Near-Tropopause Ozone Variability at Tropical and Subtropical Ozonesonde Sites: Analysis with Self-Organizing Maps

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Talk Road Map

1) Why Cluster Ozonesonde Data? Introduction to Self-Organizing Maps (SOM)

2) Previous Tropical Ozonesonde SOM Classification (i.e. Jensen et al., 2012, JGR)

3) Clustering Free Troposphere/Lower Stratosphere SHADOZ Ozonesonde Profiles with SOM
   - Station differentiation, separation into O_3 regimes/ regions
   - Upper troposphere/TTL O_3 example: Comparisons with O_3 climatology

1) Why Cluster Ozonesonde Data? Introduction to Self-Organizing Maps (SOM)

- Ozonesonde (high resolution, high accuracy) measurements are preferred method for model and satellite profile validation
- Coarse vertical resolution from satellites and chemical models often struggles to capture tropopause O_3 gradients
- Stauffer et al. (2015, submitted JGR) show with CONUS data that monthly O_3 climatology fails to reproduce O_3 variability both in free troposphere and near tropopause
  - Satellites and models use ozonesonde climatologies as a first guess
  - Approach: Cluster ozonesonde profile data to capture variability and identify dominant O_3 profile types

The Self-Organizing Map (SOM; Kohonen, 1995)

- User defines a lattice of *nodes* (e.g. 1 or 2-D rectangular shape)

- Nodes initialized with data set either randomly or linearly: PCA decomposition interpolates between largest principal components

- Data fed to nodes to find Best-Matching Unit (BMU). **Neighbor nodes also updated** based on proximity to BMU

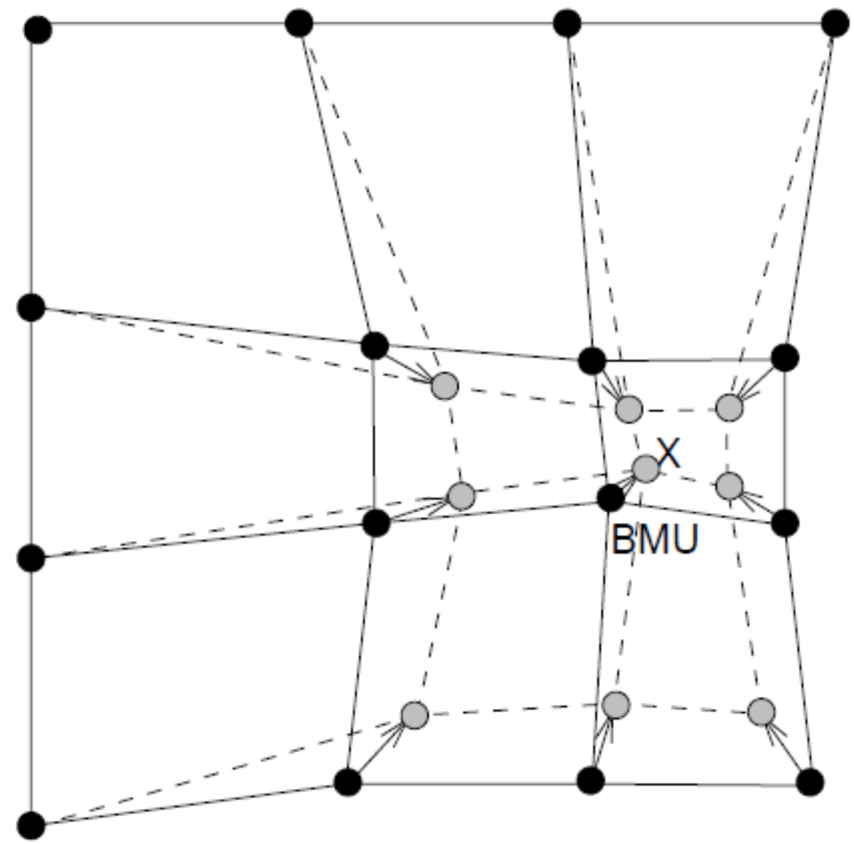
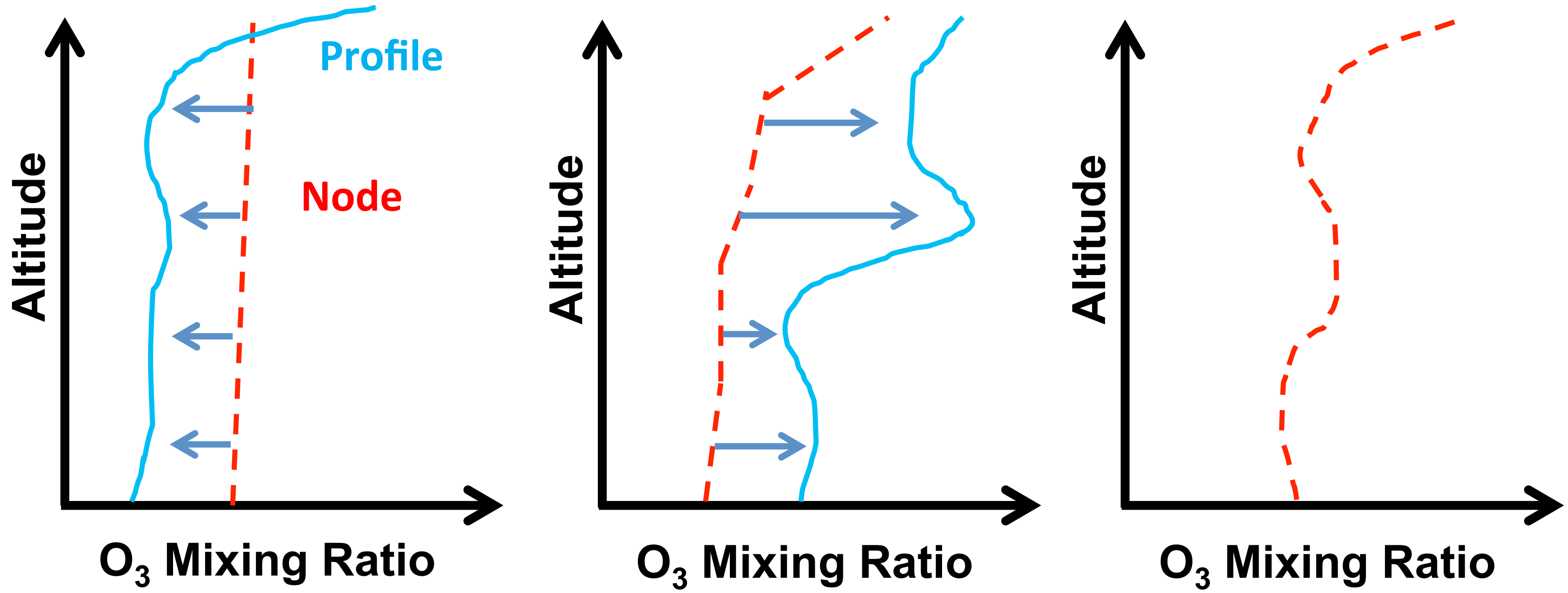


