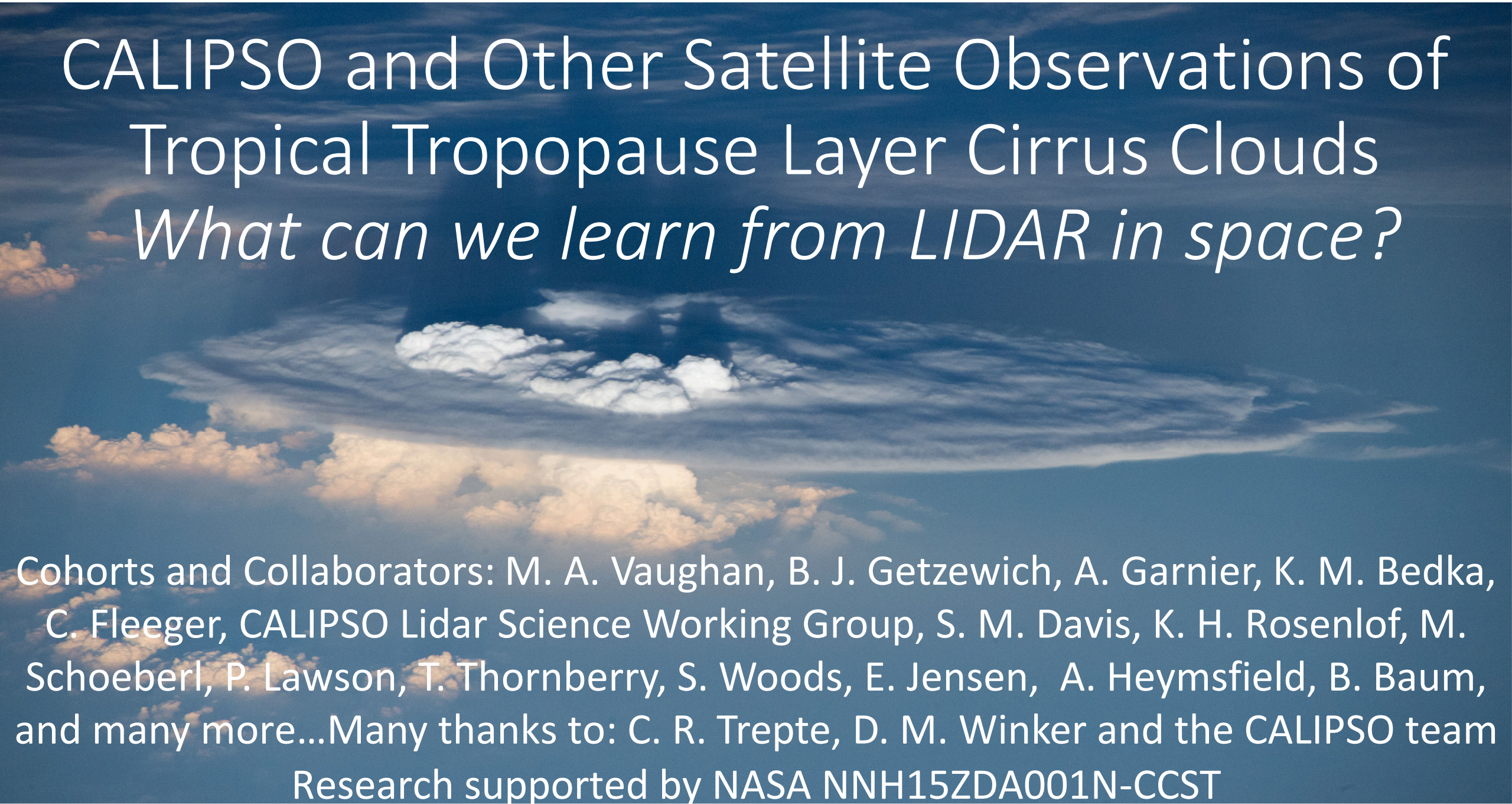


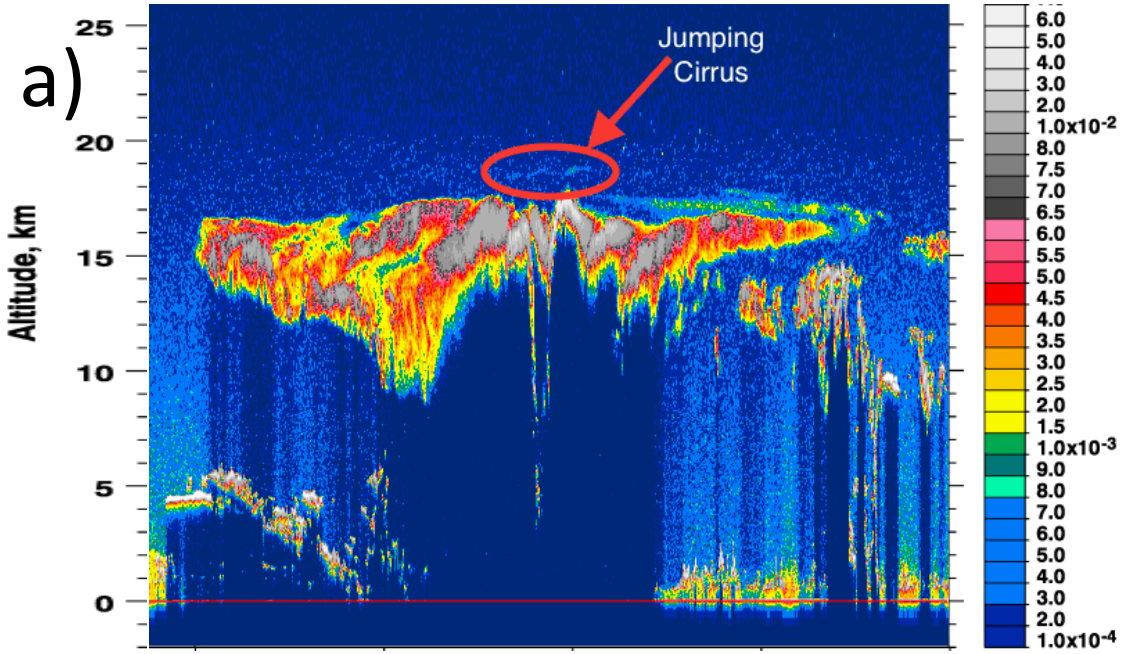
CALIPSO and Other Satellite Observations of Tropical Tropopause Layer Cirrus Clouds
What can we learn from LIDAR in space?

Cohorts and Collaborators: M. A. Vaughan, B. J. Getzewich, A. Garnier, K. M. Bedka, C. Fleeger, CALIPSO Lidar Science Working Group, S. M. Davis, K. H. Rosenlof, M. Schoeberl, P. Lawson, T. Thornberry, S. Woods, E. Jensen, A. Heymsfield, B. Baum, and many more…Many thanks to: C. R. Trepte, D. M. Winker and the CALIPSO team

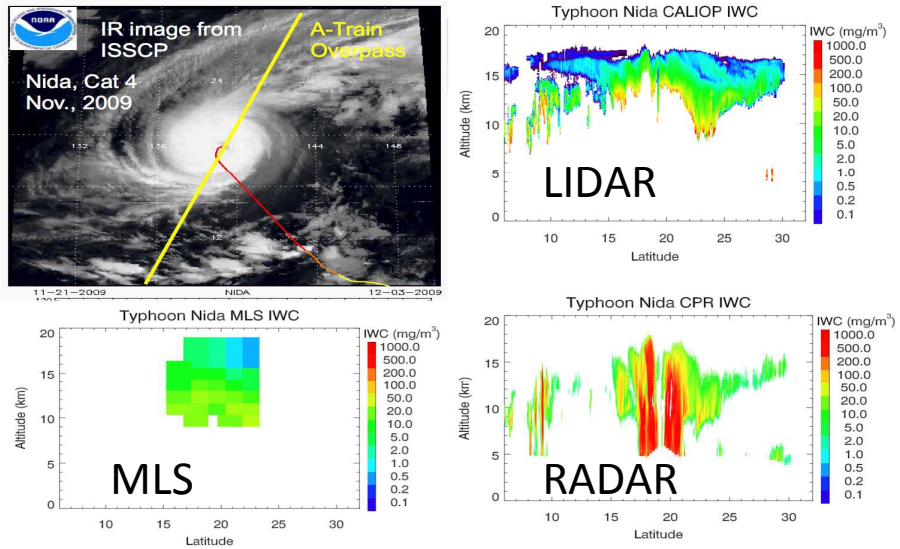
Research supported by NASA NNH15ZDA001N-CCST

Example Observations of a Large Convective System: Typhoon Nida

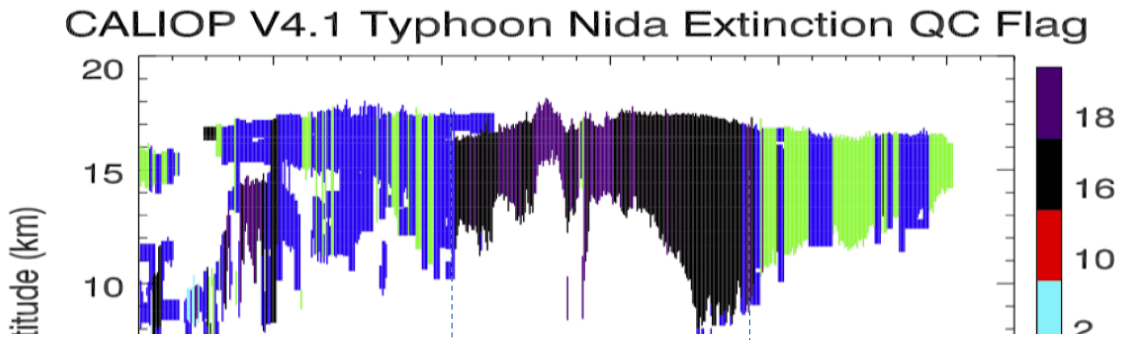
a)



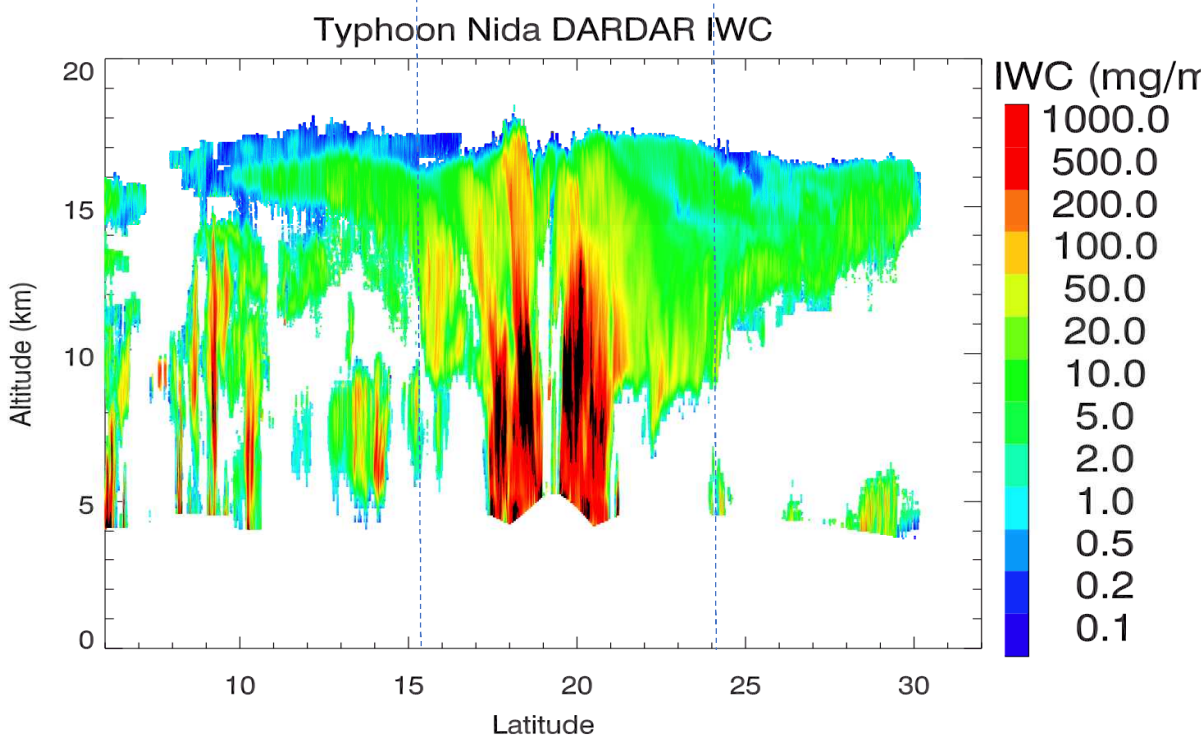
b)



c)

