Examination of Bow Masts and Instrumentation on Research Icebreakers and Ships

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Making over-ocean atmospheric, ice, and upper ocean measurements from ships is

1) difficult to make accurately

- degree of difficulty depends on parameter
- flow distortion/ship wake major problems for many parameters
- "heat island", superstructure shadowing, surface accessibility/visibility other considerations
- instrument selection, siting, and available platforms (e.g., bow masts) are key

2) important to make accurately

- success of research campaigns depend on them
- operational coupled models currently being developed (ONR, NOAA) will need these parameters for improved accuracy – feedback for icebreaker operations

R/V Oden
Makarov Basin, 84° N
2233 UTC Sep 23, 2014 (YD266)
Winds: 12.2 m/s, 208°

To help flow distortion effects (doesn't remove!):

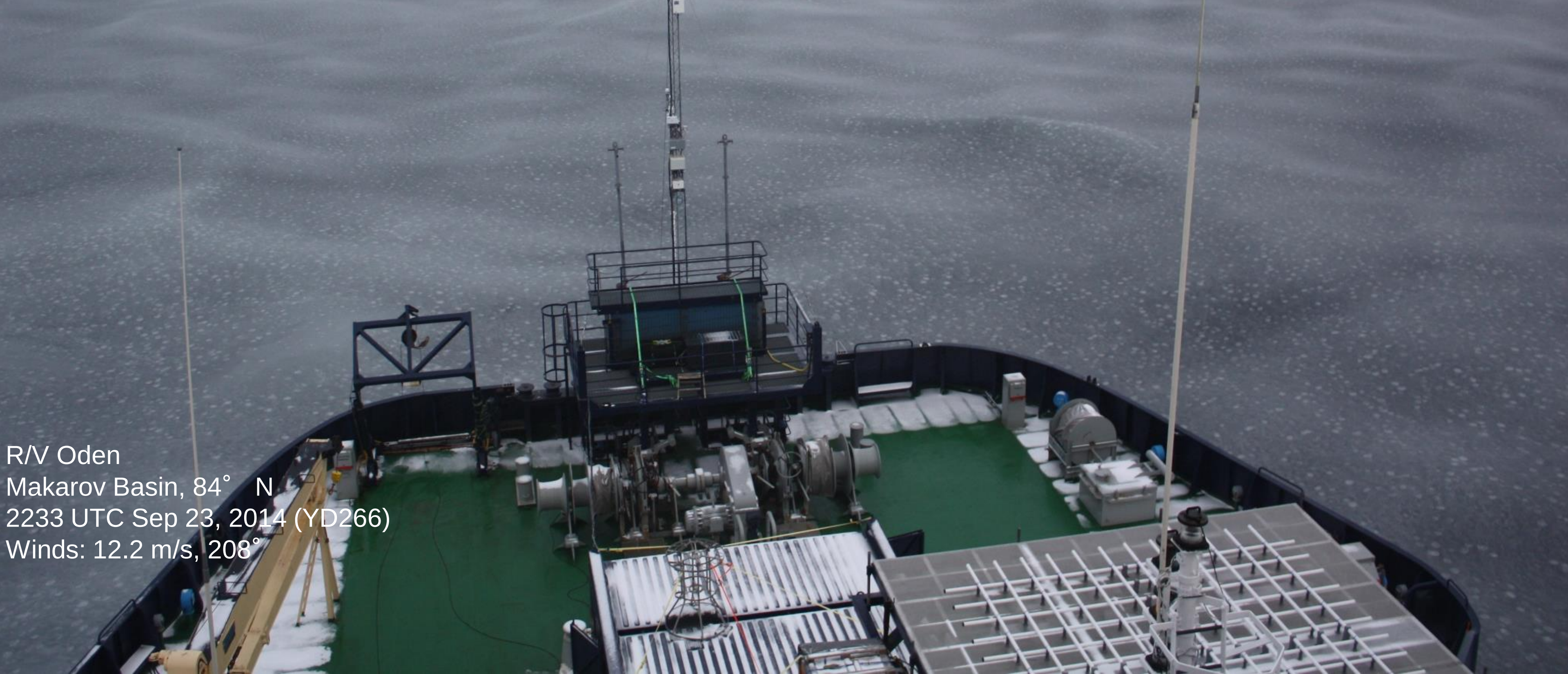
a) measure as far in front as possible - before airflow disturbed by ship

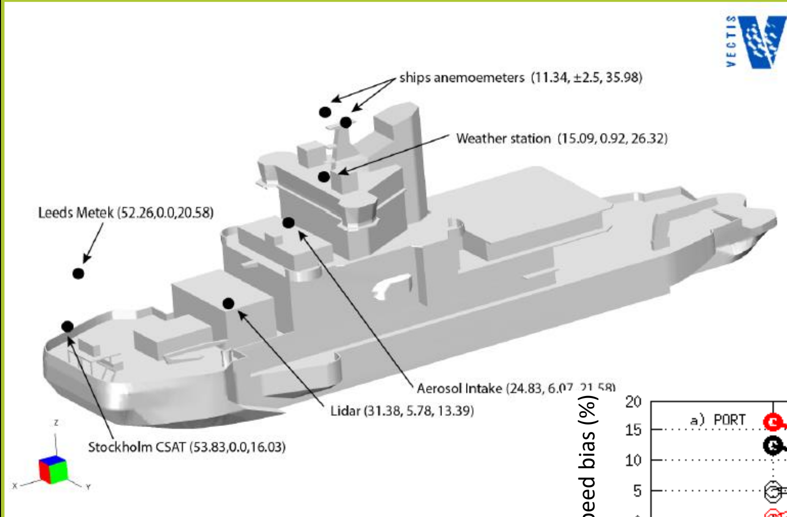
b) measure as high as possible – above ship disturbance

Airflow mapping recommended (e.g., National Oceanography Centre, Southampton, U.K.)

Bow mast – still within disturbed streamlines, but disturbance reduced

High on main mast – may also be in reduced streamline disturbance, but may not represent ~10 m above surface often wanted





Airflow study – R/V Oden (Moat et al 2015

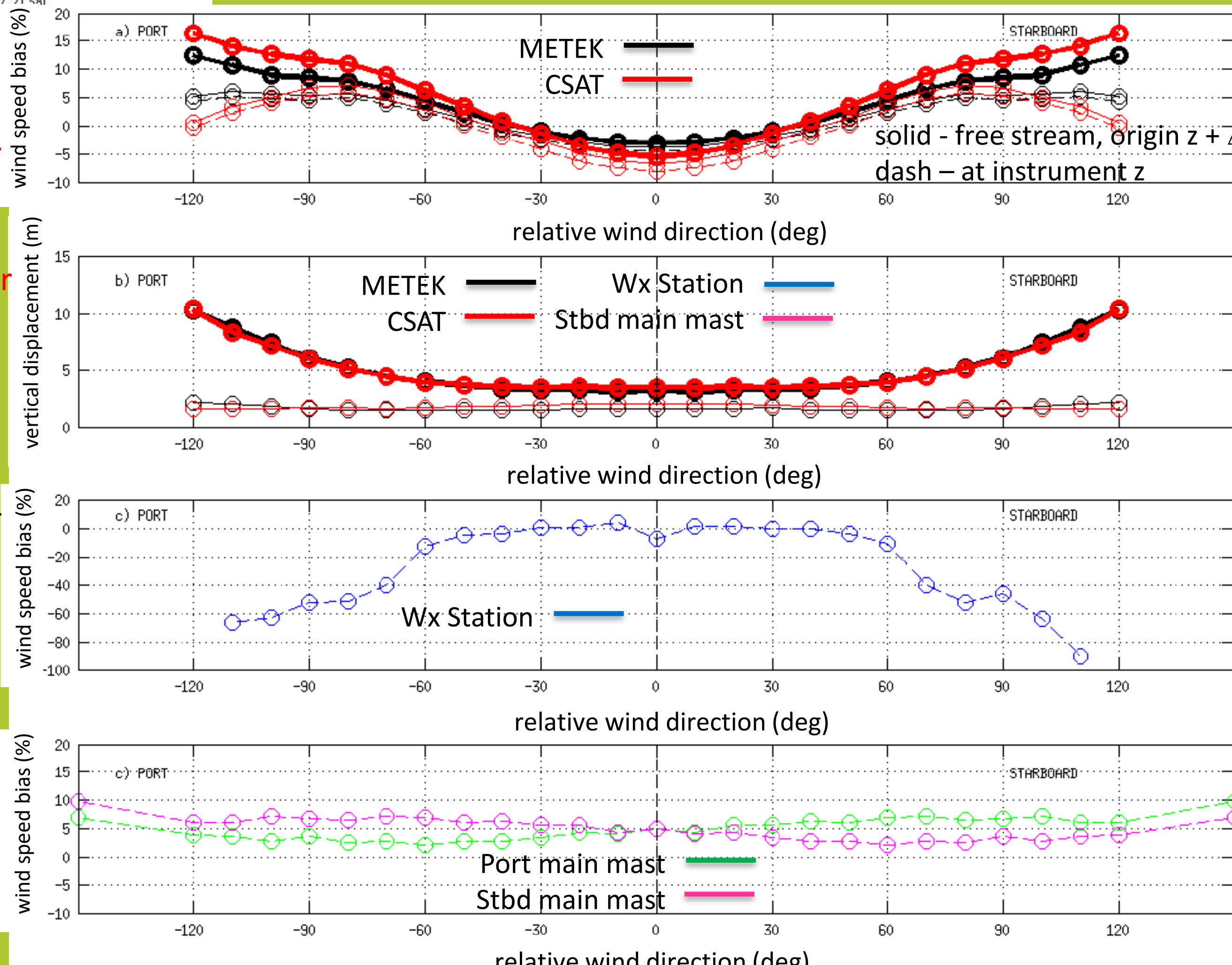
National Oceanography Centre, Southhampton, UK

