Ka-band Doppler Scatterometer for Measurements of Ocean Surface Vector Winds and Currents

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Why Measure Ocean Currents?

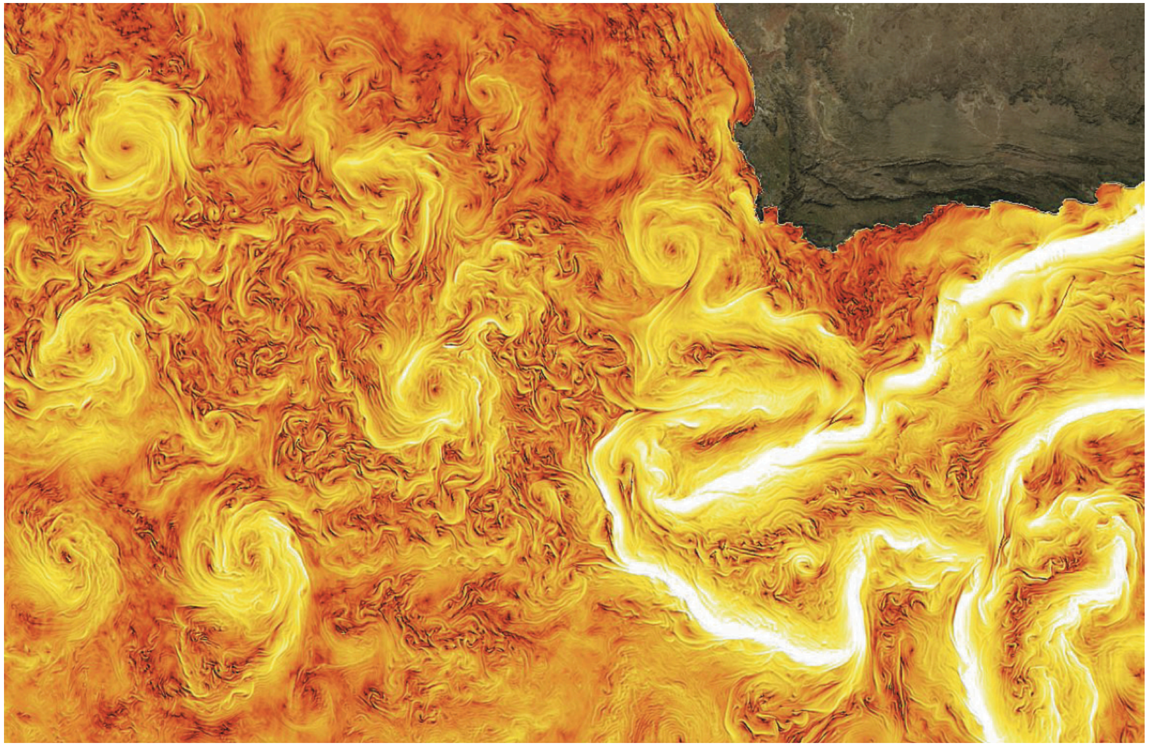


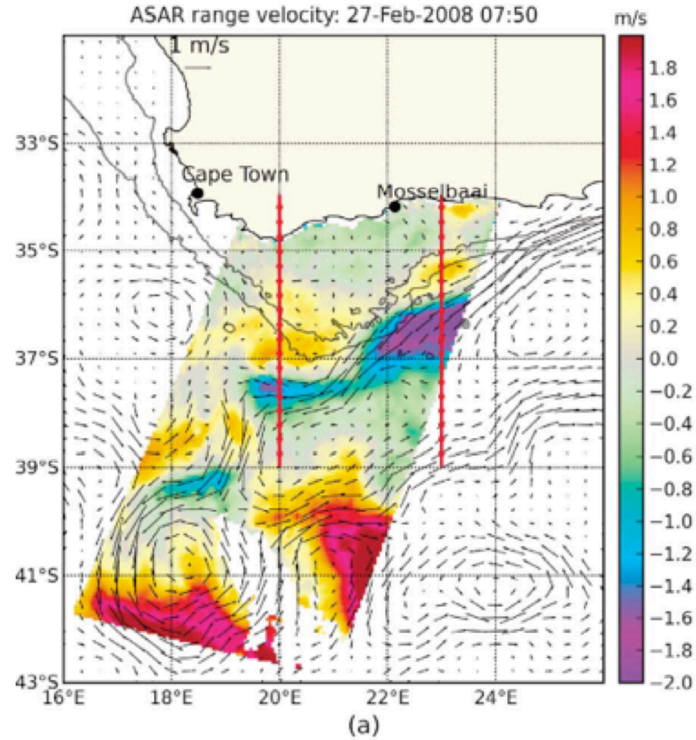
Image of modeled ocean surface currents from the high resolution ECCO2 model (courtesy D. Menemenlis, JPL).

