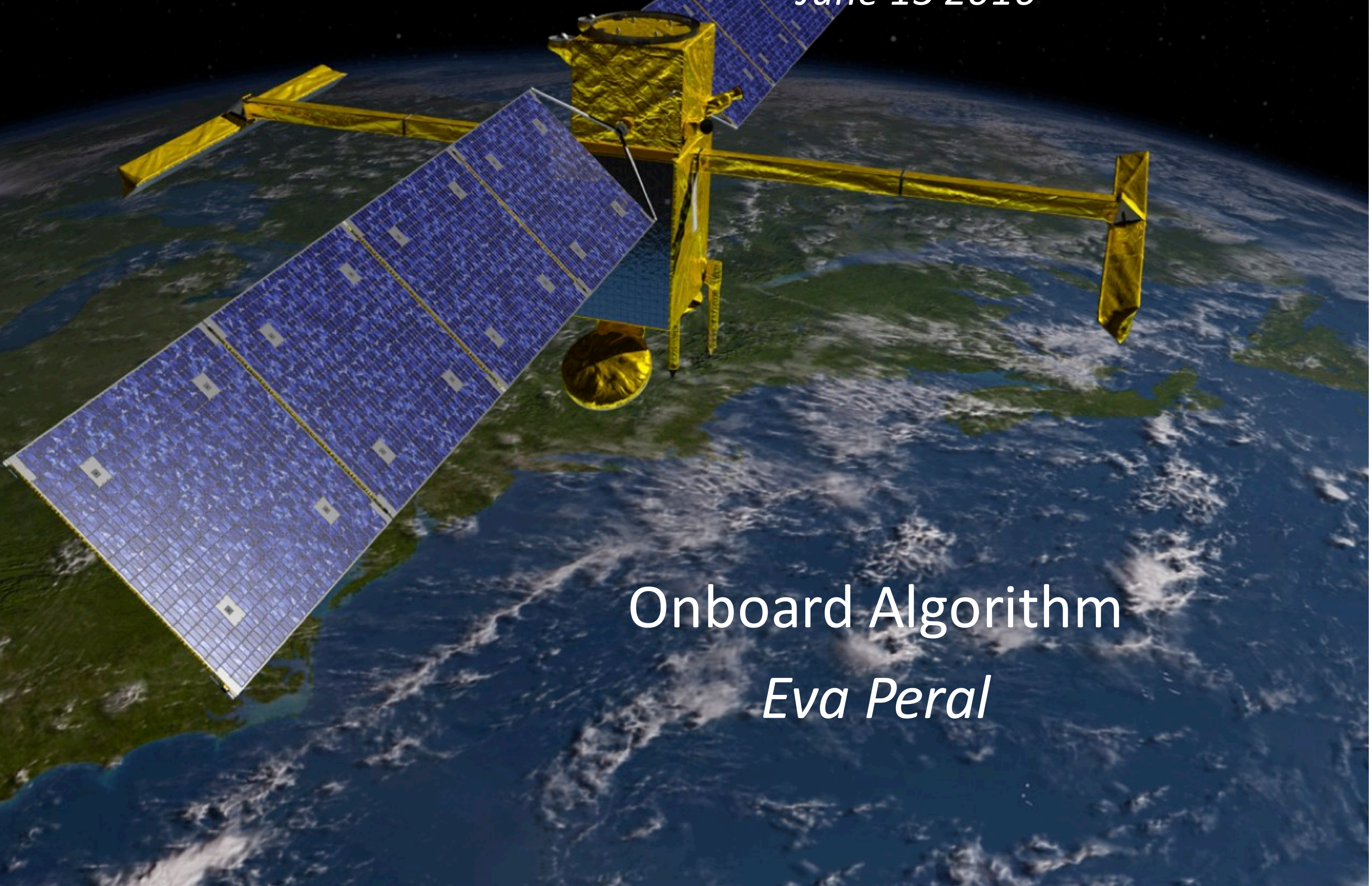
National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Surface Water and Ocean Topography (SWOT) Mission

