Extra-Tropical Cyclones in a Warming Climate:

Observational Evidence of Trends in Frequencies and Intensities in the North Pacific, North Atlantic, & Great Lakes Regions

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IPCC & CCSP Assessments

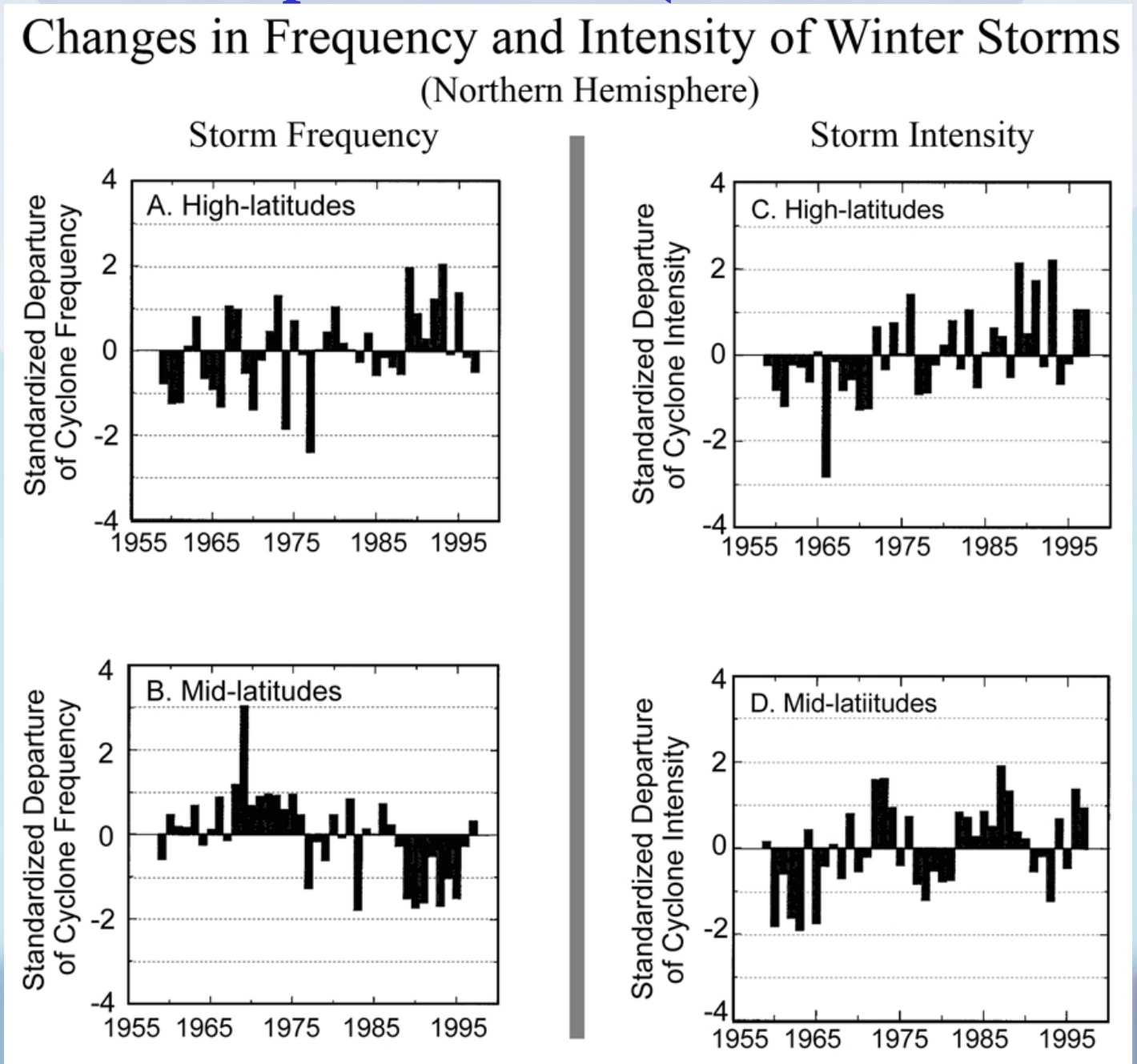
- ✓ **IPCC AR4:**
  - WG1 concluded that there has been a northward shift in storm tracks in the Northern Hemisphere of ~180 km
  - Evidence of increasing counts of ETCs in High Latitudes, and a decrease in counts of ETCs in Mid-Latitudes

- ✓ **CCSP Synthesis & Assessment Product 3.3 – "Weather & Climate Extremes in a Changing Climate"**
  - Focus is on North America, Caribbean & Pacific Islands
  - Assessment of changes in ETCs along Pacific & Atlantic Coasts
  - Also changes in ETCs over interior regions (i.e. Great Lakes, Canada, etc.)

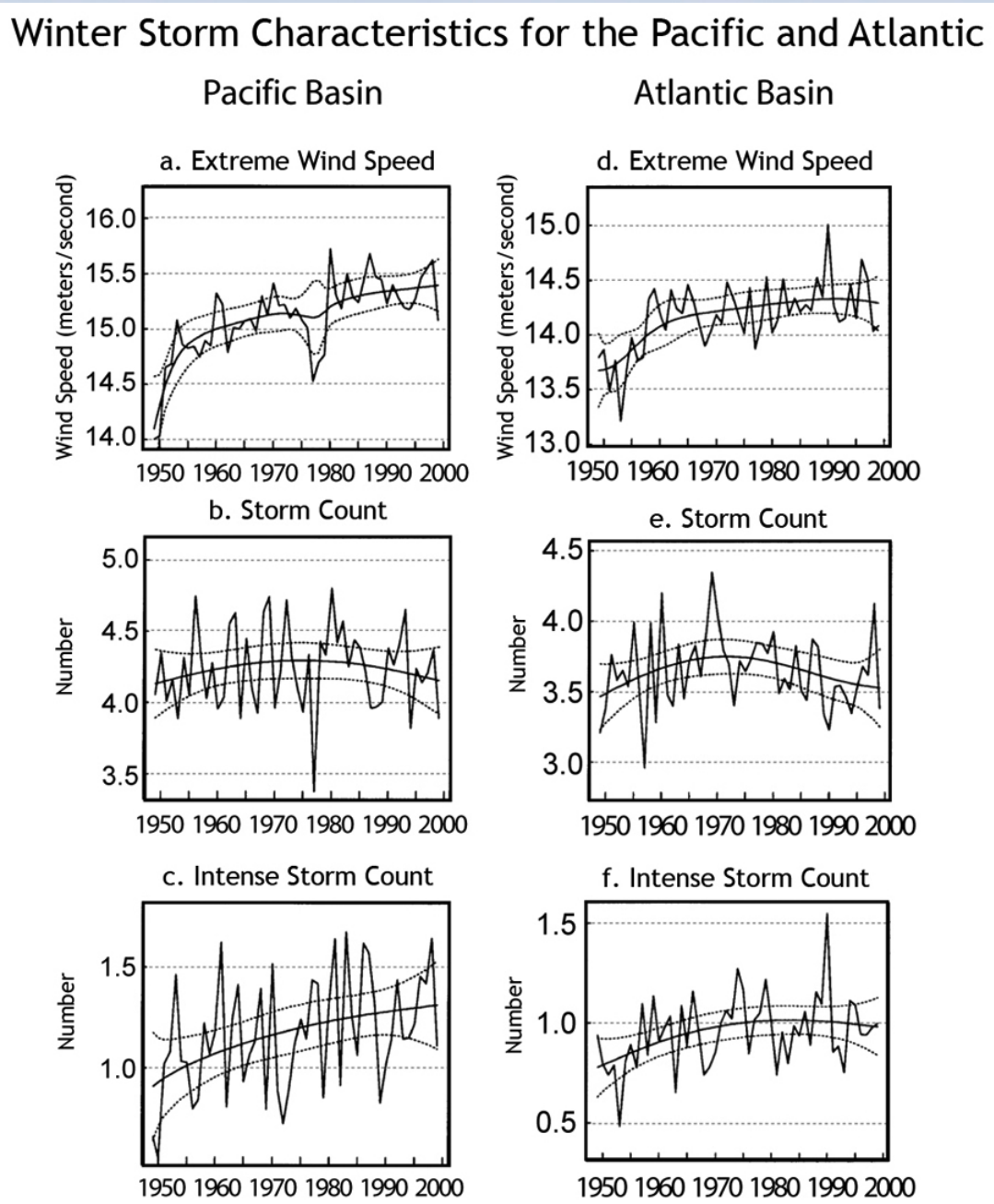
Tracking Changes in Extra-Tropical Cyclones

