Wind field measurements and WRF model simulations of the PBL over Long Island Sound during the 2018 LISTOS campaign

JOHN E. MAK[1,3]
KEENAN R. FRYER[1], BRIAN A. COLLE[1], ALICIA MULLALEY[2]

1. *School of Marine and Atmospheric Sciences, Stony Brook Univ., Stony Brook, New York*
2. *Dept. of Chemisty and Biochemistry, Manhattan College, Bronx, New York*
3. *UltraPure Air, LLC*

This project supported by NESCAUM

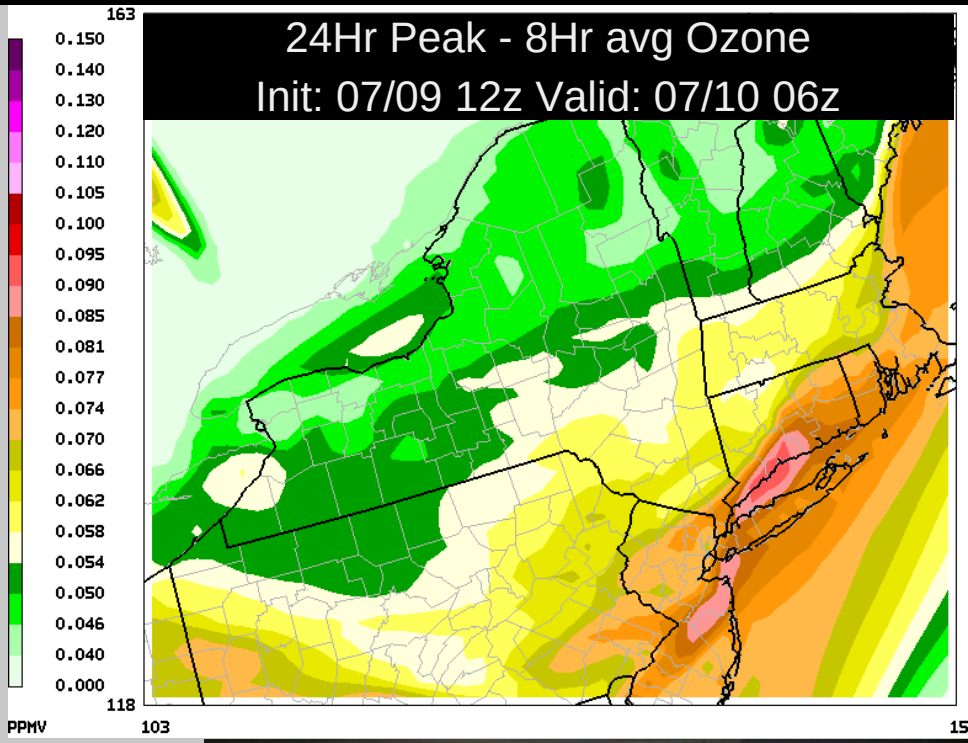
We thank NESCAUM for supporting this work!

Research Questions

- What are the kinetic and thermodynamic characteristics of the boundary layer above Long Island, Connecticut, and the adjacent coastal waters during high ozone events?
- How does the boundary layer then evolve during high ozone events?
- How well can a small ensemble of WRF runs employing different PBL schemes represent this boundary layer structure and evolution?

LISTOS 2018

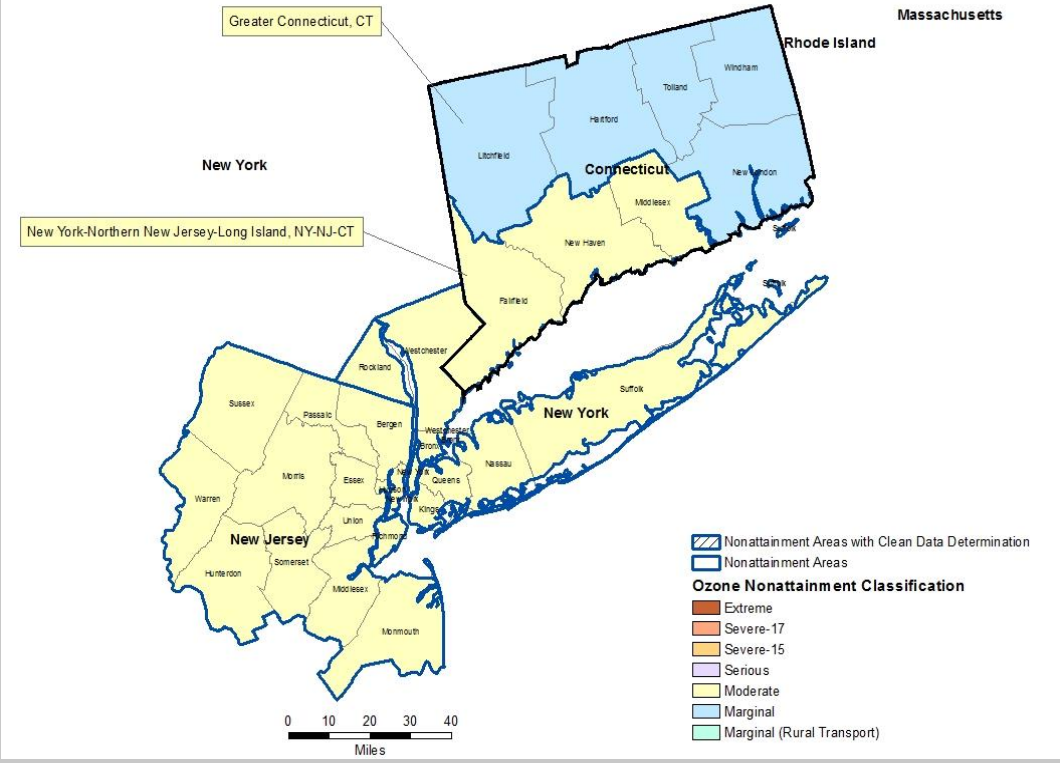
- Research aircraft fitted with Aventech AIMMS-20 (aircraft integrated meteorological measurement system) measures 3-D wind vector at 20 Hz, T at 1 Hz and RH at 0.5 Hz
- 14 observation flights from June 30 to Jul 28 2018
- Supplemental data: O_3 (2B technologies), CO_2 (Licor 6252)



Background and Motivation

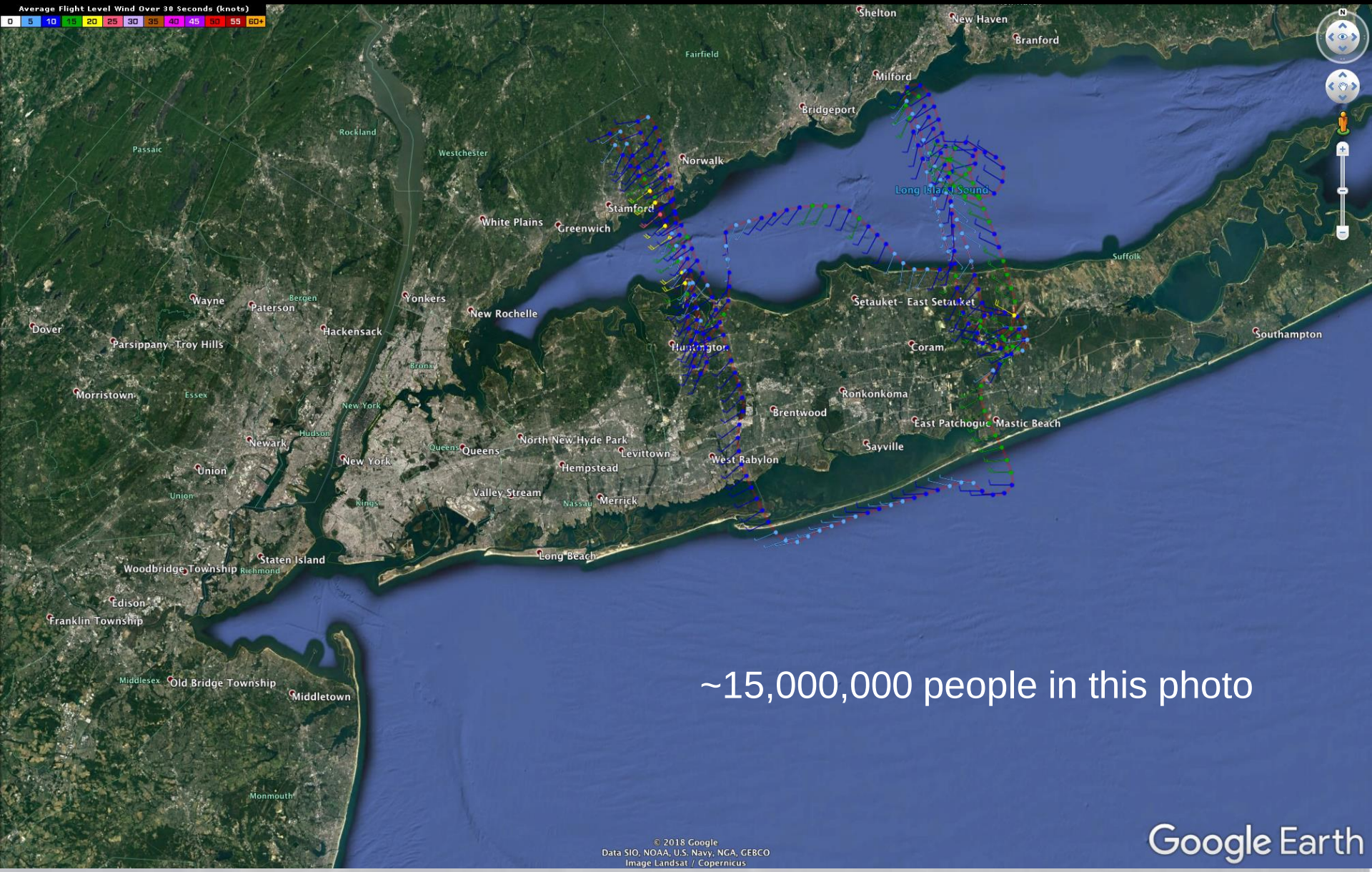
- Surface ozone over LI, CT, and NY metro frequently exceed NAAQS levels for humans.
- Amplification of these plumes due to complex interplay of over-land and marine boundary layer dynamics is not well understood.

8Hr Non-attainment Areas in LI and CT



- Two case-study days for this talk (Jul 9 and 10) are chosen due to the extremely high ozone levels predicted and observed over LIS as well as the presence of a lower level jet (LLJ).
- WRF simulations have been shown to struggle with low level coastal winds (Colle et al. 2016).

LISTOS 2018

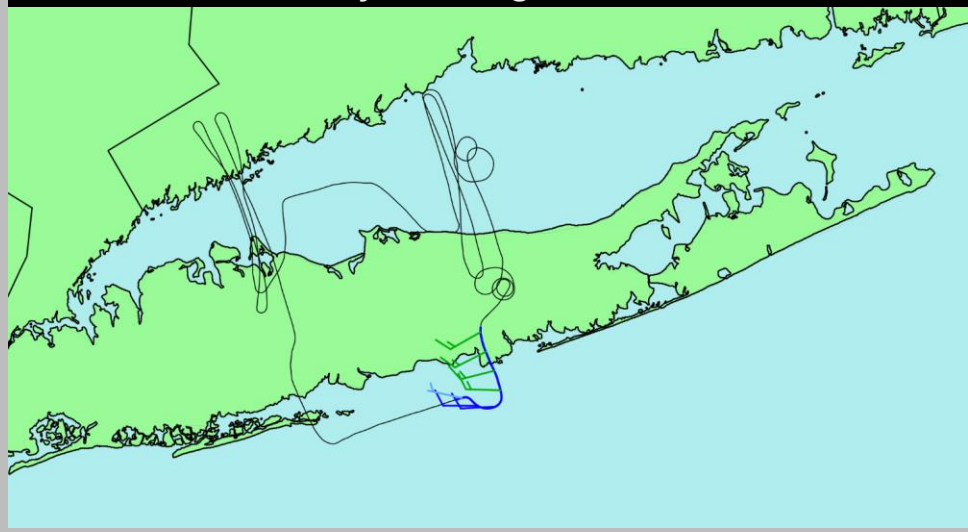

Average Flight Level Wind Over 30 Seconds (knots)
0 5 10 15 20 25 30 35 40 45 50 55 60+
Shelton
New Haven
Branford
Fairfield
Milford
Bridgeport
Rockland
Passaic
Westchester
Norwalk
Long Island Sound
Stamford
White Plains
Greenwich
Suffolk
Wayne
Paterson
Bergen
Yonkers
New Rochelle
Setauket- East Setauket
Dover
Parsippany-Troy Hills
Hackensack
Huntington
Coram
Southampton
Bronx
Morristown
Essex
New York
Ronkonkoma
Brentwood
East Patchogue
Mastic Beach
Newark
Hudson
North New Hyde Park
Queens
Queens
Levittown
Sayville
Union
New York
West Babylon
Hempstead
Union
Valley Stream
Kings
Nassau
Merrick
Staten Island
Long Beach
Woodbridge Township
Richmond
Edison
Franklin Township
Middlesex
Old Bridge Township
Middletown
Monmouth
~15,000,000 people in this photo
© 2018 Google
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image Landsat / Copernicus
Google Earth

Long Island: heavily populated but also heavily forested (dominant species: oak, pine, sassafras, tulip, maple)

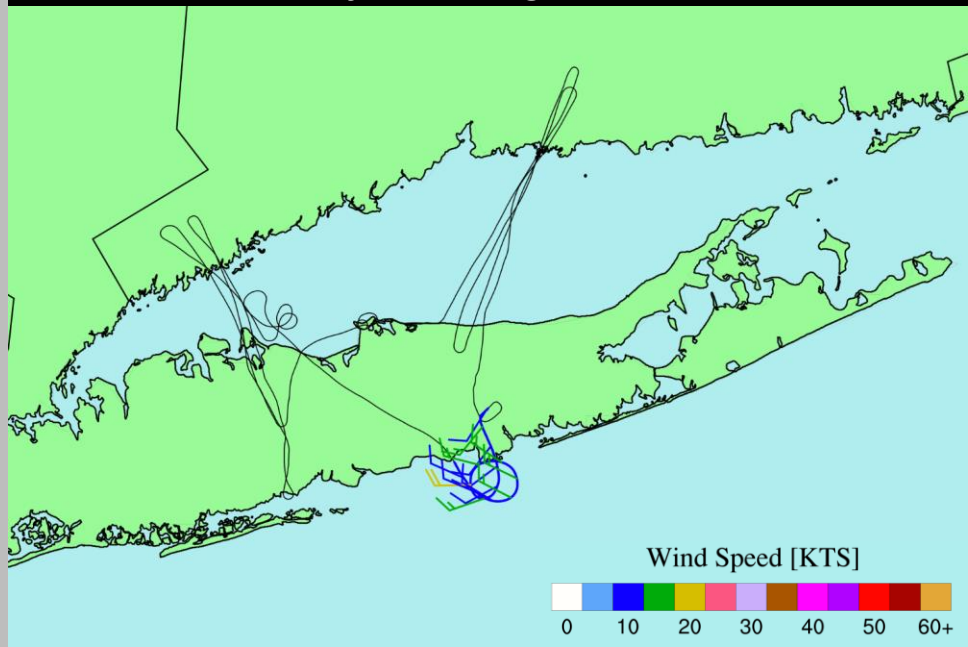
Aircraft Flights: July 9th and 10th

- Flights usually carried out between 18:30 and 21:00 UTC
- Spiraling profiles and two sets of vertically stacked, constant height, cross-sound transects
- The constant height transects allow for computation of turbulent kinetic energy (TKE)
- Vertically-stacked legs to create vertical cross-sections

July 9th Flight track



July 10th Flight track



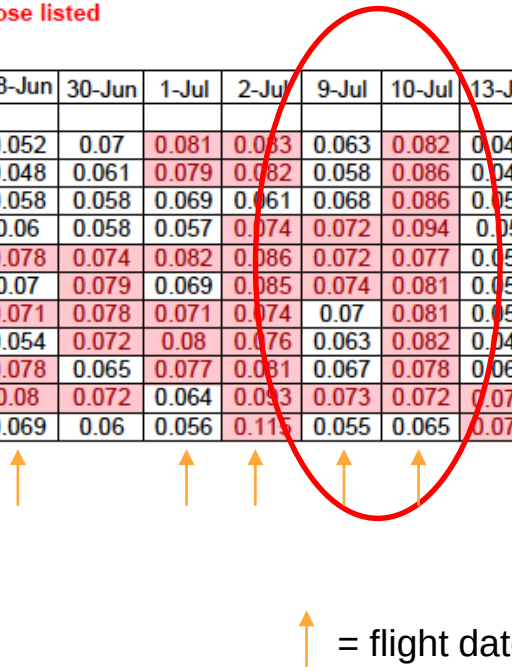
Six out of 14 research flights were during high ozone events in the region.

