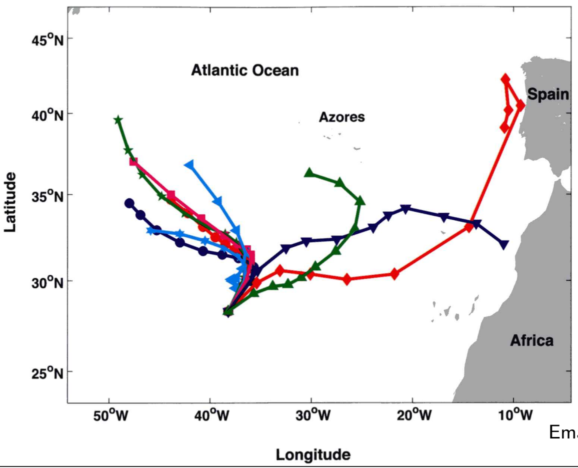
Hurricanes IV: Forecasts and risks

http://www.ci.huntington-beach.ca.us/images/users/fire/Hurricane%20Katrina%20Response2.jpg

Announcements for assignment 5

- Arguments are important (for convincing the opposite camp)
- We (Peter and Ulrike) will be neutral (in sense of argumentation for/against impact of climate change)
- In the discussion the audience (without Peter and Ulrike) is the jury and will decide at the end of the panel discussion which camp had the more convincing arguments

Motivation



Emanuel, 2005

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Some fundamentals

Definition: Areas of the globe prone to TC occurrence are referred to as "basins", e.g. Atlantic basin (North Atlantic Ocean, Caribbean Sea, Gulf of Mexico)

- Pike and Neumann (1987): Australian basin is the most difficult basin for TC forecasts. $\sim$ 3 day forecasts for the Atlantic basin are reasonable
- Fraedrich and Leslie (1989): Predictability time scale for TC forecasting in the Australian basin is $\sim$ 24 h.
- Aberson (1998): TC track forecasting in the Atlantic basin up to $\sim$ 5 days possible

Forecasting of TC's on a short time scale (up to $\sim$ 1 day) is quite accurate (nowcasting) but for longer time intervals the accuracy of forecasts is strongly limited

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Forecast models

Different types of models:

- Statistical models
- Dynamical models
- Intensity models
- Storm surge models
- Risk assessment models

In the following we focus on models which are used in the Atlantic basin (hurricane forecasting)

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Statistical models

Start with the location of the storm and time of the year
$\longrightarrow$ forecast is based upon the history of storms in the database with similar characteristics.
Example: CLIPER (CLImatology and PERsistence, Neumann, 1972): Multiple regression statistical model that utilizes the persistence of the current motion and climatological information. Predicts future zonal/meridional movements of TC's at 12-hr intervals to 72 hours. Used predictors:

- Current/previous 12-hr position of TC's
- Current/previous 12-hr storm motion
- Day of year
- Maximum surface wind

CLIPER was hard to beat until the 1980's. It's now used as a benchmark for other (more detailed) models

Statistical models

Input for CLIPER forecast (database of tracks):

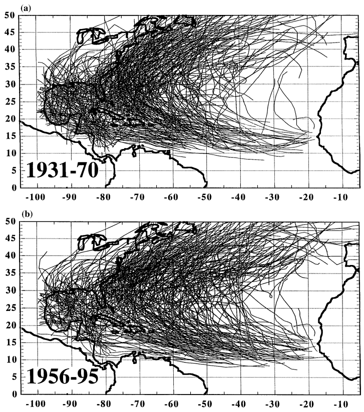


Fig. 1. Tracks of North Atlantic tropical cyclones during the periods (a) 1931–70 and (b) 1956–95.

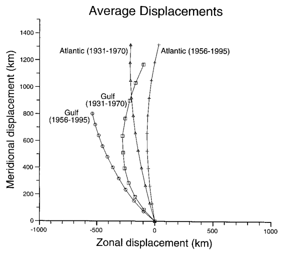


Fig. 2. Average displacements of tropical cyclones in the North Atlantic. Triangles represent displacements in the Atlantic region (1931–70), plus marks those in the Atlantic region (1956–95), squares those in the Gulf of Mexico region (1886–1979), and octagons those in the Gulf of Mexico region (1956–95). Marks are every 12 h from the origin.