- ✓ **Annual/Seasonal Storm Counts:**
  - Derived from reanalysis studies (NCEP-NCAR, ERA-40)
- ✓ **ETC Intensities:**
  - Changes in MSLP
  - 500-hPa Geopotential Heights
- ✓ **Observed changes in surface wave heights & energy:**
  - Buoy time series analysis
- ✓ **Impacts on Coasts**
  - Shoaling waves and erosion
  - Damage estimates and fatalities
- ✓ **Other metrics:**
  - Multiple parameter analysis

Northern Hemisphere ETCs (McCabe et al. 2001)



Northern Hemisphere ETCs (Paciorek et al. 2002)



Conclusions

- ✓ **Northward shift in North Pacific & North Atlantic storm tracks verified by a number of studies**
  - Trends in frequency from reanalysis data (NCEP-NCAR & ERA-40) have the most statistically significant results

- ✓ **Strong/Extreme ETCs appear to be intensifying over the North Pacific and North Atlantic**
  - However, no apparent change in Nor'easter intensity (or frequency)
    - ➢ Likely due to the smaller study area along coast
  - Longer-term records show several periods of enhanced storm activity in the late 19th & early 20th centuries

Conclusions (Cont.)

- ✓ **Great Lakes Cyclones**
  - Long-term increase in annual frequency based on station data
  - Most significant increases observed during cold season, especially late Fall (Nov – Dec)
  - More analysis needed to be extend record (currently ends in 1990)

- ✓ **Trends in *Hs* in North Atlantic Deep Water Buoys Suggest a Northward Shift in ETC activity**
  - Limited number of statistically significant trends in buoy data
    - ➢ Decrease in # of events in Cape May record
    - ➢ Increase in mean *Hs* and mean duration in Cape Cod record for the most extreme events (5.4 m threshold)
    - ➢ Short record and data gaps preclude definitive verification
  - Buoy records need to be re-checked for any instrumentation, processing or location changes
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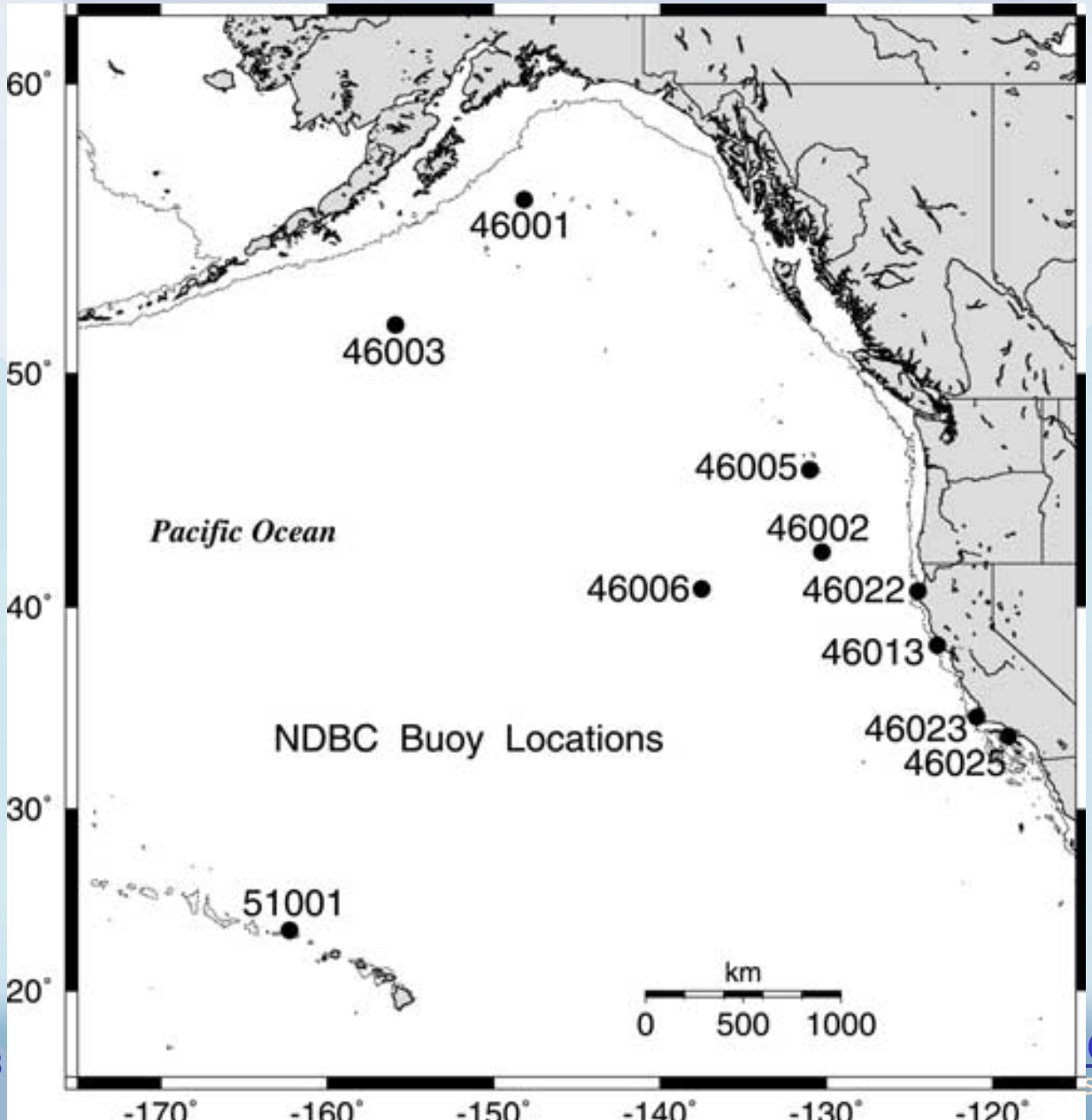
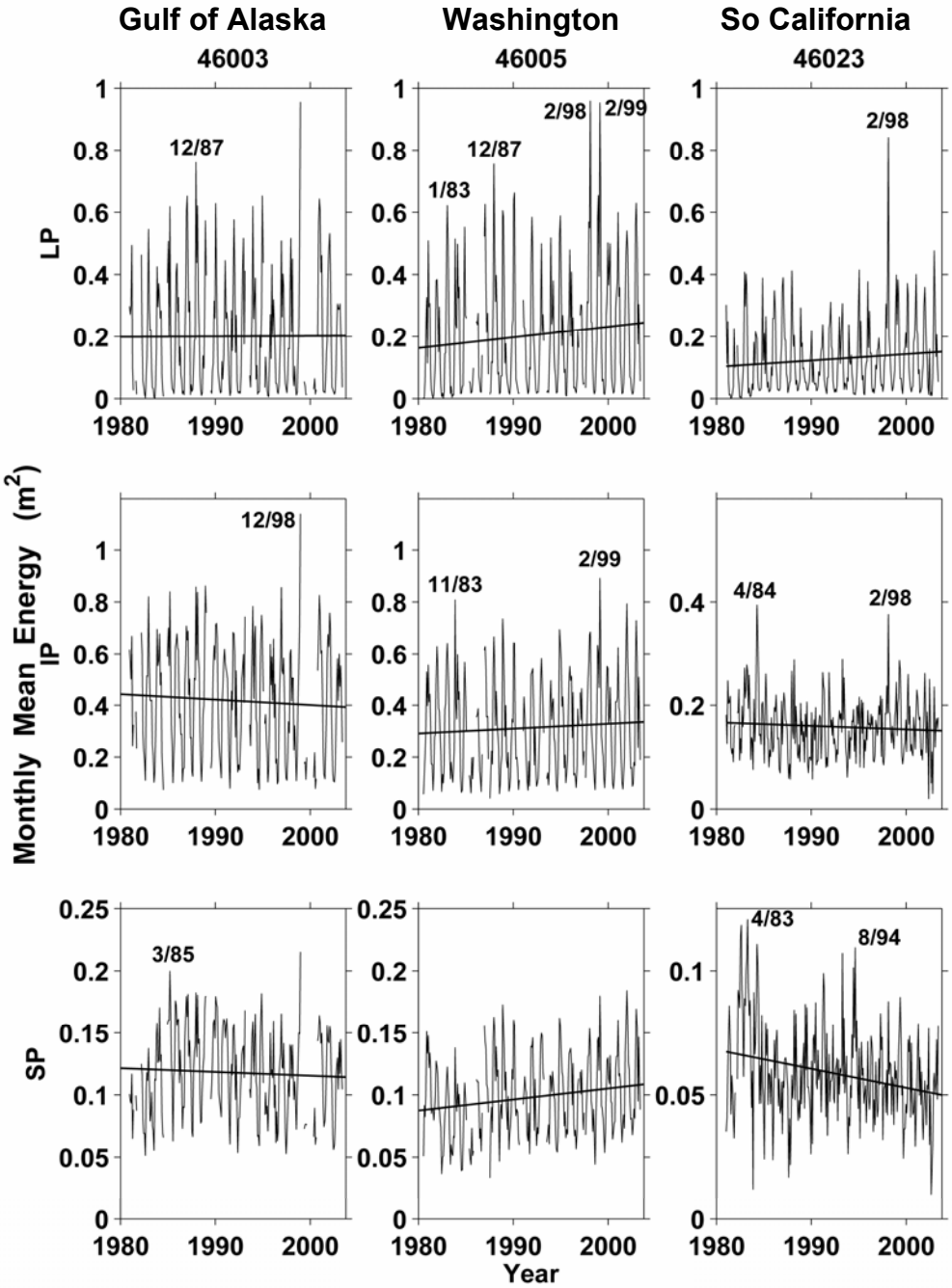
East North Pacific Basin Buoys

