Impact of Revisions to RRTMG Cloudy Radiative Transfer on Tropical Cyclone Evolution in HWRF

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Introduction

•Radiative transfer in NWP models must accommodate the sub-grid scale variability of clouds

•Assumptions for the vertical correlation of cloud layers will influence the model prognostic state variables through changes to the radiative heating rate profiles

•This preliminary NWP study has been funded through the Developmental Testbed Center (DTC) Visitor Program

•Main objectives:

- Implement a new Exponential (EXP) cloud overlap method – that better matches observations - in the RRTMG radiation code developed at AER for Hurricane WRF (HWRF)
- Investigate effects of EXP method on:
  - large-scale meteorological fields and radiative heating rates:
  - storm track and intensity of recent Tropical Cyclones (TCs) in 2015-2017 seasons, with an ongoing focus on 2017 Atlantic basin priority Hurricanes Harvey, Irma and Maria

RRTMG MR and EXP Cloud Overlap Approaches

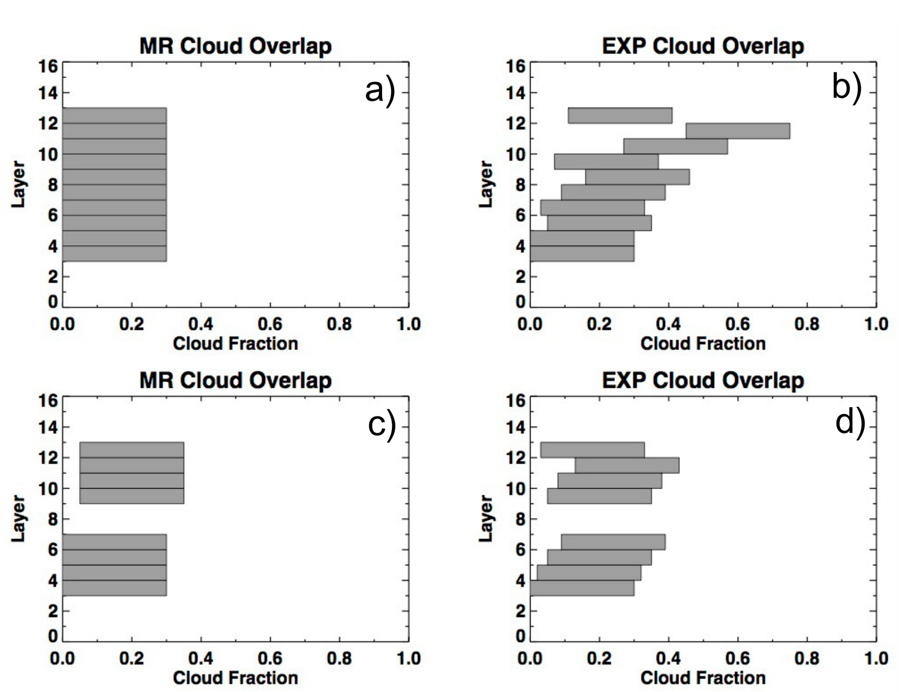

Fig. 1 - Schematic diagram showing idealized cloud overlap differences for a single block of cloud layers (top panels) with cloud fraction indicated by the gray boxes and for two separated blocks of cloud layers (bottom panels) between default Maximum-Random overlap (MR, left) and new Exponential (EXP, right).

•**Maximum-Random (MR):** Radiative transfer through adjacent fractional cloud layers uses maximum overlap (vertical correlation) of clouds (Fig. 1a)

•Blocks of cloud layers separated by a clear layer overlap randomly (no vertical correlation) (Fig. 1c)

•**Exponential (EXP):** Radiative transfer through adjacent fractional cloud layers uses overlap that transitions exponentially through cloud block from maximum to random (Fig. 1b):

•Cloud overlap parameter, $\alpha = e^{-dz/Z_0}$
•$\alpha \rightarrow 1$ = "max", $\alpha \rightarrow 0$ = "random"

•Constant decorrelation length (Z_0 = 2 km) used in HWRF experiments; dz is vertical distance through cloud

