A Reformulation of the Logistic Growth Equation Model (LGEM) for Ensemble and Extended Range Intensity Prediction

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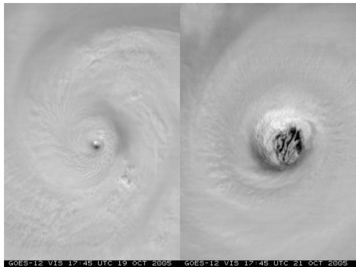
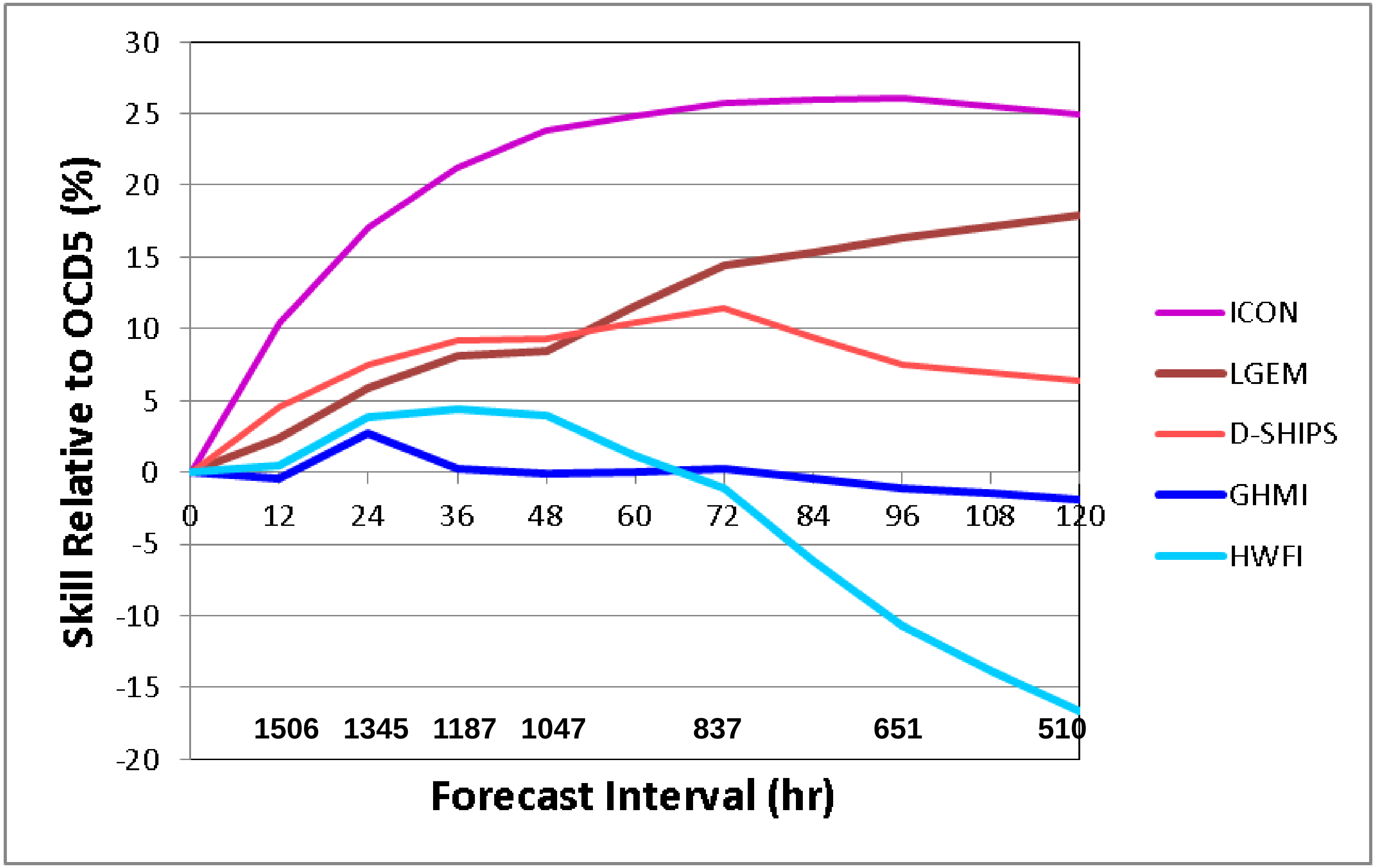


