An Ocean Surface Wind Vector Model Function for a Spaceborne Microwave Radiometer and Its Application

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Presentation Outline

• Dissertation Objective

• Background
  – Brief history of wind observation from space
  – Planck’s Blackbody radiation
  – Passive microwave measurement
  – Active microwave measurement

• ADEOS-II satellite
  – AMSR → brightness temperature
  – SeaWinds scatterometer → wind vector

• Dataset collocation
Presentation Outline

- Atmospheric independence
- Passive wind vector model function
  - AV-H
  - Model variance
- Model function application
  - Combined passive and fore-look scatterometer for wind direction retrieval
- Conclusion
- List of Publications
Dissertation Objective

• To characterize the passive wind direction signature for vertical and horizontal polarizations
  – Develop passive wind vector model function

• Secondary objective
  – To evaluate combined passive and active wind direction retrieval
    • Fore-look scatterometer
Background
Why measure ocean vector wind?

- Ocean circulation science
- Weather forecasting
- Long-term global climate change science
- Ship routing
- Coastal flooding
- Oil production
- Fishing production
Wind observation satellite missions

- **Aircraft Experiment**
  - 1960’s

- **Proof of Concept**
  - Skylab
  - 1973 1974
  - Seasat
  - 1978

- **Cancelled U.S. mission**
  - 1980’s

- **ERS-1**
  - 1991

- **ERS-2**
  - 1996

- **NSCAT**
  - 1999

- **QuikSCAT**
  - 2000

- **ADEOS-II**
  - 2002

- **WindSat**
  - 2003

- **MetOp-A (ASCAT)**
  - 2006

- **GCOM-W**
  - 2009

- **MetOp-B**
  - 2010

- **MetOp-C**
  - 2014
Wind measurement technology

- **Active Microwave**
  - SASS (Seasat)
  - AMI (ERS-1,2)
  - NSCAT (ADEOS-I)
  - SeaWinds (QuikSCAT, ADEOS-II)
  - ASCAT (MetOp-A)
    - Normalized radar cross-section (NRSC) or sigma-0 ($\sigma^0$) measurement

- **Passive Microwave**
  - WindSat (Coriolis)
    - Polarimetric system
      - 3rd and 4th Stokes parameter
  - New System
    - Require only linear polarization (V and H)
Planck’s Blackbody Radiation

\[ S_f = \frac{2\pi hf^3}{c^2} \left( \frac{1}{e^{\frac{h}{kT}} - 1} \right) \]

- \( k \) = Boltzmann’s constant, \( k = 1.38 \times 10^{-23} \text{ J/K} \)
- \( h \) = Planck’s constant, \( h = 6.63 \times 10^{-34} \text{ J} \)
- \( c \) = light speed, \( c = 3 \times 10^8 \text{ m/s} \)
- \( f \) = EM frequency, Hz
- \( T \) = absolute temperature, K
Rayleigh-Jeans Law

\[ S_f = \frac{2\pi hf^3}{c^2} \left( \frac{1}{e^{hf/kT} - 1} \right) \]

Given \( hf/kT << 1 \)

\[ e^{hf/kT} - 1 \approx hf/kT \]

\[ S_f = \frac{2\pi f^2 kT}{c^2} = \frac{2\pi kT}{\lambda^2} \]

Watts/m²/Hz
Radiometer Antenna

\[ P_t = \frac{2\pi kT}{\lambda^2} \text{IFOV} \]

\[ \Omega_p = \frac{\text{IFOV}}{R^2} \]

\[ A_{\text{eff}} = \frac{\lambda^2}{\Omega_p} \]

\[ P_r = P_t \frac{2}{4\pi R^2} A_{\text{eff}} \]

(Efriss transmission)
Radiometer received power

- Power density at the radiometer antenna
  \[ P_r = kT \text{, Watts/Hz} \]

- Power received by the radiometer with system bandwidth B
  \[ P_r = kTB \text{, Watts} \]
Brightness Temperature

- For non-blackbody, the equivalent radiometric blackbody temperature defined as

\[ T_B = ET_{phy} \]

E = emissivity
T_B = brightness temperature
T_{phy} = physical temperature of the target

- Received power becomes

\[ P_r = kT_B B \]
Radiative Transfer Model (RTM)

