Government of India
MINISTRY OF NEW AND RENEWABLE ENERGY

NATIONAL INSTITUTE OF WIND ENERGY

Karthik Ramanathan

Indian Experiences on Solar Resource Assessment

National Institute of Wind Energy
Chennai, India

14th BSRN Science & Review Workshop

Bureau of Meteorology
Canberra, Australia
28-04-2016

AN UNIQUE PROJECT ON
"SOLAR RADIATION RESOURCE ASSESSMENT IN INDIA"

INITIATED BY

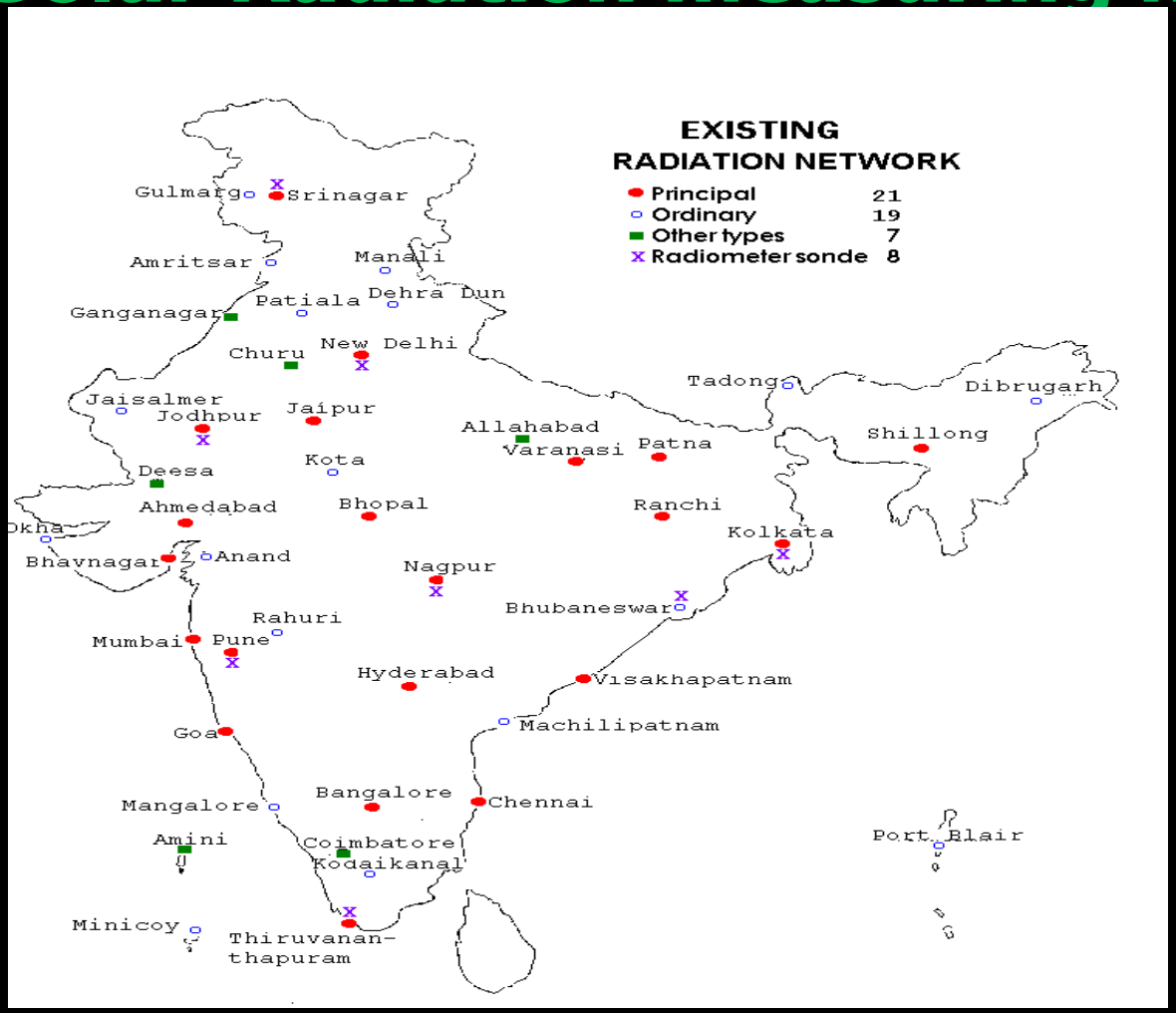
MINISTRY OF NEW AND RENEWABLE ENERGY
&
NATIONAL INSTITUTE OF WIND ENERGY

COMMENCED ON FEBRUARY, 2011

Availability Solar Radiation Data

- "Solar Radiation over India" *by A Mani*,
- "Handbook of Solar Radiation" by *A Mani and S.Rangarajan*
- "Solar Radiant Energy over India (2009)" by *Ministry of New and Renewable Energy ,GOI.*
- NISE(SEC)-NREL
- NASA
- Very limited measured solar radiation data is available for the country.

IMD -Solar Radiation measuring network

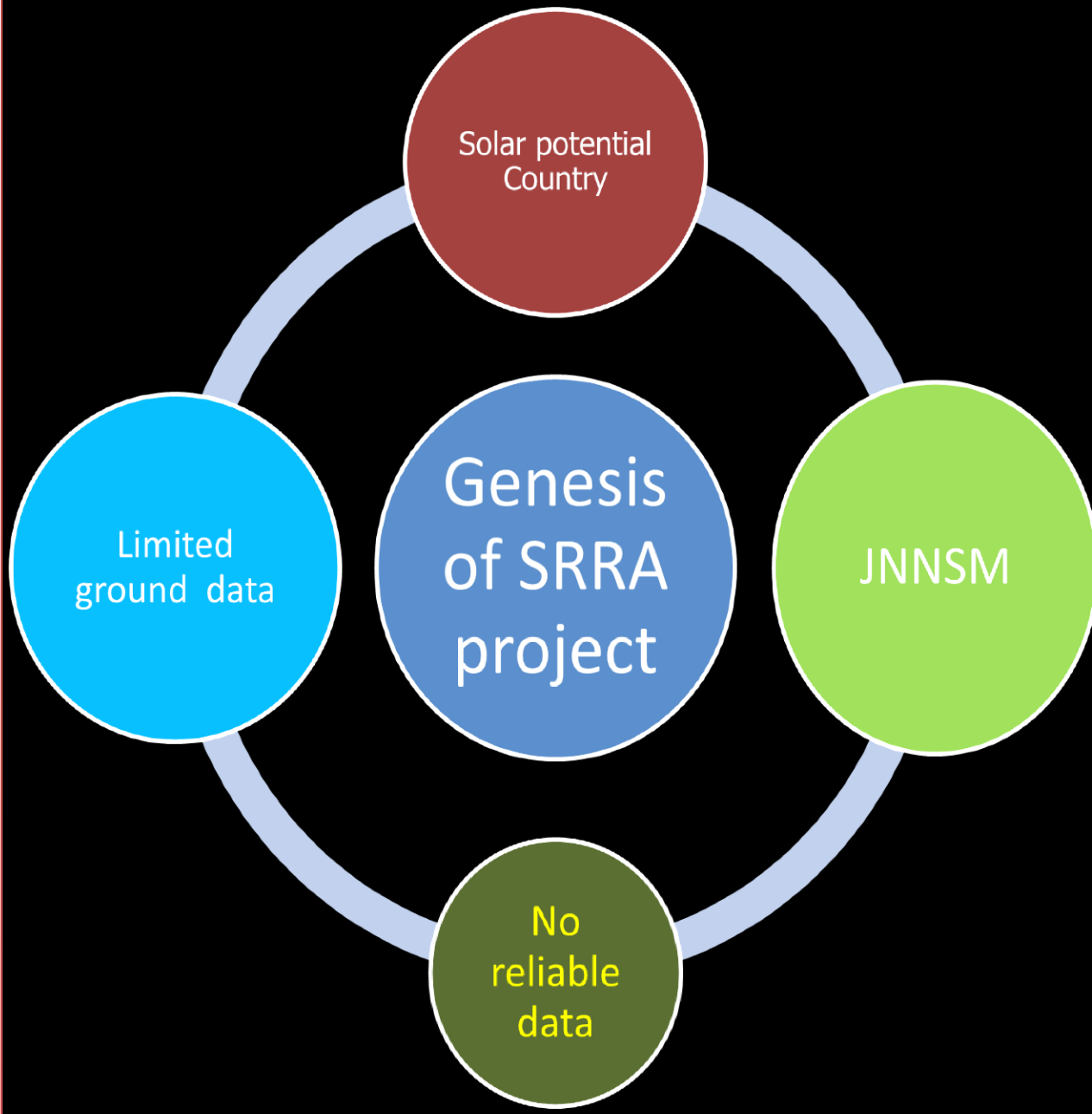


❑**Solar Radiation over India" *by A Mani*,**

❑**Handbook of Solar Radiation" by *A Mani and S.Rangarajan***

❑**"Solar Radiant Energy over India (2009)" by *MNRE.***

❑**India Meteorological Department (IMD) Stations.**



An unique project on

Ground Measurement of Solar Radiation data

Initiated by

Ministry of New and Renewable Energy

Implemented by

National Institute of Wind Energy

Commenced from

2010 in staggered phases

Objectives



Installation

- To Install Solar Radiation and Weather data measuring station
- To create countrywide organizational structures for solar radiation data collection system.

Solar Atlas

- To develop a strong database of accurate Solar radiation Data
- To develop solar radiation atlas of India.

Dissemination

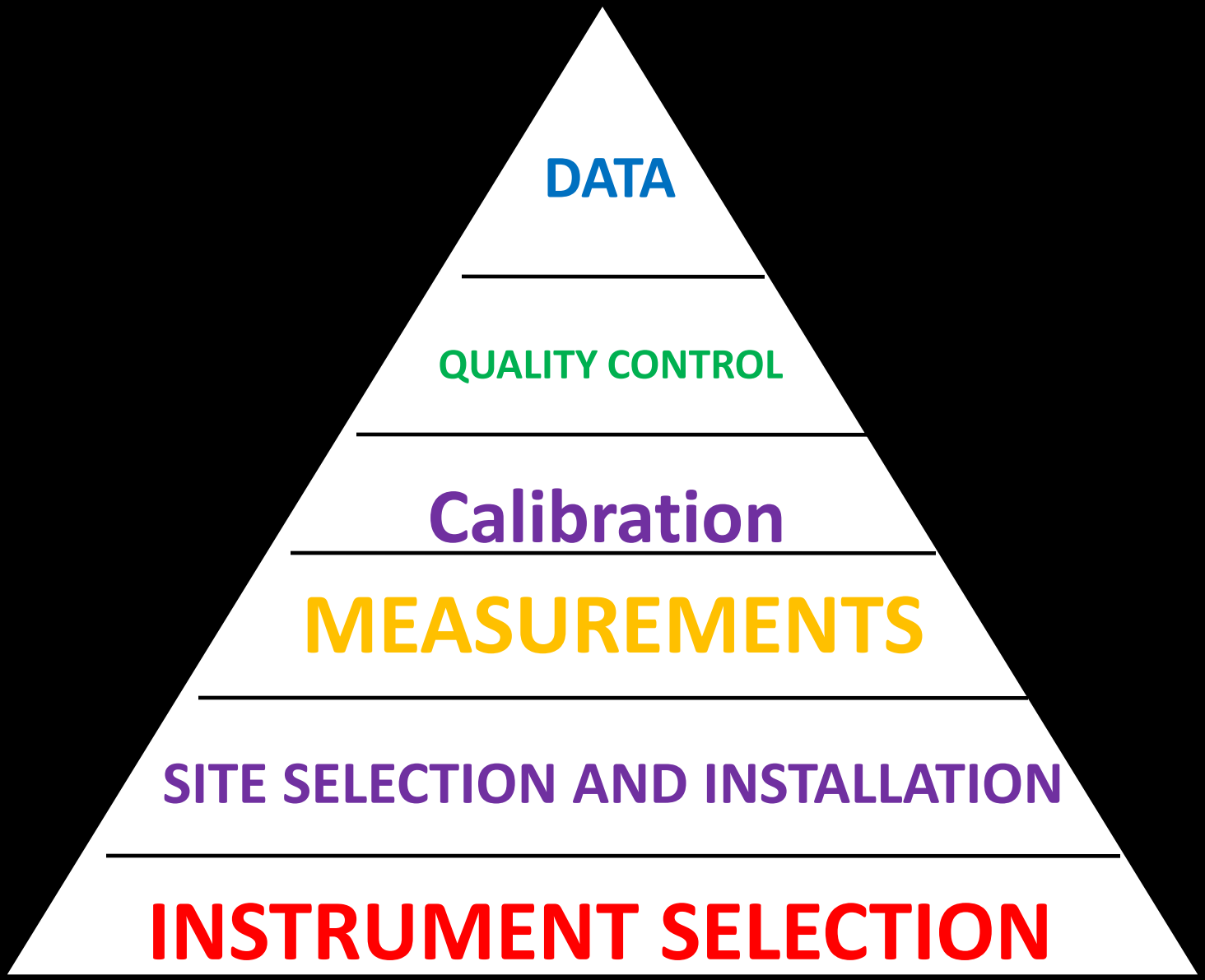
- To make Solar Data Products ready for solar developers, FIs, Policy makers, R & D institutions etc
- Support for marketing and bankability of solar projects