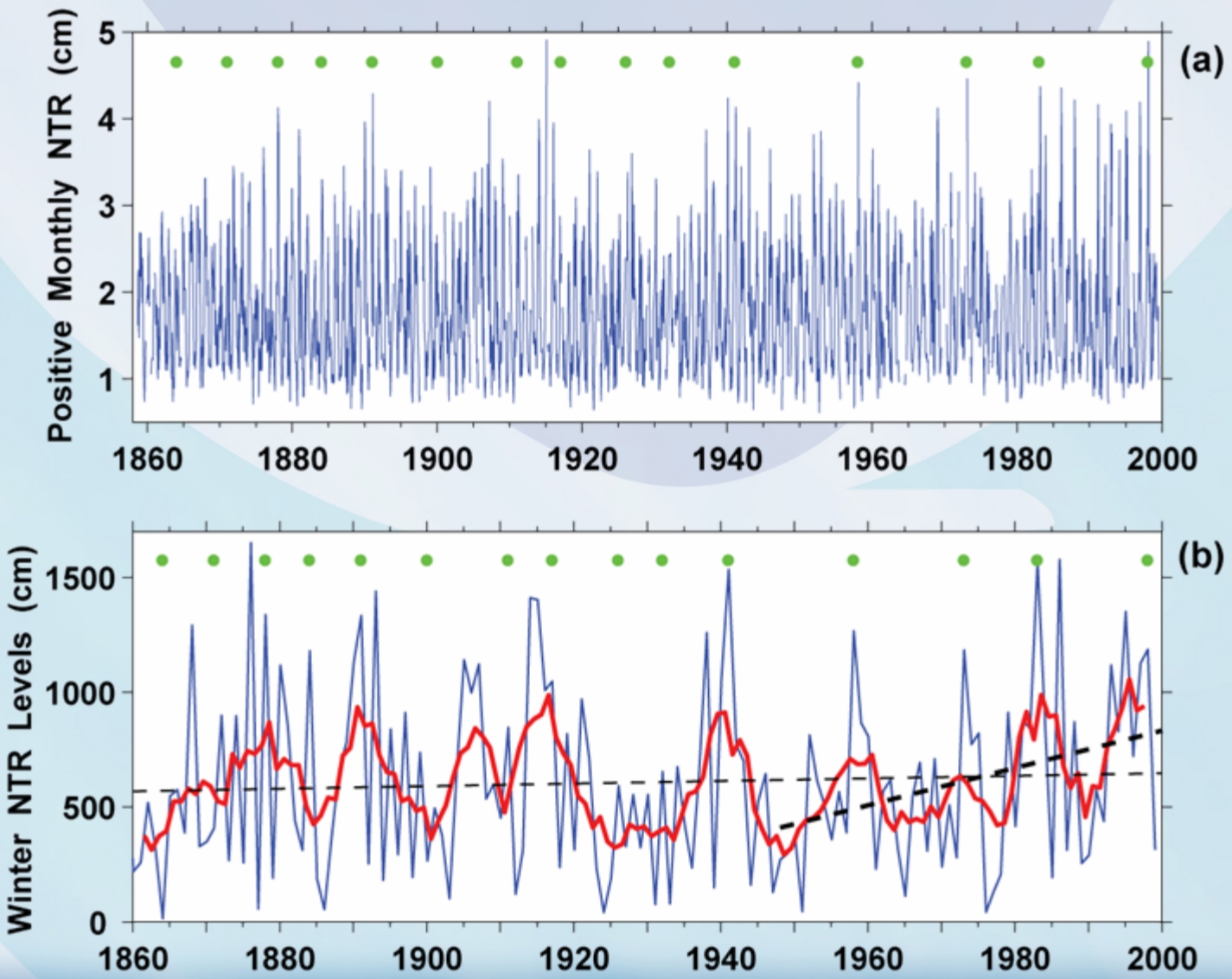


East North Pacific

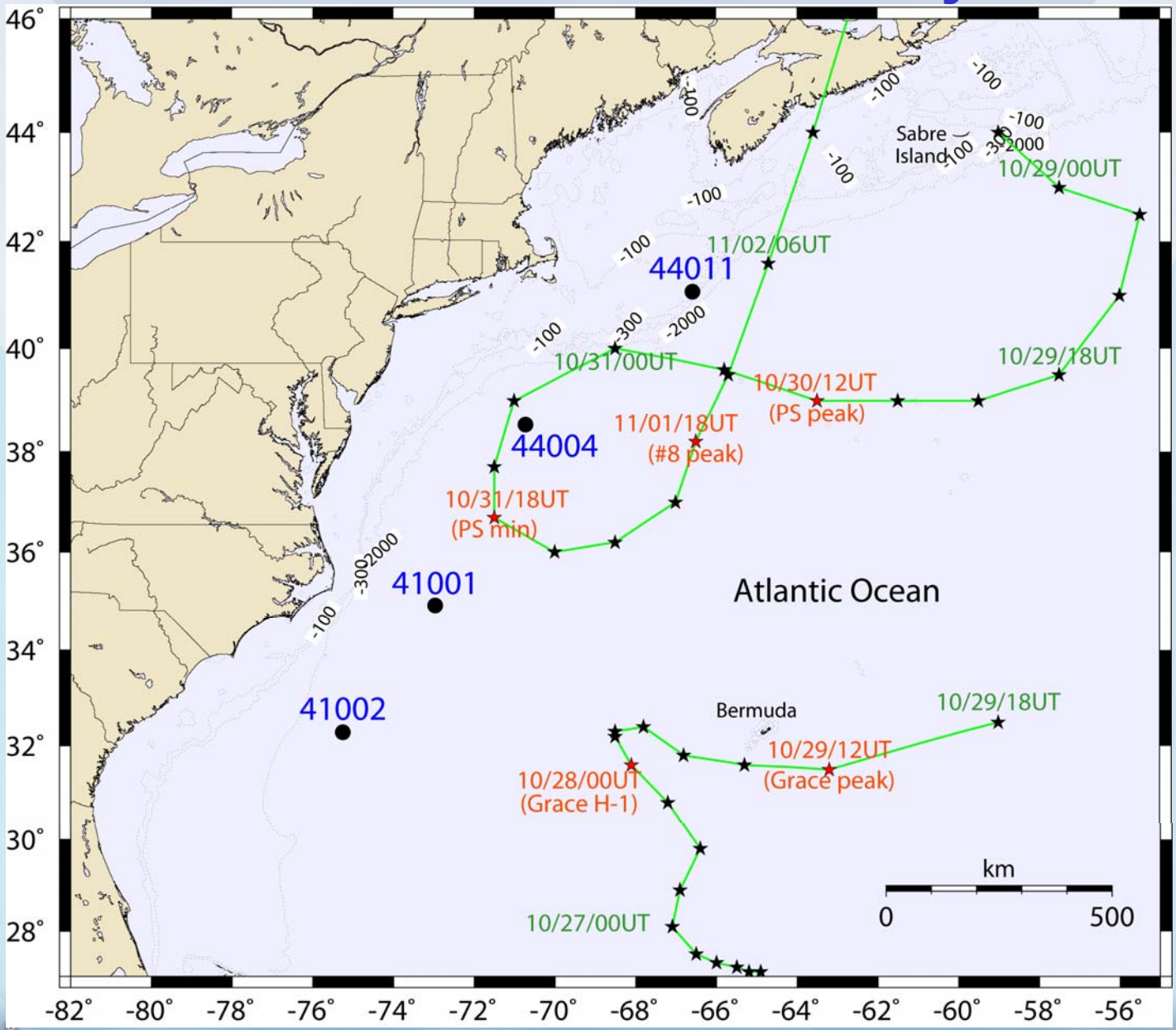
- ✓ **Bromirski et al. (2005)**
  - Short Period Wave Energy (SP) along SoCal coast is decreasing
  - Long Period (LP) and SP wave energy along Pacific NW is increasing
  - No definitive change in Gulf of Alaska
  - Storm tracks appear to be shifting northward
  - Tracks also appear to be more zonally oriented



