Weather & Climate Adaptation Planning for Renewable Energy System

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Climate Change Adaptation for the Energy and Industrial Sectors, Taiwan, 13 Oct 2016

Outline

- Meteorological Products for Renewable Energy
- Quality of Meteorological Products
- Integrating Meteorological Products for the Grid: Solar

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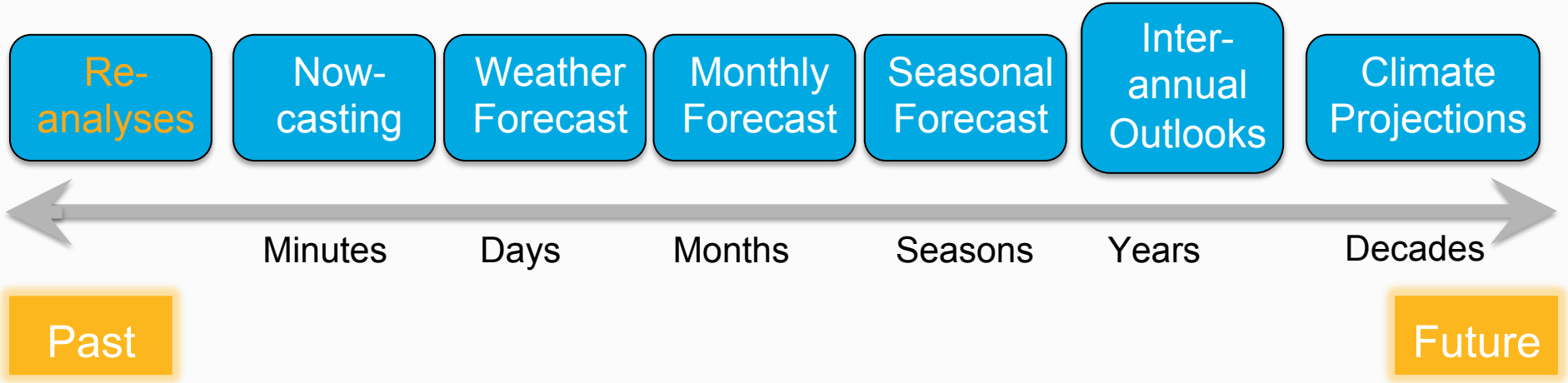
Meteorological products



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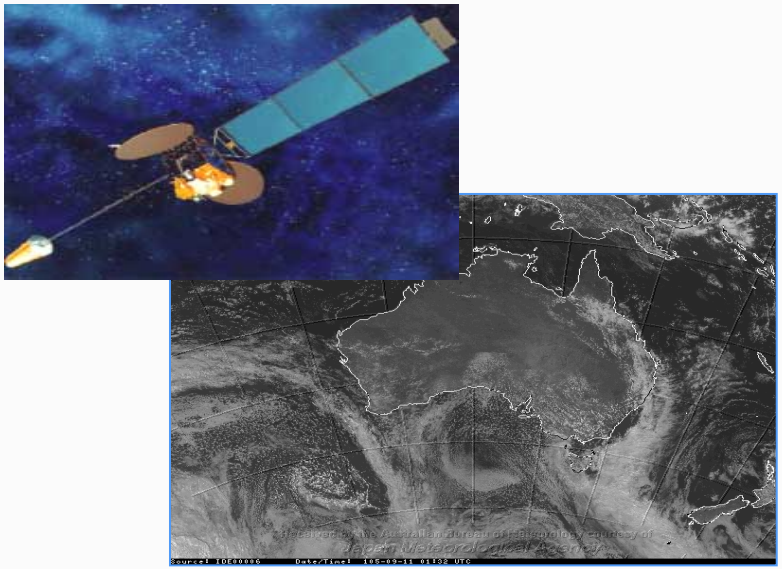
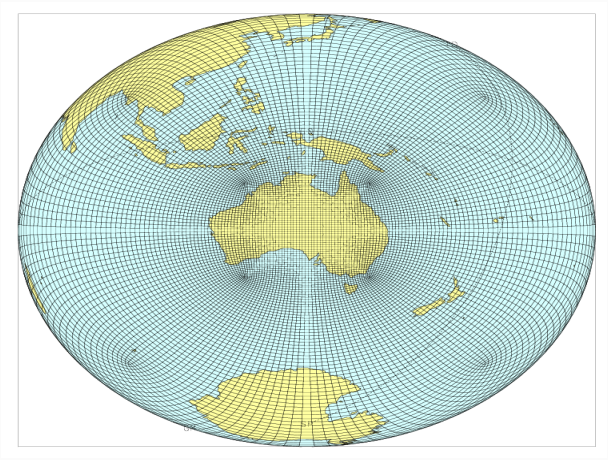
Fundamental Components of Met Products





Observations

Mathematical/
Physical Models

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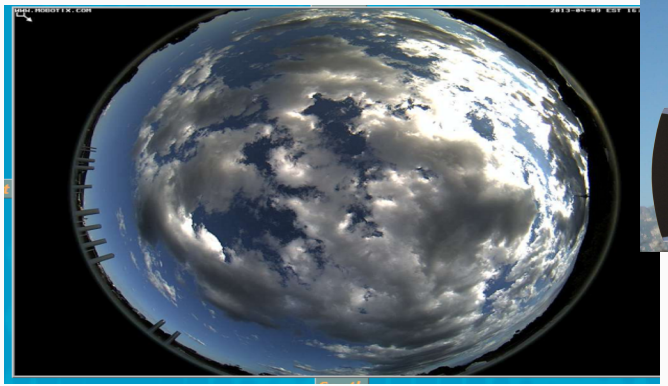
Observations – Ground



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Observations – You can set up your own!

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Important to measure PV panel temperature

PV panel temperature: $T_{PV} \approx \alpha\ GI + T_{air}$

with GI: Global Irradiance on PV plane, and α an empirical coefficient

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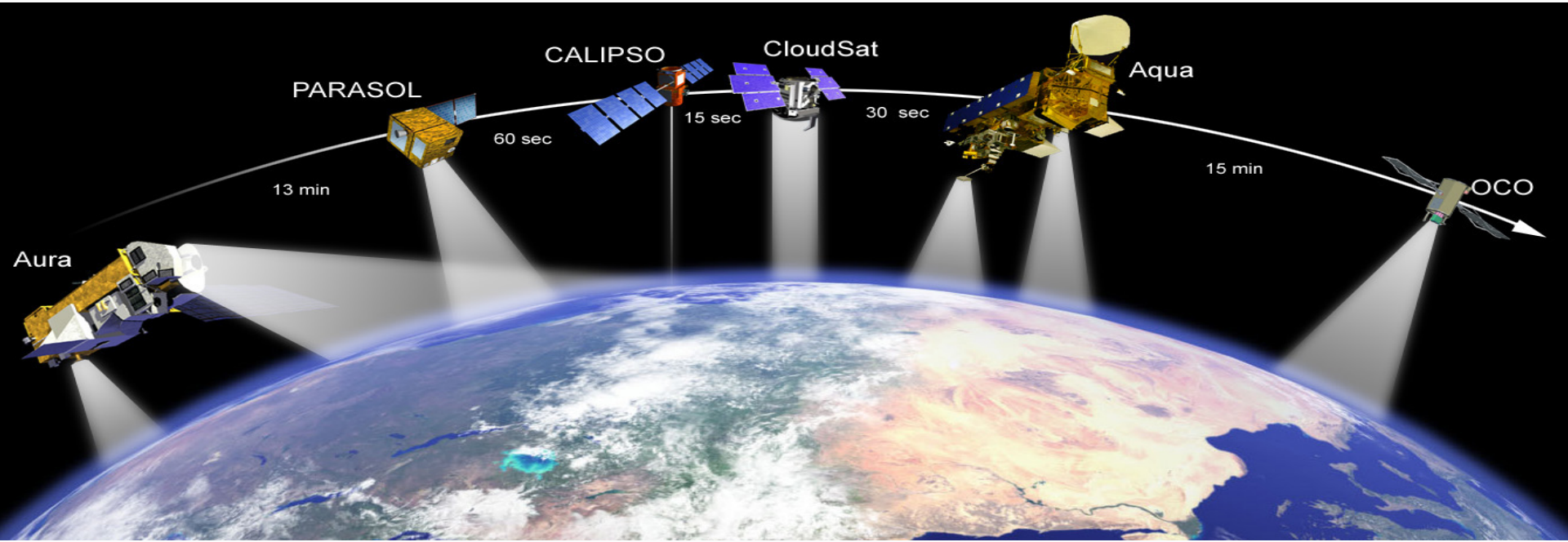
PV production is highly dependent on the temperature of PV panels, which in turn depends on air temperature. As a rule of thumb, an increase of 20C in PV panel temperature leads to a decrease in PV production of 10%

Observations – Space



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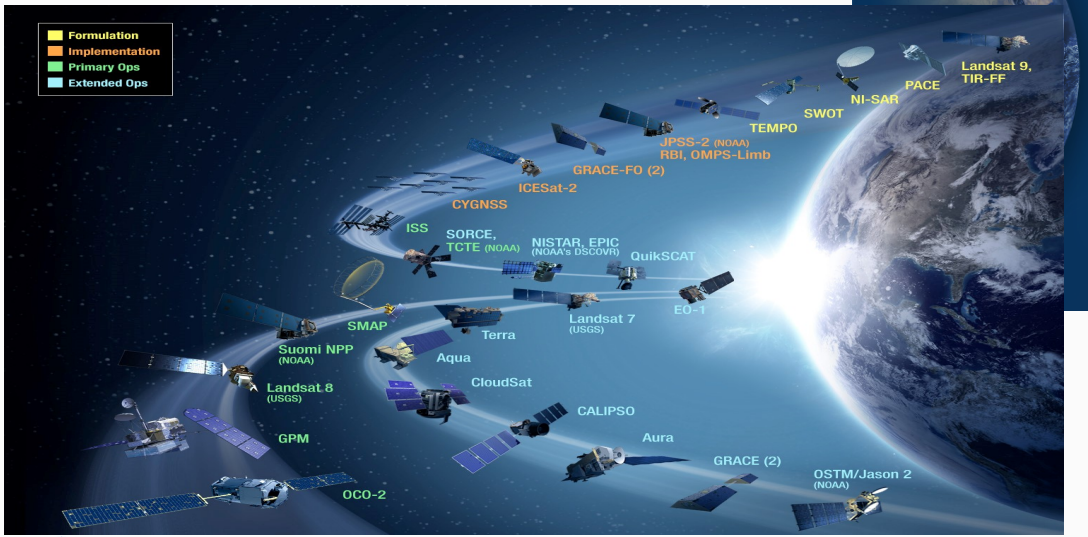
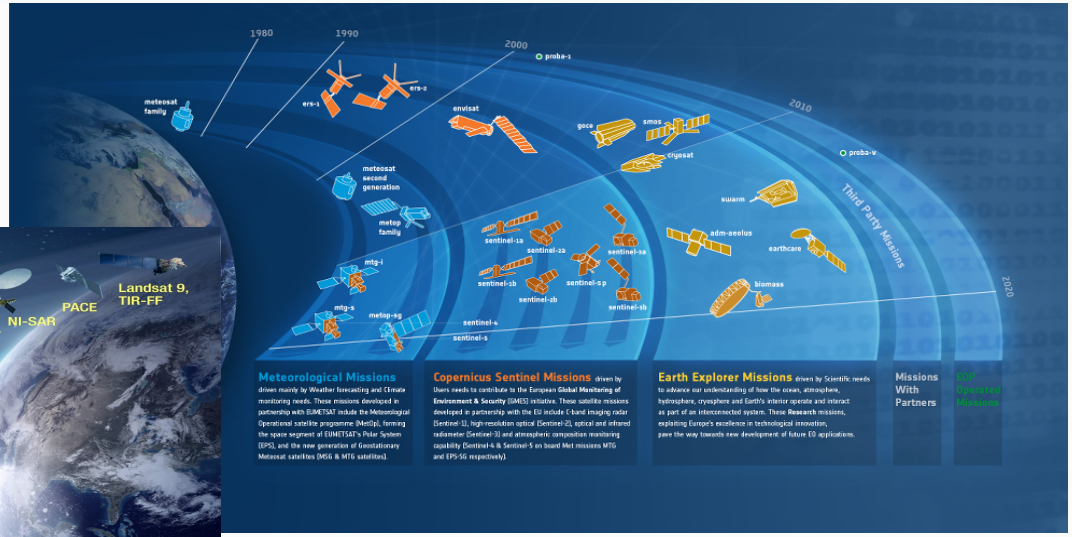
Observations – Space (NASA & ESA)





Hundreds of millions of observations

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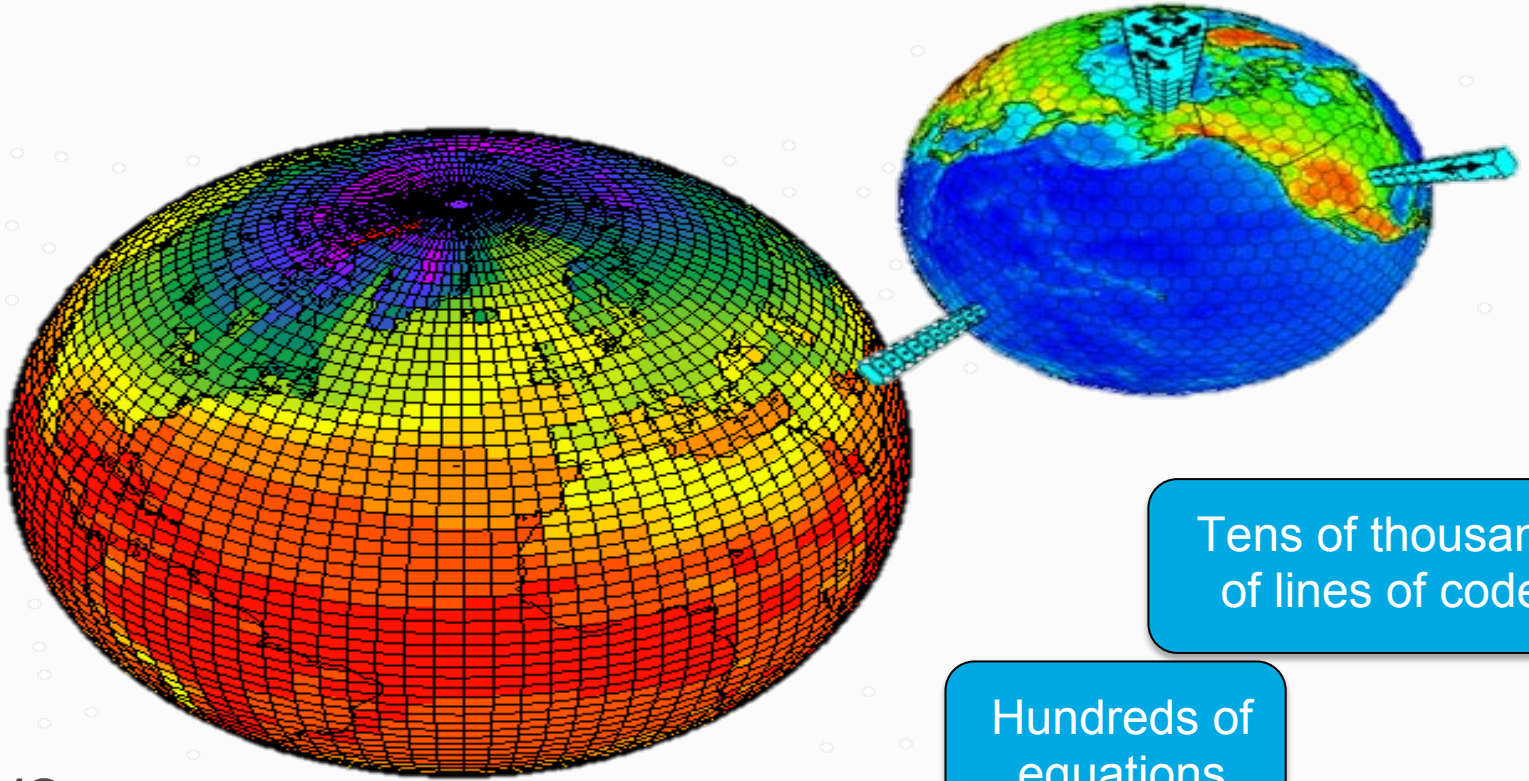
Physical/Mathematical Models



