Rapid Prototyping Experiment:

INTEGRATING NASA DATA AND MODEL PRODUCTS FOR CROP SURVEILLANCE AND PRODUCTIVITY ESTIMATION TO PROVIDE ENHANCED INPUTS TO USDA FAS PECAD/CADRE DST

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**INTRODUCTION**

- Regional yield forecasting is an important national or regional economic need.
  - *timely yield forecast helps in food import/export decision*
  - *defines the food pricing on the global market*

- United States Department of Agriculture (USDA)/Foreign Agricultural Services (FAS) Production Estimation and Crop Assessment Division (PECAD) work specifically in providing timely crop yield forecasts.

- NASA has designated “Agricultural Efficiency” as one of national application areas out of 12 designated applications.

- Remote Sensing and other spatially referenced datasets provide the ability to efficiently monitor crop bio-productivity and to provide datasets that can be used in lieu of intensive ground data collection.
RESEARCH OBJECTIVE

The main research objective is to evaluate the use of remote sensing (current and future sensors) and grid based meteorological datasets to reduce the need for field data and for providing improved predictive capabilities to monitor and model agricultural bio-productivity.
METHODOLOGICAL FRAMEWORK/ SCOPE

• Evaluate the baseline method for regional yield prediction using ground data. The research focuses on soybean yields in Argentina and a refactored Sinclair Crop Model is used for crop yield predictions.
  
  • *Compare with gridded South American Land Data Assimilation System (SALDAS)*

• Evaluate remote sensing inputs for regional yield prediction for soybean using MODIS (AQUA & TERRA) Normalized Difference Vegetation Index.
  
  • *Compare with simulated Visible/Infrared Imager/Radiometer Suite (VIIRS) sensor product*

• Development of daily NDVI composites to enable the ability to closely monitor vegetation condition and detect key events in the crop cycle.

• Development of geoprocessing framework to enable the use of remote sensing and gridded dataset for crop modeling.
SINCLAIR MODEL

Semi-mechanistic model researched and developed by Dr. Thomas Sinclair.

Used by USDA/FAS PECAD for soybean estimations. Currently in used operationally by South American growers for crop estimations and for rotation planning in land use intensification.

Sinclair Crop Model Initializing Parameters
- Planting Date
- CSEVP: Soil Evaporation Coefficient
- DYSE: Days after rain before planting
- DEEP: Initial soil moisture at 90 cm depth
- ESW: Initial soil moisture at 15 cm depth
- WH: Water Holding Capacity

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STUDY AREA: ARGENTINA
METEOROLOGICAL SAMPLING SITES

AWIFS Imagery

Rio Segundo
Rafaela
Monte Buey
La Carlota
Marco Juarez
Magiolo
Pergamino
CROP AND FIELD DATA SITES
DATA SOURCES

- **Weather (Ground Stations Continuous Measurements)**
  - Minimum Temperature, Maximum Temperature, Solar Radiation, Precipitation

- **Soil Moisture (Near Monthly Measurements)**

- **Planting dates, Cultivars, Yields**

- **SALDAS (South American Land Data Assimilation System)**
  - High performance land surface modeling and data assimilation system
  - Provide daily meteorological datasets at 1/8 of a degree resolution
MODIS (Moderate Resolution Imaging Spectroradiometer)
- 2 Platforms: MODIS–AQUA (AM); MODIS-TERRA(PM)
- 36 discrete bands
- 3 spatial resolution : Bands 1-2: 250m; Bands 3-7: 500m; Bands 8-36: 1000m
- Data Collection: Multiple data products from 2004 – 2007 to provide crop data across 3 growing seasons. Current focus is on the 2006-2007 crop season.

VIIRS (Visible/Infrared Imager/Radiometer Suite)
- National Polar-orbiting Operational Environmental Satellite System (NPOESS)
- Spectral Bands:
  - Visible/ Near IR: 9 plus
  - Day/Night Band
    - Mid - Wave IR: 8
    - Long - Wave IR: 4
- Resolution: Visible and IR channels: 400 m at Nadir
- VIIRS Data Simulation: Simulated for complete MODIS time-series collection.
Normalized Difference
Vegetation Index (NDVI)
NDVI = \frac{NIR - R}{NIR + R}

For day from 1 to 5
if angle is less than 48 AND mask is Land
   select pixel
else
   get next pixel
If no pixel is selected
   select pixel with highest NDVI
Normalized Difference
Vegetation Index (NDVI)
NDVI = NIR-R/NIR+R

