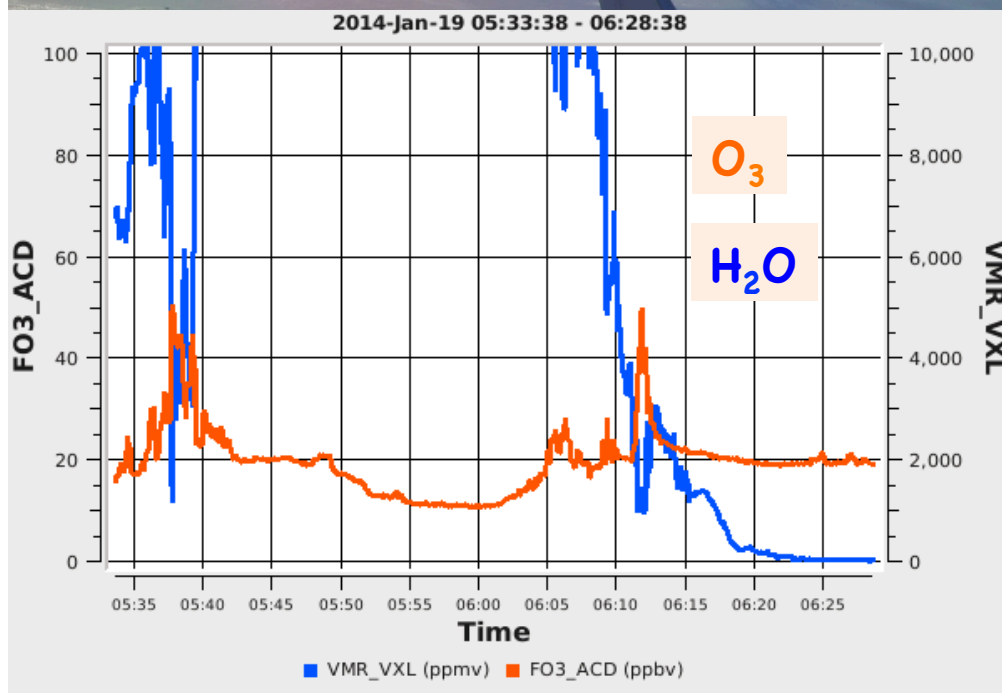


AWAS and TOGA Samples

# Outline and Summary

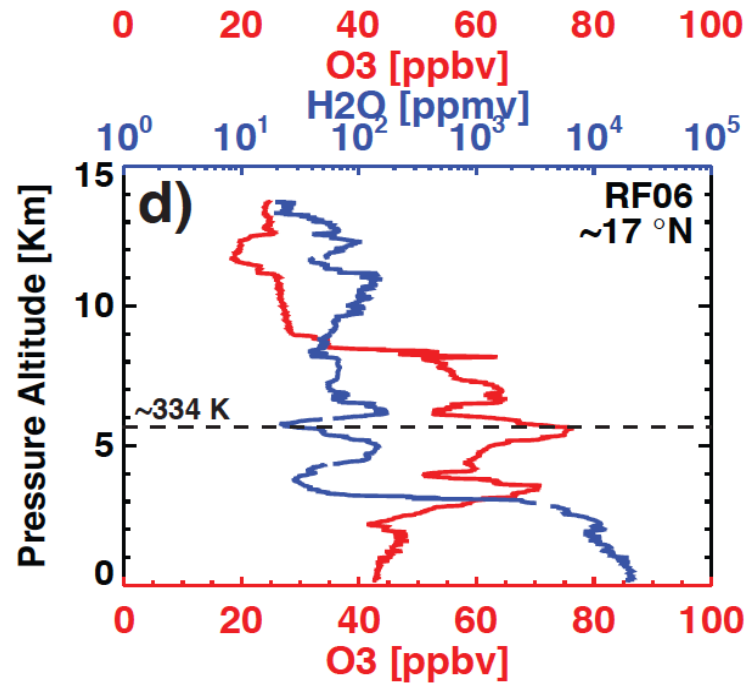
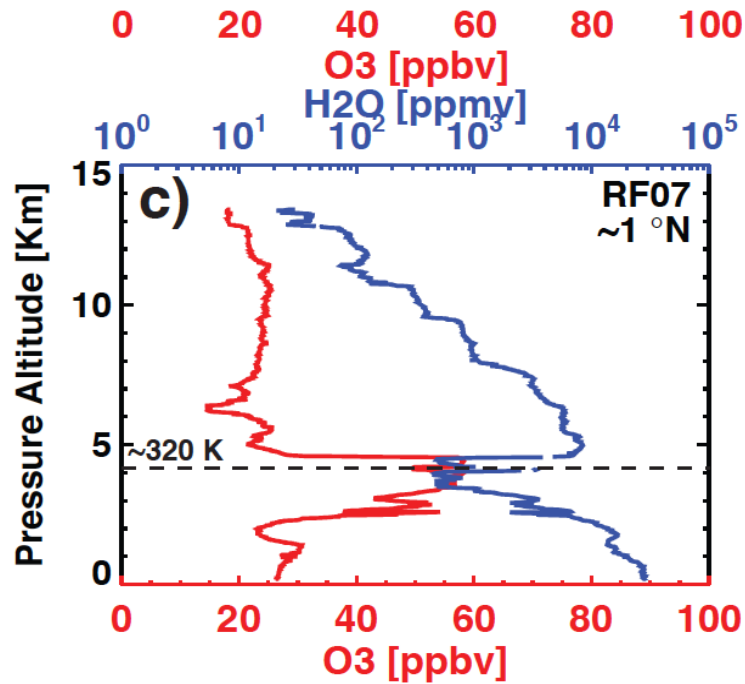
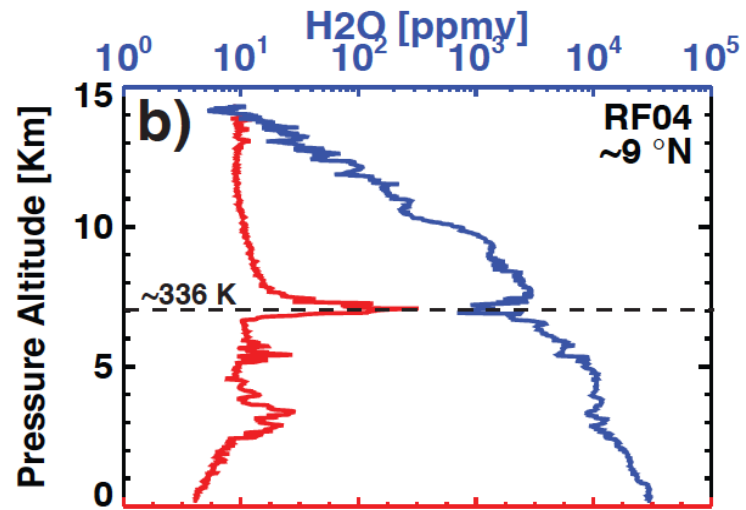
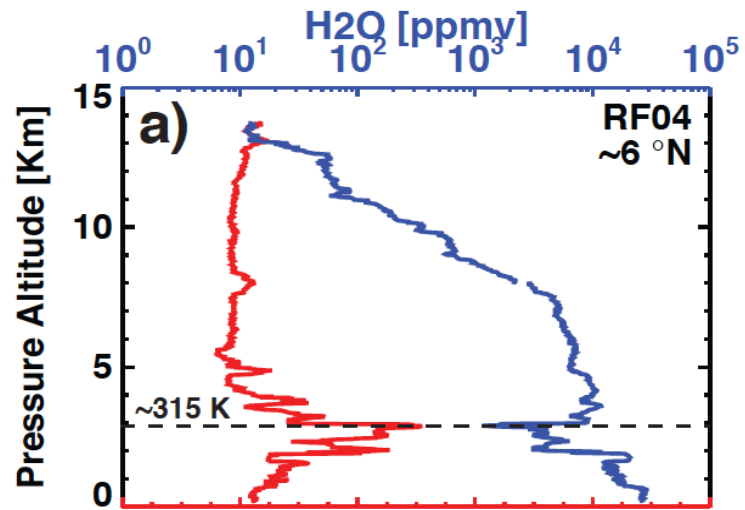
- **Discovery of a bi-modal distribution of tropical ozone**
  - Anti-correlated  $O_3$  and  $H_2O$  layers form an ozone-enhanced mode with dry air.
- **Indications of controlling mechanisms from the data and model**
  - Primary mode (convectively controlled deep tropical mode)
  - Secondary mode (“non-local” mode?)
- **Implications of these new observations**
  - A fresh view of how we evaluate Chemistry-Climate models
  - How ubiquitous is the bi-modal structure in the tropics?
  - Alternative interpretation of the “S-shaped” tropical ozone profile

# GV observations of anti-correlated $O_3$ - $H_2O$ layers



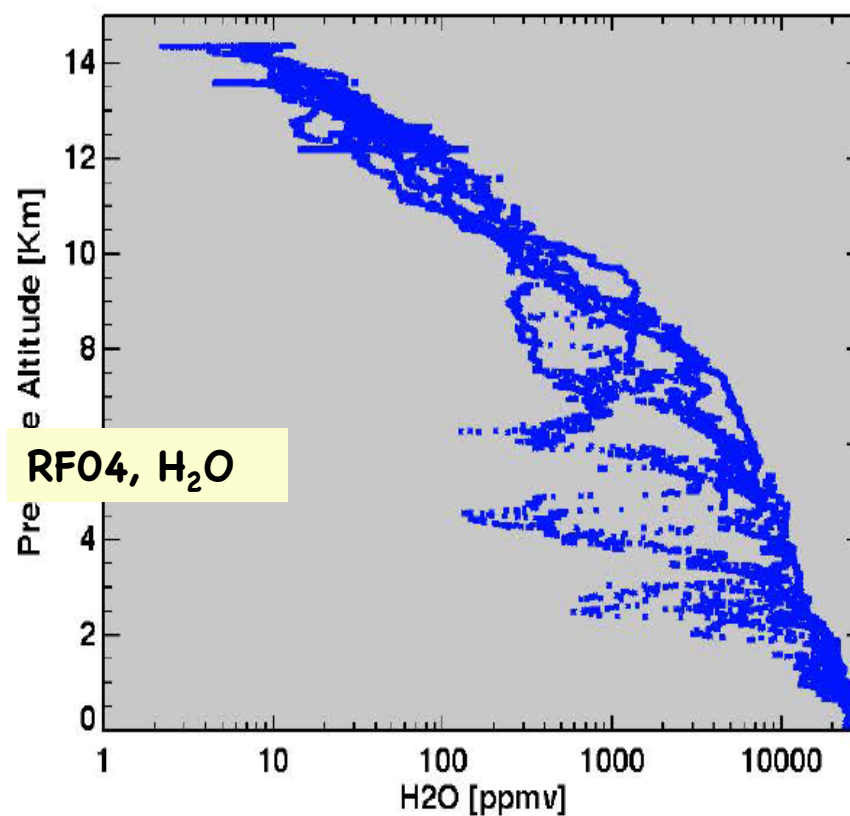
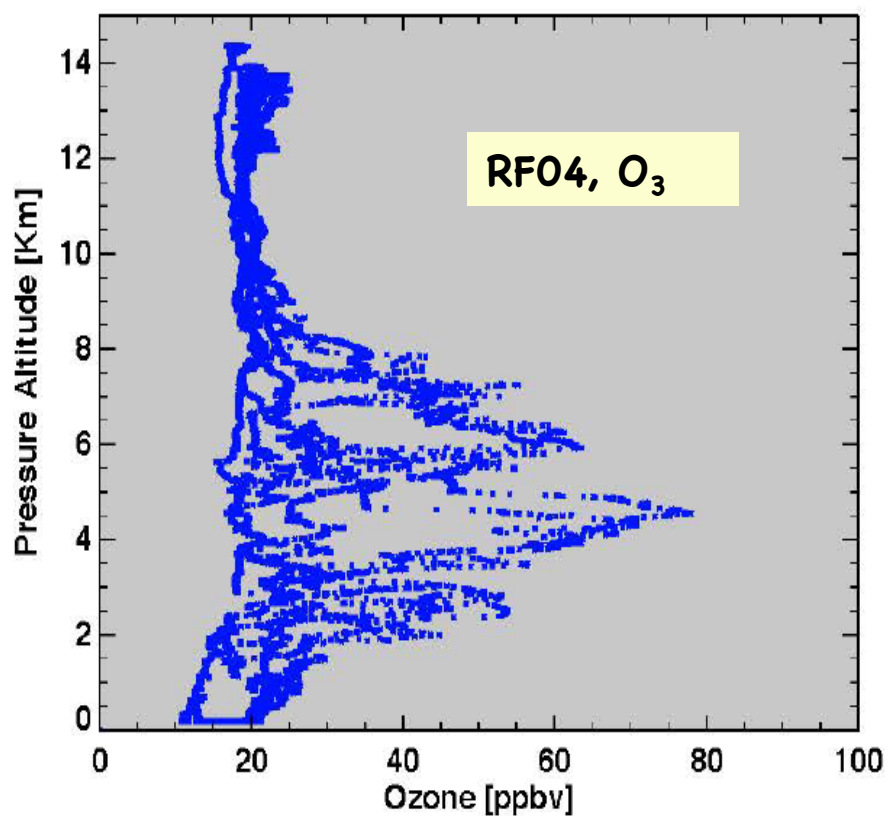
GV was at  $\sim 500$  ft between approximately 05:45  $\rightarrow$  06:00. The ozone- water vapor anti-correlation structure was near 20-25 Kft.

