(2017 SCORE Meeting)

Coupled Air Sea Processes and EM Ducting Research (CASPER)

ONR FY2014 Multi-disciplinary University Research Initiative (MURI)

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Meteorology Department
Naval Postgraduate School, Monterey, CA

Outline

- Scientific issues
- Objectives
- Approaches
- CASPER-East
- CASPER-West
- Potential area of accomplishments

EM Propagation and Marine Atmospheric Boundary Layers

Marine Atmosphere

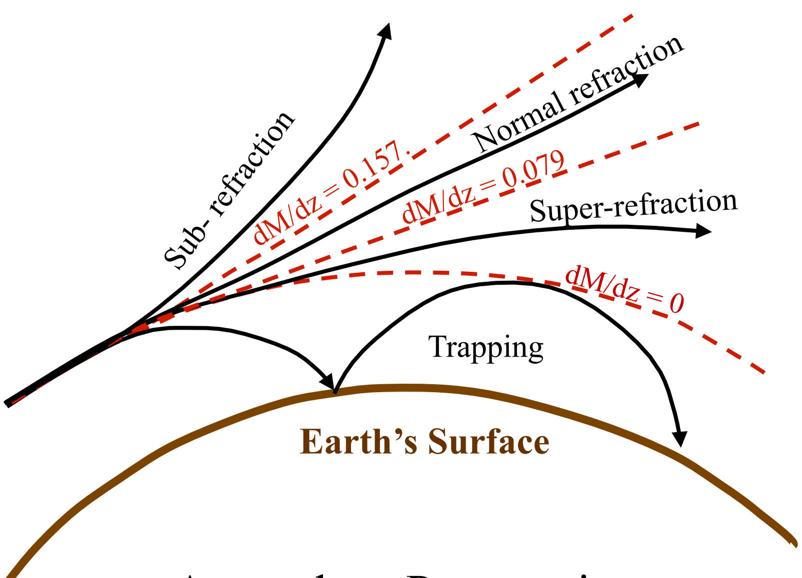
Atmospheric State
(p, e, T)

$$M = \frac{77.6}{T}\left(p + 4810\frac{e}{T}\right) + \frac{z}{R_e} \times 10^6$$

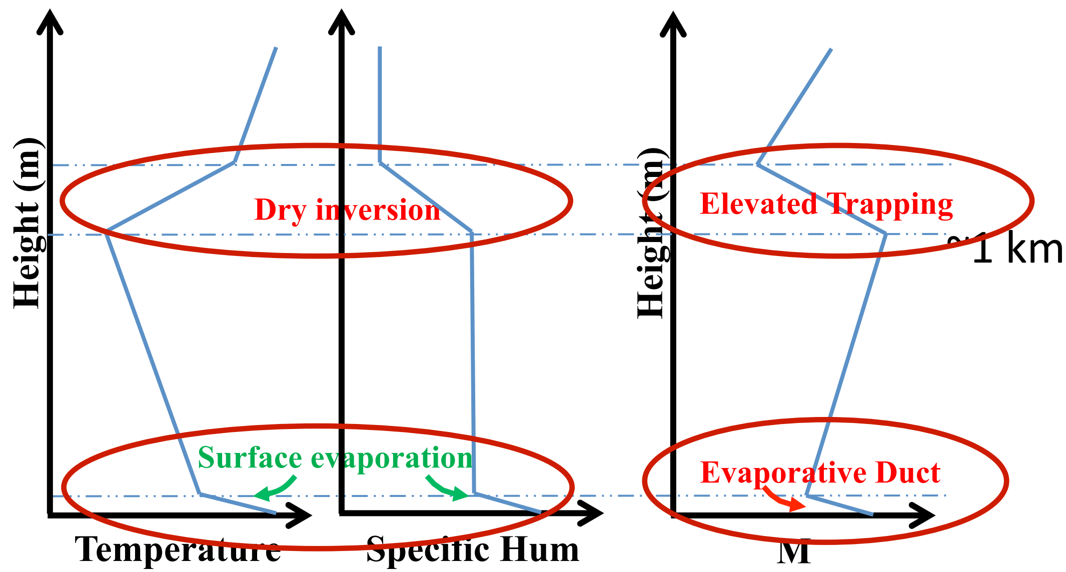
EM Propagation

Modified Refractivity (M)

(Environment variables: Temperature, water vapor pressure, pressure)



Anomalous Propagation

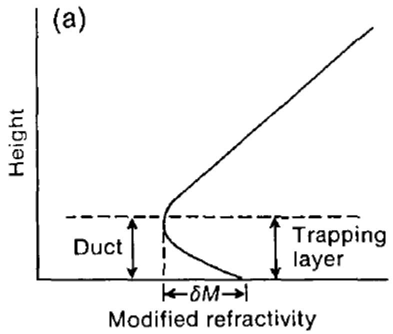


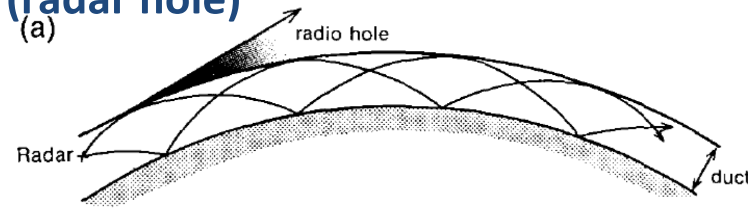
Negative moisture gradient layers result in trapping of EM waves.

Anomalous RF propagation in the atmosphere affects US Navy’s Electromagnetic Maneuver Warfare (EMW)

- Enhanced signal level within the duct
- Reduced signal level above and below the duct (radar hole)

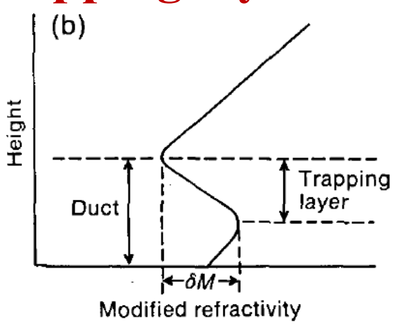
Evaporation Duct:

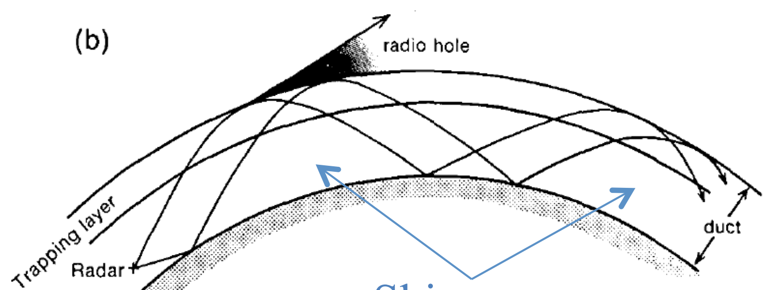




Affecting surface operations

Elevated trapping layer

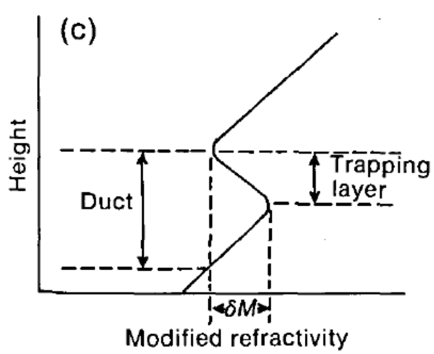


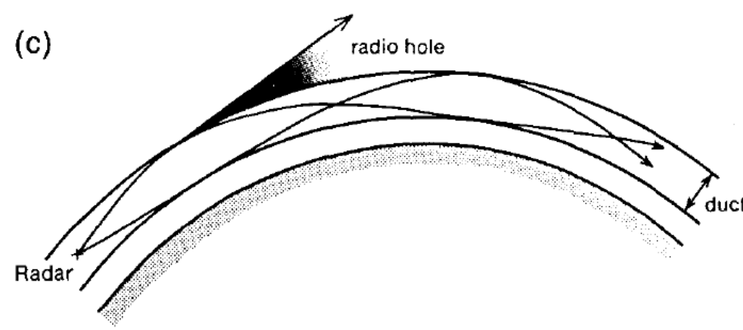


Surface-based duct (SBD)

