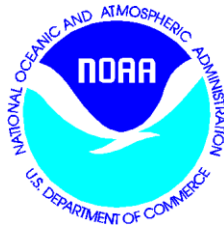


Evolution of the GFDL hurricane model in research and transition to NMC operations

Robert E. Tuleya
(Saic, EMC & CCPO/ODU)
Morris Bender (GFDL)
Isaac Ginis (URI)
Tim Marchok (GFDL)



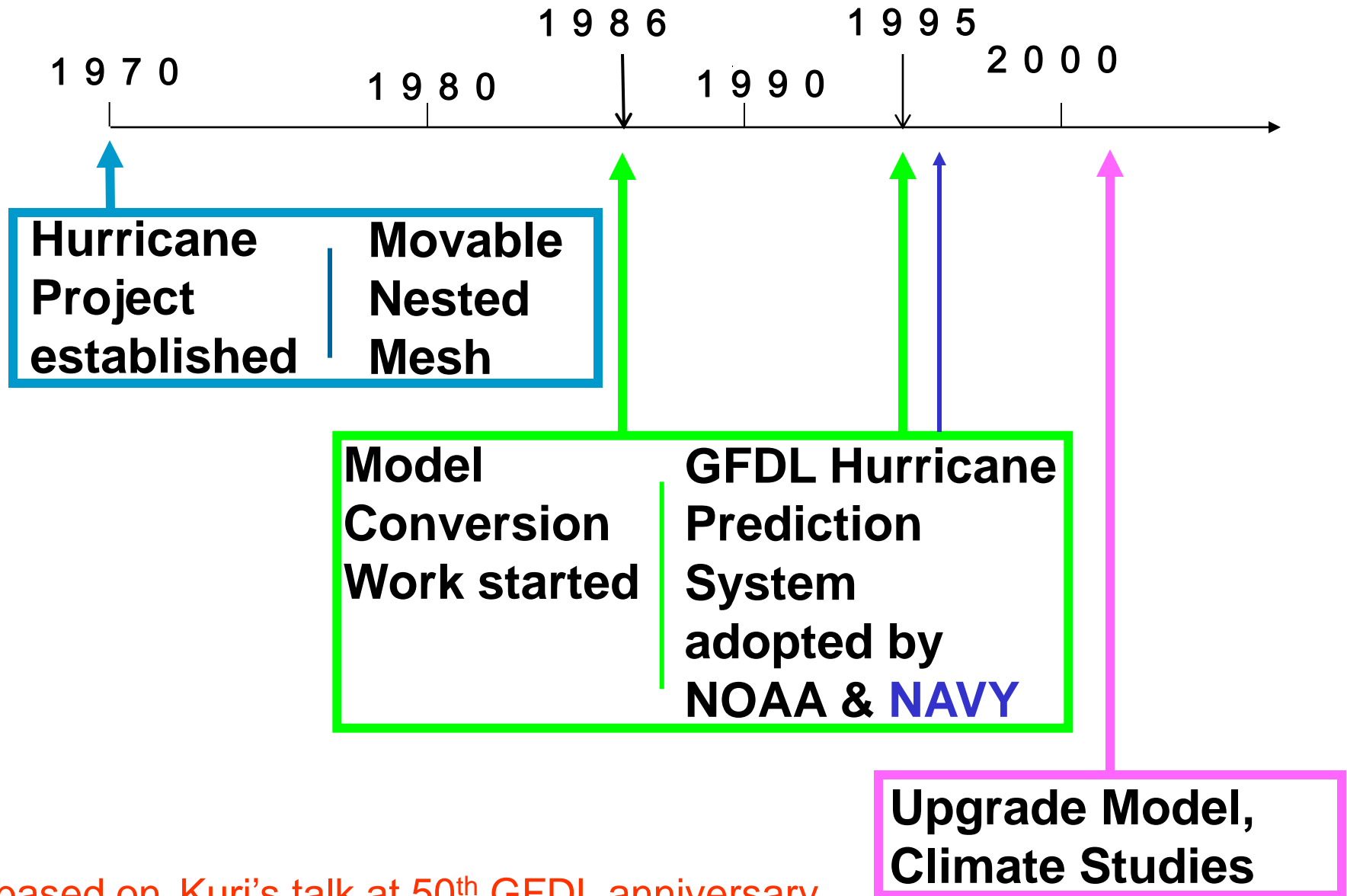
URI/GSO



Y. Kurihara with GFDL's Founder Joe Smagorinsky



CHRONOLOGY of HURRICANE MODELING at GFDL



based on Kuri's talk at 50th GFDL anniversary

Development of Box Method (1967,MWR)

August 1967

Yoshio Kurihara and J. Leith Holloway, Jr.