Tens of thousands of lines of codes

Hundreds of equations

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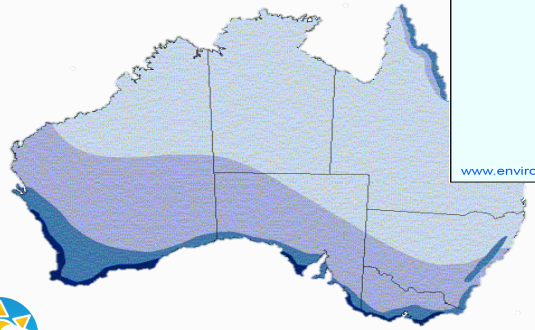
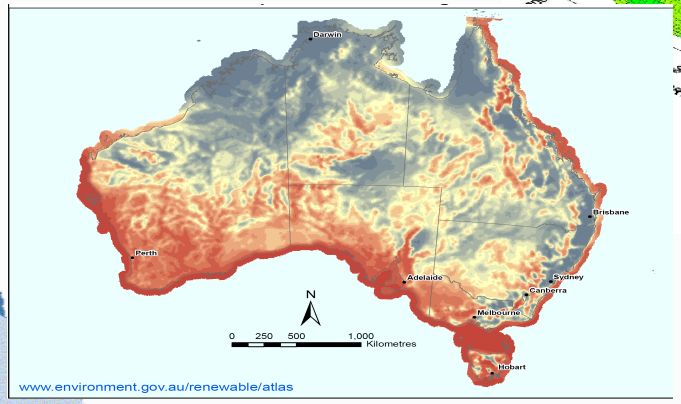
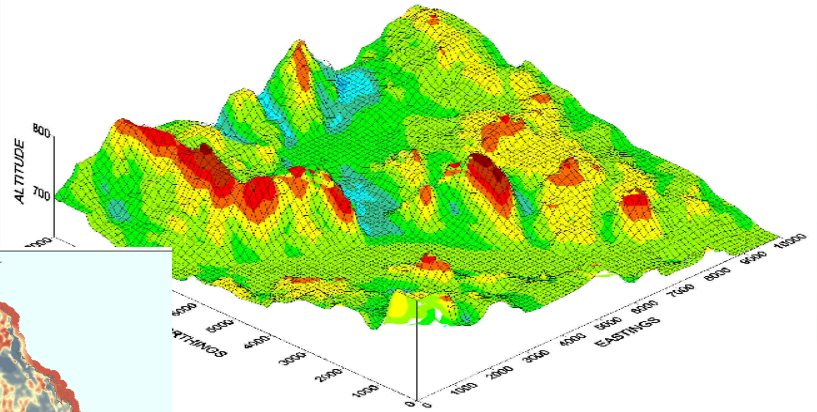
Physical/Mathematical Models







Wind turbine annual energy yield

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Meteorological Variables for Energy

Cloudiness

Short-wave radiation

Humidity

Rainfall

Wind speed and/or direction

Snowfall and ice accretion

Air Temperature

Water Temperature

Sea level

Wave height

River Flow

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Energy and Meteorological ‘pairings’

Demand
- Air temperature
- Cloud cover
- Water vapour
- Albedo
- Nighttime lights

Hydro
- Soil moisture
- Precipitation
- Snow cover
- Elevation
- River/lake par
- Gravimetry

Solar
- Solar irradiance
- Cloud cover
- Water vapour
- Aerosols
- Albedo
- Air Temperature
- Land cover
- Elevation

Biomass
- Solar irradiance
- Air Temperature
- Precipitation
- Soil moisture
- Land cover
- Cloud cover
- Albedo
- Elevation

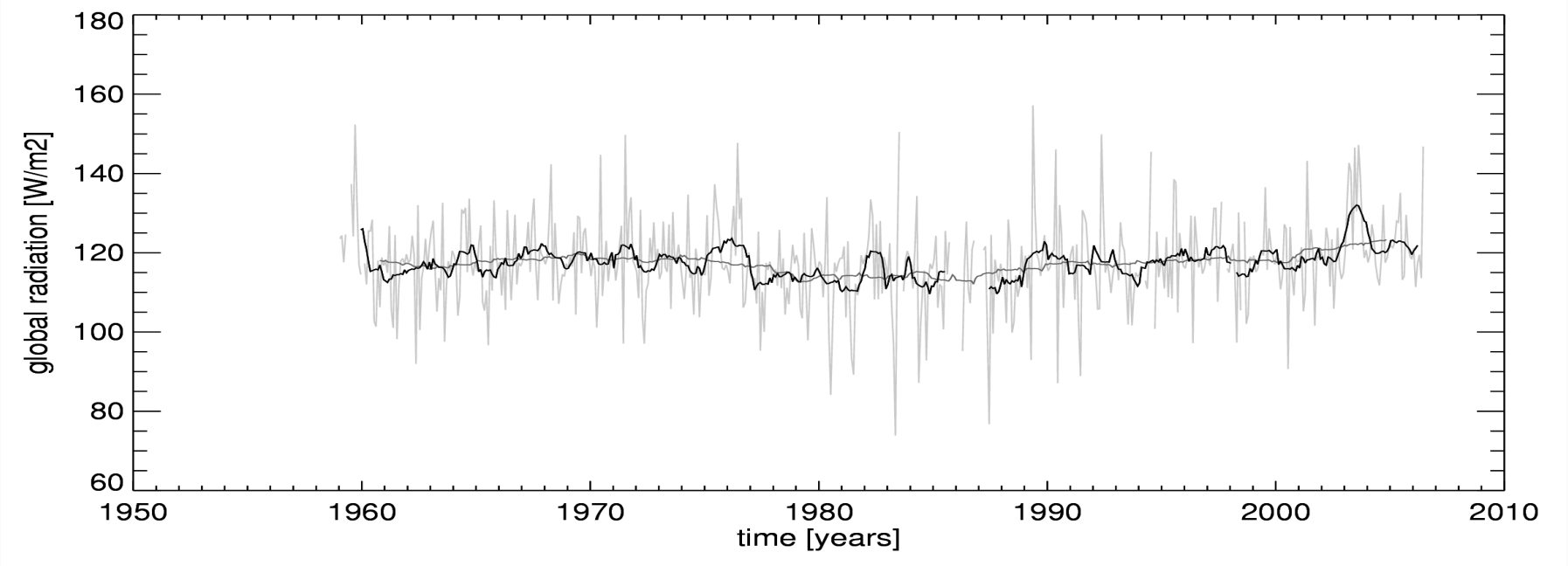
Wind
- Elevation
- Offshore winds
- Wave/currents
- Ocean altimetry

Marine
- Offshore winds
- Wave/currents
- Ocean altimetry

Thermal
- Air Temperature
- River/lake par

Oil & Gas
- Offshore winds
- Wave/currents
- Ocean altimetry

Historical Observations – Solar Radiation for NH



Monthly data, 1 year and 5 year running means

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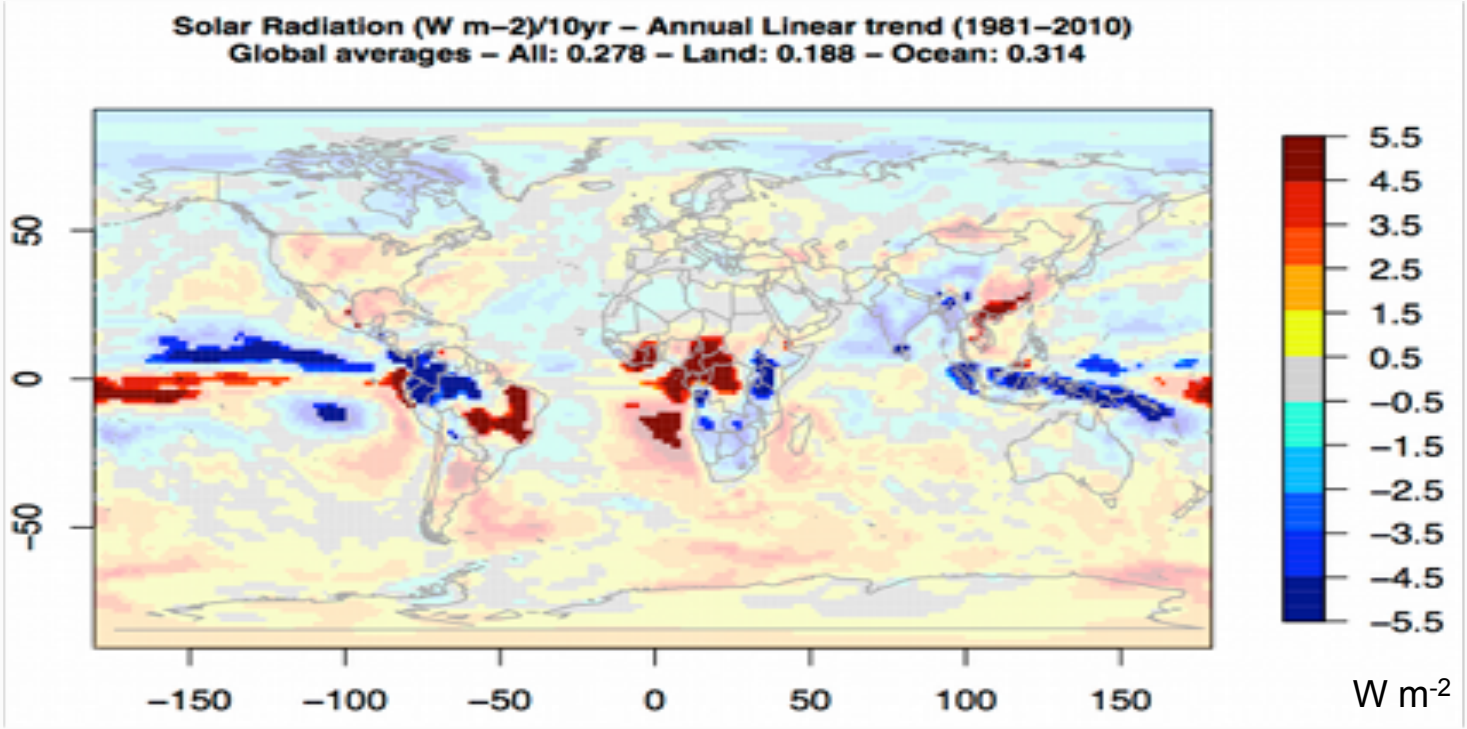
Historical Reanalysis – Solar Radiation (1981-2010)



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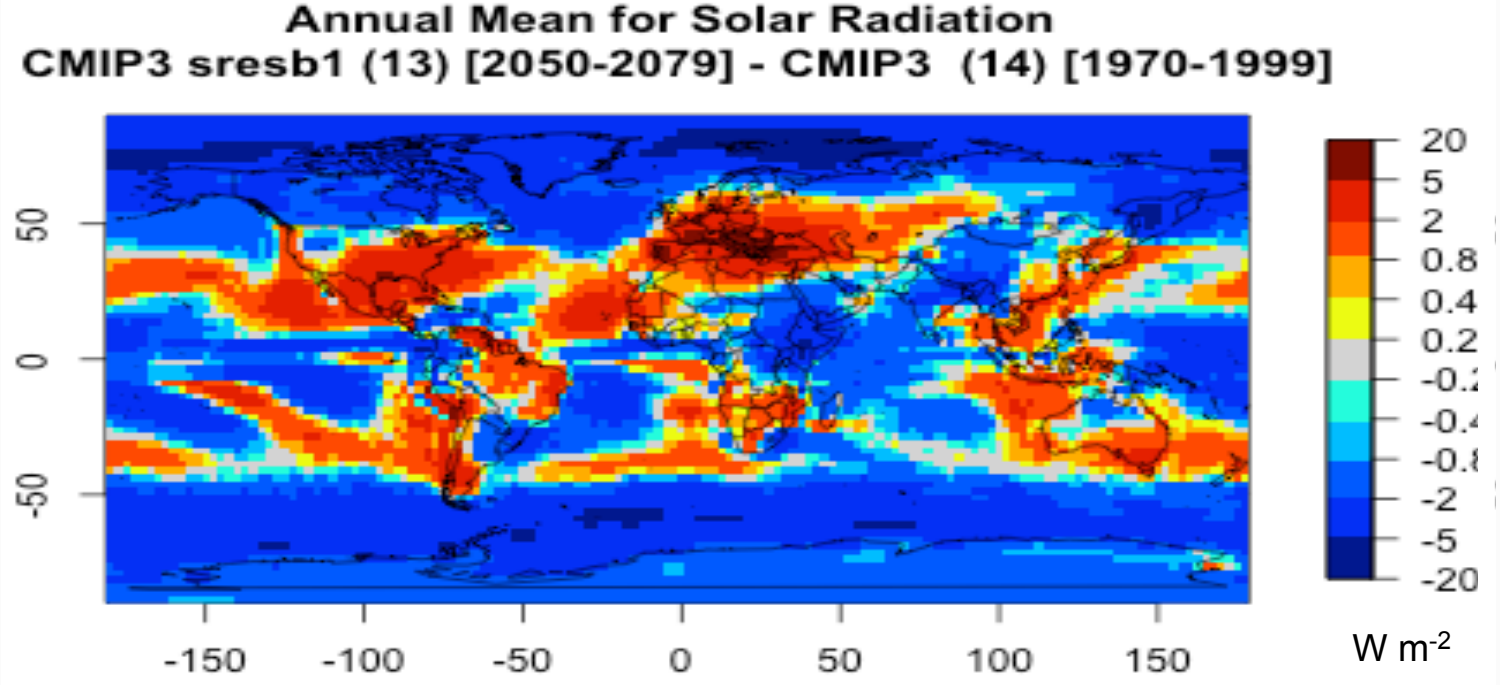
Climate Projection – Solar Radiation (2050-2079)



