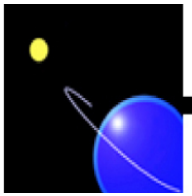

SPACE ENVIRONMENT TECHNOLOGIES

Space Research *Space Operations* *Space Standards*

AF Operational Real-Time Thermospheric Density Monitoring Project HASDM

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Outline

- HASDM Overview
- HASDM Density Accuracies
- HASDM Prediction Accuracy Improvements
- Covariance Prediction Improvements

HASDM Overview

- HASDM – High Accuracy Satellite Drag Model started in 2000
- DCA – Dynamic Calibration Atmosphere program using AF Space Surveillance Network observations every orbit from multiple radars
- Produces density corrections every 3 hours using multiple calibration satellites (~75-85) consisting of spheres, R/B, debris at altitudes from 200 to 800 km
- Original correction of Jacchia 1970 density model (J70MOD)
  - Correction varies with latitude, longitude, altitude, and time
  - Density correction predicted out 3 days as a function of predicted solar/ geomagnetic indices

Goal: Improve 24-72 hour satellite position predictions

- Developed new atmospheric model (Jacchia-Bowman-2008 derivative – JBH09) for all solar conditions and geomagnetic storms
- Developed new solar EUV indices and a new geomagnetic storm index to be used for computing density values using real-time satellite observations
- Developed geomagnetic storm Dst Anemomilos prediction model
- Operationally implemented in 2013

HASDM Calibration Set

HASDM Jun 2014 Calibration Satellites

Height Km	190	250	300	380	420	500	550	600	700	**Total**
Inclination	250	300	380	420	500	550	600	700	800	
20-30	1	1	2	1	1					
30-40	3	1	1	1			1			
40-50		2								
50-60	3	1			1			1		
60-70	1	1		1	1					
70-80			3	1				1	2	
80-100		1	7	9	14	10	6	2	3	
Total	**8**	**7**	**13**	**13**	**17**	**10**	**7**	**4**	**5**	**84**

Calibration Sat Constellation Monitoring

- **During 2013:**

- Number of constellation decays: 4
- Number of constellation additions: 4
- Number of constellation rejections: 3
- Future launches: 3 calibration spheres in polar orbits
- Sensor tasking: 4 categories based on orbit inclination and eccentricity

