Processes in the Upper Troposphere/Lower Stratosphere (UT/LS) Observed by SHADOZ

Anne Thompson, Penn State Univ.
amt16@psu.edu

With: Sonya Miller, A L Allen, A A Jensen (PSU)
J Witte (SSAI), S J Oltmans (NOAA) , F Schmidlin (NASA)

Introduction to Three Related Talks

- SHADOZ & UT/LS Processes **Tuesday**
  - Importance of Tropical UT/LS (TTL)
  - Regional differences in convection, extra-tropical influence, pollution (biomass burning, urban)
  - Climatological approach, Laminae (LID), SOMs
- Tropical Atmospheric Chemistry (I) **Wednesday**
  - Interannual variability (QBO, ENSO), trends (LS -yes, UT ?)
  - Remote sensing – SHADOZ motivation, progress, challenges
- Tropical Atmospheric Chemistry (II) **Thursday**
  - SHADOZ & related data collection – quantity and quality
  - African Fulbright research – “science & service”
  - Mega-city – Johannesburg, So Africa, trends or no?

Road Map – SHADOZ & UT/LS

- SHADOZ: What/when/where/how
- Importance of Tropical UT/LS (TTL)
- UT/LS Processes
  - Convective, pollution, large-scale transport signatures in troposphere & TTL ozone
  - Climatological approach: seasonality, profiles classified in distinct regions
  - Laminar Identification (LID) of Gravity Waves. Use Index to quantify convection
  - SOMs (self-organizing maps) for classifying pollution, stratospheric, convective impacts

What-Where-When-How SHADOZ?
(So. Hemisphere Additional Ozonesondes)

Strategic Design Addresses Questions – 1998->

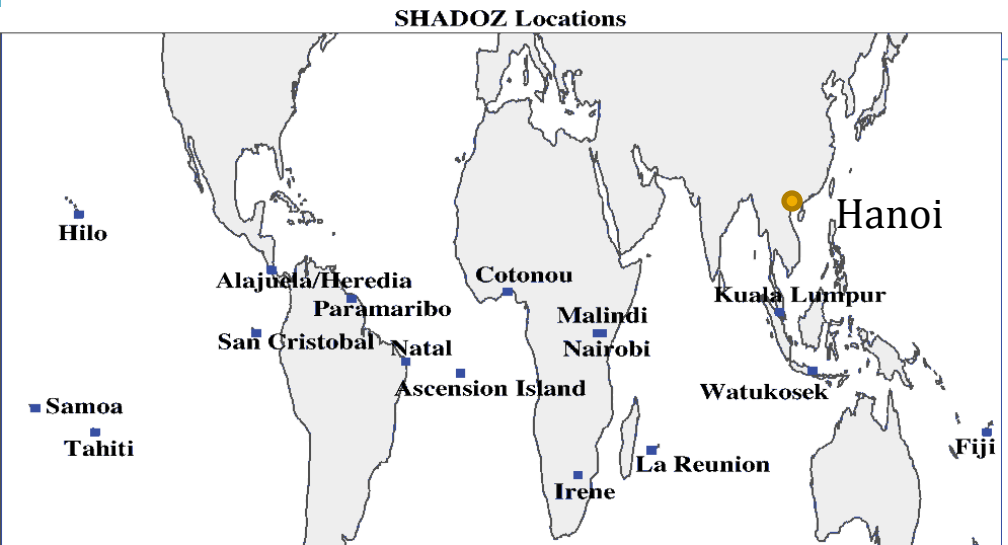
1> Satellite/model validation & optimization

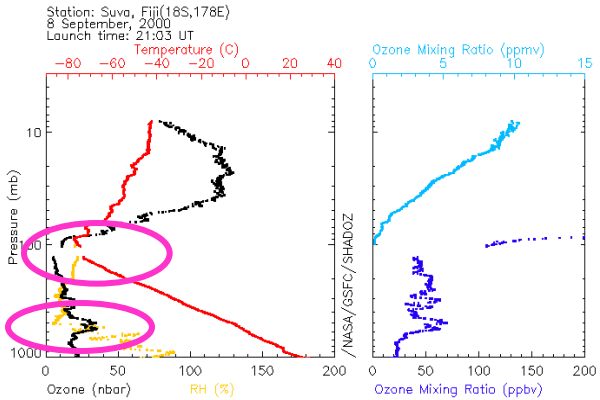
2> **Nature of zonal wave-one**

3> **Ozone variability on multiple time, space scales**

- Resolution in *stratosphere, troposphere* requires soundings
- Full zonal coverage – 9 sites in 1998, now 13; weekly soundings
- Complements campaigns & archives data (SAFARI-2000, TC4)
- **2011 - > 5000 profiles** at http://croc.gsfc.nasa.gov/shadoz

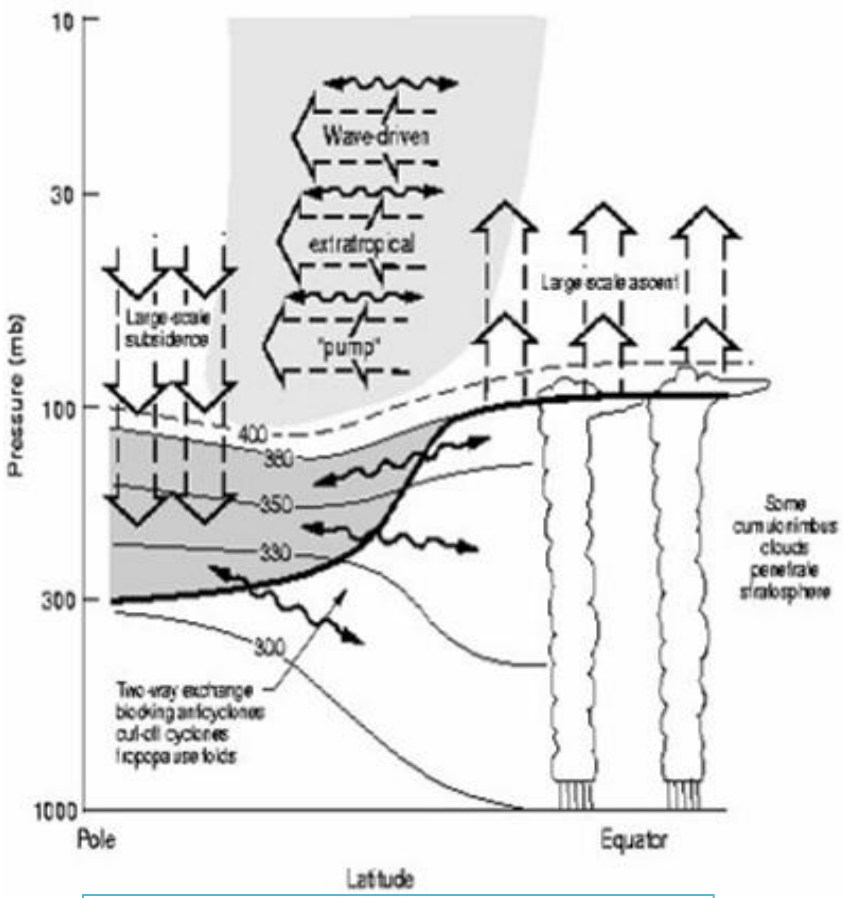
4> **Keys to success**: **Leverage resources to sustain sites. Open access. Additional distribution through WOUDC (woudc.org).**





