

# METplus

The Long and Winding Road to Unified  
Verification

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Tara Jensen

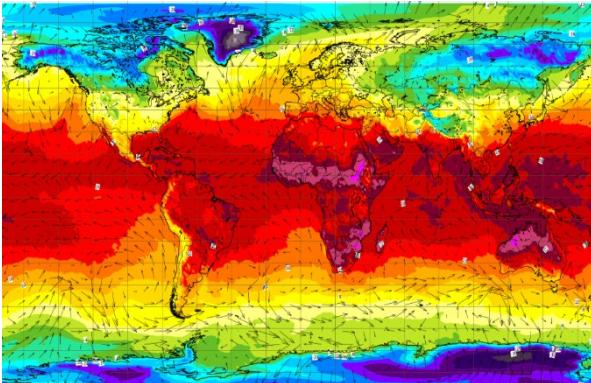
NCAR/RAL and DTC

9 Nov 2023

Workshop on Correctness and Reproducibility for Climate and Weather Software

# Why Unified Verification?

Forecasters



Operational Centers



Universities and  
National Laboratories



Comprehensive and unified verification tool - Make R20 more efficient - Provide a consistent set of metrics

Allows researchers and operational scientists to speak a “common verification” language

METplus

User support of unified package provides greater opportunity to train all on verification best practices

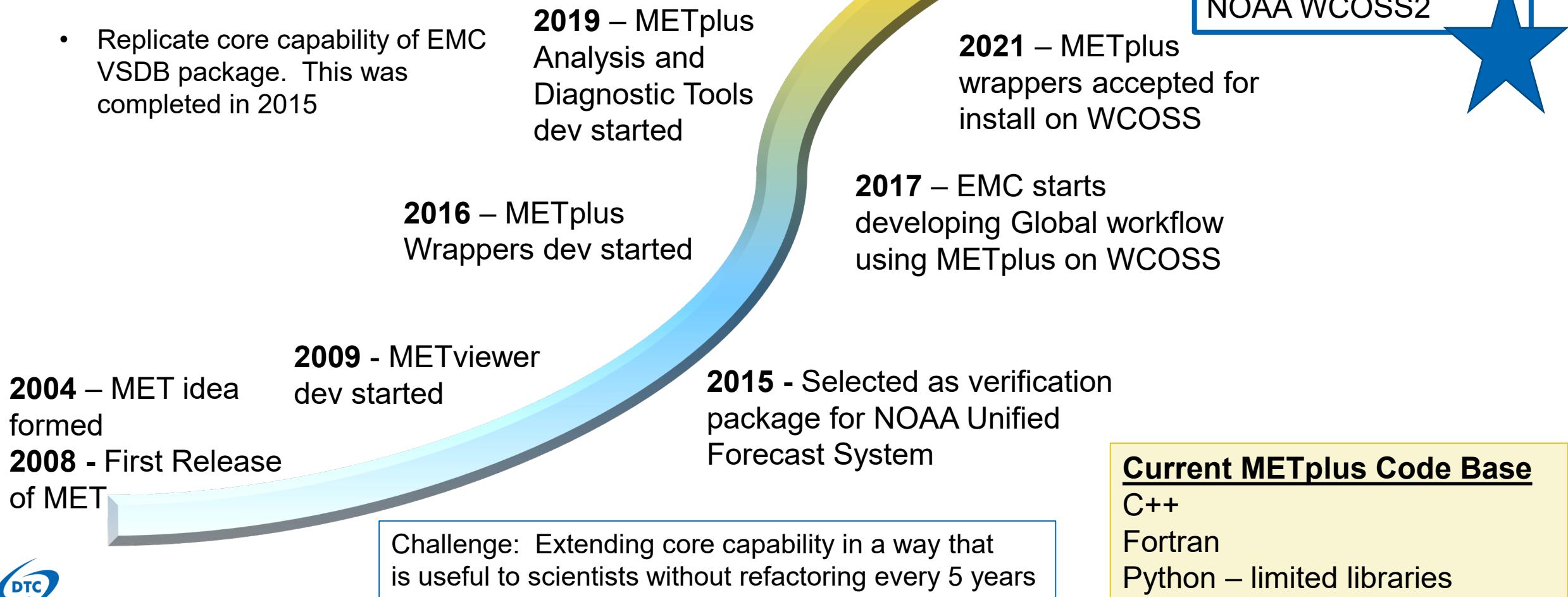
# METplus Team and Core Collaborators

- Management:
  - Tara Jensen<sup>1</sup>, Molly Smith<sup>2</sup>, Bonny Strong<sup>2</sup>, Matt Wandishin<sup>2</sup>
- MET Engineering:
  - John Halley Gotway<sup>1</sup>, Howard Soh<sup>1</sup>, Dave Albo<sup>1</sup>, Randy Bullock<sup>1</sup>, Seth Linden<sup>1</sup>,
- METplus Engineering:
  - George McCabe<sup>1</sup>, Julie Prestopnik<sup>1</sup>
- METplus Analysis Suite Engineering:  
*METviewer, METexpress, METdataio, METcalcpy, METplotpy*
  - Tatiana Burek<sup>1</sup>, Minna Win-Gildenmeister<sup>1</sup>, Hank Fisher<sup>1</sup>, Molly Smith<sup>2</sup>, Randy Pierce<sup>2</sup>
- Atmospheric Science:
  - Tara Jensen<sup>1</sup>, John Opatz<sup>1</sup>, Dan Adriaansen<sup>1</sup>, Tina Kalb<sup>1</sup>, Jonathan Vigh<sup>1</sup>, Jason English<sup>2</sup>, Jeff Hamilton<sup>2</sup>, Mrinal Biswas<sup>1</sup>.
- Statistics:
  - Eric Gilleland<sup>1</sup>, Barb Brown<sup>1</sup>
- EMC
  - Jason Levit, Alicia Bently, Mallory Row, Perry Shafran, ***and the rest of VPPPG Branch***
- Met Office
- Air Force
- Naval Research Lab
- Community
  - **UFS Verification and Validation Cross Cutting Team**
  - Other NCEP Centers: WPC, CPC, SWPC, SPC, OPC, NCO
  - NOAA Labs: GSL, PSL, MDL, ARL
  - NCAR and UCAR: RAL, MMM, CGD, ACOM, COMET
  - Universities and Cooperative Institutes: UW CIMMS, CSU CIRA, CU CIRES, George Mason University, SUNY Albany, SUNY Stony Brook, Embry Riddle U, University of Illinois Urbana Champagne, University of Miami
  - Private: AER, SPIRE

# METplus History

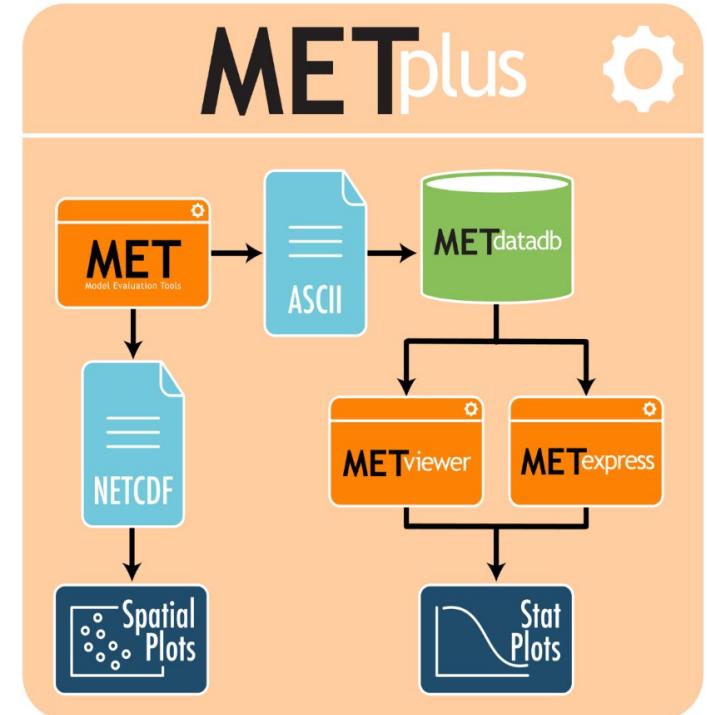
## Goals

- Develop a model/forecast verification package that can be used across the community
- Replicate core capability of EMC VSDB package. This was completed in 2015



**Current METplus Code Base**  
C++  
Fortran  
Python – limited libraries

# What is METplus?

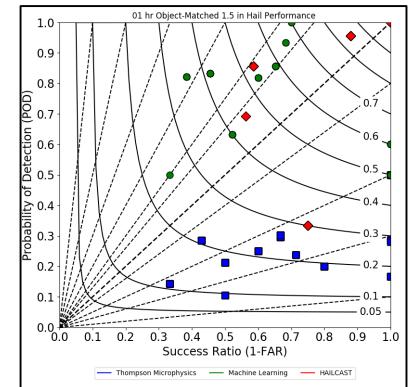
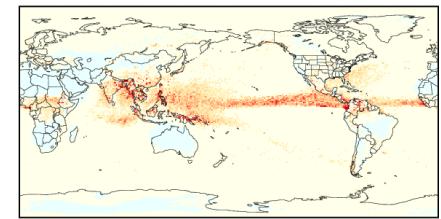
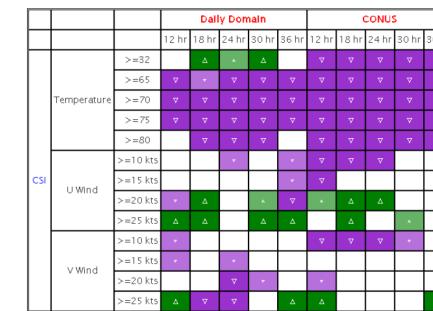
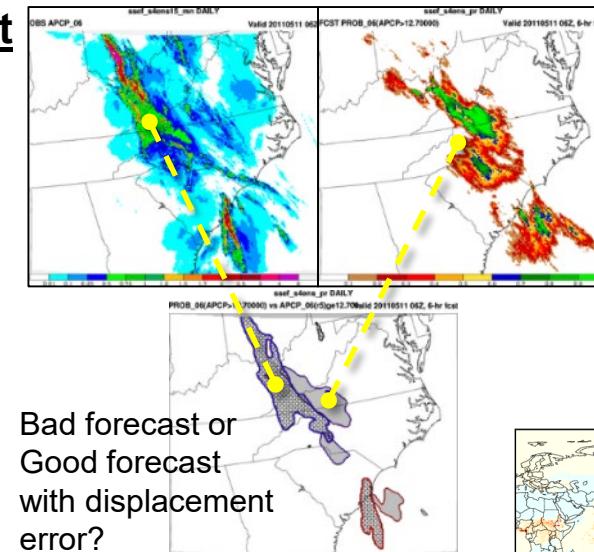