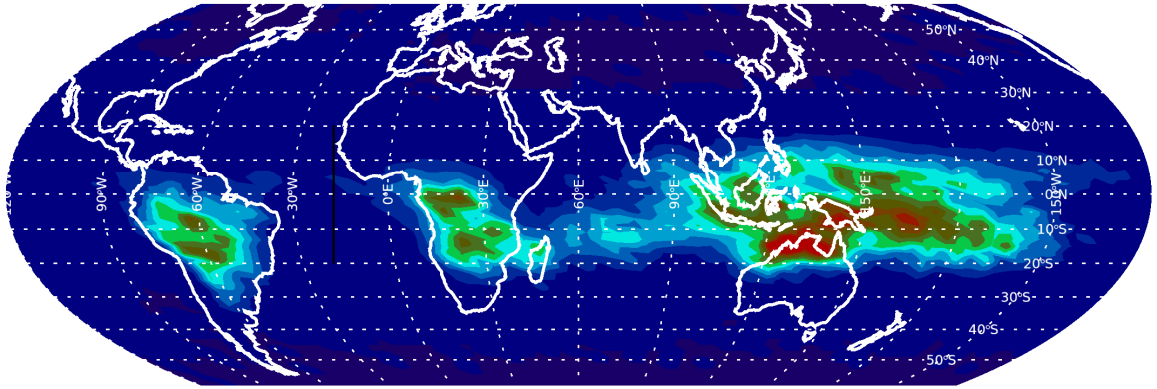


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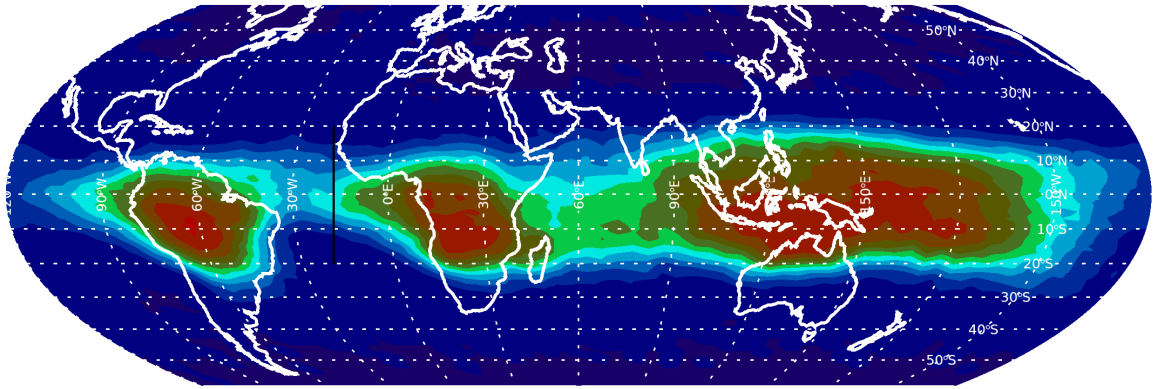