Skip zones

Affecting low-level flying operations



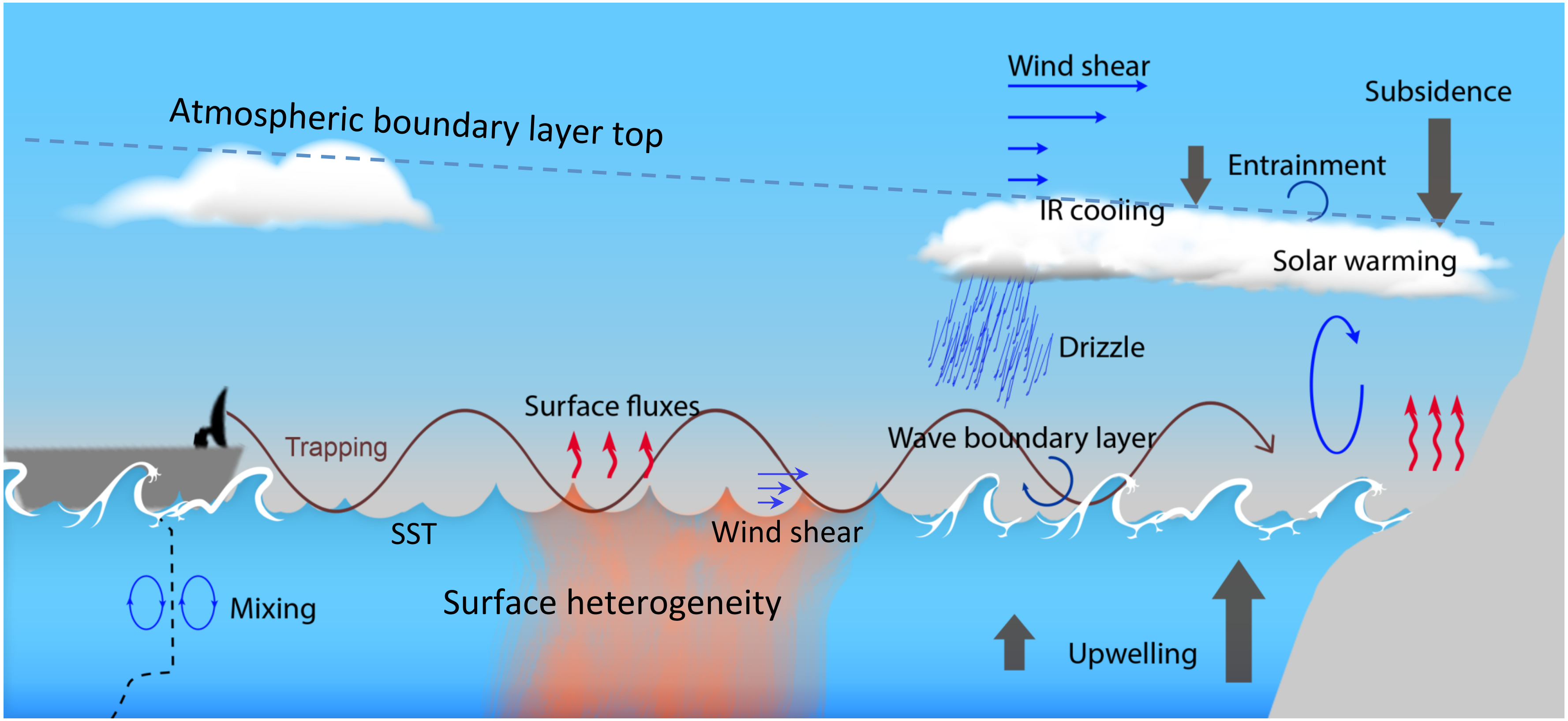


Elevated duct

(Turton et al. 1988)

Evaporation Duct Prediction

- Models are based on Monin-Obukhov Similarity Theory (MOST) that describes the surface layer temperature and humidity profiles in relation to dynamic and thermodynamic forcing.
- Basic assumption of MOST: stationary and homogeneity.
- Empirical relationship used in MOST is derived from land-based measurements.



The marine atmospheric surface layer is never homogeneous!

Challenges in EM Propagation Prediction

- **Clear deficiency in model physics**
  - Land surface results used for marine environment
  - Missing key physical processes: surface inhomogeneity, waves effects
  - Insufficient vertical grid resolution at the cloud level
  - Strictly engineering approach in blending results from the two models
- **Subgrid scale variability** in refractivity is not accounted for
  - Environmental prediction ~ O(1 km)
  - EM propagation: ~O(1 cm or 1 mm)
- Most pressing issue: **LACK OF DATA** adequate for model evaluation and/or improvement
  - Concurrent measurements of refractivity field and EM propagation
  - Near surface over the ocean measurements

CASPER Objectives

- **Data Collection**
  - Obtaining COMPLETE dataset to characterize refractivity field, EM propagation, and physical processes
  - Near surface sampling over the ocean
  - Sampling in different EM propagation environment
- **Better understanding of the surface layer and boundary layer physics**
  - Marine surface layer physics including wave effects
  - Validity of the basic Monin-Obukhov similarity theory in heterogeneous conditions
- **Understanding the effects of subgrid-scale variability of atmospheric refractivity and their impact on EM propagation**
- **Evaluation and improvements of evaporation duct model and mesoscale model for EM application**

CASPER Approaches

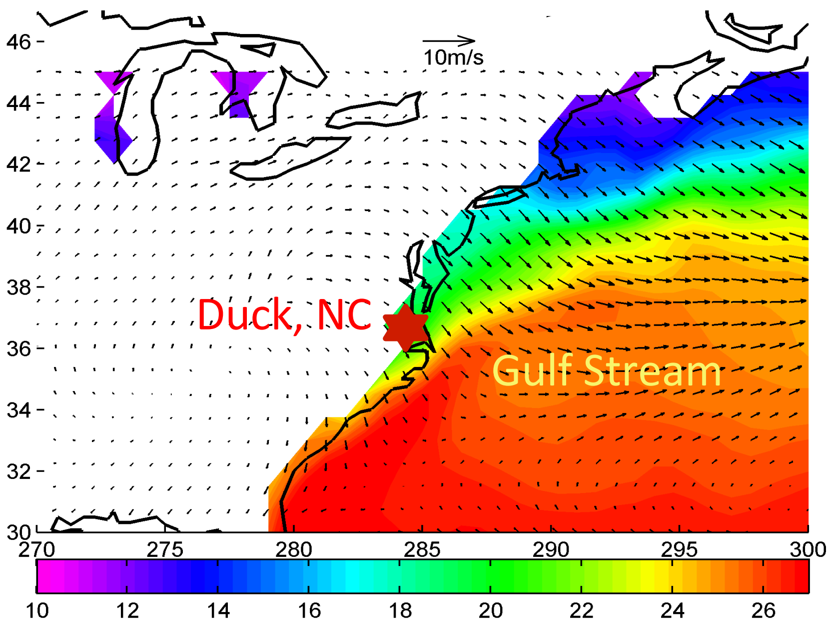
- **Theoretical developments**
  - Explore beyond MOST
  - Identify key scaling parameters
- **Field program**
  - Develop new measurement capabilities targeted for collecting data to address RF propagation science issues.
  - Conduct intensive field campaigns at two representative locations (CASPER East and CASPER West)
- **Modeling efforts**
  - Air-wave-ocean dynamically coupled large eddy simulation (LES) studies
  - 3-D mesoscale and single column model approaches
  - Electromagnetic propagation modeling
- **Collaborating projects**
  - Leverage with related projects

CASPER Field Program

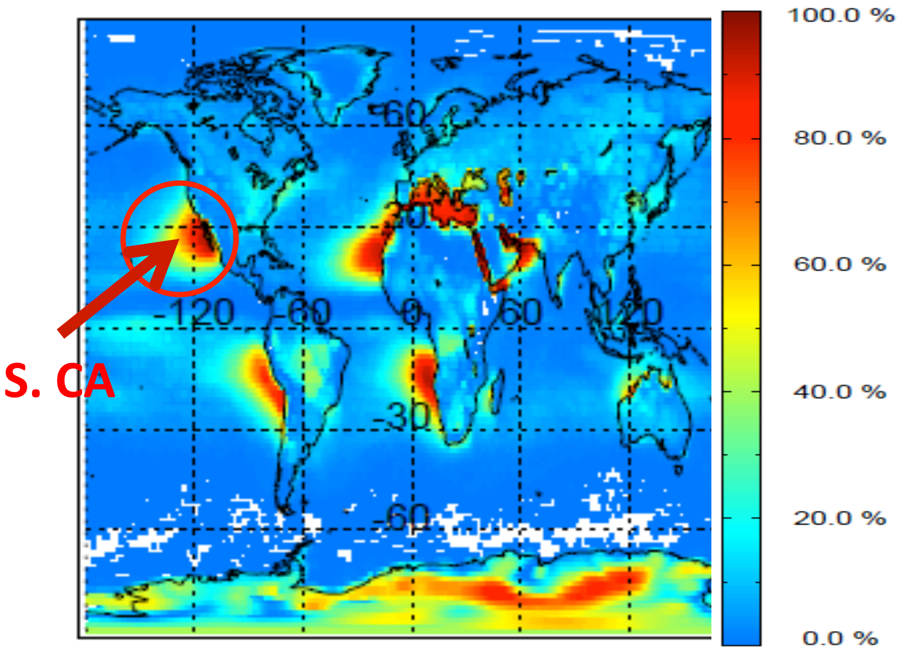
Intensive Observation Periods (IOP):

