PennState

Coastal Thunderstorms

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6 December 2021, CIWRO Workshop on Meso-scale and Storm-scale Meteorology

Coastal Heterogeneities Impact Squall Lines

My group looks at the impact of surface and lower-atmosphere heterogeneities on deep convective storm (squall line) evolution

Our focus is largely on heterogeneities of the coastal zone

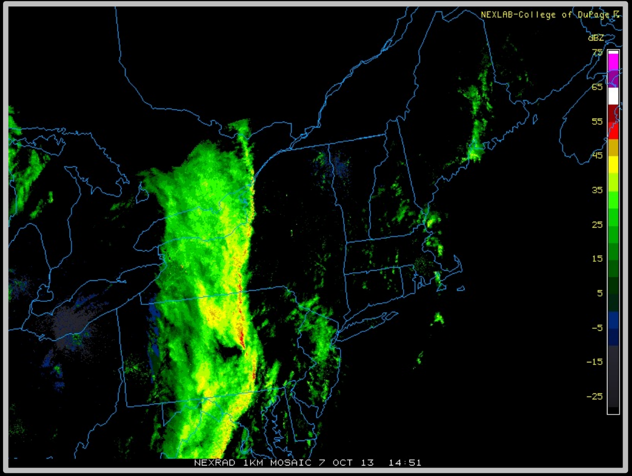
We study coastal squall lines globally, but our focus is the eastern US (Atlantic Coast, Gulf Coast, Great Lakes) for CIWRO

Storms Evolve in Different Ways at the Coast

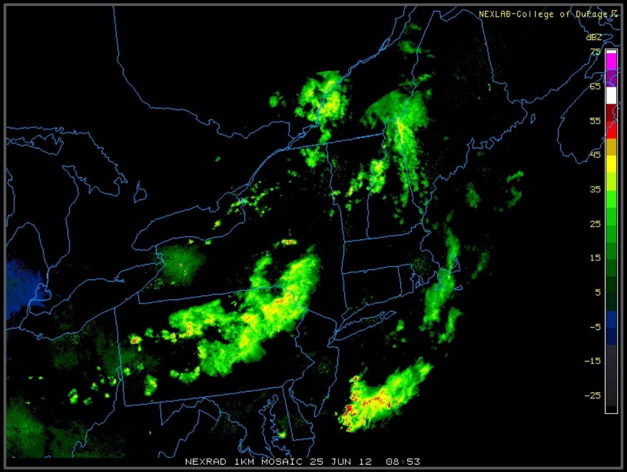
As squall lines move toward the coast and encounter sea breezes, i.e., stable marine atmospheric boundary layer (MABL; can propagate inland 10s km)..

..interesting changes occur in storm dynamics, evolution / life cycle, intensity, and precipitation

