

Ionospheric Structures Detected by Radio Tomography during the Geomagnetic Disturbances

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Outline

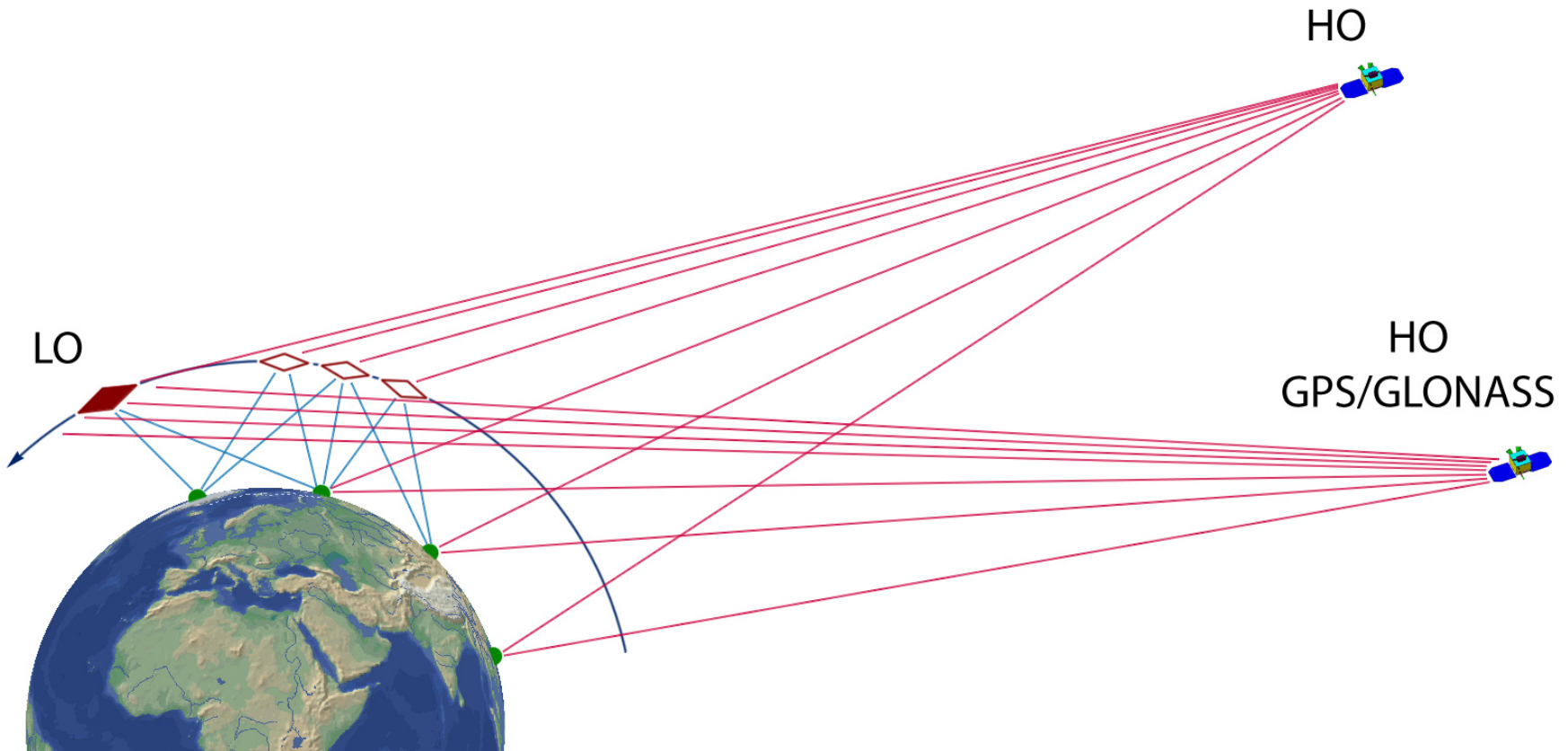
- **The geomagnetic disturbances deeply affect the dynamical regime of the ionosphere and cause significant variations in the ionospheric parameters.**

We discuss the ionospheric structures imaged by satellite radio tomography during the geomagnetically disturbed periods of solar cycles 23 and 24.

Special emphasis is placed on the results from low orbiting radio tomography (LORT).

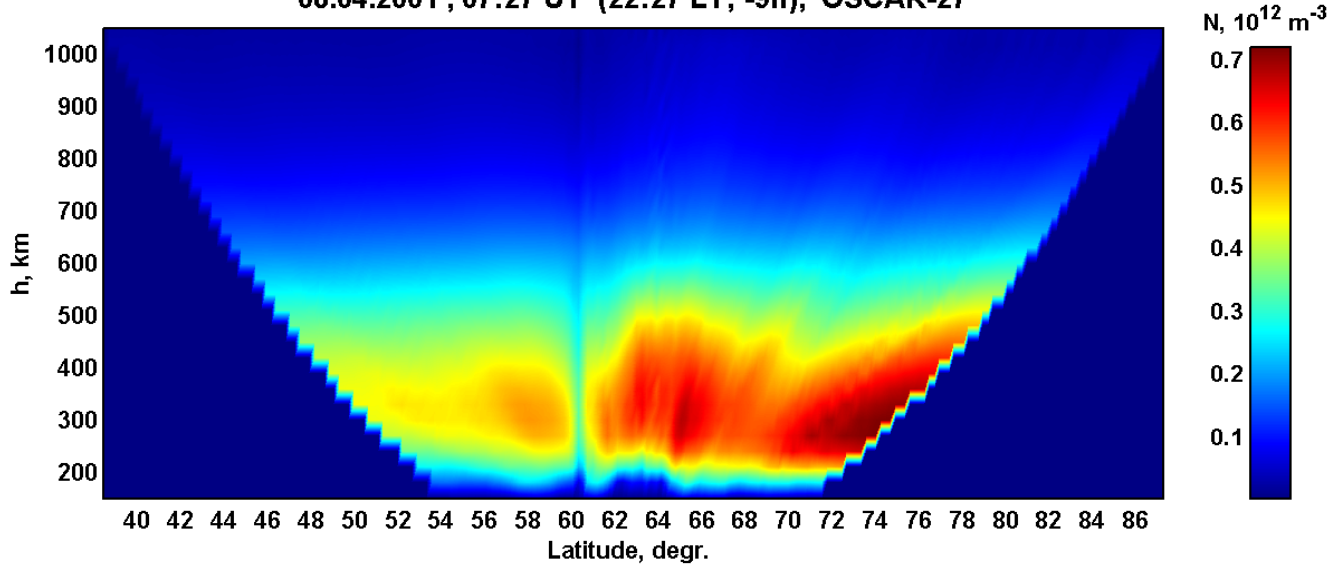
- **Various wavelike disturbances, isolated spots of enhanced and depleted electron density, sharp wall-like density gradients, and ionospheric troughs are revealed by LORT in the northwestern Russia, Alaska, U.S. West Coast, and South East Asia.**
- **High-orbiting RT (HORT) reconstructions based on GPS/GLONASS satellite systems help to more accurately locate the positions and trace the dynamics of the ionospheric irregularities detected by LORT.**

Satellite radiosounding and Radio Tomography of the nearspace environment



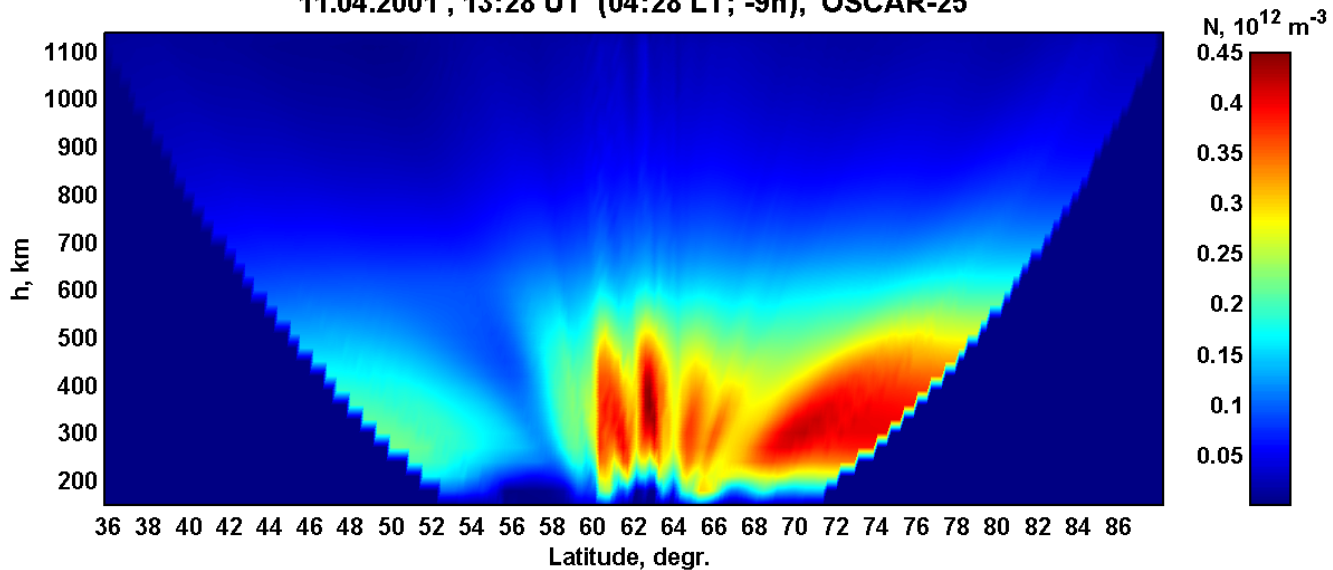
Alaska region

08.04.2001 , 07:27 UT (22:27 LT; -9h), OSCAR-27



LORT image above Alaska on April 8, 2001, 07:27 UT ($K_p = 5$)

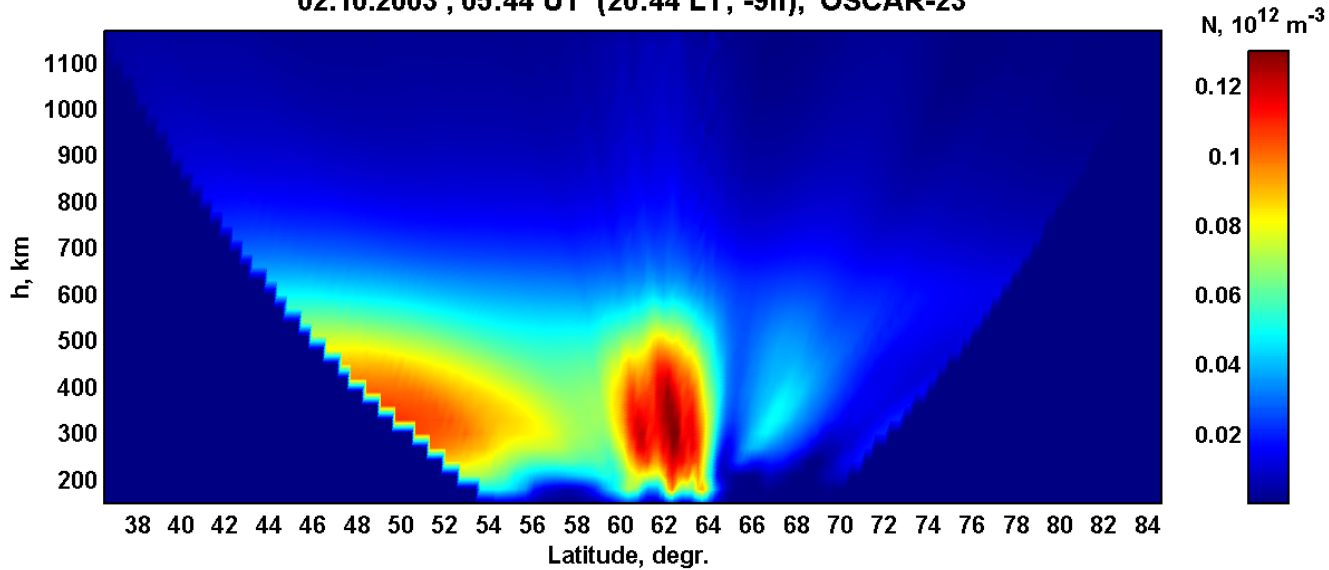
11.04.2001 , 13:28 UT (04:28 LT; -9h), OSCAR-25



LORT image above Alaska on April 11, 2001, 13:28 UT ($K_p = 7$)

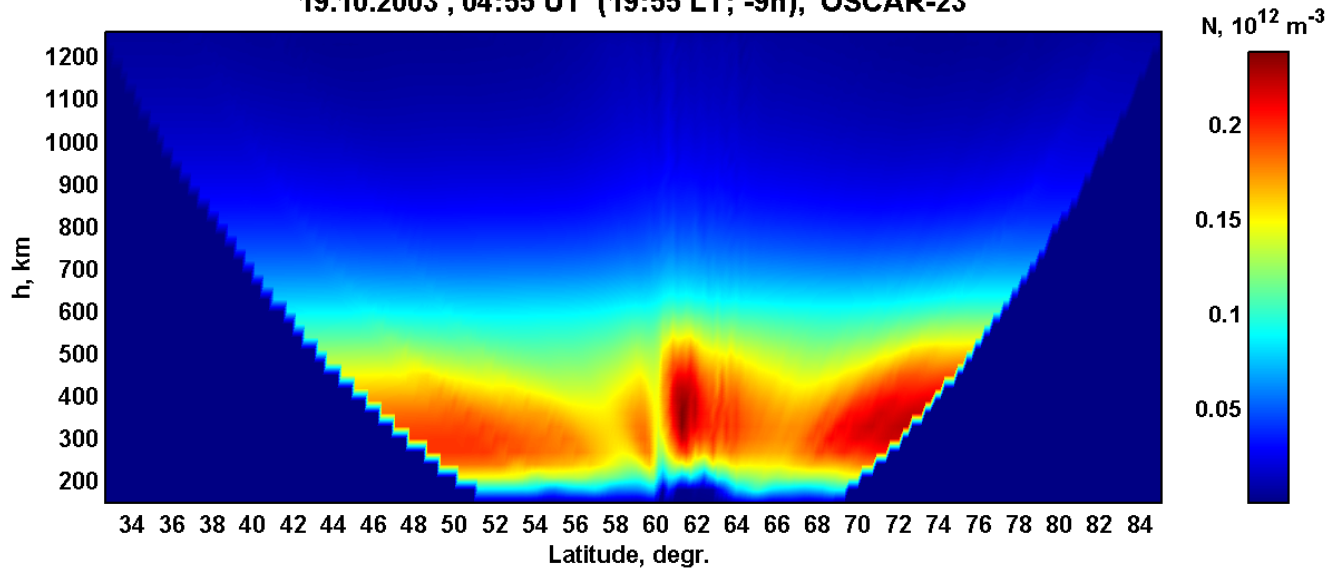
Alaska region

02.10.2003 , 05:44 UT (20:44 LT; -9h), OSCAR-23



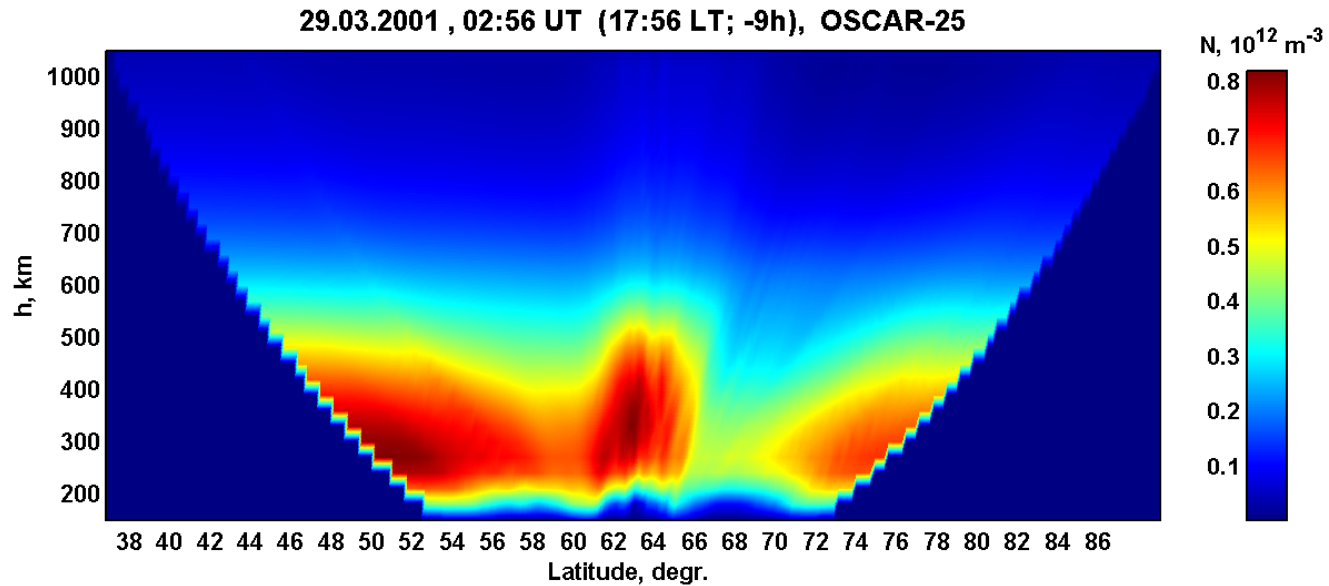
LORT image above Alaska on October 2, 2003, 05:44 UT ($K_p = 2.3$)

19.10.2003 , 04:55 UT (19:55 LT; -9h), OSCAR-23

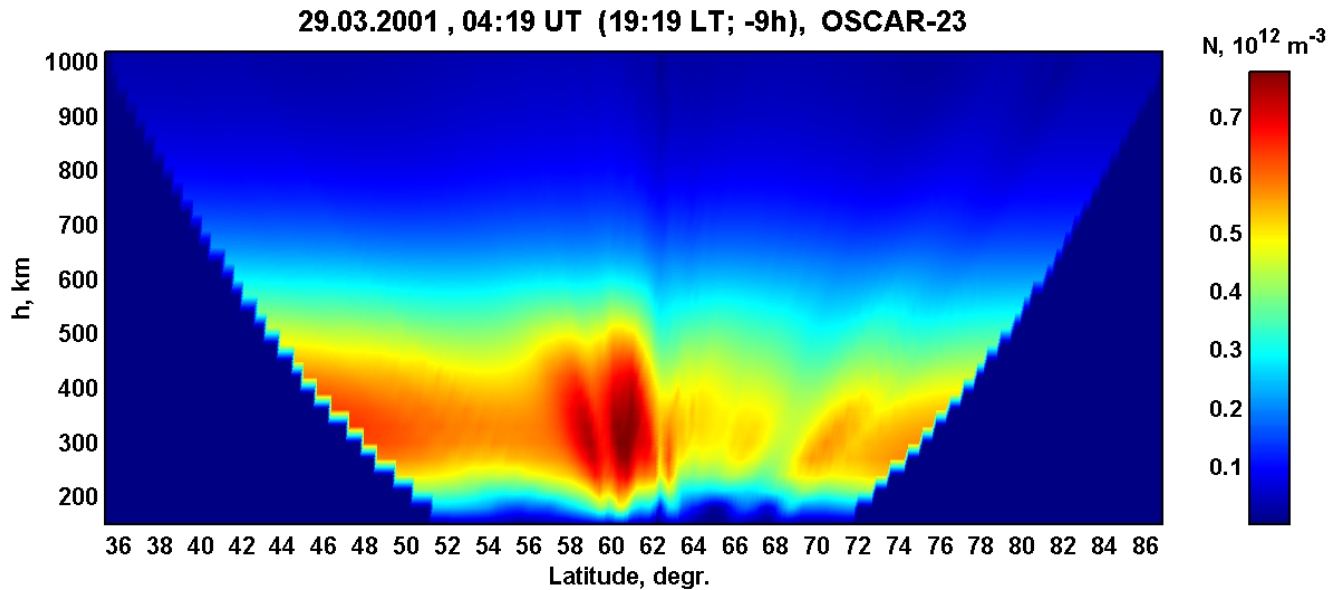


LORT image above Alaska on October 19, 2003, 13:28 UT ($K_p = 4.3$)

Alaska region



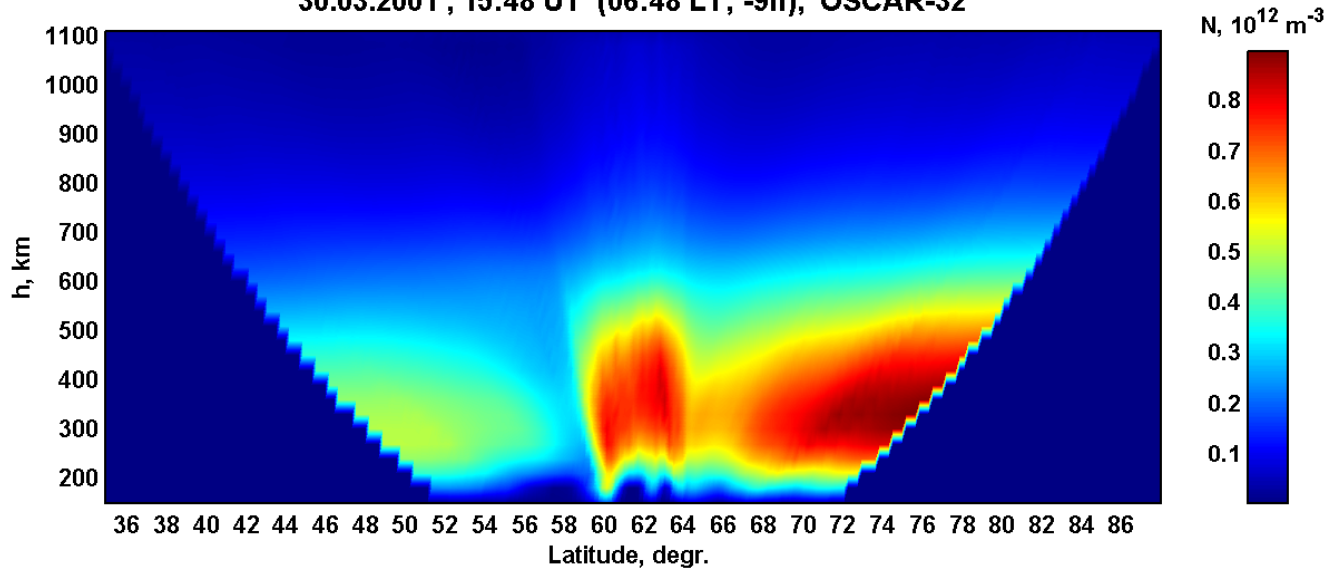
LORT image above Alaska on March 29, 2001, 02:56 UT ($K_p = 4$)



LORT image above Alaska on March 29, 2001, 04:19 UT ($K_p = 4.7$)

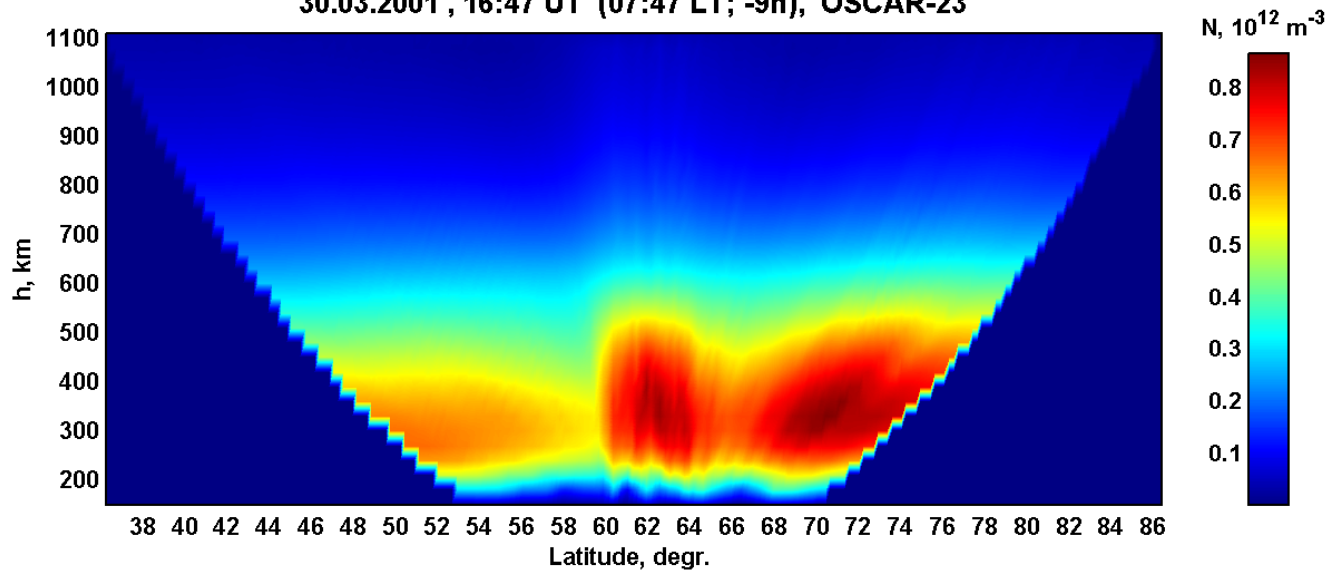
Alaska region

30.03.2001 , 15:48 UT (06:48 LT; -9h), OSCAR-32



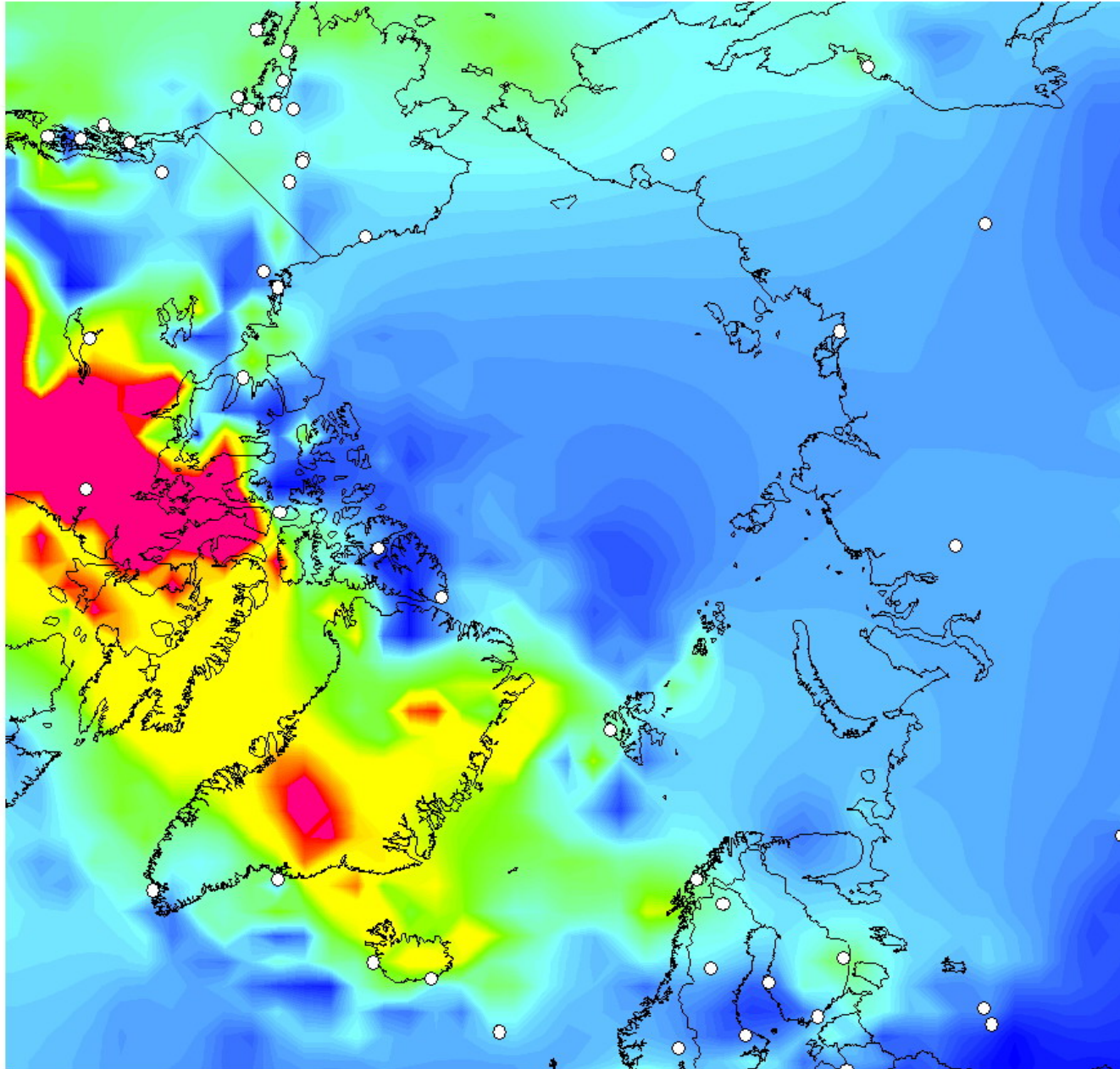
LORT image above Alaska on March 30, 2001, 15:48 UT ($K_p = 2.7$)

30.03.2001 , 16:47 UT (07:47 LT; -9h), OSCAR-23

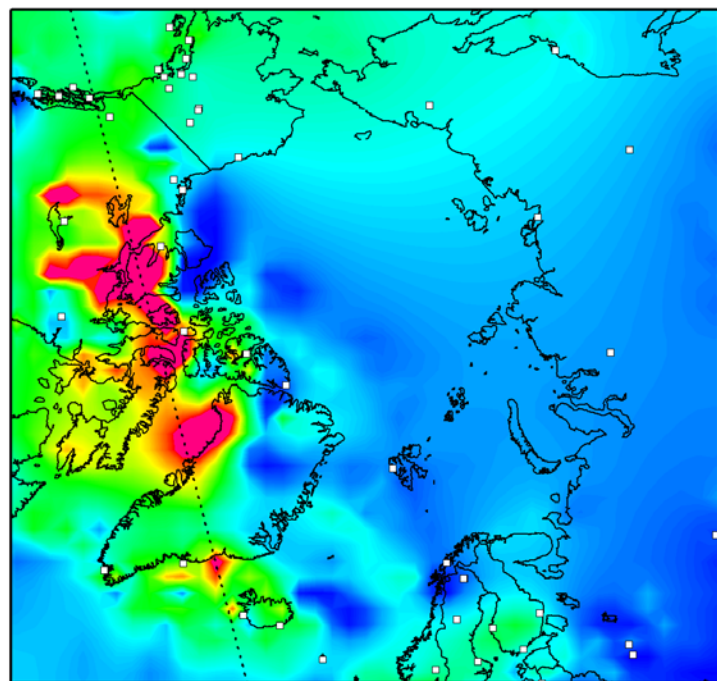


LORT image above Alaska on March 30, 2001, 16:47 UT ($K_p = 3$)

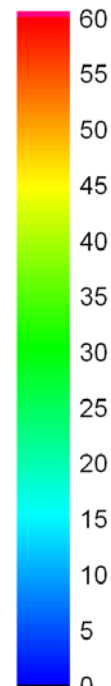
29.10.2003 21:00 UT



29.10.2003 22:00 UT

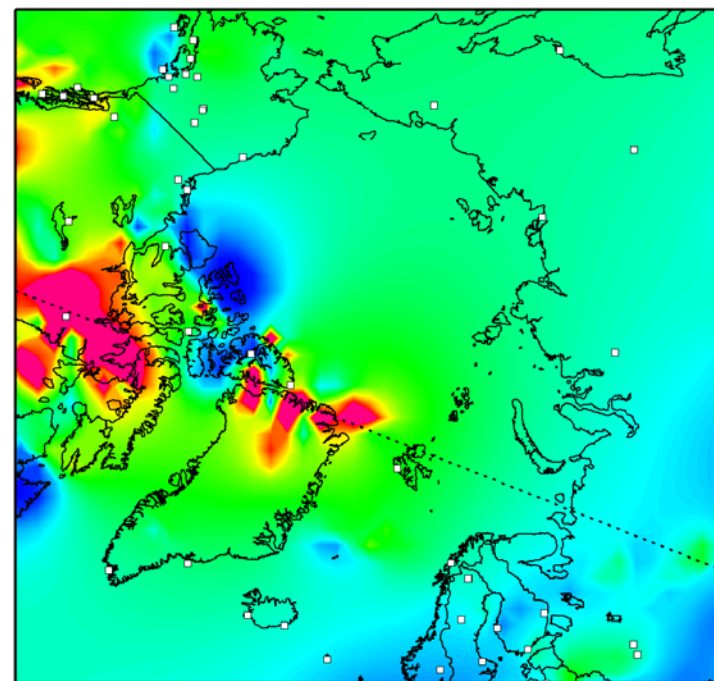


TECU



a)

30.10.2003 21:00 UT

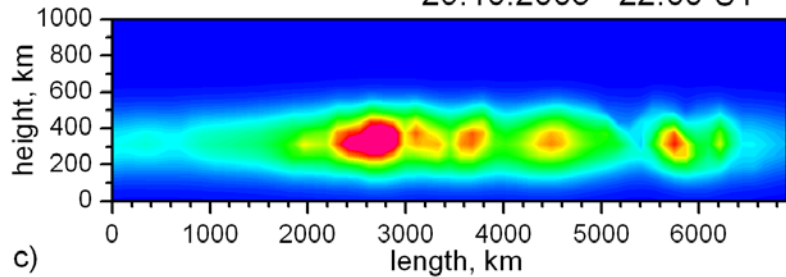


TECU

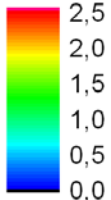


b)

29.10.2003 22:00 UT

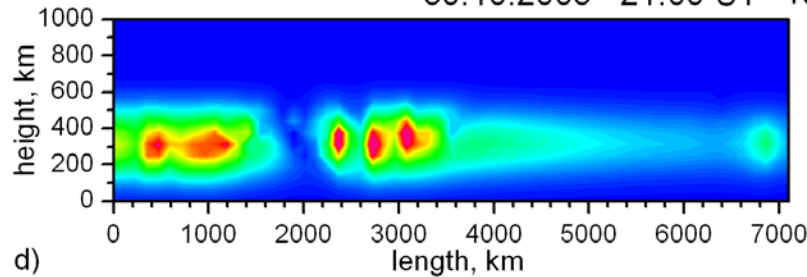


$N, 10^{-12} \text{ m}^{-3}$

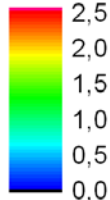


c)

30.10.2003 21:00 UT

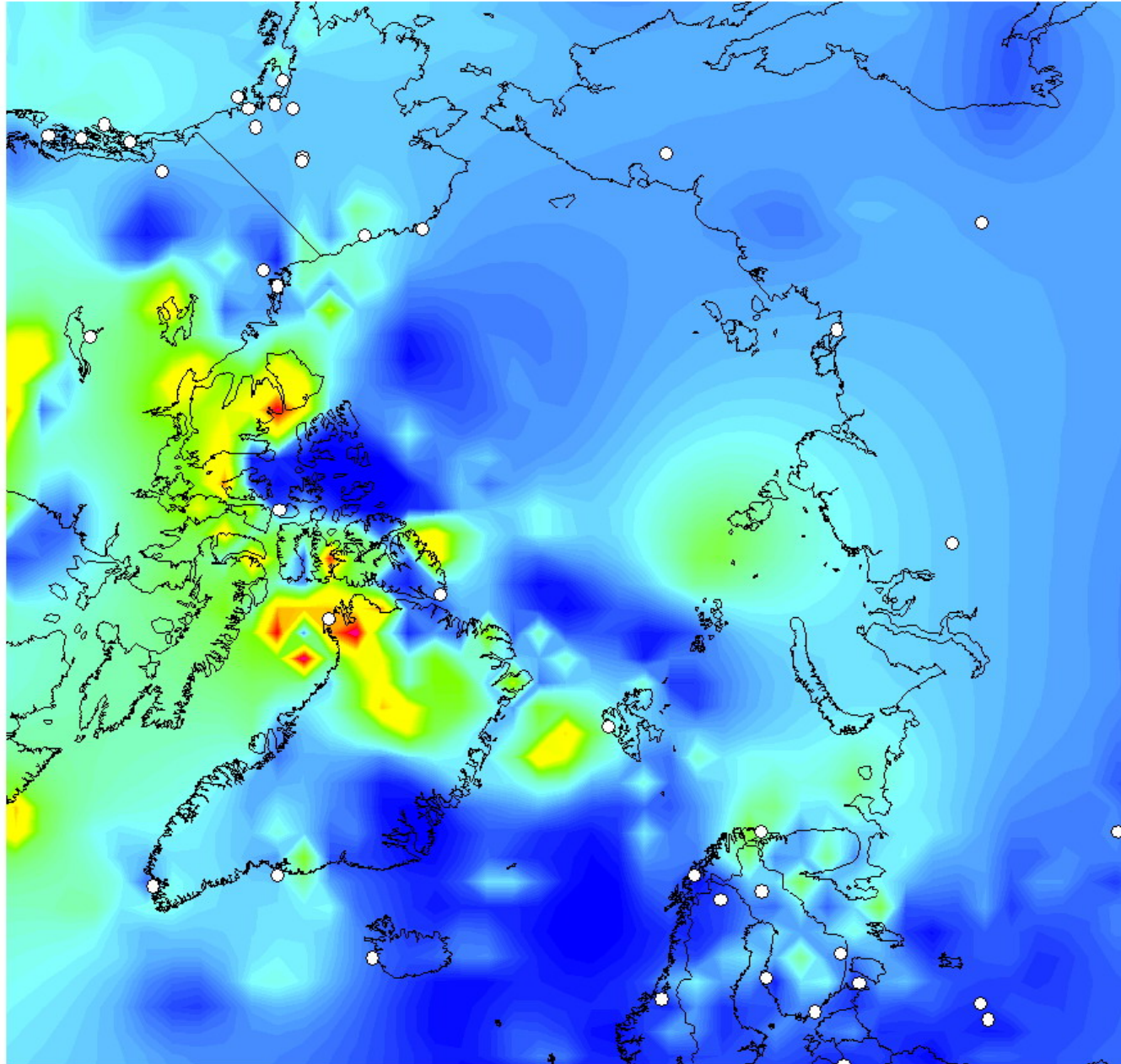


$N, 10^{-12} \text{ m}^{-3}$

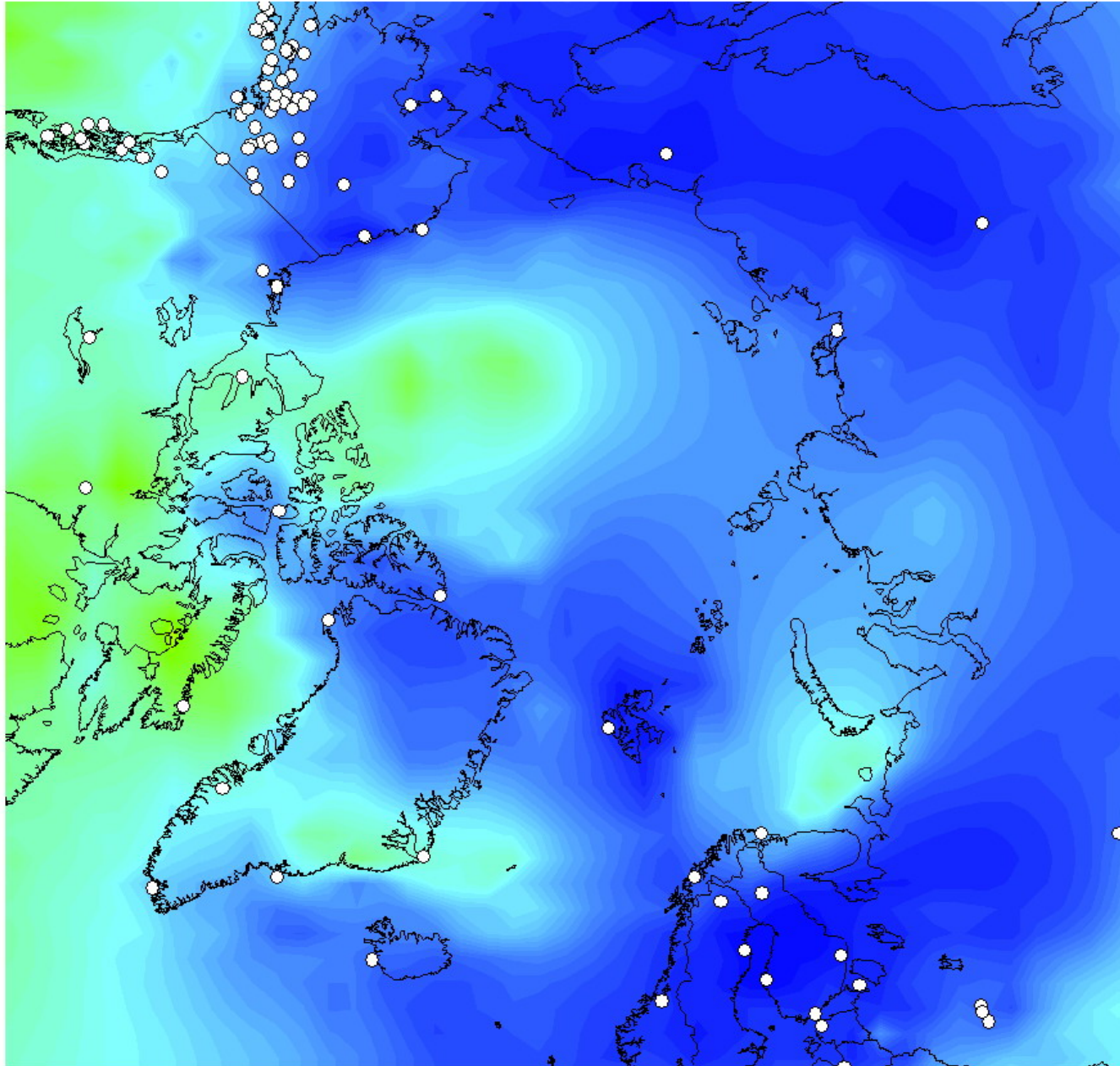


d)

