SPACE AND ATMOSPHERIC SCIENCES
AT SOUTH OF BRAZIL

Nelson Jorge Schuch

SCOSTEP - 11TH QUADRENNIAL SOLAR TERRESTRIAL PHYSICS SYMPOSIUM
SUN, SPACE PHYSICS AND CLIMATE
CLIMATE AND WEATHER OF THE SUN-EARTH SYSTEM - CAWSES
CAWSES PROGRAM IN BRAZIL
RIO DE JANEIRO – BRAZIL
MARCH, 2006
Main building of the SOUTHERN REGIONAL SPACE RESEARCH CENTER CRSPE/INPE – MCT under construction in the “Campus” of the FEDERAL UNIVERSITY OF SANTA MARIA – UFSM March - 2006
PASSIVE SITE AT THE SOUTHERN SPACE OBSERVATORY:

- SPACE WEATHER FORECASTING
  - GROUND-BASED COSMIC RAY – MUON DETECTORS NETWORK FOR SOLAR - TERRESTRIAL RESEARCH

- LOWER ATMOSPHERE AND CLIMATE
  - SONDA - NATIONAL NETWORK OF ENVIRONMENTAL DATA FOR RENEWABLE ENERGY RESOURCE ASSESSMENT
  - SWERA – SOLAR AND WIND ENERGY RESOURCES ASSESSMENT
  - AERONET - AEROSOL ROBOTIC NETWORK PROGRAM
  - BSRN - BASELINE SURFACE RADIATION NETWORK
  - PMOA - UV AND ATMOSPHERIC OZONE MONITORING PROGRAM
  - METEOROLOGICAL DATA COLLECTING AT SSO

- MAGNETOSPHERE
  - GEOMAGNETISM AT THE SOUTHERN SPACE OBSERVATORY

- THERMOSPHERE – IONOSPHERE
  - ATMOSPHERIC NIGHT AIRGLOW AT SSO
  - IONOSPHERIC OPACITY MONITOR WITH A IMAGING RIOMETER
  - IONOSPHERIC SCINTILATION MONITOR WITH A GPS RECEIVER INTERFEROMETER

ACTIVE SITE AT THE UFSM’s CAMPUS:

- MIDDLE ATMOSPHERE
  - INTERNATIONAL COOPERATIONS AT CRSPE/INPE ON MESOSPHERIC DYNAMICS
  - INTERNATIONAL COOPERATIONS AT CRSPE/INPE ON IONOSPHERE SOUNDING
CAWSES IN SOUTHERN BRAZIL

SPACE WEATHER FORECASTING
GROUND-BASED COSMIC RAY – MUON DETECTORS NETWORK
FOR SOLAR - TERRESTRIAL RESEARCH

AN INTERNATIONAL COLLABORATION
AT

SOUTHERN REGIONAL SPACE RESEARCH CENTER
CRSPE/INPE
SOUTHERN SPACE OBSERVATORY
SSO/CRSPE/INPE

BY THE TEAM OF THE INTERNATIONAL MUON DETECTORS NETWORK
The physical mechanism causing the loss-cone precursor. A solar disturbance propagating away from the Sun affects the pre-existing population of galactic cosmic rays in a number of ways. Most well-known is the Forbush decrease, a region of suppressed cosmic ray density located downstream of a CME shock. Some particles from this region of suppressed density leak into the upstream region and, traveling nearly at the speed of light, they race ahead of the approaching shock and are observable as a precursory loss-cone anisotropy far into the upstream region. Loss-cones are typically visible 4-8 hours ahead of shock arrival for shocks associated with major geomagnetic storms (Munakata et al., JGR, 105, 2000).
MUON DETECTORS NETWORK COLLABORATION

PRINCIPALS INVESTIGATORS TEAM

CONSISTING OF 9 INSTITUTES FROM 7 COUNTRIES

- Shinshu Univ., JAPAN (K. Munakata) – International General Coordinator
- STE Lab., Nagoya Univ., JAPAN (M. Kojima)
- Bartol Res. Inst., Univ. of Delaware, USA (J. W. Bieber)
- Australian Antarctic Div., AUSTRALIA (M. L. Duldig)
- INPE, BRAZIL (N. J. Schuch)
- Univ. Federal Santa Maria, BRAZIL (D. K. Pinheiro)
- Kuwait Univ., KUWAIT (I. Sabbah)
- Alikhanyan Physics Inst., ARMENIA (A. Chilingarian)
- Univ. of Greifswald, GERMANY (F. Jansen)
THE INTERNATIONAL MUON DETECTOR NETWORK TEAM

JAPAN:
- K. Munakata, T. Hattori, K. Inoue, S. Yasue, C. Kato – Physics Department, Faculty of Science, Shinshu University, Matsumoto.
- M. Kojima, Z. Fujii – Solar Terrestrial Environment Laboratory, Nagoya University, Nagoya.
- K. Fujimoto – Nagoya Women’s University, Nagoya.