511

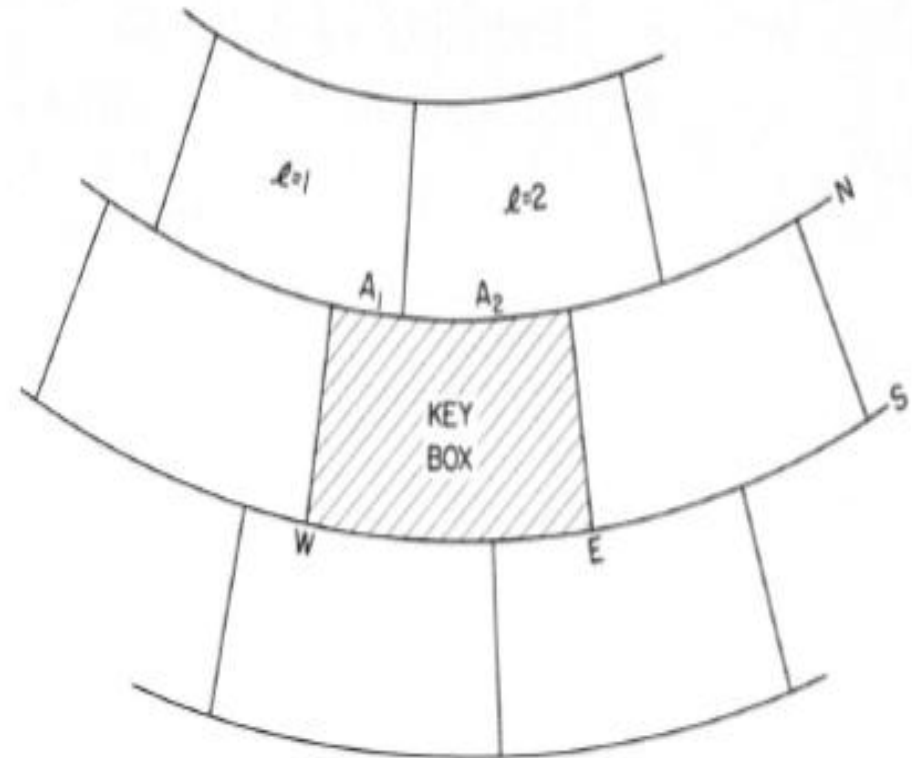
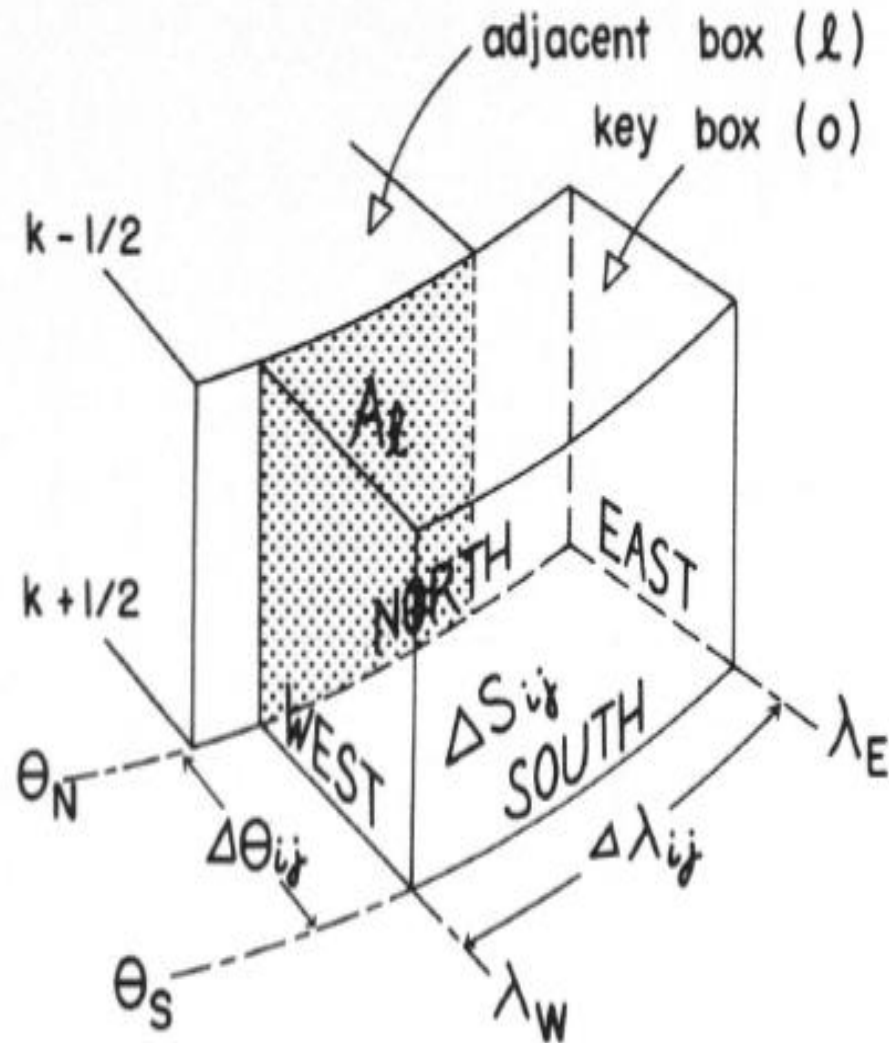
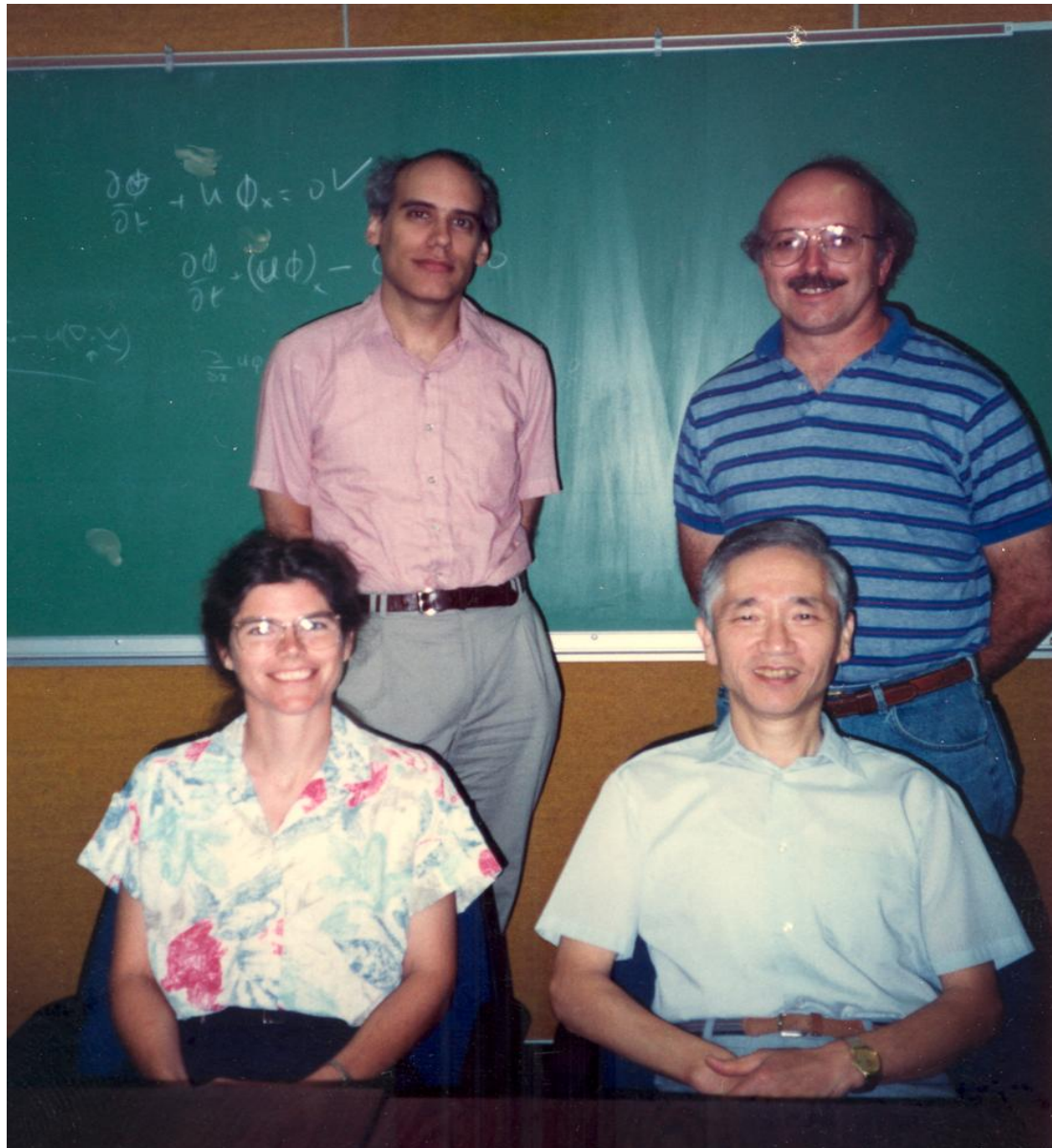


FIGURE 2.—Diagram of a key box surrounded by six adjacent boxes. On the north the key box joins box one at interface A_1 , and box two at interface A_2 . Two additional boxes, of course, contact the key box on the top and bottom.

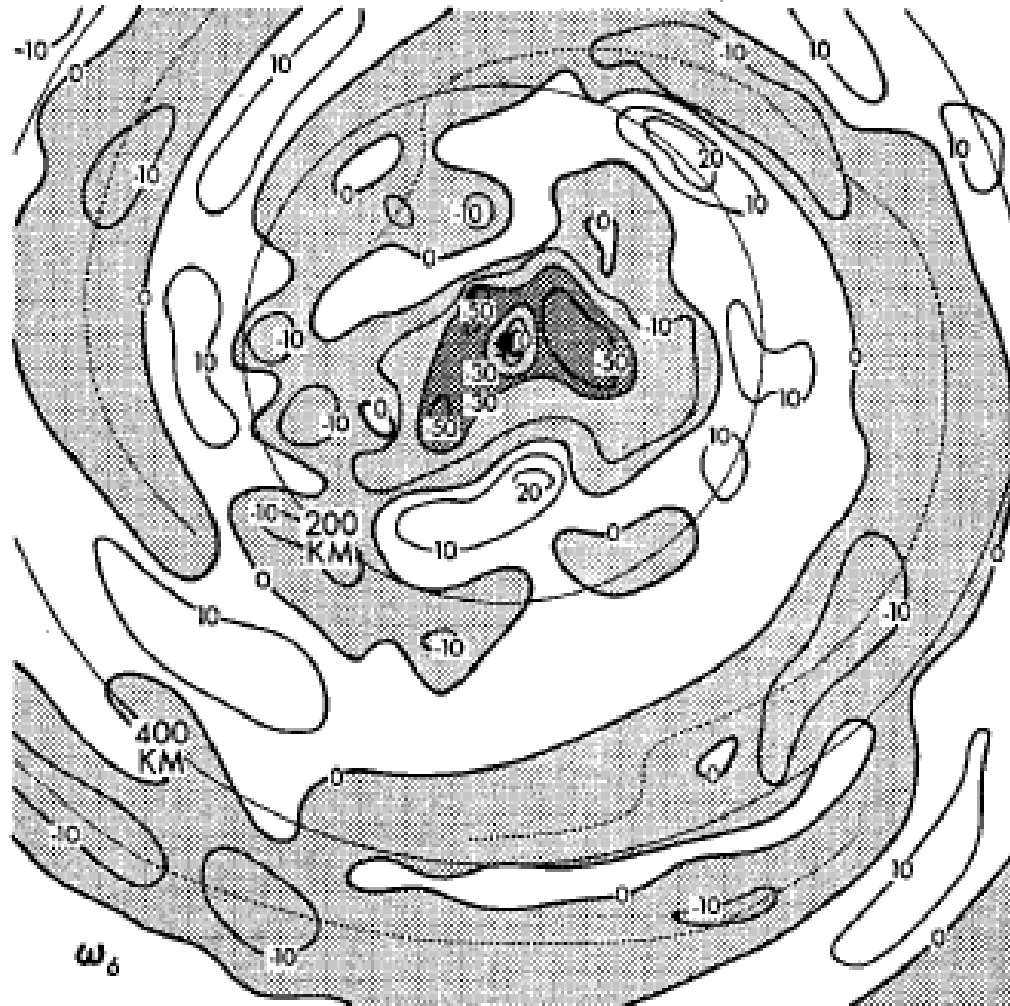
the sole surviving a-grid model !??

GFDL Hurricane Group (~1990)



Early 3-D model (hurricane in a box!)

