Mauna Kea Weather Center
User’s Meeting
5-6 October 2006

Outline
- MKWC Update
- Climatology of Mauna Kea: new initiative
- A postmortem of March storms
- Crystal Ball: The 06/07 El Niño
- Parting Flash
MKWC Update

- Dr. Steven Businger, Direction
- Dr. Tiziana Cherubini, Numerical Weather Prediction
- Mr. Ryan Lyman, Lead Forecaster/System Admin.

Status of MKWC Seeing Modeling

MM5 Sea-Level Pressure and PW
Implementation of WRF Model

Progress in implementing the new Weather Research and Forecasting model has been slow, primarily a result of the unique architecture of the Subaru supercomputer.

- Pre-processing on mkwc1: Installed/active
- Post-processing on mkocn2 (Subaru): Installed/inactive
- WRF Compilation: Not yet

Understanding the Seeing Environment of MK

Observational Data Sets

- CFHT Telescope/MegaPrime: Feb ’05 - now
- Subaru DIMM: Jun ’05 - now
- Subaru Auto-guider (sub-set): Jun ’05 - now
- UH DIMM: Jun ’05 - Jul ’06
- UKIRT Cassegrain, WFCAM: from 2004
We are in the process of building a climatology of seeing for the Mauna Kea summit.

Number of observations of better seeing increase during the middle hours of the night (data for May 06).
How do different data-sets compare/correlate?

UH vs Subaru DIMM
(1 hr averaged)

One year of data: from June 2005 to June 2006
Subaru vs CFHT (1 hr averaged data)

One year of data: from June 2005 to June 2006

UH vs CFHT (1 hr averaged data)

One year of data: from June 2005 to June 2006
What causes the differences among observations?

- DIMMs vs Telescope seeing: Instrumental differences (turbulence outer scale, dome/telescope seeing).

- DIMM vs DIMM: different locations with respect local topography and surrounding buildings.
DIMM location at Subaru

View from the top

View from the side (looking East)

Thanks to Fumihiro Uruguchi

Subaru DIMM vs AG - Wind

Certain degree of overestimation is seen when winds are from the ESE
Validation of Forecast Seeing

Seeing and $C_n^2$ are currently calculated in two ways:
1. Hourly seeing trends are produced during MM5 output post-processing
2. Every three seconds $C_n^2$ profiles and seeing are calculated while model is running.

UH88 DIMM vs MM5 Forecast

1. Low-res seeing
2. High-res seeing
Why is there a discrepancy?

1 Low-res seeing
2 High-res seeing

Reviewing the Algorithm

\[ \phi = 0.98 \frac{\lambda}{r_0} \]

\[ r_0 = \left[ 0.423 \cdot \left( \frac{2\pi}{\lambda} \right)^2 \int_0^\infty C_n^2(z) dz \right]^{-2/3} \]

\[ C_n^2(z) = \left( \frac{80 \cdot 10^{-6} p}{T^2} \right)^2 C_T^2(z) \]

\[ C_T^2(z) = 1.6 \cdot \epsilon_\theta \cdot \epsilon^{-1/3} \]

\[ \epsilon_\theta = -2w' \frac{\partial \theta_L}{\partial z} \]
Eddy diffusivity scheme in the lowest levels

\[ e_\theta = -2w' \partial \theta_L / \partial z \]

In the model:

\[ K_\theta = -2\omega' \partial \theta' = L_h \sqrt{TKE} \]

\[ K_\theta = \max[K_\theta, L_h L_M K_{zogs}] \]

We need to refine the eddy diffusivity parameterization

Lowest model levels

- Low-res seeing
- High-res seeing

We need to refine the eddy diffusivity parameterization
Calibrating the Eddy Diffusivity

Seeing Algorithm Refinement
Sensitivity to the Eddy Diffusivity Scheme

Eddy diffusivity scheme in the lowest levels

One year of data: from June 2005 to June 2006, hourly averages
Seeing Algorithm Refinement
Sensitivity to the Eddy Diffusivity Scheme