SDT Meeting

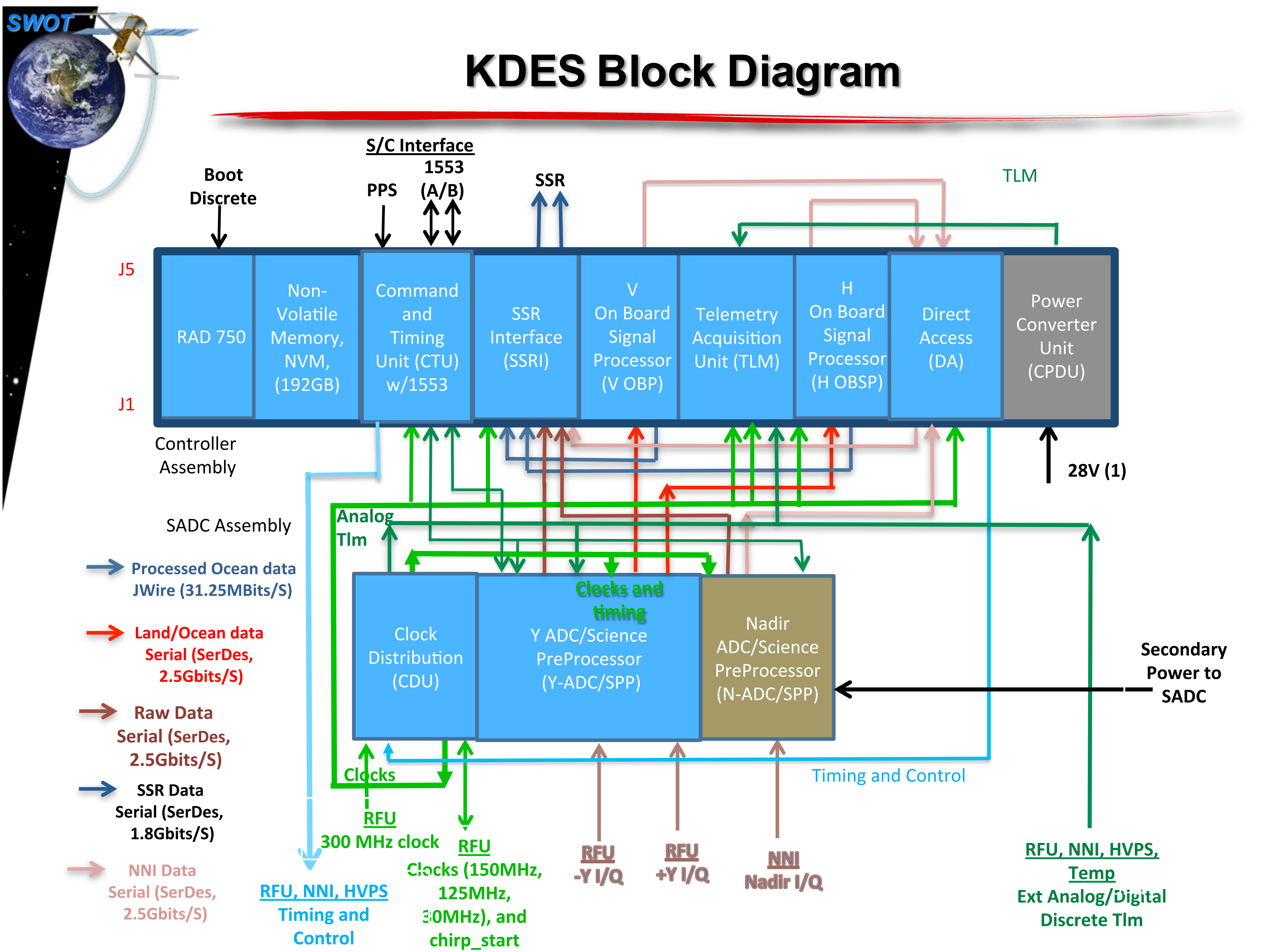
June 13 2016



Onboard Algorithm

Eva Peral

KDES Block Diagram

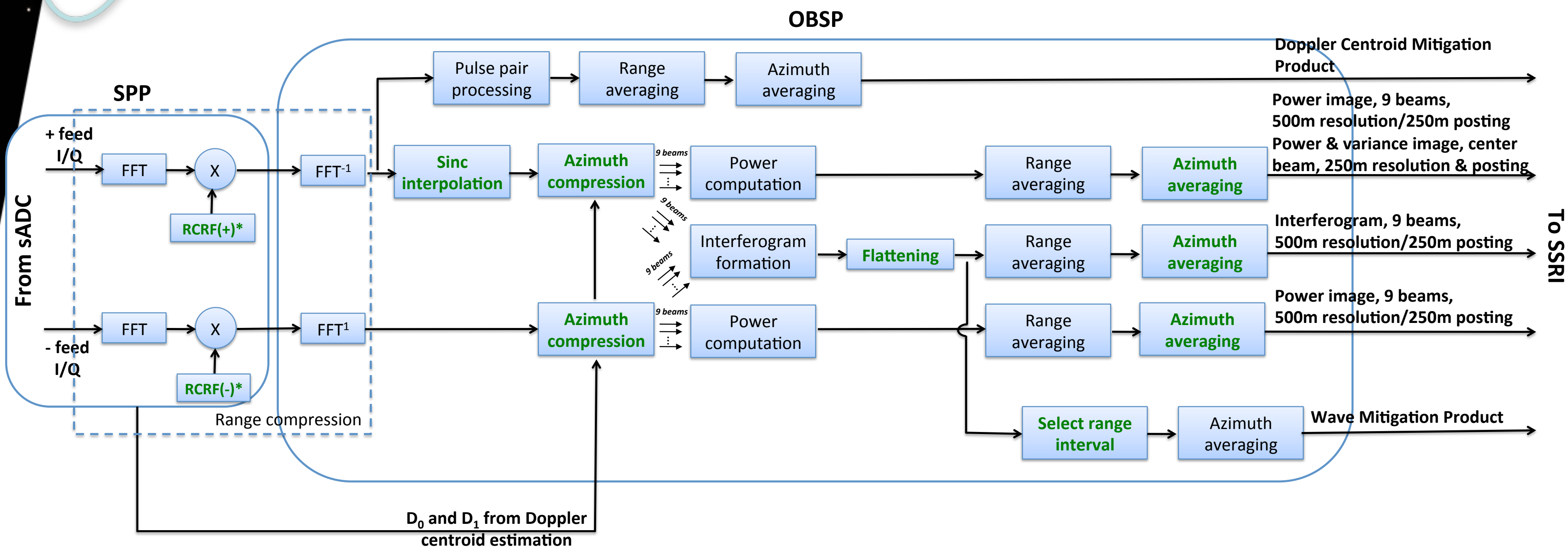


Principle Driving Requirement
The OBP Golden Model

- KaRIn is unique among radar instruments for its complex On-Board Processor (OBP) algorithm.
- The algorithm is described by the so called Golden Model, a *floating point* model implementation of the algorithm in Matlab.
- The KDES team derives the OBP bit-true models from the golden model, which is a *fixed point* implementation of the algorithm.
- The KDES team derives the OBP *firmware* from the bit-true model. The firmware matches the bit true model.
- Five distinct algorithms are implemented:
  - Ocean processing algorithm
  - Calibration algorithm
  - Doppler centroid estimation algorithm
  - Land processing algorithm

