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The Use of Analog Ensembles to Improve Short-Term Solar Irradiance Forecasting

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Background

- AWS Truepower developed the Solar and Wind Integrated Forecast Tool (SWIFT) (Zack et. al., 1:30 PM).
- As part of SWIFT, a Pyramidal Image Matcher (PIM) cloud advection algorithm has been employed as a short term solar irradiance forecast tool.
- Analog Ensemble (AE) has been successfully applied to day-ahead NWP output by by Delle Monache, et. al. (2013).

Question

- Can AE improve upon the PIM irradiance forecast?

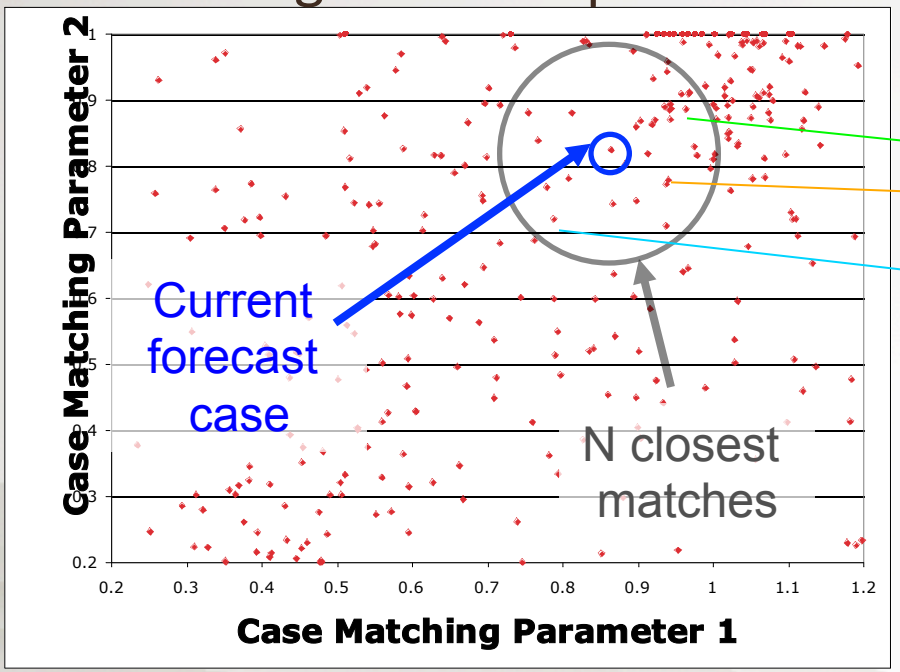
Delle Monache, Luca, F. Anthony Eckel, Daran L. Rife, Badrinath Nagarajan, Keith Searight, 2013: Probabilistic Weather Prediction with an Analog Ensemble. *Mon. Wea. Rev.*, **141**, 3498–3516.

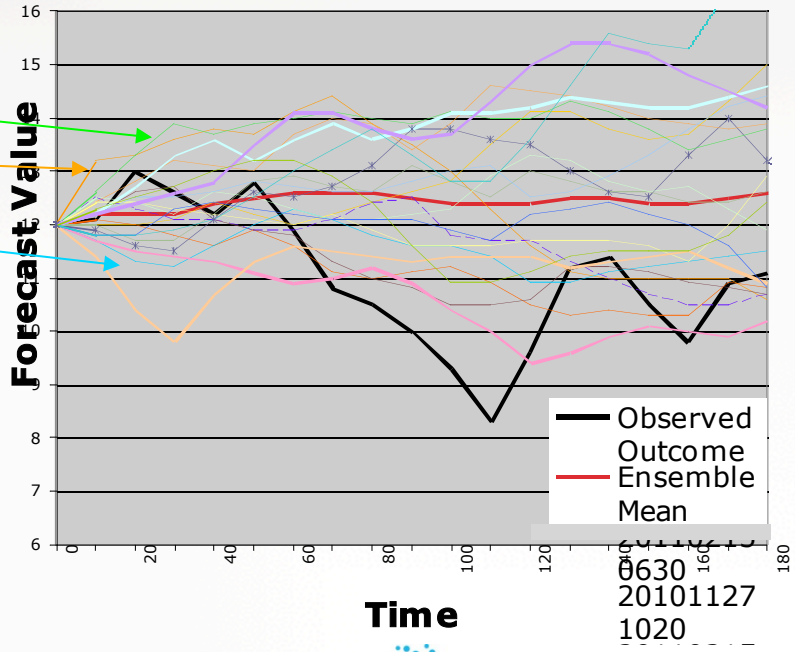
Analog Ensemble Method

1) Compute one or more normalized case-matching variables for the current case and each case in the training sample

2) Case-matching score: distance between current case and a training sample case in case-matching variable space.

3) Choose the N cases with the lowest case matching scores.





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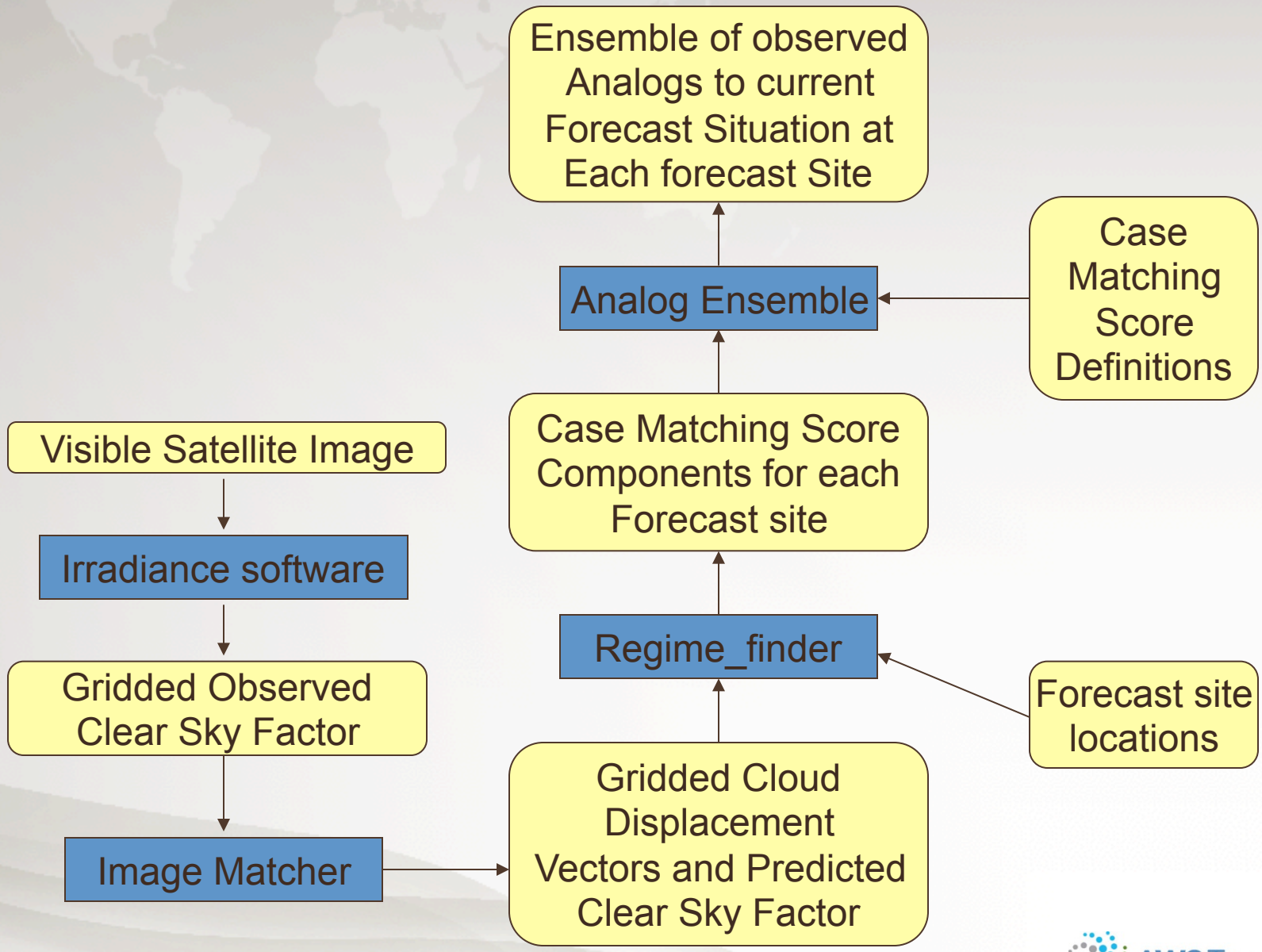
Analog Ensemble Details