For day from 1 to 5
if angle is less than 48 AND mask is Land
    select pixel
else
    get next pixel
If no pixel is selected
    select pixel with highest NDVI
Fusion, Geoprocessing, and Comparison

- AQUA/TERRA MODIS GQK, GGAD, GSQ files
- ART VIIRS SIMULATION
- FUSED MODIS NDVI, Angle, Mask files
- Zonal Processing And Analysis
- Results and comparison

- AQUA/TERRA simulated VIIRS GQK, GGAD, GSQ files
- FUSED MODIS NDVI, Angle, Mask files
- Zonal Processing And Analysis
<table>
<thead>
<tr>
<th>Date</th>
<th>Image</th>
<th>Date</th>
<th>Image</th>
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<td>AQUA</td>
<td>Nov 12, 06</td>
<td>FUSED</td>
<td>Nov 14, 06</td>
<td>TERRA</td>
</tr>
<tr>
<td>Nov 11, 06</td>
<td>AQUA</td>
<td>Nov 13, 06</td>
<td>FUSED</td>
<td>Nov 12, 06</td>
<td>TERRA</td>
</tr>
</tbody>
</table>
VIIRS SIMULATION

Application Research Toolbox (ART): Integrated set of algorithms developed in Matlab [NASA]

Real or synthetic data with sensor specification → ART → Simulated Datasets

AQUA MODIS
NDVI
250m

Simulated VIIRS
NDVI
400m
COMPARISON: MODIS & VIIRS

MODIS and VIIRS Data Comparison:
- 2006 – 2007 Crop Year
- Field-Based AOIs
- Mean Daily Value Plots

MODIS NDVI Scatterplot for MODIS and VIIRS
Rio Segundo Soy/Soy field

VIIRS NDVI

MODIS NDVI

R² = 0.9738

MODIS NDVI Scatterplot for MODIS and VIIRS
Marcos Juarez Soy/Malze Field

VIIRS NDVI

MODIS NDVI

R² = 0.9165
COMPARISON: MODIS & VIIRS

Rio Segundo Soy/Maize

VIIRS NDVI
MODIS NDVI

P = Planting Date
E = Emergence
TLG = Termination of leaf growth

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COMPARISON: MODIS & VIIRS

Monte Buey Soy/Wheat

VIIRS NDVI
MODIS NDVI

P = Planting Date
E = Emergence
TLG = Termination of leaf growth

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SOUTH AMERICAN LDAS DATA

- Daily Minimum Temperature (K)
- Total Daily Precipitation (mm/day)
- Average Daily Soil Moisture (kg/m²)
- Daily Maximum Temperature (K)
- Average Daily Solar Radiation (W/m²)

Resolution: 1/8 of a degree
GROUND MET. OBSERVATIONS Vs. SALDAS

- SOLAR RADIATION
  - Solar Radiation vs SALDAS (MLimb): R²=0.80968

- MINIMUM TEMPERATURE
  - Min Temperature vs SALDAS (C): R²=0.93388

- MAXIMUM TEMPERATURE
  - Max Temperature vs SALDAS (C): R²=0.95082

- PRECIPITATION
  - Daily Precipitation vs SALDAS (mm): R²=0.81973
SALDAS SOIL MOISTURE COMPARISON

Rio Segundo Plant Water Availability (PWA) OBS x SALDAS (mm)

- SALDAS Mean
- Circ A
- Circ B
- Lote 32
- Lote 39

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GEOPROCESSING FRAMEWORK

Day 1.............................Day N

A. South American LDAS Meteorological inputs
B. Interpolated Grid

Soybean Field Vector data

Assign Field Zonal Ids (1...Z)

Rasterize

Calculate Zonal Mean for Soybean farms in the region

Automated Database manipulation

Field Boundaries

Yield_zone 1

Yield_zone z

SINCLAIR MODEL
Temporal NDVI

Growing Degree Day (GDD) = \[ \frac{(\text{Max. Temp} + \text{Min. Temp})}{2} \] – base temperature

Detect onset of greenness using cumulative GDD

Detect planting date

Temporal NDVI Phenology curve
GDD AND PHENOLOGY

Soybean Phenology with Growing Degree Days
Rio Segundo (Soybean/Soybean)

NDVI
GDD

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Soybean Phenology with Growing Degree Days
MonteBuey (Soy/Wheat)

2006-2007
Can we improve the estimation of planting date by using detected emergence and cumulative growing degree days?