WINTER

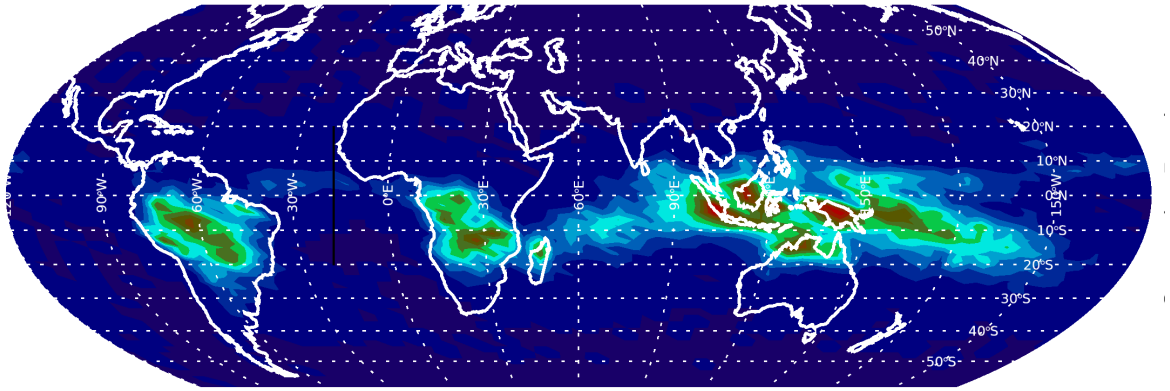
a) Winter 2006-2016 Mean V4 IWP > 14 km



b) Winter 2006-2016 Mean V4 Cloud Fraction

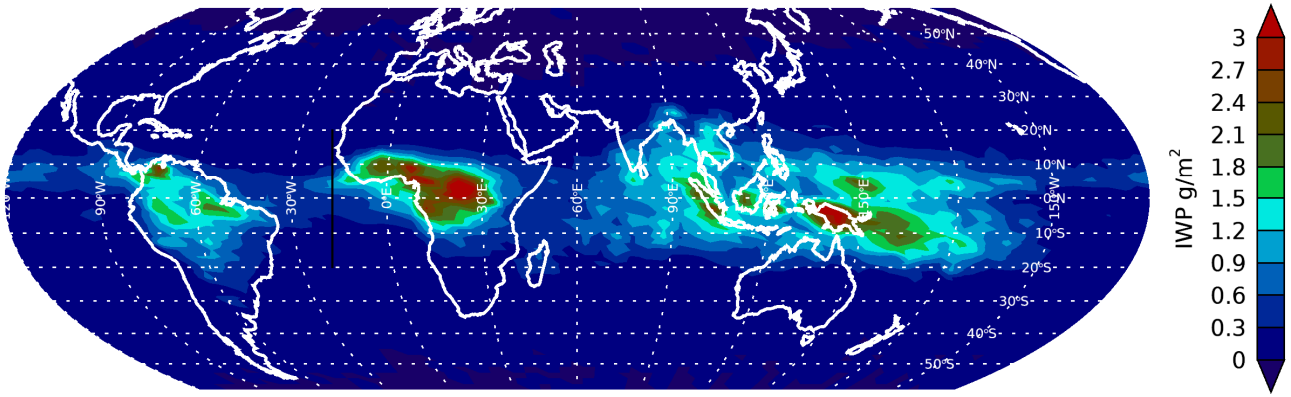


c) Winter 2006-2016 Mean V4 Convective Fraction

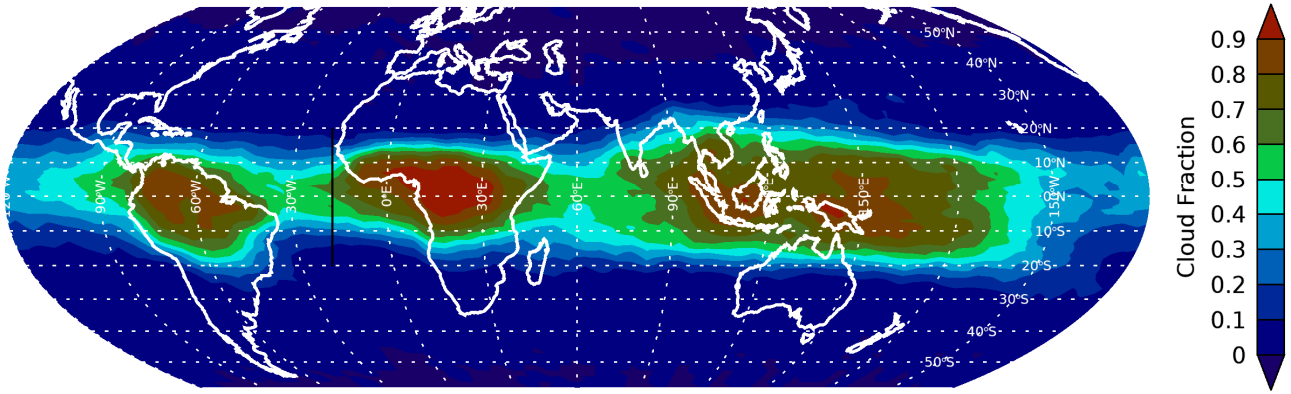


SPRING

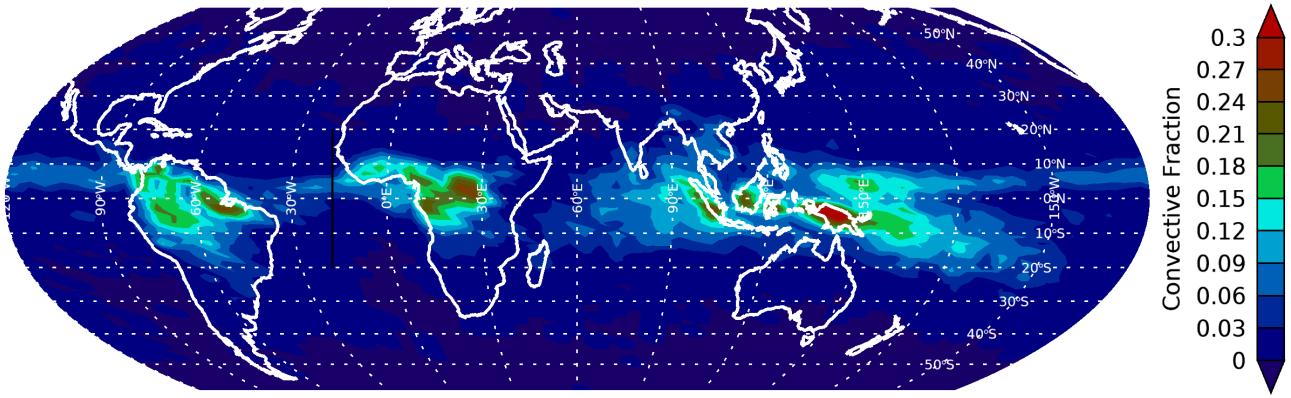
a) Spring 2007-2017 Mean V4 IWP > 14 km



b) Spring 2007-2017 Mean V4 Cloud Fraction

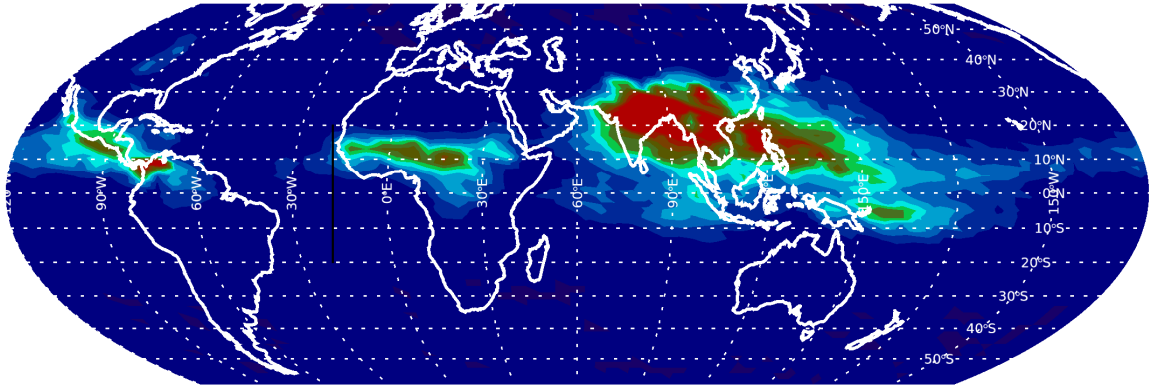


c) Spring 2007-2017 Mean V4 Convective Fraction

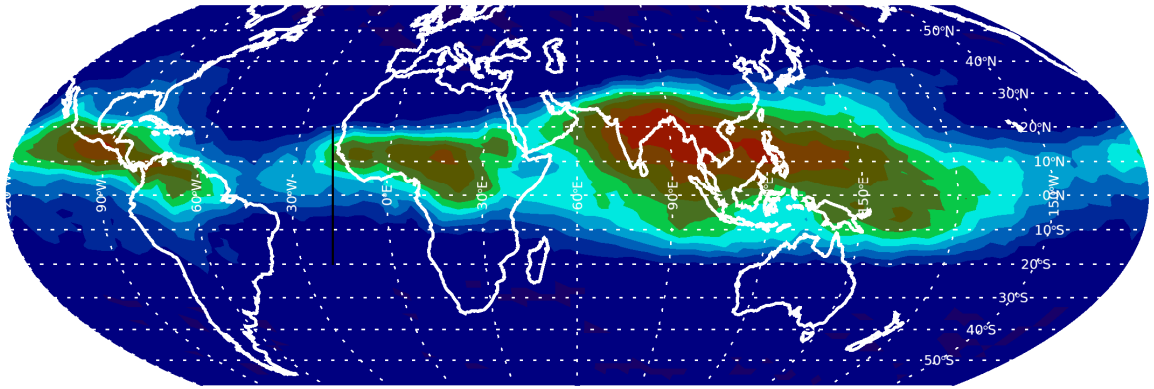


SUMMER

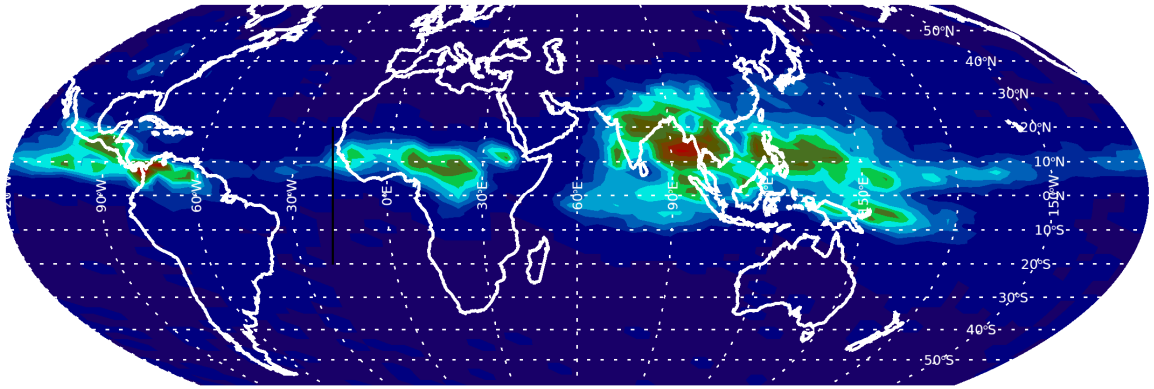
a) Summer 2006-2016 Mean V4 IWP > 14 km



b) Summer 2006-2016 Mean V4 Cloud Fraction

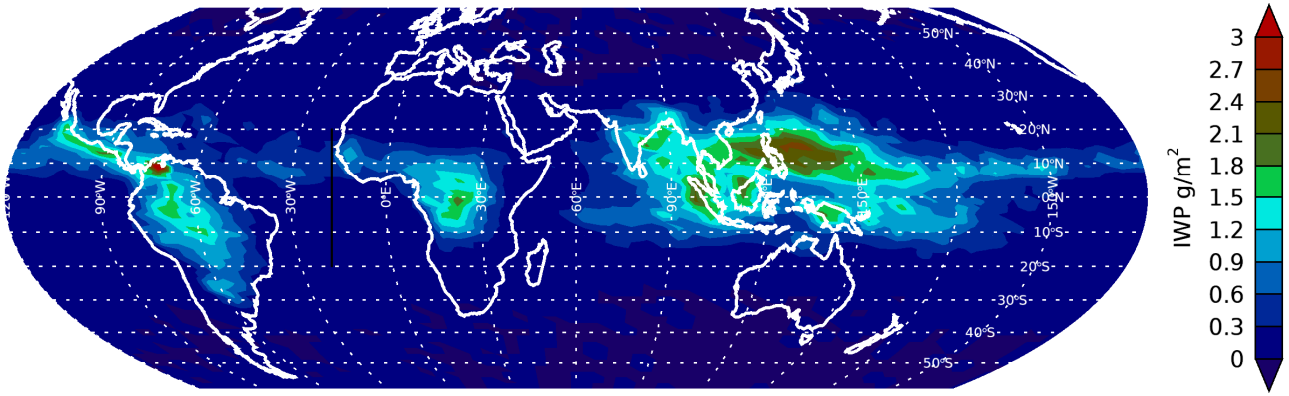


c) Summer 2006-2016 Mean V4 Convective Fraction

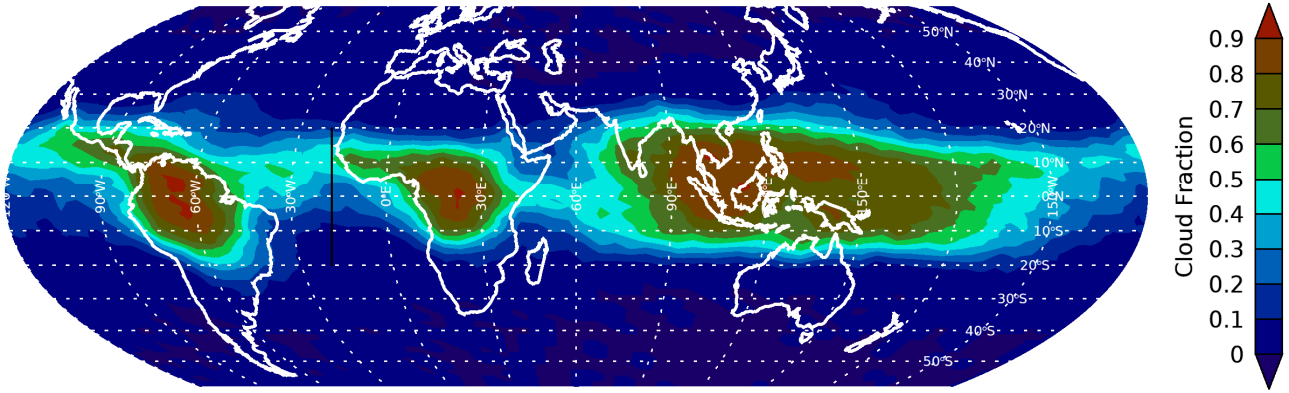


FALL

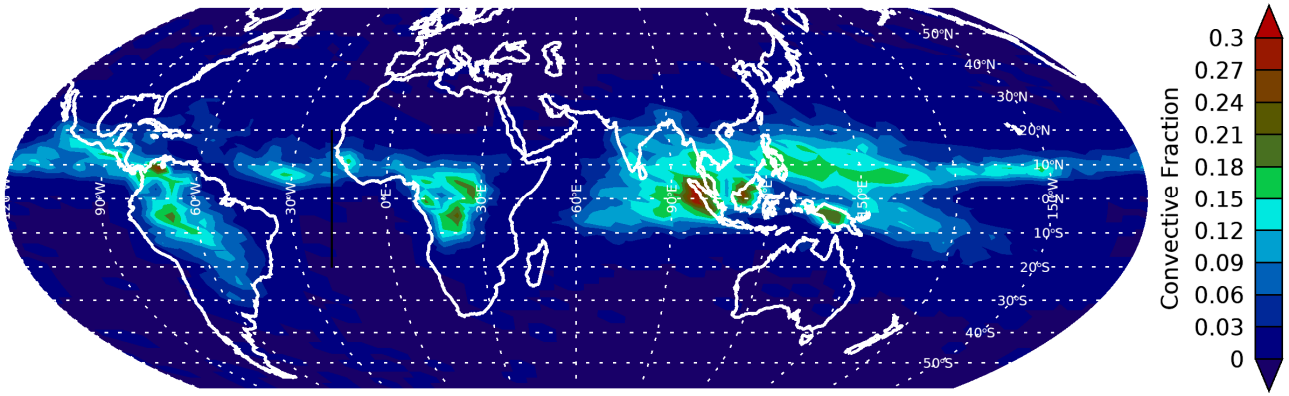
a) Fall 2006-2016 Mean V4 IWP > 14 km



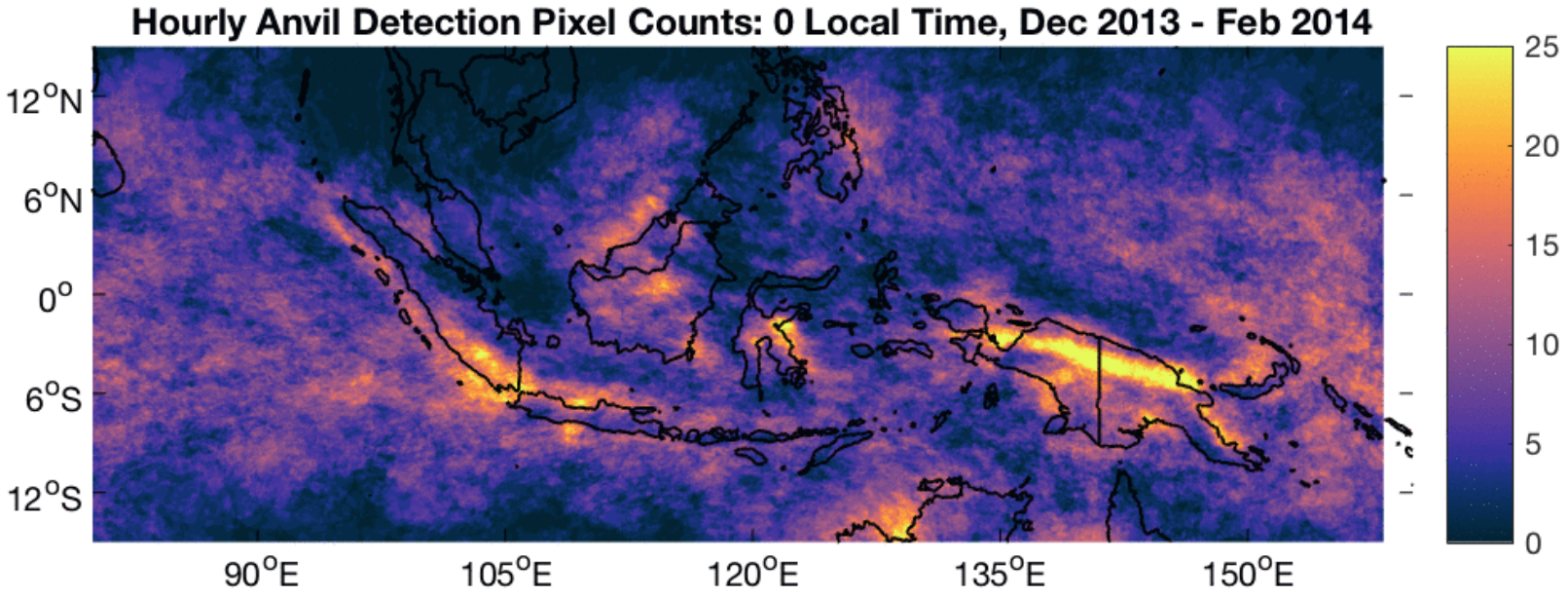
b) Fall 2006-2016 Mean V4 Cloud Fraction



c) Fall 2006-2016 Mean V4 Convective Fraction



Winter 2013: TWP Hourly Anvil MTSAT Pixel Counts



Animation by Kris Bedka

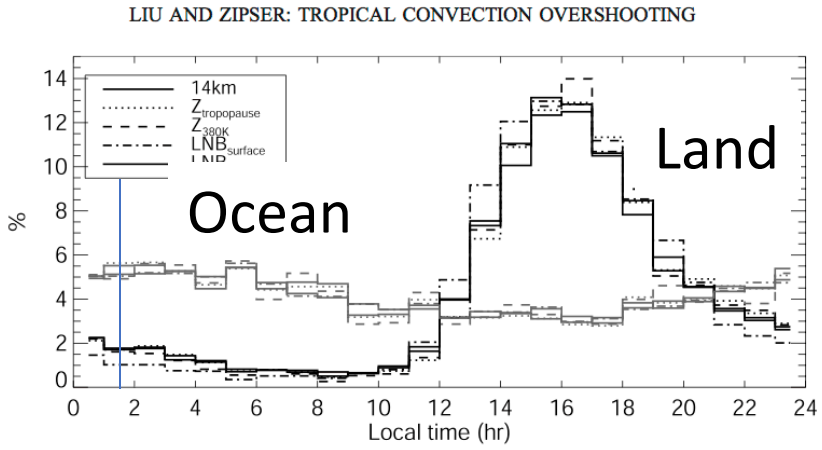
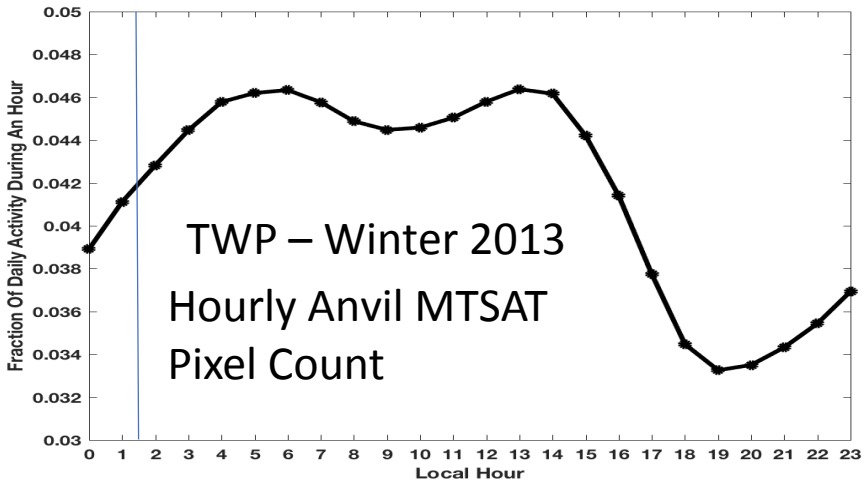
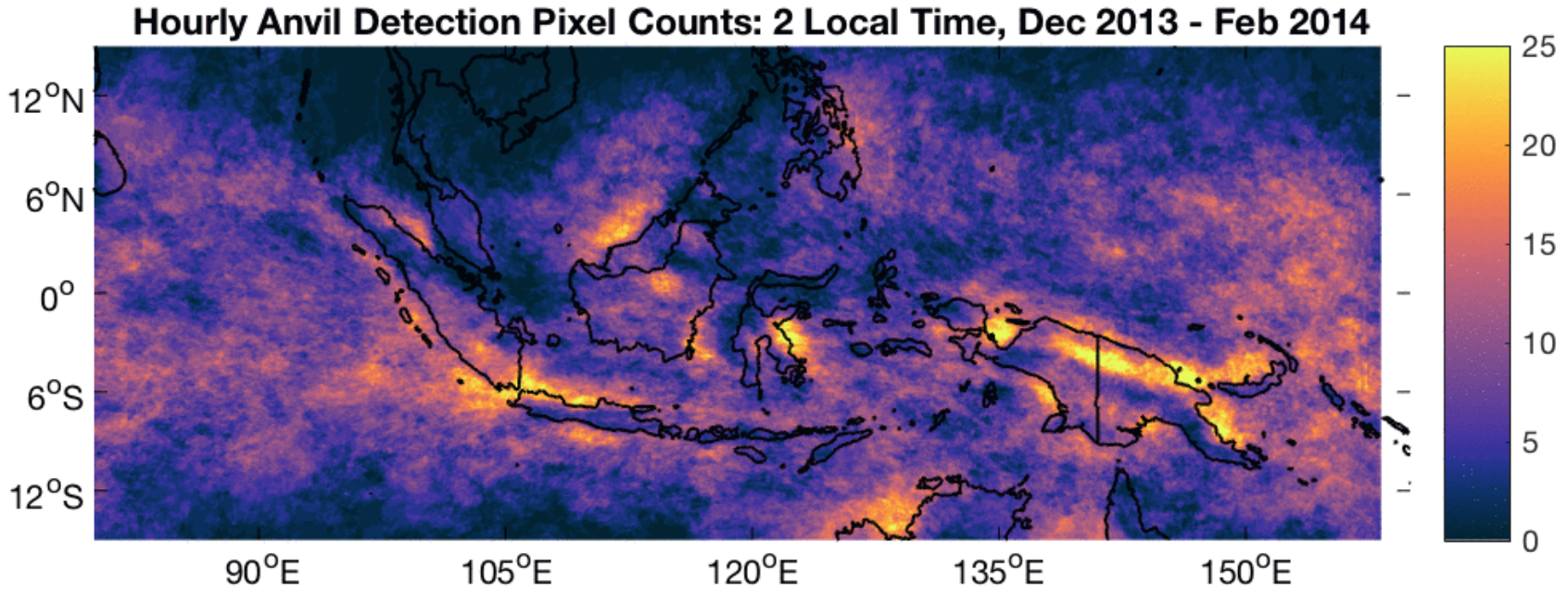


Figure 3. Diurnal variation of population of 20°N–20°S OPFs identified with five reference heights over land (solid) and ocean (shaded).