Eddy diffusivity scheme in the lowest levels

\[ K_\alpha = \max \{ K_\alpha, \frac{L_3}{L_\text{vis}} K_{\text{mag}} \} \]

One year of data: from June 2005 to June 2006, hourly averages
Eddy diffusivity scheme in the lowest levels

One year of data: from June 2005 to June 2006, hourly averages

\[ K_{\alpha} = \max\{K_{\alpha}, \frac{L}{E_{zL}}, K_{\text{pe}}\} \]

Seeing Algorithm Refinement
Sensitivity to the Eddy Diffusivity Scheme

One year of data: from June 2005 to June 2006, hourly averages

Eddy diffusivity scheme in the lowest levels

April 2006 only

One year of data: from June 2005 to June 2006, hourly averages
Summary and future work

- The seeing/$C_n^2$ algorithm is sensitive to the eddy diffusivity parameterization scheme
- An initial first order calibration has been performed.

Future Work:
- Repeat the calibration using only those nights characterized by weak free-atmosphere shear
- Improve the eddy diffusivity scheme through application of very high resolution turbulence model
- Use data from Ground Layer Adaptive Program (GLAO) to refine the algorithm
- Once the surface turbulence is well constrained, focus on high wind-shear cases in free atmosphere

Fog Statistics (Past 2 Years)

<table>
<thead>
<tr>
<th>Night</th>
<th>% Fog occurred:</th>
<th>when not forecasted</th>
<th>when forecasted</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4% (47/1295)</td>
<td>95% (164/173)</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>3% (37/1208)</td>
<td>97% (89/92)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>6% (62/1103)</td>
<td>89% (41/46)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>7% (38/549)</td>
<td>86% (6/7)</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>9% (49/560)</td>
<td>60% (3/5)</td>
<td></td>
</tr>
</tbody>
</table>

In the last 6 months for night 1:
3 Misses 2 false alarms
# PW and Temperature Statistics

<table>
<thead>
<tr>
<th>Night</th>
<th>1 mm</th>
<th>2 mm</th>
<th>3 mm</th>
<th>4 mm</th>
<th>5 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.15</td>
<td>0.15</td>
<td>0.16</td>
<td>0.16</td>
<td>0.17</td>
</tr>
<tr>
<td>2</td>
<td>0.30</td>
<td>0.37</td>
<td>0.36</td>
<td>0.38</td>
<td>0.41</td>
</tr>
<tr>
<td>4</td>
<td>0.62</td>
<td>0.75</td>
<td>0.90</td>
<td>0.95</td>
<td>1.00</td>
</tr>
<tr>
<td>Tmp</td>
<td>1 °C</td>
<td>1.3 °C</td>
<td>1.5 °C</td>
<td>1.7 °C</td>
<td>2 °C</td>
</tr>
</tbody>
</table>

PW shows an increase in RMS with time/PW$_{max}$

<table>
<thead>
<tr>
<th>Percent Temp Forecast &lt; 1 °C</th>
<th>Night</th>
<th>All</th>
<th>Good*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Night</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>60%</td>
<td>72%</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>49%</td>
<td>59%</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>48%</td>
<td>50%</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>39%</td>
<td>38%</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>37%</td>
<td>35%</td>
</tr>
</tbody>
</table>

*RH<80% & winds<50 mph

# MKWC Web Server Stability

- MKWC1 was down 1248 hrs in 2005 and 114 hrs in 2006.
- MKWC2 and MKWC_WEB have not had any down time through hardware failures.
- Installed ‘heartbeat’ software on old and new server to make web access transparent to user.
- Still have a few bad disks on MKWC1, which are being replaced.
**Archive Status**

- Presentations
- Forecasts
- Satellite Imagery – Rebuilding...
- LAPS Images – Rebuilding...
- Model Images
- Case Studies
- Observatory Surface Weather Data

- Working to rebuild and expand archive back in time from Met Dept archive tapes
- Creating an archive inventory

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**New Forecast Products**

- Quantitative Seeing and Percent Probability PW < 0.8 mm are now displayed on forecast table.
- Seeing forecasts are now plotted on the graphical forecast trends, and are used to develop seeing forecast statistics.
Symposium on Seeing

