a continental-scale neutral-wind observatory

Jonathan J. Makela (University of Illinois)

with significant contributions from A. Ridley, G. Bust, M. Conde, J. Meriwether (and others)
overview

• motivation for a distributed network focusing on neutral wind measurements

• what instrumentation could a wind-measuring network utilize?

• a possible deployment scenario to study the spatial-temporal properties of thermospheric winds over north america

• challenges, caveats, and conclusions
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• the winds transport (or advect) mass, momentum, and energy throughout the atmosphere system

\[ \frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{U}) = 0 \]  
(continuity equation)

\[ \rho \left( \frac{\partial \mathbf{U}}{\partial t} + \mathbf{U} \cdot \nabla \mathbf{U} \right) = -\nabla p + \mathbf{g} \]  
(momentum equation)

\[ \frac{\partial p}{\partial t} + \mathbf{U} \cdot \nabla p + \gamma p (\nabla \cdot \mathbf{U}) = 0 \]  
(energy equation)

• winds also move plasma through drag/collisions and can induce currents and electric fields

• at high-latitudes, ion motions drive the wind at short spatial/temporal scales

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importance of wind measurements
• how do gradients in the parallel-to-$\mathbf{B}$ neutral winds affect the vertical distribution of plasma and its lifetime?
  • during storms, the change in these gradients may relate to features seen in electron densities at mid-latitudes
• how does the polar thermosphere respond to forcing from the magnetosphere via electric fields through ion drag and Joule heating?
  • neutral wind and temperature field maps would unambiguously show this effect
• how does an air-parcel move from polar to mid-latitudes?
  • requires tracking spatial gradients in the wind field over a large area
• is the day-to-day variability we see in the neutral winds due to the wind field being fundamentally different each day, or is the wind field the same but the overall field wanders over a given site, giving the impression of variability?
  • spatially resolved wind fields are required to resolve these possibilities
• despite importance of neutral winds, they are vastly under sampled

• current ground-based network is quite sparse

• historically, <1,000 wind measurements per day

• satellite increase global density of measurement during their lifetimes (e.g., WINDII, CHAMP, GRACE, GOCE... SWARM, ICON)

• (rough) estimate of current ground-based network provides ~20K measurements per day

• SuperDARN provides ~1M measurements per day!

neutral wind measurement availability
• dynamics of the plasma state have been elucidated by networks of sensors over the past decade
• ability to decipher the dynamics has led to the discovery of new phenomena and a deeper understanding of underlying physics

plasma spatial/temporal dynamics
assimilative models

Ne data
GPS TEC, COSMIC TEC, ISR, etc

Electrodynamics data
$E$-field/ion drifts: DMSP, C/NOFS, magnetometer $\Delta H$, ISR, CSR, SuperDARN
Winds: ???

Empirical/climatological models
MSIS, IRI, HWM

IDA4D
3D global map of Ne, Ne error covariance

EMPIRE
Estimated winds and fields

Physics-based model
(continuity equations)

Predicted Ne and covariance at t+1
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• challenges, caveats, and conclusions
• ~2° field-of-view
• 7-cm diameter etalon with 1.5-cm fixed gap
• high QE thermoelectrically cooled CCD with low readout noise
• sky scanning mirror system to dynamically choose look directions
• capable of multiple wavelength observations utilizing a filter slider
• produces observations of ~10 orders of the interferogram, yielding estimates of winds (±5 m/s) and temperatures (±15 K)
• robust and automatic operation and analysis routines developed

narrow-field fabry-perot interferometer (FPI)
storm response: 14 nov 2012
storm response: 14 nov 2012 (temperatures)
wind flow maps from NATION
• ~70° field-of-view
• large diameter (10-15 cm) etalon with piezoelectrically-scannable etalon
• electron-multiplying, thermoelectrically cooled CCD
• capable of multiple wavelength observations utilizing a filter wheel
• produces observations of ~5-8 orders of the interferogram as well as image of the sky emission
  • 115 “zones” analyzed to produce map of neutral wind field
• robust and automatic operation and analysis routines developed

scanning doppler imager (SDI)
Movie courtesy of M. Conde
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existing wind-measurement network
potential wind-measurement network
• network of 20 SDIs and 35 FPIs would provide ~125K wind measurements per day
  • close to an order of magnitude increase over current data levels
  • data would be available in (near) real-time and could be ingested into assimilative forecasting models

• algorithms have been developed to coordinate distributed FPI observations with the ability to modify the observing strategy in realtime to respond to current conditions
  • existing algorithms can analyze multi-static SDI and FPI observations to obtain vector wind fields

potential data output
• rough estimates for instrumentation and infrastructure (probably some quantity discounts)
  • narrow-field FPI ~$100K
  • SDI ~$400K

• 20 SDIs + 35 FPIs = ~$11.5M

• could add:
  • wide-angle imaging systems at all FPI sites for additional ~$3.5M
  • magnetometers at all sites for ~$1M
  • GPS at all sites for ~$500K

• operations would involve some local collaborators (proven model with good broader impacts implications), but still requires centralized management

• would also need computing infrastructure (storage/processing) to handle data analysis and serving to community databases

• “spare” instruments would be needed for rapid deployment in case of failure of a field sensor
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• this discussion has been predicated on thermospheric wind measurements. what about mesospheric winds?
  • can be added through inclusion of filters (reducing temporal cadence) or deploying more instruments side-by-side (increasing cost)

• the proposed network only covers ~4% of the globe. what about the other 96%?
  • satellites (e.g., ICON) are excellent for specifying the global-scale wind fields
  • outstanding question in understanding the spatial-temporal dynamics that occur on a more local scale length
  • proposed network overlaps significant infrastructure currently in place (e.g., GPS CORS, SuperDARN, Millstone Hill)
  • concept is extendable, depending on funding levels

challenges and caveats
• there are other instruments that provide wind measurements. why the SDI and FPI?
  • alternates exist (e.g., Michelson interferometers, systems utilizing solid etalons). trades in terms of cost, performance, and availability need to be made
  • these instruments only provide observations during the night. what about daytime?
  • multi-etalon systems (e.g., SOFDI) could extend observations into daytime (increase cost)
  • it is likely that specifying the wind field immediately before sunrise will improve results of assimilative models for several hours into the day

challenges and caveats
• a large-scale, distributed wind observation network is within our current technological capabilities

• such a network would provide measurements that address many fundamental, unresolved questions in understanding the near-space environment

• wind data are crucial for improving results from assimilative models and predicting space weather

conclusions