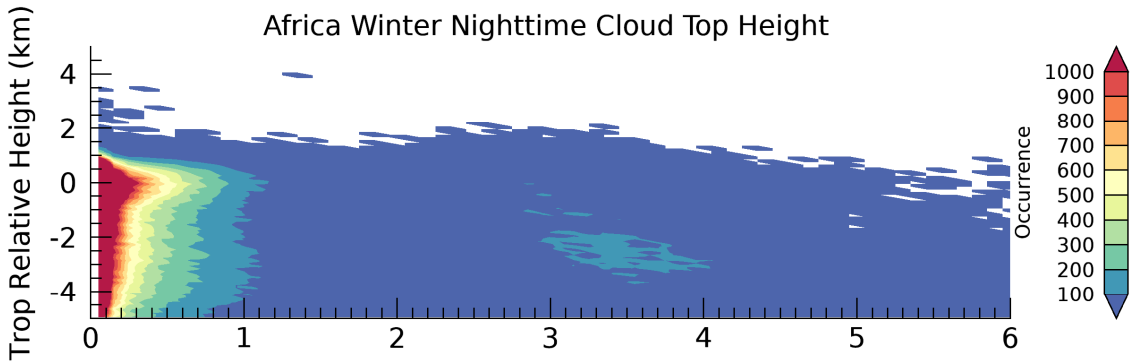
Liu and Zipser, 2005

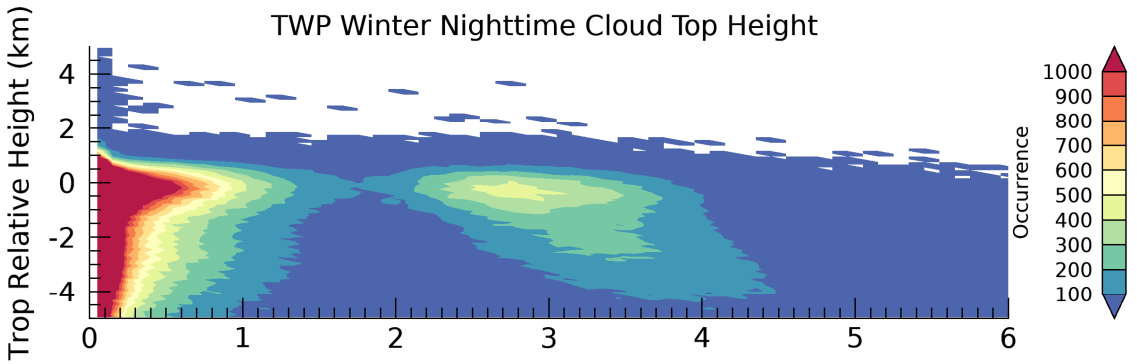


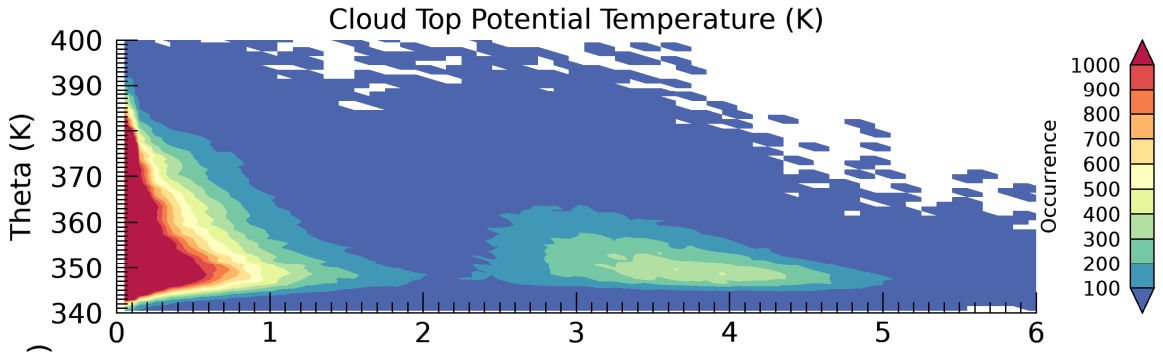
MTSAT, Just the TWP

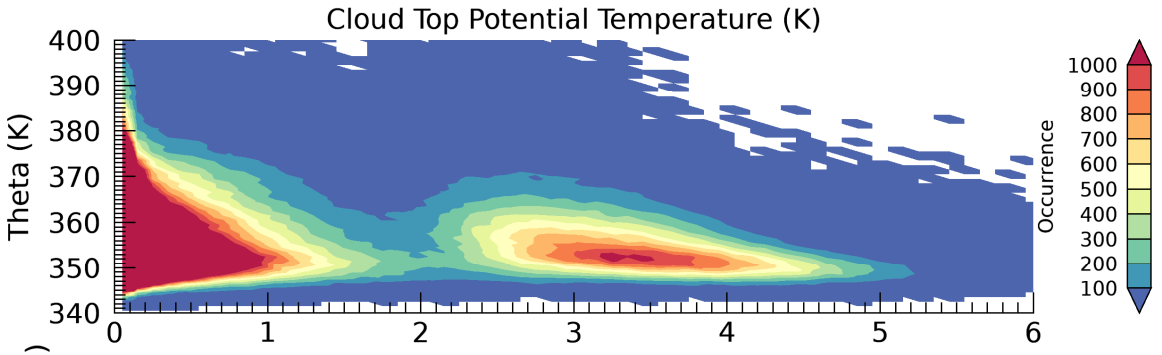


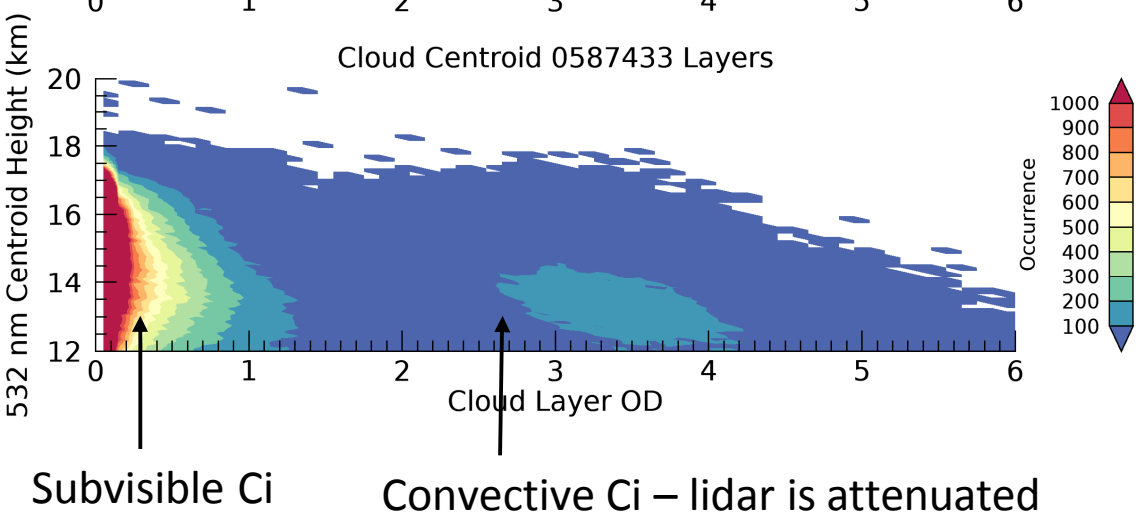
Cloud Tops and Centroids in NH Winter, Africa (LHS) vs TWP(RHS)