8-Hour Averages

Values (in red) below are maximum daily 8-hour ozone concentrations measured in parts per million, exceeding the 2015 Federal standard of .070 ppm.

Note: 4th Max. column indicates that the 4th highest 8-hr avg for all days to date, not just those listed

	ID	4th Max.	2-May	24-May	25-May	26-May	29-May	17-Jun	18-Jun	30-Jun	1-Jul	2-Jul	9-Jul	10-Jul	13-Jul	14-Jul	16-Jul	28-Jul	6-Aug
NYC METRO																			
Babylon	5150-02	0.074	0.069	0.067	0.063	0.064	0.046	0.069	0.052	0.07	0.081	0.083	0.063	0.082	0.046	0.060	0.066	N/A	0.074
Holtsville	5151-10	0.076	0.07	0.063	0.062	0.059	0.051	0.068	0.048	0.061	0.079	0.082	0.058	0.086	0.049	0.063	0.067	0.051	0.076
Riverhead	5155-01	0.072	0.072	0.062	0.068	0.075	0.061	0.068	0.058	0.058	0.069	0.081	0.068	0.086	0.055	0.067	0.074	0.048	0.070
Flax Pond	5151-12	0.074	N/A	N/A	N/A	N/A	N/A	0.064	0.06	0.058	0.057	0.074	0.072	0.094	0.059	0.073	0.074	0.045	0.065
CCNY	7093-25	0.077	0.066	0.062	0.061	0.062	0.068	0.071	0.078	0.074	0.082	0.086	0.072	0.077	0.055	0.058	0.071	0.068	0.074
Pfizer Lab	7094-10	0.077	0.067	0.063	0.065	0.064	0.064	0.073	0.07	0.079	0.069	0.085	0.074	0.081	0.059	0.063	0.072	0.068	0.077
IS 52	7094-07	0.071	0.066	0.062	0.063	0.065	0.06	0.07	0.071	0.078	0.071	0.074	0.07	0.081	0.054	0.062	0.068	0.066	0.071
Queens College 2	7096-15	0.073	0.071	0.068	0.073	0.067	0.054	0.07	0.054	0.072	0.08	0.076	0.063	0.082	0.047	0.063	0.071	0.066	0.071
Fresh Kills West	7097-17	0.077	0.065	0.061	0.064	0.057	0.074	0.067	0.078	0.065	0.077	0.081	0.067	0.078	0.060	0.057	0.071	N/A	0.062
White Plains	5902-04	0.078	0.072	0.062	0.07	0.065	0.074	0.072	0.08	0.072	0.064	0.093	0.073	0.072	0.071	0.064	0.080	0.078	0.065
Rockland County	4353-02	0.072	0.072	0.056	0.066	0.064	0.058	0.059	0.069	0.06	0.056	0.115	0.055	0.065	0.072	0.059	0.073	0.051	0.043

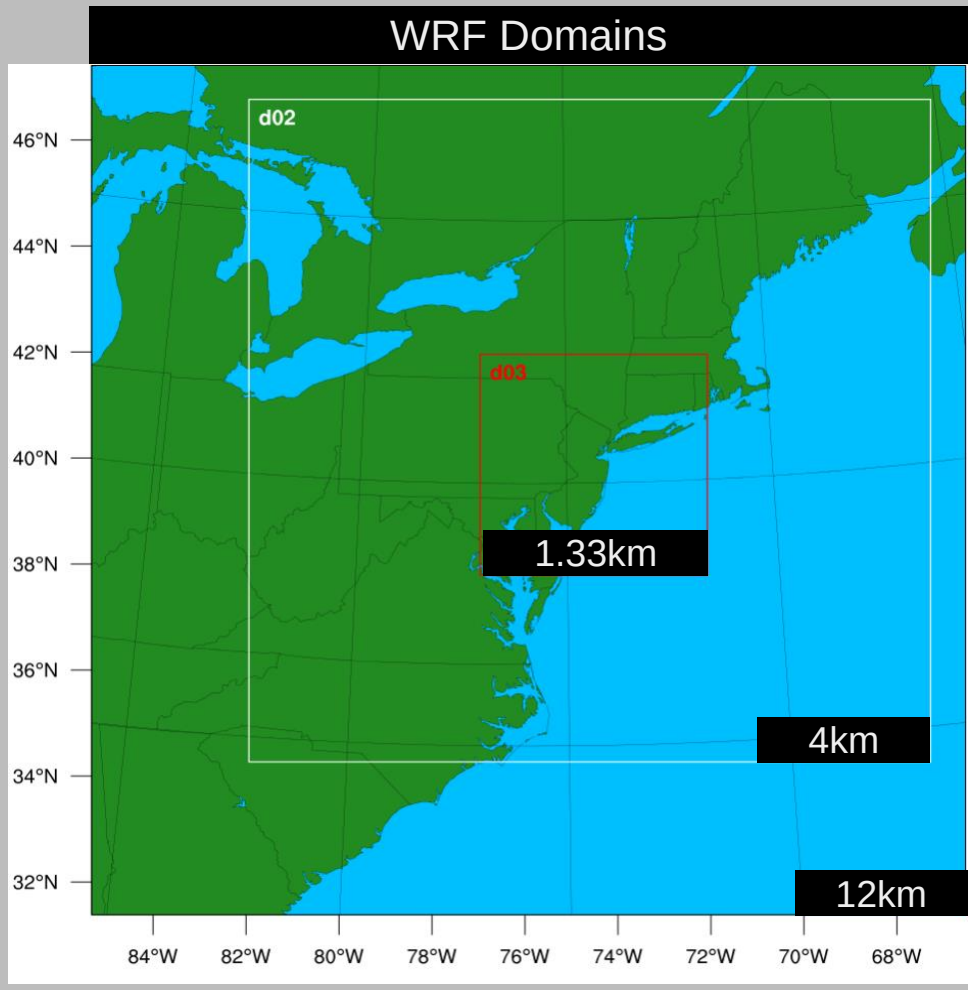


= flight date

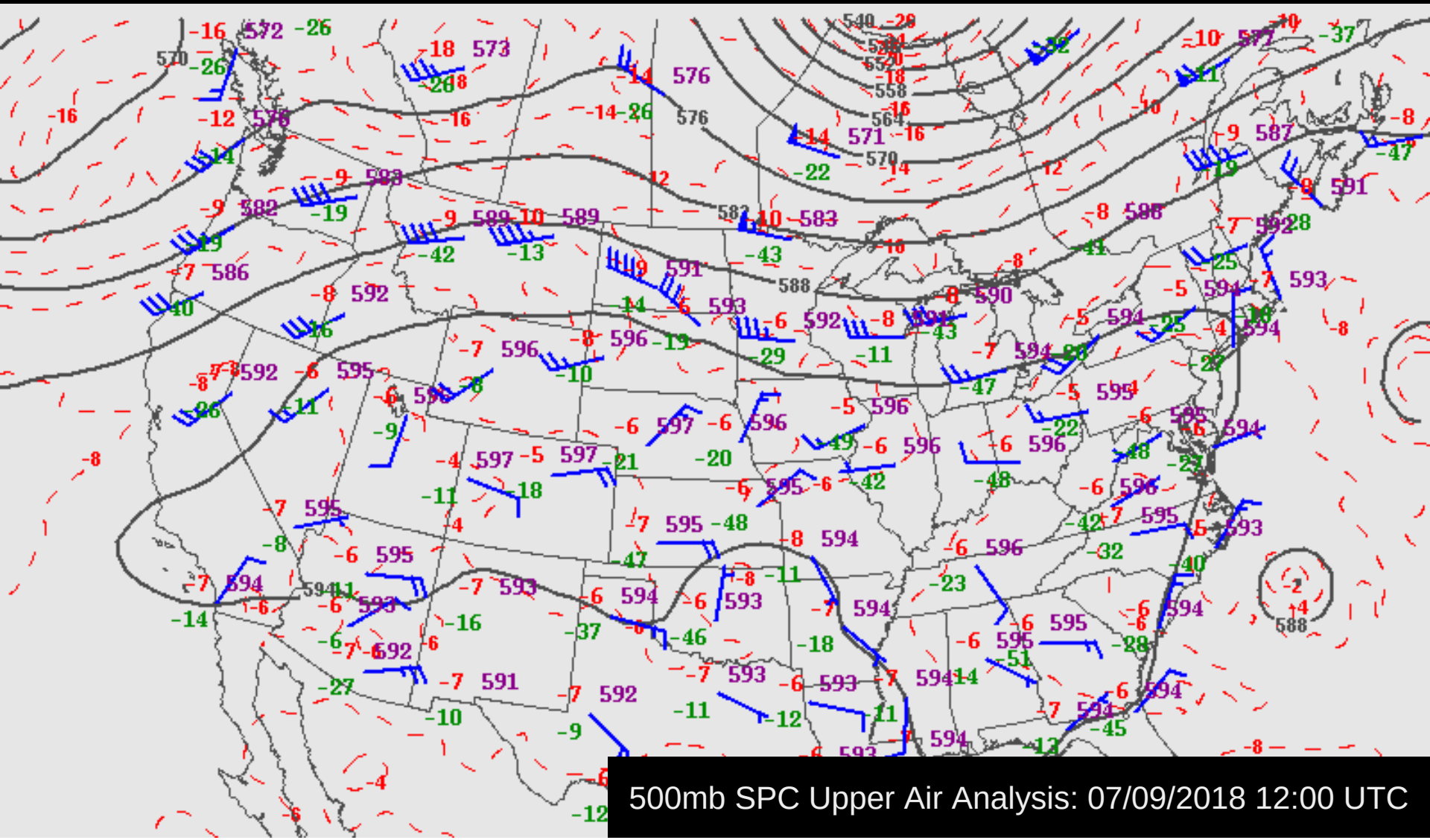
Source: NYSDEC (https://www.dec.ny.gov/chemical/38377.html)

The WRF Model Setup (K. Fryer)

- Three runs for each case varying the PBL schemes:
  - ACM2, YSU, and MYNN2
- 12, 4, and 1.33km domains
- 38 vertical levels with 13 below 1000m
- Thompson microphysics, and Kain-Fritsch used on 12-km domain
- Initialized using RAP analyses at 00 UTC the day of event [~ 18 hr spinup]
  - Hourly boundary conditions
- Model output saved every 5 minutes for interpolating the model to the aircraft flight track

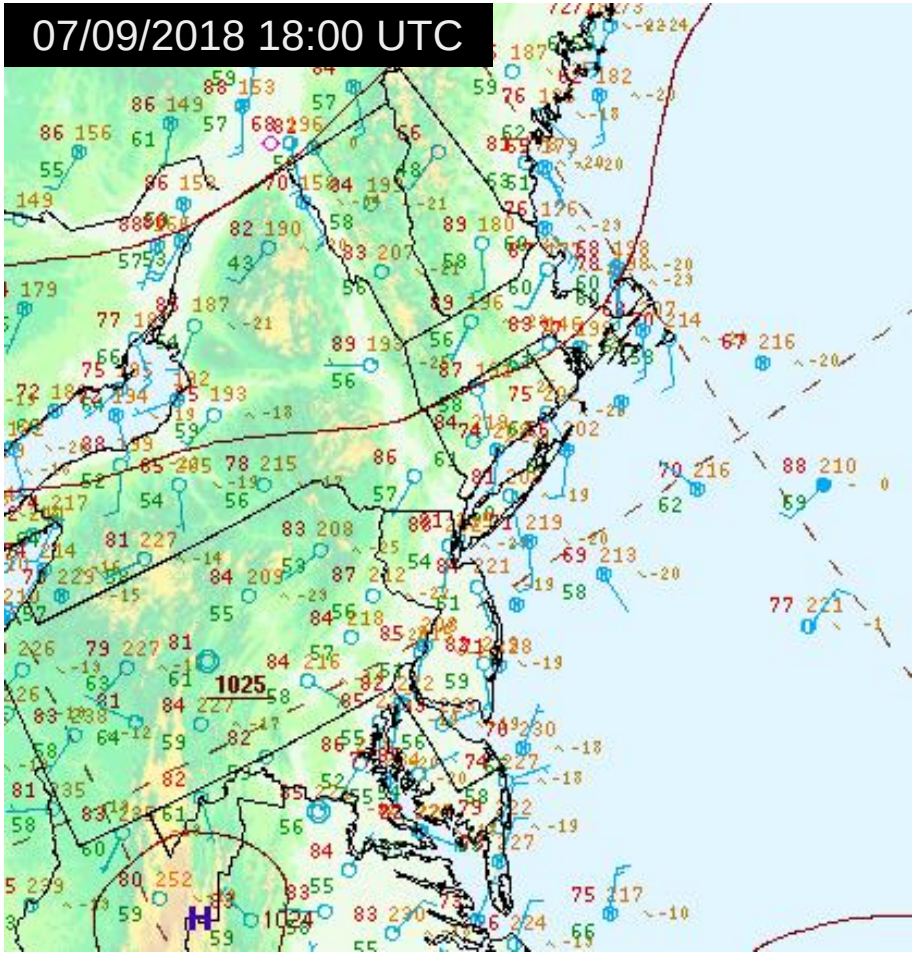


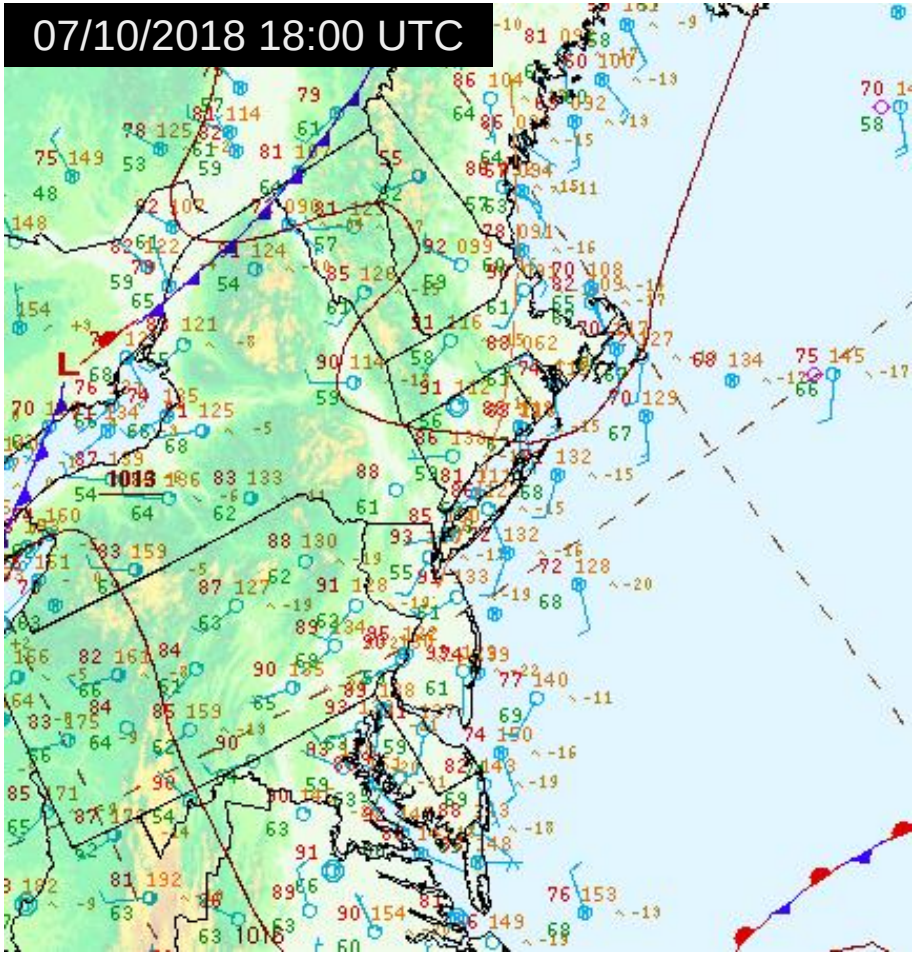
Synoptic Background: 500 hPa Analysis



- Broad trough north of Wisconsin at 12z on the 9th, moves east through the case study period and by 00z on the 11th, trough is deeper and north of Maine

