Atmospheric Chemistry & Physics through the Lens of Ozone –

Anne Thompson
Penn State Univ

URI • UMCP • NASA • NOAA • MSC
IONS
INTEX Ozonesonde Network Study
UMich • HowardU • UAH • RiceU

NASA • GSFC
SHADOZ
Southern Hemisphere ADditional OZonesondes

The Tropical Ozonesonde Dataset for Satellite Validation, Processing and Modeling.

Strategic Ozonesonde Networks: Design and Scientific Accomplishments

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FULBRIGHT SOUTH AFRICA

NASA

Environment Canada

Environnement Canada

NOAA

PENNSTATE 1855

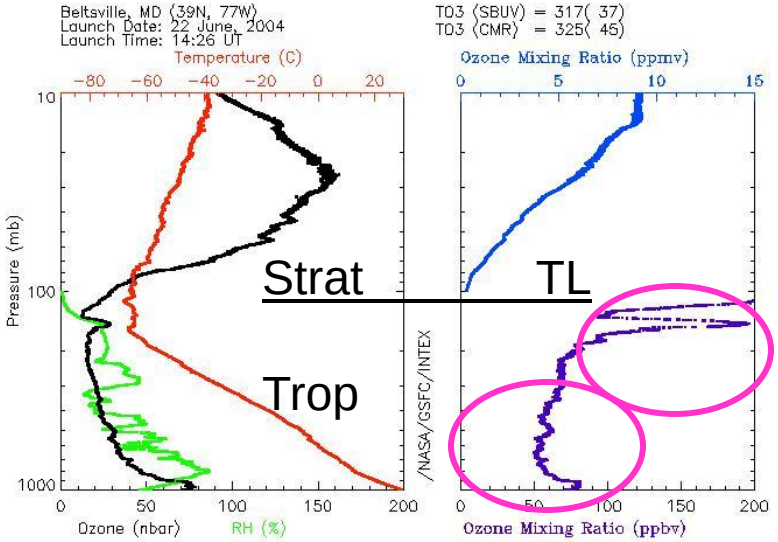
Road Map

- Ozone – Friend/Foe?
  - Units, measurement of ozone
  - Why do we care?
- "Strategic Ozonesonde Network" – Technological Motivation with Scientific Achievements
- The **IONS** series, 3-6-week campaigns
  - No. American campaigns - Summers 2004, 2006, 2008
  - "It's not all Pollution"
- **SHADOZ** – A tropical global network, 1998-2011
  - Snapshot today => **Full SHADOZ talk Tues, 1100**
  - **Tropical Chemistry/Remote Sensing, Wed, Thurs**

Good & "Bad" Ozone

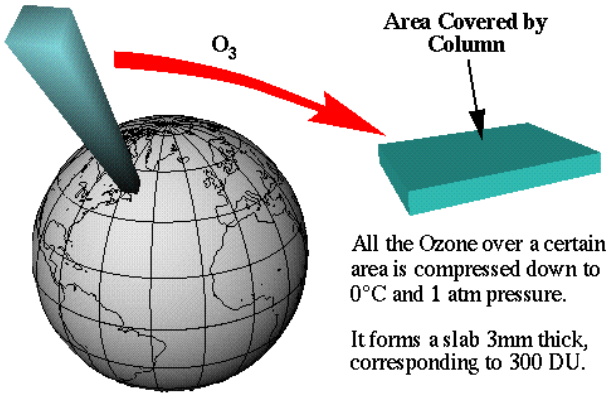
UNITS: Partial Pressure, Mixing Ratio, Dobson

Left – Mid-latitude; Lower – Dobson; Right – "Hole"

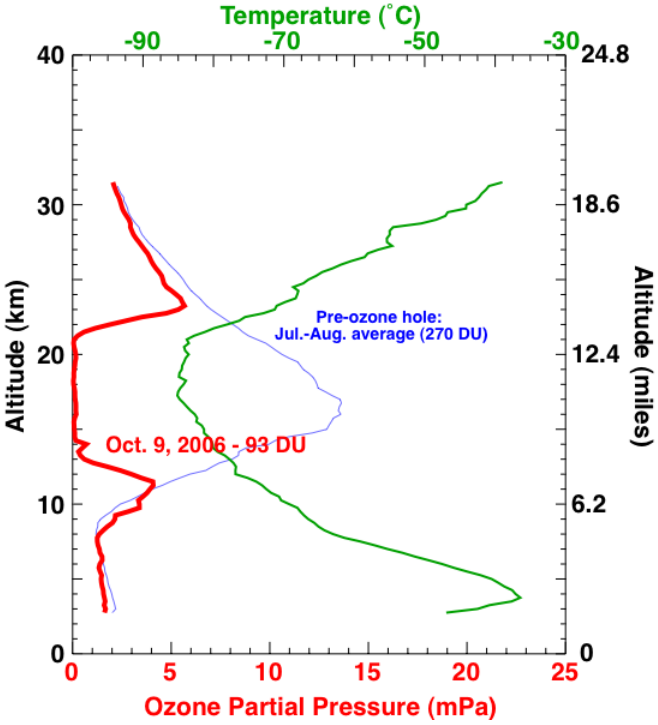


← Near surface to 200 hPa
Peak near tropopause – Strat-trop intrusion (STE)?
Surface pollution > 80 ppbv
←Example, suburban DC, June

<- BL to 1-2 km



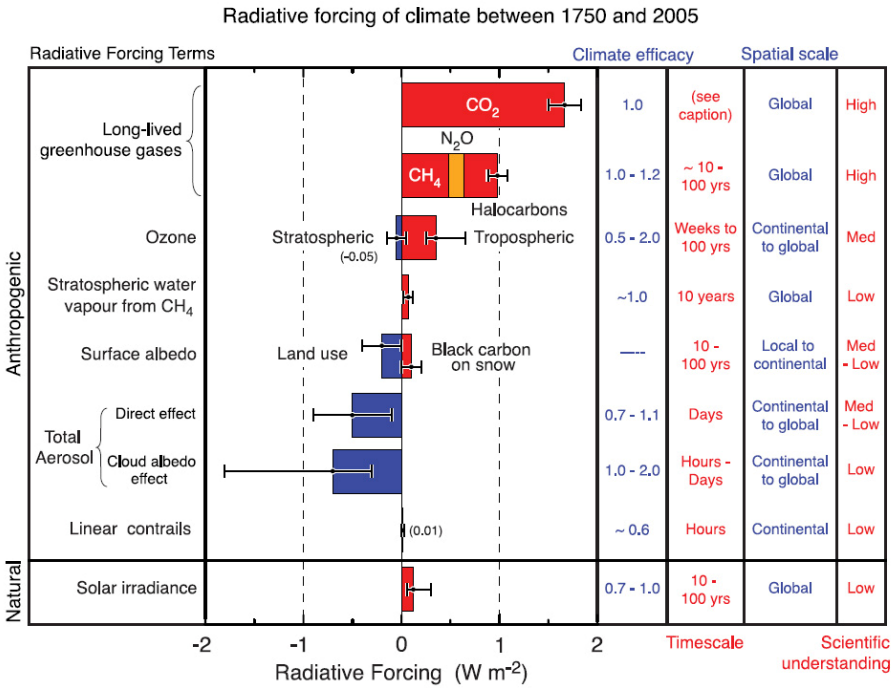
Antarctic "O_3 Hole"
270 DU to 93 DU
9 Oct 2006
"Bite" at coldest T,
Particle-Cl reaction

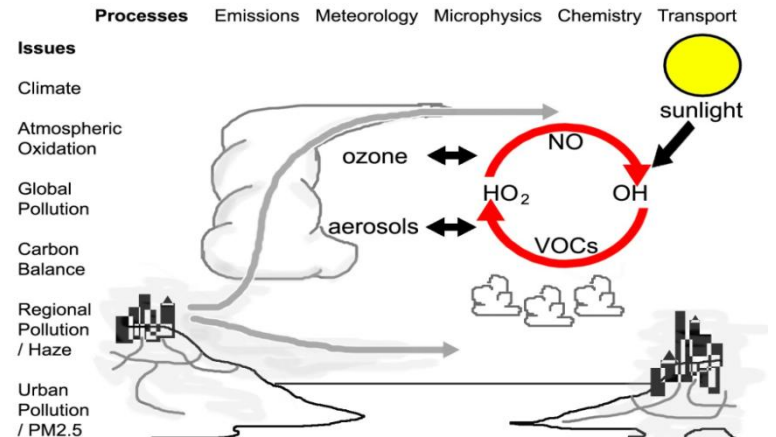


NOAA's B Johnson & D Hoffman ->

Why We Care: Ozone & Global Change

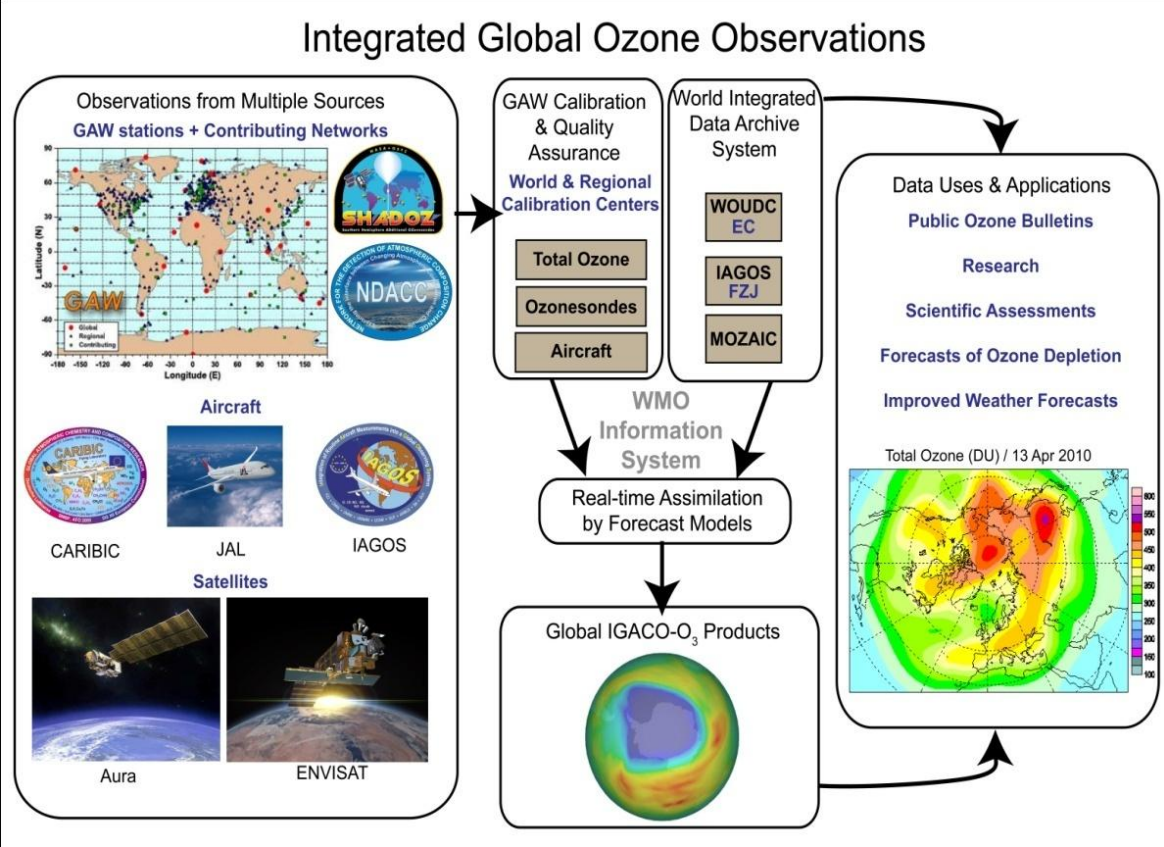
- Stratospheric ozone – uv absorption regulates strat T. Ozone depletion has cooled stratosphere
- Tropical Tropopause Layer (TTL) regulates rate of ozone, reactive gases, water vapor entry to stratosphere
- Tropospheric ozone is ~25% of past 150 years' warming
  - Feedbacks among methane-ozone in strat and trop.
  - Varying pollution scenarios (CO, NO_x, VOC) used to determine uncertainties in radiative effects of methane, O_3

