A Generalized Rapid Intensification Prediction Framework

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Jonathan L. Vigh
National Center for Atmospheric Research, Boulder, CO

C. M. Rozoff, E. A. Hendricks, M. K. Biswas, J. Lin, K. Emanuel, D. J. Gagne II, I. C. Mac
Kucera, M. DeMaria, J. A. Knaff, C. R. Sampson, and R. Ríos-Berríos

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Progress and Challenges in Predicting Rapid Intensification

Significant improvements in limited area 3-d full physics models

- Although these models exhibit a relatively low probability of detection (POD) and high false alarm rate (FAR), these models can now occasionally predict rapid intensification (RI)
  - Hurricane Weather Research and Forecasting System (HWRF)
  - Coupled Ocean/Atmosphere Mesoscale Prediction System for Tropical Cyclones (COAMPS®-TC) models.

Statistical techniques and data mining

- Machine learning is starting to show some promise, however, such models come with their own special challenges.
  - SHIPS, LGEM, DTOPS
  - *Marbleri* (Gagne et al. 2020)
  - Hurricane LOGistic Regression Model (HLOG, MacDaniel et al., **4B.10 3:50 PM May 10**)

It remains a grand challenge to obtain an RI prediction technique that is both reliable and accurate

Global models and ensembles

- Forecasts of Hurricanes using Large-ensemble Outputs (FHLO, Lin et al. 2020; **4B.8 3:40 PM May 10**)
- COAMPS-TC ensemble

Nature of RI

- Environment (e.g., MPI, shear) vs. internal processes
- Deterministic vs. stochastic
- Role of vortex structure, SWAMI (Hendricks et al.; **Poster 9, 2:00 PM May 10**)

Have we framed the problem correctly?

- Case-based vs. event-based

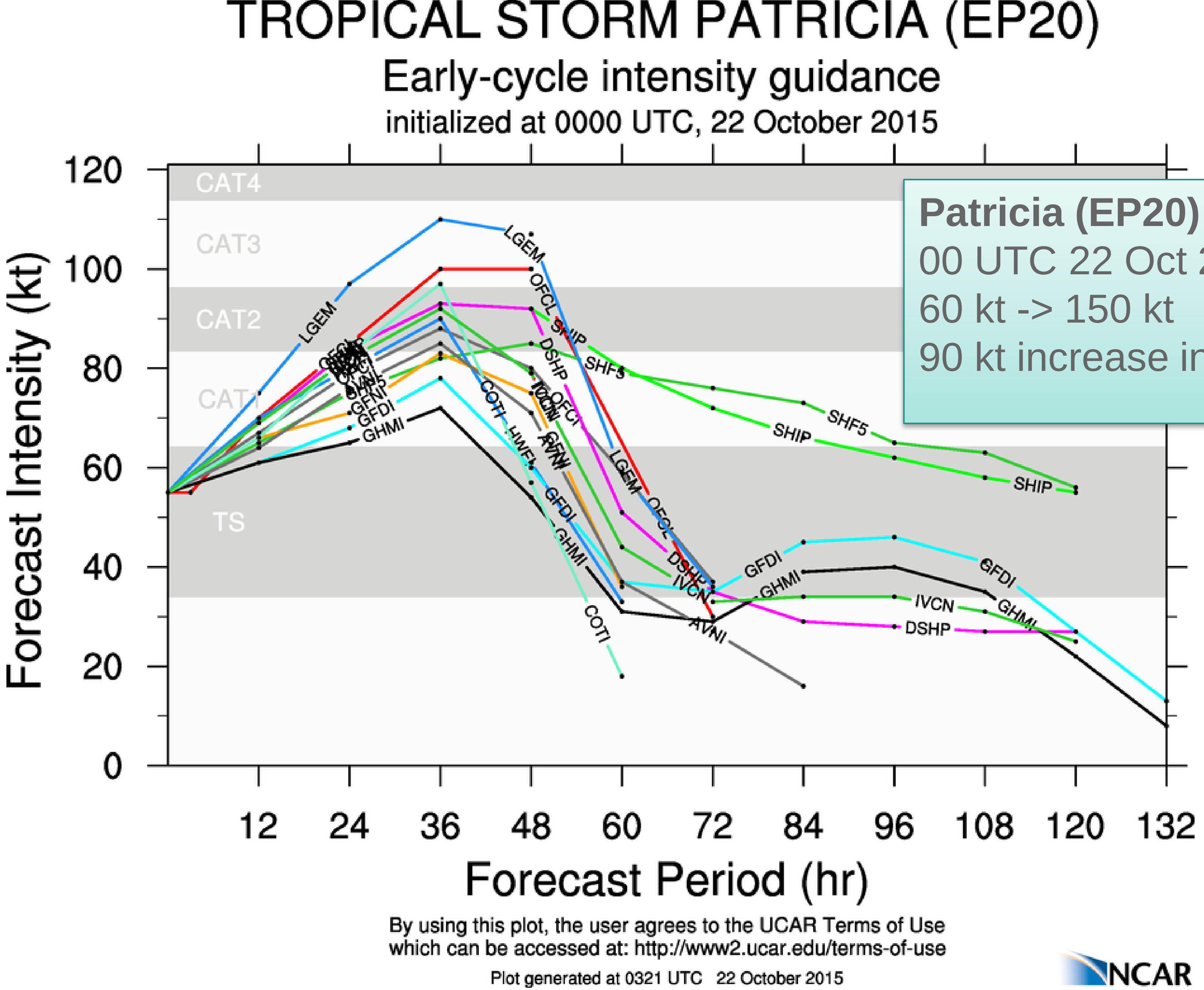
Can we improve upon current models with a new prediction framework which accounts for the probabilistic nature of RI?

Objectives of Current Work

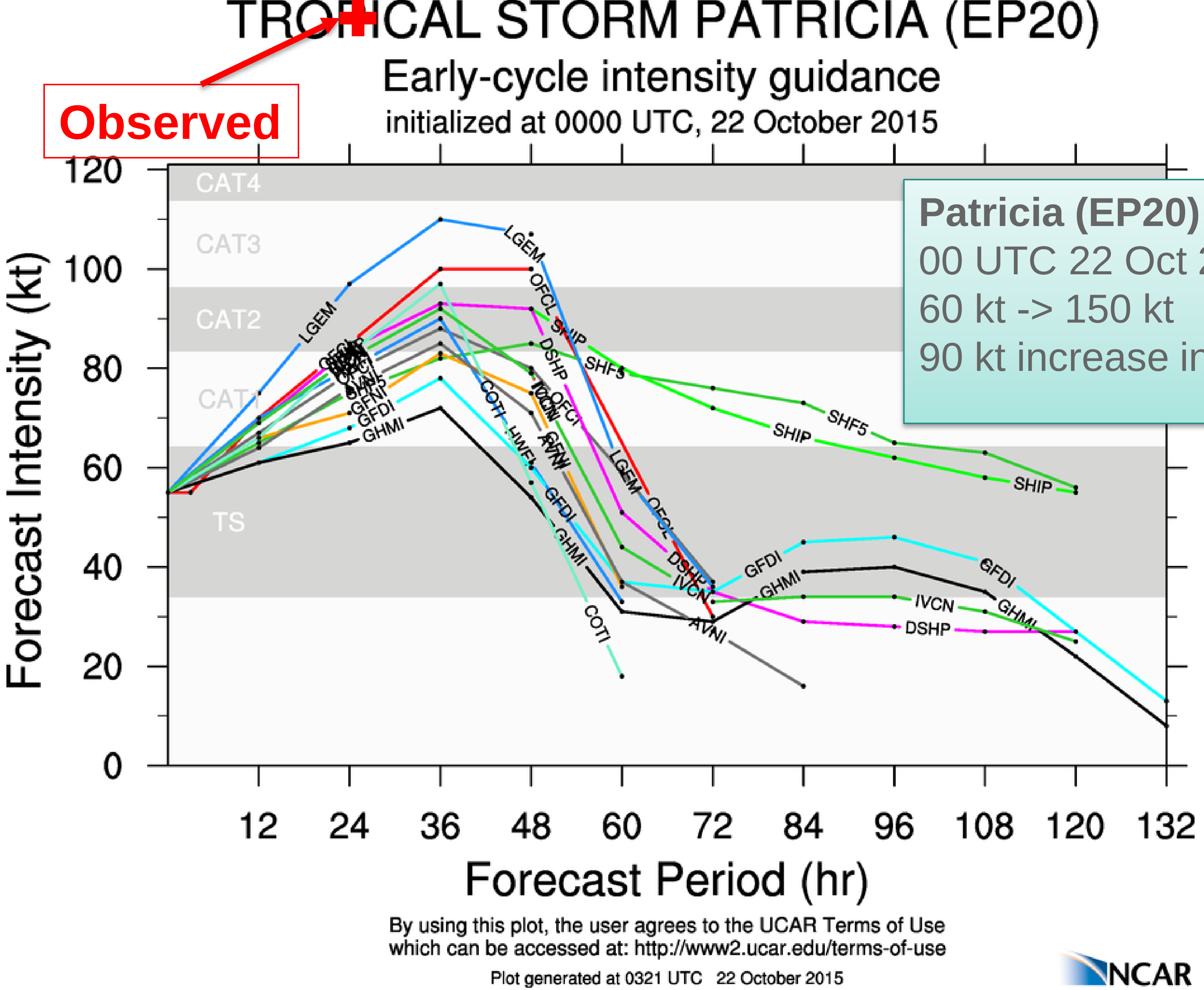
1. Formulate a post-processing framework that combines existing forecast aids in a way that accounts for the probabilistic nature of RI