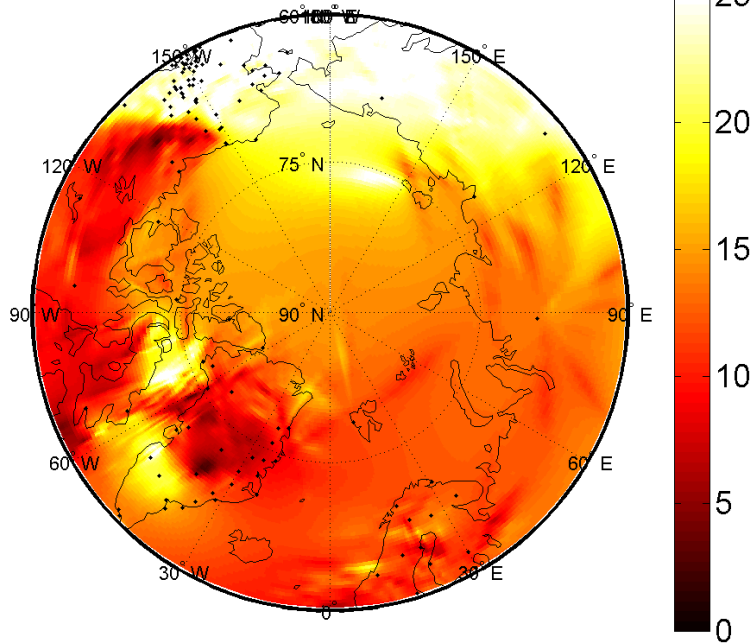
31.10.2003 18:00 UT



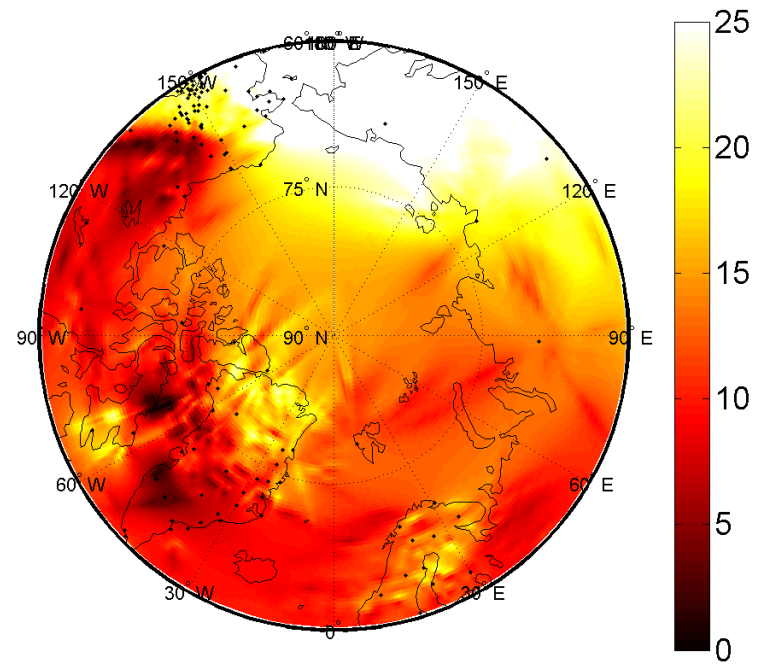
16.12.2006 19:00 UT



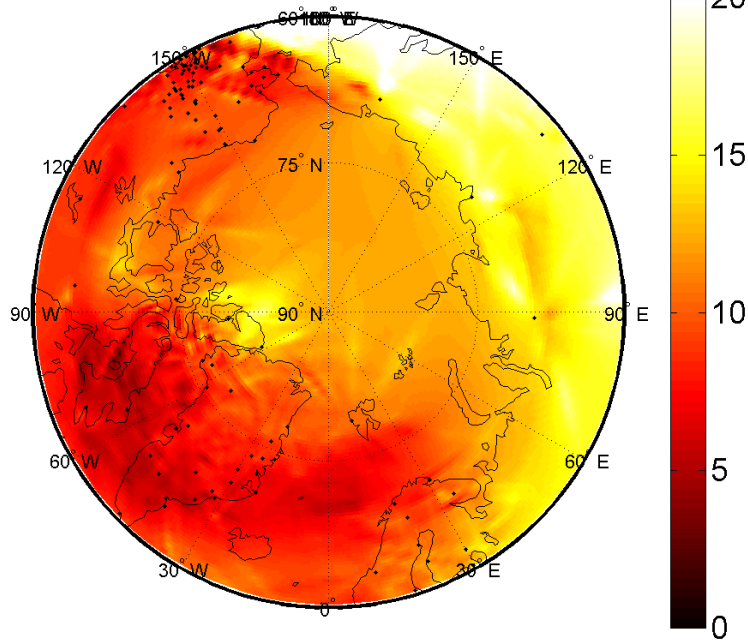
09.02.2014 02:00 UT



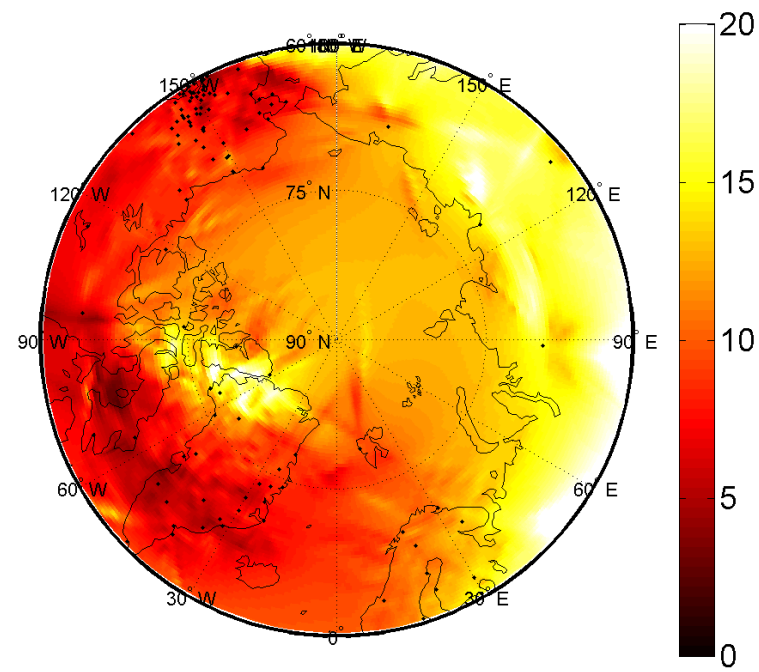
09.02.2014 03:00 UT



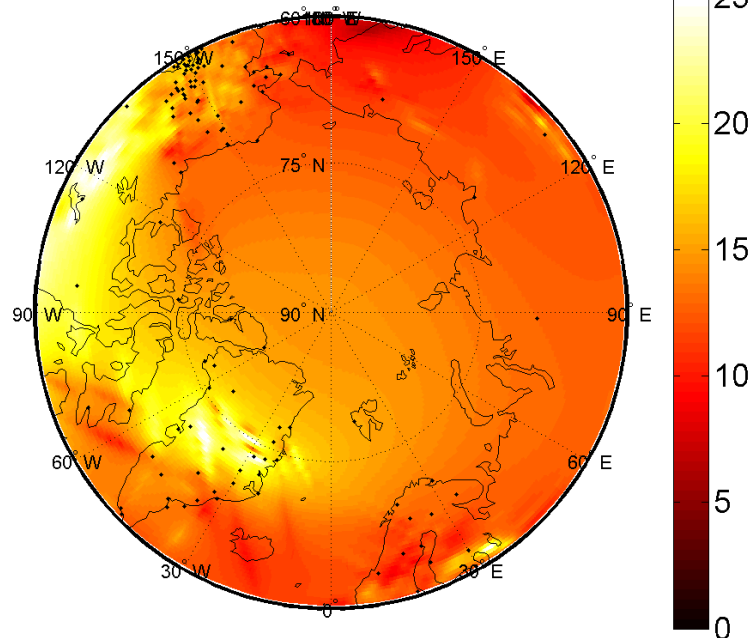
13.04.2014 06:00 UT



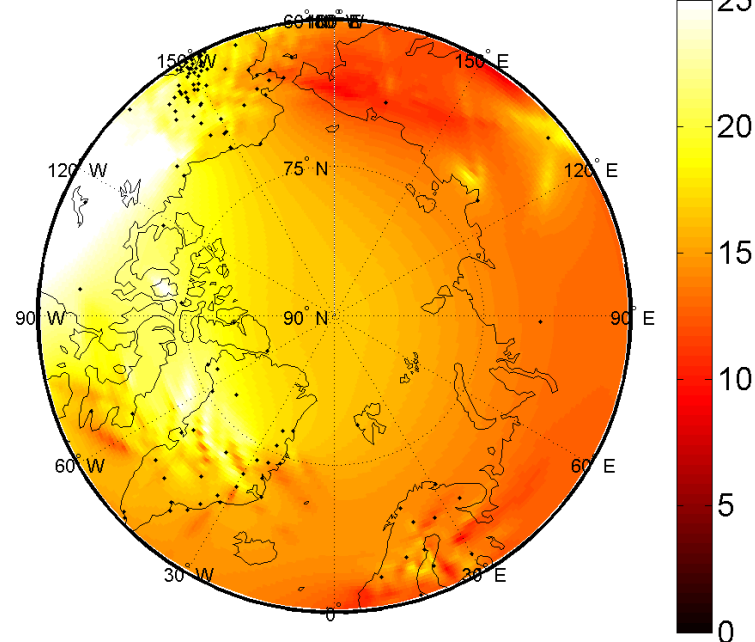
13.04.2014 07:00 UT



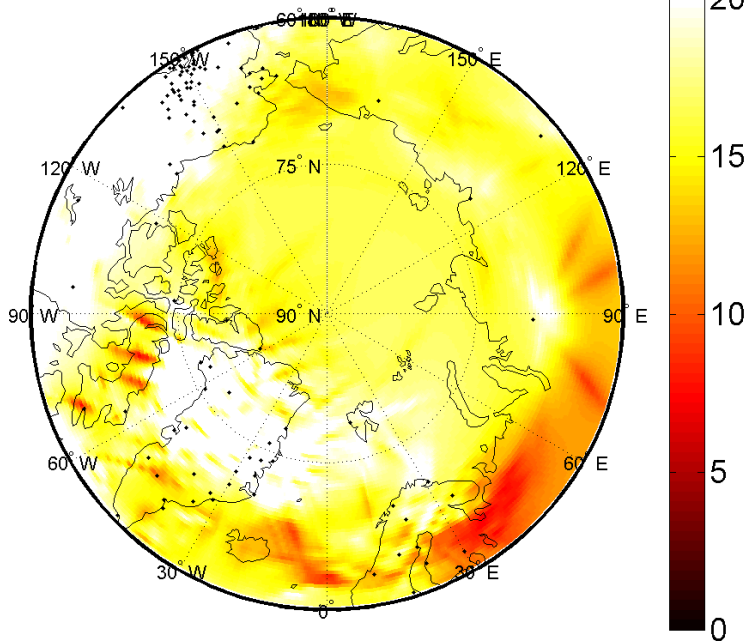
08.02.2014 20:00 UT



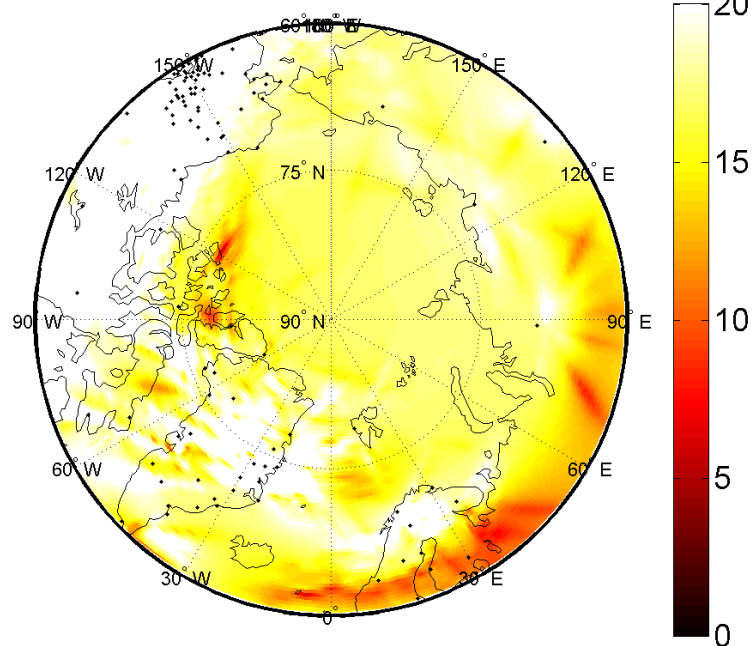
08.02.2014 21:00 UT



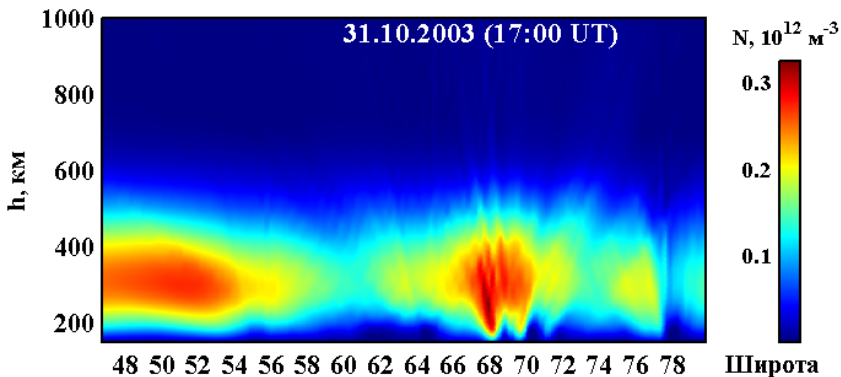
14.04.2014 21:00 UT



14.04.2014 22:00 UT



Сопоставление РТ-сечений с данными DMSP (Москва – Шпицберген)



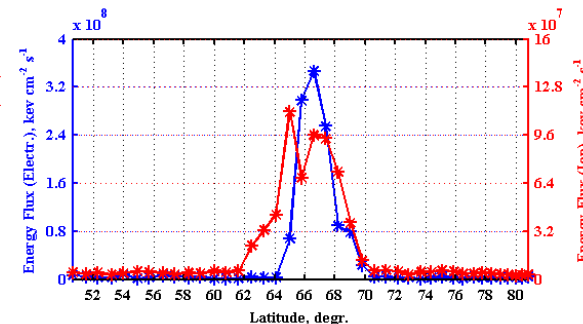
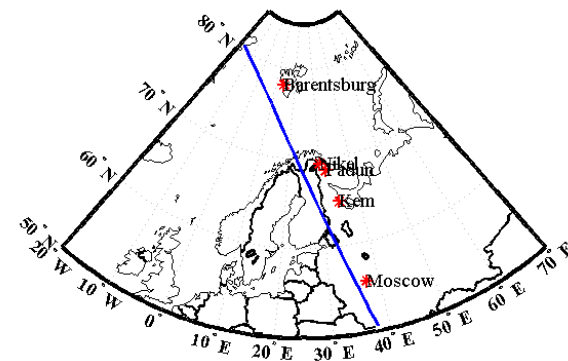
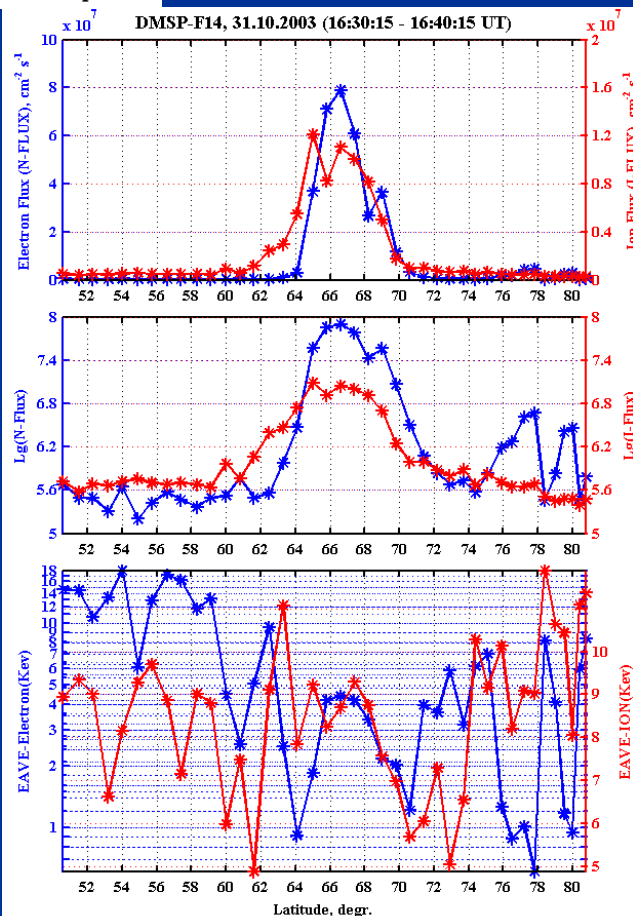
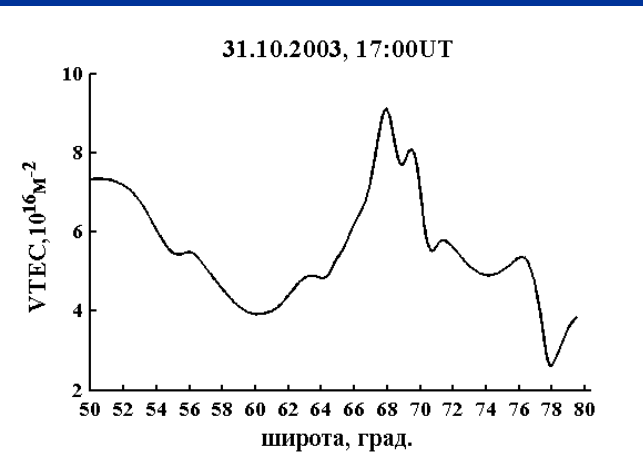
$K_p=5$

$K_{\text{ЛОВЗЕРО}}=5$

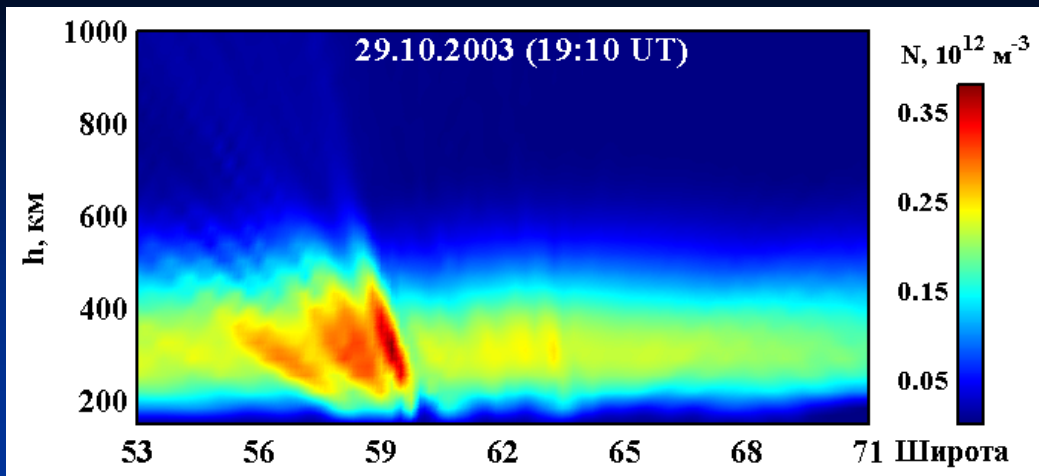
$\text{NFLUX}_{\text{max}} = 3,3 \cdot 10^8 \text{ см}^{-2} \text{ сек}^{-1}$

$\text{EFLUX}_{\text{max}} = 3,4 \cdot 10^8 \text{ КэВсм}^{-2} \text{ сек}^{-1}$

$\Delta \text{TEC} \sim 4 \text{ TECU}$



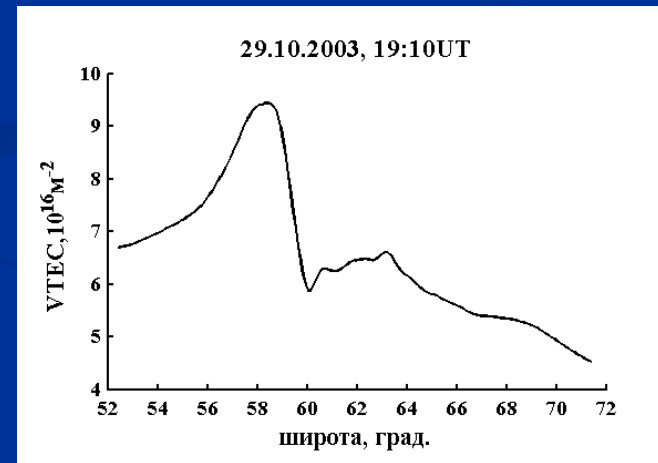
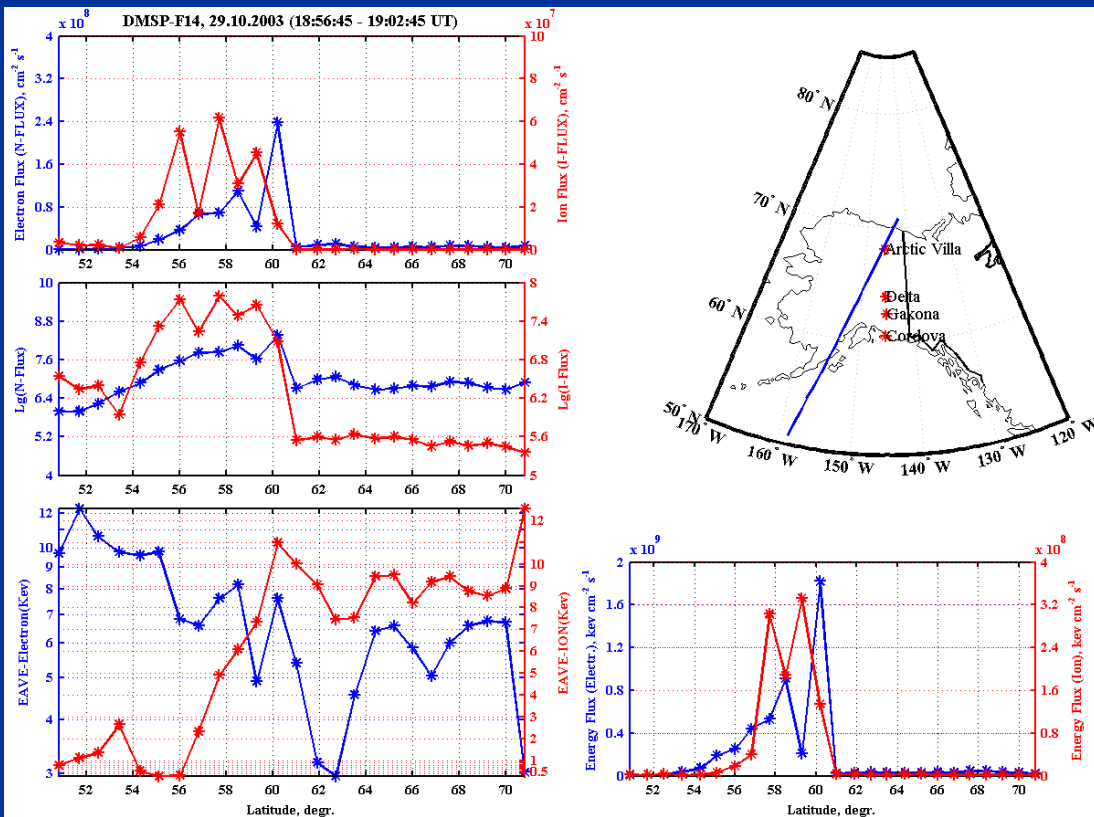
Сопоставление РТ-сечений с данными DMSP (район Аляски)



$K_p = 8,7$
 $K_{College} = 8$

$NFLUX_{max} = 2,4 \cdot 10^8 \text{ cm}^{-2} \text{ сек}^{-1}$

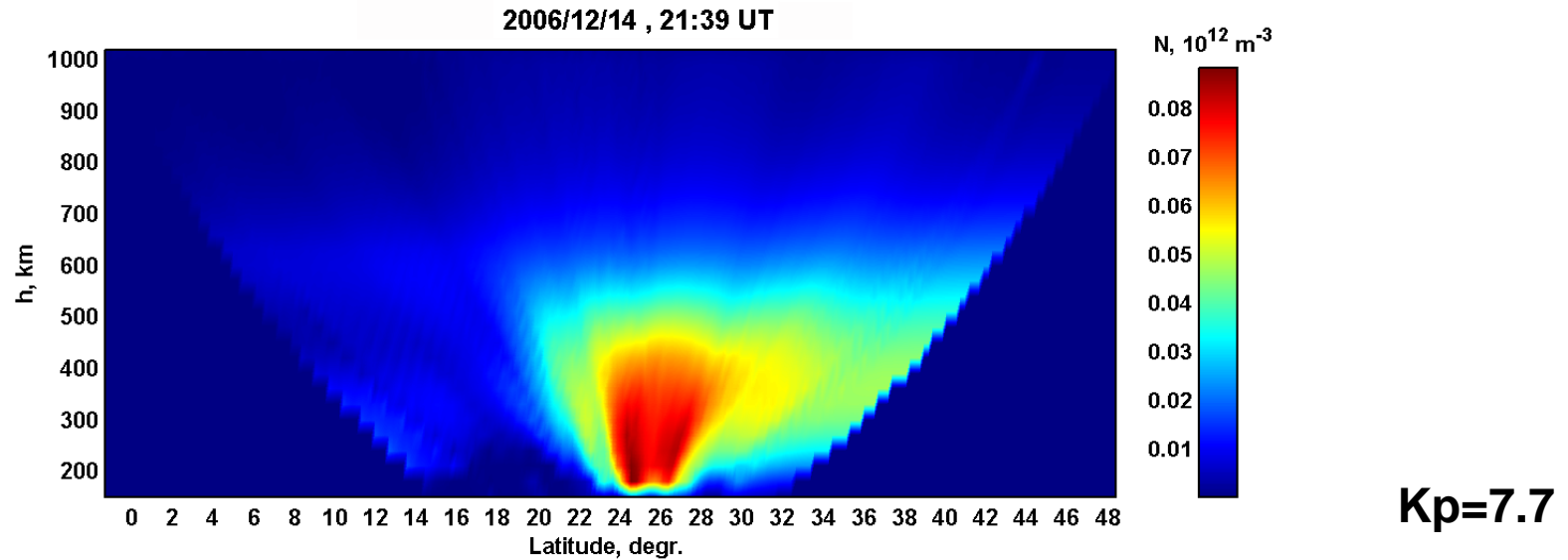
$EFLUX_{max} = 18,1 \cdot 10^8 \text{ КэВсм}^{-2} \text{ сек}^{-1}$



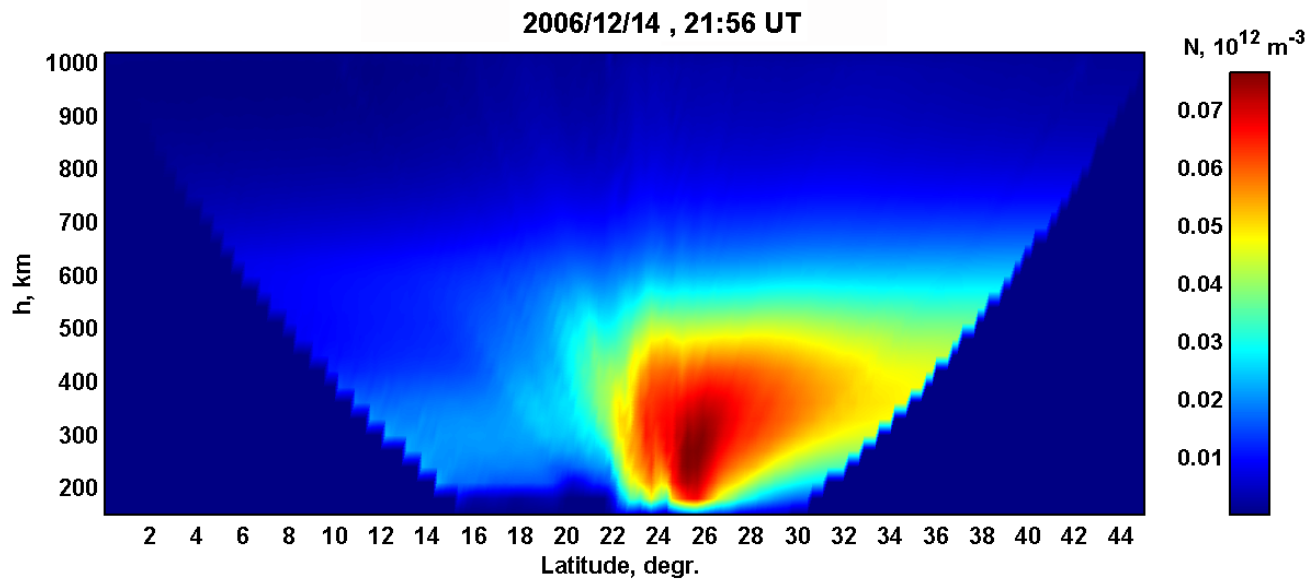
$\Delta \text{TEC} \sim 3 \text{ TECU}$

Taiwan region

geomagnetic storm of December 2006



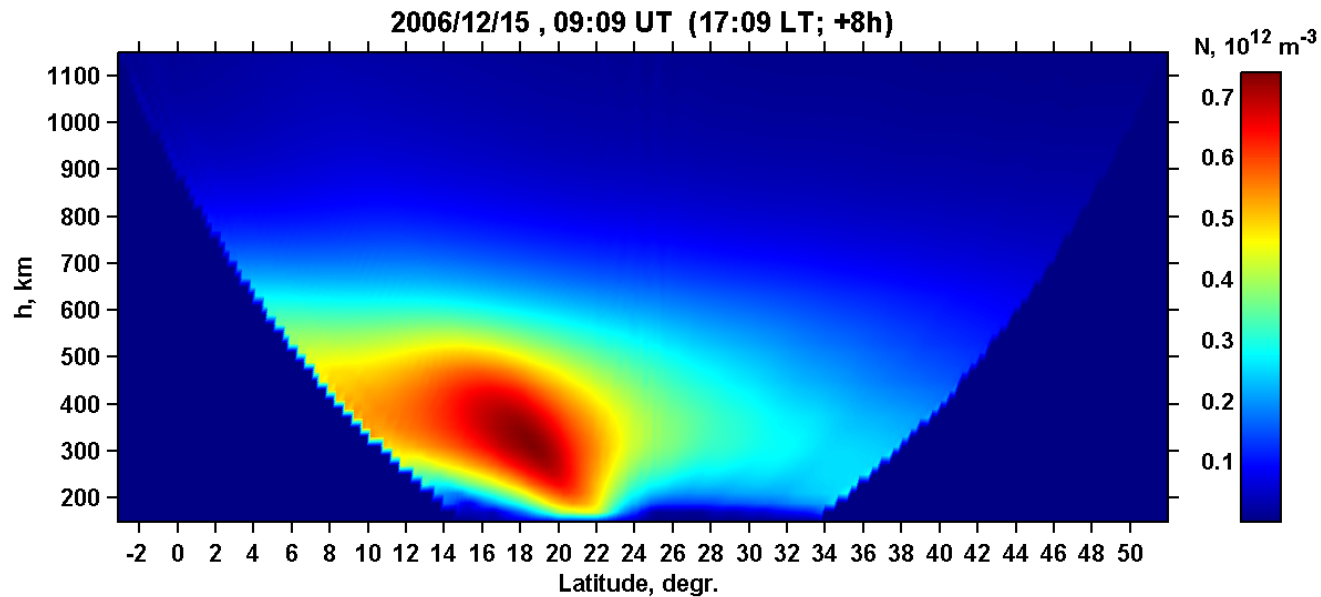
LORT image above the Taiwan region on December 14, 2006 , 21:39 UT



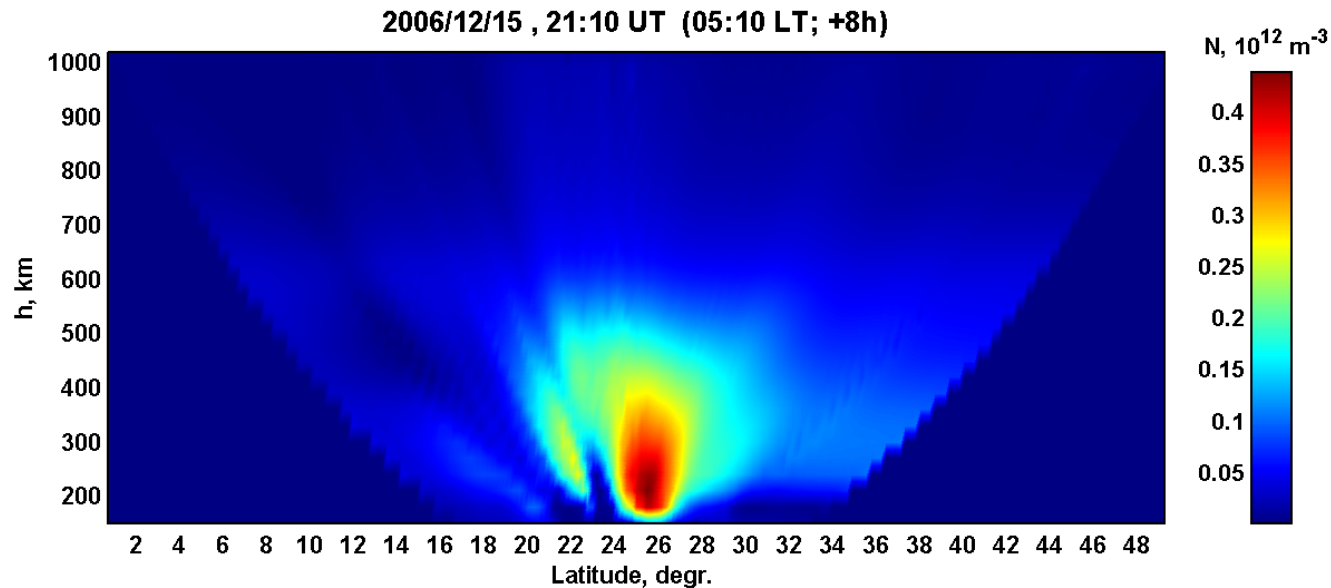
LORT image above the Taiwan region on December 14, 2006 , 21:56 UT

Taiwan region

geomagnetic storm of December 2006

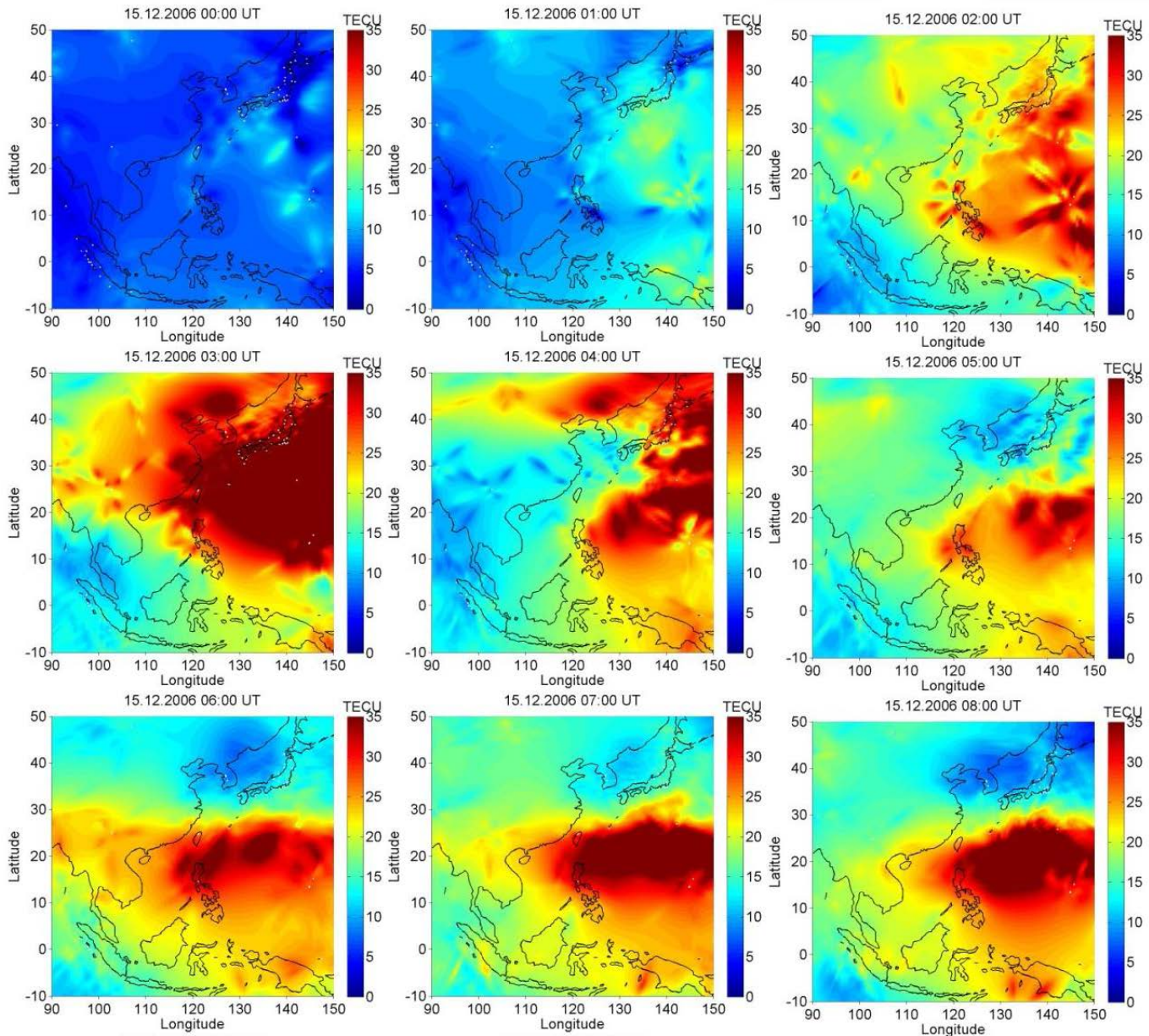


LORT image above the Taiwan region on December 15, 2006, 09:09UT

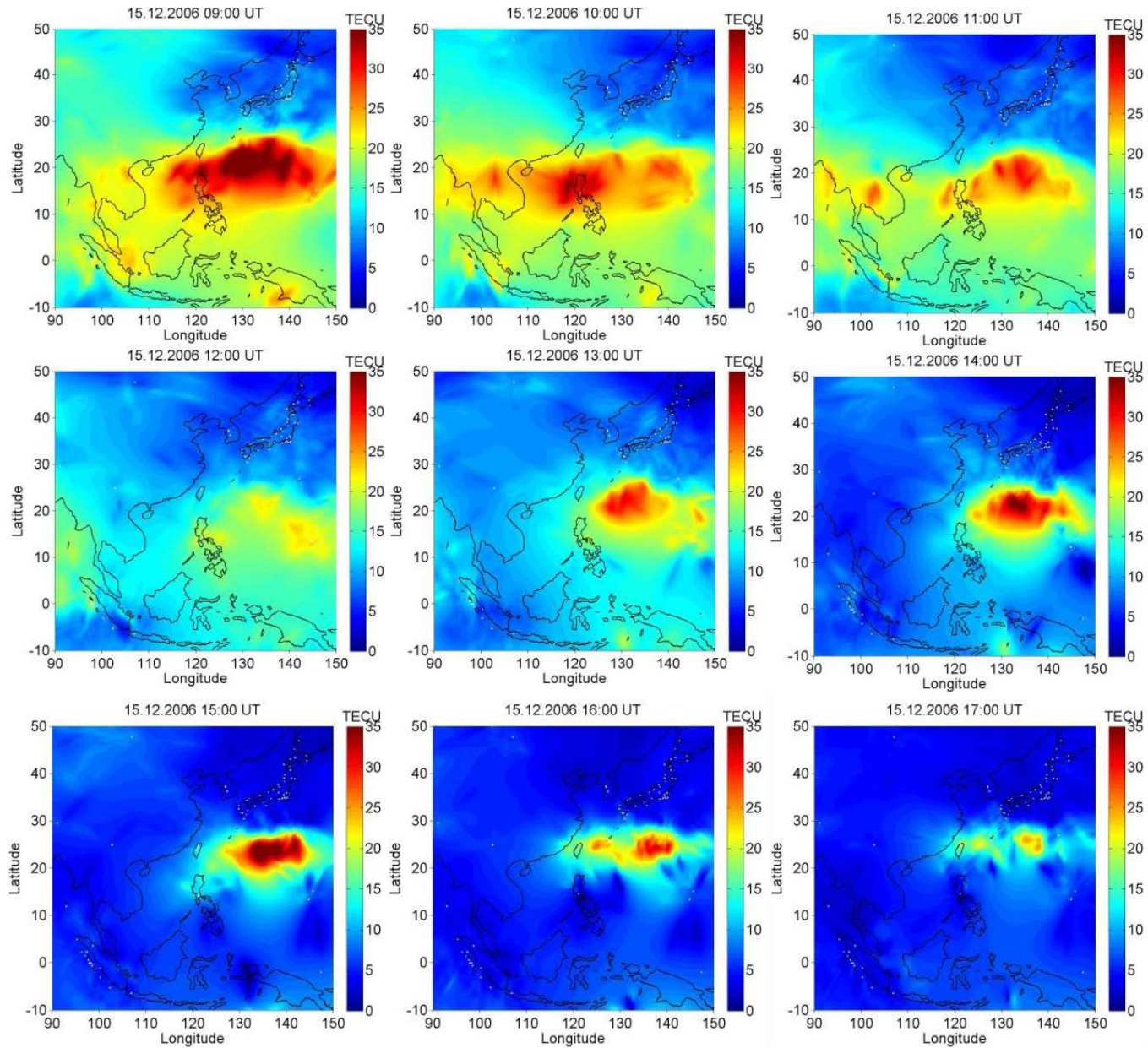


LORT image above the Taiwan region on December 15, 2006, 21:10UT

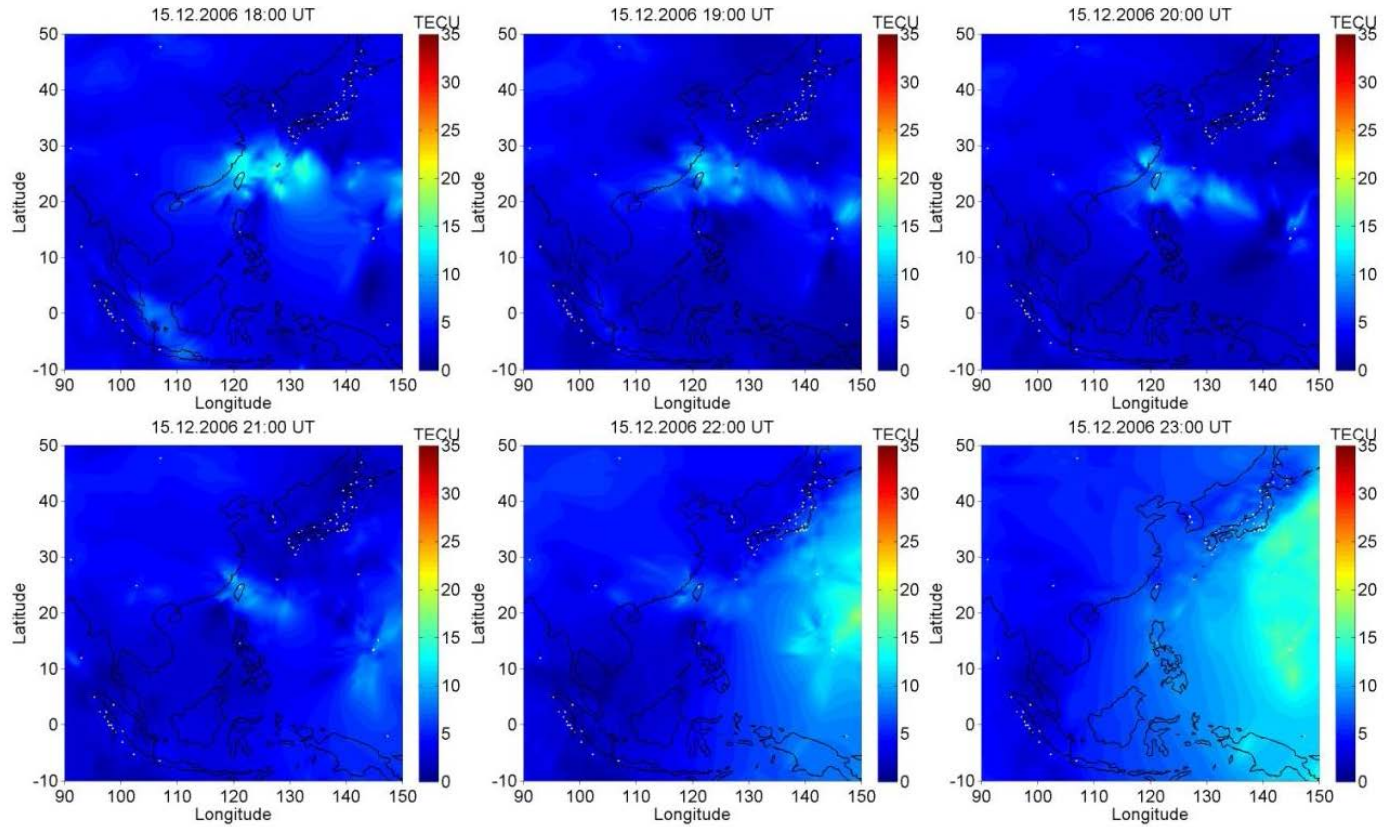
Vertical TEC above South-East Asia according to 4D HORT during geomagnetic storm 15.12.2006 (00:00 UT-08:00 UT)