Synoptic Background: Surface Analysis

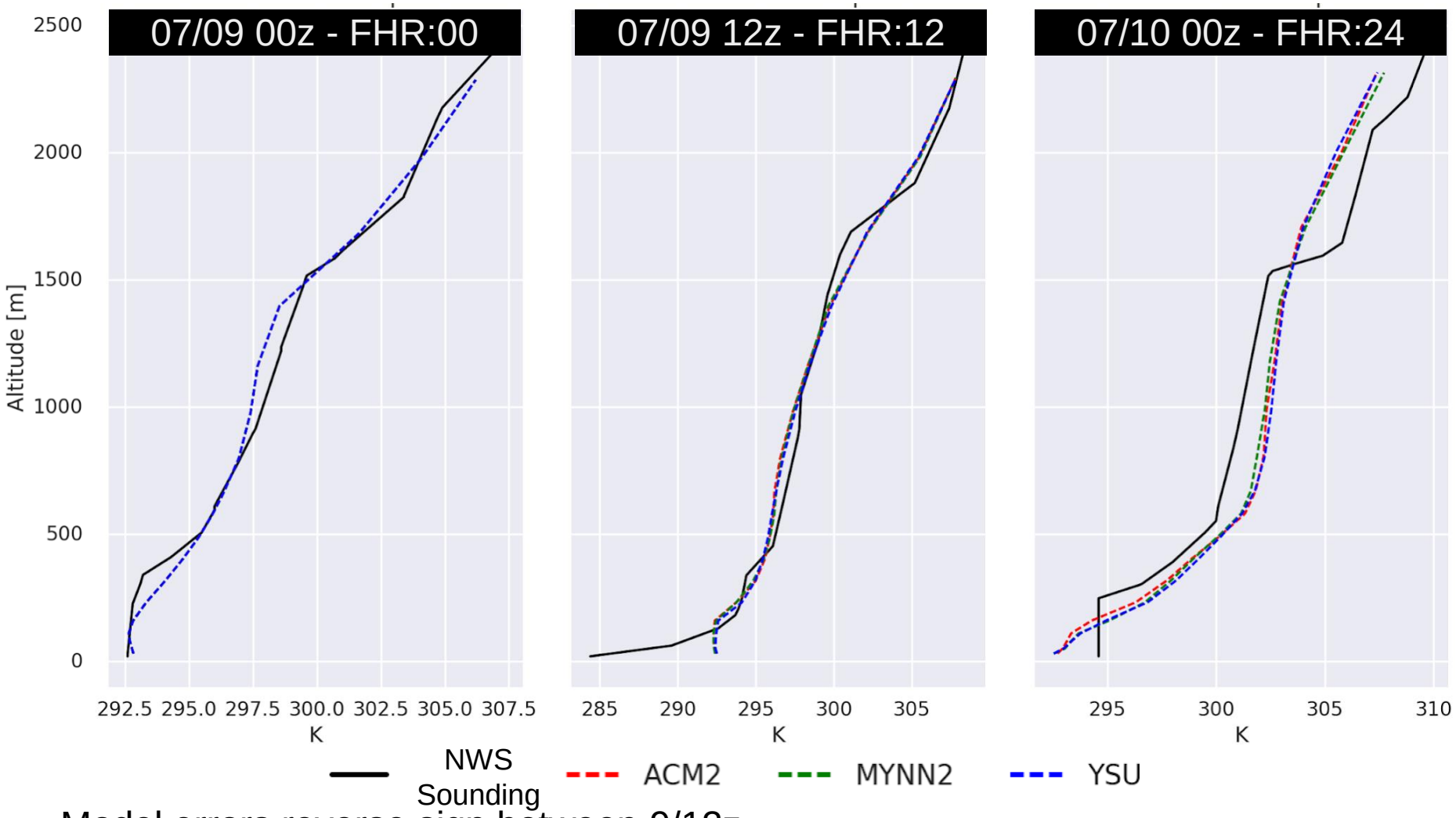




- Weak high pressure and weak pressure gradients over Northeast U.S.
- Coastal trough develops during the afternoon with the warm temperatures.
- Dominant flow is from the southwest

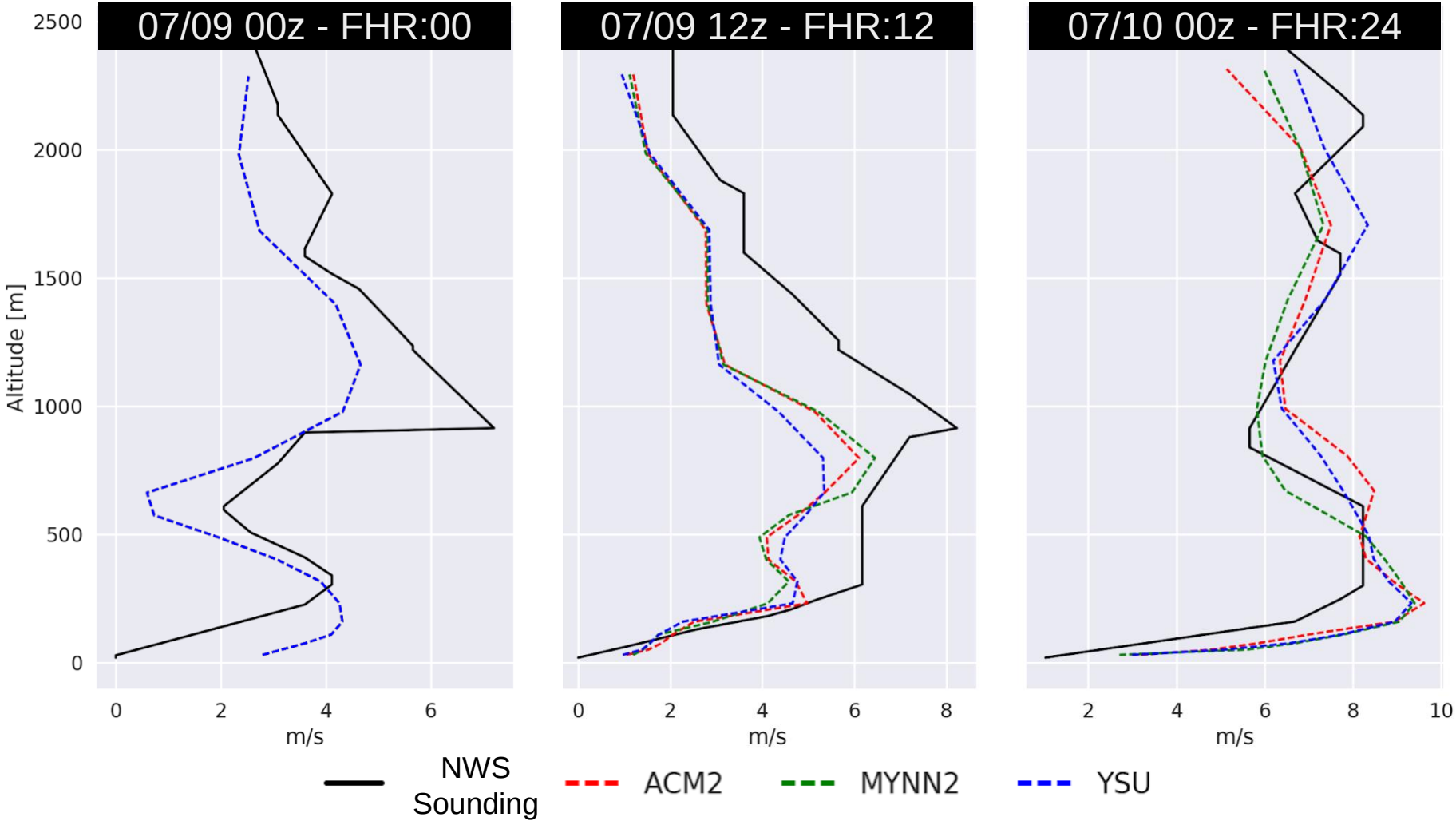
9 July 2018 Case Study

July 9th: Potential Temperature Soundings @ OKX



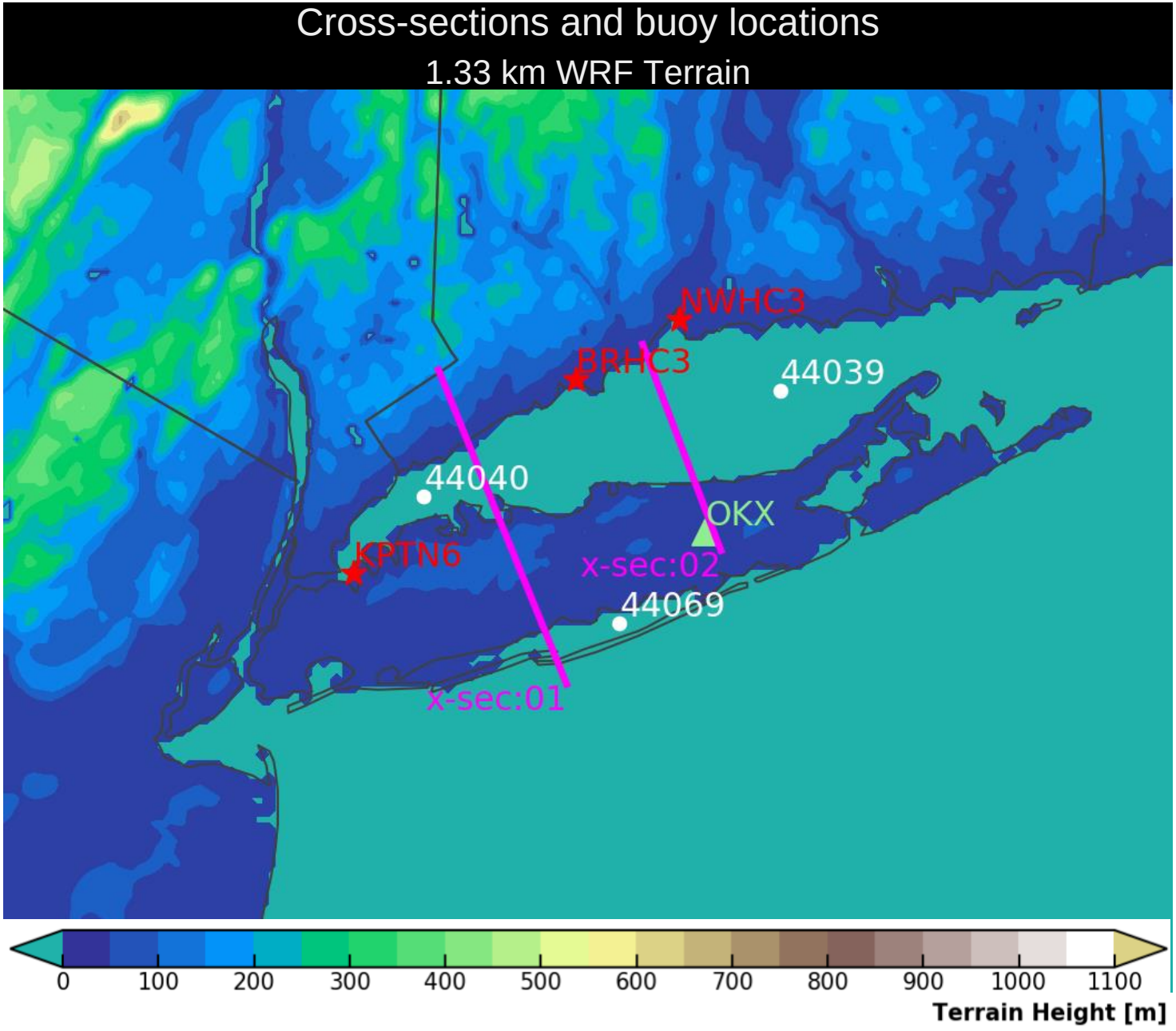
- Model errors reverse sign between 9/12z and 10/00z in lowest few hundred meters.
- WRF too warm early AM and too cool by following 10/00Z
- WRF too warm from 300 to 1500 m.
- Small differences between PBL schemes

July 9th: Wind Speed Soundings @ OKX

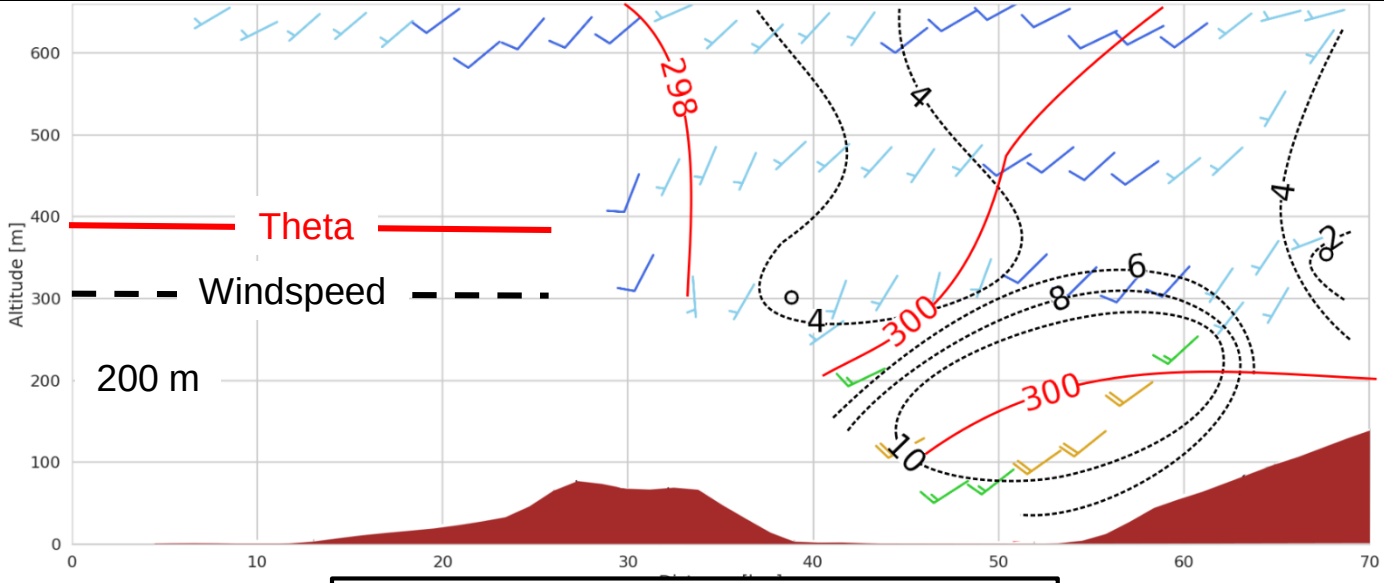


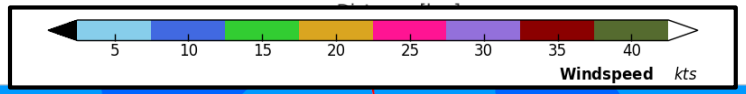
- WRF initialized ok
- A bit weak at 12z
- Strong again at 00z but not significant

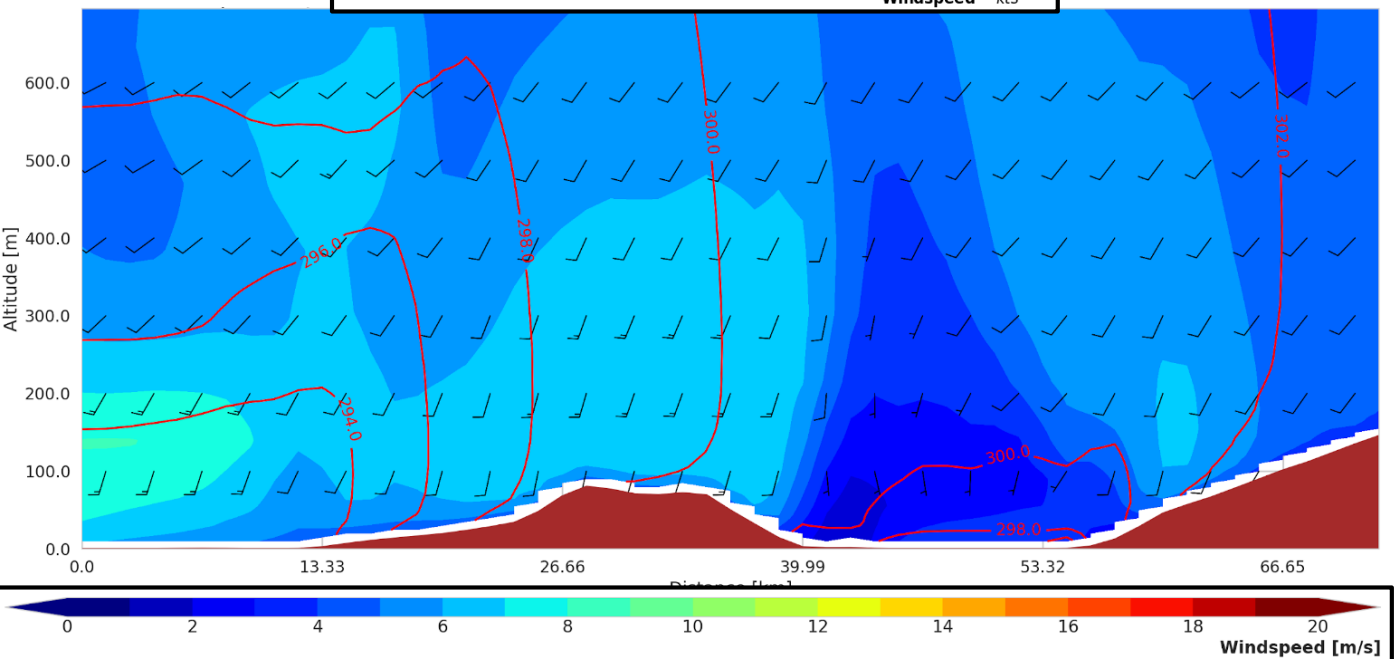
July 9th, 2018



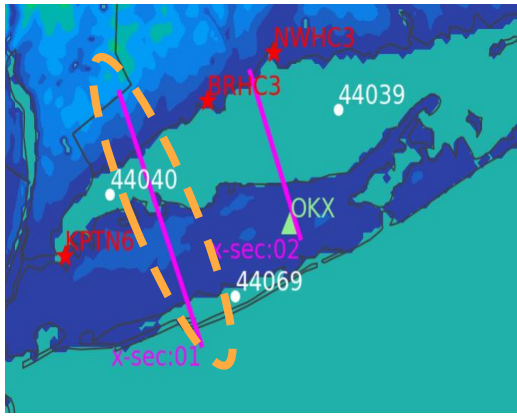
July 9th: W LIS N-S Cross-section 01 [19-20z]