- All case-matching variables are normalized.
- Ensemble is calculated independently at each forecast interval with some blending to prevent abrupt transitions.
- Case matching variables are chosen by trial and error using local forecasting knowledge.

Analog Ensemble Forecast Process



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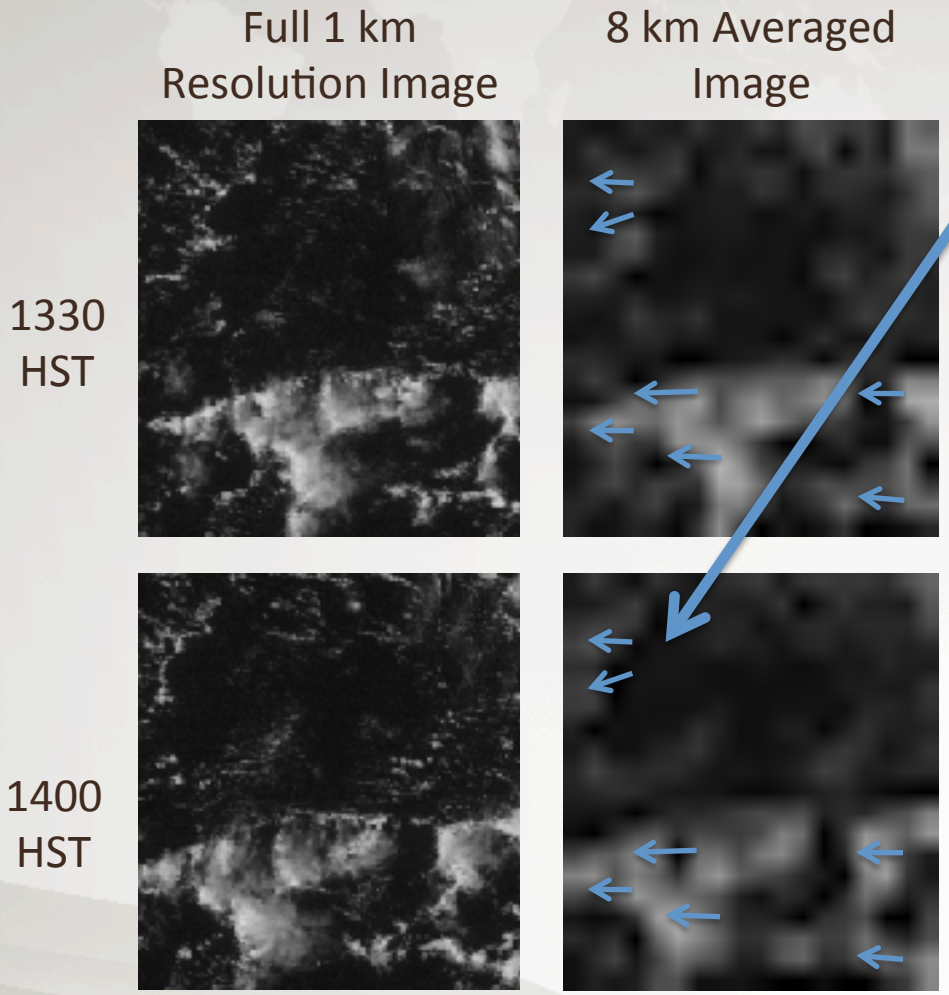
Pyramidal Image Matcher Attributes

- Multi-scale approach enables the PIM to capture the motion and development/dissipation of clouds at all important scales of motion.
- Estimates coarse cloud motion vector field a larger scales using visible satellite images averaged to coarse resolution.
- Refines cloud motion vector field at successively finer scales until the full resolution image is reached.
- Estimates future images by propagating current image forward in time using the motion vector field.

ZINNER, T., H. MANNSTEIN, A. TAFFERNER, 2008: Cb- TRAM: Tracking and monitoring severe convection from onset over rapid development to mature phase using multi- channel Meteosat-8 SEVIRI data. − Meteor. Atmos. Phys. 101, 191–210, DOI 10.1007/s00703-008-0290-y.

Pyramidal Image Matcher Method



Step 1: Compute 8-km averaged images.

Step 2: Compute Motion Vectors at 8 km resolution.

Step 3: Use motion vectors to estimate1400 HST 1 km from 1330 image.

Step 4: Average estimated 1 km image to 4 km.

Step 5: Estimate correction to motion vectors using 1330 HST observed 4 km and estimated 1400 HST observed 4 km images.

Step 6: Repeat steps 2-4 at 2 km and 1 km scales.

