Evaluating the Impact of Improved Track and Intensity Forecasts on Hurricane Watches and Warnings

Mark DeMaria, NOAA/NESDIS/StAR
Andrea Schumacher, CIRA/CSU
Dan Brown and Ed Rappaport, NHC

HFIP Workshop, 4-8 May 2009

Motivation

- Generally accepted that improvements to hurricane forecasts will benefit society
  - Longer lead times → more time to prepare
  - Better track forecasts → reduce areas warned and/or evacuated unnecessarily
- However, *quantifying* these benefits is a difficult task
  - How much will warning area be reduced?
  - How much money will a better forecast save?
  - How many lives could be saved?

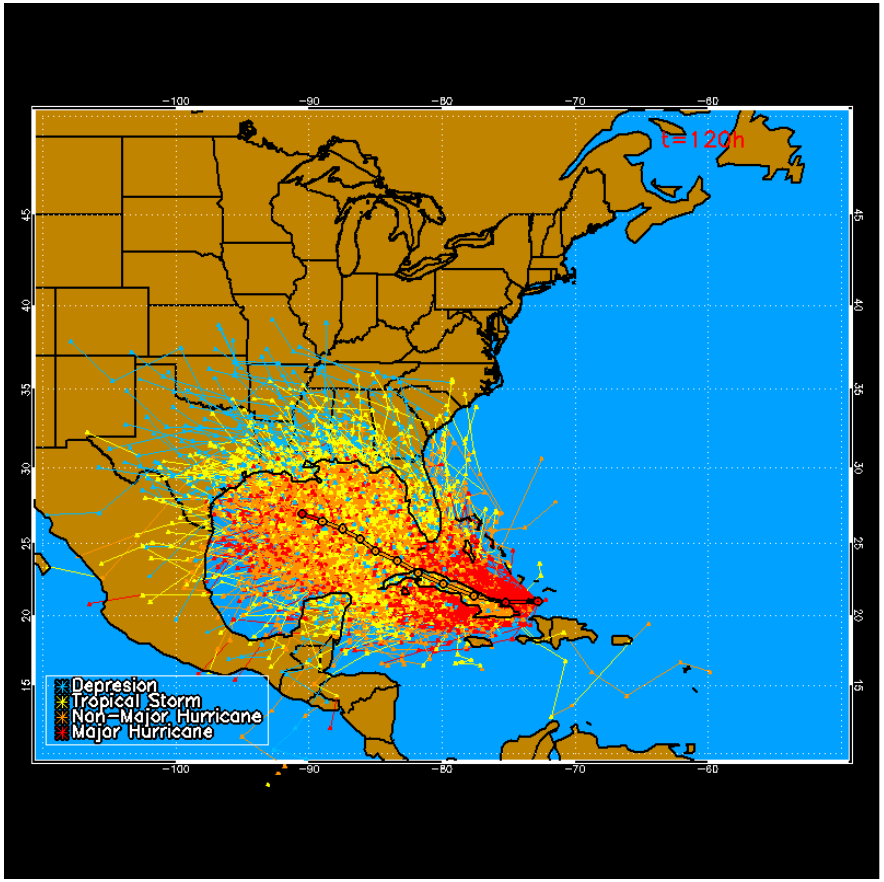
Project Outline

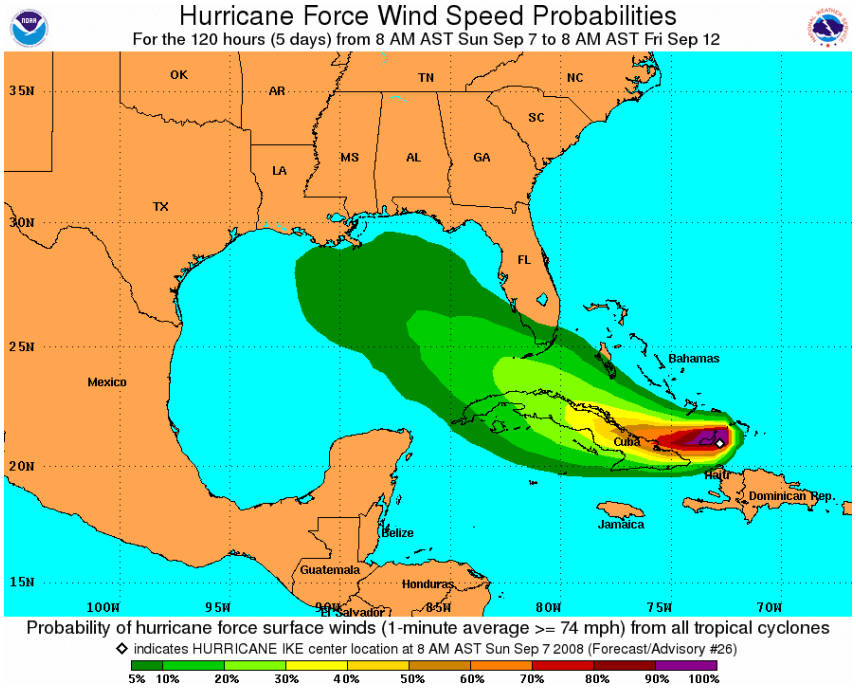
- Use wind speed probability model to…
  - Develop an objective warning scheme that reasonably simulates official NHC warnings (building off previous work by M. Mainelli and M. DeMaria)
  - Artificially “improve” input forecasts, use warning scheme to diagnose changes in *warning properties*
- Warning properties considered (links to societal benefits)
  - Coastal distance
  - Duration

Monte Carlo Wind Speed Probability Model

- Operational at NHC since 2006 (replaced Strike Probability Program)
- Methodology