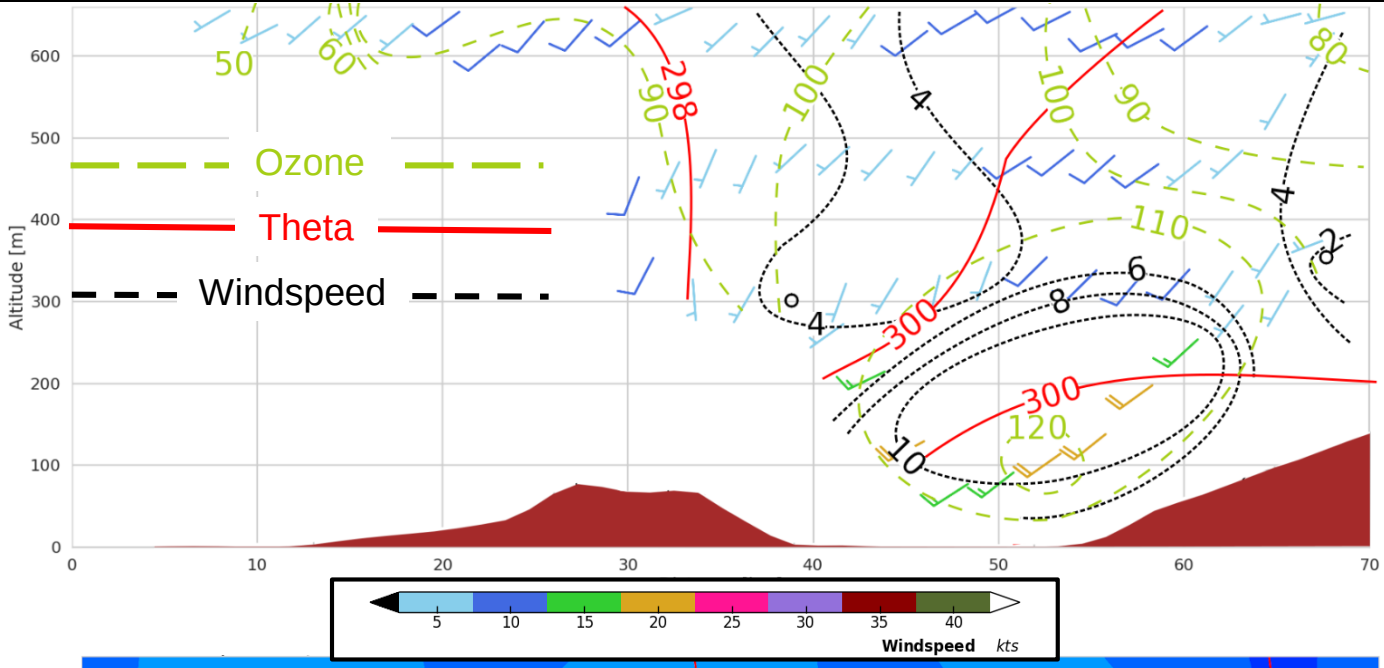


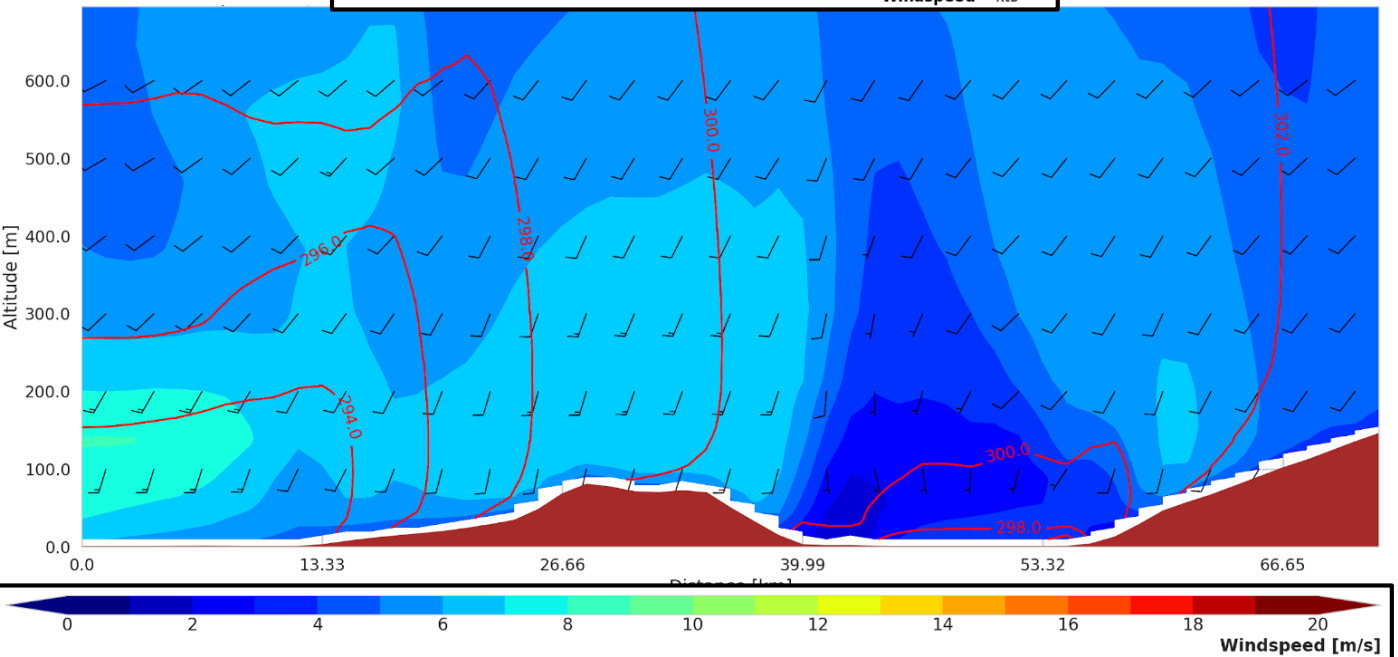


- Max winds 100-200 m along CT coast. WRF winds too weak.
- WRF is too warm over LI and CT
- Some suggestion WRF PBL over LIS may be too shallow.

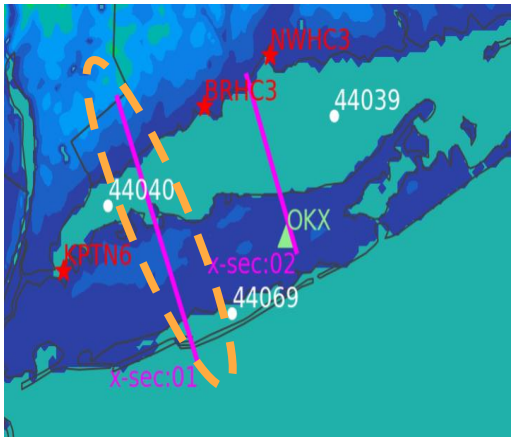


July 9th: W LIS N-S Cross-section 01 [19-20z]

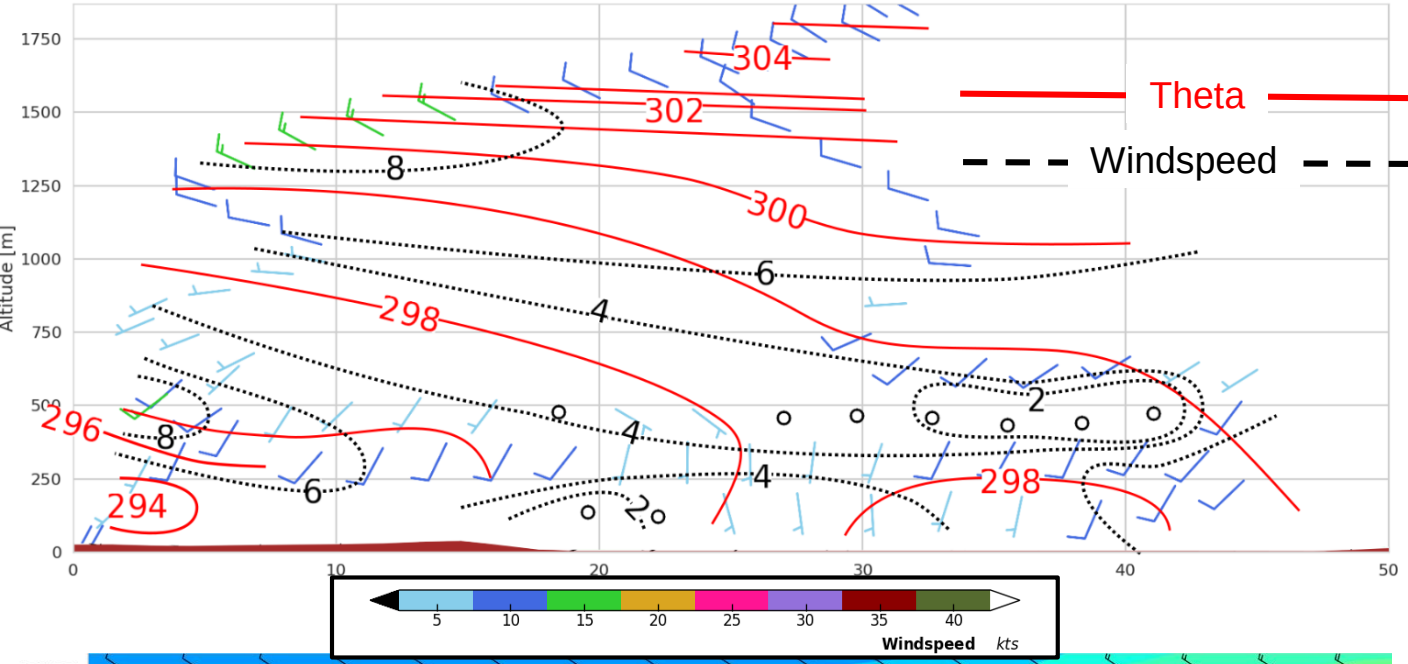


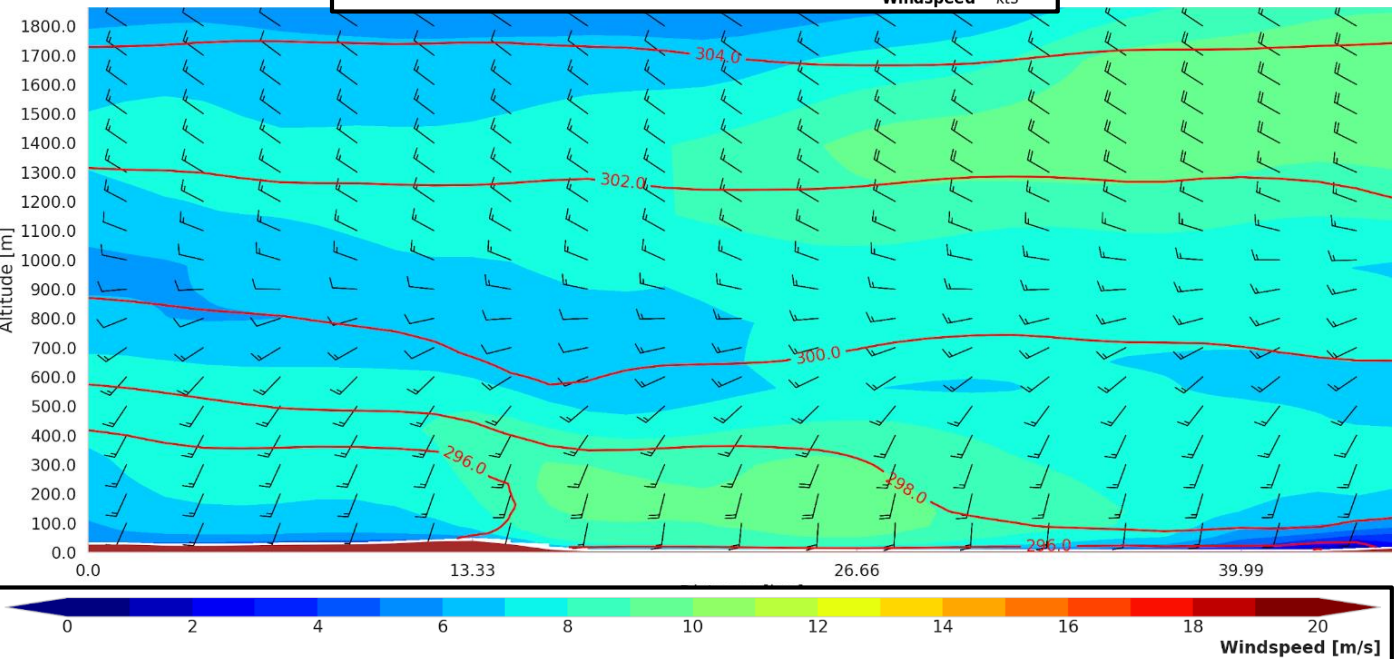


- Highest ozone concentrations coincide with warmer air and maximum wind speeds

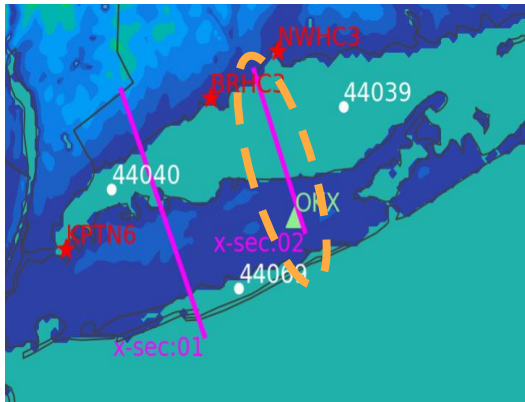


July 9th: Central LIS N-S Cross-section 02 [20-21z]

