Warm weather’s a comin’!

**Highlights**
- Low pressure departing today with rain chances diminishing through the day
- Highs in the 50s and 60s Friday
- Temperatures seasonal this weekend.
- Much warmer next week

**Social Media**
- [NWS Des Moines Twitter](https://www.twitter.com/NWSDesMoines OR @NWSDesMoines or iawx or nwsdmx)

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National Weather Service
Des Moines, Iowa
Performance Dependence on Closure Constants of the MYNN PBL Scheme for Wind Ramp Events in a Stable Boundary Layer

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Definition of Wind Ramp

Change in power > 50% wind power capacity within 1-2 hours (depending on respondent)

Figure taken from Ferreira et al. (2010)
Definition of Wind Ramp

- For 1.5MW turbine, a wind ramp translates to a change in wind 3 m/s over 1-4 hrs.
- In this study, used change of >= 3 m/s in <= 1 hr.

Figure taken from Deppe, Gallus & Takle (2013)
Causes of Wind Ramps

**Fronts**
- Mesoscale models do well in identifying fronts, although timing can be an issue

**Storm outflow**
- Storm initiation is an issue and can be of various scales (local or regional)
- Strength of storm downdraft determines strength of storm outflow (related to microphysics)

**Nocturnal low-level jet (LLJ)**
- Develops as layer just above BL is decoupled from surface friction effects and winds increase (inertial oscillation)

Ramp events can be caused by various weather situations, each with its own forecast issues.
Causes of wind ramps

Based on 58 wind ramp cases between 06/08-06/09

Figure taken from Deppe, Gallus & Takle (2013)
Causes of wind ramps

Based on 58 wind ramp cases between 06/08-06/09

With work contributed also by Aaron Rosenberg!!
Wind Forecasting using Numerical Weather Prediction (NWP)

- Mesoscale weather models often predict the height of the LLJ too high and the magnitude too low
- Overwhelming consensus in research community is a need to improve BL schemes (effect of subgrid features such as turbulence)
Accuracy of Wind Ramp NWP Forecasts

- Study by Deppe, Gallus, Takle (2013)
  - Evaluated 6 different PBL schemes
    - Local mixing scheme (MYJ, MYNN)
    - Non-local mixing scheme (YSU)
  - General results
    - Non-local mixing scheme performed best for 80m height wind forecasts
    - Local mixing scheme performed best for wind ramp forecasting
Limitations of research to date

- Bulk of research has involved the evaluation of existing PBL schemes and not modification to the model itself
- PBL schemes have been developed as a “one size fits all” approach
- PBL schemes have, for the most part, been tuned for neutral cases (i.e., not directly for the SBL)
Limitations of research to date

- Bulk of research has involved the evaluation of existing PBL schemes and not modification to the model itself.
- PBL schemes have been developed as a “one size fits all” approach.
- PBL schemes have, for the most part, been tuned for neutral cases (i.e., not directly for the SBL).

→ Leaves room for unique research in improving PBL schemes:
  - Digging into the scheme to seek means for improvement.
  - Specifically for the stable boundary layer (SBL) and wind ramp events.
MYNN Scheme: Prognostic Eq. for Turbulence Momentum Flux

\[ \frac{Du_i u_j}{Dt} = \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \]

- Time-tendency
- Energy redistribution
- Dissipation
- Buoyancy term
- Diffusion
- Shear production
MYNN Scheme: Prognostic Eq. for Turbulence Momentum Flux

\[
\frac{D u_i u_j}{Dt} = p \left( \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) + \nu \frac{\partial u_i}{\partial x_k} \frac{\partial u_j}{\partial x_k} + g u_j \theta + u_i u_j u_k + \frac{u_k u_i}{u_i u_j} \frac{\partial U_j}{\partial x_k}
\]
Closure Equation: Dissipation

\[-\nu \frac{\partial u_i}{\partial x_k} \frac{\partial u_j}{\partial x_k} = \frac{1}{B_1} - \frac{q^3}{3L} \delta_{ij}\]

\[q = \left[u^2 + v^2 + w^2\right]^{\frac{1}{2}}\]
Closure Equation: Dissipation

\[- \nu \frac{\partial u_i}{\partial x_k} \frac{\partial u_j}{\partial x_k} = \frac{1}{B_1} - \frac{q^3}{3L} \delta_{ij} \]

\[q = \left[ u^2 + v^2 + w^2 \right]^{\frac{1}{2}} \]

\[B_{1\text{MYNN}} = 24.0 \quad X \quad [0.2, 0.5, 2.0, 5.0] \]
Model Simulations

