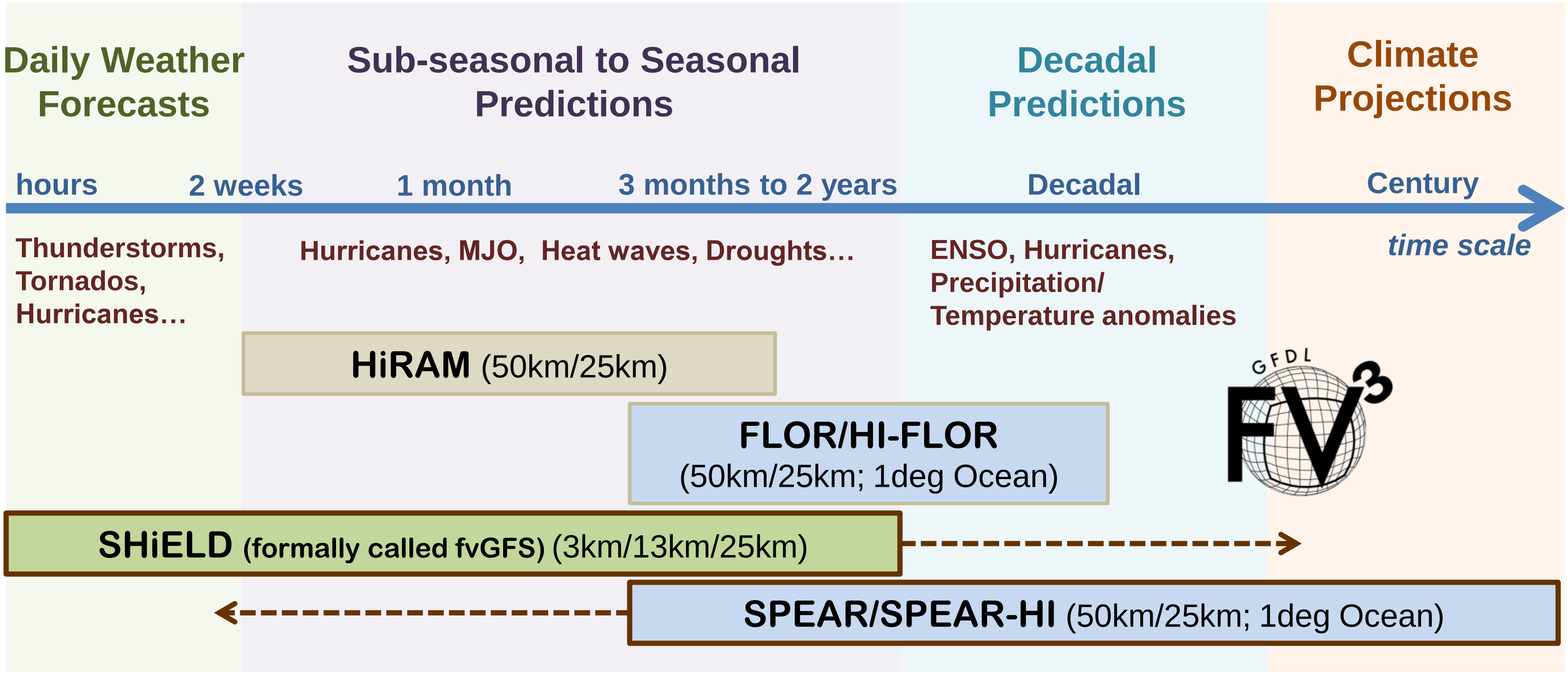
Tropical cyclone genesis in the GFDL FV3-powered global model

Jan-Huey Chen, Morris Bender,
Shian-Jiann Lin, Xi Chen, and Linjiong Zhou

NOAA/GFDL

20190726 CWB, Taipei, Taiwan

GFDL Prediction Modeling System



Development Path of SHiELD (fvGFS)

System for **Hi**gh-resolution prediction on **E**arth-to-**L**ocal **D**omain

Version	NGGPS Phase II submission	fvGFS_v2016	fvGFS_v2018	fvGFS_v2019
Time of code release/ online real-time forecasts	March 2016	August 2016	June 2018	July 2019
Features/Updates:	• FV3 dycore • NOAH land model • 2015 GFS Physics	• **Zhao-Carr MP → GFDL MP** • Major bug fixes: energy conservation, surface cycle, surface albedo, surface emission	• Vertical level: 63 → 91 • SAS → Scale-aware SAS • YSU PBL • Inline GFDL MP • Mixed Layer Ocean Model • Higher land resolution • PD tracer advection	• Big fixes: radiation, YSU • Updates: cloud-radiation interaction, GFDL MP, ocean surface roughness, YSU, cloud water to rain autoconversion, new could diag. species

TC Track/Intensity/Genesis forecasts

Chen et al. (2019, MWR)

