Characteristics of Multiple Tropopauses in Data Assimilation Systems as a Context for Analysis of Satellite-based Trace Gas Measurements

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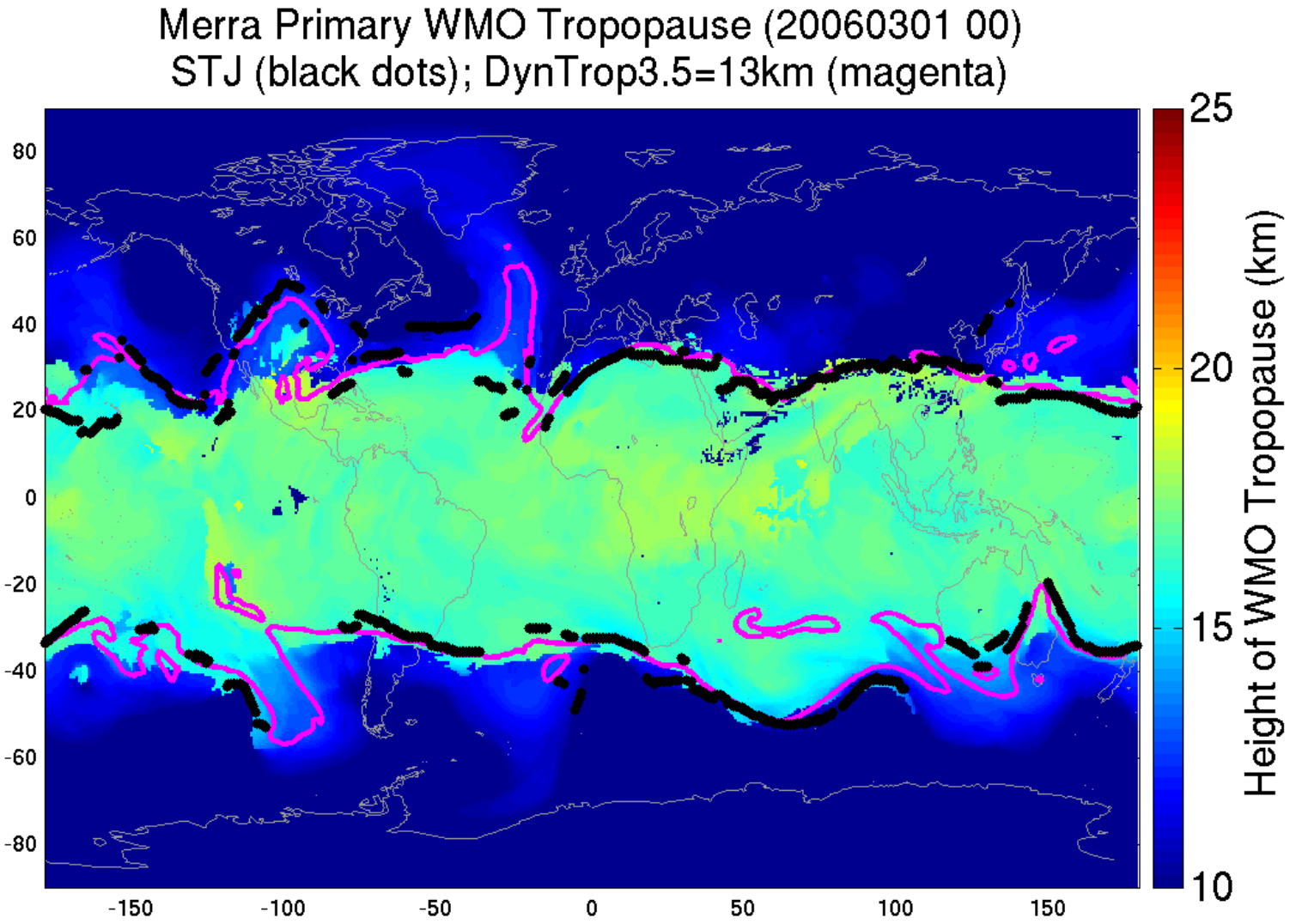
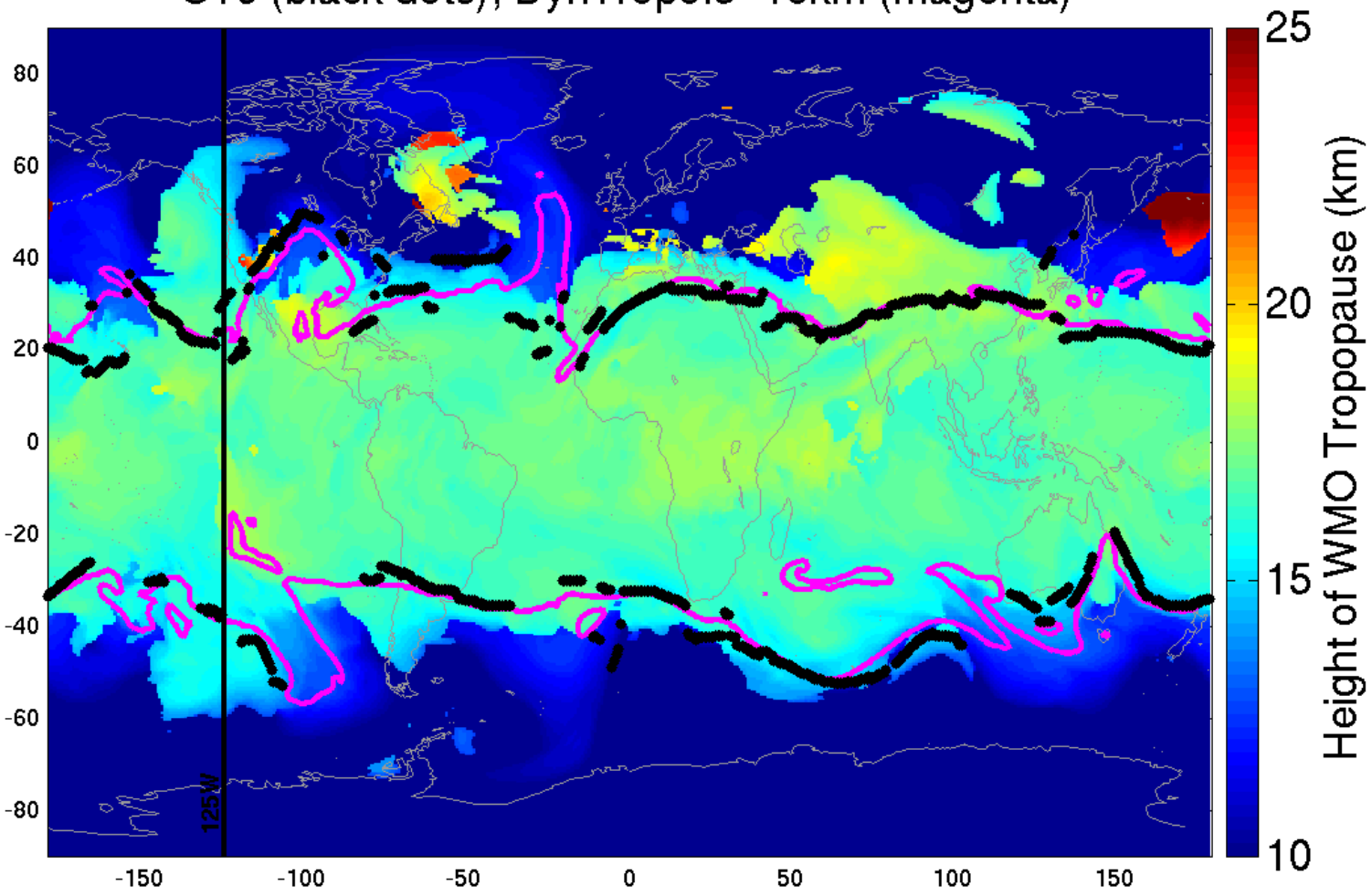
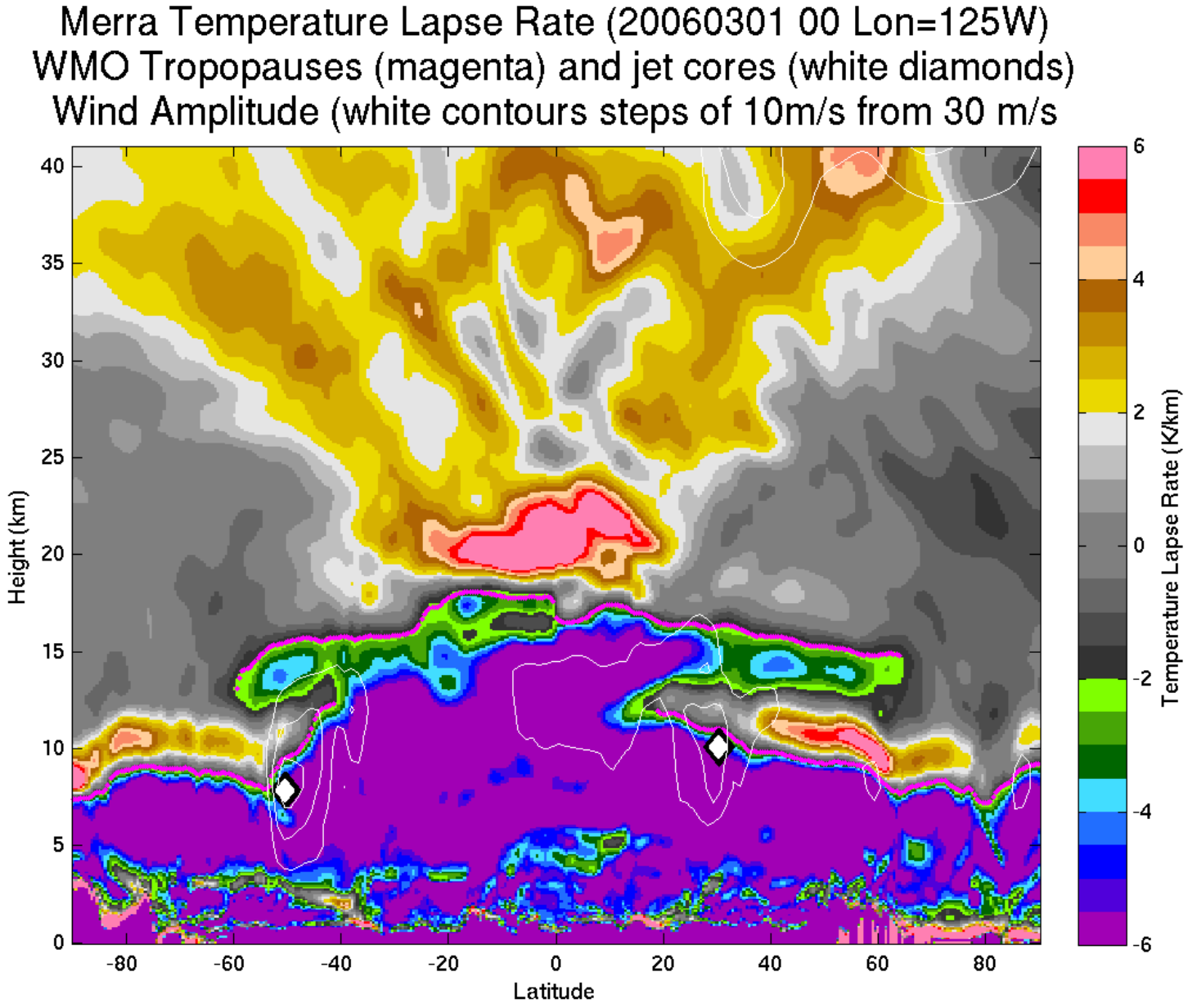
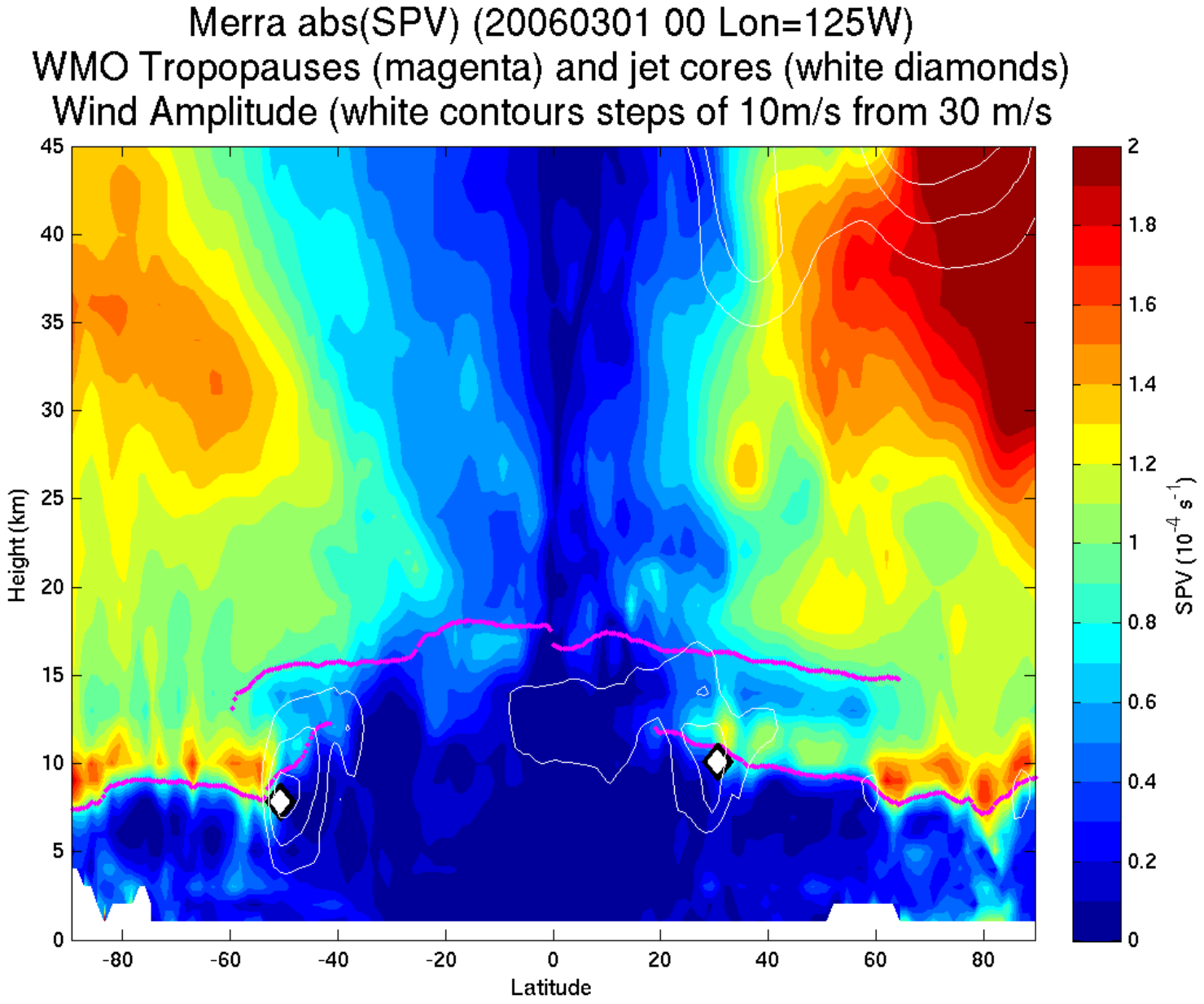
Introduction

- The extra-tropical tropopause region is dynamically complex, with frequent occurrences of multiple tropopauses. Tropopause structure is zonally-asymmetric, time-varying and, along with the UTLS jets, defines barriers and pathways that control UTLS transport.
- Data assimilation systems (GEOS-5.2, ERA-Interim, NCEP-GFS) provide realistic temperature, PV and wind fields from which tropopauses and jets may be identified. These in turn provide a context in which satellite-based measurements of trace gases in the extra-tropical tropopause region may be understood.
- Mid-latitude secondary tropopauses are typically extensions of the tropical tropopause across the subtropical jet. They can cover a large region, at times extending poleward beyond 60 degrees latitude, and sometimes connecting to the tempearture structure of the winter polar subvortex.
- In the upper part of these inter-tropopause layers, above the layer of enhanced static stability, air is found to have characteristics suggesting low-latitude, often tropospheric, origin.
- We examine MLS, HIRDLS and ACE-FTS UTLS trace gas profiles in the context of extra-tropical tropopause and UT jet structures identified from GEOS-5 fields to gain understanding of UTLS trace gas distributions and transport barriers. Some comparisons will be made with products from other data assimilation systems.

