

Tropospheric Mesoscale Systems and their Signatures within Ionosphere

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Abstract.

Ionosphere behavior is predominantly determined by solar and geomagnetic forcing. An important part of its energy budget however, comes from the lower-laying atmospheric regions. The energy transfer between distant regions happens due to atmospheric waves that propagate from their source region up to ionospheric heights. Experimental observations and theoretical studies show the importance of involvement of the troposphere mesoscale systems. With the changing climate severe weather systems occur more often. On the measurements from troposphere up to ionosphere we demonstrate changes within atmospheric parameters up to ionospheric F layer induced by a severe tropospheric frontal system passing above Europe.

Introduction

It is generally accepted now that wave coupling from below is the major source of the observed differences in the ionosphere parameters on the consequent days with stable forcing from above. Ionospheric data cover several solar cycles. On a solar cycle scale, we see that ionospheric parameters well follow the solar variability. Decomposing signal into dominant component that follows solar cycle and irregular part we can see that irregular part form a substantial part of the signal. Decomposition of critical frequency f_oF2 for station Juliusruh is demonstrated in Fig. 1.

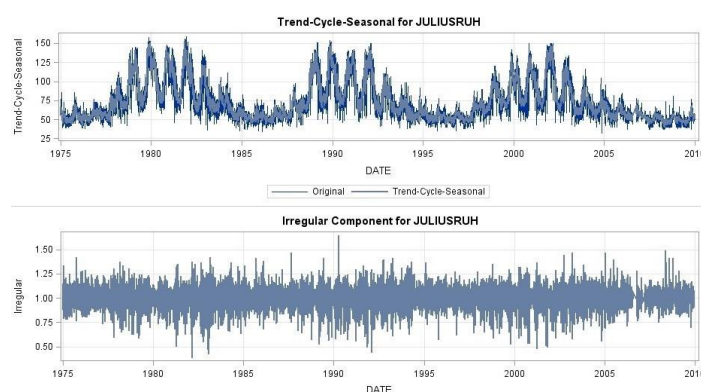


Fig.1. Data from ionospheric station Juliusruh: original data with trend (upper panel) and irregular component (lower panel).

The Earth atmosphere system is not simply vertically coupled. The coupling within the regions must be understood on the multiple space and time scales. The memory of the system cannot be neglected. Distant regions are coupled by dynamical, chemical and electrical processes. The energy transfer between distant atmospheric parts happens due to atmospheric waves that propagate from their source region up to ionospheric heights. Experimental observations show the importance of involvement of the lower atmosphere in ionospheric variability studies in order to accurately capture smaller-scale features of the upper atmosphere [Koucká Knížová et al., 2021].

Coherency between periodic component within solar signals on one side and ionospheric and stratospheric variability on the other side points to the apparent common variability domains. However, they are not stable and vary during solar cycle and/or from one cycle to the following one [Koucká Knížová et al., 2018].

In a recently published paper [Podolská et al., 2021], we analyzed relationship between solar and ionospheric parameters by mean of probabilistic graphical models (CIG). We identified three groups of dependencies. Within them there is no sign of geomagnetic dependence that might lead to splitting into the three groups. But we got three groups that differs in climate regime of the troposphere: East Asia stations (D class – cold), Europe stations (C class – moderate) and North American stations (B class – arid).

It is assumed that the neutral atmosphere effects on the ionosphere have limits in their spatial extent. Evolution of correlation between stations with distance for long time series of foF2 identified “break point” at 10 degrees in longitude and/or Earth’s distance of ~1000 km [Koucká Knížová et al., 2015]. Irregular component for close stations is forced by common source. Since the scale of ~1000 km correspond to the typical sizes of mesoscale tropospheric systems, this finding supports connection between the lower atmosphere and the F2 region.

Mesoscale tropospheric systems, especially those that are fast moving, seems to play an important role in the atmospheric vertical coupling, particularly in atmospheric wave generation that are propagate up to the ionospheric heights. Detail analyses of Fabienne storm revealed significant changes associated with rapidly moving cyclone across the Europe [Koucká Knížová et al., 2020]. Following part of this paper focuses on severe cyclone Zyprian and its signatures in the atmosphere up to ionospheric F2 layer.

