Applications of Satellite Data to Tropical Cyclone Forecasting

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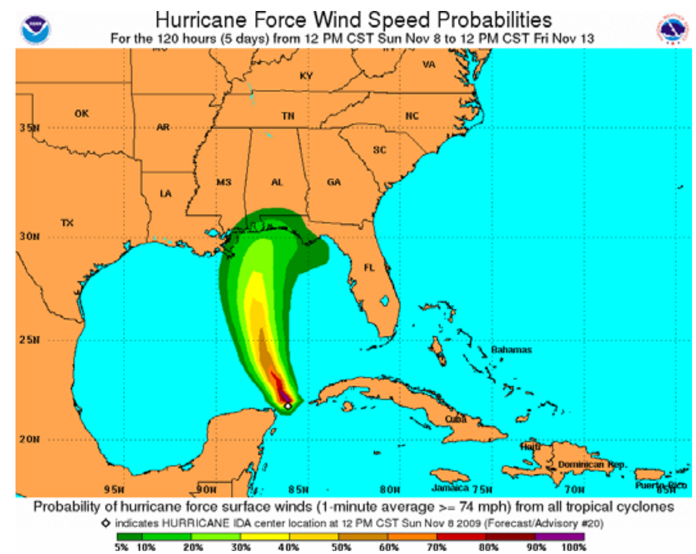
Theme IV- Severe Weather and Hazards

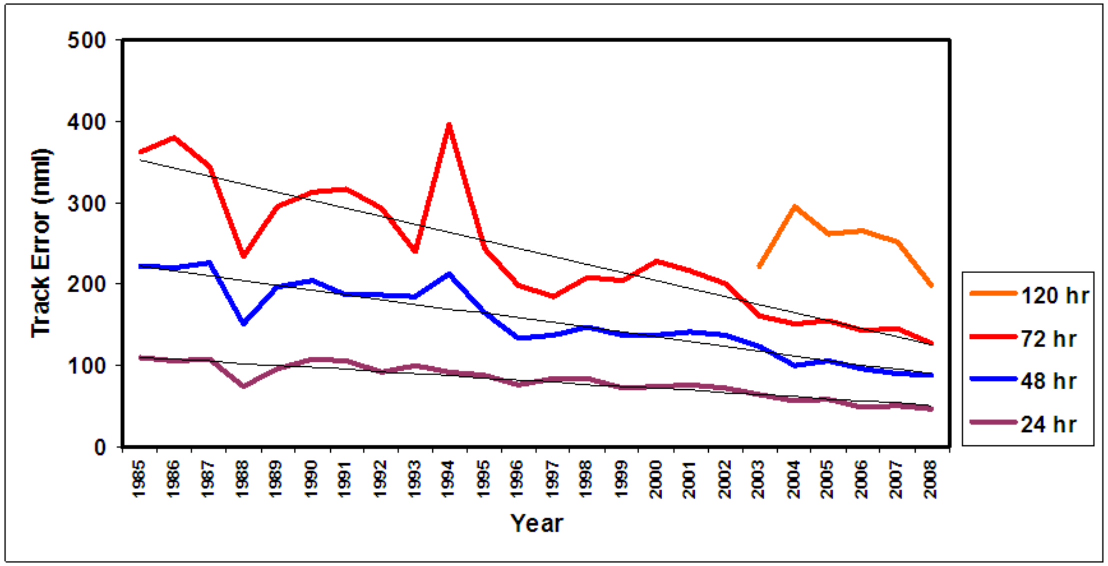
National Hurricane Center Tropical Cyclone Forecast Parameters

- Track
  - tropical cyclone positions 0 to 120 hr
- Intensity
  - maximum wind 0 to 120 hr
- Wind Structure
  - Radii of 34, 50 kt winds 0 to 72 hr
  - Radii of   64 kt winds 0 to 36 hr
- Watches
  - Hurricane conditions possible in next ~36 h
- Warning
  - Hurricane conditions likely in next ~24 h
- Probabilities of 34, 50 and 64 kt winds 0 to 120 hr
- General guidance on rainfall and storm surge
- Probability of TC formation in the next 48 h
- *All forecast products updated every 6 hours*

