

Regional Cloud Forecast Verification using Traditional, Spatial and Object-based Methods

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Motivation

- How well does the Navy's regional and global model predict clouds?
- Does the **object-based verification** offer additional insights compared to the traditional standard grid-point verification?

Project Scope

- Explore the user-defined parameter sensitivity within MET/MODE for cloud verification
- Utilize MET/MODE to verify regional and global cloud regimes against GOES retrieved clouds
- Compare regional and global model cloud forecast performance
- Formulate a set of verification metrics for potential transition

MET: model evaluation tools

MODE: method for object-based diagnostic evaluation

Traditional Verification Scores

Contingency Table
(grid-point)

		Observation	
		Yes	No
Forecast	Yes	Hit (n_{11})	False alarm (n_{10})
	No	Miss (n_{01})	Correct negative (n_{00})



Skill score

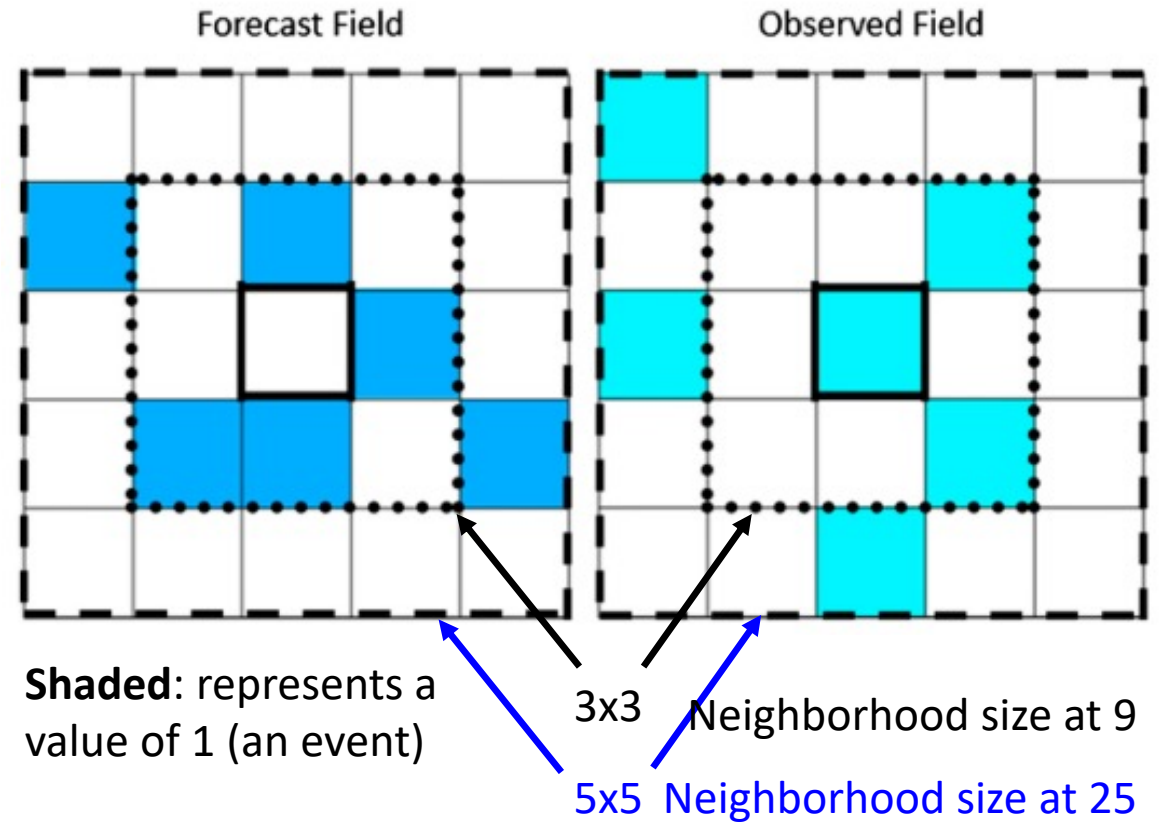
Score	Range
Bias = $(n_{11} + n_{10}) / (n_{11} + n_{01})$	$0 \leq \text{bias} \leq \infty$; perfect score = 1
ETS = $(n_{11} - C_{\text{ref}}) / (n_{11} + n_{10} + n_{01} - C_{\text{ref}})$, where $C_{\text{ref}} = (n_{11} + n_{10})(n_{11} + n_{01}) / T$	$-1/3 \leq \text{ETS} \leq 1$; No-skill forecast = 0; perfect score = 1
POD = $n_{11} / (n_{11} + n_{01})$	$0 \leq \text{POD} \leq 1$; perfect score = 1
FAR = $n_{10} / (n_{11} + n_{10})$	$0 \leq \text{FAR} \leq 1$; perfect score = 1

ETS: equitable threat score
POD: probability of detection
FAR: False alarm

Spatial Verification Score

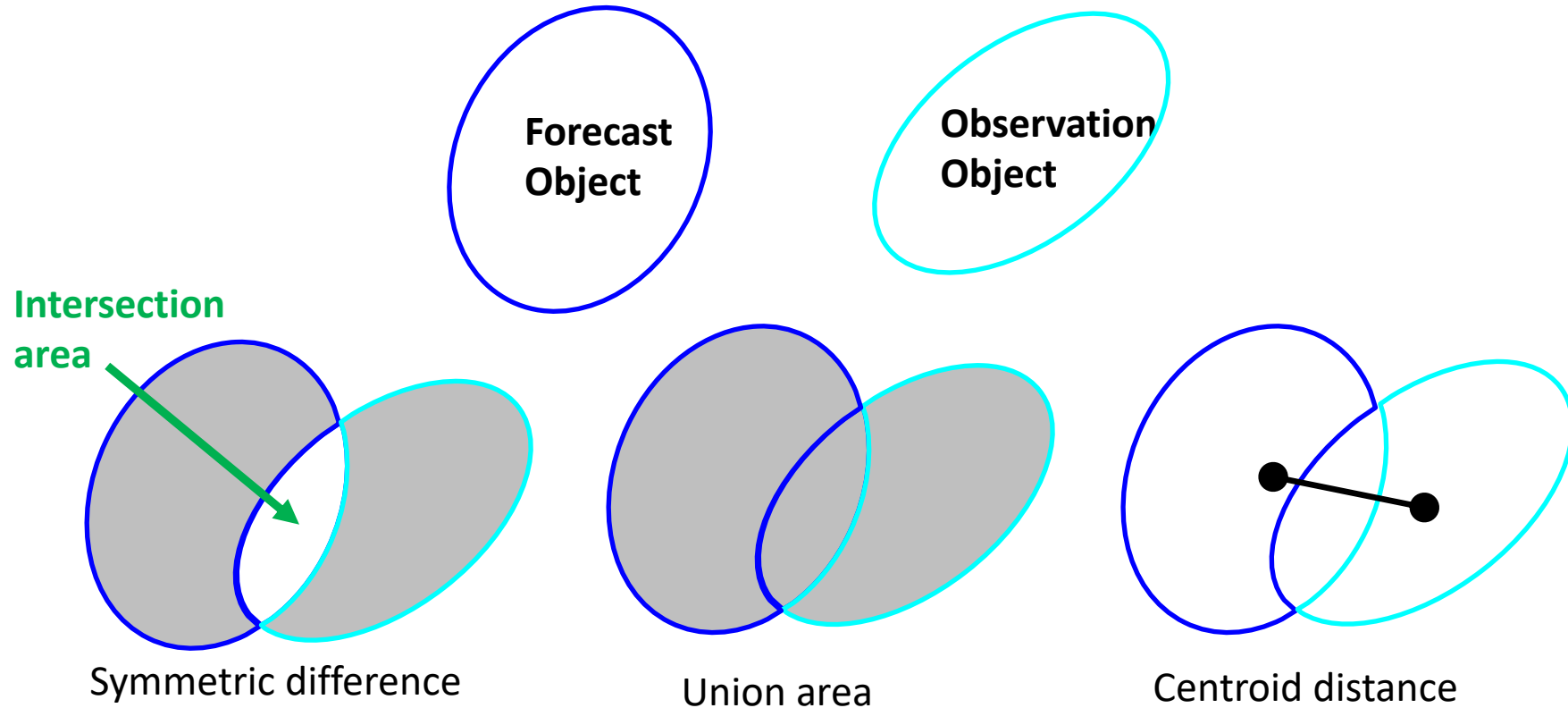
Score	Range
$\text{FSS} = 1 - \text{MSE}/\text{MSE}_{\text{ref}}$ <p>Where $\text{MSE} = \frac{1}{N_x N_y} \sum_{i=1}^L \sum_{j=1}^L [O(i,j) - F(i,j)]^2$</p> $\text{MSE}_{\text{ref}} = \frac{1}{N_x N_y} \left[\sum_{i=1}^L \sum_{j=1}^L O(i,j)^2 + \sum_{i=1}^L \sum_{j=1}^L F(i,j)^2 \right]$	$0 \leq \text{FSS} \leq 1;$ perfect score = 1

- Traditional verification metrics would reveal no forecast skill (no overlap between fcst and obs)
- At scale of 25 grid squares, both forecast and observation fields have events in 6 out of 25
- Fractions skill score (**FSS**) reveals model forecast skill at a given length scale



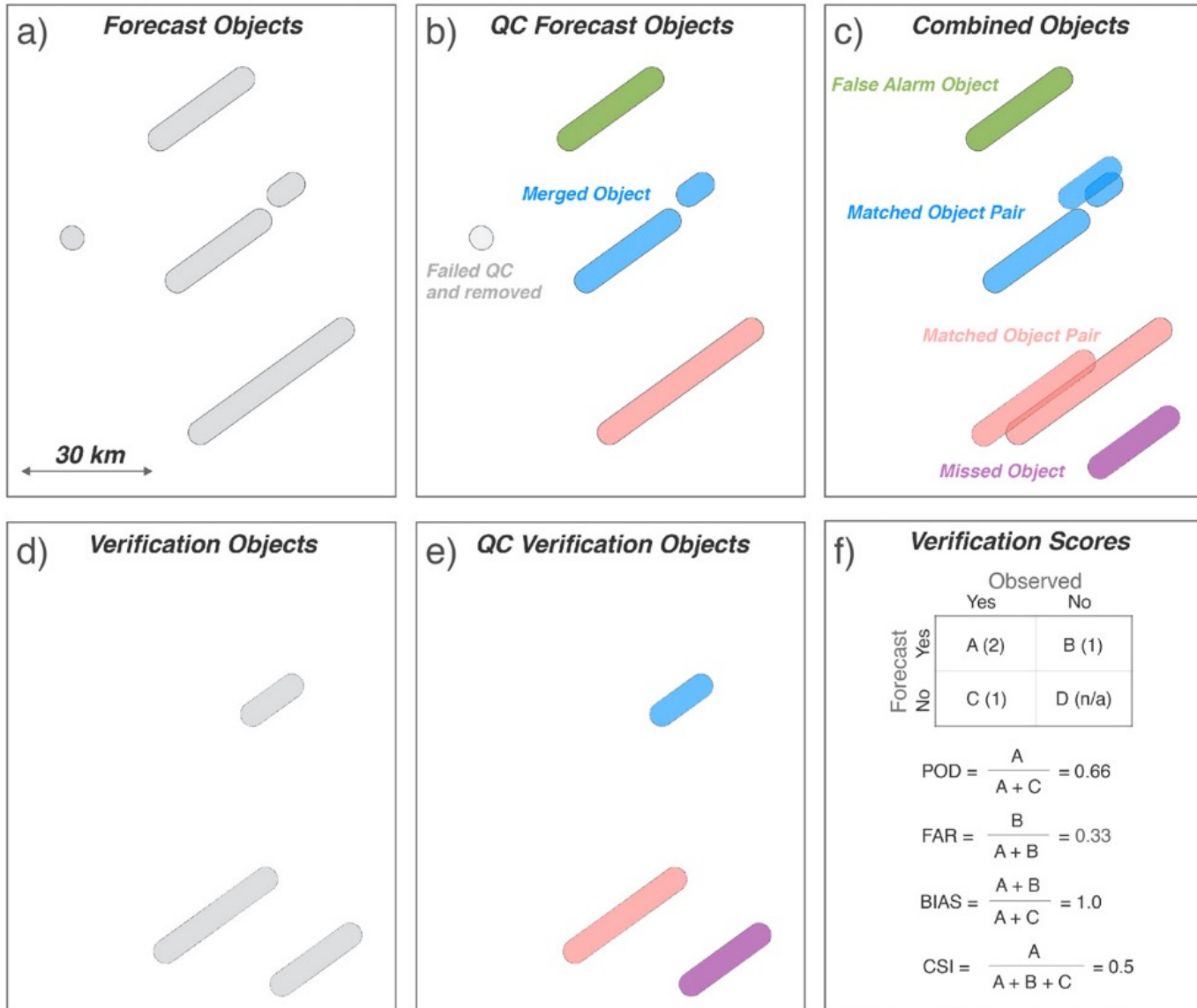
Wolff et al. (2014)
Roberts and Lean (2008)