Ocean Algorithm Block Diagram

Objective: To reduce ocean data rate prior to data downlink



- **Range compression:** to achieve high resolution (proportional to 1/Bandwidth) with a long pulse, which improves SNR
- **Time co-registration** (via sinc interpolation) : Due to different looking geometries, the echo from a point target arrives at different times for each antenna and the target impulse responses are shifted in time. If uncorrected, this would decorrelate the interferogram.
- **Doppler removal & Azimuth compression:** unfocused squinted SAR processing is implemented and 9 beams are created within the real aperture azimuth antenna pattern
- **Interferogram formation and power computation**
- **Interferogram flattening**: to remove, prior to averaging, rapidly varying phase fringes caused by the looking geometry
- **Range and azimuth averaging**: to reduce data rate

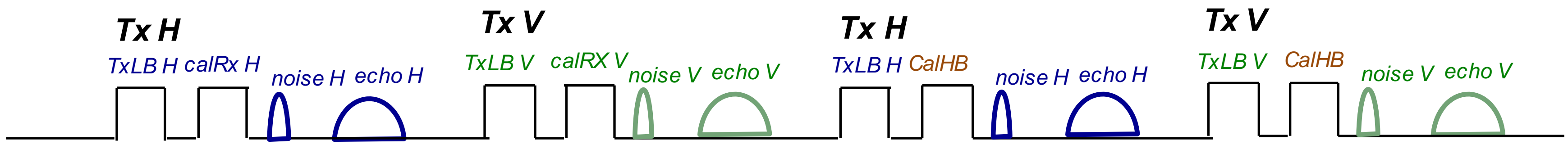
OBP Ocean Products

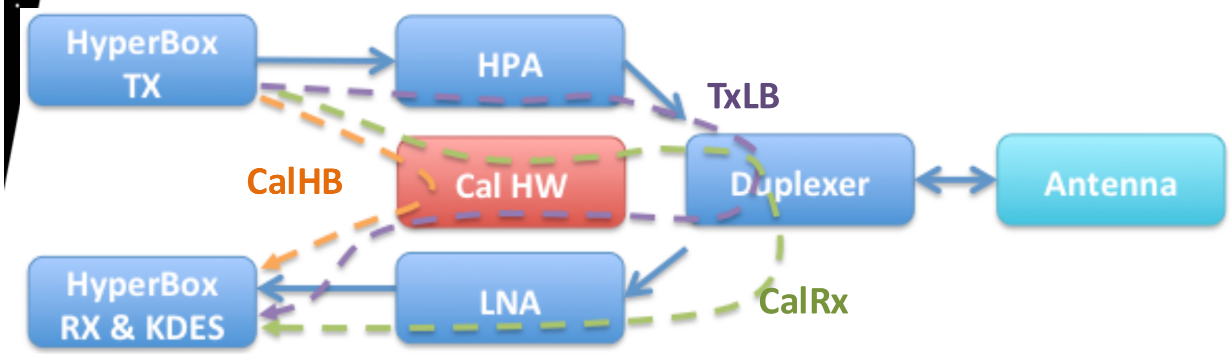
(after July'15 SDT, CR pending)

- Baseline products:
  - 9 complex interferogram and +/- SAR images at 500m x 500m pixels and 250m posting
- Additional products:
  - Average power and power variance at 250m x 250m pixels and 250m posting for the center beam for each swath (rectangular averaging)
    - Enables ground algorithms to detect/flag anomalous pixels (rain/ships/coastal and ice boundaries, etc.) and stress cases over the oceans at higher resolution than the interferograms, where detection may not be possible.
  - Doppler centroid image for each swath (from range compressed data)
    - Enables ground algorithms to extract ocean velocities with the potential to improve science return beyond current performance requirements.
  - High resolution cross-track interferogram (averaged in along track)
    - Enables ground algorithms to extract wave spectra with the potential to improve science return beyond current performance requirements.

