What's next in Solar Weather Monitoring, Modelling and Forecasting ?

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StoA 5: Solar Weather / Solar Activity Forecast and Predictions
1 December 2004

Scheme of the Talk

A. SPACE METEOROLOGY ONTOLOGY

B. THE MONITORING SCENARIO

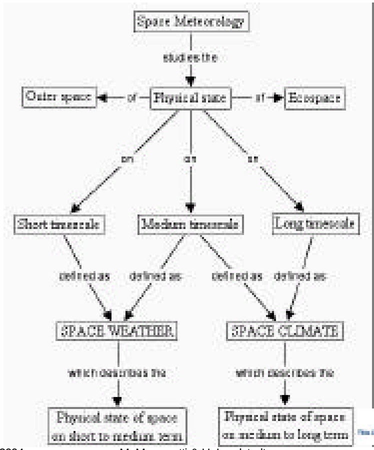
C. THE MODELLING SCENARIO

D. THE FORECASTING SCENARIO

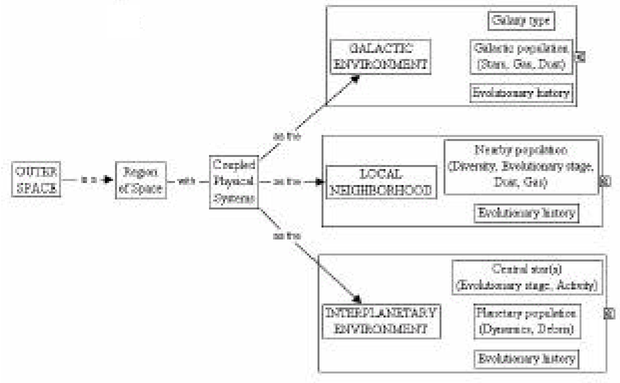
E. SOLAR WEATHER VISIONS

A. SPACE METEOROLOGY ONTOLOGY

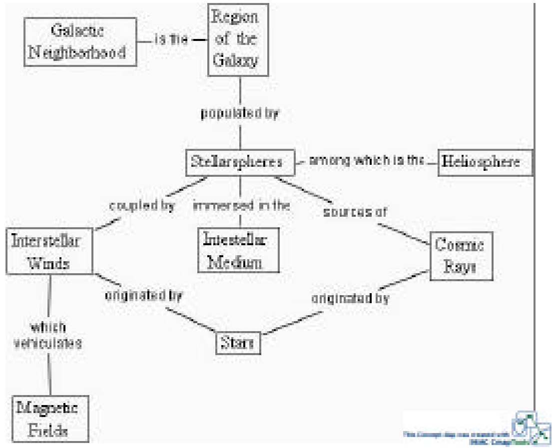
Ontology of Space Meteorology



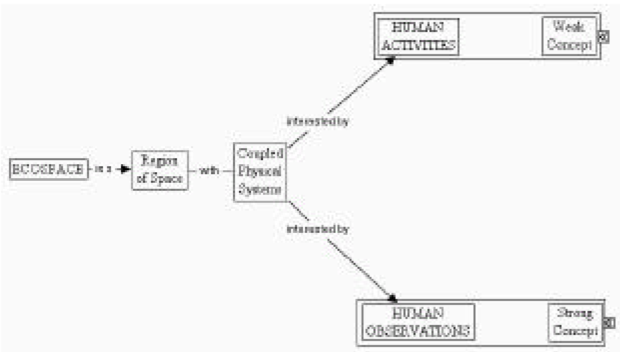
The Outer Space Environment



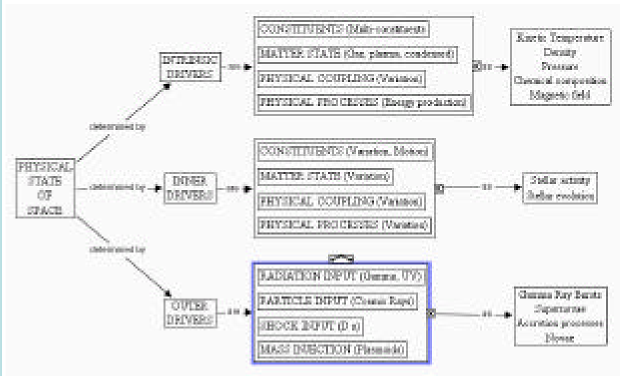
The Galactic Neighborhood



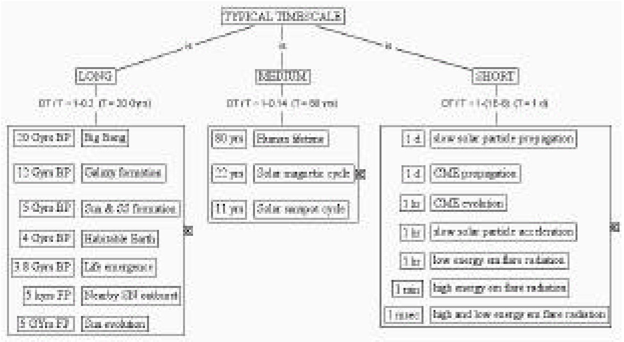
The Ecospace



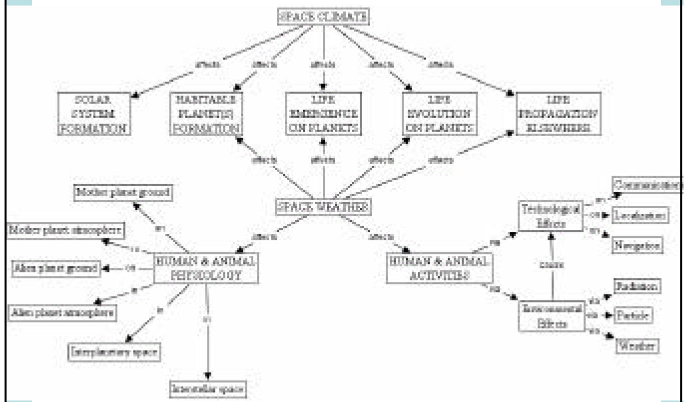
Physical State of Space

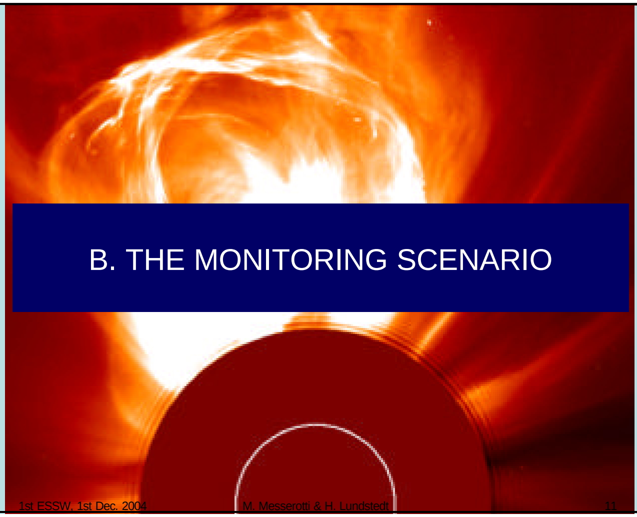


Phenomenological Timescales



Space Conditions Impacts





B. THE MONITORING SCENARIO

Monitoring Scenario: The Pros

- SOLAR WEATHER MONITORS
  - Radiation & particles
    - Space-based detection (e.g. SOHO)
    - Ground-based detection (many instruments)
  - Monitored phenomenology
    - Inner plasma
    - Photospheric plasma
    - Chromospheric plasma
    - Coronal plasma
    - Extended coronal plasma

Monitoring Scenario: The Cons

- SPACE-* and GROUND-BASED MONITORS
  - INCOMPLETENESS in
    - Phenomenology coverage
    - Spatial coverage
    - Temporal coverage
    - Energy coverage
  - MOSTLY NON-REAL-TIME OPERATIONS
  - LIMITATIONS IN TELEMETRY*
  - UNGUARANTEED MISSION*/OPERATION CONTINUITY
  - LIMITED MISSION*/OPERATION DURATION
  - MISSION*/INSTRUMENTATION DESIGN DRIVEN BY “ALCHEMIC POLITICAL” CONSTRAINTS

Monitoring Scenario: The Data Issues

- COMMON TO SPACE- AND GROUND-BASED MONITORS:
  - HUGE NUMBER OF DATA SETS
  - LARGE NUMBER OF DATA STANDARDS
  - LIMITED DATA AVAILABILITY
  - NON-REAL-TIME AVAILABILITY
  - LIMITED DATA ACCESSIBILITY
  - NON-USER-FRIENDLY SEARCH AND RETRIEVAL
  - DIFFICULT DATA CALIBRATION
  - COMPLEX DATA ANALYSIS
  - LIMITED CROSS-DATA AN.