Tropical UT/LS (TTL) Issues

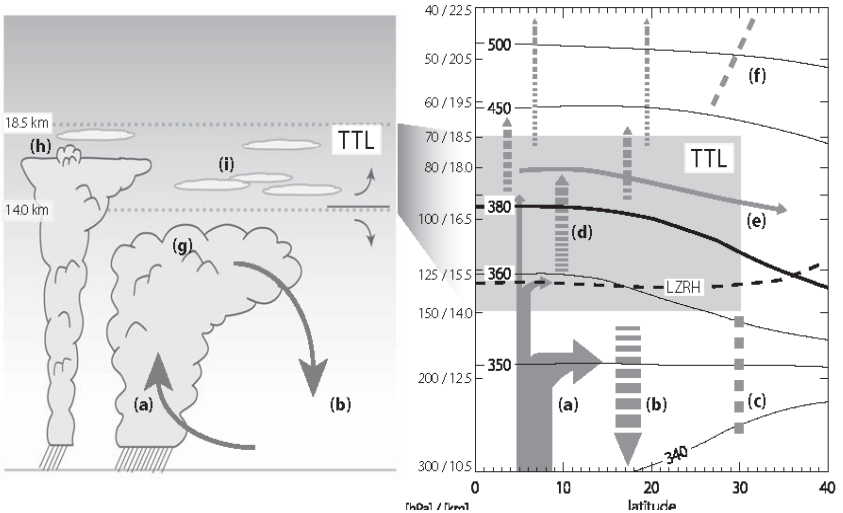
- "Tropical Pipe" – entry of tropospheric constituents into stratosphere
- TTL is where ozone depletion & Delta-temperature intersect ➔ impact on circulation? Feedbacks?
- Investigate with:
  - Models (GCM, coupled chemistry-climate, with-w/o assimilation)
  - Theory
  - **Data** – temperature, water vapor, ozone & other constituents. In-situ, satellite

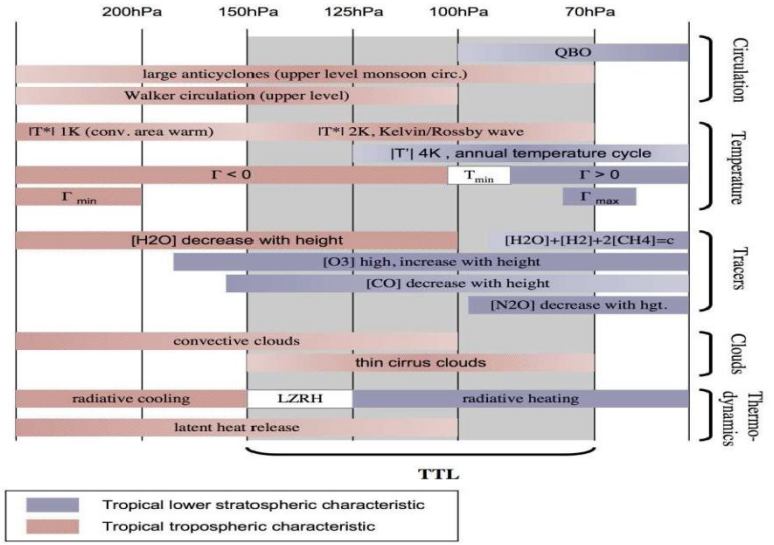


After Holton et al., 1995

Free Troposphere-TTL-Lower Stratospheric Processes (Fueglistaler et al, *Rev Geophys*, 2009)

- **TTL defined as**:
  - 14-18.5 km or 150-70 hPa
  - 140-185K absolute
  - 355-400K potential temp
- **Processes:**
  - Convection, dehydration, subsidence (left & right =a). Cirrus formation
  - Zonal mean circulation (right)
  - TTL properties w/ strat and trop character. Values and/or gradients (lower)

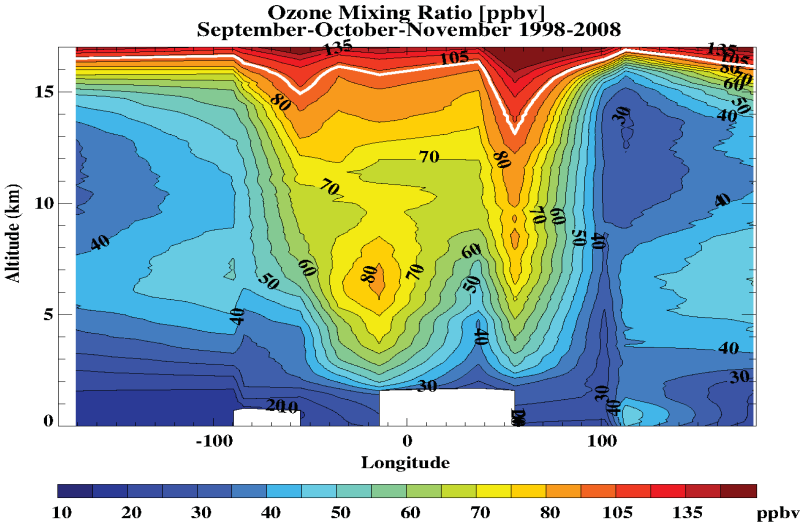


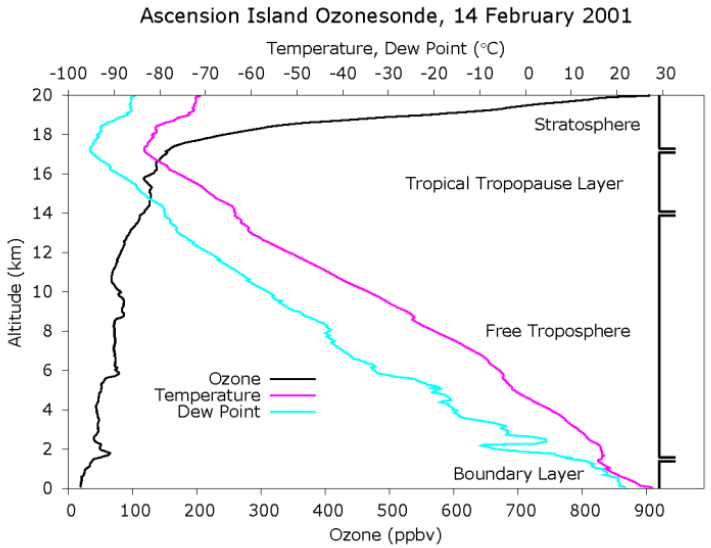


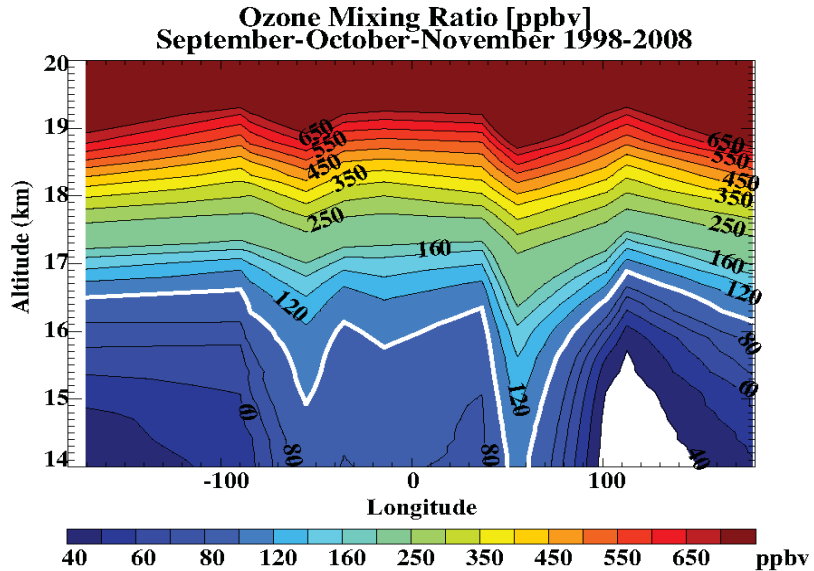
Scope of Recent FT (Free Trop) & TTL Ozone Studies

"Wave-one" feature indicates **3 processes**:

- Convection, low-BL ozone introduced into UT, TTL => S-shape
- UT ozone enriched by subsidence, extra-tropical air, "more stratospheric"
- High FT O_3 layers => pollution typically biomass burning, some lightning

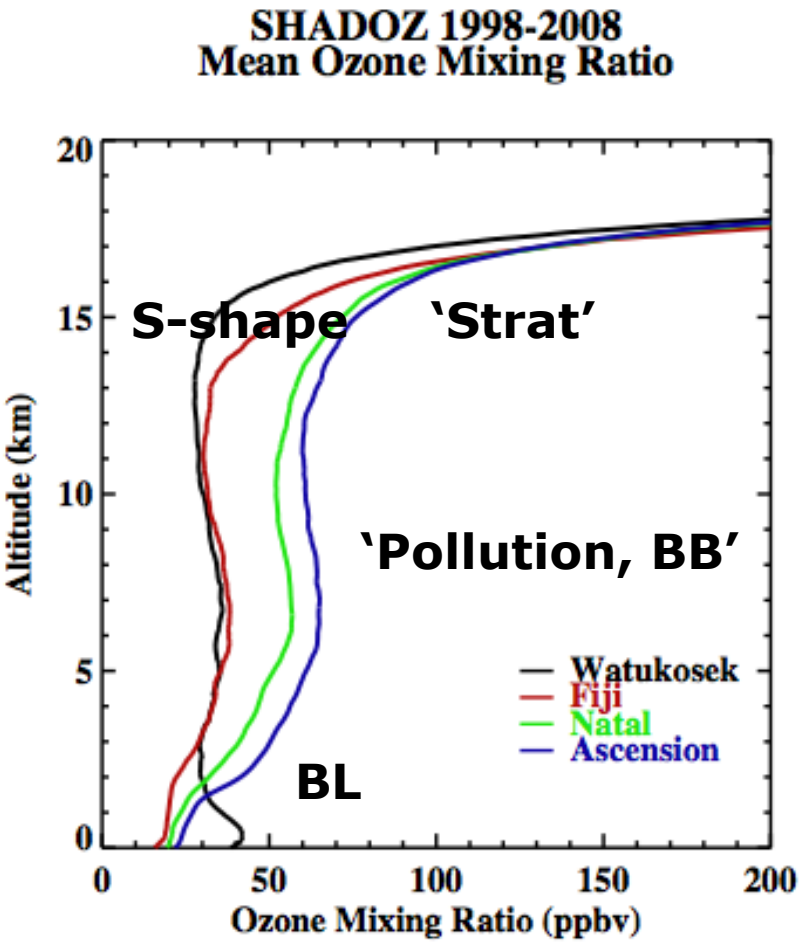




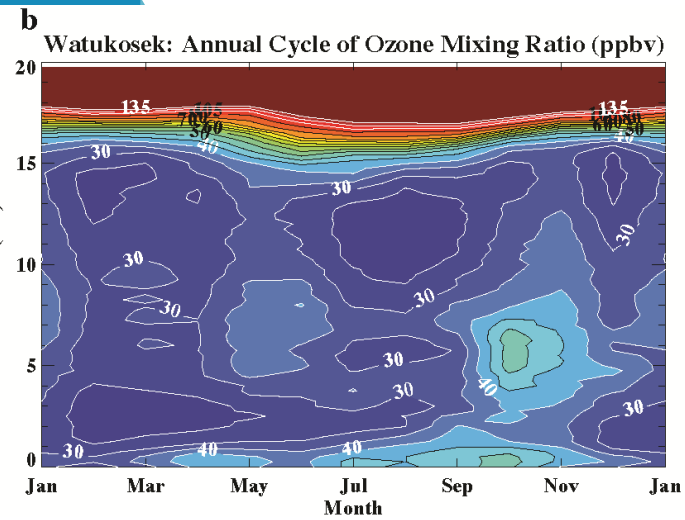


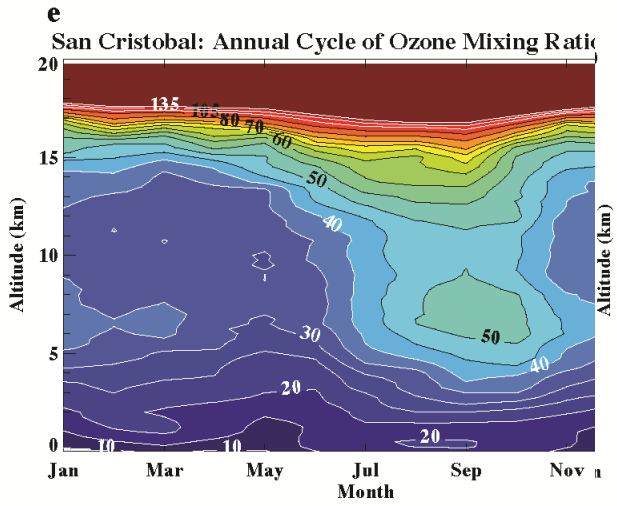
Methods Used in Recent FT & TTL Ozone Climatological Studies

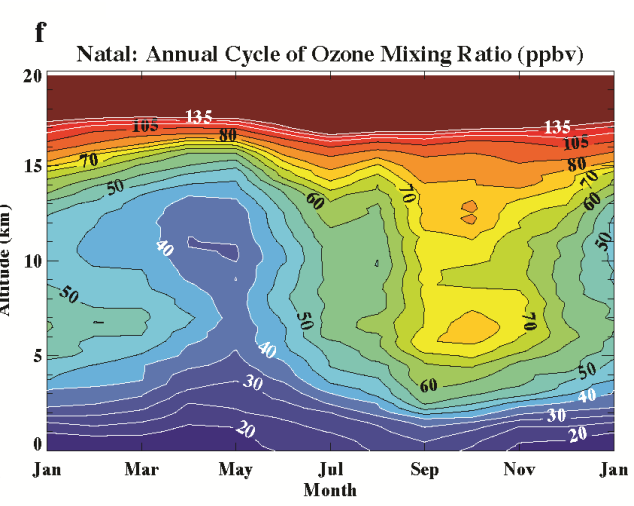
1. Climatology - Regional differences based on mean profiles & seasonal cycles. T'pause height, "S-shape" [*Thompson et al.,* 2011a] →
2. TTL closeup – Convective comparisons inferred from gravity wave activity using Laminar Identification (LID) [*Thompson et al.,* 2011b]
3. FT-UT closeup – Pollution, convection influences classified by Self-Organizing Maps (SOMs) [*A Jensen MS Thesis,* 2011]

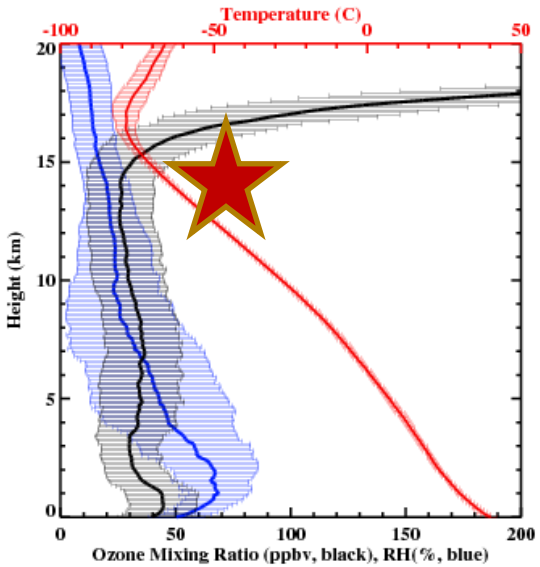


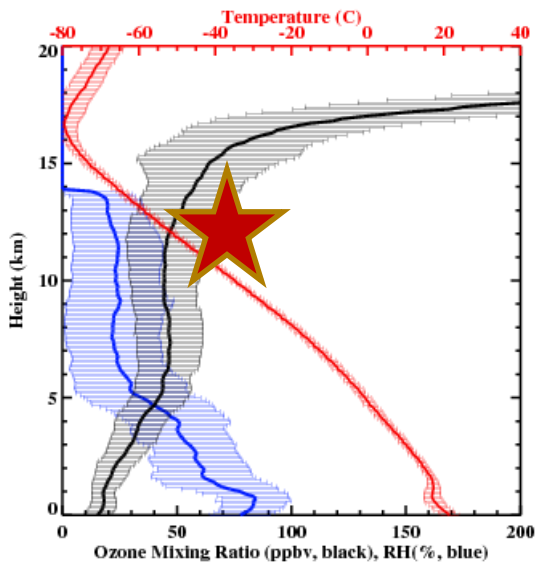
Three Distinct Regions: W Pacific, 'Equatorial Americas,' Atlantic-Africa