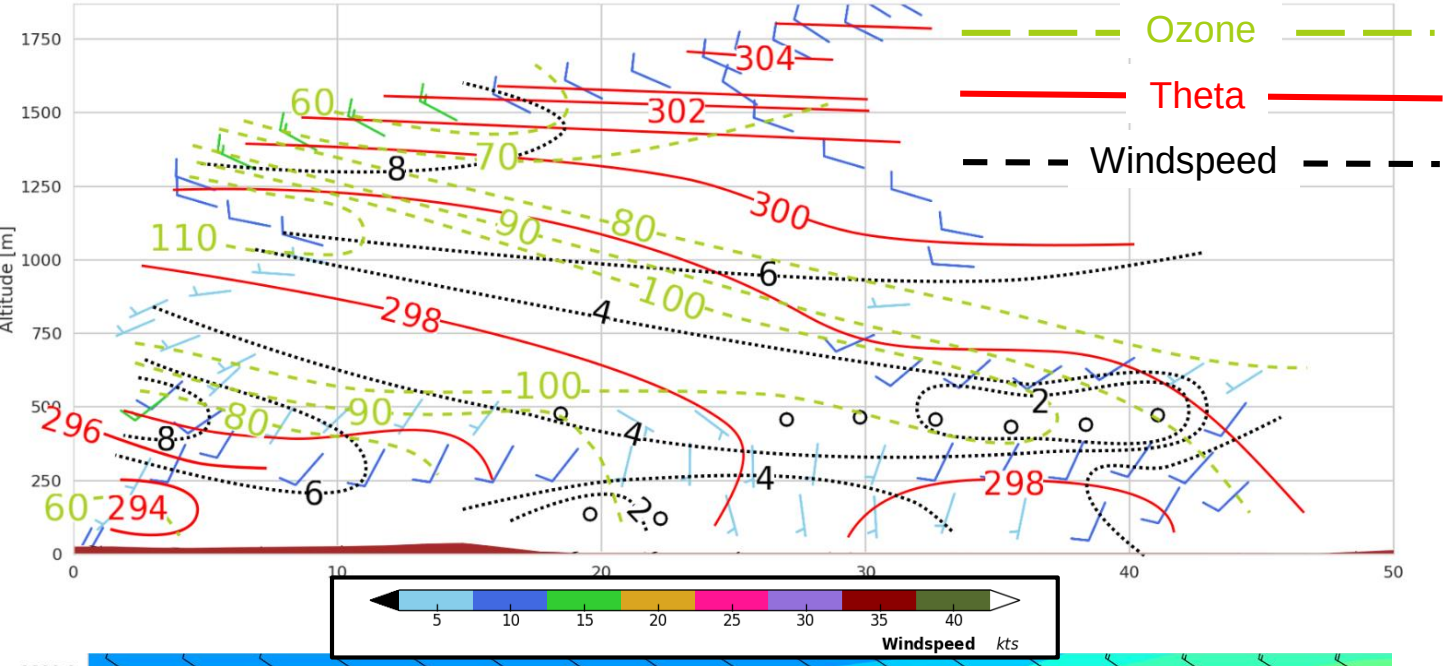


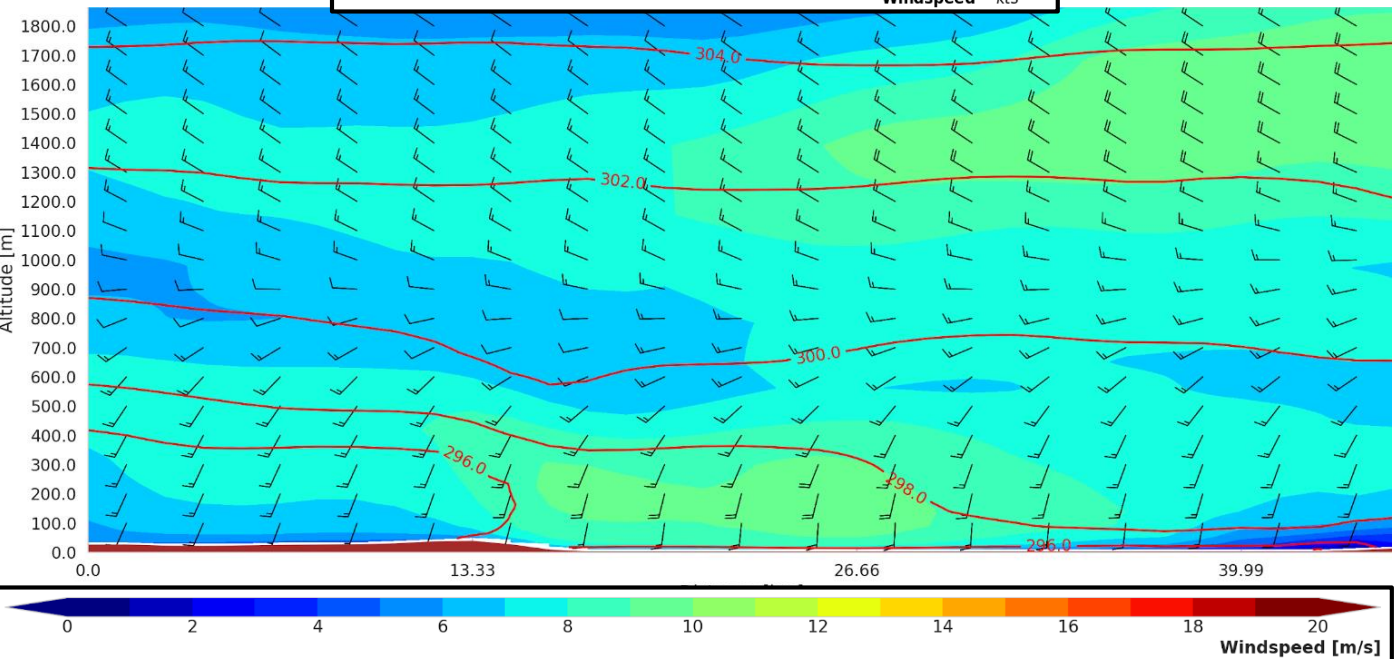


- No wind max near CT coast
- Stronger winds above LI
- Stable layer at 1500m not present in WRF over LIS
- WRF slightly warmer than obs above 100m and cooler below

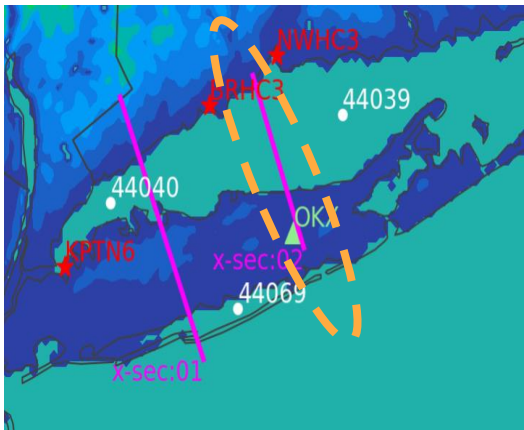


July 9th: Central LIS N-S Cross-section 02 [20-21z]

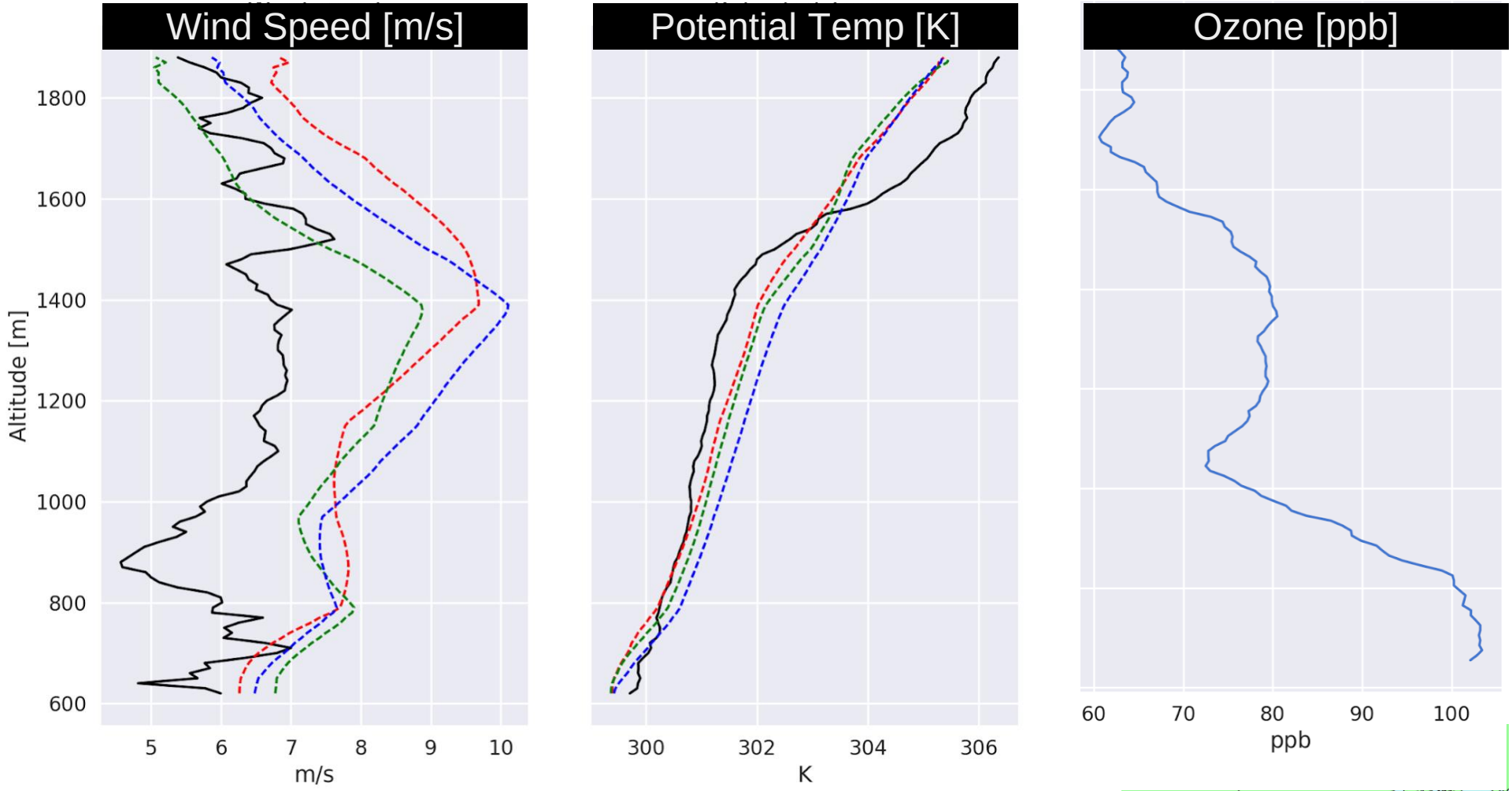




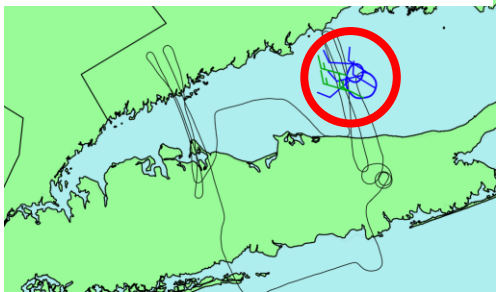
- Highest ozone levels between 1500m stable layer and shallow MABL



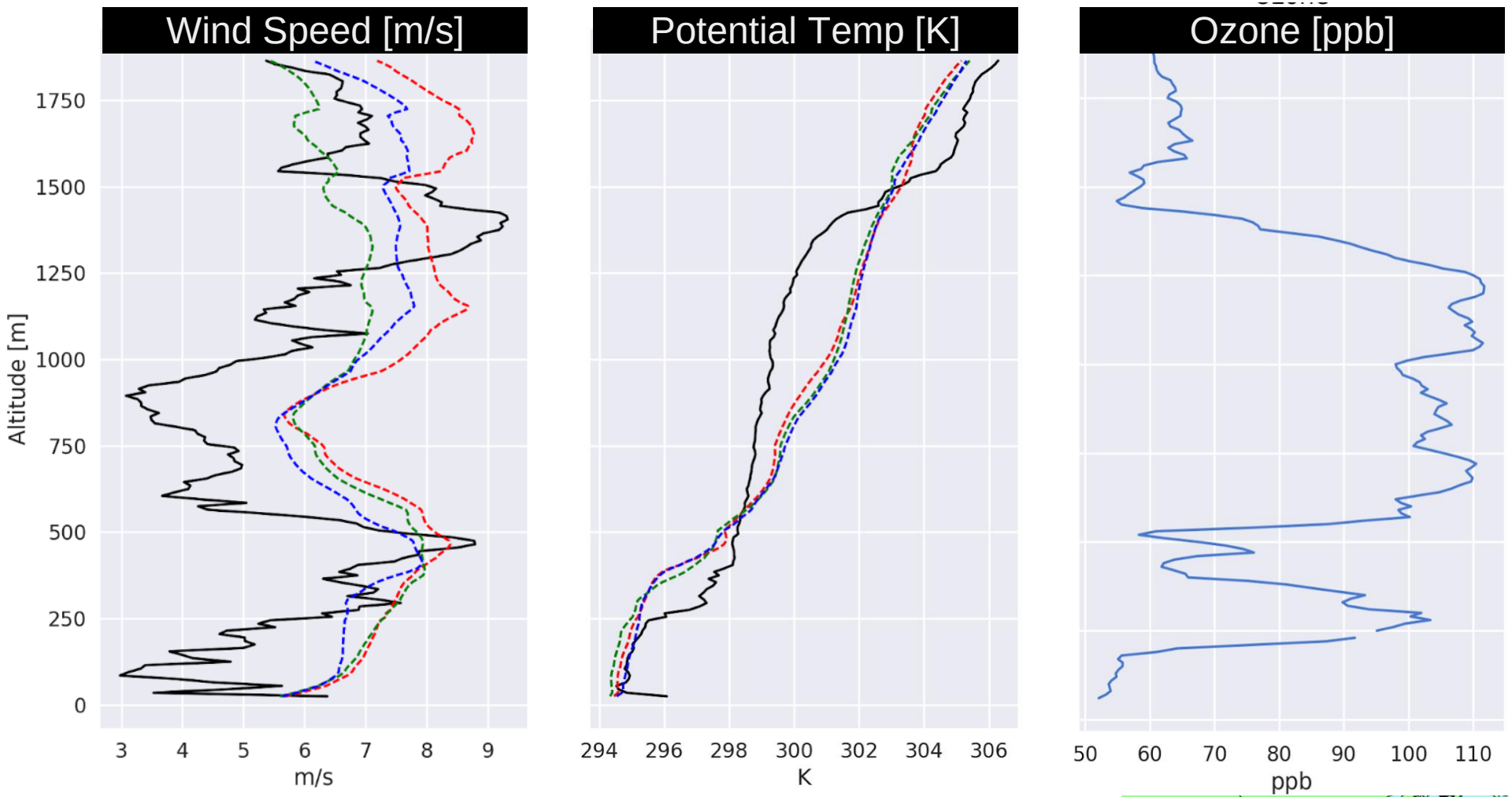
July 9th: WRF Profiles over Central LIS at ~2045 UTC



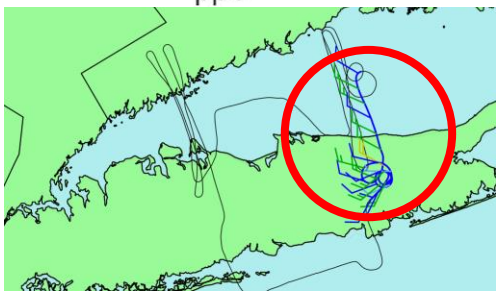
- WRF Slightly too cool below 300 m, and slightly too warm 300-1500 m. WRF too strong.
- Little sensitivity to PBL



July 9th: WRF Profiles over Central LI at ~ 2100 UTC



- WRF 1500m inversion not present and low level inversion is too high. WRF winds still too high.
- Wind max just above stable layer at both levels

