Gravity wave forcing and its effects in entire middle atmosphere: Study under Atmospheric Forcing and Responses (SAFAR), a major NARL campaign

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• Introduction to SAFAR

• Motivation and Experimental facilities available for SAFAR

• Gravity wave climatology over Indian region
  ★ Characteristics of convectively generated GWs
  ★ Characteristics of Jet stream generated GWs
  ★ Climatological characteristics of IGWs
  ★ Identification of high-frequency GWs from Radiosonde data

• Summary and Conclusions
Introduction to various forcings over Indian region and expected responses
Major Objective

Characterize the elements of atmospheric forcing, both natural and anthropogenic, and study the atmospheric responses at different altitude levels and the feedback process.

Achieving this by generating ‘climate quality’ data
NARL is identified as a ‘super site’ for validation of various satellite observations.

Validated:
CHAMP/COSMIC: Ratnam et al., 2004; 2009
SABER: Kishore, Ratnam et al., 2009
Megha Tropiques: Well planned

Complementary Data from other sources:
INSAT cloud images
GMS data of TBB, NOAA OLR
DWR-Chennai (120 km from Gadanki)
COSMIC/GPS
SABER/TIMED
Radiosonde data from other stations
Complete May-June and Sep.-Oct. in alert mode for capturing convection events.

Once detected, Radar is operated continuously for 8 hours (3 beams).

One more radiosonde is launched after the event.

This experiment will over ride all other experiments if convection is detected.

We also make sure about the smoothing running of other co-located instruments which are running continuously (AWS, Disdrometer, ORG, GPS Receiver, SODAR, RASS etc.).

We also continuously monitor the motion of clouds through Indian satellite (INSAT) and Doppler Weather Radar at Chennai.
MST Radar
Jan.08-13, 2009 – Every 6 hours 15mints. Lower atmospheric mode
- Every 6 hours 15 mints. Mesospheric mode
Jan.08-13, 2009 – Night time lower atmospheric mode – 19hrs-04hrs
Jan. 16-17, 2009 – Diurnal cycle, continuous
Jan. 15-18, 2009 – Every 6 hours radiosonde launches

Jan.18-28, 2009 – Day time lower, meso, iono mode – 0930-1630hrs
Jan. 18-28, 2009 – Night time ionosperic mode - 18hrs-06hrs

Rayleigh Lidar:
Jan. 08-13, 2009 – Rayleigh mode – 19hrs – 02hrs
Jan. 15-18, 2009 – Rayleigh mode – 19hrs-05hrs

Jan.18-28, 2009 – Rayleigh mode – 19hrs-02hrs
- Na mode – 02hrs-06hrs

Complete spectrum of GWs throughout the middle Atmosphere can be obtained
Background conditions over Indian region: Gravity Wave sources

- Convection and strong shear co-exists during SW monsoon
- Which mechanism dominate in generating GWs?

Gadanki is unique region which experiences two monsoon systems: SW monsoon (JJAS) and NE monsoon (ON)

MAM: Localized deep convections and Thunderstorms
JJAS: Meso-scale convection, cyclones and TEJ
ON: Localized deep convections

Ratnam et al., JGR, 2008
Background conditions over Indian region: Gravity Wave sources
Convectively generated GWs during wet and dry spells (Typical examples)

**Definition of Wet /Dry spells**

Rainfall should be more than climate normal (30 years) for more than 3 consecutive days

Rajeevan and Jyoti, Curr. Sci., 2008

Uma et al., JASTP 2011 (In press)
Wet spells: 11 (4) events show $t > 20$ mints. (40 mints.)

Surprisingly, the amplitudes of these low frequency waves are found to be less than 0.5 m/s.

Dry spells: 14 (3) events show $t \leq 10$ mints. (15-20 mints.)

In general, the amplitudes of these high frequency waves in the dry spell are found to be more than that of wet spell.

Wet spells
- More conducive for generation of GWs
- Less probability to propagate into LS
- Mainly due to strengthening of TEJ

Importance of prevailing background conditions in exciting/filtering GWs

\[ \omega^2 = \frac{N^2(k^2 + l^2)}{(k^2 + l^2 + \tilde{m}^2)} \]

Uma et al., JASTP, 2011 (In press)
WRF (3.0) model simulations of MCS events and features related to Thunderstorm activity observed on 21 May 2008 (SAFAR pilot campaign)

Vertical levels: 38
Top of model: 10 hPa
Initialization: GFS initial conditions at 0.5°
Additional data: 230 AWS stations, MST radar and GPS sonde
Radiation: RRTM long-wave scheme, a spectral-band radiative transfer model using the correlated K-method (Mlawer et al., 1997) and the Dudhia (1989) shortwave scheme.
Land surface process: Noah LSM scheme

Microphysical schemes considered in the study

<table>
<thead>
<tr>
<th>Scheme</th>
<th>Reference</th>
<th>Number of variables</th>
<th>Ice-phase processes</th>
<th>Mixed phase processes</th>
</tr>
</thead>
<tbody>
<tr>
<td>WSM6</td>
<td>Hong et al. (1994)</td>
<td>6</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Purdue Lin</td>
<td>Chen and Sun (2002)</td>
<td>6</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Thompson</td>
<td>Thompson et al. (2004)</td>
<td>7</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Morrison</td>
<td>Morrison et al. (2009)</td>
<td>10</td>
<td>Y</td>
<td>Y</td>
</tr>
</tbody>
</table>

Rajeevan et al., Ann. Geophys. 2010
The model was able to simulate many features of the thunderstorm, but with some differences.

