ATVNP: ANTHROPOGENIC TEMPORAL VARIATION OF NO₂ OVER PAKISTAN

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Abstract

Life on the Earth exists because of atmosphere that surrounds it. As with the passage of time population increases and with this increases anthropogenic activities increases which is adversely affecting our atmosphere. That is why temperature of cities is soaring up. As our atmosphere is occupied by different gases, whose increase or decrease can substantially affects our environment. The major air pollutants, due to human activities, are carbon monoxide (CO), carbon dioxide (CO₂), nitrogen dioxide (NO₂), ozone (O₃), sulfur dioxide (SO₂) and particulate matter (PM). Among these pollutants, NO₂ plays a big role as it can be produced due to road traffic and combustion of fossil fuels. In this paper, we investigated NO₂ in Pakistan troposphere through Sentinel-5 Precursor (S5-P) satellite. Data from the S5-P, with TROPO phosphoric Monitoring Instrument (TROPMI) as payload, became available in July 2018, having spatial resolution nine times higher than that of OMI. S5-P launched by European Space Agency (ESA) with one-day revisit cycle, has the capability to sense all atmospheric gases. Our area of study is Pakistan. We processed S5-P datasets in Google Earth Engine (GEE) and produced results of four seasons, during 2018-2019, of NO₂. Different regions of Pakistan, which have excess NO₂ in its troposphere, are also shown. This increase is supported by the fact that with time the increase in urban population causes dramatic negative effects on the atmosphere. Compared to traditional methods, this study will substantially increase the capability of the government and policy makers to take timely action on anthropogenic activities in mentioned cities, in order to mitigate emission of NO₂. Our findings illustrate the decrease of NO₂ in summer, and surges in autumn and vice versa. In autumn Karachi,
Sheikhupura, Raiwind, Lahore, Jamber, Faisalabad and Rawalpindi have highest concentration of \( \text{NO}_2 \). In winter excess \( \text{NO}_2 \) spots over Karachi, Sheikhupura, Lahore, Raiwind, Jamber and Rawalpindi are detected. After winter, spring season shows further decrease in \( \text{NO}_2 \) concentration in which Karachi, Dera Ghazi Khan Sheikhupura, Rawalpindi and Lahore have highest \( \text{NO}_2 \) concentration and in summer \( \text{NO}_2 \) in Pakistan troposphere is further reduced to Sheikhupura, Raiwind and Jamber cities.

**Keywords**: Earth, Atmosphere, Urban Pollution, NO4, Google Earth Engine, Sentinel 5P, Omi.

**I. Introduction**

In science, the word environment stands for composition of Earth’s atmosphere. Earth’s atmosphere is a combination of five sub layers. These are troposphere, stratosphere, mesosphere, thermosphere and exosphere. There are no physical boundaries between these layers, but an imaginary line at different heights, as shown in Fig. 1, from where the next layer starts [XX].

An imaginary line, known as Karman line, at height of 100km from Earth surface separate space from atmosphere [XXIV]. The part of the atmosphere which is an area our study is known as the troposphere. Above Earth surface, the first layer is Troposphere which is, approximately, up to 20km from earth surface. “Troops” means “change” [XX]. The name is due to constantly changing weather and most of atmosphere gases are mixing in this portion [XX].

Our environment plays a key role in health of the inhabitants of Earth. It is essential for us to keep our eyes on our environment and monitor it for anomalies. The major air pollutants are carbon dioxide (\( \text{CO}_2 \)), carbon monoxide (CO), nitrogen dioxide (\( \text{NO}_2 \)), ozone (\( \text{O}_3 \)), sulfur dioxide (\( \text{SO}_2 \)) and particulate matter (PM). A pollutant, which can severely affect living things health is nitrogen dioxide \( \text{NO}_2 \)[XIII]. The \( \text{NO}_2 \) is red-brown acidic gas [I].