- CASPER East: Duck, NC, Oct/Nov 2015
- CASPER West: Pt. Mugu Sea Range, CA, Sept/Oct 2017

October Wind and SST

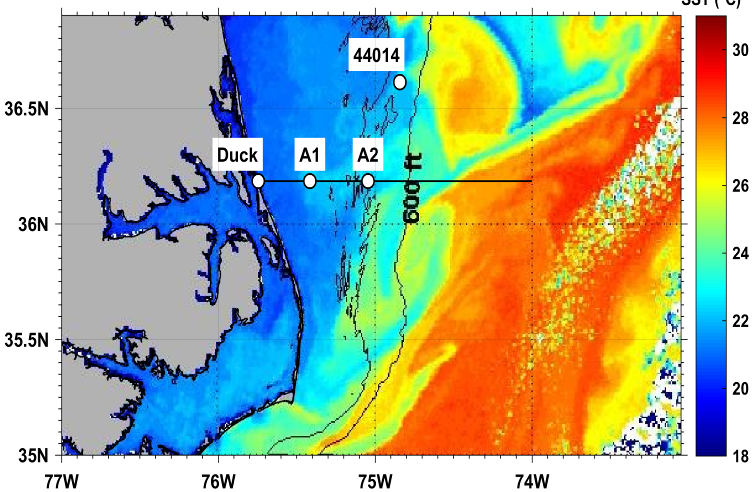


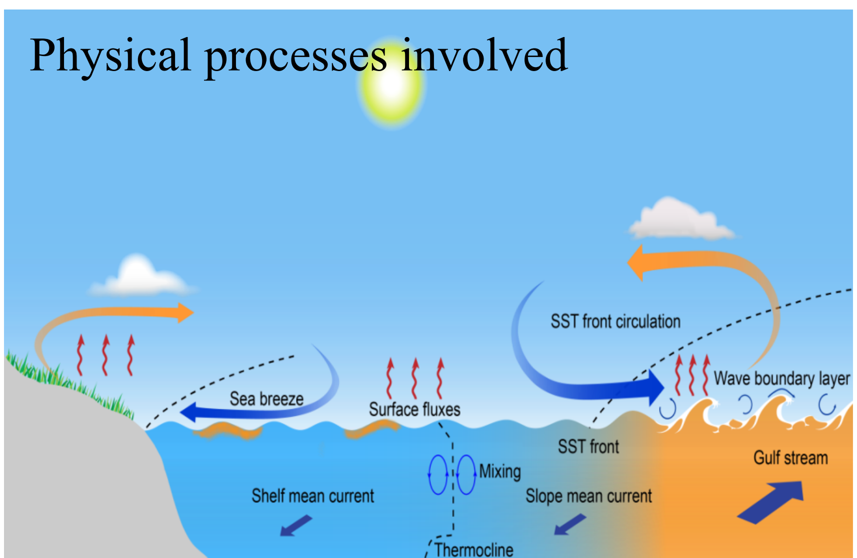
US west coast ducting climatology



CASPER-East:10 October - 6 November 2015, Duck, NC

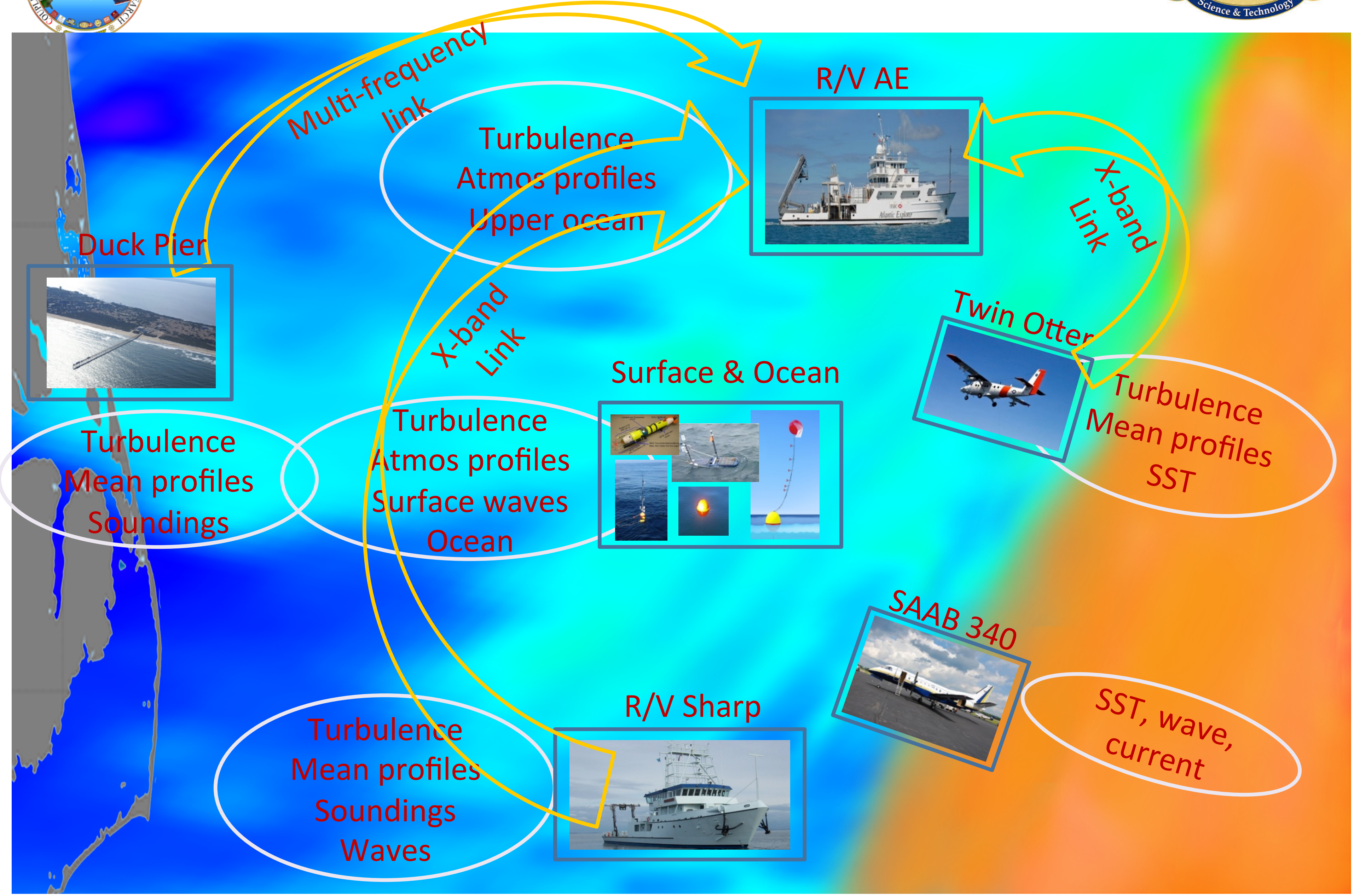
CASPER-Track and SST variability





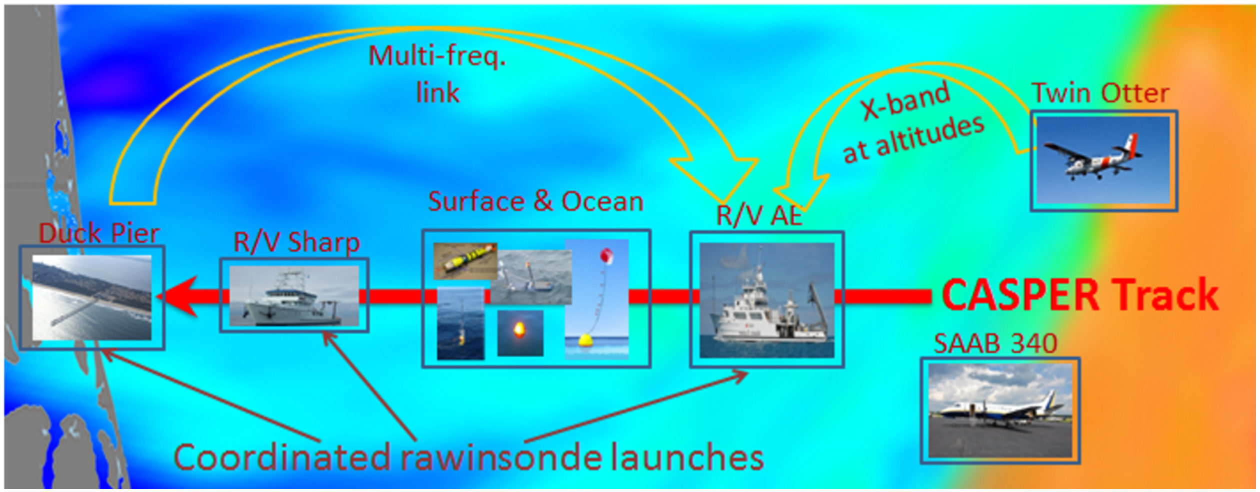
Measurement platforms