- Comprehensive verifications for the early version fvGFS

Impacts of new dycore

Impacts of updated physics

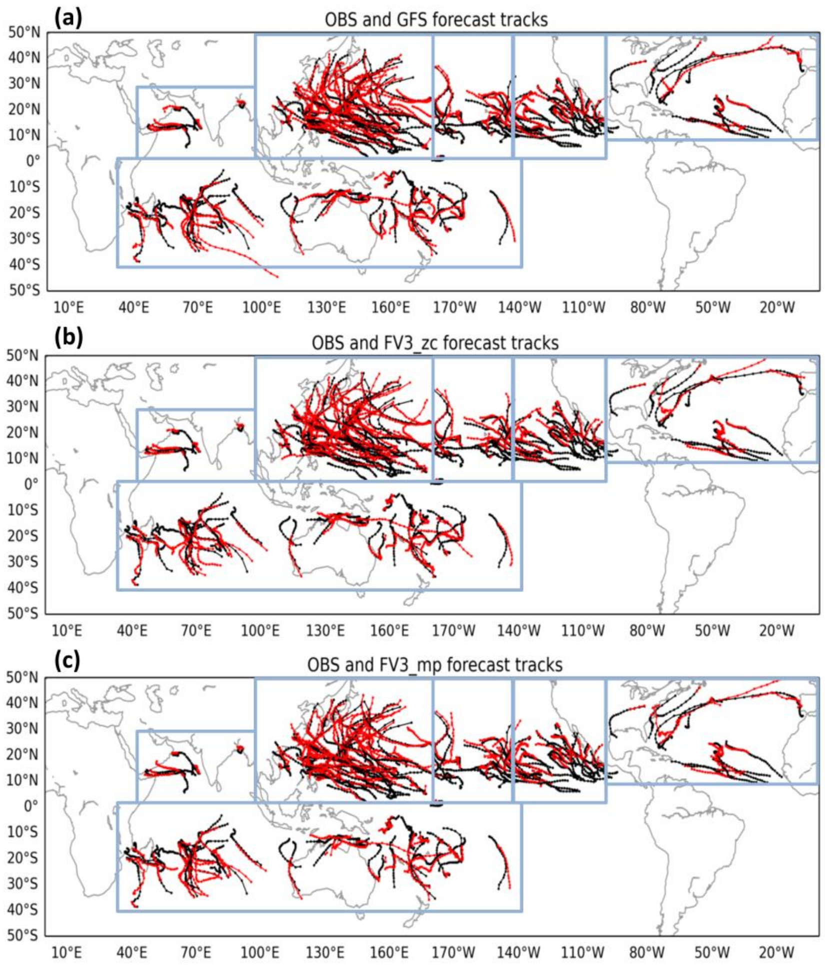
GFS
NCEP/GFS operational forecasts

FV3_ZC
NGGPS Phase II submission
- **FV3 dycore**
- **NOAH land model**
- **2015 GFS Physics**

FV3_mp
fvGFS_v2016
- **Zhao-Carr MP → GFDL MP**

Model data:

- 363 10-day retrospective forecasts from 2015/01/16 to 2016/01/16
- IC: NCEP/GFS analyses at 00Z
- Resolution: 13 km (T1534 v.s. C768)
- GFDL simple tracker was applied on **native resolution** model data

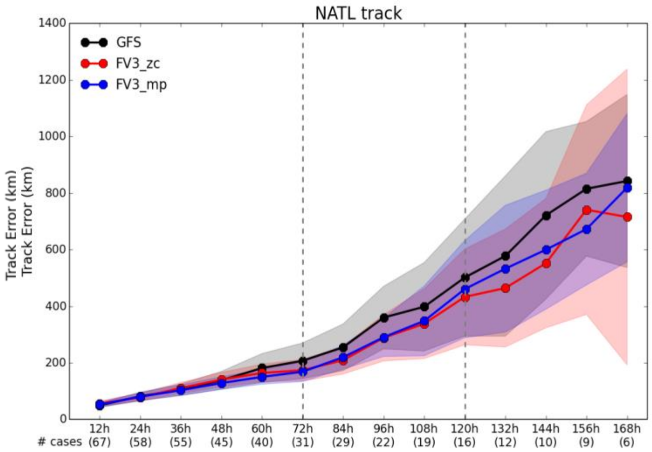


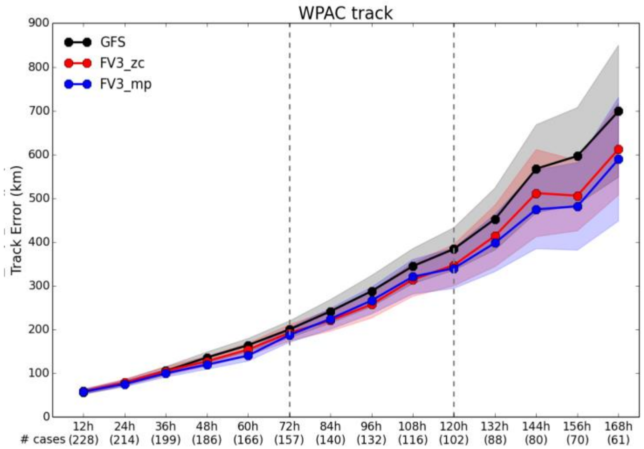
TC number in the year of 2015 (ATCF data set):

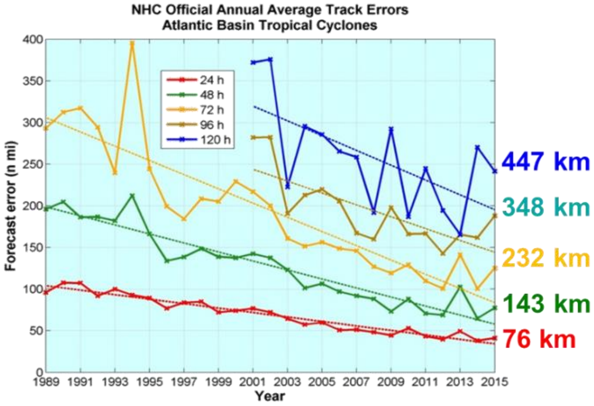
- North Atlantic (NATL): 2
- East Pacific (EPAC): 22
- West Pacific (WPAC): 29
- Central Pacific (CPAC): 9
- North Indian Ocean (NIO): 5
- South Indian/Pacific Ocean (SHEM): 25

The differences among the 3 sets of forecast tracks are very subtle.

