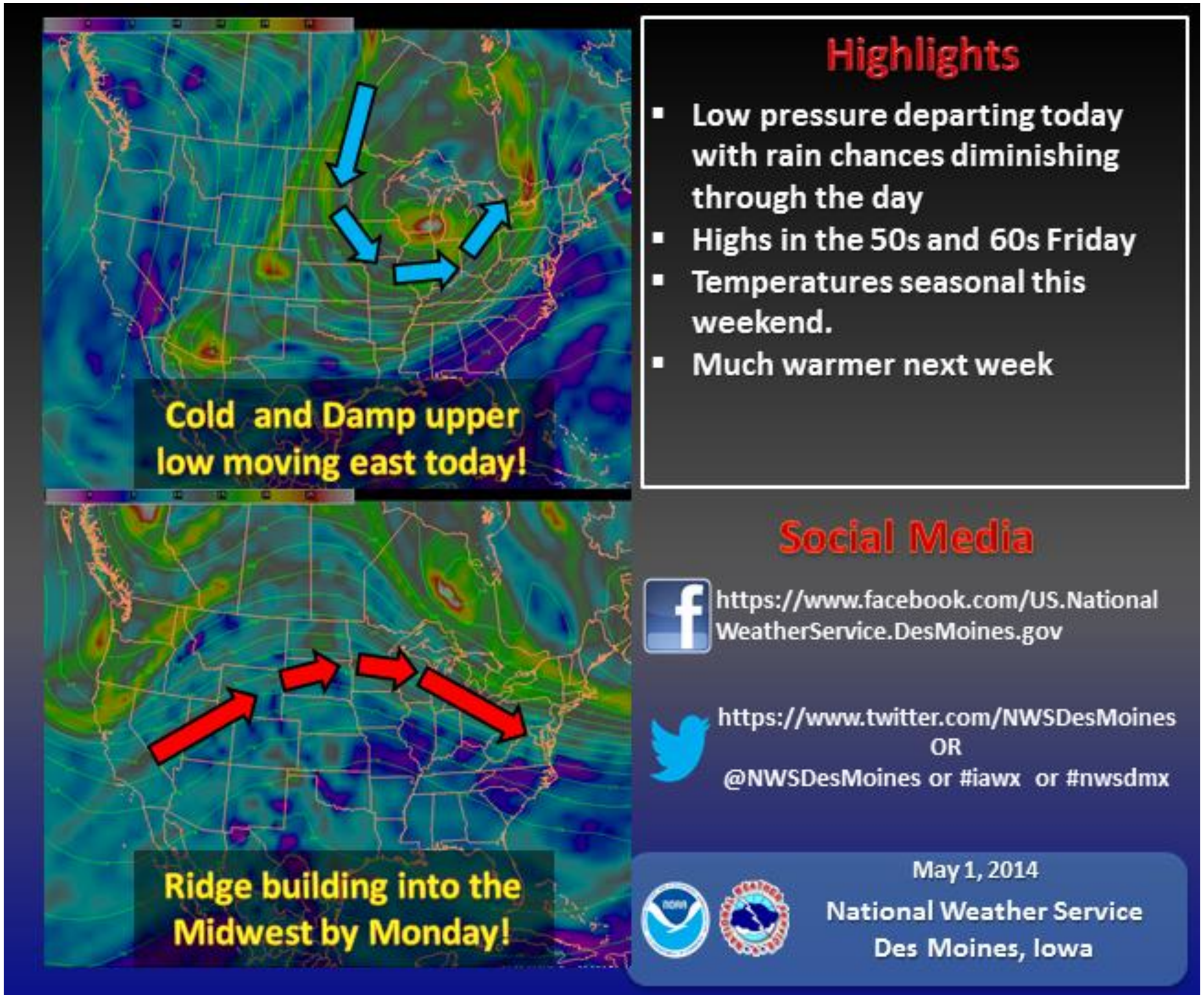
Warm weather's a comin'!



Cold and Damp upper low moving east today!

Ridge building into the Midwest by Monday!

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

https://www.facebook.com/US.NationalWeatherService.DesMoines.gov

https://www.twitter.com/NWSDesMoines
OR
@NWSDesMoines or #iawx or #nwsdmx

May 1, 2014
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

David E. Jahn

IGERT Wind Energy Science Engineering and Policy (WESEP) Program
And Dept. of Geological and Atmospheric Sciences
Iowa State University