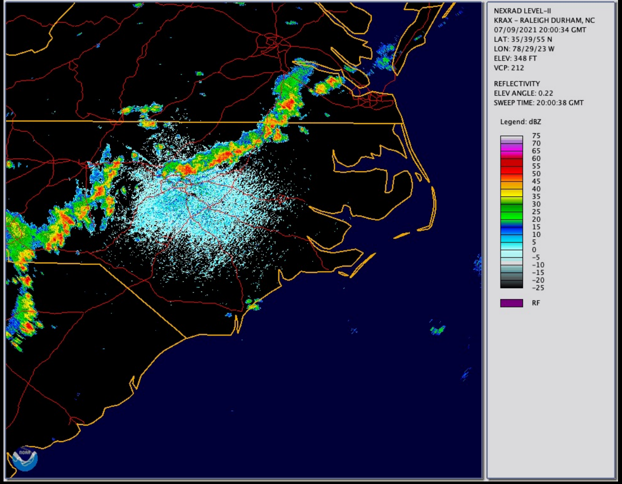
storm decays at coast



storm intensifies at coast



propagate discretely



Evolution Determines Potential for / Timing of Hazards


Flooding

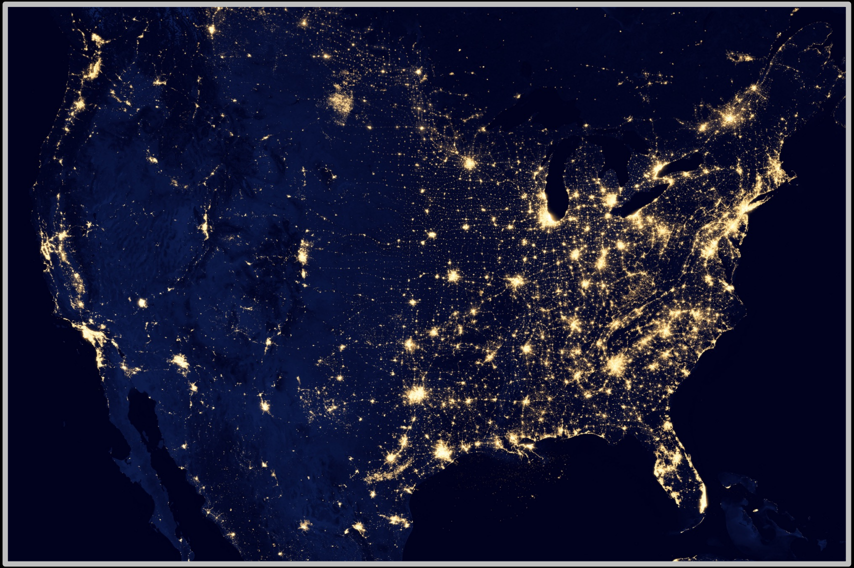

Hail

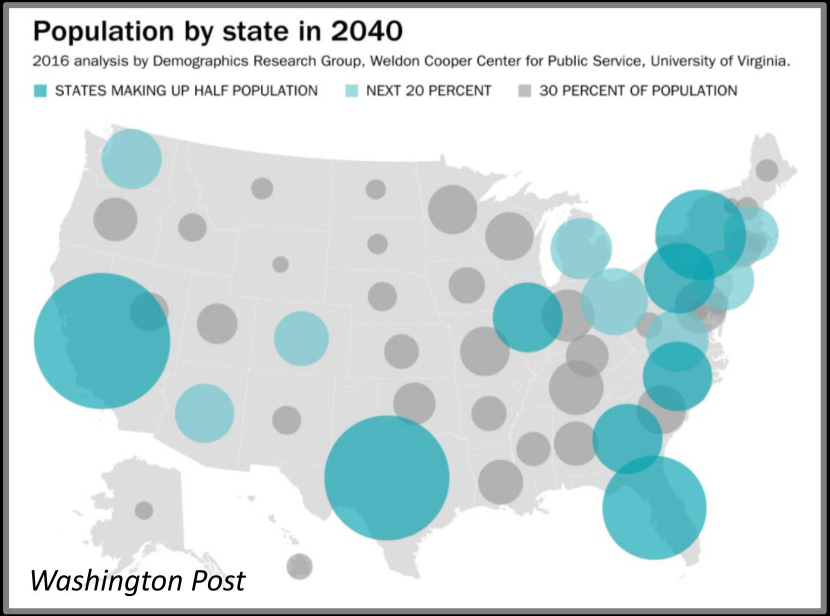

High Winds


Frequent Lightning


Tornadoes/Waterspouts

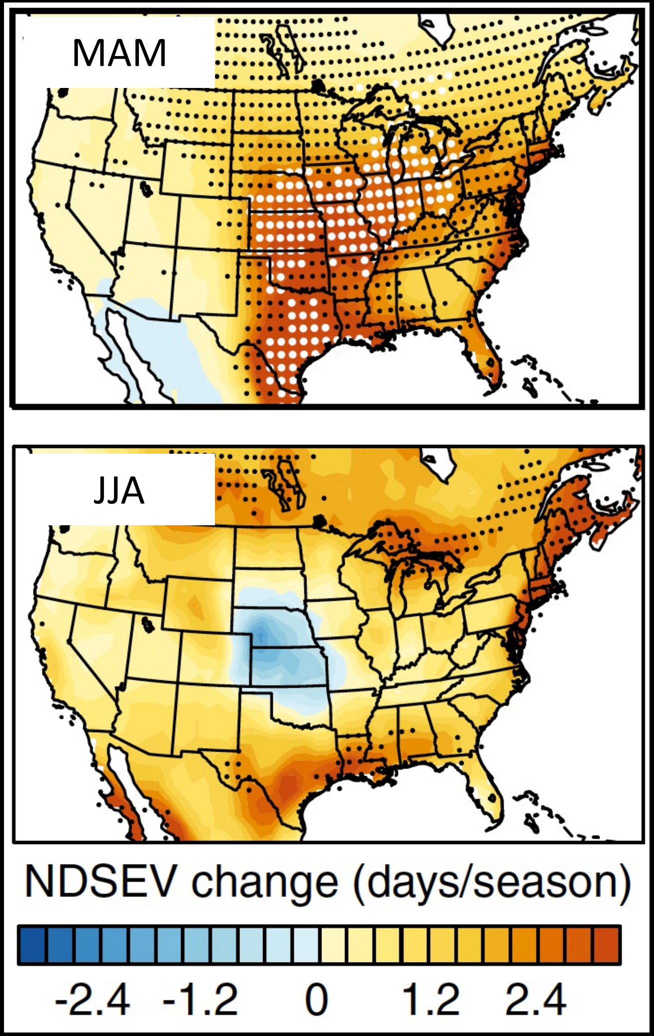
High Impact Events: Affect the Populous Coastline