Requires:

a) detailed ship plans

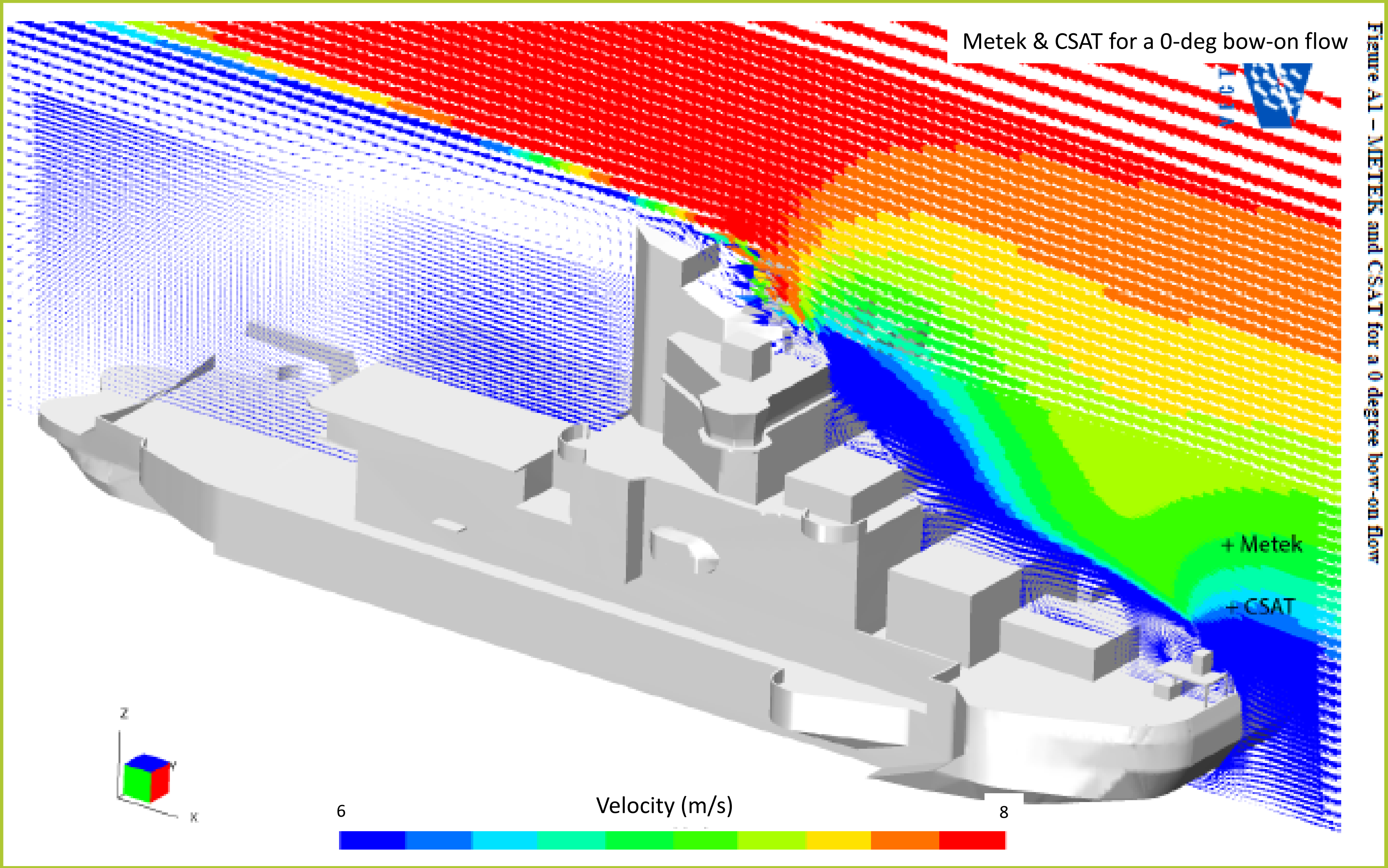
b) identification of key locations/instruments (x,y,z coordinates)

Percent errors at bow larger at lower heights (CSAT vs Metek) for a given relative wind direction. Vertical displacement of streamlines is similar



Wind speed bias and vertical displacement at the Leeds METEK anemometer (black), Stockholm CSAT anemometer (red), weather station (blue), ship's port main mast anemometer (green), and starboard main mast anemometer (magenta). The thick solid lines indicate the wind speed bias using the free stream velocity from the height it originated (i.e. includes the full vertical displacement Δz) and the thin solid lines indicate the wind speed bias using the free stream velocity from the height 2 seconds upstream of the anemometer location. (i.e. includes Δzt=2). The dashed lines indicate a wind speed bias at the height of the instrument.

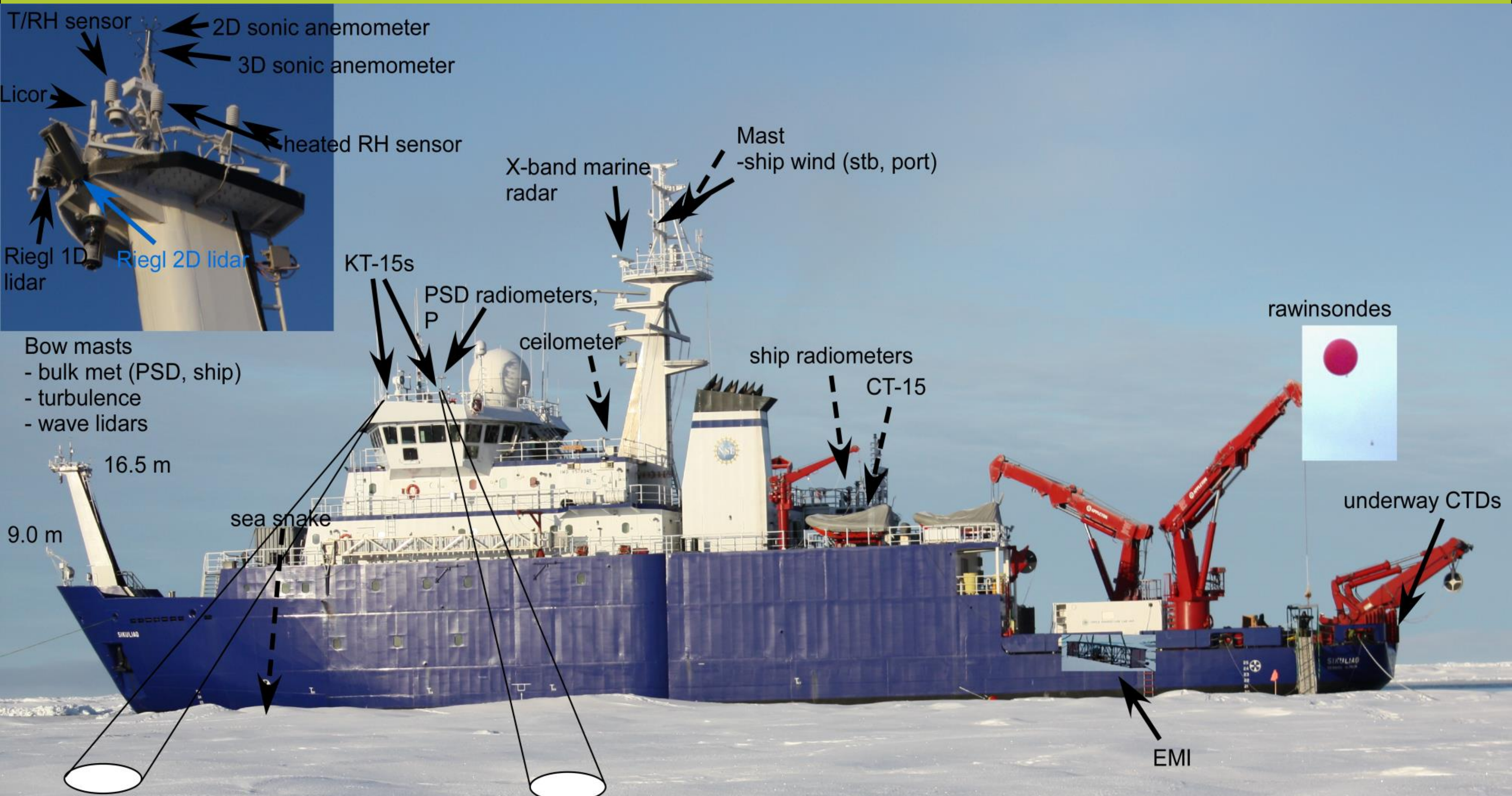
Airflow study cross-section – R/V Oden, 2015