TC Track Forecasts

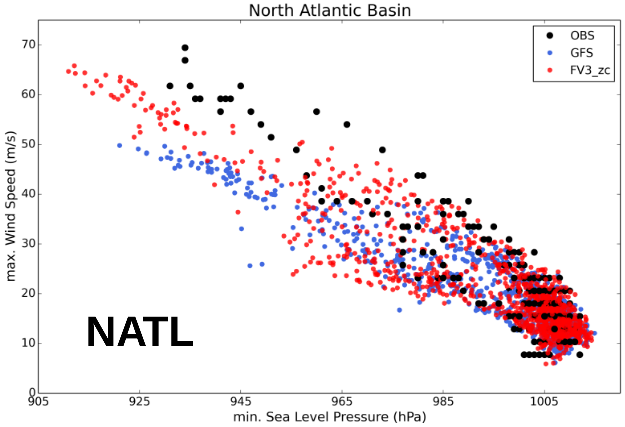


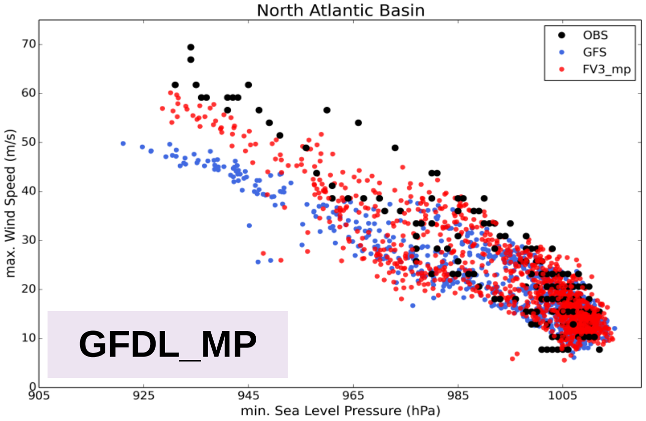




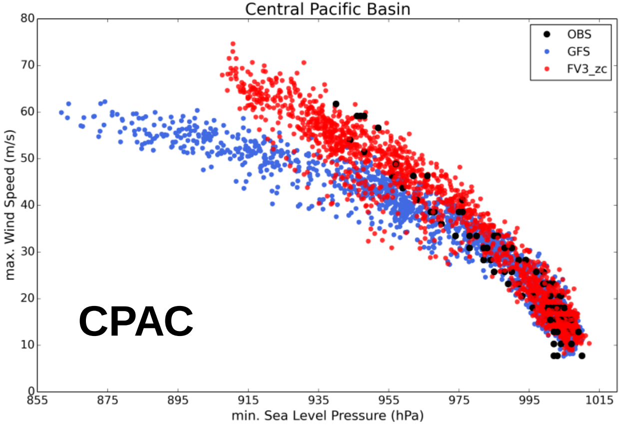
- The impact from updating FV3 dycore in GFS to the TC track forecast is positive.
- For fvGFS, the impacts of updated GFDL microphysics scheme are not prominent in NA and WP.

