Verification and Inter-comparison of Mesoscale Models in the Coastal Marine Atmospheric Boundary Layer

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1. Abstract

Numerical Weather Prediction (NWP) models forecast atmospheric conditions by modeling physical interactions in the environment. In near-coastal regions, it is imperative that the U.S. Navy and Marine Corps understand and predict atmospheric boundary layer (ABL) interactions for planning and operations. A recently completed investigation sponsored by the Office of Naval Research (ONR) seeks to better understand the model performance and representation of physical processes in the ABL. This research includes comparison of the U.S. Navy's Coupled Ocean/Atmosphere Prediction System (COAMPS®) (Hodur 1997) which uses a Level 2.5 Mellor Yamada-based ABL scheme and the Unified Model (UM) of the U.K. Met Office (UKMO) which uses the Lock ABL scheme (Lock 2000). To evaluate model performance, we used observation data from a 2022 field campaign of the Coastal Land-Air-Sea Interaction (CLASI) (Haus et al. (2022)) ONR Departmental Research Initiative (DRI). The observation set is principally gathered from buoys in the northern Monterey Bay in late summer 2022. Through verification and model inter-comparison, we quantified model performance in forecasting various ABL fields, as well as differences and trends in model representation of the ABL.

2. Model Configuration and Fields

A version of COAMPS approved for use in 2020 was used for all COAMPS simulations. Investigators simulated the CLASI 2022 campaign period with three different sources of initial and boundary conditions. These runs are referred to collectively as 'C20*'. The UKMO provided an additional simulation of the period using a high-resolution configuration of the UM.

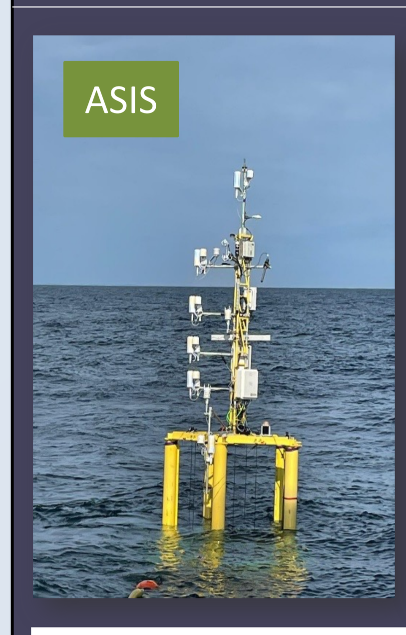
- **C20_NAVGEM** – COAMPS using NAVGEM
- **C20_GFS** – COAMPS using GFS
- **C20_UM** – COAMPS using UM global fields
- **UM** – UM, UKV configuration (1.5 km grid increment size)

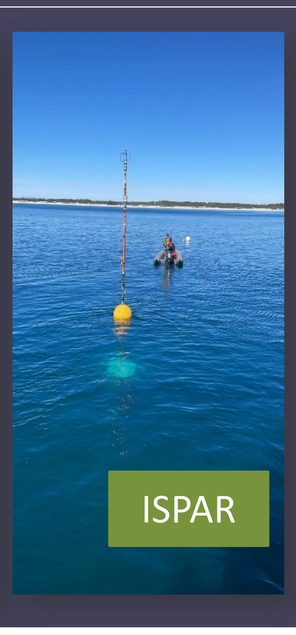
Numerical configuration for C20* simulations

- Initializations completed using Naval Research Laboratory's Atmospheric Variational Data Assimilation System (NAVDAS)
- One-way nested grid sizes were 40.5, 13.5, 4.5, and 1.5 km
- Single daily analysis at 0000 UTC
- Three discrete periods over 10 non-consecutive days with "cold starts" at the beginning of each period
  - 22 to 26 August 2022
  - 28 to 29 August 2022
  - 31 August to 02 September 2022
- Model output forecast hours 1 through 24 were used in time-series analyses

Fields of Interest: Air and Surface Temperature, Air-Sea Temperature Difference, Wind Speed, ABL Height, Cloud Base Height, Surface Turbulent Flux

3. Observations





Buoys were mainly clustered in the Santa Cruz Harbor and surrounding area. ISPAR are generally closer to the coast while ASIS were more than 1 km from the coast.