$T_c = 2.7 \text{ K}$
Ocean Brightness Temperature

- Power emitted and reflected from ocean surface is strongly polarized
- Emissivity is depend of the air/sea boundary power reflection coefficient

\[ E = 1 - R = 1 - |\rho|^2 \]

\[ T_B = E \cdot SST \]

\[ \rho_V = -\left( \frac{\varepsilon_r \cos \theta - \sqrt{\varepsilon_r - \sin^2 \theta}}{\varepsilon_r \cos \theta + \sqrt{\varepsilon_r - \sin^2 \theta}} \right) \]

\[ \rho_H = -\left( \frac{\cos \theta - \sqrt{\varepsilon_r - \sin^2 \theta}}{\cos \theta + \sqrt{\varepsilon_r - \sin^2 \theta}} \right) \]

\varepsilon_r = \text{dielectric constant of sea water}

SST = sea surface temperature
Atmospheric brightness temp.

- Atmospheric emission is isotropic and non-polarized
- Emissivity characterize by atmospheric absorption coefficient, $\alpha(z)$, Neper/m (assume non-scattering)

$$
T_{BU} = \int_{0}^{\infty} \alpha(z)T(z)\tau(z,S)dz
$$

$$
T_{BD} = \int_{0}^{\infty} \alpha(z)T(z)\tau(0,z)dz
$$

$$
\tau(z_1,z_2) = \exp\left(-\int_{z_1}^{z_2} \alpha(z)dz\right)
$$

$\tau(z_1,z_2)$ = atmospheric transmissivity

$T(z)$ = atmospheric physical temperature profile
Special case for homogeneous atmosphere

\[ T(z) \approx T = \text{constant} \]
\[ \alpha(z) \approx \alpha = \text{constant} \]

Up-welling and down-welling brightness temp is approximated:

\[
T_{BU} = T_{BD} \approx \int_{0}^{S} \alpha \cdot T \cdot e^{-\alpha \cdot z} \, dz = (1 - e^{-\alpha \cdot S})T
\]

\[
\tau = \tau(0, S) = e^{-\alpha \cdot S}
\]

\[
T_{BU} = T_{BD} \approx (1 - \tau)T
\]

= total atmospheric transmissivity
Apparent brightness temperature

- Total brightness temperature “seen” by radiometer antenna:

\[
T_{AP} = T_{BU} + \tau R (1 + \Omega) (T_{BD} + \tau T_{C}) + \tau E \cdot SST
\]

- \( \Omega \) = roughen surface scattering factor due to wind speed
Radiometer System

\[ P_A = kT_B B \]

\[ P_{sys} = P_A + P_{rec} = kT_{sys} B \]

\[ T_{sys} = T_B + T_{rec} \]

\[ \Delta T_{sys} = \frac{T_{sys}}{\sqrt{B \tau}} = \text{measurement standard deviation} \]

\[ \langle V_{out} \rangle = G_s P_{sys} = G_s kT_{sys} B \]
Scatteromery

• Scatterometer is a radar instrument designed primarily to measure ocean vector wind (speed and direction)
• Backscatter signal is relatively insensitive to the atmosphere except for present of rain
• Basic Radar Equation:

\[
P_r = \frac{P_t G^2 \lambda^2}{(4\pi)^3 R^4} \sigma
\]

\[
\overline{P_r} = \frac{\lambda^2}{(4\pi)^3} \int \frac{P_t G^2 \sigma^0 dA}{R^4}
\]

\[
\sigma^0 = \left\langle \frac{\sigma_i}{\Delta A_i} \right\rangle = \text{normalized radar cross-section (NRSC)}
\]

\[
\sigma = \text{radar cross-section}
\]
Geophysical Model Function

• Empirical relationship between $\sigma^0$ and wind vector is known as GMF
• GMF may be modeled as two harmonic cosine functions

$$\sigma^0 = C_0(wspd) + C_1(wspd)\cos(\chi) + C_2(wspd)\cos(2\chi)$$

• GMF is also a function of incidence angle and observed polarization
Relative Wind Direction ($\chi$)
GMF for Scat V-Pol (C₀ mean removed)
GMF for Scat H-Pol

($C_o$ mean removed)
Retrieval Algorithm

• Scatterometer requires backscatter measurements from multiple direction (fore and aft) to resolve wind direction

• Retrieval algorithm is based on maximum likelihood estimation (MLE)

\[ \zeta = \sum_i \left( \frac{\sigma_i^0 - GMF(wspd, \chi)}{\text{Variance}_{\sigma_i^0}(wspd, \chi)} \right)^2 \]

