AIR-SEA INTERACTION LAB
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Measurements of the marine atmospheric boundary layer and air-sea interaction from ship-launched ScanEagle UAVs

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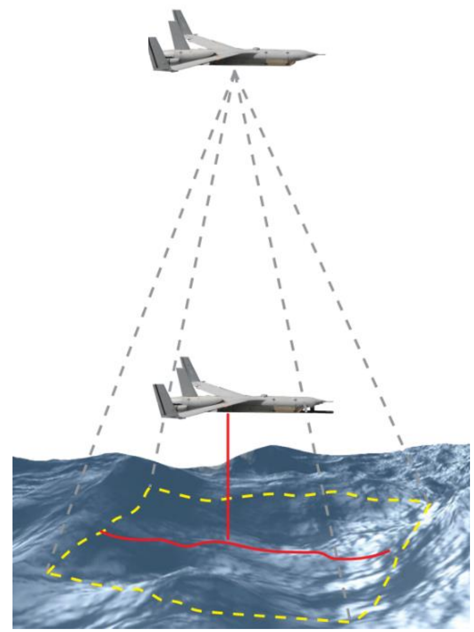
SCOAR Meeting
4 June 2014



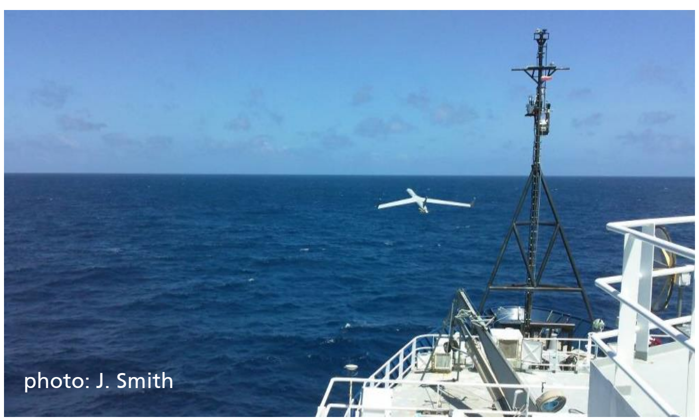


photo: J. Smith


photo: ScanEagle

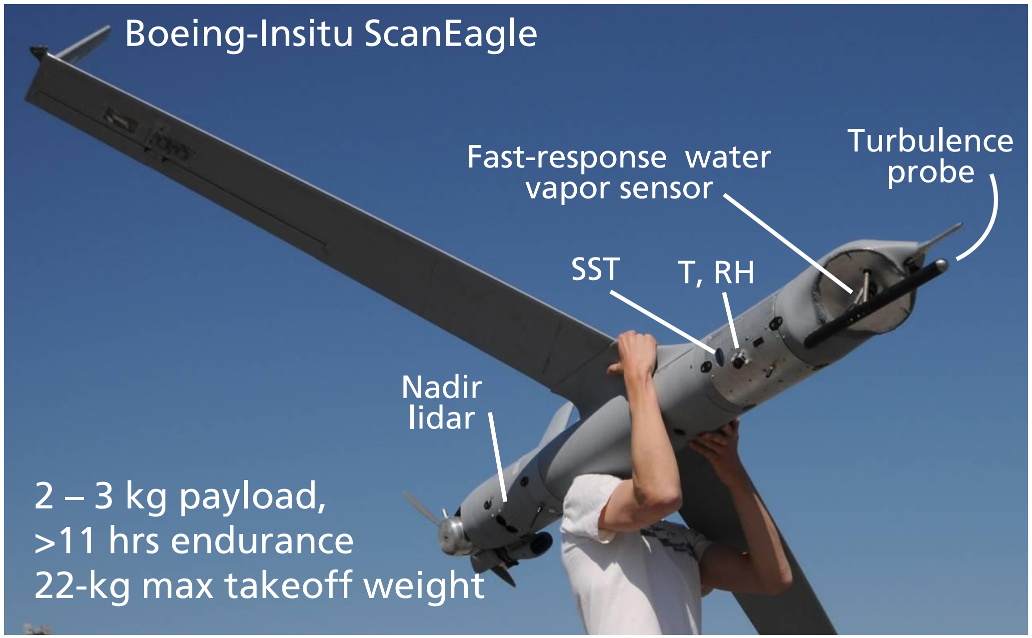
Overview of air-sea interaction and surface processes

- **Coupling** of **atmospheric and oceanic boundary layers** plays an important role in local and global **fluxes of mass, momentum, and energy**
- Transfers actively modulated by the surface wave field
- **Wind forcing** injects energy into the wave field
  - Mixes surfaces waters
  - Directly influences turbulent heat transfer
- **Wave breaking**:
  - Energy transferred to **currents and turbulence**
  - Also important for **gas transfer** and **aerosol generation**
- Air-sea fluxes are not well understood, especially in **high wind and wave** environments (e.g., high latitudes, extreme conditions)

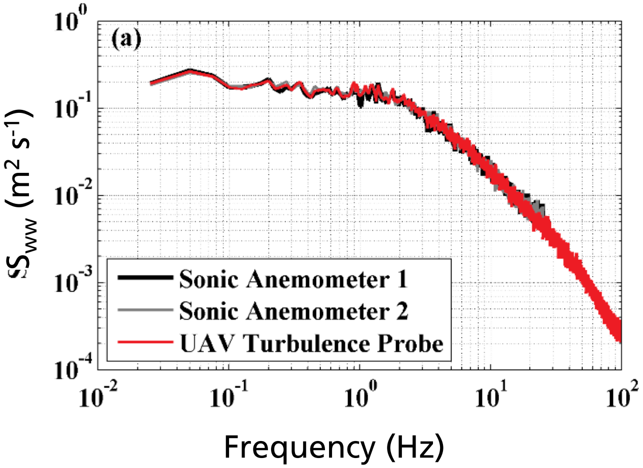
- Aircraft provide an **efficient** way to measure meter to mesoscale processes over **large spatial** ranges
- To measure surface fluxes, need to be close to the surface (≤30 m)
- Transition to **smaller, lighter, safer** platforms
- Unmanned Aerial Vehicles: safety, endurance, ship-launched (remote locations)

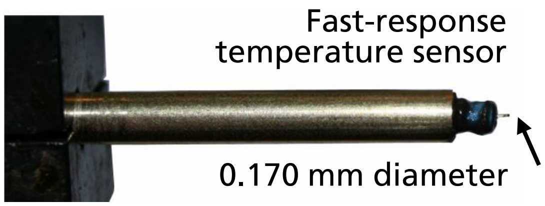
"Flux" payload: wind, momentum and scalar flux measurements