BRAZIL:
- D. K. Pinheiro, N. R. Gomes, L. F. F. Nascimento – Space Sciences Laboratory of Santa Maria – LACESM/CT/UFSM, Santa Maria.

USA:
- B. T. Tsurutani – Space Plasma Physics, Jet Propulsion Laboratory, California Institute of Technology, Pasadena.

AUSTRALIA:
- M. L. Duldig – Australian Antarctic Division, Kingston, Tasmania.
- J. E. Humble – School of Mathematics and Physics, University of Tasmania, Hobart.

KUWAIT:
- I. Sabbah – Department of Physics, Faculty of Science, Kuwait University, Kuwait City.

ARMENIA:
- A. Chilingarian – Cosmic Ray Division, Alikhanyan Physics Institute, Yerevan.

GERMANY:
- F. Jansen – University of Greifswald, Berlin.
Ground-based detectors measure byproducts of the interaction of primary cosmic rays (predominantly protons and helium nuclei) with Earth’s atmosphere.

Typical energy of primary ~50 GeV for Galactic cosmic rays (surface muon detector)

The detector of the Muon Telescopes at SSO
NAGOYA-TYPE MUON DETECTOR

- Coincidences between top and bottom layers provide information on incident direction of cosmic ray primary
- A single detector measures intensity in several directional channels (e.g., 17 at Nagoya)
**SOUTHERN SPACE OBSERVATORY**

Main Gate and buildings 1, 2, 3, 5 and 6 at the São Martinho da Serra, RS, Brazil

**Geographic Coordination:**
- Latitude: 29º 26’ 24”,06 S
- Longitude: 53º 48’ 38”,98 W
- Ellipsoidal Altitude: 488 m

**Geomagnetic Coordination:**
- Latitude: 19º 13’ 48” S
- Longitude: 16º 30’ E
- Inclination or “dip”: 33º S
- Total Geomagnetic Field: 22,800 nT.

**A PASSIVE SITE FOR INSTRUMENTATION SYSTEMS**
THE SOUTHERN SPACE OBSERVATORY MUON DETECTOR
PROTOTYPE OF 2 x 2 x 2 IN SÃO MARTINHO DA SERRA, BRAZIL

Started working on March 2001
Disconnected on May 2005 for the upgrade to the extended telescope
Each of symbols (squares, triangles and circles) shows the asymptotic viewing direction (after correction for geomagnetic bending of cosmic ray orbits) of a particle incident to each telescope with the median primary rigidity.

Open symbols display the existing viewing directions, while full symbols represent the directions to be added by the planned installation and extension of detectors.

The track through each symbol represents the spread of viewing directions corresponding to the central 80% of each telescope's energy response.
SSO MUON DETECTION – OCTOBER/NOVEMBER 2003

Geomagnetic Dst Index

SSO Cosmic Ray - Muon Observation (% variation to annual avg.)

Decrease of more than 10%
Geomagnetic Dst Index on superintense geomagnetic storm

Count rate of muon detector stations

Dst index and Count Rate for three Muon Detectors Network Telescopes: São Martinho da Serra, Hobart, and Nagoya.
THE SOUTHERN SPACE OBSERVATORY EXTENDED MUON DETECTOR TELESCOPE OF 4 x 7 x 2 IN SÃO MARTINHO DA SERRA, BRAZIL

Started to work on December 2005
The geographic location of each detector is indicated by a big star. The detectors and its viewing directions are displayed with different colors, as:

- **Black**: Nagoya, Japan.............17 directions
- **Brown**: Hobart, Australia........13 directions
- **Blue**: Greifswald, Germany....9 directions
- **Purple**: Aragats, Armenia........11 directions
- **Green**: Kuwait, Kuwait...........13 directions
- **Red**: São Martinho da Serra, Brazil:
  - V, N, S, E, W, NE, NW, SE, SW, N2, S2, E2, W2, UPPER SINGLE, LOWER SINGLE, WIDE TOTAL...........16 directions
CAWSES IN SOUTHERN BRAZIL

LOWER ATMOSPHERE AND CLIMATE

AT

SOUTHERN REGIONAL SPACE RESEARCH CENTER
CRSPE/INPE

SOUTHERN SPACE OBSERVATORY
SSO/CRSPE/INPE
SONDA - NATIONAL NETWORK OF ENVIRONMENTAL DATA FOR RENEWABLE ENERGY RESOURCES ASSESSMENT

The main purpose of the project SONDA is to expand the national capacity to develop and improve models for solar and wind resource assessment. One of its chief tasks is to provide high quality environmental data through the setup and development of a national network of environment ground data acquisition stations positioned in characteristic climatic regions of Brazil. At the same time, the project will bring together the existing national expertise and infrastructure in meteorology and climatic modeling to develop specific models for the assessment of the renewable energy resources in Brazil - http://www.cptec.inpe.br/sonda

Brazilian Principal Investigator :  
Enio B. Pereira  
Centre for Weather Forecast and Climate Studies/National Institute for Space Research  
DMA/CPTEC/INPE – MCT

Local Team at SSO/CRSPE/INPE - MCT:  
Nelson J. Schuch, Marcelo P. Pes, Marcus Guedes, Rafael Bertagnolli and Daniel V. Fiorin
SONDA PROJECT WITH PLATAFORM BESIDE BUILDING 1 AT SSO

SONDA PROJECT AT SSO AND OTHERS
SONDA STATIONS INSTALLED IN BRAZIL

Kind of Station
- Reference
- Advanced Solar
- Basics Solar
- Winds Towers

BRAZIL
SWERA – SOLAR AND WIND ENERGY RESOURCE ASSESSMENT is a project financed by United Nations Environment Program - UNEP, with co-financing by Global Environment Facility - GEF, in the area of renewable energies, and more specifically solar and wind energy. The project includes the efforts of several countries, but is primarily directed to developing countries.

The project will bring together high quality information on solar and wind energy resources into consistent Geographic Information System - GIS analysis tools. The project is aimed at the public and private sectors involved in the development of the energy market and it shall enable policy makers to assess the technical, economic and environmental potential for large-scale investments in technologies that enable the exploitation of the two increasingly important sources of renewable energy – [http://SWERA.UNEP.net](http://SWERA.UNEP.net) and [http://www.cptec.inpe.br/swera/swera_home.html](http://www.cptec.inpe.br/swera/swera_home.html)

**International Principal Investigator**: Tom Hamlin, Project Manager

**Brazilian Principal Investigator**: Enio Bueno Pereira – DMA/CPTEC/INPE – MCT
SONDA and SWERA AT SSO

Air Temperature Sensor
Two sensors installed at the tower

Anemometers
Wind Velocity and Direction at 25 and 50 meters; installed at the anemometric tower

Barometric Pressure Sensor

Temperature Sensor and Air Humidity Sensor
AERONET - AEROSOL ROBOTIC NETWORK PROGRAM is an inclusive federation of ground-based remote sensing aerosol networks established by AERONET and PHOTONS (which is part of the sunphotometer network AERONET) and greatly expanded by AEROCAN (AEROCAN is a sunphotometer and sky-scanning radiometer network which is also part of the federated AERONET network. AEROCAN's mission is to acquire sufficient spatio-temporal data to validate the development of a Canadian) and other agency, institute, and university partners. The goal is to assess aerosol optical properties and validate satellite retrievals of aerosol optical properties. The network imposes standardization of instruments, calibration, and processing. Data from this collaboration provides globally distributed observations of spectral aerosol optical depths, inversion products, and precipitable water in geographically diverse aerosol regimes. Three levels of data are available on website: Level 1.0 (unscreened), Level 1.5 (cloud-screened), and Level 2.0 (Cloud-screened and quality-assured). Descriptions may be found of program objectives, affiliations, the instrumentation, operational issues, data products, database browser "demonstrat", research activities, links to similar data sets, NASA EOS links and personnel involved in AERONET - http://aeronet.gsfc.nasa.gov