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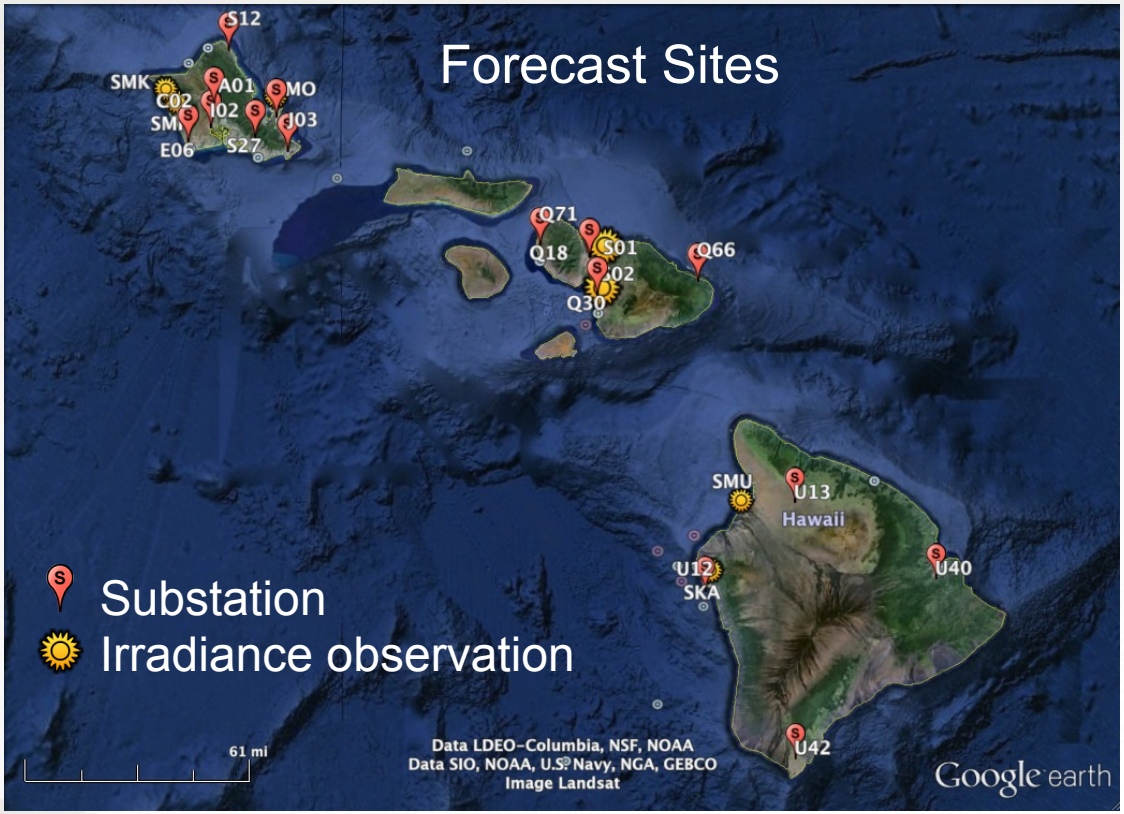
Pyramidal Image Matcher Configuration

- Motion vector field is derived from the most recent 2 observed images at 16 km resolution, then refined at 8, 4 and 2 km.
- Prediction is done using clear sky factor or CSF.
  - CSF = transmissivity / clear sky transmissivity
  - CSF is derived from visible brightness using the techniques of Perez, et. at. (2002)
  - A bias correction is applied to CSF. Correction varies by solar zenith angle, cloud amount and time (before noon, after noon).
- A 7 hour forecast is produced at 15-minute intervals.

PEREZ, R., P. INEICHEN, K. MOORE, M. KMIECEK, C. CHAIN, R. GEORGE and F. VIGNOLA, 2002: A new operational model for satellite-derived irradiances: Description and validation. Solar Energy, 73, 307-317.

Experiment Details

- 363 Day Training Period 03 December 2012 - 30 November 2013.
- Two forecast periods: January 2013, August 2013.
- The period from 7 hours before to 2 weeks after each forecast time is excluded from its training sample.
- Forecast locations:
  - Sample of electric substations with substantial rooftop PV.
  - Surface irradiance observations.
- Verification Variables:
  - Satellite-estimated irradiance.
  - Observed irradiance.
  - Both converted to CSF.



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Choice of Case Matching Variables

- Mean over a 10 km box centered on the forecast site.
  - CSF (CSF MEAN).
  - Cloud Displacement vector amplitude (DISPAMP).
  - Cloud displacement vector direction (DISPDIR).
  - Standard deviation of CSF (20 km box) (CSF STDEV).
- Mean cloud X and Y displacement over a larger area 50-100 km upstream in the prevailing east-northeasterly flow (DISPXY).
- Time of day
  - As a case matching variable (TMATCH).
  - As a regime variable (limit ensemble members to those within a certain time window) (TWIN).

Choice of Case Matching Variables

Baseline Forecasts

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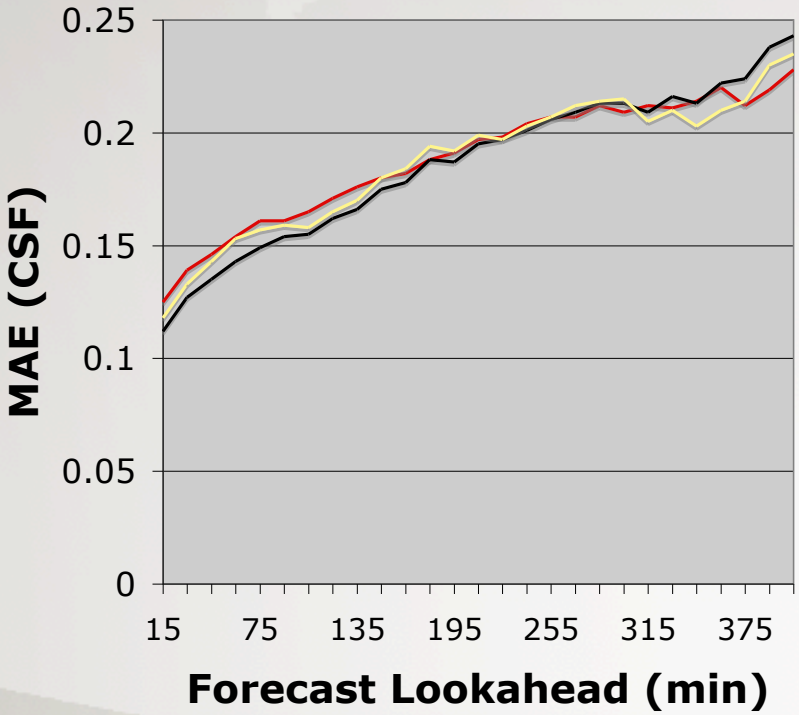

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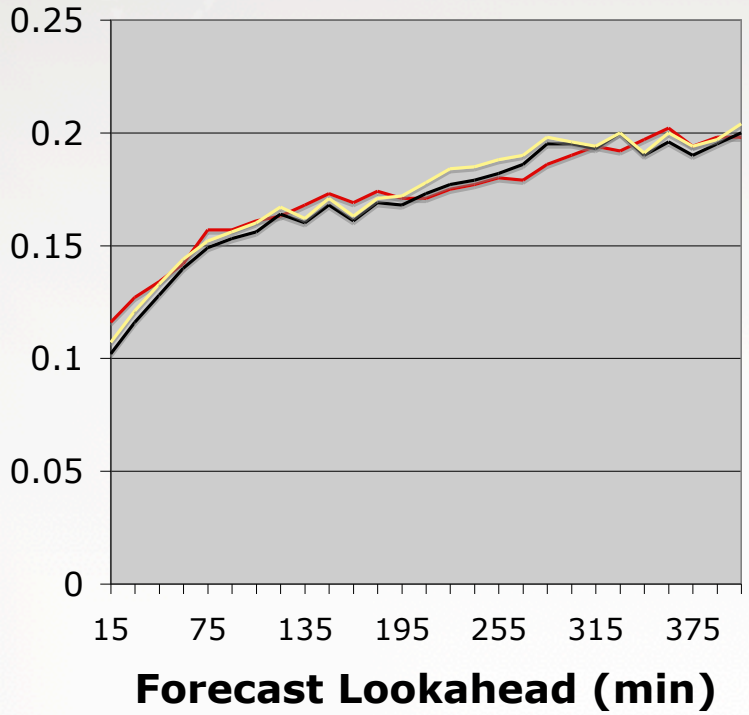

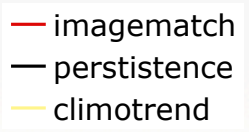

Mean MAE of ensemble 50% POE over all sites, times vs. satellite estimated CSF.