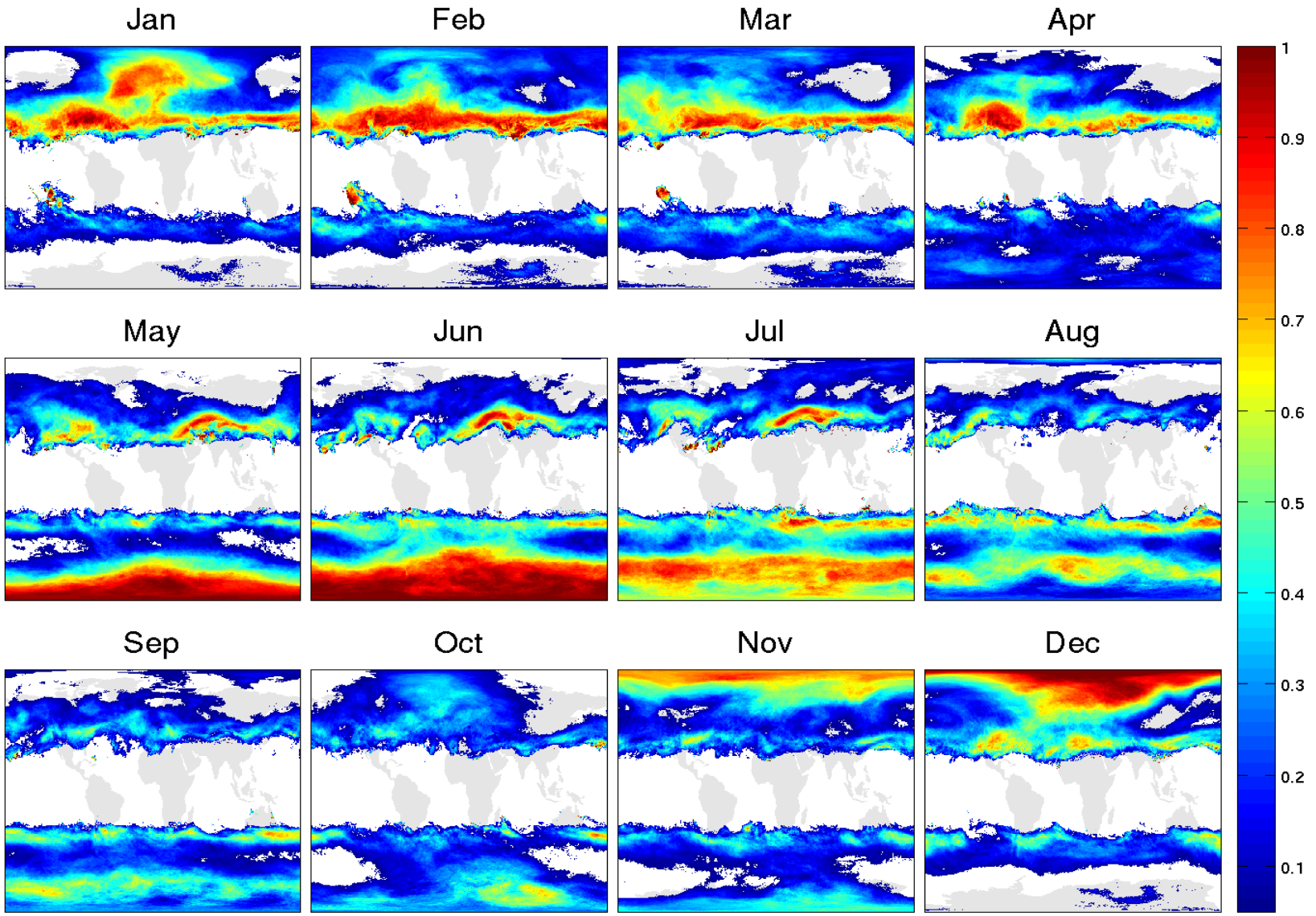

Merra Primary WMO Tropopause (20060301 00)
STJ (black dots); DynTrop3.5=13km (magenta)
80
60
40
20
0
-20
-40
-60
-80
-150
-100
-50
0
50
100
150
25
20
15
10
Height of WMO Tropopause (km)


Merra Multiple WMO Tropopauses (3 on 2 on 1) (20060301 00)
STJ (black dots); DynTrop3.5=13km (magenta)
80
60
40
20
0
-20
-40
-60
-80
125W
-150
-100
-50
0
50
100
150
25
20
15
10
Height of WMO Tropopause (km)

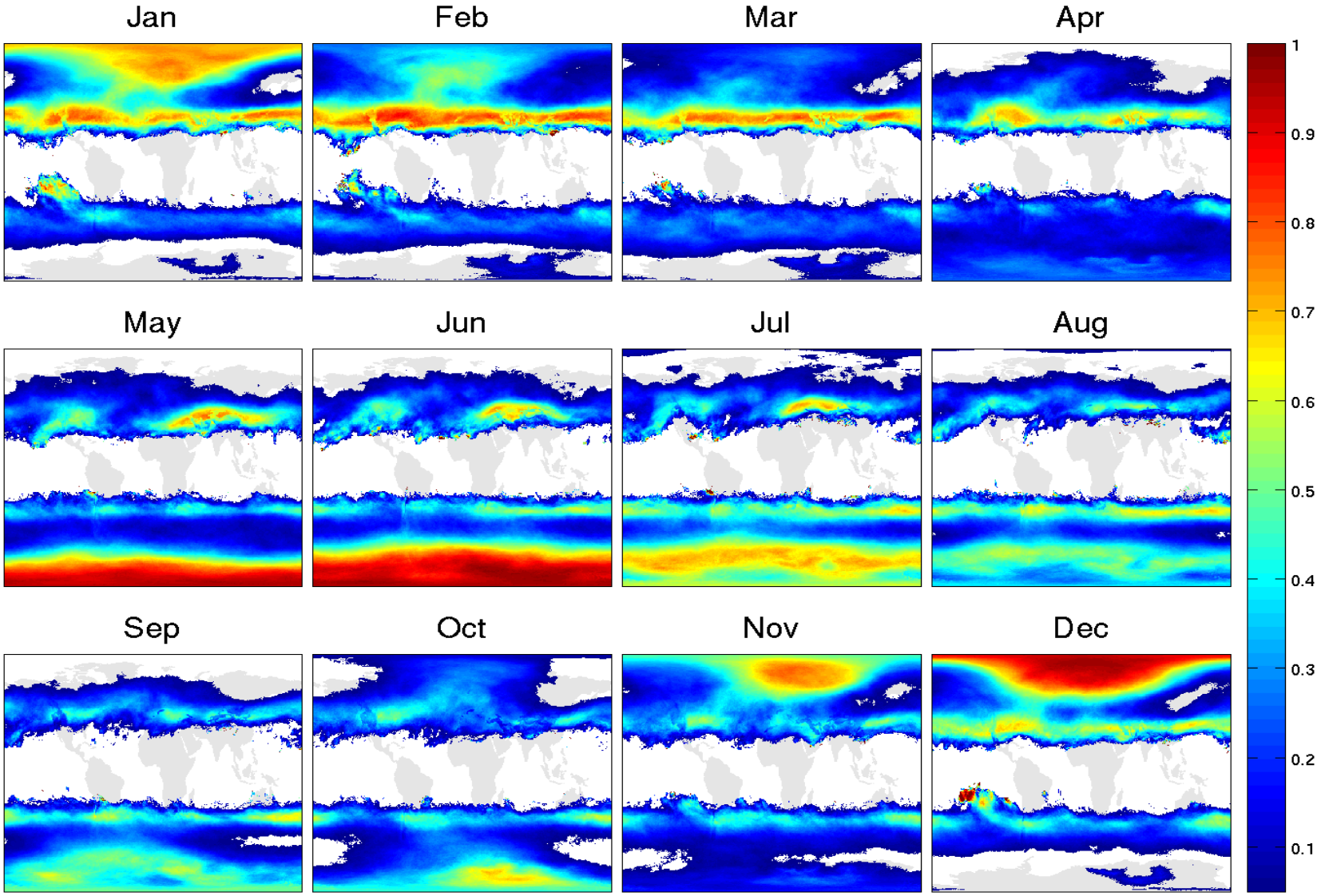

Merra Temperature Lapse Rate (20060301 00 Lon=125W)
WMO Tropopauses (magenta) and jet cores (white diamonds)
Wind Amplitude (white contours steps of 10m/s from 30 m/s
Height (km)
0
5
10
15
20
25
30
35
40
-80
-60
-40
-20
0
20
40
60
80
Latitude
6
4
2
0
-2
-4
-6
Temperature Lapse Rate (K/km)


Merra abs(SPV) (20060301 00 Lon=125W)
WMO Tropopauses (magenta) and jet cores (white diamonds)
Wind Amplitude (white contours steps of 10m/s from 30 m/s
Height (km)
Latitude
SPV (10^{-4} s^{-1})
0
5
10
15
20
25
30
35
40
45
-80
-60
-40
-20
0
20
40
60
80
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2

Merra 2006 Multiple Tropopause Occurance Rate



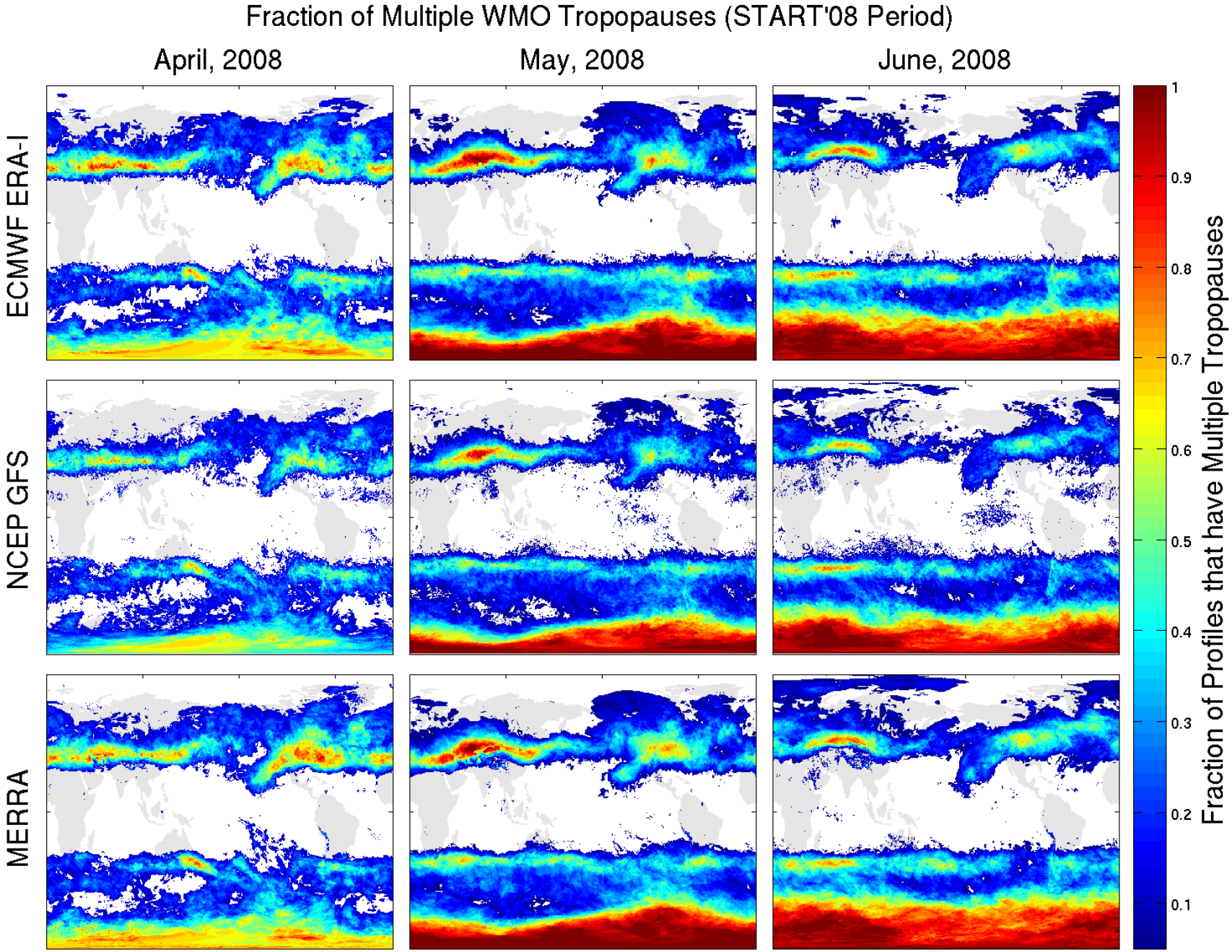
Merra 2005—2010 Multiple Tropopause Occurance Rate



Analyses from which DMPs are being produced (Tropopauses and Jets)

- MERRA
  - GMAO GEOS-5.2 30-year reanalysis
  - 540x361x72 model levels
  - PV is interpolated from 288x144x42 fixed pressure levels
- ECMWF ERA-Interim
  - 480x241x60
  - Currently processed for 2011 and START08 period
- NCEP GFS
  - Forecast system provided for START08 on 47 fixed pressure surfaces
  - 1152x576x47