Jawaharlal Nehru National Solar Mission..

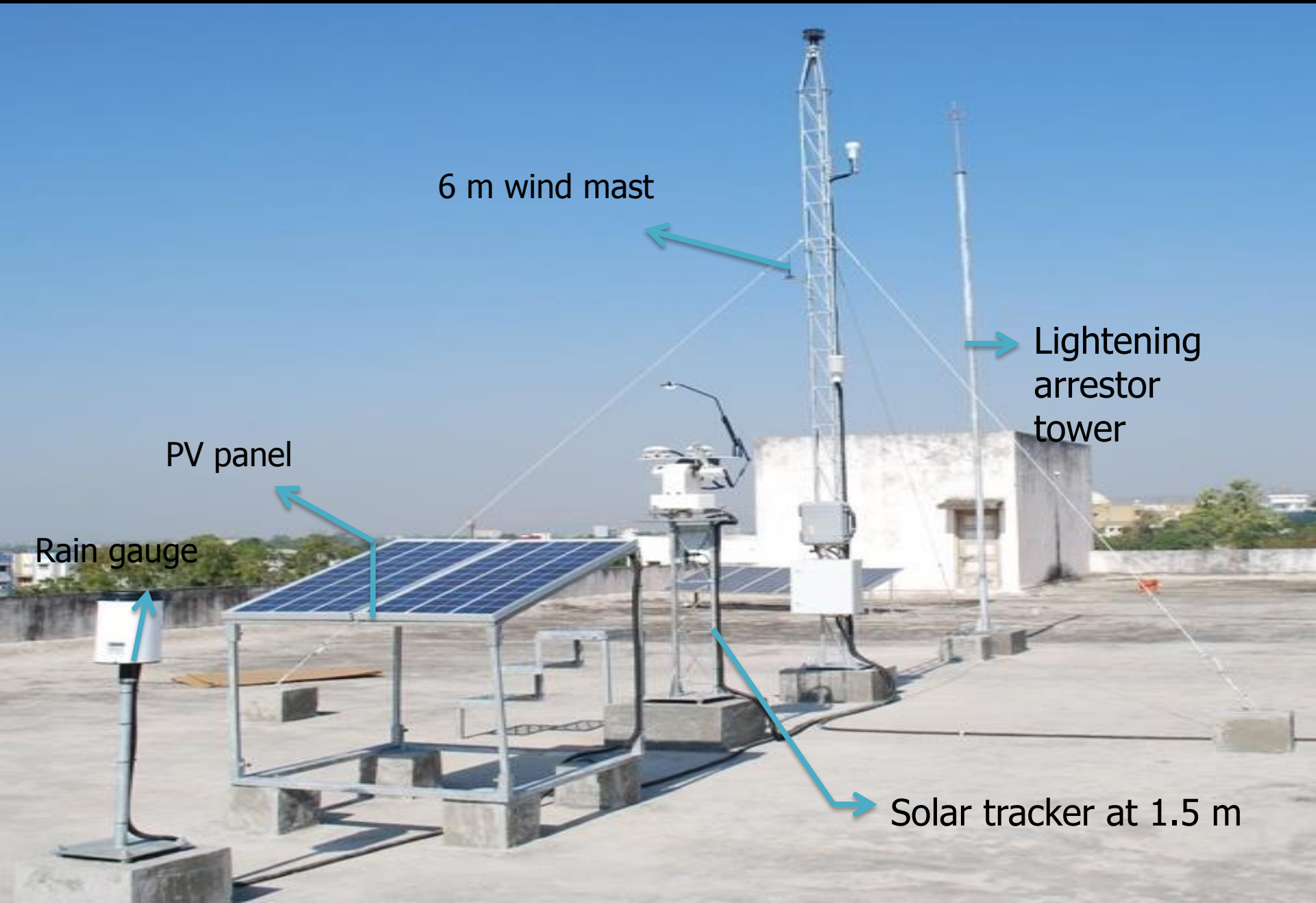
Application segment	Target for Phase I (2010-13)	Target for Phase 2 (2013-17)	Target for Phase 3 (2017-22)
Solar collectors	7 million sq. meter	15 million sq. meter	20 Million sq. meter
Off grid solar application	200 MW	1000 MW	2000 MW
Utility grid power, including roof top	1000-2000 MW	4000-10000 MW	20000 MW

1. **As per the updated targets the National Solar Mission, India aims to have an installed solar power capacity of 100 GW by 2022.**
2. **100 GW capacity will include 40 GW rooftop solar power capacity and 60 GW utility-scale solar power projects**