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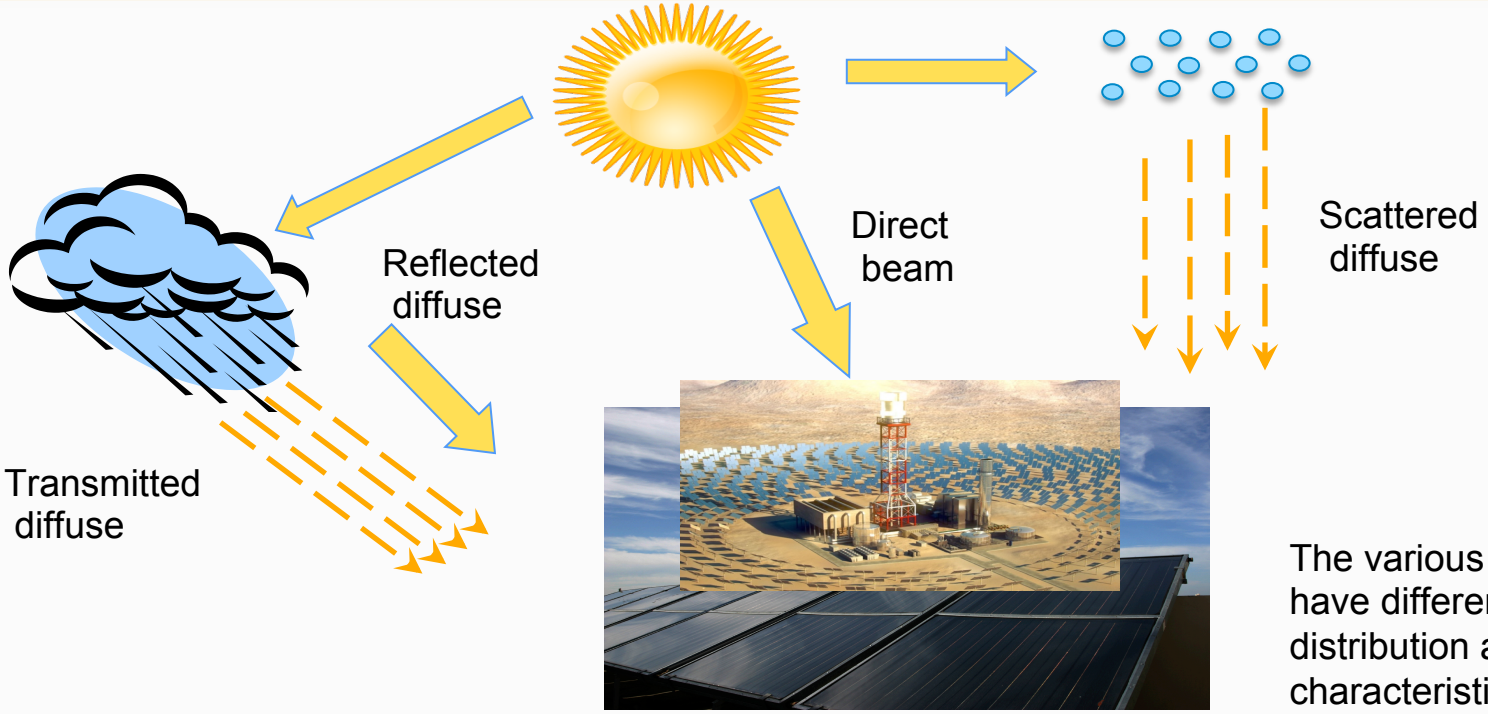
Solar Radiation Components



The various radiation sources have different spatial distribution and spectral characteristics

Global radiation = Direct Beam + (Refl. d. + Backsc. d. + Trans. d.) =
Direct Beam + Diffuse radiation

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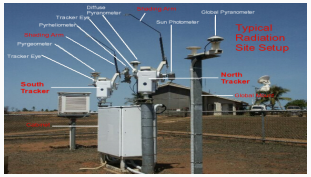
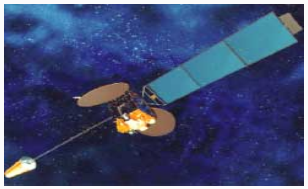
Pros & Cons of Solar Radiation Data Sources



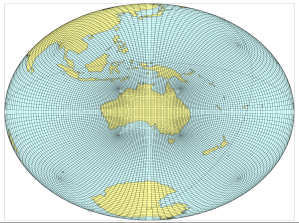
Ground stations

- **P:** Measure exactly the radiation received by the ground
- **P:** High frequency (energy) data (1-sec)
- C: Limited coverage
- C: Maintenance costs, particularly at remote locations



Satellite

- **P:** Wide and frequent coverage (e.g. 5 km, 30 min)
- **P:** Algorithms specific for solar radiation
- C: Instantaneous (power) measure; DNI derived from GHI
- C: Technical limitations such as parallax, air composition



Atmospheric model

- **P:** Wide and frequent coverage (e.g. 5 km, 30 min)
- **P:** Flexible in choice of periods and domains
- C: Radiation schemes computationally expensive
- C: Models not tuned to produce best radiation

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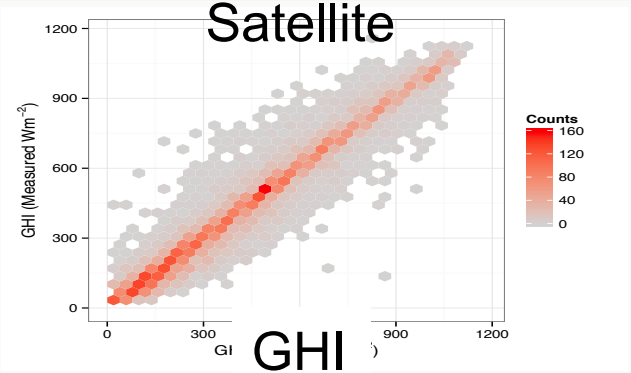
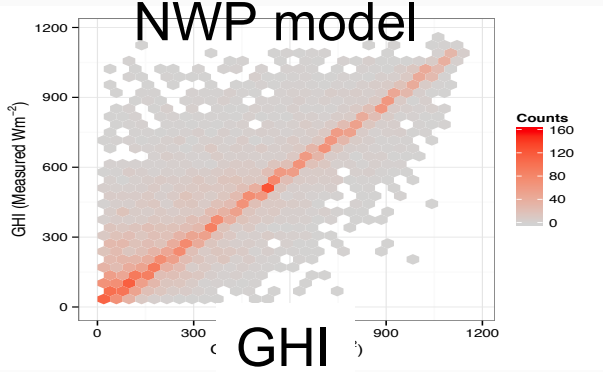
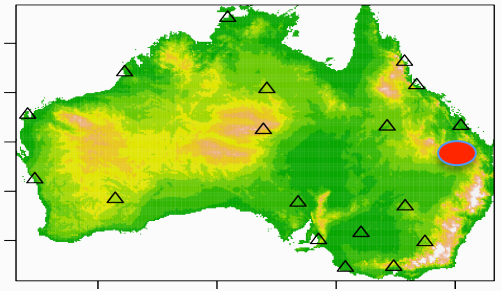
Solar Radiation Assessment







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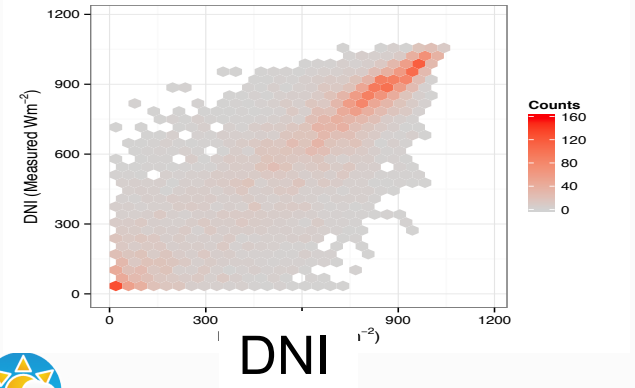

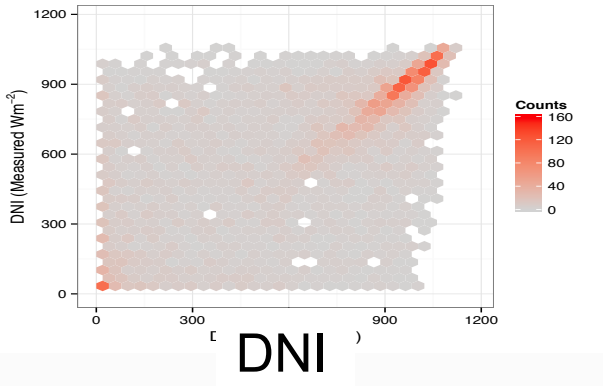

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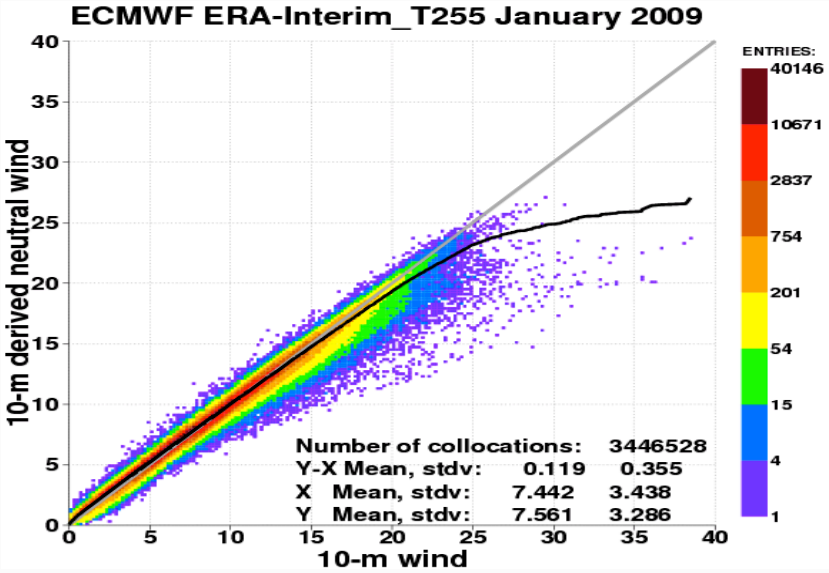
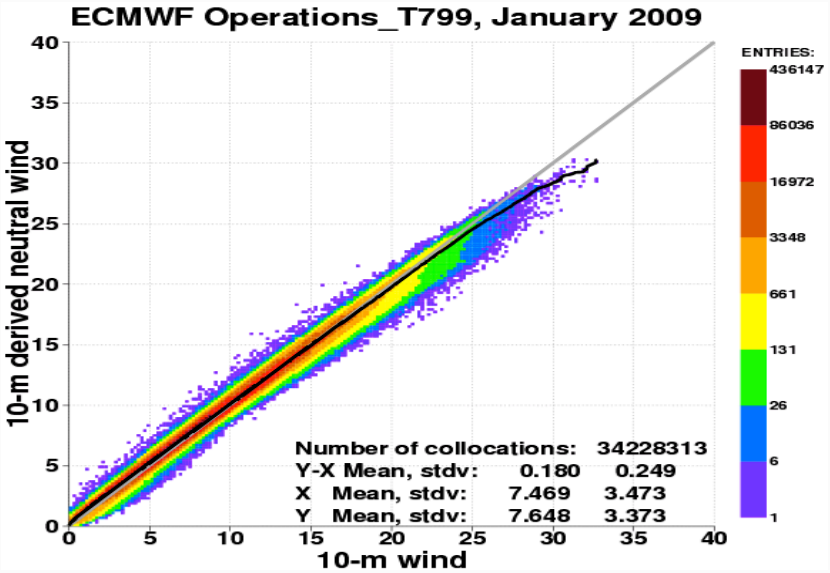
Davy et al (2016)

Wind Speed Assessment





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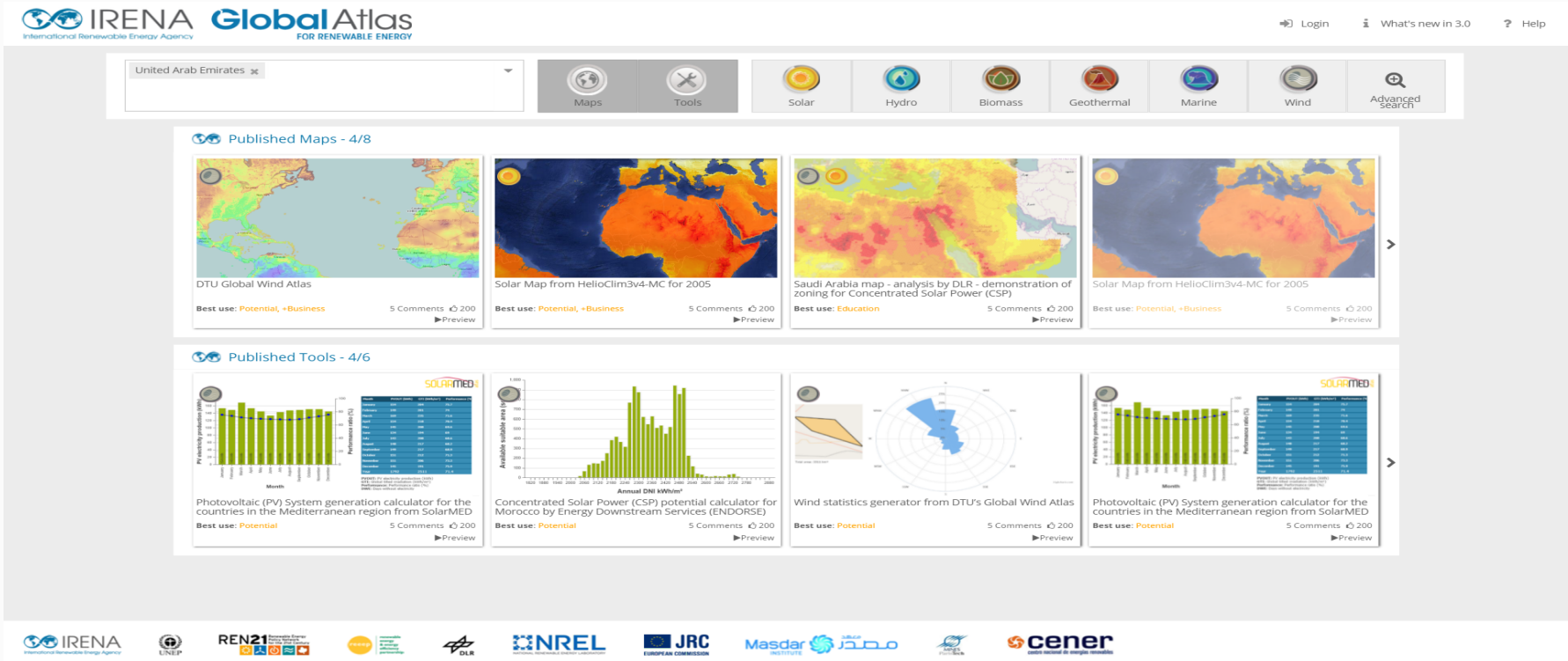
Some issues for winds > 25 m/s @ T255