<table>
<thead>
<tr>
<th>Field</th>
<th>Crop</th>
<th>Planting Date</th>
<th>Emergence Date (150 C-GDD)</th>
<th>NDVI Jump Detected</th>
<th>Corresponding C-GDD</th>
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</thead>
<tbody>
<tr>
<td>Rio Segundo</td>
<td>Soy/Soy</td>
<td>10 Oct, 06</td>
<td>22 Oct, 06</td>
<td>13 Nov, 06</td>
<td>406</td>
</tr>
<tr>
<td>Rio Segundo</td>
<td>Soy/Maize</td>
<td>11 Oct, 06</td>
<td>23 Oct, 06</td>
<td>17 Nov, 06</td>
<td>451</td>
</tr>
<tr>
<td>Marcos Juarez</td>
<td>Soy/Maize</td>
<td>31 Oct, 06</td>
<td>13 Nov, 06</td>
<td>25 Nov, 06</td>
<td>338</td>
</tr>
<tr>
<td>Rosario</td>
<td>Soy/Soy</td>
<td>10 Oct, 06</td>
<td>21 Oct, 06</td>
<td>7 Nov, 06</td>
<td>377</td>
</tr>
<tr>
<td>Monte Buey</td>
<td>Soy/Wheat</td>
<td>7 Nov, 06</td>
<td>18 Nov, 06</td>
<td>3 Dec, 06</td>
<td>366</td>
</tr>
</tbody>
</table>
Soyabean Phenology Curve
Rio Segundo (Soybean/Soybean)

NASAl MODIS NDVI FIELD AVERAGES
DAILY MODIS NDVI FIELD AVERAGES

Soybean Phenology Curve
MonteBuey (Soyabean/Wheat)

PHENOLOGY CURVE

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Soybean Phenology Curve
MarcoJaurez (Soybean/Maize)

NDVI

0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

31-Aug
14-Sep
28-Sep
12-Oct
26-Oct
9-Nov
23-Nov
7-Dec
21-Dec
4-Jan
18-Jan
1-Feb
15-Feb
29-Feb
14-Mar
28-Mar
11-Apr
25-Apr
9-May

2006-2007

PHENOLOGY CURVE
### SINCLAIR MODEL INPUT PARAMETERS

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>CROP_ROTATION</th>
<th>CSEVP</th>
<th>DYSE</th>
<th>DEEP</th>
<th>ESW</th>
<th>WH</th>
<th>Planting date</th>
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</thead>
<tbody>
<tr>
<td>Marcos Juarez</td>
<td>Soy/Maize</td>
<td>0.3</td>
<td>1</td>
<td>120.7</td>
<td>22</td>
<td>0.21</td>
<td>Oct 31/2006</td>
</tr>
<tr>
<td>Marcos Juarez</td>
<td>Soy/Wheat</td>
<td>0.65</td>
<td>8</td>
<td>24.7</td>
<td>10</td>
<td>0.21</td>
<td>Nov 24/2006</td>
</tr>
<tr>
<td>Monte Buey</td>
<td>Soy/Wheat</td>
<td>0.65</td>
<td>1</td>
<td>70.4</td>
<td>19</td>
<td>0.21</td>
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<tr>
<td>Pergamino</td>
<td>Soy/Soy</td>
<td>0.7</td>
<td>4</td>
<td>153.7</td>
<td>24.6</td>
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<td>Nov 3/2006</td>
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<tr>
<td>Pergamino</td>
<td>Soy/Wheat</td>
<td>0.65</td>
<td>1</td>
<td>145.9</td>
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<td>0.19</td>
<td>Dec 15/2006</td>
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<tr>
<td>Pergamino</td>
<td>Soy/Maize</td>
<td>0.3</td>
<td>4</td>
<td>101.5</td>
<td>11</td>
<td>0.19</td>
<td>Nov 3/2006</td>
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<tr>
<td>Rio Segundo</td>
<td>Soy/Soy</td>
<td>0.7</td>
<td>7</td>
<td>103.3</td>
<td>20</td>
<td>0.16</td>
<td>Oct 10/2006</td>
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<td>Rio Segundo</td>
<td>Soy/Wheat</td>
<td>0.65</td>
<td>0</td>
<td>27.7</td>
<td>4</td>
<td>0.16</td>
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<td>8</td>
<td>95.9</td>
<td>17</td>
<td>0.16</td>
<td>Oct 11/2006</td>
</tr>
</tbody>
</table>

CSEVP: Soil Evaporation Coefficient  
DYSE: Days after rain before planting  
DEEP: Initial soil moisture at 90 cm depth  
ESW: Initial soil moisture at 15 cm depth  
WH: Water Holding Capacity
Yield (Sinclair Local) was derived by a model expert; whereas Met and Interpolated Data (Geoprocessing based) simulated yields were derived by the experiment team.

