Strategic Implementation Plan (SIP) for a Community-based Unified Forecast System (UFS)

Model Physics Working Group

Presented by

Jack Kain, NCEP/EMC

Coordination Meeting for UFS SIP

May 14-16, 2019; College Park, MD

Model Physics WG Membership

- *Jim Doyle** (NRL)*
- *Georg Grell** (ESRL/GSD)*
- *Jack Kain** (NCEP/EMC)*
- *Chris Bretherton** (UW)*

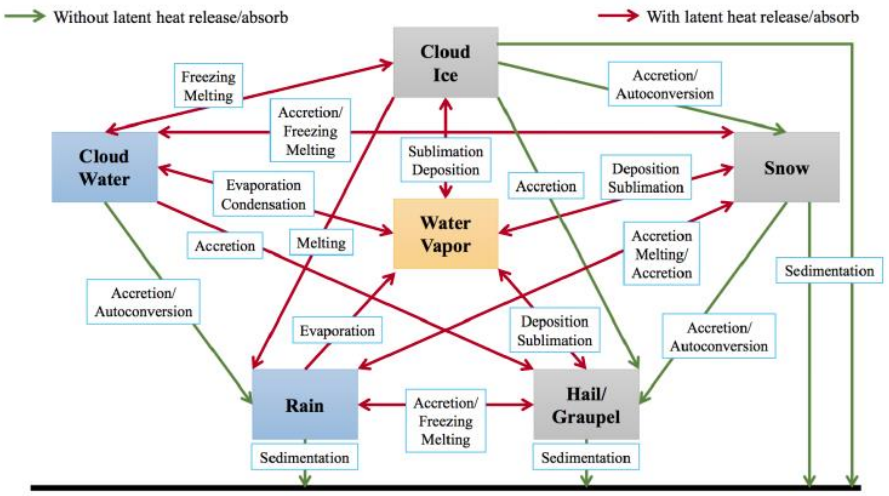
***Co-Chairs*

- Jordan Alpert (NCEP/EMC)
- Jian-Wen Bao (ESRL/PSD)
- Ligia Bernardet (DTC/GSD/CU)
- Fei Chen (NCAR)
- Rob Cifelli (ESRL/PSD)
- Jimy Dudhia(NCAR)
- Stephen Eckermann (NRL)
- Mike Ek (NCAR)
- Grant Firl (NCAR/DTC)
- Timothy Fuller-Rowell (CU/SWPC)
- Gopal Gopalakrishnan (AOML/HRD)
- Andy Hazelton (AOML/HRD/CIMAS)
- Jongil Han (NCEP/EMC)
- Yu-Tai Hou (NCEP/EMC)
- Steve Krueger (U. of Utah)
- Shian-Jiann Lin (GFDL)
- Shrinivas Moorthi (NCEP/EMC)
- Louisa Nance (NCAR)
- Joe Olson (DTC/GSD/CU)
- Robert Pincus (CU)
- Bill Putman (NASA)
- Suru Saha (NCEP/EMC)
- Ruiyu Sun (NCEP/EMC)
- Vijay Tallapragada (NCEP/EMC)
- Joao Teixeira (JPL)
- Greg Thompson (NCAR)
- Helin Wei (NCEP/EMC)
- Fanglin Yang (NCEP/EMC)
- Valery Yudin (CU/SWPC)
- Chunxi Zhang (OU/CAPS)
- Ming Zhao (GFDL)
- Linjiong Zhou (GFDL)
- Xiaqiong Zhou (NCEP/EMC)

Model Physics WG
Project Milestone Accomplishments

- **SIP project accomplishments to date:**
  - **GFSv15 implementation June 2019**
    - **FV3 dynamic core**
    - **GFDL Microphysics with enhanced radiation interactions**
    - **NRL O3, H2O Photochemistry Parameterization**

GFDL MP at a glance



Model Physics WG Accomplishments

- **SIP project accomplishments to date:**
  - **GFSv16 Physics options selected, pending validation; GFSv15 Physics with these changes:**
    - **PBL/turbulence: K-EDMF => sa-TKE-EDMF**
    - **Land surface: Noah => Noah-MP**
    - **GWD: separate orographic/non-orographic => unified gravity-wave-drag**
    - **Radiation: updates to cloud-overlap assumptions, empirical coefficients, etc. in RRTMG**
  - **Community engagement in physics upgrade process**

Model Physics WG Challenges

- **SIP project issues this year:**
  - **CCPP code acceptance at EMC delayed**
  - **Fresh-water Lake Model (FLAKE) implementation delayed**
  - **RRTMGP radiation upgrade delayed**

Model Physics WG
Team Coordination and Dependencies

- Team coordination/dependency successes:
  - Ensemble Team (GEFS development) collaboration led to improved representation of interactions between GFDL microphysics and atmospheric radiation

- Team coordination/dependency issues:
  - CAM Team coordination could be better
  - System Architecture Team collaboration re: land-model coupling
  - Marine Models/Dynamics and Nesting Team interactions need to improve re: hurricane physics
  - Need to enhance collaboration with DA WG

Model Physics WG Team Coordination and Dependencies

- Projects to be accelerated through **Hurricane Supplemental** Funding:
  - Development of Hierarchical Testing Framework for Physics (HTFP) Architecture
  - Process-level assessment of physics innovations using HTFP
  - Stochastic Physics Development
  - EMC-GSD focused improvement of parameterizations for moist convection, microphysics, and PBL/turbulence, drawing primarily from schemes used in recent physics-suite evaluations (more later)
  - Develop more advanced unified gravity-wave drag parameterization (orographic/non-orographic/form)
  - Final development of RRTMGP radiation; exploration of machine-learning approaches to radiation parameterization

Model Physics WG
Team Coordination and Dependencies

- Based on experience to date, what change(s) do you recommend to your working group (different composition, focus, charter/ToR, need to continue, etc.)
  - **Smaller size and/or emphasis on sub-groups**
  - Perhaps…

    - Formation of funded small, multi-organization **working sub-groups** (2-4 people, including at least one person from EMC - need EMC bandwidth) to focus on collaborative Research, Development, Testing, and Evaluation of parameterizations for **individual physical processes** (e.g., PBL, moist convection, microphysics, etc).
    - A commitment to **publish** all significant advances in parameterization development, at a minimum in Weather and Forecasting's NCEP NOTES (make engagement more attractive for publish/perish inhabitants)
    - **Incentivize** collaborative work to **improve existing operational parameterizations** rather than to design new parameterizations/suites

Advancing Model Physics in the GFS: A strategic approach combining

- Improvement of individual parameterizations
- Replacement of individual parameterizations
- Replacement of parameterization *suites* (multiple schemes at once)

Primary GFSv15 (FV3-GFS) *Physical Parameterizations*

1) **Moist Convection:** Scale-aware Simplified Arakawa-Schubert (sa-SAS)
2) **Microphysics:** GFDL single-moment
3) **PBL/Turbulence:** Scale-Aware Eddy-Diffusivity Mass-Flux (sa-K-EDMF) scheme
4) **Radiation:** RRTMG scheme (~currently used in NAM/RAP-HRRR/GFS) currently being updated and improved
5) **Land:** Noah LSM
6) **Gravity-Wave Drag (GWD)**: separate orographic/non-orographic components
7) Stratospheric water vapor/ozone chemistry

GFSv16 plans:

Possible Replacement of

- *Microphysics (MP)*
- *moist convection (CP)*
- *PBL/Turbulence (PBL)*

parameterization suite

Why “MP-CP-PBL combo”?

