Dynamical Drives of aerosol-cloud radiation interactions over the North Atlantic Ocean

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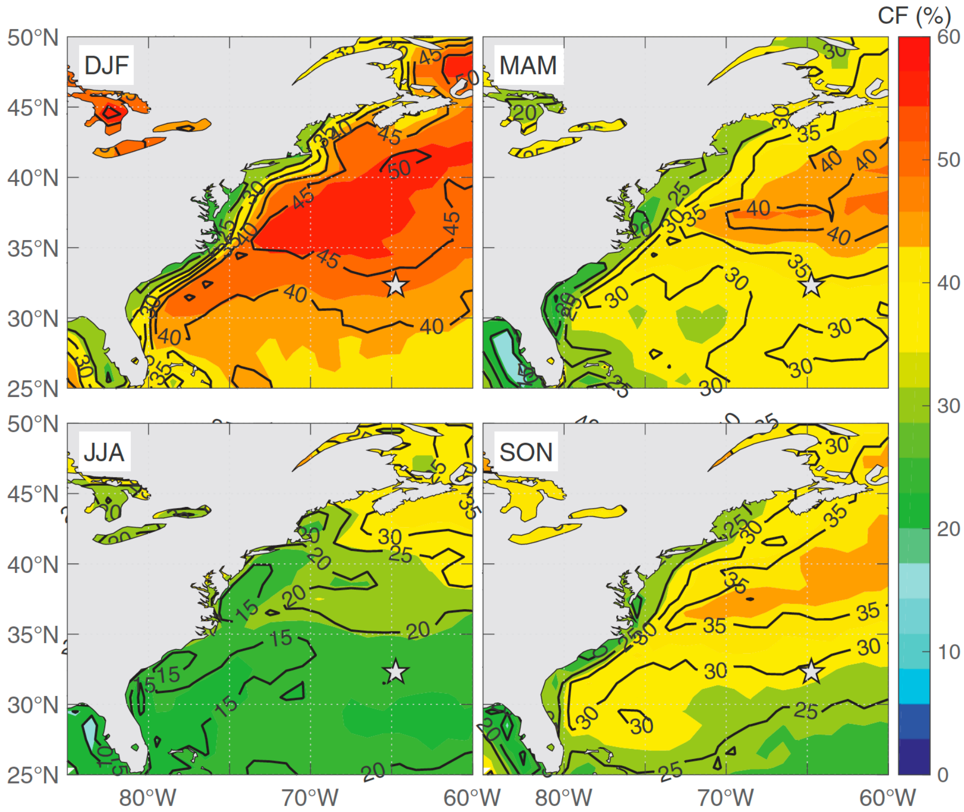
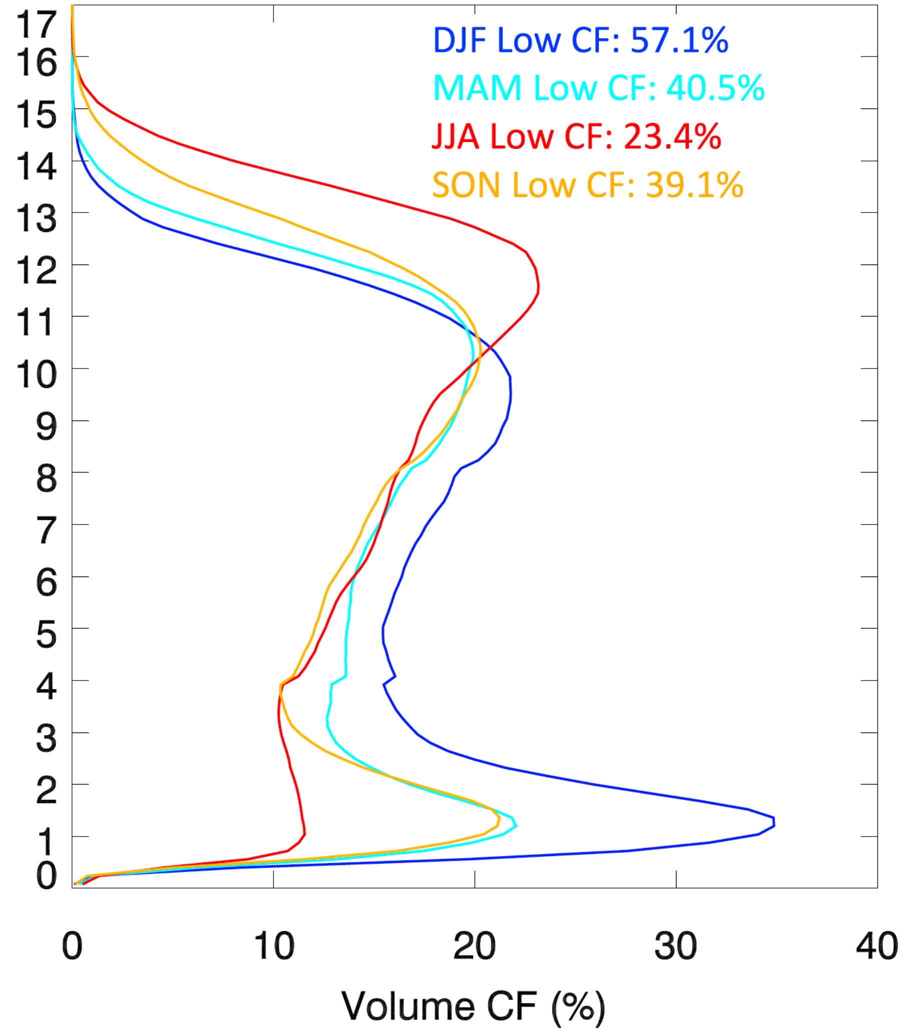
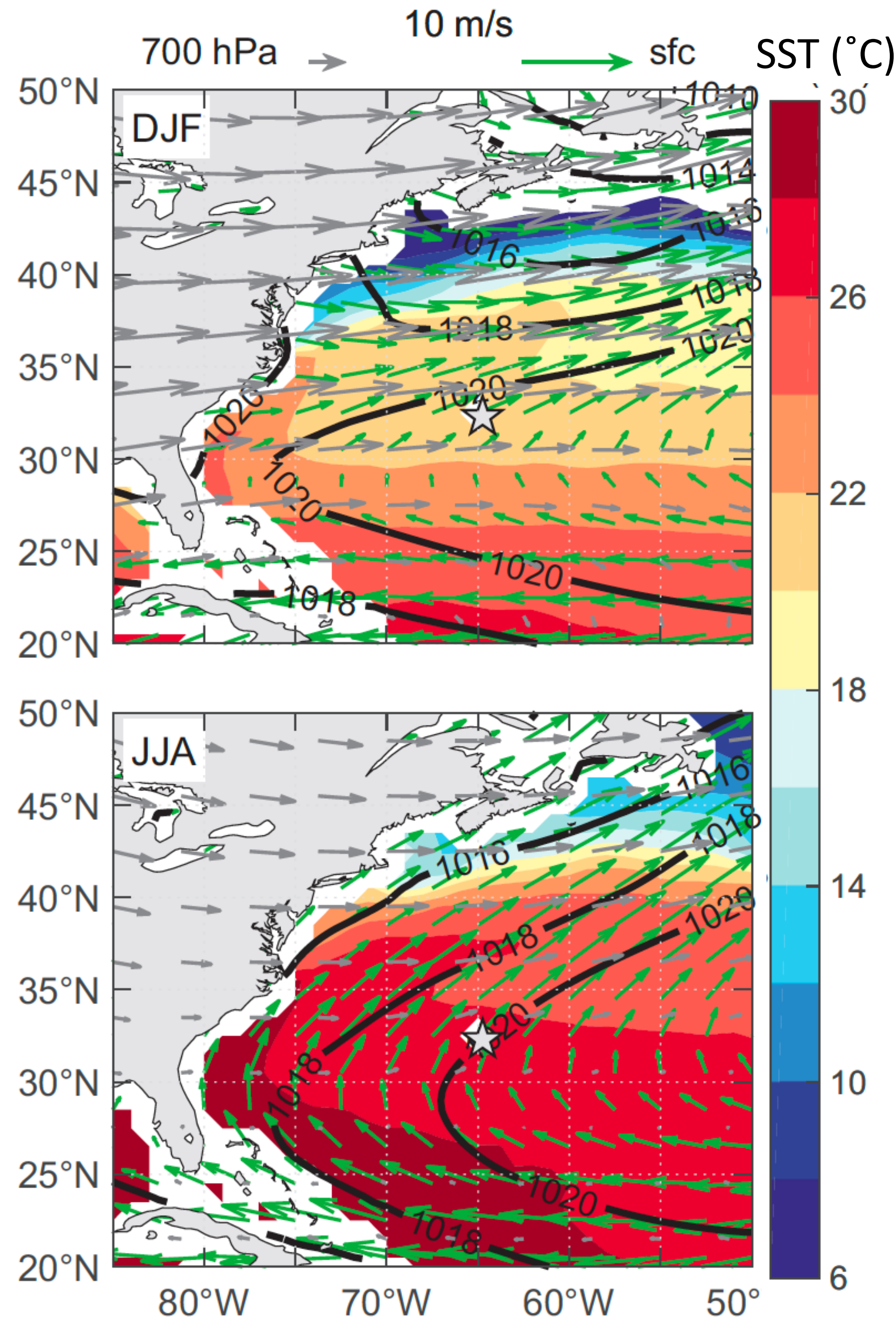
Motivation: Occurrence of boundary layer clouds in the extra-tropics.