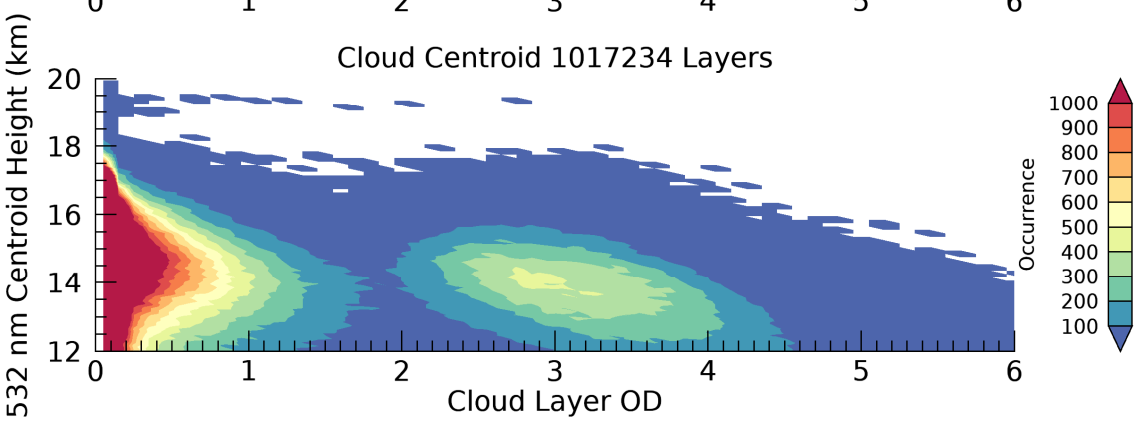




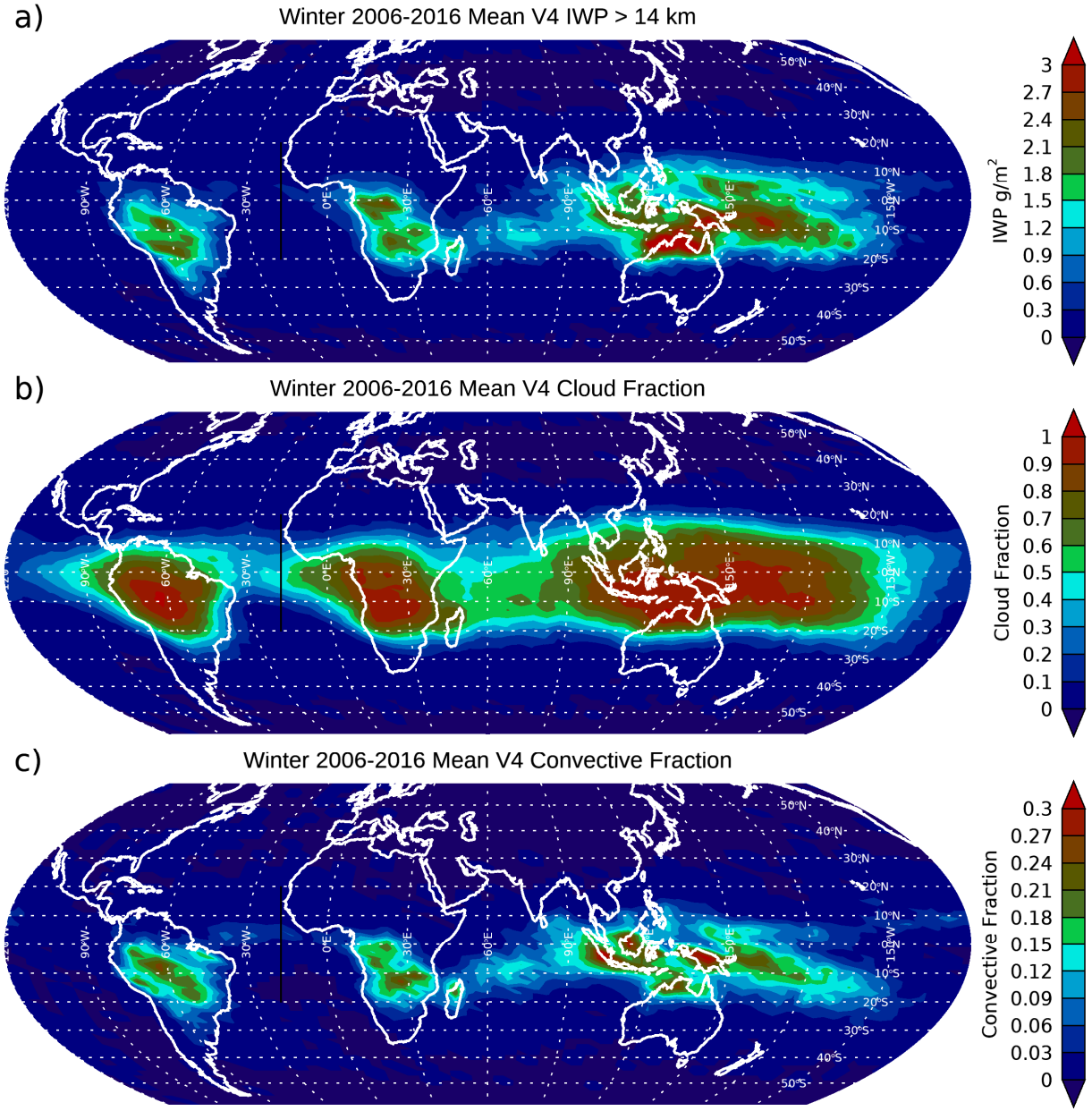




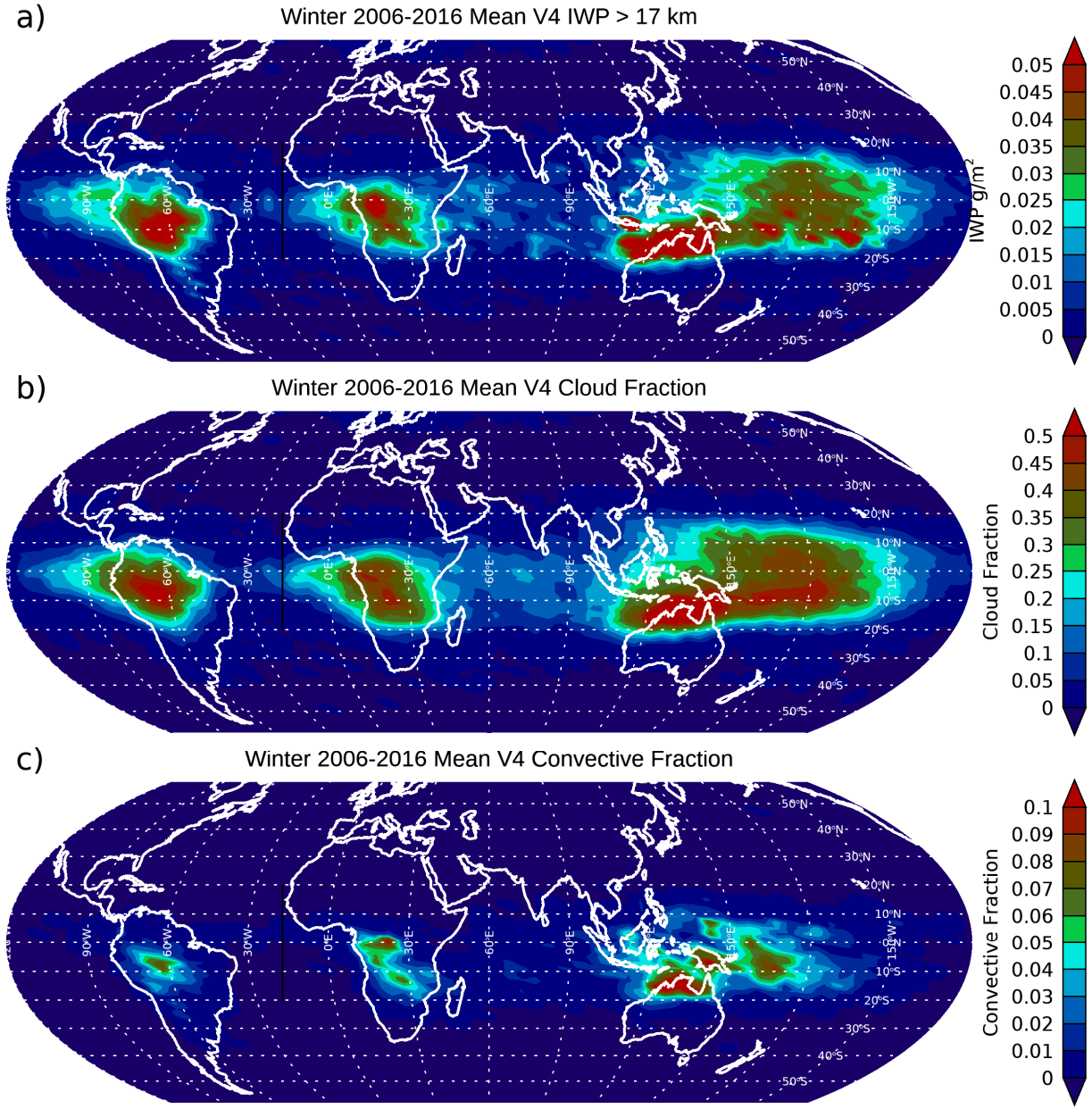




WINTER, IWP > 14 km



WINTER, IWP > 17 km

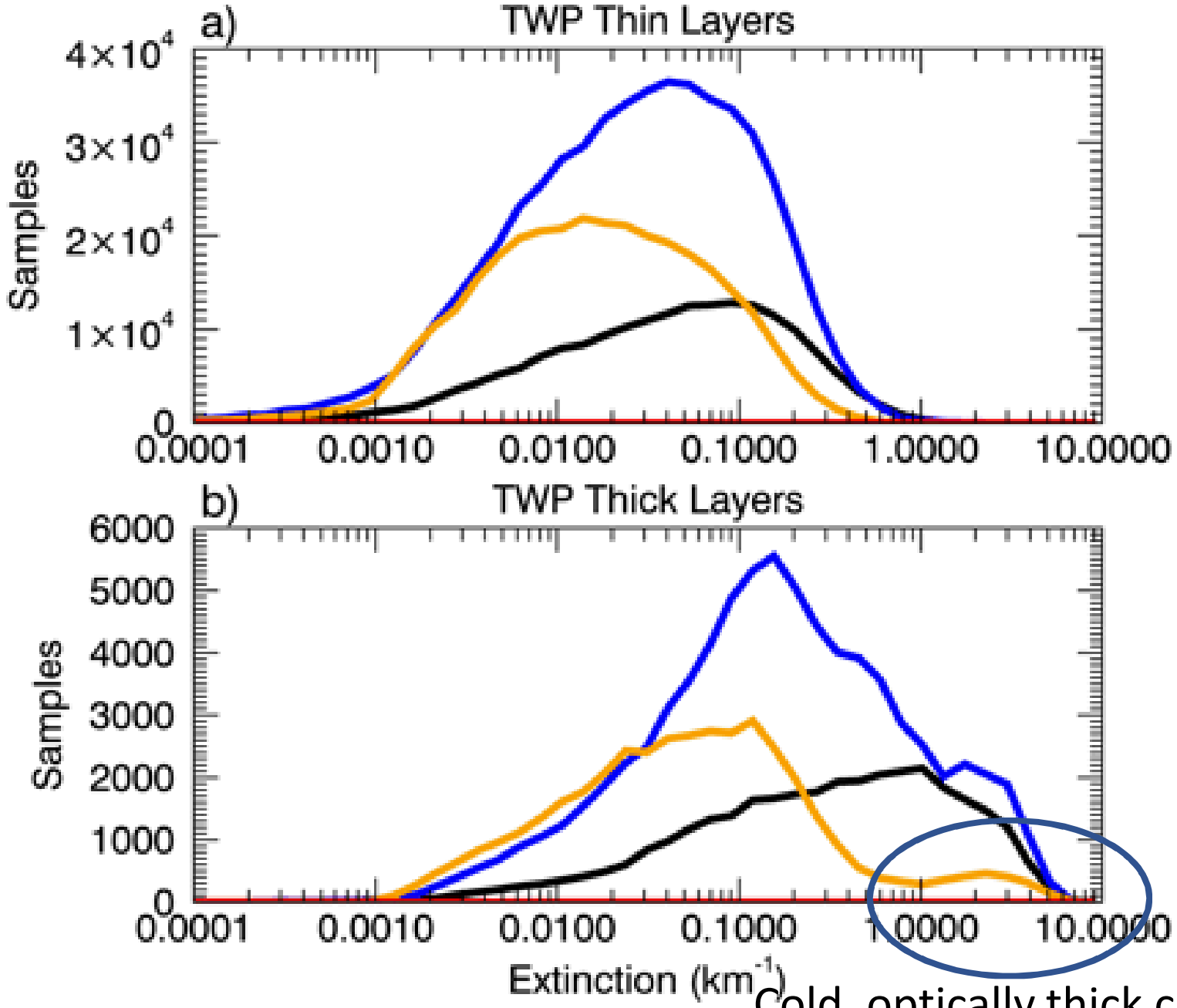


V4.1 Extinction Distributions for Optically Thin (top) and Thick (bottom) Layers

February, 2014
Nighttime

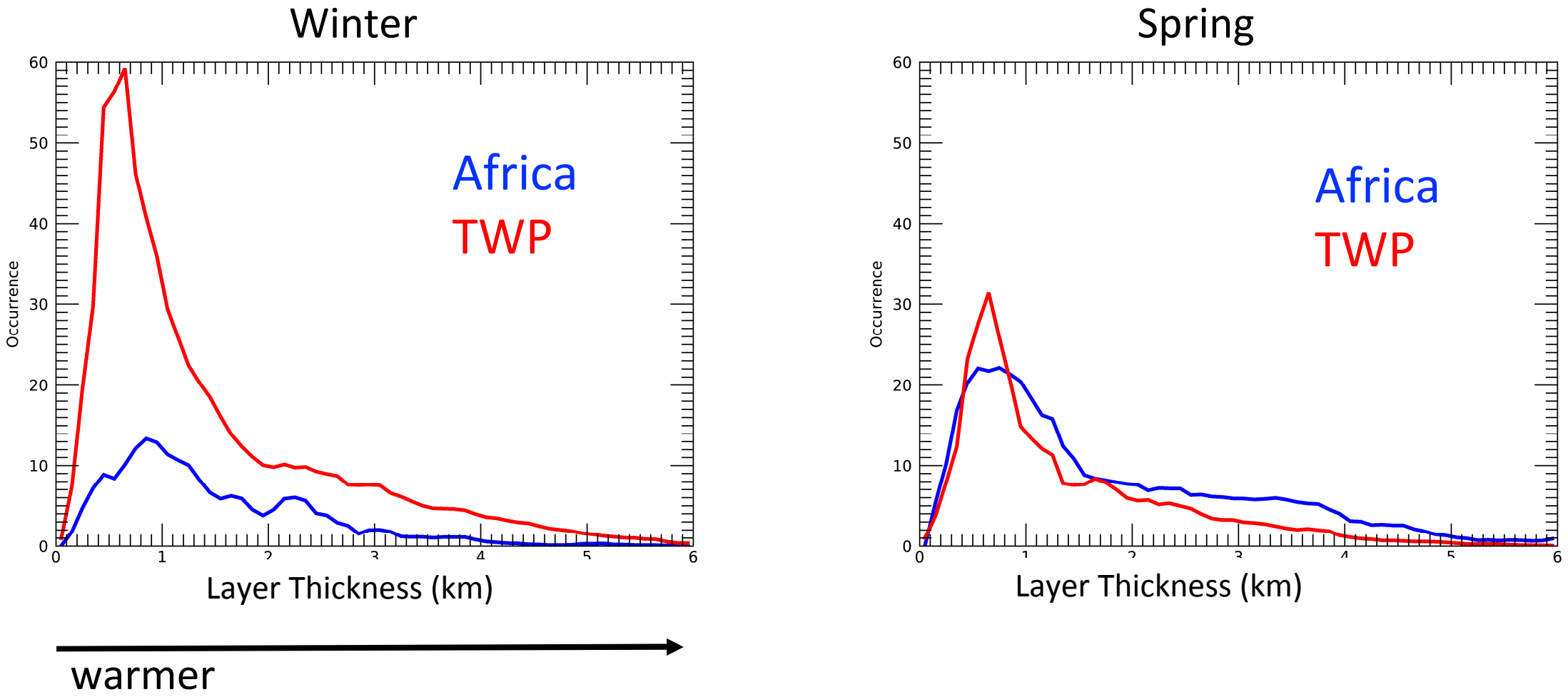
During the ATTREX, 2014 Time Period

- = -60 to -70 °C
- = -70 to -80 °C
- = -80 to -90 °C

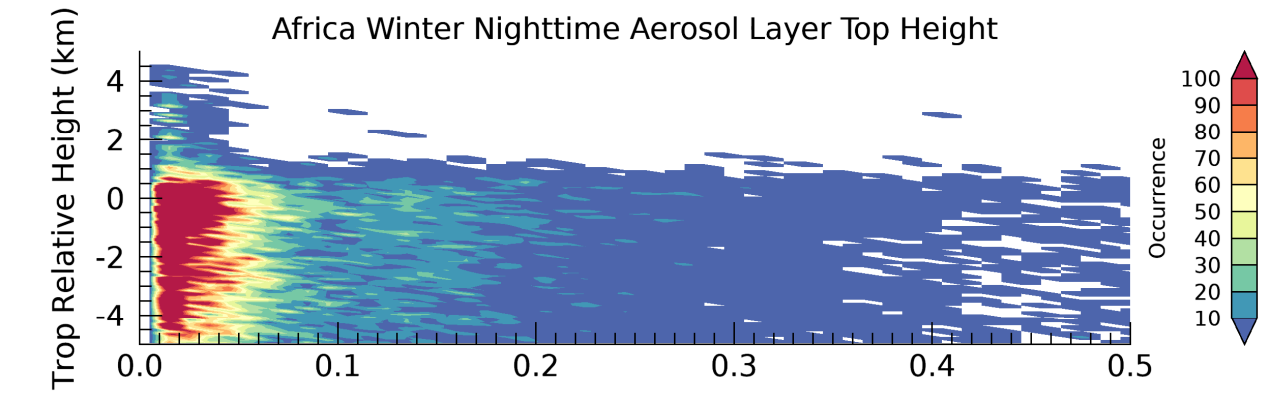


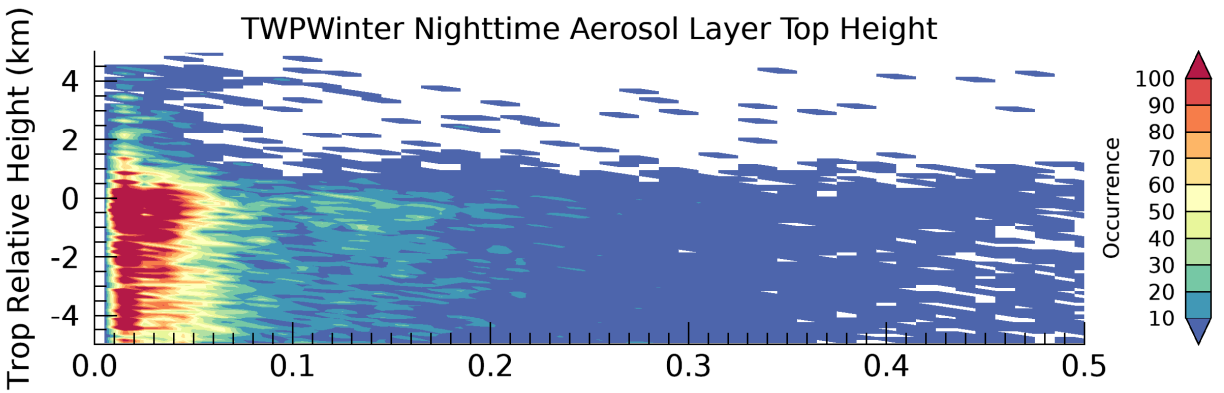
Cold, optically thick clouds

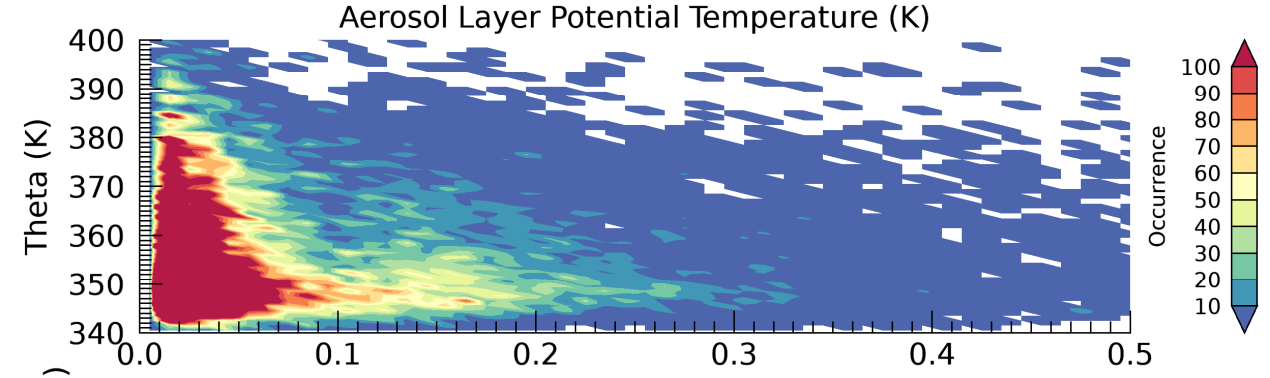
Winter vs Spring: Overshooting Opaque Cloud Layer Thickness

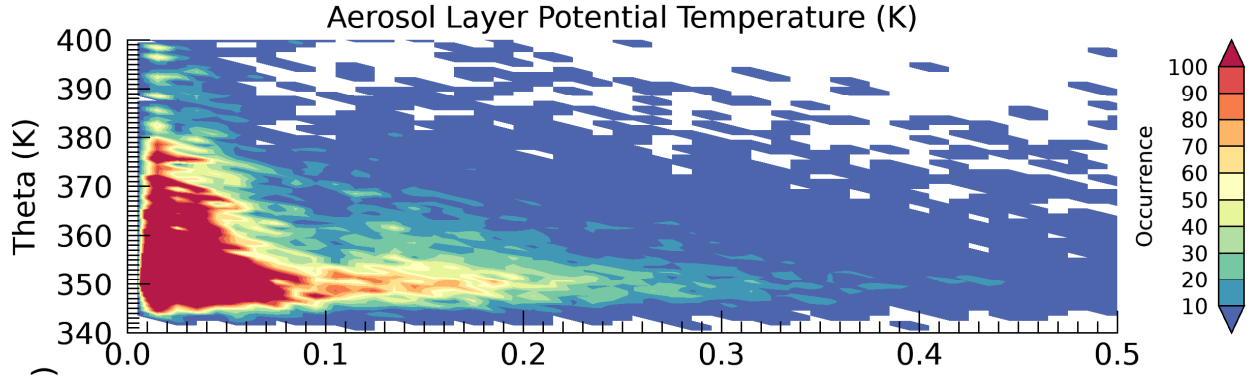


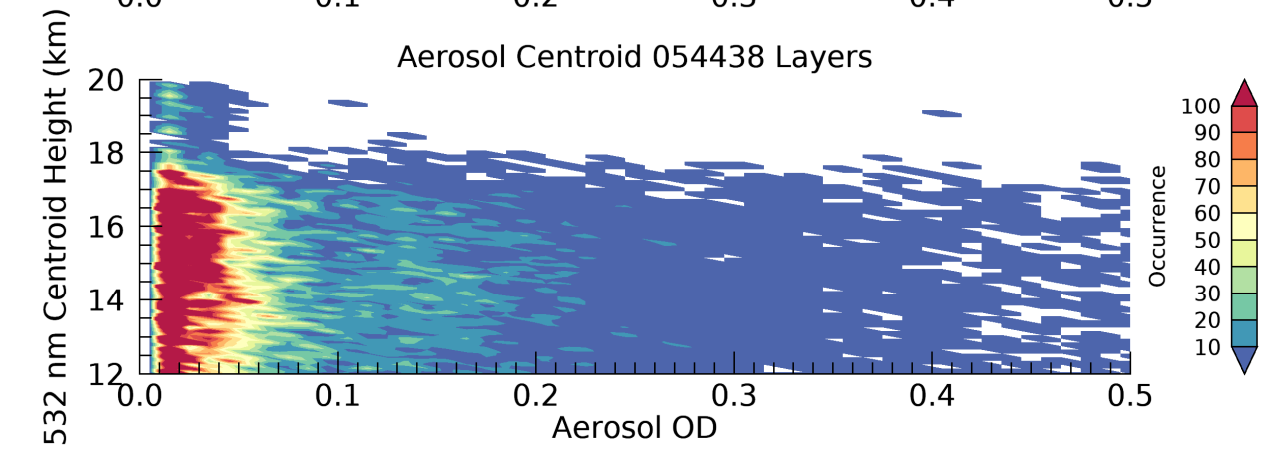