- Physics schemes in any model are highly inter-dependent
- optimal performance of any individual scheme requires a long period of aggregate “tuning” of all parameterizations in a suite
- **Our experiment:** Is it feasible to do a forklift replacement with a pre-tuned suite/combination?

Parameterization Options within Suites:

- Convection:
  1. Simplified Arakawa-Schubert (SAS) – operational GFS
  2. Simplified Arakawa-Schubert (SAS) – operational GFS
  3. Chikira-Sugiyama (CS) - Climate modeling community
  4. Grell-Freitas (GF) – operational RAP

Parameterization Options within Suites:

- Microphysics:
  1. GFDL – soon to be operational in GFSv15
  2. GFDL – soon to be operational in GFSv15
  3. Morrison-Gettelman (MG3) – NCAR climate, other apps
  4. Thompson – RAP/HRRR, other

Parameterization Options within Suites:

- PBL/Turbulence:
  1. K-EDMF – soon to be operational GFS
  2. TKE-EDMF – upgrade of K-EDMF with prognostic TKE
  3. K-EDMF – soon to be operational GFS
  4. MYNN-EDMF - RAP/HRRR, other

PHYSICS SUITES ASSESSED FOR POSSIBLE GFSv16 IMPLEMENTATION

	Suite 1 (GFS v15)	**Suite 2**	**Suite 3**	**Suite 4**
Deep convection	sa-SAS	sa-SAS	sa-CS	sa/aa-GF
Shallow convection	sa-MF	sa-MF	sa-MF	MYNN-EDMF and sa GF
Microphysics	GFDL	GFDL	aa-MG3	aa-Thompson
PBL/Turbulence	K-EDMF	sa-TKE-EDMF	K-EDMF	MYNN-EDMF
Land Surface Model	Noah	Noah	Noah	RUC

~ EMC operational

Roots primarily in global/climate community

RAP/HRRR suite - Roots primarily in mesoscale community

*sa = Scale-aware

*aa = aerosol aware

Physics Suite-Selection:

Scope of Testing - Forecast only (no DA/cycling):

- Initialize with ECMWF full-resolution analyses
- C768L64 (as in current FV3GFSv1; ~ 13 km dx, 64 vertical levels)
- 10-day forecasts
- Initialize every 5 days between 1 Jan 2016 – 31 Dec 2017, alternating between 00Z and 12Z
- Case studies (~16 cases, selected by EMC MEG) focusing on particularly challenging/"big" events over CONUS, known deficiencies of GFS/FV3GFS, and tropical cyclones

UFS

Unified Forecast System

Physics Suite-Selection:

High-impact/special interest cases (selected by MEG)

10/1/15 00z	**TC Joaquin and flooding in SC**
10/2/16 00z	**TC Matthew**
8/26/17 00z	**TC Harvey**
9/7/17 00z	**TC Irma**
10/4/17 00z	**TC Nate**
8/19/18 00z	**TC Lane**
9/11/18 12z	**TC Florence**
7/31/17 00z	**TC Noru**
1/18/16 12z	**Blizzard of 2016 - progressive**
4/22/16 00z	**Plains severe weather - progressive, also a chance to examine drylines**
3/10/17 00z	**"Pi Day" Blizzard - Precipitation type**
4/20/17 00Z	**Valley flooding in MS**
7/29/17 00z	**Too hot in FV3GFS in CA**
10/16/17 12z	**Inversions and 2-m temperature**
1/1/18 00z	**"Bomb" cyclone**
3/15/17 00z	**Atmosphere river - progressive**

Physics Suite-Selection Verification Metrics

- Same as those used for our operational systems, focusing on days 3-10 forecasts to minimize spin-up issues:
  http://www.emc.ncep.noaa.gov/gmb/emc.glopara/vsdb
- Including (over CONUS) precipitation, instability, and PBL structures
- Hurricane track and intensity
- subjective analysis of case studies by MEG
- additional metrics derived by GMTB using METplus

Physics Suite-Selection Decision-making process/factors

- EMC MEG provides detailed analysis of case studies, considers global and CONUS verification statistics
- Independent* expert panel considers all available diagnostics, statistics, and MEG assessment, makes a formal recommendation to EMC
- EMC considers all factors and recommendations, makes a decision on what parameterizations/suite to develop for GFSv16

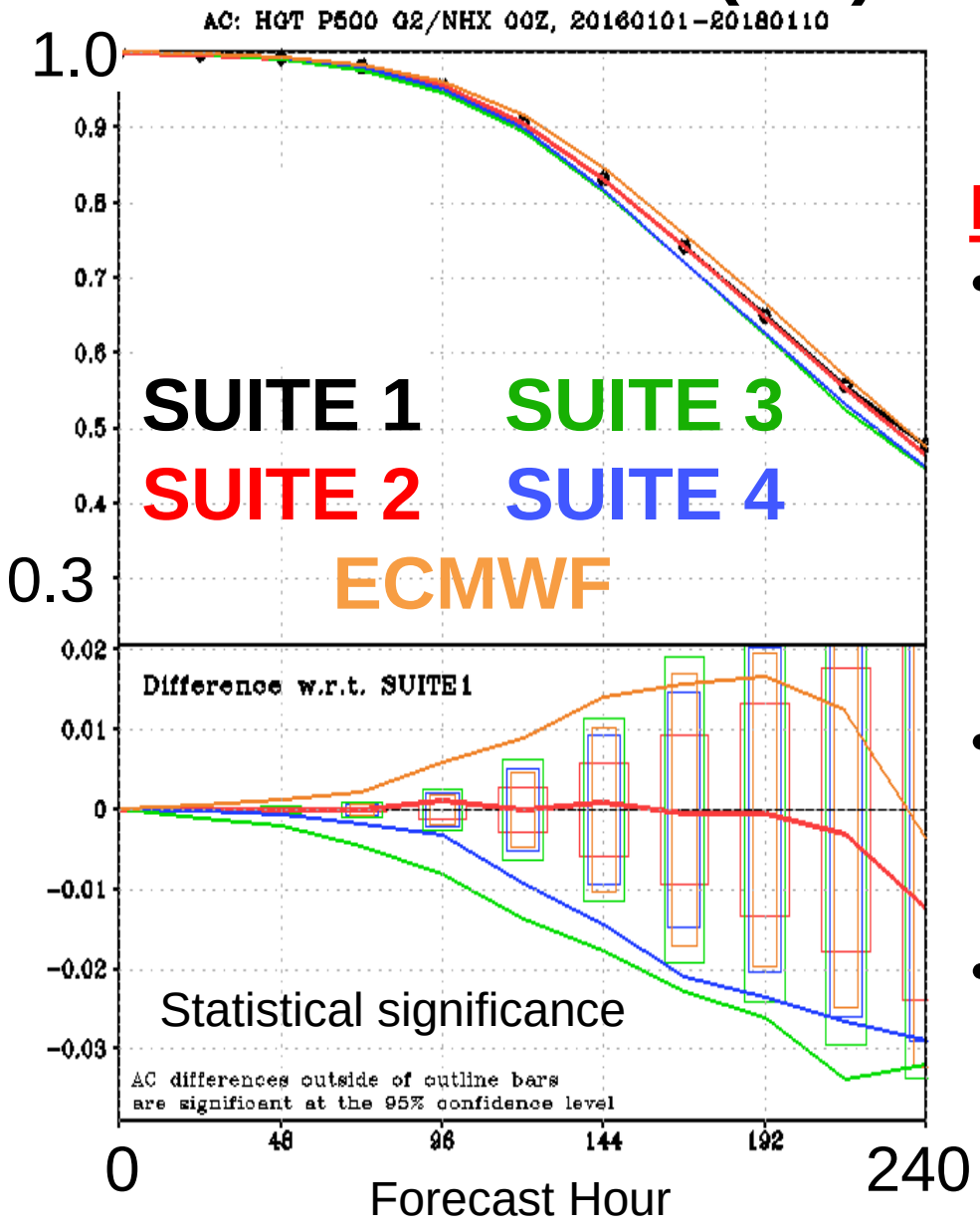
**No real or perceived conflict of interest wrt any of the candidates for implementation*