R/V Sikuliaq – solid bow tower with top instrument platform

- Power on platform and sheltered cable ways
- Partially sheltered platform access
- Platform easier to work on than just lattice mast
- boltdown patterns on platform, bow and elsewhere for science-supplied installations

- ship "operational" sensors on tower platform (ultrasonic wind, T, RH, CO_2 intake)
- Solid tower & platform produces some local flow distortion (as compared with open lattice mast)



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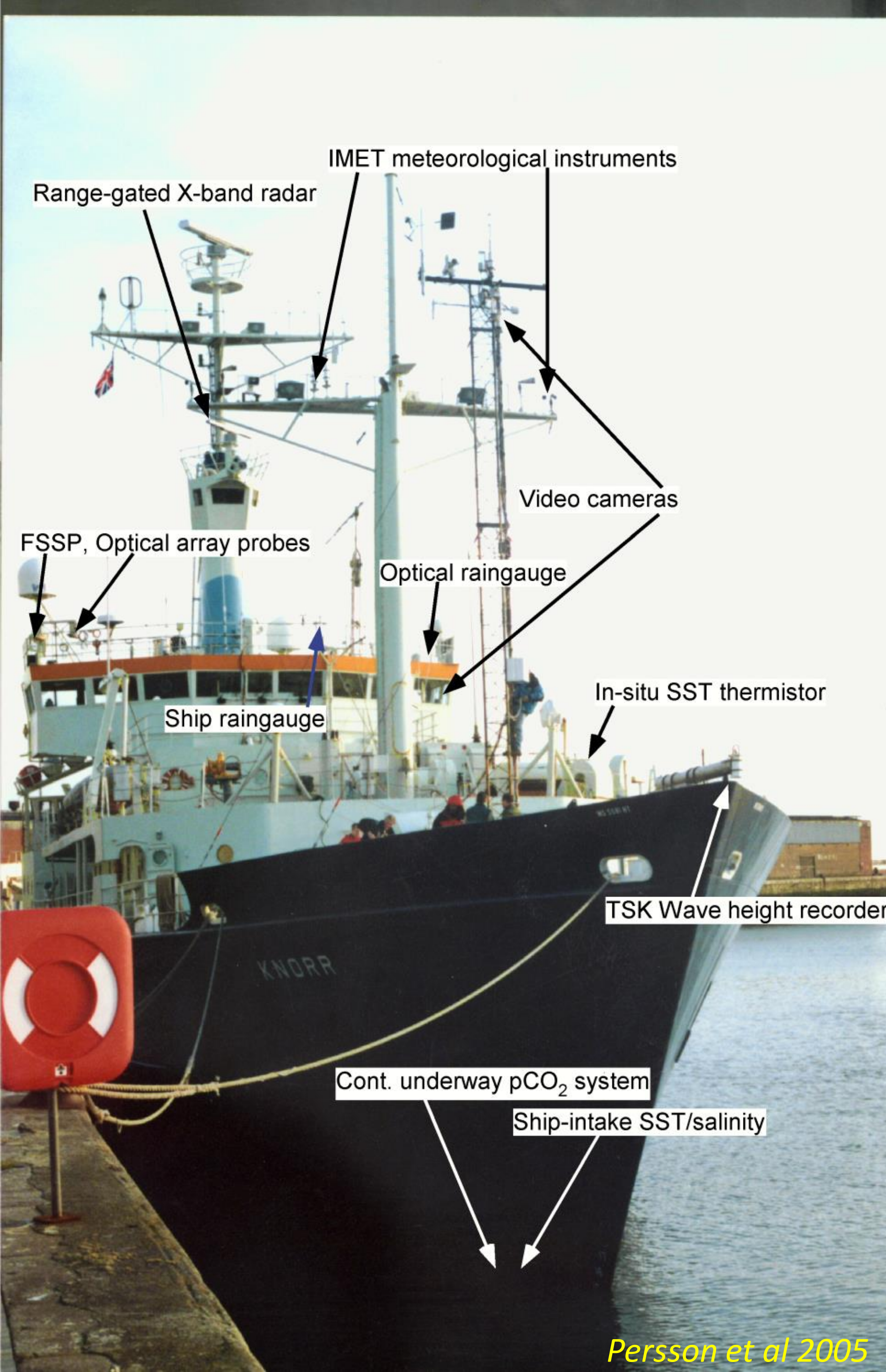
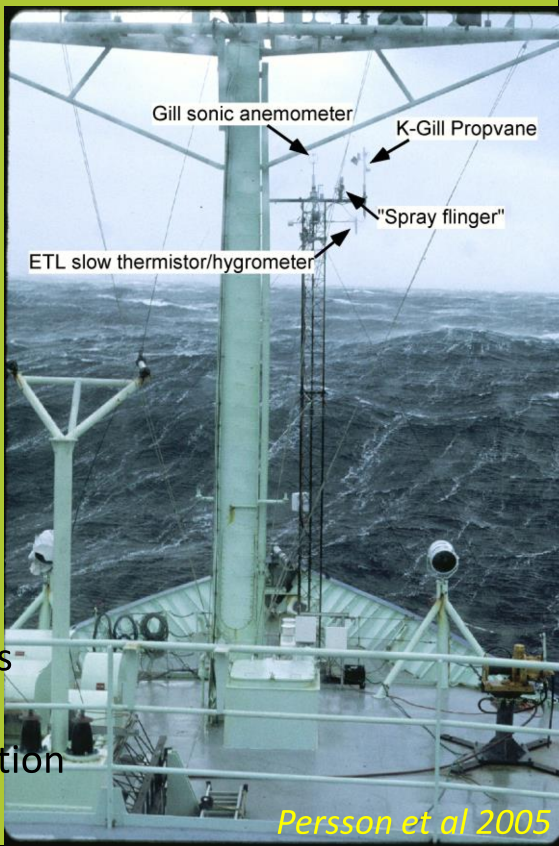
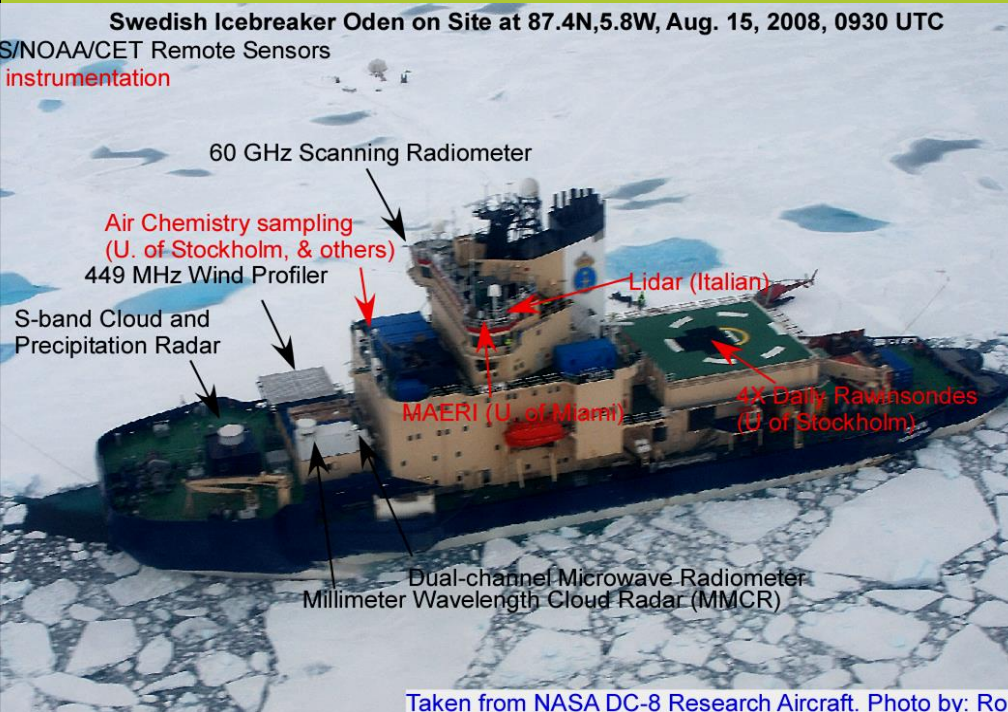