Washington Post

Projected change in days/environments that favor severe thunderstorms

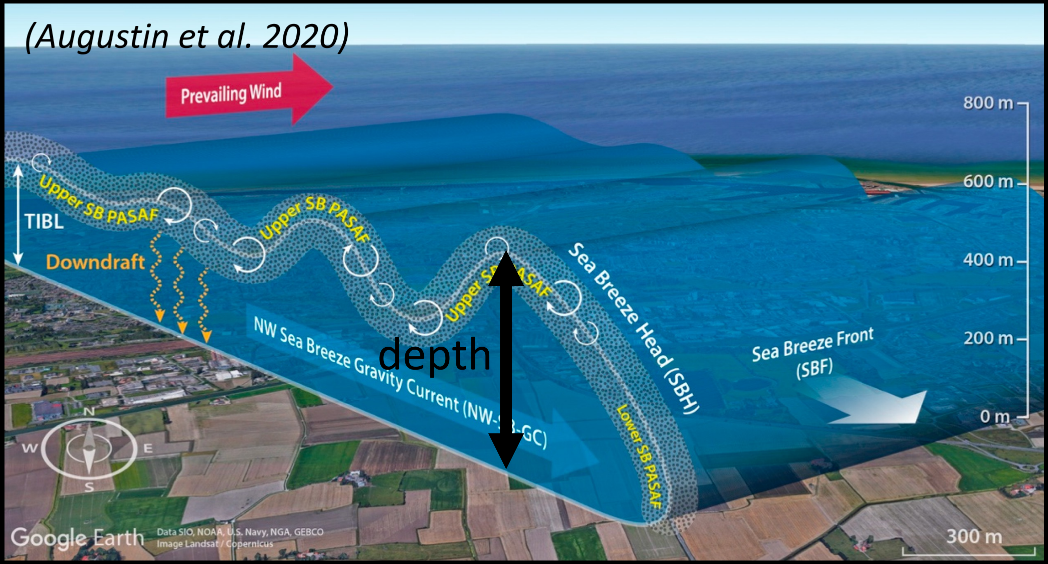


(Diffenbaugh et al. 2013)

Predicting Coastal Squall Line Evolution is Challenging

Coastal squall line evolution is sensitive to the

- environment (thermodynamic, kinematic, synoptic, mesoscale)
- storm dynamics and microphysics (cold pool)
- depth and density (buoyancy) of the MABL associated with the sea breeze


(Augustin et al. 2020)

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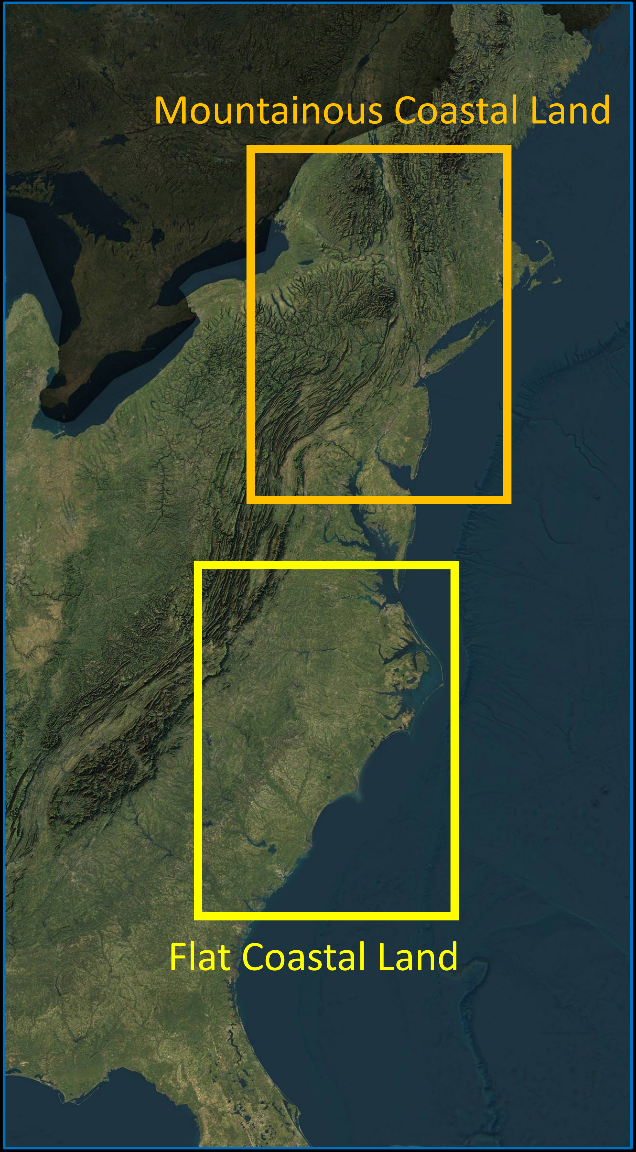
- storm dynamics and microphysics (cold pool)
- depth and density (buoyancy) of the MABL associated with the sea breeze
- height and slope of the coastal mountain (if present)



Idealized Simulations Simplify a Complex Problem

Use idealized numerical experiments to isolate the impact of a parameter space of MABL, mountain, thermal and wind vertical profile characteristics on storm evolution *(Lombardo and Kading 2018; Lombardo 2020; Wu and Lombardo 2021; Wu and Lombardo submitted)*

Identify the conditions that support the different evolutions and the driving physical processes

A couple societally-relevant results from our work:

As inland storms move toward the coast, there can be an increase in precipitation (hazards) BEFORE or WHILE the storm encounters the sea breeze

Once the storm encounters the sea breeze front, a change in the storm lifting mechanism (i.e., originally the cold pool) can prevent offshore decay..