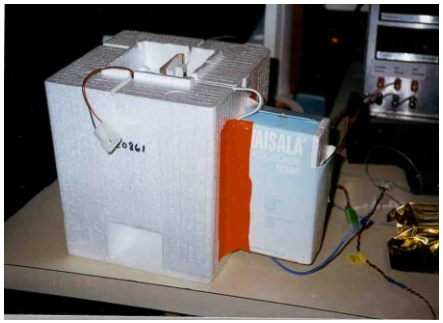




Validation, Prediction: Ozonesondes Integrate In-Situ Data, Satellites, Models

- **High vertical resolution (~100 m), consistent sonde location guide data-assimilation, satellite sampling & algorithms**
- **IONS & SHADOZ support aircraft missions, Aura's 4 O_3 sensors (July 2004-), ACE, GOME, SCIAMACHY, SMILES**





What is a Strategic Sounding Network?**

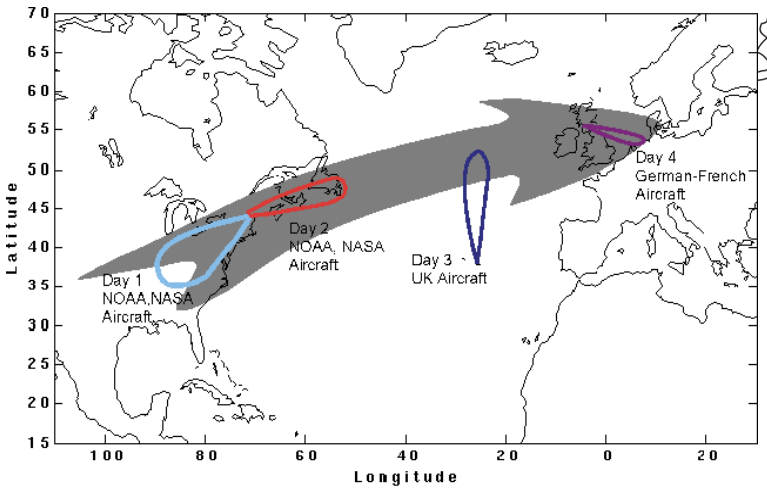
- **"Strategic Ozonesonde Networks"**
  - Spatial, temporal design target specific scientific issues
  - Coordinated launches from existing sites (usually) across sites; time for a/c, satellite
  - Data distribution via open web access: profiles for satellite validation, model evaluation.
- **Two Classes of Strategic Networks**
  - Campaign or "process studies" with aircraft in a regional network, 1-2 dozen sites, 3-7 times/week – *IONS, European-Canadian-US-Japan MATCH, TRACE-A*
  - Longer term – investigate regional differences, seasonal, interannual variability, eg 1-2 dozen sites, 2-4 x month – *SHADOZ*

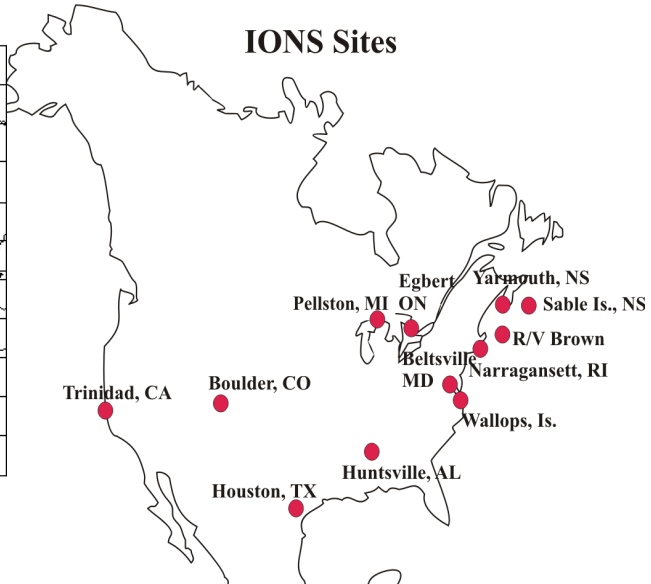
** Review, *Atmos. Environ.* 45 (2011) 2145-2163

IONS (2004) Design Strategy

Design (INTEX Ozonesonde Network Study = IONS; INTEX = Intercontinental Transport Expt - NA) to answer:

1. Can O_3 be followed during INTEX? Similar to "Match"
2. Tropospheric Budgets: How much No Am pollution reaches Europe? How much O_3 is from stratosphere-troposphere exchange (ST), advection (AD), lightning (RCL), local boundary-layer (BL) pollution?
3. Can O_3 pollution be measured from satellite? Predicted?



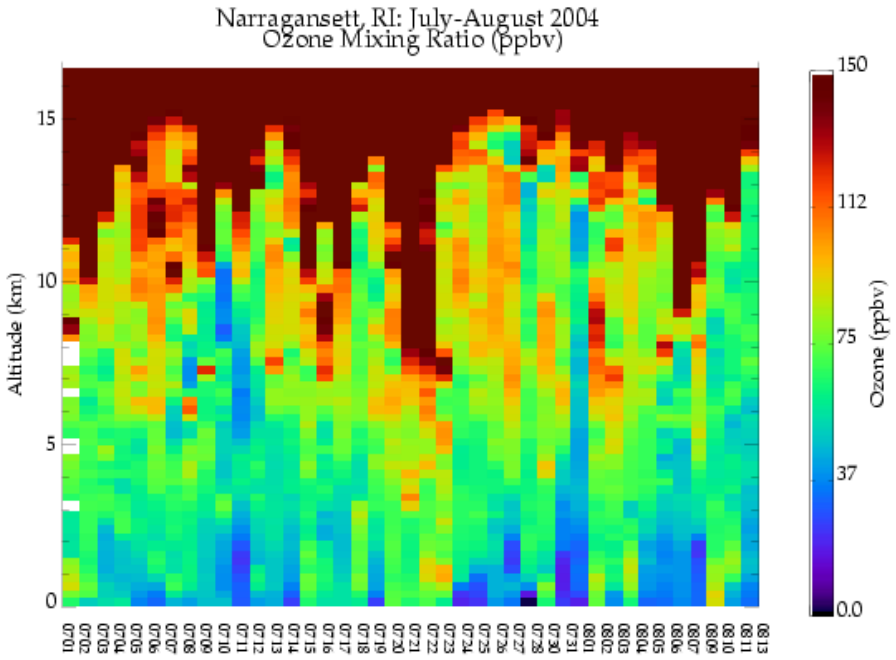


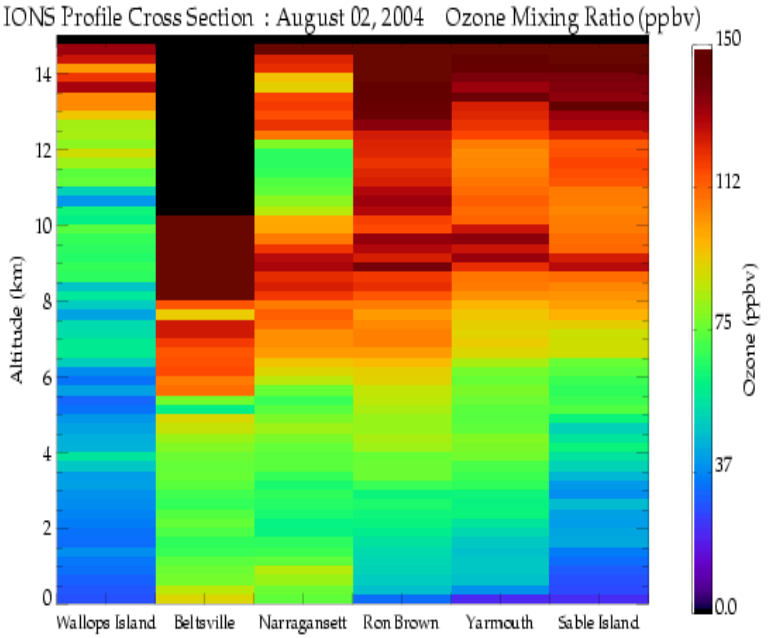
Operated 6 weeks, July-August 04,
http://croc.gsfc.nasa.gov/ions

290 sondes

Ozone Variability in IONS Curtains

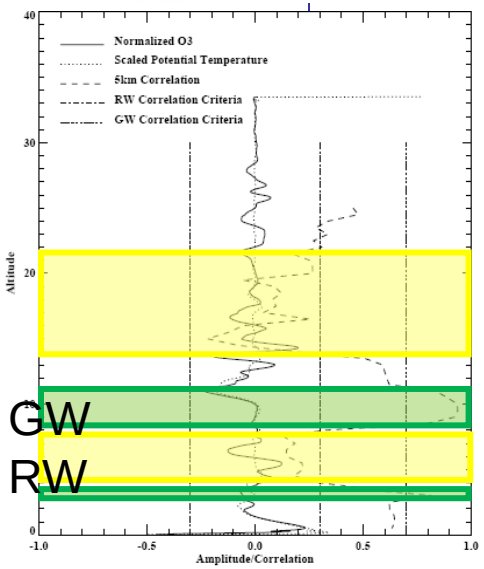
~300 Sondes, 6 weeks; Most Sites Daily

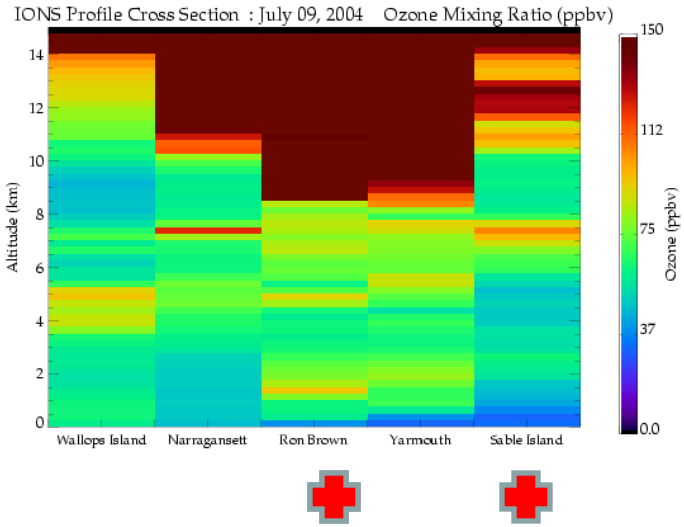


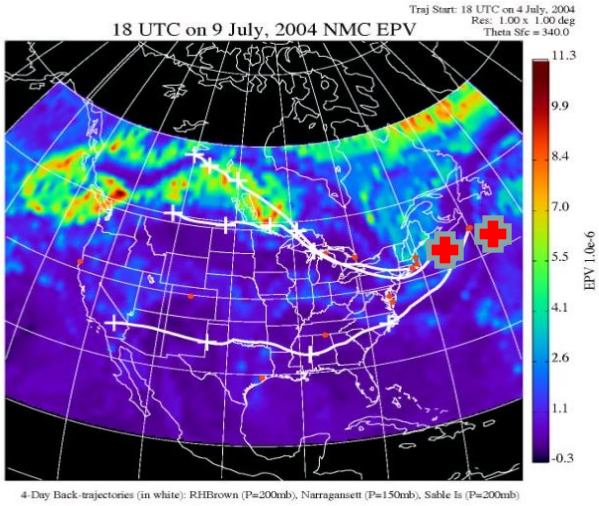


- **<u>Single site variability:</u> Strong ST influence: Narragansett (left), other NE No American (NENA) sites similar**
- **<u>Single day variability:</u> NENA Sites, 2 Aug 04, low t'pause (ST O_3) with mixed advected (AD) pollution, lightning**

