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

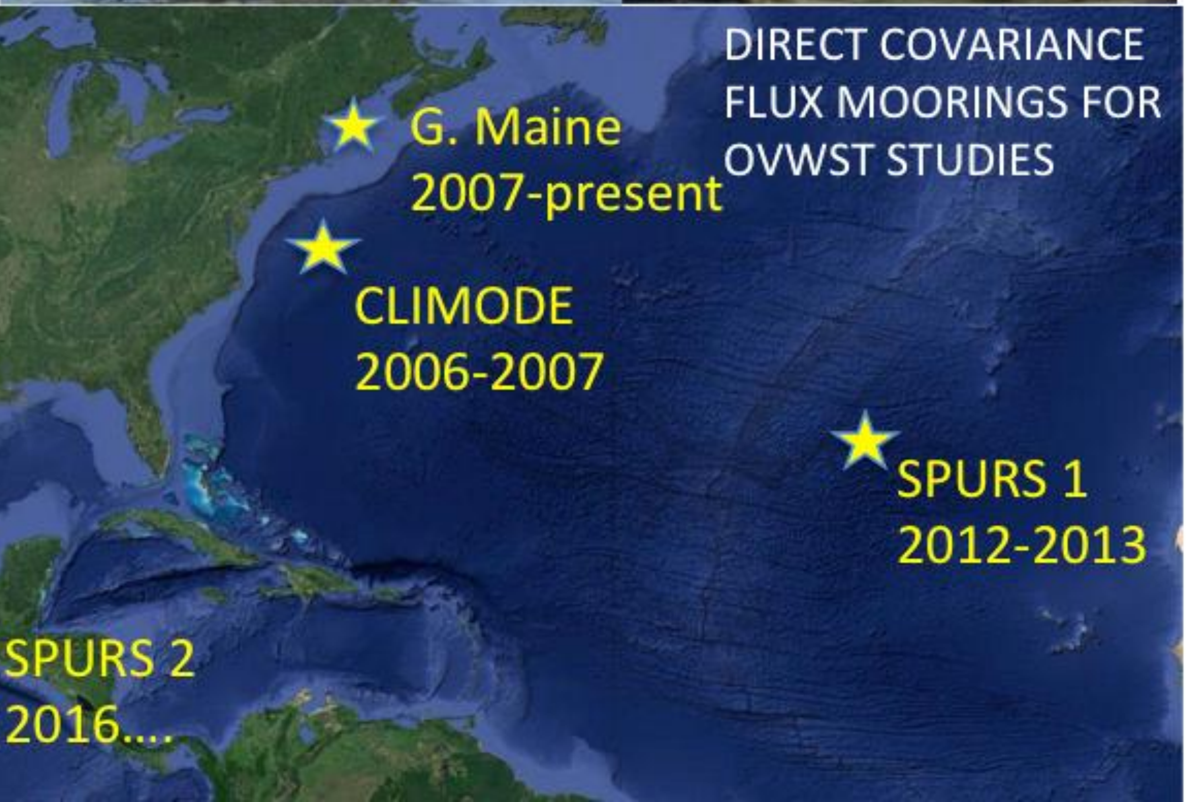
Is this a valid assumption, and for all sensors?

$\boldsymbol{\tau_a} = \langle \rho_a \cdot C_{d10EN} \rangle \cdot |\mathbf{U_{10EN\_sat}}| \cdot U_{10EN\_sat} = \rho_a\, |\mathbf{u^*}|\, u^*$

Motivations

Are there 1st or 2nd order distinctions between τ and U_{10EN_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 $U10EN_{SAT}$ and τ_{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 2014-2105 tied to flagging and motion correction, files will be in open access UNH website July 2015 or email me

Scatterometer – Flux Buoy Comparison Datasets

Mission	N	Sites
QuikSCAT821	C,GM	
ASCAT-A	710	GM,S
OSCAT	847	GM,S
Aquarius	051	S
Rapidscat	168	GM

Radiometer – Flux Buoy Comparison Datasets

Mission	N	Sites
SSM/I	4322	C,GM,S
AMSR-E	0910	C,GM
WINDSAT1443	C,GM,S	
AMSR-2	0530	S, GM

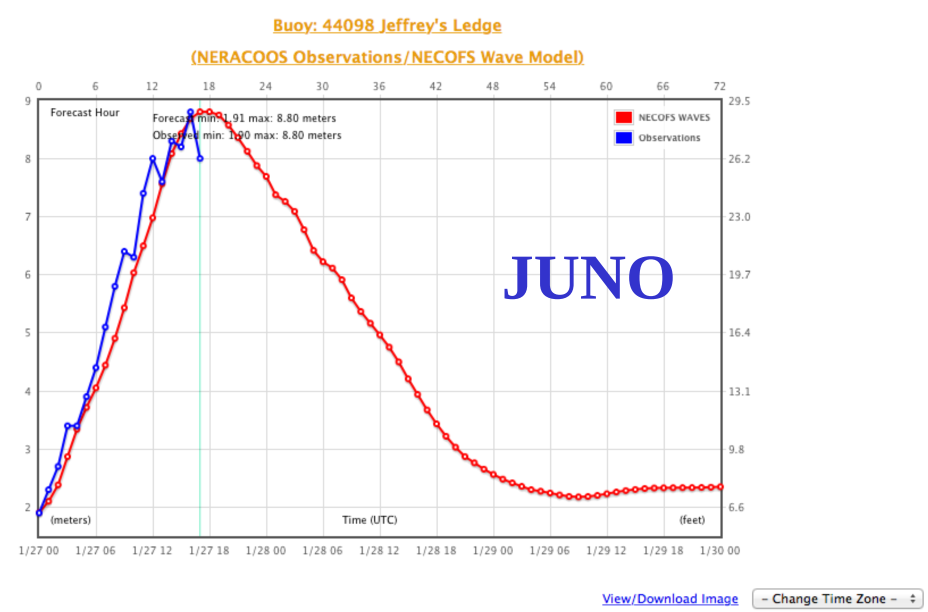
2014-2015 : a rough winter in the Gulf of Maine for fluxes (but more high winds!)

