Analysis of Traveling Ionospheric Disturbances during Stratospheric Warming Events

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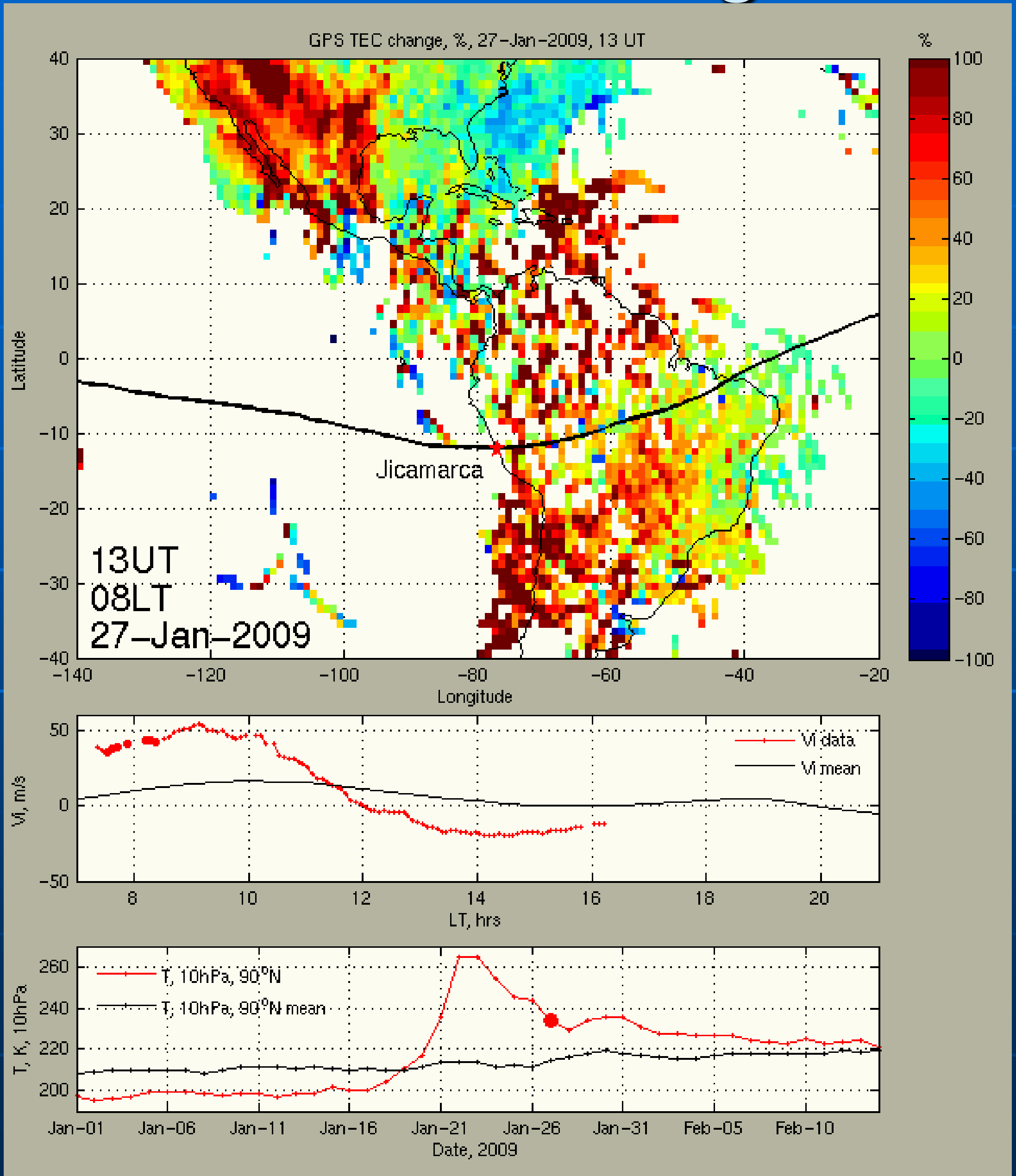
Outline

- Review of sudden stratospheric warming
- Review of Large and Medium Scale Traveling Ionospheric Disturbances
- Summary of SuperDARN observations
- Case study of January 2013
- Other examples
- Summary

GPS TEC change during the warming

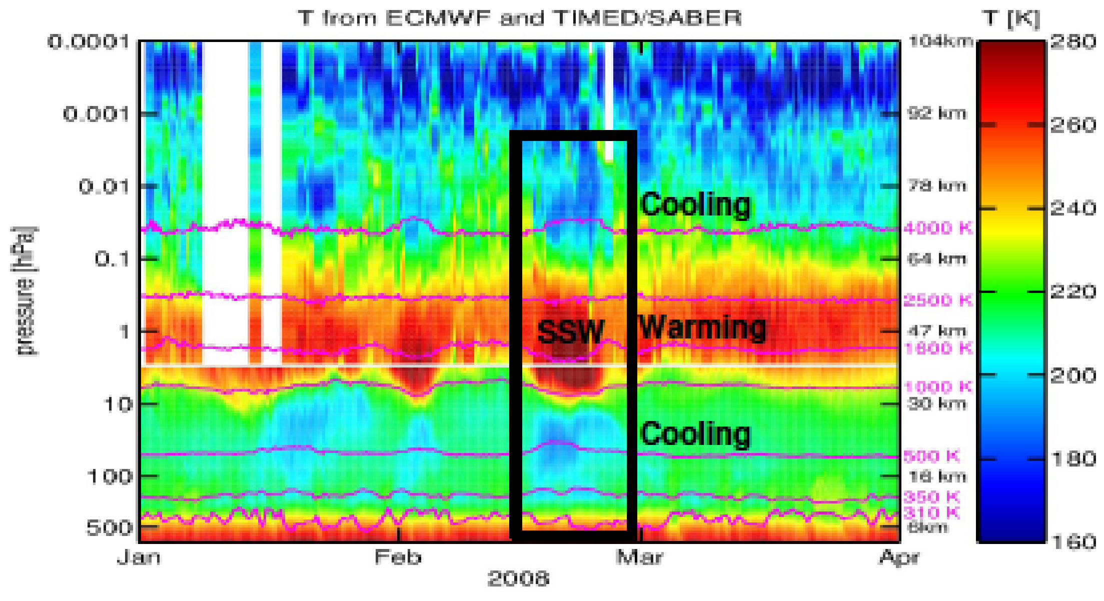


- The entire daytime ionosphere is affected
- Persistent behavior for several days around stratospheric warming

1. What is a stratospheric warming (SSW)?

A SSW is characterized by a sudden temperature increase of at least 25 K at 10 hPa (~32 km) lasting for several days in winter and it can be accompanied by a zonal wind reversal from eastward to westward.

A strong SSW was observed at Bern in February 2008 and at the end of January 2009.



Temperature profiles over Bern from troposphere to thermosphere. Magenta lines show constant potential temperature and display up- and downwelling responsible for cooling and warming. The SSW is accompanied by lower stratospheric – and mesospheric cooling.

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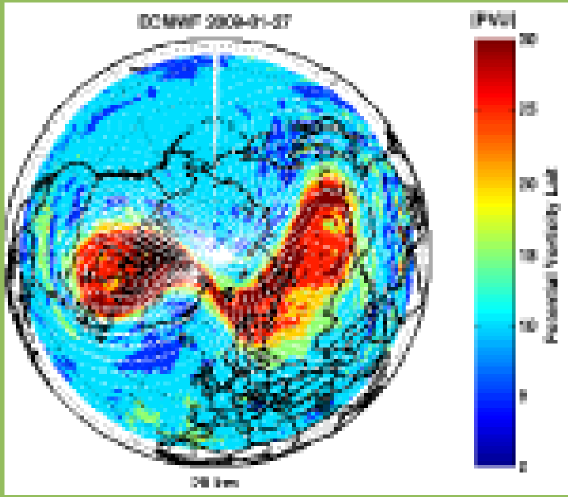
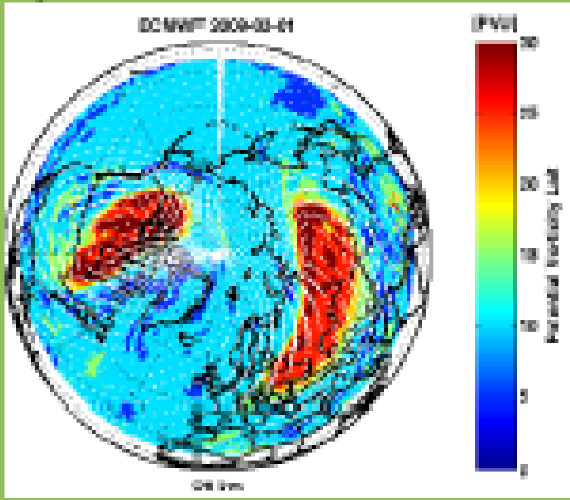
2. Why the warming?

Atmospheric waves ascending from the troposphere interact with the stratospheric eastward flow in polar regions. Breaking waves can reverse the flow which leads to the displacement or splitting of the polar vortex towards mid-latitudes.

The warming is a consequence of energy deposition by breaking waves and adiabatic heating by strong downward motion in the upper stratosphere.



Polar vortex split at 20 km altitude (~55 hPa) on 27 January 2009 and the two vortices on 1 February. Arrows denote wind direction and show the southward flow over the US (27 Jan) and Europe (1 Feb). Colors display modified PV units.



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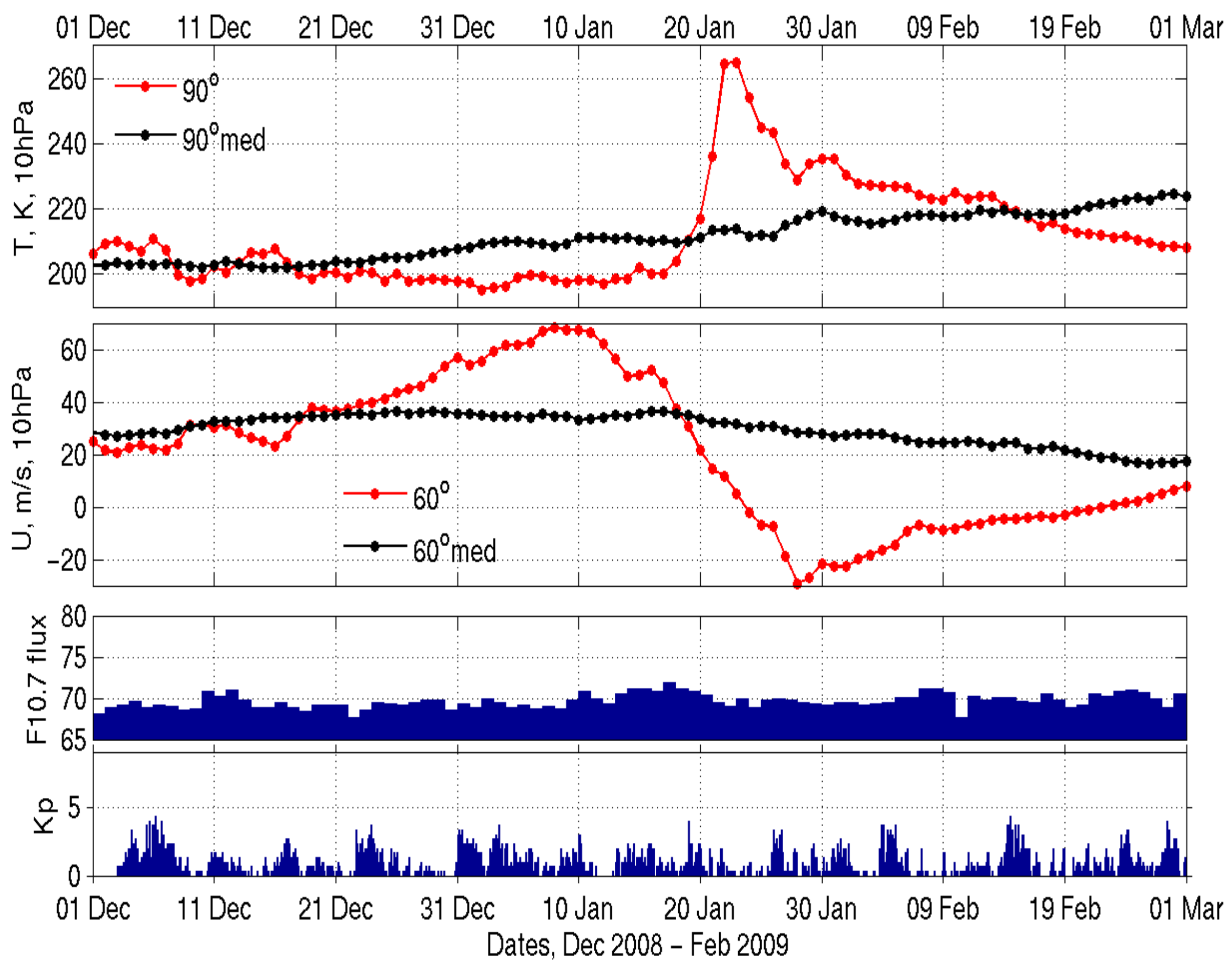
Sudden Stratospheric Warming and Solar Parameters [Jan 2009]