DATA QUALITY PYRAMID



Typical SRRA Station

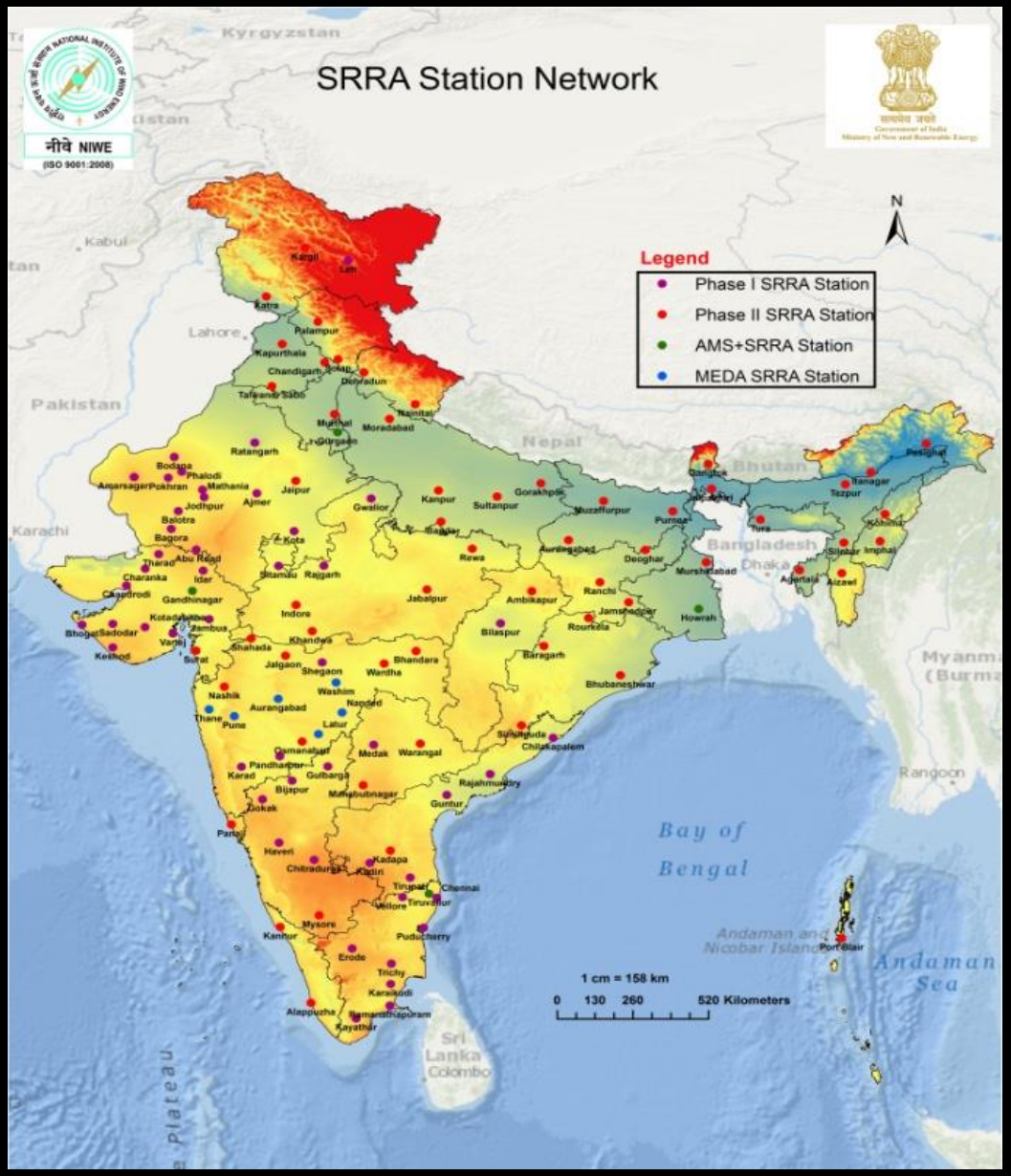


Site Photograph

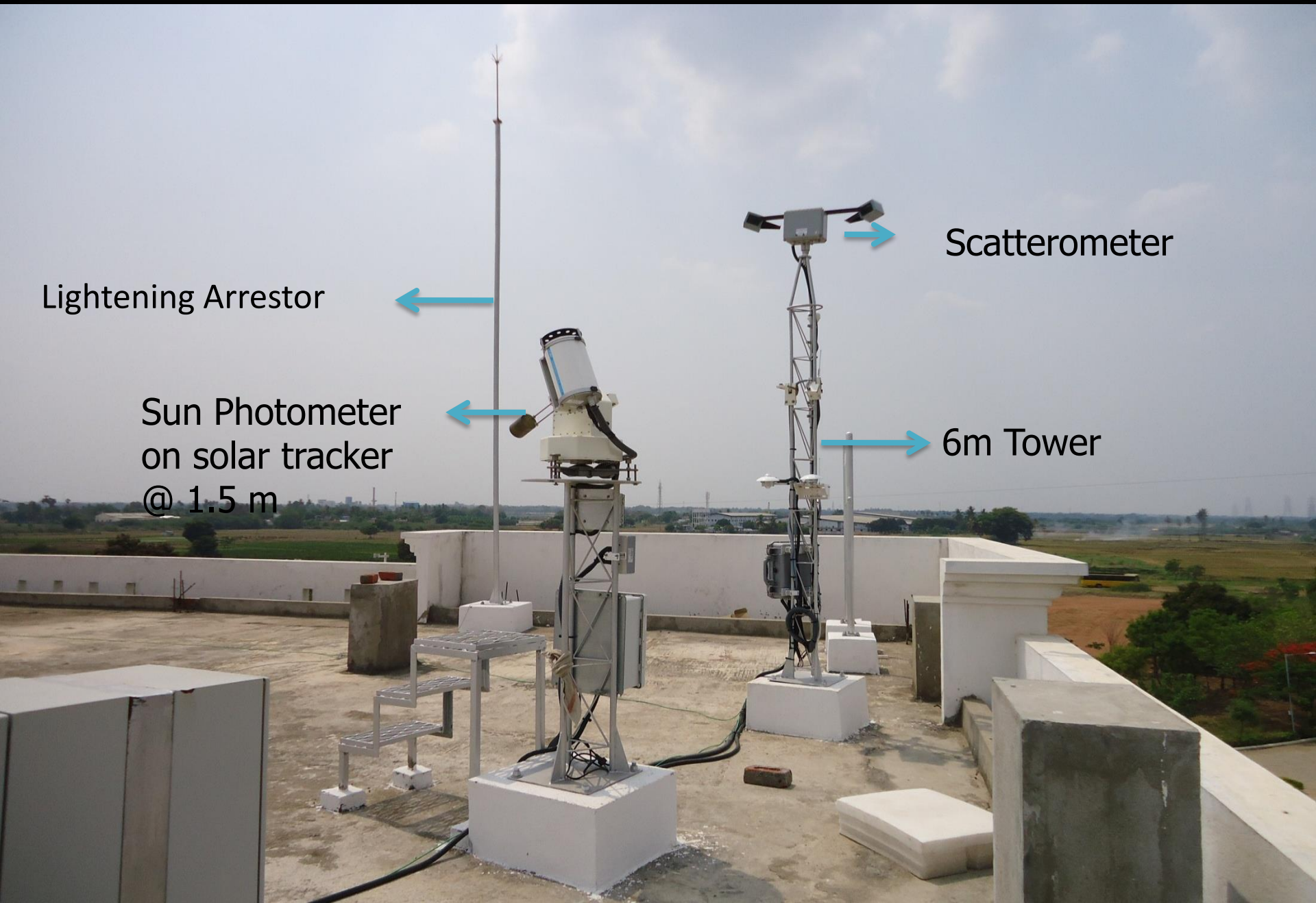
SRRA Stations-Phase-I

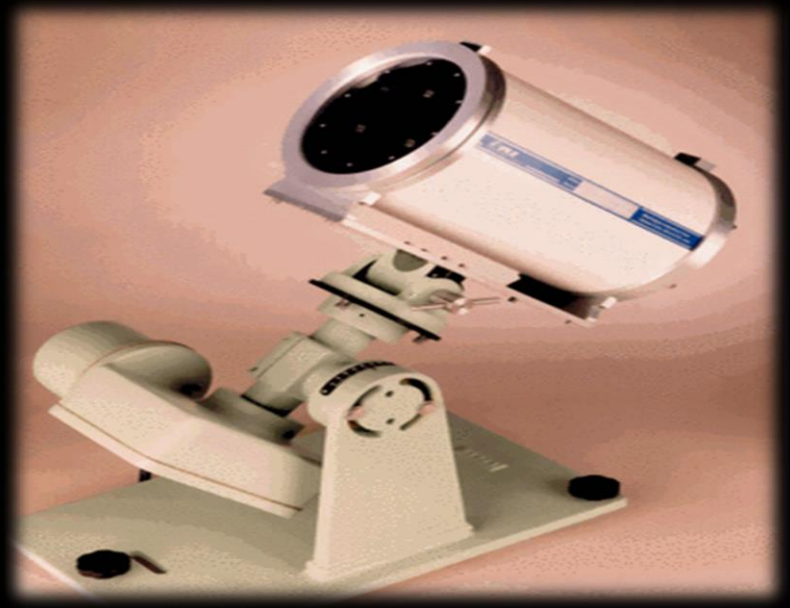
Dedicated SRRA stations

Phase I	51
Phase II	60
MEDA	06
AMS	04
Total	121



Advanced Measurement Station(AMS)





Direct Beam Filter Spectrometer-YES, USA

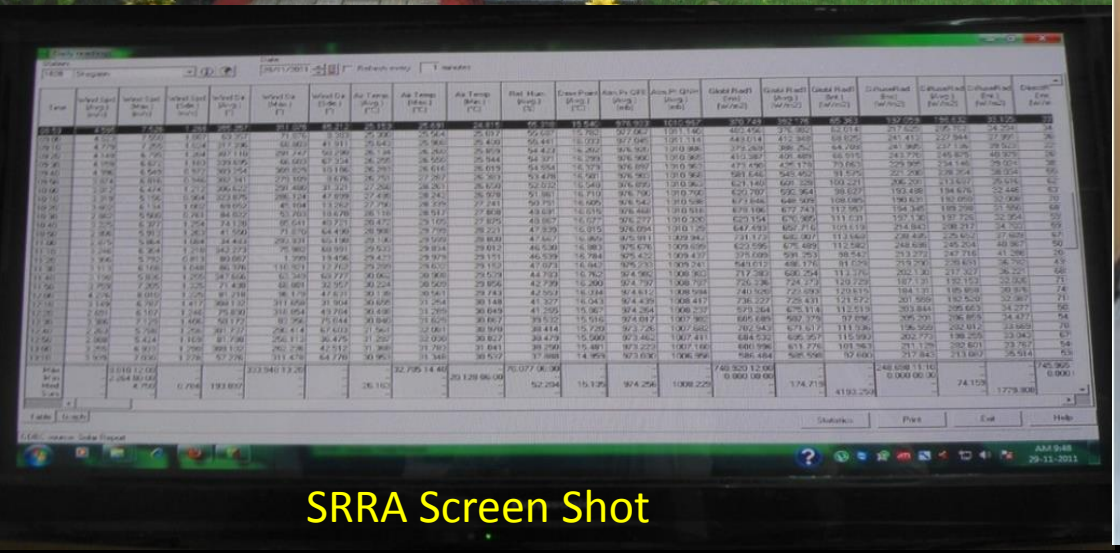
Scatterometer - Envirotech USA

Albedometer-Hukseflux-SRA20

Silicon Pyranometer

Pyrgeometer-Hukseflux-IR20

CWET SRRA Station



SRRA Screen Shot

SRRA Servers

SolMap Servers

SRRA-Servers comprising of Primary, Secondary and Web server receiving & archiving data from all SRRA stations: 1 s data sampling at stations averaged to 1 min. SolMap-Servers for quality check (QC), assessment and SRRA product generation.

Data Collection & Quality Control

Sampling period	Averaging period	Duration
10 sec	10 min	Up to Nov 2011
1 sec	10 min	Up to August 2012
1 sec	1 min	From August 2012 till date

For solar radiation parameters, the applied quality control is based on Baseline Surface Radiation Network (BSRN) rules by the World Meteorological Organisation(WMO), elaborated by the Management and Exploitation of Solar Resource Knowledge(MESOR)

Field Experiences

Gap Filling Procedures – Basic Gap Filling

1. Basic Gap Filling

Gap filling methodology depends on

a) availability of three solar radiation components:

Global Horizontal Irradiance (GHI)
Diffuse Horizontal Irradiance (DHI)
Direct Normal Irradiance (DNI)

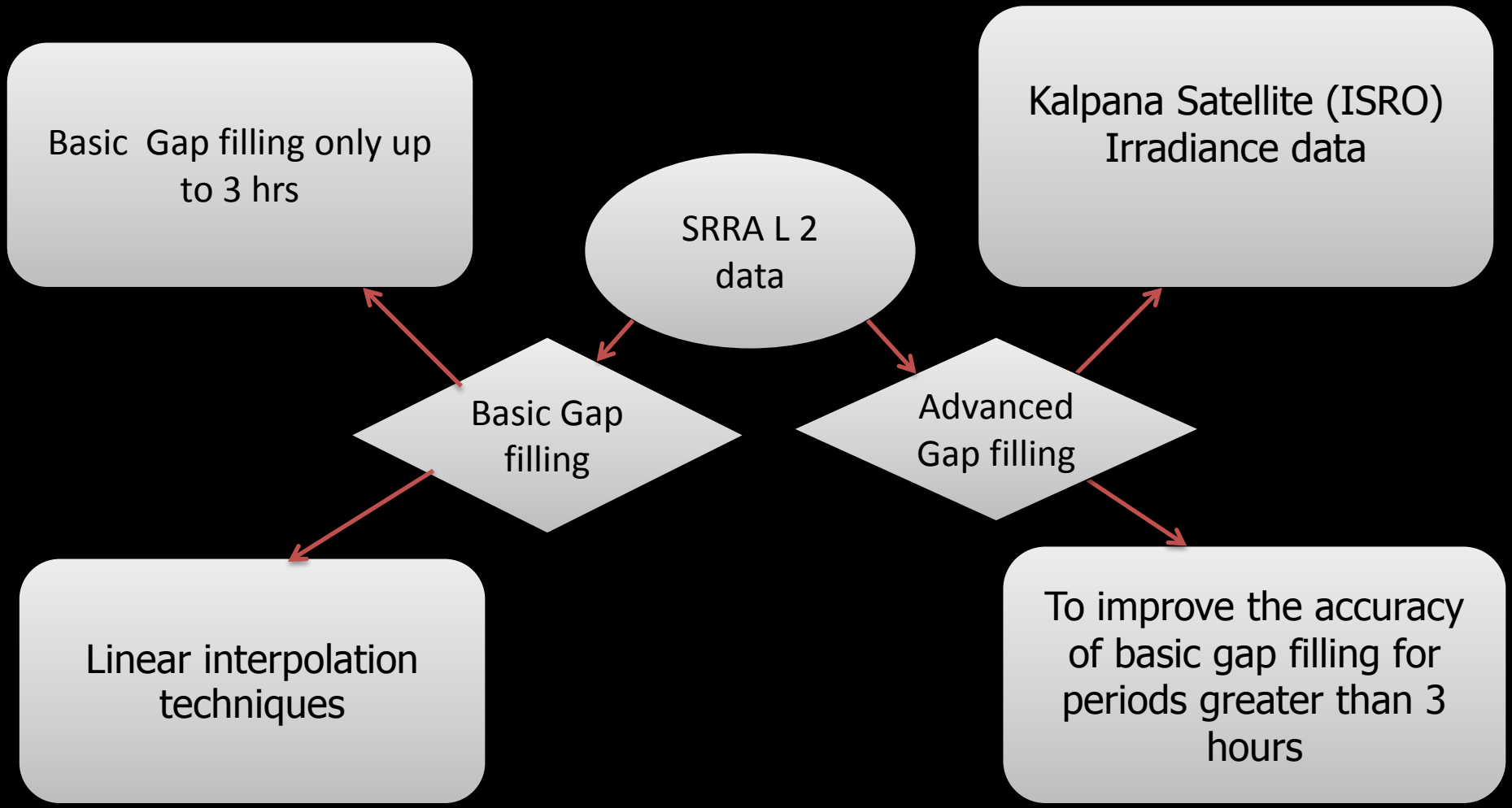
- Case 1: gap for one component (GHI only or DHI only or DNI only)
- Case 2: gap for two components (DHI and DNI**)**
- Case 3: gap for all three solar radiation components (GHI, DHI and DNI)

b) the duration (length) of the gap:

- up to 3 hours
- greater than 3 hours

L3 Basic Gap Filling

- Basic gap filling procedures developed under SRRA/SolMap for data products
- The methodology depends on the availability of 3 radiation parameters and duration
- At the moment basic gap filling is done with 1 hour resolution time series
- Advanced gap filling techniques using satellite derived values are being implemented under SolMap project now and expected to be operational in a few months
- The impacts of basic gap filling was tested with al 51 stations of SRRA phase 1
- Accuracy of basic gap filling method was tested by creating artificial gaps
  - Mean bias of about 3% observed over GHI, DNI, DHI over all types of gaps
  - This accuracy is close to the accuracy of the measuring instruments indicating the gap filled values stay within tolerance limits


Basic Gap filling only up to 3 hrs
SRRA L 2 data
Kalpana Satellite (ISRO) Irradiance data
Basic Gap filling
Advanced Gap filling
Linear interpolation techniques
To improve the accuracy of basic gap filling for periods greater than 3 hours

SRRA products: example of L2 ASCII

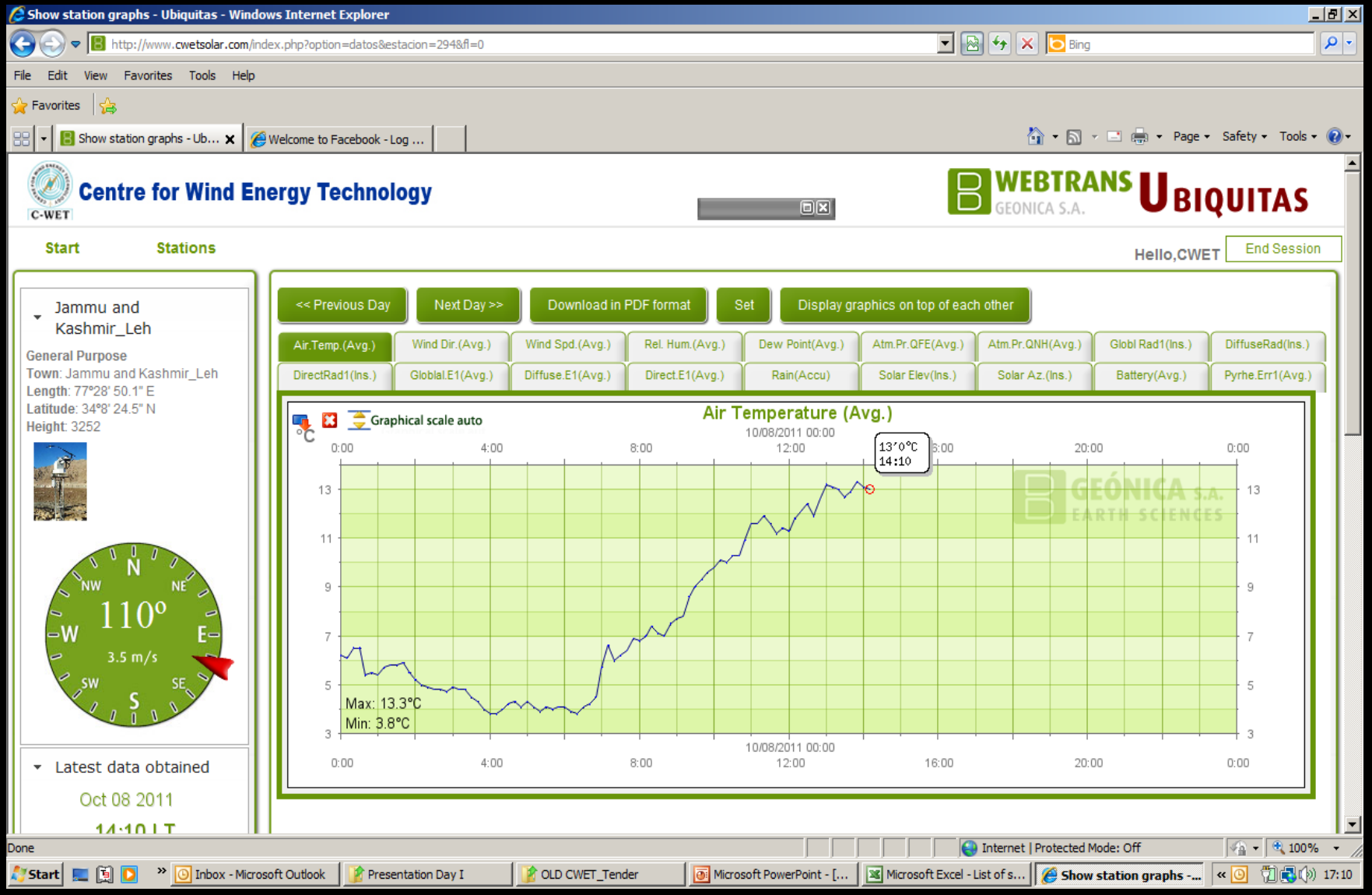
SRRA_Cwet_20120201_0001-20121101_0000_1min__UTCplus5_20121115 - Notepad

File Edit Format View Help

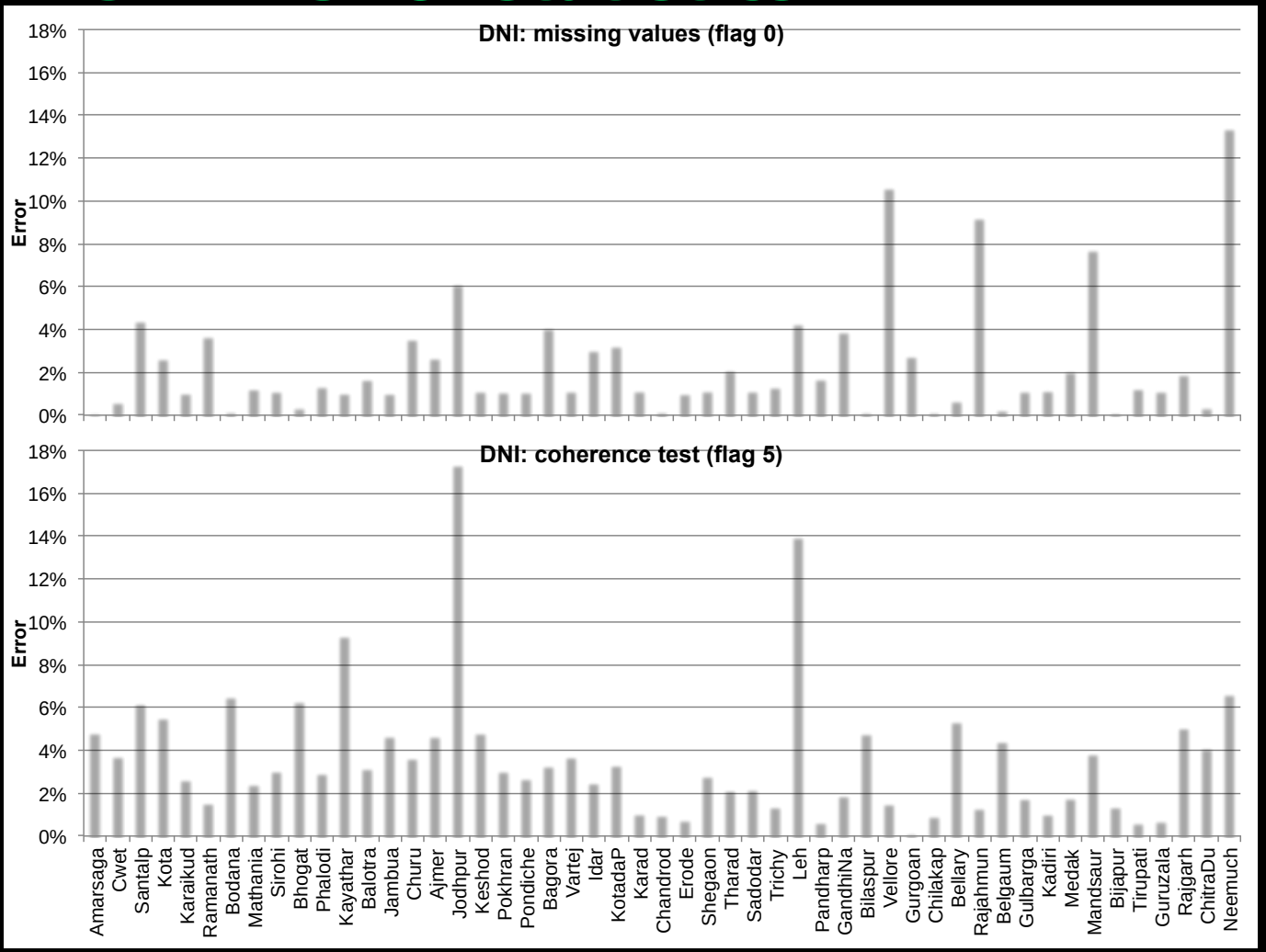
2012-10-25 11:13	64.7	173.9	899	10000	726	10000	261	10000	3.0	10000
2012-10-25 11:14	64.7	174.5	902	10000	715	10000	273	10000	3.8	10000
2012-10-25 11:15	64.7	175.0	927	10000	735	10000	280	10000	3.9	10000
2012-10-25 11:16	64.7	175.6	938	10000	743	10000	285	10000	2.9	10000
2012-10-25 11:17	64.7	176.2	942	10000	746	10000	286	10000	4.0	10000
2012-10-25 11:18	64.8	176.7	935	10000	722	10000	300	10000	3.1	10000
2012-10-25 11:19	64.8	177.3	912	10000	669	10000	325	10000	3.7	10000
2012-10-25 11:20	64.8	177.9	348	10000	22	10000	323	10000	3.2	10000
2012-10-25 11:21	64.8	178.5	767	10000	481	10000	354	10000	3.4	10000
2012-10-25 11:22	64.8	179.0	661	10000	341	10000	361	10000	4.7	10000
2012-10-25 11:23	64.8	179.6	909	10000	686	10000	308	10000	4.5	10000
2012-10-25 11:24	64.8	180.2	915	10000	721	10000	282	10000	3.6	10000
2012-10-25 11:25	64.8	180.8	911	10000	727	10000	272	10000	3.4	10000
2012-10-25 11:26	64.8	181.3	895	10000	718	10000	263	10000	4.7	10000
2012-10-25 11:27	64.8	181.9	896	10000	717	10000	264	10000	4.4	10000
2012-10-25 11:28	64.8	182.5	905	10000	711	10000	279	10000	4.3	10000
2012-10-25 11:29	64.8	183.0	905	10000	690	10000	299	10000	4.7	10000
2012-10-25 11:30	64.7	183.6	918	10000	696	10000	306	10000	4.1	10000
2012-10-25 11:31	64.7	184.2	923	10000	709	10000	300	10000	4.5	10000
2012-10-25 11:32	64.7	184.8	928	10000	705	10000	309	10000	3.5	10000
2012-10-25 11:33	64.7	185.3	NaN	40050	700	10000	334	10000	4.3	10000
2012-10-25 11:34	64.7	185.9	NaN	40010	670	10000	358	10000	4.1	10000
2012-10-25 11:35	64.6	186.5	707	10000	413	10000	348	10000	5.0	10000
2012-10-25 11:36	64.6	187.0	928	10000	702	10000	314	10000	4.9	10000
2012-10-25 11:37	64.6	187.6	913	10000	704	10000	295	10000	4.4	10000
2012-10-25 11:38	64.5	188.2	745	10000	520	10000	290	10000	4.1	10000
2012-10-25 11:39	64.5	188.7	838	10000	643	10000	277	10000	4.3	10000
2012-10-25 11:40	64.5	189.3	909	10000	726	10000	271	10000	3.6	10000
2012-10-25 11:41	64.4	189.8	895	10000	705	10000	276	10000	4.1	10000
2012-10-25 11:42	64.4	190.4	899	10000	705	10000	280	10000	3.8	10000
2012-10-25 11:43	64.3	190.9	896	10000	692	10000	290	10000	5.6	10000
2012-10-25 11:44	64.3	191.5	869	10000	664	10000	287	10000	4.7	10000
2012-10-25 11:45	64.2	192.1	867	10000	680	10000	272	10000	4.8	10000
2012-10-25 11:46	64.2	192.6	872	10000	706	10000	253	10000	4.7	10000
2012-10-25 11:47	64.1	193.1	873	10000	716	10000	246	10000	4.7	10000
2012-10-25 11:48	64.1	193.7	872	10000	712	10000	248	10000	3.6	10000
2012-10-25 11:49	64.0	194.2	868	10000	702	10000	254	10000	3.0	10000
2012-10-25 11:50	64.0	194.8	876	10000	701	10000	263	10000	3.5	10000
2012-10-25 11:51	63.9	195.3	880	10000	696	10000	273	10000	4.9	10000
2012-10-25 11:52	63.8	195.8	879	10000	687	10000	279	10000	5.2	10000
2012-10-25 11:53	63.8	196.4	897	10000	712	10000	276	10000	4.3	10000
2012-10-25 11:54	63.7	196.9	888	10000	713	10000	267	10000	4.4	10000
2012-10-25 11:55	63.6	197.4	866	10000	697	10000	259	10000	3.8	10000
2012-10-25 11:56	63.5	198.0	858	10000	690	10000	257	10000	3.2	10000
2012-10-25 11:57	63.5	198.5	871	10000	709	10000	253	10000	3.5	10000
2012-10-25 11:58	63.4	199.0	870	10000	713	10000	251	10000	3.1	10000
2012-10-25 11:59	63.3	199.5	875	10000	727	10000	245	10000	4.8	10000
2012-10-25 12:00	63.2	200.0	860	10000	708	10000	245	10000	4.5	10000
2012-10-25 12:01	63.1	200.5	864	10000	717	10000	242	10000	4.1	10000
2012-10-25 12:02	63.1	201.0	859	10000	711	10000	242	10000	5.1	10000
2012-10-25 12:03	63.0	201.5	860	10000	704	10000	250	10000	4.3	10000