..though it does not determine storm intensity (air above the MABL important)

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Different processes can cause this coastal precipitation maximum, and depend on

(1) the base-state environment

(2) if the coastline is flat or mountainous

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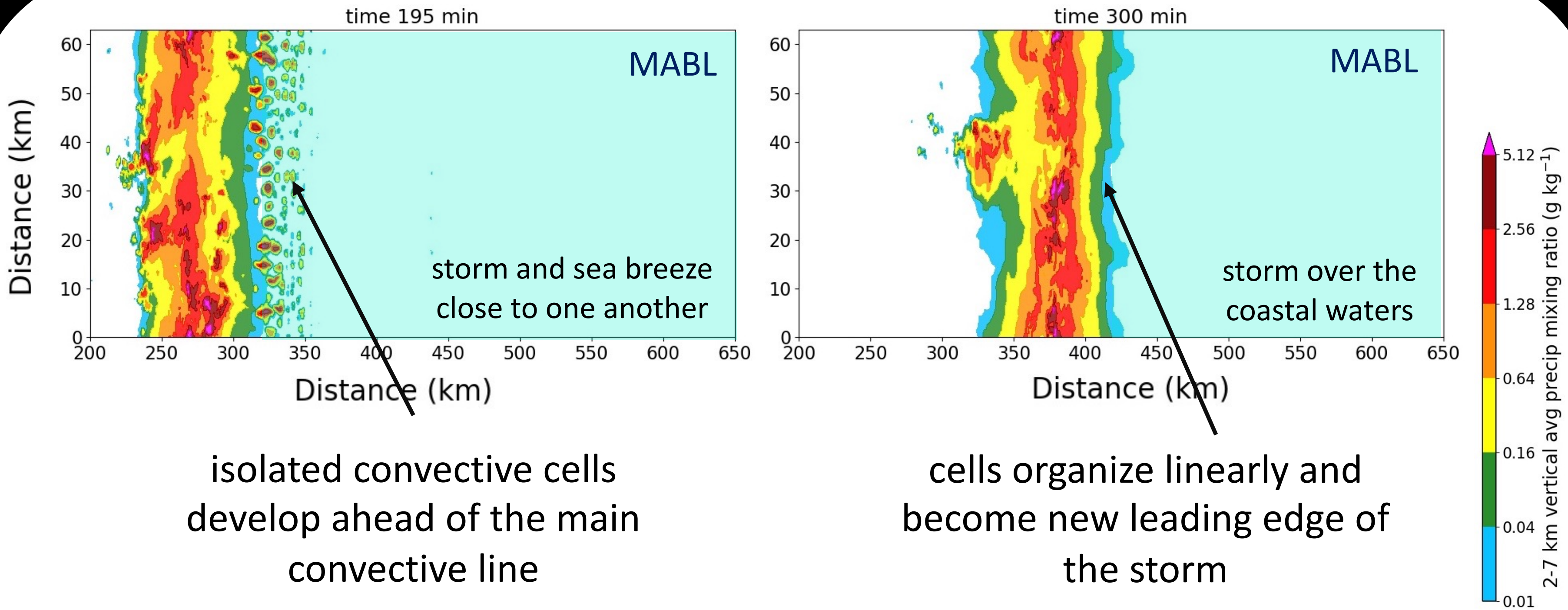
Precipitation Maximum over *Flat* Coastal Land

Coastal discrete propagation can lead to a coastal precipitation maximum

plan view of 2-7 km vertically averaged q_{prcp}



storm and sea breeze close to one another

storm over the coastal waters

isolated convective cells develop ahead of the main convective line

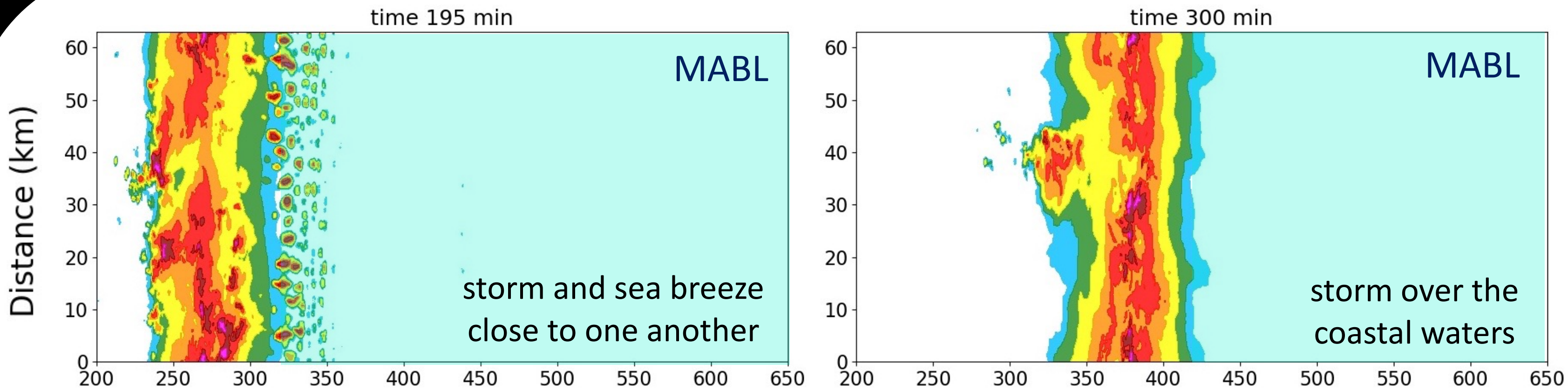
cells organize linearly and become new leading edge of the storm