Physics Suite-Selection

Timeline:

- 1 Dec 2018 – 9 Feb 2019: Complete all model forecasts
- 10 Feb – 15 March 2019: Verification and diagnostic analyses of results
- 21 March 2019: MEG presentation and discussion of results
- 25 March 2019: Independent expert panel submits formal recommendation(s) to EMC
- 29 March 2019: EMC decision on path forward

500-hPa Geopotential Height Anomaly Correlation (AC) Scores



KEY POINTS:

- Suites 1 and 2 have statistically significantly better AC scores than Suites 3 and 4 well into medium range
- Suites 1 and 2 have nearly identical AC scores
- Suite 4 is slightly better AC scores than Suite 3

EMC Verification Scorecard
Symbol Legend
▲ SUITE2 is better than SUITE1 at the 99.9% significance level
▵ SUITE2 is better than SUITE1 at the 99% significance level
SUITE2 is better than SUITE1 at the 95% significance level
No statistically significant difference between SUITE2 and SUITE1
SUITE2 is worse than SUITE1 at the 95% significance level
▿ SUITE2 is worse than SUITE1 at the 99% significance level
▼ SUITE2 is worse than SUITE1 at the 99.9% significance level
Not statistically relevant
Start Date: 20160101
End Date: 20180110

00Z RUNS

SUITE 2

			N. American						N. Hemisphere						S. Hemisphere						Tropics					
			Day 1	Day 3	Day 5	Day 6	Day 8	Day 10	Day 1	Day 3	Day 5	Day 6	Day 8	Day 10	Day 1	Day 3	Day 5	Day 6	Day 8	Day 10	Day 1	Day 3	Day 5	Day 6	Day 8	Day 10
Geopot. Height		250hPa	▼						▼							▲	▵									
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Anomaly Correlation

EMC Verification Scorecard
Symbol Legend
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SUITE3 is worse than SUITE1 at the 95% significance level
▼ SUITE3 is worse than SUITE1 at the 99% significance level
▼ SUITE3 is worse than SUITE1 at the 99.9% significance level
Not statistically relevant
Start Date: 20160101
End Date: 20180110

00Z RUNS

SUITE 3

			N. American						N. Hemisphere						S. Hemisphere						Tropics					
			Day 1	Day 3	Day 5	Day 6	Day 8	Day 10	Day 1	Day 3	Day 5	Day 6	Day 8	Day 10	Day 1	Day 3	Day 5	Day 6	Day 8	Day 10	Day 1	Day 3	Day 5	Day 6	Day 8	Day 10
Geopot. Height		250hPa	▼	▼	▼	▼	▼		▼	▼	▼	▼	▾		▼	▼	▼	▼	▼	▼						
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Anomaly Correlation

00Z
RUNS

SUITE 4

EMC Verification Scorecard
Symbol Legend
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No statistically significant difference between SUITE4 and SUITE1
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▼ SUITE4 is worse than SUITE1 at the 99% significance level
▼ SUITE4 is worse than SUITE1 at the 99.9% significance level
Not statistically relevant
Start Date: 20160101
End Date: 20180110

			N. American						N. Hemisphere						S. Hemisphere						Tropics					
			Day 1	Day 3	Day 5	Day 6	Day 8	Day 10	Day 1	Day 3	Day 5	Day 6	Day 8	Day 10	Day 1	Day 3	Day 5	Day 6	Day 8	Day 10	Day 1	Day 3	Day 5	Day 6	Day 8	Day 10
Geopot. Height		250hPa	▼	▼	▾	▾			▼	▼	▼	▼			▼				▾	▾						
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Anomaly Correlation