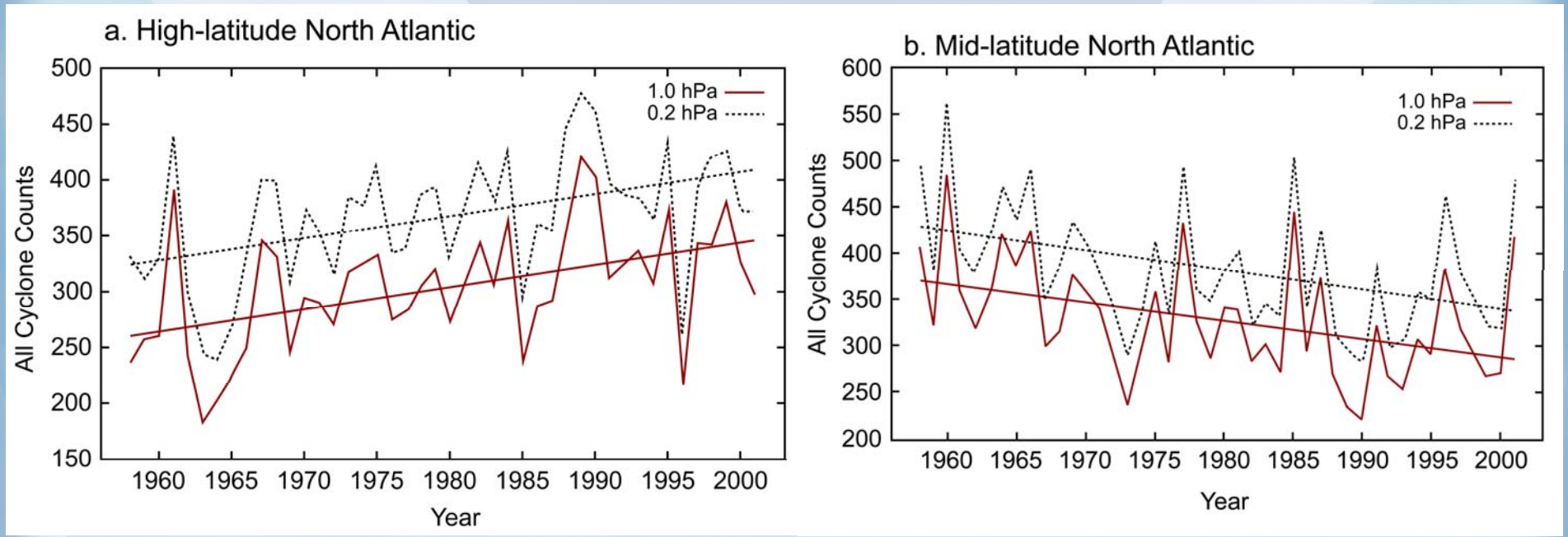
San Francisco - Non-Tide Residuals



Northwest Atlantic Buoys

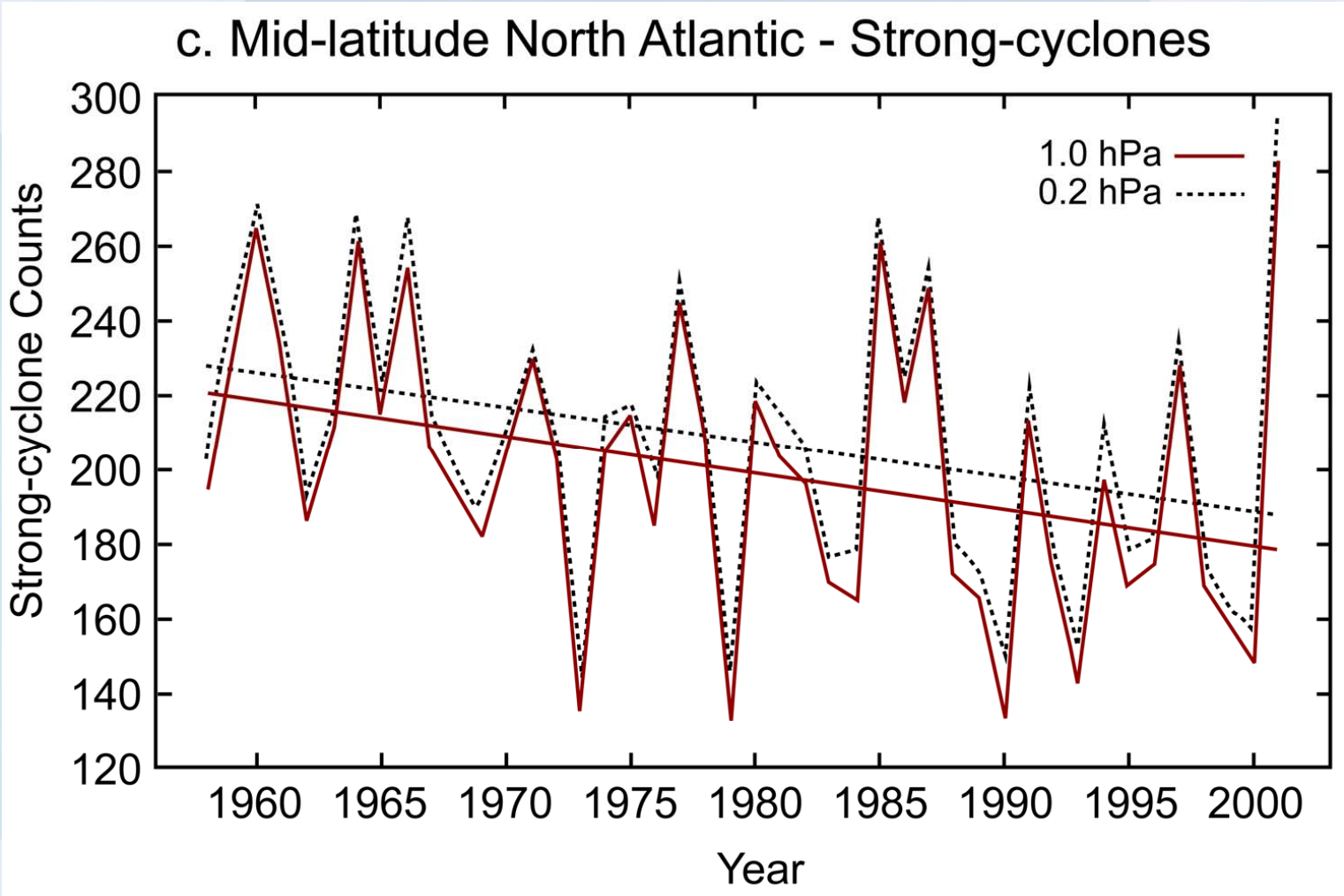


Trends in Atlantic ETCs
Wang et al. (2006)