Definition of Wind Ramp

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

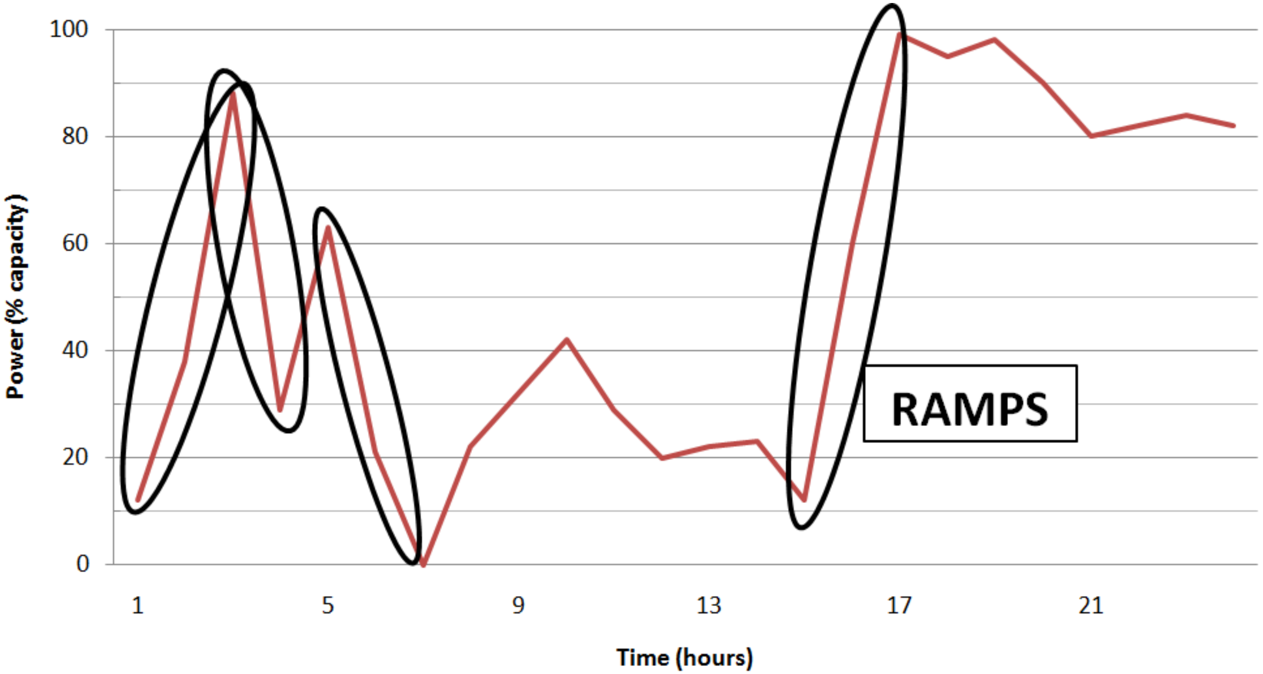


Figure taken from Ferreira et al. (2010)

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.

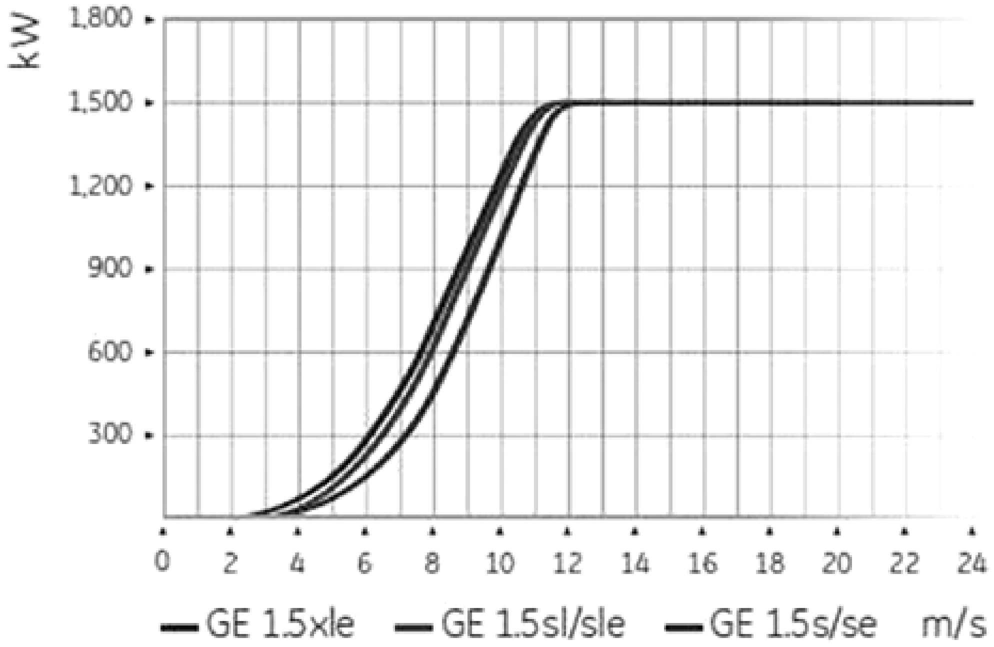


Figure taken from Deppe , Gallus & Takle (2013)

Causes of Wind Ramps

Fronts

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

Storm outflow

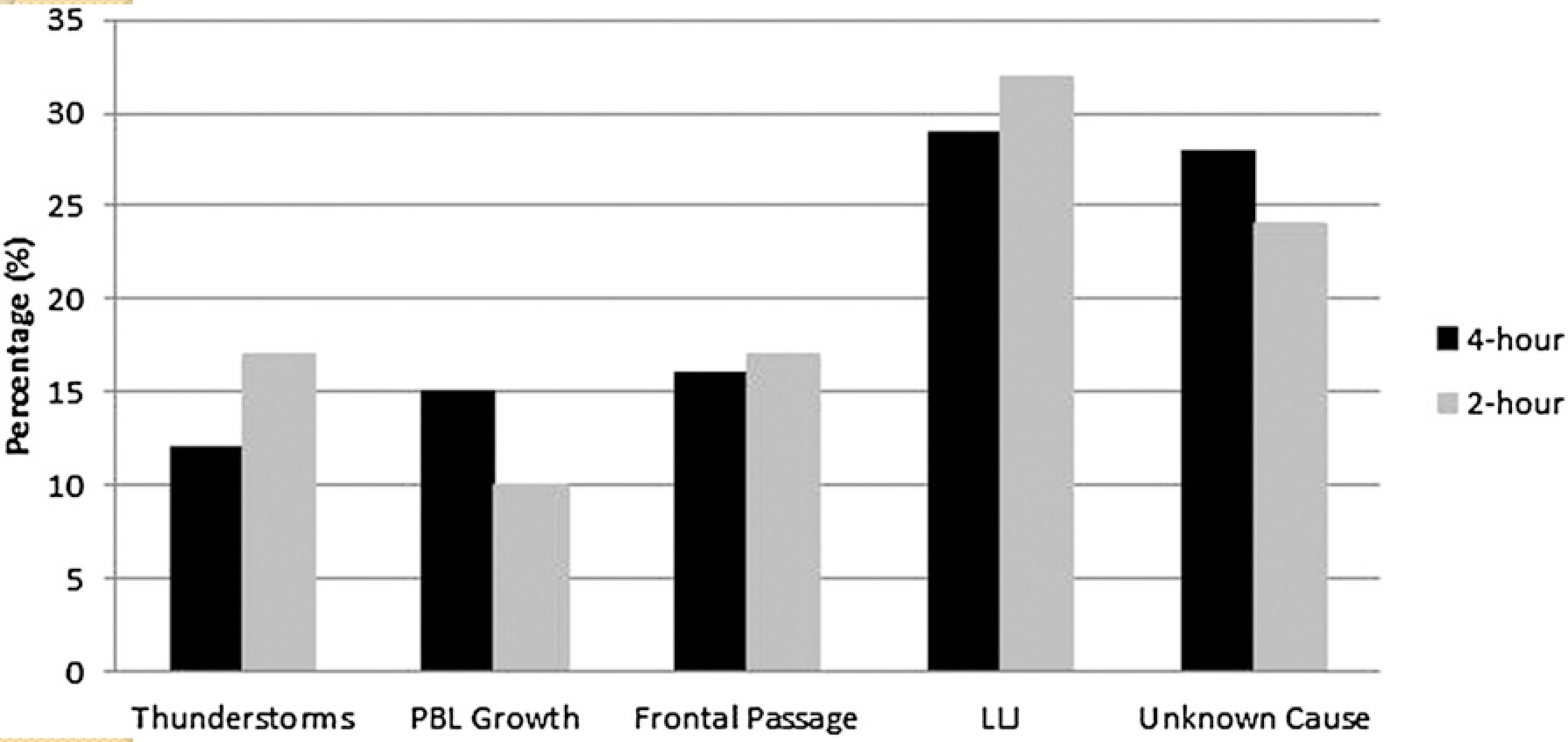
- Storm initiation is an issue and can be of various scales (local or regional)
- Strength of storm downdraft determines strength of storm outflow (related to microphysics)

