DASI Optical instruments: Imagers, FPIs, and Spectrographs

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key question: What can a network of optical instruments do for aeronomy and space physics?

In brief:
- study phenomena that involves interplay among many elements: i.e., system dynamics
- quantify energy transfer processes
- observe ion-neutral coupling effects
•The Earth has an envelope of emitting gas encircling the globe.

•The Earth’s airglow and aurora generate emission at 557 nm, OH wavelengths, 732 nm, and 630 nm: very useful for remote sensing studies with all-sky imagers and high resolution Fabry-Perot interferometers.
  •557 nm or OH => mesospheric dynamics
  •630 nm => thermospheric dynamics
  •732 nm => plasma drifts

•Other wavelengths also available, such as H for geocorona studies.
Why a network?

- Phenomena that matter in the upper atmosphere occur over a wide range of spatial scales, some being global in extent.

- Extended coverage in longitude as well as latitude needed to obtain tidal phases and to study effects that might be dependent upon magnetic declination.

- Several sites desirable for certain local studies.

- Many observatories desirable for global coverage.
Why global?

• Each latitudinal region has its own personality:
  — auroral zone, polar cap
  — mid-latitudes
  — equatorial latitudes

• Energy transfer between regions important issue

• Energy transfer via gravity waves, tidal waves, planetary waves from below to above also important

• Optical instruments valuable for such studies.
Imagers have been applied to both studies of mesospheric dynamics and F-region phenomena.

The science for both of these areas benefits from a global coverage.
The issue of gravity waves is particularly complex

- Gravity waves drive mesospheric dynamics!
- Majority of momentum transferred by short-period (<1 hour) gravity waves.
- Primary sources reside in lower atmosphere.

**Major unknowns:**
- Global abundance and characteristics
- Seasonal/hemispheric variability
- Dominant sources and geographic distributions
- Filtering effects of background atmosphere
- Momentum transport and deposition
- Realistic input into global-scale models
Imagers can observe GW events at different heights.
Example of Wave Breaking Event

- Short-period gravity waves break at mesospheric altitudes, depositing large amounts of momentum.
- Gravity wave events are episodic yet their effects are global.
- Source anisotropy and wave propagation remain major unknowns.
Example of imager chain observations

Site
- BLO
- Grand Junction
- Socorro
- Fort Collins
- McDonald

Institute
- USU
- UCB
- UIUC
- CSU
- BU

All-sky Imager
- multi-spectral
- OH/O$_2$
- OH
- OH
- multi-spectral

1500 km

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F-region imagers have made contributions to heating experiments and studies of extended plasma bubbles and mid-latitude spread-F.
A network of imagers is particularly valuable at high latitudes.

- Extensive arrays exist at high-latitudes to study auroral processes
  - Time History of Events and Macroscale Interactions during Substorms (THEMIS)
  - Magnetometers-Ionospheric Radars-Allsky Cameras Large Experiment (MIRACLE)
Fabry-Perot interferometer

- Observe dynamics of mesosphere and thermosphere over mesoscale distances (100-800 km) by measurements of Doppler shifts of spectral emissions ($O^1S$, $OH$, $O^+2D$)
- Observe neutral dynamical effects of ion-neutral coupling
- Point measurements, line of sight
- Common volume required to get all three components of wind vector within 20-50 km.
- Global coverage desirable for studies of thermospheric dynamics
- Nightglow FPI can be constructed @100 K, Dayglow@500 K
Neutral winds have significant effect upon F-region density

• The electron density may vary an order of magnitude depending upon the direction and speed of the wind.

• $h_{\text{max}}$ heights may vary by 100 km depending on direction of meridional component
Measurements of thermospheric winds by FPI observatories located at Sondrestrom and Thule illustrate the sensitivity of polar dynamics to $F_{10.7}$ and IMF By parameters (from Killeen et al., 1995)
FPI measurements of the MTM at Arecibo and Arequipa show dynamical signatures that should be studied with a meridional chain of FPI observatories.
We should appreciate that there is great science potential for studying small scale effects with a network of FPI stations, especially when coordinated with the AMISR facility.

ASC and FPI observations of aurora, Poker Flat at 630 nm (Conde et al., 2002)

FPI-ISR radar collaboration important means for studying ion-neutral coupling at polar latitudes
Spectrograph Applications

- Identify emitting species—not obvious for weak signals
- Monitor composition changes
- Measure mesospheric temperature accurately with high temporal resolution.
- Determine characteristic energy for auroral precipitation—electrons & protons
- Observe simultaneously, multiple emissions whether mesosphere or thermosphere
- Can use twilight geometry to get height profiles of emitting species, e.g., $O^+$
Modern spectrographs can observe weak airglow emissions with high accuracy.

Fig. 1. Portion of the $\Delta v = 0$ sequence of the $\text{O}_2(b^1\Sigma_g^+ - X^2\Sigma_g^-)$ Atmospheric Band system, from Keck/HIRES. The most intense lines in the spectrum belong to the 8-3, 4-0, and 9-4 OH Meinel Band system.
Current global distribution of FPIs(*) and imagers(•)
The "super chain" with "pearls"

The pearls would be placed within each region at sites of clear skies.

Pearl composition

- Rayleigh Doppler lidar
- Na W/T lidar
- FPI local chain
- imager local chain
- high resolution spectrograph

Passive Optics workshop recommended formation of a superchain with "pearls" in American and Asian sectors.
Network needs for DASI, SW and support of spacecraft operations - TIMED, LWS,others

- More imager & FPI observatories needed to improve sampling of the global circulation pattern of thermospheric and mesospheric dynamics.

- Upgrade of existing imager & FPI observatories essential to improve sensitivity and wavelength selection to get observations of mesospheric and thermospheric dynamics with good temporal resolution.

- Internet connectivity crucial to enable real-time feedback of data to central archival storage for data assimilation into global SW model such as Schunk’s GAIM. Satellite link Internet feasible.

- Extension of FPI network into daytime sector highly desirable for improved sampling of global thermospheric wind pattern.

- 24/7 coverage highly desirable and feasible for mountain sites in arid locations.
Summary

- Capability now exists to quantify the role of gravity waves (and tides) on the global MLT dynamics.
- A distributed network of complementary ground-based instruments is required. These will couple together existing (and new) key cluster facilities to investigate regional and global scale dynamics.
- A major step towards a global network will utilize existing infrastructure within North and South America to create a pole to pole chain.
- These data are crucial for accurate parameterization of global-scale wave models.