



The Long and Winding Road to Unified Verification

Tara Jensen

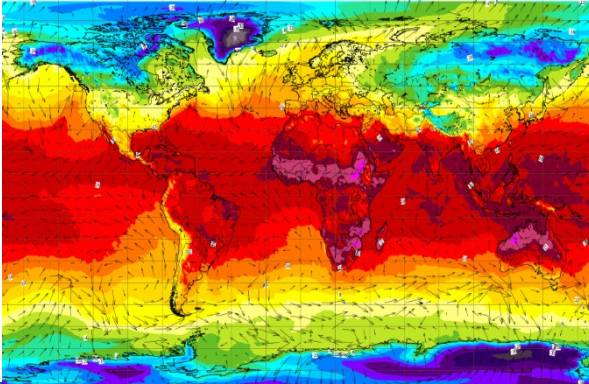
NCAR/RAL and DTC

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 Jensen¹, Molly Smith², Bonny Strong², Matt Wandishin²
- MET Engineering:
 - John Halley Gotway¹, Howard Soh¹, Dave Albo¹, Randy Bullock¹, Seth Linden¹,
- METplus Engineering:
 - George McCabe¹, Julie Prestopnik¹
- METplus Analysis Suite Engineering:
METviewer, METexpress, METdataio, METcalcpy, METplotpy
 - Tatiana Burek¹, Minna Win-Gildenmeister¹, Hank Fisher¹, Molly Smith², Randy Pierce²
- Atmospheric Science:
 - Tara Jensen¹, John Opatz¹, Dan Adriaansen¹, Tina Kalb¹, Jonathan Vigh¹, Jason English², Jeff Hamilton², Mrinal Biswas¹,
- Statistics:
 - Eric Gilleland¹, Barb Brown¹
- 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

2004 – MET idea formed

2008 - First Release of MET

2009 - METviewer dev started

2016 – METplus Wrappers dev started

2019 – METplus Analysis and Diagnostic Tools dev started

2015 - Selected as verification package for NOAA Unified Forecast System

2017 – EMC starts developing Global workflow using METplus on WCOSS

2021 – METplus wrappers accepted for install on WCOSS

2023 – All components accepted for install on NOAA WCOSS2

Challenge: Extending core capability in a way that is useful to scientists without refactoring every 5 years

Current METplus Code Base

C++

Fortran

Python – limited libraries

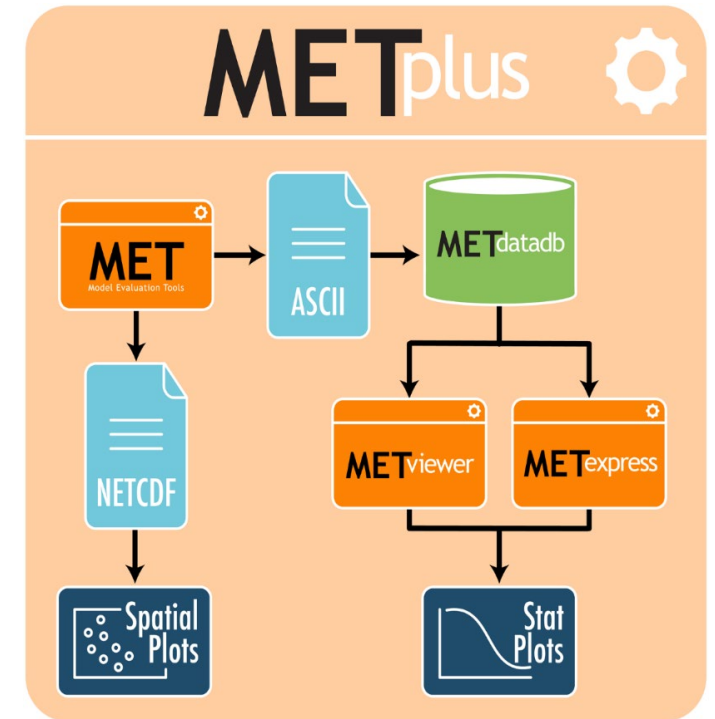


What is METplus?

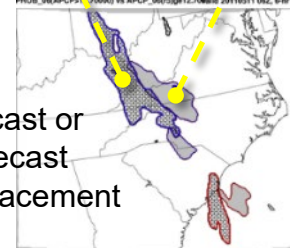
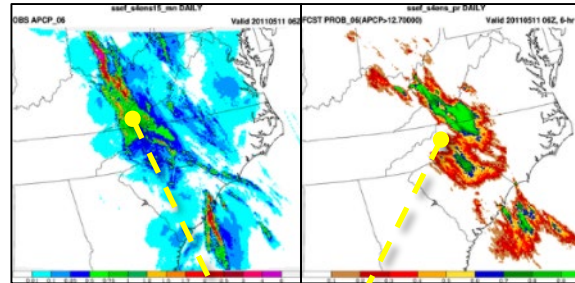
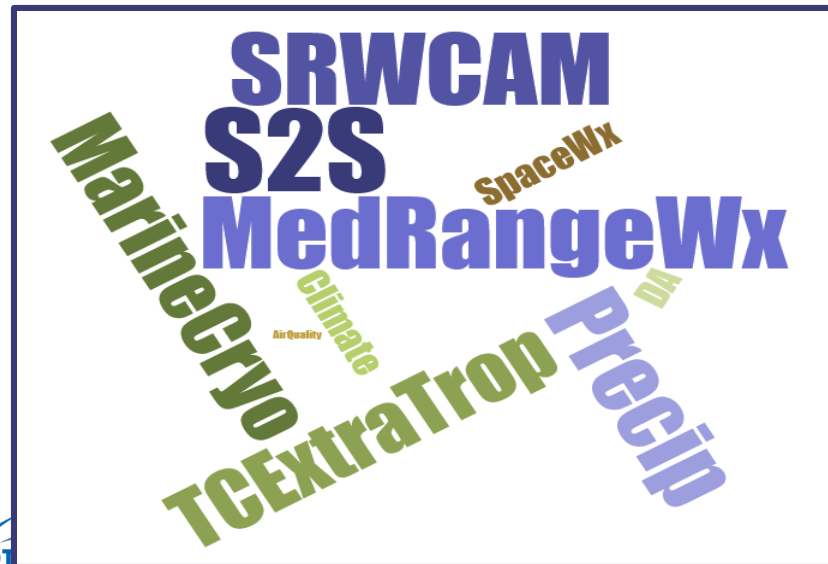
Suite of Python wrappers around

- 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

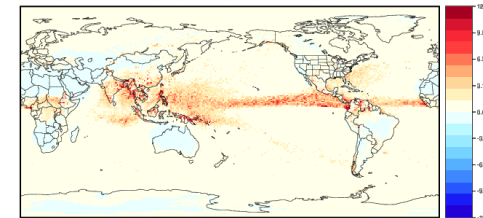
- Over 150 traditional statistics and diagnostic methods for both point and gridded datasets
- 15 interpolation methods
- Mix of C++, Fortran, Python – language driven by operational reqs
- Developed to allow for easy sharing of config files for reproducible results
- 3500+ users; US and Int'l



METplus Examples/Use-Case In Development



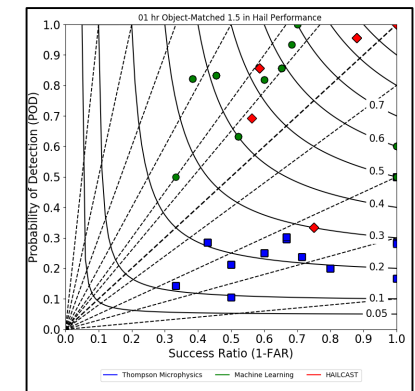
Bad forecast or
Good forecast
with displacement
error?