Courtesy ECMWF

IRENA Global Atlas



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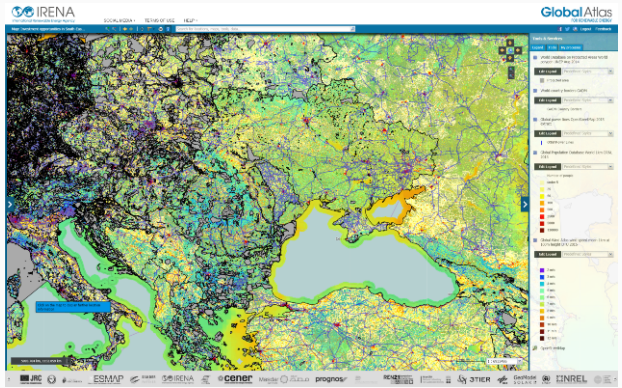
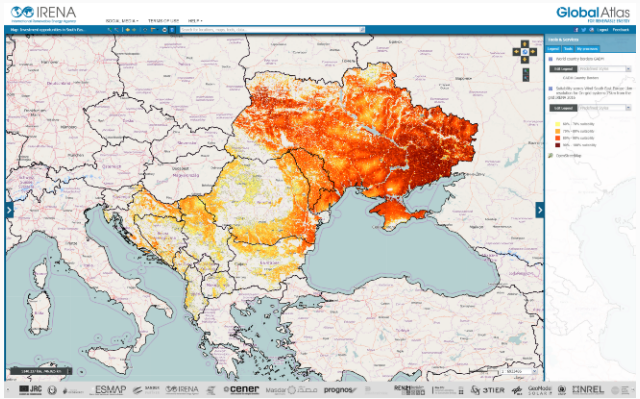
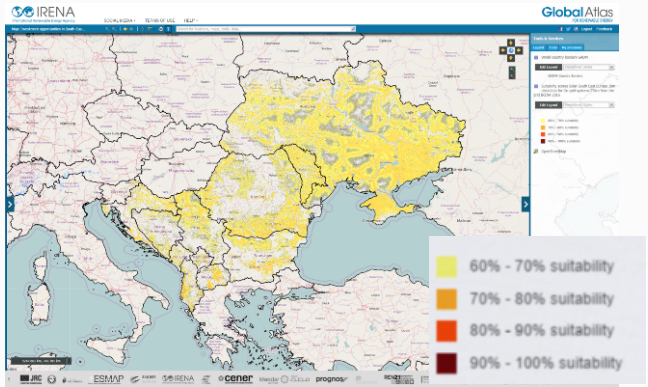
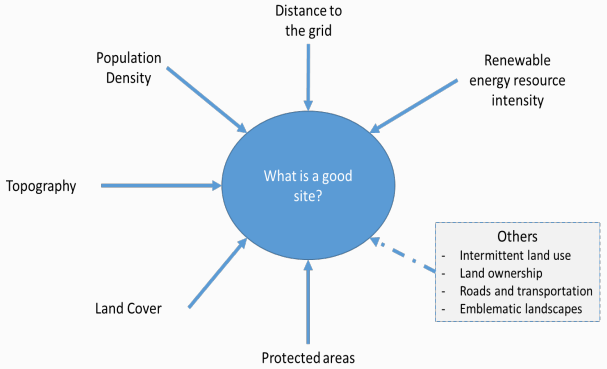
Combining RE maps with ancillary information









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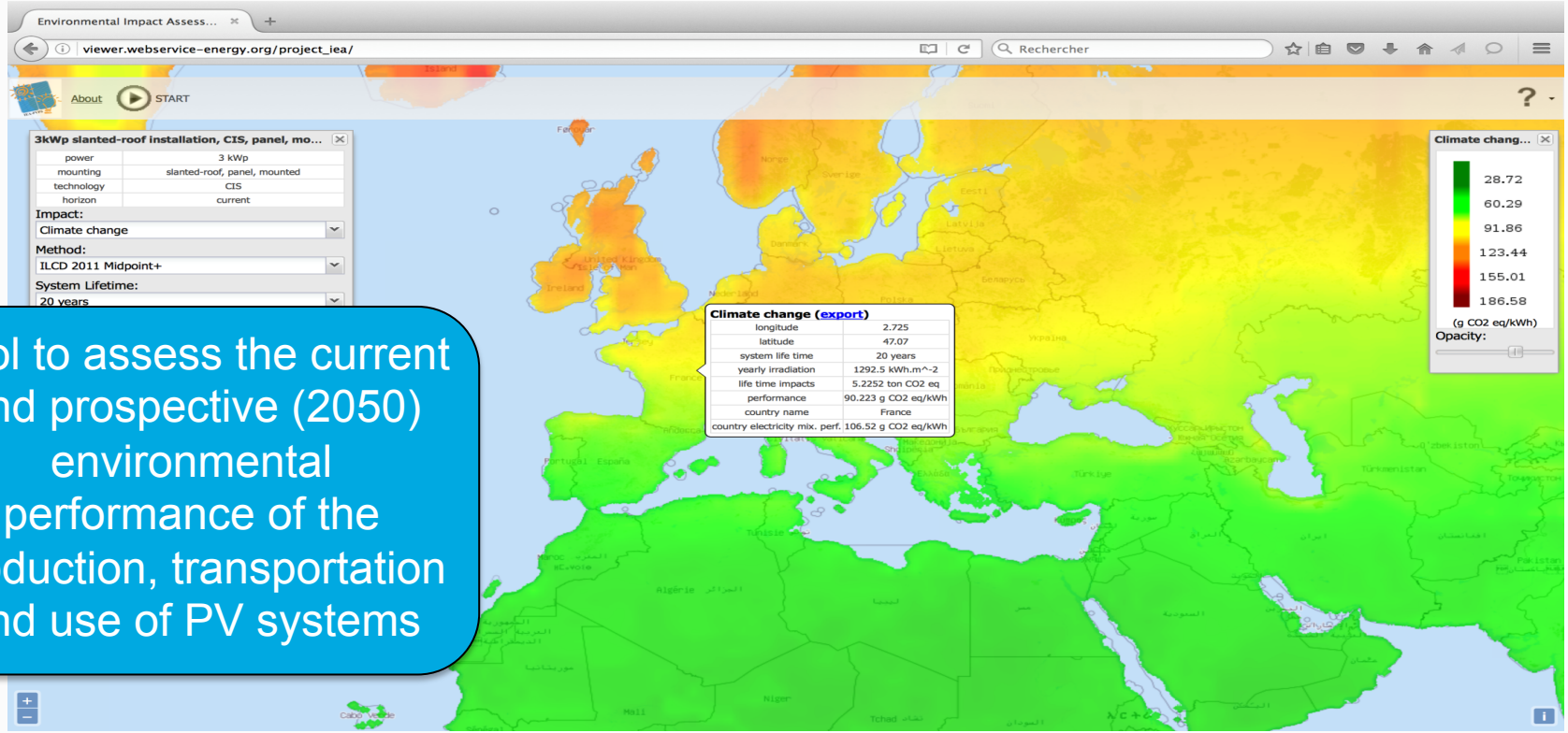
IRENA
International Renewable Energy Agency

Environmental performance tool for PV



Tool to assess the current and prospective (2050) environmental performance of the production, transportation and use of PV systems

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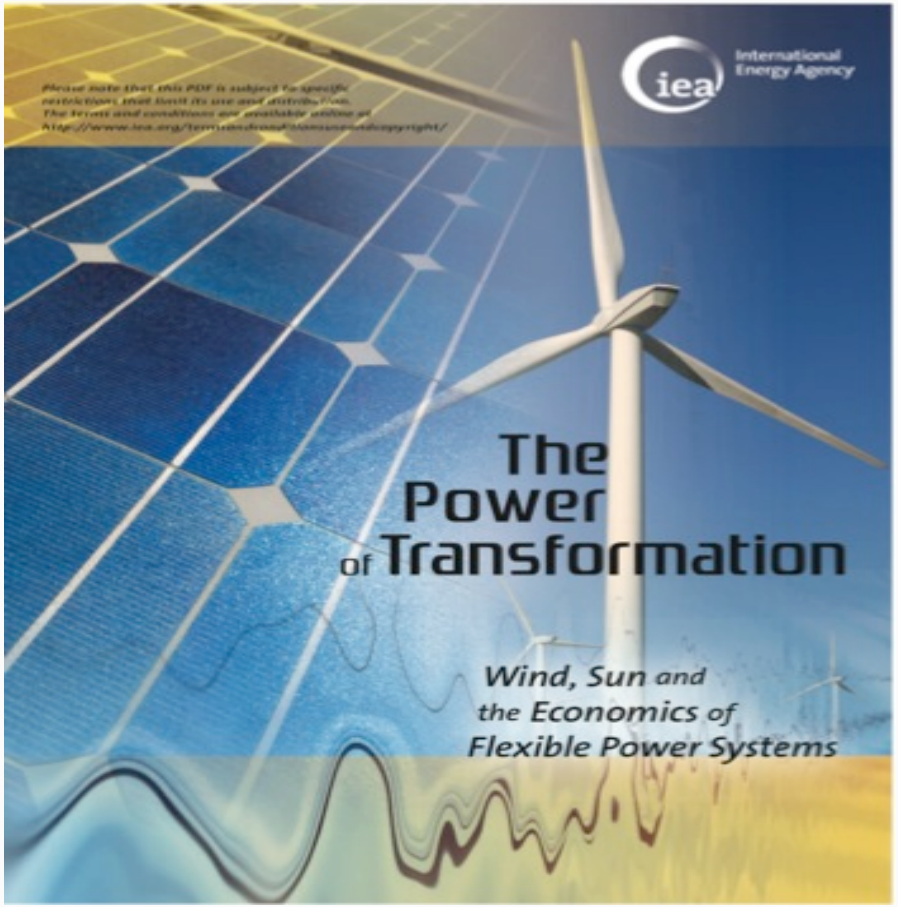
http://www.webservice-energy.org/web-gis-client

The Power of Transformation

"… Integration of Variable Renewable Energy (VRE) is not simply about adding VRE to "business as usual", but transforming the system as a whole. And it requires a system-wide approach" (2014)

Maria van der Hoeven
(IEA Executive Director)



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NREL VIDEO

http://www.nrel.gov/grid/ergis.html

Courtesy NREL

Focus on …

Solar Radiation and Power Forecasting

1. An Operational System
2. Some Research Results
3. Outstanding Challenges

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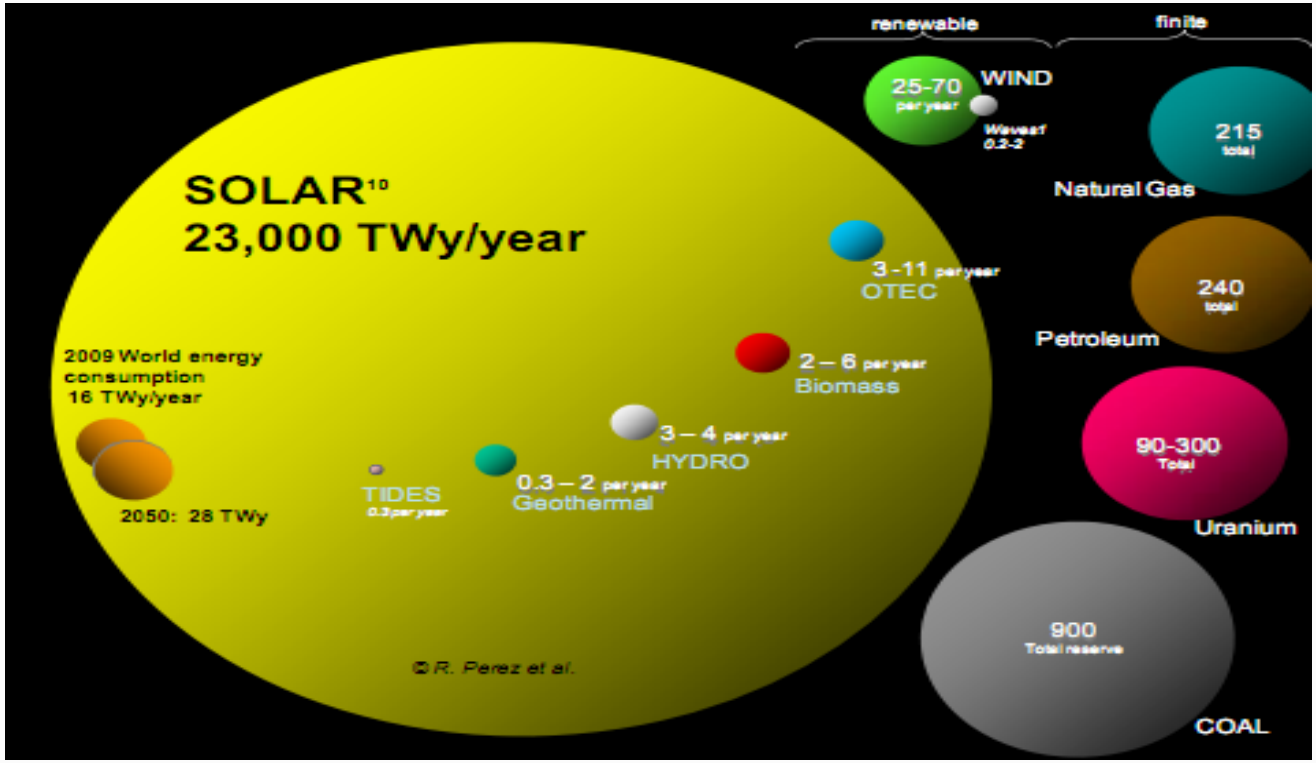
Solar Power Potential



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Significant science & technical challenges

