Thursday 11 January 2024

A Review of Wernli and Gray (Ch. 2-4): The importance of diabatic processes for the dynamics of synoptic-scale extratropical weather systems—A review

Recommendation: Accept with minor revision (lots of little things)

A potpourri of possible additional references is also appended.

Overview:

Wernli and Gray have produced a very valuable, highly informative, and an extensively documented research review paper on the importance of diabatic processes that govern the dynamics of synoptic-scale extratropical weather systems. This extensive research review paper will be both a very valuable addition to the refereed literature and a "must have" document for advanced graduate students and early career scientists who have strong research interests in synoptic-dynamic meteorology. Noteworthy attributes of this synoptic-dynamic meteorology review paper include: 1) a broad-based historical perspective on the scientific ideas that have governed the field synoptic-dynamic meteorology going back to the 19th century, 2) an assessment of the original thinking that resulted in critical new breakthroughs in the development of innovative fundamental science ideas that have driven the growth of synoptic-dynamic meteorology, 3) an overview of critical past and present research in synoptic-dynamic meteorology that has driven the field forward, and 4) an outlook for future new research opportunities going forward that could further broaden and deepen the field. This extensive and detailed synoptic-dynamic meteorology review paper is suitable for both advanced graduate students and early career scientists who possess a strong interest in synoptic-dynamic meteorology.

Bottom line: "The importance of diabatic processes for the dynamics of synoptic-scale extratropical weather systems—a review" is thorough and offers a comprehensive overview of the history of extratropical cyclone dynamics using a PV framework. The authors demonstrate a strong foundation of synoptic-scale extratropical dynamics and present a clear and accessible synthesis of the historical literature. The inclusion of recent references and an overall balanced discussion add significant value for the reader.

Introduction:

Wernli and Gray write: "the main three aims of this review article are (i) to provide evidence that our understanding of how diabatic processes affect extratropical weather systems has grown considerably since the review article on PV by Hoskins et al. (1985) and the comprehensive book chapter on the rapid intensification of extratropical cyclones by Uccellini (1990), (ii) to portray in detail the historical evolution of a specific research field over several decades and thereby to exemplify how scientific progress results from the combination and integration of complementary research approaches, and (iii) to promote the relevance of this research area in dynamical meteorology." This purpose statement is accompanied by a schematic overview figure that outlines the text pathways that follow.

Theoretical Background:

I didn't realize how much hard-core fundamental theoretical and dynamical meteorology I had forgotten (please forgive me, Joe Pedlosky) until I read through Ch. 2. That said, I think that this chapter as written in several places can come across as a bunch of research fluid dynamicists talking more to themselves than the intended audience. An example would be the discussion surrounding Fig. 2. Several of the panels in Fig. 2 (e.g., panels c and f) are quite obscure and need more context and explanation. In the case of panel c it would be helpful if the location of the snapshot relative to the larger scale flow on a weather map could be indicated for perspective purposes. Likewise, panel (f) supposedly references a convective updraft. Is this updraft located in the warm sector of an extratropical cyclone or elsewhere? Again, more context is needed.

Line 196: Check that "Q" was defined previously.

Omega in equation 3 needs to be defined for completeness.

The "M" lines on the Fig. 3c panel are undefined.

Define WCB on line 230 even though we all know what it means.

Lines 233–242: Perhaps a relationship between the magnitude and spatial scale of a PV anomaly and the associated induced tropospheric wind and thermal fields can be referenced quantitatively here? In other words, consider including the Rossby penetration depth and its relation to the static stability in the context of moist processes to add clarity for sections 2.2, 4 and 5.2.1

Lines 259-262: What does the DSI (dynamical state index) tell us that we don't already know by other means?

Fig. 3b is not very readable. No point in showing a figure that requires the use of a magnifying glass to read it properly.

Likewise, Fig. 3c needs more explanation to be understood properly.

Define the two dipole axes in Fig. 3e. This figure panel needs more explanation to be understood.

Sections 3.3–3.4 are excellent.

Section 3.5 is also excellent.