• Require nudging and median filtering to select a unique wind vector (known as direction ambiguity removal)
ADEOS-II Satellite

- **AMSR**
  - Dual-Polarization Multi-frequency:
    - 6.9, 10.7, 18.7, 23.8, 36.5, 89.0 GHz
  - Incidence angle: 55°
  - Integration time: 2.6 ms
  - Bandwidth:
    - 100-3000 MHz

- **SeaWinds**
  - Dual-Polarization
    - 13.4 GHz, 110 W, 189 PRF
  - Incidence angle:
    - 54° V-pol,
    - 46° H-pol
  - 18 RPM
  - Bandwidth: 250 kHz
Measurement Geometry

Satellite ground track

H-Pol swath = 1400 km
AMSR Swath = 1600 km
V-Pol Swath = 1800 km

Multi-channel $T_B$’s
V-pol $\sigma^0$
H-pol $\sigma^0$
Satellite data product

- **AMSR**
  - Overlay L2A product
    - Brightness Temp. \((T_B)\): 10, 18, 37 GHz
    - Water vapor
    - Cloud liquid water
    - Rain
    - SST

- **SeaWinds**
  - L2A product
    - Sigma-0
  - L2B product
    - Wind speed
    - Wind direction

![Grid with labels](image)
Other required data

- **AMSR azimuth**
  - Calculated from AMSR measurement geometry, scan radius (940 km) with WVC location

- **Sea surface temperature (SST)**
  - NCEP’s Global Data Assimilation System (GDAS)
  - Global map generated every 6 hr.
  - $1^\circ \times 1^\circ$ resolution
Data Match-Ups

• AMSR and SeaWinds data were automatically collocated
• GDAS’s SST match-up required additional work
  – Four point interpolation surrounding AMSR WVC’s quadrants
• Average AMSR parameters into single WVC’s
• All data were match-up over entire mission period of Apr - Oct, 2003
• Filtered out rain and high cloud liquid water (<0.1mm)
Binned Data Scheme

Wind Speed: ±0.5 m/s

-1.0 ... 11.0 13.0 15.0 ... ... 29.0 31.0 33.0

Relative Direction: ±5.0°
RTM Assumption

• Atmosphere is homogeneous: Temp. profile and absorption is constant

\[ T_{BU} = T_{BD} = (1 - \tau)T \]

• Air/Sea temperature is the same: Effective temperature

\[ T = SST = T_{eff} \]

\[ T_{BU} = T_{BD} = (1 - \tau)T_{eff} \]
RTM Assumption -2

\[ T_{AP} = \left\{ T_{BU} + \tau R \left( 1 + \Omega \right) (T_{BD} + \tau T_{C}) + \tau E \cdot SST \right\} \]

upwelling component

\[ T_{BU} = (1 - \tau)T_{eff} = T_{eff} - \tau T_{eff} \]

scattering component

\[ \text{scattering} = \tau RT_{BD} + \tau R\Omega T_{BD} + \tau^2 R(1 + \Omega)T_{C} \]
\[ = \tau R(1 - \tau)T_{eff} + \tau R\Omega(1 - \tau)T_{eff} + \tau^2 R(1 + \Omega)T_{C} \]
\[ = \tau T_{eff} - \tau^2 RT_{eff} + \tau R\Omega(1 - \tau)T_{eff} + \tau^2 R(1 + \Omega)T_{C} \]

surface component

\[ \text{surface} = \tau E \cdot SST = \tau (1 - R) \cdot T_{eff} = \tau T_{eff} - \tau RT_{eff} \]

\[ T_{AP} = T_{eff} - R \tau^2 T_{eff} + R \tau \Omega(1 - \tau)T_{eff} + R \tau^2 (1 + \Omega)T_{C} \]

\[ T_{AP} \approx (1 - R \tau^2) \cdot T_{eff} \]
Atmospheric cancellation

- The brightness temperature for vertical and horizontal polarization may be represented as:

\[ T_{BV} = (1 - R_V \tau^2)T_{eff} \]
\[ T_{BH} = (1 - R_H \tau^2)T_{eff} \]

- Define a new parameter, \( A \) as a ratio of V and H-pol

\[ A \equiv \frac{R_H}{R_V} \]

