A Geostationary air quality monitor for the Middle East

R M Suleiman, K Chance and X Liu

1Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138, USA
Email: rsuleiman@cfa.harvard.edu

Abstract. Atmospheric pollution measurements from space have been evolving from low-earth-orbits (LEO) to geostationary orbits (GEO), to track the diurnal variation of atmospheric emissions. There are three GEO instruments in development. TEMPO is NASA’s first Earth Venture Instrument, to be launched during 2018-2021. It will measure atmospheric pollution for greater North America using ultraviolet and visible spectroscopy. The European Sentinel-4 and the South Korean GEMS will measure atmospheric pollution for Europe and Southeast Asia, respectively. In this paper, we describe NASA’s TEMPO instrument and we propose a similar instrument in GEO to provide hourly atmospheric pollution measurements for the Middle East at very high spatial resolution. The proposed Middle-East TEMPO instrument will cover Arab Countries, and parts of Asia and Europe. The measurement will include the spectra required to retrieve \( O_3 \), \( NO_2 \), \( SO_2 \), \( H_2CO \), \( C_2H_2O_2 \), \( H_2O \), aerosols, cloud parameters, and UVB radiation.

1. Introduction

NASA selected TEMPO as the first Earth Venture Instrument in 2012 for launch during 2018-2021. It will measure atmospheric pollution for greater North America from space using ultraviolet and visible spectroscopy. TEMPO [1], [2] measures from Mexico City and Cuba to the Canadian tar sands, and from the Atlantic to the Pacific, hourly and at high spatial resolution (2 km N/S × 4.5 km E/W at 36.5°N, 100°W).

TEMPO provides tropospheric measurements that include the key elements of tropospheric air pollution. Since LEO instruments can only measure each point on Earth once per day and lack time resolution [3], TEMPO measurements will be from a GEO orbit, in order to capture the high variability in the diurnal cycle of emissions. GEO measurements will also provide much smaller spatial footprints, to resolve pollution sources at small spatial scales. TEMPO will be hosted on a commercial GEO host spacecraft to provide a modest cost mission. TEMPO will be launched as the North American component of the global geostationary constellation of pollution monitoring together with European Sentinel-4 and Korean GEMS, which will all be launched during 2018-2022. TEMPO and its European and Asian constellation partners will make the first tropospheric trace gas measurements from GEO. TEMPO’s measurements from GEO are built on the heritage of six [4], [5] spectrometers flown in LEO [6], [7]. The TEMPO retrieval algorithms are being developed by TEMPO Science Team members and based on the operational algorithms currently running in operational environments [8], [9].

2. Middle-East Tropospheric emissions: Monitoring of pollution (ME-TEMPO)

In this section, we describe NASA’s TEMPO instrument and we highlight how a TEMPO instrument can be applied to the Middle East.
2.1. NASA’s TEMPO Instrument Description and Data Products

NASA’s TEMPO will measure atmospheric pollution for greater North America from space using ultraviolet and visible spectroscopy.

TEMPO measurement will include the spectra required to retrieve $O_3$, $NO_2$, $SO_2$, $H_2CO$, $C_2H_2O_2$, $H_2O$, aerosols, cloud parameters, and UVB radiation. TEMPO will provide near-real-time air quality products that will be made widely, publicly available.

Table 1. TEMPO Baseline Products.

| Species/Products | Typical Value $^a$ | Required Precision $^a$ | Expected Precision $^b$ |
|------------------|--------------------|-------------------------|--------------------------|
| 0-2 km (ppbv) $^c$ | 40                 | 10                      | 9.15 9.00                |
| FT (ppbv) $^c$   | 50                 | 10                      | 5.03 4.95                |
| SOC $^c$   | 8x10 $^3$          | 5%                      | 0.81% 0.76%              |
| Total $O_3$ $^d$ | 8x10 $^3$          | 5%                      | 0.81% 0.76%              |
| NO$_2$ $^d$      | 6                  | 1.00                    | 0.65 0.54                |
| $H_2CO$ (3/day)  | 10                 | 10.0                    | 2.30 1.95                |
| $SO_2$ (3/day)   | 10                 | 10                      | 8.54 5.70                |
| $C_2H_2O_2$ (3/day) | 0.2               | 0.4                     | 0.23 0.17                |
| AOD $^d$         | 0.1 – 1            | 0.05                    | 0.041 0.034              |
| AAOD $^d$        | 0 – 0.05           | 0.03                    | 0.025 0.020              |
| Aerosol Index (AI) | -1 +5               | 0.2                     | 0.16 0.13                |
| Cloud Fraction   | 0 – 1              | 0.05                    | 0.015 0.011              |
| Cloud Top Pressure (hPa) | 200 – 900         | 100                     | 85.0 60.0                |

Spatial resolution: 8×4.5 km$^2$ at the center of the FOR. Time resolution: Hourly unless noted. Threshold products are at 8×9 km$^2$, at 80-minute time resolution.

$^a$ Units are 10$^{15}$ molecules cm$^{-2}$ for gases and unitless for aerosols and clouds unless specified.