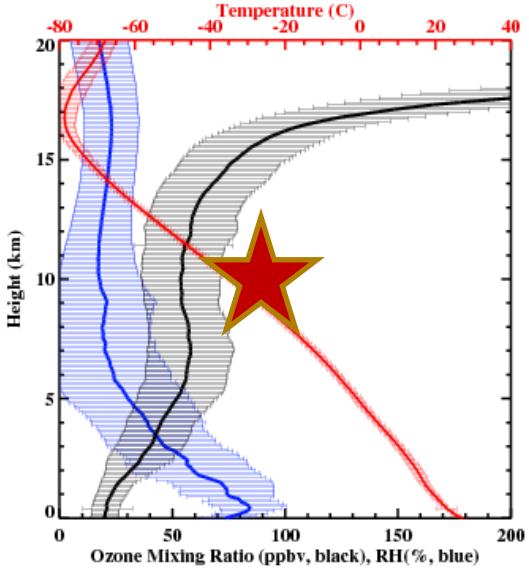












Ozone from Sondes in TTL & Tropospheric Convection, Pollution Signals

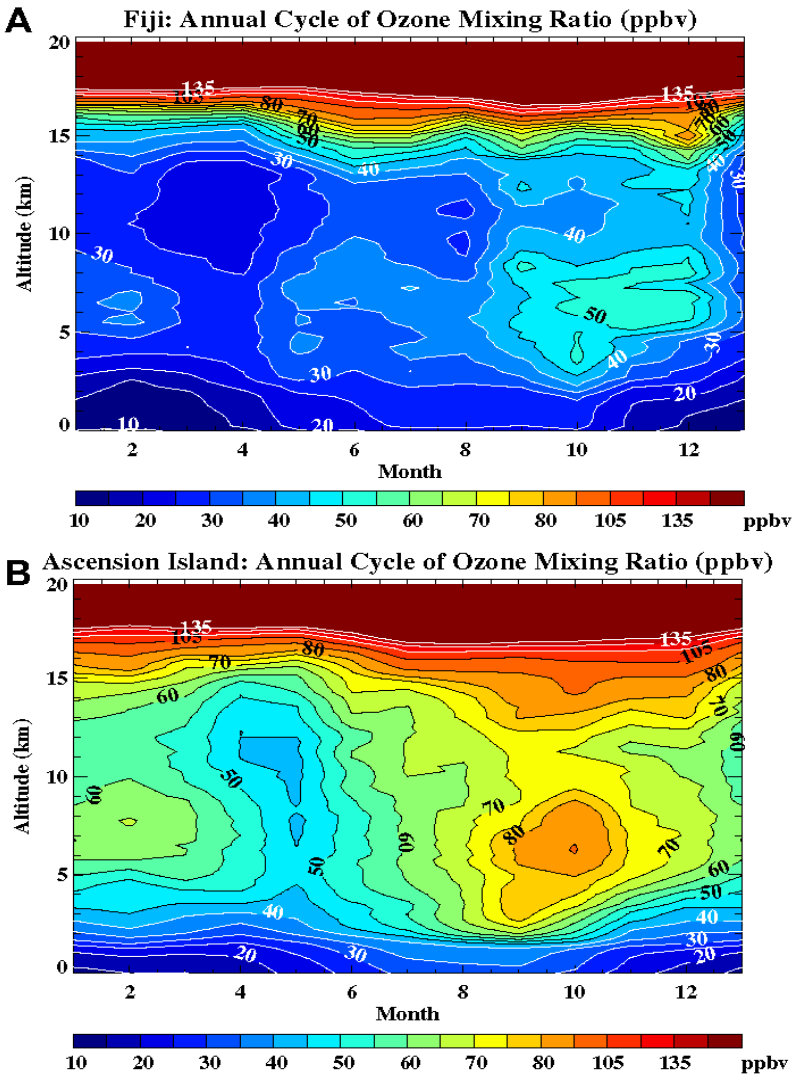
Questions relating to TTL transport of constituents

Ques 1: Does convective seasonality match period of most active KW/GW?

→ Examine *all* SHADOZ profiles w/ laminar formalism (*Teitelbaum et al,* 1994; *Pierce & Grant,* 1998)

Ques 2: Does wave activity, detected by LID, link to active convection in individual profiles?

→ Examine TC4 soundings



Apply Laminar Identification (LID) to Every SHADOZ Sonde – Goal is Vertical, Seasonal Wave Climatology.

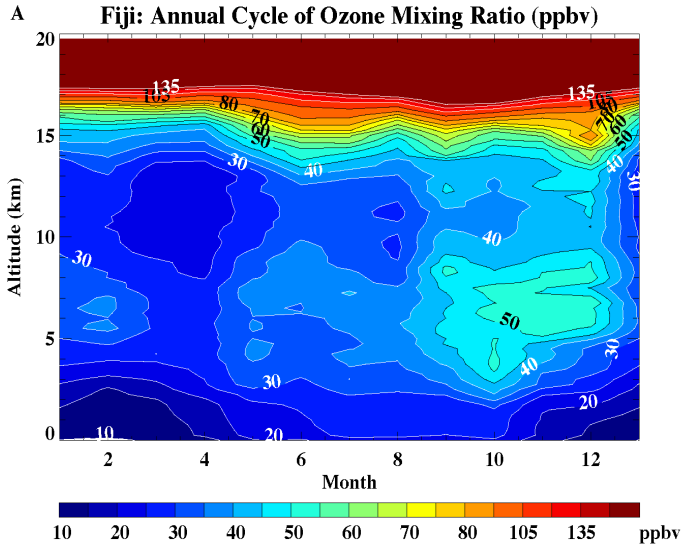
Method of Thompson et al. (2007b; 2010; 2011b)

Scientific Rationale: "Laminae" normalized to running mean ozone, PT used to detect presence of "waves"

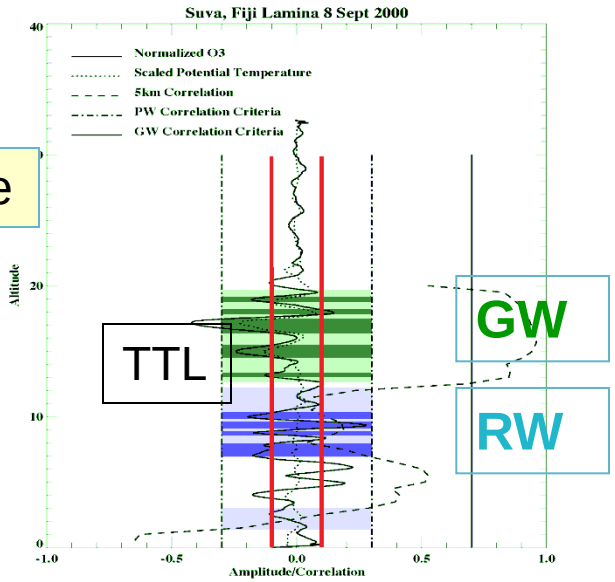
Advective (horizontal) motions, "Rossby Waves"