Spatial Object-based Verif. Metrics



Area difference	Forecast area minus observation area	Quantify how large the area errors in forecasts
Centroid difference	Distance between two paired objects centroids	Indicator for “over the target” accuracy; Displacement errors
Overlap ratio	Intersection area/Union area	Indicator for spatial hits

Object-based Skill Score



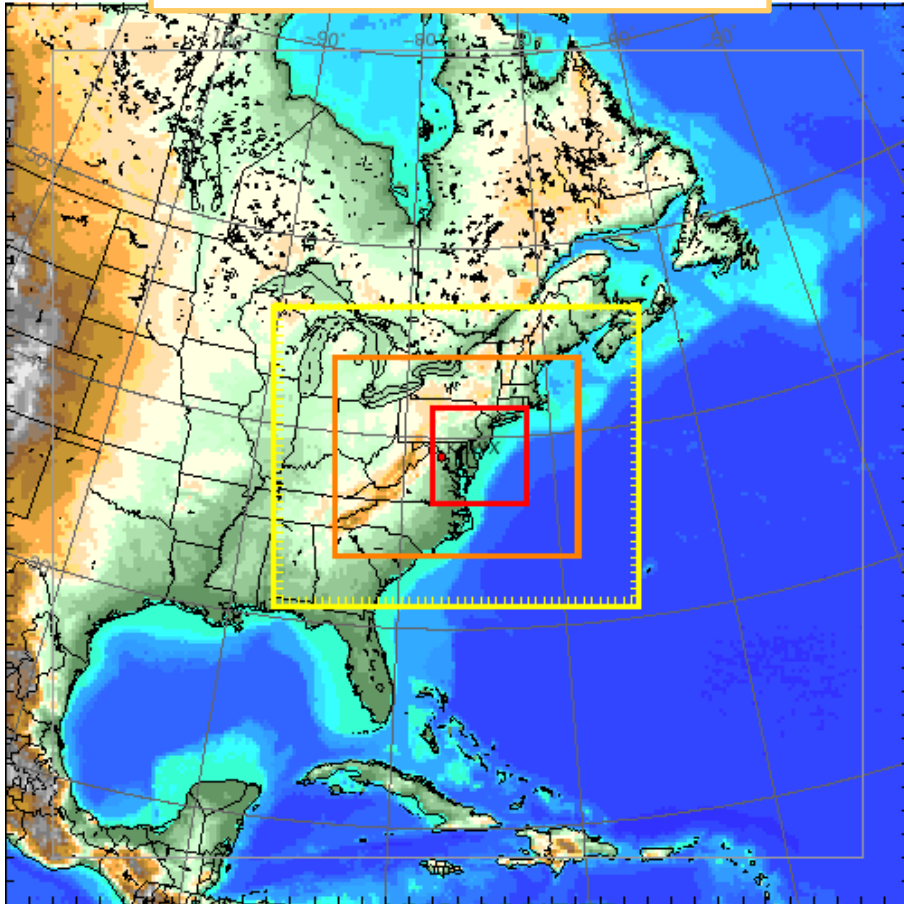
Matched paired objects – “hits”
 Unmatched forecast objects – “false alarm”
 Unmatched verification objects – “misses”



Derive contingency table based skill scores for objects

Datasets

COAMPS VACAPES Region

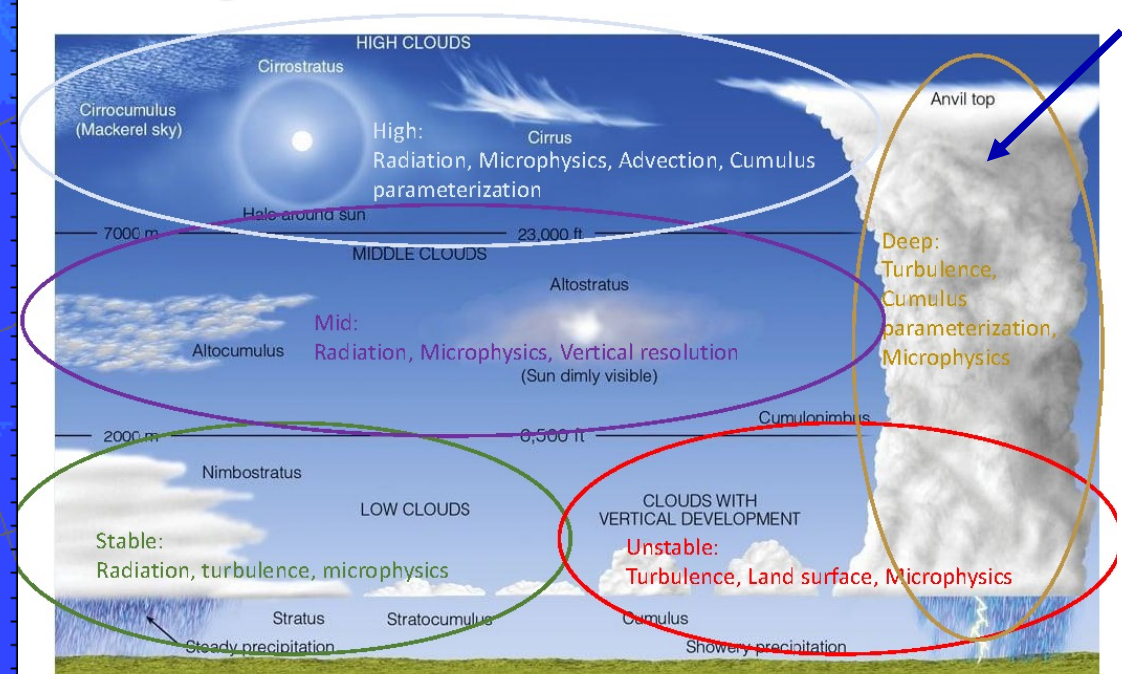


UNCLASSIFIED

COAMPS: Coupled Ocean/Atmosphere
Mesoscale Prediction System

NAVGENM: Navy Global Environmental Model

Cloud Regimes for GOES and COAMPS/NAVGENM



Deep precipitating
clouds

High clouds

Mid-clouds

Stable, unstable
clouds

- **COAMPS** and **NAVGENM** 5-km cloud masks for five different regimes against GOES-16 retrievals (Nachamkin et al. 2022)
- Initiated at 12 UTC and forecasted out to 12 h at every 3h intervals
- MET/MODE is used for verification

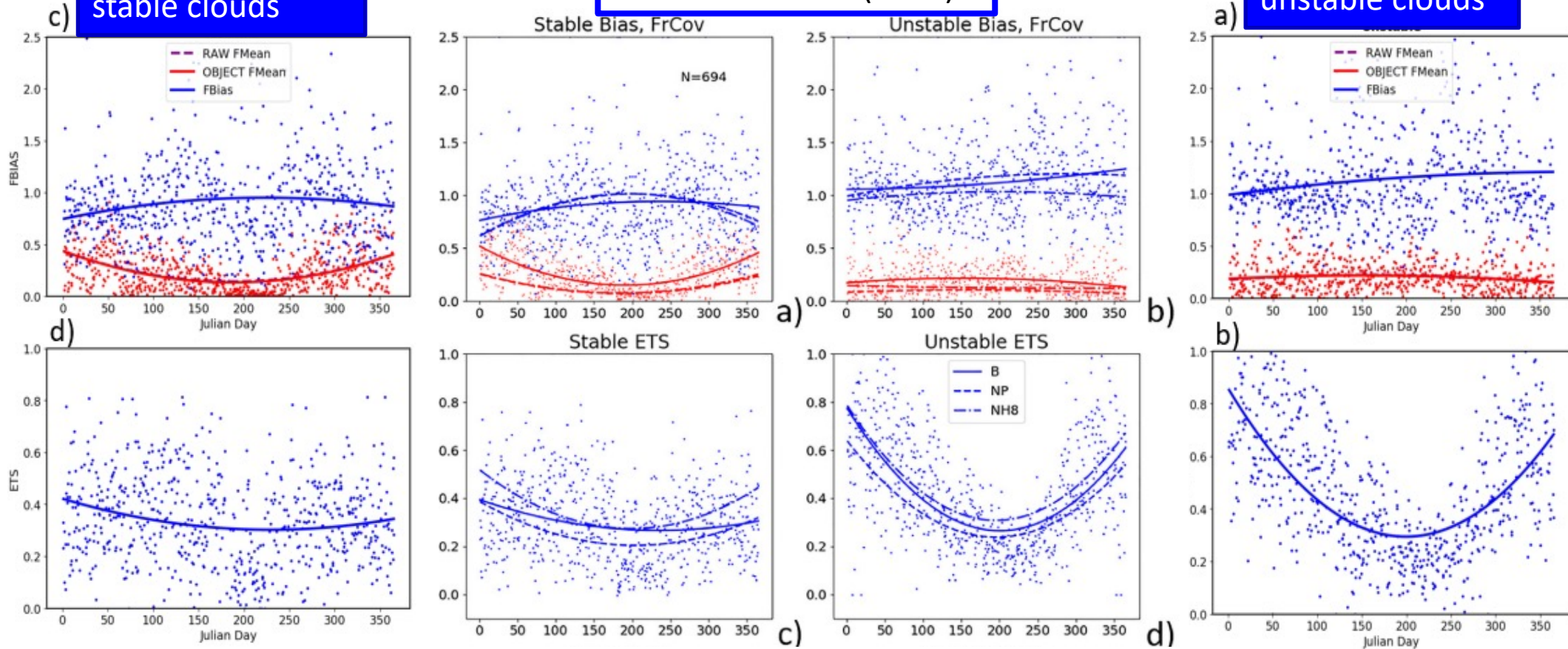
Contingency-table Stats for COAMPS Low Clouds

