Using Constellations of Small Satellites to Address Large Problems

Aaron Ridley
What Science To Investigate?

• Small-scale dynamics
  — Ground-based instrumentation can provide a wealth of information at a single location.
  — Multiple instruments at the same location can provide both neutral and ion data.

• Regional-scale dynamics
  — Chains of ground-based instrumentation can (once again) provide data over relatively large regions.
  — Instruments such as magnetometers and GPS are very cheap and can be deployed in relatively dense arrays.

• Global Scales Climatology
  — Satellites typically have provided global-scale results.
  — Can put many instruments (ion and neutral) to explore ion-neutral coupling.
Problems with Ground-Based Instrumentation

• (There are no problems with ground-based instrumentation)
• (Especially incoherent scatter radars)
Problems with Ground-Based Instrumentation

• They are tied to certain locations on Earth
  – For example, we have studied the (magnetic) equatorial ionosphere in the American sector in great detail, but have not studied it in the African sector very much at all

• Oceans
  – Those damn oceans. 70% - really?

• Clouds
  – “Wow, the neutral wind was really boring last night during that geomagnetic storm.”

• Daylight
  – Do you have any idea how much a triple etalon costs???

• The ionosphere is much easier to study than the thermosphere from the ground because of the you can use radars which can measure through clouds and 100s of km away.
Problems with Low Earth Orbiting Satellites

• Satellites are constantly moving, so it is difficult to get a time-series of anything that takes place on shorter time scales.
  – The ionosphere and thermosphere are strongly driven, so they can change quite rapidly.
• Polar orbiting satellites are tied to a single local time for long periods (weeks to months)
  – During a storm, you don’t come back to the same place each orbit, you come back to the same local time, while the Earth has orbited by ~23 degrees.
  – How do you separate out local time vs longitude vs time?
• Satellites never orbit where you want them to
  – Equatorial? Polar? Which is more important? (polar, obviously!)
• Satellites cost a lot to build and a lot to put into orbit
  – Since single satellites are so rarely launched, they need to work the first time, which ends up increasing the cost dramatically.
What if we want to study global-scale dynamics?

• Example science questions:
  – How is mass, momentum and energy moved throughout the thermosphere and ionosphere after a large increase in magnetospheric forcing?
  – How rapidly does the tidal forcing change during different seasons?
  – What is the dynamic interplay between winds, composition and electrodynamics in driving change in the ionosphere?
  – How are different scales coupled within the thermospheric and ionospheric system?
• Typically, most missions have a single monolithic satellite that is well instrumented
  – Data in one location
  – Need statistics to understand the system response

• 5 Consecutive ascending node ½ orbits of CHAMP mass density data are shown.
• What is going on?
Two Satellites During a Storm

12 minutes worth of data are shown on each frame.

Color is the thermospheric temperature while the vector shows the neutral winds.
Thoughts on Constellations

• Many missions in the Decadal Survey were constellation missions
  – “Kitchen Sink” Missions
  – Extremely Expensive

• We need to change the way we think about satellites in order to accomplish a real constellation mission
  – NSF CubeSat funding has really led the way

• Sacrifice measuring everything really well for measuring some things all over the place

• If you want to do global-scale science this is really the only way to accomplish it with satellites
General Idea

• Launch many very small satellites (CubeSats, NanoSats, whatever) that can measure things that the community wants over the entire globe

• Example instrumentation
  – UT Dallas Suite to get ion density, temperature and drifts
  – NRL/Goddard Suite to measure ion/neutral density, temperature and winds
  – SRI imager to remotely measure O/N2, precipitation, etc
  – Langmuir probes to measure electron/ion density and temperatures

• Don’t put ALL of these on the satellites, put one or two to keep costs way down.
32 satellites

12 minutes worth of data are shown on each frame.

Color is the thermospheric temperature while the vector shows the neutral winds.
Science Enabling Example

- Global Maps – Having many satellite around the globe allows the investigation of dynamics of the system!
Advantages

• Measure northern, southern, dayside and nightside all at the same time.
• Pass over the same place on the Earth significantly more than once or twice a day.
• Can start to unravel the spatial/temporal ambiguity that satellite measurements have.
• Data covers nearly all latitudes, so it would be useful to the entire CEDAR/GEM communities.
  – Especially if an instrument or two were selected that measured quantities of interest to both communities
• Could cover all local time sectors in a matter of weeks instead of months.
Science Enabling Example

- Meso-Scale Science – When the satellites are close together, we will be able to investigate very small phenomena, such as gradients in the temperature, flows and densities.

Mark Conde and his student made this image!
How Many Satellites Are Needed?
We can figure that out!
Costs?

• There are many mature CubeSat busses that exist. It would cost approximately $1M/satellite to build and test them to NASA standards.
  – This is for many satellites.
• Instruments would cost on the order of $500K to build and test to NASA standards. Let’s say $1M/satellite.
• Operations costs would be about $250K/satellite for 2 years.
  – This is mainly to get the data to the ground.
• We are up to about $2.25M/satellite
Scale?

- If you launched each as a secondary payload on an existing launch, the launch costs could be as low as $200K/satellite
  - You might not get all of the satellites exactly where you want them
  - But, it doesn’t matter if you really want global coverage (could have some polar orbits, some equatorial orbit, some mid-latitude orbits)
  - Raises cost to about $2.5M/satellite
  - Scale to, say, 24 satellites gives you $60M. 48 would be $120M.
  - Managing this would take a large team, on the order of $1M/year.
  - If you launched them as secondary payloads, they would be deployed over a series of many years, allowing data to be collected for 5-10 years.
Scale

• If you wanted a dedicated launcher, it would cost on the order of $50M.
  – This would allow you to put the satellites where you want them, but at a high price
  – If you launch, say, 40 satellites, it would cost roughly ($2.25M * 40 + $50M = ) $140M.
  – Management would cost a lot of money for this type of a program.
NSF? Really?

• I don’t think that NSF would ever fund a full mission including launch costs for a single launch vehicle.
  – That is NASA prerogative.
• But, I could imagine NSF funding the building of ~40-50 CubeSats that get launched as secondary payloads on many different rockets.
  – NSF has already launched 6 satellites into space.
  – This would spread the constellation out very quickly, and would really be the most inclusive of the entire community
• Can think of these as “space buoys”. Distribute them across the thermosphere and ionosphere to address system-level science.
  – Community would benefit greatly from the huge amount of data made available by such a mission.
Summary

• There are advantages and disadvantages with ground-based instruments, satellites and constellations of satellites.

• Constellations that have a sensor that can measure a few things at many different locations allows system-level science to be accomplished.

• If we as a community sold this as something comparable to deploying sensors everywhere, it might fly as an NSF sponsored program.