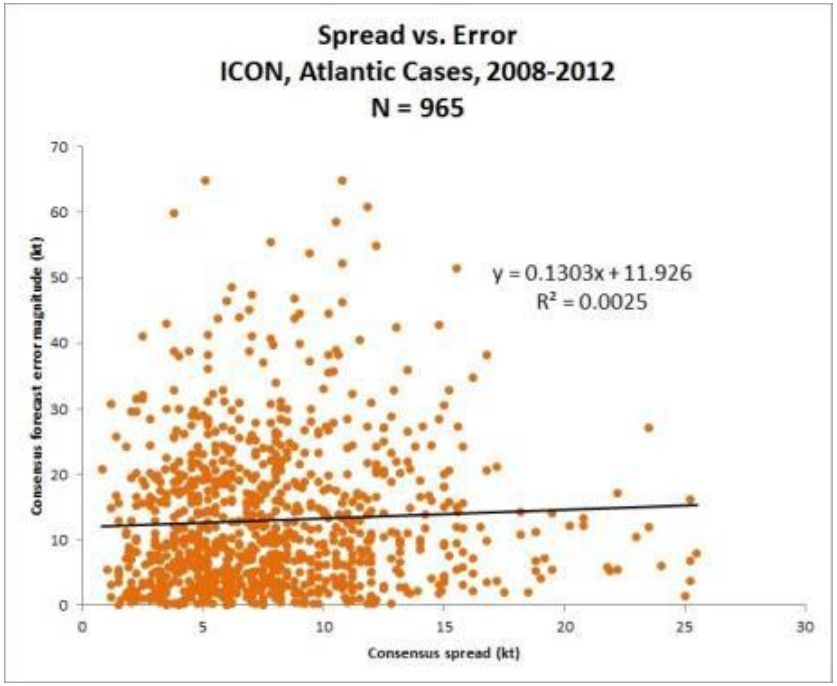
Outline

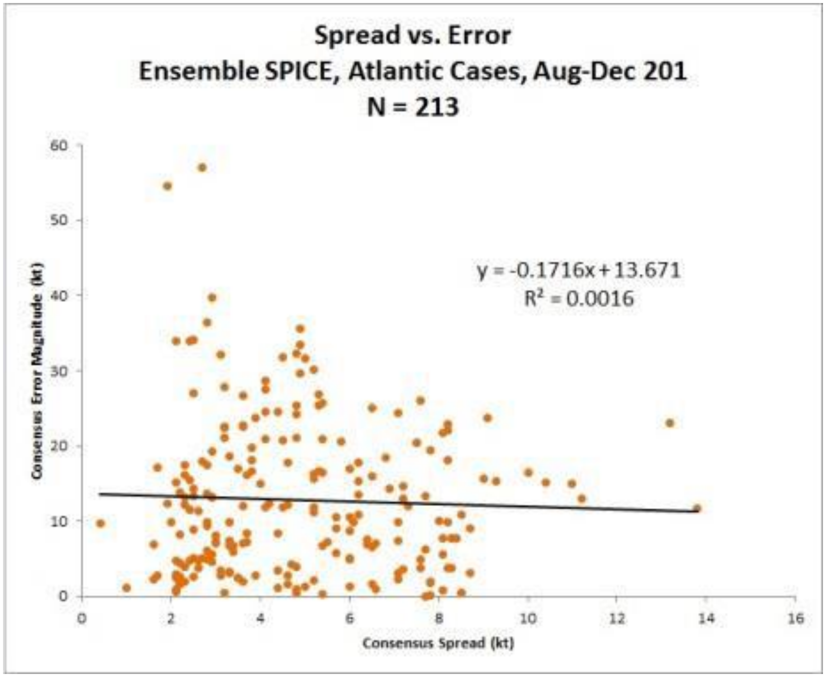
- Ensemble intensity forecast limitations
- Overview of operational LGEM
- LGEM reformulation
  - More physics, less predictors
    - New MPI calculation
    - SST cooling algorithm
  - Modification of fitting technique
- Plans for ensemble and long range prediction

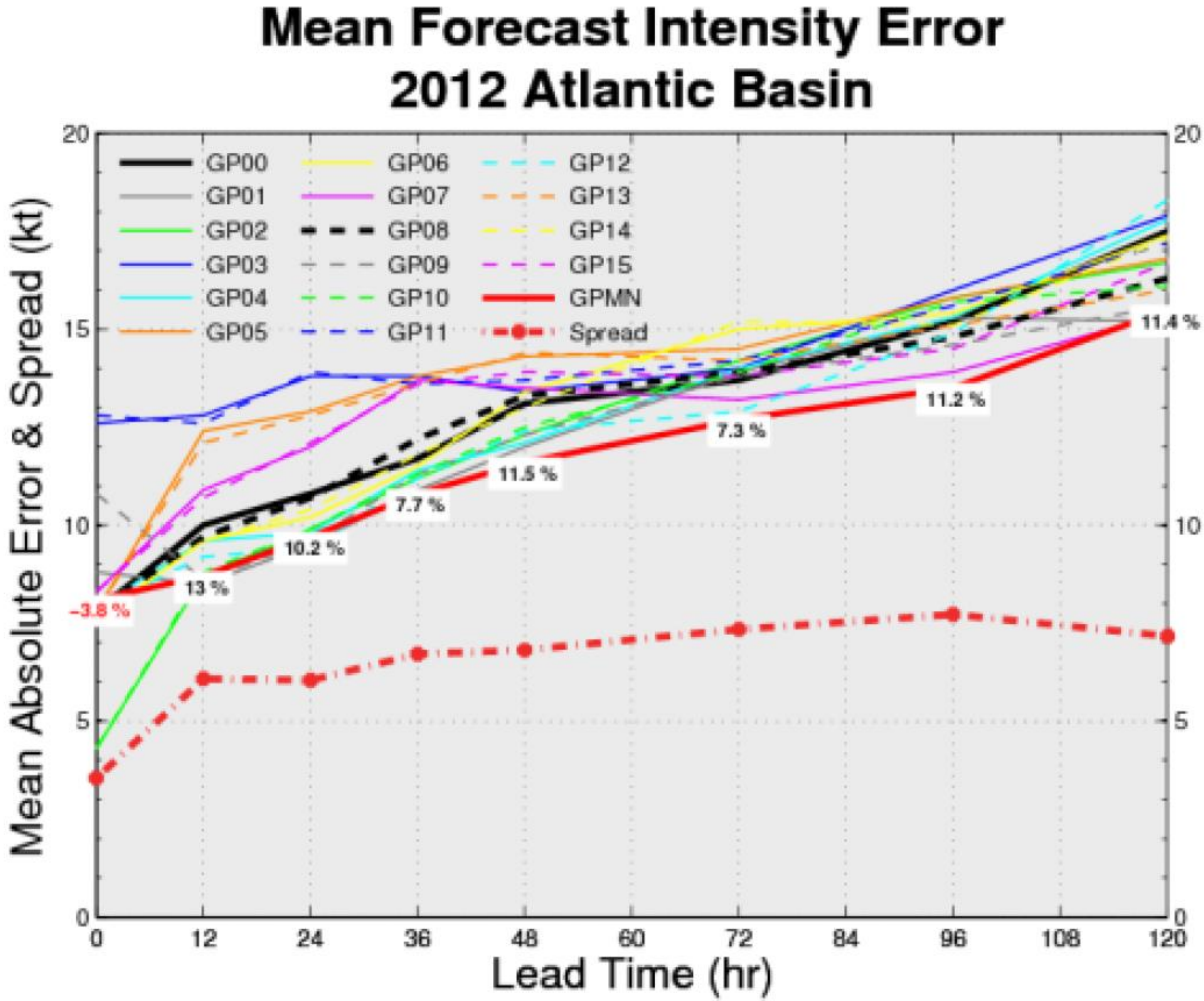
Atlantic Intensity Model Skill 2008-2012



Spread-Error Relationships ICON and Global-SPICE







Mean Forecast Intensity Error
2012 Atlantic Basin
Mean Absolute Error & Spread (kt)
Lead Time (hr)
GP00
GP01
GP02
GP03
GP04
GP05
GP06
GP07
GP08
GP09
GP10
GP11
GP12
GP13
GP14
GP15
GPMN
Spread
-3.8 %
13 %
10.2 %
7.7 %
11.5 %
7.3 %
11.2 %
11.4 %

Operational LGEM Intensity Model

$$\frac{dV}{dt} = \kappa V - \beta (V/V_{mpi})^n V$$

(A) **(B)**

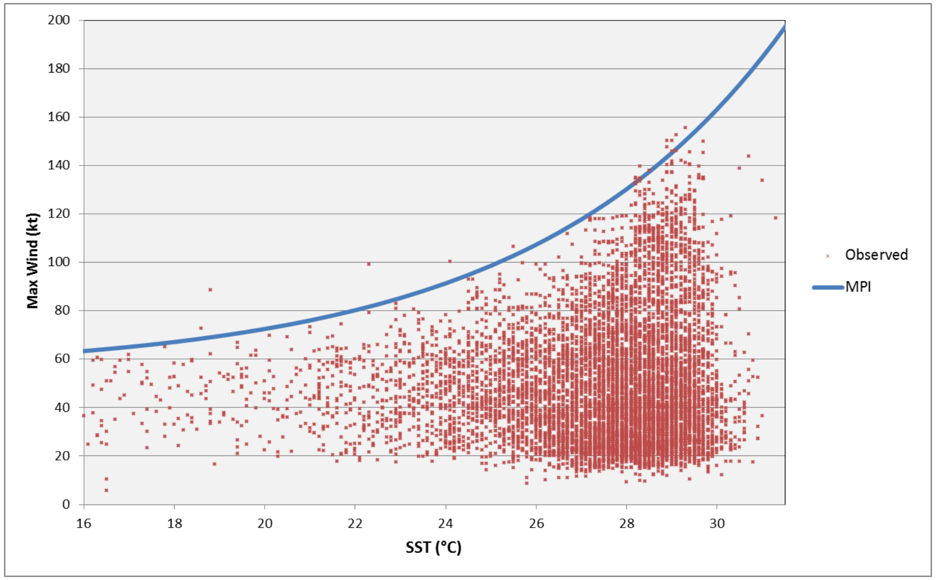
V_{mpi} = Maximum Potential Intensity estimate