***R/V* Knorr**

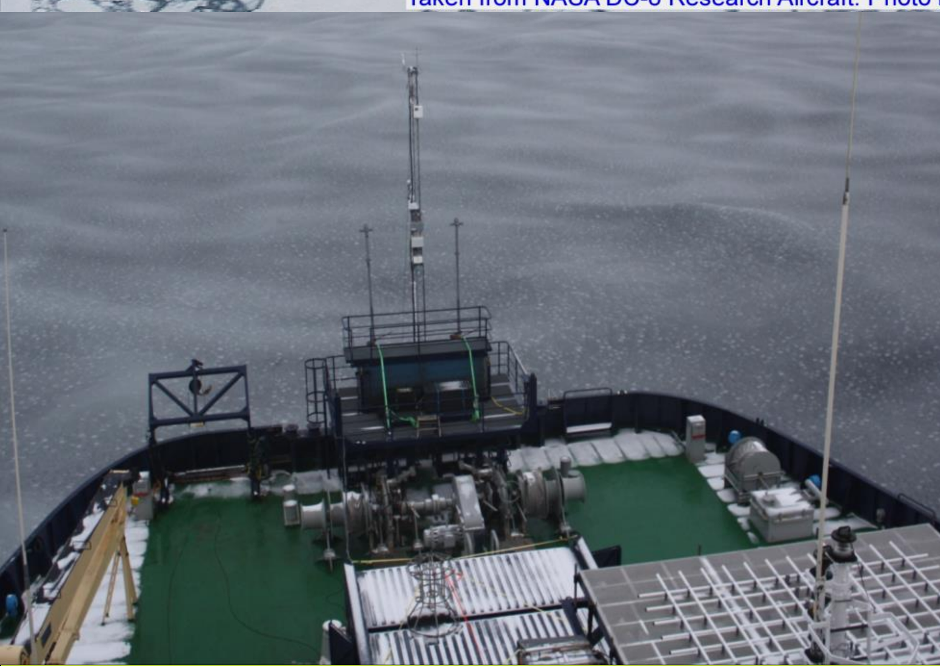
- research design
- ~15 m from deck
- open lattice
- climbable
- collapsible for easy instrument mounting and maintenance (in fair weather)
- set back from bow
- tolerated storms
- some icing concerns
- deck boltdown patterns
- flow distortion effects correctable after distortion study

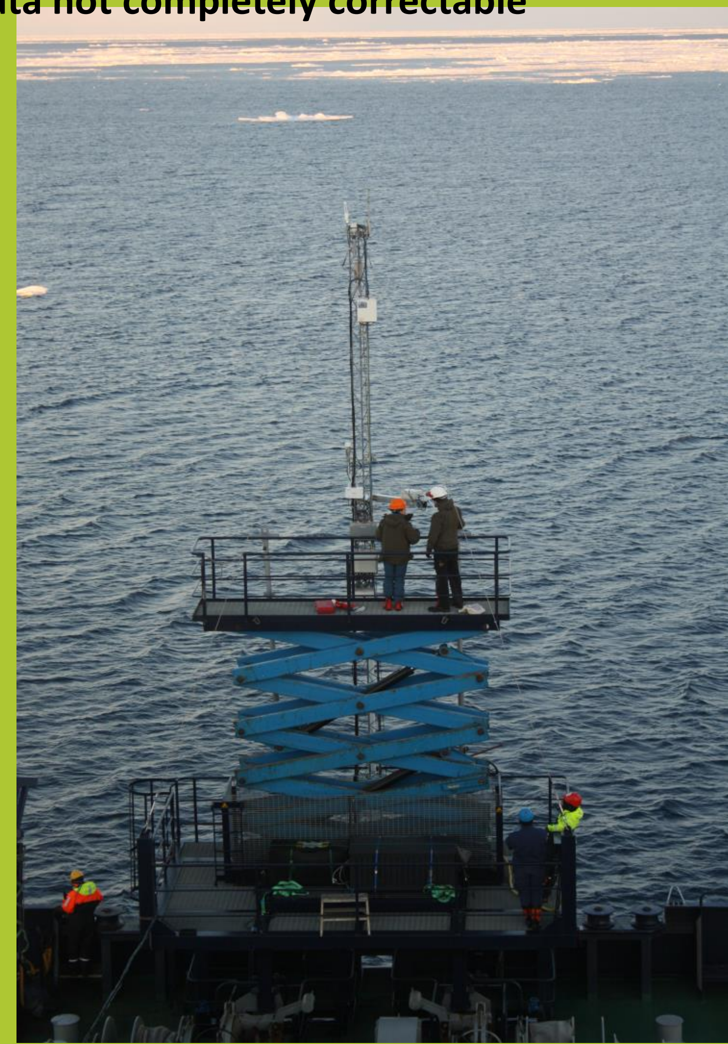


R/V Oden – Swedish icebreaker, "Shovel-nose" bow



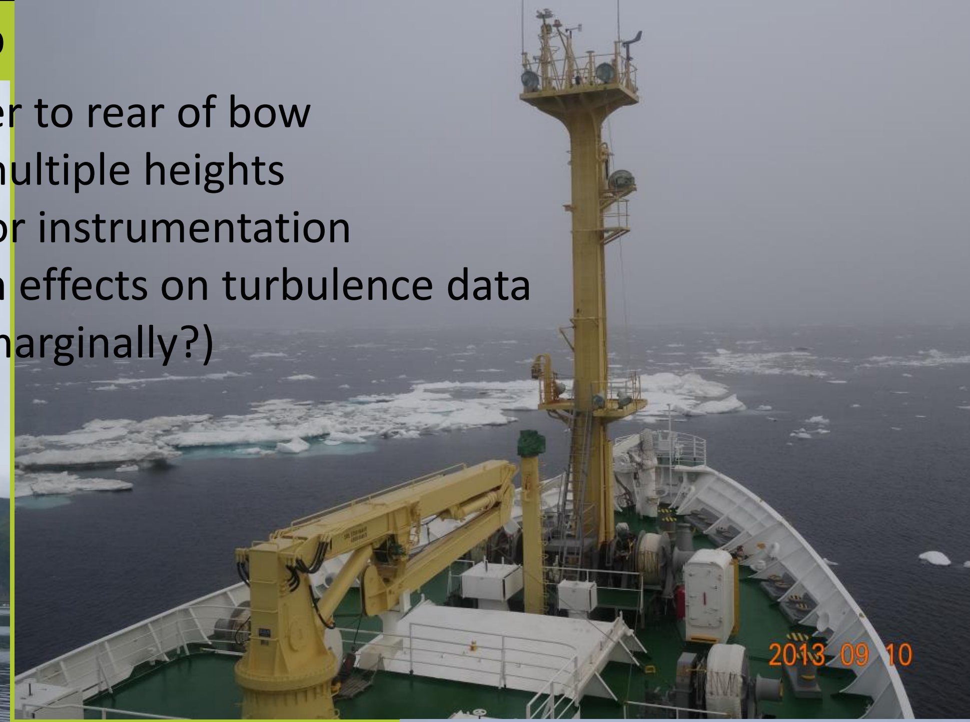
- Open lattice tower installed ~2012
- Basic met works well
- Scissor jack platform for maintenance (port or fair weather only)
- deck boltdown patterns
- **flow distortion effects (flat bow) on turbulence data not completely correctable**





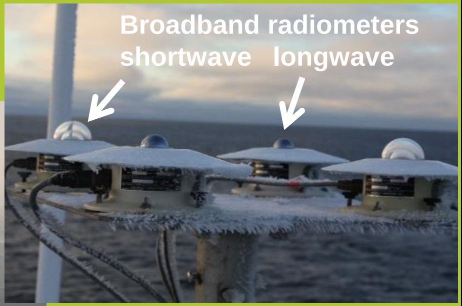
R/V Mirai – large Japanese "ice-hardened" ship

- tall, solid tower to rear of bow
- platforms at multiple heights
- ample room for instrumentation
- flow distortion effects on turbulence data
  correctable (marginally?)