2. Demonstrate that such performance can be potentially useful for improving deterministic predictions of RI

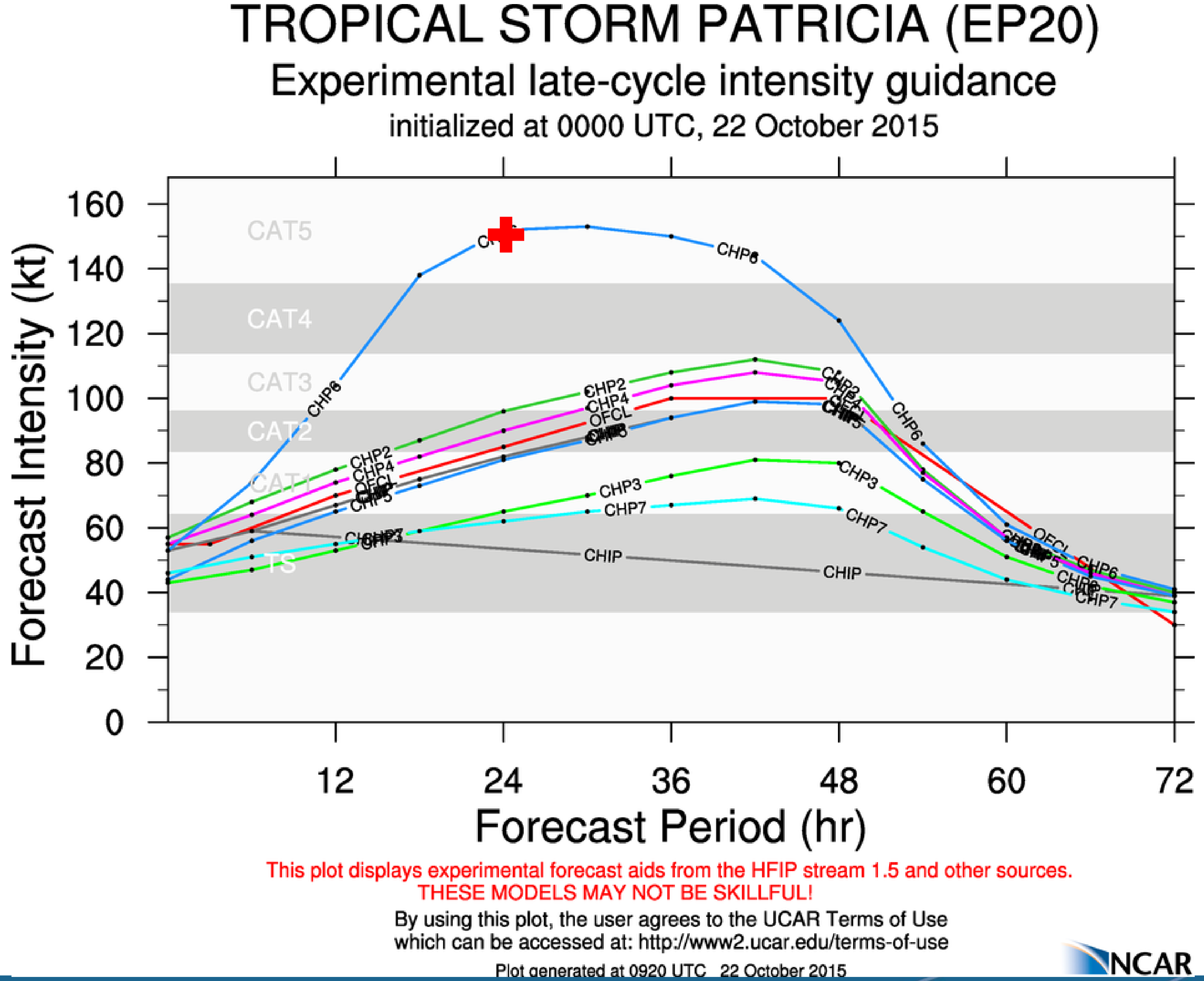
3. Such a framework should improve upon the reference model's Probability of Detection (POD) for RI without introducing large biases or significantly increasing the False Alarm Rate

