Il valore delle osservazioni e delle previsioni meteorologiche per le energie rinnovabili

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University of East Anglia (UK)

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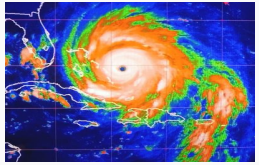
festival meteorologia

Rovereto (Italia), 11-12 Nov 2016

Energia e meteorologia vanno a braccetto

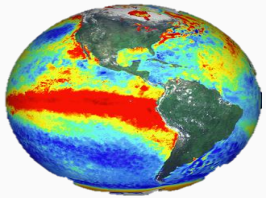
Passing clouds

Drop in solar power



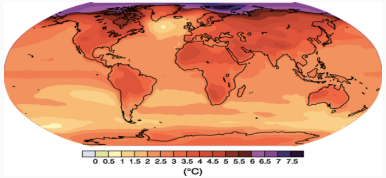
Hurricanes

Disruptions to oil rig operations



El-Niño

Changes in Demand Patterns



Long term changes

Renewable Resource Assessment

Seconds Minutes Days Months Seasons Years Decades

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Ma cosa significa la parola Meteorologia?

Il termine deriva dal greco μετεωρολογία, *meteōrologία*, da μετέωρος *metéōros*, "elevato" e λέγω *légō*, "parlo", quindi "discorso razionale intorno agli oggetti alti". La parola μετέωρος ha un'etimologia incerta, forse da μετά *metá* "con, dopo" e αἴρω *áirō* "alzo"

The word "meteorology" is from Greek μετέωρος *metéōros* "lofty; high (in the sky)" (from μετα- *meta-* "above" and ἀείρω *aeiro* "I lift up") and -λογία *-logia* "-(o)logy",

i.e. "**the study of things in the air**".

WORLD METEOROLOGICAL ORGANIZATION

WEATHER CLIMATE WATER

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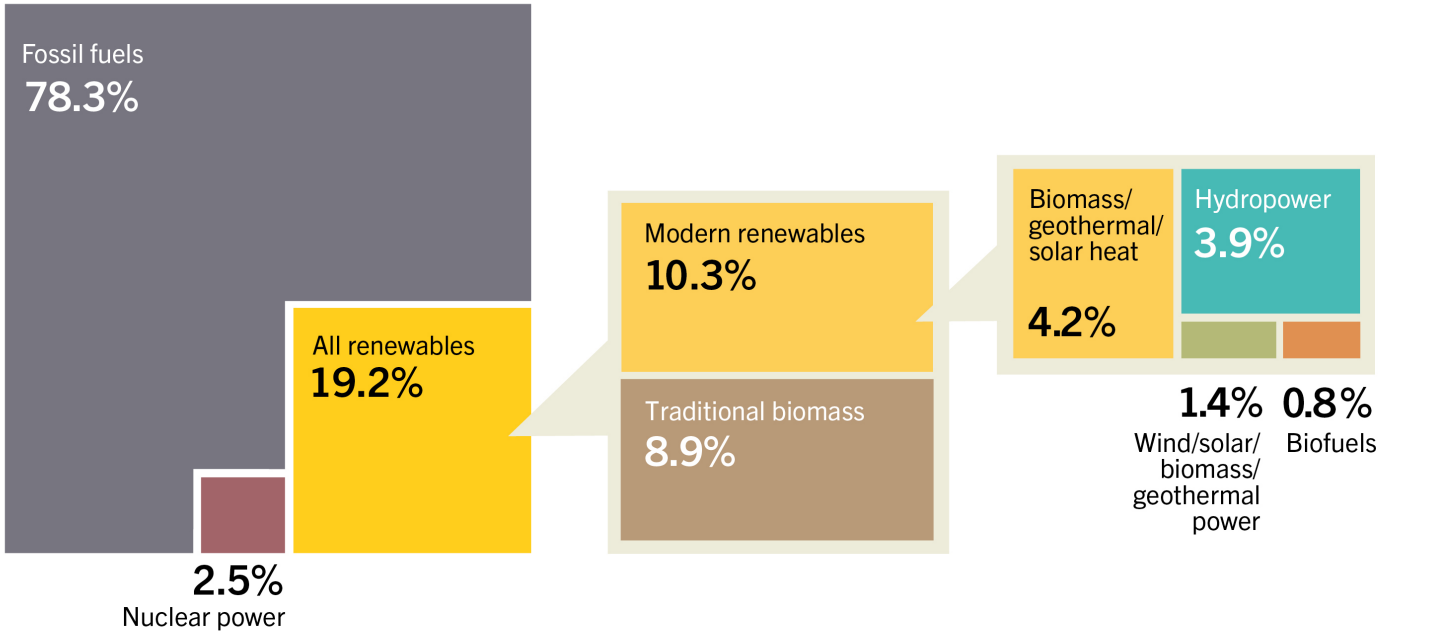
Global Final Energy Consumption



REN21 *Renewables 2016 Global Status Report*

REN21 Renewable Energy Policy Network for the 21st Century

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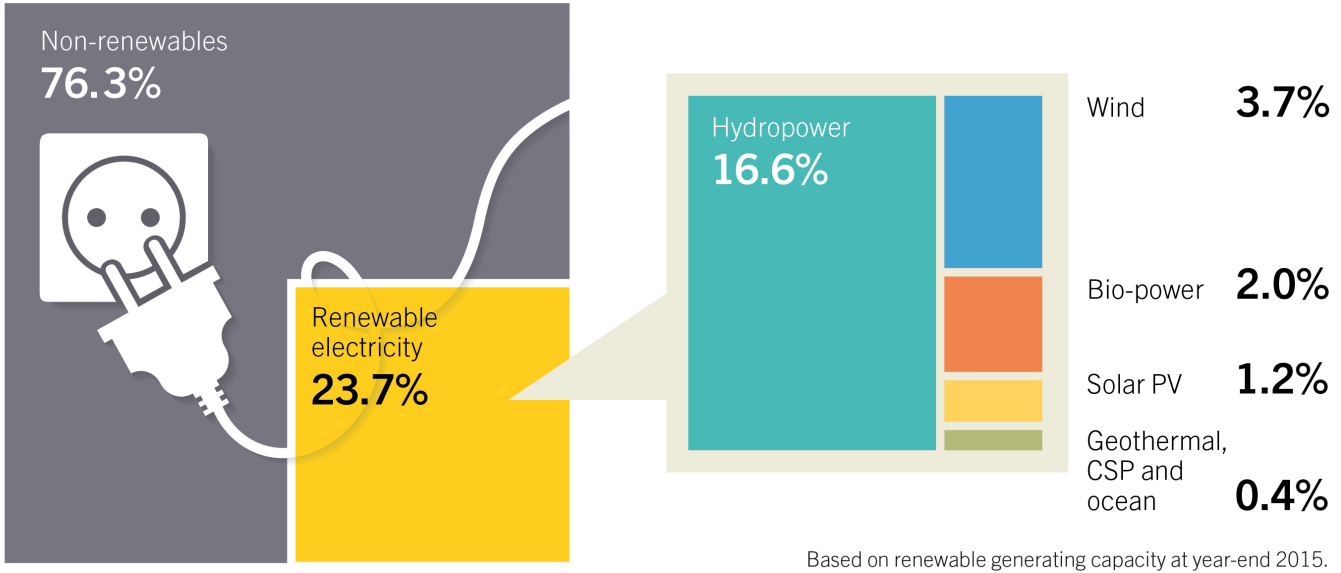
RE Share of Global Electricity Production



REN21 *Renewables 2016 Global Status Report*

REN21 Renewable Energy Policy Network for the 21st Century

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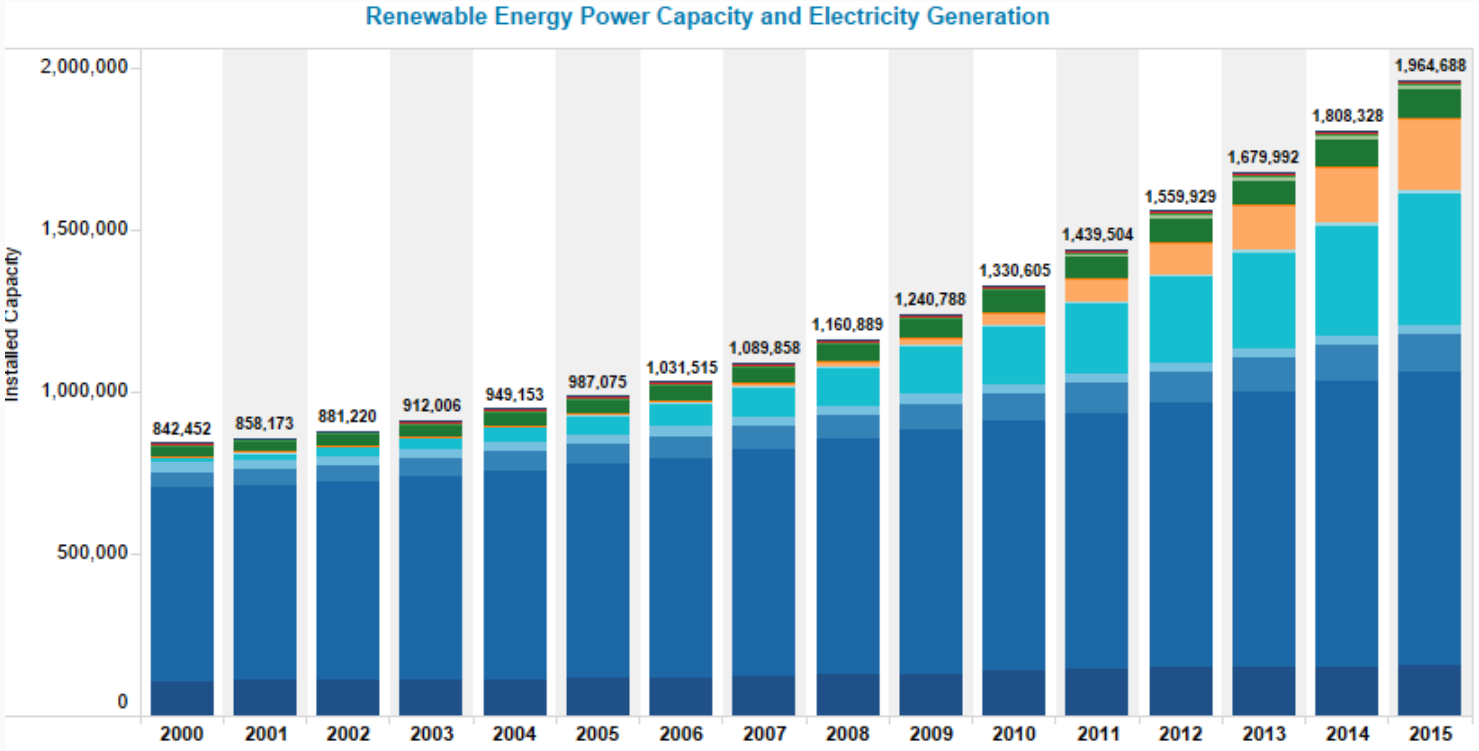
Strong growth in renewables



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IRENA (2016)

Non solo aumento delle rinnovabili …

Efficienza energetica

Impatti su strutture energetiche

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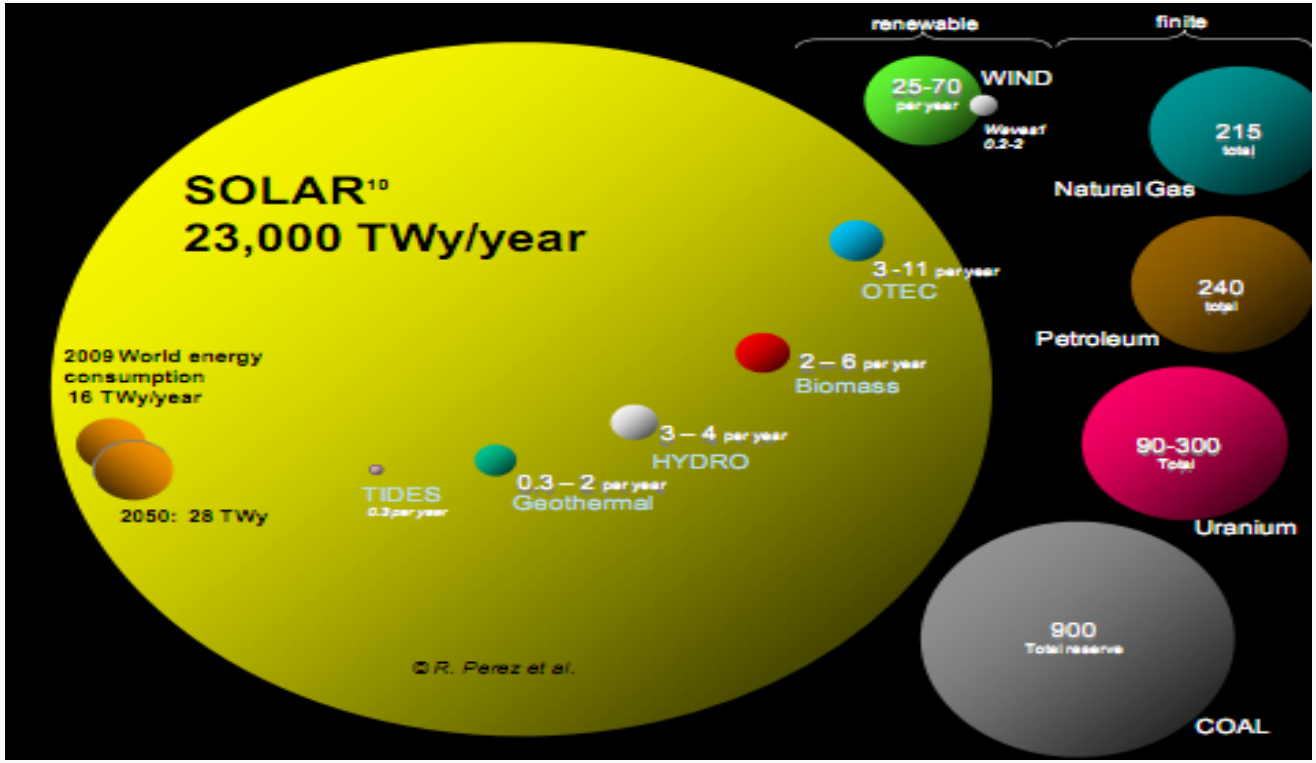
Solar Power Potential



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Significant science & technical challenges