- A distinct annual is observed, with maximum cloud coverage in winter.

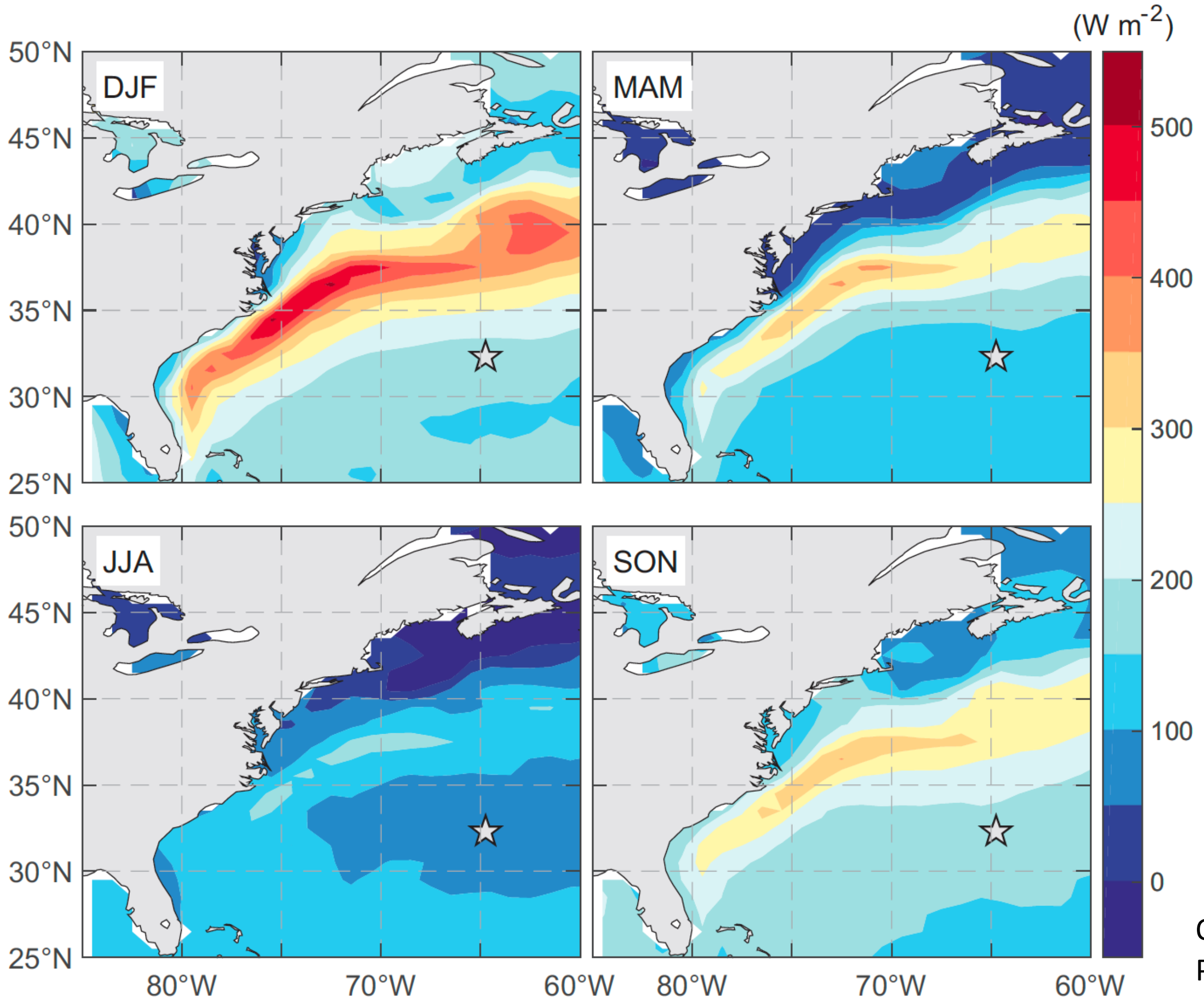




Winter low clouds and climatological factors

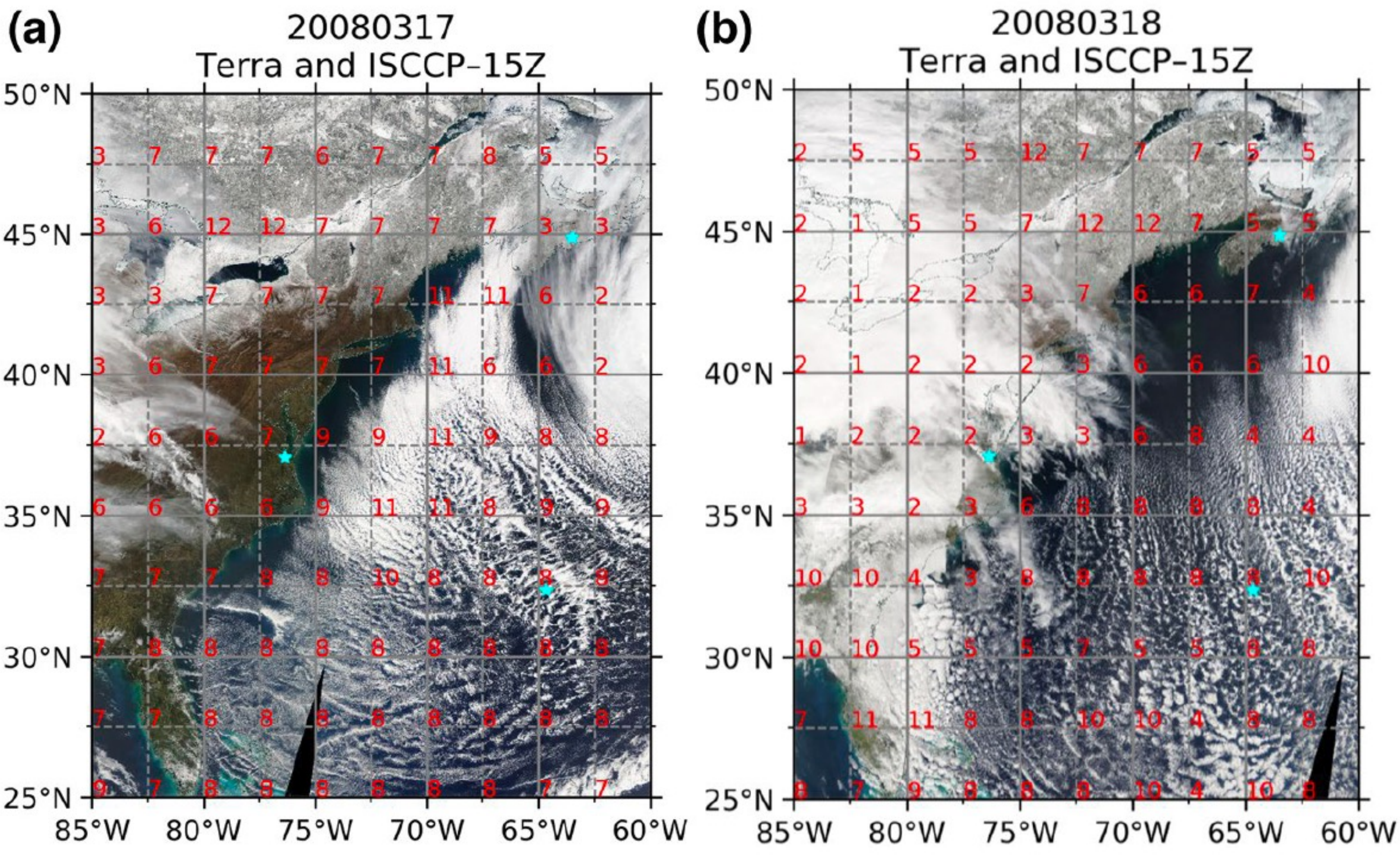


Motivation: Air-sea interactions

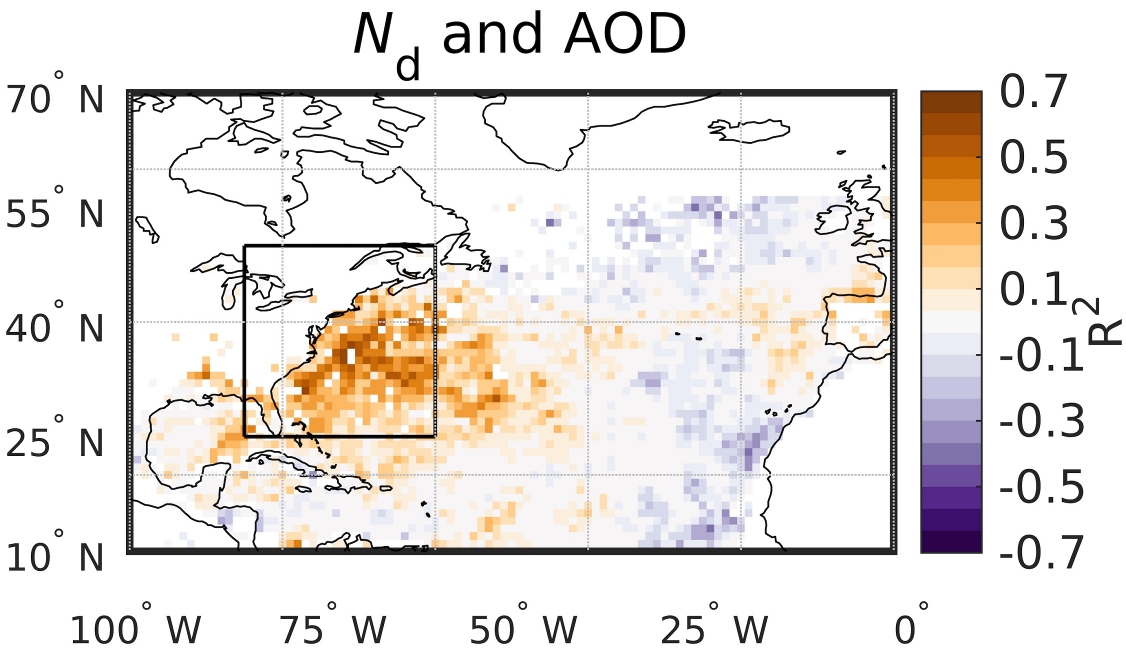


OAFlux surface turbulent fluxes, Painemal et al. (2021)

Typical mesoscale structures



- Aerosol-cloud covariations are evinced over the WNAO



Long-term correlations between MODIS AOD and CERES-MODIS Nd.