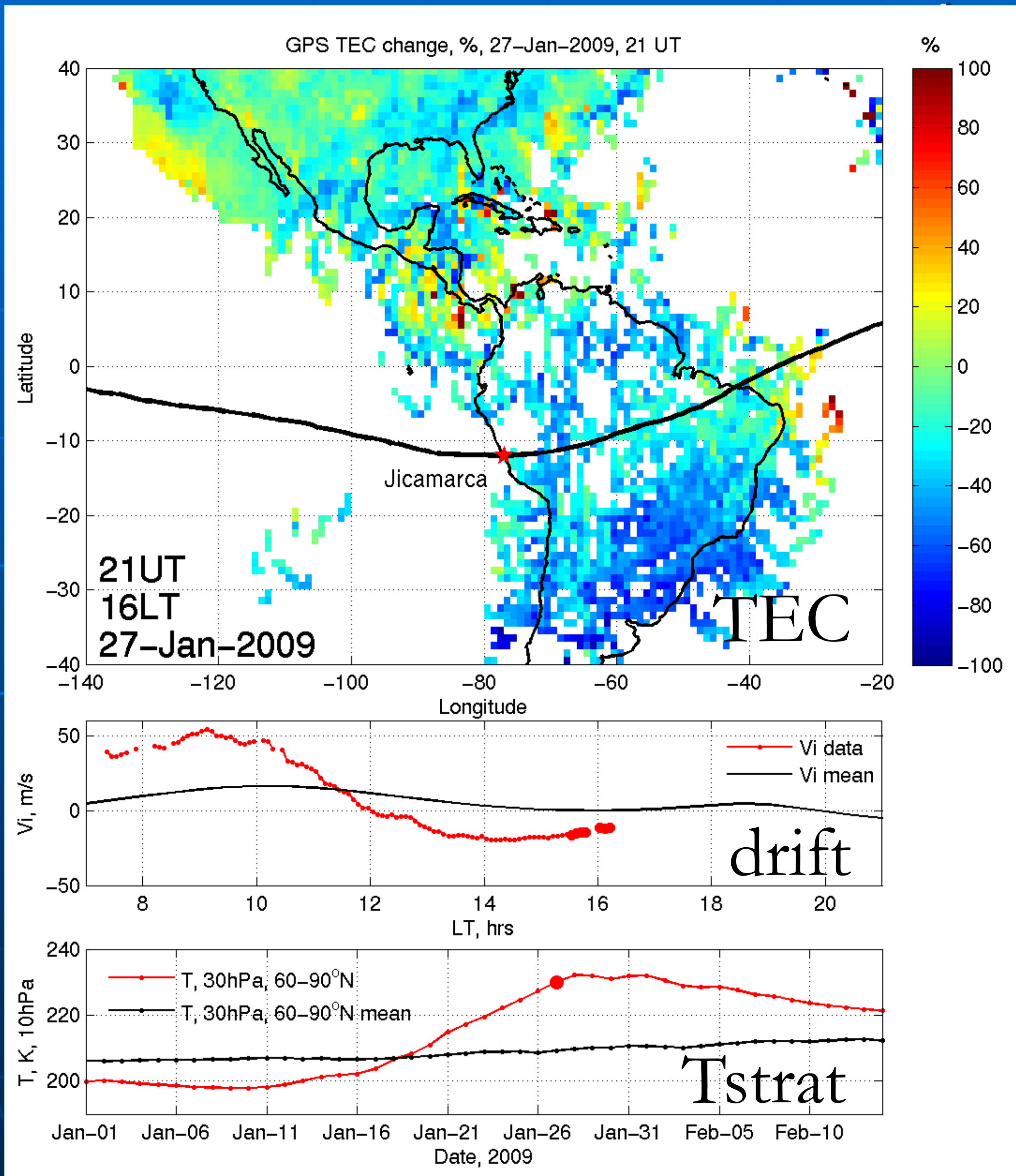
Stratospheric Temperature over the Arctic

Stratospheric Zonal wind at 60ºN

Solar activity Minimum: F10.7 < 80

Magnetic activity Quiet: Kp < 3

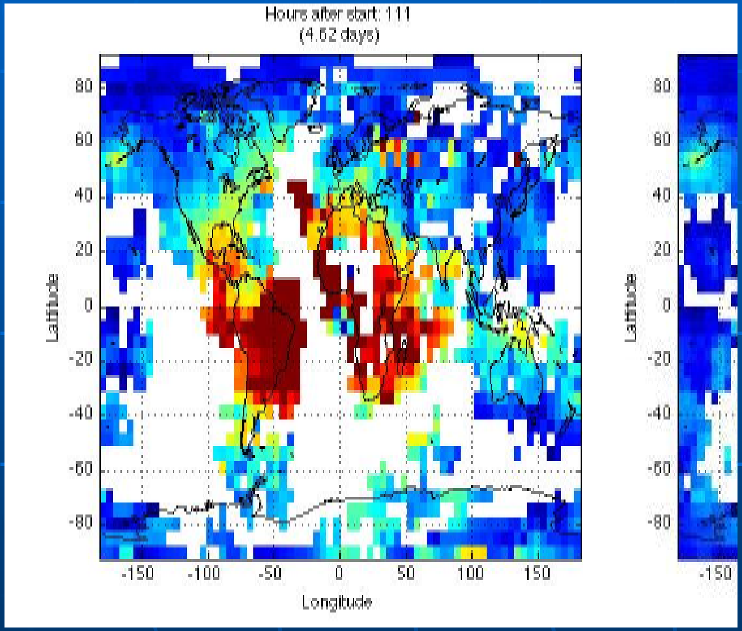
GPS TEC during warming: afternoon

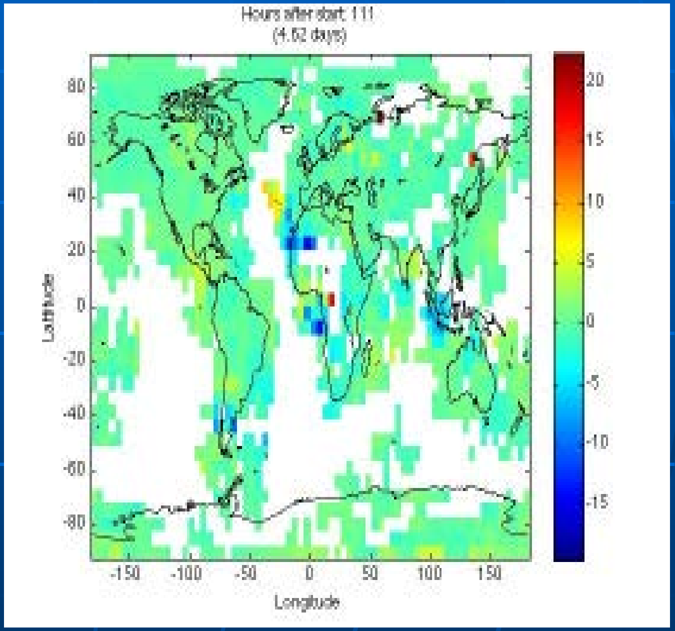


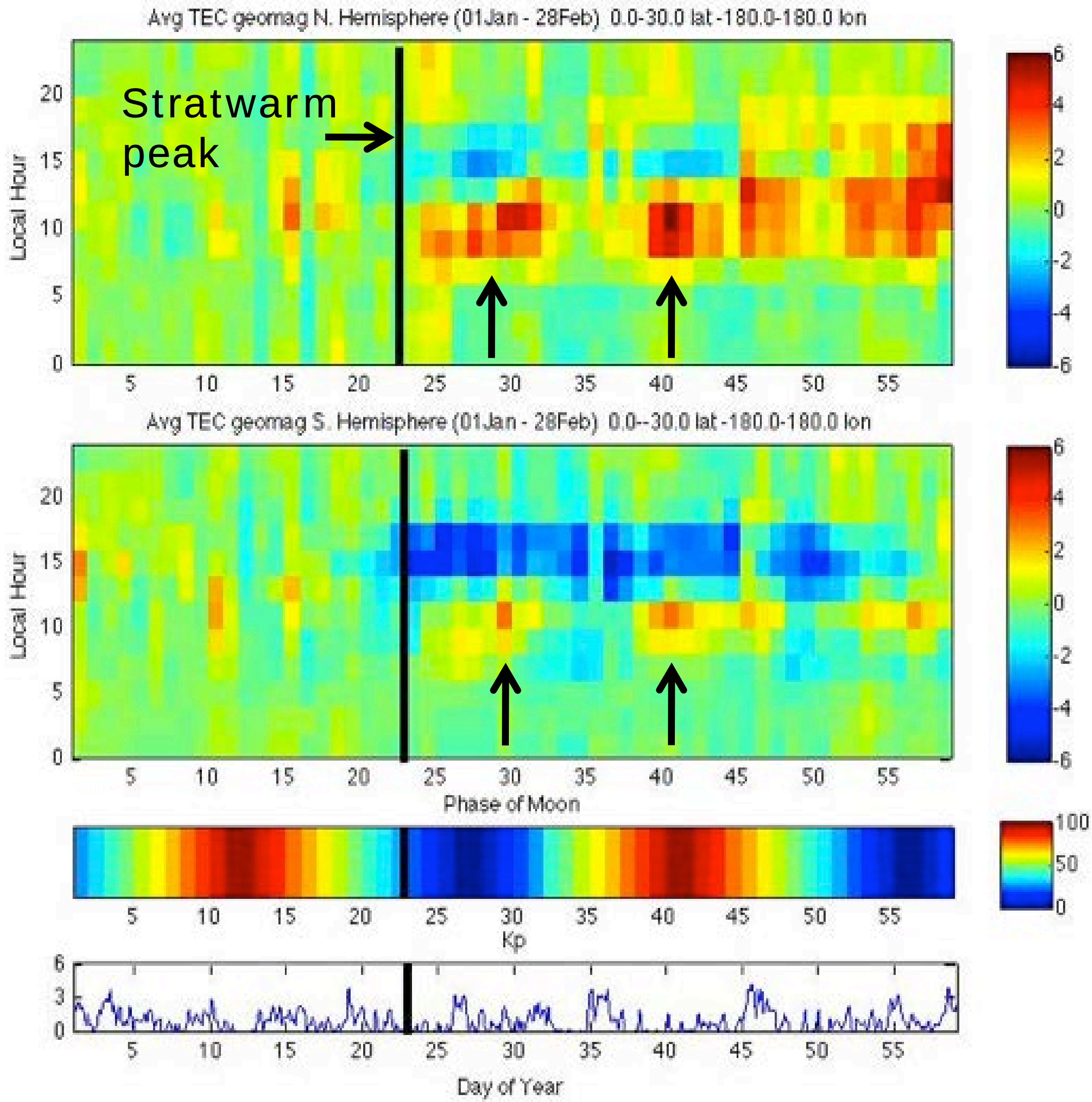
- During stratwarming, TEC decreases by ~50% in the afternoon
- Large downward drift at Jicamarca

Method

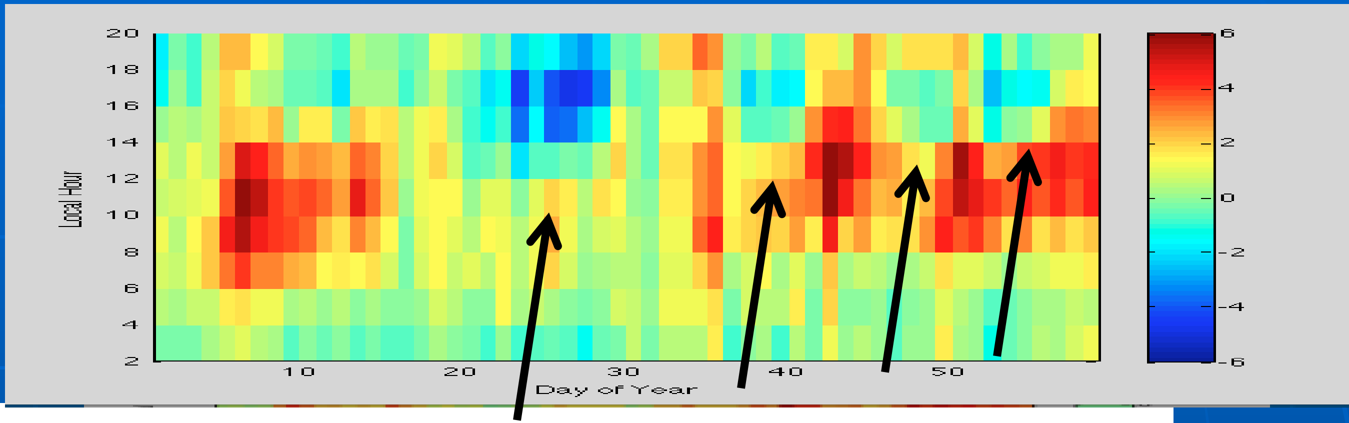
Daily Data **27-Day Average** **Difference**