Large-scale solar PV

An explosion in rooftop PV

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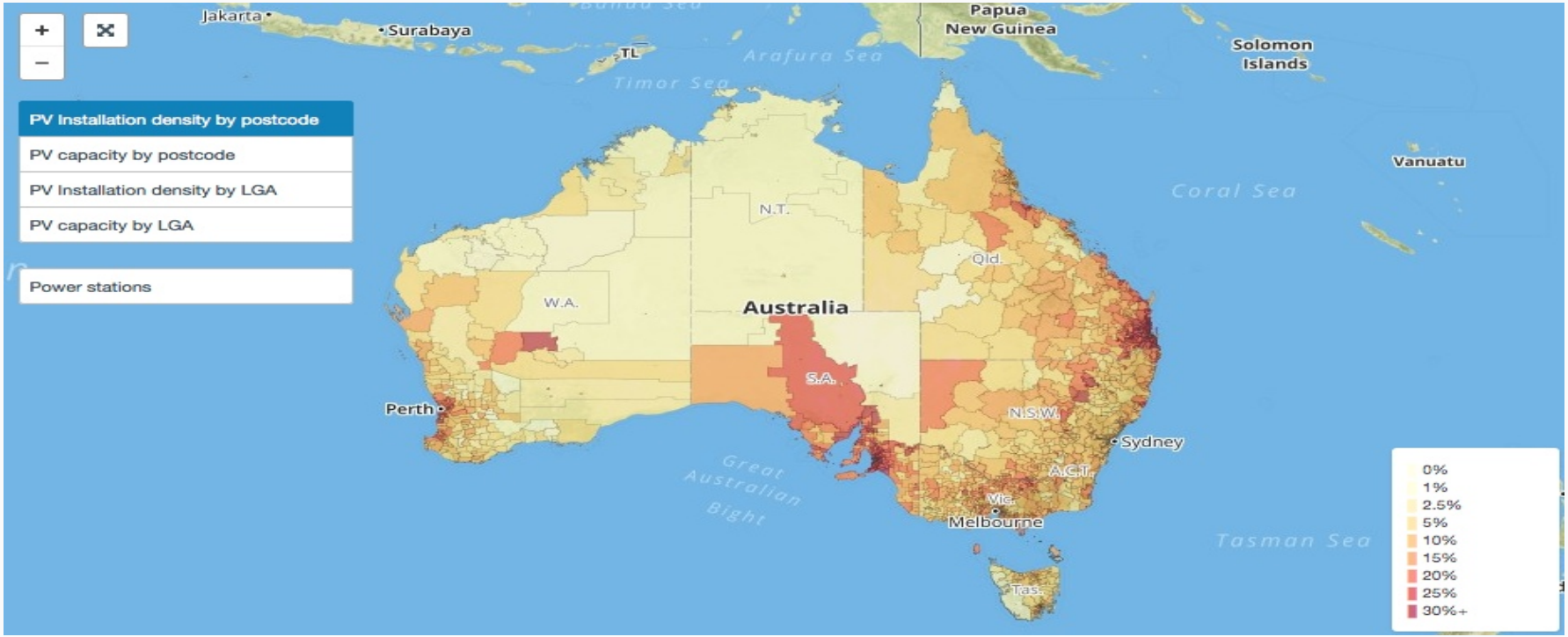
PV Installations in Australia by postcode



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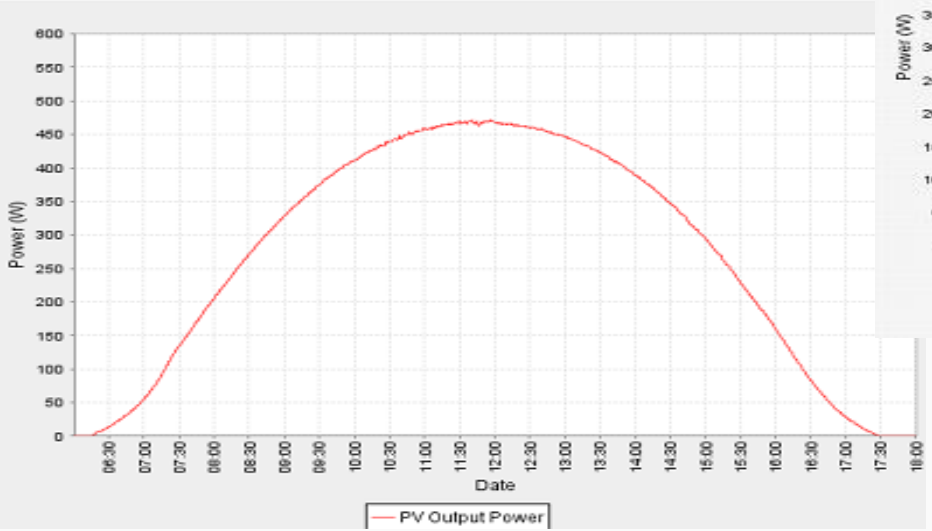
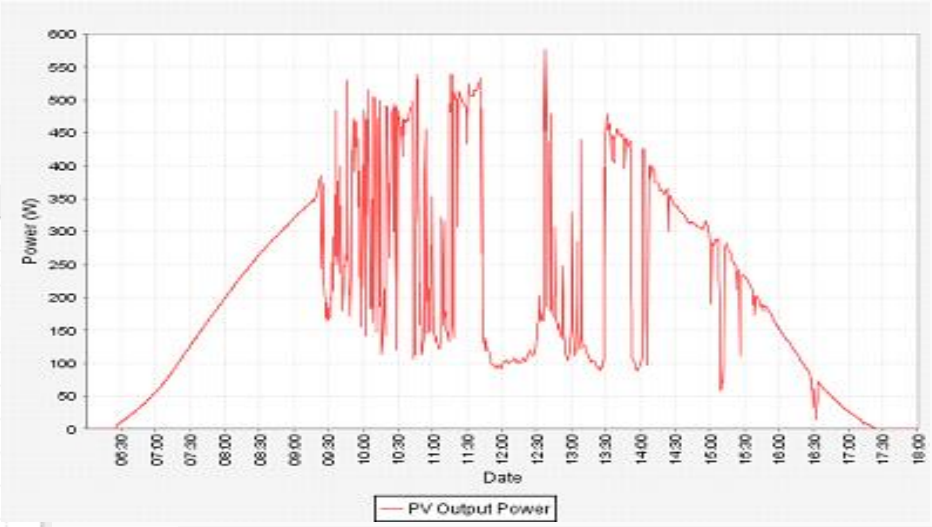
APVI (2015)

Solar radiation – can be very highly variable





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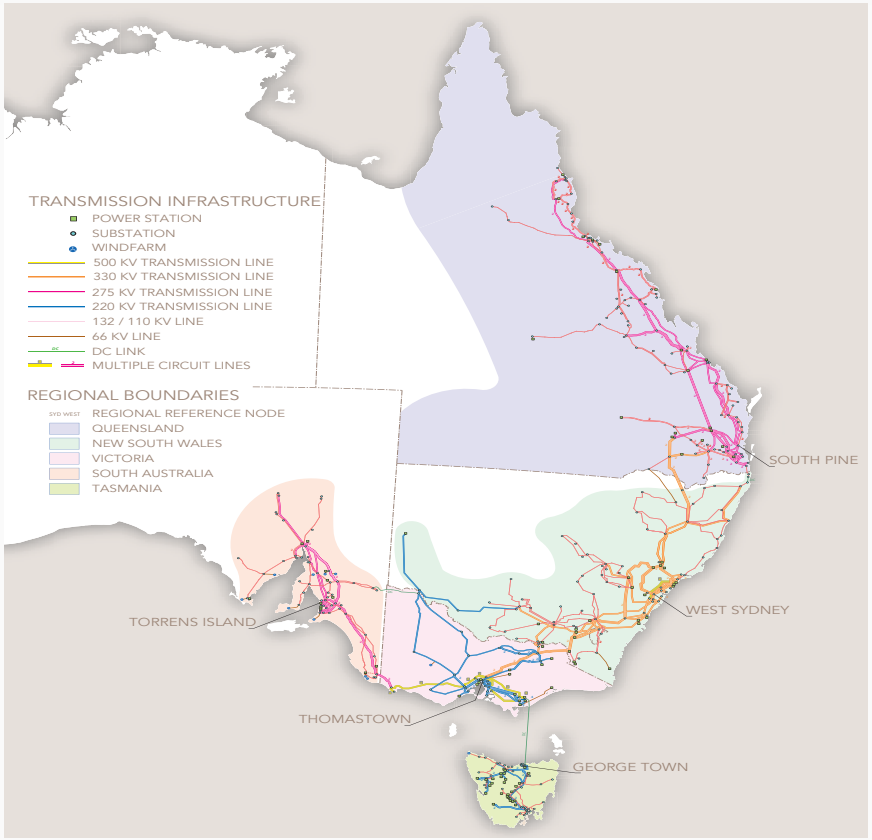
PV production is highly dependent on the temperature of PV panels, which in turn depends on air temperature. As a rule of thumb, an increase of 20C in PV panel temperature leads to a decrease in PV production of 10%

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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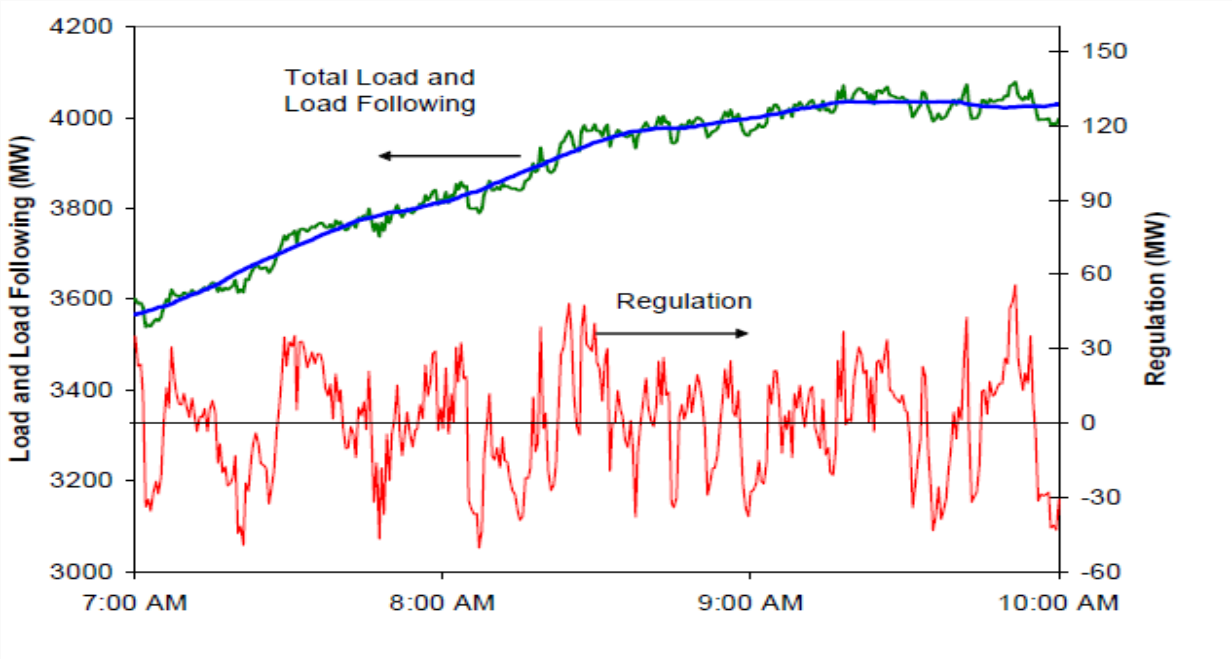
Regulation Services Demand



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

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Why Forecast Variable Renewable Power?

- From seconds to minutes
  - System control
  - Electricity system stability
- From minutes to hours
  - Alternative Generation scheduling
  - Storage system scheduling, peak shaving
- From hours to days
  - Alternative Generation scheduling, load shifting
  - Power system adequacy assessment
- From days to months to years
  - Power system adequacy assessment
  - Resource assessment

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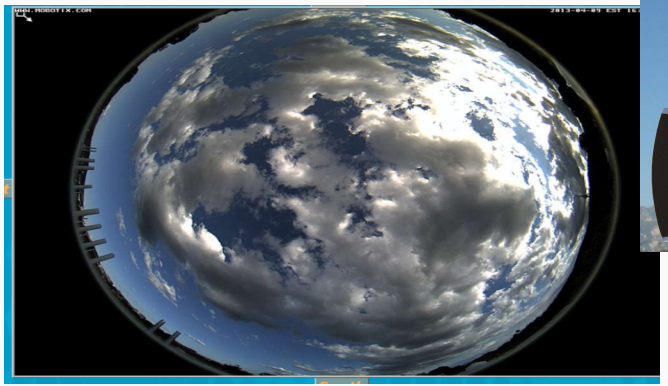
Observations – Ground



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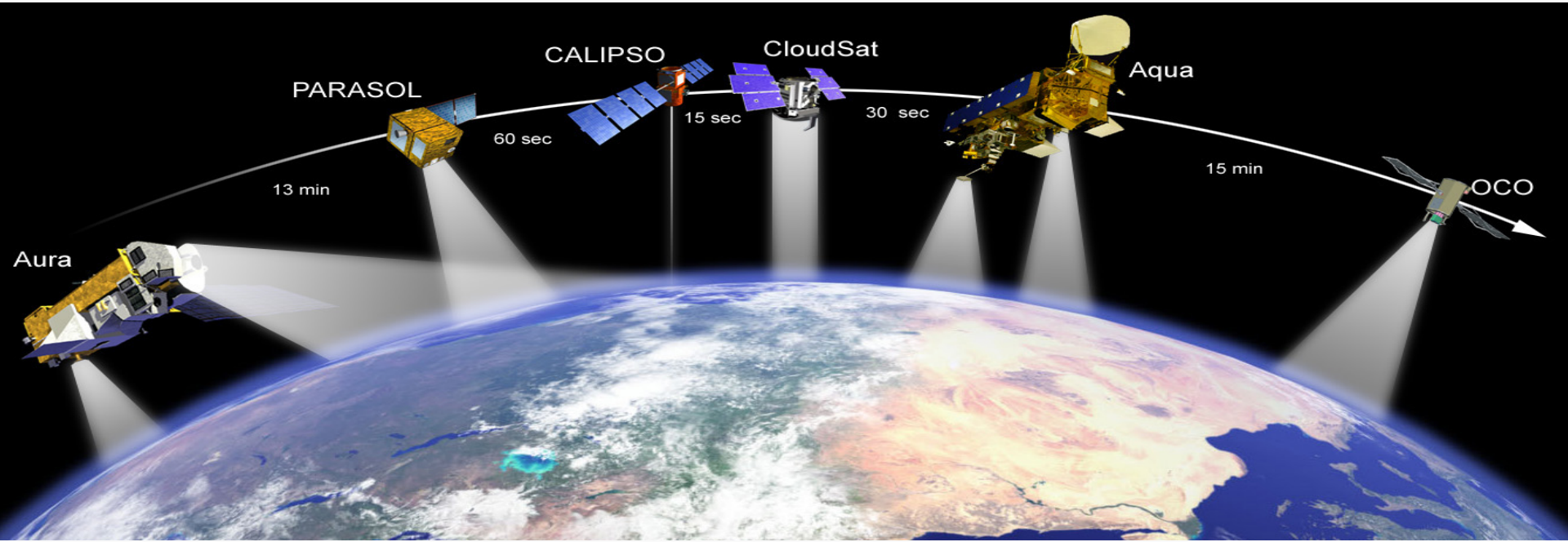
Observations – Space