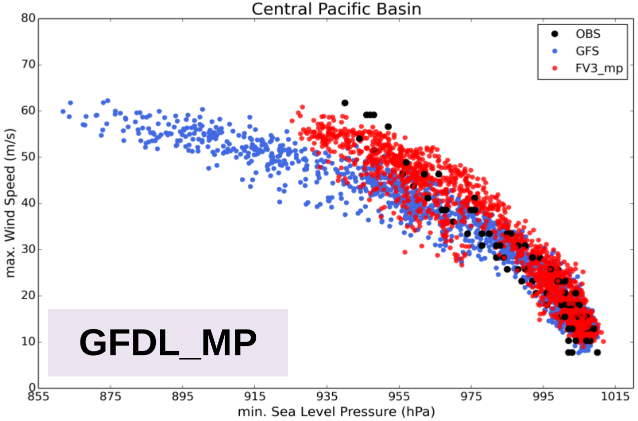
TC Intensity Forecasts



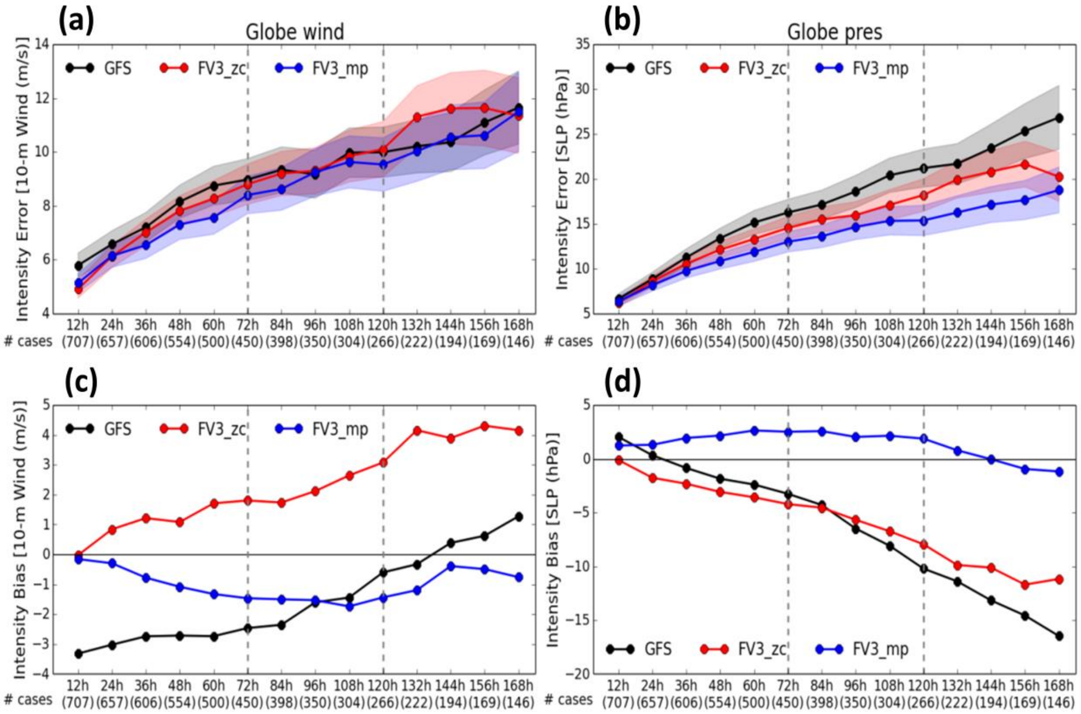


Wind-Pressure relationship





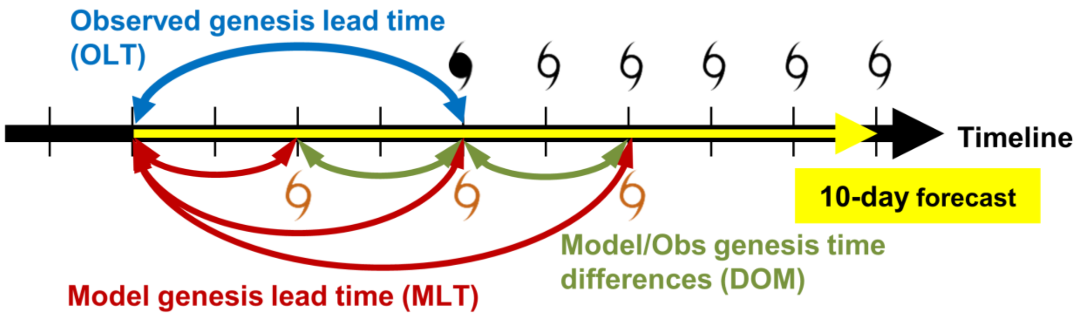
TC Intensity Forecasts



10-m wind **SLP**

- The impact to TC track forecasts from updating to the FV3 dynamical core in the GFS is small, but an improvement.
- For intensity forecasts, there is a much stronger wind-pressure relationship for FV3_zc than for the GFS.
- The main benefit of replacing the Zhao-Carr scheme with the GFDL microphysics scheme is the **improvement in intensity prediction**.

TC Genesis Forecasts



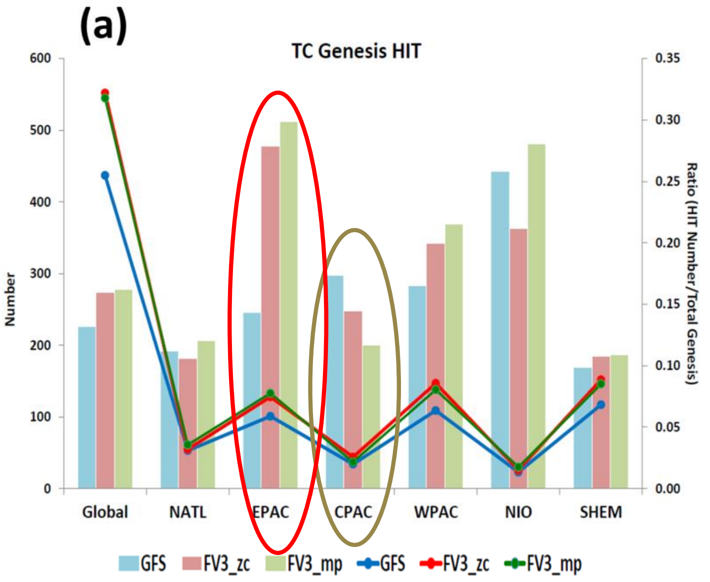
- Considering the 10-day forecasts which were **initialized before** the observed TC genesis time which is the first "**TD** (tropical depression)" record in the ATCF best track data.
- All TCs found by the GFDL simple tracker **but not exist in the IC**, were counted as genesis events.
- A genesis storm showed a matched track to the observed TC → a "***hit event***".

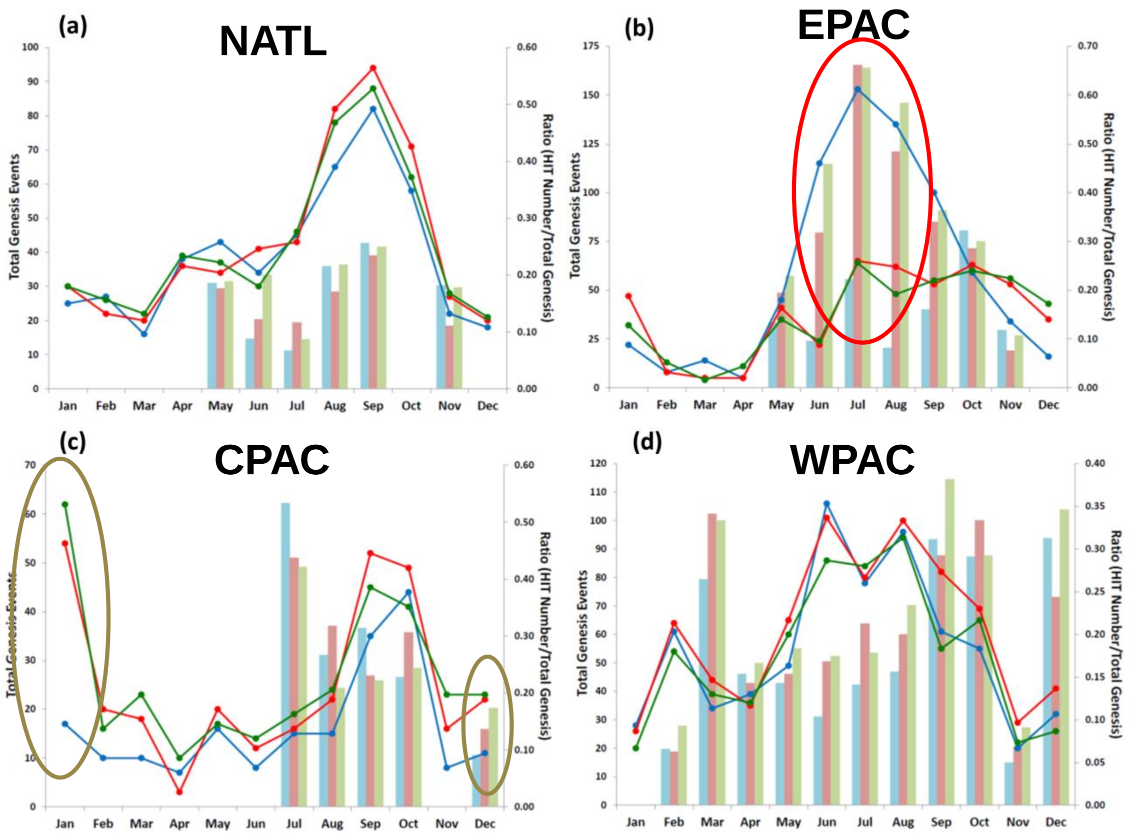
  Otherwise, it is a "***false alarm***".