Vertical TEC above South-East Asia according to 4D HORT during geomagnetic storm 15.12.2006 (09:00 UT-17:00 UT)

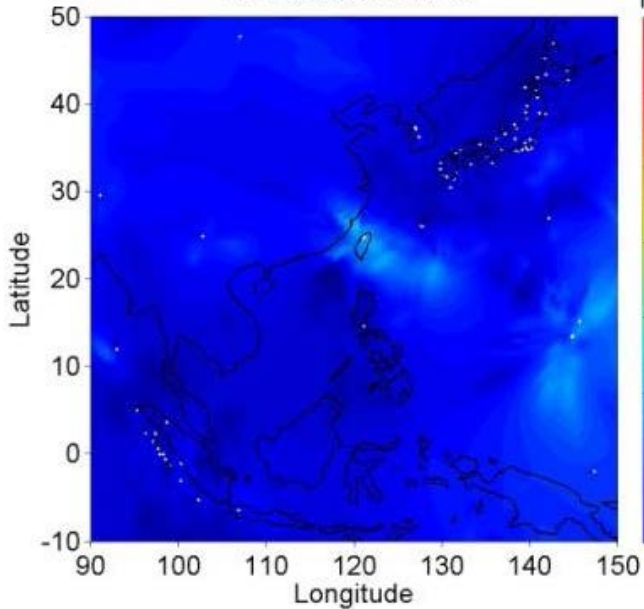


Vertical TEC above South-East Asia according to 4D HORT during geomagnetic storm 15.12.2006 (18:00 UT-23:00 UT)



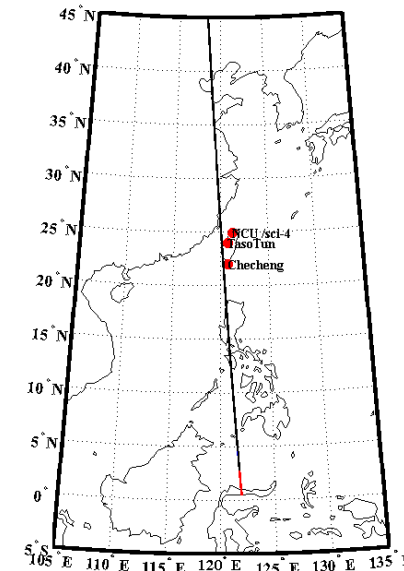
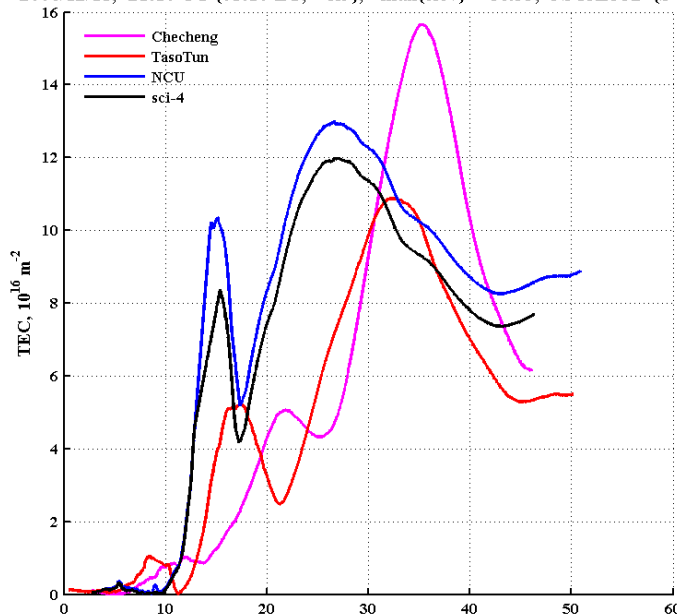
HORT

15.12.2006 21:00 UT

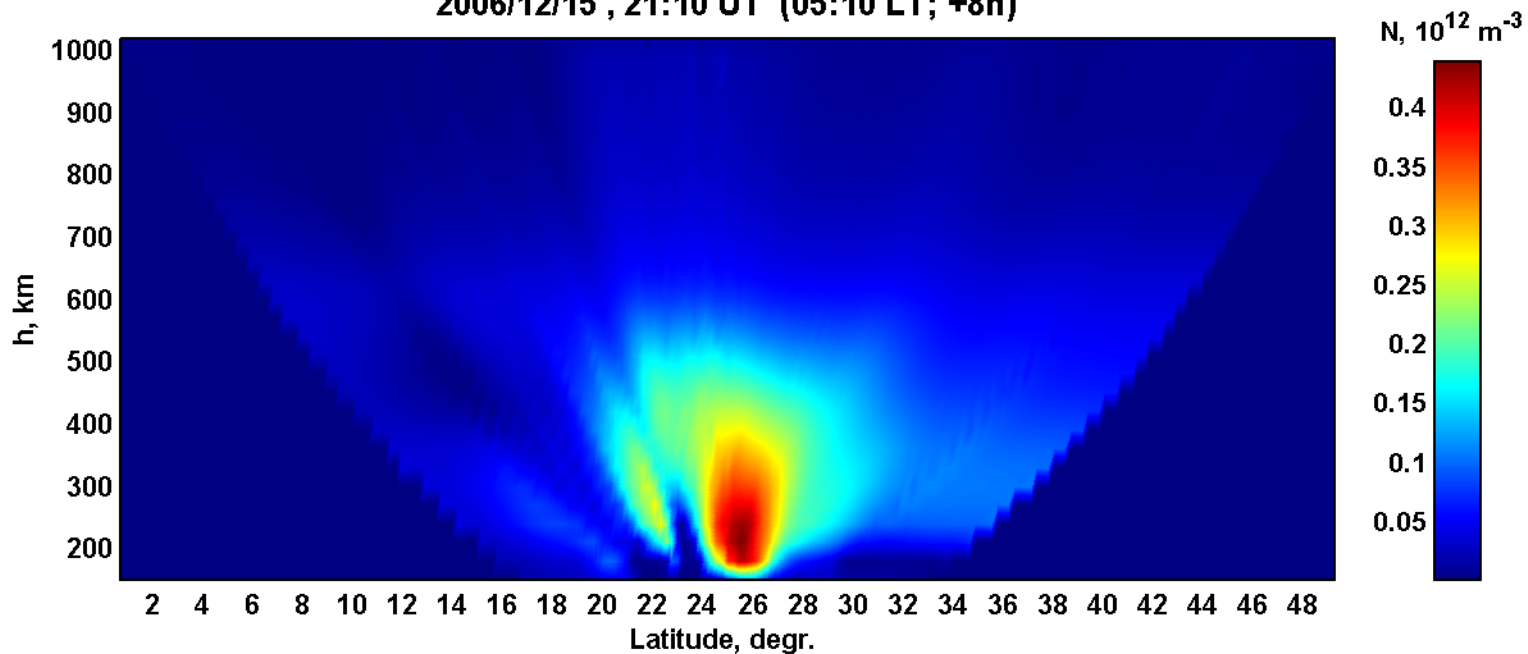


LORT

2006/12/15, 21:10 UT (05:10 LT; +8h), max(elev)= 86.33, OSCAR-32 (S->N)

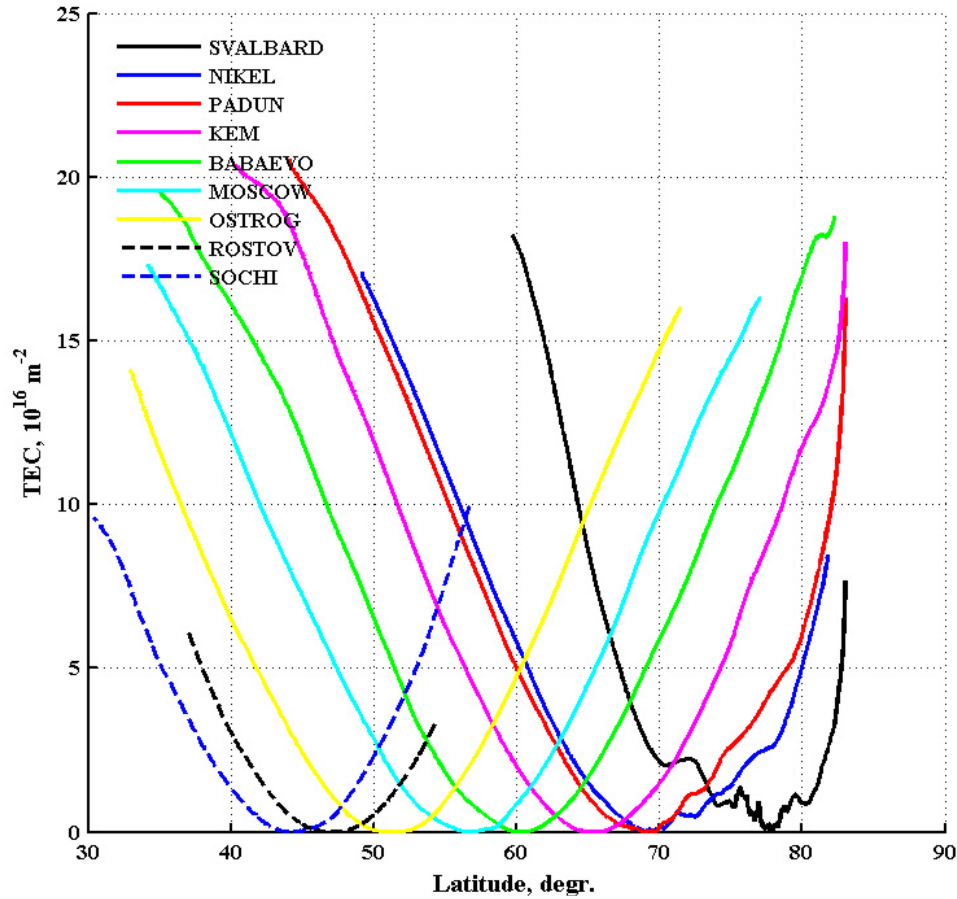


2006/12/15, 21:10 UT (05:10 LT; +8h)



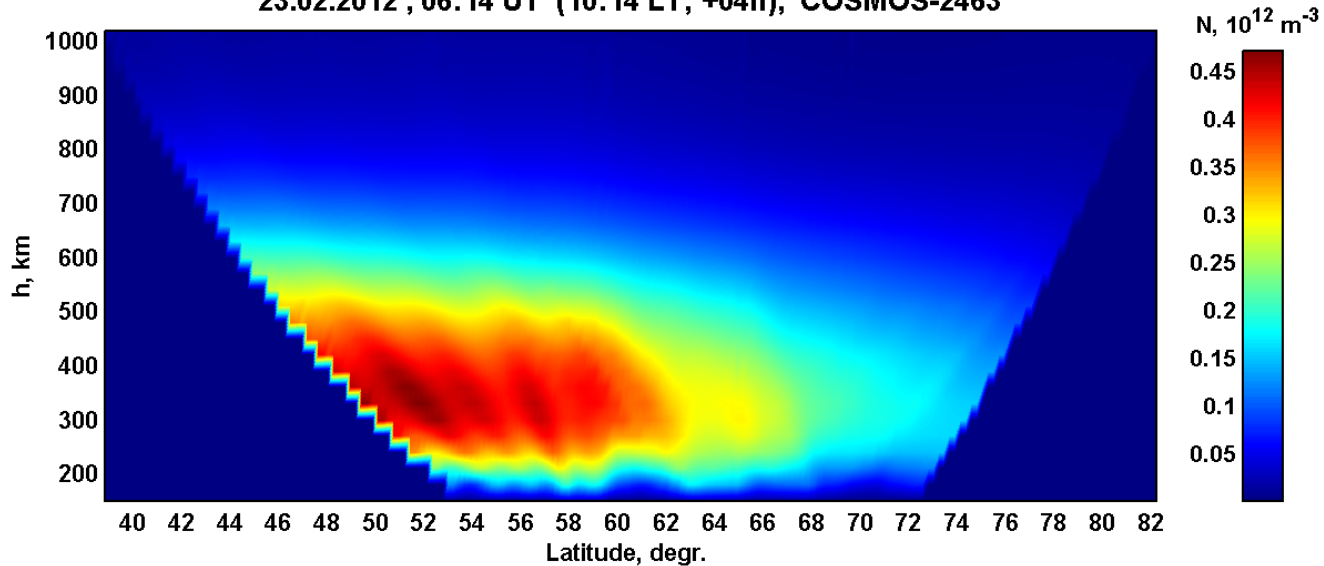
Russian LORT system (Svalbard – Moscow - Sochi)

31.08.2012 (17:27UT) COSMOS-2407



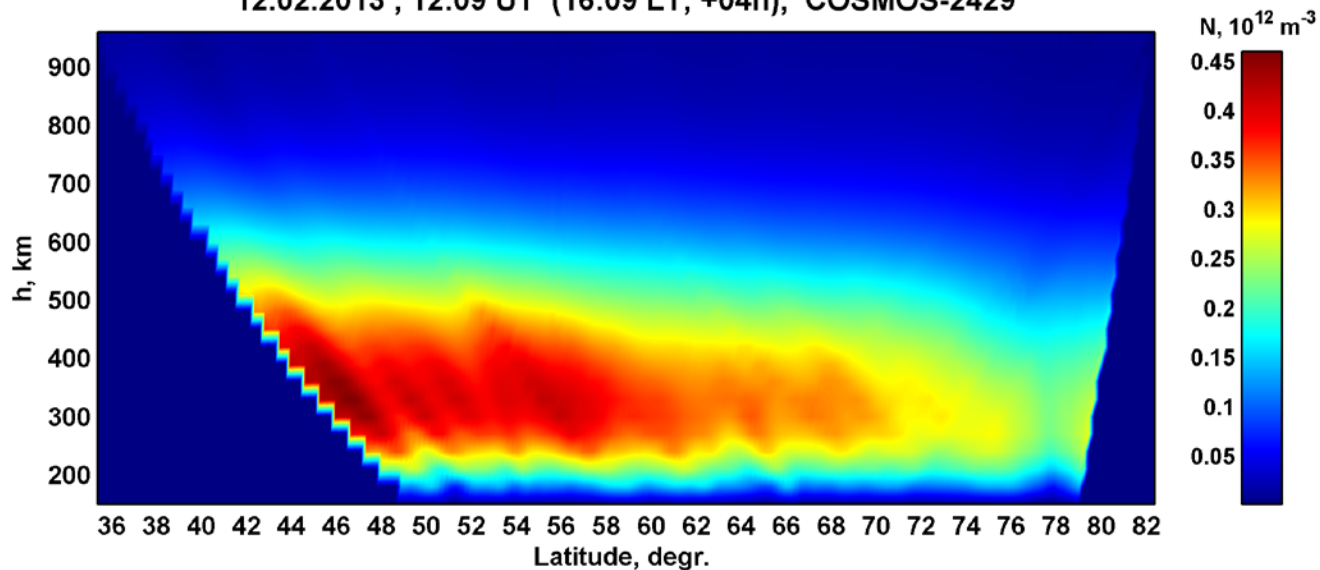
TIDs (Northwest of Russia)

23.02.2012 , 06:14 UT (10:14 LT; +04h), COSMOS-2463



LORT image above Russian RT chain on February 23, 2012 , 06:14 UT

12.02.2013 , 12:09 UT (16:09 LT; +04h), COSMOS-2429

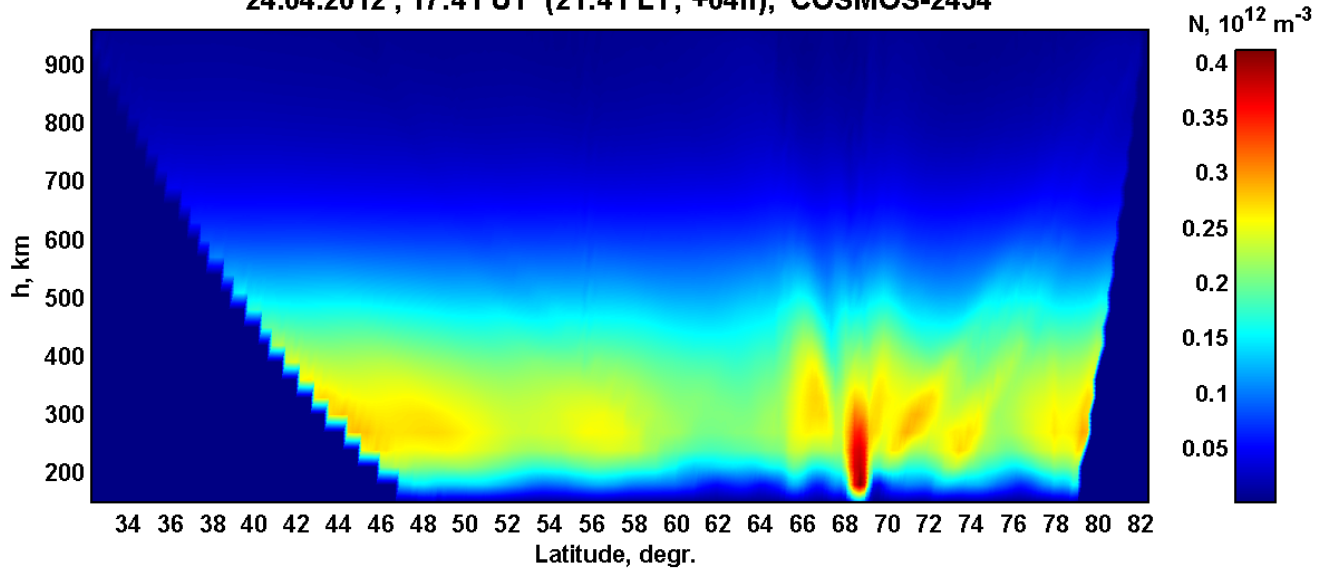


LORT image above Russian RT chain on February 12, 2013 , 12:09 UT

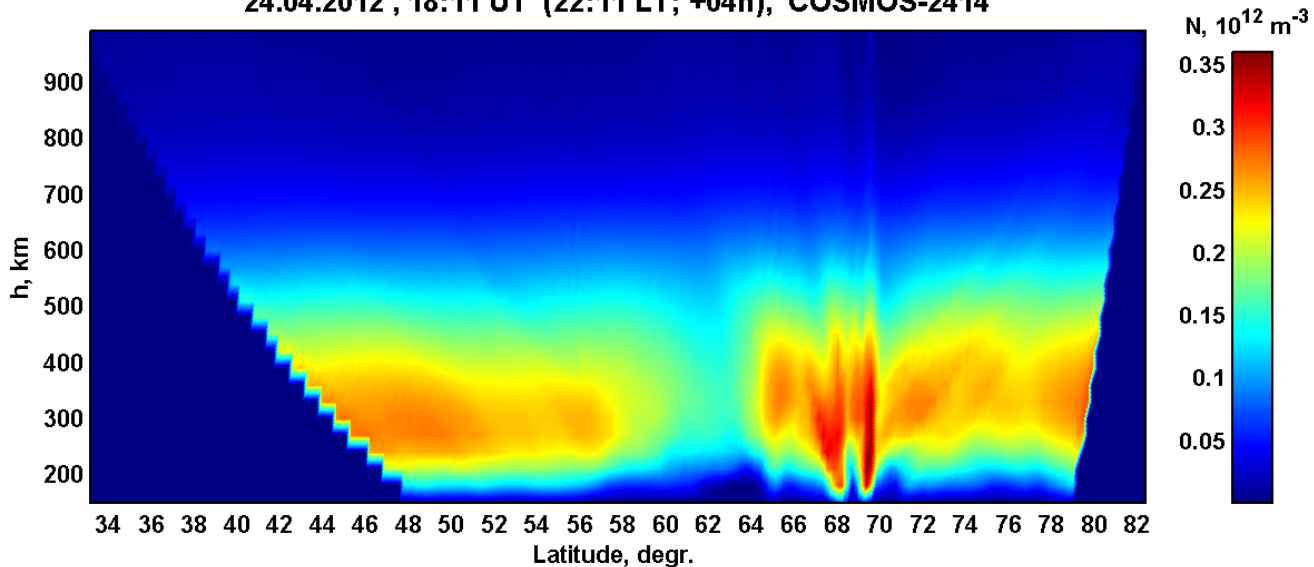
Region of Russian LORT system

ionospheric features are probably associated with particle precipitation

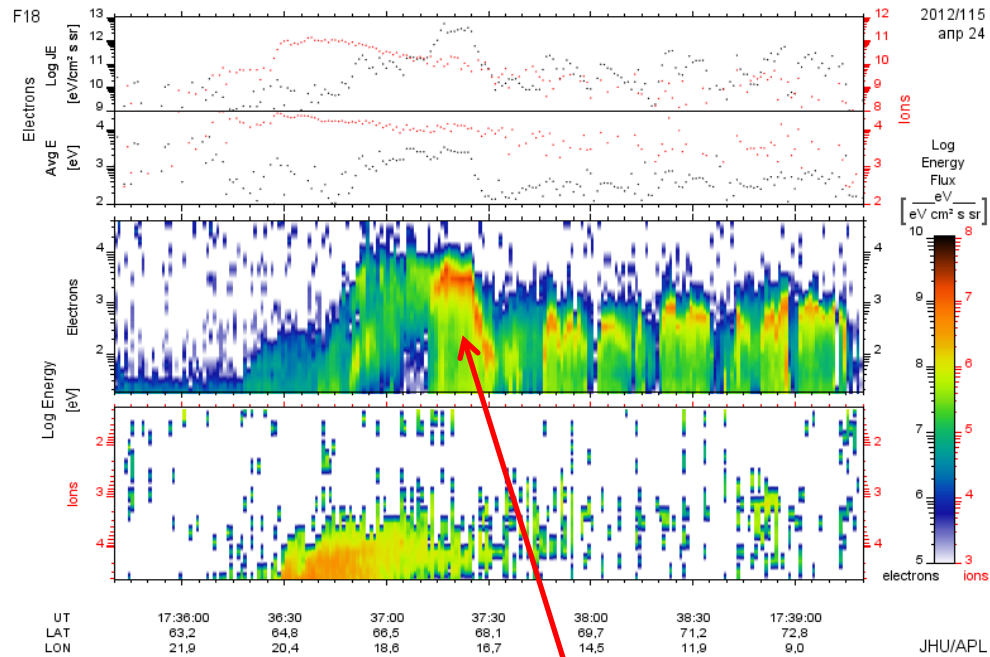
24.04.2012 , 17:41 UT (21:41 LT; +04h), COSMOS-2454



24.04.2012 , 18:11 UT (22:11 LT; +04h), COSMOS-2414

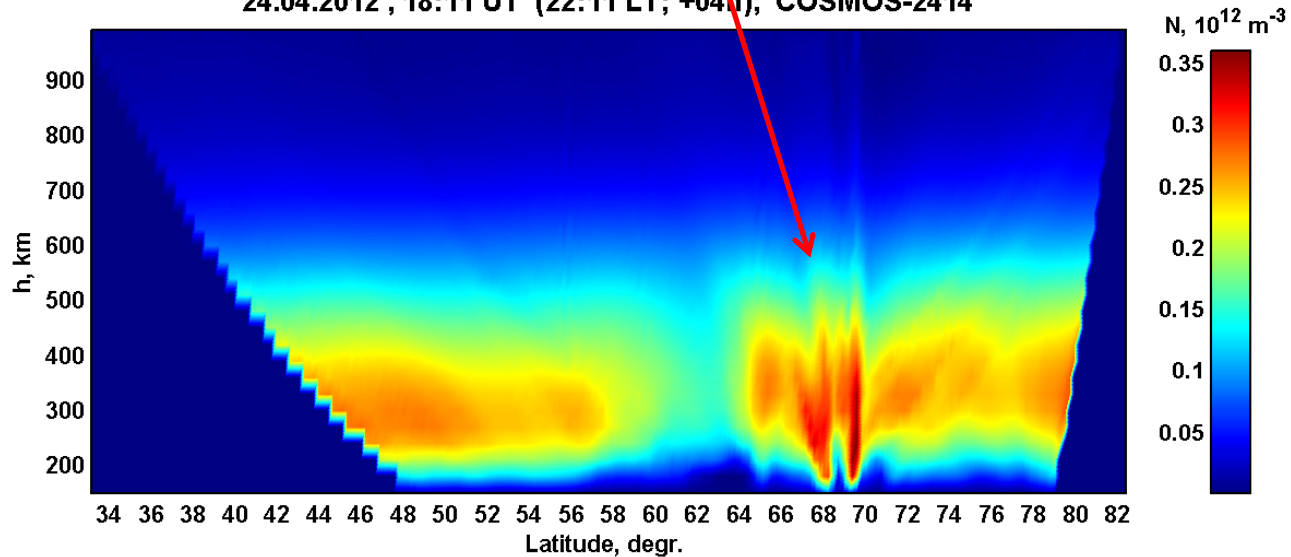


LORT images above Russian RT chain on April 24, 2012 , 17:41 and 18:11 UT



DMSP F18 spectrogram of precipitating particles, April 24, 2012, 17:35-17:39 UT

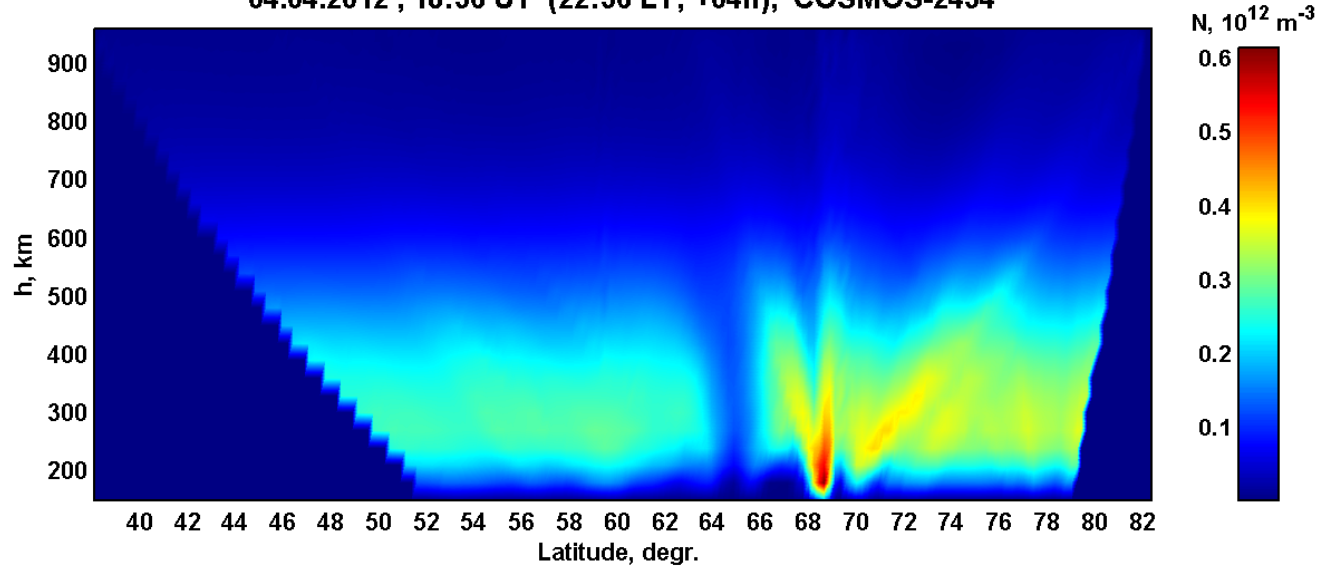
24.04.2012 , 18:11 UT (22:11 LT; +04h), COSMOS-2414



LORT image above Russian RT chain on April 24, 2012 , 18:11 UT

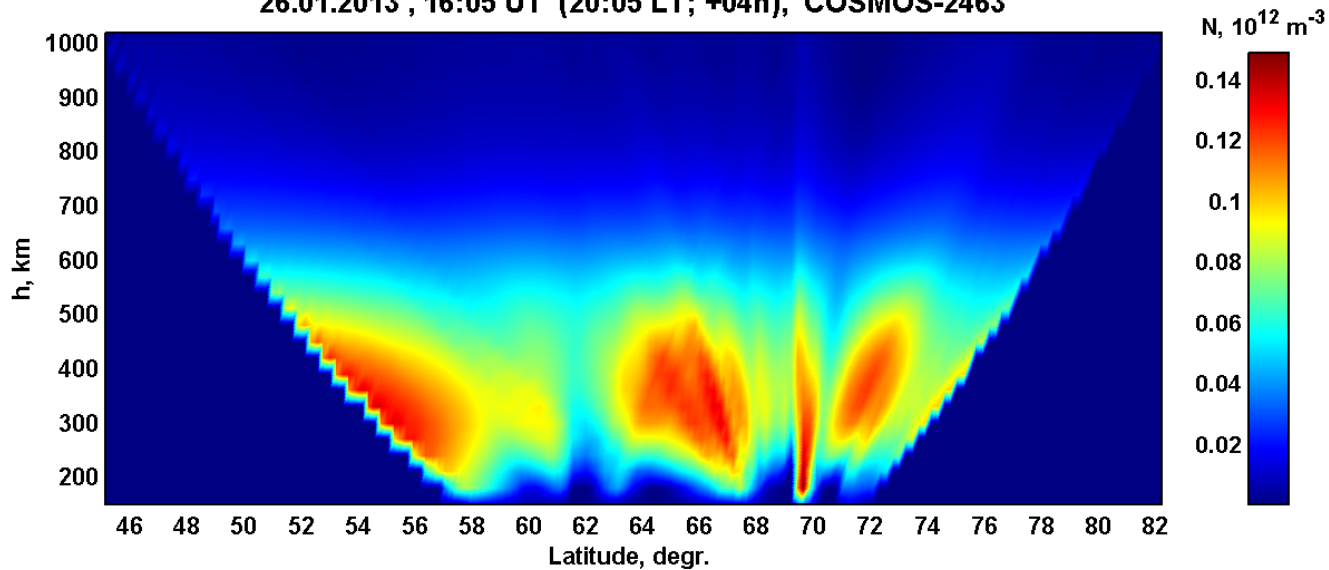
Region of Russian LORT system

04.04.2012 , 18:56 UT (22:56 LT; +04h), COSMOS-2454



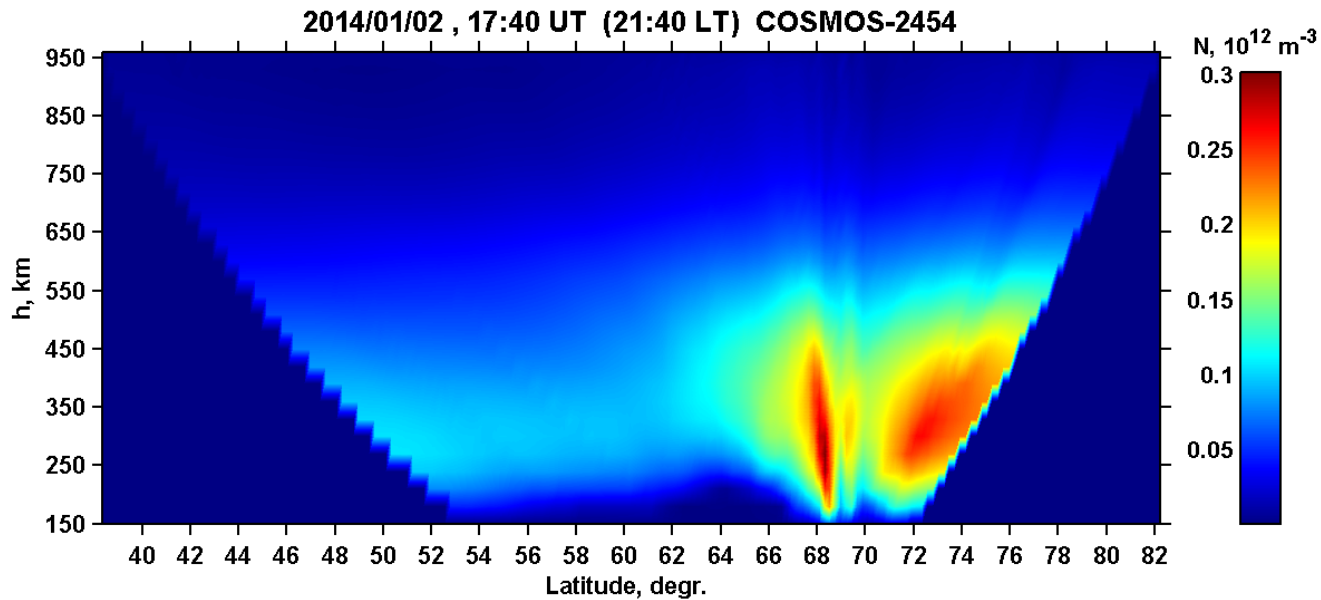
LORT image above Russian RT chain on April 4, 2012 , 18:56 UT

26.01.2013 , 16:05 UT (20:05 LT; +04h), COSMOS-2463

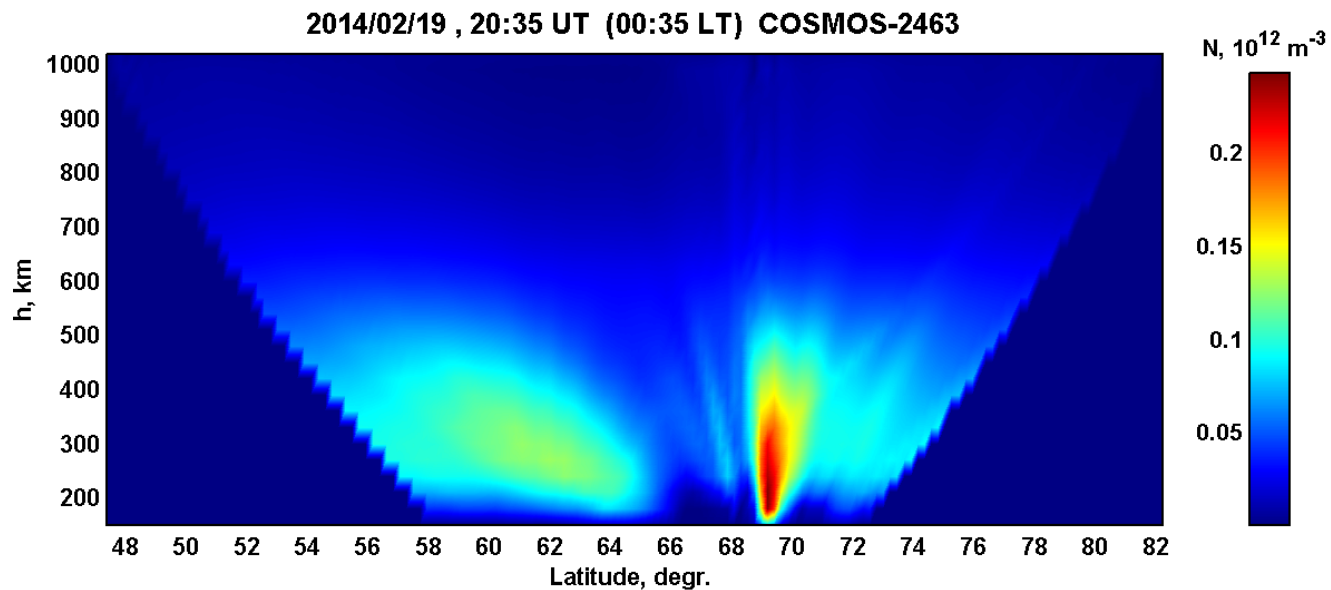


LORT image above Russian RT chain on January 26, 2013 , 16:05 UT

Region of Russian LORT system



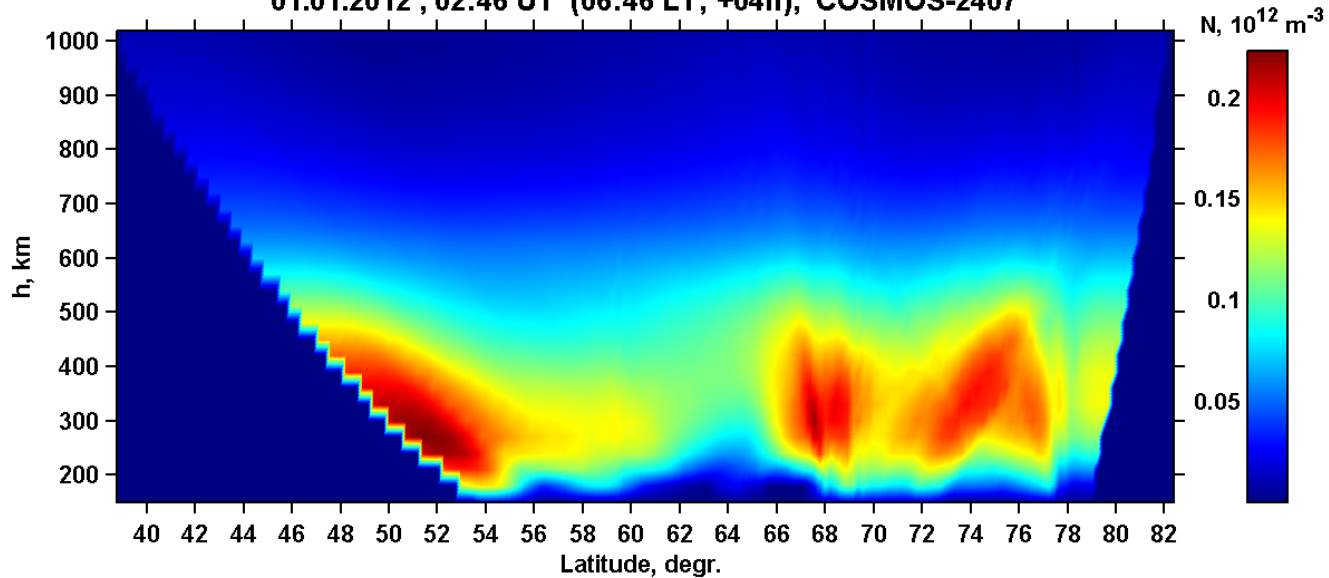
LORT image above Russian RT chain on January 2, 2014 , 17:40 UT