METviewer CAM Scorecard
for NSSLFV3 and HRRR_nsslgrid

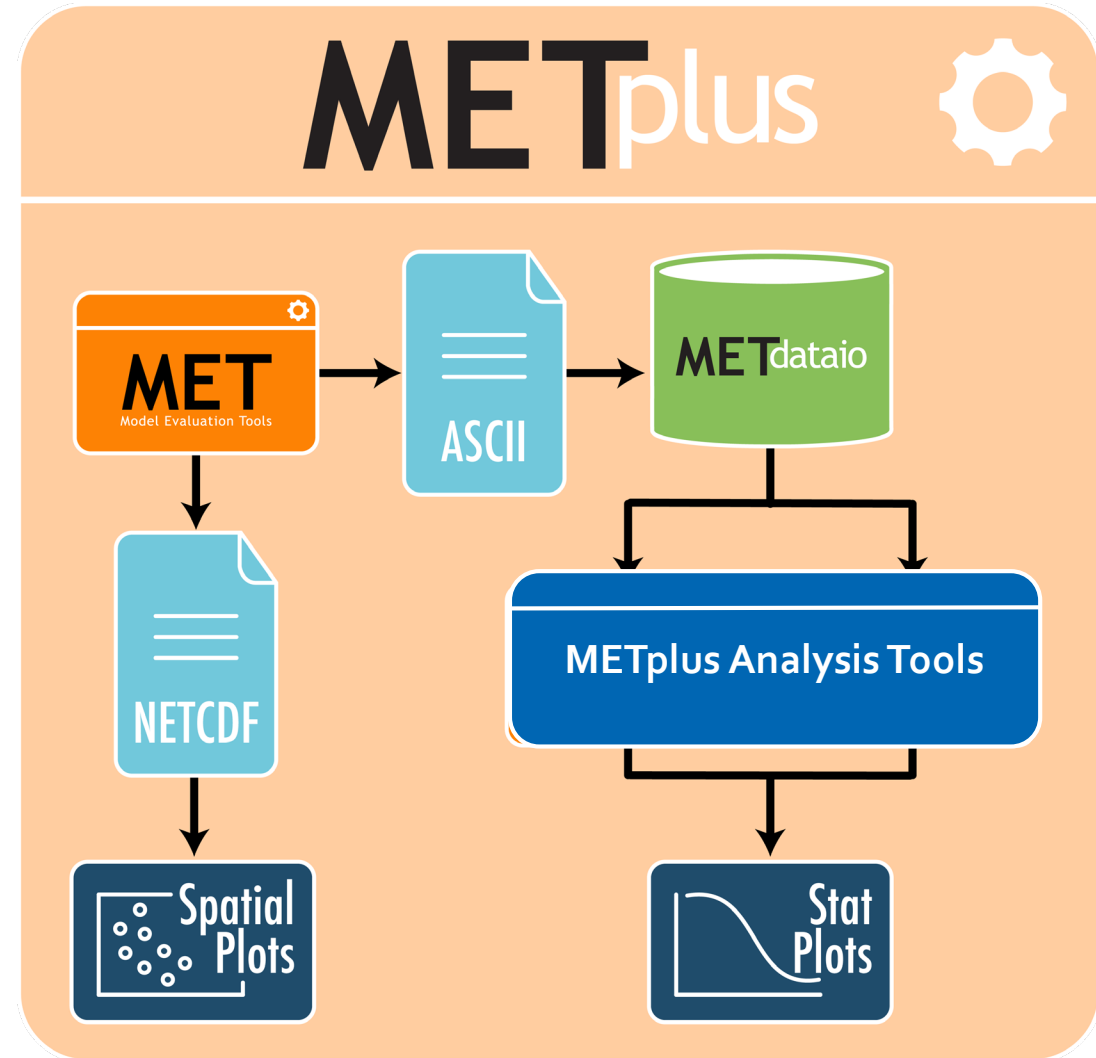
2018-04-30 00:00:00 - 2018-06-01 00:00:00

		Daily Domain					CONUS				
		12 hr	18 hr	24 hr	30 hr	36 hr	12 hr	18 hr	24 hr	30 hr	36 hr
Temperature	>=32	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
	>=65	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
	>=70	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
	>=75	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
	>=80	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
U Wind	>=10 kts	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
	>=15 kts	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
	>=20 kts	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
V Wind	>=10 kts	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
	>=15 kts	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ
	>=20 kts	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ



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

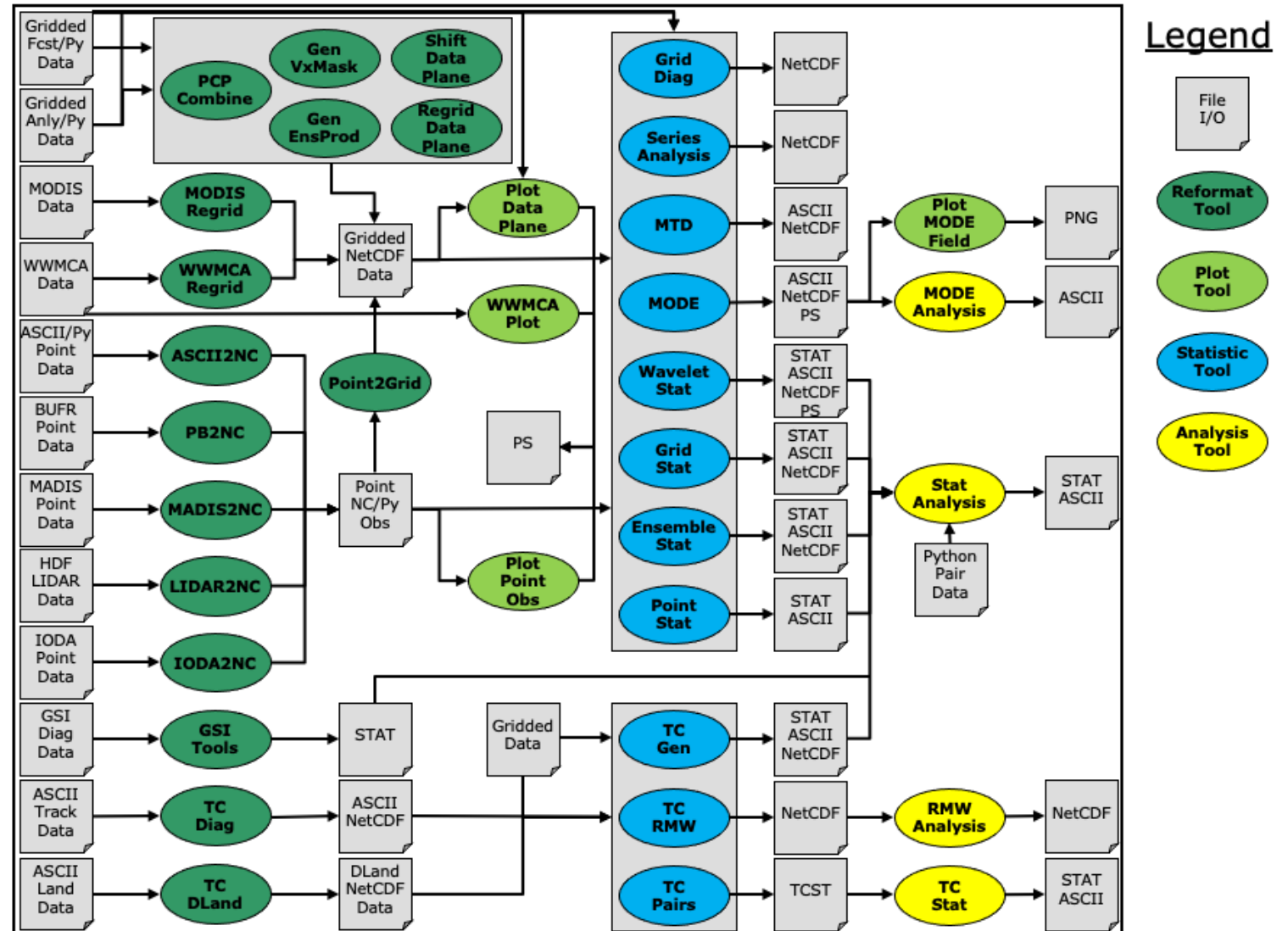


- [Version 5.1 released Aug 1st](#)

Core MET Tools

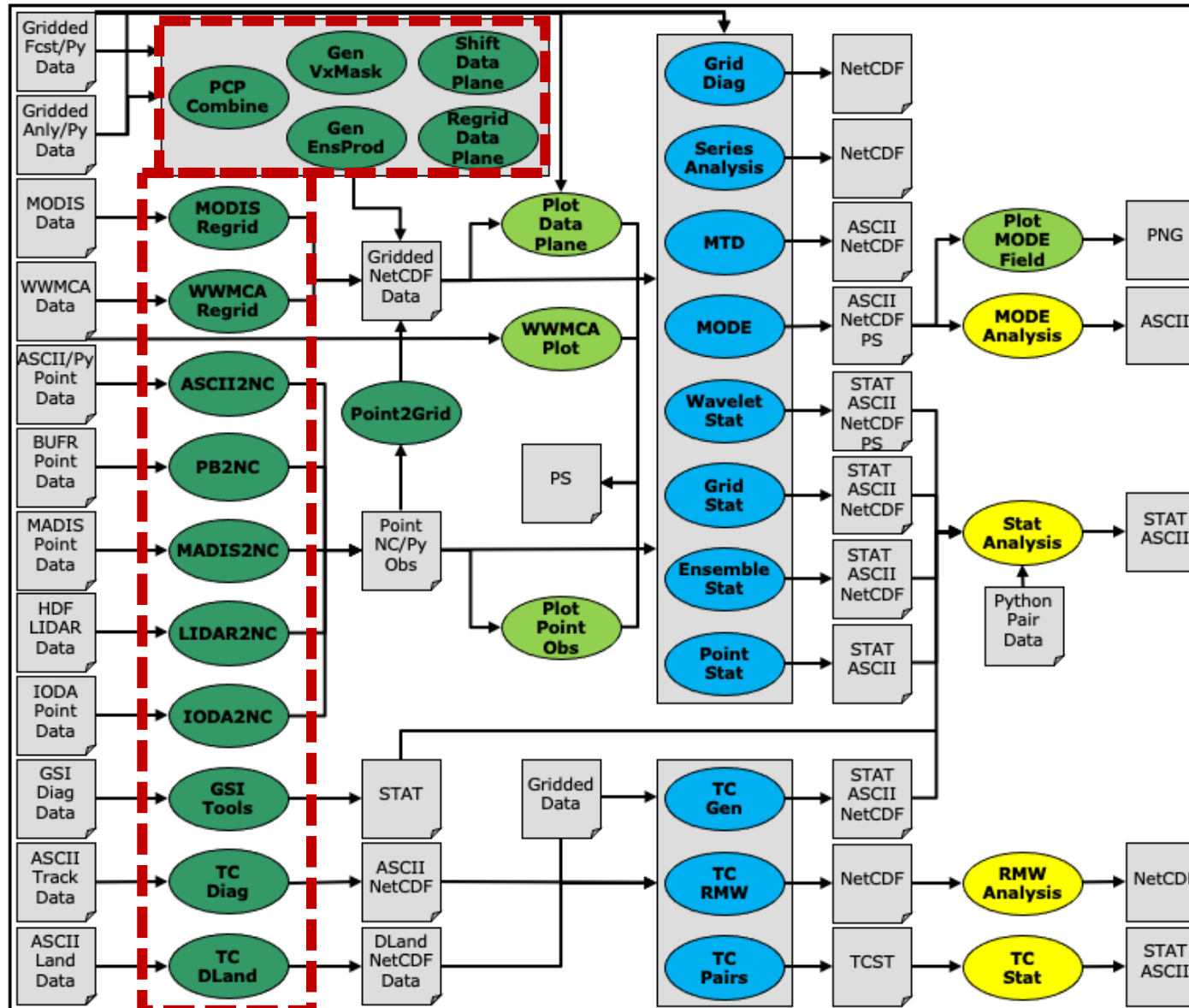
- **MET** – suite of statistical and diagnostic tools
- Reformatting tools
- Data Inspection tools
- Statistical tools
- Analysis tools
- Traditional grid-to-grid and grid-to-point statistics
- Ensemble statistics
- Spatial methods
- TC methods

