Severe Weather Ingredients

Material prepared by Tom Galarneau and Rich Thompson

Ingredients for Organized Severe Thunderstorms

- Instability (Lapse Rates)
- Lift (QG, mesoscale, convective scale)
- Moisture (return flow, soil moisture, evapotranspiration)
- Vertical wind shear



Vertical wind shear

- a separate lecture

Instability: Elevated Mixed Layer (EML)

- Deep mixed layer forms over Rockies and Sierra Madre in response to surface heating
- Stronger heating and/or cooler temperatures aloft results in deeper mixed layer
- Mixed layer is advected eastward and becomes elevated east of the Rockies and Sierra Madre (really, east of the dryline)
- Differential advection (eastward advection of EML above northward advection of moisture from GoM) created "loaded gun" profile

Elevated Mixed Layer (EML) Differential Advection



EML at OUN (0000 UTC 4 May 1999)





Climatology of Lid Occurrence

- Series of papers by Lanicci and Warner (1991)
 - Weather and Forecasting (June issue)
- Distribution of maximum surface potential temperature
 - What is the "normal" dry adiabat value by month over the high terrain of the west?
 - See their Fig. 6 for April (36-40 C), May (40-44 C), and June (48-52 C)



FIG. 5. Mean number of lid days over the region (see text for the definition of a "lid day"). An asterisk (*) next to the station means that the 1200 UTC lid frequency is greater than or equal to twice the 0000 UTC frequency. Charts are shown for a) April, b) May, and c) June. The change in lid days from April to June is shown by the difference field in (d). Lanicci and Warner (1991)

Climatology of Surface $\boldsymbol{\theta}$







FIG. 6. Climatological mean maximum surface potential temperature analysis (in °C) over northern Mexico and the western U.S. for a) April, b) May, and c) June. Values greater than or equal to 44° C are alternately highlighted in 4° C intervals as shown in the lower left corner of chart (a).

Lanicci and Warner (1991)





• Lid strength is related to:

• EML *θ*

• Depth/quality of moisture

• Surface heating and mixing in moist sector





EML Potential Temperature

- EML θ values 36-40C in April, 40-44C in May, 48-52C in June
- Warmer than normal surface temperatures over Rockies can lead to very warm EML and strong lid (or, cap) in Plains
- Cooler than normal surface temperatures over Rockies <u>might</u> suggest not much EML formation
- EML develops over a few days (like moisture return)

Lift

- Synoptic-scale lift
 - 1-10 cm/s for many hours (6 hours ~2 km ascent (SFC-800 hPa))
 - 6 hours to reach LFC
 - Conditions environment for deep, moist convection over broad area
 - Layered clouds in regions of isentropic lift; some elevated storms can form
- Mesoscale lift
 - 1 m/s for minutes to hours (1 hour ~3.6 km ascent (SFC-650 hPa))
 - < 1 hour to reach LFC</p>
 - Narrow zones of ascent along boundaries and terrain features
 - Direct initiation of thunderstorms
- Storm-scale lift
 - 10 m/s for minutes (15 mins ~9 km of ascent (SFC-300 hPa))
 - 5 minutes to reach LFC
 - Storm maintenance and propagation (supercells, MCSs, squall lines, etc.)

Synoptic-Scale Lift

- QG sources
 - Warm advection/isentropic lift and differential vorticity advection
- Jet streaks (also QG)
 - Straight jet: ascent in right entrance and left exit regions
 - Curved jet: ascent downstream and along jet core















Synoptic-Scale Lift Summary

- Gradual ascent over many hours
 - Warm advection and differential vorticity advection are primary drivers
- Primary role of QG ascent is to precondition environment for convection
 - Can also initiate elevated storms in regions of warm advection
 - Most surface-based storms are triggered by mesoscale ascent

Mesoscale Lift

• Focused and narrow zones of lift for minutes to hours

• Fronts

- Rising on warm side with frontogenesis
- Isentropic ascent on sloped warm front ("overrunning"); similar to synoptic lift except in focused bands

Outflow boundary

• Lift is governed by depth/strength of cold pool and low-level vertical wind shear [Rotunno-Klemp-Weisman (RKW) Theory]

• Dryline

- Lift on dry/hot side due to frontogenesis
- Lift also governed by depth of mixing west of dryline and depth of moist layer east of dryline















Dryline Summary

- Focused ascent along dryline can be ~1 m/s (~1 hour to reach LFC)
 - Lift depends on depth of mixing west of dryline
- Convection initiation linked to the residence time of air in the zone of ascent
 - Winds above the surface parallel to dryline keeps air in zone of life longer
- Convection will initiate in points or bands
 - Usually the mode of initiation for surface-based supercells in central/southern Plains

Moisture

- Moisture in PBL needs to be large and deep enough for convection
- Return flow
- Inland vertical mixing/diurnal processes
- Evapotranspiration

Low-level Moisture Return Flow

- Key elements include air mass modifications over warmer water and return flow trajectories
- Air mass modification is a multi-date process
- Ask yourself the following:
 - Where is the air coming from?
 - What are the underlying ocean characteristics?
 - What is the character of the returning moist layer?