- Analyses have been processed using DMP system described by Manney to identify to produce a host of derived products including
  - WMO and dynamical tropopauses
  - UT and stratospheric jet cores and edges


Fraction of Multiple WMO Tropopauses (START'08 Period)
April, 2008
May, 2008
June, 2008
ECMWF ERA-I
NCEP GFS
MERRA
Fraction of Profiles that have Multiple Tropopauses
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1

25-May-2008 12

25-May-2008 12

ECMWF ERA-Interim

NCEP GFS

GMAO MERRA

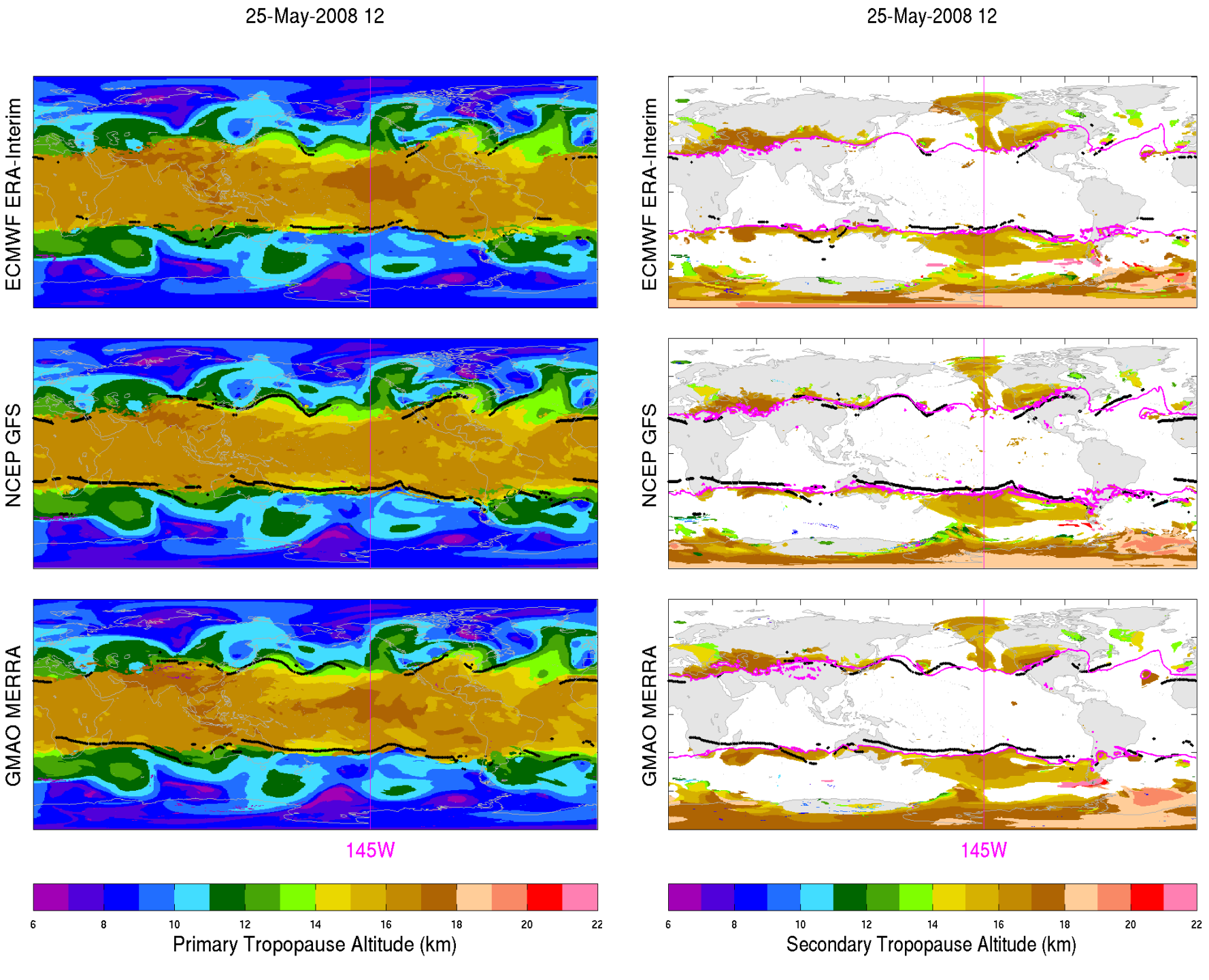
145W

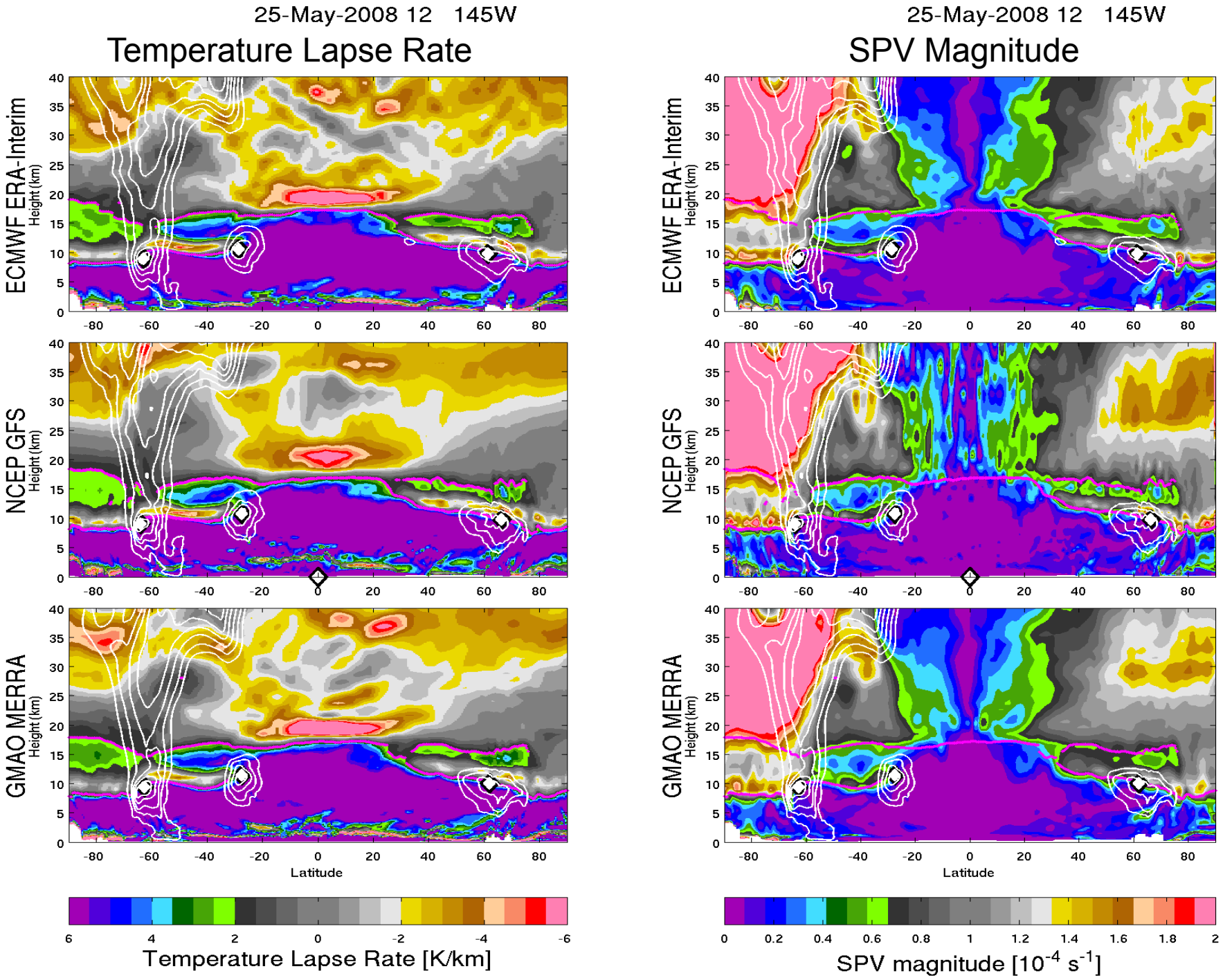
8 10 12 14 16 18 20

Primary Tropopause Altitude (km)

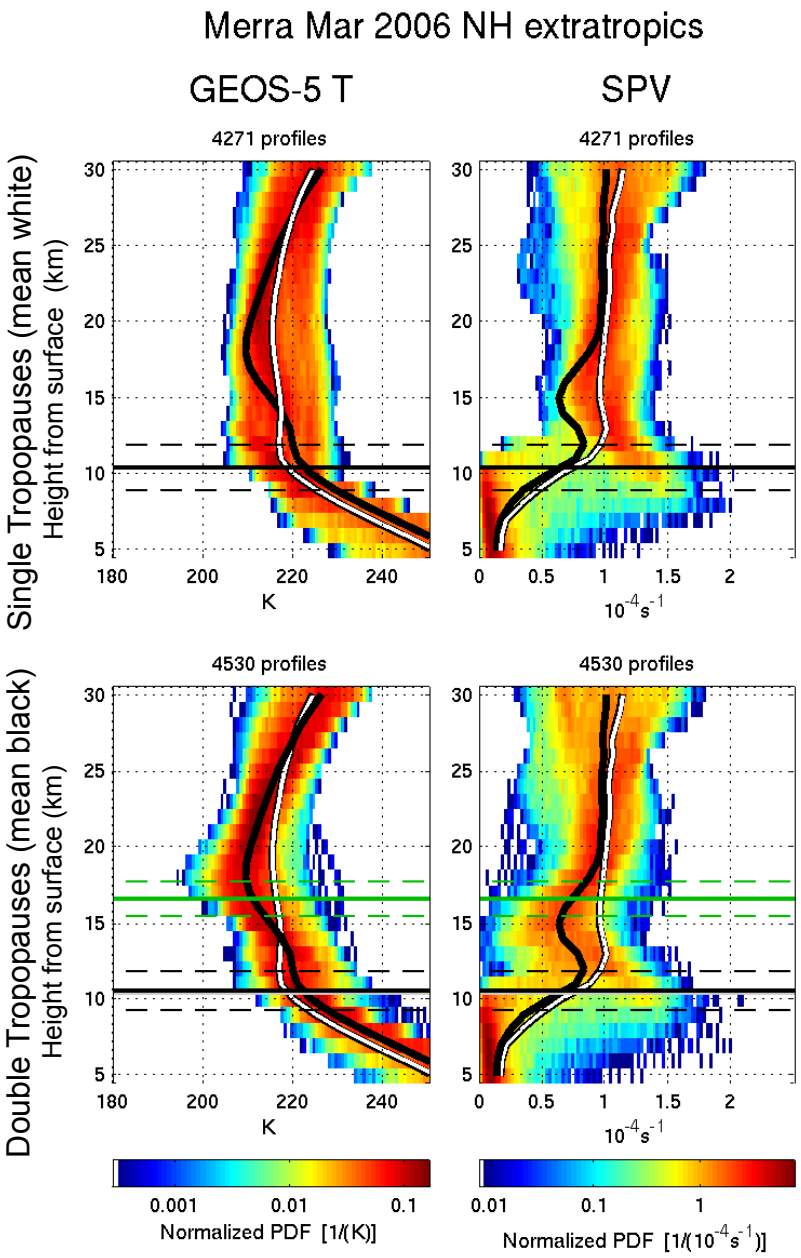
8 10 12 14 16 18 20

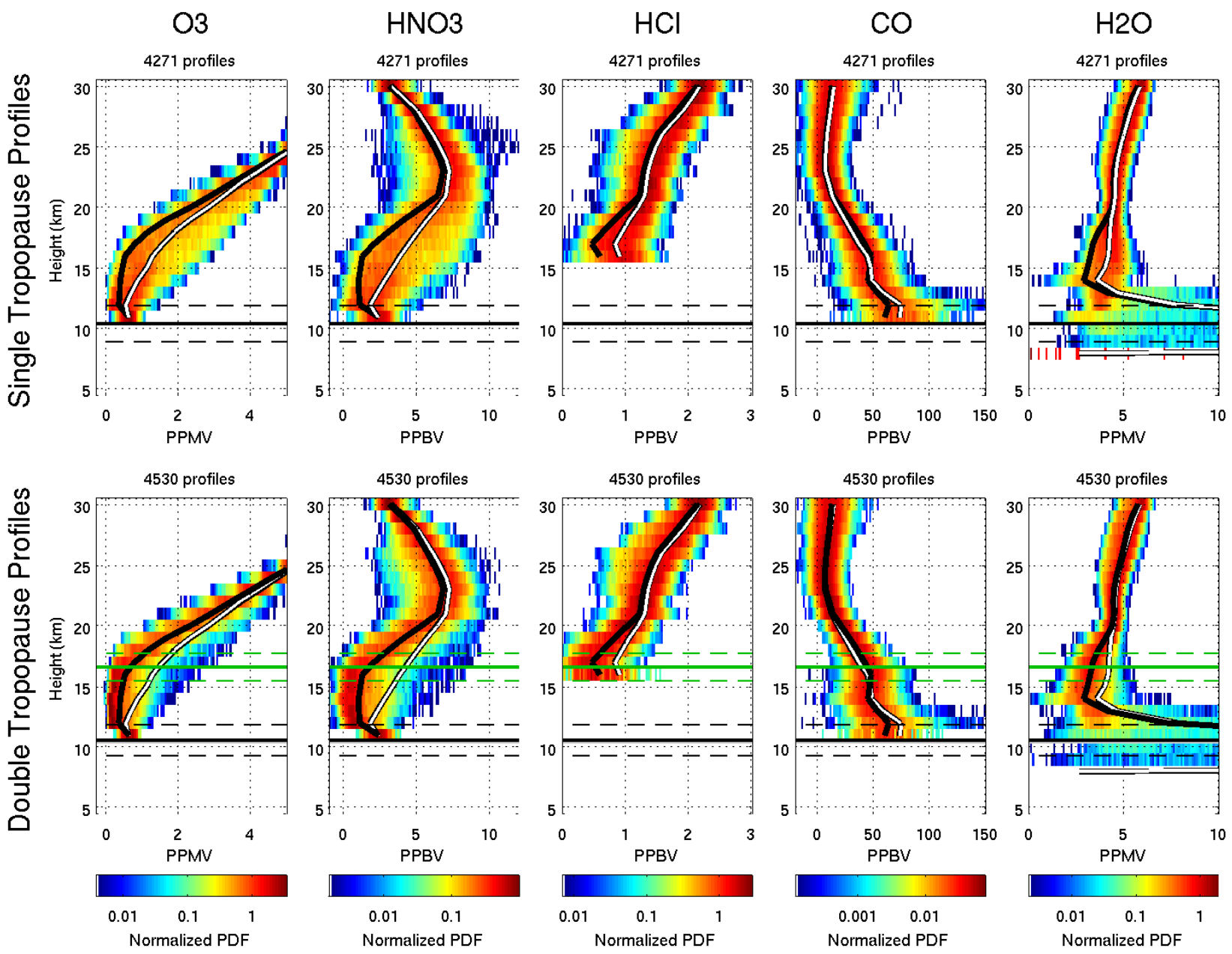
Secondary Tropopause Altitude (km)

