Scatterometer Algorithm

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Seattle

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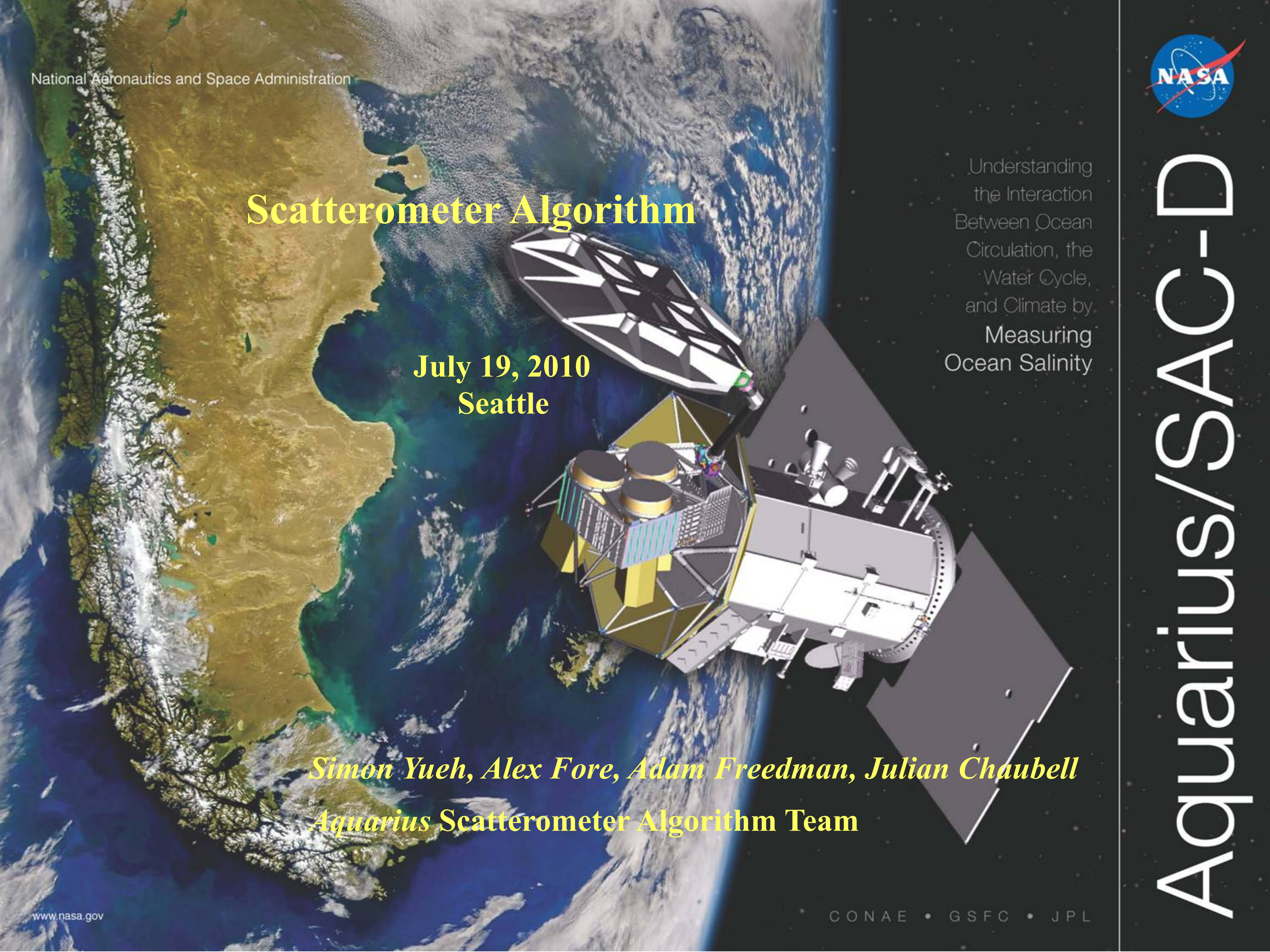
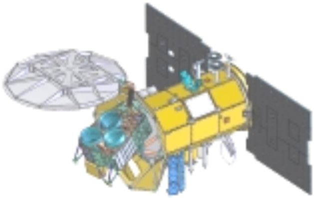
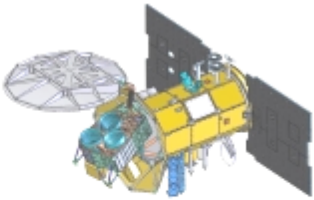


Outline



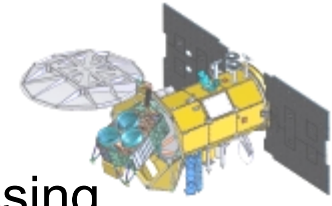
- Key Requirements
- Technical Approach
- Algorithm Development Status
  - L1A-L1B
  - L1B-L2A
- Post-Launch Cal/Val Plan
- Remaining Issues and Plans

Key Scatterometer Algorithm Requirements

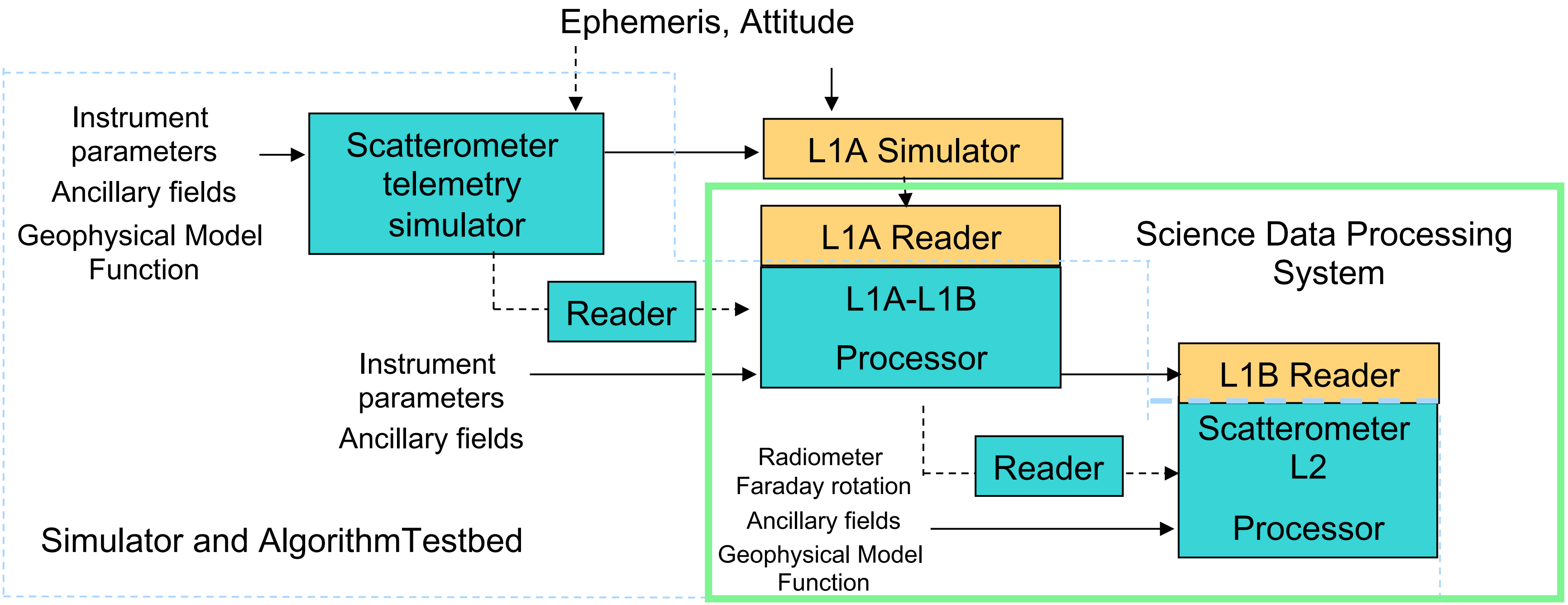


- Produce geolocated, calibrated normalized radar cross-sections (Sigma0)
  - Locate each Sigma0 on Earth.
  - Convert the L1A Aquarius data from counts to calibrated normalized radar cross-sections (Sigma0)
  - Generate an error estimate (Kpc) for Sigma0.
  - Incorporate quality control flags (RFI, land fraction, etc)
- Generate ocean surface wind speed estimates for corrections of surface roughness effects on Tb

Technical Approach



- Develop scatterometer simulator for end-to-end data processing system testing and post-launch cal/val tool development.
- The simulator will be updated and used as a testbed to develop new algorithms.
- Algorithm/software will be modularized to allow plug and play.