  - Samples errors from NHC track and intensity forecasts over last 5 years to generate 1,000 forecast realizations
  - Wind radii of realizations from radii CLIPER model
  - Calculates probabilities over domain from realizations
- Versions for Atlantic, NE and NW Pacific
- Current products
  - Cumulative and incremental probabilities
  - 34, 50 and 64 kt winds
  - 0, 12, …, 120 hr
  - Text and graphical products
  - Distributed via NHC web page, NDFD, AWIPS

Monte Carlo Wind Speed Probability Model





64 kt 0-120 h Cumulative Probabilities

Step 1:

Develop an objective hurricane warning scheme that simulates NHC warnings

Methodology –Objective Hurricane Warning Scheme

- Rerun MC probability model
  - Used 64-kt (hurricane force) wind probabilties
  - Used 36-h cumulative probabilities (best match for NHC hurricane warning criteria)
  - U.S. mainland hurricane warnings from 2004-2008 (20 tropical cyclones)
  - 343 breakpoints
- Choose wind speed probability thresholds
  - $p > p_{up}$ –> put warning up
  - $p < p_{down}$ –> take warning down

Scheme Validation - Statistics

First Guess (prior work, Mainelli/DeMaria) : p_{up} = 10.0%, p_{down} = 2.0%

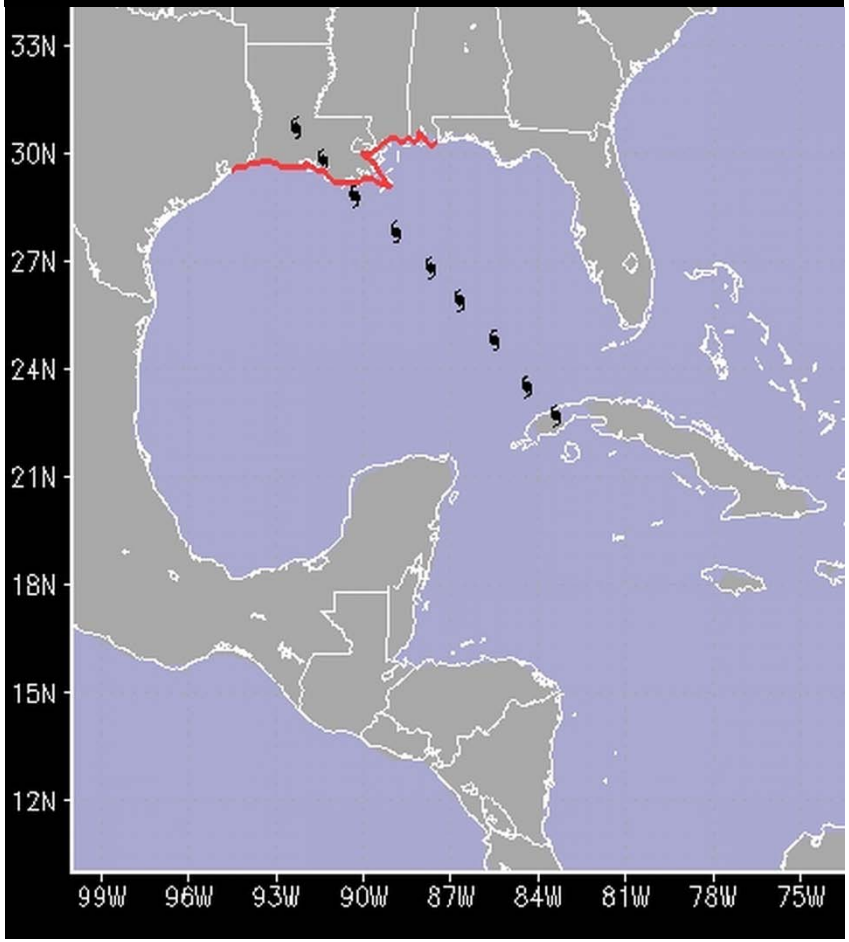
Best fit (MAE, R^2, POD, no misses) : p_{up} = 8.0%, p_{down} = 0.0%