Currently, we have no way to validate these results at high resolution.

- Ocean surface currents are an essential climate variable
- Knowledge of ocean surface currents will improve our knowledge of energy transfer between the atmosphere and the ocean and our understanding of the advection of heat, nutrients, and pollutants in the ocean.
- Ocean surface currents are a unique complement to the geostrophic currents measured by the forthcoming SWOT mission.

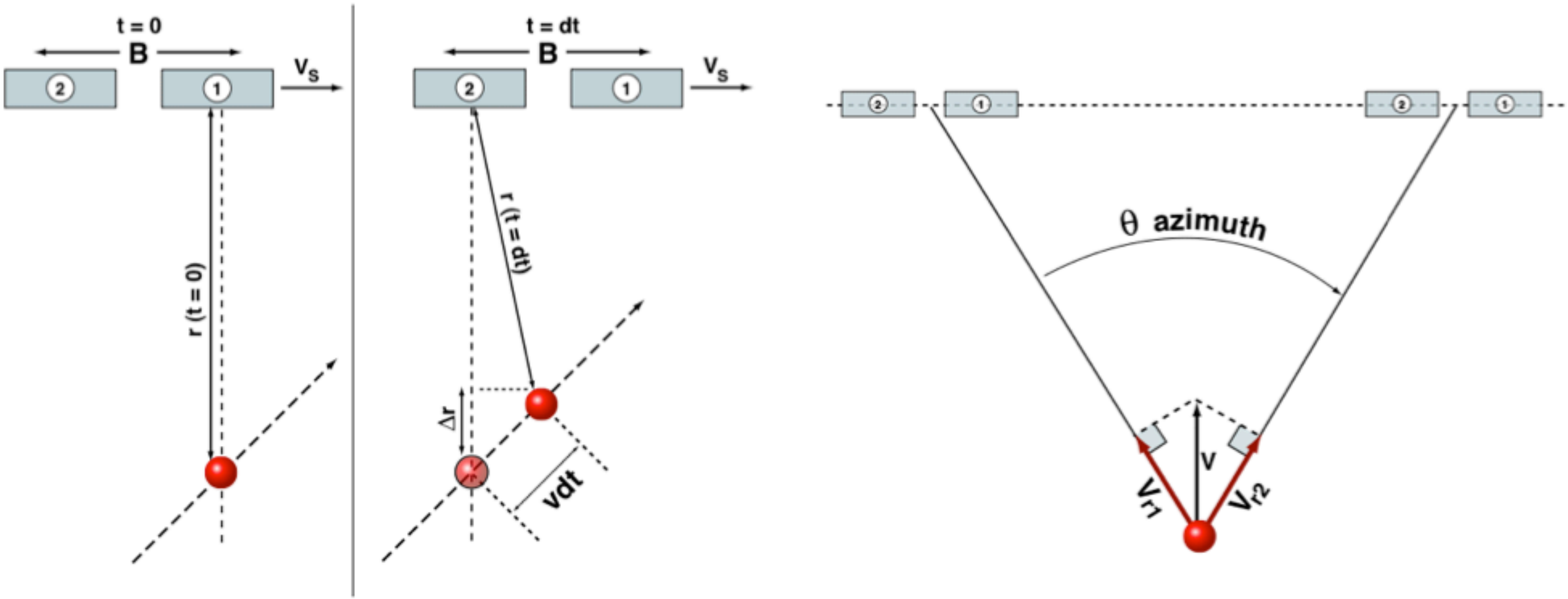
The DopplerScatt Concept

- Coherent radars can measure radial velocities by measuring Doppler shifts.
- The use of Doppler for one component of the surface current velocity has been demonstrated from space using SAR's.
  - Since SAR only looks in one direction, only one component of the velocity is retrieved.
  - Swath width and data rate limitations make SAR's impractical for global coverage
- Rodríguez (2012, 2014) has extended the concept to be able to measure ***both*** components by using a pencil-beam scanning scatterometer.
  - A wide swath coverage would enable global coverage in one day
  - The same instrument would also measure high resolution winds
- The DopplerScatt IIP will demonstrate the feasibility and accuracy of this concept using an airborne instrument and the results will be applicable to future spaceborne missions.