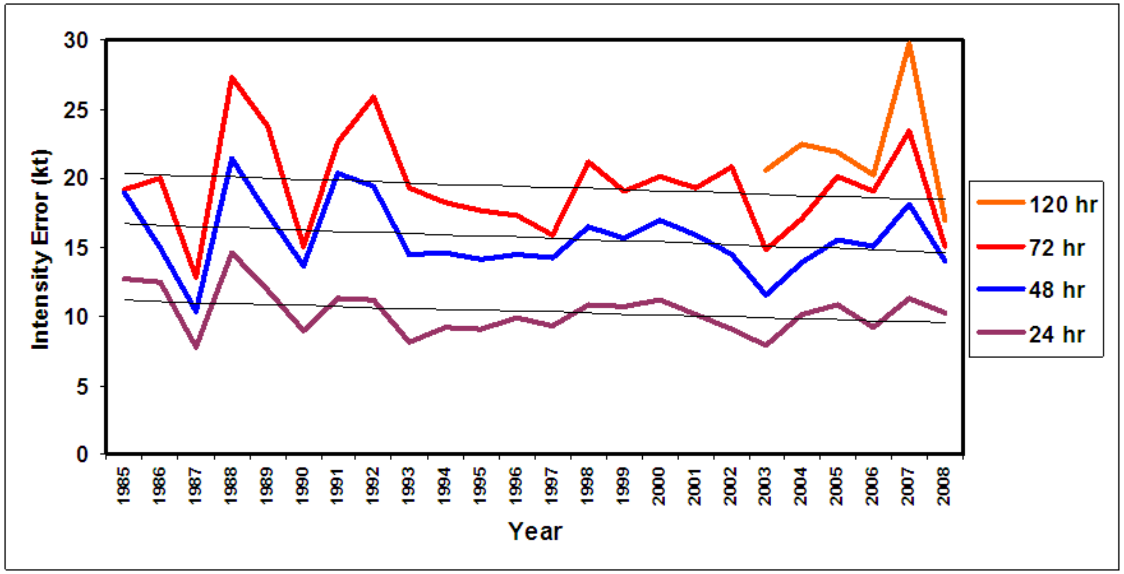


Hurricane wind probability product for Hurricane Ida
8 Nov 2009, 18 UTC

Mean Absolute Error of NHC Official Atlantic Track and Intensity Errors1985-2008



48 hr Track Improvements ~3.7% per year



48 hr Intensity Improvements ~0.6% per year

Models for Operational Tropical Cyclone Track and Intensity Forecasting

- Track
  - Global models: NCEP-GFS, ECMWF, NOGAPS, UKMet
  - Regional models: GFDL, HWRF
    - Both include coupled ocean model
  - Simple climatology and persistence (CLIPER) for skill baseline
  - Simple trajectory models
- Intensity
  - Regional models: GFDL, HWRF
  - Statistical-dynamical models: SHIPS, LGEM
  - Rapid Intensity Index: Discriminant analysis technique
  - Simple climatology and persistence (SHIFOR) for skill baseline

- Models in red were most accurate over the last 5 years

Satellite Data Utilization in Hurricane Forecasting

- Identify cloud clusters that may form TCs
- Center location and intensity estimates
  - Vis/IR Dvorak techniques, microwave methods
- Synoptic feature identification
  - Feature track winds, WV imagery
- Wind structure analysis
  - Scatterometer, passive microwave
- Sea surface temperature products
- Assimilation into numerical models
  - Atmosphere and ocean
- Predictors in statistical intensity forecast models
  - Oceanic heat content from satellite altimetry
  - GOES data for convective analysis
  - Microwave imagery
  - Lightning data on GOES-R using proxy ground based systems

Satellite data used in NCEP's operational data assimilation systems

- **HIRS sounder radiances**
- **AMSU-A sounder radiances**
- **AMSU-B sounder radiances**
- **AIRS radiances**
- **IASI radiances**
- **GOES sounder radiances**
- **GOES, Meteosat, GMS winds**
- **GOES precipitation rate**
- **SSM/I precipitation rates**
- **TRMM precipitation rates**
- **SSM/I ocean surface wind speeds**
- **ERS-2 ocean surface wind vectors**
- **ASCAT ocean surface wind vectors**
- **QuikSCAT ocean surface wind vectors***
- **AVHRR SST**
- **AVHRR vegetation fraction**
- **AVHRR surface type**
- **Multi-satellite snow cover**
- **Multi-satellite sea ice**
- **SBUV/2 ozone profile and total ozone**
- **AIRS**
- **MODIS Winds**
- **Altimeter sea level observations (ocean data assimilation and wave data assimilation system)**

Satellite data also used to help estimate initial storm position, motion, intensity and wind structure for "TC Vitals" file used to initialize regional models