	MCP	NHC
Average Distance Warned (mi)	378.6	381.5
Average Warning Duration (hr)	33.6	32.4

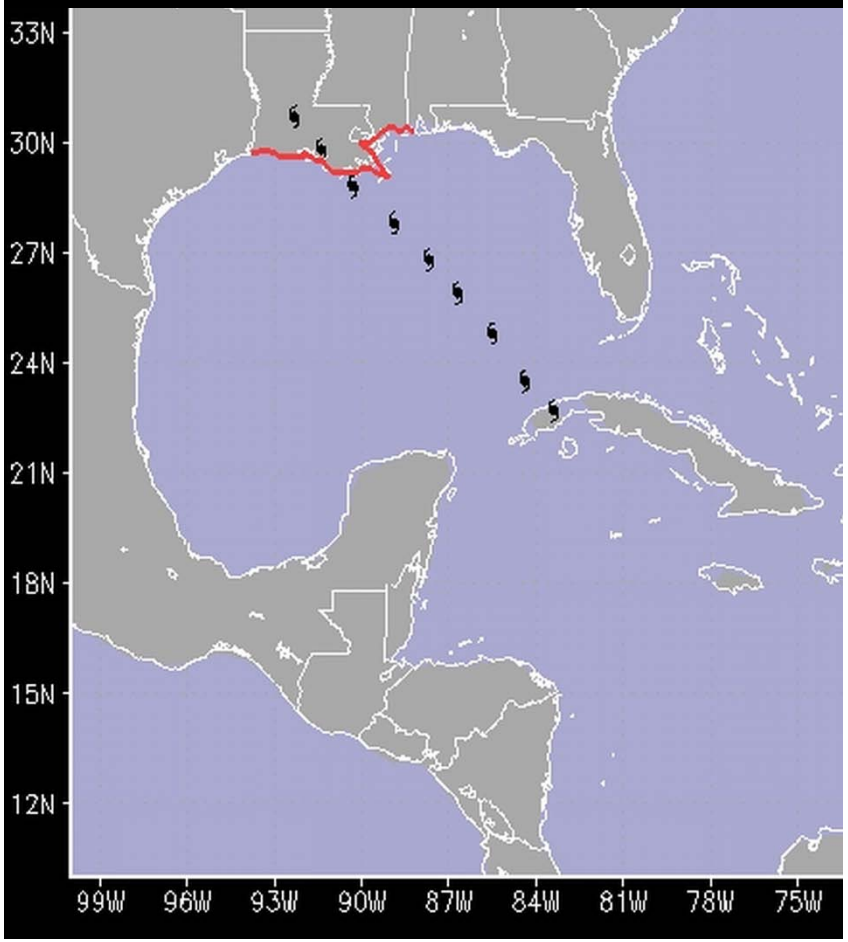
	MCP Objective vs. NHC
MAE, Distance (mi)	65
MAE, Duration (hr)	7
R^2, Distance	0.94
R^2, Duration	0.71
POD / FAR	0.83 / 0.16

Warning Scheme Performance Example: Hurricane Gustav 2008

NHC Hurricane Warning



Objective Scheme Warning



Scheme Validation – TC by TC

Step 2:

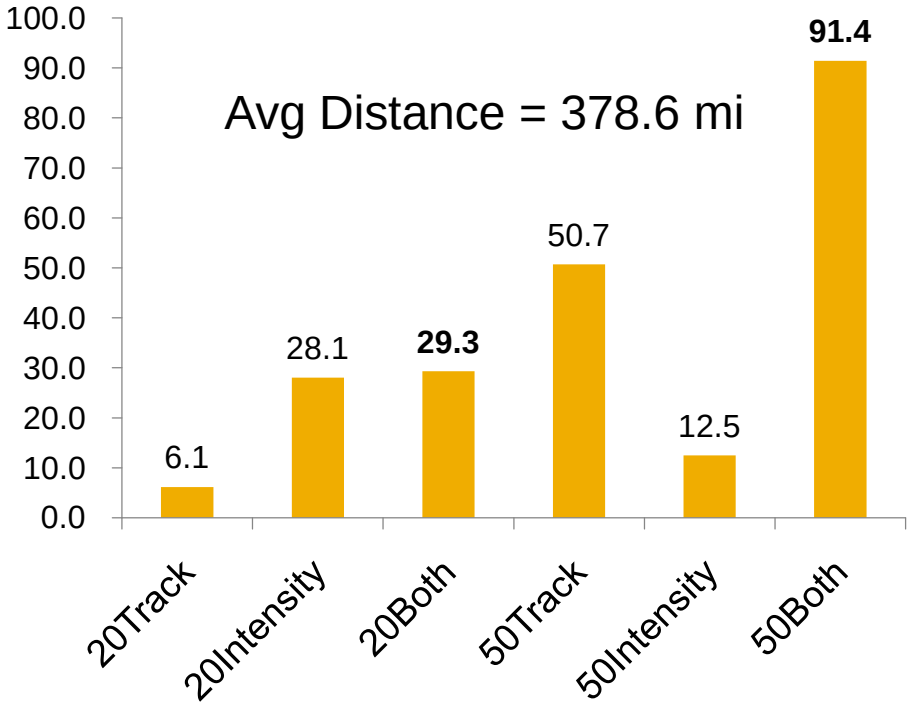
Artificially "improve" forecasts and apply warning scheme to examine changes in hurricane warning properties

Artificially "Improving" forecasts

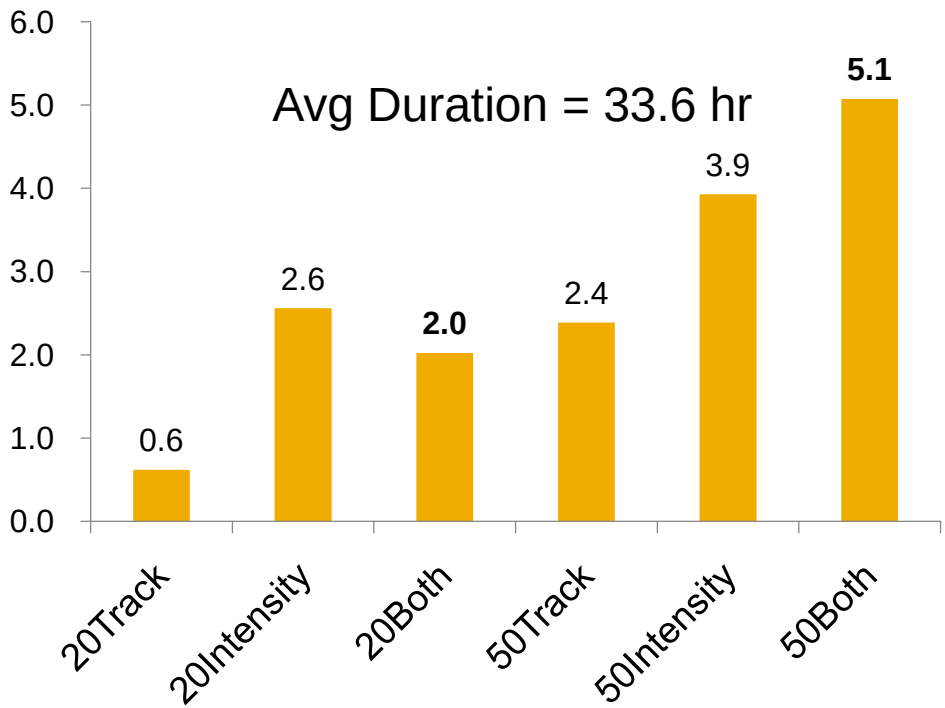
- Two steps needed
  - Use best tracks from ATCF to adjust tracks and intensities closer to observed values
  - Scale the sampled track (intensity) errors in the Monte Carlo scheme
- For this study, 20% and 50% error reductions used
- Apply objective hurricane warning scheme to MC wind speed probabilities based on "improved" forecasts