From Luo et al., 2008: Cold high clouds and Warm high clouds; Cold high clouds attenuate the Lidar faster (so they appear to be “thinner”).

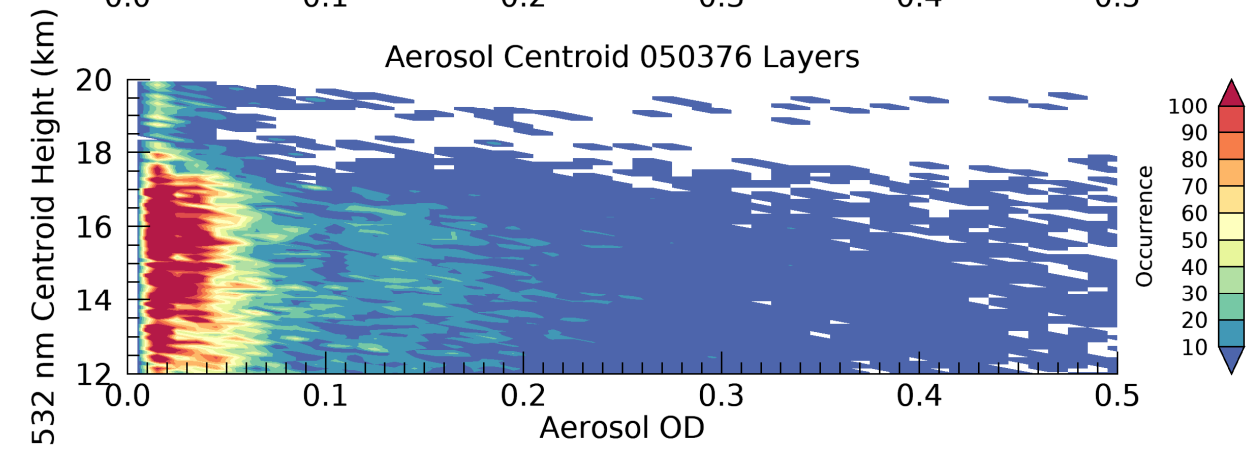

Africa Winter Nighttime Aerosol Layer Top Height
Trop Relative Height (km)
4
2
0
-2
-4
0.0
0.1
0.2
0.3
0.4
0.5
Occurrence
100
90
80
70
60
50
40
30
20
10


TWPWinter Nighttime Aerosol Layer Top Height
Trop Relative Height (km)
4
2
0
-2
-4
0.0
0.1
0.2
0.3
0.4
0.5
Occurrence
100
90
80
70
60
50
40
30
20
10

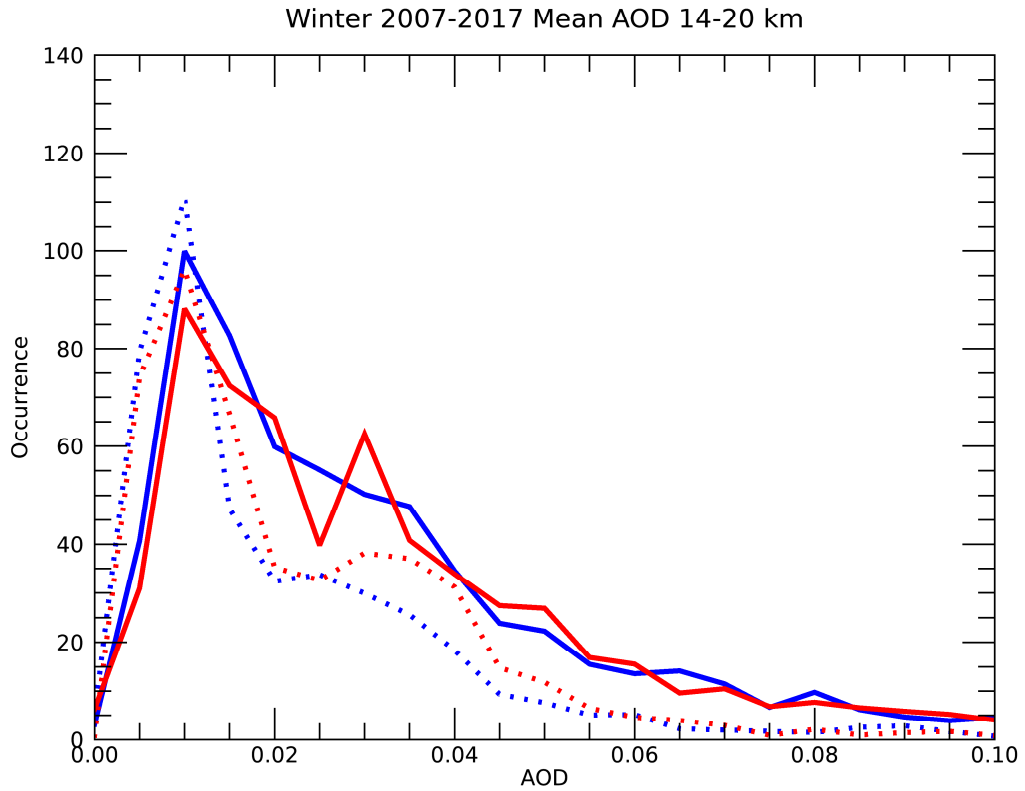

Aerosol Layer Potential Temperature (K)
Theta (K)
400
390
380
370
360
350
340
0.0
0.1
0.2
0.3
0.4
0.5
Occurrence
100
90
80
70
60
50
40
30
20
10


Aerosol Layer Potential Temperature (K)
Theta (K)
400
390
380
370
360
350
340
0.0
0.1
0.2
0.3
0.4
0.5
Occurrence
100
90
80
70
60
50
40
30
20
10