Deployment – Oct. 2014

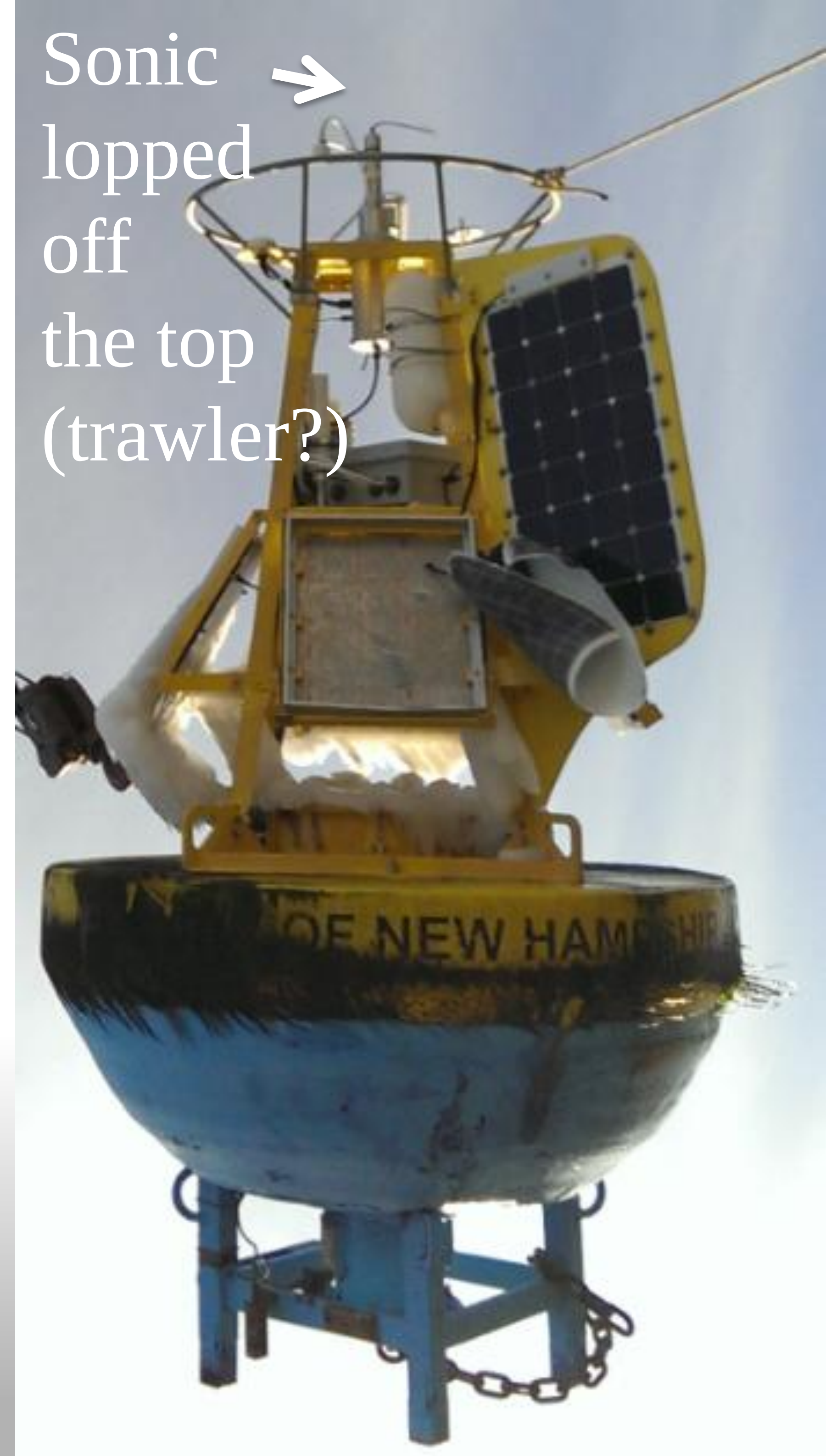
Recovery – March 2015

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



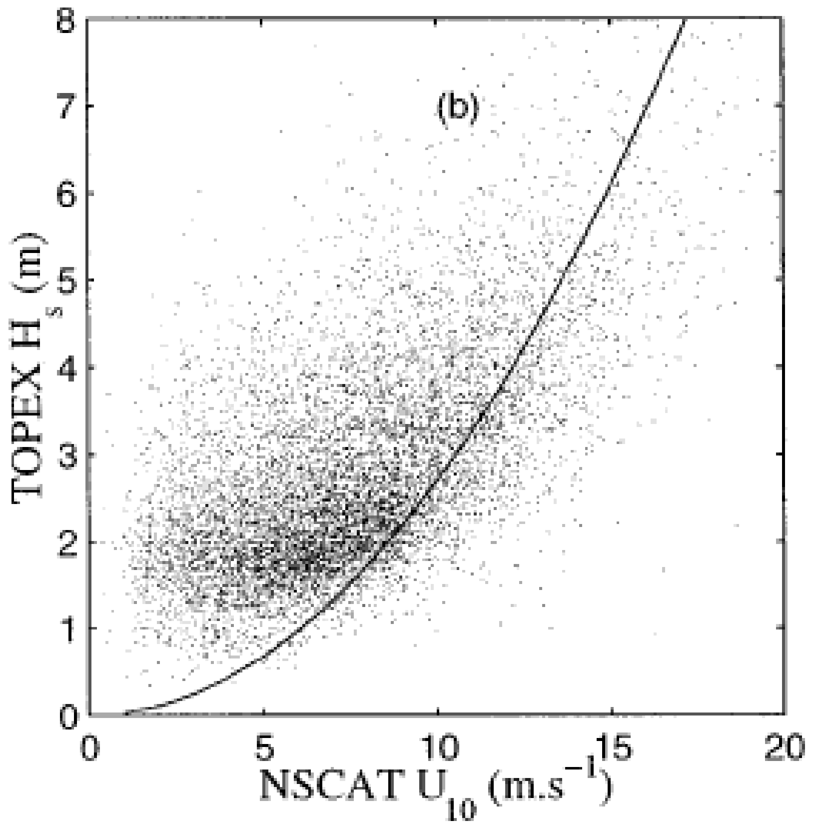

Feb. 2015, Sonic
stopped reporting
data ?????


Sonic
lopped
off
the top
(trawler?)

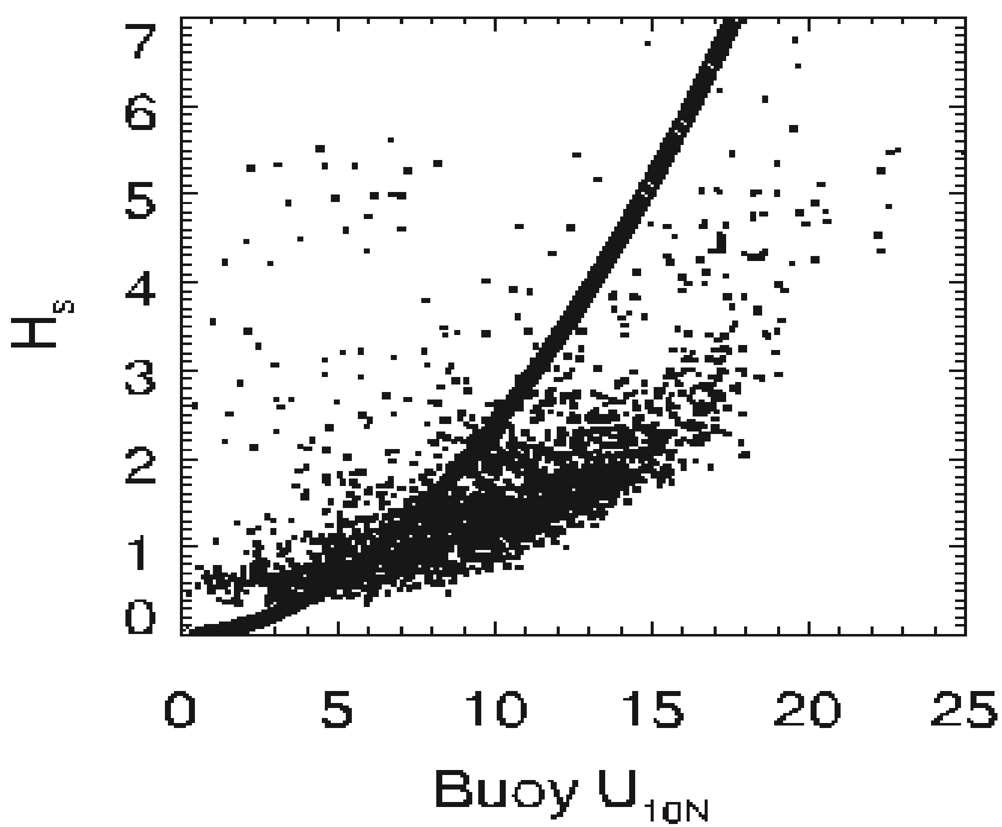
DCFS combined datasets – expanded wave conditions

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?

$$\boldsymbol{\tau}_{\mathbf{a}} = \; < \rho_a \cdot C_{d10EN} > \cdot |\mathbf{U}_{\mathbf{10EN\_sat}}| \cdot U_{10EN\_sat} = \rho_a \, |\mathbf{u^*}| \, u^*$$

alternately

$$< \rho_a \cdot C_{d10EN} > \cdot |\mathbf{U}_{\mathbf{10EN\_sat}}| \cdot U_{10EN\_sat} = \rho_a \, C_{d10EN} \, |\mathbf{U}_{\mathbf{10EN}}| \cdot U_{10EN}$$

$$|\mathbf{U}_{\mathbf{10EN\_sat}}| \cdot U_{10EN\_sat} \neq |\mathbf{U}_{\mathbf{10EN}}| \cdot U_{10EN}$$

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

$$\boldsymbol{\tau}_{\mathbf{a}} = \rho_a \cdot u_*^2 = \rho_a \cdot C_{d10EN} \cdot |\mathbf{U}_{\mathbf{10EN}}| \cdot U_{10EN}$$

$$\boldsymbol{\tau}_{\mathbf{a\ sat}} = < \rho_a \cdot C_{d10EN}(U) >|_{GMF} \cdot |\mathbf{U}_{\mathbf{10EN\_sat}}| \cdot U_{10EN\_sat}$$

IF VALID AND $<C_{d10EN}> \sim= C_{d10EN}$, THEN

$$U_{10EN\_sat} / U_{10EN} = (\rho / <\rho>)^{1/2} = f(P, T_{air}, rH)$$

Note:
- T_{air} highly correlated with SST
- Neglecting SST-dependent viscosity of water -> short wave variation

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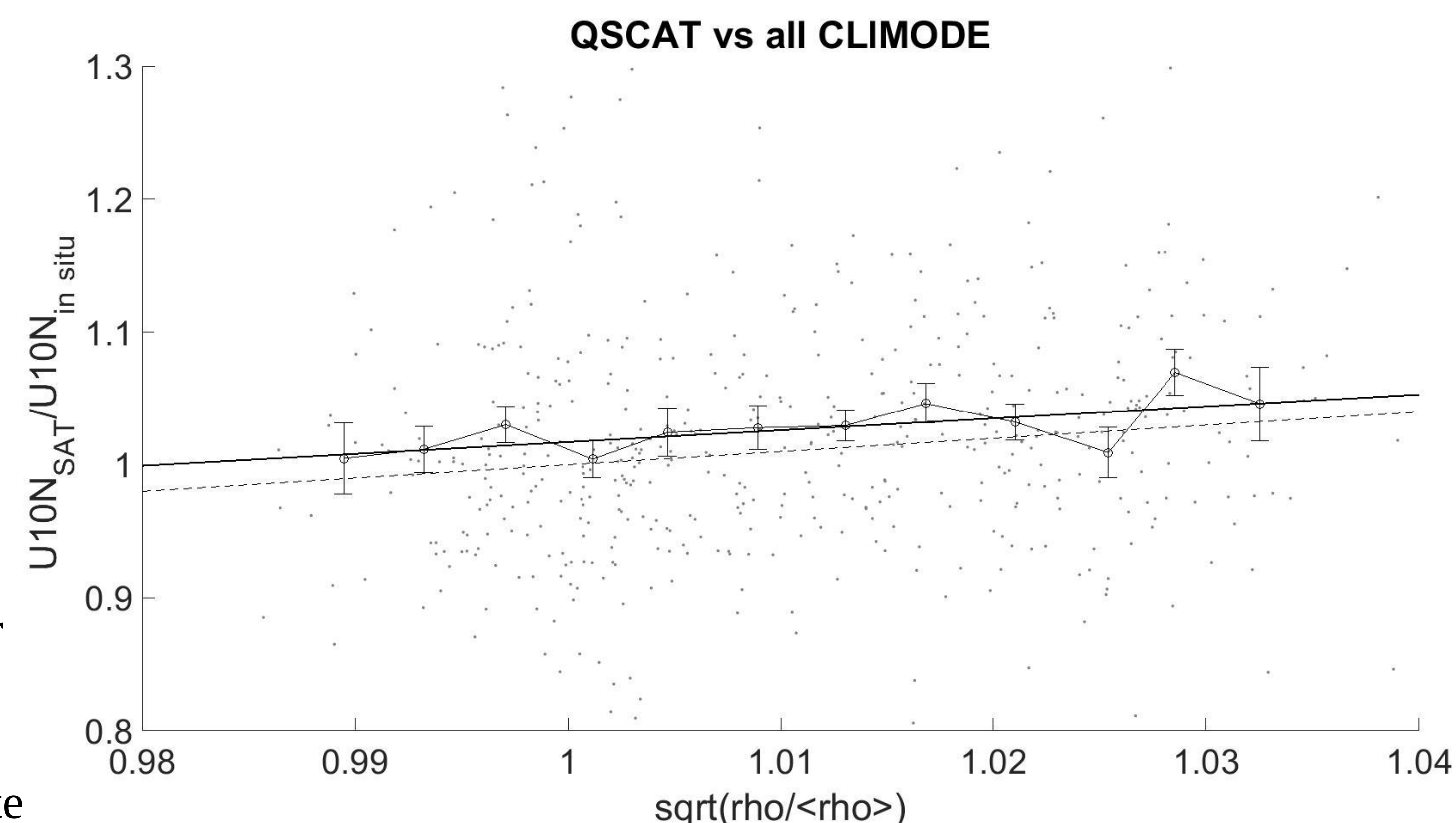
$$U_{10EN\_sat} / U_{10EN\_InSitu} = (\rho / \langle\rho\rangle)^{1/2}$$

True for Ku-band scatterometers?

