Application of Ocean Heat Content to Operational Forecasting in the 2004 and 2005 Hurricane Seasons

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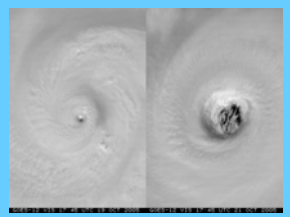


Outline

- Ocean influences on TC intensity
- Atmospheric response to OHC changes
- Transition of research to NHC operations
  - Real time OHC product
  - Inclusion of OHC in the SHIPS model
    - Impact on category 5 storms
  - Qualitative use of OHC analyses
- Future work

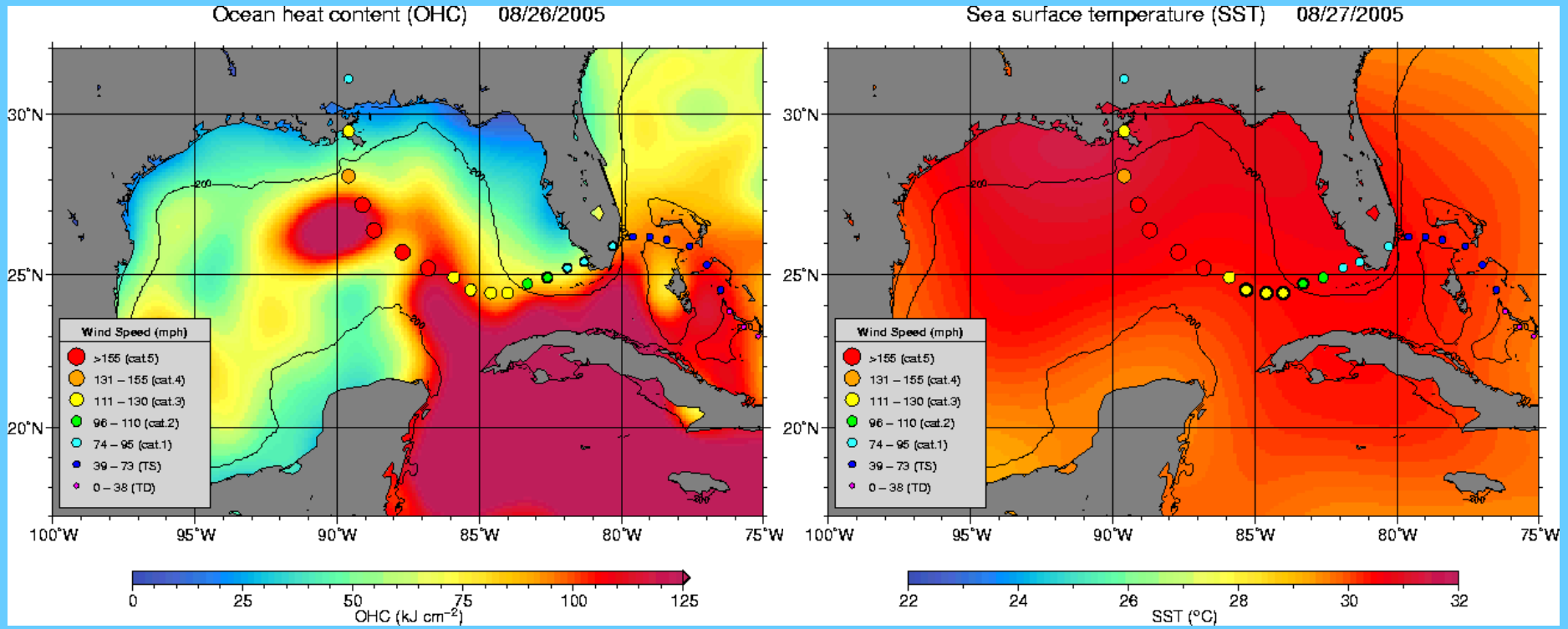
Ocean Influence on Hurricane Intensity

- Warm SST is necessary condition for TCs
  - Shaw (1922), Palmen (1948)
- Provides upper bound on TC intensity
  - Miller (1958), Emanuel (1987), …
- Upper ocean response to TC
  - Fischer (1958), Giesler (1970), Liepper (1967)
- Modeling and case study research
  - Chang and Anthes (1978), Shay (2000), …