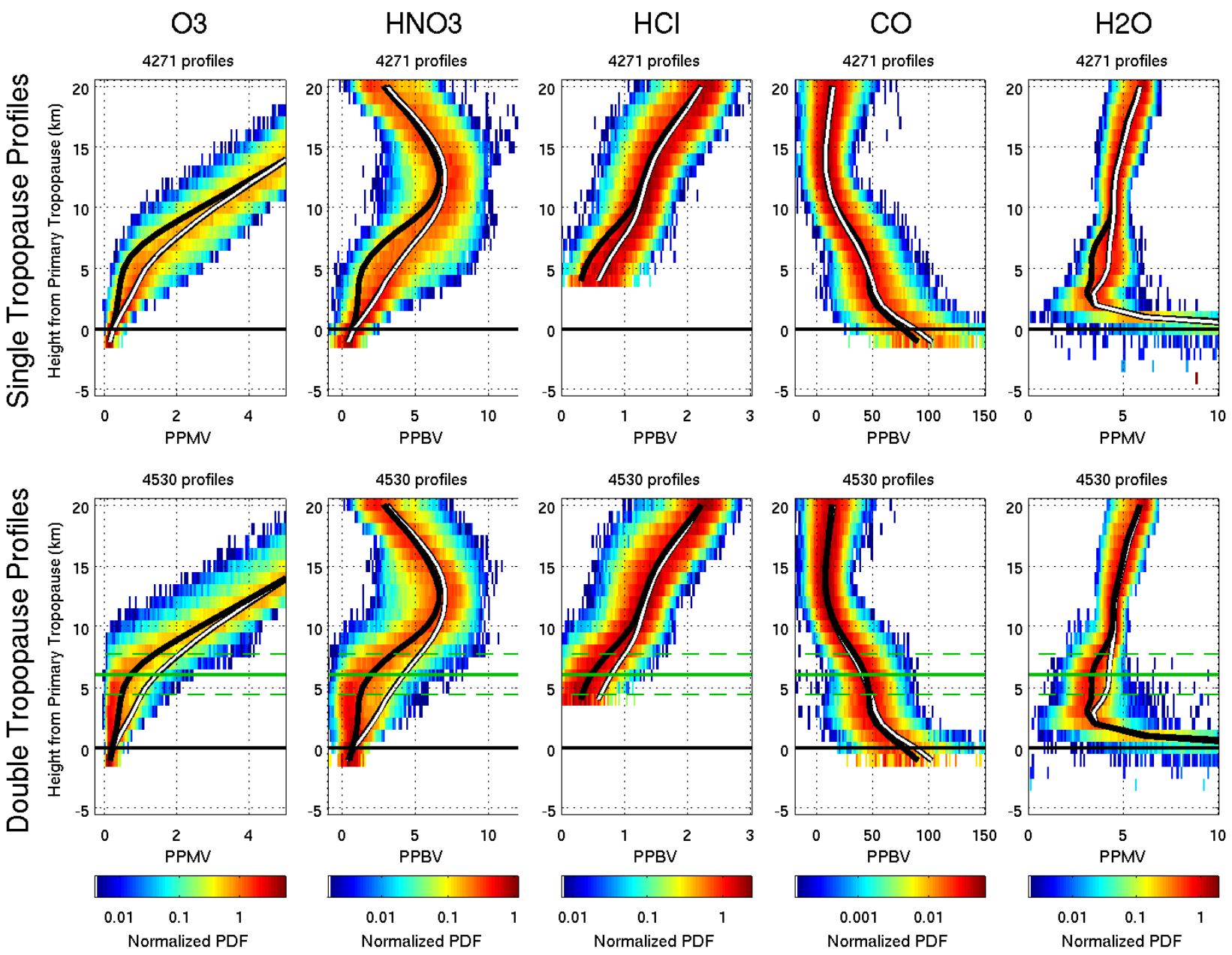

25-May-2008 12
25-May-2008 12
ECMWF ERA-Interim
NCEP GFS
GMAO MERRA
ECMWF ERA-Interim
NCEP GFS
GMAO MERRA
145W
145W
6
8
10
12
14
16
18
20
22
Primary Tropopause Altitude (km)
6
8
10
12
14
16
18
20
22
Secondary Tropopause Altitude (km)


25-May-2008 12 145W
Temperature Lapse Rate
25-May-2008 12 145W
SPV Magnitude
ECMWF ERA-Interim
NCEP GFS
GMAO MERRA
Height (km)
Latitude
Temperature Lapse Rate [K/km]
SPV magnitude [10^-4 s^-1]

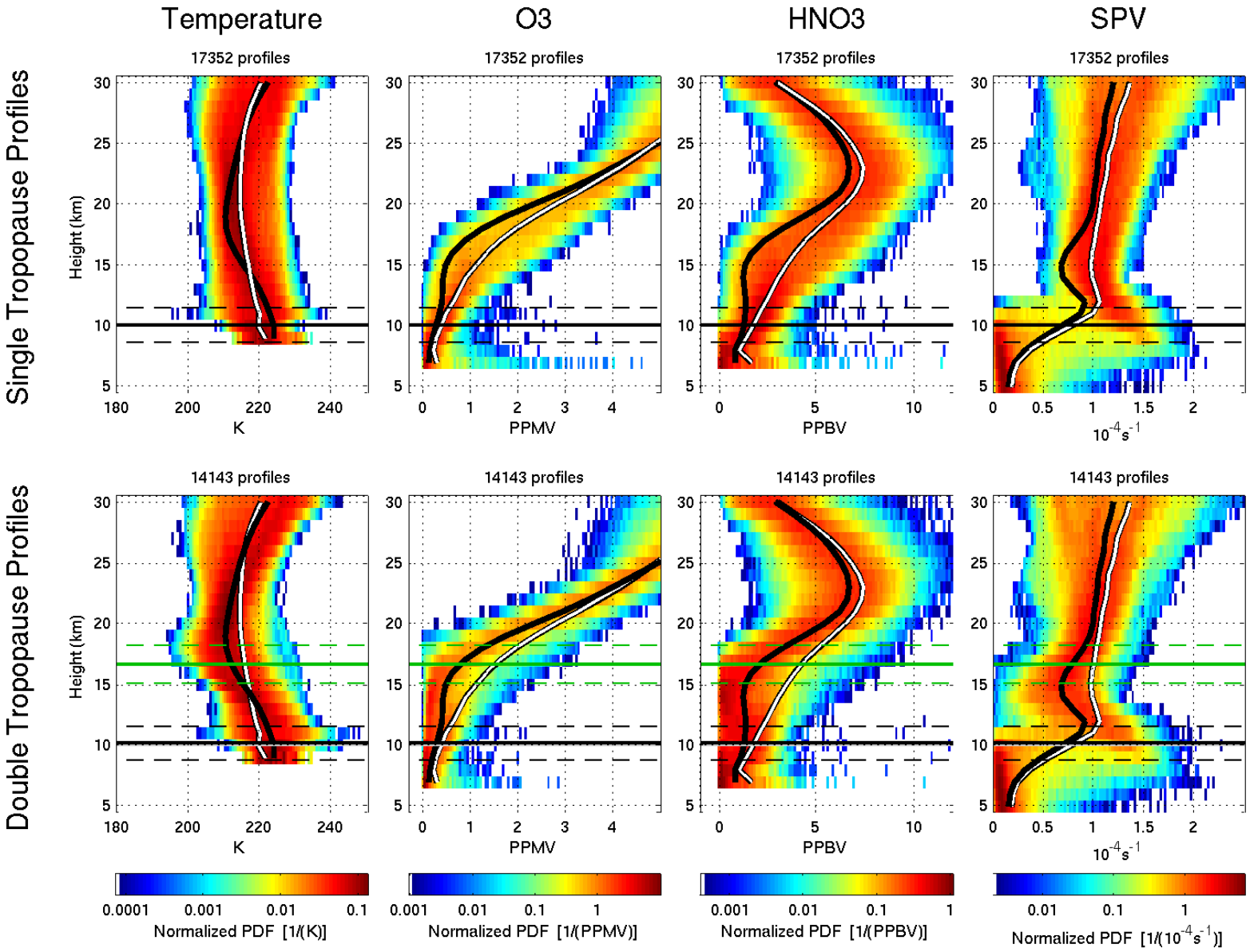
- Merra temperature and SPV are shown for single-tropopause (upper panels) and double-tropopause (lower panels) cases.
- Colors are histograms (log scale) giving an estimate of the PDFs. A tenfold drop in color would slightly more than 2 sigma for a Gaussian PDF.
- The black curves are the mean of the double-tropopause cases, the white are the single tropopause cases. They are repeated on each other's plots (underneath where they cross.)
- Black horizontal lines indicate the mean height of the primary tropopause. The secondary is in green. Dashed lines are +/- one standard deviation of the tropopause heights.



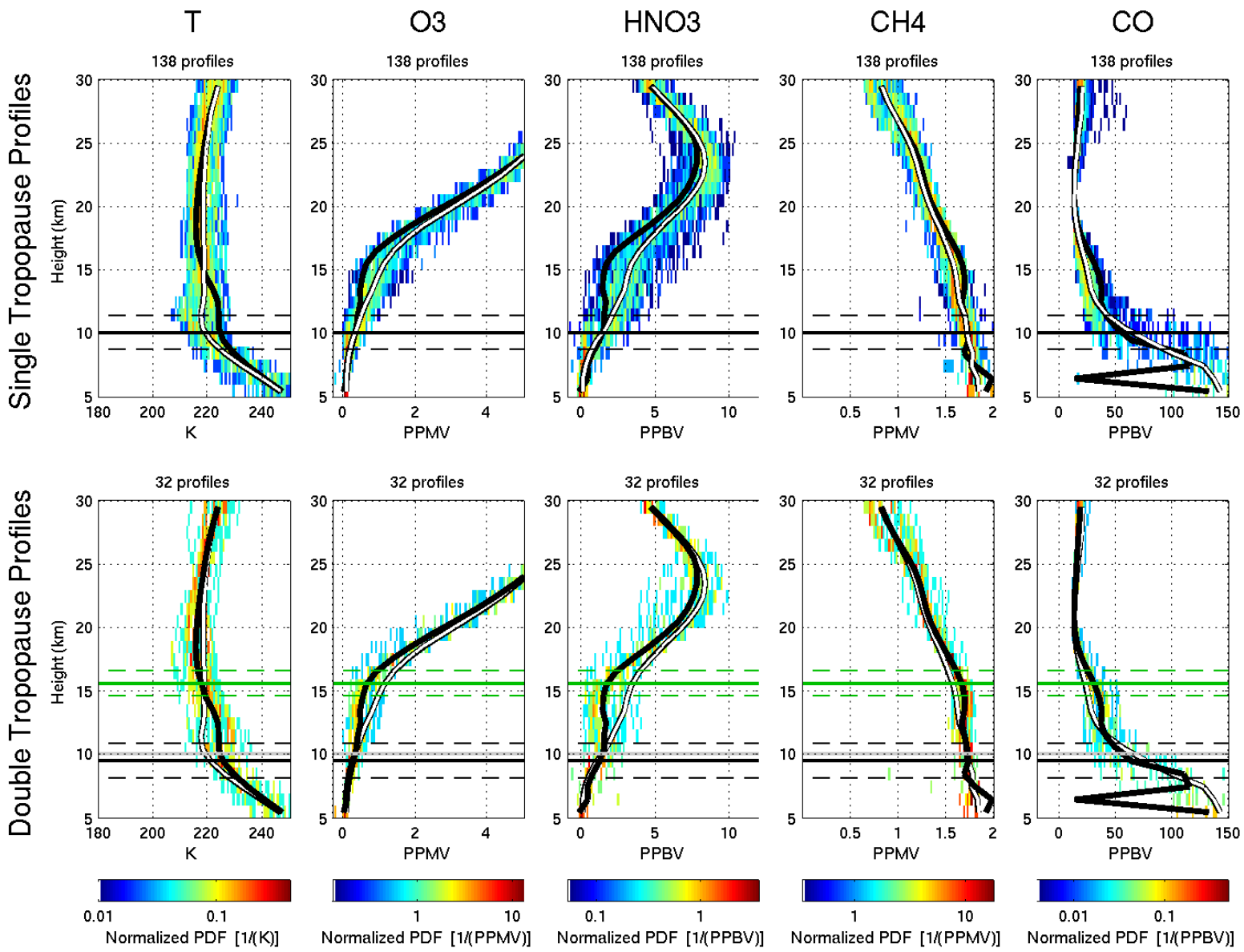

MLS fields March 2006 NH extratropics excluding sub-Vortex
O3
HNO3
HCl
CO
H2O
Single Tropopause Profiles
Double Tropopause Profiles
4271 profiles
4530 profiles
Height (km)
PPMV
PPBV
Normalized PDF


MLS fields March 2006 NH extratropics excluding sub-Vortex
O3
HNO3
HCl
CO
H2O
Single Tropopause Profiles
Double Tropopause Profiles
4271 profiles
4530 profiles
Height from Primary Tropopause (km)
PPMV
PPBV
Normalized PDF