Verification for COAMPS Unstable/Stable Cloud Masks at 1800 UTC

Object-based for
stable clouds

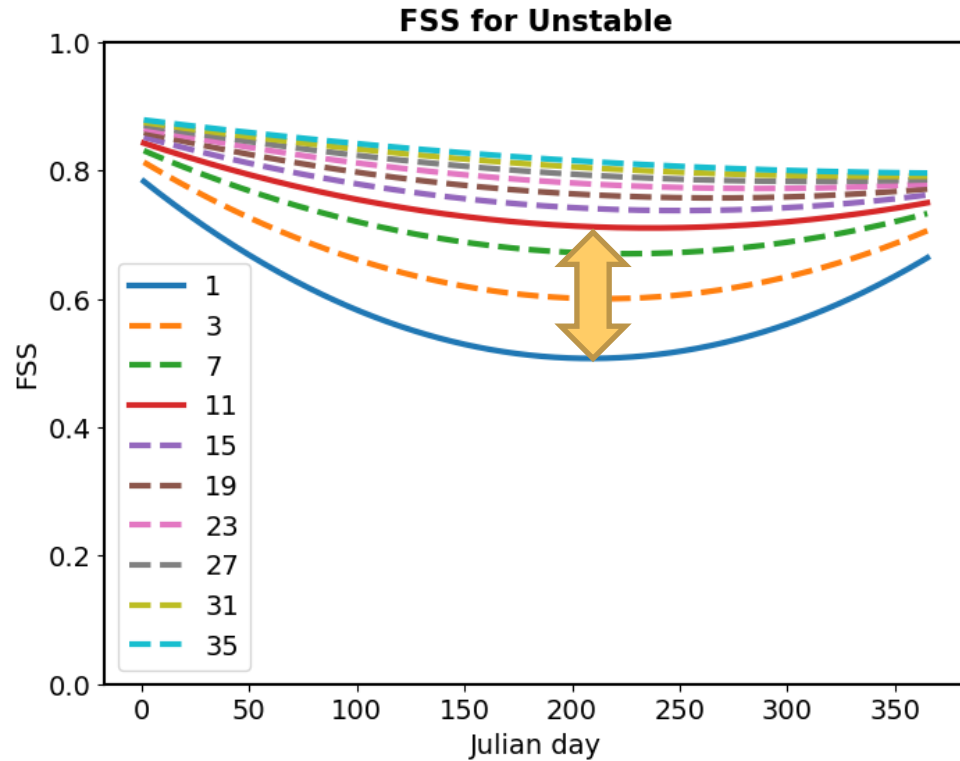
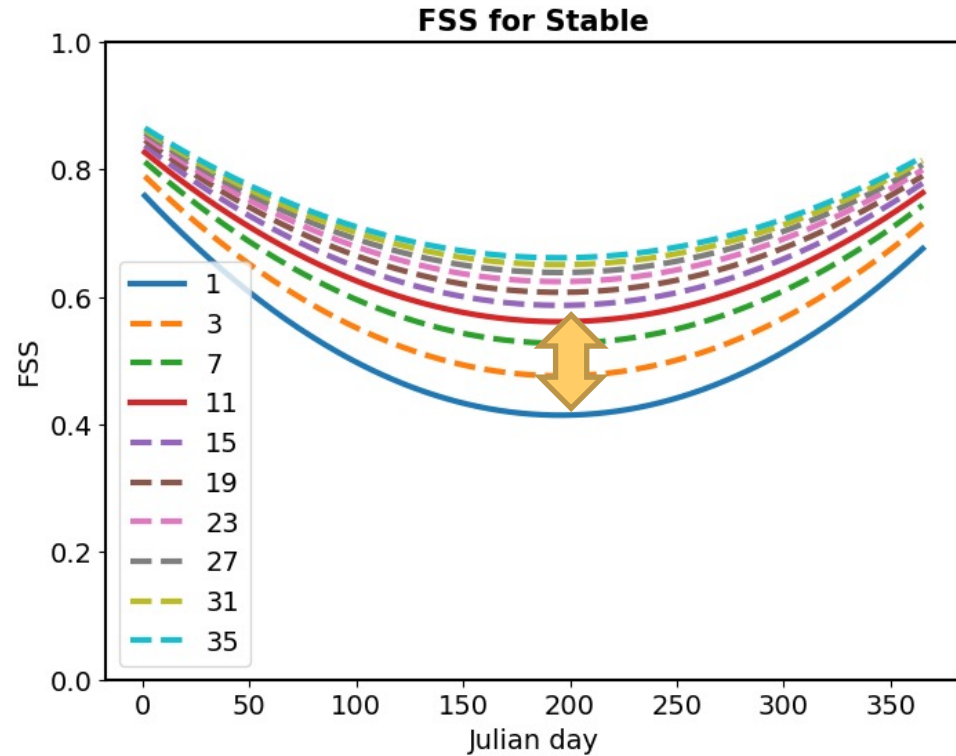
Nachamkin et al. (2022)

Object-based for
unstable clouds



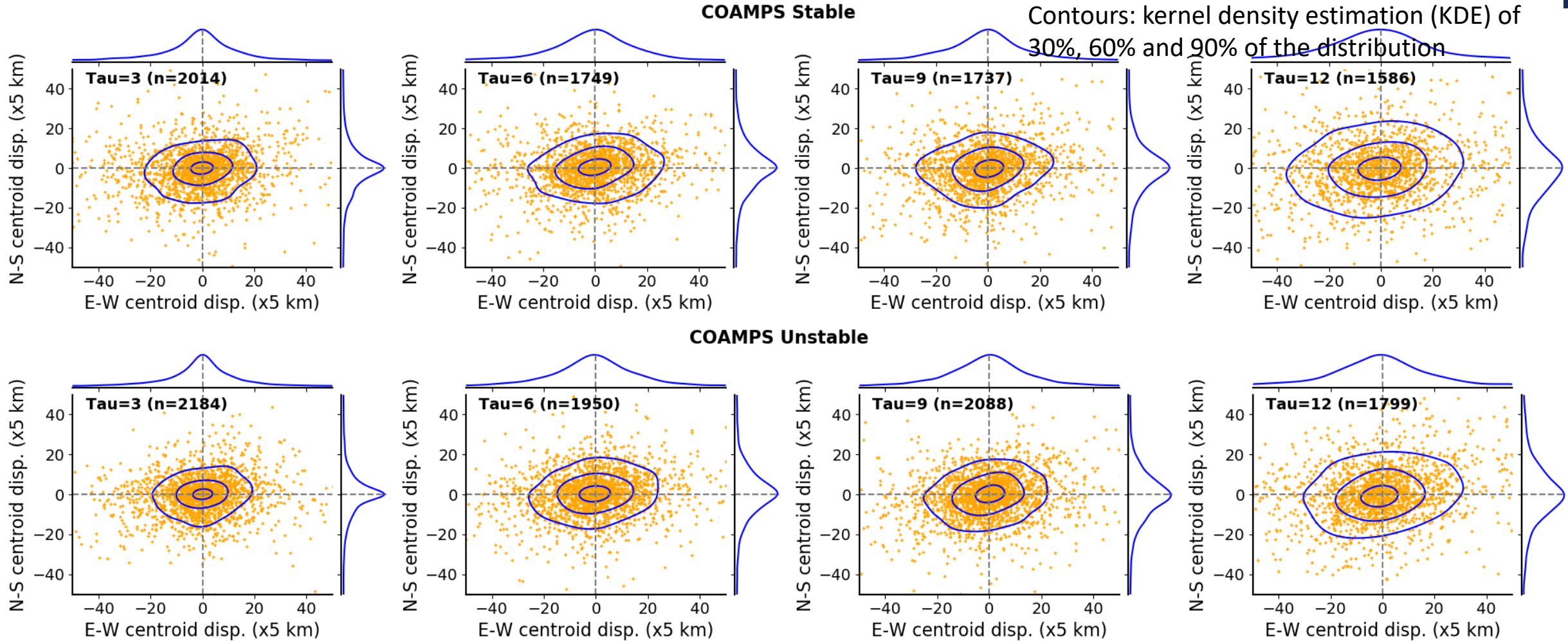
Object-based skill scores are comparable to grid-point skill scores

FSS for COAMPS Low Clouds



Improved rate of FSS is faster for unstable than stable clouds,
consistent with unstable clouds are more sensitive to localized errors

Displacement Error for COAMPS Low Clouds



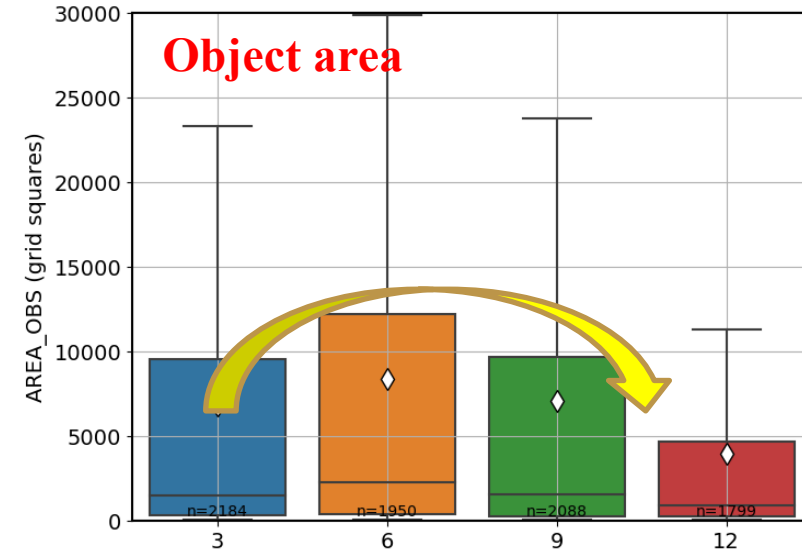
- COAMPS general places the stable and unstable cloud objects at the right locations
- Slightly larger position errors at the east-west direction than the north-south direction

Area Uncertainty for COAMPS Low Clouds

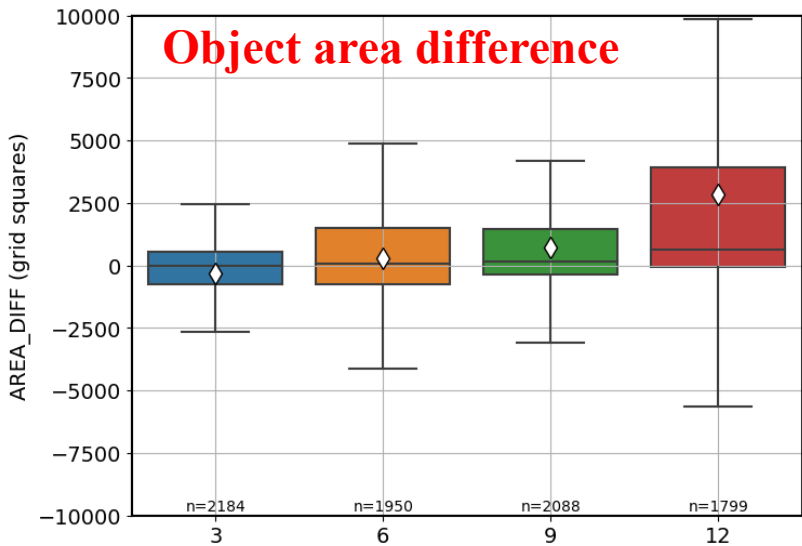
Unstable clouds

- Object area for observed shows a slightly diurnal pattern, indicating they aggregate largest at the optimal sunlight (forecast lead time 6h, local time 1pm EST)
- COAMPS model predicts unstable clouds well from 3-9 h lead time

