The Mauna Kea Weather Center:

Custom Atmospheric Forecasting Support for Mauna Kea

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Brief History of Weather Center

Memorandum of understanding between UH Meteorology & IfA established the Mauna Kea Weather Center in July 1998.

Three principal objectives:

(i) Provide weather forecasts and nowcasts for MKO.

(ii) Determine and meteorological conditions that provide the best astronomical observing conditions.

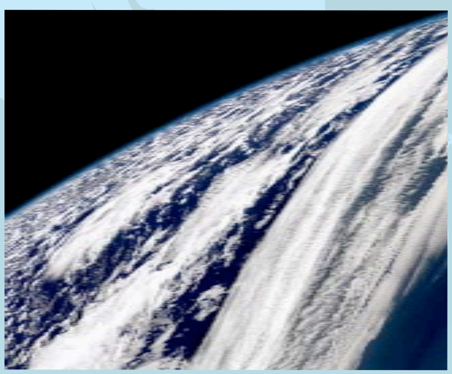
(iii) Communicate forecasts, meteorological data, and imagery to observatories.

Goal: To provide forecast products

– relevant to astronomical observing quality &
– to mitigate high impact weather

Forecasts Relevant to Observing Quality

- Telescope mirror temperature
- Telescope wind shake
- Precipitable water
- Cloudiness and Fog
- Seeing and C_n^2



Weather Hazard Mitigation

Anticipating High Winds and Frozen Precipitation

– Tropical cyclones
– Cold frontal passages
– Upper level troughs/lows
– Strong subtropical highs (strong summit winds)
– Kona lows

Current Status

MKWC forecasts issued twice daily, Monday through Friday

Twice Daily Weather Research& Forecast (WRF) model runs

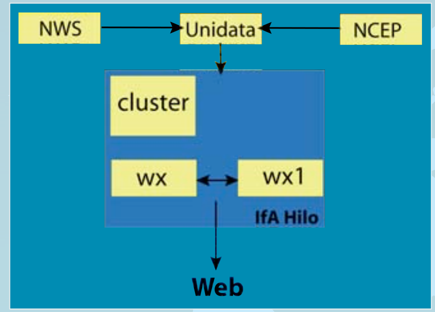
Satellite and model graphics provided by web server(s)

Comprehensive data archive developed & maintained

Experience is accumulating in custom forecasting

Research and development are ongoing

mkwc.ifa.hawaii.edu



Two Linux Servers provide

- Data ingest
- Data assimilation and WRF input
- Graphic/Web
- Redundant product distribution
- Archive function

Silicon Mechanics HPC

The MKWC HPC system is comprised of 16 compute nodes, 128 CPUs (Intel Xeon L5420 Quad-Core 2.50GHz), with high-speed communication links between nodes (Infiniband cards and switches). The system includes a RAID-6 storage component.