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

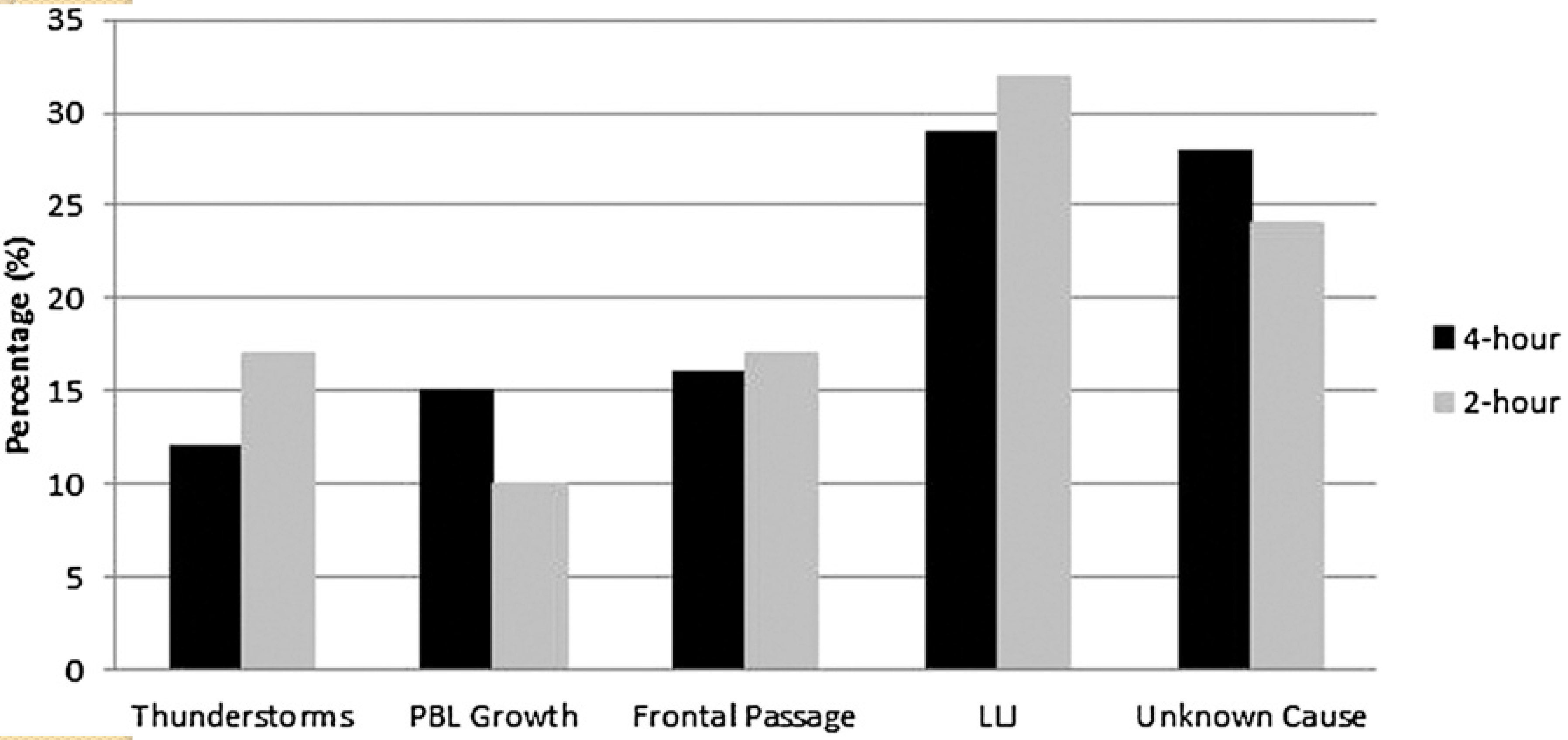


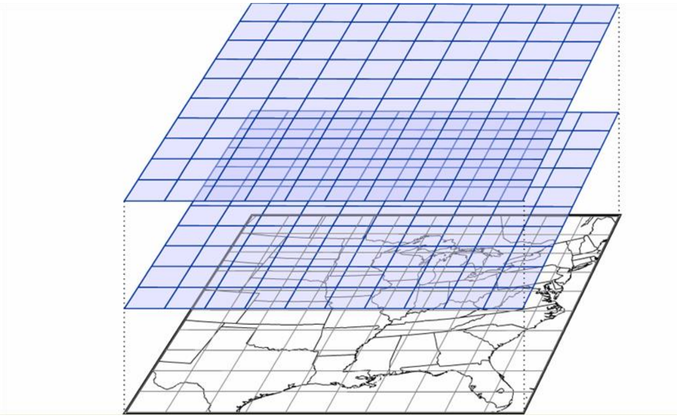
Figure taken from Deppe , Gallus & Takle (2013)