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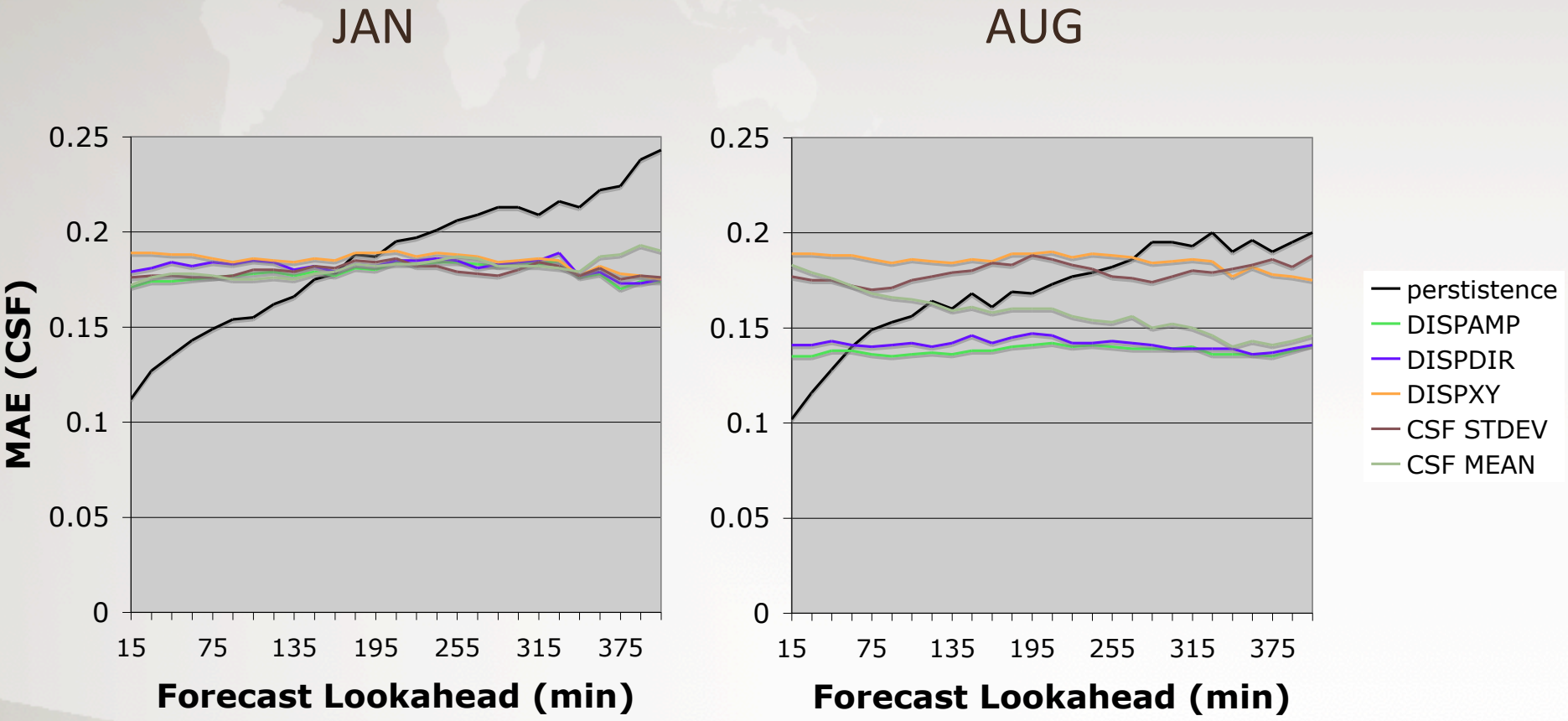
Choice of Case Matching Variables

Single Variables



Mean MAE of ensemble 50% POE over all sites, times vs. satellite estimated CSF.

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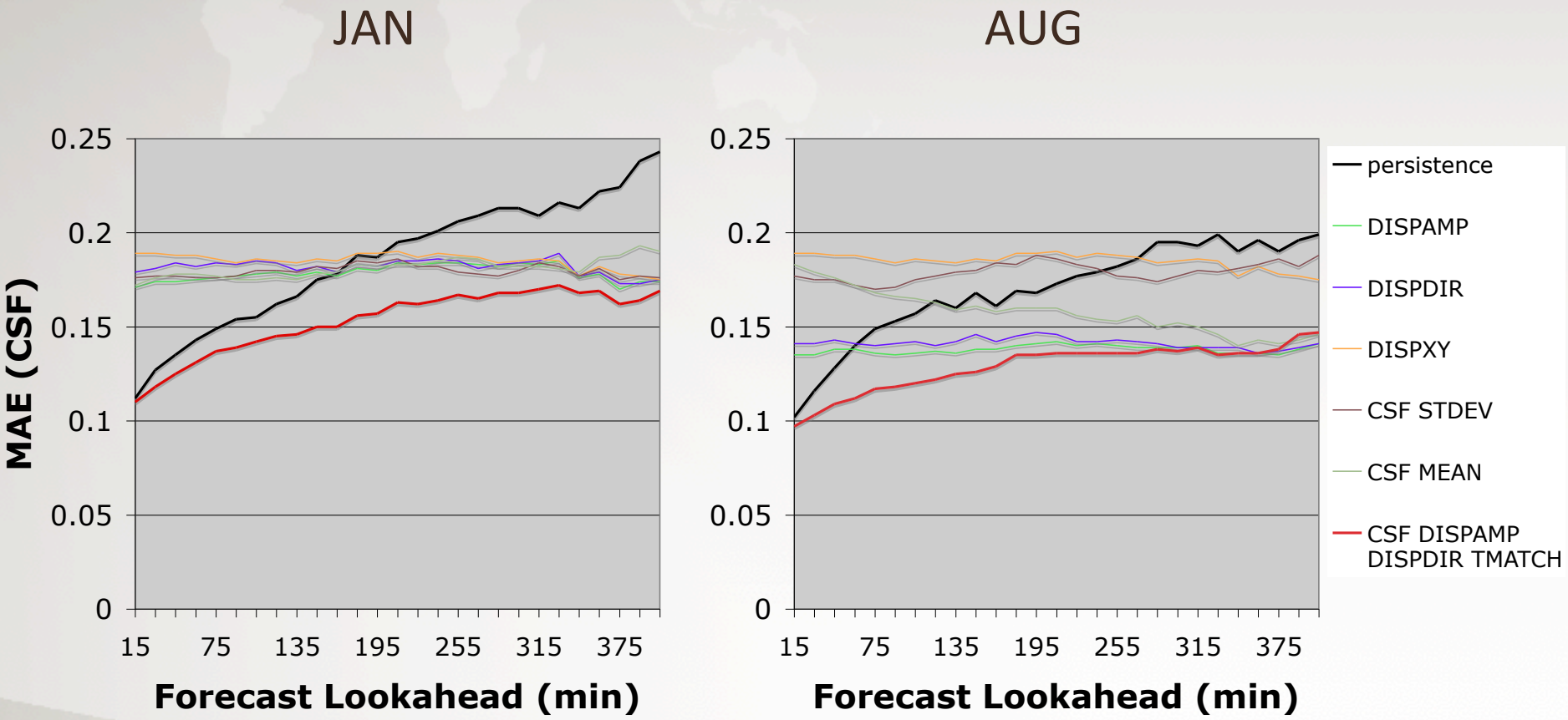
Choice of Case Matching Variables