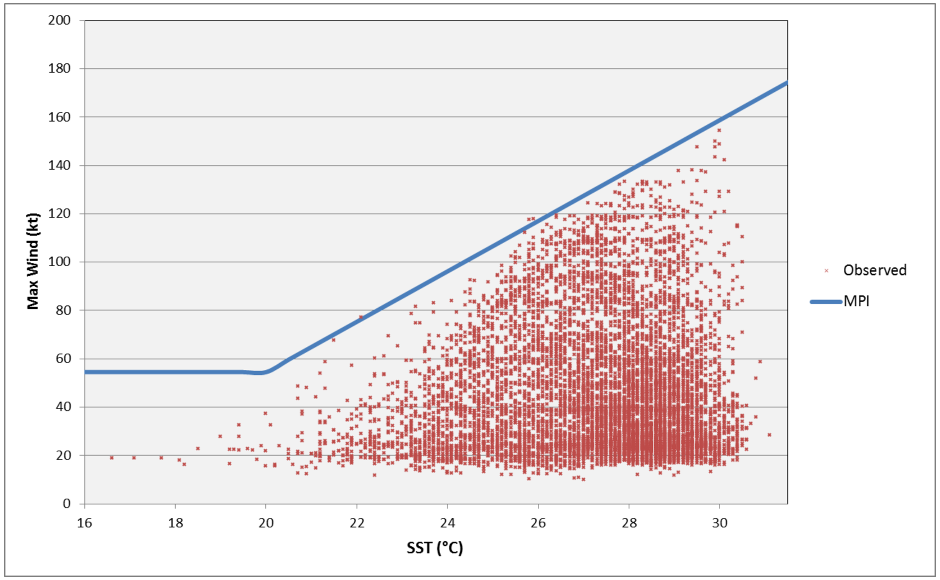
κ = Max wind growth rate

β, n = empirical constants = 1/24 hr, 2.5

Steady State Solution: $V_s = V_{mpi}(\beta/\kappa)^{1/n}$

V_{mpi} Used in LGEM





Atlantic

East/Central Pacific

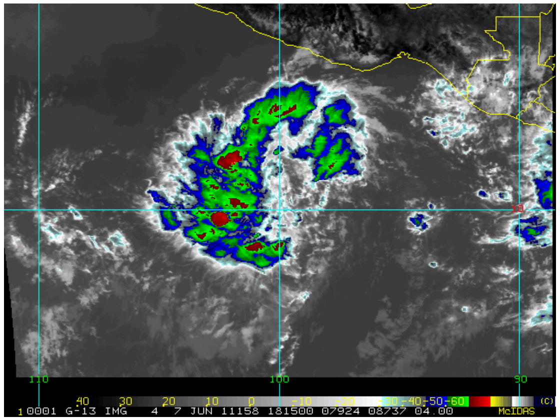
$$V_{mpi} = f(SST) + 1.5c^{0.63}$$

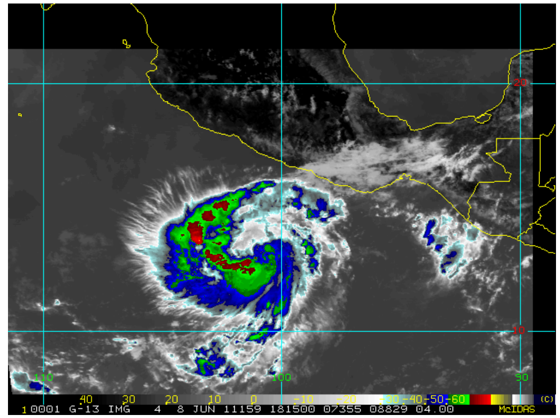
Estimation of LGEM Growth Rate (κ)

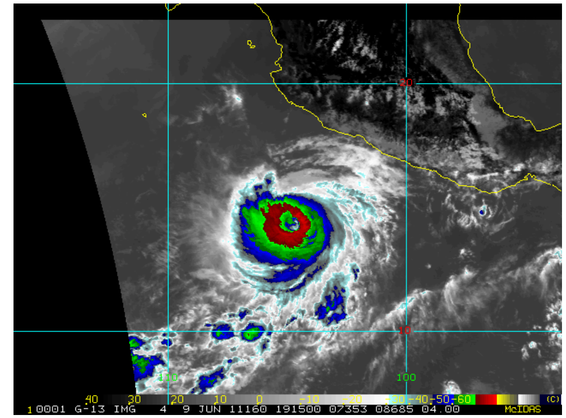
$\kappa = a_0 + a_1 x_1 + a_2 x_2 + \ldots a_{19} x_{19}$ predictors x_i include:

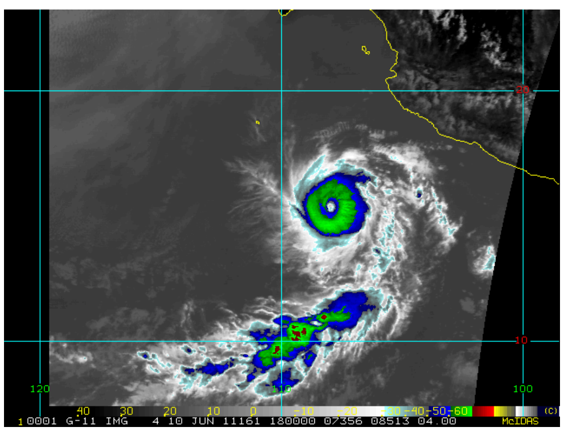
1. Climatology
2. Persistence
3. V_{max} (t=0)
4. %GOES pixels < -20^{o}C
5. Steering layer pressure
6. Zonal storm motion
7. Ocean heat content
8. SST
9. T at 200 hPa
10. T at 250 hPa
11. θ_e of sfc parcel - θ_e of env
12. 850-200 hPa env shear
13. Shear direction
14. Shear*sin(lat)
15. Shear from other levels
16. 0-1000 km 850 hPa vorticity
17. 0-1000 km 200 hPa divergence
18. GFS vortex tendency
19. Low-level T advection

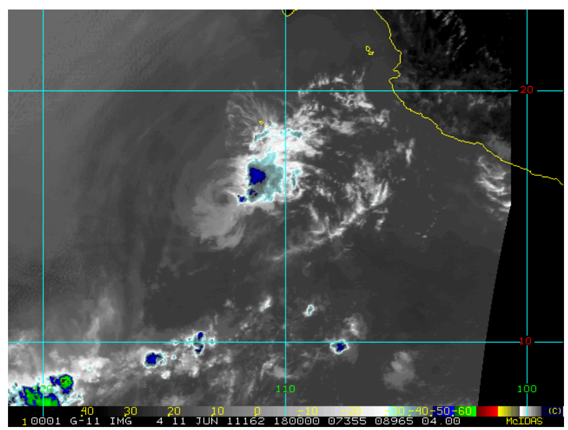
Hurricane Adrian (EP012011)