CASPER East Measurements

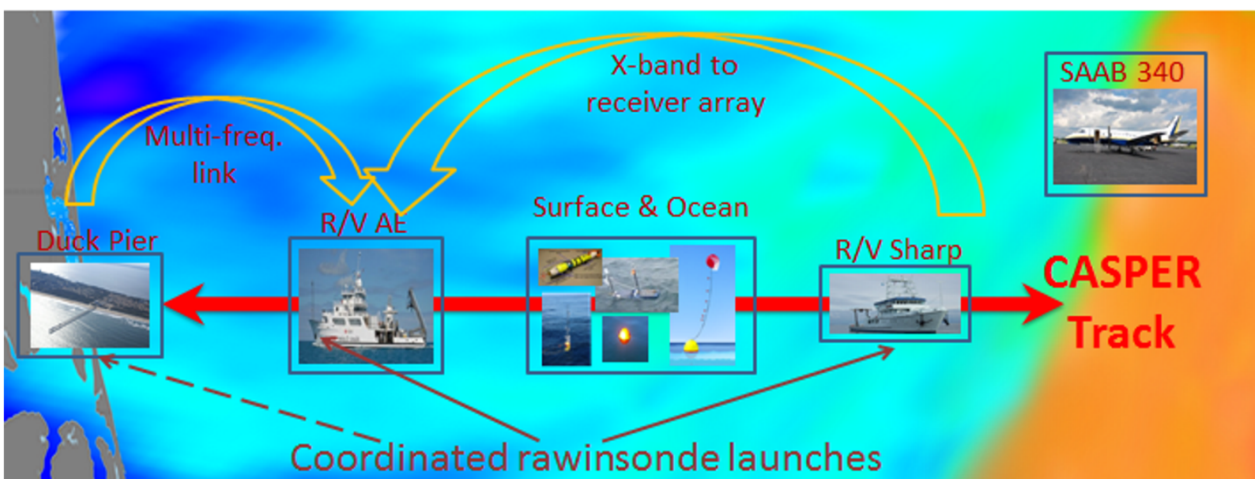


Coordinated EM and Air-Sea Process Measurements

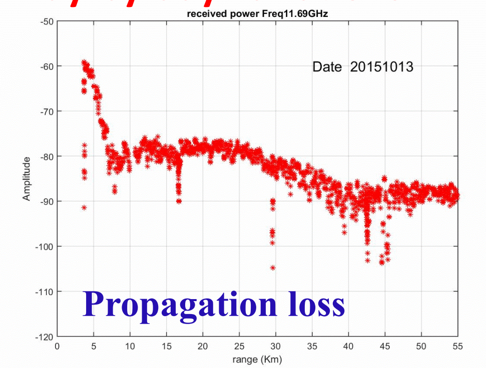
17 Inbound (IBD) range-dependent measurement



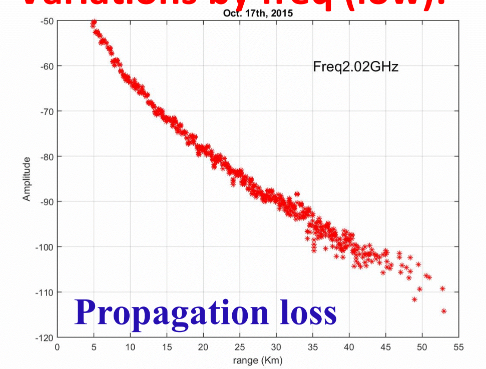
31 ship-ship rapid evolution (SSR):



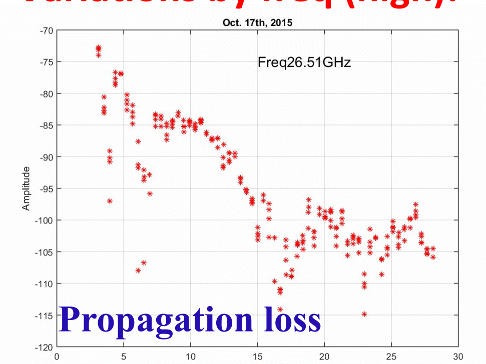
Day-by-day variations:



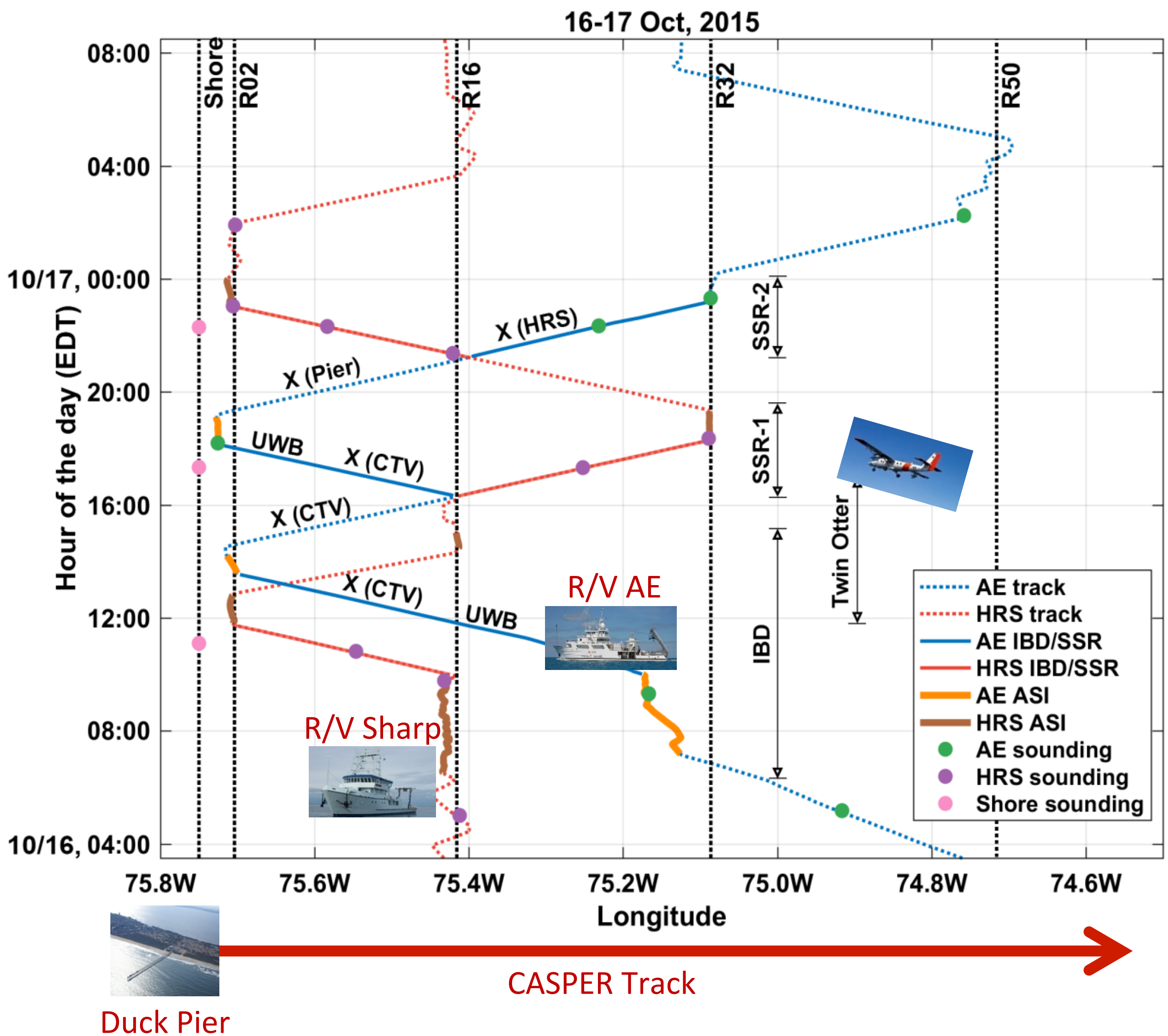
Variations by freq (low):