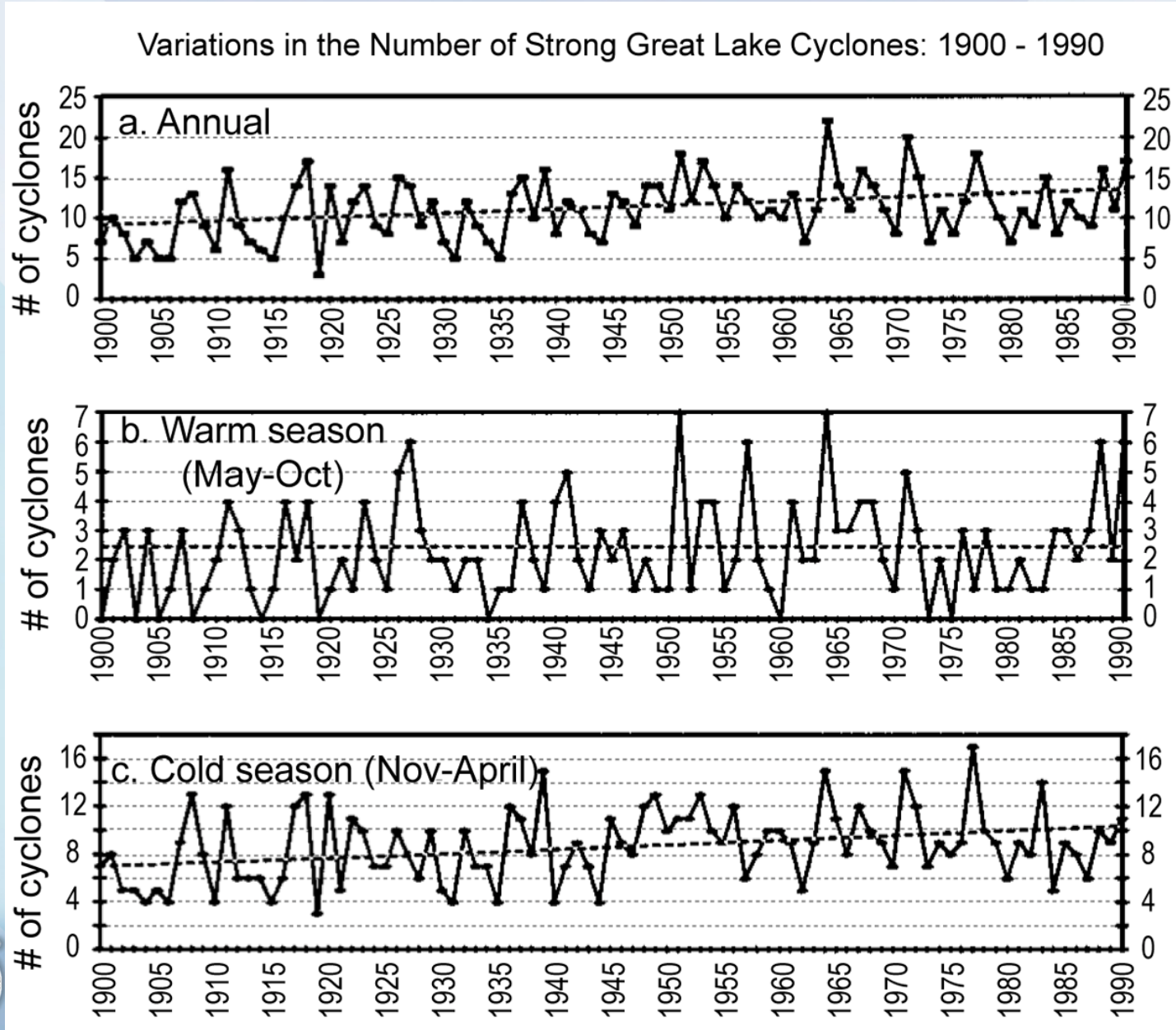


Trends in Strong Atlantic ETCs

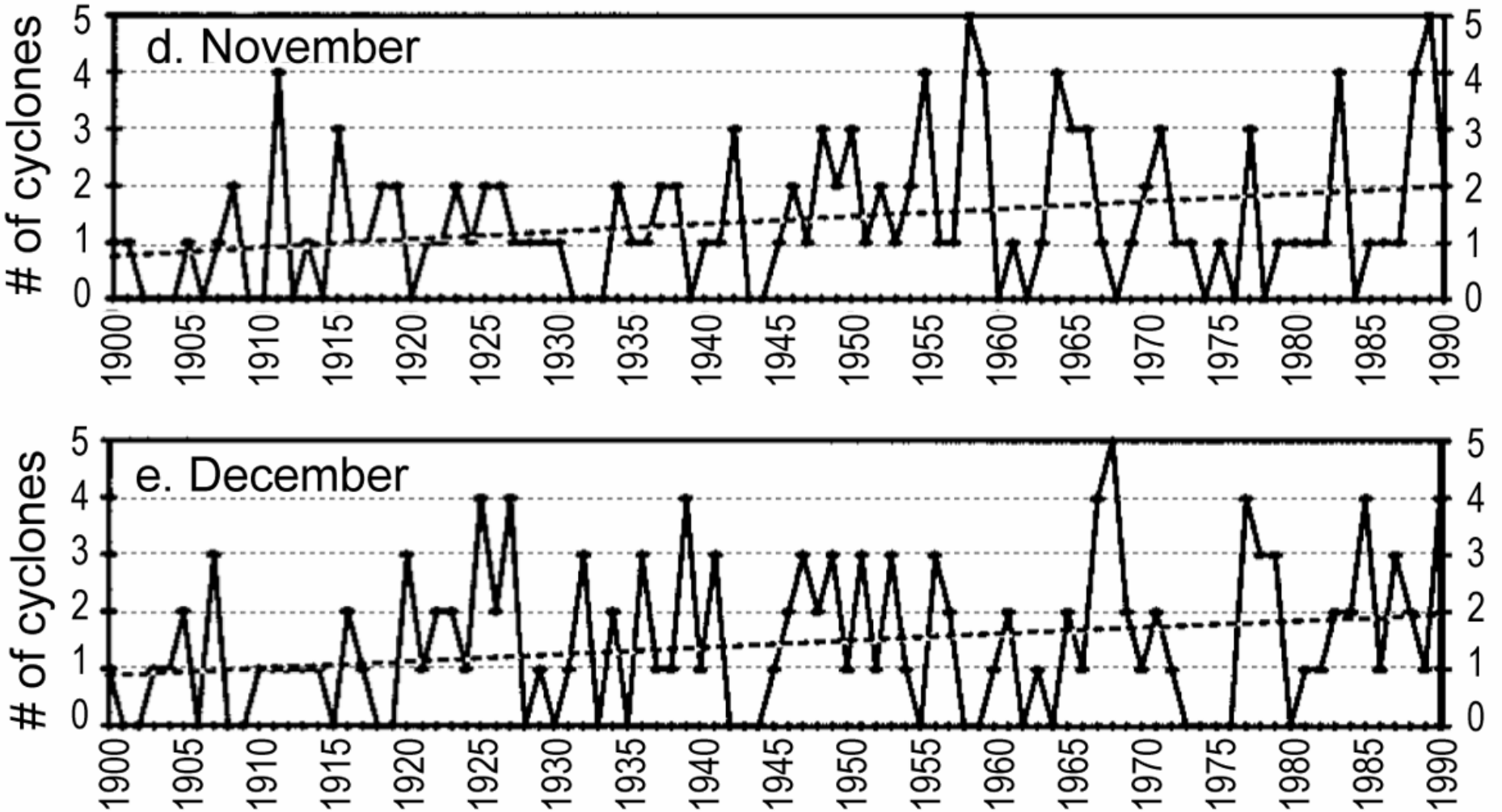
Wang et al. (2006)



Great Lakes Cyclones
Angel and Isard (1998)