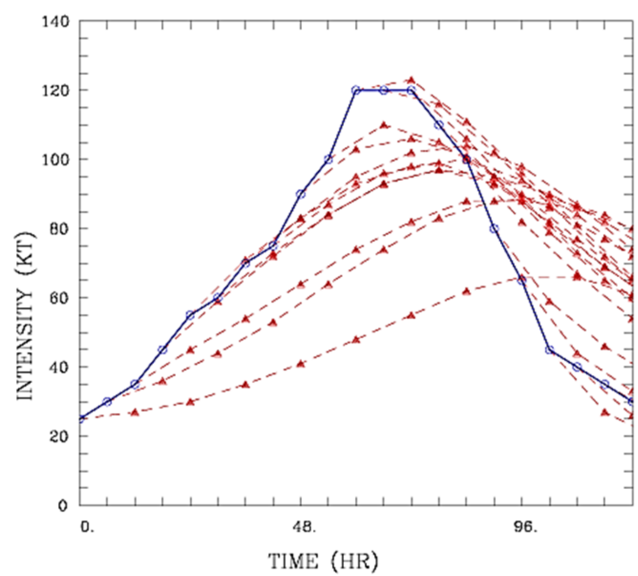












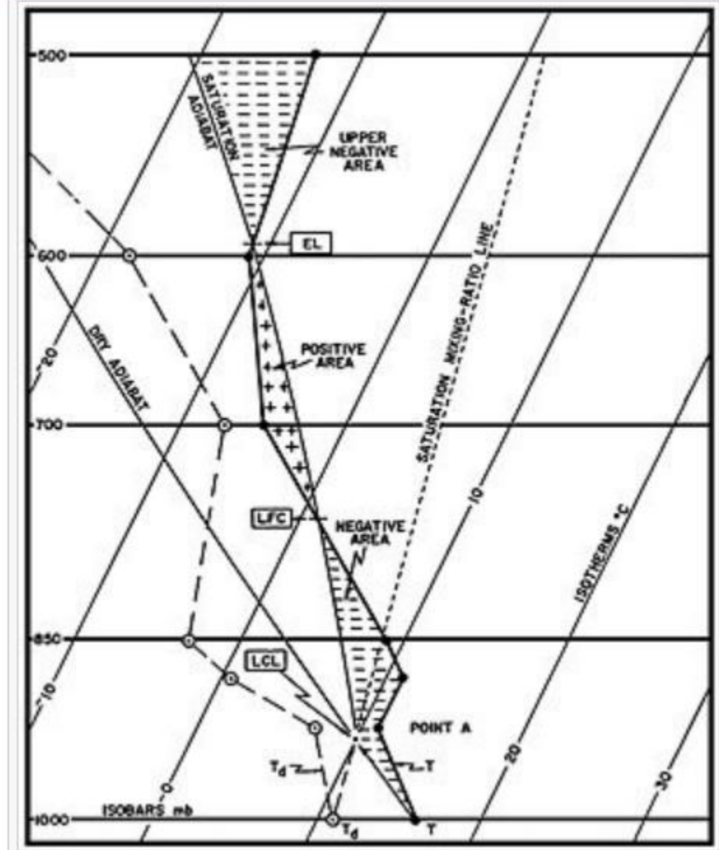
Bister and Emanuel (2002) MPI

$$V_{mpi}^2 = (T_s/T_o)(C_k/C_D)[CAPE^*-CAPE]|_m$$

- T_s = Sea Surface Temperature
- T_o = Outflow temperature
- C_k/C_D = Surface exchange coefficient ratio
- CAPE = Convective Available Potential Energy of eyewall parcel
- CAPE* = Value of CAPE for RH=100% at the surface

Calculation of CAPE

$$CAPE = \int_{z_f}^{z_n} g \left(\frac{T_{v,parcel} - T_{v,env}}{T_{v,env}} \right) dz$$



A Skew-T diagram with important features labeled

Assumptions:

- Pseudo-adiabatic process
  - Neglect condensate weight
- No entrainment
- Neglect ice phase
- Neglect friction

Generalized CAPE From Equations for Spherical Air Parcel

$$\frac{dw}{dt} = g\left(\frac{T_v - \bar{T}_v}{\bar{T}_v}\right) - \mu_c g - \left(\frac{c_E + c_D}{R}\right) w^2$$

$$\frac{dM}{dt} = \frac{Mwc_E}{R} \quad \Longrightarrow \quad \left(\frac{1}{M}\frac{dM}{dz} = \frac{c_E}{R}\right)$$, C_E=0.1, R=500 m

Mass doubles in ~5km

$$\frac{d\mu}{dt} = \frac{wc_E}{R}(\bar{\mu} - \mu) - \propto \mu_c$$

$$\frac{ds}{dt} = \frac{wc_E}{R}(\bar{s} - s)$$

$w =$ parcel vertical velocity

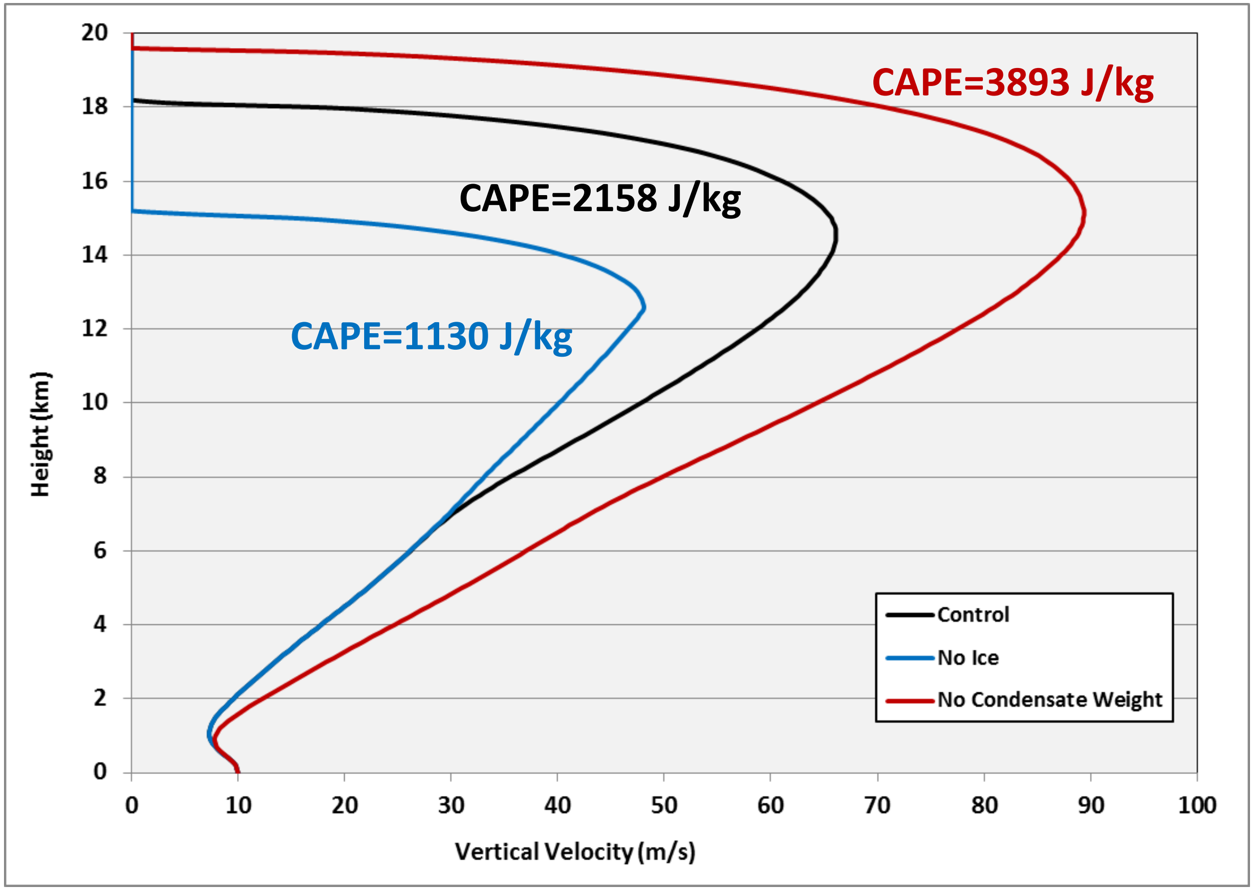
$\mu =$ Total water mixing ratio $= \mu_v + \mu_c$