Comparison of surface current radial component measured by ASAR and geostrophic currents from the AVISO altimetry product. Rouault, M. J., Mouche, A., Collard, F., Johannessen, J. A. & Chapron, B. Mapping the Agulhas Current from space: An assessment of ASAR surface current velocities. Journal of Geophysical Research 115, (2010).

Doppler Measurement Concept



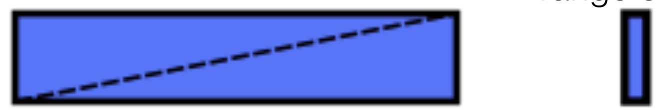
Pulse-pair Phase Difference: $\Delta\Phi = 2k\Delta r$
Radial velocity component: $v_r = \Delta r/dt = \Delta\Phi/(2kdt)$

Vector currents are estimated by combining multiple (2-4) radial velocity measurements

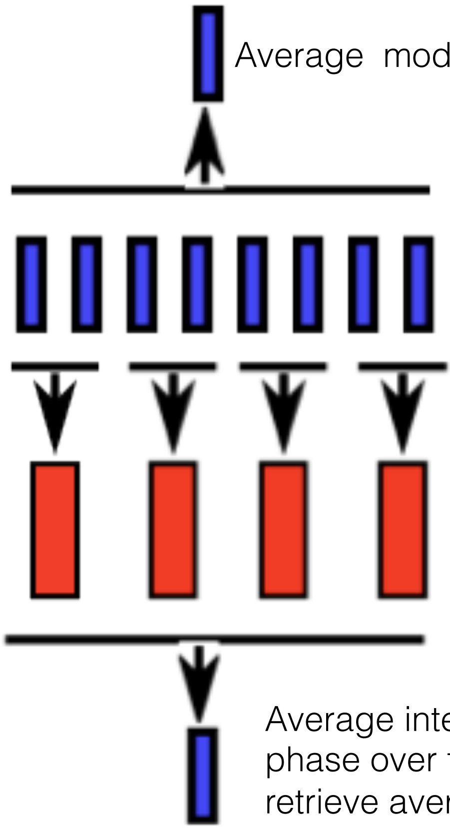
- Conventional scatterometers transmit a long (1.5 msec) pulse
- Transmit instead N (~10) closely spaced shorter duration pulses with the same bandwidth (spatial resolution) and estimate Doppler by comparing return pulse phase differences.
- Estimate vector currents by combining multiple azimuth measurements.

Onboard Data Processing

Conventional Scatterometer



Doppler Scatterometer



The added processing steps in the new processing are well understood and can be implemented onboard using an FPGA. The final data rate is ~2x the conventional scatterometer data rate and many orders of magnitude smaller than the SAR data rate. A more complicated processor has been implemented for SWOT.

DopplerScatt vs Doppler SAR/ATI from Space

DopplerScat

- Wide swath: ~1800 km
- Global Coverage: ~daily
- Pencil beam scatterometer
- Rotating 2m x 1m antenna
- Simultaneous vector winds and currents
- Antenna pointing solved by Doppler tracking over full cycle
- 10 cm/s @25 km

SAR/ATI

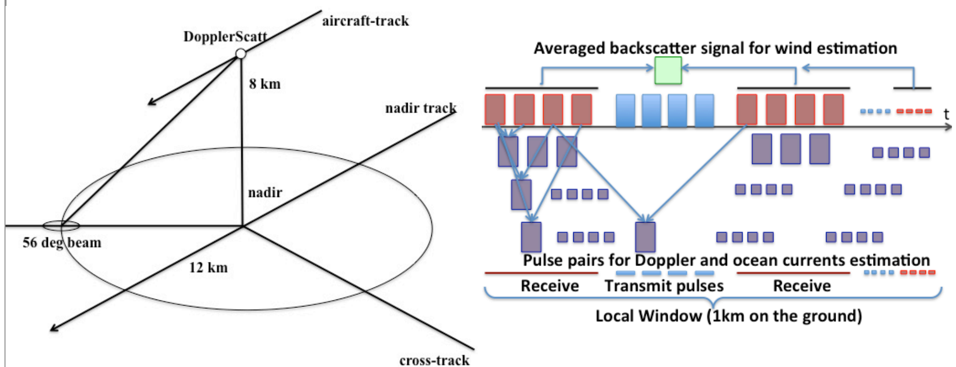
- Swath < 400 km
- Global Coverage: >weekly
- Single beam
- ~5m scanSAR antenna
- Only one component of currents, winds rely on surface feature for direction
- Antenna pointing problematic, relies on land
- 10 cm/s @1km