MET Overview v11.1.0



Tools for Preprocessing

MET Overview v11.1.0



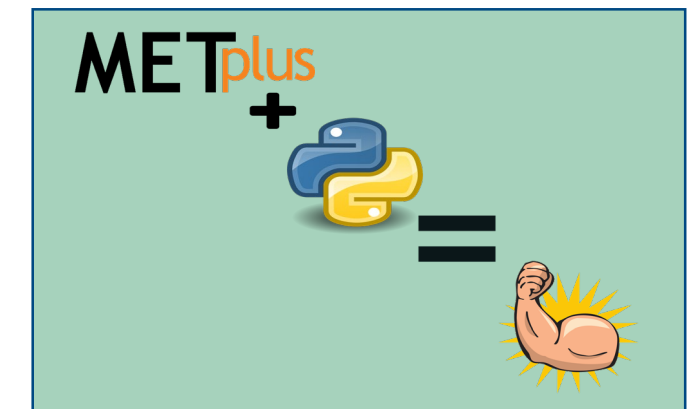
Legend



Includes tools for:

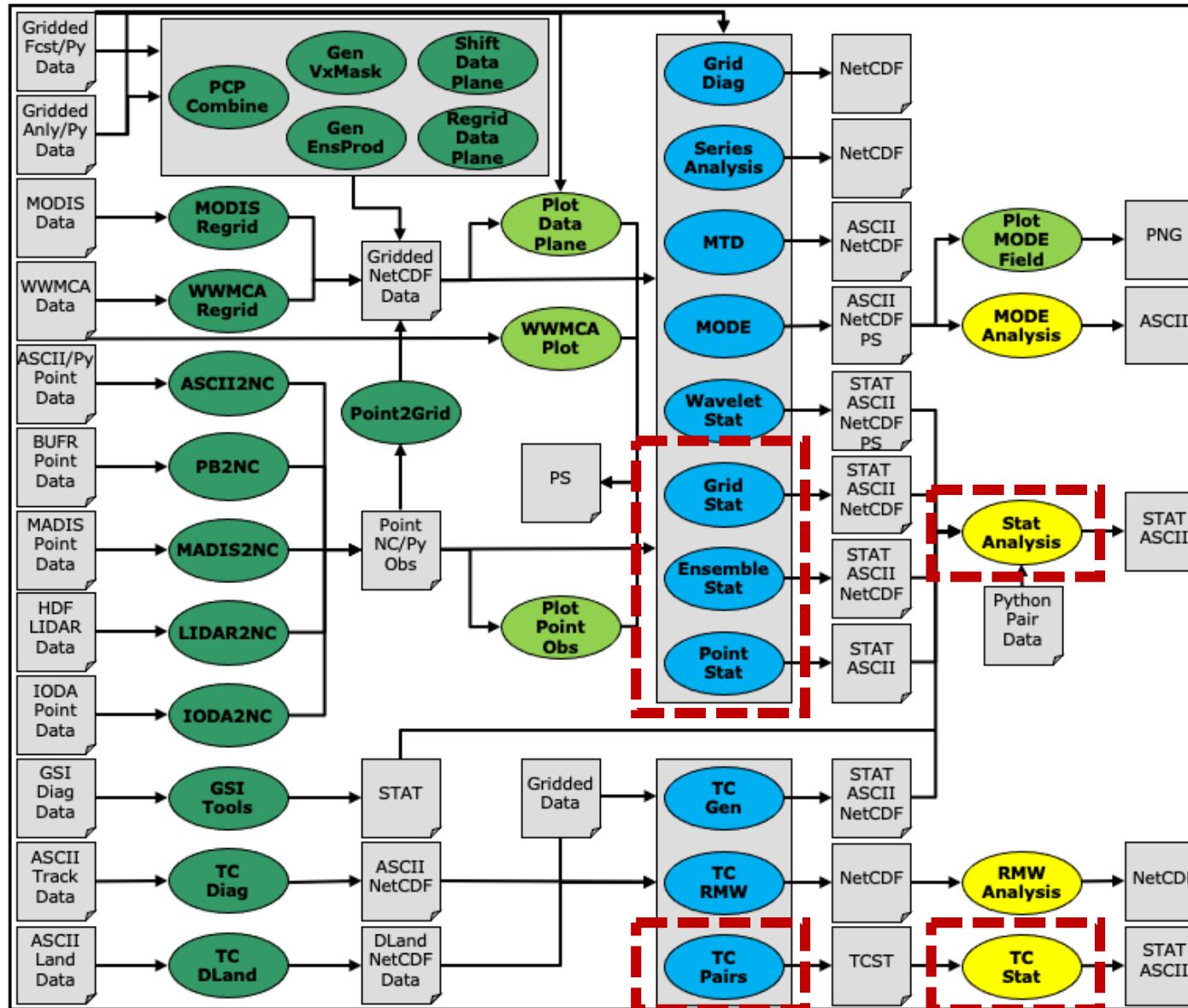
- Reformatting
- Quick look plotting
- Statistics computation
- Analysis

PythonEmbedding



Tools for Standard Statistics

MET Overview v11.1.0



Legend



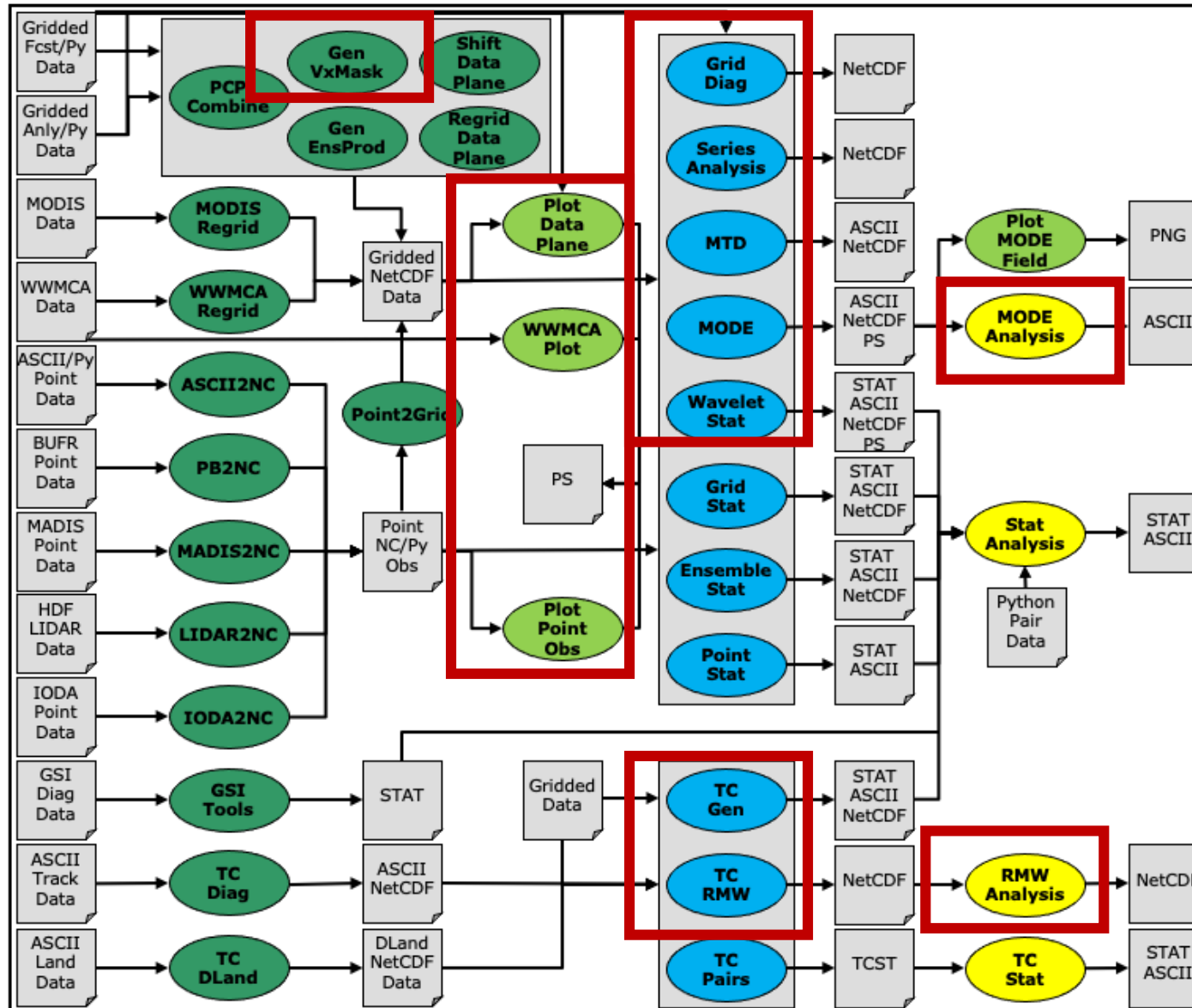
Includes tools for:

- Reformatting
- Quick look plotting
- Statistics computation
- Analysis

METviewer
METexpress

Tools for Diagnostics

MET Overview v11.1.0



Legend



Includes tools for:

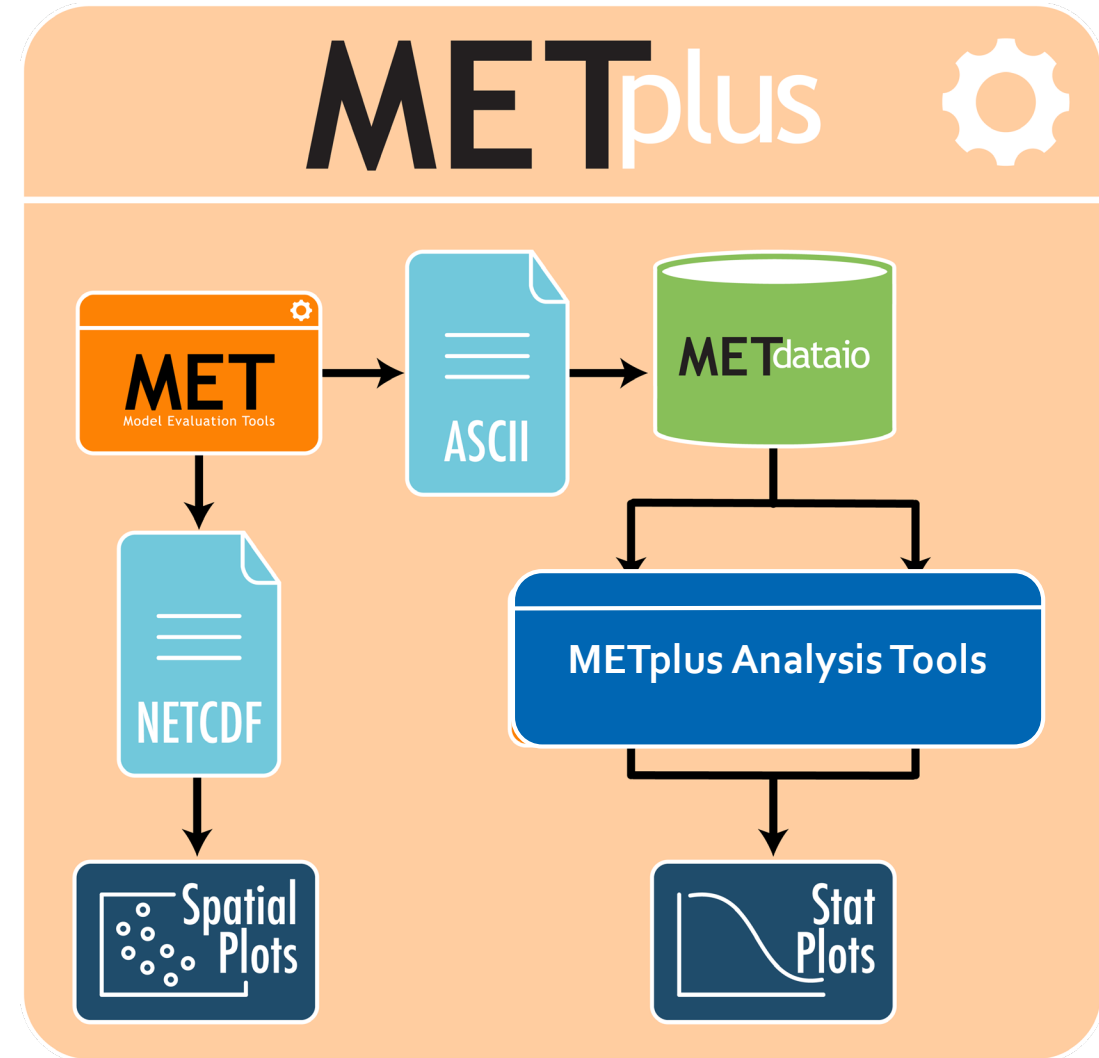
- Reformatting
- Quick look plotting
- Statistics computation
- Analysis

METcalcpy

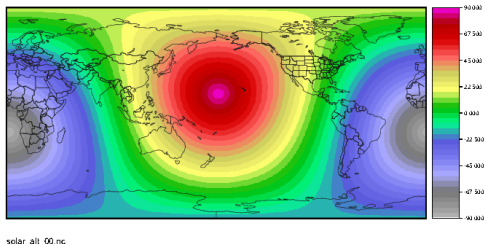
METplotpy

METplus Components

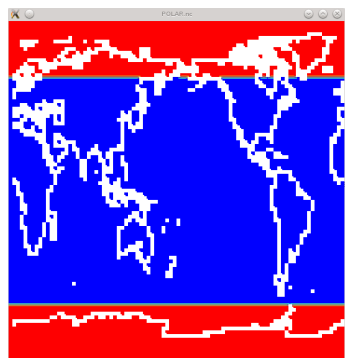
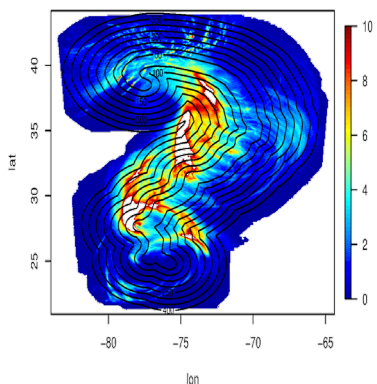
- **Wrappers** - represented by black arrows – low level workflow
- **MET** – suite of statistical and diagnostic tools
- **Analysis Tools** – available for advanced analysis includes
 - METviewer and METexpress user interface
 - METdataio, METcalcpy, METplotpy Python components
- Work in progress to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



Reproducible Statistics and Methods

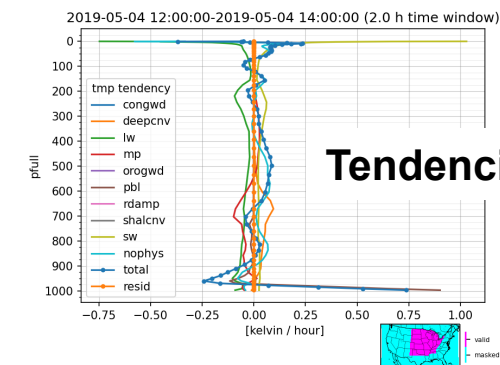
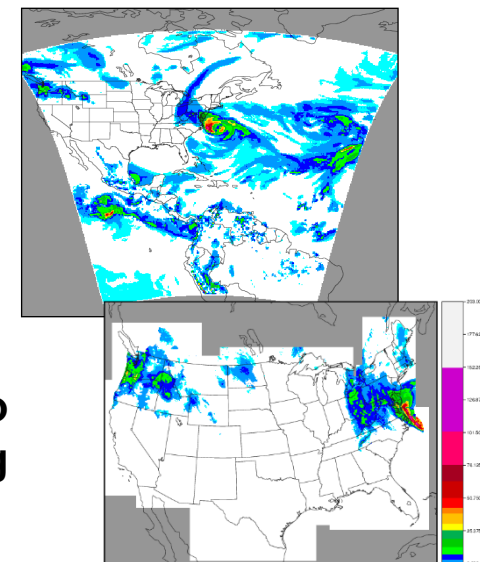


Masking



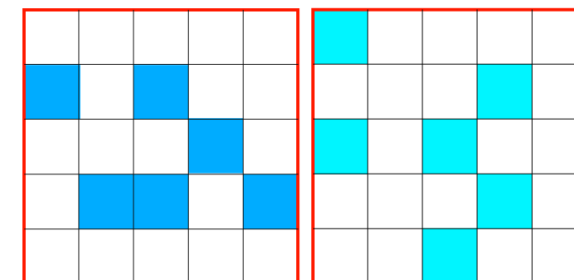
Traditional	
Grid-Stat, Point-Stat, Series-Analysis Contingency table statistics (CTS) Continuous statistics Probability forecast statistics Confidence intervals	Ensemble-Stat CRPS, CRPSS Rank prob., Prob. Integral Transform (PIT), and Relative Position histograms Spread/Skill Ignorance Confidence intervals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