You might want to emphasize that very important aspect of the Presidents' Day storm of Feb 1979 as discussed by Bosart (1981) was the comparatively low level (~900-hPa) of the ascent maximum associated with coastal front cyclogenesis (see his Fig. 9b and subsequent figures below) and the associated low-level frontogenesis maximum at ~950-hPa (Fig. 10c). Note also the derived kinematic ascent maximum below 800-hPa in Fig. 14. This low-level ascent maximum ensured that strong low-level cyclonic vorticity was being generated along the aforementioned coastal front. Subsequently, the arrival of the upper-level trough fostered impressive rapid surface cyclogenesis (see Fig. 18), given the presence of pre-existing cyclonic vorticity along the antecedent coastal front. Bottom line: The low-level d(omega)/dp profile was critical for the rapid spin-up of the Presidents' Day cyclone and should be mentioned.

Section 4.1.1 is excellent overall.

In section 4.1.1 consider showing and/or referencing a d(omega)/dp for the aforementioned Presidents' Day storm paper to help the reader better understand how the rapid growth of low-level vorticity along the coastal front occurred.

Section 4.1.2 is also excellent overall

PV Inversion, Trajectories, and Model Simulations (lines 670-677): Excellent discussion of Davis and Emanuel (1991) and Hoskins and Berrisford (1988). From my personal perspective, Hoskins and Berrisford (1988) was an eye-opening paper and a "must read" paper as well.

Line 704 and subsequent lines. Nice discussion of the warm-conveyor belt to include the Nieman and Shapiro papers. Other relevant Mel Shapiro papers that you cite include Shapiro (1976), and Keyser and Shapiro (1993). What may not be fully appreciated is that Mel Shapiro obtained all kinds of critical mesoscale data on upper-level fronts via his research flights on NCAR and NOAA aircraft. These aircraft-derived datasets permitted him (and others) to make the calculations on the evolution of PV in upper level fronts and associated PV anomalies that are discussed in this section.

Good discussion of the important escalator-elevator concept on lines 715-720.

Lines 754–760: Very important insight by Reed and Albright (1986) on how fast symmetric instability can develop in an explosively deepening bomb cyclone.

Lines 784–787: Thanks for reminding me of the importance of the Shutts (1990a, 1990b) papers with regard to SCAPE (an open and "shutt" case to make a bad pun).

Section 4.1.3: Frontal Wave Cyclones

Key point on lines 810-815: Breakthrough in understanding frontal wave cyclones inspired by the Hoskins and Berrisford (1988) diagnostic study on the infamous UK October storm and related papers by Thorpe and Emanuel, 1985; Joly and Thorpe, 1990; Schär and Davies, 1990; and Malardel et al.,1993). These papers (and others) collectively revealed how diabatically produced bands of low-level PV were a prerequisite for the occurrence of low-level frontal wave instability.

Lines 814-815 make an important point about the "essential role of diabatically produced low-level bands of PV or surface as a prerequisite for frontal wave instability to occur." Highlight this point a bit more?

Lines 847-850: Reference Fig. 9 from Rogers and Bosart (1986), given that this figure shows that the saturation equivalent potential temperature maximizes in excess of 315 K over the cyclone center at the time of lowest SLP? There is also an ~13 K increase in the saturation equivalent potential temperature over the cyclone center in the 24 h period ending 1200 TC 4 October 1965.

Lines 850-855: Discuss the assorted composites of East Coast cyclones from Manobianco (1989a) in a bit more detail?

Lines 895-900: This text "screams" for a supporting illustrative figure.

The excellent text on lines 900-920 would benefit from the addition of at least one new trajectory-related figure.

WCB discussion on lines 900-966 would benefit from the addition of a couple of new figures. Existing Figs. 7e,f are inadequate. Redo existing Fig. 7 into panels a-d and create a new figure consisting of the old e and f panels from Fig. 7? Check also whether Fig. 7f is adequately referenced in the text.

Section 4.1.5 (Lagrangian view and coherent airstreams) is very well done.

Cordeira and Bosart (2011; https://journals.ametsoc.org/view/journals/mwre/139/6/2010mwr3537.1.xml?tab_body=pdf) would be an appropriate additional reference for the evolution of PV structure in a tropical cyclone (Grace) that formed via a tropical transition (see Fig. 2, 4, 7, 11, and 12)

Figures:

The text-figure balance needs to be improved. There is a lot of text and comparatively few relevant illustrative figures. It is also unfortunate that few if any color figures are available from the older literature. I would like to suggest that the authors try to grab more relevant figures from the refereed literature to illustrate key points and bolster key arguments advanced in the text. It might also be appropriate for the authors to construct a few additional schematic figures to help to better illustrate/reinforce key points that they are trying to make in the text. Any new schematic figures should be constructed in color. Can existing black and white figures be digitized and then converted to color images using AI methodologies?