Ka-band Doppler Scatterometer for Measurements of Ocean Vector Winds and Surface Currents (DopplerScatt)

PI: Dragana Perkovic-Martin, JPL

Objective

- Develop a proof-of-concept Ka-band Doppler scatterometer (DopplerScatt) to demonstrate simultaneous direct measurements of ocean vector winds and surface currents over a wide swath for future spaceborne scatterometer.
  - These coupled measurements will enable improved understanding of relevant air-sea interactions and their influence on heat transport, surface momentum and gas fluxes, ocean productivity and marine biology .
- Demonstrate the concept and performance of DopplerScatt in lab tests over temperature and in airborne test flights.



Pencil-beam concept for airborne DopplerScatt, with wide-swath coverage (left) and combination of burst measurements for estimation of phase shift and power (right)

Approach

- Development of loopback calibration capabilities.
- Development of a scanning 56 deg antenna subsystem and its airborne accommodation with a custom radome.
- Laboratory testing of functions and performance at subsystem and system end-to-end levels over airborne thermal environment.
- Integration of instrument into a stand-alone package, coupled to a precision inertial measurement unit (IMU).
- Flying engineering flights on the DoE King Air B200 aircraft.

Co-Is/Partners:

Mauricio Sanchez-Barbetty, Maxim Neumann, Ernesto Rodriguez, JPL; Gordon Farquharson, APL/U. Washington

