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Methods of Improving Methane Emission Estimates in California Using Mesoscale and Particle Dispersion Modeling

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Global Change Education Program

Overview

- **Why Methane is Important:**
  - Assembly Bill 32
  - Radiative Forcing and Green House Gases
- **Inverse Modeling:**
  - What is Inverse Modeling?
  - How is it applied?
- **The Weather Research & Forecasting Model:**
  - Model Setup
  - Evaluation and Comparison

The Importance of Methane

- California's Assembly Bill 32 (AB32):
  - Passed in 2006
  - The law requires that California reduce the state's greenhouse gas emission levels to 1990 levels by the year 2020

- Greenhouse Gases* in order of Radiative Forcing:
  - Carbon Dioxide (CO_2)
  - Methane (CH_4)
  - Nitrous Oxide (N_2O)
  - Hydrofluorocarbons (HFCs)
  - Perfluorocarbons (PFCs)
  - Sulfur Hexafluoride (SF_6)

*as listed in Assembly Bill 32 and the Kyoto Protocol

Inverse Modeling

- Inverse Model:
    - $G m = d$
- Goal:
    - Improve source emission estimates
    - Quantify uncertainty in the estimates
- Surface layer height is half the PBL Height:
    - Assumed to be well mixed
    - Emissions only come from surface layer

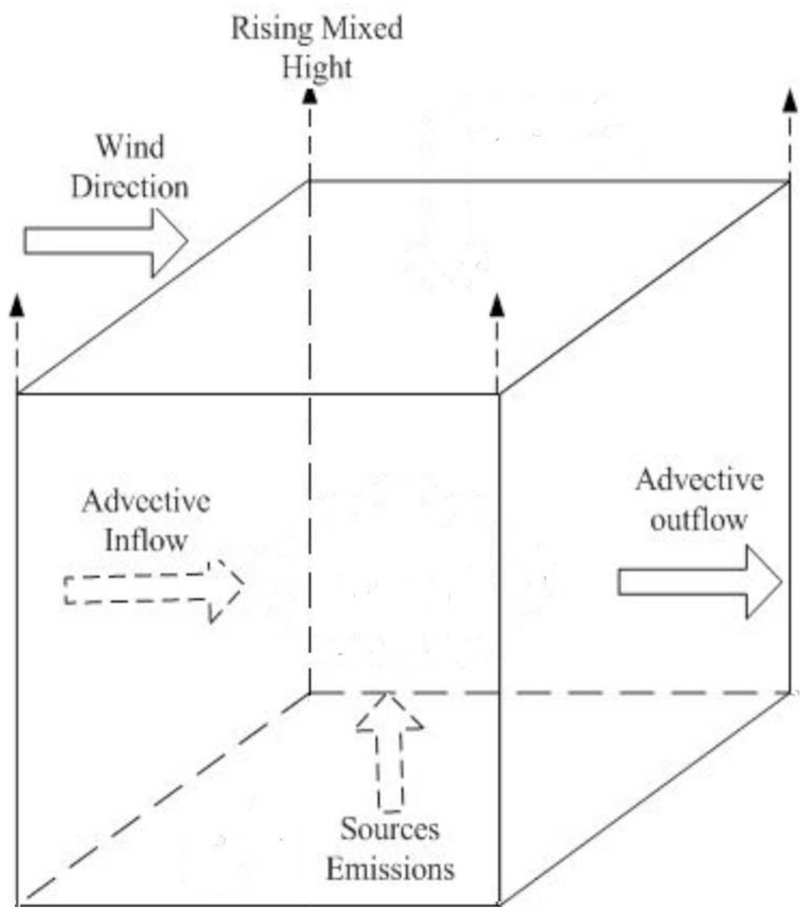

Figure 1: Box model of the atmosphere adapted from *Handbook of Air Quality Management*.