# A few Examples:

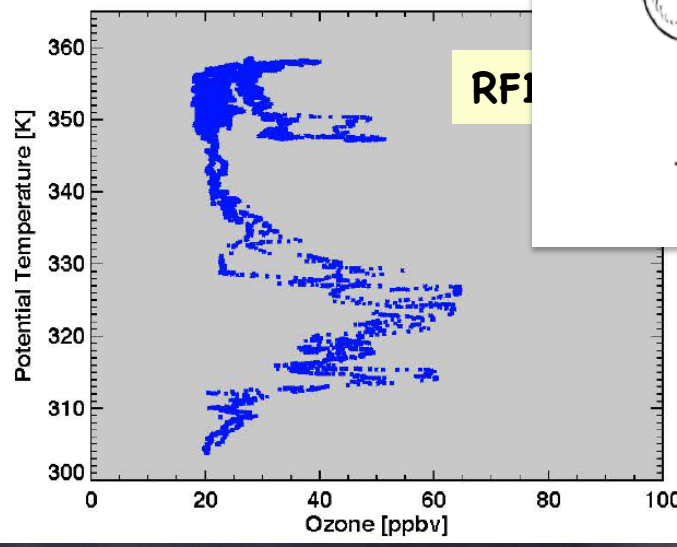
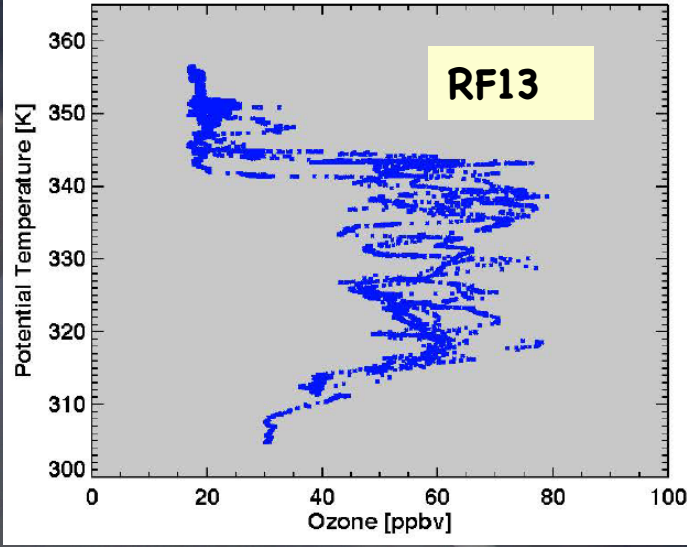
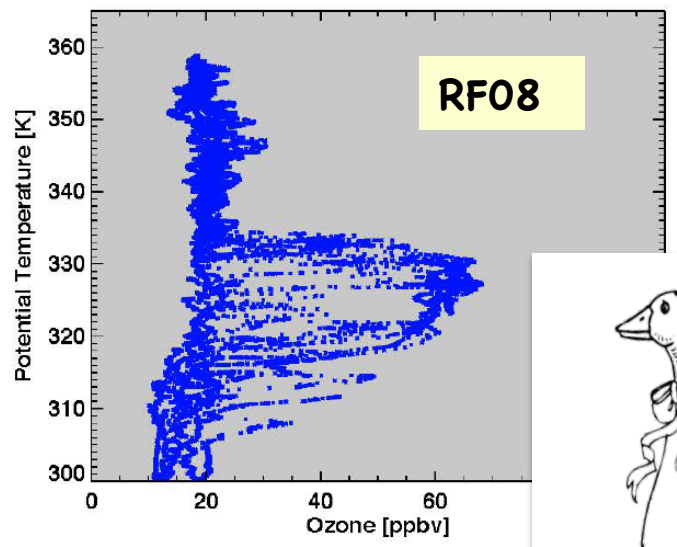
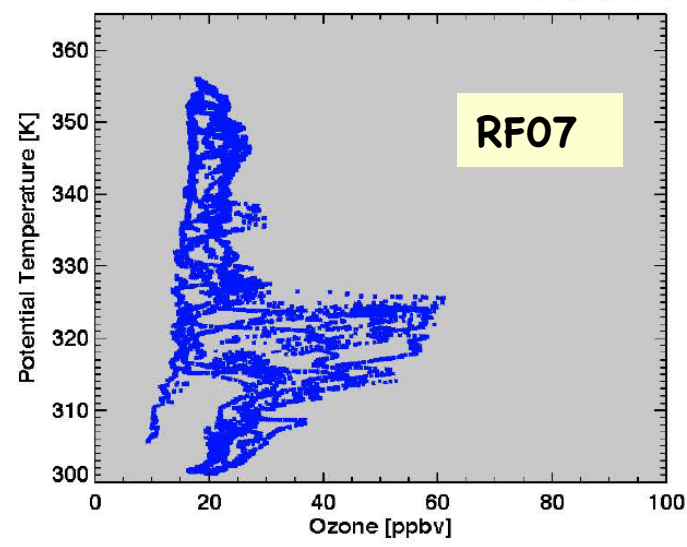


# Persistent presence of layers of anti-correlated $O_3$ & $H_2O$

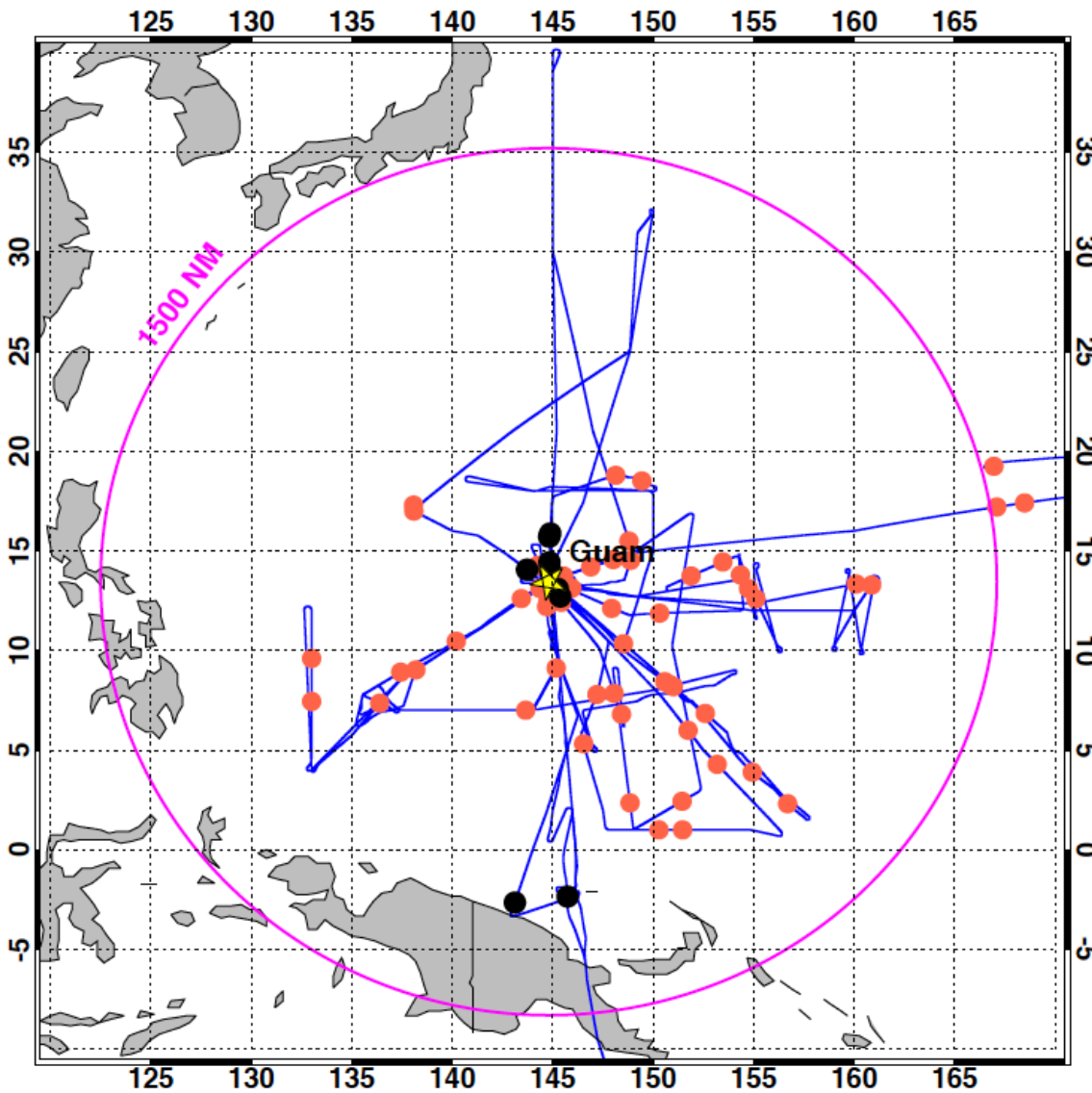
CONTRAST GV 01/19/2014 rf04







# CONTRAST All Deep profiles and the Anti-Correlated Layers

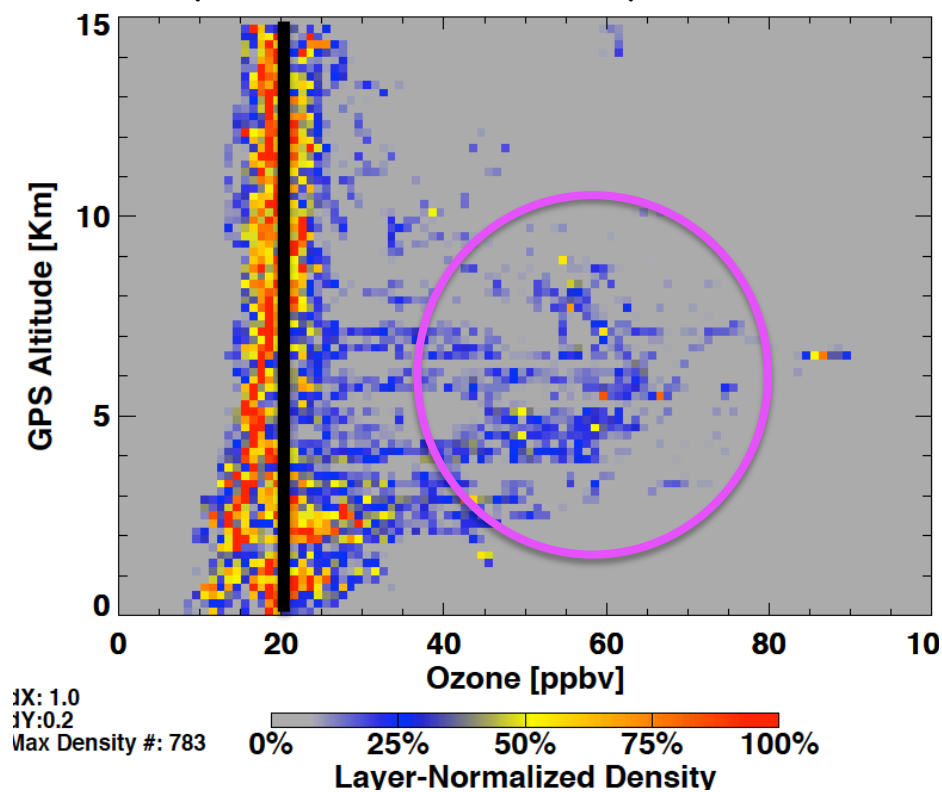


Defined by joint conditions of  $O_3 > 30$  ppbv and  $RH < 45\%$

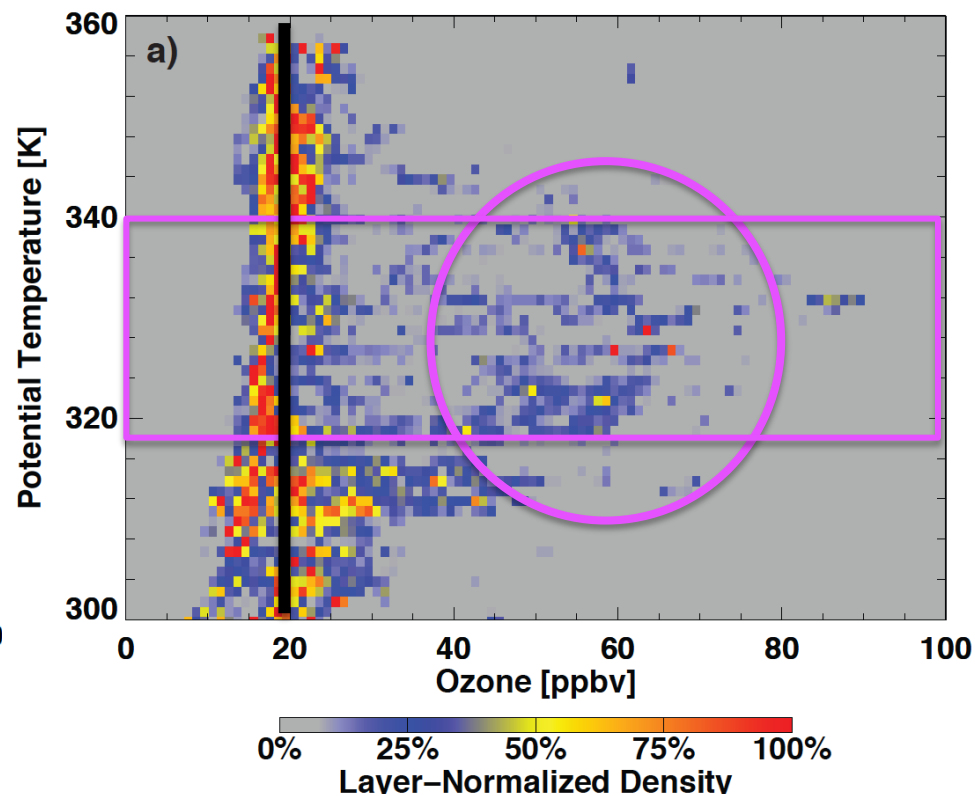
76 out of all 85 profiles

# WP Tropospheric O<sub>3</sub> – a Bi-modal Distribution

Primary mode: convectively controlled, “deep - tropical”