Variations by freq (high):

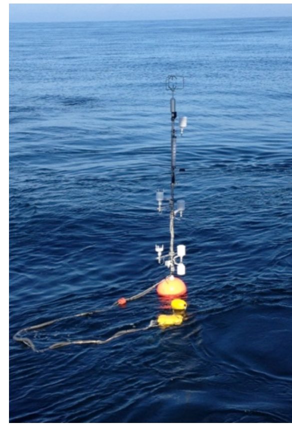


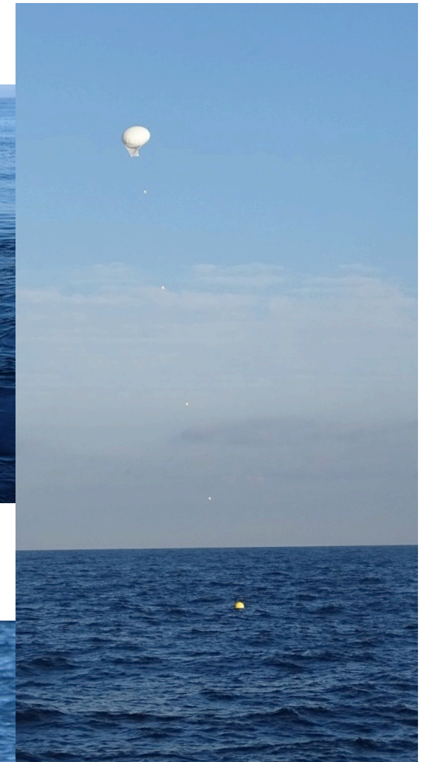
CASPER Coordinated Measurements



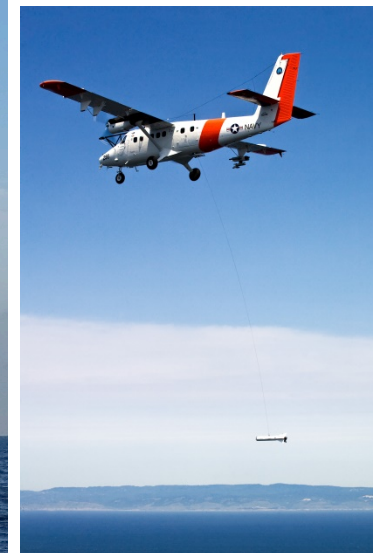
Sampling with New Measurement Capabilities

In situ measurements to quantify evaporative duct properties.

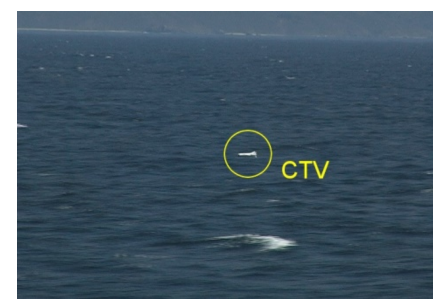




Just after release



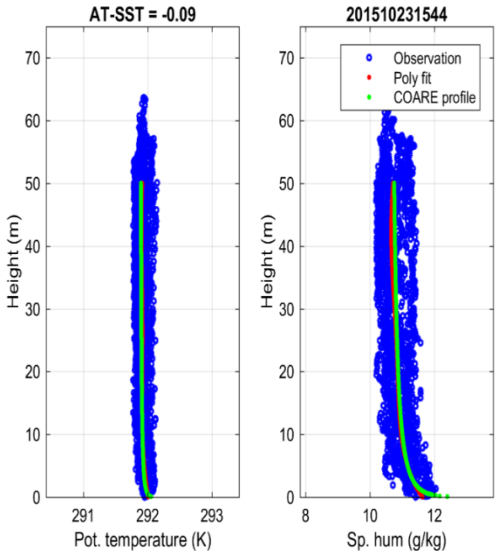
On flux leg at 10 m



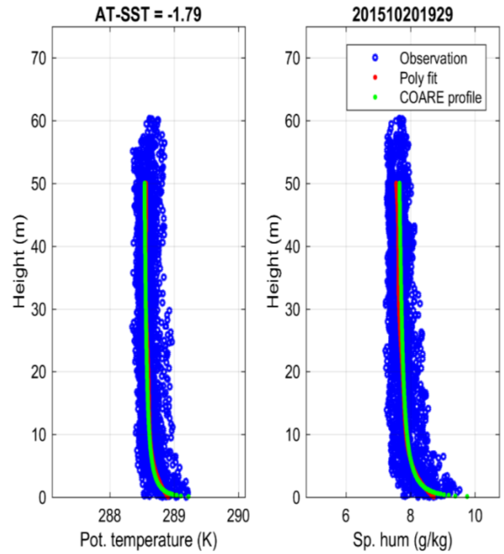
Sampling in undisturbed environment with new measurement capabilities.

