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SURREBUTTAL TESTIMONY OF

JAMES L. ARNDT, Ph.D.

ON BEHALF OF

GRAIN BELT EXPRESS CLEAN LINE LLC

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I. WITNESS INTRODUCTION AND PURPOSE OF TESTIMONY

Q. Please state your name, present position and business address.

A. My name James L. Arndt. I am a Senior Project Manager at Merjent, Inc. ("Merjent"). My business address is 800 Washington Avenue North, Suite 315, Minneapolis, MN 55401.

Q. Have you previously submitted prepared testimony in this proceeding?

A. Yes, I have previously submitted direct testimony on August 29, 2016.

Q. What is the subject matter of your surrebuttal testimony?

A. I am providing this testimony to respond to certain issues presented in the rebuttal testimony of Missouri Landowners Alliance ("MLA") witness Dale Pence, Show-Me Concerned Landowners witnesses Donald Shaw, John Turner, and Charles Kruse, Matthew and Christina Reichart's witness Jack Garvin, and witness Charles Henke on behalf of Charles and Robyn Henke regarding the agricultural impact of the construction and operation of the Grain Belt Express transmission project ("Project").

II. RESPONSE TO REBUTTAL TESTIMONY OF DALE PENCE

Q. What are the issues that Mr. Pence raises regarding potential impacts of the Grain Belt Express Project on aerial agriculture in Missouri?

A. Mr. Pence's issues fall into three categories:

1. Configuration of the high voltage transmission lines ("HVTL") can affect the efficiency of aerial spraying, increasing aerial application operational cost;
2. Decreasing spray application efficiency or preventing spray application completely in the affected portions of fields that contain HVTL wires results in

reduced yield and/or increased production costs, reducing grower net incomes; and

3. Increasing the risk to the aerial applicator.

Q. Are these issues considered by Grain Belt Express Project as it microsites individual fields and farming operations?

A. Yes. All three categories are considerations for the Project depending on the configuration and visibility of the lines and towers in relationship to the specific setting of the field, the crop and crop condition, weather conditions, and time of year. Most of the issues raised by Mr. Pence were addressed in my direct testimony at page 27 lines 21-23, page 28, line 1-23, and page 29, 1-22. None of this testimony was mentioned by Mr. Pence.

Q. Does Grain Belt Express have any established policies or protocols related to avoidance, minimization, and mitigation of impacts to agriculture operations and landowners?

A. Yes. Two documents are applicable, the Agricultural Impact Mitigation Policy ("AIM Policy") and the Missouri Agricultural Impact Mitigation Protocol ("MO Ag Protocol") that were attached to my direct testimony as Schedules JA-3 and JA-2, respectively. Both of these documents address concerns regarding aerial application. The AIM Policy emphasizes a commitment to consider potential impacts to aerial application when making routing adjustments and negotiating easements.

Q. What specific protocols has Grain Belt Express developed to deal with aerial agriculture?

A. Grain Belt Express will coordinate with landowners during routing to identify routes that may avoid and minimize impacts to agricultural operations, and include the following Construction Standards and Policies:

1. MO Ag Protocol Section 1. Landowner Tenant Coordination. Prior to construction, Grain Belt Express will coordinate with the Landowner and Tenant to identify the types of crops grown or livestock raised on the property, as well as identification and location of any agricultural infrastructure that may be located on the property and be potentially impacted by the Project.

2. MO Ag Protocol Section 4.A. Support Structure Type and Placement. The use of guy wires on Croplands will be avoided to the extent practicable. If guy wires are required, they will be marked with highly visible guards. A concerted effort will be made to place guy wires and their anchors out of Croplands, placing them instead along existing division lines (e.g., property lines, section, quarter, and half section lines, field edges, and/or fence lines) and on land not used for Croplands.

3. MO Ag Protocol Section 4.B. Support Structure Type and Placement. Grain Belt Express will discuss structure placement issues with Landowners. To the extent reasonably practicable, support structures will be spaced in such a manner as to minimize their interference with Cropland.

4. MO Ag Protocol Section 4.C. Support Structure Type and Placement. Grain Belt Express will provide the Global Positioning System ("GPS") coordinates of the Project support structure locations, including guy wire anchors, to all Landowners or Tenants.

Q. Mr. Pence indicated that chemicals could be ground-applied to areas where aerial applications are temporarily or permanently precluded, but that certain situations such as tall crops and wet conditions may prevent ground application. Do you agree?

A. My agreement is conditional. There may be situations where ground applications may be temporarily precluded by wetness or crop conditions, but they may be resumed when conditions improve. The ground-based application of agricultural chemicals by high ground clearance sprayers is commonly used by growers that are not actively using aerial spraying.

Q. If conditions dictate that inefficiencies and loss of aerial applications reduce crop yields or increase costs, does Grain Belt Express have protocols in place to compensate the landowner?

A. Yes. It is incorrect to assume that lowered yields would inevitably represent a loss of farm income. First, in most cases, landowners can develop an application plan using ground based application equipment, such as high clearance spray vehicles, to cover areas for which aerial application is temporarily or permanently precluded. Second, crop yield losses due to the configuration of structures and transmission lines can be recovered from Grain Belt Express. Referring to Deann Lanz's testimony starting on page 7. Line 19-23 and page 8 Line 1-4:

> "Grain Belt Express will pay landowners for any agricultural-related impact ("Agricultural Impact Payment") resulting from the construction, maintenance or operation of the Project, regardless of when they occur and without any cap on the amount of such damages. For example, if the

landowner experiences a loss in crop yields that is attributed to the project, then Grain Belt Express will pay the value of such loss in yield for so long as such losses occur. In other words, the intent is that the landowner be made whole for any damages or losses that occur as a result of the Project for so long as the Project is in operation."

Payment for such damages are addressed in the Damages Calculation Sheet described in the Transmission Line Easement Agreement attached as Schedule DKL-4 to Ms. Lanz's testimony.

Q. Can you summarize how Grain Belt Express has addressed issues relating to aerial agriculture, including the aerial application of herbicides, fungicides, pesticides and fertilizers that have been raised by Mr. Pence?

A. Yes. Mr. Pence's concerns involve location of wires and structures resulting in inefficient aerial spray application, potential increases in applicator costs that would be transferred to the grower, and inevitable loss of farm income due to increased costs and reduced yields. Mr. Pence's concerns are mitigated by the following practices:

- Grain Belt Express has committed to collaborating with landowners to site structure locations to avoid, minimize, and mitigate impacts to their agricultural practices. In many cases, we anticipate that minor adjustments to the structure locations can place structures and transmission lines in locations that avoid or minimize impacts to aerial spraying of agricultural chemicals.
- Grain Belt Express has committed to affected landowners that they will be made whole for any damages or losses that occur as a result of the Project for so long as the

Project is in operation. A process for the calculation of agricultural damages has been provided and is addressed in the Easement Agreement.

III. RESPONSE TO REBUTTAL TESTIMONY OF JACK GARVIN

Q. What are the concerns stated in Mr. Garvin's Testimony?

A. Mr. Garvin has agricultural and construction-related concerns that include the following:

1. Mr. Garvin is concerned that the proposed Project crossing of Brush Creek may result in damage to the riparian zone, causing soil erosion and sediment loading to the creek.
2. Portions of the property that may be affected by construction would be subject to soil compaction.
3. Though not formally registered as an Organic Farm under the National Organic Program, Mr. Garvin produces "organic" fruits and vegetables for his family, and is concerned that there is a potential for herbicides used for right-of-way maintenance contaminating garden plots, Brush Creek, ponds, and other waterways.
4. Mr. Garvin is concerned that there is a possibility of product spills such as fuel and/or oil contaminating land and water.

Q. What policies and commitments would Grain Belt Express follow to address Mr. Garvin's concerns?

A. As prescribed in the AIM Policy and Mo Ag Protocol, Grain Belt Express has a commitment to consult with landowners to avoid, minimize, and mitigate impacts to the extent practicable as discussed in my direct testimony at page 11, lines 11-17. Mr. Garvin himself points out in his rebuttal testimony at pages 6-7 that Grain Belt Express representatives met with him to discuss routing concerns, which resulted in relocating the

Proposed Route to minimize impacts to his property. This commitment to coordinate with landowners also extends to easement negotiations with Mr. Garvin. Grain Belt Express will work with Mr. Garvin on structure placement to minimize impacts to riparian areas, ponds, and other areas, and would restore areas affected by construction and operations.

Q. What protections are in place to ensure that construction-related activities do not result in erosion of and/or damage to the riparian zone adjacent to Brush Creek?

A. Right-of-way clearing must be performed to ensure proper clearances of conductors from vegetation including trees and brush, safe operation and safe access for construction, line inspection and maintenance operations. Initial clearing will include the removal of woody vegetation from the full width of the right-of-way. Any marketable timber that is cleared from the right-of-way and access roads would belong to Mr. Garvin, and would be stacked at the edge of the right-of-way or another agreed-upon location. The cleared and other areas within the construction right-of-way that would be affected by construction are disturbed areas from which erosion is to be minimized according to the conditions of the Project Storm Water Pollution and Prevention Plan ("SWPPP") that implements the National Pollution Discharge Elimination System ("NPDES").

Q. Please describe how the SWPPP and NPDES relate to the Grain Belt Express Project and its construction.

A. The SWPPP and the NPDES and their role in preventing erosion are covered in my direct testimony at page 24, lines 14-23, page 25, lines 1-22, and page 26, lines 1-10. The NPDES permit and associated SWPPP are authorized by the Missouri Department of Natural Resources under a Land Disturbance Permit ("LDP"). Grain Belt Express will develop the Project SWPPP for all potentially disturbed sites along the Project, including

cleared areas. The SWPPP will provide specific information on site characteristics (e.g. size, configuration, soils, slope degree and length, vegetative cover, etc.) and the suite of best management practices ("BMP") selected to control erosion, including installation specifics. It will also provide information on compliance inspection. The mandated implementation of the SWPPP within areas proposed for construction will ensure that erosion along the route has been avoided, minimized, and mitigated to the extent practicable. Finally, the SWPPP will require regular inspections, with additional inspections after significant rain events to ensure that the prescribed erosion control BMPs are operational and effective.

Q. What protections are in place to ensure that construction-related soil compaction is avoided, minimized, or mitigated?

A. Stumps and root systems would be left in place in forested areas, protecting the soil from excessive compaction. Avoidance, minimization, and mitigation of soil compaction, rutting, and soil mixing resulting from construction in open areas (e.g. fields and pastureland) and agricultural land are discussed in my direct testimony at page 20, lines 18-23; pages 21 and 22, inclusive; and page 23, lines 1-17. Restoration of soils in the event compaction and rutting takes place is also addressed in the MO Ag Protocol Section 8.

Compaction avoidance and minimization procedures include, but are not limited to defining travel corridors to reduce the area traversed by equipment, utilizing mats for construction equipment, requiring the use of low ground pressure tire or tracked equipment, and limiting construction during wet weather. When soil compaction is observed, the degree of compaction would be evaluated by comparing on versus off right-

of-way soil density using a cone penetrometer. Remediation efforts for compacted soils may include decompaction or deep tillage as necessary. Rutted land may require recontouring, liming, tillage fertilization, or the use of other soil amendments. Organic soil fertilizers and amendments are an option at the direction of the landowner and as a condition of the Mo Ag Protocol.

Q. What protections are in place to ensure that landowner-approved methods for vegetation control and fertilization are used during construction, restoration, and maintenance?

A. The use of synthetic herbicides, pesticides, and fertilizers is not mandatory for any part of the Grain Belt Express construction right-of-way or permanent easement. Restoration of disturbed land can be accomplished with landowner-approved seed mixes, fertilizers, and herbicide/pesticides at the direction of the landowner. Merjent restoration specialists have experience permitting linear projects through formally recognized Organic Farms that are certified under the National Organic Program without loss of certification by using construction, restoration, and maintenance procedures that are consistent with the growers Organic System Plan. Grain Belt Express' commitment to growers concerned about contamination with unapproved pesticides, herbicides, and fertilizers is provided in the AIM Policy in the "Specialty Crops and Organic Farms" section.

Also, as described in the Construction Plan (included as Schedule TFS-4 to Thomas F. Shiflett's Direct Testimony), Grain Belt Express will implement a Vegetation Management Program incorporating principles of Integrated Vegetation Management (IVM), which when implemented will promote and manage sustainable vegetation

communities within the ROW, and specifically the vegetation community adjacent to Brush Creek.