Objectives

- Describe the synoptic evolution of WNAO marine boundary layer (MBL) clouds in winter.
- Analyze the processes that modify the cloud microphysics and explain aerosol-cloud interactions.
- Discuss outstanding problems in our understanding of extra-tropical MBL clouds

Winter synoptic classification

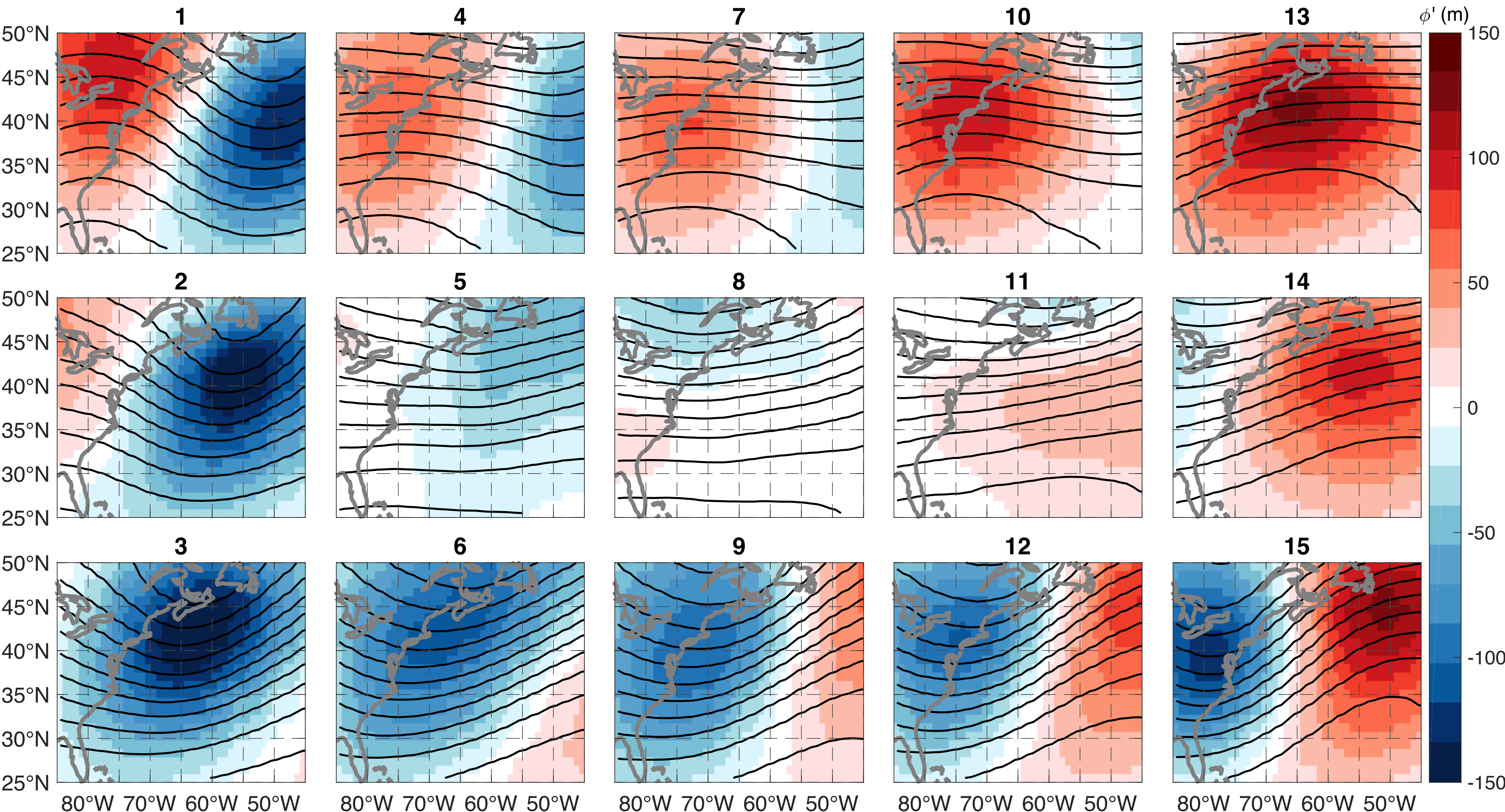
- Goal: Describe the synoptic evolution for the ACTIVATE domain.
  - Facilitate the interpretation of ACTIVATE data
  - Understand ACTIVATE observations in the context of regional-scale processes.
  - Address the ”constant meteorology” condition in aerosol-cloud interactions.
- Method: clustering analysis based on Self-Organized Maps (SOM) applied to geopotential height at 600 hPa.
- 12 year of daily data for Jan-Feb-March

Synoptic classification

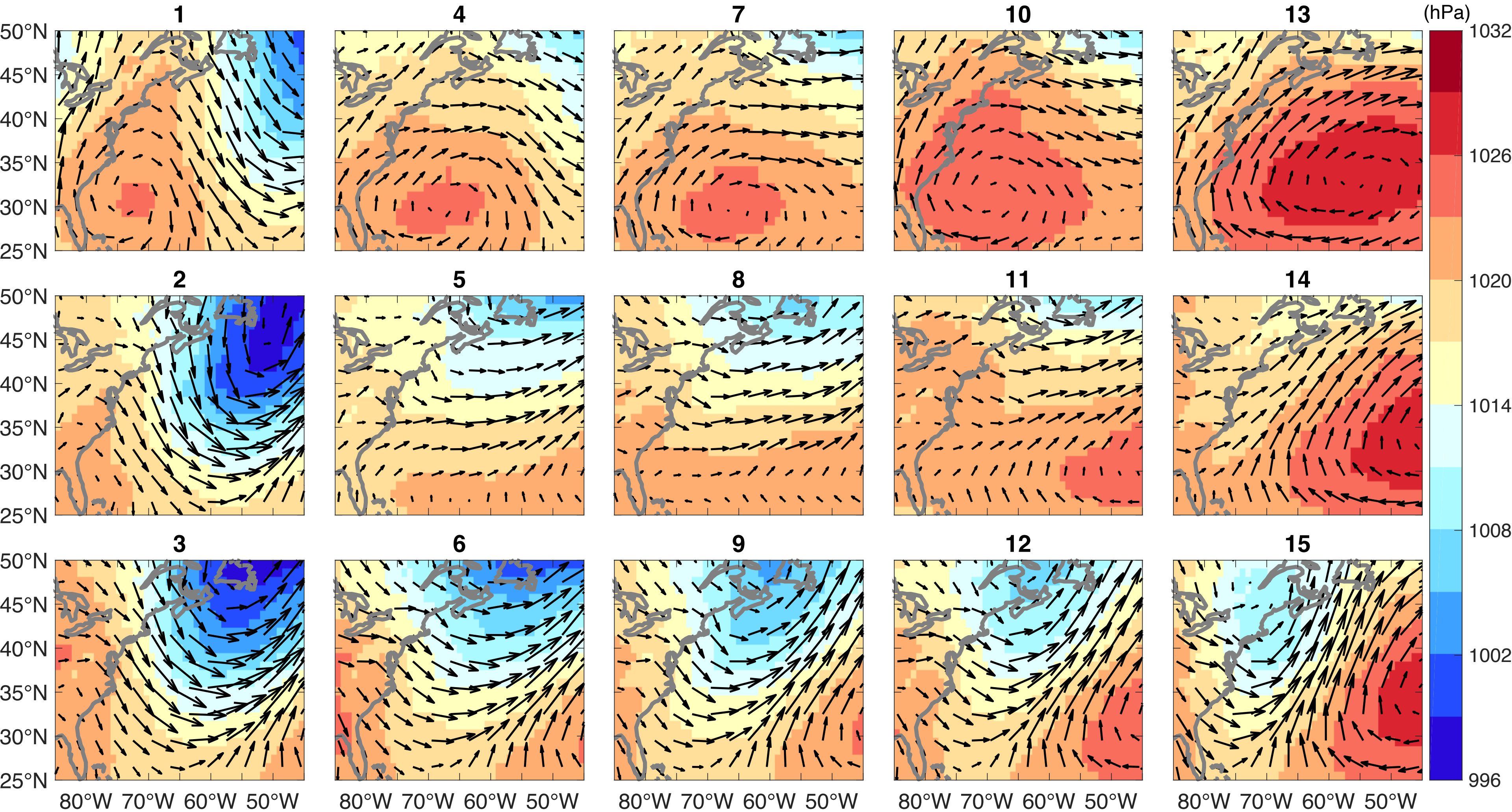
- Spatial patterns are identified using a (pseudo) neural network: Kohonen's self organizing maps.
- The technique identifies patterns (nodes) associated with a given number of observations, by minimizing the distance between the node and the data to be classified.
- Methods for determining an optimal number of nodes exist, however, a balance need to be kept between simplicity and number of synoptic patterns.
- Geopotential height (GH) at 600 hPa is used for the SOM classification. The fields are deseasonalized and normalized by their monthly standard deviation.
- GH is more appealing than sea level pressure(SLP) because postprocessing based on trough and ridge is quite simple. It will be shown that GH wave train evolution is linked to variations in SLP and circulation.