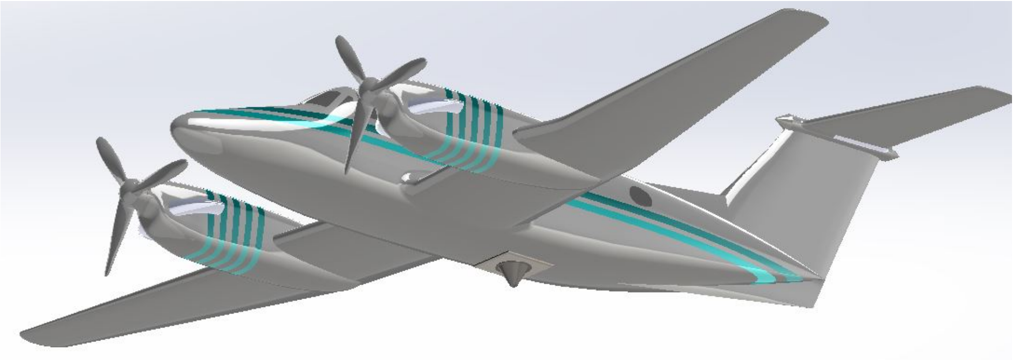
Key Milestones

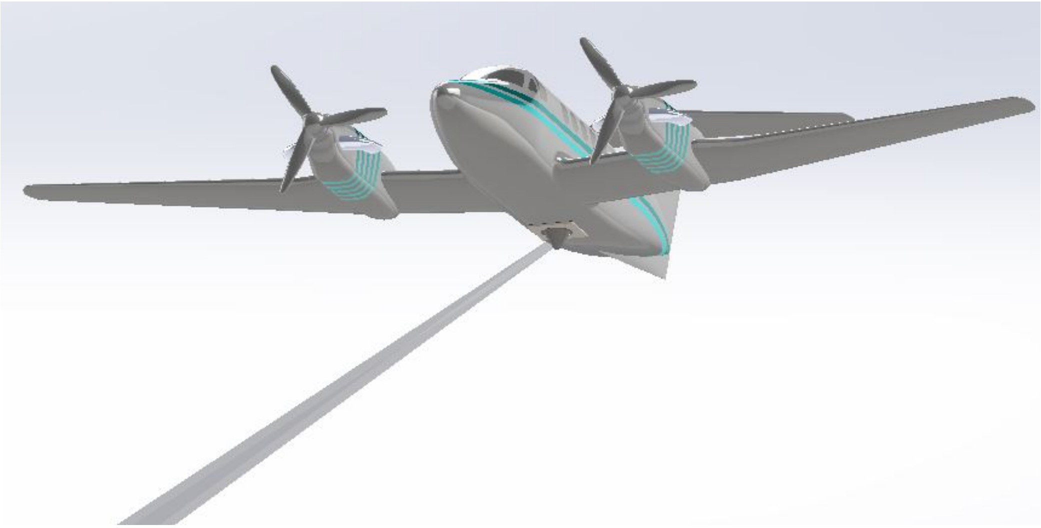
Milestone	Original	Current
Develop system requirements	08/14	09/14
Develop system design and architecture	09/14	08/14
Integrate and test calibration loop over temperature	05/15	
Integrate and test antenna subsystem (including spin mechanism, rotary joint and antenna)	03/16	
Complete spaceborne system study and technology readiness assessment	05/16	
Complete instrument integration and end-to-end testing in a thermal chamber	12/16	
Complete engineering test flights	04/17	
Complete measurement validation	05/17	

TRL_{in} = 3 $TRL_{current}$ = 3

Airborne System Requirements

Parameter	Value
Center Frequency	35.75 GHz
Peak Transmit Power	90 W
Burst Repetition	8 kHz (max)
System Noise Figure	10 dB (max)
Antenna Rotation Rate	5-25 rpm
Antenna Beamwidth	2.9 deg
Velocity Bias	1.0 cm/s
Velocity Precision	10 cm/s
Wind Speed Accuracy	2 m/s (3-20 m/s) 10 % (20-30 m/s)
Wind Direction Accuracy	20 deg
Resolution cell size	5 km