Q. The Project is anticipated to cross numerous waterways. What protections are in place to ensure that construction-related impacts do not result in fuel/oil contamination of waterways and wetlands?

A. Protections that address fuel and oil spills are provided in a Spill Prevention Control and Countermeasures Plan ("SPCC Plan"). Grain Belt Express will develop a SPCC plan that is consistent with Federal Regulations under 40 CFR 112 administered by the Region 7 of the EPA. Potential sources of construction related spills include machinery and equipment failure, fuel handling, transfer accidents, and storage tank leaks. Any spill is a concern, but rapid clean-up is essential if there is the potential for contamination of a waterway or waterbody. SPCC plans have specific contents that are modified to suit project conditions. Plan components may include but are not limited to:

1. Designating a trained Spill Coordinator familiar with implementing and coordinating spill prevention, containment, and clean-up protocols, and reporting procedures.
2. Training employees who handle fuels and other regulated substances to prevent spills and to quickly and effectively contain and clean up spills that may occur.
3. Training Environmental Inspectors to ensure that all hazardous containment procedures are being followed, including storage, proper transfer and refueling protocols, and that no refueling, fuel storage, or equipment parking is permitted within a specific distance of a waterbody.
4. Making sure that all necessary tools, material, and manpower are on site and available to stop the spill, and initiate immediate clean-up response.

The most important consideration for preventing spill contamination of waterbodies and wetlands is to ensure that fuel, lubricants, and vehicles are not stored near the sensitive waterbody, and that all equipment is properly maintained and free of lubricant leaks.

IV. RESPONSE TO REBUTTAL TESTIMONY OF DONALD SHAW

Q. What is the subject of Mr. Shaw's Testimony?

A. Mr. Shaw is a retired executive formerly with Central Electric Power Cooperative and has a background in electrical engineering. Mr. Shaw provided rebuttal testimony on the need for the Grain Belt Express Project.

Q. Did Mr. Shaw provide testimony regarding climate change relative to the need for the Project?

A. Yes.

Q. What background did Mr. Shaw provide to show credibility to address climate change issues?

A. Mr. Shaw has attended several seminars that included climate change presentations and discussions. He indicated that he has had one-on-one discussions with climate experts from Arizona State University and the University of Missouri, and that he had done independent research and made climate change presentations.

Q. What background do you have to address Mr. Shaw's rebuttal testimony on climate change?

A. Mr. Shaw provides alleged scientific data and technical references on climate change to support his conclusion that there is no justification for the Project based on climate data. Notably, however, Grain Bet Express does not propose the Project is justified based on climate change concerns. My background includes the experience and education to

address the data, references and conclusions made by Mr. Shaw regarding climate change. I have a Ph.D. in soil science, with coursework in climatology and microclimatology. I have over 40 publications, including 15 peer-reviewed publications in scientific journals and a book chapter. I have been a peer reviewer for the highly regarded scientific journals Wetlands, Soil Survey Horizons, Soil Science Society of American Journal, the Journal of Hydrology, and the National Science Foundation. Like Mr. Shaw, I have an interest in climate change and have attended conferences where specialists have discussed the impacts of climate change on the economy, society, and natural ecosystems.

Q. Can you provide an example?

A. Yes. As a member of the Minnesota Plant Society, I attended the 2016 Minnesota Native Plant Society meetings and attended a presentation by Dr. Lee Froelich, Research Associate and Director, Center for Forest Ecology, University of Minnesota dealing with impacts of climate change on the past, current, and projected ecological features of Minnesota's Boundary Waters Wilderness.

Q. Do you have any comments on Mr. Shaw's background relative to providing expert testimony on climate change?

A. Mr. Shaw has not provided any technical background to substantively comment on climate change. He has not indicated how many seminars he attended that included climate change presentations or discussion, or who sponsored the seminars. He has not provided the titles of the presentations, or the names of the speakers. He indicated that he has spoken to experts in climate at Arizona State University and the University of Missouri, but has not indicated who the experts were or their departmental affiliation, or

provided their statements. He has indicated that he has made climate change presentations, but has not provided the presentations.

Q. What is included in Schedules DWS-1 and DWS-2?

A. Schedules DWS-1 and DWS-2 are taken from the web site of the Global Warming Petition Project (Oregon Petition Project) (http://www.petitionproject.org/index.php). The Oregon Petition Project was started in 1997 and is sponsored by the Oregon Institute of Science and Medicine. The project solicits degreed individuals to sign a petition stating the following:

> "We urge the United States government to reject the global warming agreement that was written in Kyoto, Japan in December, 1997, and any other similar proposals. The proposed limits on greenhouse gases would harm the environment, hinder the advance of science and technology, and damage the health and welfare of mankind.
>
> There is no convincing scientific evidence that human release of carbon dioxide, methane, or other greenhouse gases is causing or will, in the foreseeable future, cause catastrophic heating of the Earth's atmosphere and disruption of the Earth's climate. Moreover, there is substantial scientific evidence that increases in atmospheric carbon dioxide produce many beneficial effects upon the natural plant and animal environments of the Earth."

Schedule DWS-1 is a pdf printout of a portion of the website, and Schedule DWS-2 is an alleged peer reviewed review article written by Arthur B Robinson (President of the Oregon Institute of Science and Medicine), his son Noah E. Robinson,

and Willie Soon. The article is written in the format of the Proceedings of the National Academy of Sciences, but was published in the Journal of American Physicians and Surgeons (2007, issue 12, pages 70-90).

Q. Can you comment on Schedules DWS-1 AND DWS-2?

A. The Oregon Petition has been criticized by reputable climate scientists and review sources. Claiming over 31,478 degreed signatories, an insignificant number (<0.5%) are potentially categorized as climate scientists. The list has been criticized for its lack of verification, with pranksters successfully submitting the names of Charles Darwin, a member of the Spice Girls and characters from Star Wars, and getting them briefly included on the list.

Regarding Schedule DWS-2, the National Academy of Science ("NAS") printed a Statement in 1998 signed by the National Academy of Sciences Council disavowing the Global Change Petition (Schedule DWS-1), and the journal article provided as Schedule DWS-2.[1] The NAS statement is provided as **Schedule JLA-6** attached to this surrebuttal testimony. Appropriate quotes are provided below.

> "The Council of the NAS is concerned about the confusion caused by a petition being circulated via a letter from a former president of this Academy. This petition criticizes the science underlying the Kyoto treaty on carbon dioxide emissions (the Kyoto Protocol to the Framework Convention on Climate Change), and it asks scientists to recommend rejection of this treaty by the U.S. Senate. The petition was mailed with an op-ed article from The Wall Street Journal and a manuscript in a format

[1] http://www8.nationalacademies.org/onpinews/newsitem.aspx?RecordID=s04201998

that is nearly identical to that of scientific articles published in the Proceedings of the National Academy of Sciences. The NAS Council would like to make it clear that this petition has nothing to do with the National Academy of Sciences and that the manuscript was not published in the Proceedings of the National Academy of Sciences or in any other peer-reviewed journal."

Q. Please describe Schedule DWS-3?

A. Schedule DWS-3 provides brief summary data from the research of Dr. Roy Spencer, a Climate scientist with the University of Alabama in Huntsville. Dr. Spencer has published extensively on climate modeling, and suggests that global warming is mostly due to natural inherent variability, and the climate insensitive to humanity's greenhouse gas emissions. His research is commonly cited by people and organization that disavow climate change.

Q. Can you comment on Schedule DWS-3?

A. DWS-3 provides excerpts from Dr. Spencer's research that are controversial and that are not generally supported by the scientific community. Ninety-seven percent of climate scientists agree that climate-warming trends over the past century are very likely due to human activities, and most of the leading scientific organizations worldwide have issued public statements endorsing this position.[2] In contrast to DWS-3, actual data provided in the climate record shows the magnitude of climate change based on current data[3], and

[2] http://climate.nasa.gov/evidence/

[3] http://climate.nasa.gov/scientific-consensus/

suggests that the rise in temperature is related to man-induced increases in CO2.[4] The National Academy of Sciences and the United Kingdom Royal Society released a statement in 2014 announcing a joint publication (Climate Change Evidence and Causes) that explains the clear evidence that humans are causing the climate to change, and that addresses a variety of other key questions commonly asked about climate change science.[5] The press release is provided as **Schedule JLA-7** attached to this rebuttal testimony.

Q. Do you have an opinion regarding climate change?

A. As a natural resources scientist, based on the preponderance of the scientific evidence, I agree with the vast majority of climate scientists and scientific research indicating that climate change is occurring and is causing significant changes to the earth climate. It is my opinion that, based again on the preponderance of the evidence, increased levels of greenhouse gases including CO2 are the likely cause for the demonstrated increases in the global temperatures and that climate change as a result of man's activities resulting in a demonstrated increase in greenhouse gases, especially CO2 is real, and of concern.

V. RESPONSE TO REBUTTAL TESTIMONY OF JOHN TURNER

Q. Mr. Turner indicates you made a statement in your direct testimony that no center pivot structures were present along the route. He further states that your statement is wrong, and that he is aware of at least three irrigation systems crossed in Monroe County. What is your response?

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[4] http://climate.nasa.gov/climate_resources/24/

[5] http://www8.nationalacademies.org/onpinews/newsitem.aspx?RecordID=18730

A. My conclusions regarding the absence of irrigation systems along the route were based on detailed route studies conducted in 2014 and 2016. "The Missouri Route Selection Study (March 2014) conducted by the Louis Berger Group, Inc. on behalf of Grain Belt Express indicated that there were no center pivot irrigation systems crossed by the Project. The 2016 Route Selection Study Addendum (June 2016, attached to the Direct Testimony of Company witness James Puckett as Schedule JPG-2) also confirmed that there were no center pivot irrigation systems crossed by the Proposed Route in Missouri."

Upon further review and investigation into Mr. Turner's claim, the statement in my direct testimony that no center pivots are crossed by the Project is in need of clarification. Subsequent review of the 2014 Routing Study and discussion with members of the routing team confirmed that the Project crosses fields with center pivots irrigation systems. However, the route was purposefully sited across the outside edge of the pivot irrigation areas, resulting in very short span lengths across the irrigator swept area. Grain Belt intends to avoid placing structures in the footprint of the irrigator boom radius, and the presence of the immediately adjacent County Road 104W and County Road104E provides the option to access any part of the easement directly from the road, avoiding any impacts to the operation of the irrigation system during or after construction. To clarify my direct testimony on this subject; the Project does cross fields with center pivot irrigation but structure placement avoids directly impacting the operation of these systems.

Q. Mr. Turner indicates that several statements made regarding irrigation suitability are not entirely correct. Specifically:

1. "The statement aquifers and soils in most of the Missouri counties crossed by the proposed line are not suitable for large-scale center pivot irrigation. This is not true." (Turner Rebuttal Page 3, Lines 9-11).
2. "Based on the 1977 General Soil Map of Missouri by the Soil Conservation Service about 57 percent of the proposed route crosses soils and topography suitable for irrigation. (Turner Surrebuttal, Page 4, Lines 14-19)"
3. "It is a misconception that land need be relatively flat for irrigation. For… but driving through Central Nebraska will show that sprinkler irrigation, including center pivots, is quite adaptable to land that is quite rolling." (Turner Surrebuttal, Page 4, Lines 14-19)

What are your responses?

A. Mr. Turner has a background in irrigated agriculture, and many of the statements he makes are educated generalizations that would need further refinement to implement for any anticipated irrigation project. My comments regarding irrigation suitability were to highlight why irrigation systems are not very common in the project area. For example, the general soil map of Missouri referenced by Mr. Turner may not be detailed enough to determine whether or not a particular parcel is irrigable. The detailed county soil survey ("SSURGO") as provided in be Web Soil Survey[6] would be detailed enough to indicate if the soils in the parcel are uniform and have the appropriate soil physical and chemical characteristics to plan a center pivot irrigation system. The NRCS provides soil criteria for irrigation.[7] Many soils and landscape settings included by Mr. Turner in his estimate of 57% irrigable soils in Missouri have significant restrictions, including steep topography and unfavorable surface textures. This is not to say that irrigation of soils with limiting features cannot be done. The data imply that extensive irrigation of soils with multiple unsuited features needs to be carefully considered, and may present

[6] https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm

[7] NRCS Staff. 1997. Irrigation Guide. National Engineering Handbook Part 652. 210-vi-NEH, September 1997).

limitations that affect soil productivity that limit choices and may preclude irrigated agriculture. I believe that a determination of 57% irrigable soils is a simplification that suggests there is more irrigable land than could be realistically irrigated, otherwise more irrigation would be evident throughout the state outside of extensive river terraces and the extremely favorable irrigation district in the bootheel of Missouri that exploits the Embayment aquifer mentioned by Mr. Turner (rebuttal Testimony of John Turner, page 13, lines 13-14).