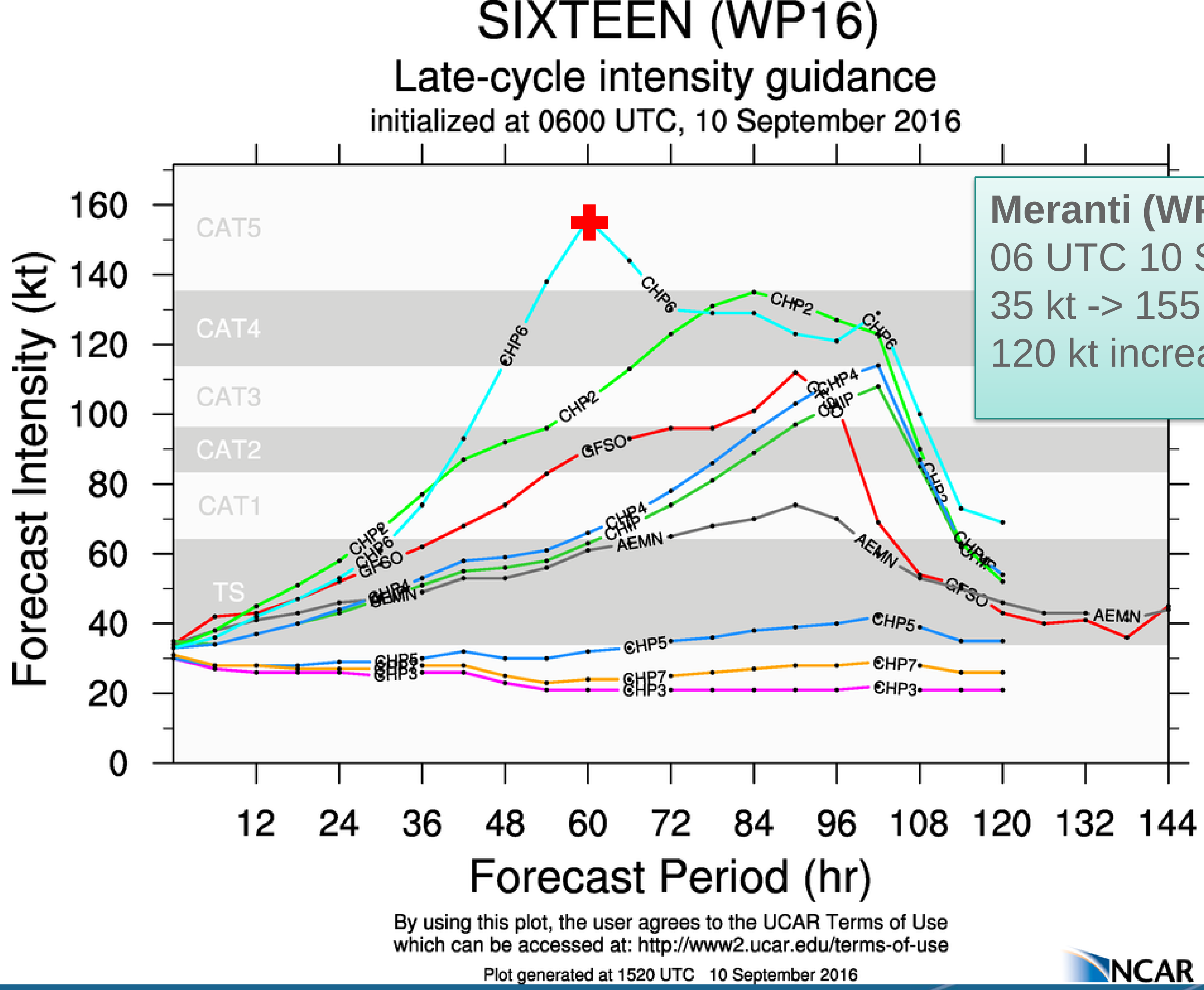


Patricia (EP20)
00 UTC 22 Oct 2015
60 kt -> 150 kt
90 kt increase in 24 h



Patricia (EP20)
00 UTC 22 Oct 2015
60 kt -> 150 kt
90 kt increase in 24 h


TROPICAL STORM PATRICIA (EP20)
Experimental late-cycle intensity guidance
initialized at 0000 UTC, 22 October 2015
Forecast Intensity (kt)
0
20
40
60
80
100
120
140
160
CAT5
CAT4
CAT3
CAT2
CAT1
TS
CHP6
CHP2
CHP4
OFCL
CHP5
CHP3
CHP7
CHIP
12
24
36
48
60
72
Forecast Period (hr)
This plot displays experimental forecast aids from the HFIP stream 1.5 and other sources.
THESE MODELS MAY NOT BE SKILLFUL!
By using this plot, the user agrees to the UCAR Terms of Use
which can be accessed at: http://www2.ucar.edu/terms-of-use
Plot generated at 0920 UTC 22 October 2015
NCAR



Meranti (WP16)
06 UTC 10 Sep 2016
35 kt -> 155 kt
120 kt increase in 60 h

Generalized Rapid Intensification Prediction Framework (GRIP) Components

- **Reference model**
  - Any model that generally does well at deterministic intensity prediction
  - Does not need to be good at predicting RI
  - Candidates:
    - HWRF
    - Consensus aids such as HCCA and IVCN

- **Upper bound model**
  - Coupled Hurricane Intensity Prediction Scheme (CHIPS, Emanuel et al. 2004) ensemble
    - Member 6 - CHP6: initial intensity enhanced by 3 m/s in previous 24-hr period (ramped up) with vertical wind shear set to zero at all times
  - Provides a time-varying plausible upper bound for the intensity forecast
  - An alternative upper bound model could be provided by FHLO or a full physics ensemble

- **Probabilistic RI model**
  - Hurricane LOGistic Regression Model (HLOG) **MacDaniel et al. 2021, 4B.10 3:50 PM May 10**

GRIP Configurations

- **Naïve baseline for comparison**
  - GBHC: Simple average of HWRF and CTCX
- **Weighted averages with fixed weights (half GRIP)**
  - GH6N: HWRF with CHP6 upper bound at fixed blending percentages varying from 10-90%: GH6[0-9]
  - GC6N: HCCA with CHP6 upper bound at fixed blending percentages varying from 10-90%: GC6[0-9]
  - GI6N: IVCN with CHP6 upper bound at fixed blending percentages varying from 10-90%: GI6[0-9]
- **Full complexity GRIP**
  - GH6L: HWRF with CHP6 upper bound with varying blending percentage based on HLOG RI probabilities
  - GC6L: HCCA with CHP6 upper bound with varying blending percentage based on HLOG RI probabilities
  - GI6L: IVCN with CHP6 upper bound with varying blending percentage based on HLOG RI probabilities

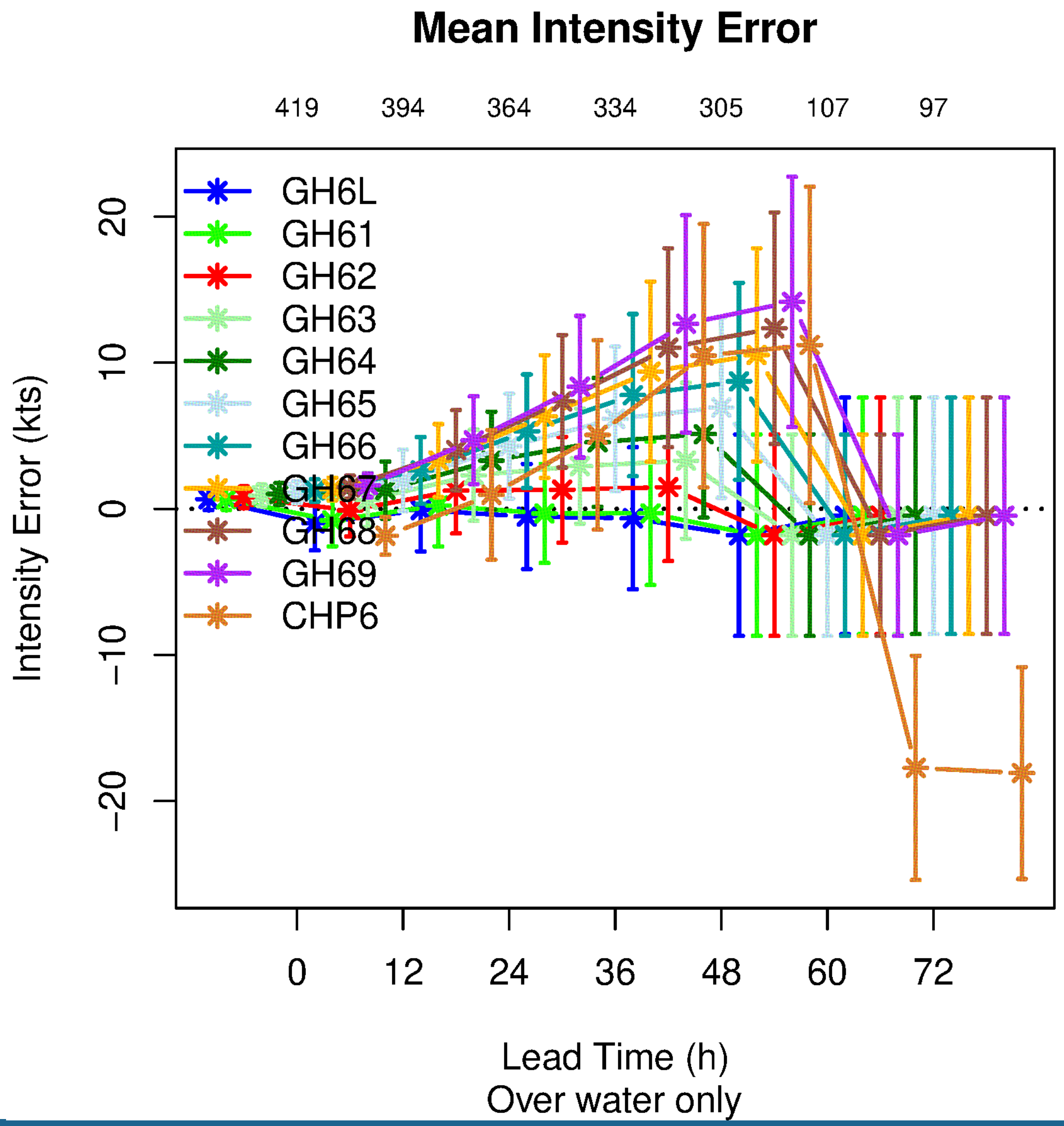
NOTES

- the full complexity GRIP forecasts are only available 2018-2019 due to limitations on HLOG availability
- HLOG currently only provides the probability of RI at 24 h