Operational Solar/Geomagnetic Indice Data Sources

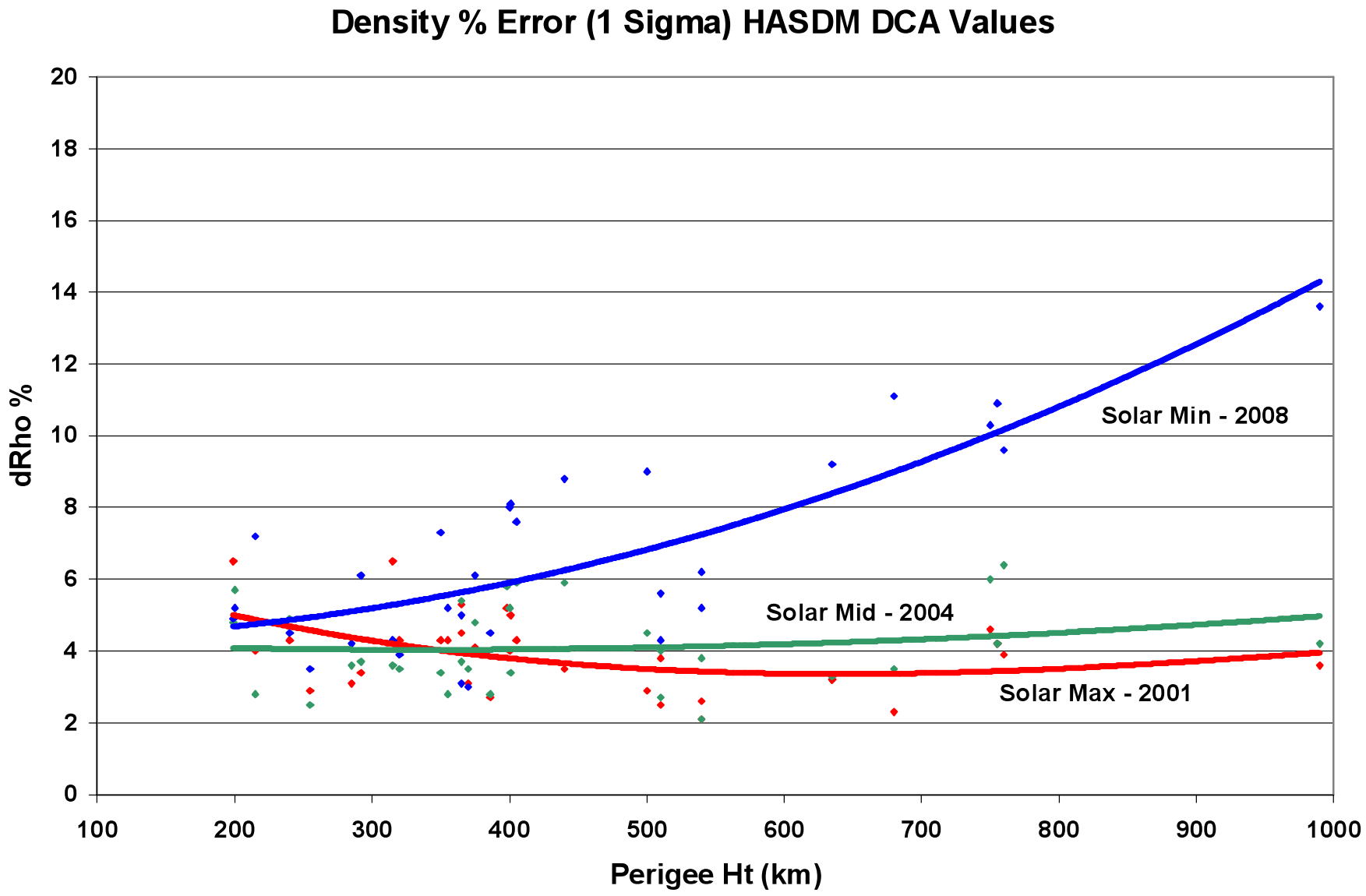
Solar indices

- **S10:**
  - A (GOES/EUVS)
  - B (SOHO/SEM; TIMED/SEE; SDO/EVE)
- **M10:**
  - A (NOAA 18/SBUV; METOP-A/B GOME)
  - B (NOAA 17/SBUV; SORCE/SOLSTICE)
- **Y10:**
  - A (GOES/XRS, GOES/EUVS)
  - B (SDO/EVE, TIMED/SEE, SORCE/SOLSTICE)
- **F10:**
  - A (Penticton/Radio)
  - B (SET/E10, AFRL/NSO ADAPT)