It is among the highly reactive group of gasses known as “oxides of nitrogen” or "nitrogen oxides (NOX)" with nitrous acid and nitric acid [VII]. Its presence in troposphere adversely impacts human health and visibility. It also contributes to the formation of tropospheric ozone (\( \text{O}_3 \)), fine particle pollution, summer smog and acid rain[XXVIII]. Previous studies claimed that exposure of \( \text{NO}_2 \) to crops can alter their growth rate and may increase the growth rate of fungal pathogens and herbivorous insects [XXVI]. Among many sources of \( \text{NO}_2 \), the mostly produced sources are natural lightening, soil emissions, biomass fuel burning, industrial burning processes, and crop residue burning [XXII]. According to environmental specialists the climate conditions variability is mostly linked with \( \text{NO}_2 \)[XXXI].

As we have 78% of Nitrogen gas(\( \text{N}_2 \)) in the atmosphere, their oxidation in air gives Nitrogen oxides but some are produced when organic nitrogen fuels are burnt which is anthropogenic process[VIII]. The \( \text{NO}_2 \) in troposphere increases exponentially since the middle of 20th century [XXXI]. Not only is \( \text{NO}_2 \) damaging the ecosystem, it also causes significant health issues contributing to respiratory problems ranging from

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causing cardio-pulmonary ailments, to exacerbating asthma and even impacting cognitive abilities [XIII].

Pakistan is 2nd most polluted 5th most populated country in the world [V]. Due to rapid growth in industries, population, deforestation, and energy crises leading to a massive increase of NO₂, as shown in Fig. 2, in troposphere Pakistan. Therefore, in order to develop strategies for reduction of NO₂ in troposphere of Pakistan, a temporal analysis of NO₂ in Pakistan troposphere is much needed. Traditional methods of NO₂ measurements (ground based and airborne) are temporally and spatially limited but satellite can measure NO₂ temporally and spatially with global coverage [VI]. Compared to traditional methods, remote sensing has substantially increased the capability of the decision makers to take appropriate measures [II].

Recently, satellite remote sensing of tropospheric NO₂ has been effectively used to study the spatial patterns of NO₂ at local, regional, and global scales [XVIII], [XIX], [XXX]. One of the emerging applications of remote sensing is pollution monitoring through S5-P. The Copernicus S5-P satellite, with TROPOMI as payload, was...
The TROPOMI is a spectrometer measuring in the UV, visible, near-infrared and short-wave infrared, which allows the retrieval of trace gas species like O$_3$, NO$_2$, HCHO, SO$_2$, CO, CH$_4$ and aerosol aspects like the aerosol index [XIV]. Error! Reference source not found. shows details of the products of S5-P. TROPOMI has a full global coverage each day, but with a much improved resolution (3.5 x 7 km$^2$) compared to the one providing measurements since 2004 [XXV]. Compared to OMI and GOME (as shown in Error! Reference source not found.), the S5-P observations are expected to be of significant importance for estimating pollutant concentrations and emissions at the scale of smaller towns, individual power plants, wildfires and major infrastructures [XI].

Table 1: The planning and control components

| Parameters                        | S5-P (Irizar et al., 2019) | OMI (Boersma et al., 2008) | GOME (Richter & Burrows, 2002) |
|-----------------------------------|-----------------------------|-----------------------------|---------------------------------|
| Spatial Resolution (km$^2$)       | 3.5 x 7                     | 13 x 25                     | 40 x 320                        |
| Revisit cycle (day)               | 1                           | 1                           | 1                               |
| Spectral Range (nm)               | 270 to 2385                 | 270 to 500                  | 240 to 790                      |
| Spectral Resolution (nm)          | 0.25                        | 0.5                         | 0.4                             |
| Operational (Y/N)                 | Y                           | N                           | N                               |

Table 1: S5-P L2 Products

| S.N0 | S5-p Data Product (Ingmann et al., 2012) | Main Parameter                        | Spectral Resolution (nm) (Ingmann et al., 2012) |
|------|------------------------------------------|---------------------------------------|--------------------------------------------------|
| 1    | Ozone profiles                           | Total and tropospheric profiles       | 270-330                                          |
| 2    | Sulphur Dioxide (SO$_2$)                 | Total column                          | 308-325                                          |
| 3    | Ozone (O$_3$)                            | Total column                          | 325-337                                          |
| 4    | UV Aerosol Index                         | Total column                          | 364-440                                          |
| 5    | Formaldehyde (HCHO)                      | Total column                          | 336-360                                          |
| 6    | Nitrogen Dioxide (NO$_2$)                | Total column                          | 405-500                                          |
| 7    | Aerosol Layer Height                     | mid-level pressure                    | 440-460                                          |
| 8    | Cloud                                    | Fraction, albedo, top pressure        | 460-490                                          |
| 9    | Methane (CH$_4$)                         | Total column                          | 1590-1675                                        |
| 11   | Carbon monoxide (CO)                     | Total column                          | 2305-2385                                        |

