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# Graph Theoretic Observation Thinning for Satellite Radiances

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# Satellite Data Usage

## Why don't we use all of the available satellite data?

- Computational cost of pre-processing and QC
- Ensemble and variational solvers may take too long or even fail to converge
- Spatially correlated observation error
  - A function of how close two similar obs are in space and time
  - Properly accounting for spatially correlated error is an open research question for most data types
  - If ignored, data are treated as if their errors are independent, degrading the analysis
  - We need to select data that are far enough apart to be truly independent, free from correlated observation error

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# Flaws in Current Practice

## How do operational/research centers select data?

- Choose a fixed, approximately equispaced grid on Earth's surface
- Then, for each instrument at each gridpoint,
- Choose the single observation closest to that gridpoint
  - Absent further constraints, the MEAN distance between observations is equal to the grid spacing; however,
  - The MINIMUM distance is unconstrained, allowing correlated error
  - Additional constraints enforcing a larger minimum distance between obs locations leave data gaps
- Averaging (a.k.a. superobbing) instead is not the answer; averaging treats data as independent, baking in any spatially correlated error
- The FUNDAMENTAL problem is that observation selection needs to happen in observation space, not on an arbitrary grid

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# A Problem from Graph Theory

- Given a set of geometric shapes (e.g. circles on a 2D surface), find the maximum independent set (MIS), which consists of the largest number of those shapes that do *not* overlap any other shape
- The MIS problem can be posed as a graph with a node for each shape, and edges between shapes that overlap
- There are known but very slow methods to find the optimal solution, and approximate methods to find good solutions quickly
- The MIS problem maps *directly* onto data selection:
  - Draw a circle at each observation location, with D reflecting the desired local observation density (smaller D => denser obs) – some circles will overlap
  - ***Note that these circles are an abstraction, NOT the satellite footprint***
  - Choose the largest possible set of non-overlapping circles (i.e. solve the MIS)
- The result will be the (nearly) largest set of observations that obey local and global density constraints, and are never closer than the smallest chosen D

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# Graph Thinning Visualization

## Visualizing graph theoretic abstraction for data selection

After legacy thinning on fine grid

**New algorithm**

Each ob is a node (coin), two obs that might be spatially correlated share an edge (overlap), algorithm removes overlapping nodes to find the maximum disjoint set of obs

Final observations retained

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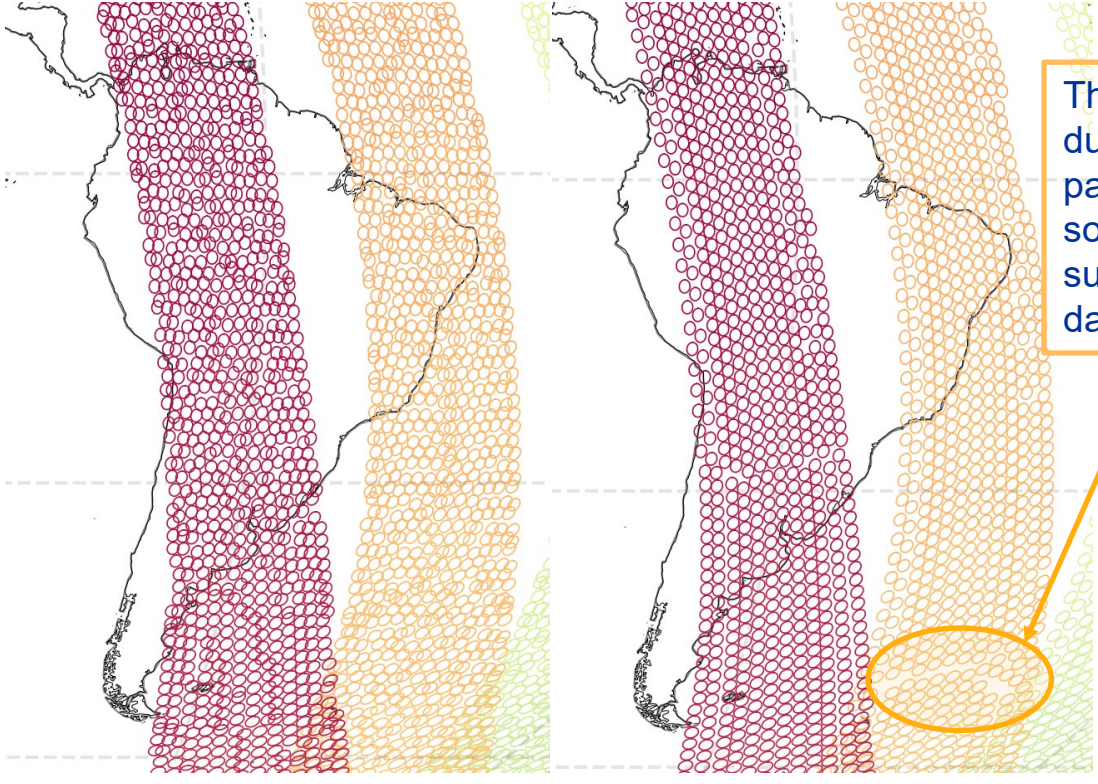
# Grid Thinning vs Graph Thinning