Aberson, 1998

Statistical models

Errors for CLIPER forecasts based on the old (circles) and new (triangles) model version (Aberson, 1998):

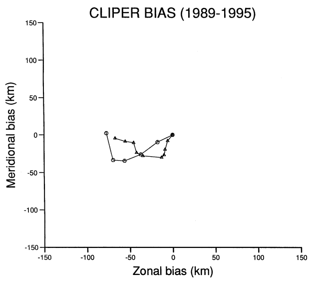


Fig. 6. Average meridional and zonal biases of the two versions of CLIPER for all cases 1989–95. The current version of CLIPER is represented by octagons; the new version by triangles. The values shown from the origin are for 12, 24, 36, 48, 72, 84, 96, 108, and 120 h. The current version extends only to 72 h.

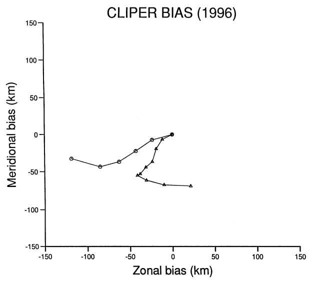


Fig. 7. Average meridional and zonal biases of the two versions of CLIPER for all cases in 1996. The current version of CLIPER is represented by octagons; the new version by triangles. The values shown from the origin are for 12, 24, 36, 48, 72, 84, 96, 108, and 120 h. The current version extends only to 72 h.

1956-1995: improved data set, which is entirely within the era of regular aircraft reconnaissance.

Dynamical models

Numerical weather prediction models solving the equations of motion, of thermodynamics and the continuity equation.
Two types:

- barotropic models (move weather systems along wind fields)
- baroclinic models (full variability and interactions)

In general baroclinic model are very computing time consuming but usually more accurate whereas barotropic models run very fast and it is easy to generate many forecasts with changed initial/boundary conditions (→ ensemble forecasts)

Barotropic models

Example: VICBAR (Aberson and Demaria, 1994)
Nested barotropic model that uses NCEP synoptic analyses and solves shallow–water–equations for the track prediction

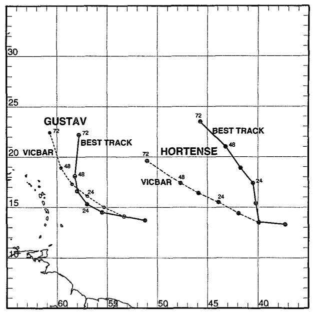


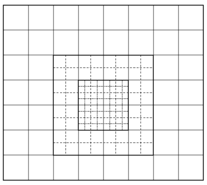
FIG. 12. VICBAR track forecasts and best tracks of Hurricane Gustav and Tropical Storm Hortense for 0000 UTC 26 August 1990. The best track location 12 h previous (1200 UTC 25 August) is also shown.

Problems:

- High vertical wind shear
- Interacting TC pairs

Baroclinic models

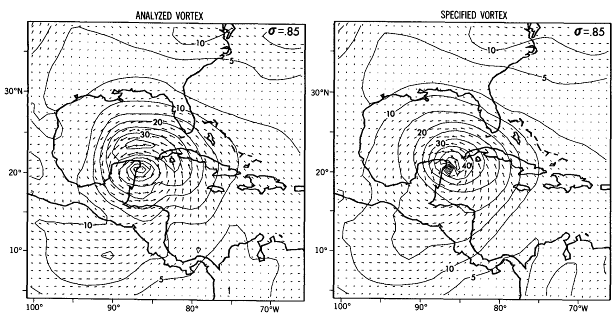
- Example: Geophysical Fluid Dynamics Laboratory (GFDL) model: Limited area baroclinic model (developed for TC forecasts) on 3 nested grids:



where the inner grid follows the TC.
- The model contains parameterizations for radiation, convection and PBL.
- Initial/boundary conditions are taken from the Medium Range Forecast (MRF) model or National Hurricane Center (NHC) analyses.