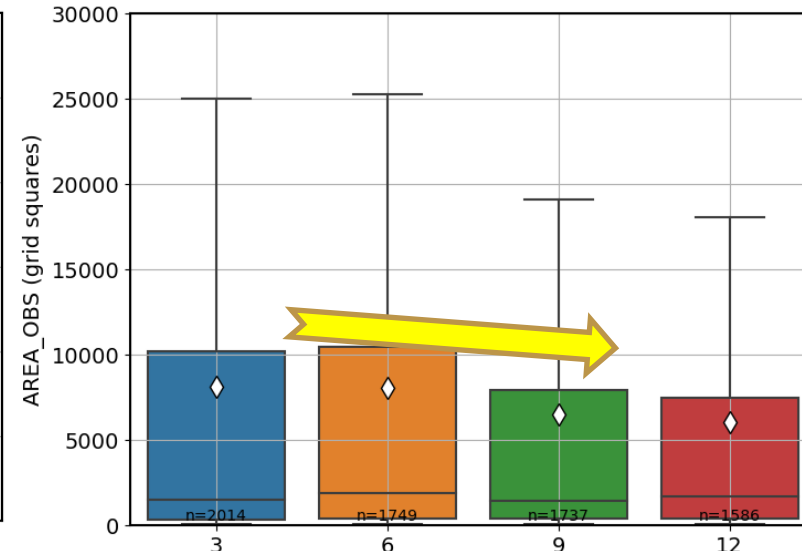
COAMPS Unstable object area_obs (grid squares)



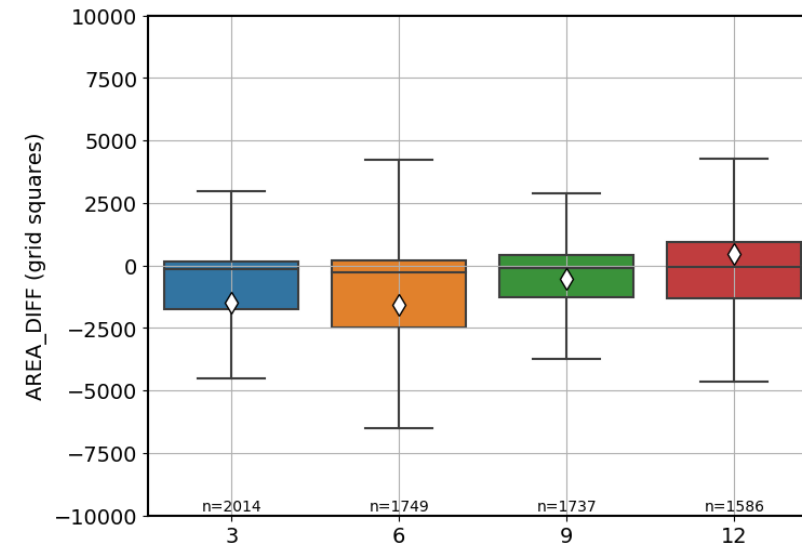
COAMPS Unstable object area_diff (grid squares)



COAMPS Stable object area_obs (grid squares)



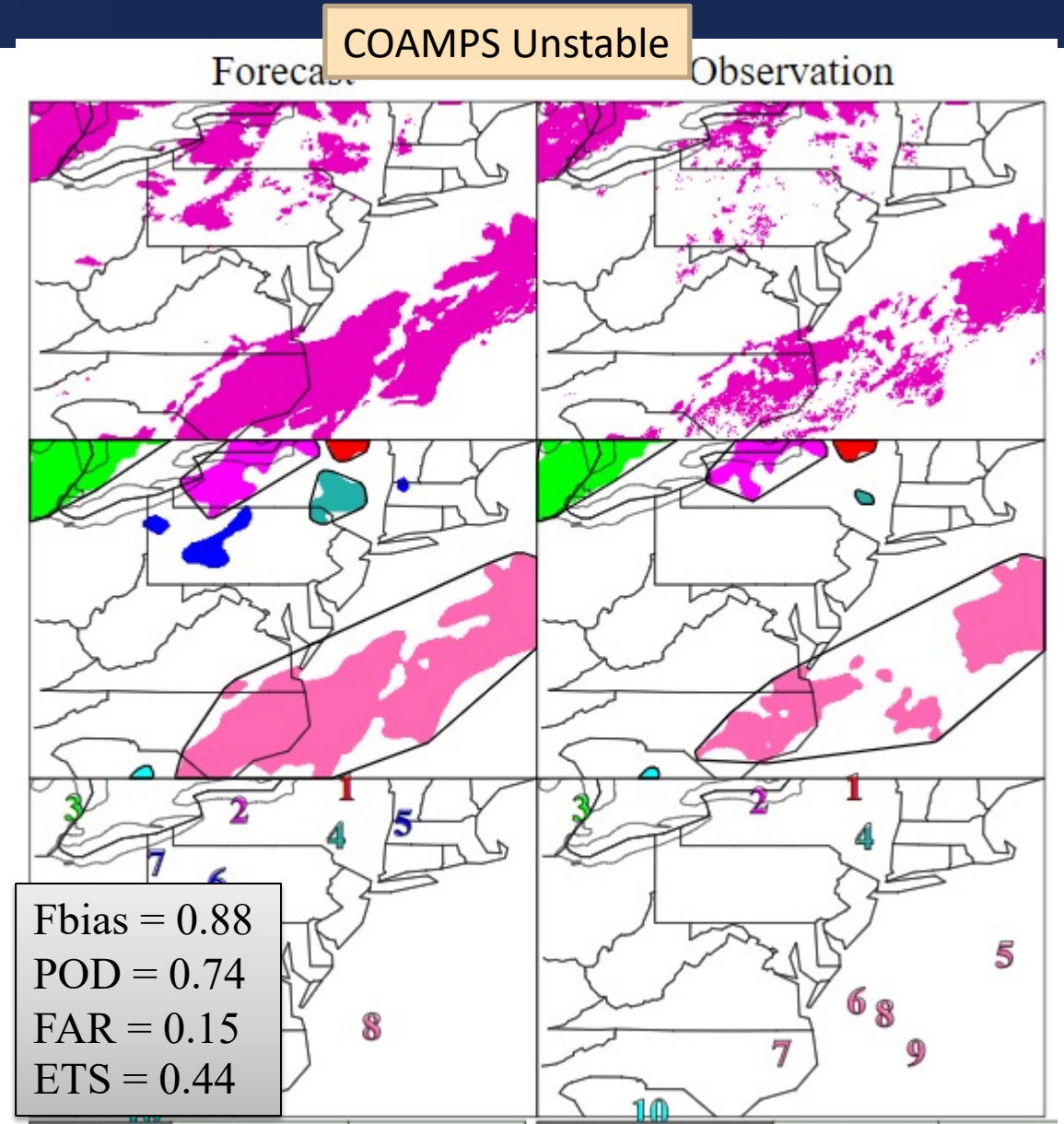
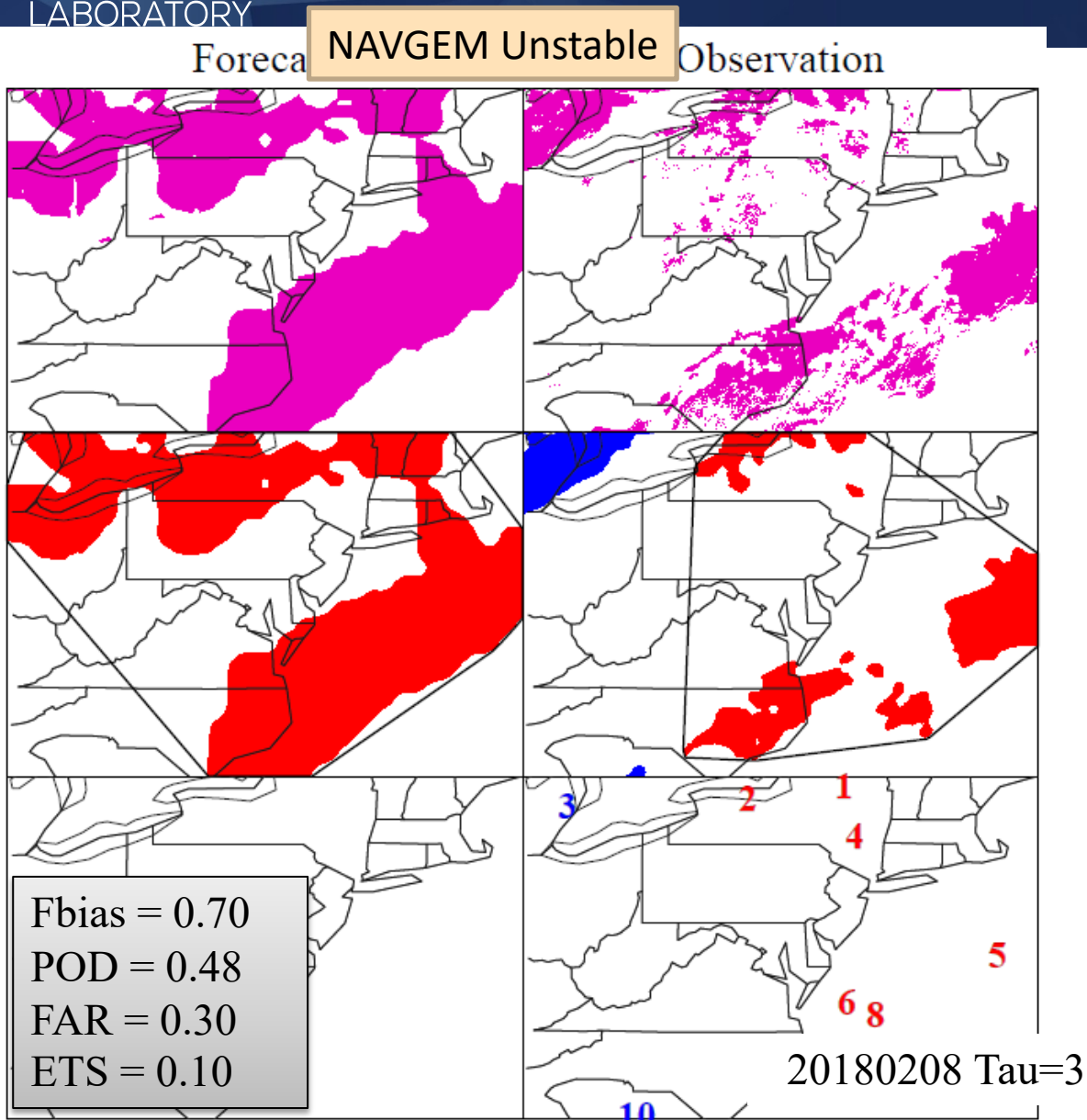
COAMPS Stable object area_diff (grid squares)