$M =$ parcel mass $R =$ parcel radius

$s =$ moist entropy density

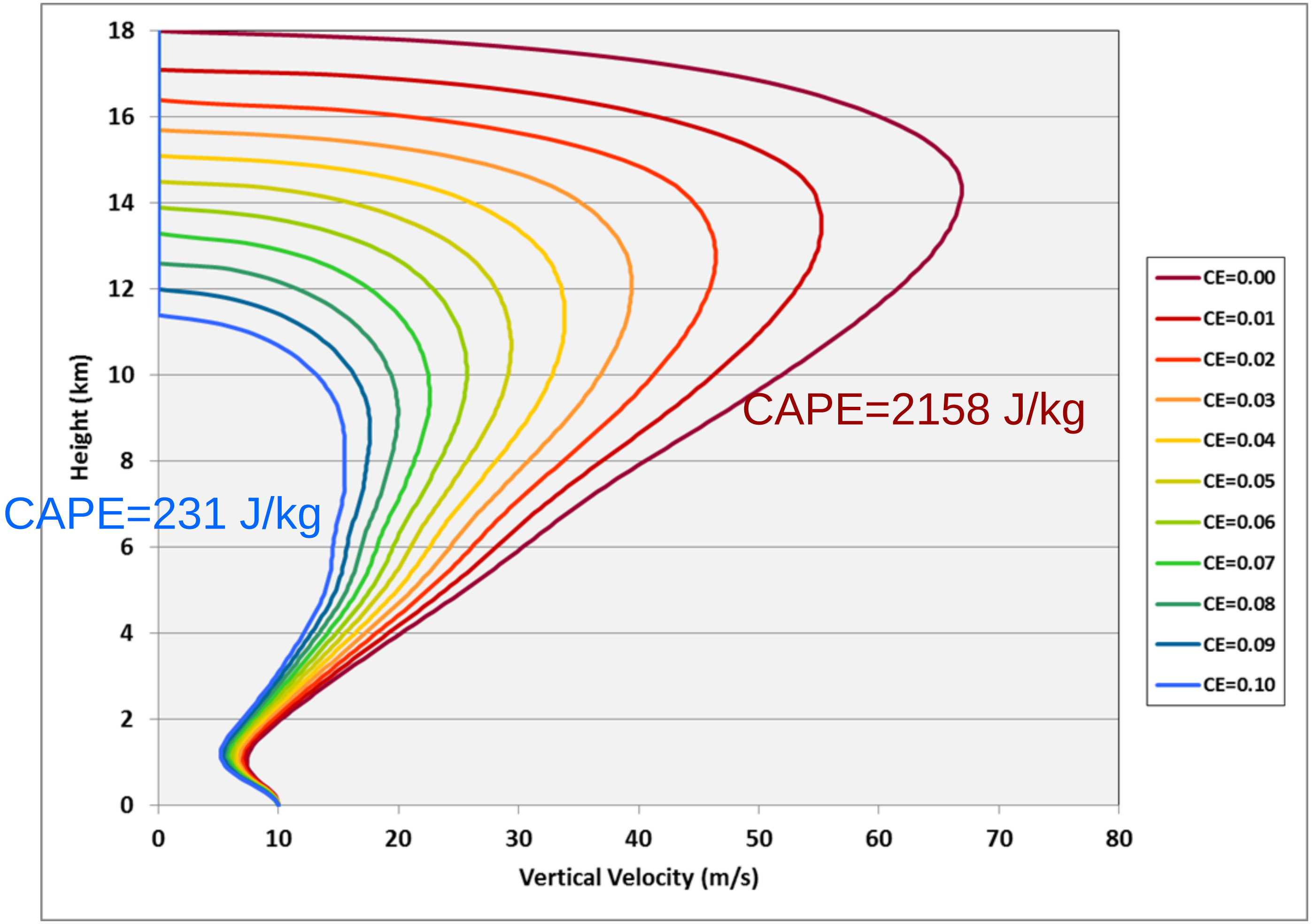
T_v, μ_v, μ_c diagnosed from μ, s using Ooyama (1990) formulation (includes ice phase)