Satellite Altimetry

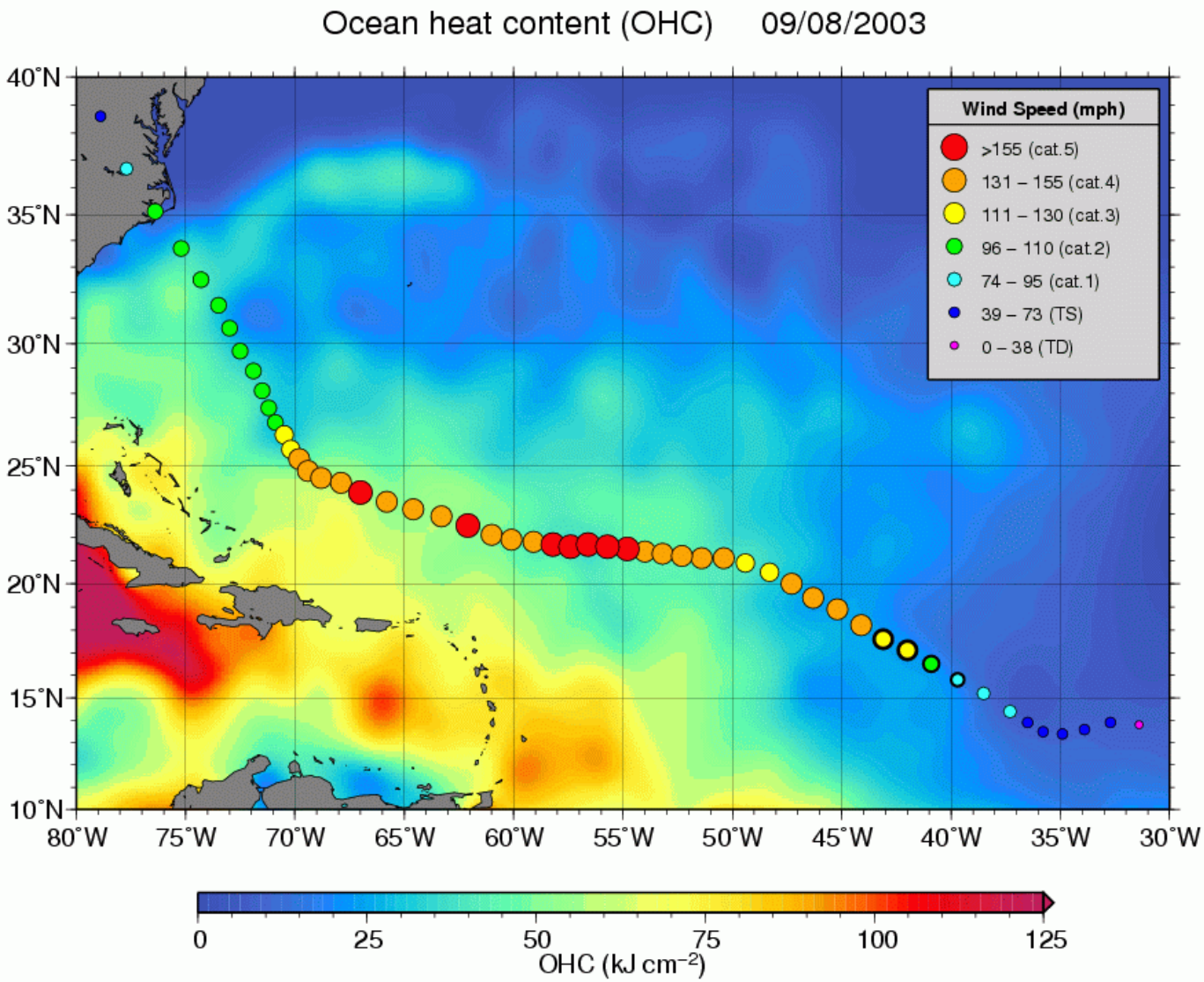
- Ocean altimetry provides routine measures of upper ocean heat content
  - Topex/Poseiden, GFO, Jason, Envisat …NPOESS
- Integrated heat excess from depth of 26^{o}C isotherm to the surface
- NHC operational algorithm (Atlantic basin)
- AOML algorithm (global)
  - Tropical Cyclone Heat Potential (TCHP)