# Suite of Python wrappers around

- **MET (core)**
  - Analysis Tools
    - METviewer/METexpress User Interface
    - METviewer Batch Engine
    - **Python-based Diagnostics and Plotting**
  - **Communication between MET & python algorithms**
  - Using manage\_externals to connect repos

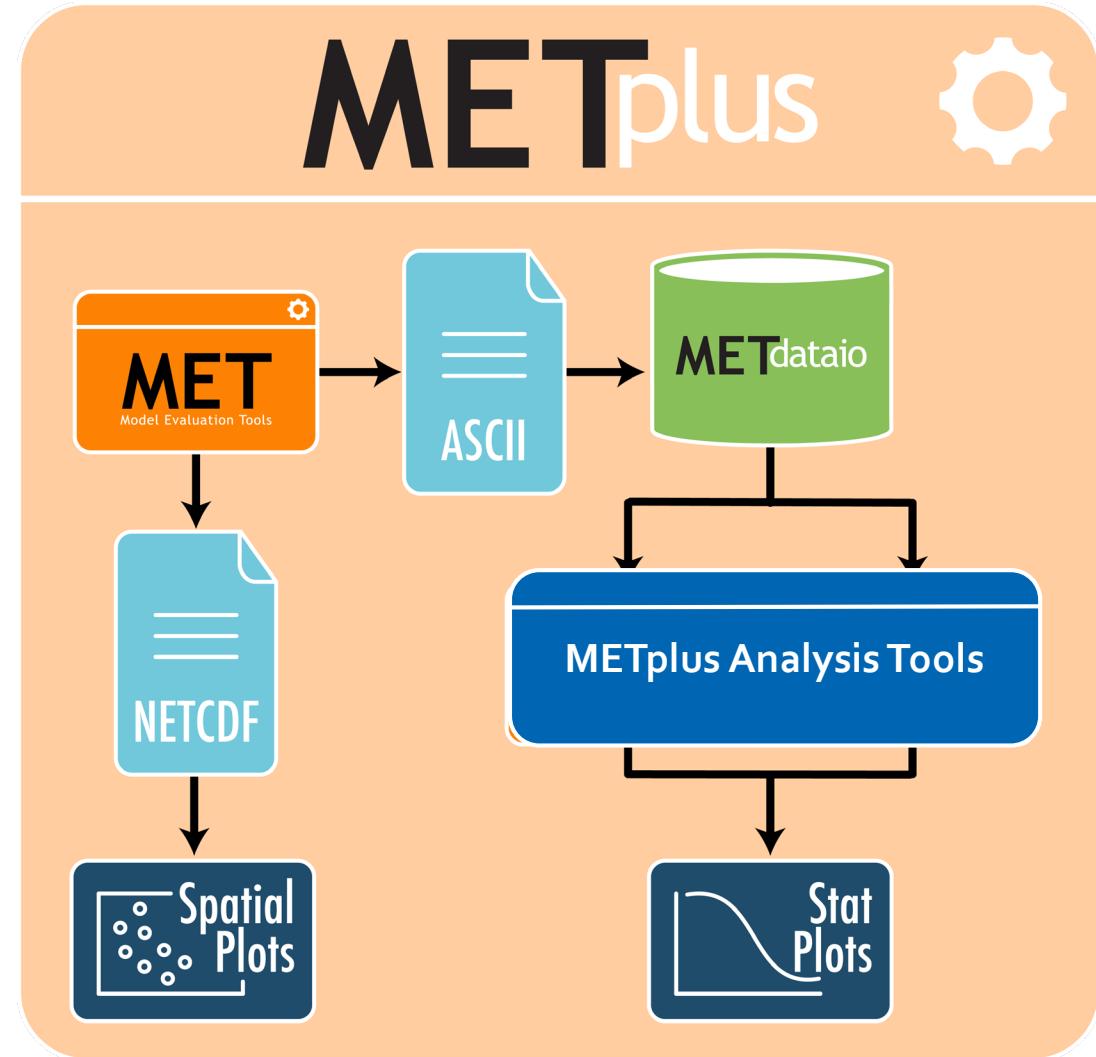
- Over 150 traditional statistics and diagnostic methods for both point and gridded datasets
  - 15 interpolation methods
  - Mix of C++, Fortran, Python – language driven by operational reqs
  - Developed to allow for easy sharing of config files for reproducible results
  - 3500+ users; US and Int'l

## **METplus Examples/Use-Case In Development**



# METplus – A Layered System

- **Wrappers** – around core MET statistics tools - represented by black arrows – low level workflow
- **MET** – suite of statistical and diagnostic tools
- **Analysis Tools** – available for advanced analysis includes
  - METviewer user interface
  - METexpress user interface
  - METdataio, METcalcpy, METplotpy Python components

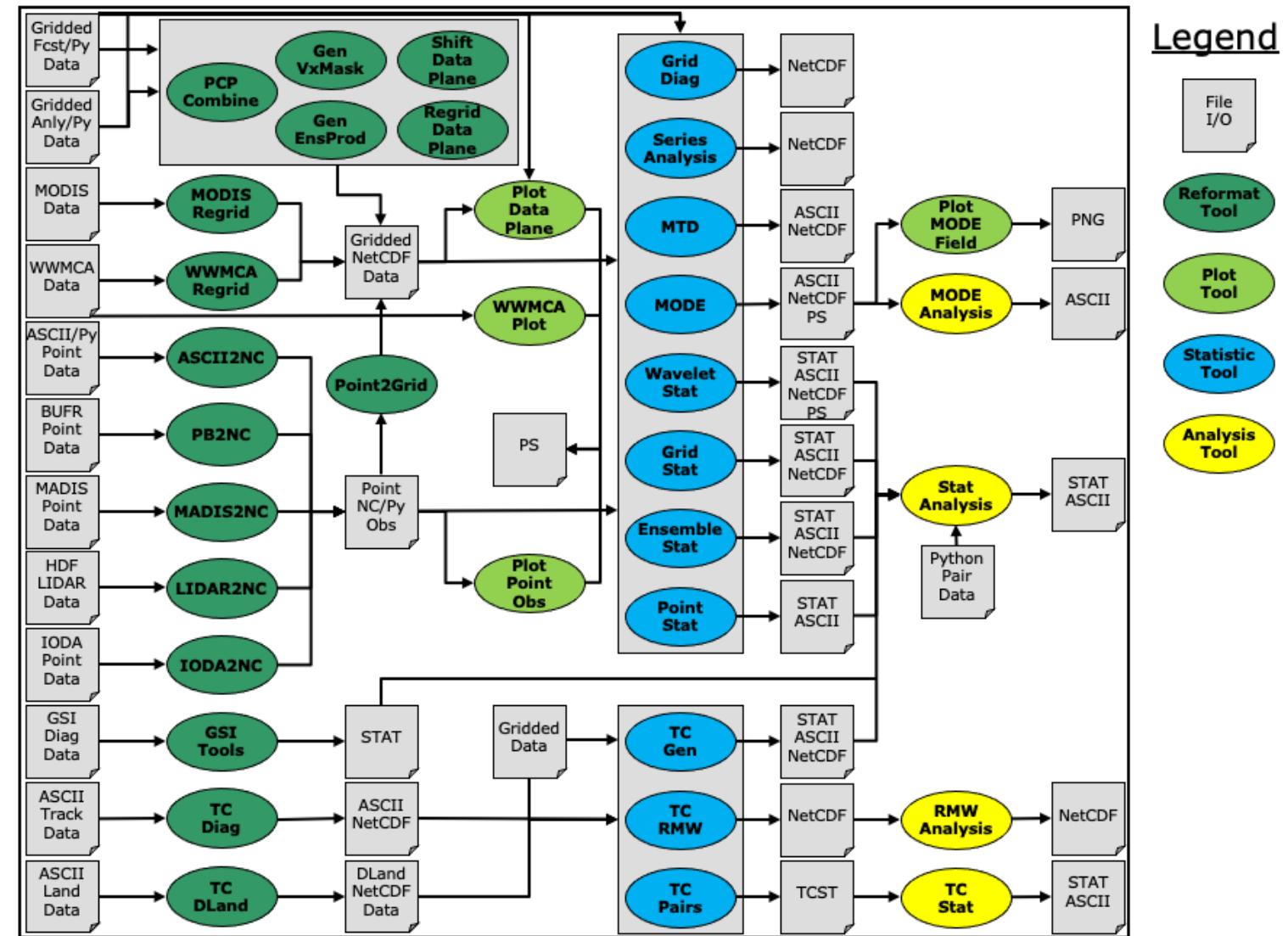


- Version 5.1 released Aug 1st

# Core MET Tools

- MET – suite of statistical and diagnostic tools
- Reformatting tools
- Data Inspection tools
- Statistical tools
- Analysis tools
- Traditional grid-to-grid and grid-to-point statistics
- Ensemble statistics
- Spatial methods
- TC methods