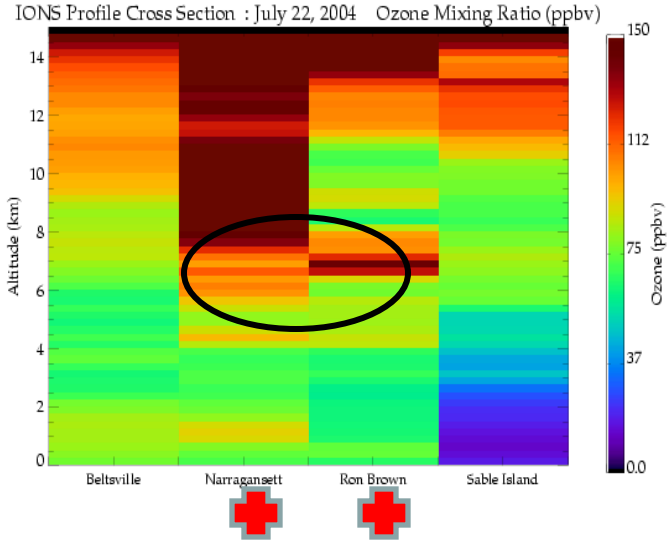
Budgets from LID = Laminar Identification. For Each Sonde, Combine O_3-Pot. Temp Layer ID with Tracers, eg Satellite Fires, PV for Stratosphere



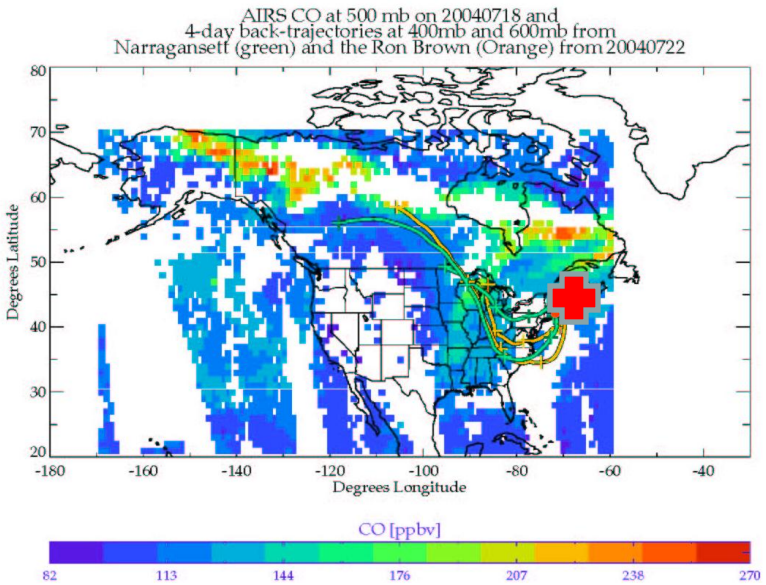




PV at ~ 10 km

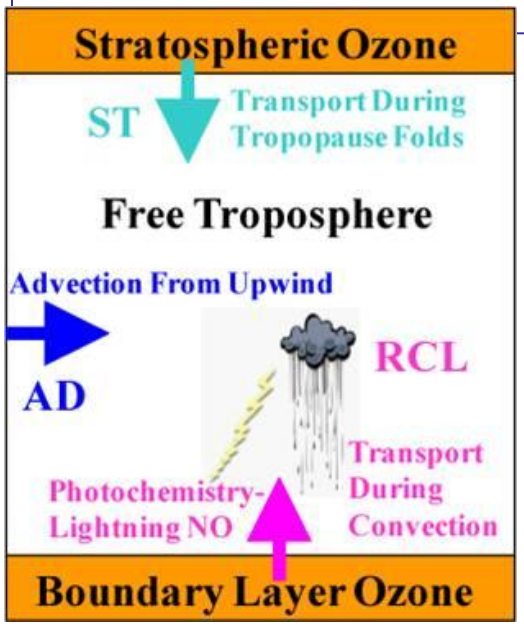


(Thompson et al., 2007a,b)

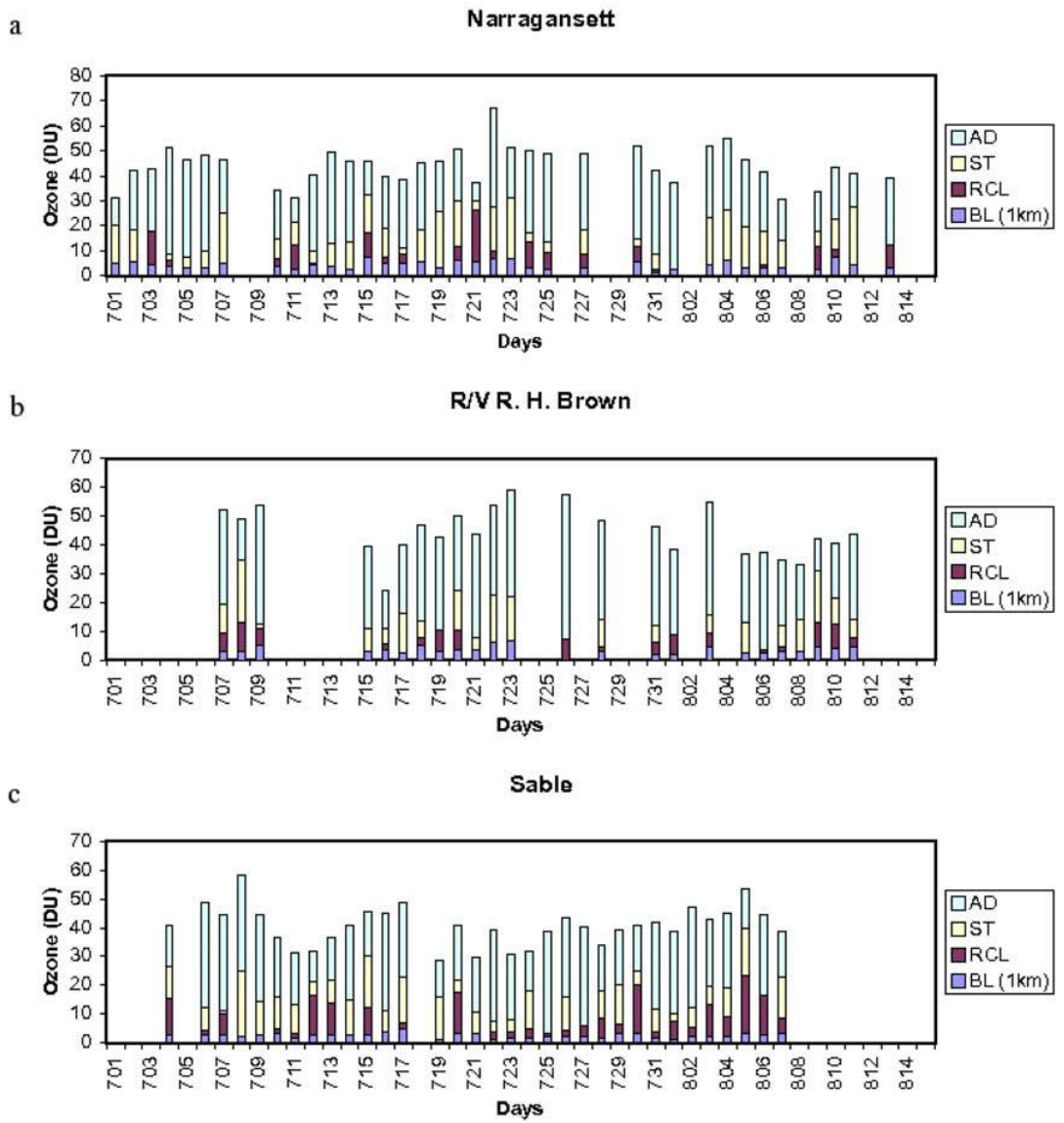


AIRS CO @ 5-6 km – Fires supply this O_3-precursor

Tropospheric O_3 Budget Computed For *Each* IONS Sounding

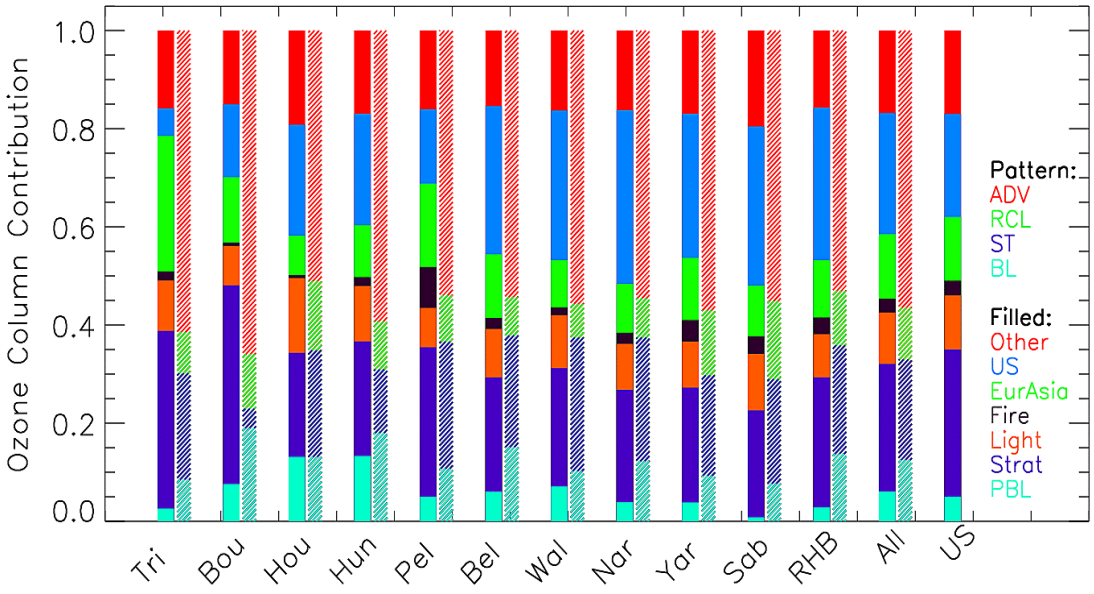


- ST O_3 from Rossby Wave (RW); confirm by PV, H_2O
- RCL from Gravity Wave, Lightning Map
- BL integrated to 1 km
- Balance = ADvected O_3