Appears so…..
Slope of 0.9



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

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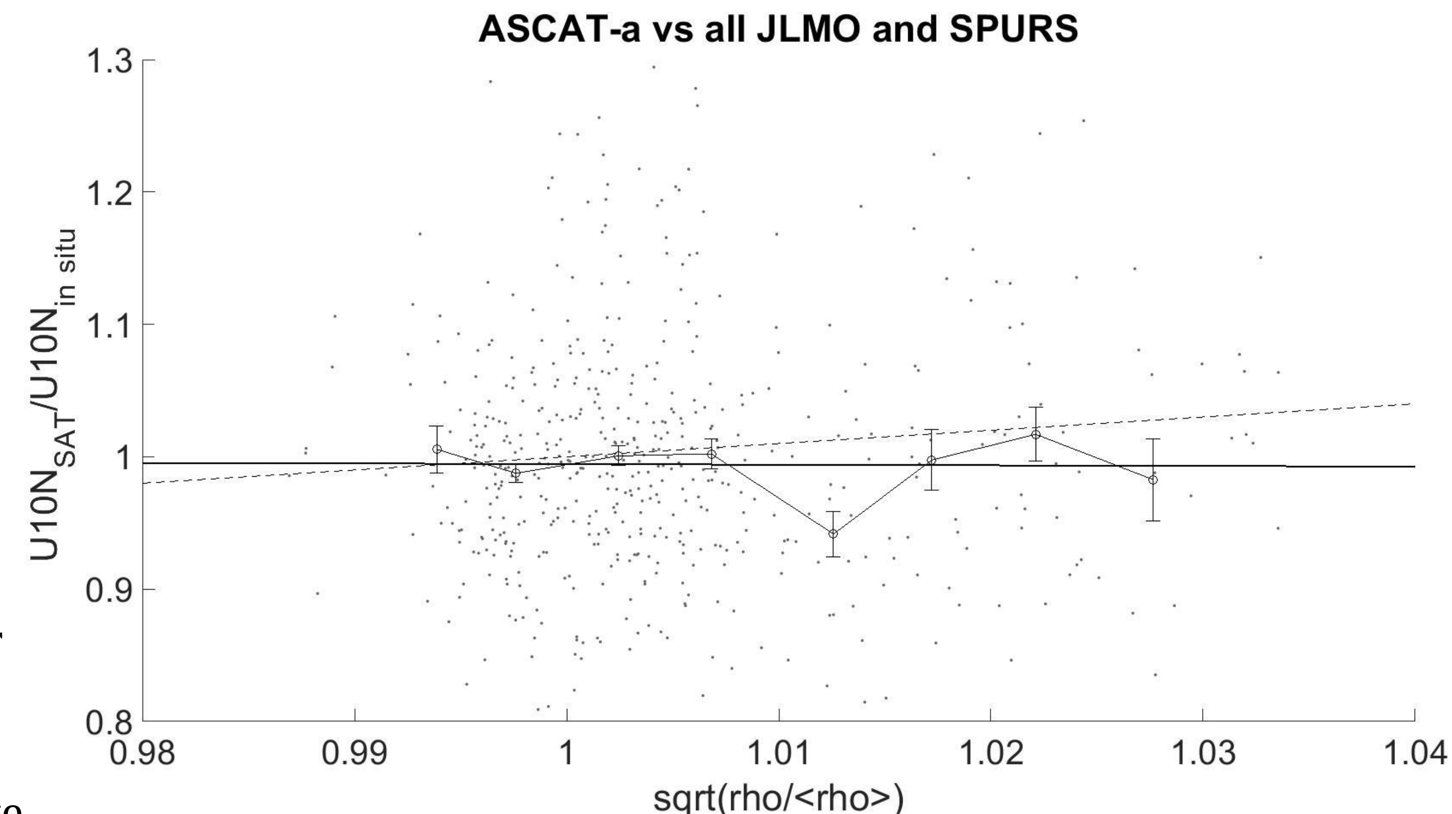
$$U_{10EN\_sat} / U_{10EN\_InSitu} = (\rho / \langle\rho\rangle)^{1/2}$$

True for C-band ASCAT?

No correlation observed

But less data…



Data filtering:
<ρ> @ 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

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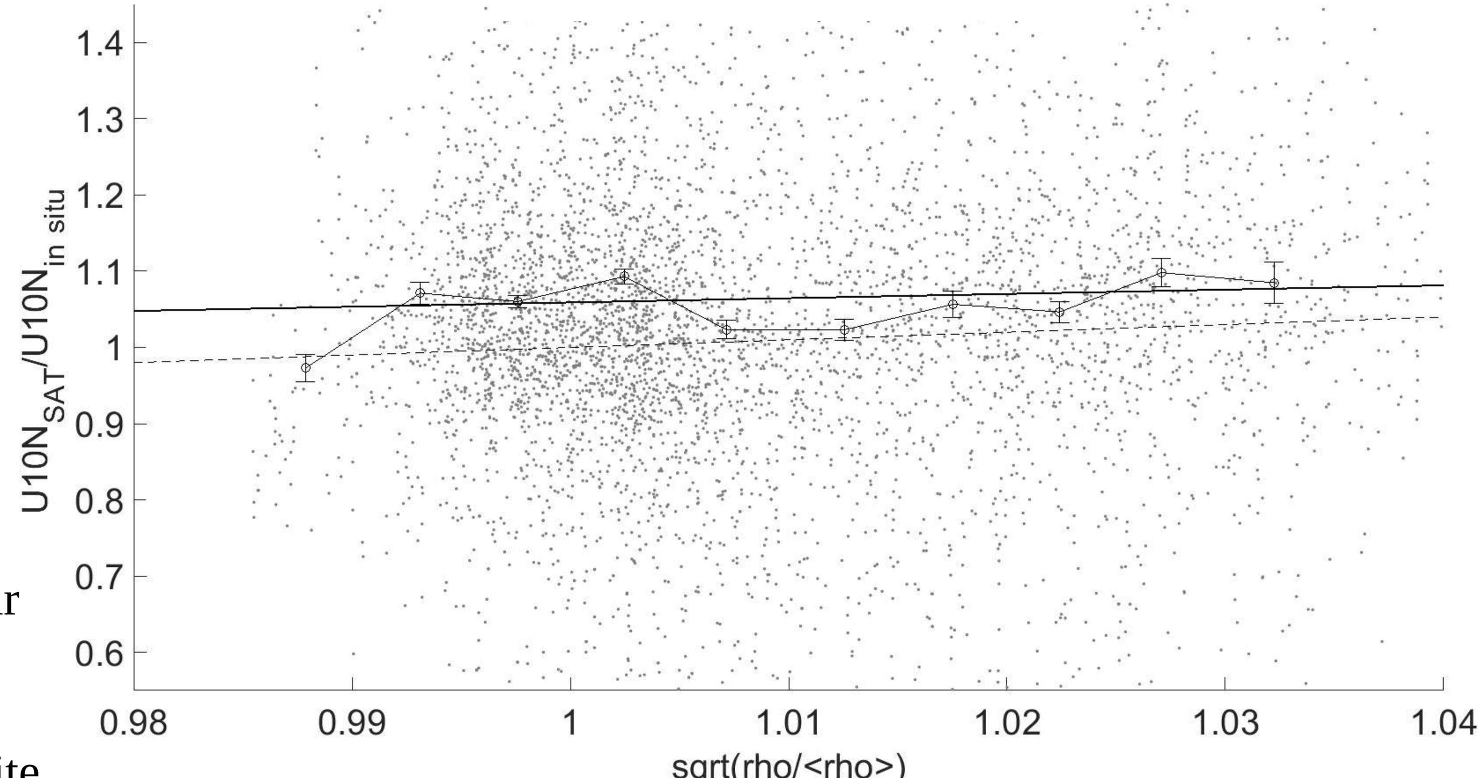
$$U_{10EN\_sat} / U_{10EN\_InSitu} = (\rho / \langle\rho\rangle)^{1/2}$$

True for radiometer wind speeds?

Likely, slope of 0.6 but needs further work

SSM/I and WINDSAT



Data filtering:
<ρ> @ 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

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 :

ρ_a (1020., 24., 85%rH) = 1.185 (trades, U=8)

ρ_a (1000., 05., 85%rH) = 1.249 (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)