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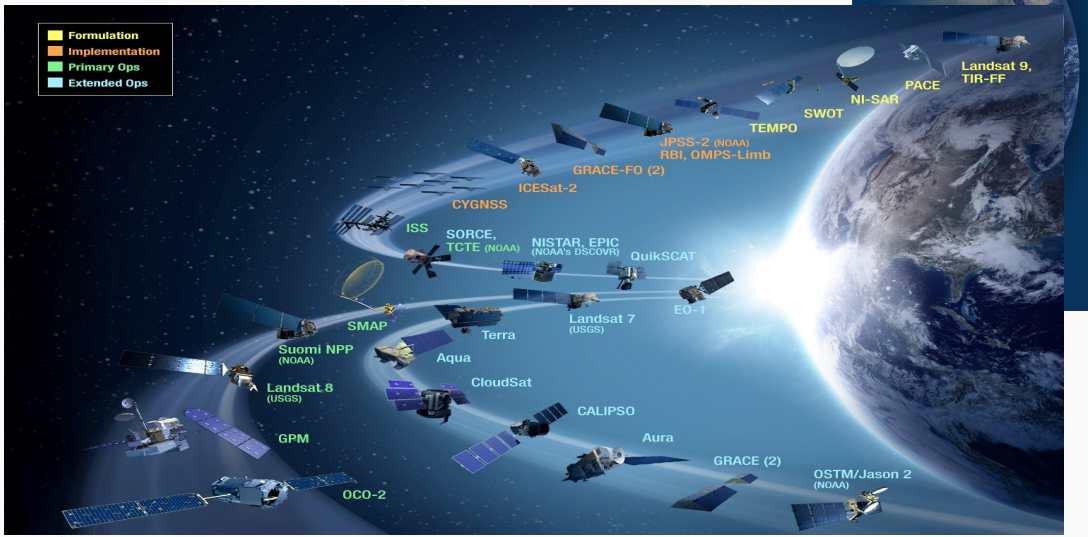
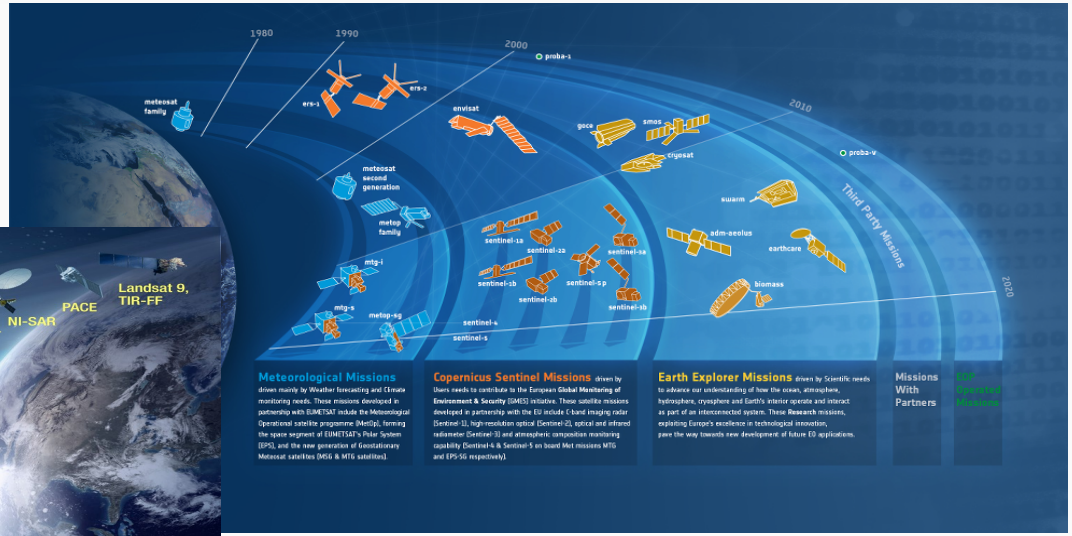
Observations – Space (NASA & ESA)





Hundreds of millions of observations

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Observations – You can set up your own!

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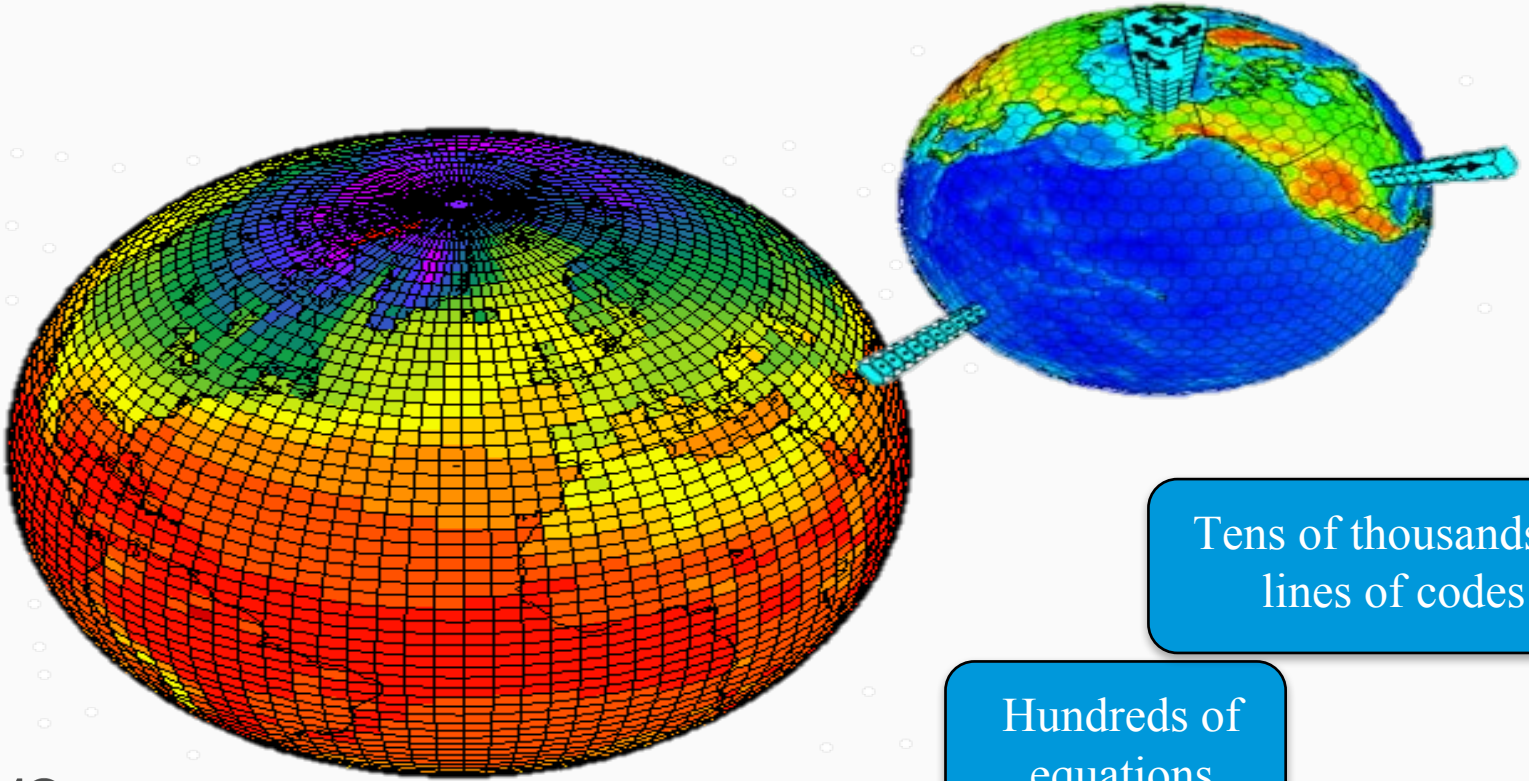
Physical/Mathematical Models



Tens of thousands of lines of codes

Hundreds of equations

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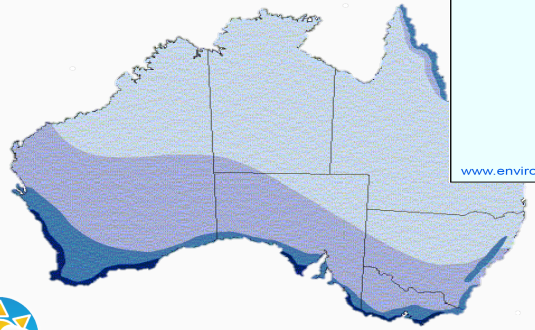
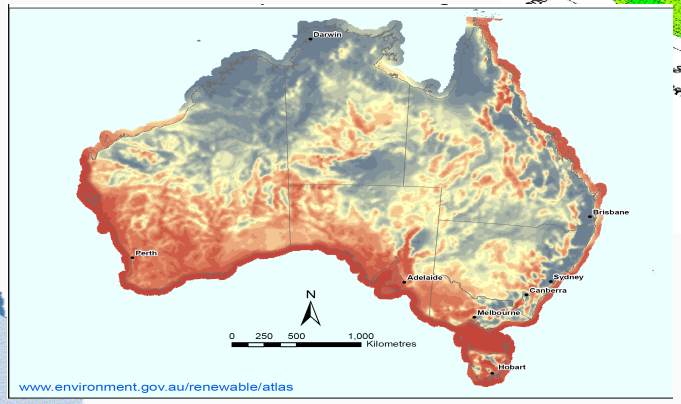
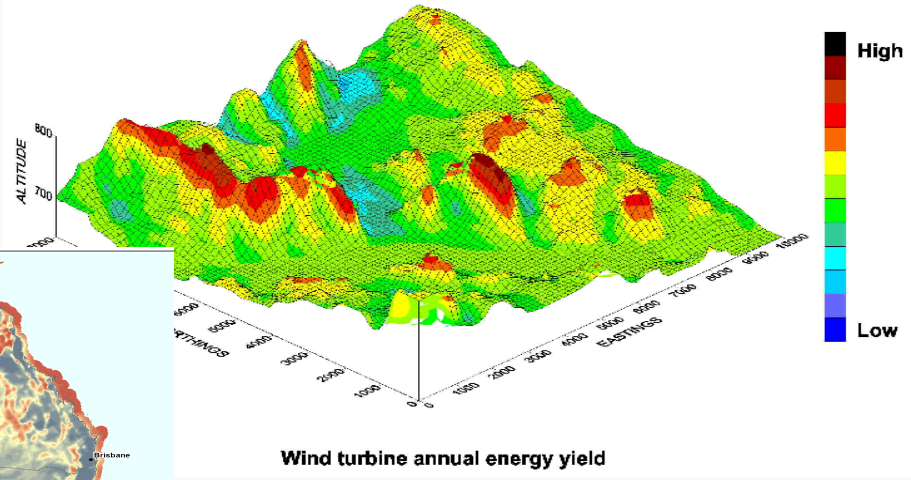
Physical/Mathematical Models







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

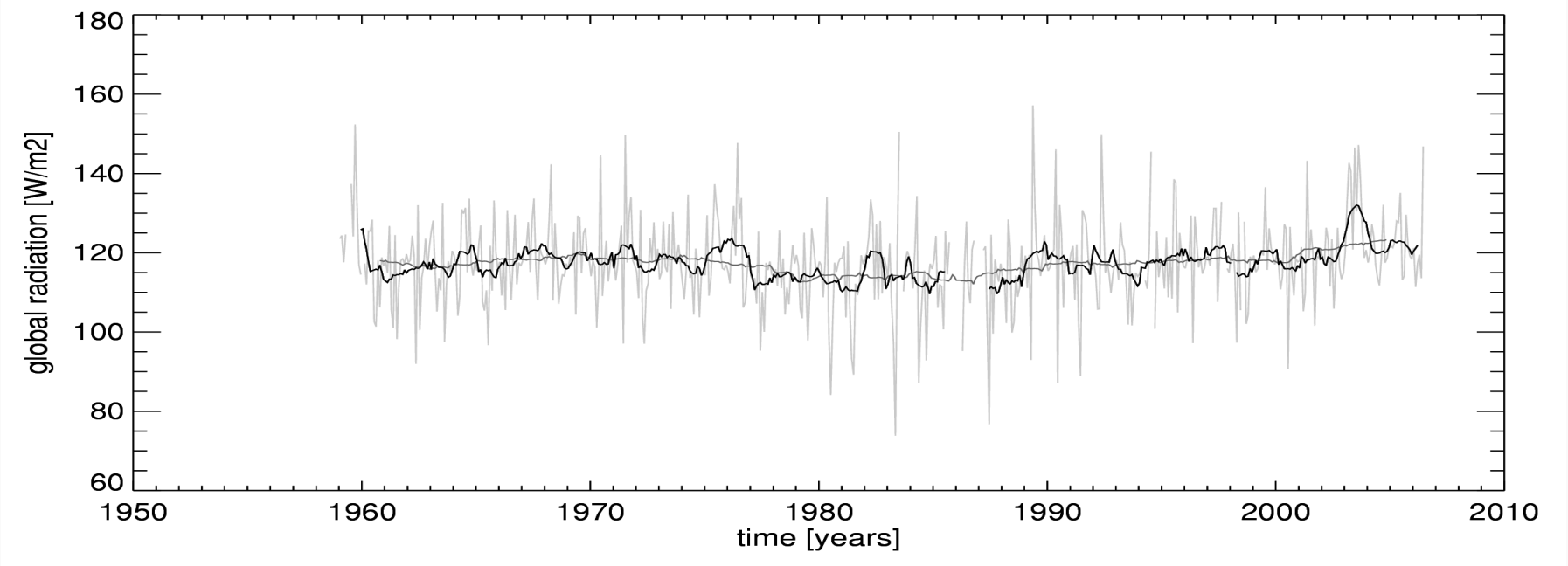
Wind
Elevation
Offshore winds
Wave/currents
Ocean altimetry