$$Hit\ Ratio = \frac{number\ of\ hit\ events}{number\ of\ total\ genesis\ events(\ hit\ events + false\ alarms)}$$

- A forecast run should generate a storm but not → ***missing case***

Hit evens and False alarms





- fvGFS generally show more hit events and higher hit ratios than GFS.
- In the CPAC, GFS over-predicted genesis in peak season.
- In EPAC, both fvGFS show many false alarms in Jan and Dec.

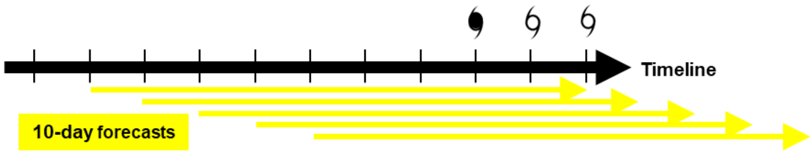
Missing Cases

- Numbers of missed TCs for the genesis forecasts:

Basins	NATL	EPAC	CPAC	WPAC	NIO	SHEM
Numbers of observed TCs	12	22	9	28	5	26
Numbers of missed TCs in the genesis forecasts of						
GFS	0	2	1	2	0	1
FV3_zc	1	0	1	1	0	0
FV3_mp	1	0	0	1	0	0

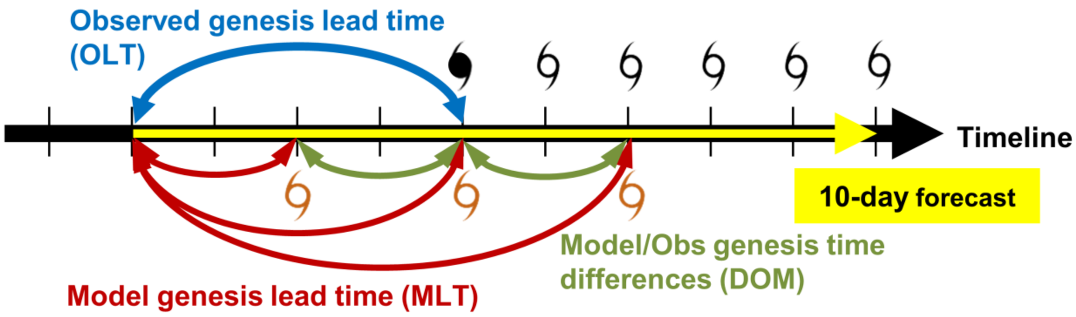
- Ratios of missing cases:

$$\boldsymbol{Missing\ ratio} = \frac{\boldsymbol{number\ of\ missing\ cases}}{\boldsymbol{number\ of\ expected\ genesis\ observations}\ (\mathbf{9\ or\ 10})}$$



Basins	NATL	EPAC	CPAC	WPAC	NIO	SHEM
GFS	55.8	53.2	62.2	60.5	53.1	53.0
FV3_zc	54.2	40.7	**51.1**	**46.7**	46.9	**39.0**
FV3_mp	**49.2**	**38.4**	58.9	50.0	**38.8**	41.4