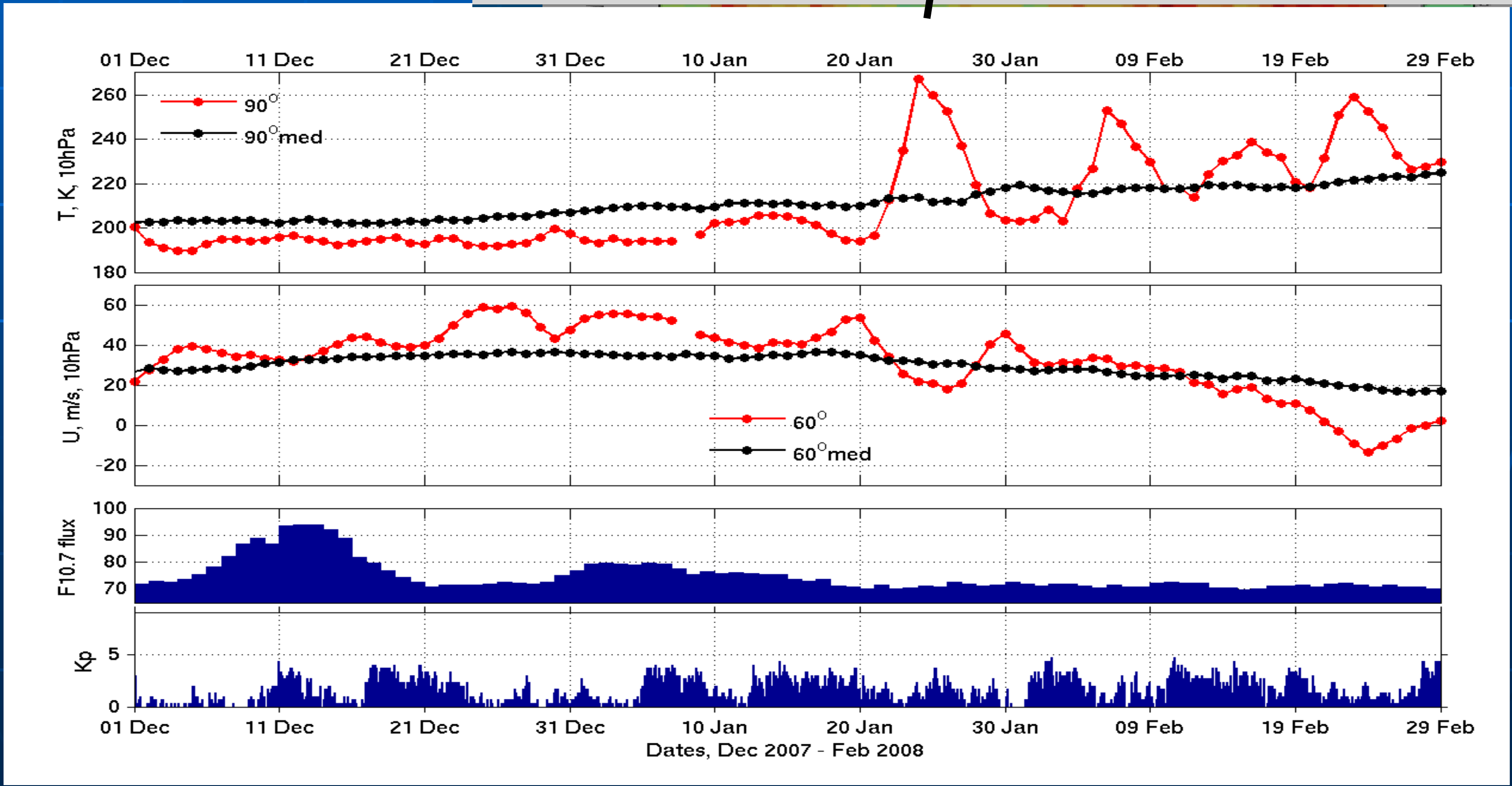




Avg TEC geomag N. Hemisphere (01Jan - 28Feb) 0.0-30.0 lat -180.0-180.0 lon
Stratwarm peak
Local Hour
Avg TEC geomag S. Hemisphere (01Jan - 28Feb) 0.0--30.0 lat -180.0-180.0 lon
Local Hour
Phase of Moon
Kp
Day of Year

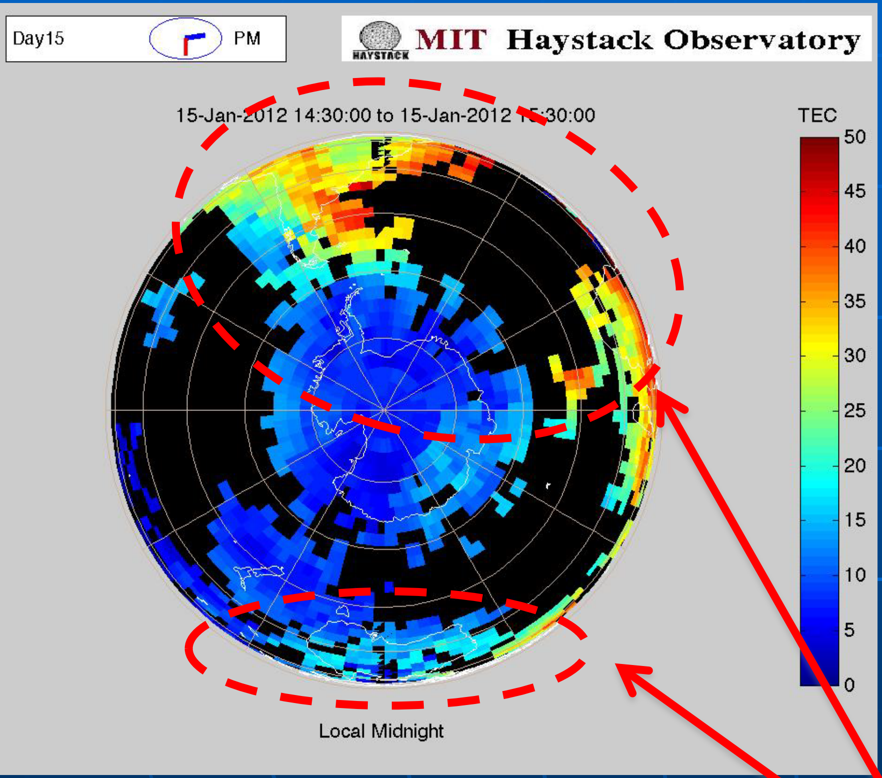


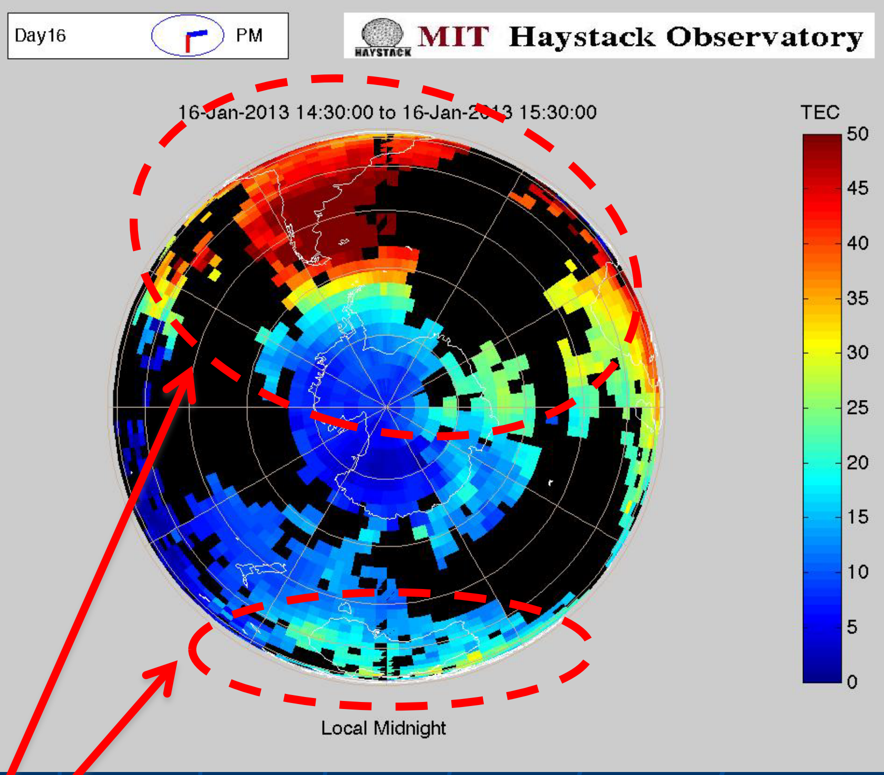
Local Hour
Day of Year



90°
90°med
T, K, 10hPa
60°
60°med
U, m/s, 10hPa
F10.7 flux
Kp
Dates, Dec 2007 - Feb 2008

TEC, Southern Hemisphere





TEC Before SSW
Jan 15, 2012
F10.7=133, Ap=4

Increase in TEC in the morning to afternoon sector and around local midnight

TEC During SSW
Jan 16, 2013
F10.7=137, Ap=5

Summary

- Evidence of dramatic changes in electron density during stratospheric sudden warmings
- Consistent with increase in Jicamarca electric field data and E-region dynamo mechanism
- Strong 12-h signature
- Increase in TEC in the morning sector by 50-150%; suppression in the afternoon by ~50% in American Longitude sector
- Disturbances extend to middle latitudes
- Shift to later local times
- Effects are noticed GLOBALLY – from Pole to Pole

Heavy Snowfall and Ozone Depletion triggered by Stratospheric Warmings

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5. Which role plays the SSW in heavy snow fall?

At the end of January 2009 a cold snap set in over much of the US with unusual and heavy snow storms. On 2 February London got 20 cm of snow and Paris was also snow covered.

The SSW and polar vortex split are responsible for both extraordinary events! The two cells of the splitted vortex (see Figures on the left) reached deep into the troposphere and brought cold polar air to the US and western Europe. The cold air lifted the warmer and wetter air up what resulted in snowfall.

Snow has to be removed for two different reasons: In Paris for the tourists preventing them from wet and cold feet and on the Zugspitze (right) for accurate stratospheric measurements with our microwave radiometer MIAWARA-C (X), which needs to be snow-free.(photos: Reuters, IAP)

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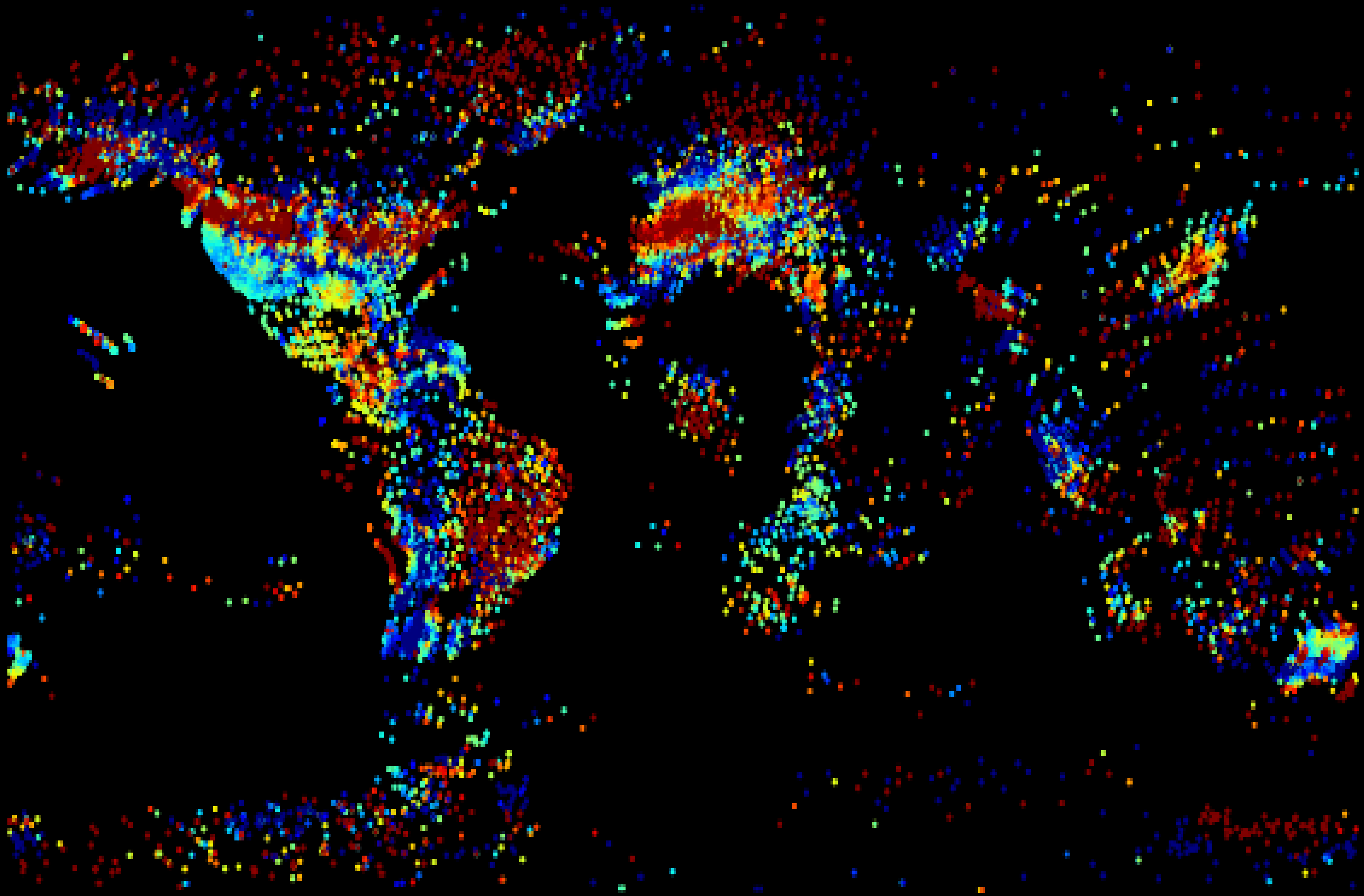
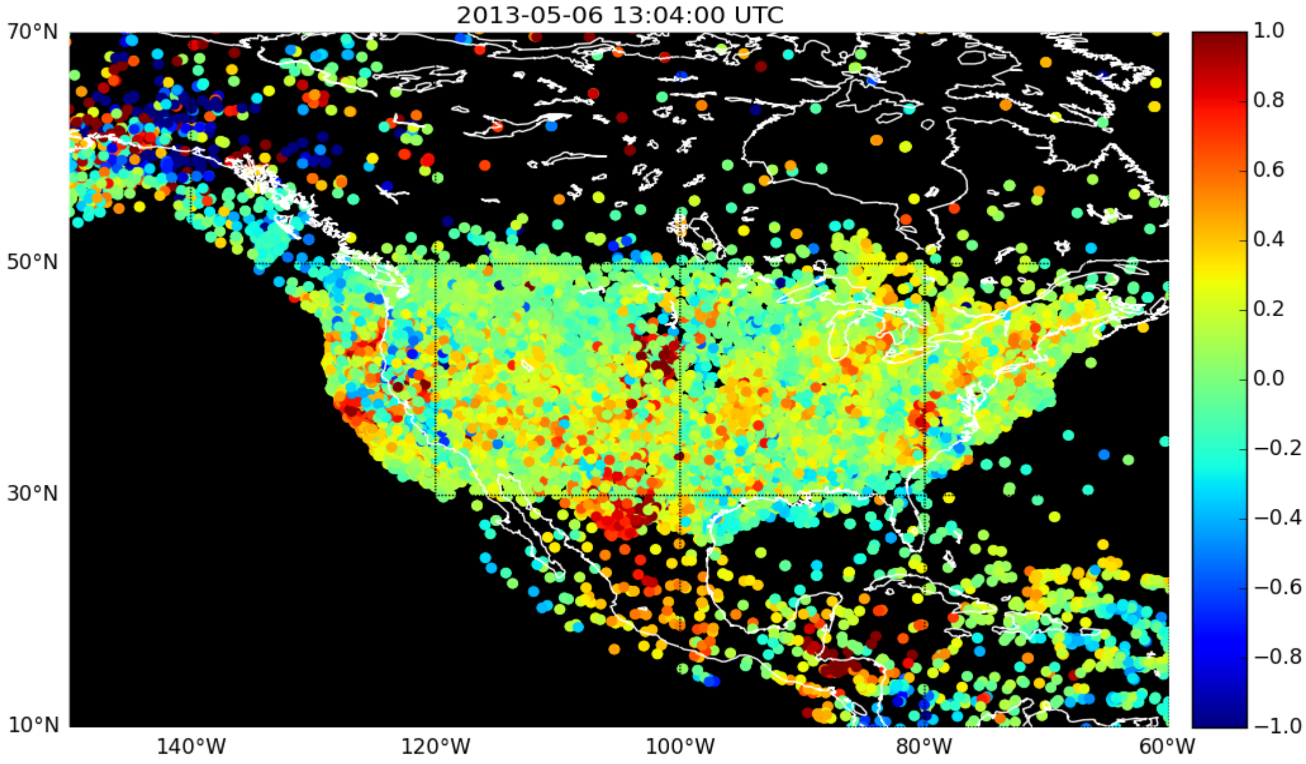
ΔVTEC
2013-03-17 10:12:00

