Revisions to RRTMG cloud radiative transfer 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 was performed through the 2016 Developmental Testbed Center Visitor Program

•Main objectives:

- Implement a new Exponential-Random (ER) cloud overlap method – that better matches observations - in the RRTMG radiation code developed at AER for Hurricane WRF (HWRF)
- Investigate effects of ER method on:
  - large-scale meteorological fields and radiative heating rates:
  - storm track and intensity of several Tropical Cyclones (TCs):
    - Atlantic basin: Joaquin, Edouard, Gonzalo (2015) and Matthew (2016)
    - Eastern Pacific basin: Dolores (2015)

RRTMG MR and ER Cloud Overlap Approaches

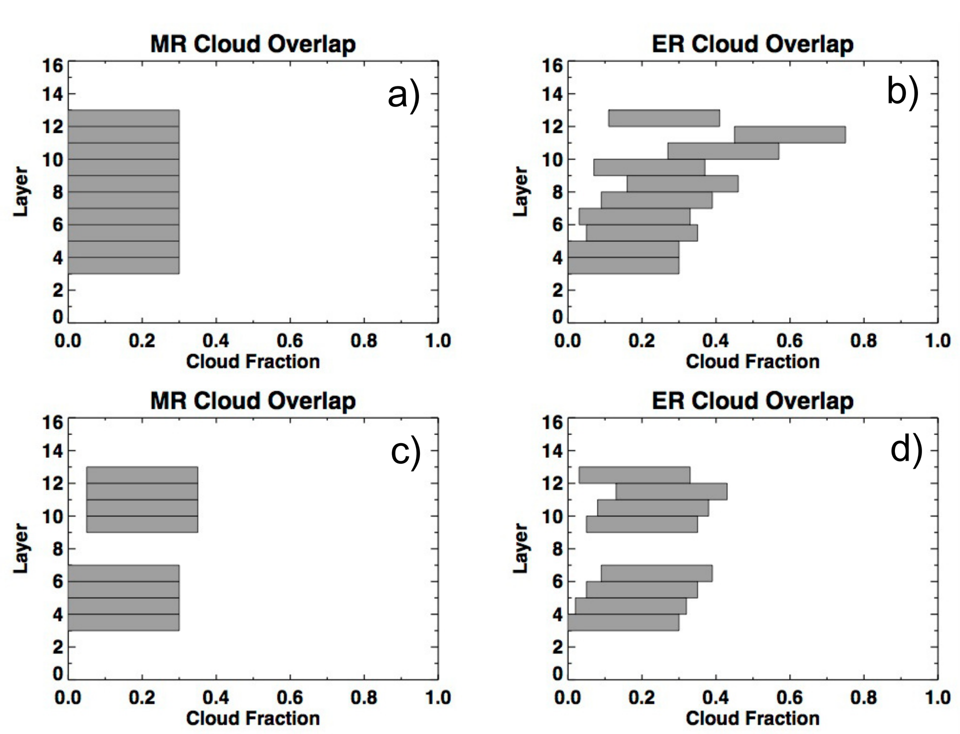

Fig. 1 - Schematic diagram showing idealized cloud overlap differences for a single block of cloud layers (top panels) with cloud fraction indicated by the gray boxes and for two separated blocks of cloud layers (bottom panels) between default Maximum-Random overlap (MR, left) and new Exponential-Random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