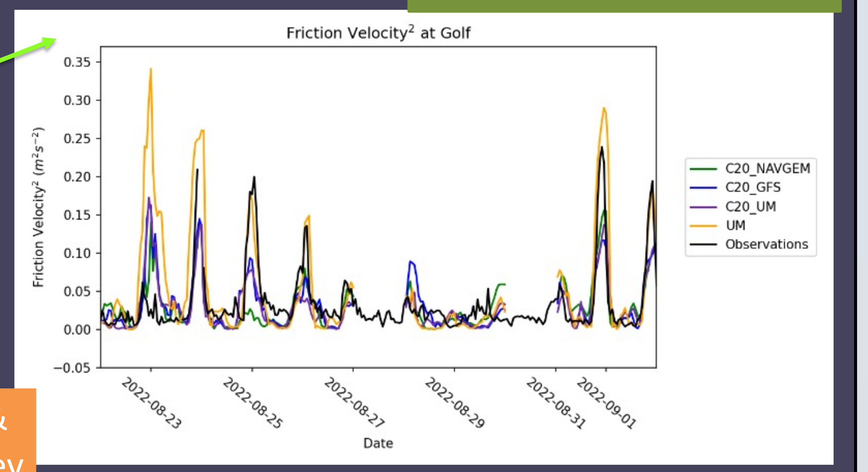
Photographs of an Air-Sea Interaction SPAR (ASIS) buoy (far left) and an Inner Shelf Spar (ISPAR) buoy (second from left) deployed over the Gulf of Mexico during a DRI CLASI Experiment in 2023. ASIS photo credit: Dr. Hans Graber, U. Miami; ISPAR photo credit: LCDR Charlotte Benbow, the Naval Postgraduate School.

4. Time-Series Analysis

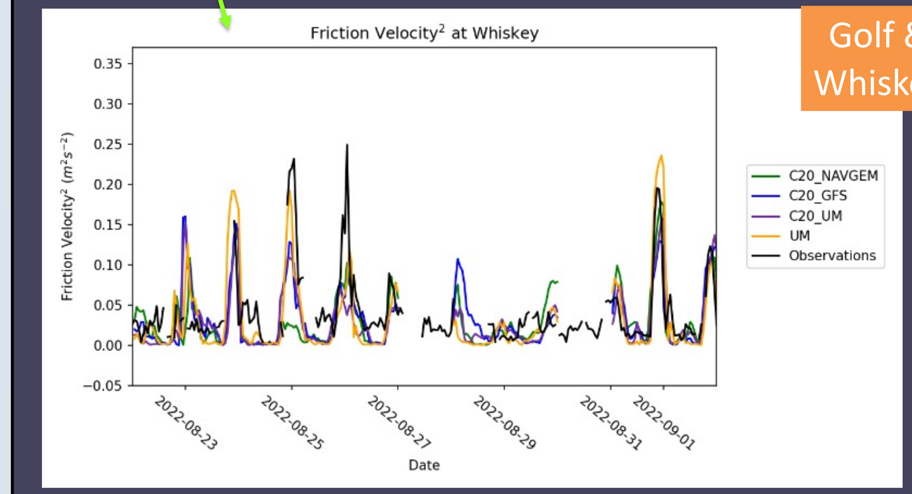
Time-Series analysis, as well as bias and root-mean-square error (RMSE) statistics were performed for each buoy location for model verification

Kinematic Wind Stress

Golf → located ~ 1 km offshore, just over 1 km west of Santa Cruz
Whiskey → located > 1 km offshore, south of Santa Cruz



Golf & Whiskey



- Nearest neighbor approximations were used to compare model and observation data
- These analyses show how models perform based on location and time of day
- Models struggle noticeably with kinematic wind stress in the afternoons

5 m Air Temperature

	C20_NAV (°C)	C20_GFS (°C)	C20_UM (°C)	UM (°C)	# of OBS
Bias	-0.29	-0.25	-0.14	0.05	2670.0
RMSE	1.71	1.83	1.7	1.22	2670.0

Statistics (Bias and RMSE)
- At each buoy (ASIS and ISPAR)
- At all ISPAR buoys (not shown)
- At all ASIS buoys (not shown)
- For each model

- Statistics above compare each observation at every ASIS and ISPAR buoy
- All C20* demonstrated a cold bias, UM has very slight warm bias
- RMSE shows UM is more accurate predicting 5 m air temperature than C20*