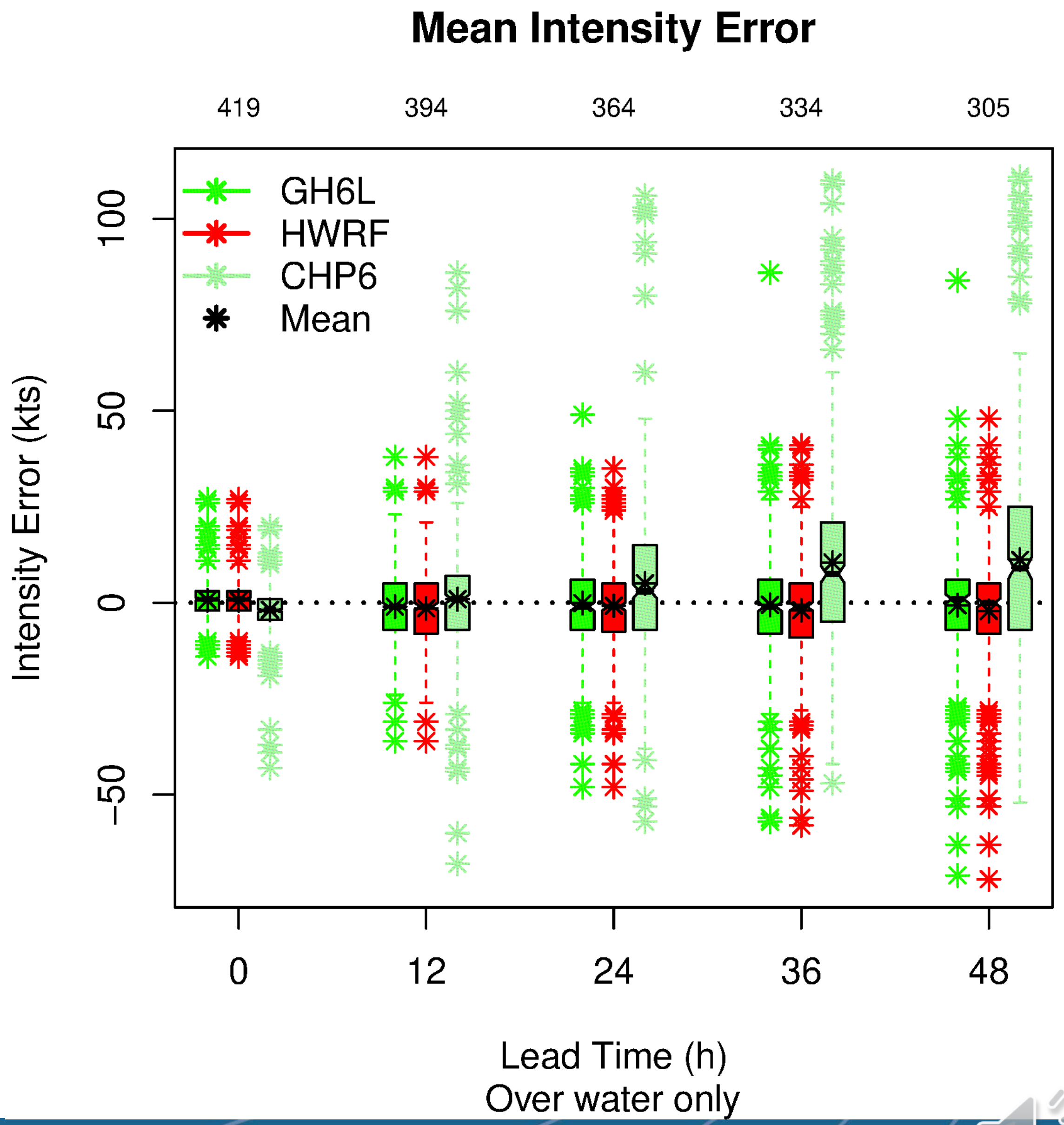
Verification Protocol

- Atlantic-only storms
- Post-season best tracks from NHC/JTWC for 2013-2016
- Post-season best tracks from NHC for 2016-2019
- Provisional best tracks for 2020
- Over water (land cases excluded)

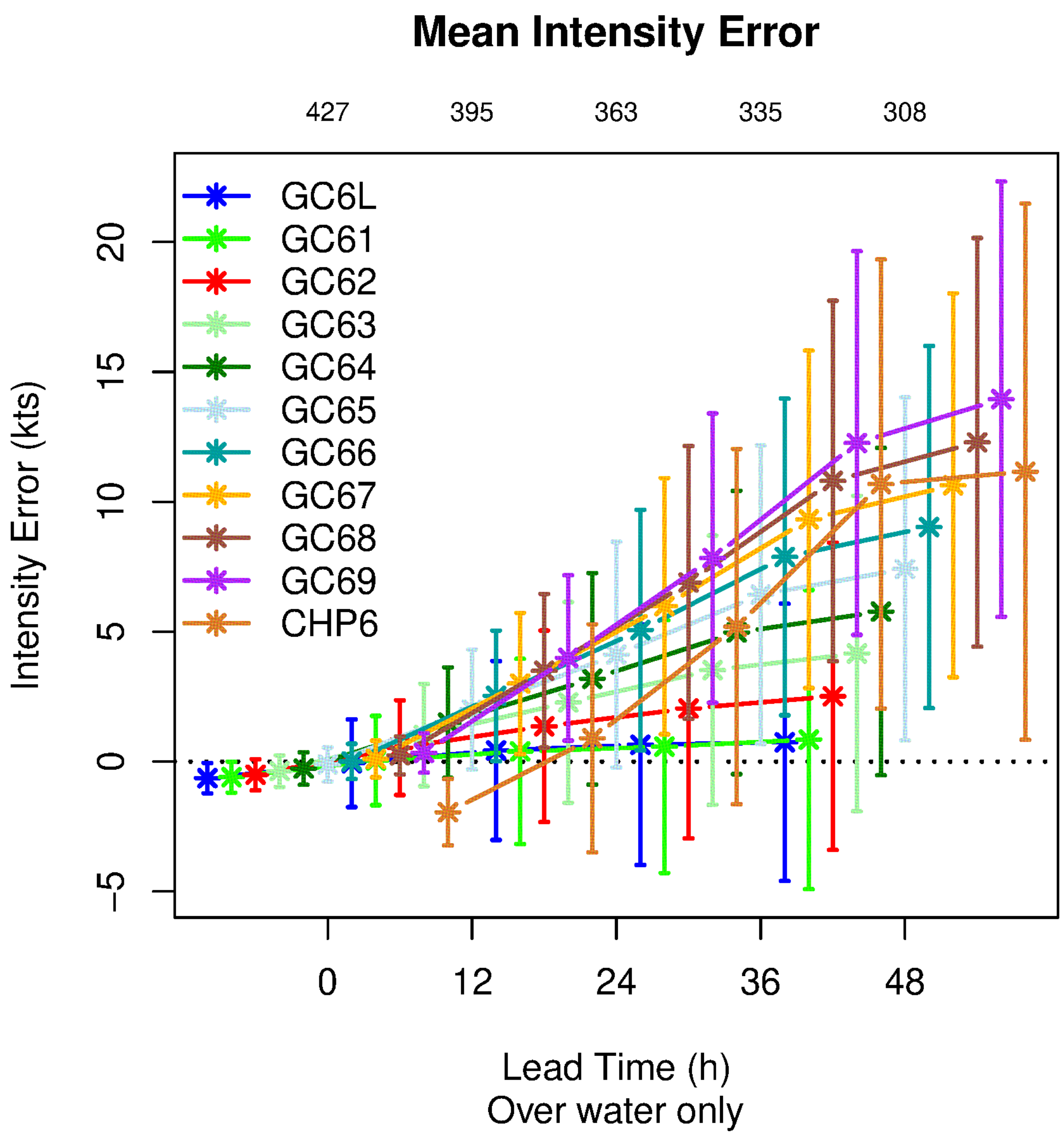
- Models included for comparison: HWRF, HCCA, IVCN, CHP6, CTCX, OFCL
- **Used the Model Evaluation Toolkit for Tropical Cyclones (MET-TC) v9.1**

