First Observations from the Winds Cross-Track Instrument on the Dynamo 2 Mission

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Abstract

The first neutral wind measurements of the Winds Cross-Track (WCT) instrument, taken during the recent Dynamo 2 campaign, are presented and discussed. This campaign launched two sounding rockets with identical payloads, each with a WCT on board, on different days in July, 2021 into the lower ionosphere to characterize the strong, daytime meridional currents of the global dynamo system and also the daytime neutral winds in the lower thermosphere. The two rockets reached apogees of ˜124 and ˜131 km, and the WCT took measurements above ˜80 km on both the up- and downleg of both flights. As the rocket traveled through the atmosphere, the neutral gas was rammed into the instrument, where an ionization gauge measured the gas pressure. By modulating the incoming flux with a rotating baffle, the WCT measured the components of the neutral wind vector perpendicular to the trajectory of the rocket as well as the gas temperature. These in-situ wind and temperature profiles will be compared to the wind profiles observed remotely by the ICON satellite, which was in conjunction with the launch of both Dynamo 2 rockets.

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Key Takeaways

The Dynamo 2 Campaign launched July 2021 to study the global dynamo current

On board was the **Winds Cross-Track instrument**, which **measures the neutral wind vector frequently and accurately**

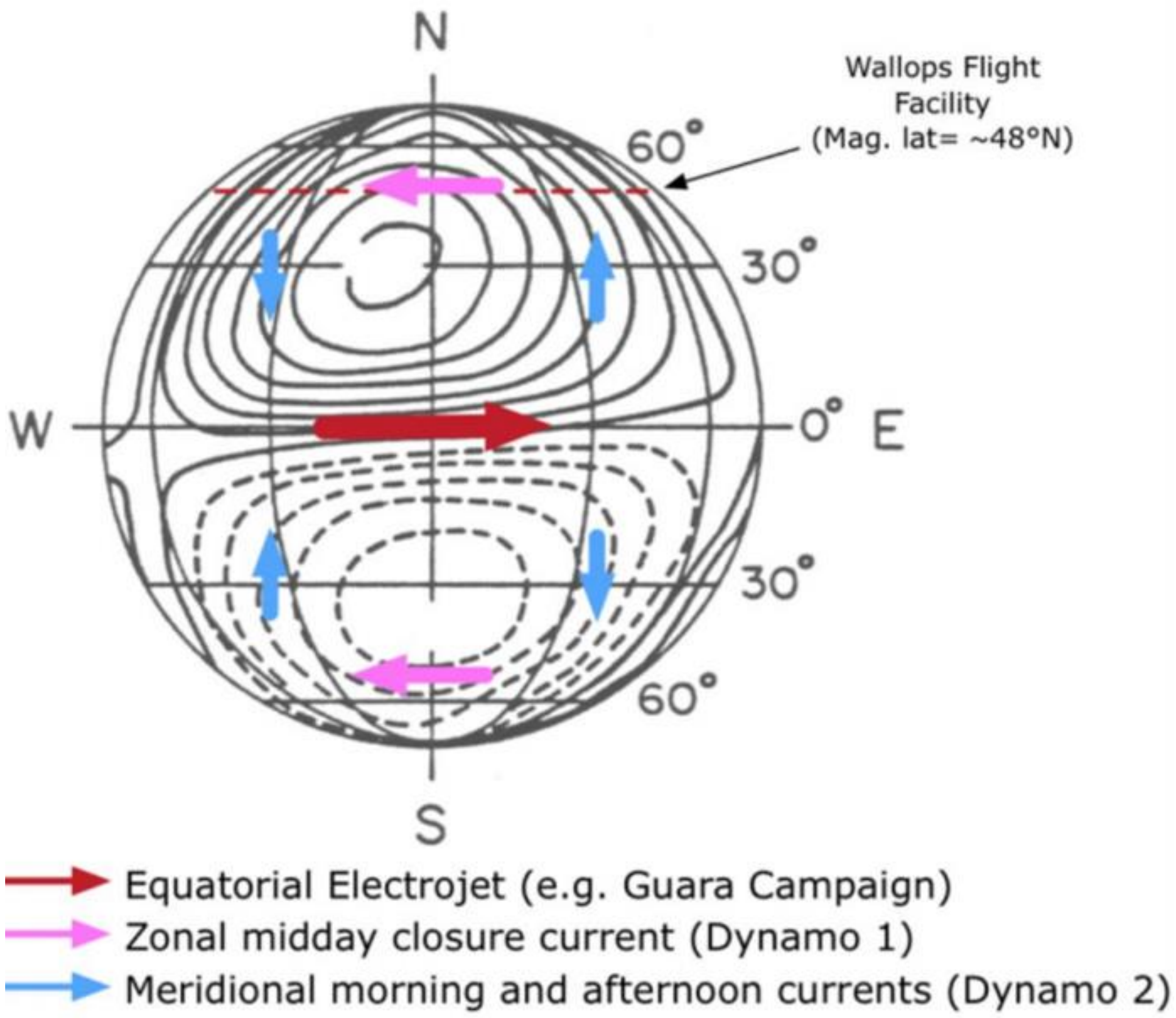
Initial, preliminary results are promising and show wind speeds ~50-150 m/s between altitudes 110-130 km