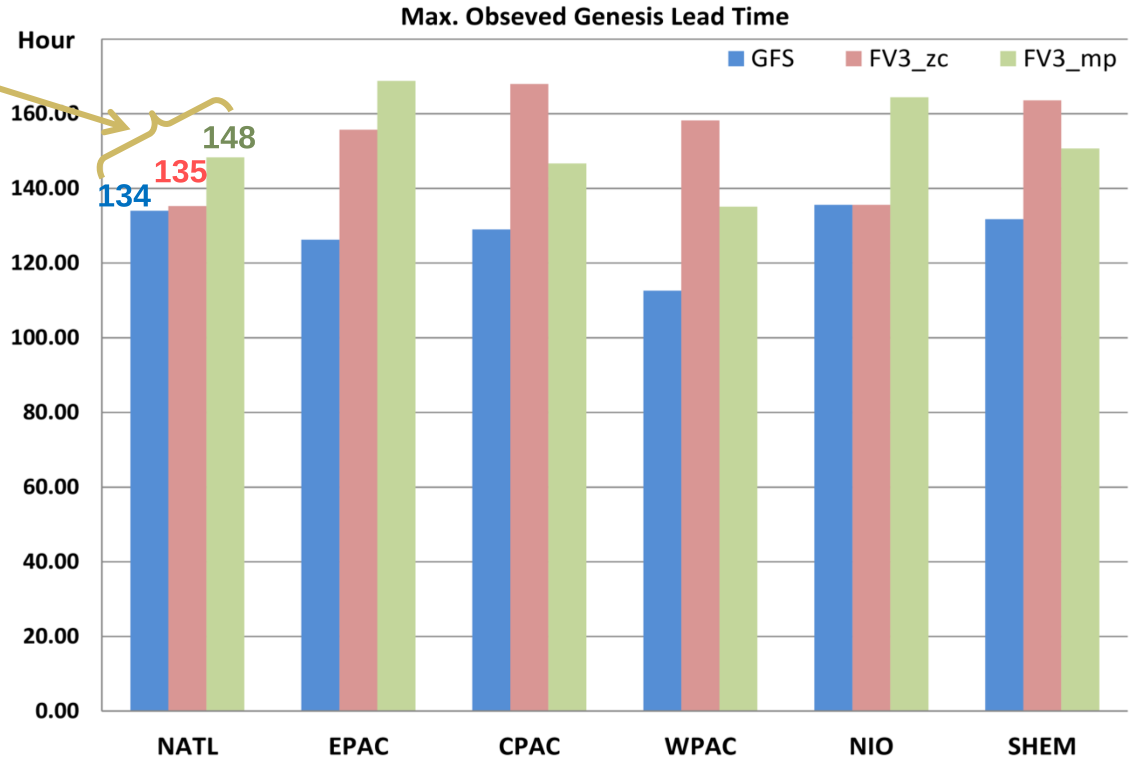
Genesis Lead Time



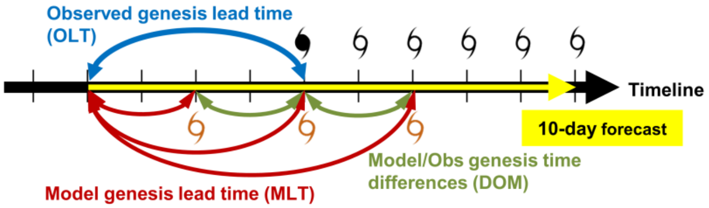
- **Longer OLT → Earlier** correctly **predict** the TC genesis.
- DMO:
  - **Shorter** DMO → **More accurate** in generating storms at the observed TC genesis time
  - **Positive** DMO → Model forecast TC generates **later** than the observed TC genesis time
  - **Negative** DMO → Model forecast TC generates **earlier** than the observed TC genesis time.

Observed Genesis Lead Time

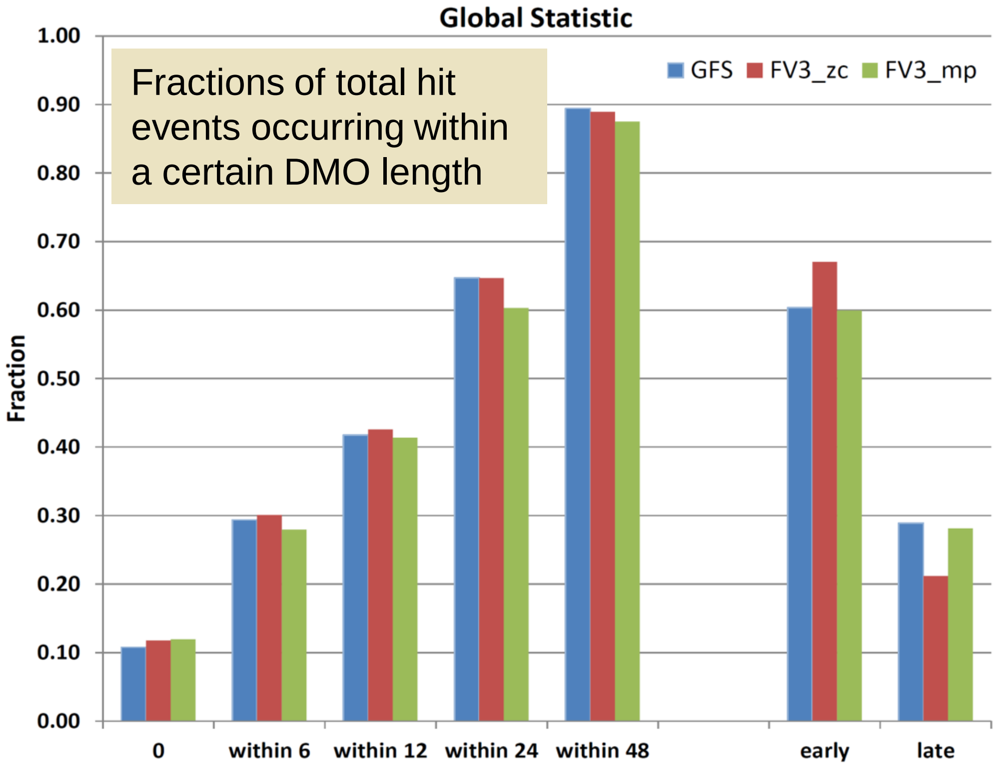
- The average earliest time for **GFS** to successfully predict a hit event is 134 hours before the observed TC genesis.
- It is **1 hour earlier** for **FV3_zc** to predict a hit event in this basin.
- **FV3_mp** can predict a hit event **14 hours earlier** than GFS.