Protections afforded irrigated agriculture are covered in my direct testimony at page 15, lines 22-23 and page 16, lines 1-13, Section 7, parts A, B and C in the Mo Ag Protocol, and in the section on "Irrigation", page 2 of the AIM Policy. Potential impacts to irrigated agriculture are also provided in the surrebuttal testimony provided in response to irrigation concerns raised by Charles Kruse.

Q. Mr. Turner indicated that much of the state could be irrigated with surface water from existing or planned surface reservoirs, and that the Grain Belt Project would preclude development of planned irrigation systems, as well as other conservation practices planned for the future. What is your response?

A. As I previously discussed, Grain Belt has implemented an AIM Policy and Mo Ag Protocol that focus on coordination with landowners as an integral tool to help address potential impacts to agricultural operations. These documents support the commitment Grain Belt Express has made to collaborate with landowners on routing, structure placement, and landowner-specific construction prescriptions including the location of current and planned improvements or facilities.

Q. Mr. Turner indicated that the impacts of farming around obstruction such as support structures is more disruptive than just providing a footprint acreage and calculating how much land is lost. What is your response?

A. Mr. Turner is correct. Farm equipment is not made to turn on a dime, avoidance of structures can result in a "swerve" that may render a small area on either side of the structure difficult to cover by seeding, tillage, and cultivation. This affected area may be larger for lattice towers and smaller for monopoles. However, in any event this area is not expected to result in a significant loss of acreage for any given landowner. Mr. Turner is also correct that Grain Belt Express has committed to site structures to minimize their interference with cropland.

Additional information on the effect of structures on GPS, equipment usage efficiency and precision agriculture are provided in my response to Mr. Kruse below.

VI. RESPONSE TO REBUTTAL TESTIMONY OF CHARLES HENKE

Q. In your opinion has Grain Belt Express adequately addressed the potential for soil impacts that Mr. Henke describes.

A. Yes. As described in my direct testimony, the Project recognizes the potential for impacts to agriculture, and has developed the AIM Policy and the Mo Ag Protocol to address the issues. The measures and commitments included in these documents specifically focus on preserving the fertility of agricultural soils, and identify methods the project has and will continue to implement to avoid, minimize, and mitigate these potential impacts. My surrebuttal responses to Mr. Garvin and Mr. Kruse describe in further detail the specific practices that can be employed to mitigate project related soil compaction and erosion.

Q. Mr. Henke describes concerns with impacts to his cattle operation during construction. Based on your experience with linear infrastructure development, is the project likely to have any significant impacts to livestock production?

A. No. As described in the Mo Ag Protocol, the Project has committed to coordinating directly with each landowner to discuss the specific agricultural operations that take place on the parcel, including the types of livestock that occur on the property and any potential sensitivities associated with the livestock operations. This coordination effort provides the landowner an opportunity to better understand the specific location and timing of construction activities in relation to their livestock operation. Based on my experience, construction activities associated with transmission lines are typically concentrated at each structure location, and activities on any given parcel only occur for a short duration in comparison to the construction of the entire project. Based on the short duration of construction activities and the preconstruction coordination proposed for each landowner, disturbance to the livestock, if any, would be limited and short term. It's unlikely that any significant impacts to Mr. Henke's cattle operation would occur; however, if project-related impacts or damages to the cattle operation or facilities were realized, the Project would be responsible to compensate the landowner for damages as described in the Mo Ag Protocol and as contemplated in the easement agreement.

VII. RESPONSE TO REBUTTAL TESTIMONY OF CHARLES KRUSE

Q. What is the subject of Mr. Kruse's Testimony?

A. The subject of Mr. Kruse's testimony is the potential negative impacts to farming and land as a result of the construction of the Project. He specifically addresses potential impacts to soil and land including soil compaction, erosion, irrigation equipment

interference, aerial applications, GPS interference, equipment maneuverability, precision farming, and concerns regarding storm recovery.

Q. In addition to reviewing the Projects AIM Policy and MO Ag Protocols, does Mr. Kruse refer to any other documents?

A. Mr. Kruse makes specific reference to Schedule CEK-1, which is a report "Environmental Impacts of Transmission Lines" prepared by the Wisconsin Public Service Commission (Wisconsin PSC Report). He makes reference to several of the impacts, and indicates that all of the impacts are valid.

Q. What is your opinion regarding Mr. Kruse's use of the Wisconsin PSC Report.

A. Mr. Kruse misuses the information in the document, and does not place the document in proper context. The document is not a study of impacts, but a listing of known potential impacts resulting from the construction and operation of transmission lines that may need to be addressed in construction plans in order to avoid, minimize, and mitigate impacts. Mr. Kruse implies in his testimony that the document suggests that impacts are severe, and cannot be mitigated. However, the report itself is clear that numerous mitigation strategies exist that avoid, minimize, and mitigate impacts. The document states in the introduction: "[T]he first part provides a general summary of the types of analysis and the means to measure and identify environmental impacts. *The second part is an alphabetic list of potential impacts and the available methods to minimize or mitigate the impacts* [emphasis added]." (Schedule CEK-1, p.1). Mr. Kruse does not acknowledge any of the mitigation strategies provided in Table 1. Examples of Mitigation Strategies, nor does he acknowledge significant mitigation strategies associated with most of the agricultural impacts that are provided with a discussion of the impact.

Q. Can you provide examples of mitigation strategies cited in the Wisconsin PSC Report?

A. Yes. Mr. Kruse provides a direct quote from the Wisconsin PSC report indicating the potential severity of soil compaction (page 6 lines 18-19 and page 7 lines 1-17), providing a photographic example of potential rutting and compaction. However, Mr. Kruse's testimony ignores the key section of the Wisconsin PSC Report that provides mitigation strategies that address the impact discussed in Mr. Kruse's testimony. These strategies include:

1. Avoidance strategies, including identifying sensitive soils and developing route and access alternatives that avoid heavy traffic on these areas, utilizing existing roads to the extent possible, constructing during winter, avoiding trafficking sensitive soils during wet conditions.
2. Minimization strategies including restricting construction traffic to those vehicles with low ground pressure or tracked equipment, and matting, and appropriate topsoil stripping, segregation, and replacement.
3. Mitigation strategies, including on versus off right of way compaction testing with cone penetrometers, and chisel plowing or deep ripping as appropriate.

Furthermore, as described in my direct testimony, several of these options are specifically identified or implied in Grain Belt's AIMP and Mo Ag Protocol.

Q. Mr. Kruse indicated that there would be very significant soil compaction and rutting problems associated with the Project. As discussed in more detail in the surrebttual testimony of Company witness Deann Lanz, Grain Belt Express has committed to incorporate the terms and conditions of the AIM Policy and MO Ag

Protocol into its easements with landowners. What protections are provided in the AIM Policy and MO Ag Protocol that deal with compaction and rutting?

A. Mitigative actions for compaction and rutting are provided in Section 8, p. 8 of the MO Ag Protocol. Mitigative actions for compaction and rutting, and soil mixing are also addressed in detail in my direct testimony at page 20, lines 18-23, page 21 and 22 inclusive, and page 23, lines 1-17.

Q. Mr. Kruse indicated in his rebuttal testimony that he had reviewed the MO Ag Protocol and that the mitigative actions proposed "[are] nice sounding words. These words are similar to Clean Line claiming that they will attempt to stop the rain from falling and restore a house burned by fire." (Charles Kruse rebuttal testimony, page 8 lines 8-10.) What is your response?

A. The mitigative actions in the Grain Belt Express MO Ag Protocol and AIM Policy are very similar to and consistent with the sections on mitigation for soil compaction and rutting described in the Wisconsin PSC report that Mr. Kruse quotes extensively. In fact, Grain Belt Express considered the mitigation procedures provided in the Wisconsin PSC Report along with recommendations from several agricultural impact statements prepared for transmission lines by the Wisconsin DATCP[8], as well as the mitigative actions recommended by the Illinois Department of Agriculture.

Mr. Kruse's incorrect statements regarding the commitments that Grain Belt Express has made fail to recognize that compaction is a hazard associated with any equipment trafficking of farmland, and the mitigative actions provided in the MO Ag Protocol and AIM Policy essentially mirror those that growers use to mitigate compaction

[8] Wisconsin Department of Agriculture, Trade, and Consumer Protection.

associated with farm equipment. The simple truth is that the mitigative actions such as avoiding construction traffic on saturated soils, matting, and deep ripping, and topsoil stripping work to avoid and minimize compaction and rutting, as acknowledged in the Wisconsin PSC report.

Q. Mr. Kruse provides three methods to control erosion: terracing, tiling, and grassed waterways, and indicates that erosion control measures provided in the AIMP Policy and MO Ag Protocol would not adequately protect the land during construction or in the future. What is your response?

A. Mr. Kruse is emphasizing conservation practices but is silent on construction erosion control measures. They are two different issues. Both have been addressed by Grain Belt Express in testimony, the MO Ag Protocol, and the AIM Policy. The cleared and other areas within the construction ROW are disturbed areas from which erosion is to be minimized according to the conditions of the Project Storm Water Pollution and Prevention Plan ("SWPPP") that implements the National Pollution Discharge Elimination System ("NPDES"). The SWPPP and the NPDES and their role in preventing erosion are covered in my direct testimony at Page 24, lines 14-23, Page 25, lines 1-22, and Page 26, lines 1-10. The NPDES permit and associated SWPPP are authorized for a given project by the Missouri Department of Natural Resources under a Land Disturbance Permit ("LDP"). Grain Belt Express will develop the Project SWPPP for all potentially disturbed sites along the Project, including cleared areas. The SWPPP will provide specific information on site characteristics (e.g. size, configuration, soils, slope degree and length, vegetative cover, etc.) and the suite of BMPs selected to control erosion, including installation specifics. It will also provide information on compliance

inspection. The mandated implementation of the SWPPP within areas proposed for construction will ensure that erosion along the route has been avoided, minimized, and mitigated to the extent practicable. In addition, the SWPPP will require regular inspections, with additional inspections after significant rain events to ensure that the prescribed erosion and sediment control BMPs are operational and effective.

The erosion control practices that Mr. Kruse provides in his surrebuttal testimony include terracing, grassed waterways, and drain tiling. Protections afforded terracing and grassed waterways are covered in my direct testimony at page 19, lines 1-22 and page 20, lines 1-17, in the MO Ag Protocol, Section 10, parts A, B and C, and in the section on "Drainage and other Soil Conservation Practices", page 2 of the AIM Policy.

Q. Mr. Kruse indicated that erosion control measures provided in the AIM Policy and MO Ag Protocol would not adequately protect the land during construction or in the future. What is your response?

A. Mr. Kruse's assessment is unsubstantiated and invalid. Industry standard Best Management Practices are mandated in the Project SWPPP to control erosion on the portions of the ROW that are disturbed during construction. Environmental Inspectors will be routinely evaluating erosion controls and erosion control devices and after all significant rains to ensure that they are operating and in good repair. The SWPPP is a required authorization. Violation of permit conditions can result in fines or work stoppage

Mr. Kruse's speculation as to permanent, construction-related damage to conservation practices such as terraces, grassed waterways, and drain tile installations are unfounded. Mr. Kruse is suggesting that the practices that have been installed would not

be repaired if damaged, as though he expects that Grain Belt Express simply would not do it. Grain Belt Express has committed to control erosion during construction as required by state and federal regulations, has demonstrated a commitment to work with landowners to identify conservation practices, and will repair the practices to preconstruction condition consistent with the AIM Policy, the MO Ag Protocol, and any permit or conditions that would be attached to authorizations such as the CCN should the Project be granted a certificate.