- Fast-response **turbulence probe** (3D wind) + temperature, water vapor sensors
- Calibration: wind tunnel + in-flight maneuvers (Reineman et al. 2013)
- Main purpose: measure **momentum and scalar heat fluxes**
- Also includes: **point lidar**, GPS/Inertial Measurement Unit (IMU), data acquisition



Comparison of measured vertical wind spectra between turbulence probe and CSAT sonic anemometer

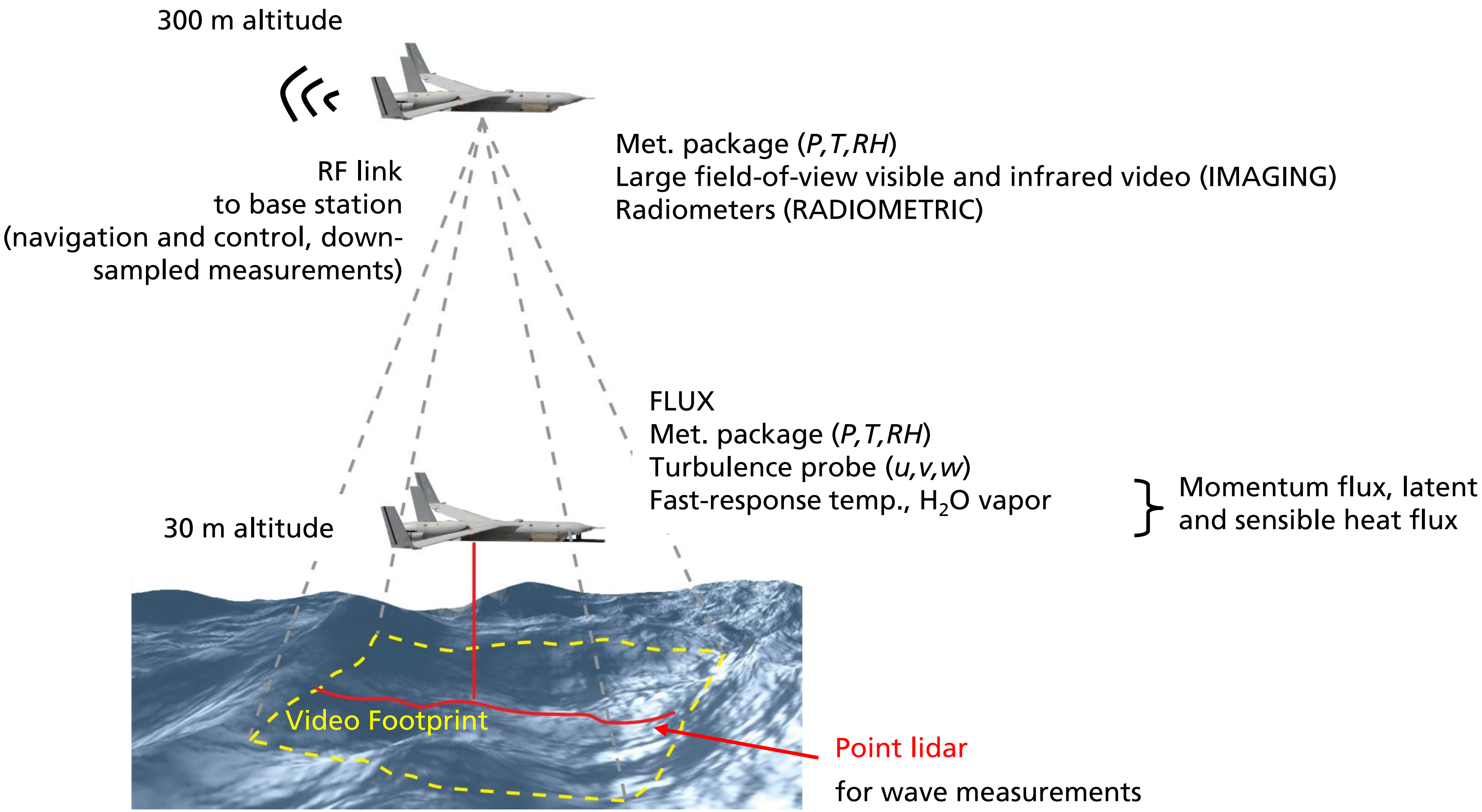




Fast-response temperature sensor

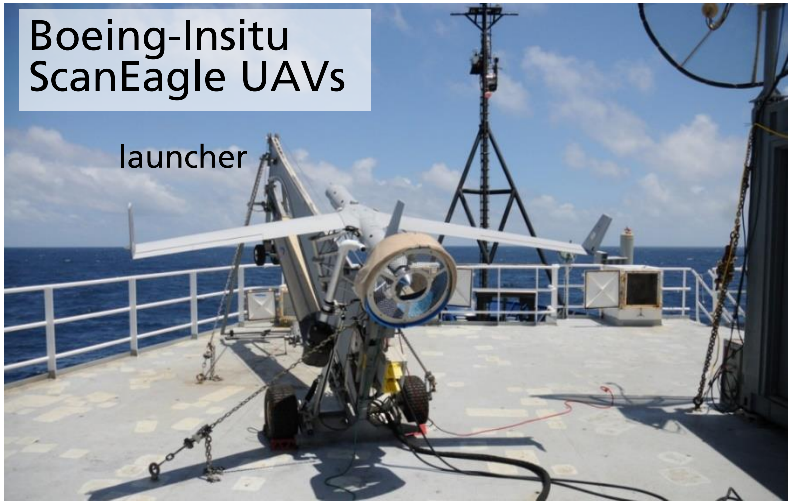
UAV “stacked" flight configuration, measured parameters

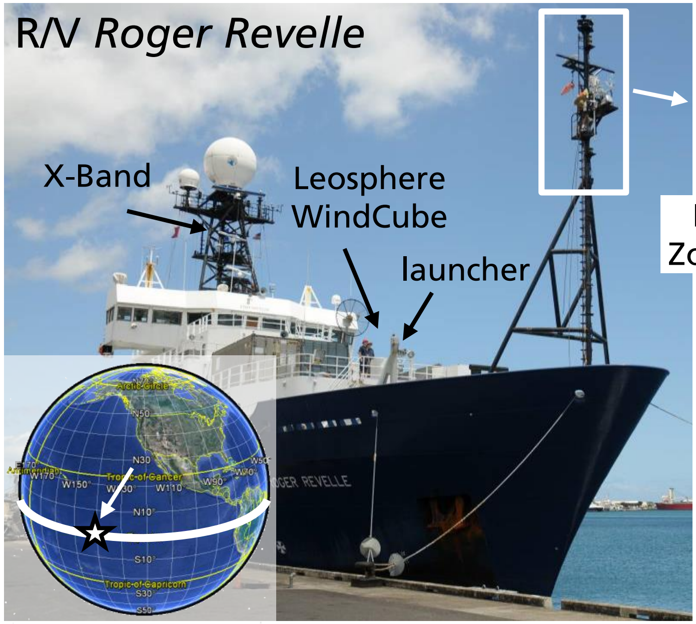
- Coincident remote sensing and measurements of energy and momentum fluxes

