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Comments on a Recent Article on Meteorological and Intelligence Evidence of Long-Distance Transit of Chemical Weapons Fallout from Bombing Early in the 1991 Persian Gulf War

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The recent article by Tuite and Haley [1] aims to provide evidence of long-distance transport of chemical weapons fallout from bombings during the 1991 Persian Gulf War. In brief, the authors suggest the following series of events: (1) Coalition bombings on the night of 18–19 January 1991 destroyed the Iraqi chemical warfare agent infrastructure. (2) The bombings led to chemical warfare agents being lofted by buoyant plumes, penetrating the nocturnal atmospheric boundary layer into the residual layer aloft [2]. (3) The nocturnal jet in the residual layer rapidly transported the plumes over a long distance, along the wind direction as suggested by the large-scale pressure gradient. (4) After sunrise, solar heating caused the daytime mixed layer to reestablish and the chemical warfare agents to mix down to the surface, leading to chemical agent alarms at US and Coalition troop locations more than 500 km away from the bombing sites.

While the article addresses an enormously important issue, i.e. US and Coalition troops' well-being, as described below, it unfortunately seems to suffer some major shortcomings and errors. The comments discussed here primarily concern the meteorological aspect of the article and address these three areas: (1) some meteorological concepts may have been applied out of context, (2) the necessary supporting quantitative analysis seems lacking, and (3) more correct interpretations of weather maps and satellite images are needed.

Application of Meteorological Concepts out of Context

There are a few places in the article where the authors seem to have juxtaposed certain meteorological concepts without proper consideration of relevant scales. For example, the authors try to infer mesoscale features (horizontal scales up to a few hundred kilometers) using hemispheric weather maps. The latter, due to their large horizontal scales (up to tens of thousands of kilometers), are necessarily smooth and thus lack the required resolution and details to discern smaller scale weather features. The meteorological

community recognized the difficulties associated with the lack of high quality data for the period in question (the Iraqis terminated all meteorological reporting) and joined together to generate a refined data set which has become the basis for most modeling exercises. This reanalysis data set is available from the National Center for Atmospheric Research in Boulder, Colo., USA.

The authors suggest that the 'thermal' plume rising over the bombing sites retained its temperature characteristics while traveling over a long distance. In reality, only an 'air mass', with a horizontal scale up to thousands of kilometers, has this property [3]. The plume resulting from bombings is much smaller, perhaps only a few hundred meters initially; will be diluted rapidly, through mixing with the background air; and will quickly lose its initial temperature characteristics.

Furthermore, the authors imply that bombings of the Iraqi chemical weapons infrastructure caused all warfare agents to be instantaneously captured by the buoyant debris plume that subsequently penetrated the nocturnal atmospheric boundary layer into the residual layer. While plume rise is a well-studied subject [4], whether all the agents were captured in this initial buoyant plume is highly uncertain. In fact, field and laboratory testing for another incident during the 1991 Gulf War (i.e. US demolition operations at the Khamisiyah ammunition depot [5]) show that only about 10% of the agents was released instantaneously into the atmosphere, whereas the remaining 90% was released through continuous, time-varying evaporation from agent-soaked soil and wood. Release from this slow evaporation will not have the sufficient buoyancy to penetrate the nocturnal boundary layer. Moreover, evaporation is likely to last well into daytime when the nocturnal boundary layer is no longer relevant.

Lack of Necessary Quantitative Data Support

In order to firmly support its hypothesis, the article should provide stronger quantitative evidence including observations if available (e.g. vertical temperature and wind profiles) and computer modeling (e.g. the Khamisiyah analysis [5]). The only data used in the article are weather maps and satellite images whose interpretations appear questionable (to be described later). In other words, solid evidence for the existence of a nocturnal boundary layer and a nocturnal jet, both of which are critical to the article's hypothesis, is lacking. Weather maps and satellite images alone are insufficient for essentially a trajectory analysis that is highly sensitive to the initial conditions and three-dimensional wind fields [6].

Incorrect Interpretations of Weather Maps and Satellite Images

The authors include many infrared satellite images to support their arguments, but their interpretation of these images draw

scrutiny. In satellite meteorology, infrared images are inverted so that the higher the radiance the darker the pixel. In this case, clouds, usually colder than the surface, appear white so as to be consistent with visible images [7]. However, the authors have an opposite interpretation that a brighter area in satellite images indicates warmer air.

In addition, the authors appear to be mistaken in interpreting a temperature inversion. For example, the article's figure 3 caption states that an inversion is indicated on the surface weather map by 'crossed isobars'. But isobars do not cross. Otherwise, it would suggest a location to have two different pressure readings simultaneously, which is not physically valid. Figure 4's caption further suggests that satellite images also indicate the presence of a temperature inversion. Satellite images can be used to interpret many weather phenomena, but a temperature inversion is not one of those [7]. The same limitation also applies to surface and isobaric weather maps [8]. This is because a temperature inversion pertains to the atmosphere's vertical structure, whereas weather maps and satellite images are horizontal by nature. The only tried-and-true method to verify the existence of a temperature inversion is through such instruments as an acoustic sounder, wind profiler, or radiosonde [3].

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