Precipitation and Cloud Structure in Midlatitude Cyclones

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with Paul Field, NCAR
Solberg (1928) examined all types of waves in the atmosphere using a two-level baroclinic model:

Why cyclones?

Short waves stabilized by gravity

Long waves stabilized inertially (earth’s rotation)

(from Bjerknes and Holmboe, J. Met. (1944))
When, where?

- Zonal winds peak in hemisphere with strongest $\partial T/\partial y$
  
  $\Rightarrow$ large growth rates for baroclinic disturbances

Holton, 1992
Hemispherical view

500 hPa geopotential height

wavenumber $\sim 7$

$\lambda \approx 4000$ km

May 17 2007
The structure of a midlatitude cyclone

From Schultz et al. (1998)
Idealized cyclone

Carlson 1998

Figure 10.1  Idealized cyclone. (From Bjerkens and Solberg, 1926.)
Multisensor cyclone database

- Synthesize data from useful satellite datasets and reanalysis to examine mid-latitude cyclone structure

- Cyclone-relative coordinate system to facilitate comparisons and composite analysis

- Make available to community
  - www.atmos.washington.edu/~robwood/data/cyclones.html
Cloud Compositing

Lau and Crane 1995
Satellite data

- MODIS: Cloud top temperature and optical thickness (1° daily data)
- AMSR: Rain rate; column WVP; SST
- Quikscat: Surface wind speed and direction
- All available data from 2003-2004
- ~2000 cyclones in total for NP, NA, SP, SA over oceanic regions
- NCEP: reanalysis MSLP, T profiles ($WVP_{sat}$)
Regions examined

Major midlatitude storm track regions of the northern and southern hemispheres
Cyclone strength and size: Region

- N Atl
- N Pac
- S Atl
- S Pac

Cyclone center pressure [hPa]

Cyclone radius [km]
Cyclone strength and size: Season

Season reversed for SH storms

Mak 1982
Quikscat winds (all NA storms)

[Image of a map showing wind patterns with color-coded areas and arrows indicating wind direction and speed. The color bar on the right indicates the speed in meters per second (m s^{-1}).]
Warm Conveyor Belt

\[ R = \kappa \langle WVP \rangle \langle V \rangle \]

\[ q_0 = \langle WVP \rangle / S \]
Generate new composites (combine NA, NP, SA, SP)

**Strength**

\[ \langle V \rangle \quad r < 2000 \text{ km} \]

**Moisture**

\[ \langle WVP \rangle \quad r < 2000 \text{ km} \]

**Quikscat windspeed**

**WVP**
Warm conveyor model

- Simple model quantifies cyclone-wide precip. as a function of its strength and WVP
- WVP controlled by SST

$$R = \kappa \langle WVP \rangle \langle V \rangle$$

Clausius-Clapeyron

![Diagram showing correlation between WVP, SST, and rainfall rate]
Column mean relative humidity

\[ RH_{col} = \frac{\langle WVP \rangle}{\langle WVP_{sat} \rangle} \]

invariant to changes in storm strength or vapor
Cloud Top Temperature

Normalised pdfs of composited cyclones

Rainrate

All N Atl. cyclones

Bjerknes and Solberg
Implications: precipitation and storm density under a warmed climate

- \( dR_{\text{ext}} + dR_T = LdP \)
- \( LdP = k \, dT - 2.5 \)
- \( k \approx 3 \, \text{W m}^{-2} \text{K}^{-1} \) (quite robust across models)

Number and/or strength of storms must decrease

also Mitchell et al. 1987
Implications: cloud feedback

- Fewer and/or weaker storms under warmed climate
  - ⇒ less high cloud ⇒ more OLR
  - ⇒ negative feedback

- But, assumes constant albedo ("midlatitude blanket" argument)

- Future work: Test using radiative transfer calculations/CERES
Conclusions

- Multisensor database of midlatitude cyclones
- Preliminary exploration of the structure of clouds, precip, and winds in midlatitude systems
- Expand to longer timescales/space scales to improve statistics
- Use to evaluate the performance of climate models
Cyclones and climate change

- Carnell and Senior (change in distribution of storm strength)
- Poleward movement of the storm tracks (Fyfe, Yin, Bengtsson, Fu et al., Lorenz, Salatthe...)
- More precipitation/less precipitation?
Fewer weak storms, more strong ones?

Storm tracks

Number of storms per month per 5x5° area

Bengtsson et al. (2006)
Poleward storm track movement?

Change in number of storms per month per 5x5° area (C 21st- C 20th)

Bengtsson et al. (2006)

Mean values 5-15

Also, Fu et al. (MSU), Yin, Fyfe....
Conclusions
THE END
Uncertainty about behavior of clouds is the leading cause of spread of temperatures under $2\times\text{CO}_2$ conditions.
Levels of understanding

• Bjerknes – high clouds and precipitation associated with ascending regions of the cyclone
• QG theory – spatiotemporal variations and strength of ascending regions understood as first order response to....
• Marriage of QG theory and moisture (latent heating) incomplete
• Limitations upon what quantitative questions can be answered from a theoretical perspective (e.g. climatological response of cyclones to changing baroclinicity
Trends in cyclone strength dependent upon diagnostic used to define storm strength
(pressure depth vs vorticity)
Cyclones in the community atmosphere model (CAM)

- Community Atmosphere Model (CAM 3.0) run for 5 years with different model configurations/parameterizations
- Identical cyclone location methodology
- Different model configurations:

  - *control*: standard version but at 1x1° resolution
  - *micro*: with new microphysics scheme (Morrison)
  - *ssat*: increase critical RH for ice (from 90% to 100%)
  - *nodeep*: deep convection scheme turned off
  - *noconv*: deep and shallow convection schemes turned off
  - *4x5*: lower resolution (4x5°)

Thanks to Rich Neal, Andrew Gettelman, Phil Rasch
Cyclone mean rain rate in CAM

- Models show similar increases in R with WVP consistent with obs.
- Model R is more strength-dependent than obs.
Clausius-Clapeyron constraints

- Clausius-Clapeyron constrains water vapor changes with SST in model and obs. cyclones

Lapse rate changes needed to explain WVP changes

**WATER VAPOR PATH**

- Clausius-Clapeyron
  - no lapse rate feedback
  - with lapse rate feedback

![Graph showing water vapor path with Clausius-Clapeyron constraints and various data points for different SST changes.](image-url)
Clausius-Clapeyron constraints

- Clausius-Clapeyron constrains precipitation changes in model and obs. cyclones

⇒ Large-scale precipitation changes governed by changes in cyclone strength and frequency
High clouds

- Very sensitive to model configuration
- Models show stronger moisture dependence than observations