Ocean wind stress as measured using ocean satellite sensors

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Outline

- Approach – provide complement to the nominal triplet approaches using instead *in situ* stress data

\[
U(z) - U_s = \frac{u^* a}{\kappa} \left[ \ln \frac{z}{z_0} + \phi(z, z_0, L) \right]
\]

- density
- stability
- drag coefficient
- surface current

Is this a valid assumption, and for all sensors?

\[
\tau_a = < \rho_a \cdot C_{d1\text{EN}} > \cdot |U_{10\text{EN_sat}}| \cdot U_{10\text{EN_sat}} = \rho_a |u^*| u^*
\]
Motivations

Are there 1\textsuperscript{st} or 2\textsuperscript{nd} order distinctions between $\tau$ and $U_{10\text{EN\_SAT}}$ and amongst the OW sensors?

- Need still exists to address long-standing issue of validating the scatterometer as a wind stress estimator, in large part due to lack of ground truth
- Desire climate data record Ocean Wind (OW) consistency amongst many different passive & active ocean wind configurations– i.e. the remote sensing aspect comes into play
- Support for interpretation of OW as an area-mean stress and validated methods for moving between $U_{10\text{EN\_SAT}}$ and $\tau_{\text{SAT}}$
- New L-band data (Aquarius/SMAP/CYGNSS) + CFOSAT is/will provide expanded and alternate view of wind-waves & winds
- Surface current missions envisioned – will open another new window
Momentum Flux
Meteorological Platforms
2006-2015

Primary sensor

3D 20 Hz sonic anemometer with motion package (DCFS - Direct Covariance Flux System)

Range of Conditions -
marginal sea, tides, short fetch
Gulf Stream & fronts
Subtropical gyre & swell

Hourly data collection for months to years
Ocean wind satellite datasets

• **Scatterometer:**
  - QuikSCAT: 12km (L2 V3 PO.DAAC + RSS Gridded)
  - ASCAT-A (L2 and Coastal KNMI + RSS gridded)
  - OSCAT (L2B PO.DAAC)
  - Rapidscat (L2B PO.DAAC)

• **Radiometer (all V7 RSS, gridded):**
  - AMSR-E, AMSR-2
  - WINDSAT
  - SSM/I(S) (many)

• **Altimeter (GDR):**
  - Jason-1
  - Jason-2
  - Envisat RA-2
  - Saral/AltiKa
Creation of quality-controlled satellite ocean wind stress assessment datasets

- Consistent in situ flux data: use of moored direct covariance momentum flux measurements and consistent data processing
- Three differing locations to date and coming soon 4 global-node OOI(NSF) mooring + OOI pioneer array data: higher DOF and wind-wave conditions
- Satellite matchups performed in consistent manner with latest version wind products, including scatterometer, radiometers and altimeters
- Significant QA/QC efforts in 2014-2015 tied to flagging and motion correction, files will be in open access UNH website July 2015 or email me

Scatterometer – Flux Buoy Comparison Datasets

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<td>Rapidscat</td>
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<td>GM</td>
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Radiometer – Flux Buoy Comparison Datasets

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<td>AMSR-2</td>
<td>0530</td>
<td>S, GM</td>
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2014-2015: a rough winter in the Gulf of Maine for fluxes (but more high winds!)

Deployment – Oct. 2014
Recovery – March 2015

Range of Conditions –
- 300 hrs with U10 > 15 m/s
- 9.2 m $H_s$ in Winter Storm Juno, 21 Jan 2015
- Offshore Icing events > 10
- Data failure in Feb 2015
Feb. 2015, Sonic stopped reporting data.

Sonic lopped off the top (trawler?)
DCFS combined datasets – expanded wave conditions

G. Maine = young seas (limited swell, limited duration)

Global Altimeter data
incl. fully-developed (FD) sea model

Winter G. Maine station 2014-15
- Data far fall below FD line
Back to basic question….

Is this a valid assumption, and for all sensors?

\[
\tau_a = \langle \rho_a \cdot C_{d10EN} \rangle \cdot |U_{10EN_{sat}}| \cdot U_{10EN_{sat}} = \rho_a |u^*| u^*
\]

alternately

\[
\langle \rho_a \cdot C_{d10EN} \rangle \cdot |U_{10EN_{sat}}| \cdot U_{10EN_{sat}} = \rho_a C_{d10EN} \cdot |U_{10EN}| \cdot U_{10EN}
\]

\[
|U_{10EN_{sat}}| \cdot U_{10EN_{sat}} \neq |U_{10EN}| \cdot U_{10EN}
\]
Satellite winds, wind stress, and near-surface air density