Geopotential height composited into 15 SOMs

- We prescribe 15 classes to be generated by SOM. These patterns are used to categorize daily maps of geopotential heights

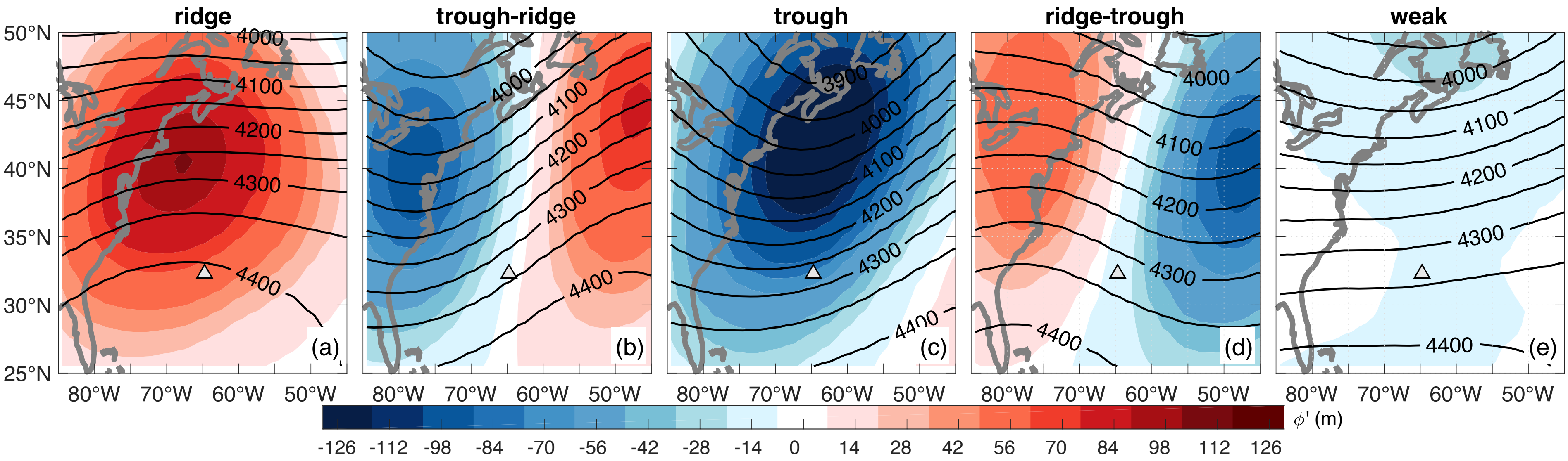


Composited sea level pressure and BL winds based on the previous 15 SOMs



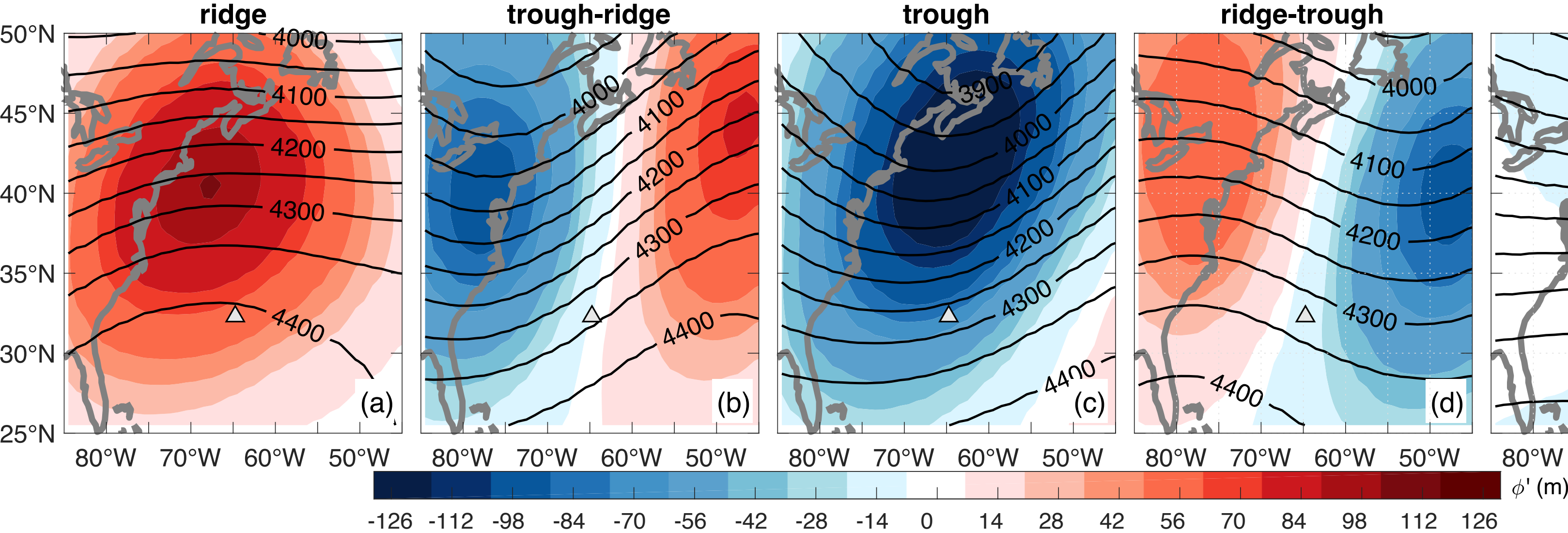
Winter synoptic classification

- Let's further simplify the problem by regrouping the 15 SOMs into 5 categories.
- Groups: 1) dominant ridge, 2) dominant trough, 3) ridge-trough, and 4) trough-ridge (from east to west). 5) An additional group corresponds to days in which the geopotential height resemble the climatological mean.

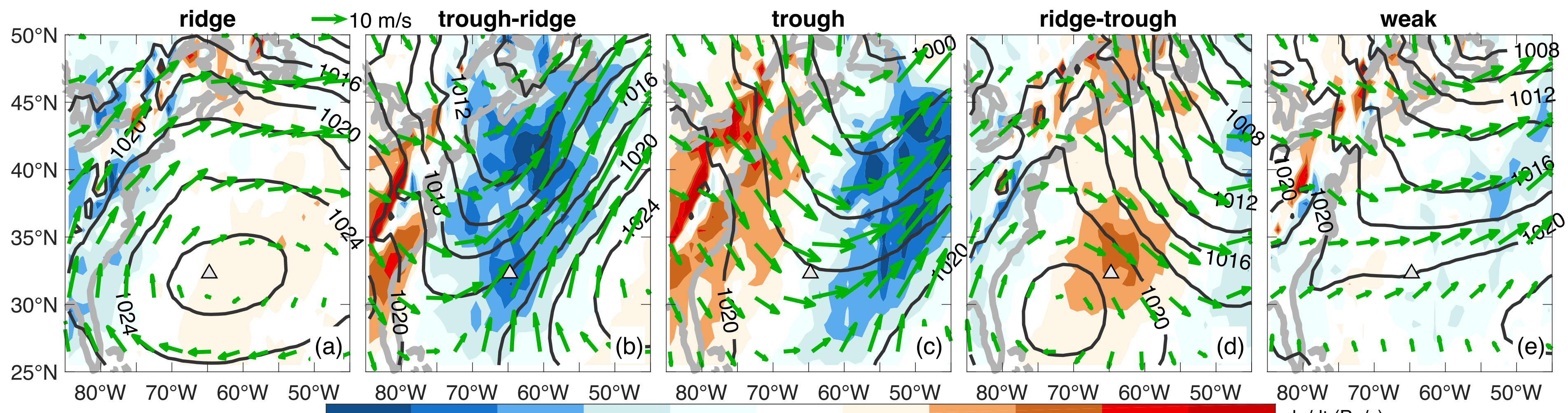


Winter synoptic classification

Geopotential height at 600 hPa (ϕ)