Kurihara, Y., and R. E. Tuleya, 1974 . JAS



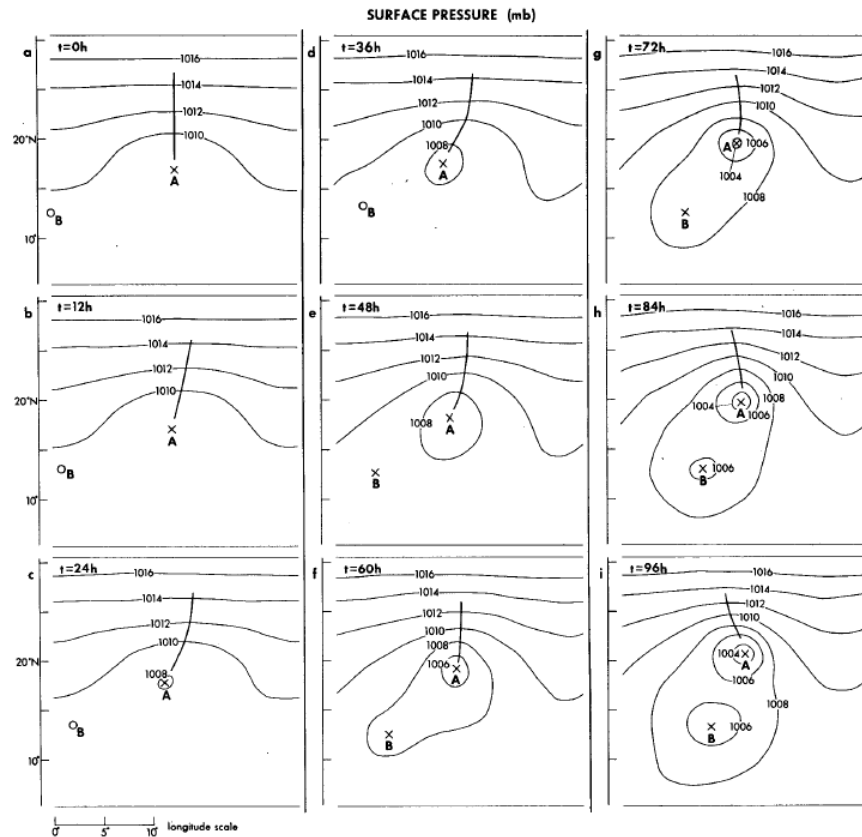
TC genesis-impact of environment

Kurihara, Y., and R. E. Tuleya, 1981, MWR

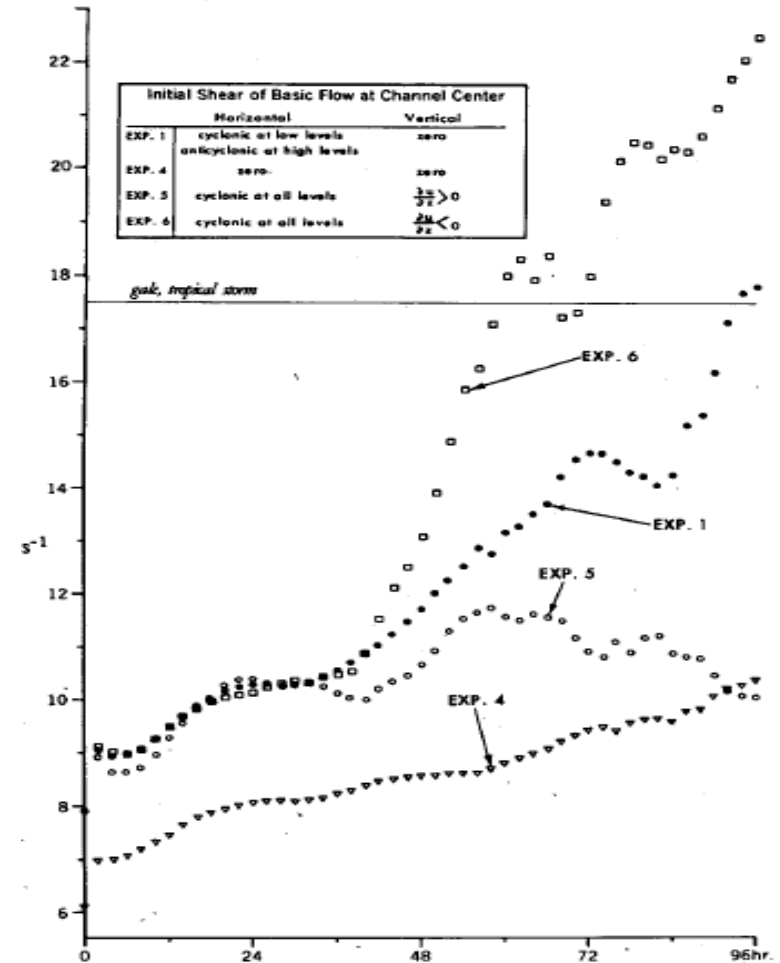
AUGUST 1981

YOSHIO KURIHARA AND ROBERT E. TULEYA

1639



Wave → TC

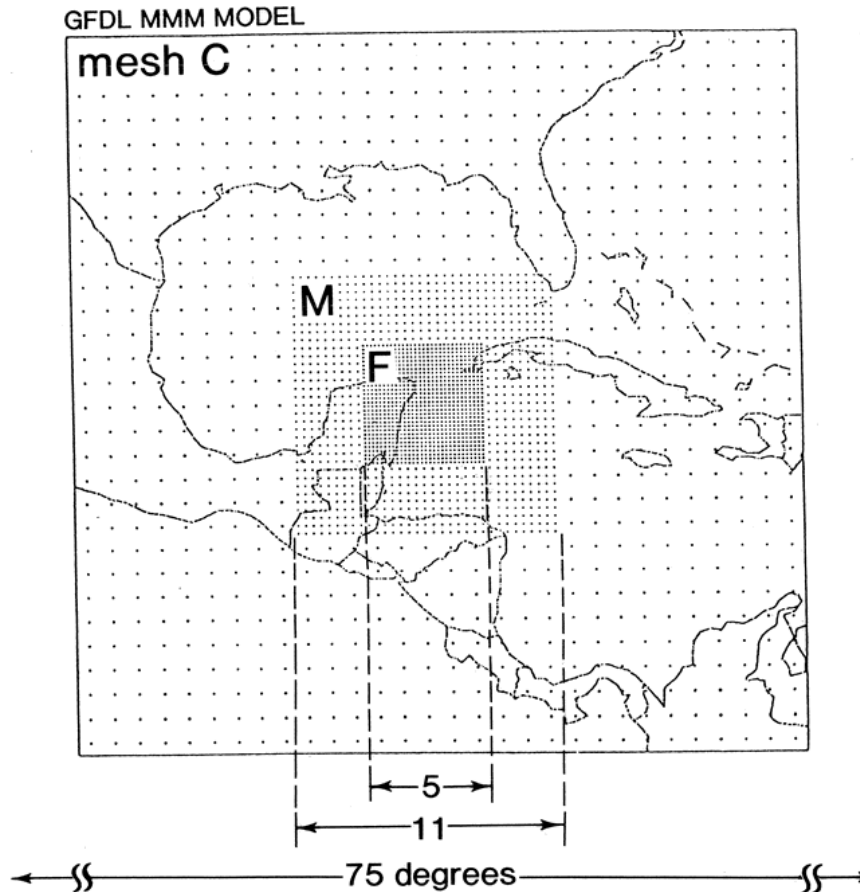


Effect of shear

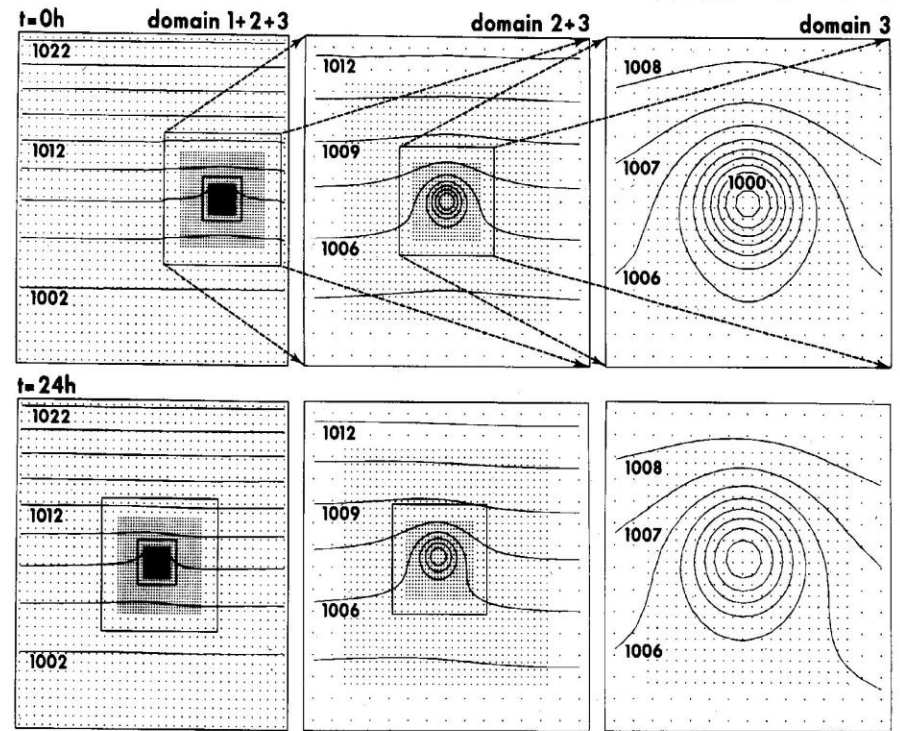
Nested Grid System

(an impressive scientific tool !)