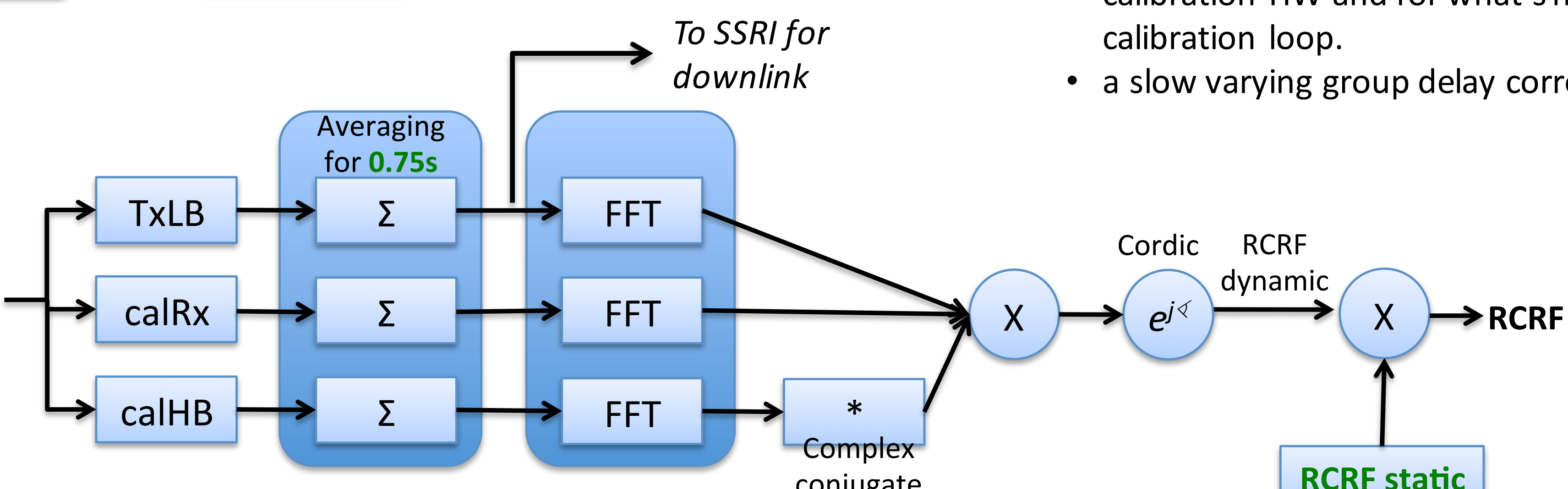
Calibration Algorithm

Objective: To construct the Range Compression Reference Function (RCRF) to be used during Range Compression



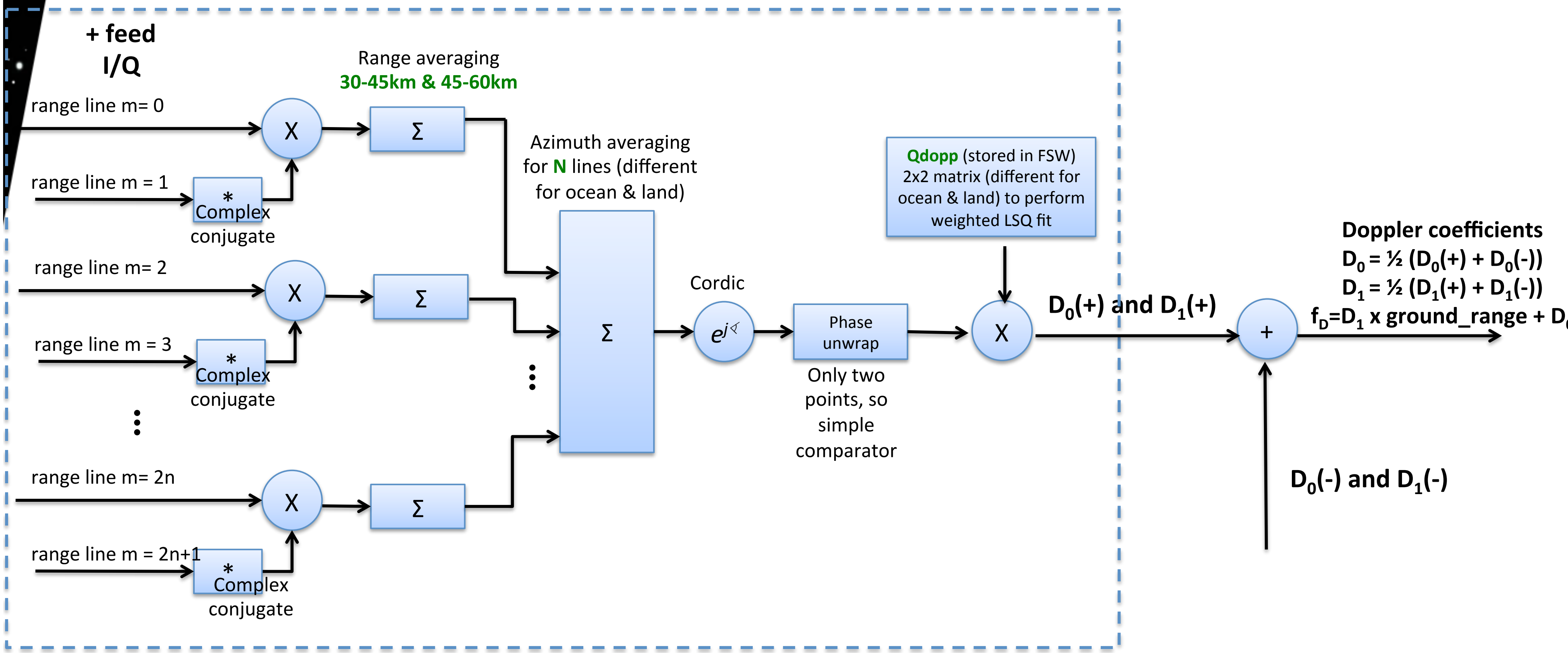


- RCRF is computed for each channel +/- and swath H/V
- Two components:
  - Dynamic: computed by OBP calibrates the phase measured by the calibration paths
  - Static:
    - an amplitude tapering and a phase correction to compensate for the calibration HW and for what's not in the calibration loop.
    - a slow varying group delay correction