Key Variables in Twice-Daily MKWC Forecasts

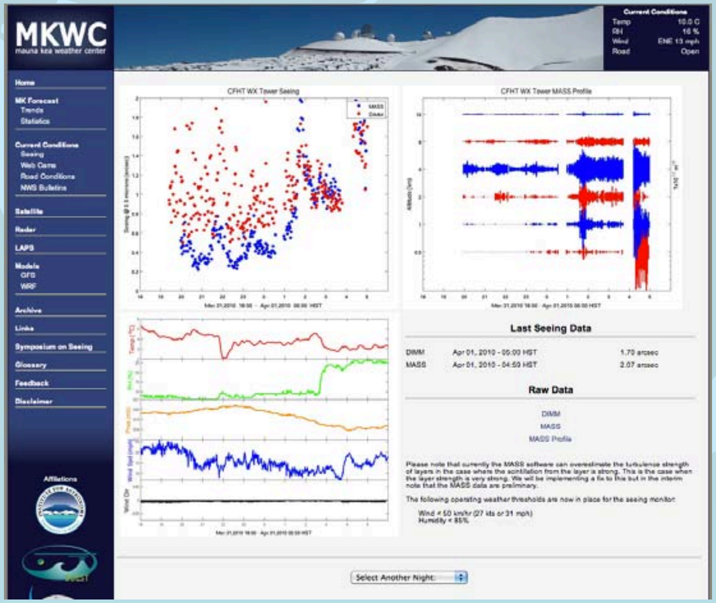
Cloud cover, fog, precipitation

Summit winds and temperature

Precipitable water

Seeing, C_n^2, and wind profiles

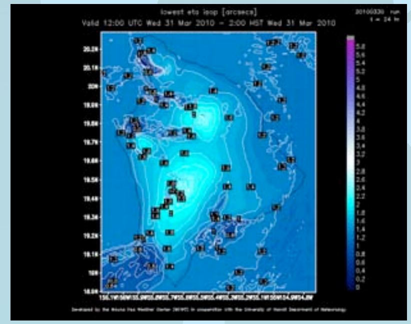
Seeing Page

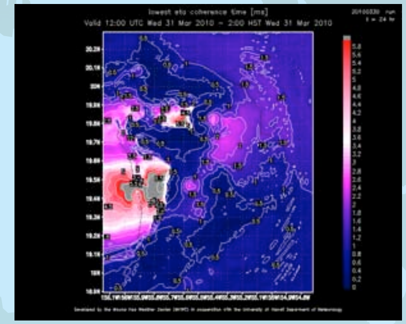


Astro-climatic parameters

The following parameters have been added to the WRF web products:

- *Isoplanatic angle;*
- *Coherence time*





Fog Statistics

% Fog occurred:		When Not Forecast	Δ%	When Forecast	Δ%
Night	1	3.9%	0	90.2%	0
	2	4.2%	+0.2	91.7%	0
	3	5.3%	-0.1	82.1%	0
	4	6.0%	-0.1	88.9%	0
	5	7.4%	-0.2	71.4%	0

Temperature Statistics

Percent Temp Forecast < 1 ºC					
Night	All Nights	Δ%	*Good Nights	Δ%	RMS
1	58.7%	+0.6	74.1%	+0.1	0.96°
2	50.7%	+0.2	59.8%	+0.8	1.23°
3	48.8%	-1.2	48.6%	+0.5	1.41°
4	44.0%	-1.2	44.6%	+0.3	1.65°
5	41.9%	-1.9	44.0%	+0.7	1.88°

Subtle changes over the last 6 months

* Defined as: RH < 80%, winds < 50 mph

PW Statistics

	Night	1	2	3	4	5
PW_{max}	1 mm	0.15	0.16	0.18	0.20	0.23
	2 mm	0.31	0.37	0.36	0.38	0.39
	4 mm	0.64	0.77	0.81	0.90	0.94

- General increase in RMS with fcst time and PW_{max}
- Not much change in the last 6 months

Primary Research Challenge: Accurate Seeing Forecasts

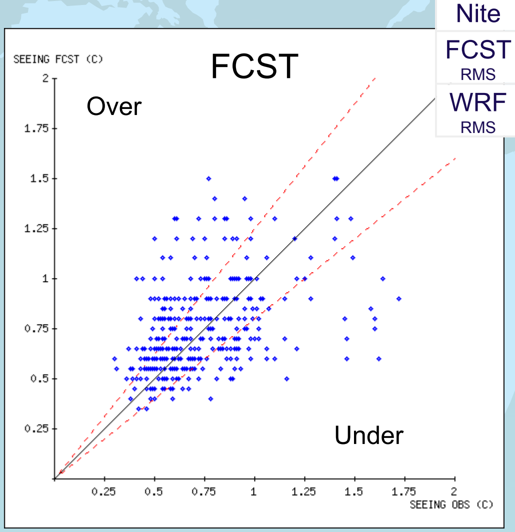
To construct prediction of C_n^2 profile need to obtain fine vertical and horizontal resolution forecasts of temperature, wind and turbulence related variables.

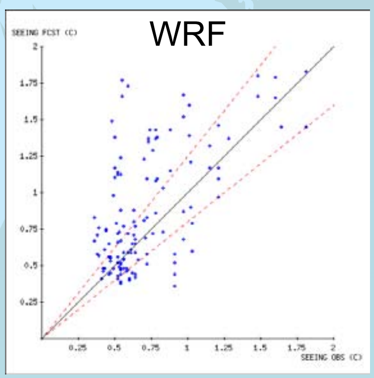
Calculate optical turbulence parameters by integrating the C_n^2 profiles