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


www.clker.com

MYNN Scheme: Prognostic Eq. for Turbulence Momentum Flux

Time-tendency

$$\frac{D\overline{u_i u_j}}{Dt}$$

=

Energy redistribution

$$\overline{p(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i})}$$

+

Dissipation

$$\nu \overline{\frac{\partial u_i}{\partial x_k} \frac{\partial u_j}{\partial x_k}}$$

+

Buoyancy term

$$g\overline{u_j \theta}$$

+

Diffusion

$$\overline{u_i u_j u_k}$$

+

Shear production

$$\overline{u_k u_i} \frac{\partial \overline{U_j}}{\partial x_k}$$

MYNN Scheme: Prognostic Eq. for Turbulence Momentum Flux

Time-tendency

$$\frac{D\overline{u_i u_j}}{Dt}$$

$$=$$

Energy redistribution

$$\overline{p\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)}$$

$$+$$

Dissipation

$$\boxed{\nu\overline{\frac{\partial u_i}{\partial x_k}\frac{\partial u_j}{\partial x_k}}}$$

$$+$$

Buoyancy term

$$\boxed{g\overline{u_j\theta}}$$

$$+$$

Diffusion

$$\boxed{\overline{u_i u_j u_k}}$$

$$+$$

Shear production

$$\boxed{\overline{u_k u_i}\frac{\partial \overline{U_j}}{\partial x_k}}$$

Closure Equation: Dissipation

$$\boxed{-\nu\overline{\frac{\partial u_i}{\partial x_k}\frac{\partial u_j}{\partial x_k}}} = \frac{1}{B_1}\boxed{-\frac{q^3}{3L}\delta_{ij}}$$

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

Closure Equation: Dissipation

$$\boxed{-\nu\overline{\frac{\partial u_i}{\partial x_k}\frac{\partial u_j}{\partial x_k}}} = \frac{1}{B_1}\boxed{-\frac{q^3}{3L}\delta_{ij}}$$