SSMIS F18 20210715T1800Z



The gap is due to the parallel solve of subsets of data

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# Experiments with SSMIS

- **Control run with operational grid thinning, experiment with graph thinning (SSMIS only), flat thinning at grid thinning size**
- **NAVGEM cycling DA runs using all operational conventional and satellite data from June 29 – Oct 2, 2022**
  - ***N.B.*** *grid pre-thinning enhances the speed of the graph thinning with little effect on the final result*

| Control | Graph_flat |
|---|---|
| Grid thinning for all radiances, **~41K** SSMIS profiles | Graph thinning for **SSMIS only**, **~32K** SSMIS profiles, 22% fewer |
| 1 ob per 140km box per 30 minutes | **Prethin:** 1 ob per 33 km box per 30 minutes |
| No diameter assigned; no graph thinning | D=140km for all SSMIS |

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# Verification Metrics

- **Satellite vs simulated obs from short forecasts (aka fit2obs)**
  - Time series of ratio (between experiments) of spatial standard deviation of obs minus background for each channel
  - If the confidence interval (CI) contains the ratio 1.0, then the test cannot distinguish between the two experiments for that channel
- **Fit2obs categorical scorecard (subjective)**
  - Attempt to put similar channels in categories, and evaluate the category as a function of fit2obs wins, losses, and ties (ratio CI contains 1.0)
  - Still a work in progress; wlt_score is very conservative
- **Forecast verification against independent ECMWF analyses)**
  - Each panel shows pressure vs forecast lead time for a given variable (row) and a given region (column) for an experiment vs the control
  - Colors indicate percent improvement or degradation w.r.t. ECMWF analyses; hashing indicates 95% statistical significance