Validate and refine the optical turbulence algorithm

Seeing Statistics

Nite	1	2	3	4	5
FCST RMS	0.25	0.30	0.31	0.33	0.30
WRF RMS	0.36	0.41	0.52	N/A	N/A

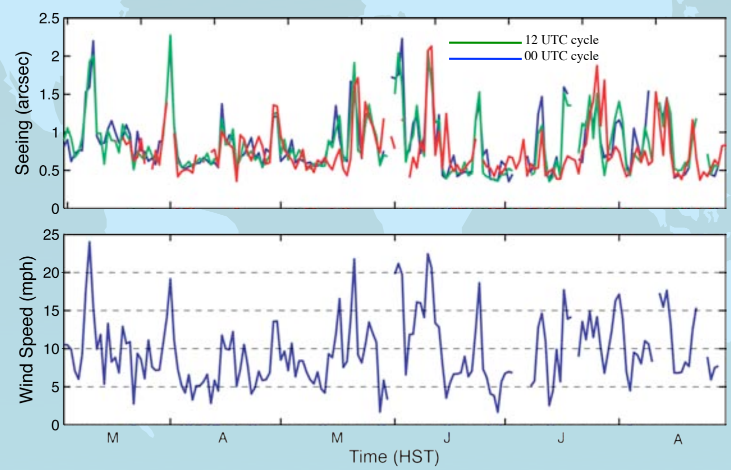




WRF Seeing Verification using MKAM

DIMM data from March to the end of August:

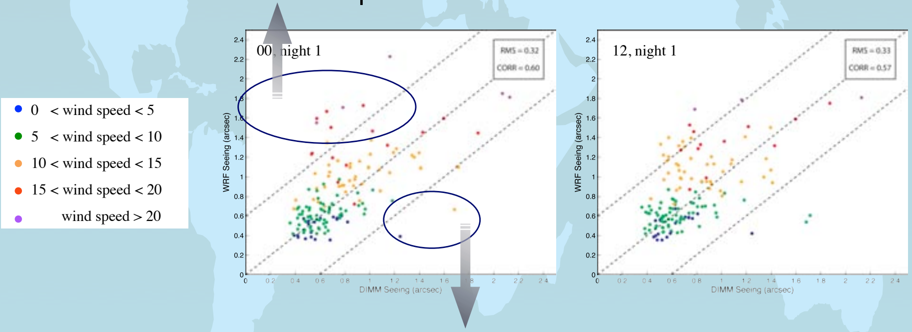
8 hours (8pm to 4am HST), nightly averages



Seeing Verification using MKAM

Data: March to August, 8 hours (8pm to 4am HST), nightly averages

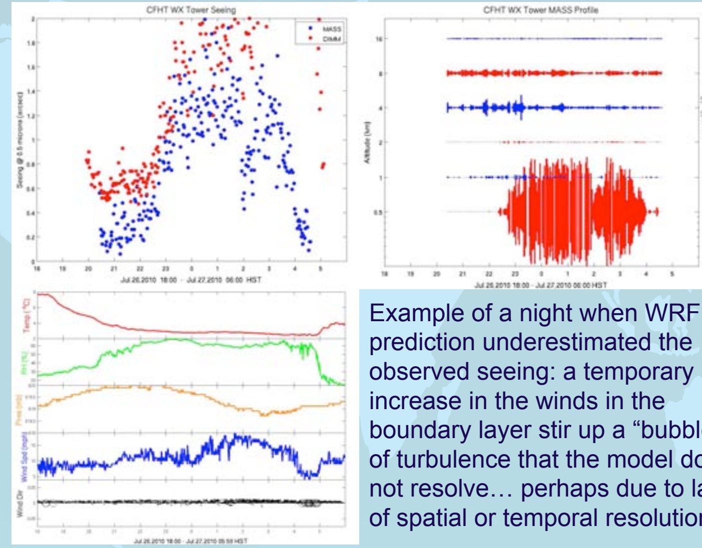
Tendency to overestimate episodes of higher surface wind speed under stable conditions.



Transitional “bubble” of turbulence

By eliminating these cases from the dataset: RMS = 0.28 and CORR = 0.7

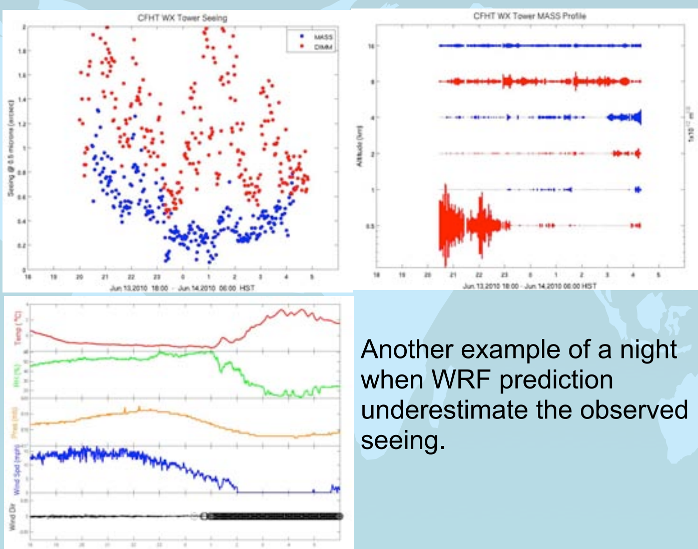
Seeing Verification using MKAM



Example of a night when WRF prediction underestimated the observed seeing: a temporary increase in the winds in the boundary layer stir up a “bubble” of turbulence that the model does not resolve… perhaps due to lack of spatial or temporal resolution.