Ephemeris, Attitude

Instrument parameters
Ancillary fields
Geophysical Model Function

Scatterometer telemetry simulator

L1A Simulator

L1A Reader

Science Data Processing System

Reader

L1A-L1B Processor

Instrument parameters
Ancillary fields

L1B Reader

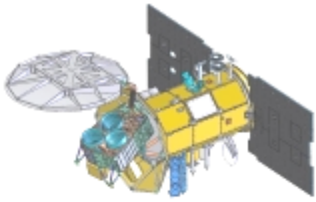
Scatterometer L2 Processor

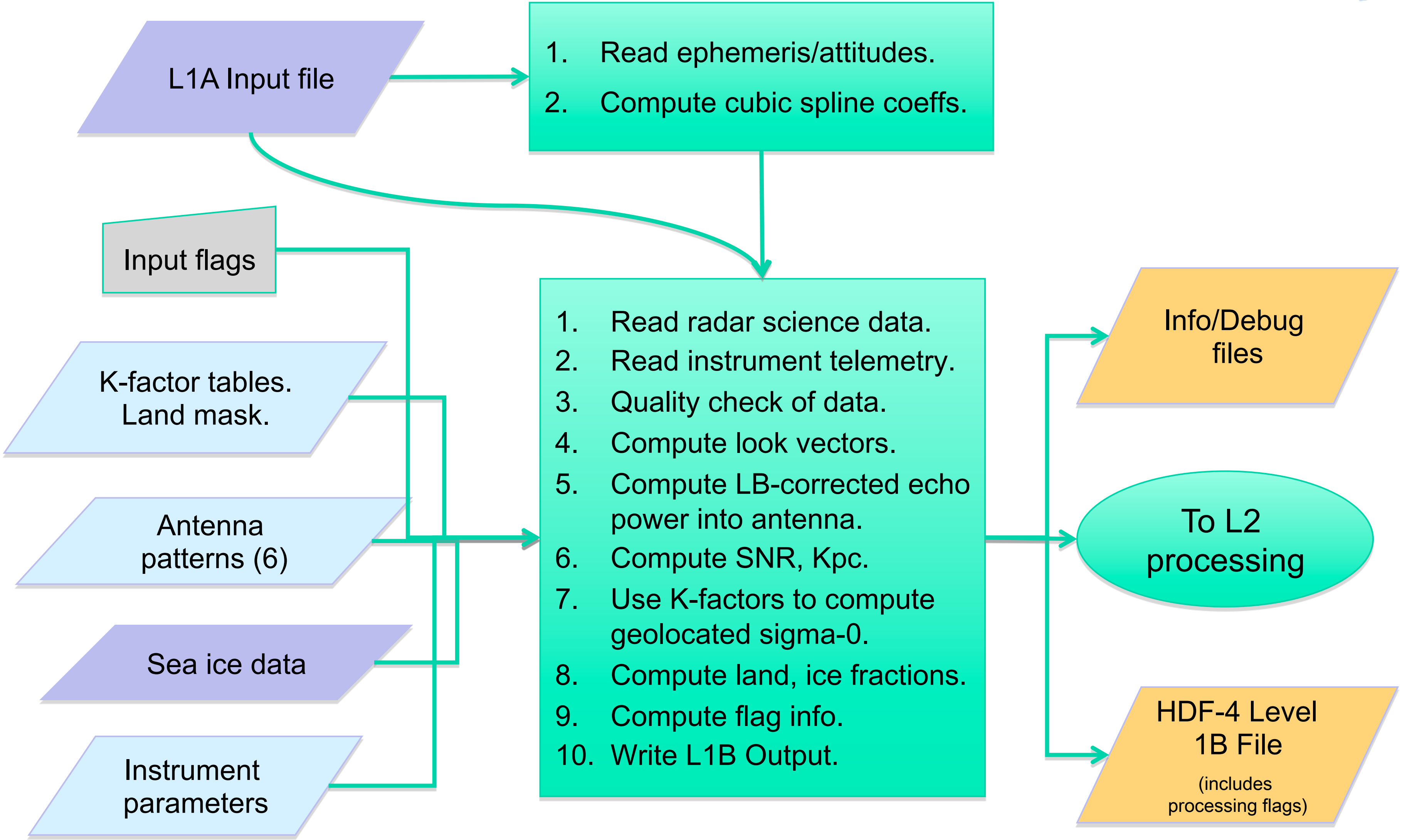
Radiometer Faraday rotation
Ancillary fields
Geophysical Model Function

Reader

Simulator and AlgorithmTestbed

L1A to L1B Algorithm Structure





L1A Input file

1. Read ephemeris/attitudes.
2. Compute cubic spline coeffs.

Input flags

K-factor tables.
Land mask.

Antenna
patterns (6)

Sea ice data

Instrument
parameters

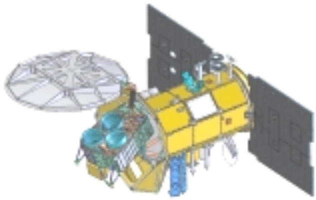
1. Read radar science data.
2. Read instrument telemetry.
3. Quality check of data.
4. Compute look vectors.
5. Compute LB-corrected echo power into antenna.
6. Compute SNR, Kpc.
7. Use K-factors to compute geolocated sigma-0.
8. Compute land, ice fractions.
9. Compute flag info.
10. Write L1B Output.

Info/Debug
files

To L2
processing

HDF-4 Level
1B File
(includes
processing flags)

Level 1 ATBD (Calibration Equation)



Define the following terms:

$$X_{\text{int}} = \iint_{area} \frac{g_r g_t h dA}{R^4}$$

Antenna pattern and radar equation

$$X_{cal} = \frac{\lambda^2}{(4\pi)^3}\left(\frac{P_{cal} L_{lbc} L_{cal} G_{bp_{pk}}^2}{L_{op} L_T L_R B_{bp_t p_r}}\right)$$

Electronics cal (Cal loop&losses)

$$P_s = P_e - P_n$$

Noise Subtraction

Then:

$$\sigma_0 = \frac{P_s}{X_{cal} X_{\text{int}}}$$

Radiometric cal

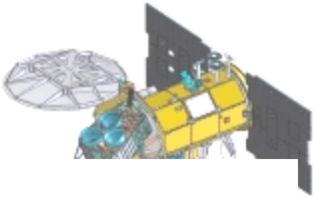
This is an expression for σ_0 in terms of parameters either measured by Aquarius or derivable from geometry and pre-launch test measurements.

- Ps= signa+noise data, Pn=noise only data and Pcal= cal-loop data.