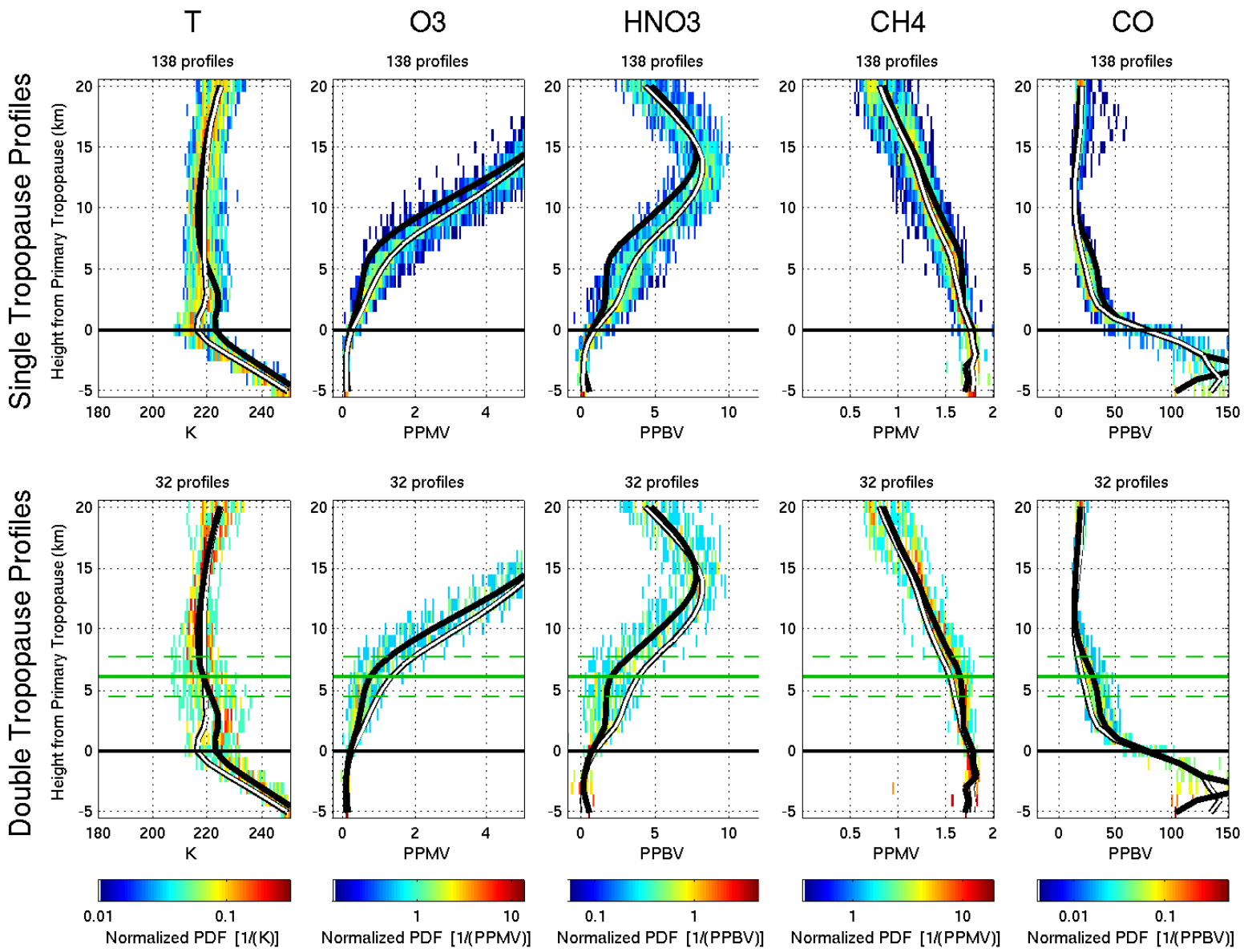
HIRDLS fields, March 2006, NH extratropics excluding sub-Vortex



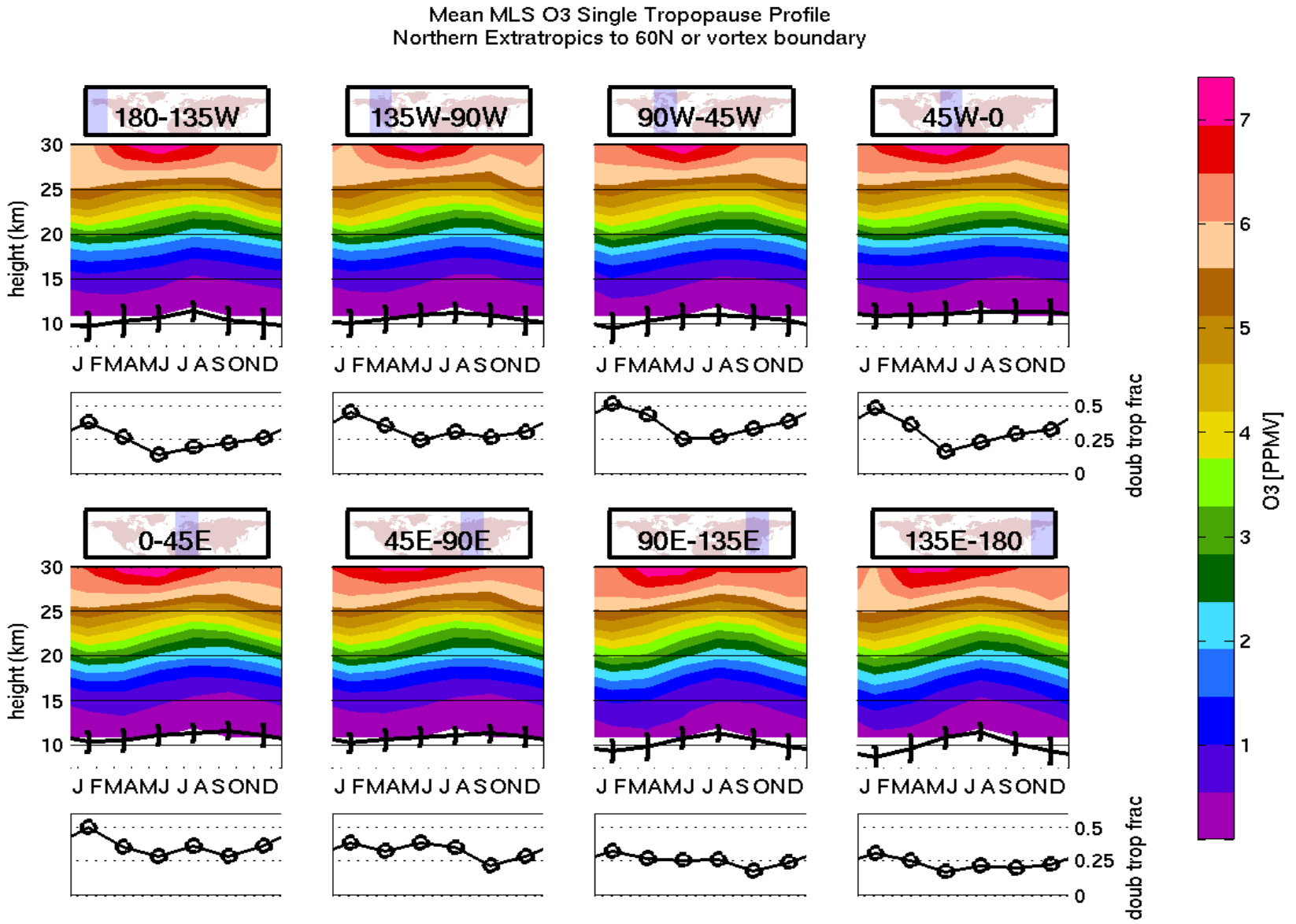
ACE-FTS fields, March Climatology, NH extratropics excluding sub-Vortex

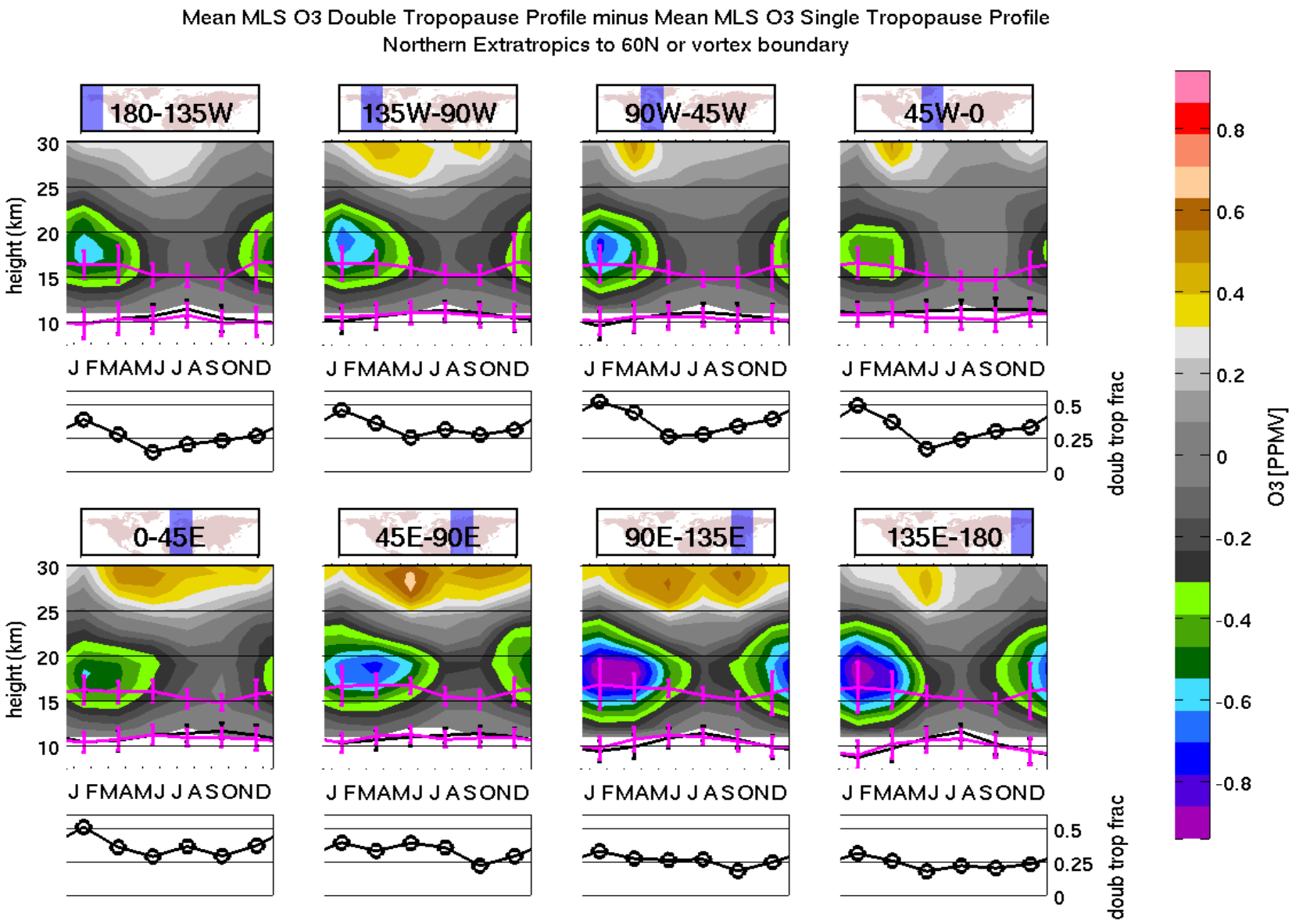


ACE-FTS fields, March Climatology, NH extratropics excluding sub-Vortex



Example of Climatologies being developed: MLS NH mid-latitude Single Trop O3




Mean MLS O3 Double Tropopause Profile minus Mean MLS O3 Single Tropopause Profile
Northern Extratropics to 60N or vortex boundary
180-135W
135W-90W
90W-45W
45W-0
0-45E
45E-90E
90E-135E
135E-180
height (km)
30
25
20
15
10
J FMAMJ J ASOND
0.5
0.25
0
doub trop frac
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
O3 [PPMV]

Conclusions and Further Work

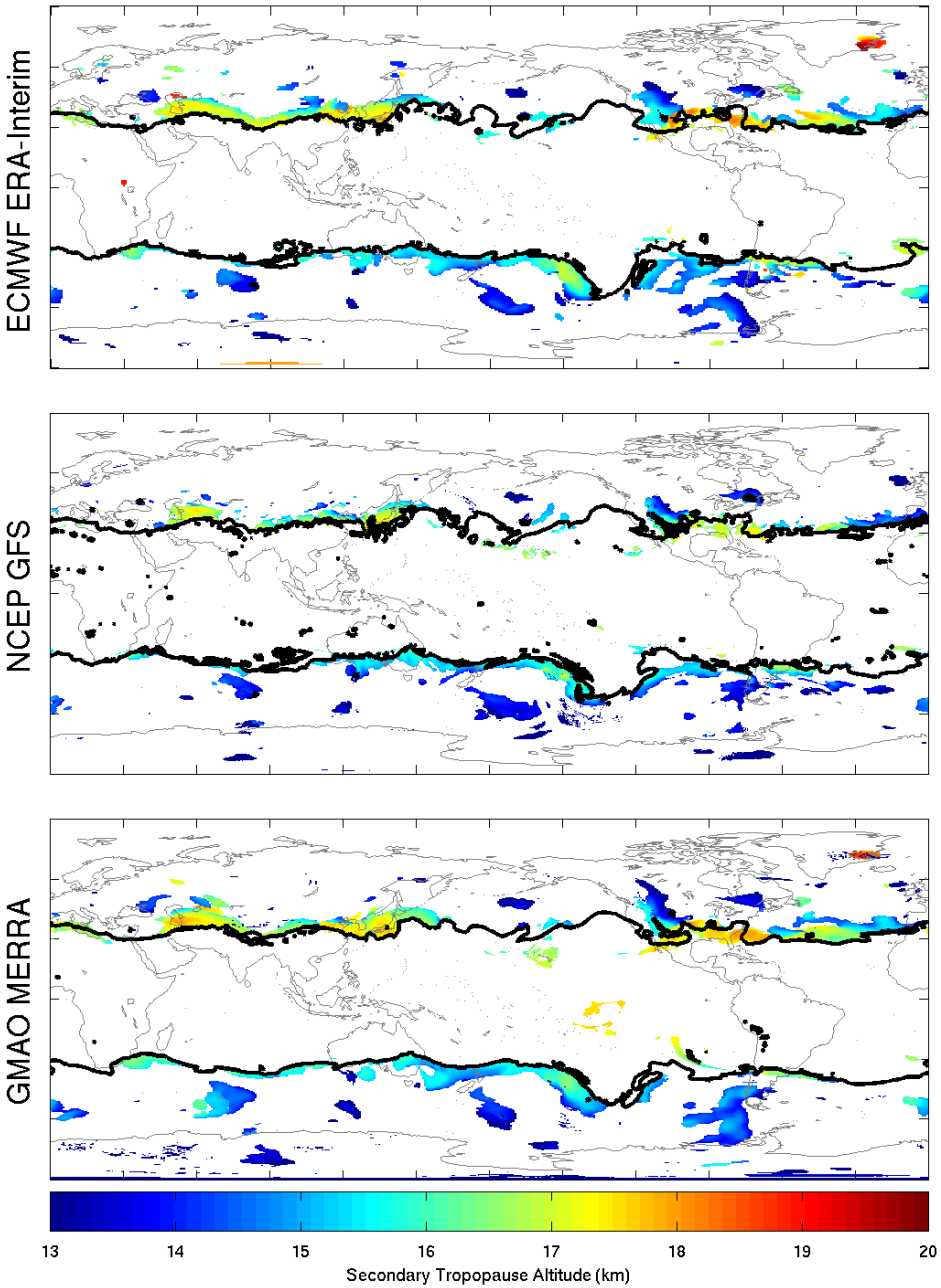
- DMPs from MERRA, ERA-Interim and NCEP-GFS provide generally-consistent multiple tropopauses that are geophysically useful for categorizing airmasses.
- MLS, HIRDLS and ACE-FTS provide a consistent picture of tropical tropospheric air in the layer between double tropopauses in the extratropics.
- In double-tropopause case, stratospheric source gases (O3, HNO3, HCl) have low values, characteristic of the troposphere, up to the level of the secondary tropopause.
- CO values are higher near the secondary tropopause than they are at the level of the primary tropopause and in the layer just above the primary tropopause. This morphology is in both MLS and ACE-FTS.
- ACE-FTS sampling is weighted to high latitudes, limiting the number of profiles of interest.