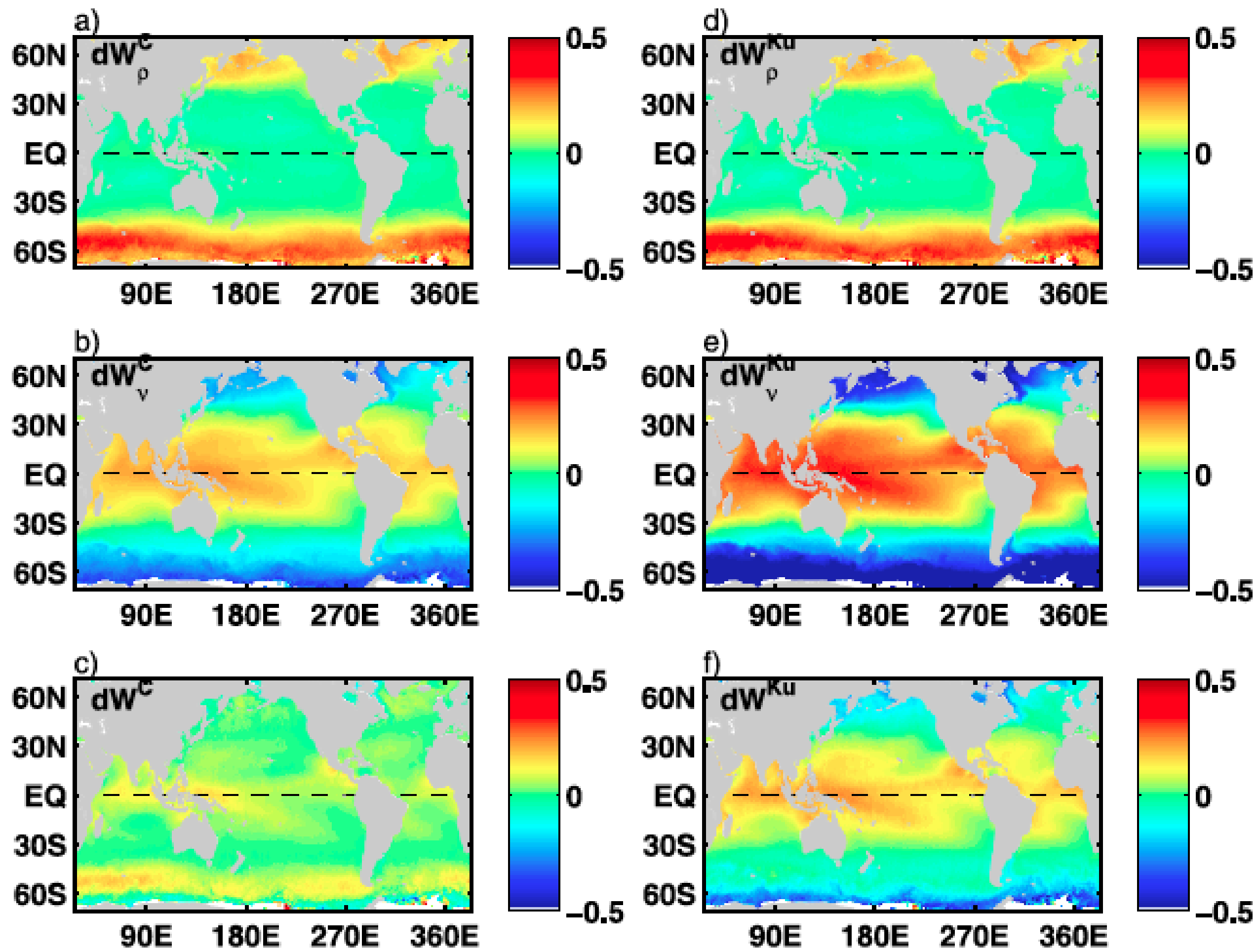


Figure 5. Spatial distribution of model wind retrieval errors in (left) C-band, (right) Ku-band. (a, d) Error due to SST-induced variation in air density (ρ_a), (b, e) error due to SST-induced variation in water viscosity (ν), (c, f) total error. Radar calibration is assumed corresponding to the global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

Wave influence? : Drag Coefficient variation for fixed wind speed

$\boldsymbol{\tau_a} = \langle \rho_a \cdot C_{d10EN} \rangle \cdot |\mathbf{U_{10EN\_sat}}| \cdot U_{10EN\_sat}$

$U_{10EN\_sat} / U_{10EN\_InSitu} = \sqrt{ (C_{dN10} / C_{dN10}\_bulk) }$

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:

$Cd_{N10} (z_0) = F (u^*, u^*/C_p, ak, mss)$

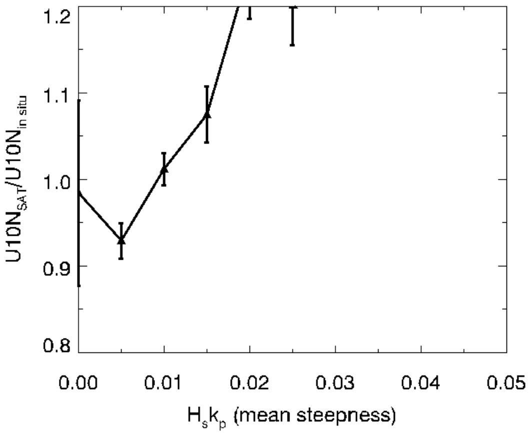
And then the remote sensing questions:

? $z_{0\ SCATT} \sim= z_{0\ Radiometer}$?

? $z_{0\ C\_SCATT} \sim= z_{0\ Ku\_SCATT}$?

Drag coefficient variation in Windsat…

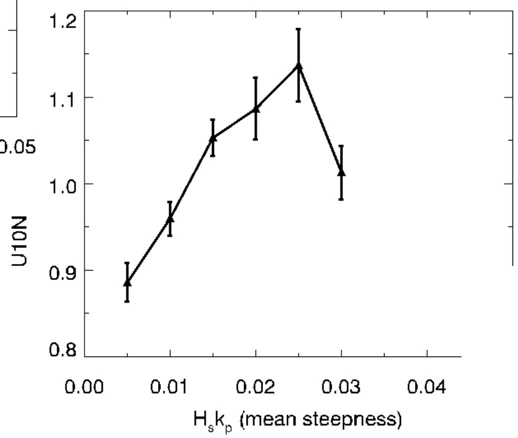
Satellite wind excess versus wave steepness



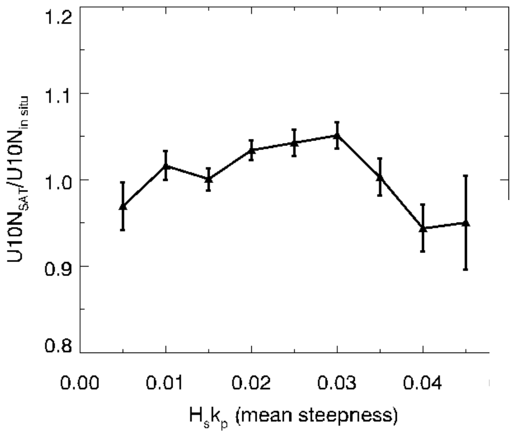
U=4 m/s +-1.5

Apparent wave dependence at light to moderate wind

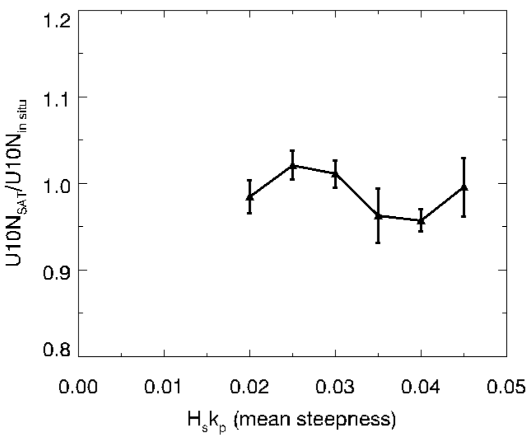
Flat at winds > 10 m/s (foam?)



U=6 m/s +-1.5



U=10 m/s +-1.5

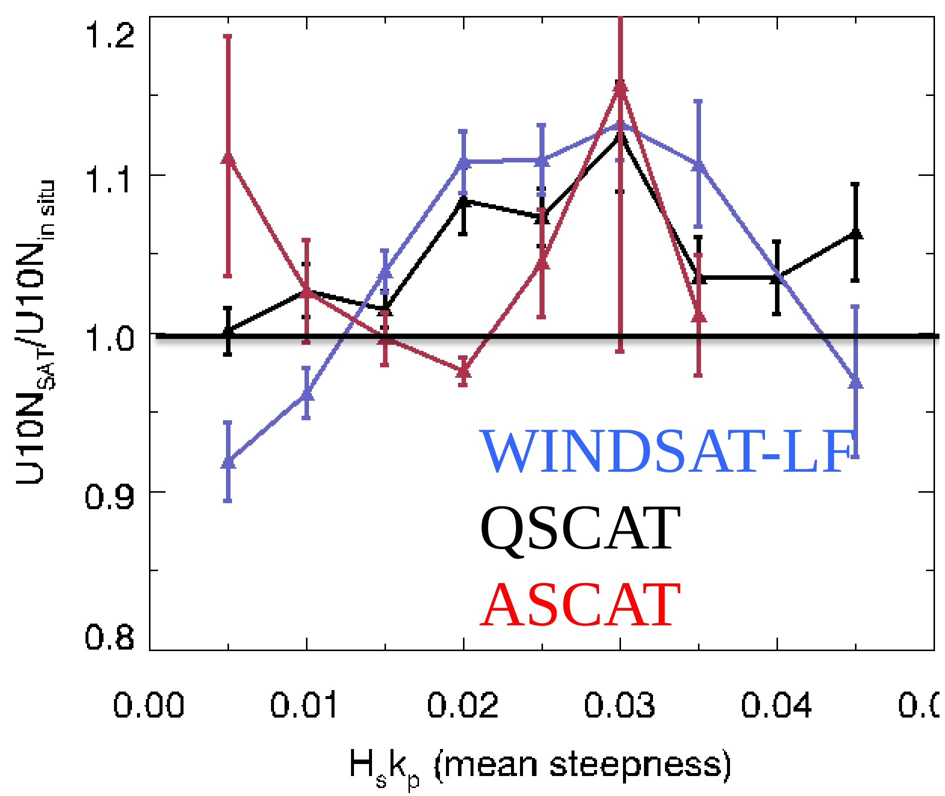


U=14 m/s +-1.5

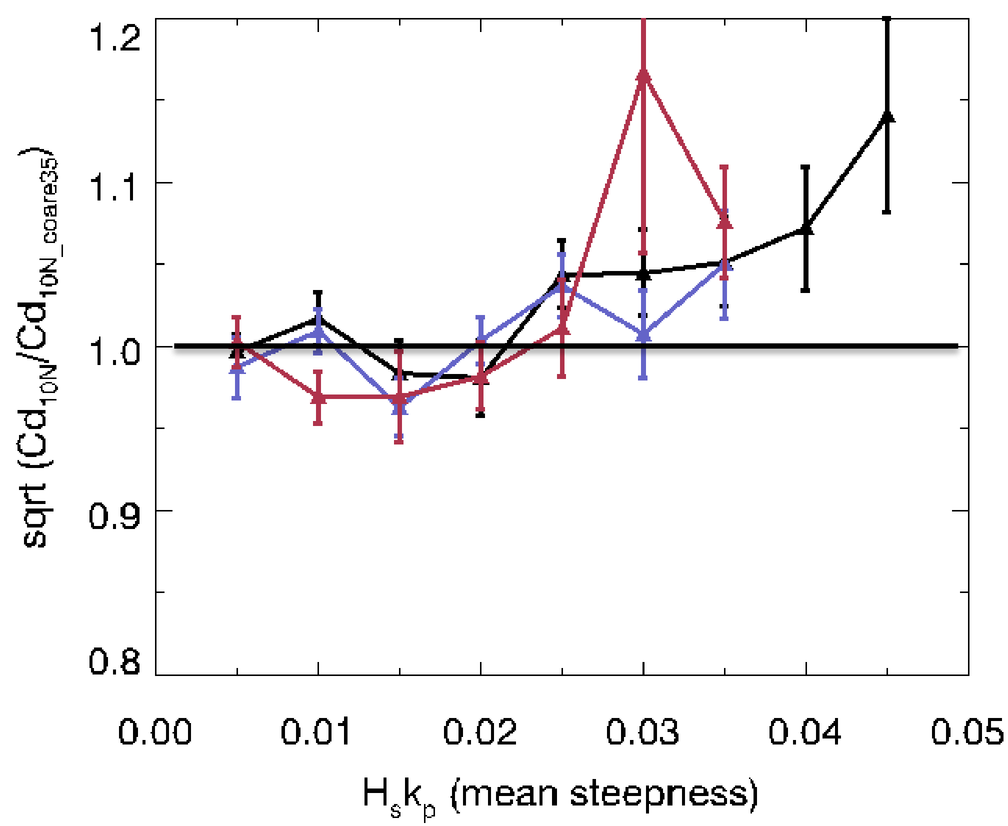
Is *in situ* drag coefficient variation vs. waves same as for scatts and radiometer?