It is very time consuming to carry out the 2-d numerical integration (X*int*) for all orbit steps and attitude

Impractical for in-line data processing

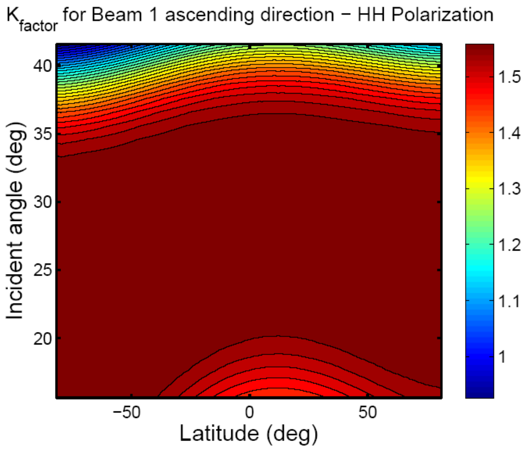
K-factor and Radiometric Calibration



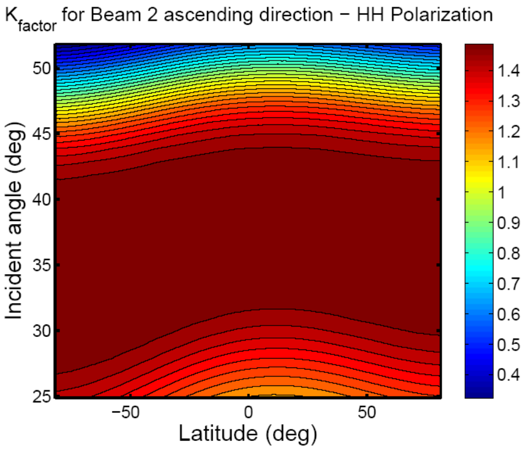
$$K^{ij}_{factor}(lat, lon, yaw, roll, pith) = \frac{R_c(lat, lon, yaw, roll, pith)^4}{A_{3dB}(lat, lon, yaw, roll, pith)} X^{ij}_{int}(lat, lon, yaw, roll, pith)$$

$$\bar{\sigma}^{ij}_0 = \frac{R_c(lat, lon, yaw, roll, pith)^4 P_{signal}}{A_{3dB}(lat, lon, yaw, roll, pith) \bar{K}^{ij}_{factor}(lat, \theta) X^{ij}_{cal}}$$

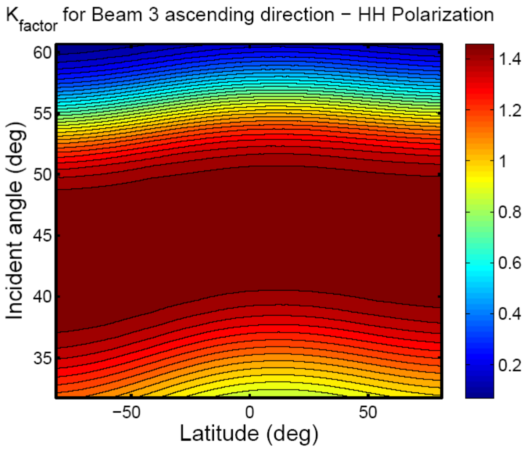
- K-factor will be a look-up table with 4 parameters: beam#, polarization, latitude and incidence angle, rather than 7 parameters



K_{factor} for Beam 1 ascending direction − HH Polarization



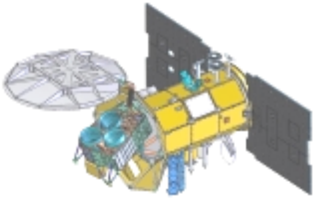
K_{factor} for Beam 2 ascending direction − HH Polarization



K_{factor} for Beam 3 ascending direction − HH Polarization

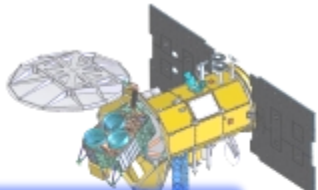
- The difference between full scalar radar equation integration and K-factor approximation is < 0.01 dB

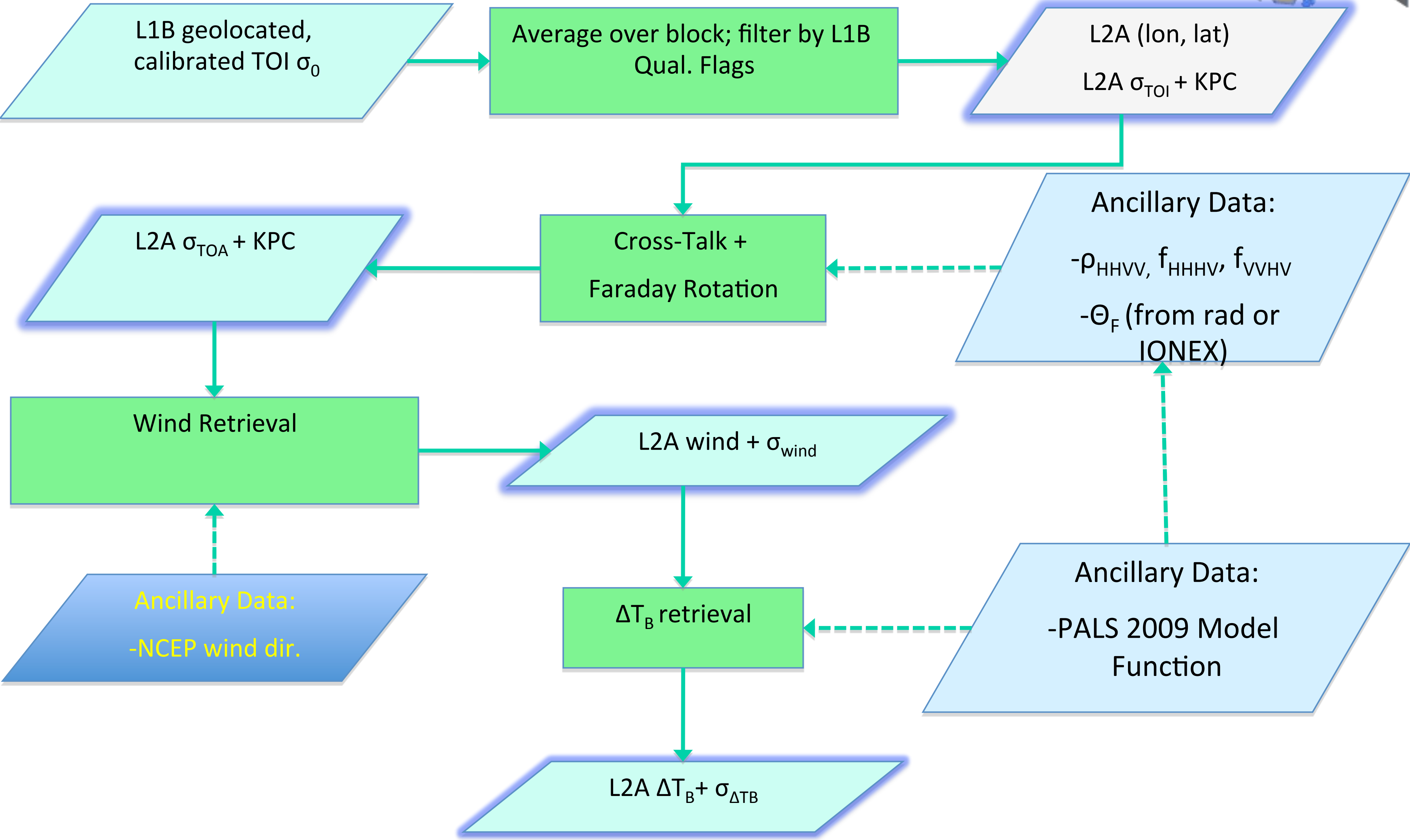
Key Characteristics and Content of L1B data File



- A special Cal/Val product – not planned for routine production
- Data block at 1.44 sec interval
- S/C position and attitude
- Latitude and longitude of footprint center and corners
- Radar quad pol (VV, HH, VH and HV) data at 0.18 sec interval
- Incidence and azimuth angles
- Measurement uncertainty (kpc)
- Land fraction: fraction of land surface weighted by antenna gain
- Ice fraction: fraction of sea ice weighted by antenna gain
- RFI flag

Baseline L1B-L2A Processing Flow





L1B geolocated, calibrated TOI σ_0

Average over block; filter by L1B Qual. Flags

L2A (lon, lat)

L2A σ_{TOI} + KPC

Cross-Talk +

Faraday Rotation

Ancillary Data:

-ρ_{HHVV}, f_{HHHV}, f_{VVHV}

-Θ_F (from rad or IONEX)

L2A σ_{TOA} + KPC

Wind Retrieval

L2A wind + σ_{wind}

Ancillary Data:

-NCEP wind dir.