Fig. 3 from Vesanto et al. (2000)

Example with O_3 Data



Feed profile data, update the node(s)

Feed more profile data, update the node(s)

Nodes become more like input data and representative of their closest vectors

Final Product: Each SOM node is the mean of its member data, map organized with like nodes adjacent in the map

For more SOM methods info see Stauffer et al. (2015, submitted JGR)

2) Previous Tropical Ozonesonde SOM Classification (i.e. Jensen et al., 2012, JGR)

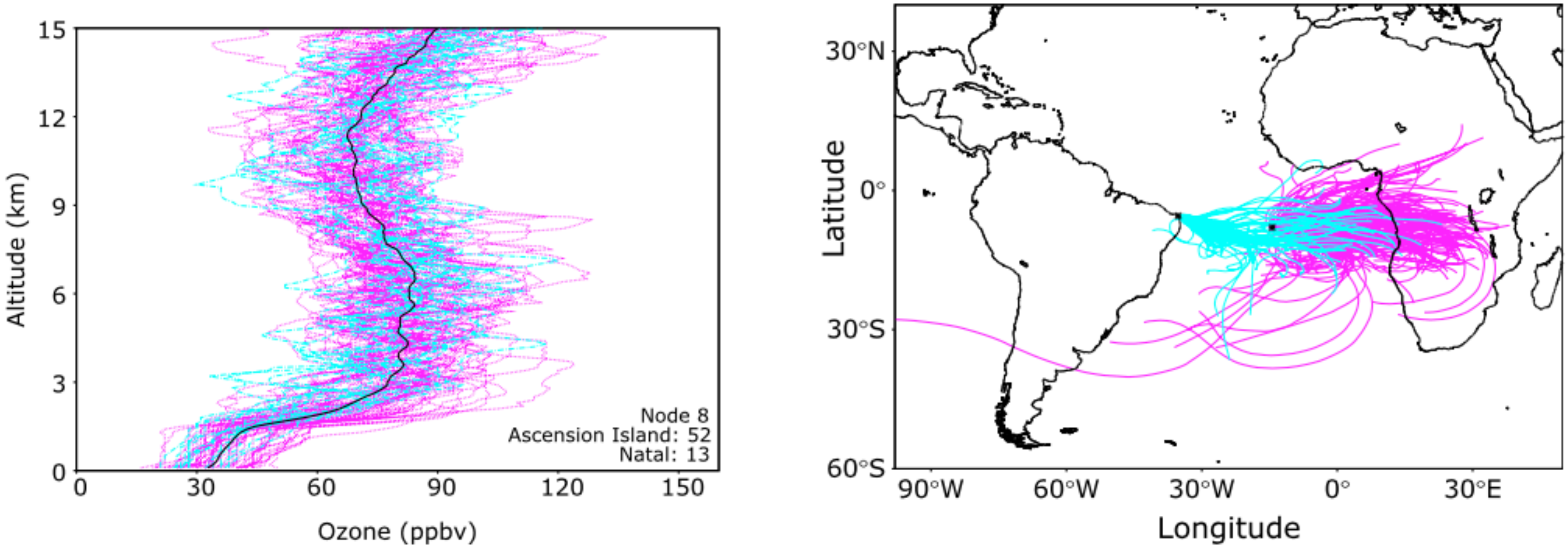


Fig. 16 from Jensen et al. (2012)