LID Tropospheric Ozone Budget - Consistent Basis for Model Comparison

- **Mean IONS-04 Budgets:**
  - **25% from Stratosphere**
  - **15% RCL – convection lightning**
  - **10% - BL – local pollution**
  - **50% - ADvected fires and aged pollution**
- **How do LID budgets compare to CTM budgets that are based on tagged sources of NO_x, the main ozone precursor? Quite well! MOZART better at differentiating sources**



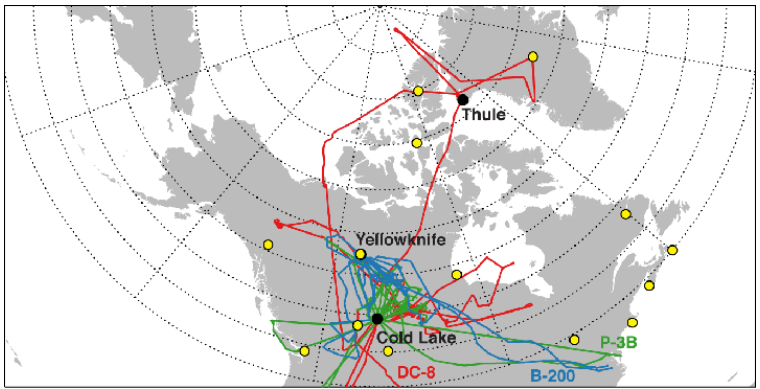
MOZART = Model of Ozone And Related Tracers, v 4. NCEP-GFS-winds, 2.8 x 2.8 º

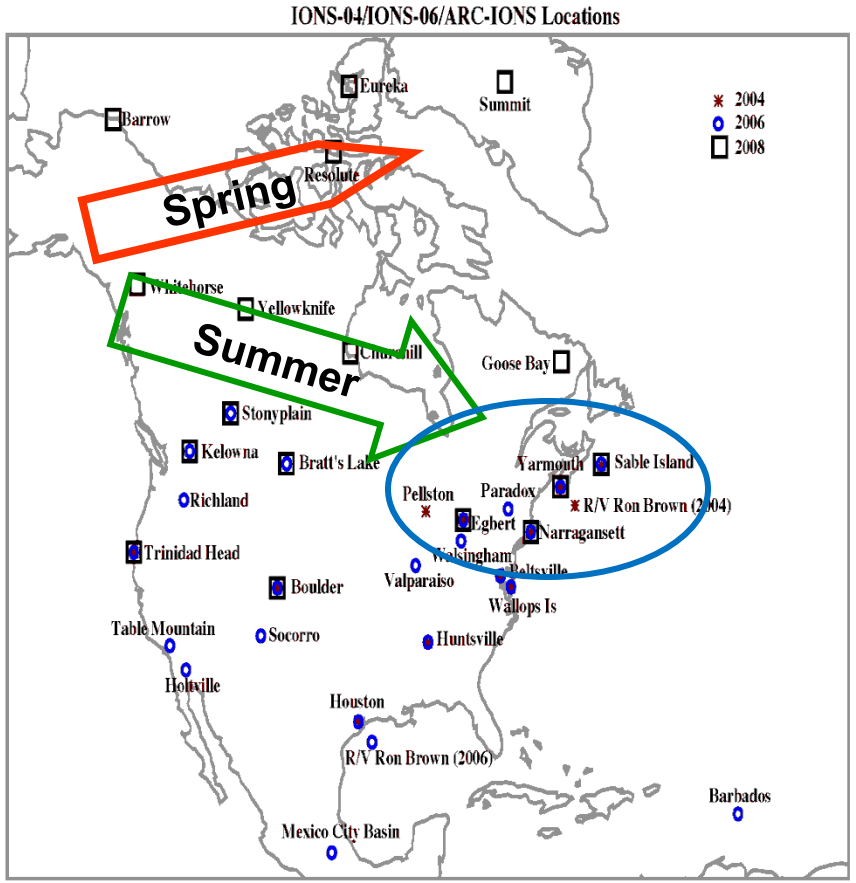
- **For each site, mean tropospheric O_3 budget.**
- **MOZART labeled "NO_X" sources (Left); LID budget (Right).** **Pfister et al, *JGR*, 2008**

ARCTAS* & ARCIONS (2008)

***Arctic Research of the Composition of the Troposphere from Aircraft and Satellites**

- How much pollution (CO, NO_x, O_3) is caused by fires?
- How do 2004, 2006, 2008 ozone budgets compare?
- How do fire impacts from Asia, Canada, US compare?
- Three aircraft in June-July (below). Data at: http://www-air.larc.nasa.gov/missions/arctas

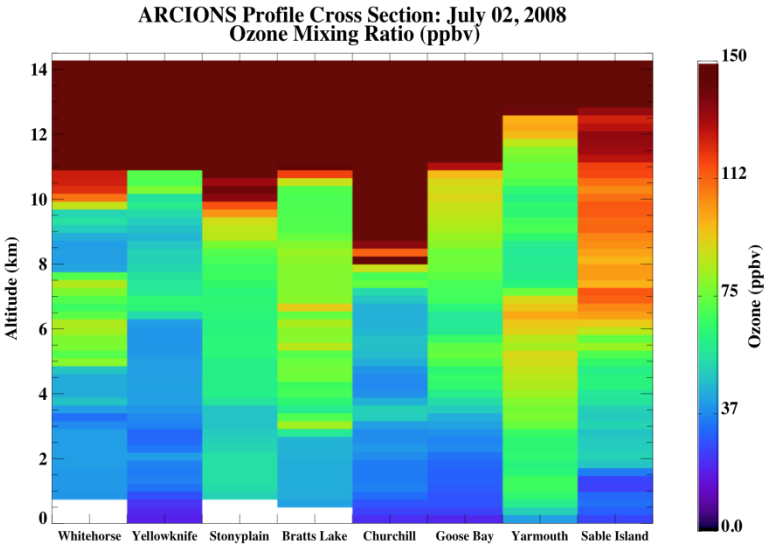


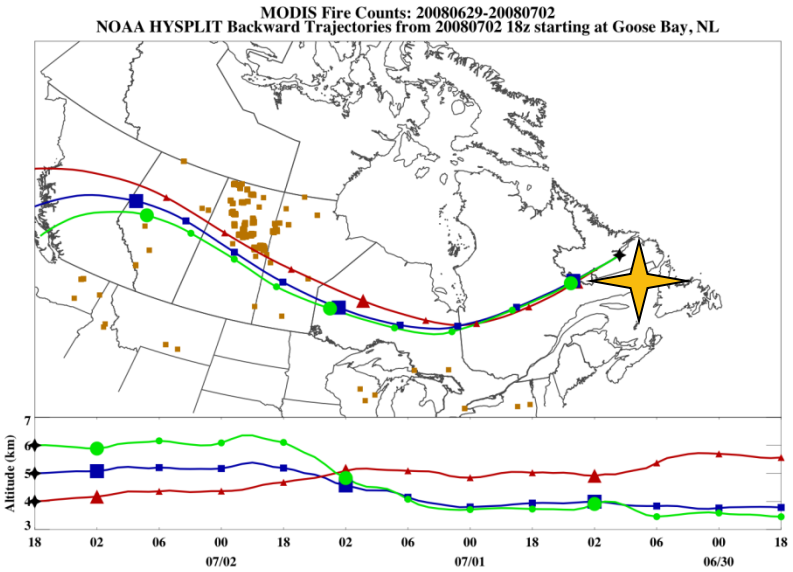


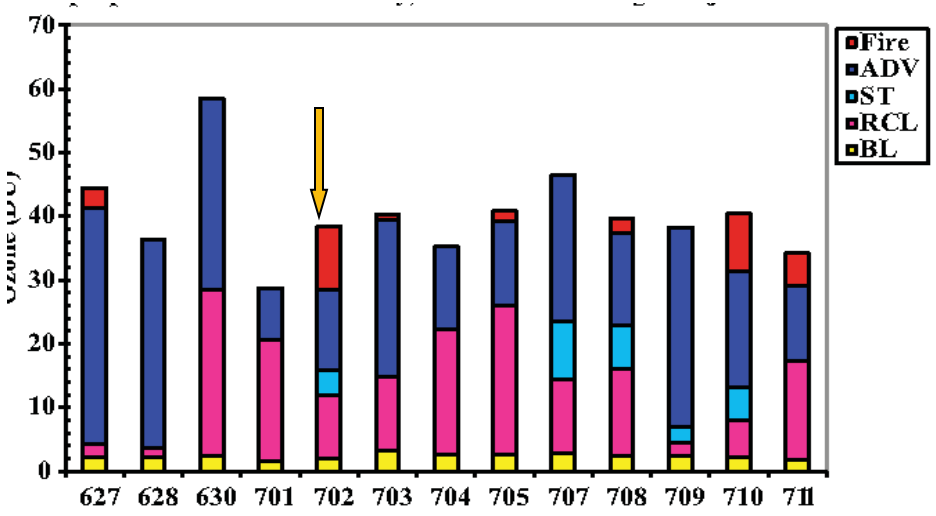
ARCIONS Ozone Budgets

– Ozone curtain & pollution, red-yellow-green, > 60 ppbv

– Saskatchewan fires linked to Goose Bay sounding, produce 25% of tropospheric ozone on 2 July 08, 5-10% on average