Stable clouds

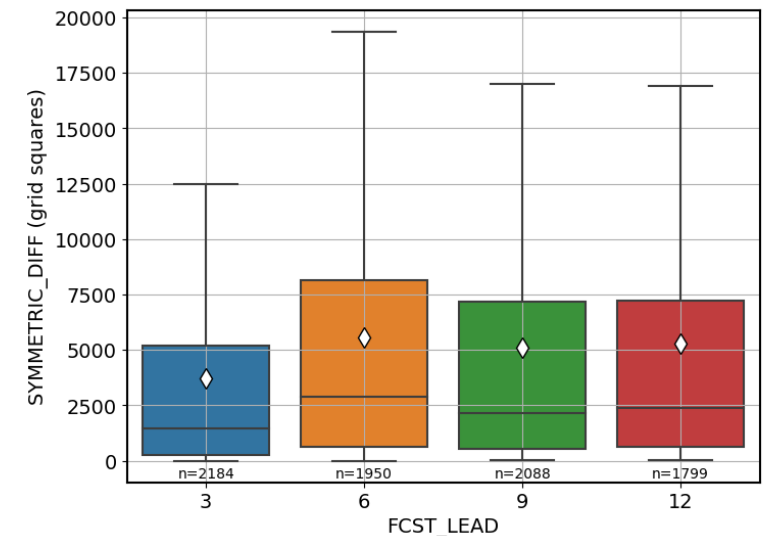
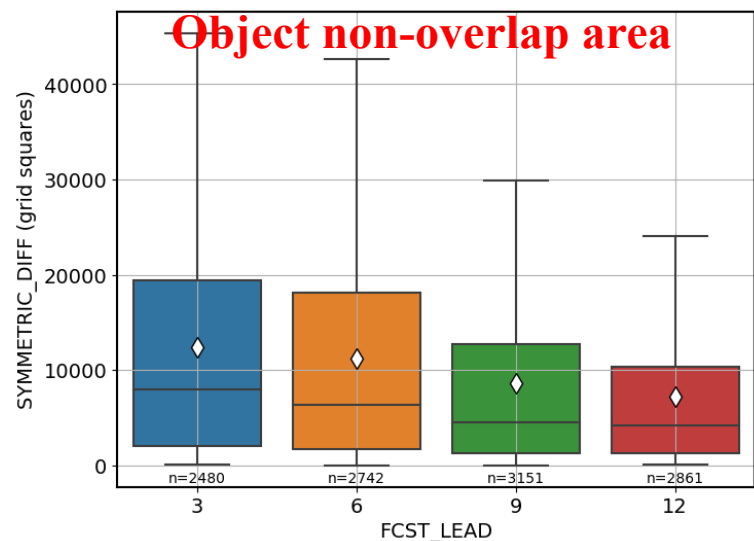
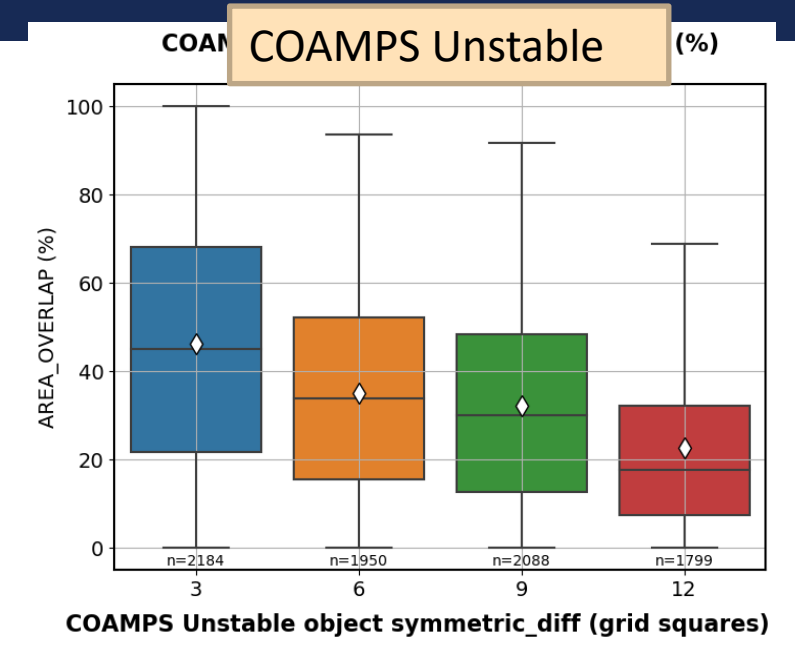
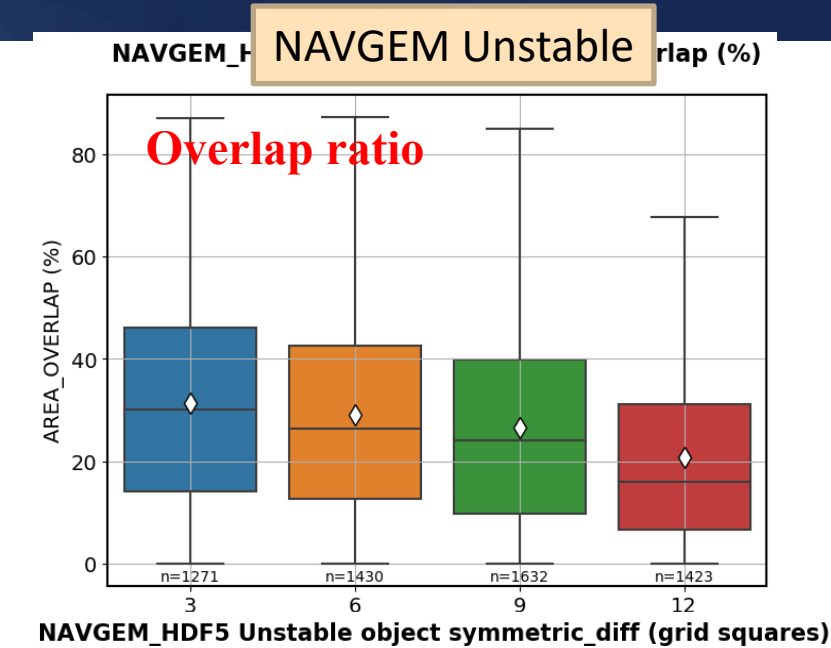
- Object area remains nearly constant throughout the day
- COAMPS under-predicts the area coverage, consistent with the negative bias

NAVGEM and COAMPS Unstable Clouds

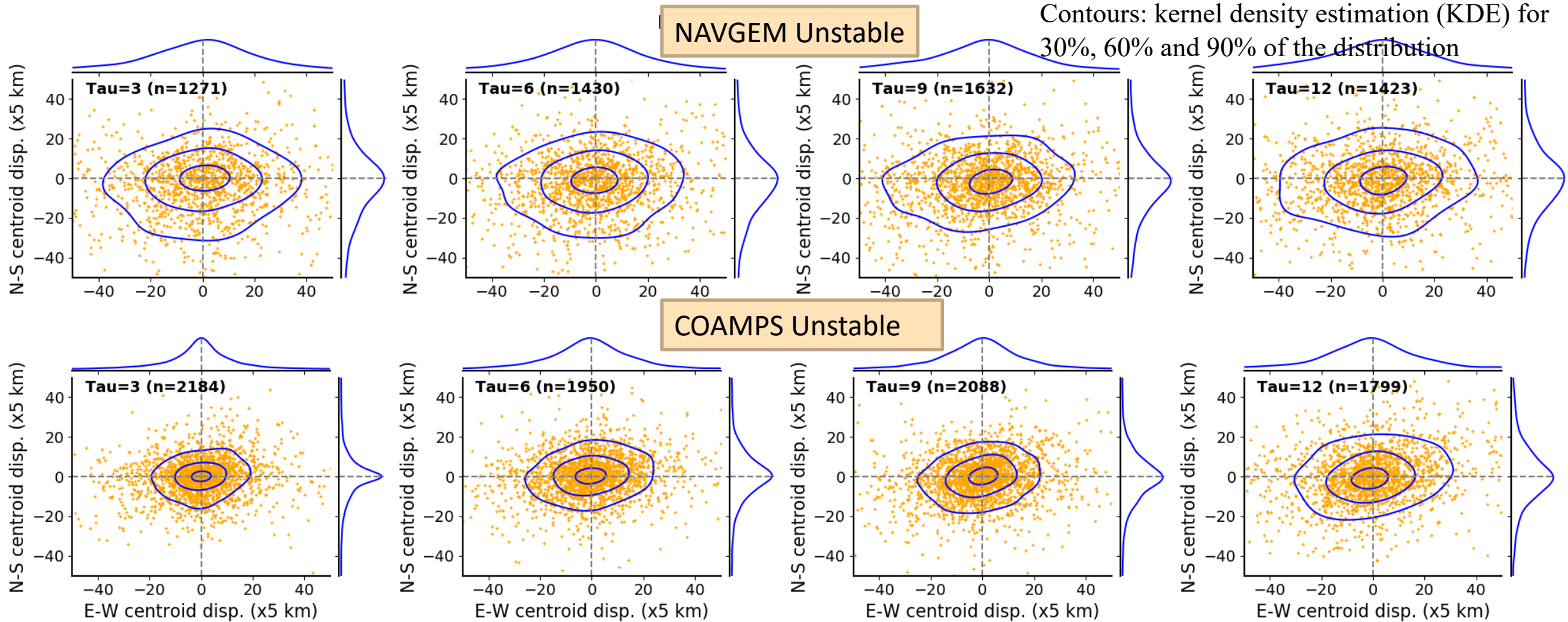


NAVGEM and COAMPS Unstable Clouds

- Less overlapped area for NAVGEM unstable clouds at every forecast lead hour (larger non-overlap area, as well as likely larger displacement error)
- Objects from Forecasts are larger in area, less overlapped by Observations



NAVSTEM and COAMPS Unstable Clouds



NAVSTEM unstable clouds have larger spread of displacement errors than the COAMPS ones

Summary and Future Direction

- Standard, spatial and object-based verification metrics are complementary, conveying the model performance in a consistent manner (good to detect bugs)
- Navy's regional model (COAMPS) generally predicts clouds well (low clouds shown here), with low displacement error and decent skill score
- The global model (NAVGEM) has larger displacement error and lower skill score for clouds compared to the regional model, in part due to model lower resolution and parametrized model physics

FY22-23

- Explore the user-defined parameter sensitivity within MODE
- Utilize MET/MODE to verify regional and global cloud regimes and GOES cloud masks
- Compare stable and unstable clouds verification from the regional and global model

FY24

- Focus on global ensemble cloud variables verification
- Explore parameter sensitivity within MET/MODE for ensemble verification

EXTRA SLIDES

Technical Capability

- Utilize community software for Navy's regional and global cloud regime verification against GOES-16 retrievals
 - Offer feature-based verification

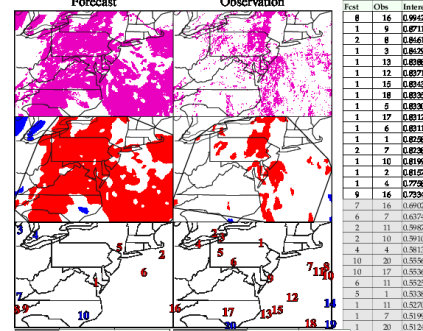
Warfighter Impact

- Improved understanding on Navy's cloud forecast general performance
- Mission planning and operations (ships, airborne, etc.) involved clouds
- Beneficial for downstream products (visibility)

FY22-23 Accomplishments

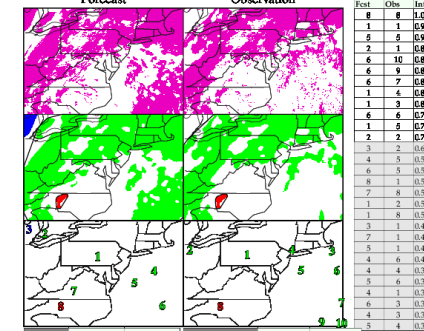
- Sensitivity test for feature-based verification setup
- Evaluated Navy's regional and global model labelled cloud regimes
- Compared regional and global model cloud forecast performance