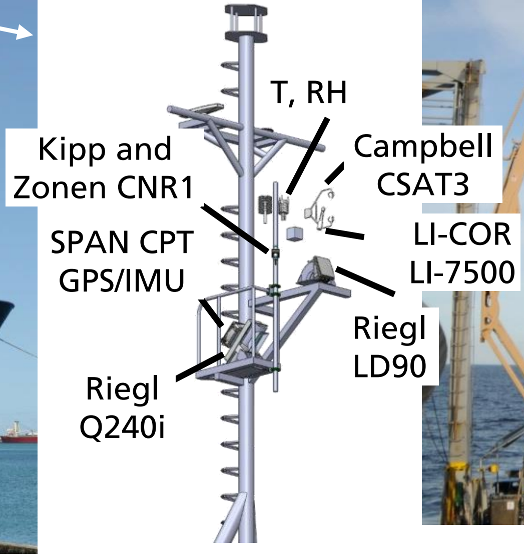


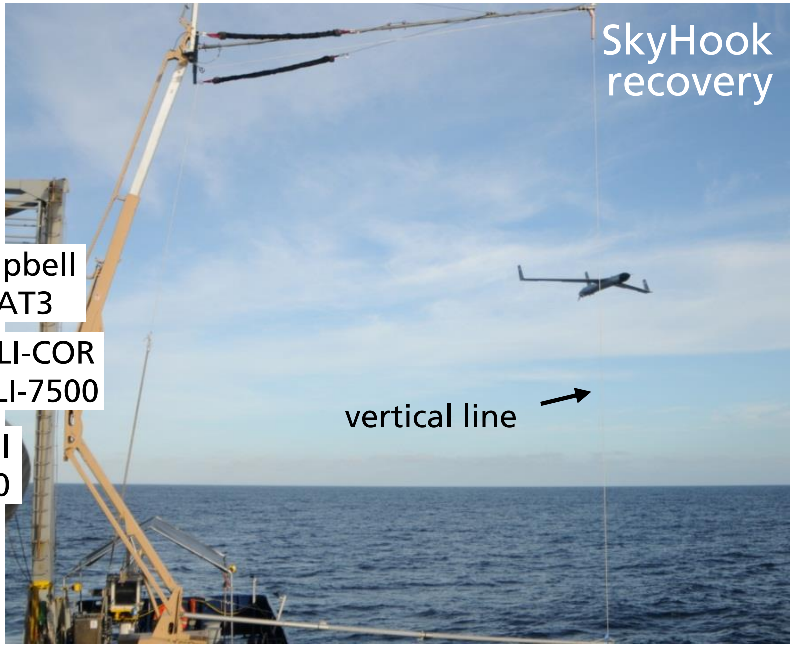
Ship-based UAV operations, Equatorial Mixing Expt., Oct 2012

- Central equatorial Pacific (0°N, 140°W)
- Other groups (chief scientist: J. Smith, SIO) measured turbulence and mixing in upper water column
- UAVs provided atmospheric boundary layer measurements and remote sensing of surface structure (11 flights, 71 hrs)
- Supporting ship equipment: X-Band WaMoS system, eddy-covariance system on foremast, laser Doppler WindCube