- Changes in brightness temperature with respect to atmospheric transmissivity

\[ \partial T_{BV} = -2R_V \tau T_{eff} \partial \tau \]
\[ \partial T_{BH} = -2AR_V \tau T_{eff} \partial \tau \]

\[ \partial \left( AT_{BV} - T_{BH} \right) \over \partial \tau = 0 \]
“A” Parameter

• Linear combination of V and H brightness temperature is independent of atmosphere

\[ AT_{BV} - T_{BH} = A(1 - R_v \tau^2)T_{eff} - (1 - R_H \tau^2)T_{eff} \]

\[ = (A - 1)T_{eff} - (AR_v - R_H)\tau^2T_{eff} \]

\[ A = \frac{T_{BH} - T_{eff}}{T_{BV} - T_{eff}} \]

\[ T_{eff} = SST \]
“$A$” Parameter -2

- $A$ parameter has Gaussian distribution
- $A$ was found as a function of wind speed (wspd) and sea surface temperature (SST)
A parameter for 10 GHz
A parameter for 18 GHz
A parameter for 37 GHz
Model Function Procedure

- $AT_{BV} - T_{BH}$ (AV-H) was found as a function of wind speed, wind direction and SST
- AV-H is model as a linear sum of each components

$$AT_{BV} - T_{BH} = F(SST) + C_0(WSPD) + C_1(WSPD) \cdot \cos(\chi)$$

$$\quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad + C_2(WSPD) \cdot \cos(2\chi)$$

- Wind directional signal modeled as two harmonic cosine function

$$F(WDIR) = C_0(WSPD) + C_1(WSPD) \cdot \cos(\chi) + C_2(WSPD) \cdot \cos(2\chi)$$
AV-H for 10 GHz
AV-H for 18 GHz
AV-H for 37 GHz
Procedure -2

- Assume sea surface is smooth: wind speed = 0 m/s
- AV-H become a function of only SST
  \[ AT_{BV} - T_{BH} = F(SST) + C_0(WSPD) + C_1(WSPD) \cdot \cos(\chi) + C_2(WSPD) \cdot \cos(2\chi) \]
- This initial \( F(SST) \) found from extrapolation to zero wind speed values
- Appropriate function that best describes the measurement is found
Initial $F(SST)$
Procedure - 3

• Subtract AV-H from initial $F(SST)$. 
• Remaining AV-H become a function of wind speed and direction 

$$(AV - H) - F(SST) = F(WDIR)$$

• Find regression to the measurement in the form:

$$F(WDIR) = C_0(WSPD) + C_1(WSPD) \cdot COS(\chi) + C_2(WSPD) \cdot COS(2\chi)$$
First iteration $F(WDIR)$
Procedure -4

• The $C$’s coefficient was found for discrete values of wind speed bin
• Regression fit was found for each of the $C$’s coefficient. $F(WDIR)$ is found for all wind speed values.
• Iterative process has established

$$(AV - H) - F(WDIR) = F(SST)$$
Model Equations

\[ AT_{BV} - T_{BH} = F(SST) + C_0(WSPD) + C_1(WSPD) \cdot \cos(\chi) + C_2(WSPD) \cdot \cos(2\chi) \]
## Model Coefficients

<table>
<thead>
<tr>
<th>AMSR Channels</th>
<th>F(SST)</th>
<th>C₀(WSPD)</th>
<th>C₁(WSPD)</th>
<th>C₂(WSPD)</th>
</tr>
</thead>
</table>
| **10 GHz**    | a= 253.8939018  
b= -0.007207942  
c= -1.827465510  
d= 1.3108e-05  
e= 0.003314763 | a= 0.517115747  
b= -0.140174737  
c= -3.734401755  
d= 0.003843883  
e= 0.787061774  
f= 0.003616502  
g= -0.101162061 | a= -0.653431016  
b= -0.042740230  
c= 0.205632786  
d= 0.001052848 | a= -1.395843862  
b= -0.073649495  
c= 0.283917140  
d= 0.002780937  
e= -0.008776347 |
| **18 GHz**    | a= 234.5302360  
b= -0.003810786  
c= -0.898157560 | a= -0.268136601  
b= -0.110325789  
c= -3.522010565  
d= 0.043939984  
e= -0.167645682  
f= 0.000277041  
g= -0.075276385 | a= -2.095456244  
b= -0.039566361  
c= 0.508449429  
d= 0.001709247 | a= -2.2041331797  
b= -0.068904176  
c= 0.501358865  
d= 0.002615589  
e= -0.017071887 |
| **37 GHz**    | a= 193.3863684  
b= -0.004205115  
c= -0.907046083 | a= 3.246690433  
b= 0.139539136  
c= -13.19966520  
d= -0.006413733  
e= 0.318536521  
f= 0.000286851  
g= -0.022678385 | a= -5.056542254  
b= -0.008215836  
c= 1.147747275  
d= 0.001194255 | a= -2.019721861  
b= -0.086047248  
c= 0.430587232  
d= 0.002842379  
e= -0.015823182 |
Model Function for 10 GHz
Model Function for 18 GHz