Q. Mr. Kruse takes issue with your statement that irrigation is not expected to be a common agricultural land use along the preferred route in Missouri. He calls the statement "unbelievable", and provides Schedule CEK-2 providing data from the Missouri Agricultural Statistics Service to show that 120 farms in excess of 10,636 acres of land irrigated are in the 8 counties crossed. He calls this a significant portion of the eight counties affected. What is your response?

A. Mr. Kruse is misinterpreting the data. In fact I used the same agricultural statistics data, combined with previous route assessment of irrigated agricultural operations and a basic knowledge of irrigation requirements, to conclude that irrigation is not a significant land use along the Project route. I have expanded the 2012 agricultural statistics data to clarify my statement, provided as **Schedule JLA-8.** The data show that as of 2012, irrigated farms were only 1.6% of the total farms in the counties crossed (120 irrigated farms of 7,354 farms in the counties). The acreage of irrigated farms is even smaller, at 0.8% (18,084 acres of irrigated farms of 2,311,636 farmed acres). These data do not support Mr.Kruse's contention that irrigated farms are a significant portion of the eight counties crossed.

Supporting this conclusion is the observation that no irrigated farms were crossed in the Project's original route evaluation, as stated in my direct testimony at Page 15, Lines 4-11. Subsequently, three center pivot irrigated fields have been found to be crossed in Monroe County. In the irrigated area, the route parallels a road to the very north of the center pivots. While construction may temporarily affect irrigation, it will not, as Mr. Kruse indicates, "cause significant problems, which will be very costly, and in some cases almost impossible to resolve" (Charles Kruse Rebuttal Testimony, page 12, Lines 12-16).

Q. Mr. Kruse has indicated that "It is at best impractical and at worst impossible to reconfigure a center pivot system around a structure such as the one Clean Line is proposing." (Rebuttal Testimony of Charles Kruse, Page 12, Lines 114-16). What is your response?

A. Mr. Kruse assumes that a structure would be located within the area irrigated by the Center Pivot. However, Grain Belt Express has evaluated the route and indicated that structures would not be placed within the irrigation boom-swept area in Missouri. Concerns that an irrigation system in Missouri would need extensive reconfiguration are unfounded. More detailed information on protections afforded irrigated agriculture are covered in my direct testimony at page 15, lines 22-23 and page 16, lines 1-13, Section 7, parts A, B and C in the MO Ag Protocol (Schedule JLA-2), and in the section on "Irrigation", page 2 of the AIM Policy (Schedule JLA-3).

Q. Mr. Kruse has indicated that the Grain Belt Express would impact aerial application of agricultural chemicals, increasing farm operator costs and decreasing profits. What is your response?

A. Applications of agricultural chemicals are covered in my direct testimony at page 27, lines 21-23, page 28 lines 1-23, page 28, lines 1-23, and page 29, lines 1-11, the section on "Aerial Application", page 3 of the AIM Policy, and are addressed in detail in this testimony provided in response to Dale Pence. Mr. Kruse's comments regarding the potential impacts of the Grain Belt Express project are fully discussed in the surrebuttal testimony to Dale Pence's rebuttal testimony. Mr. Kruse is silent on any of the impact mitigation measures that the Project has developed to address potential impacts.

In summary, Mr. Kruse's concerns are mitigated by the following practices.

- Grain Belt Express has a strong commitment to collaborate with landowners to develop structure locations and transmission lines that avoid, minimize, and mitigate impacts to their agricultural practices. Impacts would include effects to aerial spraying applications. In many cases, we anticipate that minor adjustment to the structure locations can place structures and transmission lines in locations that avoid or minimize impacts to aerial spraying of agricultural chemicals.
- There may be temporary and long term effects on farm income resulting from the need to accommodate the Grain Belt Express structures and transmission lines when aerially applying agricultural chemicals. Grain Belt Express has committed to affected landowners that they will be made whole for any damages or losses that occur as a result of the Project for so long as the Project is in operation. A process for the calculation of agricultural damages has been provided and is addressed in the Easement Agreement.

Q. Mr. Kruse has indicated that there may be possible Global Position Systems ("GPS") interference associated with the conductors and structures for the Project. What is your response?

A. Potential Impacts to GPS systems that are commonly used for aerial applications and precision farming are addressed in my direct testimony at page 26, lines 11-20 and page 27, lines 1-5. As Mr. Kruse correctly notes, interference for GPS is unlikely. "[T]o be fair the [2002] study[9] did indicate that major interference was unlikely, but importantly that further study was warranted" (rebuttal testimony of Charles Kruse, P. 15, lines 24-25.

Mr. Kruse does not acknowledge more recent studies have been done, and GPS civil survey and precision agriculture is routinely performed in close proximity to transmission lines. A more recent, highly detailed investigation of the effects of proximity to a 500,000 volt DC transmission line was performed specifically to evaluate the impacts of transmission lines to agricultural use of GPS. That document is attached to my surrebuttal as **Schedule JLA-9**. No transmission line effect on Global Navigation Satellite System ("GNSS") measurements was found to influence the quality of the navigation solutions provided by GPS. In addition, the test results showed normal operation of a highly accurate, commercially available survey grade RTK system and its radio link (450 MHz) when in close proximity to the transmission lines. Confirming the lack of significant effect of transmission lines on GPS operation or use is the fact that

[9] As cited in Massie, L., A. Halpin, and M. Wyatt. Agricultural Impact Statement, American Transmission Company, LLC Rockdale – West Middleton Transmission Line, Dane County. Wisconsin Department of Agriculture, Trade, and Consumer Protection DATCP #3487. P. 56

survey grade GPS equipment is used to survey features in direct proximity to or under transmission line wires.

Q. Based on the data you have reviewed on GPS impacts, do you believe that the Grain Belt Express Project will have any effect on GPS use for survey, precision agriculture, or aerial applications of agricultural chemicals?

A. I do not think there will be any noticeable effect.

Q. Mr. Kruse also states that it would be a "nightmare" to utilize modern, large farm equipment around structures, and asserts that the use of precision farming would be much harder in the presence of such structures. What is your response?

A. The literature, and common civil survey and precision agriculture practice indicate that the impacts of HVTL conductors on GPS operation are negligible. Moreover, the structures used to support the wires are widely spaced, and would be located so as to minimize the numbers of structures within agricultural fields. Issues with maneuvering large farm equipment around structures will be limited to only a few locations for any single landowner. Agricultural practices under the conductors would continue unimpeded. The use of GPS systems to steer farm equipment will greatly reduce the inconvenience associated with navigating around support structures. The current precision farming technologies allow for more efficient farming practices around obstacles that may occur in a field by implementing auto-row shut-offs on planter and section control on sprayers, fertilizer spreaders, and toolbars, all of which help to minimize any farming overlap issues, thus decreasing or avoiding any inefficiencies or impacts to crop yields.

Q. Mr. Kruse expresses concern that occasional storms could topple structures and lay conductors across farm fields, and that the resulting storm recovery efforts would do significant damage to the land. What is your response?

A. Mr. Kruse's storm recovery concerns are addressed in Grain Belt Express' contingency plans as discussed in the direct testimony of Tom Shiflett.

Q. Does this conclude your Direct Testimony?

A. Yes.

BEFORE THE PUBLIC SERVICE COMMISSION
OF THE STATE OF MISSOURI

In the Matter of the Application of Grain Belt Express Clean Line LLC for a Certificate of Convenience and Necessity Authorizing it to Construct, Own, Control, Manage, Operate and Maintain a High Voltage, Direct Current Transmission Line and an Associated Converter Station Providing an Interconnection on the Maywood-Montgomery 345 kV Transmission Line	)	Case No. EA-2016-0358

AFFIDAVIT OF JAMES L. ARNDT

STATE OF Minnesota)
) **ss**
COUNTY OF Hennepin)

James L. Arndt, being first duly sworn on his oath, states:

1. My name is James L. Arndt. I am a Senior Project Manager at Merjent, Inc.

2. Attached hereto and made a part hereof for all purposes is my Surrebuttal Testimony on behalf of Grain Belt Express Clean Line LLC consisting of 44 pages, having been prepared in written form for introduction into evidence in the above-captioned docket.

3. I have knowledge of the matters set forth therein. I hereby swear and affirm that my answers contained in the attached testimony to the questions therein propounded, including any attachments thereto, are true and accurate to the best of my knowledge, information and belief.

James L. Arndt

Subscribed and sworn before me this 21 day of February 2017.

Melissa Adele Dellwo
Notary Public
State of Minnesota
My Comm. Exp. 1-31-19

Notary Public

My commission expires: January 31, 2019

STATEMENT BY THE COUNCIL
OF THE NATIONAL ACADEMY OF SCIENCES
REGARDING GLOBAL CHANGE PETITION

April 20, 1998

The Council of the National Academy of Sciences (NAS) is concerned about the confusion caused by a petition being circulated via a letter from a former president of this Academy. This petition criticizes the science underlying the Kyoto treaty on carbon dioxide emissions (the Kyoto Protocol to the Framework Convention on Climate Change), and it asks scientists to recommend rejection of this treaty by the U.S. Senate. The petition was mailed with an op-ed article from The Wall Street Journal and a manuscript in a format that is nearly identical to that of scientific articles published in the *Proceedings of the National Academy of Sciences*. The NAS Council would like to make it clear that this petition has nothing to do with the National Academy of Sciences and that the manuscript was not published in the *Proceedings of the National Academy of Sciences* or in any other peer-reviewed journal.

The petition does not reflect the conclusions of expert reports of the Academy.

In particular, the Committee on Science, Engineering, and Public Policy of the National Academy of Sciences, the National Academy of Engineering (NAE), and the Institute of Medicine (IOM) conducted a major consensus study on this issue, entitled *Policy Implications of Greenhouse Warming* (1991,1992). This analysis concluded that " ...even given the considerable uncertainties in our knowledge of the relevant phenomena, greenhouse warming poses a potential threat sufficient to merit prompt responses. ... Investment in mitigation measures acts as insurance protection against the great uncertainties and the possibility of dramatic surprises." In addition, the Committee on Global Change Research of the National Research Council, the operating arm of the NAS and the NAE, will issue a major report later this spring on the research issues that can help to reduce the scientific uncertainties associated with global change phenomena, including climate change.

and J. Virgil Waggoner Regents Chair in Chemistry
Department of Chemistry
University of Texas
Austin

Ralph E. Gomory(2)
President
Alfred P. Sloan Foundation
New York City

David M. Kipnis
Distinguished University Professor
Department of Internal Medicine
Washington University School of Medicine
St. Louis

Daniel E. Koshland Jr.
Professor in the Graduate School
Department of Molecular and Cell Biology
University of California
Berkeley

Mary-Lou Pardue
Boris Magasanik Professor
Department of Biology
Massachusetts Institute of Technology
Cambridge

Luis Sequeira
J.C. Walker Professor Emeritus
Department of Plant Pathology
University of Wisconsin
Madison

I.M. Singer
Institute Professor
Department of Mathematics
Massachusetts Institute of Technology
Cambridge

Robert H. Wurtz
Chief
Laboratory of Sensorimotor Research
National Eye Institute
National Institutes of Health
Bethesda, Md.

Richard N. Zare
Marguerite Blake Wilbur Professor
Department of Chemistry
Stanford University
Stanford, Calif.

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(1) abstained
(2) unable to participate

NEWS FROM THE NATIONAL ACADEMIES

NATIONAL ACADEMY OF SCIENCES
NATIONAL ACADEMY OF ENGINEERING
INSTITUTE OF MEDICINE
NATIONAL RESEARCH COUNCIL

Date: Feb. 27, 2014

FOR IMMEDIATE RELEASE

U.S. National Academy of Sciences, U.K. Royal Society Release Joint Publication on Climate Change

WASHINGTON -- The U.S. National Academy of Sciences and the Royal Society, the national science academy of the U.K., released a joint publication today in Washington, D.C., that explains the clear evidence that humans are causing the climate to change, and that addresses a variety of other key questions commonly asked about climate change science.

"As two of the world's leading scientific bodies, we feel a responsibility to evaluate and explain what is known about climate change, at least the physical side of it, to concerned citizens, educators, decision makers and leaders, and to advance public dialogue about how to respond to the threats of climate change," said NAS President Ralph J. Cicerone.

"Our aim with this new resource is to provide people with easy access to the latest scientific evidence on climate change, including where scientists agree and where uncertainty still remains," added Sir Paul Nurse, president of the Royal Society. "We have enough evidence to warrant action being taken on climate change; it is now time for the public debate to move forward to discuss what we can do to limit the impact on our lives and those of future generations."