Global Dynamo

- Solar heating and gravitation tides generate neutral winds
- Wind drives unmagnetized electrons across field lines
  →Generates Currents
- Dynamo Equation

$$\vec{J} = \overline{\sigma}(\vec{E} + \vec{U} \times \vec{B})$$

- Strongest between ~80-135 km

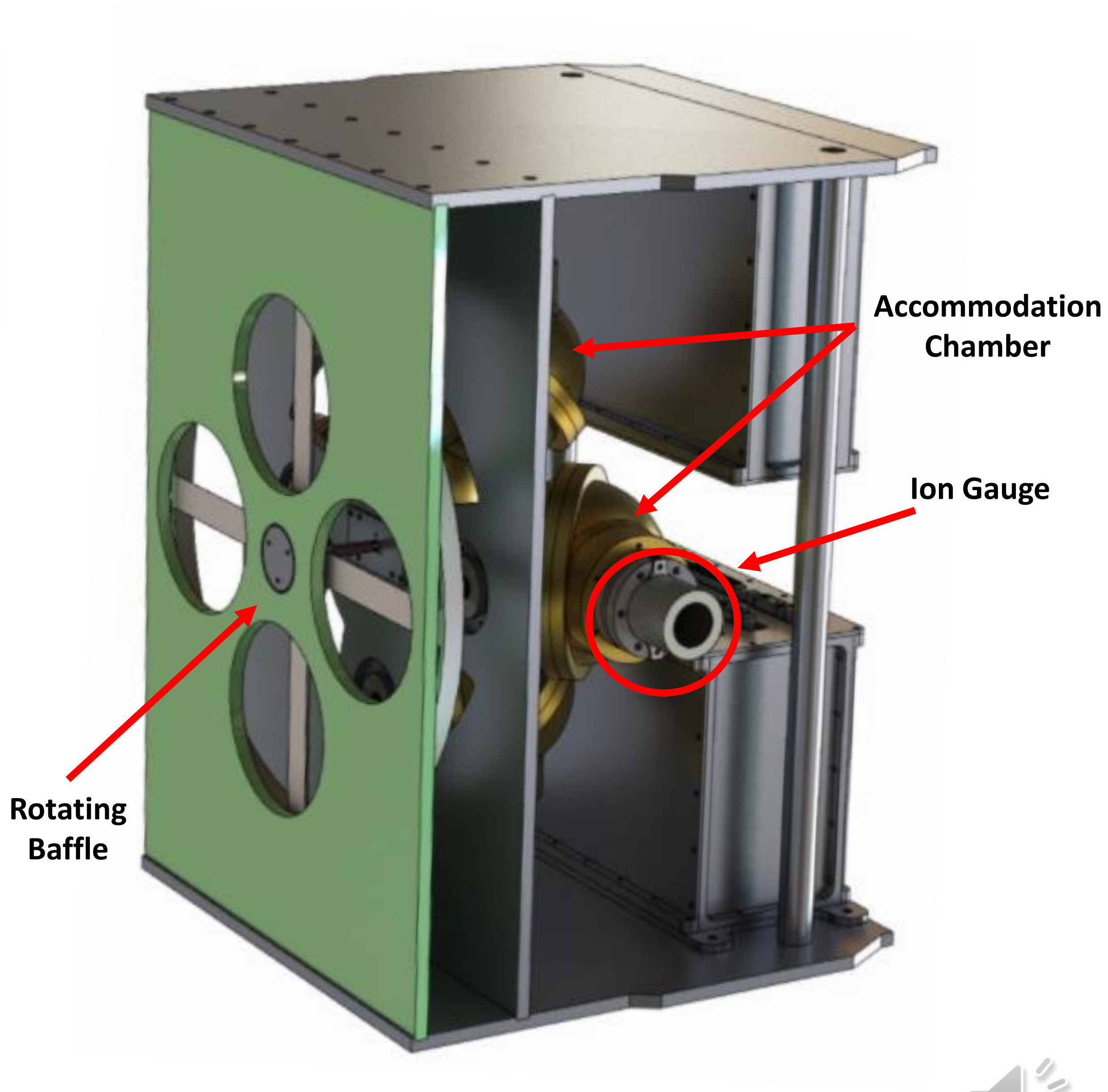


Dynamo 2 Campaign

- Investigate meridional currents and characterize the Dynamo equation as a function of altitude
  - Driven primarily by imposed electric fields, large neutral winds, or both?
- Obtain accurate, vector **neutral wind profiles** of the daytime E-region
- Two identical rockets were launched separately in July 2021 from Wallops Flight Facility
- Instruments include: Electric field probes, magnetometers, Langmuir Probes, Ionization Gauges, **Winds Cross-Track** and In-Track, and Ion Mass Spectrometer