Wind Direction Dependence for 18 GHz

- 5 m/s
- 7 m/s
- 9 m/s
- 12 m/s
- 15 m/s
- 20 m/s

Relative Wind Direction (Degree)
Model Function for 37 GHz
Coefficient $C_1$
Coefficient $C_2$
Wind speed dependence dc
SST dependence dc
Model standard deviation

- Directional model standard deviation was found as a function of relative direction and wind speed.
- Standard deviation was modeled the same way as the model function in the form:

\[ \text{STD} = C_1(WSPD) \cdot \cos(\chi) + C_2(WSPD) \cdot \cos(2\chi) \]

- Same regression process was repeated.
Measurement Noise
Standard deviation
Standard deviation for Upwind

\[
\text{Mean} = \text{Std}
\]

9 m/s
Wind Vector Retrieval

- Wind vectors are ideally retrievable using the model function for AV-H measurement and given SST
- Retrieval algorithm based on maximum likelihood estimation (MLE)

\[
\zeta = \sum_{\text{freq}=1, 18, 37 \text{GHz}}^{} \left( \frac{\text{AVH}_{\text{Meas}} - \text{AVH}_{\text{Model}}(\text{wspd, rel.dir}, \text{SST})_{\text{freq}}}{\text{Variance}_{\text{AVH}}(\text{wspd, rel.dir})_{\text{freq}}} \right)^2
\]
Wind Vector Retrieval -2

- In practice measurements standard deviations are relatively high for wspd < 9 m/s
- Wind retrieval from AV-H alone will not achieve required accuracy
- AV-H brightness may be combined with the other measurements to be able to retrieve wind vector
Combined Active/Passive retrieval

- Use favorable geometry measurements of AMSR’s $T_B$ and SeaWinds’ $\sigma^0$ on ADEOS-II
- Only fore-look $\sigma^0$ measurements were used
  - Assess usability of AV-H model function
  - Simplifies instrument design
    - Adds two feed and electronics to multi-channel conical scanning radiometer
- Given SST available from GDAS, and known wind speed retrieved from SeaWinds scatterometer
Wind speed transfer function
Active/Passive Algorithm

\[ \zeta = \sum_{freq=10,18,37\,GHz} \left( \frac{AVH_{\text{Meas}} - AVH_{\text{Model}}(\text{wspd}, \chi, SST)_{freq}}{\text{Variance}_{AVH}(\text{wspd}, \chi)_{freq}} \right)^2 \]

\[ + \sum_{pol=V,H} \left( \frac{\sigma_0 - \text{GMF}(\text{wspd}, \chi)_{pol}}{\text{Variance}_{\sigma_0}(\text{wspd}, \chi)_{pol}} \right)^2 \]

\[ \chi = \text{azimuth} - \text{direction} \]
Wind direction ambiguities

• Wind direction solution is not unique - caused by biharmonic nature of the model functions

• Wind direction solutions were kept up to four and ordered according to the inverse values of MLE
  – i.e. 1st ranked solution corresponds to minimum MLE value, 2nd ranked is the second minimum, …

• Of these ambiguities, only one of the solutions is the “correct” wind direction
Measurements residual

Combine active/passive retrieval

Measurements residual (normalized)

Relative Wind Direction (Degree)

1st

2nd

3rd

101

188

323
Wind Retrieval Comparison

Active/Passive Retrievals
• For best case scenario, ambiguities were compared to the known surface truth and the closest direction solution was selected
• GDAS was used as the surface truth (independent source)

Active fore-look
• Wind direction comparisons were also made for the “closest” solution retrieved without using passive AV-H measurements
Closest Ambiguity Comparison