EMC Verification Scorecard
Symbol Legend

Start Date: 20160101
End Date: 20180110

SUITE 2

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	No statistically significant difference between SUITE2 and SUITE1
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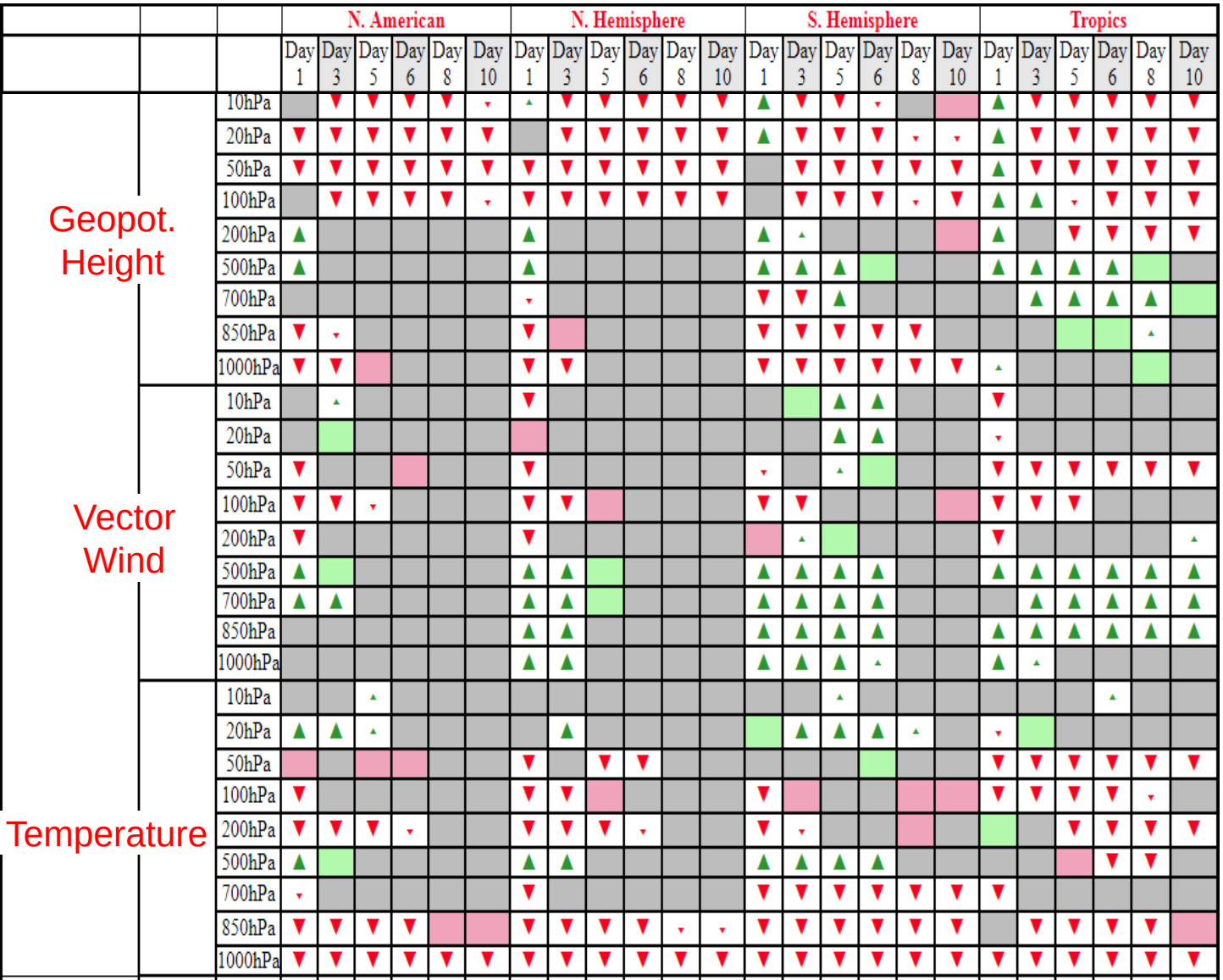
00Z RUNS



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EMC Verification Scorecard
Symbol Legend

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End Date: 20180110

SUITE 3

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	No statistically significant difference between SUITE3 and SUITE1
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	Not statistically relevant

00Z RUNS

			N. American						N. Hemisphere						S. Hemisphere						Tropics					
			Day 1	Day 3	Day 5	Day 6	Day 8	Day 10	Day 1	Day 3	Day 5	Day 6	Day 8	Day 10	Day 1	Day 3	Day 5	Day 6	Day 8	Day 10	Day 1	Day 3	Day 5	Day 6	Day 8	Day 10
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RMSE

EMC Verification Scorecard
Symbol Legend

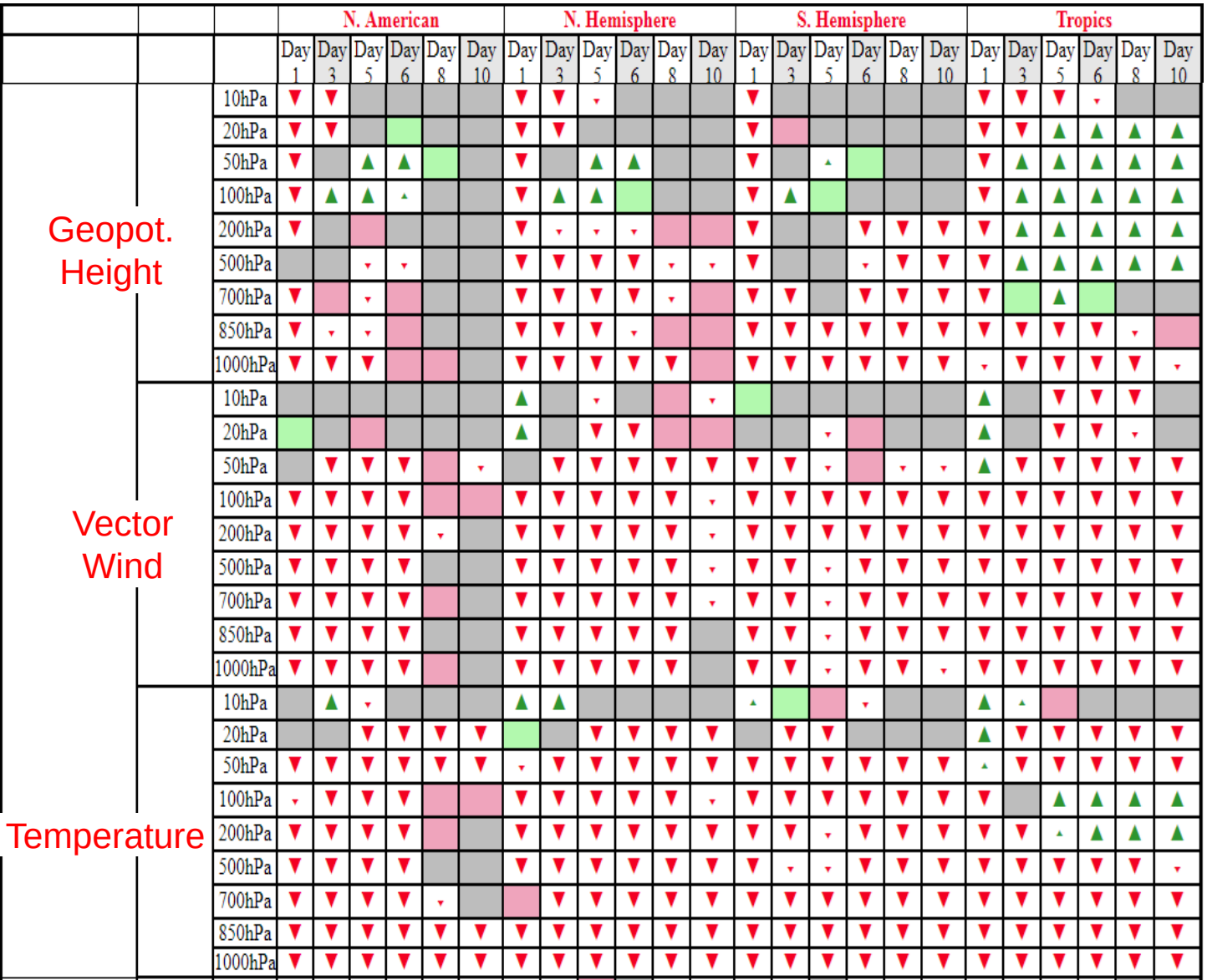
Start Date: 20160101
End Date: 20180110

SUITE 4

▲	SUITE4 is better than SUITE1 at the 99.9% significance level
▵	SUITE4 is better than SUITE1 at the 99% significance level
	SUITE4 is better than SUITE1 at the 95% significance level
	No statistically significant difference between SUITE4 and SUITE1
	SUITE4 is worse than SUITE1 at the 95% significance level
▿	SUITE4 is worse than SUITE1 at the 99% significance level
▼	SUITE4 is worse than SUITE1 at the 99.9% significance level
	Not statistically relevant