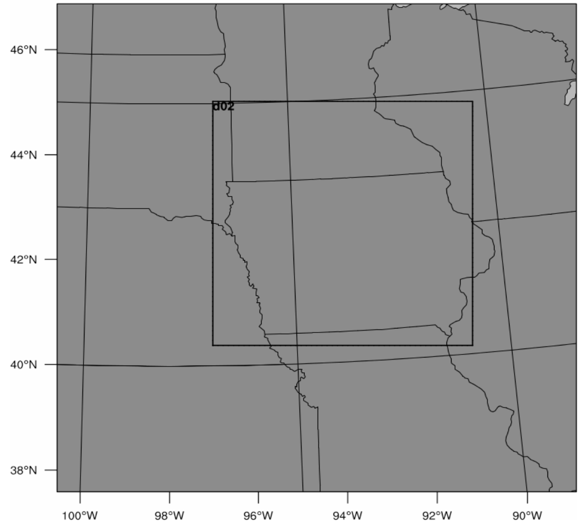
$$q = [u^2 + v^2 + w^2]^{\frac{1}{2}}$$

$$B1_{MYNN} = 24.0 \quad X \ [0.2, 0.5, 2.0, 5.0]$$

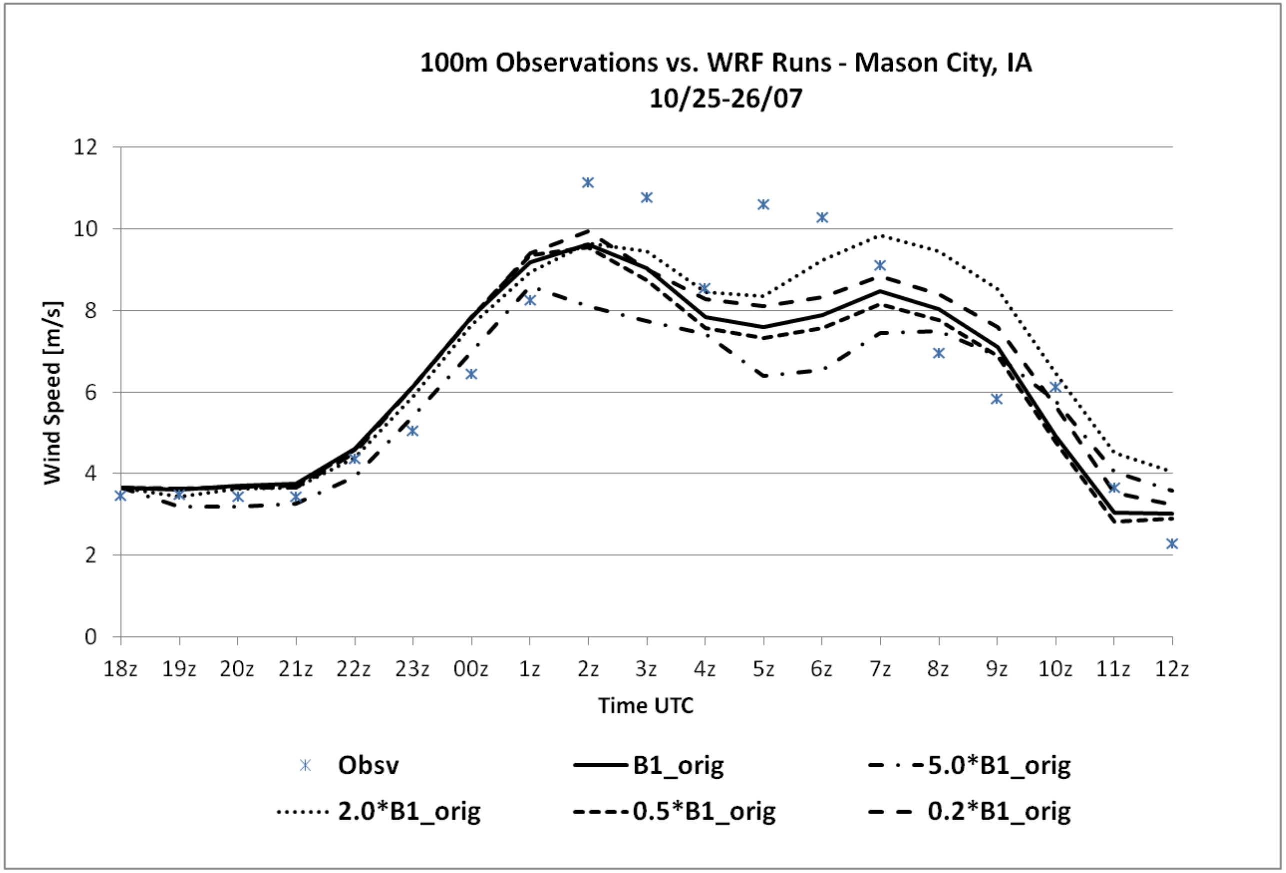
Model Simulations

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



Next Step

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

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

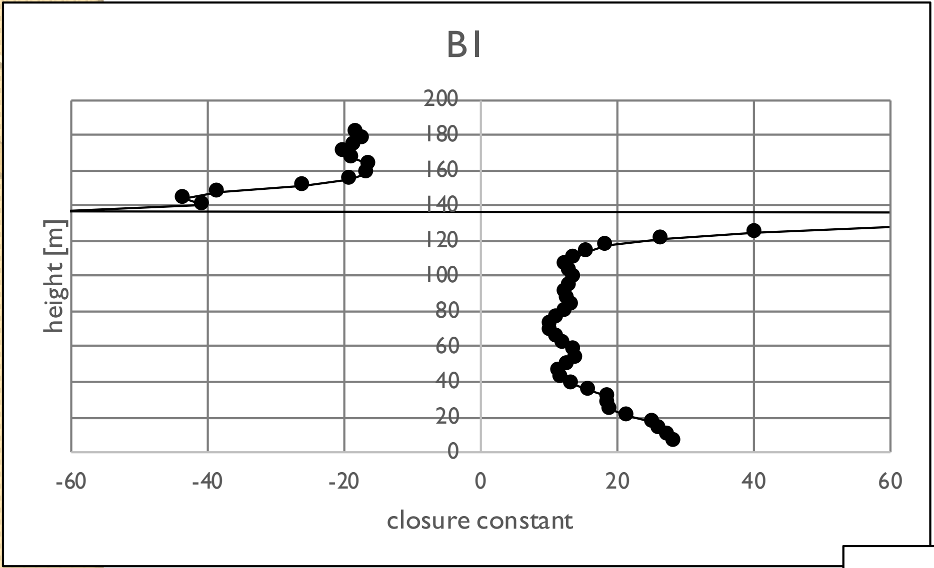
$$\epsilon = -\frac{q^3}{B_1 L}$$

$$B1 = \frac{q^3}{L}[-\overline{uw}\frac{\partial U}{\partial z} + \frac{g}{\Theta_o}\overline{w\theta}]^{-1}$$