Hurricane Katrina Intensity and SST and NHC Ocean Heat Content Analysis

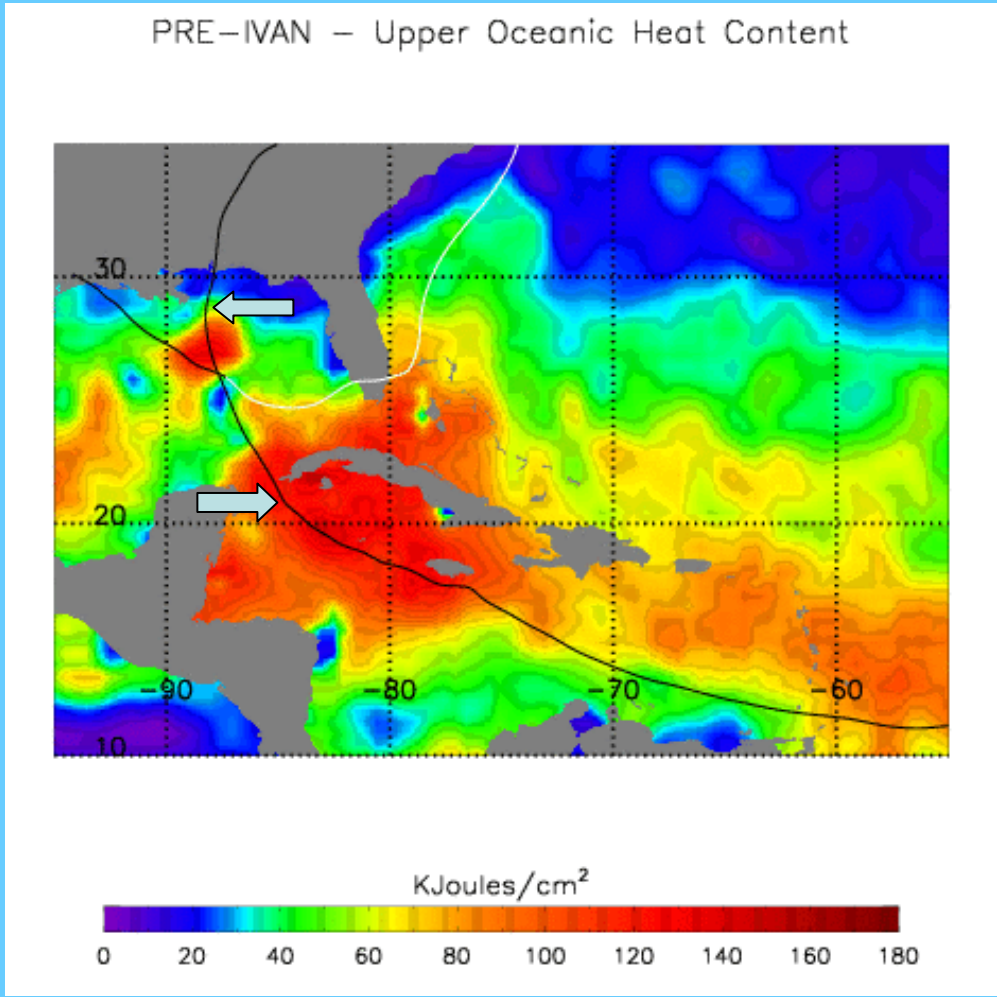


OHC **SST**

Hurricane Isabel Intensity and NHC Ocean Heat Content Analysis

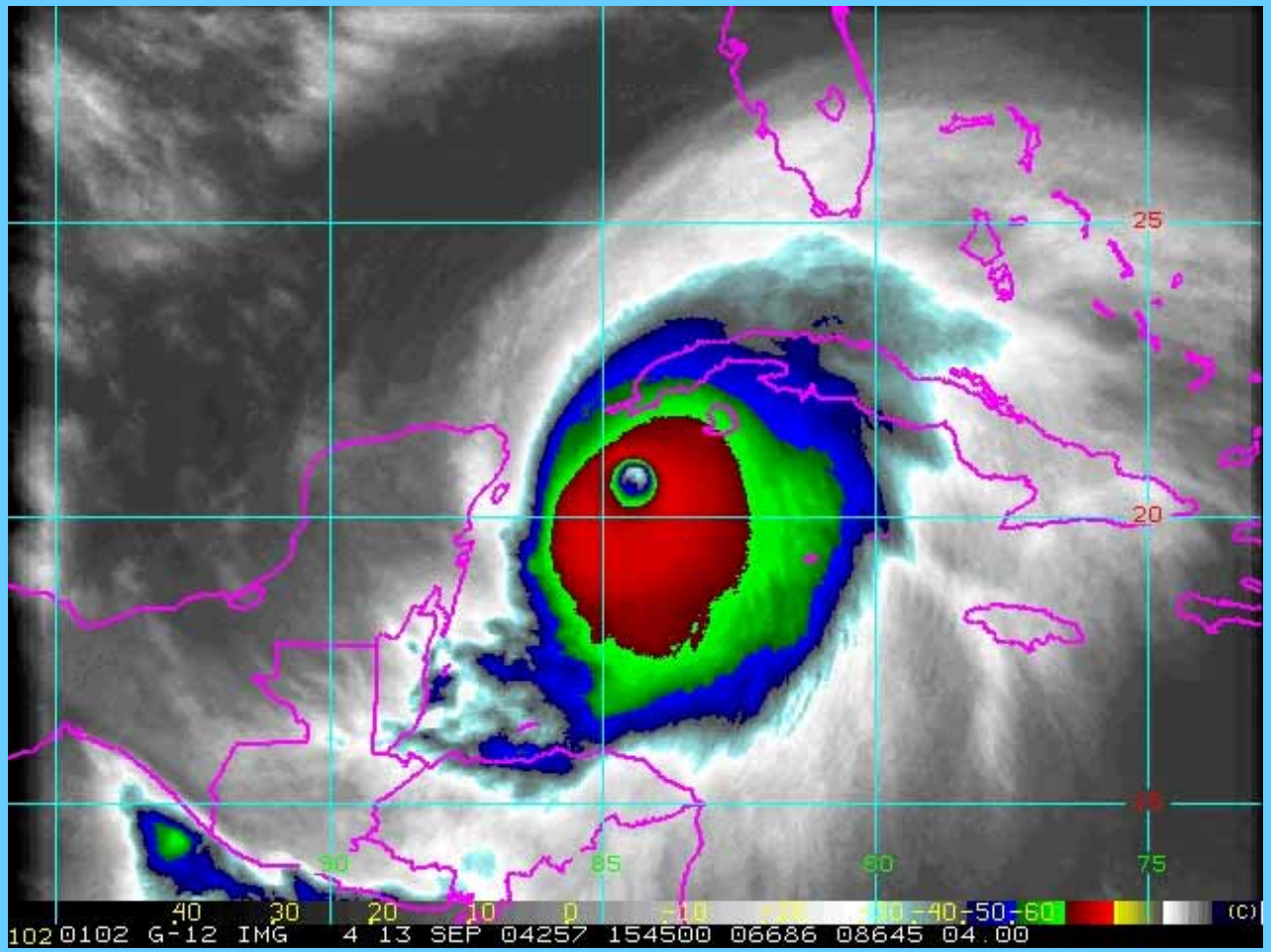


Atmospheric Response to OHC