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50°N
30°N
10°N
140°W
120°W
100°W
80°W
60°W
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0.4
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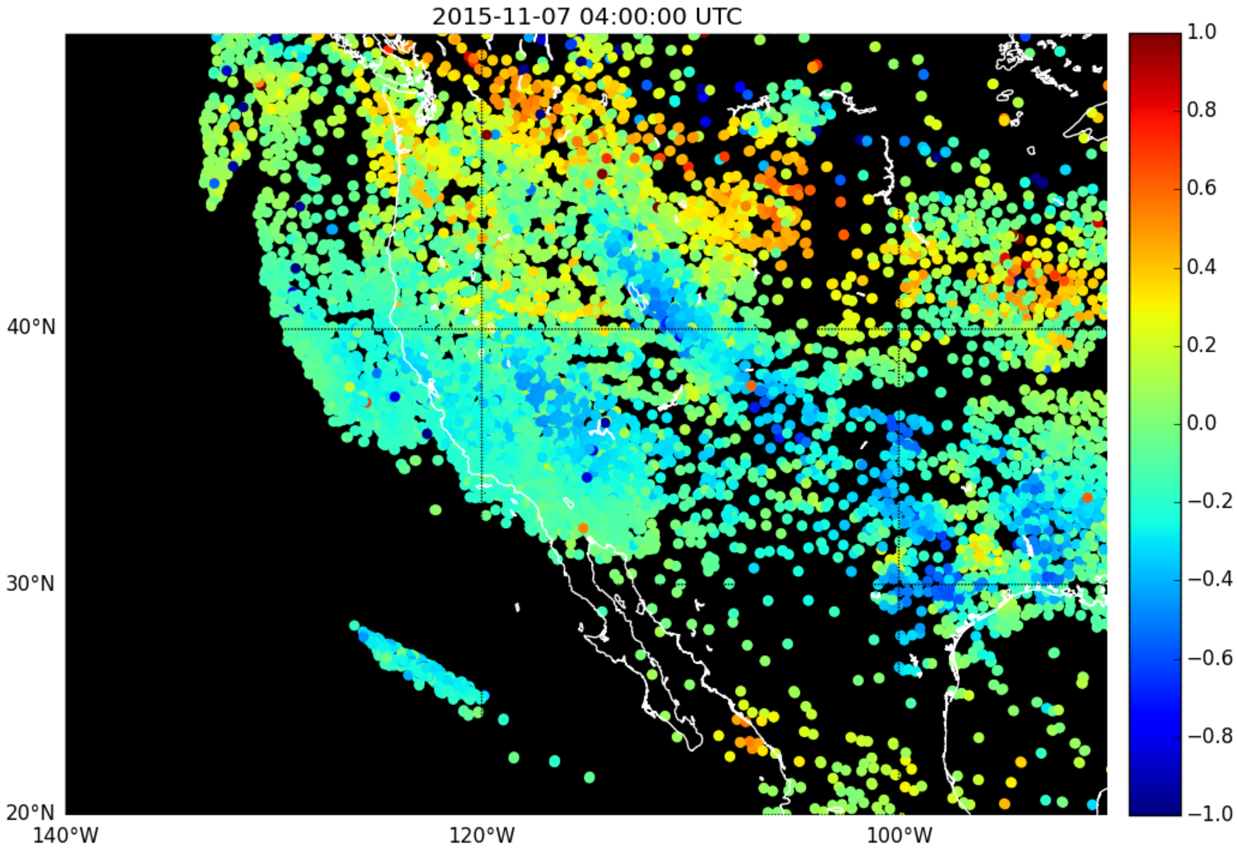
−0.4
−0.6
−0.8
−1.0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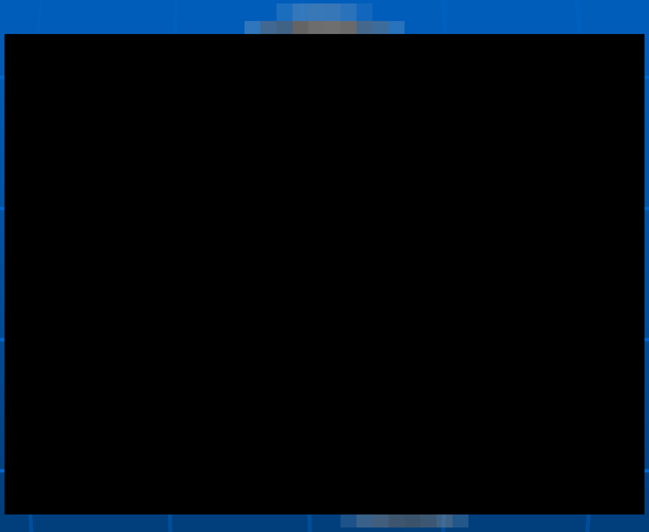

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3. Stratospheric, solar and geomagnetic conditions of winter 2012/2013

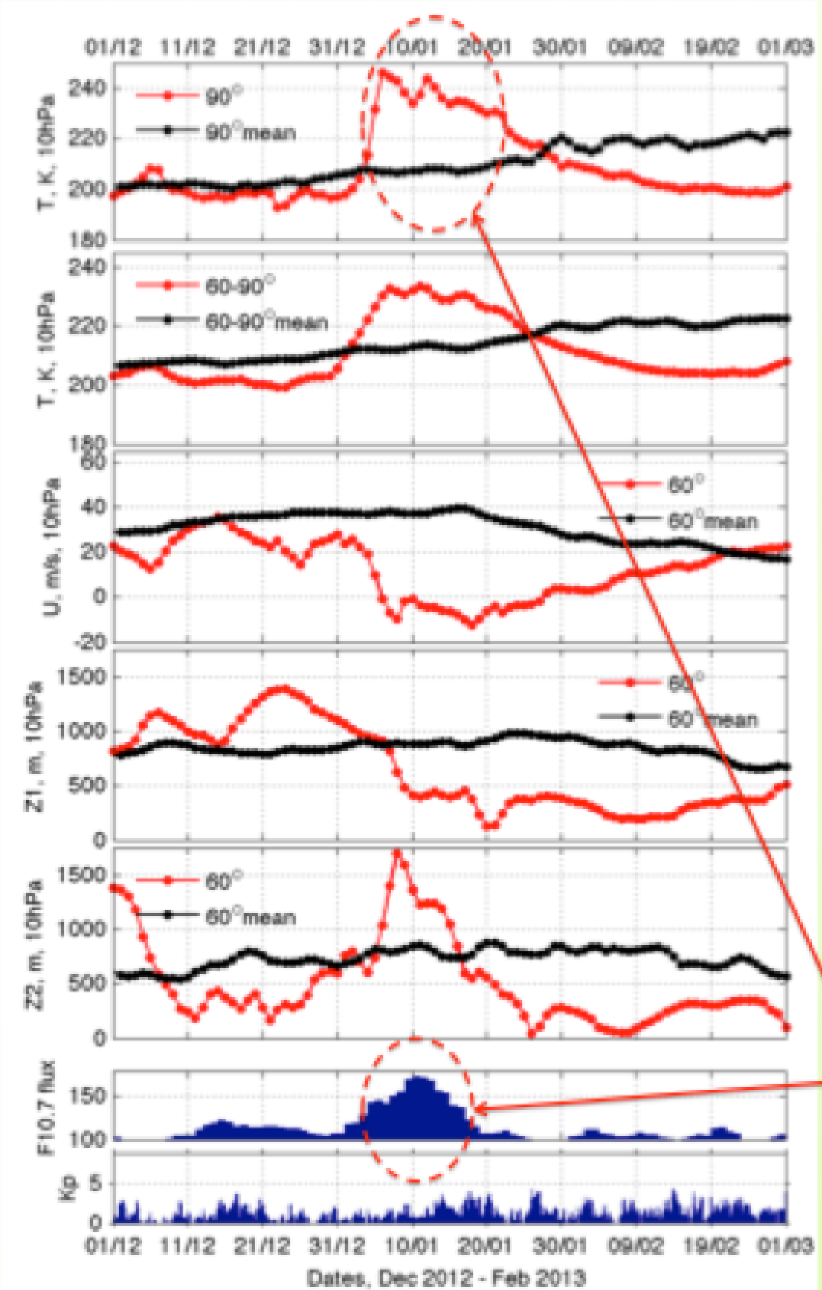


Figure 1. Summary of stratospheric and solar parameters during the winter of 2012/2013:

a) Temperature at 90°N, 10hPa (~32 km)

b) Temperature at 60-90°N, 10hPa

c) Zonal mean zonal wind at 60°N, 10hPa

d) Amplitude of planetary wave 1 calculated from geopotential height data at 10hPa

e) Amplitude of planetary wave 2 calculated from geopotential height data at 10hPa