The rest of the paper is organized as follows. Section 3, which is related work, sheds light on recent literature of collection of NO$_2$ through satellites. After that section 4, Experimental Setup (section 5) states about tools used in this work. Our study area is discussed in section 6 which shows our study area. Following section 6, section 7 is results and discussion which shows the hotspots of NO$_2$ over
Pakistan. The last section which is conclusion and future work will summarize our work.

II. Related Work

As our area of study is Pakistan, so there is no enough research work of satellite based environment monitoring of Pakistan. However, in this section, we will provide some of up-to-date remotely detection of NO\textsubscript{2} in Pakistan and some other countries.

In [XXVIII], authors used OMI (ozone monitoring instrument) dataset from December 2004 to November 2008 to detect NO\textsubscript{2} over Pakistan. The results showed that Islamabad, Rawalpindi, Lahore, Dera Ghazi Khan and Karachi have highest concentration of NO\textsubscript{2} in Pakistan Troposphere. Along with this, the authors explored the main causes of NO\textsubscript{2} in these cities which were soil emissions, fossil fuel burning, industrial burning and motor vehicles.

In [XXI], authors measured NO\textsubscript{2}, SO\textsubscript{2}, and CO concentrations in Dalian, China and Faisalabad, Pakistan from January to December 2013. The measured values were cross matched with ambient air quality standards such as National Environmental Quality Standards (NEQS) Pakistan, NAAQSUSEPA, CNAAQS-China, and global standard WHO. The comparison showed that the annual average NO\textsubscript{2} concentration in Faisalabad Pakistan was higher than NEQS, USEPA, CNAAQS, and WHO and there was a little decrease for Dalian. While comparing the concentration of NO\textsubscript{2} in both cities, Faisalabad and Dalian, authors stated to mitigate negative health impacts air quality in Faisalabad Pakistan should be controlled.

In [III] troposphere air quality of Lahore city of Pakistan was studied. The study period was from June to August. The highest concentration of NO\textsubscript{2} was recorded for month of June in troposphere of Lahore city. Also the industrial areas were observed more polluted as compared to residential and commercial areas as fuel combustion is in excess in industrial areas as compared residential areas.

To investigate spatiotemporal variability of NO\textsubscript{2} in troposphere of South Asia OMI (ozone monitoring instrument) data from October 2004 to January 2015 is used in [XXVII]. NO\textsubscript{2} Hotspots over some most populated cities and industrial areas are shown. Which shows an average increase of 14% NO\textsubscript{2} concentration over study region? Highest increase was found for Dhaka (Bangladesh) and lowest for Karachi (Pakistan). Strong seasonality of NO\textsubscript{2} concentration is observed with the highest value in March and the lowest in August.

In [XXXI] NO\textsubscript{2} concentration in troposphere of China, of 2018, were investigated using S5-P satellite. The coherence analysis with the NO\textsubscript{2} surface monitoring concentration released by China Urban Air Quality Monthly Report reflects the high correlation between the NO\textsubscript{2} column concentration inverted by TROPOMI and the measured surface concentration, which reveals the great potential of the TROPOMI NO\textsubscript{2} column concentration in indicating urban surface air pollution conditions. The results showed a seasonal NO\textsubscript{2} variation in which high concentration were recorded.
for winter season and lowest for summer along with this NO$_2$ spatial distribution pattern were east high and west low.

In [X] authors investigated NO$_2$ concentration in the troposphere of India using Global Ozone Monitoring Experiment (GOME) and Scanning Imaging Absorption Spectrometer for Atmospheric CHartographY (SCIAMACHY) during time period of 1996 to 2006. Different regions having maximum seasonal concentration of NO$_2$ were identified. Concentration of NO$_2$ was recorded maximum during winter and summer seasons and lowest during monsoon season. The results were cross matched with the surface level measurement of NO$_2$. The excess of NO$_2$ in summer and winter was due to enhanced biomass activity in thermal power plants, densely populated region, large urban and industrial regions in India. Excess NO$_2$ were found over Mumbai-Gujarat industrial corridor, Delhi and east and northeastern India coal mine regions. The Increasing rate was due to industries and exponential growth of population.