Wentz (stress working group comm.), Hersbach (2010), Bourassa et al. (2010), Grodsky et al. (2012), Pierson and Donelan (1987) and back to Seasat... The assumption: U10N_satellite is not equal to U10N_insitu when near surface air density changes from some nominal density tied to the GMF

\[
\tau_a = \rho_a \cdot u_*^2 = \rho_a \cdot C_{d10EN} \cdot |U_{10EN}| \cdot U_{10EN}
\]

\[
\tau_{a \text{ sat}} = < \rho_a \cdot C_{d10EN}(U) >_{\text{GMF}} \cdot |U_{10EN_{\text{sat}}}| \cdot U_{10EN_{\text{sat}}}
\]

IF VALID AND \(<C_{d10EN}> \sim C_{d10EN}, \ THEN\)

\[
U_{10EN_{\text{sat}}} / U_{10EN} = (\rho / <\rho>)^{1/2} = f(P, T_{\text{air}}, rH)
\]

Note:
- \(T_{\text{air}}\) highly correlated with SST
- Neglecting SST-dependent viscosity of water -> short wave variation
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\[
U_{10\text{EN}_{\text{sat}}}/U_{10\text{EN}_{\text{InSitu}}} = (\frac{\rho}{<\rho>})^{1/2}
\]

True for Ku-band scatterometers?

Appears so….. Slope of 0.9

Data filtering: 
\(<\rho> \ @ 22\text{degC}, \text{using T}_{\text{air}}\) and not SST, 
\(U > 3 \text{ m/s}, \)
\(\Delta U < 3\text{Std}, \text{closest satellite matchup}\)
Satellite winds, wind stress, and near-surface air density

Wentz (stress working group comm. 2013), Hersbach (2010), Bourassa et al. (2010), Grodsky et al. (2012), Pierson and Donelan (1987) and way back to Seasat... The assumption: $U_{10N_{satellite}}$ is not equal to $U_{10N_{insitu}}$ when near surface air density changes from some nominal density tied to the GMF.

$$\frac{U_{10EN_{sat}}}{U_{10EN_{InSitu}}} = \left( \frac{\rho}{\langle \rho \rangle} \right)^{1/2}$$

True for C-band ASCAT?

No correlation observed

But less data...

Data filtering: $\langle \rho \rangle$ @ 22degC, using T_air and not SST, $U > 3$ m/s, deltaU< 3Std, closest satellite matchup
Satellite winds, wind stress, and near-surface air density

Wentz (stress working group comm. 2013), Hersbach (2010), Bourassa et al. (2010), Grodsky et al. (2012), Pierson and Donelan (1987) and way back to Seasat... The assumption: \( U_{10N_{\text{satellite}}} \) is not equal to \( U_{10N_{\text{insitu}}} \) when near surface air density changes from some nominal density tied to the GMF.

\[
U_{10E_{\text{sat}}}/U_{10E_{\text{InSitu}}} = (\rho/\langle\rho\rangle)^{1/2}
\]

True for radiometer wind speeds?

Likely, slope of 0.6 but needs further work

Data filtering: \( \langle\rho\rangle @ 22\text{degC} \), using \( T_{\text{air}} \) and not SST, \( U > 3 \text{ m/s} \), \( \Delta U < 3\text{Std} \), closest satellite matchup
Satellite winds, wind stress, and near-surface air density

A couple fine points(?) raised yesterday and last year

To use satellite U10N for stress, user must supply \(<\rho_a>\)....

What value(s) does one apply?

- Is mean density used in GMF \(<\rho_a>\) a systematic function of U?
- Does most higher wind occur at lower SST and thus an increased mean air density?
- Likely depends on each GMF training dataset and approach – should be able to readily evaluate this (KNMI, IFREMER talks)

Extreme (?) example :

\[
\rho_a (1020., 24., 85\%rH) = 1.185 \quad \text{(trades, } U=8) \\
\rho_a (1000., 05., 85\%rH) = 1.249 \quad \text{(ACC, } U=12)
\]

Difference is 5.5% and directly proportional to wind stress
Also need to reconcile/consider Ku and C-band results with added potential impact of surface viscosity as function of water temperature (Bentamy talk).

Figure 5. Spatial distribution of model wind retrieval errors in (left) C-band, (right) Ku-band. (a, d) Error due to SST-induced variation in air density ($\rho_a$), (b, e) error due to SST-induced variation in water viscosity ($\nu$), (c, f) total error. Radar calibration is assumed corresponding to the global mean SST = 19°C. Calculations are done for V-pol, upwind, and $\theta = 45^\circ$. 
Wave influence? : Drag Coefficient variation for fixed wind speed

\[ \tau_a = \langle \rho_a \cdot C_{d10EN} \rangle \cdot |U_{10EN_sat}| \cdot U_{10EN_sat} \]

\[ \frac{U_{10EN_sat}}{U_{10EN_InSitu}} = \sqrt{\frac{C_{dN10}}{C_{dN10_{bulk}}}} \]

Here \( C_{dN10_{bulk}} \) would be the avg drag (Liu and Tang) for each ENW wind speed in the GMF training set.