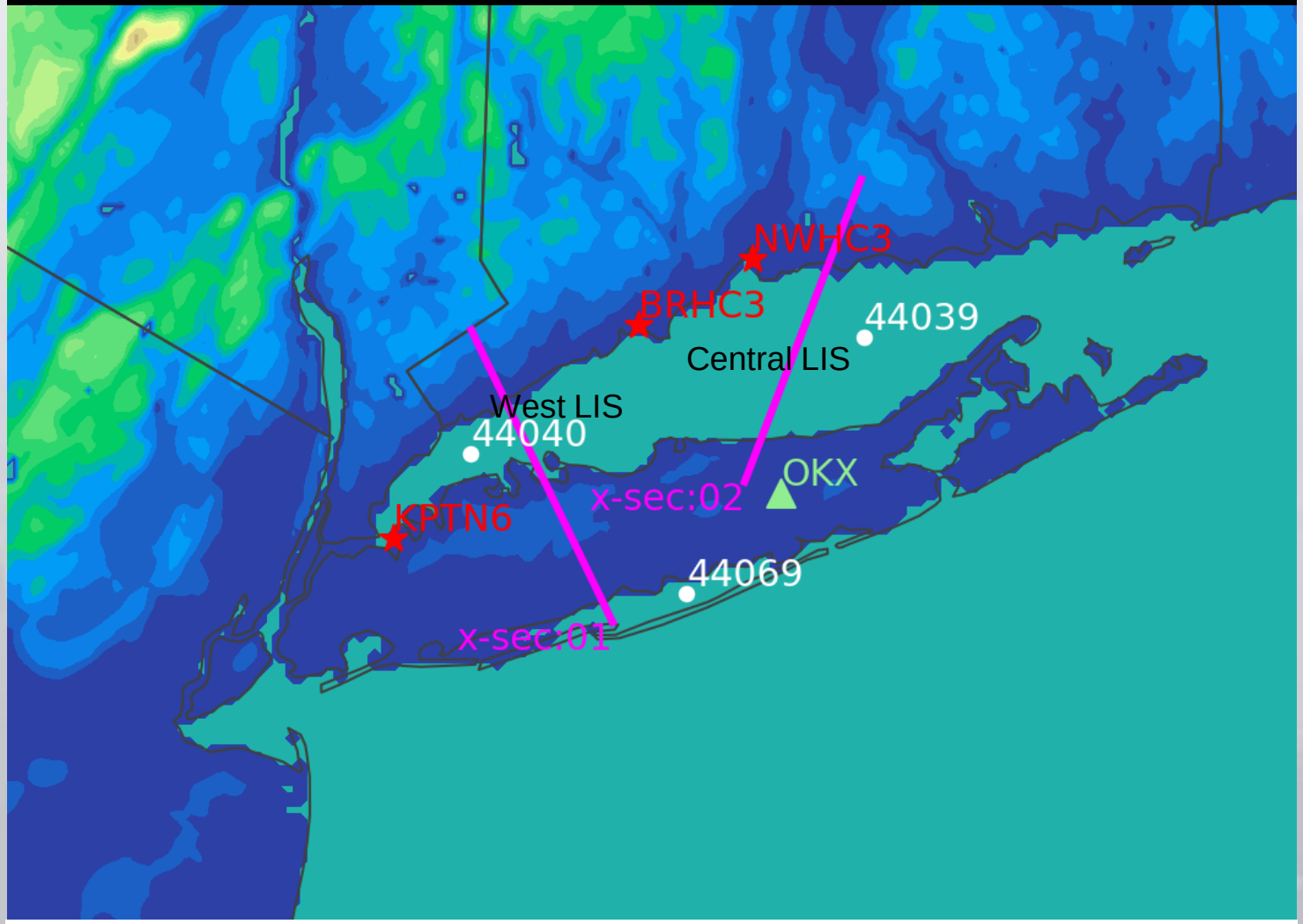


10 July 2018 Case Study

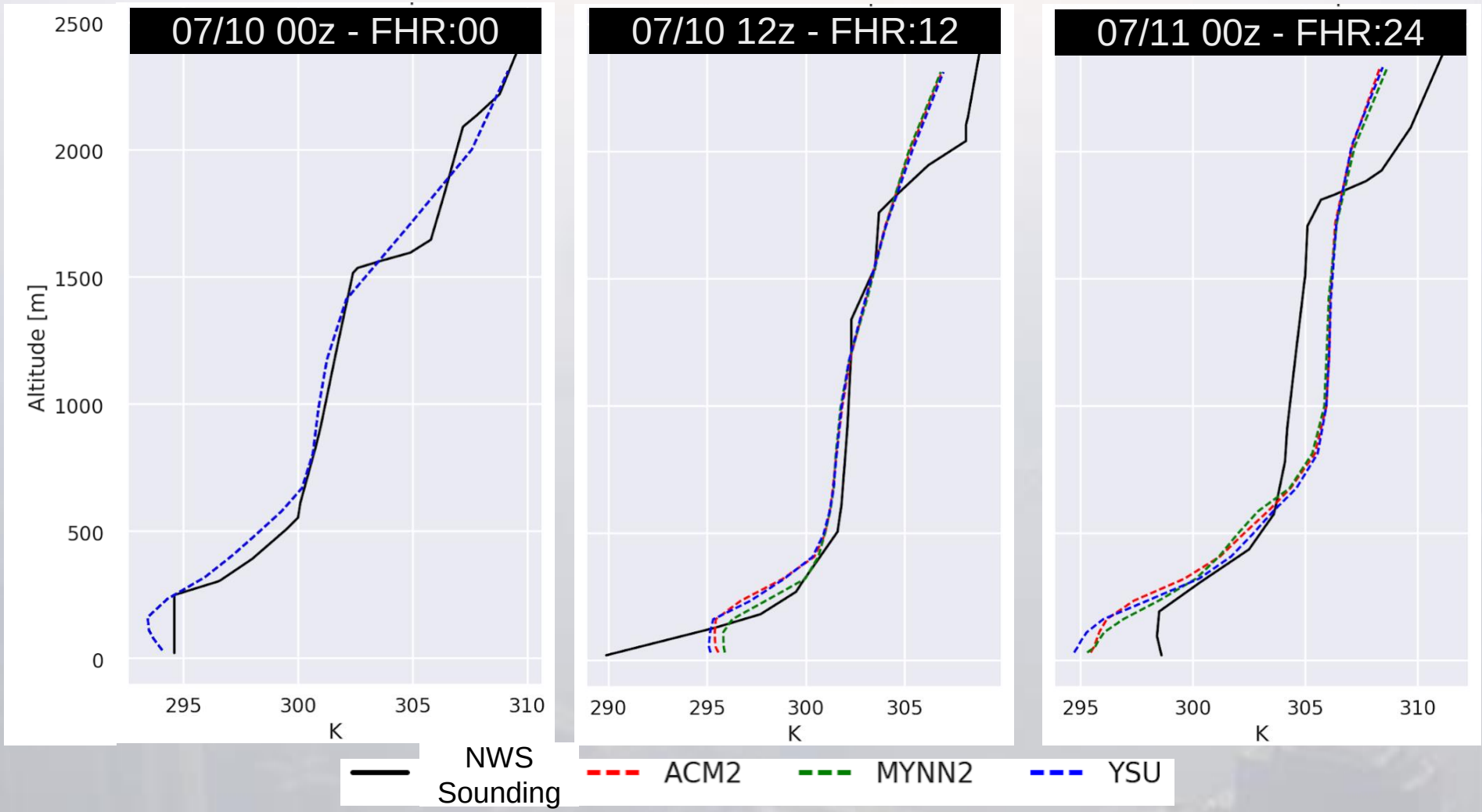
July 10th, 2018

Cross-sections and buoy locations

WRF Model Terrain Field

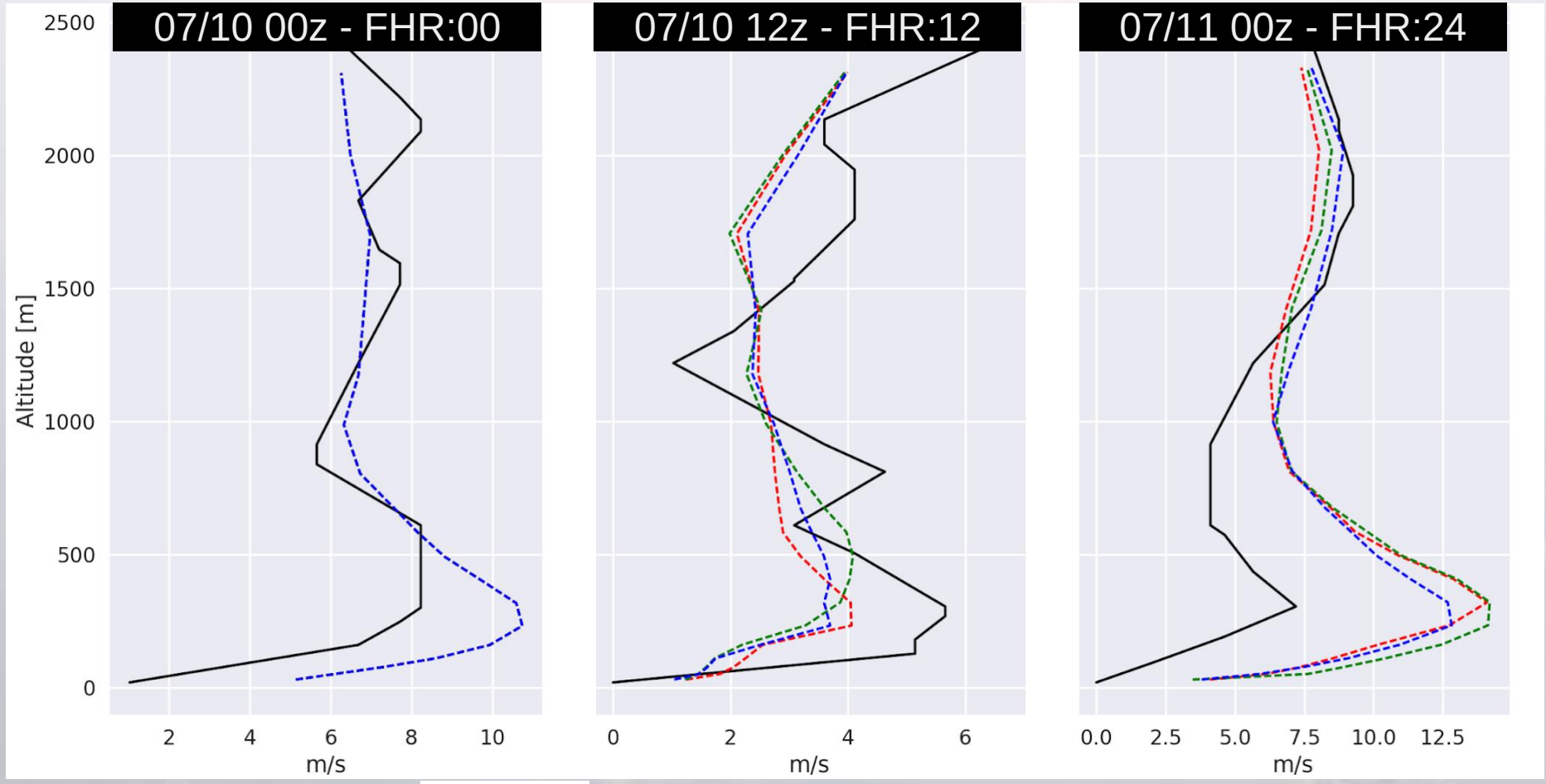


July 10th: Potential Temperature Soundings @ OKX



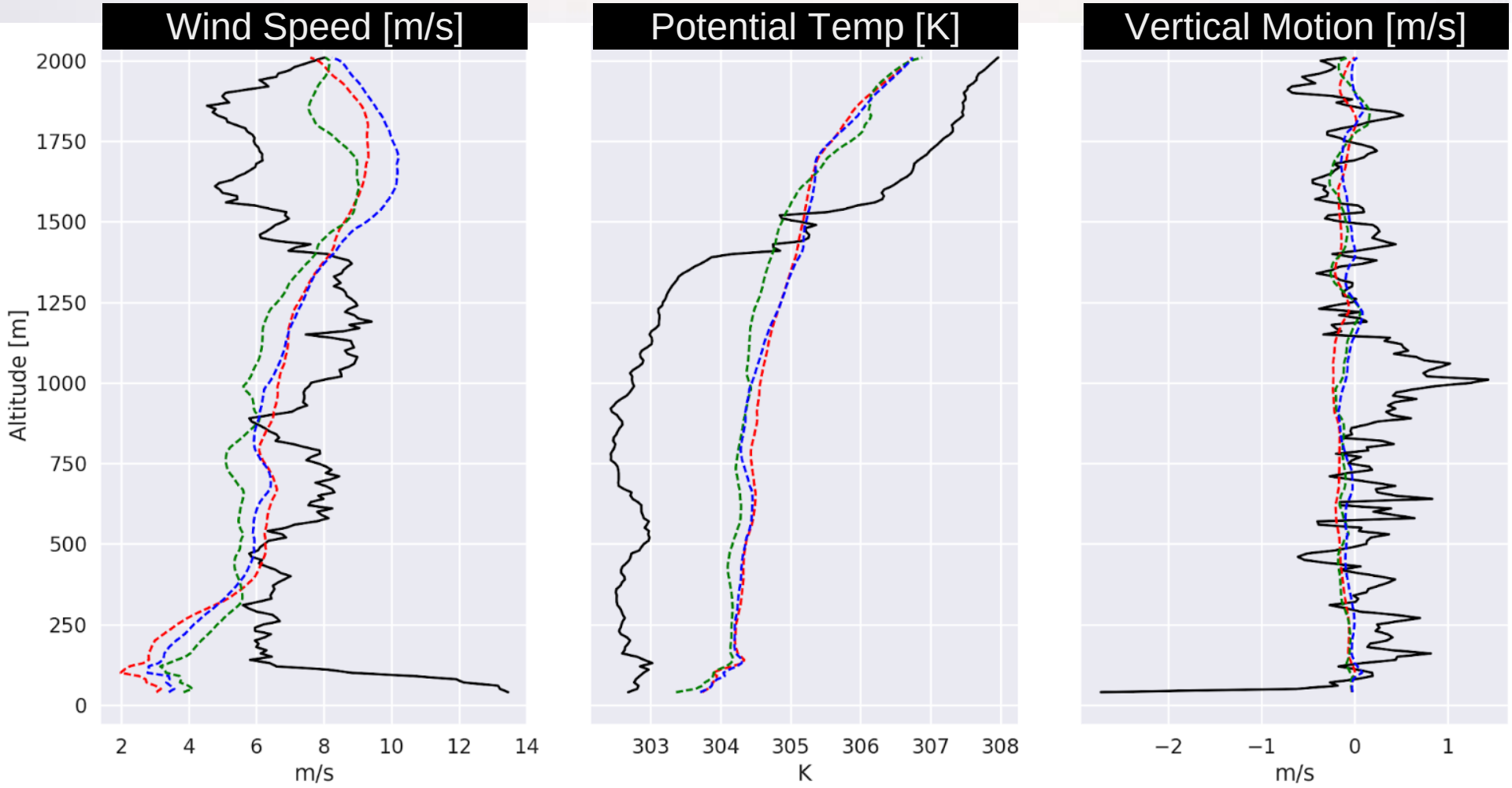
- WRF errors again reverse sign between 12z and 00z
- WRF too cool in PBL by early evening
- WRF has weak stable layer at 1500m

July 10th: Wind Speed Soundings @ OKX

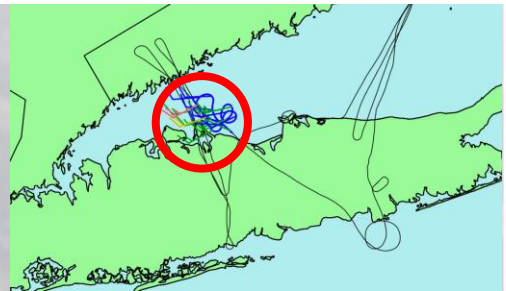


- WRF initialized strong
- Weak at 12z
- Strong again at 00z

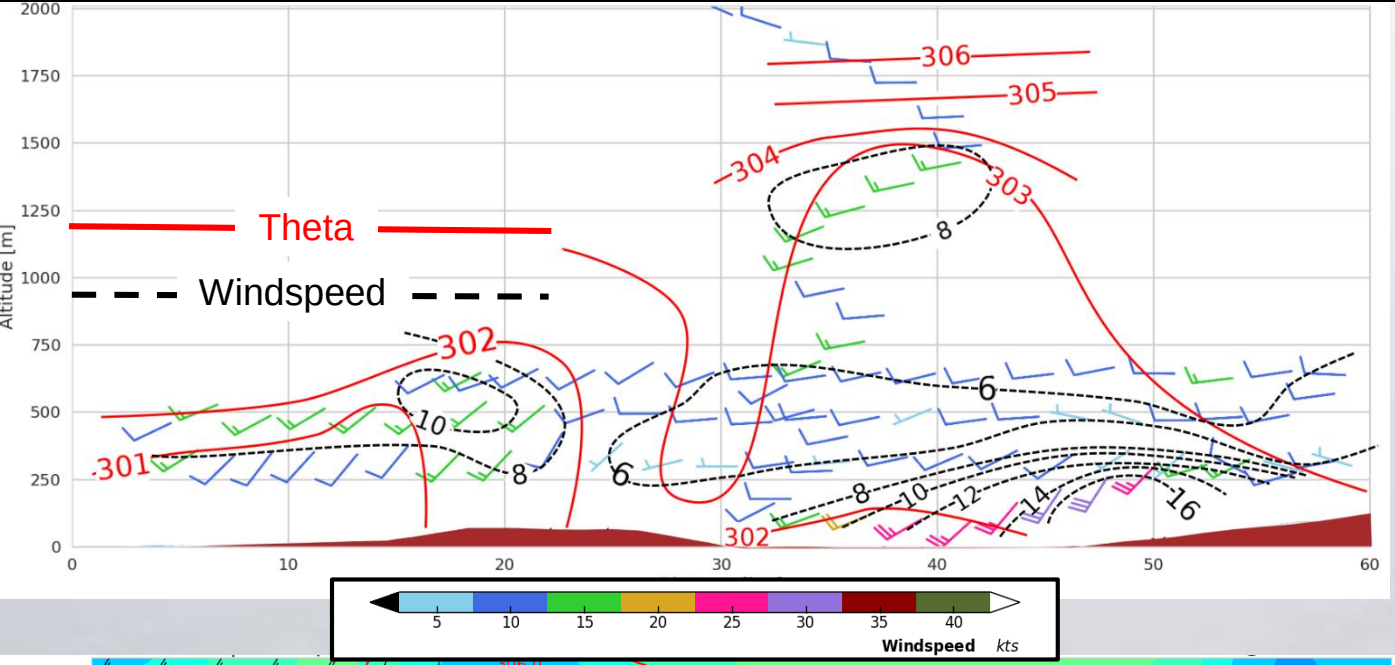
July 10th, 2018: Profile over Western LIS at ~19 UTC