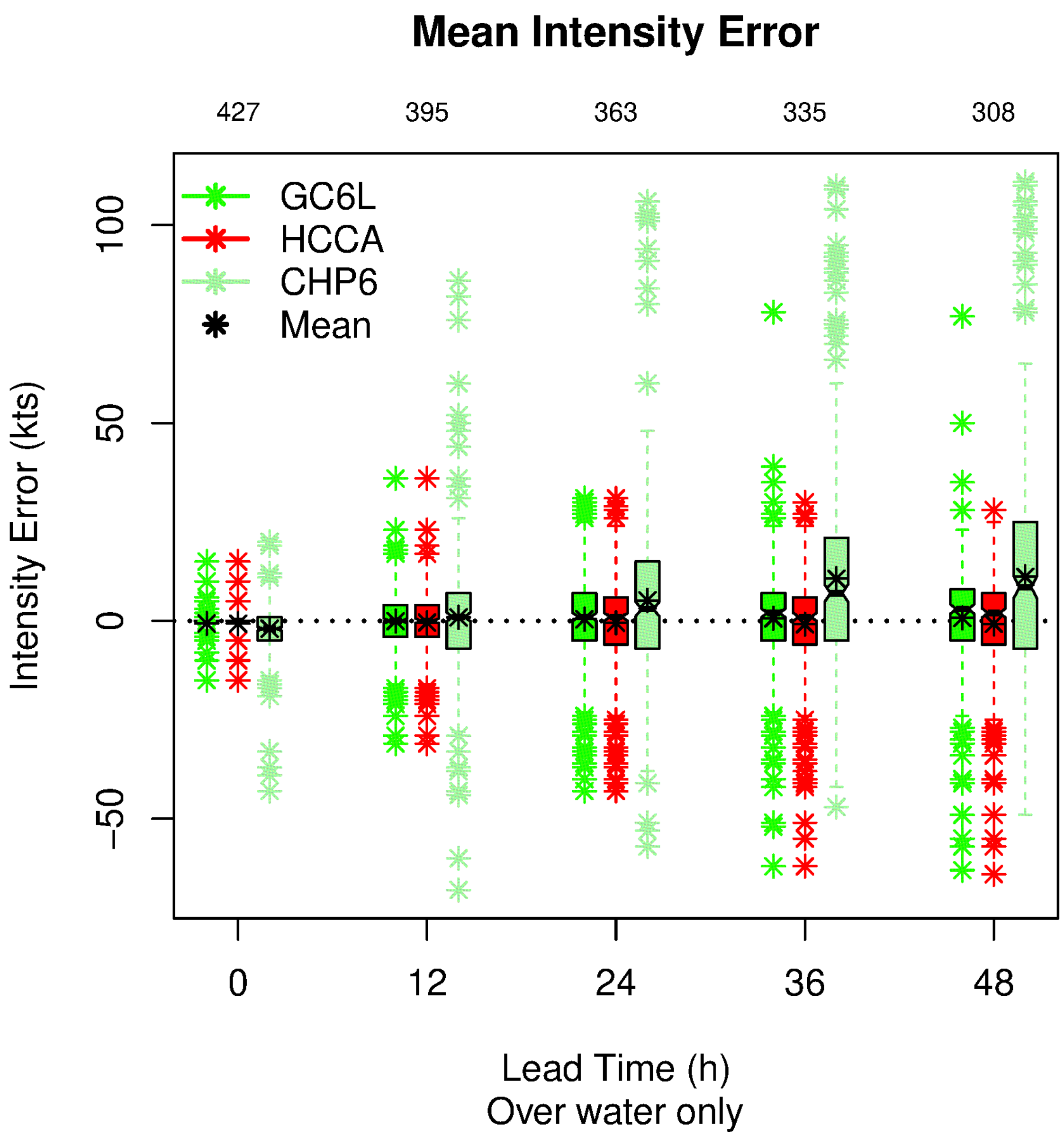


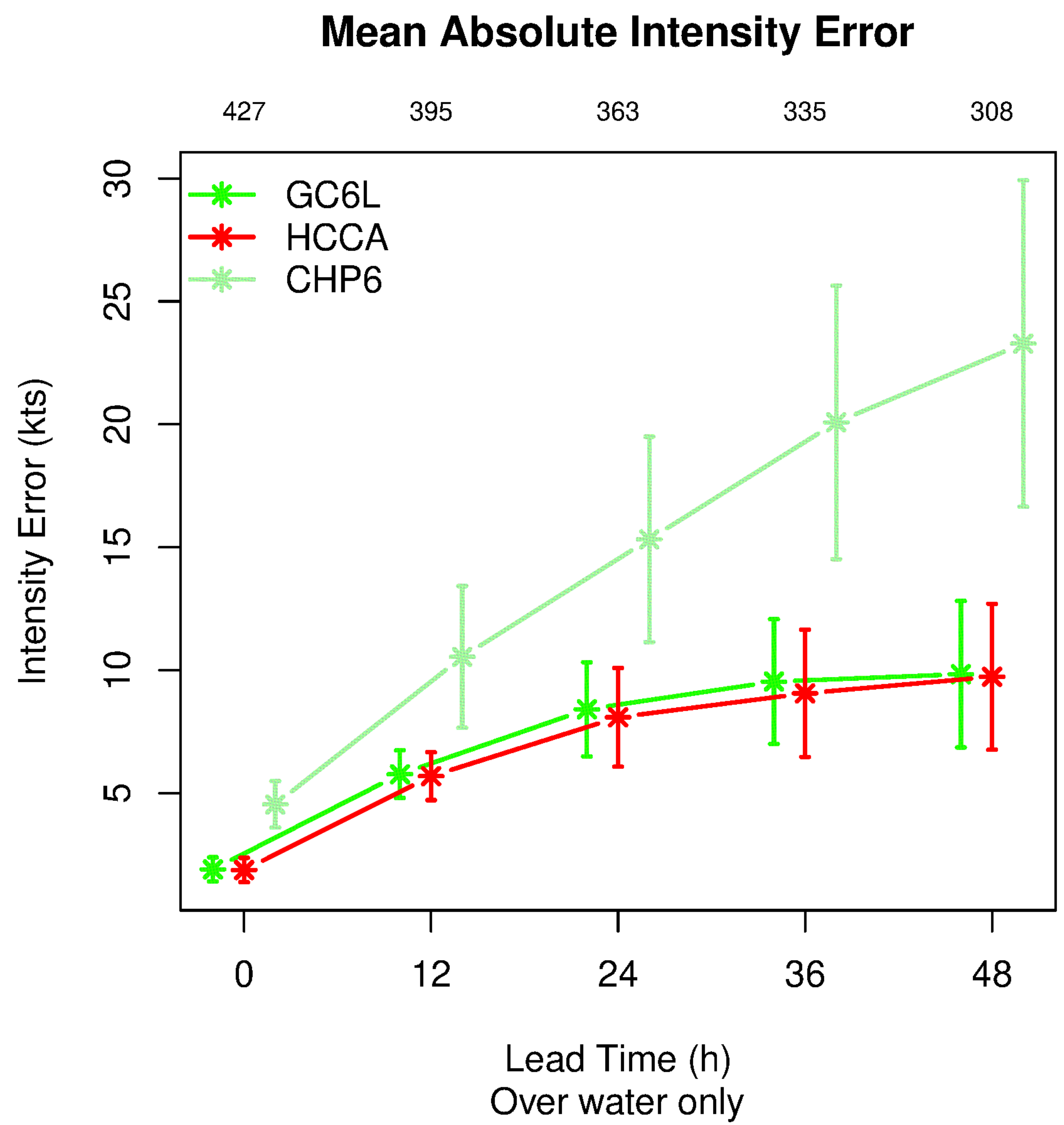
Mean Intensity Error
419
394
364
334
305
107
97
GH6L
GH61
GH62
GH63
GH64
GH65
GH66
GH67
GH68
GH69
CHP6
Intensity Error (kts)
20
10
0
−10
−20
0
12
24
36
48
60
72
Lead Time (h)
Over water only