Online data from C-Wet Solar Website

www.cwetsolar.com



SRRA error statistics



Most frequent shortcomings DNI:

<- Missing values on average 2.3 %

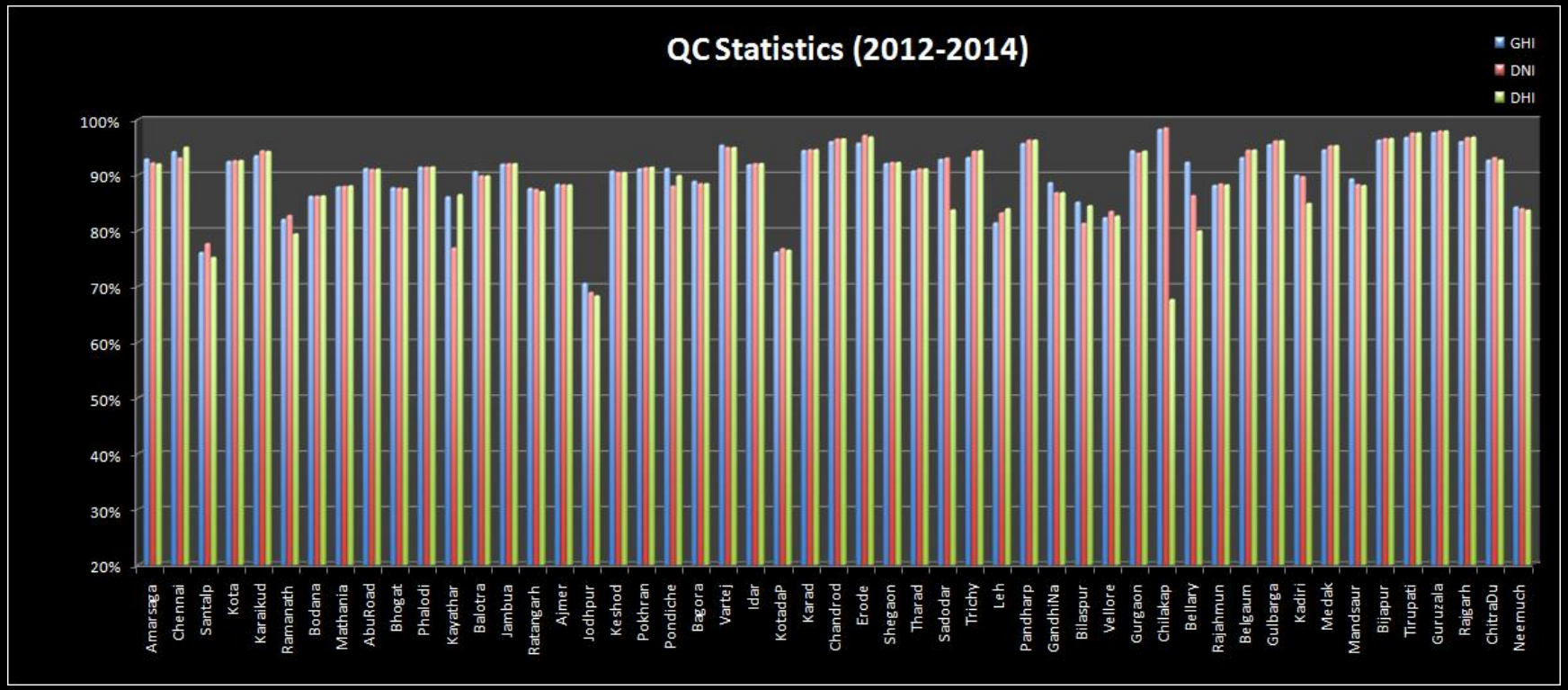
<- Coherence test on average 3.6 %

Tracking error on average only 0.7 %

Error Statistics

Error Percentage (2013)						
State	GHI		DNI		DHI	
	flagged correct	flagged incorrect	flagged correct	flagged incorrect	flagged correct	flagged incorrect
	[%]	[%]	[%]	[%]	[%]	[%]
Jammu &Kashmir	90.15%	9.85%	92.85%	7.15%	95.30%	4.70%
Tamil Nadu	91.21%	8.79%	90.95%	13.30%	90.18%	9.82%
Rajasthan	93.98%	6.06%	94.36%	5.64%	94.40%	5.60%
Pondicherry	95.40%	4.60%	94.60%	5.40%	94.60%	5.40%
Madhya Pradesh	94.83%	5.18%	95.29%	4.87%	94.95%	5.05%
Maharashtra	96.33%	3.54%	96.88%	3.13%	97.01%	3.12%
Karnataka	95.81%	4.19%	93.41%	6.59%	90.31%	9.69%
Harayana	95.00%	5.01%	95.28%	4.74%	98.51%	1.49%
Gujarat	91.47%	8.52%	92.43%	9.80%	92.95%	7.06%
Chhattisgarh	90.80%	9.20%	91.04%	8.96%	91.15%	8.84%
Andhra Pradesh	94.00%	5.90%	94.10%	6.30%	94.10%	5.90%

SRRA Phase I Performance(51Stations)



SOLAR ATLAS

- 16 years of Satellite derived maps (1999-2014) were procured from M/S 3 Tier by competitive bidding.
- Developed of Quality Assessment Protocol for validation of long term solar irradiance data of 3 Tier against SRRA ground measurements.
- Analysis, quality check and comparison of Satellite based time series data for 115 locations against SRRA stations ground data for preparation of Solar Radiation Map of India.
- Measurements from 54 SRRA stations spread over India were used to adjust satellite derived estimates on a monthly basis. The final map products were validated against the remaining 61 SRRA stations. Using both ground measured solar radiation data of three years and long term satellite data, Solar Atlas of India has been prepared. The atlas consists of 90 solar radiation maps with spatial resolution of 3km X 3km, 30 maps each for GHI, DNI and DHI which comprises of log term averages, long term monthly average, annual average, annual variability maps and uncertainty maps.

3 Tier Satellite Data Sources

Satellite Platform used

- Meteosat-5 covered India from July 1998 through February 2007. Meteosat-7 covers India from February 2007 through February 2014 and is in continuing service. Both satellites are from the first generation of Meteosat satellite and the visible band (0.45 – 1.0 μm) is used.
- Geo-location of Meteosat-5 from around 2005 onwards was difficult due to difficulties to stabilize the satellites

orbit. Thus, likelihood of erroneous data is higher until Meteosat-7 took over in 2007

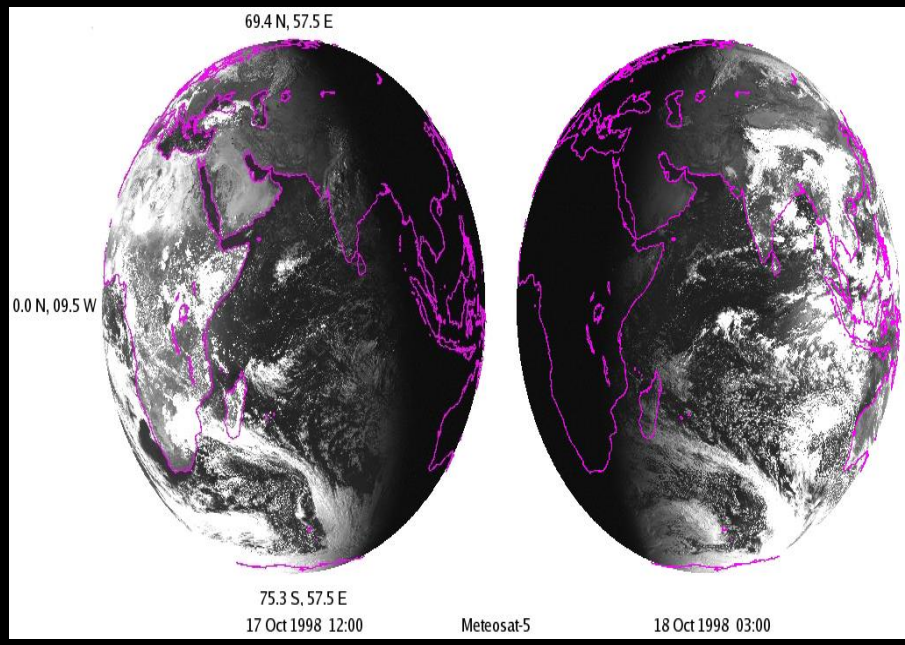
Satellite Position

- Meteosat-5 from mid 1998 was located at
- approx. 63°E, while M-7 from late 2006 was
- at around 57°E

Temporal coverage of Satellite_ Start date/ End date and Operational duration

- Meteosat 5 02/05/1991 – 16/04/2007, Indian Ocean position started on 01/07/1998.

Meteosat 7 02/09/1997 to 01/31/2014 (ongoing), Indian Ocean position started on 01/11/2006.