NOAA / AOML / PHOD Wed Jan 28 02:02:20 EST 2015

NOAA/NESDIS GEO-POLAR BLENDED 5 km SST ANALYSIS Air temperature after cold front passage FOR THE GULF OF MEXICO





Loop: 2 🖃

20



Stop




C.

















Inland Vertical Mixing

- Surface moisture can decrease during the daytime when:
 - Daytime heating/mixing extends deeper than original moist layer depth
 - Moisture advection is not enough to offset mixing
 - Compounded by dry soil, little green vegetation, and ongoing drought
- Daytime mixing is governed by:
 - Vertical moisture structure
 - Height and strength of lid/cap
 - Upstream moisture sources
 - Local moisture sources







U.S. Drought Monitor CONUS

April 5, 2011

(Released Thursday, Apr. 7, 2011) Valid 7 a.m. EST

Drought Conditions (Percent Area)



Intensity:



D4 Exceptional Drought

D2 Severe Drought

The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. See accompanying text summary for forecast statements.

Author(s):

Mark Svoboda National Drought Mitigation Center





















Evapotranspiration

- Need moist soil and growing vegetation
- Plentiful rain previous 1-2 weeks
- Maturing crops (wheat, corn, or canola)
- Capped boundary layer to trap moisture; relatively weak winds
- Almost always a significant return flow contribution (in addition)

U.S. Drought Monitor CONUS

August 19, 2014

(Released Thursday, Aug. 21, 2014) Valid 8 a.m. EDT

Drought Conditions (Percent Area)



Intensity:



D2 Severe Drought

The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. See accompanying text summary for forecast statements.

Author(s): Richard Tinker

CPC/NOAA/NWS/NCEP



















Lee Cyclogenesis

- Midlevel flow crosses high terrain:
 - Subsidence and warming E of mountains
 - Stronger diabatic heating across slope results in rising motion from induced katabatic flow. (Frontogenesis)
 - Warming of column and rising motion leads to "warm core" low formation
 - Strongest pressure falls with strongest flow crosses highest terrain
- The lee trough/cyclone deepens before arrival of strongest Q-G forcing for ascent:
 - Head start on differential advection, "loaded gun" sounding, and veering winds with height















Lee Cyclogenesis PV Framework

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- Conservation of Potential Vorticity
 - Assumptions:
 - Constant density/stable

ΔZ

- Adiabatic
- Frictionless
- Stretching of the column vertically requires an increase in relative vorticity between the theta surfaces inducing positive vorticity.
- Stretching also lowers the static stability of the atmosphere.

Θ+ΔΘ

Θ

Nocturnal Low-Level Jet (LLJ)

- Plains often see early nocturnal low-level jet (LLJ) ramp up with lee cyclogenesis
- Related to two primary factors:
 - Boundary-layer decoupling and loss of surface friction ("inertial oscillation")
 - Diurnal temperature variations over sloped terrain (thermal wind)
- Part of the process that can favor late evening/early overnight tornadoes (with favorable moisture/CAPE)

Nocturnal Low-Level Jet (LLJ) Formation

- LLJs form in response to difference in terrain heights, heat fluxes and thickness across pressure surfaces that induces a horizontal Pressure Gradient Force.
- Coriolis forcing turns the momentum northward resulting in an enhanced southerly flow.
- Surface decoupling favors lower friction and acceleration of the jet above the surface
- Lee Cyclones can also enhance it by increasing the DCL.


EF2+ supercell events



Nontornadic supercell events



Lee Cyclogenesis Summary

- Lee cyclogenesis occurs where upper-level flow is perpendicular to terrain features (westerly flow for Rockies)
- Lee cyclogenesis more robust with lower static stability
- Lee cyclone helps drive low-level moisture return
- Nocturnal low-level jet associated with lee cyclone is driven by inertial oscillation and thermal wind increased low-level shear and tornado threat in evening and after dark if adequate CAPE