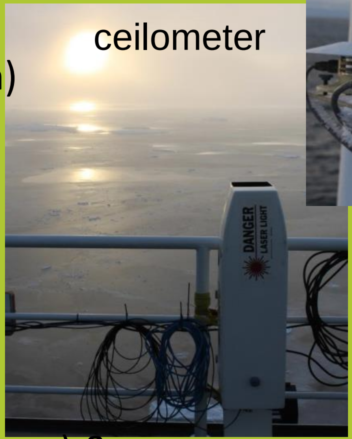


Suggested Instrumentation – operations, basic research

Basic, on bow mast (10-20 m above water surface; 5-10 m above deck)
- heated anemometer (2D Metek sonic deicing works well) – hor. winds (correct with a flow distortion study)
- temperature, pressure, relative humidity (Vaisala heated system – more accurate at high RH)
- consider heated 3D sonic (also provides momentum and sensible heat flux)



On Main Mast
- high height wind sensors (for when ship-relative wind from stern)
- marine radar (ice radar) – archive images



<u>**Elsewhere on ship**</u>

Away from superstructure shadows:
- broadband downwelling solar and longwave radiation
- ceilometer – cloud base, cloud presence

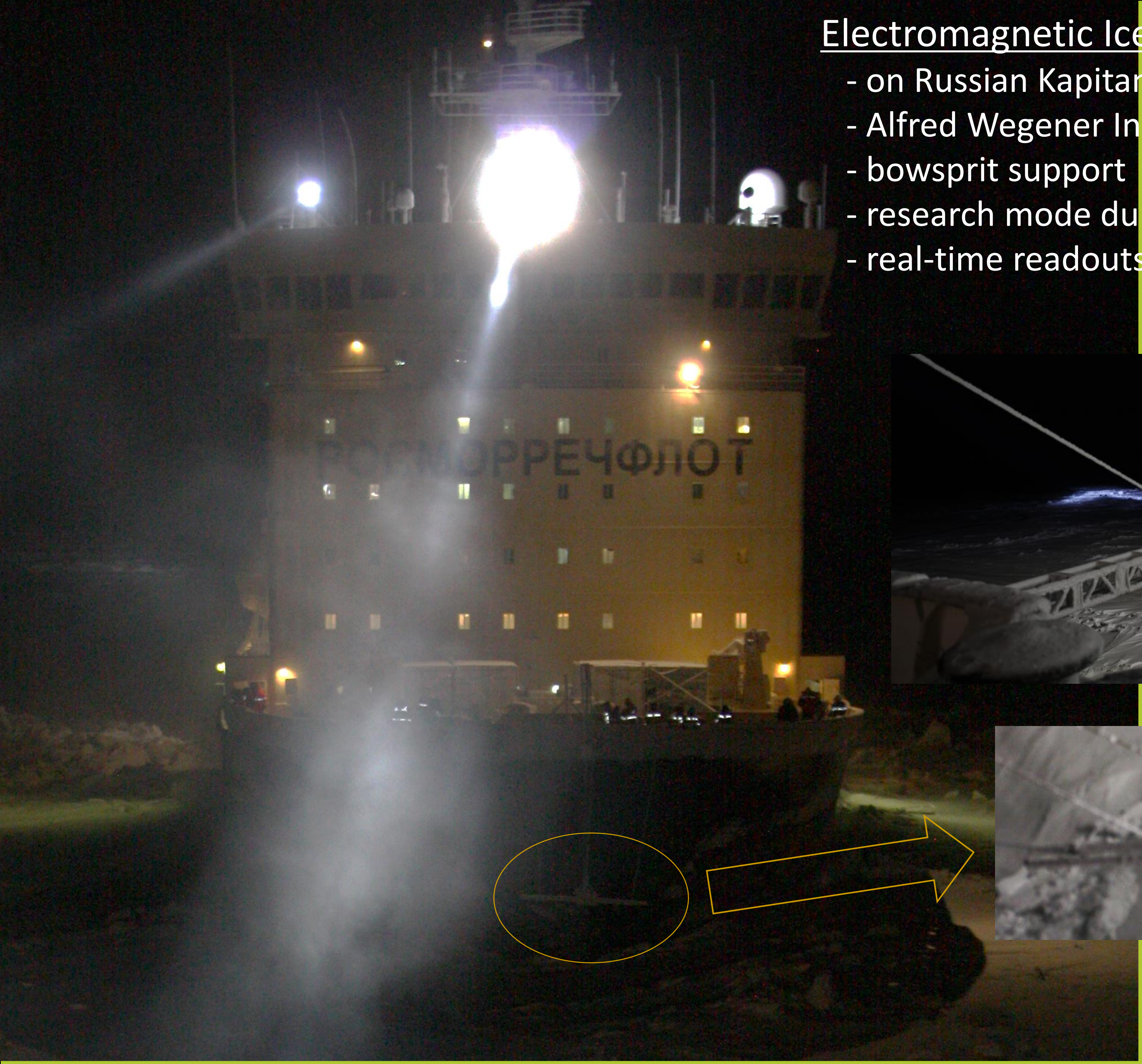
Top deck away from updrafts (NOT center leading edge of bridge top) & superstructure
- optical precipitation gauge
- pressure sensor (backup if bow mast damaged)

With good view of surface:
- Radiative surface temperature (e.g., KT-15 or CT-15; consider two instruments, key measurement & estimate ice thickness in non-summer; angle away from ship)
- wave-height sensor (bow?) – wave height, wave spectra
- electromagnetic ice thickness sensor (bow?) – ice thickness

Fantail or helideck:
- 2x daily soundings operational mode (GTS submission) (4x daily research mode)
- underway CTD (?) – upper-ocean T & S (to 75-100 m)

Electromagnetic Ice Thickness Sensor

- on Russian Kapitan Dranitsyn
- Alfred Wegener Institute, Germany
- bowsprit support
- research mode during MOSAiC transits
- real-time readouts on bridge



Ship-Based Soundings in the Arctic

Why are they done? Why are they especially needed in the Arctic?

- Key measurement for initializing global operational forecasting – 00Z & 12 Z
  - profile information will also provide spatial information to the model
  - model experiments show very large impacts over large portions of the Arctic with only a few sounding sites
  - operationally useful data must be sent to GTS (Global Telecommunications System?)
- Key measurement for many atmospheric research projects
- No regular sounding measurements over the Arctic Ocean; only a few Arctic Ocean coastal sites (Barrow, Alert, Ny Aalesund, Tiksi, Station Nord)
- Satellites are poor in profiling, especially below ~2-3 km; most key atmospheric structures below 2 km height in the Arctic