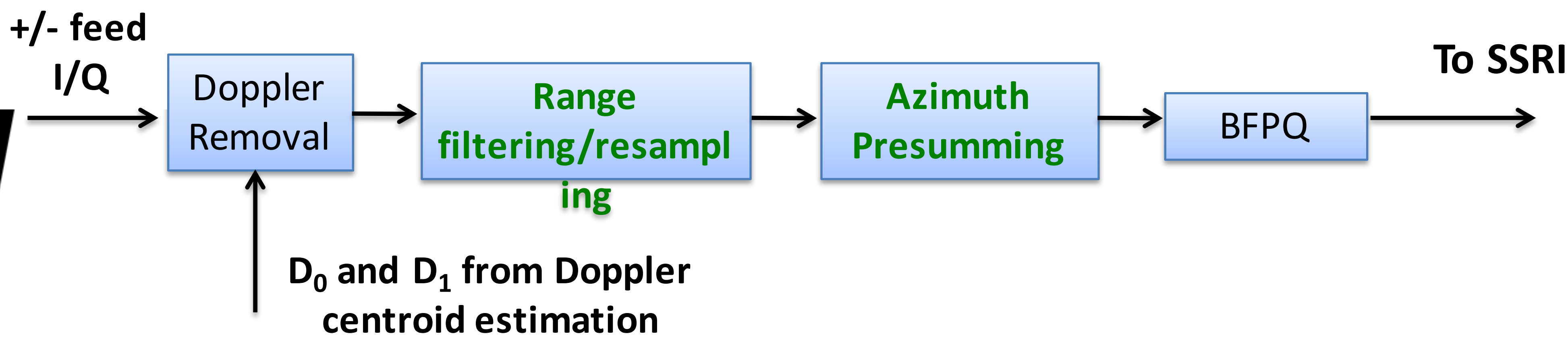
Doppler Centroid Algorithm

Objective: Estimation of a linear fit to the Doppler Centroid, which is used in presumming for land and azimuth compression for ocean, to avoid SNR loss due to a shift between the echo Doppler spectrum and the azimuth filtering window.



OBP Land Algorithm – Block Diagram

Objective: To reduce land data rate prior to data downlink



- **Doppler Removal**
- **Presumming**: perform azimuth pre-summing to reduce data rate and volume
  - Two possible options of the pre-summing factor, either 2.125 (baseline) or 2.4375, which can be selected by ground command.
- **Filter and Resampling**: to remove possible excess bandwidth and subsampling data with output rate 200 MHz
- **BFPQ:** to compress data
  - 3 bits mantissa, 5 bit exponent, 32 complex samples block size

Flexibility

- KaRIn's OBP has been designed with significant flexibility.
  - Anything that can be parameterized is part of the static parameter table.
  - A new static parameter table can be uploaded during flight if needed.
- Doppler Centroid
  - Range averaging intervals
  - Azimuth averaging length (different for ocean/land)
  - Matrix for least square fitting (different for ocean/land)
- Ocean
  - RCRF static, including time dependent group delay correction
  - Sinc interpolation window
  - Azimuth compression window
  - Topography parameters used to compute flattening
  - Static phase screen for flattening
  - Azimuth averaging window
- Land
  - Range filtering/resampling filter coefficients
  - Azimuth presumming filter coefficients

Documentation

- Ocean (includes Calibration) ATBD, JPL D-79130
  – The ATBD contains a wealth of test cases which extend beyond the definition of the algorithm itself to characterize the overall performance for cases with wave spectra and SWH, waves motion and surface currents, backscattering modulation, ocean slicks, attitude, etc.
- Land ATBD, JPL D-55533
- Flight Software Algorithm Definition, JPL D-55573
- Data dictionary, JPL D-61942

Status

- Baseline algorithms
  - The baseline ocean, land, calibration and Doppler golden and bit true models have been completed and delivered to the firmware developers.
- Additional ocean products
  - The golden model for the additional products has been completed.
  - The project has directed the KaRIn team not to proceed with the bit true model implementation until the science benefits and algorithm are documented in an ATBD, and reviewed.
  - The bit true model has to be completed by Aug 1st, so the justification/documentation should be finalized by July 15th
  - Initial drafts for the science justification and ATBD have to be delivery by June 30th to be reviewed by the SDT and ADT leads
  - The KaRIn SE team will support the SDT/ADT in this effort by providing descriptions of the golden model implementation, which has been designed to fit within the HW resources.