Mesoscale cyclone Zyprian

Cyclone Zyprian is a recent event from July, 2021. System brought severe weather on the frontal borders and heavy rains followed by floods. Cyclone Zyprian dominated the weather in Germany. Low-pressure area formed in the lee of the Alps. As a result, strong convective storm appeared in a very unstable air mass, including very large hail and wind gusts up to 40 m.s^{-1} . Especially on Thursday 8 July, the cold front brought showers and thunderstorms that were regionally strong. Figure 2 shows synoptic situation above Europe and temperature map at 2 m above the ground zooming on the Czech Republic.

a) Tropospheric situation

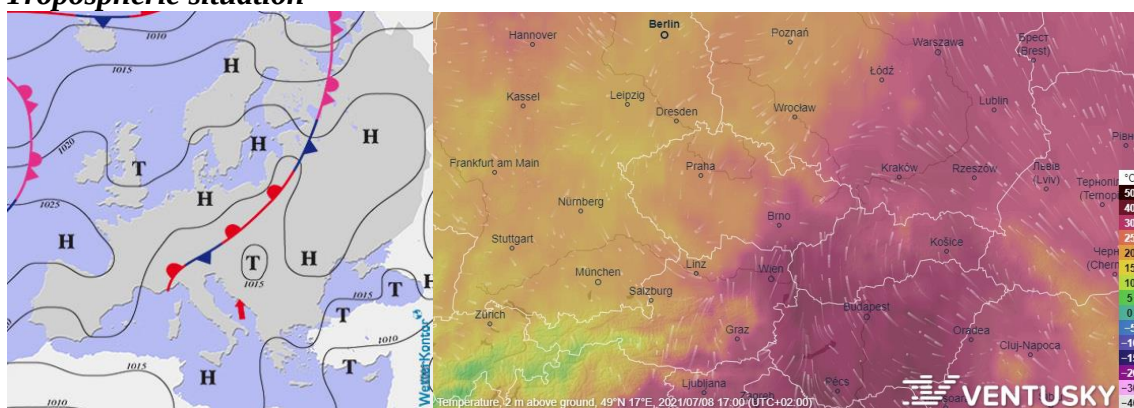


Fig.2. Meteorological situation: Synoptic map (left panel) and temperature radar data (right panel).

Frontal boundary is extending along the Alps through central Poland as seen on Fig.2 on the synoptic map (left panel). This frontal boundary divides hot and well-mixed air masses across the Balkans from moist and cooler air to the west. Along the frontal boundary the strong cyclogenesis occurs. The temperature drop on the frontal border was about 16°C as seen on

detail zoom in Fig.2 (right panel) above the Czech Republic. Strong low-level windshear of $20\text{--}28\text{ m}\cdot\text{s}^{-1}$ (in the 0–6 km layer) was recorded. Showers and thunderstorms on the frontal border were regionally very strong. The ESTOFEX storm space distribution vs. Lightning is shown in Fig.3. on the left map. High lightning activity is seen on the radar helicity index data on the right panel of Fig.3. The helicity index is rather high reaching values of $200\text{--}300\text{ m}^2\cdot\text{s}^{-2}$ in the 0–1 km layer during the late afternoon and evening.

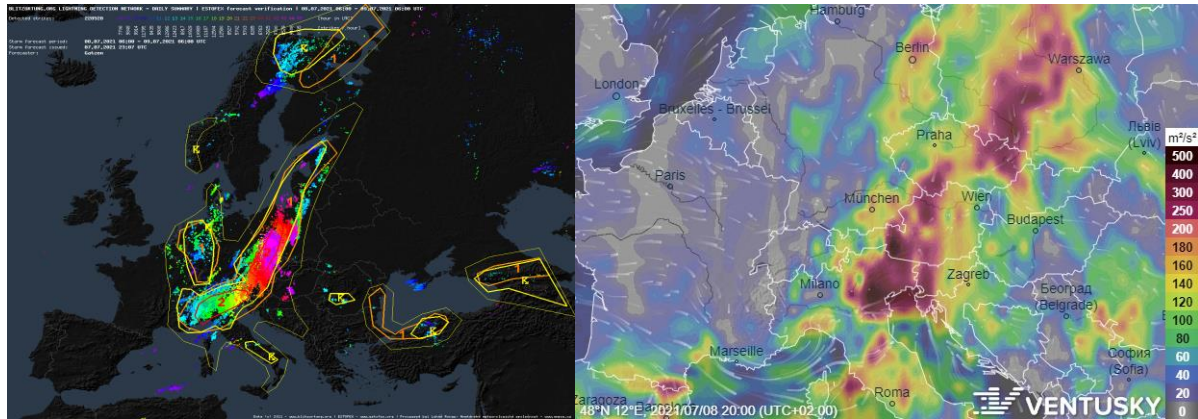


Fig.3. ESTOFEX storm space distribution vs. Strokes Blitzortung measurement 8.7.2021 8 CEST 9.7.2021 8 CEST (left panel) and helicity index radar data (right panel).