Oden - heli deck, exposed balloon fill container

Polarstern – heli deck, sheltered balloon fill

Sikuliaq – fantail, sheltered balloon fill

Knorr – fantail, exposed balloon fill

Mirai – automatic sounding system – 8x daily

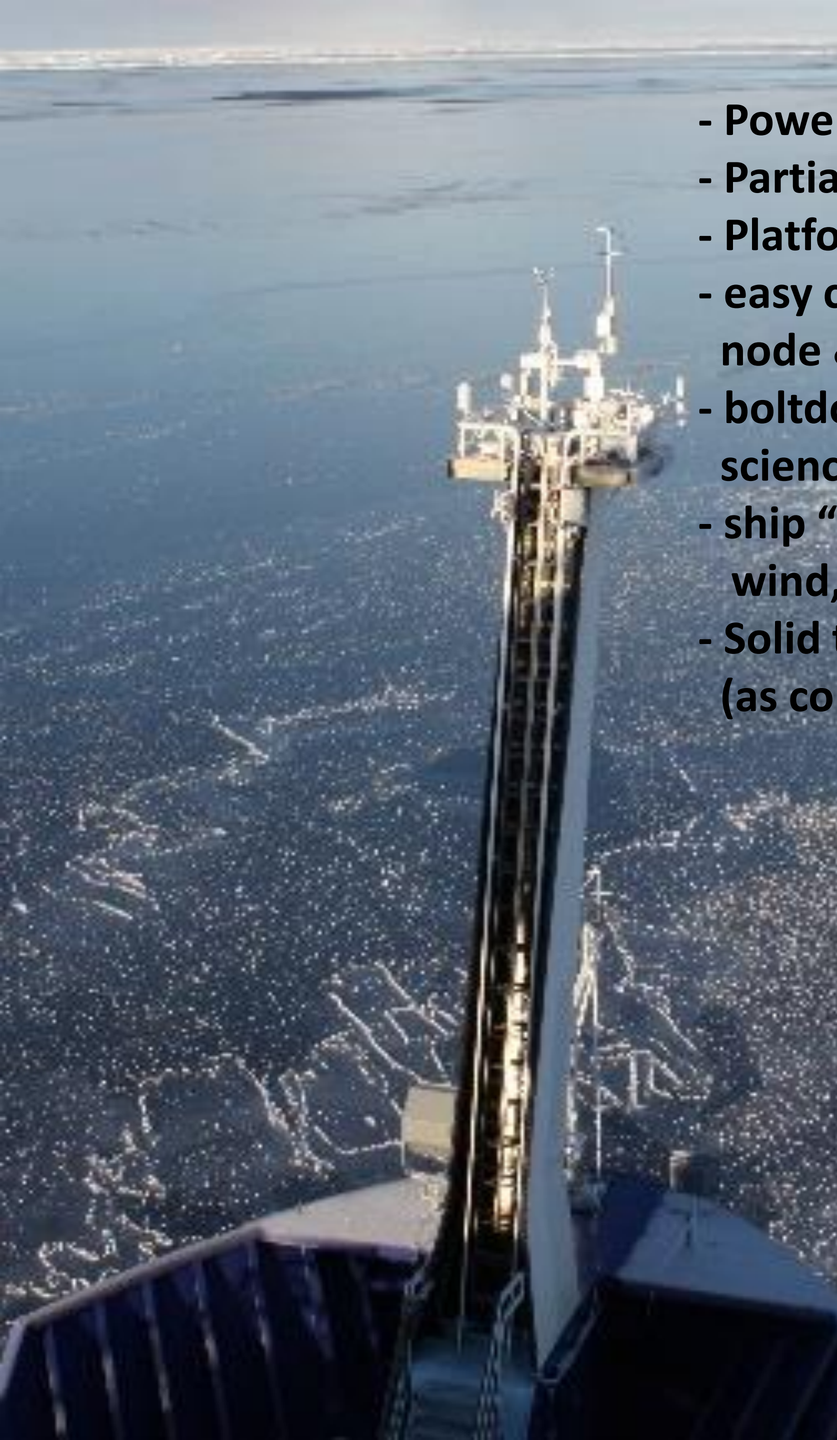
Icebreaker Instrumentation Recommendations

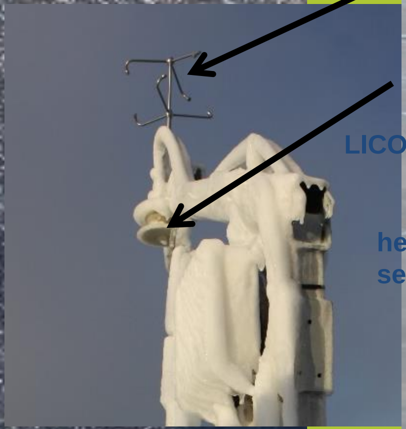
1) Flow distortion studies
2) Consider
    a) bow shape
    b) bow mast characteristics (solid/open lattice, height, bow distance, etc)
3) Bow mast - basic “operational” instruments; redundant instruments elsewhere
4) Other instrument locations based on flow-distortion study, shadowing, view of sfc, etc.
5) Strongly consider underway measurements of:
    a) lower atmosphere (soundings, ceilometer),
    b) ice (EM-ice probe),
    c) upper ocean (underway CTD)
    - likely significant benefit to development of operational models and forecasting (NOAA, ONR); direct benefit to icebreaker operations & research

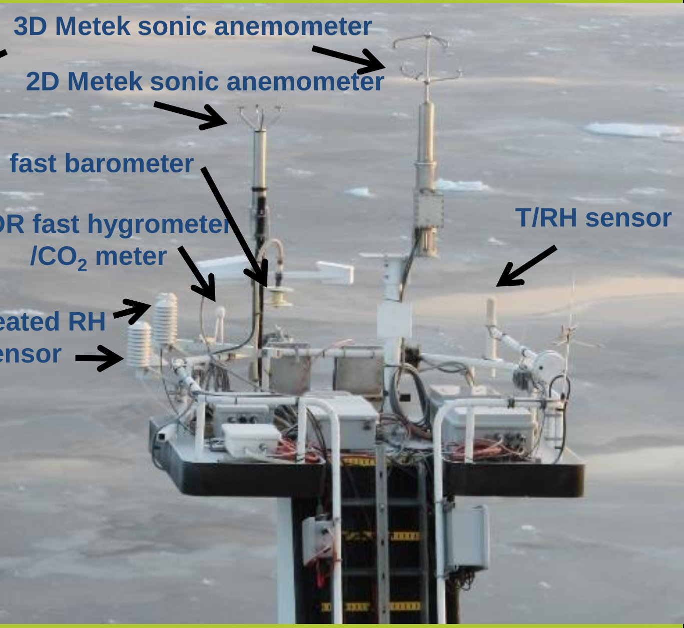
THANK YOU

R/V Sikuliaq

- Power on platform and sheltered cable ways to below deck
- Partially sheltered platform access
- Platform easier to work on than just lattice mast
- easy cable routing within ship infrastructure, incl. science node & goose neck transit to Main Lab
- boltdown patterns on platform, bow and elsewhere for science-supplied installations
- ship “operational” sensors on tower platform (ultrasonic wind, T, RH, CO_2 intake)
- Solid tower & platform produces some local flow distortion (as compared with open lattice mast)







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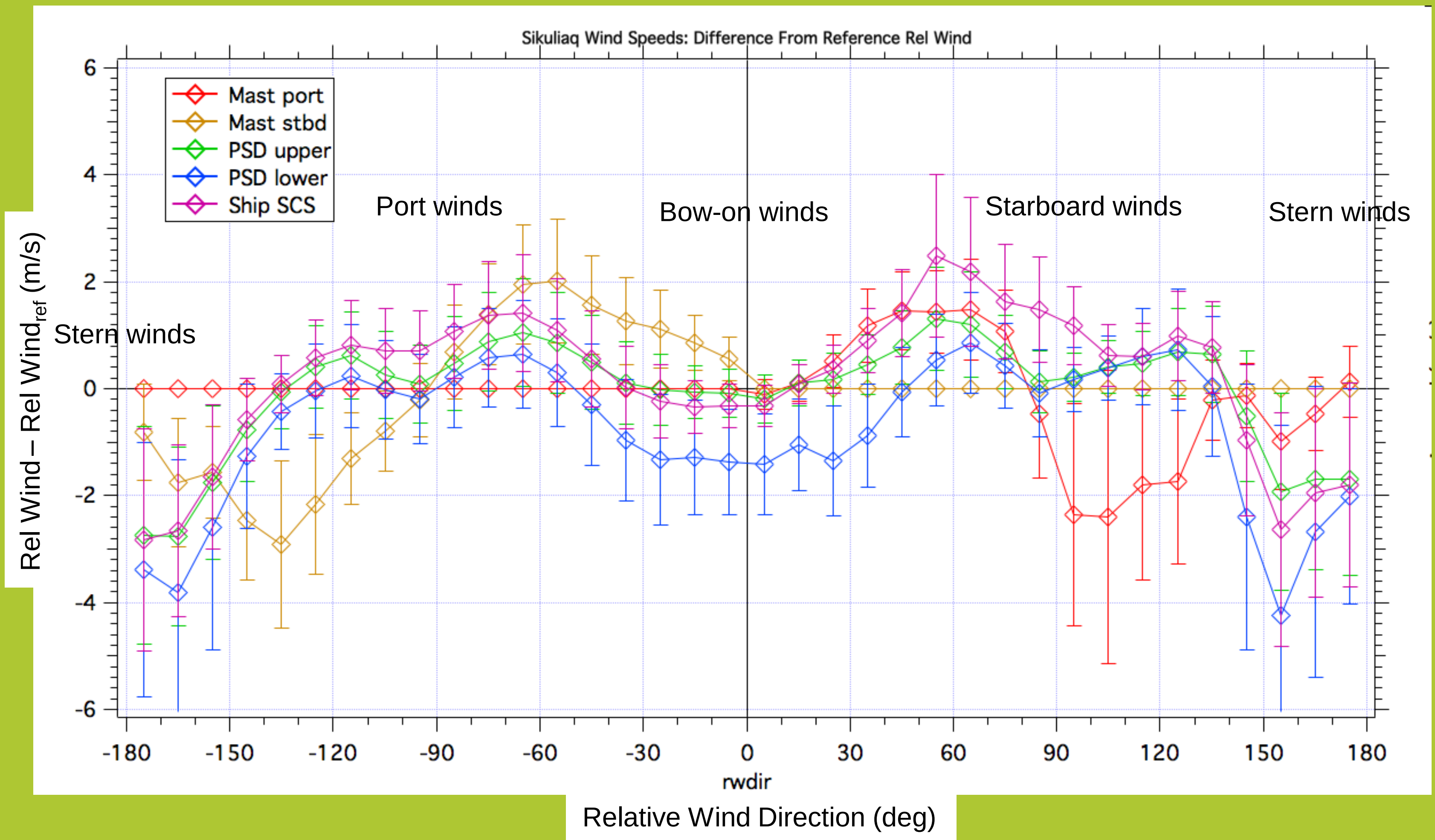
Wind Speed Comparisons as Function of Ship-Relative Wind Direction (Sea State, R/V Sikuliaq)