Hurricane Ivan (2004) Example

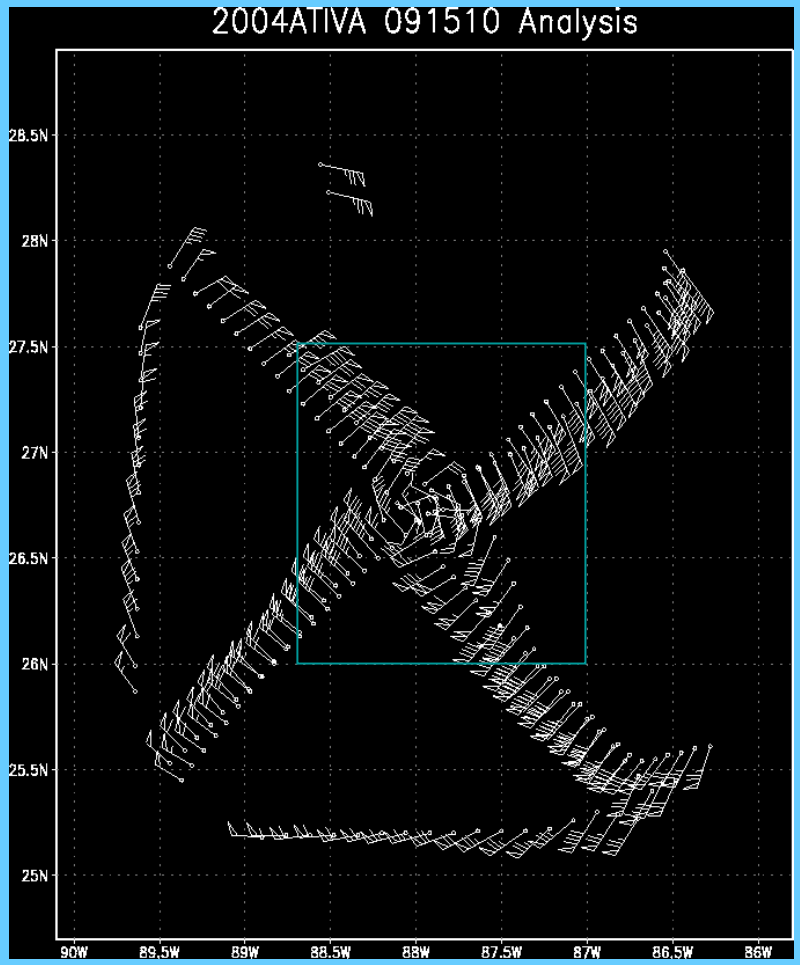


- Rapid variations in OHC from 13 Sept 18 UTC to 15 Sept 18 UTC ⇨ ⇦
- Response in IR imagery
- Response in low level θ_e near storm center from aircraft recon data