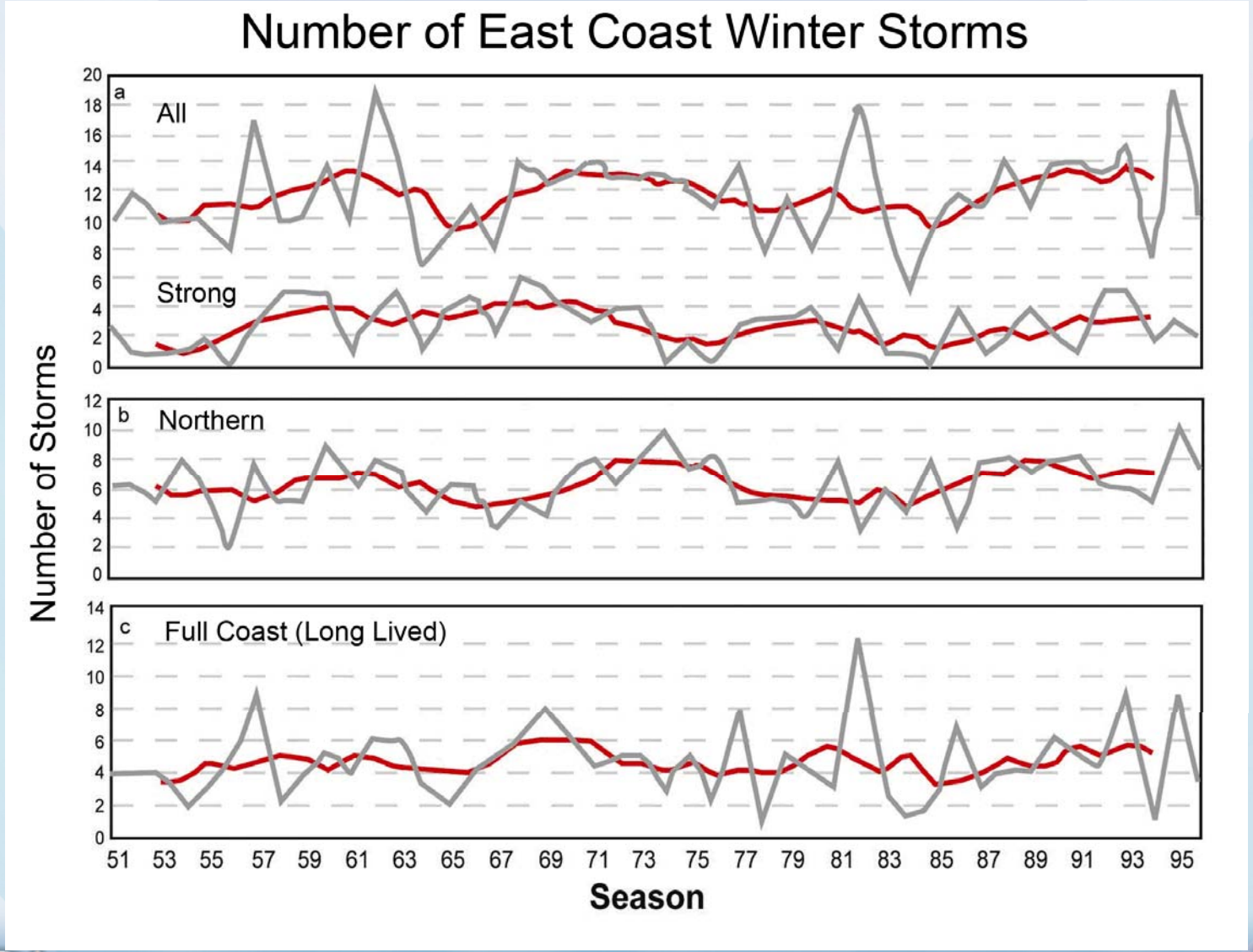


Great Lakes Cyclones - Autumn
Angel and Isard (1998)

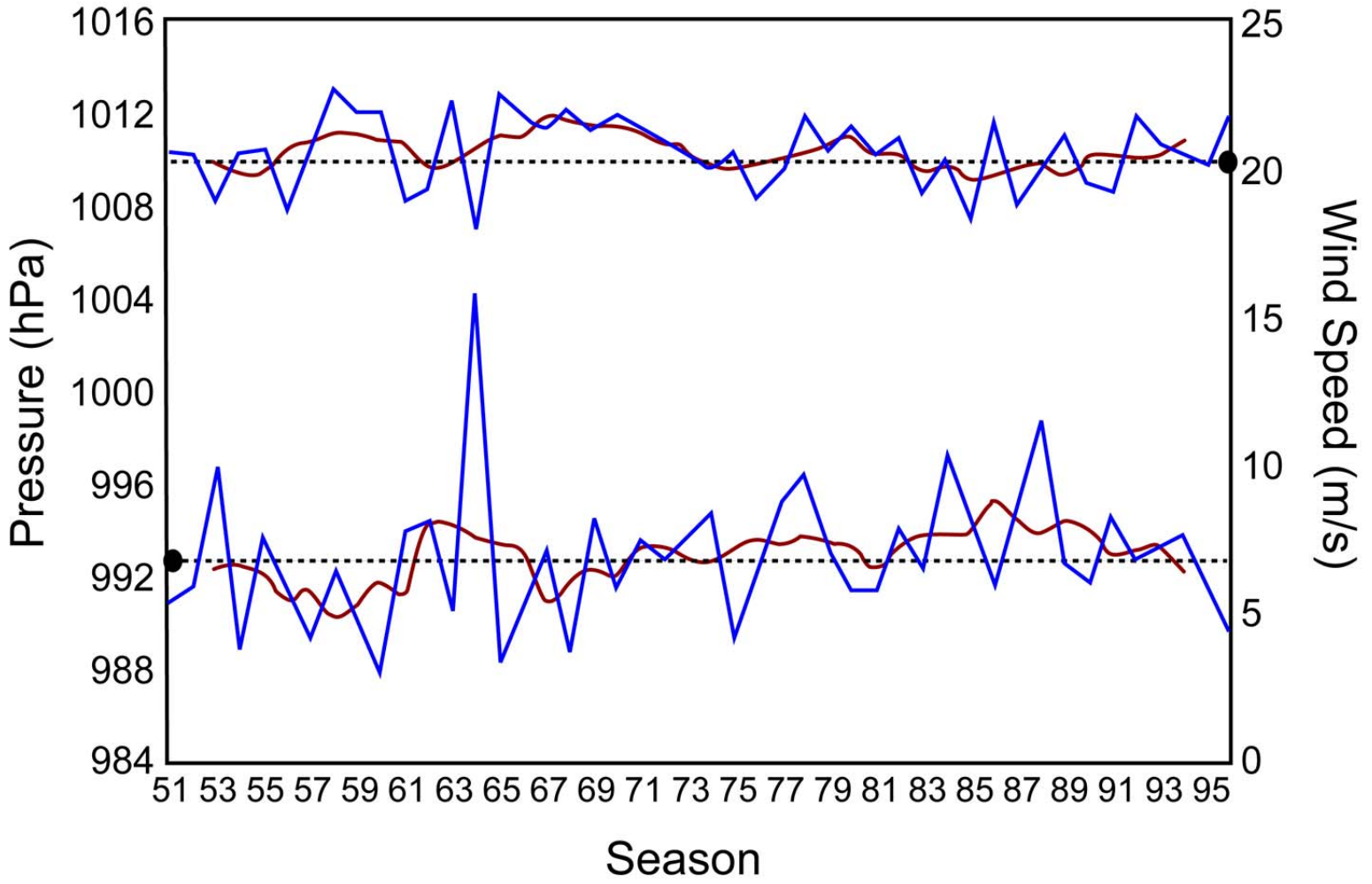


East Coast Winter Storms – Nor'easters

Hirsch et al. (2001)



Average Annual Nor'easter Intensity (Hirsch et al. 2001)



Buoy Wave Analysis

✓ NDBC Buoy Significant Wave Heights (Hs)

- Trends of mean significant wave height (*Hs*), total wave events, and mean wave event duration (hr)

- Analysis applied >2m and >5.4m thresholds on *Hs* using hourly buoy data from the NOAA NDBC

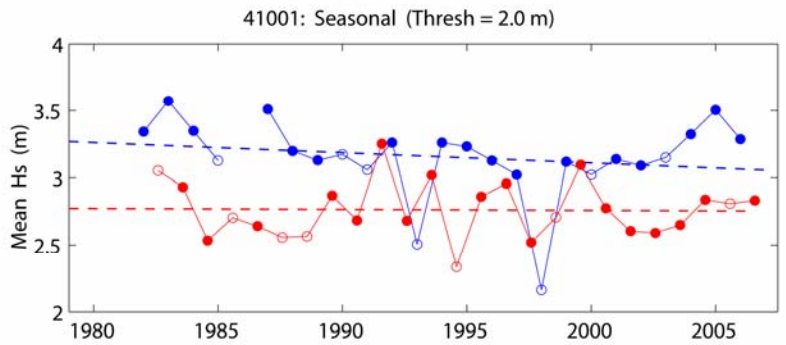
- Seasonal means calculated for both the cold and warm seasons:
  - Cold season (Nov – Apr)
  - Warm Season (Jun – Oct)