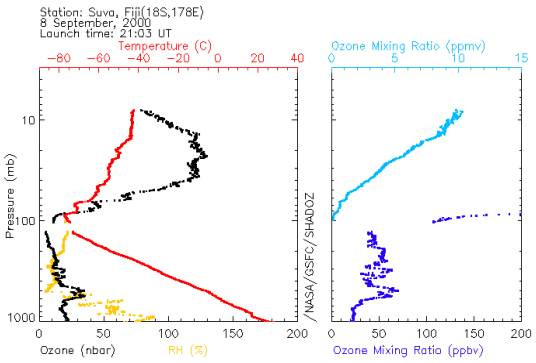
Convective (vertical) motions, "Gravity Waves"

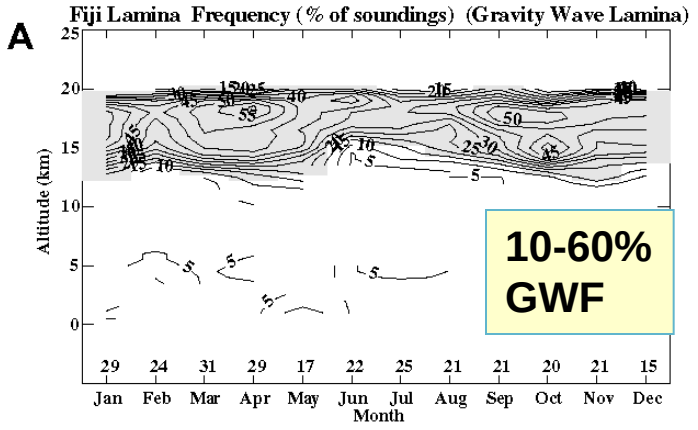
Lamina amplitude, frequency computed



15-20% amplitude

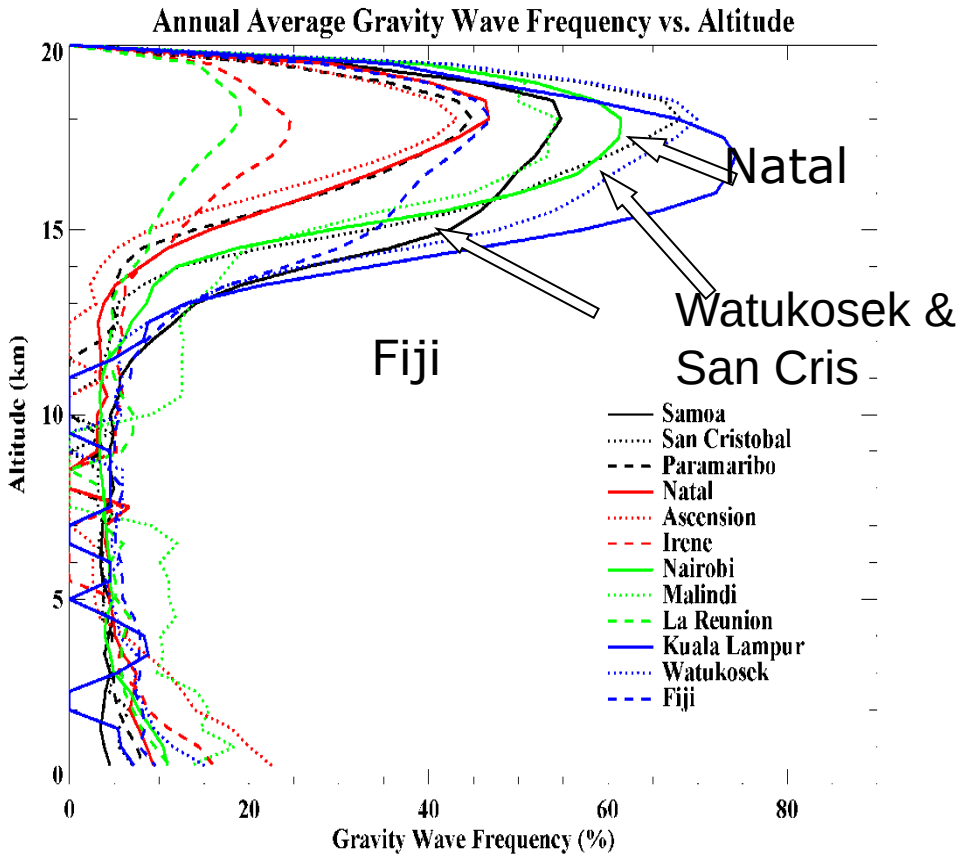






Annually-averaged GW Frequency (Left) West (W Pac) to East (Atl-Africa) Regions Classify by Declining Convection, Increasing Pollution (Right)

Persistent GW/KW initiated By convection



Summary statistics point to lower t'pause, increasing FT (5-15 km) pollution, decreasing convection [GWI] west-to-east

- WePac Eq Am Atl

Property	Watuk.	San Cris.	Natal
T'pause Alt (km)	16.6	16.6	16.0
Mean Mix Rat (5-15 km)	33 ppbv	46 ppbv	58 ppbv
GW Index, Mean (arb unit)	18.5	12.6	10.9

Thompson et al., *JGR*, 2011b

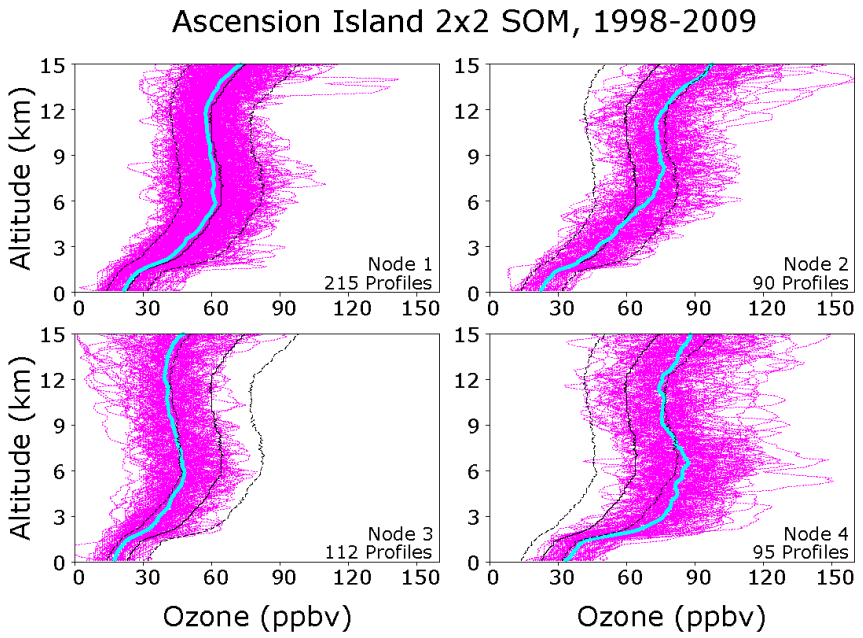
Statistical Classification by SOMs (Self-Organizing Maps)