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

Changes to Heating Rates

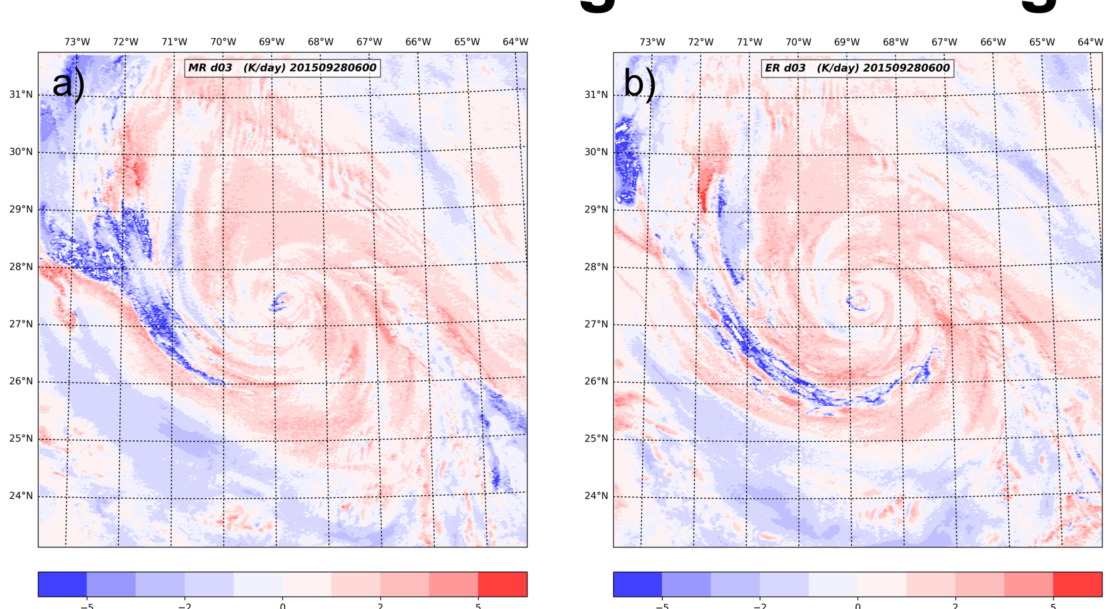

Fig. 2 – Longwave heating rate (K/day) at ~900 mb for Hurricane Joaquin using a) MR cloud overlap and b) ER cloud overlap, valid at 1200 UTC 2 October 2015, and initialized at 0600 UTC 28 September 2015. Red (blue) colors denote heating (cooling).

•Use of ER changes the spatial pattern of heating rates in grid boxes with partial clouds

•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, are modeled differently in MR (Fig. 2a) compared to ER (Fig. 2b) for Hurricane Joaquin

Changes to Large-Scale Fields: Hurricane Joaquin (2015)