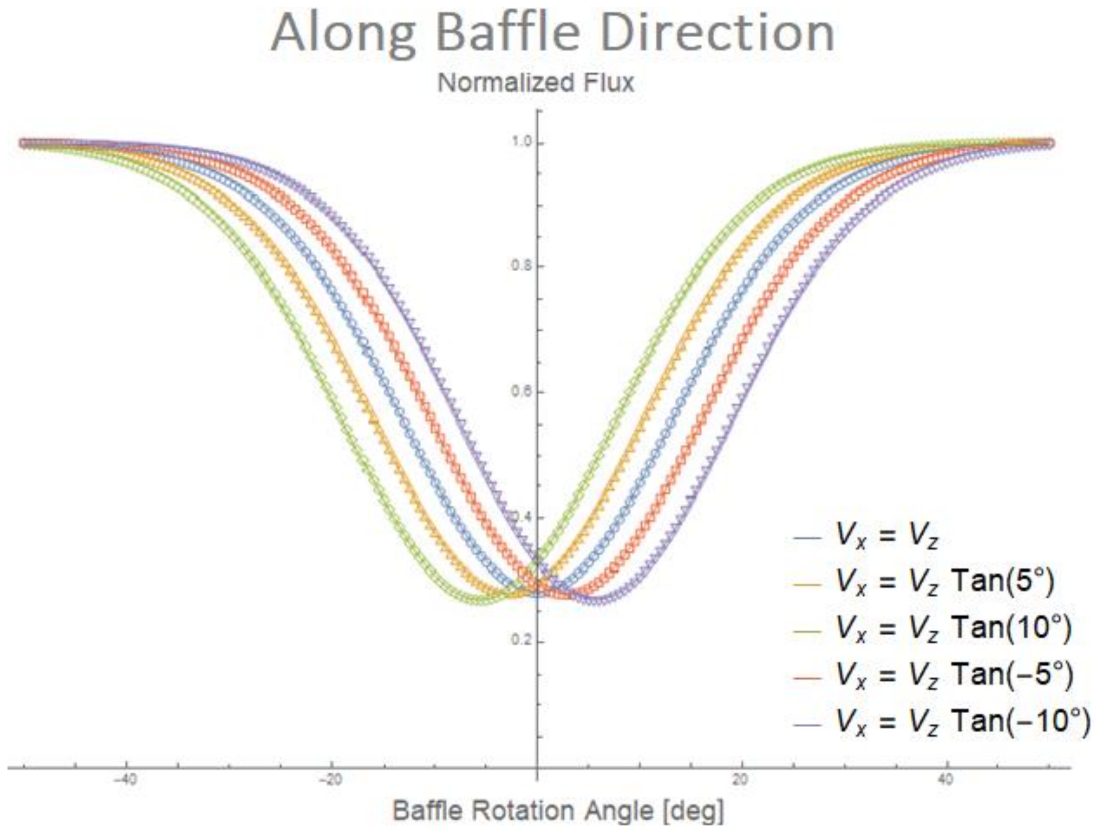
Winds Cross-Track Instrument

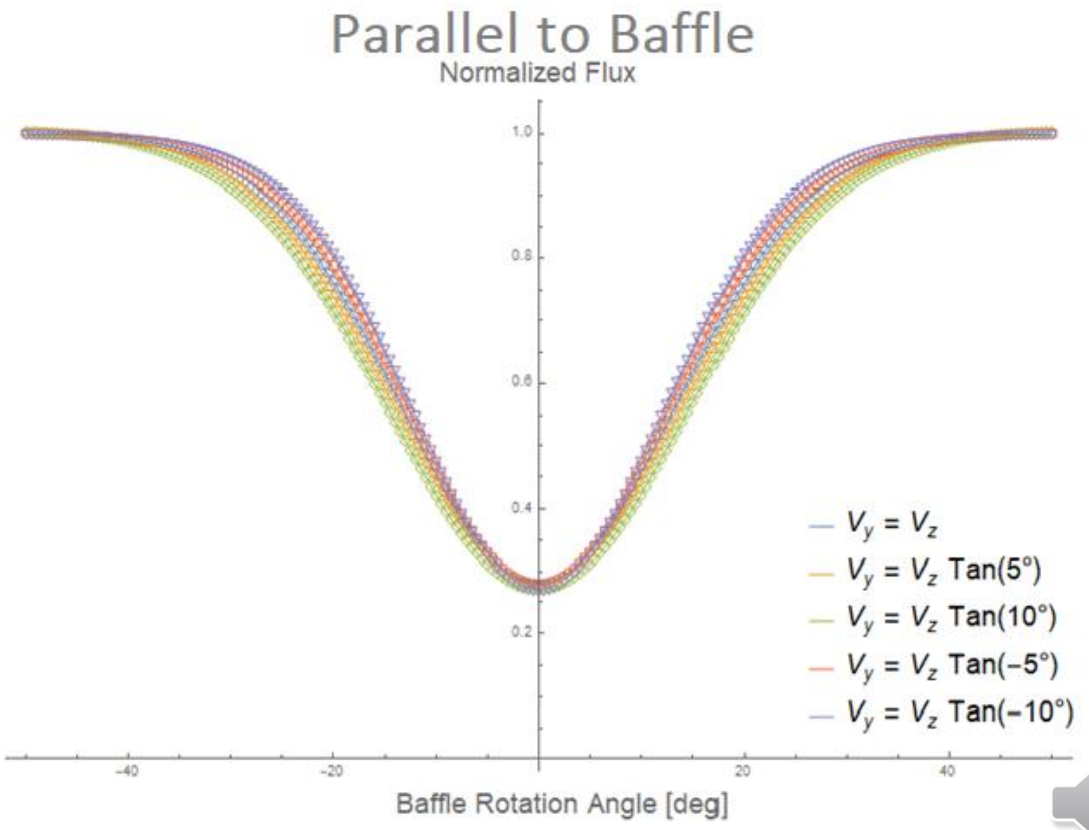
- Goal: Measure the **cross-track** (perpendicular to ramming direction) **neutral wind vector** components, **thermal velocity** of ambient gas, and **mean molecular mass**
- Incoming flux is rammed into the instrument and modulated by a rotating baffle, forming a wake
- When gas impacts the accommodation chamber, the gas obtains the known temperature of the chamber
- 4 Ionization gauges, oriented in 90° increments, measure how the density changes as a function of baffle rotation at 1000 samples per second
- **Neutral wind sampled 8 times per second**