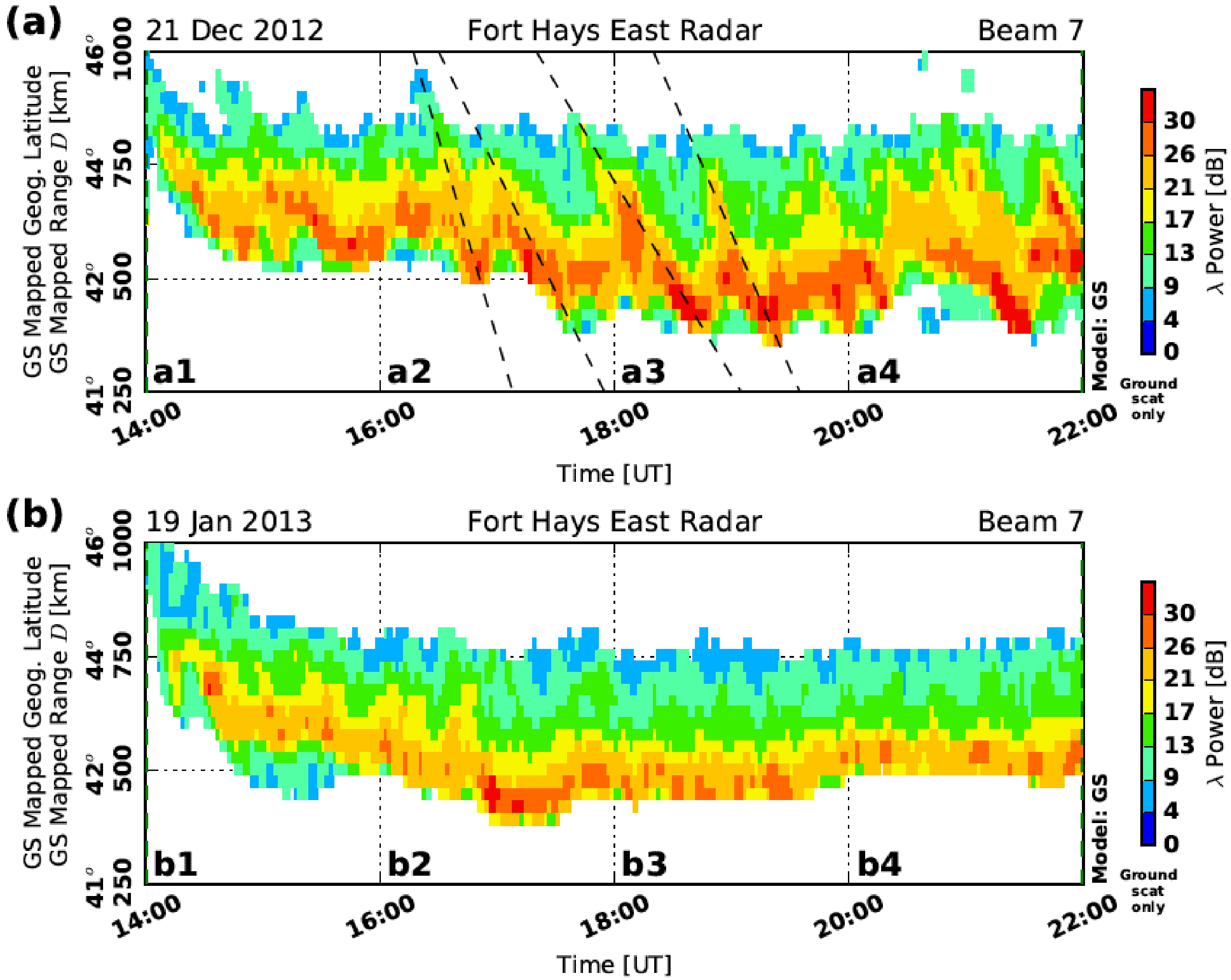
f) F10.7 index

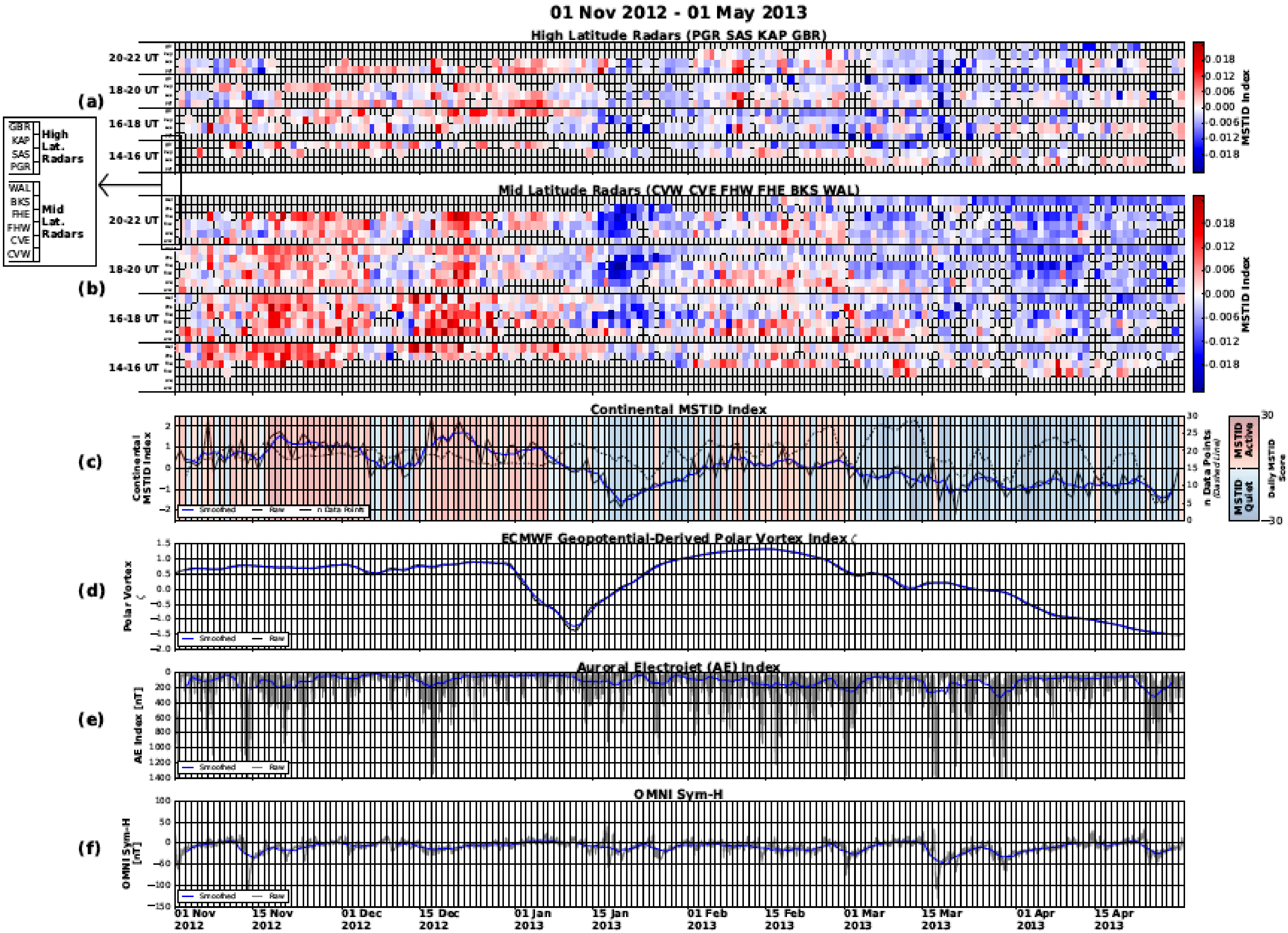
g) Kp index

Red lines show data for 2012/2013, black lines show means from 30 years of stratospheric data.

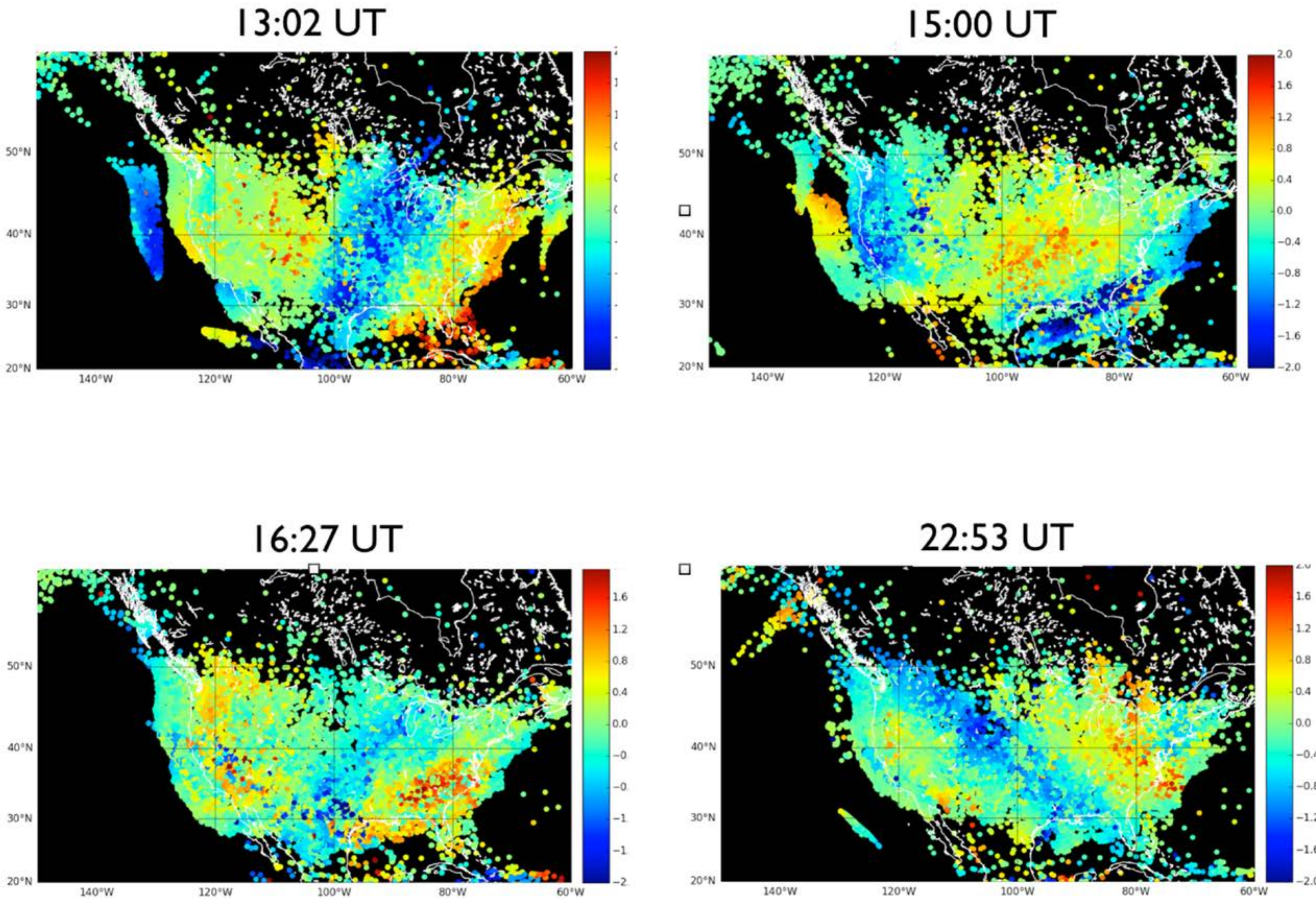
Main features of SSW 2013:

- Major, long-lasting SSW
- Peak stratospheric temperature increase on Jan 6-15; anomalously cold stratosphere until April 2013
- Major disturbance in stratospheric dynamics on Jan 5 – Feb 5
- Driven by amplification in planetary wave 1
- **Strongest SSW since 2009, but weaker than 2009**
- **Major SSW coincides with increase in solar flux to moderate-to-high levels (up to F10.7=174)**


(a)
21 Dec 2012
Fort Hays East Radar
Beam 7
GS Mapped Geog. Latitude
GS Mapped Range D [km]
46°
1000
44°
750
42°
500
41°
250
a1
a2
a3
a4
14:00
16:00
18:00
20:00
22:00
Time [UT]
Model: GS
Ground scat only
30
26
21
17
13
9
4
0
λ Power [dB]
(b)
19 Jan 2013
Fort Hays East Radar
Beam 7
GS Mapped Geog. Latitude
GS Mapped Range D [km]
46°
1000
44°
750
42°
500
41°
250
b1
b2
b3
b4
14:00
16:00
18:00
20:00
22:00
Time [UT]
Model: GS
Ground scat only
30
26
21
17
13
9
4
0
λ Power [dB]


01 Nov 2012 - 01 May 2013
High Latitude Radars (PGR SAS KAP GBR)
20-22 UT
18-20 UT
16-18 UT
14-16 UT
(a)
GBR
KAP
SAS
PGR
High Lat. Radars
WAL
BKS
FHE
FHW
CVE
CVW
Mid Lat. Radars
MSTID Index
0.018
0.012
0.006
0.000
-0.006
-0.012
-0.018
Mid Latitude Radars (CVW CVE FHW FHE BKS WAL)
(b)
Continental MSTID Index
(c)
Continental MSTID Index
Smoothed
Raw
n Data Points
n Data Points (Dashed Line)
MSTID Active
MSTID Quiet
Daily MSTID Score
ECMWF Geopotential-Derived Polar Vortex Index ζ
(d)
Polar Vortex ζ
Smoothed
Raw
Auroral Electrojet (AE) Index
(e)
AE Index [nT]
Smoothed
Raw
OMNI Sym-H
(f)
OMNI Sym-H [nT]
Smoothed
Raw
01 Nov 2012
15 Nov 2012
01 Dec 2012
15 Dec 2012
01 Jan 2013
15 Jan 2013
01 Feb 2013
15 Feb 2013
01 Mar 2013
15 Mar 2013
01 Apr 2013
15 Apr 2013

01-16-2013



13:02 UT
15:00 UT
16:27 UT
22:53 UT
50°N
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140°W
120°W
100°W
80°W
60°W
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1.2
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0.4
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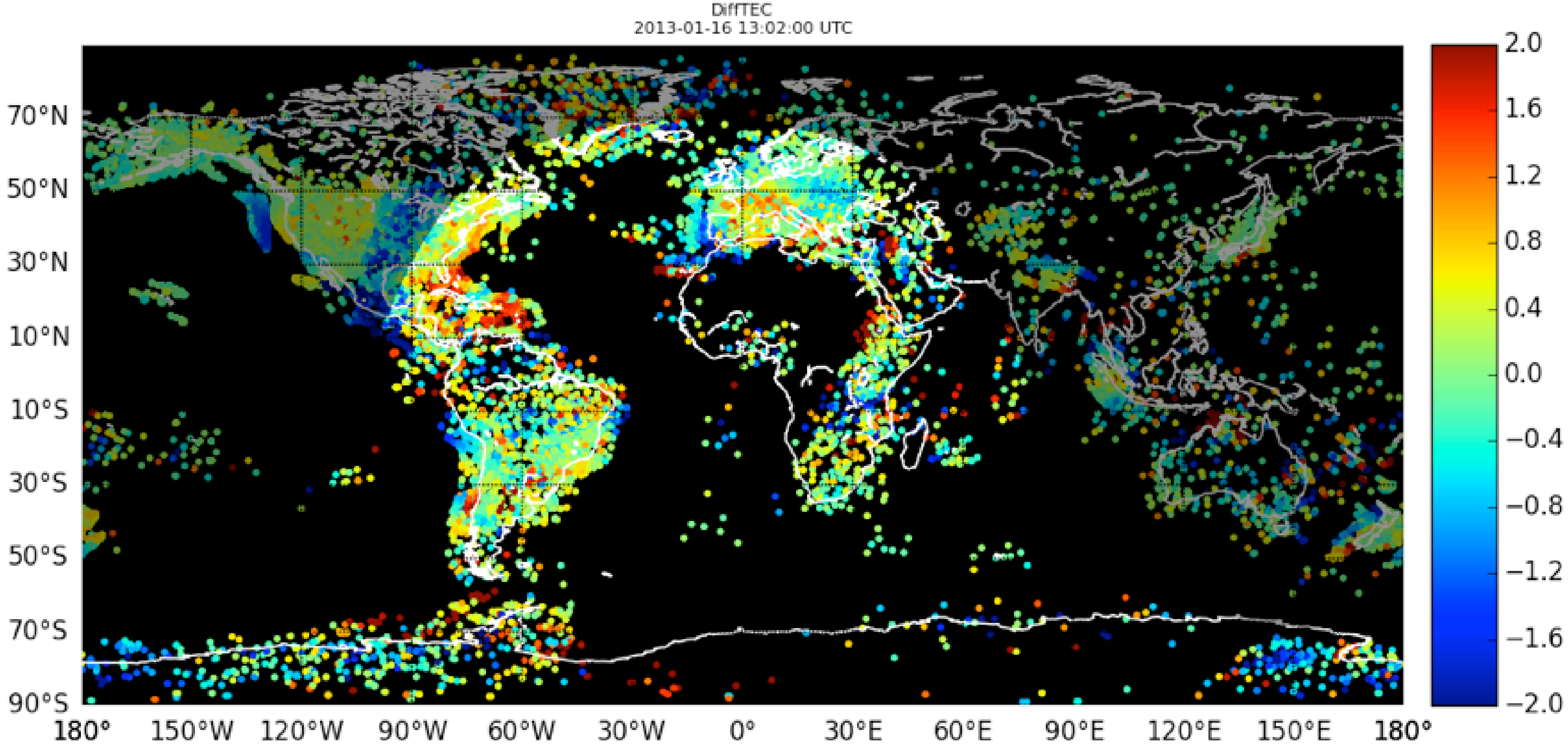
−0.8
−1.2
−1.6
−2.0