- POSSIBLE SOLUTIONS TO MOST ISSUES:
  - NONE: WILL INCREASE TO PBs
  - COORDINATION ON COMMON STANDARDS
  - AGREEMENT ON DATA POLICIES
  - DEVELOPMENT OF VIRTUAL MONITORS
  - IMPROVEMENT IN WEB ACCESSIBILITY
  - ADVANCED DATA HANDLING
  - INCORPORATION OF SW LIBRARIES
  - DEVELOPMENT OF VIRTUAL OBSERVATORIES

HS NETWORKING, HPC, I-GRID

Development of
VIRTUAL MONITORS

An Advanced System for Data Handling in SPW

STEVM

Solar-Terrestrial Environment Virtual Monitor

The Solar-Terrestrial Data Planetary Meta-Archive

Solar and Geophysical Databases:
the Tiles of a Planetary Meta-archive

M. Messerotti

Abstract

In the frame of solar-terrestrial physics and the related space weather applications, a brief overview is given on the available resources to access solar, interplanetary, geospace and geophysical data, with special emphasis on the creation of a Solar-Terrestrial Data PlanetaryMeta-Archive (STDPMA) to exploit their full potentialities as a huge, inhomogeneous, distributed dataset in a user-transparent way by means of the new technologies in database management and user interface design.

Reference

The solar cycle and terrestrial climate, Solar and space weather Euroconference (1 : 2000 : Santa Cruz de Tenerife, Tenerife, Spain) Proceedings of the 1st Solar and Space Weather Euroconference, 25-29 September 2000, Santa Cruz de Tenerife, Tenerife, Spain. Edited by A. Wilson. Noordwijk, Netherlands: ESA Publications Division, 2000 xi, 680 p. ESA SP, Vol. 463, ISBN 9290926937, p. 563

Space Weather as Driver of Data Homogeneization

- Inhomogeneous and fragmented character of available observations

CAUSES

Difficulties in carrying out a posteriori modelling of complex phenomena

- These limitations are intrinsic to data acquisition mode

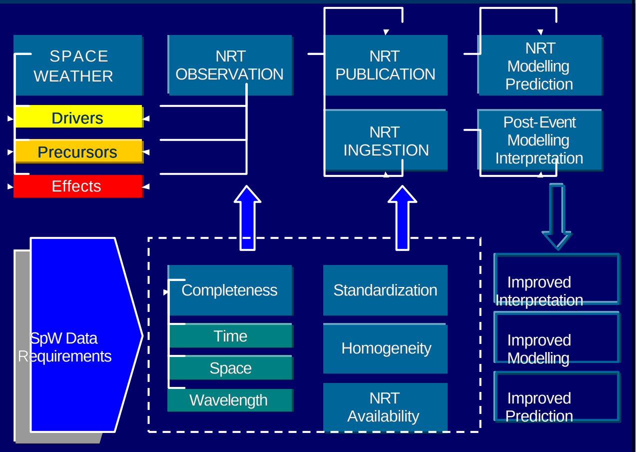
HENCE

Even advanced data search by Grid architectures cannot overcome

DRAWBACKS OF DATA INADEQUACY

- The outcomes are:
  - Inadequate modelling
  - Limited to a subset of phenomenological and physical aspects
  - Often neglects the complex interplays among different processes