The [IV] authors used Global Ozone Monitoring Experiment (GOME) to measure weekly cycles of troposphere NO$_2$ concentration globally. Minimum NO$_2$ on Sunday was recorded for industrial regions and cities in US, Europe and Japan. Compared to working days, Sunday NO$_2$ is about 20-50% lower. Weekly NO$_2$ patterns were correlated with religious and culture background. China NO$_2$ concentration are shown independent of weekly cycle pattern. Shifted NO$_2$ cycles were also observed, depending on religion and culture like, Israel showed minimum NO$_2$ concentration on Saturday and some Islamic countries showed minimum weekly cycle of NO$_2$ on Friday due to minimum anthropogenic activities on Friday.

The study in [IX] identified NO$_2$ hotspots, using GOME and SCIAMACHY, over different regions of world during 1996 to 2006. The study suggested that tropospheric NO$_2$ column amounts is higher in some industrial developing regions. Furthermore, Hotspots of NO$_2$ were shown for China, South Asia, Middle East, Eastern US, Europe and South Africa troposphere. Among them the highest concentration was recorded for South Asia and lowest for Europe.

In [XVII], authors investigated the troposphere of Turkey for NO$_2$ vertical column densities (VCD) using Sentinel-5P which is recently launched by ESA. They collected July 2018 to January 2019 data of S5P and the mean value of NO$_2$ during this period over different regions were calculated. Theses NO$_2$ VCDs over different regions were compared with its respective population which was recorded in 2017. A high correlation of about 0.72 was found between NO$_2$ values and population.

The study in [XVI] compares column NO$_2$ measurements from PSI (ground-based spectrometers) with those from OMI and TROPOMI during the 2018 OWLETS-2 campaign. Comparisons are performed at two sites: NASA Goddard Space Flight Center (GSFC) and the University of Maryland, Baltimore County (UMBC). TROPOMI’s higher resolution allowed for mean satellite-PSI agreement to fall within 10% at the less-polluted GSFC site and within 20% at the more-polluted UMBC site. In addition, statistically significant correlations between satellite and ground-based NO$_2$ measurements were found at both sites.

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III. Experimental Setup

We processed S5-P level 3 datasets in Google Earth Engine (GEE). GEE is an open source tool and is a cloud-based platform for planetary-scale geospatial analysis that brings Google's massive computational capabilities to bear on a variety of high-impact societal issues including deforestation, drought, disaster, disease, food security, water management, climate monitoring and environmental protection. It is unique in the field as an integrated platform designed to empower not only traditional remote sensing scientists, but also a much wider audience that lacks the technical capacity needed to utilize traditional supercomputers or large-scale commodity cloud computing resources [XII]. We processed S5-P datasets of 4 seasons of 2018 to 2019 as shown in Table 2. For individual season, its temporal data mean is calculated. The NO\textsubscript{2} concentration is shown, for individual cities of Pakistan, by different colors like "blue", "purple", "cyan", "green", "yellow", "red". As The color becomes more reddish that area will have excess amount of NO\textsubscript{2}.

| S.NO | Season | Period(yy-mm-dd) |
|------|--------|------------------|
| 1    | Autumn | 2018-09-23 to 2018-12-21 |
| 2    | Winter | 2018-12-22 to 2019-03-21 |
| 3    | Spring | 2019-03-22 to 2019-06-21 |
| 4    | Summer | 2019-06-22 to 2019-09-23 |

IV. Study Area

Our area of study is Pakistan as it is 2nd most polluted in world. Pakistan latitude is 30.3753\(^{\circ}\) N, which shows positioning of Pakistan in the northern hemisphere, and longitude is 69.3451\(^{\circ}\) E, which denotes that Pakistan is part of eastern hemisphere. According to the recent research [V], Pakistan is found to be 5th most populated country having a total area of 796,095 km\(^2\) (770,875 km\(^2\) of land and 25,220 km\(^2\) of water).