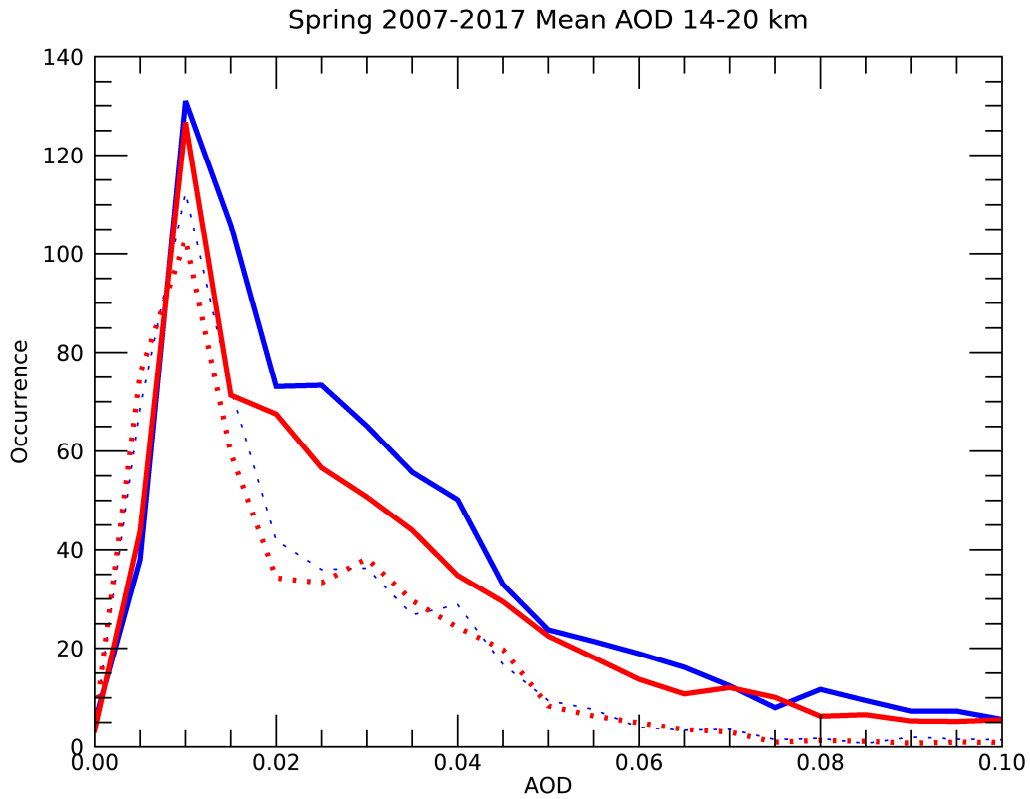

Aerosol Centroid 054438 Layers
532 nm Centroid Height (km)
20
18
16
14
12
0.0
0.1
0.2
0.3
0.4
0.5
Aerosol OD
Occurrence
100
90
80
70
60
50
40
30
20
10


Aerosol Centroid 050376 Layers
532 nm Centroid Height (km)
20
18
16
14
12
0.0
0.1
0.2
0.3
0.4
0.5
Aerosol OD
Occurrence
100
90
80
70
60
50
40
30
20
10

Winter vs Spring: Tropical UTLS Aerosol Optical Depth



AOD; 14-20 km



AOD; 14-20 km

Africa

TWP

Tropospheric (above 14 km)

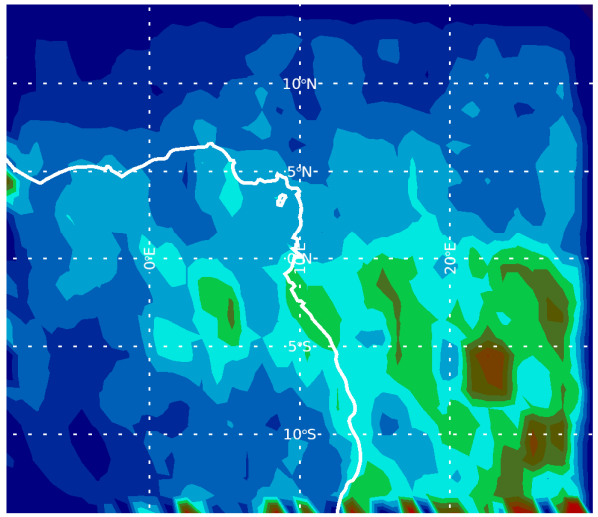
Stratospheric (below 20 km)

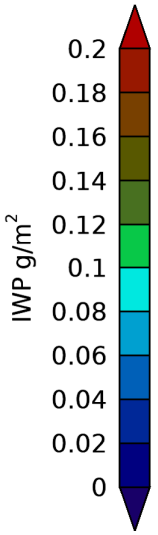
Africa

TWP

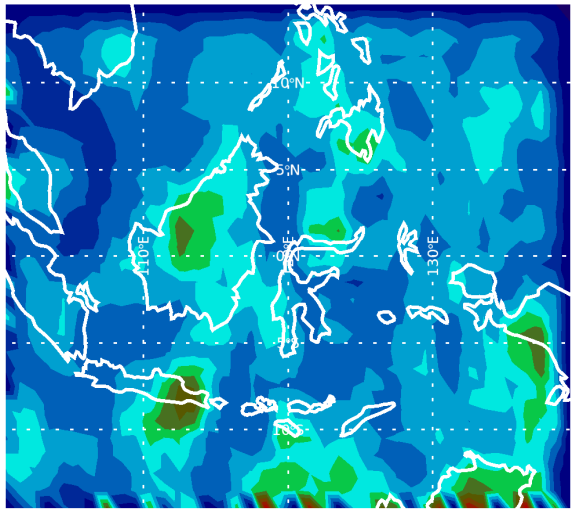
Winter

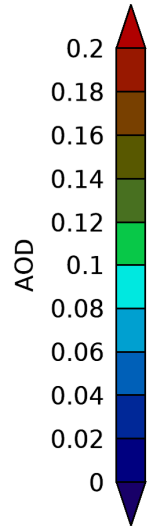
Africa NH Winter 2006-2016 Mean AOD 14-20 km





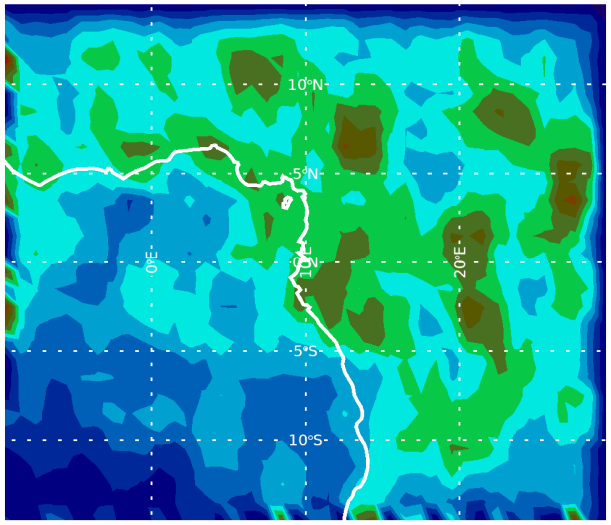
TWP NH Winter 2006-2016 Mean AOD 14-20 km

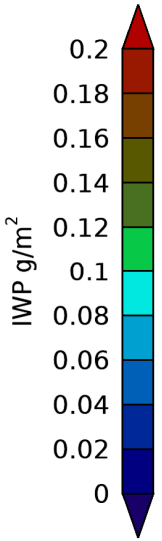




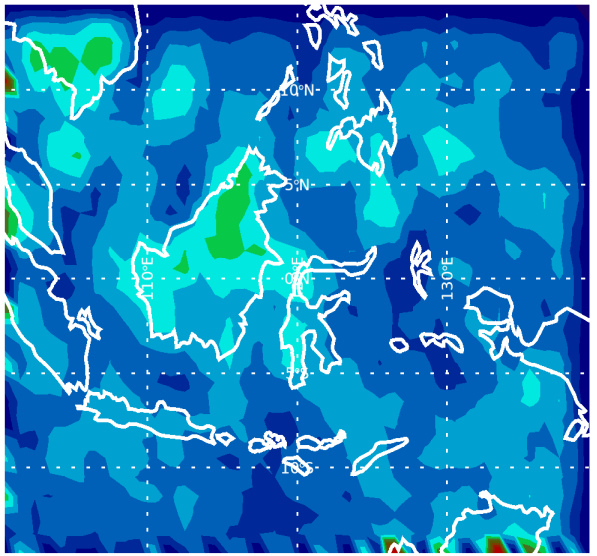
Spring

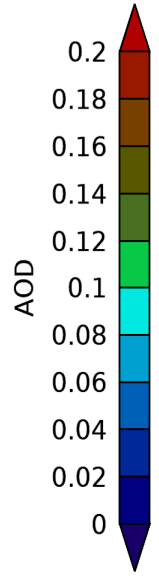
Africa Spring 2007-2017 Mean AOD 14-20 km





TWP Spring 2007-2017 Mean AOD 14-20 km

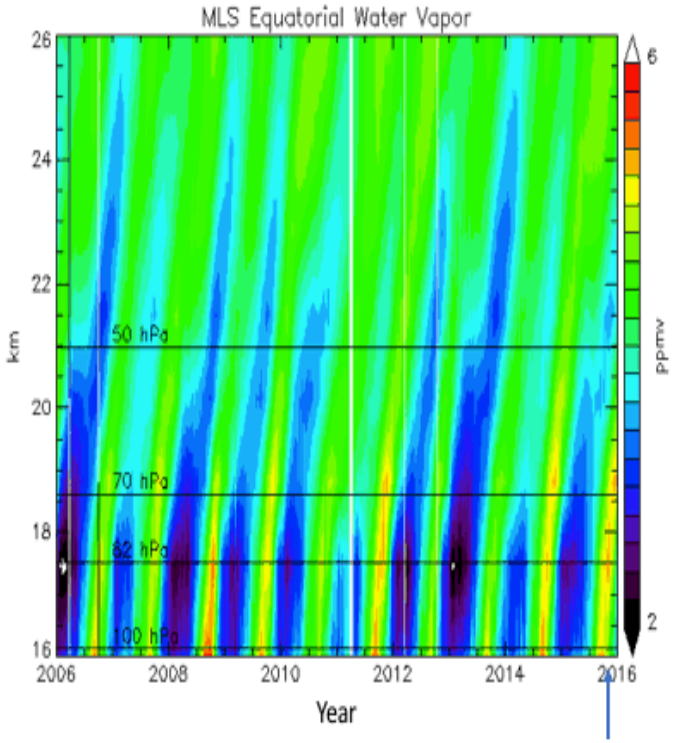




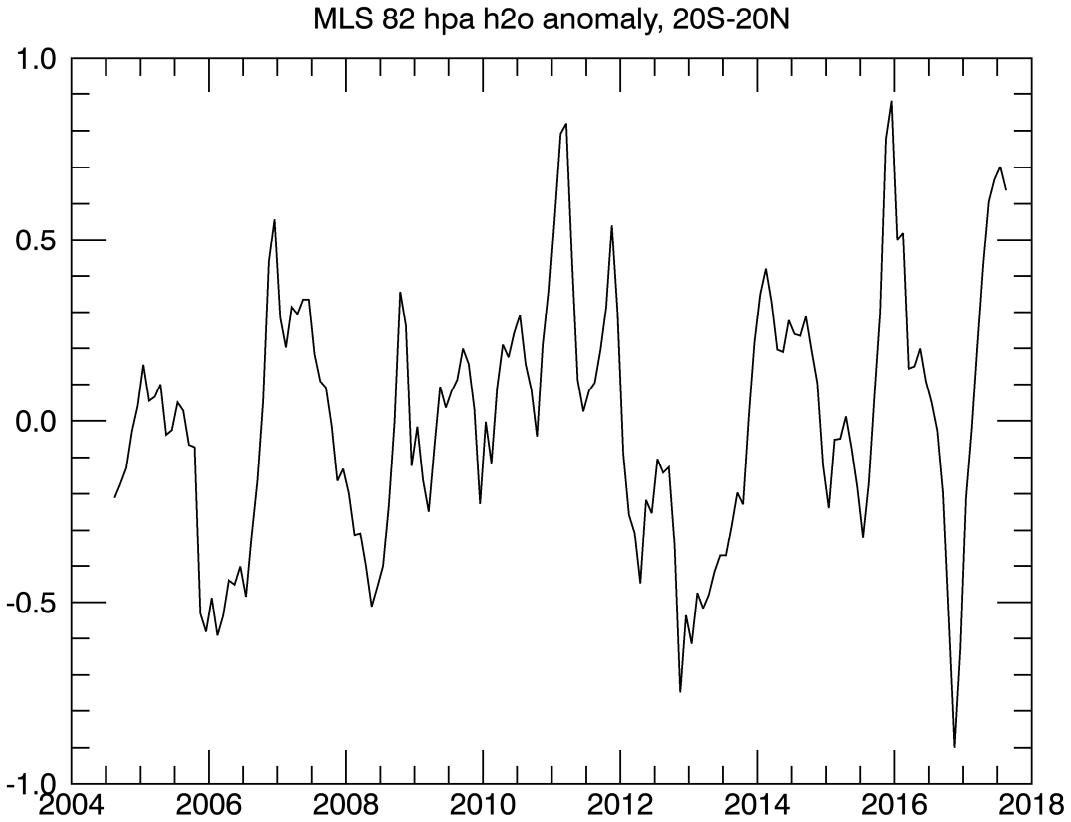
TWP Spring 2007-2017 Mean AOD 14-20 km

MLS water vapor, stratospheric “Tape Recorder”