00Z RUNS

RMSE



EMC Verification Scorecard
Symbol Legend

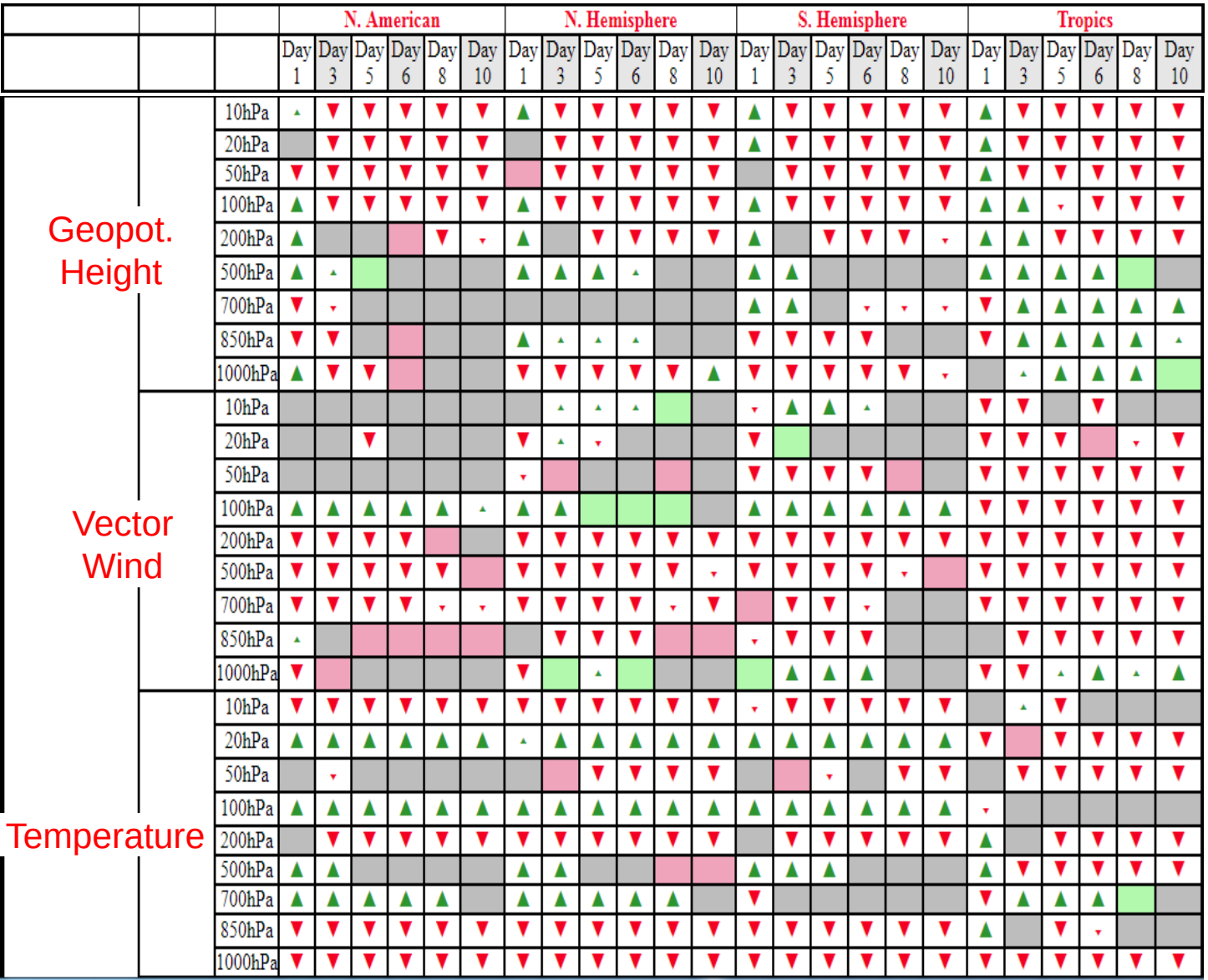
Start Date: 20160101
End Date: 20180110

SUITE 2

▲	SUITE2 is better than SUITE1 at the 99.9% significance level
▵	SUITE2 is better than SUITE1 at the 99% significance level
	SUITE2 is better than SUITE1 at the 95% significance level
	No statistically significant difference between SUITE2 and SUITE1
	SUITE2 is worse than SUITE1 at the 95% significance level
▿	SUITE2 is worse than SUITE1 at the 99% significance level
▼	SUITE2 is worse than SUITE1 at the 99.9% significance level
	Not statistically relevant

00Z RUNS

BIAS



EMC Verification Scorecard
Symbol Legend

Start Date: 20160101
End Date: 20180110

SUITE 3

▲	SUITE3 is better than SUITE1 at the 99.9% significance level
▲	SUITE3 is better than SUITE1 at the 99% significance level
▲	SUITE3 is better than SUITE1 at the 95% significance level
	No statistically significant difference between SUITE3 and SUITE1

	SUITE3 is worse than SUITE1 at the 95% significance level
▼	SUITE3 is worse than SUITE1 at the 99% significance level
▼	SUITE3 is worse than SUITE1 at the 99.9% significance level
	Not statistically relevant