3 Variables - Time is Case Matching Variable



Mean MAE of ensemble 50% POE over all sites, times vs. satellite estimated CSF.

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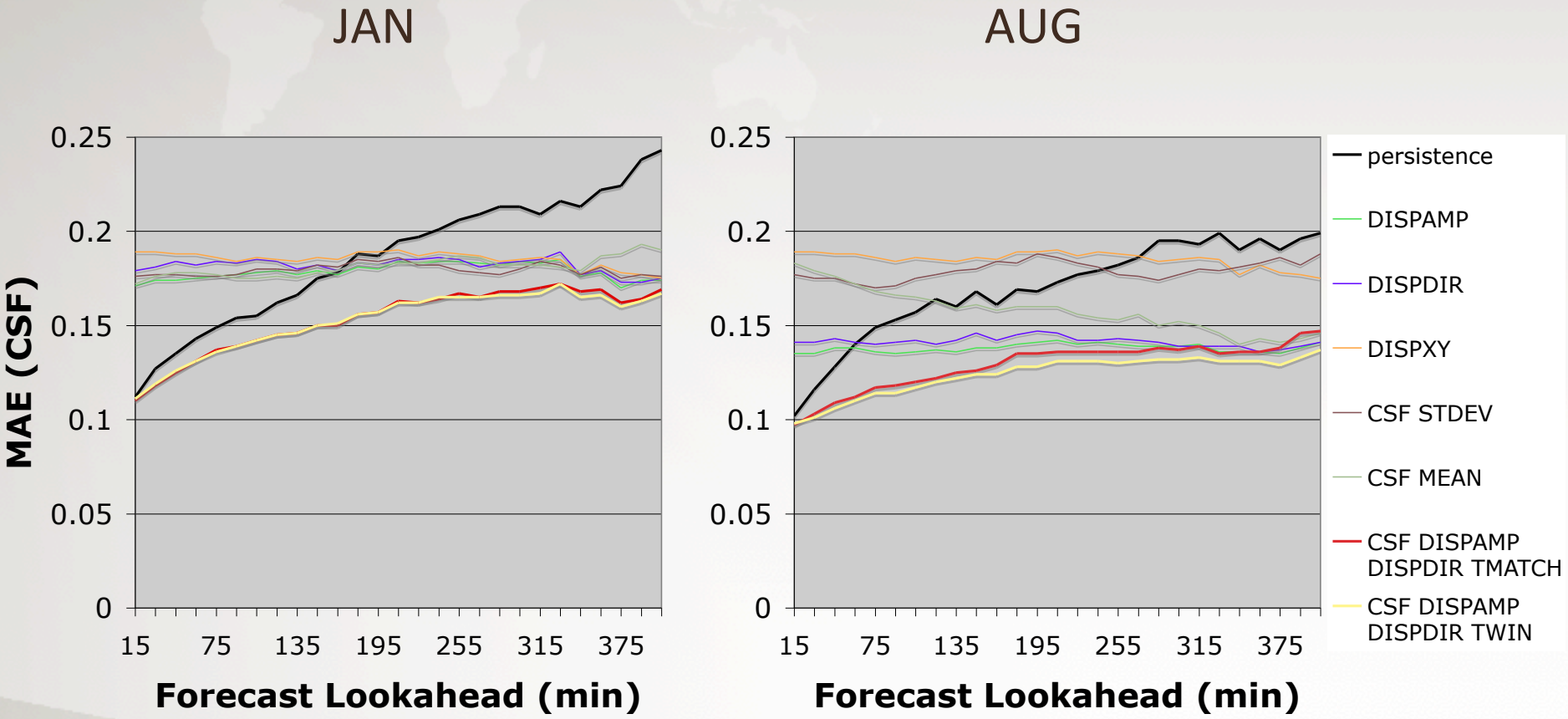
Choice of Case Matching Variables

3 Variables - Time is Regime Variable



Mean MAE of ensemble 50% POE over all sites, times vs. satellite estimated CSF.

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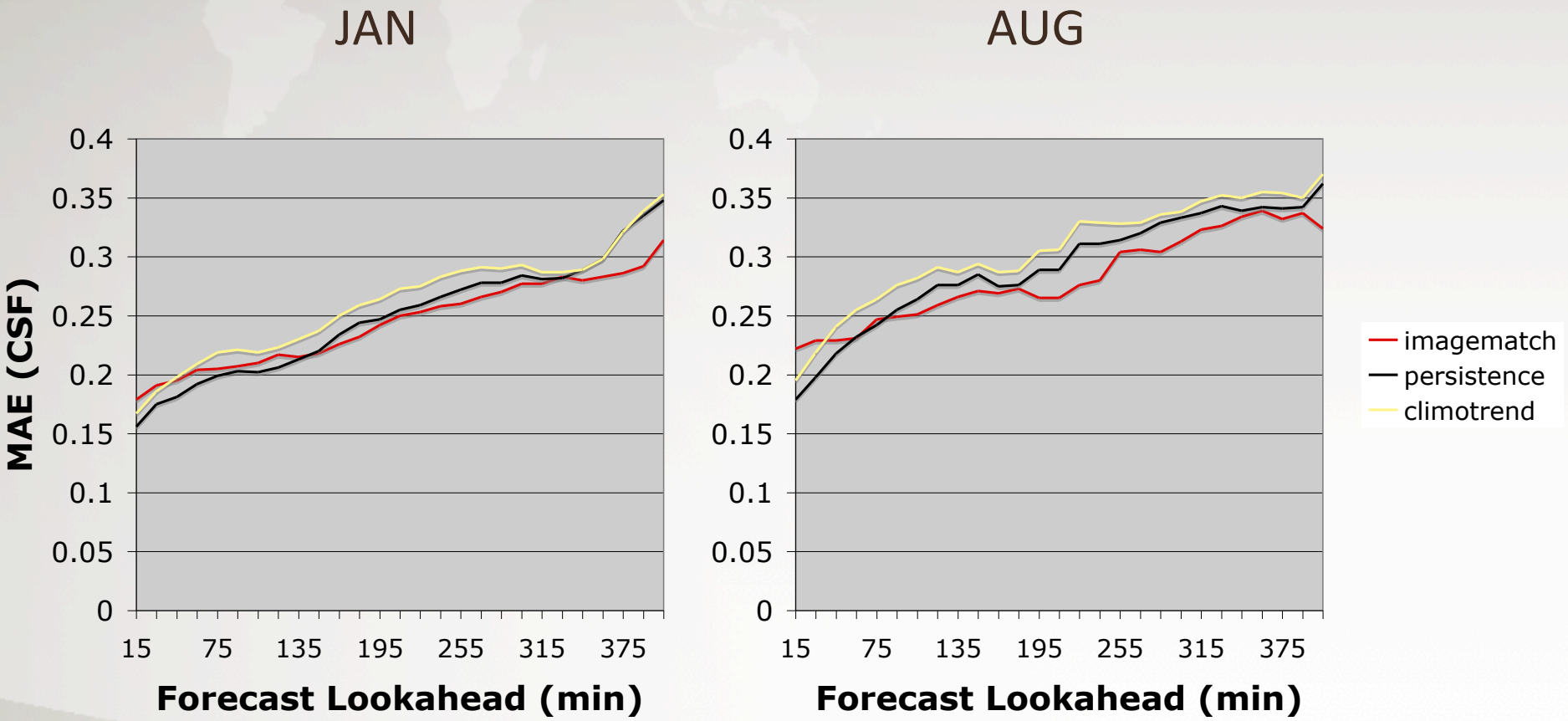
Choice of Case Matching Variables