13:02 UT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10°S
30°S
50°S
70°S
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180°
150°W
120°W
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60°W
30°W
0°
30°E
60°E
90°E
120°E
150°E
180°
2.0
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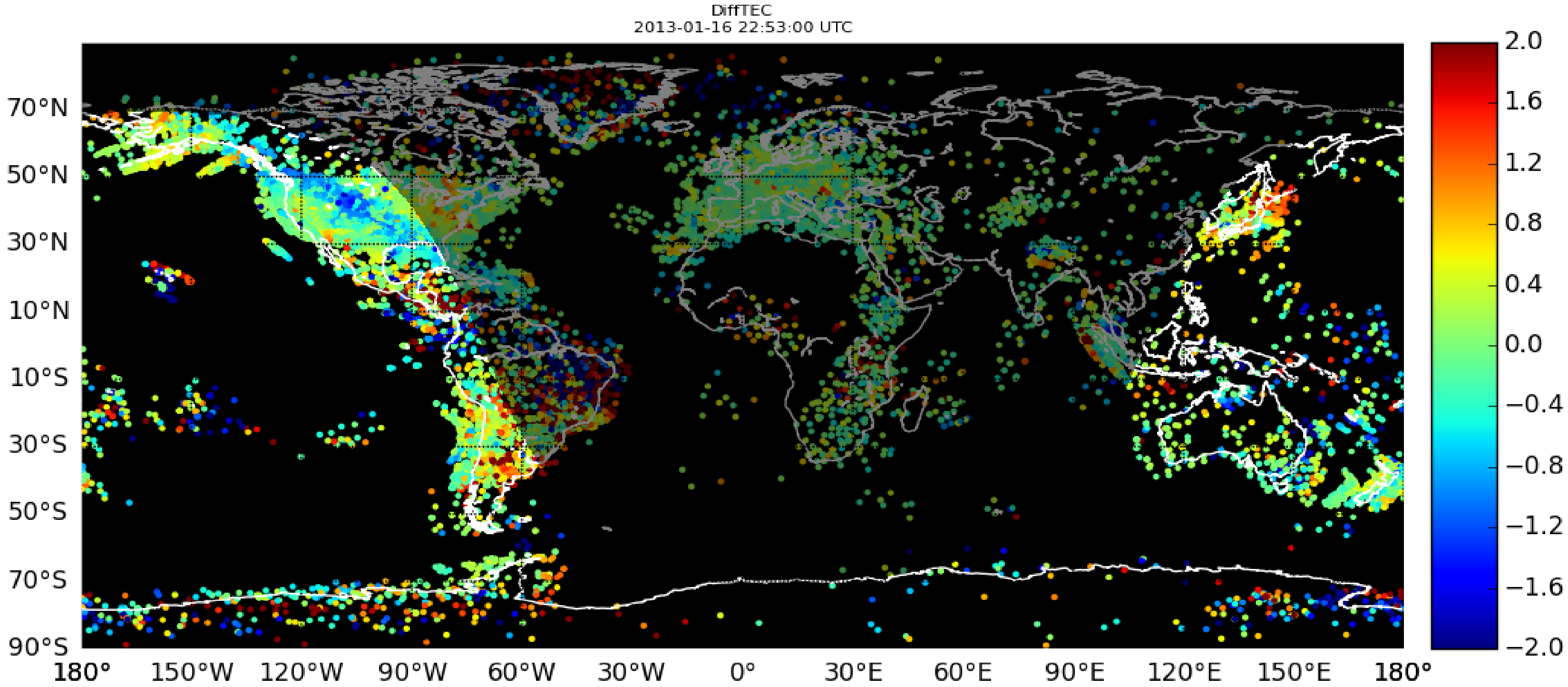
22:53 UT



DiffTEC
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30°S
50°S
70°S
90°S
180°
150°W
120°W
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60°W
30°W
0°
30°E
60°E
90°E
120°E
150°E
180°
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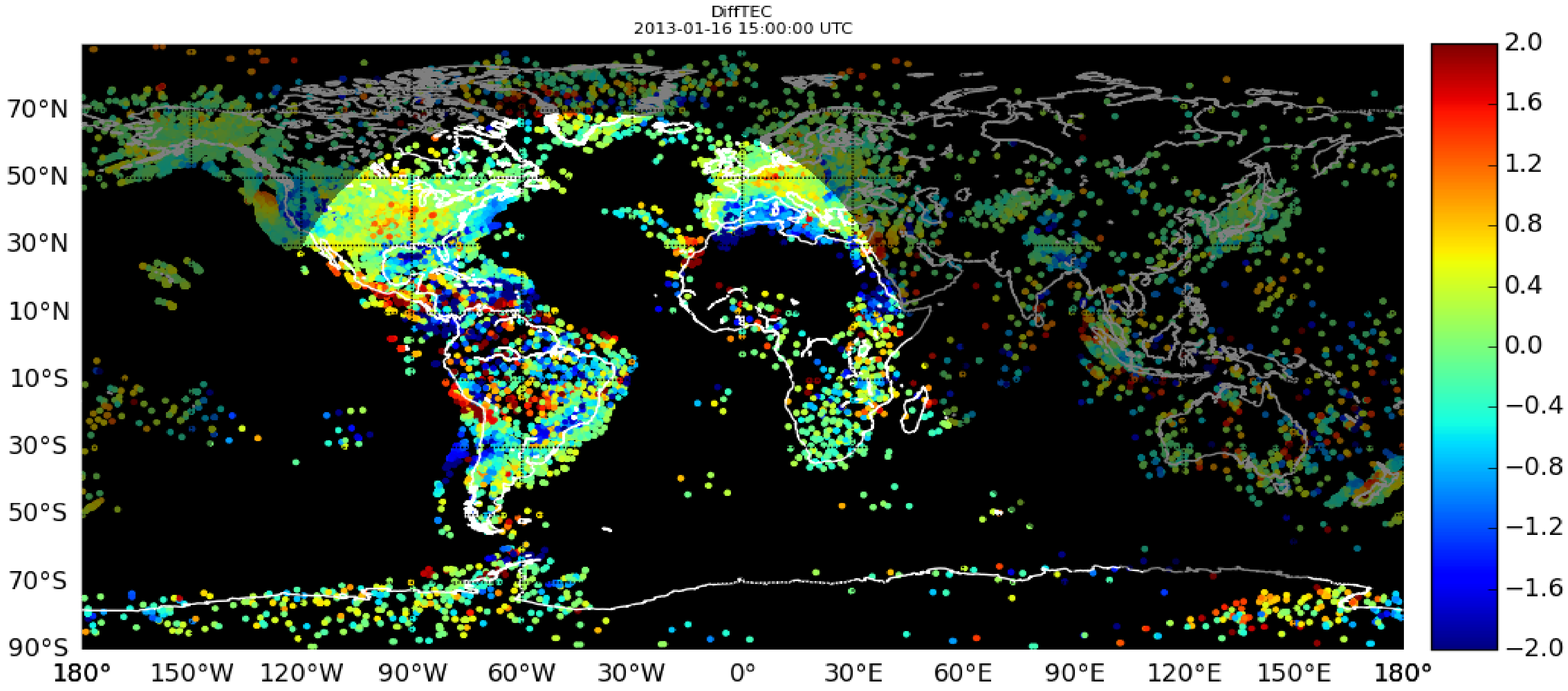
−1.6
−2.0

15:00 UT



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30°S
50°S
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0°
30°E
60°E
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120°E
150°E
180°
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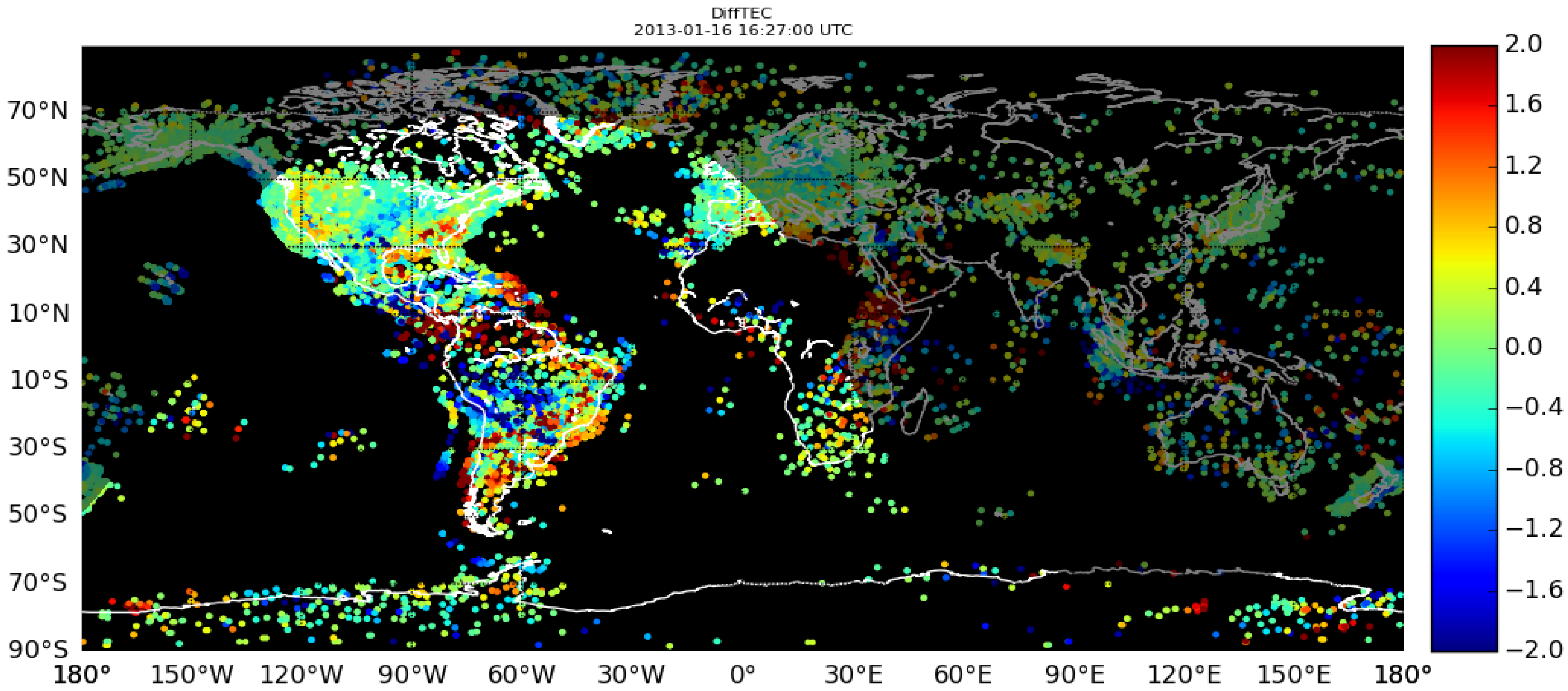
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0°
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150°E
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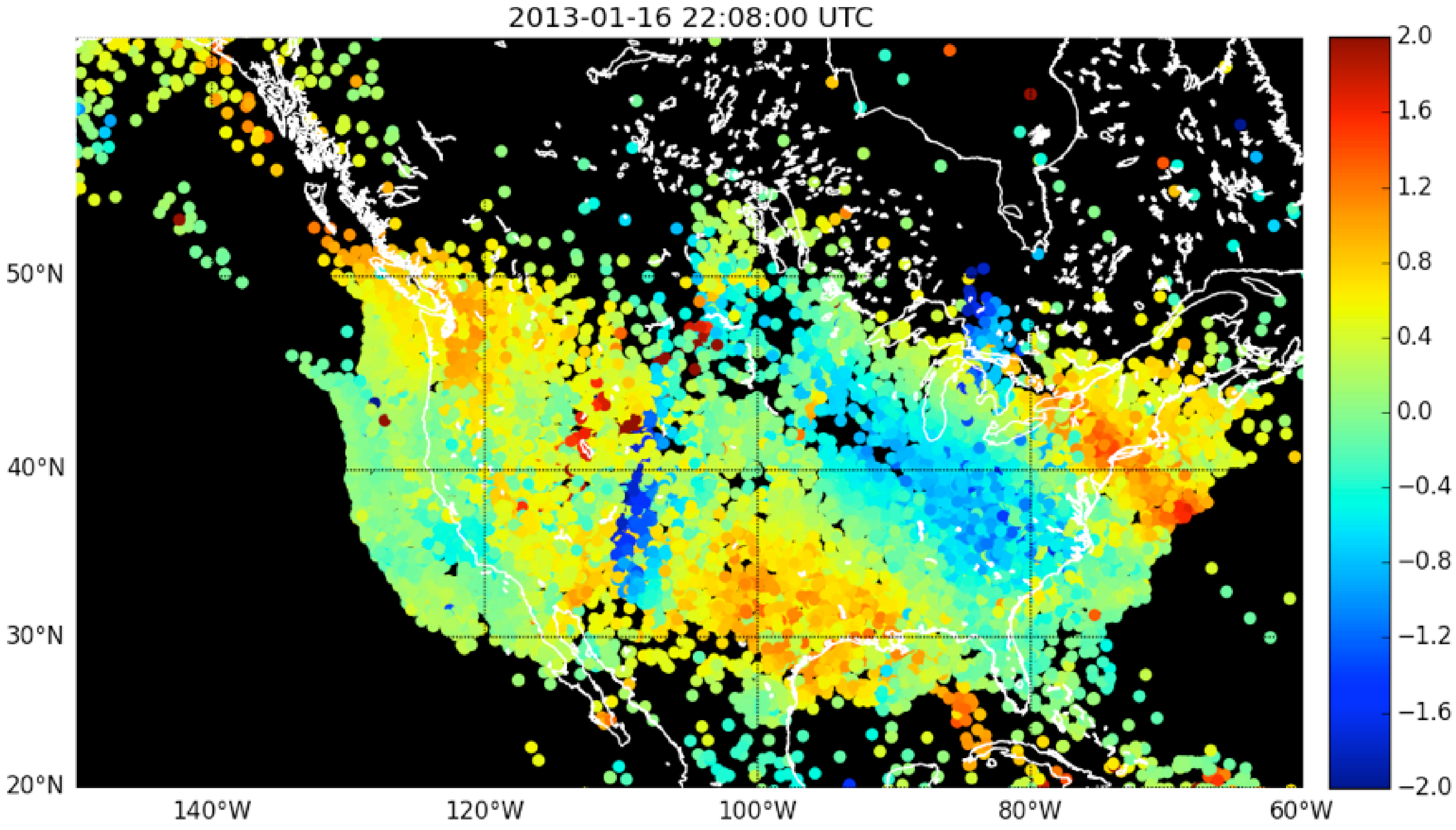