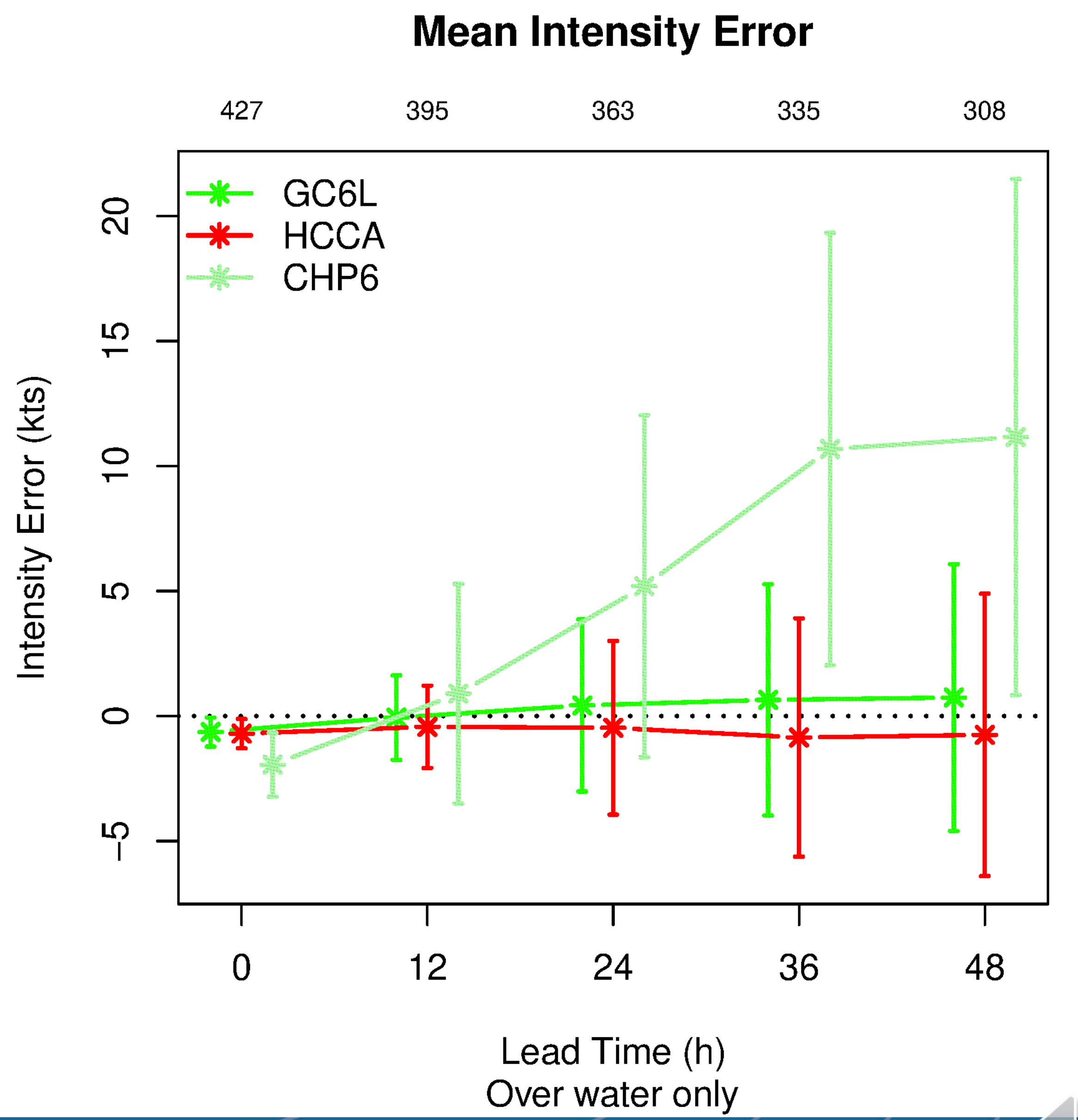


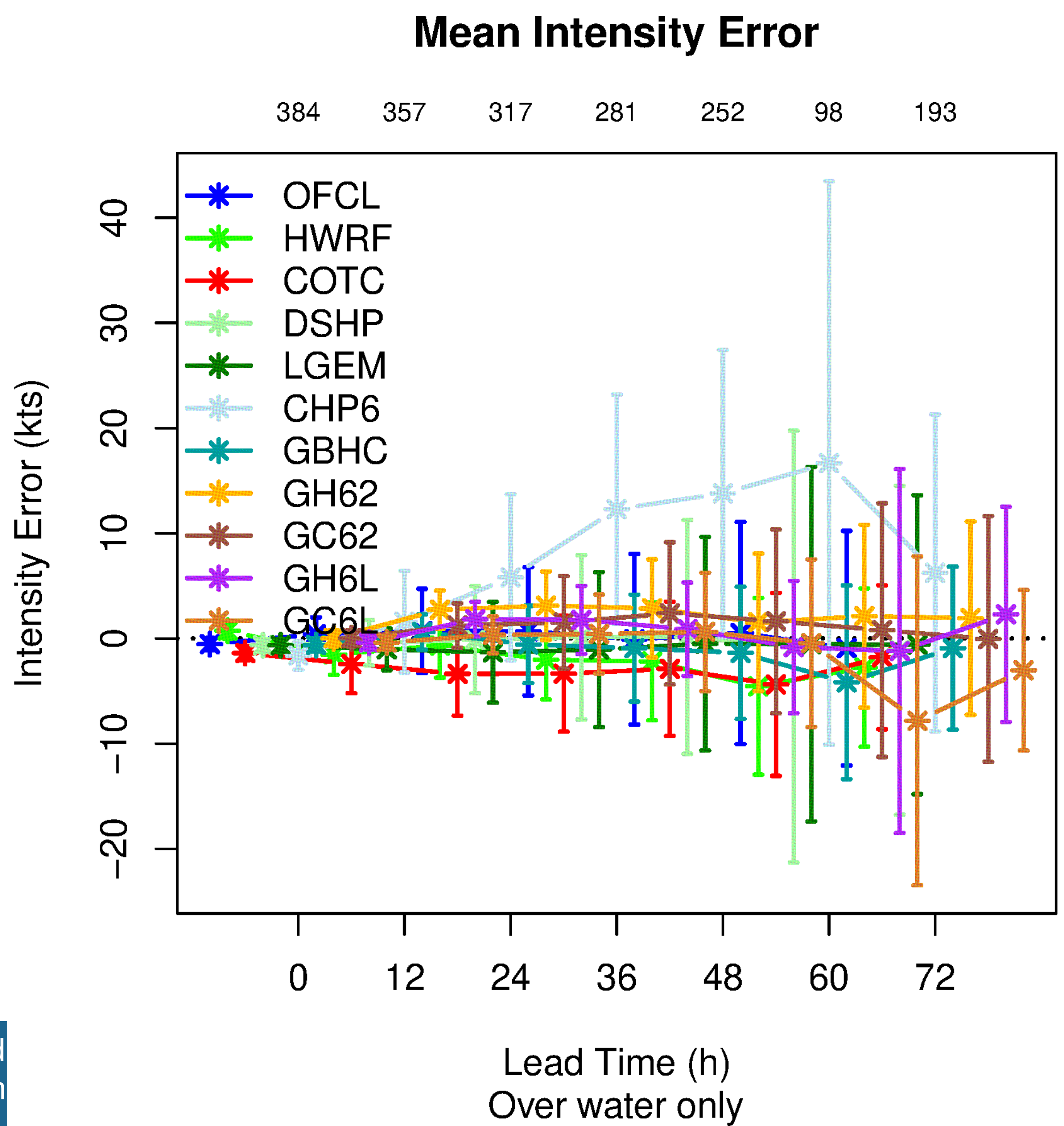
Mean Intensity Error
419
394
364
334
305
GH6L
HWRF
CHP6
Mean
Intensity Error (kts)
100
50
0
−50
0
12
24
36
48
Lead Time (h)
Over water only


Mean Intensity Error
427
395
363
335
308
GC6L
GC61
GC62
GC63
GC64
GC65
GC66
GC67
GC68
GC69
CHP6
Intensity Error (kts)
−5
0
5
10
15
20
0
12
24
36
48
Lead Time (h)
Over water only


Mean Intensity Error
427
395
363
335
308
GC6L
HCCA
CHP6
Mean
Intensity Error (kts)
−50
0
50
100
0
12
24
36
48
Lead Time (h)
Over water only


Mean Absolute Intensity Error
427
395
363
335
308
GC6L
HCCA
CHP6
Intensity Error (kts)
5
10
15
20
25
30
0
12
24
36
48
Lead Time (h)
Over water only