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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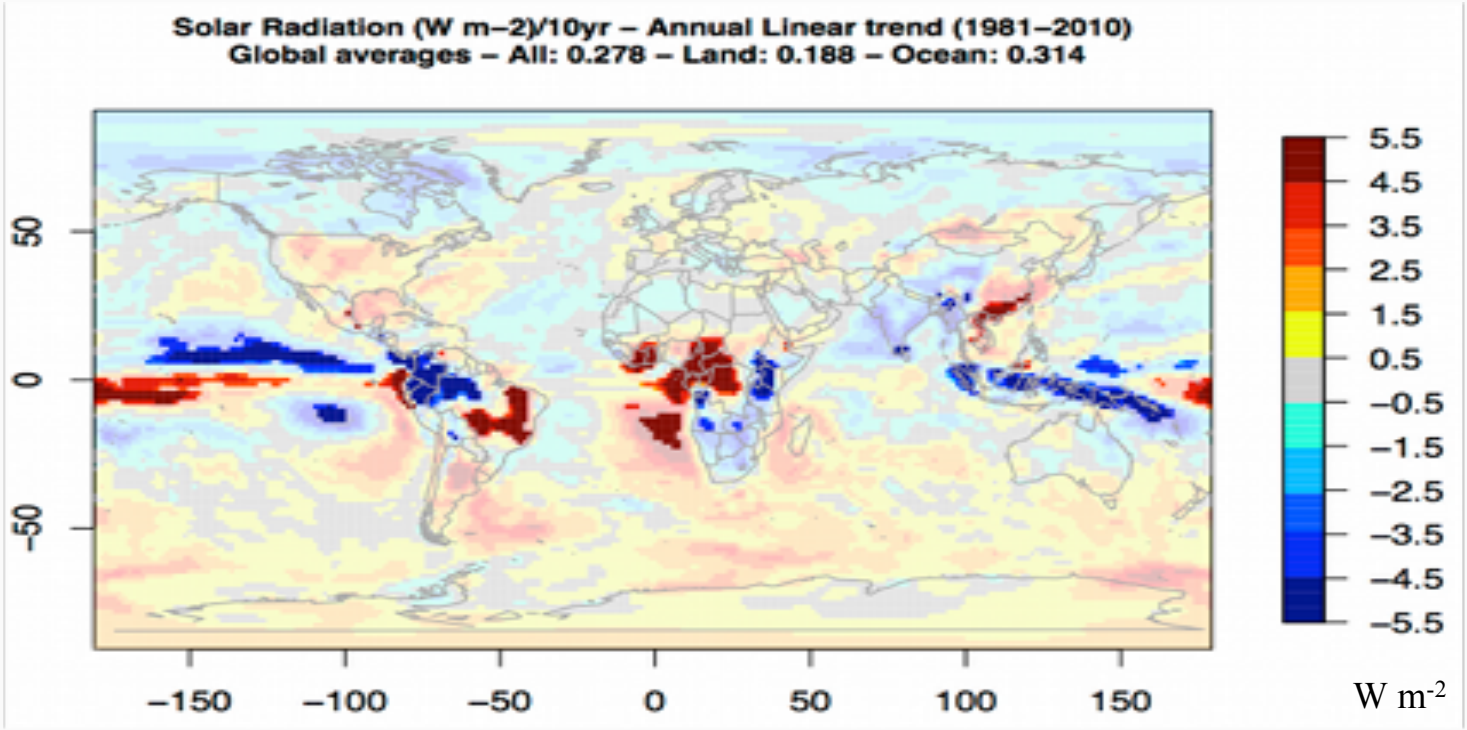
Historical Reanalysis – Solar Radiation (1981-2010)



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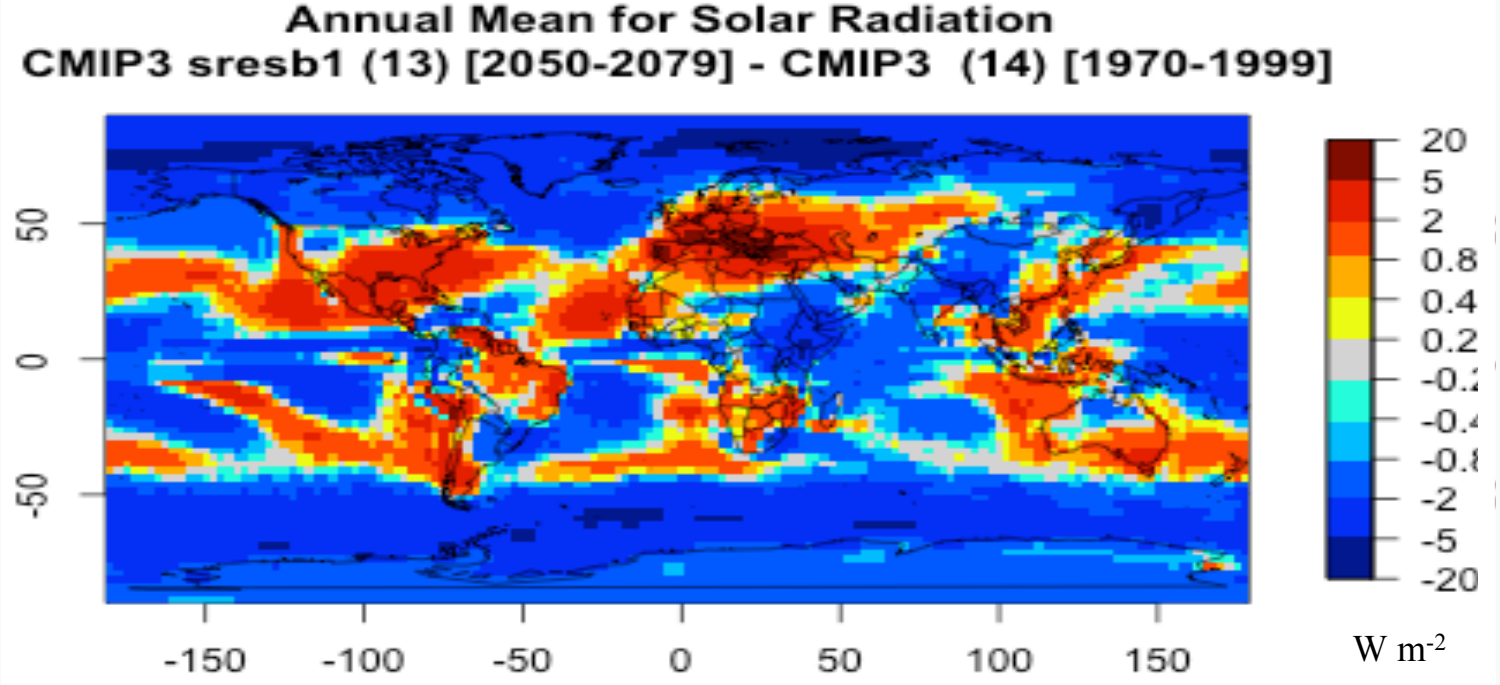
Climate Projection – Solar Radiation (2050-2079)



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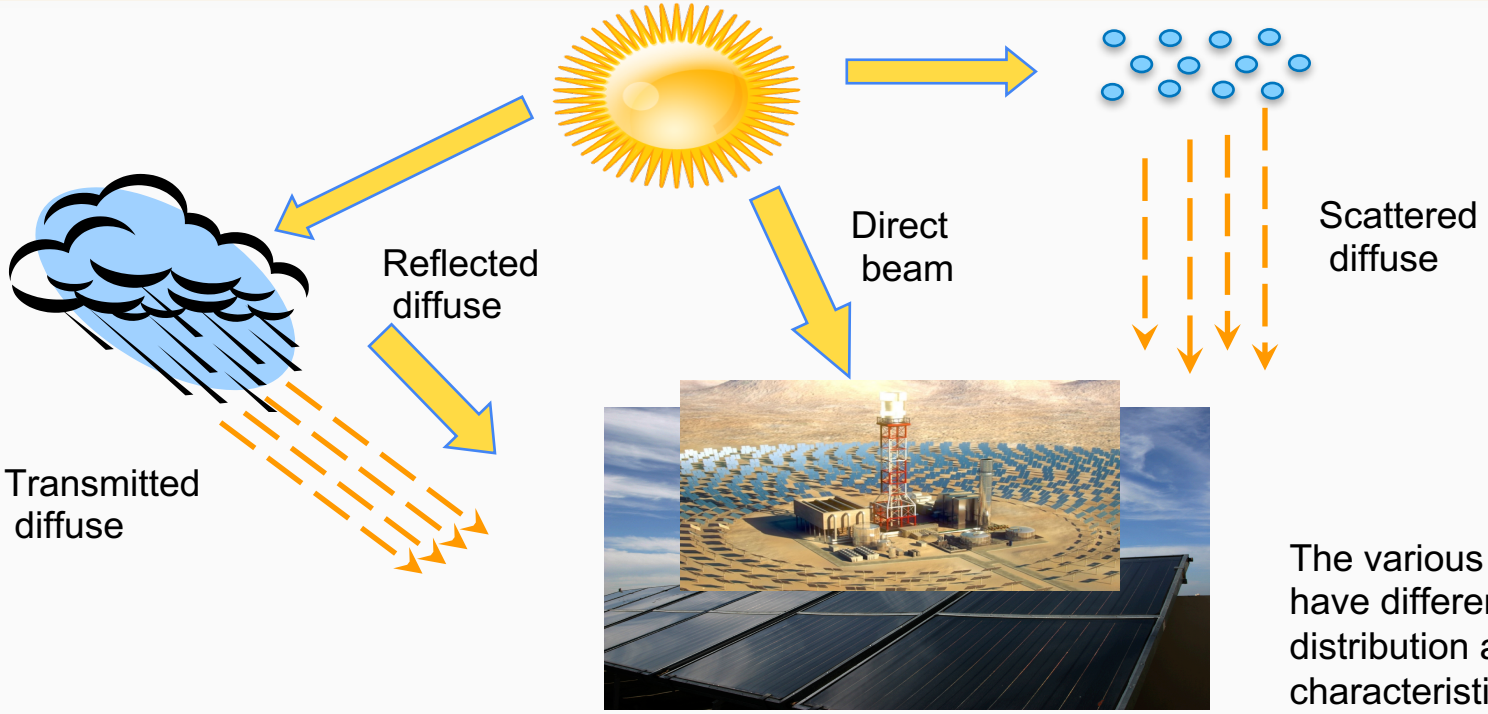
Solar Radiation Components



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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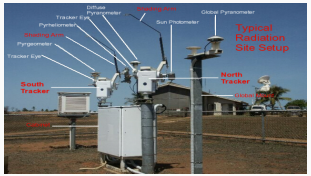
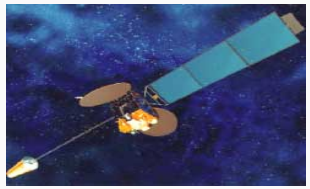
Pros & Cons of Solar Radiation Data Sources



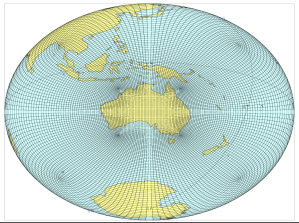
Ground stations

- **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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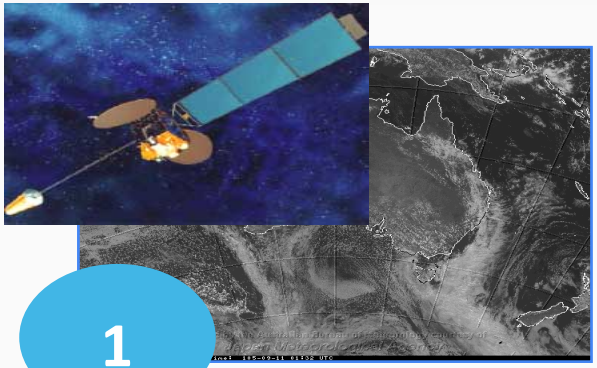
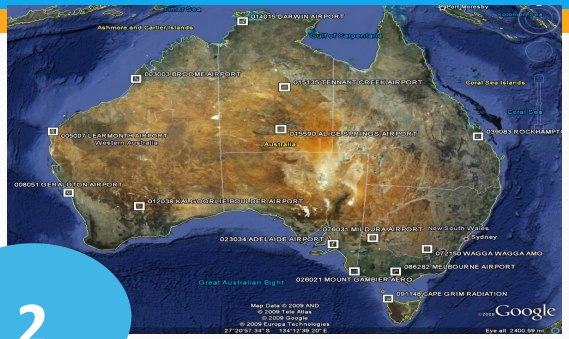
Blending of data sources



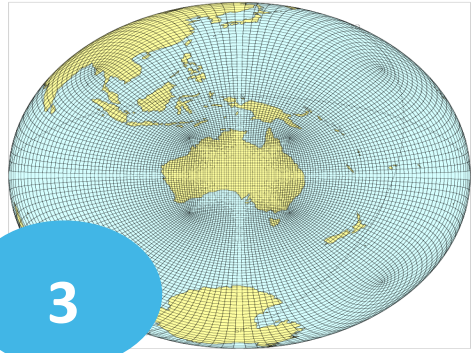
1

Satellite



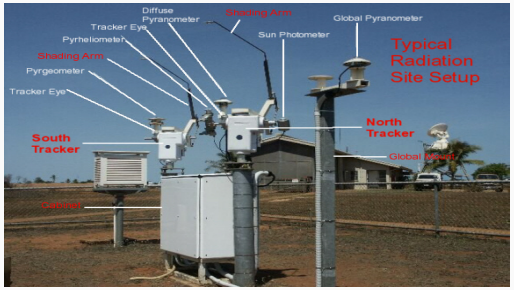
2

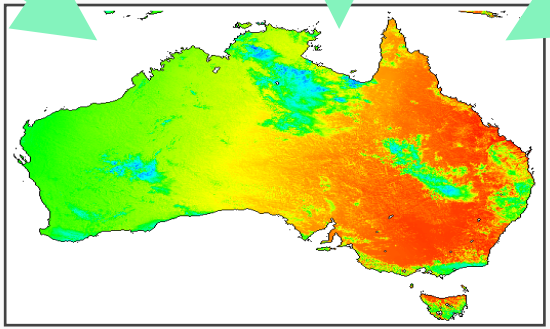
Ground stations



3

Atmospheric model





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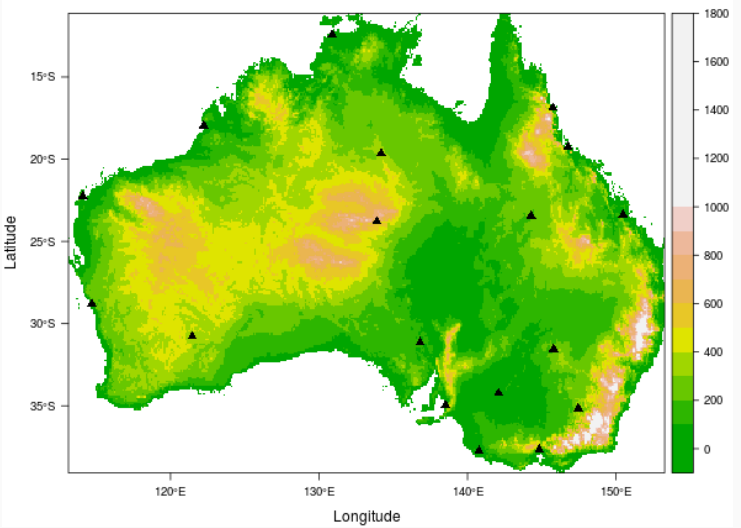
Blending of solar radiation data sources

- Fit generalised additive model (GAM) to hourly ground station data:

$$k_m \sim f(k_s, k_c, \cos(\theta_z))$$



k_m: measurements clear sky index

k_s: satellite clear sky index (nearest grid point)

k_c: weather model clear sky index (nearest grid point)

θ_z: solar zenith angle

Cross validate at each ground station by reserving half the data

Baseline model: satellite GAM $k_m \sim f(k_s, \cos(\theta_z))$

Davy et al. (2015)