Model Response to Neutral Winds

- The **displacement of the wake** indicates a **neutral wind vector component along the baffle rotation direction**
- The component parallel to the baffle is more difficult to measure, thus why the apertures are oriented in 90° increments

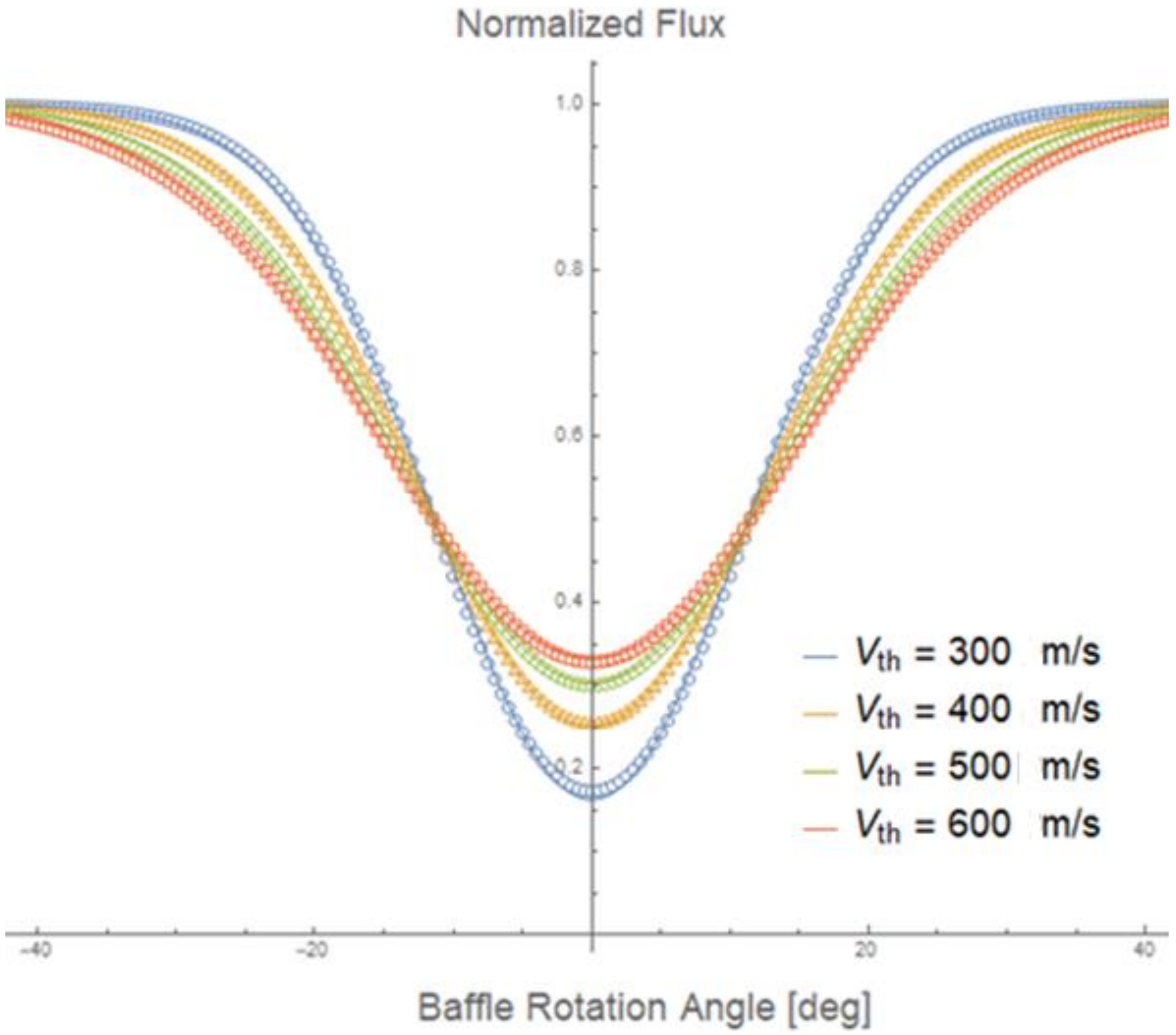




Response to changing neutral wind vectors as a function baffle rotation angle for velocities expected for Dynamo 2