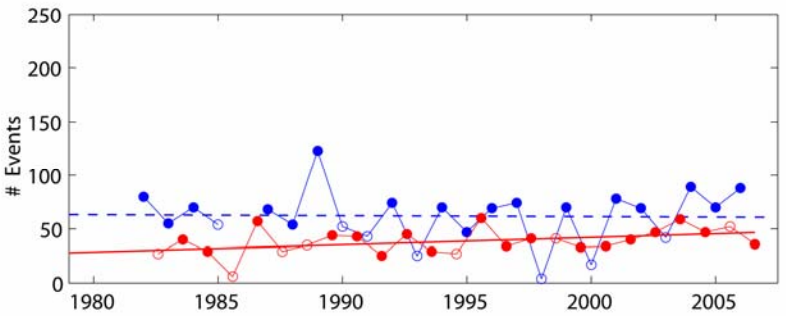
Buoy #41001: off Cape Hatteras NC

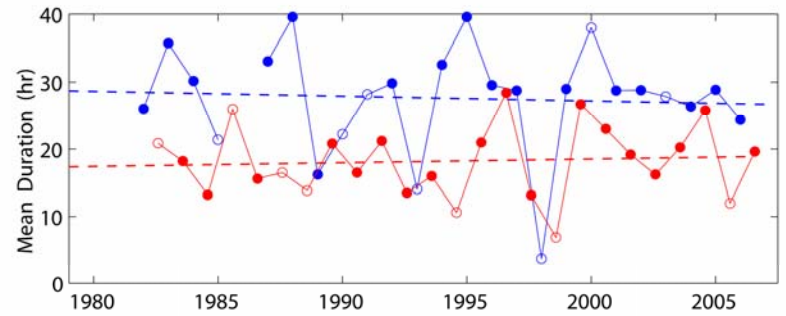
Solid circles >75% obs - Open circles <75% obs

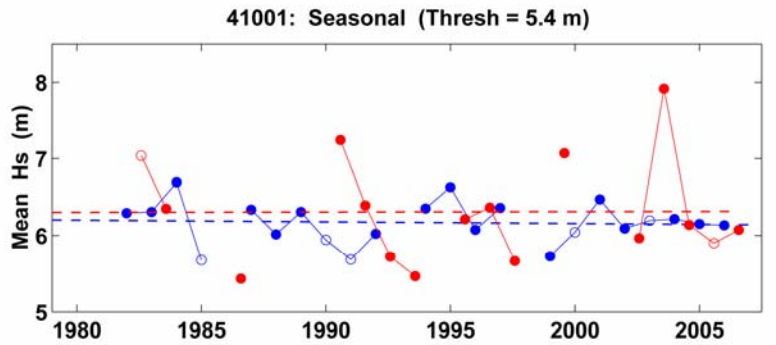
Solid trends significant >90% CL (α < 0.1)

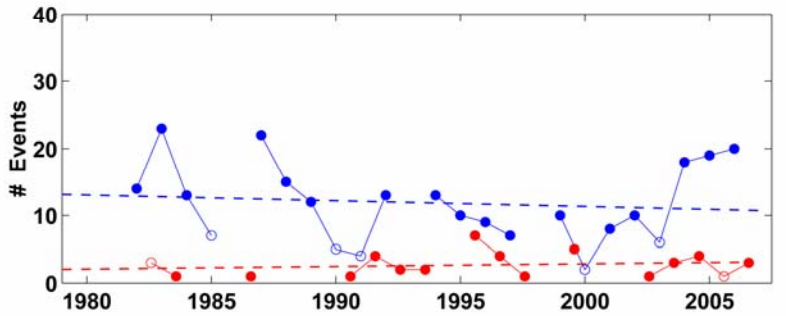
Dashed trends <90% CL (α > 0.1)

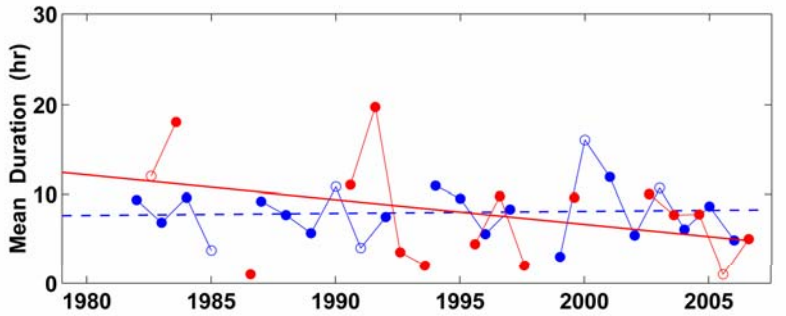








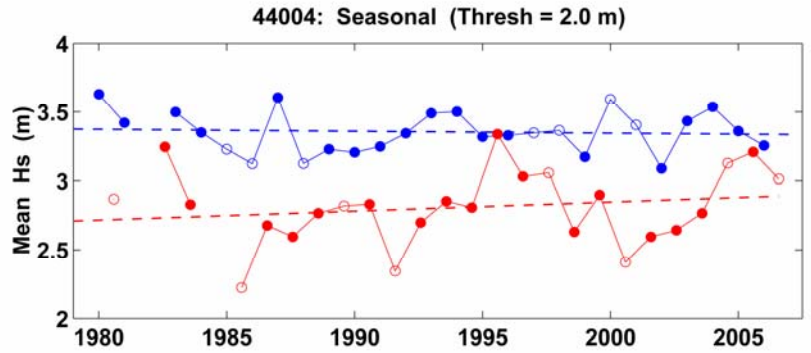


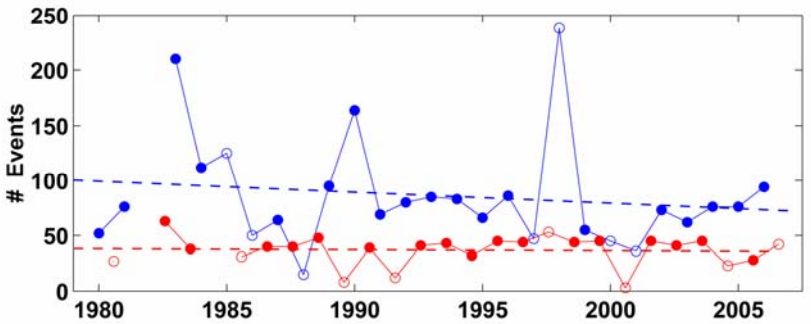


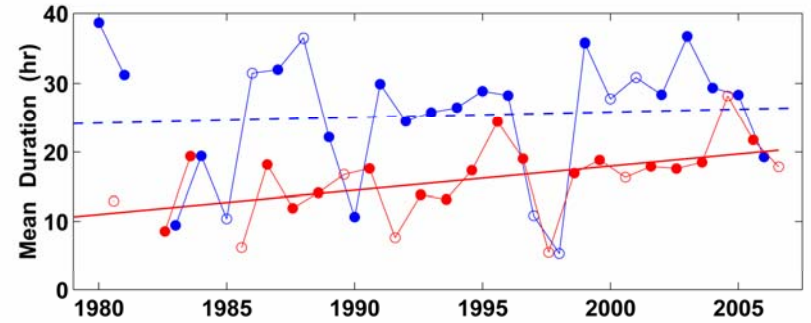
Buoy #44004: off Cape May NJ

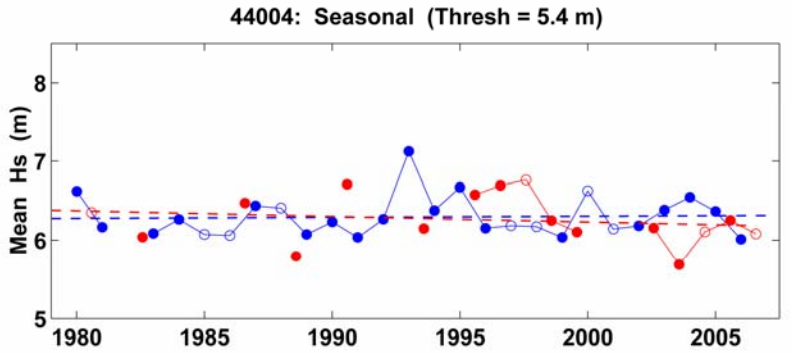
Solid circles >75% obs - Open circles <75% obs