LORT image above Russian RT chain on February 19, 2014 , 20:35 UT

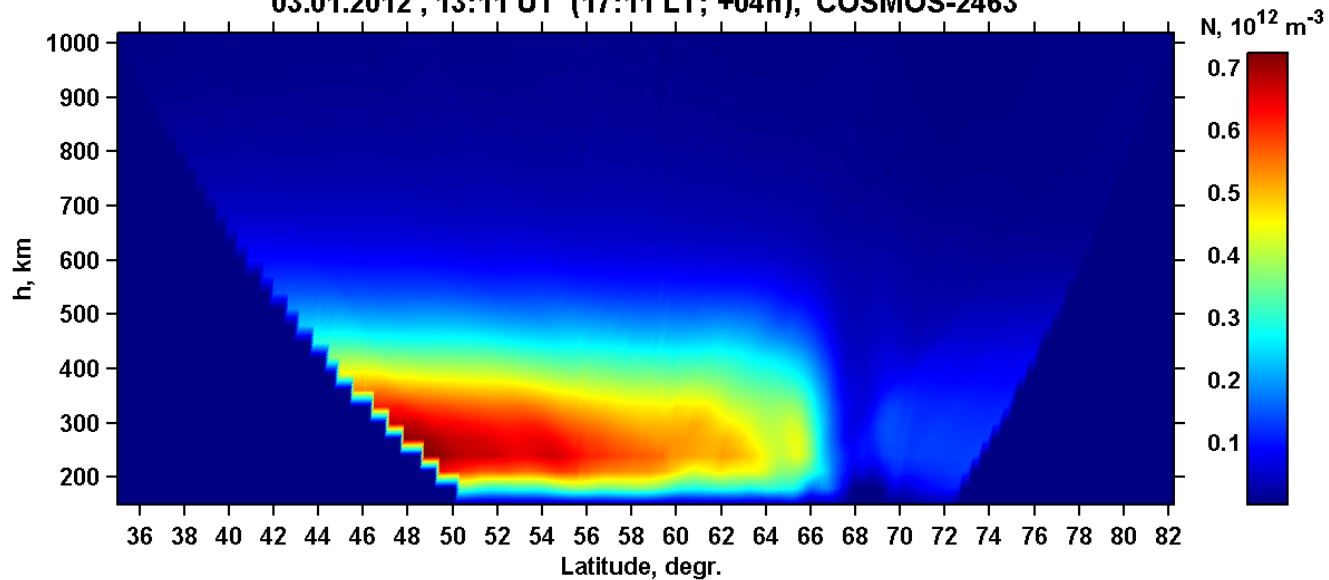
Region of Russian LORT system

01.01.2012 , 02:46 UT (06:46 LT; +04h), COSMOS-2407



LORT image above Russian RT chain on January 1, 2012 , 02:46 UT

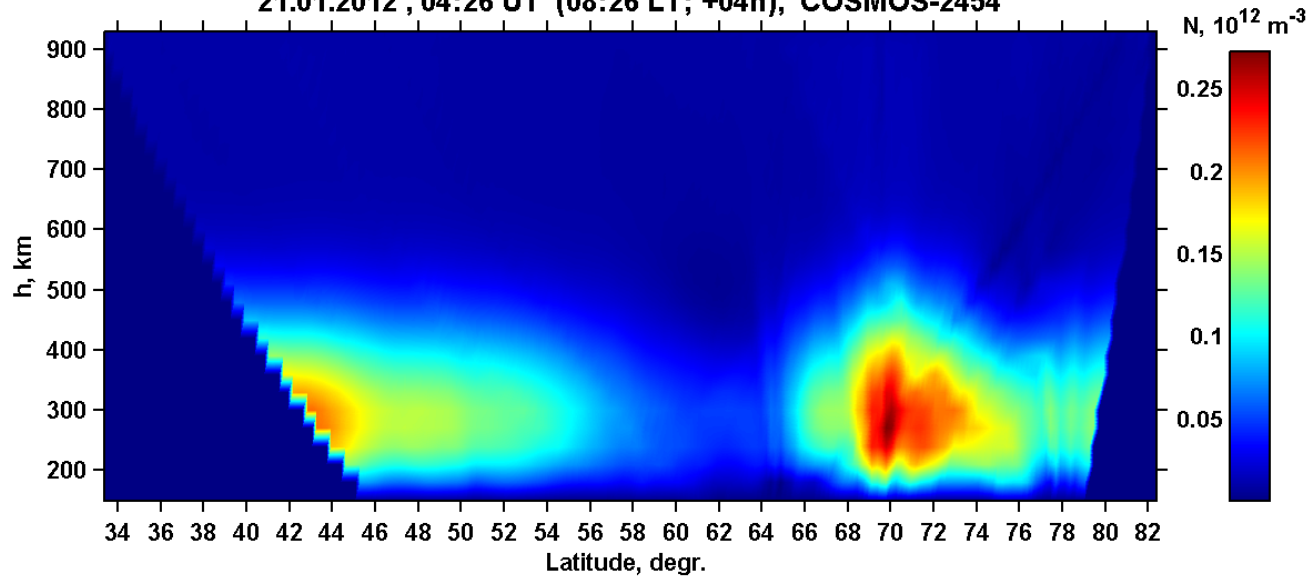
03.01.2012 , 13:11 UT (17:11 LT; +04h), COSMOS-2463



LORT image above Russian RT chain on January 3, 2012 , 13:11 UT

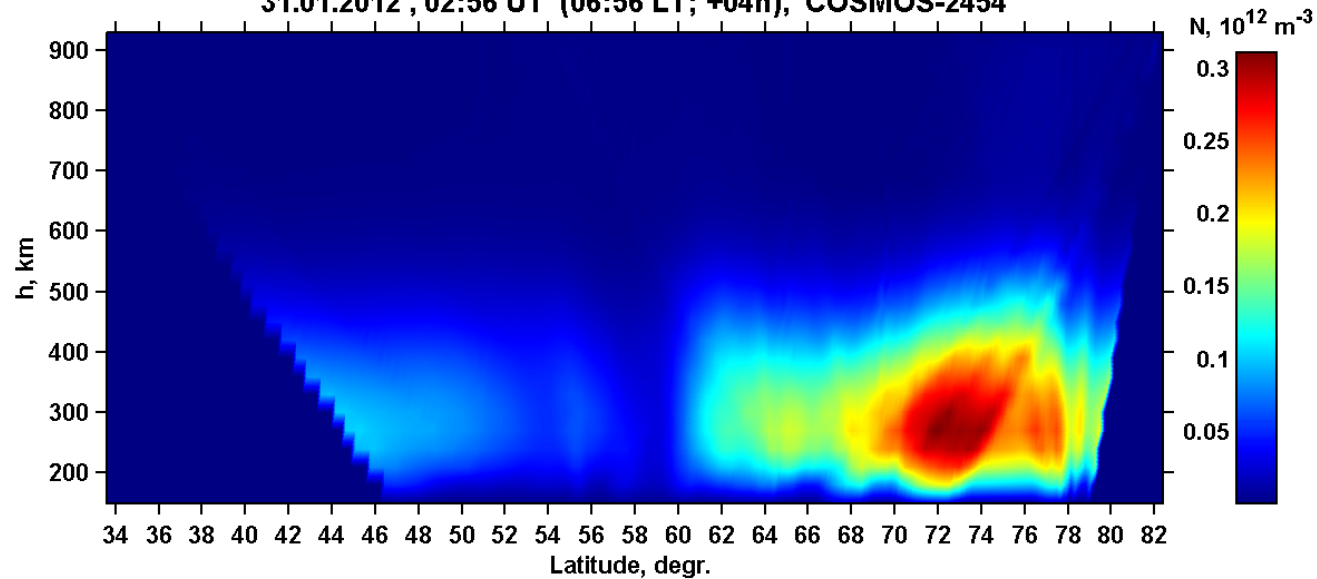
Region of Russian LORT system

21.01.2012 , 04:26 UT (08:26 LT; +04h), COSMOS-2454



LORT image above Russian RT chain on January 21, 2012 , 04:26 UT

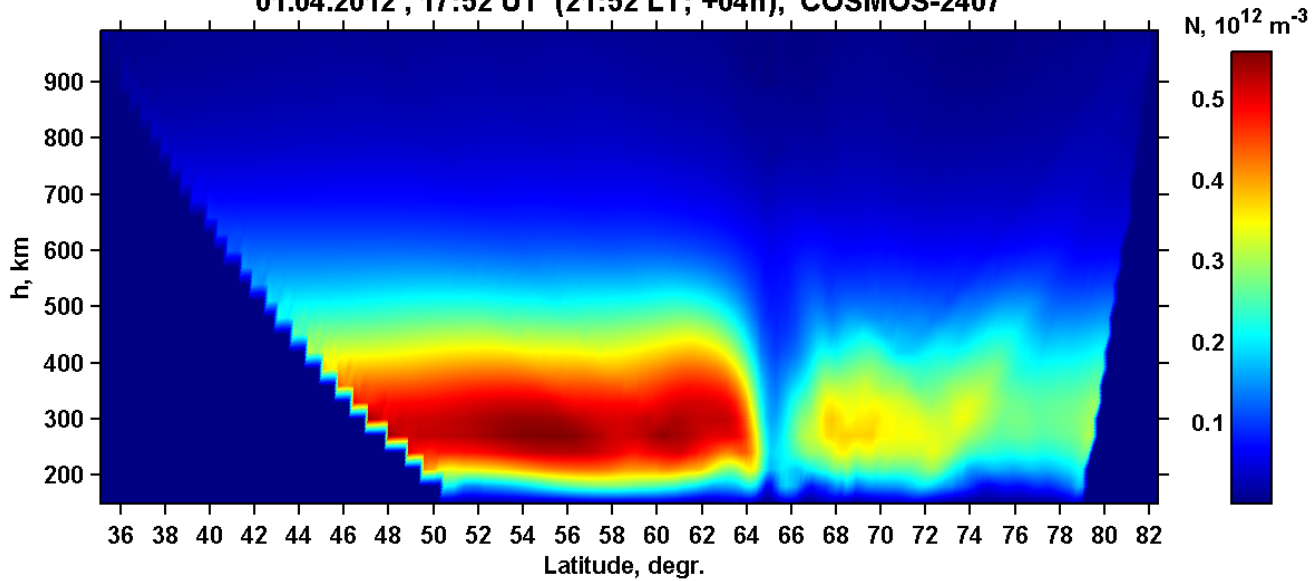
31.01.2012 , 02:56 UT (06:56 LT; +04h), COSMOS-2454



LORT image above Russian RT chain on January 31, 2012 , 02:56 UT

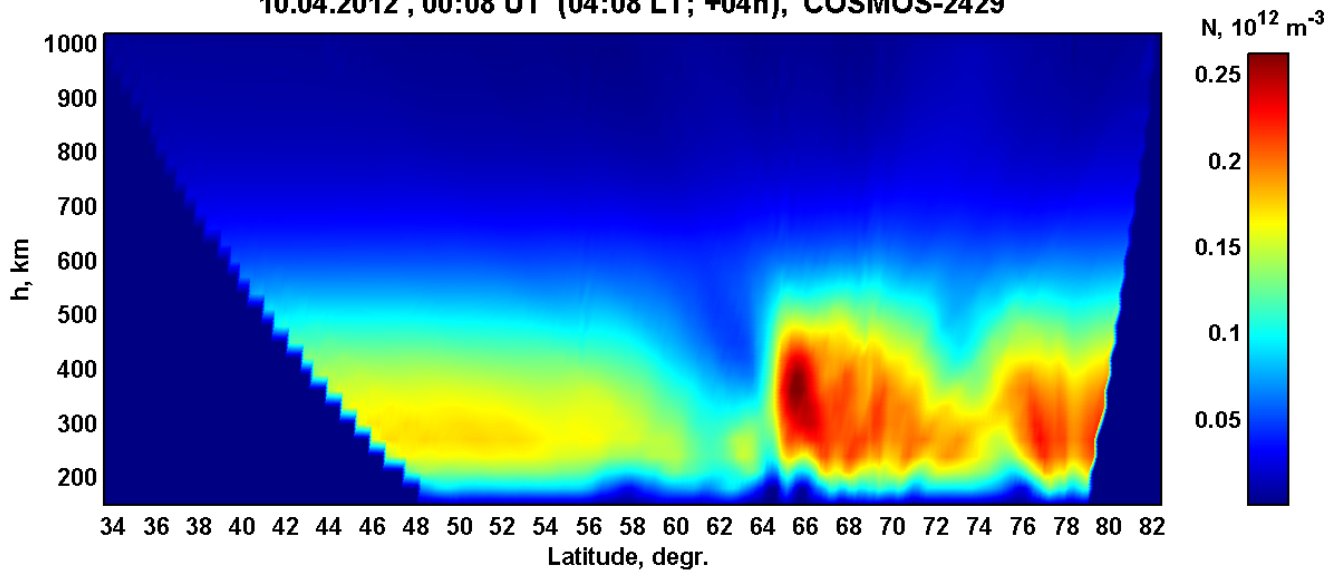
Region of Russian LORT system

01.04.2012 , 17:52 UT (21:52 LT; +04h), COSMOS-2407



LORT image above Russian RT chain on April 1, 2012 , 17:52 UT

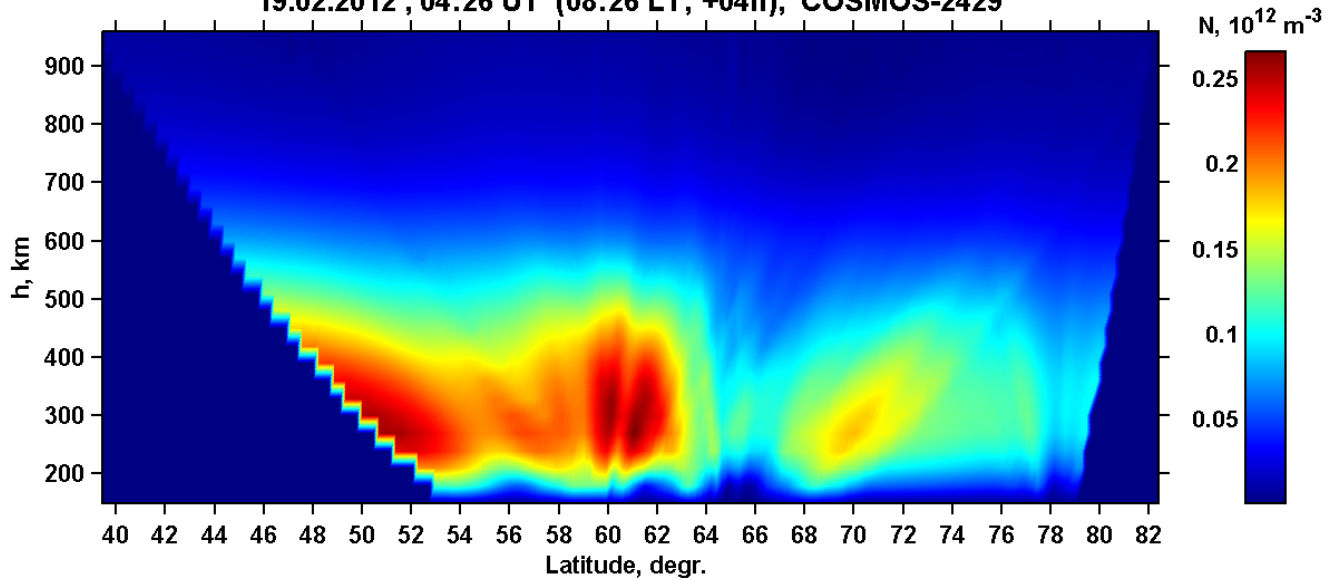
10.04.2012 , 00:08 UT (04:08 LT; +04h), COSMOS-2429



LORT image above Russian RT chain on April 10, 2012 , 00:08 UT

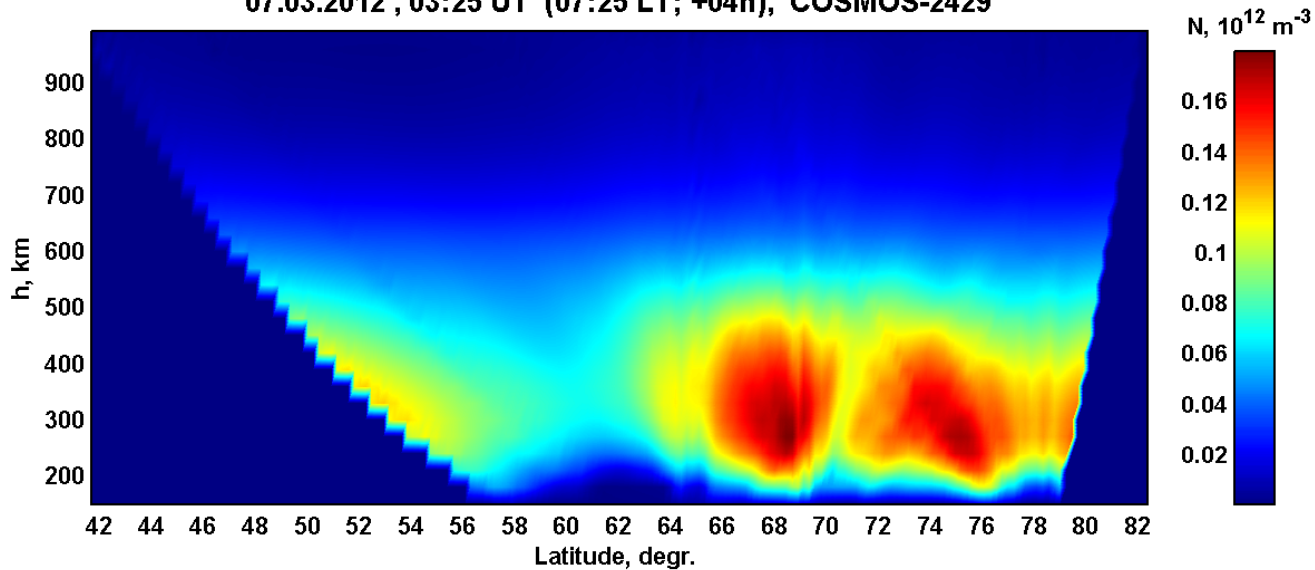
Region of Russian LORT system

19.02.2012 , 04:26 UT (08:26 LT; +04h), COSMOS-2429



LORT image above Russian RT chain on February 19, 2012 , 04:26 UT

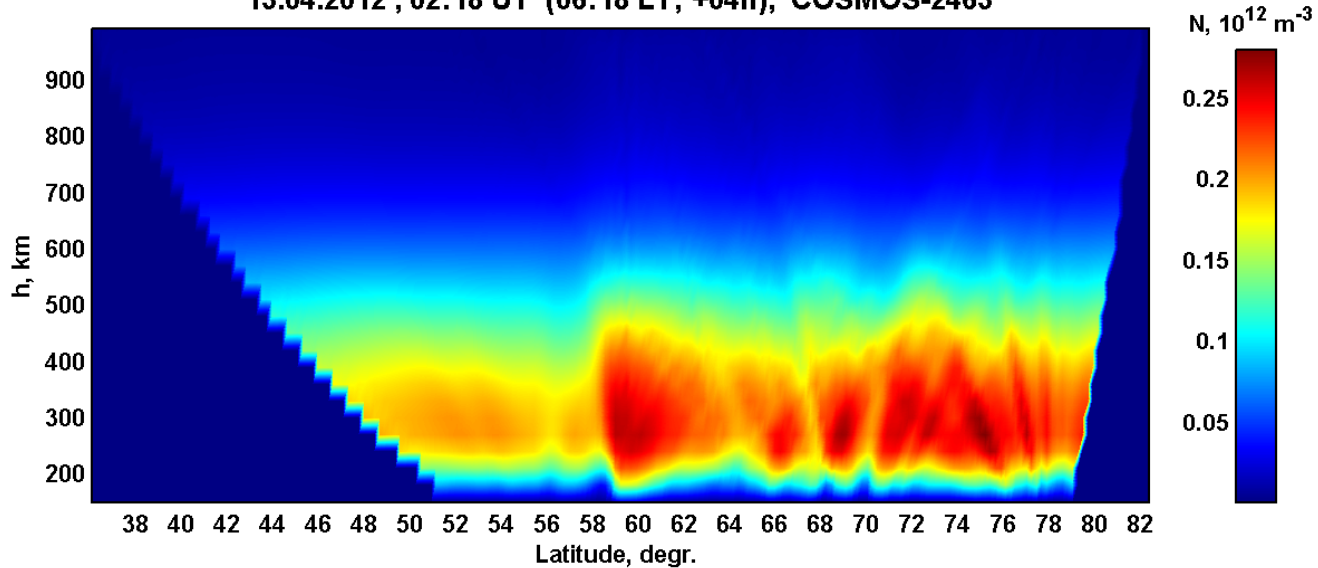
07.03.2012 , 03:25 UT (07:25 LT; +04h), COSMOS-2429



LORT image above Russian RT chain on March 7, 2012 , 03:25 UT

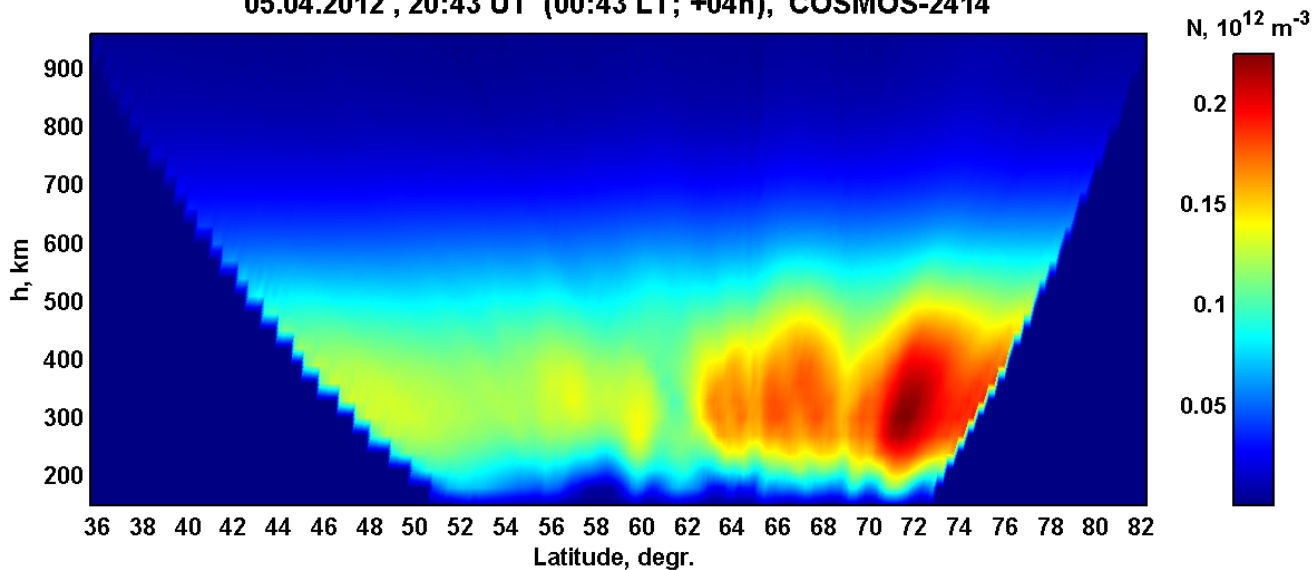
Region of Russian LORT system

13.04.2012 , 02:18 UT (06:18 LT; +04h), COSMOS-2463



LORT image above Russian RT chain on April 13, 2012 , 02:18 UT

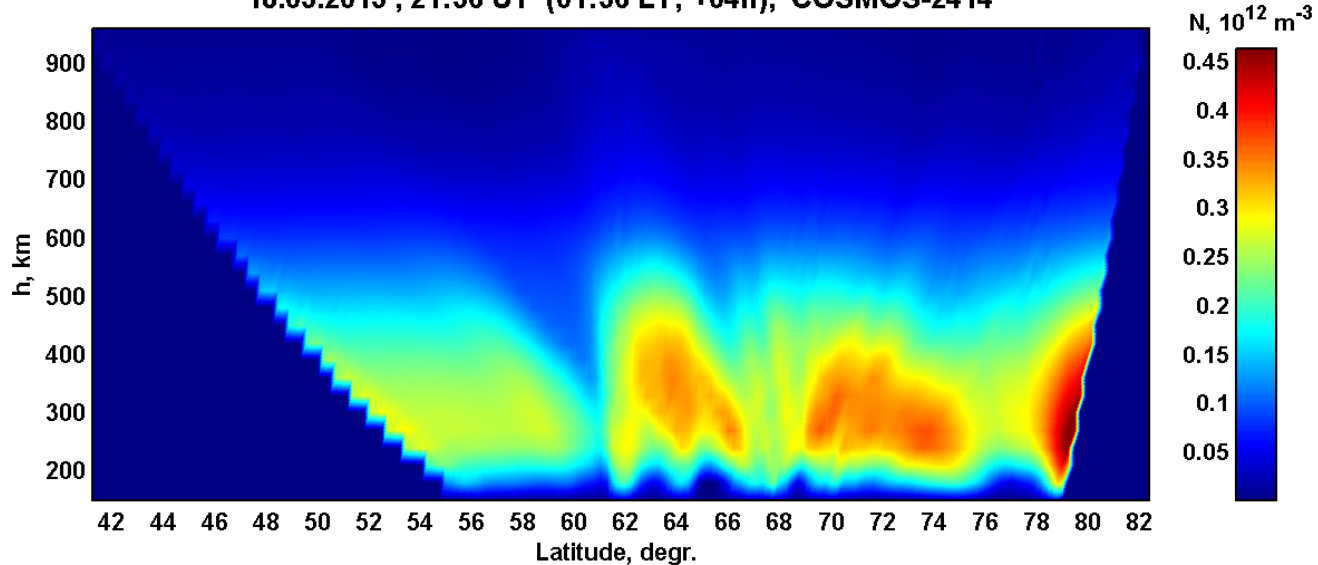
05.04.2012 , 20:43 UT (00:43 LT; +04h), COSMOS-2414



LORT image above Russian RT chain on April 5, 2012 , 20:43 UT

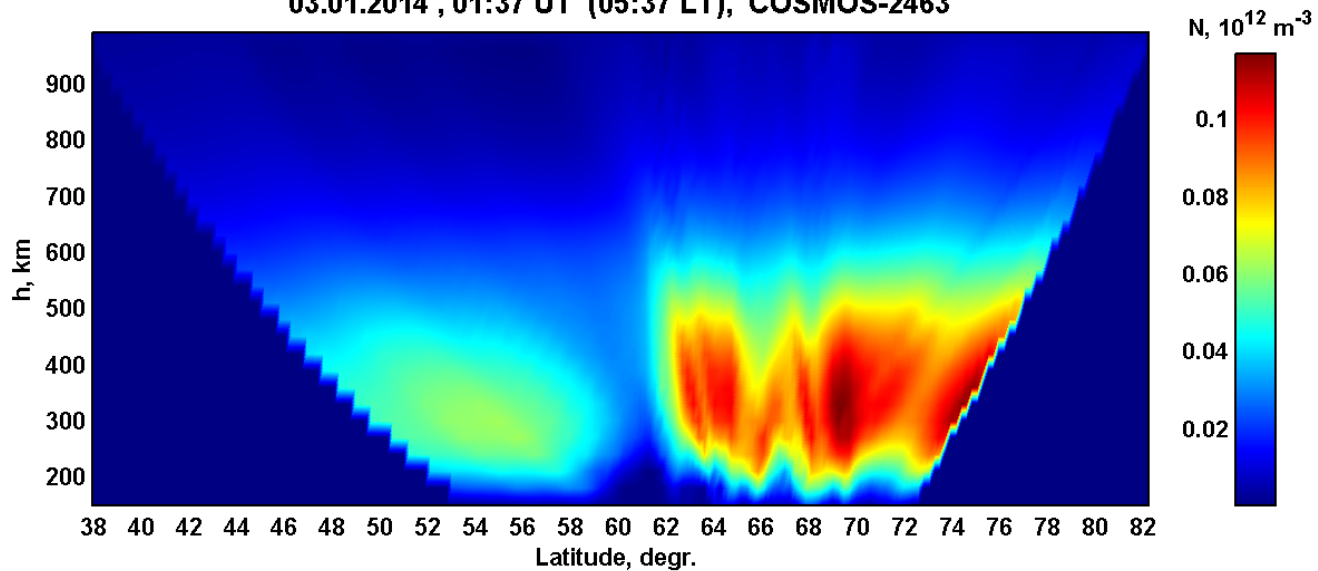
Region of Russian LORT system

18.05.2013 , 21:36 UT (01:36 LT; +04h), COSMOS-2414



LORT image above Russian RT chain on May 18, 2013 , 21:36 UT

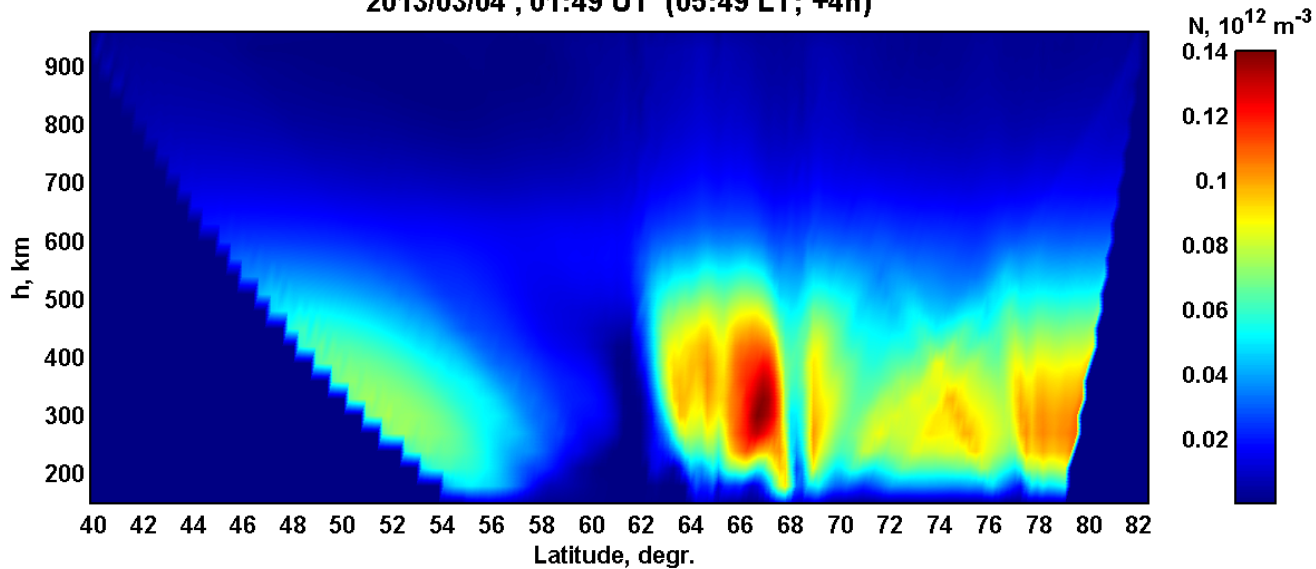
03.01.2014 , 01:37 UT (05:37 LT), COSMOS-2463



LORT image above Russian RT chain on January 1, 2014 , 01:37 UT

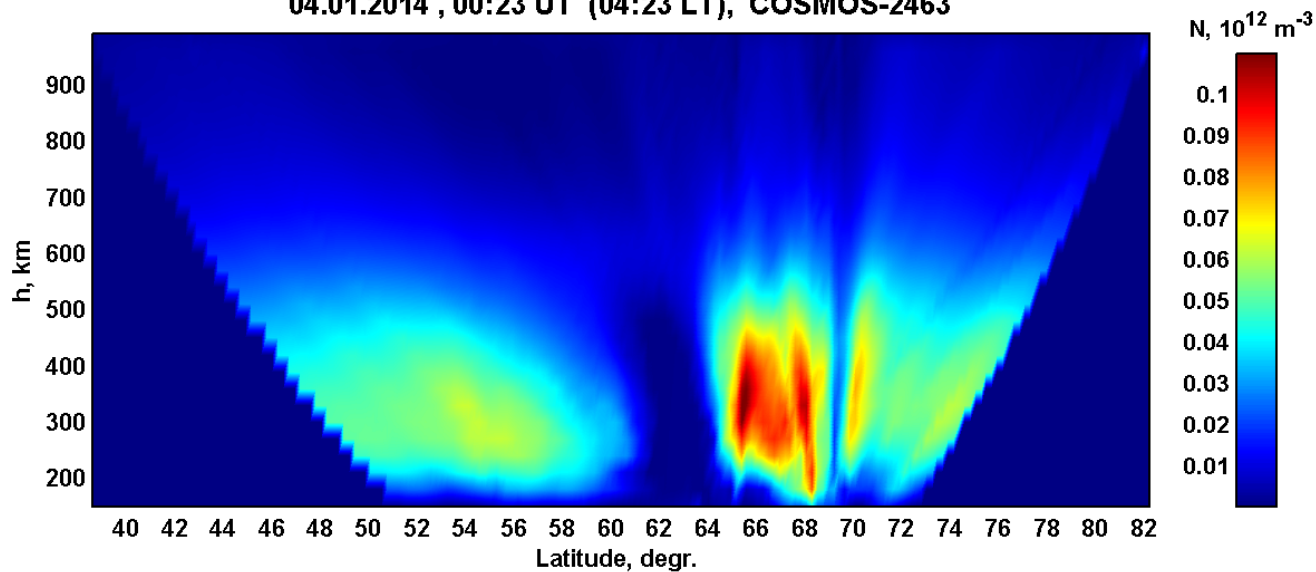
Region of Russian LORT system

2013/03/04 , 01:49 UT (05:49 LT; +4h)



LORT image above Russian RT chain on March 4, 2013 , 01:49 UT

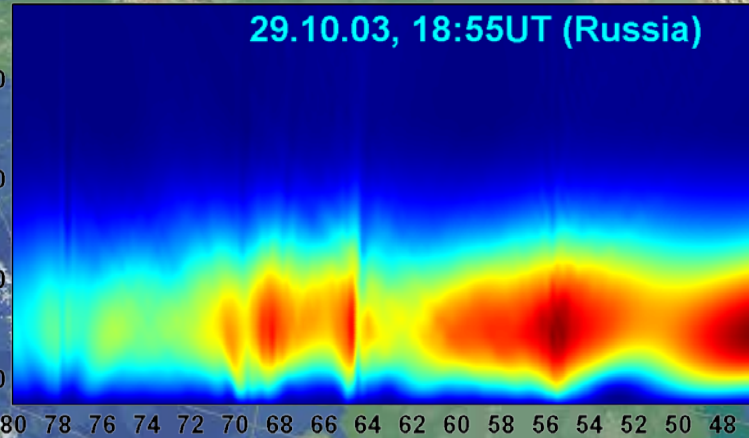
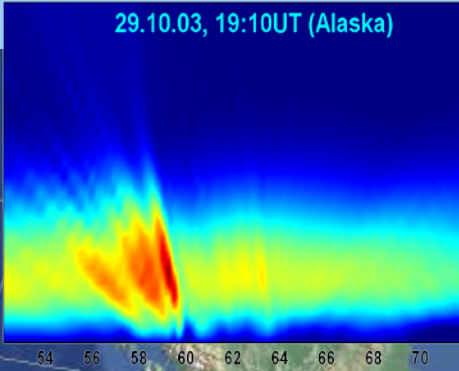
04.01.2014 , 00:23 UT (04:23 LT), COSMOS-2463



LORT image above Russian RT chain on January 4, 2014 , 00:23 UT



29.10.2003 { Alaska – Russia
 19:10UT – 18:55UT
 (10:10LT) – (21:55LT)