First of all, convection was initiated in the model, almost an hour earlier than observed.

However, all the simulations correctly suggested passage of two convective cores over Gadanki, as observed by the MST and Doppler Weather radars.

Significant variations are observed in the simulations of updraft/downdraft cores, surface rainfall and hydrometeor profiles.

Model simulated updraft and downdrafts were weaker than observed and also constrained below about 10 km.

Among the four schemes considered, the Thompson scheme simulations were closer to observations.
Gravity Wave sources mechanisms over Indian region

17-21 km: Monsoon high

‘Monsoon waves’

\[ E_k = \frac{1}{2} [u^2 + v^2 + w^2] \]

4-14 km: Winter high

Ratnam et al., JGR, 2008
Although both the convection and shear dominates during monsoon, shear is identified as key element in generating various frequency of waves.

What happen to waves generated due to convection?

Intensity of the shear does not correlate with the GW amplitudes.

Orography is identified as source of GWs during winter.

Number of events showing the direction of propagation of the gravity waves, in vertical, observed in different seasons during 1995-2004

<table>
<thead>
<tr>
<th>Season</th>
<th>Clockwise rotation</th>
<th>Anti-clock rotation</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monsoon</td>
<td>31(144)</td>
<td>288(113)</td>
<td>319(257)</td>
</tr>
<tr>
<td>Post monsoon</td>
<td>43(50)</td>
<td>38(32)</td>
<td>81(82)</td>
</tr>
<tr>
<td>Winter</td>
<td>109(67)</td>
<td>54(59)</td>
<td>163(126)</td>
</tr>
<tr>
<td>Total</td>
<td>269(338)</td>
<td>423(254)</td>
<td>692(592)</td>
</tr>
</tbody>
</table>

*Values in brackets are for lower stratosphere

Ratnam et al., JGR, 2008
Monsoon season (2006-2010)

Data used: GPS Radiosonde launched daily from Gadanki at 12:00 UT during 2006-2010
Method: Hodograph analysis

‘Can we get characteristics of high frequency gravity waves using Radiosonde?’
We can extract the high frequency gravity wave components using either calculating ascent rate or by least square method.

Using ascent rate:

- Earlier studies (Marvin. A. Geller and Jie Gong, JGR, 2010), shown that we can observe high frequency gravity waves using Radiosonde by calculating vertical fluctuation from ascent rate.

  \[
  KE = \frac{1}{2}(u^2 + v^2) = 0.25 \left[ \frac{(1 + (f/\omega)^2)}{(1 - (f/\omega)^2)} \right] \left( \frac{m^2P^2}{N^2} \right)
  \]

  \[
  PE = \frac{1}{2} \left( \frac{g}{N} \right)^2 \left( \frac{T}{T_0} \right)^2
  \]

  \[
  VE = \frac{1}{2} w^2 = 0.25 \left( \frac{\omega^2 m^2 P^2}{N^4} \right)
  \]

  \[
  \frac{KE}{PE} = \left[ \frac{(1 + (f/\omega)^2)}{(1 - (f/\omega)^2)} \right]
  \]

  \[
  \frac{VE}{PE} = \frac{\omega^2}{N^2}
  \]

- KE is more sensitive towards low frequency GWs and VE is more sensitive towards high frequency GWs.
Using least square method:

We have conducted several experiments during 13-17 Jan. 2010 using MST Radar, GPS Radiosonde and Rayleigh lidar to study the characteristics of high frequency GWs.

Method: Least square method applied in space domain.

Necessary condition: Amplitude should be high and RMS deviation should be less.
What periods does these higher wavelengths corresponds?
Detection of dominant periods corresponding to higher vertical wavelengths using MST radar

Verification of the results by using same method in time domain (in order to find the period) using MST Radar data which is operated during the same time. Observed 2-4 hr period is dominant.
Confirms the possibility of extraction of high frequency gravity waves from Radiosonde data using simultaneous observations from Indian MST radar.

Uniqueness of Gadanki is that we can study complete spectrum of gravity waves in entire middle atmosphere by combining the MST radar, GPS radiosonde and Rayleigh lidar observations.
Experiments conducted under SAFAR campaign provided unique opportunity to study the complete spectrum of GWs in middle atmosphere.

Characterization of sources of GWs is initiated. Wave generation and propagation is found completely different during moist and dry convection.

Though existing schemes represents some of the features of convection, however large differences exists between observations and model simulations in characterizing the convection over Indian region.

Although both the convection and shear dominates during monsoon, shear is identified as key element in generating various frequency of waves.

However, intensity of the shear does not correlate with the GW amplitudes.

Modeling efforts are missing in the current analysis and hopefully advanced tools like ray tracing will shed light in locating the GW sources precisely over Indian region.

MF estimates (‘Monsoon waves’) from various satellites (ex: Corwin et al., HIRDLS; Ern et al., SABER) can be validated over Indian region.

Thank you!