$^b$ Expected precision is viewing condition dependent. Results are for worst and nominal cases.

$^c$ FT = free troposphere, 2km – tropopause; SOC = stratospheric $O_3$ column.

$^d$ Background value. Pollution is higher, and in starred constituents, the precision is applied to polluted cases.

TEMPO is a dispersive grating spectrometer that measures solar back-scattered light in the UV-Vis spectral range to measure trace gases, aerosols, and clouds.$^{1,2}$ The TEMPO instrument is based on LEO instrument subassembly heritage with modification to geostationary GEO operations. A scan mirror steps the spectrometer slit across the Field Of Regard (FOR) from East to West. A three-mirror telescope images the scene onto the slit of an Offner-type spectrometer. Spectra are imaged onto two $2K × 1K$ CCD focal plane arrays. One array measures 2K ground pixels from 290-490 nm and the other from 540-740 nm $^{[1]}$, $^{[2]}$. Figure 1 shows the range of expected Earth radiance spectra to be measured by TEMPO, expressed as reflectances. The spectra $^{[1]}$, $^{[2]}$ are derived from ESA GOME-1 measurements $^{[6]}$, $^{[7]}$ and cover varied scenes measured over the Earth.
Figure 1. Earth reflectance spectra derived from the ESA GOME-1 instrument for the range of conditions to be monitored by TEMPO.

TEMPO will measure as standard baseline data products O3 profiles, total O3, NO2, H2CO (3/day), SO2 (3/day), C2H2O2 (3/day), the aerosol optical depth (AOD), the aerosol index (AI), cloud fraction, and cloud top pressure (see table 1). The improved spatio-temporal resolution of the TEMPO measurements is ideally suited for constraining regional air quality (AQ) prediction systems employing global chemical data assimilation systems developed to utilize LEO trace gas data [10]. These prediction systems will benefit significantly from TEMPO’s multiple observations of a given region each day at a horizontal resolution that is commensurate with regional AQ prediction. Additionally, TEMPO UV-Vis measurements of tropospheric O3 [11] can substantially improve the analysis and assimilation of surface O3 concentrations, reducing errors by 50% [12]. TEMPO’s high spatio-temporal resolution allows a more detailed assessment of emission inventories, than is possible with LEO observations [13].

Figure 2. NO2 concentrations from OMI instrument on AURA over the FOR for a Middle Eastern TEMPO.

2.2. Application to the Middle East
The TEMPO instrument concept and design can be applied to the Middle-East region without any significant changes to optics or the overall telescope design. The FOR of a future Middle-East
TEMPO-like instrument will extend from (5°N, 20°E) to (40°N, 90°E) with the center of the FOR being at (24.4°N, 24.4°E) (UAE/Sharjah as the center of FOR). The spatial resolution for a Middle Eastern instrument is 1.74 km N/S × 4.7 km E/W native pixel resolution (7.87 km²). This spatial resolution will be better than NASA’s TEMPO for the same instantaneous field of view since it will be closer to the equator.

As shown in figure 2, a Middle-East TEMPO-like instrument FOR will cover a region from Djibouti (south) to the Black Sea (north) and from Calcutta, India (East) to Croatia (west). This FOR will have an overlap with ESA’s Sentinel-4 and Korea’s GEMS instruments. The FOR shown in figure 2 will be scanned every hour, where each 1.74 km × 4.52 km pixel is a 2K element spectrum from 290-740 nm. The Middle-East TEMPO instrument will scan 1250 steps from the east to the west where each step is 110 μrad. In the north to south it will measure 2000 pixels, each 40.6 μrad N/S. This will produce $2.5 \times 10^6$ spectra per hour of observations. The ground sample area (GSA) for various locations within the FOR are shown in table-2. The data products will be measured hourly with the spatial resolution demonstrated in table 1.

Table 2. The ground sample area (GSA), assuming 2000 pixels N/S, and the spatial resolution for various locations within the FOR.

| Location  | N/S (km) | E/W (km) | GSA (km²) |
|-----------|----------|----------|-----------|
| 25°N, 55°E | 4.52     | 1.74     | 7.87      |
| Mecca     | 4.52     | 1.75     | 7.91      |
| Sharjah   | 4.77     | 1.69     | 7.87      |
| Riyadh    | 4.60     | 1.74     | 10.2      |
| Jerusalem | 5.05     | 1.99     | 9.73      |
| Cairo     | 5.26     | 1.97     | 9.90      |
| Istanbul  | 5.57     | 2.52     | 12.77     |
| New Delhi | 5.15     | 1.91     | 9.48      |

3. Discussion
A future instrument like TEMPO over the Middle East will provide high spatial resolution measurements of Earth’s atmosphere. Additionally, it will provide a significant Arab contribution (along with TEMPO (US), Sentinel-4 (ESA) and GEMS (Korea)) to the understanding of the diurnal cycle of emissions, photochemistry, and dynamical transport coupling air quality and climate change.

4. References
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