When Does MOST Fail? CASPER East Results

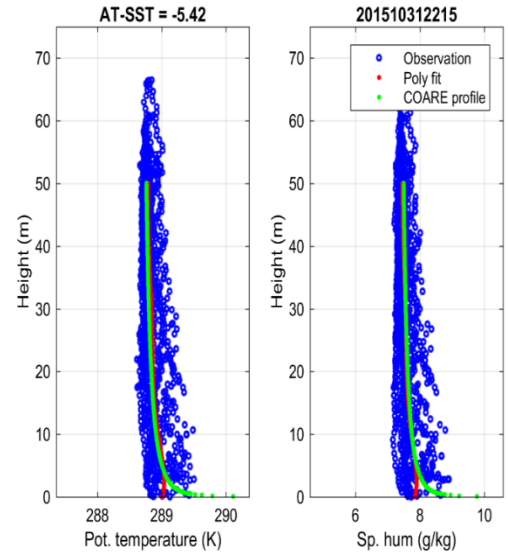
Near neutral



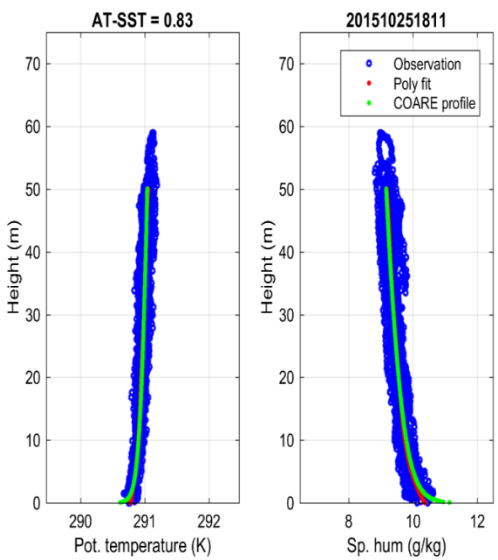
Moderately unstable



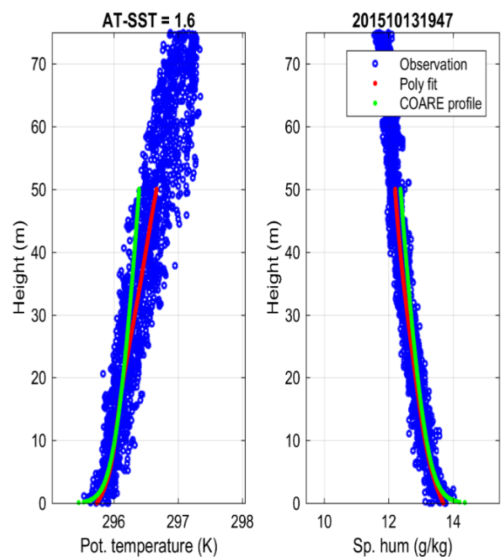
Strongly unstable



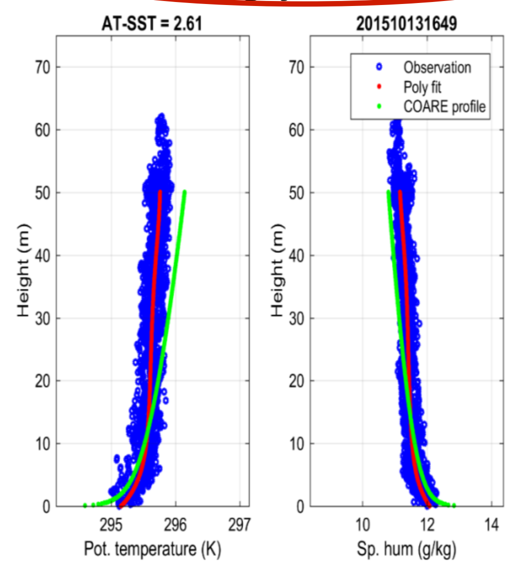
Near neutral



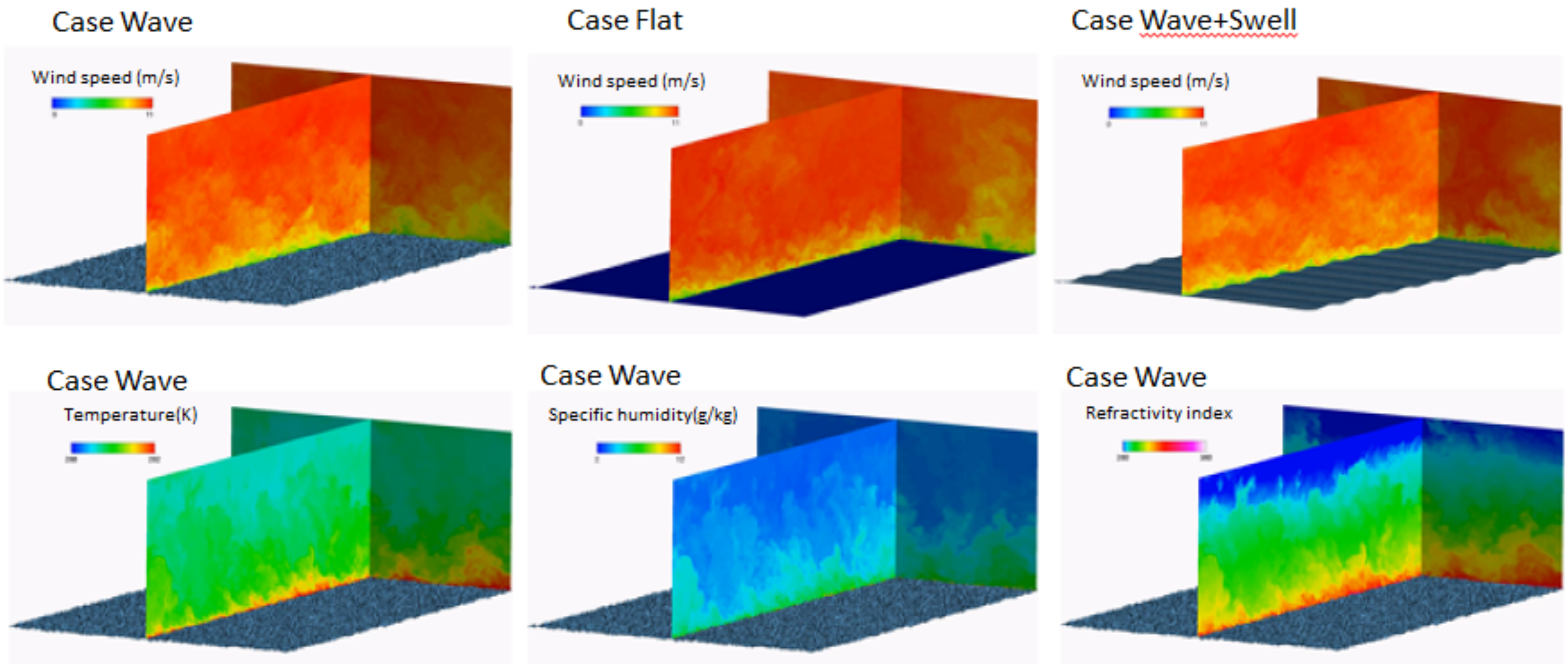
Moderately stable



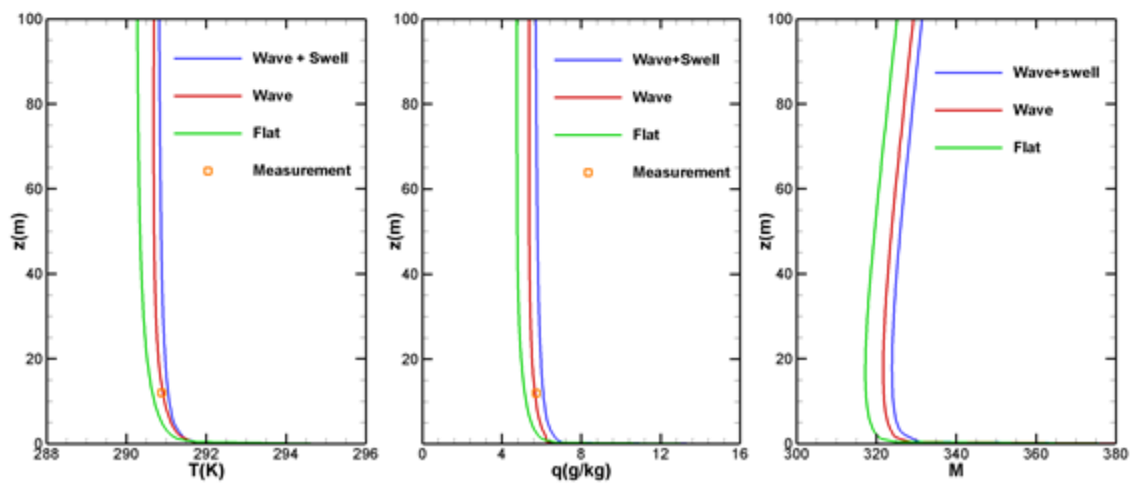
Strongly stable



Large-Eddy Simulation in Open Ocean

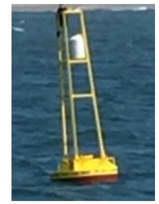


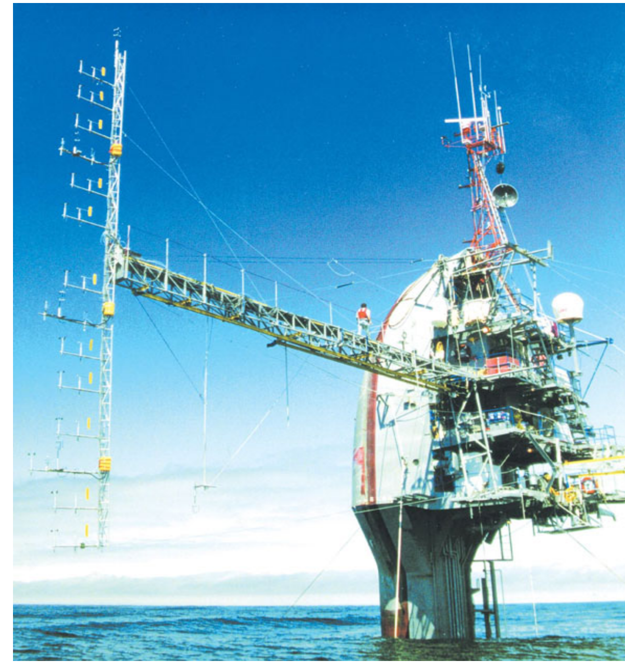
- LES in open ocean on Oct. 17, 2015 for CASPER-East. Convective condition.
- Measurements on bowmast of R/V Sharp used for comparison.
- Case Wave: real waves are used; benchmark.
  Case Flat: sea surface treated as flat, i.e., no wave.
  Case Wave+Swell: waves artificially superimposed with a swell.
- Comparison among the above three cases shows the effects of waves and swell on the profiles of temperature, humidity, and refractivity index.