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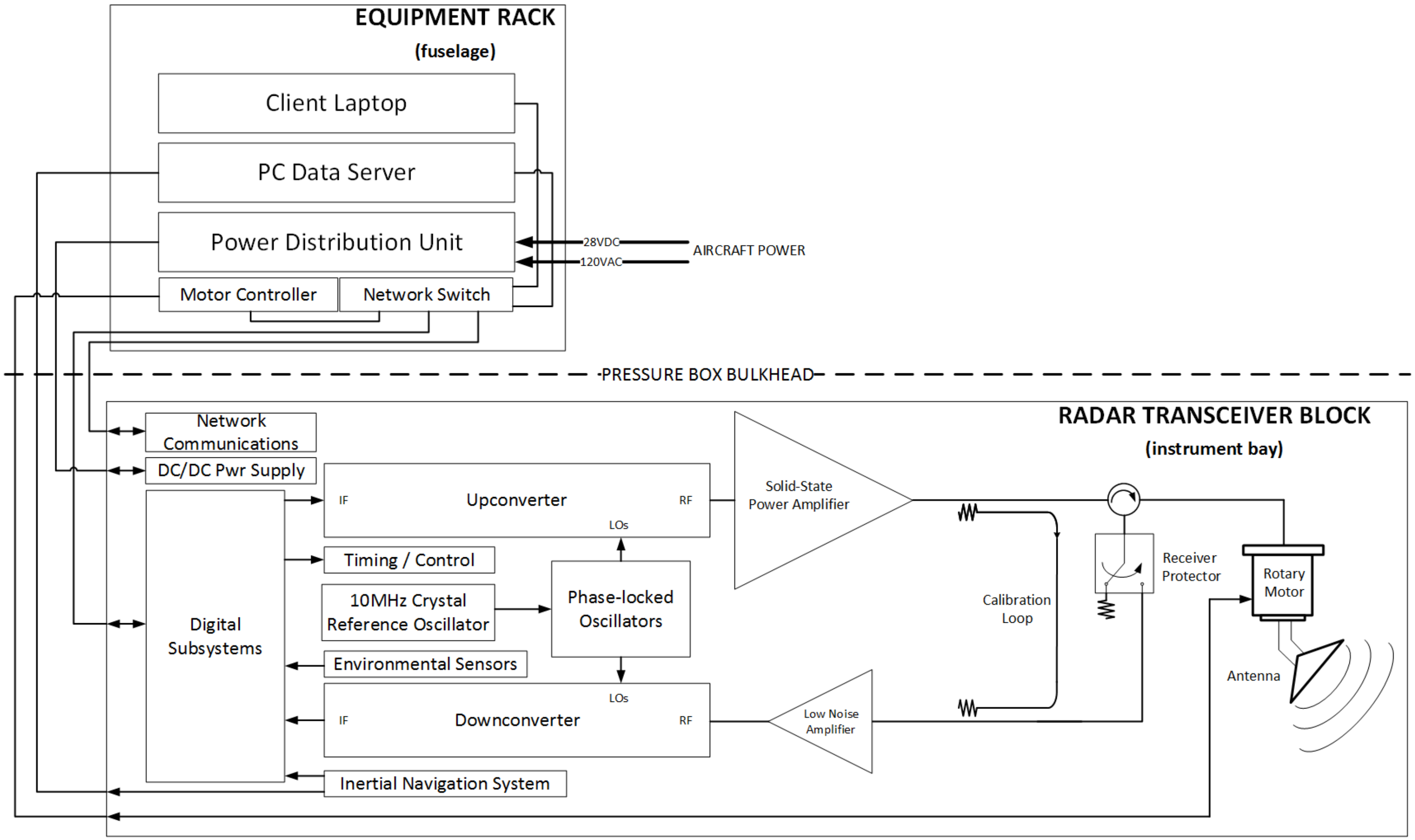