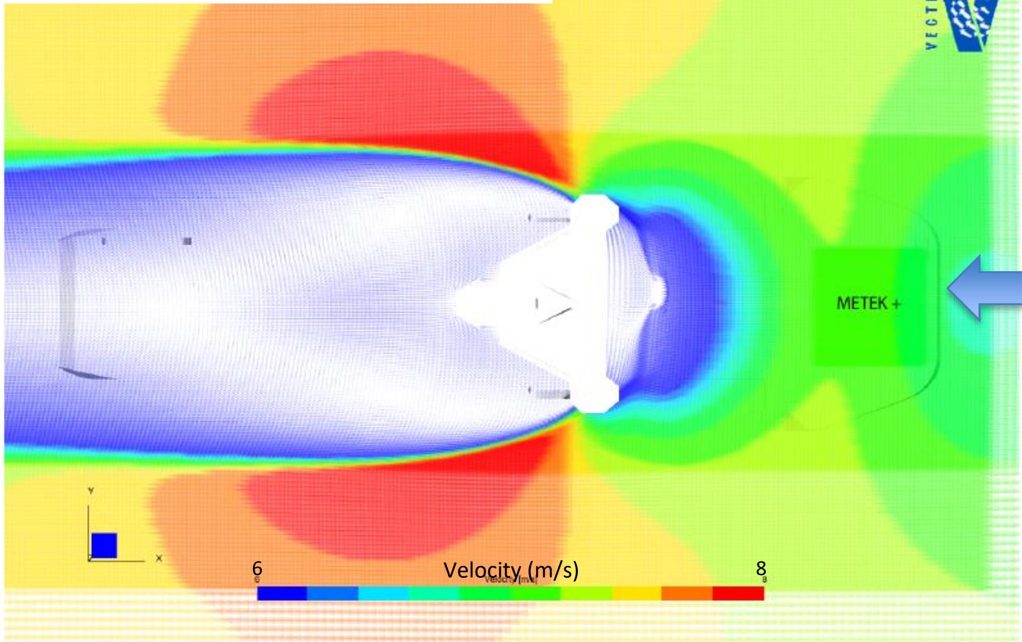


- mast port/starboard sensor used as reference for ship-relative winds (SHR winds) from port/starboard
- mast starboard/port sensor differs by -3 m/s to +2 m/s of port/starboard sensor for SHR winds from port/starboard
- PSD upper bow winds between 0 to +1 m/s of reference wind for SHR winds between ±135˚
- PSD lower bow winds 0 – 1 m/s lower than PSD upper winds
- 1-2 m/s acceleration near ±50-70˚
- 1-4 m/s deceleration with winds from stern
- ship bow 2D sonic ("Ship SCS") shows asymmetric acceleration relative to PSD upper (which it is right next to)

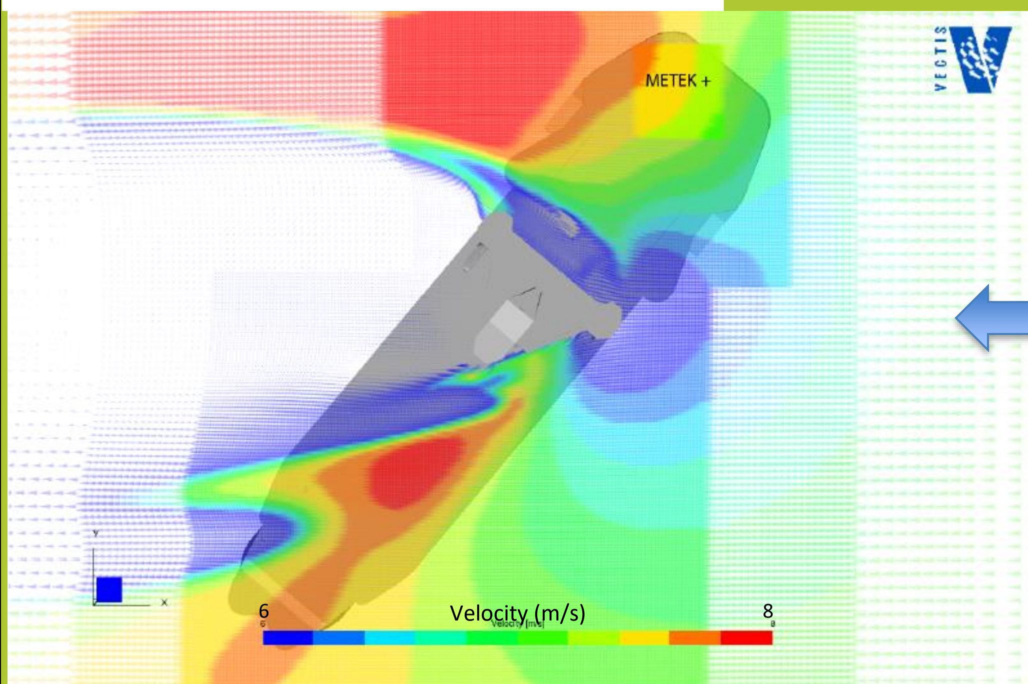
A file with 5-min "best" winds will be created

Airflow study plane view – R/V Oden, 2015

METEK height – flow 0 degrees bow-on



METEK height – flow 50 degrees over starboard side



	Relative wind direction (degrees)													
	0	±10°	±20°	±30°	±40°	±50°	±60°	±70°	±80°	±90°	±100°	±110°	±120°	±150°
METEK	-3.10 (-3.81)	-2.95 (-3.67)	-2.20 (-2.99)	-0.93 (-1.78)	0.48 (-0.48)	2.41 (1.25)	4.44 (3.03)	6.45 (4.67)	7.94 (5.65)	8.46 (5.37)	8.90 (5.67)	10.67 (6.10)	12.39 (5.32)	- -
CSAT	-5.53 (-6.72)	-4.87 (-6.09)	-3.56 (-4.90)	-1.29 (-2.72)	0.90 (-0.69)	3.46 (1.60)	6.27 (4.02)	9.00 (6.15)	10.98 (7.11)	11.73 (6.66)	12.59 (5.02)	13.99 (3.37)	16.33 (0.61)	- -

Table 4. The percentage wind speed bias at the sensor location accounting for the height the airflow was raised ΔU_z (i.e. at height z - Δz). The values in brackets indicate the wind speed error using a free stream velocity from a location 2 seconds upstream of the anemometer site ΔU_{zt2}, i.e. z - Δzt=2 (after Yelland et al., 2002). The anemometers were on the centreline of the ship, which results in a symmetric wind speed bias.

	Relative wind direction (degrees)													
	0	±10°	±20°	±30°	±40°	±50°	±60°	±70°	±80°	±90°	±100°	±110°	±120°	±150°
METEK	-4.50	-4.36	-3.68	-2.44	-1.13	0.59	2.37	3.98	4.92	4.60	4.88	5.24	4.39	-10.37
CSAT	-8.14	-7.50	-6.32	-4.11	-2.03	0.28	2.74	4.87	5.77	5.31	4.10	2.47	-0.33	-29.58

Table 5. The percentage wind speed bias at the sensor location ΔU. The anemometers were on the centreline of the ship, which results in a symmetric wind speed bias.