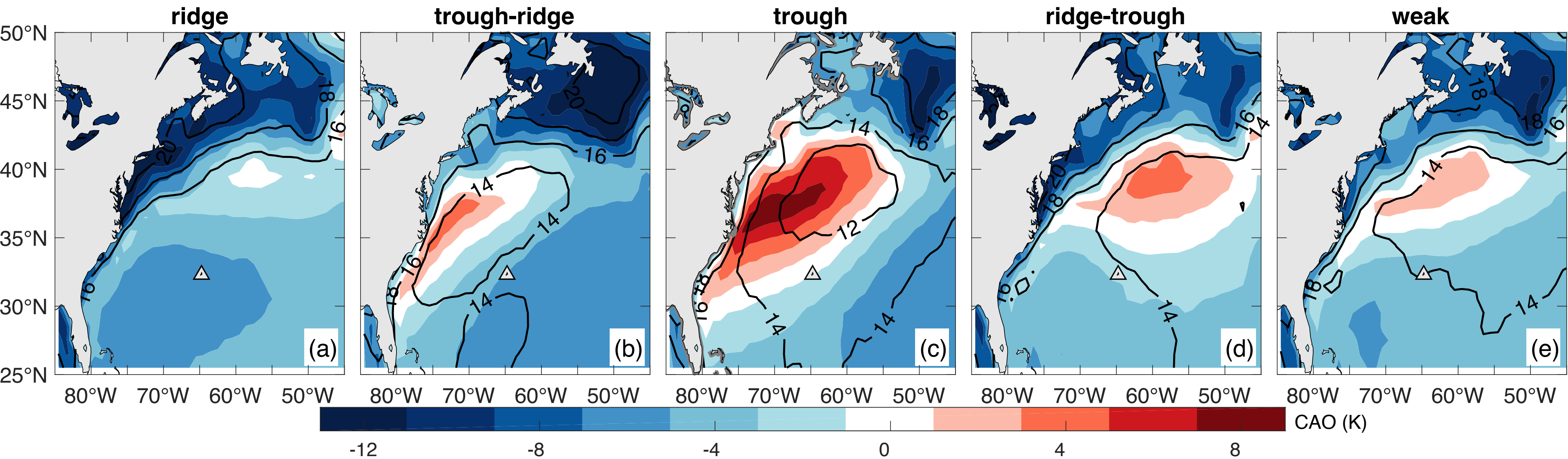


Sea level pressure (contour), winds at 925 hPa (arrow), and dp/dt (color, ∝ -w)

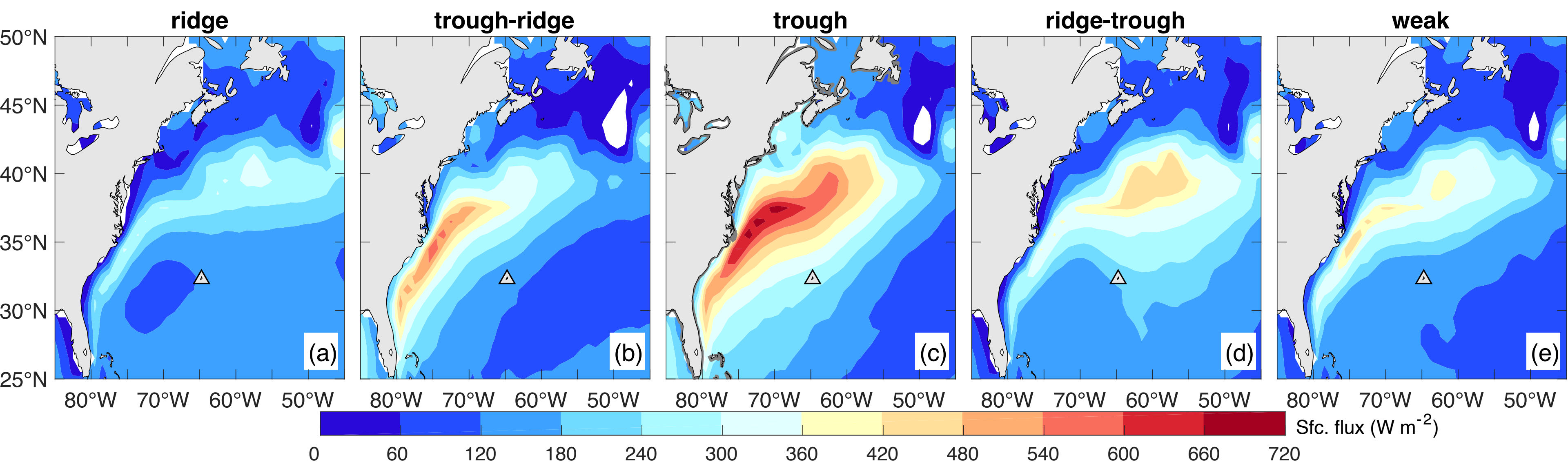


Cold-air outbreak index and surface fluxes

- CAO Index=θ_{SST}- θ_{800hPa} and Lower trop stability (LTS, contours)

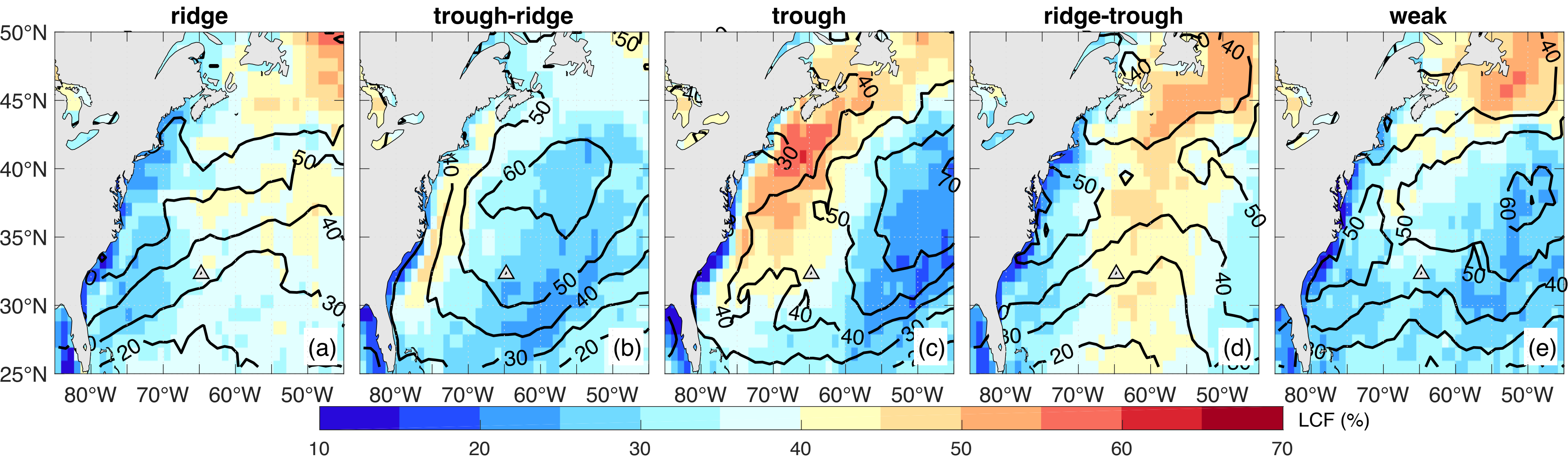


- OaFlux surface fluxes (latent+sensible)

