Achieving closure on the question of energy and momentum coupling between the lower and the upper atmosphere

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Ever since the seminal 1960 paper by Colin Hines on Internal Atmospheric Gravity Waves at Ionospheric Heights, the upper atmospheric/space science community has focused significant efforts in understanding the coupling between lower and upper atmospheric regions – how the waves deposit energy and momentum at various heights, the role that neutral wind filtering plays in propagation of gravity waves, the role that planetary waves and tides play in the energy and momentum coupling, and what sources in the lower atmosphere lead to medium scale gravity waves observed all the way up in the F-region ionosphere. There have been several successful efforts to model the sources and resulting gravity waves at both global and local scales, and new computational capabilities are making it possible to model these at increasingly smaller scales, including acoustic wave scales. What has typically been lacking is the observational capabilities tracking these waves as they vertically propagate through various regions.

In last couple of decades, we have had satellite based instruments like TIMED SABER, and AIM SOFIE that sample vertical profiles in the atmosphere. While these profiles are nearly 'global', they are inadequate to provide temporal information in the gravity wave propagation. We have used flight and balloon based measurements to obtain vertical profiles with dedicated campaigns, which have given us a much smaller scale view of propagating gravity waves. We have used ground-based vertical profilers like LIDAR, ionosondes, and incoherent scatter radars to obtain temperature and density profiles from lower to the upper atmosphere. Then we have wave fields captured at a single altitude by imaging instruments that take 2D snapshots at a particular altitude or altitude range, such as optical imagers from space and ground observing at a specific wavelength and GPS Total Electron Content (TEC) measurements. Recently multistatic radar systems and amateur ham radio signals have also been used to measure traveling ionospheric disturbances in the upper atmosphere, which can be related to gravity waves originating in the lower atmosphere.

The sources of variability in the lower atmosphere are varied, and with the existing instrumentation, it is difficult to capture them both across a variety of spatial and temporal scales and swaths. General circulation models and localized wave propagation models do a reasonable simulation of expected impacts in the middle and upper atmosphere from given lower atmospheric sources. However, we have inadequate instrumentation to validate these modeling results.

The question is, how do we get around this challenge of having inadequate instrumentation so that we can achieve closure on at least the most common sources of variability from from lower atmosphere that play a role into upper atmospheric variability.

In recent years, there have been concerted efforts from the ground-based instrumentation community to address this problem using instrument networks. The unintended networks of GPS receivers that is expanding with time is a great example of this approach. Similarly, networks of optical imagers at various wavelengths are coming into play. As technology progresses, it becomes easier to mass-produce some instruments that could only be considered for standalone infrastructure in prior years due to associated costs. It has already been shown that networks of heterogeneous instruments on the ground provide window into a large spatial area with temporal consistency.

In order to resolve the question of energy and momentum transfer via gravity wave coupling, we need two kinds of measurements: Vertical profiles that give gravity wave parameterization, and 2D maps of wave fields that show impact of wave propagation and momentum deposition at a particular altitude.

These measurements need to be obtained at strategic spatial regions on earth that encompass a variety of lower atmospheric sources causing upper atmospheric variability. This can be achieved by creating ground-based observing facilities at these strategic locations that complement space-based measurements from AIRS, AIM, TIMED, and most recently ICON. The key discussion topics that should get community input are:

1. What are the strategic locations where we should create observing facilities? These should be decided by the variability observed in the lower atmosphere (e.g. thunderstorm frequency), and regions of upper atmospheric variability.
2. What should these observing facilities look like? For some instruments, it is easy to create large networks – e.g. GPS TEC receivers, optical imaging at F-region wavelengths, etc. For some instruments, it takes many, and sometimes more complex infrastructure, e.g. LIDARs, FPIs, Multistatic radars, optical imaging in mesosphere and lower thermosphere etc.

One possible arrangement would be to create nested networks of instruments, where multiple scales and multiple techniques can be represented. E.g. a network of LIDARs, nested inside a network of mesospheric and lower thermospheric imagers, FPIs and multistatic radars, nested inside a network of upper atmospheric imagers (e.g. 630nm wavelength) and GPS TEC receivers.

If we take advantage of continuously improving technological infrastructure, we should be able to strategically create these observing facilities across the globe at strategic locations, combined with key space based measurements, modern data assimilation methods, and modeling efforts, and really bring closure to the question of energy and momentum coupling within the next 2 decades.