Input data for the Solar Radiation Atlas of India

long-term satellite data	+	ground-measured data

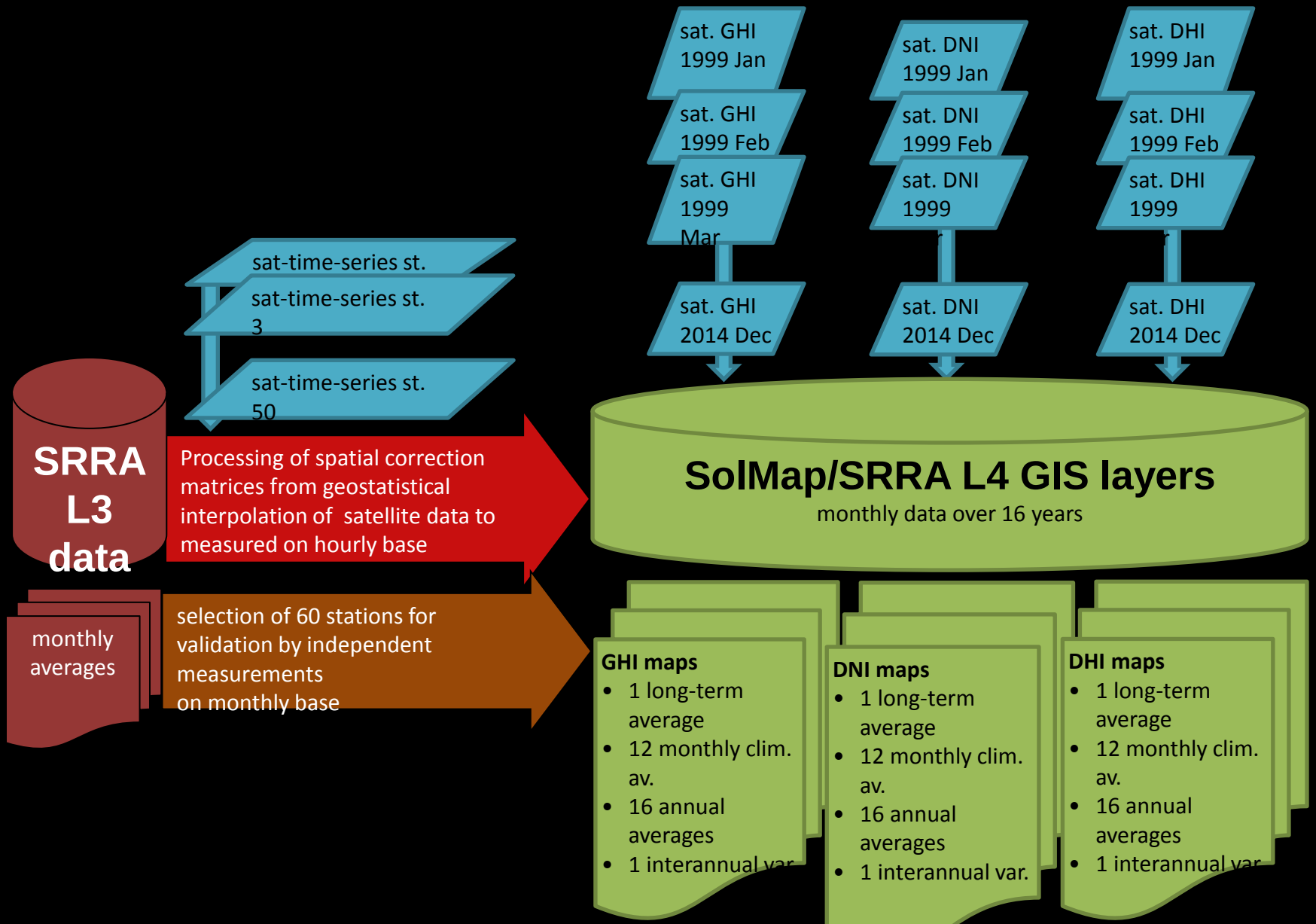
- 3TIER satellite-derived monthly maps of India & time-series for SRRA stations
  - 1999 to 2014 => **16 years**

  Delivered in March 2015

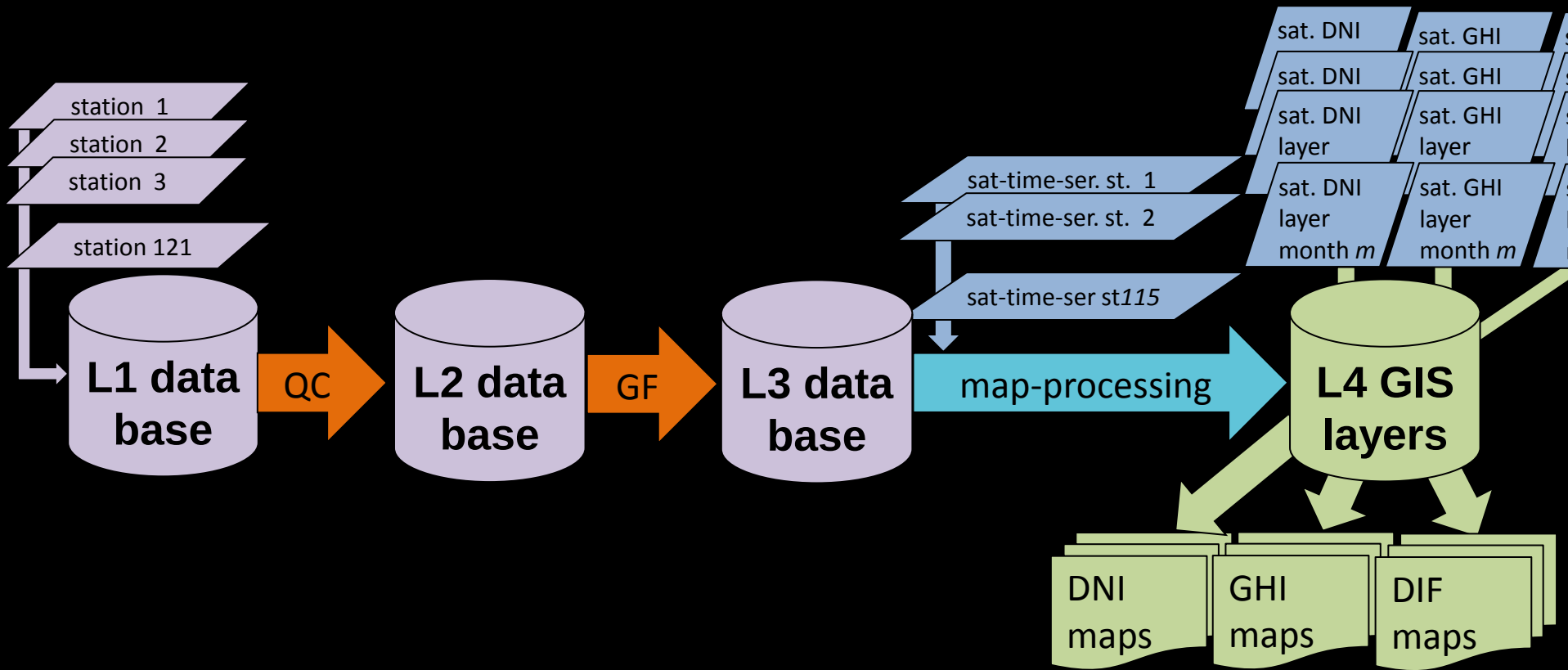
SRRA 'ground truth'

- Phase 1: 51 stations starting 2011, operational since 2012
- Phase 2: 64 + 6 MEDA stations stations starting 2014
- Total: **115 - 121 stations**
  => 2012 to 2014
  => **½ to >3 years**