Multi-panel Figure 7 is in desperate need of improvement (or color!). Geography is mostly unreadable in panels b and c. Panel c is “fuzzy”. Panels d-f demand improvement to be more readable because in present form they do not do justice to the text.

Lines 1152-1177: This discussion seems out of place here. I get that you have a separate section entitled: More Systematic Investigations. That said, the distinction seems a bit forced. Personally, I would have welcomed this discussion earlier in the text.

Section 4.2.3: PV perspective on moist vs. dry experiments: I can’t decide whether this section works best as a stand-along section as it is now or whether the findings documented in this section should be integrated into earlier sections.

I am OK with section 4.3: Idealized numerical simulations of cyclones.

Lines 1305-1318: Discussion of Emanuel (1987) is well done.

Lines 1434-1457: This section, especially beginning with the discussion of Thorncroft and Hoskins (1990) on line 1441, seems especially relevant. That said, I could easily argue that this discussion is out of place and should appear earlier. Although I understand why the authors did what they did, it seems to me that an equally convincing argument can be made to embed this material into an earlier section. Personally, I find the climate change argument (footnote 15) unconvincing.

General comment after scrutinizing sections 2-4. I would like to reinforce what I said earlier. The ratio of text to figures is too high throughout. There are a number of places throughout the text where the inclusion of additional figures would make it easier to follow the discussion. That said, figure quality needs to be significantly improved in many places. I fully appreciate that this presents a problem for old non-digitized black and white figures. A possible compromise might be to separate multi-panel black and while figures that a marginally readable (at best) into individual single or double figures that are larger and possibly easier to read.

Additional Comments by Bosart Ph.D. students: Tyler Leicht and Alexander Mitchell

I've finished my review of the Wernli and Gray review paper. It is an exceptionally well-written paper, covering nearly 150 years of research in great detail. I think this will be a great research and educational resource for years to come. I only have a few minor comments that I think could improve the paper if considered.

In section 2.1, I would like to see a (brief) description of the QG height tendency and omega equations as they relate to diabatic heating. I know the paper mainly focuses on a PV perspective, but in order to argue that PV thinking is best for understanding the impact of diabatic heating on midlatitude weather systems (stated on line 3019), one must first outline the QG perspective and compare the two frameworks. QG theory is alluded to in sections 2.2, 3.4, and 3.5, but the reader does not have an immediate reference in this text to the equations the way they do for the PV fundamentals. I would also rephrase the sentence ending in line 2965 stating that QG theory is synonymous with dry dynamics, since my view is that QG and PV can both be treated adiabatically and diabatically.

Otherwise, I think this was a very successful review paper. Let me know what you think of my suggestion, and I'll be curious to see what you and Alex think would improve this paper.

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Overview:

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Lines 233–242: Perhaps a relationship between the magnitude and spatial scale of a PV anomaly and the associated induced tropospheric wind and thermal fields can be referenced quantitatively here? In other words, consider including the Rossby penetration depth and its relation to the static stability in the context of moist processes to add clarity for sections 2.2, 4 and 5.2.1

Minor Comments:

Section 1:

Line 98: Should quasi-geostrophic be abbreviated as (QG) throughout the article?
Line 110: Remove hyphen for "life-cycles"
Lines 110-114: Consider splitting these into 2 sentences
Line 116: Revise to "clouds can"
Line 117: Revise to "..Carbone, 2004), and…"
Line 121: Revise to "..up to several 1000 km"..
Line 138: Revise to "..and challenges to stimulate further.."

Section 2:

Line 206: Define $\dot{\theta}$?
Line 265: Revise to "..subsequent precipitation usually occur through"
Line 301: Revise to "..However, as discussed by Schultz and Schumacher (1999), many.."
Lines 349–355: Consider splitting this into two sentences.
Line 394: Remove the comma after "currents"

Section 3:

Lines 375–379: Insert "(a)", "(c)" and "(d)" as well since (b) is written in the sentence.
Line 402: Revise to "..and examined stability criteria.."
Lines 486–487: Revise to "..at the level of maximum wind speed. The hypothesis was made that these maxima were diabatically.."
Lines 489–492: Revise to "..It is interesting to note that the initial research on STE near upper-level fronts and tropopause folds mainly discussed how radiation and turbulence can modify PV, but overlooked the potential effects of latent heat release in clouds. However, this focus changed almost 20 years later.."
Lines 510–512: Omit "In"
Line 526: Revise to "We claim this paradigm shift.."