Weather Research and Forecast (WRF) Model

- Model set-up
  - Initialized model using the North America Region Reanalysis (32-km horiz. resolution, 25mb vertical resolution) acquired from the NOAA National Climate Data Center (NCDC)
  - Nested forecast domains at 10-km and 3.33km grid resolution centered of Mason City, IA
  - Vert. resolution 10 pts. below 250m
  - Used MYNN PBL scheme
  - 18-hr. forecasts initialized at 18Z
Dissipation Term Sensitivity Tests

100m Observations vs. WRF Runs - Mason City, IA
10/25-26/07

- Obsv
- B1_orig
- 5.0*B1_orig
- 2.0*B1_orig
- 0.5*B1_orig
- 0.2*B1_orig
Next Step

Current Work

- Determine closure constant values for the SBL using LES-produced data for select LLJ cases

\[
\frac{\partial q^2}{\partial t} = -\frac{\partial}{\partial z}(wq + 2wp/\rho) - 2(uw \frac{\partial U}{\partial z} + uw \frac{\partial V}{\partial z}) + 2 \frac{g}{\Theta_o} \overline{w\theta} - 2\epsilon
\]

\[
\epsilon = -\frac{q^3}{B_1 L}
\]

\[
B1 = \frac{q^3}{L} \left[-uw \frac{\partial U}{\partial z} + \frac{g}{\Theta_o} \overline{w\theta}\right]^{-1}
\]
LES Simulation of a LLJ case

- **WRF-LES model**
  - 4m grid resolution (dx, dy, dz)
  - Domain 400m x 400m x 1300m
  - Initialized using a vertical profile of wind velocity and pot. temp. extracted from mesoscale WRF forecast
  - Horizontally homogeneous
Calculate Closure Constants

\[ B1 = \frac{q^3}{L} \left[ -\bar{uw} \frac{\partial U}{\partial z} + \frac{g}{\Theta_o} \bar{w\theta} \right]^{-1} \]
Base State

Wind velocity

Potential Temp
MYNN Scheme: Prognostic Eq. for Turbulence Momentum Flux

Time-tendency
\[ \frac{Du_i u_j}{Dt} \]

Energy redistribution
\[ p \left( \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) \]

Dissipation
\[ \nu \frac{\partial u_i}{\partial x_k} \frac{\partial u_j}{\partial x_k} \]

Buoyancy term
\[ g u_j \theta \]

Diffusion
\[ u_i u_j u_k \]

Shear production
\[ \frac{u_k u_i}{\partial x_k} \frac{\partial U_j}{\partial x_i} \]
Closure Equation: Energy Redistribution

\[
\begin{align*}
\text{Energy redistribution} & \quad = \quad \frac{1}{A_1} \\
\quad & \quad - \frac{q}{3L} u_i u_j \\
\text{TKE-Mean shear term} & \quad = \quad C_1 q^2 \left( \frac{\partial U_i}{\partial x_j} \right) \\
\text{Buoyancy term} & \quad = \quad C_2 \frac{g}{\Theta_o} u_i \theta \\
\text{Covariance-Mean shear term} & \quad = \quad C_4 \frac{u_i u_k}{\Theta_o} \frac{\partial U_j}{\partial x_k} \\
q^2 & = \overline{u_i^2}
\end{align*}
\]

(Adapted from Mellor 1973, Mellor & Yamada 1974, 1982, Nakanishi 2001)
Closure Equation: Energy Redistribution

\[
\begin{align*}
\text{Energy redistribution} & \quad \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \\
\quad & = \quad \frac{1}{A_1} - \frac{q}{3L} u_i u_j \\
\quad & + \quad C_1 \quad q^2 \left( \frac{\partial U_i}{\partial x_j} \right) \\
\quad & + \quad C_2 \quad \frac{g}{\Theta_o} u_i \theta \\
\quad & + \quad C_4 \quad \frac{u_i u_k}{u_i u_k} \frac{\partial U_j}{\partial x_k} \\
\quad & = \quad q^2 = u_i^2
\end{align*}
\]