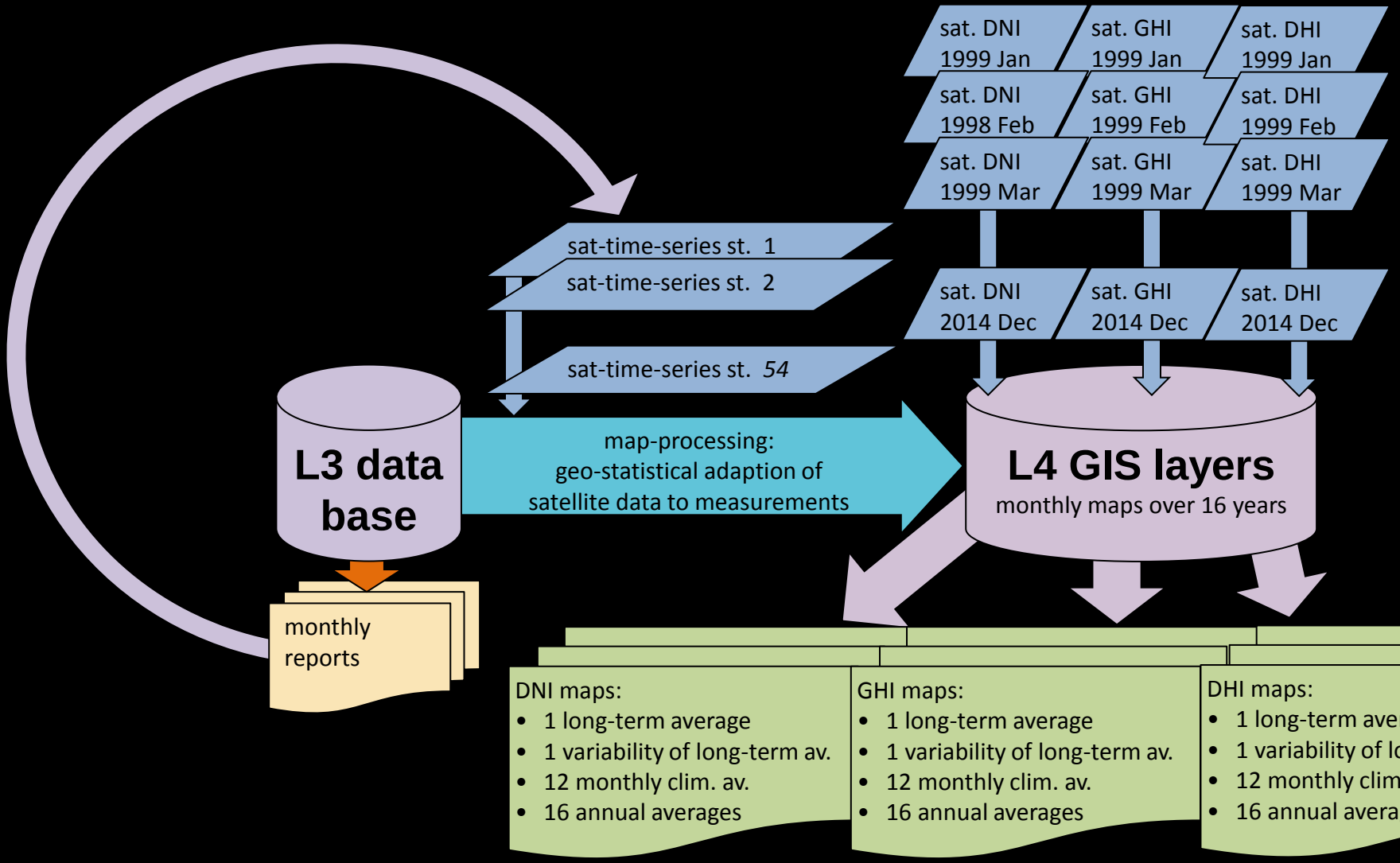
Processing of solar maps



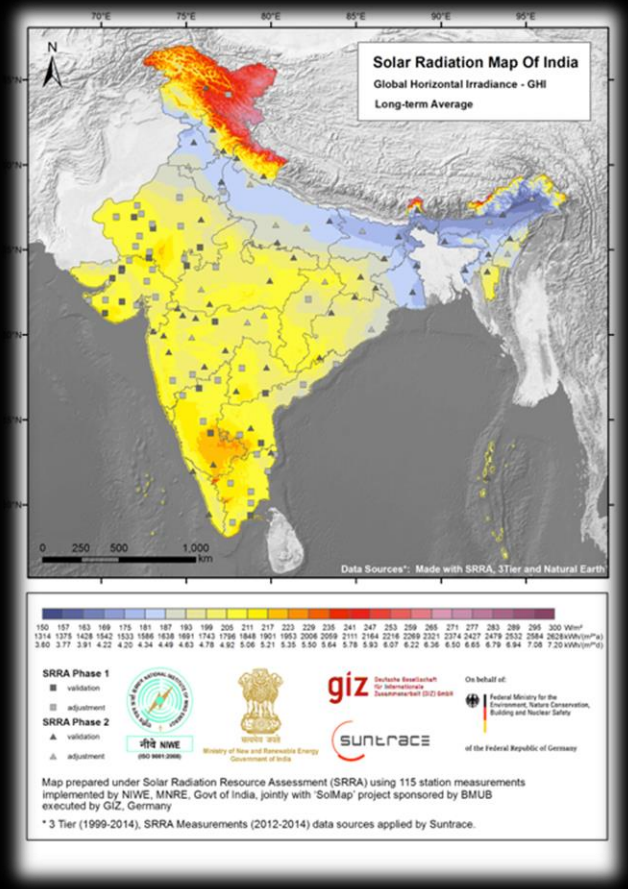
Map Making Methodology – processing steps



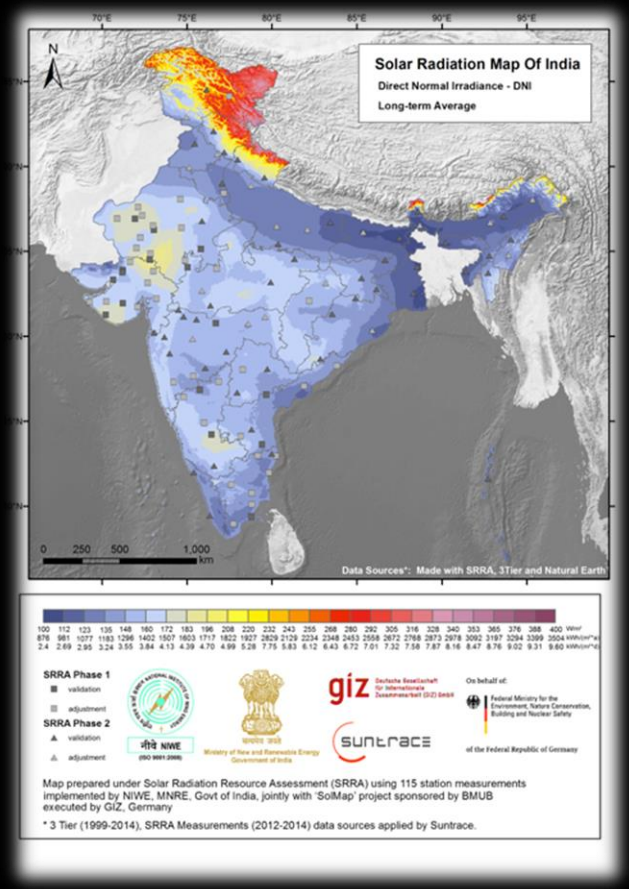
Map Making Methodology – processing steps