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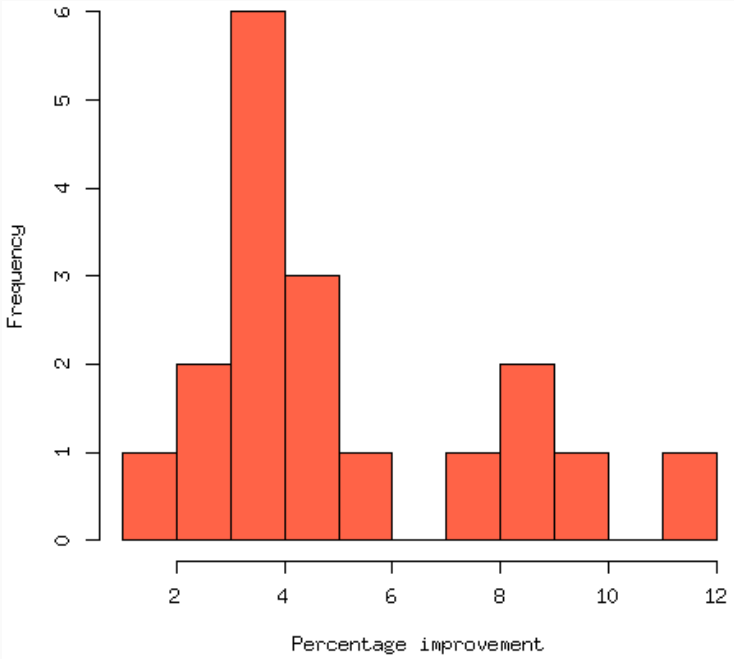
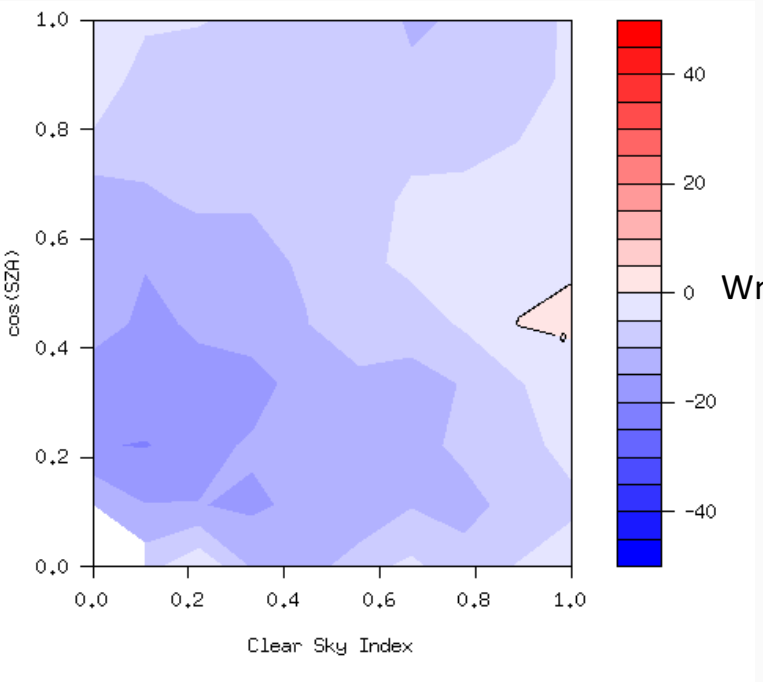
Need to use

RMSE improvement for GHI by including CCAM



Wagga Wagga GHI – SD changes relative to satellite



Miglioramento in tutte le 18 stazioni

Davy et al. (2015)

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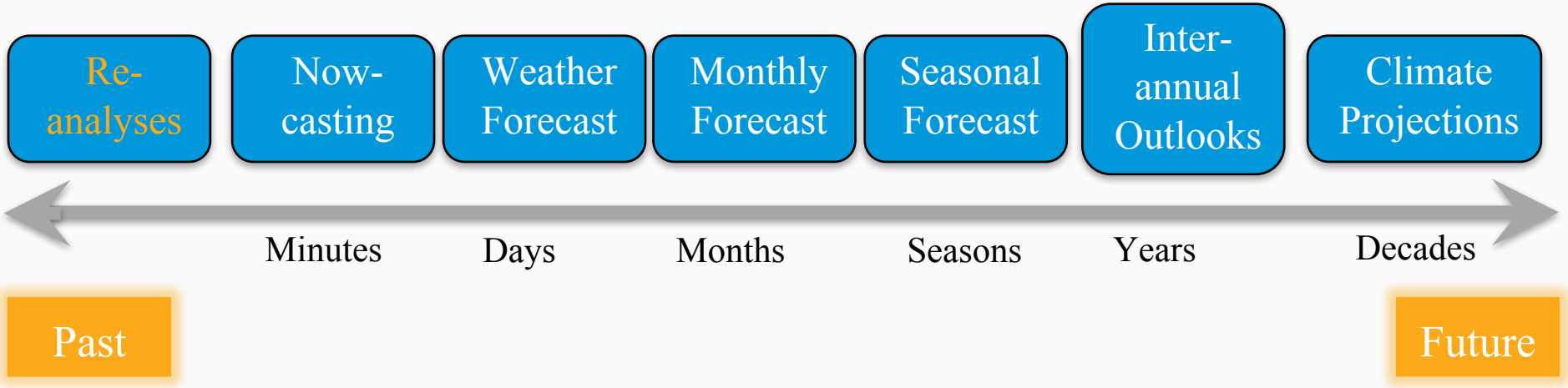
Meteorological products



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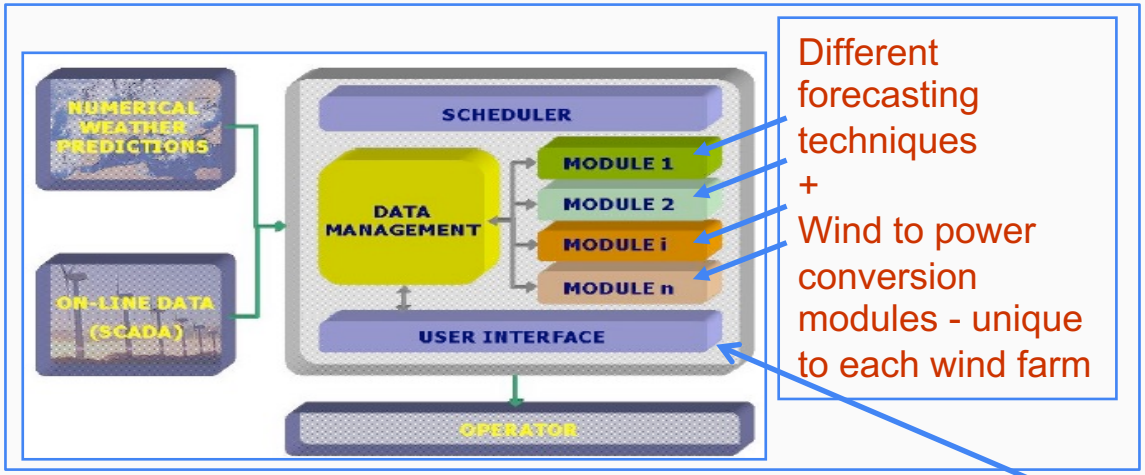
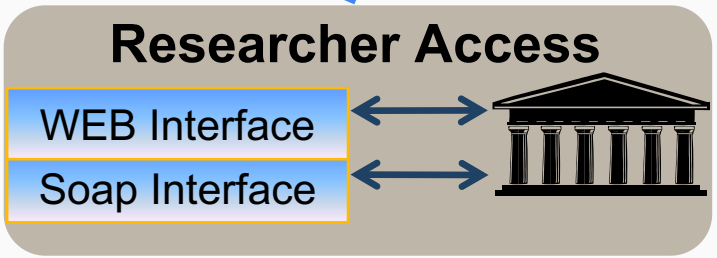
Building on Wind Forecasting at AEMO

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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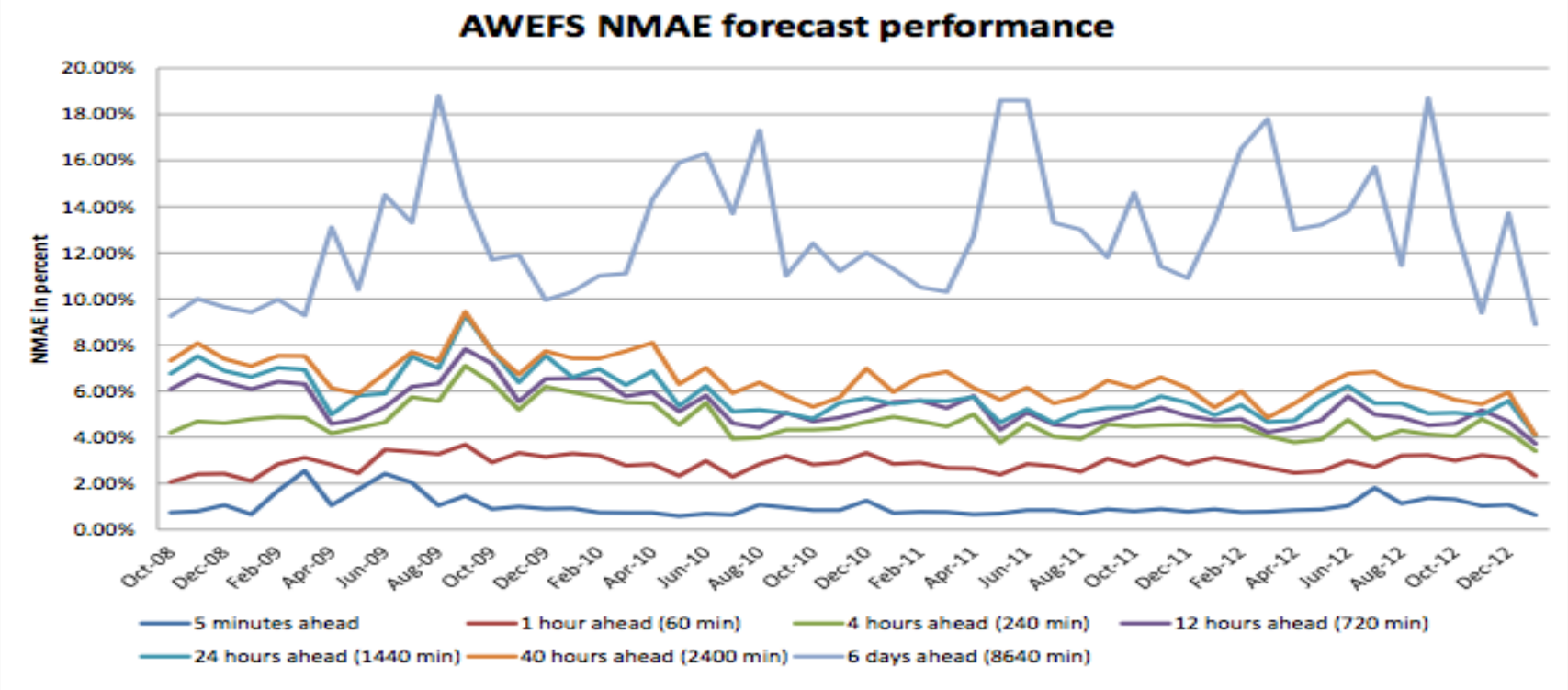
AWEFS Performance



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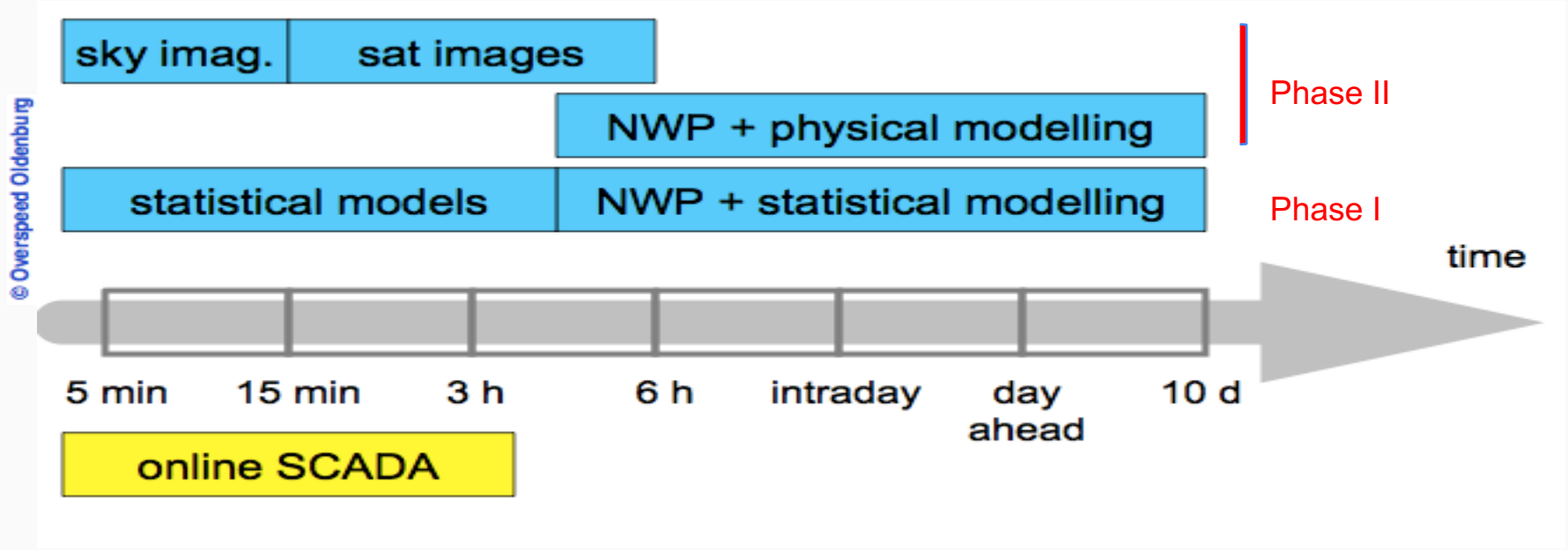
Solar forecasting techniques for different timescales