Further Work

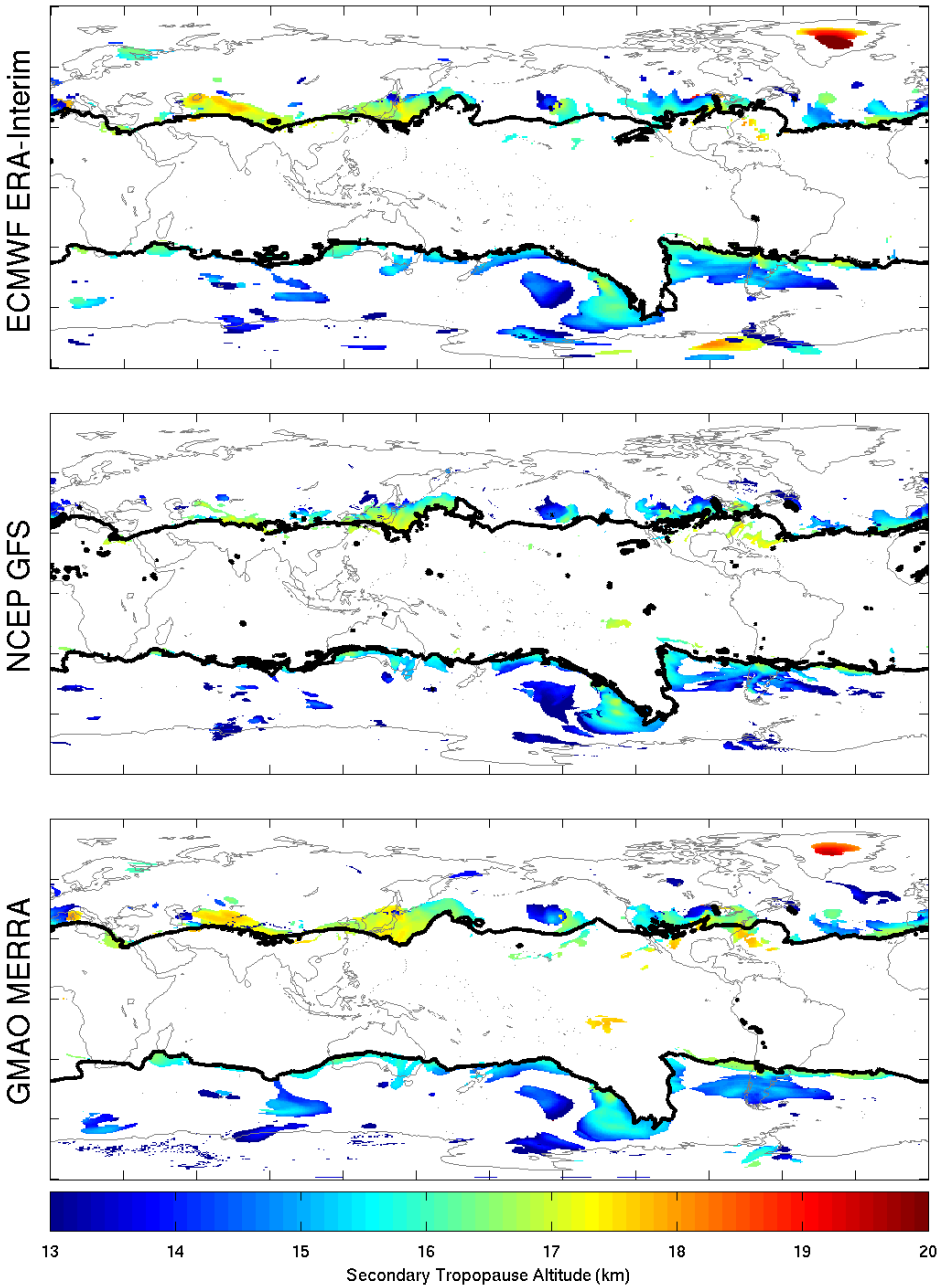
- As DMPs are available, compare climatologies of trace-species sorted by tropopause multiplicity and examine seasonal and inter-annual variability.
- Trajectory analysis will be used to find the origins and destinations (15-day timescale) of parcels of interest in the intra-tropopause layer.

Backup Slides

10-Apr-2008 12



11-Apr-2008 12



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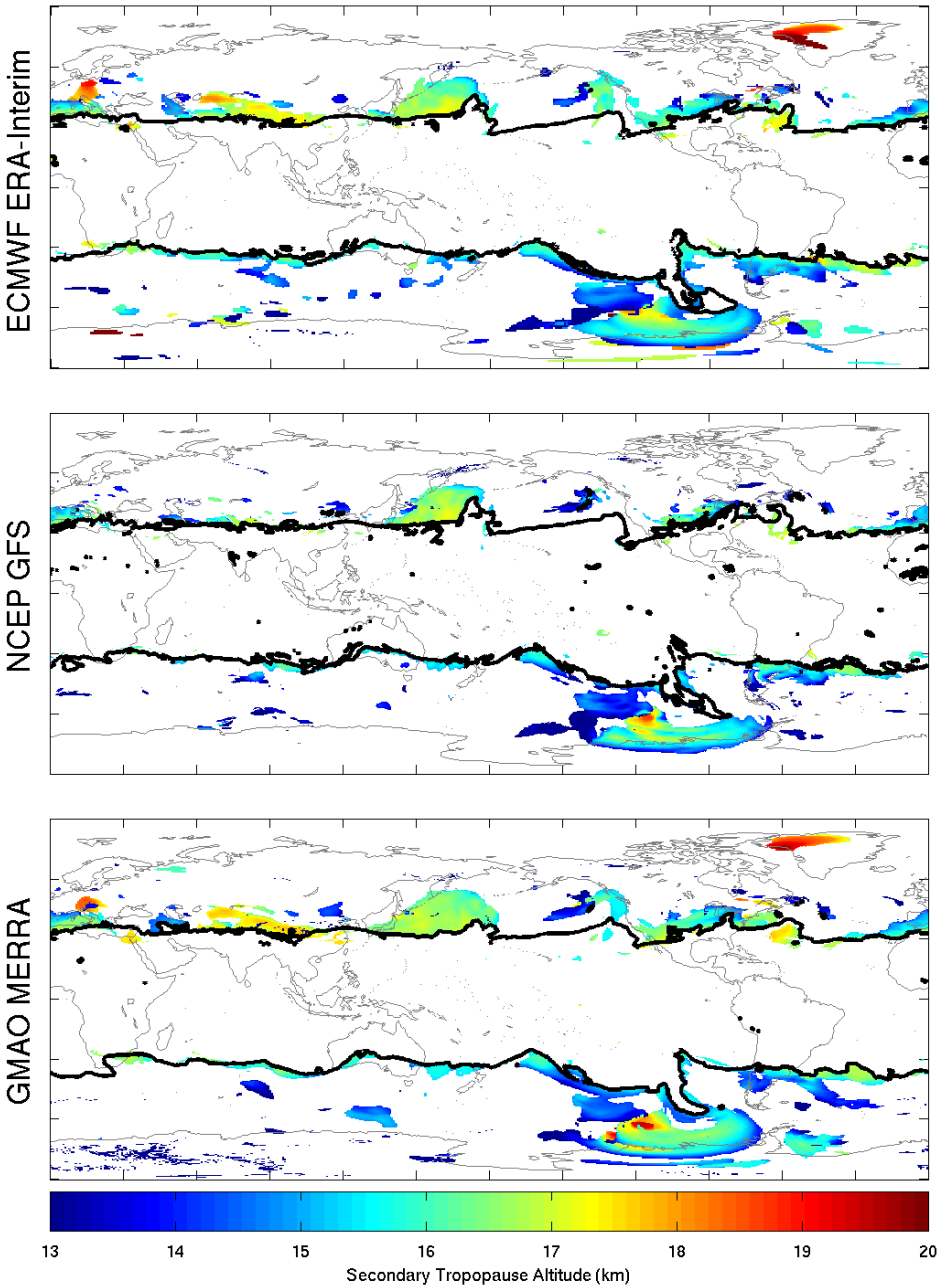
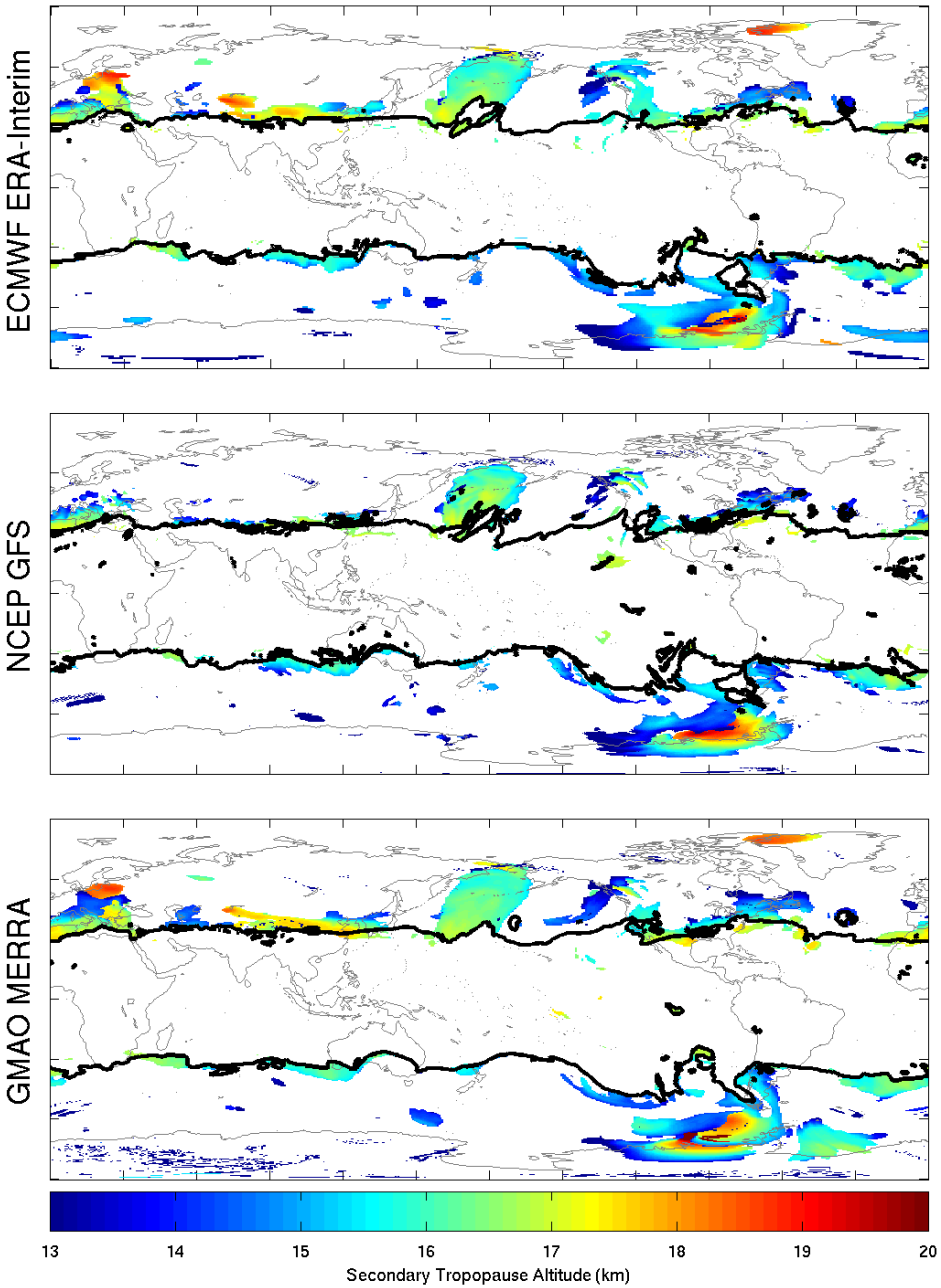
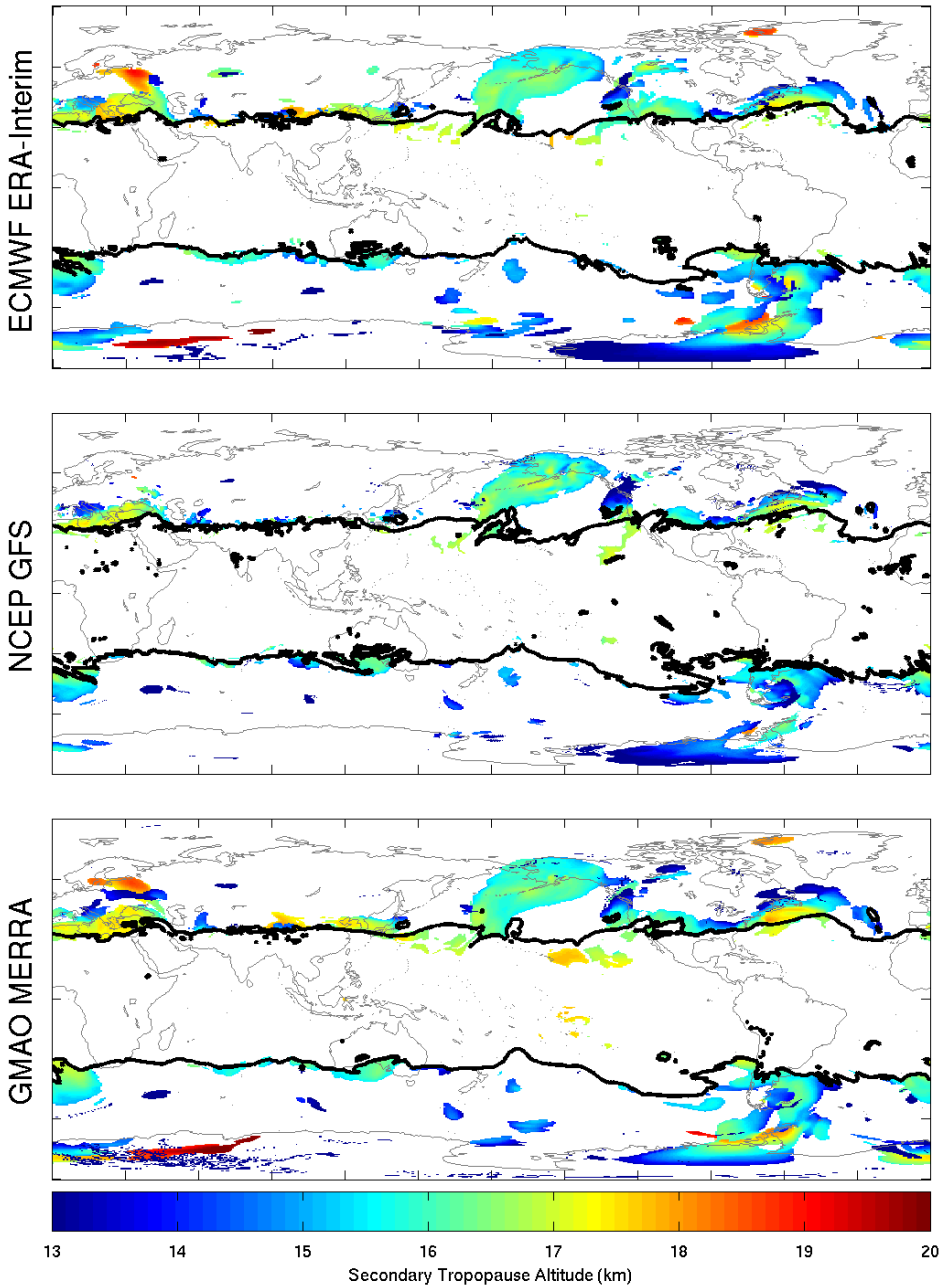