Large-scale solar PV

An explosion in rooftop PV

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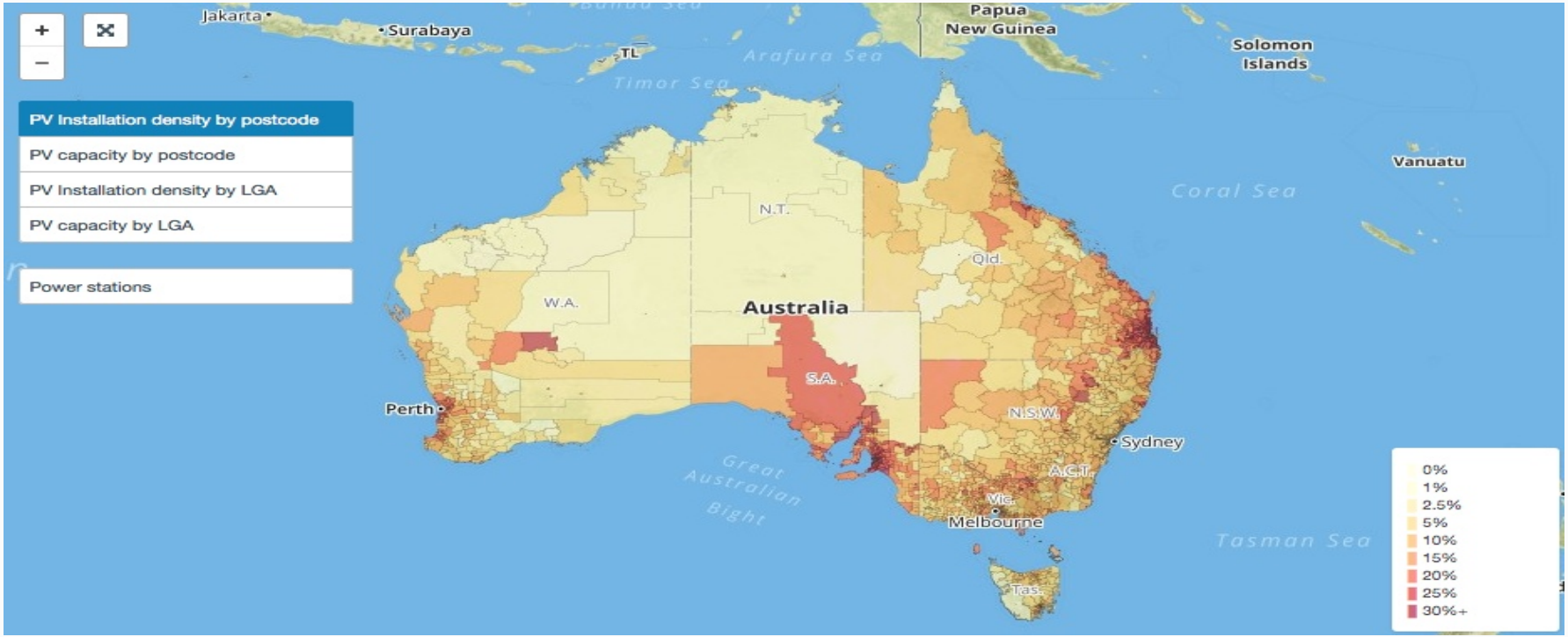
PV Installations in Australia by postcode



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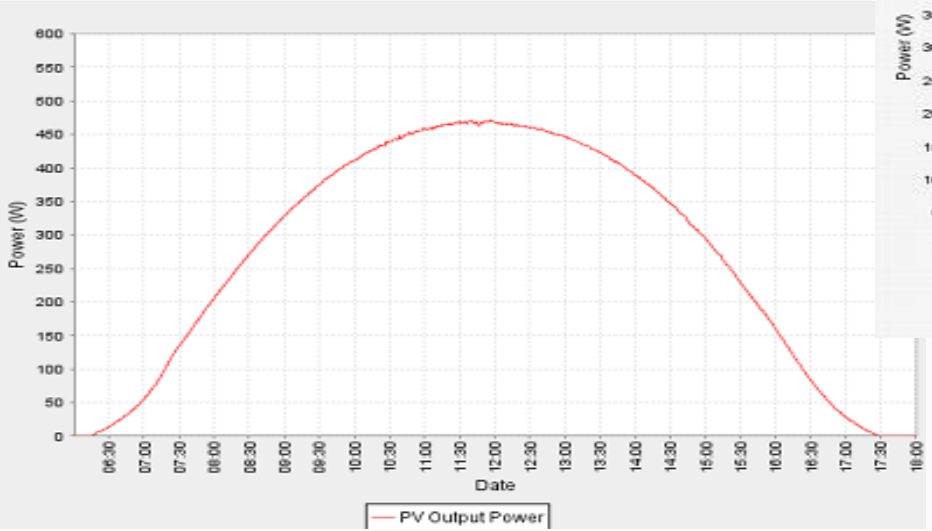
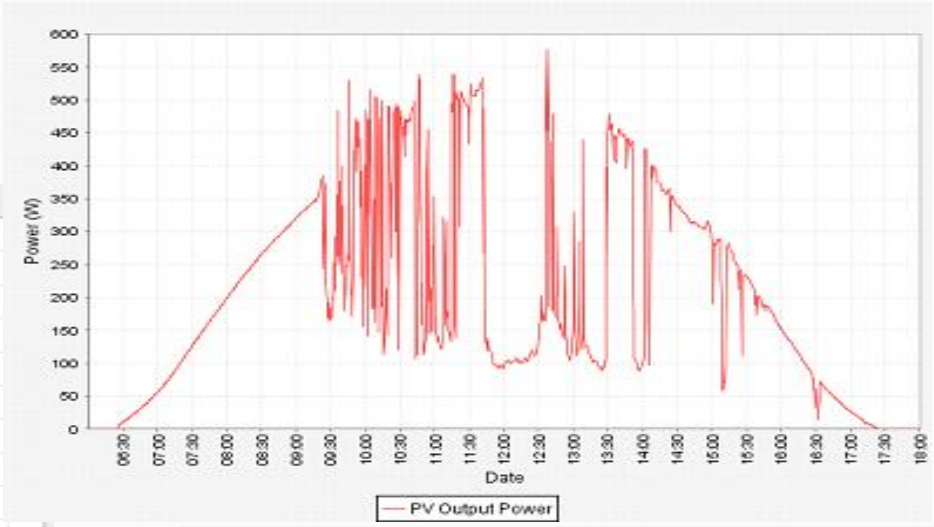
APVI (2015)

Solar radiation – can be very highly variable





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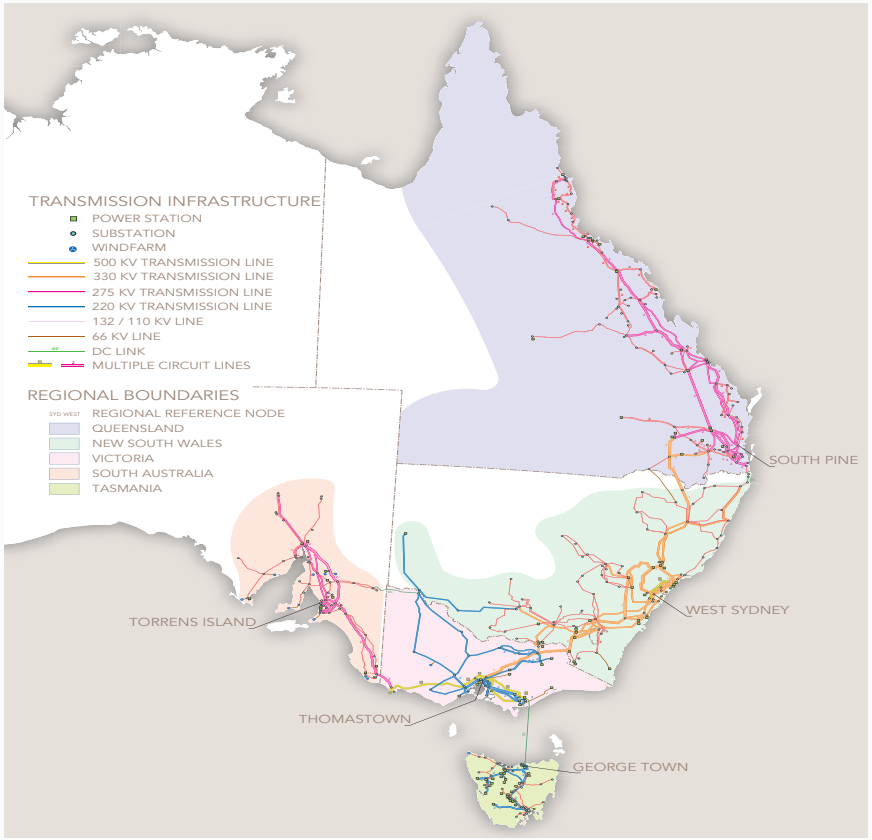
Australian National Energy Market

- Run by Australian Energy Market Operator (AEMO)
  - ~50GW installed capacity
  - Market coupled to physical operation at 5 min intervals
- Wind & Solar (now & 2030)
  - Wind ~4GW → 10GW
  - Solar PV ~5GW →13 GW
- Wind forecasting since 2009 (AWEFS)
- Solar forecasting since 2014 (ASEFS)



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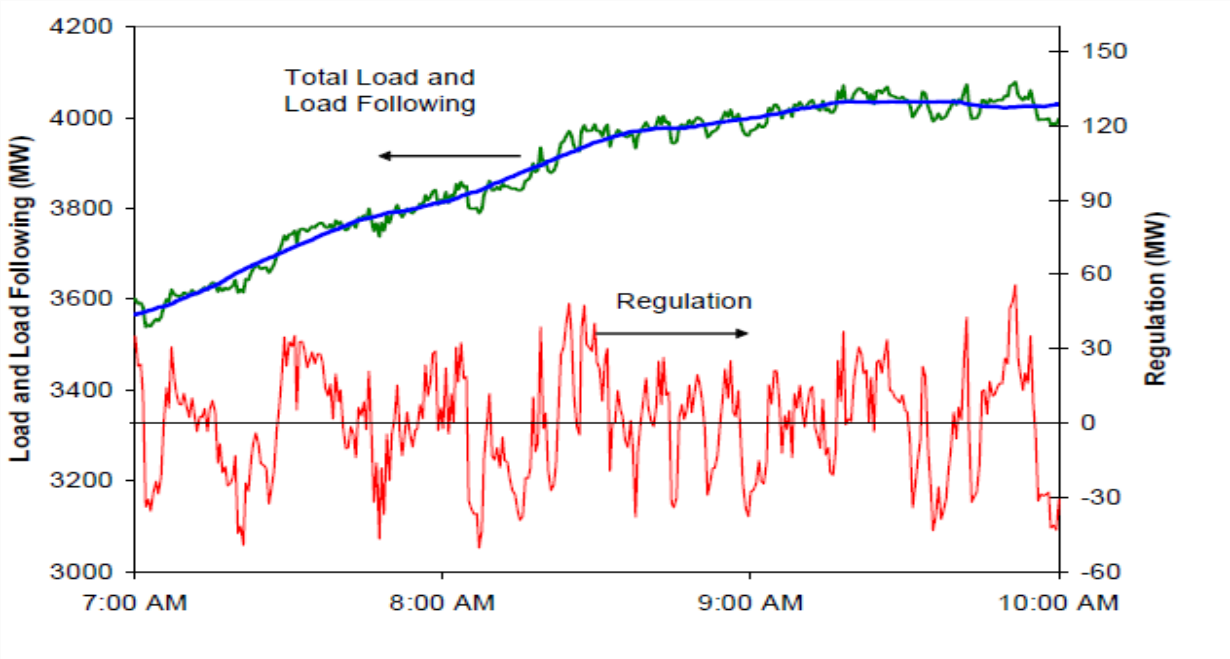
Regulation Services Demand



- With large quantities of intermittent generation this demand can exceed spinning reserve
- Normally supplied by conventional generators

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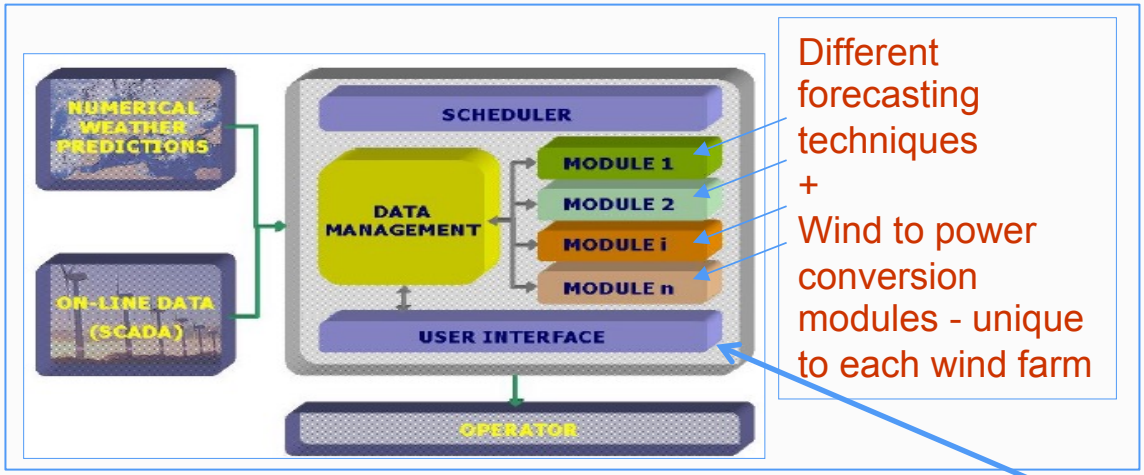
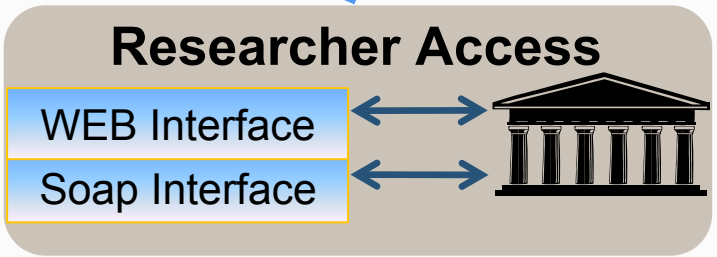
Building on Wind Forecasting at AEMO

AWEFS - ANEMOS Wind forecasting system



- Compulsory centralised forecasting
- 10 sec SCADA feed required
- Up to 200 wind farms
- Operational since 2008