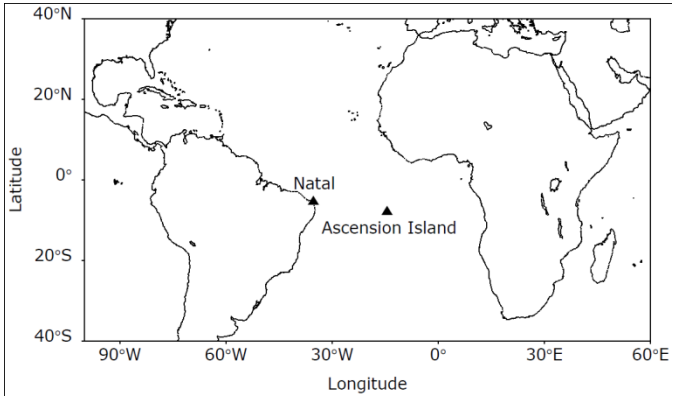
- Statistical classification methods were applied to ozone profiles by *Diab et al.* (2003, 2004) & Phahlane (MS, 2006) who used SOMs on Irene data. Groupings separated by meteorological conditions over southern Africa
- SOMs were applied to Ascension (SN= 512) and Natal (SN=425) by Jensen* to determine:
  - Whether SOM-classified categories cluster 'best match' profiles (SOMs, *Kohonen,* 1995) that are associated with seasons, sources, meteorological conditions
  - Optimal classification schemes for each dataset, ie desirable for satellite algorithms, model initialization, etc
  - Whether Natal and Ascension, that are generally similar (2300 km apart) in 'mean profile,' can be distinguished in convective biomass burning influences, interaction with Walker circulation

*** A A Jensen, MS Thesis, April 2011; Paper in preparation**

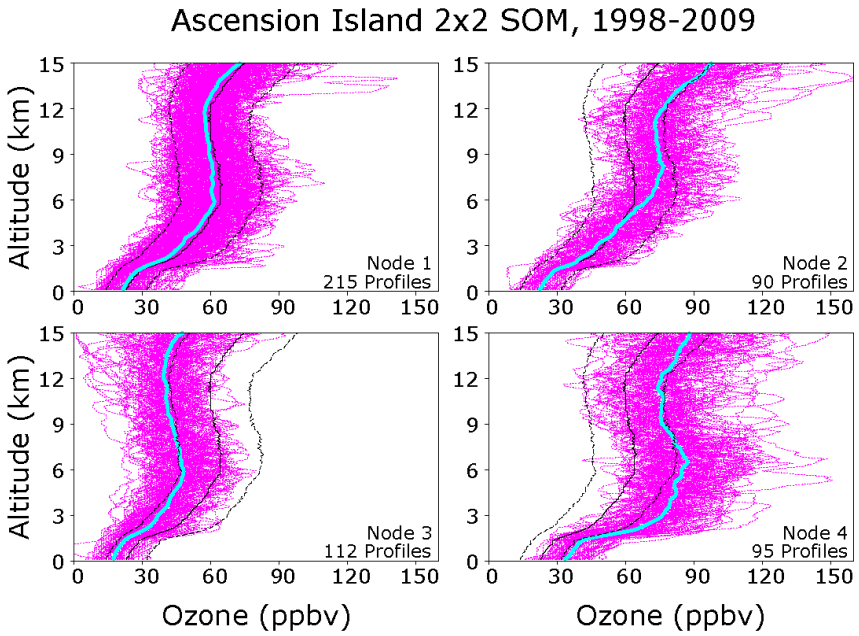
Ascension 2x2 Ozone Profile SOMs

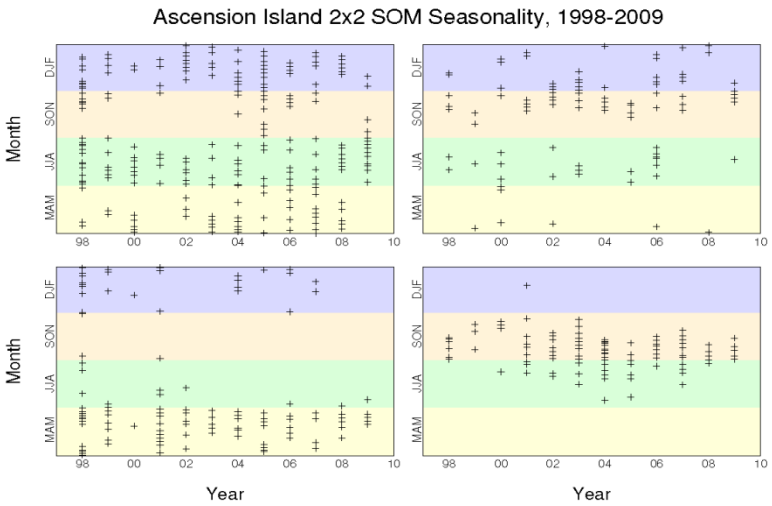
- How to interpret?
- **Node 1:** most profiles resembles the mean in black. Is mode, "typical," and possibly median
- **Node 3:** One Std dev < mean – S shape, convective-influence?
- **Node 4:** One Std dev > mean, esp below 9 km. Biomass burning pollution?

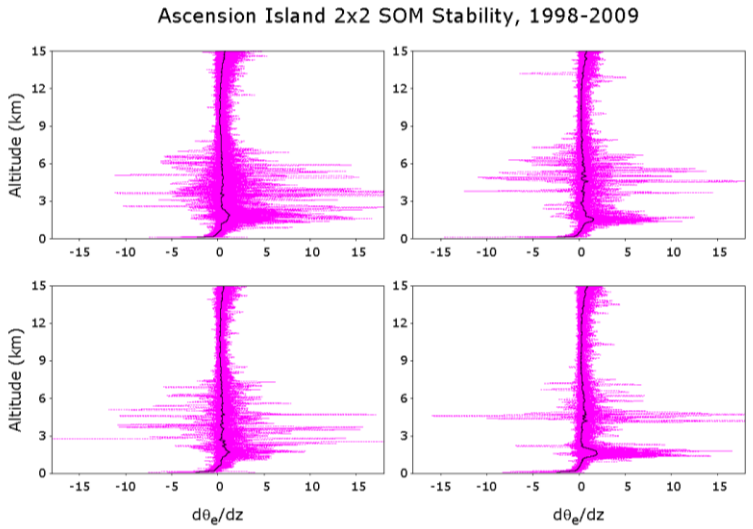




Ascension SOMs Link to Biomass Burning w/ High Stability at 2.5 km(SON); Convection (MAM)