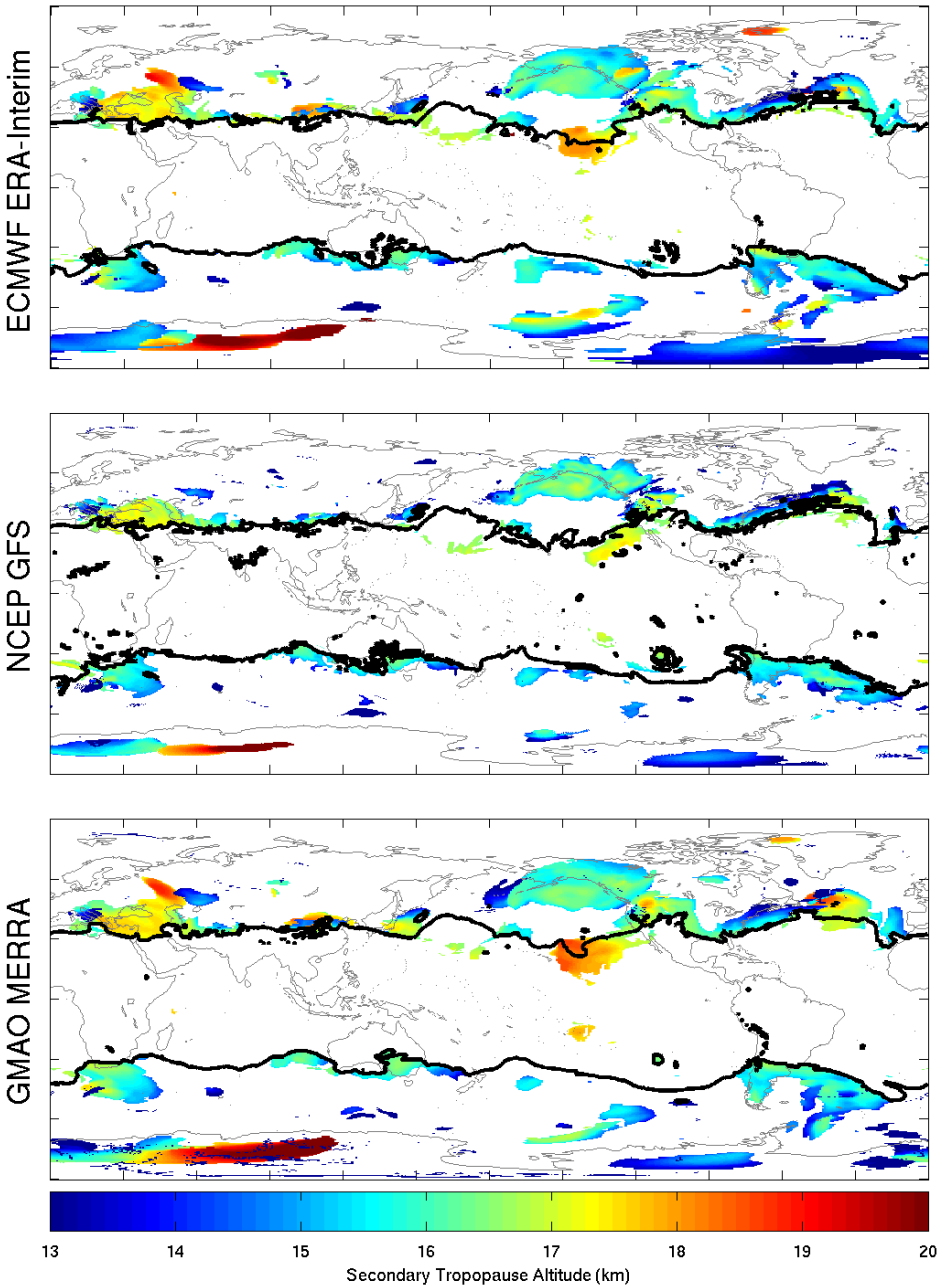
13-Apr-2008 12



14-Apr-2008 12



15-Apr-2008 12



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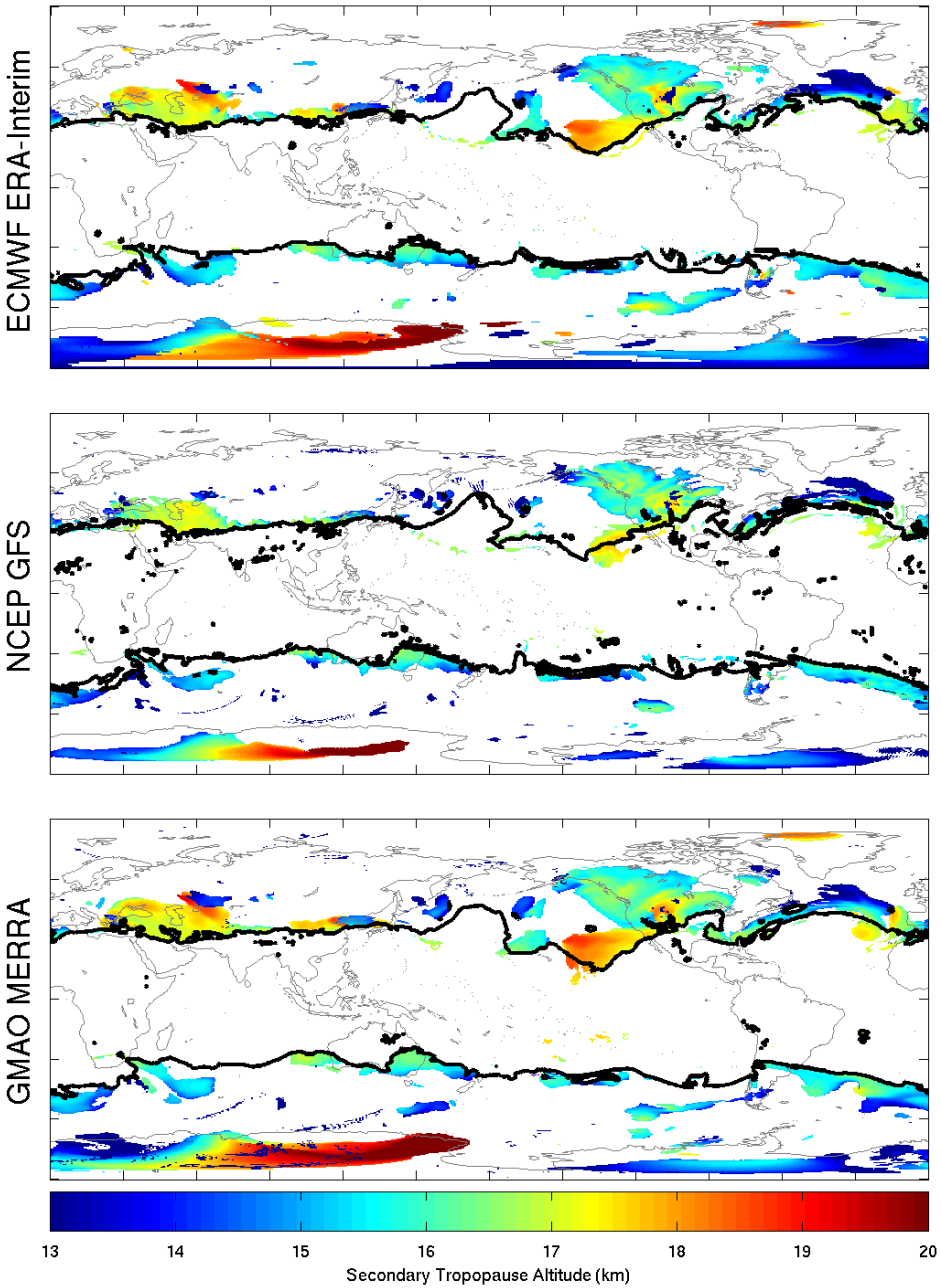

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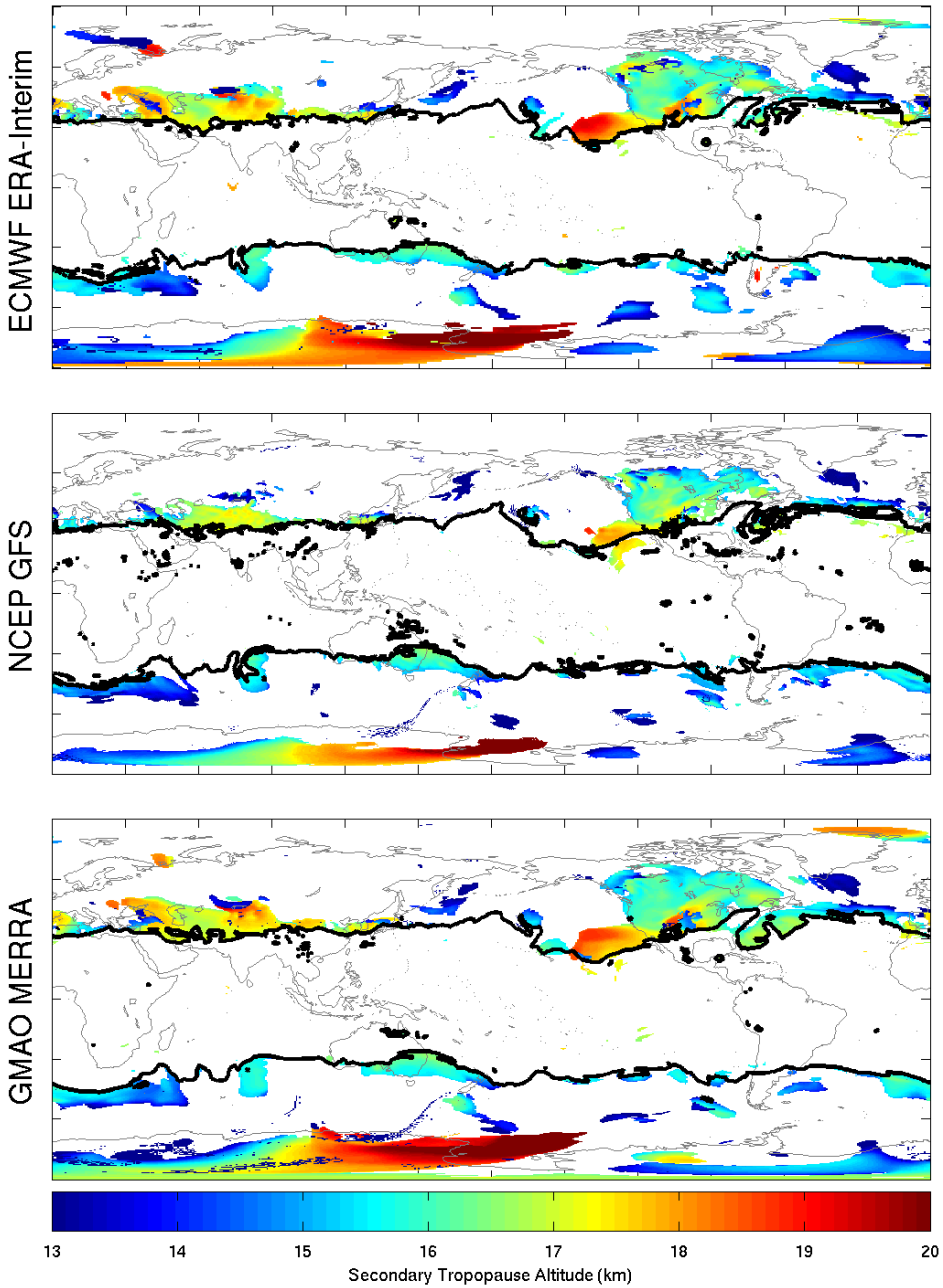