Tropical Cyclone Research Projects at NESDIS/RAMMB and CIRA

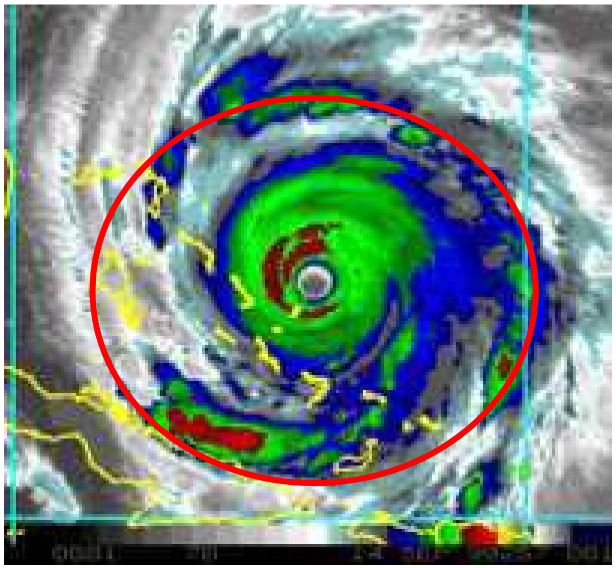
- Improvements to operational statistical hurricane intensity models using satellite data
  - Better use of GOES data
  - Oceanic Heat Content from satellite altimetry
  - Inclusion of passive microwave imagery
  - Advanced statistical algorithms
  - GOES-R studies using proxy data
    - SEVERI for ABI and ground-based lightning for GLM
- Tropical cyclone genesis prediction
  - Combing model, GOES, climatology data in a discriminant analysis
- Multi-platform estimation of tropical cyclone intensity and structure
- Advanced satellite data assimilation for tropical cyclone models
- Development and improvements of NHC's wind speed probability model

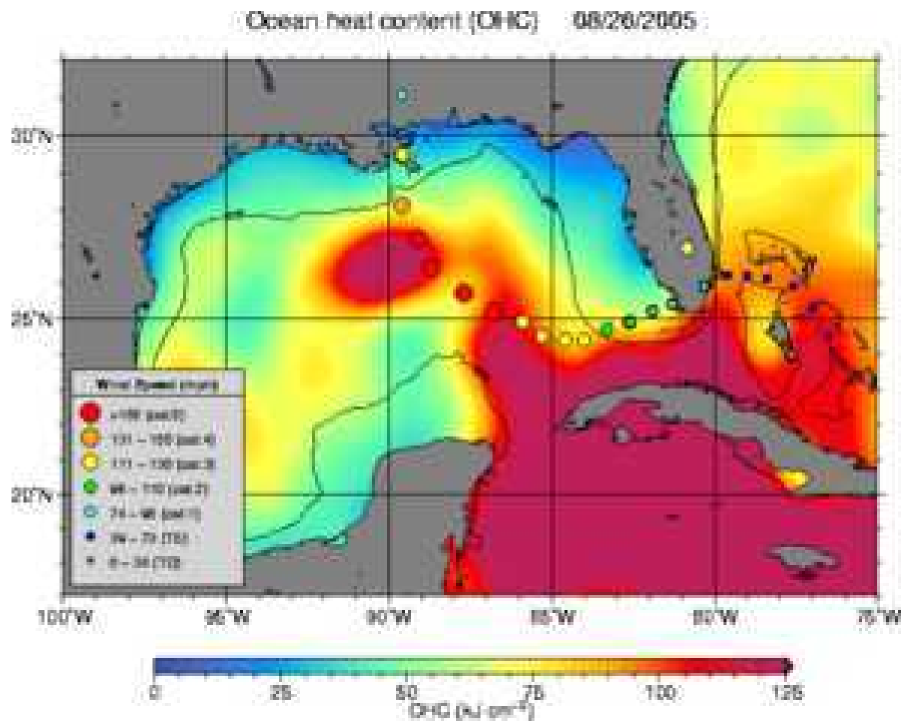
Statistical/Dynamical Intensity Models

SHIPS (Statistical Hurricane Intensity Prediction Scheme)

- Multiple regression model
- Predictors from climatology, persistence, atmosphere and ocean
  - Atmospheric predictors from GFS forecast fields
  - SST from Reynolds weekly fields along forecast track
  - Predictors from satellite data
    - Oceanic heat content from altimetry
    - GOES IR window channel brightness temperatures
- Decay SHIPS
  - Climatological wind decay rate over land