Inverse Modeling

- Coupled Model (WRF-STILT):
  - Regional Mesoscale Model:
    - Weather Research & Forecasting Model (WRF)
  - Lagrangian Particle Dispersion Model:
    - Stochastic Time-Inverted Lagrangian Transport Model (STILT)

- WRF provides meteorology data to drive the STILT model

- Critical Variables passed to STILT:
  - U-Wind Fields (East-West Component)
  - V-Wind Fields (North-South Component)
  - Planetary Boundary Layer (PBL) Height

WRF Model Output

- Radar wind profilers
  - Located in and around the Central Valley
  - Provide wind and PBL Height measurements

- Planetary Boundary Layer
  - Rises during the day and falls at night
  - Marine boundary layer stays relatively low

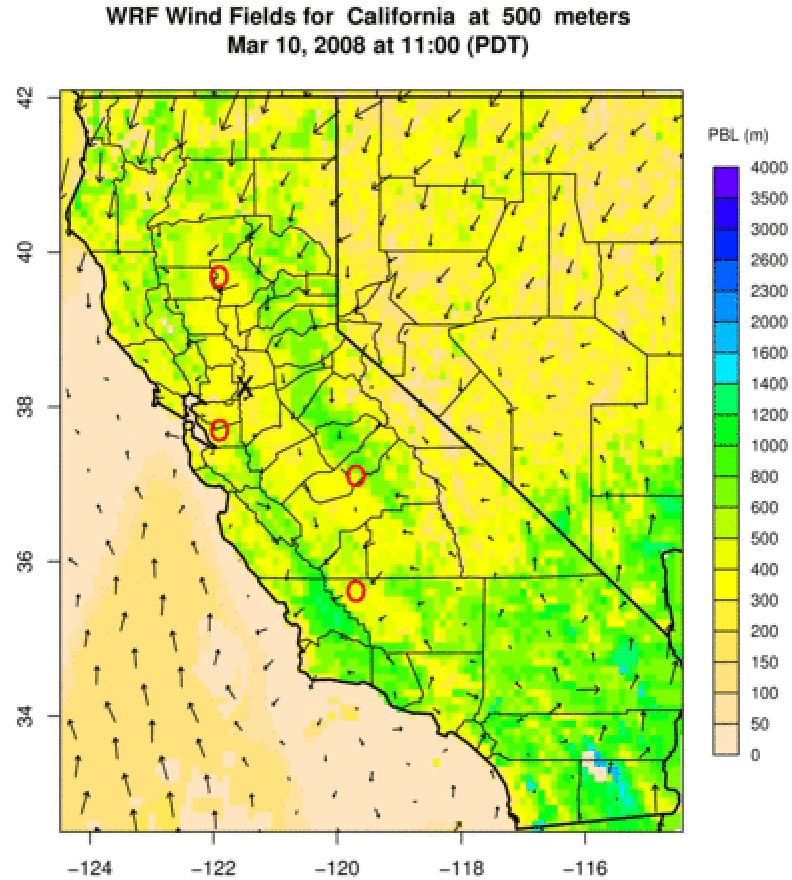

Figure 2: WRF calculated Wind Fields and Planetary Boundary Layer Heights during daytime hours in March 2008.

WRF Model Setup

- Model setup
  - 5 domains with 36 km, 12 km, 4 km, 1.333 km, and 1.333 km grid spacing respectively
  - Reinitialized the model daily with NARR data
- 3 Boundary Layer Schemes
  - Yonsei University (YSU)
  - Mellor-Yamada-Janic (MYJ)
    - LBNL reparametrization of the MYJ scheme (CZhao)