- A three day workshop on seeing has been funded by the NSF
- Location: Kona Coast Marriott
- Dates: March 20–22, mark your calendars
- NSF program managers from Astronomy and Geosciences plan to attend the meeting.
Symposium on Seeing

Sessions
1. Instrumentation and observations of atmospheric optical turbulence
2. Adaptive optics, interferometry, and other approaches to mitigate atmospheric optical turbulence
3. Approaches for modeling atmospheric optical turbulence
4. Applications of optical turbulence observations and custom forecasting in telescope astronomy
5. Panel led session to develop a science plan for a field experiment

Climatology of the Summit of Mauna Kea
aka in search of the wekiu bug
Objectives of New Initiative

1. to better understand the climatic variability and climate trends experienced at the summit of Mauna Kea through analysis of meteorological observational data collected on Mauna Kea and Mauna Loa.
2. to refine our understanding of the ecological controls that help define the spatial distribution of the Wekiu bug through a combination of directed observations and microscale atmospheric modeling.

Proposal calls for 3 automated weather stations to be placed in the MK summit region.

Data Sets Analyzed to Date

<table>
<thead>
<tr>
<th>variable</th>
<th>CFHT data</th>
<th>UKIRT data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>March 1995 - March 2006</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Aug 2001 - Dec 2005</td>
</tr>
<tr>
<td>dew point</td>
<td>not available</td>
<td>May 1991 - Sep 2004</td>
</tr>
<tr>
<td></td>
<td></td>
<td>May 2005 - Dec 2005</td>
</tr>
<tr>
<td></td>
<td></td>
<td>May 2005 - Dec 2005</td>
</tr>
</tbody>
</table>
Temperature: Monthly Means

- $T_{\text{max}} = 4.47 \, ^\circ C$
- $T_{\text{min}} = -0.28 \, ^\circ C$
- $T_{\text{med}} = 2.21 \, ^\circ C$
- $\Delta T = 4.75 \, ^\circ C$

Temperature: Annual cycle

- $A_1 = 2.22 \, ^\circ C$
- $A_2 = 0.26 \, ^\circ C$
- $\sigma = 1.62 \, ^\circ C$
- $T_{\text{max}} = 4.47 \, ^\circ C$
- $T_{\text{min}} = -0.28 \, ^\circ C$
- $T_{\text{med}} = 2.21 \, ^\circ C$
**Temperature: Daily Mean**

Temperature: Daily Mean

**Temperature: Diurnal Cycle**

T = 24 h

max = 13 h

min = 5 h

A (Sep) = 4.46 °C

A (Feb) = 3.52 °C
Wind Speed: Monthly Mean

- $A_1 = 1.72\text{ m/s}$
- $A_2 = 0.81\text{ m/s}$
- $\sigma = 1.49\text{ m/s}$
- $ws_{\text{max}} = 10.182\text{ m/s}$
- $ws_{\text{min}} = 4.68\text{ m/s}$
- $ws_{\text{mean}} = 6.82\text{ m/s}$
- $\Delta ws = 5.5\text{ m/s}$

January Wind Rose

- NE - SE: 22 %
- Strong winds: 8 %
- E: 11 %
- Strong winds: 5 %

- NW - SW: 51 %
- Strong winds: 29 %
- W: 27 %
- Strong winds: 16 %
September Wind Rose

NE - SE: 53 %
Strong winds: < 5 %
E: 19 %
Strong winds: < 3 %
NW - SW: 25 %
Strong winds: < 5 %
W: 8 %
Strong winds: < 3 %

Recent MKWC Publications

Recurrent Kona Low in 2006

Kona lows contribute >50% of the heavy rain events on the Island of Hawaii

Monthly distribution of heavy rain events on the SE slope of Mauna Loa by synoptic type (Kodama and Barnes 1997).
Weather Hazards in Kona Lows

- blizzards at altitude
- flash floods
- high winds
- waves and swell
- severe thunderstorms
  - high winds
  - large hail
  - tornados

Kona lows also supply much need rains to leeward coasts.