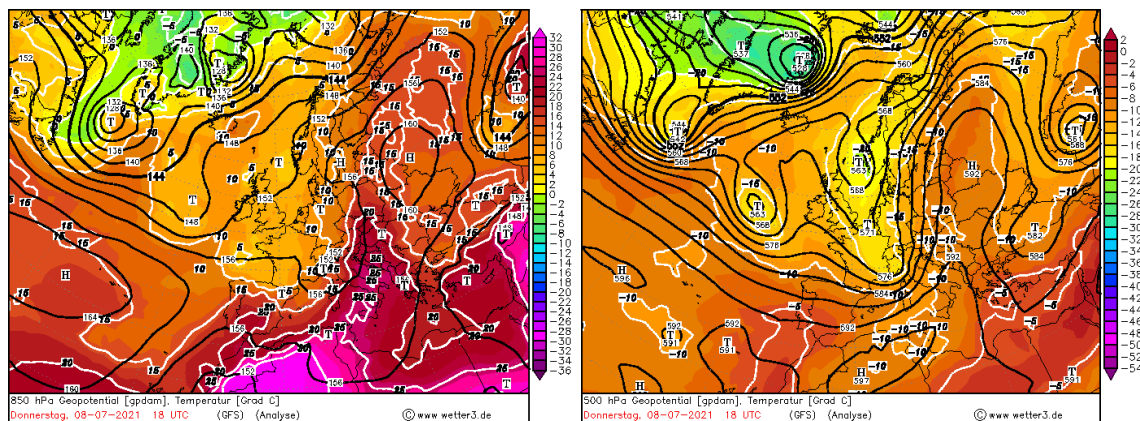


Fig.4. Geopotential temperature at the level of 850hPa (left panel) and 500hPa (right panel).

Fig.4 shows map of geopotential temperature at two levels 850hPa (left panel) and 500hPa (right panel). The division of two air masses with significantly different temperatures is well visible up to the middle troposphere approx. 5.5 km height above the ground.

b) Stratospheric situation

Fig.5 shows three consequent days (7–9 July, 2021) of Aeolus ESA satellite Rayleigh scattering observations of wind profiles (in the middle panels) and the Mie MDS wind velocity profiles (on the right panels). An important feature is seen on the right panels. The position of the polar jet is significantly shifted the after the cyclonal passage.