MODE: cu-mask-cbh-co at Surface vs cu-mask-goes at Surface



Model	Forecast	Observation	Mask M/G/P	Forecast	Observation
Field	COAMPS	COAMPS	Mask M/G/P	Forecast	Observation
Level	Surface	Surface	Cont. Radius	5	5
Units	%/A	%/A	Cont. Thresh	>=0.5	>=0.5
Initial	2018 10 11 12:00:00	2018 10 11 12:00:00	Inter Perc	0.90	0.90
Valid	2018 10 11 12:00:00	2018 10 11 12:00:00	Merge Thresh	>=0.4	>=0.4
Accum	00:00:00	00:00:00	Matching	match	match
			Simplex/MU	10/6/4	20/17/3
Centroid/Boundary	2.00 4.00	2.00 4.00	Area	44326/1964	8744/7305
Convex Hull/Angle	0.00 1.00	0.00 1.00	Area MU	1	1
Aspect/Area	0.00 1.00	0.00 1.00	Cluster	1	1
Int Area/Covariance	2.00 0.00	2.00 0.00	M/M1	0.6638	0.6812
Complexity/Intensity	0.00 0.00	0.00 0.00	M/M1 #F=O	0.6268	0.6268
Total Interest Thresh	0.70	0.70			

MODE: st-mask-cbh-co at Surface vs st-mask-goes at Surface



Model	Forecast	Observation	Mask M/G/P	Forecast	Observation
Field	COAMPS	COAMPS	Mask M/G/P	Forecast	Observation
Level	Surface	Surface	Cont. Radius	5	5
Units	%/A	%/A	Cont. Thresh	>=0.5	>=0.5
Initial	2018 10 11 12:00:00	2018 10 11 12:00:00	Inter Perc	0.90	0.90
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Accum	00:00:00	00:00:00	Matching	match	match
			Simplex/MU	8/7/1	10/70/0
Centroid/Boundary	2.00 4.00	2.00 4.00	Area	42467	21126
Convex Hull/Angle	0.00 1.00	0.00 1.00	Area MU	44567/900	10102/0
Aspect/Area	0.00 1.00	0.00 1.00	Cluster	2	2
Int Area/Covariance	2.00 0.00	2.00 0.00	M/M1	0.6629	0.6626
Complexity/Intensity	0.00 0.00	0.00 0.00	M/M1 #F=O	0.6526	0.6526
Total Interest Thresh	0.70	0.70			

2018 Oct 11
Hurricane
Michael

Unified Cloud Regime Verification Milestones and Work Unit Outline

CY1

- Set up and test MODE object definition for cloud regimes
- Verify stable and unstable clouds with MODE and compare them with existing traditional statistical verification
- Explore the user-defined parameter sensitivity within MODE for the regional cloud regimes to the output statistics
- Expand the MODE verification to mid-, high and deep precipitating clouds

CY2

- Utilize MODE to verify global cloud regimes and GOES cloud masks
- Compare stable and unstable clouds verification from the regional and global model

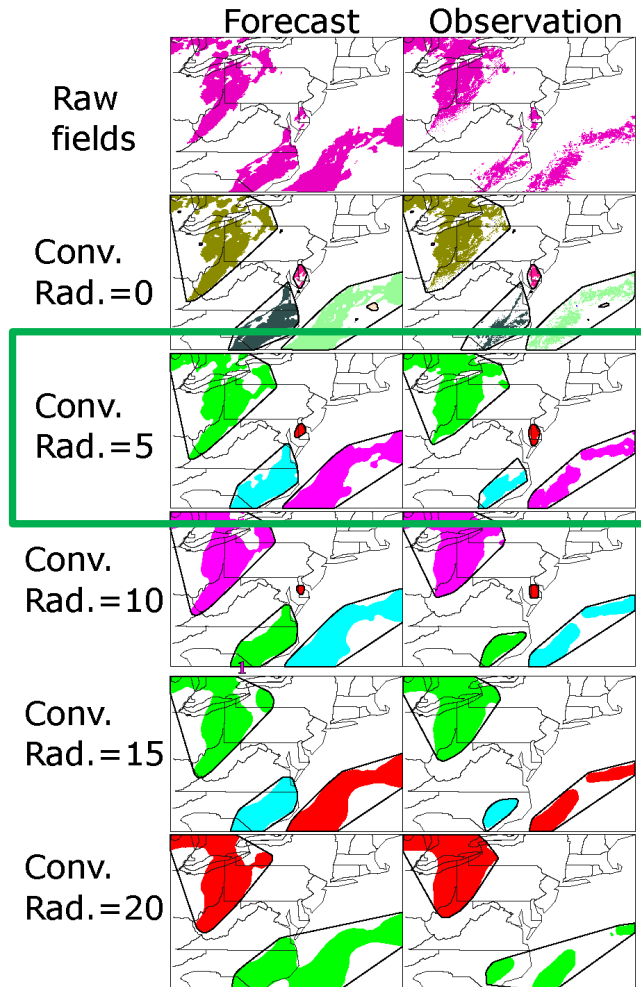
CY3

- Focus on global ensemble cloud variables verification
- Explore parameter sensitivity within MODE for ensemble verification

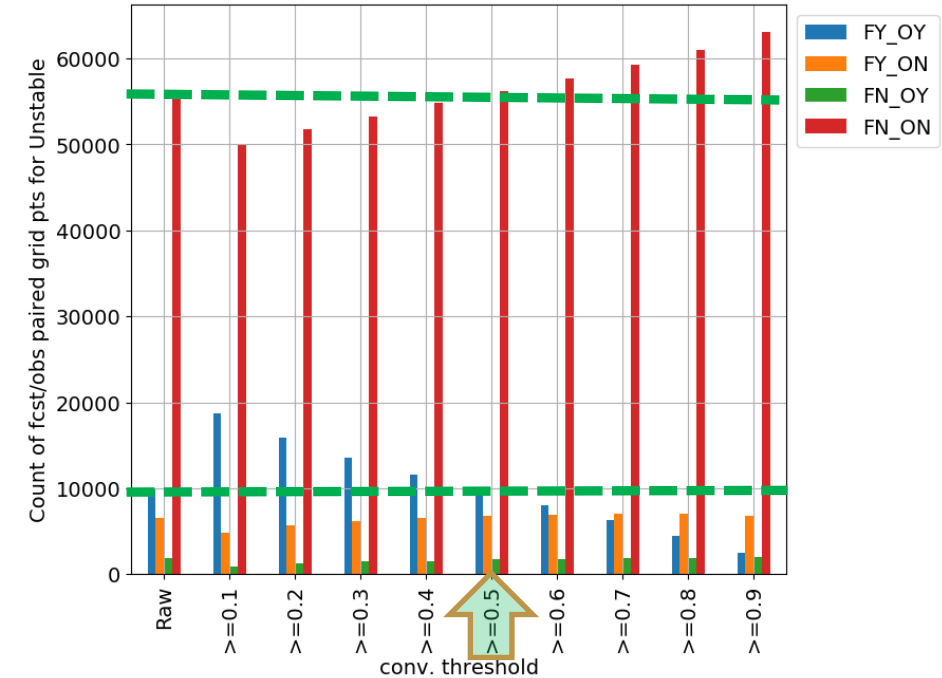
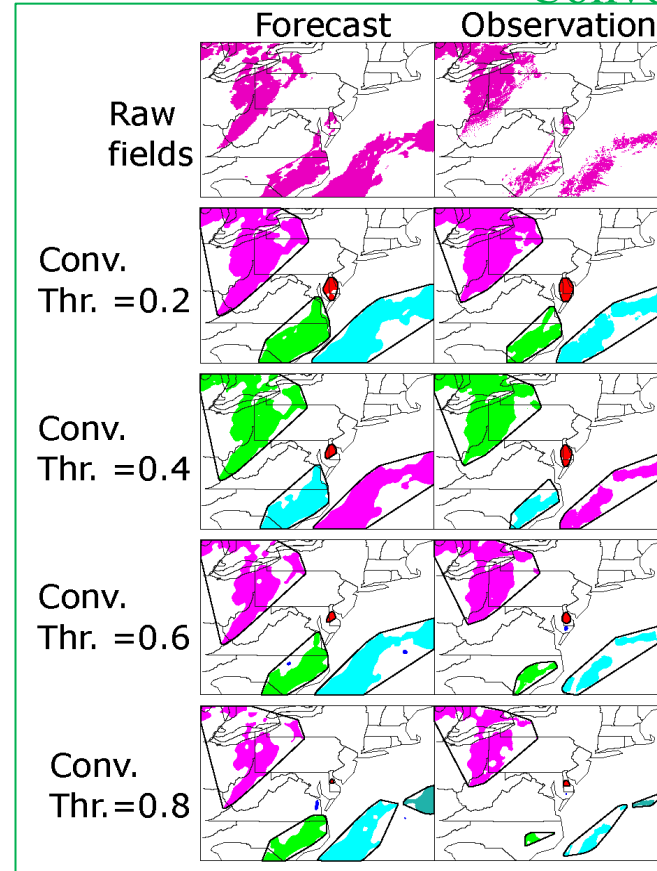
Unified Cloud Regime Verification