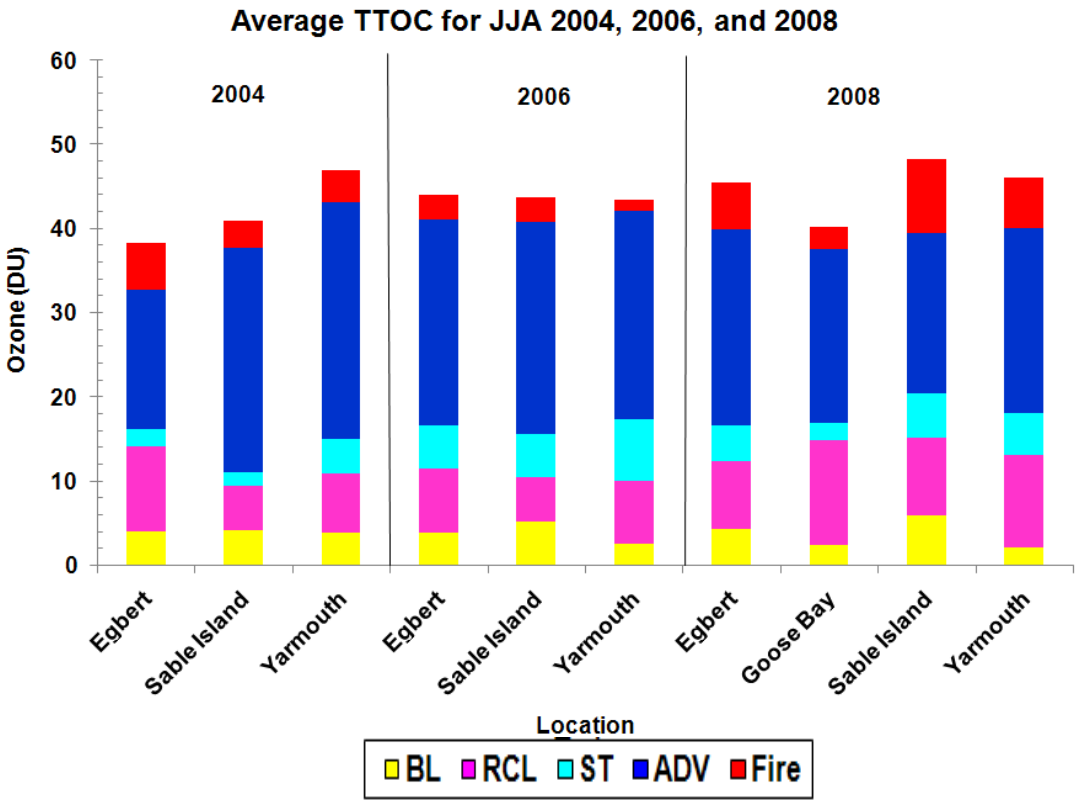


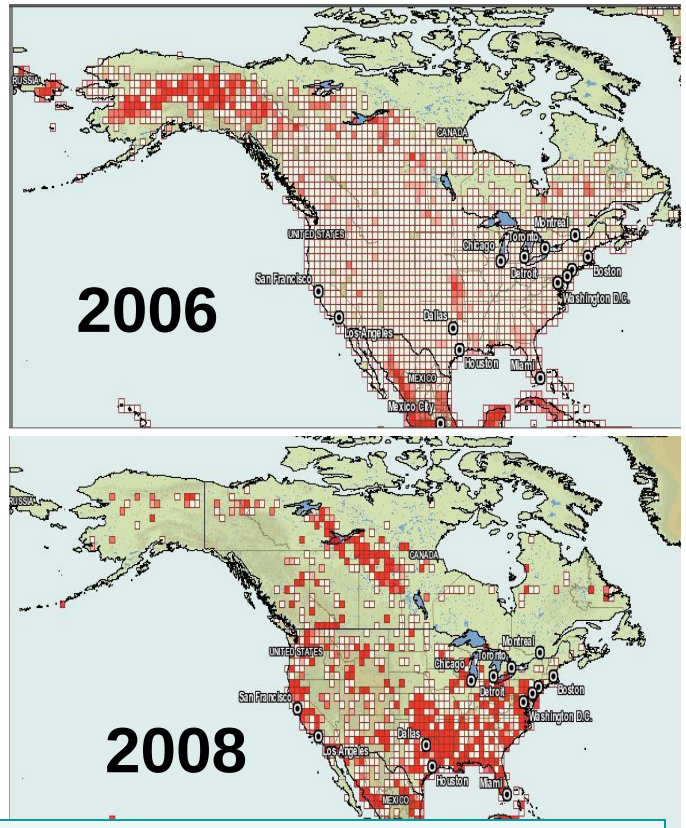




ARC-IONS vs IONS-04, 06 Budgets.

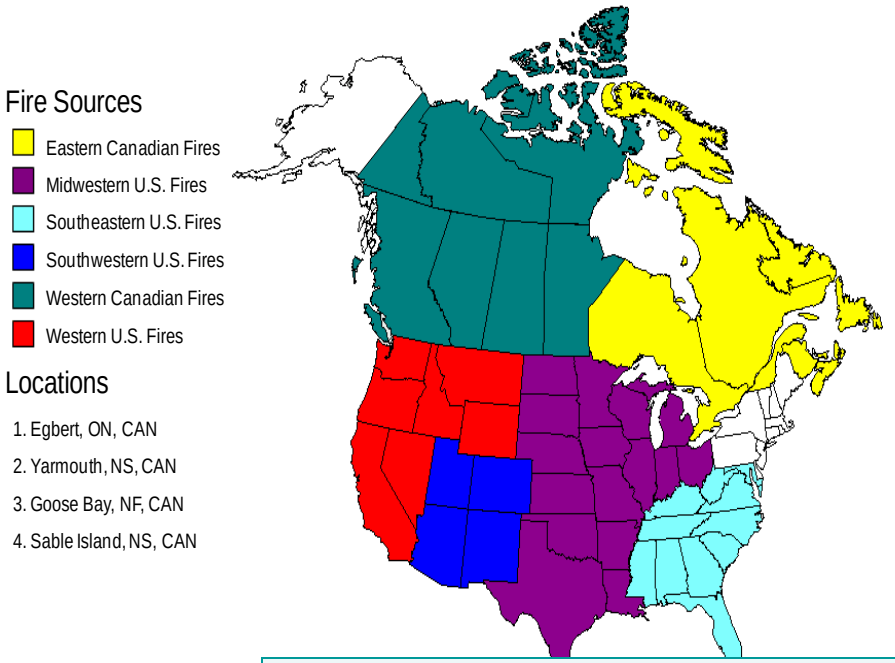
Consistent w/ Fire Amount, Distribution?

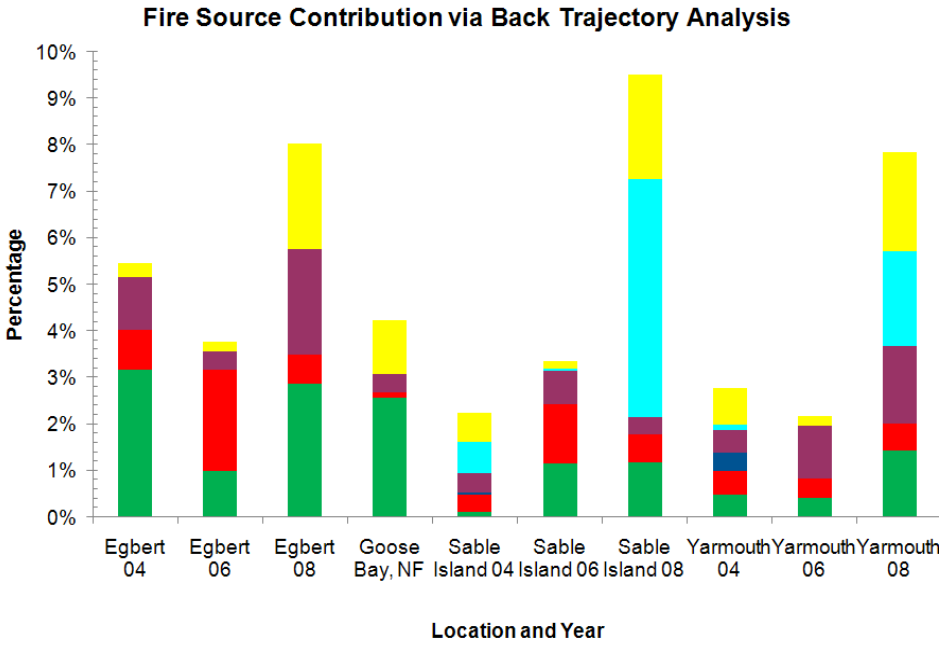




- **Higher TTOC (total tropospheric ozone column) & fires in 2008**
  - **SK, Calif, Midwest-SE US fires dominate**
  - **Fewer fires and ozone in 2006 (and 2004, fires not shown).**
- **Composite maps: (http://firefly.geog.umd.edu/firemap/)**

Which Regions Contribute to East Canada Ozone in IONS Campaigns?





ARCIONS (2008) impacts highest in trajectory numbers and contribution to ozone.

- → East and Mid- Canada, SE US fires dominant
- → Western & central US fire contributions are substantial

Summary: Mid-latitude O_3 from Strategic Sondes

O_3 & Measurement Strategy Design

- **Well-designed sonde network vital for following regional & global pollution. For process studies, satellite & model verification.**
  - ☛ Subtext – we raised "simple" traditional technology to "state of art"
- **IONS-04, IONS-06, ARCIONS sampling ~12-20 sites, 1/day**

Analyses: Ozone - Not all pollution, even in urban areas

- **IONS Series: Laminar and tracer-based budgets provide consistent view of ozone variability**
- **Intense stratospheric, convective wave activity in Summer => Total tropospheric ozone on average 25% from stratosphere (Europe similar)**
- **Fire contributions to ozone budget vary regionally, interannually. In recent years US as well as Asian, Canadian fires contribute to southern & eastern Canadian ozone**

Why-What-Where-When-How SHADOZ? (Southern Hemisphere Additional Ozonesondes)

Strategic Design Addresses Questions – 1998->

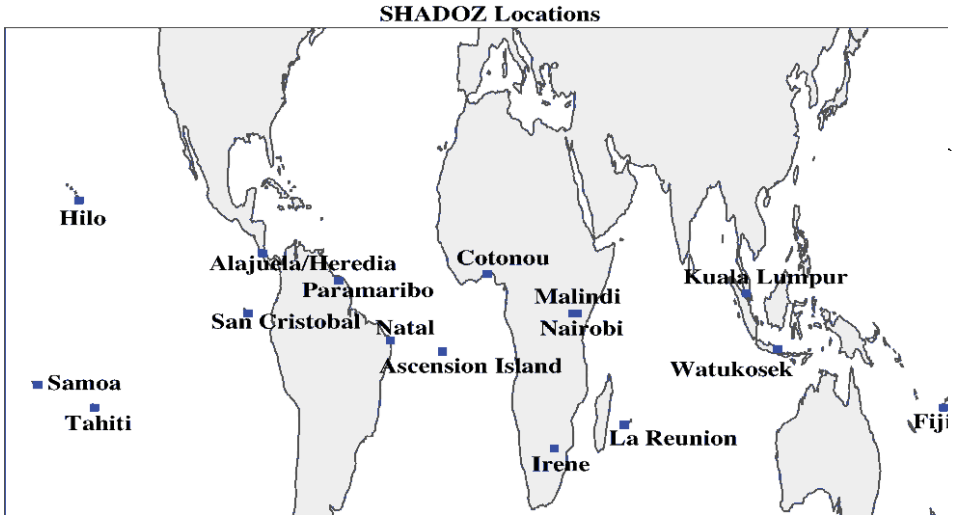
1> Satellite/model validation & optimization

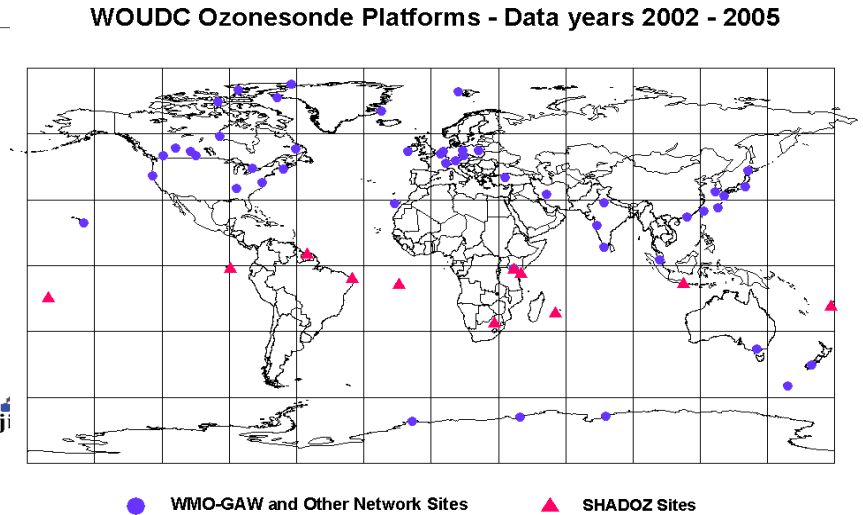
2> Nature of zonal wave-one

3> Ozone variability on multiple time, space scales

- 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); NDACC.