Geomagnetic indices

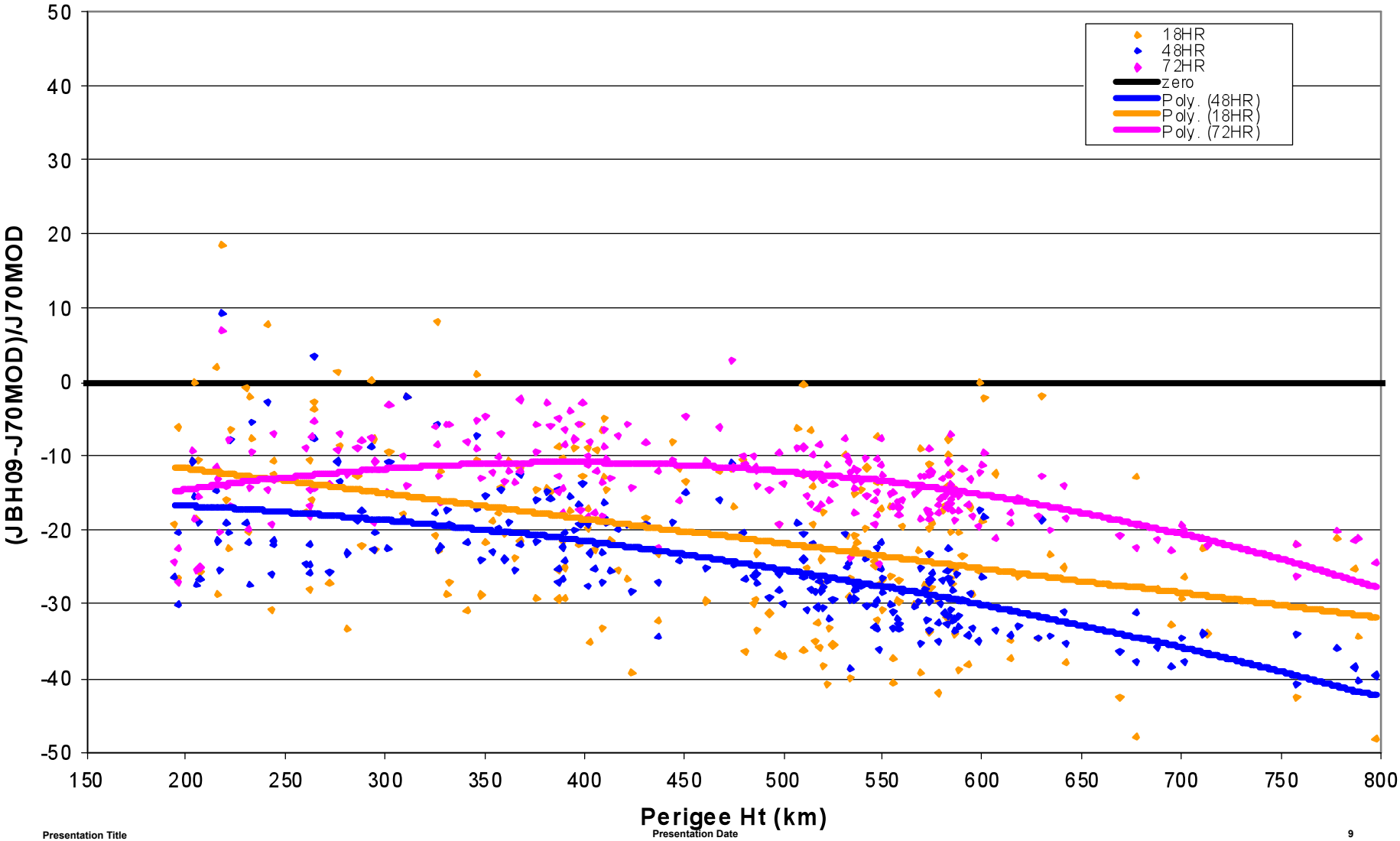
- **Dst:**
  - A (real-time: WDC/Kyoto; forecast: NOAA/ENLIL/Rice Dst)
  - B (real-time: SEC/RDst, USGS/Dst, AER/DMSP, SET/DMSP; forecast: SET/Anemomilos, CCMC/ENLIL, CRC/Dst)
- **ap:**
  - A (real-time: NOAA/ESWDS; forecast: NOAA/ESWDS; ENLIL/Rice Kp)
  - B (real-time: SET/ApOps; forecast: SET/ApOps)