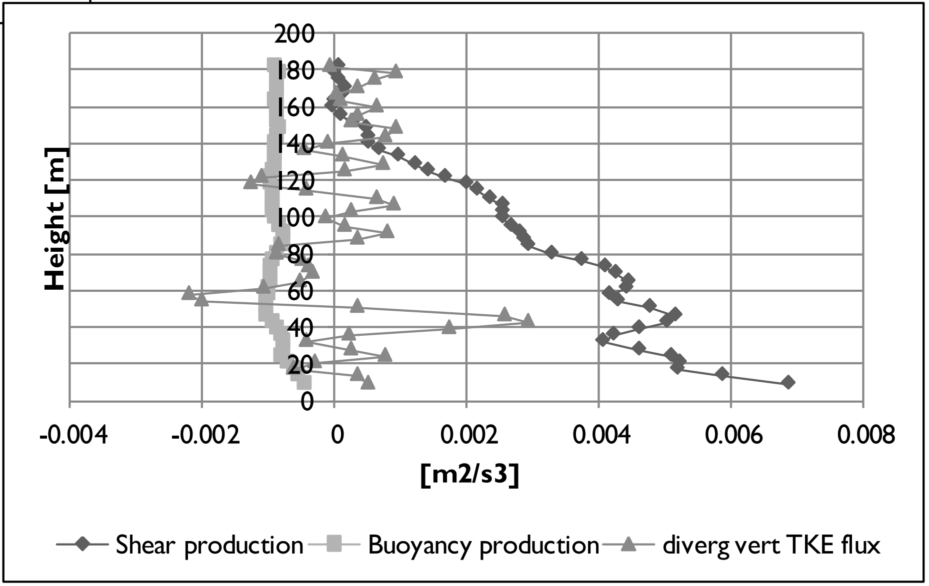
LES Simulation of a LLJ case

- 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

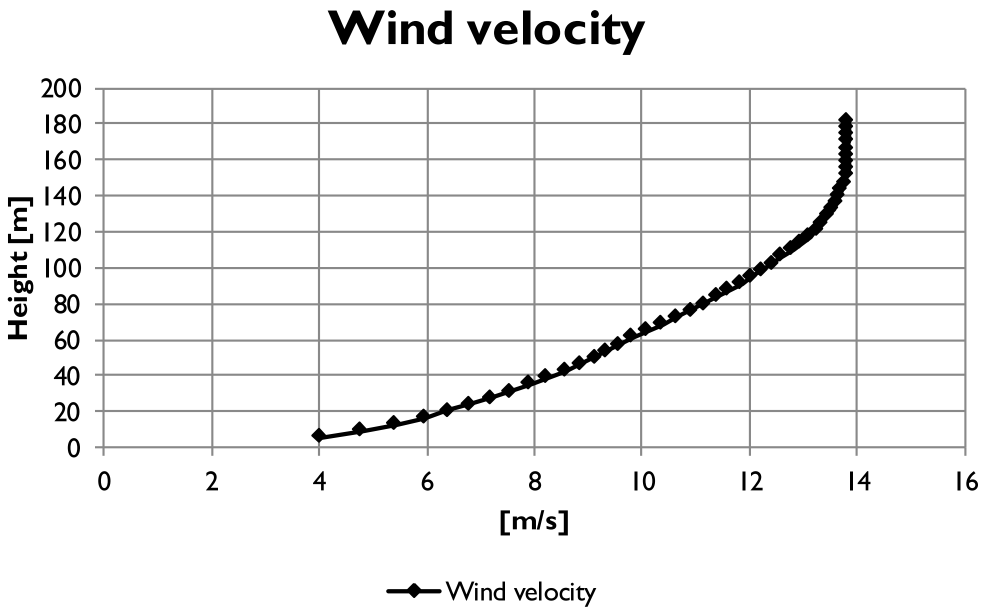
Calculate Closure Constants

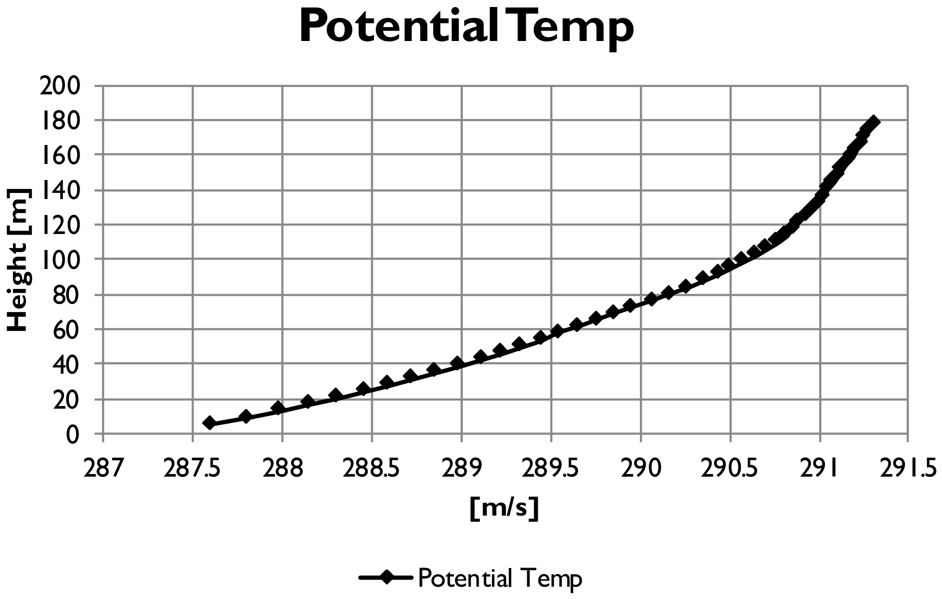


$$B1 = \frac{q^3}{L}[-\overline{uw}\frac{\partial U}{\partial z} + \frac{g}{\Theta_o}\overline{w\theta}]^{-1}$$



Base State


Wind velocity
Height [m]
200
180
160
140
120
100
80
60
40
20
0
0
2
4
6
8
10
12
14
16
[m/s]
Wind velocity


Potential Temp
Height [m]
200
180
160
140
120
100
80
60
40
20
0
287
287.5
288
288.5
289
289.5
290
290.5
291
291.5
[m/s]
Potential Temp

MYNN Scheme: Prognostic Eq. for Turbulence Momentum Flux

Time-tendency

$$\frac{D\overline{u_i u_j}}{Dt}$$

$=$

Energy redistribution

$$\overline{p\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)}$$

$+$

Dissipation

$$\nu \overline{\frac{\partial u_i}{\partial x_k} \frac{\partial u_j}{\partial x_k}}$$

$+$

Buoyancy term

$$g\overline{u_j \theta}$$

$+$

Diffusion

$$\overline{u_i u_j u_k}$$

$+$

Shear production

$$\overline{u_k u_i} \frac{\partial \overline{U_j}}{\partial x_k}$$

Closure Equation: Energy Redistribution

Energy redistribution

$$\overline{p\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}\right)}$$

$$=\frac{1}{A_1}$$

Covariance term

$$-\frac{q}{3L}\overline{u_iu_j}$$

$$+\;C_1$$

TKE-Mean shear term

$$q^2\left(\frac{\partial\overline{U_i}}{\partial x_j}\right)$$

$$+\;C_2$$

Buoyancy term

$$\frac{g}{\Theta_o}\overline{u_i\theta}$$

$$+\;C_4$$

Covariance-Mean shear term

$$\overline{u_iu_k}\frac{\partial\overline{U_j}}{\partial x_k}$$

$$q^2=\overline{u_i^2}$$

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

Closure Equation: Energy Redistribution

Energy redistribution

$$\overline{p\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}\right)}$$

$$=\frac{1}{A_1}$$

Covariance term

$$-\frac{q}{3L}\overline{u_i u_j}$$

$$+\;C_1$$

TKE-Mean shear term $q^2\left(\frac{\partial \overline{U_i}}{\partial x_j}\right)$