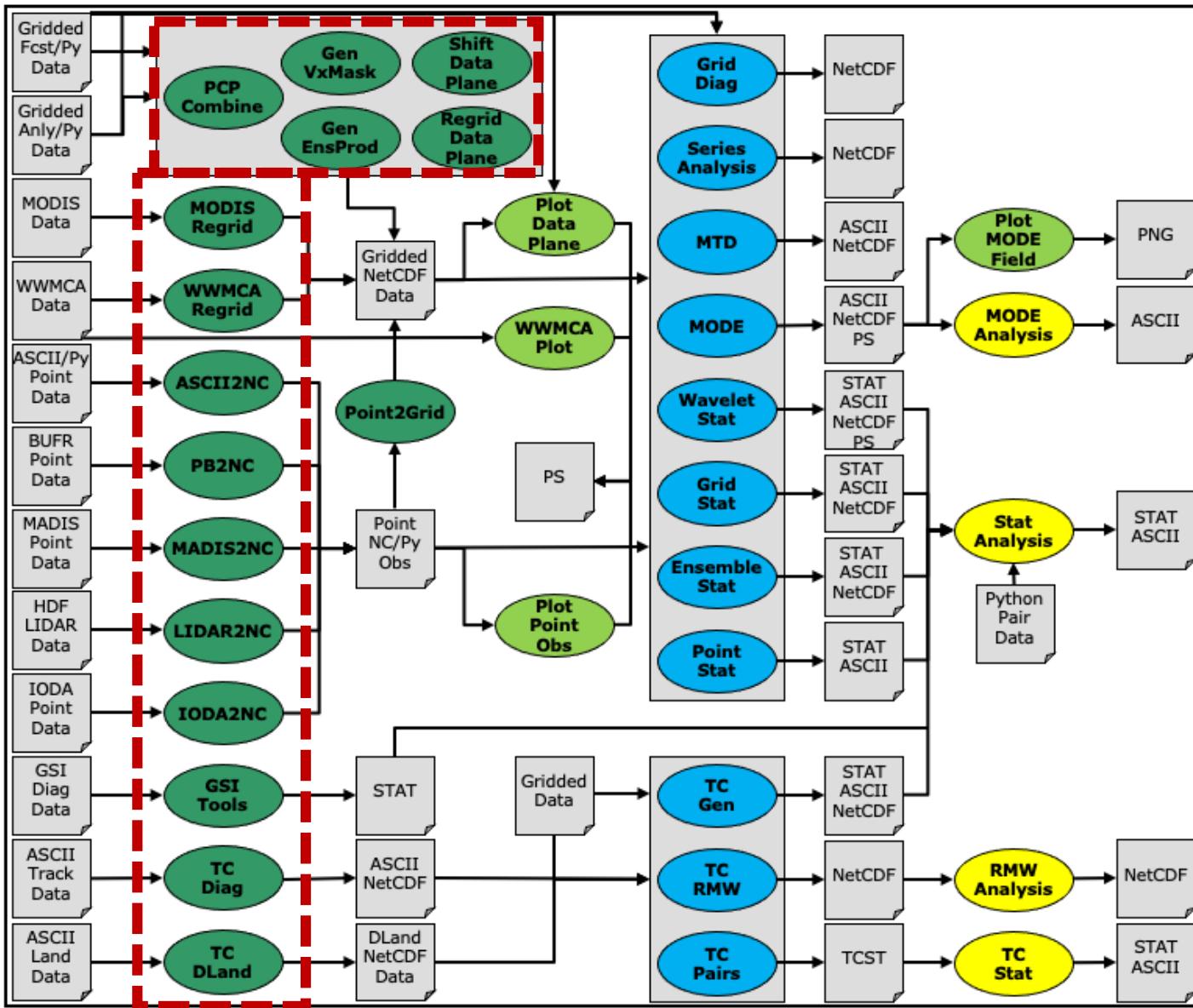
## MET Overview v11.1.0



# Tools for Preprocessing

## MET Overview v11.1.0

Legend

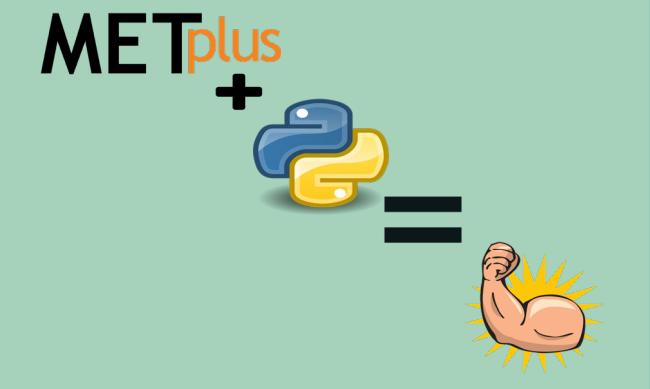


**Includes tools for:**

- Reformatting
- Quick look plotting
- Statistics computation
- Analysis



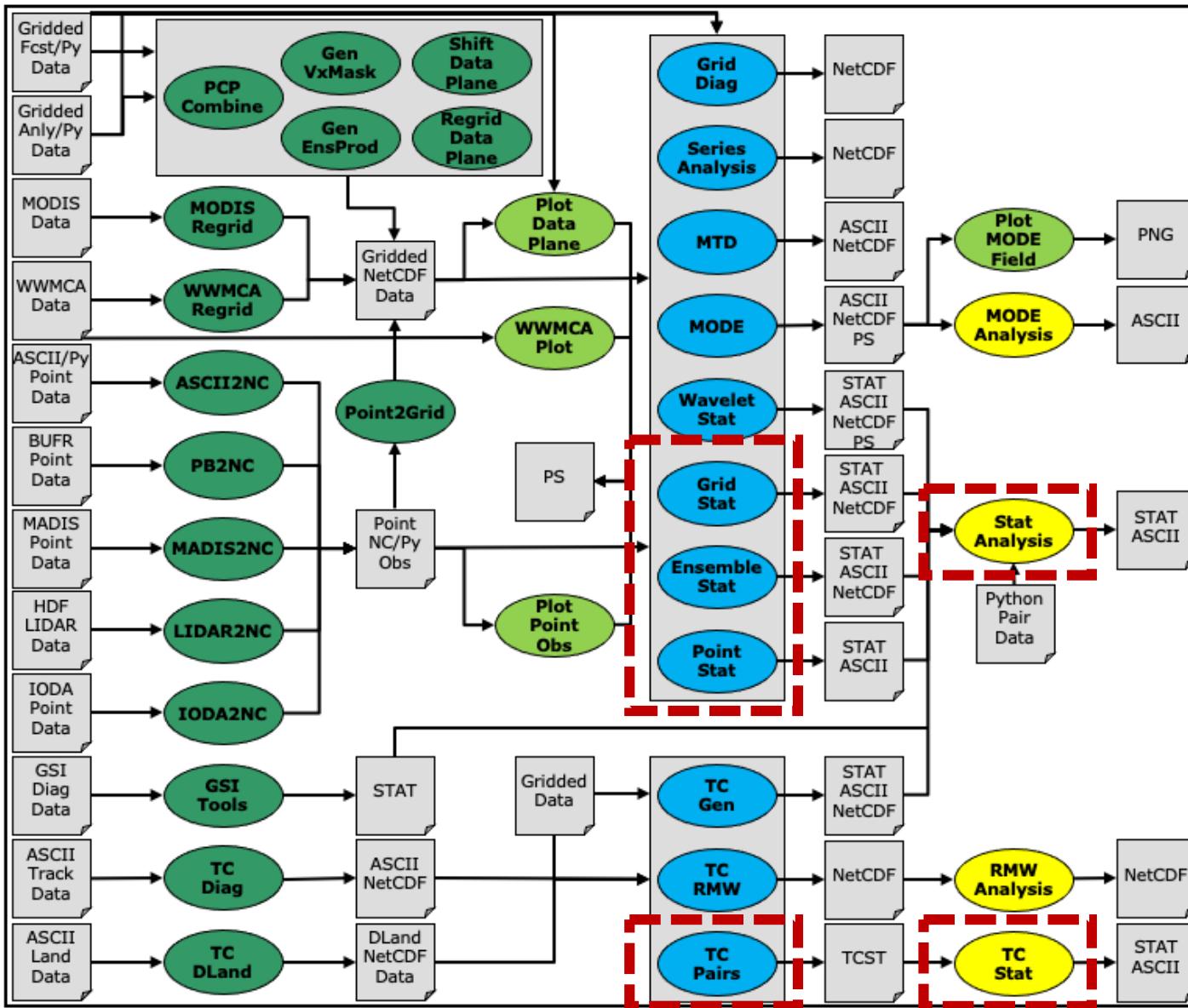
**Python Embedding**



# Tools for Standard Statistics

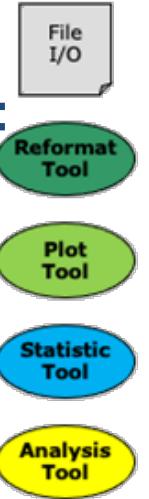
## MET Overview v11.1.0

## Legend



**Includes tools for:**

- Reformatting
- Quick look plotting
- Statistics
- computation
- Analysis



# METviewer

# METexpress

# Tools for Diagnostics

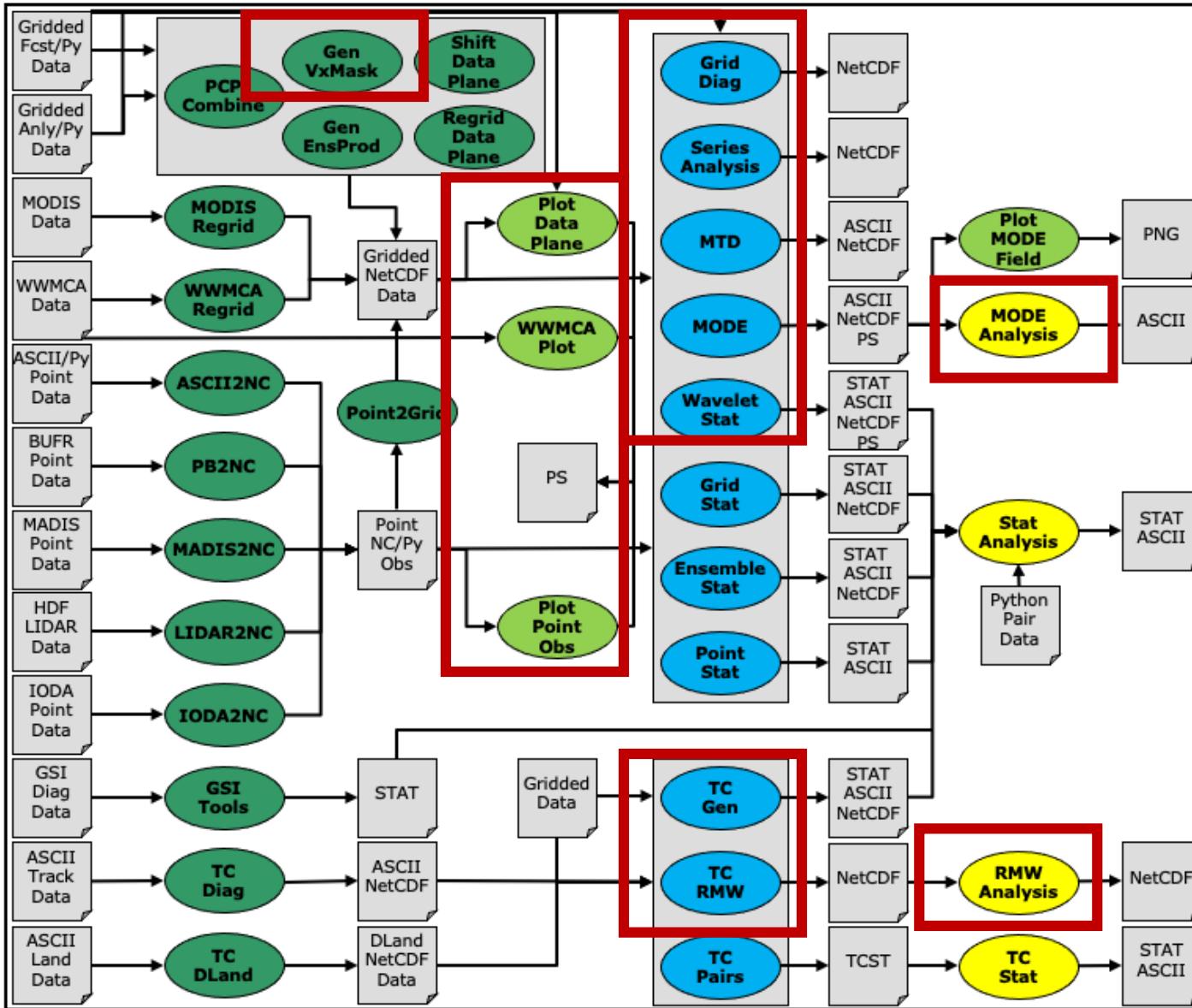
## MET Overview v11.1.0

Legend



Includes tools for:

- Reformatting
- Quick look plotting
- Statistics computation
- Analysis

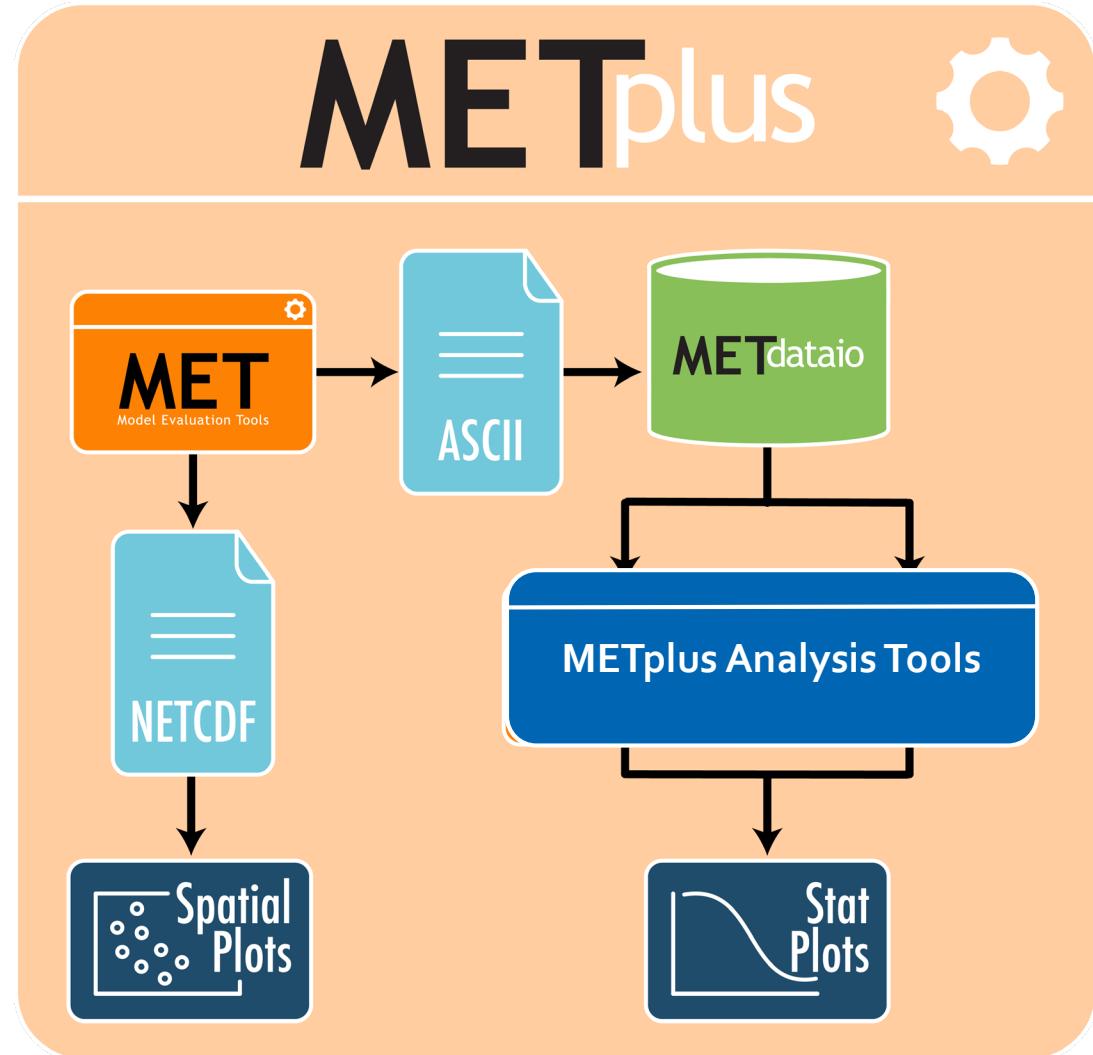


METcalcphy

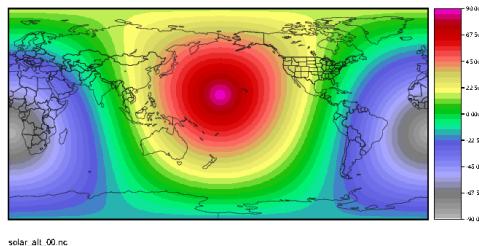
METplotphy

# METplus Components

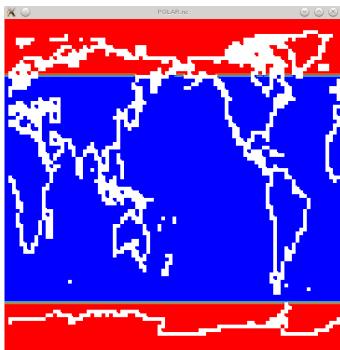
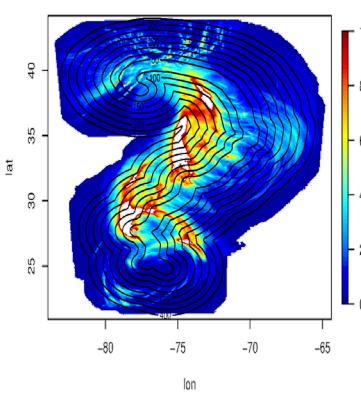
- **Wrappers** - represented by black arrows – low level workflow
- **MET** – suite of statistical and diagnostic tools
- **Analysis Tools** – available for advanced analysis includes
  - METviewer and METexpress user interface
  - METdataio, METcalcphy, METplotpy Python components
- Work in progress to allow for command line use of analysis tools