5 m/s, 7 m/s, 9 m/s, 12 m/s, 15 m/s, 20 m/s

Active/Passive direction

GDAS direction
## Closest solutions comparison

<table>
<thead>
<tr>
<th>Wind Speed (meter/sec)</th>
<th>Number of Points</th>
<th>Closest Ambiguities: Standard Deviation Error</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Passive + fore-look Scat</td>
</tr>
<tr>
<td>5</td>
<td>337493</td>
<td>20.8°</td>
</tr>
<tr>
<td>7</td>
<td>441818</td>
<td>23.6°</td>
</tr>
<tr>
<td>9</td>
<td>309717</td>
<td>17.4°</td>
</tr>
<tr>
<td>12</td>
<td>99563</td>
<td>17.5°</td>
</tr>
<tr>
<td>15</td>
<td>33520</td>
<td>17.1°</td>
</tr>
<tr>
<td>20</td>
<td>1680</td>
<td>19.1°</td>
</tr>
</tbody>
</table>

Current scatterometer is capable of wind speed measurement of 3-20 m/s
- wind speed accuracy: 2 m/s
- wind direction accuracy: 20°
Instrument Skill

• The instrument skill is a metric to determine the performance of the wind ambiguity removal based upon ambiguity ranking.

• The higher the probability that 1\textsuperscript{st} ranked solutions are the closest solution, the greater the skill of the instrument.

• Usually in four-look scatterometry, the 1\textsuperscript{st} and 2\textsuperscript{nd} ranked solutions are the most probable closest wind vector.
## Skill Comparison

<table>
<thead>
<tr>
<th>Wind Speed (meter/sec)</th>
<th>Closest Ambiguity Ranking</th>
<th>Passive + fore-look Scat</th>
<th>Only fore-look Scat</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1&lt;sup&gt;st&lt;/sup&gt;</td>
<td>2&lt;sup&gt;nd&lt;/sup&gt;</td>
</tr>
<tr>
<td>5</td>
<td>30 %</td>
<td>35 %</td>
<td>23 %</td>
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<tr>
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<td>30 %</td>
<td>34 %</td>
<td>23 %</td>
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<td>30 %</td>
<td>37 %</td>
<td>27 %</td>
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<tr>
<td>12</td>
<td>61 %</td>
<td>28 %</td>
<td>10 %</td>
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<tr>
<td>15</td>
<td>82 %</td>
<td>15 %</td>
<td>2 %</td>
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<tr>
<td>20</td>
<td>91 %</td>
<td>9 %</td>
<td>0 %</td>
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# Active/Passive Skill Improvement

<table>
<thead>
<tr>
<th>Wind Speed (m/s)</th>
<th>Skill improvement (1\textsuperscript{st} and 2\textsuperscript{nd} rank combined)</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td>Passive + fore-look Scat</td>
</tr>
<tr>
<td>5</td>
<td>9 %</td>
<td>14.1 °</td>
</tr>
<tr>
<td>7</td>
<td>15 %</td>
<td>10.8 °</td>
</tr>
<tr>
<td>9</td>
<td>15 %</td>
<td>9.0 °</td>
</tr>
<tr>
<td>12</td>
<td>9 %</td>
<td>9.0 °</td>
</tr>
<tr>
<td>15</td>
<td>5 %</td>
<td>9.5 °</td>
</tr>
<tr>
<td>20</td>
<td>6 %</td>
<td>13.7 °</td>
</tr>
</tbody>
</table>
Conclusion

• Linear combination of vertical and horizontal brightness temp. (AV-H) is a function of only surface parameters
  – $A$ is a $f$(Freq, pol, SST and wind speed)
  – Effects of atmosphere cancel
  – Large DC bias is $f$(Freq, pol, SST and wind speed)

• Empirical relationship between AV-H and surface parameter is defined for wind vector and SST.
Conclusion -2

• Measurement noise (deltaTb) dominates over wind directional signal for wind speed < 9 m/s
  – May prevent wind retrieval using passive measurement alone

• Combined active and passive has been investigated with fore-look geometry
  – Closest ambiguity shows that retrieval achieves wind direction accuracy of < 20 °
  – However, wind direction accuracy degrades compared to closest fore-look active measurement alone
  – But, instrument skill is higher (than using fore-look active measurement alone)
List of Conf. Publications


List of Conf. Publications - 2

Refereed Publications