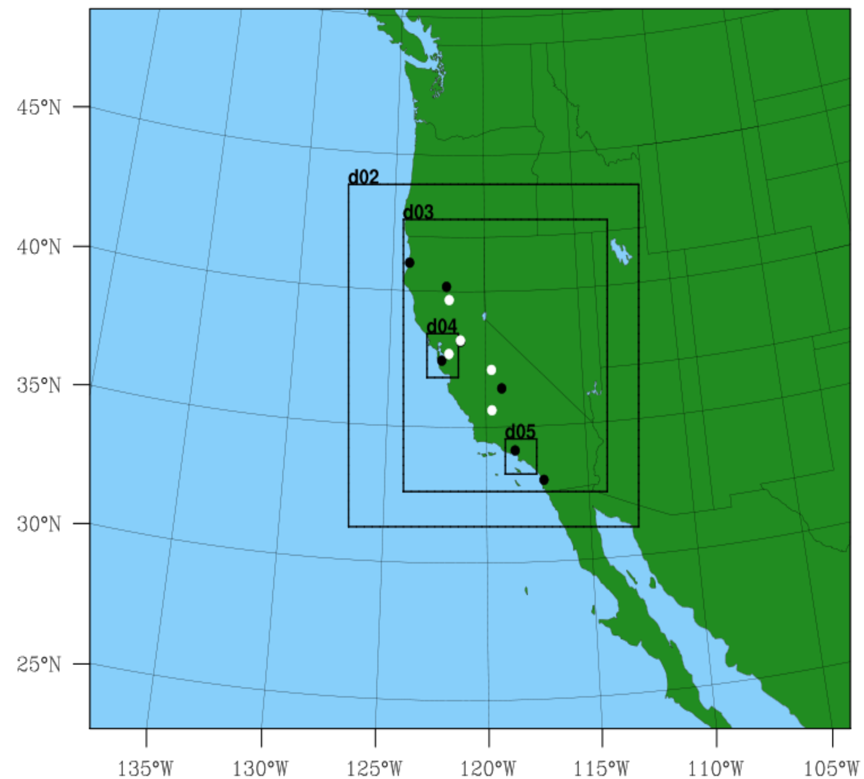

Figure 3: Map of the five WRF domains. The white points represent radar wind profilers and the black points represent Tower sites.

Predicted and Observed Winds

- WRF is matches very well with observations for some parameters
  - The model accurately captures most of the major wind events in all seasons

- Diagnosing model bias and uncertainty
  - Propagate the error through the inverse analysis

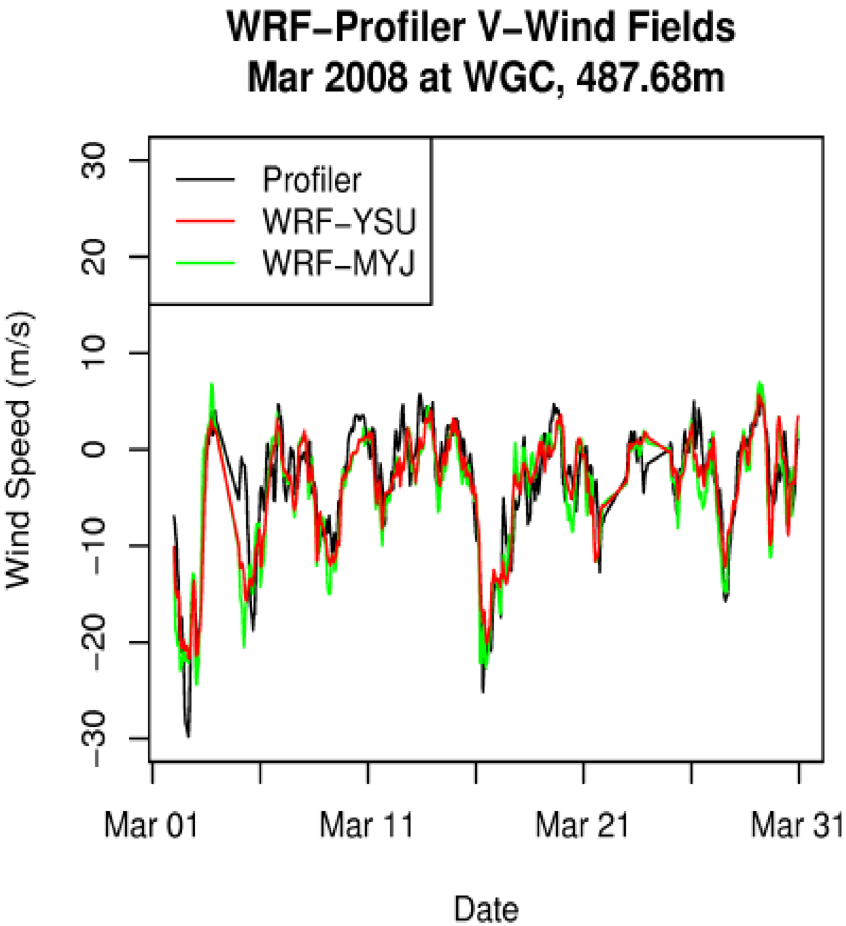

Figure 4: Time series plot of the observed and predicted North-South wind component at the Walnut Grove Creek Tower site (-121.49°, 38.27°) during March of 2008 at 487 m.