Climate Change: Evidence and Causes, written and reviewed by leading experts in both countries, lays out which aspects of climate change are well-understood, and where there is still uncertainty and a need for more research.

Carbon dioxide (CO_2) has risen to levels not seen for at least 800,000 years, and observational records dating back to the mid-19th century show a clear, long-term warming trend. The publication explains that measurements that distinguish between the different forms of carbon in the atmosphere provide clear evidence that the increased amount of CO_2 comes primarily from the combustion of fossil fuels, and discusses why the warming that has occurred along with the increase in CO_2 cannot be explained by natural causes such as variations in the sun's output.

The publication delves into other commonly asked questions about climate change, for example, what the slower rate of warming since the very warm year in 1998 means, and whether and how climate change affects the strength and frequency of extreme weather events.

Many effects of climate change have already become apparent in the observational record, but the possible extent of future impacts needs to be better understood. For example, while average global sea levels have risen about 8 inches (20 cm) since 1901, and are expected to continue to rise, more research is needed to more accurately predict the size of future sea-level rise. In addition, the chemical balance of the oceans has shifted toward a more acidic state, which makes it difficult for organisms such as corals and shellfish to form and maintain their shells. As the oceans continue to absorb CO_2, their acidity will continue to increase over the next century, along with as yet undetermined impacts on marine ecosystems and the food web.

Even if greenhouse gas emissions were to suddenly stop, it would take thousands of years for atmospheric CO_2 to return to its levels before the industrial era. If emissions continue unabated, future climate changes will substantially exceed those that have occurred so far, the publication says.

The authoring committee offers this brief explanation of the science of climate change to help inform policy debates about the choices available to nations and the global community for reducing the magnitude of climate change and adapting to its impacts. The publication is available to download for free at www.nap.edu and as an interactive website at http://nas-sites.org/americasclimatechoices/events/a-discussion-on-climate-change-evidence-and-causes/.

The project was sponsored by the Raymond and Beverly Sackler U.S.-U.K. Scientific Forum. The National Academy of Sciences is a private, independent nonprofit institution that provides science, technology, and health policy advice under a congressional charter granted to NAS in 1863. For more information, visit http://national-academies.org.

The Royal Society is a self-governing fellowship of many of the world's most distinguished scientists drawn from all areas of science, engineering, and medicine. The society's fundamental purpose, reflected in its founding charters of the 1660s, is to recognize, promote, and support excellence in science and to encourage the development and use of science for the benefit of humanity. For further information, visit http://royalsociety.org.

Contacts:
William Kearney, Director of Media Relations
National Academy of Sciences

202-334-2138; e-mail news@nas.edu

Chloe McIvor, Press Officer
The Royal Society
020 7451 2514; e-mail chloe.mcivor@royalsociety.org

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U.S. NATIONAL ACADEMY OF SCIENCES AND THE ROYAL SOCIETY

Climate Change: Evidence and Causes

Eric Wolff, FRS (*co-chair*)
University of Cambridge

Inez Fung* (*co-chair*)
University of California
Berkeley

Brian Hoskins, FRS
Imperial College London and University of Reading

John Mitchell, FRS
U.K. Met Office

Tim Palmer, FRS
University of Oxford

Benjamin Santer*
Lawrence Livermore National Laboratory

John Shepherd, FRS
University of Southampton

Keith Shine, FRS
University of Reading

Susan Solomon*
Massachusetts Institute of Technology

Kevin Trenberth
National Center for Atmospheric Research

John Walsh
University of Alaska
Fairbanks

Don Wuebbles
University of Illinois
Urbana-Champaign

* Member, National Academy of Sciences

Schedule JLA-8

Number of Irrigated Farms in Missouri, 2012

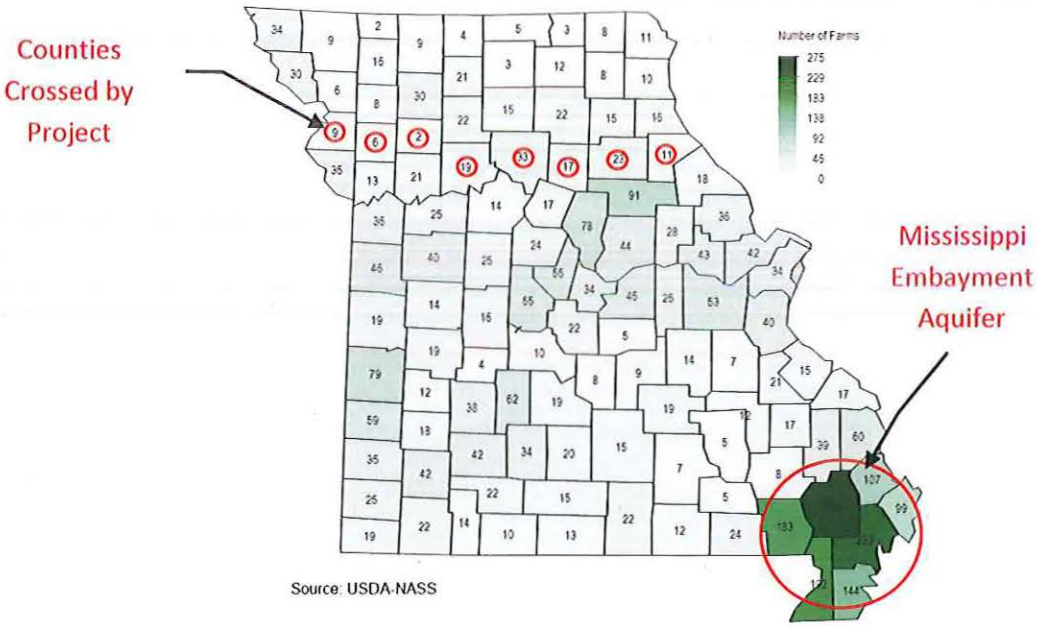

Table 1. Irrigation Agriculture as a Percentage of Number of Farms and Farm Acres in the Eight Counties crossed by the Grain Belt Express Project.[1]

County	Number of Farms (2012)		Irrigated Farms as a Percentage of Total	Acres of Farms (2012)		Irrigated Farms as a Percentage of Total
	Total Agriculture	Total Irrigated		Total Agriculture	Total Irrigated	
Buchanan	727	9	1.2	188,688	3621	1.9
Clinton	758	6	0.8	191,602	2079	1.1
Caldwell	1,035	2	0.2	244,528	1748 (2007)	0.7
Carroll	1,112	19	1.7	431,832	3,480	0.8
Chariton	1,120	33	2.9	406,355	3,876	1.0
Randolph	818	17	2.1	209,491	1,086	0.5
Monroe	1,061	23	2.2	355,654	1,060	0.3
Ralls	723	11	1.5	283,486	1,134	0.4
Totals	***7,354***	***120***	***1.6***	***2,311,636***	***18,084***	***0.8***

1 Data from 2012 Census of Agriculture – County Data Missouri, Table 10 Irrigation: 2012 and 2007. https://www.agcensus.usda.gov/Publications/2012/Full_Report/Volume_1,_Chapter_1_State_Level/Missouri/

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Validation of GNSS under 500,000 Volt Direct Current (DC) Transmission Lines

J.B. Bancroft*, A. Morrison and G. Lachapelle

j.bancroft@ucalgary.ca, ajmorris@ucalgary.ca, gerard.lachapelle@ucalgary.ca

Position, Location and Navigation Group, Schulich School of Engineering, University of Calgary

2500 University Drive, NW, Calgary, Alberta T2N 1N4, Canada

Phone Number: 001 403 210 9802

*Corresponding Author

Abstract

The use of Global Navigation Satellite Systems (GNSS) is common amongst agricultural users and enables the producer to optimize crop production within soil variant fields to provide better farming practices. Many agricultural navigation systems are dependent on real time GNSS navigation solutions to aid and control farm machinery. Direct current (DC) and Alternating Current (AC) transmission lines overhead are often suspected to create interference with GNSS equipment preventing farmers from utilizing their GNSS supported equipment. This paper provides evidence that only non-impeding effects on the receiver or incoming signals, in the form of cycle slips, were measured or detected from either the overhead lines and/or their corresponding support towers. No effect on code measurements was detected. The latter effect is due to reflection or brief masking by the towers. Tests were conducted under a set of three transmission lines, two 500 kV DC lines and one 230 kV AC line. Several GNSS receivers and processing methods, including real time and post-processed data, are used to measure and process data to study the position accuracy, dilution of precision, number of satellites tracked, code and phase errors, location and number of carrier phase cycle slips, carrier-to-noise density and L1-L2 carrier divergence. One commercial Real Time Kinematic (RTK) survey system was also used to verify the 450 MHz data link was operational.

Keywords: GNSS, High Voltage Transmission Lines, Interference, Precision Agriculture, Direct Current

1. Introduction and Background

Agricultural and survey grade GNSS receivers within farming equipment are often used for automated steering, custom geographic seeding and fertilizing and harvest yield mapping. These systems are often dependent on real time GNSS receivers operating with centimetre accuracy. Code and carrier phase measurements made by the receivers are used to obtain such a high accuracy level. These systems often utilize real time corrections from an additional static receiver or from other satellite or terrestrial based systems (e.g. Omnistar or the United States Coast Guard (USCG) Differential GPS Network). Thus, the issue of operating agricultural and survey grade GNSS equipment has three potential failures: the GNSS satellite network, the receiver itself or the additional communication system providing real time corrections (or data) to the moving receiver. This paper provides an in depth analysis of GNSS receivers tracking and navigation performance beneath 500 kV DC lines and confirming the correct operation of a single commercially available 450 MHz data link.

Regarding the issue of GNSS interference from overhead high voltage transmission lines, Silva & Olsen (2002) presented some results for 120 and 345 kV AC lines. Using a single Trimble GPS receiver of that period, they observed no adverse effects on the carrier to noise density of the incoming signal. Since signal strength alone cannot determine the full impact of multipath signals r the lines and their corresponding towers more analysis in the observation and position

domains is required. Silva (2002) discussed the effect of interference on the communication link between 283.5 - 325 kHz, which is the band where the USCG DGPS network broadcasts corrections. Although the effects at this frequency are beyond the scope of this paper, the author concludes that there is minimal impact on the data link resulting from high voltage transmission lines in the 283.5 - 325 kHz band. Phaiboon et al (2000) provides a novel survey of interference from 500 kV transmission lines. The paper addresses interference with the 0.5 - 100 MHz band, but concludes that higher band frequencies (such as GPS L1 at 1575 MHz) should experience no effect.

The origins and effects of corona discharge are described by Juette (1971), Pacific Gas and Electric (2005) and Phillips (2007). While it is generally believed that transmission line noise is not typically observable above 1 MHz, Juette (1971) has shown that interference is possible even on much higher frequency signals. For this reason one must consider the possibility that interference may be observed at GNSS signal populated frequency bands.

The locally ionized atmosphere around the high voltage conductors as discussed by Pacific Gas and Electric (2005) could be superficially compared to the naturally occurring ionized atmosphere in the ionosphere, however the direct calculation of this field is extremely challenging. The mechanism by which a current of charged particles could flow between the conductors of a transmission line system must be due to one of the three possible modes of current flow. Conduction current as defined by Sadiku (2001) requires the satisfaction of Ohms law whereby the current density in the conductor $\mathbf{J}$ is equal to the product of the material conductivity σ and the applied electric field $\mathbf{E}$. Since a conductor is defined as having a σ approaching infinity, this implies an electric field within the conductor is approaching zero. Further, Gauss Law states that if the electric field intensity is zero ($\mathbf{E}=0$), the charge density within the conductor ρ_v must also be zero (Sadiku 2001, pp.165). Obviously, since air is not a conductor, the leakage current between the transmission line conductors must be explained by phenomena other than conduction.