(Lombardo 2020)

Precipitation Maximum over *Flat* Coastal Land

Peak in precipitation 20-30 min prior to storm meeting sea breeze front

plan view of 2-7 km vertically averaged q_{prcp}



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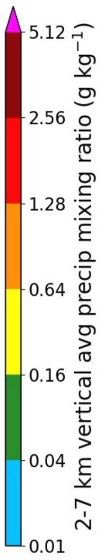
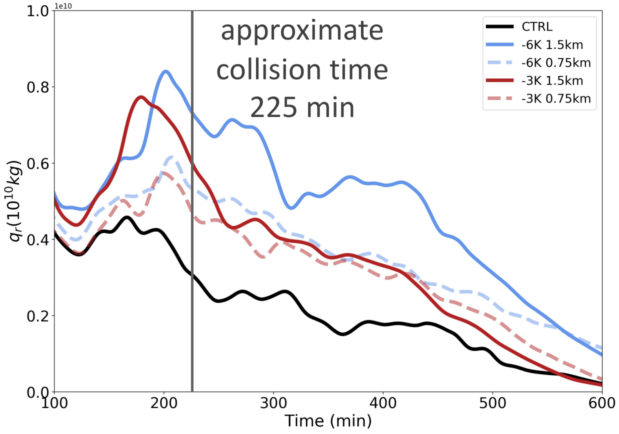


Precipitation hazard is larger, occurs before the storm and sea breeze front interact

More precipitation for deeper, colder MABLs

total mass of rain (kg) in the domain



approximate collision time 225 min

(Lombardo 2020)

Propagation Physics Sensitive to the Environment

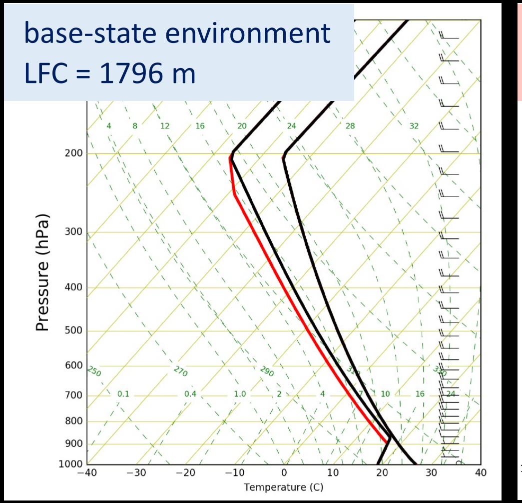
Environment 1

Sea breeze too shallow to lift parcels to base-state LFC

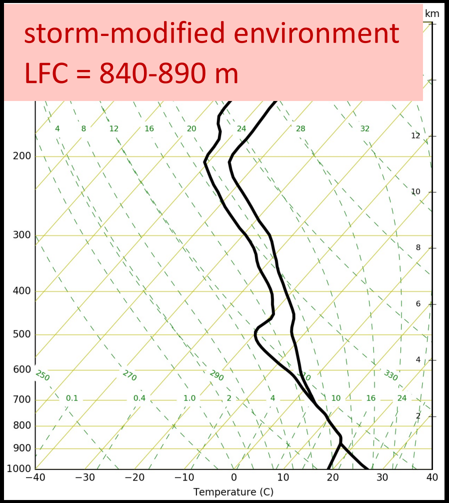
A *subset* of sea breezes were deep enough to lift parcels to the storm-modified LFC

Thus, CI near the storm

(Lombardo and Kading 2018)