Changes to Heating Rates

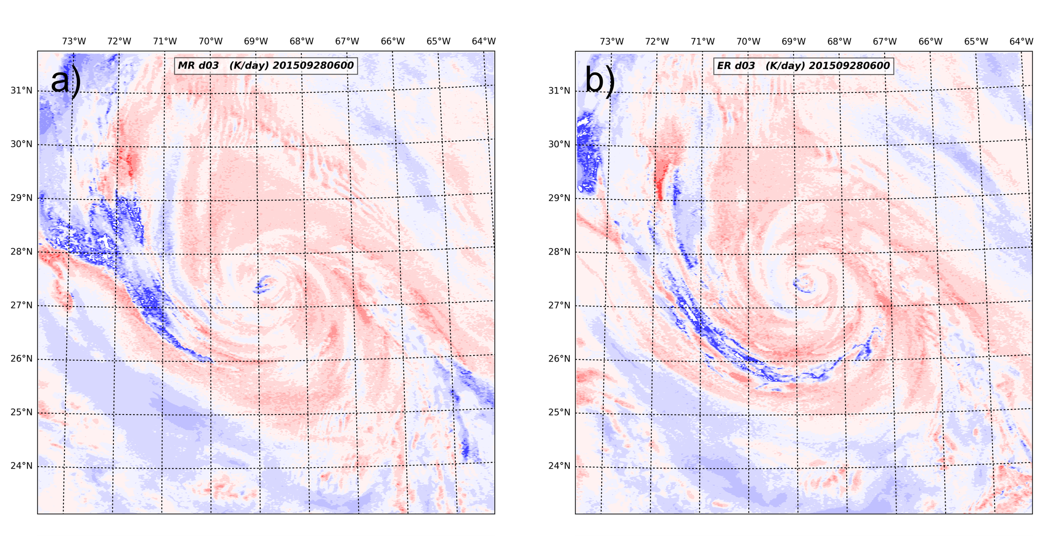

Fig. 2 – Longwave heating rate (K/day) at ~900 mb for Hurricane Joaquin using a) MR cloud overlap and b) EXP cloud overlap, valid at 1200 UTC 2 October 2015, and initialized at 0600 UTC 28 September 2015. Red (blue) colors denote heating (cooling).

•Use of EXP initially changes the spatial pattern of heating rates in grid boxes with partial clouds, but these changes spread spatially over time

•Effects are more likely in spiral bands of weaker or developing TCs, or outside the central dense overcast of mature storms

•Cloud-free or partial-cloud regions, which permit longwave cooling of the atmosphere, exhibit differences in MR (Fig. 2a) compared to EXP (Fig. 2b) for Hurricane Joaquin

Changes to Large-Scale Fields: Joaquin (2015)