00Z RUNS

BIAS

		N. American						N. Hemisphere						S. Hemisphere						Tropics					
		Day 1	Day 3	Day 5	Day 6	Day 8	Day 10	Day 1	Day 3	Day 5	Day 6	Day 8	Day 10	Day 1	Day 3	Day 5	Day 6	Day 8	Day 10	Day 1	Day 3	Day 5	Day 6	Day 8	Day 10
Geopot. Height	10hPa	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲
	20hPa	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▼	▼	▲	▲	▲	▲
	50hPa	▲	▼	▲	▲	▲	▲	▼	▼	▼	▲	▲	▲	▼	▼	▲	▲	▲	▲	▼	▼	▼	▼	▼	▼
	100hPa	▲	▼	▲	▲	▲	▲	▼	▼	▼	▼	▲	▲	▼	▼	▼	▲	▲	▲	▼	▼	▼	▼	▼	▼
	200hPa	▲	▼	▲	▲	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▲	▲	▼	▼	▼	▼	▼	▲
	500hPa	▲	▲	▲	▲	▲	▼	▲	▲	▼	▼	▼	▼	▲	▲	▲	▲	▲	▲	▼	▼	▼	▼	▼	▼
	700hPa	▲	▲	▲	▲	▲	▼	▲	▲	▲	▲	▲	▲	▼	▼	▼	▼	▼	▼	▼	▲	▲	▲	▲	▲
	850hPa	▼	▲	▲	▲	▲	▼	▲	▲	▲	▲	▲	▲	▼	▼					▼	▲	▲	▲	▲	▲
	1000hPa	▼						▼	▼	▾				▼	▲	▲	▲	▲	▲	▼	▼		▵	▲	▲
Vector Wind	10hPa				▼	▾			▵		▾	▼	▾	▼		▾	▼	▼	▼		▲	▲	▼		
	20hPa	▵		▼				▵	▲		▲	▲	▵		▲					▲	▲	▼	▲	▲	
	50hPa	▲		▵		▲	▾	▲	▼	▼	▼	▼	▼	▲	▼	▼	▼	▼	▼	▲			▼		▵
	100hPa	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▲	▼	▼	▼	▼	▼
	200hPa	▲	▲	▲	▲	▲	▵	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▼	▲	▲	▲	▲	▲
	500hPa	▲	▲			▾	▼	▲	▲		▾	▼	▼	▲	▲			▼	▼	▲	▲	▲			▼
	700hPa	▼				▼	▼				▾	▼	▼	▵			▾	▼	▼	▲	▲	▲			▼
	850hPa						▾	▲	▵				▾	▲		▼	▼	▼	▼	▼	▼	▼	▼		▾
	1000hPa	▾	▾				▵			▲	▲	▲	▲	▼		▲	▲	▼	▲	▼		▲	▲	▲	▼
Temperature	10hPa			▲	▲	▵	▵			▲	▲	▵								▲	▲	▲	▲	▲	▲
	20hPa		▼				▾		▼	▾	▾	▼	▾							▼	▼	▼	▼	▼	▼
	50hPa	▼	▲	▲	▲	▲						▾	▼	▾			▵			▼	▼	▼	▼	▼	▼
	100hPa	▼	▼	▼	▼	▼	▼		▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▲	▲	▼	▼	▼	▼
	200hPa	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▼	▲	▲	▲	▲	▲	▲	▼	▼	▼	▼	▼
	500hPa	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼
	700hPa	▲	▲	▲	▲	▲	▲	▼	▼	▼	▼	▼	▼	▲	▲	▲	▲	▲	▲	▼	▼	▼	▼	▼	▼
	850hPa	▼	▼	▲	▲	▲	▲	▼	▼	▼	▼	▼	▼	▲	▲	▲	▲	▲	▲	▼	▼	▼	▼	▼	▼
	1000hPa		▲	▲	▲	▲	▲	▼	▵	▲	▲	▲	▲	▼	▼		▵	▲	▲	▼	▲	▲	▲	▲	▲

EMC Verification Scorecard
Symbol Legend

Start Date: 20160101
End Date: 20180110

SUITE 4

▲	SUITE4 is better than SUITE1 at the 99.9% significance level
▵	SUITE4 is better than SUITE1 at the 99% significance level
	SUITE4 is better than SUITE1 at the 95% significance level
	No statistically significant difference between SUITE4 and SUITE1
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▿	SUITE4 is worse than SUITE1 at the 99% significance level
▼	SUITE4 is worse than SUITE1 at the 99.9% significance level
	Not statistically relevant

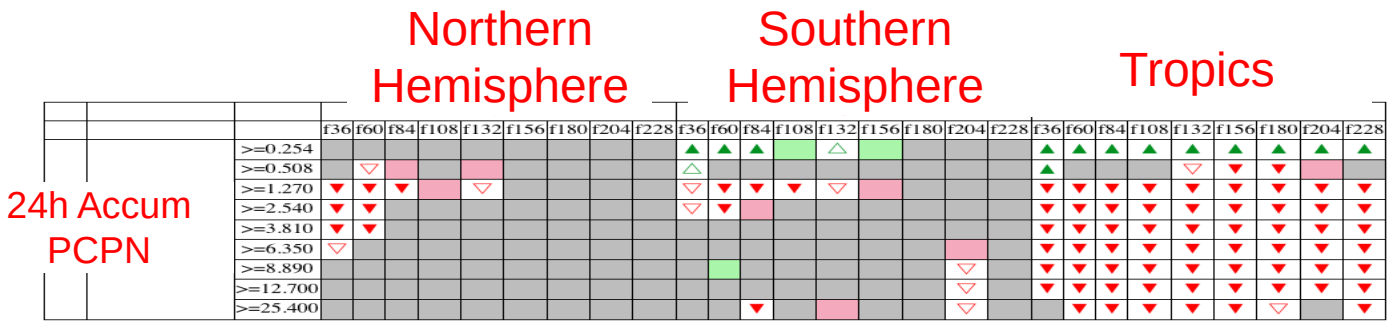
00Z RUNS

			N. American						N. Hemisphere						S. Hemisphere						Tropics					
			Day 1	Day 3	Day 5	Day 6	Day 8	Day 10	Day 1	Day 3	Day 5	Day 6	Day 8	Day 10	Day 1	Day 3	Day 5	Day 6	Day 8	Day 10	Day 1	Day 3	Day 5	Day 6	Day 8	Day 10
Geopot. Height		10hPa	▼	▼	▲	▲	▲	▲	▼	▼			▲	▲	▼	▼		▵	▲	▲	▼	▼	▼	▼		
		20hPa	▼	▼	▲	▲	▲	▲	▼	▼		▲	▲	▲	▼	▼	▵	▲	▲	▲	▼	▼	▲	▲	▲	▲
		50hPa	▼	▲	▲	▲	▲	▲	▼	▲	▲	▲	▲	▲	▼		▲	▲	▲	▲	▼	▲	▲	▲	▲	▲
		100hPa	▼	▲	▲	▲	▲	▲	▼	▲	▲	▲	▲	▲	▼	▲	▲	▲	▲	▲	▼	▲	▲	▲	▲	▲
		200hPa	▼	▲	▲	▲	▲	▲	▼	▲	▲	▲	▲	▲	▼	▲	▲	▲	▲	▲	▼	▲	▲	▲	▲	▲
		500hPa		▲	▲	▲	▲	▲	▵	▲	▲	▲	▲	▲	▼	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲
		700hPa	▼	▲	▲	▲	▵	▵		▲	▲	▲	▲	▲	▼	▲	▲	▲	▼	▼	▼	▲	▲	▲	▲	▲
		850hPa	▼	▼					▼	▿			▲	▲	▲	▲	▵				▼	▼				
		1000hPa	▲	▼					▼	▼	▿	▼	▼	▼	▼	▼	▼	▼			▲					
Vector Wind		10hPa									▲	▲	▵				▵	▲			▲			▲		
		20hPa	▲	▲	▲				▲	▲	▲				▲	▵	▲				▲	▲	▲	▼		
		50hPa	▲						▲	▲	▲	▼	▼	▿		▲	▲	▵			▼		▼		▿	
		100hPa	▼	▵	▲	▲	▼	▼	▼	▲	▲	▲	▲	▲	▼	▲	▲	▲	▲	▲	▼	▼			▲	▲
		200hPa	▼	▲	▲	▲	▲	▲	▼	▲	▲	▲	▲	▲	▼	▲	▲	▲	▲	▲	▼	▲	▲	▵	▲	▲
		500hPa	▲	▲	▲	▲	▲		▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▼	▲	▲	▼	▼	▼
		700hPa	▲	▲	▲	▲	▲		▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▼	▲	▲	▲	▼	▼
		850hPa	▼	▲	▲	▲			▼	▲	▲	▲	▲		▲	▲	▲	▲	▲	▲	▼	▼	▼	▼	▼	▼
		1000hPa			▿	▿			▲						▲	▼	▼	▼	▼	▼	▲	▲				▼
Temperature		10hPa	▲	▲	▼	▿			▲	▵	▼	▲	▲	▵	▲	▵	▼				▲	▲	▲	▲	▲	▲
		20hPa	▼	▼	▼	▼	▿		▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼
		50hPa	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼
		100hPa	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▼	▲	▲	▲	▲	▲
		200hPa	▼	▼	▼	▼	▼		▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▿	▼	▼	▲	▲	▲	▲
		500hPa	▼	▲	▲	▲	▲	▲	▼	▼	▼	▼	▼	▼	▼	▲	▲	▲	▲	▲	▼	▼	▲	▲	▲	▲
		700hPa	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▲	▼	▲	▲	▲	▲	▲	▲	▼	▼	▼	▼	▼	▼
		850hPa	▿		▵	▵	▲	▲	▼	▲	▲	▲	▲	▲	▼		▲	▲	▲	▲		▼	▼	▼	▼	▼
		1000hPa	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼	▼