2 possibilities for initializing the vortex:

- analysed vortex in global analysis: radius of max. wind: 350 km
- specified vortex: radius of max. wind reduced to 60 km



Bender et al., MWR, 1993

Example: Forecasting hurricane Gloria

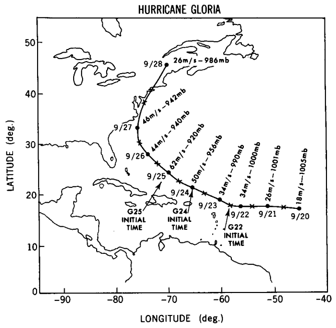


FIG. 2. Observed track (best track determined by the National Hurricane Center) of Hurricane Gloria during the period from 0000 UTC 20 September 1985 until 0000 UTC 28 September 1985. The storm's minimum sea level pressure (mb) and maximum low-level wind (m s^{-1}) at 0000 UTC each day are shown. The large dots indicate the position of the storm at 0000 UTC and the X's indicate the 1200 UTC storm positions. The initial starting times for the three sets of Hurricane Gloria forecasts are also indicated.

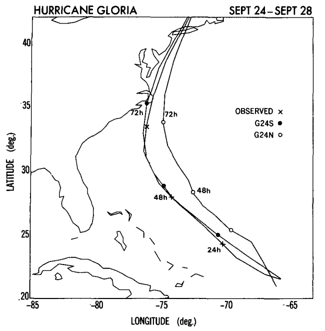
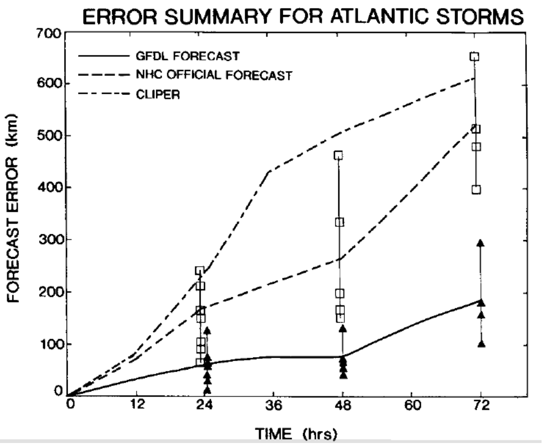


FIG. 6. A portion of the storm tracks from forecasts G24S and G24N (0000 UTC 24 September 1985 starting time). For comparison, the observed track (best track) is also plotted. The symbols indicate the daily storm positions valid at 0000 UTC each day.

s=specified vortex; n=vortex from NMC global analysis

Comparison of hurricane track forecasts



Kurihara et al., MWR, 1993

Intensity models

- Statistical Hurricane Intensity Prediction Scheme (SHIPS, Demaria and Kaplan, 1994):
  SHIPS uses standard multiple regression methods with climatology, persistence and synoptic predictors:
  - intensification potential
  - vertical wind shear
  - persistence (intensity change within the last 12 hours)
  - average 200 hPa temperature and wind components
  - average 850 hPa relative vorticity
  - day of year
  - flux average of angular momentum at 200 hPa
- A deterministic intensity model (K. Emanuel, *http://wind.mit.edu/ emanuel/home.html*)
- Intensity forecasts with the GFDL model

Intensity models (Emanuel, Nature, 1999)

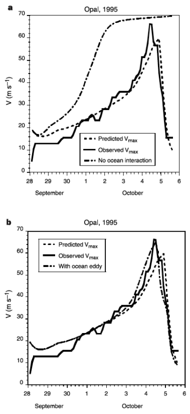


Figure 1 Evolution of the maximum wind speed in Hurricane Opal. In **a**, the solid line shows the observed evolution, the dashed line shows the modelled evolution, and the dash-dot line shows evolution modelled without ocean interaction. In **b**, the dash-dot line shows evolution modelled in the presence of a warm ocean eddy.