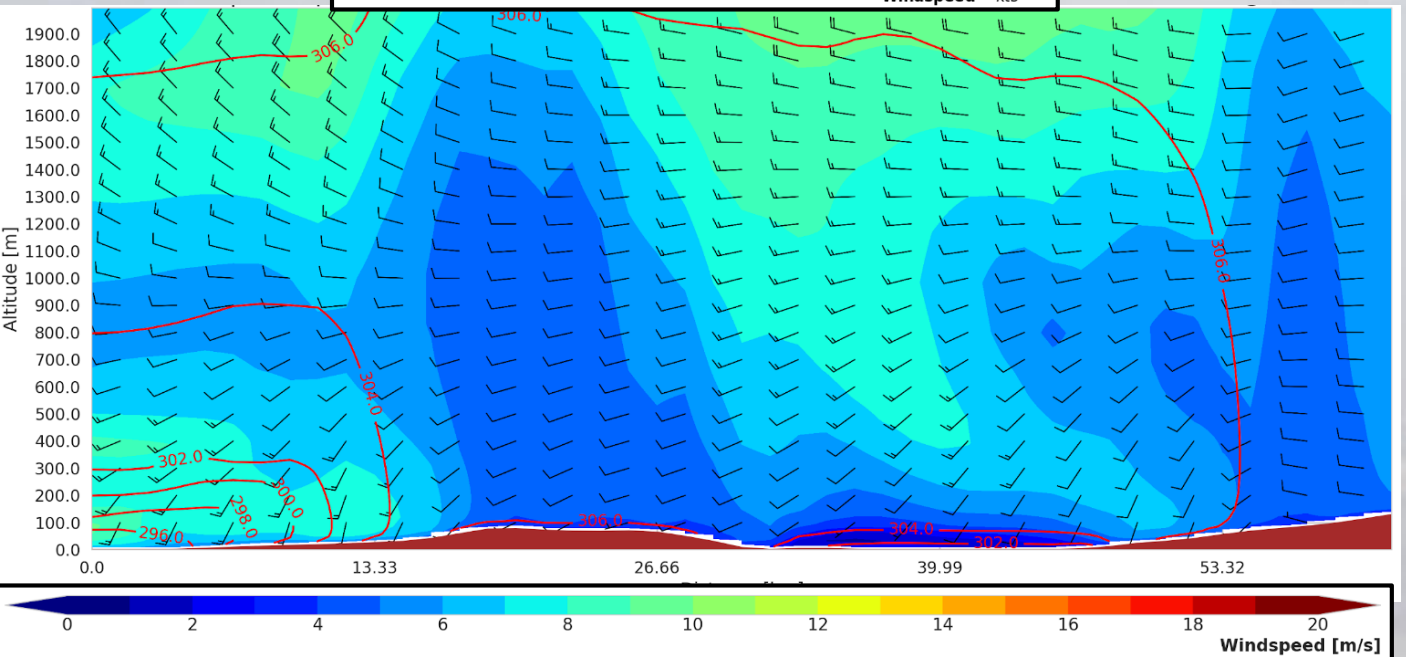


- Strong winds below 150 m...not an error, even stronger winds observed as plane continued to traverse LIS at this low level
- Wind max completely absent in model
- Model temperatures between 1500m and 50m are running 1-3 K warm

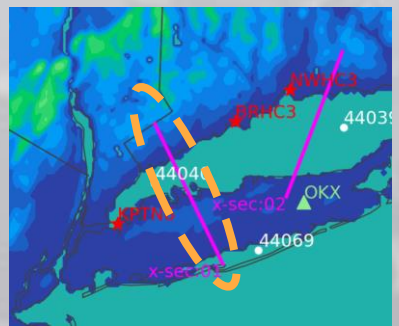


July 10th: W LIS N-S Cross-section 01 [19-20z]

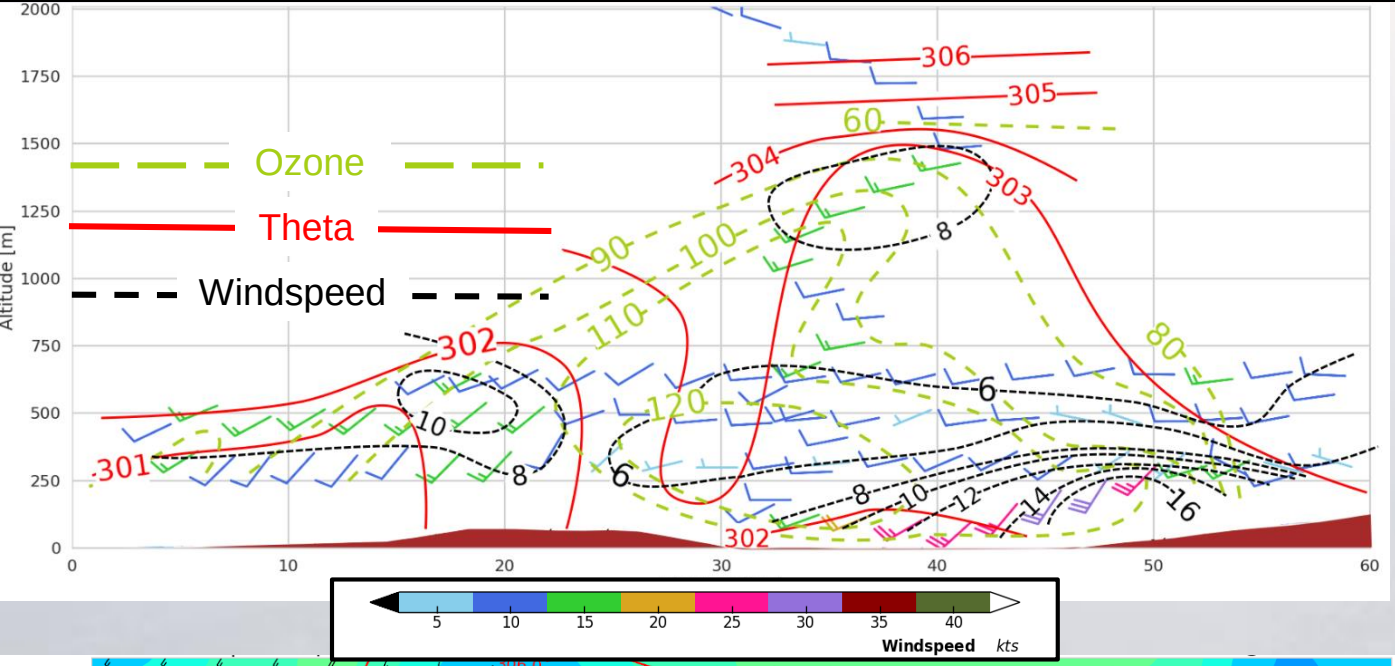


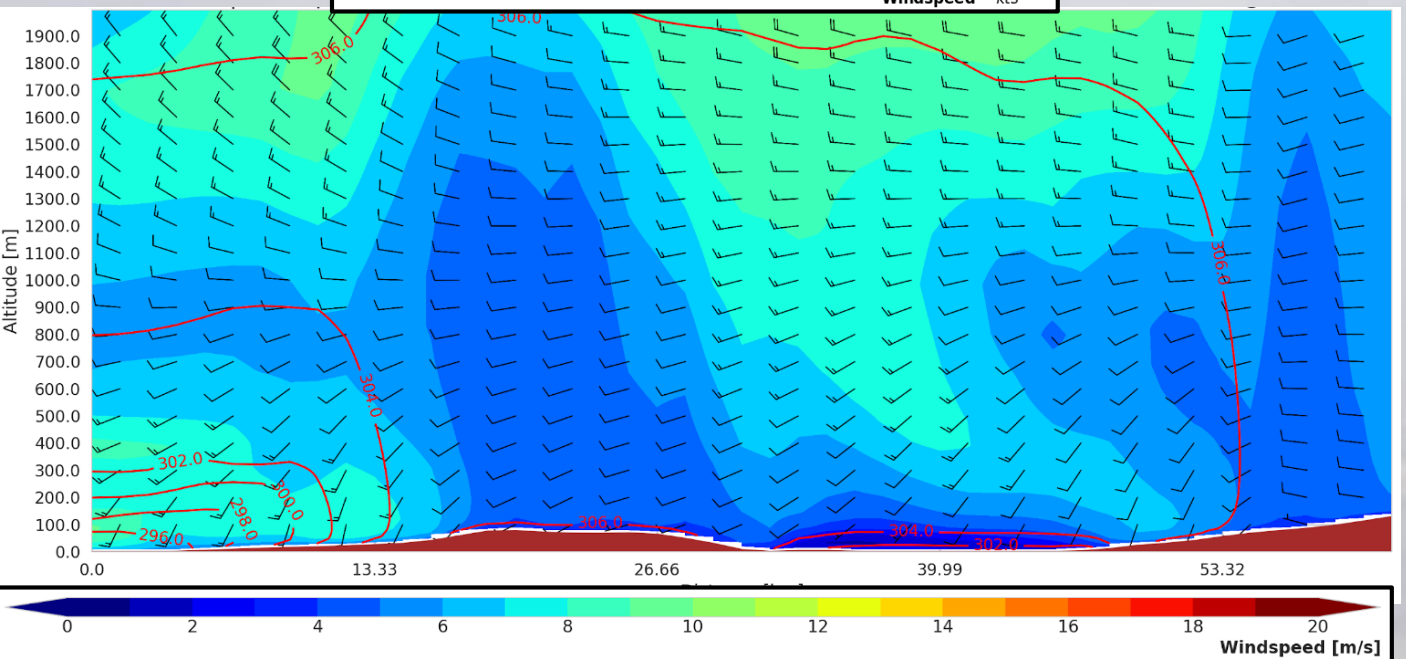


- Strongest winds adjacent to CT coast
- WRF winds 8-12 m/s weak with jet
- WRF temps much warmer than obs over LI by ~4-5K and over LIS by ~2K

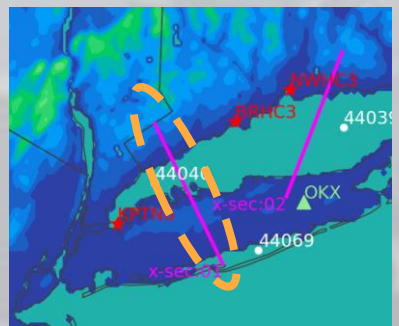


July 10th: W LIS N-S Cross-section 01 [19-20z]

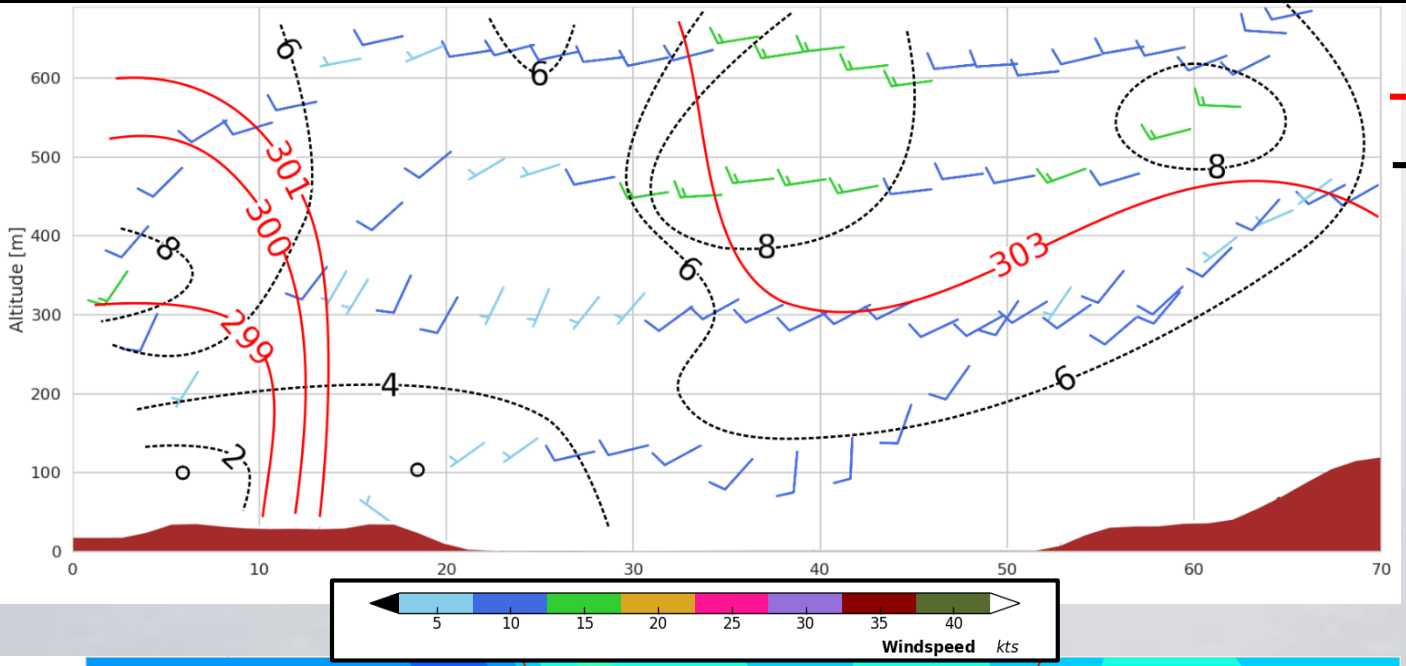


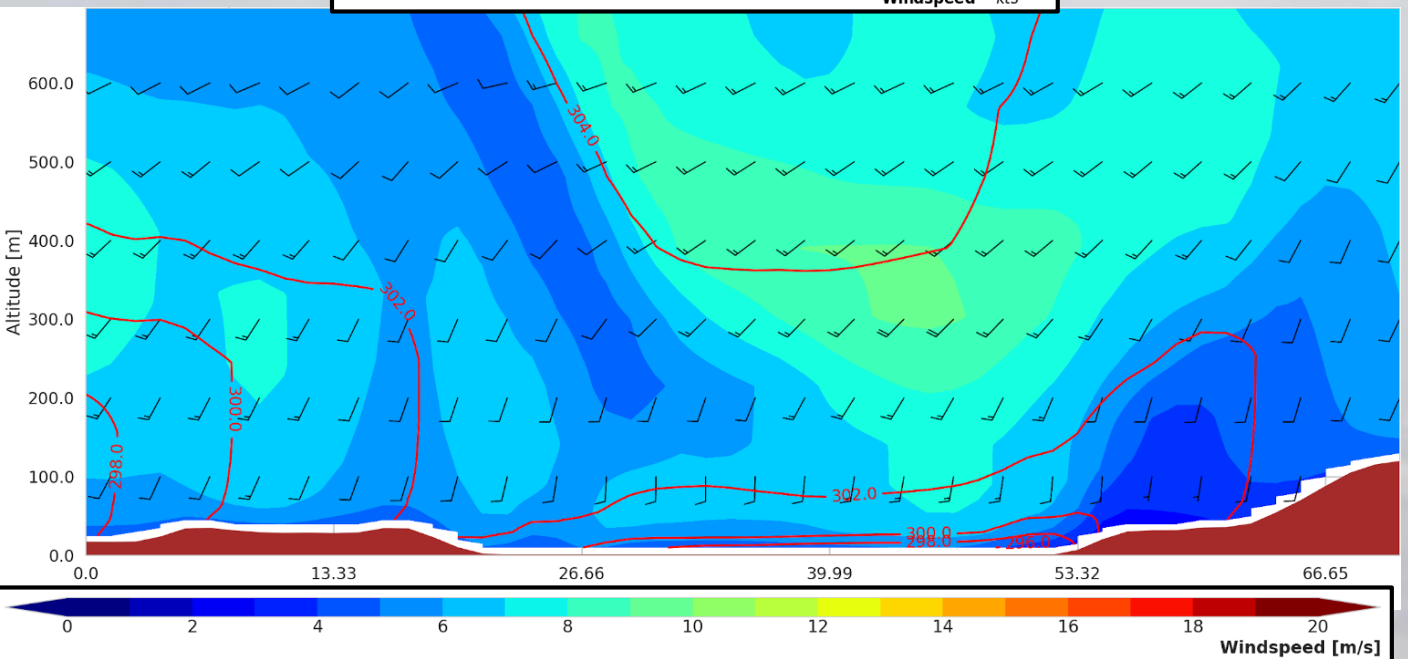


- Greatest ozone along LI coast but plume extends over LIS



July 10th: Central LIS N-S Cross-section 02 [20-21z]