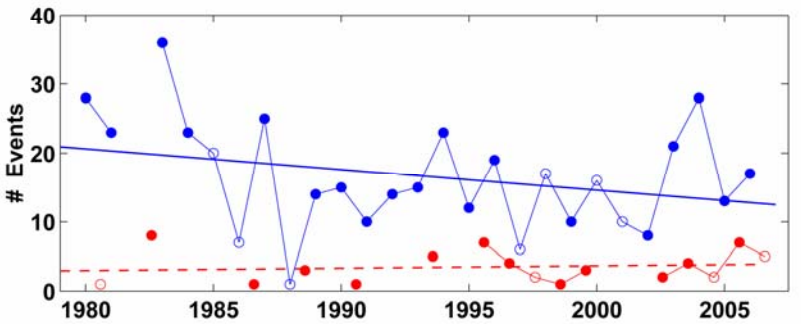
Solid trends significant >90% CL (α < 0.1)
Dashed trends <90% CL (α > 0.1)

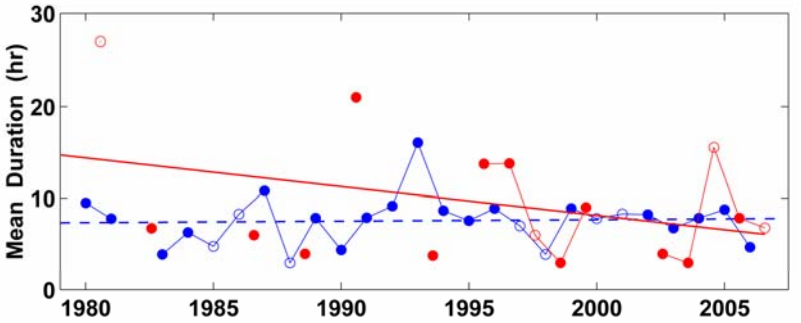












Buoy #44011: off Cape Cod MA

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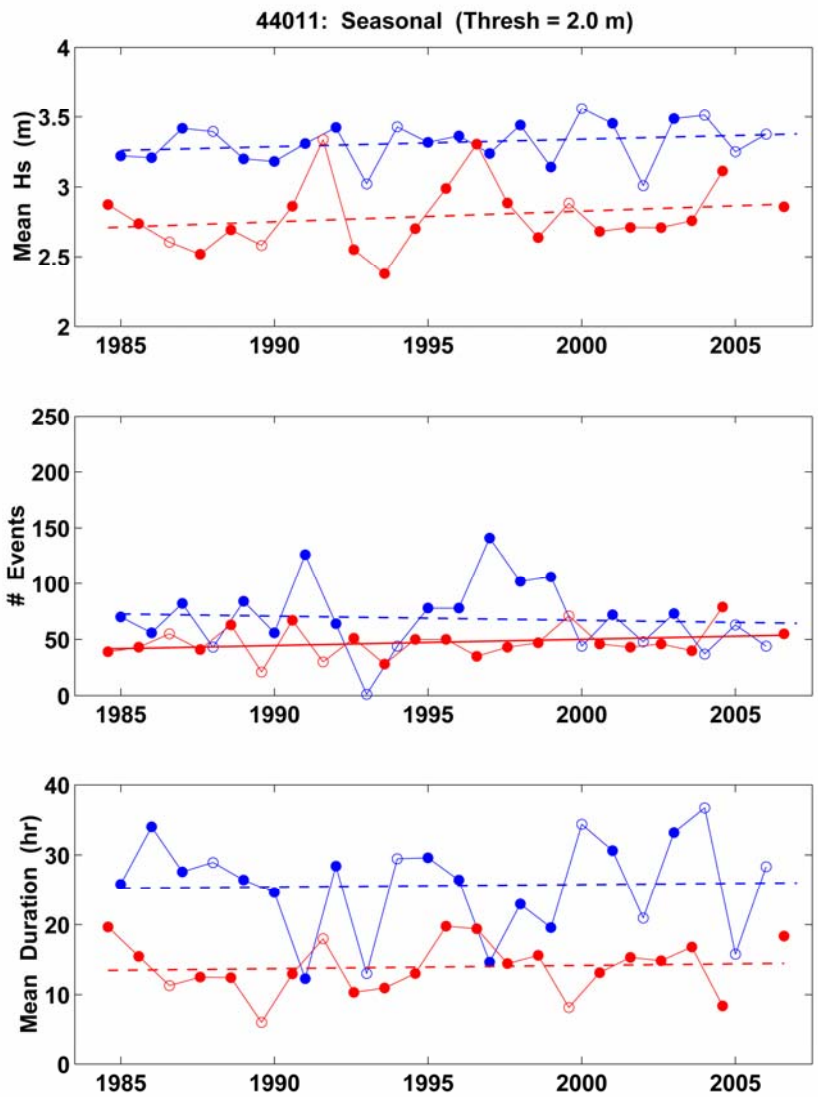
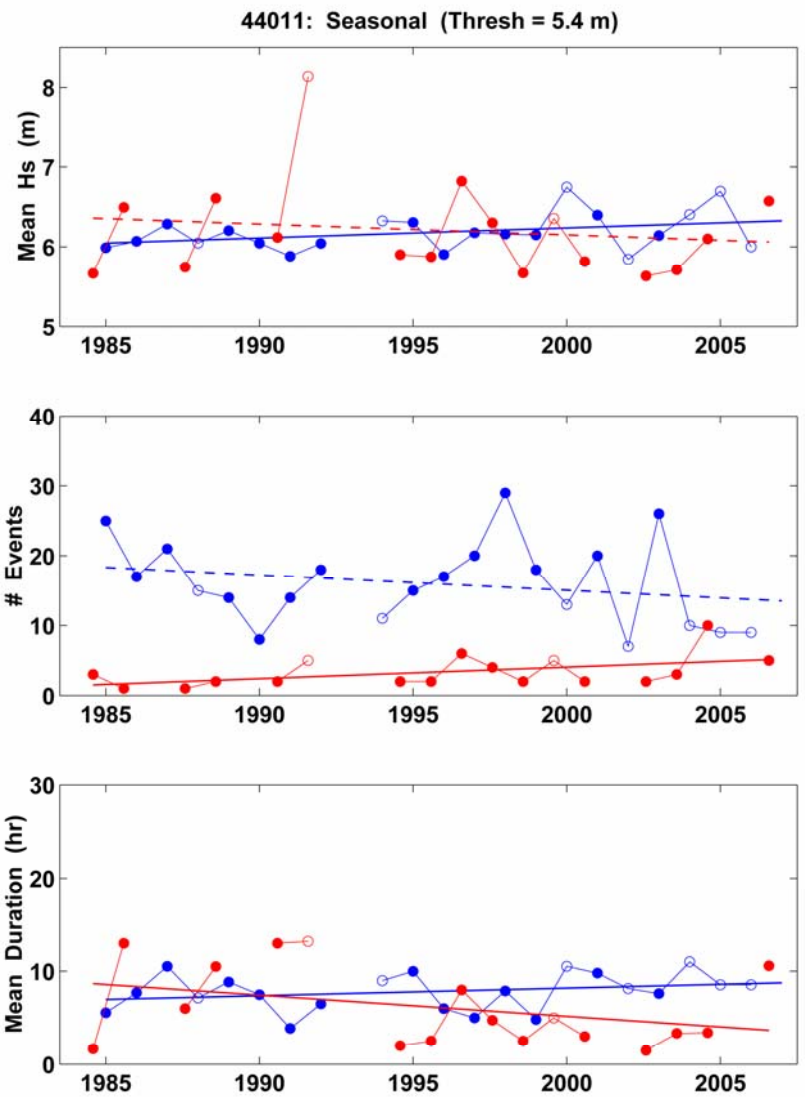
Solid trends significant >90% CL (α < 0.1)

Dashed trends <90% CL (α > 0.1)





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Mahalo nui loa!