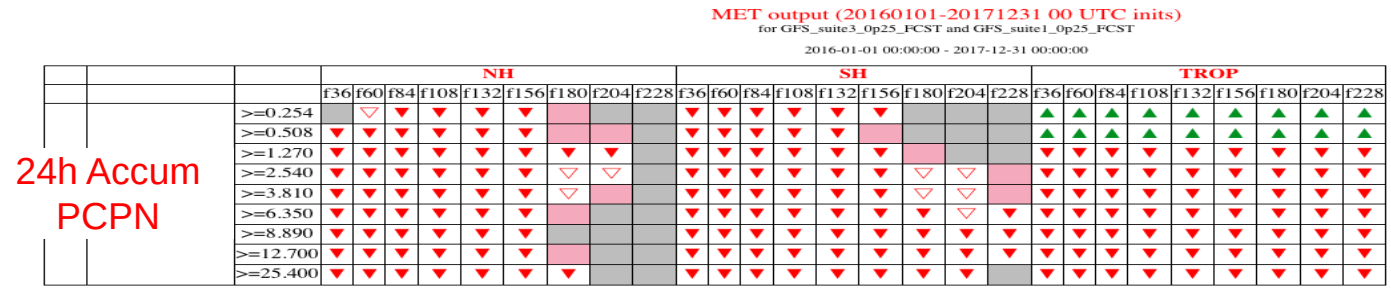
BIAS

PRECIPITATION SCORECARDS

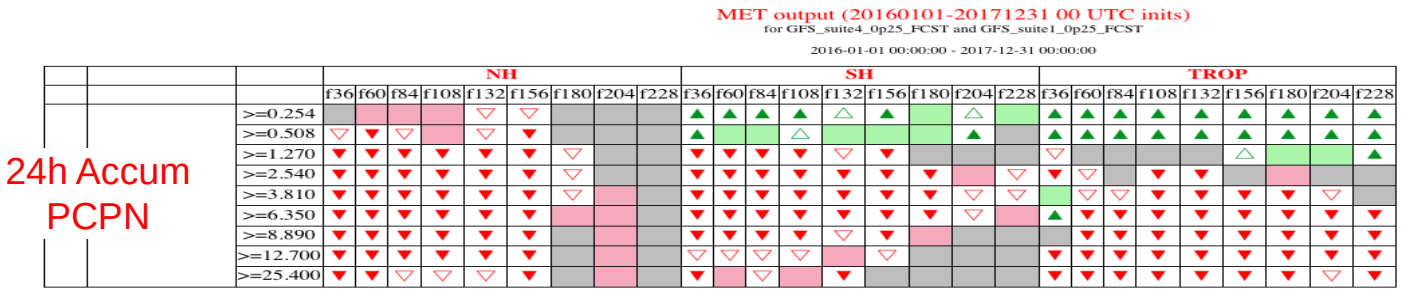
ETS for NH, SH, & Tropics. All symbols are relative to Suite 1



SUITE 2



SUITE 3



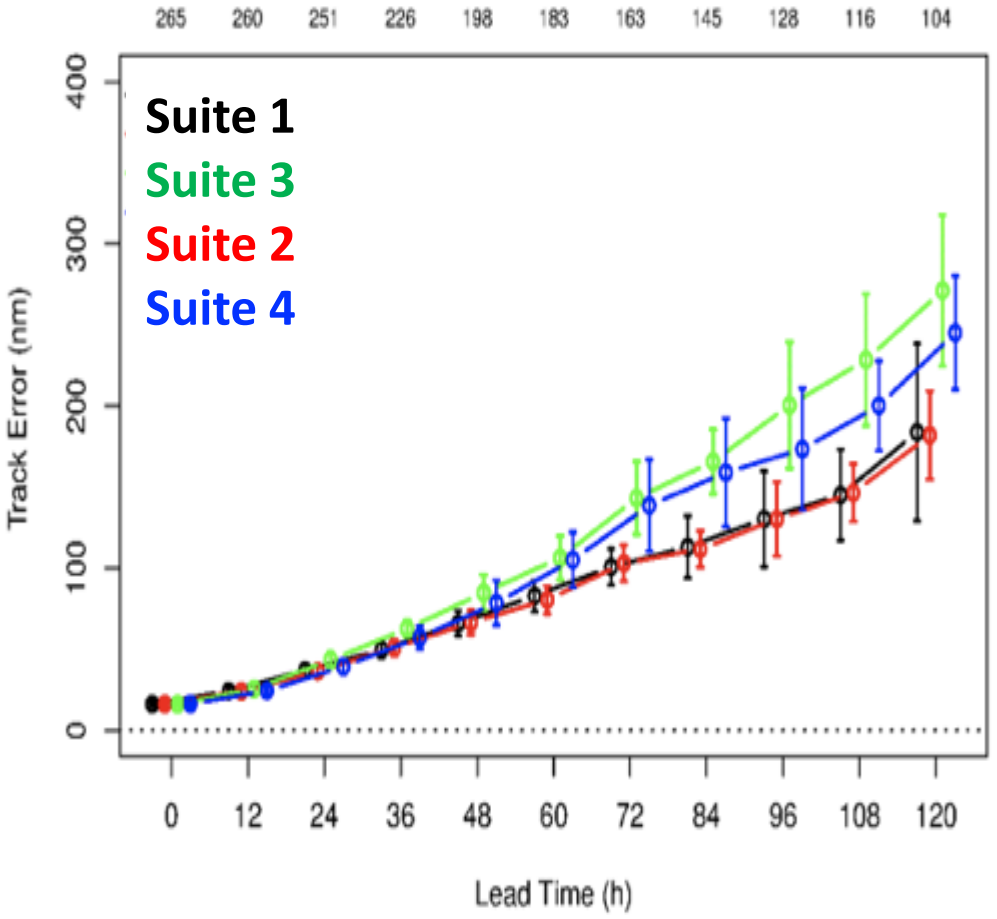
SUITE 4

▲ GFS_suite4_0p25_FCST is better than GFS_suite1_0p25_FCST at the 99.9% significance level
△ GFS_suite4_0p25_FCST is better than GFS_suite1_0p25_FCST at the 99% significance level
GFS_suite4_0p25_FCST is better than GFS_suite1_0p25_FCST at the 95% significance level
GFS_suite4_0p25_FCST is worse than GFS_suite1_0p25_FCST at the 95% significance level
GFS_suite4_0p25_FCST is worse than GFS_suite1_0p25_FCST at the 95% significance level
▽ GFS_suite4_0p25_FCST is worse than GFS_suite1_0p25_FCST at the 99% significance level
▼ GFS_suite4_0p25_FCST is worse than GFS_suite1_0p25_FCST at the 99.9% significance level
Not statistically relevant