Section 4:

Line 568: Revise to "..novel data thanks to.."
Line 573: Revise to "..they have served as.."
Line 589: Revise to "..together with the ascent.."
Line 623: Add comma, "In several of the studies, the.."
Line 700: Revise to "..was considered the main reason.."
Line 703: Revise to "..to present an overview of the.."
Line 729: Revise to "..first to quantify.."
Lines 877–878: Revise to "This subsection summarizes research from 1980–2000 on using trajectories to investigate moist airstreams and extratropical cyclone dynamics."

Section 6:

Line 2974: Revise to "..time failed to predict these.."
Line 3012: Add a comma after "for instance"
Line 3024: Add a comma after "More recently"
Lines 3049–3054: Revise to "This improvement will allow for better representation of steep topography and the ability to turn off the parameterization of deep moist convection. In the context of this review article, this implies that, e.g., fast-ascending motion in convective cloud systems and associated diabatic processes will be simulated with the same numerics and cloud microphysics as the more slowly ascending and larger-scale warm conveyor belts. As discussed in Sect. 5.5.2, this change will have

direct implications for the diabatic modification of PV in the upper troposphere and, in turn, for the large-scale flow evolution."

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Potential additional references (aka shameless plugs) to add to the Wernli and Gray Review Paper. Use anywhere from 0–48 of these suggested references as you see fit.

1. **Archambault et al. (2010): Relationships between Large-Scale Regime Transitions and Major Cool-Season Precipitation Events in the Northeastern United States**
2. **Archambault et al. (2013): A Climatological Analysis of the Extratropical Flow Response to Recurving Western North Pacific Tropical Cyclones**
3. **Archambault et al. (2015): A Composite Perspective of the Extratropical Flow Response to Recurving Western North Pacific Tropical Cyclones**
4. **Bals-Elsholz et al. (2001): The Wintertime Southern Hemisphere Split Jet: Structure, Variability, and Evolution**
5. **Bentley et al. (2017): Upper-Tropospheric Precursors to the Formation of Subtropical Cyclones that Undergo Tropical Transition in the North Atlantic Basin**
6. **Bentley et al. (2019): A Climatology of Extratropical Cyclones Leading to Extreme Weather Events over Central and Eastern North America**
7. **Bell and Bosart (1993): A Case Study Diagnosis of the Formation of an Upper Level Cutoff Cyclonic Circulation over the Eastern United States**
8. **Biernat et al. (2023): A Climatological Comparison of the Arctic Environment and Arctic Cyclones between Periods of Low and High Forecast Skill of the Synoptic-Scale Flow**
9. **Bosart (1984): The Texas Coastal Rainstorm of 17–21 September 1979: An Example of Synoptic Mesoscale Interaction**
10. **Bosart and Bartlo (1991): Tropical Storm Formation in a Baroclinic Environment**
11. **Bosart and Dean (1991): The Agnes Rainstorm of June 1972: Surface Feature Evolution Culminating in Inland Storm Redevelopment**
12. **Bosart and Lackmann, 1995: Postlandfall Tropical Cyclone Reintensification in a Weakly Baroclinic Environment: A Case Study of Hurricane David (September 1979)**
13. **Bosart and Sanders (1986): Mesoscale Structure in the Megalopolitan Snowstorm of 11–12 February 1983. Part III: A Large-Amplitude Gravity Wave**
14. **Bosart and Sanders (1991): An Early-Season Coastal Storm: Conceptual Success and Model Failure**