Key Accomplishments: Sensitivity of MODE Config

Convolution radius Sensitivity



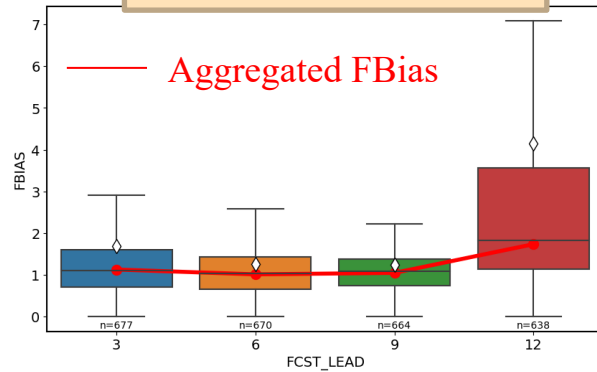
Convolution threshold Sensitivity



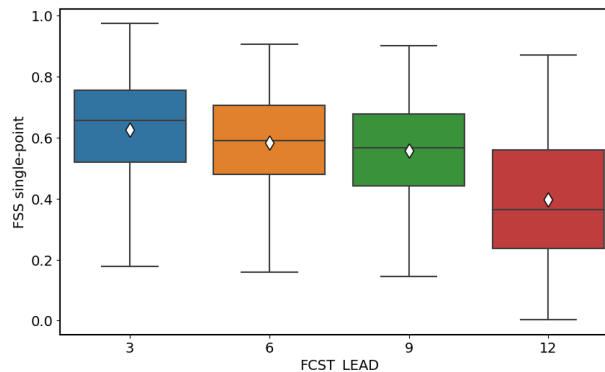
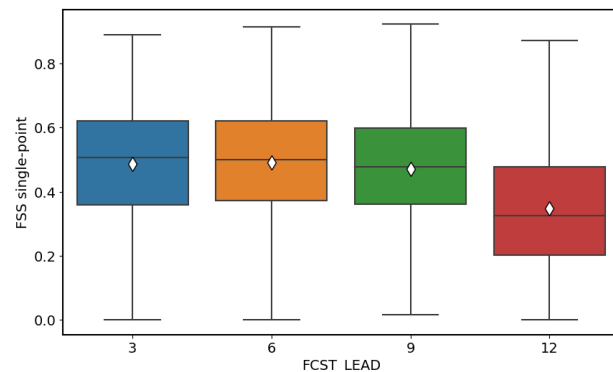
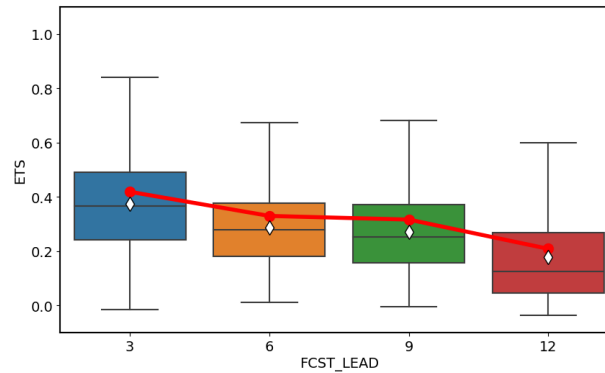
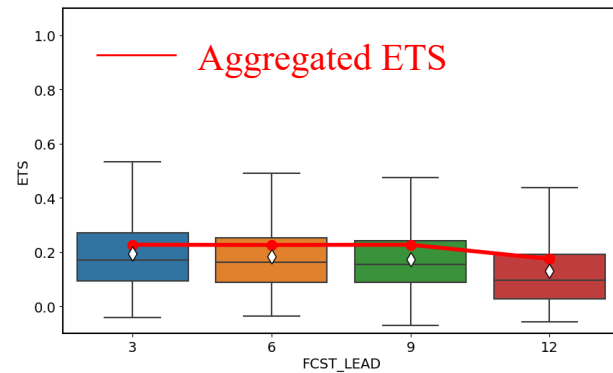
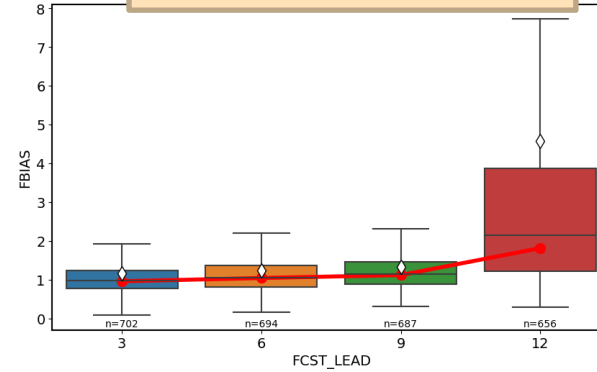
An optimal Configuration of MODE for cloud verification is critical

Comparison of NAVGEM and COAMPS Unstable Clouds

NAVGEM Unstable



COAMPS Unstable

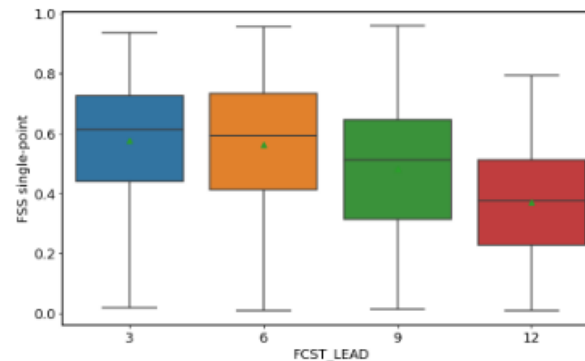
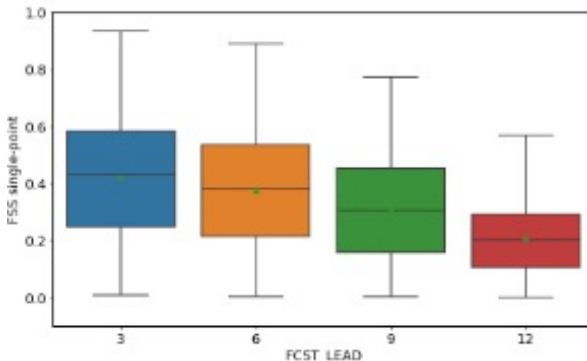
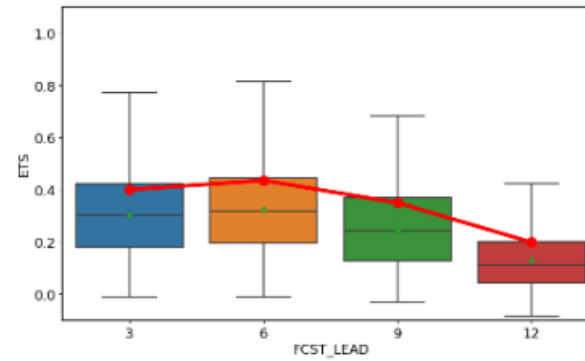
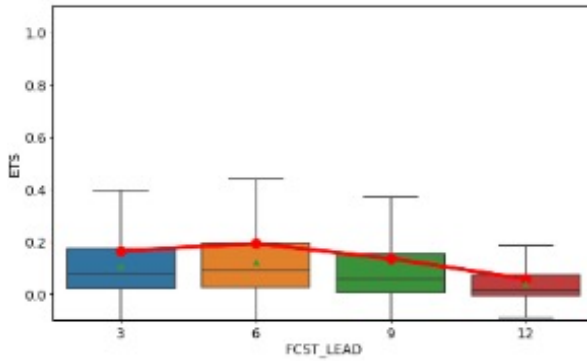
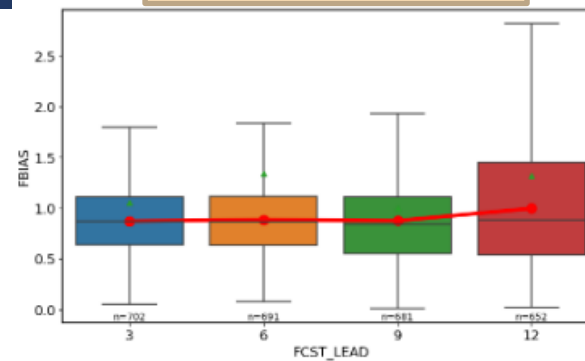
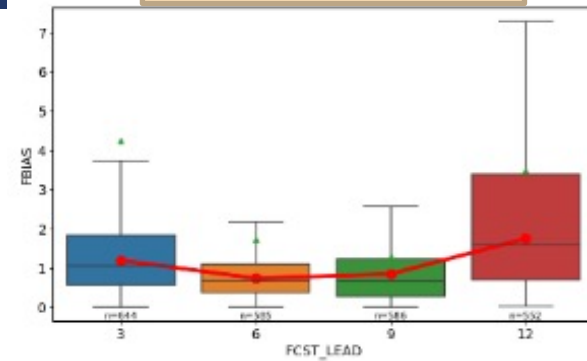


- MODE and GridStat configuration files are the same between COAMPS and NAVGEM, given that they are in the same domain, during the same time period and at the same resolution
- NAVGEM unstable clouds show much lower skill score (ETS and FSS) compared to COAMPS unstable clouds

Paired Object Properties

Metrics	Description	Implication
Area ratio	Forecast area divided by observation area	Perfect match = 1
Area difference	Forecast area minus observation area	Quantify how large the area errors in forecasts
Centroid difference	Distance between two paired objects centroids	Indicator for “over the target” accuracy
Union area	Total area shared between matched objects	Area_overlap_ratio = Intersection_area/Union_area Area_nooverlap_ratio = Symmetric_diff/Union_area
Intersection area	The area that two matched objects overlap	
Symmetric difference	The combined total area between two matched objects that do NOT overlap	
Total interest	Weighted object attributes for matched pairs (attributes considered: 1) centroid distance separation, 2) minimum separation distance of obj boundaries, 3) orientation angle diff, 4) area ratio, 5) intersection area)	Perfect score = 1

Comparison of Stable Cloud Masks

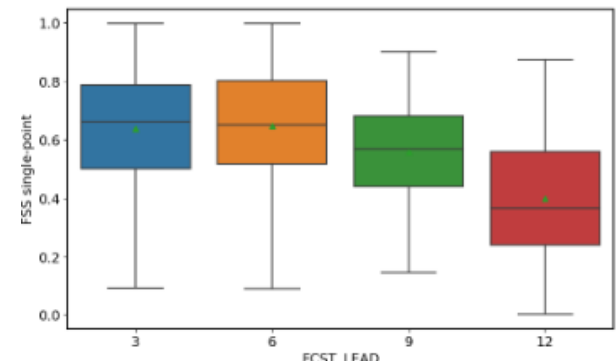
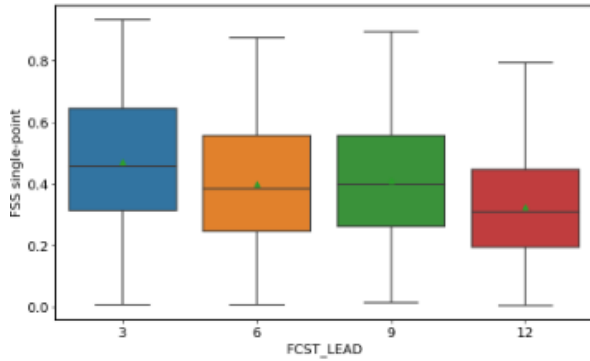
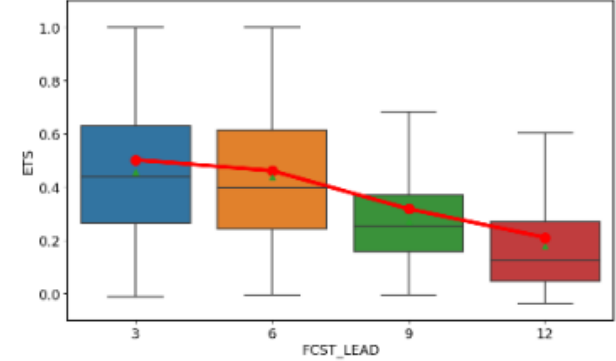
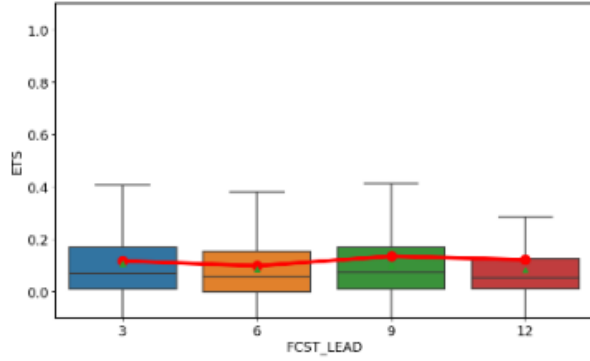
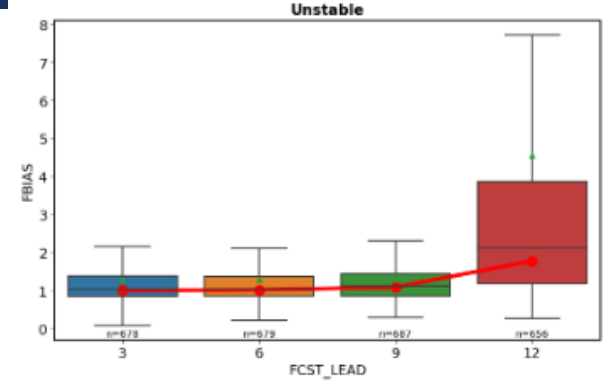
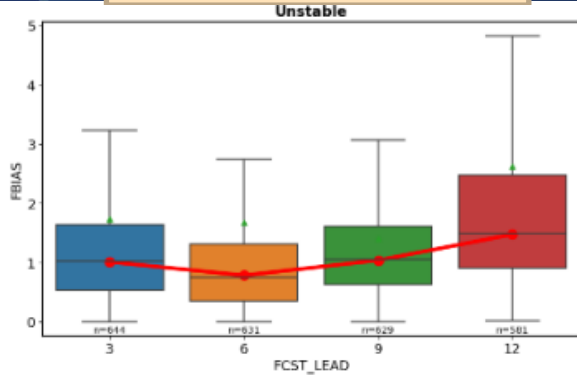