Kurihara, Y., and M. A. Bender, 1980, MWR



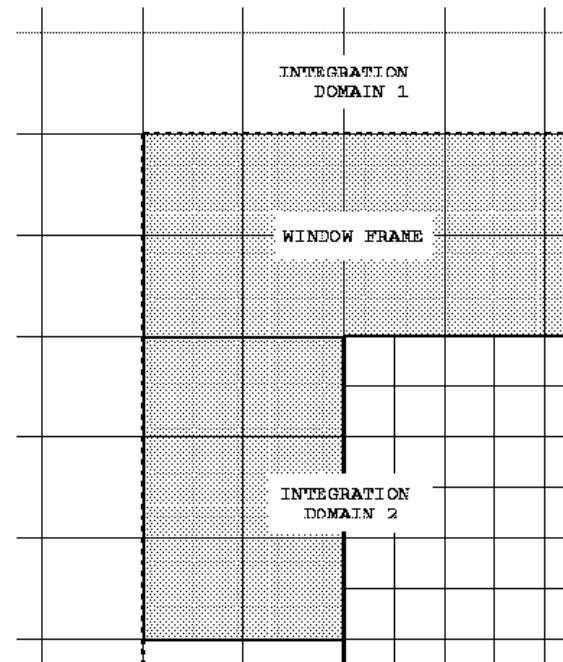
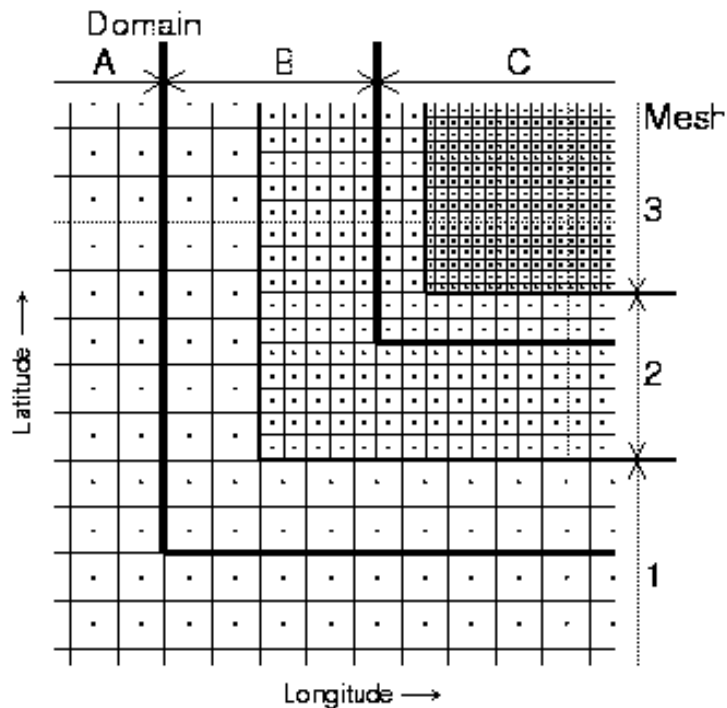
SURFACE PRESSURE



1. 101

Principles of Nested Mesh Design

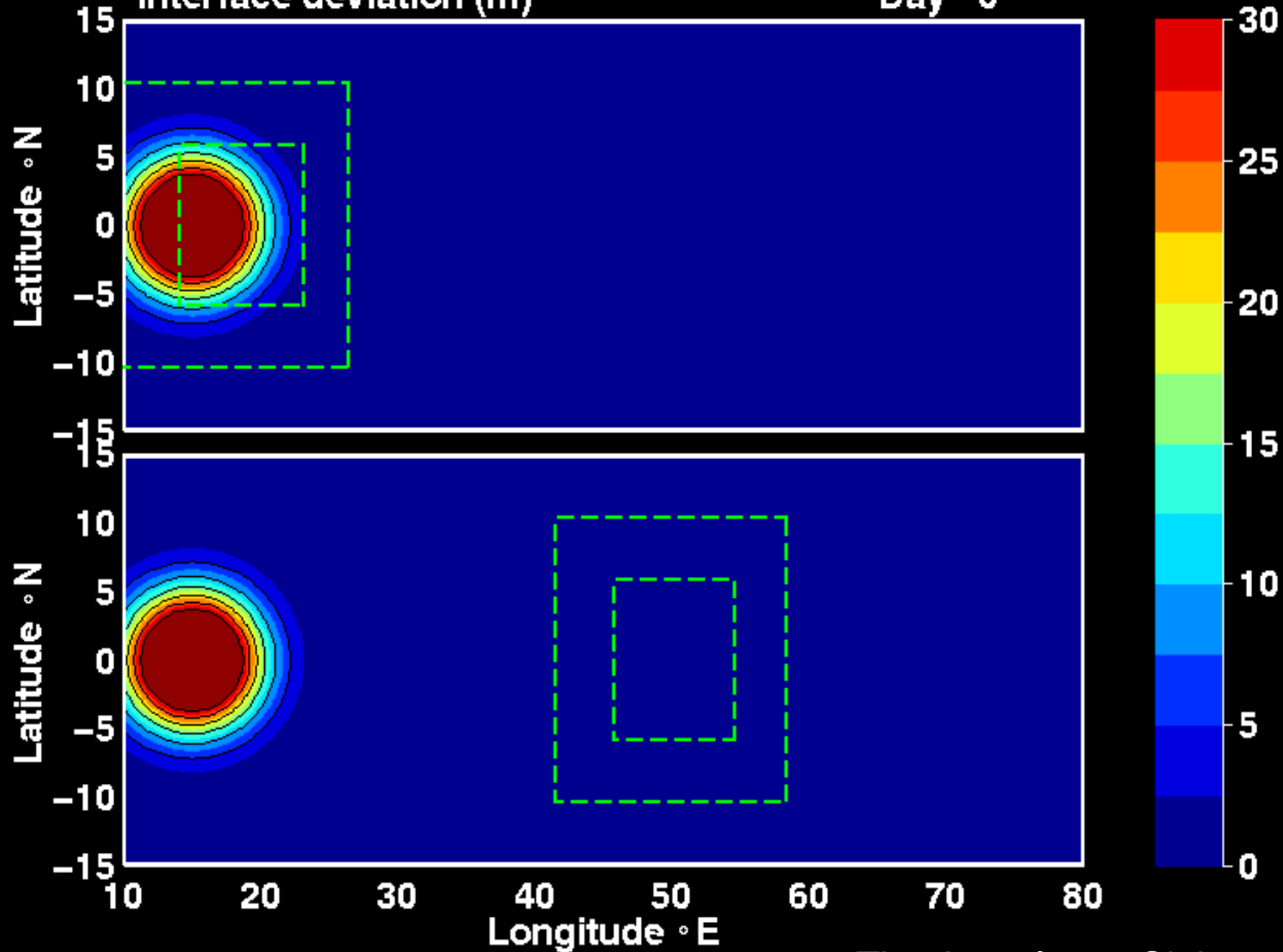
- Separation of the mesh and dynamical interfaces



Kurihara, Y., G.J. Tripoli, and Bender, 1979: Design of a movable nested-mesh primitive equation model. *Mon. Wea. Rev.*, 107, 239-249.

Interface deviation (m)

