CUAD: Constellation for Upper Atmosphere Dynamics

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Dynamic coupling of lower to upper atmosphere is huge and nearly unobserved

- Lower atmosphere dynamics impacts thin upper atmosphere
- Imprints weather signature into the upper atmosphere.
- Only now learning how to read the coupling language
- But, it is largely unobserved
- THAT VOID CAN NOW BE ELIMINATED
Gravity wave effects generated by surface winds in the Andes

High altitude zonal wind field near 50° south from gravity waves generated by winds over the Andes. Surface winds ramped up during the first hour, kept constant for the second hour.

Upper atmosphere winds reach ±200 m/s.

Wind jets induce wave breaking and turbulence, spawning secondary, tertiary, and acoustic signatures.

Dramatic signatures induced by waves from the lower atmosphere interacting with upper atmosphere winds over 100 m/s.
Technique Comparisons

Current technology can’t see it.

Doppler Scanning with Gas Filters (DSGF) removes that deficiency, by observing wind and temperature with a leap in resolution.

Opens the door to major advances in forecasting weather and turbulence.
1. Temperature and pressure fields without radiance calibration from Tstar and limb DSGF (DWTS).

2. $CO_2$ fields from T/P fields and limb $CO_2$ emission measurements (LCER).

3. Wave structure from limb temperature and nadir DSGF (HATS).

4. Wind from limb DSGF (DWTS).

5. No Onboard Calibration.
CUAD MicroSat

Tstar (Star Field Imager)

Sparse lower strat temperature fields
Temperature profiles used for CO$_2$ calibration (Method used with Tstar)

- Atmospheric refraction from vertical extent of distorted image
- Patented 2-point occultation method
- Can be accomplished with sun or moon or star fields!
- Requires very simple imager measuring in the visible spectrum
- Operational on SOFIE AIM

Achieving 0.3 Kelvin accuracy
T from star field compression/refraction
Turbulence from star twinkle

Random star pattern

Field of view as would be seen without atmosphere

Field of view as seen with atmosphere

Progressive deformation due to refractive index affecting apparent altitude
Statistical comparison of SOFIE temperature with NCEP

From edge tracking

2009-03-21 to 2009-03-26
SS-81.5 75 events

32nd Annual Small Satellite Conference
August 4-9, 2018
CUAD MicroSat

DWTS (limb)
DSGE (limb)

Dense wind and upper atmosphere temperature fields
DWTS – Doppler Wind and Temperature Sounder

A new method of wind and temperature measurement

- Simple static limb imager
- Hi-resolution spectral scanning using Doppler shift
- From low earth orbit, it looks through a gas cell at the limb, perpendicular to the velocity vector
- The gas cell acts as a filter that scans atmospheric spectra with the same gas cell spectra
- Three imagers could provide wind and temperature from cloud top to 200 km on 10 km along-track spacing, \textit{day and night}

→ See DWTS tutorial at \url{www.gats-inc.com/future_missions.html}
Illustration of DWTS concept using one emission feature.

Top panel is NO gas cell transmission vs wavelength.

Middle 7 panels are atmospheric emission reaching the detector vs. wavelength for 7 different shifts.

Bottom Panel shows DIP signal (see Gordley 2011).

Knowing $\sigma_c$ and $\sigma_m$, the atmosphere $\sigma_a$, and therefore Temperature $T_a$ can be determined.

Position of the signal minimum provides CT wind component.

DIP area (shaded green), normalized by the maximum signal, provides a direct measure of cell content.
DWTS coverage

- Comparison to existing technology

Current measurements provide inadequate altitude, and day/night coverage

DWTS has an order of magnitude better horizontal resolution

* Note that altitudes denoted by “A” or “B” would not be covered by a single channel (only NO) path finder instrument
LCER (Limb CO₂ Emission imaging Radiometer) Limb

Dense limb pressure and temperature fields for seeding HATS retrievals
**LCER**  **Limb CO₂ Emission Radiometer**

- Simple static imager of broadband limb emission
- Uses CO₂ emission and CO₂ concentration to retrieve Temperature profiles.
- Uses CO₂ emission, and T/P profiles from DWTS and TSTAR, to retrieve CO₂
- Temperature retrievals used to seed HATS retrievals
- Major challenge for limb imagers is stray light
  - Technology can now address that challenge
CUAD MicroSat

HATS (High Altitude Thermal Sounder)

High horizontal resolution thermal wave structure using limb T, P seed as a priori profile
HATS Instrument Concept

16 U example (12U may be possible)
7 Nadir viewing channels/sensors
20 degree FOV
Primary challenge is cooling
HATS™ – High Altitude Thermal Sounder

- Averaging kernels resulting from 7 selected bands, each observed by a separate imager.
- Derived from principal component analysis of the 7 modulation functions produced during Doppler scans.
- Potential 10-20 km horizontal resolution

Concept first suggested by:

P. D. Curtis, J. T. Houghton, G. D. Peskett and C. D. Rodgers

Mean Altitude of Emission for various resolutions
HATS™ temperature retrieval

- The dotted is the a priori profile (the guess)
- The solid is the truth
- The dashed is the retrieved
- The optimal estimation technique uses the measurements to estimate the “differences” between the a priori guess and the truth

White paper on HATS is available on request.
Reconstruction of GW over the Andes
Summary

- Global monitoring of upper atmosphere Wind, Temperature and Waves
- Result: Better forecasting of weather and turbulence
- The synergy between the imagers will enable a 100% vicarious calibration scheme. No onboard calibration systems required
- Proven analysis techniques, novel new techniques, plus advances in ADCS, FPAs, Cooling Systems, Processors, AR Coating, Interference Filters, telemetry Communication Bandwidth and GPS systems make it possible with Cubesat Sized Static Technology
Satellite weather operations from pole-to-pole, surface to space, 24/7. ge <30-minute refresh. Constellation of ~150 LEO Satellites, 25-50 Kg Class, Total Cost

- **Theater Weather Imaging and Cloud Characterization Satellite (TWICCS)**
  - Constellation for Upper Atmosphere Dynamics (CUAD)
  - Multi-spectral Imager for using top ABI Bands and Day Night Band with optional Lightning Imager.
  - TWICCS Phase II SBIR AF171-073
  - NASA H-TIDES, Selected 2018
  - NOAA SBIR Phase I 2018
  - PM: Capt. Brandon Mueller AFRL

- **Microwave CubeSat Sounder (MCS) and Compact Microwave Imager (CMI)**
  - Microwave Sounders for temperature & humidity profiles, cloud liquid water, precipitation, and more.
  - Microwave Imager for ocean wind vector, snow status, sea surface temperature, sea ice, and soil moisture.
  - Proposed to DARPA Blackjack 2018

- **Compact Hyperspectral Infrared Sounding Interferometer (CHISI)**
  - Nadir Interferometric Sounders for Temperature, AMV Winds, Humidity, and Precip.

- **Space Weather Limb-Observing SmallSat (SWeLS)**
  - Doppler Wind & Temperature Sounder, and UV-spectrometer, In Situ measurement.

- **MetNet™: the Small Weather Satellite Network**

- **GEO and Multi-Apogee Polar HEO**
  - Size: 180 Kg

- **BRANDYWINE PHOTONICS**

For more information contact: John Fisher, Brandywine Photonics M: (484) 459-9589.
Thank you from the MetNet Space Alliance
Come join us!

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Industry Members:
- GATS: Global Atmospheric Technologies and Sciences
- SwRI: Southwest Research Institute
- ABB
- ASTRA
- Remote Sensing Systems

University Collaborators:
- Tropical Cyclones
- IR Sounding Science
- Space Computing

And others