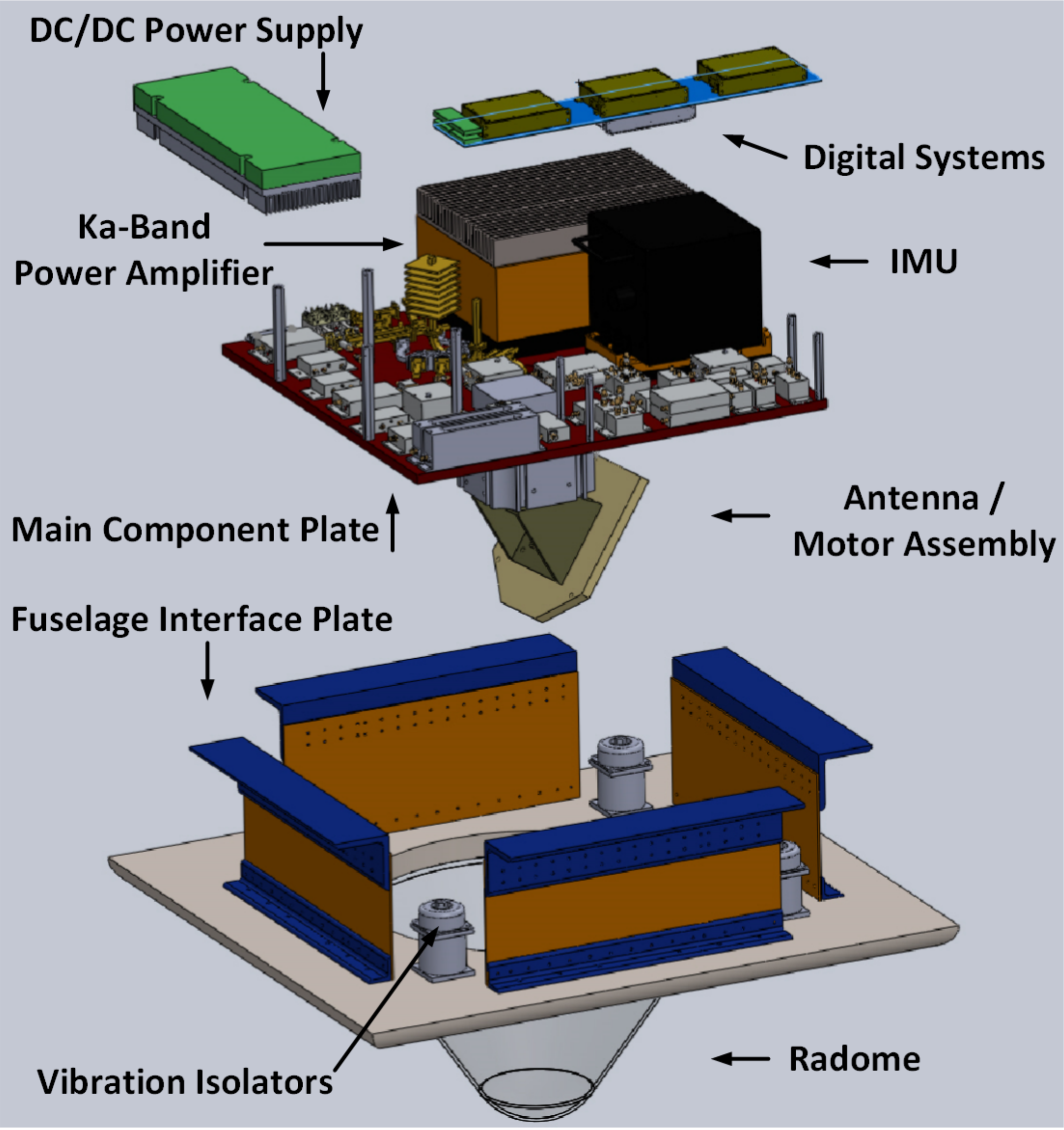
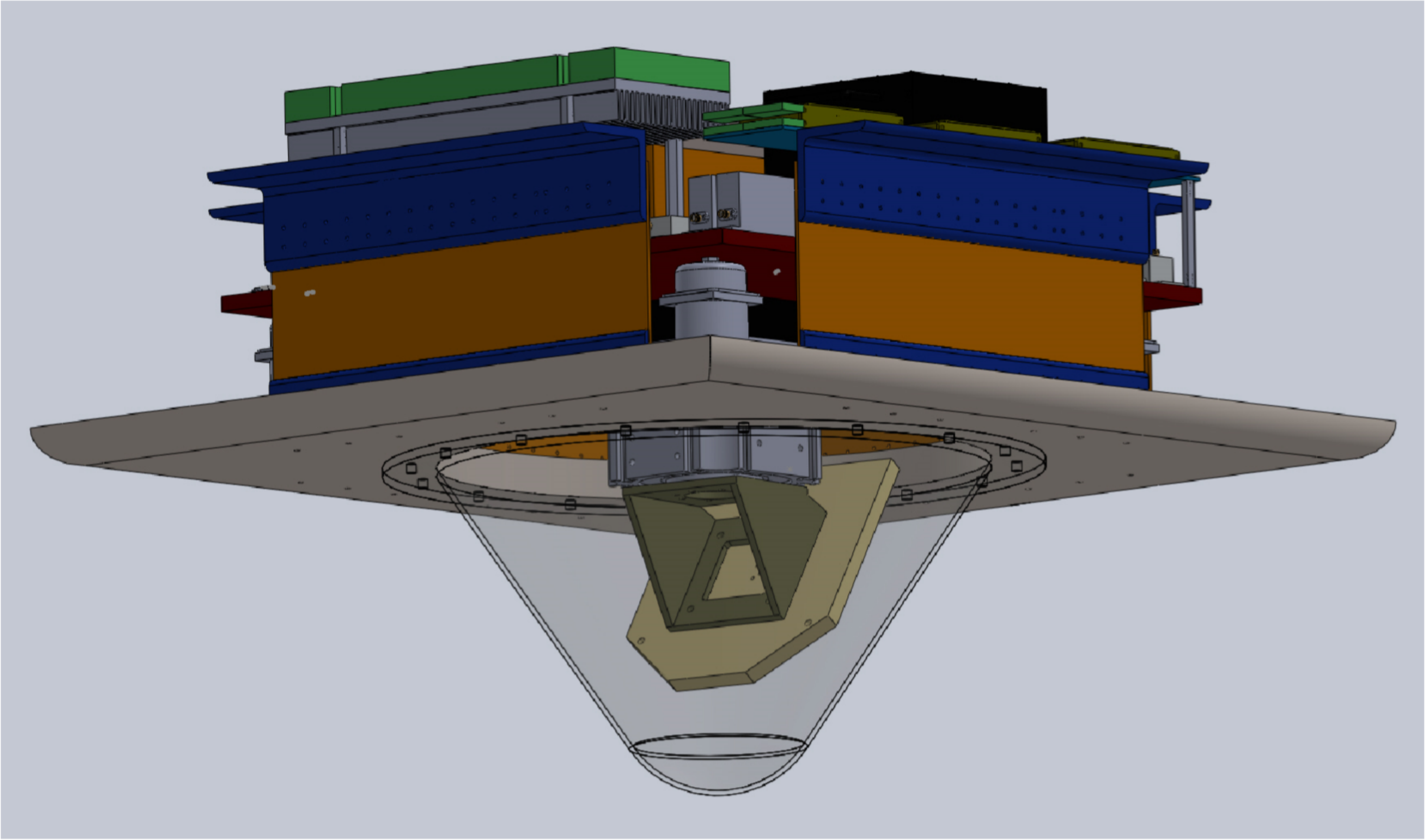
Instrument Notional Block Diagram