Model Response to Thermal Velocity

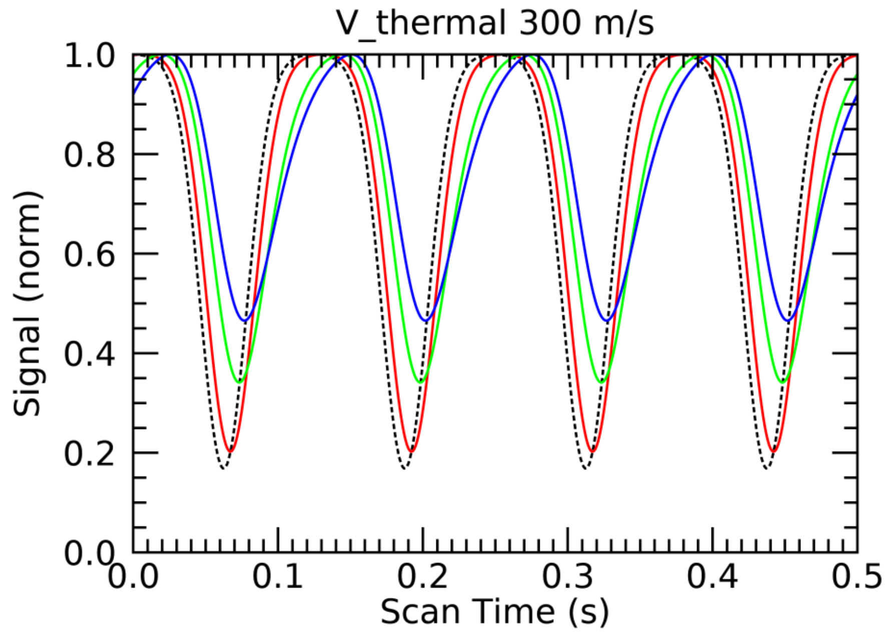
- The response of the WCT to a variety of gas parameters was modeled
- For **increasing thermal velocity, the width of the wake increases**



Response to changing thermal velocity as a function baffle rotation angle for velocities expected for Dynamo 2

Accommodation Chamber Time Constant

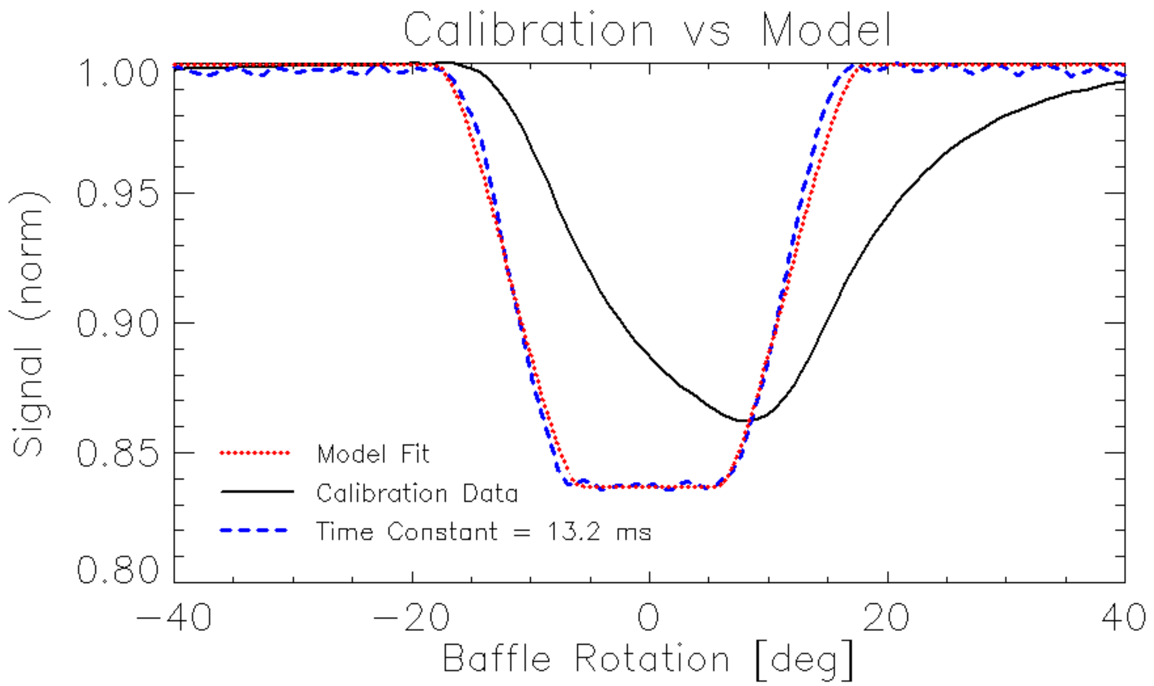
- The incoming flux rammed into the accommodation chamber must balance the outgoing flux
- The measured wake thus has a delayed response to the incoming flux as it takes some time for the gas to exit the chamber
- This time constant is proportional to the thermal velocity
- **Combine with the independently measured thermal velocity to get temperature and mean molecular mass of the ambient gas**



Modeled response to for different time constants: 5 ms (red), 15 ms (green), and 25 ms (blue)