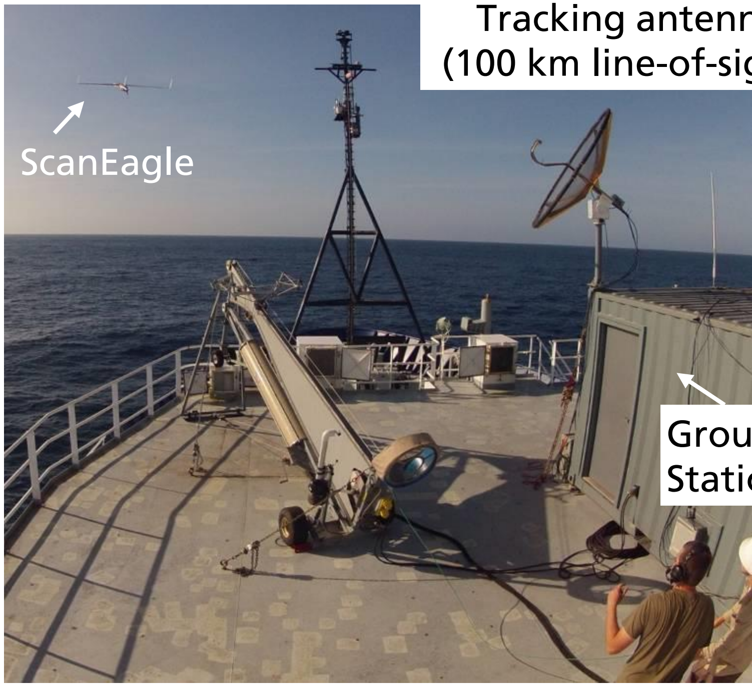




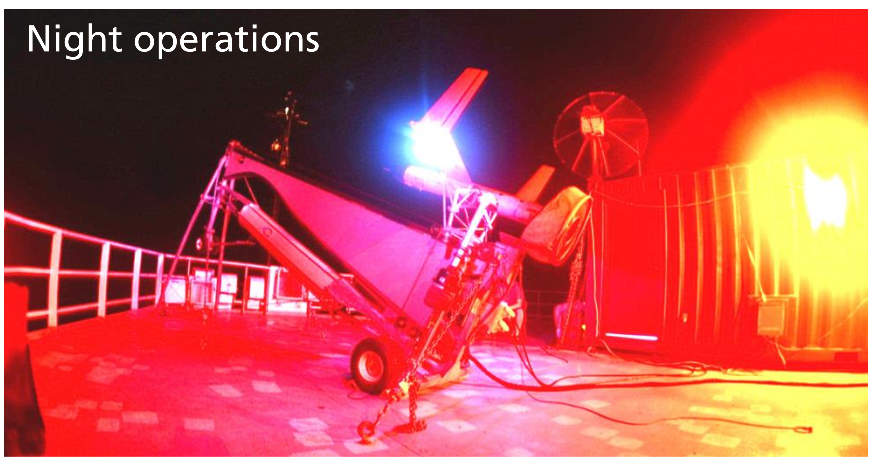


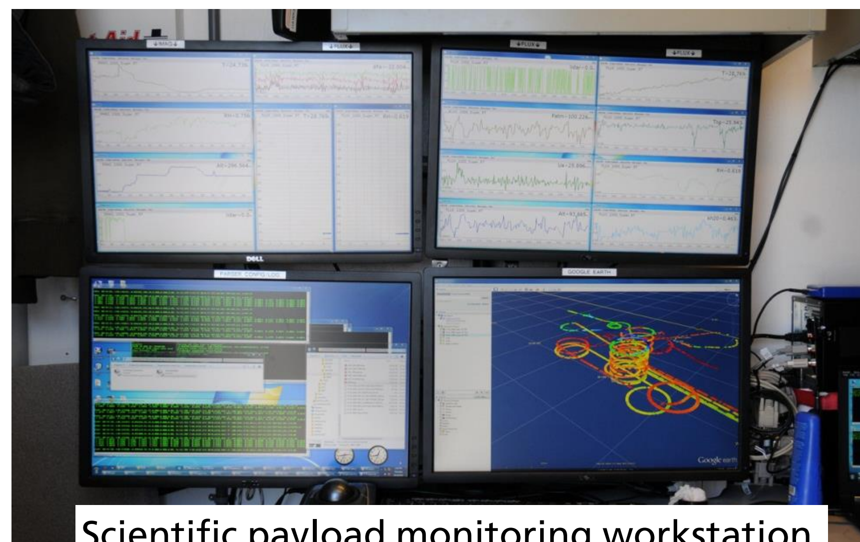


Ship-based UAV operations

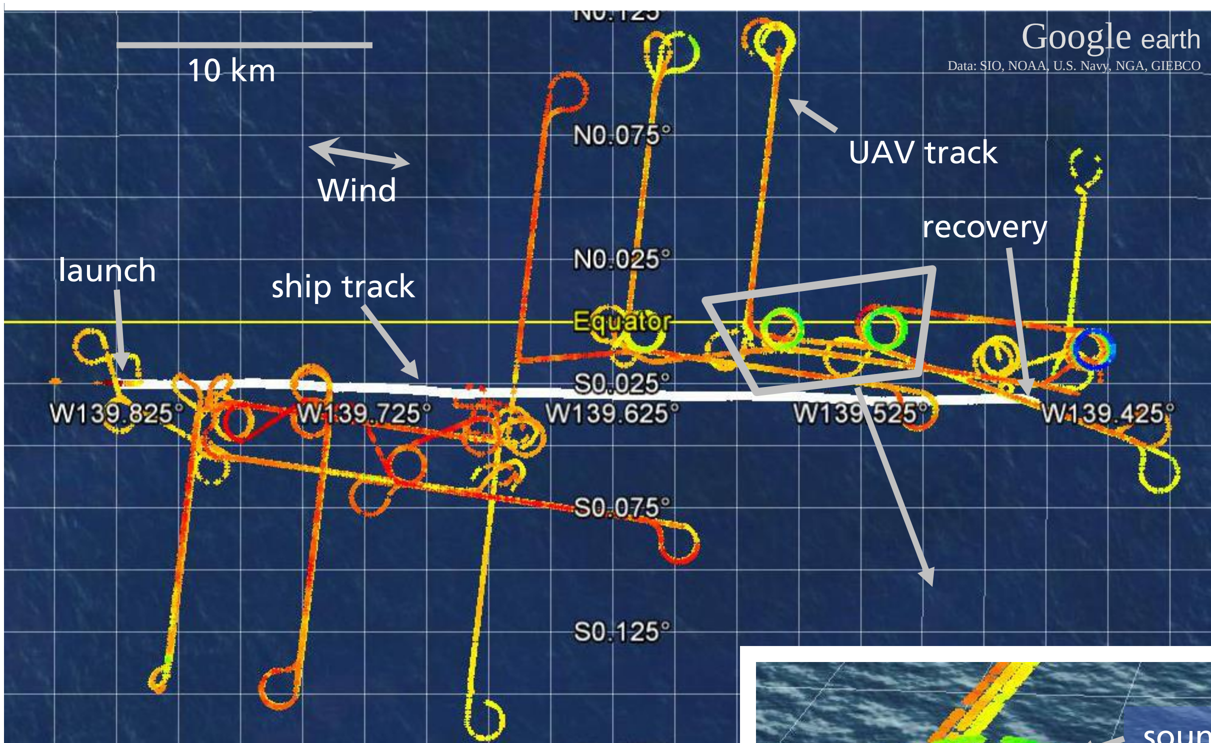


Inside the Ground Control Station:

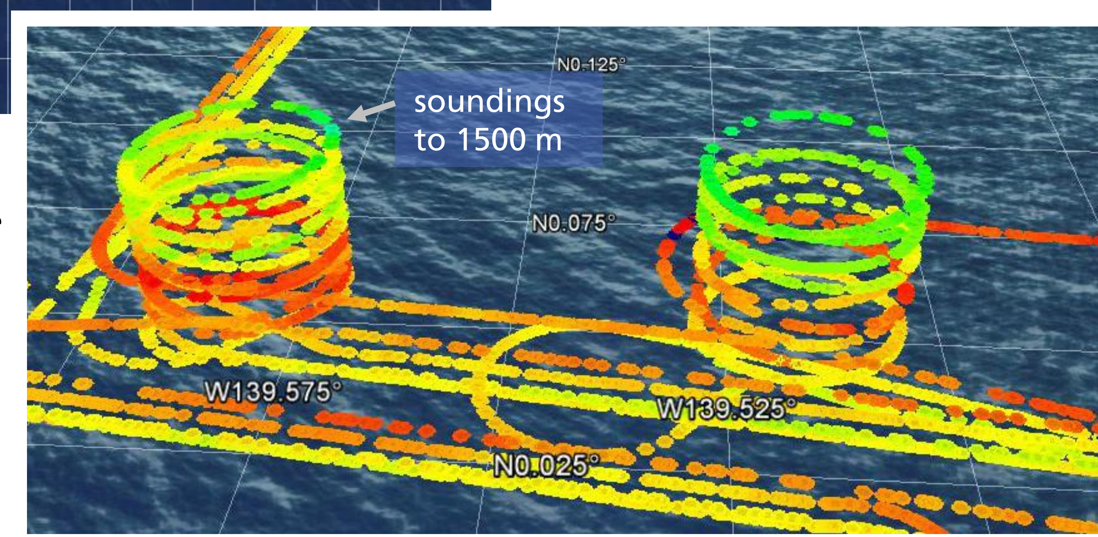


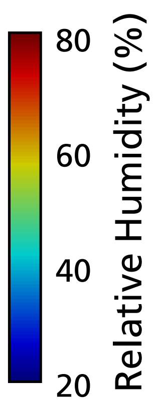


Real-time Google Earth plotting sample: 11-hr “Flux” payload flight



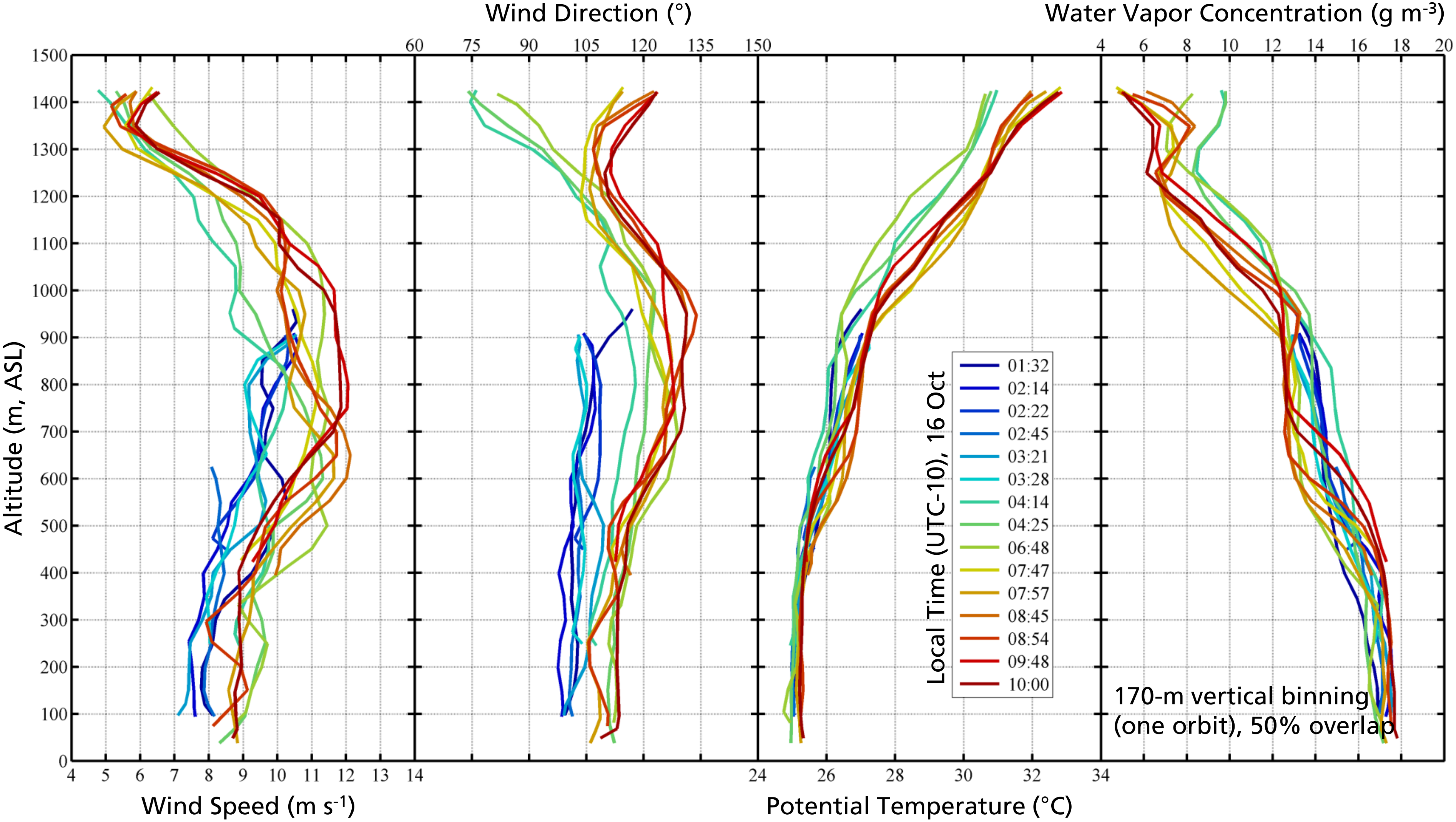
- Sub-sampled (1-Hz) data transmitted through the radio link
- Plot any variable as color along the flight track
- Use for “**on-the-fly**” flight **mission planning**





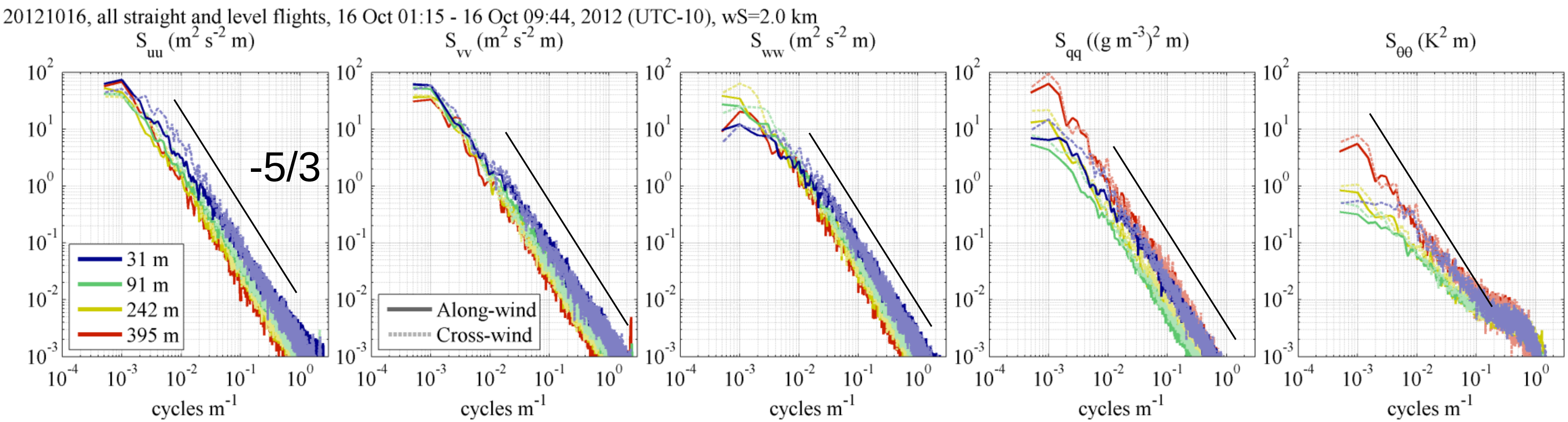
Vertical atmospheric profiles, 16 Oct. 2012