Resulting Warning Changes

Reduction in Coastal Distance of Warnings (mi)



Reduction in Duration of Warnings (hr)

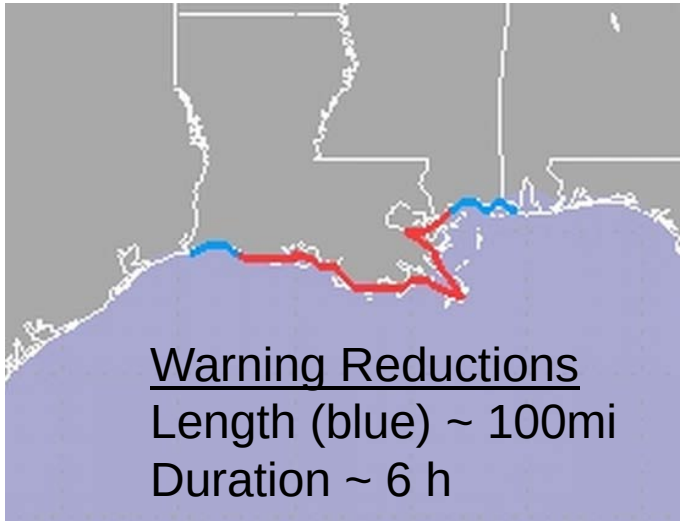


We're closer.. Developed relationship between forecast improvements and warning length & duration… but what are these worth to society?

Future Work – Case by case analysis

20% Track and Intensity Forecast Improvement

50% Track and Intensity Forecast Improvement



Million Dollar Question:

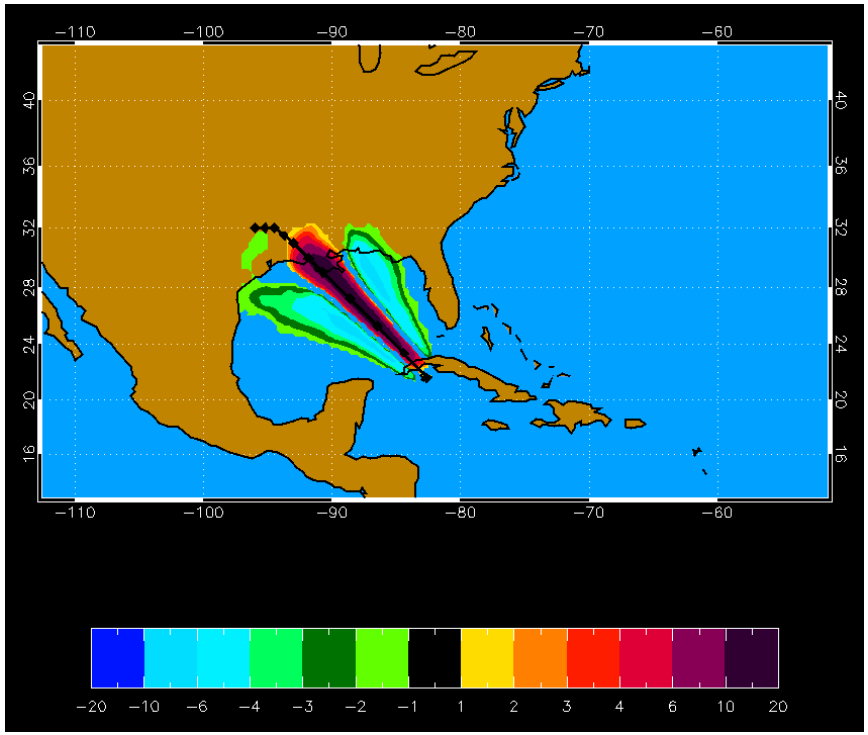
What is the socioeconomic cost of an over-warning (and hence what is saved by reducing over-warnings)?