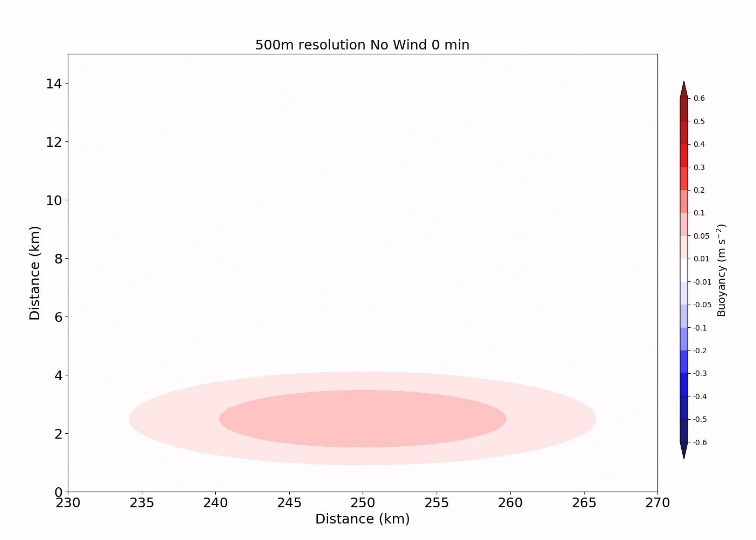


base-state environment
LFC = 1796 m



storm-modified environment
LFC = 840-890 m

generation of a buoyant updraft, buoyancy (shaded) and vertical motion (positive is solid, negative is dashed)



Environment 2

CI was not due to a lowering of the LFC

CI due to the constructive interference of gravity waves generated by the storm and by the sea breeze front

All sea breezes supported CI

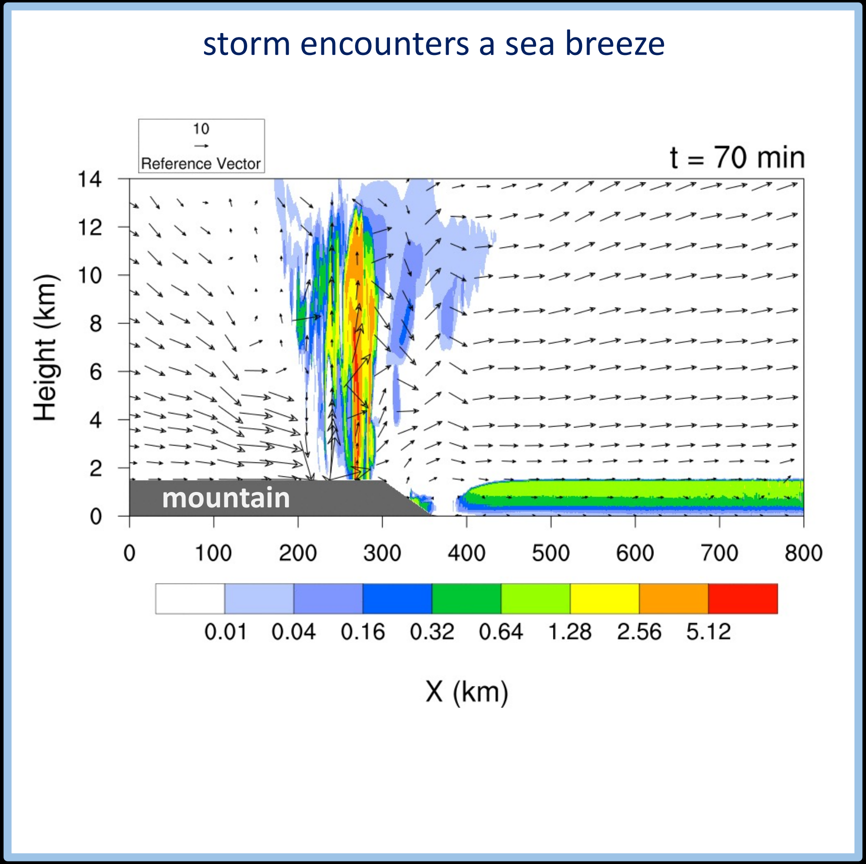
(Lombardo 2020)

Precipitation Maximum over *Mountainous* Coastal Land

No discrete propagation occurs when coastal mountains are included (Environment 2)

Interaction between the storm cold pool and sea breeze front lead to a coastal precipitation maximum near the cold pool-sea breeze collision time