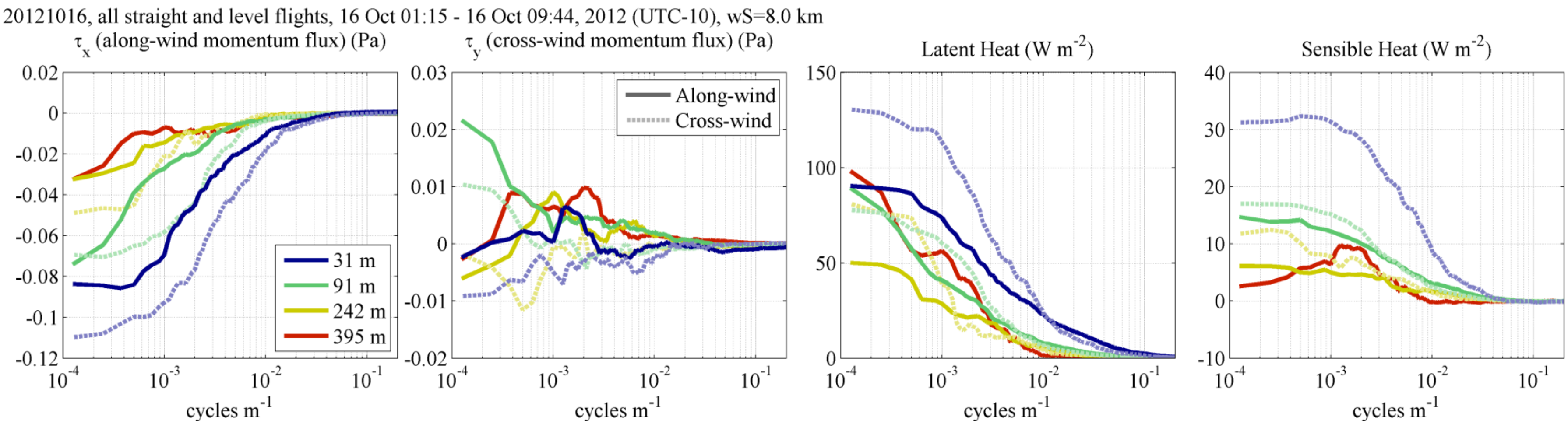
- Helical vertical soundings over 11-hour flight, 30 to 1450 m AGL (100 to 900 m at night)
- Local profile time given (UTC-10)



Spectra and integrated co-spectra, 16 Oct. 2012

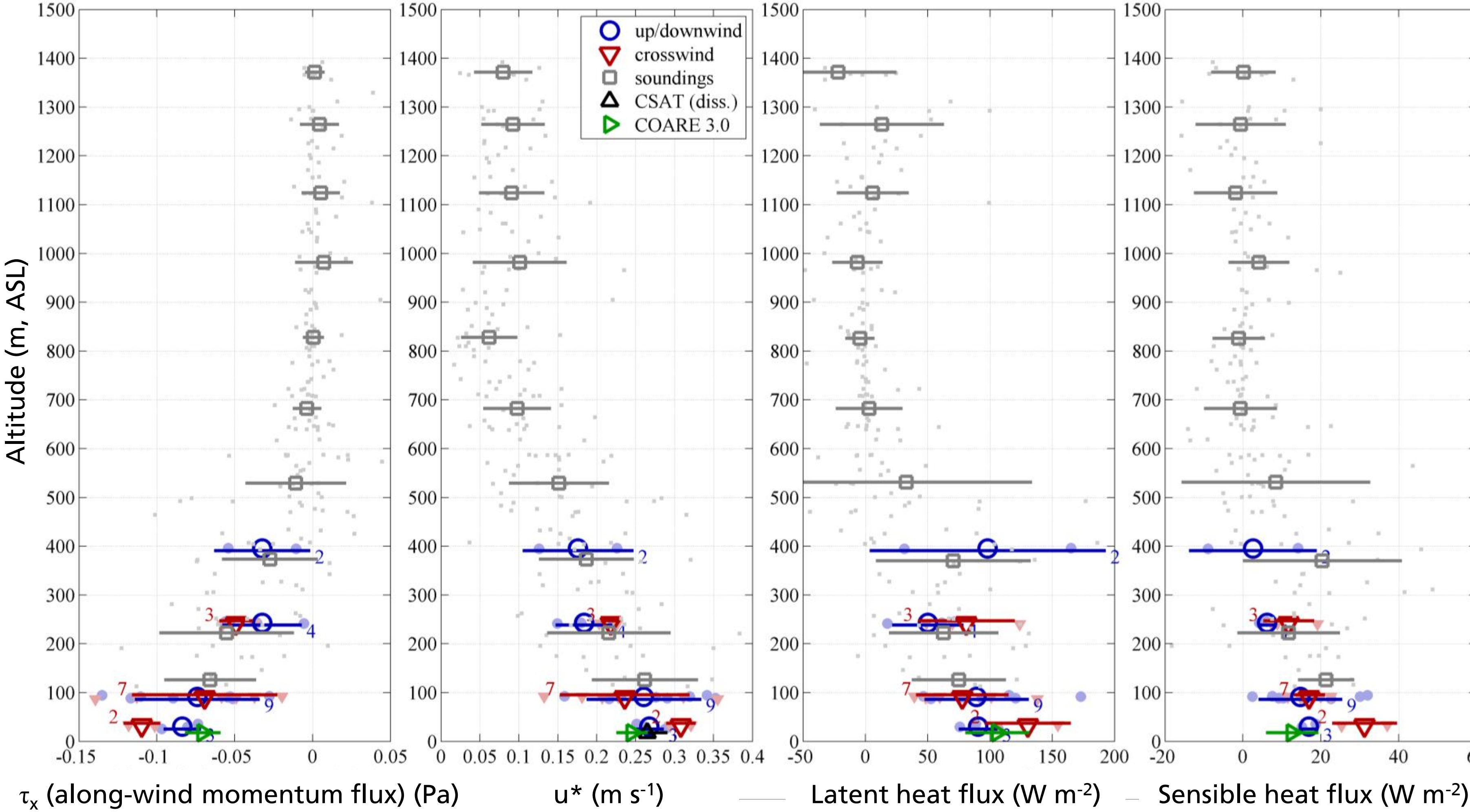
- Large-scale (O(1 km)) persistent, along-wind coherent structures
- Evident in different shape of integrated co-spectra, larger final flux value





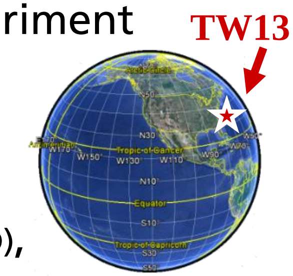
Vertical flux profiles, 16 Oct. 2012

- Red: crosswind flight segments, Blue: up/downwind; 8-km windowing (~5 minutes)
- Gray: vertical helical soundings (1500-m diameter), half-orbit windows (83-s)
- Atmospheric rolls on this day; generally larger fluxes from cross-wind segments
- U_{10} = 7 – 9 m/s, H_{BL} ≈ 400 m; data from 11 flight-hrs, midnight to 11am LT