Determining the cost of over-warning: An interdisciplinary problem

- Future work to focus on understanding the impacts of official hurricane warnings on…
  - Issuance of evacuations (EM's)
    - Would a reduced warning area lead to a reduced evacuation area?
  - Evacuation behavior
    - Important social science research topic, past and present
    - Requires understanding of risk perception and individual response
  - Cost of evacuations
    - Jarell and DeMaria 1999 suggested $600k/mile
    - Whitehead 2003 shows how variable this number is, depending on location
    - Researchers at the Hazard Reduction and Recovery Center at Texas A&M are collecting data on these costs, hope to integrate into the Emergency Management Decision Support System in the future (M. Lindell, personal communication)

MC Model Framework for Utilizing Ensemble Information

- New version of MC model being developed to utilize track model spread to refine probability distributions
  - NHC historical error distributions stratified into terciles of model spread
- Improved measures of uncertainty from HFIP work can be tested
- Provides direct feed from research into NHC operational probabilistic forecast products



64 kt wind cumulative probability changes due to model spread input
Hurricane Gustav (2008), low-spread case

Summary

- An objective hurricane warning scheme was developed
  - Scheme issues hurricane warnings when p>8% and lowers warnings when p=0%
  - Scheme simulates official NHC hurricane warnings from 2004-2008 relatively well
- 20-50% improvement in both track & intensity forecasts yields
  - 29-91 mile (5-13%) reduction in coastal length overwarned
  - 2-5 hr (8-24%) reduction in warning duration
- Future work to focus on quantifying the socioeconomic value of these warning reductions

References

- DeMaria, M., J. A. Knaff, R. Knabb, C. Lauer, C. R. Sampson, R. T. DeMaria, 2009: A New Method for Estimating Tropical Cyclone Wind Speed Probabilities. *Wea. Forecasting*, Submitted.
- Jarell, J.D. and M. DeMaria, 1999. An Examination of Strategies to Reduce the Size of Hurricane Warning Areas. *23rd Conference on Hurricanes and Tropical Meteorology*, Dallas, TX, 10-15 Janurary 1999.
- Lindell, M.K. and C.S. Prater, 2007: A hurricane evacuation management decision support system (EMDSS). *Natural Hazards*, 40, 627-634.
- Whitehead, J.C., 2003: One million dollars per mile? The opportunity costs of Hurricane evacuation. *Ocean and Coastal Management*, 46, 1069-1083.

HFIP Diagnostics Workshop Summary

Mark DeMaria and Naomi Surgi

Agenda Summary

- Operational input from NHC
- Atmospheric diagnostics
  - EMC, NESDIS, CSU, GFDL, ESRL
- New verification techniques
  - JNT/NCAR
- Land surface, ocean, flux studies
  - GFDL, ESRL, EMC, URI, RSMAS

Atmos Diagnostic Work Matrix

	Models	Diagnostic Types	Tools
NESDIS/CIRA	HWRF	Large-scale atmos., Ocean, atmos. Energetics and PV, synthetic IR imagery	IDL, fortran
NCEP/NHC	HWRF, GFS, GFDL	Large-scale, Vortex scale atmos.	N-AWIPS
NCEP/EMC	HWRF, GFS	Large and vortex scale atmos and ocean, CD/CE sensitivity	grads-based HPLOT
OAR/GFDL	HWRF, GFDL, GFS	Rainfall and vortex verification	fortran, grads?
OAR/ESRL/NCAR	GFS, FIM, ECMWF	Large-scale, Vortex scale atmos., advanced verification tech., synthetic IR imagery	"Open-grads" application, DTC model evaluation toolkit
AOML/HRD	HWRF-X	Large-scale, vortex scale, convective scale atmos.	Java/Worldwind(?)/grads interpolation/visualization/diagnostic package
FSU	ARW	Large-scale, vortex scale atmos., PV, dQ/dp, ang mom, div eqn.	Fortran, grads?