Scheme of SpW Data Requirements



The Role of Observing Requirements for SpW

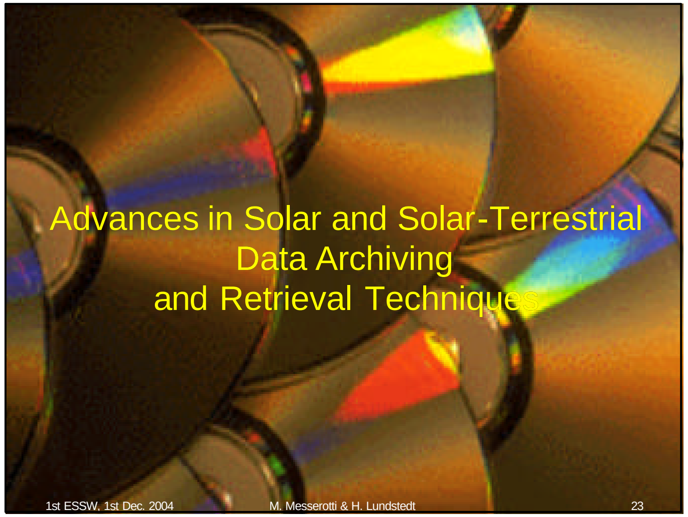
Observing requirements for SpW and SpW drivers observation in monitoring and nowcasting can play a primary role in providing:

1. homogeneization in observations
2. near real-time data ingestion in archives
3. unified data access via web through a user friendly GUI

capable to facilitate:

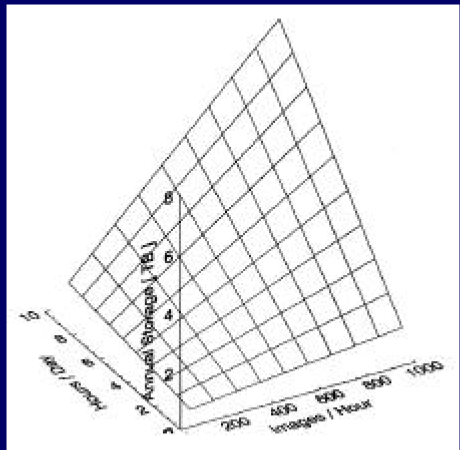
1. data availability in near real-time
2. full exploitation of the data information content by pointing out interrelationships in different datasets
3. self-consistent modelling

Development of VIRTUAL OBSERVATORIES

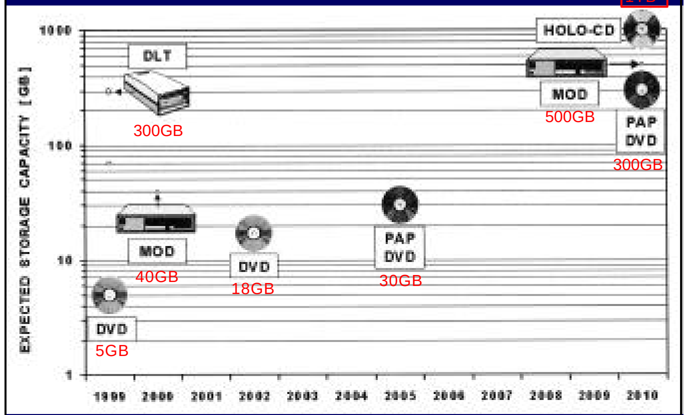


Advances in Solar and Solar-Terrestrial Data Archiving and Retrieval Techniques

LOW-END ANNUAL DATA STORAGE VOLUME



EXPECTED STORAGE MEDIA EVOLUTION



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BASIC CONSIDERATIONS

- Solar space and ground-based observatories operate
  - set of instruments which operate
    - at different wavelenghts and produce
      - inhomogeneous 1-, 2-, 3-, 4-D datasets
- Many solar archives exist all over the world
- Modern archiving techniques allow
  - efficient data search and retrieval through
    - a Relational Data Base Management
      - onsite or in a distributed environment

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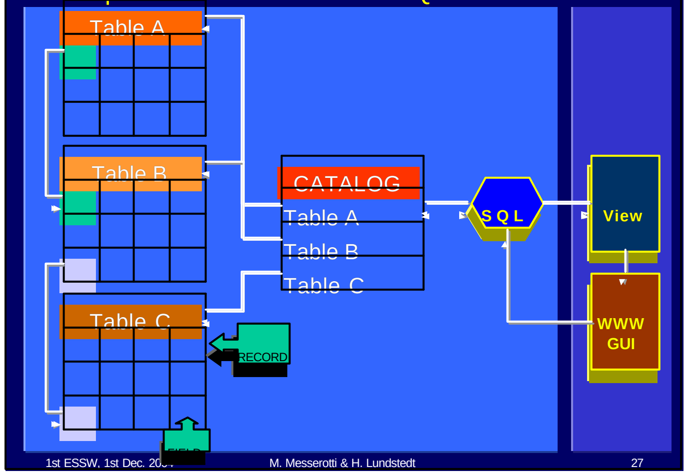
Simplified Architecture of an SQL-Based RDBMS



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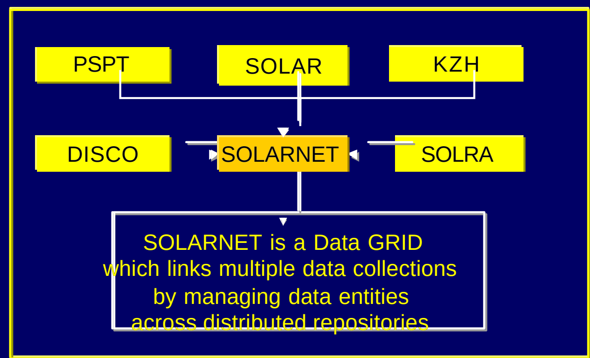
DATA GRID Architecture