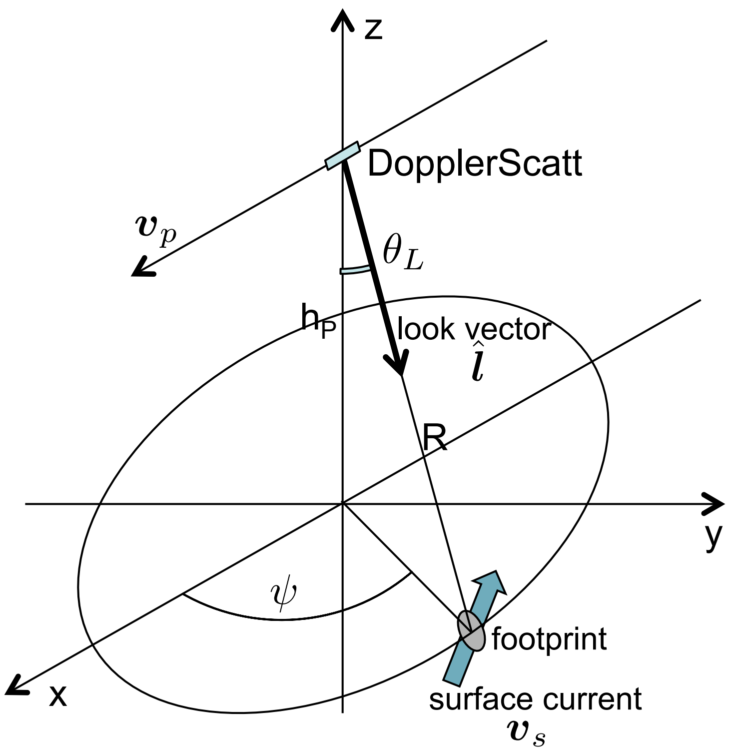
Notional Instrument Exploded View



Notional Instrument Upper View



System Error Analysis: Surface Velocity Model



Pulse-pair phase model

$$\langle E_1 E_1^* \rangle = A; \qquad \langle E_1 E_2^* \rangle = A\gamma e^{i\phi}$$

$$\phi = \phi_1 - \phi_2 = \arg(s_1 s_2^*) = 2k(R_2 - R_1) = \frac{4\pi}{\lambda}\tau v_r$$

where radial velocity is a combination of platform velocity, surface currents velocity and wind velocity components.

Surface velocity model

$$v_{rs} = \boldsymbol{v}_s \cdot \hat{\boldsymbol{l}} = v_s \sin\theta \cos\psi_s$$

$$= -\frac{\lambda}{4\pi\tau}\phi + v_{rp} - v_{rR} - v_{rG} - v_{rA}$$

Decorrelation sources model

$$\gamma = \gamma_{temp}\gamma_{therm}\gamma_{doppler}\gamma_{range}\gamma_{quant}$$

Sensitivity of estimated velocity

$$\delta v_{rs} = -\frac{\lambda}{4\pi\tau}\delta\phi - \frac{\phi}{4\pi\tau}\delta\lambda + \frac{\lambda\phi}{4\pi\tau^2}\delta\tau + \delta v_{rp} - \delta v_{rR} - \delta v_{rG} - \delta v_{rA}$$

Error Budget

- Total error budget for Doppler velocity estimation: 10 cm/s

Error Source	Velocity error	Current design expected error
Random phase errors	5 cm/s	1-3 cm/s
Frequency	<0.1 cm/s	0.002 cm/s
Timing	<0.1 cm/s	0.0017 cm/s
Platform velocity	0.5 cm/s	0.4 cm/s
Look angle	1 cm/s	0.32 cm/s
Azimuth angle	1 cm/s	0.65 cm/s
Velocity gradients, random variation due to wave interactions, and asymmetry bias*	2.5 cm/s	data / model dependent

* We will be refining the error allocations as the system components get tested and built.