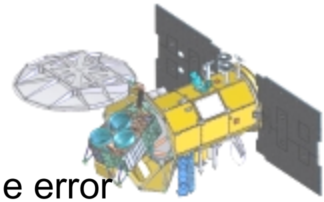
ΔT_B retrieval

Ancillary Data:

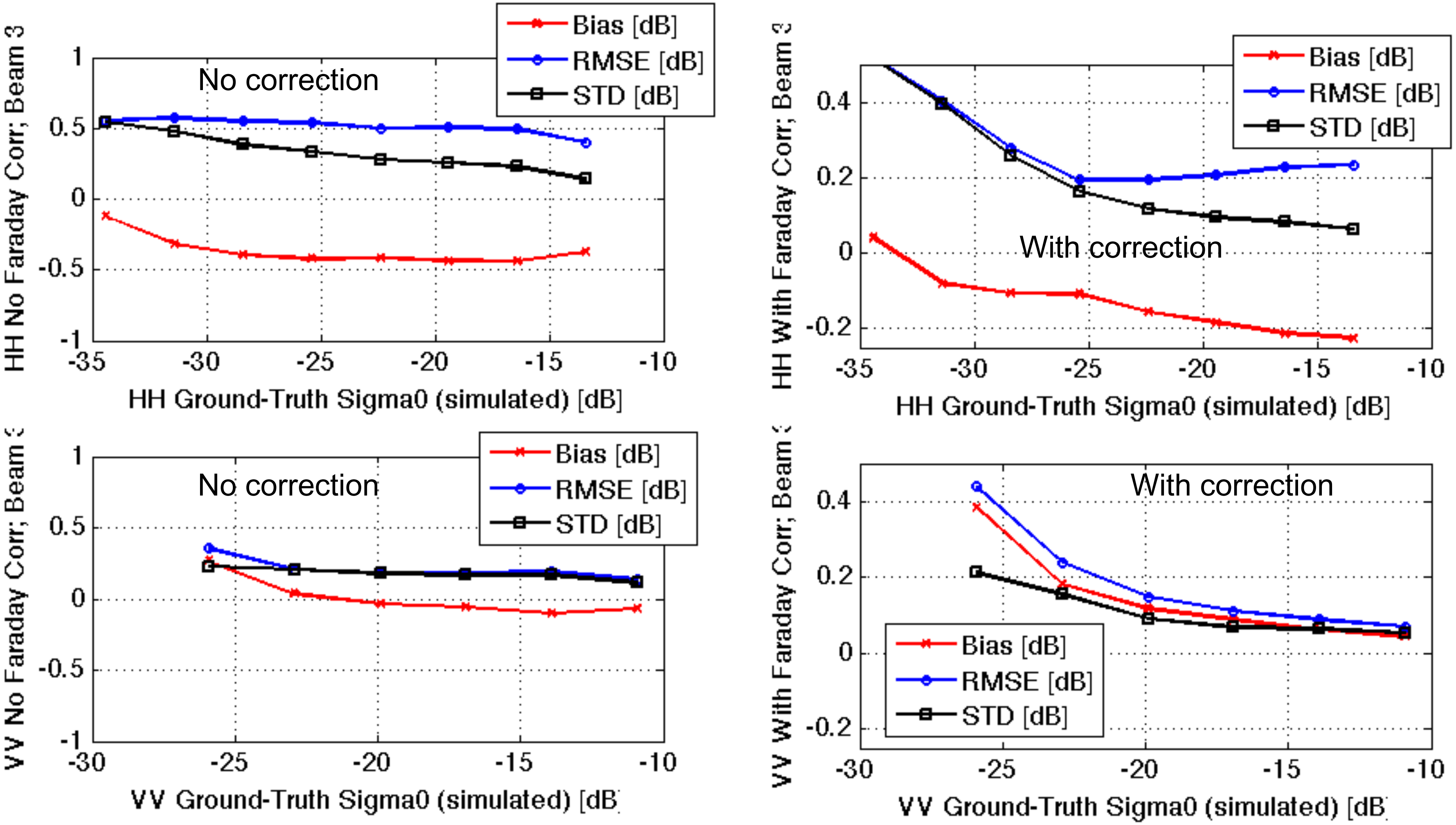
-PALS 2009 Model Function

L2A ΔT_B+ $\sigma_{\Delta TB}$

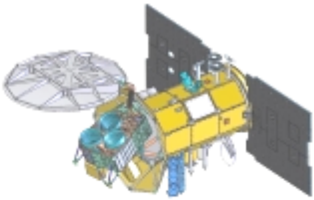
Cross-pol/Faraday Rotation Correction Beam 3



- The algorithm using the antenna pattern and faraday rotation data significantly reduces the error of each polarized VV, HH, VH and HV sigma0s. (<0.1 dB for strong backscatter)
- See Alex Fore et al’s paper for details of the correction algorithm