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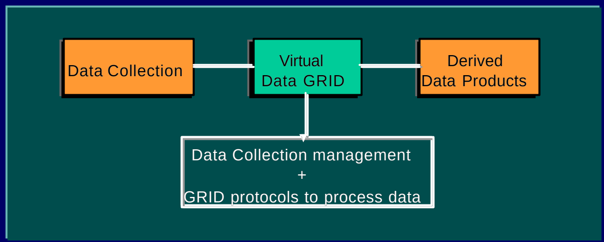
VIRTUAL DATA GRID Architecture

A consistent modelling requires a multi-instrument multi-wavelength approach

DATA ANALYSIS must be provided in addition to **SEARCH and RETRIEVAL**

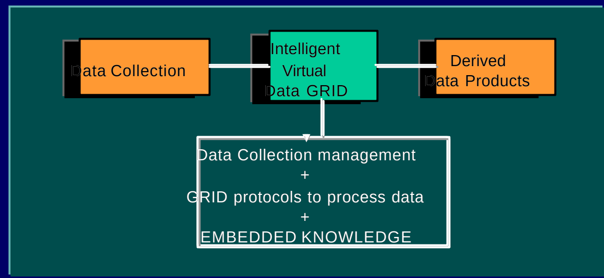


EGSO European Grid of Solar Observations

INTELLIGENT VIRTUAL DATA GRID Architecture

KNOWLEDGE DISCOVERY IN DATABASES (KDD)

DATA ASSOCIATION AND GUIDED PROCEDURES are EMBEDDED



DATA ORGANIZATION

• **Matter of Fact**	**Huge amount of space and g-b data**
• **Data Storage**	**Magnetic, Magneto-Optical, Optical Media**
• **Data Organization**	**Databases, Archives, Meta-Archives**
• **Data Indexing**	**Tables, Catalogs managed by RDBMS**
• **Data Access**	**FTP, TELNET, WWW via GUI**
• **Data Search**	**Local, Distributed over the net**
• **Data Analysis**	**Local**

SCIENTIFIC REQUIREMENTS

a) **Physical modelling**
1. **MULTIWAVELENGTH DATA SEARCH**
2. **MULTIWAVELENGTH DATA DISPLAY**
3. **MULTIWAVELENGTH DATA ANALYSIS**

via a common unified, user-friendly interface

b) **Space Weather**
1. **SOLAR, SPACE, EARTH DATASETS**
2. **MULTI-EVENT MODELLING**
3. **LARGEST COVERAGE POSSIBLE**

c) **Event Prediction**
1. **CROSS-SEARCH OVER ARCHIVES**
2. **DISTRIBUTED STATISTICAL ANALYSES**
3. **REAL-TIME DATA AVAILABILITY**

SCIENTIFIC MOTIVATIONS

- Some major Solar-Terrestrial Data Portals exist
- Mainly Resource Indexing is available
- Few resources partially allow complex, distributed data searching over limited subsets of databases
- Very few resources partially allow data analysis on inhomogeneous datasets

A PLANETARY META-ARCHIVE IS NEEDED TO EXPLOIT THE FULL SCIENTIFIC POTENTIALITIES OF MULTIWAVELENGTH MODELLING IN SOLAR-TERRESTRIAL PHYSICS

GOALS

1. Index observational resources in S-T Physics
2. Index theoretical resources in S-T Physics
3. Allow
   - User-transparent data access to distributed datasets all over the world
   - Complex data searching, retrieval and analysis via a simplified common GUI

PRESENT DATA ARCHIVING TECHNOLOGIES ALLOW THE ACHIEVEMENT OF SUCH GOALS PROVIDED THAT A GLOBAL COORDINATION AND COLLABORATION IS ESTABLISHED AS WELL AS THE ALLOCATION OF PROPER FINANCIAL RESOURCES BY THE PARTICIPATING ORGANIZATIONS

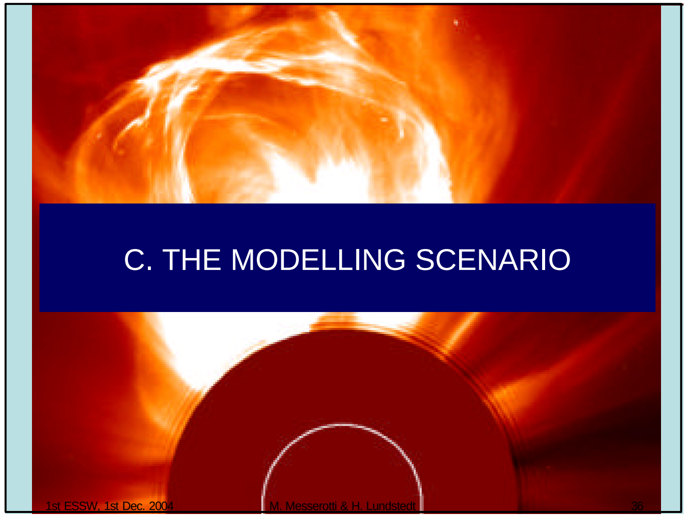
ADVANCED GOAL

- Pointing out the physical associations in multi-wavelength datasets is the basis of interpretative scientific research
- Concept association is the kernel of knowledge
- Automated storage and search of knowledge in databases is possible through advanced techniques and is called

  Knowledge Discovery in Databases (KDD)

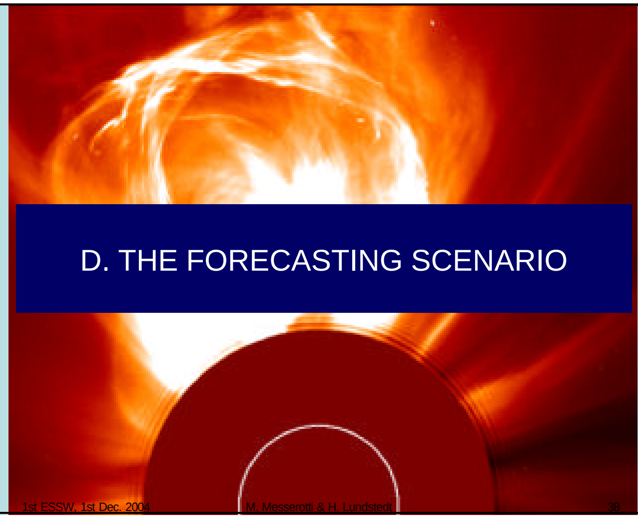
- Advanced techniques are based on Artificial Intelligence (AI) and Expert Systems (ES) embedding