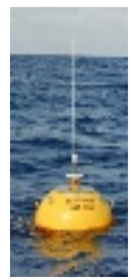


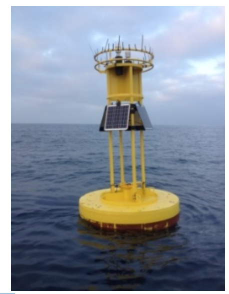
Temperature Specific humidity Modified refractivity index

CASPER-West: 27 Sept - 26 Oct. 2017, Pt. Mugu, CA



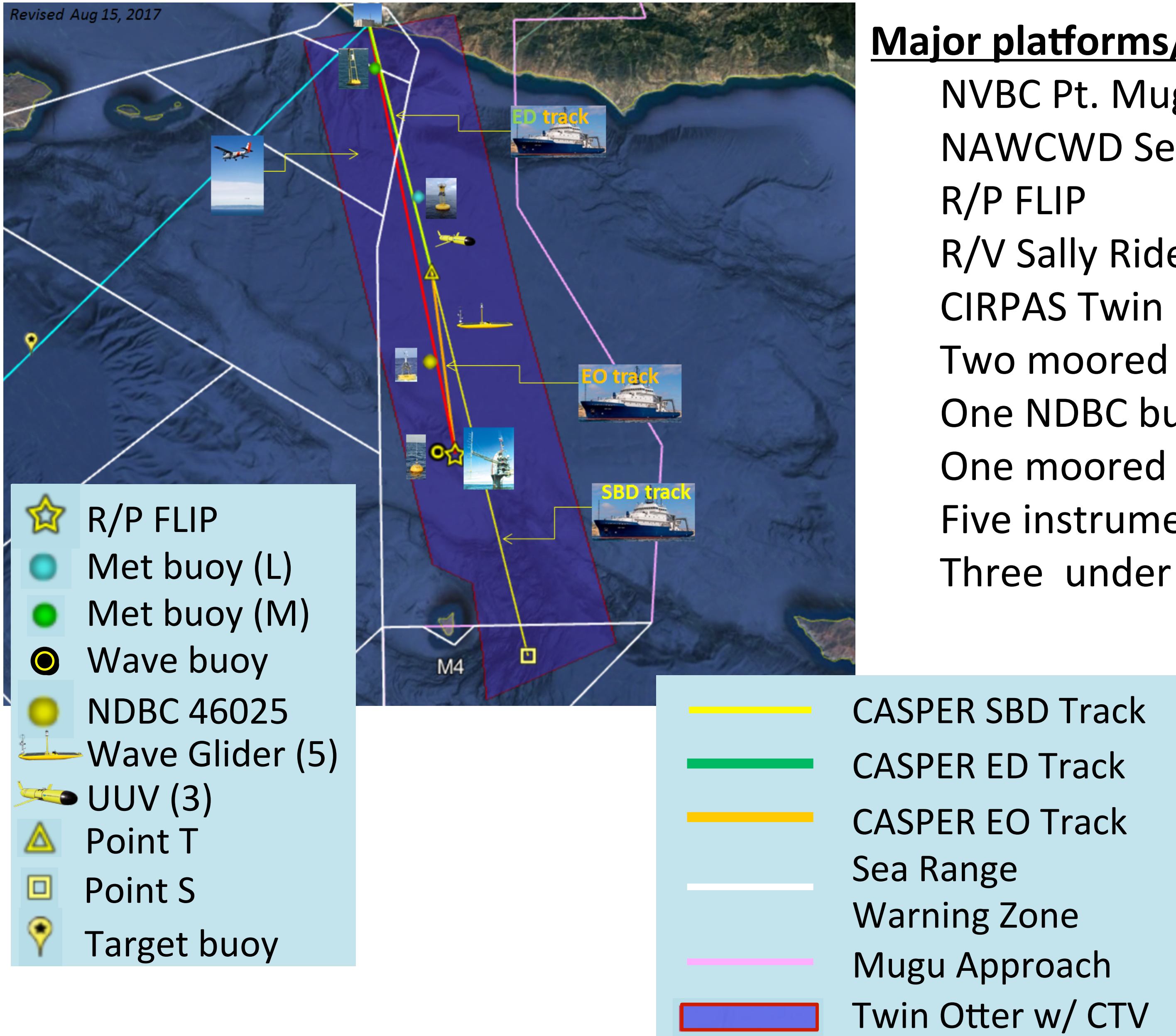






Platforms

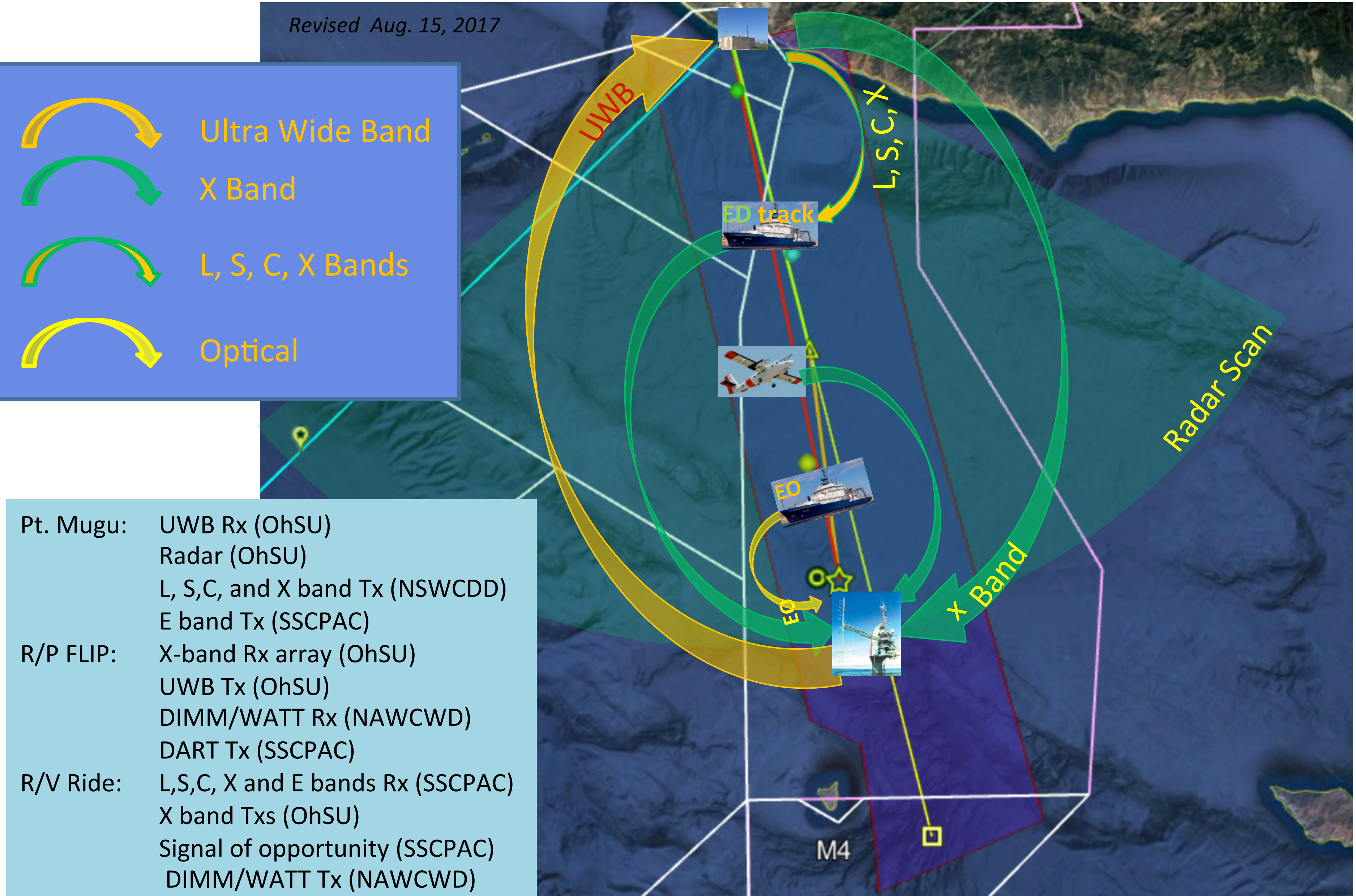
CASPER West, Location and Platform Overview



Major platforms/sites:

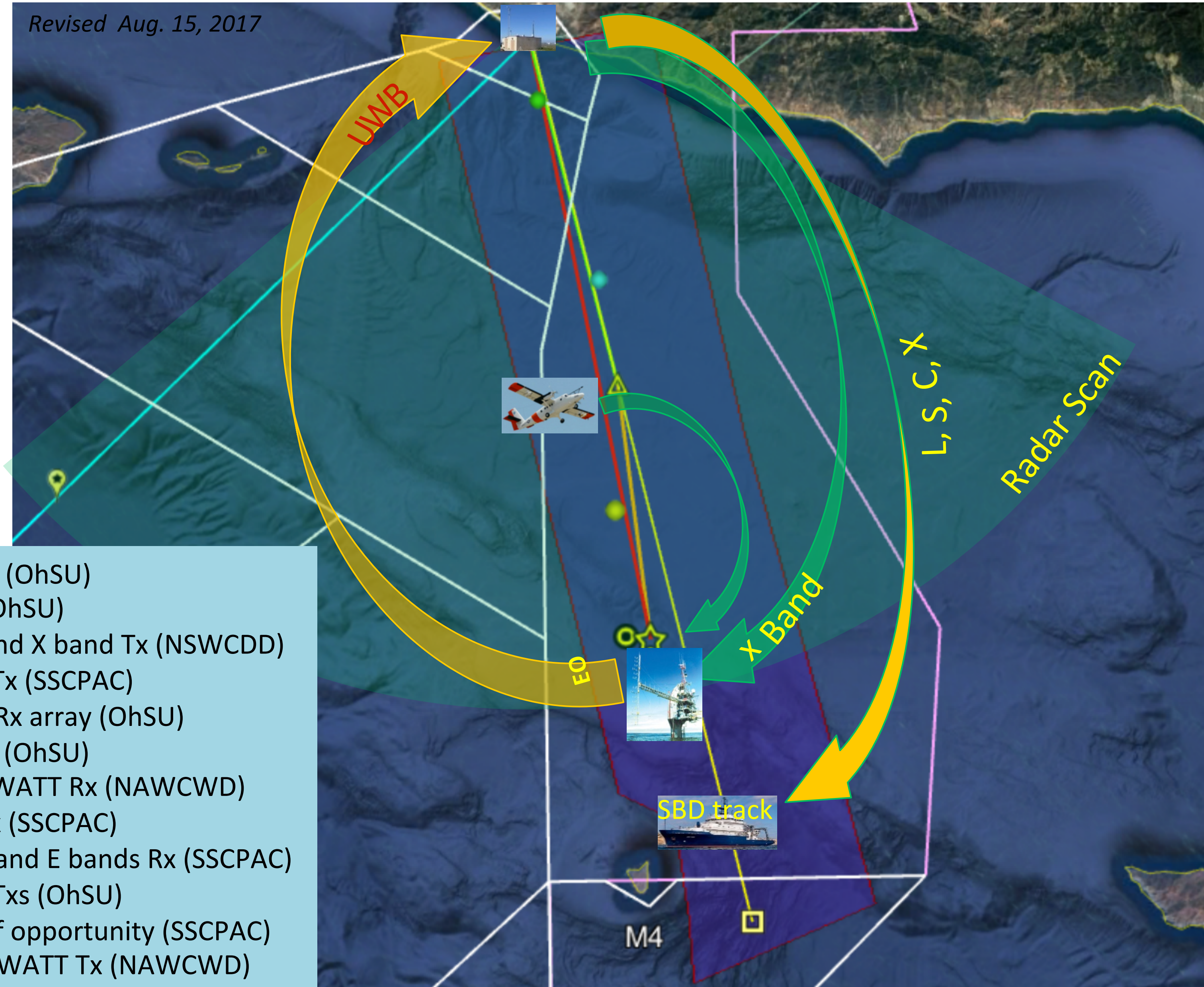
NVBC Pt. Mugu (shore site)
NAWCWD Sea Range
R/P FLIP
R/V Sally Ride
CIRPAS Twin Otter
Two moored met buoys
One NDBC buoy
One moored wave buoy
Five instrumented Wave Gliders
Three under water vehicles (UUV)

Evaporative duct track



Pt. Mugu:	UWB Rx (OhSU)
	Radar (OhSU)
	L, S,C, and X band Tx (NSWCDD)
	E band Tx (SSCPAC)
R/P FLIP:	X-band Rx array (OhSU)
	UWB Tx (OhSU)
	DIMM/WATT Rx (NAWCWD)
	DART Tx (SSCPAC)
R/V Ride:	L,S,C, X and E bands Rx (SSCPAC)
	X band Txs (OhSU)
	Signal of opportunity (SSCPAC)
	DIMM/WATT Tx (NAWCWD)
	DART Rx (SSCPAC)
Twin Otter:	X band Tx (OhSU)

SBD track



Pt. Mugu:	UWB Rx (OhSU)
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	DIMM/WATT Tx (NAWCWD)
	DART Rx (SSCPAC)
Twin Otter:	X band Tx (OhSU)

Multidisciplinary MURI PI Team

- **Qing Wang**, Meteorology, Naval Postgraduate School
- **Bob Burkholder**, Electrical and Computer Engineering, Ohio State Univ.
- **Joe Fernando**, Civil & Environmental Engineering and Geosciences, Univ. of Notre Dame
- **Djamal Khelif**, Mechanical & Aerospace Engineering, Univ. of California, Irvine
- **Kipp Shearman**, College of Earth, Ocean and Atmospheric Sciences, Oregon State Univ.
- **Lian Shen**, Mechanical Engineering, Univ. of Minnesota

Other Participants:

Senior researcher and associates: 12

Technical Staff: 14

Post docs: 7

Graduate Students : 16 PhD, 9 MS (Total 25)

Undergraduate Students: 11

Collaborators

- **DOD and government collaborators**
  - Ted Rogers (SSCPAC): RF measurements and field experiment design
  - Kate Horgan (NSWCDD): RF emitter and sounding measurements
  - Tracy Haack/Teddy Holt (NRLMRY): Navy's mesoscale model for RF propagation
  - Ivan Savelyev (NRLDC): Upper ocean dynamics and SST
  - Rick Allard (NRL Stennis): ocean wave modeling
  - Paul Fredrickson (NPS): Operational evaporative duct model
  - Qingfang Jiang (NRLMRY): Large eddy simulations with wave effects
  - Ed Creegan (ARL): LIDAR and tethered balloon observations of the lower atmosphere
  - Chris Fairall (NOAA, ETL): ship-based flux measurements

- **University collaborators**
  - Eric Terrill/Tony De Paolo (Scripps/U San Diego): surface wave characterization
  - Tom Hanley (John Hopkins U/APL): RF and meteorological measurements from shore and from small boat
  - Dana Savige (Skidway): bottom mounted ocean current monitoring
  - Erin Hackett (Coastal Carolina University): Alternative approach for evaporation duct modeling
  - Brian Haus (U Miami, potential): water tank measurements of evaporation duct

Future Plan

- **Extensive data analyses with CASPER East and CASPER pilot data**
  - **Individual PI publications**
  - **Collaborative analyses and publications, particularly collaborations among researchers in different disciplinary area.**
- **CASPER West (Sept 24 – Oct 26, 2017)**
  - **Improvements in measurement strategy build upon previous field work**
  - **Elevated ducting layer**
  - **Wave/swell field effect**
- **Close collaboration between modeling and measurement efforts**

- **Providing data to collaborating researchers to help accelerate the transition from basic to applied research.**

Summary: Potential Breakthroughs

- **Large amount of unique and coordinated data for model evaluation and development**
  - First time of directly measured evaporation duct properties
  - Data collection designed for model evaluation and development
  - Repeated measurements with certain control variables (e.g., location, time)
  - Repeated measurements of range-dependent RF propagation loss at different altitude and frequencies
- **New insight to surface layer theory**
  - Surface layer flux profile relationship in marine environment, few previous studies
  - Effects of surface wave on the surface layer profiles and its parameterization
  - Validity and remedy of surface layer theory in heterogeneous conditions
  - Surface layer profile-flux relationship in cases of waves and strong currents in the Gulf Stream
- **New modeling approaches**
  - Dynamically coupled LES provides insights on wave and surface layer interaction
  - Physics-based evaporation duct and upper air profile blending scheme
- **Data sharing with collaborators on applied research may accelerate the transition from basic to applied research.**