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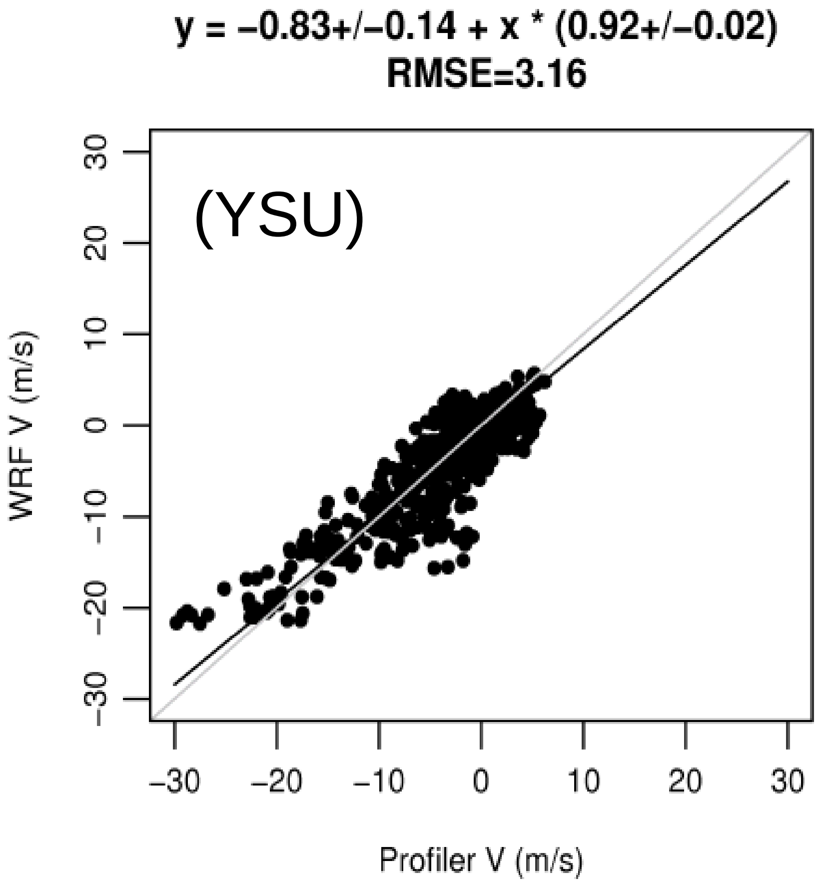

Figure 5: RMS scatter plot of the predicted vs. observed North-South wind component at the Walnut Grove Creek Tower site (-121.49°, 38.27°) during March of 2008 at 487 m.

Predicted and Observed PBL Heights

- Mean diurnal variation
  - Does not show any synoptic variation
- Model is reproducing the diurnal cycle
- Systematic Differences
  - MYJ produces highest PBL
  - CZhao produces lowest PBL