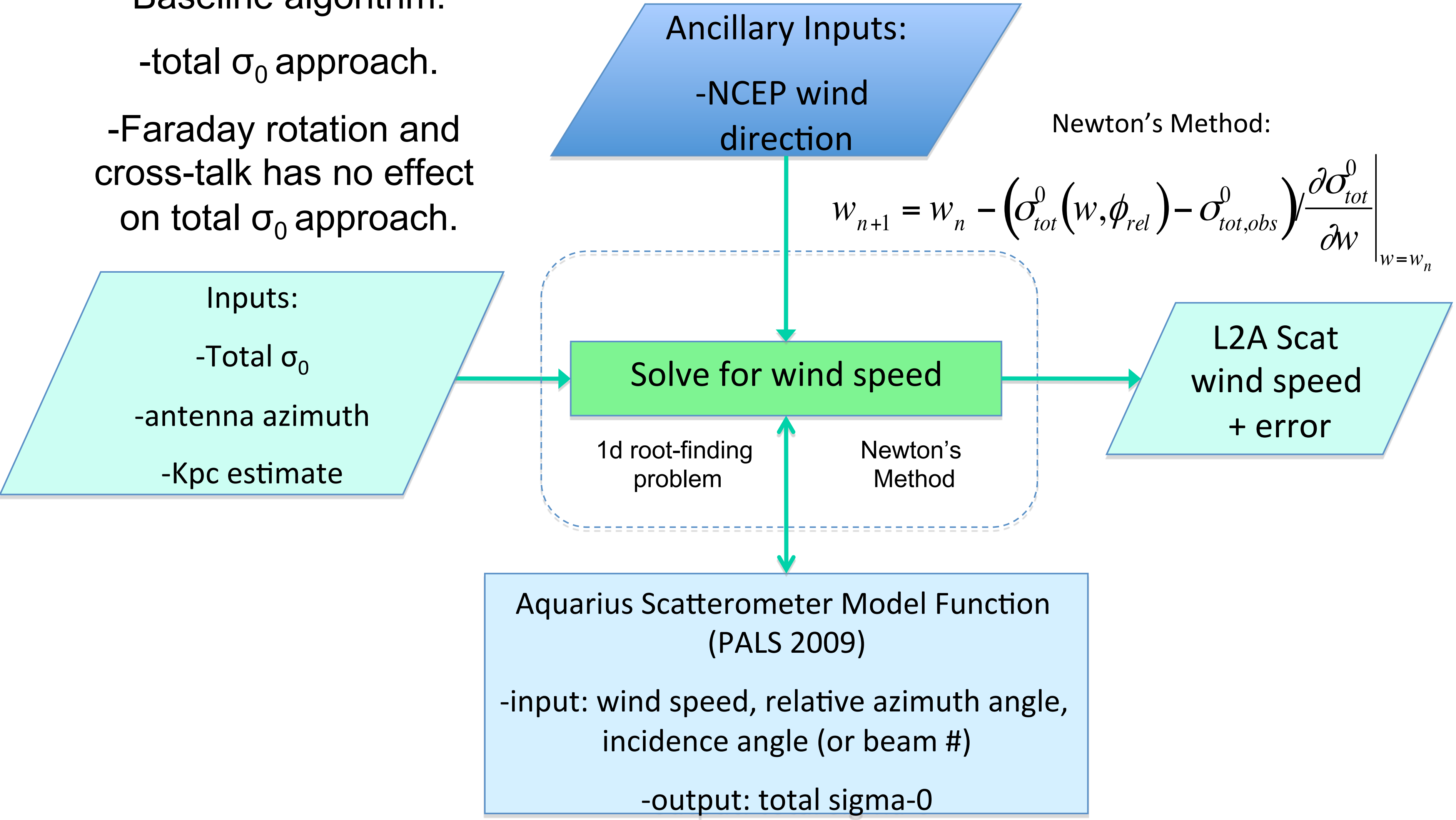
L2A Wind Retrieval Process Flow



Baseline algorithm:

-total σ_0 approach.

-Faraday rotation and cross-talk has no effect on total σ_0 approach.



Ancillary Inputs:

-NCEP wind direction

Newton's Method:

$$w_{n+1} = w_n - \left(\sigma^0_{tot}\left(w,\phi_{rel}\right) - \sigma^0_{tot,obs}\right) \Big/ \left.\frac{\partial \sigma^0_{tot}}{\partial w}\right|_{w=w_n}$$

Inputs:

-Total σ_0

-antenna azimuth

-Kpc estimate

Solve for wind speed

1d root-finding problem

Newton's Method

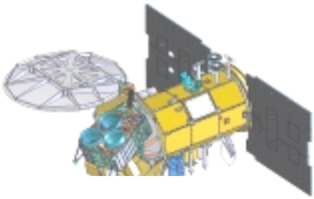
L2A Scat wind speed + error

Aquarius Scatterometer Model Function (PALS 2009)

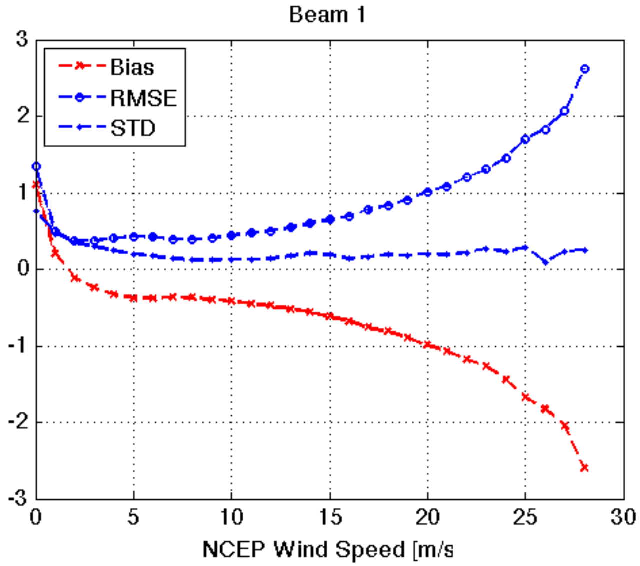
-input: wind speed, relative azimuth angle, incidence angle (or beam #)

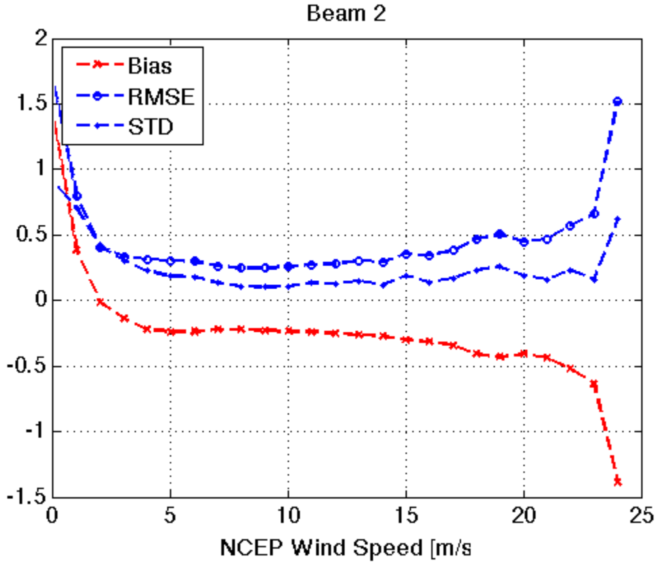
-output: total sigma-0

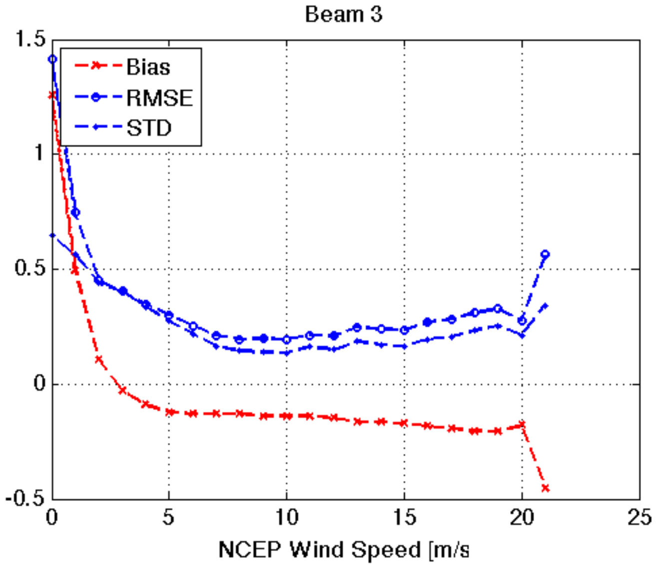
Simulated Total σ_0 Wind Retrieval Performance



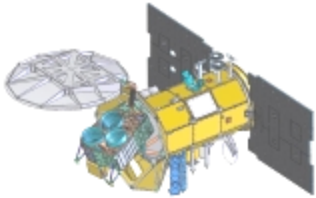
- Total σ_0 performance is independent of any Faraday rotation corrections or cross-talk removal.
- As compared to beam-center NCEP wind speed:
  - Wind Speed B1 std: 0.205 m/s
  - Wind Speed B2 std: 0.186 m/s
  - Wind Speed B3 std: 0.226 m/s
- By construction, when we derive the model function from the data there will be no bias.