Natal, Brazil and Ascension Island example cluster (left), with corresponding back trajectories (right). Enhanced O_3 above the boundary layer connected to biomass burning on African continent. SOM clusters of O_3 profiles correspond to seasonality, stability, OLR, and biomass burning effects (above)

What we've learned so far from Jensen et al. (2012), Stauffer et al. (2015, submitted JGR):

1) Deviations from climatology, especially near the tropopause can be profound
2) Closely located sites can have large O_3 distribution differences exposed by SOM

3) Clustering Free Troposphere/Lower Stratosphere SHADOZ Ozonesonde Profiles with SOM

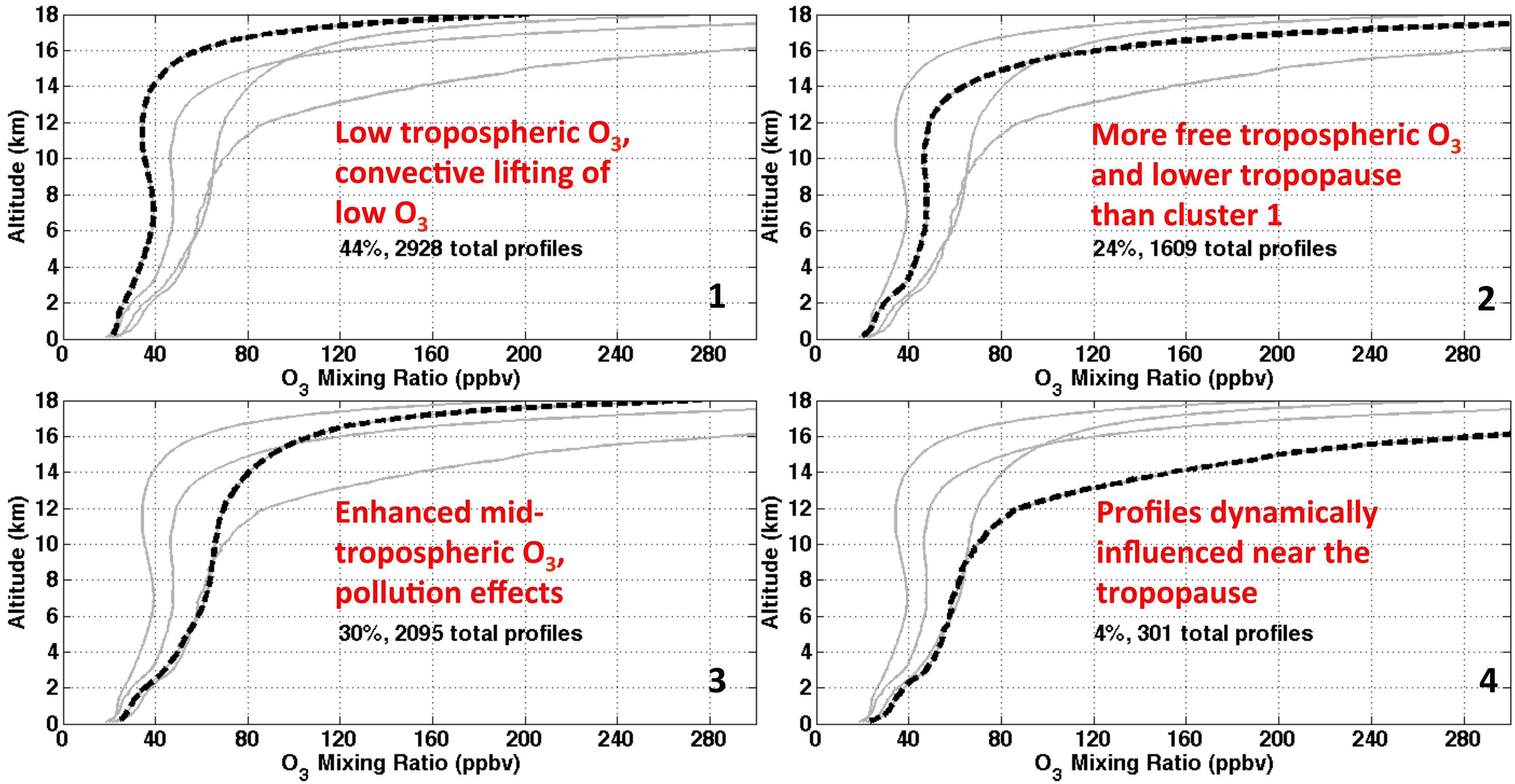
SHADOZ Logo from
http://croc.gsfc.nasa.gov/shadoz/