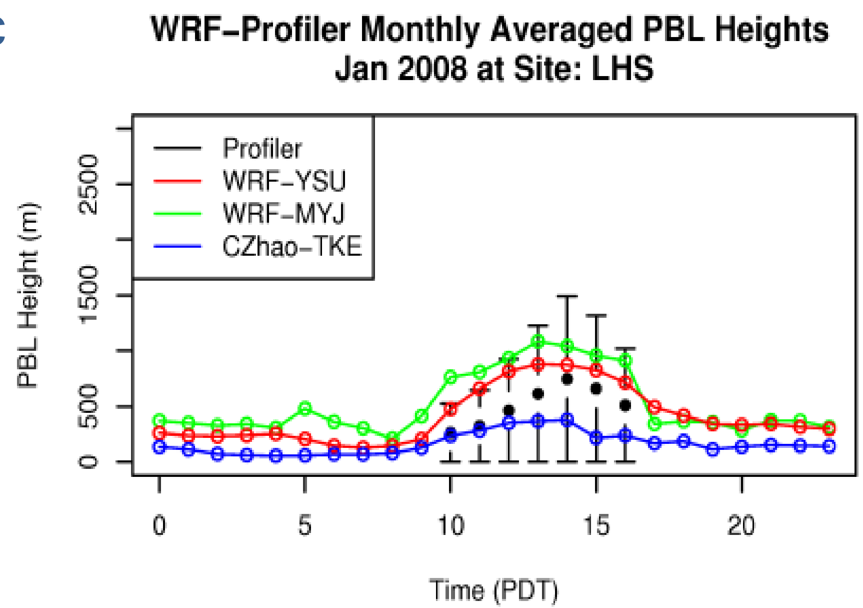

Figure 6: Monthly mean diurnal variation of PBL Heights at the Lost Hills (-119.69°, 35.62°) radar wind profiler during January of 2008.

Predicted and Observed PBL Heights

- PBL Heights are accurately simulated during Fall, Winter and Spring

- PBL Heights are over predicted in the summer
  - NOAH Land Surface Model (LSM) does not take irrigation into account
  - Incorrect balance of Latent and Sensible Heat

- CZhao scheme was designed to reduce this bias

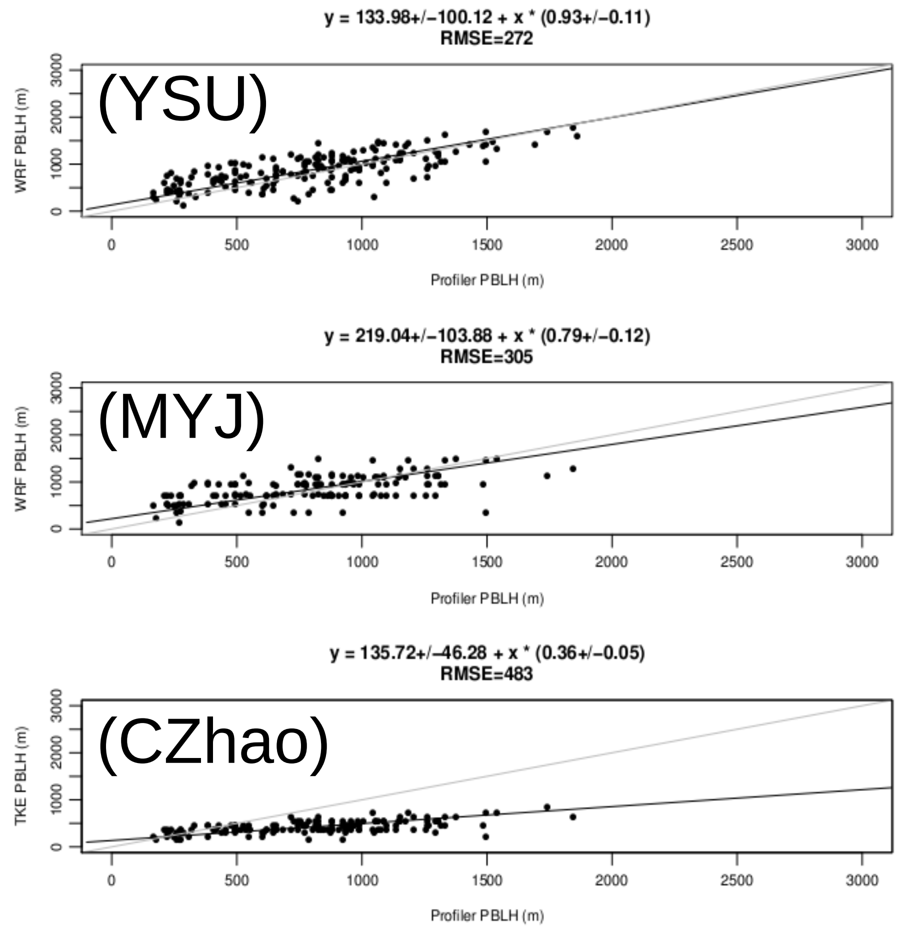

Figure 7: RMS scatter plot of predicted vs. observed PBL Heights in June 2008 at the Sacramento (-121.30°, 38.20°) site.