Application of Time Constant

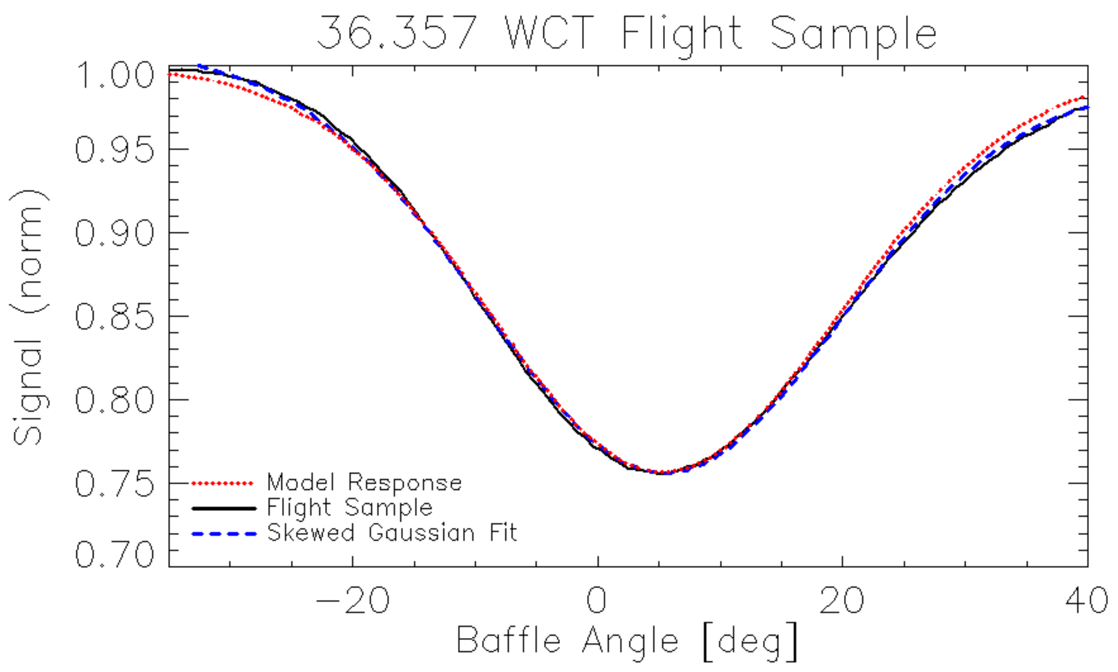
- Laboratory calibration data utilizing supersonic molecular beam
  - Such beams are cold (few K), thus the “blockish” wake
- Time constant selected which best symmetrizes the signal about its minimum
  - At normal incidence, signal is well-fit by a gaussian, i.e., it is symmetric
- Best fit **time constant was 13.2±0.1 ms**, which corresponds to a **mean molecular mass of ~28.3±0.5 amu → N2**!
- Similar results for finding Ar molecular mass
- The adjusted signal matched well with the modeled incoming flux



Calibration Data for N2 at Normal Incidence

Turning Flight Signals into Gas Parameters

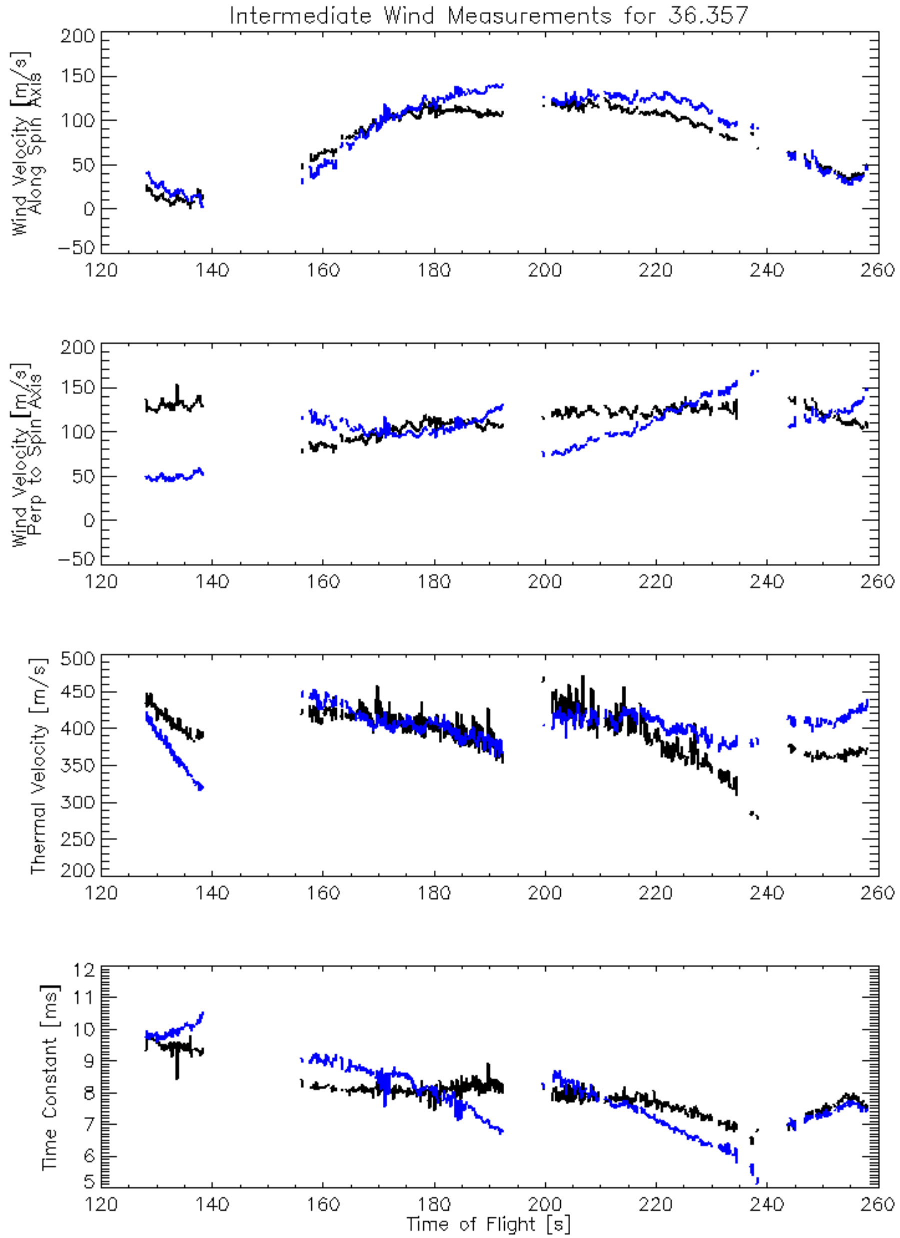
- A skewed Gaussian is fit to each sample
- Broadly speaking:
  - Displacement → wind along baffle rotation
  - Width of wake → thermal velocity
  - Skewness of wake → time constant of instrument and high wind vector angle
    - → mean molecular mass
    - → temperature
- Fit parameters are then compared against a catalog of known, modeled signals
  - Closest match inverts the measured fit into gas parameters
- Note each gas parameter affects each fit parameter to some extent