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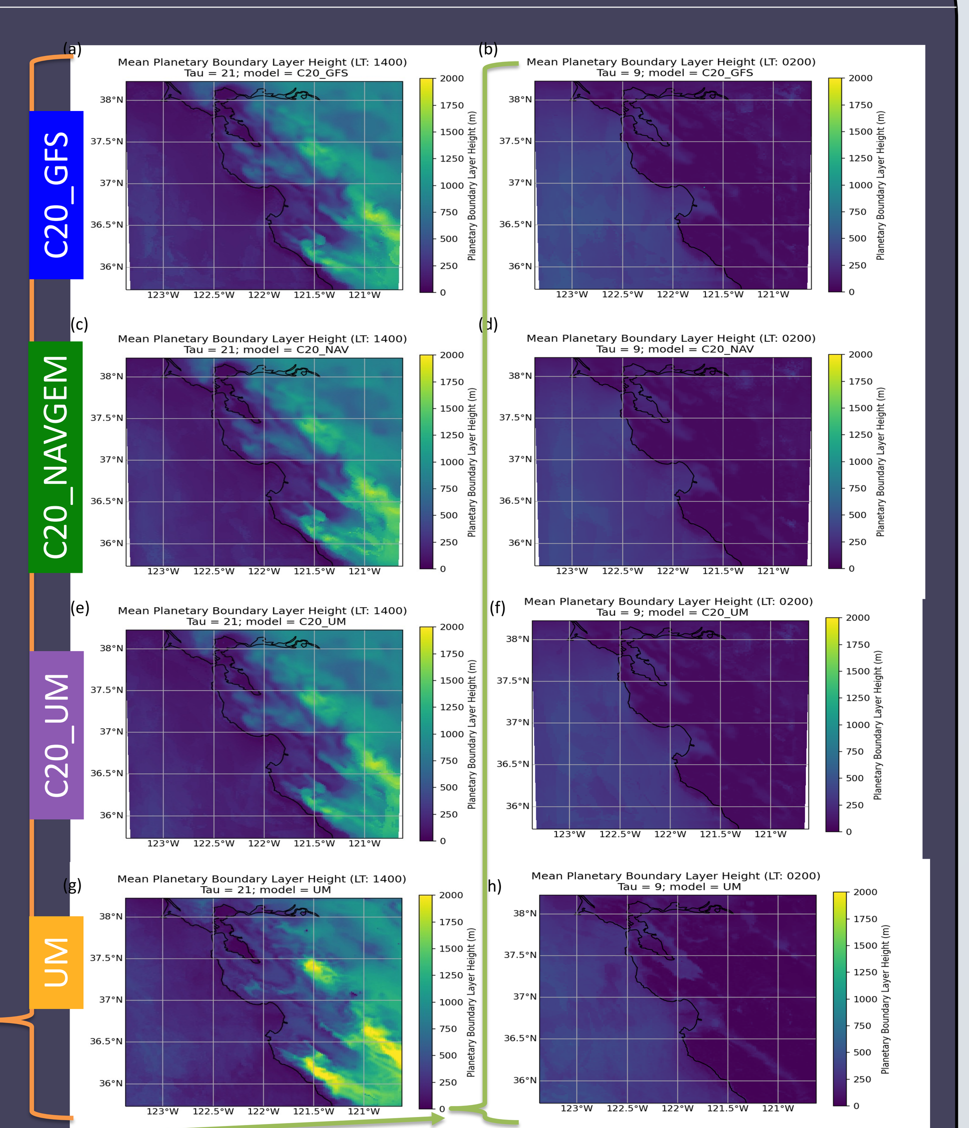
5. Model Field Inter-comparison

- C20* simulations show a shallower ABL along the coast, but sharp, step-like changes at higher elevations
- UM simulation shows a finer horizontal gradient associated with changing terrain height
- Model differences may be driven by land surface representation and corresponding surface flux over land