Auto Regridding



Tendencies

Neighborhood Methods

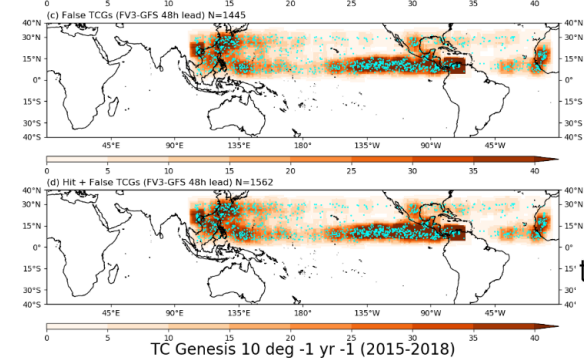
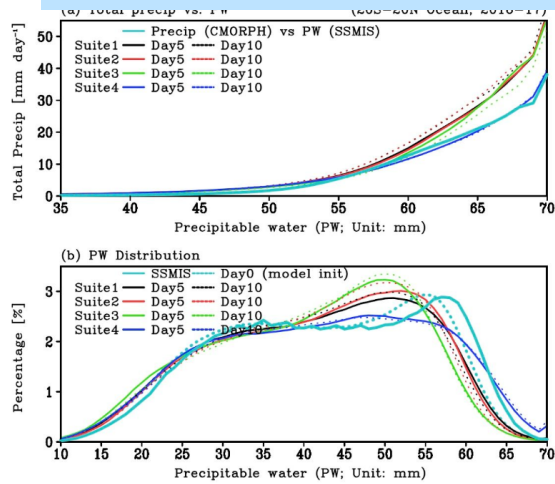


Fraction = 6/25 = 0.24

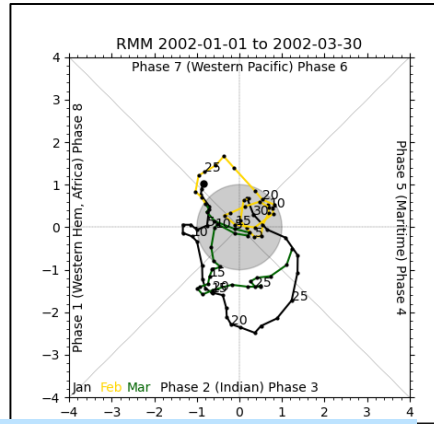
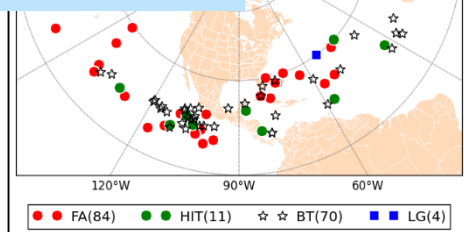
Fraction = 6/25 = 0.24

Examples of Community Contributions

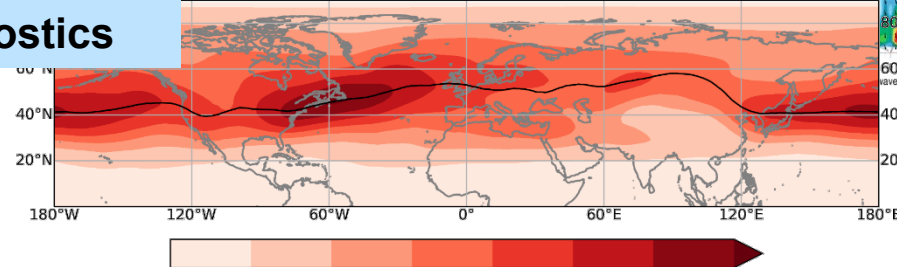
S2S Multivariate Distributions



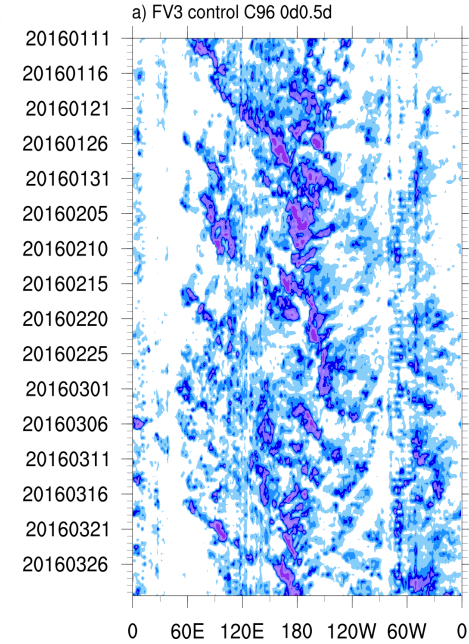
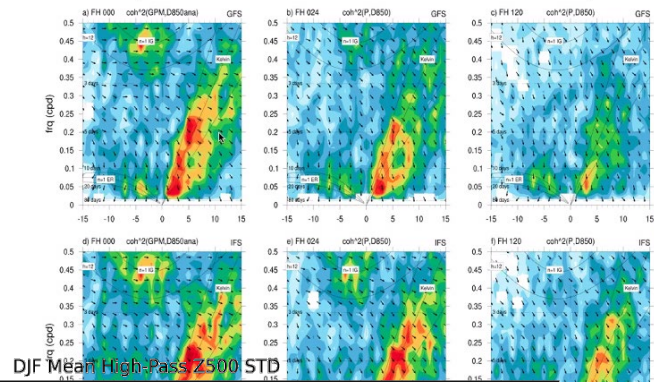
S2S TC-Genesis



S2S Diagnostics

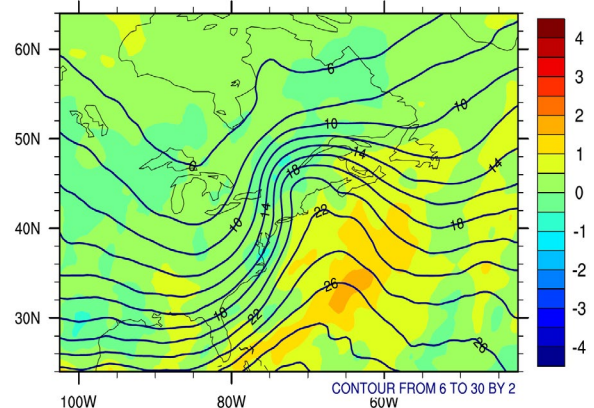


Space-time coherence spectra

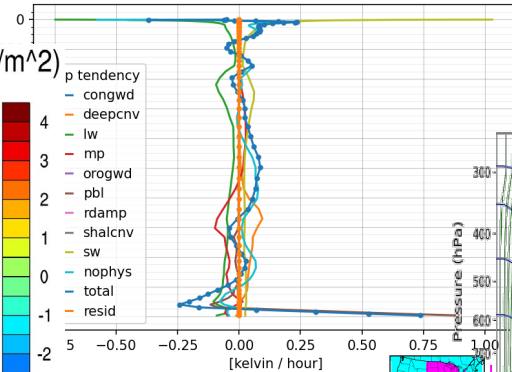


Systematic Errors

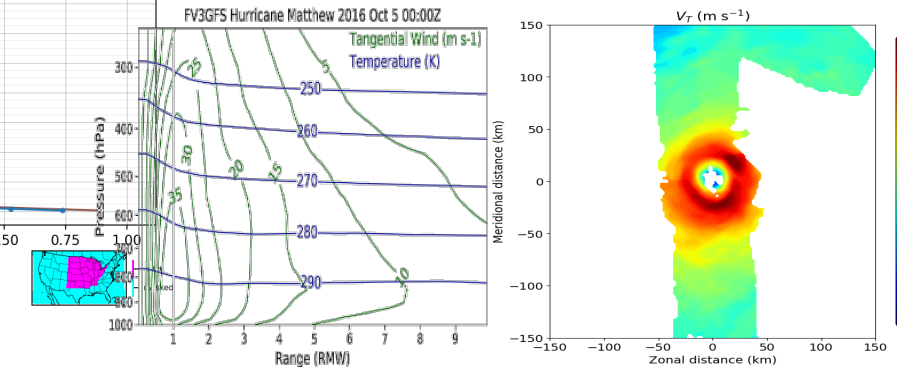
total water bias evol for (-)495 cases h54-72(kg/m²)



2019-05-04 12:00:00-2019-05-04 14:00:00 (2.0 h time window)

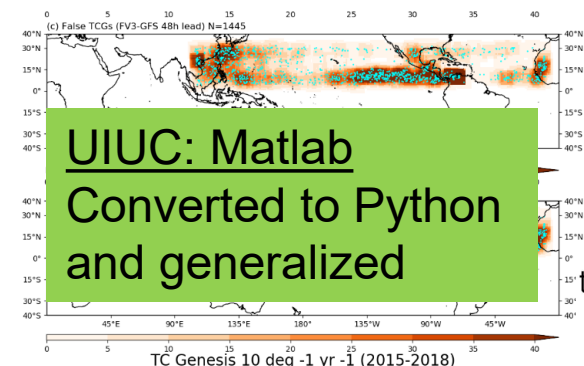
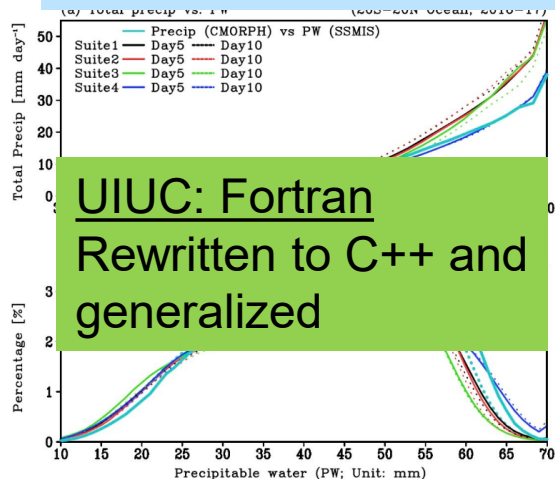