AERONET International Principal Investigator:
Brent Holben (Project Head) NASA Goddard Space Flight Center, USA

Brazilian Principal Investigator:
Enio Bueno Pereira – DMA/CPTEC/INPE – MCT – Cachoeira Paulista, SP, Brazil
BSRN - BASELINE SURFACE RADIATION NETWORK

WORLD RADIATION MONITORING CENTER (WRMC)

BSRN is a project of the World Climate Research Programme (WCRP) and the Global Energy and Water Experiment (GEWEX) and as such is aimed at detecting important changes in the earth's radiation field at the earth's surface, which may be related to climate changes. The data are of primary importance in supporting the validation and confirmation of satellite and computer model estimates of these quantities. At a small number of stations (currently fewer than 40) in contrasting climatic zones, covering a latitude range from 80°N to 90°S, solar and atmospheric radiation is measured with instruments of the highest available accuracy and with high time resolution (1 to 3 minutes). The BSRN was recently, 2004, designated as the global baseline network for surface radiation for the Global Climate Observing System (GCOS) - http://bsrn.ethz.ch

International Principal Investigator:

Prof. A. Ohmura - Director of the WRMC - Institute for Atmospheric and Climate Science - Zurich, Switzerland

Brazilian Principal Investigator:

Enio Bueno Pereira – DMA/CPTEC/INPE – MCT – Cachoeira Paulista, SP, Brazil
SONDA, SWERA, AERONET and BSRN AT SSO

- TSI – Total Sky Image
- Cimel Photometer 318-1 (AERONET)
- Pirgeometer PIR
  Infrared Radiometer
  (3500 - 50000 nm)
- Piranometer CM 22
  Difuse Solar Radiation
  (200 - 3600 nm)
- PAR lite and LUX lite (400 - 700 nm)
- Piranometer CM 21
  Global Solar Radiation (300 - 2800 nm)
- Pirleliometer NIP
  Direct Solar Radiation
  (200 – 4000 nm)
The Atmospheric Ozone Monitoring Program – PMOA was created in 1992 with the main goal to study the atmospheric ozone behavior and the incidence of Ultraviolet Radiation in the Southern of Brazil. The PMOA equipments were transferred to the Southern Space Observatory, Brazil on 1996. One of the most important results of the Program was the discovered of the Antarctic Ozone Hole Secondary Effects over low latitudes like 30°S, which were not expected for the scientific community on 1993. The Program maintains a constant monitoring of the total ozone column, UVB and UVA Radiation, Erithema Radiation, Biologically Active Radiation by Brewer Spectrophotometer and Spore Dosimeter, atmospheric and aerosol optical depth and tropospheric and stratospheric temperature and ozone profiles by soundings.

Principal Investigator:
Damaris Kirsch Pinheiro – Space Science Laboratory of Santa Maria - LACESM/CT-UFSM

Local Team LACESM/CT - UFSM and CRSPE/INPE - MCT:
Nelson J. Schuch, Caroline Bertagnolli, Germano Possani, Tiele Caprioli, Pabulo Henrique Rampelotto
UV-Biometer 501-A
UV Radiation Biologically Active

UV-B Radiometer MS-210W
(280 - 315 nm)

Grating Spectroradiometer MS-701
(295 - 400 nm)

UV-B Radiometer MS-212W
(280 - 315 nm)

UV-A Radiometer MS-212A
(315 - 400 nm)

Brewer Spectrophotometer MKIII #167
O$_3$ and UV from 286.5 to 363 nm

GUV-511C
305, 320, 340, 380nm and PAR (400-700nm)

W-9000 Meteorological System

UV - PMOA – UV AND ATMOSPHERIC OZONE MONITORING PROGRAMS
SSO’s BUILDING 1 WITH PLATAFORM
SECUNDARY EFFECTS OF OZONE HOLE AT SSO

1993
SSO ATMOSPHERIC RESULTS

- Equipment Change in 1999

- 

O\textsubscript{3} Total Column Average at SSO

274.8 +/- 17.04 DU

- Aerosol Optical Thickness

- Mornings

- Atmospheric Pressure (hPa)

- Ozone Partial Pressure (hPa)

- Daily Integral Energy (Wm\textsuperscript{-2})