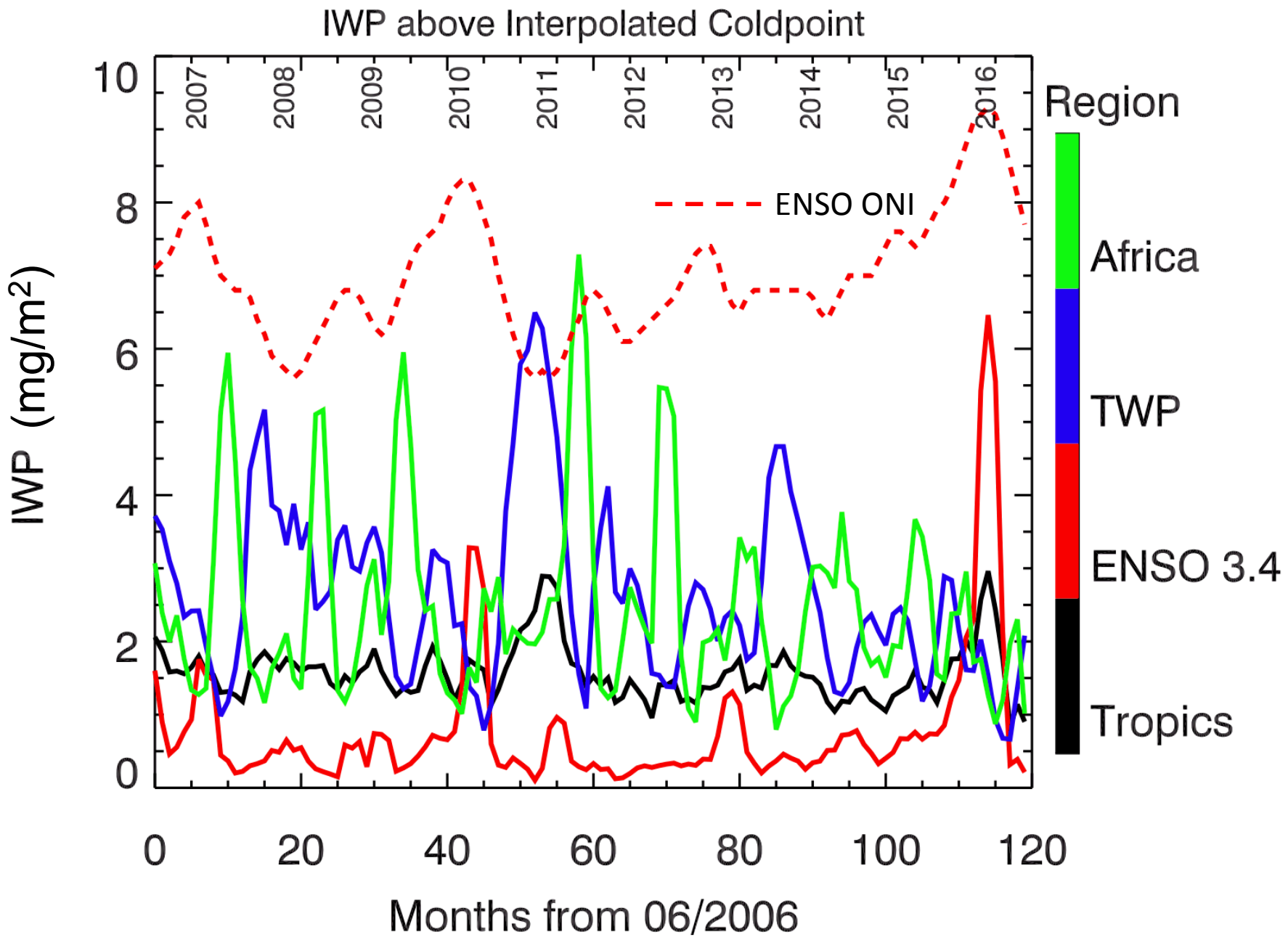
MLS water vapor, stratospheric “Tape Recorder”



Plot by Mark Schoeberl

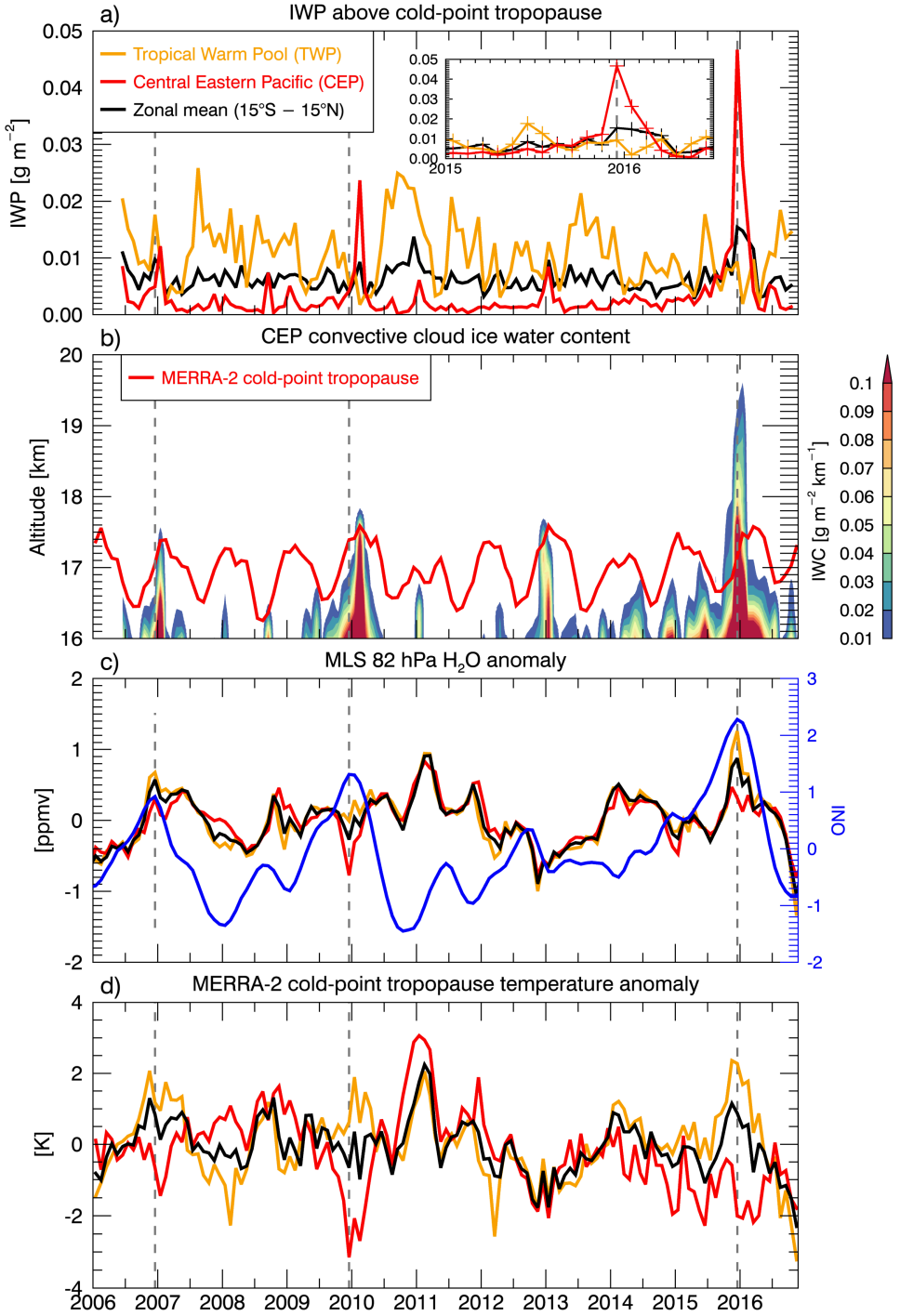


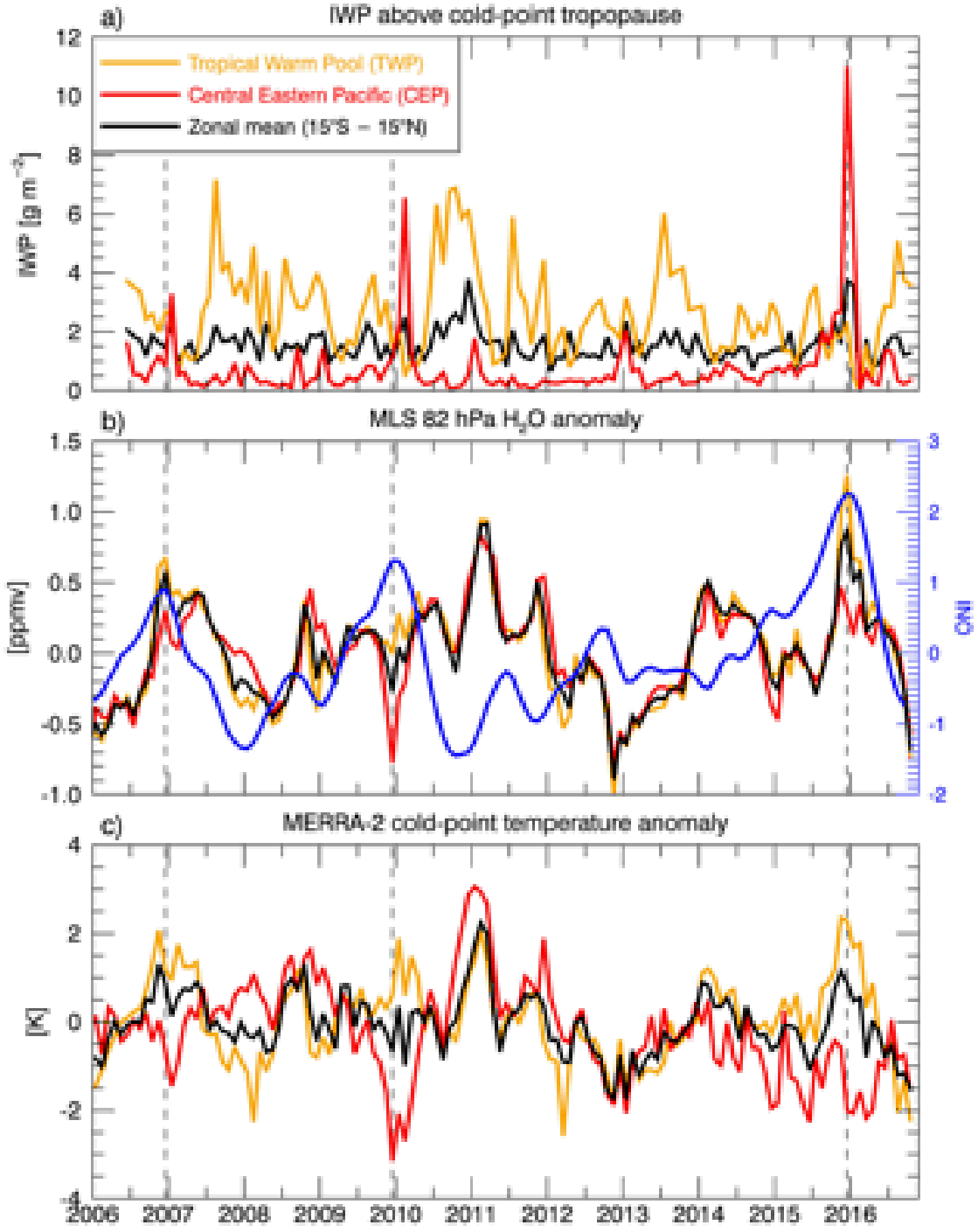
Plot by Sean Davis


IWP above Interpolated Coldpoint
IWP (mg/m²)
10
8
6
4
2
0
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
ENSO ONI
0
20
40
60
80
100
120
Months from 06/2006
Region
Africa
TWP
ENSO 3.4
Tropics

Summary of Ideas:

- Observational evidence suggests that with deep convection there may be transport of cloud ice, aerosols into the lower stratosphere, impact to water vapor, as well as changes in local dynamics (temperature structure).
- Convection matters! Non-equilibrium conditions, local perturbations impact the larger scales. Models need to do a better job with convection.
- Convection can hydrate and dehydrate (Schoeberl, Jensen, Ueyama).
- Residual aerosols (dust) can nucleate new clouds in the TTL.
- Increasing lower stratospheric water vapor is a positive feedback on surface temperature.


a)
IWP above cold-point tropopause
Tropical Warm Pool (TWP)
Central Eastern Pacific (CEP)
Zonal mean (15°S – 15°N)
IWP [g m^{-2}]
b)
CEP convective cloud ice water content
MERRA-2 cold-point tropopause
Altitude [km]
IWC [g m^{-2} km^{-1}]
c)
MLS 82 hPa H_2O anomaly
[ppmv]
ONI
d)
MERRA-2 cold-point tropopause temperature anomaly
[K]
2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016



Regional Time Series
A-Train Time Frame (2006 – 2016)

a) CALIOP ice water path (above the interpolated MERRA-2 cold-point)
b) MLS 82-hPa water vapor anomaly
c) MERRA-2 cold-point temperature anomaly

Key:
Blue line is the ENSO ONI index
Black lines are the 15S – 15N zonal mean
Red lines are the Central Pacific
Orange lines are the Tropical Warm Pool (Western Pacific)