Kp=8.7

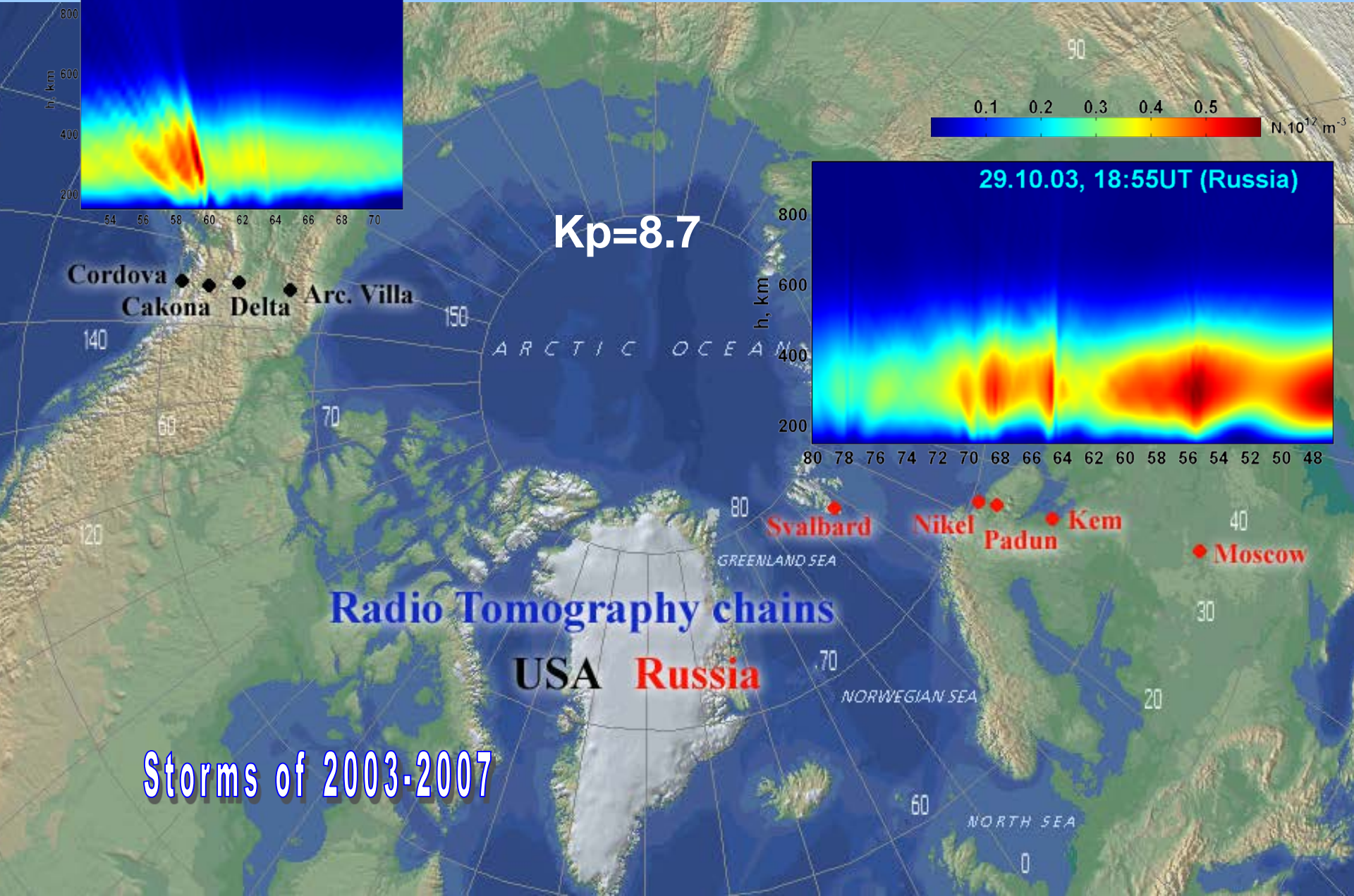
Cordova ● ● ● Arc. Villa
 Cakona Delta

Svalbard ● Nickel ● Padun ● Kem ● Moscow ●

Radio Tomography chains

USA Russia

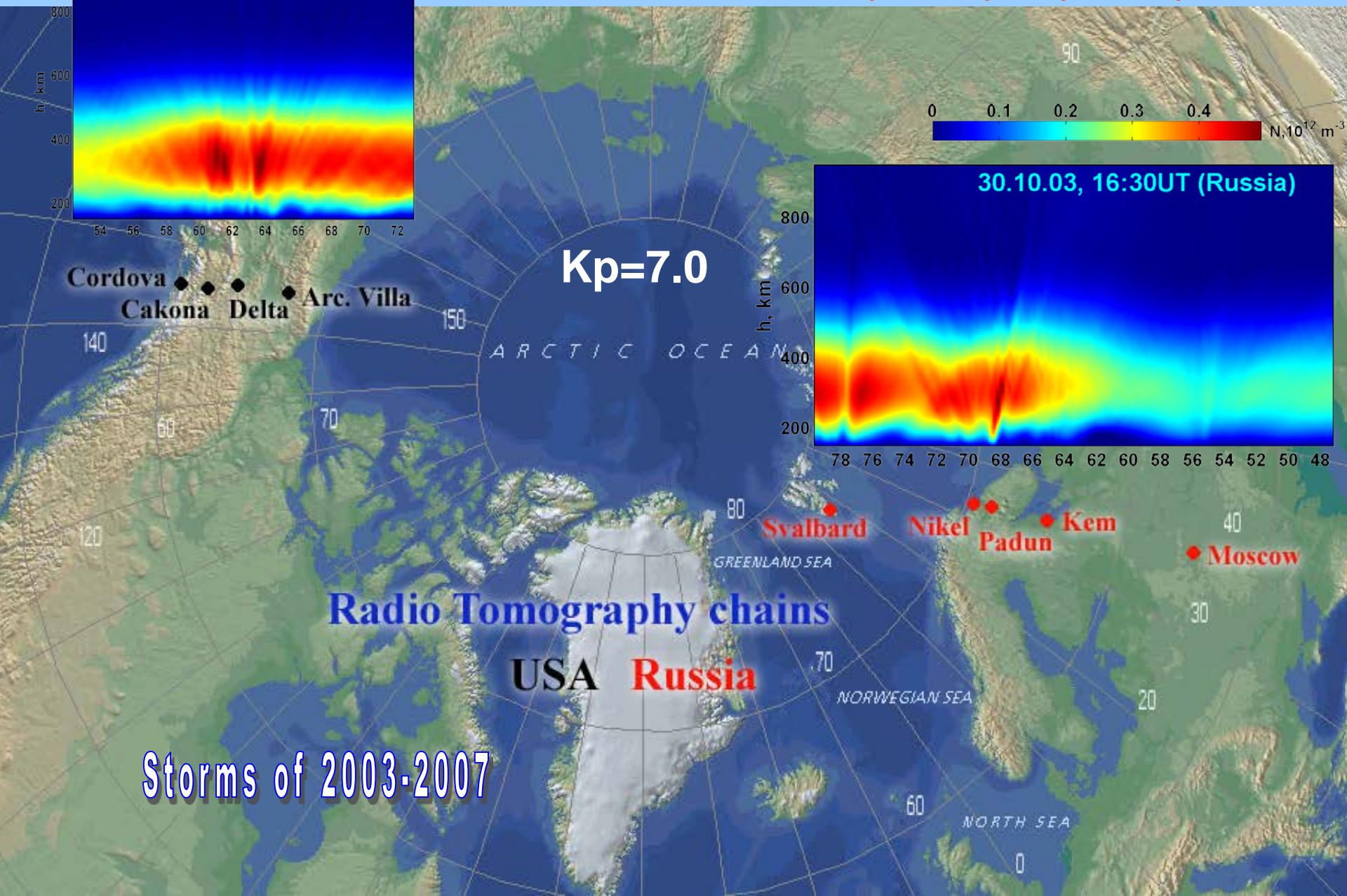
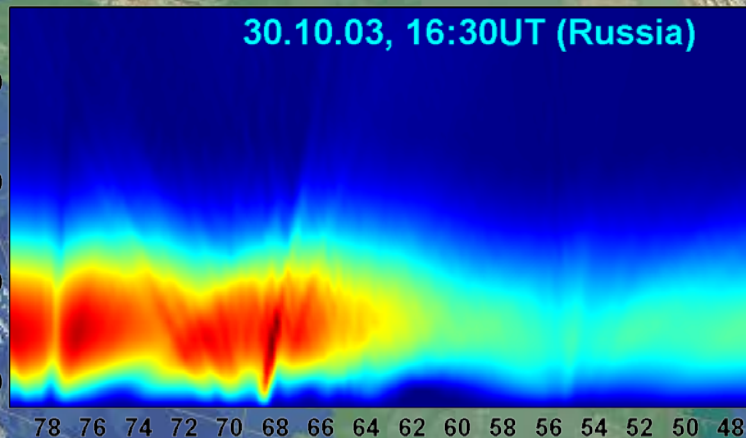
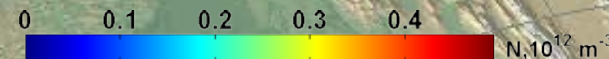
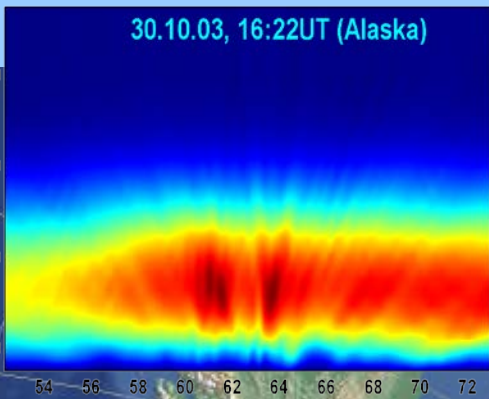
Storms of 2003-2007





30.10.2003

Alaska – Russia
 16:22UT – 16:30UT
 (07:22LT) – (19:30LT)



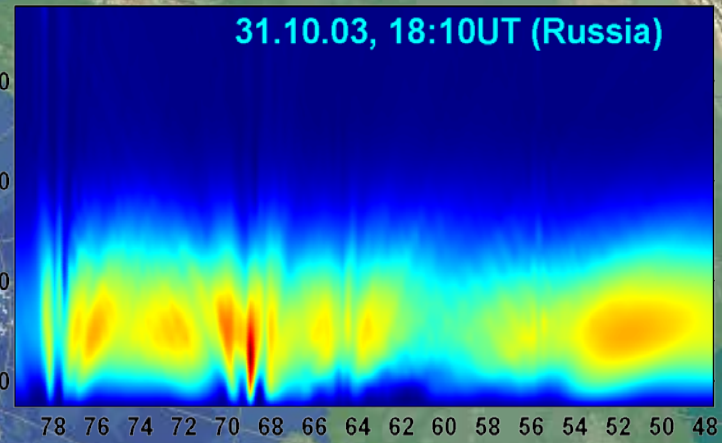
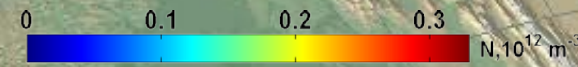
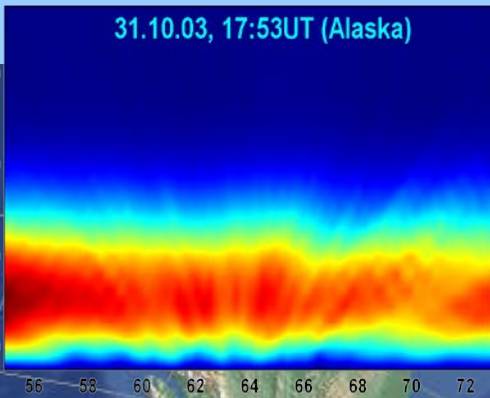
Radio Tomography chains

Storms of 2003-2007



30.10.2003

Alaska – Russia
 17:53UT – 18:10UT
 (08:53LT) – (21:10LT)



Kp=9.0

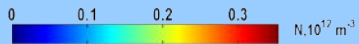
Cordova ● ● ● ●
 Cakona Delta Arc. Villa

Svalbard ●
 Nickel ● ●
 Padun ●
 Kem ●
 Moscow ●

Radio Tomography chains

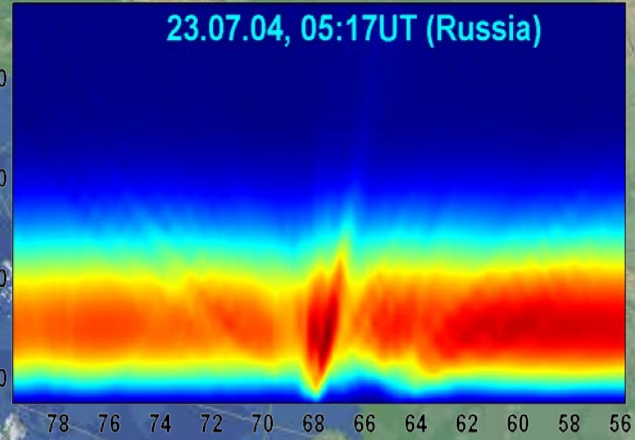
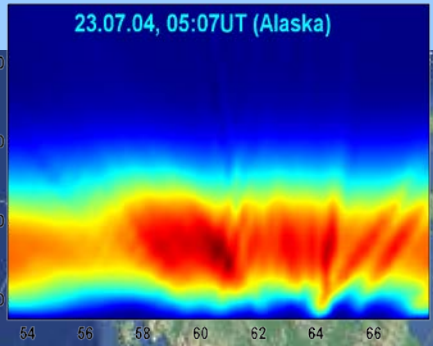
USA Russia

Storms of 2003-2007



23.07.2004 { Alaska – Russia
05:07UT – 05:17UT

22.07.2004(20:07LT) - 23.07.2004(08:17LT)



Kp=5.7

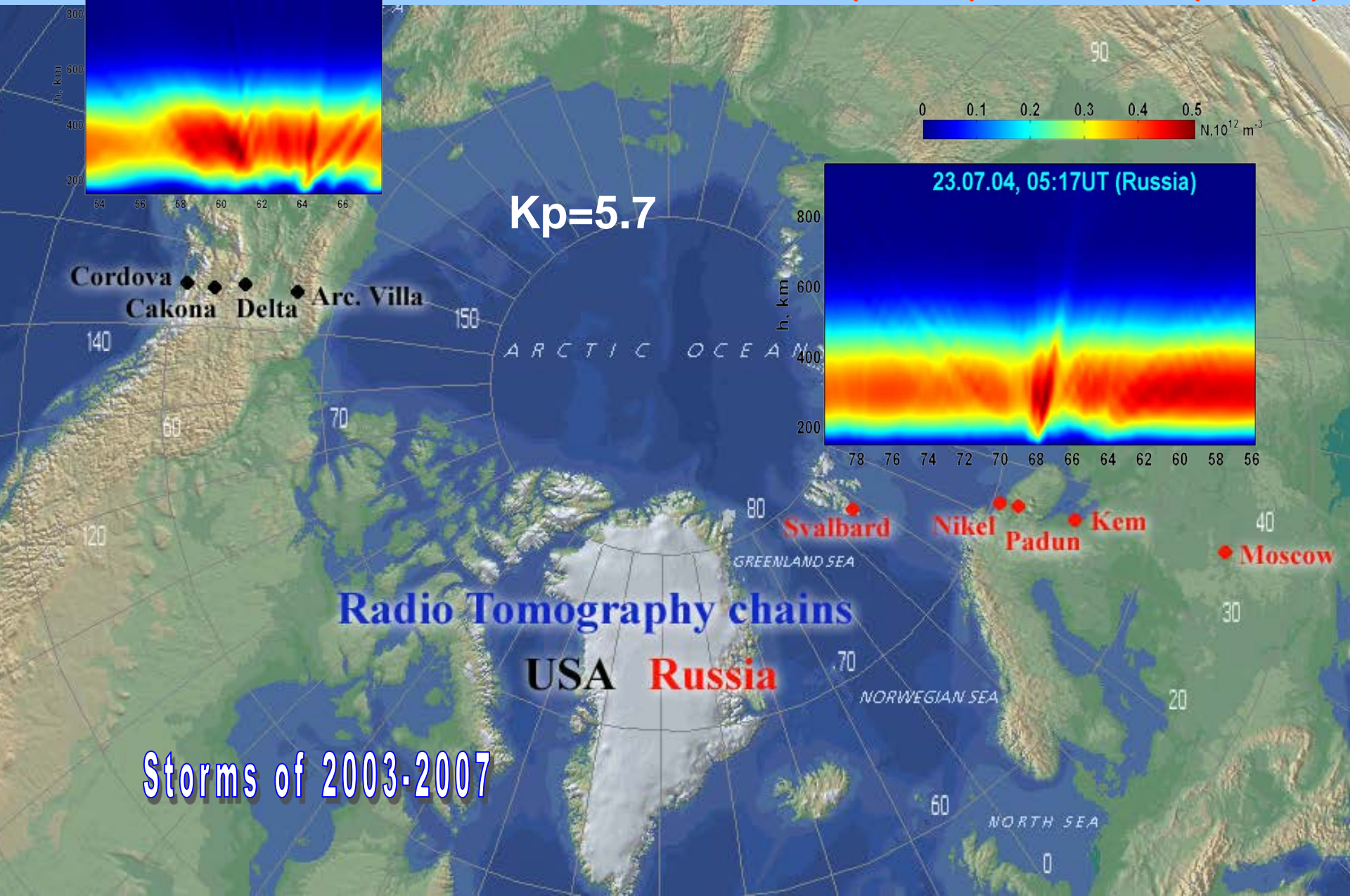
Cordova ● ● ● Arc. Villa
Cakona Delta

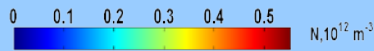
Svalbard ● Nickel ● Padun ● Kem ● Moscow ●

Radio Tomography chains

USA Russia

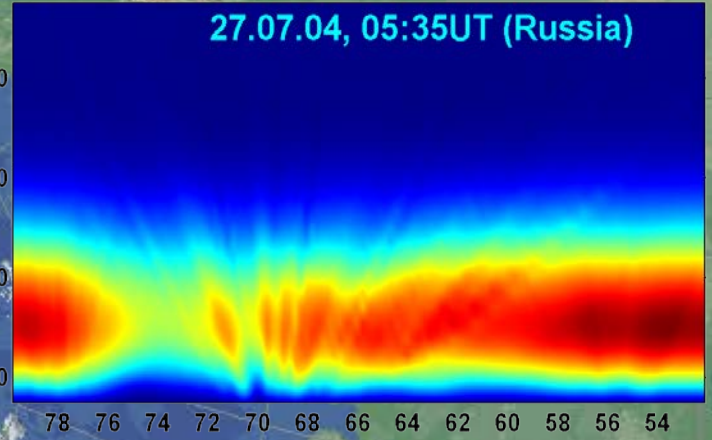
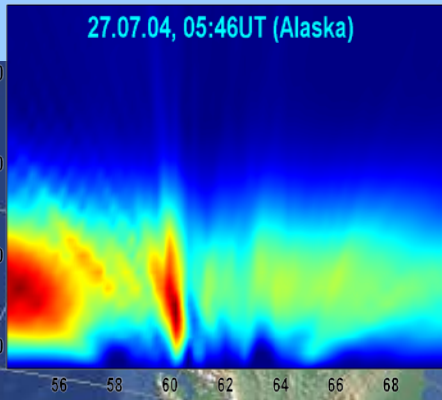
Storms of 2003-2007





27.07.2004 { Alaska – Russia
05:46UT – 05:35UT

26.07.2004 (20:46LT) - 27.07.2004 (08:35LT)



Kp=7.3

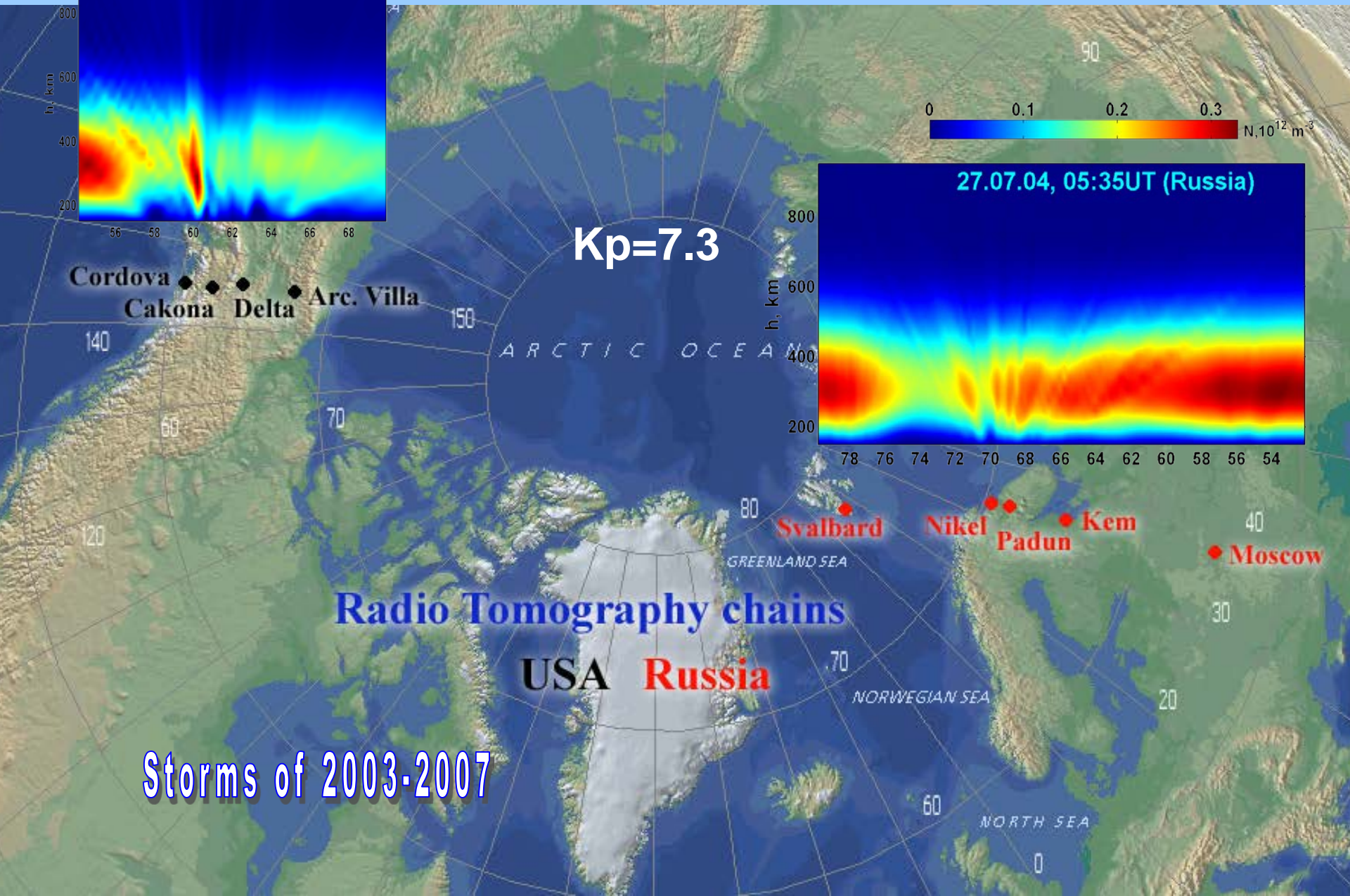
Cordova ● ● ●
Cakona Delta Arc. Villa

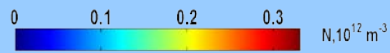
Svalbard ●
Nikel ● ●
Padun ●
Kem ●
Moscow ●

Radio Tomography chains

USA Russia

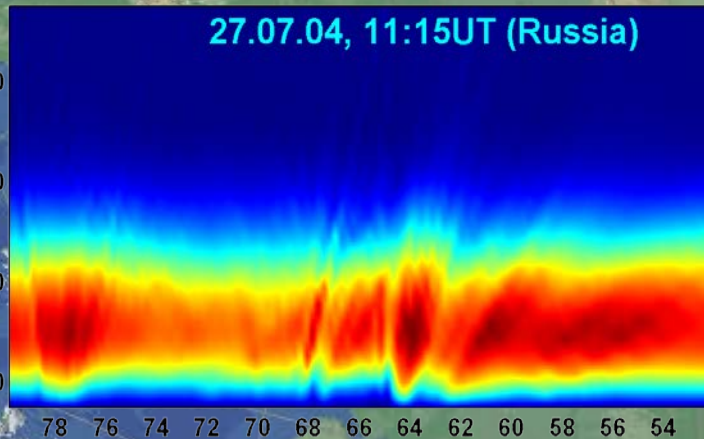
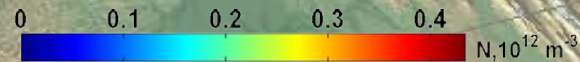
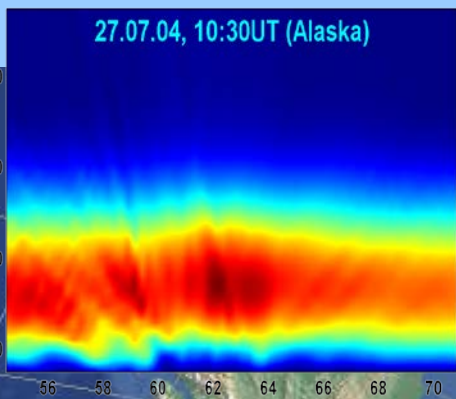
Storms of 2003-2007





27.07.2004

Alaska – Russia
 10:30UT – 11:15UT
 (01:30LT) – (13:15LT)



Kp=8.3

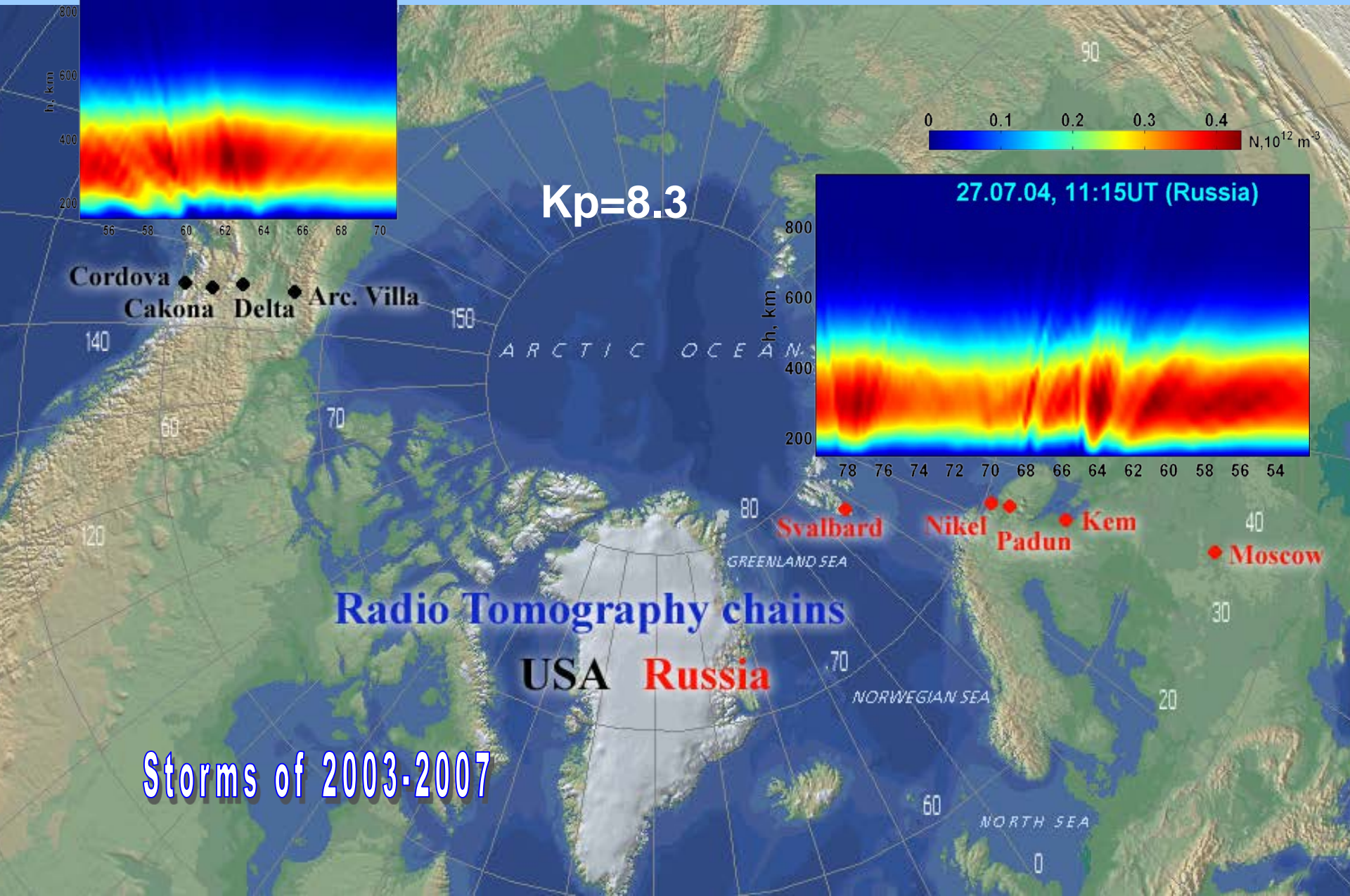
Cordova ● ● ●
 Cakona ● Delta ● Arc. Villa ●