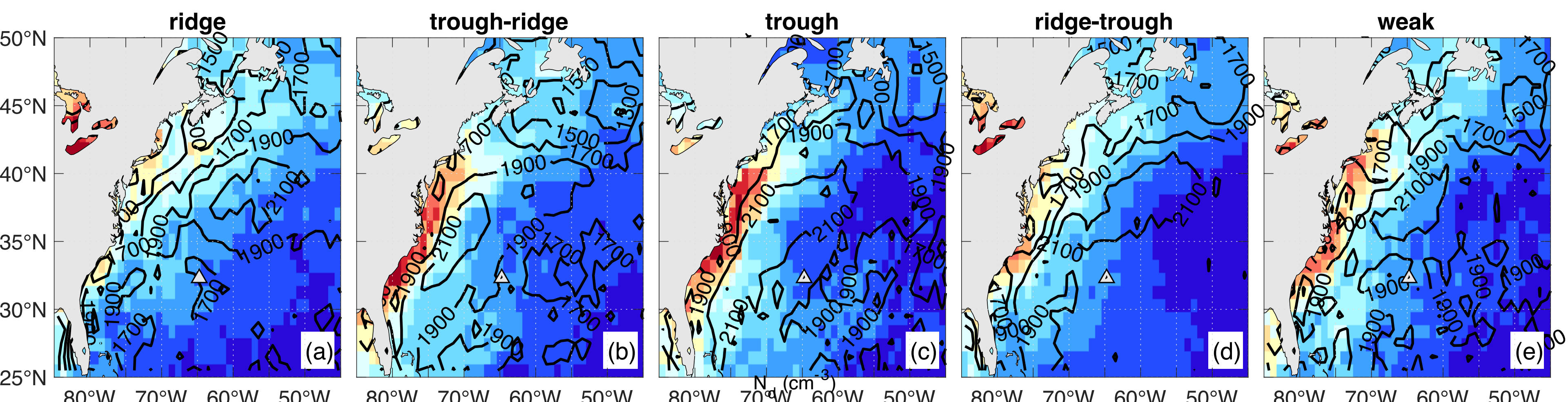


CERES-MODIS cloud fields

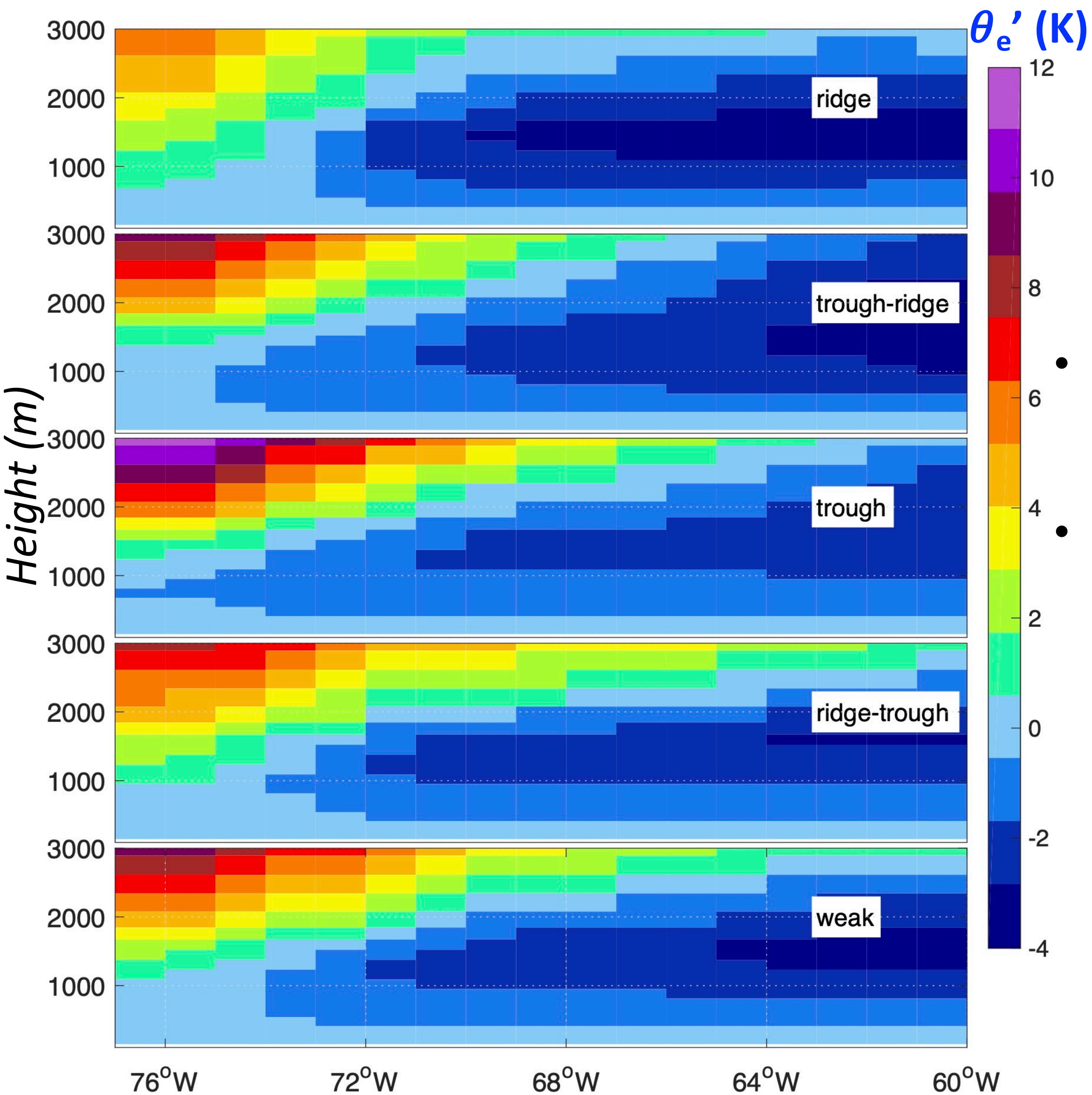
- CERES-MODIS cloud coverage: low (color) and mid-high (contour)



CERES-MODIS cloud droplet number conc (N_d) and height (contours)



Vertical profiles of equivalent potential temp (θ_e)



Profiles 35˚N-40˚N zonal band

θ_e': θ_e after subtracting near-surface θ_e

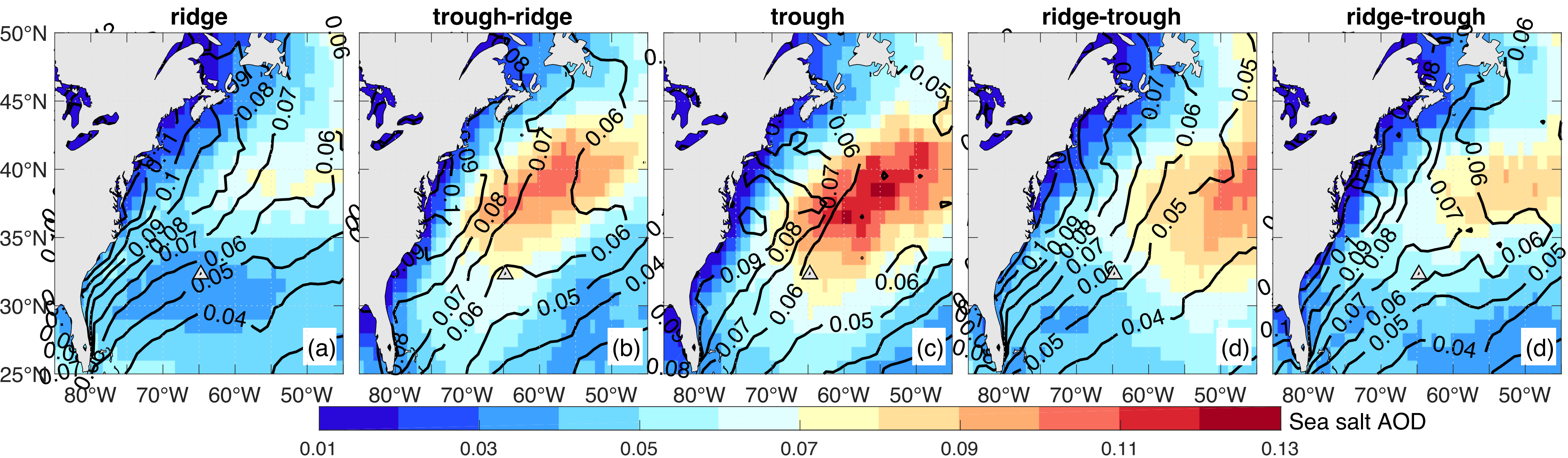
- Profiles similar to those in cloud-topped boundary layers are primarily observed west of 70˚W.
- Trough θ_e concomitant with subsidence and strong surface fluxes.

Synoptic classification

- Five synoptic patterns capture the evolution of weather systems over the ACTIVATE domain.
- This analysis provides a useful summary of atmospheric features during the winter campaign.
- The method is particularly suitable for detecting synoptically-forced stratocumulus clouds associated with cold air outbreaks.
- The regime classification can be further applied to study aerosol-cloud interactions.

MERRA-2 Aerosol optical depth (AOD)

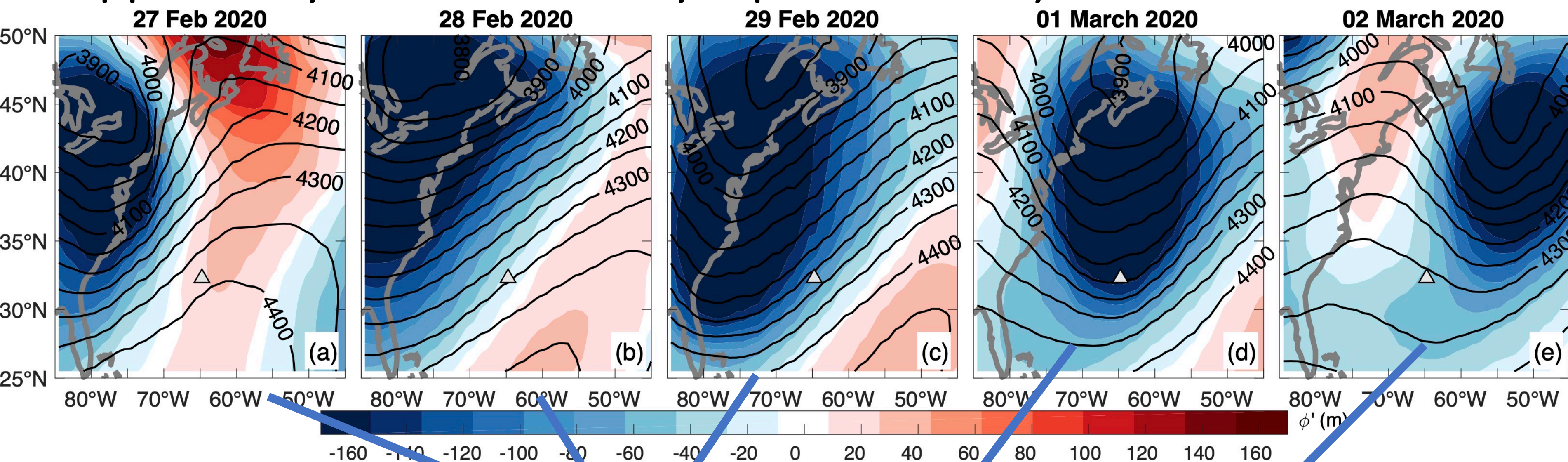
- Color: sea salt
- Contours: sulfate+BC+OC



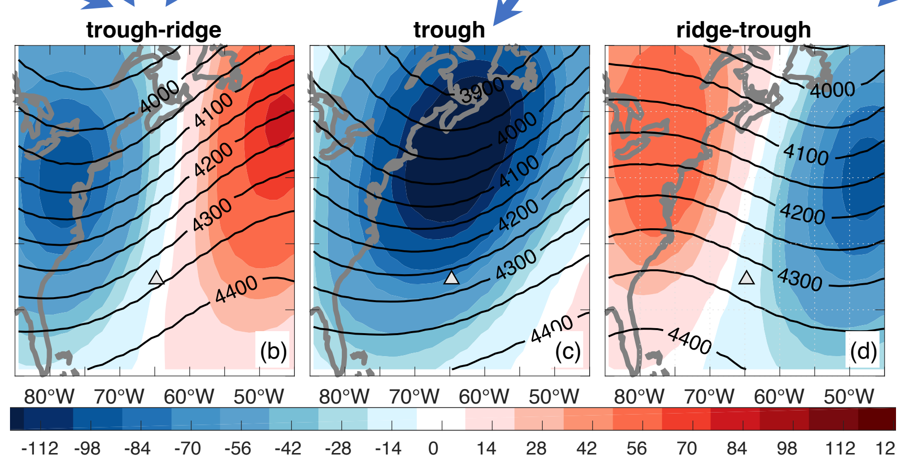
- Spatial variability of sea salt AOD is consistent that for surface winds.
- Unclear differences for SO4+BC+OC along the coast.