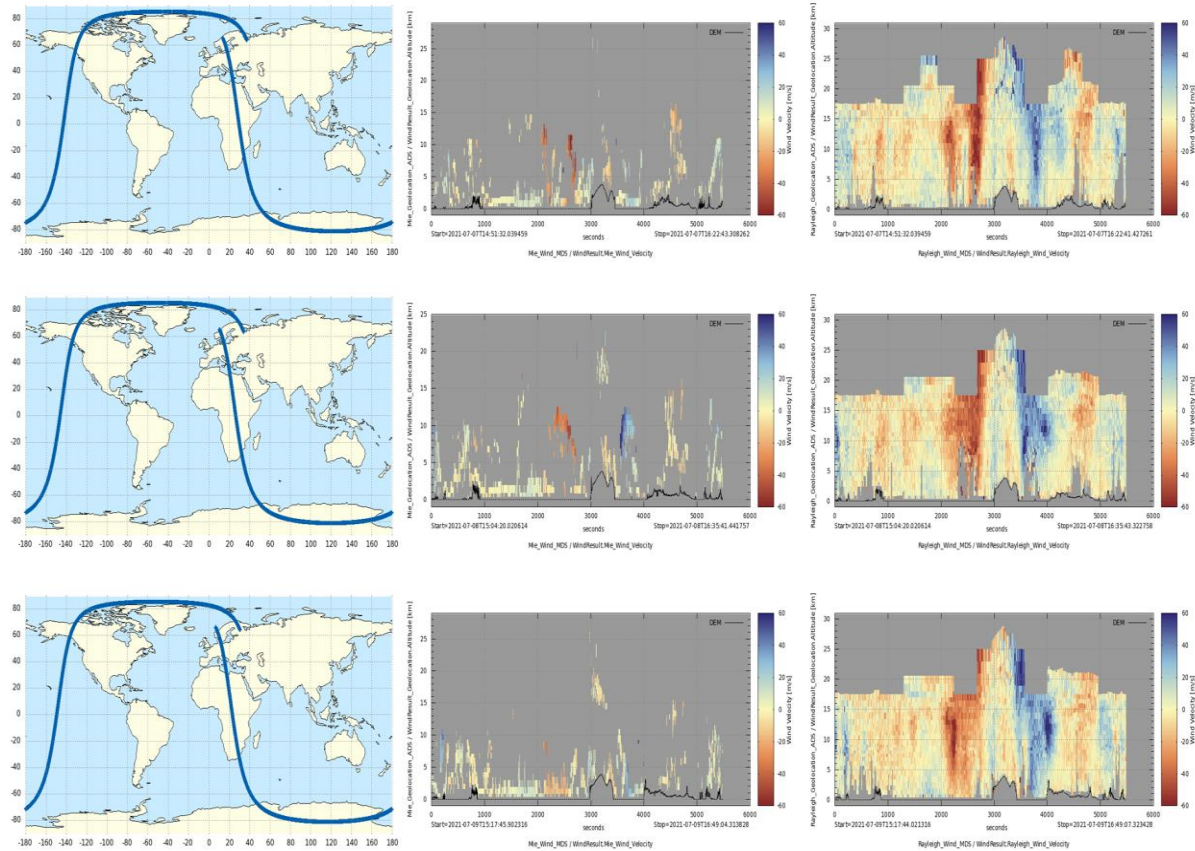


Fig.5. Aeolus satellite measurement for three consequent days, one day before (upper panel), day of cyclone passage (middle panel) and day after (lower panel) the cyclone passage. Visualisation from http://aeolus-ds.eo.esa.int/socat/L1B_L2_Products.

c) Ionospheric situation

Cyclone Zyprian occurred during rather stable solar and geomagnetic situation. The Kp value is less than 3. On the sequence of critical frequency, we see only small decrease. Fig.6 shows three-day sequence of ionograms recorded after 21UT with 15-minute time difference. In the middle panel, there are ionograms with spread F echo, indicating disturbed ionosphere. Ionosphere remains disturbed during following day and then returns to regular stratification. During the day before the cyclone passage, the recorded ionograms indicate well stratified ionosphere without irregularities or undulation caused by propagating waves. From Fig.6 it is evident that critical frequency foF2 does not vary significantly. Fig. 7 represents directogram measurement. The increase in horizontal plasma flow is well visible in the middle part. Change in the color indicate plasma flow shears.

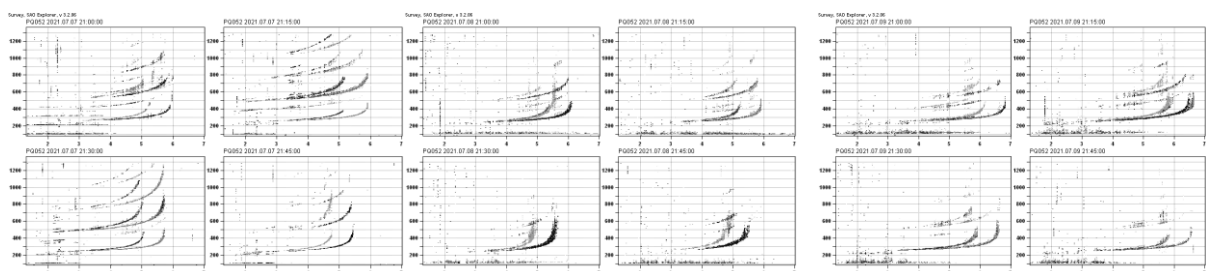


Fig.6. Ionospheric measurement (ionograms) for three consequent days, one day before (upper panel), day of cyclone passage (middle panel) and day after (lower panel) the cyclone passage