(Adapted from Mellor 1973, Mellor & Yamada 1974, 1982, Nakanishi 2001)
Select Wind Ramp Case

- Ramp event at Mason City, IA on 06/13/08

Data provided by Iowa Energy Center/ISU working with AWS Truepower (2007-08)
Results

100m Observations vs. WRF Runs - Mason City, IA
06/13-14/08

- Obsv
- f2 = C2 "on"
- f1 = C1 "on"
- f12 = Cntl (all on)
- C3 "off"
Closure Equation: Energy Redistribution

\[ \frac{\text{Energy redistribution}}{p \left( \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right)} = \frac{1}{A_1} - \frac{q}{3L} \bar{u}_i \bar{u}_j \]

\[ + \quad C_1 \quad \text{TKE-Mean shear term} \quad q^2 \left( \frac{\partial \bar{U}_i}{\partial x_j} \right) \]

\[ + \quad C_2 \quad \text{Buoyancy term} \quad \frac{g}{\Theta_o} \bar{u}_i \theta \]

\[ + \quad C_4 \quad \text{Covariance-Mean shear term} \quad \frac{\bar{u}_i \bar{u}_k}{\bar{u}_k} \frac{\partial \bar{U}_j}{\partial x_k} \]

\[ q^2 = \bar{u}_i^2 \]

(Adapted from Mellor 1973, Mellor & Yamada 1974, 1982, Nakanishi 2001)
Summary

- **Sensitivity tests**
  - Tests involving energy distribution reveal dominance of terms dependent on mean wind shear
  - Tests involving energy dissipation show a non-negligible sensitivity to variations in closure constants

- Define closure constants for LLJ cases in the SBL (B1 and B2)
  - Values vary by height
  - Constant values may be appropriate over vertical depths of similar dynamic structure
Future Work

- Sensitivity tests
  - Expand number of LLJ test cases (4 considered to date)
  - Consider remaining closure constants: A1, A2 (associated with energy redistribution term)
- Define closure constants for LLJ cases in the SBL
  - Expand number of LES simulations of test cases (2 considered to date)
  - Calculate suite of closure constants (A1, A2, C1-C5)
- Comparison to observations
References

- Benjamin, S., J. Olson, E. James, C. Alexander, J. M. Brown, S. Weygandt, T. Smirnova, and J. Wilczak, 2013: Advances in Model Forecast Skill from 2012 - 2013 Assimilation and Modeling Enhancements to NOAA Hourly Updated Models. UVI Workshop on Forecasting Applications, Salt Lake City, UT.
References

Discussion
Mixing Length

\[
\frac{1}{L} = \frac{1}{L_S} + \frac{1}{L_T} + \frac{1}{L_B}
\]

\[
L_S = \begin{cases} 
  \frac{kz}{3.7}, & \zeta \geq 1 \\
  \frac{kz(1 + 2.7\zeta)^{-1}}{\zeta}, & 0 \leq \zeta < 1 \\
  \frac{kz(1 - \alpha_4\zeta)^{0.2}}{\zeta}, & \zeta < 0,
\end{cases}
\]

\[
L_T = \alpha_1 \int_0^\infty \frac{qz \, dz}{\int_0^\infty q \, dz}
\]

\[
L_B = \begin{cases} 
  \frac{\alpha_2 q}{N}, & \frac{\partial \Theta}{\partial z} > 0 \text{ and } \zeta \geq 0 \\
  \frac{\alpha_2 q + \alpha_3 q(q_c/L_T N)^{1/2}}{N}, & \frac{\partial \Theta}{\partial z} > 0 \text{ and } \zeta < 0 \\
  \infty, & \frac{\partial \Theta}{\partial z} \leq 0,
\end{cases}
\]

If MYNN has a non-local component, here it is.