NMP – Numerical Weather prediction

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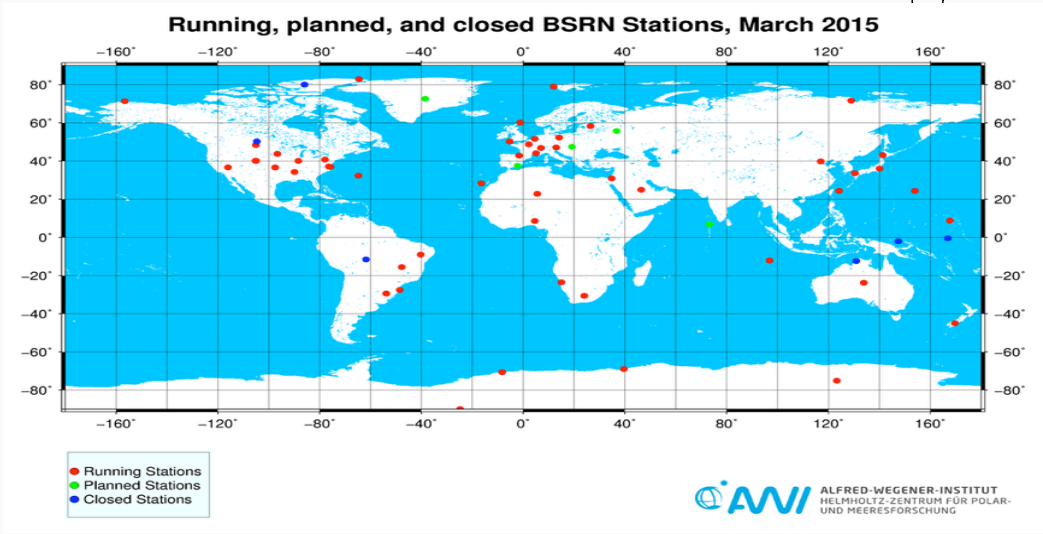
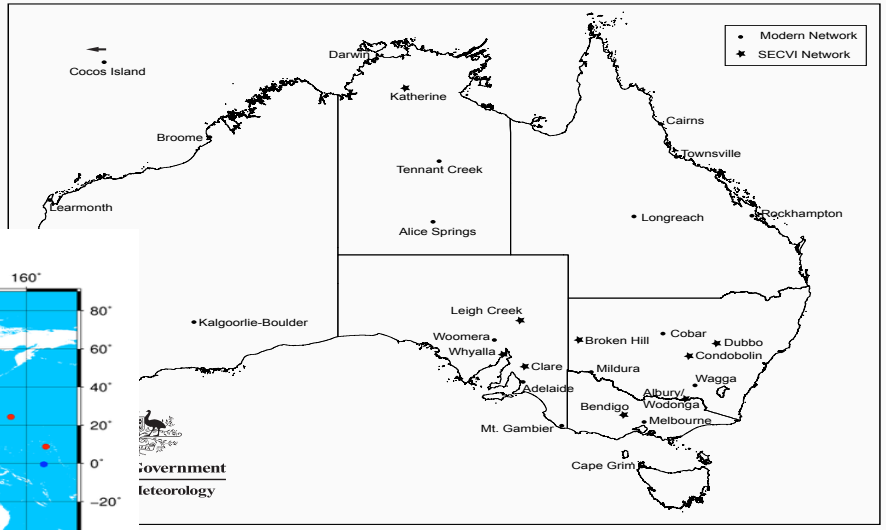
Assessment – Solar Radiation Stations





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Canberra Reference Site: ‘Solar Lab’

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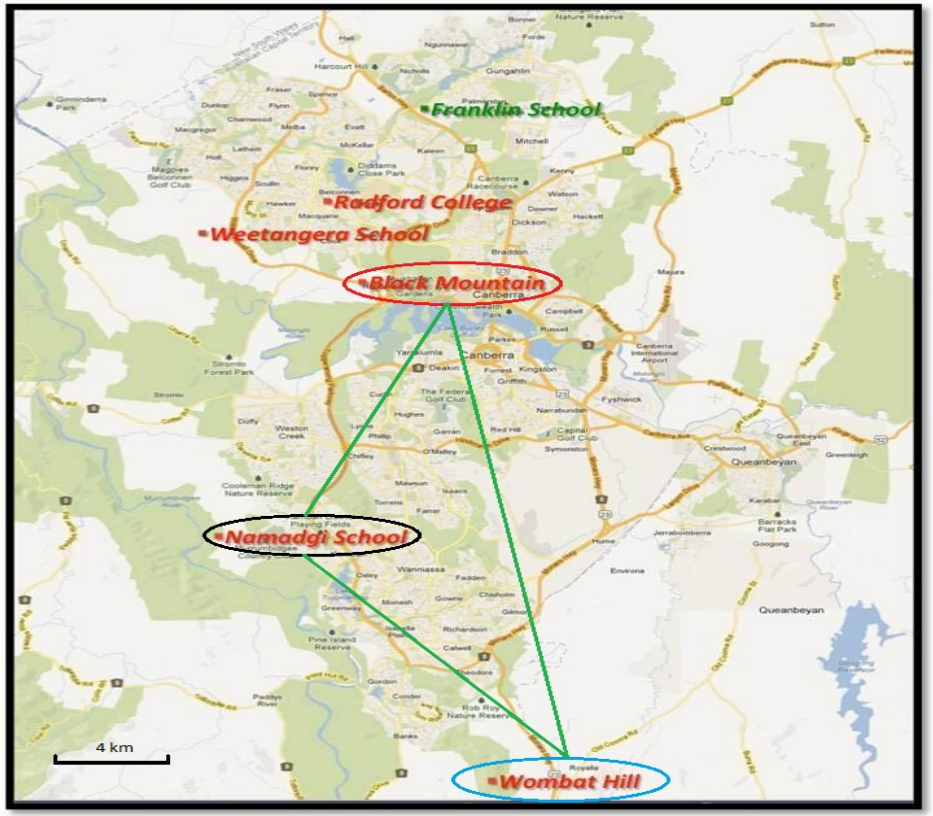
Canberra Solar radiation and power network

- 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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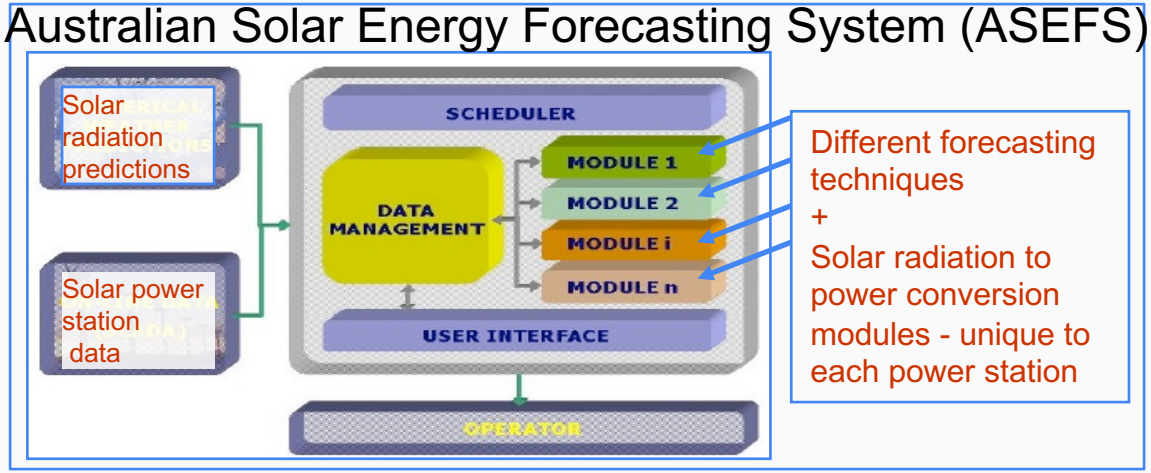
The Australian Solar Energy Forecasting System



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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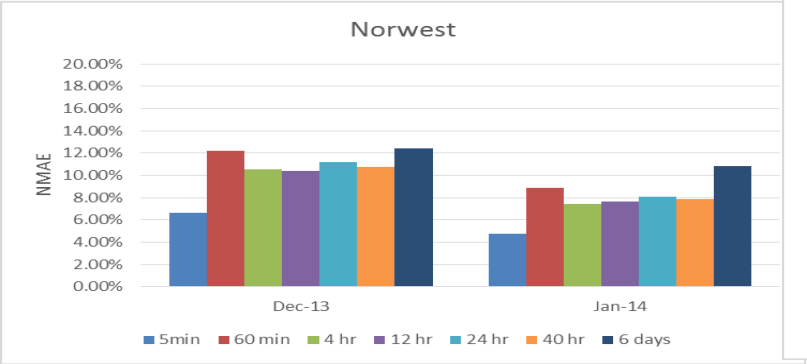
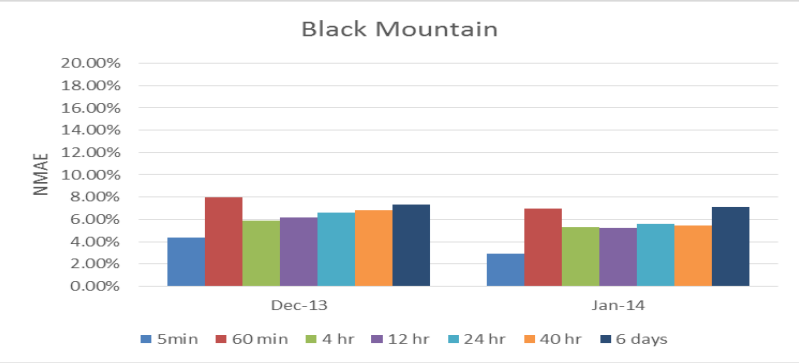
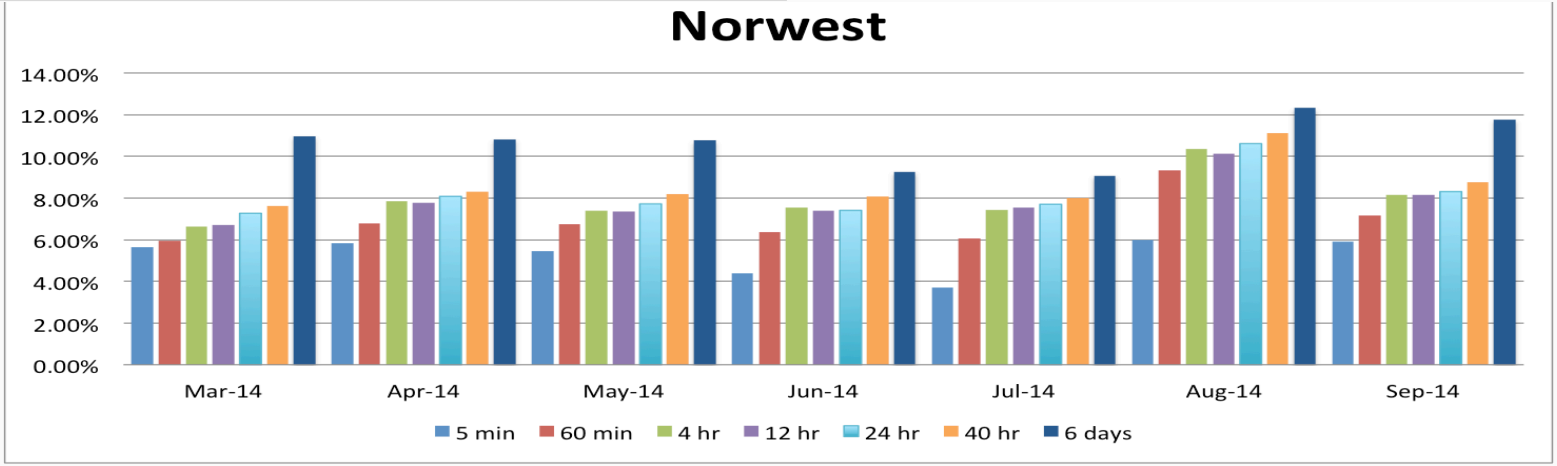
ASEFS test results







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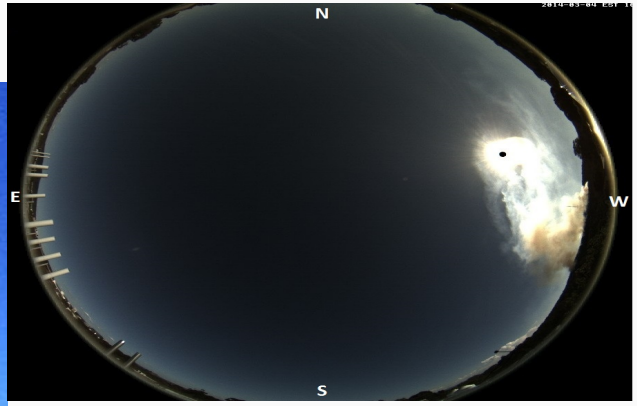
Alcuni risultati da studi di ricerca

Effect of aerosols (smoke) on PV

Canberra, 4th March 2014



Perry & Troccoli (2015)

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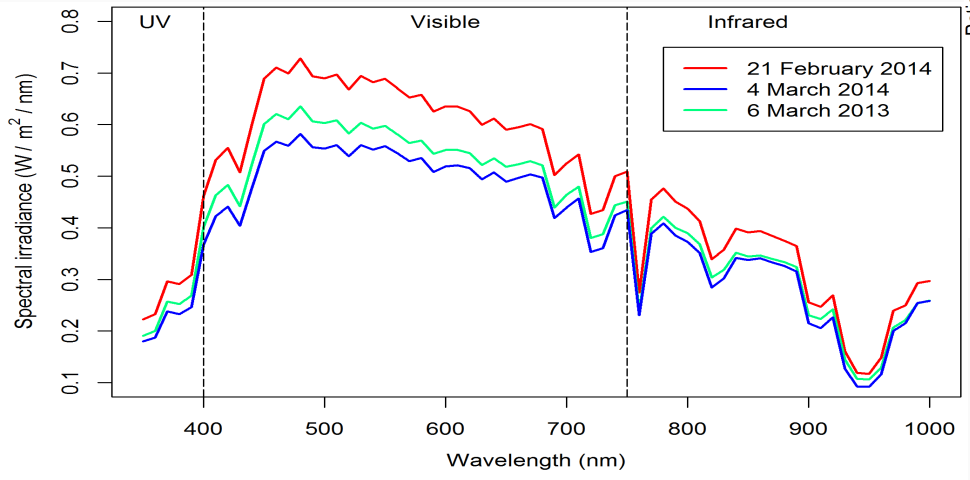
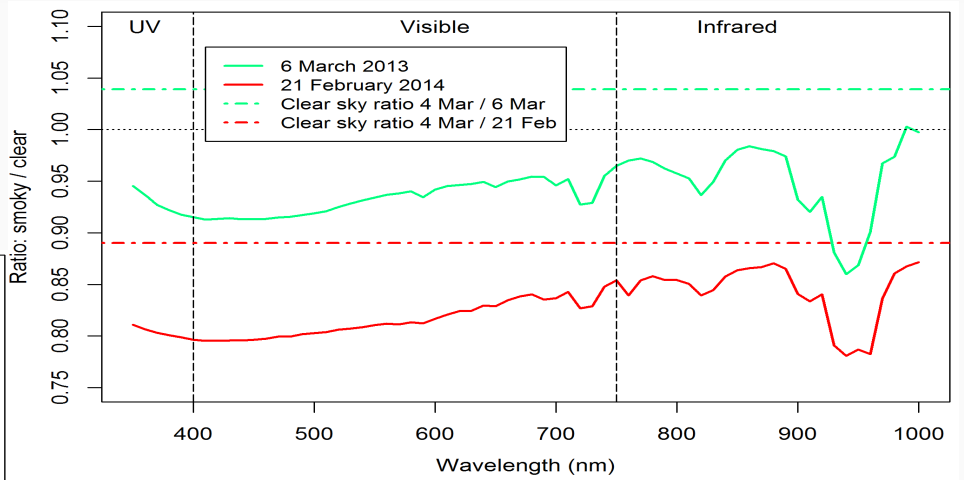
Effect of aerosols on PV