Day 0

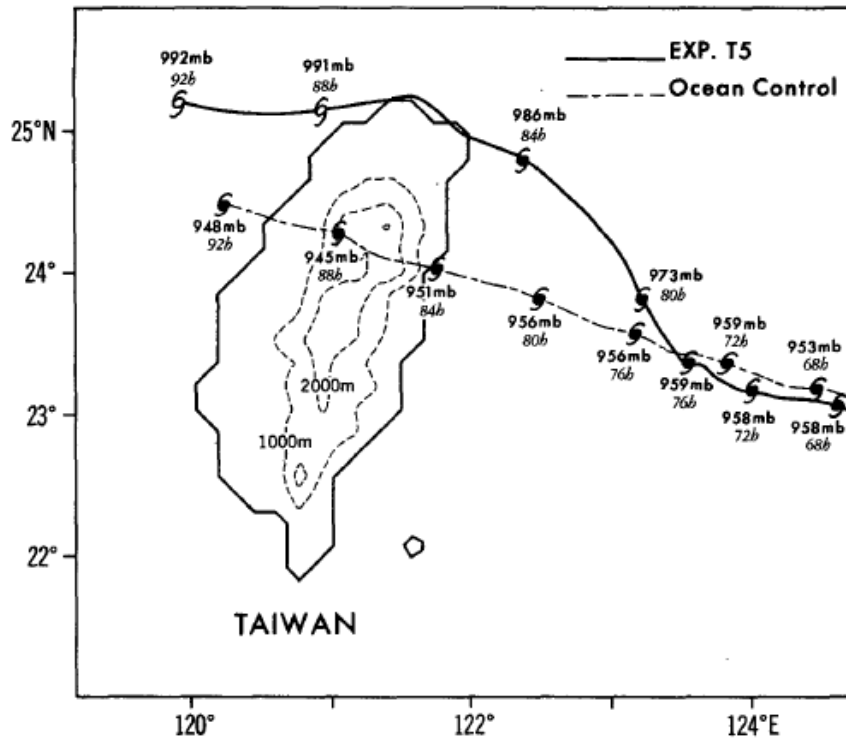


Thanks to Isaac Ginis

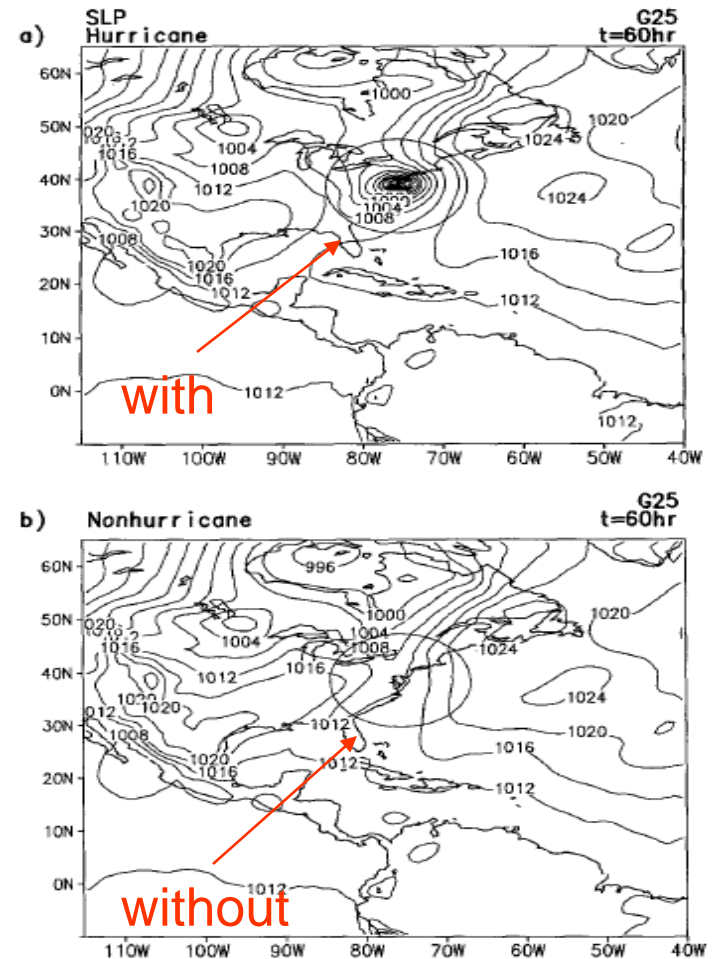
Impacts **on** and **by** TC

Bender, M.A., R.E. Tuleya and Y. Kurihara, 1987, MWR

Ross, R. J., and Y. Kurihara, 1995, MWR



Topographical impact



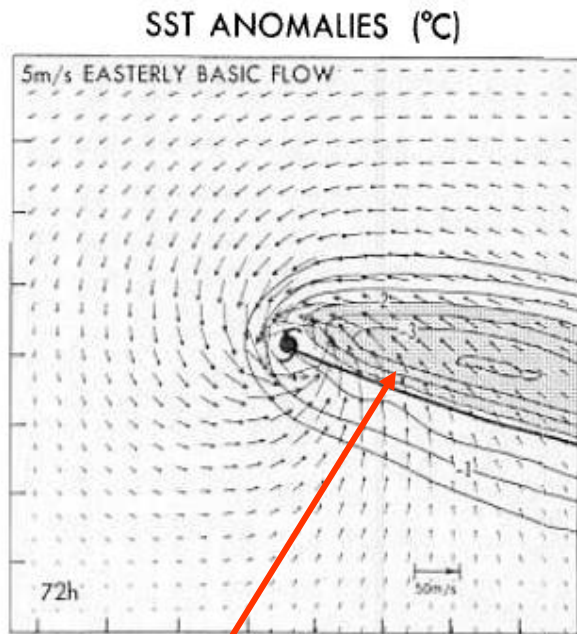
TC's impact on coastal front

Addition of visiting scientists **Ginis** & **Wu**

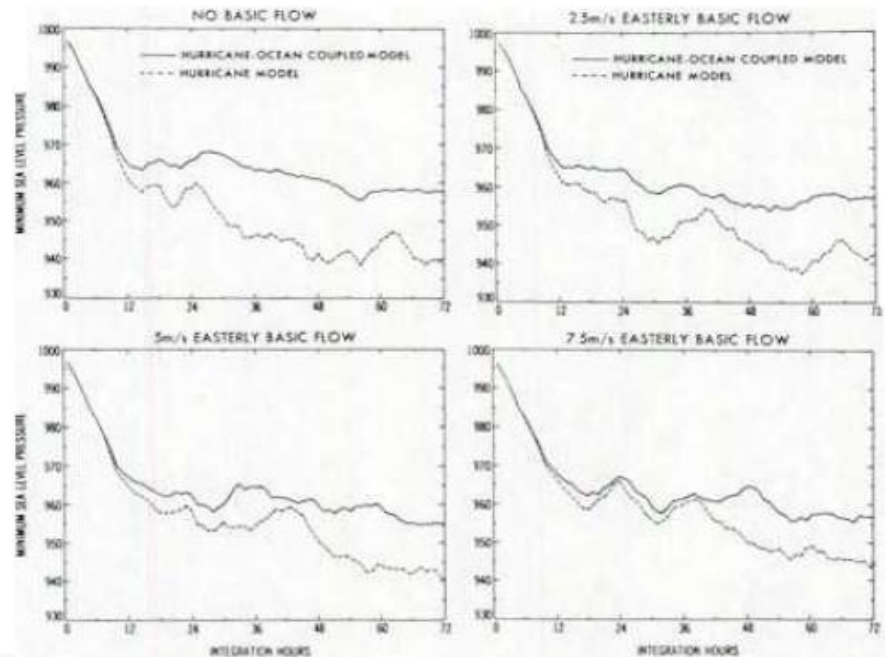


Effects of ocean coupling on TC

Bender, M. A., I. Ginis, and Y. Kurihara, 1993, JGR



Cold wake



Effect on intensity depended on TC speed

Other Research

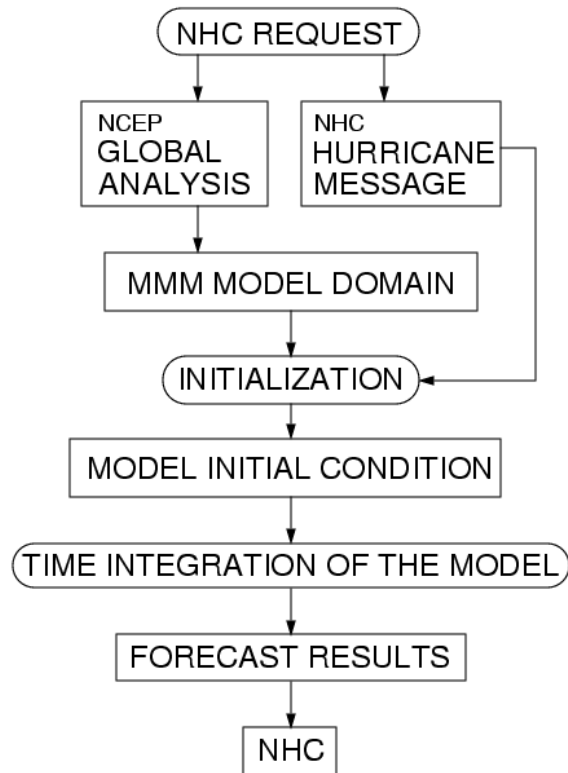
- Time differencing scheme
- Lateral boundary conditions
- Convective adjustment scheme
- Idealized & model spiral band analyses
- Vortex specification
- Hurricane eye and landfall simulations
- Hurricane & Climate

Development of Operational System

(includes vortex initialization, boundary conditions, & model)

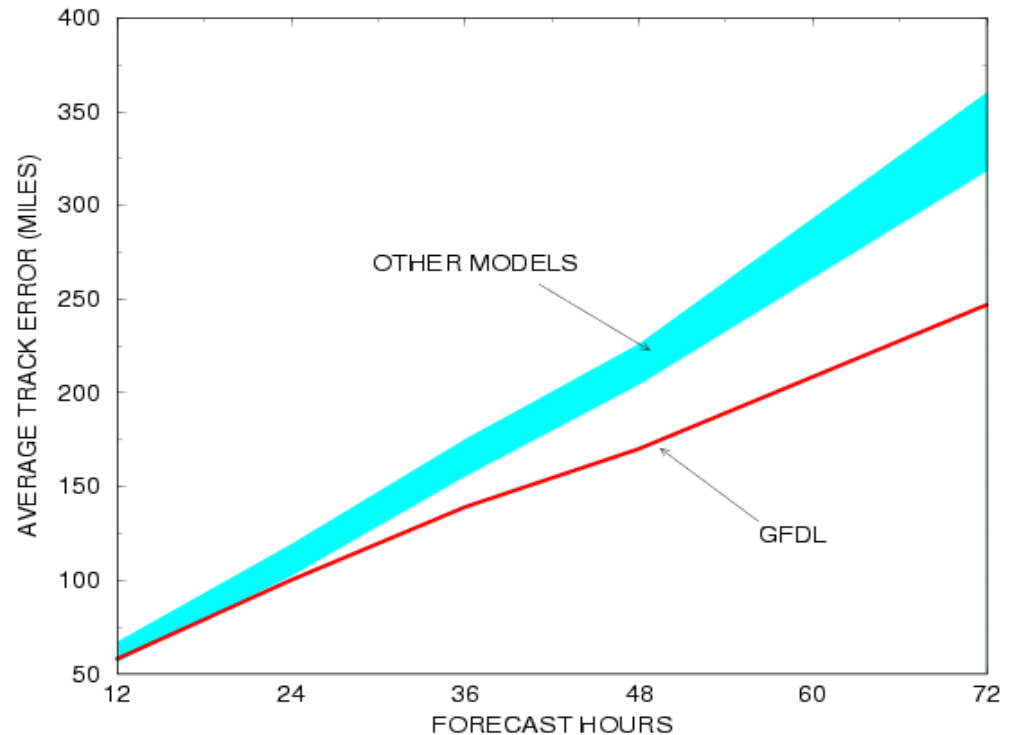
Kurihara, Y., R. E. Tuleya, and M.A. Bender, 1998 , MWR