NHC Needs That May Require More Attention

- Guidance on Guidance
- Forecast reliability
- Predictability
- Ensemble applications
- *TC Genesis tracker, verification and diagnostics, with input from NHC*
- Methods to transition research tools to operations if appropriate

Discussion Issues

1. HFIP Baseline:
   - 20% improvement at all forecast intervals in 5 years
   - 50% in 10 years
   - Need to be defensible and reasonable
   - **Recommend using the current 3-year (2006-2008) NHC operational consensus (TVCN, ICON) error statistics**
   - **Predictability** limit? **Recommend pursuing more research to identify these limits**
   - Change absolute improvement to rate of improvement
   - Recommend running historically bad forecast storms with reanalysis
2. What data sets do we need to share and how do we do it? Who is responsible for what?
   - Archive HWRF (GFDL?) grib files for **atmosphere** & **ocean**
   - Current EMC capacity – run every 6 h, keep 6 h output with 1 h for rain
   - HWRF-X available in HRD database/visualization system
   - Need to keep fields for lifecycle – pre-storm, invest, mature, landfall
   - Spatial domains, resolution -
   - Temporal resolution – 6, 3, 1, 0.5 h
   - Where do we keep it?
   - **Recommend forming working group to come up with approach to address the needs within resource limitations (ESRL, NESDIS, NCEP, HRD, ?) – DeMaria, Rogers, Tallapragada, Kim, Fiorino, Pasch, Nance, Surgi, Yablonsky**

Discussion Issues (continued)

3. Need to address Tracker issues (how do we distribute tracker code to community
   - **Recommend support for implementing the tracker for the demo project this summer** – how do we support running tracker on any models we want to run this summer? Fiorino and Marchok will be focal points to coordinate use of tracker for demo project.
   - **Recommend including tracker with HWRF release to repository through DTC in February 2010**
4. What fields should we save?
   - No limitations for grib2 – can save anything we can imagine – not a technical issue
   - Limitations for operational model due to time and space available – may be able to turn on extra variables
   - **Recommend making available variables not in current operational grib files (vertical radiation profiles, vertical microphysical profiles for each species, non-hydrostatic pressure, HYCOM (POM?) ocean) if at all possible**

Discussion Issues (continued)

5. Software tools – how do we share and utilize (for operations, research)?
    - Open source, AWIPS-II (Red Hat Enterprise Linux, Java, netCDF4, HDF5) compatible – need to be consistent with NHC plans – grib2 converted to netcdf4 for AWIPS II
    - NHC has beta version of AWIPS II under development - Chris Lauer POC
    - **Recommend stick to NHC operational path for model fields and applications**
    - POC for software tools – to insure no duplication of effort
        - HPLOT (GrADS)– Tallapragada & Marchok
        - HRD visualization system – Gopal (Thiago)
        - Diapost GrADS scripts - Rogers
        - OpenGrADS extensions – Fiorino
        - COAMPS tools – Hao
        - DTC MET – Brown
        - Ocean model tools (MatLab/Octave) – Kim & Yablonsky
        - Recommend developing openGrADS extension library for as many of the GrADS applications (HPLOT, HRD Diapost, ESRL extensions) – Fiorino, Rogers, Marchok
    - **Recommend involvement in AWIPS II beta program – DeMaria POC**

Discussion Issues (continued)

6. Collaborations and responsibility
    - Ensure no duplication of effort
    - Ongoing collaborations and coordination
        - EMC – weekly HWRF meetings (telecon) includes J.-W. Bao, Ginis, HYCOM team – noon-1 PM EST – POC Tallapragada
        - HRD – monthly model meeting 3rd Thursday every month (VTC, telecon, gotomeeting) – coordinate with EMC HWRF weekly meeting. Includes ESRL, DTC, FSU, RSMAS, NPS, NHC, ? – POC Gopal
        - HRD monthly DA meeting 4th Thursday every month (VTC, telecon, gotomeeting) - 11-noon – POC Aberson
    - **Recommend quasi-quarterly verification/diagnostic team telecon/gotomeeting – DeMaria, Marchok**
    - **Recommend we get HPC involved – Talk to Bob Kelly to see if we can approach Dave Roth**
7. How do we report to HFIP? Demo?
    - Review current HFIP milestones and insure we are on track
    - Inform HFIP leadership for quarterly status reports and provide input to Annual Operating Plan and milestone development for FY10
    - Coordinate with other 10 teams – November HFIP team meeting
    - **Recommend annual team meeting at NHC early in the Spring – TBA (avoid HWRF tutorial, IHC, AMS tropical meeting, WMO course)**
    - **Review Action items**