HASDM Density Accuracy

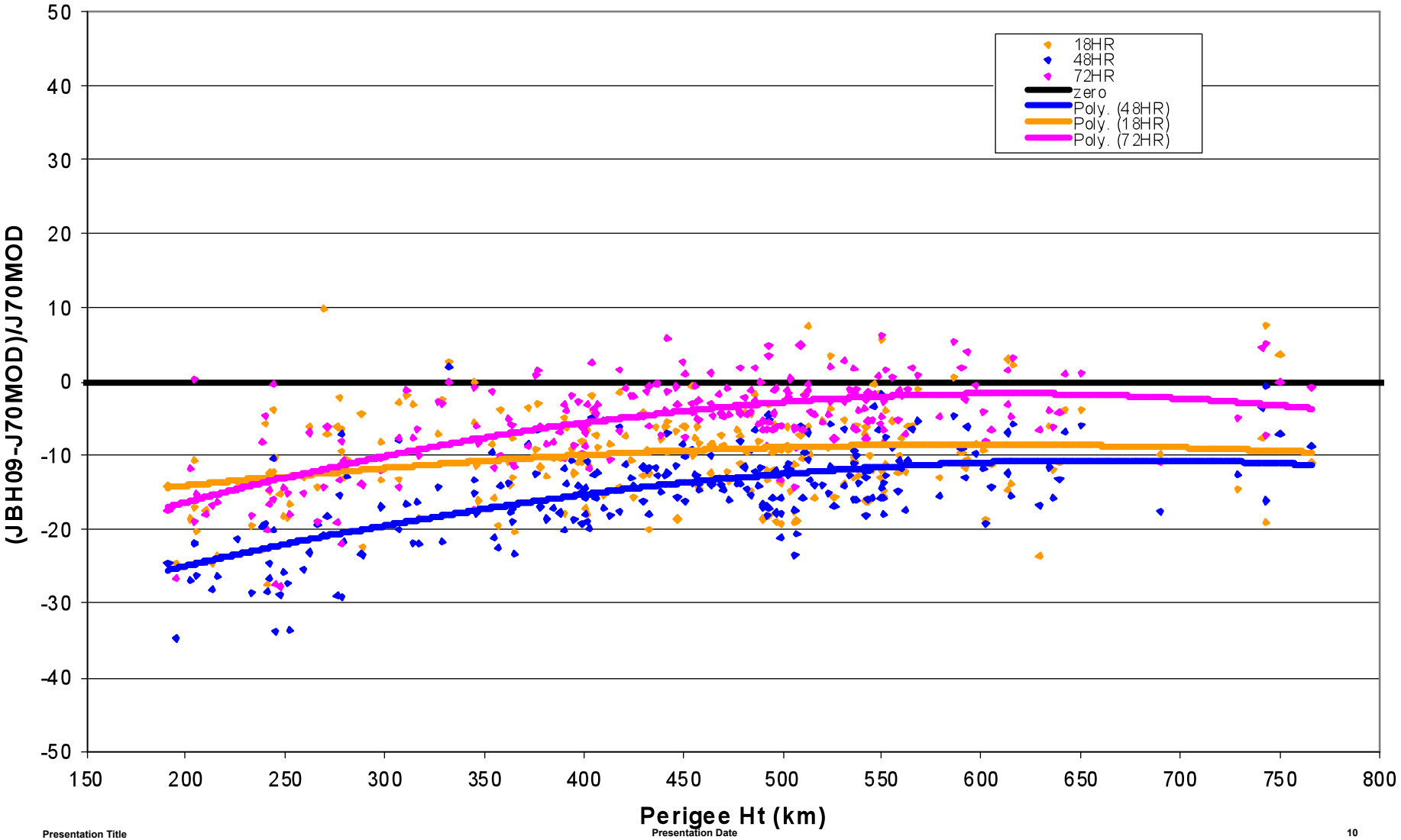


In-Track Position Prediction Improvements

2001 RMS Improvement, 2x0 16-Day 8-Order, High Solar All ap Pred Error Mag



In-Track Position Prediction Improvements



Covariance Prediction Improvements

- Current operational covariance prediction method:
  - Based on 12% density error obtained from 1999 study of orbit errors at 400 km altitude
  - 1 sigma 12% error applied as constant for entire catalog
- Covariance Prediction Improvements:
  - Equations based on solar max to min density errors computed by historical HASDM density values
  - Dynamic as a function of geomagnetic activity producing density variations at different altitudes
  - Equations already developed and currently scheduled for full catalog numerical evaluation
  - Estimated implementation Dec 2014 – Feb 2015

ap Occurrence Percentage of Time

Percent occurrence during Solar Max	
0 < ap <= 10	69%
10 < ap <= 25	19%
25 < ap < 50	8%
Dst <= -75	4%

Main Source of Density Errors

- ap predictions currently obtained from SWPC Kp predictions
- Prior to 2011 the ap forecasts were the responsibility of the USAF.
- SWPC started producing Kp forecasts November 16, 2011.
- No objective algorithm or even a 'cut and dry' procedure for the production of the geomagnetic forecast exists.
- SWPC forecasters review all available data at the time, consider recent solar activity, seasonal effects, current geomagnetic conditions, current solar wind conditions, input from local experts, consideration of model runs, consideration of past statistics, and so on, to use their best judgment concerning the geomagnetic forecast and for determining the probability for disturbances, arrival times, durations, and intensities.
- Information above from Space Weather Prediction Center (SWPC), 2014
- Dst primary prediction using Space Environment Technologies Anemomilos model (stream B)
- Dst secondary prediction using ENLIL/Rice Dst model (stream A)

Conclusions

- HASDM upgrade has been proven to greatly increase satellite position prediction accuracies over 72 hour predictions
- New solar and geomagnetic indices represent more accurately the solar influence on the atmospheric providing better realistic density variations
- The new SET LAPS system of hardware, software, and multiple data source redundancy has proven to maintain the accuracies of the new solar and geomagnetic indices
- Current operational monitoring of the DCA data has been implemented to maintain HASDM orbit accuracies
- Covariance prediction improvements have been developed and are waiting full catalog testing with operational implementation