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80°W
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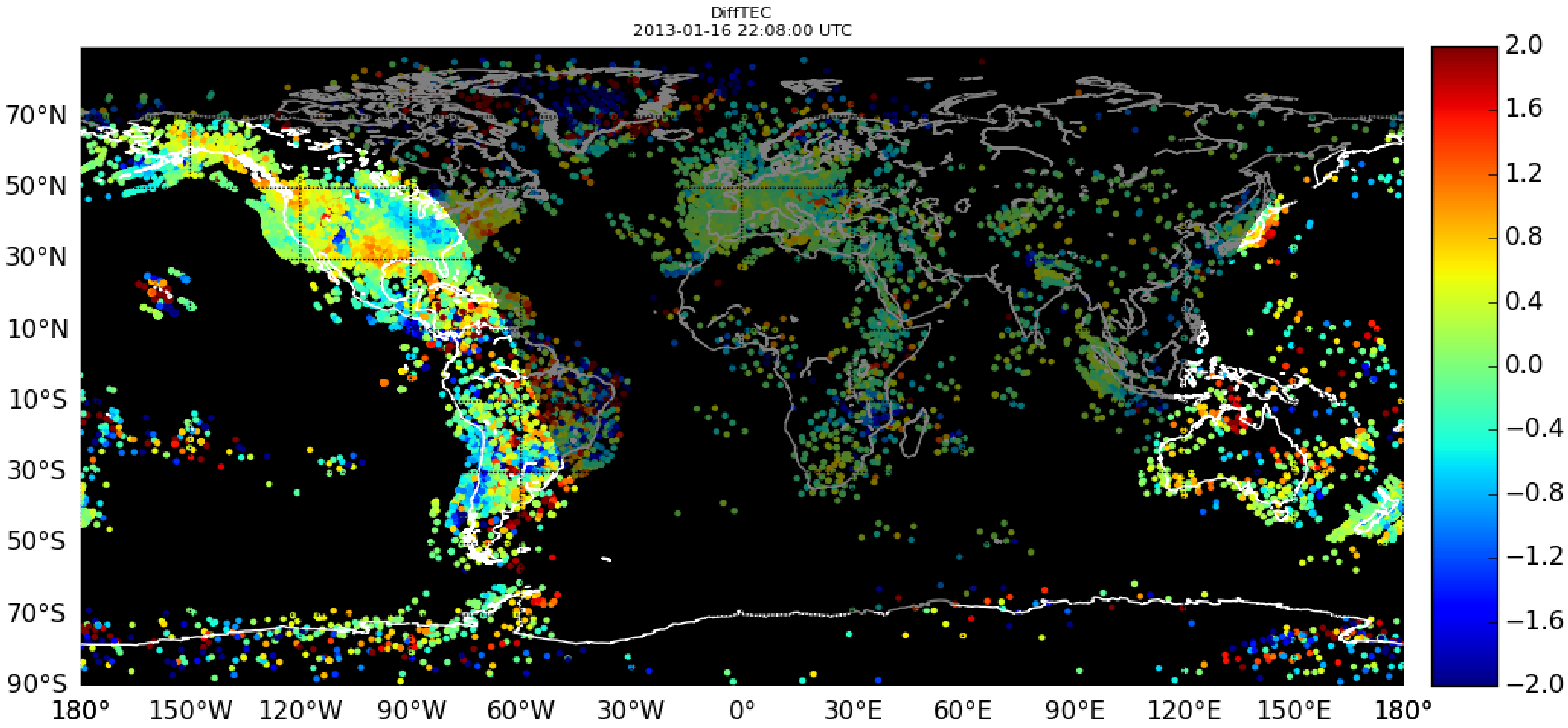
22:08 UT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150°W
120°W
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2.0
1.6
1.2
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−0.4
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−1.2
−1.6
−2.0

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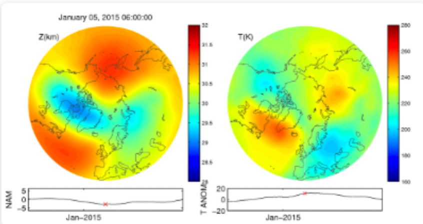
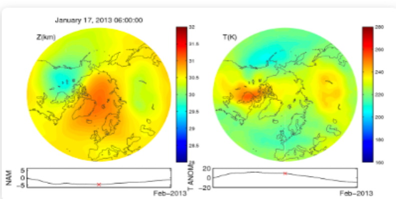
Stratospheric Sudden Warming , January 5 2015 , Stratospheric Vortex Weakening

- Minimum NAM during event -2.69



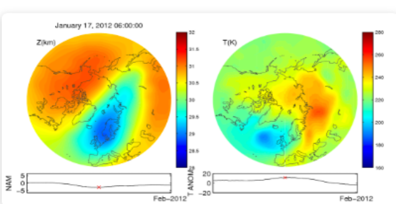
Stratospheric Sudden Warming , January 17 2013 , Stratospheric Vortex Weakening

- Minimum NAM during event -4.42

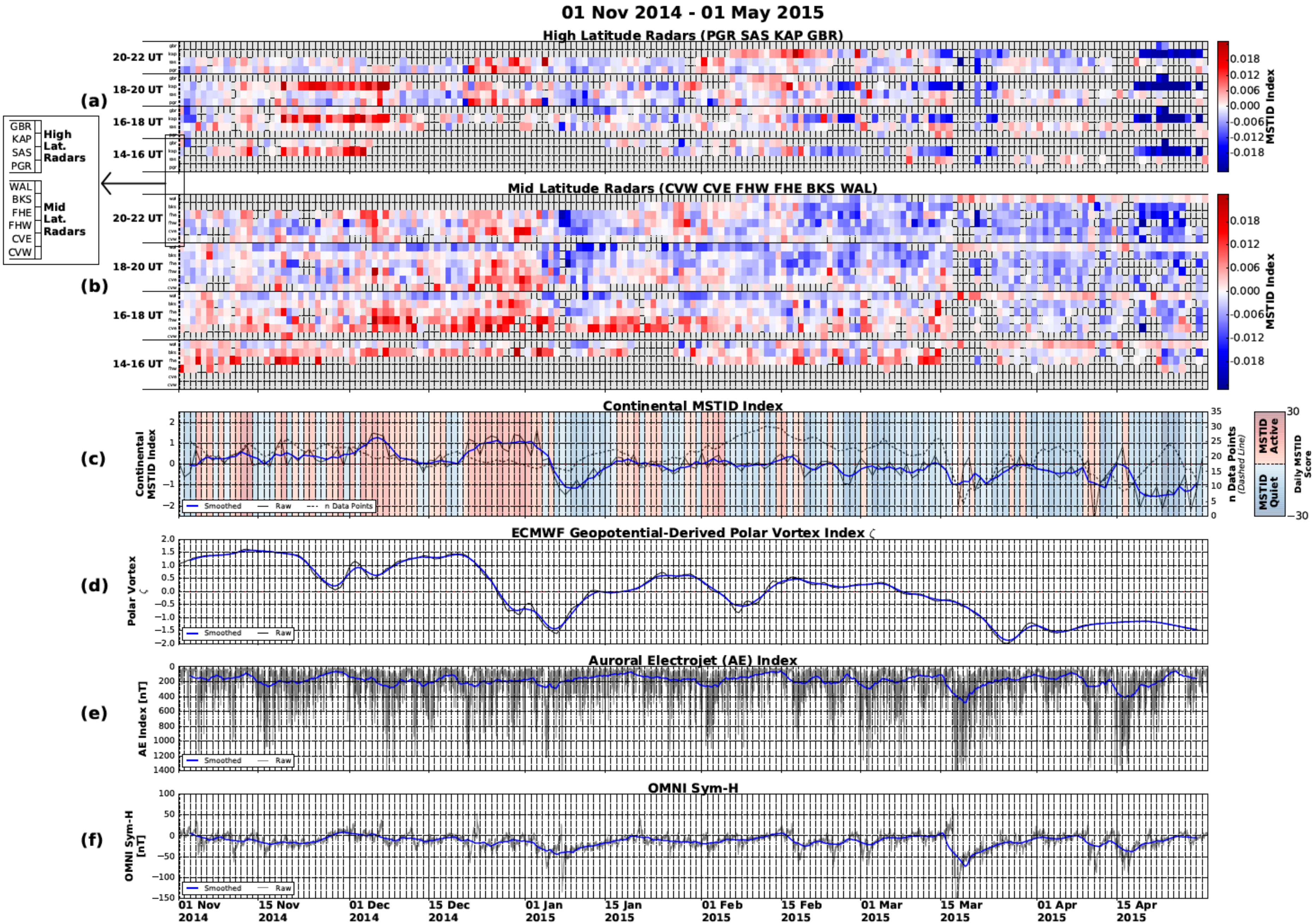


Stratospheric Sudden Warming , January 17 2012 , Stratospheric Vortex Weakening

- Minimum NAM during event -2.71



P. Martineau –
McGill University



01 Nov 2014 - 01 May 2015
High Latitude Radars (PGR SAS KAP GBR)
20-22 UT
18-20 UT
16-18 UT
14-16 UT
(a)
GBR
KAP
SAS
PGR
High Lat. Radars
WAL
BKS
FHE
FHW
CVE
CVW
Mid Lat. Radars
MSTID Index
Mid Latitude Radars (CVW CVE FHW FHE BKS WAL)
(b)
Continental MSTID Index
(c)
Continental MSTID Index
Smoothed
Raw
n Data Points
n Data Points (Dashed Line)
MSTID Active
MSTID Quiet
Daily MSTID Score
ECMWF Geopotential-Derived Polar Vortex Index ζ
(d)
Polar Vortex ζ
Auroral Electrojet (AE) Index
(e)
AE Index [nT]
OMNI Sym-H
(f)
OMNI Sym-H [nT]
01 Nov 2014
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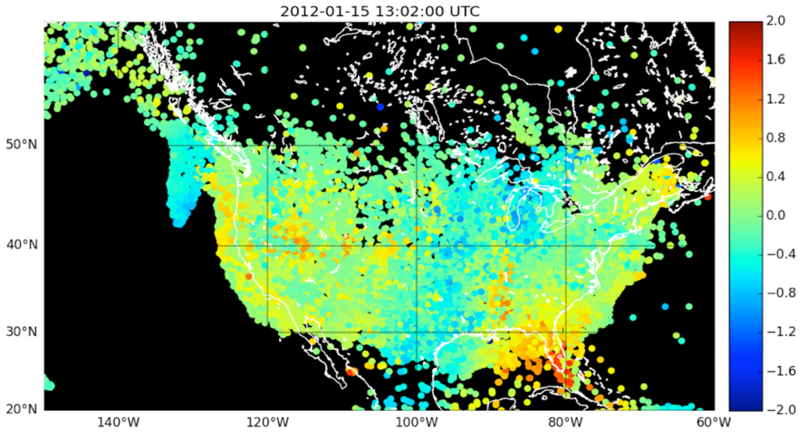
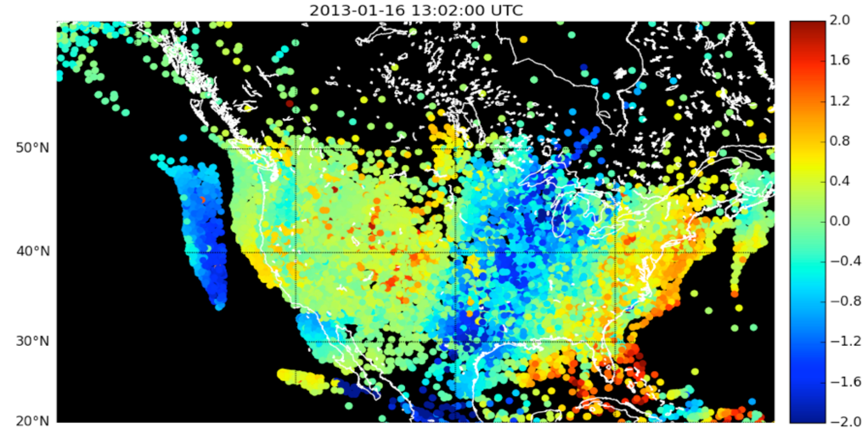
15 Feb 2015
01 Mar 2015
15 Mar 2015
01 Apr 2015
15 Apr 2015