SHADOZ O_3 Profile Locations

- Data set of 6933 O_3 mixing ratio profiles from 14 SHADOZ sites (some record length differences, all months well-represented)
- Jensen et al. (2012): SOM run on surface to 15 km data to avoid tropopause O_3 gradients in the tropics
- We run SOM on surface to 18km O_3 mixing ratios to capture TTL variability
- Run SOM both on combined SHADOZ data set (identify site differences) and for each individual site (comparisons with climatology)

Site	Lat	Lon	Elevation	# Profiles	Record
Alajuela, Costa Rica	9.98	-84.21	899 m	360	2005-2013*
Ascension Island	-7.98	-14.42	91 m	526	1998-2010
Suva, Fiji	-18.13	178.4	6 m	328	1998-2013
Hanoi, Vietnam	21.02	105.8	7 m	190	2004-2014
Heredia, Costa Rica	10.0	-84.11	1176 m	360	2005-2013*
Hilo, HI, USA	19.43	-155.04	11 m	1399	1982-2015
Irene, South Africa	-25.9	28.22	1524 m	289	1998-2014
Watukosek-Java, Indonesia	-7.5	112.6	50 m	319	1998-2013
Kuala Lumpur, Malaysia	2.73	101.7	17 m	340	1998-2013
Nairobi, Kenya	-1.27	36.8	1795 m	717	1998-2015
Natal, Brazil	-5.42	-35.38	42 m	488	1998-2014
Paramaribo, Suriname	5.81	-55.21	7 m	530	1999-2014
Reunion Island	-21.06	55.48	24 m	512	1998-2014
Pago Pago, American Samoa	-14.23	-170.56	77 m	551	1998-2015
San Cristobal, Galapagos	-0.92	-89.60	8 m	403	1998-2014

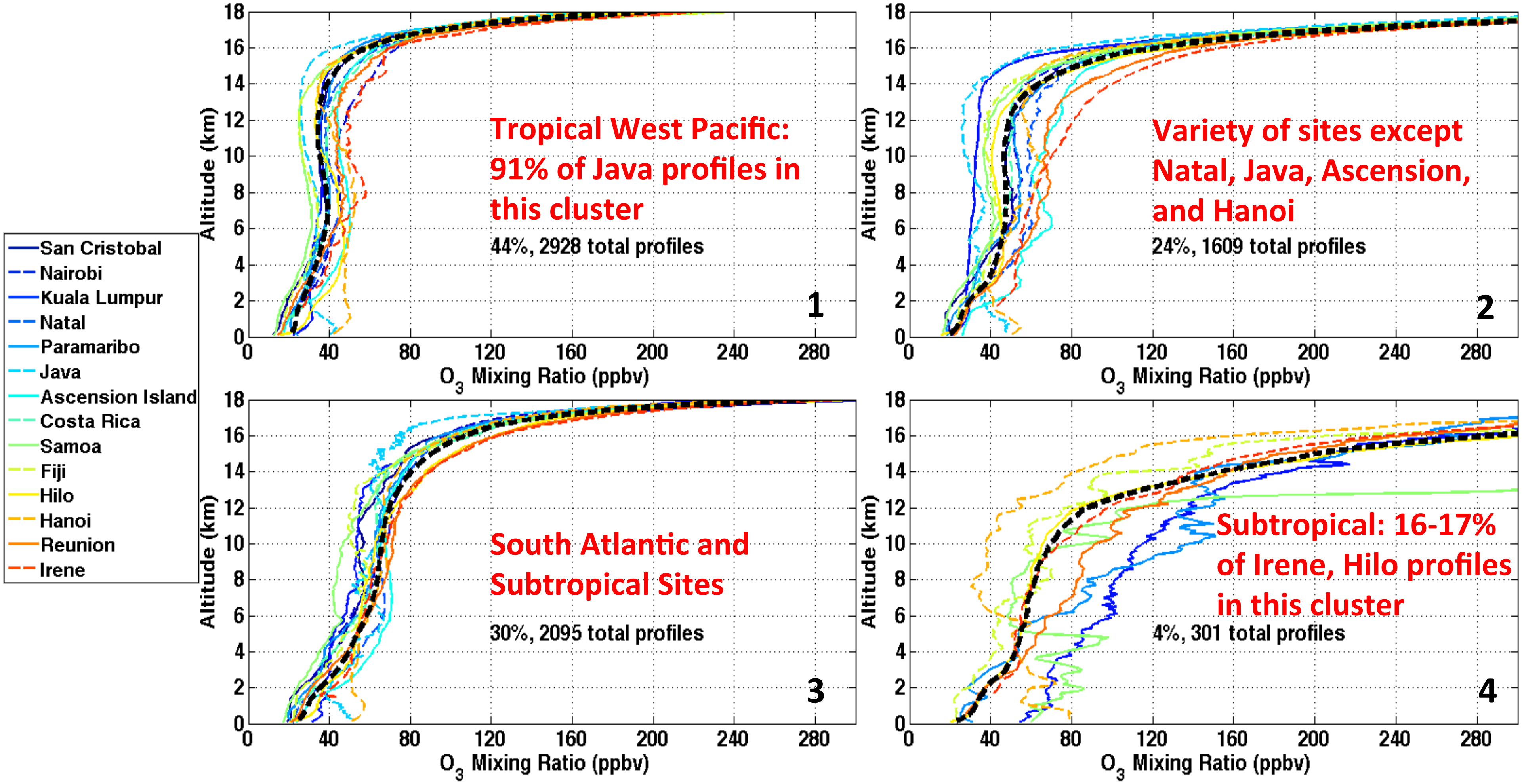
All SHADOZ sites, 2x2 SOM (4 clusters)