All profiles between 20S-22N

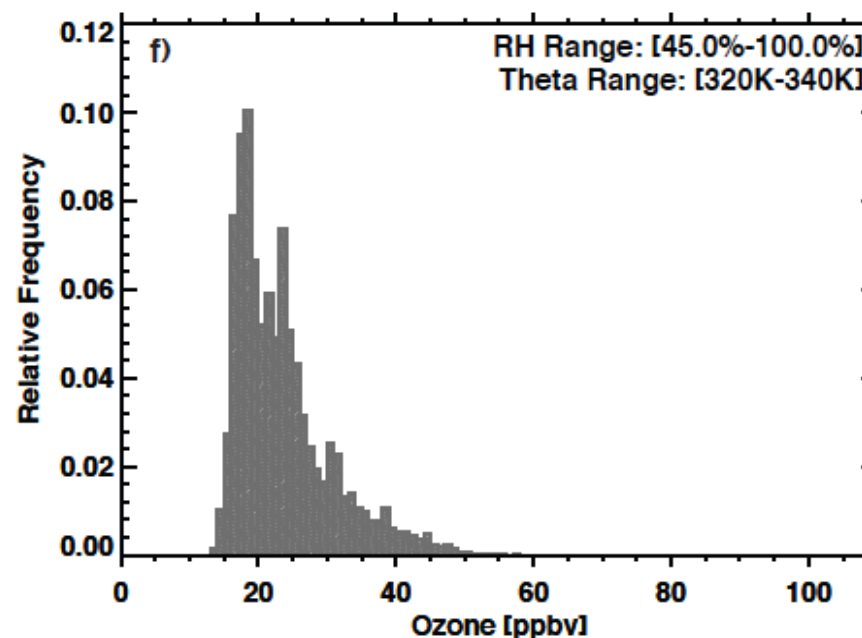
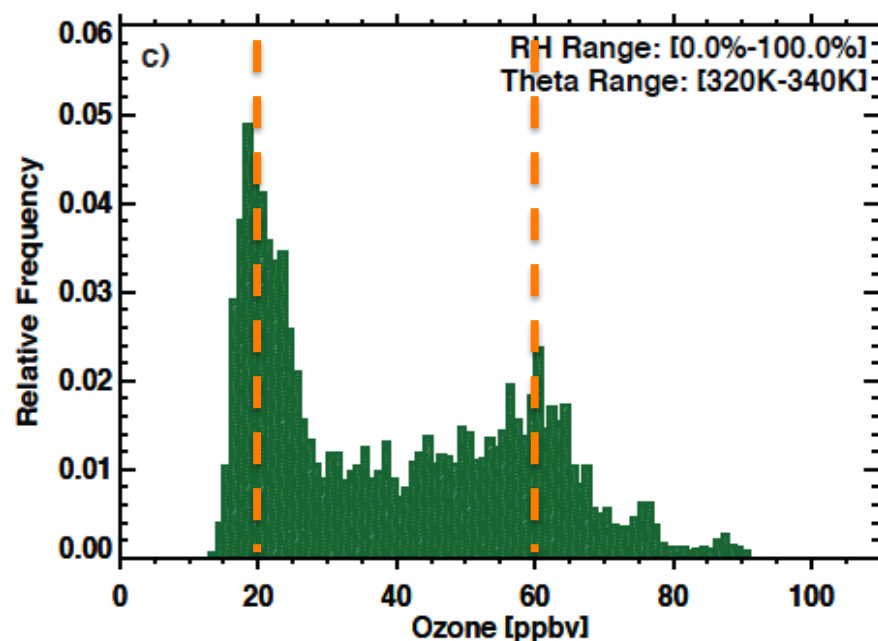


Secondary mode: “Non-Local”

# TWP Tropospheric O<sub>3</sub> – a Bi-modal Distribution

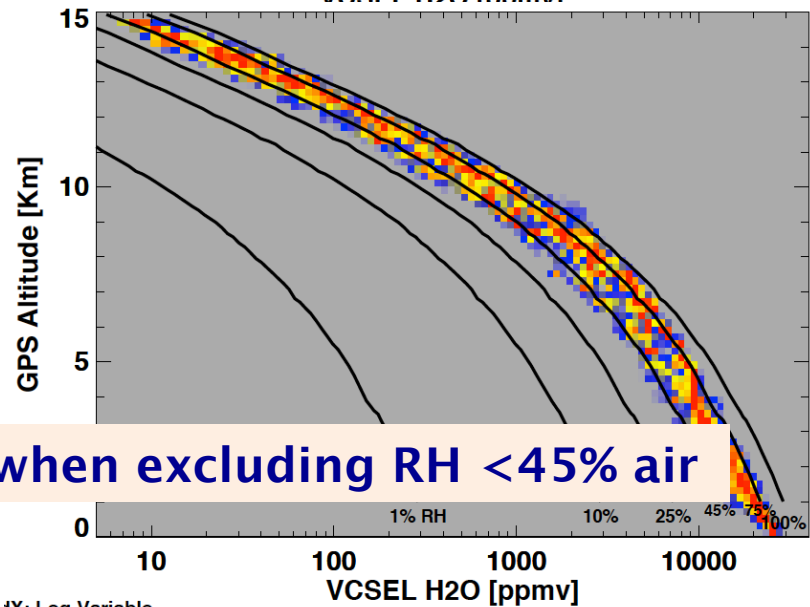
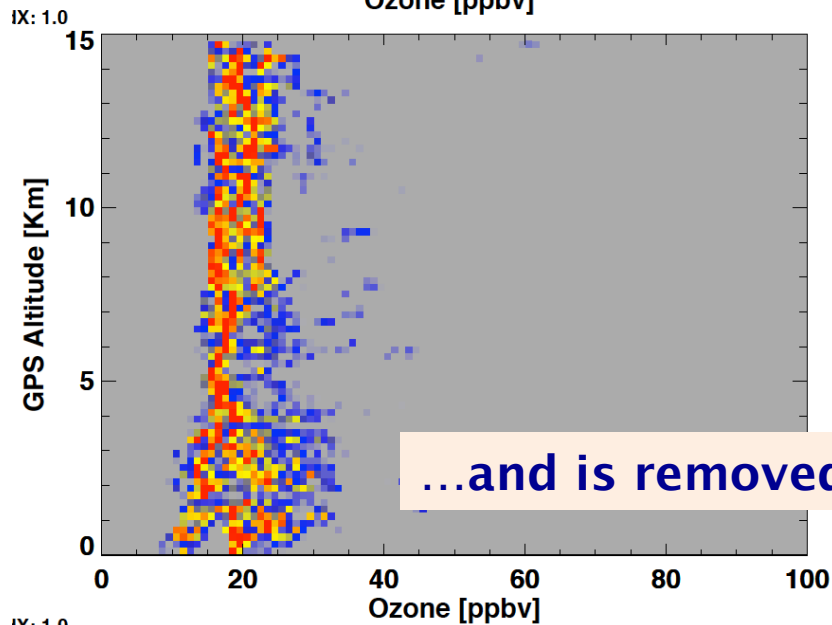
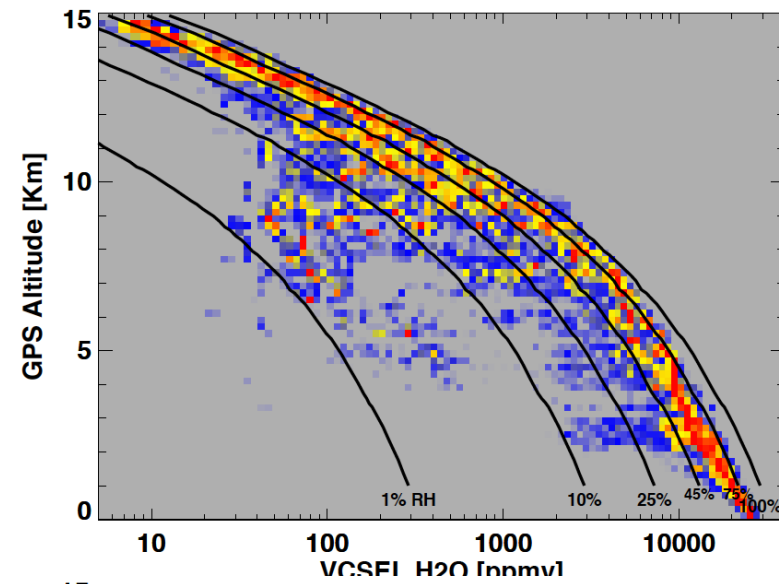
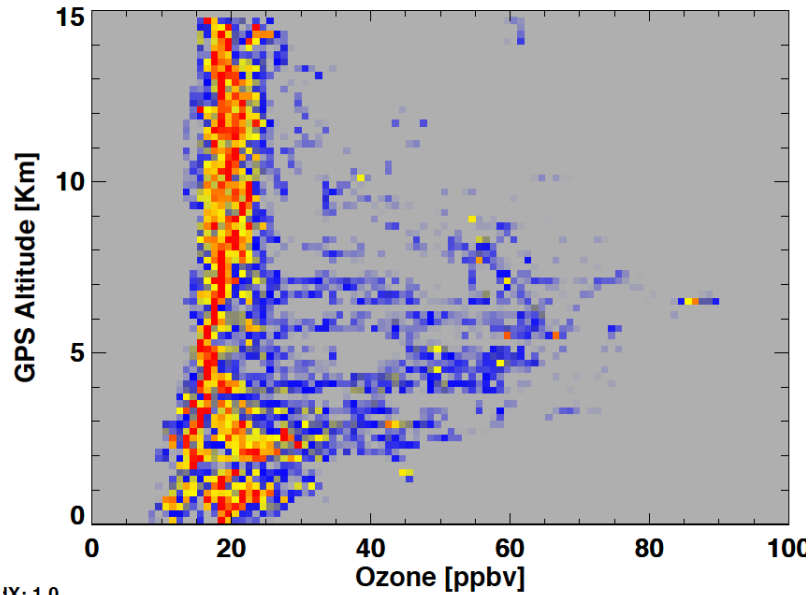


## O<sub>3</sub> distribution in 320-340 K layer

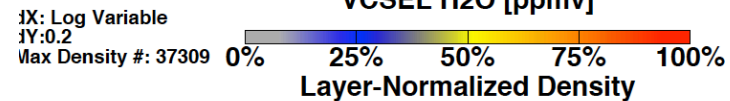
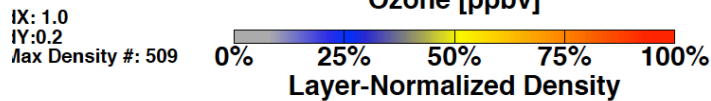