Vertical Velocity Profiles with Reversible Thermodynamics

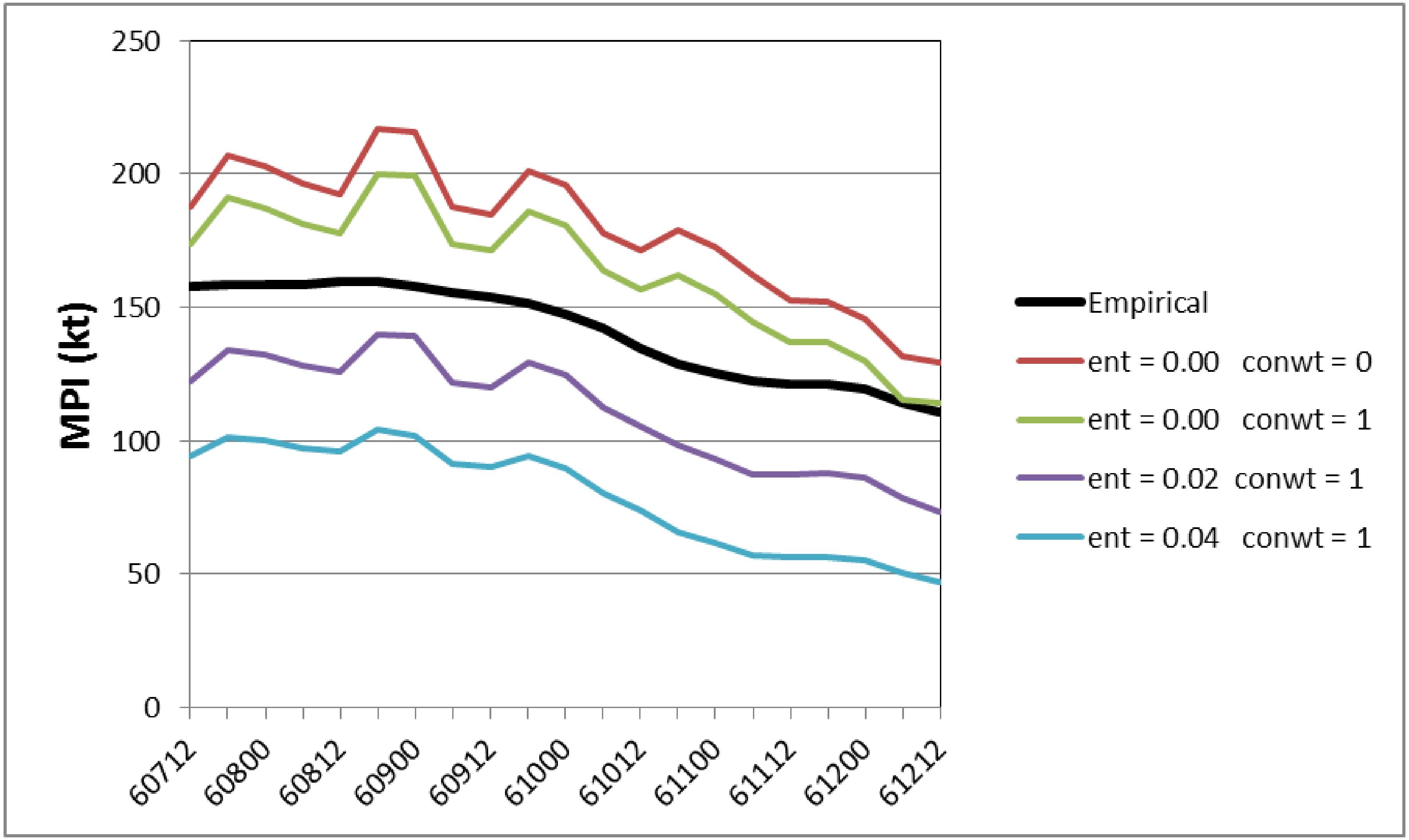


J. Dunion non-SAL mean tropical sounding

CAPE Sensitivity to Entrainment Coefficient



MPI for Hurricane Adrian (2011)



Base Parcel Model: R(0) = 500 m, Precip e-fold time= 300 s, ice=1

Entrainment Coefficient Variability

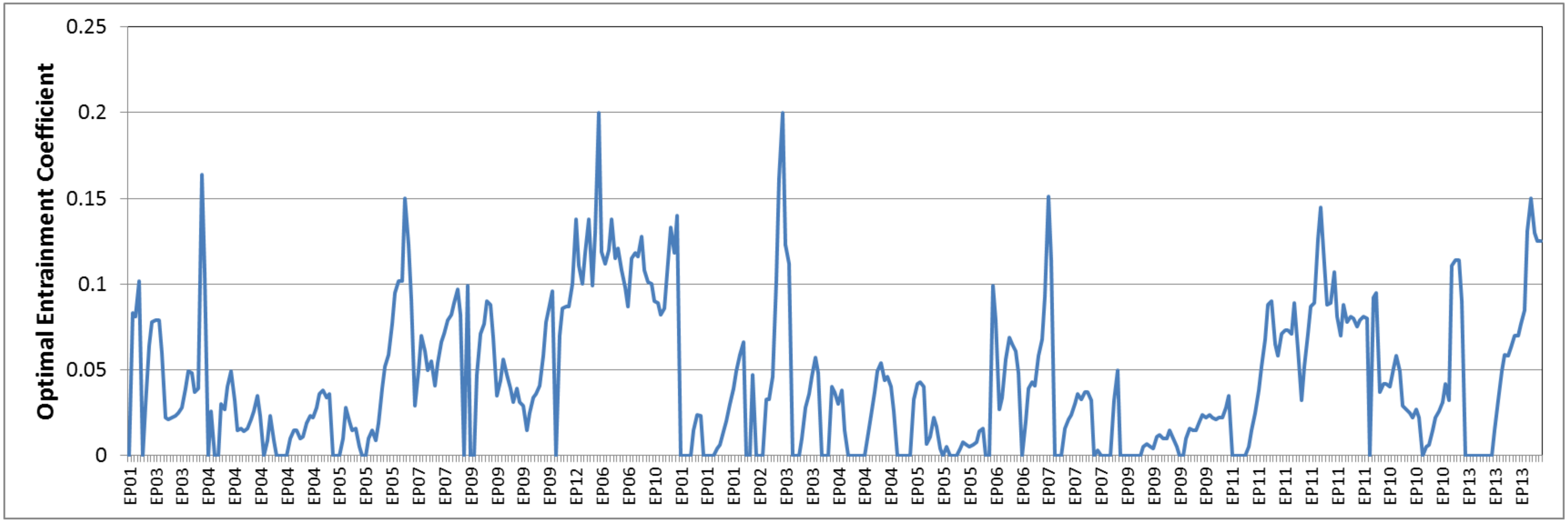
- Choose entrainment coefficient so LGEM intensity tendency best matches observed tendency

Specify κ, β, n, Choose C_E to minimize $|(dv/dt)_{LGEM} - (dv/dt)_{obs}|$

$$dV/dt = \kappa V - \beta (V/V_{mpi})^n V$$

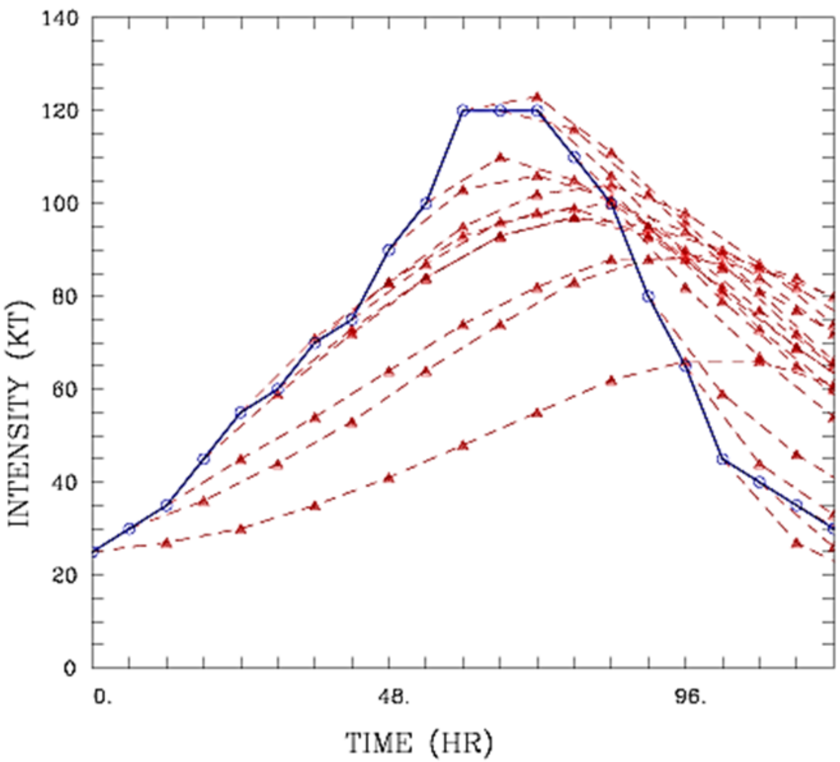
- Parameterize optimal entrainment coefficient in terms of storm environment (shear, etc)