Statistics provided by GMTB
Figure provided by EMC MEG

TROPICAL CYCLONES

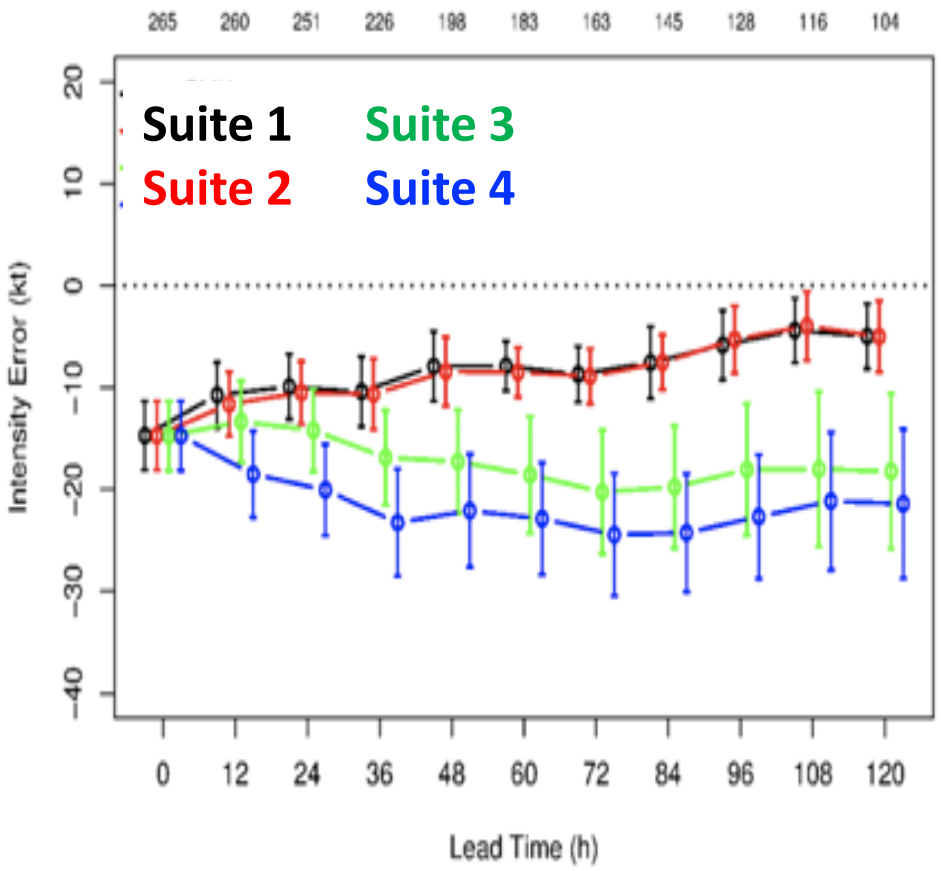
Track Performance – Composite Track Errors



Statistics provided by GMTB

- For many of the 8 TCs examined by the MEG, track forecasts were fairly comparable
- Track errors for Suites 1 and 2 were nearly identical
- Incorrect outlier track solutions were largely limited to forecasts from Suites 3 and 4
- Composite stats for all TCs in all basins show that beyond Day 3, Suites 3 and 4 did have larger track errors than Suites 1 and 2

Intensity Performance – Composite Vmax Errors



- As expected, all suites had a weak intensity bias compared to Best Track data
- Intensity errors for Suites 1 and 2 were nearly identical
- Intensity forecasts from Suites 3 and 4 were significantly weaker beyond Day 1, while Suites 1 and 2 reduced the intensity errors with time

Statistics provided by GMTB

Executive Summary (independent panel)

- Overall none of the 3 developmental suites were clearly superior to the control GFSv15 physics Suite 1.
- The performance of suite 2 was closest to suite 1 even improving some aspects of the forecasts.
- We encourage work to continue on other suites and new physics packages for future testing.
- We also encourage a similar testing and independent evaluation process on an annual basis in the future.

Model Physics WG Accomplishments

- **SIP project accomplishments to date:**
  - **GFSv16 Physics options selected, pending validation; GFSv15 Physics with these changes:**
    - **PBL/turbulence: K-EDMF => sa-TKE-EDMF**
    - **Land surface: Noah => Noah-MP**
    - **GWD: separate orographic/non-orographic => unified gravity-wave-drag**
    - **Radiation: updates to cloud-overlap assumptions, empirical coefficients, etc. in RRTMG**

Questions?

Recommendations on Physics Suites From Independent Panel

- Suite 2, which features a more advanced closure in the PBL scheme, was the closest in performance to Suite 1 and exhibited improvements in some important aspects including somewhat better capturing surface-based inversions and some better precipitation statistics over CONUS.
- Although overall Suite 2 did not perform as well as Suite 1, there are enough positive aspects in the Suite 2 performance to consider further experimentation and tuning in the near term (time permitting) to see if Suite 2 can be implemented in GFSv16. The panel believes the more advanced PBL may ultimately provide improved forecasts of the PBL.
- Suites 3 and 4 both showed promising results in a number of aspects. We strongly encourage and recommend that the developers of both Suites 3 and 4 continue development and testing. We also recommend the developers to consider consolidating the best aspects of all suites, so attention can be focused on a single advanced development suite in the future.

Recommendations for the Future From Independent Panel

- We are supportive of a continued annual process in which an independent panel provides analysis and recommendations on the evaluation of parameterization suites considered for future operations.
- We encourage the testing and evaluation of other combinations of physics from the existing four suites, in addition to emerging physical parameterizations.
- Adequate time for tuning and evaluation is needed prior to test phase. The panel is aware of some issues related to the setups of suites 3 and 4 that impacted their results in this round and that these suites would have been improved given adequate pre-testing.
- Our recommendation is that a pre-test period of a few weeks should be built into the schedule using some of this year's initial data (but independent of the data in the next test).
- It is recognized that this year was special because the physics framework was being changed at the same time as new physics were added, but the new framework should make implementations easier in the future.
- Data assimilation cycling was not included in the current test suite and