GFDL HURRICANE PREDICTION SYSTEM



TRACK ERROR

1995 ATLANTIC HURRICANE SEASON



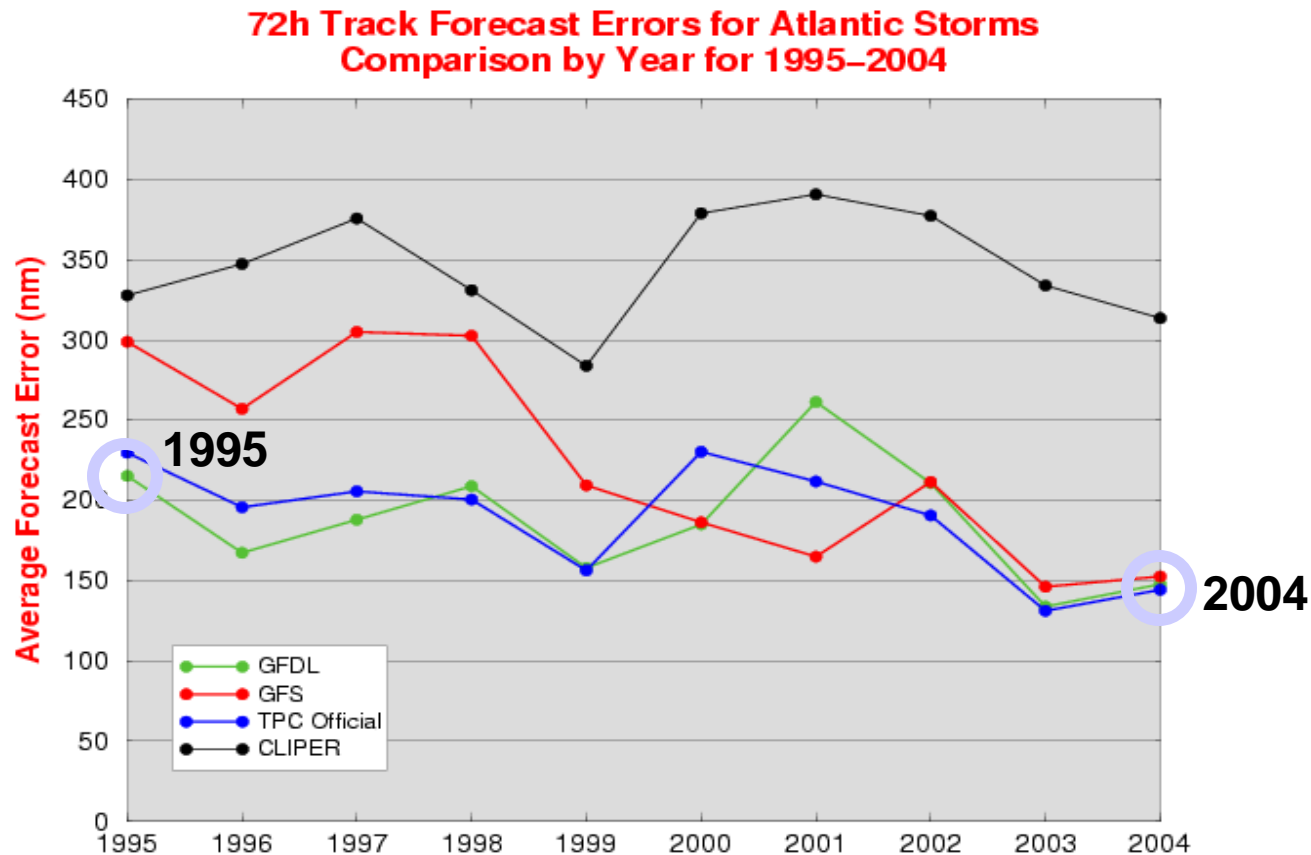
GFDL skill soon followed by global model improvements

Transition to Operations

Keys to success

- NOAA management gave assignment without micro-management.. Bonner, McPherson, Eugenia Kalnay, Lord, Surgi (NCEP) -- Smagorinsky, Mahlman, Orlanski, Leetma (GFDL)
- 1 memorandum of understanding...no committees, workshops, reports, testbeds, etc. --- Contrast with new era of community model development
- GFDL Hurricane group's ability and desire to apply their results to the practical application of operational NWP...
- A top-notch, efficient model and adequate computer power
- Personnel willing to do technical detailed work at considerable expensee.g Tim Marchok (EMC,GFDL), Chris Kerr (GFDL) & Biju Thomas (URI)

72h Forecast Errors for the GFS, GFDL and the Official Forecast Since 1995 in the Atlantic