- Node 1- mode/median
- Node 3 – Convective
- Node 4 – Biomass burning

Fire Seasonality from MODIS/NASA Website

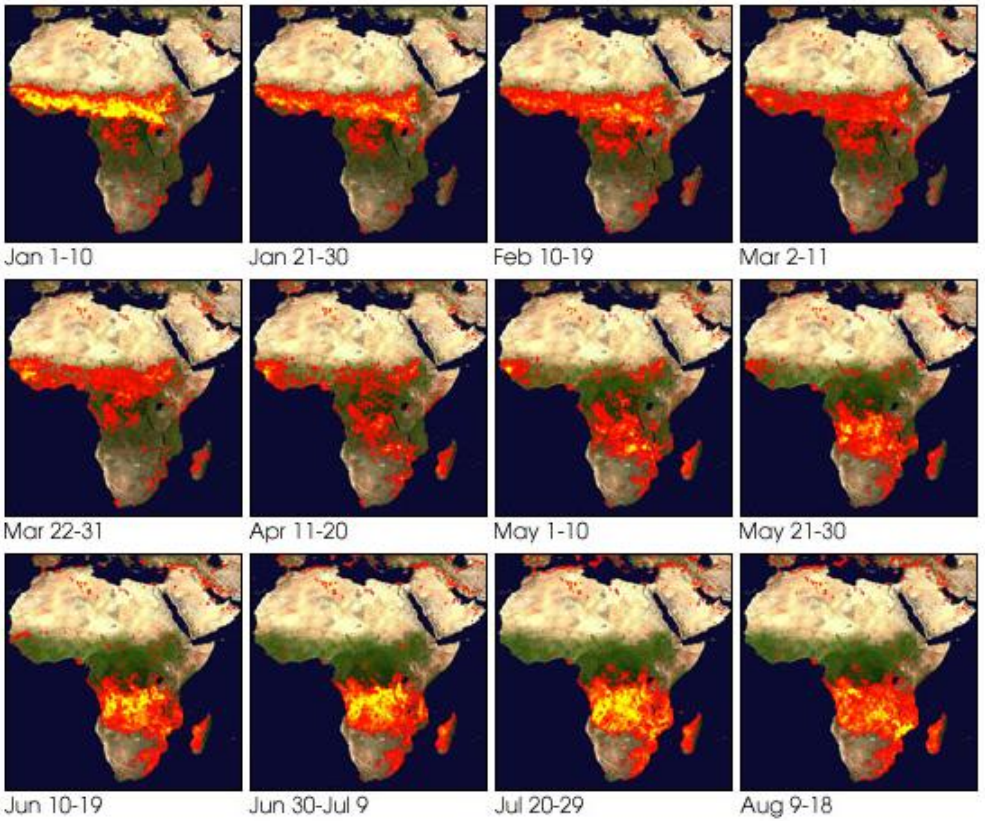
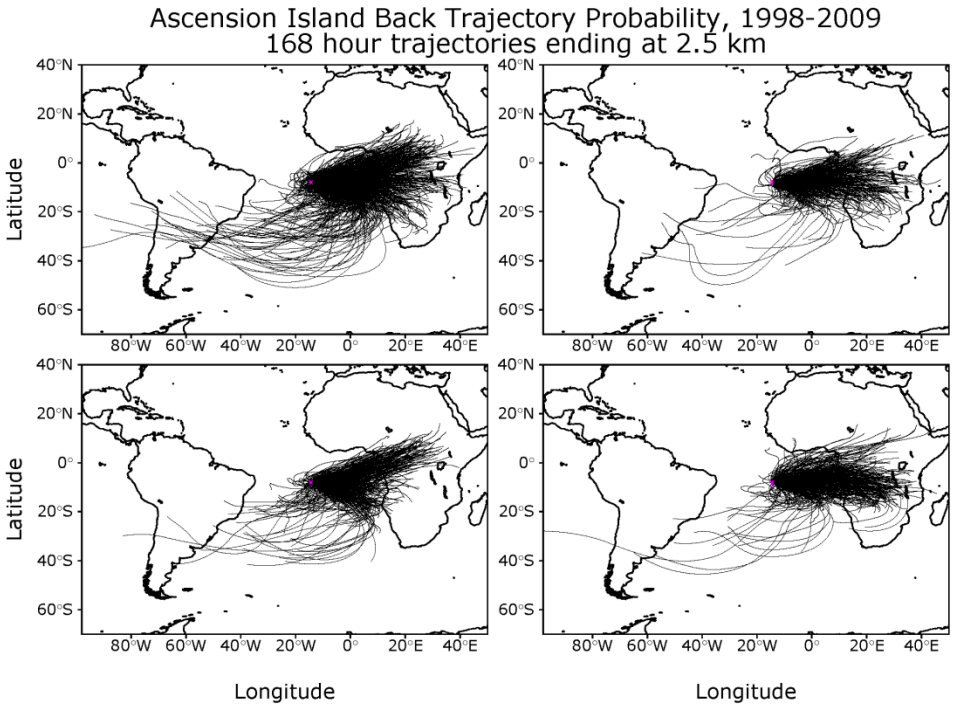
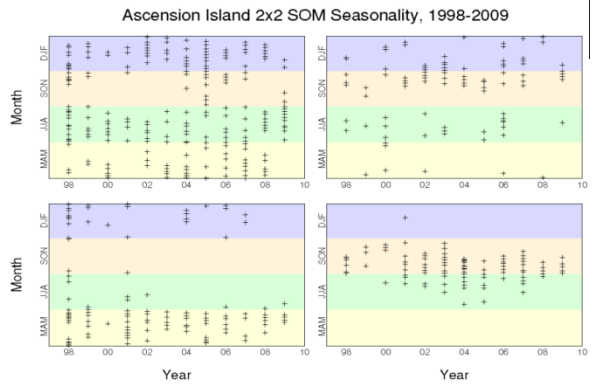


Figure 1.3: 2005 African fires detected by MODIS. Image courtesy the National Aeronautics and Space Administration (NASA).

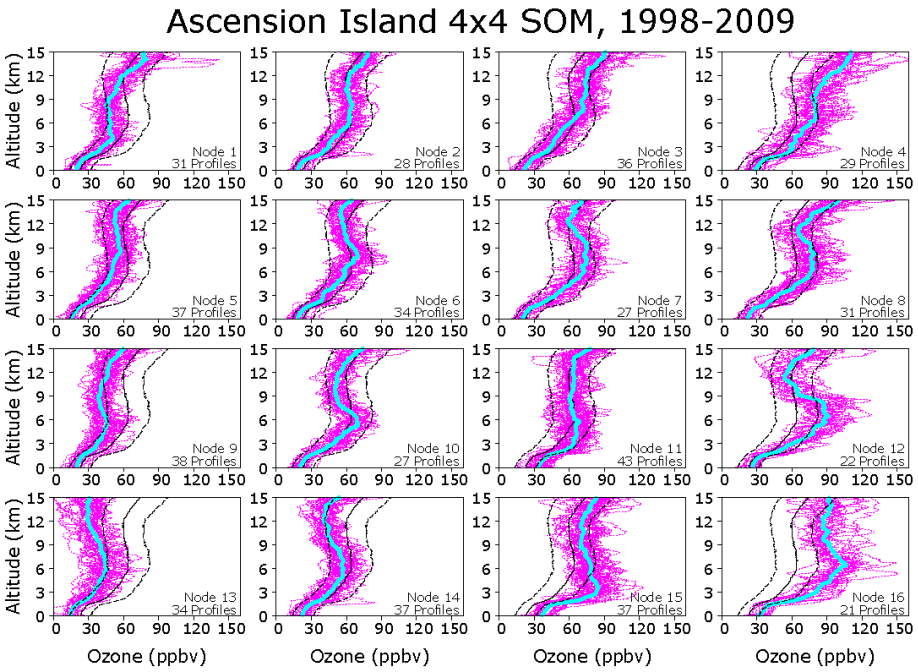
Biomass Burning – Trajectory LInks

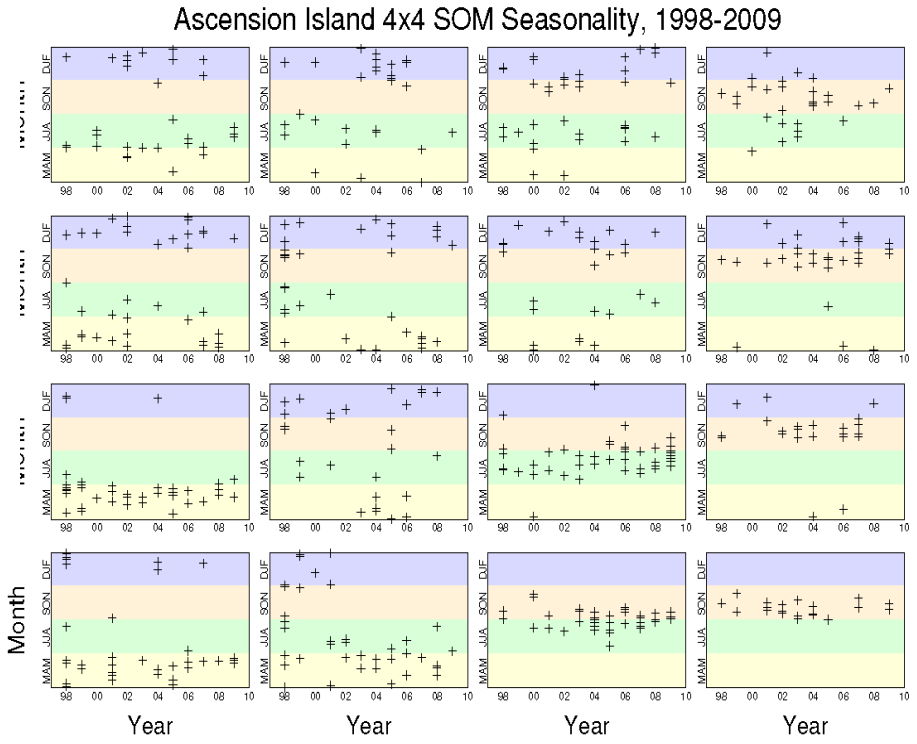
- SON burning maximum, 0-20S
- MAM – convective maximum. Trajectory origins over non-burning region