$$+\;C_2$$

Buoyancy term

$$\frac{g}{\Theta_o}\overline{u_i\theta}$$

$$+\;C_4$$

Covariance-Mean ~~shear term~~

$$\cancel{\overline{u_i u_k}\frac{\partial \overline{U_j}}{\partial x_k}}$$

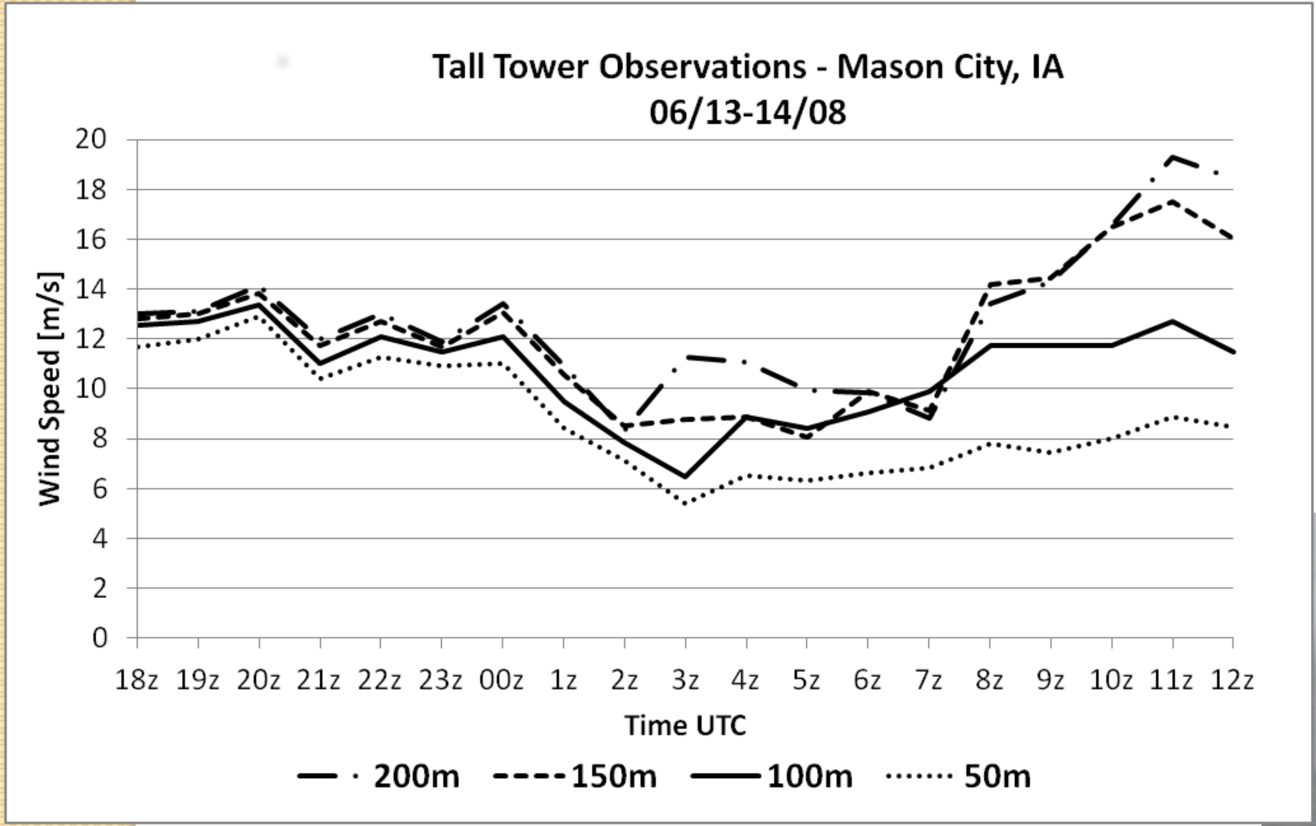
OFF

$$q^2=\overline{u_i^2}$$

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

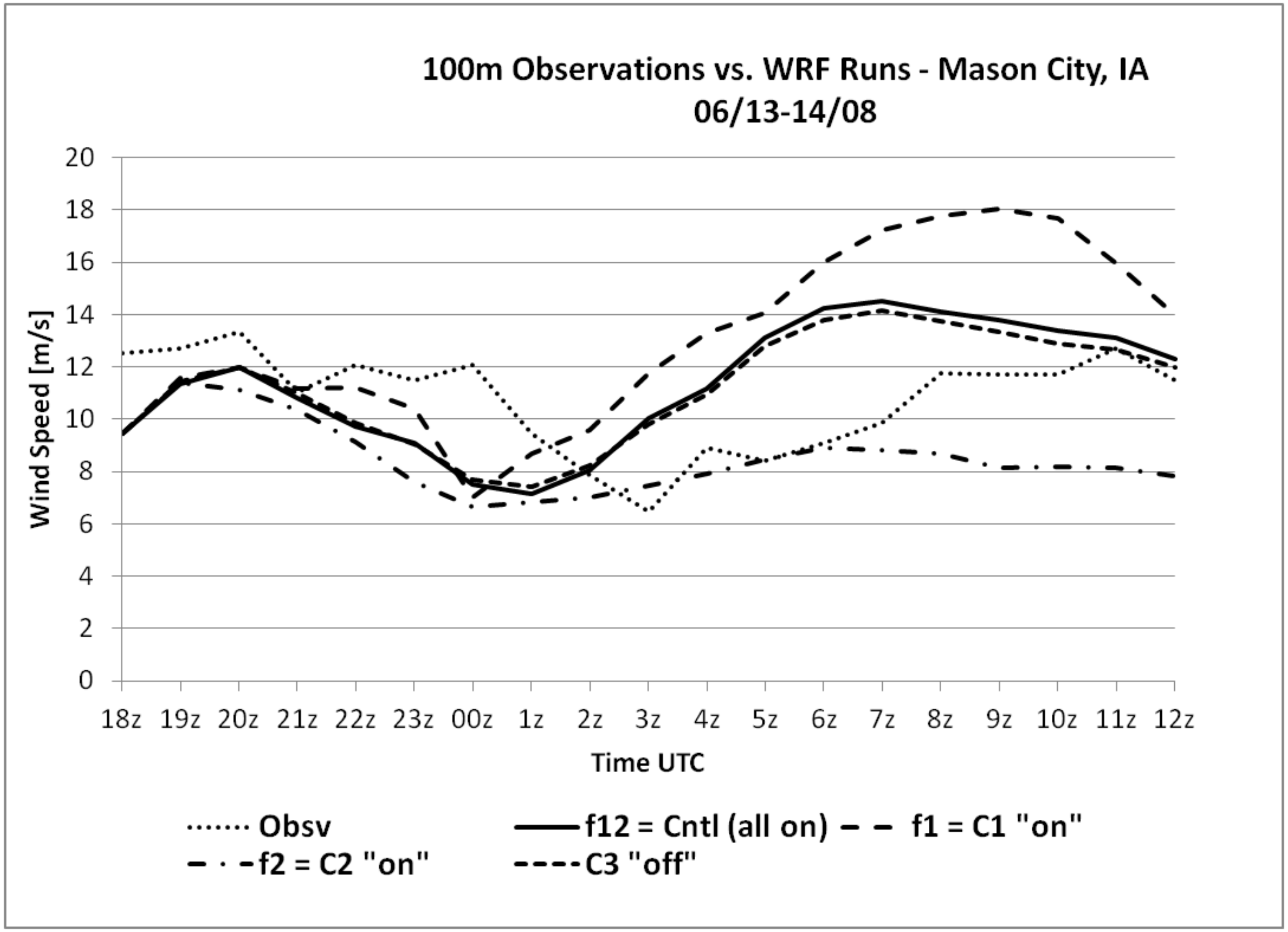
Select Wind Ramp Case

- 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
Wind Speed [m/s]
20
18
16
14
12
10
8
6
4
2
0
18z
19z
20z
21z
22z
23z
00z
1z
2z
3z
4z
5z
6z
7z
8z
9z
10z
11z
12z
Time UTC
Obsv
f12 = Cntl (all on)
f1 = C1 "on"
f2 = C2 "on"
C3 "off"

Closure Equation: Energy Redistribution

Energy redistribution

$$\overline{p\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}\right)}$$

$$=\frac{1}{A_1}$$

Covariance term

$$-\frac{q}{3L}\overline{u_i u_j}$$

$$+\;C_1$$

TKE-Mean shear term

$$q^2\left(\frac{\partial \overline{U_i}}{\partial x_j}\right)$$

$$+\;C_2$$

Buoyancy term

$$\frac{g}{\Theta_o}\overline{u_i\theta}$$

$$+\;C_4$$

~~Covariance-Mean shear term~~

$$\cancel{\overline{u_i u_k}\frac{\partial \overline{U_j}}{\partial x_k}}$$

OFF

$$q^2=\overline{u_i^2}$$

(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 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 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

- AWS Truepower, LLC (2010). Final Report: Iowa Tall Tower Wind Assessment Project. Prepared for Iowa Energy Center, Iowa State University.
- 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. UVIG Workshop on Forecasting Applications, Salt Lake City, UT.
- Deppe, A., G. Takle, W. Gallus, 2013. A WRF Ensemble for Improved Wind Speed Forecasts at Turbine Height. Wea. & Forecasting. **28**, pp 212-228.
- Fernando, H. J. S. and J. C. Weil, 2010: Whither the Stable Boundary Layer? A Shift in the Research Agenda. *Bulletin of the American Meteorological Society*, 91 (11), 1475–1484
- Ferreira, C. et al., 2010. Report: A Survey on Wind Power Ramp Forecasting. Argonne National Laboratory, U.S. Dept. of Energy. 27 pp.