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>CROP</th>
<th>EXPERT SIMULATED</th>
<th>ACTUAL YIELD</th>
<th>MET DATA</th>
<th>INTERPOLATED DATA</th>
<th>SALDAS</th>
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</thead>
<tbody>
<tr>
<td>PERGAMINO</td>
<td>S/S</td>
<td>488</td>
<td>420</td>
<td>480.34</td>
<td>555.38</td>
<td>396.98</td>
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<tr>
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<td>S/W</td>
<td>440</td>
<td>320</td>
<td>441.11</td>
<td>NO DATA</td>
<td>205.75</td>
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<tr>
<td>PERGAMINO</td>
<td>S/M</td>
<td>475</td>
<td>420</td>
<td>480.72</td>
<td>520.57</td>
<td>401.18</td>
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<tr>
<td>MARCOS JUAREZ</td>
<td>S/M</td>
<td>484</td>
<td>468</td>
<td>493</td>
<td>519.72</td>
<td>475.24</td>
</tr>
<tr>
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<td>S/W</td>
<td>473</td>
<td>401.2</td>
<td>467</td>
<td>460.33</td>
<td>275.39</td>
</tr>
<tr>
<td>MONTE BUEY</td>
<td>S/W</td>
<td>376</td>
<td>340</td>
<td>387.98</td>
<td>526.91</td>
<td>358.51</td>
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<tr>
<td>RIO SEGUNDO</td>
<td>S/S</td>
<td>497</td>
<td>460</td>
<td>514.25</td>
<td>515.98</td>
<td>296.29</td>
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<tr>
<td>RIO SEGUNDO</td>
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<td>400</td>
<td>453.27</td>
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<td>248.15</td>
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<tr>
<td>RIO SEGUNDO</td>
<td>S/M</td>
<td>503</td>
<td>484</td>
<td>511.52</td>
<td>510.44</td>
<td>310.34</td>
</tr>
</tbody>
</table>
Actual Yield Vs. Simulated Yield

$y = 0.694x + 190.09$

$R^2 = 0.7581$

YIELD SIMULATIONS: BASELINE MET SIM
SINCLAIR – SALDAS SENSITIVITY AND COMPARITIVE ANALYSIS RESULTS

GIVEN:
Base Yield = Simulated yield using the Sinclair Crop Model with input data from local ground meteorological data stations

Individual Parameter Substitution Sensitivity Test Scenarios: For meteorological parameters in the SINCLAIR model, substitute SALDAS data for each observed meteorological data parameter individually to create SINCLAIR input data sets that include observed meteorological data except for the substitution of the one parameter from SALDAS - creating the following sensitivity test scenarios:

- Minimum Temperature
- Maximum temperature
- Solar Radiation
- Precipitation

Full Substitution Sensitivity Test: Prepare a SINCLAIR input data set which includes all of the SALDAS parameters and none of the observed meteorological data.

Run the SINCLAIR model for each parameter sensitivity scenario as well as for the full substitution sensitivity test. Compare the results against the baseline model run which used local observations and compare against actual reported yields.
Inputs to “Refactored” Sinclair Model

Meteorological Data
NASA SOUTH AMERICAN LAND DATA ASSIMILATION SYSTEM

Satellite Reflectance
MODIS
VIIRS]

Use of temporal cube and temporal map algebra to detect onset of greenness

Detection of emergence/Planting date estimation

LAI

Soil Moisture

Temperature

Precipitation

Solar Radiation

Latitude

Day length

OUTPUT

PREDICTED YIELD

MODIFIED SINCLAIR MODEL

Modified from original form to adapt the model to accept spatial datasets
SINCLAIR BASE SIMULATION RESULTS

Comparison between simulated yield using local ground met. data with actual yield.