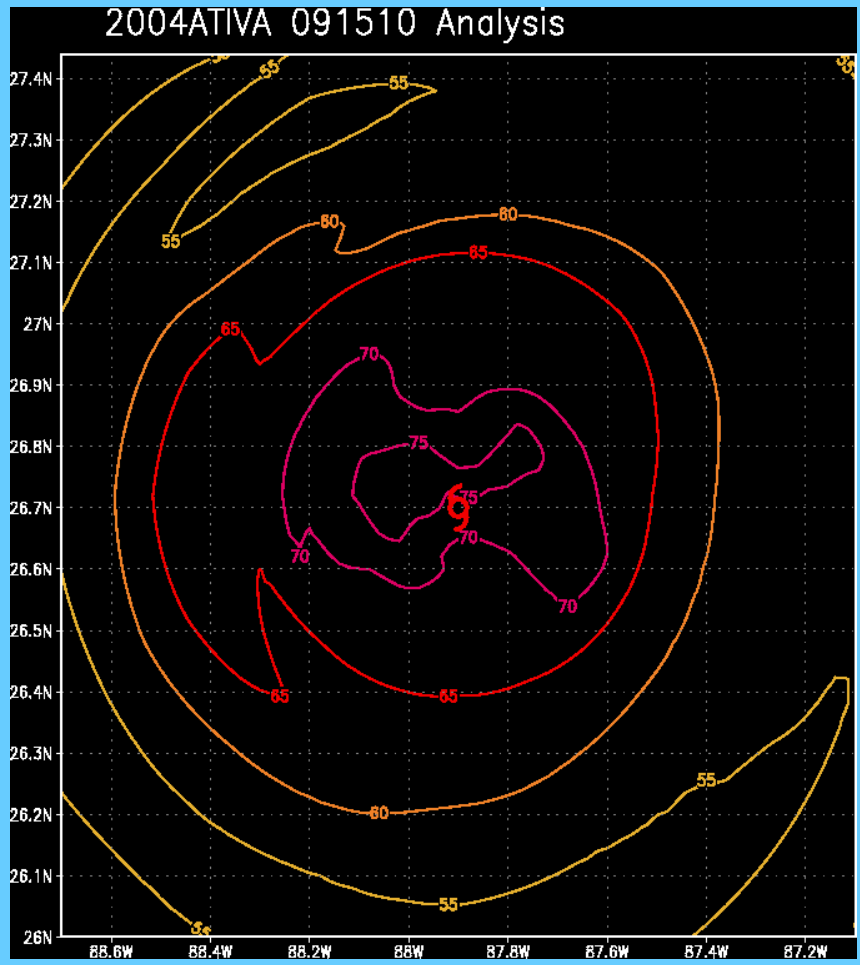
Time-Averaged GOES IR Imagery



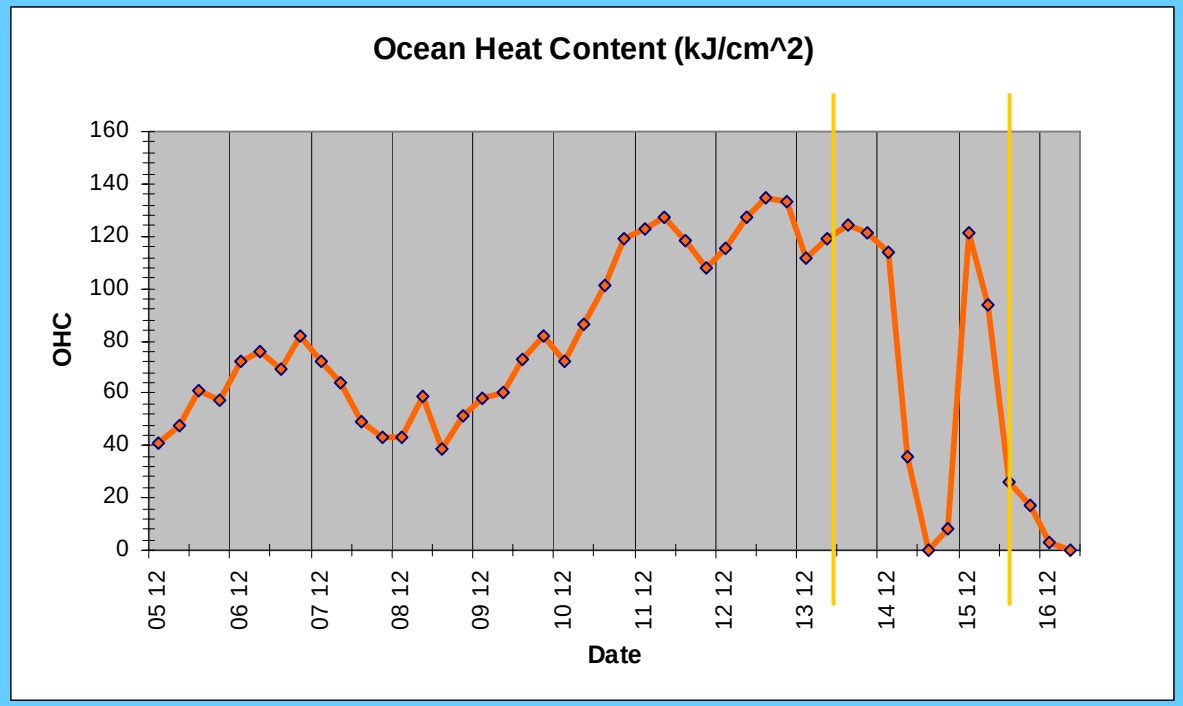
Sample θ_e Analysis for Ivan

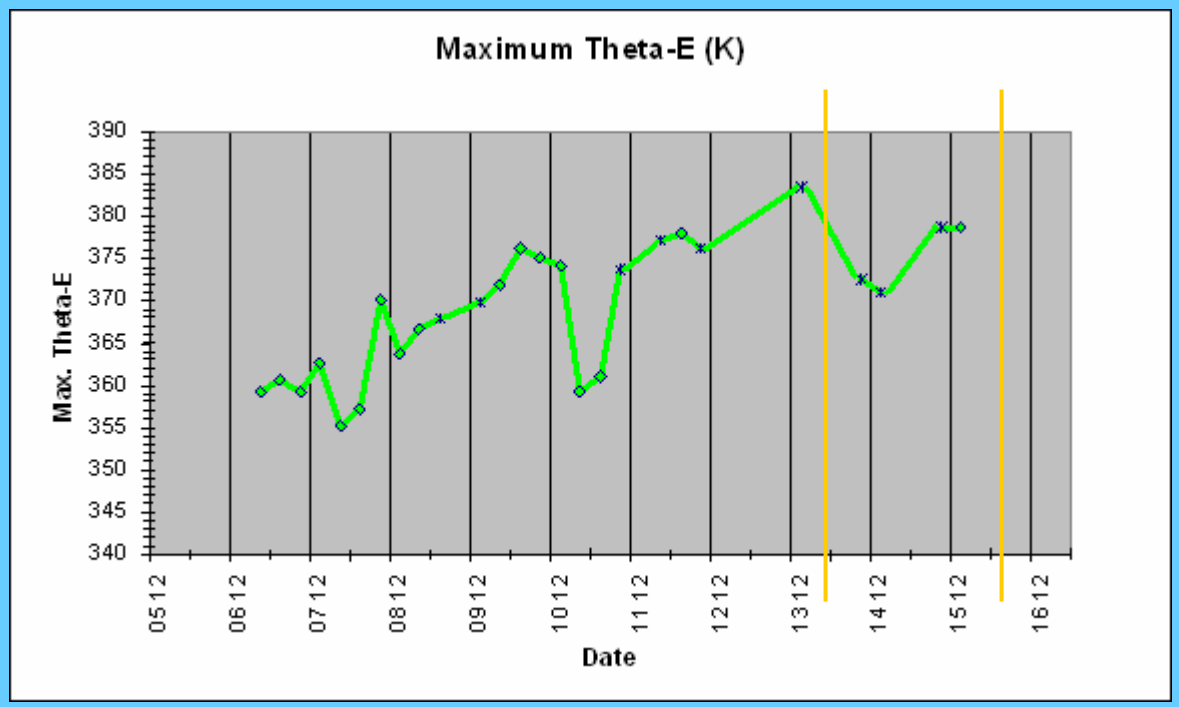


U.S. Air Force Reserve flight level (700 hPa) winds



Analyzed θ_e (^oK-300)


Ocean Heat Content (kJ/cm^2)
OHC
160
140
120
100
80
60
40
20
0
05 12
06 12
07 12
08 12
09 12
10 12
11 12
12 12
13 12
14 12
15 12
16 12
Date


Maximum Theta-E (K)
Max. Theta-E
390
385
380
375
370
365
360
355
350
345
340
0512
0612
0712
0812
0912
1012
1112
1212
1312
1412
1512
1612
Date