Svalbard ●
 Nikel ● Padun ●
 Kem ●
 Moscow ●

Radio Tomography chains

USA Russia

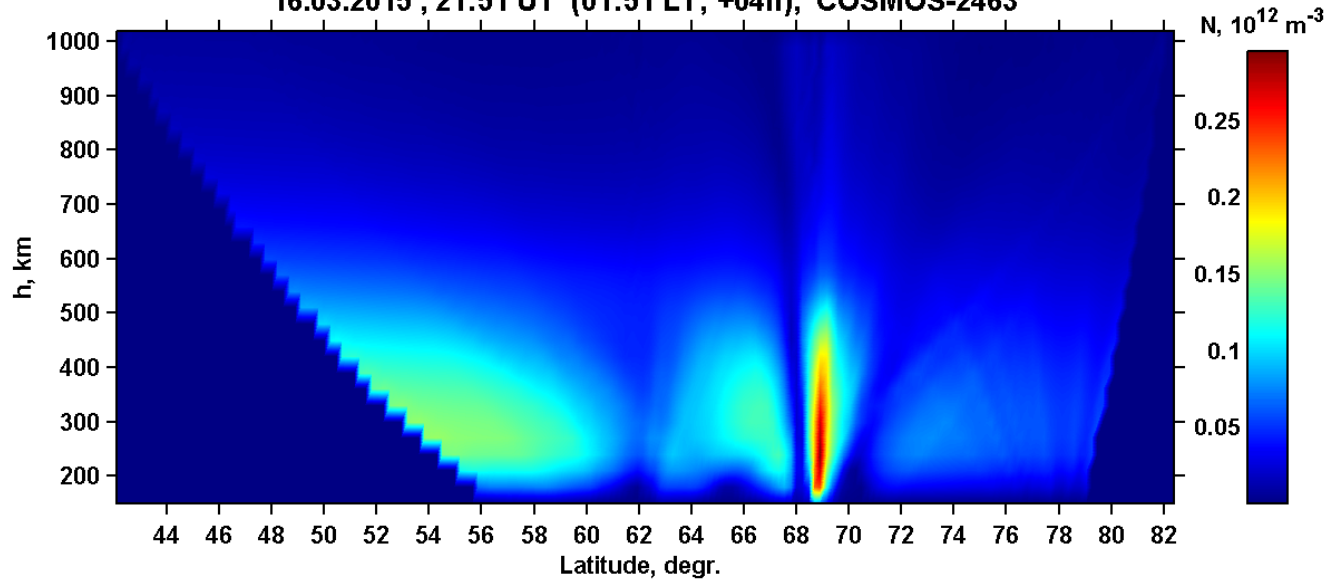
Storms of 2003-2007



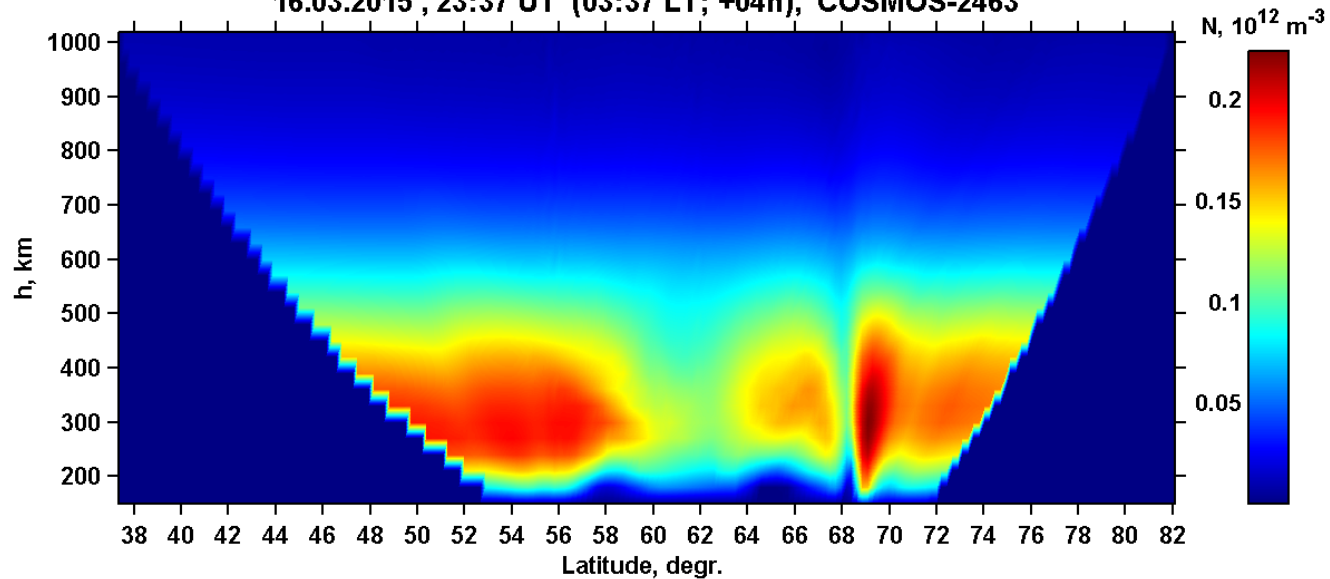
Region of Russian LORT system

geomagnetic storm of March 2015

16.03.2015 , 21:51 UT (01:51 LT; +04h), COSMOS-2463



16.03.2015 , 23:37 UT (03:37 LT; +04h), COSMOS-2463

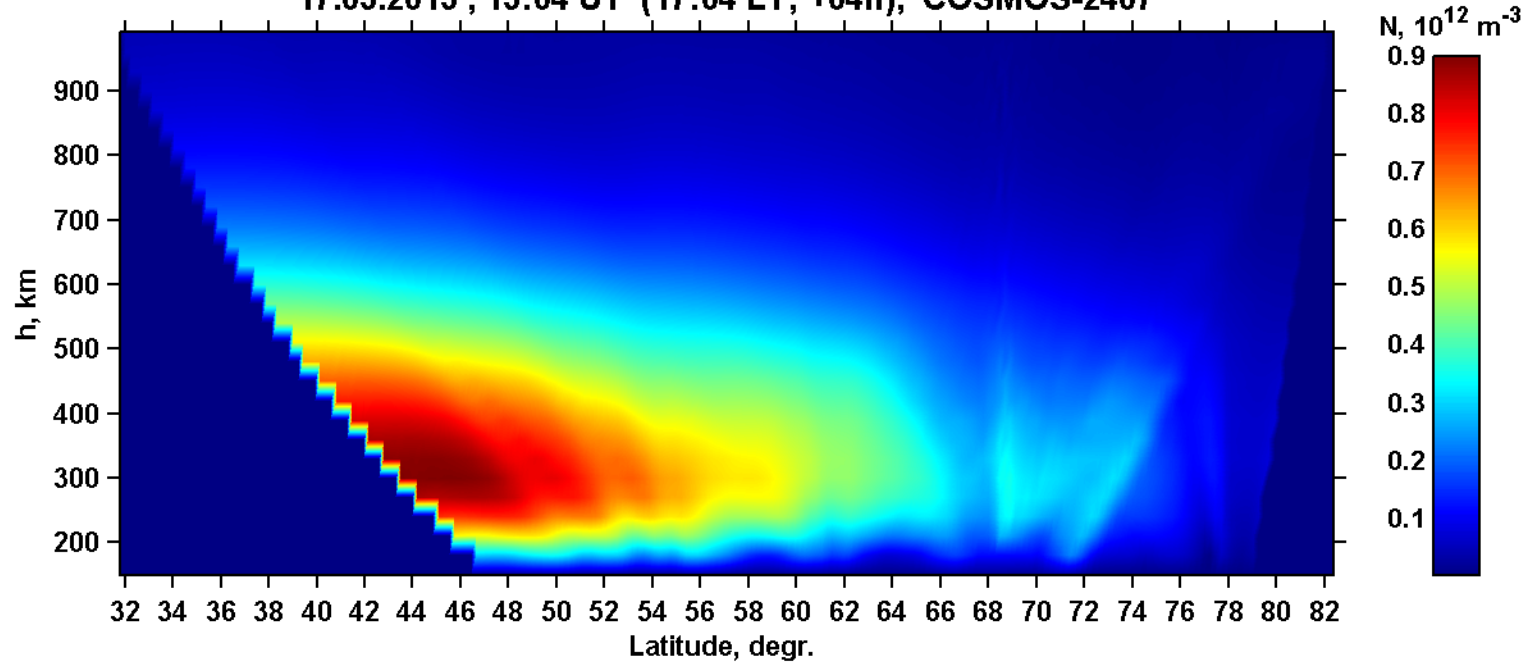


LORT image above Russian RT chain on March 16, 2015 , 21:51 and 23:37 UT

Region of Russian LORT system

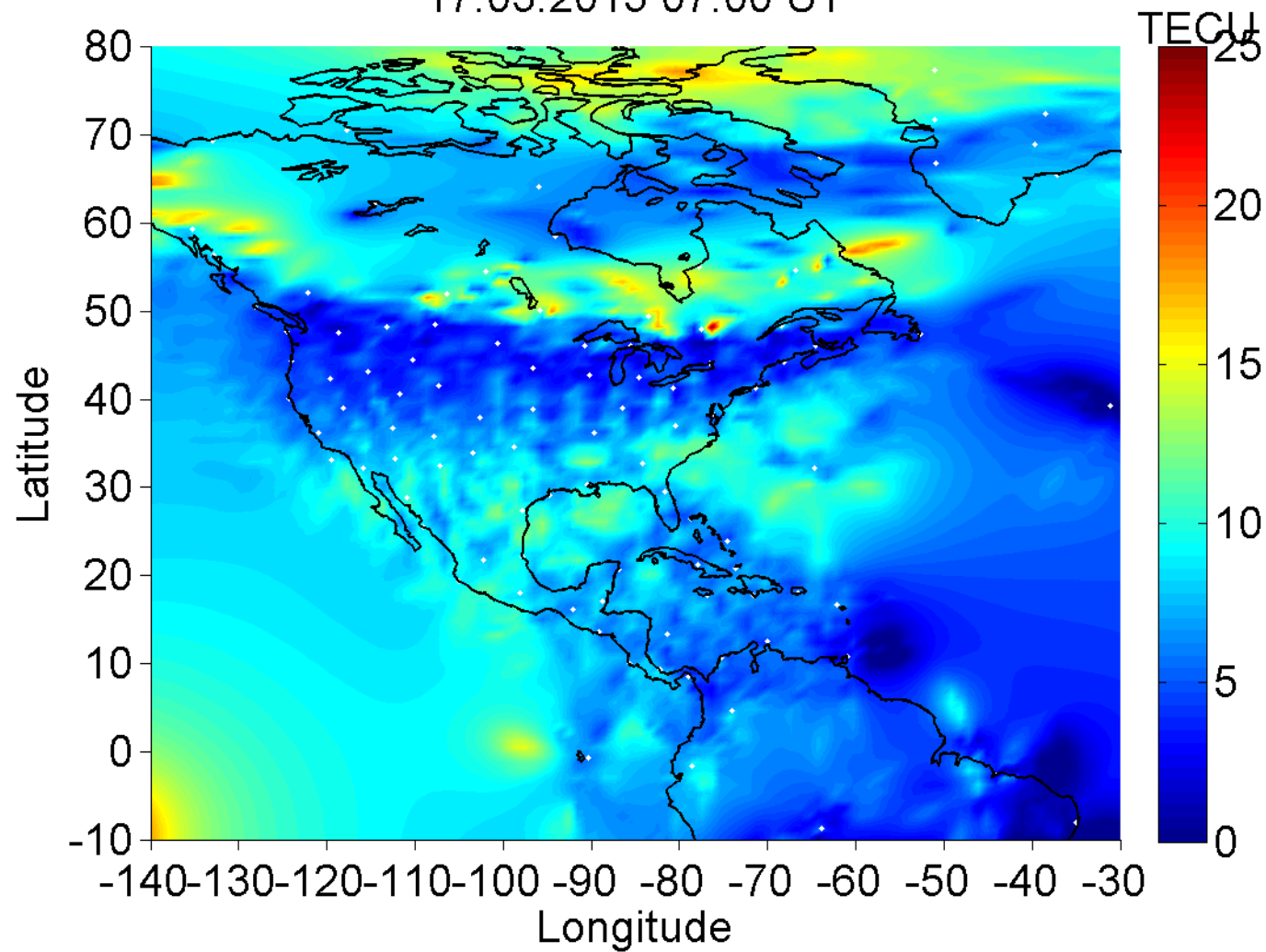
geomagnetic storm of March 2015

17.03.2015 , 13:04 UT (17:04 LT; +04h), COSMOS-2407

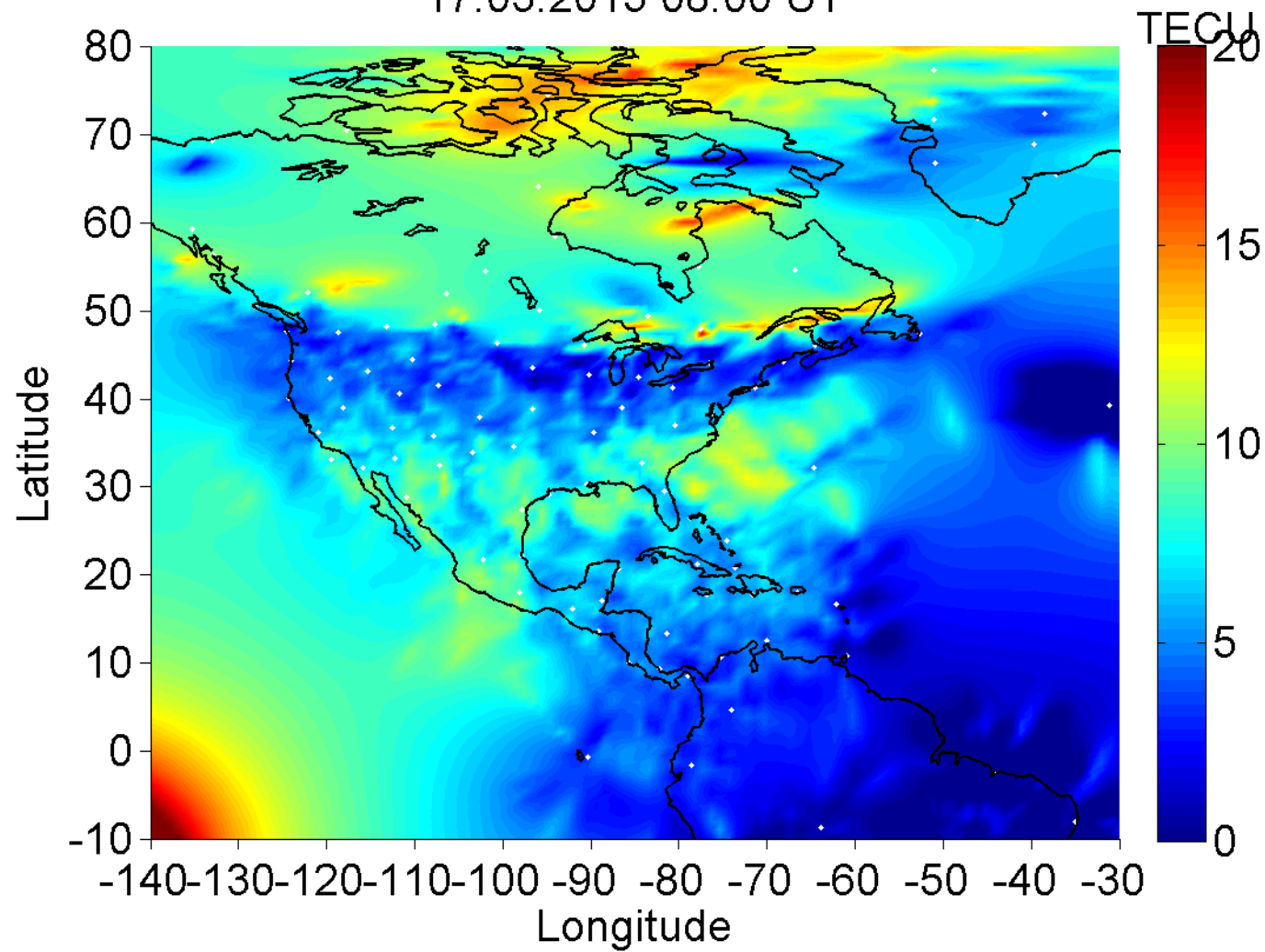


LORT image above Russian RT chain on March 17, 2015 , 13:04 UT

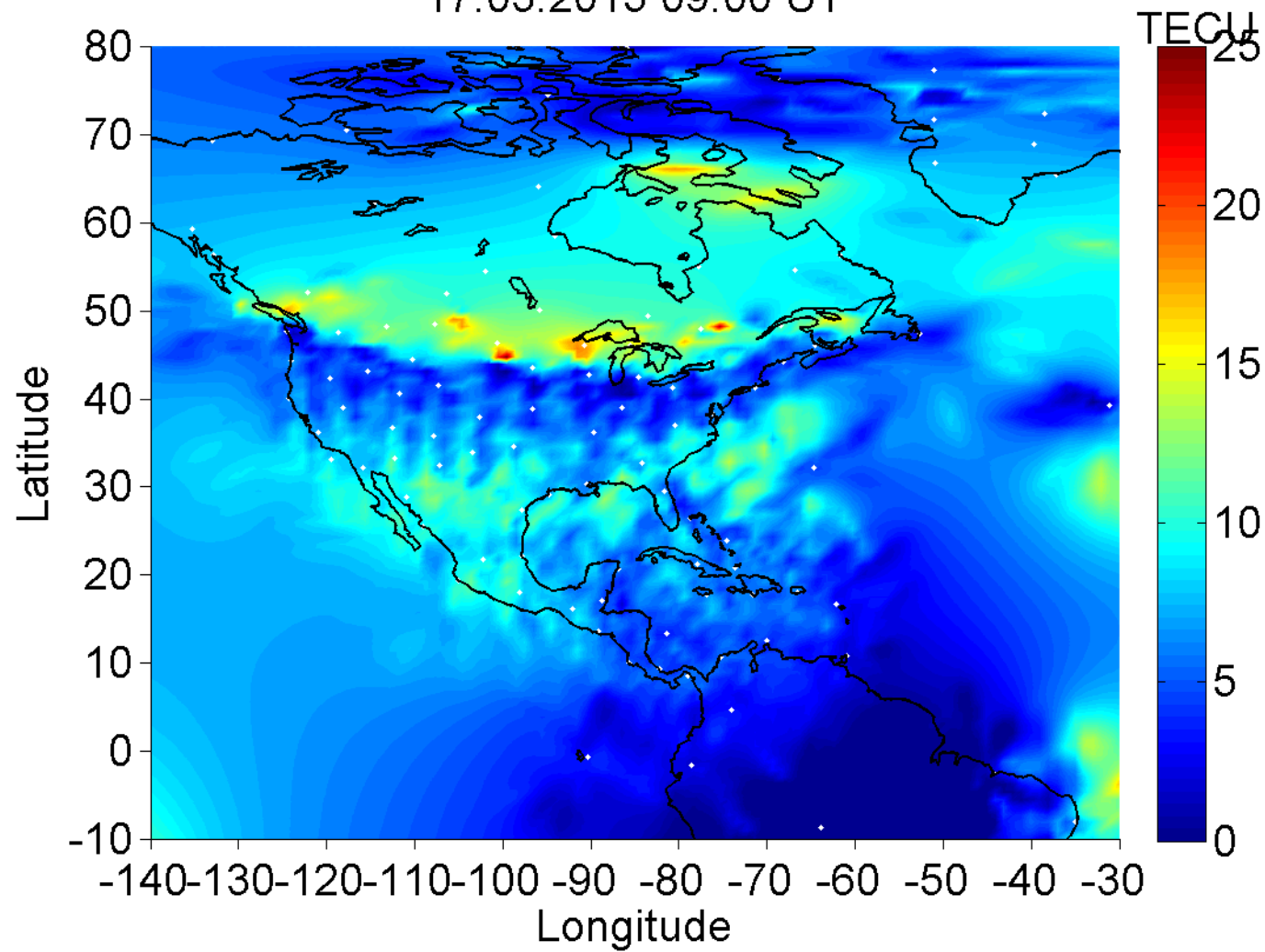
17.03.2015 07:00 UT



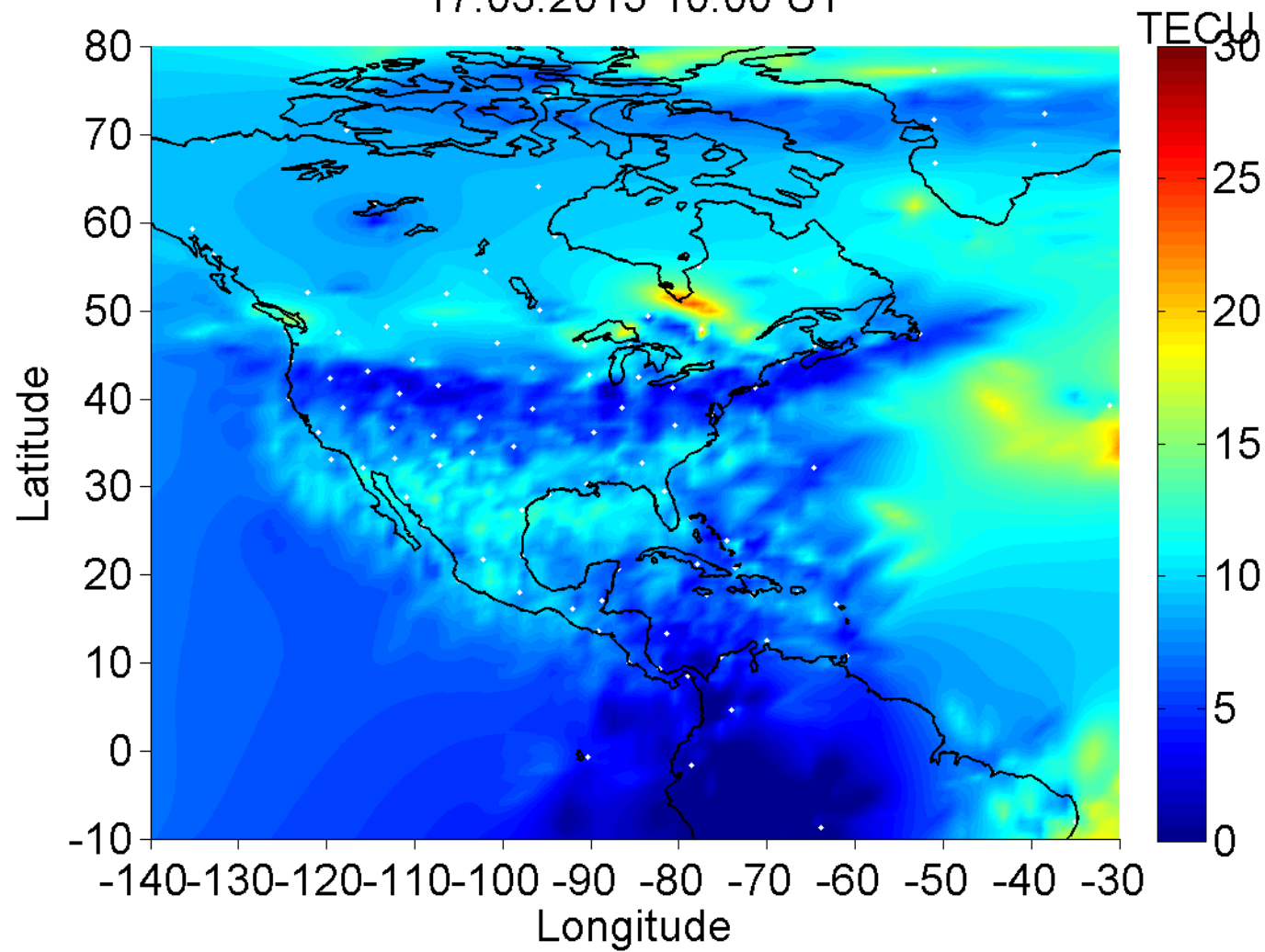
17.03.2015 08:00 UT



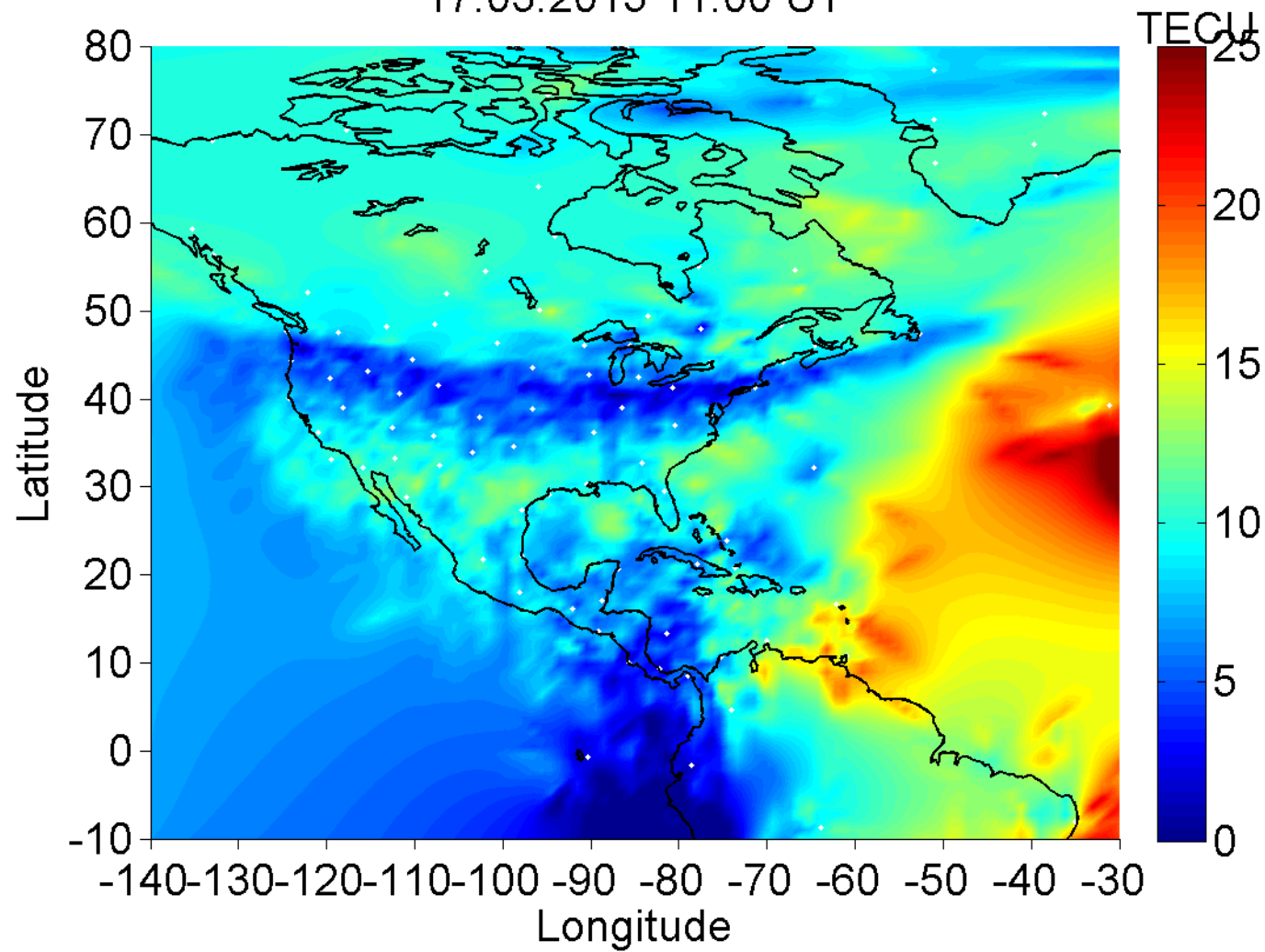
17.03.2015 09:00 UT



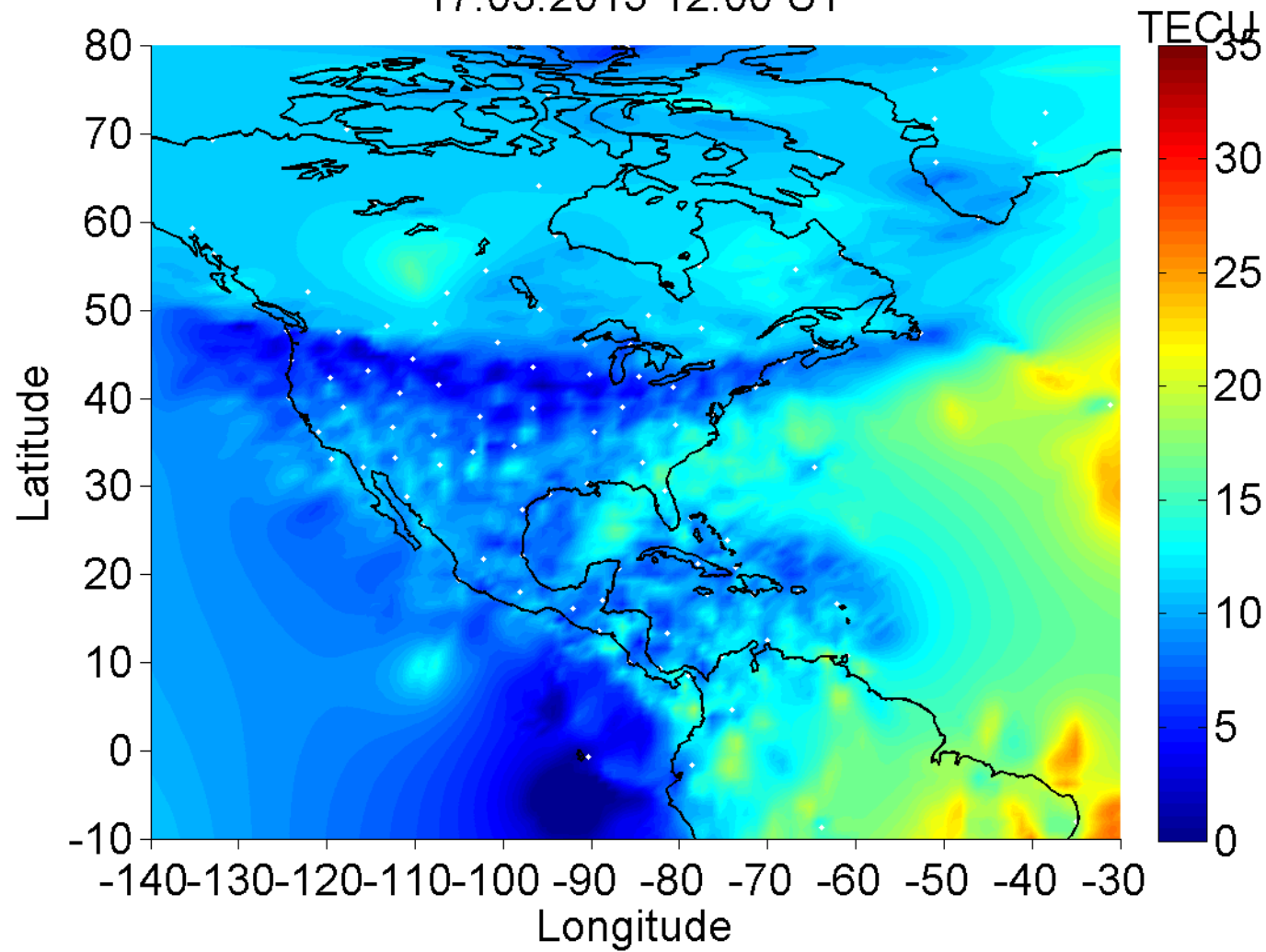
17.03.2015 10:00 UT



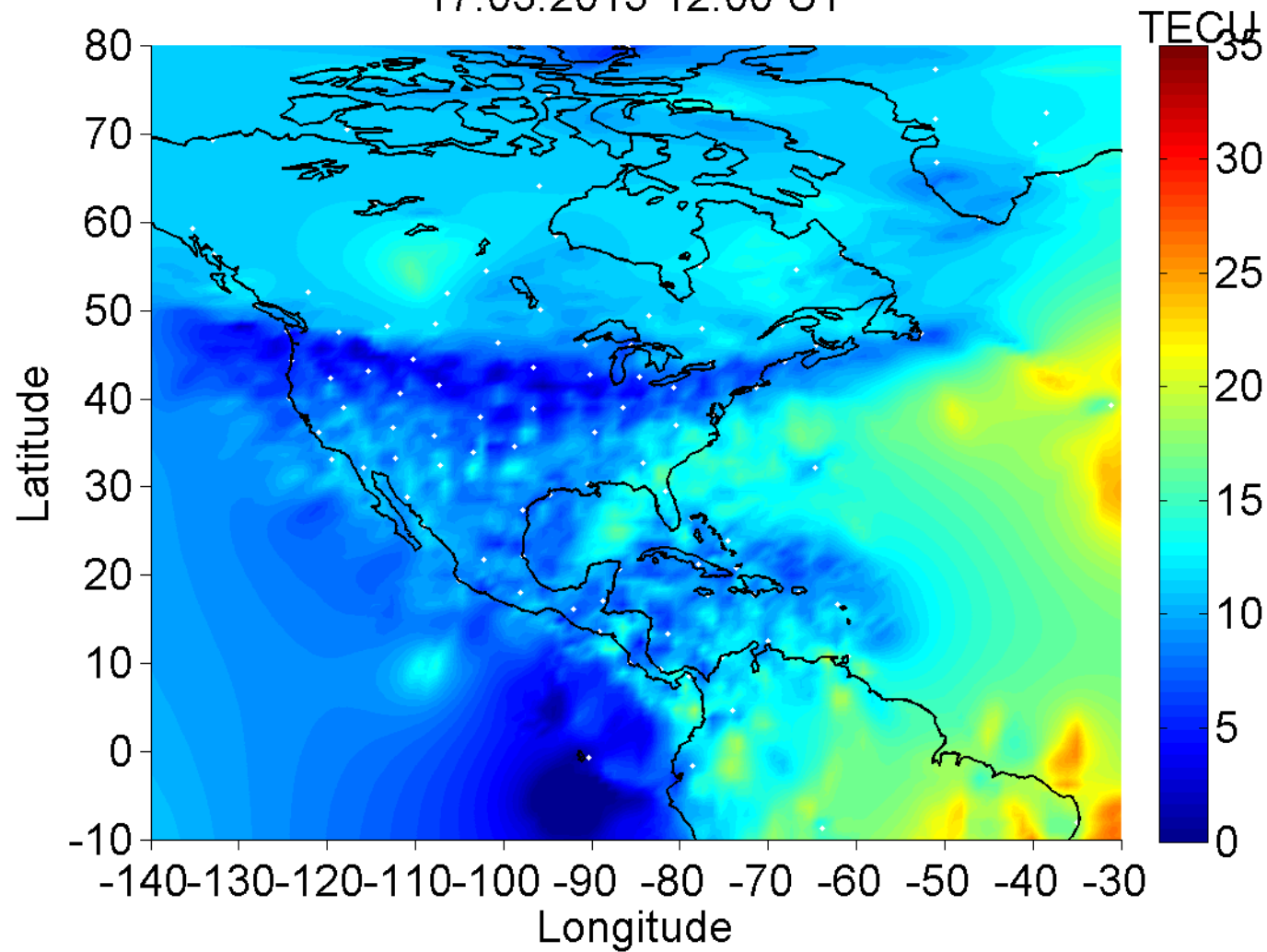
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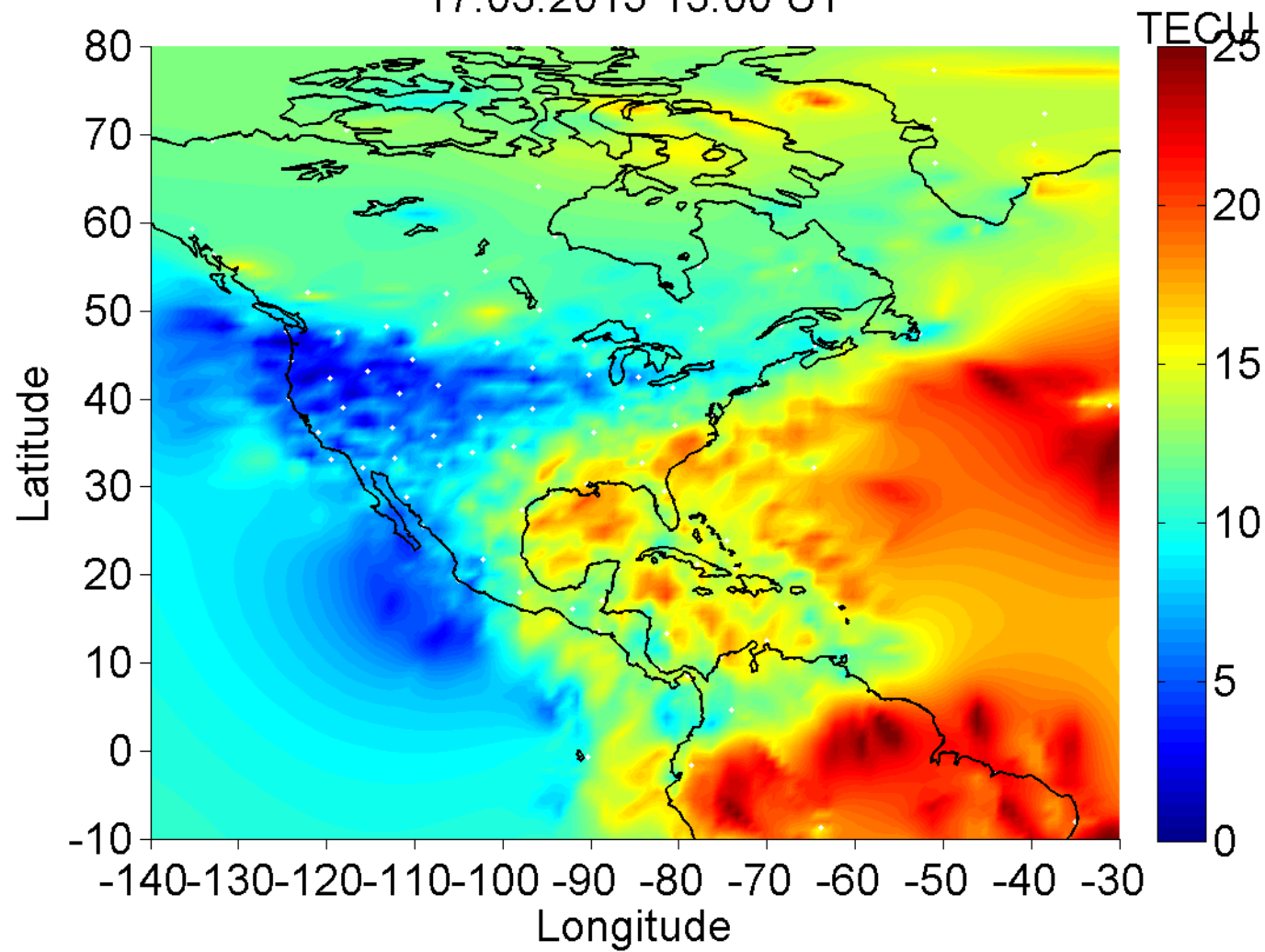
17.03.2015 12:00 UT



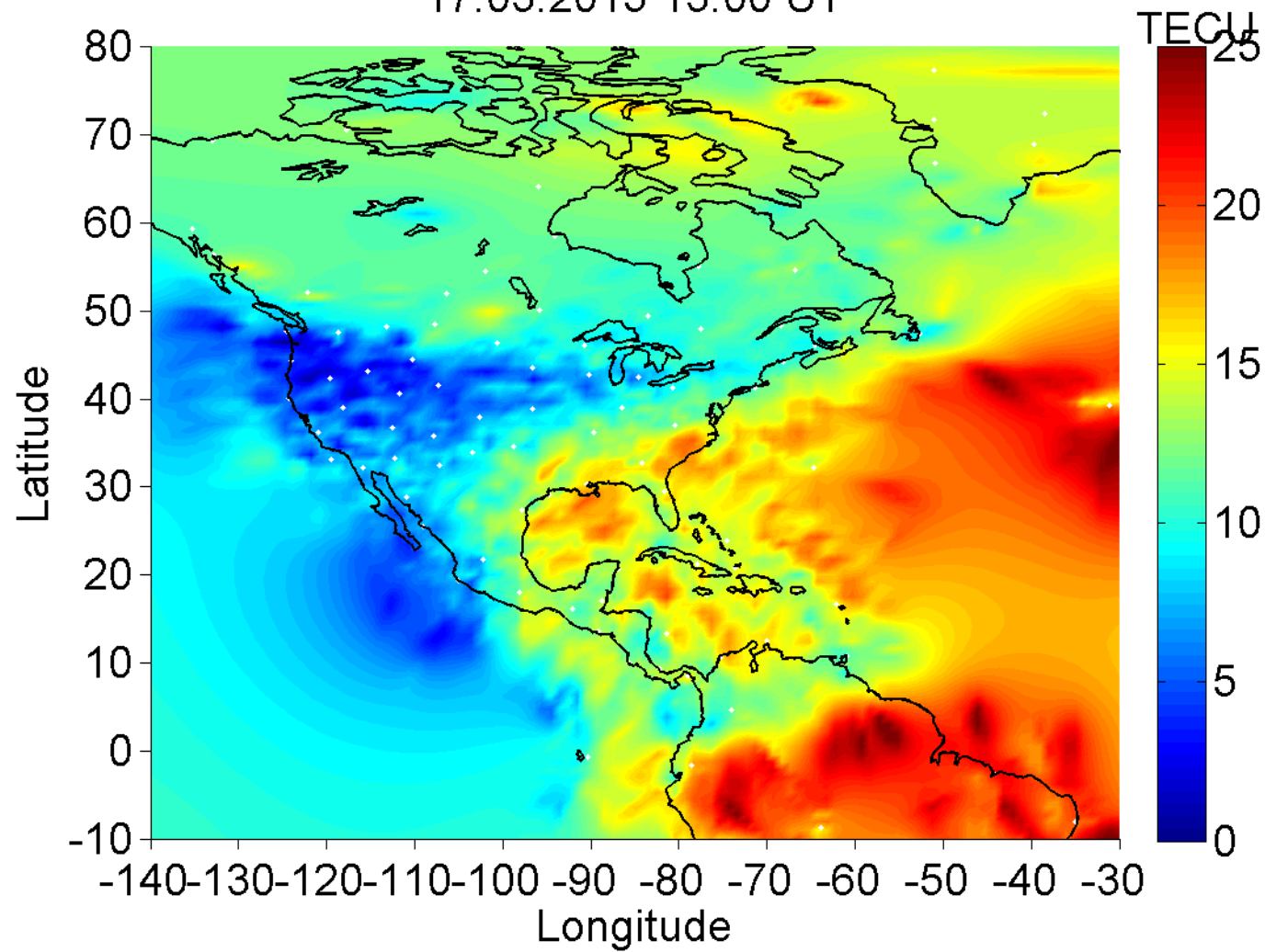
17.03.2015 12:00 UT



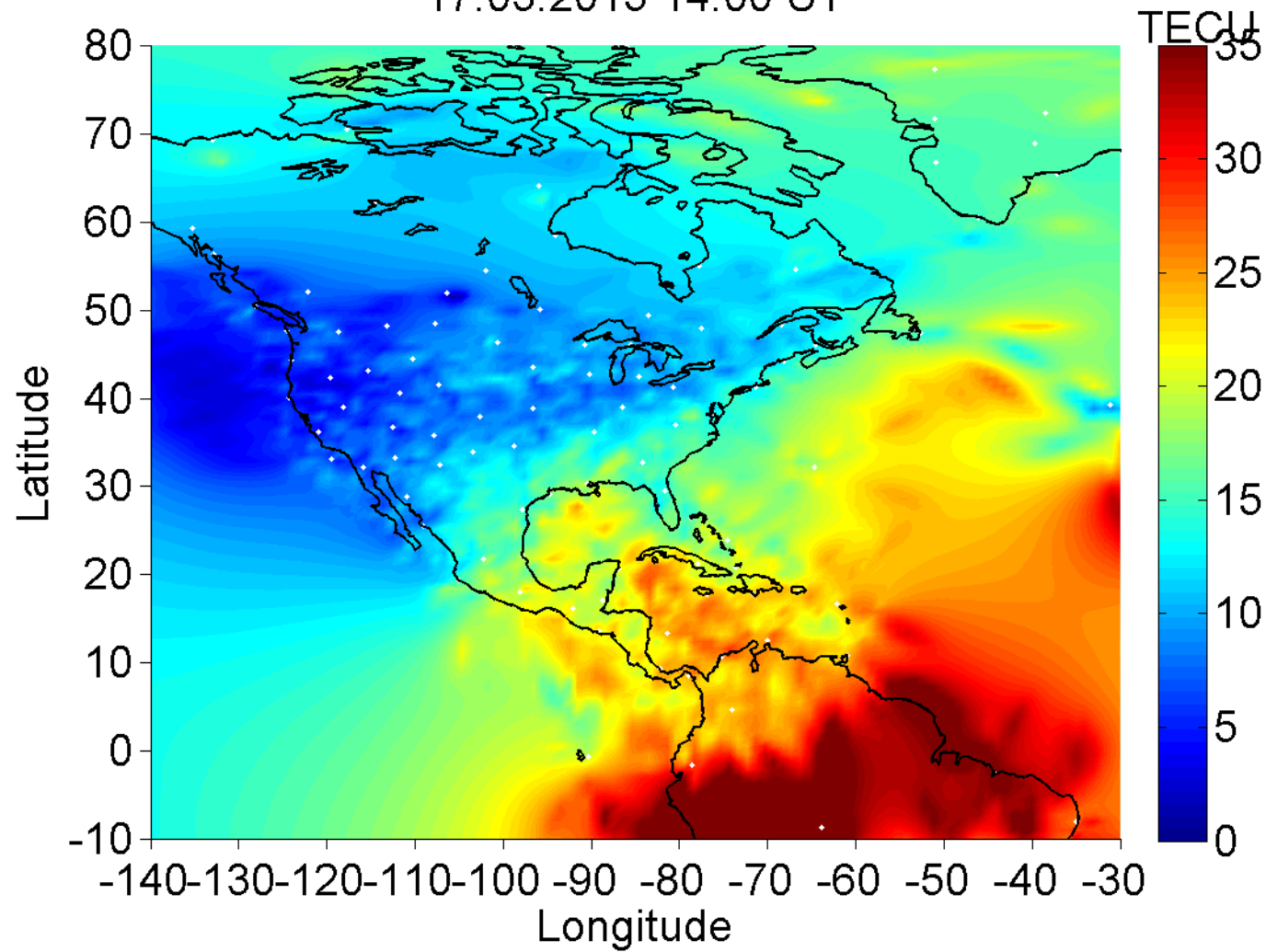
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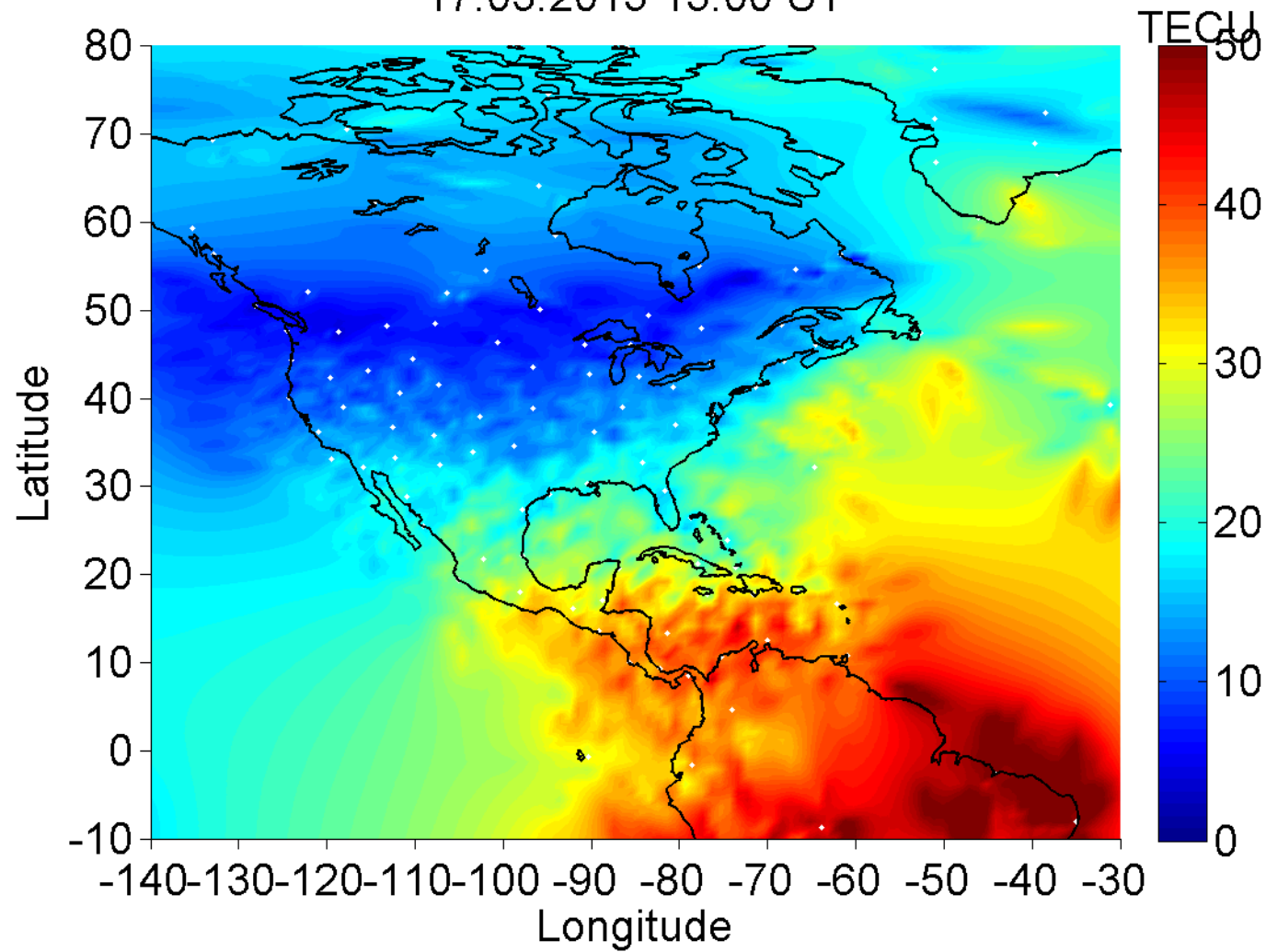
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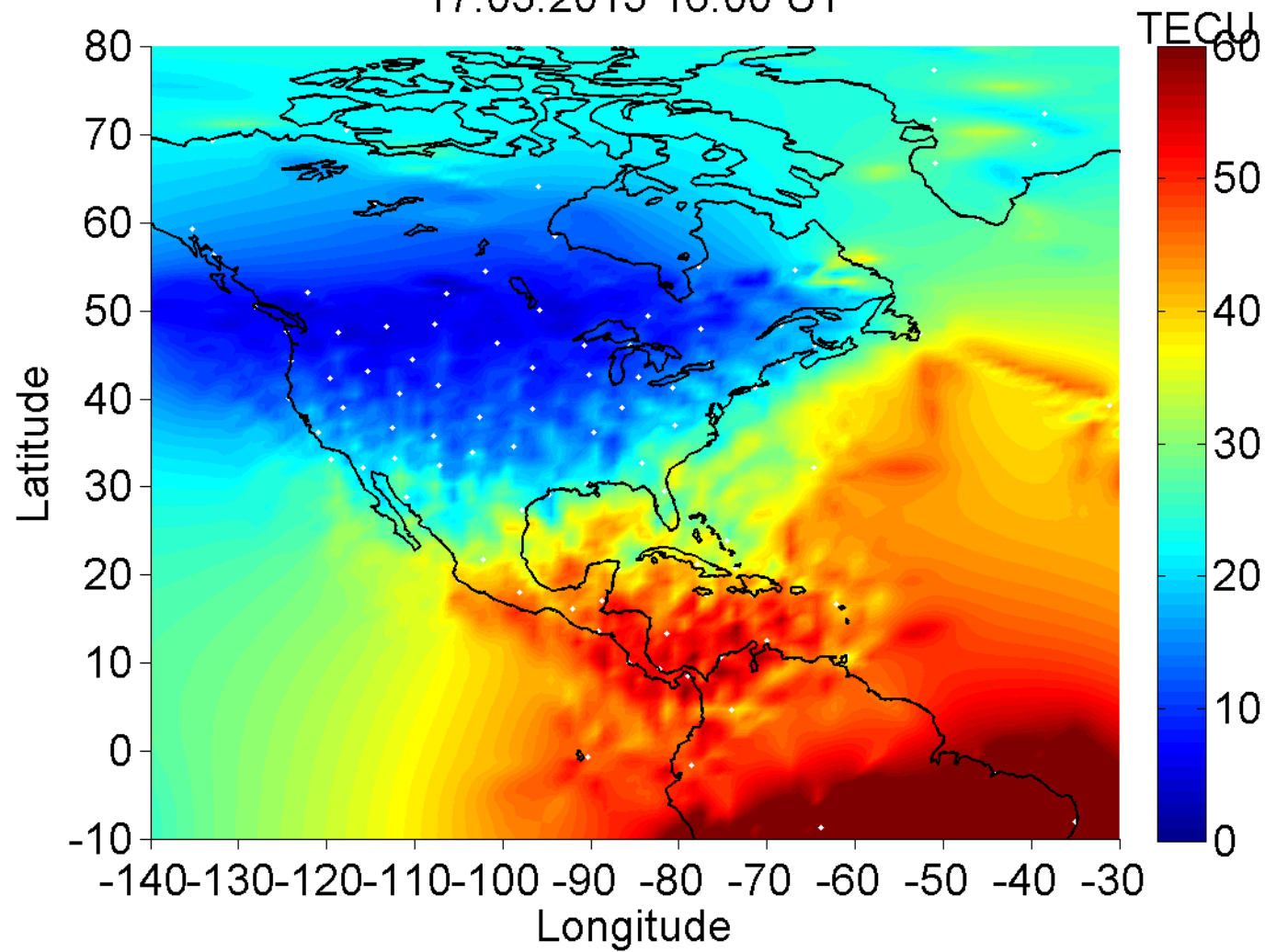
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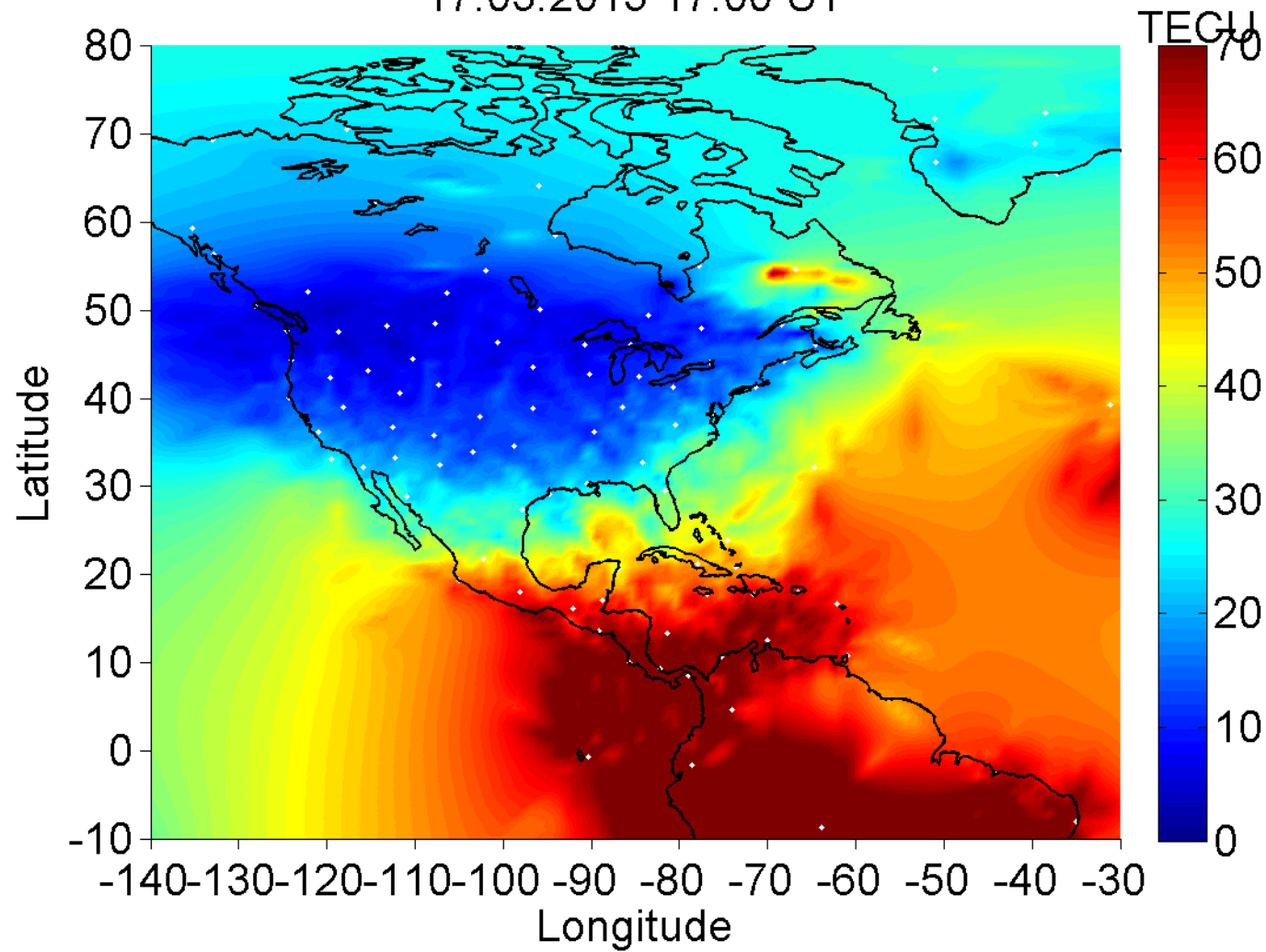
17.03.2015 15:00 UT