WCT Sample from Flight 36.357

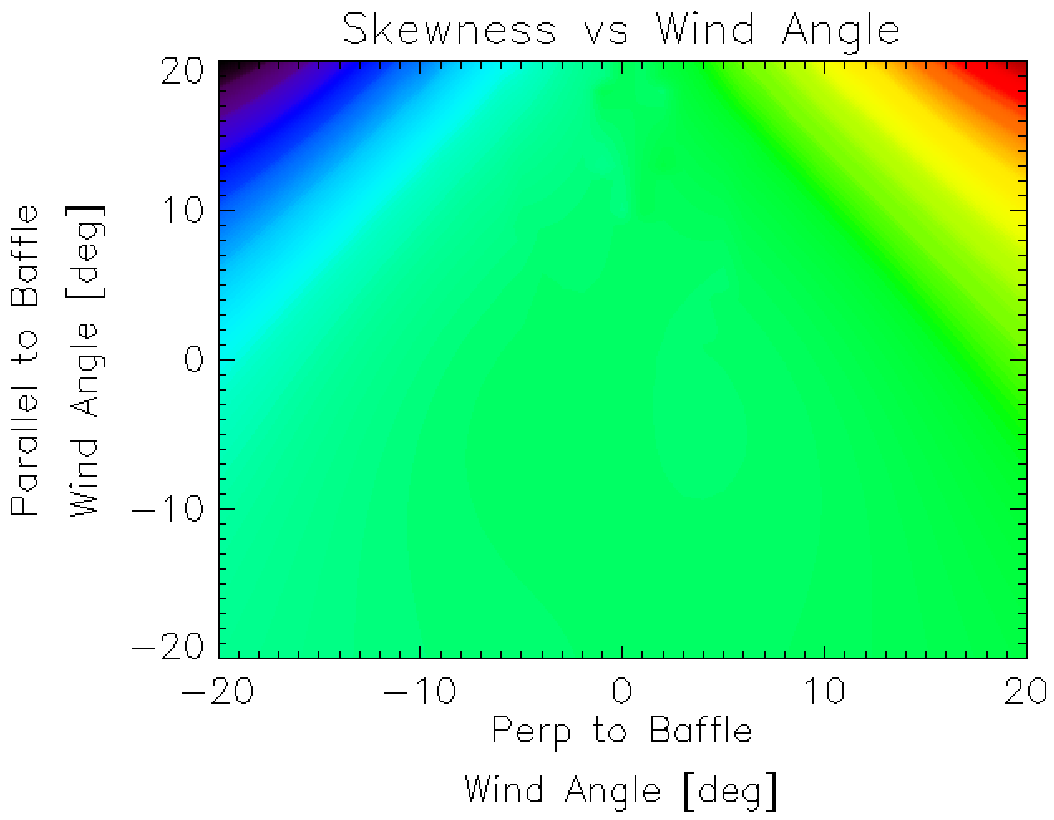
Intermediate Results

- Status of WCT measurements from Dynamo 2
- As expected, winds in the range of 50-150 m/s are observed at altitudes between 110-130 km
- An accurate In-Track component is required to turn the WCT measurements into accurate wind and thermal velocity measurements
- Data in the gaps needs further work, measurements complicated by high angles of attack or ACS maneuvers
- Thermal velocity and time constant measurements require further work



Road Ahead

- The current conversion from fit to gas parameters assumes that skewness is dependent solely on the time constant
- However, at high wind angles (+/-15°), skewness caused by the high-angles becomes comparable to chamber-caused skew
- Separating the high-angle and chamber-caused skews is the next step
- Accounting for effects of scale height and more accurate rotation rates are further steps