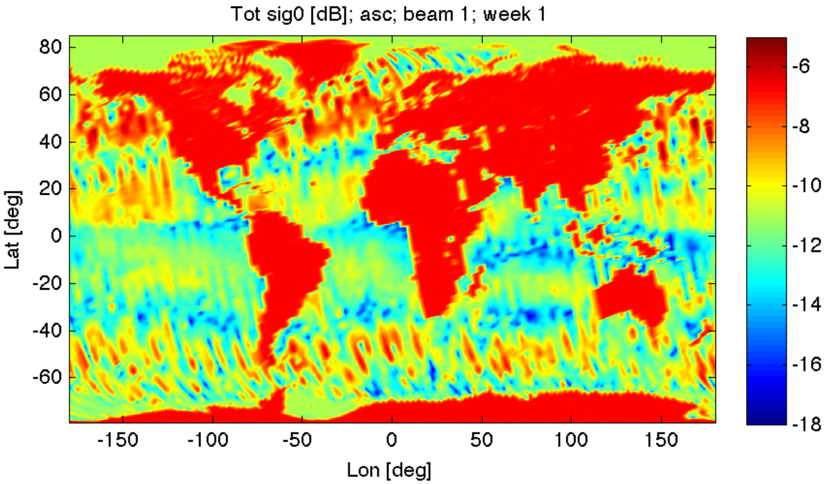


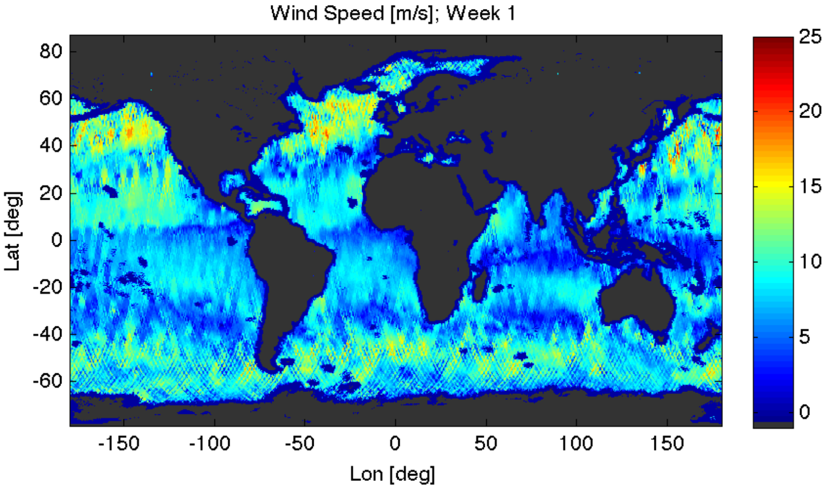
Scatterometer Performance Simulation



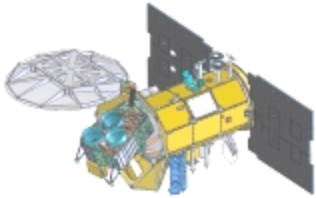
Radar sigma0 simulation (weekly for 2007)

Wind speed estimate simulation (weekly for 2007)





L2A ΔT_B Estimate



- L2 ΔT_B will be the scatterometer wind speed times the PALS dT_B/dw. (Note: not included in v1 delivery)
  - We estimate the ΔT_B errors due to the wind RMSE numbers.
  - The simulated sd error is about 0.05 K for vertical polarization and 0.07 K for horizontal polarization, better than the 0.28K allocation

$$\Delta T_v = \frac{\partial T_v}{\partial w} w \qquad \mathrm{var}(T_v) = \frac{\partial T_v}{\partial w} \mathrm{var}(w)$$

$$\Delta T_h = \frac{\partial T_h}{\partial w} w \qquad \mathrm{var}(T_h) = \frac{\partial T_h}{\partial w} \mathrm{var}(w)$$

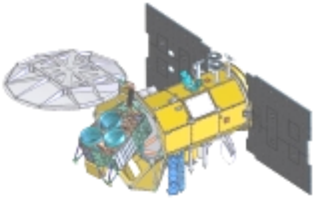
	Beam 1	Beam 2	Beam 3
dT_v / dw	0.266	0.258	0.235
dT_h / dw	0.343	0.347	0.340
$\sigma_{\Delta Tv}$	0.0545	0.0480	0.0532
$\sigma_{\Delta Th}$	0.0702	0.0646	0.0769

PALS Tb relation:

$$\frac{\partial T_v}{\partial w} = 0.275 - 0.0024153 \times \theta_{inc} + 0.00014026 \times \theta_{inc}^2 - 2.3326 \times 10^{-6} \times \theta_{inc}^3$$

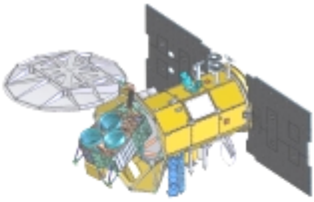
$$\frac{\partial T_h}{\partial w} = 0.275 + 0.003001 \times \theta_{inc} - 2.5181 \times 10^{-6} \times \theta_{inc}^2 - 6.9763 \times 10^{-7} \times \theta_{inc}^3$$

Key Scatterometer Prodcuts in L2A



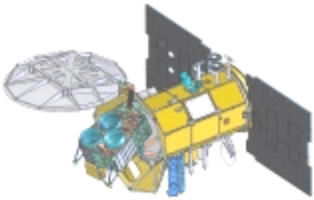
- Average over 1.44 sec
- TOI Radar Sigma0 (VV, HH, VH and HV)
- TOA Radar Sigma0 (VV, HH, VH and HV)
- Scatterometer wind speed and expected standard deviation
- TBV and TBH corrections and expected standard deviation
- Scatterometer land fraction – not the same as radiometer land fraction
- Scatteroemter sea ice fraction – not the same as radiometer ice fraction

Post-Launch Cal/Val Conceptual Plan



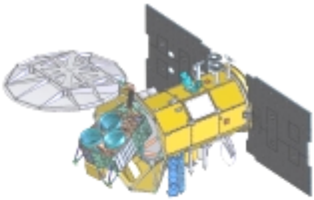
- Telemetry Analysis
  - Time series of system noise, temperature, voltage and current
- L1B analysis
  - Pointing angle analysis using sigma0 changes along land/sea crossings
  - Sigma0 Calibration stability
    - Time series of radar sigma0 over distributed targets (Antarctic, Dome-C, Amazon, Greenland)
    - Global ocean sigma0 histogram vs time
  - Faraday rotation analysis (comparison with modeling analysis using IONEX and IGMF B fields)
- L2 analysis
  - Sigma0 geophysical model function (Aquarius, NCEP wind, SST, and wave matchup)
  - Sigma0-TB geophysical model function (Aquarius, NCEP, SST, and wave matchup)