1.1 Displacement Current

The concept of displacement current $\mathbf{J}_d$ is very important in radio frequency applications, as it is the displacement current which explains the propagation of electromagnetic waves through free space (Sadiku 2001, pp. 382). Considering the long spans of parallel transmission line cable to the plates of a capacitor, it is conceptually possible to explain the presence and flow of leakage current between the conductors as being a manifestation of the displacement current. While this would imply that the integral of the magnetic field intensity $\mathbf{H}$ with respect to the flow of current I over any closed surface $\mathbf{S}$ between the two conductors taken along a path L would be equal to the surface integral of the conduction current density $\mathbf{J}$ as shown in Equation (1), it is already known that $\mathbf{J}$ is zero for a non-conducting medium such as air.

$$\oint_L \mathbf{H}\bullet d\mathbf{l} = \int_S \mathbf{J}\bullet d\mathbf{S} = I \qquad (1)$$

However, since the conduction current $\mathbf{J}$ is known to be zero in non-conducting air, the total current density is redefined as the conduction current $\mathbf{J}$ plus the displacement current $\mathbf{J}_d$. Thus Ampere's circuit law involves the time rate of change of the electrical flux density $\mathbf{D}$ (Sadiku 2001, pp. 383) as shown below to produce the time rate of displacement of charge Q.

$$\oint_L \mathbf{H}\bullet d\mathbf{l} = \int_S \mathbf{J}_d \bullet d\mathbf{S} = \frac{d}{dt}\int_S \mathbf{D}\bullet dS = \frac{dQ}{dt} = I \,. \qquad (2)$$

The conclusion is that the displacement current cannot be responsible for the flow of charge between the High Voltage Direct Current (HVDC) lines, as the electrical flux density $\mathbf{D}$ is constant with respect to time under steady state conditions, and therefore so is the integral of it over any arbitrary surface between the conductors of an HVDC line.

1.2 Convection

A convection current is defined as a flow of current through a non-conductor medium such as a liquid or gas (Sadiku 2001, pp. 163). The mechanism of convection flow is easily understood in terms of the applied electric field intensity $\mathbf{E}$ which causes a force $\mathbf{F}$ to act on each electron in the field according to Equation (3). Any ions within the field would experience the same magnitude of force but opposite in direction

$$\mathbf{F} = -e\mathbf{E}. \qquad (3)$$

For each electron of mass m the average drift velocity $\mathbf{u}$ of the convection current will be related to the field intensity by Newton's law in Equation (4) (the average

change in momentum of the free electron must match the applied force (Sadiku 2001, pp.164)), where τ is the average time between collisions according to

$$\frac{m}{\tau}\mathbf{u} = -e\mathbf{E}. \quad (4)$$

Rearranging Equation (4), velocity is stated in Equation (5) as

$$\mathbf{u} = \frac{-e\tau}{m}\mathbf{E}. \quad (5)$$

If the volume charge density ρ_v is expressed per Equation (6) such that

$$\rho_v = -ne. \quad (6)$$

then the convection current density $\mathbf{J}_{con}$ is given in terms of the collision time and charged particle mass (as conductivity σ) by (Sadiku 2001, pp. 164) in Equation (7) where

$$\mathbf{J}_{con} = \rho_v\mathbf{u} = \frac{ne^2\tau}{m}\mathbf{E} = \sigma\mathbf{E}. \quad (7)$$

The conductivity of air is given by Pawar (2009) to be as low as 0.295×10^{-14} Siemens per metre, though this figure is recognized to vary with altitude, humidity, and temperature.

While the stated equations are easily applicable to theoretical problems involving infinite plane conductors at infinite distance from any other surfaces, and in the absence of moving air (wind), they quickly become intractable for the real life problem of braided transmission lines near the surface of the earth, exposed to wind. For this reason advanced computer simulation involving finite element analysis via specialized software is required to approximate the convection current, and therefore the term of interest, the charge density between such conductors. For this reason, the values published by Lundkvist et al (2009) for similar 500kV DC bipole transmission lines are accepted as a reference level for current flow rate and spatial charge density between the conductors.

The effect of the ionosphere on the propagation of navigation satellite signals is directly observable when using multiple signals at different frequencies originating from the same satellite such as the L1 and L2 civil signals from GPS and GLONASS. This is due to the charged atmospheric layers being dispersive at L-Band frequencies, thereby imparting a varying signal delay effect inversely proportional to the square of the carrier frequency as discussed in Morrison (2010):

$$\Delta S_{iono,g} = \frac{40.3 \bullet TEC}{f^2}. \quad (8)$$

In Equation (8) ΔS is the change in unit of length (metres) of the apparent signal path length, TEC (Total Electron Content) is the amount of charge encountered within a 1 m^2 column around the ray path of the signal where 10^{16} ions is one unit of TEC, and f is the carrier frequency of the signal. Since the GPS L1 carrier is located at 1575.42 MHz while the L2 carrier is located at 1227.6 MHz, this has the consequence of introducing a 16.2 cm per unit of TEC bias in the L1 range measurement and a 26.7 cm per unit of TEC (TECU) bias in the L2 range measurement. The magnitude of the effect on the carrier phase is equal, but the sign is reversed such that increasing levels of TEC appear to cause a decreasing range between the satellite and the user. By measuring the time series of the difference between the L1 and L2 carrier phase observations it is possible to measure the changes in encountered charge with a high level of certainty. This is since each TECU of charge by which the encountered charge quantity increases or decreases will cause a phase difference magnitude change of 10.5 cm between the two carriers.

Conceptually, the local ionization of the atmosphere adjacent to the high voltage conductors could cause a similar effect, however the expected ion current density of 60 nA/m^2 as discussed in Lundkvist et aL (2009), caused by a 500 kV DC line would be expected to produce a completely negligible effect on the order of microns. If one assumes that the peak referenced current density is uniform over a 1 metre vertical cross section between the bipole conductors, this would cause a GNSS signal passing through this region from directly above to encounter a charge of 60 nano Coulombs. Since one Coulomb is equivalent to 6.24×10^{18} elementary charges, the total encountered charge would be equivalent to 3.74×10^{11} elementary charges. In terms of the previously discussed units of TEC, this total encountered charge could be stated as 3.74×10^{-5} TECU. Since one TECU of encountered charge increase or decrease causes a 10.5 cm divergence between the L1 and L2 carrier measurements, the total encountered charge of 3.74×10^{-5} TECU would produce an expected carrier phase difference change of only 0.004 mm, while the absolute range error would be 0.006 mm on L1 and 0.010 mm on

L2. Since the L5 signal (1176.45 MHz) is in the same band, the effects would presumably be similar to those of L2, both in theory and in the measurement domain.

Thus, the purpose of this paper is to confirm the negligible effect of the corona effect and other potential interference and confirm that GNSS receivers can still operate correctly beneath and adjacent to 500 kV DC transmission lines. Data was collected under the lines in order to prove this hypothesis.

2. Data Collection

Figure 1 shows a picture of the test site located on the Nelson River Bipole system, operated by Manitoba Hydro in Winnipeg, Manitoba, Canada. Two visually identical 500 kV DC bipoles are located on the right side, with one parallel AC line at the left. Lines were located approximately 5 m above the ground. Data was collected over two days. During the first day of data collection the HVDC lines had a 537 MW and 531 MW load. During the second day of the data collection, the HVDC lines had 1124 MW and 1218 MW loading. Despite the loading difference, results were consistent on both days.

Figure 1 - Test Site

The GNSS receivers chosen were able to collect data from the Global Positioning System and the Russian GLONASS (Global Navigation Satellite System). Two receiver configurations were used to collect data, namely (i) commercially available GNSS receivers and (ii) a front-end to collect GNSS baseband data.

Two GNSS base stations, one utilizing a NovAtel DL-V3 receiver (FW 3.500), the other utilizing a Trimble R8 (FW 4.19) survey receiver were placed approximately 500 m (350 m on the 2nd day) from the DC bipoles, where they logged data continuously. The base stations served as reference stations for processing the data in differential mode, a mode commonly used for precise positioning applications such as those encountered in farming and construction.

The mobile equipment was installed in a vehicle and included four GNSS receiver systems, including a second NovAtel V3 (FW 3.620), a Trimble R8 (FW 4.19) rover, a high sensitivity u-blox receiver (u-blox Antaris 4, FW 5.0), and a NovAtel SPAN Inertial Navigation System (INS) system, which consisted of an LCI Inertial Measurement Unit (IMU) and a NovAtel SPAN SE GNSS receiver. Since INS's are self-contained and are not affected by external signals, they are used to further verify the accuracy and integrity of the GNSS-derived solutions.

To provide an extra dimension of certainty in the analysis of potential interference, the PLAN group's Leapfrog-II L-band RF front-end was used to collect direct observations of the GNSS signals from both GPS and GLONASS satellites in the L1 and L2 navigation bands. By collecting and digitizing the microwave frequencies it was possible to post-process the data using the PLAN group's GSNRx™ software receiver (Petovello et al 2009) and provide extensive signal analysis capabilities not output by commercial hardware based receivers. By using observations from high elevation angle satellites whose ray path intersect the transmission lines and the charged air between them during a perpendicular crossing run of the lines, direct measurement of the effect of air ionization was made possible via the aforementioned differential L1 and L2 carrier propagation rates in charged atmosphere.

The Trimble R8 receiver includes a 450 MHz data link that received corrections from the R8 base station, as long as the test vehicle remained within approximately 1 km of the base station. Since this data link operates on a frequency separate from the GNSS carrier frequencies, it was tested to ensure continuous operation during a subset of the test runs.

Data collected by the base stations included GPS and GLONASS pseudorange, carrier-phase, ephemeris and clock measurements. The Trimble R8 base station collected raw GNSS data and broadcasted corrections based on internal measurements and a temporary virtual point (the correct coordinates were determined after the data collection). The NovAtel V3 recorded all

information to an internal memory card for later post-processing use.

Data was collected in two kinematic modes where the vehicle moved at low speeds to simulate that of typical agricultural machinery, namely 10 - 20 km/h. First, a first trajectory approximately perpendicular to the transmission lines was traversed to a point approximately 500 m each side of the first HVDC bipole and second a trajectory running along the right of way, under and approximately parallel to the transmission lines was taken spanning the distance between three supporting towers. These trajectories were selected to assess any effects as a function of distance from the line.

In order to comply with the rated radio link limitation of 1 km while still allowing traversal testing under both HVDC bipoles as well as data collection parallel to and beneath multiple tower spans of the HVDC lines, the base stations were deployed at the position indicated in Figure 2.

Figure 2 - Map of test location showing location of the NovAtel V3 base stations for each day (green triangles), range of Trimble R8 450 MHz data link (blue circle), and position of HVDC bipoles 1 and 2 (black lines), position of AC Line (green lines) and trajectory throughout the day of the test vehicle (red). Base map from Google (2011).

Equipment supporting the mobile portion of the collection effort was divided between the roof of the test vehicle, depicted in Figure 3, and the cab of the truck where the operation of the navigation systems were monitored and managed.

Specific components of the test equipment installed on the vehicle roof were the Trimble R8 rover unit, the antenna for the high sensitivity GPS receiver, the NovAtel 702 GG pinwheel antenna used by the V3 mobile unit, the NovAtel SPAN INS, and the PLAN group Leapfrog-II L-Band Front-End module. The IMU component of the NovAtel SPAN SE system was deployed on the roof of the vehicle to provide a rigid and stable mounting point via four magnets.

Figure 3 - Mobile GNSS, inertial, and RF equipment elements mounted on roof of test vehicle. Trimble R8 rover unit at bottom right, high sensitivity GPS antennas on roof at right, NovAtel 702 GG dome antenna center left directly adjacent to LCI IMU (gray box) at center left.

The block diagram of the complete navigation test system suite is shown in Figure 4.

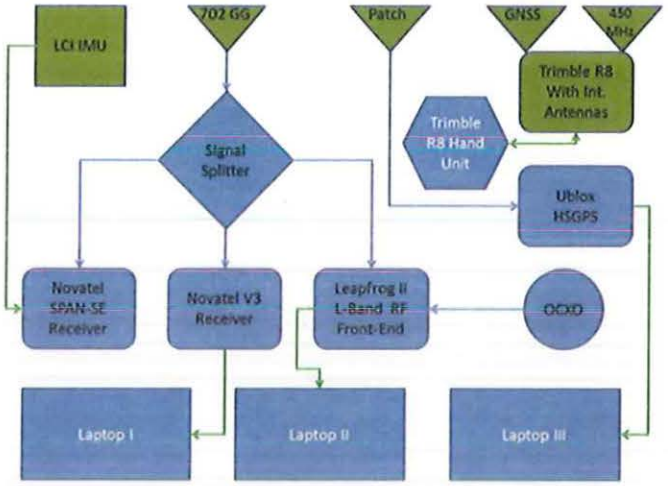

Figure 4 - Deployed equipment functional diagram. Equipment external to vehicle shown as green elements (antennas, IMU, Trimble R8), equipment

installed inside vehicle shown in blue. Cabled RF links shown with blue arrows, digital data links shown with green arrows. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

3. Data Evaluation

Nineteen segments of data were selected from the two day collection period to show key indicators of GNSS quality in real time differential and single point positioning modes. Each segment was analyzed independently and results as presented were consistent with each data segment. The exact trajectory can be seen in Figure 2, where the east/west trajectory is marked in red along Highway 321. The data and figures shown herein all refer to segment 14, a traverse perpendicular to the lines on the second day. Static data and data from the north/south trajectory were included in the other segments.