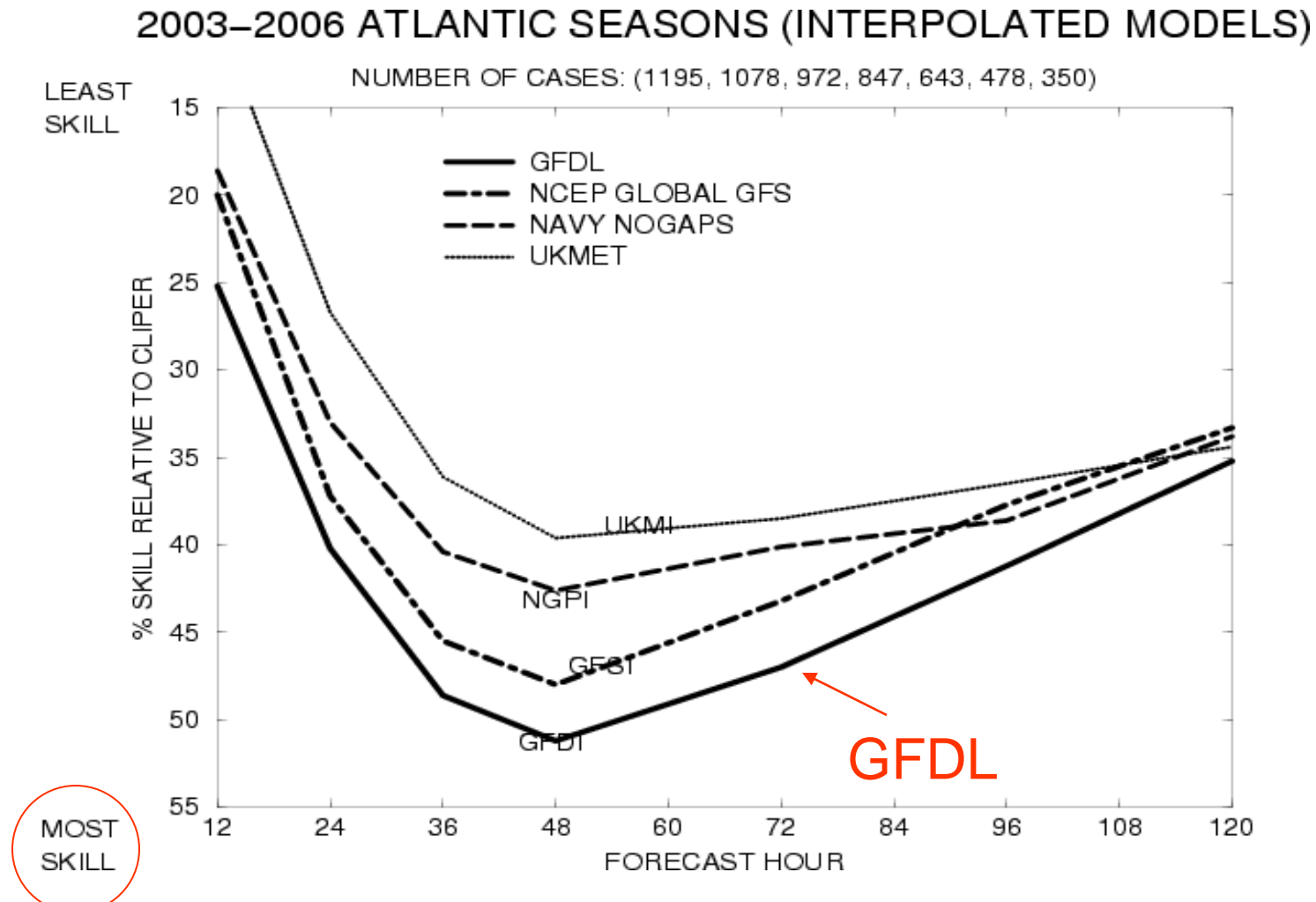


#CASES 127 95 22 133 88 142 132 141 155 243

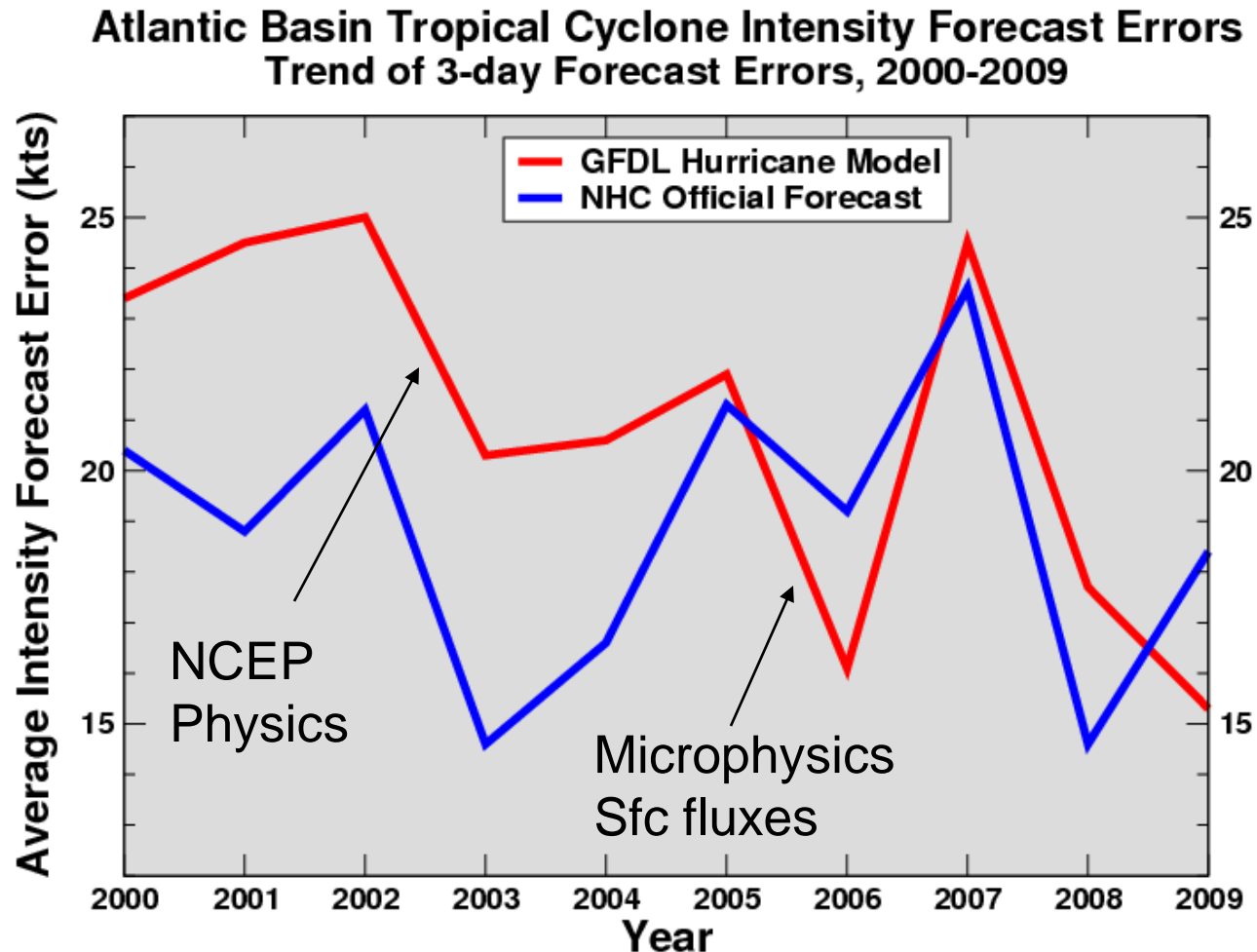
Year of Upgrade	Operational Upgrades to the GFDL Forecast System
1998	<ul style="list-style-type: none"> •Beta-gyre in specified vortex replaced by asymmetries obtained from previous 12 hour forecast •Vertical distribution of target wind in vortex spin-up made a function of storm intensity
2001	<ul style="list-style-type: none"> •Atmospheric model coupled to a high-resolution version of the Princeton Ocean Model (POM) •Upgrade of vertical diffusion from 2.0 to 2.5 Mellor & Yamada closure scheme •Effect of dissipative heating added
2002	<ul style="list-style-type: none"> •Increase of horizontal resolution in outer nest from one to one-half degree •Expansion of region covered by finest mesh (From 5 degree square domain to 11 degrees) •Modification of filter to remove global vortex in vortex initialization (Enables more small-scale features in the global analysis to be retained) •Improved vortex removal algorithm in initialization (Less distortion of environmental fields)
2003	<ul style="list-style-type: none"> •Increased vertical resolution (number of vertical levels increased from 18 to 42) •Kurihara Cumulus Parameterization replaced by Simplified Arakawa-Schubert (SAS) •Mellor and Yamada 2.5 vertical diffusion scheme replaced by Troen and Mahrt non-local scheme •Improved mass initialization for temperature and Sea-level Pressure (Reduced noise over mountains) •Improved pressure gradient computation (Use of virtual temperature) •Effect of evaporation of rain added •Further refinements to vortex removal algorithm in initialization •More consistent target wind in vortex initialization •Ocean coupling expanded to entire ocean domain •Gulf Stream assimilation added to ocean initialization
2005	<ul style="list-style-type: none"> •Addition of third nest with one-twelfth degree resolution •Improved vortex spin-up with model physics consistent with 3D model •Elimination of mass initialization step
2006	<ul style="list-style-type: none"> •Replaced the large-scale condensation scheme with Ferrier cloud micro-physics package •Improved air-sea momentum flux parameterization in strong wind conditions •Assimilation of Loop Current and warm-core eddies in Gulf of Mexico added to ocean initial condition

Continued Success of GFDL Forecasts

M. Bender , I. Ginis , R. Tuleya, B.Thomas and T.Marchok, 2007, MWR



GFDL Intensity Forecasts 2000-2009

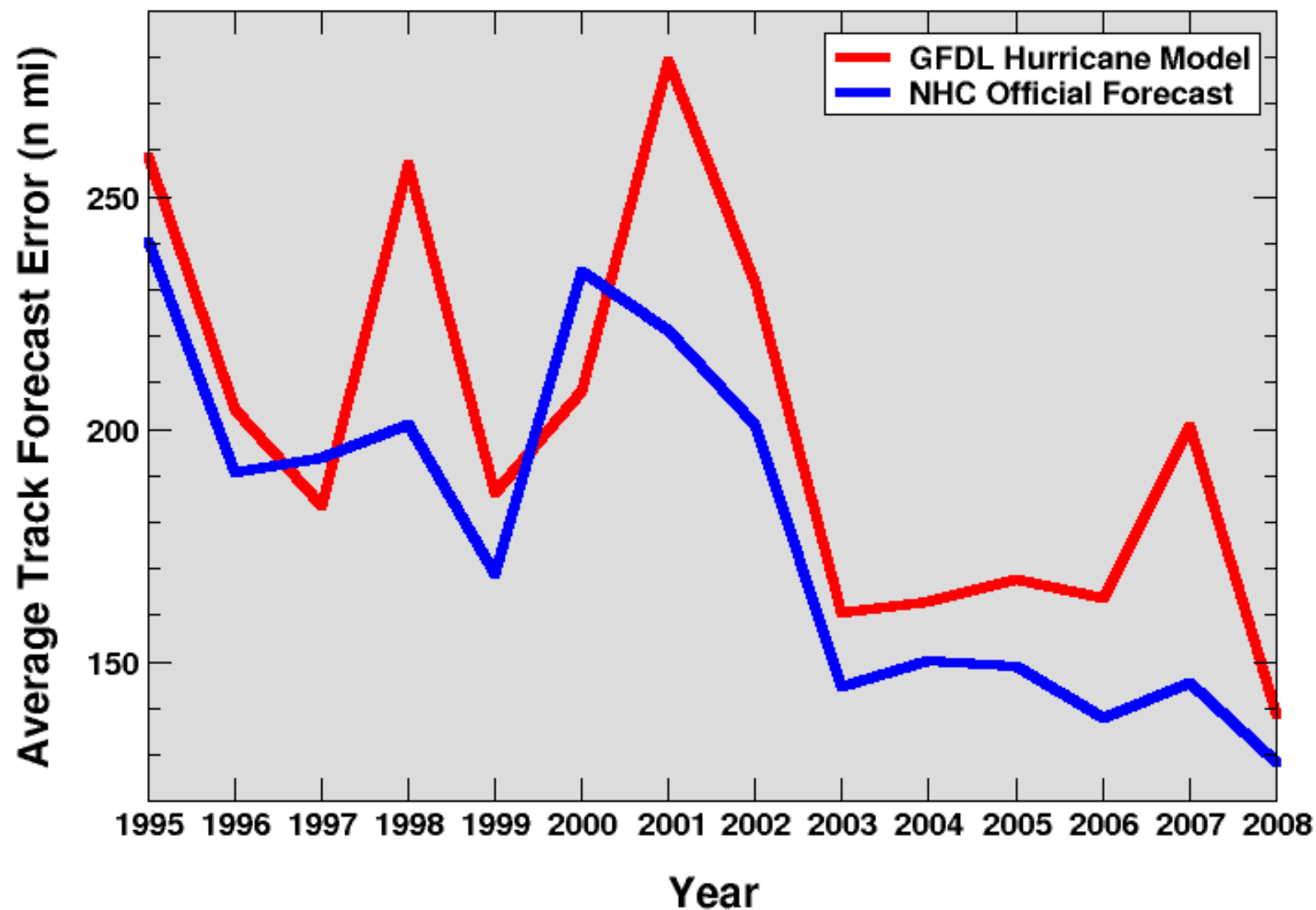


Where do we go from here??