Summary

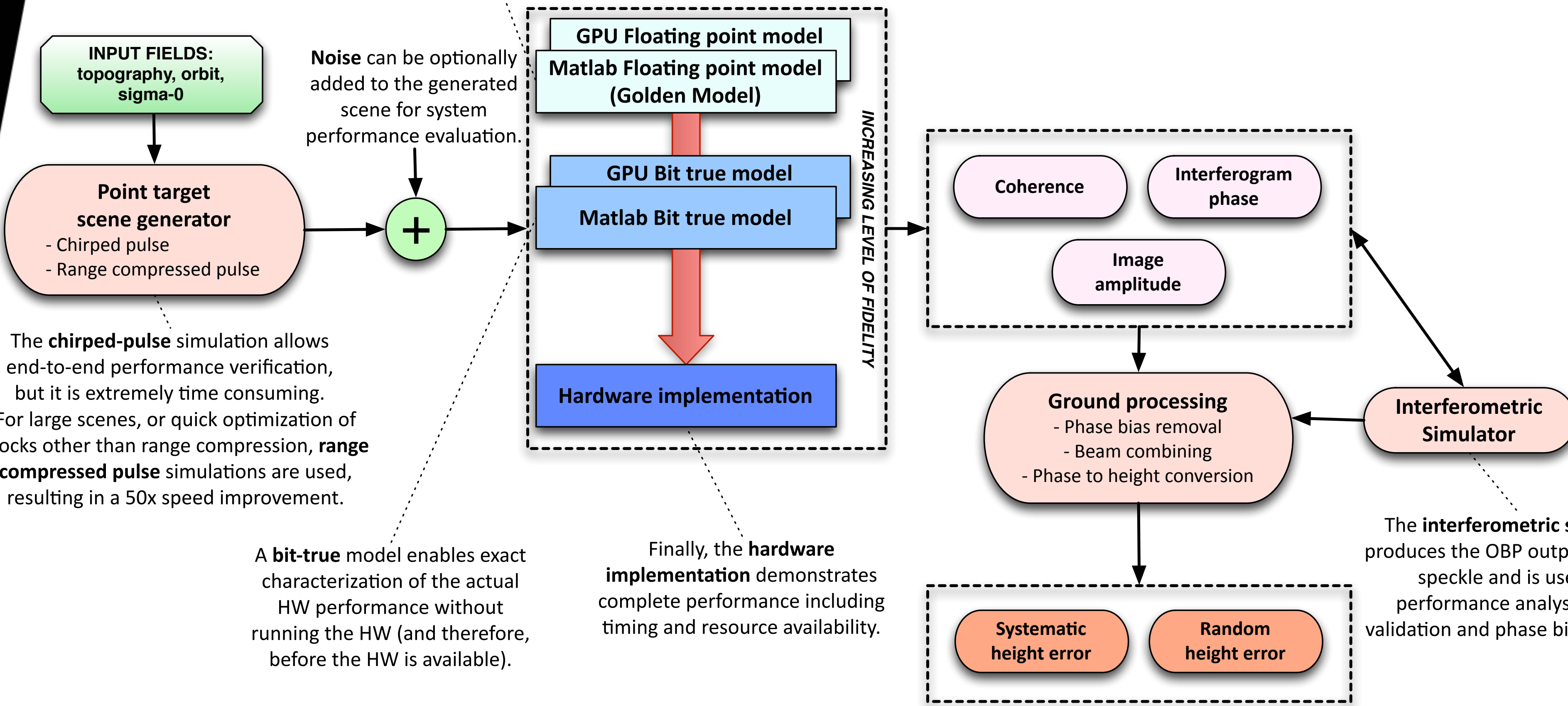
- OBP algorithms are well understood, finalized, and documented in order to support implementation.
- OBP algorithms validation is mature, extensive, extensively reviewed, and demonstrates responsiveness to the requirements.
- The system team has all the tools to analyze the OBP performance and support the KDES team throughout its development should implementation trades or need for simplifications/optimizations arise.
- Simple, computationally inexpensive risk mitigation products have been incorporated to increase performance robustness. However, in order to proceed with the implementation of these products, the science benefit has to be well justified and documented.

BACK UP SLIDES

OBP Validation Flow

The **floating point model**, also known as Golden Model, is used for algorithm optimization and ultimate performance analysis.

Noise can be optionally added to the generated scene for system performance evaluation.



The **chirped-pulse** simulation allows end-to-end performance verification, but it is extremely time consuming. For large scenes, or quick optimization of blocks other than range compression, **range compressed pulse** simulations are used, resulting in a 50x speed improvement.

A **bit-true** model enables exact characterization of the actual HW performance without running the HW (and therefore, before the HW is available).

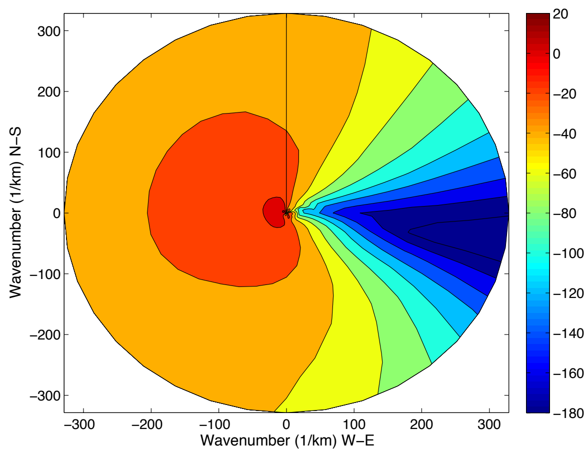
Finally, the **hardware implementation** demonstrates complete performance including timing and resource availability.

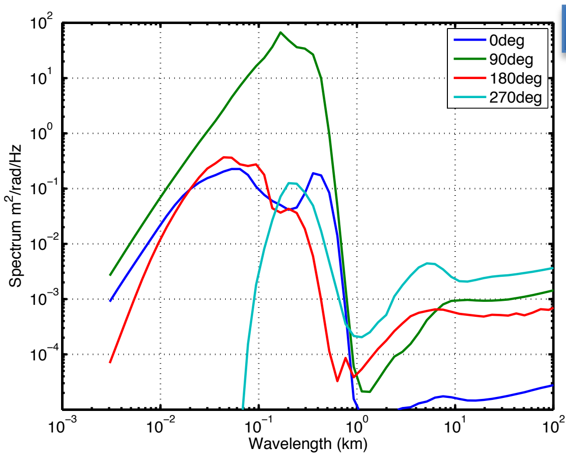
The **interferometric simulator** produces the OBP outputs without speckle and is used for performance analysis, cross validation and phase bias removal.

The output from the previous models is used to compute coherence and interferogram phase to produce the final key performance metrics: systematic and random height error.