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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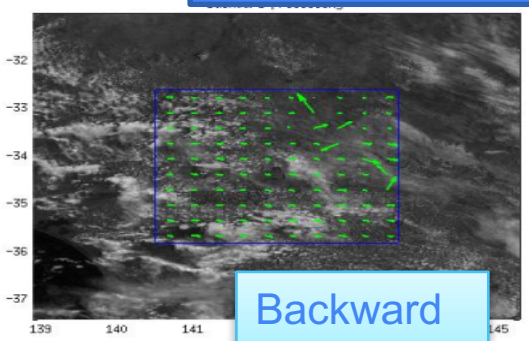
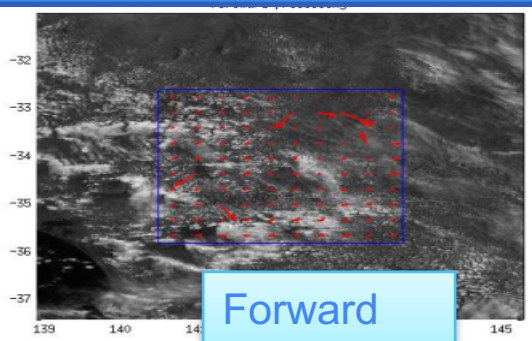
Perry & Troccoli (2015)

Cloud Motion Vectors

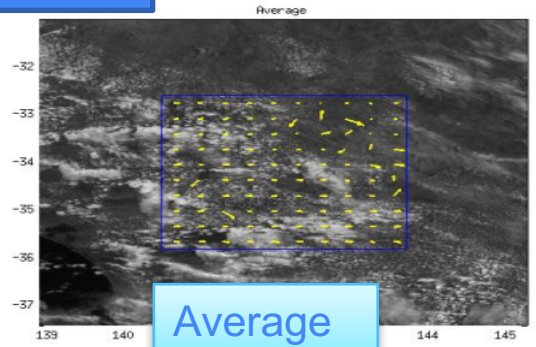
CMVs produced at Mildura site on 16/03/2014 at 0030, 0040, 0050 UTC



Backward Processing

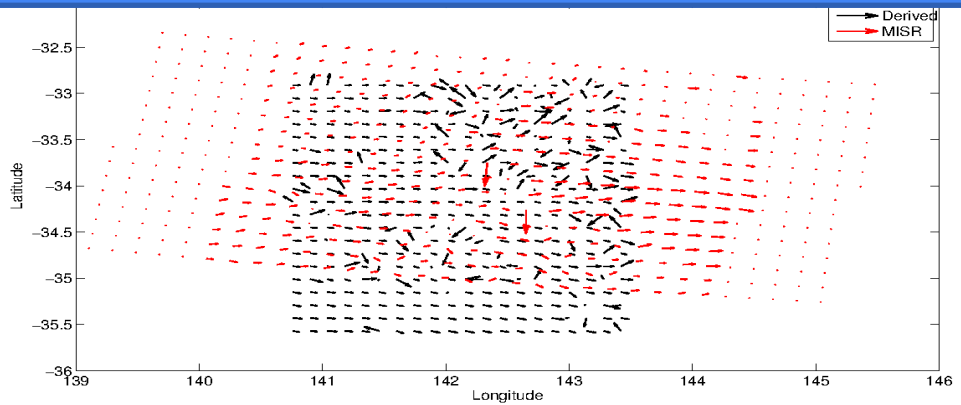


Forward Processing



Average

Derived CMVs compared to MISR instrument on TERRA satellite



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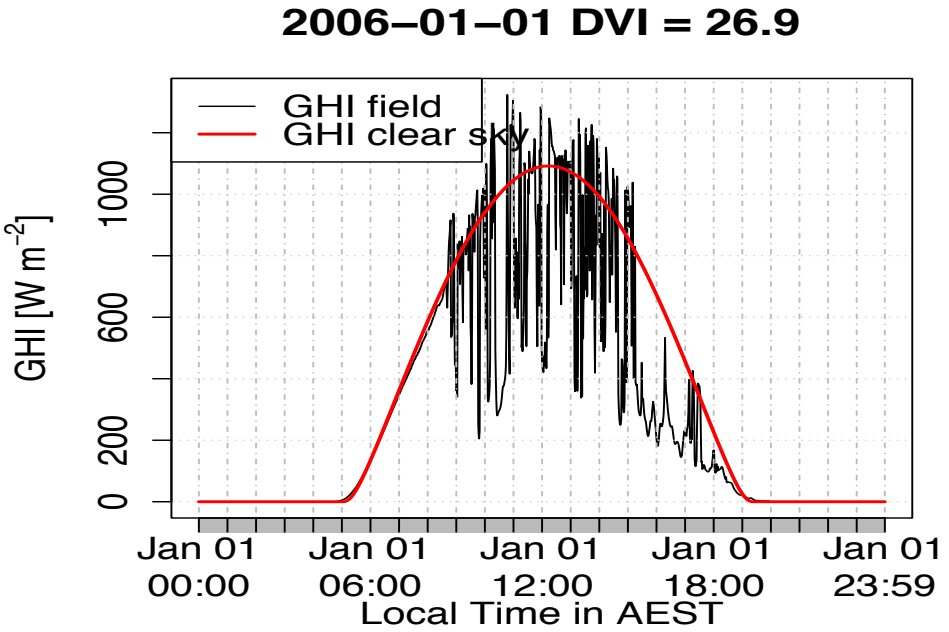
Courtesy UNSW

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)

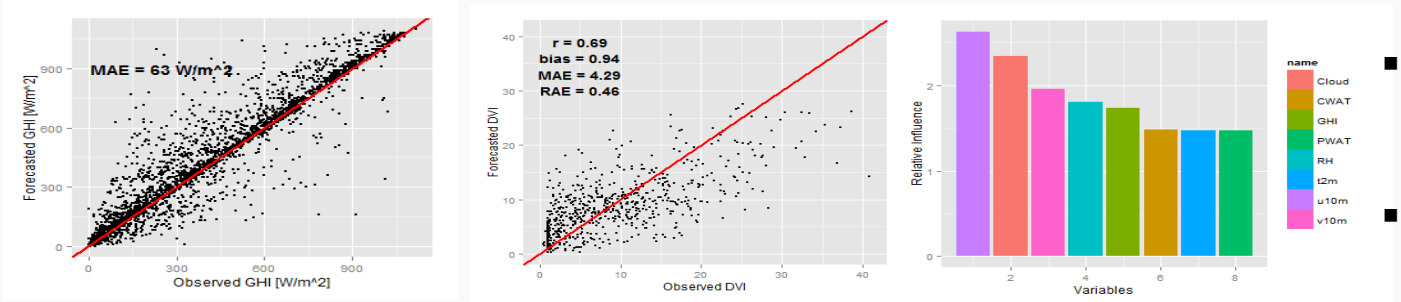
Daily Variability Index (DVI) Prediction

3h mean GHI

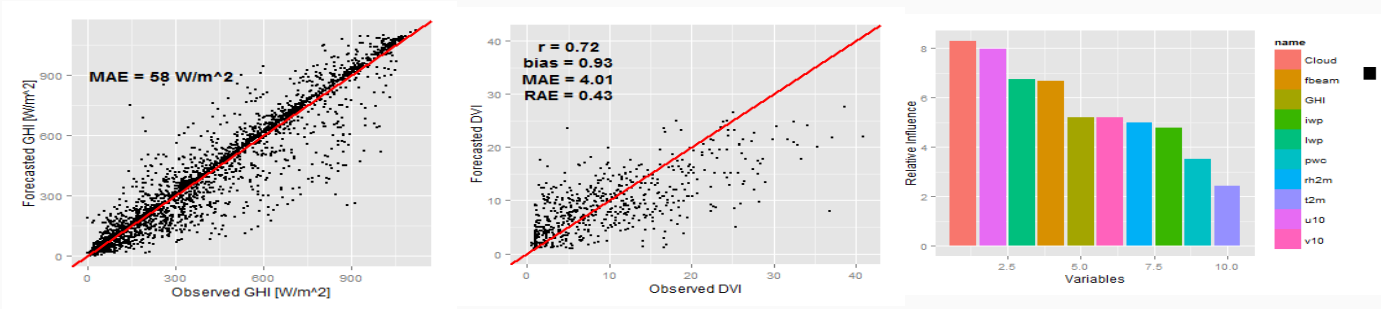
DVI

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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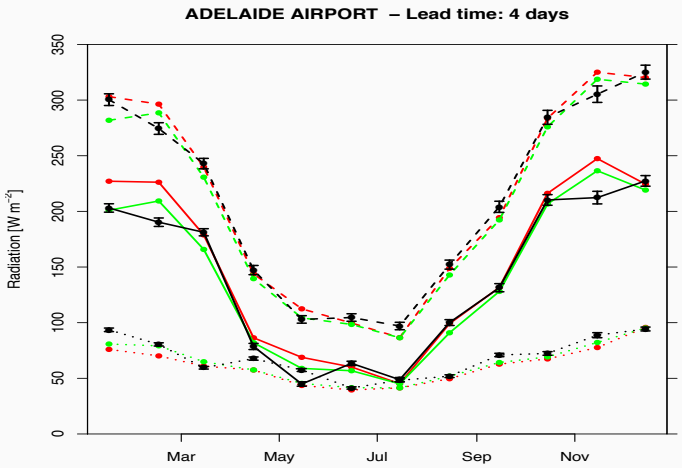
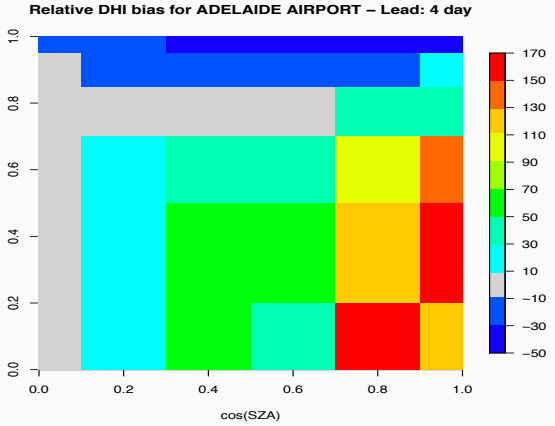
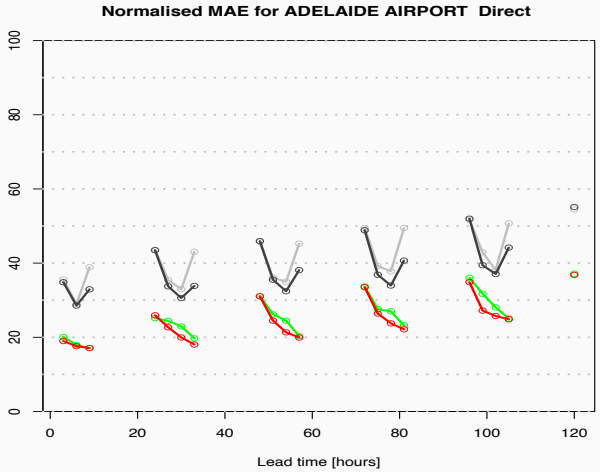
Solar NWP– pushing it to 5 days ahead



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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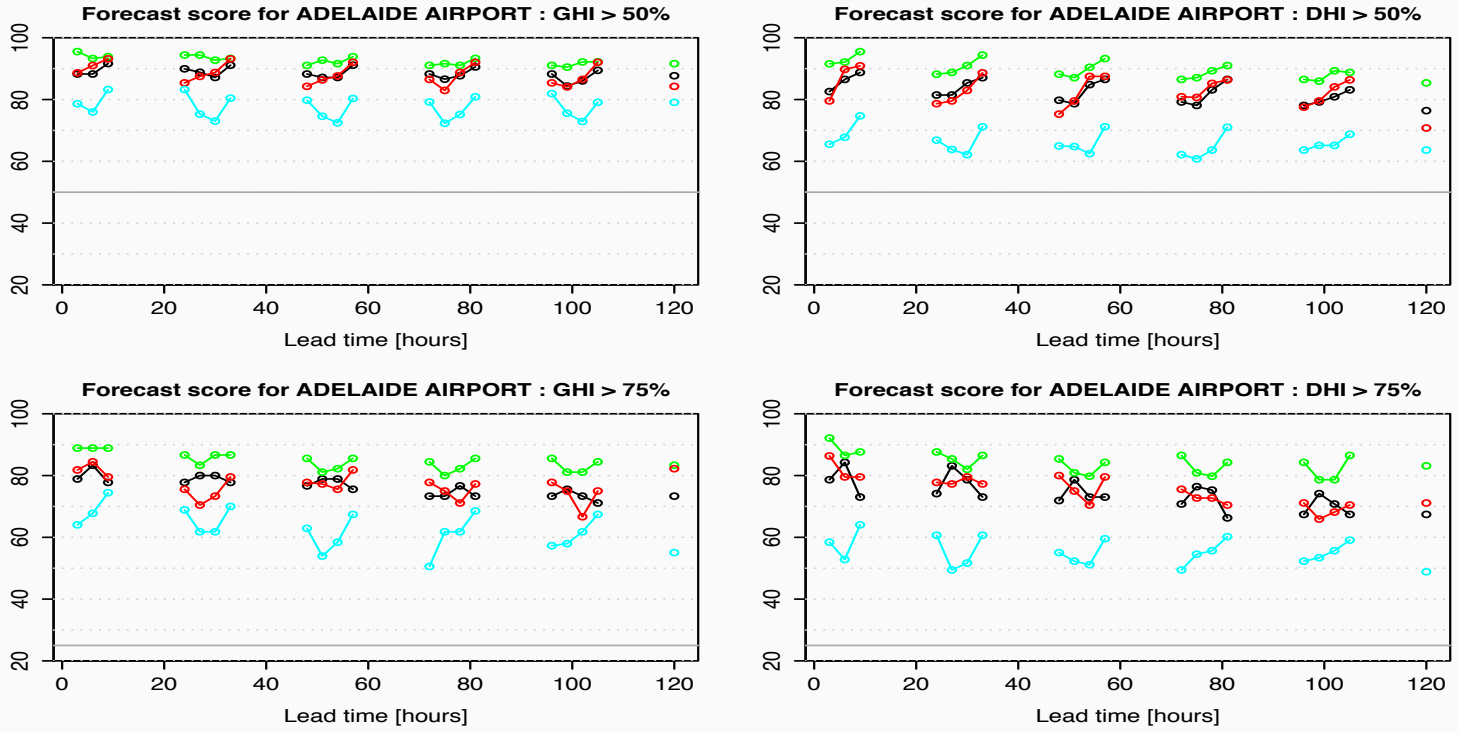
Troccoli and Morcrette (2014)