APR/2000 to NOV/2003
Percentage of UV Variation for 1% Ozone Change at SSO
METEOROLOGICAL DATA COLLECTING AT SSO

Antenna of VHF Receiver Station for Receiving Meteorological Data from Satellites

Meteorological Data Collecting Plataforma

http://tempo.cptec.inpe.br:9080/PCD/metadados.jsp?uf=20&id=32466&tipo=MET
CAWSES IN SOUTHERN BRAZIL

MAGNETOSPHERE

AT

SOUTHERN REGIONAL SPACE RESEARCH CENTER
CRSPE/INPE
SOUTHERN SPACE OBSERVATORY
SSO/CRSPE/INPE
SOUTHERN REGIONAL SPACE RESEARCH CENTER - CRSPE/INPE - MCT
FEDERAL UNIVERSITY OF SANTA MARIA - UFSM

GEOMAGNETISM AT THE SOUTHERN SPACE OBSERVATORY - SSO

SOUTH ATLANTIC GEOMAGNETIC ANOMALY REGION IN SOUTH AMERICA
TOTAL MAGNETIC FIELD - F INTENSITY (nT)
The secular variation in the total geomagnetic field $F$ and the westward drift of South Atlantic Anomaly - SAA has been observed in South of Brazil since 1985, in cooperation with the Space Environment Research Center – Kyushu University (http://www.serc.kyushu-u.ac.jp). The main objective of the Magnetic Observatory at SSO is to monitor the westward drift of the SAA and to provide valuable observations for the Space Weather studies at CRSPE/INPE – MCT and LACESM/CT - UFSM. According to IGRF2000 the present value of $F$ at Southern Space Observatory - SSO/CRSPE/INPE – MCT is 22883 nT a value close to the measured one. The secular variation in $F$ at this station is -28 nT per year. It is difficult to forecast the drift movement of the Anomaly (SAA) in the coming years however it is a matter of concern should the field continue to decrease at the present rate or even faster. Both continuous and impulsive pulsations observed in the H component of the geomagnetic field by the Geomagnetic Monitoring Program at SSO/CRSPE/INPE – MCT are enhanced due to the particle precipitations in the SAA region.

**International Principal Investigator:**
K. Yumoto - Space Environment Research Center – Kyushu University

**Brazilian Principal Investigator:**
Nalin Babulal Trivedi - Space Science Laboratory of Santa Maria – LACESM/CT - UFSM

**Local Team CRSPE/INPE - MCT:**
Nelson J. Schuch, Cássio E. Antunes, Fagner C. Rother, Josemar de Siqueira, Sandro F. Bertagnolli
Fluxgate Magnetometers

H component magnetograms showing sudden impulsive event recorded at low-latitude stations and from satellites.
CAWSES IN SOUTHERN BRAZIL

THERMOSPHERE - IONOSPHERE

AT

SOUTHERN REGIONAL SPACE RESEARCH CENTER
CRSPE/INPE
SOUTHERN SPACE OBSERVATORY
SSO/CRSPE/INPE
International Cooperation Brazil – Japan at SSO
Photometers, Detectors and CCD Cameras

Local Team CRSPE/INPE – MCT:
Plasma Irregularities observed through airglow emission at SSO on March 09th, 2002 At 23:40 – 23:51 LT. Rate: 1 image/minute

Zenith Photometer Measurements at SSO
Variation on the Airglow emission of OI557.7 nm and OI630.0 nm
BUILDING 6 AT SSO: OPTICAL LABORATORY WITH THE MERIDIONAL IMAGE SPECTROPHOTOMETER
IONOSPHERIC OPACITY MONITOR WITH A IMAGING RIOMETER AT SSO – 38.2 MHz

Japanese Principal Investigator: Kazuo Makita

Riometer Control System

Imaging Riometer
Dipole Antenna Array
IONOSPHERIC SCINTILATION MONITOR WITH A GPS RECEIVER INTERFEROMETER AT CRSPE/INPE

International Principal Investigator: Paul M. Kintner - Electrical and Computer Engineering - Cornell University
Brazilian Principal Investigator: Eurico Rodrigues de Paula – DAE/CEA/INPE - MCT

GPS “S” Station at CRSPE/INPE main building
GPS receivers interferometer operation frequency for the S and T Stations: 1.57542 GHz (L1)