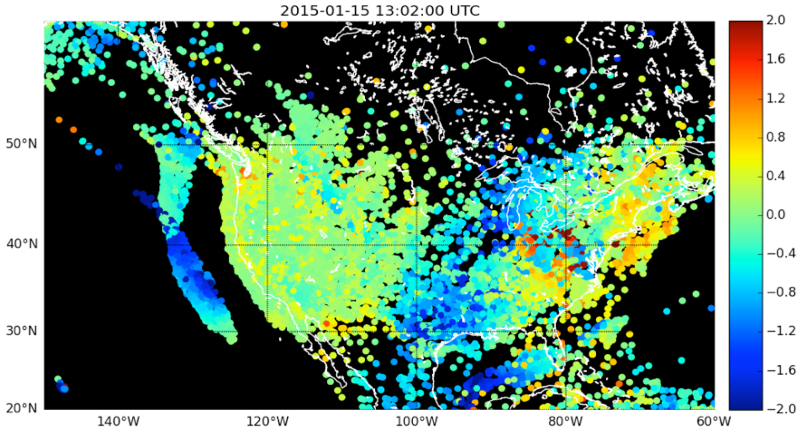
2012



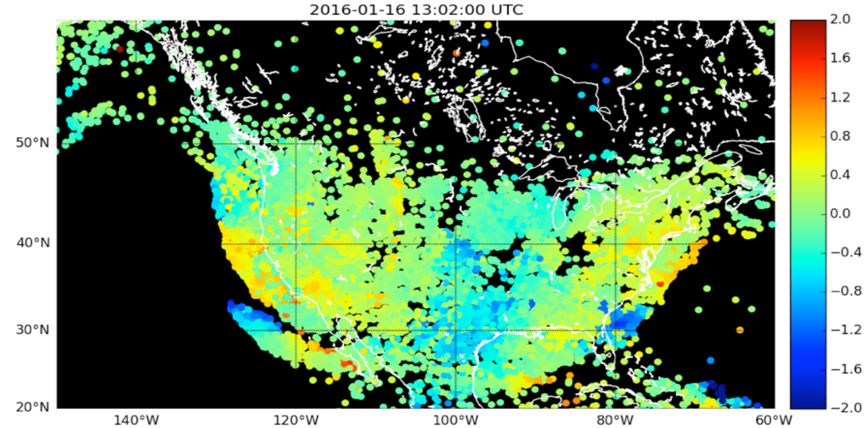
2013



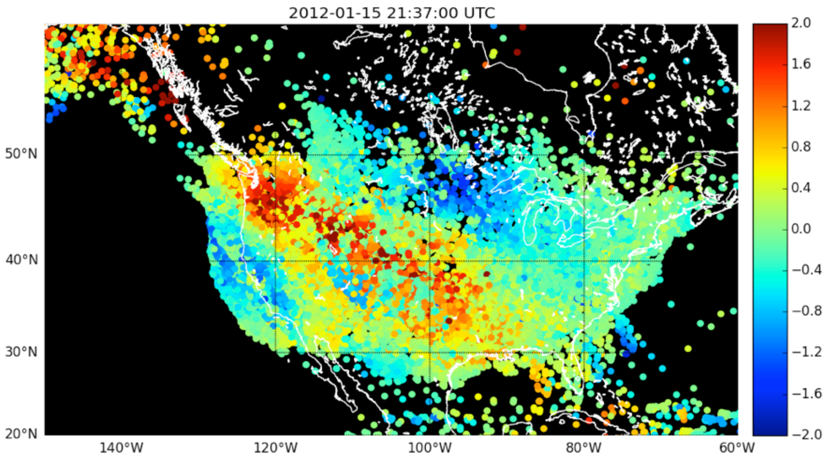
2015



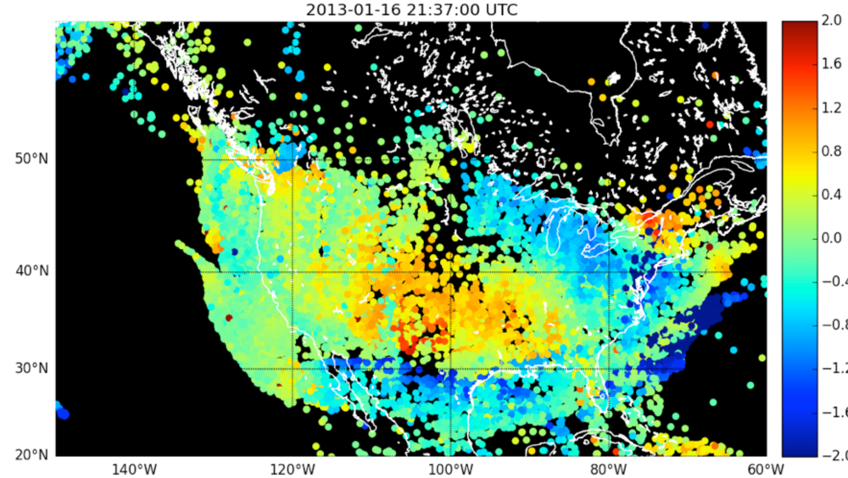
2016



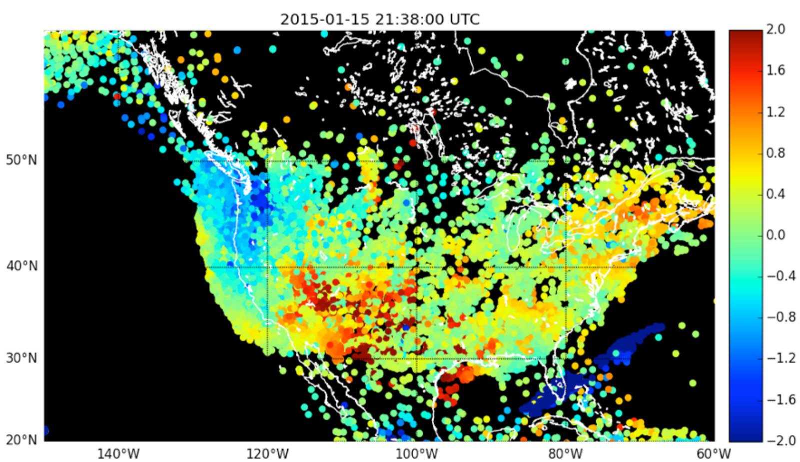
2012



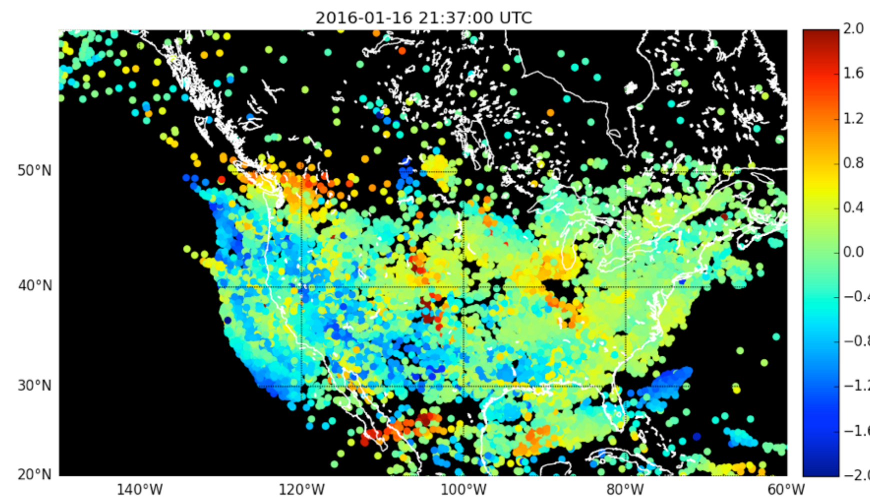
2013



2015



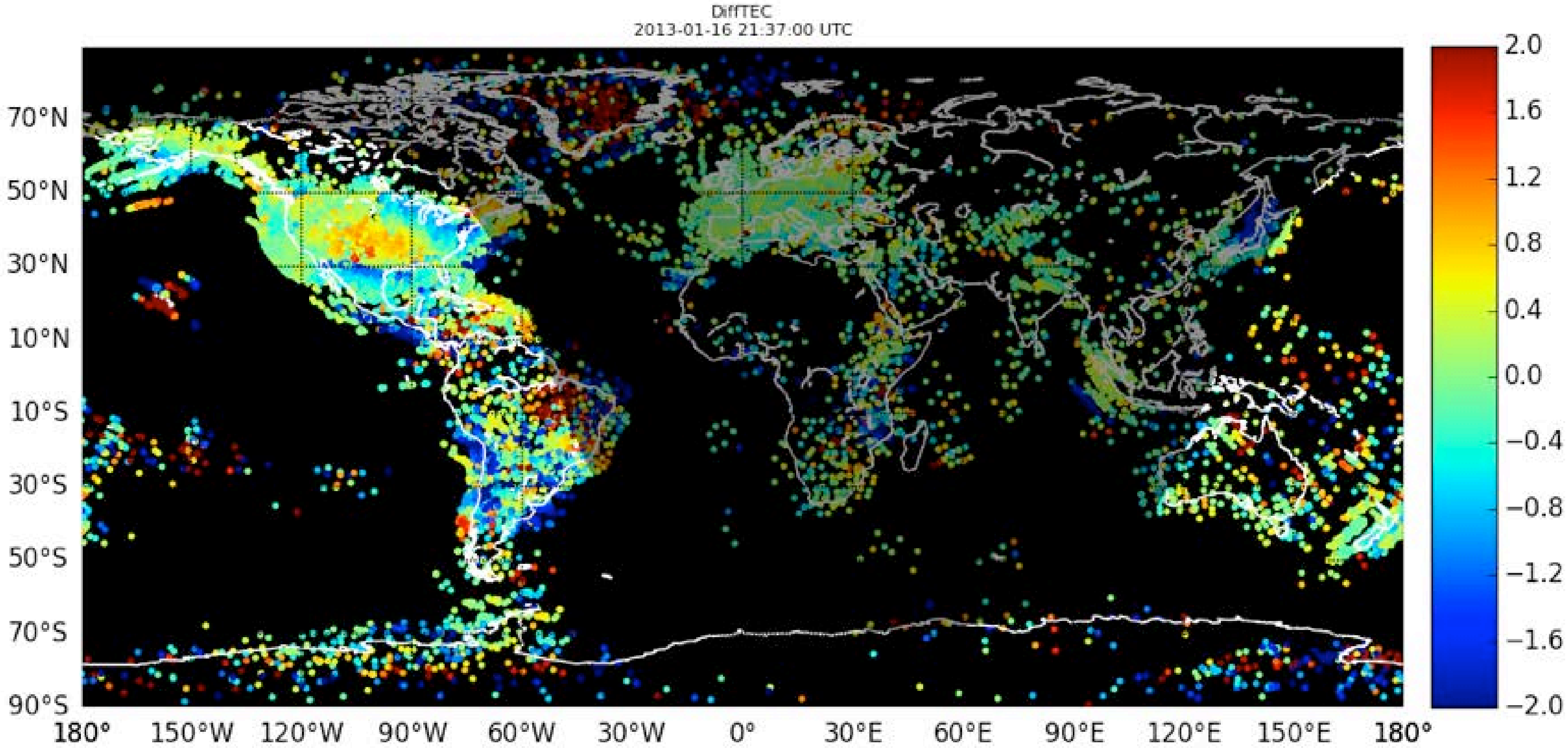
2016



Summary

- Large-scale TIDs are observed during SSW time periods when medium-scale TIDs are damped
- Persistence and size of LSTIDs unusual
- Most of these large scale TIDs, but not all, are related to day/night transition
- What is mechanism for this?

21:37 UT



DiffTEC
2013-01-16 21:37:00 UTC
70°N
50°N
30°N
10°N
10°S
30°S
50°S
70°S
90°S
180°
150°W
120°W
90°W
60°W
30°W
0°
30°E
60°E
90°E
120°E
150°E
180°
2.0
1.6
1.2
0.8
0.4
0.0
−0.4
−0.8
−1.2
−1.6
−2.0