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V. Observation and Discussions

We retrieved season wise S5-P NO$_2$ data of Pakistan using time period for seasons as given in Table 2. The seasonal behavior of NO$_2$ in Pakistan Troposphere is discussed. Approximately 23 major cities troposphere of Pakistan is investigated which are listed in Table 3.

Table 3: NO$_2$ concentration over Cities of Pakistan under study

| S.N o | City       | Latitude, Longitude | Autumn ($10^{10}$ molec./cm$^2$) | Winter ($10^{10}$ molec./cm$^2$) | Spring ($10^{10}$ molec./cm$^2$) | Summer ($10^{10}$ molec./cm$^2$) |
|-------|------------|---------------------|-----------------------------------|-----------------------------------|----------------------------------|-----------------------------------|
| 1     | Mardan     | 34.1989° N, 72.0231° E | 9.70                              | 9.11                              | 9.14                             | 9.61                              |
| 2     | Nowshera   | 34.0105° N, 71.9876° E | 10.93                             | 10.72                             | 10.79                            | 11.47                             |
| 3     | Peshawar   | 34.0151° N, 71.5249° E | 13.46                             | 11.89                             | 10.55                            | 11.89                             |
| 4     | DI Khan    | 31.8626° N, 70.9019° E | 11.76                             | 9.88                              | 14.15                            | 11.34                             |
| 5     | Kalabagh   | 32.9599° N           | 9.60                              | 8.68                              | 13.26                            | 12.82                             |

Fig. 3: Study Area[1]
|   | City   | Latitude   | Longitude   | First | Second | Third | Fourth |
|---|--------|------------|-------------|-------|--------|-------|--------|
| 6 | Kohat  | 33.5889°  | 71.4429°    | 11.56 | 8.92   | 8.90  | 10.0   |
| 7 | Quetta | 30.1798°  | 66.9750°    | 7.88  | 6.49   | 7.79  | 8.44   |
| 8 | Karachi| 24.8607°  | 67.0011°    | 23.45 | 22.90  | 16.86 | 10.86  |
| 9 | Wah    | 33.7832°  | 72.7231°    | 11.49 | 11.38  | 11.00 | 10.78  |
| 10| Taxila | 33.7463°  | 72.8397°    | 13.56 | 11.37  | 12.30 | 11.59  |
| 11| Islamabad | 33.6844° | 73.0479°    | 16.79 | 15.16  | 11.87 | 10.77  |
| 12| Rawalpindi | 33.5651° | 73.0169°    | 20.66 | 17.14  | 14.10 | 12.86  |
| 13| Srinagar| 34.0837°  | 74.7973°    | 87.54 | 7.70   | 8.14  | 7.93   |
| 14| Faisalabad | 31.4504° | 73.1350°    | 13.87 | 12.98  | 15.16 | 13.09  |
| 15| Sahiwal | 30.6682°  | 73.1114°    | 11.52 | 11.19  | 12.67 | 11.56  |
| 16| Gujranwala | 32.1877° | 74.1945°    | 12.6131 | 11.66 | 12.38 | 11.301 |
| 17| Narowal | 32.1014°  | 74.8800°    | 11.17 | 10.51  | 13.11 | 12.26  |
| 18| DG Khan | 30.0489°  | 73.0169°    | 11.83 | 11.43  | 14.52 | 11.94  |
A. Autumn Season (2018-09-23 to 2018-12-21)

The results obtained here are of the autumn season of 2018, which was from 2018-09-23 to 2018-12-21. These results in Fig. 4, which is mean concentration of NO$_2$ from 2018-09-23 to 2018-12-21, shows that during this season almost 23 cities have high concentration of NO$_2$. The decreasing order of NO$_2$ over cities is Karachi, Rawalpindi, Sheikhupura, Lahore, Raiwind, Islamabad, Jamber, Peshawar, Faisalabad, DI Khan, DG Khan, Multan, Mardan, Kalabagh, Quetta, and Srinagar. Error! Reference source not found. Shows that as we go from Karachi towards Faisalabad the concentration increases.