July 26/27, 2010 (HST)

Seeing Verification using MKAM



Another example of a night when WRF prediction underestimate the observed seeing.

June 13/14, 2010 (HST)

Seeing Verification using MKAM

The dates corresponding to cases of “large” overestimation have all in common the same synoptic scenario:

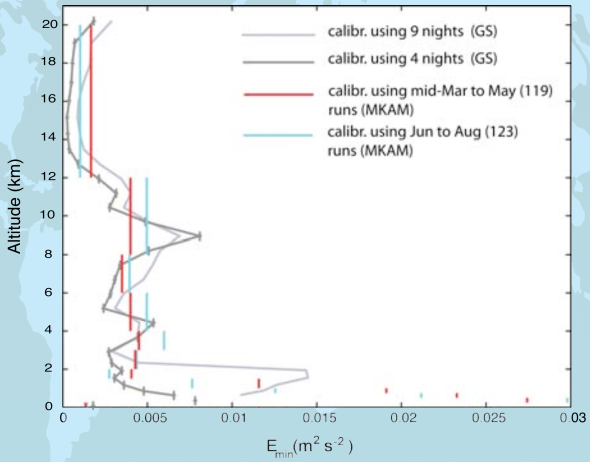
- Strong large scale subsidence → very stable atmosphere
- Strong/tight surface pressure gradients resulting in moderate to high winds at the summit (wind speed > 15-18 mph).

The atmospheric stability does not allow turbulence to develop, therefore good/average seeing is observed.

WRF generates more turbulence than it should as a consequence of the high surface winds → skew in the scatterplot.

Seeing Calibration using MKAM

Third Calibration – Current E_{min} profile



Calibration of the background TKE (E_{min}) is performed for each integral layer (6 MASS layers + 1 GL layer):

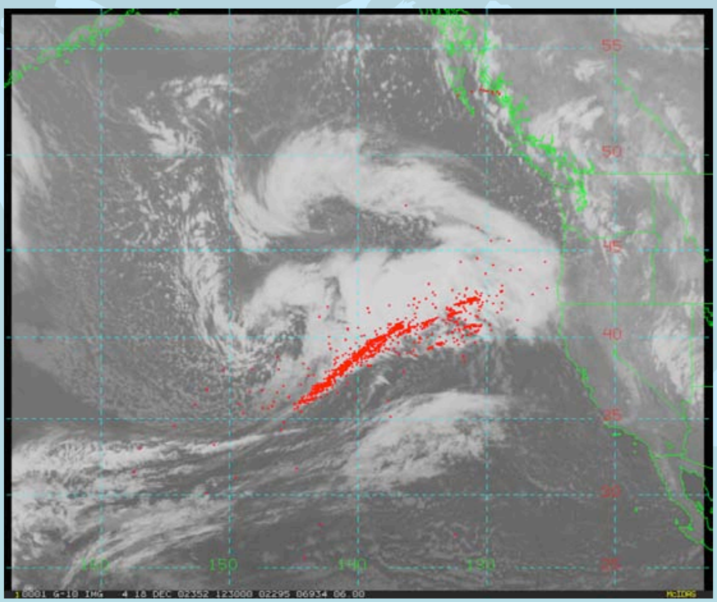
Seeing Calibration using MKAM

Statistics have been run for the two nights of each WRF cycle verifying the MKAM observations. Data are nightly averaged: 8 hours from 8pm to 4am HST.