Conclusions

- Both YSU and MYJ perform significantly better than the CZhao scheme for predicting PBL Heights with the exception of summer
    - Chuanfeng's parametrization was based on WRFv2.2 and needs to be modified
- Both YSU and MYJ are overestimating the PBL Height during the summer
    - The NOAH Land Surface Model does not include irrigation and may be causing WRF to poorly estimate the PBL Heights in California's Central Valley during the summer
- YSU performs slightly better than MYJ in all seasons for predicting PBL Heights
- YSU performs slightly better than MYJ in all seasons for predicting Wind Fields
    - Both YSU and MYJ do a good job of predicting the Wind Fields

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Questions?

References

Hong, S.-Y., Y. Noh, and J. Dudhia, 2006: A new vertical diffusion package with explicit treatment of entrainment processes. Mon. Wea. Rev.

Hu, X.-M., J. Nielson-Gammon, F. Zhang, 2010: Evaluation of Three Boundary Layer Schemes in the WRF Model. J. App. Met. Clim.

Janjic, Z. I., 1990: The step-mountain coordinate: physical package. Mon. Wea. Rev.

Janjic, Z. I., 1994: The step-mountain Eta coordinate model: Further developments of the convection, viscous layer, and turbulence closure schemes. Mon. Wea. Rev.

Janjic, Z. I., 2001: Nonsingular Implementation of the Mellor-Yamada Level 2.5 Scheme in the NCEP Meso model. NOAA/NWS/NCEP Office Note #437

Lin, J. C., C. Gerbig, S. C. Wofsy, A. E. Andrews, B. C. Daube, C. A. Brainger, B. B. Stephens, P. S. Bakwin, and D. Y. Hollinger (2004), Measuring fluxes of trace gases at regional scales by Lagrangian observations: Application to the CO2 Budget and Rectification Airborne (COBRA) study, J. Geophys. Res.

References cont.

Mellor, G. L., and T. Yamada, 1982: Development of a turbulence closure model for geophysical fluid problems. Rev. Geophys.

Skamarock, W. C., J. B. Klemp, J. Dudhia, D. O. Gill, D. M. Barker, M. Duda, X.-Y. Huang, W. Wang, and J. G. Powers, 2008: A description of the advanced research WRF version 3. NCAR Tech. Note TN-475_STR

Zhao, C., A. E. Andrews, L. Bianco, J. Eluszkiewicz, A. Hirsch, C. MacDonald, T. Nehrkorn, and M. L. Fischer (2009), Atmospheric inverse estimates of methane emissions from Central California, J. Geophys. Res.

Zhao, C., A. E. Andrews, L. Bianco, J. Eluszkiewicz, T. Nehrkorn, W. Salas, J. Wilzak, and M. L. Fischer (In Progress), Seasonal Variation of CH4 Emissions from Central California.

Planetary Boundary Layer Schemes

- YSU PBL Scheme[1]
  - Dependent on the buoyancy profile
- MYJ PBL Scheme[2]
  - The upper limit is determined by the buoyancy profile and the wind shear
- CZhao PBL Scheme[3]
  - An ad hoc reparametrization of the MYJ scheme developed by a former member of Dr. Fischer's group at LBNL.
  - Based on the Turbulent Kinetic Energy (TKE) profile and parametrized on radar wind profiler PBL height data

For a more detailed description see the following:

[1] *Skamarock et al.* [2008], *Hong et al.* [2006], *Hu et al.* [2010]

[2] *Skamarock et al.* [2008], *Janic* [1990, 1994, 2001], *Mellor and Yamada* [1982], *Hu et al.* [2010]

[3] *Zhao et al.* [In Progress]

Future Work

- Run the STILT model to generate signals and footprints
  - Generate emission maps from the WRF output

- Conduct an ensemble of model runs with perturbed initial conditions
  - Determine the model sensitivity to various parameters

- Assimilate soil moisture data into the NOAH Land Surface Model to more accurately depict California's Central Valley irrigation
  - Possibly collaborate with the California Irrigation Management Information System (CIMIS) to determine when farmers begin irrigating their crops.