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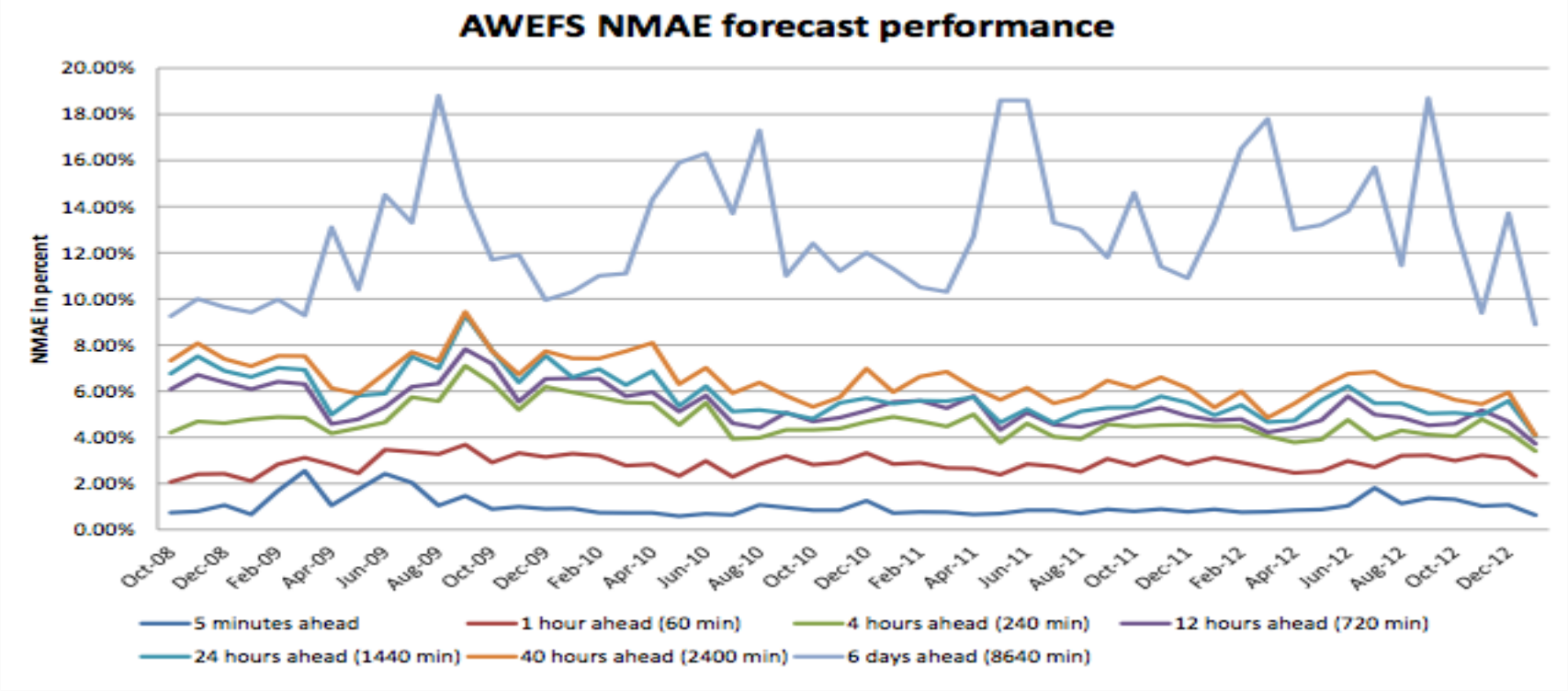
AWEFS Performance



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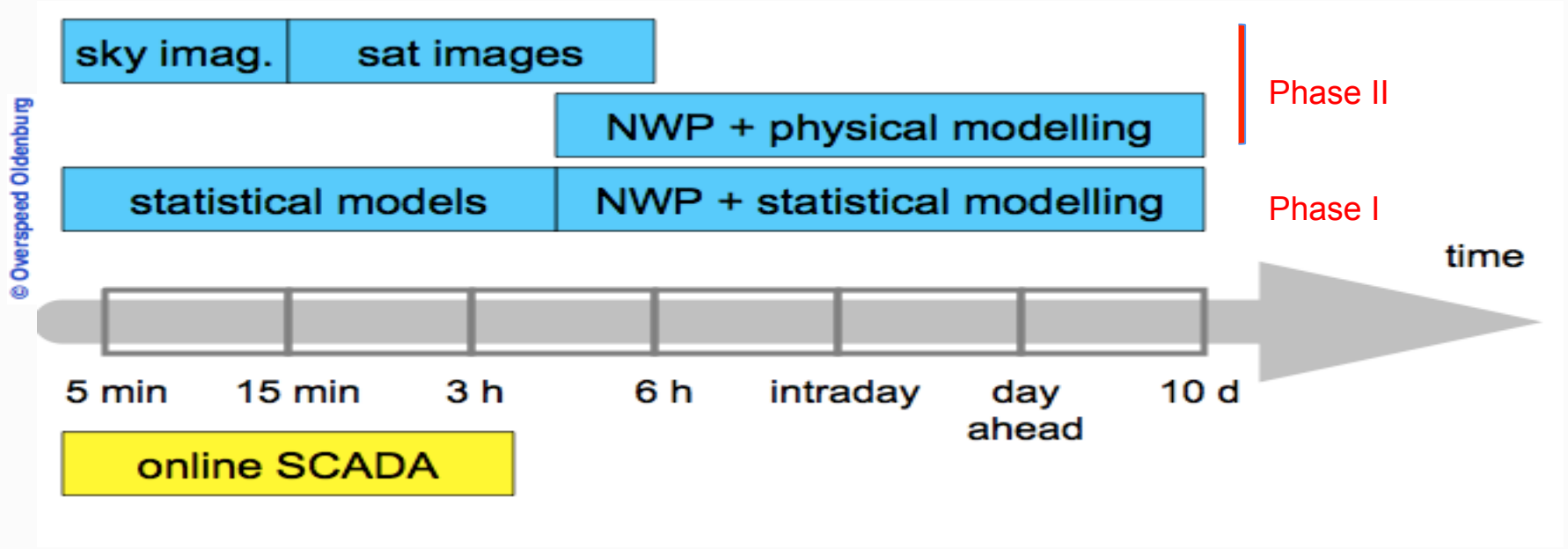
Solar forecasting techniques for different timescales



NMP – Numerical Weather prediction

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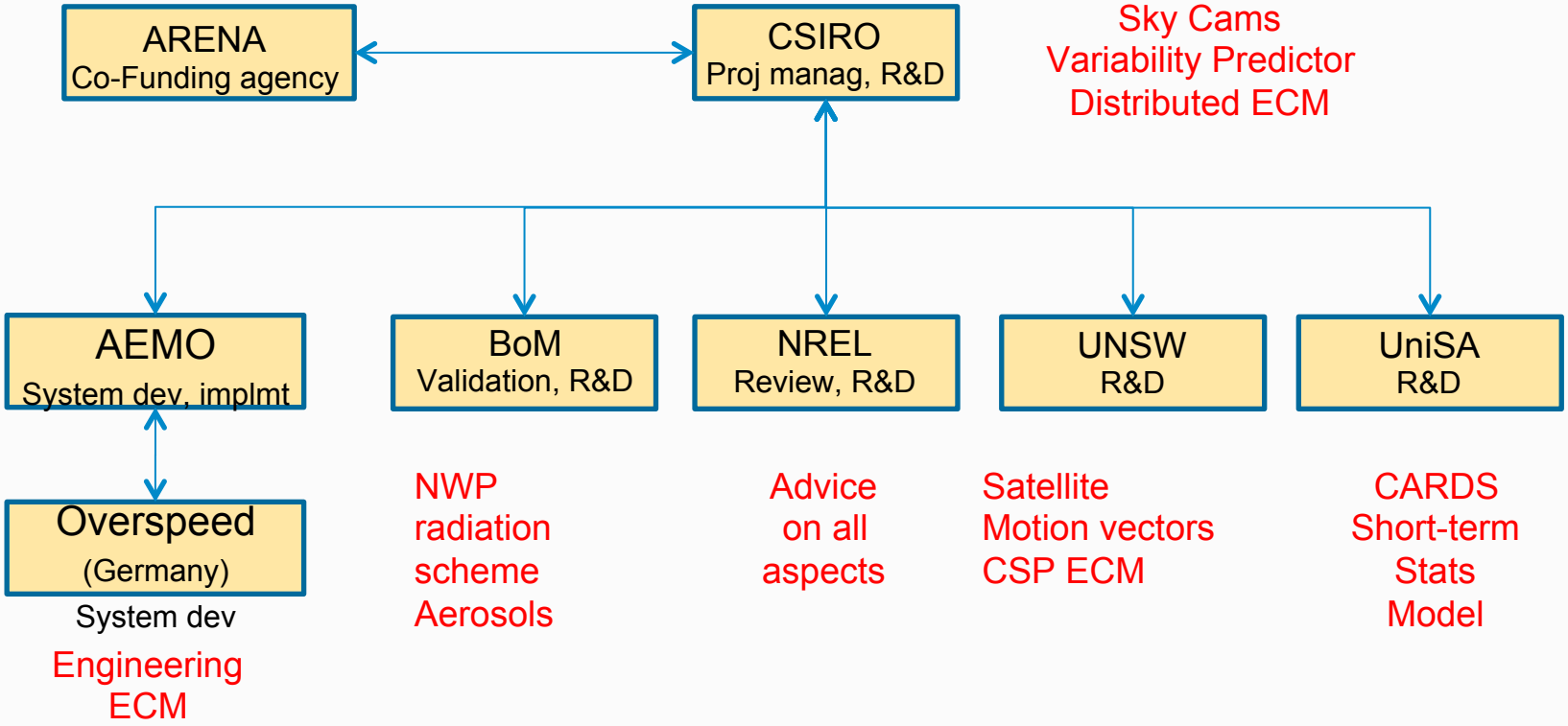
The Australian Solar Energy Forecasting System



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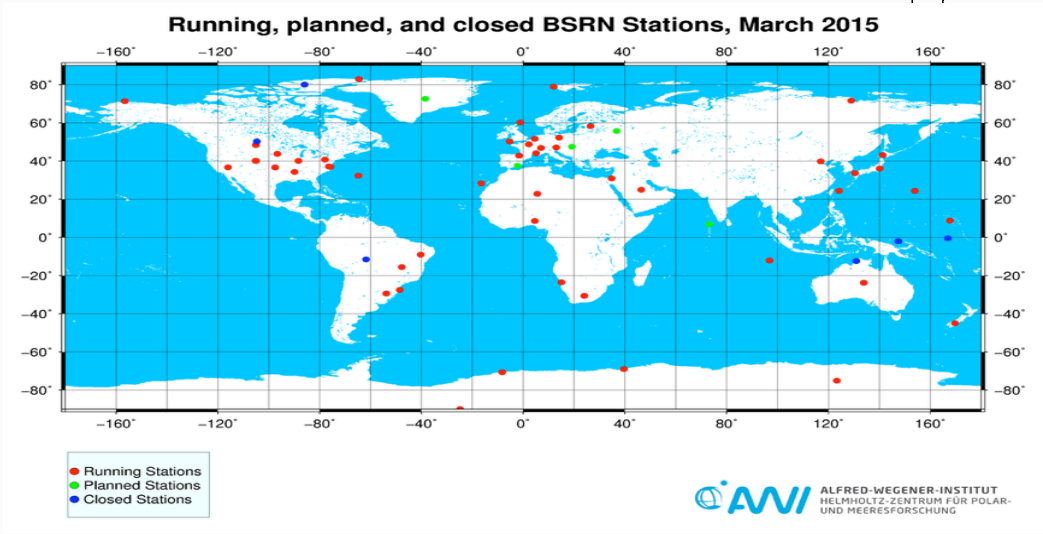
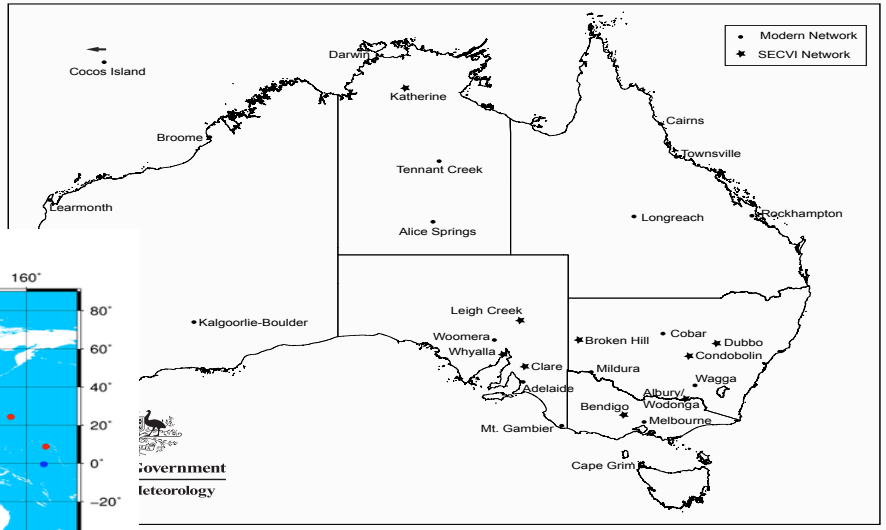
Assessment – Solar Radiation Stations





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Canberra Reference Site: ‘Solar Lab’

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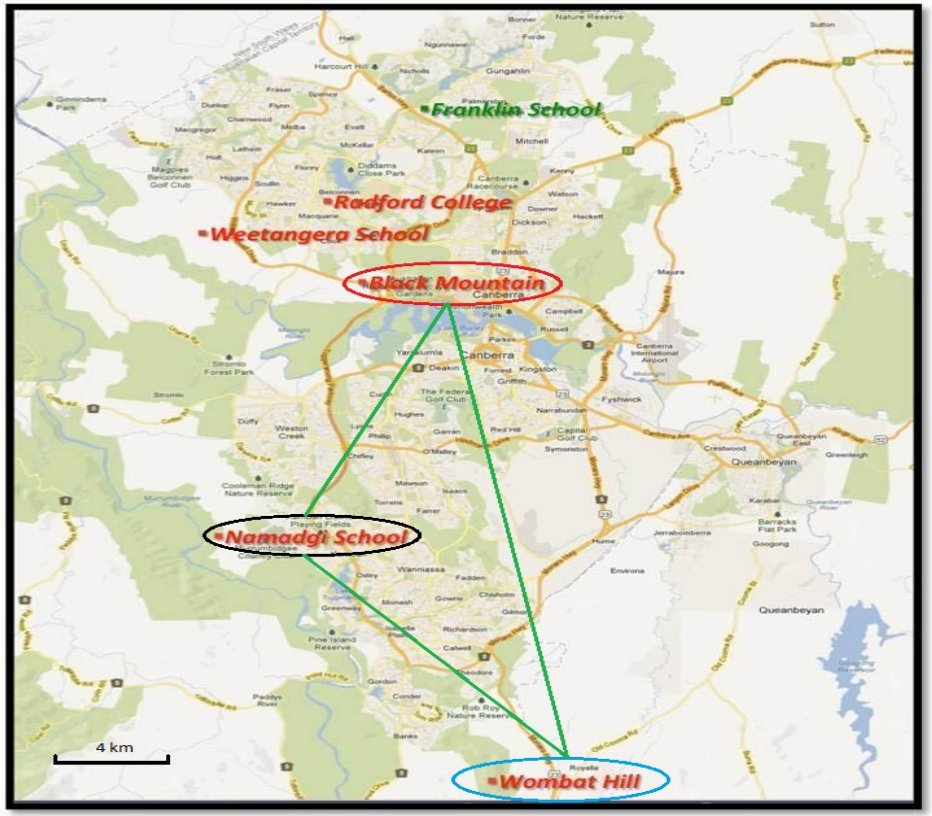
Canberra Solar radiation and power network