THE EMBEDDING OF AI-ES TECHNIQUES IN THE GRID ARCHITECTURE REPRESENTS THE NEXT GENERATION IN DATA SEARCH, RETRIEVAL, PROCESSING AND ANALYZING



Modelling Scenario: The Cons

- NO SELF-CONSISTENT THEORY for:
  - AR formation & evolution
  - FLARE triggering, acceleration, radiation
  - PROMINENCE fomation & eruption
  - CME generation & propagation
  - CME plasmoid structure and magnetic field
  - SLOW SW generation, evolution & topology
  - FAST SW generation, evolution & topology
  - IP MAGNETIC FIELD topology
  - INTERACTION with GMF

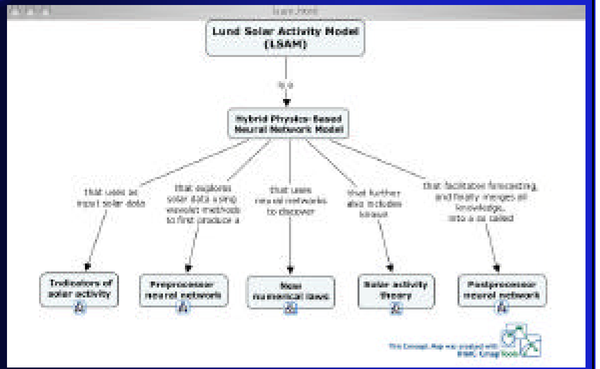


Forecasting Scenario: The Cons

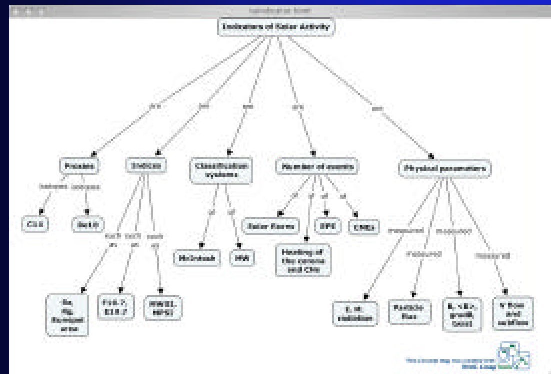
- LIMITED RESULTS for:
  - AR formation & evolution
    - Expert Systems based on a posteriori modelling
  - FLARE occurrence & class
    - Statistical methods based on precursors & SOC
    - Mainly nowcasting
  - CME formation & evolution
    - Statistical methods based on precursors
    - Mainly nowcasting
- STATE-OF-THE-ART based on hybrid approach involving AI TECHNIQUES
- MAIN ISSUE is LACK of SCIENTIFIC KNOWLEDGE on the PHYSICS

Solar Activity Explored and Forecasted: A New Approach

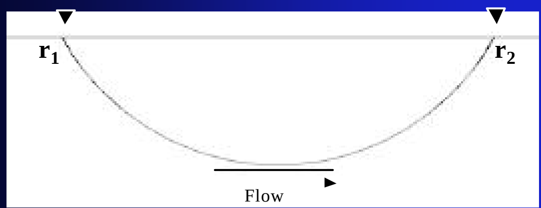
LSAM
The Lund Solar Activity Model



The Indicators of Solar Activity



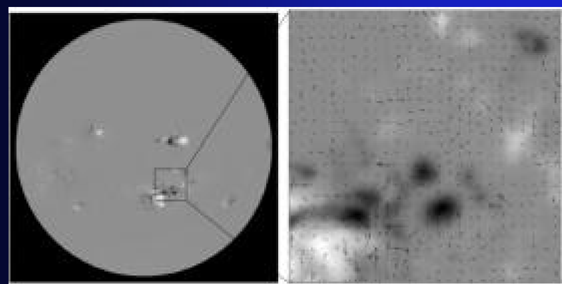
Time-Distance Helioseismololgy



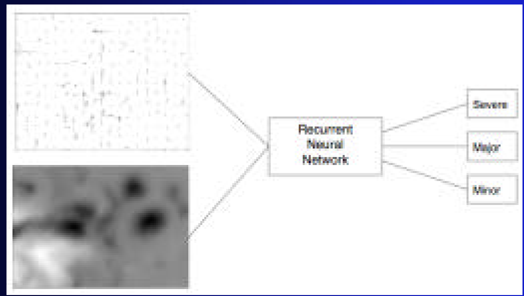
Cross Correlation:

Time Distance Flow Maps

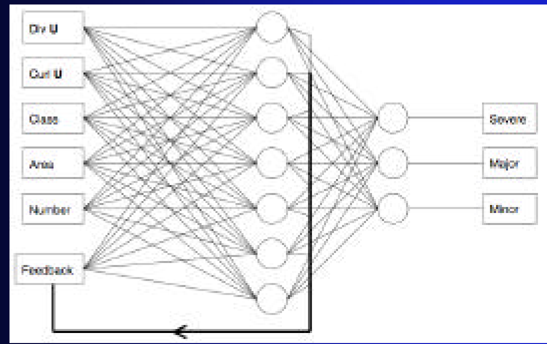
AR 486, 29th of October 2003



Vector Field Neural Network



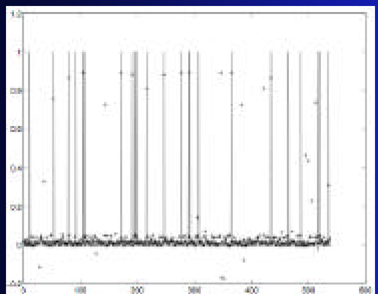
Scalar Neural Network



Neural Network Predictions

Without Flows

With Flows



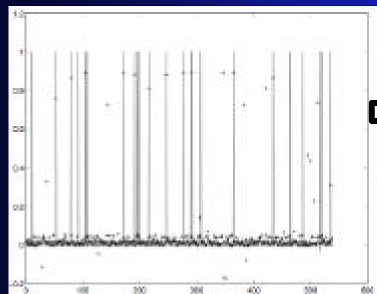
Hit Rate ~ 47%

False Alarm ~ 2%

Neural Network Predictions

Without Flows

With Flows



⇨ ?