Data was processed with six different software packages. The Trimble R8 receiver combination operating in real time, in double difference ambiguity fix mode via the internal 450 MHz data link. Table 1 provides the details of each processing software package.

The reference solution was determined using a NovAtel INS. Since the INS derives its relative position from internal sensors not sensitive to electromagnetic interference of the overhead lines, this system provides an independent verification of the truth solution used.

Table 1 - Software processing strategies.

Software	GNSS Data*	Processing Methods	Purpose
NovAtel's Inertial Explorer	IMU + L1L2 GG	Post Mission Differential, Forward/Reverse processing and RTS Smoothing	Provided reference solution
University of Calgary's PLANSoft™	L1 GG	Post Mission Differential	Provide similar processing to that of precision farming navigation equipment
University of Calgary's GSNRx™	L1L2 GG	Post Mission Single Point	Provide a clear indication of tracking capabilities and carrier anomalies if present
NovAtel's GrafNav	L1L2 G	Post Mission Differential	Second commercial software package to confirm processing techniques
Trimble's R8 Internal RTK Solution	L1L2 GG	Real Time Differential with 450 MHz radio link	RTK, similar to those of Land Surveyors
u-blox Internal	L1 G	Real Time Single Point	High Sensitivity GPS receivers used in low cost

The system operated using GNSS observations to provide an absolute position. NovAtel's Inertial Explorer was used to process the data. Data was processed in the forward and reverse directions, smoothed using an RTS smoother (Gelb 1974) and finally combined to form a final navigation solution. The reference solution provided an estimated standard deviation of better than 1.7 cm (1σ).

3.1 Trimble RTK Analysis

The position differences between the Trimble Real Time Kinematic (RTK) system and the reference trajectory are shown in Figure 5. Position differences of several centimetres are common amongst receiver manufacturers and processing software, thus the differences shown on the top of Figure 5 are completely normal. The differences are due to antenna phase center variation, projection of the reference solution to the Trimble R8 antenna phase center, carrier phase noise and multipath and differences in filtering and estimation techniques used.

The horizontal dilution of precision (HDOP) and number of satellites presented in the bottom half of Figure 5 is consistent with open sky conditions. The solution of the RTK system may, for example, reject a satellite without a fixed ambiguity, occlude some satellites near the horizon or have difficulty maintaining signal lock for a

low elevation satellite. The values presented in Figure 5 show ideal data, with no reason to yield navigation impediments. An HDOP of 0.6 is among the best values currently available with a GPS+GLONASS receiver at the latitude of the tests (50.1° N).

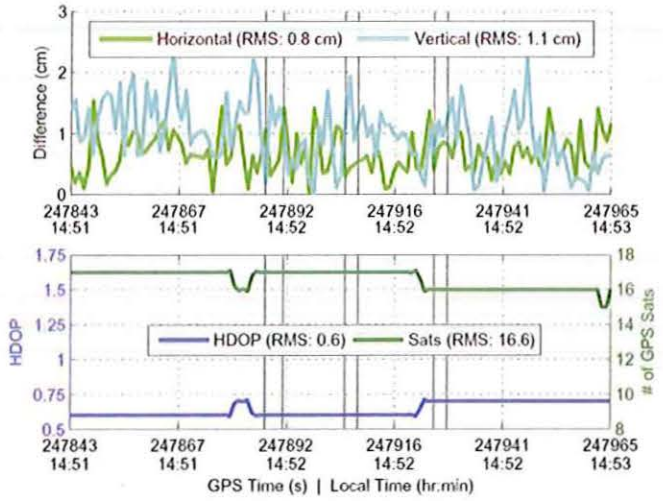

Figure 5 - Position differences and satellite geometry (vertical lines represent time directly beneath transmission lines), receiver: Trimble R8, processed by: Trimble Internal RTK Solution, data: L1 + L2 + GPS + GLONASS, test segment: 14.

Figure 6 shows the results of the data from the Trimble units, but processed with NovAtel's GrafNav software. This provides a secondary check on the data to ensure other software packages are able to fix the carrier phase ambiguities. For this test, GLONASS observations were removed to ensure that a correct GPS only solution was possible.

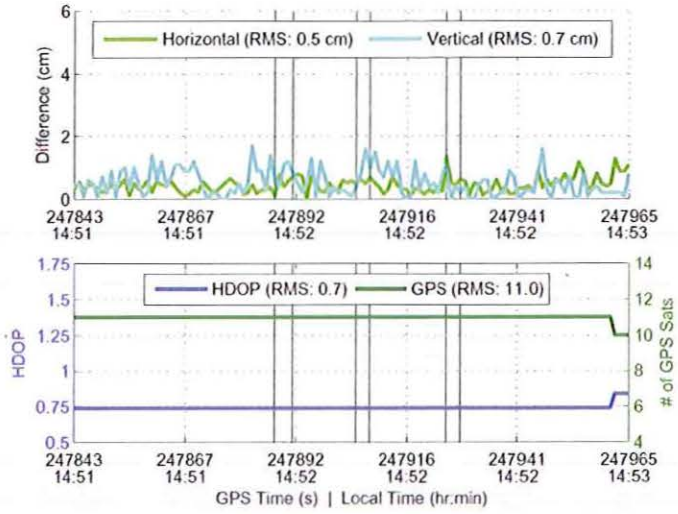

Figure 6 - Position differences and satellite geometry (vertical lines represent time directly beneath transmission lines), receiver: Trimble R8, processed by: NovAtel's GrafNav, data: L1 + L2 + GPS, test segment: 14.

3.2 NovAtel Receiver Analysis

Figure 7 shows the average carrier to noise density (C/N_0) for all satellites tracked by the NovAtel OEMV3 receiver. These results are comparable to those of open sky data and no evidence of transmission line disturbances is present. L2 signals are broadcast at 1.5 dB lower power (IS-GPS-200E 2010) than L1 and the 702GG antenna gain pattern amplifies the L2 signal 3 dB less than the L1 signal at zenith (NovAtel Inc. 2010). Further, the antenna gain pattern rolls off more rapidly on L2 than on L1, the consequence of which is the several dB lower signal level observed on L2 relative to L1. In short, a lower L2 power level is an expected effect and not a result of transmission line interference.

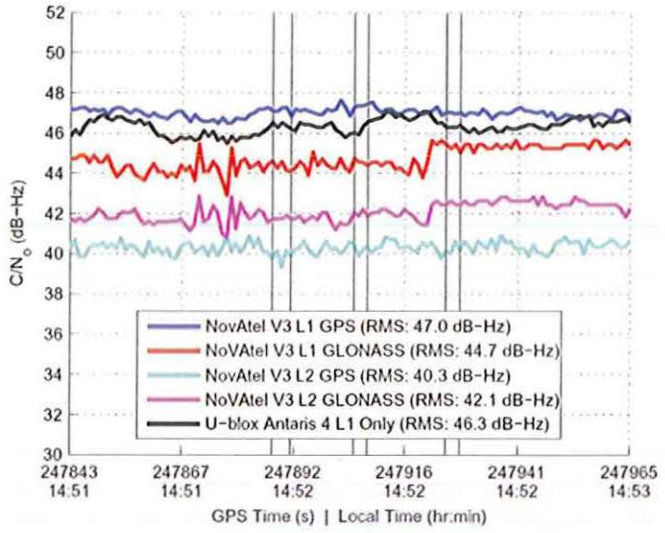

Figure 7 – GNSS signal strength (vertical lines represent time directly beneath transmission lines), receiver: NovAtel V3, data: L1 + L2 + GPS + GLONASS, test segment: 14.

Position differences as processed by PLANSoft™ are shown in Figure 8 with differences less than 1.1 cm as compared to the reference trajectory. The HDOP is exceptional throughout both segments and the number of satellites remains consistent with open sky conditions. No transmission line effect is detected as the vehicle traverses the line.

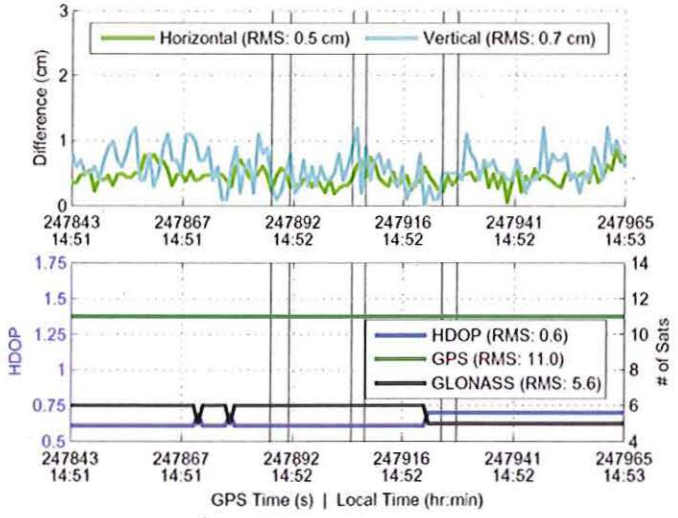

Figure 8 - Position differences and satellite geometry (vertical lines represent time directly beneath transmission lines), receiver: NovAtel V3, processed by: PLANSoft™, data: L1 + GPS + GLONASS, test segment: 14.

3.3 Residual Errors

PLANSoft™ outputs the residual error of each measurement used in the filter and residuals are often used to validate the solution. Small residuals indicate that the measurements are consistent with each other. There are additional factors that contribute to larger residuals, namely multipath and noise. Errors due to transmission line effects would result in higher residuals.

Figure 9 shows the RMS of the residuals for all measurements used within an epoch. Measurements rejected by the fault detection algorithm within the software are not used in the computation of the residual RMS. There was a minimal rejection rate (i.e. 0.067 %), a common occurrence among GNSS data gathered under open sky conditions. The rejection rate was not higher than normal due to operation under the transmission lines. Code residuals of 0.5 m and less are considered good and indicate quality observations with no hindrances. Phase residuals are also excellent at less than 1 cm. Given the number of satellites used, it is clear from this residual analysis that the receiver is functioning normally with no adverse effect from the transmission lines.

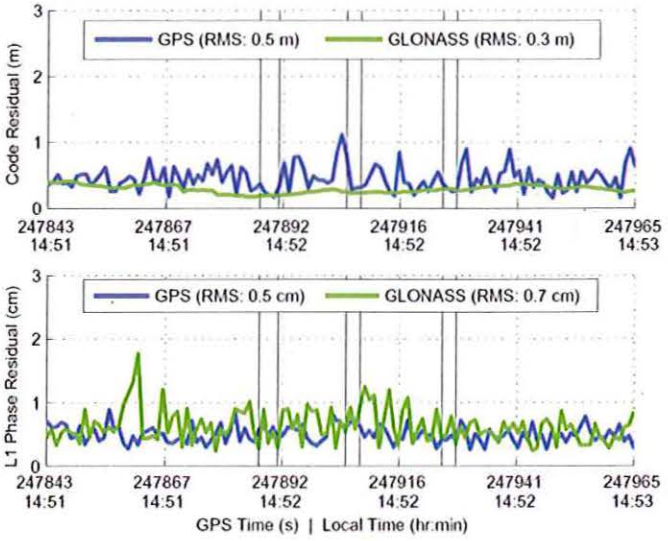

Figure 9 - RMS of residuals (vertical lines represent time directly beneath transmission lines), receiver: NovAtel V3, processed by: PLANSoft™, data: L1 + GPS + GLONASS, test segment: 14.