Baseline



Mean MAE of ensemble 50% POE over all sites, times vs. 7 surface observations.

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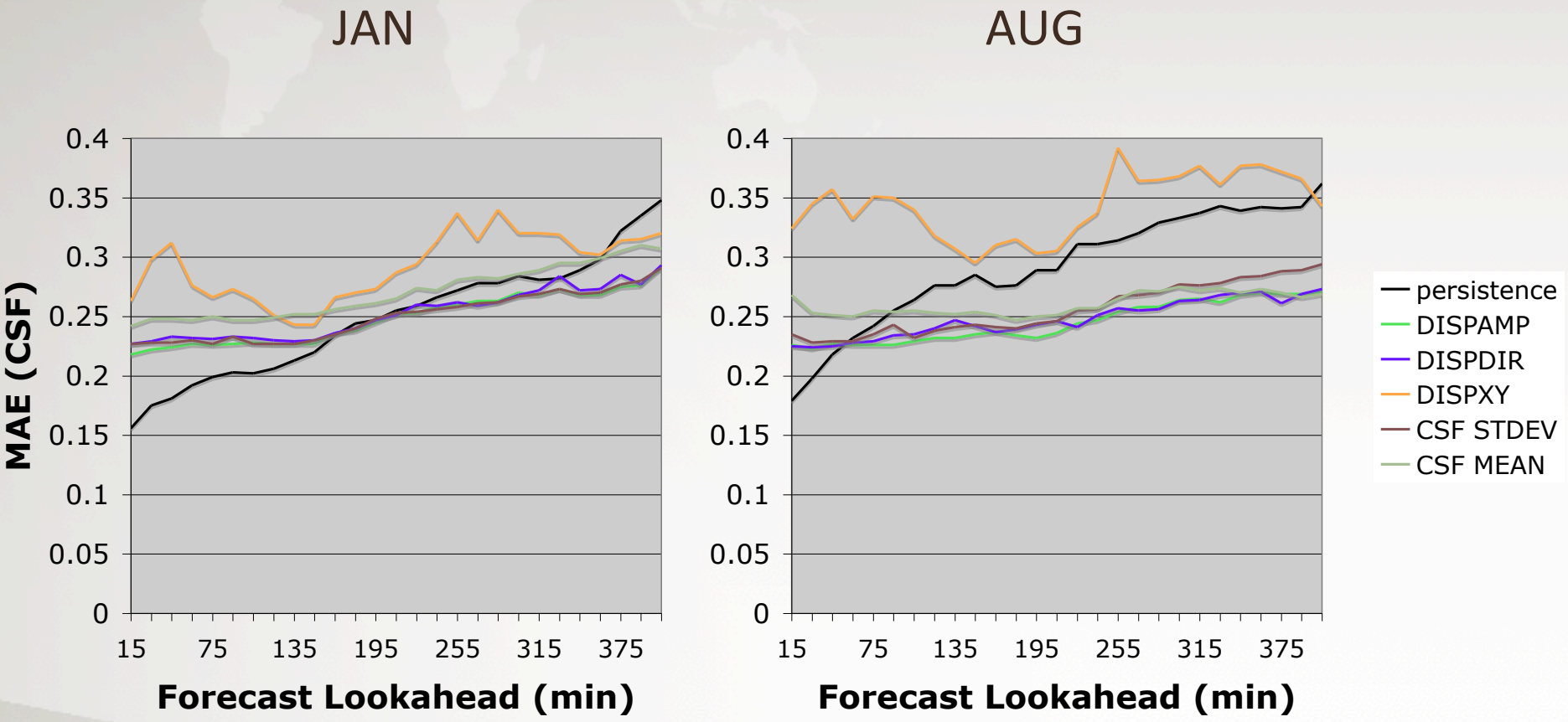
Choice of Case Matching Variables

Single Variables



Mean MAE of ensemble 50% POE over all sites, times vs.
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Choice of Case Matching Variables