SHADOZ & Wave-One in Total Ozone

"Wave-one"

- Originally described by

Fishman & Larsen, 1987; Shiotani, 1992; Kim, Hudson, Thompson (1996)

- Total ozone 15-20 DU more over Atlantic-Africa-eastern SA than Pacific
- SHADOZ resolves "tropospheric" wave (Thompson et al., 2003)
- Summary figure update from 11 years of SHADOZ data (Thompson et al., 2011)

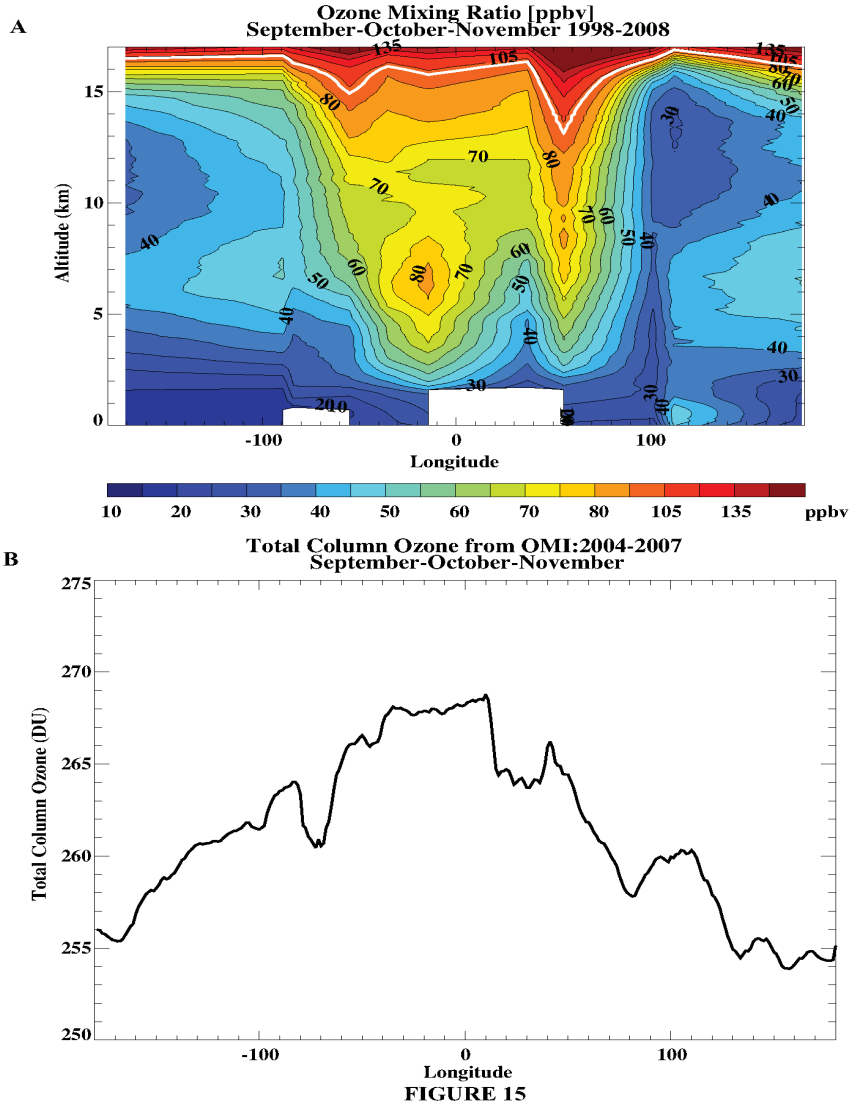


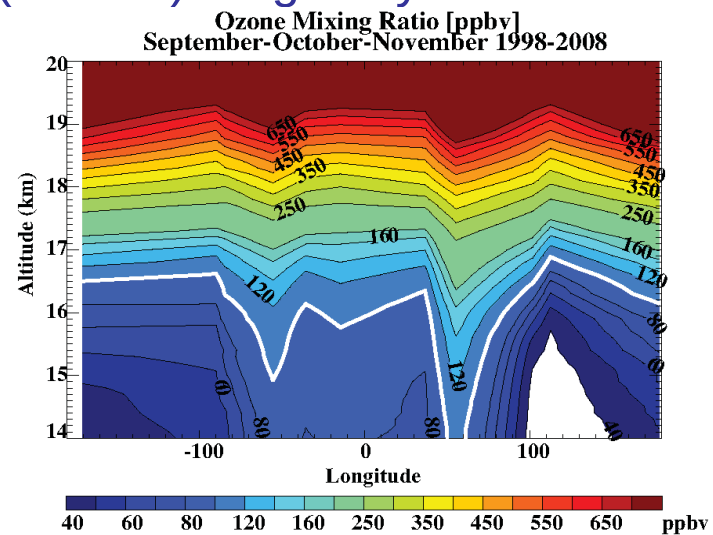
FIGURE 15

Tropical Tropopause Layer, "TTL" New Focus with SHADOZ Data

Transition zone wrt convection, dehydration, advection, radiative heating/cooling, wave activity (after Fueglistaler et al., *Rev Geophys*, 2009 - Right)

Tuesday Lecture: TTL closeup with SHADOZ & campaign data

Wed-Thurs: Tropical O_3 complexities (1991-2011). 'Paradox', ENSO, & (African) mega-city.



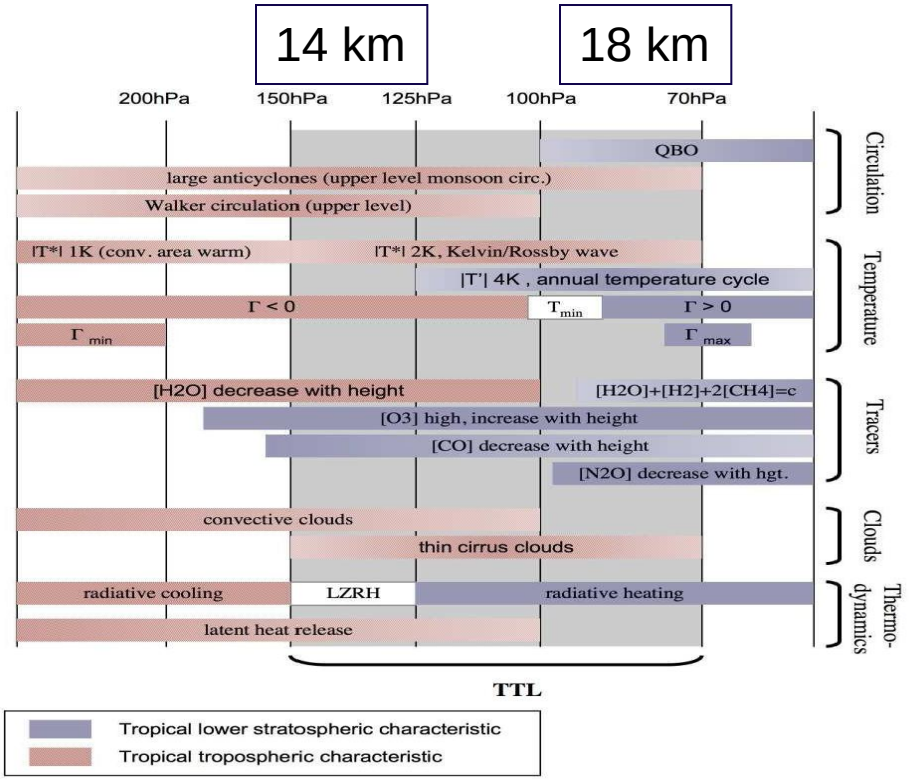


Figure 14. Summary of tropospheric/stratospheric characteristics, and transitions thereof (symbolically shown as fade-out of colored pattern). Abbrev.: Γ: temperature lapse rate, T_{min}: Temperature minimum of profile, |T*|: Amplitude of quasi-stationary zonal temperature anomaly, |T'|: Amplitude of tropical mean temperature seasonal cycle,

THANK YOU FOR YOUR ATTENTION!

Acknowledgments, References

* Aura Validation & SHADOZ (M J Kurylo, K Jucks, NASA); NOAA GMD (S J Oltmans, B Johnson); D W Tarasick (Environment Canada)
* WMO & JOSIE (M. Proffit, L. Barrie, G. Braathen, H. G. J. Smit)

- References

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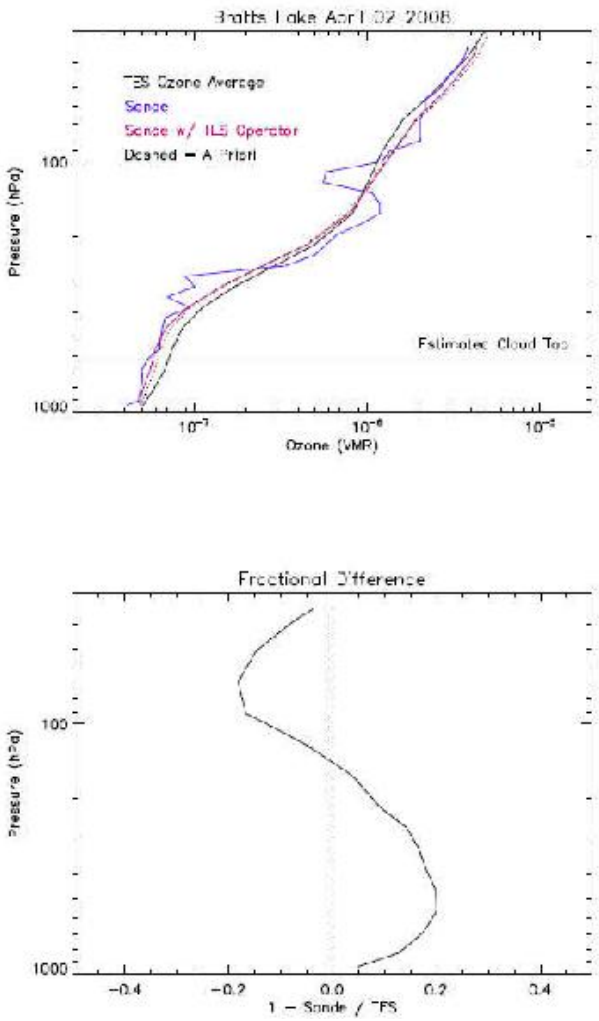
  - D. W. Tarasick et al., An ozone climatology for INTEX and ARCTAS from IONS ozonesondes, J. Geophys. Res.,115, D20301, doi: 10.1029/2009JD012918, 2010
  - A. M. Thompson, et al., Southern Hemisphere Additional Ozonesondes (SHADOZ) 1998-2000 tropical ozone climatology. 2. Tropospheric ozone variability and the zonal wave-one, *J. Geophys. Res.,* 108, D2, 8241, doi: 10.129/2002JD002241, 2003
  - A. M. Thompson, et al., IONS (INTEX Ozonesonde Network Study, 2004). 1. Summertime UT/LS (Upper Troposphere/Lower Stratosphere) Ozone over Northeastern North America, *J. Geophys. Res*., 112, D12S12, doi: 10.1029/2006JD007441, 2007a.
  - A. M. Thompson, et al., IONS (INTEX Ozonesonde Network Study, 2004): 2. Tropospheric Ozone Budgets and Variability over Northeastern North America, *J. Geophys. Res*., 112, D12S13, doi: 10.1029/2006JD007670, 2007b.
  - A. M. Thompson et al., Strategic ozone sounding networks: Review of design and accomplishments, *Atmos. Environ.* 45, 2145-2163, 2011.