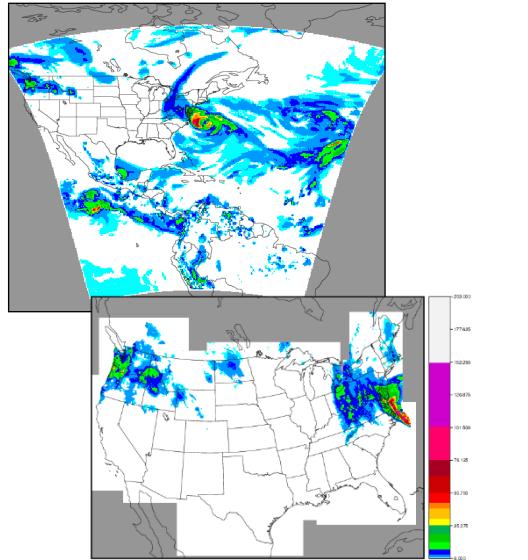
# Reproducible Statistics and Methods



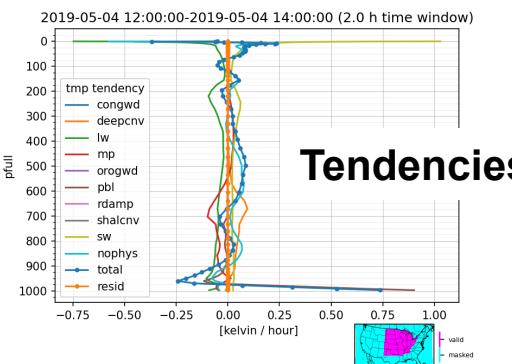
## Masking



Traditional	
Grid-Stat, Point-Stat, Series-Analysis	Ensemble-Stat <i>CRPS, CRPSS</i> Rank prob., Prob. Integral Transform (PIT), and Relative Position histograms Spread/Skill Ignorance Confidence intervals
<i>Contingency table statistics (CTS)</i> Continuous statistics Probability forecast statistics Confidence intervals	
Spatial	
<b>MODE</b> Location differences Geometric attribute differences Intersection area Intensity distributions & differences CTS measures	<b>MODE-TD</b> Time and location differences Volume differences Velocity differences Intersection volume Intensity distributions & differences
<b>Wavelet-Stat</b> MSE by scale Energy by scale Intensity-scale skill score	<b>Grid-Stat and Point-Stat</b> <i>FSS, HiRA</i> Distance Measures: MED, Baddeley, Hausdorff, Zhu, etc.
Tropical Cyclones and Diagnostics	
<b>MET-TC</b> Track error (along, cross, total) Intensity errors (pressure, wind) Rapid intensification/weakening errors CTS measures of TC genesis	<b>Grid-Diag</b> Distributions of fields for use in contour plots
<b>TC-GEN</b> CTS measures of TC genesis	<b>TC-RMW</b> Radius of maximum wind errors and metrics