Model Function Development Methodology

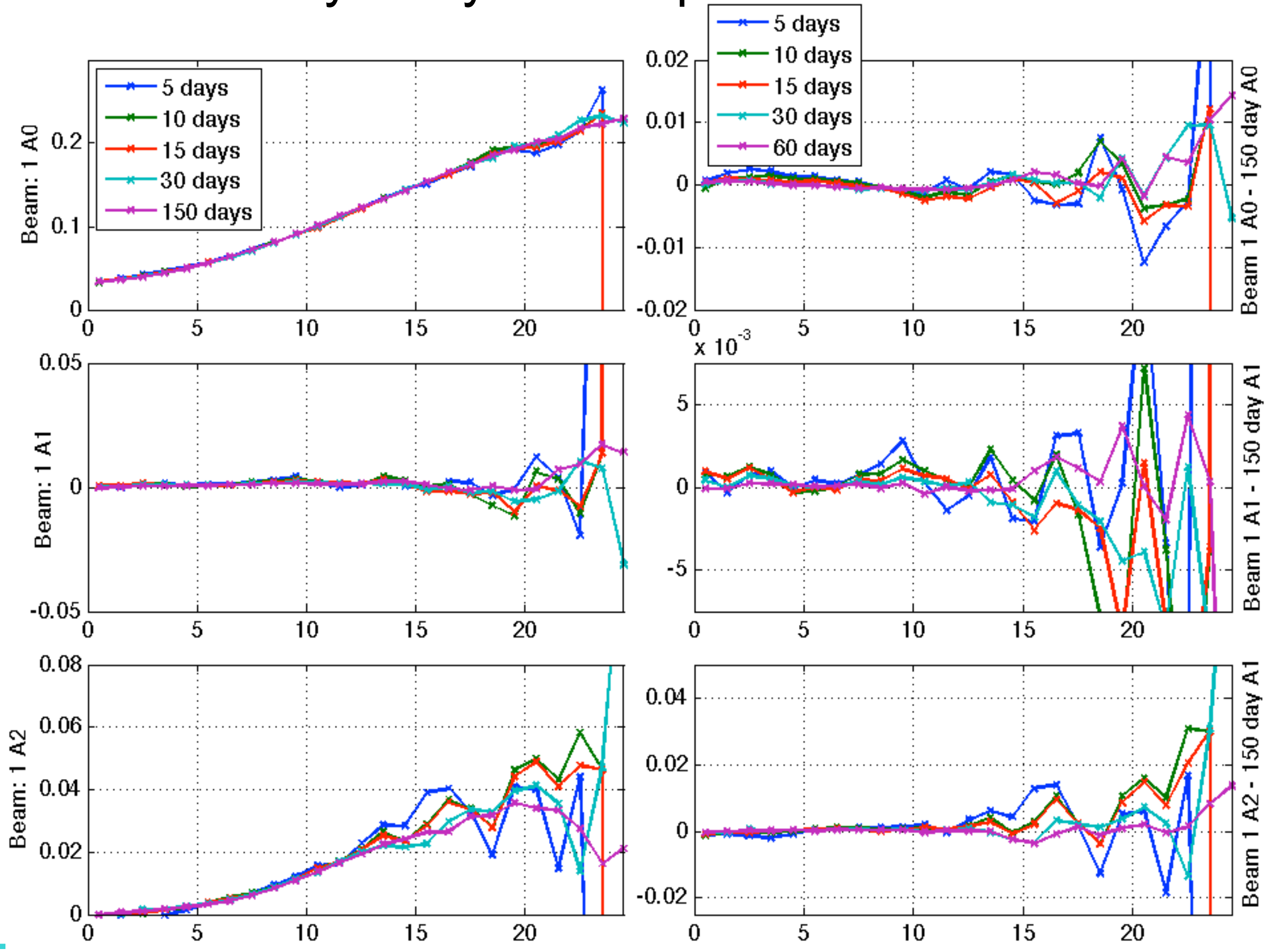


- Process all 2007 data to level 2.
- Collocate simulated scatterometer σ^{tot} observations with NCEP wind vectors.
  - Filter observations with non-zero land/ice fractions.
  - Use NCEP data that is offset by 6h from simulated scatterometer observations.
    - 6h as compared to 0h: rms spd diff: 1.9 m/s; rms dir diff: 27.5 deg. (computed @ beam center)
  - Average NCEP winds over beam footprint. (Not done for these results).

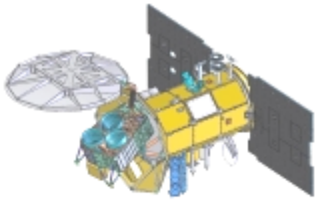
Model Function for Beam 1 Cosine Series (6h offset)

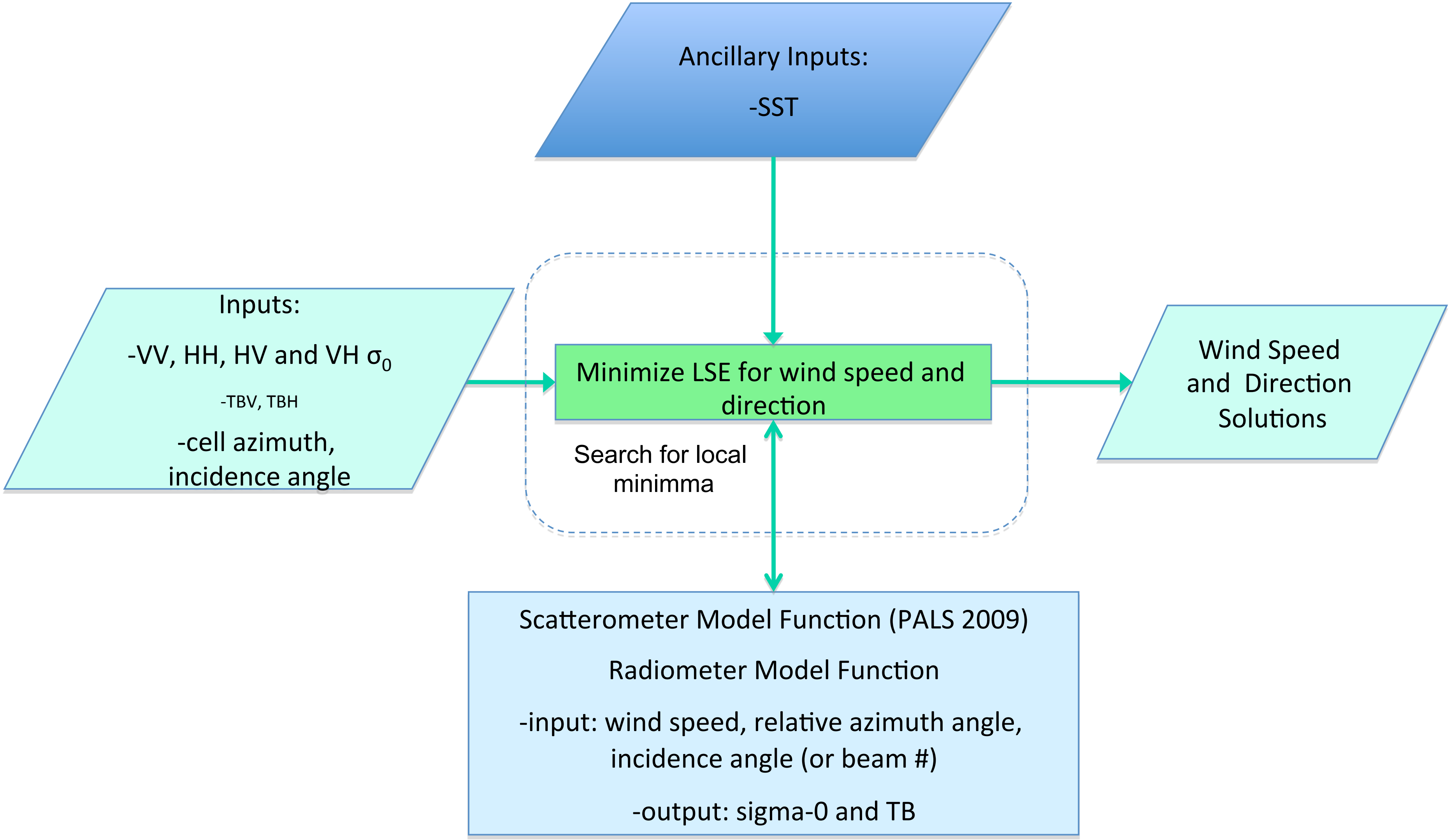


- Need probably 3 months of data for convergence for <20 m/s wind speed.
- The error caused by noisy matchup needs to be resolved.