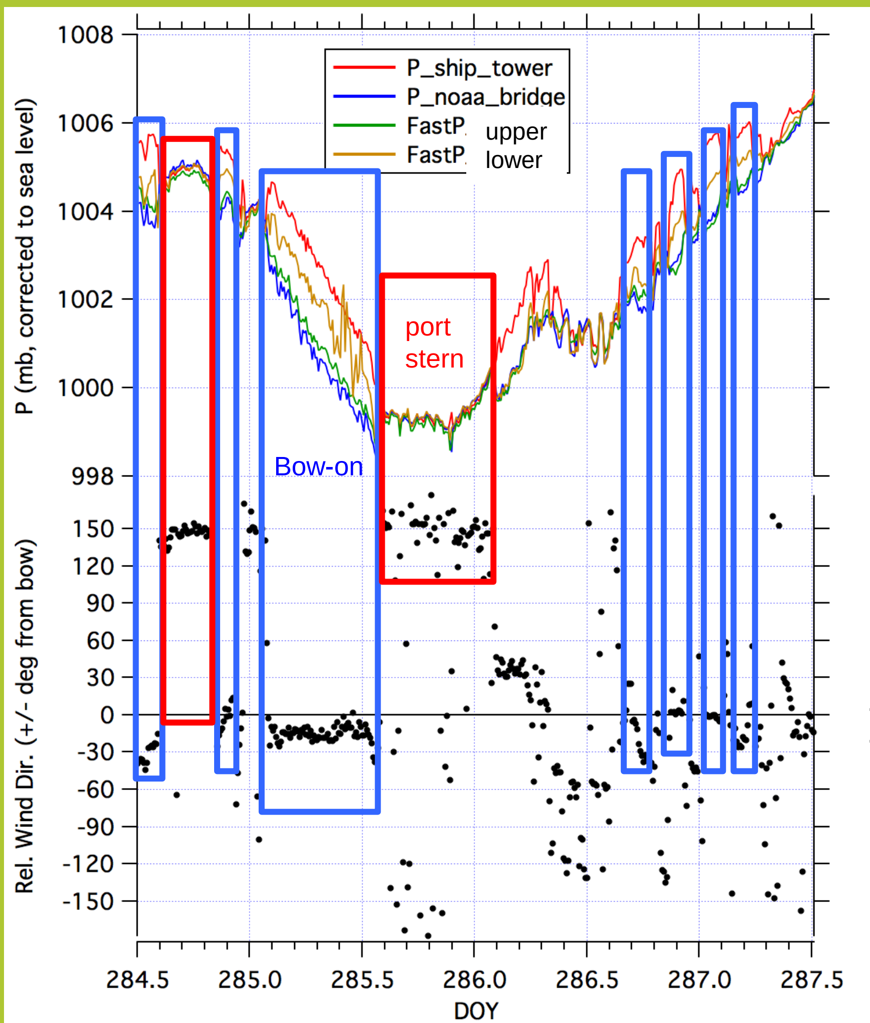
Tables: percent errors larger at lower height at bow for a given relative wind direction

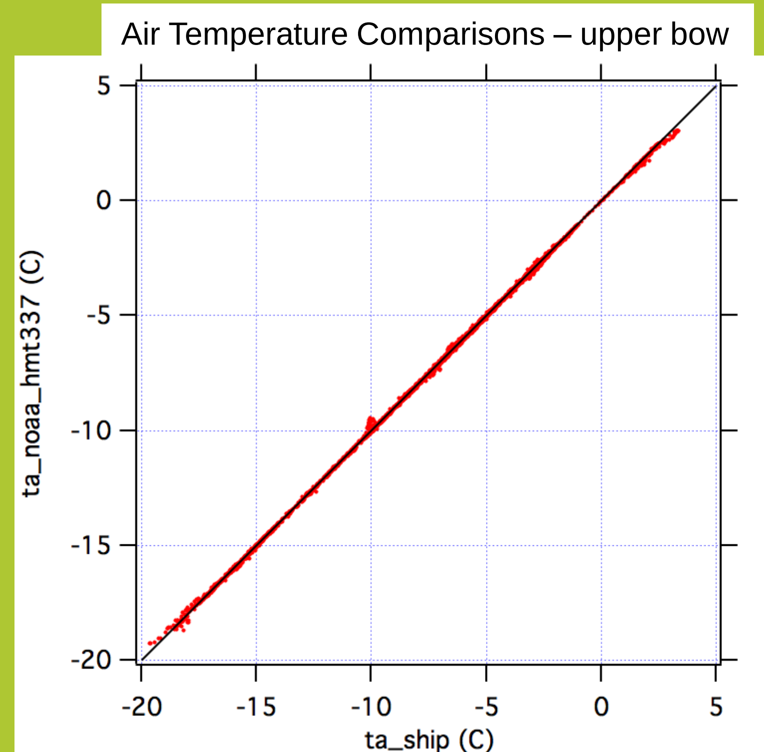
Comparisons of Basic Met Parameters

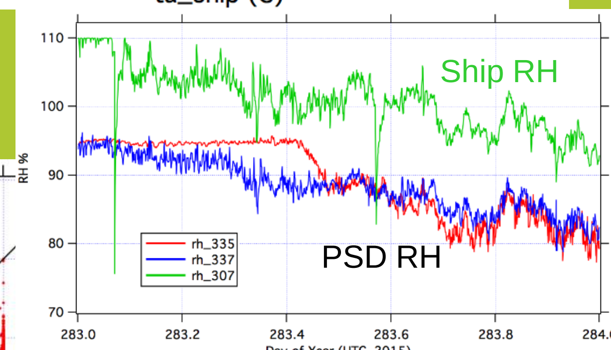
-R/V Sikluiaq/Sea State (Oct-Nov 2015)

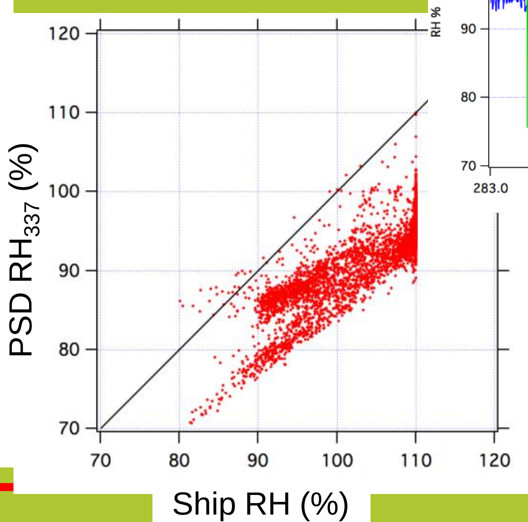
RESULTS

- ship - PSD T_{air} in good agreement
- SLP can vary by nearly 2 mb depending on ship-relative wind; NOAA bridge & fast upper generally in agreement -- best(?)
- ship RH 15-18% too high; unheated PSD RH sensor can "freeze" at times



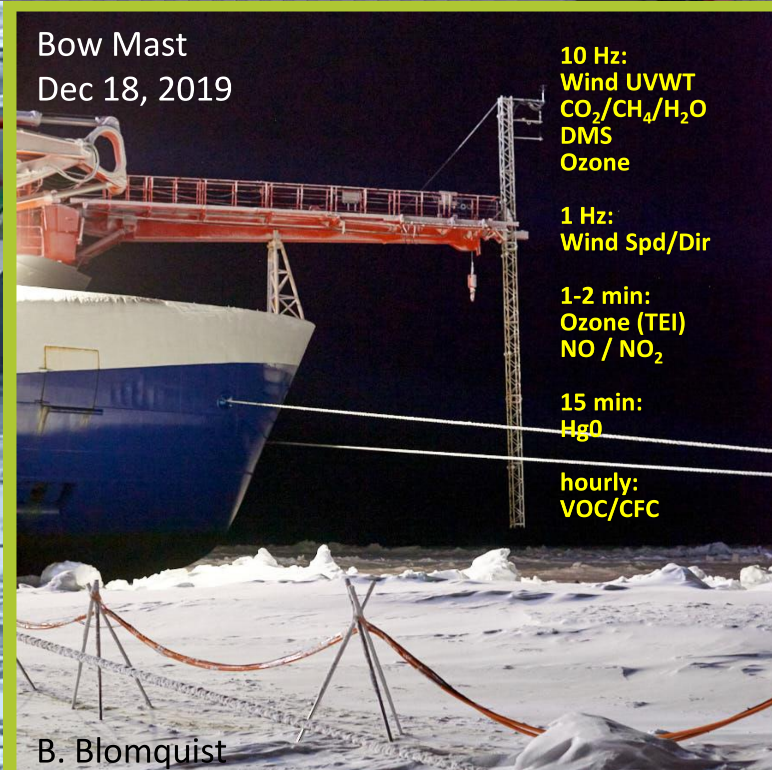






R/V Polarstern

- normally only small jackstaff
- Large open-lattice bow mast extended ahead while stationary at MOSAiC – retractable for maintenance



Recommendations (start discussion)

1) flow distortion study
2) solid or open lattice bow mast?
   - solid: number of platforms
   - lattice: collapsible (Knorr)
3) safe height & shortest bow distance?
4) instrument bow mast with at least basic “operational” instruments
5) provide easy installation of science-supplied instruments

Recommendations (cont.)

6) install other basic instruments at non-bow locations
7) regular maintenance/calibration of ship-run instruments