Intensifying Stage
250-mb wind and divergence

Genesis and life cycle explored by Morrison and Businger (W&F 2001) using reanalysis data.
Kona Low Climatology

Deepening of Kona lows linked to vorticity advection aloft

Intensifying Stage – Unstable Air

Cold air aloft moves over warm air below causing instability and thunderstorms.
Climatology of Kona Lows

Monthly Variability

Mean Life Cycle
Kona Lows are Poorly Predicted by NWS Global Model

(Morrison and Businger 2001)

Simulation of a Kona Low

MM5 Nested Domains

Inner domain is 3 km, middle domain is 9 km, outer domain is 27 km.

Cherubini, T., S. Businger, C. Velden, and R. Ogasawara, MWR 2006
GOES Atmospheric Motion Vectors

MM5 250 mb Height and PVA
Indian Ocean Dipole

QuikSCAT wind anomalies 9/22-24/06

Conditions in the equatorial East Indian Ocean

Z20 (-40 m)

Anomalous easterly wind

Thermocline shoaling in the east

SST (-1.5C)

Cooling in the east

Indian Ocean feedback on ENSO development (Sep-Nov)

IO Warming

Strong easterlies in Equatorial Pacific unfavorable for El Nino growth

IOD

Weak Pacific winds

El Nino with IOD grows bigger

Annamalai et al. (2005, JC)

Zonal wind anomaly (150E-180, 5S-5N)
Synopsis: El Niño conditions have developed and are likely to continue into early 2007.
ENSO Outlook

SST anomaly forecast for the central equatorial Pacific

Impact of the Last El Niño

Animation starting at the peak of the 1998 el niño.
Enso Sea-level Pressure Anomalies

El Niño vs La Niña

\[ T = 0.33 \, ^\circ C \]
\[ T_{EN} = 2.79 \, ^\circ C \]
\[ T_{LN} = -0.65 \, ^\circ C \]
\[ \Delta_{EL} = 2.46 \, ^\circ C \]
\[ \Delta_{LN} = -0.98 \, ^\circ C \]

Temperature (Dec - March)
**El Niño vs La Niña**

Wind Speed (Dec - March)

- $w_s = 8.67 \text{ m/s}$
- $w_{s\text{EN}} = 6.55 \text{ m/s}$
- $w_{s\text{LN}} = 8.98 \text{ m/s}$
- $\Delta_{EL} = -2.12 \text{ m/s}$
- $\Delta_{LN} = 0.3 \text{ m/s}$

Relative Humidity

- $RH = 36.98 \%$
- $RH_{EN} = 18.36 \%$
- $RH_{LN} = 33.23 \%$
- $\Delta_{EL} = -18.59 \%$
- $\Delta_{LN} = -3.71 \%$
El Nino Wind Rose

NE - SE: 23 %
Strong winds: < 5 %
E: 8 %
Strong winds: < 3 %
NW - SW: 50 %
Strong winds: 16 %
W: 26 %
Strong winds: 10 %

Dec - March

La Nina Wind Rose

NE - SE: 61 %
Strong winds: 25 %
E: 20 %
Strong winds: 8 %
NW - SW: 19 %
Strong winds: 9 %
W: 8 %
Strong winds: < 3 %

Dec - March
Climatology

Dec - March

WIND SPEED (m/s)

- Strong winds: 12%
- Strong winds: 5%
- Strong winds: 20%
- Strong winds: 10%

Climatology of Kona Lows

Interannual variability

Caruso and Businger (2006)
Parting Shot

Central Sea-Level Pressure vs Lightning Rate
Rita

TRMM 87 GHz and Ice Product w/ lightning strikes
1506 UTC – 1617 UTC 21 September.

Rita
Aircraft radar reflectivity
TRMM ice product
and lightning strikes
1506 UTC – 1617 UTC 21 September.
Conceptual Model

During high lightning rates: eye wall is steep and eye is small, vertical velocities and ice concentrations are large.

During low lightning rates: eye is large, eye wall is sloped, vertical velocities are modest, and ice concentrations are low.

Questions?

Davis Instruments Weather Station for HP