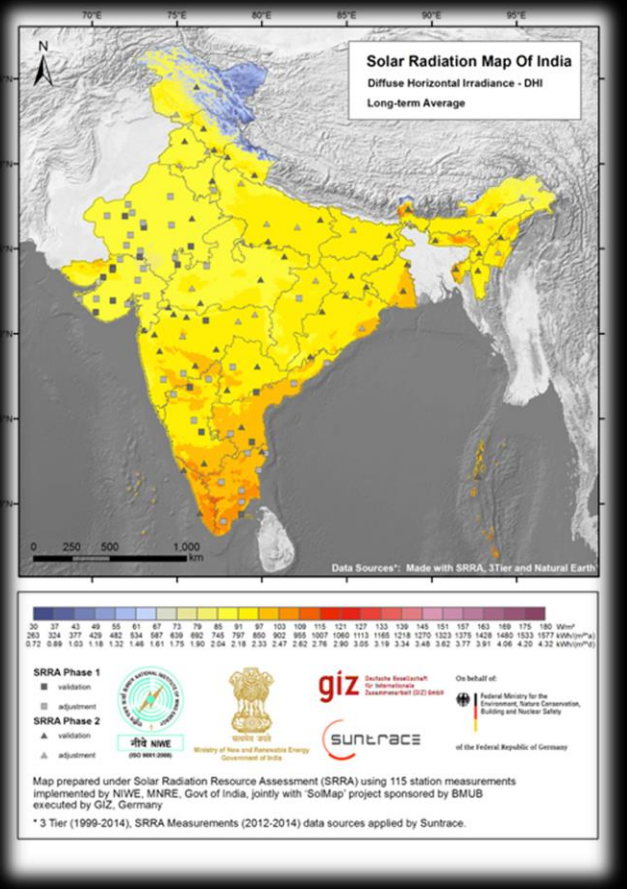
Comparison GHI

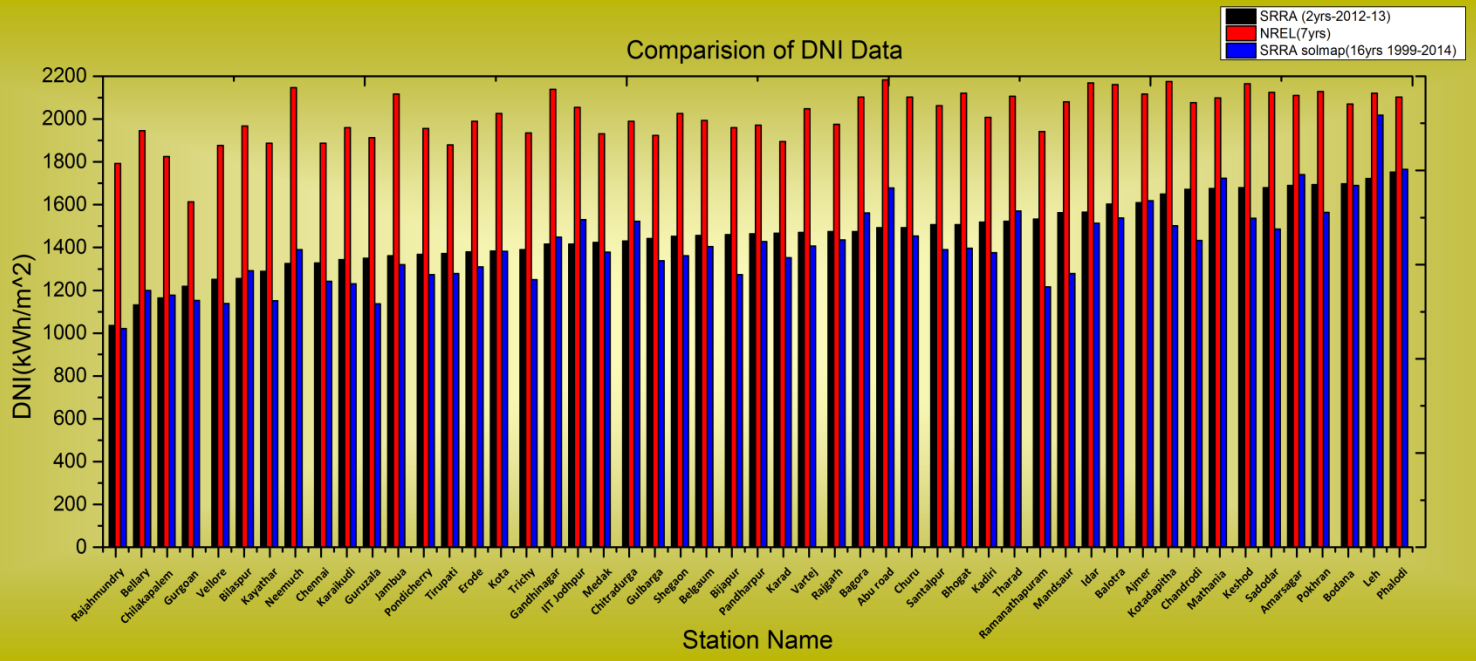


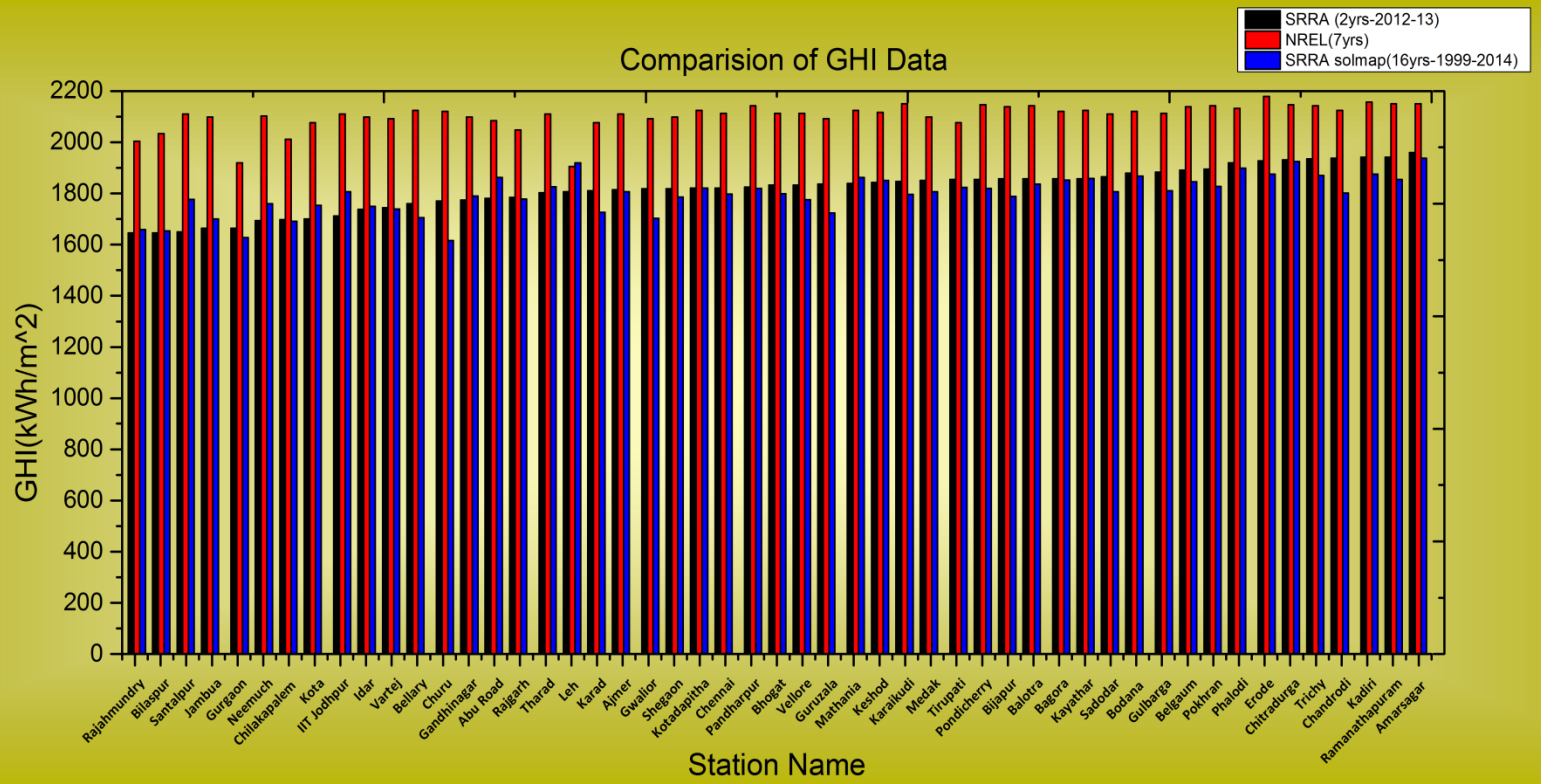
Direct normal DNI



Diffuse DHI




Comparision of DNI Data
SRRA (2yrs-2012-13)
NREL(7yrs)
SRRA solmap(16yrs 1999-2014)
DNI(kWh/m^2)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
Rajahmundry
Bellary
Chilakapalem
Gurgoan
Vellore
Bilaspur
Kayathar
Neemuch
Chennai
Karaikudi
Guruzala
Jambua
Pondicherry
Tirupati
Erode
Kota
Trichy
Gandhinagar
IIT Jodhpur
Medak
Chitradurga
Gulbarga
Shegaon
Belgaum
Bijapur
Pandharpur
Karad
Vartej
Rajgarh
Bagora
Abu road
Churu
Santalpur
Bhogat
Kadiri
Tharad
Ramanathapuram
Mandsaur
Idar
Balotra
Ajmer
Kotadapitha
Chandrodi
Mathania
Keshod
Sadodar
Amarsagar
Pokhran
Bodana
Leh
Phalodi
Station Name


Comparision of GHI Data
SRRA (2yrs-2012-13)
NREL(7yrs)
SRRA solmap(16yrs-1999-2014)
GHI(kWh/m^2)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
Rajahmundry
Bilaspur
Santalpur
Jambua
Gurgaon
Neemuch
Chilakapalem
Kota
IIT Jodhpur
Idar
Vartej
Bellary
Churu
Gandhinagar
Abu Road
Rajgarh
Tharad
Leh
Karad
Ajmer
Gwalior
Shegaon
Kotadapitha
Chennai
Pandharpur
Bhogat
Vellore
Guruzala
Mathania
Keshod
Karaikudi
Medak
Tirupati
Pondicherry
Bijapur
Balotra
Bagora
Kayathar
Sadodar
Bodana
Gulbarga
Belgaum
Pokhran
Phalodi
Erode
Chitradurga
Trichy
Chandrodi
Kadiri
Ramanathapuram
Amarsagar
Station Name

Calibration lab

Calibration of solar instruments under commercial mode

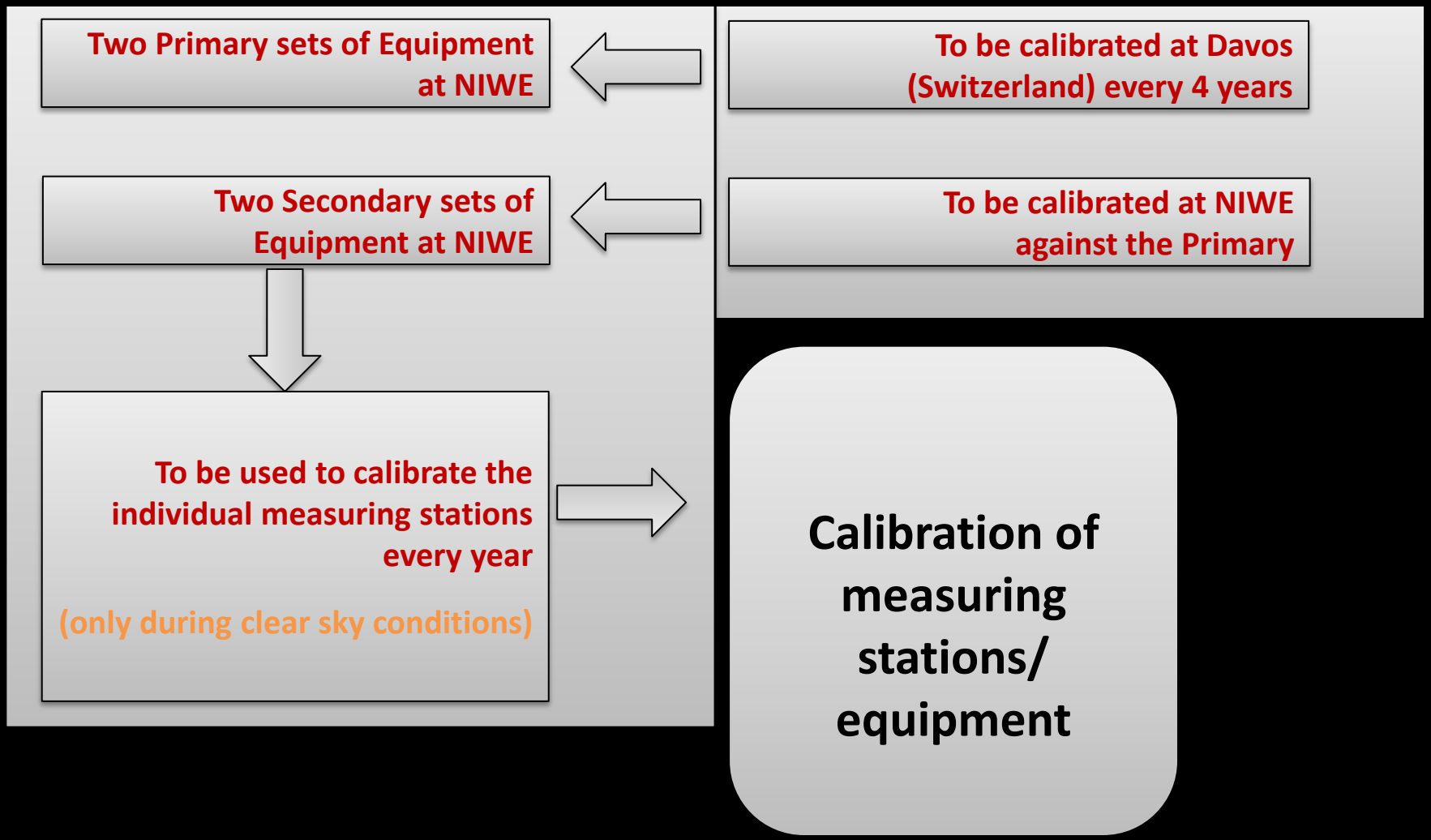

giz
A S
C E
Centre for Assessment of Solar Energy
PRATHYUSHA INSTITUTE OF TECHNOLOGY AND MANAGEMENT
SRRA STATIONS

Primary Sensors

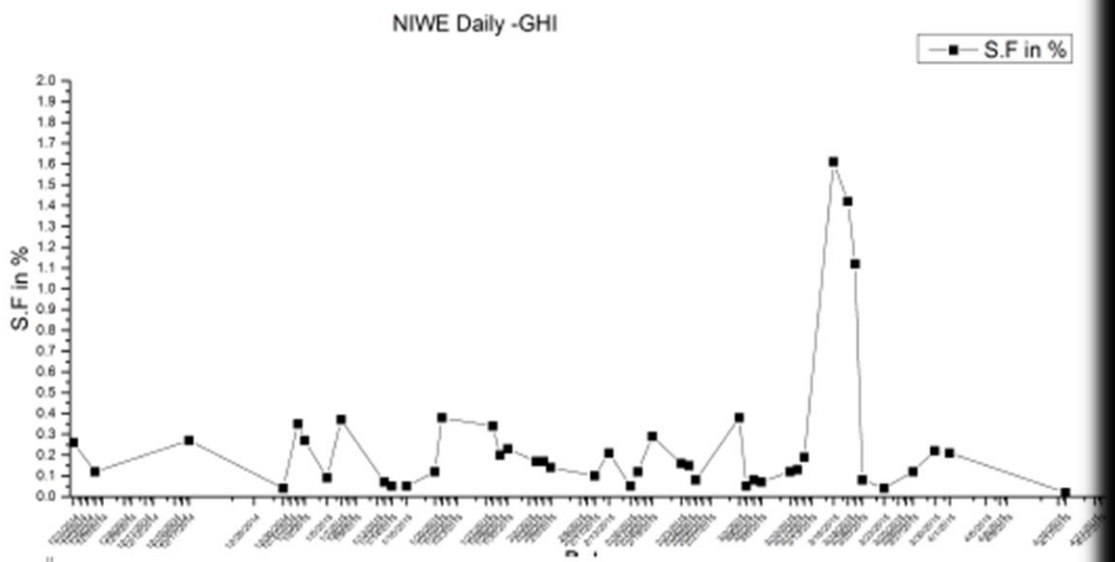
- The calibration laboratory has two no. of AWX-AHF and PMO6 CC sensors

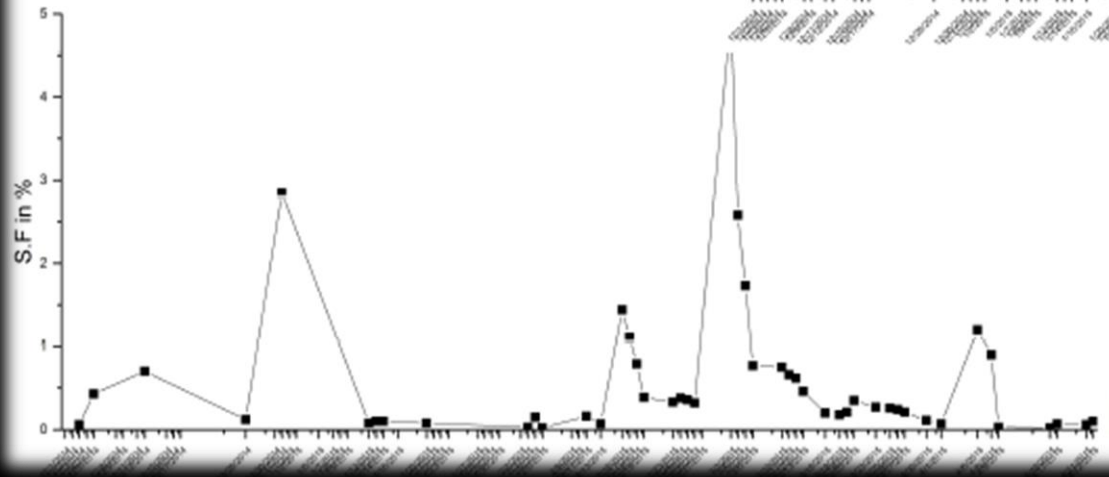
- These equipments are maintained in the laboratory for inter-comparison and calibration of the sensors used in the field stations.

Calibration Scheme



Analysis of Soiling Correction





Future Plan

1. Solar Power Forecasting.
2. To validate ISRO Kalpana Satellite data against SRRA ground measurements for the overlapping period from 2012.
3. Up gradation of solar atlas, development of value added products by applying ISRO'S Land Use Land Cover data.
4. To utilize ISRO data for gap filling of SRRA measurements.


THANK YOU