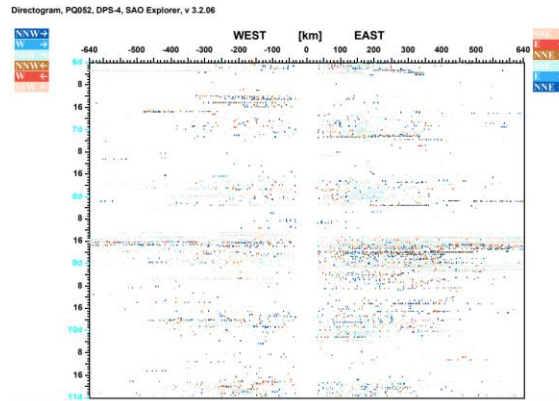


Fig.7. Ionospheric directogram measurement (ionograms) for five consequent days. Significant increase of echo is seen in the central part.

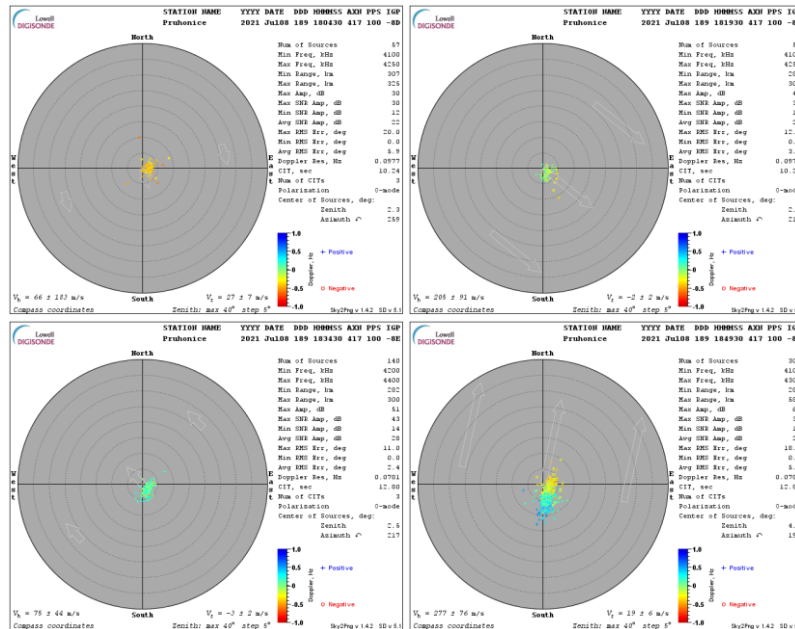


Fig.8. SKYmaps recorded during one hour at 18.04 UT (upper-left panel), 18.19 (upper-right panel), 18.34 (bottom-left panel) and 18.49 UT (bottom-right panel).

Fig. 8 of the sequence of SKYmaps demonstrates how the plasma flow rapidly changes within one hour. There are 15-minute time difference between each measurement. The measurement represents plasma flow at approximately same height below F2 peak. On the top-left panel, plasma flows in South-south East direction, top-right panel 15 minutes later South-East, bottom-left panel North-West and finally bottom-right panel in North North-East. It should be emphasized that geomagnetic activity is low, hence the TIDs of auroral origin are unlikely to be observed. We suppose that there should not be contamination by geomagnetic activity.

Results

Mesoscale systems Zyprian occurred at the beginning of July, 2021. It dominated weather above Western Europe. Large frontal border was characterized by high temperature drop with strong cyclogenesis. Frontal boundary moved rapidly across Europe. High wind gusts were recorded. Heavy rains caused large damages, especially in Germany. Within stratosphere, a shift of polar jet stream was observed. At the ionospheric heights irregular stratification and radio wave reflection planes undulation was observed. Irregularities are attributed to the upward propagating waves launched from frontal boundary as the solar and geomagnetic conditions were low. Strong increase of wave-like activity was detected on ionograms the directograms. On directograms and SKYmaps, strong and rapid changes in the horizontal plasma motion were recorded. However, no prevailing plasma motion direction was identified within F-layer.

Conclusions

Mesoscale systems are effective sources of atmospheric disturbances that can reach ionospheric heights and significantly alter atmospheric and ionospheric conditions. Convective systems like Zyprian and others could affect Earth's atmosphere on a continental scale and up to F-layer heights. Variability within ionosphere are attributed mainly to Zyprian cyclone as it developed during low geomagnetic activity and stable solar forcing.

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