TCs New Projections and Obs



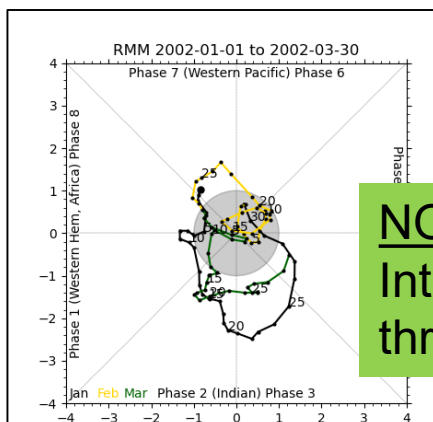
Examples of Community Contributions

S2S Multivariate Distributions



S2S TC-Genesis

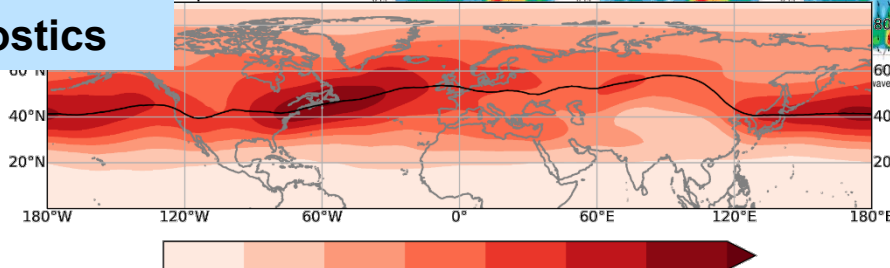
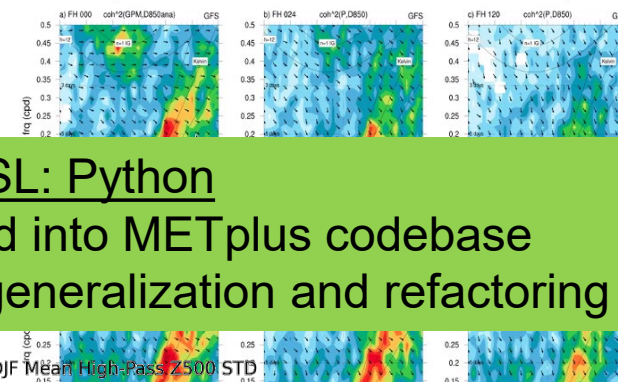
ERU: Algorithm
Coded in C++ and generalized



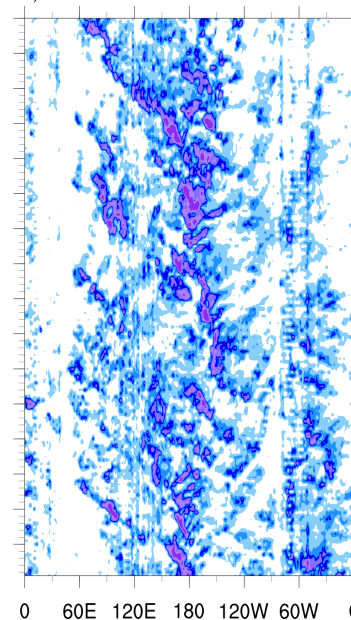
S2S Diagnostics

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

Space-time coherence spectra

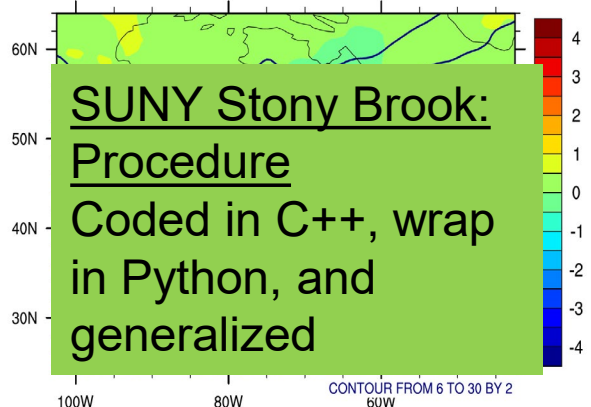


a) FV3 control C96 0d0.5d



Systematic Errors

total water bias evol for (-)495 cases h54-72(kg/m²)



2019-05-04 12:00:00-2019-05-04 14:00:00 (2.0 h time window)

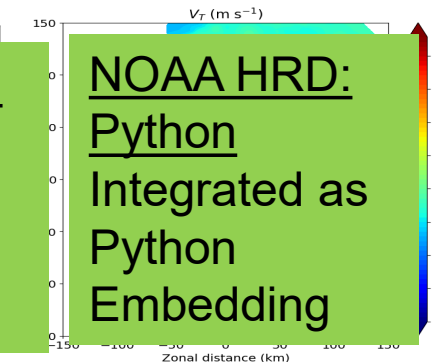
NCAR MMM:
Python
Integrated into METplus codebase

TCs New Projections and Obs

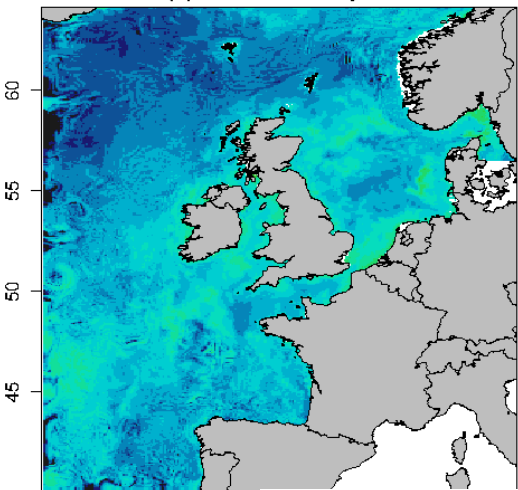
FV3GFS Hurricane Matthew 2016 Oct 5 00:00Z

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

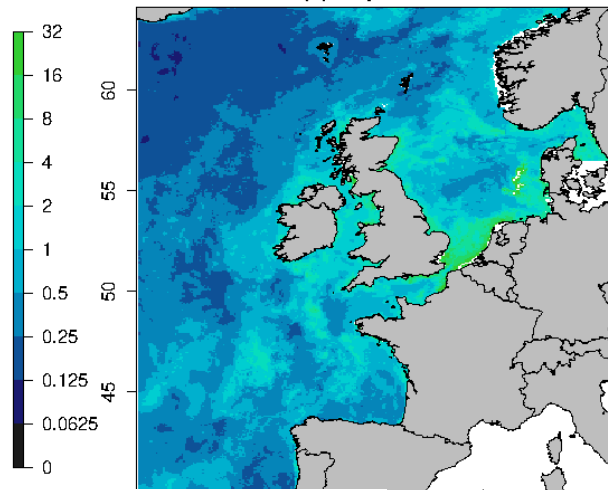
NOAA HRD:
Python
Integrated as Python Embedding