DMO Analysis -- How accurate a model is in generating storms at the observed TC genesis time

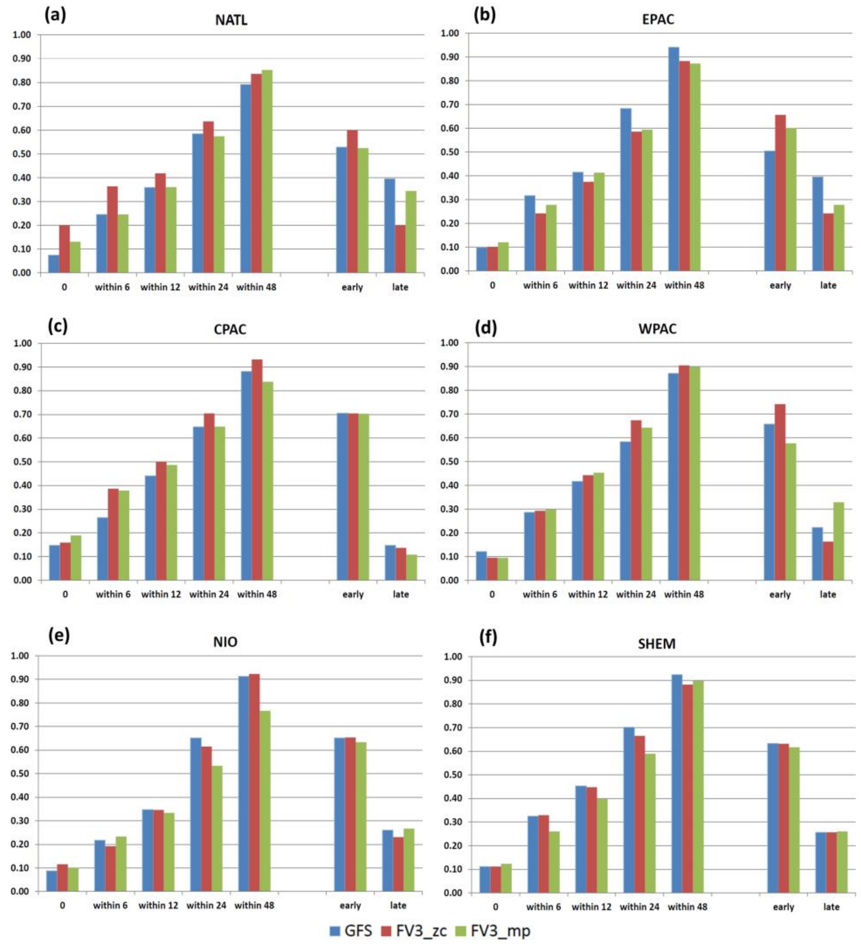


- The differences among the three sets of forecasts are smaller than 3%.
- More than **88%** of the hit events in any of the forecasts occur by the **48-hour DMO**.
- More than **60%** hit events occurring **before** the observed TC genesis times rather than after.

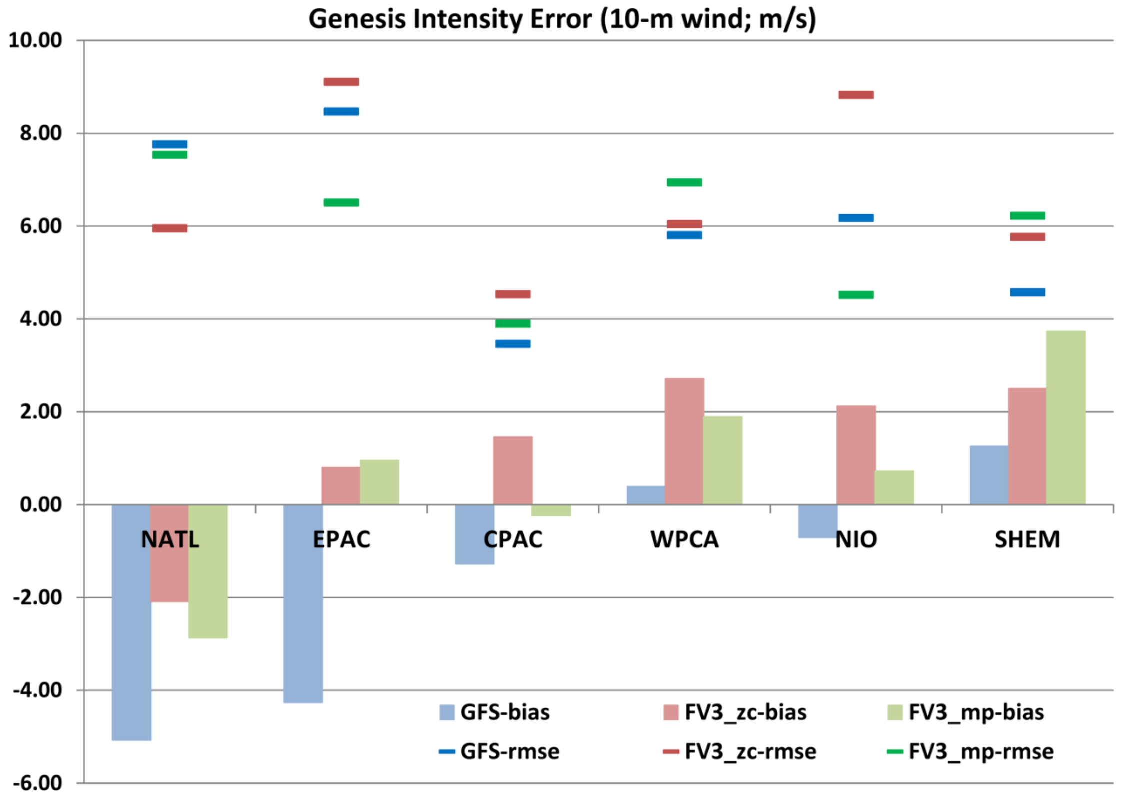


DMO Analysis

- A large variation can be found among the six basins.
- All three sets of forecasts show more hit events occurring before the observed TC genesis time rather than after in all six basins.
    - → This is related to the choice of the "observed TC genesis time" which is defined as the first "TD (tropical depression)" record for each TC in the ATCF best track data.
    - → However, the model predicted genesis events often occur during the precursor stage of the observed TC.