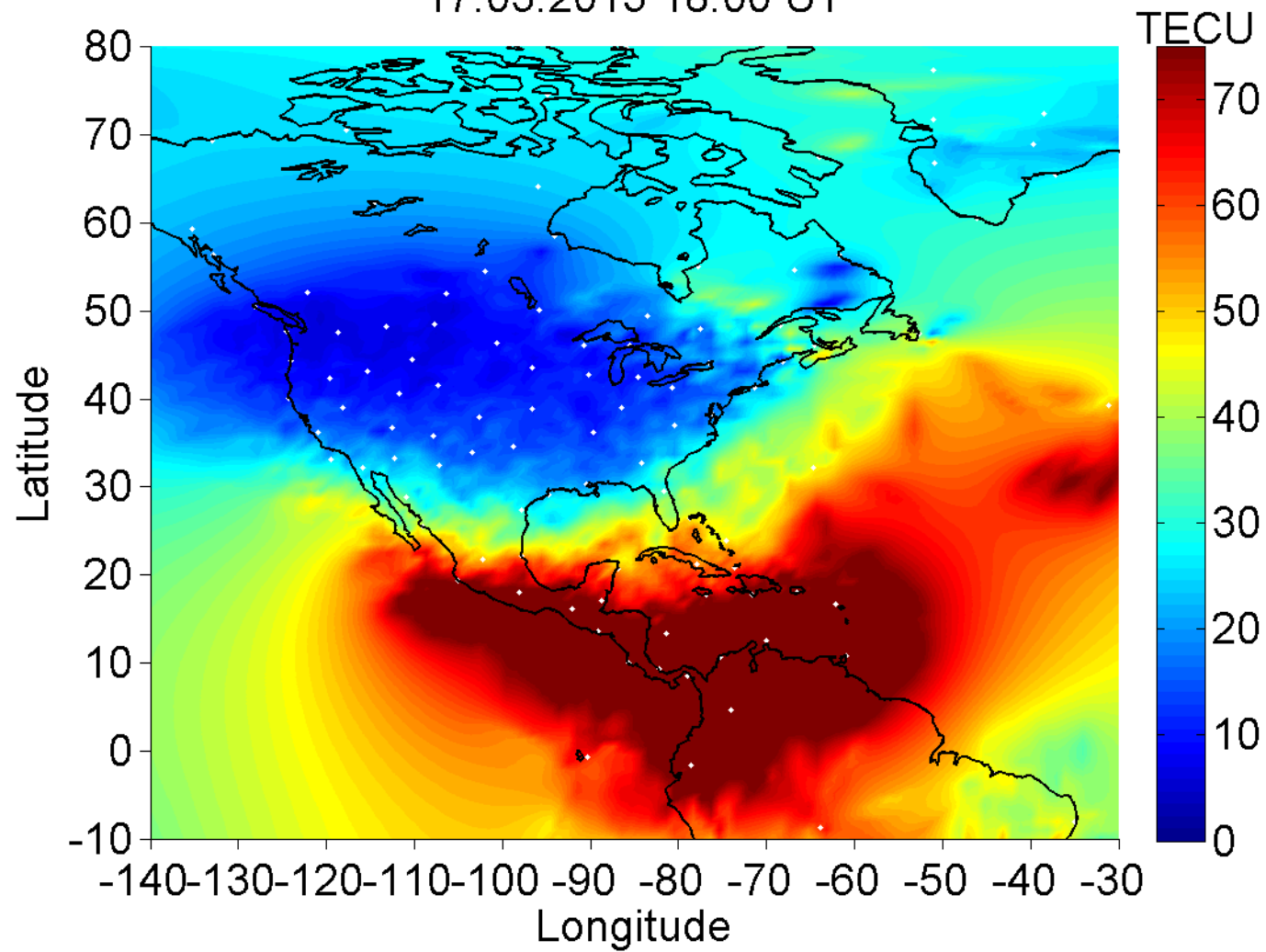
17.03.2015 16:00 UT



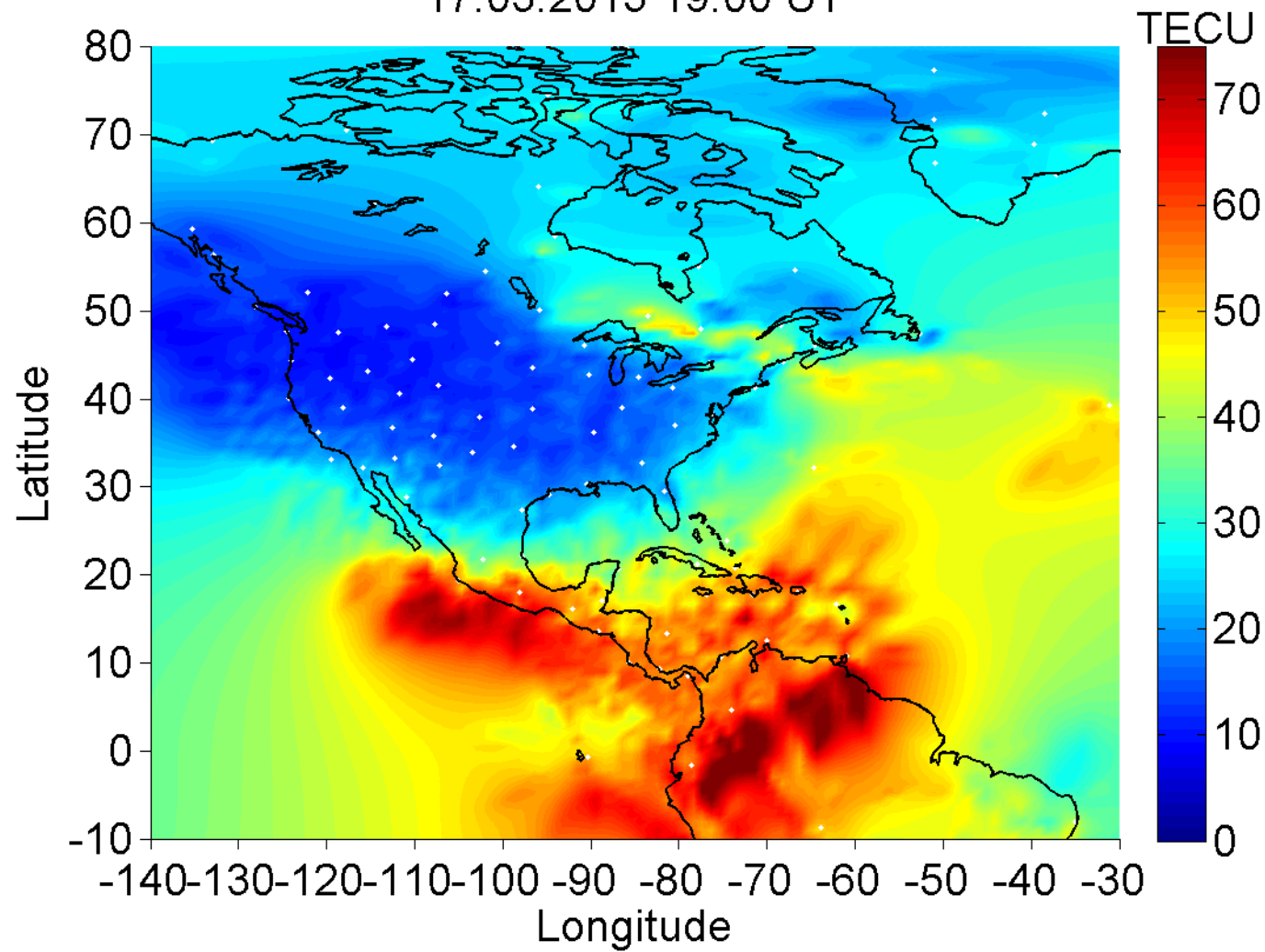
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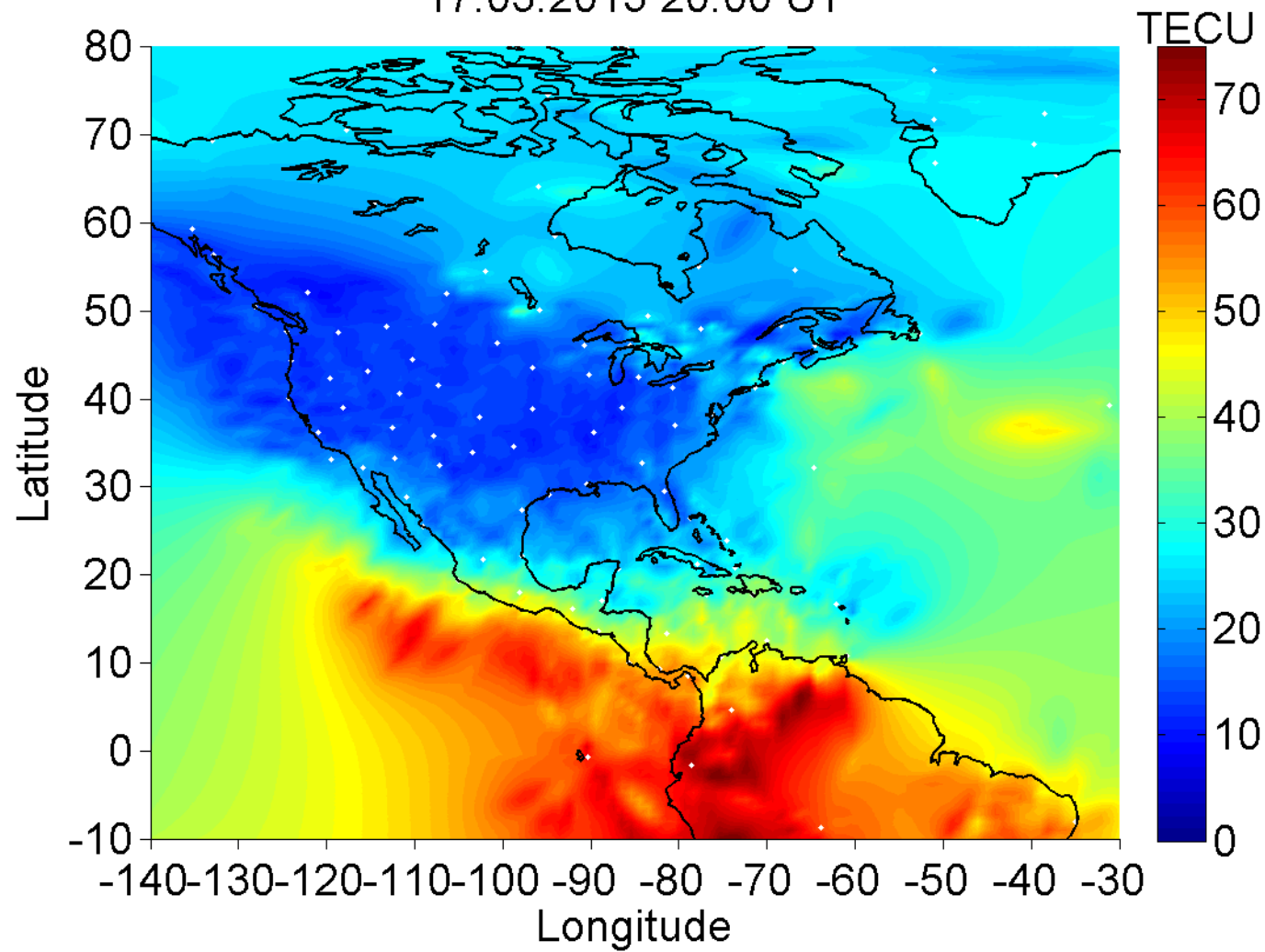
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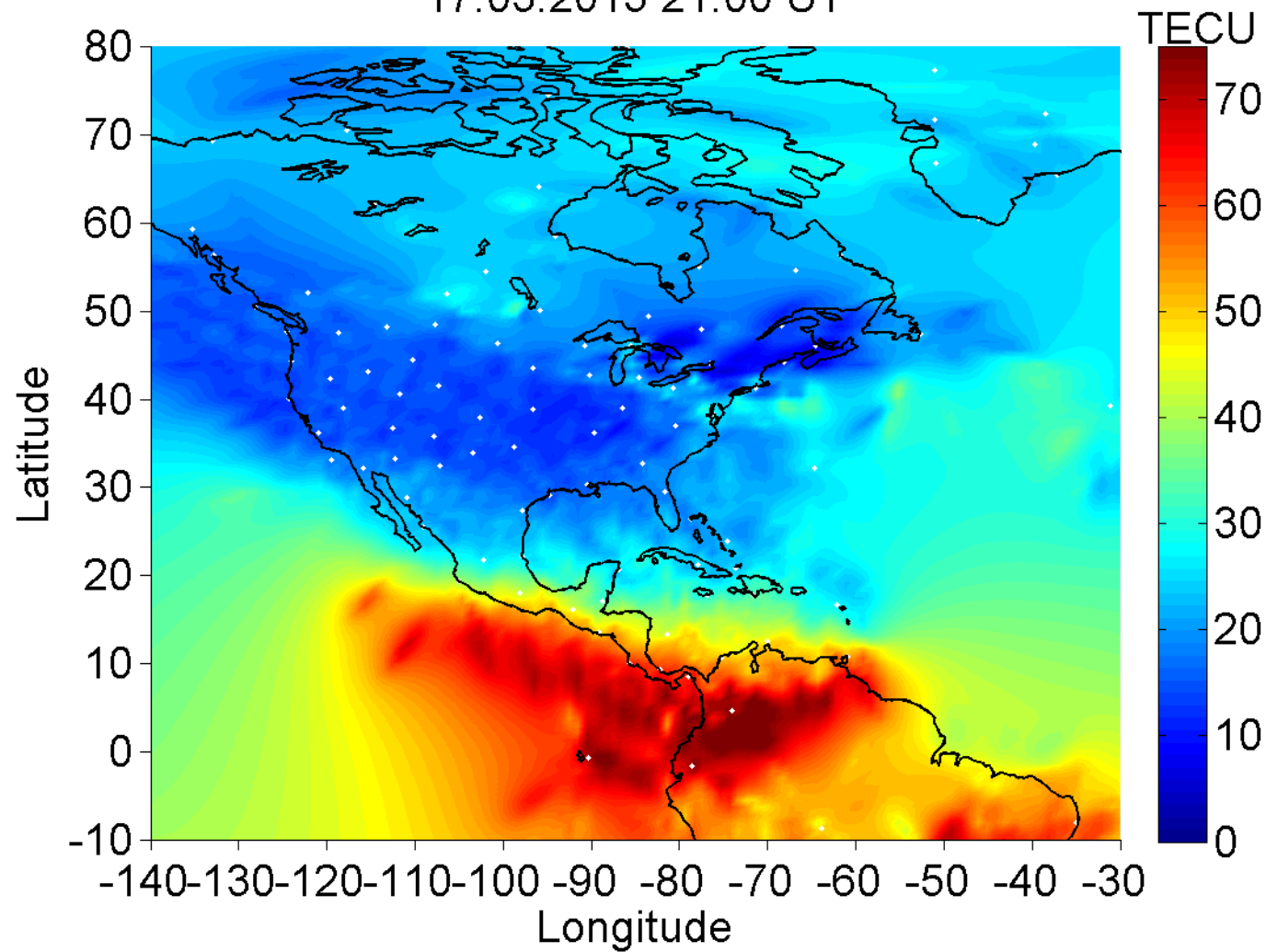
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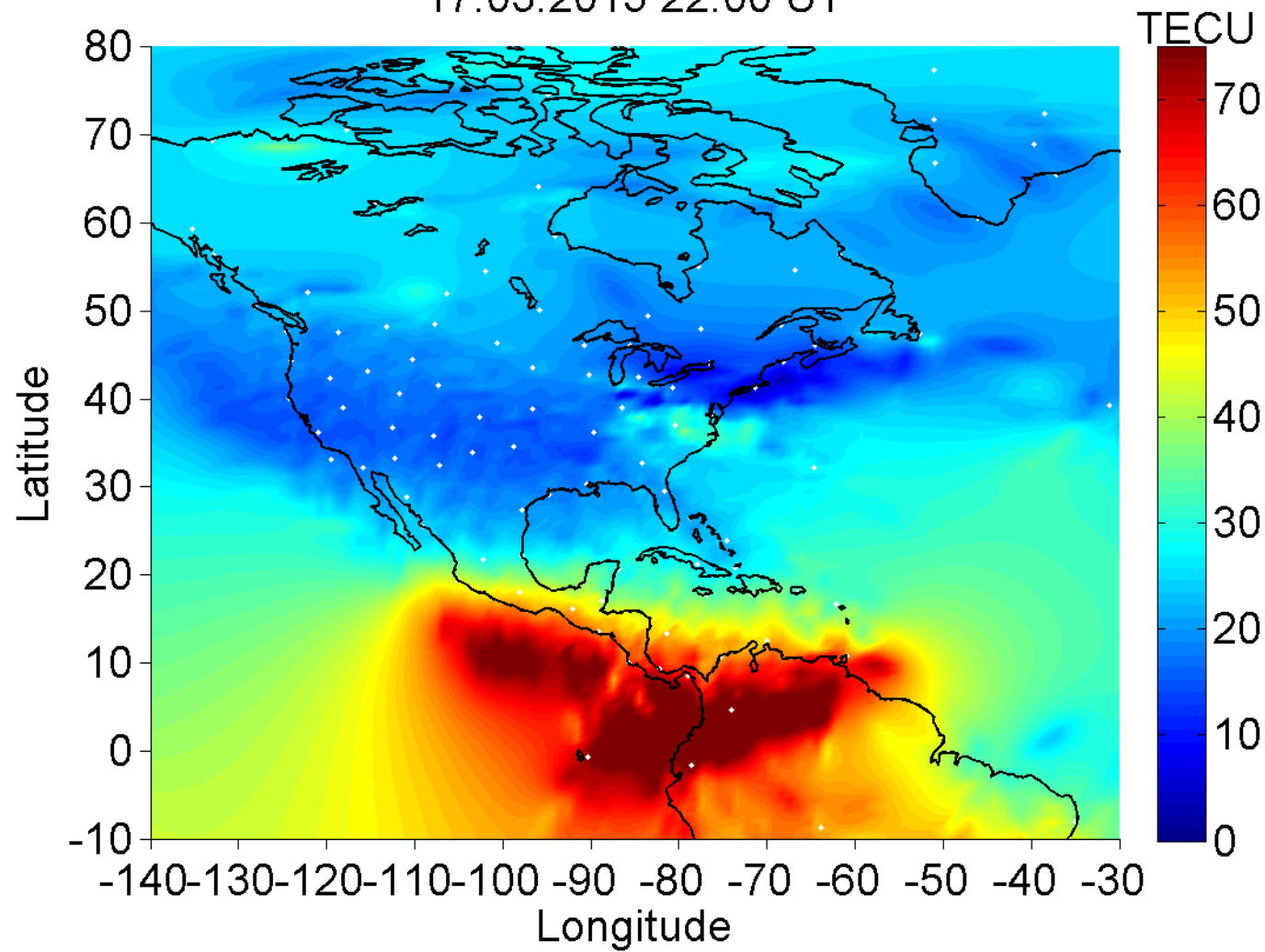
17.03.2015 20:00 UT



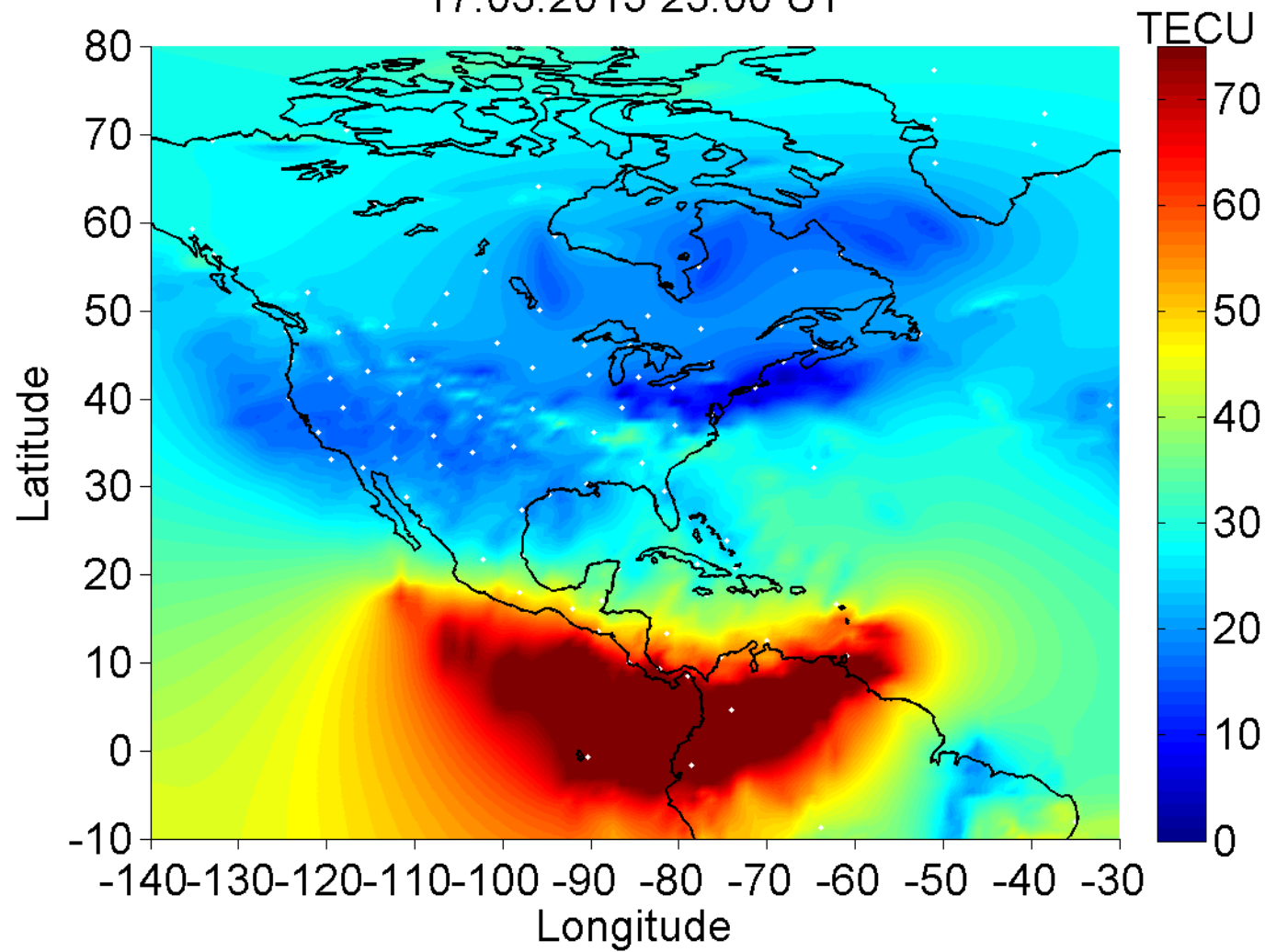
17.03.2015 21:00 UT



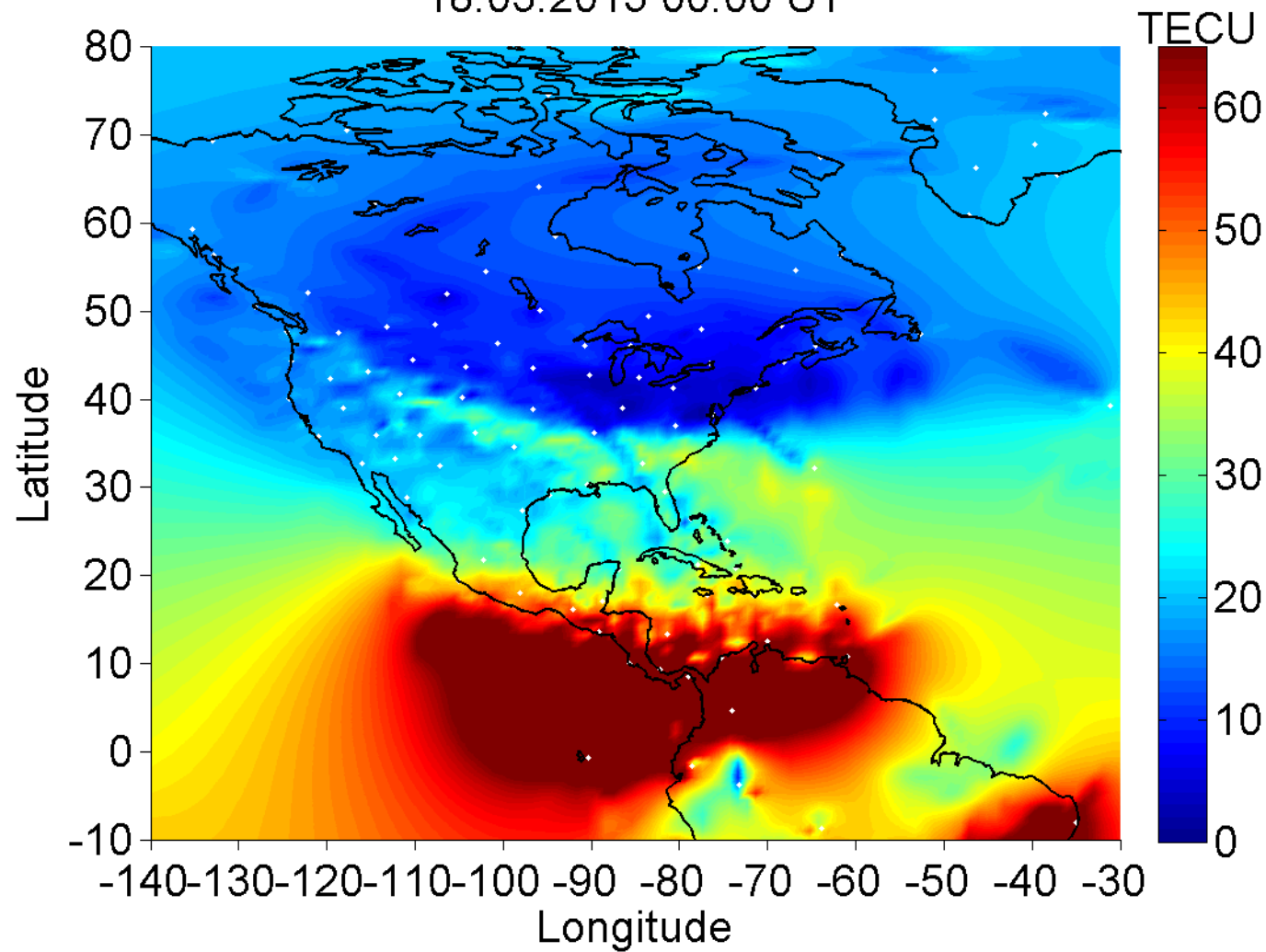
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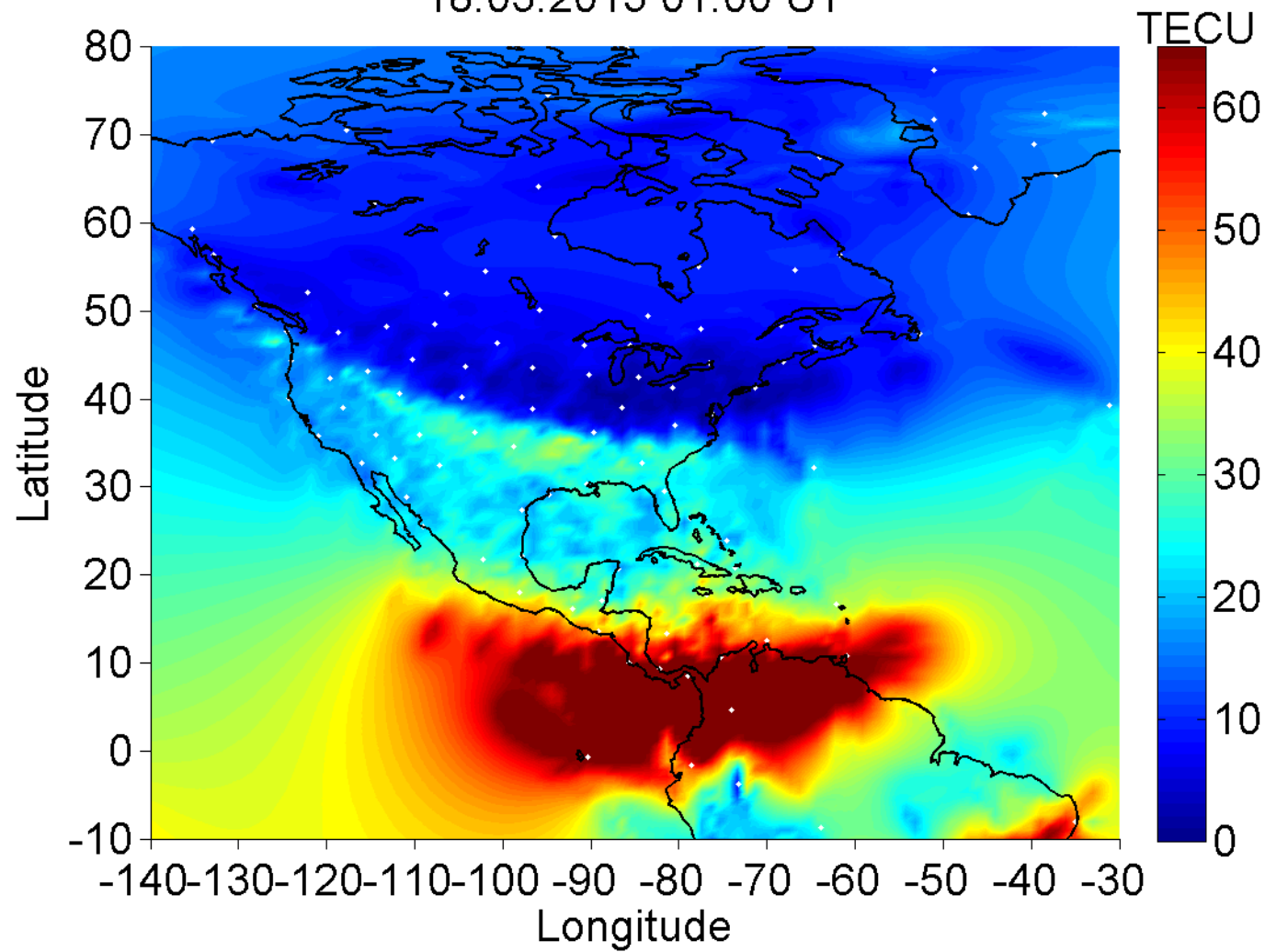
17.03.2015 23:00 UT