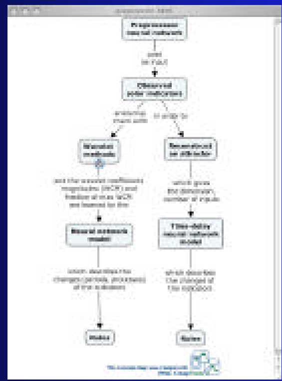
Hit Rate ~ 47%

False Alarm ~ 2%

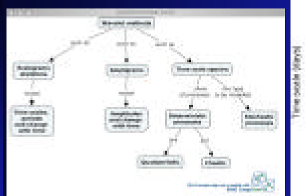
Project Goals

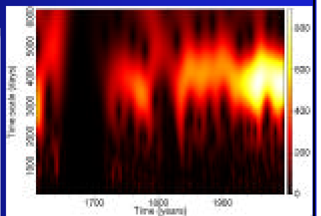
- Establish a database of flowmaps from GONG+ data
- Use database to train a neural network
- “Nowcasting” of observed flows using single site data
- Develop a fast and robust time-distance code

Preprocessor Neural Network

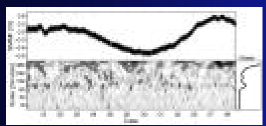


Wavelet methods

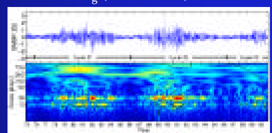




R_g (1610 -1995)



SMMF (SOHO) March 17 - April 10, 1999

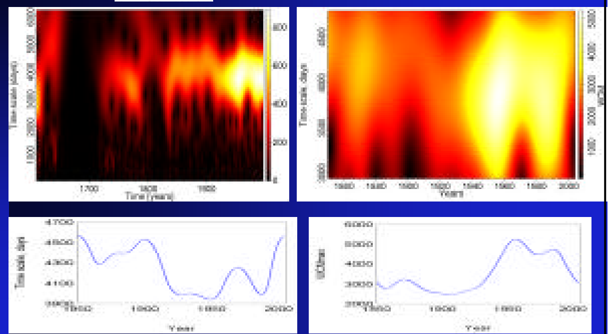


SMMF (WSO) 1975-2001

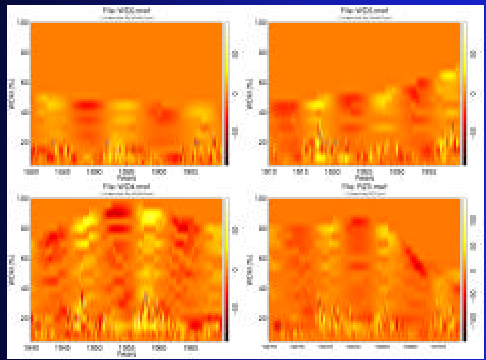
Cycle Length (Time Scales) Period vs. Solar Activity (WCMmax)

$R_g = \frac{12.08}{N}\sum k_i G_i$

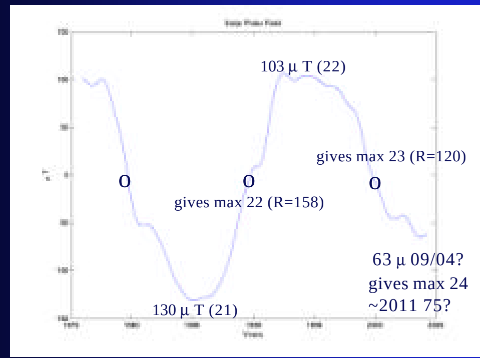
$R_z = k(10g+f)$



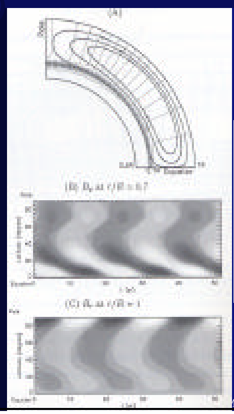
Ampligram of Rz



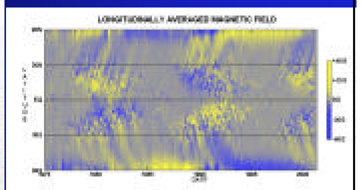
Solar polar field



a w, Meridional-Dynamo

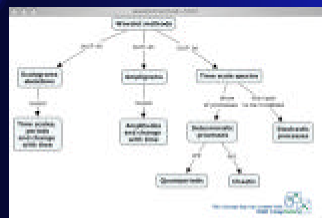


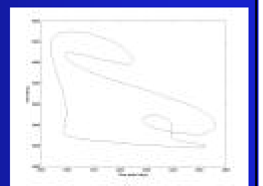
Peter Gillman and Mausumi Dikpati (Astrophys. J, 2001)



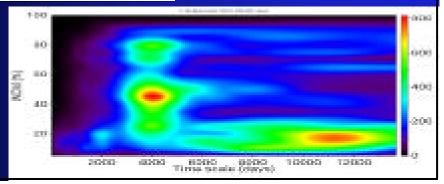
$$T = 56.8 u_0^{-0.89} s_0^{-0.13} h_T^{0.22}$$