cross section of mixing ratio (prcp, cloud), wind



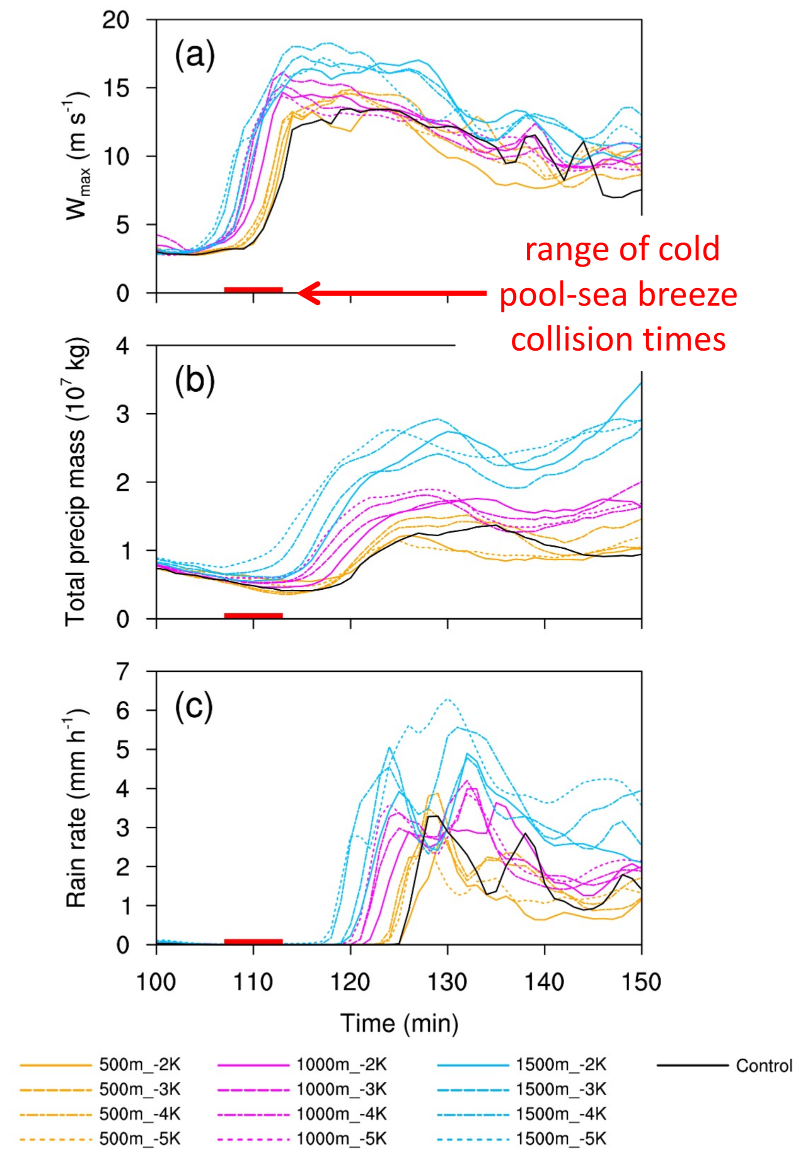
(Wu and Lombardo 2021)

Precipitation Maximum over *Mountainous* Coastal Land

Maximum in ascent occurs at the cold pool-sea breeze collision time, with the precipitation peak ~10 minutes later

Greater ascent, total precipitation, and rain rate for deeper (and colder) MABLs

Reduction in the baroclinic generation of horizontal vorticity behind the cold pool leading edge, the associated p', and downward inertial acceleration



range of cold pool-sea breeze collision times

(Wu and Lombardo 2021)

Once the storm encounters the sea breeze front, a change in the storm lifting mechanism (i.e., originally the cold pool) can prevent offshore decay..

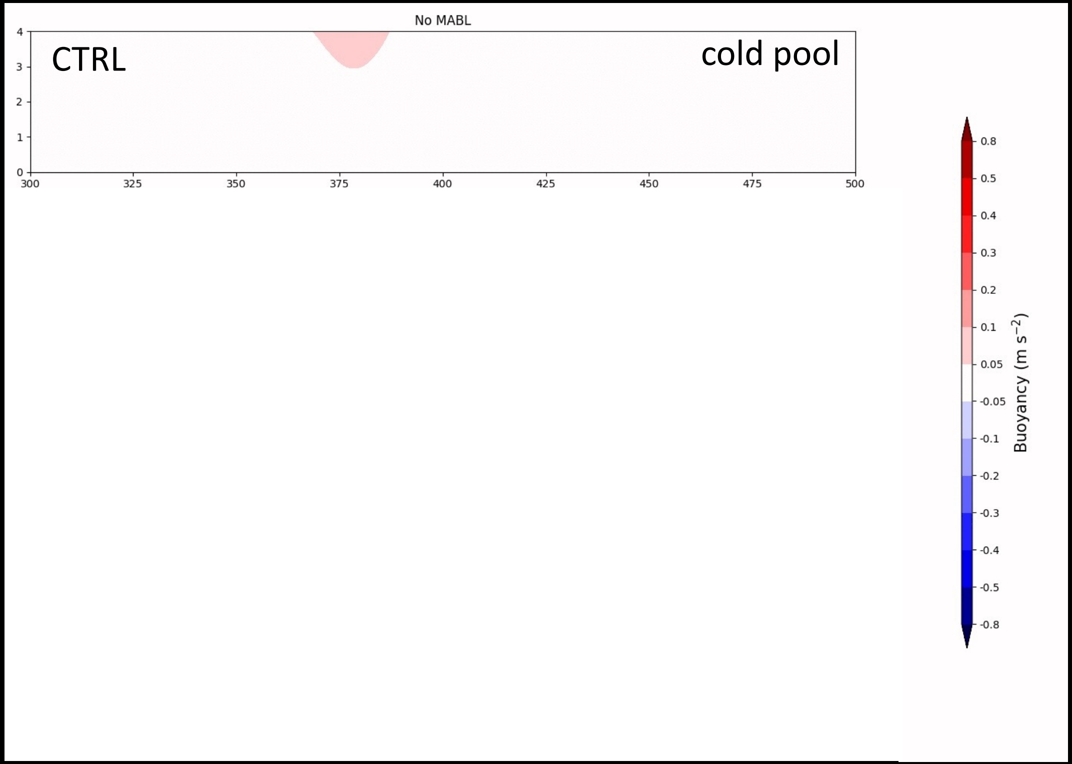
..though it does not determine storm intensity (air above the MABL important)