All 6933 profiles separated into four clusters with SOM. Black highlights the cluster average with all four clusters shown in grey on each plot for comparison.

Note tropopause height variability: Top left = High tropopause, low tropospheric O_3
Bottom right = Low tropopause, dynamically influenced

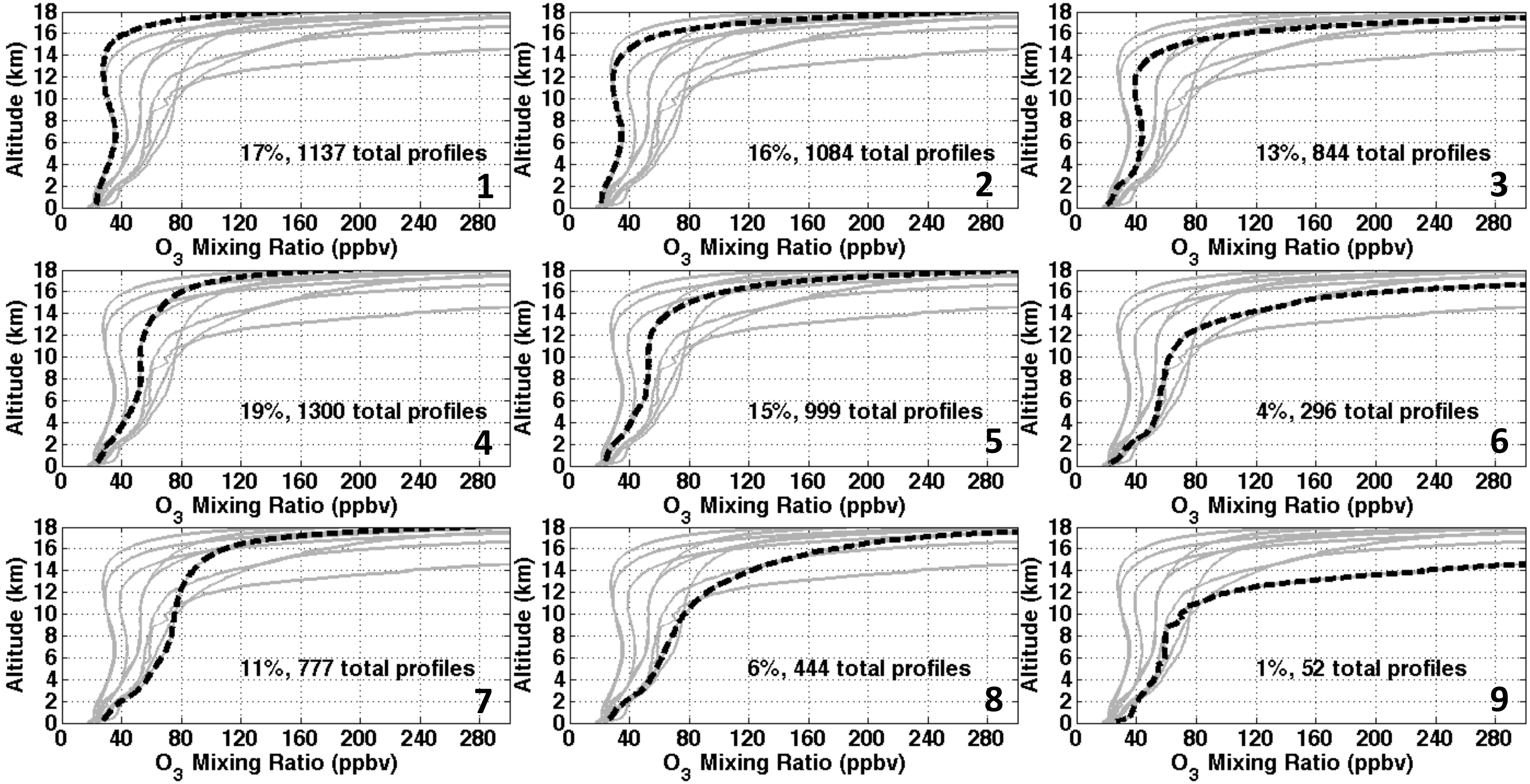
All SHADOZ sites, 2x2 SOM (4 clusters)