Second calibration – Jun to Aug

	00 UTC cycle		**12 UTC cycle**	
	N1	N2	N1	N2
RMS	0.33	0.34	0.34	0.35
CORR	0.62	0.63	0.60	0.60

Synergy with Meteorology Community



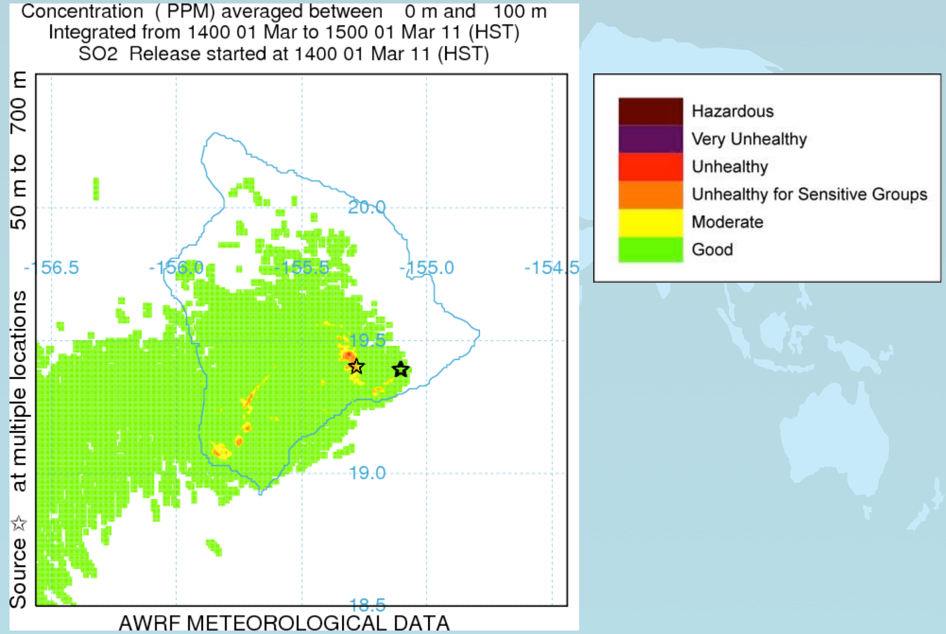
Synergy with Meteorology Community

- WRF is a community-supported research and forecast model. NSF and NOAA funding – yearly updates and improvements.
- Local Analysis and Prediction System (LAPS) data assimilation application for WRF developed in collaboration with NOAA ESRL.
- Unidata provides much of the input data for LAPS/WRF and the web distribution software used by MKWC.
  - Satellite derived atmospheric motion vectors (e.g., cloud drift winds) from UW CIMSS.
  - COSMIC Satellite Constellation: refractivity data from limb-soundings – National Center for Atmospheric Research
  - GPS IPW in collaboration with UH Geophysics and NOAA.
  - Calibration and assimilation of lightning data in collaboration with ONR and NASA.
- Vog Measurement and Prediction (VMAP) Project

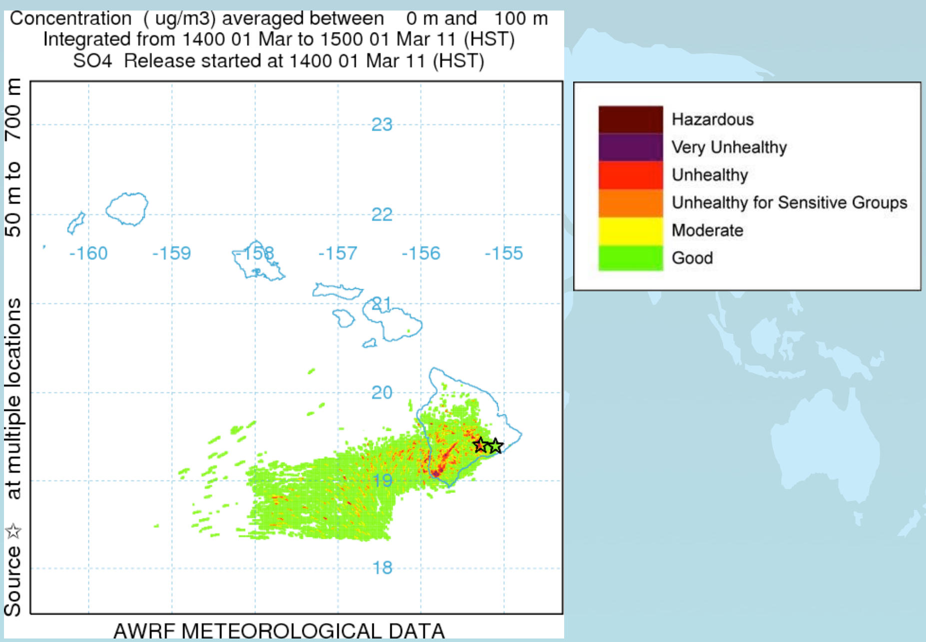
Vog Measurement and Prediction

VMAP project is facilitated by MKWC. See
http://mkwc.ifa.hawaii.edu/vmap/index.cgi