[Bar chart showing comparison between simulated and actual yields for various crops in different locations.]
ANALYSIS OF SALDAS MIN. TEMPERATURE

Base met data: Substituting SALDAS Min Temp

- Actual Yield (gm/m2)
- Base Yield (gm/m2)
- Yield with SALDAS Min. Temp. (gm/m2)
ANALYSIS OF SALDAS MAX. TEMPERATURE

Base met data: Substituting SALDAS Max Temp
ANALYSIS OF SALDAS SOLAR RADIATION

Base met data: Substituting SALDAS Solar Radiation

![Bar chart showing solar radiation comparison](chart.png)

Legend:
- **Actual Yield (gm/m²)**
- **Base Yield (gm/m²)**
- **Yield with SALDAS Solar Radiation (gm/m²)**

Locations:
- Rio Segundo
- Rio Segundo
- Rio Segundo
- Monte Bue
- Marcos Juan
- Marcos Juan
- Pergamino
- Pergamino
- Pergamino

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ANALYSIS OF SALDAS PRECIPITATION

UNREFINED SALDAS PRECIPITATION: Initial Precipitation Data Contained Problems – Precipitation improvements are ongoing!
ANALYSIS OF SALDAS PRECIPITATION

Base met data: Substituting Enhanced SALDAS Precipitation
Cumulative Precipitation SALDAS VS Ground
Cumulative Precipitation SALDAS VS Ground
Comparison between actual yield, base simulated yield, and full SALDAS simulated yield.
## RESULTS: COMPARISON

<table>
<thead>
<tr>
<th>Location</th>
<th>Crop Rotation</th>
<th>Actual Yield (gm/m²)</th>
<th>Base Yield (gm/m²)</th>
<th>SALDAS Yield (gm/m²)</th>
<th>% Difference (Actual Vs. Base)</th>
<th>% Difference (Actual Vs. SALDAS)</th>
<th>% Difference (Base Vs. SALDAS)</th>
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<tbody>
<tr>
<td>RioSegundo</td>
<td>Soybean/Soybean</td>
<td>460</td>
<td>514.25</td>
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<td>453.27</td>
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<td>-13.32</td>
<td>37.96</td>
<td>45.25</td>
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<td>-5.69</td>
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<td>367.54</td>
<td>-14.37</td>
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<td>Pergamino</td>
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<tr>
<td>Pergamino</td>
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<td>441.11</td>
<td>205.75</td>
<td>-37.85</td>
<td>35.70</td>
<td>53.35</td>
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</tbody>
</table>
CONCLUSIONS

- The spatial and temporal resolution of MODIS data are effective for crop growth and development monitoring:
  - MODIS NDVI based phenology curves are able to detect the onset of greenness with respect to the planting date
  - The phenology curves portrayed the growth phases as simulated from the Sinclair model
- Sinclair model simulation of soybean growth and yield simulations were validated
  - Sinclair model estimates and the actual yield shows good correlation.
  - Cross validation between Sinclair model simulated crop growth phenology stages matched well with MODIS phenology curved
- Geo-processing framework enables efficient regional soybean yield prediction using spatially referenced grid datasets.
Fusion-based Temporal Map Algebra delivered high-temporal resolution composites which allowed field vegetation to be monitored and extracted to create NDVI phenology curved for studying the growth and development of soybean.

Analysis using SALDAS showed the following:

- SALDAS Minimum, Maximum Temperature and Solar Radiation performed on par with ground meteorological data
- SALDAS precipitation under performed compared to the other datasets. Improvements are needed for precipitation inputs!

The correlation coefficient between MODIS NDVI and VIIRS NDVI was around 0.9 for initial samples. The VIIRS NDVI performed similarly to MODIS in providing soybean phenological characteristic curves.

Quantifying the relationship between soybean crop phenology (using NDVI values) and growing degree days will deliver enhanced understanding of crop planting, growth, maturity, and ultimately productivity.
Next Steps: Summer Activities

Our rich data storehouse and science questions allow us to finish up exciting work aimed at the following issues:

- An Enhanced Geoprocessing Framework for NDVI-Based Adaptive Feedback and Steering to the Sinclair Crop Model
- Estimating Crop Planting Date, Monitoring Growth, and Modeling Productivity
- Enhanced Vegetation Data Products Evaluating the General Bioproductivity of Agricultural Regions for Evaluating the General Bioproductivity of Agricultural Regions
- Use of AWIFS for Validation of MODIS simulated VIIRS
Future Research Needed

- Extend the use of simulated VIIRS to refine its applicability in crop growth monitoring as a replacement for MODIS data streams.

- Further automated work flow for data transformation and geo-processing to enable efficient use of NASA data and model products for regional crop-modeling.

- Investigate the utility of enhanced precipitation products by use of simulated GPM to provide model-ready rainfall data to test its accuracy with respect to crop yield forecasting.

- Use of DCM and/or AWIFS as gap-filler Landsat or proxy LDCM for field boundary delineation, crop residue estimation, and crop type classification.
Publications

Questions?

THANK YOU!

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