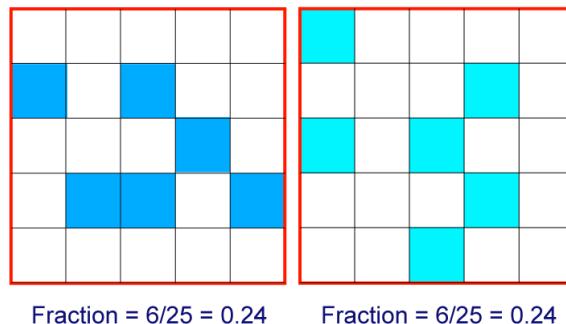


## Auto Regridding



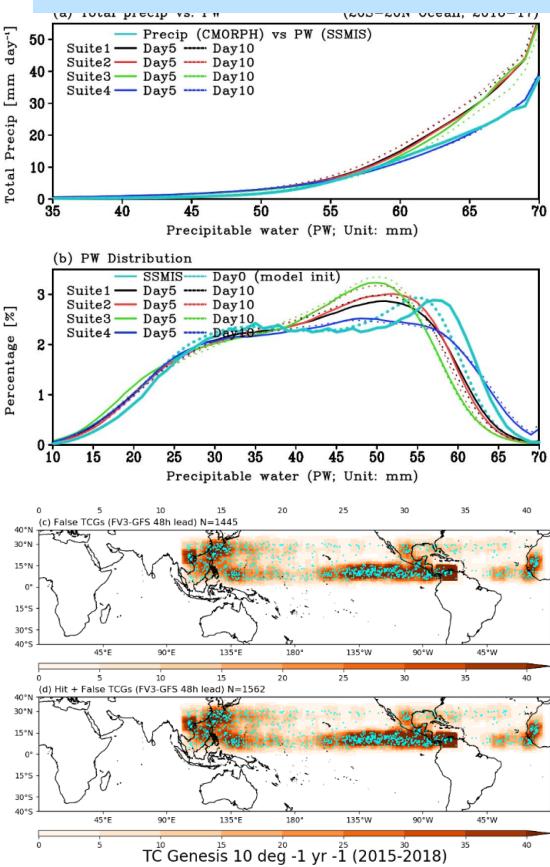
## Tendencies

## Neighborhood Methods

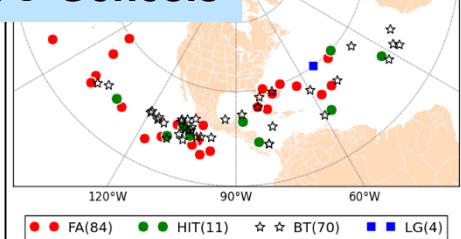


# Examples of Community Contributions

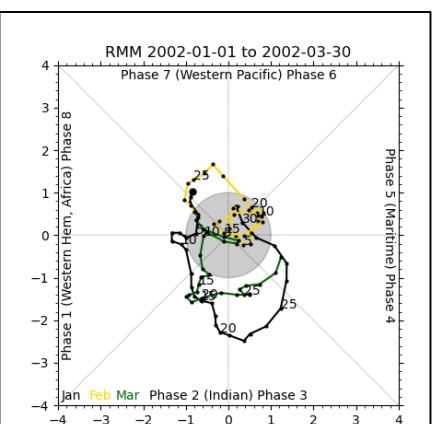
## S2S Multivariate Distributions



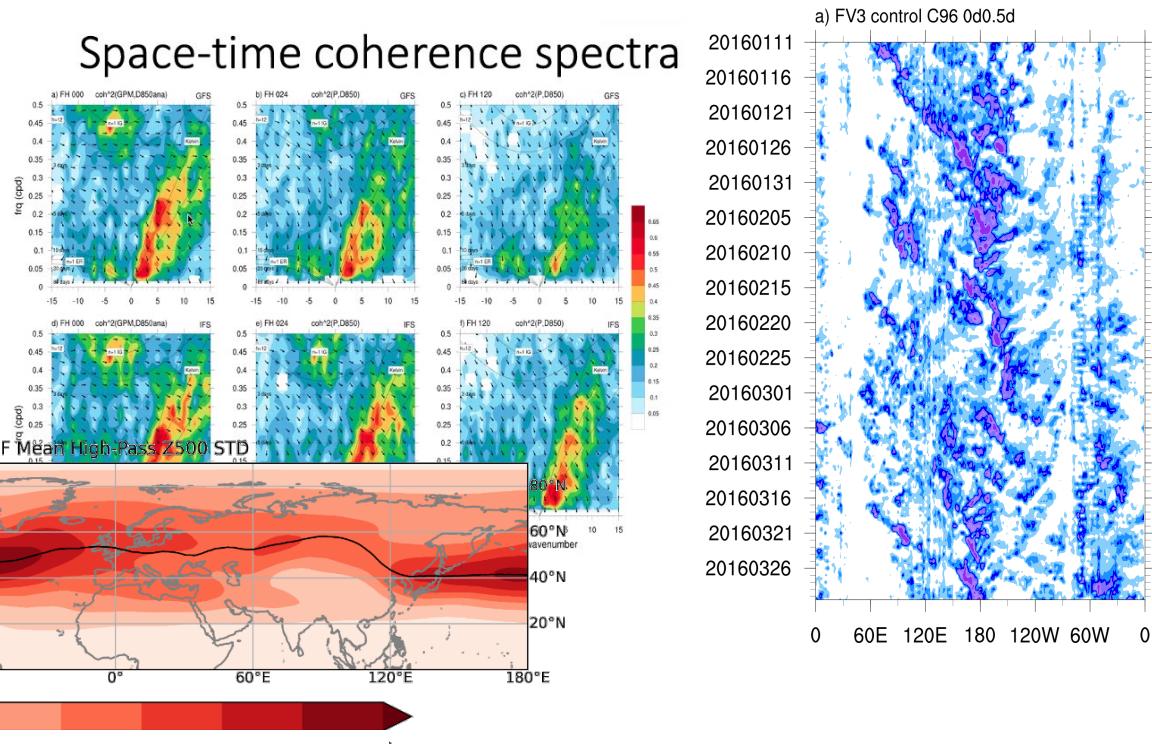
## S2S TC-Genesis



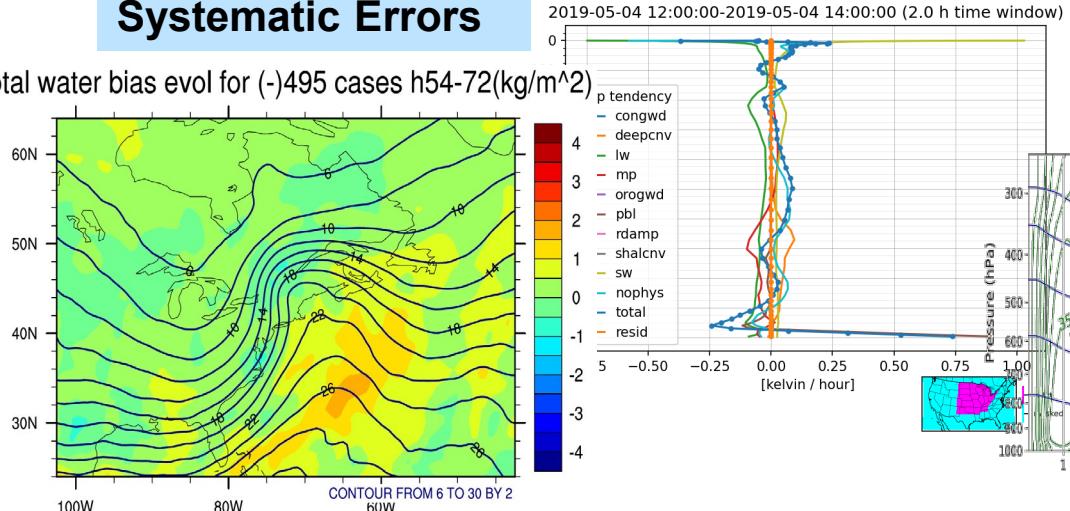
## S2S Diagnostics



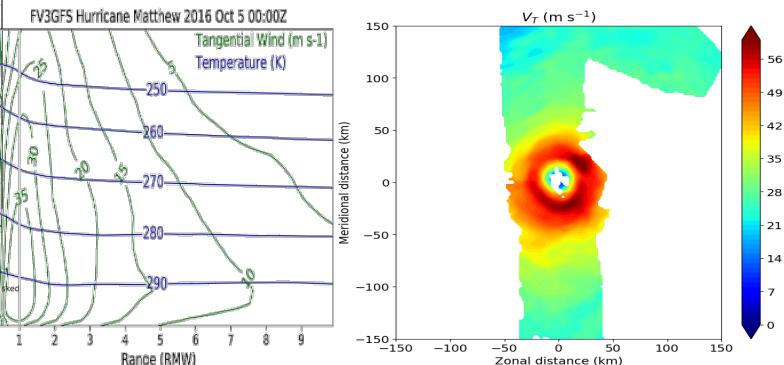
## Space-time coherence spectra



## Systematic Errors

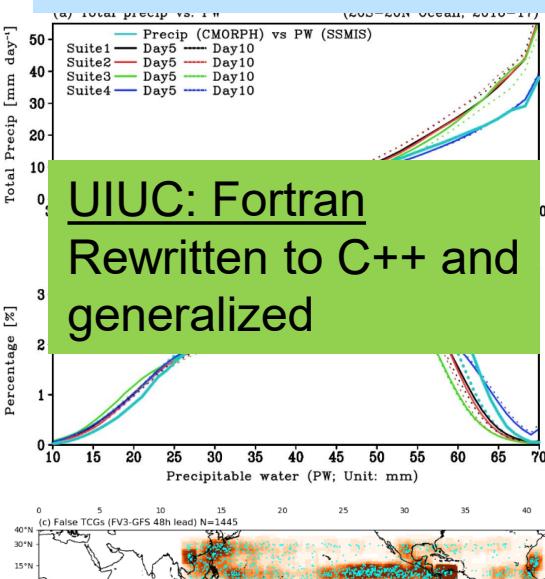


## TCs New Projections and Obs



# Examples of Community Contributions

## S2S Multivariate Distributions

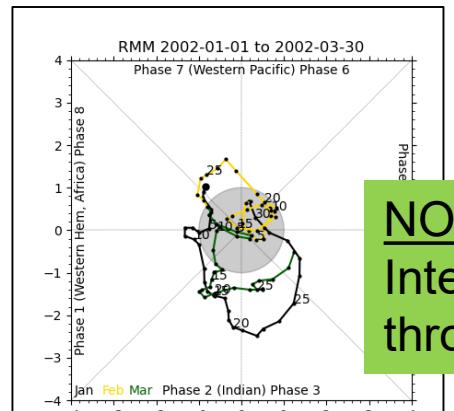


UIUC: Fortran  