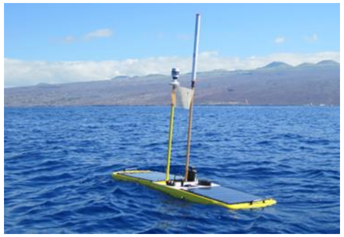
Trident Warrior (July 2013, Norfolk, VA)

- Employ unmanned systems in forward operating areas: demonstration experiment aboard R/V *Knorr*



- Autonomous vehicles:

  Instrumented Wavegliders (SPAWAR), SLOCUM (OSU), ScanEagles (SIO, NSWCDD),

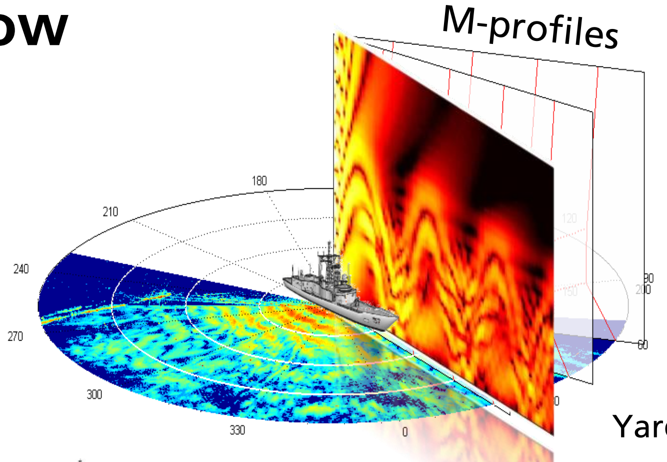


  met. and wave buoys (NPS, SIO), profiling balloon and kite radiosondes (NSWCDD, NPS)

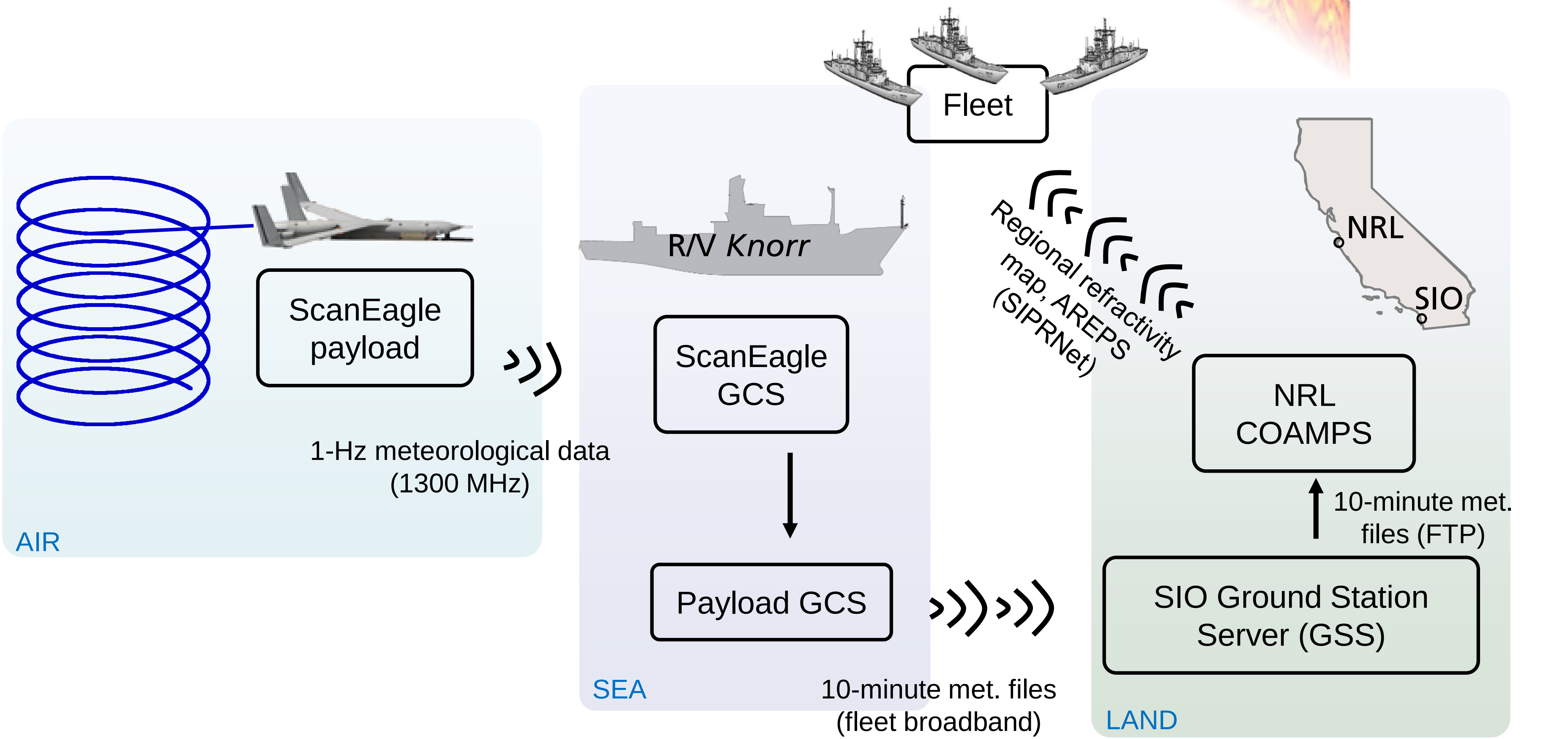
- Science objectives, measurements:
  - Time-varying 3D structure of MABL (vert. profiles wind, temp, humidity)
  - Response of MABL to SST, subsurface structure, and visa versa
  - **Real-time data assimilation** of measurements into Coupled Ocean/Atmosphere Prediction System (COAMPS) (SIO, NPS, NRL)
  - Electromagnetic propagation monitoring, model evaluation (SPAWAR, SIO)

Trident Warrior real-time UAV data flow

- Meteorological data measured by ScanEagle payload transferred to NRL for assimilation into COAMPS model
- Near-real-time measurements (10-minute files) and assimilation