Back Up Slides

Issues/Action Items -1

- Sharing of data/software
  - Not everything needs to be shared
    - Propose to make HWRF grid files, grib readers, some grads software available
  - How can outside users utilize HRD java application?
  - IR forward model collaboration CIRA/ESRL
  - Need method for sharing HRD observations, NESDIS satellite imagery, operational data (ATCF, etc)
- Access to ocean model output
- Additional HWRF variables needed for future work
  - Non-hydrostatic pressure, sigma-coordinate data, condensate profiles, ocean model fields

Issues/Action Items -2

- Use rainfall verification techniques on wind swaths
- Collaboration on tracker software
- Consider sfc fluxes, ocean response in CD/CE study
- Input to Barb Brown on TC applications of advanced verification
- Outside user access to HRD diagnostic application
- Coordination of FSU work, especially with CIRA and EMC
- Sharing of diagnostic results with other teams
  - How is feedback provided to model developers?

Issues/Action Items 3

- Storm-relative diagnostics
- Data from high-res test made available to diagnostics team (DTC)

Frank’s Slides

What Operations Need (R. Pasch):

- Increased model diagnostics activities
  - Focus on infamous cases for track/intensity forecasts
  - More “guidance on guidance”, e.g. selective consensus
- More model diagnostics tools for
  - 4-d structural analyses, e.g. point and click cross sections
  - 3-d trajectory analysis
  - Budget studies
  - Quality/fidelity of initialization; ability to analyze how well model assimilates observations of interest
  - –Forecaster-specified layer to layer shear analysis
  - –Center locations at multiple vertical levels; depiction of vertical coherence
  - Calculations of metrics/measures of forecast reliability
- Genesis probabilities derived from ensemble forecasts of global ensembles and possibly high-res pre-TC models

Issues added in discussion:

- Pedictability – are 6-7 day forecasts for track realistic, same for intensity forecasts beyond 48 h where models show decreasing skill – critical to HFIP
- Validity of CLIPER/SHIFOR for guidance beyond 3 days. The current versions were not designed to address longer forecasts. Need to rethink process.

ACTION ITEMS:

1. We need to know what to look for in developing diagnostic tools for genesis guidance from models – need input for operations. Could use input from operations on what they fins useful. (NHC)
2. Diagnostics/verification tools needed for large-scale impacts on model guidance as shown by Fiorino.
3. Strong need for storm-relative diagnostic/evaluation tools (e.g., Rogers and Tallapragada talks)
4. Diagnostics/verification tools needed for ocean initialization and model guidance (especially for SST). Major stumbling block is lack of ocean model output in standard formats such as GRIB or netCDF.
5. Diagnostics/verification tools needed for ensemble guidance – very little shown that demonstrated these types of tools (Fiorino, Talapragada).
6. How do we normalize storm-relative information for multiple storms, ensembles for vortex scale diagnostics (RMW, ?)?

ACTION ITEMS:

7. Need to insure that operational and research model fields (including ocean) get out to the community in standard formats (GRIB or native netCDF) for the development of diagnostic/verification tools. Should include INVEST runs (EMC, DTC?). For research models insure higher res model output from high-res test are made available for diagnostic/verification effort (DTC).
8. Need to insure observational data sets for verification and diagnostics are easily available to community. (HRD)
9. Need to insure operational guidance products and data sets (ATCF, wind radii, rain, surge) are available to community (NHC).
10. How many trackers do we need to develop more trackers/tracker skill? Should form subgroup to come up with a set of tools for trackers, particularly to look at weaker systems. Also high-resolution models and how to track.
11. Coordinate evaluation of the air-sea physical processes and parameterizations to insure no duplication of effort (NRL/EMC/HRD/ESRL/URI/UM/?).

ACTION ITEMS:

12. Get input to Barb Brown about what other diagnostic/evaluation tools (e.g. Marchok et al rain and surface wind tools) that have been developed for TCs and ported to DTC MET package.
13. How can we make HRD (Thiago's) Java tool and database for visualization available to more of the community (AWIPS II, Web Applet, ?). Get input for Thiago about what to have in the 3D overlays. Functions, data platforms.
14. How do coordinate all of these different diagnostic tools? Need to get common tools available to as many folks as possible (HPLOT, wrf_post, Diapost, Trackers, Fiorino openGrADS extensions, Thiago's visualization, DTC MET, DTC high-resolution diagnostic packages, etc.)