U =7+-/ 2 m/s

Satellite



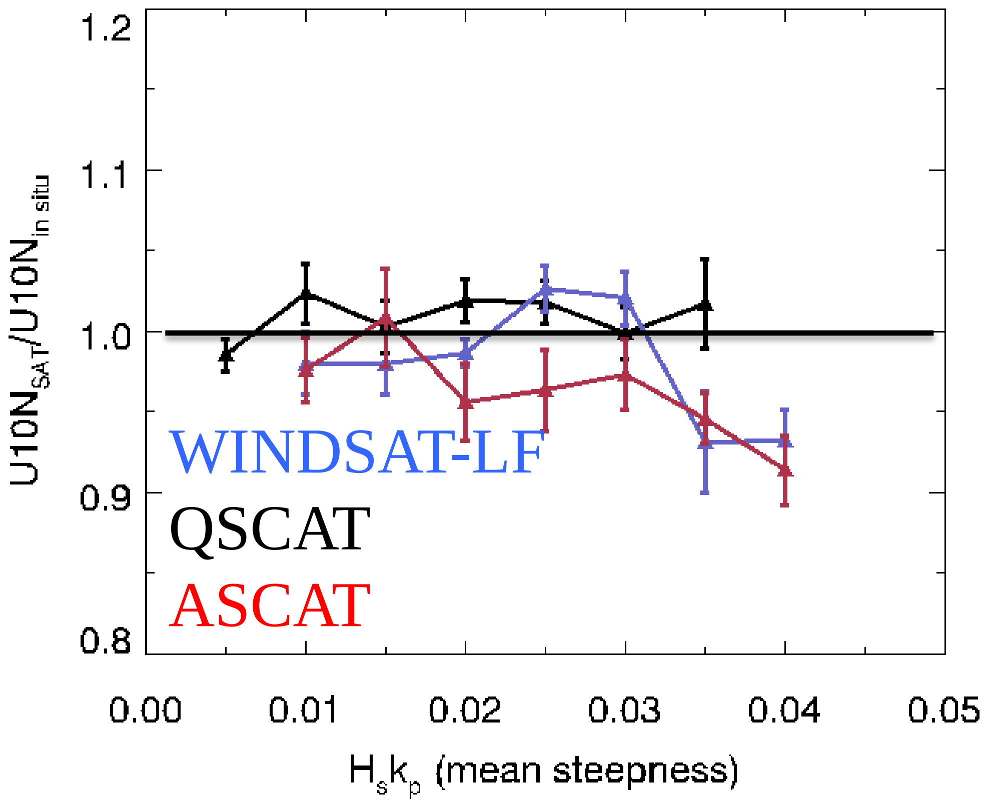
In situ



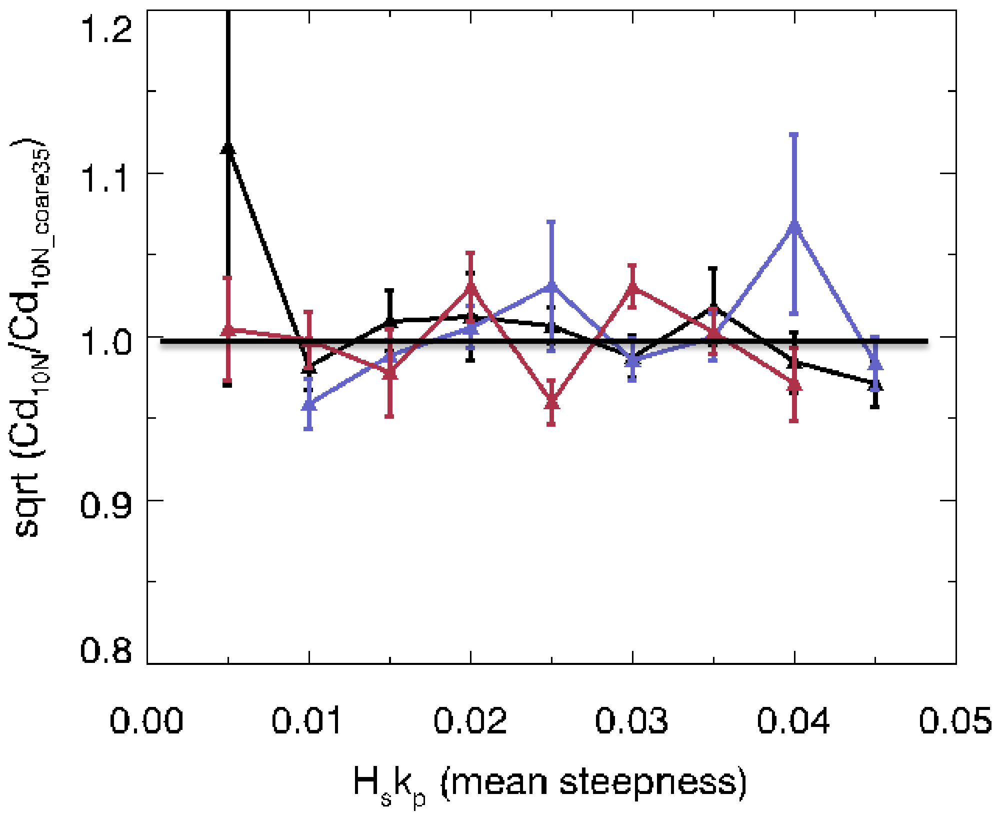
Is *in situ* drag coefficient variation vs. waves same as for scatts and radiometer?