Optimal Entrainment Coefficient 2010-2011 EP Over-Water Cases

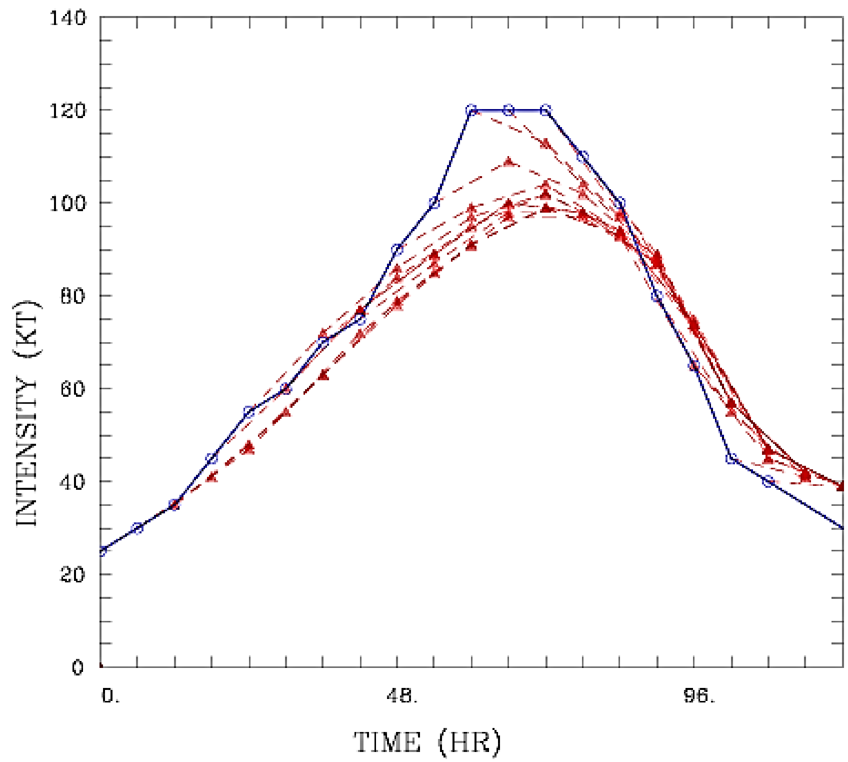


Median $C_E = 0.03$ ⇒ Parcel mass increases by ~50% in 10 km

LGEM forecasts for Hurricane Adrian tuned to new MPI

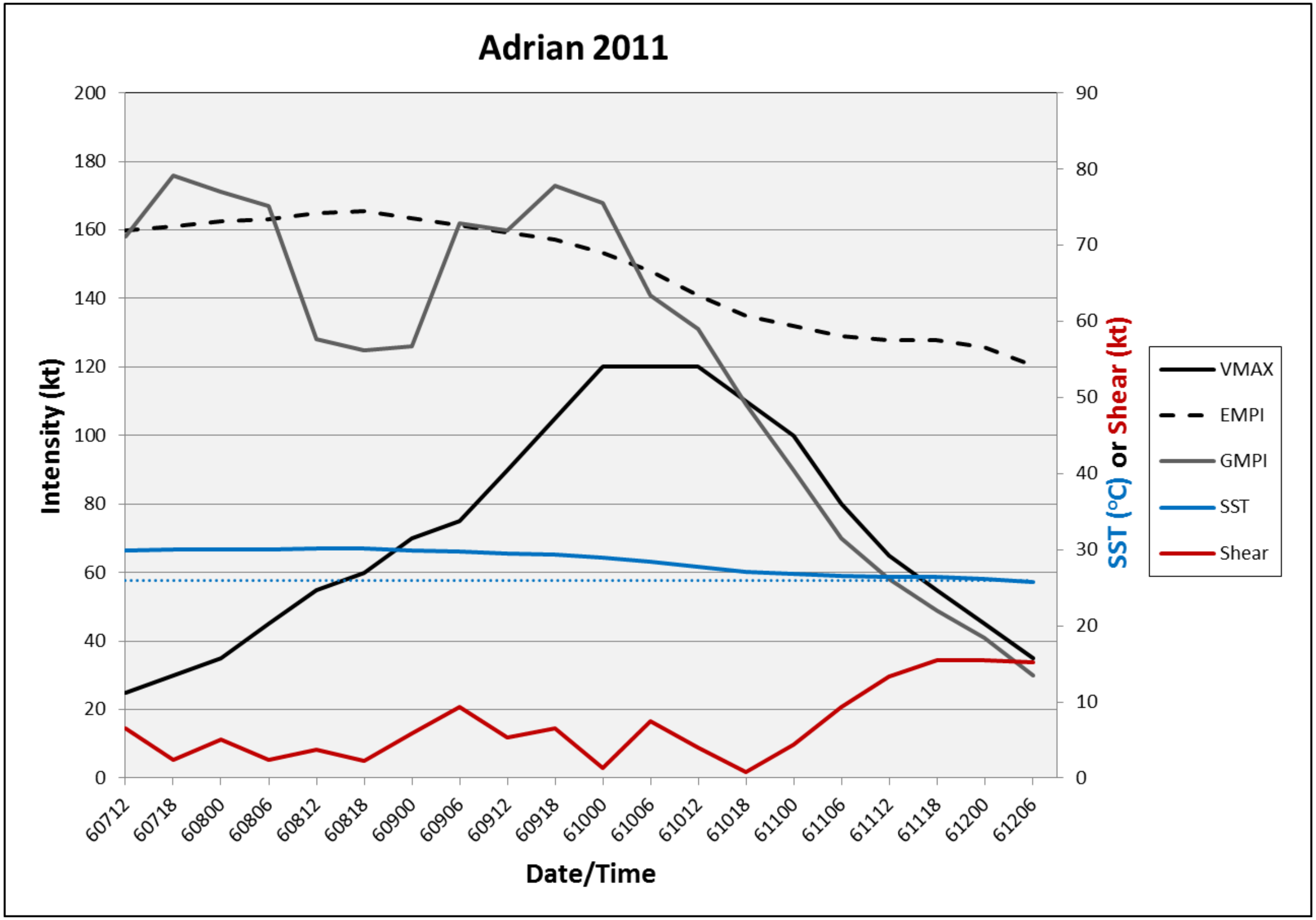


Operational



New Formulation:
κ = constant = 1/36 hr
C_E= a*shear

V_{mpi} for Optimized Adrian Case

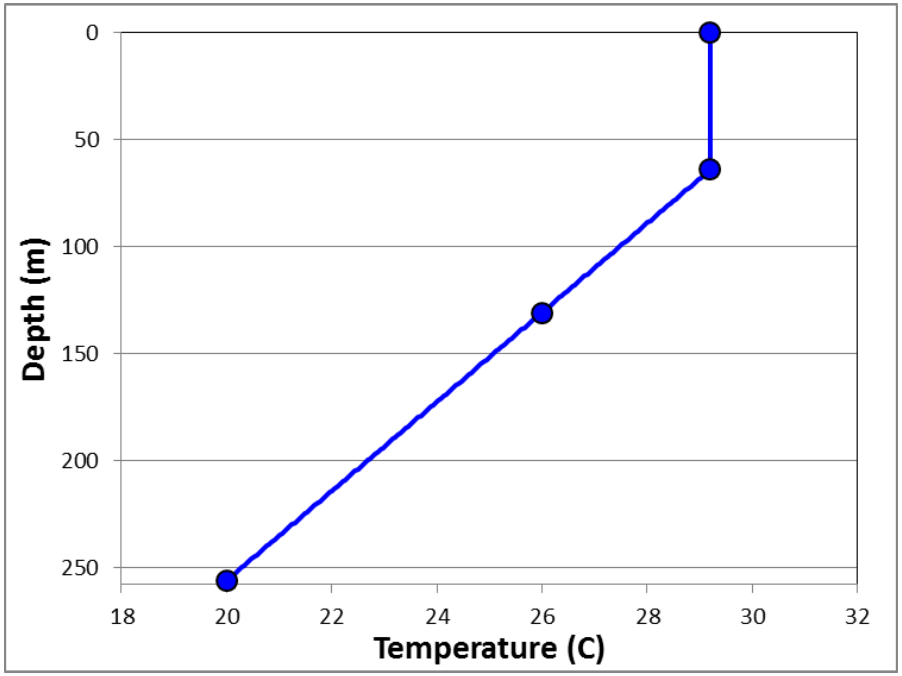


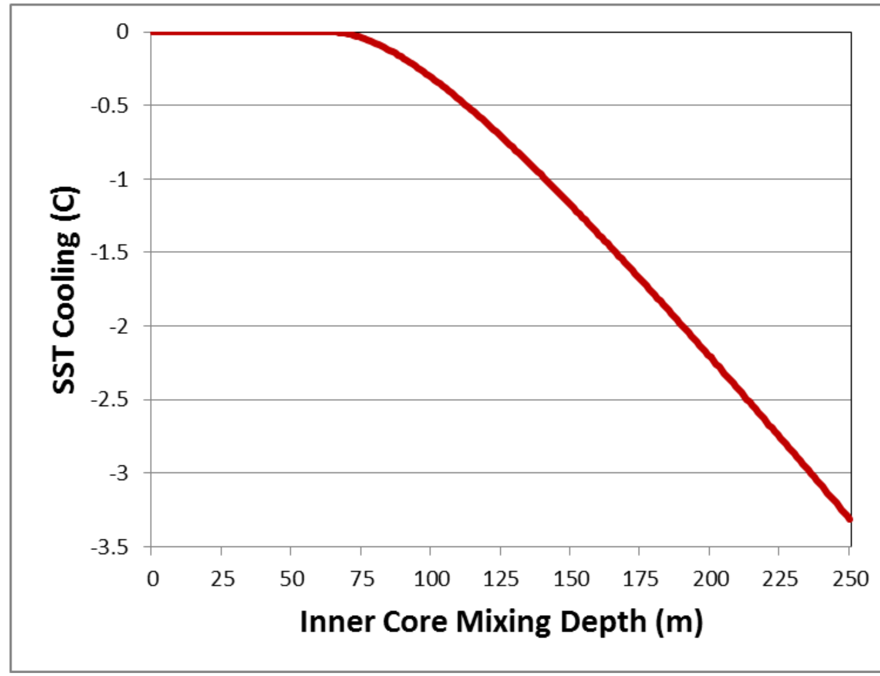
SST Cooling Algorithm
Based on I-I lin (2012)

- Pre-storm ocean parameters from satellite altimetry, NCODA analysis and SST files
  - SST
  - Depth of mixed layer
  - Depth of 26^{o} isotherm
  - Depth of 20^{o} isotherm
- Inner core SST from mixing ocean T profile down to D_{core}
- D_{core} = f(c) , c=storm translation speed

Ocean T Profile and SST Cooling

Hurricane Earl 18 UTC 28 Aug 2010





SST = 29.2^{o}C   DML = 64 m

D26 = 131m   D20 = 256 m

Additional Physical Factors

- Baroclinic energy, ET transition
  - Rely on GFS model

    Lat < 30^oN MPI = MPI_{BE}

    Lat > 30^oN MPI = $Max(MPI_{BE}, GFS_{vmax})$
- Initial storm organization
  - Fit model to full storm life cycles without t=0 variables (GOES, V(-12)-V(0), etc)
  - Adjust global κ based on GOES and recent storm history
  - Phase out adjustment with forecast time

$$\kappa(t) = \kappa_G + \kappa_A e^{-\alpha t}$$

Summary of Reformulated LGEM