Coastal Crossing Mechanism/Success Determined by MABL

Over land, cold-pool driven ascent supports storm propagation

The ability of the cold pool to lift parcels, and even the ascent mechanism itself (i.e., no longer cold-pool-driven ascent) can change after the cold pool and sea breeze front collide and the storm moves over the coastal waters

Cross sections of buoyancy from idealized numerical simulations of a squall line moving over a marine layer

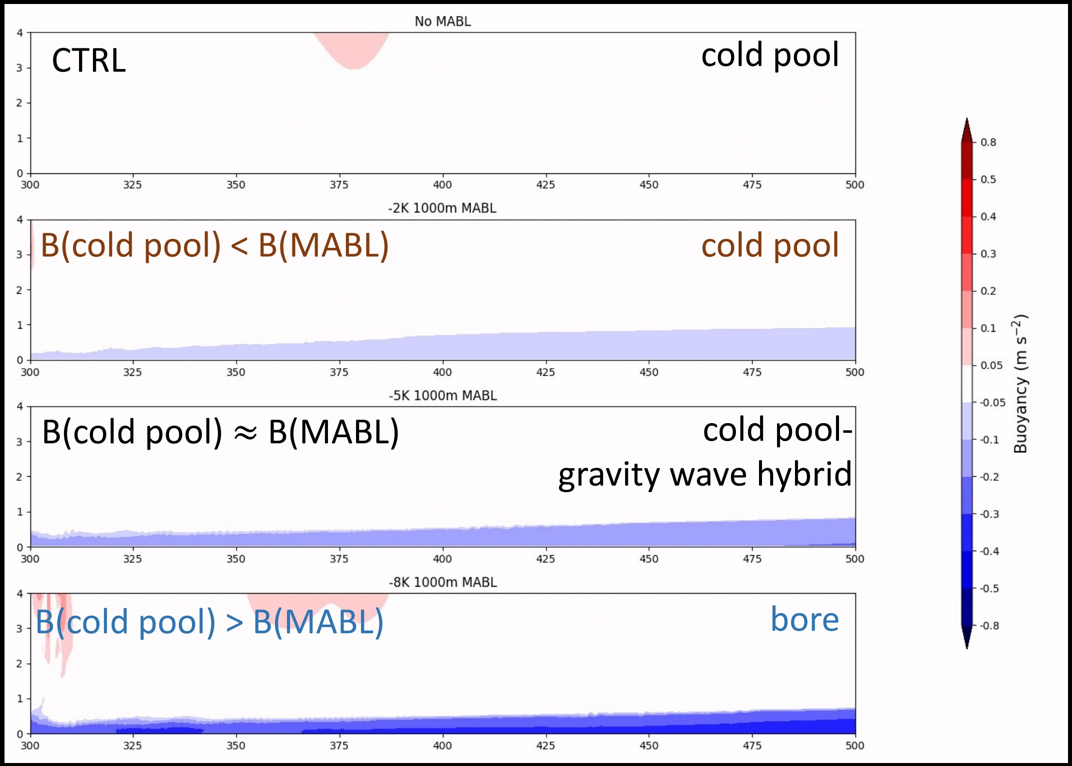


(Lombardo and Kading 2018; Lombardo 2020; Wu and Lombardo 2021)

Coastal Crossing Mechanism/Success Determined by MABL

The buoyancy of storm cold pool relative to the buoyancy of the MABL determines the parcel ascent mechanism as storms move over the coastal waters

Cross sections of buoyancy from idealized numerical simulations of a squall line moving over a marine layer



Buoyancy gradient across the cold pool leading edge weakens, cold-pool-driven ascent can be reduced leading to storm decay

(Lombardo and Kading 2018; Lombardo 2020; Wu and Lombardo 2021)

Bore generation allows the storm to move successfully offshore

Environment 1
storm is weaker offshore

Environment 2
storm intensified offshore
(but only if the coastline is flat)

Ok, so you showed us a bunch of idealized modeling stuff that highlights the messiness of coastal convective storm processes.

What does this have to do CIWRO?

Use this Idealized Work to Inform New Avenues

Improved Understanding of Observed Coastal Convection:

Combine convection-allowing modeling studies with observational campaigns to understand the controls on coastal deep convective storm initiation, intensification, and hazard development near and along coastlines

Forecast Improvement of Coastal Storms:

Envision collaborations with the Warn-on-Forecast project/team to improve predictions of coastal convection

Exploration of Additional Observed Coastal Complexities:

Target the role of heterogeneities in offshore marine air mass characteristics, coastline shape, and land surface (e.g., urban vs rural), while identifying local regions with recurring convection initiation and storm intensification

Looking Forward to Future Collaborations!

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CIWRO

Cooperative Institute for Severe and High-Impact Weather Research and Operations