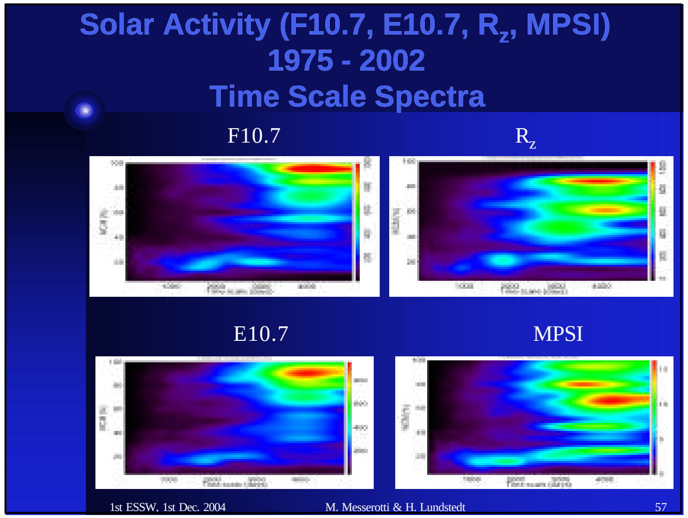
Wavelet Methods





R_z
1850-2002




Solar Activity (F10.7, E10.7, R$_z$, MPSI)
1975 - 2002
Time Scale Spectra
F10.7
R$_Z$
E10.7
MPSI
1st ESSW, 1st Dec. 2004
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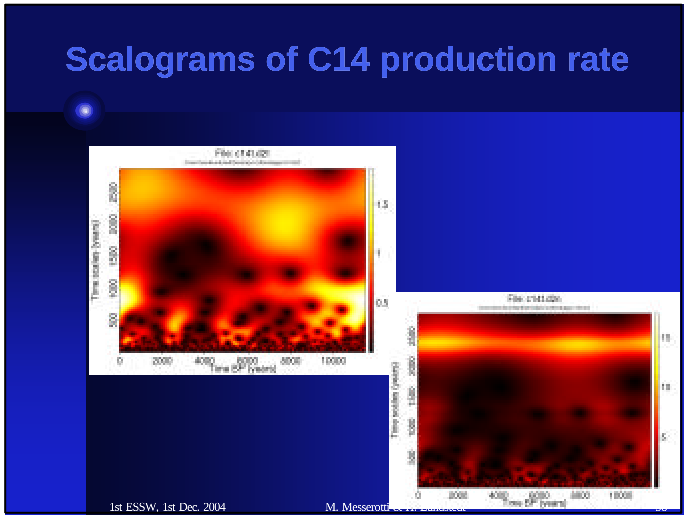
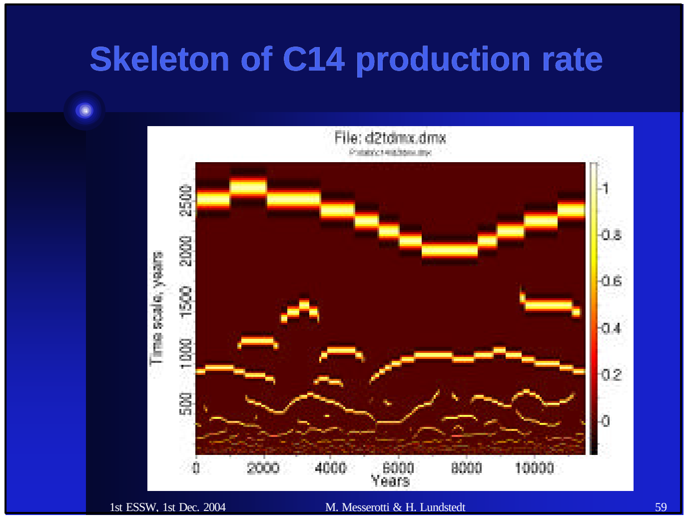

Scalograms of C14 production rate
1st ESSW, 1st Dec. 2004


Skeleton of C14 production rate
File: d2tdmx.dmx
Time scale, years
Years
1st ESSW, 1st Dec. 2004
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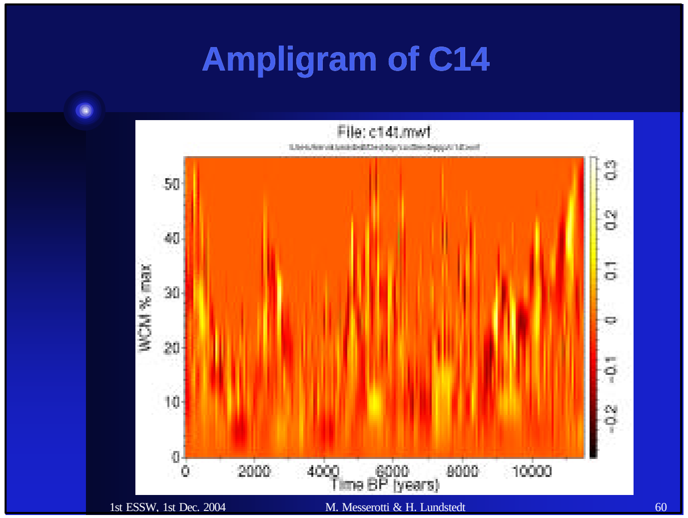
Ampligram of C14
File: c14t.mwt
WCM % max
Time BP [years]
1st ESSW, 1st Dec. 2004
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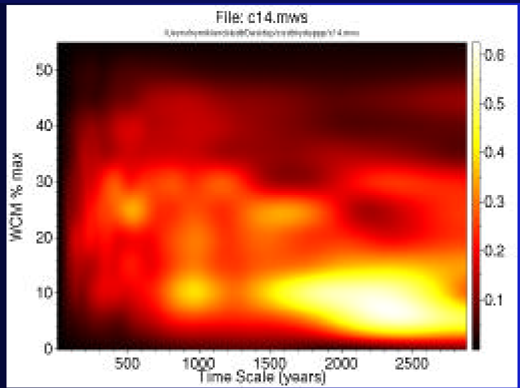
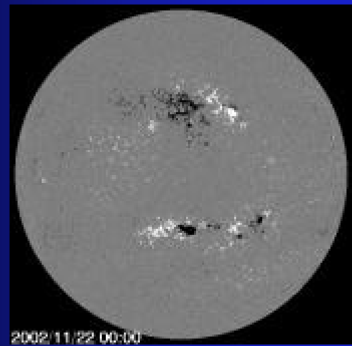
Time Scale Spectra of C14