Same four clusters shown with each site's contribution color coded. Clustering with all sites combined allows simple intercomparison of tropical/subtropical ozonesonde sites

Quickly establish facts like Hilo and Irene exhibit the most frequent subtropical O_3 profile characteristics, more than Hanoi and Reunion at similar latitudes

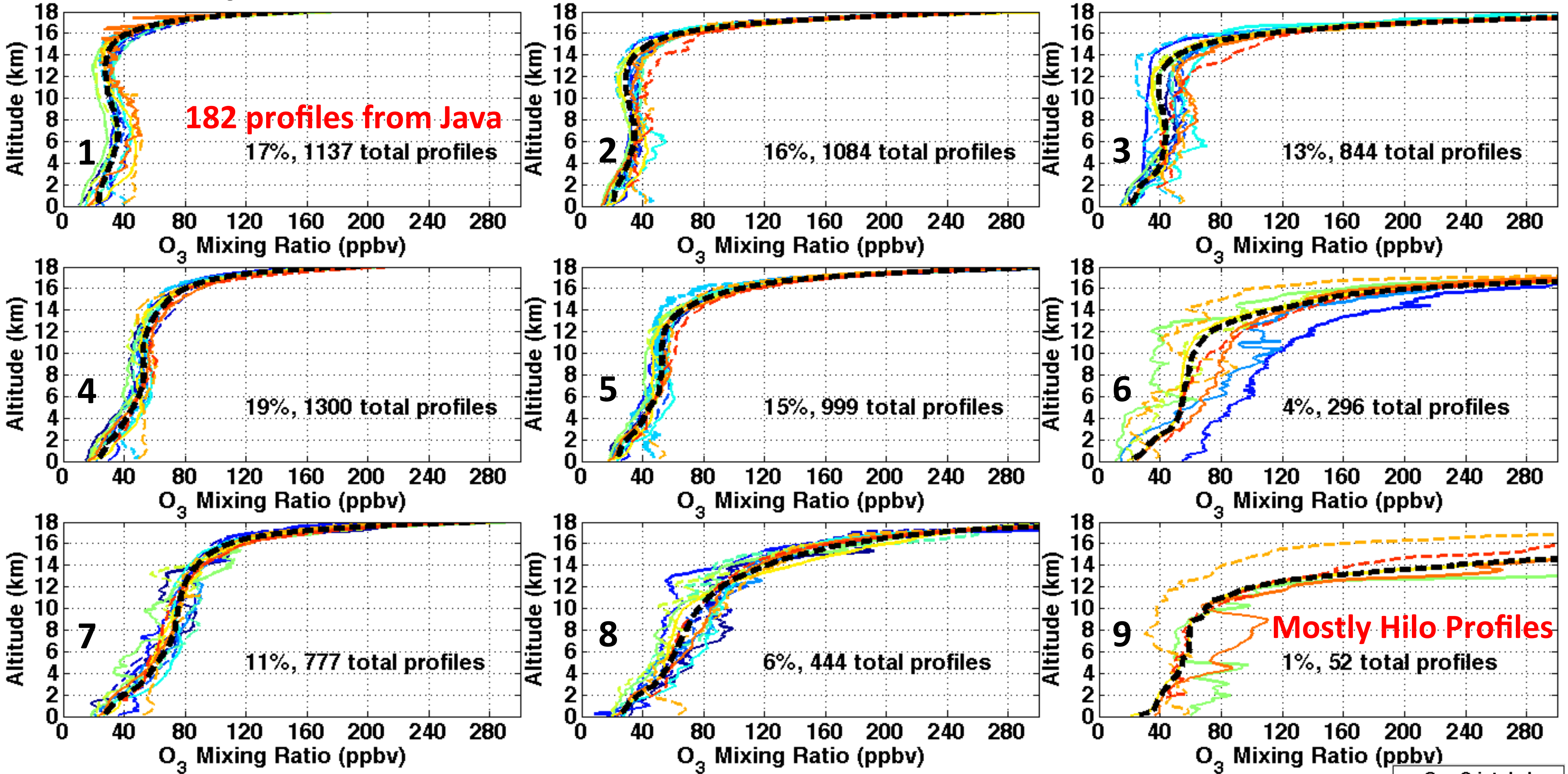
Expand to 3x3 SOM (9 clusters): More Detail



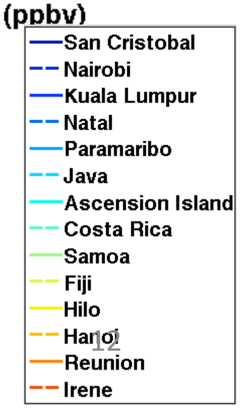
Same as previous plot. Cluster highlighted in black, all nine clusters in grey for comparison. Organizational features of SOM more apparent with 9 clusters, like clusters adjacent

Similar organization as 2x2 SOM, Top left = High tropopause, low tropospheric O_3
Bottom right = Low tropopause, dynamically influenced