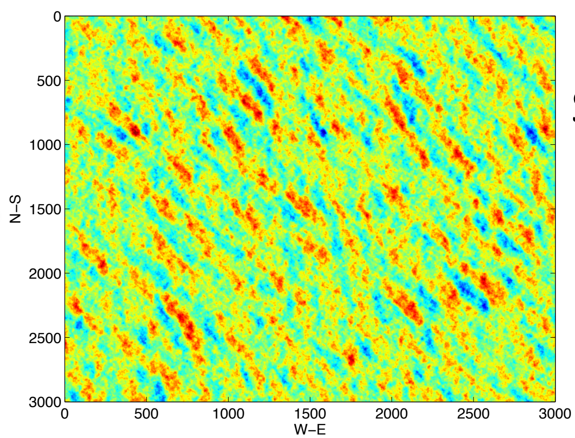
Ocean Waves Scene (I)

Wave spectrum
(SWH=4m)



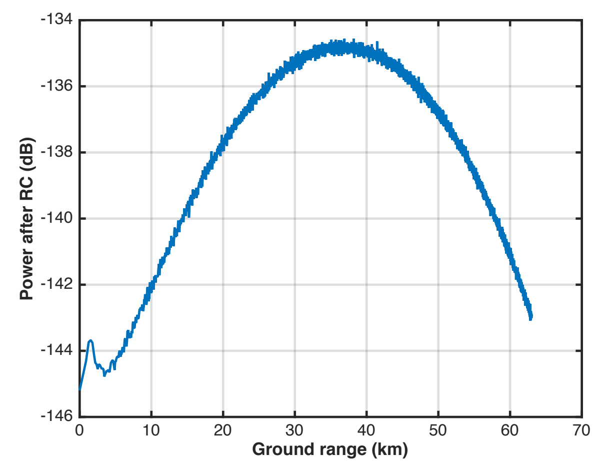


Wave scene



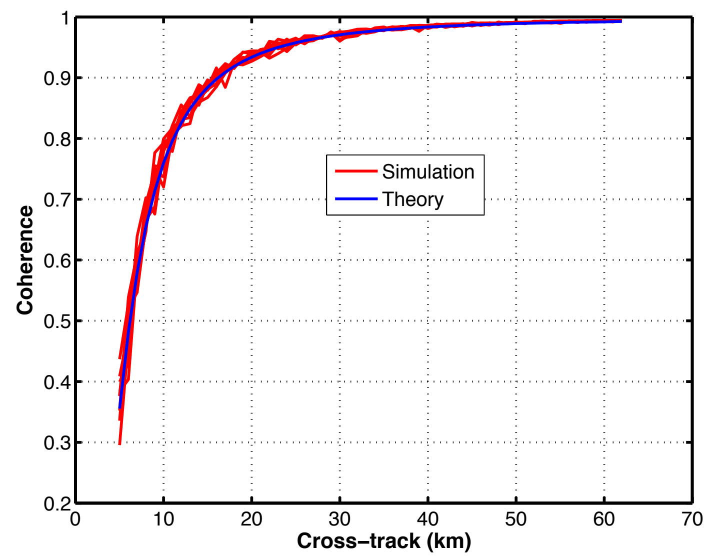
SWOT
Target
Simulator

Range compressed
echoes

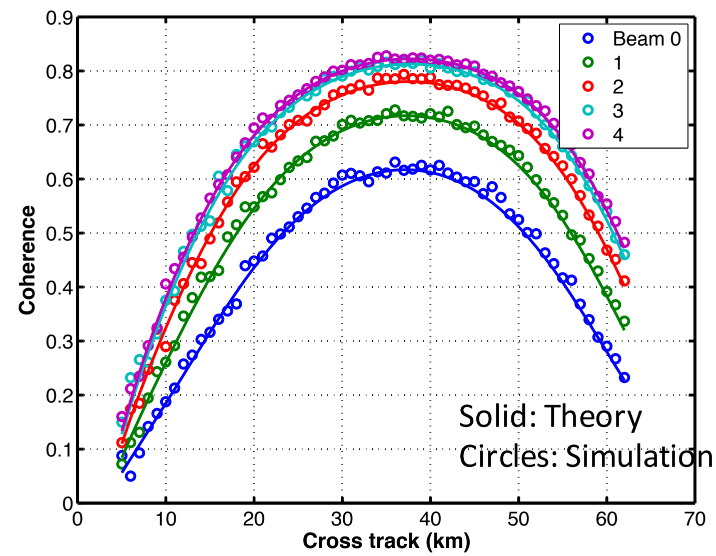


Ocean Waves Scene (II)