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)

Troccoli and Morcrette (2014)

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Approcci di ricerca emergenti

Videocamere per la previsione di energia solare

1. Classificare Nuvole
2. Caratterizzare la distorsione della lente
3. Estrarre vettori di movimento delle nuvole
4. Estrapolare i vettori tenendo conto della distorsione della lente
5. Valutare tempo di copertura nuvole

High-resolution 180 degree panorama cameras (Mobotix Q24M)

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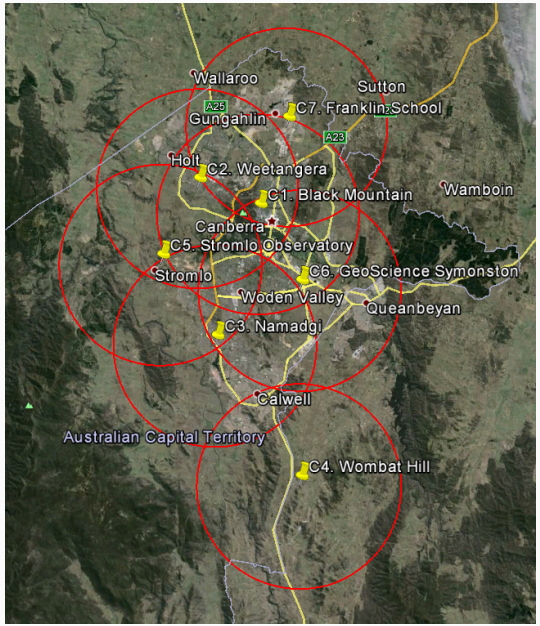
Courtesy CSIRO

VIDEOCAMERA MOVIE

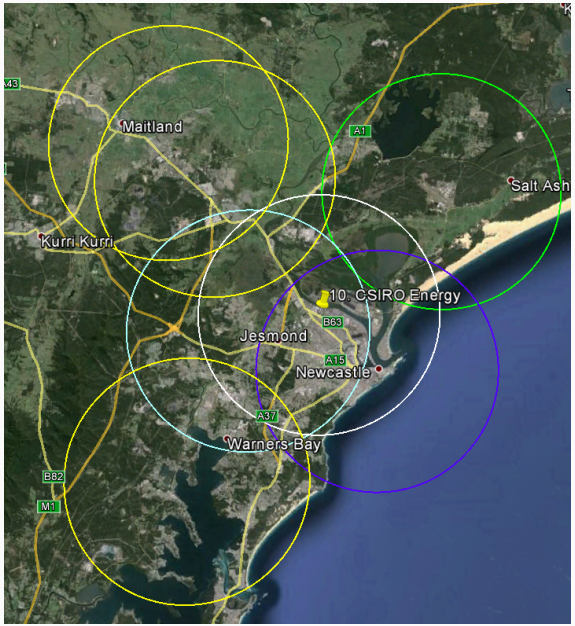
Courtesy CSIRO/ARENA

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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Il problema dell'immagazzinamento di energia

Custom Built Pumped Hydro – Missouri - 450MW

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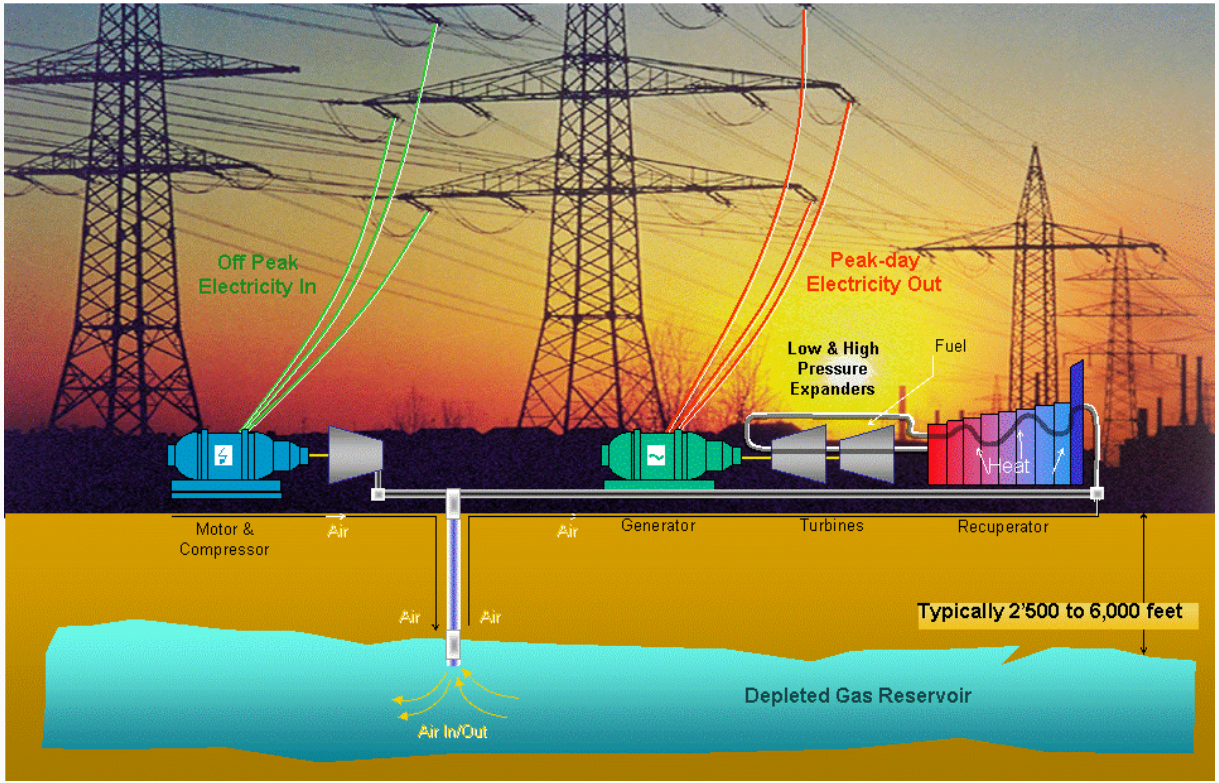
Compressed Air Storage

Huntdorf, Germany (290 MW) & McIntosh, Alabama. (110 MW)



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Sodium Solphur (NaS) and Lithium-Ion Batteries

NGK 1.2MW/ 7.2 MWhr
substation (upgrade deferral) system (6 hrs storage, NaS)

A123
2MW/ 0.5 MWhr
Multi-purpose system
(15 min storage)

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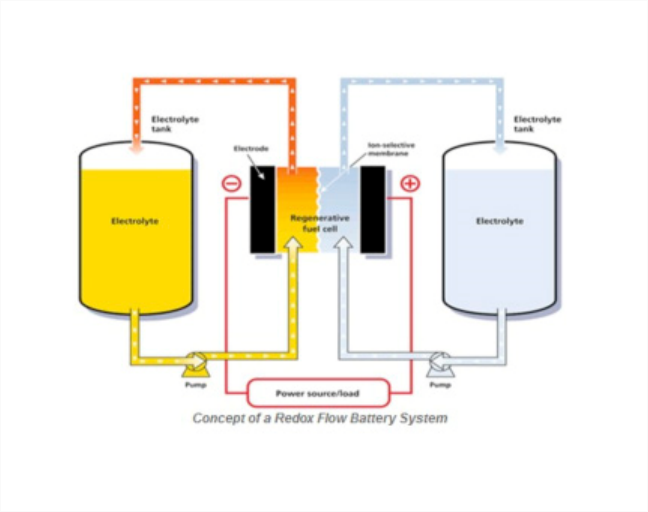
Vanadium Redox Flow Battery – King Island Tasmania



Concept of a Redox Flow Battery System

VRB Power Systems
200kW/ 800 kWhr
(4 hrs storage)

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Flywheel - Regulation Services

Beacon Power
20MW / 5MWhr
(15 min storage)

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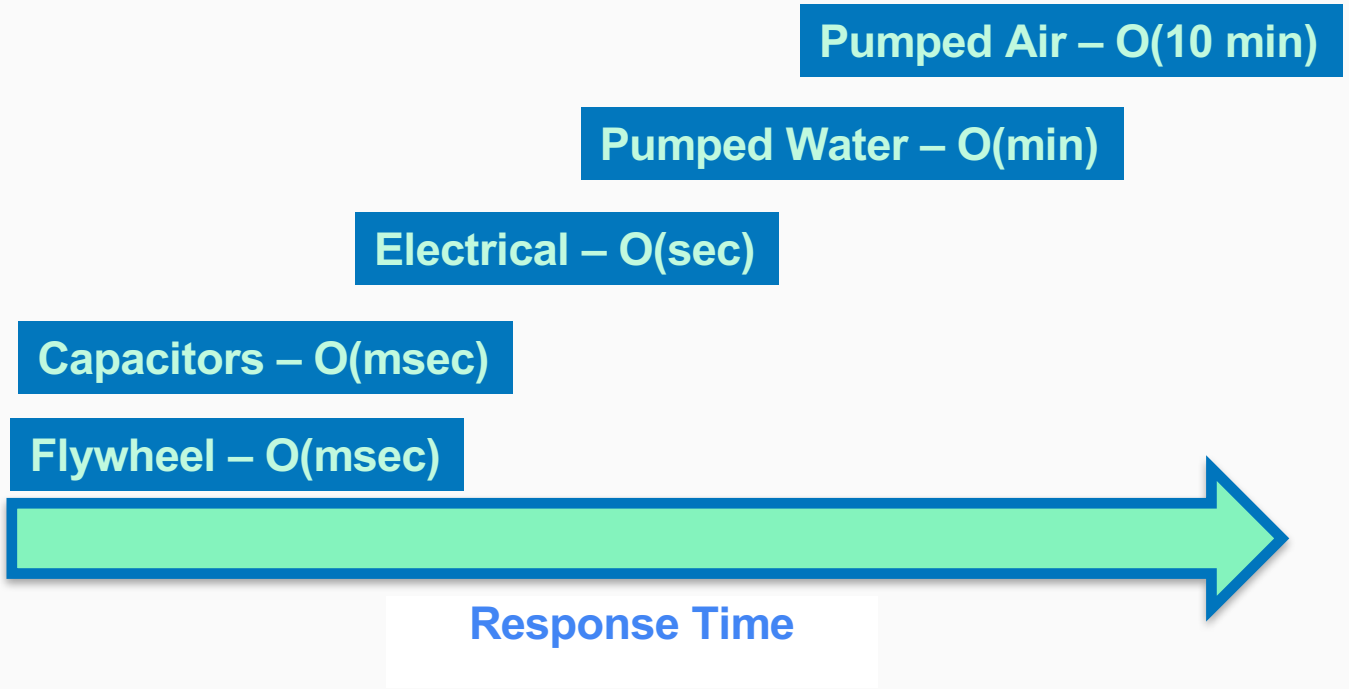
Summary of storage response times



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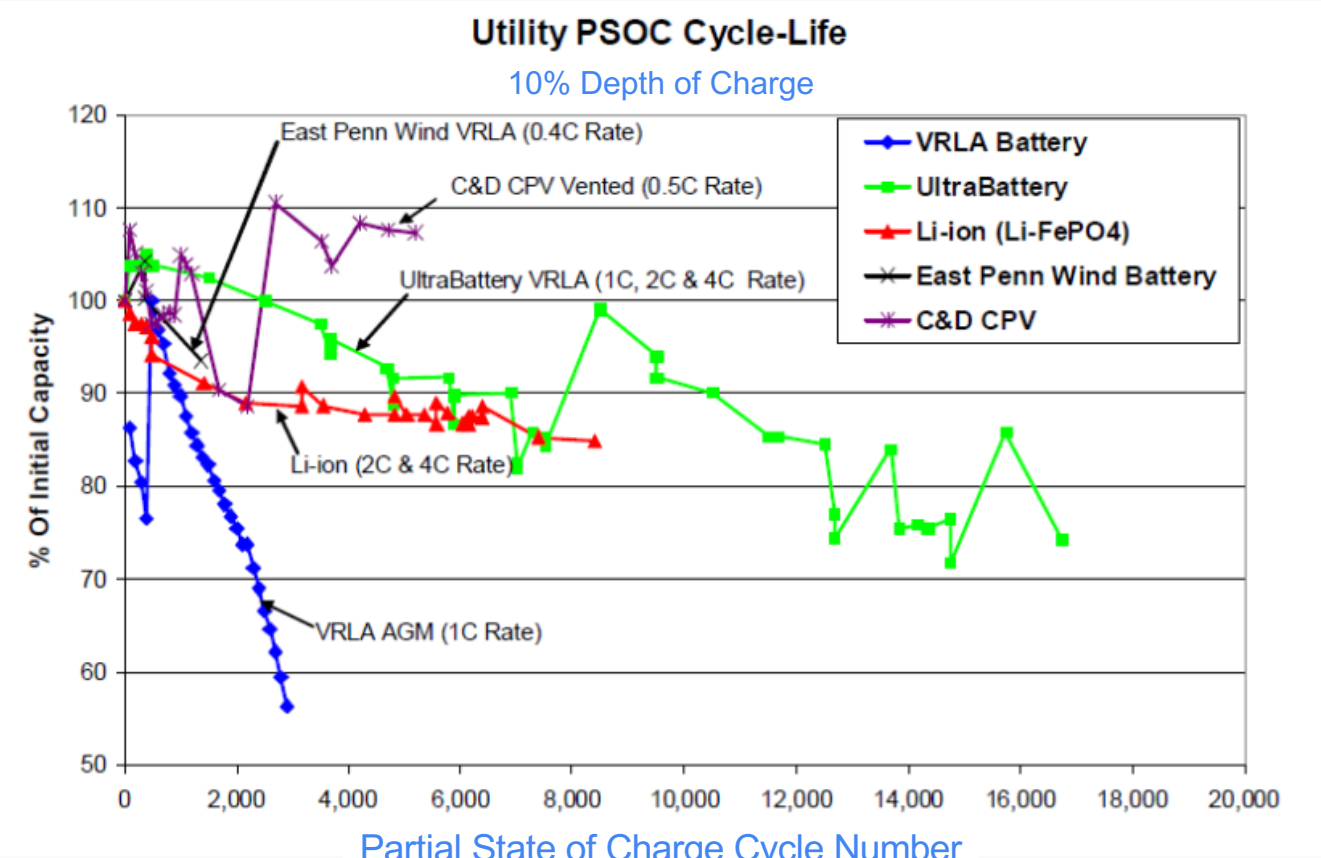
Tests su cicli ricarica batterie



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Il valore delle previsioni per energia eolica e solare

- NCAR wind power system for Xcel energy
  - Cost a few million USD, yielded an improvement of around 40% in forecast accuracy, which led to a cost saving of USD 49 million/yr
- NCAR solar power system for Xcel energy
  - A forecast improvement of ca 50% → cost saving of USD 820k/year
  - Projected to be USD 10-21 million/yr

Haupt et al. (2016)

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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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The Energy & Meteorology Conference Series

2015

2013

2011

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