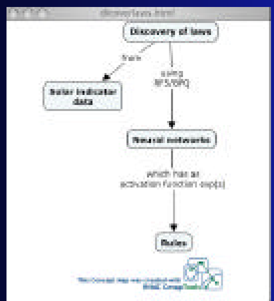


Wavelet Study of Time Series of Solar Magnetograms

Scalograms, skeletons, ampligrams and time scale spectra applied to time series of magnetograms require cluster of computers



Neural Networks Discover Numerical Laws



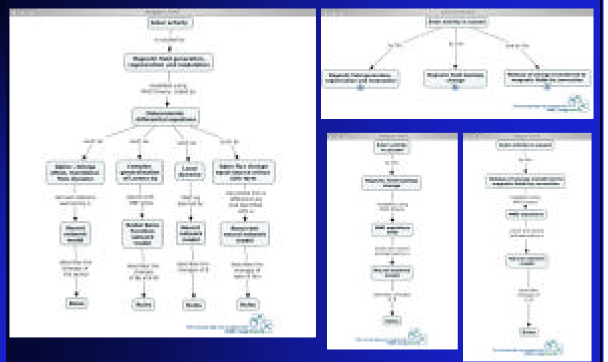
$$y_i = c_0 + \sum_{i=1}^{h} c_i x_{i1}^{w_{i1}} \dots x_{in}^{w_{in}}$$

Numerical law

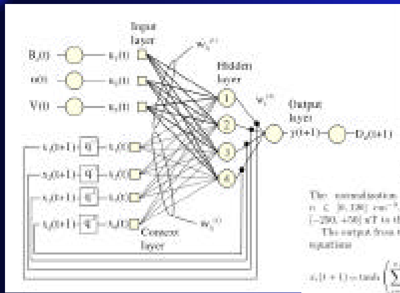
$$y_i = c_0 + \sum_{i=1}^{h} c_i \exp\left(\sum_{j=1}^{n} w_{ij} \ln(x_{ij})\right)$$

Three-layer feedforward neural network

Solar Theory Included



Transferring a Differential Equation to a Difference Equation and Then Comparing With a Recurrent Neural Network



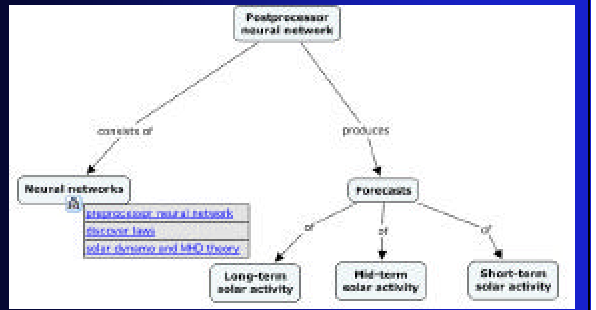
The solar wind-magnetosphere coupling

$$\frac{dDst^*}{dt} = Q - \lambda Dst^*$$

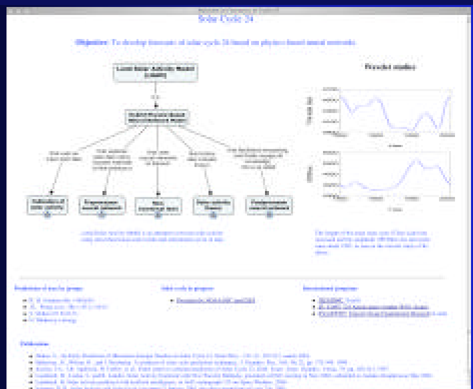
$$\frac{d\Phi_0}{dt} = \gamma E - \frac{\Phi_0}{\tau_0}$$

Open solar flux, where E is the flux emergence rate
τ is decay time scale

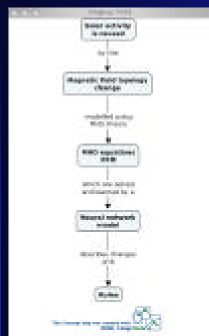
Forecasts

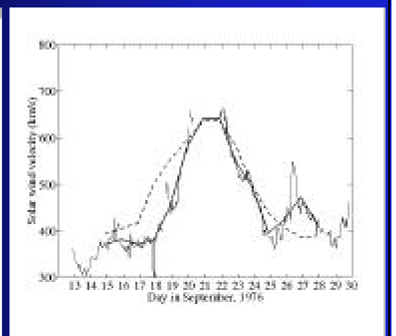


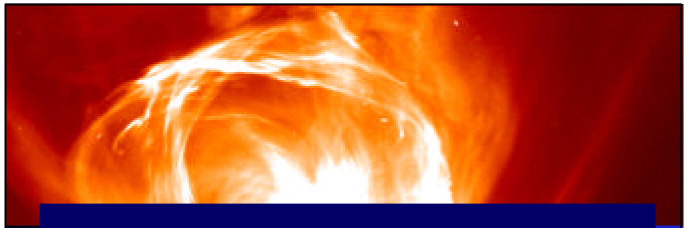
Forecasting Cycle 24



Forecast of Solar Wind Velocity Using a RBF Network and the Expansion Factor Calculated Using a PFM







E. SOLAR WEATHER VISIONS

SOLAR WEATHER VISIONS

- Improved knowledge of
  - Physics of solar activity processes
  - Propagation & coupling
  - Precursors, timings & occurrence frequencies
- Comprehensive network of space- & ground-based real-time observatories
- Solar-Terrestrial Virtual Monitor I-Grid
- Geospace models fully incorporate Solar Weather key parameters

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IMPROVED NOWCASTING & FORECASTING

The Dream Solar Weather Network

- 3-D solar in situ monitoring (6 RTT spacecrafts)
- 3-D IP in situ monitoring (3 RTT spacecrafts)
- 3-D Earth in situ monitoring (6 RTT spacecrafts)

RTT - Real-Time Telemetry

- Complete ground-based observing network
- Real-time data storage & indexing
- Real-time data availability & analysis
- Real-time modelling & forecasting