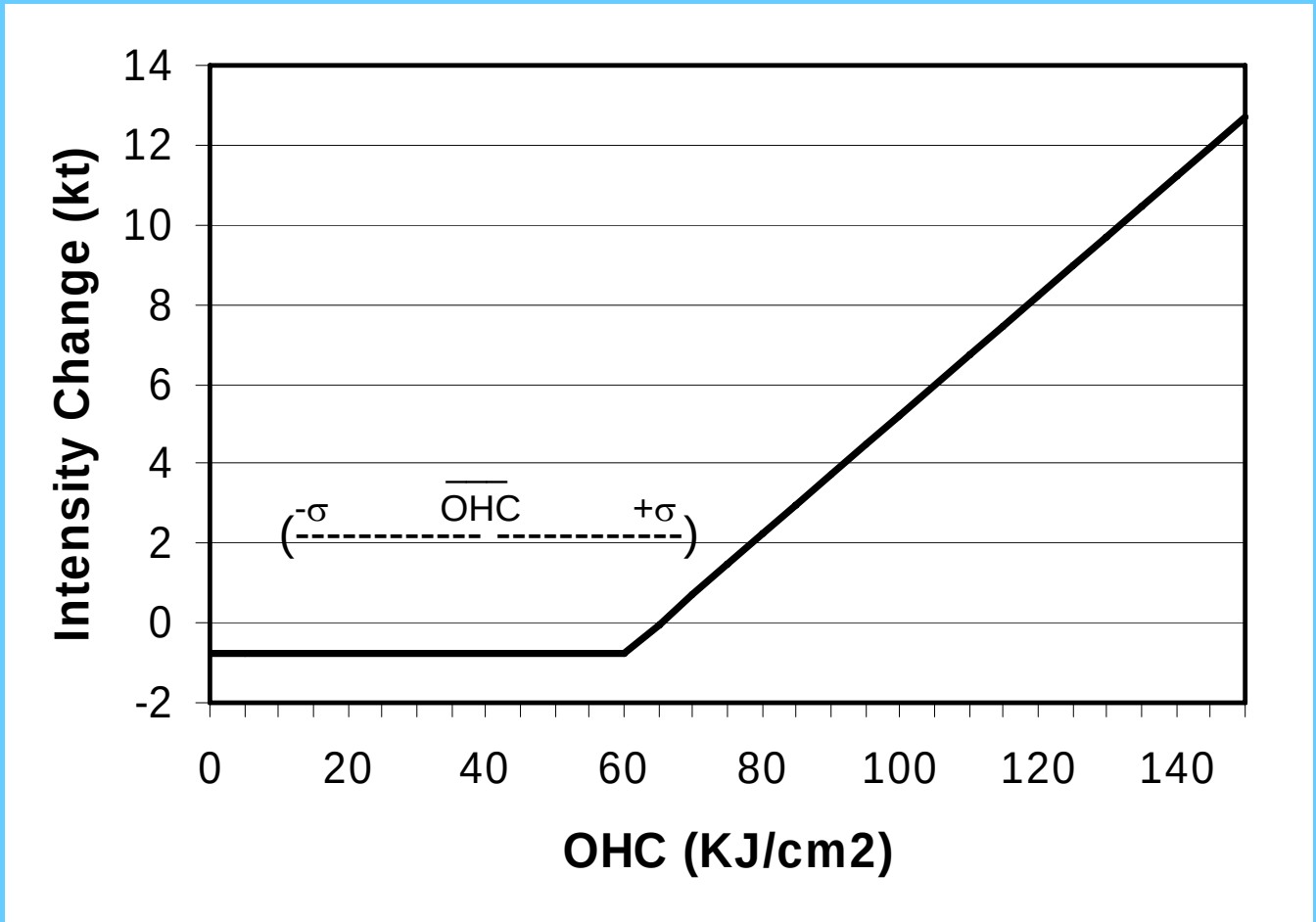
Transition to NHC Operations

- Coupled version of operational NCEP/GFDL hurricane model implemented in 2001
  - Ocean initialization primarily from climatology
  - Ocean assimilation under development
- Real-time OHC analysis at NHC
  - Implemented in 2002 by M. Mainelli and N. Shay
  - OHC added as a predictor in the operational Statistical Hurricane Intensity Prediction Scheme (SHIPS)
  - Parallel runs in 2002-2003
  - Operational beginning in 2004
  - JHT project