- Greaves, B., J. Collins, J. Parkes, A. Tindal, G. Hassan, S. Vincent, and S. Lane, 2009: Temporal Forecast Uncertainty
- for Ramp Events. Wind Engineering, 33 (4), 309–320,
- Grisogono, B., 2010: Generalizing z-less mixing length for stable boundary layers. *Quarterly Journal of the Royal Meteorological Society,* 136 (646), 213–221.
- Mellor, G., 1973. Analytic prediction of the properties of stratified planetary surface layers. *J. Atm. Sci.*, **30**, pp. 1061-1069.
- Mello,r G., T. Yamada, 1974. A hierarchy of turbulence closure models for planetary boundary layers. *J. Atm. Sci.*, **13**, pp. 1791-1806.
- Mello,r G., T. Yamada, 1982. Development of a turbulence closure model for geophysical fluid problems. *Rev. of Geophys. And Space Phys.*, **20**, pp. 851-875.

References

- Nakanishi, M., 2001: Improvement of the Mellor-Yamada Turbulence Closure Model Based On large-Eddy Simulation Data. *Boundary-Layer Meteorology*, 99, 349–378.
- Rotta, J.C., 1951. Statistische Theorie nichthomogener Turbulenz. *Zeitschrift fur Physik*. **131**, p. 547-572.
- Schreck, S. , J. Lundquist, and W. Shaw, 2008: US Dept. of Energy workshop report: Research needs for wind resource characterization. Tech. Rep. NREL/TP-500-43521, Nat. Renewable Energy Laboratory.
- Stein, U. and P. Alpert, 1993: Factor Separation in Numerical Simulations. *Journal of the Atmospheric Sciences,* 50, 2107–2115.
- Storm, B. and S. Basu, 2010: The WRF Model Forecast-Derived Low-Level Wind Shear Climatology over the United States Great Plains. Energies, 3 (2), 258–276.
- Stull, R. B., 1988. *An Introduction to Boundary Layer Meteorology*. Kluwer Academic, 666 pp.

Discussion

Mixing Length

$$\frac{1}{L} = \frac{1}{L_S} + \frac{1}{L_T} + \frac{1}{L_B}$$

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

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

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

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

NOTES