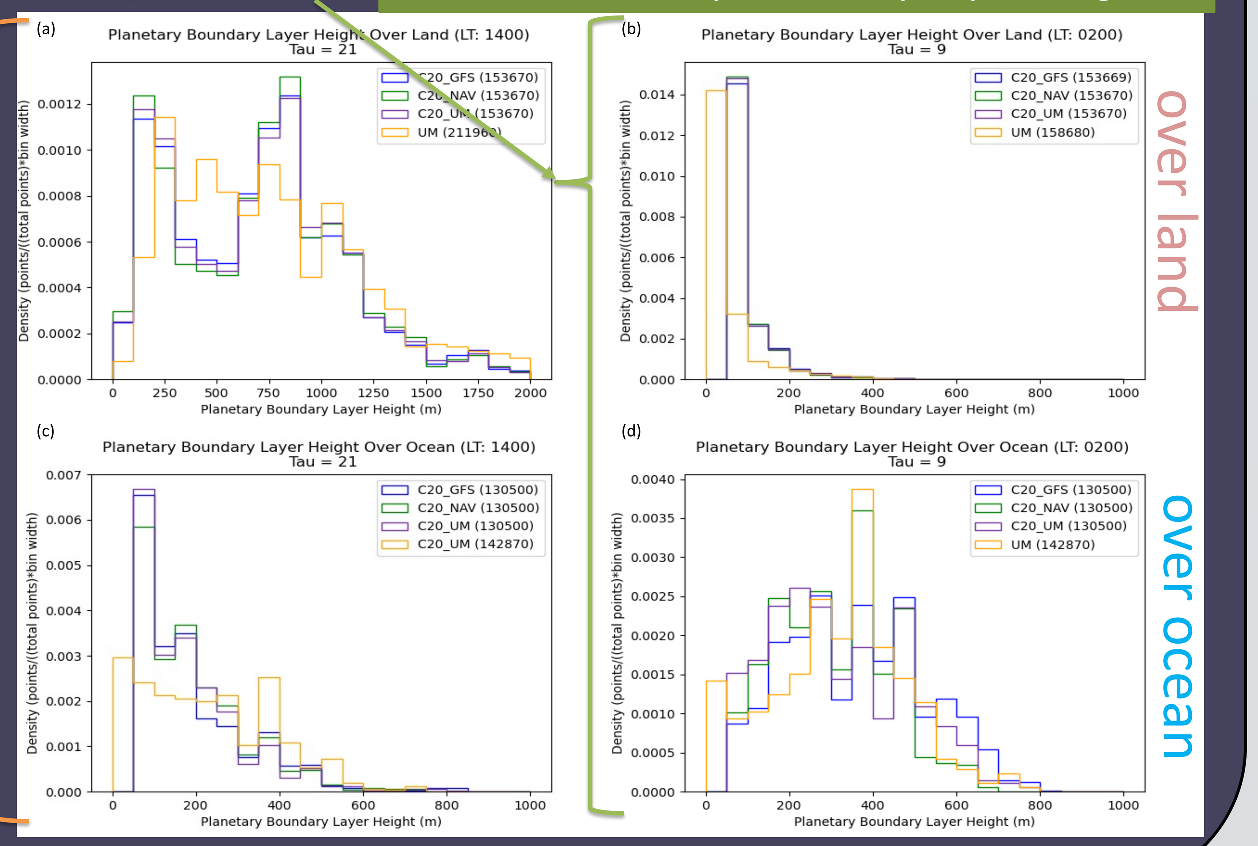


daytime

nighttime

Mean Planetary Boundary Layer Height

Figures show an average of all data from each observation day at specific forecast lead times (tau) (tau = 21 → LT 1400, tau = 9 → LT 0200) for all land points (top) and all ocean points (bottom)



over land

over ocean

6. Conclusions

1. **Air Temperature** – Low model bias from all simulations, some elevated RMSE scores from C20* simulations due in part to differences in the littoral zone
2. **Moisture** - UM is slightly drier over land during daytime and drier over both land and water overnight than C20* simulations
3. **Wind Speed** - UM shows weaker wind speeds than C20* over land, possibly due in part to differences in drag representation in the momentum roughness length parameterizations
4. **ABL Height** – Differences in the resolution of land surface representation between COAMPS and UM likely contribute to differences in areas of sharp change in surface cover
5. **Cloud Base Height** – C20* simulations yielded more frequent and abundant cloud cover (mostly stratocumulus) over the ocean, with cloud base heights typically 100-150 m AGL, versus 200 to 300 m AGL from UM during the night and 500 m AGL during the day
6. **Surface Turbulent Flux** – C20* and UM are generally comparable over land during the day. C20* simulations have differences over the ocean at night, possibly due to variations in low cloud cover across simulations.

References

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