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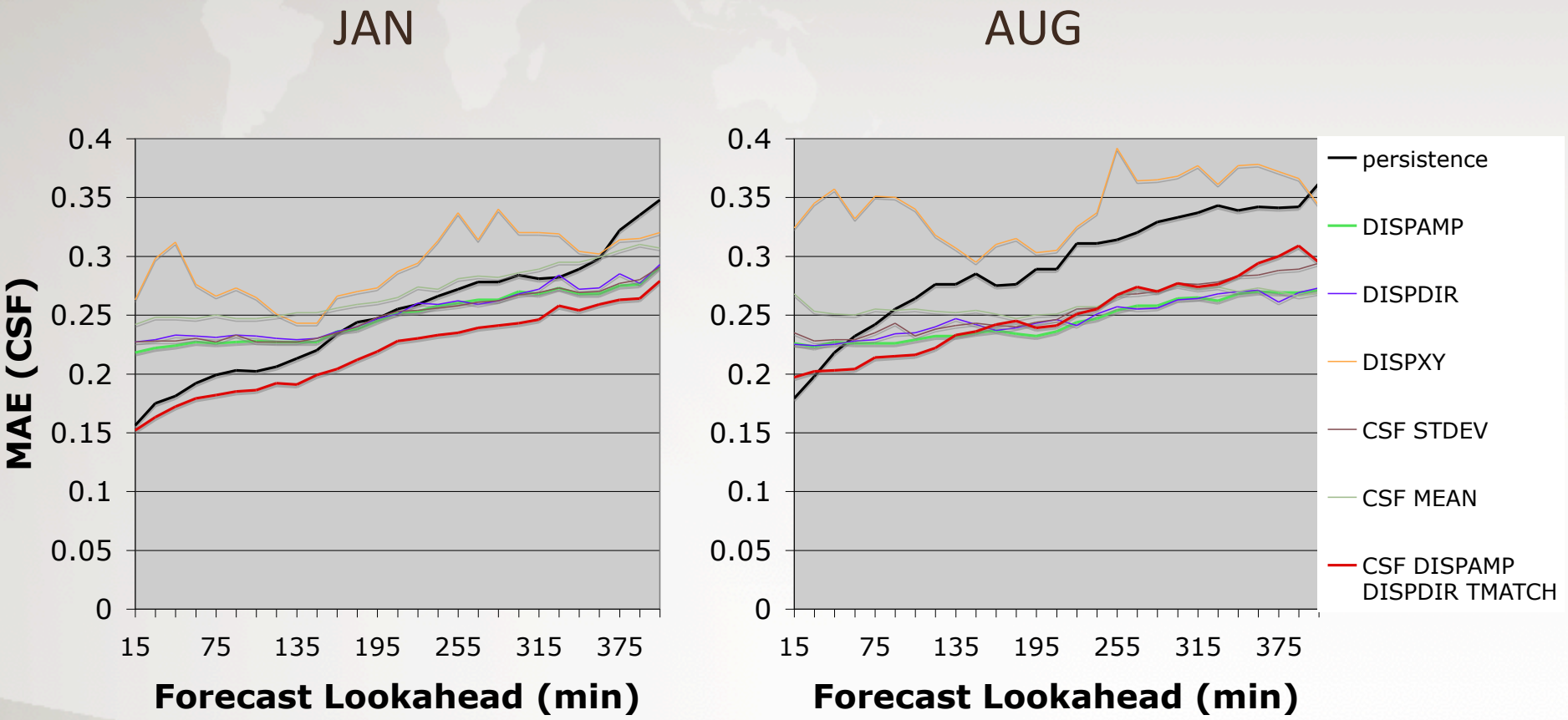

Mean MAE of ensemble 50% POE over all sites, times vs. 7 surface observations.

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Choice of Case Matching Variables

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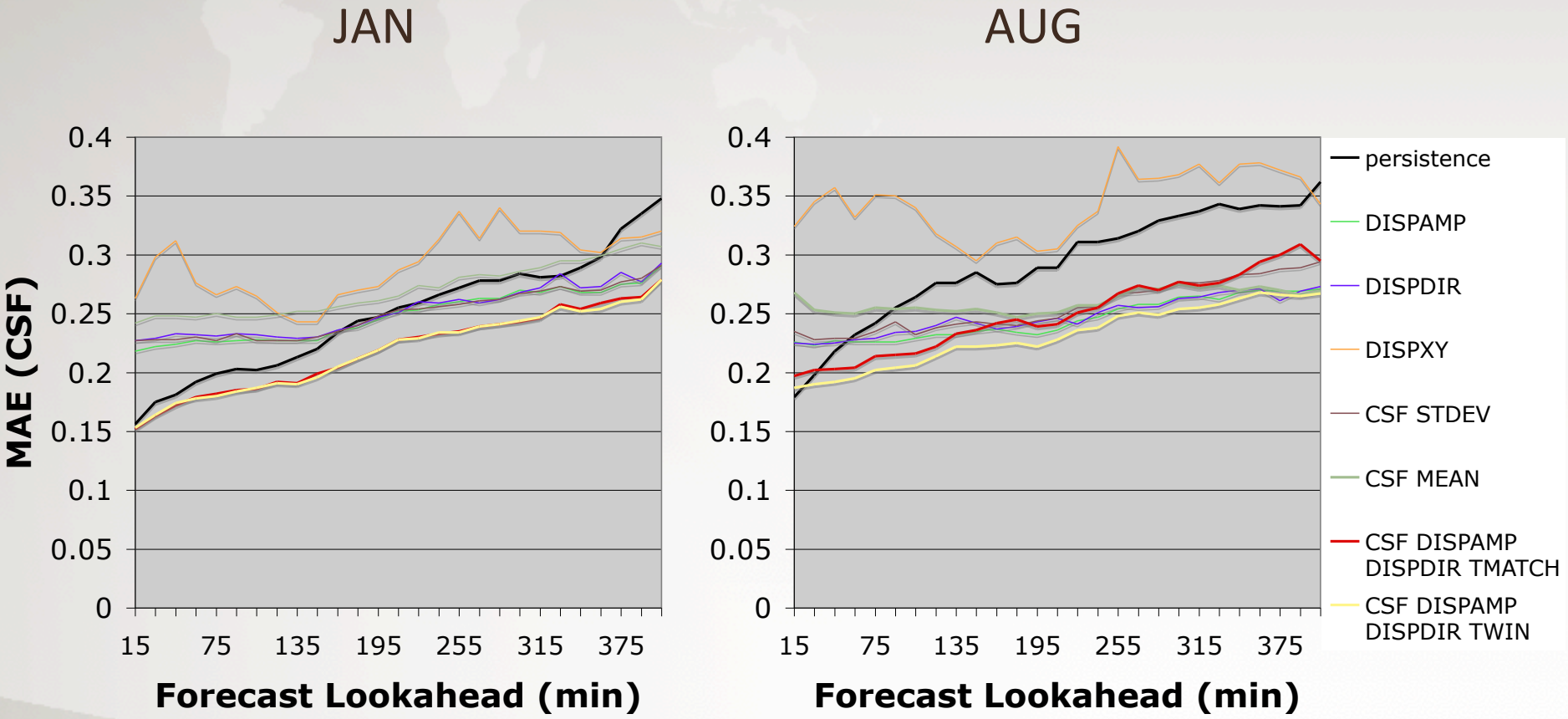

Mean MAE of ensemble 50% POE over all sites, times vs. 7 surface observations

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Performance By Island

Skill Score vs. Persistence.

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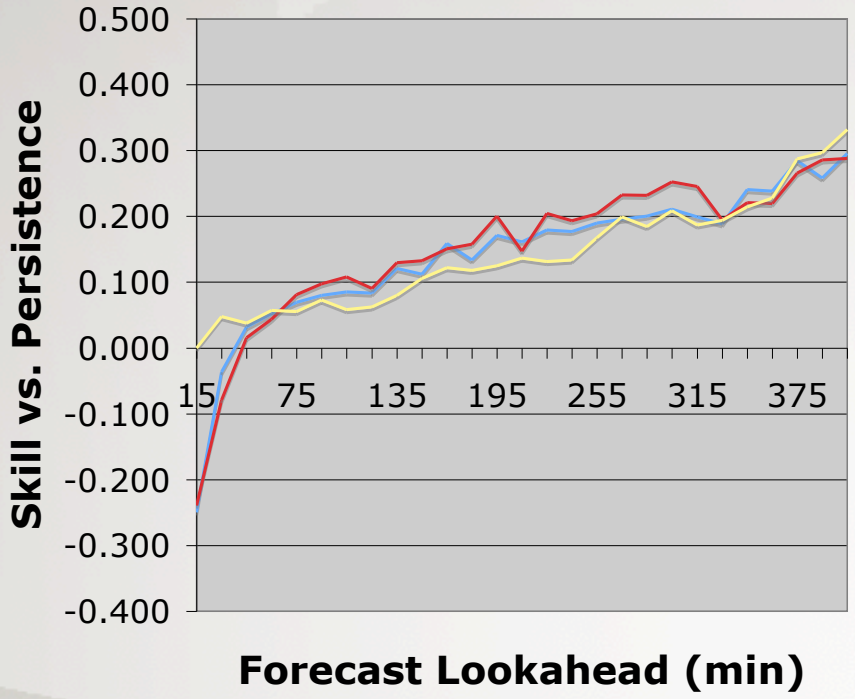