- MODE and GridStat configuration files are the same between COAMPS and NAVGEM, given that they are in the same domain, during the same time period and at the same resolution
- NAVGEM stable clouds shows much lower ETS compared to COAMPS stable clouds

Comparison of Unstable Cloud Masks

NAVGEM Unstable

COAMPS Unstable

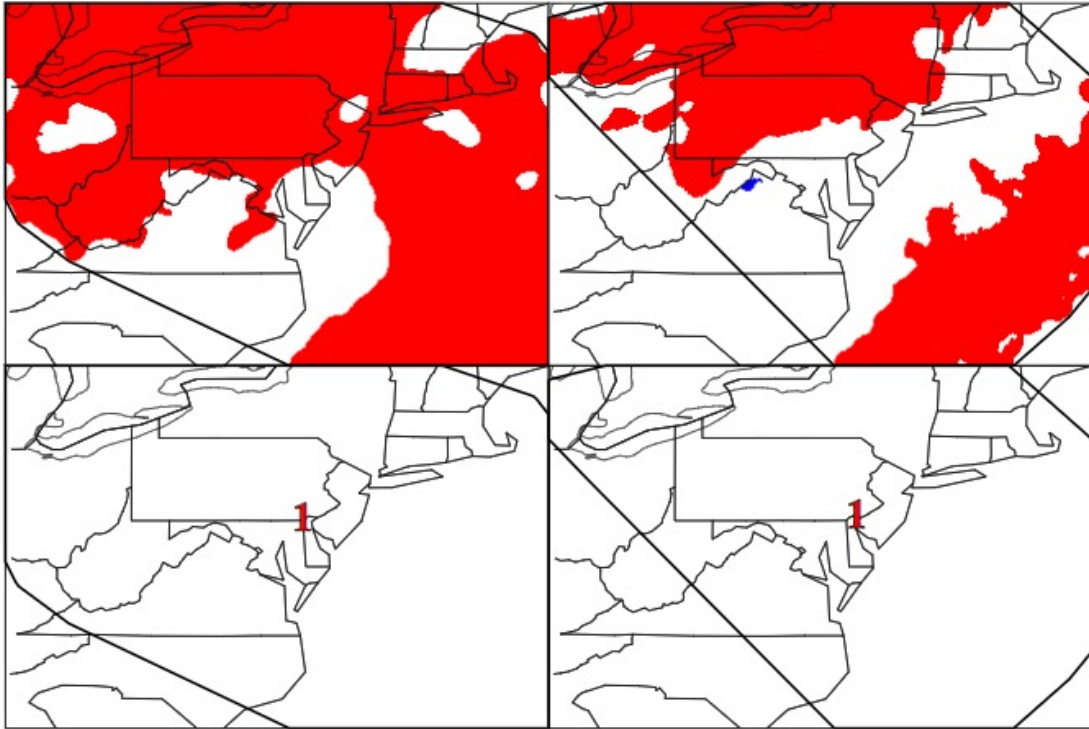


- MODE and GridStat configuration files are the same between COAMPS and NAVGEM, given that they are in the same domain, during the same time period and at the same resolution
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Cluster Object Information

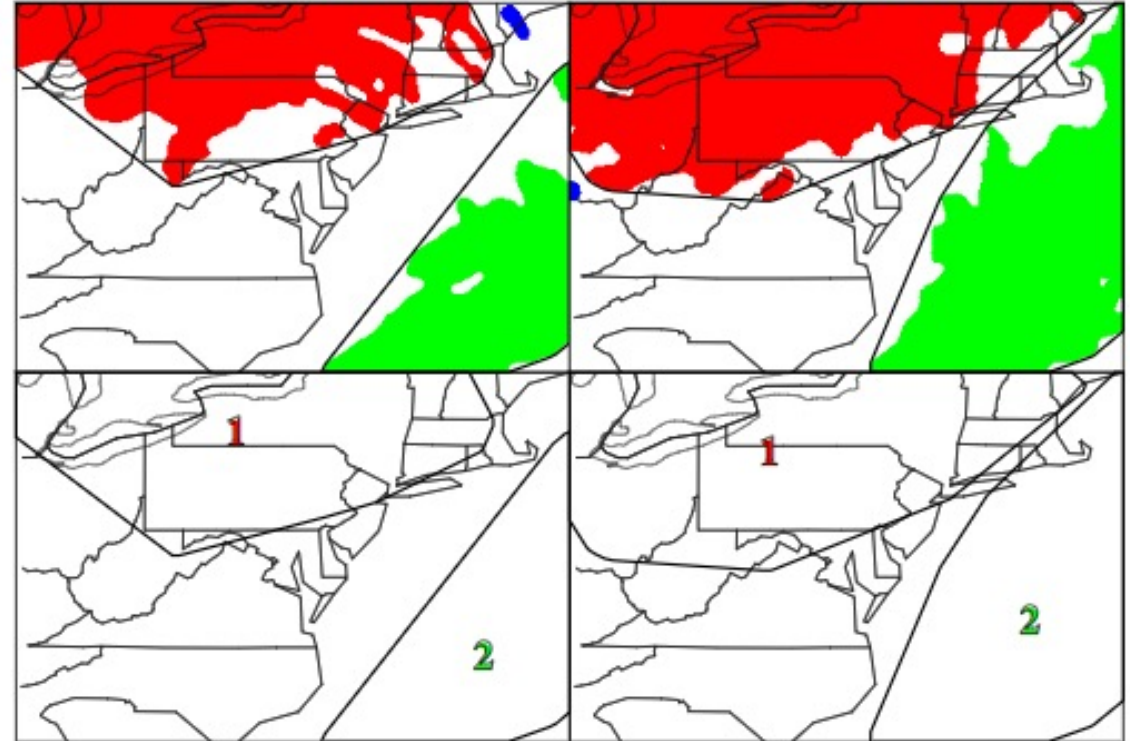
Forecast

Observation



Forecast

Observation



CLU S PAIR	CEN DIST	AREA RATIO	UNION AREA	INTER AREA	SYMM DIFF	TOT INTR
1	6.63	0.61	50175	28660	21515	0.97

Overlap = 57.1%
Non-overlap = 43.9%

20180208 Tau=9

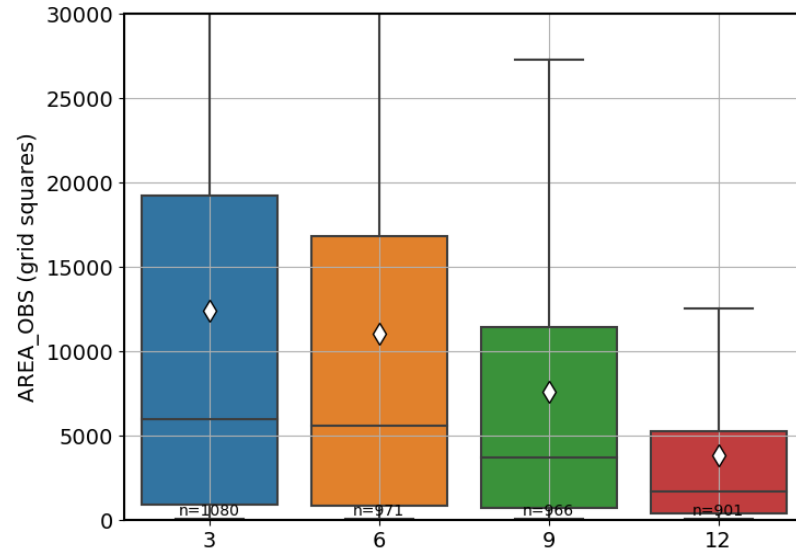
CLUS PAIR	CEN DIST	AREA RATIO	UNION AREA	INTER AREA	SYMM DIFF	TOT INTR
1	17.11	0.68	24498	15844	8654	0.98
2	21.95	0.65	16851	10535	6316	0.97

Overlap = 63.6%
Non-overlap = 36.4%

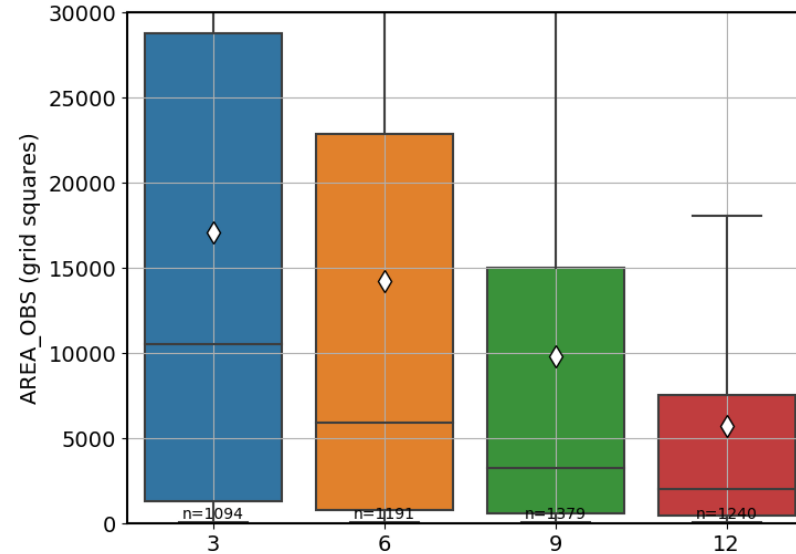
Unified Cloud Regime Verification

NAVGEN Clouds

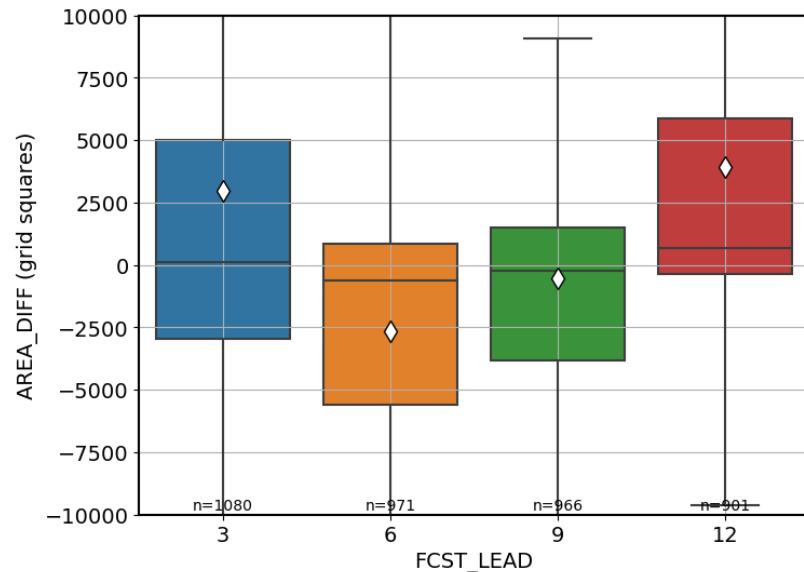
NAVGEN Stable object area_obs (grid squares)



NAVGEN Unstable object area_obs (grid squares)



NAVGEN Stable object area_diff (grid squares)



NAVGEN Unstable object area_diff (grid squares)