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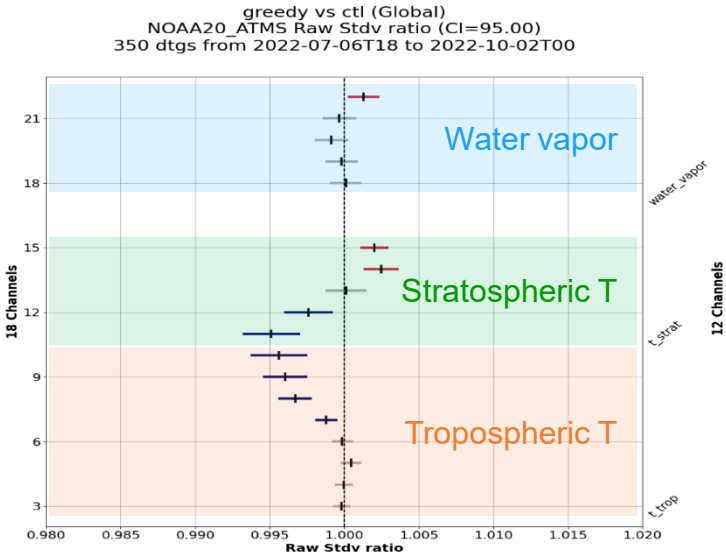
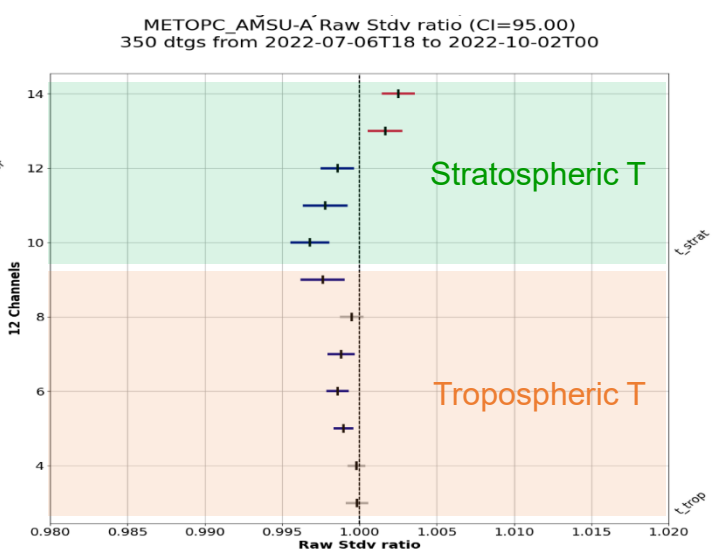
# Graph_flat vs Control