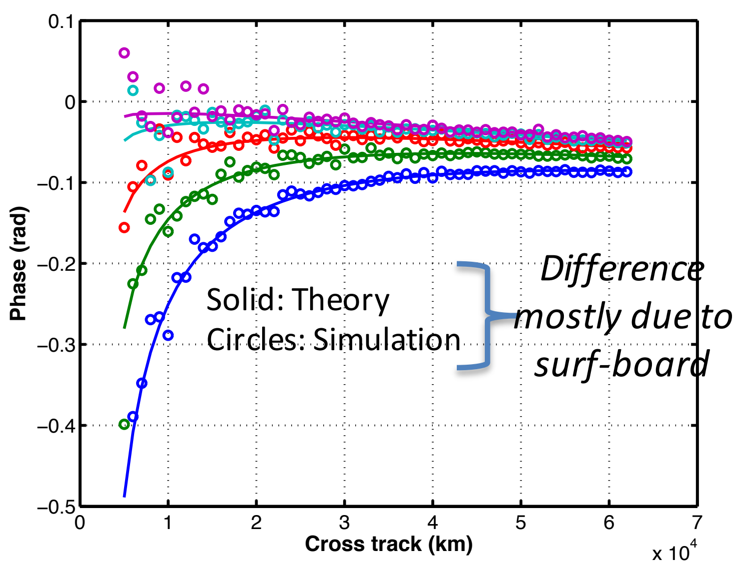
OBP Products **without** noise

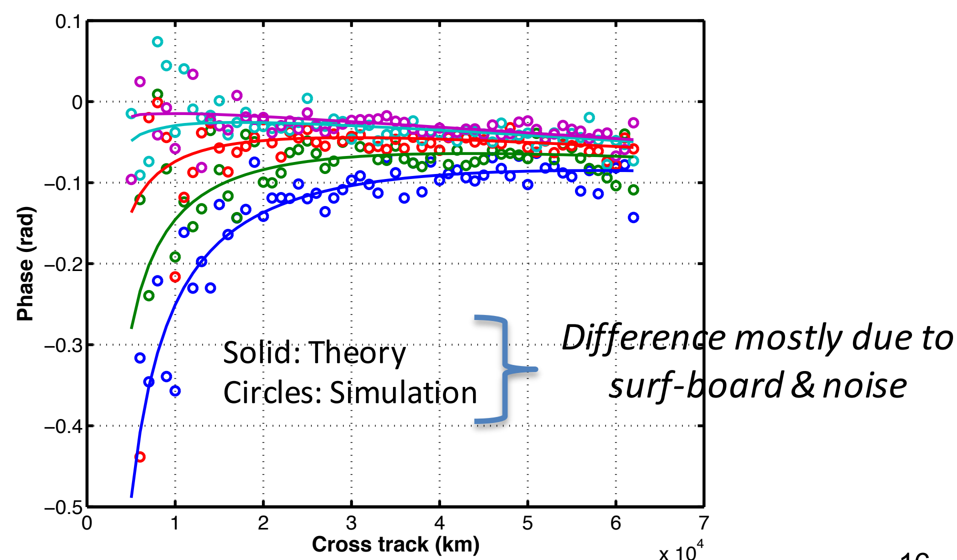


OBP Products **with** noise



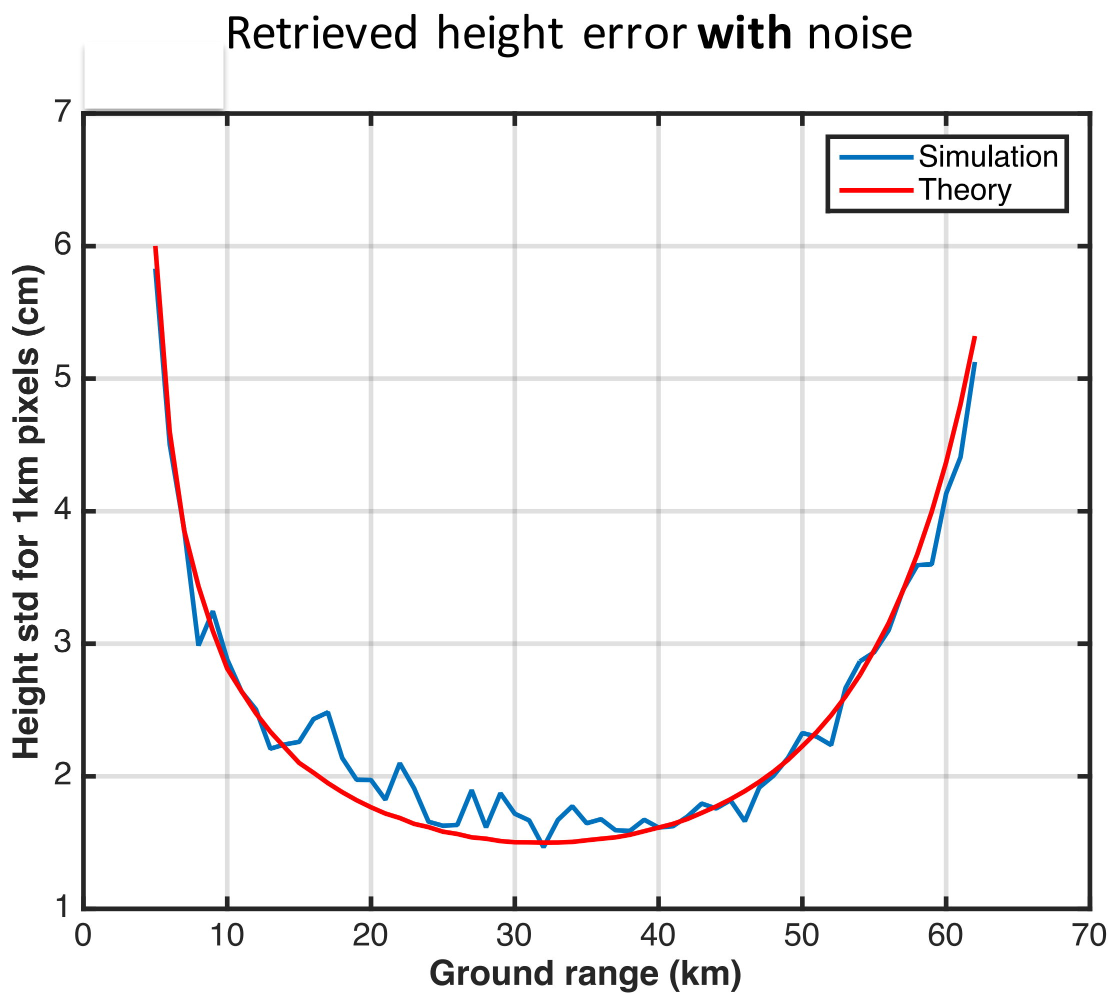
OBP Golden model





Ocean Waves Scene (III)

Ground processor



Conclusion: results agree with the analytical theory laid out in the ATBD