After excluding RH<45% data

# The Secondary Mode is correlated with dry air mass

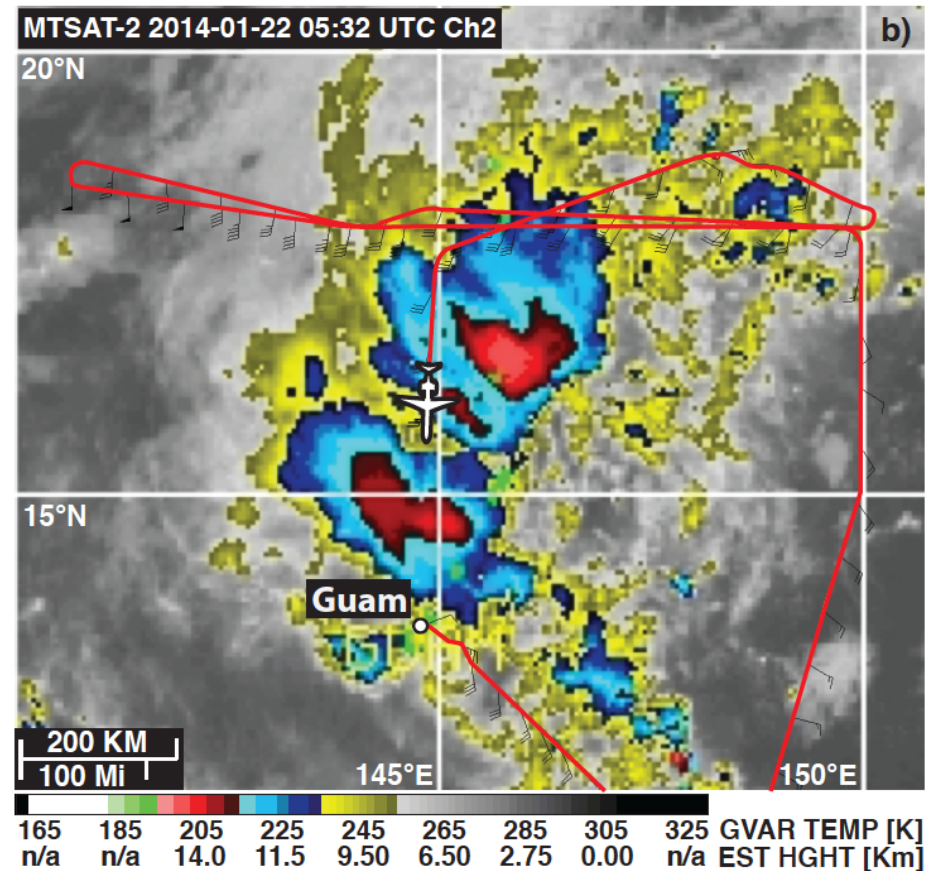
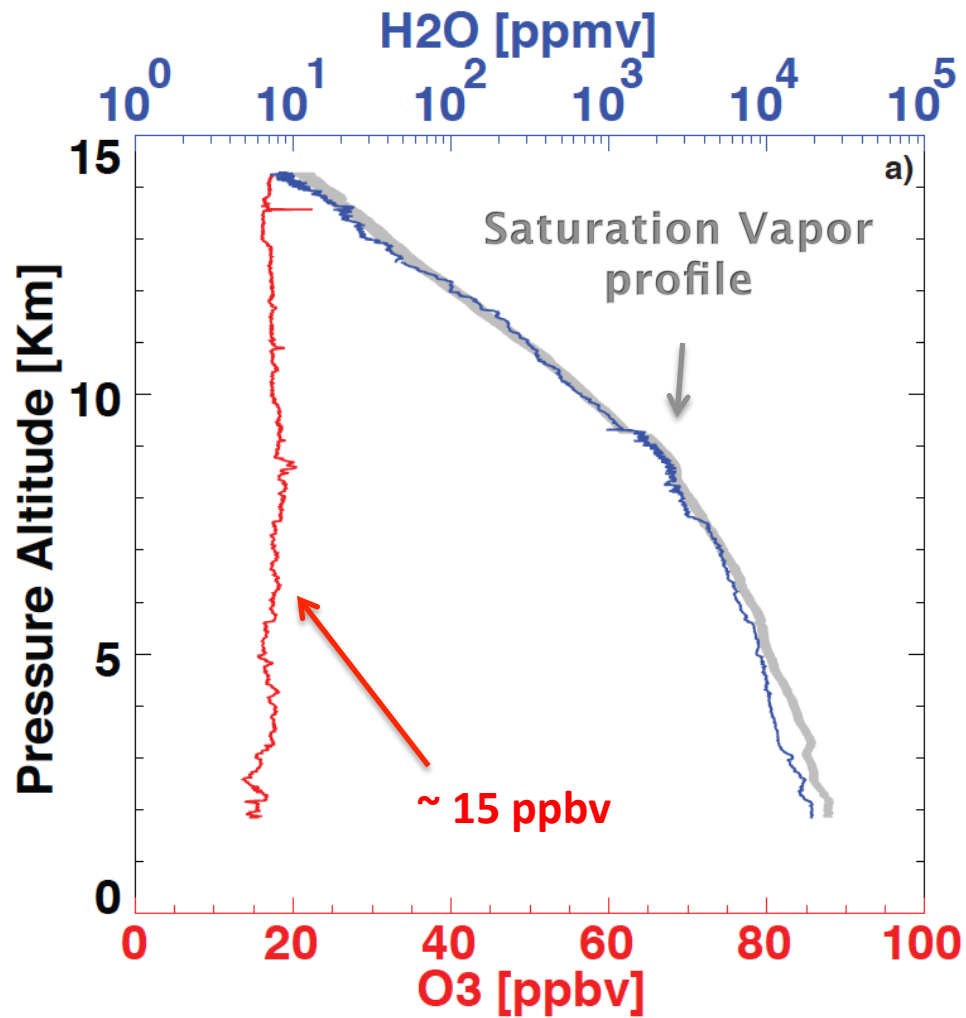


...and is removed when excluding RH < 45% air



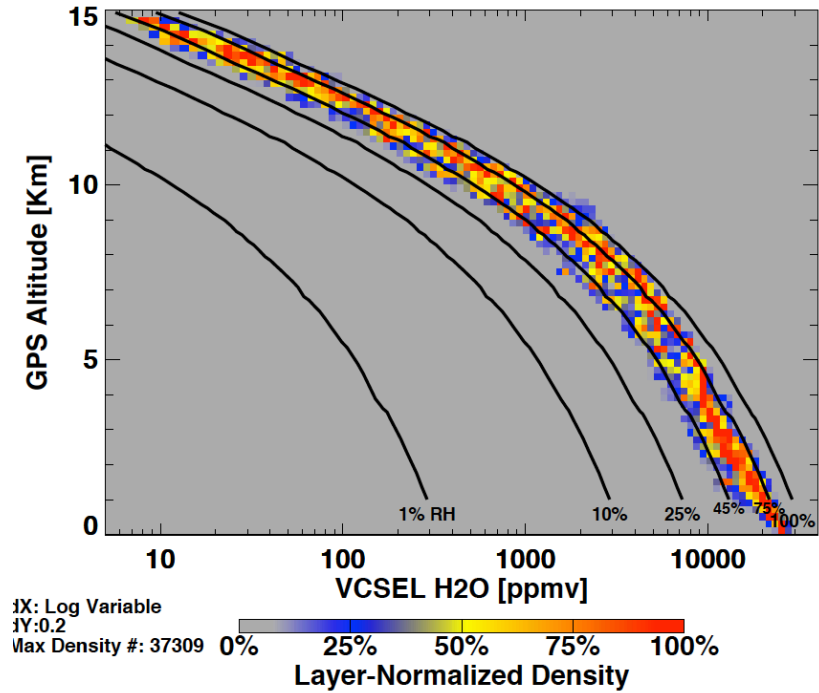
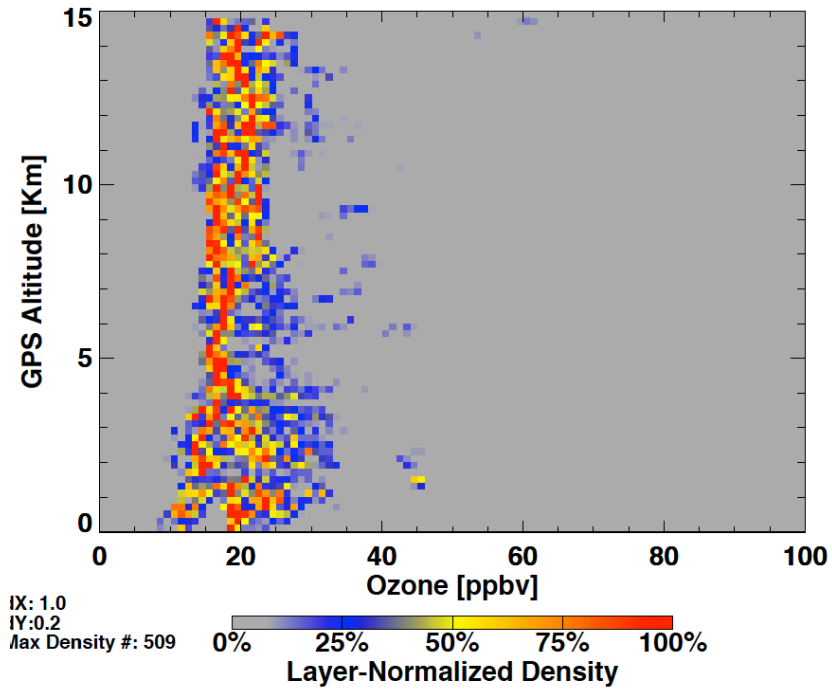
**What processes create and maintain  
the primary mode?**

# An example of the primary mode profile – convectively controlled $O_3$ – $H_2O$ profile:



RF05, 22 January 2015, 2° N of Guam

# The Primary Mode



... TWP warm pool ozone if entirely convective control



**Candidate processes create and maintain the secondary mode**

# Previous observations of dry layers

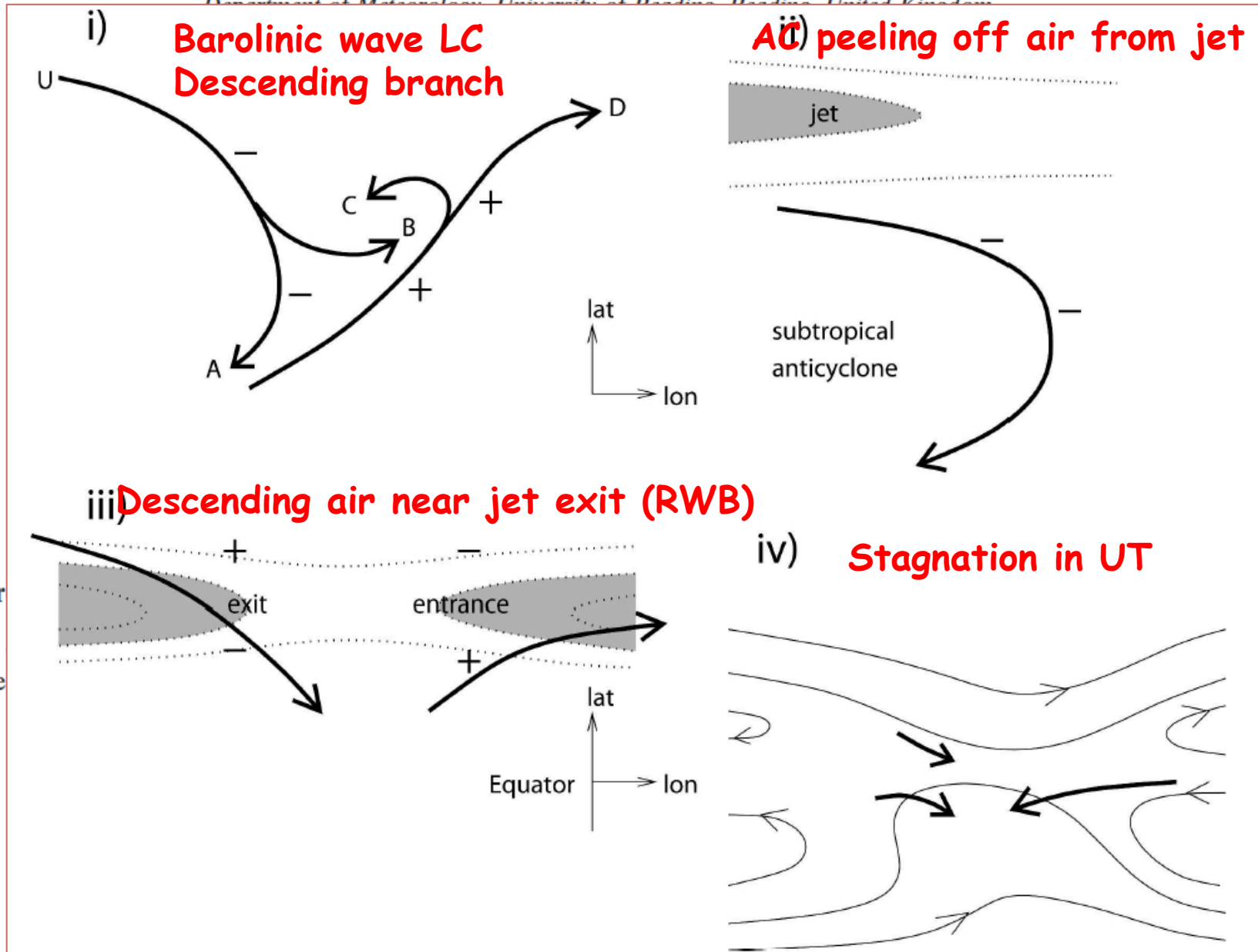
- TOGA COARE: “Dry intrusions” – significant influence of jet dynamics, descending into deep tropics following wave event

Parsons et al., 1994; Mapes and Zuidema, 1996;  
Yoneyama and Parsons, 1999; Cau et al., 2005; 2007