## NOAA20 ATMS




6 wins; 9 ties; 3 losses

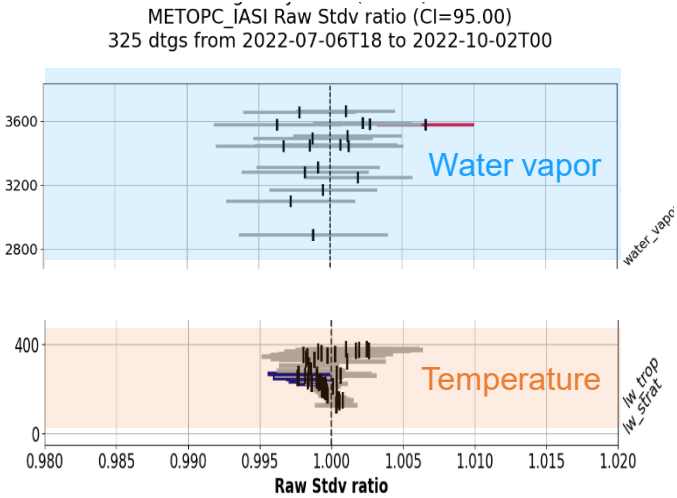
## METOPC AMSU-A




7 wins; 2 ties; 2 losses

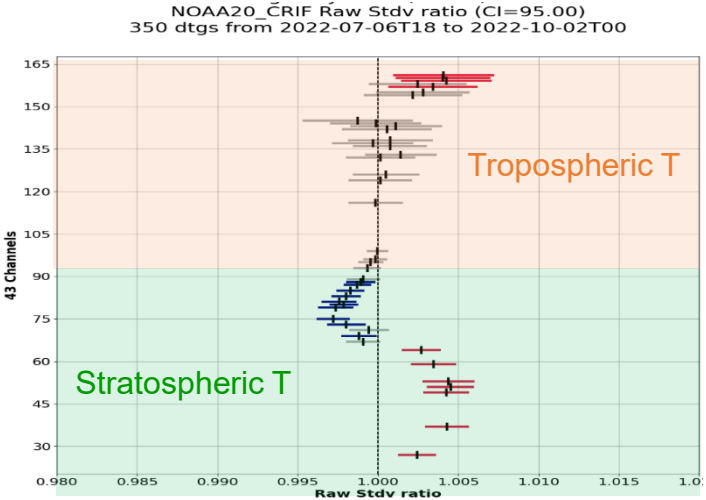
# Graph_flat vs Control

## METOPC IASI




6 wins; 61 ties; 1 loss

## NOAA20 CrIS FSR




10 wins; 22 ties; 11 losses

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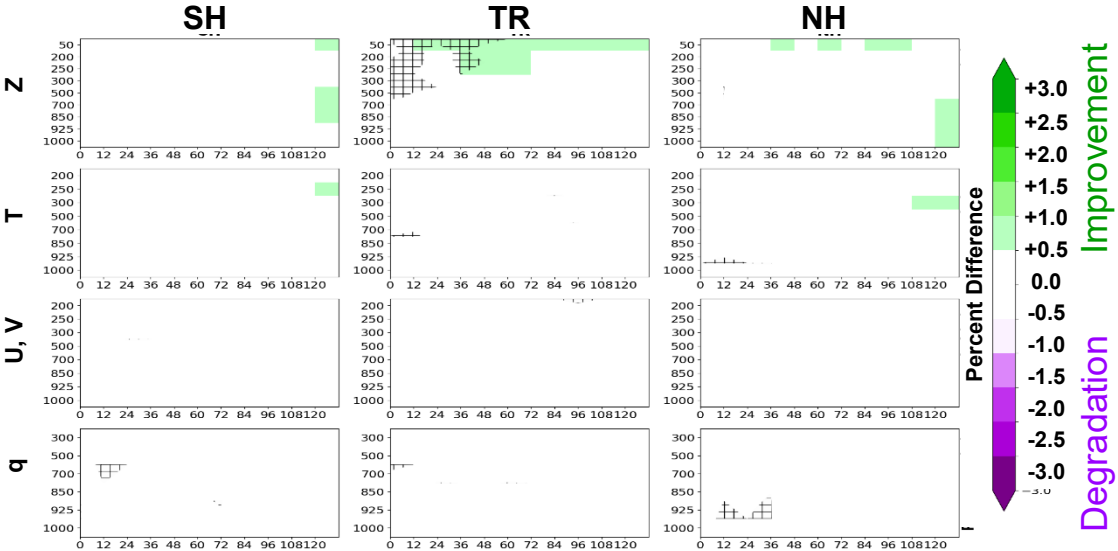
# Graph_flat vs Control Stats

## Verification against ECMWF Analyses



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# Graph Thinning Advantages

- The new method sets an INVIOLATE MINIMUM distance between two similar observations, while simultaneously retaining the maximum number of observations obeying that constraint
- It works in observation space, independent of any grid, and dynamic in space and time
- The freedom to assign each observation its own radius given by a density function, where the users expertise is implemented to influence which obs will be more or less likely to be retained, with a myriad of potential applications
- The density function is arbitrary: it can depend on obs error, other metadata such as orbital parameters, surface type, flow of the day, etc.
- The maximum density is constrained by the minimum safe distance to mitigate spatially correlated error; minimum density is chosen by the user
- Even if the density function is constant, there is a significant benefit, because we are restricting the MINIMUM obs distance rather than the MEAN obs distance

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# Future Work

- **Apply the methodology to existing sensors of interest such as ATMS and CrIS FSR, and future sensors such as TROPICS, TEMPEST, and COWVR, starting with flat thinning in a NAVGEM context**
- **Expand the science by investigating application of novel density functions, for example targeting increased observation density near developing storms or hurricanes**
- **Investigate spatially correlated error with complete control over minimum distance between observations**
- **Anisotropic data thinning across frontal boundaries, geographic features**
- **Subset thinning for different channels at the same spatial location (e.g. greater density for moisture channels than temperature channels while retaining full channel profiles where possible)**
- **Weighted superobbing accounting for spatially correlated error may be more straightforward to address on a graph in observation space**

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# Questions?

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