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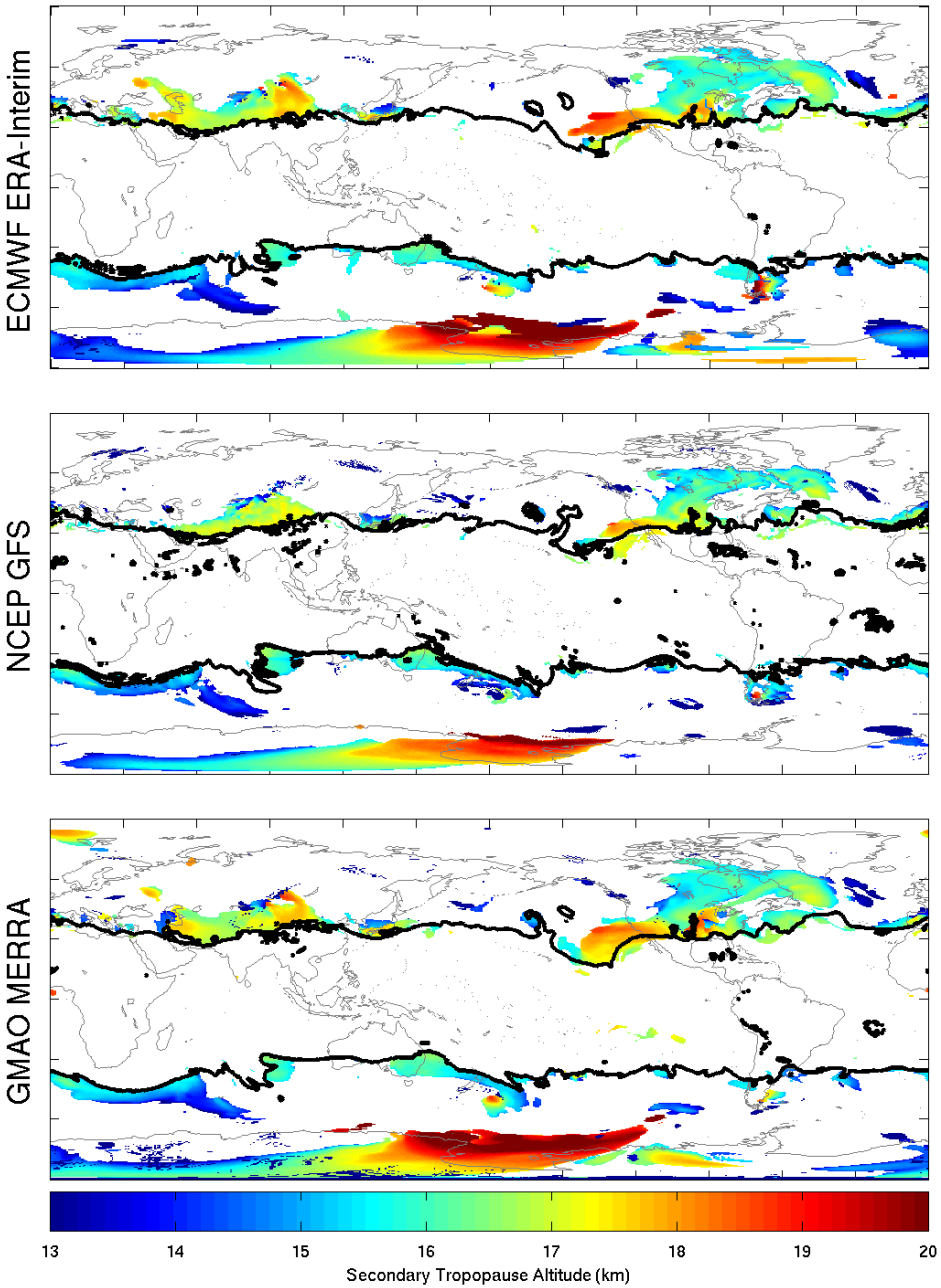
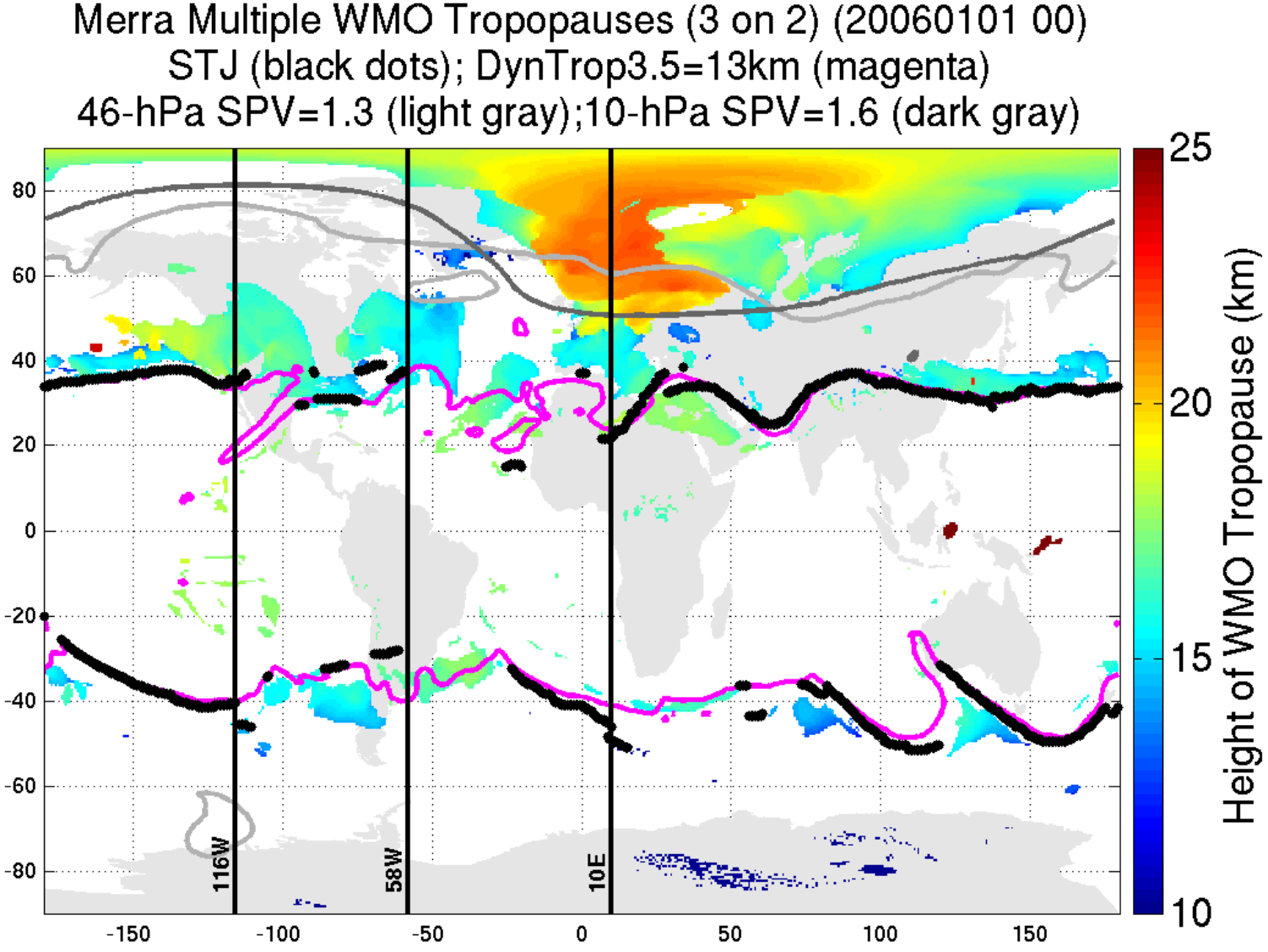
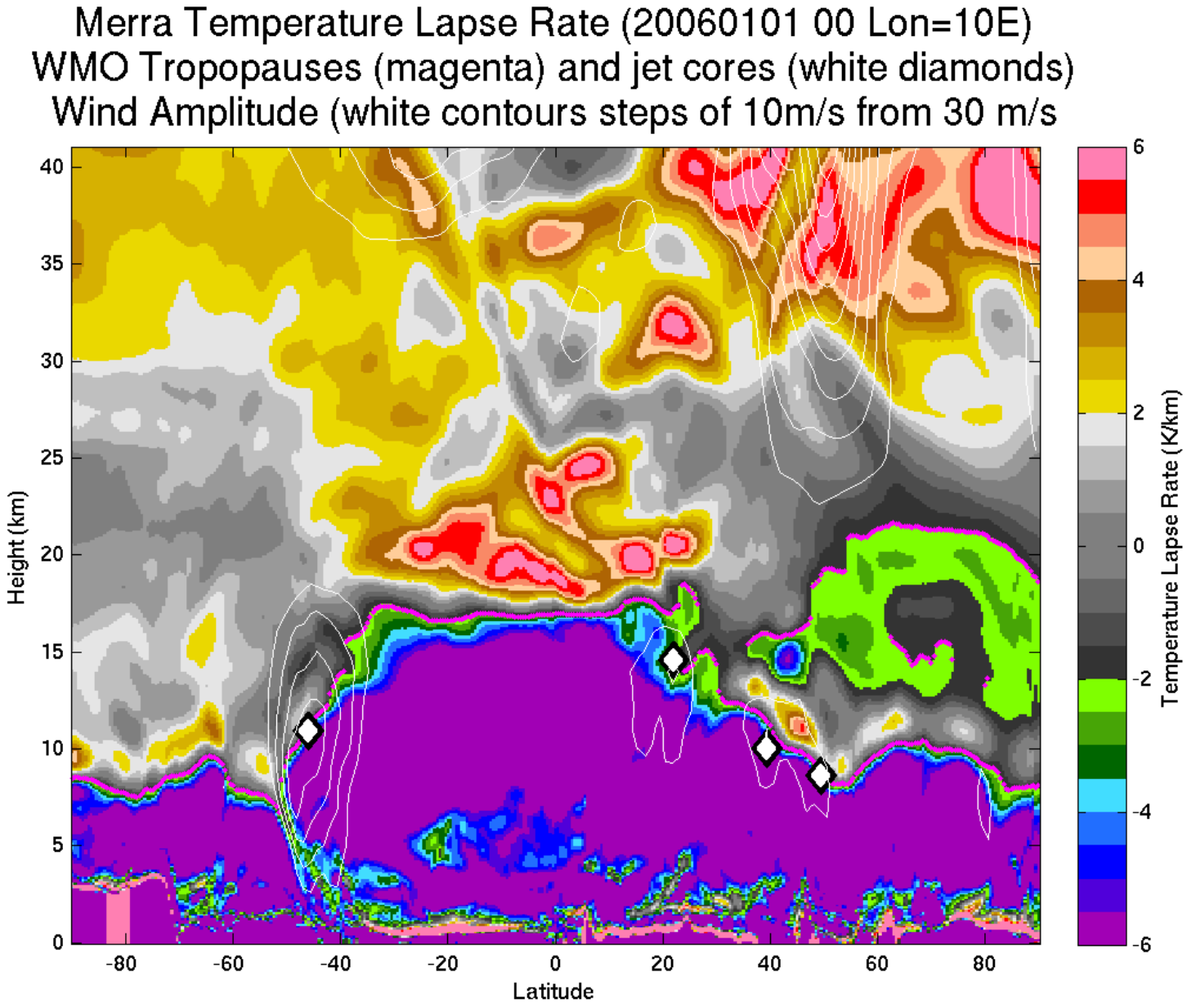
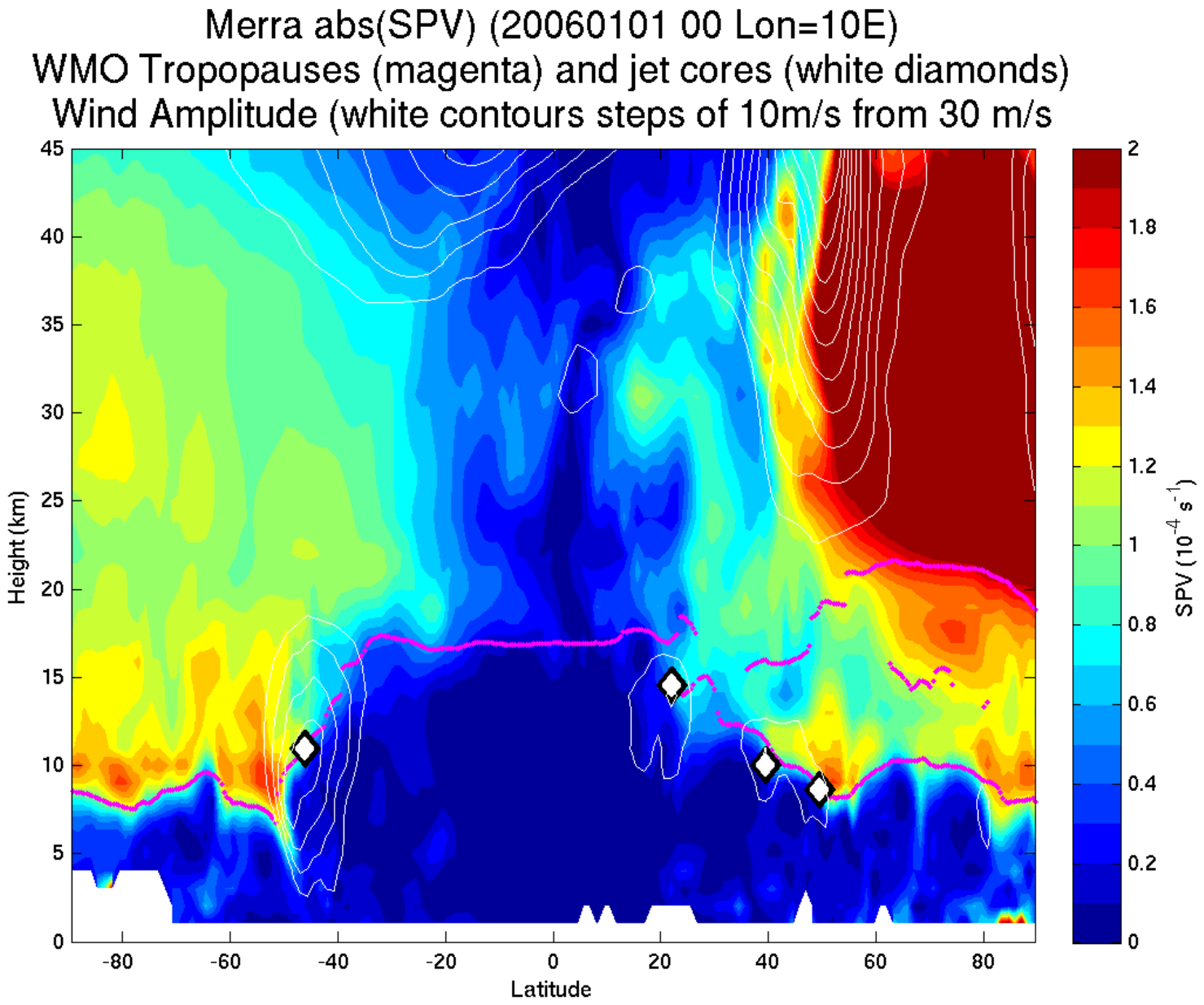



Merra Multiple WMO Tropopauses (3 on 2) (20060101 00)
STJ (black dots); DynTrop3.5=13km (magenta)
46-hPa SPV=1.3 (light gray);10-hPa SPV=1.6 (dark gray)
80
60
40
20
0
-20
-40
-60
-80
116W
58W
10E
-150
-100
-50
0
50
100
150
25
20
15
10
Height of WMO Tropopause (km)


Merra Temperature Lapse Rate (20060101 00 Lon=10E)
WMO Tropopauses (magenta) and jet cores (white diamonds)
Wind Amplitude (white contours steps of 10m/s from 30 m/s
Height (km)
0
5
10
15
20
25
30
35
40
Latitude
-80
-60
-40
-20
0
20
40
60
80
Temperature Lapse Rate (K/km)
6
4
2
0
-2
-4
-6


Merra abs(SPV) (20060101 00 Lon=10E)
WMO Tropopauses (magenta) and jet cores (white diamonds)
Wind Amplitude (white contours steps of 10m/s from 30 m/s
Height (km)
Latitude
SPV (10^{-4} s^{-1})
0
5
10
15
20
25
30
35
40
45
-80
-60
-40
-20
0
20
40
60
80
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2