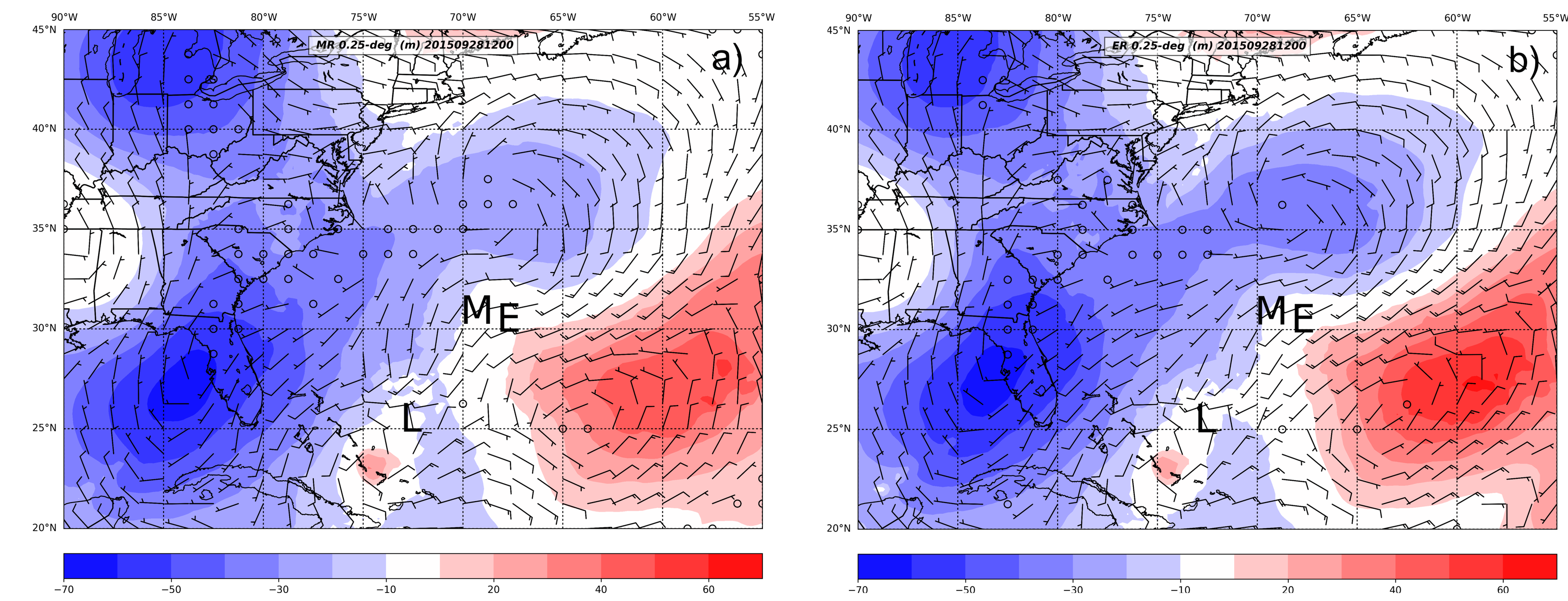

Fig. 3 – HWRF forecast errors with respect to six-hourly GFS analyses of 200-mb height (m) and wind (standard notation, 10 kn=barb) using a) MR and b) ER cloud overlap, averaged over single HWRF 48-120-h forecast initialized at 1200 UTC 28 September 2015 and valid between 1200 UTC 30 September 2015 and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

•ER 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 ER is located 160 km to the southeast of the MR position

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

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

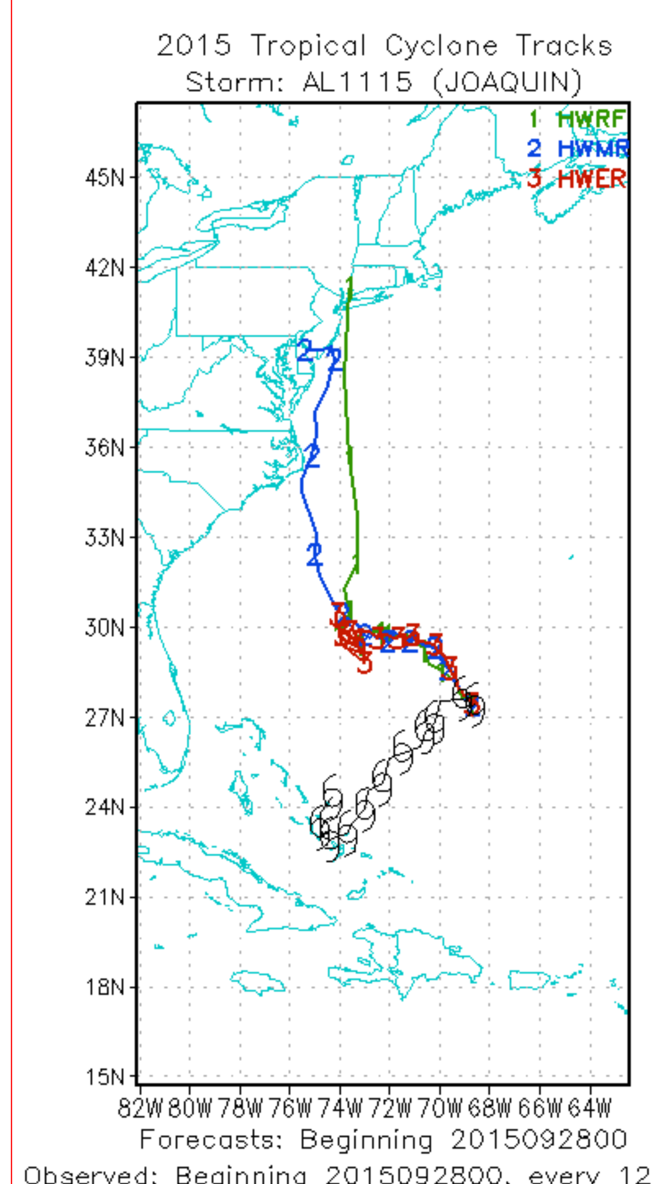

Fig. 4 – Forecasted track for Hurricane Joaquin (2015) using 2015 operational HWRF (green), 2016 operational HWRF with MR cloud overlap (blue) and 2016 HWRF with ER cloud overlap (red). Best track is shown in black. Initialization of HWRF is at 0000 UTC 28 September 2015. Symbols are plotted every 12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

•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 ER for set of Atlantic TCs

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

•Individual runs can exhibit profound track changes when a poorly organized TC is embedded within a diffuse steering flow; use of ER (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