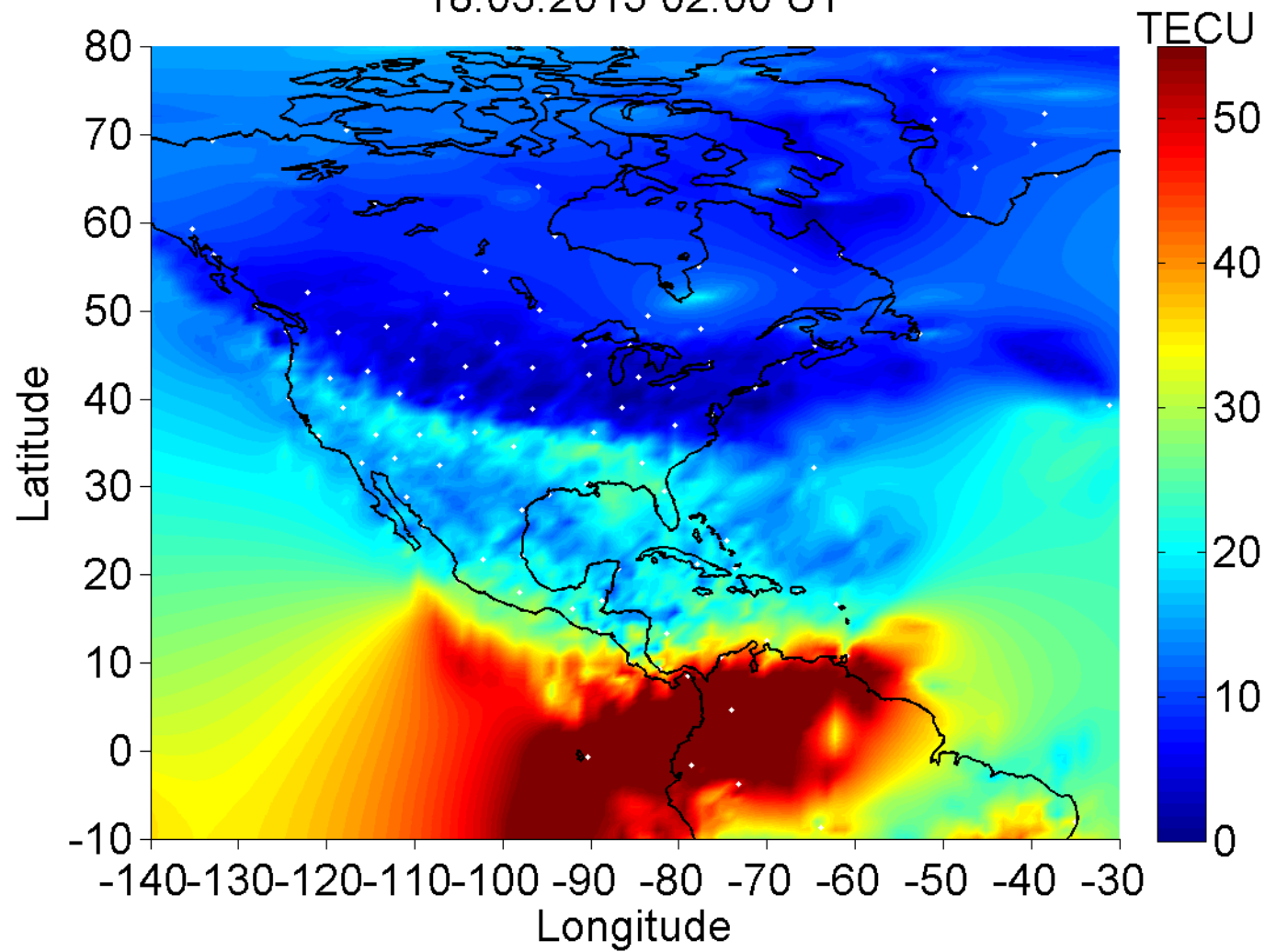
18.03.2015 00:00 UT



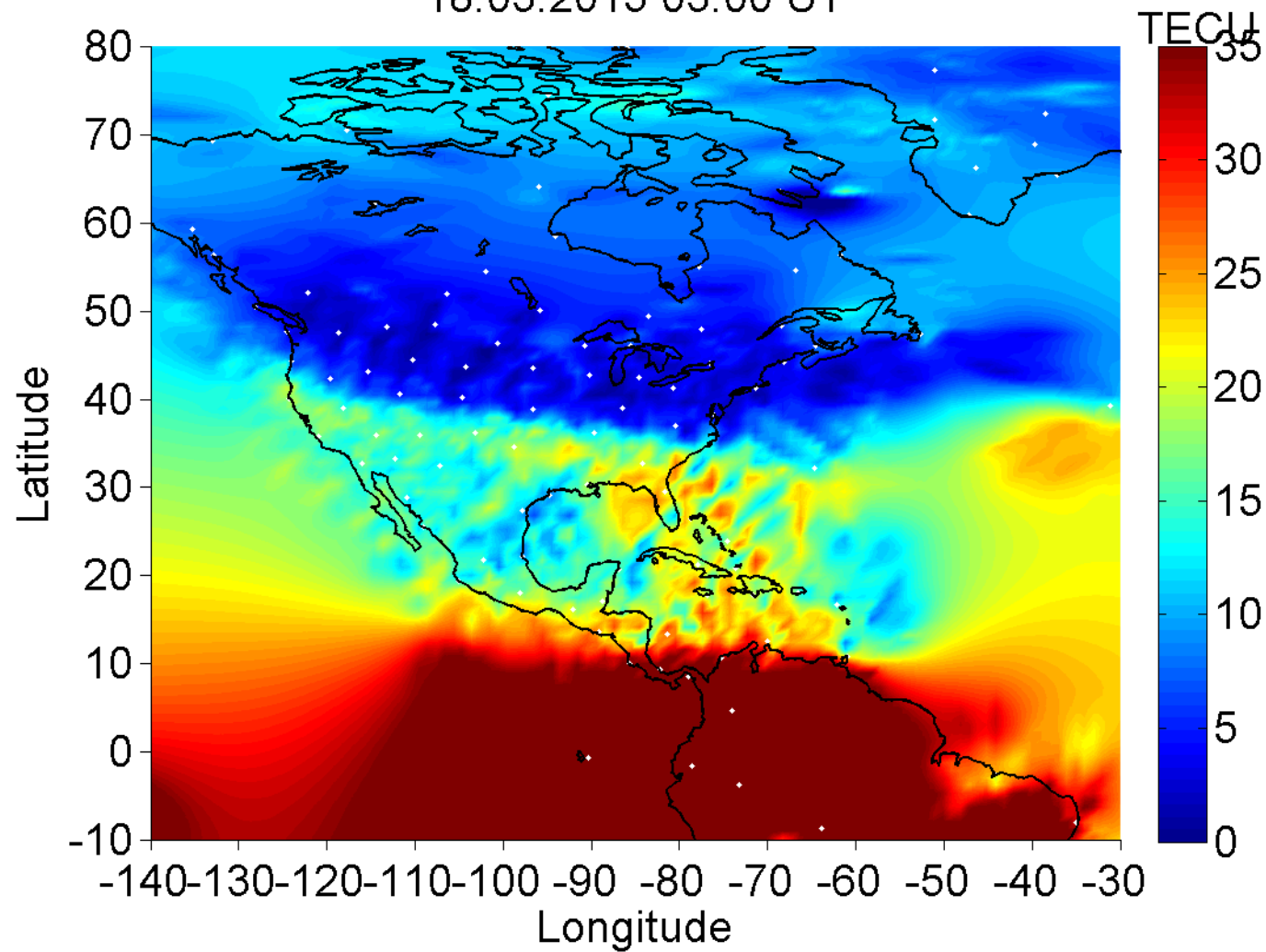
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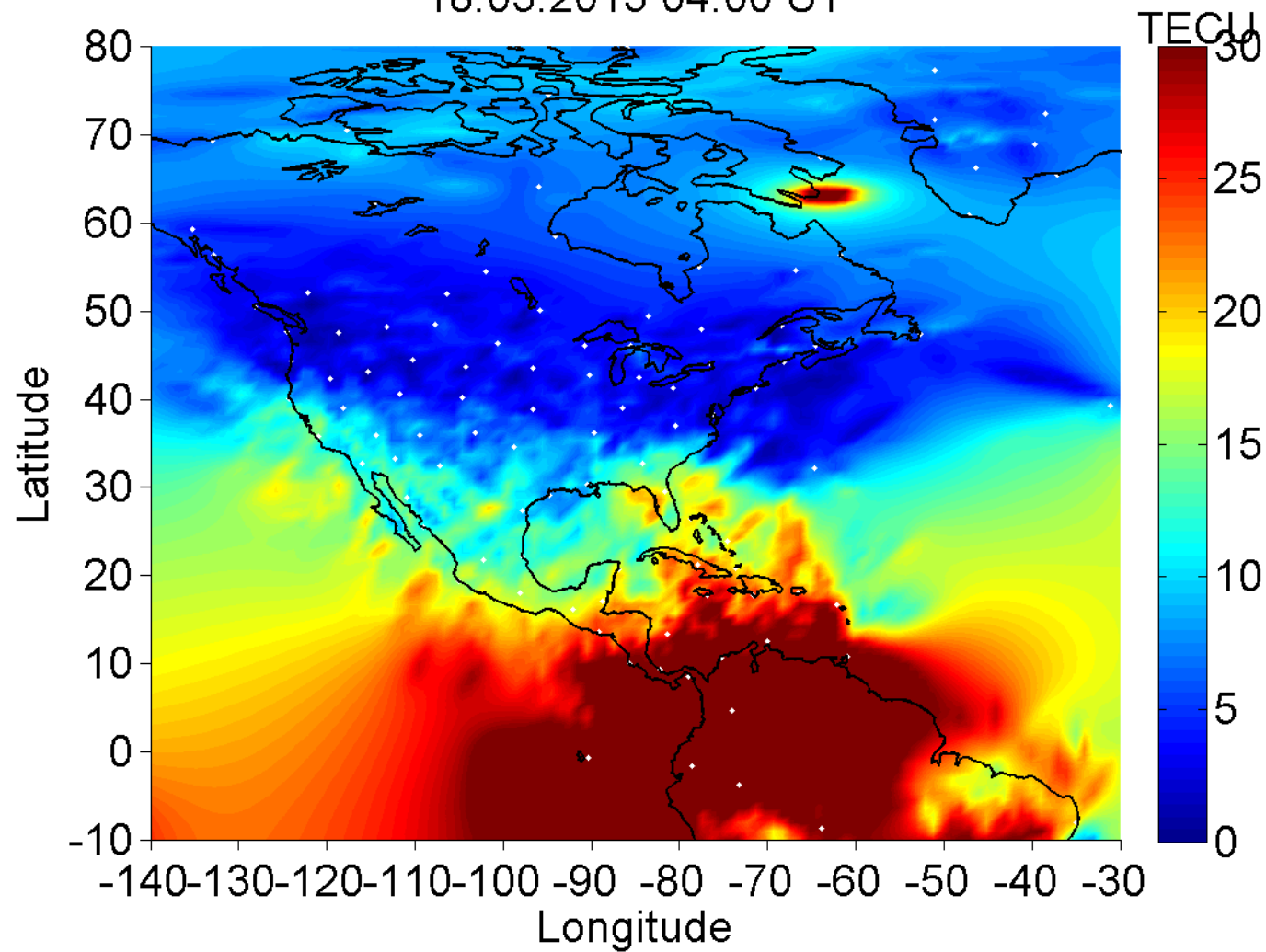
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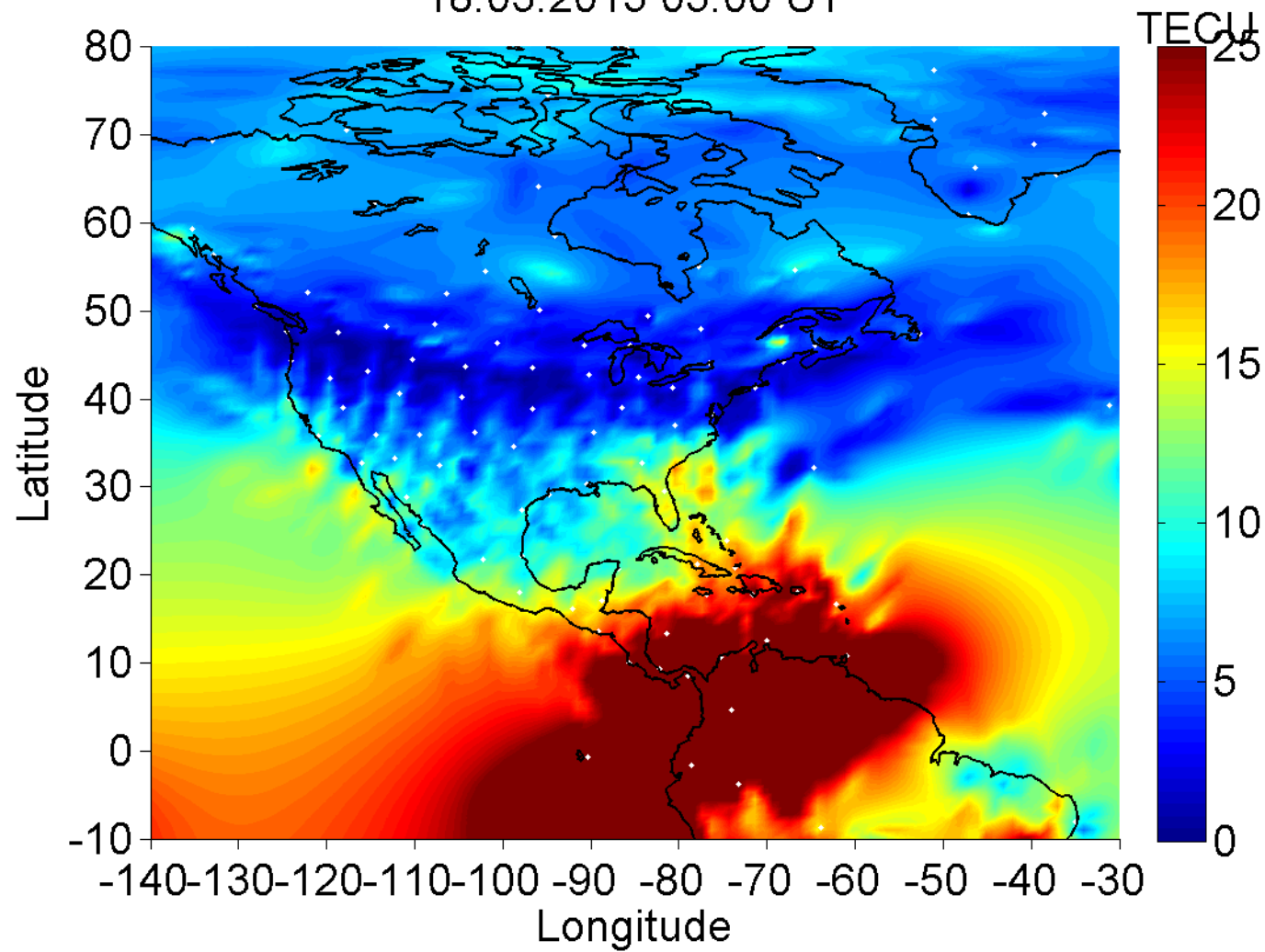
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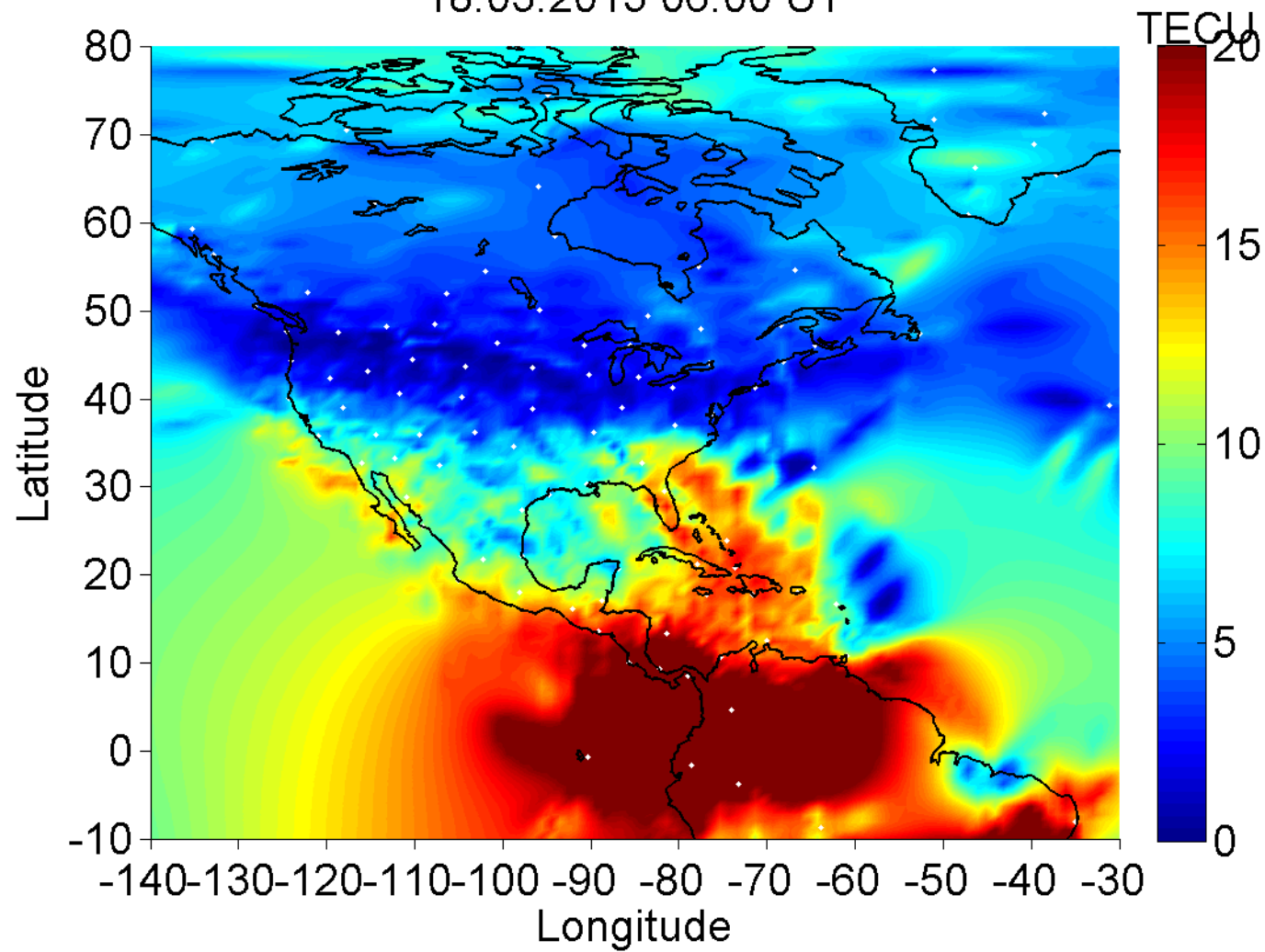
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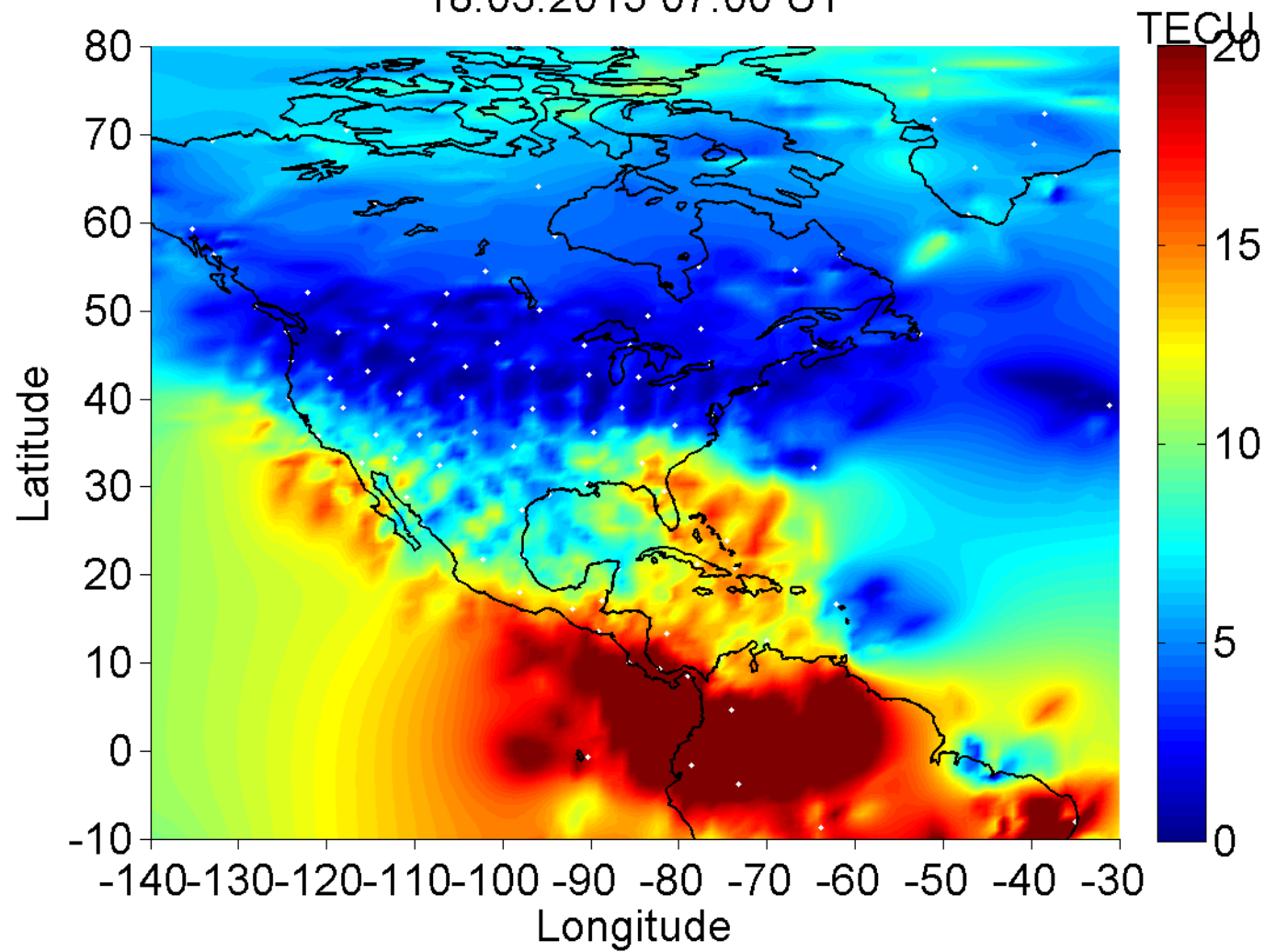
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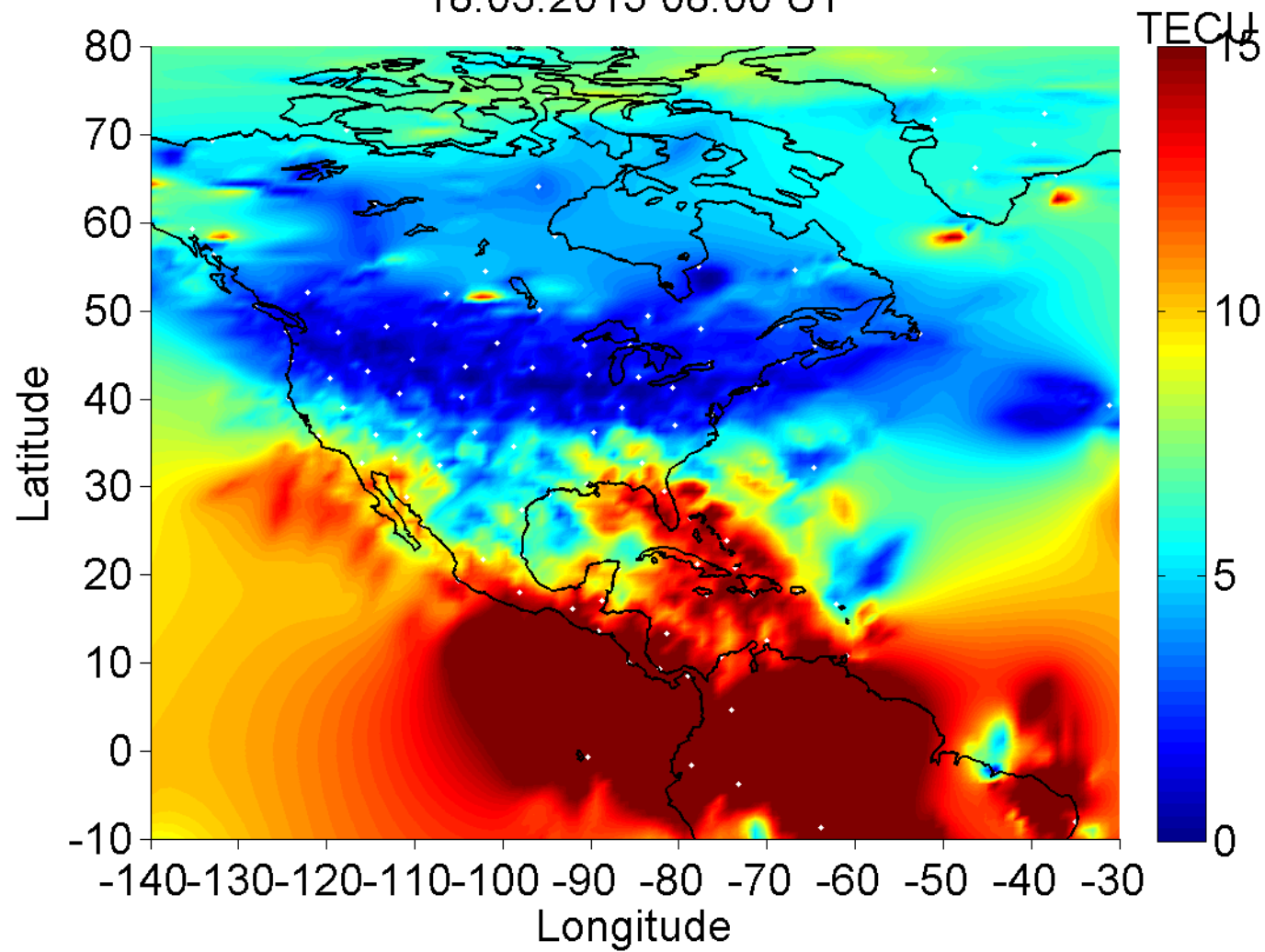
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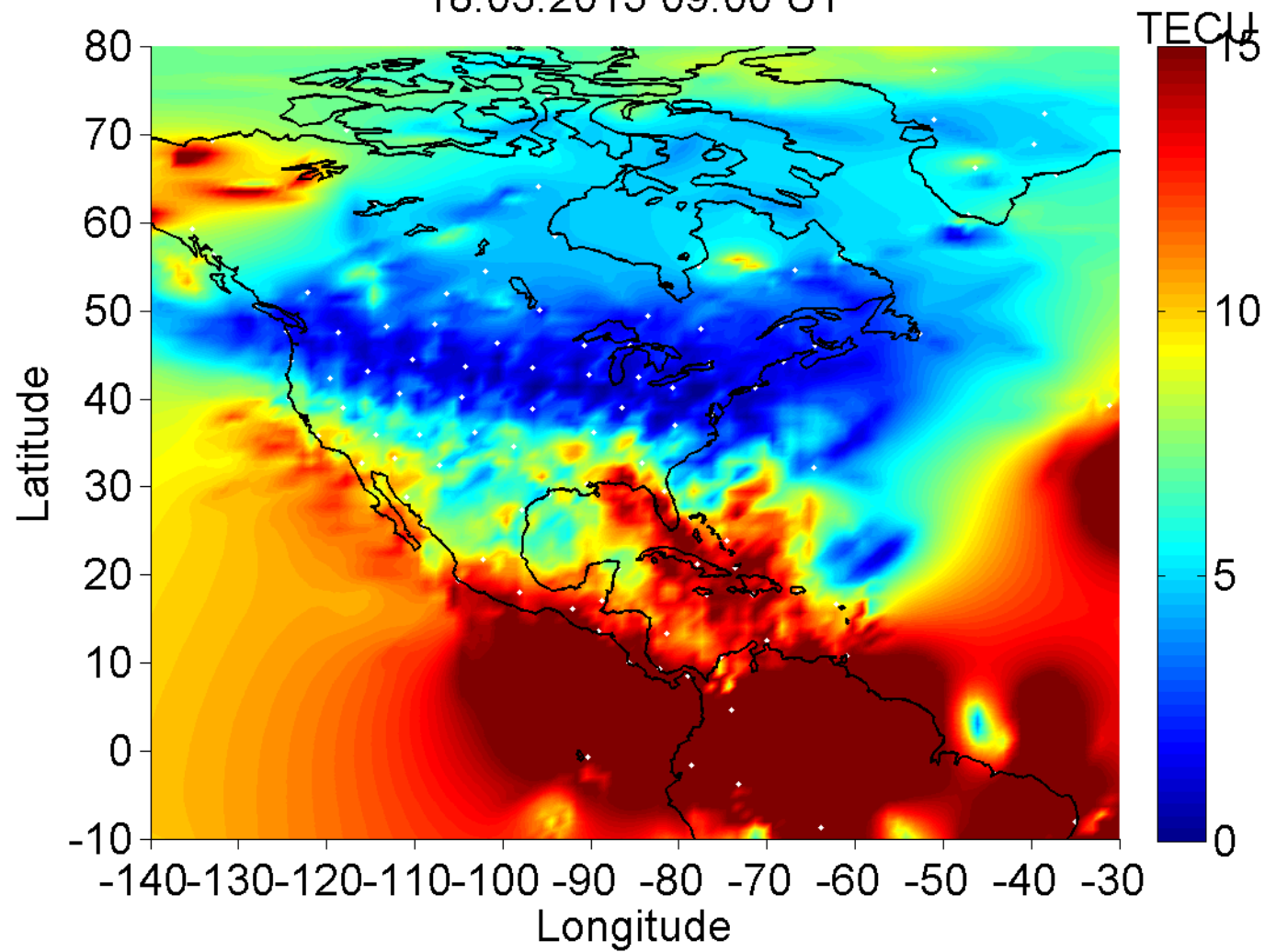
18.03.2015 07:00 UT



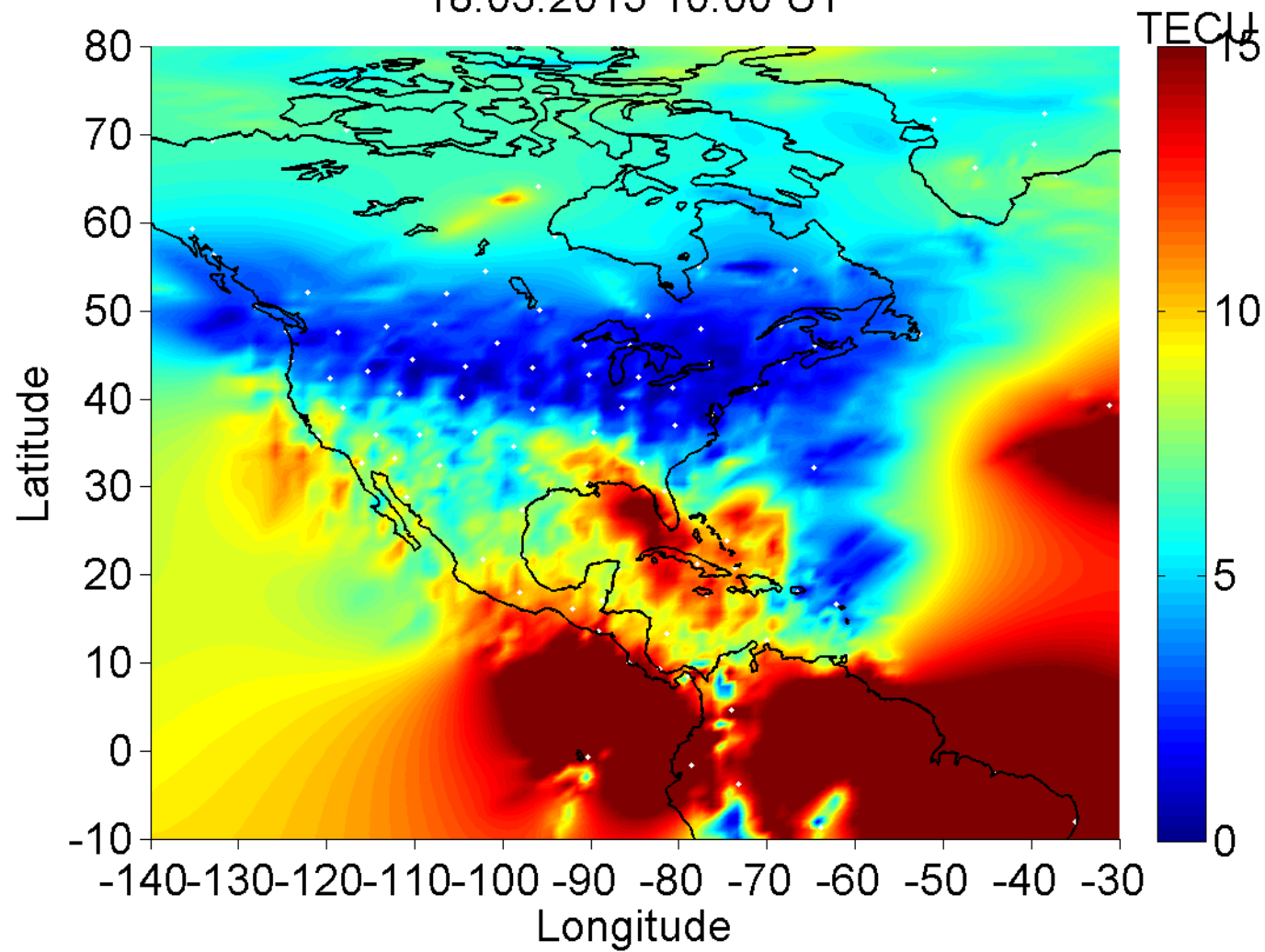
18.03.2015 08:00 UT



18.03.2015 09:00 UT



18.03.2015 10:00 UT



CONCLUSIONS

- The LORT images of the ionosphere in Russia, North America, and South East Asia during the periods of geomagnetic disturbances show a great variety of density features.

The RT reconstructions revealed the ionospheric trough with different intensity and shape, which migrated with the enhancement and decay of geomagnetic disturbances.

Various complicated density distributions with numerous spots of increased and decreased ionization are identified. Wavelike structures are present. In some cases, it is possible to locate the origin of the wave disturbance and to trace the evolution of the wavelike structure.

A series of the ionospheric features are probably associated with particle precipitation.

- Combination of HORT and LORT methods supported by the other ground- and satellite-based observations will probably shed the new light on the processes controlling the distributions of ionospheric plasma at different latitudes during the geomagnetic disturbances.

ACKNOWLEDGMENTS

We are deeply grateful to NWRA, Radio-Hydro-Physics LLC, and Center for Space and Remote Sensing Research at the National Central University, Taiwan for providing the data for LORT analysis.

Russian-American Radar-Tomography Experiment

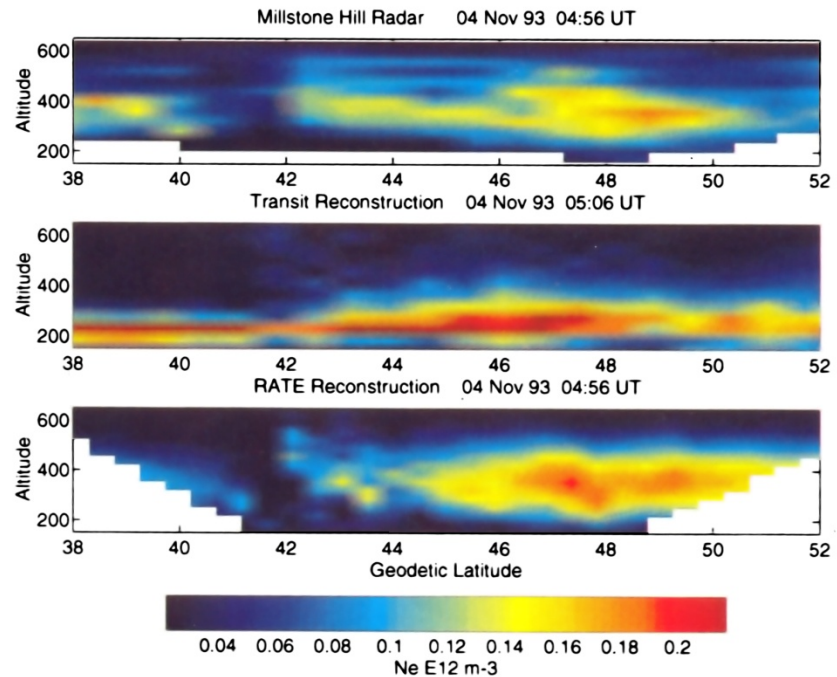
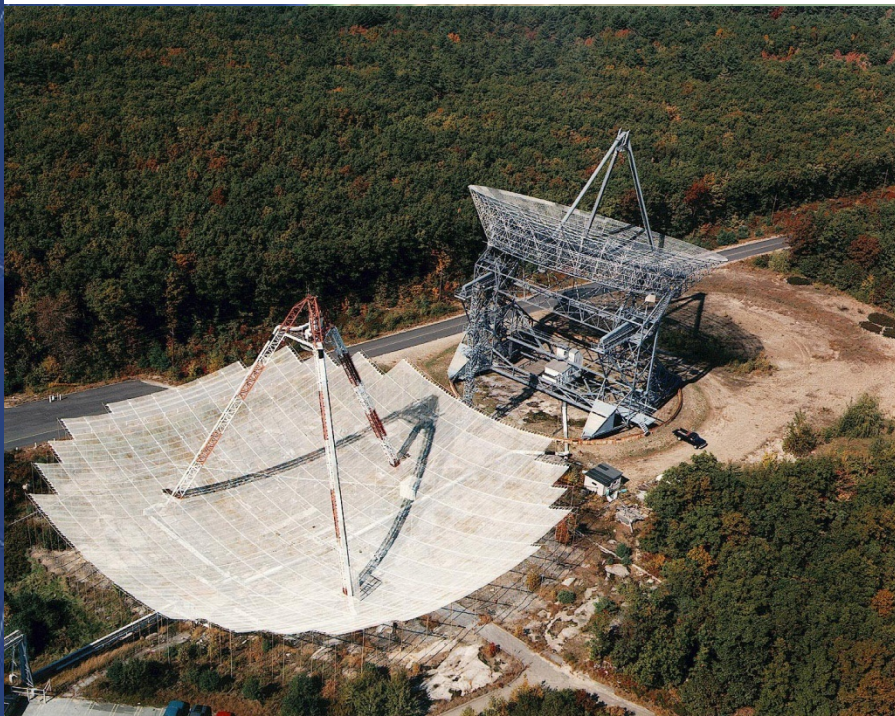


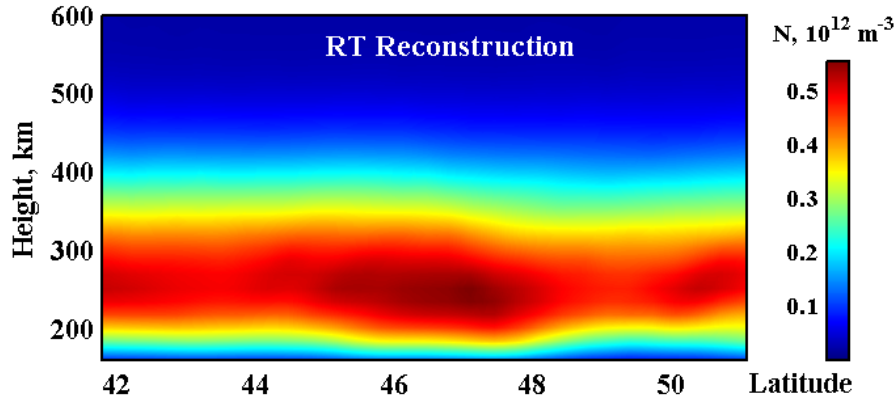
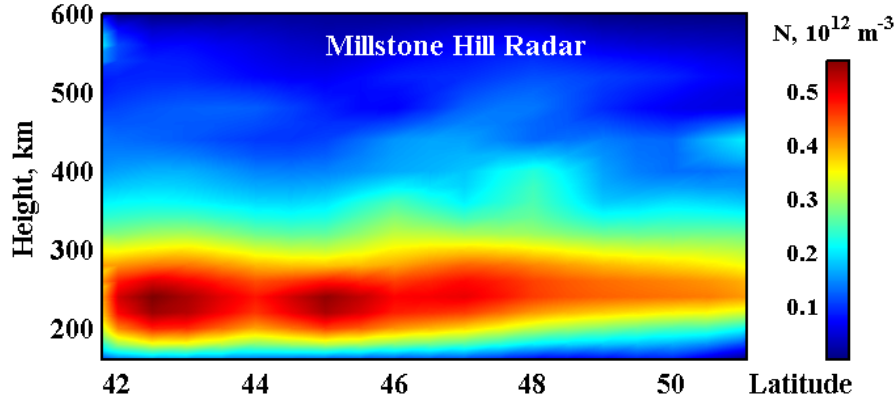
Figure 9. Foster et al. p. 157.



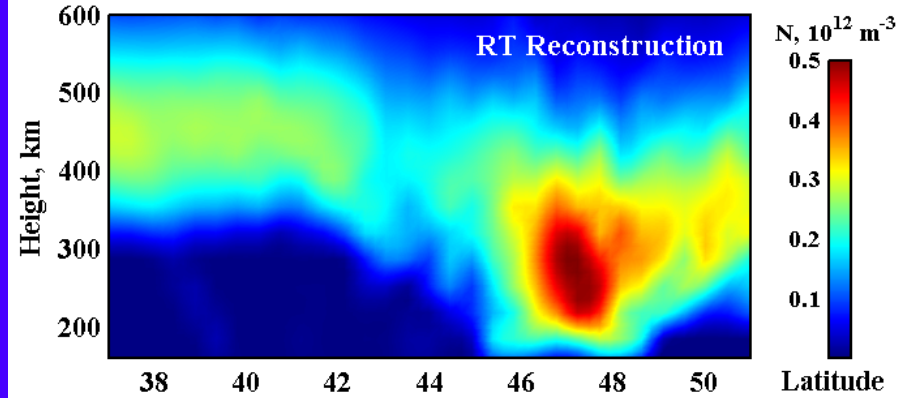
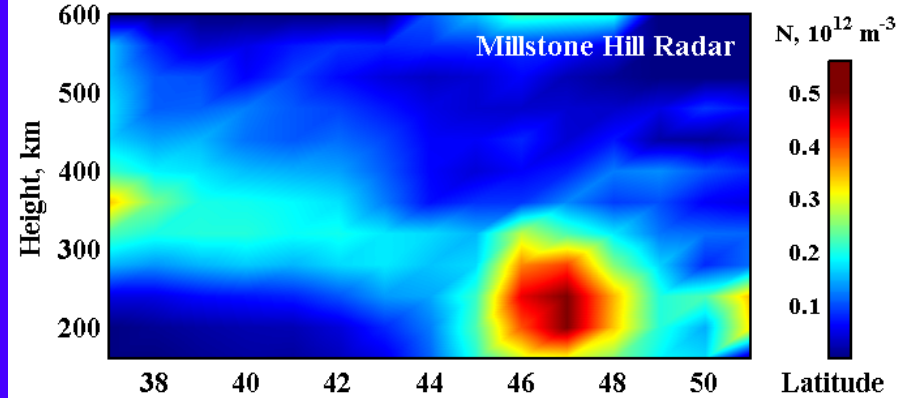
Апробация лучевой радиотомографии

Сопоставление с Радаром Некогерентного Рассеяния

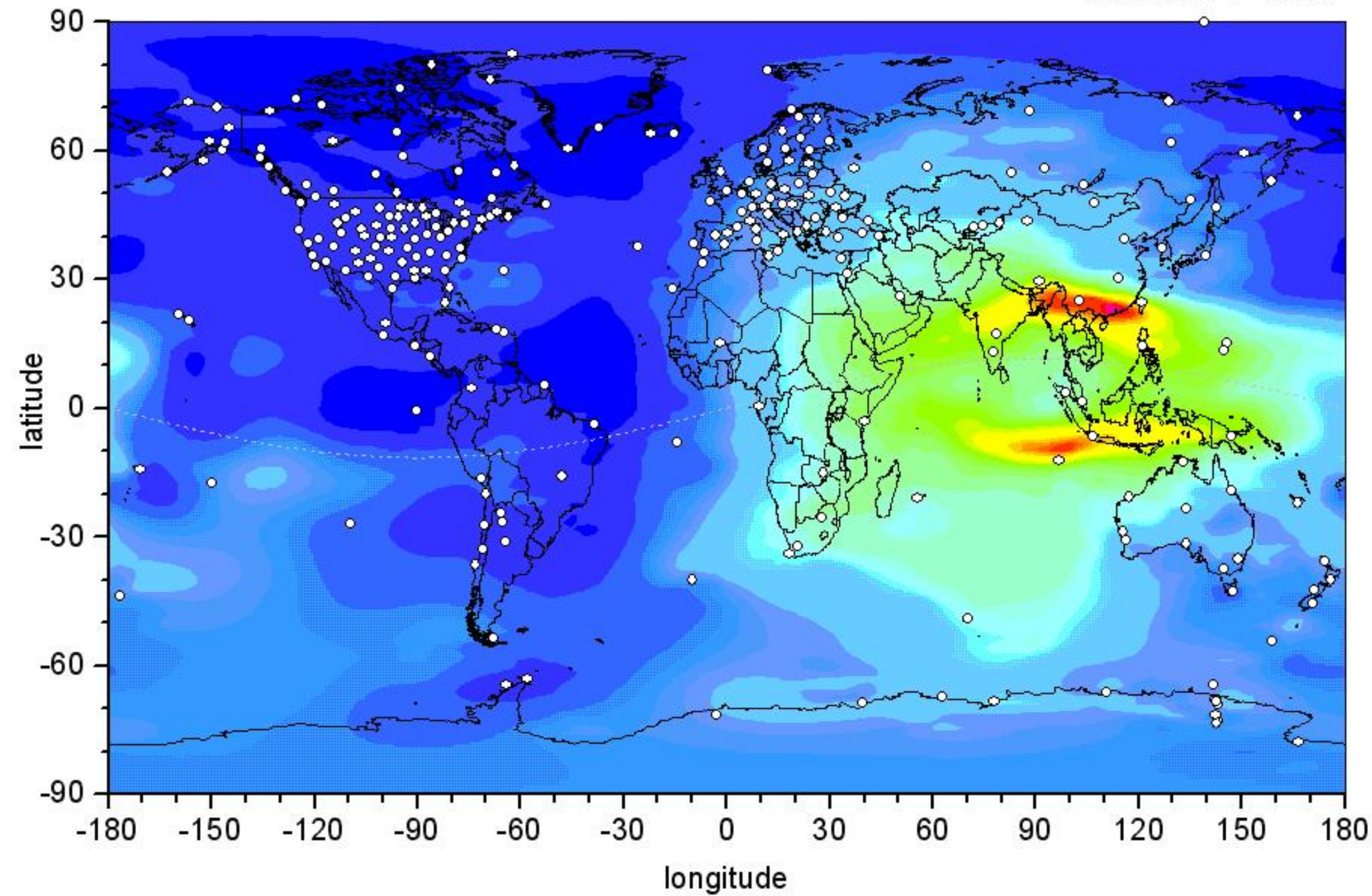
03.11.1993 (22:05UT)



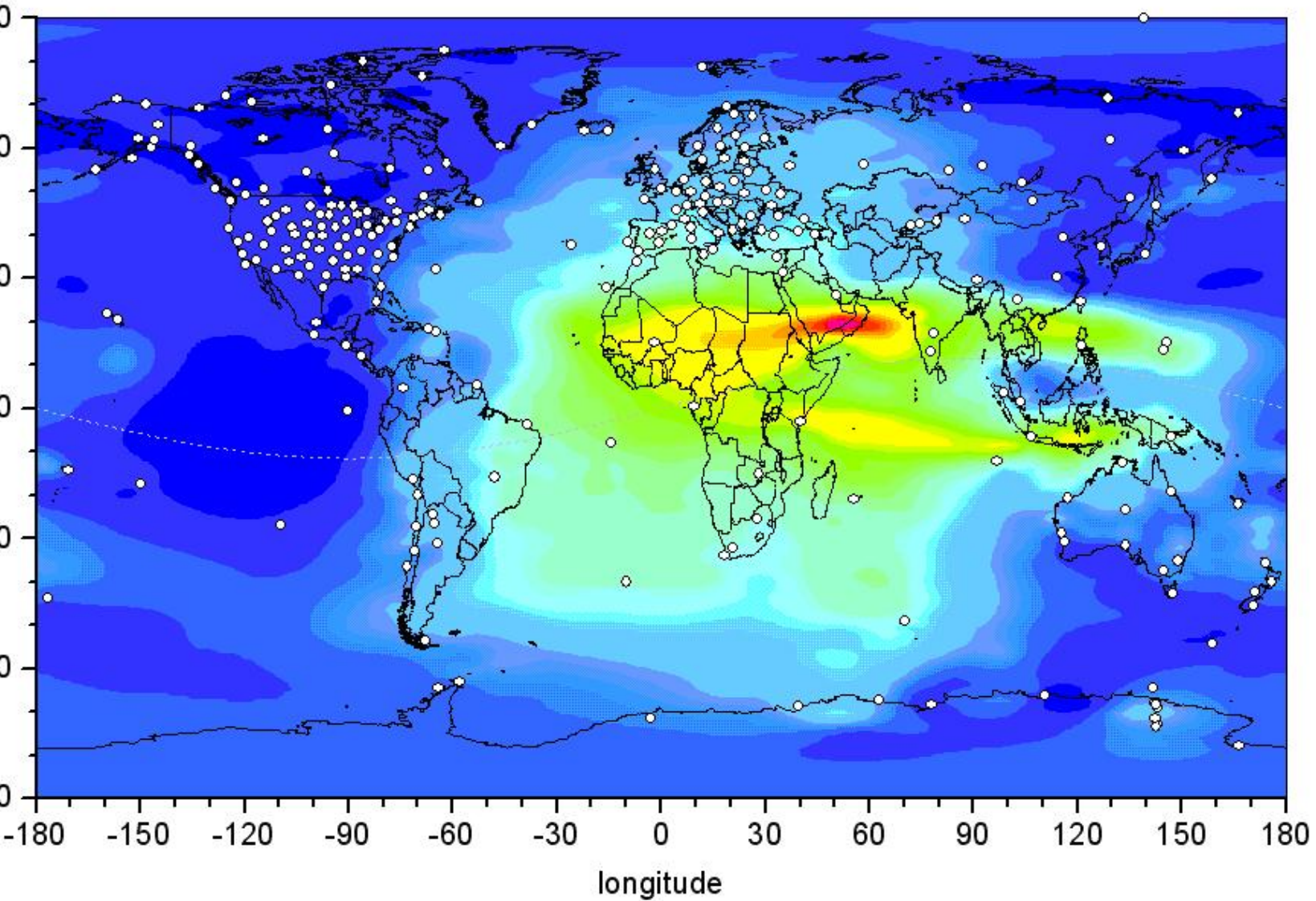
04.11.1993 (04:56UT)



22/02/2004 08:00



22/02/2004 12:00



13.12.2006 19:00 UT