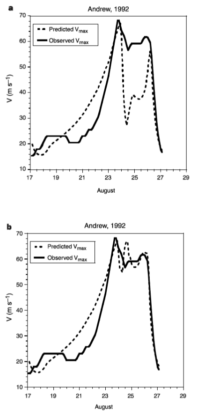
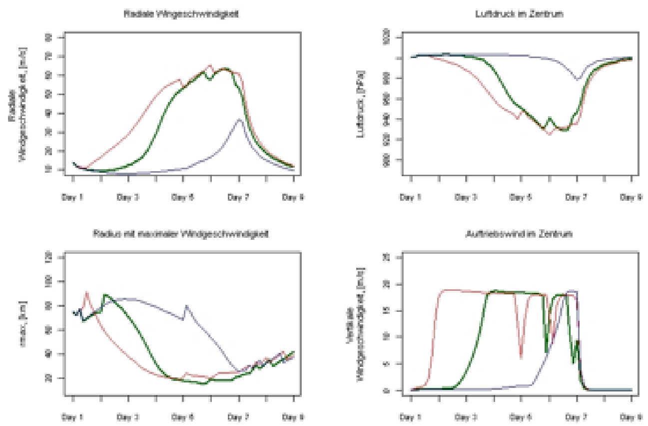


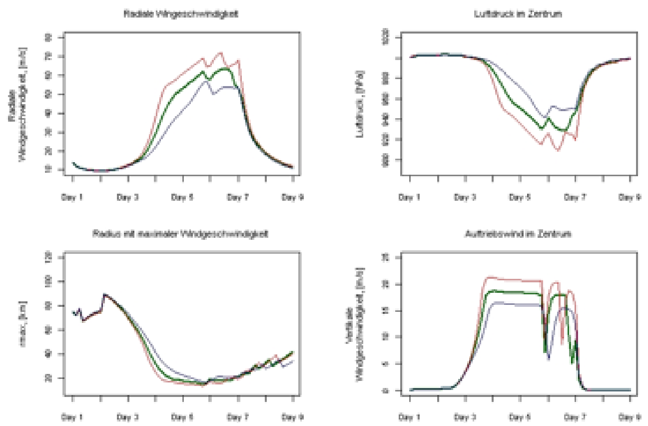
Figure 2 Evolution of the maximum wind speed in Hurricane Andrew. Solid lines are observations and dashed lines are modelled values. The nominal model run is shown in **a**, while the run in **b** takes into account the swamp in southern Florida and the shallow continental shelf to its west (see text for details).

Sensitivität von "Relative Luftfeuchtigkeit"

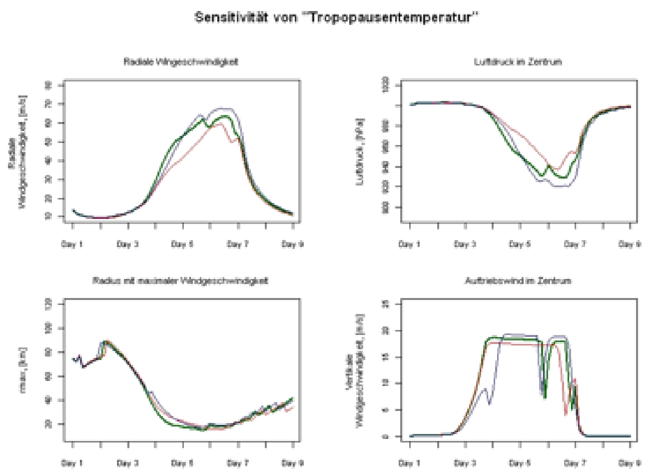


Lines: control simulation, +15%, -15% [Semesterarbeit Markus Fischer, 2006]

Sensitivität von "Meeresoberflächentemperatur"



Lines: control simulation, +15%, -15% [Semesterarbeit Markus Fischer, 2006]



Lines: control simulation, +15%, -15% [Semesterarbeit Markus Fischer, 2006]

Risk assessment models

Different damage sources:

- precipitation (not well understood)
- wind
- storm surge (coupled with wind)

Several efforts to assess risks associated with TC's winds:

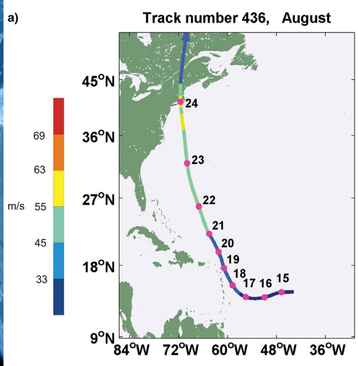
1. Historic compilation of TC tracks and intensities ("best tracks", e.g. HURDAT, *http://www.aoml.noaa.gov/hrd/hurdat/*)
2. Estimation of TC intensity along randomly produced tracks (from mathematical models using the database)