Experimental Wind Retrieval Process Flow





Ancillary Inputs:

-SST

Inputs:

-VV, HH, HV and VH σ_0

-TBV, TBH

-cell azimuth, incidence angle

Minimize LSE for wind speed and direction

Search for local minimma

Wind Speed and Direction Solutions

Scatterometer Model Function (PALS 2009)

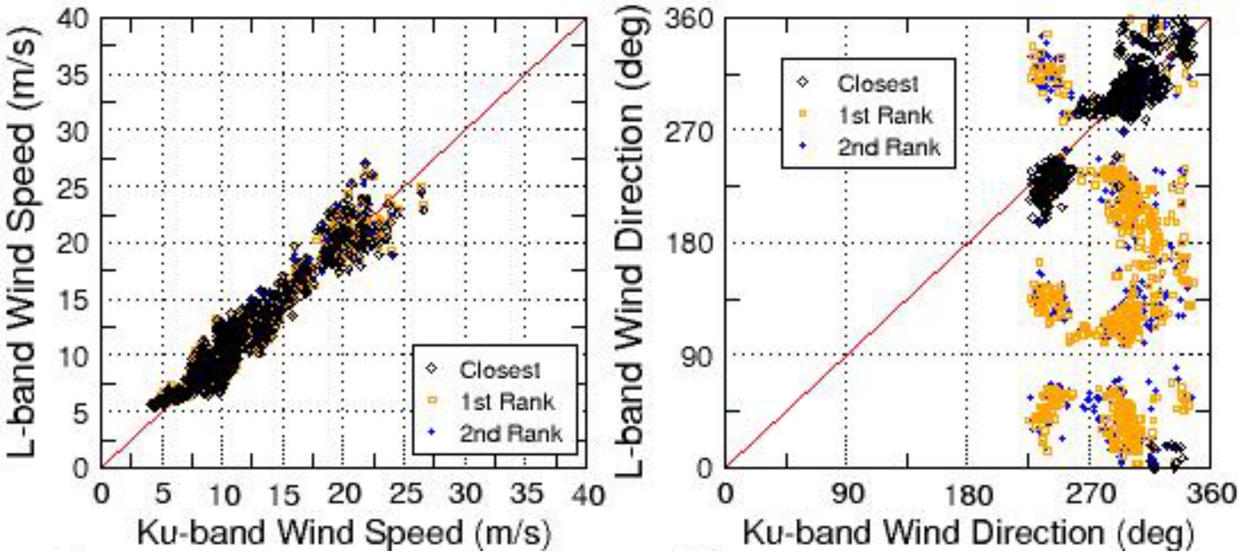
Radiometer Model Function

-input: wind speed, relative azimuth angle, incidence angle (or beam #)

-output: sigma-0 and TB

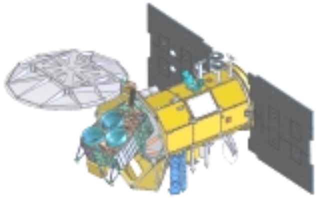
Wind Vector Estimate Using VV and TH

- Distinct characteristics of TB and Sigma0 will allow the estimate of wind speed and direction.
  - The RMS differences between PALS (closest solution) and POLSCAT winds are 1.4 m/s and 15 deg.

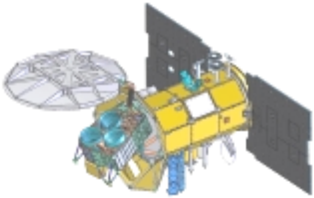


Wind speed and direction solutions derived from PALS radiometer T_H and radar σ_{VV} data are illustrated versus the ocean surface wind speed and direction derived from the POLSCAT Ku-band measurements acquired on 26 February, 2 March and 5 March 2009. In general, the single azimuth look observations will allow four directional solutions. SMAP's fore and aft-look geometry will allow the discrimination of two of the solutions.

Remaining Issues and Plans

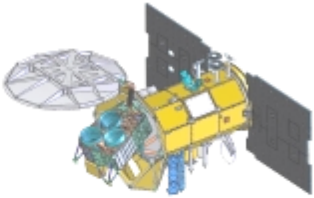


- Develop operational simulator for ADPS testing
- Develop analysis tools for cal/val
  - Detection of pointing and time tag errors
  - Removal of sigma0 calibration bias and drift
  - Assessment of sigma0 quality and flags (rain, RFI) and adjustment of threshold for flags
  - Model function development and accuracy assessment
  - Scatterometer wind validation using matchup analysis of NCEP and any other available wind products (ASCAT, MWR, AMSR, Windsat)
  - Advanced wind retrieval and TB correction techniques



Backup

Level 1 ATBD (Calibration Loop Data)



Define:

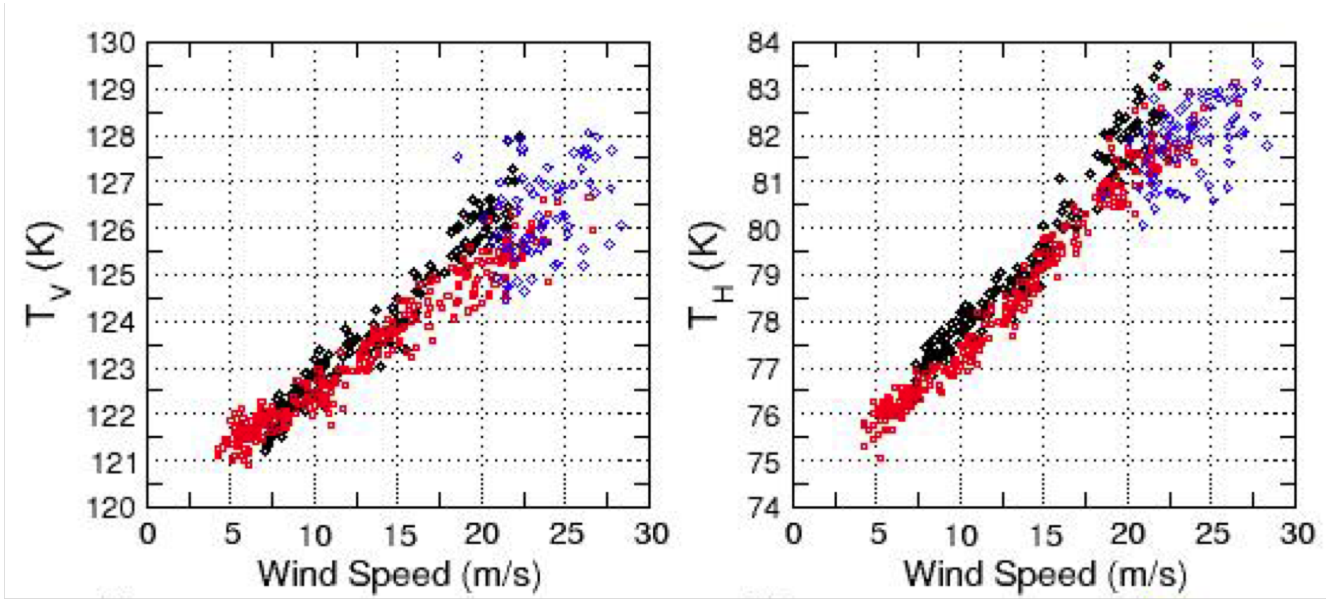
L_{lbc}	Loss through the Loop-back attenuator.
L_{cal}	Loss through the variable attenuator during a loop-back calibration pulse.
L_{op}	Loss through the variable attenuator during measurement pulses.
P_{cal}	The measured value of a loop-back pulse.
P_s	The signal power in the received radar echo
$B_{bp_t p_r}$	Bias terms to compensate for accumulated (but constant) measurement error

Then the measured power during a loop-back calibration pulse will be:

$$P_{cal} = \frac{P_t G_r L_{op}}{L_{lbc} L_{cal}}$$

PALS Model Function

- We find very high correlation between wind speed and T_B(> 0.95).
- We also find a similarly high correlation between radar backscatter and T_B.
  - Suggests radar σ_0 is a very good indicator of excess T_B due to wind speed.
  - Caveat: we need ancillary wind direction information for Aquarius: PALS results show a significant dependence on relative angle between the wind and antenna azimuth.



PALS TB Model Function

- From all of the data we derived a fit of the excess T_B wind speed slope as a function of Θ_{inc}.