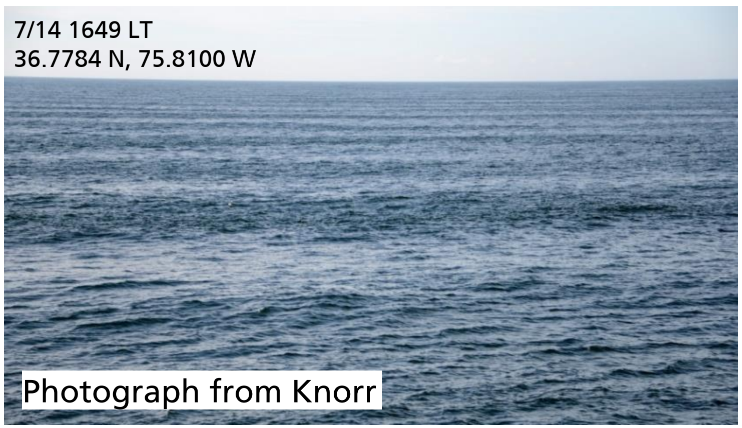


Yardim 2007

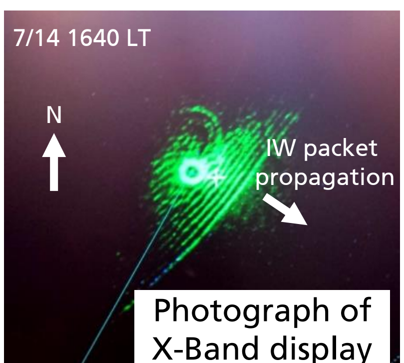


Long-wave infrared imagery during stacked flight (Trident Warrior)

- Sample infrared imagery sequence during TW13
- Stacked flight: FLUX at 100 m ASL, IMAGING at 910 m ASL
- Surface signatures of internal waves, generated at Chesapeake Bay inlet (30 km to the NW)



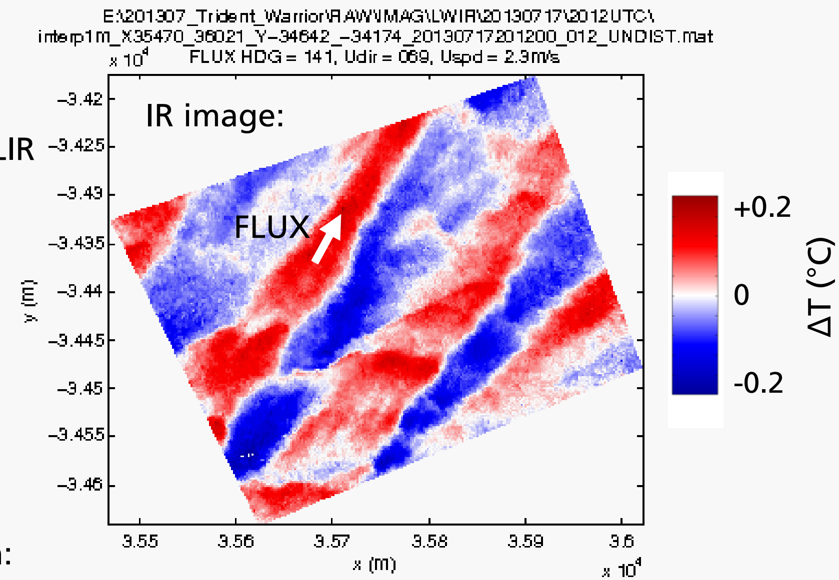
Photograph from Knorr



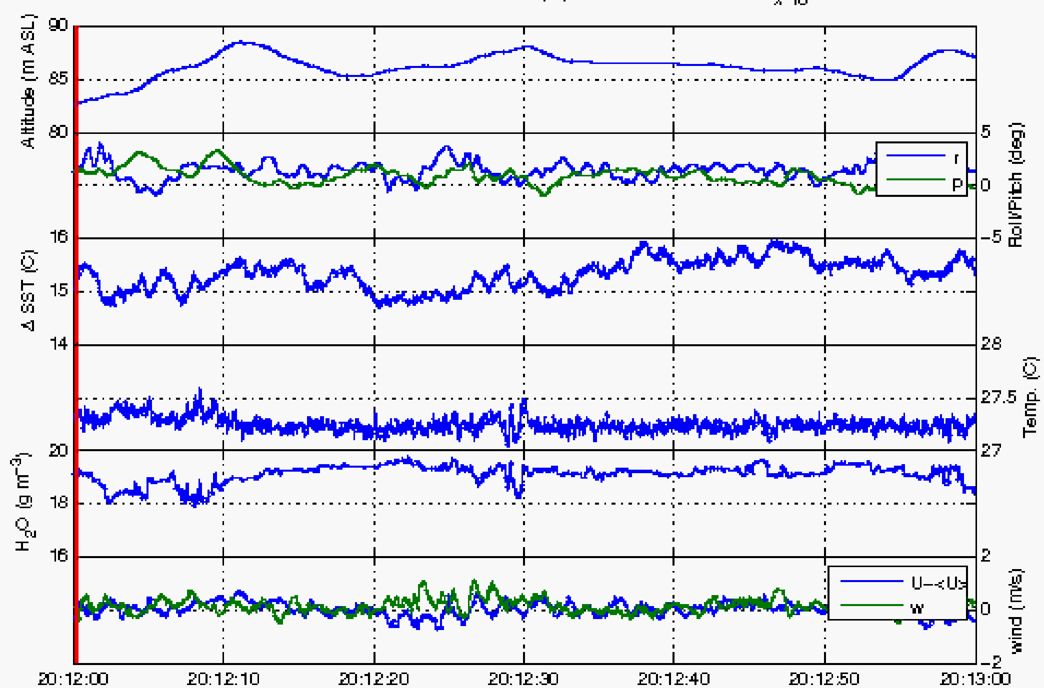
Photograph of X-Band display

ScanEagle NoseCam

IMAGING payload: FLIR A325 LWIR Camera



FLUX data:



Summary and outlook: UAV-based atmospheric, oceanic research

- Developed instrumentation for measurement of **momentum, energy fluxes** within atmospheric boundary layer from UAVs
- Permit coincident remote sensing measurements of surface (imagery, IR, lidar)
- Operational uses (besides surveillance): **improve radar** accuracy (measured M-profiles)

- Advantages over manned aircraft experiments:
  - Introduces ***no significant human risk*** (e.g., low-altitude flights)
  - Long endurance (> 11 hours), pilots easily rotate out
  - No transit times (not limited to coastal waters)
  - Greatly **extend the scientific reach** of a research vessel to 10s to 100s of km around ship laterally, 1000s m vertically
  - Ship-launched: can combine with **simultaneous surface and subsurface ship measurements**

- Accurate in situ air-sea flux measurements essential for **improving flux parameterizations**, which underlie all **satellite-derived products** and **global climate models**

http://airsea.ucsd.edu → "Field Experiments"

Reineman, B. D., L. Lenain, N. M. Statom, W. K. Melville, 2013. Development and testing of instrumentation for UAV-based flux measurements within terrestrial and marine atmospheric boundary layers. *J. Atmos. Oceanic Technol.*, **30**, 1295 – 1319.

Photo composite: San Nguyen