# Origins of Dry Air in the Tropics and Subtropics

PIERO CAU, JOHN METHVEN, AND BRIAN HOSKINS

*Department of Meteorology, University of Reading, Reading, United Kingdom*



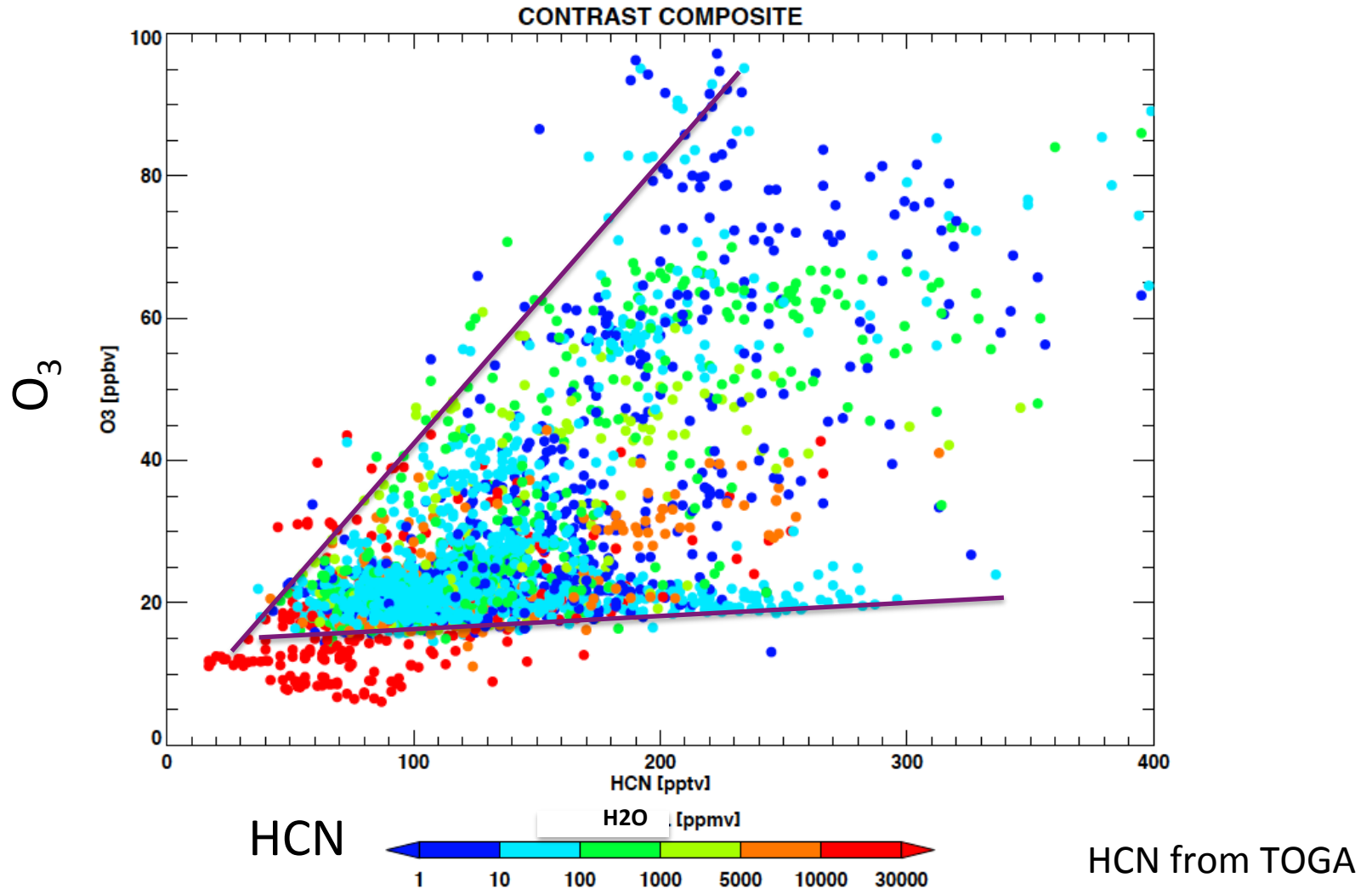
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The  
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# Previous studies of Ozonesonde and DC-8 data

- Ozone enhancement in the tropics: “Biomass burning”:
  - Gregory et al, 1999; Kita et al., 2000; Oltsman, et al., 2001; Kondo et al, 2002 ;
- From O<sub>3</sub>+H<sub>2</sub>O- layer observations: stratospheric influence or midlatitude UTLS
  - Stoller et al., 1999; Thouret et al., 2001; Hayashi et al., 2008

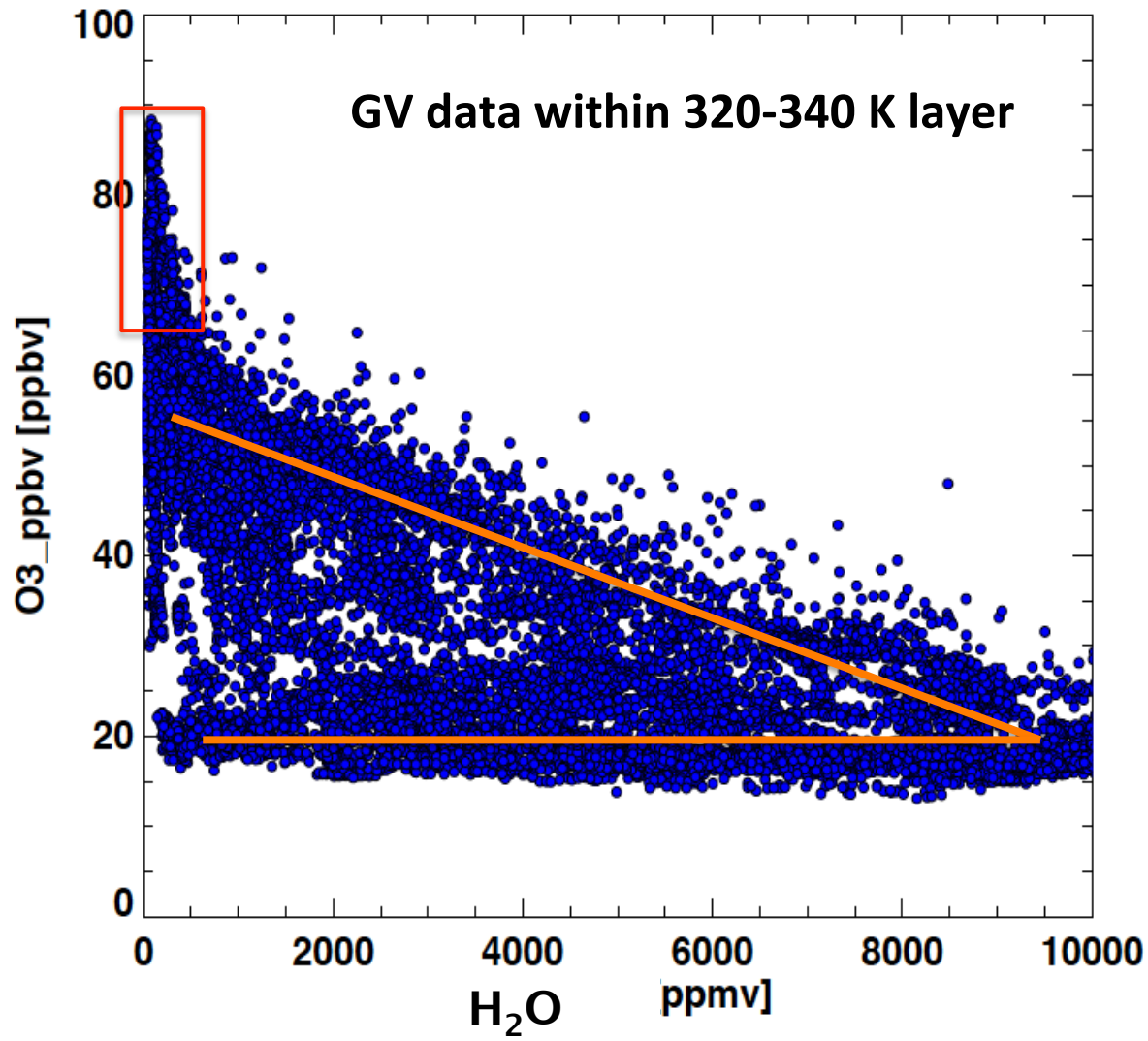
# Also observed: Significant correlation of ozone and HCN:

-Role of Biomass Burning (BB)?

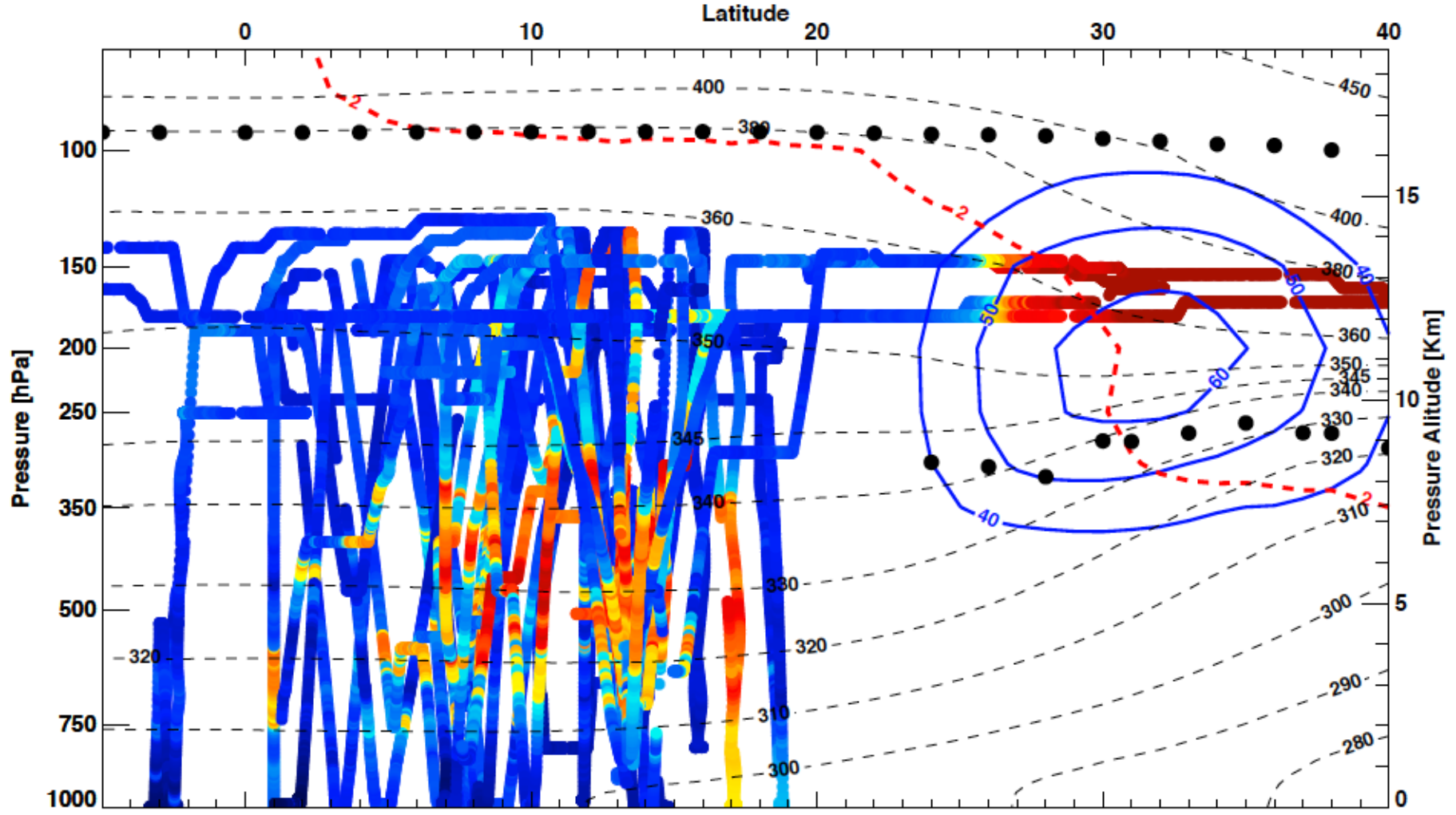


# Significant correlation of ozone and H<sub>2</sub>O:

-Role of mixing with subtropical UTLS air?



# CONTRAST Ozone, Jan-Feb, 2014



Mean Wnd. Spd. [m/s][Blu]

Mean Pot. Temp. [K][Blk]