Mean Intensity Error
427
395
363
335
308
GC6L
HCCA
CHP6
Intensity Error (kts)
−5
0
5
10
15
20
0
12
24
36
48
Lead Time (h)
Over water only

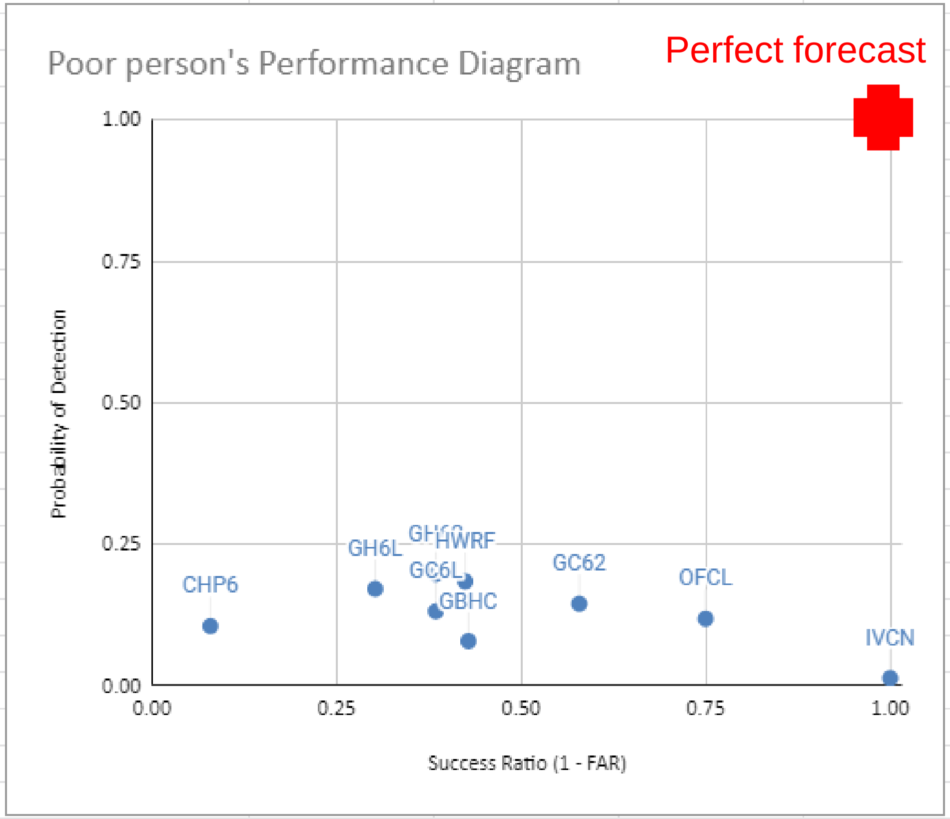

Mean Intensity Error
384
357
317
281
252
98
193
OFCL
HWRF
COTC
DSHP
LGEM
CHP6
GBHC
GH62
GC62
GH6L
GC6L
Intensity Error (kts)
40
30
20
10
0
−10
−20
0
12
24
36
48
60
72
Lead Time (h)
Over water only

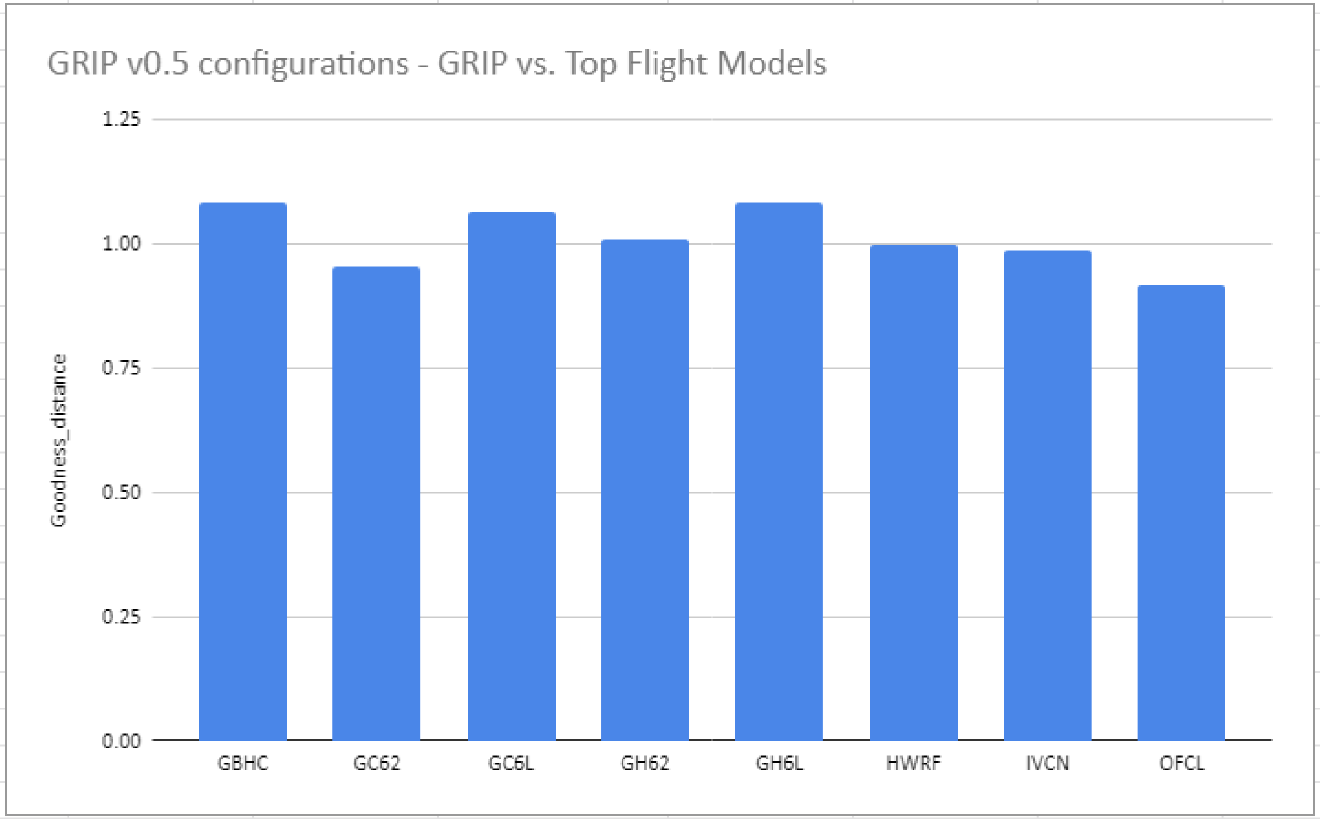
GRIP v0.4 - GRIP with top-flight models | 1011 cases | 2018-2019 | Atlantic only

Data source	irma:/d1/biswas/hfip-eval/OFCL_HWRF_COTC_DSHP_LGEM_CHP6_GBHC_GH62_GC62_GH6L_GC6L/OFCL_HWRF_COTC_DSHP_LGEM_CHP6_GBHC_GH62_GC62_GH6L_GC6L_water_only_
Verification protocol	standard NHC VX rules
RI threshold	30 kt in 24 h

Values that are input by hand

	PODY	FAR	FBIAS	1 - POD	SR	Bias sign	Goodness_distance	GSS	CSI
CHP6	0.10526	0.92079	1.32895	0.89474	0.07921	1	1.283905718	0.0025248	0.047337
GBHC	0.078947	0.57143	0.18421	0.921053	0.42857	1	1.083914606	0.059647	0.071429
GC62	0.14474	0.42105	0.25	0.85526	0.57895	1	0.9532852512	0.11592	0.13095
GC6L	0.13158	0.61538	0.34211	0.86842	0.38462	1	1.06435231	0.089349	0.1087
GH62	0.19737	0.61538	0.513166	0.80263	0.38462	1	1.011388877	0.12433	0.15
GH6L	0.17105	0.69767	0.56579	0.82895	0.30233	1	1.083467365	0.095045	0.12264
HWRF	0.18421	0.57576	0.43421	0.81579	0.42424	1	0.9985053338	0.12451	0.14737
IVCN	0.013158	0	0.013158	0.986842	1	1	0.986842	0.012181	0.013158
OFCL	0.11842	0.25	0.15789	0.88158	0.75	1	0.9163423467	0.10369	0.113992