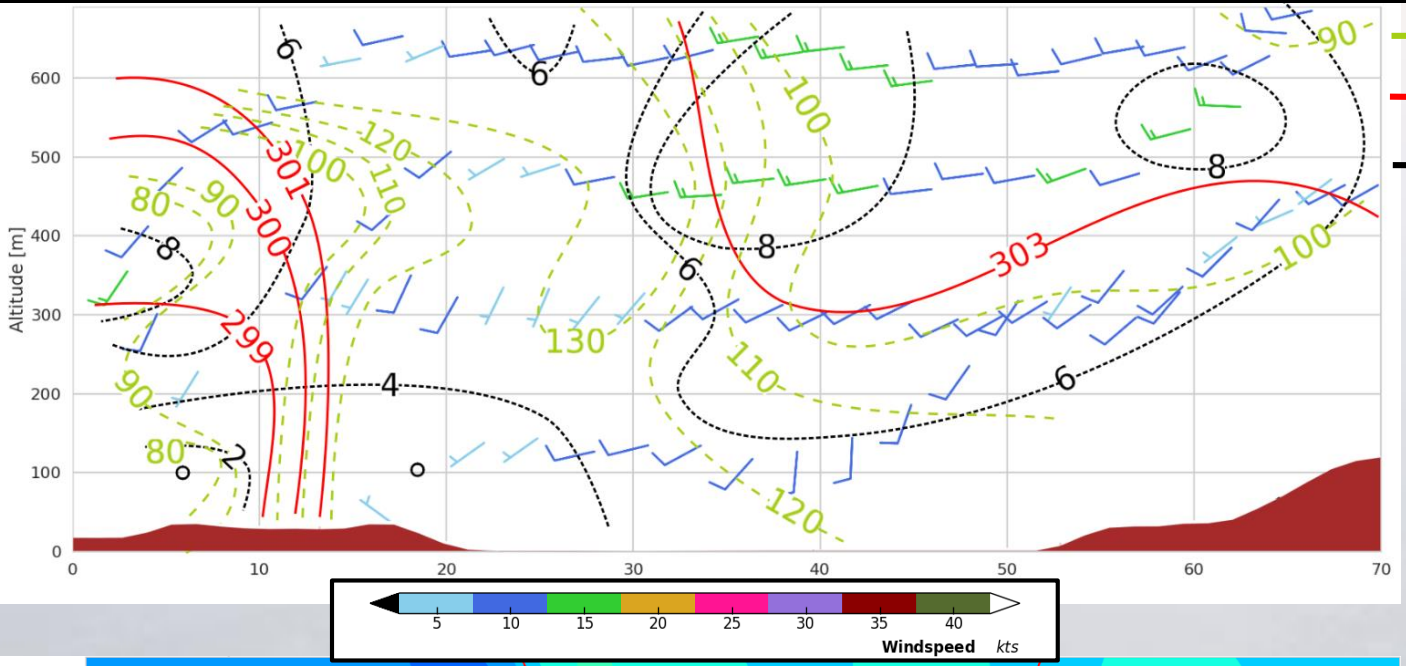


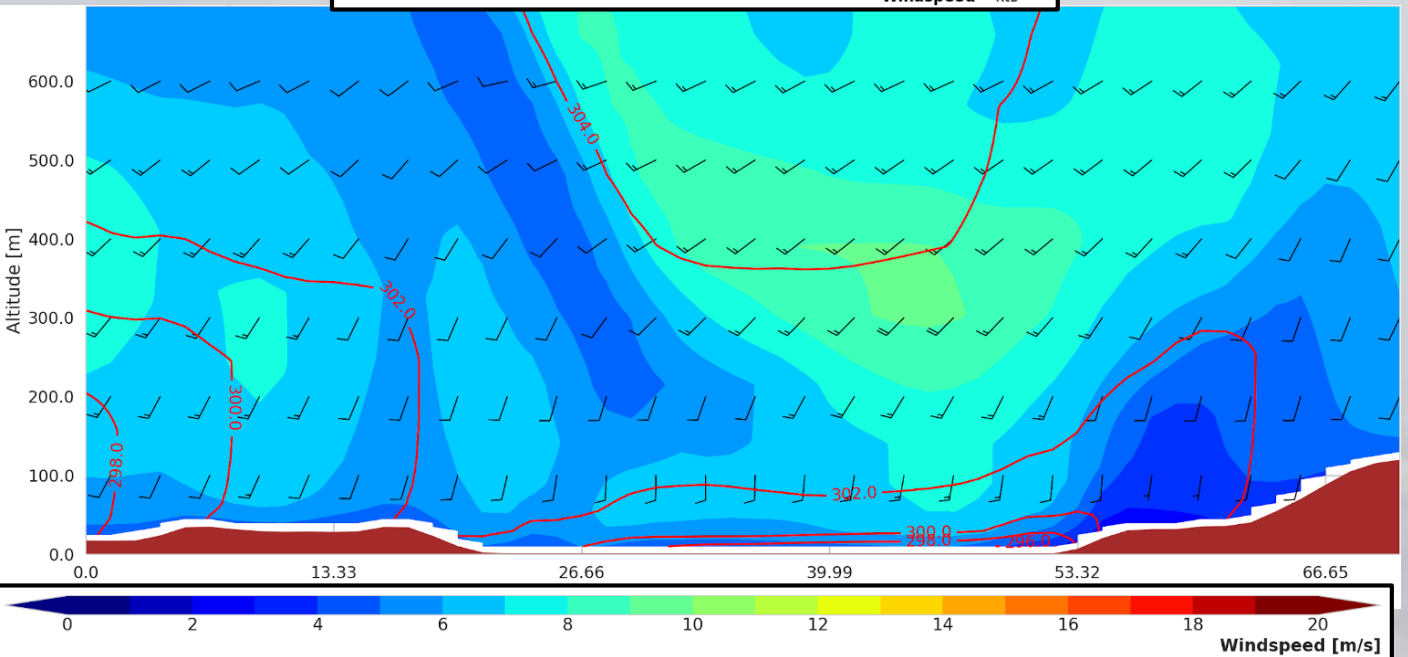
Theta

Windspeed

- WRF winds close to obs here or even slightly strong
- WRF running slightly warmer at 500m but cooler below 100m

July 10th: Central LIS N-S Cross-section 02 [20-21z]





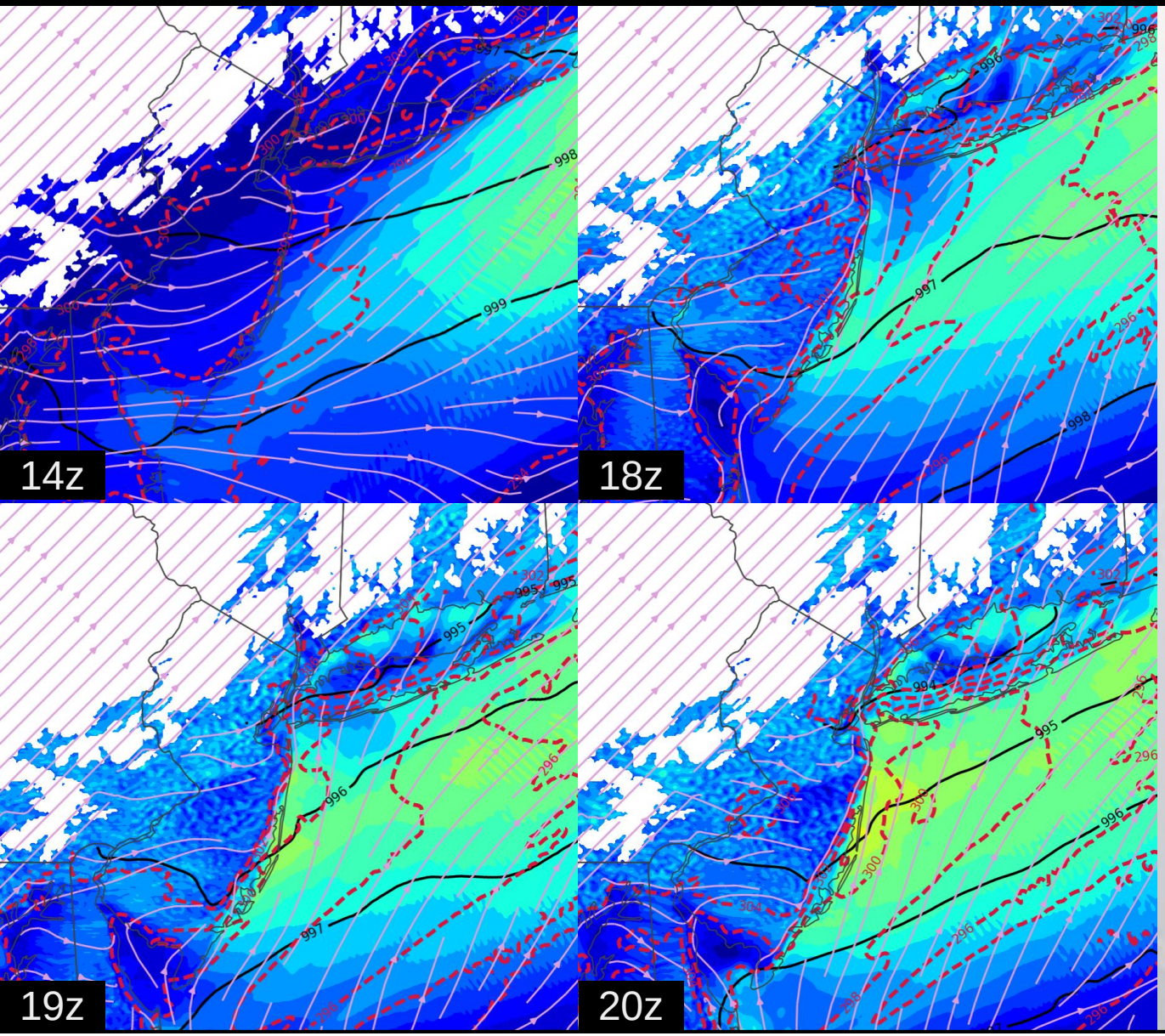
Ozone

Theta

Windspeed

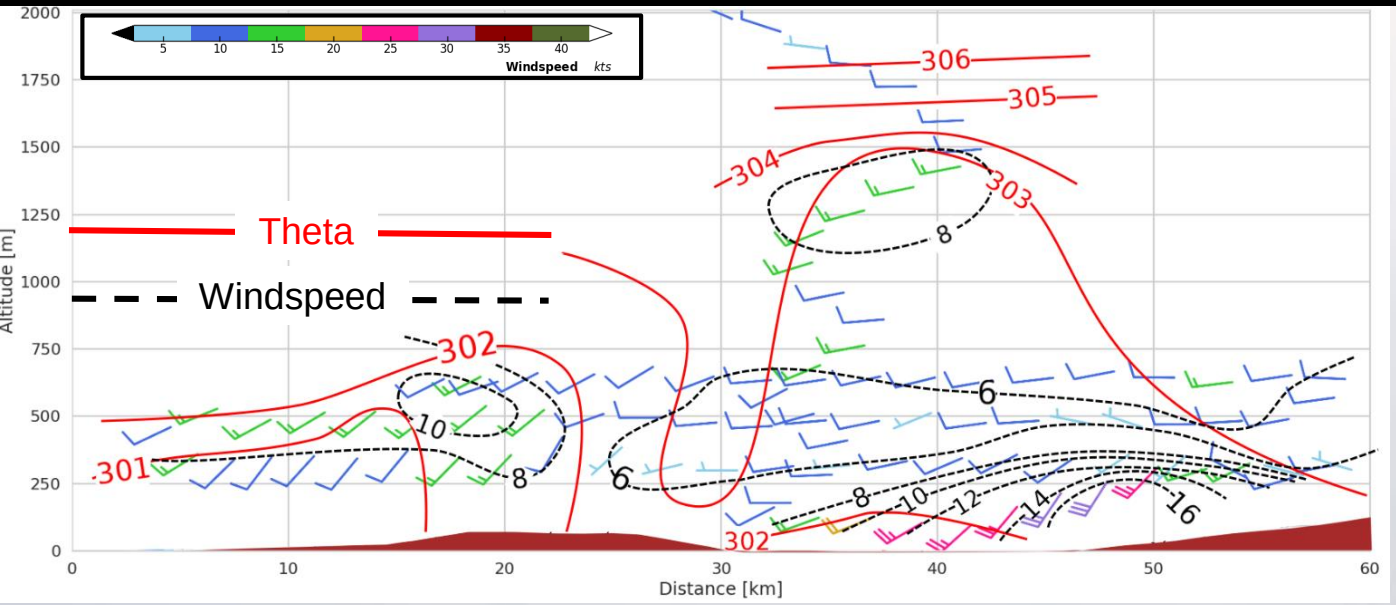
- Highest ozone again adjacent to LI MABL and extending northward to CT coast

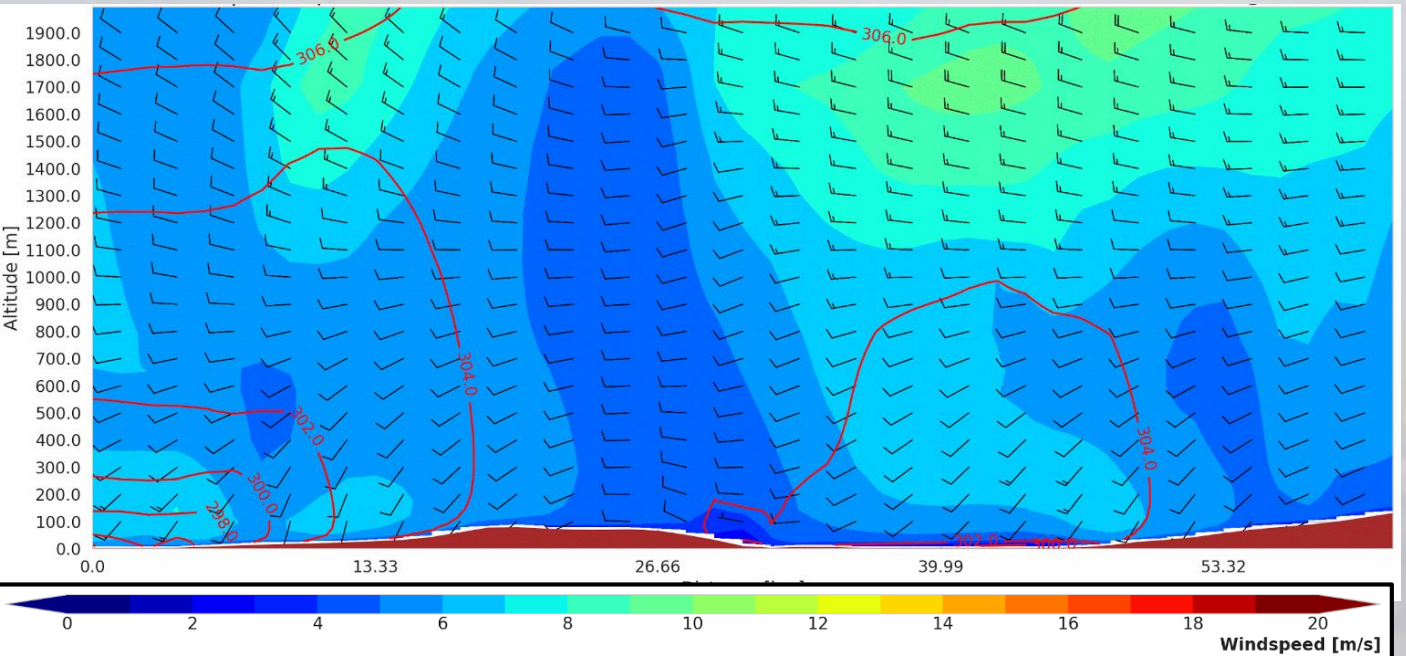
How does the boundary layer evolve (150m)?



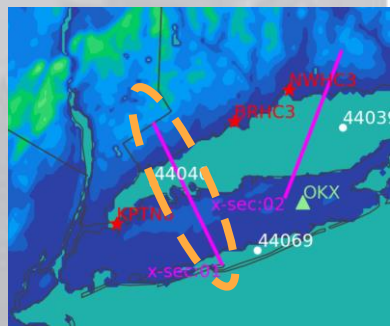
- From 12z to 00z on the 10th the pressure gradient tightens up driving this widespread LLJ
- LLJ begins spreading to LIS along the western portion of the CT coast as well as more broadly across the eastern LIS
- Gap in LIS LLJ noticeable near the location of xsec 1

July 10th: W LIS N-S Cross-section 01 [19-20z]





- WRF runs warm over LI
- Warm air ventilates over LIS
- As PBL over LI begins to weaken, flow from Atlantic moves over the island into the sound
- This produces a weak jet structure a few hours late



Conclusions

- 24 hour forecasts with our WRF are in general pretty good; however the details of transport (timing, magnitude) at any given location are very difficult to predict. Hindcast simulations should do better…
- The timing and movement of the Jersey seabreeze front onto the south shore of LIS (and to points north) is a moving target. The movement of this front will impact the LIS dynamics.
- WRF hardly captures the presence of a strong easterly low lying jet off the coast of CT. This jet is analogous to a jet we observed offshore the New Jersey Coast (for the first time) during the Cape Wind studies (Colle et al., BAMS, 2016). High O_3 was observed within this jet.
- For chemical weather studies (e.g., O_3 chemistry and its temporal and spatial evolution), the specifics in the transport characteristics for discrete events ought to be known/measured.