Forecasts of TC Genesis Intensity



- Relatively large RMSEs in the fvGFS forecasts.
- fvGFS also show larger positive bias than the GFS globally.

The over-predicted TC genesis intensity in the fvGFS is consistent with the results of the wind-pressure relationship for all TCs.

Summary

- The performance of global TC forecasts of fvGFS and the operational GFS was investigated based on 363 cases of 10-day forecasts in 2015.
  - **Fair comparison:** TCs in the forecasts from GFS and fvGFS were tracked by the same tracker at models' native resolution.
- For TC track and intensity forecasts:
  - The impact of using FV3 on TC track forecasts: small, but positive.
  - Intensity forecasts have been largely improved, especially after replacing the Zhao-Carr scheme with the GFDL microphysics scheme.

- For TC genesis forecasts:
  - In hit events, false alarms, and missing cases : FV_mp > FV_zc > GFS.

  → Simply using the up-to-date dynamical core but keeping the original physics package the same, the prediction of TC genesis in the model can be improved.

  The upgraded cloud microphysics scheme can further improve the model TC genesis performance with the updated dynamical core.

  - **A novel method** was developed to evaluate the performance of model storm genesis based on the **lead time lengths of hit events**.
    - The results of maximum OLT (observed genesis lead time) showed **that both fvGFS versions predicted TC genesis earlier than GFS** in all six basins.
    - **A large variation was found for the model accuracy in generating storms at the observed TC genesis time.** None of the three sets of forecasts shows an overwhelmingly higher accuracy in all six basins.

Discussion 1

- Comparing the TC genesis forecast skills between models is still a relatively new area:
  - Consensus of what methodology, tool, definition, or even how to use the best track data has not been reached for TC genesis verifications.

  - *The choice of the "observed TC genesis times" can influence the results:*

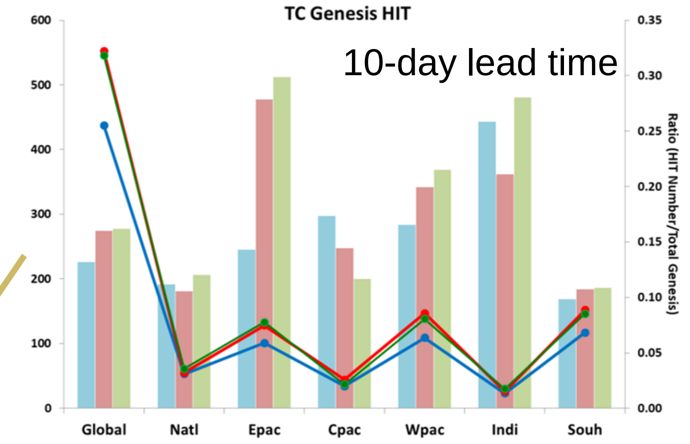
    Before TD, the precursor stage could be "DB (disturbance)", LO (low)" or "WV (tropical wave)". If we use the first record instead of first TD record, a substantial number of "early" events will shift to later time.

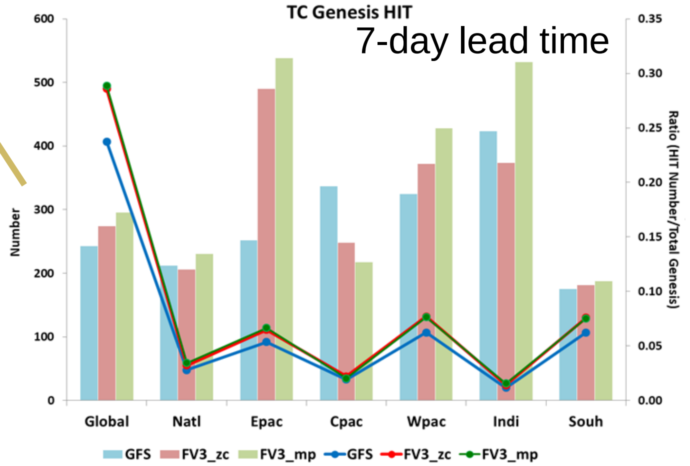
  - *The best track data set has basin dependency*.

    e.g. For TCs in the EPAC and the NIO, the time periods from the first reported "DB" ("LO" or "WV") to the first reported "TD" were relatively shorter than other basins.

Discussion 2

- How long of the lead time needs to be considered?
  Will 10 days be too long? 7 days? Or even only consider 5 days?
  - The ranking of the three sets of forecasts are identical.
  - Both false alarms and hit events are removed when shorten the lead time.
    → The false alarm ratio only drops 1% in each basin.
    → A substantial number of hit events happened in the forecasts with a long lead time.
    → fvGFS show more long-lead-time hit events than GFS.
  - Elsberry et al. (2010): 10-30 day predictability of TC genesis in the ECMWF model
  - Jiang et al. (2018):in the GFDL HiRAM model, 30% of TC genesis events can be skillfully predicted with 1-2 week lead time





Discussion 3

- How the new dynamical core and updated physics lead the better results, especially to the TC intensity?
  - The advection scheme used in the dynamical core.
    - Harris et al. (2018): The two-delta filter in the non-monotonic advection scheme and the monotonicity constraint in the tracer advection affect the model diffusivity which can also impact the diabatic heating and the location of the TC deep convection relative to the eye.
  - GFDL cloud microphysics scheme.
    - Zhou et al. (2019): The individual advection of the six species compared to the advection of a single condensate species (Zhao-Carr scheme) is a significant difference that can have a major impact on moist processes.
  - The above factors also interact with many other processes in a full 3-D dynamical model. e.g. the PBL schemem, the parameterized convection, and sub-grid terrain effects.

The improvements achieved by fvGFS on TC intensity are the fruits of many years of development. The updated dycore and advanced cloud microphysics scheme are the two most important factors but may not completely explain the improved results.