Satellite Predictors added to SHIPS in 2003





1. GOES cold IR pixel count
2. GOES IR T_b standard deviation

3. Oceanic heat content from satellite altimetry (TPC/UM algorithm)

Cold IR, symmetric IR, high OHC favor intensification

The Logistic Growth Equation Model (LGEM)

- Applies a simple differential equation to constrain the max winds between zero and the maximum potential intensity
  - Based on analogy with population growth modeling
- Intensity growth rate predicted using SHIPS model input
- More responsive than SHIPS to time changes of predictors such as vertical shear
- More sensitive track errors
- More difficult to include persistence

Logistic Growth Equation (LGE) Model

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

(A) (B)

Term A: Growth term, related to shear, structure, etc

Term B: Upper limit on growth as storm approaches its maximum potential intensity (V_{mpi})

LGEM Parameters:

$\kappa(t)$	Growth rate (from SHIPS parameters)
β	MPI relaxation rate (constant)
$V_{mpi}(t)$	MPI (from SST)
n	"Steepness" parameter (constant)

LGE replaced by Kaplan and DeMaria inland wind decay model over land

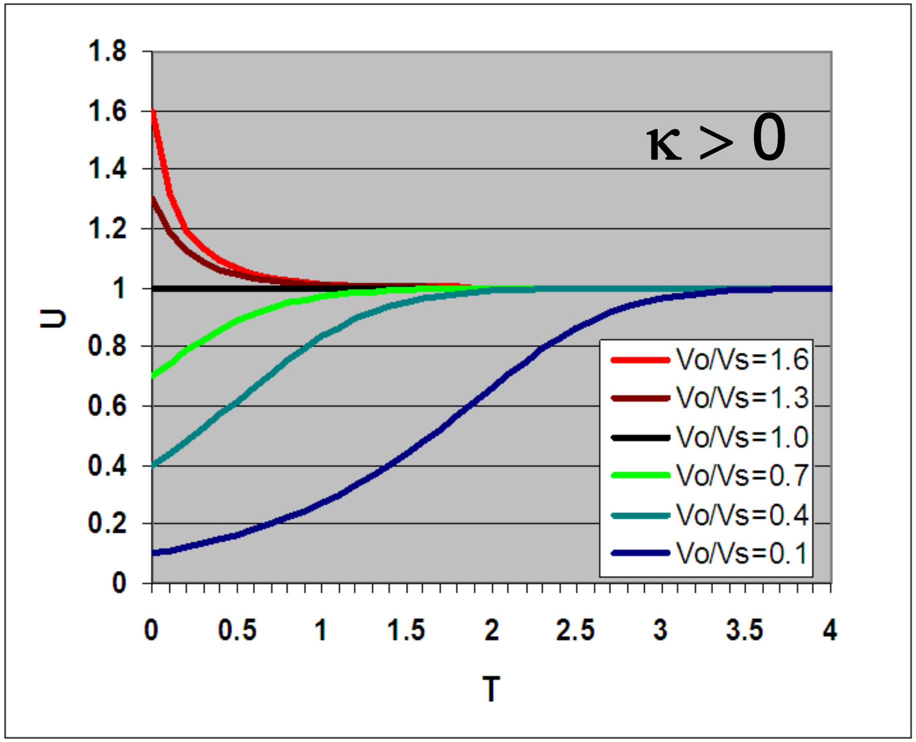
Analytic LGE Solutions for Constant κ and V_{mpi}