3.4 Carrier Phase Cycle Slip Analysis

Carrier phase cycle slips occur when the receiver loses carrier phase lock on the signals. This is commonly experienced when an obstruction blocks the direct line of sight to the signals, in which case the ambiguities affected must be re-estimated within the navigation filter. When one satellite experiences a cycle slip, the navigation filter can typically re-estimate the ambiguity within a few measurement epochs. However, if cycle slips occur on all channels simultaneously, such as when an antenna passes under an overpass, the entire ambiguity resolution process takes much longer to fix, degrading the navigation solution accuracy in the process. Thus, the number, frequency and location of cycle slips are an important metrics to analyze as they affect the navigation solution quality.

Figure 10 shows the trajectories traveled during the data collection and each cycle slip is plotted on the trajectory. Figure 10 contains all the NovAtel data collected, not just the segment analyzed (i.e. segment 14). This additional data was included to show the impact of trees on cycle slips versus the lines and towers overhead.

On the east and west ends of the data collection 362 cycle slips occurred, while only 28 cycle sips occurred beneath the transmission lines. This is due to the trees present on either side of the road, where low elevation satellites affected by these trees experience a large number of cycle slips. Some slips occur just east of the north/south trajectory where trees are present south of the road. Most importantly, although a few cycle slips occur under the lines, there is only a weak correlation between the location of the transmission line towers and the location of the cycle slips. This indicates that the transmission lines and their corresponding towers, regardless of their electric current carrying characteristics, are not causing cycle slips at a level that would impede centimetre level accuracy. Albeit cycle slips are occurring under the lines, the impact is negligible when comparing the navigation solutions to the truth solution.

It is also noteworthy that, despite a tower being located a few tens of metres from the northern most point of the data collection (where the vehicle turned to return south), no cycle slips were recorded in this area, further confirming the low effects of transmission line towers on carrier phase tracking capabilities.

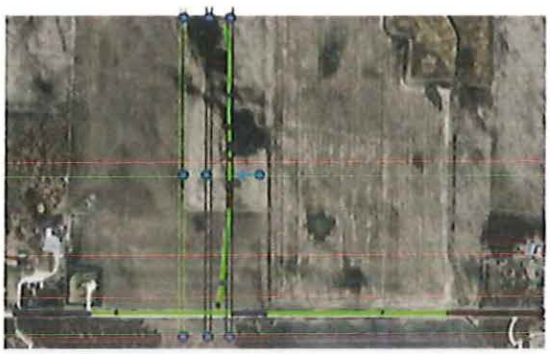

Figure 10 - Geo-located cycle slips for all data collected (red: 24 January, purple: 25 January, blue tower locations).

3.5 RF Front-End Measurement Analysis

The measurements obtained from the RF front-end can be used to derive L1-L2 carrier divergences that would occur if the air ionization from the transmission lines was far stronger than predicted, as well as signal strength fading effects that would be observable if the transmission lines were emitting interference in the L1 or L2 bands.

If air ionization effects were present, they would be observed as a change in the L1 minus L2 carrier phase observations as the ray path between the satellite and the user traversed the conductors of the transmission line, as well as the region between the conductors. If interference was emitted from the transmission lines, it would be observable as a decrease in the carrier-to-noise density ratio as the test vehicle approached the transmission lines, returning to normal as the vehicle passed to the other side of the transmission corridor. Since these effects would be most clearly discernable during a perpendicular test scenario, relevant results are presented in Figure 11.

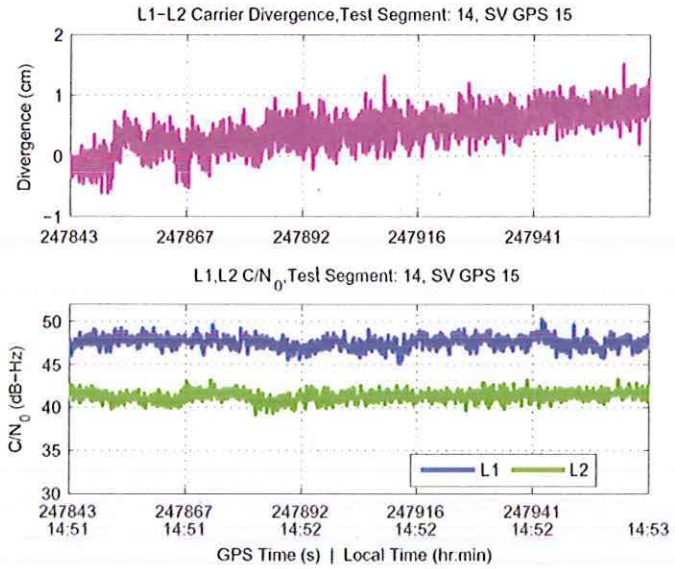

Figure 11 - L1–L2 carrier divergence and signal carrier strength of GPS PRN 15 during test segment 14. No anomalous behavior noted.

The signal characteristics presented indicate no abnormal features. No detectable RF interference is present in the GNSS navigation bands as evidenced by the nearly constant carrier signal strengths that show no noticeable reduction near the transmission lines. Additionally, the very slowly and smoothly varying carrier divergence measurement is indicative of normal background ionospheric effects, and shows no indication of a measurable effect due to air ionization adjacent to the transmission lines.

All perpendicular test trajectories produced similar null observations to those shown in Figure 11. Moving to the consideration of the carrier divergence and signal strength indicators produced during trajectories parallel to the transmission lines, deleterious effects were encountered. However, these are the result of mundane signal blockage or antenna gain pattern variations such as high vehicle dynamics requiring a 50% increase in GSNRx™ PLL bandwidth which causes a slight degradation of measurement quality. In addition, the deep fades typically associated with solid objects such as trees intersecting the ray path between a low elevation satellite and the user antenna are not due to interference from the transmission lines themselves.

Consistent changes in the carrier divergence of all satellites observed during parallel traversal tests are due to a phenomenon known as 'carrier phase wind up'. Due to the circular polarization of GPS and GLONASS signals, rotation of the receiving antenna results in apparent carrier phase advance or retreat from the point of reception. In the case of the testing executed, the windup effect is due to one half of a left turn at the far point in each trajectory where the direction of the truck is reversed from north facing to south facing. This negative one half-cycle is equivalent to a phase observed range change of -9.75 cm of GPS L1 signal phase, and approximately -12.2 cm of GPS L2 phase. The theoretical L1-L2 difference as a result of the left turn would therefore be predicted as +2.45 cm of divergence, which appears to precisely match the observed change.

3.6 HSGPS Observations

The high sensitivity GPS receiver tested herein was not hindered and suffered no additional errors other than what would be expected in a single point GPS L1 only solution. Figure 12 shows the internal solution position accuracy and satellite geometry. In general, the single point navigation solution should be within a few metres and these results are no exception. Twelve satellites were tracked continuously and the HDOP was 0.8, which is extremely good for a GPS only receiver.

Shown explicitly in Figure 7, the receiver recorded similar power levels as that of the agricultural and survey grade receivers, as expected. Variations are expected based on the low noise amplifier and gain pattern of each antenna.

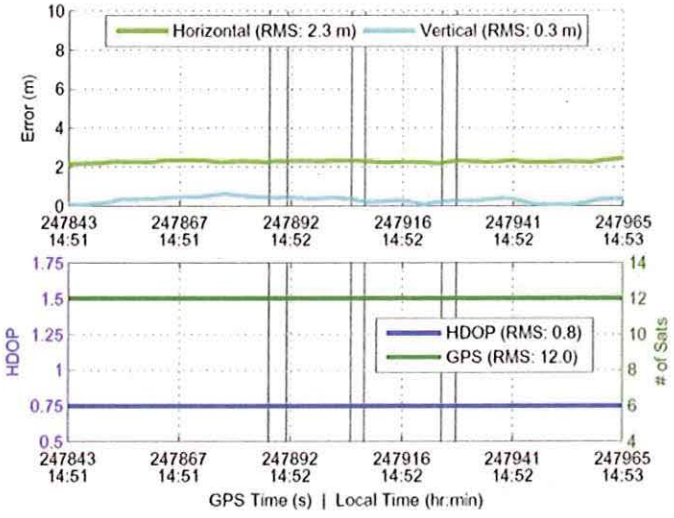

Figure 12 - Position error and satellite geometry (vertical lines represent time directly beneath transmission lines), receiver: u-blox Antaris 4, processed by: u-blox Internal Solution, data: L1 + HSGPS, test segment: 14.

4. Conclusions

GNSS data collected under two 500kV HVDC bipole lines were analyzed. Using two agricultural/survey grade GNSS receivers, a software based receiver and a high sensitivity GPS receiver, only non-impeding effects on the receivers or the L1 and L2 GNSS signals, in the form of cycle slips, were measured due to the transmission lines and their respective towers. Only a weak correlation between the location of the tower and the location of the cycle slips was observed. The cycle slips that did occur were so infrequent that the redundant measurements in the navigation solutions easily mitigated them. No transmission line effect on GNSS measurements was found to affect the quality of the navigation solutions. In addition, the test results showed normal operation of a commercially available survey grade RTK system and its radio link (450 MHz) for static and perpendicular test segments perpendicular to the transmission lines. Four different processing methods and software (GSNRx™, GrafNav, PLANSoft™, and the Trimble RTK solution) were able to provide consistent results (with the exception of the RTK solution which was not able to provide a real time fixed solution when the vehicle experienced high dynamics when driving off road). No adverse effects were measurable in the IF data as processed by GSNRx™. This paper analyzed the following metrics to form these conclusions:

1. Position Accuracy
2. HDOP
3. Number of Satellites
4. RMS of Code and Phase Residual errors
5. Location and Number of Cycle Slips
6. Carrier to Noise Density (and Average of all Satellites)
7. L1-L2 Carrier Divergence

References

Gelb, A., 1974. Applied Optimal Estimation. The Massachusetts Institute of Technology Press. Cambridge, Massachusetts.

IS-GPS-200E, 2010. Navstar GPS Space Segment/Navigation User Interface, Revision E., GPS Joint Program Office.

Juette, G.W., 1971. Evaluation of Television Interference from High-Voltage Transmission Lines. IEEE Summer Meeting and International Symposium on High Power Testing. Portland, OR, pp. 4.

Lundkvist, J., Gutman I. and Weimers, L. 2009. Feasibility study for converting 380 kV AC lines to hybrid AC / DC lines. EPRI's High-Voltage Direct Current & Flexible AC Transmission Systems Conference. Westminster, CO, pp. 11.

Morrison, A., 2010. High Latitude Ionospheric Scintillation: Detection and Isolation from Oscillator Phase Noise as Applied to GNSS, Ph.D. Thesis, Department of Geomatics Engineering, University of Calgary, Canada.

NovAtel Inc., 2010. NovAtel GPS 702 GG Antenna Data Sheet, pp. 2.

Pacific Gas and Electric, 2005. Pacific Gas and Electric Delta Distribution Planning Area capacity Increase Substation Project Proponent's Environmental Assessment: Section 16 Corona and induced current effects, No report number given, pp. 7.

Pawar, S.D., Murugavel, P., and Lal, D.M. 2009. Effect of relative humidity and sea level pressure on electrical conductivity of air over Indian Ocean. Journal of Geophysical Research, 114, D02205, pp. 8.

Petovello, M.G., O'Driscoll, C., Lachapelle, G., Borio, D. and Murtaza, H. 2009, Architecture and Benefits of an Advanced GNSS Software Receiver, Positioning, 1, 1, pp. 66-78.

Phaiboon, S., Vivek, V. and Somkuarnpanit, S. 2000. Analysis and Measurement of Radio-Frequency Interference Due to the Corona From 500kV Transmission Lines, TENCON 2000, Kuala Lumpur , Malaysia pp. 88-91.

Phillips, D., 2007. Corona Tutorial, Presented at IEEE Joint Technical Committee Meeting, San Diego CA, pp. 22.

Sadiku, M.N.O., 2001. Elements of Electromagnetics Third Edition. Oxford University Press, New York, NY.

Silva, J.M., 2002. Evaluation of the Potential for Power Line Noise to Degrade Real Time Differential GPS Messages Broadcast at 283.5-325 kHz, IEEE Transaction on Power Delivery, 17, 2, pp. 326-333.

Silva, J.M. and Olsen, R.G. 2002. Use of Global Positioning System, GPS, Receivers Under Power-Line Conductors, IEEE Transactions on Power Delivery, 17, 4, pp. 938-944.