Expand to 3x3 SOM (9 clusters): More Detail

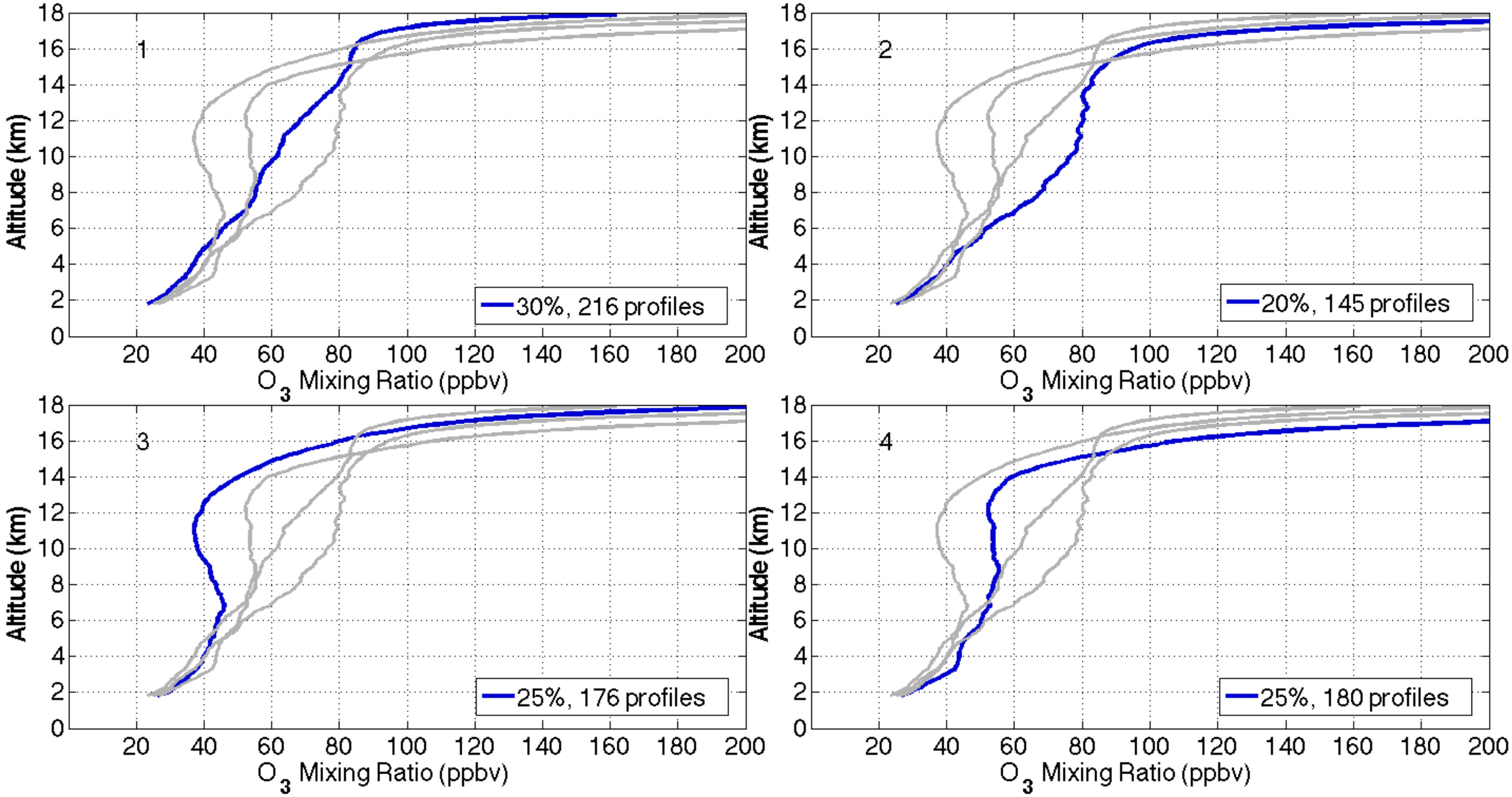


Same nine clusters shown with each site's contribution color coded. Which sites exhibit most/least variability?



- Ex: Hilo, HI well-represented in all nine clusters (cluster 9: 44 of 52 profiles from Hilo, HI), Java only even appears in five of nine clusters (90% in clusters 1 and 2)