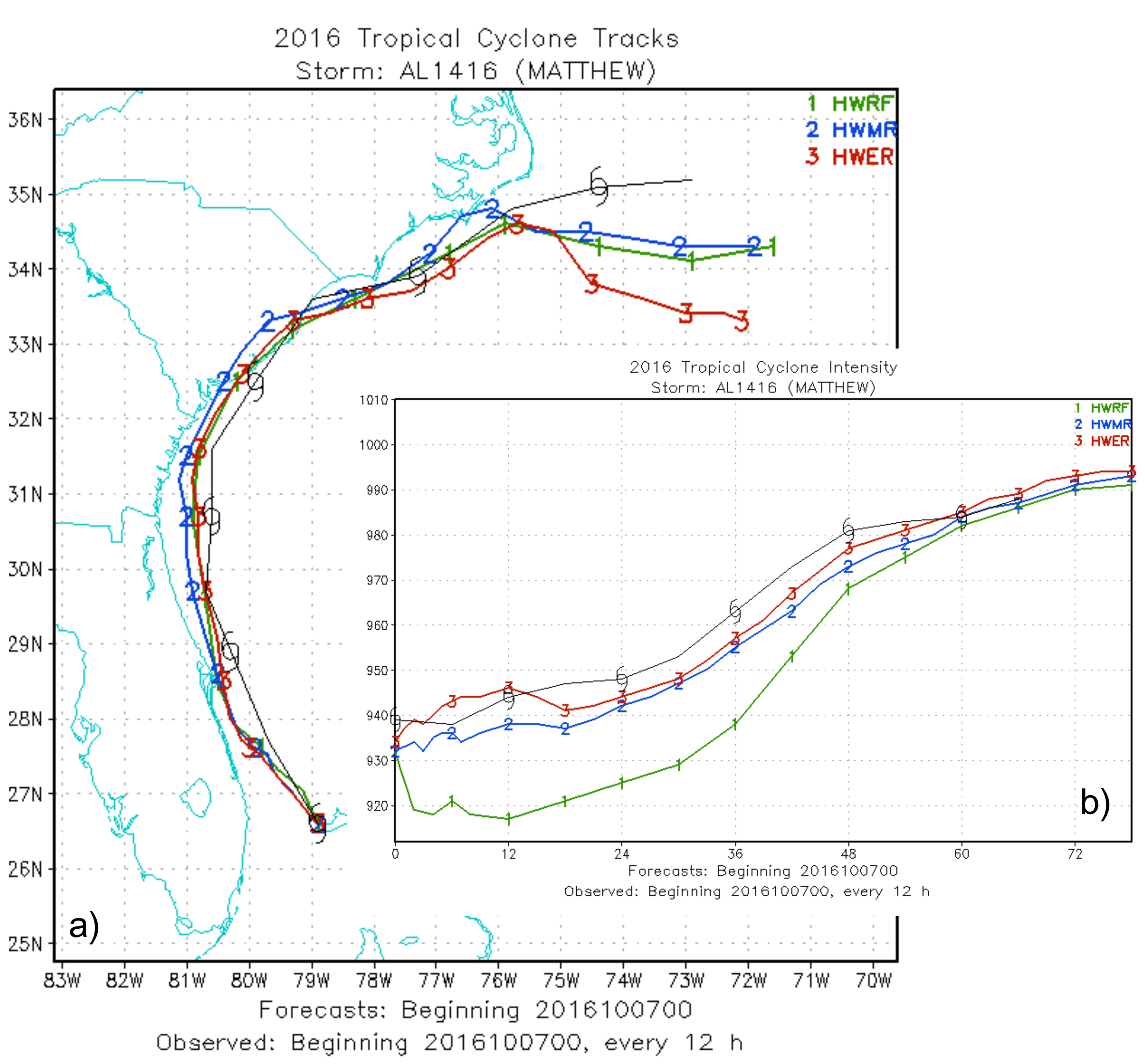

Fig. 5 – As in Fig. 4, but for track of Hurricane Matthew (2016) initialized at 0000 UTC 7 October 2016. Forecasted and observed sea-level pressure intensity (mb) is shown in panel b).

Conclusions and Future Work

•Cloud overlap assumption in the 2016 operational HWRF RRTMG radiation code was updated from Maximum-Random (MR) to Exponential-Random (ER)

•Preliminary results indicate substantial changes to the resulting radiative heating rates in both the storm environment and the synoptic-scale fields

•Overall track and intensity changes for a limited number of test storms are modest; individual forecast cycles, however, can exhibit substantially different storm tracks with obvious forecast challenges in vulnerable geographical locations, such as Hurricane Matthew's approach of the east coast of Florida during October 2016

•Future work with DTC and EMC will:

- Investigate effect of ER on storm track, intensity and larger-scale fields for additional TCs
- Analyze effect of using a spatially-variable decorrelation length that depends on latitude
- Make ER overlap method available in (H)WRF public releases

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