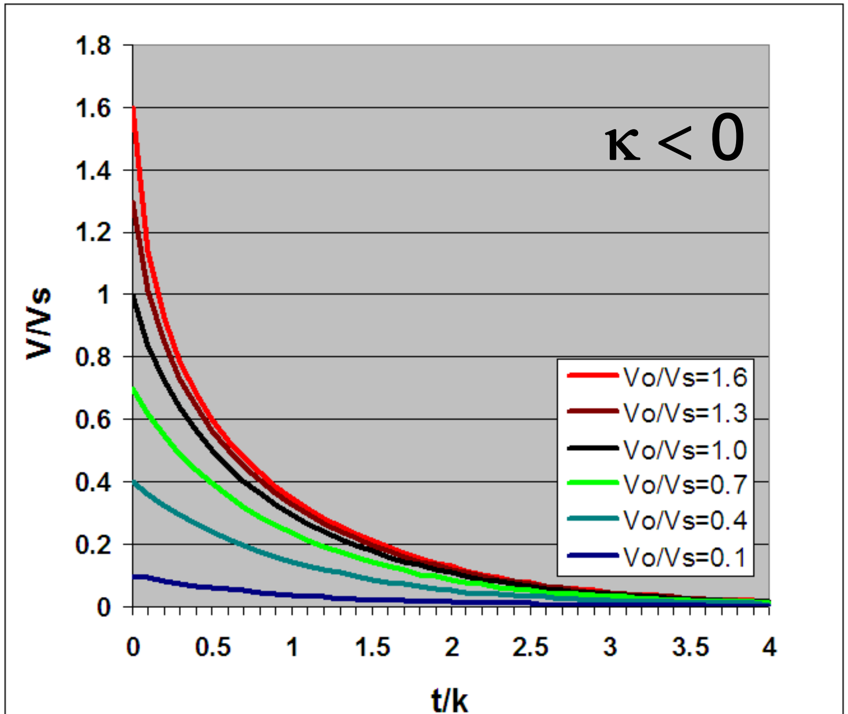
V_s = Steady State V = $V_{mpi}(\kappa/\beta)^{1/n}$