Individual Site Ex: Nairobi, Kenya 2x2 SOM

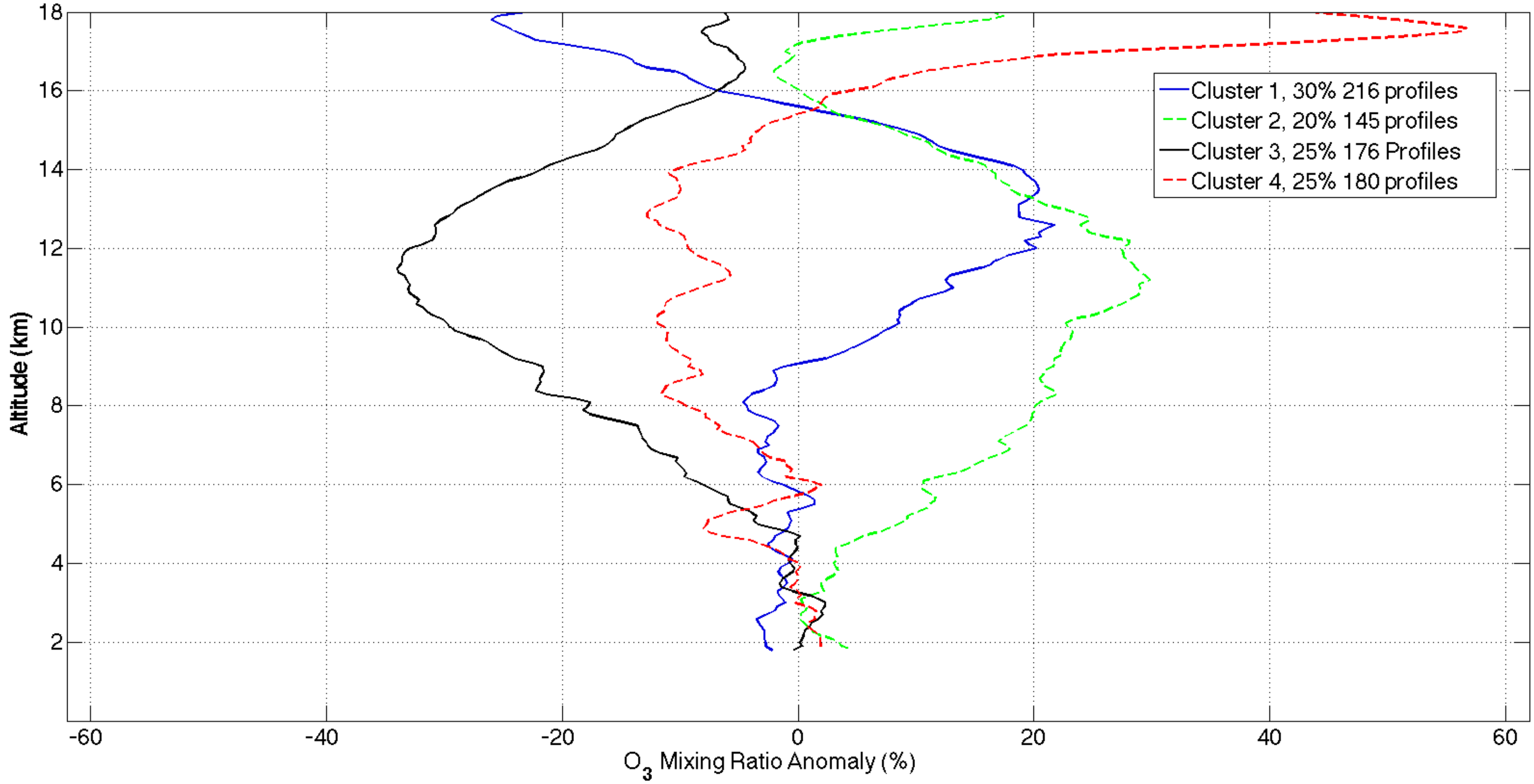


Four clusters of Nairobi, Kenya (-1.27°, 36.8°) express variability better than monthly climatology

- 12 km O_3 ranges from **45 ppbv** (Jan) to **75 ppbv** (Oct/Nov) using monthly averages
- 12 km O_3 varies by a factor of 2 from cluster 3 (**39 ppbv**) to cluster 2 (**80.5 ppbv**)

What O_3 anomalies do we observe if we compare profiles in each cluster to their respective monthly climatology (taken from ozonesonde data set)?

Comparisons with monthly O_3 climatology at Nairobi, Kenya



Average O_3 % anomalies from monthly climatology for each SOM cluster

Largest anomaly near tropopause in cluster 4, but 3 of 4 clusters, representing 75% of all profiles at Nairobi, Kenya, average > ±20% O_3 beyond climatology in upper troposphere

Even at sites close to equator, it is vital to know tropopause height, and to represent upper tropospheric O_3 variability with accuracy better than climatological averages

Summary/Two Main Conclusions

- SOM classification discriminates Tropical West Pacific, Tropical South Atlantic, Subtropical and Mixed O_3 regimes based on dominant O_3 profile shapes

- SOM quantifies near-tropopause O_3 variability otherwise masked by monthly/seasonal averaging typical of standard O_3 climatologies
  - Achieved even with as few as four clusters (Nairobi example)
  - Especially true for near-tropopause O_3 gradients in subtropics
  - Even in tropics, it is not good enough just to accurately mark tropopause height. Models and satellite profile information must improve over climatology to describe day-to-day tropical O_3 measurements

- Future applications? TTL H_2O_v clustering, comparisons with O_3

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- Thank you for your attention

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