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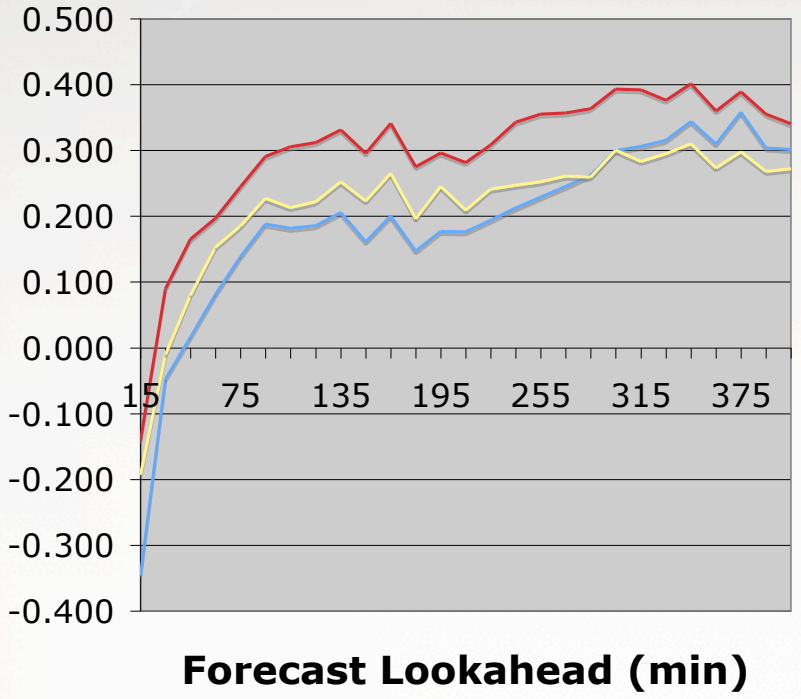

Skill is higher in August, especially for Maui

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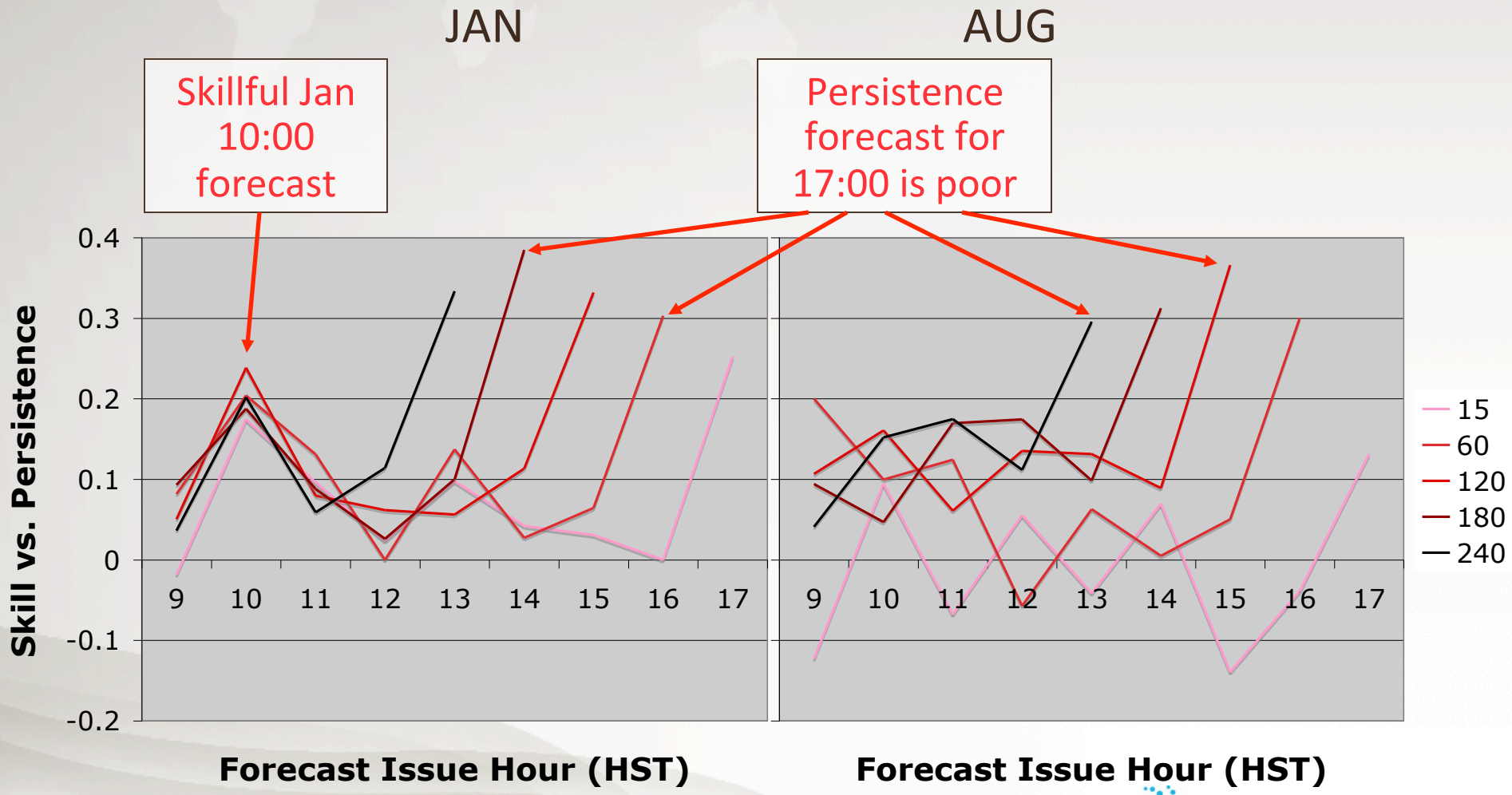
Performance by Time of Day

Skill Score vs. Persistence at Different forecast Look ahead times for 7 surface observations



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Main Points

- An analog ensemble technique was applied as a bias correction tool for a pyramidal image matcher based solar irradiance forecast..
- Verification Results over 2 months showed significant reduction of error over the raw PIM and persistence forecasts.
- Error reduction was more significant at some times of day.

Future Work

- Improve forecast skill at around solar noon.
- Add frequent update NWP-derived variables to the case-matching variables.
- Test the analog ensemble's utility as a probabilistic forecast tool.
- Apply the technique to other locations.

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Questions?

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