15. Bosart et al. (1996): Large-Scale Antecedent Conditions Associated with the 12–14 March 1993 Cyclone ("Superstorm '93") over Eastern North America
16. Bosart et al. (1998): A Study of Cyclone Mesoscale Structure with Emphasis on a Large-Amplitude Inertia–Gravity Wave
17. Bosart et al. (2000): Environmental Influences on the Rapid Intensification of Hurricane Opal (1995) over the Gulf of Mexico
18. Bosart et al. (2012): An Analysis of Multiple Predecessor Rain Events ahead of Tropical Cyclones Ike and Lowell: 10–15 September 2008
19. Bosart et al. (2017): Interactions of North Pacific Tropical, Midlatitude, and Polar Disturbances Resulting in Linked Extreme Weather Events over North America in October 2007
20. Cordeira and Bosart (2011): Cyclone Interactions and Evolutions during the "Perfect Storms" of Late October and Early November 1991
21. Davis and Bosart (2001): Numerical Simulations of the Genesis of Hurricane Diana (1984). Part I: Control Simulation
22. Davis and Bosart (2003): Baroclinically Induced Tropical Cyclogenesis
23. Davis and Bosart (2004): The TT Problem: Forecasting the Tropical Transition of Cyclones
24. DiMego and Bosart (1982): The Transformation of Tropical Storm Agnes into an Extratropical Cyclone. Part I: The Observed Fields and Vertical Motion Computations
25. DiMego and Bosart (1982): The Transformation of Tropical Storm Agnes into an Extratropical Cyclone. Part II: Moisture, Vorticity and Kinetic Energy Budgets
26. Galarneau et al. (2009): Baroclinic Transition of a Long-Lived Mesoscale Convective Vortex
27. Galarneau et al. (2015): Development of North Atlantic Tropical Disturbances near Upper-Level Potential Vorticity Streamers
28. Griffin and Bosart (2014): The Extratropical Transition of Tropical Cyclone Edisoana (1990)
29. Hakim et al. (1995): The Ohio Valley Wave-Merger Cyclogenesis Event of 25–26 January 1978. Part I: Multiscale Case Study
30. Hakim et al. (1996): The Ohio Valley Wave-Merger Cyclogenesis Event of 25–26 January 1978. Part II: Diagnosis Using Quasigeostrophic Potential Vorticity Inversion
31. Lackmann et al. (1996): Planetary- and Synoptic-Scale Characteristics of Explosive Wintertime Cyclogenesis Over the Western North Atlantic Ocean
32. Lackmann et al. (1997): A Characteristic Life Cycle of Upper-Tropospheric Cyclogenetic Precursors during the Experiment on Rapidly Intensifying Cyclones over the Atlantic (ERICA)
33. McTaggart-Cowan et al. (2006): Analysis of Hurricane Catarina (2004)
34. McTaggart-Cowan et al. (2007): Hurricane Katrina (2005). Part II: Evolution and Hemispheric Impacts of a Diabatically Generated Warm Pool

35. McTaggart-Cowan et al. (2010): Development and Tropical Transition of an Alpine Lee Cyclone. Part I: Case Analysis and Evaluation of Numerical Guidance
36. McTaggart-Cowan et al. (2013): A Global Climatology of Baroclinically Influenced Tropical Cyclogenesis
37. Moore et al. (2013): Synoptic-Scale Environments of Predecessor Rain Events Occurring East of the Rocky Mountains in Association with Atlantic Basin Tropical Cyclones
38. Moore et al. (2019): Linkages between Extreme Precipitation Events in the Central and Eastern United States and Rossby Wave Breaking
39. O'Handley and Bosart (1989): Subsynoptic-Scale Structure in a Major Synoptic-Scale Cyclone
40. Papin et al. (2020): A Feature-Based Approach to Classifying Summertime Potential Vorticity Streamers Linked to Rossby Wave Breaking in the North Atlantic Basin
41. Pyle et al. (2004): A Diagnostic Study of Jet Streaks: Kinematic Signatures and Relationship to Coherent Tropopause Disturbances
42. Röthlisberger et al. (2019): Recurrent Synoptic-Scale Rossby Wave Patterns and Their Effect on the Persistence of Cold and Hot Spells
43. Sanders and Bosart (1985): Mesoscale Structure in the Megalopolitan Snowstorm of 11–12 February 1983. Part I: Frontogenetical Forcing and Symmetric Instability
44. Schultz et al. (1997): The 1993 Superstorm Cold Surge: Frontal Structure, Gap Flow, and Tropical Impact
45. Schultz et al. (1998): The Effect of Large-Scale Flow on Low-Level Frontal Structure and Evolution in Midlatitude Cyclones
46. Winters et al. (2019): The Development of the North Pacific Jet Phase Diagram as an Objective Tool to Monitor the State and Forecast Skill of the Upper-Tropospheric Flow Pattern
47. Winters et al. (2020a): Composite Vertical-Motion Patterns near North American Polar–Subtropical Jet Superposition Events
48. Winters et al. (2020b): Composite Synoptic-Scale Environments Conducive to North American Polar–Subtropical Jet Superposition Events