(a) AMM7v11 analysis

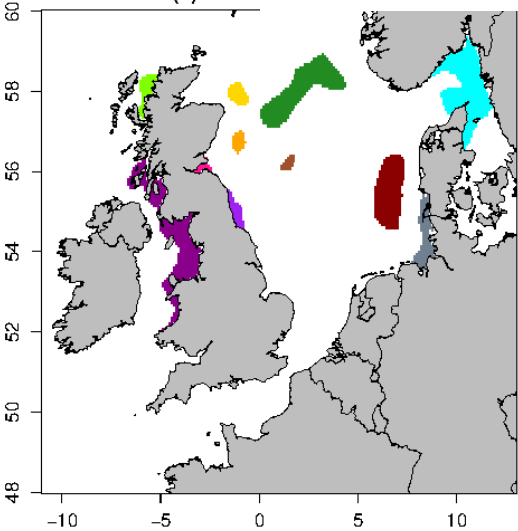


(b) L4 product

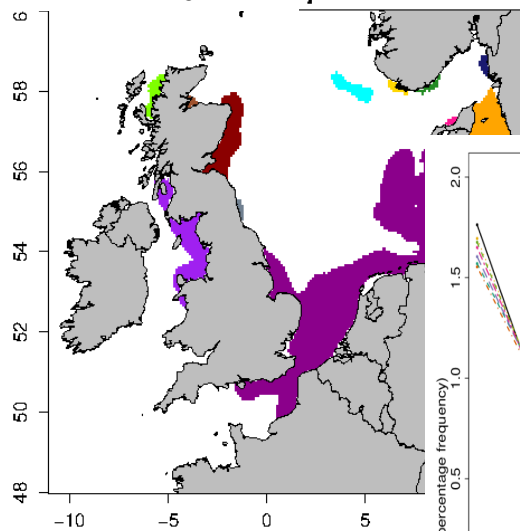


MODE output for Chlorophyll-a

(c) AMM7v11 analysis



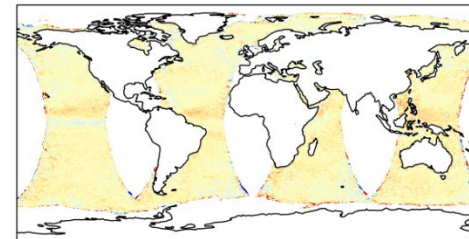
(d) L4 product



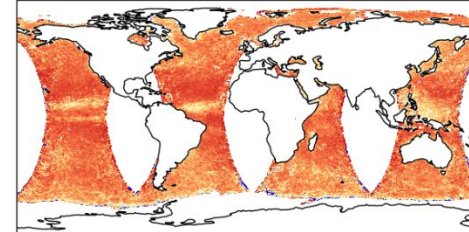
Mittermaier et al. 2021, Ocean Science

Slide Courtesy of Marion Mittermaier, Met Office

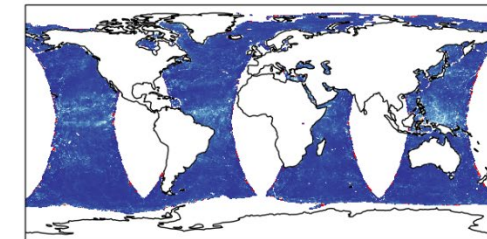
Mean Error



RMSE

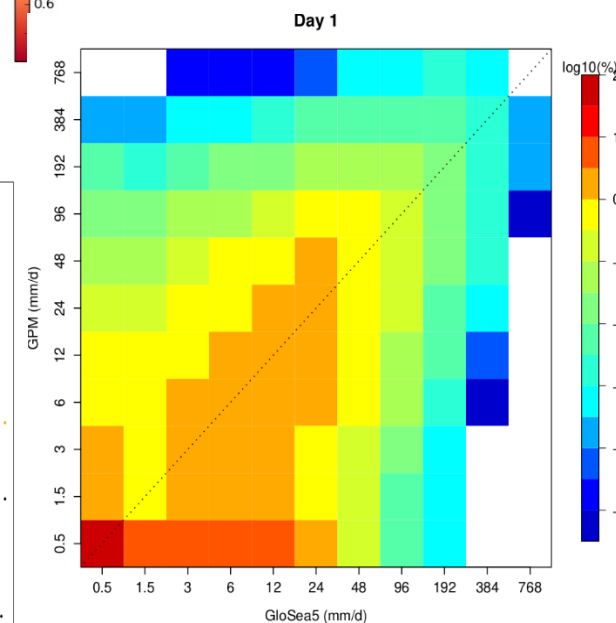
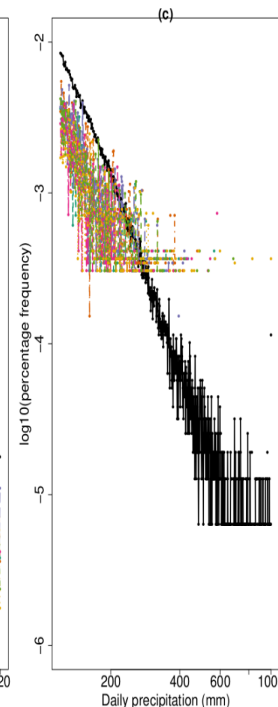
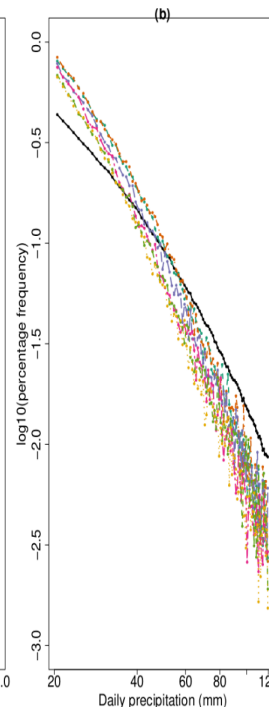
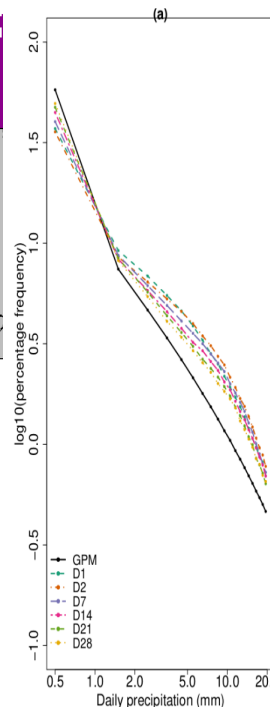


Pearson Correlation



Series-Analysis
output of
scatterometer
winds

Ric Crocker

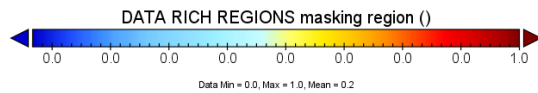
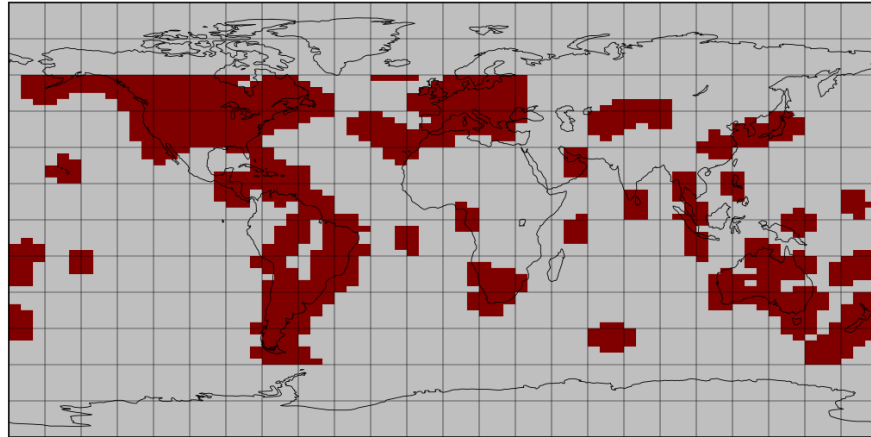


Joint and marginal
distributions
Grid-Diag

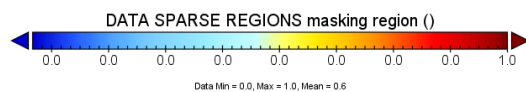
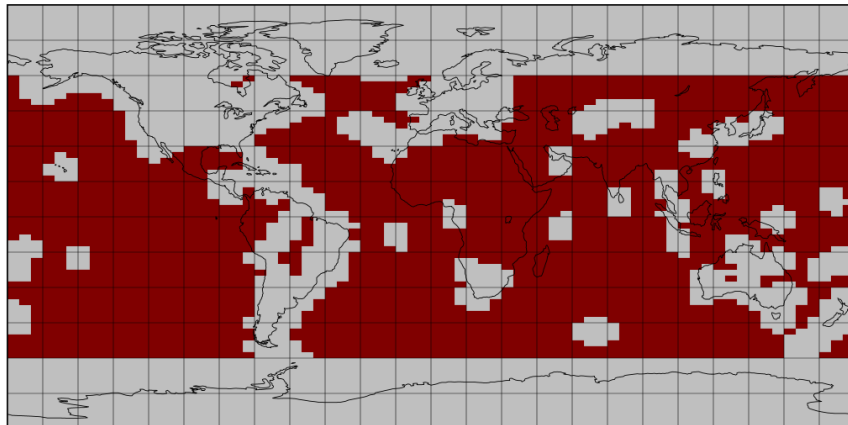
Space Weather