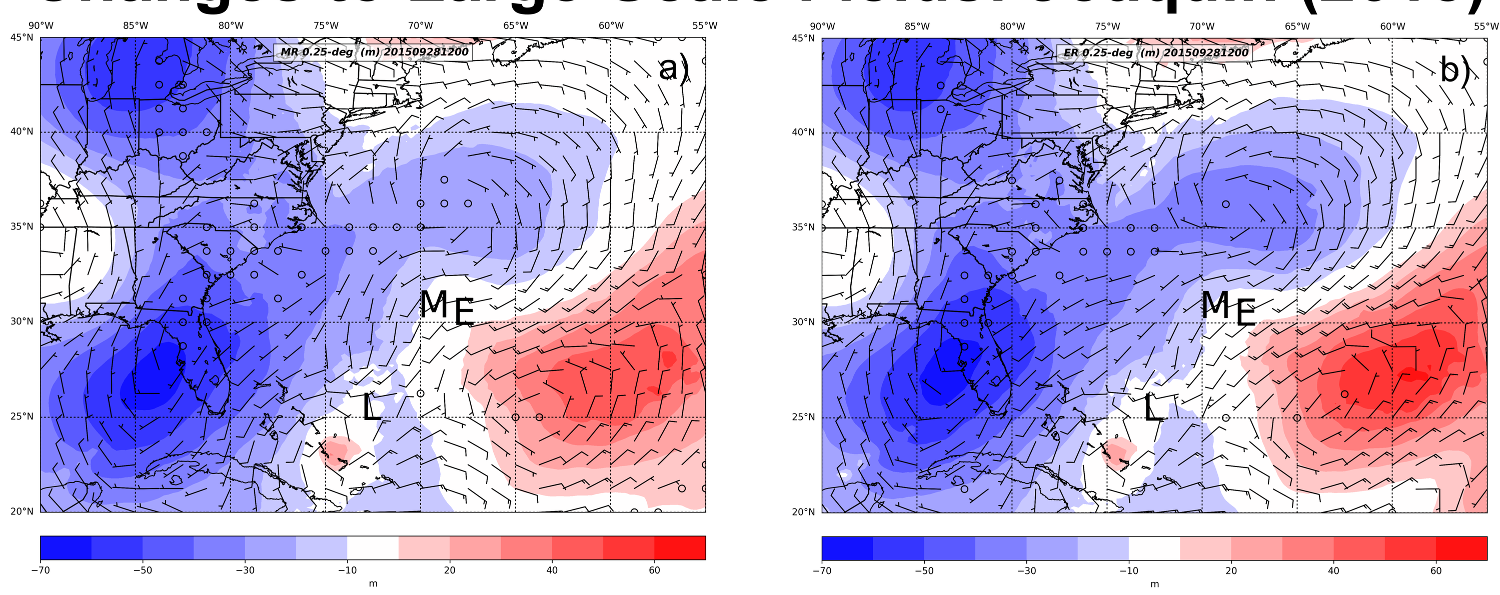

Fig. 3 – HWRF forecast errors with respect to six-hourly GFS analyses of 200-mb height (m) and wind (standard notation, 10 kn=barb) using a) MR and b) EXP cloud overlap, averaged over single HWRF 48-120-h forecast initialized at 1200 UTC 28 September 2015 and valid between 1200 UTC 30 September 2015 and 1200 UTC 3 October 2015. Shown are 1200 UTC 3 October best track (L) and forecasted positions of Joaquin in MR (M) and EXP (E).

•EXP cloud overlap scheme introduces modest changes to large-scale fields in all regions of the globe

•Example of HWRF forecast errors with respect to 0.25-degree GFS analyses (Fig. 3) shows overall spatial pattern is preserved, but Hurricane Joaquin for EXP is located 160 km to the southeast of the MR position

•Statistical validation indicates small differences in model state variables between MR and EXP for this example

Effect on Track and Intensity: Joaquin (2015) and Matthew (2016)

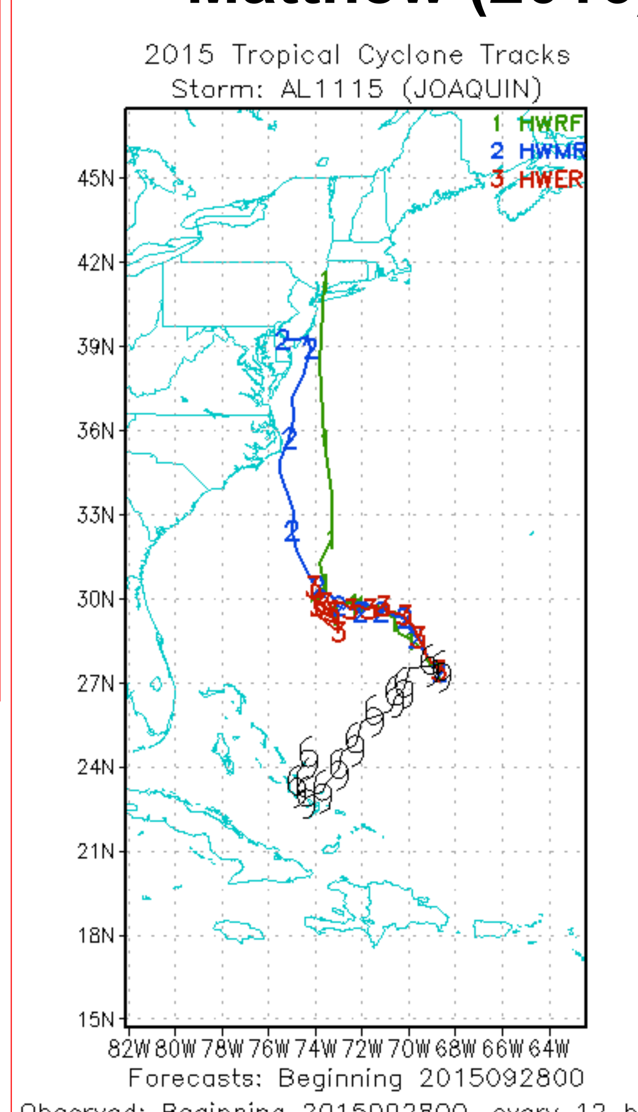

Fig. 4 – Forecasted track for Hurricane Joaquin (2015) using 2015 operational HWRF (green), 2016 operational HWRF with MR cloud overlap (blue) and 2016 HWRF with EXP cloud overlap (red). Best track is shown in black. Initialization of HWRF is at 0000 UTC 28 September 2015. Symbols are plotted every 12 h.