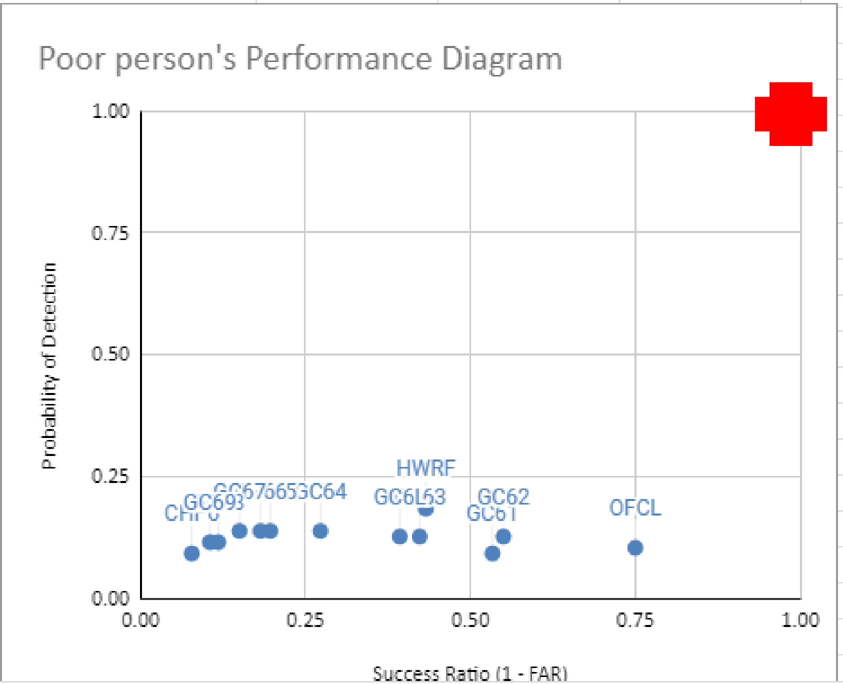


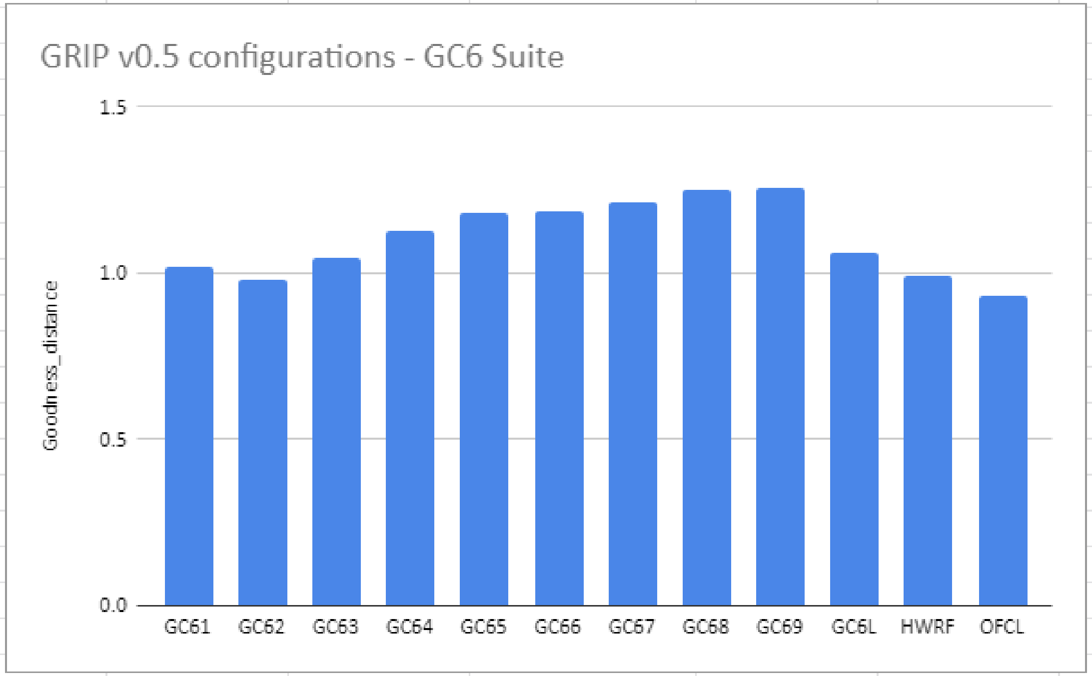
GRIP v0.4 - GC6 Suite | 1228 cases | 2018-2019 | Atlantic only

Data source	irma:/d1/biswas/hfip-eval//d1/biswas/hfip-eval/OFCL_HWRF_CHP6_GC61_GC62_GC63_GC64_GC65_GC66_GC67_GC68_GC69_GC6L/OFCL_HWRF_CHP6_GC61_GC
Verification protocol	standard NHC VX rules
RI threshold	30 kt in 24 h

Values that are input by hand

	PODY	FAR	FBIAS	1 - POD	SR	Bias sign	Goodness_distance	GSS	CSI
CHP6	0.09195	0.92233	1.18391	0.90805	0.07767	1	1.294313498	0.0040227	0.043956
GC61	0.09195	0.46667	0.17241	0.90805	0.53333	1	1.020948427	0.074645	0.085106
GC62	0.12644	0.45	0.22989	0.87356	0.55	1	0.982653079	0.10132	0.11458
GC63	0.12644	0.57692	0.29885	0.87356	0.42308	1	1.046873326	0.091435	0.10784
GC64	0.13793	0.72727	0.50575	0.86207	0.27273	1	1.12786805	0.076653	0.10084
GC65	0.13793	0.80328	0.70115	0.86207	0.19672	1	1.178313814	0.058311	0.088235
GC66	0.13793	0.81818	0.75862	0.86207	0.18182	1	1.188521433	0.053726	0.085106
GC67	0.13793	0.85	0.91954	0.86207	0.15	1	1.210646391	0.042404	0.077419
GC68	0.11494	0.88235	0.97701	0.88506	0.11765	1	1.249749065	0.025504	0.061728
GC69	0.11494	0.89474	1.095195	0.88506	0.10526	1	1.258527263	0.01793	0.05814
GC6L	0.12644	0.60714	0.32184	0.87356	0.39286	1	1.063826139	0.088381	0.10577
HWRF	0.18391	0.56757	0.42529	0.81609	0.43243	1	0.9940516048	0.12696	0.14815
OFCL	0.10345	0.25	0.13793	0.89655	0.75	1	0.9307534058	0.09147	0.1





Summary

1. Formulate a post-processing framework that combines existing forecast aids in a way that accounts for the probabilistic nature of RI

- GRIP framework has been developed to combine the best attributes of multiple forecast input sources.
- GRIP combines the proven general intensity forecast skill of existing 3-d full physics models with the substantial skill in predicting RI provided by probabilistic forecast techniques.

2. Demonstrate that such performance can be potentially useful for improving deterministic predictions of RI

- Several GRIP candidates show potential in this regard.
- In particular, GC6L demonstrates that application of the GRIP framework can maintain the quality of HCCA's consistent deterministic forecasts while improving its performance during RI.

3. Such a framework should improve upon the reference model's Probability of Detection (POD) for RI without introducing large biases or significantly increasing the False Alarm Rate

- Early generation GRIP candidates do not yet show a significant improvement for RI, but this may be due to our limited options for probabilistic forecast aid (just HLOG and only for 24 h).
- Need to evaluate intensity error characteristics during RI episodes and examine case studies.

Future work

1. Develop GRIP configurations with existing operational probabilistic RI models such as SHIPS-RII, Analog Ensemble (via ATCF e-decks)

2. Run for other basins (e.g,. Western Pacific) and compare to other probabilistic -> deterministic schemes (e.g., RIPA)

3. Develop an internally consistent version of GRIP that is based entirely from FHLO
   Use FHLO's mean as reference, 99th %-ile as upper bound, FHLO's % of members undergoing RI as the probabilistic component

4. Develop an extended version of the GRIP framework which incorporates forecast information from one or more global ensemble prediction systems

Acknowledgments and References

Questions / comments:
jvigh@ucar.edu

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