2. Data Rich vs. Data Sparse Regions

DATA RICH REGIONS masking region



DATA SPARSE REGIONS masking region

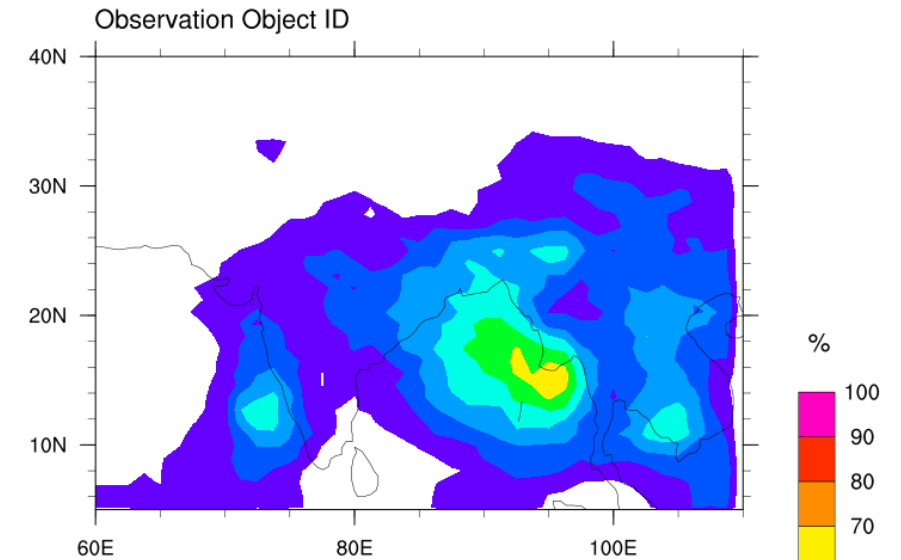


Masking:
Near
Observing
Stations

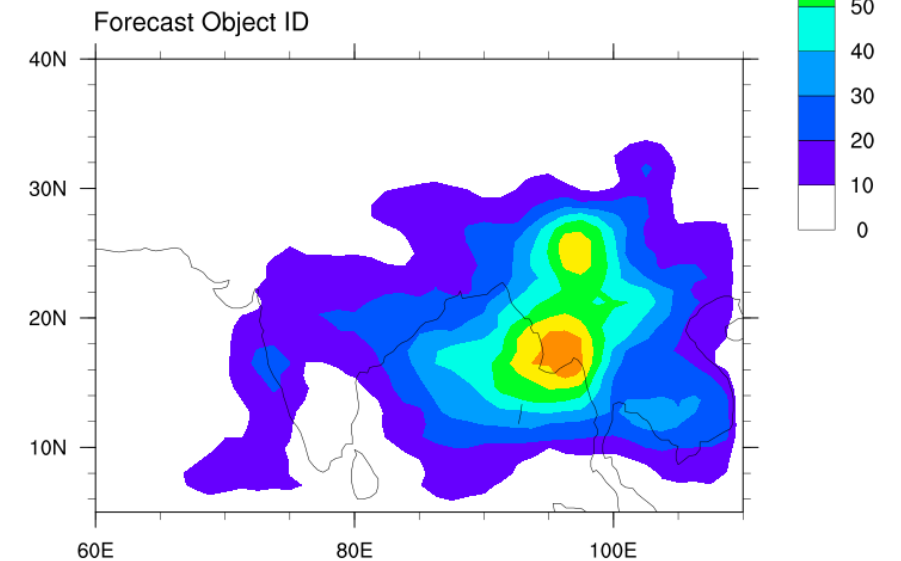
Masking:
Not Near
Observing
Stations

Climate

GPCP Object Frequency, JJA 2014



CESM 24h Object Frequency, JJA 2014



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



main_v4.0

METPLUS WRAPPERS GUIDES

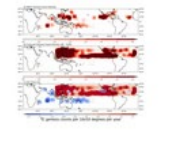
- User's Guide
 - 1. Overview
 - 2. Software Installation
 - 3. System Configuration
 - 4. Python Wrappers
 - 5. METplus Use Cases
 - 5.1. MET tools
 - 5.2. Model Applications
 - 5.2.1. Air Quality and Composition
 - 5.2.2. Climate
 - 5.2.3. Convection Allowing Models
 - 5.2.4. Cryosphere
 - 5.2.5. Data Assimilation
 - 5.2.6. Marine and Coastal
 - 5.2.7. Medium Range
 - 5.2.8. Precipitation
 - 5.2.9. Subseasonal to Seasonal
 - 5.2.10. Space Weather
 - 5.2.11. Tropical Cyclone and Extra Tropical Cyclone
 - 6. METplus Quick Search for Use Cases
 - 7. METplus Configuration Glossary
 - 8. References

User's Guide and Getting Help

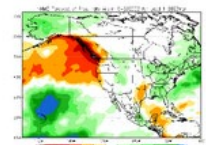
https://metplus.readthedocs.io/en/latest/Users_Guide/

5.2.9. Subseasonal to Seasonal

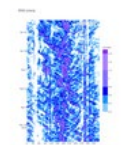
Subseasonal-to-Seasonal model configurations; Lower resolution model configurations (>4km) usually producing forecasts out beyond 14 days and up 1 year



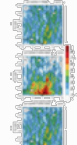
TCGen: Genesis Density Function (GDF) and Track Density Function (TDF)



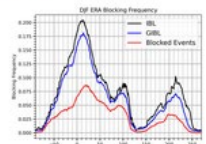
Grid-Stat and Series-Analysis: BMKG APIK Seasonal Forecast



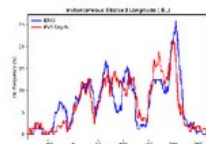
UserScript: Make a Hovmoeller plot



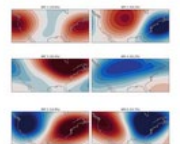
UserScript: Make a Cross Spectra plot



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>

dtcenter / METplus

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<> Code Issues 108 Pull requests 1 Discussions Actions Projects 4 Wiki

Announcements

Welcome to the METplus Components Discu...

jprestop

Announcements

Resources for Troubleshooting

jprestop

New Top: All Answered Unanswered Label New discussion

Categories

View all

- Announcements
- Configuration
- Existing Builds
- File I/O
- General
- Incoming
- Installation
- Plot Generation
- Statistical Computation
- Use Cases

Most helpful Last 30 days

- JohnHalleyGotway 5
- jprestop 3
- TatianaBurek 2
- j-opatz 2
- georgemccabe 1

- METplus-4.1.0-beta1 georgemccabe announced 4 hours ago in Announcements
- Comparing different months from same database METviewer: Plotting PerryShafran-NOAA asked 2 days ago in Plot Generation - Answered 9
- Confidence intervals for scores from aggregate_stat job for GridStat output. AnastasiaBundel asked yesterday in Statistical Computation - Unanswered 0
- Converting netCDF to GRIB2 johnlwagner asked yesterday in File I/O - Unanswered 0
- Using IMERG data for observations in MODE MET: Feature Verification MET: Python Embedding rvalenzuelar asked 3 days ago in File I/O - Answered 2
- Unit change of each files in config MET: Configuration MET: Masking Debsa7 asked 3 days ago in Configuration - Unanswered 8
- Obs_Quality flags MET: Configuration robdarvell asked 4 days ago in Configuration - Answered 2
- BUFR in Met-9.1.3 MET: PreProcessing Tools (Point) METplus 4.1 Coordinated Release AnastasiaBundel asked 10 days ago in File I/O - Answered 12
- Looping by valid time with METplus TCPairs METplus: Configuration METplus: Tropical/Extra-Tropical Cyclone mollysmith-noaa asked 16 days ago in Configuration - Answered 3
- point-stat usage on new use case MET: Grid-to-Point Verification YakelynRJ asked 10 days ago in Use Cases - Answered 2

Community guidelines

metplus.readthedocs.io

Beta Give feedback

Basic Training To Get You Started

Basic (2021-2022)

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

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 +

Prerequisite: Complete Plot-Data-Plane Hands-On


Presentation: [Announcements](#) and set up refresher


Presentation: [Gen-Vx-Mask](#)

Hands-On: [PCP-Combine](#) and [Gen-Vx-Mask](#)


Homework: Review Recording and PCP-Combine and Gen-Vx-Mask Hands-On Sessions

Recording and Chat Archive: [Chat Log](#)

 METplus Training Series - 2021-2022 Session 3




[Watch later](#) [Share](#)



METplus Training Series 2021 - 2022

Presented by the METplus Team

NCAR/RAL, NOAA/GSL, and Developmental Testbed Center



Advanced (2023)

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

 Developmental Testbed Center

ABOUT TESTING + EVALUATION COMMUNITY CODE VISITOR PROGRAM NEWS EVENTS

METPLUS ADVANCED TRAINING SERIES



APR 19 2023 | 9:00AM - OCT 31 2023 | 11:00AM | VIRTUAL-LINK FOR THE MEETING PROVIDED TO REGISTERED PARTICIPANTS

[View](#) [Edit](#)

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.

ABOUT


- [Agenda And Recordings](#)
- [Sign Up For Updates](#)
- [Resources And Support](#)

Platforms:

- AWS
- NCAR HPC: Cheyenne
- NOAA HPCs: WCOS2, Hera, Jet



Online Training



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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>

CONTENTS

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

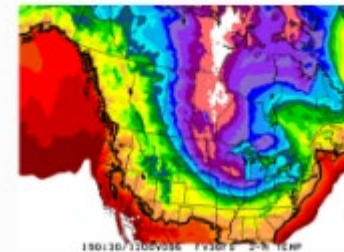
https://metplus.readthedocs.io/en/latest/Users_Guide/usecases.html

8.2. Use Cases by Application:

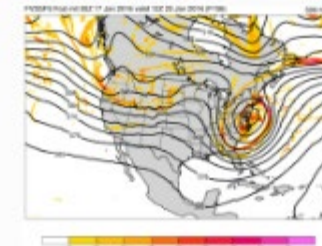
Air Quality and Composition
Climate
Clouds
Short Range
Data Assimilation
Ensemble
Land Surface
Marine and Cryosphere
Medium Range
PBL
Precipitation
Space Weather
Subseasonal to Seasonal
Subseasonal to Seasonal: Madden-Julian Oscillation
Subseasonal to Seasonal: Mid-Latitude
Tropical Cyclone and Extra-Tropical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

METplus

PyEmbedIngest: Multiple Fields in One File

15 years of reproducible results

METplus

METplus and MET [user support discussion forum](#)

METplus [website](#), [online tutorial](#), [training series](#)

METplus [repository](#), [documentation](#), [releases](#), [Docker](#), [v5.1.0](#)
[development](#)



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