Also recall air-sea studies yet to fully resolve:

\[ C_{dN10} (z_0) = F(u^*, u*/C_p, ak, mss) \]

And then the remote sensing questions:

? \( z_{0\text{ SCATT}} \approx z_{0\text{ Radiometer}} \) ?
? \( z_{0\text{ C_SCATT}} \approx z_{0\text{ Ku_SCATT}} \) ?
Drag coefficient variation in Windsat…

Satellite wind excess versus wave steepness

U=4 m/s +1.5

Apparent wave dependence at light to moderate wind

Flat at winds > 10 m/s (foam?)

U=6 m/s +1.5

U=10 m/s +1.5

U=14 m/s +1.5
Is *in situ* drag coefficient variation vs. waves same as for scatts and radiometer?

\[ U = 7 \pm 2 \text{ m/s} \]
Is *in situ* drag coefficient variation vs. waves same as for scatts and radiometer?

\[ U = 10 \pm 1.5 \text{ m/s} \]

**Satellite**

![Satellite Graph]

**in situ**

![in situ Graph]
CASE STUDY for wave impacts
Cold air outbreaks
Strong Westerlies
Fetch-limited wavefield
Use buoy network to assess cross-Gulf winds
Buoy locations with fetch, developing seas
$X = 10, 90, \text{ and } 190 \text{ km},$ winds of 10-15 m/s typical

A ship encounters wind speeds of 32 knots with land 520 km to windward

Significant wave height if fetch exceeds 520 km

Significant wave height limited by fetch

Significant wave height after 2.5 hours duration

Fetch (km)
Questions:

Do we see cross-fetch satellite wind speed ‘error’ under quasi-steady westerlies and spatial change in sea state?

…and for scatterometers vs. radiometers?
Westerly wind case study – Events Closest to Ideal

Event Criteria:
- Low sea state at onset
- Wind direction from W +- 30 deg and steady
- Mean event wind speed exceeds 10 m/s
- Wind speed steady in time and fetch
- Significant number of satellite crossovers in first 18 hours
- Hs growth with fetch ‘consistent’ with wind sea
Fetch = 60km: 2004012900

- AMSRE
- WINDSAT
- SSMI
- ASCAT
- QSCAT

buoy@10 km
buoy@100km
Wind variation with time and fetch

- fetch = 15 km
- fetch = 60 km
- fetch = 105 km
- fetch = 170 km
- fetch = 200 km

Buoy wind
Buoy SWH

- buoy@10 km
- buoy@105 km
- buoy@200 km
Questions:

Do we see cross-fetch satellite wind ‘error’ under quasi-steady westerlies and spatial change in sea state?

…and for scatterometers vs. radiometers?

Preliminary conclusions

- Reviewed 24 cases across 10 years
- Idealized cases are actually few (2-3)
- Overall answer to these questions so far:
  - No to the first, not in any statistical sense (NULL hypoth)
  - perhaps some overestimate by radiometer LF products
  - perhaps shortest fetch data overestimated
Summary

• Satellite wind validation against direct covariance flux datasets is providing some new support for satellite stress
  - air density variation is apparent, some further work to assess multi-sensor results
  - wave-dependent variation also evident, but weak
  - approach to assess satellite winds under fetch-limited conditions
• Final flux datasets and matchup validation database near completion & input welcome on particular satellite products to ingest – open access this summer
• Intend to collect stress CDR information (JPL, KNMI, IFREMER, RSS,…) and incorporate in analyses
• New flux platforms in the works to expand the database
Backup slides
QuikScat (Ku-band) wind with change in MO stability length scale

Conclusions: With present DOF (climode analyses), the quikscat data
a) clearly depart from the anemometer 10 m wind
b) follow an ENW (e.g. $\psi(z/L)$ of Coare3.5/LKB ) to within a few %
c) some possible over and under shoot hinted at for extremes in z/L
Atmospheric Stability, ocean satellite winds, and equivalent neutral wind

- Scatt wind has been evaluated by many against bulk met stability and other ancillary data approaches (e.g. Liu et al., 1984)
- Still difficult to nail down—results here indicate this dataset may still have low EOF but do see some consistent deviation in residual under stable conditions for Ku and C-band scatts as well as for Windsat

![Graph showing u10n sat/u10n in situ vs z/L](image)

Version with U = 8 +- 4 and 3.5 sdev
No oscat
LF windsat
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DCFS combined datasets – expanded wave conditions

Steepness

CLIMODE

Coastal NE
- bifurcation in steepness

SPURS I
N. Atlantic
24 N