Sulfur Dioxide Animation



Sulfate Aerosol Animation

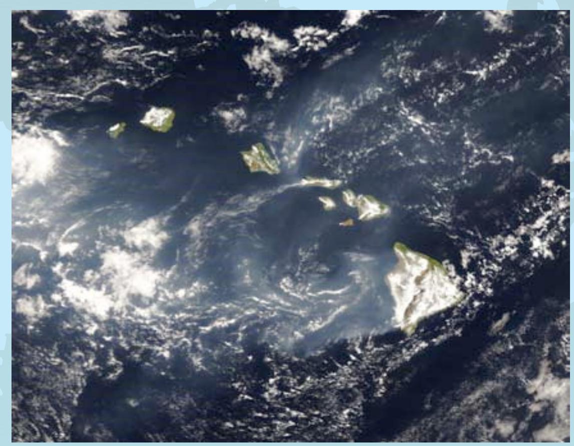


New Synergy

New Post Doctoral Fellow started this Jan – will tackle a broader WRF verification effort as part of a project to use WRF output in an ecology study funded by an NSF water resources management grant.

NOAA is funding a satellite x-band downlink that will bring NASA and NOAA POES data to UH. Project related to launch of GOES-R satellite in 2016.

- MODIS
- AQUA
- AIRS
- TRMM
- POES
- DMS



MKWC Future Work

Increase spatial and temporal resolution of WRF

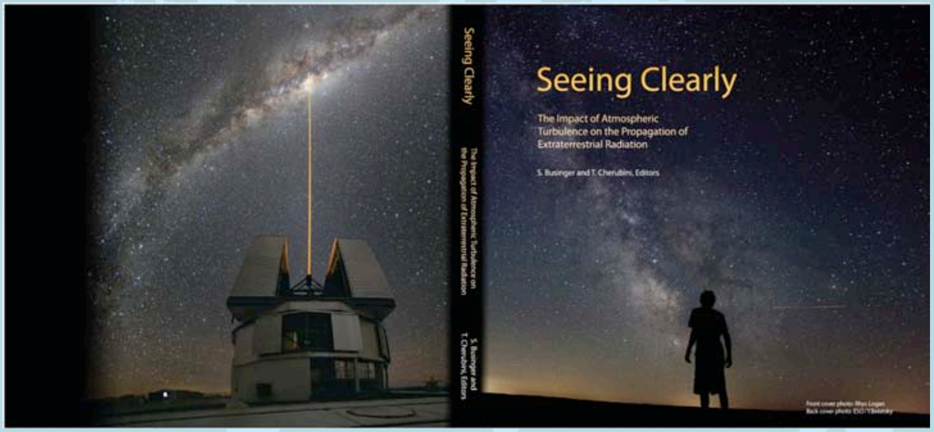
– challenge here is to overcome numerical instability due to forcing from terrain at scale of grid resolution.

Implement WRF Variational Data Assimilation

MKWC Future Work

- Increase the skill of conventional and seeing forecasts with help of validation statistics.
- Provide forecast variables with finer temporal and spatial resolution.
- Issue longer-term seeing forecasts.
- Proposal to expand MKWC service to Chile.

Textbook Now Available



Seeing Clearly

Introduction (Businger)

1. Atmospheric Turbulence — Authors
   - 1.1 Atmospheric turbulence from the perspective of a meteorologist…………………………..(Raman)
   - 1.2 Atmospheric turbulence for astronomy…………………………………………………………(Vernin)
2. Instrumentation for Observing Optical Turbulence
   - 2.1 Remote optical turbulence sensing: present and future…………………………………..(Tokovinin)
   - 2.2 Standard and commonly used optical turbulence profilers ……………………………(Chun et al.)
   - 2.3 Seeing by site monitors versus VLT image quality ……………………………………..(Sarazin et al.)
3. Adaptive Optics - Interferometry
   - 3.1 Introduction to Adaptive Optics: The Quest for Image Quality…………...(Tokovinin and Businger)
4. Modeling Optical Turbulence
   - 4.1 The "Missing Link" Between Meteorology and Astronomy…………………………..(Simons & Roy)
   - 4.2 Optical Turbulence Modeling and Forecast. Towards a new era for ground-based astrononmy…………………………………………(Masciadri)
   - 4.3 An operational perspective for modeling optical turbulence…......(Cheribini, Businger, and Lyman)

Questions?