Winter 2020

- 5 continuous days of ACTIVATE observations provide a golden opportunity to understand synoptic variability



- Corresponding synoptic patterns:



Summary

- The synoptic classification captures the meteorological evolution during 02/27/2020-03/02/2020
- Aerosol concentration increases when the trough becomes the dominant synoptic feature. This is consistent with the climatological analysis of MODIS cloud droplet number concentration (N_d).
- A similar pattern for in-situ N_d is more difficult to observe (not shown), possibly due to other factors that also modulate N_d.

Preliminary assessment of GOES-16 cloud droplet effective radius and number concentration (N_d)

$$N_d = \Gamma_{\text{appr}}^{1/2} \frac{10^{1/2}}{4\pi \rho_w^{1/2} k} \frac{\tau^{1/2}}{r_e^{5/2}}$$

Cloud optical depth

Cloud droplet effective radius

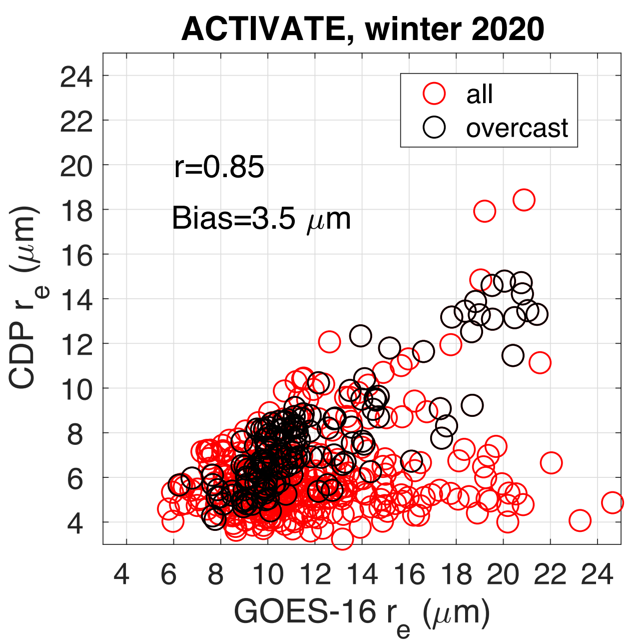
Adiabatic increase of water content with height

Parameter associated with the width of the droplet size distribution

- Satellite N_d is derived using 2-km pixel-level data. 3x3 N_d pixels are averaged before comparing GOES with in-situ data.
- In-situ N_d (CDP and FCDP) are limited to samples with water content ≥0.03 g/m^3. In-situ data are temporally averaged (30-s window).
- GOES and in-situ N_d are matched within 10 min.

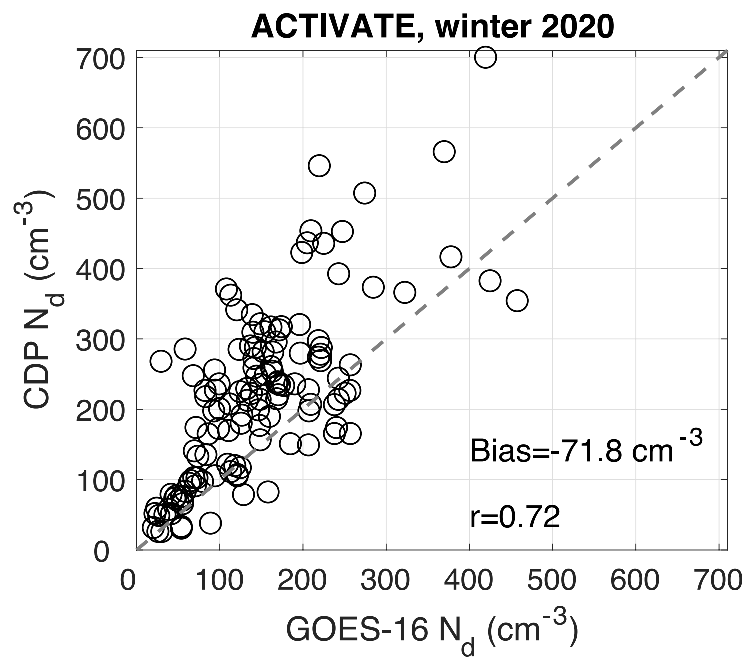
Preliminary assessment of GOES-16

Cloud droplet effective radius (r_e)



- The poor agreement is likely due to several factors: cloud sizes smaller than pixel resolution, optically thin clouds, etc.

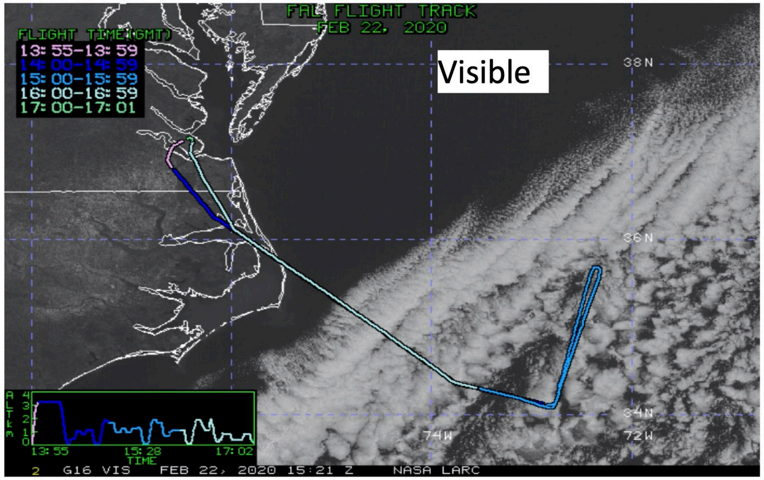
Cloud droplet number concentration



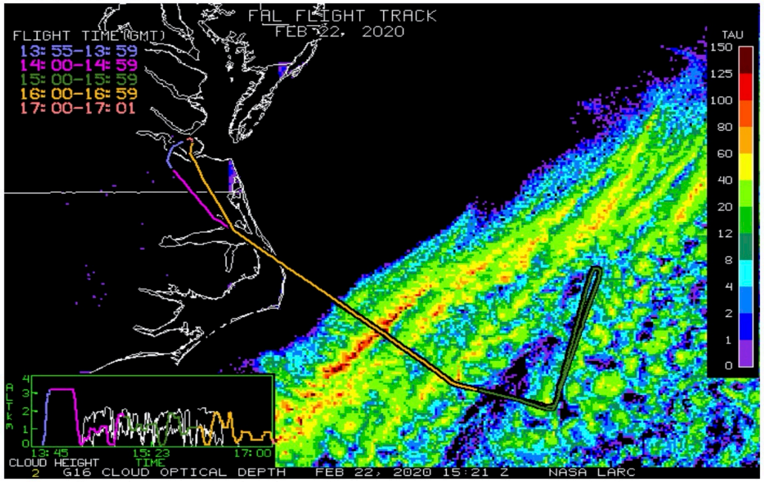
- GOES biased low but “high” correlations

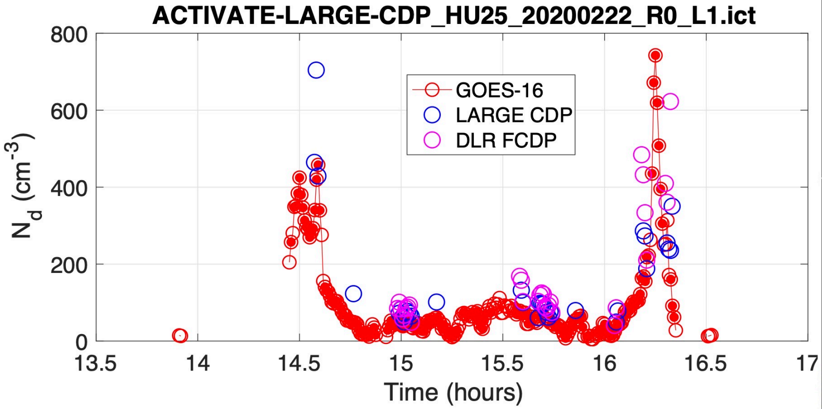
Examples: Postfrontal clouds and closed-cell Sc