![Fig. 4: NO$_2$ in Autumn Season (2018-09-23 to 2018-12-21)](image)

B. Winter Season (2018-12-22 to 2019-03-21)

During Winter Season, which was from 2018-12-22 to 2019-03-21, 22 cities have excess concentration of NO$_2$. Compared to autumn season, over all concentration of NO$_2$in Pakistan’s troposphere is less than winter season as shown in Copyright reserved © J. Mech. Cont.& Math. Sci. Nasru Minallah et al.
The decreasing order of NO\textsubscript{2} concentration is Karachi, Sheikhupura, Lahore Rawalpindi Raiwind, Islamabad, Jamber, Peshawar, Faisalabad, DG Khan, Gujranwala, DI Khan, Narowal and Quetta.

Fig. 5: NO\textsubscript{2} in Winter Season (2018-12-22 to 2019-03-21)

C. Spring Season (2019-03-22 to 2019-06-21)

Fig. 6, which is mean concentration of NO\textsubscript{2} from 2019-03-22 to 2019-06-21, shows that 21 cities have excess concentration of NO\textsubscript{2}. The decreasing order of NO\textsubscript{2} concentration is Karachi, Sheikhupura, Lahore Rawalpindi Raiwind, Islamabad, Jamber, Peshawar, Faisalabad, DG Khan, Gujranwala, DI Khan, Narowal and Quetta. Sheikhupura, Karachi, Raiwind, Lahore, Jamber, Rawalpindi, Narowal, kalabagh, Faisalabad, DI Khan, DG Khan Karachi, Peshawar ,Lahore , Wah, Taxila Islamabad and Quetta.

Fig. 6: NO\textsubscript{2} in Spring Season (2019-03-22 to 2019-06-21)

D. Summer Season (2019-06-22 to 2019-09-22)

The 2019 Summer Season, which was from 2019-06-21 to 2019-09-22, NO\textsubscript{2} concentration in Pakistan troposphere is shown in Fig. Number of cities is reduced to Nineteen (19), whose atmosphere have high concentration of NO\textsubscript{2}. Compared to other seasons, overall concentration of NO\textsubscript{2} in Pakistan troposphere is less than other 3 seasons. The decreasing order of NO\textsubscript{2} in summer (as shown in Error! Reference source not found.) over cities is Sheikhupura, Raiwind, Jamber,
Lahore, Rawalpindi, Narowal, kalabagh, Faisalabad, DI Khan, DG khan Karachi, Peshawar, Lahore, Wah, Taxila Islamabad and Quetta.

**Fig. 7: NO$_2$ in Summer Season (2019-06-22 to 2019-09-22)**

**Fig. 7: Seasonal behavior of NO$_2$ in some major cities of Pakistan**

**VI. Conclusions**

In this paper, we investigated seasonal behavior of NO$_2$ concentration in Troposphere of Pakistan through Sentinel 5p satellite. We processed individual season temporal datasets, from 2018-09-23 to 2019-09-23, in Google Earth Engine. The details of time periods of datasets are shown in Table 2. Our results show that overall NO$_2$ concentration in Pakistan troposphere increases from summer to autumn season. The seasonal maximum and minimum of NO$_2$ were in autumn and summer season respectively. A seasonal cycle is found to be 1) Autumn, 2) Winter 3) Spring and 4) summer, as shown in Fig. 7.

The season-wise details are: In Autumn Karachi, Rawalpindi, Sheikhupura, Lahore, Raiwind, Islamabad, Jamber, Peshawar, Faisalabad DI Khan, DG khan, Multan, Mardan, kalabagh, Quetta and Srinagar have excess NO$_2$ in its troposphere.

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In winter Karachi, Sheikhupura, Lahore, Rawalpindi, Raiwind, Islamabad, Jamber, Peshawar, Faisalabad, DG Khan, Gujranwala, DI Khan, Narowal and Quetta have excess NO$_2$. In Spring Karachi, Sheikhupura, Lahore, Rawalpindi, Raiwind, Islamabad, Jamber, Peshawar, Faisalabad, DG Khan, Gujranwala, DI Khan, Narowal and Quetta and in summer number of cities are reduced to Sheikhupura, Rawalpindi, Jamber, kalabagh, Lahore, Raiwind, Faisalabad and DG khan.

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