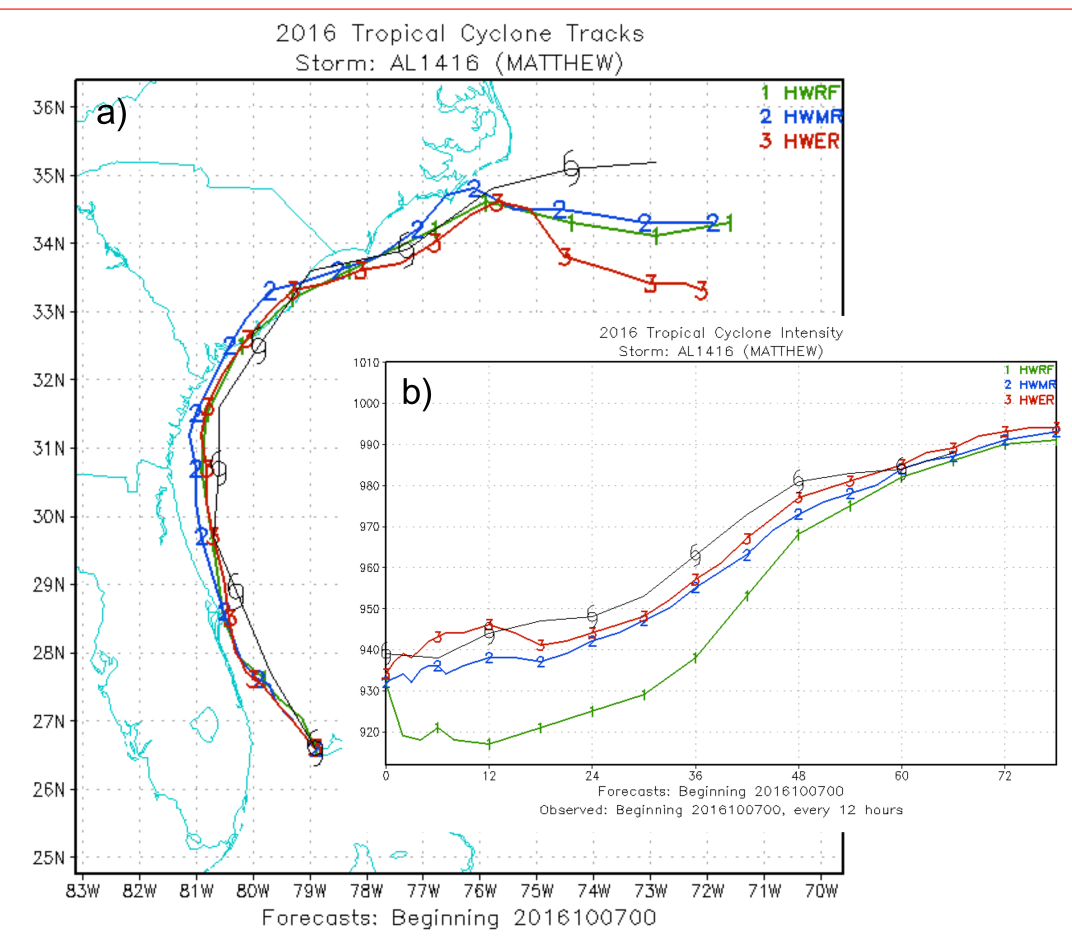

Fig. 5 – As in Fig. 4, but for a) track of Hurricane Matthew (2016) initialized at 0000 UTC 7 October 2016. Forecasted and observed sea-level pressure intensity (mb) is shown in panel b).

•Influence on storm track and intensity was investigated for a number of Atlantic and Eastern Pacific basin storms in 2015 and 2016

•Small, statistically insignificant, track error improvements seen with EXP for set of Atlantic TCs

•Overall track and intensity errors for Matthew slightly larger with EXP

•Individual runs can exhibit profound track changes when a poorly organized TC is embedded within a diffuse steering flow; use of EXP (red) improved the track (Fig. 4) compared to MR (blue) for Joaquin

•Track changes can be smaller when a strong TC, such as Matthew, is embedded in a well-defined steering flow (Fig. 5a); intensity forecasts are modestly improved (Fig 5b)

•However, even modest track changes can be important in forecast scenarios with large societal vulnerability (Fig. 5a), such as with Hurricane Matthew as it approached SE FL as a category 4 storm