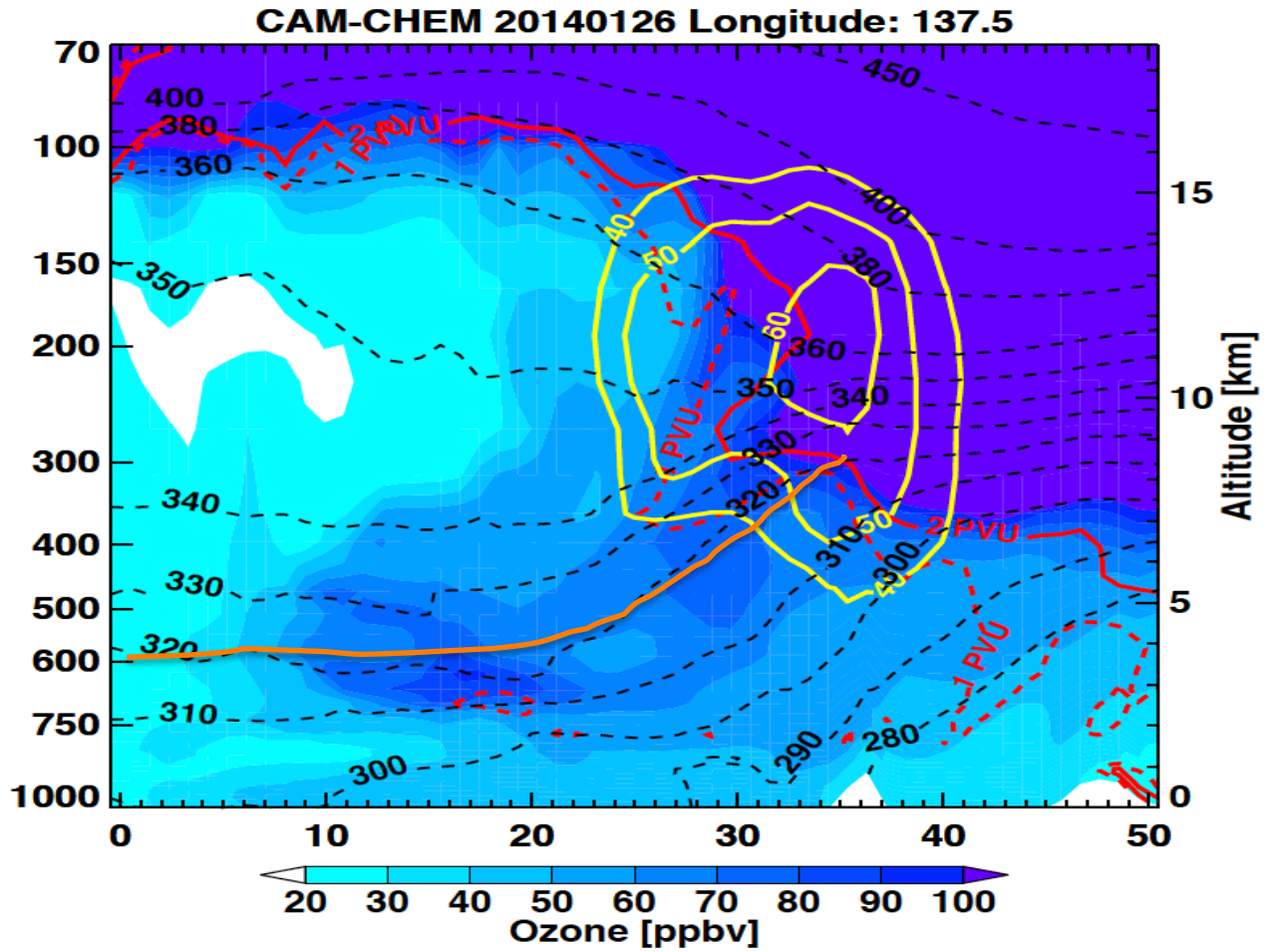
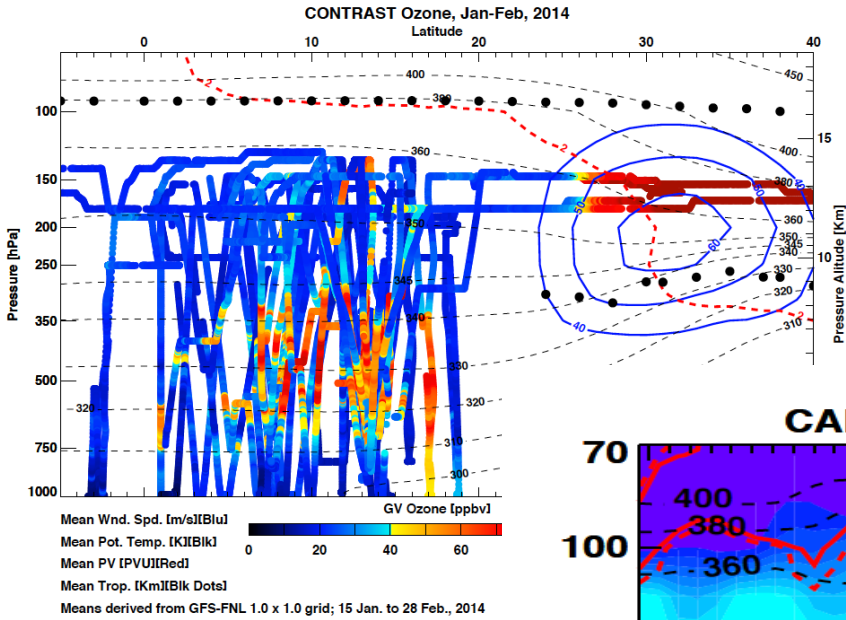
Mean PV [PVU][Red]

Mean Trop. [Km][Blk Dots]

Means derived from GFS-FNL 1.0 x 1.0 grid; 15 Jan. to 28 Feb., 2014



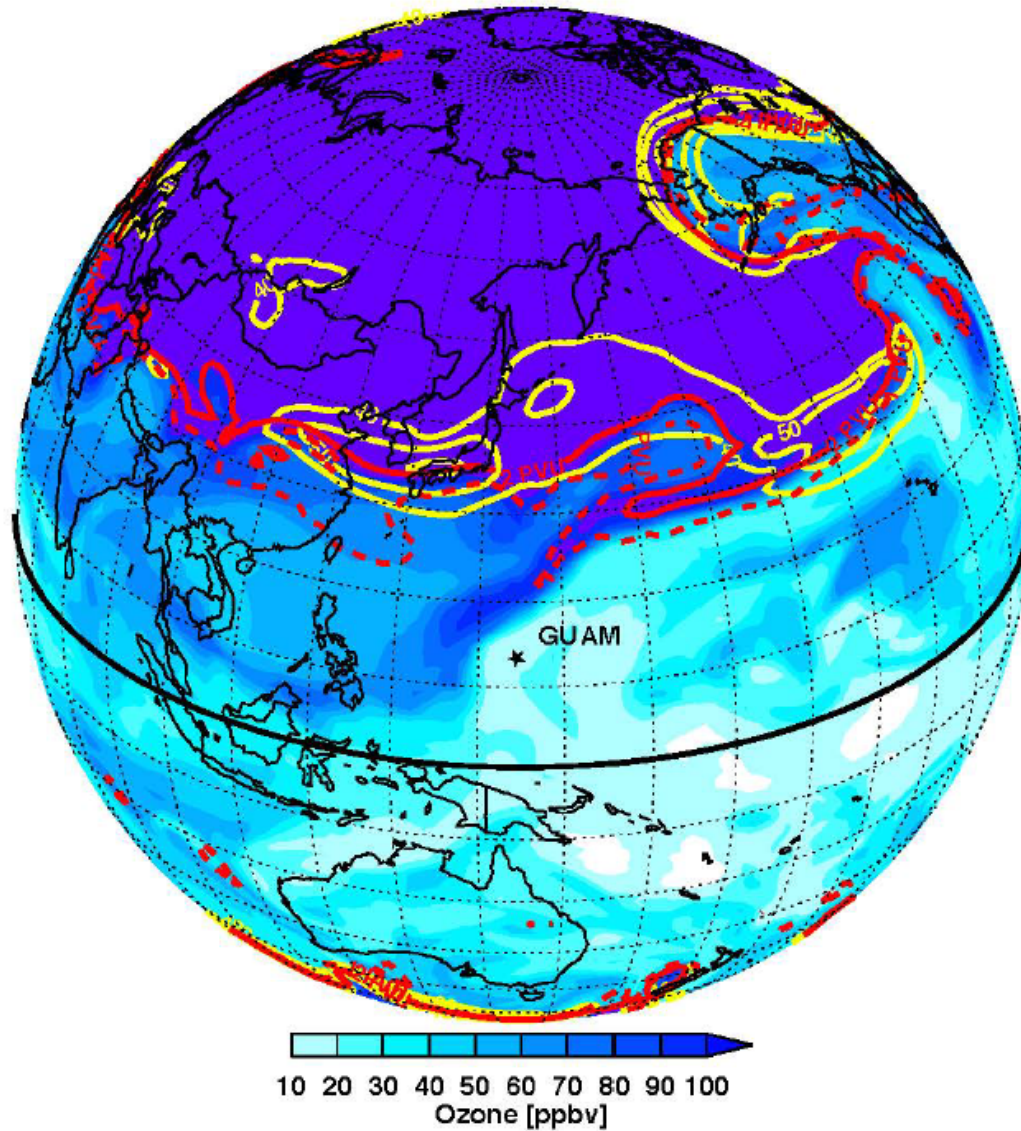
# Layer structure in the CAM-Chem model





# CAM-chem SD run for CONTRAST period

CAM-CHEM 320K 20140126

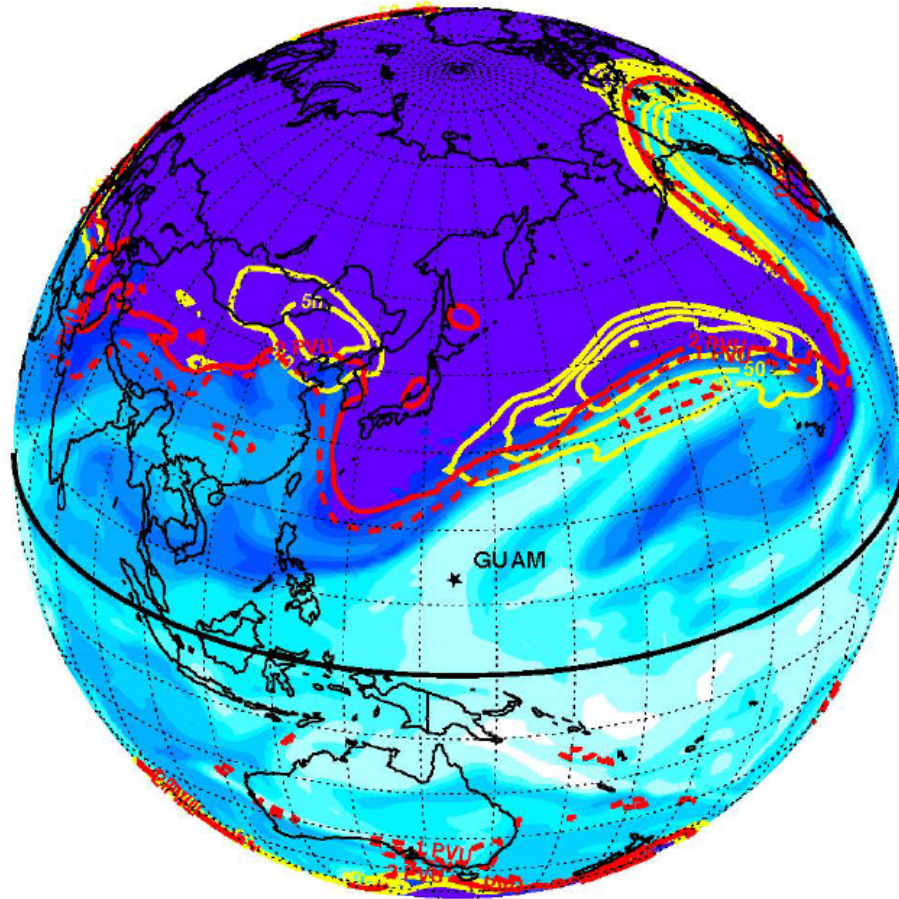


Doug Kinnison

Movie replaced by single frame

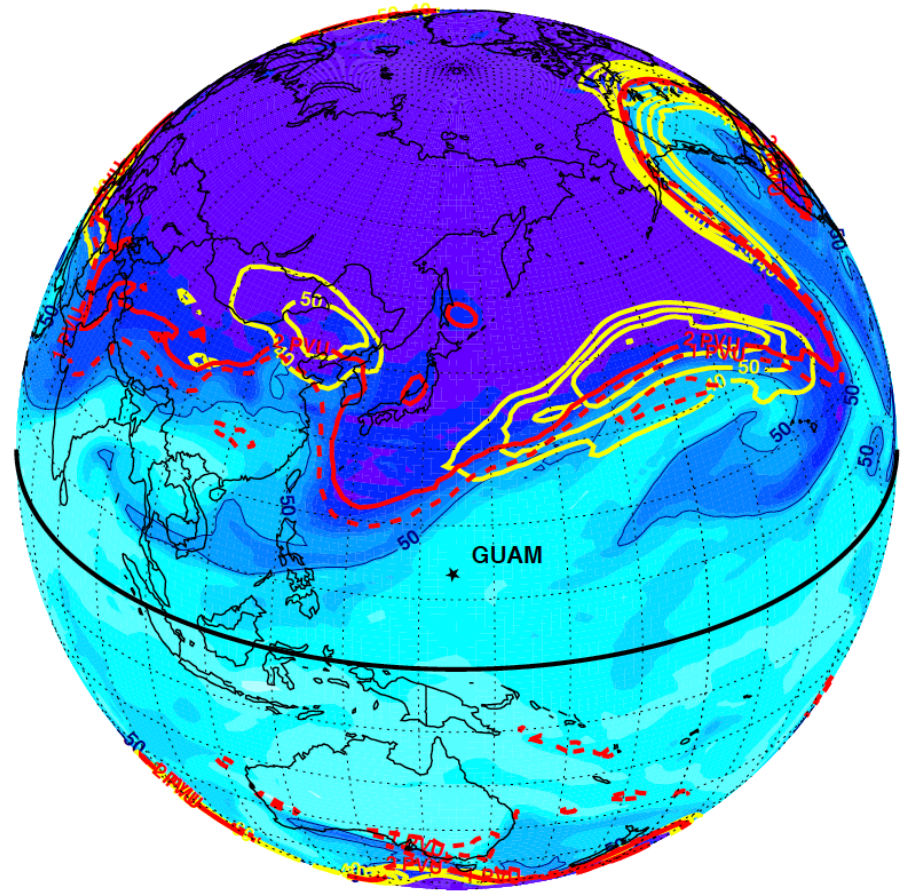
# Fraction of Stratospheric Influence from CAM-Chem

CAM-CHEM 320K 20140124



10 20 30 40 50 60 70 80 90 100  
Ozone [ppbv]