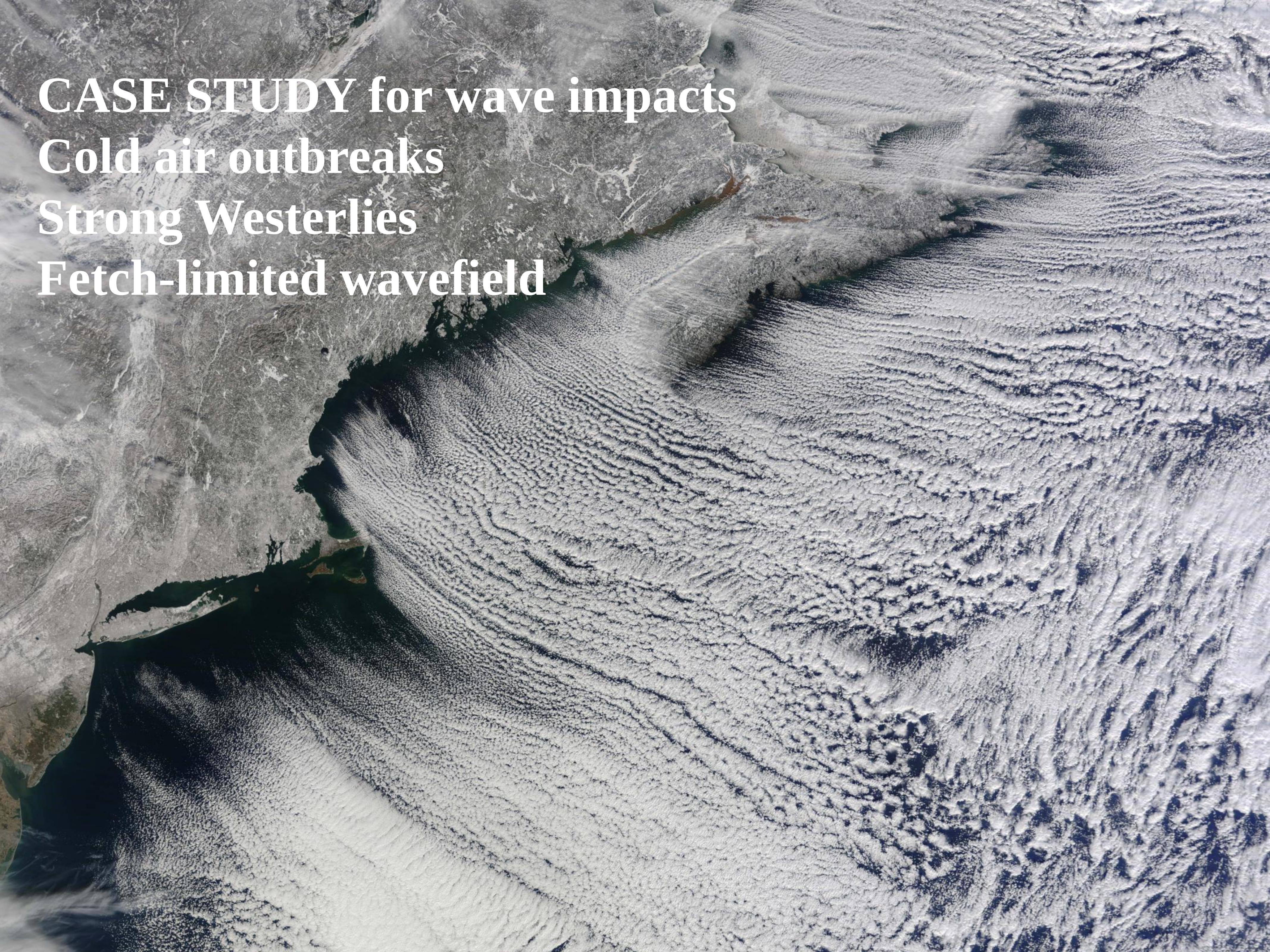
U =10+-/ 1.5 m/s

Satellite

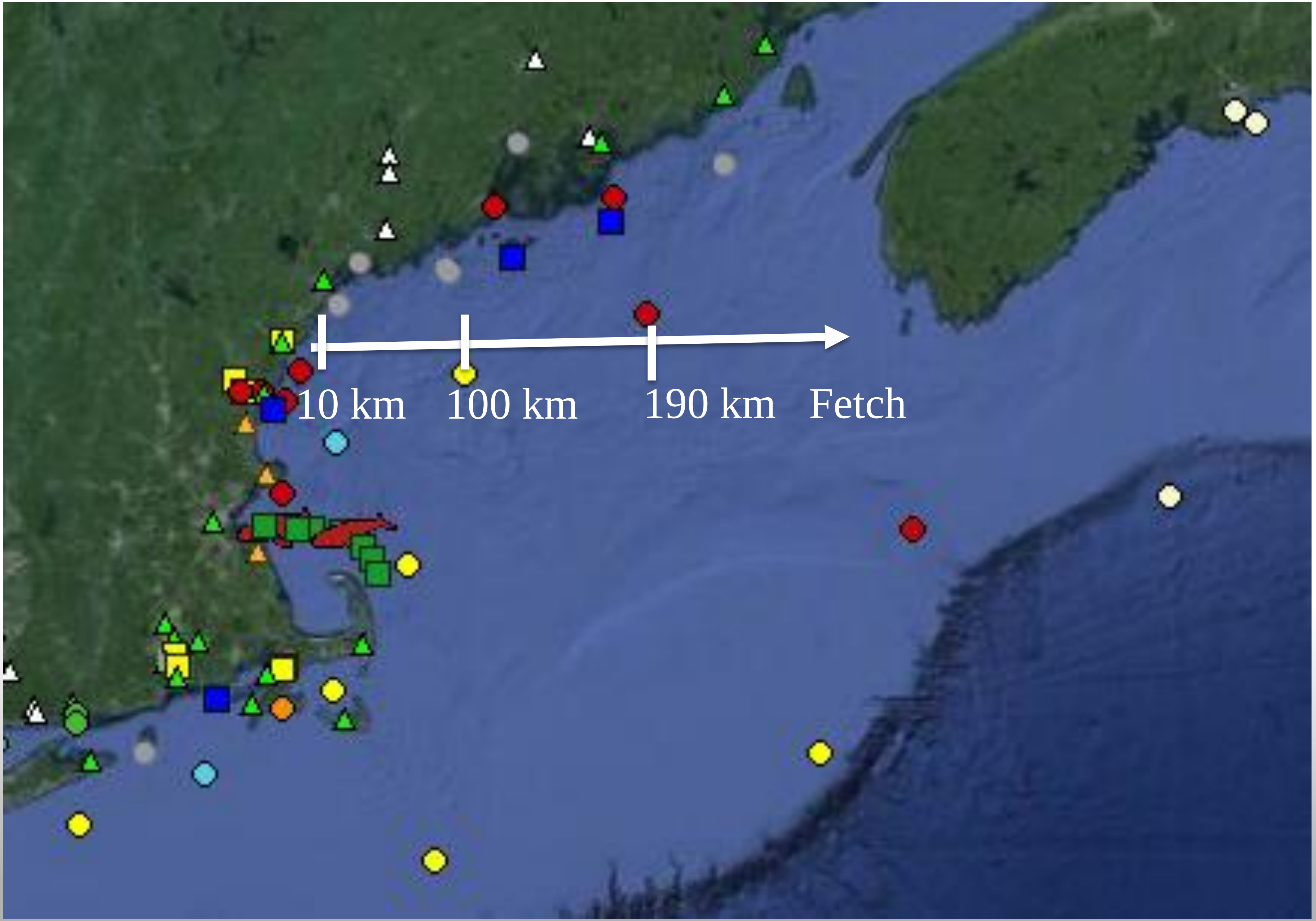


in situ

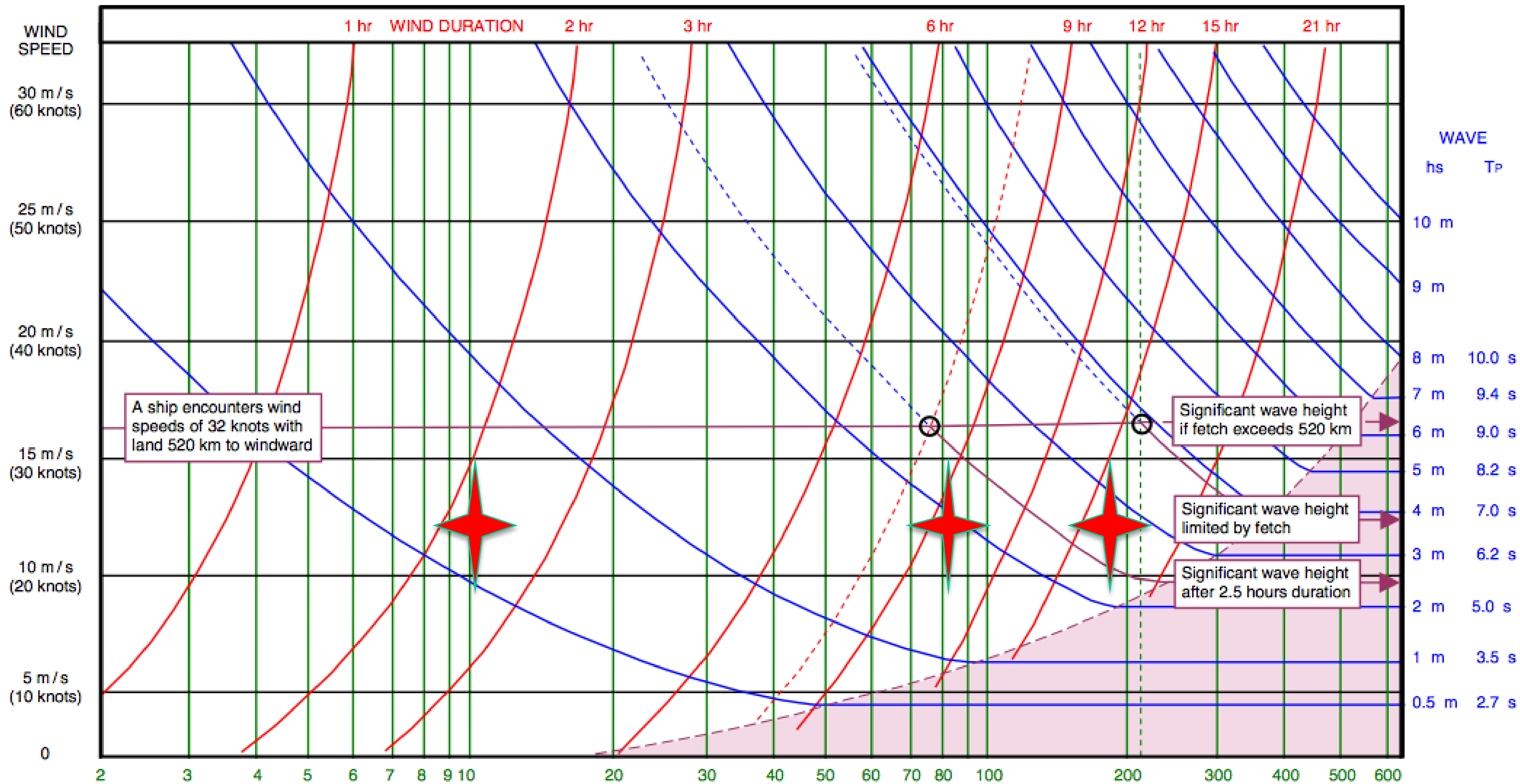



CASE STUDY for wave impacts
Cold air outbreaks
Strong Westerlies
Fetch-limited wavefield

Use buoy network to assess cross-Gulf winds



Buoy locations with fetch, developing seas
X= 10,90, and 190 km, winds of 10-15 m/s typical



Fetch (km)

Questions:

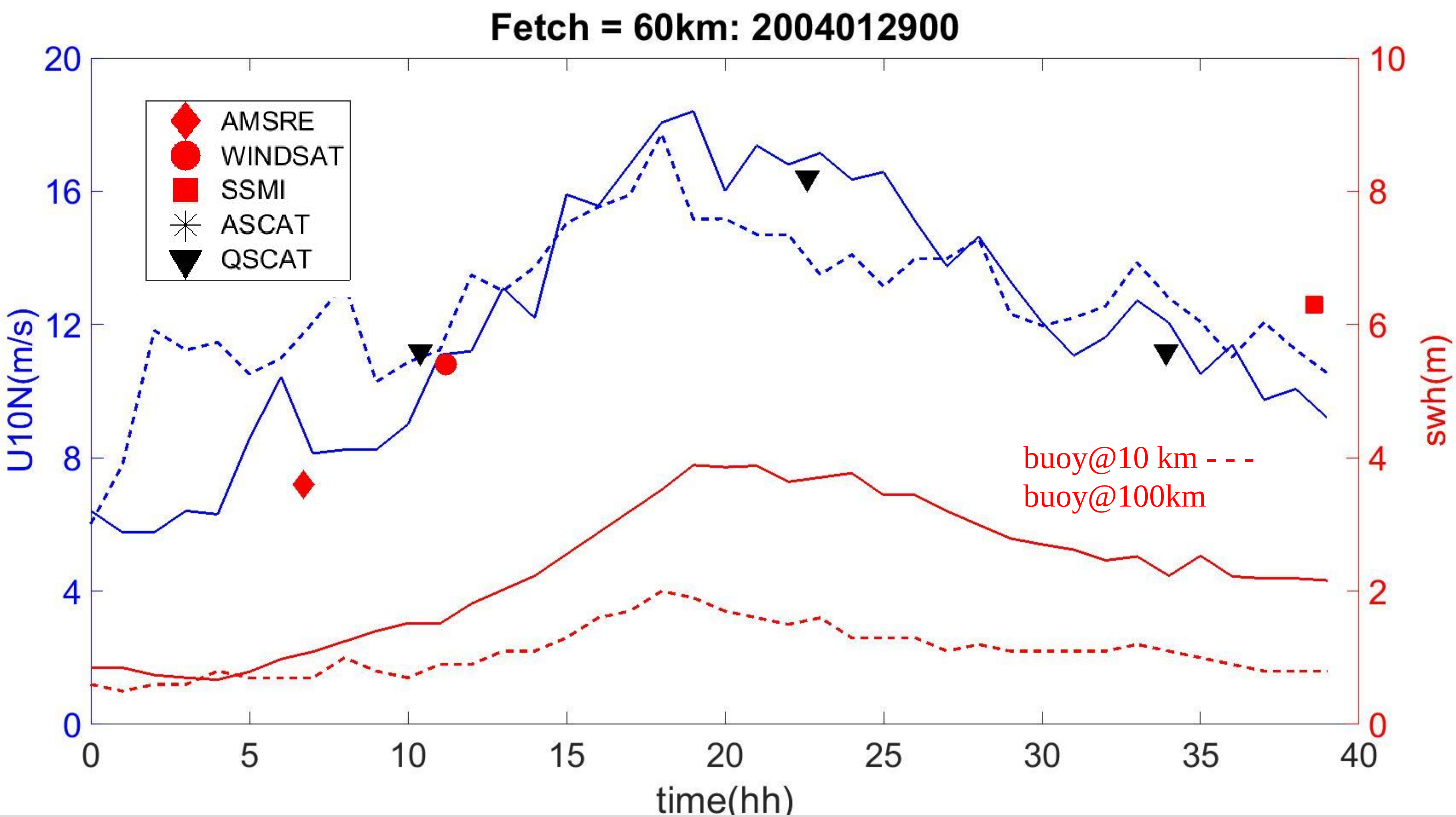
Do we see cross-fetch satellite wind speed ‘error’ under quasi-steady westerlies and spatial change in sea state?

…and for scatterometers vs. radiometers?

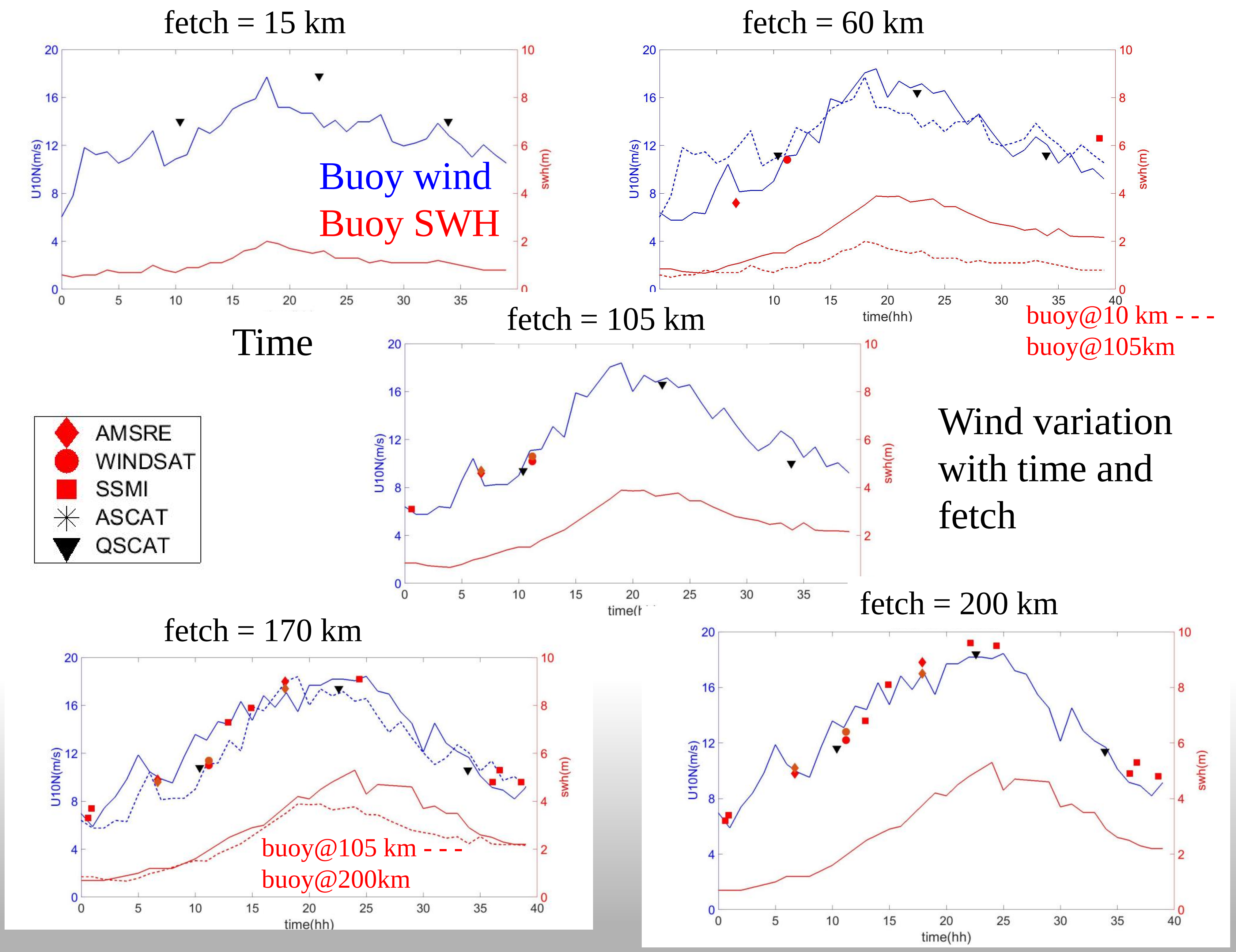
Westerly wind case study – Events Closest to Ideal

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
U10N(m/s)
swh(m)
time(hh)
buoy@10 km - - -
buoy@100km
0
4
8
12
16
20
0
2
4
6
8
10
0
5
10
15
20
25
30
35
40



fetch = 15 km
Buoy wind
Buoy SWH
Time
fetch = 60 km
buoy@10 km - - -
buoy@105km
fetch = 105 km
Wind variation with time and fetch
AMSRE
WINDSAT
SSMI
ASCAT
QSCAT
fetch = 170 km
buoy@105 km - - -
buoy@200km
fetch = 200 km
U10N(m/s)
swh(m)
time(hh)

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

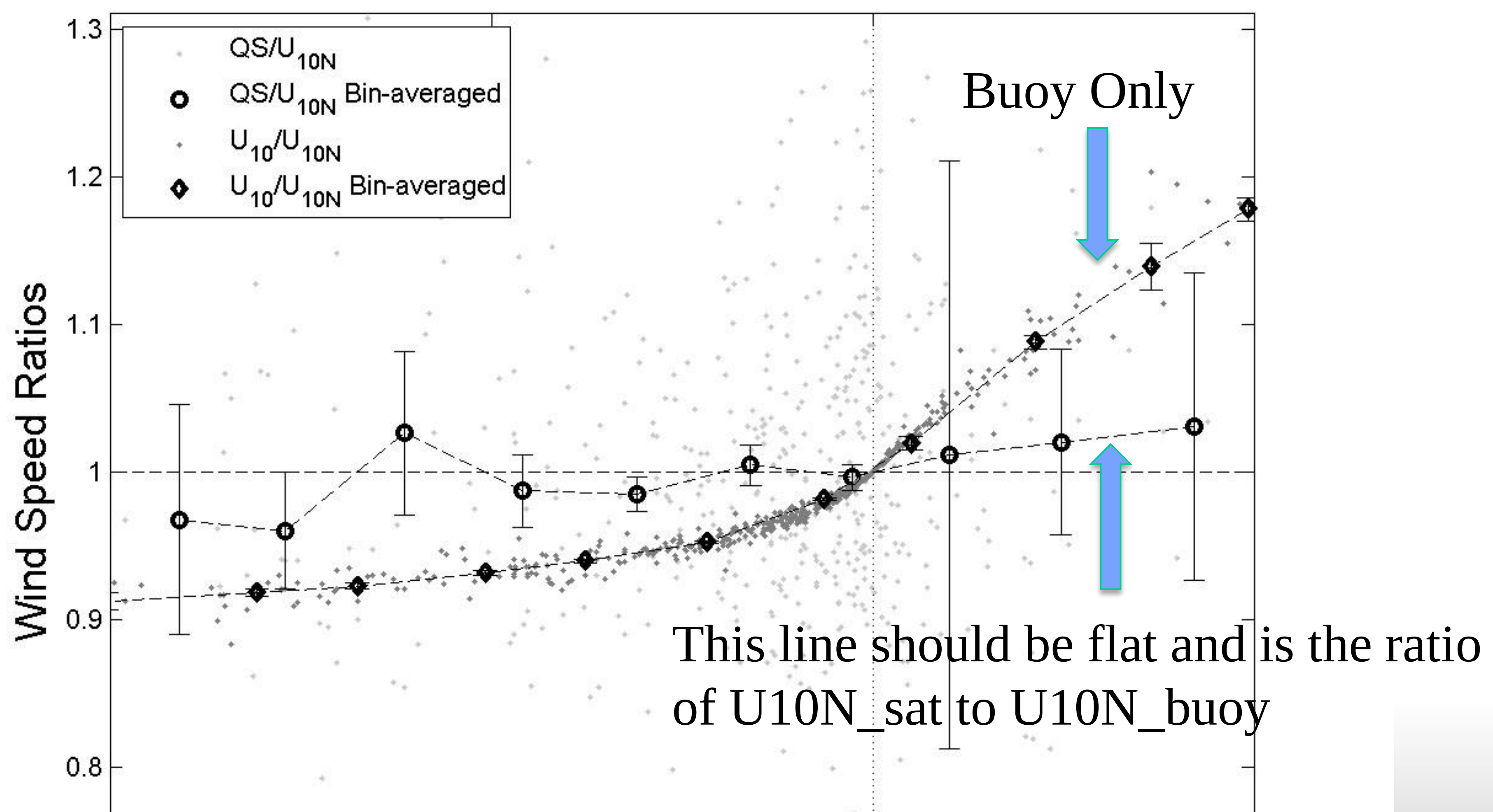
- Reviewed 24 cases across 10 years
- Idealized cases are actually few (2-3)
- Overall answer to these questions so far :
  - No to the first, not in any statistical sense (NULL hypoth)
  - perhaps some overestimate by radiometer LF products
  - perhaps shortest fetch data overestimated