Rewritten to C++ and generalized

UIUC: Matlab  
Converted to Python and generalized

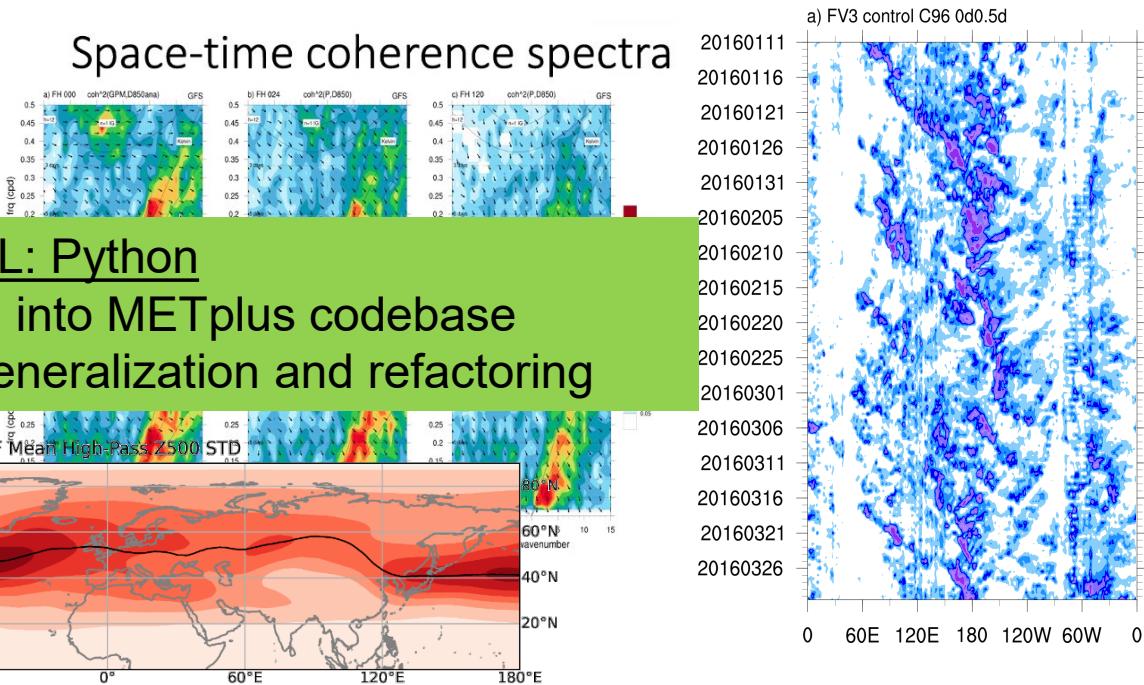
## S2S TC-Genesis

ERU: Algorithm  
Coded in C++ and generalized



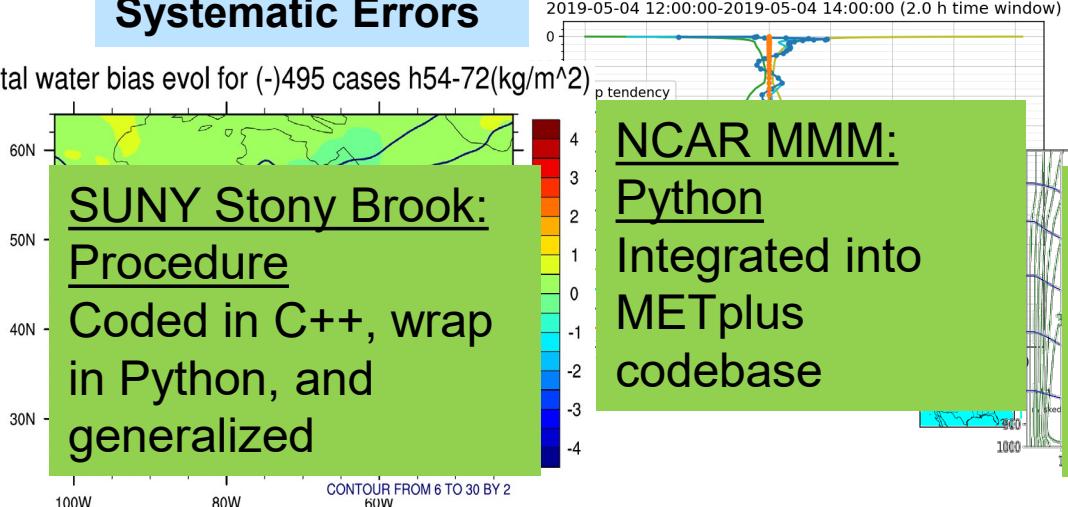
## S2S Diagnostics

## Space-time coherence spectra



NOAA PSL: Python  
Integrated into METplus codebase through generalization and refactoring

## Systematic Errors



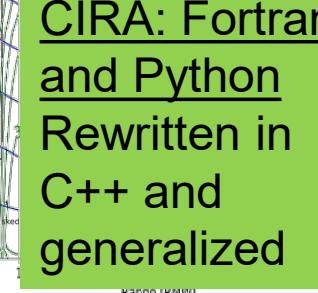
SUNY Stony Brook: Procedure  
Coded in C++, wrap in Python, and generalized

NCAR MMM: Python  
Integrated into METplus codebase

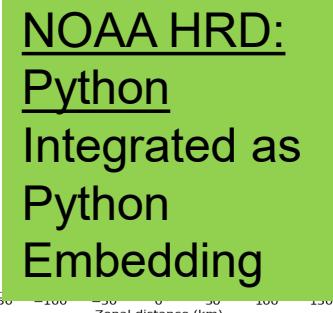
## TCs New Projections and Obs

### FV3GFS Hurricane Matthew 2016 Oct 5 00:0Z

Tangential Wind (m s<sup>-1</sup>)