Let $U = V/V_s$ and $T = \kappa t$

$dU/dT = U(1-U^n)$

$U(t) = U_o\{e^{nT}/[1 + (e^{nT}-1)(U_o)^n]\}^{1/n}$





Application of Steady State Solution

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

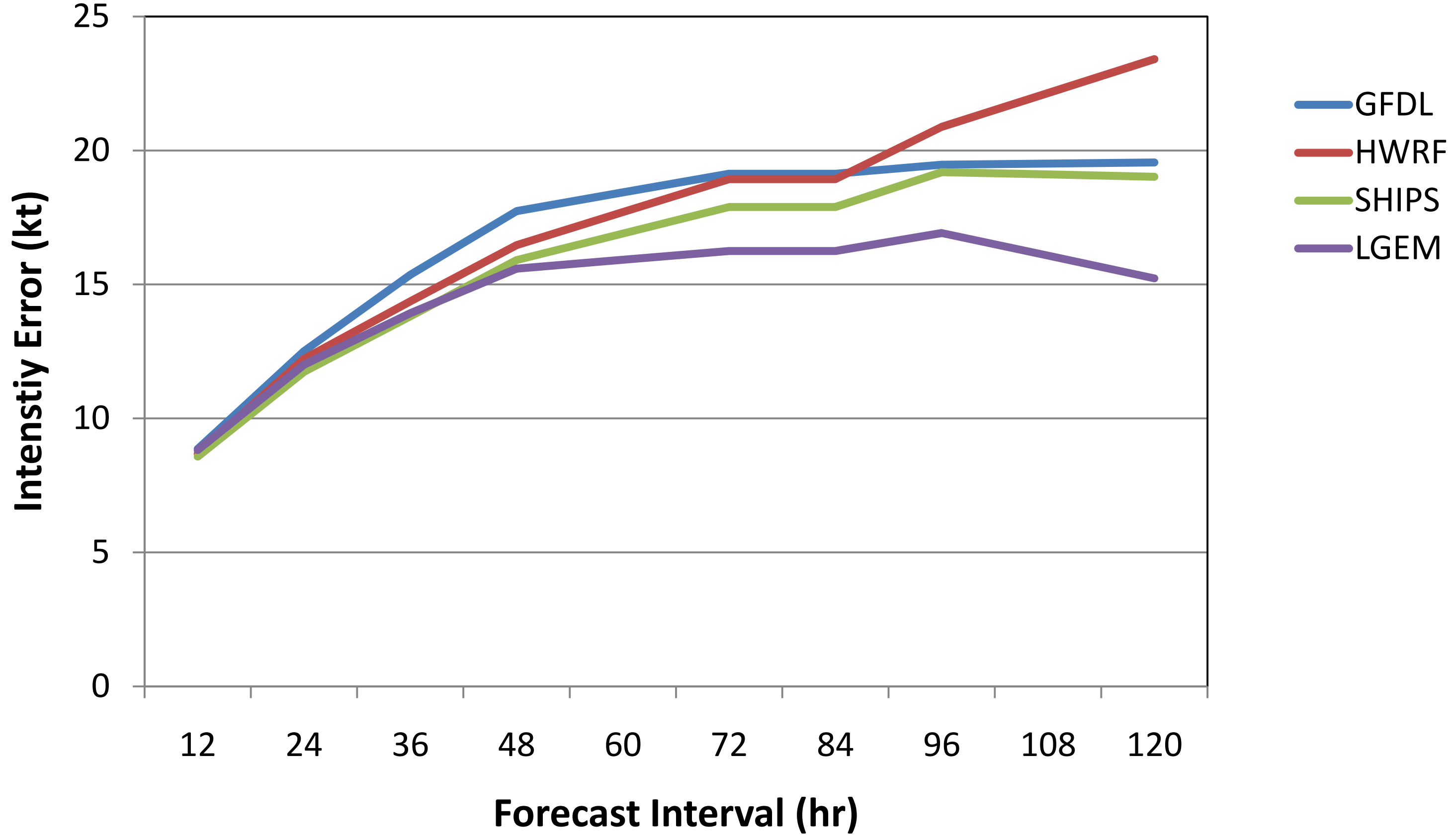
$n = 2.6$

$\beta^{-1} = 39$ hr

$\kappa = f(S,C)$

V_s is MPI modified by shear and convective instability

Operational Atlantic Intensity Model Errors (2007-2009)



GFDL, HWRF are 3-D coupled ocean/atmosphere models, ~1 hr comp. time on massively parallel computer
SHIPS, LGEM are statistical-dynamical models, ~1 second on single processor Linux system

Rapid Intensity Index

- SHIPS, LGEM do not work well for “outlier” forecasts, especially rapid intensification
- RII: Operational “classification” technique developed with subset of SHIPS input
  - Discriminant analyses technique
  - Outperforms all models for rapid intensity forecasting

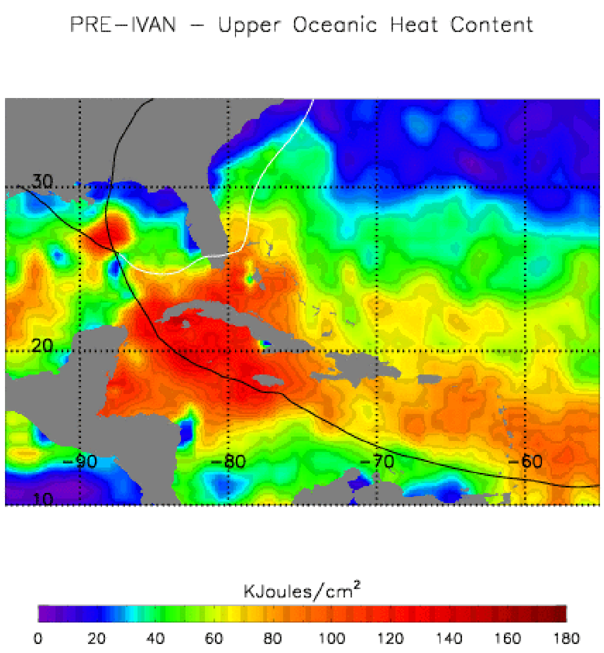
Previous RAMMB-CREST Collaborations on Hurricane Research

- 2005-06: Long-term hurricane environment climatology provided to Rouzbeh Nazari
- 2006-2007: Preliminary Rapid Intensification datasets sent to Michael Grossberg and Irina Gladkova for advanced statistical analysis
- 2008: GOES IR tropical cyclone dataset provided to Johnny Luo for advanced intensity estimation algorithm

Possible New RAMMB-CREST Research

Atmospheric response to ocean heat content

- Statistical relationship between OHC and intensity change in highly variable
  – Katrina case not typical
- What is the atmospheric response?
- Examine GOES evolution as storms cross warm/cold eddies
- Data needed
  – NHC best track, GOES IR and OHC archives



Possible New RAMMB-CREST Research

Maximum Potential Intensity Modified By Shear

- Vertical shear is primary predictor in SHIPS, LGEM
- LGEM steady state solution is modified MPI

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

- How does shear limit maximum intensity?
  - Test shear/MPI relationship from LGEM
  - Develop new modified MPI
  - Are there other measures of shear?
- Data needed: SST analyses, NCEP reanalysis fields, NHC best track

Possible New RAMMB-CREST Research

Advanced Statistical Techniques for Rapid Intensity Change Prediction

- Operational rapid intensity change index uses simple linear discriminant analysis, but still beats numerical model forecasts
- Can more advanced statistical techniques provide forecast improvements?
  - Nonlinear rule-based methods
  - Genetic algorithms
  - Additional predictive information through "data mining"
- Data needed: SHIPS model database (including satellite inputs), NHC best track

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Also see http://rammb.cira.colostate.edu