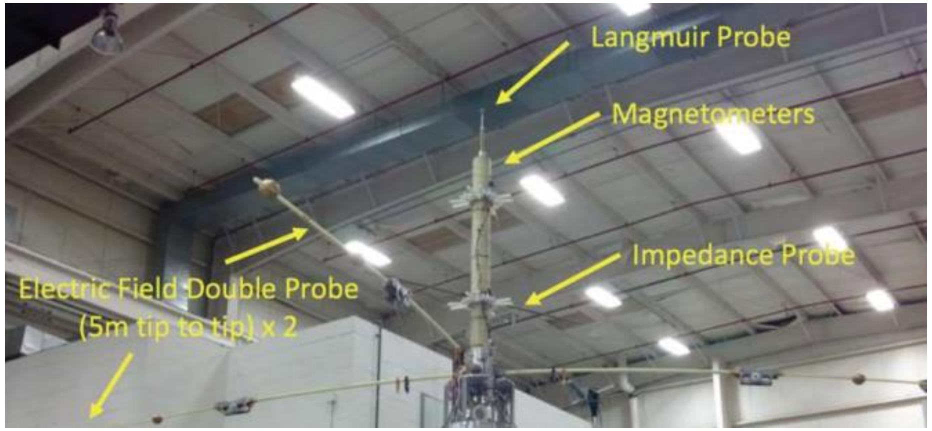


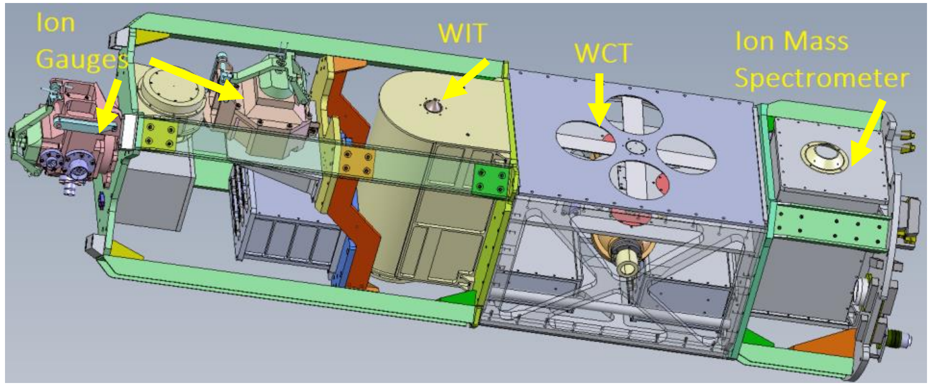
Summary

The Dynamo 2 Campaign launched July 2021 to study the global dynamo current

On board was the **Winds Cross-Track instrument**, which **measures the neutral wind vector frequently and accurately** using a rotating baffle

Initial results are promising, though further work is required to fully utilize and understand the *in situ* wind measurements



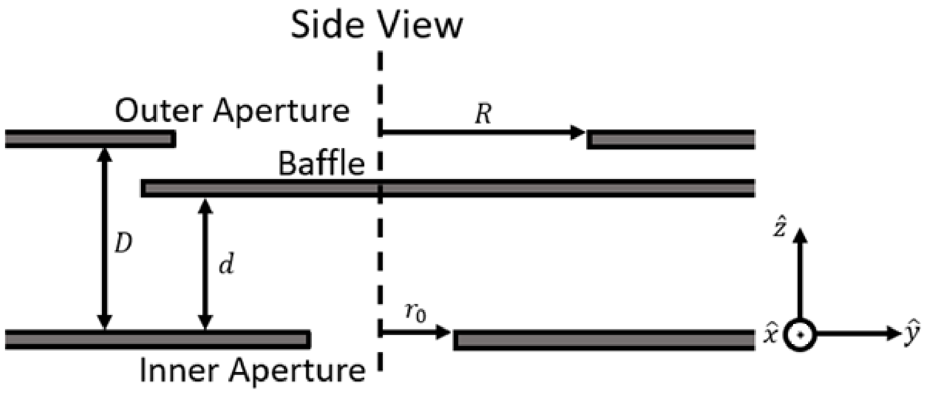


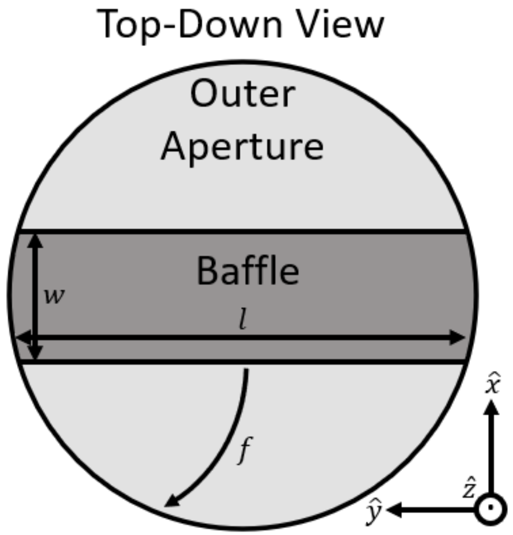
Dynamo 2 Instrumentation

- DC Electric Field Probes (E-field)
- Vector Magnetometer (B-field)
- Langmuir Probes (plasma density)
- Ionization Gauges (neutral density)
- **Wind Cross-Track** and In-Track (**neutral wind vector**)
- Ion Mass Spectrometer (plasma composition)

WCT Design

- The WCT has 4 apertures, each with an accommodation chamber and ionization gauge, oriented in 90° increments
- A baffle rotates above the apertures at a rate of 2 Hz, leading to a **fast 8 samples per second**
- A optical sensor measures the rotation rate of the baffle
- **Ion gauges measure the chamber density at 1000 samples per second** (around 0.72° of rotation per sample)





Limitations and Room for Improvement

- The rotation rate of the baffle influences how much time is available for the incoming and outgoing flux to balance
  - Primarily impacts the neutral wind velocity and time constant measurements
  - Currently sampled at a rate of 1 kHz
  - Increased time resolution can yet be gleaned from extra words in telemetry file
- The catalog of model responses can be expanded for larger wind angles and thermal velocities
- The model can be improved by including back-scattering of the outgoing gas on the baffle (likely a minor factor)