Ascension 4x4 Ozone Profile SOMs

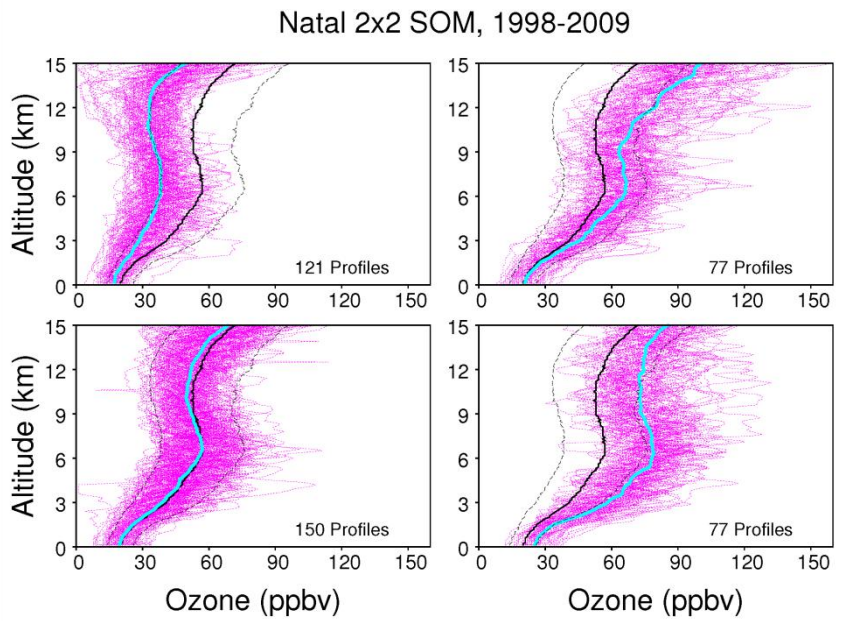


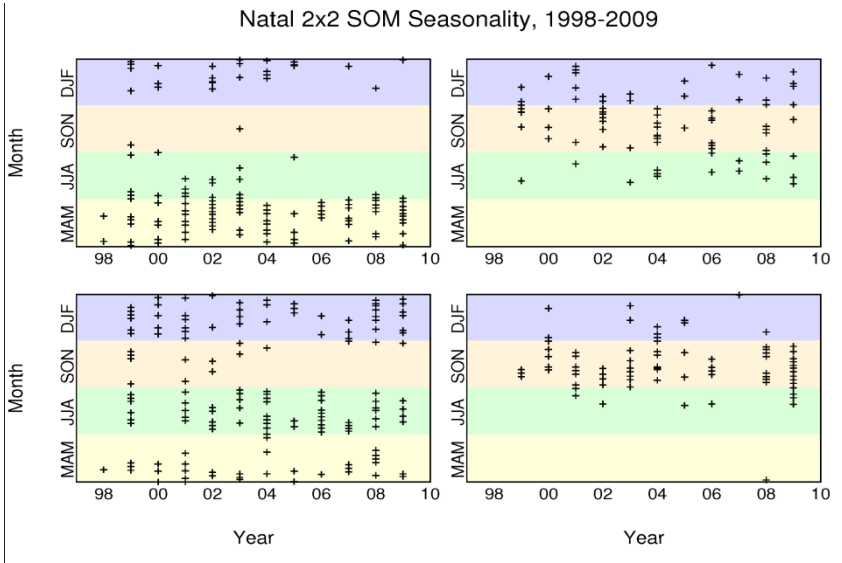


- Separates out high 2.5 km ozone from higher altitude. Temporal progression?
- Trajectories (not shown) indicate shorter time to fires => most polluted.

Natal 2x2 Ozone Profile SOMs

- Similar sort to Ascension but:
  - No one mode dominates
  - ‘Topology’ is different. Node 1 is convectively influenced ‘background’
  - OLR (proxy for convective clouds, not shown) consistent with low-ozone
  - MAM seasonality for convective influence is not exclusive



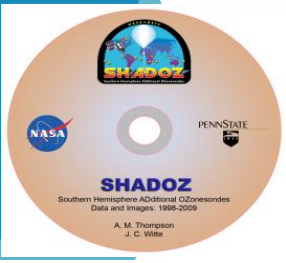


Summary – SHADOZ & UT/LS

- **UT/LS Processes √ Today**
  - Convective, pollution, large-scale transport signatures in troposphere & TTL ozone examined seasonally, regionally
  - Laminar Identification (LID) of Gravity Waves. Index for quantifying convection & classifying regions
  - SOMs (self-organizing maps) for robust statistics of pollution, stratospheric, convective impacts
- **Interannual Variability (Trends?). Remote Sensing. Tomorrow**
  - Ten years of FT, TTL ozone variability (QBO, ENSO)
  - Evidence for trends – Fujiwara/Morioka (2011), Randel/Thompson (2011)
  - Sondes & UT/LS ozone remote sensing

Acknowledgments, References

Thank You for Attention!



- Aura Validation & SHADOZ (M. J. Kurylo, NASA); NOAA GMD (S. Oltmans) GRUAN (H Voemel); WMO (M. Proffit, L. Barrie, G. Braathen)
- SHADOZ CD – Data through 2009!
- References

  - S Fueglistaler, A E Dessler, T J Dunkerton, I Folkins, Q Fu, P W Mote, The tropical tropopause layer, Rev. Geophys., 47, RG1004, doi:10.1029/2008RG000267, 2009.
  - A Jensen, Ozonesonde classification using Self-organizing Maps at Ascension Island and Natal, MS Thesis, Penn State Univ., 2011.
  - A L Loucks, Evaluation of dynamical sources of ozone laminae in the tropical troposphere and tropical tropopause layer, MS Thesis, Penn State Univ., 2007.
  - R B Pierce & W B Grant, *GRL,* 25, 1859-1862, 1998.
  - A M Thompson, et al., Southern Hemisphere Additional Ozonesondes (SHADOZ) 1998-2000 tropical ozone climatology. 2. Tropospheric ozone variability and the zonal wave-one, *J. Geophys. Res.,* 108, D2, 8241, doi: 10.129/2002JD002241, 2003.
  - A M Thompson, J C Witte, H G J Smit, S J Oltmans, B J Johnson, V W J H Kirchhoff, F J Schmidlin, Southern Hemisphere Additional Ozonesondes (SHADOZ) 1998-2004 tropical ozone climatology. 3. Instrumentation, station variability, evaluation with simulated flight profiles, *J. Geophys. Res.*, 112, D03304, doi: 10.1029/2005JD007042, 2007.
  - A M Thompson et al., Convective and wave signatures in ozone profiles over the equatorial Americas: Views from TC4 (2007) and SHADOZ, J. Geophys. Res., 115, D00J23, doi: 10.1029/2009JD012909, 2010.
  - A M Thompson et al., Strategic ozone sounding networks: Review of design and accomplishments, *Atmos. Environ*., 45, 2145-2163, 2011a.
  - A M Thompson et al., Gravity and Rossby wave influences in the tropical troposphere and lower stratosphere based on SHADOZ (Southern Hemisphere Additional Ozonesondes) soundings, 1998-2007, *J. Geophys. Res., 116, D05302, doi: 10.1029/2009JD013429*2011b.