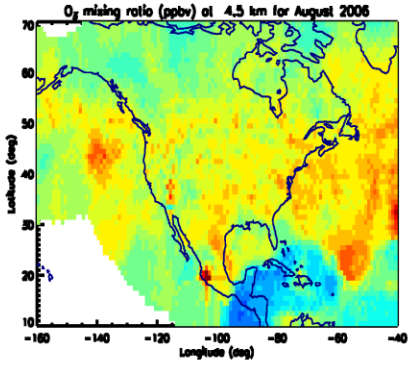
- **EXTRA Slides**

Satellite Comparisons (Left, *Boxe et al.*, 2009)
Trajectory-mapped Ozone (Right, *Tarasick et al.*, 2010)

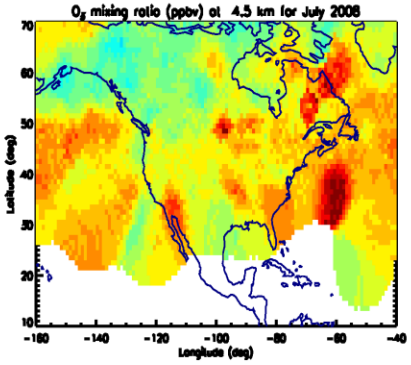
April 08 sounding improves TES O_3; overcomes high bias

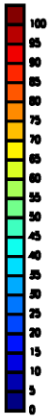


2006



2008





Products Available:

LID Budgets:

http://ozone.met.psu.edu

Maps: http://woudc.org

Nassar et al (2008): Comparisons of TES with Sondes, most No. Mid-Lat from IONS-06; No. Subtropical, Tropical from SHADOZ.

TES V002 used with Sondes from 10/04 through 10/06

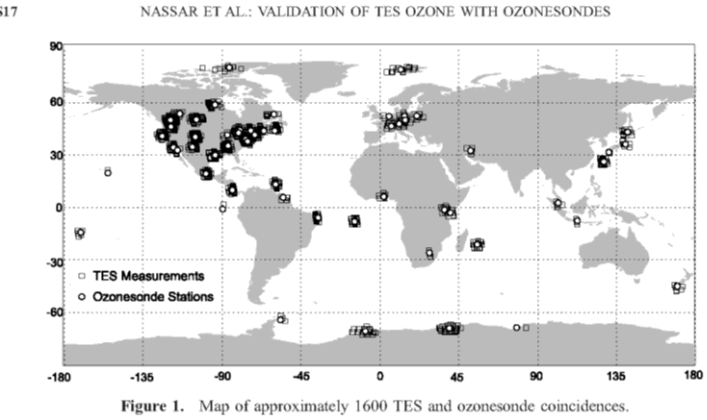
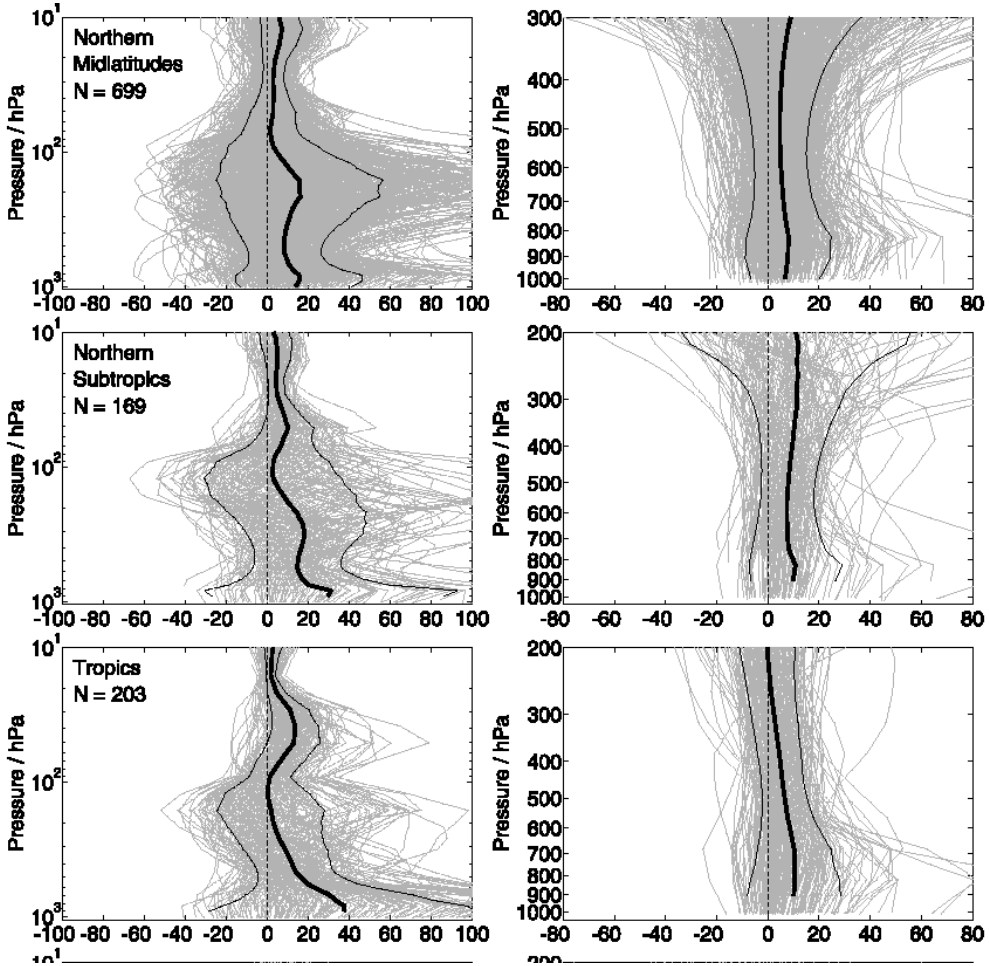
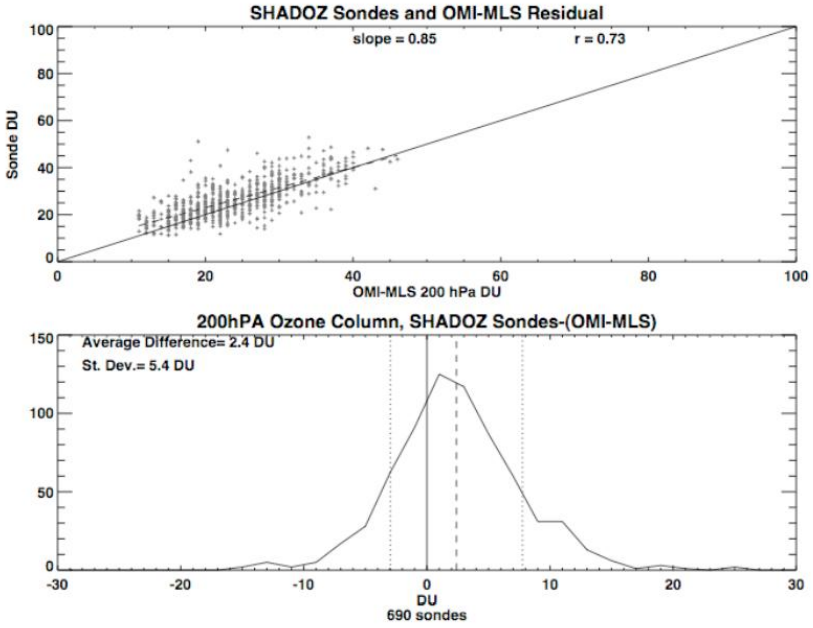


Figure 1. Map of approximately 1600 TES and ozonesonde coincidences.



IONS-06: Satellite Overpass Comparisons with Aura OMI-MLS. Tropics – SHADOZ (left) Mid-Latitude (right)



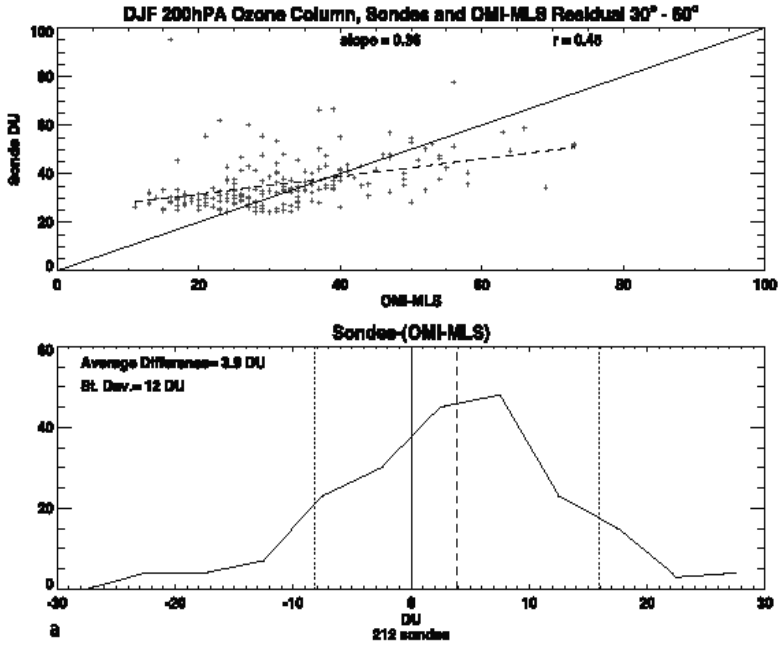
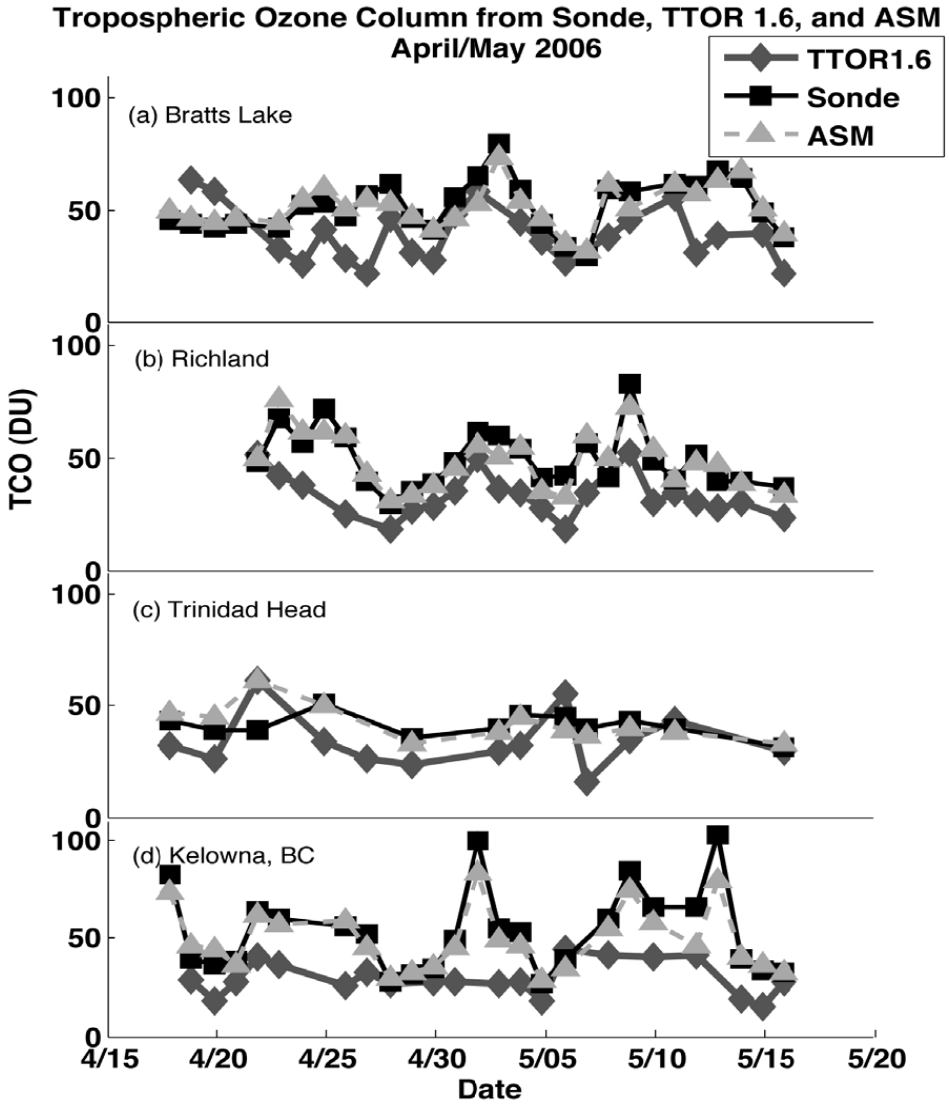