EMC 2018 Model Evaluation: MR vs EXP

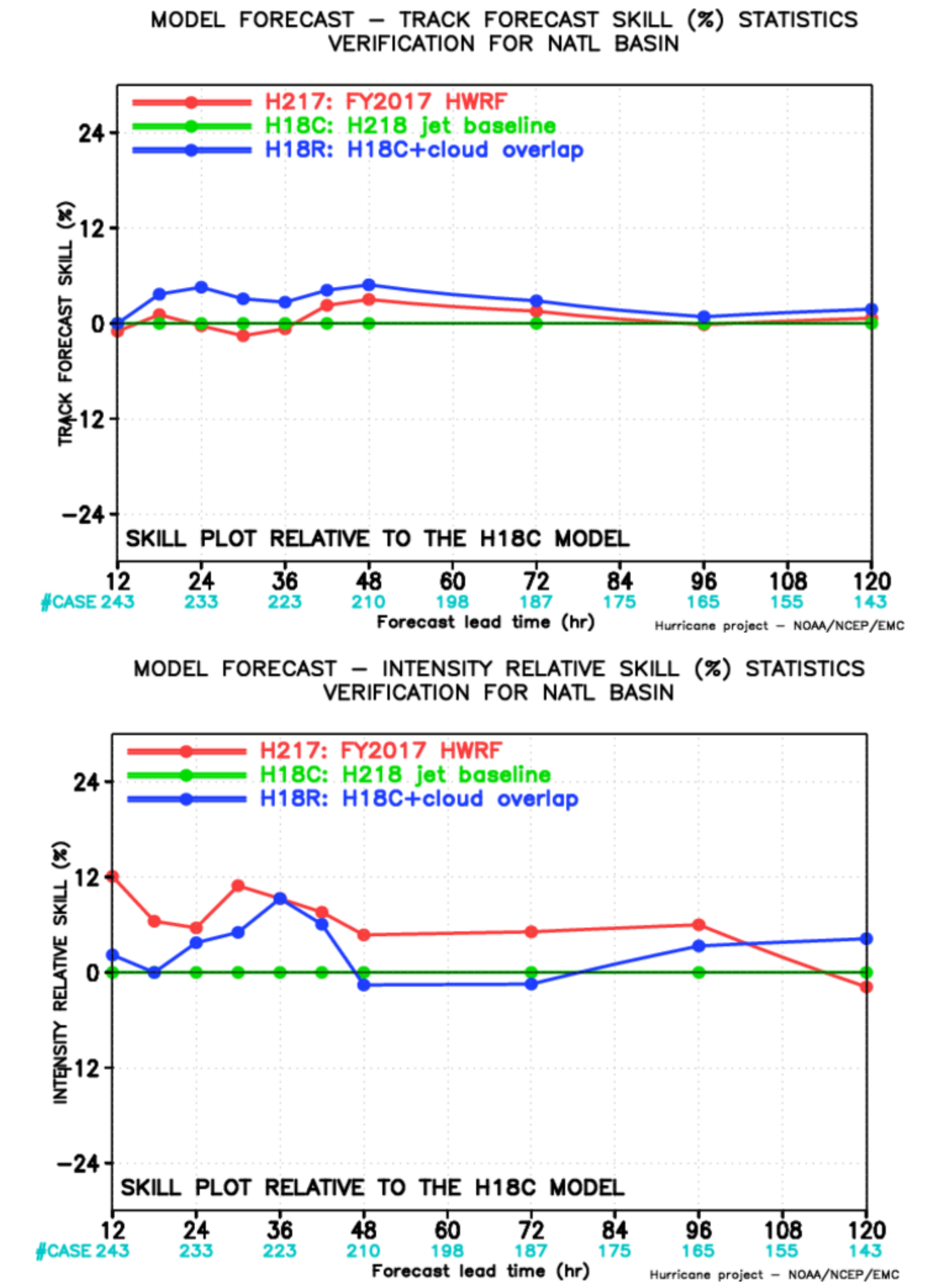

Fig. 6 – Relative skill (positive=reduced errors) of 2018 HWRF candidate using EXP cloud overlap scheme (H18R, blue) versus 2018 HWRF baseline (H18C, green). (Note that SSMI channel 2 data were not assimilated in 2018 cases)

•NOAA/EMC performing evaluation of 2018 candidate operational HWRF model for selection of priority 2017 Atlantic-basin hurricanes

•EXP cloud overlap scheme reduces track and intensity errors by ~3-5%, especially within first 48 h of simulations (Fig. 6)

Conclusions and Future Work

•Cloud overlap assumption in the 2018 operational candidate HWRF RRTMG radiation code was updated from Maximum-Random (MR) to Exponential (EXP)

•Preliminary tests of EXP indicate substantial changes to the radiative heating rates in both the storm environment and the synoptic-scale fields

•Overall, track and intensity improvement for test storms is ~3-5%; individual forecast cycles, however, can exhibit substantial track and intensity sensitivity

•**2018 HWRF (H218, running WRF v3.9.1.1) will use the EXP scheme**

•Future work with DTC and EMC will:
- Investigate effect of EXP and further-refined Exponential-Random (ER) method on storm track, intensity and larger-scale fields for more TCs
- Analyze effect of using a spatially-variable decorrelation length that depends on latitude
- Make EXP and ER overlap methods available in (H)WRF public releases

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