- Radford College (Fed 2010)
- Namadgi School (Nov 2011)
- Wombat Hill (Nov 2011)
- CSIRO Black Mountain (Mar 2012)
- WERU's Solar Lab
  - Tracking solar/PV
  - Ceilometer
  - Spectro-radiometer
  - Sky camera
- Weetangera School (Jun 2013)



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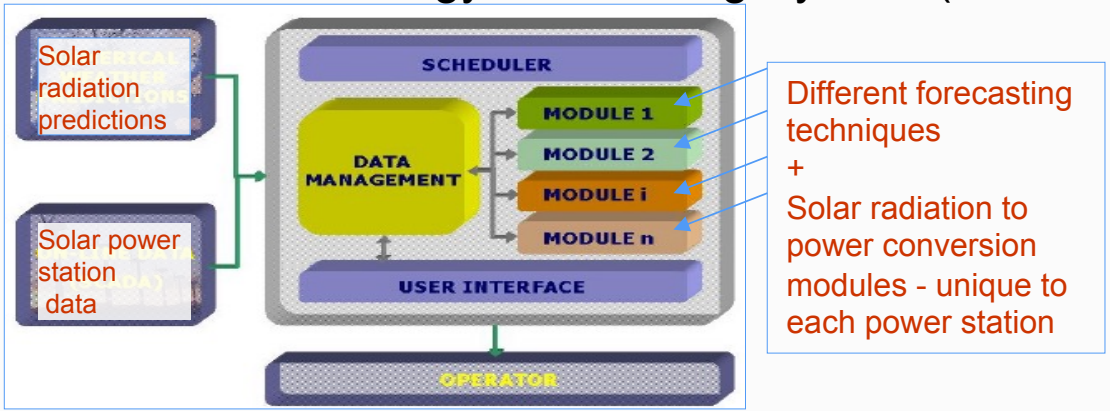
ASEFS – The solar extension at AEMO

Australian Solar Energy Forecasting System (ASEFS)



Modelled Wind Speed @location…

Wind farm standing data eg. power curve

Modelled Solar Radiation input components (direct, diffuse) @location, physical distribution, time, date, other dependent data (panel temp)

Solar farm standing data eg. power curve + any fuel conversion, storage

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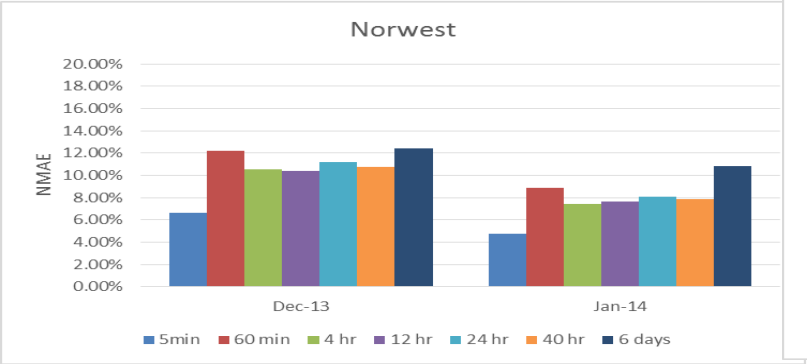
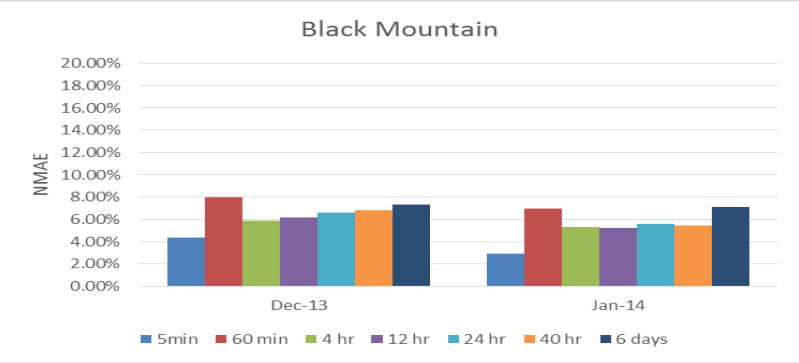
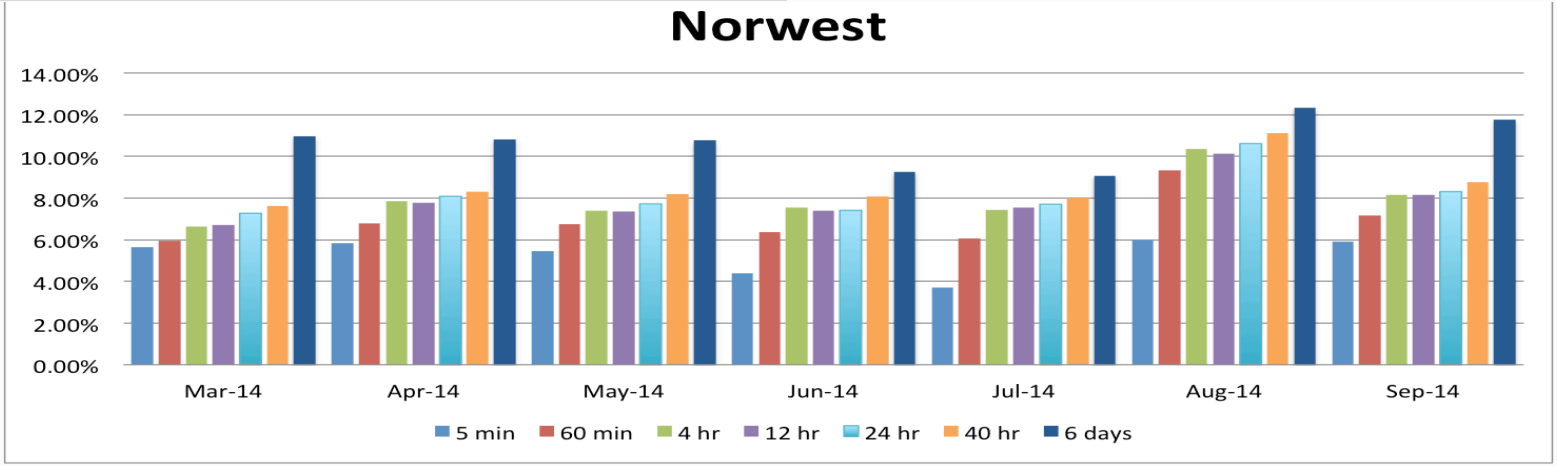
ASEFS test results







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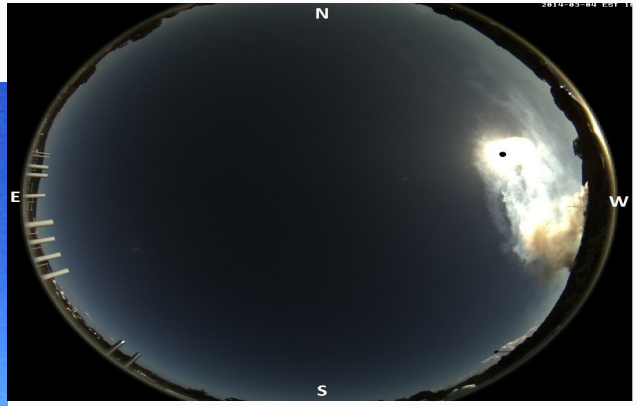
Some Research Results

Effect of aerosols (smoke) on PV

Canberra, 4th March 2014



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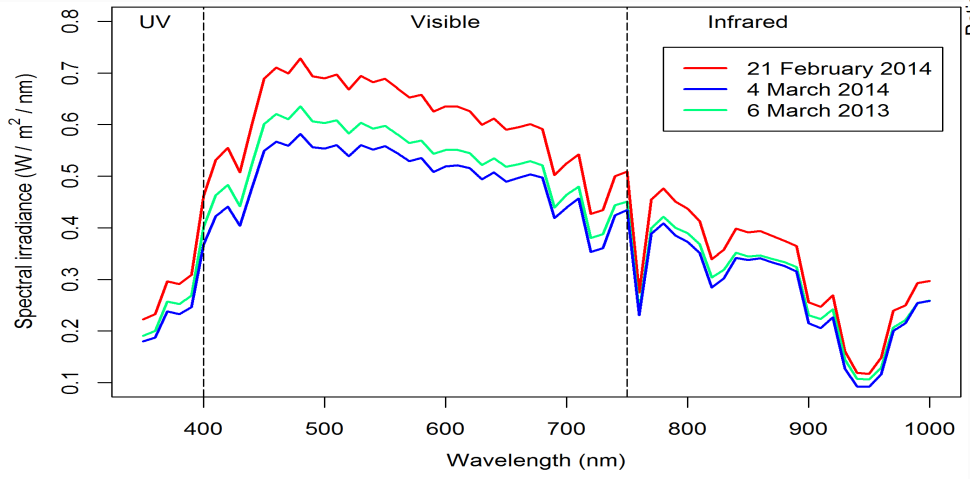
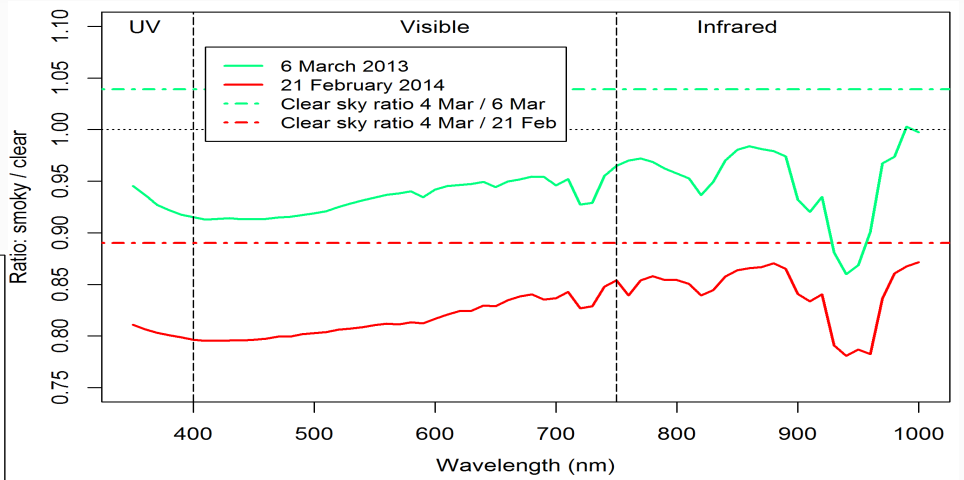
Perry & Troccoli (2015)

Effect of aerosols on PV





Technology and Mean spectral ratio (smoky/clear)	
Single crystalline silicon (mono.Si)	0.9227
Copper indium gallium selenide (CIGS)	0.9193
Multicrystalline silicon (multi.Si)	0.9192
Cadmium telluride (CdTe)	0.9157
Gallium Arsenide (GaAs)	0.9108
Amorphous silicon (a.Si)	0.9043

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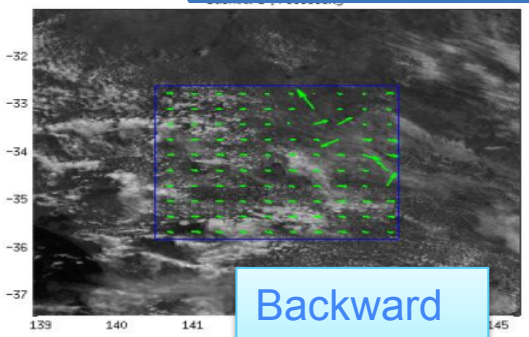
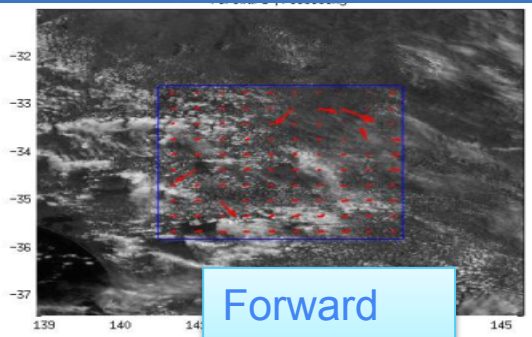
Perry & Troccoli (2015)

Cloud Motion Vectors

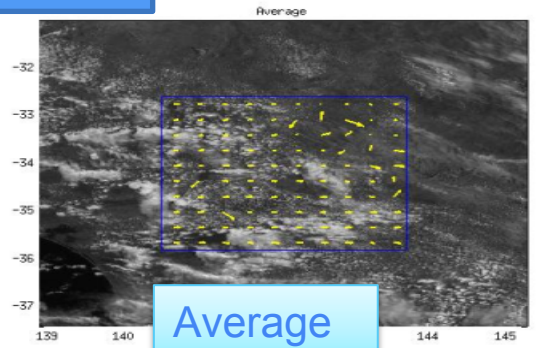
CMVs produced at Mildura site on 16/03/2014 at 0030, 0040, 0050 UTC