Inclusion of OHC in SHIPS

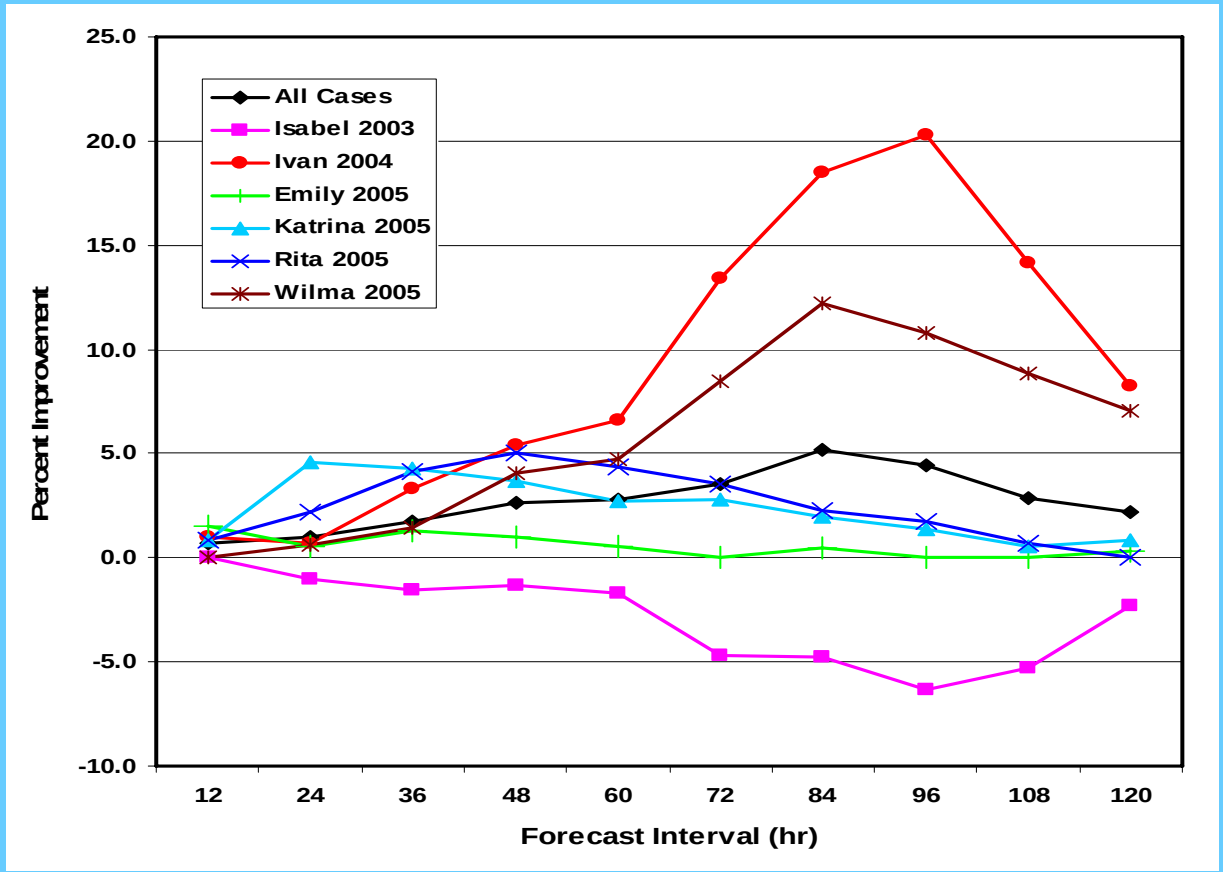
- SHIPS is multiple regression model with SST, atmospheric and climatological predictors
- Developmental sample includes ~6000 cases since 1982
  - OHC input since 1995
- OHC predictor adds small, but statistically significant improvement
  - *Intensity errors reduced by ~1%*
- Statistically significant improvement only when threshold of 60 KJ/cm^2 is applied

Adjustment of SHIPS Intensity Forecast due to OHC predictor



Impact on Operational SHIPS Forecasts for Recent Category 5 Storms

- Isabel (03), Ivan (04), Emily, Katrina, Rita, Wilma (05)
- Verify only over-water part of forecast



Qualitative Use of OHC Analyses: Quotes from NHC Discussion Products

- Katrina
  - “Katrina is expected to be moving over the Gulf of Mexico Loop Current after 36 hours, which when combined with decreasing vertical shear, should allow the hurricane to reach category four status before landfall”.
  - “This pattern in combination with the high oceanic heat content … along the path of Katrina calls for additional strengthening”.
- Rita
  - “The environment is conducive for strengthening and Rita, as Katrina did, will be crossing the Loop Current or an area of high heat content within the next 12 hour or so. This would aid the intensification process”.
  - “The intensity forecast is based on the premise that the shear and reduced outflow will cause a gradual weakening, especially after Rita moves west of the Loop Current”
- Ivan
  - “Thereafter the hurricane will be over the northwestern Caribbean Sea where there is high oceanic heat content and lower shear. So, Ivan is expected to intensify before reaching Cuba”.

Conclusions

- Sub-surface ocean structure can be an important process for tropical cyclone intensity change
  - Small impact on most cases
  - Significant impact on some
- Hurricane Ivan case documents atmospheric linkage through convective response
- Satellite altimetry is fundamental for real time upper ocean analysis
- OHC research has been transitioned to NHC operations

Future Outlook

- Validate OHC/TCHP retrievals with in situ data and improve algorithms
- Include TCHP input in JTWC western North Pacific statistical typhoon intensity model
- Improve ocean initialization in NCEP/GFDL hurricane model
- Replace OHC retrievals with full ocean data assimilation systems
- Fully coupled ocean/atmosphere assimilation and prediction systems
- Improved understanding of physical processes
  - Role of currents, stratification
  - Empirical threshold of 60 KJ/cm^2