GPS “T” Station at CRSPE/INPE main building

Local Team CRSPE/INPE – MCT:
Nelson J. Schuch, Henrique Carlotto Aveiro, Lilian Piecha Moor.
CAWSES IN SOUTHERN BRAZIL

MIDDLE ATMOSPHERE

AT

SOUTHERN REGIONAL SPACE RESEARCH CENTER
CRSPE/INPE
UFSM’s CAMPUS
SANTA MARIA

AN ACTIVE SYSTEMS SITE
INTERNATIONAL COOPERATIONS AT CRSPE/INPE ON MESOSPHERIC DYNAMICS

SKIYMET METEOR RADAR TO STUDY THE ATMOSPHERIC DYNAMICS AT THE UFSM’s CAMPUS - SANTA MARIA, AN ACTIVE SYSTEMS SITE

The SKIYMET METEOR RADAR makes use of the ionized trails left by meteors when entering the Terrestrial Atmosphere. This ionization is the result of attrition between the surface of the meteor and atmospheric molecules. Measurements of echo delay, Doppler shift and angle of arrival are used to determine the location and motion of meteor trails. The INPE’S SKIYMET METEOR RADARS are now operating at three locations in Brazil: São João do Cariri (37 W, 7 S), Cachoeira Paulista (45 W, 23 S) and Santa Maria (54 W, 30 S). These radars provide 24-hour data on upper atmosphere winds between 80 and 100 km, with a time resolution of about 1 hour. Although this radar can be used for meteor studies, the main RESEARCH interest is in its application to the study of atmospheric dynamics.

Brazilian Principal Investigator:

Barclay Robert Clemesha
Aeronomy Division/Atmospheric and Space Science Coordenaion –DEA/CEA/INPE – MCT

Local Team CRSPE/INPE – MCT:

Nelson J. Schuch, Tiago Brum Pretto, Elisa Borstmann Jensen, Saul Correa Ilhana
SKiYMET Meteor Radar – 35.24 MHz ($\lambda \approx 8.5$ m) at the UFSM Campus

ACTIVE SYSTEM

Control and Data Acquisition

Transmitter System

Receiver System
SKiYMET Meteor Radar – Network, Cooperation and Result

INTERNATIONAL COOPERATION

CANADA – ONTARIO
Dr. Wayne Hocking
University of Western Ontario
MARDOC Inc.

AUSTRALIA – ADELAIDE
Dr. Brenton Vanderpeer
Genesis Software Pty Ltda.
INTERNATIONAL COOPERATIONS AT CRSPE/INPE ON IONOSPHERE SOUNding

ACTIVE SYSTEM – DIGISONDE PORTABLE SOUNDER – DPS-4
Brazilian Principal Investigator: Mangalathayil Ali Abdu

DIGISONDE PORTABLE SOUNDER EQUIPMENTS TO BE INSTALLED AT THE UFSM CAMPUS 2006.

DIGISONDE PORTABLE SOUNDER – DPS-4, with 300 watt transmitter, and programmable variable frequency band 1 – 45 MHz, employing phase coding, digital pulse compression and Doppler integration.
MUITO OBRIGADO

THANK YOU

NELSON JORGE SCHUCH

SCOSTEP - 11TH QUADRENNIAL SOLAR TERRESTRIAL PHYSICS SYMPOSIUM
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RIO DE JANEIRO – BRAZIL - MARCH, 2006
**A SAMPLE APPLICATION:**

REMOTE SENSING SOLAR WIND DISTURBANCES

Bieber & Munakata, 2004

\[ \mathbf{B} \times \text{Gradient anisotropy} \]

\[ \vec{\xi}_{\perp}^{(W)} = R_L \vec{b} \times \nabla_{\perp} N \]

\[ \vec{b} : \text{IMF unit vector} \]

\[ \nabla_{\perp} N : \text{density gradient vector} \]

\[ R_L : \text{Larmor radius} \]

\[ \sim 0.2 \text{ AU for muons} \]

\[ R_L \nabla_{\perp} N = -\vec{b} \times \vec{\xi}_{\perp}^{(W)} \]

We deduce \( \nabla_{\perp}(t) \) from the observed \( \xi(t) \) & \( B(t) \)

\( -\nabla_{\perp}(t) \) points toward the flux rope center

\( \vec{\nabla}_{\perp} N \) pointing toward CME center