The Long and Winding Road to Unified Verification

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NCAR/RAL and DTC
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Workshop on Correctness and Reproducibility for Climate and Weather Software
Why Unified Verification?

Forecastsers  Operational Centers  Universities and National Laboratories

Comprehensive and unified verification tool - Make R2O more efficient - Provide a consistent set of metrics

METplus

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

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

1. NCAR/RAL and DTC  2. NOAA/GSL and DTC
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
2015 - Selected as verification package for NOAA Unified Forecast System
2016 – METplus Wrappers dev started
2017 – EMC starts developing Global workflow using METplus on WCOSS
2019 – METplus Analysis and Diagnostic Tools dev started
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?
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
Tools for Preprocessing
MET Overview v11.1.0

Includes tools for:
- Reformatting
- Quick look plotting
- Statistics computation
- Analysis

Python Embedding

Legend
- File I/O Tool
- Reformat Tool
- Plot Tool
- Statistic Tool
- Analysis Tool
Tools for **Standard Statistics**

**MET Overview v11.1.0**

Includes tools for:
- Reformatting
- Quick look plotting
- Statistics computation
- Analysis

**Legend**
- File I/O
- Reformat Tool
- Plot Tool
- Statistic Tool
- Analysis Tool

**METviewer**

**METexpress**
Includes tools for:
- Reformatting
- Quick look plotting
- Statistics computation
- Analysis

Tools for Diagnostics
MET Overview v11.1.0
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

<table>
<thead>
<tr>
<th>Traditional</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Grid-Stat, Point-Stat, Series-Analysis</strong></td>
</tr>
<tr>
<td>Contingency table statistics (CTS)</td>
</tr>
<tr>
<td>Continuous statistics</td>
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<tr>
<td>Probability forecast statistics</td>
</tr>
<tr>
<td>Confidence intervals</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ensemble-Stat</th>
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</thead>
<tbody>
<tr>
<td>CRPS, CRPSS</td>
</tr>
<tr>
<td>Rank prob., Prob. Integral Transform (PIT), and Relative Position histograms</td>
</tr>
<tr>
<td>Spread/Skill</td>
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<tr>
<td>Ignorance</td>
</tr>
<tr>
<td>Confidence intervals</td>
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</tbody>
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<table>
<thead>
<tr>
<th>Spatial</th>
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<tbody>
<tr>
<td><strong>MODE</strong></td>
</tr>
<tr>
<td>Location differences</td>
</tr>
<tr>
<td>Geometric attribute differences</td>
</tr>
<tr>
<td>Intersection area</td>
</tr>
<tr>
<td>Intensity distributions &amp; differences</td>
</tr>
<tr>
<td>CTS measures</td>
</tr>
</tbody>
</table>

| **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 |

| **TC-GEN** |
| CTS measures of TC genesis |

| **Grid-Diag** |
| Distributions of fields for use in contour plots |

| **TC-RMW** |
| Radius of maximum wind errors and metrics |

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**Auto Regridding**

**Tendencies**

**Neighborhood Methods**

Fraction = 6/25 = 0.24
Examples of Community Contributions

S2S Multivariate Distributions

S2S TC-Genesis

S2S Diagnostics

Systematic Errors

total water bias evol for (~)495 cases h54-72(kg/m^2)

TCs New Projections and Obs
Examples of Community Contributions

**S2S Multivariate Distributions**
- UIUC: Fortran
  - Rewritten to C++ and generalized

**S2S TC-Genesis**
- ERU: Algorithm
  - Coded in C++, wrap in Python, and generalized

**S2S Diagnostics**
- Systematic Errors

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

**TCs New Projections and Obs**
- NCAR MMM: Python
  - Integrated into METplus codebase
- CIRA: Fortran and Python
  - Rewritten in C++ and generalized
- NOAA HRD: Python
  - Integrated as Python Embedding
Joint and marginal distributions

Grid-Diag

MODE output for Chlorophyll-a

Series-Analysis output of scatterometer winds

Ric Crocker

Mittermaier et al. 2021, Ocean Science

Slide Courtesy of Marion Mittermaier, Met Office
2. Data Rich vs. Data Sparse Regions

**Space Weather**

Masking:

- **Near Observing Stations**
  - DATA RICH REGIONS masking region
  - Masking: Near Observing Stations

- **Not Near Observing Stations**
  - DATA SPARSE REGIONS masking region
  - 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
User’s Guide and Getting Help


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 Hovmoller plot
UserScript: Make a Cross Spectrum plot

Blocking Calculation: RgridDataPlane, PcpCombine, and Blocking python code
Blocking Calculation: RgridDataPlane, PcpCombine, and Blocking python code
WeatherRegime Calculation: RgridDataPlane, PcpCombine, and WeatherRegime python code

https://github.com/dtcenter/METplus/discussions
Basic Training To Get You Started

Basic (2021-2022)
https://dtcenter.org/events/2021/metplus-training-series

Advanced (2023)
https://dtcenter.org/events/2023/metplus-advanced-training-series

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


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)
15 years of reproducible results

METplus and MET user support discussion forum

METplus website, online tutorial, training series
METplus repository, documentation, releases, Docker, v5.1.0 development

Questions

Contact:
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