$$\mathbf{dV/dt = \kappa V - \beta(V/V_{mpi})^n V}$$

V_{mpi} from Bister and Emanuel formula, but with ice phase and entrainment added to CAPE calculation

$C_E = e_0 + e_1 S + e_2 \theta_{shear}$
SST from mixed temperature profile , $D_{core} = d_0 + d_1 c$

V_{mpi} from GFS model at high latitudes if > BE formula

$\boldsymbol{\kappa}$ **=** Max wind growth rate = $\kappa_G + \kappa_A e^{-\alpha t}$

New LGEM: 9 free Parameters: β, n, e_0 , e_1 ,e_2 , d_0 ,d_1 κ_G , α

Operational LGEM: 401 free parameters (β, n, 399 κ coefficients)

Reassignment of LGEM (κ) Coefficients

1. Climatology
2. Persistence
3. V_{max} (t=0)
4. %GOES pixels < -20°C
5. Steering layer pressure
6. Zonal storm motion
7. Ocean heat content
8. SST
9. T at 200 hPa
10. T at 250 hPa
11. θ_e of sfc parcel - θ_e of env
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(2)-(5) are in κ_A term
(6)-(8) are in SST cooling algorithm
(9)-(15) are in new MPI calculation
(16)-(19) accounted for by using GFS for V_{mpi} at high latitudes

Applications of Reformulated LGEM

- Extended range prediction
  - κ coefficient not time dependent so model can be run for any length
- Ensemble intensity prediction
  - Perturbations to physics and input
    - Physics through parcel model and SST cooling
    - Can be run with multiple tracks and parent models
- Initial real-time tests late Aug 2013