Risk assessment models

Example: Combining statistical tracks with deterministic intensity models (Emanuel et al., 2006)

- Generating (large numbers of) TC tracks using statistical methods (e.g. Markov chains, synthetic wind time series etc.)
- Running a deterministic intensity model on these tracks (namely the steady state model from lecture Hurricane II including changes in the environmental state)

Risk assessment models



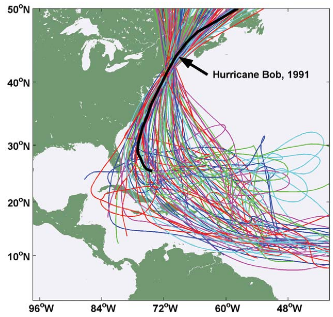


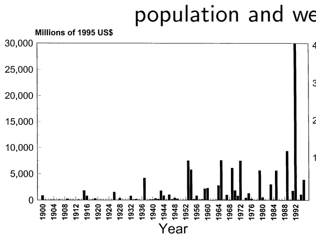
Fig. 10. Tracks of the 100 most intense of the 3,000 storms in the sample of storms affecting downtown Boston, using method 2. Shown for comparison (in black) is the observed track of Hurricane Bob of 1991.

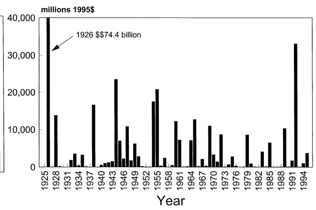
Emanuel et al., 2006

Risk assessment – normalized damages

Problem: How to estimate the damages for a long time period? Several factors change (e.g. population and settling, costs etc.)

Normalized damages taking inflation and changes in coastal population and wealth into account

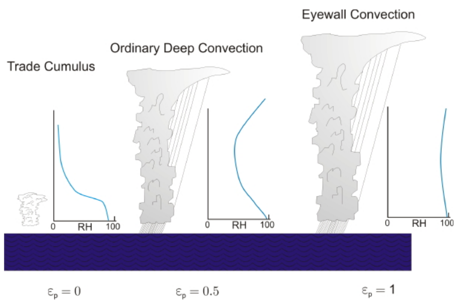




Pielke and Landsea, 1998

Heavy rain

In TC's the rainfall is very strong, because of a high "precipitation efficiency": Due to the humid environment (near saturation) the eyewall extends from the PBL to the tropopause and nearly all condensed cloud water will fall out as precipitation (nearly no evaporation of precipitation below cloud base).



Emanuel, 2005

Heavy rain

Thus, the precipitation is mostly driven by the updraft motion in the eyewall which is controlled by

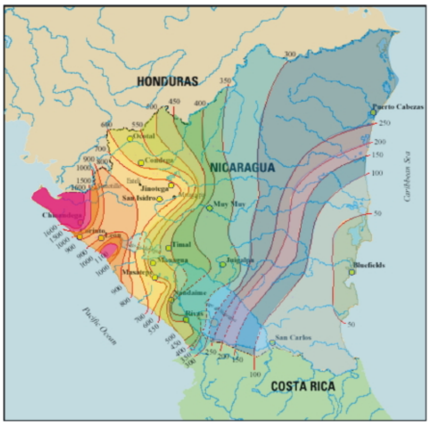
- Intensification of the TC
- Friction in the PBL

These factors control also the precipitation over land:

1. Lower intensity $\rightarrow$ less precipitation
2. Higher friction $\rightarrow$ more precipitation (remember beaker experiment: friction enhances inflow and the secondary circulation)

Usually, the first factor dominates

Heavy rain



Hurricane Mitch Emanuel, 2005

Tornadoes in TC's environment

Almost all TC's making landfall spawn at least one tornado (provided enough of the TC's circulation moves over land)

For spawning of tornadoes, the environment must have the same properties as discussed for supercell thunderstorms:

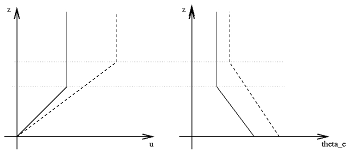
- strong vertical wind shear
- strong instability in low and mid levels

In the vicinity of TC's the environment is conditionally unstable and strong (low level) vertical wind shears occur

Differences to supercell thunderstorms:

- Instability in TC's is merely in the lower levels (up to 3-4 km) whereas in supercell tornadoes the unstable layers extend up to 10 km
- In TC's the low level shear is much stronger than for "supercell" thunderstorm environments
- Maximum wind speed in TC's occurs near 2-3 km, in "supercell" thunderstorms near 10 km

⇒ In both environments the altitudes of maximum buoyancy and wind speed coincide:



Tornadoes in TC's environment

In the Northern Hemisphere the right–front quadrant of a TC is strongly favored for tornado formation (strongest vertical wind shear)

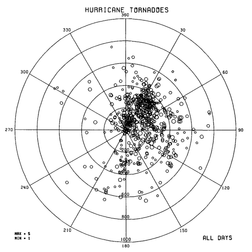


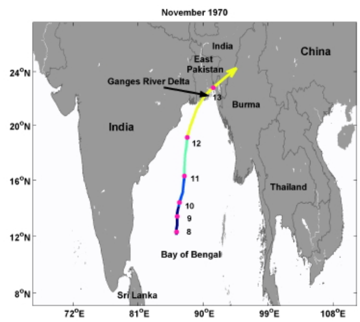
FIG. 11. Locations of all reported hurricane tornadoes, 1948–86. Format of diagram is as in Fig. 1a. Azimuths of tornado locations are defined relative to hurricane motion at tornado time. Areas of circles are proportional to unity plus the F-scale rating of the tornado. Note bimodal clustering of data points in right-front quadrant.

McCaul, 1991

Tornadoes in TC's environment are usually weaker than supercell tornadoes

Storm surge

The storm surge is the most damaging and deadly component of a TC: In 1970 a TC reaching Bangladesh killed over 300.000 people.



Great Cyclone of November 1970

Emanuel, 2005

Storm surge

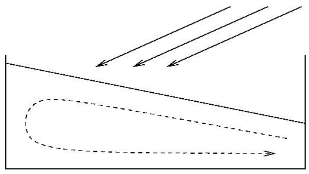
How to create a storm surge: A TC affects the elevations of the sea surface in two ways:

- Low pressure inside the storm ($\sim$ 1 cm/1hPa pressure deviation, see assignment 3, hydrostatic eq.)
- Wind stress

The wind stress induces complex currents in the deep open ocean ($v_c \sim$ few m s^{-1}) but only small elevations. Problem is the interaction of wind stress with shallow water near the coast and the coast itself

Storm surge

Simple experiment



3 effects:

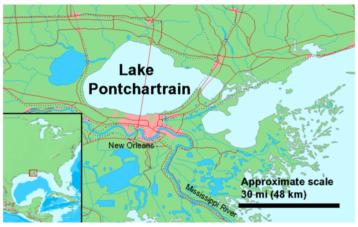
- Circulation of the water
- Surface tilts to balance the friction of the wind against pressure gradient
- Resonance: An abrupt switching off of the wind will induce a slosh back of the water. This could easily happen in nature by the moving TC and can trigger the flow in the other direction

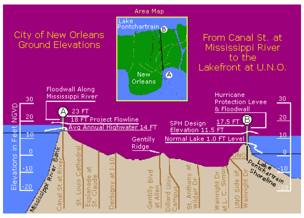
Strategies for damage prevention

Different stages for damage prevention:

- Risk assessment
- Long time strategies:
  - Marshlands/drying wetlands
  - No settling in high risk areas (development plans)
- Emergency plans (including food storage and medical care) in combination with forecasts and early warning systems
- Immediate damage prevention: dams and dikes
- Damage prevention by better/stronger construction: roofs, doors and windows (e.g. storm shutters), walls, foundations etc.
- Pumps

Location of New Orleans





http://en.wikipedia.org/wiki/Image:Lake_Pontchartrain.png

http://en.wikipedia.org/wiki/Image:New_Orleans_Levee_System.gif