Visible

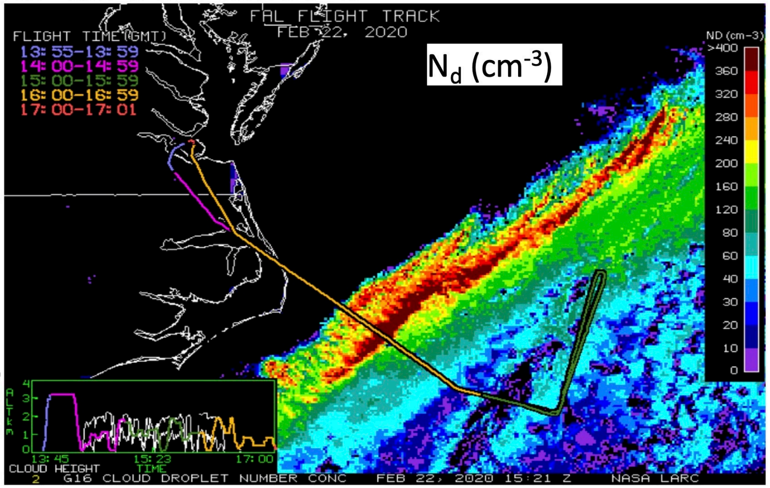


Cloud Optical Depth



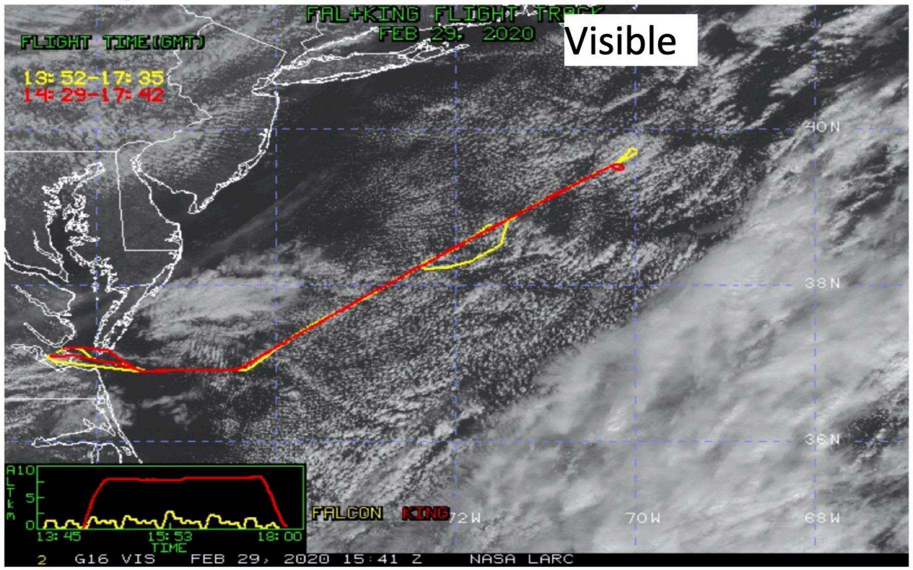


Cloud Droplet Number Concentration (cm-3)

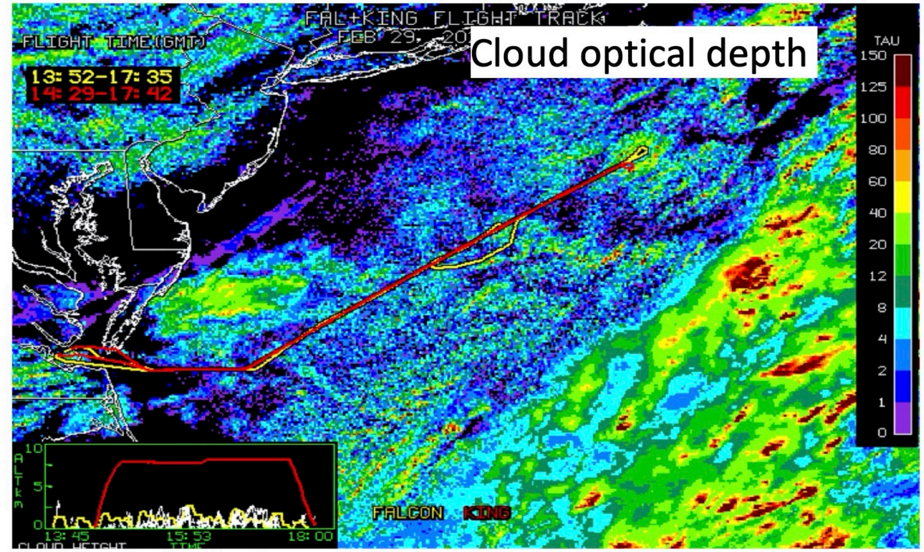


A case with substantial underestimation of GOES-16

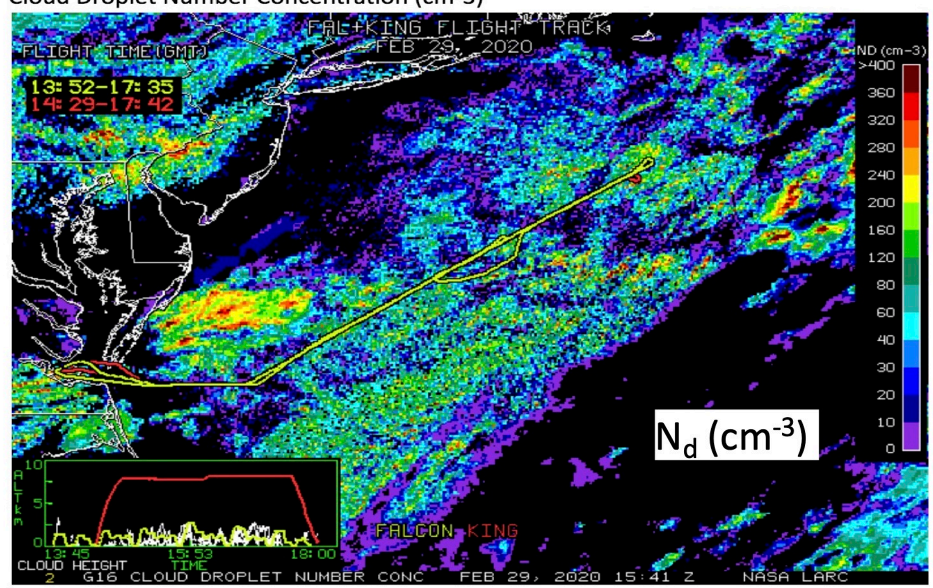
Visible Image

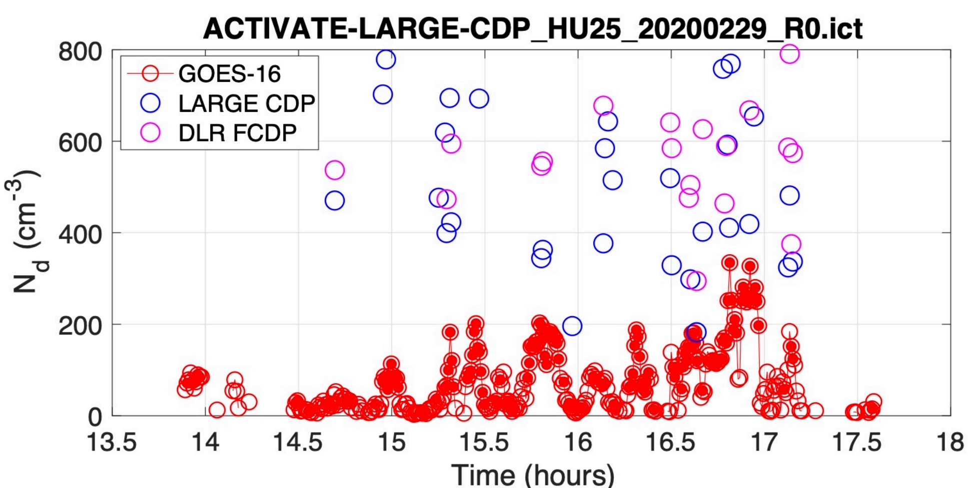


Cloud Optical Depth



Cloud Droplet Number Concentration (cm-3)





Concluding remarks

1. Does GOES-16 N_d capture the spatial transitions in N_d?:
   - **YES**
2. Is GOES-16 N_d “reliable enough” to study postfrontal Sc clouds
   - **YES**, for optically thick clouds.
3. Are there specific conditions for which GOES-16 N_d yields suboptimal results?
   - Optically thin clouds with optical depth of less than 1.
   - Cloud structures much smaller than GOES pixel resolution (2-km)
   - Cloudy pixels embedded in cloud-free scenes.
4. Why GOES-16 N_d is systematically biased low:
   - Probably, it is the consequence of an endemic overestimation of satellite cloud effective radius (e.g. NAAMES campaign, Painemal et al., 2020, AMTD).
5. Is it possible to bring GOES-16 N_d closer to observations:
   - **Yes, but** it is going to be an empirical correction. More realistic constant values in the N_d equation might not necessarily yield a better agreement.
6. Would MODIS yield better results?
   - Possibly. 1-km MODIS pixel resolution might help reduce some clear-sky contamination. Uncertainties will remain for optically thin clouds.