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

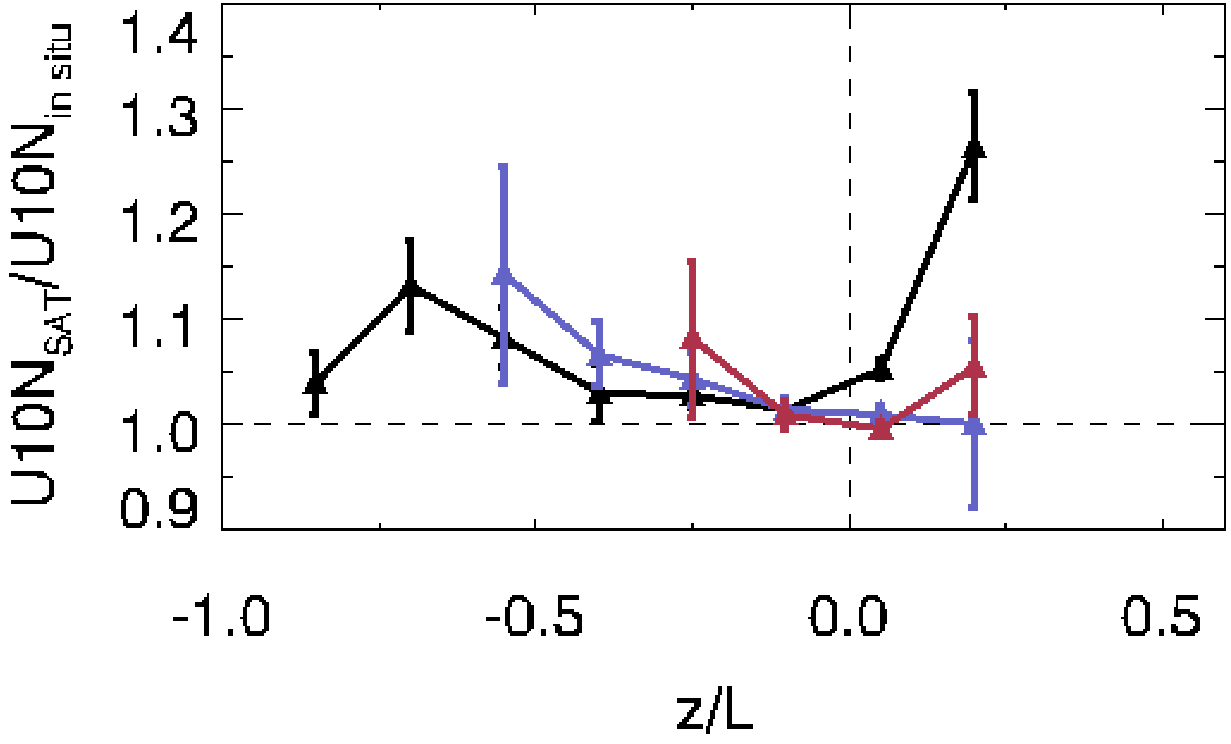


Conclusions: With present DOF (climode analyses), the quikscat data

a) clearly depart from the anemometer 10 m wind
b) follow an ENW (e.g. ψ(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



Version with
U =8 +-4
and 3.5 sdev
No oscat
LF windsat

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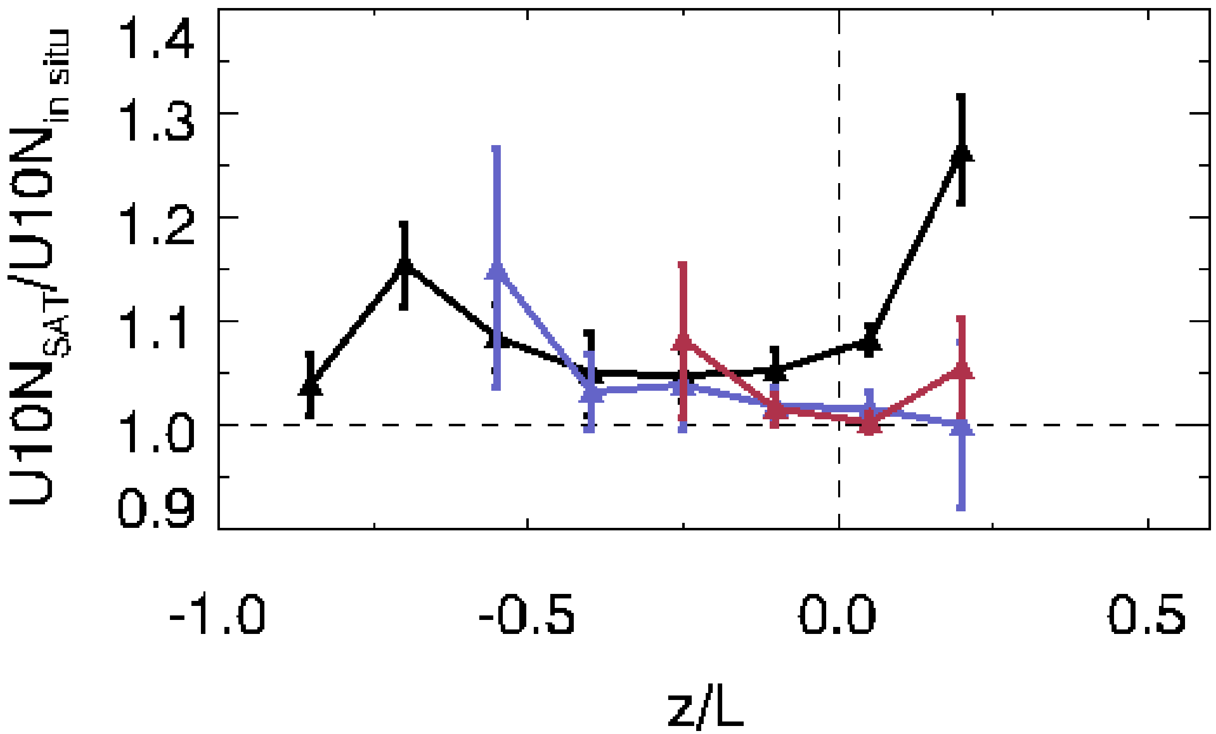

Version with
U =6 +-2
and 3.5 sdev
No oscat
LF windsat

Atmospheric Stability, ocean satellite winds, and equivalent neutral wind

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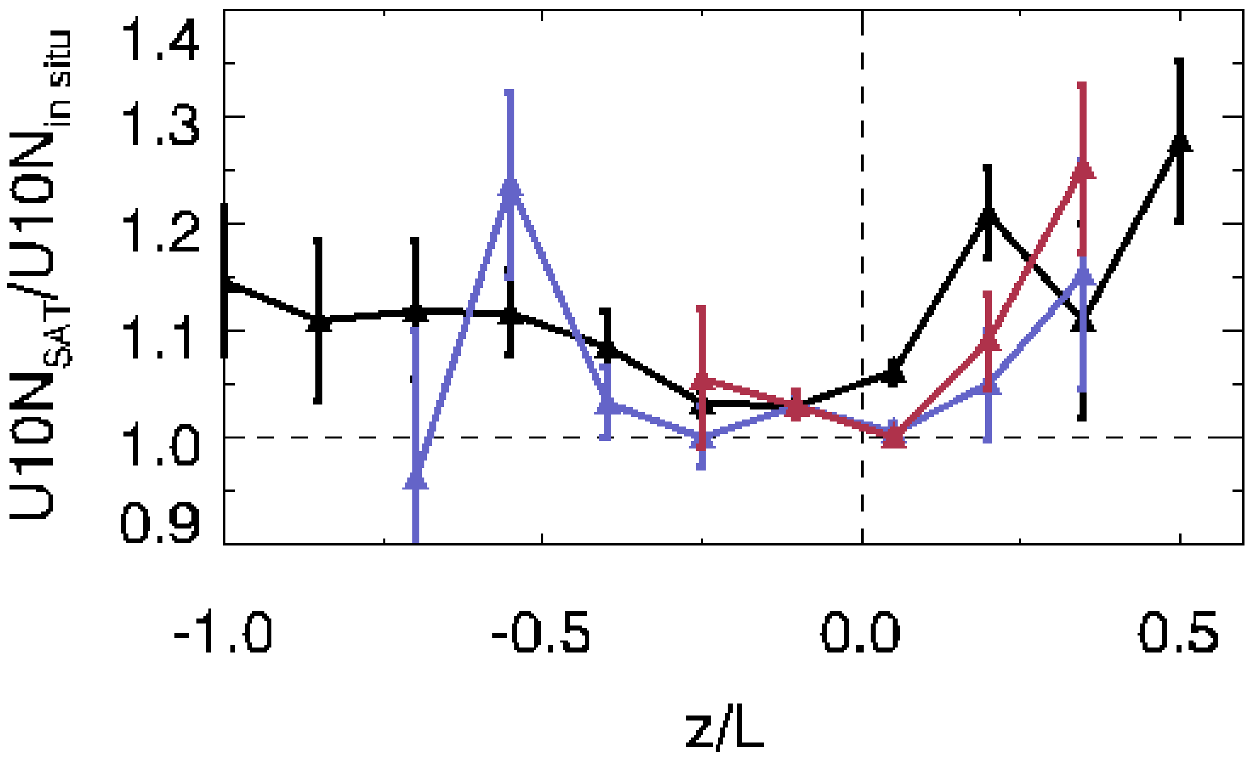

Version with
U =12 +-11
and 3.5 sdev
No oscat
LF windsat

DCFS combined datasets – expanded wave conditions

Steepness

CLIMODE

Coastal NE
- bifurcation in steepness

SPURS I
N. Atlantic
24 N