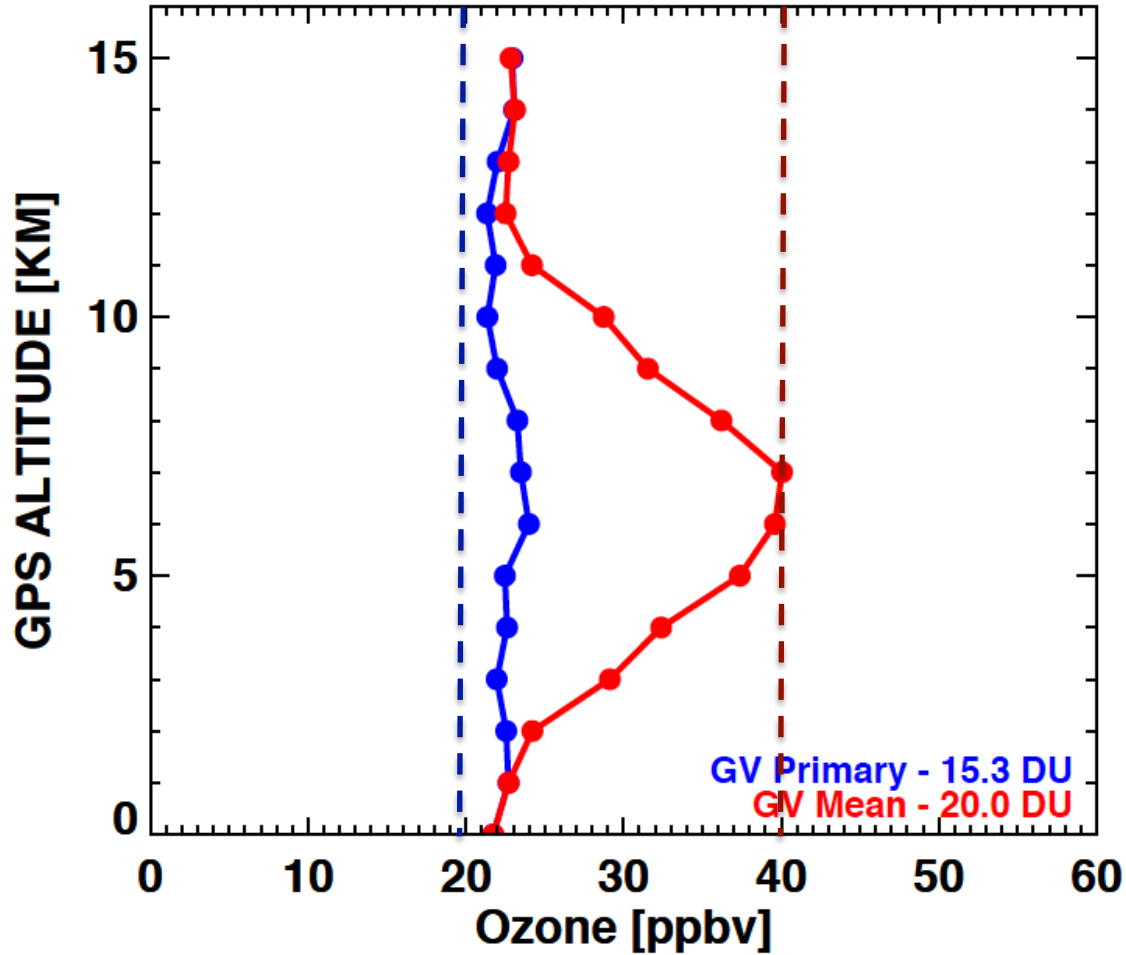
CAM-CHEM 320K 20140124



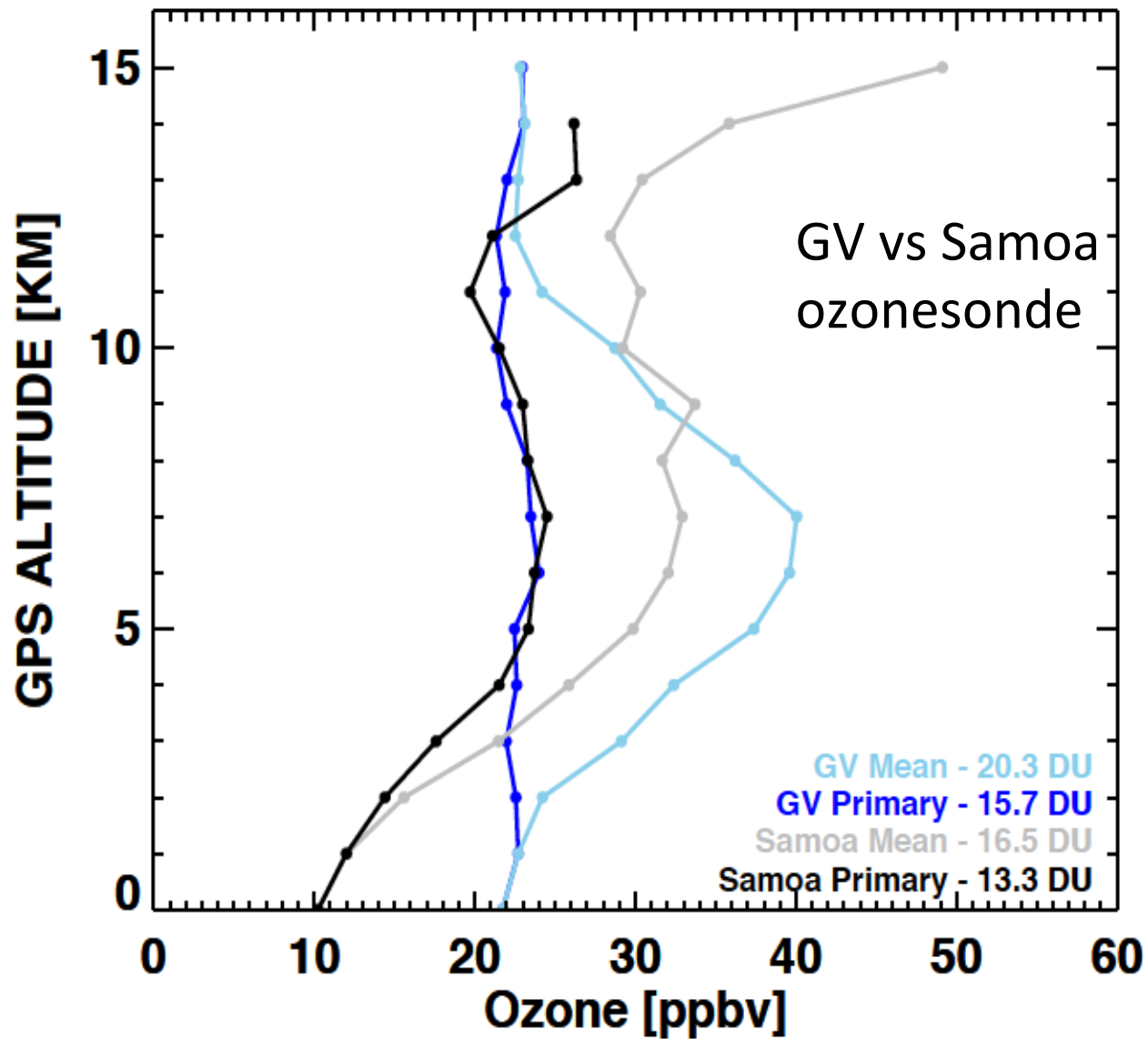
0 10 20 30 40 50 60 70 80 90 100  
Stratospheric Ozone Fraction [%]

# **Implications of the bi-modal structure**

## Representation of tropical ozone: caution against using the mean profile



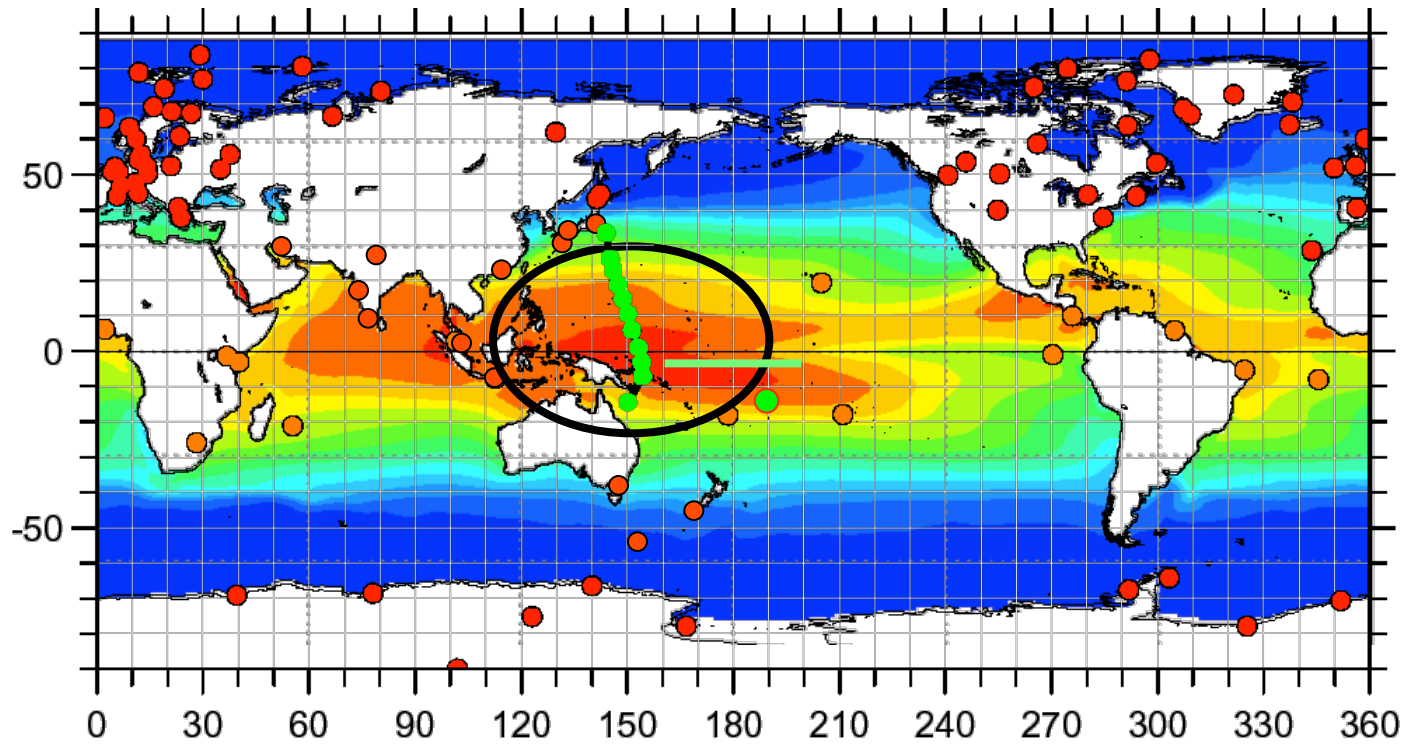
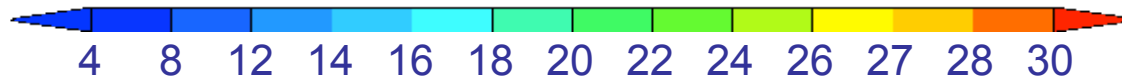
# Is the bi-modal structure TWP warm pool specific?



# ● Global ozonesonde station network and SSTs

●●●● TransBrom cruise with RV Sonne, Japan-Australia, October 2009

Long term annual mean sea surface temperature [°C]