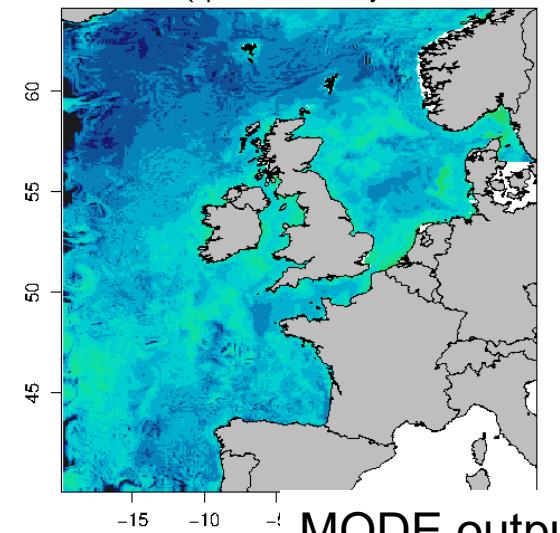


CIRA: Fortran and Python  
Rewritten in C++ and generalized

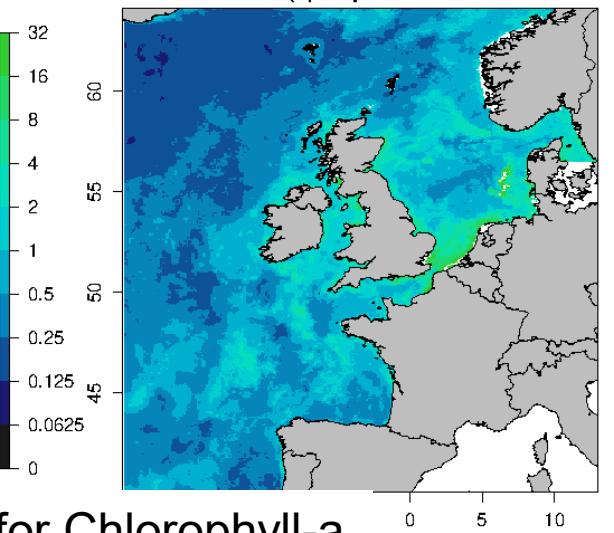


NOAA HRD: Python  
Integrated as Python Embedding

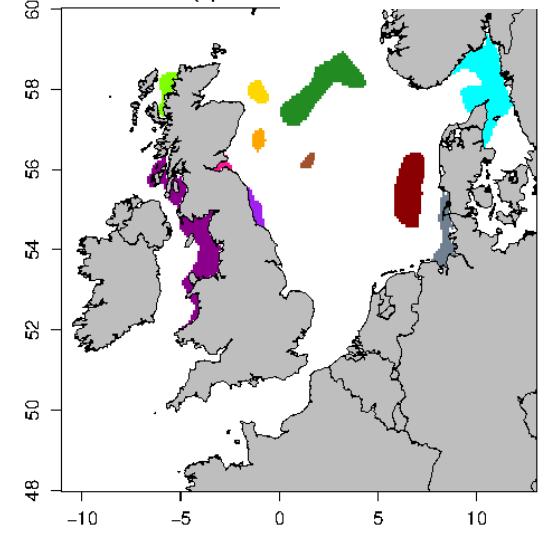
(a) AMM7v11 analysis



(b) L4 product



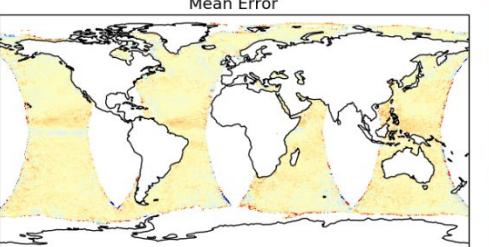
MODE output for Chlorophyll-a



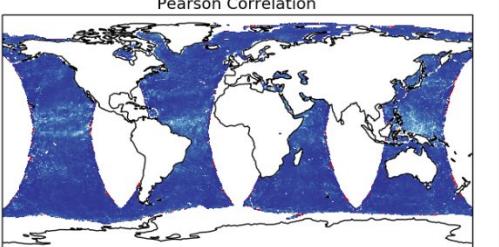
Mittermaier et al. 2021, Ocean Science

Slide Courtesy of Marion Mittermaier, Met Office

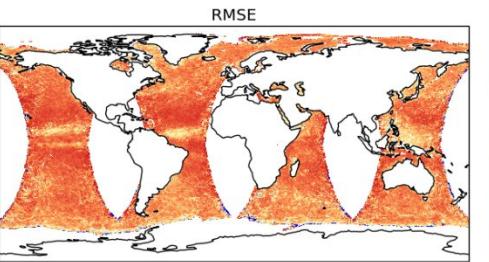
Mean Error



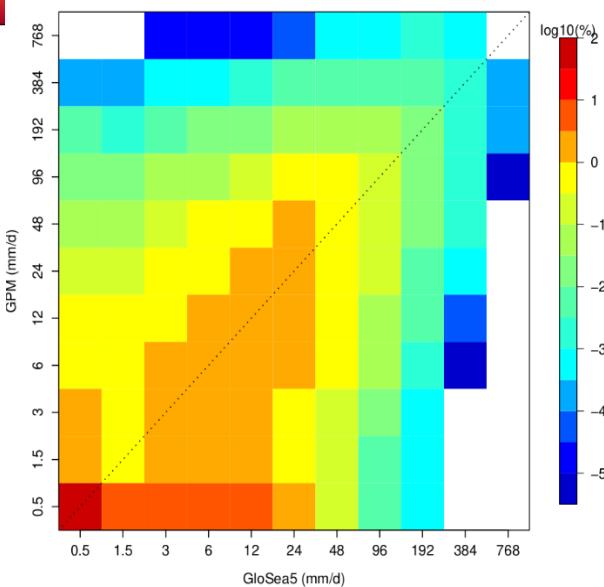
Pearson Correlation



Series-Analysis  
output of  
scatterometer  
winds

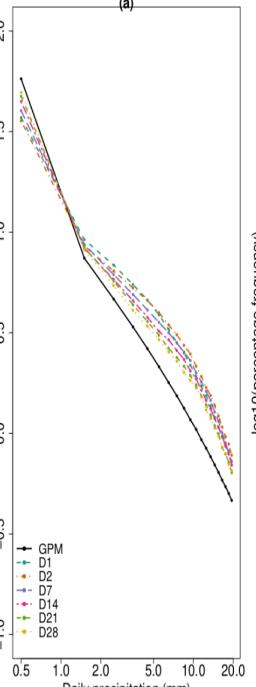


Day 1

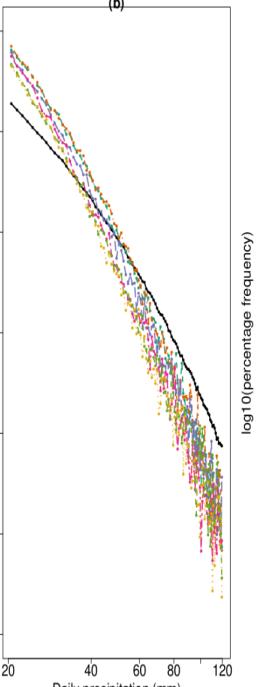


Ric Crocker

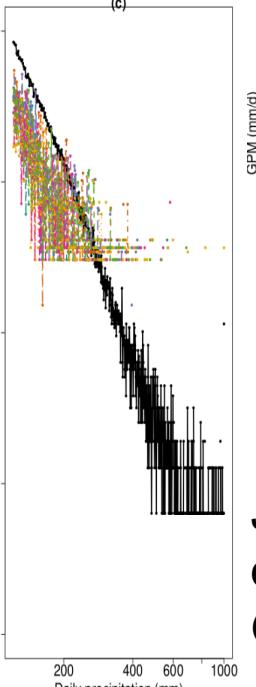
(a)



(b)



(c)

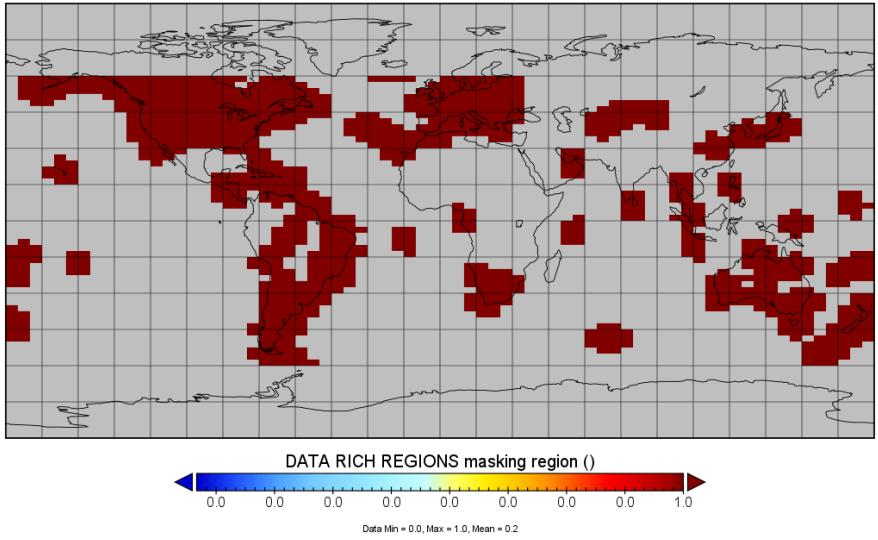


Joint and marginal  
distributions  
Grid-Diag

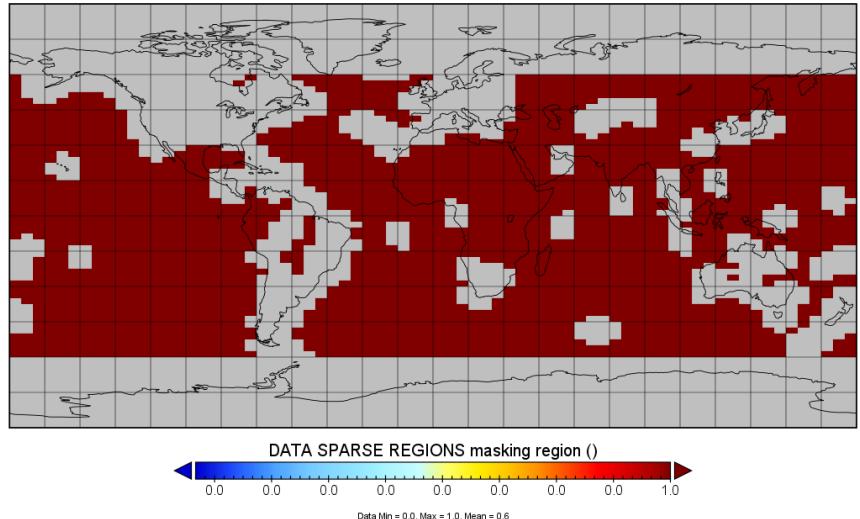
# Space Weather

## 2. Data Rich vs. Data Sparse Regions

DATA RICH REGIONS masking region



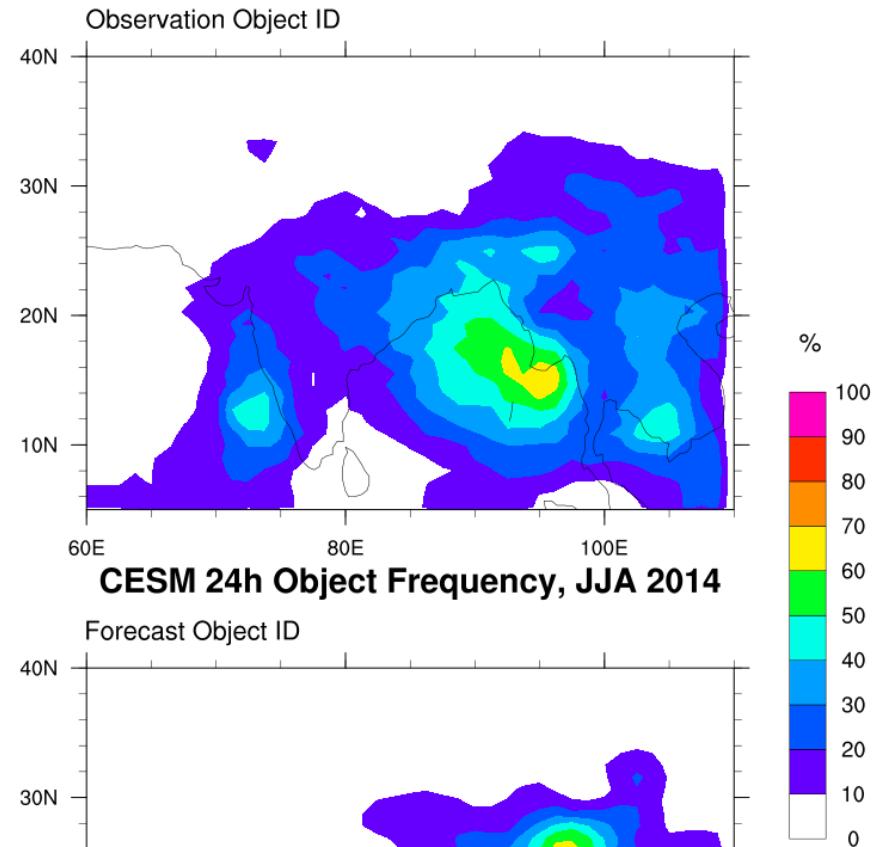
DATA SPARSE REGIONS masking region



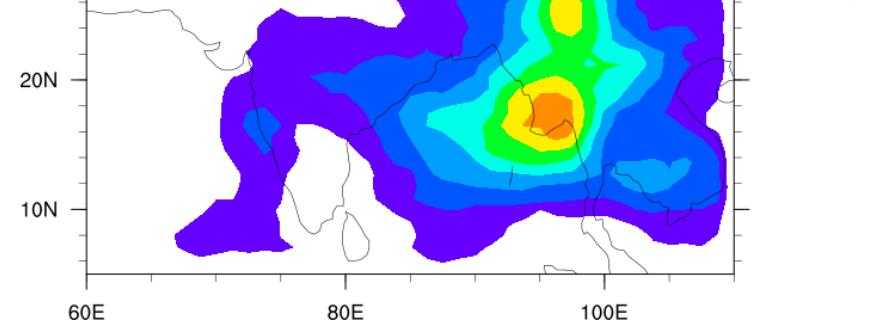
Masking:  
Near  
Observing  
Stations

# Climate

## GPCP Object Frequency, JJA 2014



Masking:  
Not Near  
Observing  
Stations



# Reproducibility and Correctness

# How Correctness is Achieved

Feature or Issue development team includes:

- Scientist, Engineer, Documentation Specialist
- Each feature or dev task has Github issue assigned. Feature Branch broken off from dev branch using Github ID when work is being performed
- **Github Actions** used for Continuous Integration testing of new features during each pull request
  - Container used for GA
  - Scientist and/or Engineer are included in pull request phase for quality assurance
- Beta releases for user and cross-platform testing purposes are published every 6-8 weeks. 4-5 Beta releases per major development cycle

# How Reproducibility is Achieved

## Configuration files for:

- METplus wrapper allows for most features to be configured
- Reads MET config file and swaps in METplus wrapper environment variables
- METplus Analysis Suite uses a combination of XML and YAML for configuration options
- Examples are published in online documentation as “use-cases” which include METplus .conf, METplus .config, sample data, and documentation on how to run
- Cross platform testing is performed during every beta release

# Support and Training

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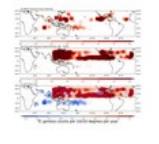
The screenshot shows the METplus main\_v4.0 interface. At the top left is the METplus logo and a search bar labeled "Search docs". Below the search bar is a sidebar titled "METPLUS WRAPPERS GUIDES" containing a tree view of documentation sections. A red box highlights the "5. METplus Use Cases" section, which is expanded to show sub-sections like "5.1. MET tools", "5.2. Model Applications", and "5.2.9. Subseasonal to Seasonal". An arrow points from this highlighted section to the corresponding page on the right.

# User's Guide and Getting Help

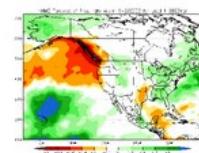
[https://metplus.readthedocs.io/en/latest/Users\\_Guide/](https://metplus.readthedocs.io/en/latest/Users_Guide/)

## 5.2.9. Subseasonal to Seasonal

Subseasonal-to-Seasonal model configurations; Lower resolution model configurations (>4km) usually producing forecasts out beyond 14 days and up 1 year



TCGen: Genesis Density Function (GDF) and Track Density Function (TDF)



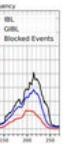
Grid-Stat and Series-Analysis: BMKG APIK Seasonal Forecast



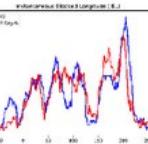
UserScript: Make a Hovmoeller plot



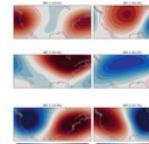
UserScript: Make a Cross Spectra plot



Blocking Calculation: RegridDataPlane, PcpCombine, and Blocking python code



Blocking Calculation: RegridDataPlane, PcpCombine, and Blocking python code



WeatherRegime Calculation: RegridDataPlane, PcpCombine, and WeatherRegime python code

<https://github.com/dtcenter/METplus/discussions>

The screenshot shows the GitHub repository page for dtcenter/METplus. At the top, there are tabs for Code, Issues (108), Pull requests (1), Discussions (selected), Actions, Projects (4), Wiki, and more. Below the tabs are two announcement cards: "Welcome to the METplus Components Disc..." and "Resources for Troubleshooting". The main area contains a search bar and filters for New, Top: All, Answered, Unanswered, Label, and New discussion. On the left, there is a sidebar with "Categories" including View all, Announcements, Configuration, Existing Builds, File I/O, General, Incoming, Installation, Plot Generation, Statistical Computation, and Use Cases. Under "Most helpful" (Last 30 days), several users are listed with their contributions. At the bottom, there are links for Community guidelines, metplus.readthedocs.io, and a "Give feedback" button.

# Basic Training To Get You Started

## Basic (2021-2022)

<https://dtcenter.org/events/2021/metplus-training-series>

The screenshot shows the METplus Training Series 2021-2022 Session 3 page. It features a sidebar with session details:

- Session 1 - November 30, 2021 9am MST / 11am EST / 1600 UTC
- Session 2 - December 7, 2021 9am MST / 11am EST / 1600 UTC
- Session 3 - December 14, 2021 9am MST / 11am EST / 1600 UTC

Below the sidebar, there are sections for Prerequisite, Presentation, Hands-On, Homework, and Recording and Chat Archive. At the bottom, there is a video player for the session and logos for NSF, NCAR, DTC, UFS, and AFRL.

## Advanced (2023)

<https://dtcenter.org/events/2023/metplus-advanced-training-series>

The screenshot shows the METplus Advanced Training Series 2023 page. It features a banner with the text "METPLUS ADVANCED TRAINING SERIES" and a sunset image. Below the banner, it says "APR 19 2023 | 9:00AM - OCT 31 2023 | 11:00AM | VIRTUAL-LINK FOR THE MEETING PROVIDED TO REGISTERED PARTICIPANTS". The page includes a "View" button, a "Edit" button, and a detailed description of the series. The description states that the METplus team is launching a new Tutorial Series on Wednesday, April 19, 2023 at 9am MST/11am EST/1600 UTC. Participants can join METplus trainers for two-hour virtual sessions where background presentations by subject matter experts will be woven together with hands-on training. Please register by April 12th. It is anticipated that the series will last approximately 8 weeks, with a long summer break. The series will start with a brief refresher on setting up, configuring, and running METplus, then move onto 1) using METplus for evaluation of the UFS prototypes; 2) advanced methods such as use of climatology, python embedding, and ensemble verification. Please refer to the Agenda page for the topics that will be covered in the first 3 sessions. The schedule for the second 5 sessions will be released in July.

## **Platforms:**

- AWS
- NCAR HPC: Cheyenne
- NOAA HPCs:  
WCOSS2, Hera, Jet

# Online Training



ABOUT ▾ TESTING + EVALUATION ▾ COMMUNITY CODE ▾ VISITOR PROGRAM ▾  
NEWS EVENTS

## WELCOME TO THE METPLUS PRACTICAL SESSION GUIDE

The METplus v5.0.0 practical consists of 11 sessions. The first six sessions contain instructions for running individual MET tools directly on the command line, followed by instructions for running the same tools as part of a METplus use case. The remaining sessions dive into special applications of METplus and the Analysis tools available in the METplus suite.

<https://dtcenter.org/metplus-practical-session-guide-version-5-0>

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Basic Verification Statistics Review	+	Session 6: Track And Intensity	+
Preliminary Work: METplus Setup	+	Session 7: Feature Relative Use Cases	+
Session 1: Grid-To-Grid	+	Session 8: METplus Analysis Tools	+
Session 2: Grid-To-Obs	+	Session 9: Python Embedding	+
Session 3: Analysis Tools	+	Session 10: Subseasonal To Seasonal (S2S)	+
Session 4: Ensemble And PQPF	+	Session 11: METplus Cloud	+
Session 5: MODE And MTD	+		

# METplus Use Cases

## 8. METplus Quick Search for Use Cases

### 8.1. Use Cases by MET Tool:

ASCII2NC  
CyclonePlotter  
EnsembleStat  
GenVxMask  
GenEnsProd  
GridStat  
GridDiag  
IODA2NC  
MODE  
MTD  
PB2NC  
PCPCombine  
Point2Grid  
PlotDataPlane  
PlotPointObs  
PointStat  
RegridDataPlane  
SeriesAnalysis  
StatAnalysis  
TCDiag  
TCMPRPlotter  
TCGen  
TCPairs  
TCRMW  
TCStat

#### Use Cases:

- Sample Data
- Sample Configuration Files
- Documentation

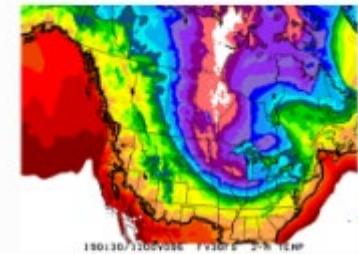
[https://metplus.readthedocs.io/en/latest/Users\\_Guide/usecases.html](https://metplus.readthedocs.io/en/latest/Users_Guide/usecases.html)

### 8.2. Use Cases by Application:

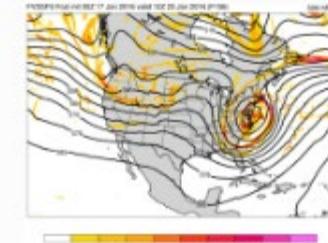
Air Quality and Composition  
Climate  
Clouds  
Short Range  
Data Assimilation  
Ensemble  
Land Surface  
Marine and Cryosphere  
Medium Range  
PBL  
Precipitation  
Space Weather  
Subseasonal to Seasonal  
Subseasonal to Seasonal: Madden-Julian Oscillation  
Subseasonal to Seasonal: Mid-Latitude  
Tropical Cyclone and Extra-Tropical Cyclone

### 8.3. Use Cases by Organization:

Developmental Testbed Center (DTC)  
National Center for Atmospheric Research (NCAR)  
NOAA Weather Prediction Center (WPC)  
NOAA Space Weather Prediction Center (SWPC)  
NOAA Environmental Modeling Center (EMC)  
NOAA Global Systems Laboratory (GSL)  
NOAA Hydrometeorology Testbed (HMT)  
NOAA Hazardous Weather Testbed (HWT)  
State University of New York-Stony Brook University (SUNY-SBU)



Grid-Stat: Standard Verification of Surface Fields



Point-Stat: Standard Verification of Global Upper Air

**MET**plus

PyEmbedIngest: Multiple Fields in One File

# 15 years of reproducible results

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METplus

METplus and MET user support discussion forum

METplus website, online tutorial, training series

METplus repository, documentation, releases, Docker, v5.1.0 development



Contact:  
Tara Jensen

[jensen@ucar.edu](mailto:jensen@ucar.edu), [molly.b.smith@noaa.gov](mailto:molly.b.smith@noaa.gov)

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