- Transition to HWRF
- Impact of HFIP
- Model upgrades
- Impact of assimilating more storm data
- Deterministic vs Probabilistic intensity forecasts
- Global vs Regional Models

Atlantic Basin Tropical Cyclone Track Forecast Errors

Trend of 3-day Forecast Errors, 1995-2008



Kuri's legacy

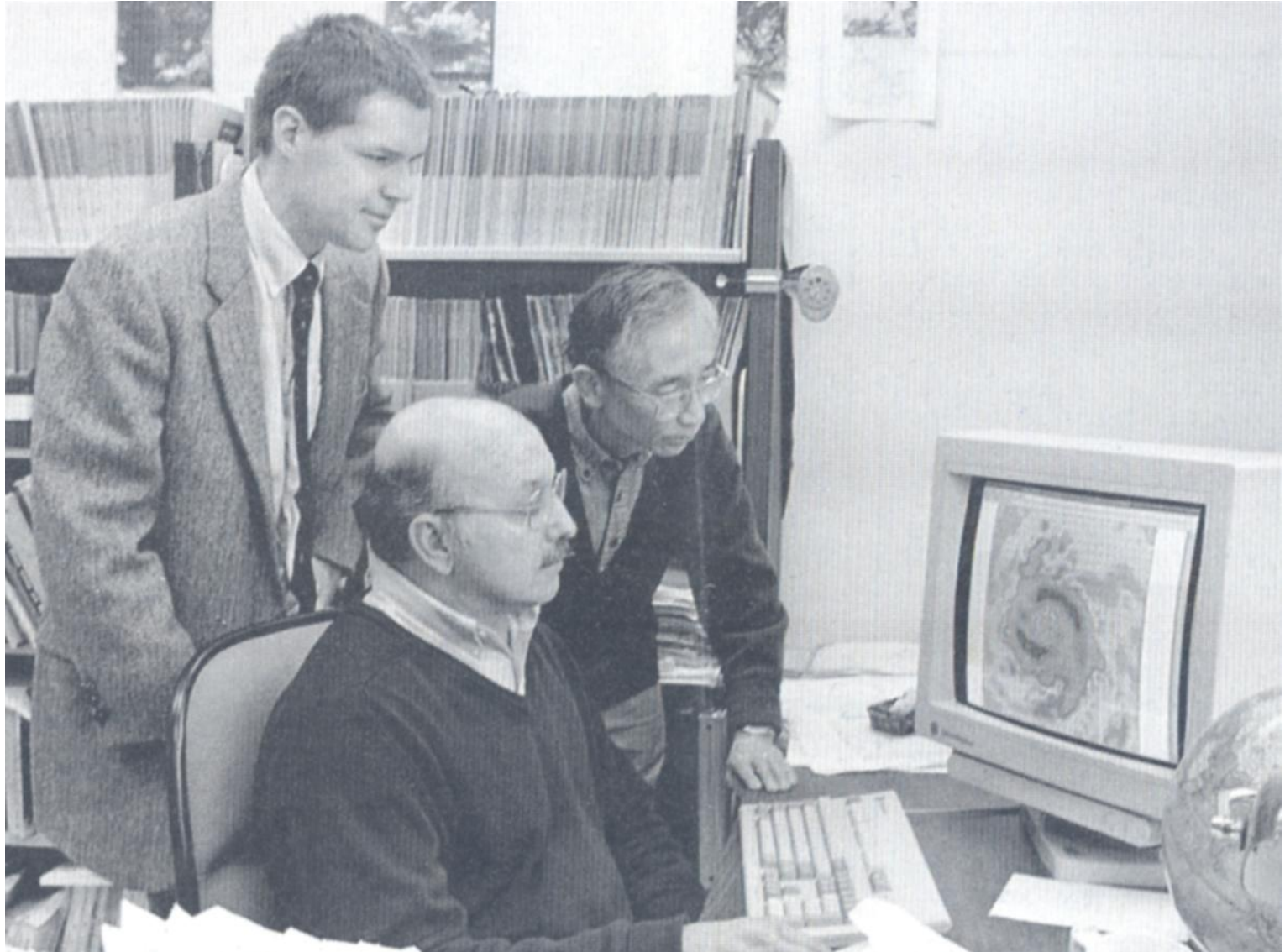
Awards

- *Charney Award (1996)*
- *Fujiwara Award (1994)*
- *DOC Gold Medal (1993)*
- *Banner Miller Awards (1984&1997)*
- *NOAA Outstanding Papers (1983&1992)*
- *AMS Fellow (1980)*

Management Style

- *Shared spotlight*
- *Precise & careful*
- *Empowered others*
- *Humble*

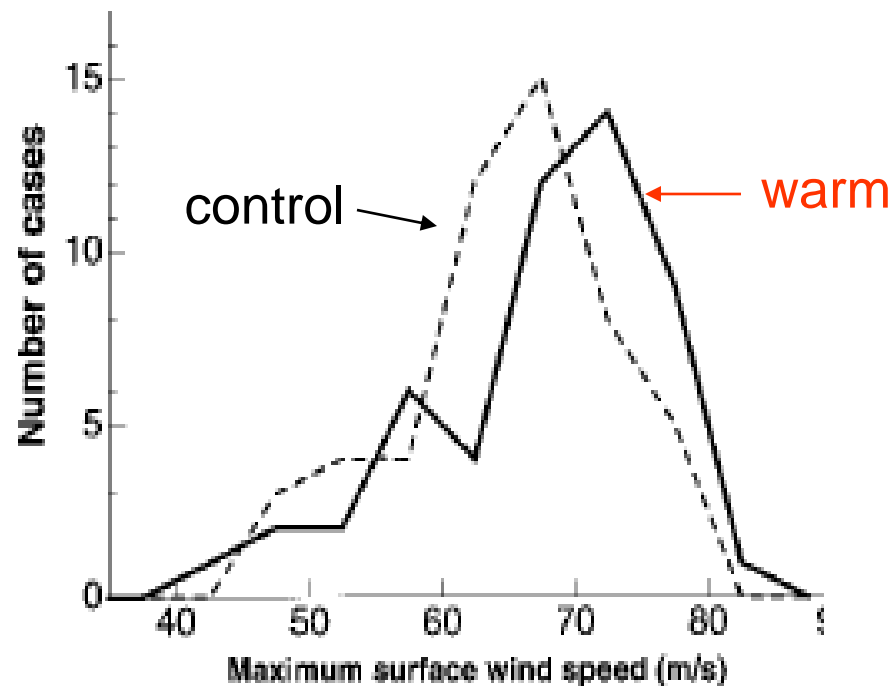
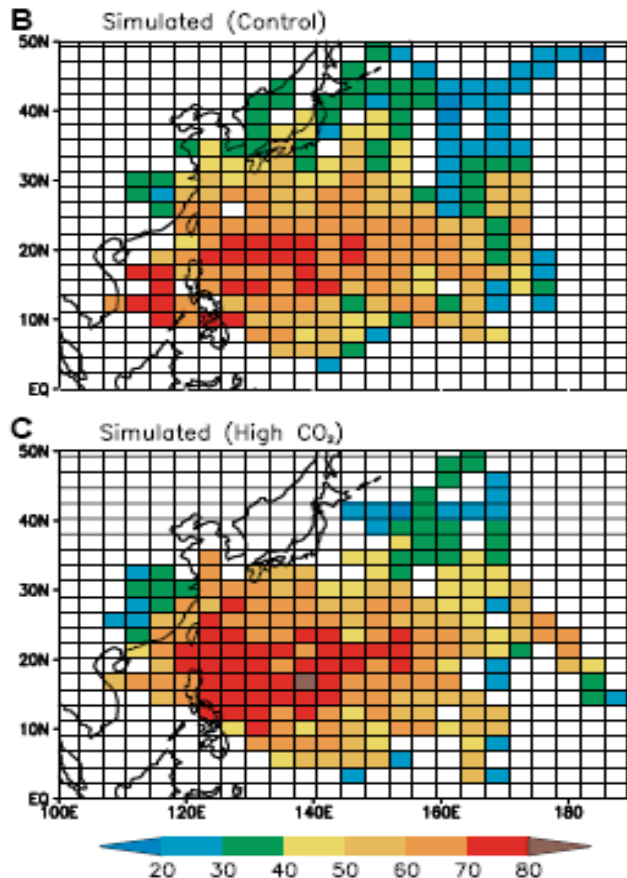
Always Involved in Pioneering Research



Impact of climate change on hurricanes

(downscaling using the GFDL nested model)

Knutson, T. R., R. E. Tuleya, and Y. Kurihara, 1998, Science



Thank you Kuri!!!!