Backward Processing

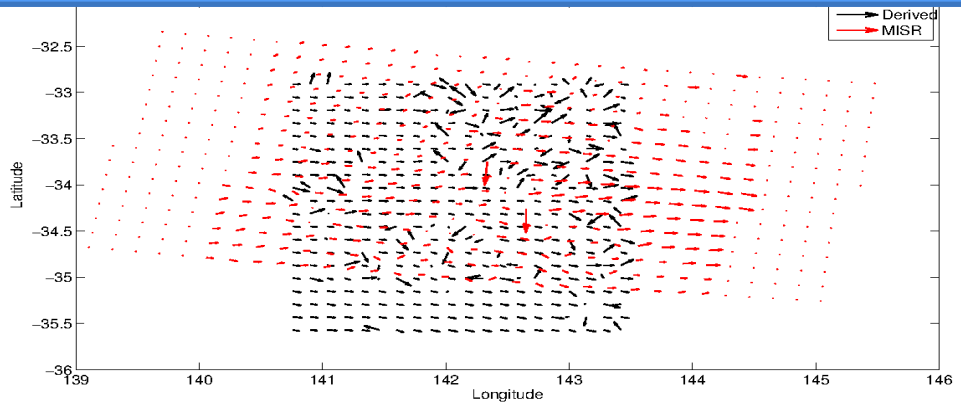


Forward Processing



Average

Derived CMVs compared to MISR instrument on TERRA satellite



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Courtesy UNSW

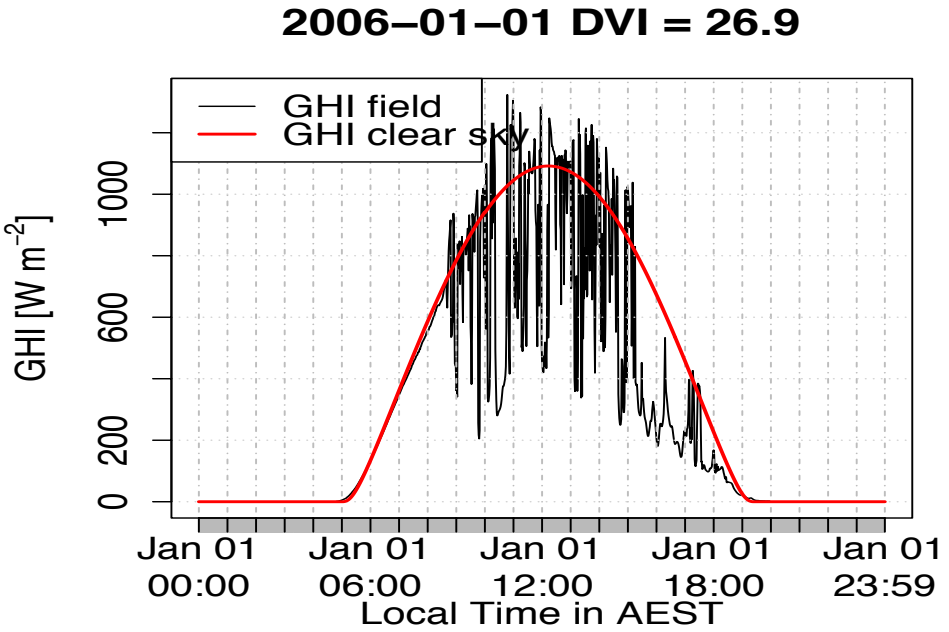
Daily Variability Index (DVI) Prediction

$$DVI = \frac{\sum_{k=2}^{n} |GHI_k - GHI_{k-1}|}{\sum_{k=2}^{n} |CSI_k - CSI_{k-1}|}$$

DVI: daily variability index

GHI: global horizontal irradiance

CSI: clear sky irradiance



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Huang et al. (2014)

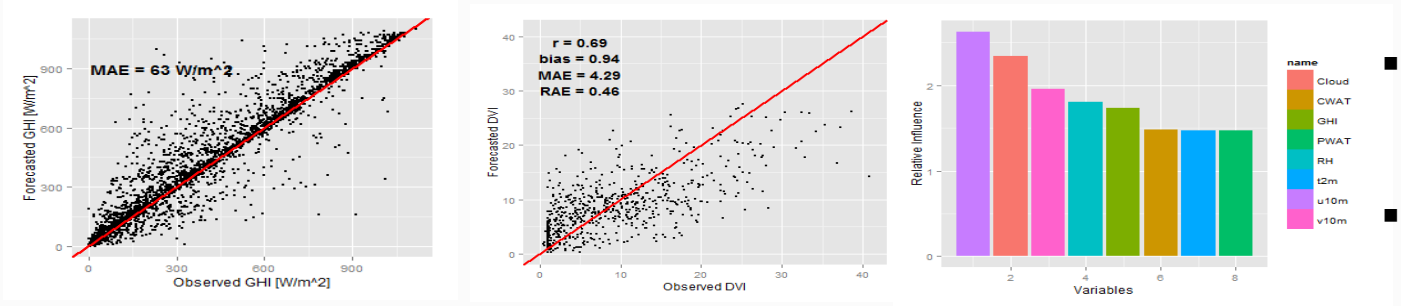
Daily Variability Index (DVI) Prediction

3h mean GHI

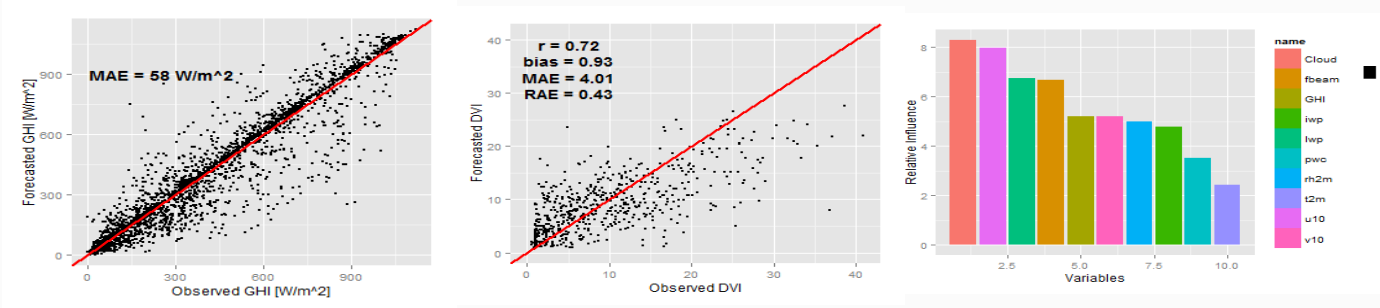
DVI

Relative influence of predictors

GFS



CCAM



- The results at the nearest grid point are used
- CCAM outperforms GFS in forecasting of both GHI and DVI
- Important predictors include cloud and wind velocities

Wagga Wagga – Inland temperate

Huang et al. (2014)

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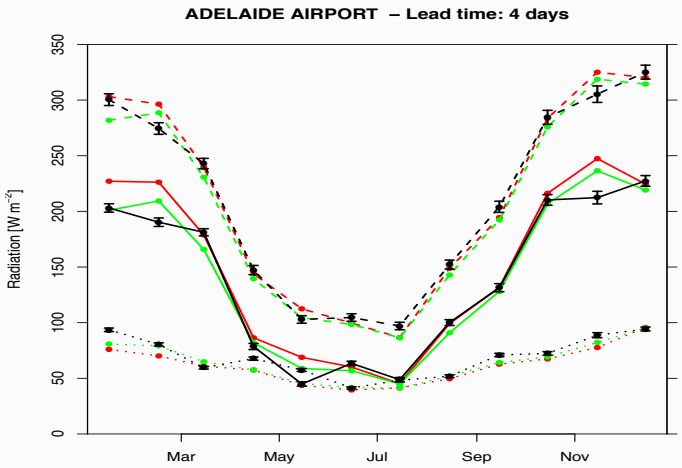
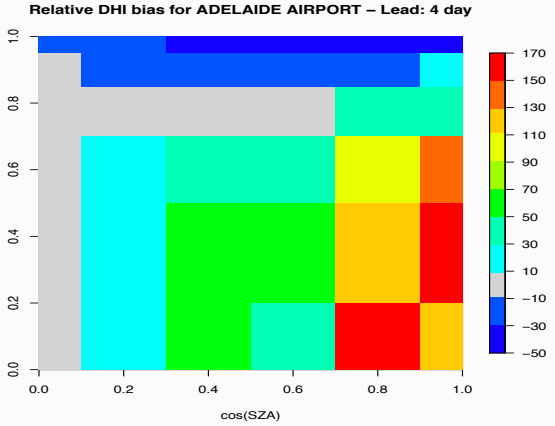
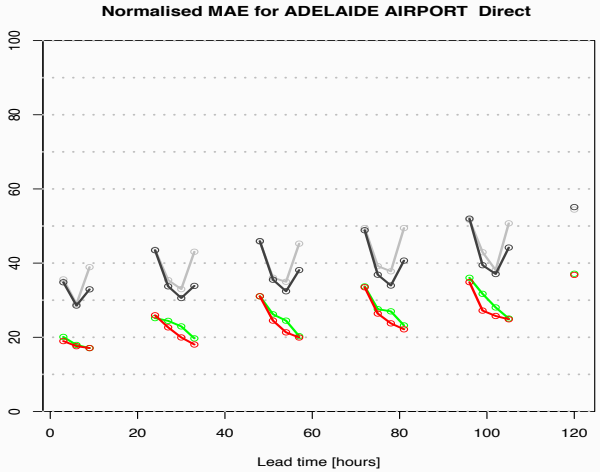
Solar NWP– pushing it to 5 days ahead



Monthly means for the three solar components



Bias based on clear sky index and zenith angle



Bias correction reduces error

Adelaide airport

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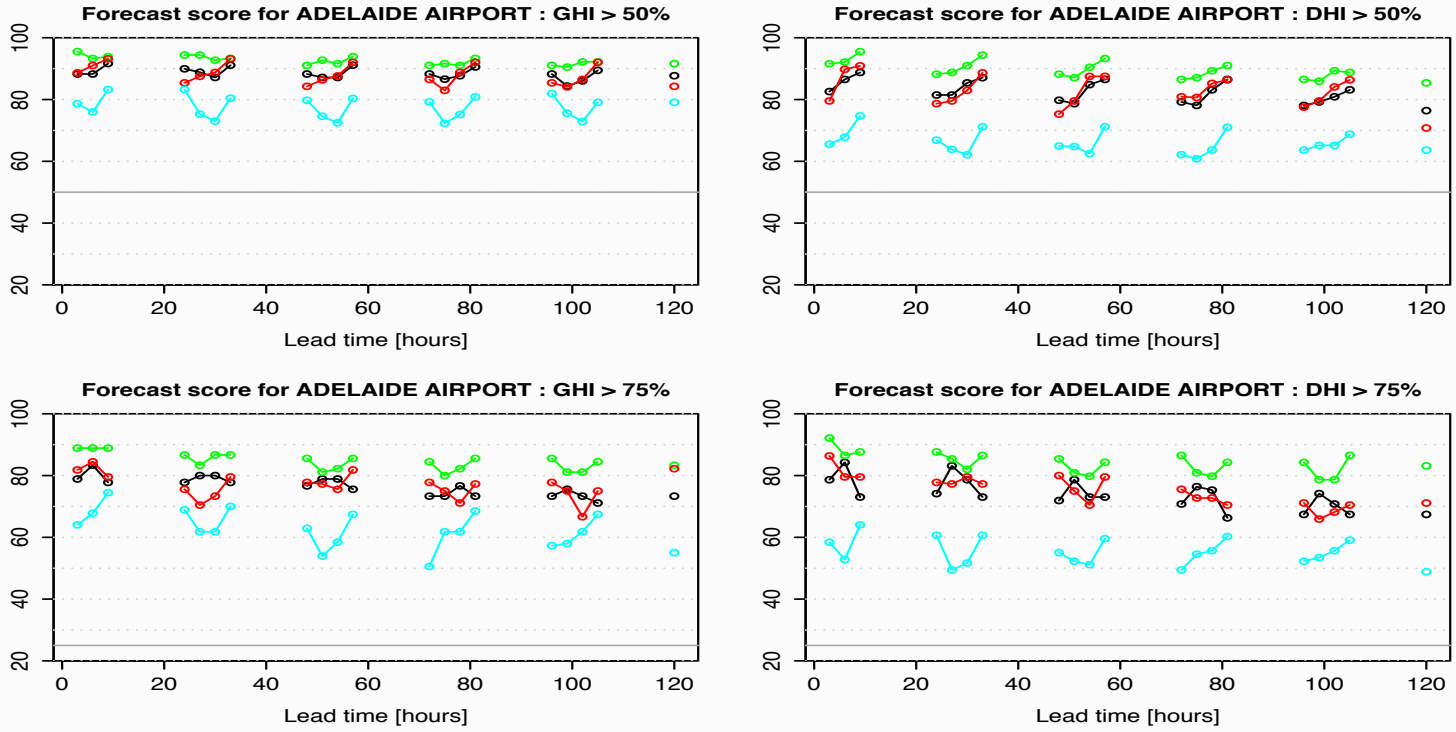
Troccoli and Morcrette (2014)

Solar NWP– pushing it to 5 days ahead



Non-corrected model (**black**), bias corrected over 2006 (**green**),
bias corrected second half 2006 (**red**) , persistence forecast (cyan)

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Troccoli and Morcrette (2014)

Outstanding Challenges

Sky camera for solar power prediction

1. Classify Clouds
2. Characterise lens distortion
3. Extract ‘Optical Flow’ vectors
4. Extrapolate vectors along distortion path
5. Estimate time-to-shading

High-resolution 180 degree panorama cameras (Mobotix Q24M)

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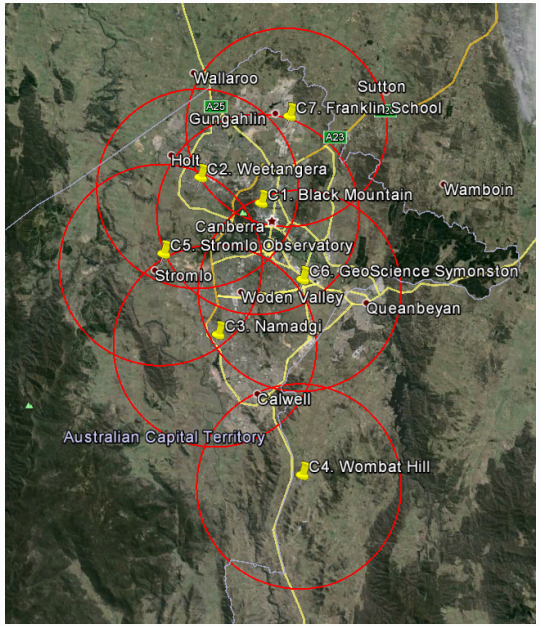
Courtesy CSIRO

SKY CAMERA VIDEO

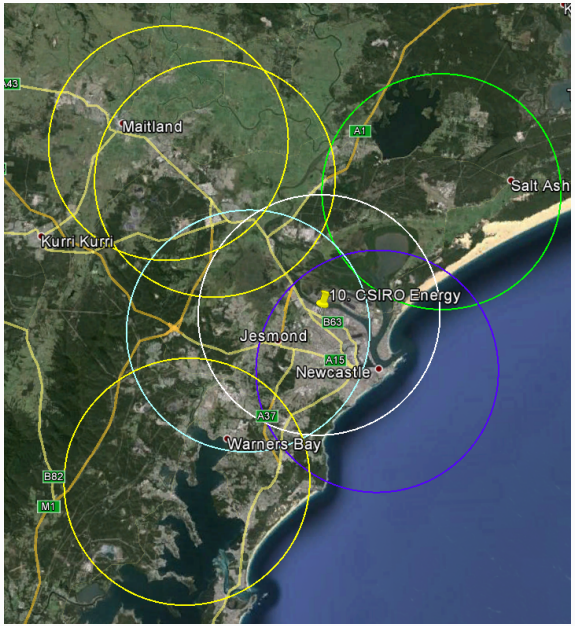
Courtesy CSIRO/ARENA

Sky camera network

- 10km radius: cover whole city with handful of cameras
- 15 sites around Canberra & Newcastle for ramp and irradiance forecasting
- Canberra sites co-located with: Pyranometer, PV arrays & weather stations



Canberra



Newcastle

Courtesy CSIRO

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Summary

- A huge amount of weather/climate observations and model output – though not so many for solar irradiance and wind speed above 10 m
- Accuracy of weather/climate products generally very good but need to understand limitations and their variability
- Wind and solar power forecasting proven to work in operational context for grid integration

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