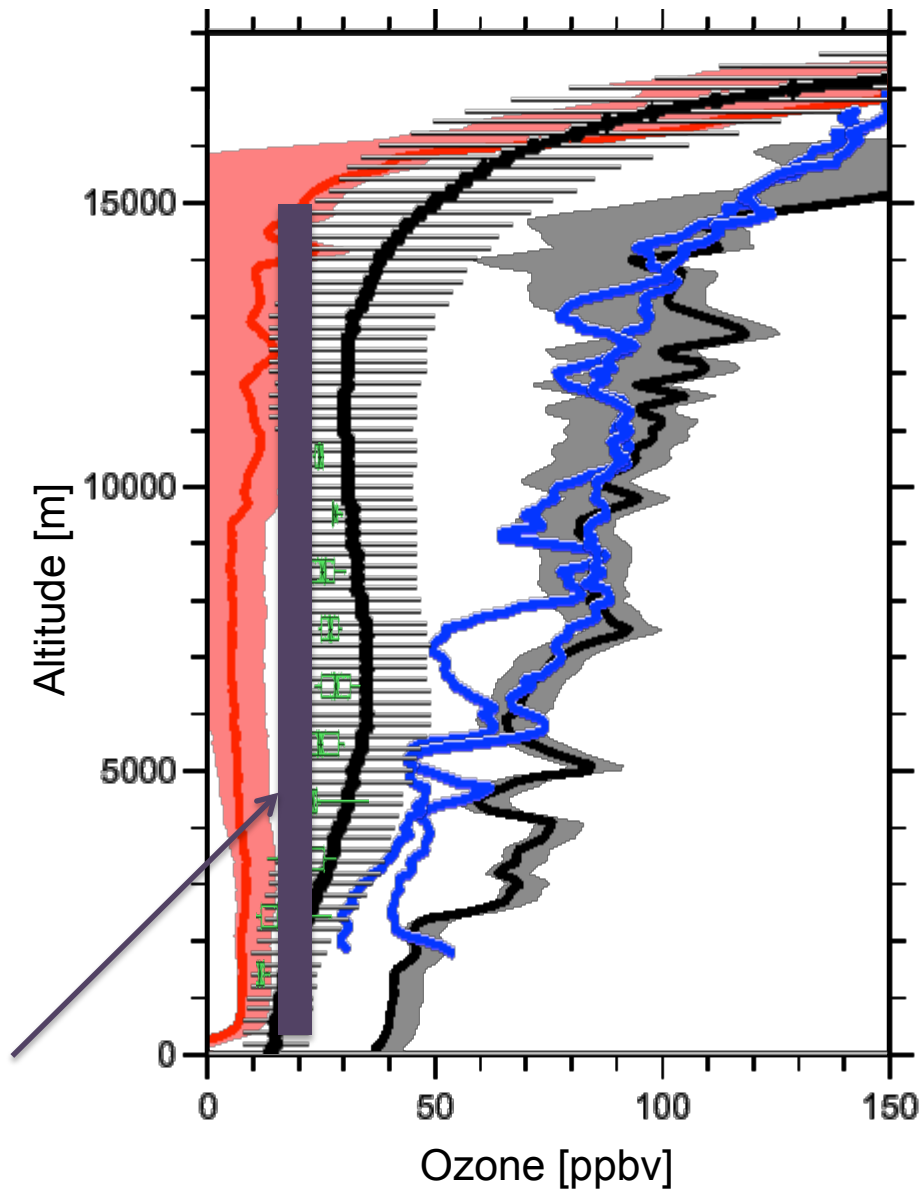


— Central Equatorial Pacific Experiment (CEPEX), *March 1993*

● Samoa ozonesonde data

## Ozone profile measurements in the West Pacific

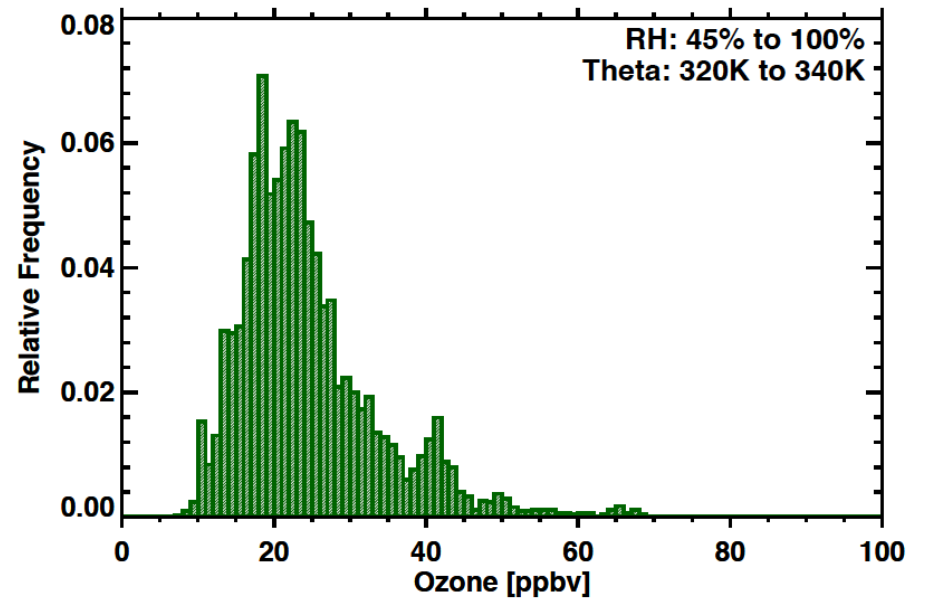
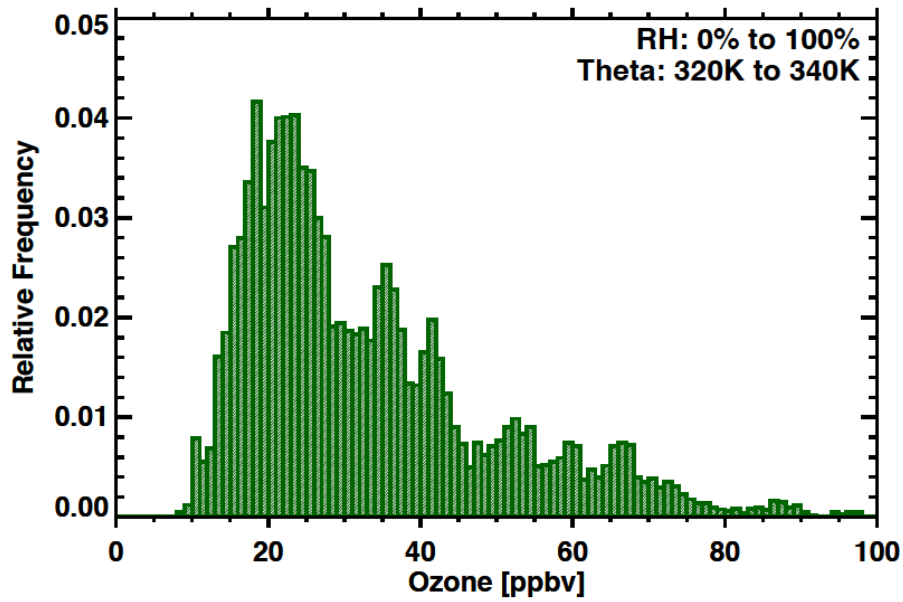
CONTRAST Primary mode



Rex et al., 2014

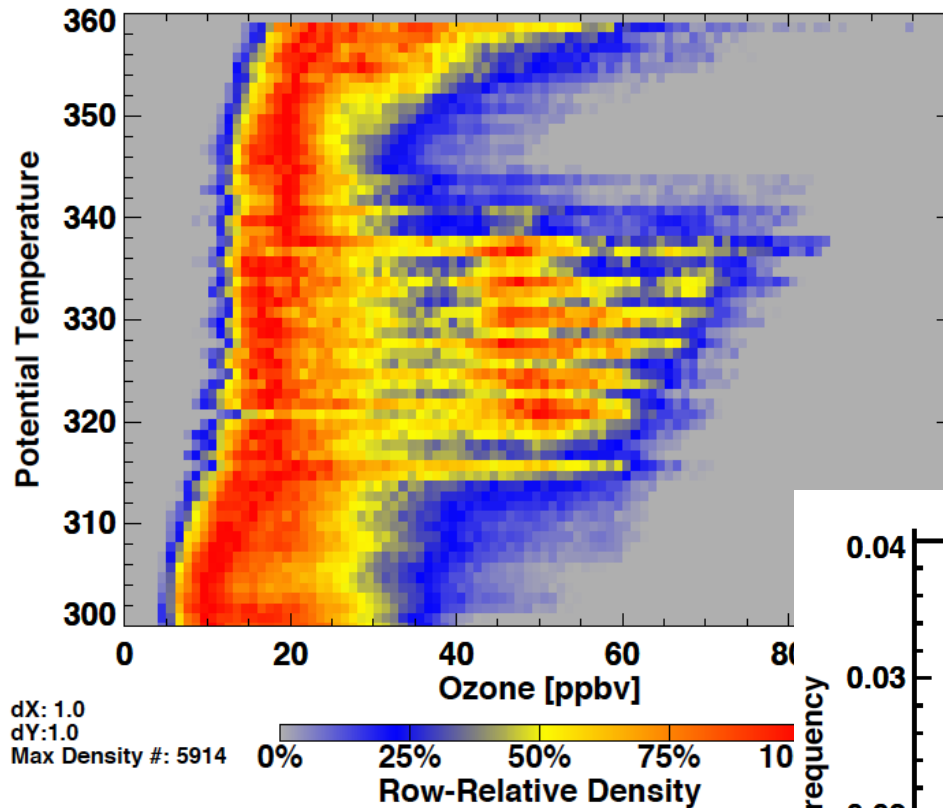
- Extratropical West Pacific ~30°
- Tropical Atlantic
- Tropical West Pacific
- Samoa, CEPEX similar (if realistic background current correction is applied)
- PEM-West (DC-8) West tropical Pacific

# Bi-modal structure in Samoa ozonesonde data?



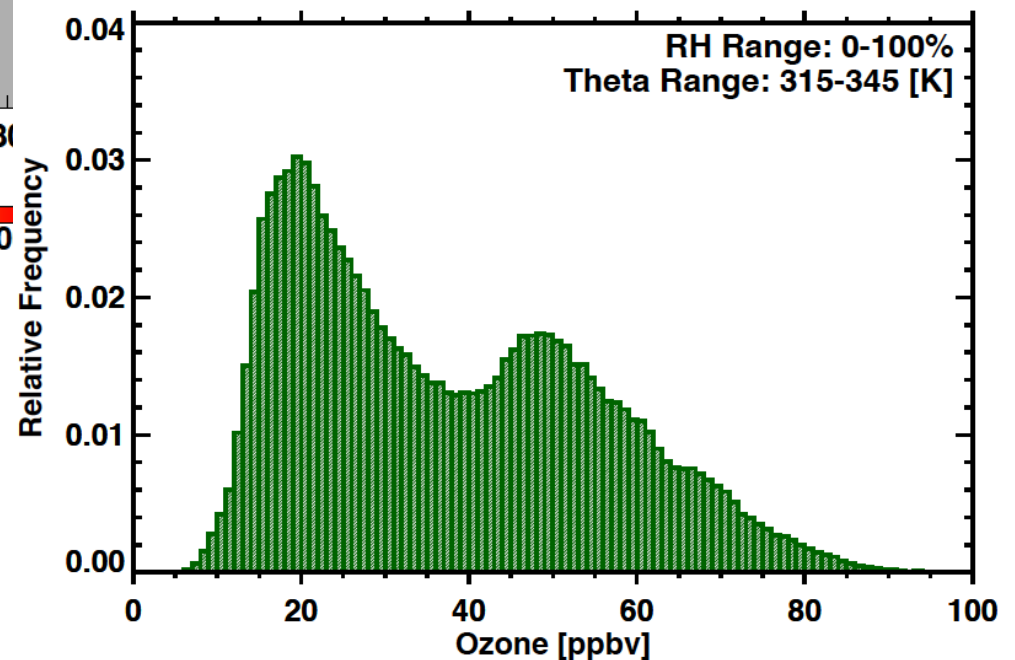


# Representation of the bi-modal structure in the global models?



NCAR CAM-Chem

All data in TWP box

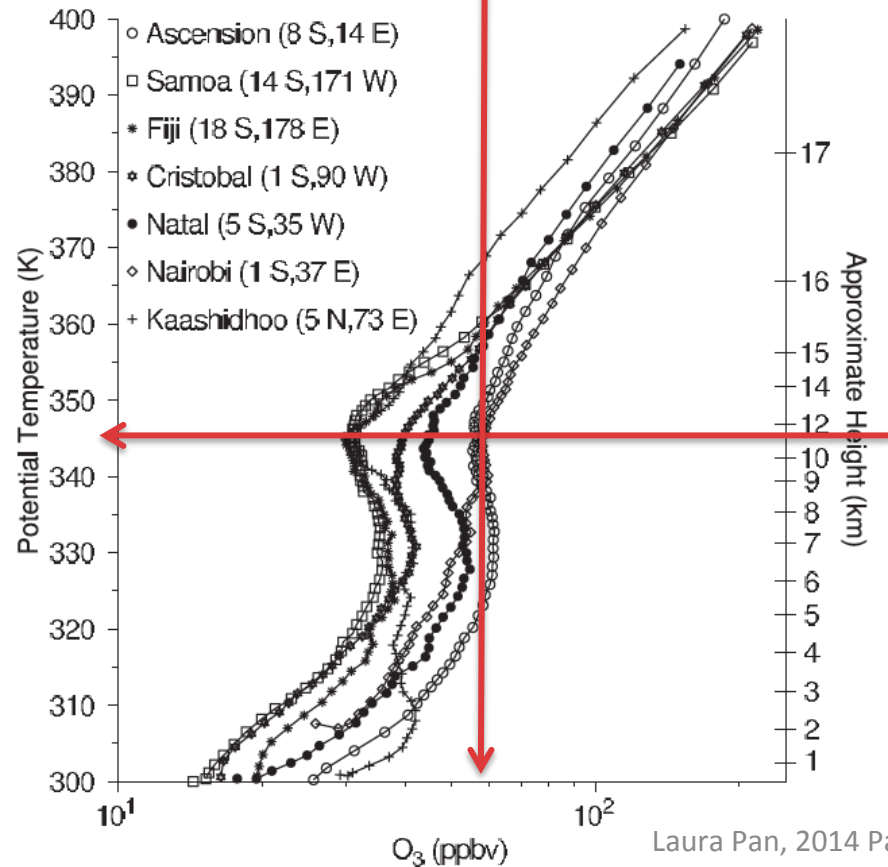


More see poster by Honomichl et al

# The “Conventional View” of the Tropical Ozone Profile: “S - shaped” or “seahorse shaped”

Tummy of the seahorse: average of two modes?

ACH 13 - 2 FOLKINS ET AL.: TROPICAL OZONE AS



Minimum at 345-350K:  
“Level of main convective  
outflow”

# Questions

- How general is the bi-modal structure of tropical ozone profiles?
- How do we quantify the contribution of different controlling mechanisms?

An aerial photograph of Earth from space, showing a vast expanse of white clouds over a dark blue ocean. The sun is visible in the upper left, creating a bright glow and casting long shadows. On the left edge, a portion of a satellite or aircraft is visible, featuring a logo and the text "National Science Foundation".

**Thank you!**