Figure 3. Comparison of ozonesondes 200TSC and the our 200TSC estimate. Upper figure shows the data poir the slope of the data (dashed line) and the correlation coefficient (r). The one-to-one line is the solid line. The lower figure shows a PDF of the difference between the sonde 200TSC with the mean and standard deviation (dashed and dotted, respectively).

Schoeberl et al., *JGR*, 2007

Doughty et al., *JGR*, 2011. Closeup of daily comparisons of TTOR (OMI/MLS) & ASM (GSFC-assimilation) with IONS-06 Sondes, Apr-May 2006



Parrington et al., 2008 – Assimilation Improves Two Models' Sonde Agreement

Example-

15 Aug 06

IONS-06 Sondes
Over No America

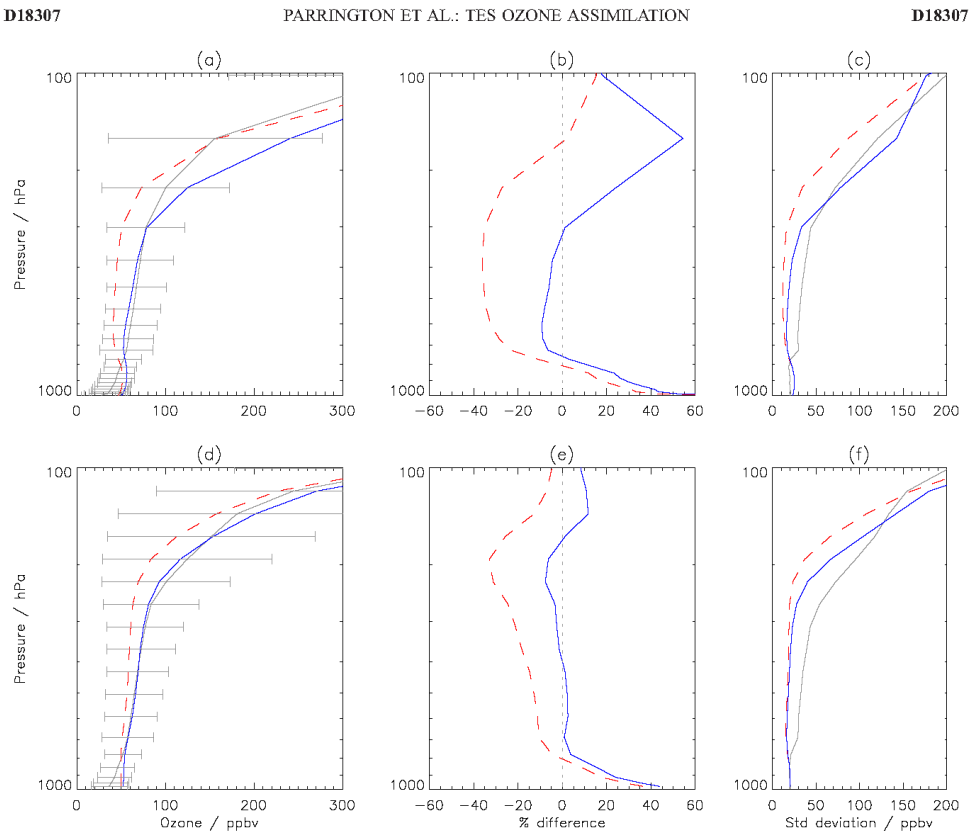
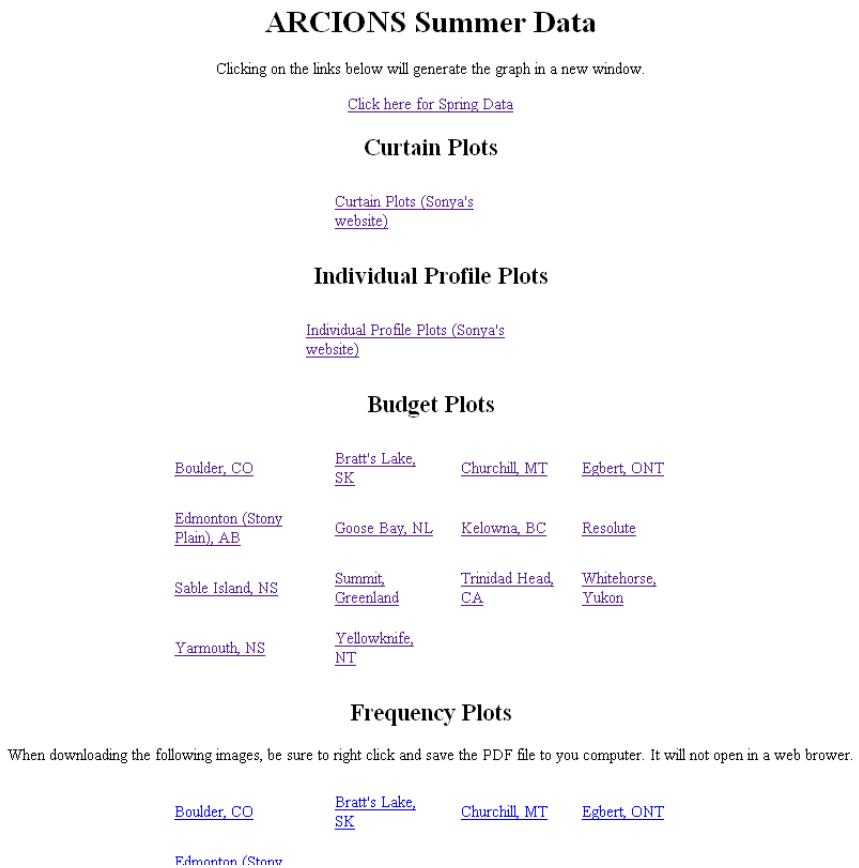


Figure 10. Comparison of mean ozone profiles over North America from the IONS-06 ozonesonde network and the AM2-Chem model (top row) and the GEOS-Chem model (bottom row). The left column shows the mean ozone profile (grey line) from the sonde data interpolated to the respective model vertical grid, the modeled mean ozone profile without assimilation (red dashed line), and the profile with assimilation (blue line). The middle column shows the differences relative to the sonde data of the models without assimilation (red dashed line) and with assimilation (blue solid line). The right column shows the vertical distribution of the standard deviation of the interpolated ozonesonde data (black line) and the models with assimilation (blue) and without assimilation (red).

ARCIONS Data Online

- Budgets
- Frequency Plots
- Curtain Plots
- Profile Plots

Available for both Spring & Summer!



ARCIONS Summer Data

Clicking on the links below will generate the graph in a new window.

Click here for Spring Data

Curtain Plots

Curtain Plots (Sonya's website)

Individual Profile Plots

Individual Profile Plots (Sonya's website)

Budget Plots

Boulder, CO	Bratt's Lake, SK	Churchill, MT	Egbert, ONT
Edmonton (Stony Plain), AB	Goose Bay, NL	Kelowna, BC	Resolute
Sable Island, NS	Summit, Greenland	Trinidad Head, CA	Whitehorse, Yukon
Yarmouth, NS	Yellowknife, NT		

Frequency Plots

When downloading the following images, be sure to right click and save the PDF file to you computer. It will not open in a web brower.

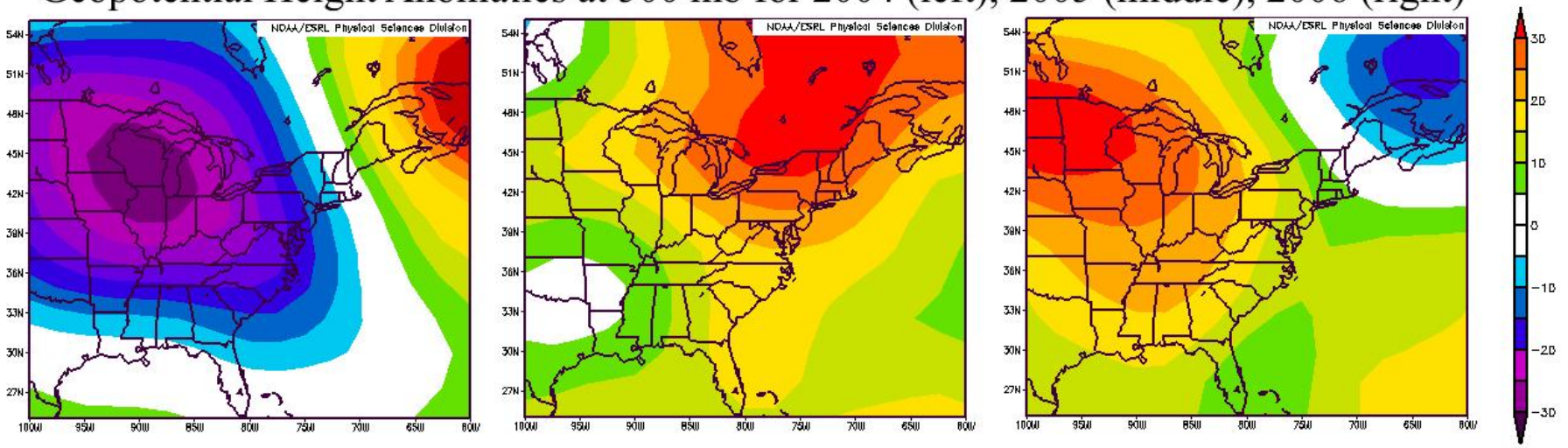
Boulder, CO	Bratt's Lake, SK	Churchill, MT	Egbert, ONT
Edmonton (Stony			

http://ozone.met.psu.edu/ARCTAS/Data/

Results – Free-Tropospheric O_3

- RCL term is higher when 500 mb geopotential heights and surface pressure are anomalously high (stronger convection in 2005)
- Higher ST ozone associated with lower than average upper-level geopotential heights and surface pressure (tropopause folds were more frequent in 2004)

Geopotential Height Anomalies at 500 mb for 2004 (left), 2005 (middle), 2006 (right)



from NOAA/ESRL Physical Science Division